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HIGH ENERGY PHYSICS

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Experimental Physics   Theoretical Physics
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Abstract

The high energy physics research program at the University of Hawaii is directed toward the study of the properties of the most basic constituents of matter and the application of the results of these studies to the understanding of the physical universe. Experiments using high energy accelerators search for new particles, test current theories, and measure properties of the known particles. Experiments using cosmic rays address both particle physics and astrophysical issues. A program of research and development of new types of detection instruments expands and improves the capabilities of these experiments. Theoretical physics research evaluates experimental results in the context of existing theories and projects the experimental consequences of proposed new theories.
Chapter 1

Introduction

In the past few years, five of the most important developments in particle physics have been:

- the convergence on the large-mixing-angle solution of the solar neutrino puzzle;
- the discovery of muon-neutrino oscillations;
- the discovery of $CP$ violation in the $B$ meson system;
- observation of cosmic rays with energies near (or maybe even above) the GZK cutoff; and
- the calculation of the Higgs boson mass from precise measurements of Standard Model parameters.

The University of Hawai‘i high energy physics group plays important roles in each of these activities:

The solar neutrino puzzle: In 2002, the KamLAND experiment reported a deficit of electron neutrinos from nuclear reactors surrounding the Kamioka site. This, taken together with results from SNO and SuperK, have established the so-called Large-Mixing-Angle (LMA) solution for electron neutrino oscillation. The Hawai‘i group has a strong participation in both the KamLAND and SuperK experiments.

Neutrino oscillations: Hawai‘i experimenters made important contributions to the SuperK analysis that discovered unambiguous evidence for muon-neutrino oscillations. The paper reporting this discovery is the most highly cited experimental particle physics paper of all time. UH theorists play a leading role in neutrino oscillation phenomenology.

$CP$ violation in $B$ meson decays: The Hawai‘i group is a major component of the Belle experiment that discovered a large $CP$ violation in neutral $B$ meson decays. This is the first example of $CP$ violation outside of the neutral $K$ meson system and a confirmation of expectations of the Kobayashi-Maskawa mechanism. UH theorists have made many contributions to the phenomenology of $CP$ violation.
**Ultra-high energy cosmic rays:** A Hawaii-led program to exploit radio detection of ultra-high-energy cosmic-ray-induced showers has already established stringent limits of the flux of high energy, diffuse AGN neutrinos. Radio detection is now recognized as a promising technique for exploring the possibility that neutrinos are the source of the events in the GZK-limit region.

**Precision tests of the Standard Model:** Hawaii theorists have developed new and powerful calculational techniques for dealing with the SM higher-order processes that are essential for precision tests. Measurements of the cross sections for $e^+e^- \rightarrow \text{hadrons}$ in the 2 GeV - 5 GeV cm energy region with the BES-II detector have substantially improved the SM value for the Higgs mass. The Hawaii group plays a leadership role in the BES-II experiment.

In the *near future*, our group will continue to play a central role in important investigations: Melnikov's calculations for Higgs production cross sections, and the ISASUSY program developed and maintained by Tata and his collaborators are essential tools for evaluating results from Tevatron and, later, LHC collider experiments. ANITA, a balloon experiment to detect radio waves produced by high energy cosmic ray neutrinos interacting in the Antarctic ice-cap, has been approved and funded (by NASA) and will have unprecedented sensitivity for detecting GZW neutrinos. (Gorham is the spokesperson for ANITA.) The Belle team's attempts to measure direct $CP$ violation in $B$ meson decays are benefiting from world-record luminosity levels in KEKB. (Olsen is a spokesperson and Browder an analysis coordinator for Belle.) The observed background levels in the KamLAND detector are very low and indicate that in addition to reactor-produced neutrino experiments, the instrument will be a powerful device for studying solar and terrestrial neutrinos.

For the *further future*, Gorham's tests on the use of salt as a detection medium show very promising results and indicate that his basic ideas for SALSA, a post-IceCube cosmic-ray neutrino detector, are sound. Browder is a leader in the planning for super-high luminosity $B$ factories that are currently under discussion at KEK and SLAC. Harris, a spokesperson for BES-II, is playing a leadership role in the organization of BES-III, a major new facility for physics in the $\tau$-charm threshold region that has recently been approved and funded by the Chinese Academy of Science.

### 1.1 Background

The Hawaii high energy physics group consists of four University-supported theoretical faculty (Melnikov, Pakvasa, Sugawara and Tata) and ten experimental faculty; eight (Browder, Harris, Gorham, Learned, Matsuno, Olsen, Peters and Yamamoto's replacement) are University supported and two (Jones and Parker) are supported by DOE.
funds,* seven DOE-supported Research Associates, and twelve graduate students. In addition, the group has two affiliate faculty: Ohnuma (accelerator physics) and Simmons (theory).

The group has permanent laboratory facilities in Watanabe Hall, Krauss Hall and the Physical Sciences Building on the University of Hawaii Manoa Campus. Much of the laboratory equipment was purchased with University funds. We have an excellent engineering support staff: Ibaraki for computing and networking, Rosen for mechanical and optical systems, and Varner for electronics. An assortment of largely university-provided computers, workstations and a 40-node PC farm are networked via Ethernet and linked to the mainland via the university’s fiber-optic T1 lines. Our experimental groups hold frequent meetings with collaborators on the mainland, in Japan, or in China, via IP and ISDN video conference systems. Our group is a major user of the physics department’s machine shop, which has two full-time, university-supported machinists. Our campus location is adjacent to the School of Ocean and Earth Science and Technology (SOEST), which has electronics and mechanical engineering and shop facilities that we occasionally use on a costed basis. In addition, we have many formal and informal contacts with the astronomers, astrophysicists and cosmologists at the University’s Institute for Astronomy.

We share some facilities and personnel with the physics department’s Free Electron Laser group, who are constructing an FEL in the basement of Watanabe Hall. When completed, this facility will include a modest low-energy electron test beam and an area for doing detection tests of electron-shower-induced RF signals as well radiation-hardness tests of silicon detectors and electronics. The presence of the (well funded) FEL activities is significantly improving the department’s research infrastructure, which is of mutual benefit to both research groups.

1.2 Recent Personnel Changes

We have recently recruited Peter Gorham, Kirill Melnikov and Hirotaka Sugawara as faculty members in our group.

Gorham, who was recruited to replace Stenger in 2001, has been leading a series of experimental studies of the Askaryan process in electromagnetic showers at SLAC that have demonstrated that the radio emission is coherent over a span of four orders of magnitude of shower energy, ranging from around 1 PeV to 10 EeV. He is the leader of the ANITA balloon experiment that will occur in 2006. The idea of using particle-shower-induced radio waves for the detection of high energy cosmic ray neutrinos have attracted world-wide interest; it was the central topic for a recent issue of the CERN

*Learned, Matsuno, Peters and Sugawara have 11-month University positions and receive no salary support from the DOE grant.
Courier (see Fig. 1.1) and the subject of Gorham’s successful Outstanding Junior Investigator award in 2002.

Figure 1.1: The cover of the April 2001 issue of the CERN Courier features the use of radio-telescopes to detect ultra-high energy cosmic-ray showers.

Melnikov, who replaced Tuan in 2002, is an expert on the application of quantum field theory to precision calculations in particle physics phenomenology, thus bringing a new direction to the theory group that fits especially nicely with the existing experimental program. His studies of the $t\bar{t}$ system near threshold at linear $e^+e^-$ colliders and his insightful assessment of the theoretical status of the muon anomalous magnetic moment are especially well known. His recent calculation of the cross-section for the Higgs boson production through gluon-gluon fusion at next-to-next-to-leading order in perturbative QCD is the state of the art estimate of the cross-section for the Higgs boson discovery channel at both the Tevatron and the LHC. This year he received an Outstanding Junior Investigator award for his proposal to develop new methods for perturbative calculations for application to problems in electroweak processes, heavy quark physics and lattice perturbation theory.

Sugawara, who has recently completed a 14-year stint as Director-General of KEK, has joined our group as the Dai Ho Chun Distinguished University Professor. His primary research interest is the relation between 11-dimensional supergravity and conformally invariant membrane theory. In particular he is trying to see if membrane theory has an anomaly that can be used to fix the dimension. He is currently applying membrane theory directly to the understanding of the flavor physics. Sugawara is also interested in understanding living things from a complex system viewpoint. During Sugawara’s tenure as KEK Director-General, the laboratory built KEKB, the world’s highest lu-
minosity colliding beam facility for $B$-meson physics, and made major progress on the technical issues for a high energy linear $e^+e^-$ collider. At Hawaii, he will continue his efforts at promoting international collaborations for next generation linear colliders and $B$-meson factories.

We are currently recruiting a faculty replacement for Yamamoto, who recently left our group for a position at Tohoku University in Japan.

## 1.3 Other Recent Highlights

**Belle:** Recently, in addition to improving the precision of the $\sin 2\phi_1$ (also called $\sin 2\beta$), Belle published the first evidence for $CP$ violation in $B \to \pi^+\pi^-$ decays. Belle also published first observations of the electro-weak penguin processes $B \to K\ell^+\ell^-$ and $B \to X_s\ell^+\ell^-$; these are especially interesting because they provide sensitive probes for physics beyond the Standard Model. Hawaii Belle members discovered the missing $\eta_c(2S)$ charmonium state in exclusive $B \to K\bar{K}S K^\pm\pi^\mp$ decays.

**BES-II:** Analysis of the 58M $J/\psi$ and 14M $\psi(2S)$ event samples has started. Hawaii researchers discovered an interesting narrow $p\bar{p}$ mass structure near the $2m_p$ threshold in the radiative decay process $J/\psi \to \gamma p\bar{p}$. We also have completed a definitive spin-parity analysis for the $f_{J}(1710)$ glueball candidate (it is $J^{PC} = 0^{++}$). No evidence is seen for the $\xi(2230)$ glueball candidate in any of its reported decays, with an order-of-magnitude improved sensitivity over the Mark-III and BES-I experiments that claimed observations.

**Detector R&D:** Parker's invention of silicon pixel sensors with electrodes that penetrate the active area (3D pixels) has stimulated major R&D efforts in the US (primarily for applications in Molecular Biology), Europe (for LHC inner detectors) and Japan (for linear collider beam profile monitoring). Tests with 3D pixel sensors, fabricated with support from the DOE Advanced Detector Research program and the NIH, have demonstrated that these devices are radiation hard and very fast; rise times less than 4 ns are seen for heavily irradiated sensors. In addition, these devices are sensitive to within a few microns of their physical edges.

**Super-Kamiokande and K2K:** The reconfiguration of the photomultipliers in the SuperK detector has been completed and neutrino-mixing studies, including the long-baseline $K2K$ experiment, have resumed. The analysis of muon-neutrino mixing with tau neutrinos has been refined and alternative physics solutions have been excluded. $K2K$ results based on 50% of the total expected integrated proton flux support the SuperK muon neutrino mixing solution. Various other limits on nucleon decay, neutrinos from GRBs, astronomical point sources of neutrinos, WIMP annihilation neutrinos, relic SN neutrinos, etc., continue to be refined, but without any
positive indications as yet. SuperK limits dominate world results in all applicable categories, and SuperK papers dominate experimental HEP citation indices.

**Theory:** Data from the E871 experiment at Fermilab to search for $CP$ violating effects in hyperon decays, which is based on the proposal by Pakvasa and his collaborators, is now being analyzed. His novel interpretation of the LSND anomaly in terms of a rare decay mode of muon rather than neutrino oscillations will be tested both by a null effect in the Mini-BOONE experiment (now under way at Fermilab) and by a precision measurement of the Michel parameter in mu-decay in the experiment TWIST (now under way at TRIUMF). The bi-maximal neutrino-mass-mixing matrix continues to receive considerable attention.

Tata and his collaborators continue to work on strategies for identifying SUSY particles at high energy colliders and elucidating their properties. The ISASUSY package they have developed and continue to refine is part of the ISAJET simulation, and has been extensively used by the CDF and D0 collaborations in their analyses of SUSY at the Tevatron. Strategies proposed by Tata and co-workers have also been used by LHC and NLC researchers in their simulation studies. In the last few years, Tata and collaborators have also examined the extent to which determination of sparticle properties can yield information about how MSSM superpartners acquire their masses. Most recently, they have been studying the possibility of constructing viable SUSY GUTs with (third generation) Yukawa couplings also unified at the GUT scale.

**Outreach:** Undergraduate students are heavily involved in preparations for our various experiments as paid part-time staff or as part of undergraduate thesis projects. Our exhibits on neutrinos, antimatter and theoretical physics are highlights of the Physics Department’s very popular annual Open House for high school students. Group members also serve as judges for Hawaii’s annual Physics Olympics. We have initiated a participation in Quarknet, a joint NSF-DOE program administered through FermiLab that gets teachers from local high schools involved in our research. This summer, Peter Grach, a teacher from Kamehameha Schools, is doing research on intrinsic limits of scintillation-based time-of-flight measurements; he is being mentored by Varner. Some of the faculty are active in the local AAPT chapter, an organization that includes many science teachers from local high school and community colleges; Jones was recently the president.
Chapter 2

Accelerator-Based Experiments

2.1 $B$-meson physics with Belle


The main purposes of the Belle experiment are the study of $CP$ violation and the search for new physics in the $B$-meson system. Hawaii is a charter member of the Belle collaboration and one of the largest non-KEK contingents.

The experiment benefits from the remarkable performance of the KEKB asymmetric energy $e^+e^-$ collider $B$ meson factory, which operates at peak luminosities in excess of $10^{34}$cm$^{-2}$s$^{-1}$. Even at the highest KEKB luminosities, all subsystems of the Belle detector work well and background levels are tolerable. The resolutions, efficiencies, etc., match the design goals to within 10% or better. The software is efficient, robust and relatively easy to use and has enabled us to generate a number of new and interesting results quickly.

By summer 2003, Belle has accumulated a data sample corresponding to an integrated luminosity of over 150 fb$^{-1}$, most of which was collected at the $\Upsilon(4S)$ resonance. The sample contains over 150 million produced $B\bar{B}$ meson pairs. These data have resulted in over 60 journal papers, including some of substantial significance.

2.1.1 Major accomplishments of Belle

In less than three years of operation, the Belle group has produced a number of significant results. These include:
CHAPTER 2. ACCELERATOR-BASED EXPERIMENTS

Observation of \( CP \) Violation in \( B \) Meson Decays

In 2001, Belle reported the clear observation (6\( \sigma \) significance) of \( CP \) violation in the neutral \( B \) meson system \([9]^{*}\). This was the first observation of \( CP \) violation outside of the kaon sector. The BaBar group reported similar results.\(^3\) In 2002, with double the luminosity (78 fb\(^{-1}\) containing \( 85 \times 10^6 \) \( B\Bar{B} \) pairs), Belle reported a measurement with improved precision [41]\)

\[
\sin 2\phi_1 = 0.719 \pm 0.074(\text{stat}) \pm 0.035(\text{sys}),
\]

where \( \phi_1 \) is the phase of the \( V_{td} \) element of the Kobayashi-Maskawa quark-mixing matrix (also known as \( \beta \)). Figure 2.1 shows the \( \Delta t \) distributions for \( B^0 \) and \( \Bar{B}^0 \) tags separately with the result of the unbinned maximum likelihood fit superimposed.\(^3\) The difference between the \( B^0 \)- and \( \Bar{B}^0 \)-tagged distributions indicates \( CP \) violation. The observed phase is consistent with the indirect determination inferred from the lengths of the sides of the unitarity triangle as indicated in Fig. 2.2.\(^2\)

![Figure 2.1: The raw, unweighted \( \Delta t \) distributions for \( B^0 \) (closed circles) and \( \Bar{B}^0 \) (closed circles) tagged samples. The curve is the result of an unbinned fit.](image)

![Figure 2.2: The average of Belle and BaBar \( \phi_1 \) results superimposed on \( \rho-\eta \) constraints from other measurements.](image)

Measurement of \( CP \) Violation in \( B \to \pi^+\pi^- \) Decays

The next step in the \( CP \) violation program is the measurement of the remaining unitarity angles \( \phi_2 \) and \( \phi_3 \) (\( \alpha \) and \( \gamma \)). Belle has reported results for \( \phi_2 \) from a time-dependent analysis of \( B \to \pi^+\pi^- \) decays. In contrast to \( B^0 \to \psi K_S \) and related modes, \( B \to \pi^+\pi^- \) includes contributions from \( V_{ub} \) tree and \( b \to d \) penguin diagrams that have different strong and weak phases. As a result, the decay is characterized by two kinds of \( CP \) violation and the extraction of the \( CP \) angle \( \phi_2 \) is somewhat more involved.\(^4\)

\(^*\)References in bold face type refer to the Belle publication list at the end of this section.
The time dependence of $B \rightarrow \pi^+\pi^-$ is given by

$$P_{\pi\pi}^q(\Delta t) = \frac{1}{4\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} [1 + qS_{\pi\pi} \sin(\Delta m_d \Delta t) + A_{\pi\pi} \cos(\Delta m_d \Delta t)] \ .$$

Here the variable $q = \pm 1$ corresponds to $B^0$ or $\bar{B}^0$ tags. The parameter $S_{\pi\pi}$ characterizes mixing-induced $CP$ violation; $A_{\pi\pi}$ is a measure of direct $CP$ violation.

With the 78 fb$^{-1}$ data sample, Belle finds [55]

$$S_{\pi\pi} = -1.23 \pm 0.41(\text{stat})^{+0.08}_{-0.07}(\text{syst})$$

$$A_{\pi\pi} = 0.77 \pm 0.27(\text{stat}) \pm 0.08(\text{syst}) \ .$$

Comparisons of the fits to projections of the data are shown in Fig. 2.3. These results rule out the $CP$-conserving case, $(S_{\pi\pi}, A_{\pi\pi}) = (0,0)$, with a 99.93% confidence level, and suggest the existence of both mixing-induced and direct $CP$ violations. BaBar reported null values for both $A_{\pi\pi}$ and $S_{\pi\pi}$ [5]. More data are needed to resolve this apparent discrepancy.

Figure 2.3: The raw, unweighted $\Delta t$ distributions for signal-region $B^0 \rightarrow \pi^+\pi^-$ event candidates with (a) $B^0$ tags; (b) $\bar{B}^0$ tags; (c) after background subtraction. (d) The background-subtracted $CP$ asymmetry.

The translation of $A_{\pi\pi}$ and $S_{\pi\pi}$ into a value of $\phi_2$ requires knowledge of the ratio of the penguin and tree amplitudes ($|P|/|T|$) and their relative strong phase ($\delta$). These can
be determined from a full set of $B \to \pi \pi$ branching fraction measurements, including $B \to \pi^0 \pi^0$. In the meantime, as an example, Fig. 2.4 shows the values of $\phi_2$ and $\delta$ that are implied by our $A_{\pi \pi}$ and $S_{\pi \pi}$ values assuming $|P|/|T| = 0.45$.

![Figure 2.5: Beam-energy-constrained mass distributions for (a) $X_s e^+ e^-$, (b) $X_s \mu^+ \mu^-$, (c) $e^+ e^-$ and $\mu^+ \mu^-$ combined and (d) $X_s e^\pm \mu^\mp$, where no signal is expected.](image)

**Measurement of $B \to X_s \ell^+ \ell^-$**

The electroweak penguin process $b \to s \ell^+ \ell^-$, where $\ell$ is either an electron or muon, has been identified as a sensitive probe for new physics. In 2001 Belle reported the first observation of the exclusive decay process $B \to K \ell^+ \ell^-$ \cite{12}; a result (with $5.3\sigma$ significance) that was subsequently confirmed by BaBar\cite{6}. Although this was an important benchmark in the study of EW penguins, uncertainties in hadronization make it difficult to use this measurement to constrain new physics scenarios. In 2002, Belle reported the first measurement of the inclusive decay $B \to X_s \ell^+ \ell^-$, where $X_s$ is a hadronic recoil system that contains a kaon. The signal is evident in the beam-energy constrained mass plots shown in Fig. 2.5. In this case, the uncertainties due to hadronization are greatly reduced and the theoretical interpretation has less ambiguity. The inclusive branching fraction is found to be

$$\mathcal{B}(B \to X_s \ell^+ \ell^-) = (6.1 \pm 1.4(stat)_{+1.4}^{+1.4}(sys)) \times 10^{-6}$$

for dilepton masses greater than 0.2 GeV/$c^2$. This result is in agreement with Standard Model calculations and helps constrain a variety of new physics scenarios.
2.1.2 Hawaii-based analyses

In addition to contributing important components to the major Belle results listed above, there are a number of analyses that are primarily done by members of our group. These are summarized here.

Figure 2.6: The missing $D$ mass for lepton-tagged partially reconstructed $B \to D^{*-} \pi^+$ event candidates.

$B^0 - \bar{B}^0$ Mixing and $\sin(2\phi_1 + \phi_3)$. Browder and (former) Hawaii student Zheng developed a method for measuring the $B^0 \bar{B}^0$ mixing parameter $\Delta m_d$ that uses the time evolution of events where there is one partially reconstructed $B^0 \to D^{*-} \pi^+$ decay and a high momentum lepton from the accompanying $B$ meson. (Partial reconstruction, first used by CLEO,\cite{CLEO} identifies $B^0 \to D^{*-} \pi^+$ decays using only the prompt $\pi^+$ and the slow $\pi^-$ from the $D^{*-} \to D^0 \pi^-$ decay.) The $B^0 \to D^{*-} \pi^+$ signal is evident in the $D^0$ missing mass distribution for lepton-tagged events shown in Fig. 2.6. Figure 2.7 shows the time evolution of $(N_{OF} - N_{SF})/(N_{OF} + N_{SF})$ for signal events, where $N_{SF}$ ($N_{OF}$) is the number of same-flavor (opposite-flavor) event candidates. The time variation of the charge asymmetry is directly related to $\Delta m_d$; the curve in Fig. 2.7 shows the results of the fit with

$$\Delta m_d = 0.505 \pm 0.017 \text{(stat)} \pm 0.020 \text{(sys)}$$

The result was described in detail in a paper in Physical Review D, with Zheng and Browder as first authors\cite{Zheng}. This analysis is now being extended to measure a time-dependent $CP$ violating asymmetry that is sensitive to $\sin(2\phi_1 + \phi_3)$. 
Amplitude analysis of $B \to D^{*-} \rho^+$. This decay provides another potential opportunity for measuring the weak $CP$-violating phase combination $2\phi_1 + \phi_3$. It is attractive because it is relatively free of hadronic uncertainties. An analysis of angular correlations between the $D^*$ and $\rho$ meson decay products is necessary to determine the contribution of $CP$-even and $CP$-odd amplitudes to the final state.

Figure 2.8: $\pi^+\pi^0$ invariant mass distribution of the $B \to D^{*-} \pi^+ \pi^0$ candidates. The curve shows a fit to a $P$-wave Breit Wigner line shape.

Using 60 fb$^{-1}$ of $\Upsilon(4S)$ data ($65 \times 10^6$ B pairs), Peters and Trabelsi have isolated a clean sample of $\sim$8000 $D^{*-} \rho^+$ candidate events. Figure 2.8 shows the $\pi^+\pi^0$ invariant mass of the $\rho$ candidate after background suppression.

The angular correlations are measured with an event-by-event unbinned likelihood fit. The fitting tools have been developed and the analysis is currently being optimized using MC data. We expect this optimization to be finalized in the near future, at which time we will apply it to the data. After the $CP$ content of the final states is determined, a time-dependent likelihood fit will be used to extract $\sin(2\phi_1 + \phi_3)$.

Figure 2.9: The $\Delta E$ (left) and beam-constrained mass (right) projections for the $B \to \eta_c K$ sample.
2.1. B-MESON PHYSICS WITH BELLE

Measurements of $B \rightarrow \eta_c K$ Decay Modes. The neutral decay $B^0 \rightarrow K^0 \eta_c$ is a $CP$ eigenstate mode. Hawaii student Fang selects the events in this channel for the measurement of the $CP$ violation parameter $\sin 2\phi_1$. In addition, Fang and Browder have carried out measurements of branching fractions for charged and neutral $B \rightarrow \eta_c K$ and $B \rightarrow \eta_c K^*$ decays where the $\eta_c$ meson is reconstructed in the $K^0_S K^\mp \pi^\pm, K^+ K^0 - \pi^+ , K^{*0} K^- \pi^+ \text{ and } p\bar{p}$ decay channels. Signals are evident in the energy difference $(\Delta E)^0$ and beam-constrained mass distributions shown in Fig. 2.9. A new measurement of the mass and width of the $\eta_c$ meson was also obtained. The results are published in Physical Review Letters with Fang as first author [45]. An offshoot of this analysis was Fang’s first observation of the charmless baryonic decay $B \rightarrow p\bar{p}K$ at an unexpectedly high branching fraction of $\sim 4 \times 10^{-6}$. This result was published in Physical Review Letters [21].

Observation of the $\eta_c(2S)$ meson. Olsen and Gyeongsang University collaborator Choi made the first observation of the $\eta_c(2S)$ ($\eta_c'$) in the process $B \rightarrow \eta_c(2S) K$, $\eta_c(2S) \rightarrow K_S K^+ \pi^-$. Figure 2.10 shows the $M_{bc}$ and $\Delta E$ projections for the signal as well as the signal yield fitted in bins of $K_S K^\pm \pi^\mp$ mass. A clear signal is seen at the $\eta_c$ mass as well as in the mass range expected for the $\eta_c(2S)$. The measured mass of the new state ($\eta_c(2S)$) is

$$M = 3654 \pm 6(stat) \pm 8(sys) \text{ MeV}/c^2$$

and we place a 90% confidence level upper limit on the width of $\Gamma < 55 \text{ MeV}/c^2$. These results, which were the subject of a recent CERN Courier article, are published in Physical Review Letters with Choi and Olsen as first authors [30].

![Figure 2.10: The $B^- \rightarrow K^- K_S K \pi$ yield versus $K_S K^\pm \pi^\mp$ mass.](image)

Studies of $B \rightarrow K \pi$ and $\pi \pi$. Browder and former Hawaii student Casey measured the branching fractions for $B^0 \rightarrow K^- \pi^+$, $B^- \rightarrow K^- \pi^0$, $B^0 \rightarrow \pi^+ \pi^-$, $B^- \rightarrow \pi^- \pi^0$, $B^- \rightarrow K_S \pi^-$, $B^0 \rightarrow K_S \pi^0$ and their charge conjugates. Signals are seen for $B \rightarrow \pi^+ \pi^-$.

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†This paper was published before Belle instituted its current first author policy.
and $\pi^+\pi^0$ (Fig. 2.11), and branching fractions are reported. With the current data sample only an upper limit is determined for $B \rightarrow \pi^0\pi^0$. These results are published in Physical Review D with Casey as first author [43]. Browder and Casey were also primary authors of earlier Belle papers on this subject [5, 25].

Figure 2.11: The beam-constrained mass distributions for the $B \rightarrow \pi\pi$ event candidates. With the current data sample only upper limits have been set for $B \rightarrow \pi^0\pi^0$. This analysis provided the $\pi^+\pi^-$ event sample used for the Belle $\phi_2$ measurements.

Figure 2.12: $\Delta E$ distributions for the charge conjugate modes (a) $B^- \rightarrow D_{CPeven}K^-$, (b) $B^+ \rightarrow D_{CPeven}K^+$, (c) $B^- \rightarrow D_{CPodd}K^-$, (d) $B^+ \rightarrow D_{CPodd}K^+$. 

**Study of $B^\pm \rightarrow D_{CP}K^\pm$ and $B^\pm \rightarrow D_{CP}K^{*\pm}$.** Here $D_{CP}$ designates a $CP$ eigenstate decay mode of the $D^0$ meson. In these decays Cabibbo-suppressed and $V_{ub}$ amplitudes interfere. This interference can produce a direct-$CP$ violating rate asymmetry between $B^+$ and $B^-$. Browder and Hawaii student Swain are measuring branching fractions and $CP$-violating asymmetries in these channels with the ultimate goal of determining $\phi_2$ in a model-independent manner. $\Delta E$ distributions for $B^+$,
$B^-$ for both $D_{CP\text{even}}$ and $D_{CP\text{odd}}$ are shown in Fig. 2.12. Current results for the $B^\pm \to D_CPK^\pm$ partial rate asymmetry based on a 78 fb$^{-1}$ data sample are

$$A_{CP\text{even}} = 0.06 \pm 0.19 \pm 0.04$$

$$A_{CP\text{odd}} = -0.19 \pm 0.17 \pm 0.05.$$  

This has been submitted for publication to Physical Review D with Swain and Browder as first authors [58]. They also contributed significantly to an earlier version of this analysis that was published in Physical Review Letters [34].

**Charm fragmentation into $D^{*\pm}$.** Recent measurements of heavy quark fragmentation functions at LEP and SLD suggest that they are more similar to that of light quarks than previously believed. Seuster is using Belle’s large sample of $e^+e^- \to c\bar{c}$ continuum events to determine the charmed-quark fragmentation function. Figure 2.13 shows the efficiency-corrected momentum distribution of $D^*$ mesons for both off- and on-$\Upsilon(4S)$ data samples. Also included are expectations using the commonly used Peterson fragmentation function$^{11}$; discrepancies with the off-resonance measurements are evident. A paper describing these results is in preparation. Previous papers on this subject were published nearly 20 years ago by ARGUS$^{12}$ and CLEO.$^{13}$

![Figure 2.13](image1.png)

Figure 2.13: $x_p (= p^*/p_{max}^*)$ distributions of inclusive $D^*$ mesons for off- (open circles) and on-$\Upsilon(4S)$ (open triangles) data samples. Discrepancies with Peterson-model expectations (solid triangles) are evident.

![Figure 2.14](image2.png)

Figure 2.14: The $K_S \to \pi^+\pi^-$ invariant mass for unmodified (dotted) and modified (dashed) track helices, and modified helices plus a fit to a common vertex (solid). This is for MC data.
The enormous data samples provided by the KEKB and PEPII B-factories require precise Monte Carlo modeling of continuum processes, which are the main source of backgrounds for measurements involving rare B-meson decay processes. Seuster is active in the Belle Monte Carlo generator group, which tunes and adjusts the parameters of various fragmentation functions to improve the match to measured characteristics of the continuum data.

**K\(_{S}\)** Detection in Belle.

The \(\sin 2\phi_1\) measurement required the reconstruction of \(B^0\) decays to \(CP\) eigenstates, most of which include \(K_S \rightarrow \pi^+\pi^-\). Fang developed the Belle standard \(K_S\) selection criteria. Since the \(K_S\) is long-lived, it frequently decays either outside of the beam pipe or outside of the silicon vertex detector, and the assumption used for most charged particle reconstruction that all tracks originate from near the origin is not correct. Instead, the multiple scattering and energy loss corrections to the error matrix and track parameters for the \(K_S\) daughter particles must be treated case-by-case and transported only through the materials that are actually penetrated. After this is done, the \(K_S\) must be refit with the constraint that the two tracks originate from a common vertex position. Fang and Trabelsi implemented this part of the \(K_S\) reconstruction, which is now part of the standard Belle analysis system. The resulting improvements in the \(K_S\) mass resolution (distribution width) and yield (total area) are shown in Fig. 2.14.

### 2.1.3 Hawaii Detector Responsibilities in Belle

Hawaii has a number of detector-related tasks in Belle. These include tracking, particle identification using time-of-flight, vertex detection and trigger systems.

**Low momentum tracking with SVD and CDC**

Trabelsi recently rewrote the Belle low momentum track finder. The bad-hit rejection procedure in the CDC and the SVD hit association algorithm were improved. These changes resulted in dramatic improvements in tracking performance for many Belle analyses. The yield of \(B^- \rightarrow D^{*-}\rho^-\) measured in data increased by 18%. In the \(CP\) eigenstate channel \(B^0 \rightarrow D^{*-}\bar{D}^{*-}\), the detection efficiency improved by 30% to 90% depending on the charged multiplicity of the \(D^0\) final state. Graduate student Kent is working on further improvements to the tracking algorithms.
2.1. B-MESON PHYSICS WITH BELLE

Calibration of the time-of-flight system

The successful measurements of $CP$ violation by the Belle experiment depend strongly upon the performance of the particle identification subsystems. The Time of Flight system, for which the Hawaii group provides major support, is the primary tool for $\pi/K$ separation in the momentum range from 0.6 to 1.2 GeV/c, the critical range for flavor tagging of the accompanying $B$ meson. The maintenance of 100 ps resolution throughout the experiment requires constant monitoring plus frequent and careful calibration. Peters wrote and maintains the TOF reconstruction and calibration software. Jones does the day-to-day data-quality monitoring and calibrations.

Constant monitoring is necessary because there are occasional sudden timing shifts that affect all TOF counters. These usually happen between runs although occasionally we have seen large shifts occur during a run. Sometimes changes occur in single TOF PMTs or in the electronics that affect only a single counter. By doing separate calibrations before and after such changes, Jones has been able to maintain a TOF time resolution near 100 ps. In fact, over the course of the experiment, the resolution has only degraded from 96 ps to 102 ps. We attribute this to a corresponding degradation in the mean attenuation length in the TOF scintillator from 300 to 230 cm. This gradual degradation is occurring at the level expected for radiation damage and aging effects.

Trigger improvements

KEKB has now exceeded 100% of design luminosity with background rates that are about 150% higher than anticipated. Consequently, improvements in the triggering for Belle are required. During the past year, Hawaii student Guler implemented a new TOF trigger system. Her Xilinx-based electronics and revised trigger algorithm reduced a 350 ns effective deadtime to 96 ns, while maintaining high efficiency.

A new vertex detector, SVD2, is being installed during the summer 2003 shutdown. An important part of this upgrade is a new pipelined trigger system that makes a fast match between CDC- and SVD-determined impact points along the beamline. Hawaii student Uchida developed the algorithm and firmware to realize this logic. She is responsible for its commissioning and subsequent operation.

Silicon vertex system

The performance of the silicon vertex system is inversely proportional to the radius of the innermost layer and the beampipe. Since background radiation levels have a similar radial dependence, the design of the vertex system requires a careful understanding of
beam-related backgrounds. Browder has been involved with this since the initial start-up of KEKB, when he led the group that built and operated a commissioning detector to survey radiation levels near the interaction region before the roll-in of the Belle detector.

The new SVD2 vertex system has four silicon layers surrounding a 1.5 cm radius beam-pipe. (The SVD1 system that it replaces had three layers and a 2 cm radius pipe.) The smaller radius will improve vertex resolution and the fourth layer will improve the tracking efficiency for low-momentum particles. Important components of the SVD2 design were Trabelsi’s modeling of spent particle backgrounds and Swain’s study of synchrotron X-ray fluxes near the Belle interaction point both for the SVD1 and SVD2 beam-pipe configurations.

**Spent particle backgrounds** An example of Trabelsi’s spent-particle simulation work is shown in Fig. 2.15, which indicates the strong radial dependence of the radiation dose. The simulation includes two parts: a simulation of the KEKB accelerator (including all magnets in both rings) and a GEANT model of the Belle detector and its immediate surroundings. The reliability of the simulation was verified with experiments with vacuum bumps and changes of accelerator parameters. These experiments indicated that Touschek intra-beam scattering is an important source of off-energy positrons in the low energy ring, and this was modeled in the simulation. At present, the simulation predicts 40.5 krad/yr from the high energy ring (HER) and 91.7 krad/yr from the low energy ring (LER) for SVD1 at design luminosity conditions. This can be compared to experimental results of 24 krad/yr (HER) and 82 krad/yr (LER). This is quite reasonable agreement for this type of calculation.

![Figure 2.15: The expected radiation dose from beam background as a function of beam-pipe radius in the silicon vertex detector for SVD1 and SVD2.](image-url)
2.1. **B-MESON PHYSICS WITH BELLE**

**Synchrotron X-rays** The large beam currents and the high beam-bunch frequency of KEKB make it difficult to mask synchrotron radiation. Swain modeled X-ray fans from all of magnetic elements in the straight sections in the Belle region, including correction magnets with all possible settings. In the \( r = 2 \) cm beampipes used for SVD1, the axis was aligned with the LER beamline and masks for HER-generated X-rays produced some unwanted heating from trapped higher-order mode RF excitations. Swain found that by tilting the axis of the beampipe to be 11 mrad from the LER (and the HER) beamline, X-ray masks with better RF properties could be configured for the SVD2 \( r = 1.5 \) cm beampipe.

### 2.1.4 R&D for future upgrades

Varner is leading a number of short- and long-term initiatives to improve the performance of the current Belle detector, as well as develop instrumentation and readout electronics for a Super B-factory detector. The short term goals are to develop electronics which will allow for efficient operation of the current detector at instantaneous luminosities and backgrounds in excess of design values. In the longer term Hawaii is involved in the development of detectors and readout electronics with the finer segmentation and pipelined readout mandated for future higher luminosity operation.

**TOF Improvement**

Although the TOF system continues to provide excellent performance, the scintillator attenuation length continues to decrease with time and higher luminosity operation produces background-induced inefficiencies and systematic errors. Varner’s successful development of STRAW2, a low-cost, high speed pulse-form sampling chip for the ANITA project,\(^{14}\) raises the possibility of using it to reduce rate-dependent systematic effects in the TOF system. During the summer of 2003, as part of the Quarknet program,\(^ {15}\) Peter Grach, an area high school physics teacher, is exploring the potential benefits of sampling electronics for TOF systems.

**Pipelined Readout**

Now that the KEKB luminosity is exceeding its design value, the data acquisition system chosen for Belle is reaching the limits of its capability. In order to accommodate anticipated luminosity increases, the DAQ system will have to be changed over to a so-called “pipeline” architecture, where analog values from the detector are continually sampled and small time windows of interest are transferred for further processing based upon simple trigger criteria. Varner and Zheng have been involved with the design and prototyping of a system for such a pipelined readout as part of a common effort for
Belle and high-trigger-rate experiments at the new 50 GeV hadron facility (J-PARC) in Japan. The COrmon Pipelined Platform for Electronics Readout (COPPER) board is being developed by KEK as the backbone of the new data acquisition architecture. The electronics unique to each subdetector are located upon FINESSE daughtercards (Front-end Instrumentation Entity for Sub-detector Specific Electronics) that plug into the COPPER boards. Details of the development of this system are available in papers [D6] and [D7].

While the COPPER system was originally intended for a major upgrade in 2006, the strain on the current electronics caused by the exceptional KEKB performance has forced us to plan for upgrades to some subsystems as soon as summer 2004. In order to evaluate the system’s data compaction performance, Zheng has developed a universal FINESSE emulator card, which can simulate different front-end electronics prior to their actual existence. This, for example, will enable us to optimize the number of readout channels on a given FINESSE during the design stage.

### PID upgrade

While the composite TOF plus threshold aerogel system currently used in Belle has been satisfactory, the BaBar collaboration has demonstrated that a Cherenkov-ring based system has better overall performance. The optimization of this technology for very high-luminosity environments will require high resolution timing measurement on a large number of channels. To meet such a requirement, Varner has developed a monolithic integrated circuit version (MTS1) of the Fastbus-sized Time Stretcher circuit used in the existing Belle TOF system to provide 25 ps resolution time measurements with a 500ps TDC. The reduced size (see Fig. 2.16) and cost of the MTS1 makes a PID system with 10~100K channels with precision timing resolution affordable. Guler is analyzing the system performance of the MTS1 and upcoming MTS2 prototypes.

### Vertexing upgrade

At higher luminosities, Belle’s current silicon strip detector readout, based on the Viking sample/hold architecture [D4], will be unusable. Therefore, for future Belle upgrades the APV25 pipelined chip, developed for the CMS experiment, has been adopted. Varner is developing a FINESSE-based interface to this readout chip.

Background levels near the interaction point will require finer segmentation than possible for a silicon strip detector. Moreover, studies by Varner and Trabelsi have demonstrated that for B-factory applications, the silicon pixel detectors developed for the LHC experiments are too thick. Thin, epitaxial monolithic detectors seem promising, and Fang is evaluating a prototype provided by the STAR group. Although it is
thin enough, the readout speed is too slow for our application. Varner is developing a high-speed variant of this device that will also be evaluated by Fang. We are planning a beam test at KEK to evaluate the performance of pixel detector options for Belle.

2.1.5 Physics at a $10^{36}$ asymmetric $e^+e^-$ $B$-factory

With asymmetric $B$ factories with luminosity approaching $10^{34}\text{cm}^{-2}\text{s}^{-1}$ Belle and BaBar have made important discoveries. It is now becoming clear that sensitive tests for new physics in the flavor sector can be made at an asymmetric $B$ factory with a luminosity around $10^{36}\text{cm}^{-2}\text{s}^{-1}$. These include searches for anomalous $CP$ violating phases in $B \rightarrow K^{(*)}\ell^+\ell^-$ and $B \rightarrow \phi K_s$ decays, study of the forward-backward asymmetry in $B \rightarrow K^*\ell^+\ell^-$ decays, and precision tests of the unitarity of the CKM matrix. The Hawaii Belle group is very interested in the physics potential of such a program.

Both the KEKB/Belle and the PEPII/BaBar communities have been seriously studying the accelerator and detector problems associated with a hundred-fold increase in luminosity. Both groups have formed study groups and held a number of workshops that address these challenges. Since it is likely that only one such facility, if any, will be built, it is important that the two efforts be closely coordinated. To this end, the Hawaii-Belle group will host a joint workshop in January 2004 that will bring together accelerator, experimental and theoretical physicists from the BaBar and Belle communities to share ideas and find areas for collaboration.
References


[3] $\Delta t$ is the decay time difference between the $B \to \text{CP}$ eigenstate decay and the flavor-tagged $B$.


[5] B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. 89, 281802 (2002). This paper reports $S_{\pi\pi} = 0.02 \pm 0.34(\text{stat}) \pm 0.05(\text{syst})$ and $C_{\pi\pi} = -0.30 \pm 0.25(\text{stat}) \pm 0.04(\text{syst})$. (Note that $C_{\pi\pi} = -A_{\pi\pi}$.)

[6] B. Aubert et al. (BaBar Collaboration), contributed paper to the Amsterdam ICHEP2002 meeting (July 2002), hep-ex/0207082.

[7] The beam-energy constrained mass is defined as $M_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2}$, where $E_{\text{beam}}$ is the beam energy and $p_B$ is the three-momentum of the candidate $B$ meson evaluated in the $\Upsilon(4S)$ rest frame.


[9] The energy difference is defined as $\Delta E = E_{\text{beam}} - E_B$, where $E_{\text{beam}}$ is the beam energy and $E_B$ is the the candidate $B$ meson’s center-of-mass frame energy.


[15] The Quarknet program is supported by the DOE and NSF, information available online: http://quarknet.fnal.gov


2.1.6 Belle publications, in order of submission

1. K. Abe et al. (Belle Collaboration), “Measurement of $B_d^0 - \bar{B}_d^0$ Mixing Rate from the Time Evolution of Dilepton Events at $\Upsilon(4S)$,” Physical Review Letters 86, 3228 (2001)

2. A. Abashian et al. (Belle Collaboration), “Measurement of the $CP$ Violation Parameter $\sin(2\phi_1)$ in $B^0$ Meson Decays,” Physical Review Letters 86, 2509 (2001)


11. K. Abe et al. (Belle Collaboration), “Observation of Color-suppressed $B^0 \rightarrow D^{0}\pi^0$, $D^{*0}\pi^0$, $D^0\eta$, and $D^0\omega$,” Physical Review Letters 88, 052002 (2002)


17. K. Abe et al. (Belle Collaboration), “Determination of $|V_{cb}|$ using the semileptonic decay $\overline{B}^0 \to D^{*+}\pi^-\nu$,“ Physics Letters B 526, 247 (2002)

18. K. Abe et al. (Belle Collaboration), “Measurement of $\text{Br}(\overline{B} \to D^{+}\ell^-\nu)$ and Determination of $|V_{cb}|$,” Physics Letters B 526, 258 (2002)


27. K. Abe et al. (Belle Collaboration), “Radiative B Meson Decays into $K\pi\gamma$ and $K\pi\pi\gamma$ Final States,” Physical Review Letters 89, 231801 (2002)

28. K. Abe et al. (Belle Collaboration), “Observation of $\overline{B}^0 \to D^{(*)0}p\overline{p}$,” Physical Review Letters 89, 151802 (2002)


34. K. Abe et al. (Belle Collaboration), “Studies of the Decay $B^0m \rightarrow D_{CP}K^\pm$,” Physical Review Letters 90, 131803 (2002)

35. R.S. Lu et al. (Belle Collaboration), “Observation of $B^{\pm} \rightarrow \omega K^{\pm}$ Decay,” Physical Review Letters 89, 191801 (2002)


50. Y.H. Zheng, T.E. Browder et al. (Belle Collaboration), “Measurement of the \(B^0\overline{B}^0\) mixing rate with \(B^0\overline{B}^0 \rightarrow D^*\pi\pi^\pm\) partial reconstruction,” Physical Review D 67, 052004 (2003)


52. N. Gabyshev, H. Kichimi et al. (Belle Collaboration), “Observation of \(B^0 \rightarrow \Lambda_c^+ \overline{\nu}\) decay,” Physical Review Letters 90, 121802 (2003)

53. P. Krokovny et al. (Belle Collaboration), “Observation of \(B^0 \rightarrow D^0 \overline{K}^0\) and \(B^0 \rightarrow D^0 \overline{K}^0\) decay,” Physical Review Letters 90, 141802 (2003)

54. K. Abe et al. (Belle Collaboration), “Study of Time-Dependent \(CP\)-Violating Asymmetries in \(b \rightarrow s\tau\overline{q}\) Decays,” Physical Review D 67, 031102 (R)(2002)

55. K. Abe et al. (Belle Collaboration), “Evidence for \(CP\)-Violating Asymmetries in \(B^0 \rightarrow \pi^+ \pi^-\) Decays and Constraints on the CKM Angle \(\phi_2\),” KEK preprint 2003–1, Belle preprint 2003–1, hep-ex/0301032
(submitted to Physical Review D)

56. M.-Z. Wang, Y.-J. Lee et al. (Belle Collaboration), “Observation of \(B^0 \rightarrow \rho \overline{K} \pi^-\),” Physical Review Letters 90, 201802 (2002)

57. Y. Unno, K. Suzuki et al. (Belle Collaboration), “Improved Measurement of the Partial-Rate \(CP\) Asymmetry in \(B^+ \rightarrow K^0 \pi^+\) and \(B^- \rightarrow \overline{K}^0 \pi^-\) Decays,” KEK preprint 2003–7, Belle preprint 2003–4, hep-ex/0304035
(submitted to Physical Review D)

(submitted to Physical Review D)


2.1.7 Belle Hardware publications with Hawaii authors


2.2 The BES Experiment

Drs. Z.J. Guo, F.A. Harris, S.L. Olsen, G. Varner and Mr. X. Cai

2.2.1 Introduction

The BES detector is a large-solid-angle multi-particle spectrometer based on a 4.5 kilogauss solenoid magnet operating at the BEPC $e^+e^-$ storage ring in Beijing. The BES experiment is a collaboration between the Institute of High Energy Physics (IHEP) and universities in China, Japan, and Korea, and Colorado State, Hawaii, SLAC and UT(Dallas) in the U.S.

The BEPC energy range spans the charm- and $\tau$-pair thresholds, making BES the only experiment, until recently, with the capability of addressing a variety of important physics questions. For example, BES measurements of $R_{\text{had}}$ at 91 different energy points between 2 and 5 GeV improved on the precision of previous measurements by a factor of 2 to 3 and had a strong effect the value of $\alpha_{\text{QED}}(m_Z^2)$ and the SM prediction for the mass of the Higgs particle. More recently, BES accumulated 58 M $J/\psi$ events and 14 M $\psi(2S)$ events, which are the world’s largest $e^+e^-$ produced charmonium samples. In the past year BES accumulated an integrated luminosity of about 20 pb$^{-1}$ at the $\psi''$.

2.2.2 Hawaii Participation in BES

Hawaii joined the BES collaboration in 1993 and since then has had a strong impact on the BES program. We are currently the largest US group in BES; Harris has been co-spokesman of the experiment since 1998. Our group participated in the analysis of the BESI $\psi(2S)$ (Varner and Paluselli’s PhD thesis subjects) and the 4.03 GeV (Pan’s PhD thesis subject) data samples, took a leading role in the $R_{\text{had}}$ measurements (D. Kong’s PhD thesis subject), and is now studying the recently accumulated $J/\psi$ and $\psi(2S)$ data samples. For the BESII detector upgrade, we prepared a laser/fiber-optic calibration system for the new time-of-flight detector and provided the front-end electronics for the new vertex detector. We also provided new, more compact preamplifier cards for the inner MDC layers that were needed to accommodate the reconfiguration of the high voltage for the MDC-II repair. Our group was responsible for the fabrication of the endplates and the outer cylinder for MDC-III, and the design and fabrication of the preamplifier cards.
2.2.3 Physics Results

Here we summarize results from recent Hawaii-based analyses of BES data.

$R_{had}$ Measurement

During the initial 1998 $R$-scan run, we made measurements of $R$ at CM energies of 2.6, 3.2, 3.4, 3.55, 4.6 and 5.0 GeV. In 1999, BES successfully completed a dense scan of $R_{had}$ measurements from 2 to 5 GeV. A total of 85 energy points were measured over a period of five months with the majority being in the very poorly determined resonance region. The final results are shown in Fig. 2.17 along with the values from the 1998 $R$-scan run. Systematic uncertainties are between 6 and 10 % with an average uncertainty of 6.3 % and are less than half of the previous uncertainties. Harris and Kong were heavily involved in this analysis. These results are published in Physical Review Letters [3,10].

![Figure 2.17: Plot of $R$ values vs $E_{cm}$.](image)

The importance of these results has been emphasized by Burkhardt and Pietryzk. With the new BES $R$-values, they obtain a new value for $\alpha^{-1}(M_Z^2) = 128.936 \pm 0.046$, where the error is about one-half the 1995 error. The CERN Electroweak Group finds that this result shifts the central value for the Higgs mass upward by about 50% to $M_H = 98$ GeV, which is more comfortably consistent with the LEP lower limits (see Fig. 2.18).

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References in bold face type refer to the BES publication list at the end of this section.
Figure 2.18: $\chi^2$ from fit to the Standard Model (solid curve) as a function of $m_H$. The fit includes the new BES R-value results.

Figure 2.19: Crosssections for $e^+e^- \rightarrow$ (a) hadrons, (b) $\pi^+\pi^- J/\psi$ and (c) $\mu^+\mu^-$ near the $\psi(2S)$ resonance.

Measurement of the $\psi(2S)$ Resonance Parameters

In order to improve the accuracy of the poorly known properties of the $\psi(2S)$ resonance, cross section measurements at 24 energy points spanning the $\psi(2S)$ resonance were done as part of the $R$-scan. These were used to determine the $\Gamma_t$, $\Gamma_{\text{hadron}}$, $\Gamma_{\mu\mu}$, and $\Gamma_{\pi^+\pi^- J/\psi}$ resonance parameters. Harris, who had previously done a comprehensive study of $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ decays with the BESI $\psi(2S)$ sample [5], analyzed this channel in the scan data; the other channels were done at IHEP. Fit results as a function of energy are shown as curves in Fig. 2.19 and listed in Table 2.1. For most of the parameters the precision of the BES measurements are improvements over the PDG averages; the $\Gamma_{\pi\pi J/\psi}$ result is a first measurement. These results are published in Physics Letters [12].

Studies of $J/\psi \rightarrow \gamma K^+ K^-$ and $\gamma K^0_S K^0_S$

Lattice Gauge Theory calculations predict that the lowest-lying glueball state should occur in the mass range 1.4~1.8 GeV, and have $J^{PC} = 0^{++}$. Since for $J/\Psi$ radiative decays to two pseudoscalar mesons, only $J^{PC}$ values in the series $0^{++}$, $2^{++}$, ... are possible, it follows that this process provides a promising environment in which to search for the lowest mass scalar glueball. The long history of uncertainty about the properties of the $f_0(1710)$, one of the earliest glueball candidates, is reviewed in detail in the latest issue of the PDG. A reanalysis of Mark III data by Dunwoodie favors
Table 2.1: $\psi(2S)$ resonance parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BES</th>
<th>Mark I</th>
<th>PDG2002$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma(keV)$</td>
<td>264 ± 27</td>
<td>228 ± 56</td>
<td>300 ± 25</td>
</tr>
<tr>
<td>$\Gamma_0(keV)$</td>
<td>258 ± 26</td>
<td>224 ± 56</td>
<td></td>
</tr>
<tr>
<td>$\Gamma_{\pi \pi J/\psi}(keV)$</td>
<td>85.4 ± 8.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Gamma_\mu(keV)$</td>
<td>2.44 ± 0.21</td>
<td>2.1 ± 0.3</td>
<td>2.19 ± 0.15</td>
</tr>
<tr>
<td>$B_0(%)$</td>
<td>97.79 ± 0.15</td>
<td>98.1 ± 0.3</td>
<td>98.10 ± 0.30</td>
</tr>
<tr>
<td>$B_{\pi \pi J/\psi}(%)$</td>
<td>32.3 ± 1.4</td>
<td>32 ± 4</td>
<td>30.5 ± 1.6</td>
</tr>
<tr>
<td>$B_\mu(%)$</td>
<td>0.93 ± 0.08</td>
<td>0.93 ± 0.16</td>
<td>0.73 ± 0.04</td>
</tr>
</tbody>
</table>

$J^P = 0^{++}$ over the earlier assignment of $2^{++}$, while the latest hadron production data of WA76 and WA102 also favor $0^{++}$.$^5,^6$

Hawai‘i postdoctoral fellow Guo is investigating the radiative decay $J/\psi \to \gamma K^+K^-$ and $\gamma K^0_S K^0_S$ with the high statistics BESII $J/\psi$ sample. Acceptance-corrected $M_{KK}$ spectra are shown in Fig. 2.20, where there are conspicuous peaks due to the $f_2'(1525)$ and $f_0(1710)$ in both the $K^+K^-$ and $K^0\bar{K}^0$ samples. Partial wave analyses (PWA) using the tensor amplitude analysis method are performed for the $KK$ mass range between 1 and 2 GeV. In a bin-by-bin analysis, angular distributions for 40 MeV-wide mass “slices” are fit with $0^+$ ($a_{0,0}$) and $2^+$ ($a_{2,0}$, $a_{2,1}$, and $a_{2,2}$) amplitudes. The resulting amplitude intensities, shown in Fig. 2.21, show a clear peak around 1710 MeV for $0^+$ and a peak for $2^+$ near 1525 MeV. Guo finds similar results for a global partial wave analysis where phase variations as a function of mass are constrained to simple Breit-Wigner behavior. From the global PWA, he obtains an $f_0(1710)$ mass and width of $1740 \pm 4^{+10}_{-25}$ MeV and $166^{+5}_{-8} \pm 15$ MeV, respectively. Spin 0 is preferred strongly over spin 2. For the $f_2'(1525)$, the mass and width are $1519 \pm 2^{+5}_{-7}$ MeV and $75 \pm 4^{+15}_{-8}$ MeV, respectively. This result will soon be submitted for publication in Physical Review D.

**Studies of $J/\psi \to \gamma p\bar{p}$**

There is evidence for anomalous behavior in the proton-antiproton system very near the $M_{p\bar{p}} = 2m_p$ mass threshold. The cross section for $e^+e^- \to \text{hadrons}$ has a narrow dip-like structure at a center of mass (cm) energy of $\sqrt{s} \approx 2m_p c^2$.$^7$ In addition, the proton’s time-like magnetic form-factor, determined from high statistics measurements of the $p\bar{p} \to e^+e^-$ annihilation process, exhibits a very steep fall-off just above the $p\bar{p}$ mass threshold.$^8$ These data are suggestive of a narrow, $S$-wave triplet $p\bar{p}$ resonance with $J^P_C = 1^{--}$ and mass near $M_{p\bar{p}} \approx 2m_p$. There is, however, no known vector meson resonance that could be associated with such a state.
Using the BESII $J/\psi$ sample, Olsen investigated the $p\bar{p}$ system produced in the radiative process $J/\psi \rightarrow \gamma p\bar{p}$. The $p\bar{p}$ invariant mass distribution for $J/\psi \rightarrow \gamma p\bar{p}$ candidate events, shown in Fig. 2.22, has a peak near 3 GeV that corresponds to $J/\psi \rightarrow \gamma \eta_c$, $\eta_c \rightarrow p\bar{p}$ plus a prominent structure with mass near $2m_p$. No corresponding structure is seen in $J/\psi \rightarrow \pi^0 p\bar{p}$. Figure 2.23(a) shows the low-mass region together with the results of a fit using an acceptance-weighted $S$-wave Breit-Wigner function to represent the low-mass enhancement plus a phase-space distribution (dashed curve) to represent the background, primarily due to $J/\psi \rightarrow \pi^0 p\bar{p}$ where one of the photons from the $\pi^0 \rightarrow \gamma\gamma$ is missed. The fit yields a peak mass of $M = 1859^{+3}_{-10}\text{(stat)}^{+5}_{-25}\text{(sys)}$ MeV/c^2 and a full width of $\Gamma < 30$ MeV. Here the systematic errors include errors determined by generating Monte Carlo samples with below threshold peak masses and measuring the shift in the output fit masses.

Further evidence that the peak mass is below the $2m_p$ threshold is provided by Fig. 2.23(b), which shows the $M_{p\bar{p}} - 2m_p$ distribution when the threshold behavior
Figure 2.22: The $p\bar{p}$ invariant mass distribution for the $J/\psi \rightarrow \gamma p\bar{p}$ event sample

Figure 2.23: (a) The near-threshold $M_{p\bar{p}} - 2m_p$ distribution for the $\gamma p\bar{p}$ event sample. The solid curve is the result of the fit; the dashed curve shows the fitted background function. (b) The $M_{p\bar{p}} - 2m_p$ distribution with events weighted by $q_0/q$. Is removed by weighting each event by $q_0/q$, where $q$ is the proton momentum in the $p\bar{p}$ restframe and $q_0$ is the value for $M_{p\bar{p}} = 2 \text{ GeV}/c^2$. The sharp and monotonic increase at threshold can only occur for an $S$-wave BW function when the peak mass is below $2m_p$. A fit using a $P$-wave BW for the signal has a poorer confidence level than the $S$-wave fit, but is still acceptable. It has been suggested that this structure is a bound state of “baryonium,” a proton-antiproton analogy to the $^1S_0$ virtual bound state of the deuteron.$^{10}$

These results have been accepted for publication in Physical Review Letters [18].

### 2.2.4 BESIII/BEPCII

The recently approved CLEO-c project will lower the CESR energy to the charm- and $\tau$-pair threshold region, where it will operate with the CLEO-II detector. CLEO-II is a modern device with much better performance than BESII, which is based on mostly out-of-date technologies. Moreover, the luminosity for CESR in the $J/\psi$ mass region is expected to be more than $1 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1},^9$ a factor of 20 times the luminosity of BEPC at the $J/\psi$ ($\sim 5 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$).

The prospect of being superseded by CLEO-c forced a reevaluation of the BES/BEPC upgrade plans by IHEP and the Chinese Academy of Science. As a result, a new two-
ring machine with an expected luminosity of $1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$ (BEPCII) and a new, state-of-the-art detector (BESIII) have been approved by the Chinese government. The BESIII plans include a small cell, helium-based drift chamber, a TOF system with better than 100 ps time resolution, a CsI crystal calorimeter, and an RPC muon detector that uses the flux-return iron of a new 1 Tesla superconducting magnet. Completion is expected in late 2006.

IHEP held a BESIII Workshop in Nov. 2001 and a BESIII collaboration meeting in June 2002. Groups from Japan, Taiwan, Korea, Russia, China, and the US attended the collaboration meeting. A second collaboration meeting planned for June 2003, which was to be the first such meeting after the official BESIII approval, had to be postponed because of the SARS problem. The University of Hawaii group plans to participate in BESIII. A natural role, already initiated by Varner, would be to contribute to the TOF system electronics because this would be symbiotic with our Belle TOF efforts. IHEP has also expressed interest in having Hawaii oversee the machining in the United States of the beryllium beampipe.

### 2.2.5 Summary

The BES/BEPC facility provides unique opportunities for investigations of a variety of important physics subjects. The US participation in this program has been important both scientifically and politically: the interest of U.S. researchers in the BES physics program has increased its visibility in China and this has helped IHEP maintain its level of support for this effort. The U.S. groups have contributed strongly to this project by providing key parts of the detector hardware and software, as well as in the analysis of data and generation of physics results.

With a rather modestly funded effort, the Hawaii group has a substantial and beneficial impact on the BES/BEPC program. We are the most active of the U.S. groups involved in BES and provide much of the leadership for the experiment. Moreover, we have produced a number of interesting physics results.
References


2.2.6 Recent BES Publications


6. J.Z. Bai et al. (BES Collaboration), “Direct measurement of $B(D^0 \to \phi X^0)$ and $B(D^+ \to \phi X^+)$,” Physical Review D 62, 052001 (2000)


18. J.Z. Bai et al. (BES Collaboration), “Observation of a near-threshold enhancement in the $p\bar{p}$ mass spectrum from radiative $J/\psi \to \gamma p\bar{p}$ decays” (hep-ex/0303006), accepted for publication by Physical Review Letters (2003).
2.3  Pixel detector R&D

S.I. Parker

2.3.1  Introduction

Silicon sensors, made by the standard planar process, have electrodes that lie in planes along the top and bottom surfaces, with electric fields that are largely perpendicular to those surfaces. Necessary bias voltages for full depletion, charge collection times, and for radiation damaged sensors, carrier capture probabilities, are strongly influenced by the sensor thickness. Parker has developed sensors in which the electrodes are perpendicular to the surfaces, forming a 3-dimensional (3D) sensor array, as shown in Fig. 2.24.

![Schematic view of a section of a 3D sensor](image)

Figure 2.24: Schematic view of a section of a 3D sensor with the front edge drawn through a row of n electrodes.

In the 3D geometry, the inter-electrode spacing can be made smaller than the wafer thickness. This makes it possible to fabricate sensors with low depletion voltages, fast charge collection, and high resistance to bulk radiation damage. In addition, by fabricating the edges with the same technology that is used to make the electrodes, it is possible to have sensors that are sensitive to within a few, rather than hundreds, microns of the physical edges. This active-edge technology has also been used to make planar interior / 3D active-edge sensors in which the interior electrodes lie on the top
and bottom surfaces, but where the sensitive area extends to within a few microns of the edges.

Initial work started late in 1995. The first paper, which presents calculations of the expected properties and proposed a sequence of fabrication steps, was published in 1997 [1]. The second described results for a prototype device, with details of the fabrication steps that were actually used, and with results of infrared micro-beam measurements of its major properties, was published in 1999 [2]. Three subsequent papers were published in 2001. One gives results from exposures to beta and x-rays [3]. A second reports on the performance after an intense proton irradiation that produced bulk damage comparable to or worse than that expected for ten years of operation in the innermost layer of the Atlas pixel detectors at the Large Hadron Collider [4]. The third gives results from sensors with wall electrode, long, flat 3D electrodes that provide a preview of the expected performance of active-edge electrodes [5].

Since the publication of these results, pulse-shape measurements have been made with fast amplifiers and two different types of sensors with active edges have been fabricated and shown to work in preliminary tests.

As the work has proceeded, the number of people and groups involved has increased:

1. Cinzia Da Via, Jasmine Hasi, Angela Kok (Brunel University);
2. Giovanni Anelli, Pierre Jarron (CERN);
3. John Morse (European Synchrotron Radiation Facility);
4. Gerrit Meddeler, Emanuele Mandelli, George Zizka (LBL);
5. Christopher Kenney and Ed Westbrook (Molecular Biology Consortium);
6. Hitoshi Yamamoto (Tohoku University).

Kenney, the Brunel and CERN groups, and Yamamoto work on high-energy physics applications, while Hasi, Morse, the LBL group, and the Molecular Biology Consortium work on National Institutes of Health-supported structural molecular biology applications. Julie Segal and Eric Perozziello, former Ph.D. students who did their thesis work at the Stanford Center for Integrated Systems, work with us as part-time consultants.

The current activities include:

1. active-edge sensor fabrication and testing of already fabricated devices in a beam at CERN for possible use in the forward-angle Roman pots of the Totem/CMS collaboration and, perhaps, also in a similar application being proposed by the Atlas collaboration;
2. further fabrication, and testing of already fabricated sensors for a proposed linear collider beam-shape monitor;

3. measurement of output pulse-shapes using fast amplifiers;

4. testing of active-edge sensors in an x-ray microbeam at the Berkeley Advanced Light Source;

5. testing of a recently fabricated pixel readout chip without active-edge sensor inputs for the NIH work, and, if the chip works, with such sensors attached;

6. fabrication of full-sized sensors for the NIH project;

7. research devoted to improvements in relevant technologies, for example, etching improvements to make holes with smaller diameters and, thus, thinner electrodes, and improvements in the connections between readout chips and sensors.

2.3.2 Radioactive source results

A $^{244}$Am pulse-height spectrum is well fit with a Gaussian function with $\sigma/E = 2.0\%$. The low-side tail is small and indicates good charge collection. Similar results are seen with $^{55}$Fe sources [4].

2.3.3 Radiation hardness

Paper [5] presents test results for sensors irradiated with $5 \times 10^{14}$ 24-GeV protons/cm$^2$, and $10^{14}$ to $10^{15}$ 55-MeV protons/cm$^2$, with the latter producing lattice damage equal to that expected for the innermost “B-layer” of the Atlas detector after ten years of operation at the LHC. Leakage currents, depletion voltages, release rates of trapped charge, and electrode capacitance measurements are reported. For the sensor exposed to $10^{15}$ 55-MeV protons/cm$^2$, a plateau that runs from 105 to 150 Volts is measured. An even further increase in hardness would result from the use of oxygen-diffused wafers. With, in addition, beneficial annealing, a substantial further reduction in depletion voltage could be expected.

2.3.4 Beam monitoring at the Next Linear Collider

At high energy linear $e^+e^-$ colliders, a large number of electron-positron pairs will be created via the QED $\gamma\gamma \rightarrow e^+e^-$ process. These pairs are predominantly directed along the beamline and acquire a $p_t$ kick from the electromagnetic field of the on-coming bunch. If the charges of the created particle and the on-coming bunch are opposite in
sign, the created particle oscillates around the beam plane and the net $p_t$ kick is small. If the particle and the on-coming bunch have the same-sign charge, the $p_t$ kick will be larger and, because of the flat shape of the linear collider beam, be mostly in the vertical direction. The distributions of $p_t$ and azimuthal angle of this large deflection can be used to infer $\sigma_x$ and $\sigma_y$ of the on-coming bunch [4]. With as many as $10^5$ pairs created per bunch crossing, a beam profile monitor with sufficient rate handling, spatial and timing resolution, as well as radiation hardness is needed. The high occupancy suggests that silicon-strip detectors are not suited for this application while CCDs, good candidates in terms of occupancy, would not give the timing information necessary to study possible structures within a train unless some external gating is applied. We are providing Yamamoto of Tohoku University with 3D sensors that are fast enough to respond before the next beam bunch arrives; he is working on the electronics and system design.

### 2.3.5 Fast pulses

![Figure 2.25: Schematic illustration of charge collection in 3D and in planar sensors.](image)

In 3D sensors, the lateral cell sizes are smaller than the standard 300-micron wafer thickness of planar sensors and, thus, the collection distances are short and the pulses fast. This is illustrated schematically in Fig. 2.25. Moreover, in 3D sensors, the field lines end on cylinders rather than on circles, giving higher average fields for any given maximum field. (At a price of larger electrode capacitance.) Most of the signal is induced when the charge is close to the electrode, where the solid angle subtended by the electrode is large. As a result, in planar sensors, the signals are spread out in time, while for the 3D case the signals from particles with tracks nearly parallel to the electrodes —the usual case— are concentrated in time as the track arrives. In addition,
if the readout electronics can has inputs from both the \( n \) and \( p \) electrodes, drift time corrections can be made.

Figure 2.26: Two sample pulse shapes. The top pulse, from a heavily irradiated sensor at room temperature, has a rise time of 3.5 ns, the bottom, one of 1.5 ns.

Almost all available integrated circuit readout chips are charge-sensitive, with pulse shaping that precludes measurements of the true pulse shape. However, working with Jarron and Anelli of CERN, we have read out 3D sensors with 0.25 \( \mu \) m-line width, radiation-hard, 3.5 ns rise time (at room temperatures), current sensitive amplifiers. For \(^{90}\)Sr betas we measure rise and fall times of 1.5 ns for the unirradiated sample and 3.5 ns for the heavily irradiated sensor, as shown in Fig. 2.26 (bottom and top, respectively).

When the temperature of the sensor and amplifier is reduced to 130\(^0\) K, the rise-time decreases to below 1.5 ns. Faster (\(\sim\)1.5 ns at room temperature) amplifiers have been fabricated, and are expected to be available for further tests.

2.3.6 Preliminary active-edge results

Two types of active-edge sensors have been fabricated: those with 3D interior and 3D edge electrodes, and those with planar interior and 3D edge electrodes. (Sensors with planar interiors will not have the speed or radiation hardness of the 3D/3D versions, but take fewer mask steps and have no dead volume in their interiors.)

Figure 2.27 shows the results of a scan across a device with a planar interior with 3D edge electrodes with an infrared beam with a 10\% to 90\% width of less than 25
microns. This demonstrates that the sensor is active to within a few microns of the physical edge [6].

Figure 2.27: Signal as an infrared micron beam was scanned across the 150-micron-pitch strip sensor. The physical edge of the sensor is at 0 microns on the horizontal axis. All four strips were electrically shorted together.

There is no significant difference in leakage currents between collection electrodes in the center of a device and those adjacent to an edge for both types of devices. The leakage currents are several times higher than the 0.25 to 1.25 nA/mm³ for interior pixels of the first run, possibly due to a plumbing error, now corrected, in the cleaning system of the oxide furnaces that injected iron impurities into the tubes.

Both types of active-edge sensors will be tested in an x-ray microbeam at the Advanced Light Source at LBL in July.
2.3.7 Recent detector R&D publications


CHAPTER 2. ACCELERATOR-BASED EXPERIMENTS
Chapter 3

Non-Accelerator Experiments


With the arrival of Gorham in mid-2001 we launched into exciting new initiatives in the radio detection of high energy neutrinos and cosmic rays, ANITA, FORTE, SALSA, and laboratory tests in Hawaii and at SLAC and ANL, as discussed below. We also have longer range involvement in discussions and proposals for future neutrino and nucleon decay detectors in Japan and the US.

We note that our SuperK collaborator, Masatoshi Koshiba, received the Nobel Prize this year for his contributions to the study of solar neutrinos and with mention of the observation of neutrinos from Supernova 1987A.

3.1 SuperK, K2K and KamLAND

The UH group was a charter member of the IMB Collaboration, and has participated in the US-SuperK Collaboration since its inception. The commitment from UH to SuperK has been in taking a major role in the up-coming muon analysis, participation in the contained events analysis, particularly in the oscillations analysis, participation in (re)construction and shift taking, and particular responsibilities for some aspects of calibrations (particularly those drawing on our group’s expertise in fiber optics, which traces back to DUMAND experience). In the K2K experiment the UH group has played a limited role, participating in KEK on-site activities and shift taking.

The UH group participated in the KamLAND detector construction, and now in calibrations and shift taking during regular operations. With the arrival of Gorham in August 2001, we took on new responsibilities in design and fabrication of a device that can move sources about inside the inner detector balloon in KamLAND.
3.1.1 SuperK and $K2K$ results

Muon Neutrino Oscillations

The neutrino revolution in elementary particle physics continues, with the general acceptance in the community of finite neutrino mass and large mixing in muon neutrinos, and now mixing in the solar/reactor neutrinos as well. Five years ago the SuperK group made the dramatic announcement at Neutrino98 of strong evidence for muon neutrino disappearance for few GeV atmospheric neutrinos traveling earth-diameter distances. (The subsequent paper, Phys. Rev. Lett. 81, 1562 (1998), is now the most cited publication of all time in experimental HEP, exceeding even citations of the discovery of the $J/\psi$. Six of the ten most highly cited experimental papers are from SuperK.)

The simplest hypothesis that fits the data invokes two-neutrino masses and mixing. The decade-old atmospheric neutrino anomaly was initially constrained to only two plausible working hypotheses: $\nu_\mu$ oscillation to either $\nu_e$ or $\nu_{\text{sterile}}$. Within two years, pure $\nu_\mu$ oscillation to a sterile neutrino was eliminated (paper published Phys. Rev. Lett. 85, 3999 (2000). Limits have been placed on the amount of $\nu_e$ or $\nu_\mu$ mixing (only around $<10\%$) in atmospheric muon neutrinos. The constraints on mass and mixing parameters continue to improve. The mass-difference-squared has crept down a little in updated analyses, to $\delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$, but the one sigma error is still around 50%. The mixing angle, $\sin^2 (2\theta)$ is greater than 0.9, with 1.0 favored.

Some further progress has been made on detection of tau appearance in SuperK, though three different analyses remain at the two-sigma level; not enough to justify a strong claim but certainly encouraging. Statistical limitation in extracting the tau remains the greatest hurdle. For example, in one analysis, we extract $92 [\pm 35 \text{(statistical)}] [\pm 18 (\Delta m^2 \text{ uncertainty})] [\pm 15 (3\text{-flavor uncertainty})]$ tau events to be compared to 74 expected (with oscillations) in the sample.

Earlier analyses that test alternative solutions to the atmospheric neutrino anomaly (solutions involving violation of Lorentz invariance, Kaluza-Klein states, failure of quantum mechanics, and neutrino decay) have all been rejected now at the greater than five sigma level.

A new $L/E$ analysis with a 70-year-effective Monte Carlo sample, which employs a number of carefully chosen criteria to select a data sample with good $L/E$ resolution, shows that SuperK has the ability to resolve the first minimum muon disappearance in $L/E$. This work, which will be released in a few months, will increase the case for rejection of all alternative solutions (neutrino decay, etc.) to the simple maximal $\nu_\mu \leftrightarrow \nu_\tau$ mixing. Small amounts of admixture of new processes (eg, sterile neutrinos) will never be eliminated, but are now generally at the uninteresting level (uninteresting in terms of solving any problem with the data).
3.1. **SUPERK, K2K AND KAMLAND**

Results from $K2K$ continue to be supportive of the SuperK $\nu_\mu$ oscillations claim. The collaboration has reported from the run ending July 2001 a total of 56 events in the SuperK fiducial volume, with $80.6^{+7.3}_{-8.0}$ expected. The low rate at SuperK of one event per two days (and only one per two weeks for single-ring contained muon events from which we can calculate the oscillated spectrum) means that accumulation of statistics has been tedious. Other analyses of near detector data is proceeding, and results will soon be forthcoming on various cross sections, particularly for the important single $\pi^0$ production.

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**Solar Neutrinos**

Three years ago the solar neutrino results from SuperK were frustrating because none of the three possible “smoking guns” for solar neutrino oscillations (spectrum, day/night and seasonal modulation) showed any positive indications. The absolute rate was about one half expectation, and that was the only sign of a solar neutrino problem in SuperK (as with the Chlorine and Gallium experiments, though each with a different fractional deficit). The actual value from 1465 days is $SK/SSM = 0.465[\pm 0.005(\text{stat})][\pm 0.016(\text{syst})]$, from 22,400 solar neutrino events.

If interpreted as oscillations, the SuperK results eliminate the small mixing angle MSW and vacuum solutions at the 95% C.L., if one takes the solar model and other experiments (Chlorine and Gallium) at face value. In June 2001, and again with improved statistics in 2002, the SNO Collaboration reported their measurement of the charged current rate of solar neutrinos on deuterium (inverse beta decay). This result, taken together with the SuperK elastic scattering result, which includes neutral current contributions from muon and tau neutrinos, makes a convincing case for neutrino oscillations as the solution to the solar neutrino problem. It is interesting to see that the old Chlorine (Davis experiment) results along with Gallium measurements (Gallex, SAGE and GNO), and the long-challenged solar neutrino flux calculations (SSM) all appear to have been substantially correct, and present a consistent picture when jointly analyzed with SuperK and SNO results. The only solution that fits all data is in the large-angle MSW region. In fact SuperK reaches that same conclusion even without SNO results: $\Delta m^2 = 7 \times 10^{-5} eV^2$, $\sin^2(2\theta) = 0.5$ (note not 1.0!). As discussed below, this is borne out by the new KamLAND results for reactor (anti)neutrinos, although the KamLAND results tend to pull a bit toward larger mixing angles.
3.1.2 SuperK and $K2K$ future plans

Recovery from SuperK Disaster of 2001

In November 2001 a cascading series of implosions destroyed about 6000 of the inner detector’s 11,000 twenty-inch photomultipliers. Similarly the eight-inch tubes in the outer detector were destroyed, and many cables and some mechanical structure was damaged. Cleanup and testing of solutions to prevent a recurrence took until Spring 2002.

Since the manufacturing rate of these large tubes would require about three years to replace the 6000 that were destroyed, it was decided to reconfigure the inner detector PMTs at about half density. Each PMT is now housed in a plastic envelope that has been tested to resist sympathetic implosion by neighbors. The reinstallation took place during Summer 2002.

The outside detector PMTs and (~700 new) WLS plates were reinstalled at full density. This was necessary as the coverage outside is less (1,885 eight-inch PMTs as opposed to the 11,146 large inner PMTs, now about 5,000) and, with reduced density in the ID, the efficient tagging of incoming events becomes all the more important. DOE, responding to a separate SuperK-USA proposal, supplied funding (via UCI) to carry out this repair and replacement.

Various studies were made to determine the consequent effect upon the physics. It appears that there will be little impact on any events more than about 7 MeV. Thus, for the supernova watch (mean energy about 20 MeV), studying atmospheric neutrinos, recording neutrinos from KEK, and seeking proton decay, there will be negligible effect. Some multi-ring events will be effected, but, generally, the most critical ongoing studies will proceed with little or no degradation.

SuperK future plans

SuperK continues to be a cornucopia of excellent physics, and will remain so for perhaps a decade. We have produced unparalleled data on solar neutrinos, atmospheric neutrinos and the search for nucleon decay. We are monitoring for supernovae, and are conducting a number of other searches for rare phenomena (e.g. WIMPS, Gamma Ray Bursts in neutrinos, Rubakov monopoles, AGN neutrinos, SN relic neutrinos, astrophysical point sources of neutrinos).

There are more thesis topics than students in SuperK. We will command the area of natural and accelerator-generated neutrino detection throughout the range of 5 MeV to around a $TeV$ for several years to a decade, depending upon energy. At the high energy end there is little competition/complementary effort. MACRO closed down
in 2000. SNO is considerably smaller than SuperK in fiducial volume and area, and the heavy water has no particular advantage for higher energy neutrino studies. No other instrument is close in terms of sensitive volume for atmospheric neutrino studies, although useful information has continued to emerge from the 1 kiloton Soudan II instrument (now shut down), and SNO has some unique up-mu detection ability because of depth. No other instrument is within an order-of-magnitude in sensitivity for supernova detection. Nor will any other instrument be within an order-of-magnitude for nucleon decay searches in the next few years. (ICARUS will be an excellent detector, but is still an order of magnitude smaller than SuperK in fiducial volume). The high energy neutrino detectors under-ice (AMANDA and ICECUBE) and underwater (NESTOR, ANTARES, NEMO and Baikal) have higher energy thresholds for neutrino studies than SuperK, and the larger of them will not be active for some years.

SuperK already has the world's largest sample of solar neutrino events (22,000), contained neutrino interactions (9,000) and through-going muon events (2,000). There is the problem of diminishing returns with time. Yet, in many studies, such as the search for the $p \to e^+\pi^0$ proton decay mode, we have not yet entered the statistics-limited domain. For supernova watches, the longer we run the better. And we are improving the control of systematics. SuperK is still some years away from plateauning in terms of the neutrino physics to be extracted, as well as for other rare phenomenon searches.

**K2K future plans**

So far about 50% of the $10^{20}$ POT promised for K2K has been delivered, and it will take at least two more years (starting in Spring 2003) to get the allotted amount. That should result in around 180 events in the SuperK fiducial volume if there were no oscillations, or about 110 with oscillations.

A more powerful, higher energy experiment (JHF 50 GeV proton machine) is scheduled to begin operation in about 2007 (with about 1 MW beam power), from a different location (JAERI, 300 km to SuperK). These experiments will permit us to continue to winnow alternative or variant models, and substantially refine the muon neutrino oscillation parameters, particularly the crucial parameter $\theta_{13}$. Plans are to evolve to a 5 MW machine and to permit the JHF to further evolve into a neutrino factory. Moreover, our Japanese collaborators are actively discussing a megaton version of SuperK for the next generation of nucleon decay searches and detailed neutrino measurements with the JHF machine. The precise UH participation in all of these future activities is at present unclear, but we have co-signed a letter of interest in participation.
Figure 3.1: The ratio of measured to expected $\nu_e$ flux from reactor experiments. The solid circle is the KamLAND result plotted at a flux-weighted average distance of $\sim 180$ km. The shaded region indicates the range of flux predictions corresponding to the 95% C.L. LMA region from a global analysis of the solar neutrino data. The dotted curve, $\sin^2 2\theta = 0.833$ and $\Delta m^2 = 5.5 \times 10^{-5}$ eV$^2$, is representative of a best-fit LMA prediction and the dashed curve is expected for no oscillations.

3.1.3 KamLAND results

The KamLAND Collaboration reported first physics results in December 2002 [Phys. Rev. Lett. 90, 021802 (2003)] wherein strong evidence is presented for electron antineutrino disappearance enroute from distant nuclear reactors. The analysis of the first 145.1 days of data, 162 ton-year of exposure, yielded 54 of the double-hit $\overline{\nu}_e$ events, with an expected background of 1 event, and where 86.8 events are expected for no oscillations. The ratio of observed $\overline{\nu}_e$ events to expected in the absence of disappearance is $(N_{\text{obs}} - N_{\text{BG}})/N_{\text{expected}} = 0.611 \pm 0.085(\text{stat}) \pm 0.041(\text{syst})$.

Figure 3.1 shows the ratio of measured to expected flux for KamLAND and previous reactor experiments as a function of average distance from the source.
Figure 3.2: Upper panel: Expected reactor $\nu_e$ energy spectrum along with $\nu_{\text{geo}}$ and background. Lower panel: Energy spectrum of the observed prompt events (solid circles with error bars), along with the expected no oscillation spectrum (upper histogram, with $\nu_{\text{geo}}$ and background shown) and best fit (lower histogram) including neutrino oscillations. The shaded band indicates the systematic error in the best-fit spectrum. The vertical dashed line corresponds to the analysis threshold at 2.6 MeV.

The expected prompt positron spectrum with no oscillations and the best fit with reduced $\chi^2 = 0.31$ for 8 degrees of freedom for two-flavor neutrino oscillations above the 2.6 MeV threshold are shown in Fig. 3.2. A clear deficit of events is evident. At the 93% C.L. the data are consistent with a distorted spectrum shape expected from neutrino oscillations, but a scaled no-oscillation shape is also consistent at 53% C.L as determined by Monte-Carlo.

The neutrino oscillation parameter region for two-neutrino mixing is shown in Fig. 3.3.
The dark shaded area is the MSW-LMA region at the 95% C.L. derived from solar analyses. The shaded region outside the solid line is excluded at the 95% C.L. from the rate analysis. The final event sample is evaluated using a maximum likelihood method to obtain the optimum set of oscillation parameters. The best fit to the data in the physical region yields $\sin^2 2\theta = 1.0$ and $\Delta m^2 = 6.9 \times 10^{-5}$ eV$^2$ while the global minimum occurs slightly outside of the physical region at $\sin^2 2\theta = 1.01$ with the same $\Delta m^2$. These numbers can be compared to the best fit LMA values of $\sin^2 2\theta = 0.83$ and $\Delta m^2 = 5.5 \times 10^{-5}$ eV$^2$ from solar analyses. The 95% C.L. allowed regions from the spectrum shape analysis for $\Delta \chi^2 = 5.99$ and two parameters are shown in Fig. 3.3.

We expect to carry out the next data reduction in September 2003, at which time the statistics should be improved by about a factor of three. We aim at being able to make a positive statement about the spectral distortion of reactor neutrinos as well as positive detection of the geo-neutrinos. Obviously several years of data accumulation will be needed to extract the full physics potential of this instrument. From the oscillation parameters inferred from the current experimental solar and reactor neutrino data, it appears that KamLAND is the only experiment with a chance of observing the energy-dependent oscillation signature in the reactor neutrino energy spectrum. Such an observation would provide model-independent evidence for the oscillation of neutrinos and remove all uncertainties related to the absolute normalization of the reactor neutrino flux.

**KamLAND plans**

Aside from the main goal of measuring neutrinos from reactors, KamLAND can make other observations. A paper is underway setting limits on $\pi_e$ from other sources in the energy range from 8.3 to 14.8 MeV. Since no events have been found we can set limits on the conversion of solar neutrinos to anti-neutrinos at the level of 0.038% of the SSM boron neutrino flux incident at earth. Another paper in draft stage reports the rate of generation of neutrons underground, including events with as many as sixty neutrons generated by cosmic ray muons. No correlations have been found with GRBs, and we have no hint of a supernova signal (but are watching).

The major challenge for KamLAND however will be the lowering of background radioactivity in order to study solar neutrinos. With the troubles of the BOREXINO experiment this becomes all the more important. The measurement is much harder than the reactor neutrinos since one has only one count, and the entire result depends upon achieving small and well understood random backgrounds. On the other hand, the $^7\text{Be}$ rate is expected to be about ten per hour, vastly greater than that for the reactor neutrinos. While some R&D is required to lower backgrounds due to $^{85}\text{Kr}$ and $^{210}\text{Pb}$, the overall operation of the KamLAND detector has been shown to be successful. With US collaboration's substantial contributions to the front-end electronics, calibrations, and analysis to the current phase of the KamLAND experiment, we expect that
Figure 3.3: Excluded regions of neutrino oscillation parameters for the rate analysis and allowed regions for the combined rate and shape analysis from KamLAND at the 95% C.L. At the top are the 95% C.L. excluded region from CHOOZ and Palo Verde experiments, respectively. The 95% C.L. allowed region of the ‘Large Mixing Angle’ (LMA) solution of solar neutrino experiments is also shown. The solid circle shows the best fit to the KamLAND data in the physical region: $\sin^2 2\theta = 1.0$ and $\Delta m^2 = 6.9 \times 10^{-5}\text{eV}^2$. All regions look identical under $\theta \leftrightarrow (\pi/2 - \theta)$ except for the LMA region from solar neutrino experiments.
the US collaboration would be in a position to play a major role in this future phase of the experiment.

### 3.1.4 Future initiatives

**Next generation nucleon decay and long-baseline detectors**

We have participated in several meetings aimed at discussing a next-generation nucleon decay detector, about an order-of-magnitude or more beyond SuperK. One plan has emerged from colleagues in SuperK, called UNO, which is a scaled up version of SuperK, but having to trade off some sensitivity for cost savings. Other plans are evolving using liquid argon. Ideas and further study will be needed before this initiative settles into a realistic plan. In the US it will depend a good deal on the outcome of the present initiative towards formation of a deep underground national laboratory as well as activities towards a neutrino factory.

There is potential synergy between a long baseline neutrino detector and a next generation nucleon decay experiment. The muon energies that are currently favored for neutrino factories are around 20 GeV, and hence detector sensitivities would be close to those needed for nucleon decay searches. A megaton instrument would be well matched to a near earth-diameter neutrino factory experiment. Moreover, there may be synergy between the necessary particle-sign discrimination needed in such an instrument and resolution of backgrounds for nucleon decay.

During the last several years we have worked with others (Cline at UCLA, McDonald at Princeton, and Sergiampietri at CERN) to develop a plan for a giant liquid argon drift detector (ICARUS style), called LANNDD. Our concept started as a plan to supplement SuperK with a large cylindrical liquid argon instrument. This has evolved into a plan for 90 kiloton facility to be placed in a site such as WIPP, where it could be used as a long baseline detector with a neutrino factory at Fermilab or BNL. Considerable interest was generated at Snowmass2001 and various workshops at Fermilab and CERN, and discussions have proceeded into several preliminary proposals for a micro-LANNDD test at either Fermilab or CERN.

**ASHRA, a New Project in Hawaii**

ASHRA, a new particle telescope design based on Baker-Nunn optics, image intensifiers and gated CCDs has been proposed for observation of ultra high-energy cosmic rays (UHECRs) and neutrinos. The optical system has an image resolution of less than 0.02° within a wide field of view of 50° angular diameter. When combined with a high-quality imaging device, the proposed design enables the directions of UHECRs and high-energy neutrinos to be determined with accuracy of better than 1 arcmin.
3.1. SUPERK, K2K AND KAMLAND

Figure 3.4: An example of a simulated $10^{20}$ eV event at an impact parameter of 53.5 km from an ASHRA station. The large one degree boxes indicate the resolution of present instruments; the small dots indicate the pixel size of the ASHRA system. It is evident that details of shower development can be studied with ASHRA.

Moreover the all-sky coverage and unique separate fluorescence and Cherenkov triggers for this device would permit an unprecedented simultaneous all-sky monitoring for TeV gamma rays.

ASHRA spokesperson Sasaki and colleagues approached the UH high energy physics group to join with them in a plan to install three large angle detectors on the Big Island of Hawai‘i, in a triangular array with a baseline of about 40km. Each station will consist of 12 telescopes, each with 4 mirrors and electronics. The sky will be covered by 80 million pixels, at an estimated cost of $0.04/pixel. This is to be compared with a cost of around $1000 per pixel for systems using photomultiplier tubes. The increase in resolution that this new technological makes possible is illustrated in Fig. 3.4.

The Japanese team, centered at the ICRR, U. Tokyo, has already constructed and operated a test telescope at the Akeno laboratory. Despite poor seeing conditions at that site, they have detected the Crab Nebula and, possibly, Mrk421. With this successful demonstration, they have gotten funding to proceed to the next phase. This will involve bringing the test telescope to Hawai‘i, followed by the initial ASHRA telescope elements over the next several years.

At UH, Browder, Learned and Olsen are interested in this project; we hope that the
UH HEP group can become a facilitator for this new project.

3.2 Summary

The UH group plans to continue to be heavily involved in the normal operations and the analysis of the SuperK, $K^2K$, and KamLAND experiments in Japan, plus several new efforts led by Gorham, and to take a role in support of the new particle-astrophysics project ASHRA to be based in Hawaii. The UH particle astrophysics group remains well positioned in the neutrino field, with continuing prospects for discoveries from SuperK and excellent initial results from KamLAND. We foresee a long and productive future in neutrino and nucleon decay research.

3.2.1 SuperK, $K^2K$ and KamLAND Publications

SuperK refereed publications


K2K Refereed Publications


KamLAND Refereed Publications


3.2.2 General NA Publications from UH


3.3 Radio detection of high energy particles


The primary physics goal of development of radio detection methods for high energy physics and astrophysics remains the detection of cosmogenic neutrinos in the $10^{18}$ eV range, where the guaranteed Greisen-Zatsepin-Kuzmin (GZK) flux from the integrated interactions of the ultra-high energy cosmic rays is predicted to peak. In the last year, the multi-faceted efforts in this emerging field have become more project-oriented, with the SAltbed Shower Array (SALSA), a detector still largely in the concept definition stage; and Antarctic Impulsive Transient Antenna (ANITA), now in an initial construction phase, taking the forefront. Much of the focus has been on building up the project infrastructure and in development of cutting-edge hardware necessary for the next-generation detectors.

Highlights of the last year of effort include:

- The first-generation Self-triggered recorder of transient waveform (STRAW) application-specific integrated circuit (ASIC) has been successfully executed and implemented. This is a state-of-the art ultra-high bandwidth switched-capacity-array chip capable of recording 16 channels of radio-frequency signals with an input bandwidth approaching 1 GHz and a sampling rate of more than 3 Gs/s.

- The GLUE project has now achieved more than 110 hours of livetime, setting the most reliable ultra-high energy neutrino limits in the ZeV energy regime.

- A compact and versatile 4-channel radio-frequency trigger board with applications in a variety of projects, such as GLUE, SALSA, ANITA, and others has been developed.

- A new antenna for above-surface detection of transmitted radio pulses has been developed in partnership with Seavey Engineering Associates. This is a dual-polarization quad-ridged horn with a 6:1 bandwidth (0.2-1.2 GHz) and excellent gain characteristics.

- A theoretical analysis of the possibility of incoherent molecular bremsstrahlung radio emission from high energy air showers have led to an experiment at the Argonne Wakefield Accelerator June 23-27 to seek the first observation of this effect, which has the potential to provide a high-duty cycle calorimetric detection method for ultra-high energy cosmic ray events.

- ANITA has been scheduled for an early Long-Duration Balloon flight of a prototype instrument for this year in Antarctica, sharing a payload with the TIGER instrument.
3.3.1 The GLUE Experiment.

The Goldstone Lunar Ultra-high energy neutrino Experiment (GLUE)* makes use of large earth-based radio telescopes situated near Barstow, CA, to search for radio pulses due to 100 EeV cascades originating in the lunar surface. Since the radio telescope field-of-view includes a large fraction of the visible surface of the moon, and since the lunar surface material (known as the regolith) is relatively transmissive for microwaves to a depth of order 10 m, GLUE can simultaneously monitor a volume of hundreds of thousands of cubic km of material. The energy threshold for pulse detection (based on the experimental accelerator results) is of order 100 EeV, making this experiment sensitive to an energy regime in the vicinity of the GZK cutoff.

The major focus in the last year has been to gain further high-sensitivity data from observations centered on the lunar limb, after significant improvements in the modeling of the experiment indicated that this provided the most optimized response of the system. As a result, we now have more than 60 hours of additional livetime in the optimized configuration, and the total of A-grade data now stands at over 110 hours. The Monte Carlo development has led to significant improvements in our understanding of the experiment on several fronts, and we now also implement full mixing of neutrino types based on further confirmation of neutrino oscillation parameters.

![Figure 3.5: Current limits from the GLUE experiment, 110 hours livetime, plotted along with various models and other limits. Also plotted in green is the projected sensitivity of ANITA after 3 flights. GLUE limits are beginning to significantly constrain one current model for Top-down models, due to Yoshida et al. 1998.](image)

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*GLUE is a collaboration between UH and JPL (C. Naudet and K. Liewer), and UCLA (D. Saltzberg).
Figure 3.5 shows the current estimate for GLUE’s differential sensitivity based on the 110 hours of livetime. GLUE is now beginning to significantly constrain at least one model for top-down ultra-high energy neutrino production.

### 3.3.2 Saltdome Shower Array (SALSA)

Gorham and Saltzberg (UCLA) have been developing an idea for an ultra-large GZK neutrino telescope that consists radio antennas embedded in one of the (many) large salt domes in the U.S. gulf-coast region. They have shown that salt dome halite has radio transparency more than adequate to act as the medium for a \(\sim 100 \text{ km}^3\) water equivalent detector. They have termed such a detector a SAltbod Shower Array (SALSA). Initial Monte-Carlo studies have indicated that such an array is likely to be the most effective GZK neutrino telescope within the reach of present technologies and resources.

The SALSA efforts have made steady progress over the last year. Contacts have been made with possible collaborators at the Univ. of Texas Austin, and initial investigations into the viability and costs of surface borehole drilling into salt domes have yielded promising results. Costs for a borehole to 6 km depth are of order $100K, a factor of \(\sim 5\) less than original estimates, and a potential candidate salt dome (Oakwood dome) is under consideration for test holes.

**Cosmic-ray Radio Testbed.** As part of Gorham’s OJI award program, we have continued development of a cosmic-ray radio testbed consisting of a 20 ton rock-salt target with embedded antennas inside a muon hodoscope. Its purpose is the radio detection of muon- or cosmic-ray-proton-induced showers with TeV energies. We are now in the process of upgrading the testbed to replace the existing time-multiplexer data acquisition system with a digitizer based on the STRAW chip. This will significantly improve the noise floor of the system, which is currently limited by switching transients and delay cable losses. We have acquired of order 8 months of livetime under the old configuration and analysis of that data is in progress.

**SLAC T460 analysis**  Our SLAC T460 experiment made further measurements of Askaryan radiation in a rock salt target and extended the coherence measurements to 8 orders of magnitude in radio pulse power. We also made detailed measurements of the pulse polarization properties \(\text{vs.}\) position, radio frequency, and shower energy.

We continue to analyze the high-quality polarization data, with the goal of establishing the polarization tracking method for radio Cherenkov radiation, which would allow vector estimation of shower parameters since the plane of polarization of Cherenkov radiation depends closely on the shower geometry. Preliminary analysis suggests that
the plane of polarization was following the expected behavior, as we reported last year. Since that time we have followed through on the amplitude and phase calibration of the data, and have reconstructed the shower axis angle with respect to several of the antennas near shower maximum.

![Figure 3.6](image)

**Figure 3.6:** Reconstructed projected track direction compared to predictions from known beam and shower geometry. The agreement is excellent, showing that Cherenkov polarization measurements alone may be used to constrain the shower track direction.

Figure 3.6 shows the results of this analysis for one set of three antennas near the shower maximum, where a characteristic change of the plane of polarization in proportion to the change of the source direction with respect to the antenna is evident. This is due to the fact that the plane of polarization is the one that contains the Poynting vector of the radiation and the shower axis.

### 3.3.3 Detector Development

**The STRAW chip.** The most exciting efforts in detector development have centered on the Self-Triggered Recorder of Analog Waveforms (STRAW) chip, which was conceptually designed last summer and fall by Gorham and Varner, and then engineered by Varner for submission to the MOSIS 0.25 micron process. The first fabricated parts were received in late January, and initial testing was very promising, with virtually all of the major goals for this production run met in the first prototype.

This device, which makes use of switched-capacitor-array technology, addresses the need for a low-power ultra-high speed digitizer to record radio-frequency data at full bandwidth in close proximity to a cluster of antennas, such as might be used for an embedded RF Cherenkov detector array. Current commercial digitizers are costly and
power hungry. The STRAW uses CMOS technology for very low-power operation, but extends the CMOS bandwidth to the GHz level by careful use of monolithic microwave integrated circuit layout techniques. Currently, the device can sample at over 3 Gsamples/s, with an input bandwidth approaching 1 GHz.

This may be compared to the Analog Transient Waveform Digitizer (ATWD) switched-capacitor array device, used in several experiments, including KamLAND, and planned for the IceCUBE experiment. The ATWD as it is currently implemented can sample at rates up to several GHz, but, in its current implementation, it has an input bandwidth of only about 120 MHz, which is inadequate for broadband radio pulse detection.

![Figure 3.7: The STRAW chip, a test board, and the frequency performance of the device to a pulse input.](image)

Figure 3.7 shows photographs of the unmounted STRAW and the packaged device on a test board. On the right we show tests of the device bandwidth at 3.3 Gs/s compared to a 1 GHz scope, using a sub-nanosecond input pulse. The spectral response, normalized to the scope response, is shown at the bottom, indicating that the nominal 3 dB bandwidth of the device is about 750 MHz. Because of the 12 bit digitizer dynamic range, however, a bandwidth of more than 1 GHz is usable for 8-bits of dynamic range, matching many of the best commercial high-bandwidth digitizers available.

**The ALTO trigger board.** In a related development effort, Varner has designed and fabricated a new general-purpose 4 channel radio-frequency trigger board, patterned on systems used by Gorham in the GLUE project. This board, in a form factor designed to fit in a single-width compact PCI module, provides up to 2 GHz of input bandwidth into a square-law detection diode, combined with input power measurement functions, onboard discriminators and coincidence logic, and a veto channel. In the GLUE or
similar experiments, it can replace of order $20K worth of front-end trigger electronics for well under $1K recurring costs.

![Diagram of antenna](image)

**Figure 3.8:** Geometry of the dual-polarization slot dipole, showing the schematic location of the feeds and the electric field vector orientation for the slot and dipole components. The response in initial tests is shown at right.

**Antennas.** Figure 3.8 shows the results of experiments to develop a dual-polarization borehole antenna for use in an embedded dielectric such as salt or ice. This has been a difficult prospect because of the restrictive geometry of a narrow borehole, but use of a slotted dipole, where the slot is fed separately from the fat dipole, shows great promise. A schematic of the geometry of the antenna is shown on the left, and the results for radiation efficiency, using a 75 ohm source impedance, are shown at right. The dipole has excellent efficiency over a very broad band, and the complementary slot provides a serviceable cross-polarized response over much of the same band. We anticipate significant improvement in the slot efficiency with more careful impedance matching.

The problem of a very broadband dual-polarization horn antenna has been addressed with the help of Seavey Engineering. The application here is for external reception of a radio pulse that has originated in a dielectric from a particle interaction but has escaped to the exterior of the dielectric. The primary application is in an experiment such as ANITA, and the development of this antenna has been supported through Gorham's startup and ANITA funds. The antenna has a 6:1 bandwidth from 200-1200 MHz, and a gain of up to 15 dBi in this range.

**New Low-frequency Anechoic Chamber** Antenna testing requirements have led to the construction of a second, larger anechoic chamber, developed using Gorham's
startup funds. The double-copper-skinned, solder-jointed chamber measures 3x4.5x8.5 m$^3$ and will be completed later this summer. It will have good frequency response down to 100 MHz, enabling characterization of antennas and devices from all of the envisioned project applications.

### 3.3.4 Argonne Wakefield Accelerator Beamtest

As this proposal is being completed we are in the final stages of shipping and experiment deployment for a beam test at the Argonne Wakefield Accelerator. The goals of the test are to: 1) investigate two radio-science aspects of high energy particle shower ionization: molecular bremsstrahlung radio emission; and 2) measure radio propagation phase shifts in a dielectric-loaded waveguide exposed to an electromagnetic shower.

The former goal centers on untested theoretical predictions of broadband RF emission from electron-molecule collisions during the plasma-cooling phase in the first 10-200 ns after a shower has passed through a gas or solid. This process has implications for shower calorimetry, as well as a close theoretical connection to the Landau-Pomeranchuk-Migdal effect. Figure 3.10 shows the compact anechoic chamber that will be exposed to the beam in this portion of the test.

If we can determine how the RF phase shifts through a shower-induced plasma in a solid-dielectric-loaded waveguide in the latter tests, it may prove a viable radiation-hard method for collider shower calorimetry at the very high center-of-mass energies of future machines. Both experiments are to our knowledge the first of their kinds and have been designed and calculated to yield publishable limits for non-detections.
3.3.5 Antarctic Impulsive Transient Antenna (ANITA)

ANITA is an experiment to detect neutrino-induced radio pulses from the Antarctic ice sheet in antennas located in a long-flight-duration balloon. The idea was proposed to NASA while Gorham was still at JPL. The proposal was approved in August 2002 and scheduled for an early 2006 launch.†

Although ANITA is a NASA-funded project, the symbiosis with our DOE-supported radio detection projects described above has been very beneficial to both projects. This is particularly true in the areas of antenna development and testing, and detector technology. The ALTO trigger board and STRAW developments described above are well-matched for both SALSA and ANITA, and will speed implementation and reduce costs in both cases. Perhaps even more important, the experience gained in development of the RF front-ends and antennas in each project is highly complementary; we have already seen significant crossover benefits in the areas of polarization measurements, low-noise RF amplifiers, and use of CATV and satellite TV technology.

ANITA will make a test flight this year in Antarctica as part of a survey of potential electromagnetic interference sources in Antarctica, and part of the survey will also involve tests of ice transmissivity. For this latter task we find additional crossover support in the development of embedded dual-polarization antennas which are necessary for the under-ice measurements, which will be made from boreholes at Amundsen-Scott station.

†Non-Hawaii ANITA collaborators include S. Barwick (UC-Irvine), J. Beatty, S. Coutu, and D. Cowen (Penn State), D. Seckel, P. Evenson, and J. Clem (Delaware), M. DuVernois (Minnesota), D. Saltzberg (UCLA), and K. Liewer and C. Naudet (JPL).
3.3. RADIO DETECTION OF HIGH ENERGY PARTICLES

Radio-detection refereed publications.


Radio-detection Conference & other publications.


Chapter 4

Theoretical Physics

Drs. J. Ferrandis, K. Melnikov, A. Mitov, S. Pakvasa, W. Simmons, H. Sugawara, X. Tata, and Messrs. A. Box and R. Kadala

4.1 Overview

The theory group currently consists of faculty members Melnikov, Pakvasa, Sugawara and Tata, affiliate faculty member Simmons, post-doctoral researcher Javier Ferrandis, and graduate student Roger Kadala. Starting Fall 2003, Alex Mitov will join the group as a post-doctoral researcher, and Andrew Box as a graduate assistant.

The research activities of the group are largely phenomenological in nature. The main theme of the research is to identify strategies to confront the Standard Model and its various extensions to experimental tests, both at high energy colliders as well as at non-accelerator experimental facilities. Melnikov’s research concentrates on the identification and evaluation of quantities that can both be precisely computed within the Standard Model and accurately measured experimentally, thereby providing stringent tests of the Standard Model. Pakvasa’s activities focus on neutrino physics, astrophysics and such flavor-physics topics as mixing, CP violation and rare decays. Sugawara mainly works on M-theory, but also has a variety of other interests, including complex systems and applications of high energy neutrino beams. Tata mainly works on the search for new physics at high energy colliders, with emphasis upon weak-scale supersymmetry. The different research directions have considerable overlap as well as a common goal, and this results in healthy interactions with one another, as well as with the Hawaii experimentalists. Our faculty also has strong ties with colleagues working at CLEO, Brookhaven, Fermilab, SLAC, KEK, as well as at non-accelerator facilities and universities in the US and abroad.

The past year was marked by important personnel changes. Kirill Melnikov was recruited as a replacement for Tuan, who retired in June 2002. Melnikov is one of the leading experts on the application of quantum field theory to particle physics phenomenology. He is a versatile researcher whose contributions encompass a wide range of subjects. His interest in cutting-edge research in precision Standard Model physics
adds a new dimension to the activities in our group. His interests both complement and overlap with those of Pakvasa (heavy-quark physics) and Tata (collider physics). He also interacts fruitfully with Hawaii experimentalists, especially those working on BELLE and BES. He received a DOE Outstanding Junior Investigator award in 2003.

In April 2003, Hirotaka Sugawara (former Director-General of KEK) accepted the Dai Ho Chun Distinguished University Professorship. This position, which is fully supported by the University, will last for at least three years with a possibility of further extension. Sugawara has been a regular visitor to Hawaii and a long-time collaborator with Pakvasa. His current interests, which include $M$-theory, add still another new dimension to our program. He will also interact with members of HEPG on various aspects of the linear collider.

Ferrandis (Valencia) has been a post-doctoral since September 2001. He has been working with Tata and collaborators on various topics in SUSY phenomenology, including the possibility of constructing SUSY models with unification of (third-generation) Yukawa couplings. He has also proposed that third-generation fermion masses are completely specified by the fixed point structure of the simplest supersymmetric SU(5) model.

Our highest priority is to expand the group to include a second post-doctoral fellow, primarily to work with Melnikov. We feel that the variety and impact of the current research of our faculty members provides ample justification for this request. We have recruited A. Mitov (Rochester) and will use part of Melnikov's start-up package for partial support for the first year of this position. We request DOE funds to continue this appointment in the longer term. Mitov has worked on issues related to bottom fragmentation in top quark decays and also on the theory of extra dimensions and its phenomenological applications.

Kadala joined our group as a graduate student in 2002, and is working with Tata on the detection of $t$-squarks at the LHC. He has a regular teaching appointment at a local community college and does not require any DOE support. Box will start work on supersymmetry in Fall 2003. We are actively trying to recruit a student to work with Melnikov, and would eventually like to increase the number of DOE supported students to two if we can recruit a student of high quality.

In the recent past, P. Mercadante (São Paulo, Brazil) and S. Hesselbach (Würzburg) were long-term visitors to our group supported by fellowships from their home institutions. Last year, N. Deshpande (Oregon) and P. Roy (Tata Institute, Bombay) each spent a sabbatical semester in Hawaii. These visits were instructive and stimulating. In Spring 2004, T. Weiler (Vanderbilt) and K. Higashijima (Osaka) will make month-long visits.

We discuss the research activities of the group since our last external review, and outline research plans for the up-coming years. This report is organized by subject,
beginning with Melnikov’s program. A list of the group’s scientific publications since the last external review appears separately.

4.2 Perturbative Quantum Field Theory: Methods and Applications (Melnikov’s Program)

4.2.1 Introduction

The goal of contemporary high-energy physics is to search for new phenomena beyond the Standard Model – the framework that has been used with great success to describe experimental data for the last thirty years. In spite of this achievement, the majority of high-energy physicists agree that, given its theoretical limitations, the Standard Model cannot be the final “Theory of Everything.” The shortcomings of the Standard Model include, among other things, an unsatisfactory approach to fermion mass generation, the untested mechanism of the electroweak symmetry breaking, and the hierarchy problem. These limitations provide a strong motivation for considering alternative theoretical models. These models predict, with varying degree of rigor, the deviations from the Standard Model that should be expected in collider and low energy experiments, either planned or already in operation. The detection of these deviations in a convincing manner and the elucidation of their underlying mechanism will be the major task of high-energy physics in the coming decade.

It is very fortunate that new high quality data will soon become available, first from the Tevatron and later from the LHC. Although we hope that unexpected phenomena will be observed, it is certain that the way to the discovery will be difficult. The problems faced by future high-energy physics experiments are complex and require a wide range of expertise that encompasses precision calculations, their incorporation into simulation programs, and the development of optimal experimental strategies. An important objective of theoretical support for future experiments is to identify the best possible signatures of new physics. The most promising candidates are quantities that can be precisely measured as well as reliably computed within the Standard Model. Unambiguous observation of deviation from the range expected within the Standard Model would then signal new physics. For this process to succeed, we must determine the precision to which such quantities can be evaluated with the current understanding of the Standard Model, and to seek new ways to improve upon this.

There are many examples where the lack of a proper understanding of Standard Model uncertainties precludes a clear interpretation of an apparent discrepancy between the Standard Model prediction and the observed experimental result. For example, the CDF collaboration has observed a possible excess in the high $E_T$ jet cross section; the DØ collaboration has obtained statistically consistent results. The measured $b$
production cross section at hadron colliders is similarly larger than the Standard Model prediction by a factor of two. Both inconsistencies may be due to an incomplete knowledge of the proton's parton distributions or higher-order perturbative corrections, or may simply be statistical fluctuations. These more mundane alternatives have to be excluded before invoking new physics as an explanation. Without further analysis within the Standard Model, no definite conclusions are possible.

These examples illustrate the importance of a strong, continuous effort to improve the Standard Model precision phenomenology for both current and future experiments. Such a program is particularly important for hadron colliders where investigation of physics beyond the Standard Model requires a good understanding of QCD. Even at the highest available energies, QCD is not fully perturbative since, in addition to hard scattering cross sections amenable to perturbative analysis, the description of a given process involves the structure and fragmentation functions, jet algorithms, hadronization and other non-perturbative effects. Moreover, in many cases the next-to-leading order (NLO) calculations for important processes at hadron colliders have uncertainties of tens of per cent and next-to-next-to-leading order (NNLO) calculations are required for an adequate theoretical prediction. The NNLO calculations will also determine to what extent such theoretical techniques as resummations, scale-setting prescriptions and choices of "appropriate" expansion parameters help in estimating higher-order effects in perturbative QCD.

Given the significance of the collider physics program and his previous experience with precision physics, Melnikov considers theoretical support for the physics programs at the Tevatron, the LHC and a future Linear Collider as his main research objective for the next few years. He plans to develop new methods for perturbative calculations in QCD and the Standard Model, especially for processes with many particles in the final state, and to apply these methods to study various processes of phenomenological interest at the LHC, the Tevatron and a future Linear Collider.

The central idea of Melnikov’s plan is to capitalize on the opportunity offered by recent advances in the technology of multiloop calculations. It is the right time to use these advances for extracting interesting physics. The proposed research will advance our understanding of perturbative QCD, relevant for the LHC, the Tevatron and a future Linear Collider (LC), and will enhance the discovery potential of these colliders.

Melnikov’s focus will be mainly on NNLO calculations of total cross-sections and differential distributions (rapidity, transverse momentum, $x_F$) for Higgs boson hadroproduction, Drell-Yan pair production, and heavy flavor production at the LHC and the Tevatron. In addition, the methods developed to perform such calculations are applicable to a wide variety of important problems; top quark threshold physics at the NLC and lattice perturbation theory are identified as two other focus points of the proposed research program.

In summary, the following results of Melnikov’s research program are anticipated:
4.2. PERTURBATIVE QUANTUM FIELD THEORY: METHODS AND APPLICATIONS (MELNIK)

- new methods for perturbative calculations in quantum field theory will be developed; these methods will make the “multi-loop technology” applicable to phase-space integrals;

- NNLO differential distributions (e.g. for the Higgs boson hadroproduction, Drell-Yan lepton pair production), required to maximize the discovery potential of future collider experiments, will be calculated;

- the NNNLO study of the top threshold production cross section at the NLC will be performed; various differential distributions in top quark decays will be investigated in higher order in QCD;

- a connection between the methods of continuum perturbation theory and lattice perturbation theory will be investigated; the calculations in lattice perturbation theory needed by the HPQCD collaboration to advance their program in light and heavy quark physics will be performed.

4.2.2 Methods

Perturbation theory is the most widely used tool of applied Quantum Field Theory. Very often a precise analysis of a given observable requires higher-order perturbative calculations. Since the complexity of the required calculations increases dramatically in higher orders of the perturbative expansion, special tools are needed to make such calculations possible. A typical calculation in the second order of perturbation theory involves a few hundred Feynman diagrams and tens of thousands of loop integrals; the enormity of this task necessitates the use of computer algebra.

The automation of perturbative calculations is based on the existence of algebraic linear relations (recurrence relations) between different Feynman integrals; these relations can be easily constructed using integration by parts with respect to the loop momentum.

Traditionally, these methods have been applied to compute virtual corrections or fully inclusive quantities such as total cross sections that can be obtained from certain virtual corrections by a simple analytic continuation. A familiar example is the calculation of $R(e^+e^- \rightarrow \text{hadrons})$ in perturbative QCD, which utilizes the imaginary part of the photon vacuum polarization. The advent of a new generation of collider experiments makes it crucial to determine whether those methods can be applied to less inclusive processes.

There are two immediate obstacles to this program: how to deal with a large number of different phase space integrals in a practical fashion, and how to generalize the methods so that the calculation of differential distributions becomes possible.
In a traditional approach to the calculation of radiative corrections to hard-scattering processes, the calculation is separated into two different parts: the calculation of the virtual corrections to tree-level partonic subprocesses and the calculation of the real emission contribution. The latter requires the integration of squares of tree level amplitudes over the phase space of the final particles. The calculation of virtual corrections is a highly automated process based on the ideas that have been sketched above. In contrast, integrating squares of real emission amplitudes over the final particle phase space is done manually and on a case-by-case basis. This is very time consuming and leads to somewhat opaque calculations.

There is a clear need to improve upon this unsatisfactory situation. One possibility is to apply methods developed for virtual corrections to the integration over the phase space of final-state particles. In collaboration with C. Anastasiou (SLAC), L. Dixon (SLAC) and F. Petriello (SLAC), Melnikov works on developing the techniques required to achieve this goal.

In order to automate the calculation of phase-space integrals one utilizes the unitarity cuts to map the phase-space integrals onto the cut loop integrals:

$$\int \frac{d^Dp}{(2\pi)^D}(2\pi)^D\delta(p^2 - m^2) \rightarrow i \int \frac{d^Dp}{(2\pi)^D} \left[ \frac{1}{p^2 - m^2 + i0} - \frac{1}{p^2 - m^2 - i0} \right].$$

The suggestion to add one extra loop seems counter-productive; however, it allows one to identify basic structures for multi-particle phase-space and in this way discover important simplifications. Since the derivation of the integration-by-parts identities for loop integrals commutes with the application of Cutkosky rules to them, the cut loop integrals satisfy the same recurrence relations as the ordinary loop integrals. Moreover, if a loop integral has more than one cut, each cut satisfies the recurrence relations separately. Since any processes with a given number of particles in the final state can be constructed from a single cut of some set of Feynman diagrams, and since the recurrence relations eventually map all Feynman integrals into a small set of master integrals, one obtains a tool for expressing any phase space integral, independent of its tensor and spinor structure, in terms of a small set of integrals. Working on the NNLO QCD corrections to inclusive Higgs boson hadroproduction, Melnikov has demonstrated that the practical implementation of this idea solves the problem of dealing with the large number of phase space integrals in an efficient way.

The above methods are very useful for computing total inclusive cross sections in higher orders of perturbation theory. Because of experimental cuts this is insufficient. Fully differential distributions are needed for detailed phenomenological studies. In higher orders of perturbation theory, this problem is very non-trivial: currently, not a single differential distribution relevant for collider physics is computed to NNLO.

It is fairly easy to generalize the idea to use the unitarity cuts to map the phase space integrals onto cut loop integrals by introducing unconventional propagators into
loop integrals. Such a generalization can make it possible to deal with the differential distributions in an efficient way.

Consider a differential distribution in a variable $x$. A constraint can be represented by the insertion of an additional $\delta$-function in the inclusive phase-space:

$$\frac{d\sigma}{dx} \sim \int d\text{Ph. Sp. } \delta(x - f(\{p_i\})).$$

This integral is mapped onto a loop integral as follows:

$$\delta(x - f(\{p_i\})) \rightarrow \frac{i}{x - f(\{p_i\}) + i0}.$$

As a consequence, the resulting loop integrals will have unconventional propagator. The fact that unconventional propagators appear does not seem worrisome because, if the constraint is a polynomial in the loop momenta, one can still derive integration-by-parts identities and perform the reduction to a few master integrals. There are many examples of interesting distributions that satisfy this criterion; for example, the rapidity and transverse momentum distributions for $W$, $Z$ or Higgs boson hadroproduction.

This is the set of ideas regarding new tools for perturbative calculations that Melnikov plans to pursue. These tools can be applied to a wide variety of important problems; some specific applications that Melnikov focuses on are described in the next Section.

### 4.2.3 Applications

**Higgs and collider physics**

Observation of the Higgs boson is one of the major goals of the Tevatron and the LHC. As long as the Higgs boson is not very heavy, the dominant production mechanism at the LHC is gluon-gluon fusion $gg \rightarrow H$; for this reason the Standard Model prediction for $gg \rightarrow H$ cross section has to be known accurately. Since the NLO corrections change the leading order cross section by roughly 70 per cent, the full NNLO calculation is required to estimate the production cross section. Melnikov has collaborated on this project with Anastasiou; the results have been published recently (Nucl.Phys. B646 (2002), 220). Apart from its phenomenological importance, it provided an opportunity to develop and test the new theoretical methods that have been described in the previous Section.

The calculation can be simplified substantially by considering the limit where the Higgs boson is much lighter than twice the mass of the top quark. In this limit, the top quark loops are replaced by point-like vertices. The corresponding effective Lagrangian provides a satisfactory description of the cross-section for a light Higgs boson.
at NLO. Nevertheless, even after this simplification, the computational challenges are formidable: for example, the total number of diagrams one has to deal with is close to one thousand. For this reason, the use of the methods discussed in the previous section is very essential.

Melnikov and Anastasiou have succeeded in deriving explicit analytic expressions for the partonic cross-sections valid within the heavy top quark approximation. The residual scale dependence of the Higgs hadroproduction NNLO cross section is approximately $\sim 15\%$ for the LHC and $\sim 23\%$ for the Tevatron. The NNLO $K$-factors are fairly large for both the LHC and the Tevatron, but the cross-section increases less from NLO to NNLO than from LO to NLO, indicating a slow convergence of the perturbative expansion.

The developed methods are, to a large extent, process independent and can be applied to other processes of phenomenological interest. As the next application, Melnikov has computed the production cross section of the CP-odd Higgs boson (which naturally appears in supersymmetric extensions of the Standard Model) in $gg \rightarrow A$ at the Tevatron and the LHC with the NNLO accuracy (Phys. Rev. D67 (2003), 037501).

In the previous section, the importance of computing QCD corrections to differential distributions has been emphasized and the new method to approach this type of problems has been suggested. In collaboration with Anastasiou and Dixon, Melnikov has applied this method to compute the NLO rapidity distribution of the Higgs boson produced in hadron-hadron collisions (Nucl.Phys.Proc.Suppl. 116 (2003), 193). The purpose of this paper is to describe the method and apply it to a relatively simple problem of phenomenological interest.

Most recently Melnikov, in collaboration with Anastasiou, Dixon and Petriello, has embarked on a much more complicated and ambitious project of computing NNLO rapidity distributions of dileptons produced in hadron-hadron collisions. They are currently at the final stages of this project focusing mostly on the “low-energy” fixed-target experiments (Fermilab E866 experiment) relevant for constraining parton distribution functions. In the short-term future, Melnikov plans to extend these results to the calculation of the rapidity distribution of $Z$ and $W$ bosons produced at the LHC and the Tevatron.

**Top quark physics**

The production of the top quark at threshold at the NLC is another example where further theoretical progress is vital. The physics motivations to study this process in the first stage of the NLC run are well known and include very precise measurement of the top quark mass, determination of its decay width, measurements of the Higgs-top Yukawa coupling and direct investigation of the CKM matrix element $|V_{tb}|$ along with
other topics. This rich physics makes the top quark threshold studies at the NLC very attractive.

The declared precision goals of this program are very ambitious (few percent uncertainty in the cross-section normalization, 100 MeV uncertainty in the top quark mass measurement); the feasibility of achieving this level of precision has been actively discussed both on the experimental and the theoretical side for the last few years. Whereas the results of the full detector simulation convincingly demonstrate that such experimental precision is possible, it is still not entirely clear if the cross section can be calculated with similar accuracy in the Standard Model.

For the top-quark threshold production, the current state of the art are the NNLO QCD calculations that were made possible due to recent breakthrough in the understanding of the non-relativistic limit in QCD. Some time ago, in collaboration with A. Czarnecki (Alberta) and A. Yelkhovsky (Novosibirsk), Melnikov computed the top-quark threshold production cross section at the NNLO in both $e^+e^-$ and $\gamma\gamma$ collisions. The results of these calculations were surprising in that, if taken at face value, the NNLO corrections turned out to be very large: for example, the normalization of the cross section increased by $15-20\%$ and a $\approx 500$ MeV shift in the position of the peak of the cross section has been found.

These large NNLO corrections have the potential to jeopardize the precision top physics program at the NLC and, for this reason, there has been a lot of discussion recently as to how this situation can be improved. One of the outcomes of this discussion was the understanding that the large shift in the peak position is related to the use of the pole mass of the top quark in the computation. It was realized that eliminating the pole mass from the calculation and resorting to more suitable short-distance masses, free of renormalon ambiguity, stabilizes the behavior of the peak position.

On the other hand, the large corrections to the normalization of the cross section remain puzzling and, in Melnikov’s opinion, an unsettled issue. Although improvement of the convergence of perturbative series can be achieved by using renormalization group methods, Melnikov believes that the actual precision of the theoretical prediction for the top quark threshold production cross section can only be established once a complete NNNLO QCD calculation of the production cross section is performed.

Currently, there are two major obstacles for the NNNLO computations: calculation of the heavy quark potential and the Wilson coefficient of the NRQCD vector current in the three-loop approximation. While even a few years ago these calculations would have been considered absolutely out of reach, Melnikov expects them to become tractable thanks to the new methods for perturbative calculations.

A complementary aspect of the top quark physics program at the NLC is the study of its decays. It is expected that, because of the large value of the top quark mass, top decay channels can be sensitive to new physics. In order to test these ideas experimentally,
one needs to have an accurate Standard Model prediction for both the total decay rate of the top quark and various differential distributions. Within the Standard Model, the lifetime of the top quark is relatively well understood but nothing is known about the differential distributions in top quark decays beyond the one-loop level. The methods for perturbative calculations that are described above permit the calculation of such quantities as the $W$-boson energy and angular distribution in $t \to Wb$ including $O(\alpha_s^2)$ corrections. The knowledge of these distributions with high precision is important to better understand the potential to study new physics effects in top quark decays.

**Lattice perturbation theory**

The program of solving QCD on the lattice is a very appealing approach to strongly interacting field theory. Although this program is non-perturbative by its origin and goals, perturbative lattice calculations are nevertheless required to match the lattice theory and the continuum perturbation theory applied at short distances. Moreover, lattice perturbation theory is known to be very complicated and the common perception is that it is intractable by analytic methods. In many cases, the lack of perturbative lattice calculations at the two- and, in some cases, even at the one-loop level for specific actions is one of the major obstacles to the high-precision lattice programs that are actively pursued by major lattice collaborations worldwide. In collaboration with T. Becher (SLAC), Melnikov works on investigating the possibility to apply analytic methods for perturbative calculations developed for continuum quantum field theory to lattice perturbation theory.

An important difference between continuum and lattice perturbation theories is the fact that in lattice perturbation theory there are more energy scales. In addition to particle masses and momenta, there is the lattice spacing, the inverse of which acts as an ultraviolet cut-off for the continuum theory. The presence of this extra scale makes perturbative calculations much more involved. However, since one is ultimately interested in the situation where the inverse lattice spacing is much larger than any actual energy scale involved, one might think that “integrating out” all the information about the lattice spacing and constructing an effective field theory for the continuum limit makes perturbative lattice calculations more feasible.

To check this idea and to see if it indeed leads to significant simplifications, Melnikov and Becher studied lattice perturbation theory at the one-loop level (Phys. Rev. D**66** (2002), 074508). They have constructed an expansion of lattice integrals in the inverse lattice spacing by effectively splitting them into the long-distance and the short-distance parts. The long-distance part describes the continuum limit of lattice field theory, while the short-distance part is the genuinely lattice part. This part is absolutely insensitive to the details of the process one studies since it can be described by lattice *tadpole* diagrams. Melnikov and Becher studied a variety of basic lattice actions
The question of practical importance that Melnikov and Becher investigated further is the usefulness of these methods for perturbative computations in lattice gauge theories with the so-called “improved” actions, such as, for example, the Luscher-Weisz gauge boson action with improved staggered fermions, used by HPQCD collaboration. Melnikov and Becher have recently completed a calculation of the staggered quark mass renormalization for that action; the paper has been accepted for publication in Phys. Rev. D. In the future Melnikov and Becher plan to study the renormalization constants of four-quark operators, light and heavy meson decay constants, radiative transition form factors and so on. Many of these quantities are highly relevant for experimental investigation of $CP$ violation and the unitarity triangle at $B$-factories and elsewhere.

### 4.3 Neutrino Physics

The properties of neutrinos, such as their masses, mixings, magnetic moments, etc., are extremely important in several ways. They are fundamental parameters, they play an important role in astrophysics and cosmology, and they tell us about what may be beyond the Standard Model (SM). Apart from direct laboratory measurements of masses from beta decay end-point measurements, the other technique for getting information on neutrino properties is the study of neutrino propagation and flavor conversion over long distances via neutrino mixing and oscillations.

It continues to be an aim of the Hawaii theory group to devise means to deduce neutrinos properties from various neutrino experiments, to propose new experiments, and to speculate on and build models for neutrino masses and mixings.

In 1999, Pakvasa withdrew from the Borexino collaboration (of which he was a founding-member) because he was able to attend very few meetings and did not feel he was participating adequately in the collaboration. He has since joined the KamLAND collaboration, as part of the UH group. The wisdom of this choice is borne out by the spectacular results of KamLAND described elsewhere in the proposal.

In 1998 SuperK announced the discovery of neutrino ($\nu_\mu$) oscillations in the atmospheric neutrino data. The strongest evidence was the existence of the up-down asymmetry of the $\nu_\mu$ flux, which was consistent with $\delta m^2 \approx 3 \times 10^{-3}$ eV$^2$ and maximal mixing of $\sin^2 2\theta \approx 1$. (It should be mentioned that this technique for proving existence of oscillations itself was pioneered by the Hawaii group: S. Pakvasa, Proc. of DUMAND Symposium, Aug. 1980 Ed. V. Stenger, 1980, Vol. 2, p.45; J. Flanagan, J. Learned and S. Pakvasa, Phys. Rev. D57, 2649(1998)). However, it was not clear that other explanations were ruled out. The possibility of an explanation based on a neutrino
decay with mixing was raised and parameters were found providing a fit as good as the conventional oscillation fit (V. Barger, J. Learned, S. Pakvasa, and T. Weiler, Phys. Rev. Lett. 82, 2640 (1999); hep-ph/9810121). It was pointed out that the decay model proposed here did not provide a good fit for the high energy thru-going muon data. However, a slightly modified decay model was able to fit all the atmospheric data very well (V. Barger, J. Learned, P. Lipari, M. Lusignoli, S. Pakvasa and T. Weiler, Phys. Lett. B462, 109 (1999)). The SuperK detector does not have sufficient resolution in $L/E$ to distinguish between this decay model and oscillations. The sharp dip that is expected for oscillations is washed out. Future long-baseline experiments such as MINOS or fine-grained detectors like MONOLITH will be able to observe the dip. Although the decay with mixing remains an unlikely scenario, it remains to be eliminated definitively.

The accumulation of data on solar neutrinos (mainly from SuperK) was changing the odds on the favored mass-mixing scenario already in 1998. Several solutions with different $\delta m^2$ but all with large mixing (LMA, Vacuum and Low) were now more likely than the previous favorite (SMA) with small mixing. Since the $\nu_\mu - \nu_\tau$ mixing was already known to be large from atmospheric neutrinos, it seemed natural to propose a phenomenological ansatz for the three flavor neutrino mixing matrix with two angles of 45°. The resulting matrix called “Bi-Maximal” has the form:

$$U_{MNS} = \begin{pmatrix} 1/\sqrt{2} & -1/\sqrt{2} & 0 \\ 1/2 & 1/2 & -1/\sqrt{2} \\ 1/2 & 1/2 & 1/\sqrt{2} \end{pmatrix}$$

This was proposed in 1998 (V. Barger, S. Pakvasa, T. Weiler and K. Whisnant, Phys. Lett. B437, 107 (1998)). The same proposal was made by A. Baltz et al., Phys. Rev. Lett. 81, 5730 (1998) and by H. Georgi and S. L. Glashow, Phys. Rev. D61, 097301 (2000). Even if the solar mixing angle is not maximal, this seems a very good approximation to the real world. At this time, it is clear that the matrix is at least near-bi-maximal even if not exactly so. The implication of such a form are (i) small neutrino-less double beta decay rate, if neutrino masses are hierarchical (with normal hierarchy i.e. $m_3 > m_2 > m_1$) and (ii) small value for the element $|U_{e3}|$. There has been a cottage industry trying to derive bi-maximal form of the matrix theoretically. Pakvasa and Tata have considered this question but have not found any compelling models.

In addition to the solar and atmospheric neutrino results, the LSND results showing presence of $\nu_e$ in the $\mu^+$ decay, also demands explanation. The most conventional explanation is of the presence of a sterile neutrino mixing with $\nu_e$ and $\nu_\mu$ with small mixing and large mass difference. A thorough model-independent analysis was carried out of all available data at that time. It was shown that so-called $2 \oplus 2$ mass spectrum was favored over the $3 \oplus 1$ spectrum. (V. Barger, S. Pakvasa, T. Weiler and
K. Whisnant, Phys. Rev. D58, 093016 (1998). With the final results from LSND and the continued non-observation by KARMEN, the situation has by now changed. In addition to the constraints from the short baseline experiments (such as CDHS, CHOOZ and Bugey), the mixing of a sterile neutrino is also tightly constrained by the solar and atmospheric data. As a result, both $2 \oplus 2$ and $3 \oplus 1$ mass patterns have difficulty providing a good fit. An alternative proposal that avoids a sterile neutrino is to postulate $CPT$ violation. In this case, in the $\nu_e$ sector the solar mass difference is replaced by the LSND scale of order $\text{eV}$. However, a firm prediction of this scenario, namely that the solar and reactor (KamLAND) $\delta m^2$ should be different, was not borne out when the KamLAND result for $\nu_e$ oscillations agreed with the LMA for solar $\nu_e$ oscillations. Under these circumstances, a proposal for LSND involving rare $\mu$-decay rather than oscillations looks attractive. The proposal is a decay mode $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\alpha$ with a branching ratio of order of $2.10^{-3}$ and $\alpha = e, \mu$ or $\tau$. This violates lepton number conservation by two units and is the only mode possible (flavor changing is not sufficient). Extensions of standard model with extra scalar fields which would give rise to such a decay can be constructed (K.S. Babu and S. Pakvasa, hep-ph/0204236).

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There are a number of predictions of such a scenario, the most striking being (a) a null result for $\nu_\mu - \nu_e$ (and $\bar{\nu}_\mu - \bar{\nu}_e$) oscillations in Mini-Boone running currently at FNAL and (b) the deviation of the effective Michel parameter in $\mu-$decay from $3/4$ to about $0.748$ and to be tested by the TWIST experiment now running at TRIUMF.

Until recently many alternate explanations to conventional oscillations of all the neutrino anomalies were viable: (i) decay with mixing; (iii) Lorentz invariance violation; (iii) Equivalence Principle violation (flavor dependence); (iv) flavor changing neutrino neutral currents (FCNC); and (v) resonant spin flavor precession (RSFP). Pakvasa reviewed all these scenarios and summarized the parameter range needed to fit all the data: S. Pakvasa, Pramana, 54, 65 (2000). The situation changed dramatically after the publication of SNO and especially the KamLAND data (Phys. Rev. Lett. 90, 021802 (2003)). All exotic (other than mass-mixing oscillations) explanations are now ruled out and can only play subsidiary or sub-dominant roles with strong constraints placed on the relevant parameters. The current situation is summarized in a comprehensive review: S. Pakvasa and J. Valle, hep-ph/0301061.

$CPT$ violation in neutrino oscillations due to the phase in the mixing matrix has been much discussed (starting with S. Pakvasa, Proc. of XX-International Conference on High Energy Physics, Madison, WI, USA 1980, Part 2, p. 1165 (1980); V. Barger et al., Phys. Rev. Lett. 45, 2084 (1980)); emphasis has been on whether it is detectable at neutrino factories. Even $CPT$ violation was considered in context of possible explanation of LSND effect, as mentioned above. More conventional $CPT$ violation occurs in theories with spontaneous violation of Lorentz invariance. The $CPT$-violating term has an oscillating argument which goes on $L$ rather than $L/E$. Interference between the two can lead to $CPT$-violating resonances. From the lack of such $L$ dependence in the current atmospheric neutrino data, stringent limits can be placed on the Lorentz and
$CPT$-violating parameter $b$: $b < 10^{-20}$ GeV. This limit is comparable to other limits
in electron and quark sector: V. Barger, S. Pakvasa, T. J. Weiler and K. Whisnant,

Oscillation studies provide only mass differences and do not fix the actual mass scale.
For this one has to depend on old fashioned methods such as the tritium end-point and
double $\beta$ decay measurements. The tritium end-point measures the combination

$$M_e = \sqrt{\sum_i m_i^2 \mid U_{ei} \mid^2}$$  (4.1)

Rates for neutrino-less double beta decay measure a different combination (provided
neutrinos are Majorana particles):

$$M_{ee} = \mid \sum_i m_i U_{ei}^2 \mid$$  (4.2)

Finally, large scale structure formation studies (such as 2$dF$ and Sloan Digital Sky
Survey) and fluctuations in the 3$^o$K background radiation are sensitive to the total
mass in neutrinos:

$$\Sigma = \sum_i m_i$$  (4.3)

In the case of only three \textit{active} neutrinos, with the current knowledge, a simple
inequality relating these three masses can be derived.

If the LSND result is explained in terms of fourth sterile neutrinos (in spite of the
difficulties discussed above) then this inequality is modified, and the ordering in
the mass spectrum becomes important. There are six possible mass patterns. P. Roy
(Tata Institute) and Pakvasa studied this problem and found that existing data already
provide strong constraints and three patterns can be ruled out. They also derived a
generalized inequality amongst three observables: $M_e, M_{ee}$ and $\Sigma$. It can be shown
that the measurement (or improved bounds) of any one of them can determine the

We now believe from the established neutrino oscillations, that neutrinos have unequal
masses. If this is true, then in general the heavier neutrinos are expected to decay into
the lighter ones via flavor changing processes. The only questions are \textit{(a)} whether the
lifetimes are short enough to be phenomenologically interesting (or are they too long?)
and \textit{(b)} what are the dominant decay modes.

It can be shown that the only decay modes that can have lifetimes short enough to be
“interesting” are two-body modes such as

$$\nu_\nu \rightarrow \nu_1 + x \, (\nu_1 + x)$$  (4.4)

where $x$ is a (nearly) massless boson, such as a Majoron (S. Pakvasa hep-ph/0004077).
For Majorana neutrinos, both $\nu_1$ and $\overline{\nu}$ are active neutrinos and the branching ratios
into $\nu_1$ and $\overline{\nu}_1$ are comparable. The current limits on the lifetimes for such decays are rather poor, the best being $\tau/m > 10^{-4}\text{s/eV}$ from the non-distortion of Super-K solar neutrino spectrum. This can be improved by the search for $\overline{\nu}_5$s from the sun in KamLAND data. But it was pointed out the observation of high energy astrophysical neutrino flavor mix can improve the limit to $10^4\text{s/eV}$ or observe the decays. The idea is very simple: the flavor mix changes from a canonical $e/\mu/\tau = 1/1/1$ to $6/1/1$ (for normal hierarchy) or $0/1/1$ (for inverted hierarchy) when both heavier eigenstates decay (J. Beacom, N. Bell, D. Hooper, S. Pakvasa and T. Weiler, Phys. Rev. Lett. 90, 181301 (2003). There are other ways in which the flavor mix can change from $1/1/1$. For example, if the neutrinos are pseudo-Dirac, with mass differences less than $10^{-12}\text{eV}^2$, then the flavor mix deviates from $1/1/1$ with a pattern somewhat different from the decay case, thus allowing a handle on such small $\delta m^2$s. In fact this may be the only way to detect such small mass differences (J. Beacom, N. Bell, D. Hooper, J. Learned and T. Weiler, in preparation). Work is also underway to determine how well the flavor mix, especially the ratio $e/\mu$ can be determined in realistic simulation of KM3 type detectors. (J. Beacom, N. Bell, D. Hooper, S. Pakvasa and T. Weiler, in preparation).

### 4.4 Supersymmetry Phenomenology

#### 4.4.1 Research Objectives

The search for the mechanism of electroweak symmetry breaking is the main reason for the construction of high energy colliders. Within the SM framework, the scalar Higgs boson is the anticipated relic of spontaneous symmetry breaking. As is well known, the instability of elementary scalar masses to radiative corrections leads to the so-called fine-tuning problem; i.e. the parameters of the theory have to be adjusted to an uncanny precision unless either (i) electroweak symmetry breaking interactions become strong at the TeV scale so that perturbative arguments are inapplicable, or (ii) there are new perturbative degrees of freedom, not present in the SM, that must manifest themselves in high energy collisions at the TeV scale. In either case, new phenomena, not described by the SM, are expected when the TeV energy scale is explored at supercolliders such as the LHC at CERN or at 0.5-2 TeV linear $e^+e^-$ colliders (such as the NLC) being considered at various places in the world. Possibilities include a strongly interacting symmetry-breaking sector (strong $W_LW_L$ scattering), composite quarks, leptons and leptoquarks, composite “Higgs bosons” (technicolor models), supersymmetry, extra space dimensions, or something even more surprising.

Over the years, Tata and his collaborators have evolved a program of study of the experimental implications of weak scale supersymmetry, particularly for experiments at high energy colliders. The codes that they have developed as well as the strategies that
they have suggested have been extensively used by the DØ and CDF Collaborations at the Tevatron in their search for supersymmetric particles, as well as by experimentalists working on the development of detectors for future facilities such as the LHC or NLC. Their work has involved the development of techniques for the discovery of supersymmetry at present and future collider experiments, and also on how one might go about elucidating any new physics that might be discovered.

For many reasons, it is assumed that supersymmetry is dynamically broken by fields that do not directly couple to SM fields. SUSY models are classified by the mechanism by which superpartners of known particles experience the effects of SUSY breaking. A long term goal of the program is to study the extent to which it will be possible to use data to elucidate the mechanism of supersymmetry breaking and its mediation to the superpartners of SM particles. With this in mind, during the last two years, Tata and collaborators have mostly focussed their attention on implications of different models, their main intention being to study whether there are observable consequences that will allow us to zero in on the underlying framework.

4.4.2 Simulation of supersymmetry at colliders

Over the years, H. Baer (Florida State) and Tata, in collaboration with F. Paige (Brookhaven) and S. Protopopescu (Brookhaven)—the original authors of ISAJET—have incorporated supersymmetry processes into the ISAJET simulation of high energy hadron collisions. They have constructed a program, ISASUSY (a subroutine of ISAJET), that, for any input set of the Minimal Supersymmetric Model (MSSM) parameters, computes the branching ratios for the decays of various sparticles. ISASUSY interfaces with ISAJET where sparticle pair production is calculated. ISAJET thus allows for a simulation of SUSY, including all the complex cascade decay patterns of SUSY particles and provides experimentalists a powerful tool for their analyses. ISAJET includes the evaluation of sparticle mass parameters by renormalization group evolution starting with a variety of boundary conditions. This allows for easy simulation of many popular models, including the mSUGRA model, various gauge mediated SUSY breaking (GMSB) models as well as the minimal Anomaly Mediated SUSY breaking (AMSB) model.

Supersymmetric processes included in ISAJET are: the production of gluinos and squarks, the production of a squark or gluino in association with a chargino or neutralino, the production of chargino and neutralino pairs, slepton pair production, and the production of top squarks at $pp$ and $\bar{p}p$ colliders. ISAJET also includes the production of SUSY Higgs bosons (with radiative corrections to their masses and couplings, as given by the effective potential method, included) either singly, in pairs, or in association with gauge bosons at hadron colliders. All $2 \rightarrow 2$ sparticle-pair production
processes that can occur at $e^+e^-$ colliders have also been incorporated into ISAJET, allowing for longitudinal polarization of the electron and/or positron beams, initial state radiation (via an electron structure function) and beamstrahlung. This allows the incorporation of cascade decays in studies of the prospects for supersymmetry at future linear colliders.

ISAJET includes the effects of $b$ and $\tau$ Yukawa couplings (these couplings are proportional to $1/\cos\beta$) on the masses as well as couplings involving bottom squarks and stau leptons, and, hence, can be used for SUSY simulations even if the parameter $\tan\beta$ is large. The effects of Yukawa couplings on sparticle masses can be especially important if they result in new two-body decay channels of the gluinos, charginos and neutralinos. However, these effects are also important when these sparticles only decay into three-body final states because of the enhancement of the $b$-squark and $\tau$-slepton propagator when these sparticles are light. Complete decay matrix elements in the simulation of gluino, chargino and neutralino three-body decays have also been included. As we describe below, large $\tan\beta$ effects can significantly alter SUSY phenomenology from naive expectations.

The most significant improvements to ISAJET that have been made since our last external review include:

- Various gauge-mediated SUSY breaking models and the minimal anomaly-mediated SUSY breaking model have been incorporated.
- The inclusion of HELAS library routines together with a simple multibody phase space generator allows the user to use code generated by MadGraph to produce multibody hard scattering states.
- The facility to input the three gaugino masses independently allows the simulation of certain string models as well as many SUSY models where gaugino masses are not universal. ISAJET similarly allows for the inclusion of arbitrary scalar masses and $A$-parameters. The so-called $D$-term contributions to SUSY-breaking scalar masses can also be included.
- Two-loop renormalization group equations for the evaluation of soft SUSY breaking parameters have been incorporated. This is crucial for reliably studying models where some matter scalars are much heavier than others.
- Effects of right handed neutrinos and sneutrinos that are now expected to be present in a wide variety of models that accommodate neutrino oscillation data have been included.
- The user has the flexibility to select the scale below which the MSSM is considered to be valid. This allows for simulation of extended models where there may be new
fields not present in the MSSM, or even string models where we need to specify the boundary conditions for RGE at the string scale.

- Radiative corrections in the relations between fermion masses and Yukawa couplings have been implemented. These are important for correctly obtaining the implications of many unified scenarios.

- Radiative neutralino decays are included. These could be significant in the so-called focus point/hyperbolic branch region of mSUGRA parameter space discussed below.

- One-loop corrections to sparticle masses have been incorporated. These are important in some parameter space regions and are crucial in some frameworks such as anomaly-mediated SUSY breaking.

Baer and Tata expect to continue working on further refinements to ISAJET. They expect to make technical improvements that should enable a better study of the focus point/hyperbolic branch region. They are also working on including a version of the AMSB model that has the virtue of preserving the scale invariance of the sfermion mass relation.

### 4.4.3 Supersymmetry searches

Supersymmetry cannot be an exact symmetry. If supersymmetry is to render the weak scale stable under radiative corrections, it must be broken softly by operators whose mass dimension is smaller than four. In MSSM, which is the framework with the fewest number of fields and interactions required for phenomenological viability and theoretical consistency, SUSY breaking is parametrized by introducing all allowed soft SUSY breaking (SSB) operators consistent with $SU(3) \times SU(2) \times U(1)$ gauge symmetry and Poincaré invariance. This general parametrization, even assuming conservation of $R$-parity, leads to over a hundred new parameters, and is intractable for most phenomenological analyses. The basic problem is that the mechanism by which MSSM superpartners acquire their masses is not yet understood. It is, therefore, customary to work within the framework of models for sparticle masses and couplings. Common to these models is a hidden sector whose dynamics breaks SUSY: the various models differ in the way the SUSY breaking effects are felt by superpartners of SM particles. Tata and collaborators have been studying the implications of various models with an eye toward identifying experimental quantities that might be determined at future colliders could serve to zero in on the right framework, once sparticles are discovered and their properties determined.
The mSUGRA framework

Most early phenomenological analyses of supersymmetry were mostly performed within the framework of the so-called mSUGRA model, which has become the paradigm framework for experimental SUSY analyses. Within this framework, the effects of SUSY breaking are conveyed to superpartners of SM particles by gravitational interactions. This framework is characterized by the universality of SSB mass and trilinear scalar couplings, renormalized at $Q \sim M_{Planck}$, that results from a technical assumption about the Kähler potential. Over the years, Tata and co-workers have identified strategies for SUSY searches at LEP 2, the Tevatron collider and its luminosity upgrades, the LHC and electron-positron linear colliders, and used ISAJET to delineate the SUSY reach of these facilities.

Just over a year back, Tata, former student Wang (now at Iowa State) and Mizukoshi (now at University of São Paulo) in collaboration with Baer, C. Balázs (now at Florida State) and A. Belyaev (Florida State) re-examined various experimental and cosmological constraints within this framework, and delineated the regions of parameter space that are favored in light of these constraints. In their analysis, they incorporated constraints from the measurement of the branching fraction for the inclusive $b \rightarrow s\gamma$ decay, the lower limit on $B_s \rightarrow \mu^+\mu^-$ decay, the determination of the anomalous magnetic moment of the muon, lower limits from direct searches for sparticles at the Tevatron and at LEP, and limits from the non-observation of any sign of Higgs boson(s) at LEP. They also included restrictions that the density of relic neutralinos not be so large that the age of the universe would be smaller than allowed by observation. Their results were published in JHEP 0207, 050 (2002). Motivated by the recent WMAP data that fix the cold dark matter density to better than 10%, Baer, Balázs, Belyaev, T. Krupovnickas (a Florida State student) and Tata, re-visited this question and also assessed the reach of the LHC in light of these measurements. They found that the region of low $m_{1/2}$ and $m_0$ where relic neutrinos annihilated via light sfermion exchange that was thought to be cosmologically favored is excluded. The three distinct regions of mSUGRA parameter space consistent with WMAP data are: (1) the stau-neutralino co-annihilation region where $\tilde{\tau}_1$ is coincidentally close in mass to $\tilde{Z}_1$ so that both staus and neutralinos are present at the time of decoupling. The large stau annihilation rate then allows a relic density consistent with data. (2) a region where neutralinos resonantly annihilate via exchange of heavy (and broad) $A$ and $H$ in the $s$-channel, and (3) a narrow region at very large $m_0$ where $|\mu|$ the SUSY higgsino mass parameter becomes small, the so-called focus point/hyperbolic branch (FP/HB) region. They find that if nature chooses options (1) or (2) the general SUSY searches at LHC will ensure discovery of SUSY at the LHC unless $\tan \beta$ is very large ($\sim 55$). For the FP/HB region though, SUSY discovery is guaranteed only if $m_{1/2} \leq 600 \rightarrow 700$ GeV. A paper reporting these results has been submitted for publication [hep-ph/0304303].

In this FP/HB region, the lightest SUSY particle (LSP) is either Higgsino-like or con-
tains a significant component of the Higgsino. Since the Higgsino preferentially couples to the third generation, gluino decays to the Higgsino-rich LSP tend to have an enhanced fraction of third generation fermions. Tata, in collaboration with Baer, Mercadante and Mizukoshi, proposes to examine whether this provides a way of extending the reach of the LHC for this interesting region of parameters.

Tata and co-workers have also been involved in devising strategies for SUSY searches at the Tevatron. They had shown that if the luminosity upgrades of the Tevatron can accumulate an integrated luminosity of 15-25 fb$^{-1}$ as advertised, the inclusive trilepton signal yields the greatest reach for SUSY within the mSUGRA framework, though specially designed soft cuts are needed if tan$\beta$ is large. Motivated by the fact that the WMAP data pick out large $m_0$ (FP/HB region) as one of the allowed regions of mSUGRA parameter space, Baer, Krupovnickas and Tata extended their earlier analyses of the Tevatron reach to these very large $m_0$ values with small $|\mu|$ where $\tilde{W}_1$ and $\tilde{Z}_{1,2}$ tend to be light and Higgsino-like, with a not very large mass gap between them and the LSP. Nevertheless, they found that in the FP/HB region, the 5$\sigma$ reach of the Tevatron upgrades extends out to $m_{1/2} \sim 190$ GeV corresponding to $m_{\tilde{g}} \sim 575$ GeV. A paper reporting this has been submitted for publication [hep-ph/0305325].

**Gauge-Mediated SUSY Breaking**

Within this framework, SUSY breaking effects are conveyed to SM superpartners by usual gauge interactions. Consequently, sparticle masses are proportional to the square of the corresponding gauge coupling of the particle. As a result, gluinos and squarks are much heavier than their electroweak counterparts. These models can accommodate a very low SUSY breaking scale. In this case, the gravitino may be the LSP. Sparticles decay as usual via gauge and Yukawa couplings to the lightest MSSM sparticle which then decays into the gravitino (really the Goldstino). The lifetime for this decay is highly parameter-dependent, so that the decay length ranges from unobservably small to several km. A determination of the decay length provides crucial information about the SUSY breaking scale. Assuming that the next lightest SUSY particle (NLSP) decays inside the detector, the visible debris from this decay (which depends on the identity of the NLSP) can provide an additional handle on SUSY signals. In the case that the NLSP is a neutralino (slepton/smuon), SUSY events will contain additional hard photons (leptons) that help to reduce SM backgrounds and, thus, enhance the SUSY reach. A careful examination of signals in this framework was the subject of Wang’s Ph.D dissertation completed in 2002. The results from these studies are also reported in a series of papers in Phys. Lett. B and Phys. Rev. D. Regardless of the details, the reach of the LHC (with just 10 fb$^{-1}$) was found to extend to at least $m_{\tilde{g}} = 2$ TeV, but could be as large as 3 TeV in the case of a slepton NLSP.
4.4. SUPERSYMMETRY PHENOMENOLOGY

**Anomaly Mediated SUSY Breaking**

In supergravity models, MSSM soft SUSY breaking parameters are thought to arise from tree level gravitational interactions of observable sector superfields with gauge singlet hidden sector fields that can acquire a Planck scale vev. There is, however, an additional one-loop contribution to SSB parameters that is always present when SUSY is broken. Usually this contribution, which originates in the super-Weyl anomaly, only makes an unimportant correction to the leading tree level SSB parameters. However, in models without SM gauge singlet superfields that can acquire a Planck scale vev, the usual supergravity contribution to gaugino masses is suppressed by an additional factor $\frac{M_{SUSS}^2}{M_P}$ relative to $m_3 = M_{SUSS}^2 / M_P$, and the anomaly-mediated contribution can dominate. The virtue of these AMSB contributions to the scalar masses is that they are scale invariant, reflecting their insensitivity to ultra-violet physics. Moreover, they are determined by just the $\beta$ functions and anomalous dimensions, so that sparticles with the same gauge quantum numbers are degenerate, consistent with constraints from flavor physics. Unfortunately, slepton squared masses turn out to be negative. Within the minimal AMSB framework, this is fixed by adding a universal contribution to scalar masses. This maintains the absence of unwanted FCNCs, but spoils the ultra-violet insensitivity of these contributions. In a paper published in Phys. Lett. B488, 367 (2000), Tata in collaboration with Mizukoshi and Baer had explored the SUSY reach of the LHC within this framework.

It had been noted by Jack and Jones that $D$-term contributions to scalar masses would not spoil the scale invariance of AMSB masses. Since left and right sleptons have opposite hypercharges, it is not possible to use the hypercharge $U(1)$ contributions to solve the “tachyonic sleptons problem” in AMSB. It is, however, possible to have additional $U(1)$’s that may be broken at very high scales whose $D$-terms give positive masses for both left- and right-sleptons. Tata, in collaboration with Baer and others, proposes to incorporate these models into ISAJET and explore its phenomenological implications for colliders.

**Gaugino-Mediated SUSY Breaking**

A novel alternative for the mediation of SUSY breaking is embodied in the so-called gaugino mediation model. The idea is that the SUSY breaking sector is confined to one brane while SM fields are assumed to live on a different brane that is spatially separated in the extra dimensions. It is assumed that gauge fields can propagate in the bulk. Gauginos, which have a substantial wave function on the SUSY-breaking brane, directly feel SUSY breaking effects and, so, acquire substantial SUSY breaking masses. The matter scalars, on the other hand, feel the SUSY breaking only indirectly via their interactions with gauginos. As a result, soft SUSY breaking scalar masses and $A$ and parameters are suppressed relative to gaugino masses. These boundary conditions
hold at the compactification scale which is assumed to be between $M_{GUT}$ and $M_{Planck}$. This framework, as we have described, is not quite consistent. The condition $B = 0$ fixes $\tan \beta$ to be too small to be compatible with $SU(5)$ grand unification. In the analysis performed by Tata in collaboration with Baer, Belyaev and Krupovnickas, $\tan \beta$ was taken to be a free parameter. They argued that $B$ would likely depend on how $\mu$ is generated, and assumed that a value consistent with grand unification would be obtained. They take $M_c = 10^{18}$ GeV. Although there is not “much room” for running between $M_c$ and $M_{GUT}$, substantial soft mass parameters are generated at the GUT scale because of large representations in the GUT group. Within this framework, they find a lower bound on $m_{1/2}$. If $m_{1/2}$ is too small, $\tilde{\tau}_1$ becomes a stable LSP, in conflict with cosmological considerations. As a result, the SUSY spectrum is predicted to be rather heavy and there will be no sparticle signals at the Tevatron. Experiments at the LHC should probe a substantial portion of the parameter space, and (assuming 100 fb$^{-1}$) should be sensitive to gluinos as heavy as 2.5 TeV via the $1\ell + jets + \not{E}_T$ channel. Confirmatory signals in multilepton channels will be present if $m_{\tilde{g}} \leq 2$ TeV. They also go on to argue (using a technique suggested earlier by Baer, Balázs, Hesselbach, Mizukoshi and Tata) that experiments at an $e^+e^-$ linear collider will be able to distinguish between this framework and the mSUGRA framework if both selectrons as well as the chargino are kinematically accessible. A paper reporting this study has appeared in Phys. Rev. D65, 075024 (2002).

4.4.4 Extracting the $b$-quark Yukawa coupling in SUSY models

An accurate determination of especially the bottom quark Yukawa coupling is needed to explore properly the phenomenological implications of SUSY models if $\tan \beta$ is large. The way this coupling is usually obtained starts with the observed value of the bottom quark mass.

Conventionally the running bottom mass extracted from experimental data is evaluated in the $\overline{MS}$ scheme at the scale $Q = m_b^{\overline{MS}}$. It is, however, the dimensional reduction ($\overline{DR}$) scheme that is used as an invariant regularization in SUSY theories, so that it is the running bottom mass evaluated at $Q = M_Z$ that serves as an important input in SUSY models. Tata and Ferrandis, in collaboration with Baer and Melnikov (then at SLAC), worked out a two-loop procedure for converting $m_b^{\overline{MS}}(m_b^{\overline{MS}})$ to $m_b^{\overline{DR}}(M_Z)$. They find that the central value of the running bottom mass changes from the frequently used 2.92 GeV to 2.83 GeV. A paper reporting these results appears in Phys. Rev. D66, 074007 (2002).
4.4.5 Is the large $\tan \beta$ limit of the MSSM fine tuned?

It is generally believed that if the parameter $\tan \beta$ is large, the MSSM parameters need to be fine-tuned. This belief originates in the tree-level minimization conditions for the Higgs potential,

$$\mu B = s_\beta c_\beta \left(m_{H_u}^2 + m_{H_d}^2 + 2\mu^2\right), \quad (4.5)$$

$$\mu^2 = \frac{m_{H_d}^2 - t_\beta^2 m_{H_u}^2}{(t_\beta^2 - 1)} - \frac{1}{2} m_Z^2, \quad (4.6)$$

Using (4.5), it is generally argued that if $\tan \beta \to \infty$, $\mu B \to 0$ and that the soft masses have to be fine-tuned to have cancellations at the level of $\frac{1}{\tan \beta}$.

Beyond tree level, the minimization conditions receive additional contributions. At the one-loop level, these can be written (in the large $\tan \beta$ limit) as,

$$\mu B = s_\beta c_\beta \left(m_{H_u}^2 + m_{H_d}^2 + 2\mu^2\right) + s_\beta c_\beta \left(\Sigma_u + \Sigma_d\right) + \Sigma_u, \quad (4.7)$$

$$\mu^2 = \frac{(m_{H_d}^2 + \Sigma_d) - t_\beta^2 (m_{H_u}^2 + \Sigma_u)}{(t_\beta^2 - 1)} - \frac{1}{2} m_Z^2, \quad (4.8)$$

where the $\Sigma$'s are obtained from derivatives of the effective potential, with the $vev$s factored out, so that these are independent of $\tan \beta$. We then see from (4.7) that $\mu B$ (while it is suppressed by a loop factor) need not vanish in the limit $\tan \beta \to \infty$. It thus seems that by allowing some hierarchy in soft parameters (to overcome part of the loop suppression) the fine-tuning argument given above can be circumvented, at least as a matter of principle. The value of $\tan \beta$ is bounded by the requirement that Yukawa couplings remain perturbative up to some scale. In models where other new physics intervenes at $Q = 100-1000$ TeV, $\tan \beta$ values up to 150-200 may be possible. A paper detailing these arguments as well as outlining some phenomenological consequences at ultra-high $\tan \beta$ has appeared in Phys. Lett. b561, 145 (2003).

4.4.6 Low Energy Constraints on Supersymmetry

Even though the Higgs sector of the MSSM is such that there are FCNC effects at tree level, such effects may be induced at the one loop level. Since there are no tree-level FCNCs in the SM either, SUSY contributions to these processes may be of the same order as the SM contributions. The best known of these is perhaps $b \to s\gamma$. In collaboration with Baer and M. Brhlik (then a student at Florida State), Tata had incorporated contributions to this that could be significant at large $\tan \beta$. Since then some higher order contributions have been computed, and they have been periodically...
upgrading the $b \to s\gamma$ calculation that they use for phenomenological analyses. In addition to this, they have also evaluated the rate for $B_s \to \mu^+\mu^-$ decays (described below), as well as $g_\mu - 2$ in various SUSY models, and incorporate constraints from these into their analyses.

$B_s \to \mu^+\mu^-$ decays as a probe of supersymmetry

We have noted above that if $\tan \beta$ is large, the relation between the fermion mass and the corresponding Yukawa coupling receives significant corrections at one loop. In particular, the down-type quark receives a contribution to its mass from the vev of the Higgs field $H_u$ so that Yukawa couplings are no longer diagonal in the mass basis, and Higgs-mediated flavor violation results. Several authors have pointed out that the branching fraction for $B_s \to \mu^+\mu^-$ decays may be potentially observable at the Tevatron if $\tan \beta$ is large. Moreover, the SUSY contribution does not decouple for large sparticle masses (it does decouple as Higgs bosons become heavy), so that this may potentially provide the first signal of new physics at the Tevatron.

Tata, Mizukoshi and Wang performed a detailed examination of this decay within the mSUGRA, GMSB and AMSB models. They showed that the effects of gluino loops that have been ignored in most other phenomenological analyses are substantial and can significantly reduce the expectation for the branching fraction of this decay. Nevertheless, they found that there are regions of mSUGRA parameter space where this decay will be probed in the current run of the Fermilab Tevatron. They also went on to examine the branching fraction for this decay in the gauge-mediated and anomaly-mediated SUSY breaking models. There, they found that the branching fraction is much smaller, and it is only when $m_A$ is accidentally small that this decay will be observable at the Tevatron. In models with non-universal gaugino masses though the rate for this decay can be very large, so that some parameter ranges are already excluded by the current CDF bound on its branching ratio. A paper reporting these results appears as Phys. Rev. D66, 115003 (2002).

4.4.7 SUSY models with Yukawa and gauge coupling unification

The interpretation of the atmospheric neutrino anomaly in the SuperK data as neutrino oscillations has provided much impetus for studying $SO(10)$ grand unified models where Yukawa couplings also unify at the GUT scale. In a series of papers, Ferrandis and Tata, along with Baer and others, have examined this scenario. It is straightforward to find consistent SUSY models with good Yukawa unification for negative values of $\mu$, but this sign is somewhat disfavored by the results of experiment E821 at Brookhaven. In a recent study, they find that Yukawa coupling unification is also possible for positive
values of $\mu$, but only if SSB matter-scalar mass parameters are in the multi-TeV range and $m_{1/2}$ is small. This also requires a splitting between the $H_u$ and $H_d$ scalars, either via $D$-terms, or otherwise. The required boundary conditions lead to a radiatively generated inverted mass hierarchy for matter scalars, with third generation scalars much lighter than the first two generation scalars. While the models are consistent with constraints from $b \rightarrow s\gamma$, $B_s \rightarrow \mu^+\mu^-$ and $(g-2)_\mu$, the relic density of dark matter tends to be too high for values of scalar masses that give good Yukawa coupling unification. A paper reporting these results has been submitted for publication [hep-ph/0302155].

SO(10) models with SO(10) broken to SU(5) offer an interesting possibility of generating the required mass splitting between the $H_u$ and $H_d$ scalars, if the SO(10) breaking scale is significantly larger than the scale associated with SU(5) unification. Then the renormalization group evolution between these scales can generate the desired splitting that would be calculable, given the right handed neutrino mass. Ferrandis, in collaboration with Tata and others, proposes to examine the viability of this scenario.

In inverted hierarchy models, third generation scalars might be the only matter scalars accessible to experiment. Although these might themselves be at the TeV scale, it would be interesting to see if there would be observable signals for these at the LHC. Signal cross sections are small (so that the highest integrated luminosity possible would be needed) but there is also no significant SUSY contamination. Hawai’i student Kadala, in collaboration with Tata, Mercadante and Mizukoshi, has begun an investigation to see whether such a scenario is detectable at the LHC.

### 4.4.8 Fermion masses in supersymmetric models

**Fermion masses from a supersymmetric SUSY SU(5) fixed point**

The understanding of the fermion mass and mixing patterns is an outstanding puzzle. Grand unified theories reduce the number of independent parameters, but they do not make definite predictions for the Yukawa couplings at the unification scale. These couplings must be fit to the experimental measurements. An alternative idea, not incompatible with the GUT approach, is the possibility that the third generation fermion masses are determined by an exact fixed point of the renormalization group equations. Specifically, Ferrandis examined the minimal supersymmetric SU(5) model. When one-loop supersymmetric thresholds are included, this unified fixed point successfully predicts the top quark mass, $175 \pm 2$ GeV. He found that the bottom quark mass prediction is sensitive to the supersymmetric thresholds; it approaches the measured value for $\mu < 0$ and multi-TeV values of $m_{1/2}$. The experimental value of $m_\tau$ determines $\tan \beta$, and the strong gauge coupling and fine structure constant fix the

Neutrino masses

It is well known that Majorana neutrino masses will be generated if there are sources of lepton number violation. One possibility, that fits naturally into the framework described above, would be through spontaneous $R$-parity violation triggered by the presence of the right handed sneutrino and the couplings in the SU(5) model. Ferrandis, in collaboration with J. W. F. Valle (Valencia), proposes to examine the extent to which the necessary couplings and fields required to induce spontaneous $R$-parity violation can appear naturally in the SUSY SU(5) model that results from the spontaneous breaking of an underlying SO(10) SUSY GUT. If the SO(10) breaking scale is $\geq 10^{17}$ GeV, these $R$-violating contributions may naturally dominate the usual see-saw contribution to neutrino masses.

4.5 Quark Flavor Physics

There are several aspects to studies of quark flavor physics. One is to devise tests of the Standard Model and/or deduce its parameters (such as KM angles and phase); another is to devise tests of various proposals for new physics beyond the standard model, and yet another is to speculate about the origin of masses and mixings (i.e. model building).

The results for search for a $CP$ violating amplitude ("direct") in $K_L$ decay, i.e. a non-zero value for $\epsilon'/\epsilon$, were ambiguous until recently. In the Standard Model, with a top quark mass of about 175 GeV, the expected value for $\epsilon'/\epsilon$ can be as small as $10^{-4}$. One can also observe $CP$ violation in the hyperon decays and, although it involves $\Delta S = 1$ transition like $\epsilon'/\epsilon$, it is sensitive to a somewhat different combination of operators and different uncertainties in the hadronic matrix elements. The SM prediction for $A$ (defined as the $CP$ asymmetry in the decay $\Xi^- \to \Lambda \pi^- \to p \pi^- \pi^-$) is in the range $10^{-5}$ to $10^{-4}$. The on-going experiment E871 at Fermilab intends to measure $A$ in the decay $\Xi^- \to \Lambda \pi^- \to p \pi^- \pi^-$ with the goal of eventually reaching a sensitivity of $10^{-4}$. This serves both as a test of Standard Model, as well as search for possible new physics. It is expected that E871 will announce their results soon, the analysis of the data is under way. (The analysis seems to be hampered by a shortage of manpower needed to analyze the enormous amount of data.)

The recent measurements of $\epsilon'/\epsilon$ by the Fermilab and CERN groups are in agreement with each other and with the 1988 CERN value. The current world average is $(2.12\pm0.46)10^{-3}$; and is not consistent with zero. Hence, direct $CP$ violation has
been seen and the “Superweak” model (Wolfenstein 1964) is essentially ruled out. The SM predictions for $\epsilon'/\epsilon$ have a large degree of uncertainty and span the range $10^{-4}$ to $3 \times 10^{-3}$. Hence, there is no obvious disagreement with the SM, but significant contributions from new physics to $\epsilon'/\epsilon$ cannot be ruled out. Pakvasa, He and collaborators are investigating the implications of such new physics proposals for $CP$ violating measurements in hyperon decays, and especially for asymmetries being measured by E871 at Fermilab. For example, they have shown that if $\epsilon'/\epsilon$ is to be accounted by (new supersymmetric contributions (via the transition gluonic EDM as proposed by A. Masiero and others), then the asymmetry $A$ exceeds a value $1.5 \times 10^{-4}$ and would be easily measurable in E871 (X-G. He, H. Murayama, S. Pakvasa and G. Valencia, Phys. Rev. D61, 07701 (R) (2000)). One more attempt to settle the question of the final state phase shifts in $\Xi \to \Lambda \pi^-$ (the knowledge of which is crucial) was made by Datta, O’Donnell and Pakvasa: hep-ph/9806374, with no change in the expected small values for the phase shifts.

In the $b$-quark sector, the main issue is still the extraction of the SM parameters. When the first data on the $B \to K\pi$ modes became available in 1999, the early indications were that the rates for the modes $K^-\pi^0$, $\overline{K}^0\pi^-$ and $\overline{B}^0 \to K^-\pi^+$ were roughly equal. Assuming this to be really true led to very interesting conclusions. Making reasonable assumptions about the matrix elements (factorization) and about strong phase shifts it was shown that (a) the electro-weak Penguin contribution can be important, (b) the unitarity angle $\gamma$ is the range $90^\circ - 120^\circ$ (or $220^\circ - 260^\circ$), (c) the branching ratio for $B^0 \to \overline{K}^0\pi^0$ is small $\sim 0(10^{-6})$ and (d) direct $CP$ Violation in $B^0 \to K^-\pi^+$ can be quite sizable with asymmetries of order of $10\%$ or larger: N.G. Deshpande, X-G. He, W-S. Hou and S. Pakvasa, Phys. Rev. Lett. 82, 2245 (1999). Subsequent extensive fits to larger data-sets confirmed these conclusions (hep-ex/9910014). A possible value of $\gamma \approx 90^\circ$ was also very encouraging to the Stech-like model considered by Bjorken, Pakvasa, Tuan (see below).

Browder, Datta, O’Donnell and Pakvasa studied the interesting decay mode $B^0,\overline{B}^0 \to D^{*+}D^{*-}K^0$. This mode can be useful in several ways. The $B^0$ may decay via the resonant mode $B^0 \to D^*D^*$, where $D^*$ is the $J^P = 1^+$ resonance which decays into $D^*K^0$. This resonance, which is anticipated at about 2600 MeV, is expected to be broad and has yet to be seen. This decay mode may be one way to find it. In any case, this mode can also serve as one more way to measure $\sin 2\beta$, without the need to measure the final state polarization. There may be some dilution of order 70% depending on the fraction of the rate which is due to the resonance (Phys. Rev. D61, 054009 (2000)).

As a corollary to an earlier study of the quasi-inclusive decays of $B \to K/K*+X$, the inclusive node $B \to \pi + X$ was considered. Although less dramatic than the case for $K$ and $K*$ final states, some useful studied can be made with enough cuts to identify the quasi two body mode $\pi + u$. The results were summarized in: X-G. He, C. P. Kao,

The issues of interest for $c$-quarks are somewhat different than for $b$-quarks. In the $b$-system, it is worthwhile to search for the $CP$ violation and “rare” decay modes as predicted by the SM since these effects are sizable and measurable at the $B$-factories. For the charmed particles all such effects, such as $D^0 - \bar{D}^0$ mixing, $CP$ Violation, rare flavor changing decays ($c \to u\gamma$ etc are predicted to be too small to be observable in the SM and, hence, the search is for new physics. Hence the first task is to have at hand careful SM estimates. Thus, in the work of G. Burdman, E. Golowich, J. Hewett and S. Pakvasa (Phys. Rev. D52, 6383 ((1995)) on weak radiative decays of charm mesons, careful estimates of both short- and long-distance contributions are made. A full analysis of the short-distance $c \to u + \gamma$ electromagnetic penguin amplitude with QCD radiative corrections was carried out. The QCD corrections enhance the branching ratio from $10^{-17}$ to $10^{-11}$; but, even so, the long-distance contributions dominate by many orders of magnitude, overwhelming the short-distance penguin contribution. For example, $D^+ \to \rho^+\gamma$ (or $D_s \to K^*\gamma$) decays are predicted to have branching ratios of about $10^{-5}$, and $D^0 \to \rho^0\gamma$ of about $10^{-6}$, etc. This also means that these radiative decays, while very useful probes to learn about long distance strong interaction effects, are not of any use in probing new, beyond-SM physics.

It is necessary to turn to rarer modes to probe new physics. Examples are $D^0 \to \mu\bar{\mu}$, $D^0 \to \gamma\gamma$, $D \to \pi\ell\bar{\ell}$, $D \to K\ell\bar{\ell}$, $D \to K\nu\bar{\nu}$, $D \to \pi\bar{\nu}\bar{\nu}$, etc.

Calculations of these modes in the SM are in progress. Another interesting topic is direct-$CP$ violation in $D$ decays. In the SM, direct-$CP$ violating rate asymmetries can only arise in CKM-suppressed modes such as $D \to \pi\pi$, $D \to K\bar{K}$, etc. Careful estimates of these SM asymmetries as well as possible signatures of new physics in $CP$ violating asymmetries in CKM allowed as well as double CKM suppressed decay modes were carried out (Burdman, Golowich, Hewett, and Pakvasa, Phys. Rev. D66, 014009 (2002)).

Other very interesting phenomena are mixing and $CP$ violation in the $D^0 - \bar{D}^0$ system. In the SM, the short distance contribution to $\delta m_D$ is known to be extremely small, of order $10^{-17}$ GeV. At one time, it was thought that there could be long distance enhancement by several orders of magnitudes. Now, there is some rethinking about this. The $CP$ violating phase is also expected to be very small. In a careful and detailed paper (Golowich, Hewett, Pakvasa and Petrov (in preparation)), the following program is carried out: an up-to-date analysis of both short distance and long distance contributions to $\delta m_D$ and the lifetime difference $\delta \Gamma_D$ between $D^0$ and $\bar{D}^0$; also $CP$-violating effects are considered; many proposed extensions of the SM are also investigated and their predictions will be compared. The phenomenology of $D^0 - \bar{D}^0$ mixing (with possible large $CPV$ effects) is discussed here as well as in the work of Browder and Pakvasa (Phys. Lett. B383, 475 (1996)). A Physics Report article on “Charm as a Probe of New Physics” is in preparation. The work of several years on
radiative decays, rare decays, mixing, $CP$ violation etc. will be consolidated into a comprehensive review. Standard Model expectations will be delineated as carefully as possible and places with largest windows for new physics signatures will be emphasized. A variety of new physics scenarios with expected signals will be discussed. The review is designed to be especially useful to experimenters, and be ready in time for new facilities with large number of charm events.

A crucial parameter in determining $\delta \Gamma$ for $D^0 - \overline{D}^0$ system from the data on the time development of $D^0$ and $\overline{D}^0$ decay modes (for example into $K^-\pi^+$ and $K^+\pi^+$) is the phase $\delta$. This is the phase difference between the decay amplitude for $D^0 \rightarrow K^-\pi^+$ and the one for $D^0 \rightarrow K^+\pi^-$. Can theory alone provide the value of $\delta$? Symmetry considerations are of only limited use. It is known that $\delta$ vanishes in the $SU(3)$ invariant world, and this result has been recognized in discussing aspects of the wrong-sign $D^0$ transitions. Thus, calculating the value of $\delta$ necessarily involves the physics of $SU(3)$ breaking. Unfortunately, our limited understanding of physics in the charm region (especially the complicating effects of QCD) makes it difficult to perform reliable calculations.

It was shown by Golowich and Pakvasa (Phys. Lett. B505, 94 (2001)) that the phase $\delta$ can be measured for the $K^*\pi$ modes without requiring knowledge of $K_L$ modes. If all the double Cabibbo suppressed modes

$$D^0 \rightarrow K^{*+}\pi^-, \ D^+ \rightarrow K^{*0}\pi^+, \ D^0 \rightarrow \overline{K}^{*0}\pi, \ D^+ \rightarrow K^{*+}\pi^0$$

are measured, and certain simplifying assumptions are made, the phase difference $\delta$ for the $K^*\pi$ mode can be extracted.

For the $K\pi$ modes this is not possible without a measurement of $K_L$ modes. Then by combining both $K_L\pi$ and $K_s\pi$ modes along with certain dynamical assumptions $\delta$ can also be extracted.

Another method suggested by Gronau et al. (hep-ph/0103110) is to use tau-charm factory and consider $e^+e^- \rightarrow D^0\overline{D}^0 \rightarrow (K^-\pi^+)(f)$ where one $D$ decays into $K^+\pi^+$ and one into a $CP$-eigenstate final state $f$ which has $CP = \pm 1)$. Then the ratio of the rates into $CP = +1$ and -1 states is given by

$$R = (1 + 2r \cos \delta)/(1 - 2r \cos \delta) \approx 1 + 4r \cos \delta \quad (4.9)$$

where $r$ is the ratio $(D^0 \rightarrow k^-\pi^+)/(\overline{D}^0 \rightarrow k^-\pi^+)$. If the integrated luminosity is about $3 fb^{-1}$, it may be possible to measure $\cos \delta$ to a level of 0.07.

Golowich and Pakvasa are now collaborating with David Asner (a CLEO experimenter) to extend these considerations to time-dependent studies of Dalitz plots of three-body decays of $D$ mesons to extract similar information on $\delta \Gamma$, strong phases as well study $CP$ violation.
The number of $\Upsilon$'s and $J/\psi$'s accumulated at current and future facilities (e.g. BES, CLEO-C, etc.) is expected be of order of $10^8$. An interesting question is whether the large sample of the $\Upsilon$ and $J/\psi$ can be used to probe flavor-changing processes in $\Upsilon$ and $J/\psi$ decays. For the quarkonium system, these flavor-changing processes are expected to be much smaller than in the case of decays of bare $B$ or $D$ mesons because of the large strong-interaction decay widths of the bottomonium and charmonium systems. Indeed the standard model contributions to $\Upsilon \to B/\overline{B}X_s$, and $J/\psi \to D/\overline{D}X_u$ are tiny. However, new physics may enhance the branching ratios for these processes. Whether this enhancement will be sufficient for these processes to be observable in the next round of experiments was investigated by Pakvasa and collaborators. In SM, the rates for these processes are expected to be negligibly small and unobservable. In a variety of scenarios that were considered, such as top-color models, the MSSM with $R$-parity violation, and two-Higgs-doublet model, branching ratios as large as $10^{-6}$ and $10^{-5}$ were found to be possible. (A. Datta, and P.J. O'Donnell, S. Pakvasa and Z. Zhang, Phys. Rev. D60, 014011 (1999)).

4.5.1 Model Building: Yet Another Extension of the Standard Model

The work of Bjorken, Pakvasa and Tuan, which began with a Bjorken seminar at UH three years ago (2000), appeared in Phys. Rev. D66, 053008 (2002). They searched for conceptually simple extensions of the SM, and explored in detail a model that they found to be attractive. The starting point is the assumption that off-diagonal CKM mixing matrix elements are directly related by lowest-order perturbation theory to the quark mass matrices. This appears to be naturally implemented by assuming that all mixing resides in the down-quark mass matrix. This assumption is in turn naturally realized by introducing three generations of heavy, electroweak-singlet down quarks that couple the the Higgs sectors diagonally in flavor, while mass-mixing couples off-diagonally with the light down-quarks. Anomaly cancellation then naturally leads to inclusion of electroweak vector-doublet leptons. It is then only a short step to completing the extension to three generations of fundamental 27 representations of $E(6)$. There are a number of implications of this model.

1. The possibility of “Stech texture” for the mass matrix, leading to an appropriate right angle ($\gamma$) in the unitarity triangle, and a value for $\sin 2\alpha = \sin 2\beta$ between 0.64 and 0.8.

2. The existence of three generations of heavy electroweak-singlet down-quarks that decay into light counterparts plus $W, Z$ or Higgs bosons. The masses should be no larger than roughly 10 TeV. The leptons most reasonably are a factor two or so lighter that their heavy-quark counterparts. The first generation quark masses may be near the current experimental bound, which is 130 GeV.
3. Flavor and $CP$ violation are induced only by “soft” mass-mixing terms and are “infrared” in nature. Therefore, above that mass scale such effects rapidly diminish, only to re-emerge if and when the mechanism for the relevant mass terms becomes dynamical. This also implies that radiative-correction effects are in all cases not divergent.

4. The “Mexican Hat” structure of the Higgs potential may be radiatively induced by new heavy quark one-loop contributions.

5. Some precision electroweak observables are, in principle, sensitive to the existence of these new degrees of freedom. The ordinary down quarks and leptons are mixed slightly with their heavy counterparts, making them not transform as pure doublets or singlets. This leads to nonuniversality of the asymmetries measured in electron-positron annihilation processes. On the other hand, a variety of one-loop radiative correction effects in the down-quark or lepton sector vanish. No significant corrections, for example, are expected in the mass mixing of kaons or neutral $B$'s, in $\epsilon$ and $\epsilon'$, in $b \to s \gamma, \mu \to e \gamma, K_L \to \mu_e$ or in the unitarity triangle. There can be significant effects in the up-quark sector e.g. in $D^0 - \overline{D^0}$ mixing, and in top-quark flavor-changing decays such as $t \to c + Z$ and $t \to c + \gamma$ (detailed calculations for these modes are under way: A. Datta and S. Pakvasa (in preparation)).

6. If the Higgs couplings to the heavy quarks are “ununiversal”, and at least as large as the Higgs coupling to the top quark, then there will be an oasis in the desert, at an energy scale of about 100 TeV, where the Higgs top-quark, and heavy down-quark couplings all become strong. Additional new physics is then assured above this energy scale.

7. If the Higgs couplings to the new quarks are hierarchical, then there need not be an oasis and, furthermore, parity violation is also “infrared” (in the gaugeless limit). If it is postulated that no oasis exists, the Higgs boson must have a mass of $160 \pm 20 GeV$.

4.6 $M$-theory and Membrane Instantons

Quantum theory has several formulations. There is the matrix mechanics of Heisenberg, and the Schrödinger formulation through the differential equation for the wave function. Feynman invented another way that uses the path integral. At the present stage of $M$ theory, there is one rather well defined method that uses the matrix formulation. It would be desirable to have another formulation that starts directly from a classical membrane formulation. This approach has not been successful so far. In the case of string theory there is a simple way to classify the world sheet and expand an amplitude based on this. This is the genus expansion. The closest method in the world volume
case is to use the Heegaard diagrams. Although the incorporation of unitarity is an outstanding problem to be solved, Sugawara has shown that it is at least possible to take into account all possible topological configurations into the membrane calculations within this framework [hep-th/0304168]. A related problem is the evaluation of the membrane instanton contribution to the superpotential (J.A. Harvey and G. Moore, hep-th/9907026) and we can apply the above method to this case.

One of the most outstanding puzzles in particle physics is the origin of flavors. Experimentally we know there are only three generations of leptons and quarks and there is some mixing between them. So far we have not been able to understand this in a fundamental way, in spite of the considerable efforts put into it during the last several decades. The most recent and probably the most promising approach to this problem is the idea of Witten [hep-th/0201018] in which he starts from $\mathcal{M}$ theory, and justifies in a way another approach that is called the “deconstruction” where the extra dimension comes in as isolated points, and thus make possible a kind of lattice gauge approach. In the $\mathcal{M}$ theory model of Witten, the gauge symmetry is somewhat mysteriously localized in a subspace of extra dimensional space, as found by Vafa and Katz sometime ago [hep-th/9606086]. Now, we can ask the following questions.

- What is happening to the supersymmetry? Is this localized in a similar way as the gauge symmetry?
- In $\mathcal{M}$ theory, just as in string theories, the superpotential vanishes in a perturbative calculation. Can we calculate it within the framework of membrane instantons?

We have to be able to do the calculation for the non-Abelian gauge sector that originates in the monodromy group of a certain singular manifold that is a fiber of the extra dimensional space of which the base space is given by a space in which gauge symmetry is localized. Sugawara feels that we can make some progress in solving these problems by first starting from the systematic description of the three dimensional manifolds [hep-th/0304168], and perhaps obtaining the simplest kind of manifold with $G2$ holonomy that could be relevant to the real world with three generations. Certain important discrete symmetries that are ad hoc in Witten’s model can then be justified in a way from the supersymmetry. He is continuing to work on these issues.

## 4.7 Miscellaneous Topics

### 4.7.1 Applications of high energy neutrino beams

In a somewhat distant future we may be able to use neutrino beams for various purposes: communication, earth studies including mineral searches, military or rather
4.7. MISCELLANEOUS TOPICS

arms control technology etc. Sugawara, in collaboration with H. Hagura (KEK) and T. Sanami (KEK), considered the possibility of utilizing a very high energy neutrino beam to destroy nuclear weapons [hep-ph/0305062]. Although there remain formidable technical issues to be solved, they find it not necessarily absurd to think about such a possibility. For this purpose, it is vital to calculate precisely what the mean free path is and what sort of interaction the neutrino beam will experience inside the earth. Their preliminary calculations, without including QCD corrections, neutrino regeneration effects, etc. have already been reported. These effects may change the high energy neutrino interaction substantially. The calculation is more or less straightforward, assuming conventional knowledge on the earth’s structure.

4.7.2 Quantum Information Science

Information science is currently undergoing a revolution as the physics basis is expanded to include quantum mechanics. When classical communications are viewed from a quantum mechanics perspective, most classical information transfer is seen to occur via the ensemble properties. In contrast, in quantum communications (and the related fields of quantum computation and quantum cryptography), information transfer occurs as the level of individual quanta.

High-energy particle physics has always entailed the study of individual quanta. Therefore, there is a natural analogy between the analysis of high-energy experiments and the exchange of information in quantum communications. For physicists familiar with the methods of high-energy physics, there is an opportunity to apply their knowledge to contribute to the development of the new field of quantum information science.

Simmons and Pakvasa have made a contribution to this new science by examining the process of direction-finding (a common classical engineering practice) in quantum communications. More specifically, they show that if information, in the form of a microscopic image, is encoded on individual $N_{\gamma} = 2$ states of the electromagnetic field, then it is possible to transmit a message through free space, in the presence of at least some noise, while remaining hidden. (W.A. Simmons and S. Pakvasa, Direction Cryptography in Quantum Communications, quant-ph/0302186).

4.7.3 Complex Systems

It is generally regarded that the immune system of vertebrate and brain system are the typical examples of complex systems. But is it really so? It seems that the immune system does not at least fall into the category of complex systems as defined by Gellmann and Lloyd. Then, what makes the immune system seemingly so complex and extremely flexible? If we understand this problem, can we apply it to the brain system
as well? These are questions that should be addressed not only by biologists but by physicists as well.

One approach may be to compare these systems to relatively complex, man-made systems such as nuclear reactors, particle accelerators, satellites, etc. How do we make these and how good can the system be? There are several important steps to be taken to reach the final product and its operation: 1) conceptual and engineering design; 2) precise scheduling of the production and the assemblage; 3) production of all the necessary components; 4) assembly of the components; 5) commissioning of the entire system; and 6) maintenance of the system. Sugawara suggests that by viewing DNA genes in this context, it may be possible to obtain a different perspective on seemingly complex systems.
4.7. MISCELLANEOUS TOPICS


Publications in refereed journals


**Contributions to conference proceedings**


3. H. Baer, T. Krupovnickas and X. Tata, Reach of the Fermilab Tevatron for minimal supergravity in the region of large scalar masses (submitted to J. High Energy Physics).

4. H. Baer, C. Balázs, A. Belyaev, T. Krupovnickas and X. Tata, Updated reach of CERN LHC and constraints from relic density, $b \rightarrow s\gamma$ and $a_\mu$ in the mSUGRA model, (submitted to J. High Energy Physics).


Conference Publications


6. X. Tata, Unraveling Supersymmetry at Future Colliders, invited talk presented at PASCOS 03, Tata Institute of Fundamental Research, Mumbai, India (January 2003), to appear in the proceedings.

7. J.K. Mizukoshi, X. Tata and Y. Wang, Rare decay $B_{s,d} \to \ell^+\ell^-$ in supersymmetric models, presented at the 23rd Brazilian National Meeting on Particle and Fields, Aguas de Lindoia, Brazil (October 2002)


Book Chapters


Unpublished Reports


Chapter 5

Relation to Other Projects

As described above, our research is highly collaborative. Consequently, we maintain many close ties with groups at other universities and laboratories. Members of our group frequently play leadership roles in these collaborations: Gorham is spokesperson for the GLUE and ANITA experiments, Harris is co-spokesperson for BES, and Olsen has been co-spokesperson for Belle since its inception. Browder has been the analysis coordinator for the Belle experiment since the position was established five years ago.

We are active in promoting international cooperation, especially between the US and Asian particle physics communities. Harris and Olsen are members of the US-PRC and US-Japan committees, respectively; Sugawara serves on a number of international committees and recently chaired ICFA.

5.1 Activities

A brief summary of some recent activities of members of our group follows.

Browder gave an invited talk on measurements of $\sin 2\phi_2 (\alpha)$ and rare decays at Physics in Collision in Stanford (June 2002), three lectures on $B$ physics (rare decays, $V_{cb}$, $V_{ub}$) at the SLAC summer institute (August 2002), and a Fermilab Colloquium on results from the $B$ factories (November 2002). In March 2003, he presented Belle results on $B \rightarrow D_{CP}K^(*)$ at the Japan Physical Society Meeting in Sendai. In June 2003, he gave a seminar at SLAC on $CP$ violation results from Belle, a mini-review of Belle $CP$ violation results at the CIPANGP2003 conference in New York and the conference summary at FPCP2003 in Paris. He will review results on the $CP$ angle $\phi_1$ at the Lepton-Photon Conference at Fermilab (August 2003).

Fang gave an invited minireview on $B \rightarrow charmonium$ decays at FPCP02 in Philadelphia (May 2002) and a contributed talk on $B \rightarrow p\bar{p}K$ and other charmless three-body modes at the Williamsburg DPF meeting (2002).

Ferrandis gave talks on masses in supersymmetric SU(5) models at PHENO 2003 in Madison, Wisconsin (May 2003) and SUSY03 in Tucson (June 2003), and a talk on top-bottom-tau Yukawa coupling unification in SUSY models at PLANCK 03 in Madrid (May 2003).
Gorham was selected as a DOE Outstanding Junior Investigator in 2002. He chaired the SPIE conference on Particle Astrophysics in Kona in mid-2002. He was invited to describe current efforts in radio detection of high energy particles to the National Science Foundation at the NESS 2002 meeting in late September, and more recently at the annual June 2003 meeting of the American Astronomical Society in Nashville.

Harris gave talks on BES results at ICHEP, Amsterdam (July 2002), the US-PRC committee meeting, Beijing (October 2002), at the Quarkonium Group Workshop, CERN (November 2002), and the Aachen EPS meeting (July 2003). He reported on BES results and future plans at the Cornell CLEO-c Symposium (June 2003).

Jones was a judge at the Hawaii State Science Fair and helped organize the annual Physics Olympics for high school students and the UH Manoa Physics Open House. He was President of the Hawaii chapter of the American Association of Physics Teachers from Fall 2001 until Spring 2003.

Learned gave lectures on Neutrino Astrophysics at the Mexican Astrophysics Summer school, in Guanajuato (August 2002), and the University of Tokyo Institute for Cosmic Ray Research (March 2003). He gave colloquia on neutrino physics at Texas (November 2003) UC-Irvine (April 2003) and Princeton (May 2003). He gave seminars at Texas (November 2002) and KITP, UC-Santa Barbara (April 2003), and a Fermilab “Heavenly Messenger” series lecture (October 2002).

Melnikov was selected as a DOE Outstanding Junior Investigator in 2003. He is one of the organizers of a three-month Workshop “Collider Physics” which will be held in Kavli Institute for Theoretical Physics (KITP) at UC-Santa Barbara starting January 2004. He has given invited talks on the physics of the muon anomalous magnetic moment at the SLAC Summer Institute (2003), MIT, the University of Buffalo, and on methods for perturbative calculations at Fermilab and the University of Alberta.

Olsen gave an invited talk on Super-B factories at the CERN ICFA seminar (November 2002). He gave talks on the BES observation of low mass $p\bar{p}$ enhancement in $J/\psi \to \gamma p\bar{p}$ decays at a symposium at Nihon University in Tokyo (February 2003) and at the Philadelphia APS/DPF meeting (May 2003). He has also given a number of colloquia and seminars on Belle results. He is a member of the KEK $B$-factory Steering Committee and the panel that reviews NLC-detector R&D proposals. He recently served on international review panels for the University of Tokyo’s International Center for Elementary Particle Physics and KIMS, a Korean dark matter search experiment. He chaired the organizing committee for Vertex2002 in Kona, Hawaii (November 2002).

Pakvasa gave invited talks on LSND and Rare Muon Decay at the International Conference on Nuclear and Particle Physics at 50 GeV in Kyoto (September 2002),
5.1. ACTIVITIES

at KEK on (November 2002), Tokyo Metropolitan University (December 2002), KITP, UC-Santa Barbara (March 2003), and TRIUMF (June 2003). He gave a talk on Beyond the Standard Model at Tohoku University (October 2002) and on Neutrino Decays and High Energy Astrophysical Neutrinos at the tenth International Conference on Neutrino Telescopes in Venice (March 2003), KITP, UC-Santa Barbara (April 2003) and the IVth International Conference on Non-Accelerator New Physics, NANP 03, in Dubna (June 2003). He gave a talk entitled “Neutrinos Yesterday, Today and Tomorrow,” at the 3rd Taiwan-U.S. Cooperative Workshop on Cosmology and Astrophysics, Taiwan (November 2002). He is a member of the International Advisory Committee for the 2003 International Symposium on Cosmology and Particle Astrophysics, to be held in Taipei in November 2003.

Parker gave invited talks on 3-D radiation sensors and their uses in biology and high-energy physics at Pixel 2002 at Carmel (September 2002), CERN (October 2002), Ecole Polytechnique in Palaiseau (October 2002), Vertex2002 in Hawaii (November 2002), and the University of New Mexico (May 2003).

Suester gave an invited talk on Belle results at the February 2003 Lake Louise Winter Institute and a contributed talk on charmed fragmentation functions at the Aachen EPS meeting (July 2003).

Sugawara served as ICFA chairman from 2000 until 2002. He is a member of a number of scientific committees of the Japanese government, is on the science councils of a number of institutions, including: ICTP in Trieste, APCPT in Korea, the National observatory of Japan, etc., and a member of the Board of Trustees for various Japanese organizations including Spring8, the Nishin Foundation, the Advanced Graduate University, etc. He gave both the introductory and the summary talks at the CERN ICFA seminar (October 2002) and talks at KEK on membranes and on neutrino applications. He is chair of the international committee for DPF2006, which will be an international meeting of all of the particle physics societies in the pacific region.

Swain gave talks on $B \to D_{CP}K$ decays at the Williamsburg DPF meeting (May 2002) and Rencontres de Moriond: Electroweak Interactions and Unified Theories (March 2003).

Tata was selected as an APS Fellow. He gave plenary talks at the plenary talks at the International Conference on Particles, Strings and Cosmology (PASCOS) held at the Tata Institute of Fundamental Research, Mumbai, India (January 2003) and at SUGRA 20, the international conference marking twenty years of supergravity held at North Eastern University (March 2003). He also presented a talk at the International Linear Collider Workshop (LCWS) on Jeju Island, S. Korea (August 2002). He was an invited lecturer at the KIAS Spring School for Particle Physics in Seoul and gave invited talks at the Weak Interaction and Neutrino Workshop...
in Christchurch, New Zealand (January 2002) and at PHENO 2002 in Madison, Wisconsin (April 2002). He also gave colloquia and seminars at the University of Oklahoma and Oklahoma State University (May 2002).

Trabelsi gave the first public report on the Belle results for $CP$ violation in $B \rightarrow \pi^+\pi^-$ decays in an invited talk at the Rencontre de Moriond (March 2002). He also reported first observations of $B$ meson decays to $D_{sJ}(2317)$ and $D_{sJ}(2460)$ at FPCP2004 in Paris (June 2004).

Varner gave talks on next generation PID and DAQ systems at the BESIII workshop in Beijing (June 2002) and the Super KEKB workshops in Shonan Village (August 2002), Osaka (November 2002) and USTC Hufei (April 2003). He gave talks on radio frequency detection of ultra-high energy neutrino interactions and associated electronics at the SPIE Conference on Instrumentation for Astronomy, Hawaii (August 2002), PSI (October 2002) and IHEP, Beijing (March 2003). He served on an electronic design review panels for the Multiple Compton Gamma-Ray Telescope, SLAC (November 2002).

Zheng gave a contributed talk on $B\overline{B}$ mixing measurements at the Williamsburg DPF meeting (May 2002) and seminars on the same subject at UCLA (March 2003) and Fermilab (April 2003).

5.2 Outreach

As the only major university physics department in the state, our department has always had strong connections to the local community of science teachers, both at the high school and college level. Members of the high energy group are active in the Hawaii chapter of the American Association of Physics Teachers and occasionally give presentations at their meetings and seminars at local high schools. Recently Jones served terms as AAPT president and vice president.

Our department has two annual outreach activities: the Open House in November and the Physics Olympics in March.

About 100 students and teachers from local high schools and colleges participated in this past year’s Open House, where four (of a total of seven) sites were high-energy physics related: antimatter (and the Belle experiment); neutrinos ( and the SuperK and KamLAND experiments); Gorham’s on-campus cosmic ray radio detector; and theoretical physics. As usual, these attracted lots of interest and attention. The event was announced in both Honolulu daily newspapers and a photo from one of the sites appeared in the Honolulu Star-Bulletin.
The 14th annual Physics Olympics competition for high school students was held on
the UH Manoa campus on 1 March. The contest was sponsored by the Hawaii AAPT
Chapter, the UH Kapiolani Engineering Club, and the UH Manoa Society of Physics
Students Chapter. Members of the high energy group help with planning and judging
of the events. Thirty-one teams of students from eleven high schools, including one on
Maui, participated.

We also engage in activities that keep the community informed about scientific subjects.
For example, Learned recently gave the Sakamaki Extraordinary Lecture. This lecture
is intended to communicate exciting research at UH to the community. There was
a packed house to hear about new results on the role of neutrinos in the universe.
Sugawara intends to give several public lectures during his tenure at Hawaii.

At any given time, about ten undergraduate students are involved in our research as
paid part-time helpers or as unpaid students doing research for class credit. Browder
helps maintain the links on department’s World Wide Web to various physics sites that
are of interest to students in undergraduate physics classes.

Varner is mentoring Peter Grach, a teacher at the Kamehameha School, on a summer
research project as part of our first year of participation in the Quarknet project.
Gorham and Learned are also participating in this project.

5.3 Meetings

Our group hosted the Workshop on Lepton Flavor Violation and Neutrino Oscillation
with High Intensity Muon and Neutrino Sources in October 2000; the annual meeting
of the US-Japan Committee for Cooperation in High Energy Physics in May 2001;
and Vertex2002, the 11th annual International Workshop on High Resolution Silicon
Detectors in November 2002. We will host a joint SLAC-KEK Workshop on Physics

We were asked by the officers of the APS Division of Particles and Fields to host the
2006 annual meeting (DPF2006). Unlike most other meetings, the DPF series is aimed
at bringing together young people and providing them opportunities to present their
work. We plan to expand the 2006 meeting to be a regional forum for students and
post-docs from all pacific-rim particle-physics communities. This plan has been well
received throughout the region; Sugawara has formed an international coordinating
committee to guide this effort. We look forward to an exciting and productive meeting
in 2006.
5.4 HEPG Visitors

Visitors to our group during the past year are listed below. In most cases they were supported either by their own, or University funds.

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<tr>
<th>HEPG Visitors</th>
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<tr>
<td><strong>2002</strong></td>
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<tr>
<td>V. Barger (Wisconsin)</td>
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<td>D. Dicus (U. Texas)</td>
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<td>E. Golowich (Amherst)</td>
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<td>K. Melnikov (SLAC)</td>
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<td>D. Kaplan (SLAC)</td>
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<td>G. Burdman (UC-Berkeley)</td>
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<td>D. Kribs (Wisconsin)</td>
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<td>Y. Shirman (Caltech)</td>
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<td>A. Sill (Texas Tech.)</td>
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<td>T. Blazek (Southampton)</td>
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<td>H. Tajima (SLAC)</td>
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<td>L. Lyons (Oxford)</td>
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Chapter 6

Shared Technical Support

Ms. D. Ibaraki, Messers J. Li and M. Rosen and Dr. G. Varner

The experimental groups’ shared technical support staff includes a manager for our computing and networking systems (Ibaraki), her full-time assistant (Li), an opto-mechanical engineer (Rosen), and an electronics design specialist (Varner). (The services and salaries of Ibaraki, Rosen and Varner are shared with other projects in the department.) In addition, we have free access to the physics department machine shop, which has two full-time state-supported machinists who are available for HEP work approximately 50% of the time. We can also purchase electronics and mechanical engineering services from shop facilities at the University of Hawaii’s School for Ocean and Earth Science and Technology and the Institute for Astronomy. These services are charged to our grant at a state-subsidized hourly rate.

We have permanent high-quality laboratory space in Watanabe Hall, where our offices are located, plus addition space in the Physical Sciences Building (PSB), which is directly across the street, and Krauss Hall annex, which is a few hundred meters away.

We have ISDN phone-based and IP internet-based video conference systems that were purchased primarily with university funds. These are heavily used for meetings with colleagues on the mainland, at KEK, Kamioka and IHEP (Beijing). In addition to reducing the need for travel, the system allows for increased participation by all group members in collaboration meetings.

6.1 Computing

Dr. F. Harris and Ms. D. Ibaraki

The general computing activities of the High Energy Physics Group are supported by our local network of computers. This includes two, newly introduced Sun Fire 280R dual processor servers with gigabit ethernet and disks managed by a Sun 438GB StorEdge raid system. In addition there are a number of AlphaStations of various
vintages that are gradually being retired. In addition to physics analysis and computations, the computers are used for communication, manuscript preparation, web page development, equipment design, and accounting. In addition, there are a number of PC computers that are used for specialized tasks such as data acquisition or computer-aided design.

The large computing and data set storage demands of the Belle, BES, and Kamland, are now mostly met by dedicated Linux computing farms. The first such farm was set up by the Belle group in 2001. During the last year, this farm has been expanded to include 20 dual-processor Pentium III computers with 3 Tbytes of disk space (6 500GB raid systems). These computers are interconnected using Gigabit Ethernet and are being used for data analysis and Monte Carlo event generation for Belle and BES. The KamLAND group has a two-server computing farm with a 876GB raid system.

6.1.1 Networking

Our computers, X-terminals, and PC’s, which are distributed throughout Watanabe Hall and the Physical Science Building (PSB), are networked together in what we call PHYSNET. This is currently connected to the University’s Network (UHNET) via a fiber-optic connection to an ITS Cisco 6505 switch. UHNET is connected to the mainland by a OC3 (155 Mbps) link to Internet2, a OC3 link to the Commodity internet, and a DS3 (46Mbps) backup connection. UH has plans to upgrade the Internet2 link to a OC12 (600 Mbps) in the near future.

PHYSNET sits behind a SonicWall firewall that provides protection to the physics subnet. We haven’t had any systems compromised since its installation. During the last year, we purchased two 10/100 ethernet switches. Now all HEPG offices are connected to switched ports, which has improved the network traffic. We are currently in the process of moving our current and newly networked equipment to a new “supernet,” which will double the maximum number IP addresses (to 508). As part of this upgrade, we will need to purchase/setup a new server to manage DHCP.

6.1.2 Future upgrades

We request funds (as summarized in Table 6.1) for the following equipment purchases:

Intel Servers: In order to increase security and enhance network performance, we plan to add four Intel servers to provide dedicated services such as web serving, DHCP, DNS, Email and, in the future, Lightweight Directory Access Protocol (LDAP). LDAP is an open-standard protocol for accessing X.500 directory services and runs over Internet transport protocols such as TCP.
Table 6.1: Computer upgrade items for FY2004.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Intel servers (Linux)</td>
<td>15,000</td>
</tr>
<tr>
<td>1 Fast Ethernet switches</td>
<td>1,200</td>
</tr>
<tr>
<td>1 Disk Storage Solution</td>
<td>10,000</td>
</tr>
<tr>
<td>1 Video Conferencing system</td>
<td>4,000</td>
</tr>
<tr>
<td>1-NET TV for Video Conferencing system</td>
<td>3,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$ 33,200</strong></td>
</tr>
</tbody>
</table>

**Ethernet Switch:** An additional 10/100 switch is needed for Watanabe Hall as there are problems with the current switch.

**Disk storage:** Much of our BES and SuperK data are stored on alphaservers and not protected against loss in the case of a disk crash. We will move it to either another Sun Raid or a NAS (Network Attached Storage) server. The NAS server is independent of operating system and can support all types of UNIX, as well as PCs.

**Video conferencing equipment:** Our PictureTel video conferencing system is now six years old. It has not been upgraded during this time and does not perform reliably. An IP video conferencing system has been installed on a PC. This has proven to be very useful for video conferences with KEK for the Belle experiment, but again the system has not been very reliable. In order to obtain a reliable ISDN and IP video conferencing system, we plan to purchase a Polycom system.

6.2 Engineering support

*Mr. M. Rosen and Dr. G. Varner*

Our internal engineering staff consisting of two senior engineers, usually about eight student engineering technicians, and two machinists. Collectively this group provides design, development and fabrication capabilities in electronics engineering, mechanical engineering, and opto-mechanics.

The facilities include an Instrumentation Development Lab and an Opto-mechanical Lab, each about 150 m². We also have use of the department’s machine shop.
6.2.1 Facilities

The **Instrumentation Development Lab (IDL)** has workstations and software for the design of printed circuit boards, FPGA/CPLD firmware and ASICs. Assembly benches and prototyping facilities are maintained with student technician support. There are test instrumentation setups for NIM, 6U/9U VME, cPCI, CAMAC, FAST-BUS and LabView/GPIB. Silicon pixel and custom detector development are facilitated by a Cascade motorized probe station, an Agilent parametric development and a K&S wire-bonder.

The **Opto-mechanical Lab** has computers and software capable of providing standard CAD, parametrically constrained solid modeling, Finite Element Analysis, and 3-D optical ray trace design and analysis. This lab is equipped with optical benches, optical breadboarding hardware, several low-power lasers ranging from UV to IR, an Ericsson FSU 900 optical fusion splicer, an Tektronix OF235 Optical Time Domain Reflectometer, assorted types of fiber optic test equipment, and a Norland fiberoptic cleave interferometer. For RF antenna development and testing, we have constructed three anechoic chambers, including one that is 9x4x3 m$^3$.

6.2.2 Summary of recent instrumentation projects

**BESII:**

- TOF Laser Calibration: 2 channel, 96 fiber, delivery system
- BESPANIK amplifier: optimized "$L3" preamp for BES MDCIII
- MDCIII mechanical assembly: ~50K precisely located holes
- MDCIII preamp array: 4000 channels fabricated and tested
- Time Stretcher: prototype for possible BESIII TOF upgrade

**Belle/KEKB:**

- TOF Laser Calibration: 3 channel, 640 fiber delivery system
- RadFET readout system: SVD irradiation monitoring readout system
- Capacitive Displacement monitor: SVD $\mu$-level movement monitor
- TOF pre-amplifier: Precision timing PMT gain drop compensation
- RF Timing fanout: 32 channel NIM fanout with $< 20\text{ps}$ timing jitter
6.2. ENGINEERING SUPPORT

- TOF Front End Electronics (TOFFEE) board: design and test
- Time Stretcher for precision time encoding: R&D 100 Award for design
- MTS1 Monolithic Time Stretcher prototype ASIC
- TOF Trigger: multiplicity and topology ID for B B-bar event isolation
- SVD radhard development: irradiation evaluation of VA devices
- SVD VA hybrid: development of common VA evaluation hybrid
- XTEST2 chip: R&D pixel detector for Belle upgrade
- COPPER board: Belle high luminosity pipelined readout upgrade
- CuEval FINESSE board: High speed Front-end Electronics emulator
- BEAST: KEKB/Belle commissioning detector
- STARBALL: robotically controlled beamline background monitor
- SVD2 beampipe: initial design and FEA modeling
- SVD2 ladders: structural design and FEA of composite members

SuperK:

- SKAT: two path, multipass beam transmissometer
- Fiberoptic switch: 8 channel 4 wavelength optical router
- Laser ball: isotropic laser/fiber light source

KamLAND:

- $4\pi$: 20m graphite/composite robotic calibration arm
RF Cherenkov detection:

- Local NaCl detector: 96 channel salt embedded dual bowtie antennas
- Anechoic test chambers
- RF Multiplexor: GHz bandwidth switch for transient digitizing
- RF amp card: multi-channel, low-noise amplifier
- STRAW2 Development: Custom RF GSa/s digitizer IC development
- RF antenna development
Chapter 7

Budget Request

In this chapter, we present a detailed, task-by-task budget request for FY04, together with comparisons with funding awards for previous fiscal years. Costs are broken down by task and a narrative is provided in order to give the reader a reasonably accurate picture of our expenditures. In most cases, projected costs are determined with reasonable reliability from previous years’ experience.

The task budgets include fractions of general experimental support and administrative costs that are itemized in Tables 7.8 and 7.9 near the end of this chapter. The indirect costs reflects an agreement that we made with the University that assigns the off-campus indirect cost rate to all of our activities, with the exception of Administrative Support, which is assigned the on-campus rate.
7.1 Electron accelerator experiment I: Belle

Table 7.1 summarizes the budget requested for the Belle activities (described above in Section 2.1). The budget request for FY03 is above last year’s award and reflects the increased activity associated with the rapidly growing data sample. (During the past twelve months, Belle has submitted more than 30 papers for publication, many with Hawaii people as first authors.)

The faculty involved in Belle are Browder, Jones, Olsen and Peters. This task includes the salaries for research physicists Jones and Trabelsi, stipends for post-doctoral fellows Barbero, Fang, and Seuster, and graduate students Guler, Kent, Swain and Uchida.

Aside from salaries, the only other substantial item is travel, most of which is to KEK. This includes trips to participate in general group meetings, for taking shifts, and for dealing with other business at KEK. (The cost for a two-week trip to KEK is $\sim$2000.) Each eligible Belle author is expected to take a week of experimental shifts each year. This accounts for about half of the travel budget. There are six group-wide meetings per year, five of which are at KEK. Olsen, as cospokesperson, and Browder, as analysis coordinator, are expected to be present at most of the meetings; other Hawaii Belle people participate in one or two meetings each year, usually in conjunction with their shifts or other duties. Some Hawaii people have responsibilities that sometimes require their presence at KEK: Trabelsi is the Belle group’s Kalman-filter track fitter expert; Varner is involved in electronics R&D for future upgrades; Guler is in charge of the TOF-derived level-0 trigger; and Uchida maintains the CDC-SVD track-matching for the level-1.5 trigger.

All graduate students in Belle are expected to do extended terms at KEK as “expert shift-takers.” This usually means that each year one of our students is resident at KEK.

This task is assessed 38.75% of administrative and 65% of shared experimental-support costs.
Table 7.1: Electron Accelerator Experiment I - BELLE

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty Overload</td>
<td>40,300</td>
</tr>
<tr>
<td>Physicists</td>
<td>71,200</td>
</tr>
<tr>
<td>Research Scientist</td>
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<tr>
<td>Postdoc Fellows</td>
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</tr>
<tr>
<td>Graduate Students</td>
<td>60,000</td>
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<tr>
<td>Fringe Benefits</td>
<td>46,900</td>
</tr>
<tr>
<td>Personnel Costs</td>
<td>385,000</td>
</tr>
</tbody>
</table>

**Instrumentation**

| Materials & Supplies            | 5,000      |
| Instrumentation Subtotal        | 5,000      |

**Computing Services**

| Telecom/Network BELLE           | 1,000      |
| Computing Services Subtotal     | 1,000      |

| Domestic                        | 10,000     |
| Foreign                         | 52,000     |

| Travel Subtotal                 | 62,000     |

**Other**

| Phone/FAX, Mail                | 1,500      |
| Freight/Delivery                | 1,000      |

| Other Subtotal                  | 2,500      |

| Total Direct Costs              | 455,500    |
| Indirect (20.6%)                | 69,500     |

| Total Budget                    | 525,000    |
| 38.75% Admin Costs              | 48,700     |
| 65% EG Costs                    | 162,000    |

| Total BELLE Budget              | 735,700    |
7.2 Electron accelerator experiment-II  BES

Table 7.2 itemizes the budget request to support the Hawaii activities on the BESII experiment at IHEP (Beijing) that are described above in Section 2.2. This is Harris’ primary research activity; Olsen and Varner also participate in this project. This task includes support for post-doctoral fellow Guo and graduate student Cai.

The requested operating funds for FY04 are 10% higher than the FY03 award and reflects what we consider to be the minimum necessary to maintain this activity. After salaries, travel to IHEP is the biggest expense. It is expected that each participant in the BES experiment be on-site in Beijing for about one month per year for shift-taking, maintenance of the Hawaii-provided detector hardware and software, and for consultation on data analysis, papers, etc. We limit this to one trip per participant per year except for Harris who, as cospokesperson and member of the US-PRC committee, must travel to Beijing more often. He also represents the BES experiment in the Quarkonium Working Group, which meets once per year. We also have been participating in the development of the design and TDR for BESIII. (Last year, as part of this, Varner traveled to USTC in Hufei, at Chinese expense, to consult on the design of the BESIII electronic data acquisition system.)

The hardware that we have provided for the BESII upgrade is working reliably. We have supplied IHEP with enough spare parts for day-to-day maintenance, where minor repairs are also carried out. Occasionally components with major failures are sent to Hawaii for repair. We need a modest amount of materials and supplies funds to support this.

This task is assessed 15% of administrative and 15% of shared experimental-support costs.
Table 7.2: EA–II; The BES–II Experiment

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel</strong></td>
<td></td>
</tr>
<tr>
<td>Faculty Overload</td>
<td>17,700</td>
</tr>
<tr>
<td>Postdoc Fellows</td>
<td>41,000</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>19,000</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>2,900</td>
</tr>
<tr>
<td>Personnel Cost</td>
<td>80,600</td>
</tr>
<tr>
<td><strong>Travel &amp; Consultants</strong></td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>4,000</td>
</tr>
<tr>
<td>Foreign</td>
<td>17,200</td>
</tr>
<tr>
<td>Travel Subtotal</td>
<td>21,200</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Phone/FAX, Mail</td>
<td>1,000</td>
</tr>
<tr>
<td>Freight/Delivery</td>
<td>500</td>
</tr>
<tr>
<td>Other Subtotal</td>
<td>1,500</td>
</tr>
<tr>
<td><strong>Total Direct Costs</strong></td>
<td>103,300</td>
</tr>
<tr>
<td>Indirect (20.6%)</td>
<td>12,800</td>
</tr>
<tr>
<td><strong>Total BES Budget</strong></td>
<td>116,100</td>
</tr>
<tr>
<td>15% Admin Costs</td>
<td>18,900</td>
</tr>
<tr>
<td>15% EG Costs</td>
<td>37,400</td>
</tr>
<tr>
<td><strong>Total BES Budget</strong></td>
<td>172,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electron Accelerator Experiments:</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle</td>
<td>735,700</td>
</tr>
<tr>
<td>BES</td>
<td>172,400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>908,100</td>
</tr>
</tbody>
</table>
7.3 Proton Accelerator Experiment: Pixel Detector R&D

This is a generic detector development activity that involves technologies from high energy physics and material science. Two major successes of this were the development of a monolithic pixel detector and, more recently, the successful development of pixel detector based on a three-dimensional (3D) electrode geometry. Lately, this activity has been more and more directed to developing three-dimensional pixel detectors for use in a beam-beam collision monitoring system at a future high energy $e^+e^-$ linear collider, the subject of DOE Advanced Detector Research Grants that Parker has received during the past three years. As discussed above in Section 2.3, Parker is collaborating with a number of groups that are refining the 3D pixel technology for a variety of applications.

Parker’s home base is at LBL where he has good access to mechanical and electronics shops and high energy physics oriented engineering expertise. In particular, the circuitry needed for pixel readout is a problem common to the Hawaii-Belle group’s and the 3D-pixel designs. Parker has very close interactions with the LBL pixel readout group that have been mutually beneficial. The current work on the 3D architecture is only possible with an STS micromachining device and the only one available to us for R&D purposes is at the Stanford Nanofabrication Facility (SNF). For these reasons, Parker is based in California.

The budget request, shown in Table 7.3, only covers Parker’s salary. All other costs for these activities come from other sources.
Table 7.3: Proton accelerator experiment; Pixel Detector R&D

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel</strong></td>
<td></td>
</tr>
<tr>
<td>Physicists</td>
<td>100,300</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>19,500</td>
</tr>
<tr>
<td>Personnel Cost</td>
<td>119,800</td>
</tr>
<tr>
<td><strong>Total Direct Costs</strong></td>
<td>119,800</td>
</tr>
<tr>
<td><strong>Indirect (20.6%)</strong></td>
<td>24,700</td>
</tr>
<tr>
<td><strong>Total Proton Budget</strong></td>
<td>144,500</td>
</tr>
</tbody>
</table>
7.4 Non-accelerator expt I: SuperK, $K2K$ and KamLAND

The budget request for Hawaii participation in neutrino experiments in Japan, SuperK, $K2K$ and KamLAND, is summarized in Table 7.4. This task includes salary support for two students and post-doctoral fellow Guillian.

Aside from salaries, the main cost item is travel. This is dominated by travel to the Kamioka detector site. The three UH SuperK/$K2K$ authors (Guillian, Learned and Matsuno) are expected to cover a total of 94 shifts per year. The six UH KamLAND authors (Gorham, Guillian, Learned, Maricic and Pakvasa) are required to spend two weeks a year at the detector site to take experimental shifts. Pakvasa’s KamLAND-associated travel comes from this task. (The cost for a two-week trip to Kamioka is $\sim$2600.)

Ph.D. students are expected to be in residence at the laboratory for a cumulative total of at least a year to help operate the detector and process data. Maricic has nearly completed her quota. Each collaboration has at least two major group meetings each year in Japan. In addition, the KamLAND-USA group also has meetings, usually in California. On average, each person attends about half of the meetings. These responsibilities dominate the travel costs.

The budget request for this activity is very nearly the same as the FY03 award. We note that this is a very cost-effective program that enjoys a high level of University support. The only salary support is for students and the (overhead-exempt) post-doctoral fellow. All of Matsuno’s salary and benefits are provided by the University even though he works full-time on research. In addition, Learned receives full salary support from the University.

This task is assessed 26.25% of administrative and 20% of shared experimental-support costs.
Table 7.4: EN-I; Super-K/K2K/KamLAND

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel</strong></td>
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<tr>
<td>Graduate Students</td>
<td>39,700</td>
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<tr>
<td>Postdoc Fellows</td>
<td>45,000</td>
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<tr>
<td>Student Help</td>
<td>4,500</td>
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<td>Fringe Benefits</td>
<td>3,200</td>
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<tr>
<td>Personnel Cost</td>
<td>92,400</td>
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<tr>
<td><strong>Instrumentation</strong></td>
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<td>Materials &amp; Supplies</td>
<td>2,000</td>
</tr>
<tr>
<td>Instrumentation Subtotal</td>
<td>2,000</td>
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<tr>
<td><strong>Computing Services</strong></td>
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<tr>
<td>Telecom/Network</td>
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<tr>
<td>Computing Services Subtotal</td>
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<tr>
<td><strong>Travel</strong></td>
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<tr>
<td>Domestic</td>
<td>17,000</td>
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<td>Foreign</td>
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<td>Travel Subtotal</td>
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<td><strong>Other</strong></td>
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<td>Phone/FAX, Mail</td>
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<tr>
<td>Freight/Delivery</td>
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<tr>
<td>Other Subtotal</td>
<td>3,000</td>
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<tr>
<td><strong>Total Direct Costs</strong></td>
<td>156,400</td>
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<tr>
<td>Indirect (20.6%)</td>
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<tr>
<td><strong>Total SuperK Budget</strong></td>
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<tr>
<td>26.25% Admin Costs</td>
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</tr>
<tr>
<td>20% EG Costs</td>
<td>49,800</td>
</tr>
<tr>
<td><strong>Total SuperK Budget</strong></td>
<td>262,100</td>
</tr>
</tbody>
</table>
7.5 Nonaccelerator expt-II: RF Detection of UHE Particles (Gorham’s OJI)

Table 7.5 lists the budget for Gorham’s research program that was the subject of his successful Outstanding Junior Investigator proposal. This includes his participation in GLUE (radio detection of ultra-high energy neutrino interactions in the limb of the Moon using the Goldstone Radiotelescope array), and the development of plans and techniques for SALSA (a possible $\sim 100\text{km}^3$ UHE cosmic-ray neutrino detector based on RF antennas embedded in a large salt dome), which includes electronics and antenna development, accelerator test-beam measurements at SLAC and ANL, and the instrumenting and operation of the cosmic-ray test stand on campus.

This budget includes one month of Gorham’s summer salary and a stipend for post-doctoral fellow Hebert. It also includes a modest amount of travel funds to the mainland for group meetings, conferences and the test-beam work at accelerators.
### 7.5. NONACCELERATOR EXPT-II: RF DETECTION OF UHE PARTICLES (GORHAM'S OJII)

Table 7.5: EN-II; Radio Detection of UHE Particles

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
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<td><strong>Personnel</strong></td>
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<td>Faculty Overload</td>
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<td>Postdoc Fellows</td>
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<td>Fringe Benefits</td>
<td>2,300</td>
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<td>Personnel Cost</td>
<td>56,400</td>
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<td><strong>Instrumentation</strong></td>
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<tr>
<td>Materials &amp; Supplies</td>
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<td><strong>Instrumentation Subtotal</strong></td>
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<td><strong>Travel</strong></td>
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<td>Domestic</td>
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<td>Foreign</td>
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<tr>
<td><strong>Travel Subtotal</strong></td>
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<tr>
<td><strong>Other</strong></td>
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<tr>
<td>Phone, fax/mail</td>
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<tr>
<td>Shipping/delivery</td>
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<tr>
<td><strong>Other Subtotal</strong></td>
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<td><strong>Total Direct Costs</strong></td>
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<tr>
<td>Indirect (20.6%)</td>
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<td><strong>Total EN-II Budget</strong></td>
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<table>
<thead>
<tr>
<th>Non-Accelerator Experiments</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuperK/K2K/KamLAND</td>
<td>262.1</td>
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<tr>
<td>Radio detection</td>
<td>85.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>347.1</td>
</tr>
</tbody>
</table>
7.6 Theoretical Physics I

The budget request for theoretical physics (other than Melnikov’s OJI) is detailed in Table 7.6. This includes salary support for one post-doc (Ferrandis), summer support for Tata and Pakvasa. We also include funds to support the activities of Sugawara. This entails his travel and some funds to provide partial support for visits by collaborators from Japan. As discussed in the text, our highest long-range priority is to increase our group’s number of postdoctoral fellows to two. Here we include funds that, when added to funds from Melnikov’s OJI budget plus some from his University-provided start-up funds, support a second postdoctoral fellow. We request additional funds for FY2005 for this position (i.e., after Melnikov’s start-up funds are exhausted). Note that Sugawara’s entire salary is provided from University funds.

This task is assessed 20% of administrative costs.
Table 7.6: Theoretical Physics I

<table>
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<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
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<td>Faculty Overload</td>
<td>40,300</td>
</tr>
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<td>Graduate Student</td>
<td>27,000</td>
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<tr>
<td>Fringe Benefits</td>
<td>14,000</td>
</tr>
<tr>
<td>Personnel Cost</td>
<td>118,000</td>
</tr>
<tr>
<td><strong>Travel &amp; Consultants</strong></td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>15,000</td>
</tr>
<tr>
<td>Foreign</td>
<td>15,000</td>
</tr>
<tr>
<td>Consultants/Collaborators</td>
<td>12,000</td>
</tr>
<tr>
<td>Travel Subtotal</td>
<td>42,000</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Publications</td>
<td>1,500</td>
</tr>
<tr>
<td>Phone/FAX</td>
<td>800</td>
</tr>
<tr>
<td>Other Subtotal</td>
<td>2,300</td>
</tr>
<tr>
<td><strong>Total Direct Costs</strong></td>
<td>162,300</td>
</tr>
<tr>
<td>Indirect (20.6%)</td>
<td>33,400</td>
</tr>
<tr>
<td><strong>Total Theory Budget</strong></td>
<td>195,700</td>
</tr>
<tr>
<td>20% Admin Costs</td>
<td>25,100</td>
</tr>
<tr>
<td>Total Theory Budget</td>
<td>220,800</td>
</tr>
</tbody>
</table>
7.7 Theoretical Physics II (Melnikov’s OJI)

Table 7.7 provides a budget for Melnikov’s Outstanding Junior Investigator award. It includes summer salary, partial support for theory postdoctoral fellow Mitov and some travel.

Table 7.7: Theoretical Physics II (Melnikov’s OJI)

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel</strong></td>
<td></td>
</tr>
<tr>
<td>Faculty Overload</td>
<td>14,000</td>
</tr>
<tr>
<td>Jr. Researcher</td>
<td>22,600</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>6,800</td>
</tr>
<tr>
<td><strong>Personnel Costs</strong></td>
<td>43,400</td>
</tr>
<tr>
<td><strong>Travel &amp; Consultants</strong></td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>6,000</td>
</tr>
<tr>
<td>Foreign</td>
<td>4,500</td>
</tr>
<tr>
<td><strong>Travel Subtotal</strong></td>
<td>10,500</td>
</tr>
<tr>
<td><strong>Total Direct Costs</strong></td>
<td>53,900</td>
</tr>
<tr>
<td>Indirect (20.6%)</td>
<td>11,100</td>
</tr>
<tr>
<td><strong>Total OJI Budget</strong></td>
<td>65,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THEORY</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory I</td>
<td>220,800</td>
</tr>
<tr>
<td>Theory II</td>
<td>65,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>285,800</td>
</tr>
</tbody>
</table>
7.8 EG Experimental Facilities

The support required for our experimental infrastructure is specified in Table 7.8. This category half-time support for computer specialist Ibaraki, opto-mechanical engineer Rosen, and electronics engineer Varner. We also support one full-time assistant for Ibaraki and part-time (mostly undergraduate) help for Rosen and Varner.

This budget also lists hardware and software maintenance and licensing costs for our assortment of computers, and a small amount for travel associated with DOE-requested reviews, etc.

These costs are assessed to the electron-accelerator (80%) and the non-accelerator (20%) experiments.
Table 7.8: EG; Experimental Support

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel</strong></td>
<td></td>
</tr>
<tr>
<td>Technical Specialist</td>
<td>29,500</td>
</tr>
<tr>
<td>Technical Computer Specialist</td>
<td>30,100</td>
</tr>
<tr>
<td>Electronics Engineer</td>
<td>25,500</td>
</tr>
<tr>
<td>Support Specialist</td>
<td>36,500</td>
</tr>
<tr>
<td>Hourly Student Help</td>
<td>18,000</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>36,900</td>
</tr>
<tr>
<td>Personnel Costs</td>
<td>176,500</td>
</tr>
<tr>
<td><strong>Computing System Support</strong></td>
<td></td>
</tr>
<tr>
<td>Computers, upgrades, etc</td>
<td>5,000</td>
</tr>
<tr>
<td>Hardware Maintenance Contracts</td>
<td>6,000</td>
</tr>
<tr>
<td>Software Maintenance Contracts</td>
<td>7,000</td>
</tr>
<tr>
<td>Telecommunications/Network</td>
<td>1,000</td>
</tr>
<tr>
<td>Computing Supplies</td>
<td>8,000</td>
</tr>
<tr>
<td>Computing Subtotal</td>
<td>27,000</td>
</tr>
<tr>
<td><strong>DOE Related Travel</strong></td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>1,500</td>
</tr>
<tr>
<td>Travel Subtotal</td>
<td>1,500</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Phone, faxes</td>
<td>200</td>
</tr>
<tr>
<td>Freight/Delivery/misc.</td>
<td>1,400</td>
</tr>
<tr>
<td>Other Subtotal</td>
<td>1,600</td>
</tr>
<tr>
<td><strong>Total Direct Costs</strong></td>
<td>206,600</td>
</tr>
<tr>
<td>Indirect (20.6%)</td>
<td>42,600</td>
</tr>
<tr>
<td><strong>Total EG Budget</strong></td>
<td>249,200</td>
</tr>
</tbody>
</table>

**Distributed:**
- Electron Accelerator Expts 80%
- Non-Accelerator Expts 20%
7.9 Administration

Our administrative needs are somewhat different than is typical for other externally supported activities on campus. We are involved in a number of projects at various laboratories in different countries and engage in close collaborative work with other groups from other universities. As the lead US group in Belle and BES, our administrative staff is often required to provide services that extend beyond the specific needs of our group itself. As a result, our group supports an administrative staff that performs functions that are normally considered in determining the indirect cost rate. Since this reduces our demands on the University’s administrative infrastructure, we have negotiated for some compensation in our indirect costs. All high energy physics activities are assessed at the off-campus rate except for administration, which uses the higher on-campus rate. This formula has the advantage of being simple and also allows the university administration to recover a total amount of indirect costs that both they and we deem reasonable. So, although this item represents a large operating expense, the cost is compensated by lower indirect costs for the other tasks.

This budget for this task, detailed in Table 7.9, is essentially all salaries, with little flexibility. However, we have managed to keep our costs for these services constant in recent years thanks to contributions from other activities in the department that share these services.

These costs are assessed to the electron-accelerator (53.75%) and the non-accelerator (26.25%) experiments, and theory (20%).
# Table 7.9: Administrative Support

<table>
<thead>
<tr>
<th>Overhead Status</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personnel</strong></td>
<td></td>
</tr>
<tr>
<td>Admin. Specialist</td>
<td>34,100</td>
</tr>
<tr>
<td>Clerk-Typst &amp; Acct Clerk</td>
<td>31,000</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>20,300</td>
</tr>
<tr>
<td>Personnel Cost</td>
<td>85,400</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Office Supplies</td>
<td>3,100</td>
</tr>
<tr>
<td>Repairs and Maintenance</td>
<td>1,500</td>
</tr>
<tr>
<td>Phone/Fax</td>
<td>1,000</td>
</tr>
<tr>
<td>Copying/Graphics/etc.</td>
<td>1,200</td>
</tr>
<tr>
<td>Other Subtotal</td>
<td>6,800</td>
</tr>
<tr>
<td>Total Direct Costs</td>
<td>92,200</td>
</tr>
<tr>
<td>Indirect (36.30%)</td>
<td>33,500</td>
</tr>
<tr>
<td><strong>Admin. Total</strong></td>
<td>125,700</td>
</tr>
</tbody>
</table>

| Distributed:                     |            |
| Electron Accelerator Expts       | 53.75%     |
| Non-Accelerator Expts            | 26.25%     |
| Theory                           | 20.00%     |
### 7.10 Budget Summary

We list in Table 7.10 the actual funding levels for FY99, FY00, FY01, FY02 and FY03, and the requested funds for FY04.

<table>
<thead>
<tr>
<th></th>
<th>FY99</th>
<th>FY00</th>
<th>FY01</th>
<th>FY02</th>
<th>FY03</th>
<th>FY04(Req)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elect Accel I</td>
<td>795</td>
<td>867</td>
<td>867</td>
<td>680</td>
<td>654</td>
<td>736</td>
</tr>
<tr>
<td>(Belle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elect Accel II</td>
<td>153</td>
<td>156</td>
<td>156</td>
<td>159</td>
<td>156</td>
<td>172</td>
</tr>
<tr>
<td>(BES)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proton Accel</td>
<td>230</td>
<td>175</td>
<td>201</td>
<td>136</td>
<td>145</td>
<td>145</td>
</tr>
<tr>
<td>(Pixel R&amp;D)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Accel I</td>
<td>157</td>
<td>187</td>
<td>201</td>
<td>260</td>
<td>265</td>
<td>262</td>
</tr>
<tr>
<td>(SuperK/K2K/KamLAND)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Accel II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>(Gorham OJI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory I</td>
<td>220</td>
<td>225</td>
<td>225</td>
<td>210</td>
<td>210</td>
<td>221</td>
</tr>
<tr>
<td>(Melnikov OJI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,555</td>
<td>1,610</td>
<td>1,650</td>
<td>1,530</td>
<td>1,580</td>
<td>1,686</td>
</tr>
</tbody>
</table>
We list in Table 7.11 the proposed task-by-task request for the ensuing four years of this five year grant proposal. In FY06 we include an extra request for support of DPF2006, which will be held in Hawaii jointly with all other particle physics societies in the Pacific region.

Table 7.11: Requests for FY05, FY06, FY07, & FY08 (in $K).

<table>
<thead>
<tr>
<th></th>
<th>FY05</th>
<th>FY06</th>
<th>FY07</th>
<th>FY08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elec Accel I</td>
<td>773</td>
<td>813</td>
<td>855</td>
<td>898</td>
</tr>
<tr>
<td>Elec Accel II</td>
<td>181</td>
<td>192</td>
<td>204</td>
<td>216</td>
</tr>
<tr>
<td>Proton</td>
<td>146</td>
<td>153</td>
<td>160</td>
<td>168</td>
</tr>
<tr>
<td>Non-Accel I</td>
<td>282</td>
<td>298</td>
<td>316</td>
<td>338</td>
</tr>
<tr>
<td>Non-Accel II</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Theory I</td>
<td>238</td>
<td>252</td>
<td>265</td>
<td>278</td>
</tr>
<tr>
<td>Theory II</td>
<td>65</td>
<td>65</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>DPF2006</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>1,770</td>
<td>1,958</td>
<td>1,950</td>
<td>2,048</td>
</tr>
</tbody>
</table>
7.11 University Support

Here we briefly summarize University support for our program. The University provides full nine-month salaries to seven of the faculty with the understanding that a 0.54 fraction of their time during the academic year is spent on research-related activities. The University provides Learned, Matsuno, Peters and Sugawara with full (11-month) salary support. Matsuno has no teaching responsibilities. In addition the Free Electron Group provides partial salary support for Ibaraki, who manages our computing system, and our administrative staff.

Our group is the primary user of the physics department’s machine shop, which has two full-time machinists and is totally supported by University funds. Our group receives technical support from the Engineering Support Facility of the School of Ocean and Earth Science and Technology, where state subsidies keep the hourly rate below actual costs. We have permanent occupancy of permanent, high quality laboratory space in Watanabe Hall and the nearby Physical Sciences Building. We are given the use of additional temporary laboratory space as needed.

The bulk of the equipment in our computer network, our copy machines and videoconference systems were purchased with University funds. (In the last five years, approximately $200K of university funds were used to purchase computer-related equipment.) The University maintains the T1 links that we use to connect to the internet. Start-up funds provided to Browder and Olsen were used to outfit the TOF lab for the BES/BELLE R&D work. Start-up funds provided to Yamamoto were used to set up a silicon detector laboratory and to purchase additional workstations and disk drives. Gorham outfitted his micro-wave electronics laboratory and built most of his comic-ray test stand with his university start-up package. Melnikov is using university start-up funds to provide partial support for theory postdoctoral fellow Mitov. University funds are used to provide partial support to a number of visitors.

The University also supports our program by assessing all of our research tasks at the off-campus indirect cost rate. In return, we provide the bulk of our administrative services.
Chapter 8

Curriculum Vita of the Principal Investigators

8.1 Stephen L. Olsen

Curriculum Vitae

Stephen Lars Olsen
Born: March 22, 1942, Brooklyn, New York (U.S. citizen)

Education:
B.S. (Physics) City College of New York, 1963 (Phi Beta Kappa, Magna cum Laude)
M.S. (Physics) University of Wisconsin, 1965
Ph.D. (Physics) University of Wisconsin, 1970

Employment:
1/70 - 11/70 Research Associate University of Wisconsin
11/70 - 9/72 Research Associate Rockefeller University
9/72 - 7/75 Assistant Professor University of Rochester
7/75 - 6/82 Associate Professor University of Rochester
6/82 - 8/92 Professor University of Rochester
8/92 - present Professor University of Hawaii

Visiting Positions:
8/82 - 8/83 Visiting Researcher High Energy Physics Laboratory (KEK), Japan
9/87 - 9/89 Foreign Scholar Tsukuba University, Japan
7/99 - 7/00 Visiting Researcher High Energy Physics Laboratory (KEK), Japan

Fellowships:
1973 - 1977 Fellow, Alfred P. Sloan Foundation
1984 Fellow, American Physical Society
1986 - 1987 Fellow, John Simon Guggenheim Foundation
1987 - 1988 Fellow, Japan Society for the Promotion of Science

Professional Service Activities:
1975 - 1978 Program Advisory Committee, Fermilab
1989 - 1992  URA Visiting Committee, Fermilab
1989 - 1993  Program Advisory Committee, SSC Laboratory
1989 - 1994  Scientific Policy Committee, SLAC
1990        HEPAP Subpanel on Research for the 1990's
1992 - present Principal Investigator, University of Hawaii High Energy Physics Group
1993        Chair, DOE Panel to Review US-Japan Cooperation Program
1994 - present B-Factory Steering Committee, KEK Japan
1995 - 1996  DOE Panel to Review the BaBar Experiment
1996 - 1998  DOE Panel to Review the CMS Experiment
1996 - present DOE Panel to Review the AMS Experiment
1998 - present Editor, Chinese Journal of High Energy Physics and Nuclear Physics
2000        DOE panel to review SLAC
2001        DOE panel to review High Energy and Nuclear Physics at MIT
2001 - present Chair of a Panel to Review the Korean Invisible Matter Search (KIMS) Experiment
2002 - present Editor, International Journal of Modern Physics A / Modern Physics Letters A
2002        Panel to review ICEPP at the University of Tokyo
2002        Chair, International Advisory Committee, International Symposium on Vertex Detectors

Major Research Activities:
1974 - 1977  Fermilab experiment 198 (Spokesperson)
1978 - 1984  CLEO experiment at the Cornell Electron Storage Ring
1983 - 1997  AMY experiment at KEK, Japan (Spokesperson)
1987 - 1989  Heavy stable matter search, Rochester Nuclear Physics Laboratory (PI)
1989 - 1992  CDF experiment, Fermilab
1991 - present BELLE experiment at KEK, Japan (Co-spokesperson)
1992 - present The BES experiment at IHEP, Beijing China

Professional Associations:
  American Physical Society (Fellow)
  American Association for the Advancement of Science
  Hawaii Academy of Science
  American Association of Physics Teachers (Hawaii branch)

Award: UH Regents Excellence in Research Medal (2002)

Ph.D. Theses Supervised:


4. Keith Chadwick (1984): “The Observation of $\chi_0$ States in the decays of the $\Upsilon (2S)$”


6. Toshinori Mori (1988): “Total Hadronic Cross Section in Electron-Positron Annihilation at Center of Mass Energies from 50 to 57 GeV”

7. Young-Kee Kim (1990): “Gluon Radiation in Electron-Positron Annihilation at Center of Mass Energies from 50 to 60.8 GeV”


10. Yue-Kuan Li (1993): “Determination of the Strong Coupling $\alpha_s$ from Jet Production Rates in $e^+e^-$ Annihilation at TRISTAN Energies”


14. Gary Varner (1999): “Hadronic Decays of the $\chi_{0,1,2}$ Charmonium States”


17. Yangheng Zheng (2002): “Measurement of $B^0\bar{B}^0$-mixing and studies of the feasibility of measuring $CP$ violation in $B \rightarrow D^*\pi$ decays”

**Some Recent Publications:**


7. C. Velissaris et al. (AMY), *Measurement of Cross Section and Charge Asymmetry for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ at $\sqrt{s} = 57.8$ GeV*, Phys. Lett. **B331**, 227 (1994).


12. J.Z. Bai et al. (BES), *Branching fractions for $\psi(2S) \rightarrow \gamma\gamma'$ and $\gamma\eta$*, Phys. Rev. **D58**, 97101 (1998).


16. K. Abe et al. (Belle), Observation of $B \to J/\psi K_1(1270)$, Phys. Rev. Lett. 87, 161601 (2001).

17. K. Abe et al. (Belle), Observation of $B \to K\ell^+\ell^-$, Phys. Rev. Lett. 88, 021801 (2002).

18. K. Abe et al. (Belle), Observation of $B^\pm \to p\bar{p}K^\pm$, Phys. Rev. Lett. 88, 181803 (2002).

19. S.-K. Choi, S.L. Olsen et al. (Belle), Observation of the $\eta_c(2S)$ in Exclusive $B \to KK\pi^+$ Decays, Phys. Rev. Lett. 89, 102001 (2002).


22. K. Abe et al. (Belle), Study of Time-Dependent CP-Violating Asymmetries in $b \to s\bar{q}q$ Decays, Phys. Rev. D67, 031102 (2003).

23. Y. Zheng, T.E. Browder et al. (Belle), Measurement of the $B^0 - \bar{B}^0$ mixing rate with $B^0(\bar{B}^0) \to D^{*+}\pi^\pm$ partial reconstruction, Phys. Rev. D67, 092004 (2003).

24. K. Abe et al. (Belle), Evidence for CP-Violating Asymmetries in $B^0 \to \pi^+\pi^-$ Decays and Constraints on the CKM angle $\phi_2$, hep-ex/0301032, accepted for publication in Physical Review.

25. J.Z. Bai et al. (BES), Observation of a near-threshold enhancement in the $p\bar{p}$ mass spectrum from radiative $J/\psi \to \gamma p\bar{p}$ decays, hep-ex/0303006, accepted for publication in Physical Review Letters.

26. S.K. Swain, T.E. Browder et al. (Belle), Measurement of branching fraction ratios and CP asymmetries in $B^\pm \to D_{CP}K^\pm$, hep-ex/03040032, submitted to Physical Review.

27. J. Zhang et al. (Belle), Observation of $B^+ \to \rho^+\rho^0$, hep-ex/03060007, submitted to Physical Review Letters.
8.2 Xerxes Tata

VITA
Xerxes Ramyar TATA

PERSONAL DATA
Date of Birth: April 27, 1954
Place of Birth: Bombay, India
Marital Status: Married

EDUCATION
Bachelor of Science Bombay University, India 1974
Master of Science Indian Institute of Technology 1976
 Bombay, India
Ph.D. University of Texas at Austin 1981

EXPERIENCE
Professor University of Hawaii at Manoa 1994-present
Associate Professor University of Hawaii at Manoa 1988-1994
Visiting Scientist KEK, Japan Sept. 1987-Feb. 1988
Assistant Scientist University of Wisconsin at Madison 1986-1988
Research Associate University of Oregon at Eugene 1985-1986
Scientific Associate CERN, Geneva, Switzerland 1984-1985
Research Scientist University of Texas at Austin 1984
Research Associate University of Oregon at Eugene 1983-1984
Lecturer in Physics University of Texas at Austin 1981-1982
Research Associate University of Texas at Austin 1981-1983

FELLOWSHIPS
Fellow, American Physical Society (2001)
RECENT SCIENTIFIC SERVICE ACTIVITIES

2. Lecturer at 1995 Theoretical Advanced Study Institute, Boulder, Colorado.
5. Lecturer at the IX Jorge Swieca Summer School, Campos do Jordão, Brazil, 1997.

SELECTED PUBLICATIONS


Chapter 9

Budget Explanations & Forms

9.1 Budget Explanation

The materials provided for individual activities for FY’04 are summarized in the Grant Application Budget Summary Form 4620.1.

Personnel The personnel are summarized in the appended table, where the University and requested DOE support are itemized.

Senior Personnel This includes the teaching faculty and senior physicists. Matsumo, Learned, Peters, and Sugawara whose 11-month salaries are completely paid by the University, are not included in this tally. Teaching faculty on this grant are allowed a 0.54 fraction of the academic year for research activities supported by this grant. The senior physicists receive full fringe benefit packages (typically 28% of the salary). The bulk of the teaching faculty’s fringe benefits for the summer are provided by the University; only Workman’s Compensation and Medicare are included in this request.

Post-Doctoral Associates This includes 2 existing personnel and one new postdoc who will commence employment in October 2003. They receive full fringe benefit packages.

Other Professionals These funds are for partial support of our computer system manager, full support of an assistant support specialist. Funds are also for partial support of our electronics engineer and our technical support person. The rest of the support for these positions are expected to be provided by the Free Electron Laser Group and the NASA (ANIT A) funded project. Here full benefit packages are included for all in this request.

Graduate Students The University considers graduate students as being half-time on research (6 months) with additional support allowed for the summer. This varies from case-to-case but averages 1.12 months extra support per student. Fringe benefits vary from student-to-student, and range up to a full package.

Undergraduate Students Undergraduate students are hired on an hourly basis to help various tasks. The only fringe benefit they receive is Workman’s Compensation.

Secretarial-Clerical The typist, and clerk receive full fringe benefit packages. Partial support is provided by NASA ANITA funded project and University funds.
Other This corresponds to the administrator, who receives a full fringe benefit package. Partial support is provided by Free Electron Laser Group and the NASA (ANITA) funded project.

Travel Domestic The primary need for domestic travel is to attend BES, Superkamiokande, and KamLAND group meetings at various collaborating U.S. institutions, and scientific meetings where results are reported.

Travel Foreign The primary need for foreign travel is travel to Japan: KEK for the BELLE and Kamioka for the SK and KamLand experiments, travel to IHEP in Beijing for the BES experiment (approximately twice per year per participant), and theoretical collaborations. In addition, there is travel to international meetings to present papers.

Other Direct Costs

Materials & Supplies These include incidental items needed to support the individuals activities, such as computer tapes, hand tools, solvents, etc. Estimated costs are based on previous experience.

Publications Estimated costs are based on previous experience.

Consultant Services These include technical consultants for research projects and seminar speakers. The standard rate is $100 per day, with a maximum of $130 per day without special approval.

Computer Services This includes hardware maintenance contracts and software licenses, as listed in Section 6.1. This also includes networking and telecommunications costs.

Other This include office supplies, communication costs, shipping, etc. Estimated costs are based on previous experience.

Indirect Costs The University rates for indirect costs are 36.3% for on-campus and 20.6% for off-campus activities. All projects, with the exception of Administrative Support have been approved at the off-campus rate. Indirect costs that were previously waived on administrative costs, computer maintenance and licenses and subcontracts at other laboratories are now subject to overhead. Previous waivers by the university are no longer applicable.

Trainee/Participant Costs Stipends Post-Doctoral Fellow: Pursuing a program of research and training. This includes 3 continued post-doc fellowships stipends and 3 new fellowship which are all exempt from overhead and fringe benefits.

Combined Support The University supports these activities with $696,500 in direct salary support, as is documented in the appended table.
## U.S. Department of Energy

### Budget Page

#### ORGANIZATION

University of Hawaii

#### PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR

Stephen Olsen

#### Requested Duration:

12 (Months)

12/1/03 - 11/30/04

#### A. SENIOR PERSONNEL: PI/PD, Co-PI’s, Faculty and Other Senior Associates

<table>
<thead>
<tr>
<th>Name</th>
<th>Funds Requested</th>
<th>Funds Granted</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Olsen (2)</td>
<td>$121,200</td>
<td></td>
</tr>
<tr>
<td>F. Harris (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. Gorham (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X. Tata (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. Browder (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. Pakvasa (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. Melnikov (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. Learned (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. Matsuno (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Peters (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H. Sugawara (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Jones</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. Parker</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### B. OTHER PERSONNEL

<table>
<thead>
<tr>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Post Doctoral Associates</td>
<td>$107,600</td>
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<tr>
<td>Other Professional (Technician, Programmer, etc.)</td>
<td>$121,600</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>$145,700</td>
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<tr>
<td>Undergraduate Students</td>
<td>$25,500</td>
</tr>
<tr>
<td>Secretarial - Clerical</td>
<td>$31,000</td>
</tr>
<tr>
<td>Other</td>
<td>$34,100</td>
</tr>
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</table>

**TOTAL SALARIES AND WAGES (A+B)**: $758,200

#### C. FRINGE BENEFITS

$152,800

**TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)**: $911,000

#### D. PERMANENT EQUIPMENT

None listed.

**TOTAL PERMANENT EQUIPMENT**

#### E. TRAVEL

<table>
<thead>
<tr>
<th>Category</th>
<th>Funds Requested</th>
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<tbody>
<tr>
<td>Domestic (incl. Canada and U.S. Possessions)</td>
<td>$57,500</td>
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<tr>
<td>Foreign</td>
<td>$129,700</td>
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</tbody>
</table>

**TOTAL TRAVEL**

$187,200

#### F. TRAINEE/PARTICIPANT COSTS

6 post-doctorals

<table>
<thead>
<tr>
<th>Description</th>
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<tbody>
<tr>
<td>Stipends</td>
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<tr>
<td>Tuition &amp; Fees</td>
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<tr>
<td>Trainee Travel</td>
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<tr>
<td>Other (fully explain on justification page)</td>
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**TOTAL PARTICIPANTS**

$246,500

#### G. OTHER DIRECT COSTS

<table>
<thead>
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<th>Description</th>
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<tbody>
<tr>
<td>Materials and Supplies</td>
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<td>Publication Costs/Documentation/Dissemination</td>
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<tr>
<td>Consultant Services</td>
<td>$12,000</td>
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<tr>
<td>Computer (DACE) Services</td>
<td>$29,000</td>
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<td>Subcontracts</td>
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<tr>
<td>Other</td>
<td>$17,200</td>
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**TOTAL OTHER DIRECT COSTS**

$83,000

#### H. TOTAL DIRECT COSTS (A THROUGH G)

$1,427,700

#### I. INDIRECT COSTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Funds Requested</th>
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<tbody>
<tr>
<td>Off campus -20.6% of $1,089,000 = 224,300</td>
<td></td>
</tr>
<tr>
<td>On campus -36.3% of $92,200 = 33,500</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL INDIRECT COSTS**

$257,800

#### J. TOTAL DIRECT AND INDIRECT COSTS (H+I)

$1,685,500

#### K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES

None listed.

#### L. TOTAL COST OF PROJECT (J+K)

$1,685,500

---

[165]
**University of Hawaii**

**Principal Investigator/Project Director**

Stephen Olsen

**Requested Duration:** 12 (Months)

### A. Senior Personnel: PI/PD, Co-PI's, Faculty and Other Senior Associates

**DOE Funded**

<table>
<thead>
<tr>
<th>Person</th>
<th>Funds Requested</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Olsen</td>
<td>$123,200</td>
</tr>
<tr>
<td>F. Harris</td>
<td>$24,600</td>
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<tr>
<td>P. Gorham</td>
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</tr>
<tr>
<td>X. Tata</td>
<td>$26,000</td>
</tr>
<tr>
<td>T. Browder</td>
<td>$12,000</td>
</tr>
<tr>
<td>S. Pakvasa</td>
<td>$12,000</td>
</tr>
<tr>
<td>K. Melnikov</td>
<td>$12,000</td>
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<tr>
<td>S. Matsuno</td>
<td>$12,000</td>
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<tr>
<td>M. Peters</td>
<td>$12,000</td>
</tr>
<tr>
<td>H. Sugawara</td>
<td>$12,000</td>
</tr>
<tr>
<td>M. Jones</td>
<td>$12,000</td>
</tr>
<tr>
<td>S. Parker</td>
<td>$12,000</td>
</tr>
</tbody>
</table>

**TOTAL SENIOR PERSONNEL**

**24.00**

**$297,500**

### B. Other Personnel (Show Numbers in Brackets)

1. **Post Doctoral Associates**
   
   **Funds Requested:** $122,800

2. **Other Professional (Technician, Programmer, etc.)**
   
   **Funds Requested:** $123,300

3. **Graduate Students**
   
   **Funds Requested:** $161,800

4. **Undergraduate Students**
   
   **Funds Requested:** $25,500

5. **Secretarial - Clerical**
   
   **Funds Requested:** $31,400

6. **Other**
   
   **Funds Requested:** $34,100

**TOTAL SALARIES AND WAGES (A+B)**

**$796,400**

### C. Fringe Benefits (if charged as direct costs)

**$156,800**

**TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)**

**$953,200**

### D. Permanent Equipment (List Item and Dollar Amount for Each Item)

**TOTAL PERMANENT EQUIPMENT**

**$34,000**

### E. Travel

1. **Domestic (incl. Canada and U.S. Possessions)**
   
   **Funds Requested:** $60,500

2. **Foreign**
   
   **Funds Requested:** $129,700

**TOTAL TRAVEL**

**$190,200**

### F. Trainee/Participant Costs

7.5 postdoc fellows

1. **Stipends**
   
   **Funds Requested:** $271,200

2. **Tuition & Fees**

3. **Trainee Travel**

4. **Other**
   
   **Funds Requested:** $3,600

**TOTAL PARTICIPANTS**

**8**

**TOTAL COST**

**$271,200**

### G. Other Direct Costs

1. **Materials and Supplies**
   
   **Funds Requested:** $24,600

2. **Publication Costs/Documentation/Dissemination**
   
   **Funds Requested:** $1,500

3. **Consultant Services**
   
   **Funds Requested:** $12,000

4. **Computer (ADPE) Services**
   
   **Funds Requested:** $33,000

5. **Subcontracts**

6. **Other**
   
   **Funds Requested:** $16,300

**TOTAL OTHER DIRECT COSTS**

**$97,400**

### H. Total Direct Costs (A through G)

**$1,502,000**

### I. Indirect Costs (Specify Rate and Base)

- off campus: 20.6% of $1,138,100 = $234,448
- on campus: 36.3% of $927,000 = $33,600

**TOTAL INDIRECT COSTS**

**$268,000**

### J. Total Direct and Indirect Costs (H+I)

**$1,770,000**

### K. Amount of Any Required Cost Sharing from Non-Federal Sources

**$0**

### L. Total Cost of Project (J+K)

**$1,770,000**
<table>
<thead>
<tr>
<th>A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates</th>
</tr>
</thead>
<tbody>
<tr>
<td>(List each separately with title; A.6. show number in brackets)</td>
</tr>
<tr>
<td>Person-mos.</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>1. Faculty (11) S. Olsen(2), F. Harris(2), P. Gorham(1), X. Tata(2),</td>
</tr>
<tr>
<td>2. T. Browder(2), S. Pakvasa(2), K. Melnikov(2), J. Learned (0),</td>
</tr>
<tr>
<td>3. S. Matsuno(0), M. Peters(0), H. Sugawara (0)</td>
</tr>
<tr>
<td>4. SRA's (2) M. Jones, S. Parker</td>
</tr>
<tr>
<td>5.</td>
</tr>
<tr>
<td>6.</td>
</tr>
<tr>
<td>7. TOTAL SENIOR PERSONNEL (1-6)</td>
</tr>
<tr>
<td>B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)</td>
</tr>
<tr>
<td>1. POST DOCTORAL ASSOCIATES</td>
</tr>
<tr>
<td>2. OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.)</td>
</tr>
<tr>
<td>3. GRADUATE STUDENTS</td>
</tr>
<tr>
<td>4. UNDERGRADUATE STUDENTS</td>
</tr>
<tr>
<td>5. SECRETARIAL - CLERICAL</td>
</tr>
<tr>
<td>6. OTHER</td>
</tr>
<tr>
<td>7. TOTAL SALARIES AND WAGES (A+B)</td>
</tr>
<tr>
<td>C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)</td>
</tr>
<tr>
<td>8. TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)</td>
</tr>
<tr>
<td>D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM)</td>
</tr>
<tr>
<td>1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)</td>
</tr>
<tr>
<td>2. FOREIGN</td>
</tr>
<tr>
<td>3. TOTAL TRAVEL</td>
</tr>
<tr>
<td>F. TRAINEE/PARTICIPANT COSTS</td>
</tr>
<tr>
<td>1. STIPENDS (Itemize levels, types + totals on budget justification page)</td>
</tr>
<tr>
<td>2. TUITION &amp; FEES</td>
</tr>
<tr>
<td>3. TRAINEE TRAVEL</td>
</tr>
<tr>
<td>4. OTHER (fully explain on justification page)</td>
</tr>
<tr>
<td>5. TOTAL PARTICIPANTS</td>
</tr>
<tr>
<td>G. OTHER DIRECT COSTS</td>
</tr>
<tr>
<td>1. MATERIALS AND SUPPLIES</td>
</tr>
<tr>
<td>2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION</td>
</tr>
<tr>
<td>3. CONSULTANT SERVICES</td>
</tr>
<tr>
<td>4. COMPUTER (ADPE) SERVICES</td>
</tr>
<tr>
<td>5. SUBCONTRACTS</td>
</tr>
<tr>
<td>6. OTHER</td>
</tr>
<tr>
<td>7. TOTAL OTHER DIRECT COSTS</td>
</tr>
<tr>
<td>8. TOTAL DIRECT COSTS (A THROUGH G)</td>
</tr>
<tr>
<td>I. INDIRECT COSTS (SPECIFY RATE AND BASE)</td>
</tr>
<tr>
<td>off campus 20.6% of $1,191,000 = $245,346; on campus 36.3% of $95,000 = $34,500</td>
</tr>
<tr>
<td>9. TOTAL INDIRECT COSTS</td>
</tr>
<tr>
<td>J. TOTAL DIRECT AND INDIRECT COSTS (H+I)</td>
</tr>
<tr>
<td>K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES</td>
</tr>
<tr>
<td>L. TOTAL COST OF PROJECT (J+K)</td>
</tr>
<tr>
<td><strong>ORGANIZATION</strong></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td><strong>University of Hawaii</strong></td>
</tr>
<tr>
<td><strong>PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR</strong></td>
</tr>
</tbody>
</table>

**A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates**

<table>
<thead>
<tr>
<th>Person-mos.</th>
<th>Funds Requested</th>
<th>Funds Granted</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL</td>
<td>ACAD</td>
<td>SUMR</td>
</tr>
</tbody>
</table>

- 1.
- 2.
- 3.
- 4.
- 5.
- 6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)
- 7. ( ) TOTAL SENIOR PERSONNEL (1-6)

**B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)**

| ( ) POST DOCTORAL ASSOCIATES |
| ( ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) |
| ( ) GRADUATE STUDENTS |
| ( ) UNDERGRADUATE STUDENTS |
| ( ) SECRETARIAL - CLERICAL |
| ( ) OTHER |

**C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)**

**TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)**

**D. PERMANENT EQUIPMENT** (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM)

**TOTAL PERMANENT EQUIPMENT**

**E. TRAVEL**

| 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) |
| 2. FOREIGN |

**TOTAL TRAVEL**

**F. TRAINEE/PARTICIPANT COSTS**

- 1. STIPENDS (Itemize levels, types & totals on budget justification page)
- 2. TUITION & FEES
- 3. TRAINEE TRAVEL
- 4. OTHER (Fully explain on justification page)

**TOTAL PARTICIPANTS**

**TOTAL COST**

**G. OTHER DIRECT COSTS**

1. MATERIALS AND SUPPLIES
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION
3. CONSULTANT SERVICES
4. COMPUTER (ADPE) SERVICES
5. SUBCONTRACTS
6. OTHER

**DPF2006 Conference**

**TOTAL OTHER DIRECT COSTS**

**$79,400**

**TOTAL OTHER DIRECT COSTS**

**$79,400**

**H. TOTAL DIRECT COSTS (A THROUGH G)**

**$79,400**

**I. INDIRECT COSTS (SPECIFY RATE AND BASE)**

- off campus 20.6% of 79,400 = $20,600

**TOTAL INDIRECT COSTS**

**$20,600**

**J. TOTAL DIRECT AND INDIRECT COSTS (H+I)**

**$100,000**

**K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES**

**$100,000**

**L. TOTAL COST OF PROJECT (J+K)**

**$100,000**
<table>
<thead>
<tr>
<th>A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates</th>
<th>DOE Funded</th>
<th>Person-mos.</th>
<th>Funds Requested</th>
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<tbody>
<tr>
<td>1. Faculty (11) S. Olsen(2), F. Harris(2), P. Gorham(2), X. Tata(2),</td>
<td>13.00</td>
<td>$130,200</td>
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<td></td>
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<tr>
<td>2. T. Browder(2), S. Pakvasa(2), K. Melnikov(2), J. Learned (0),</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. S. Matsuno(0), M. Peters(0), H. Sugawara (0)</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>4. SRA's (2) M. Jones, S. Parker</td>
<td>24.00</td>
<td>$179,500</td>
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<td></td>
</tr>
</tbody>
</table>

B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)

| 1. POST DOCTORAL ASSOCIATES | $154,400 |
| 2. OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) | $129,900 |
| 3. GRADUATE STUDENTS | $197,300 |
| 4. UNDERGRADUATE STUDENTS | $33,500 |
| 5. SECRETARIAL - CLERICAL | $35,000 |
| 6. OTHER | $36,400 |

C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | $167,800 |

D. TOTAL SALARIES AND WAGES (A+B+C) | $1,064,000 |

E. TRAVEL

| 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) | $64,500 |
| 2. FOREIGN | $135,100 |

F. TRAINEE/PARTICIPANT COSTS

| 1. STIPENDS (Itemize levels, types + totals on budget justification page) | $300,100 |
| 2. TUITION & FEES | |
| 3. TRAINEE TRAVEL | |
| 4. OTHER (fully explain on justification page) | |

G. TOTAL PARTICIPANTS | 7 |

H. OTHER DIRECT COSTS

| 1. MATERIALS AND SUPPLIES | $25,300 |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | $1,500 |
| 3. CONSULTANT SERVICES | $5,000 |
| 4. COMPUTER (ADPE) SERVICES | $43,000 |
| 5. SUBCONTRACTS | |
| 6. OTHER | $16,700 |

I. TOTAL OTHER DIRECT COSTS | $91,500 |

J. TOTAL DIRECT COSTS (A THROUGH G) | $1,655,200 |

K. INDIRECT COSTS (SPECIFY RATE AND BASE)

| 1. off campus 20.6% of $1,255,300 = 258,592: on campus 36.3% of $99,800 = $36,200 |

L. TOTAL INDIRECT COSTS | $294,800 |

M. TOTAL DIRECT AND INDIRECT COSTS (H+I) | $1,950,000 |

N. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES | |

O. TOTAL COST OF PROJECT (J+K) | $1,950,000 |
**ORGANIZATION**
University of Hawaii

**Budget Page No:** 1

**Requested Duration:** 12 (Months)

**Stephen Olsen**

12/01/07-11/30/08

<table>
<thead>
<tr>
<th>A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates</th>
<th>DOE Funded</th>
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</thead>
<tbody>
<tr>
<td>CAL</td>
<td>ACAD</td>
</tr>
<tr>
<td>1. Facult (1) S. Olsen(2), F. Harris(2), P. Gotham(2), X. Tata(2),</td>
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<tr>
<td>2. T. Browder(2), S. Pakvasa(2), K. Melnikov(2), J. Learned (0),</td>
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</tr>
<tr>
<td>3. S. Matsuno(0), M. Peters(0), H. Sugawara (0)</td>
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</tr>
<tr>
<td>4. SRA's (2) M. Jones, S. Parker</td>
<td>24.00</td>
</tr>
<tr>
<td>5. OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)</td>
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<td>6. TOTAL SENIOR PERSONNEL (1-6)</td>
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<table>
<thead>
<tr>
<th>B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)</th>
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<td>5. SECRETARIAL - CLERICAL</td>
</tr>
<tr>
<td>6. OTHER</td>
</tr>
<tr>
<td>TOTAL SALARIES AND WAGES (A+B)</td>
</tr>
</tbody>
</table>

| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | $174,300 |

| D. TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C) | $1,122,000 |

| E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) | $65,200 |
| --- |
| 2. FOREIGN | $138,900 |
| TOTAL TRAVEL | $204,100 |

<table>
<thead>
<tr>
<th>F. TRAINEE/PARTICIPANT COSTS 7 postdoctoral fellows</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. STIPENDS (Itemize levels, types + totals on budget justification page)</td>
</tr>
<tr>
<td>2. TUITION &amp; FEES</td>
</tr>
<tr>
<td>3. TRAINEE TRAVEL</td>
</tr>
<tr>
<td>4. OTHER (Fully explain on justification page)</td>
</tr>
<tr>
<td>TOTAL PARTICIPANTS</td>
</tr>
<tr>
<td>TOTAL COST</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>G. OTHER DIRECT COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. MATERIALS AND SUPPLIES</td>
</tr>
<tr>
<td>2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION</td>
</tr>
<tr>
<td>3. CONSULTANT SERVICES</td>
</tr>
<tr>
<td>4. COMPUTER (ADPE) SERVICES</td>
</tr>
<tr>
<td>5. SUBCONTRACTS</td>
</tr>
<tr>
<td>6. OTHER</td>
</tr>
<tr>
<td>TOTAL OTHER DIRECT COSTS</td>
</tr>
</tbody>
</table>

| H. TOTAL DIRECT COSTS (A THROUGH G) | $1,736,500 |

<table>
<thead>
<tr>
<th>I. INDIRECT COSTS (SPECIFY RATE AND BASE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>off campus 20.6% of $1,327,100 = 273,400; on campus 36.3% of $104,800 = 38,000</td>
</tr>
<tr>
<td>TOTAL INDIRECT COSTS</td>
</tr>
</tbody>
</table>

| J. TOTAL DIRECT AND INDIRECT COSTS (H+I) | $2,047,900 |

| K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES |  |

| L. TOTAL COST OF PROJECT (J+K) | $2,047,900 |