Instrumentation Development Laboratory: An Introduction

Gary S. Varner
Intro for visiting Lausanne Students
October 2003
Main Projects

Accelerator based:
Precision Measurement

Non-accelerator:
Highest energies

Search for new physics:
Cutting-edge of exploring our universe
And everything between...
Belle Experiment at KEK

• Tsukuba Science City
  – About 60km from Tokyo/airport
Belle Experiment at KEK

- KEK:
  - Kou-Enerugii butsuri-gaku Kenkyuu-jyou (now even longer)
KEK-B Accelerator

[Diagram of KEK-B Accelerator]

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World's highest Luminosity Collider!!

Daily luminosity: still increasing!

Exceeded $10^{34}$
A Holy Grail for Accelerator Physicists
Belle Experiment at KEK

- **Belle isn’t an acronym:**
  - Beauty in French – studying b quarks
    (also called bottom)
The **Belle** Collaboration

*A World-Wide Activity Involving ~50 Institutions*

- Frankfurt
- U. Hawaii
- Kanagawa U.
- KEK
- Krakow INP
- U. Melbourne
- National Taiwan U.
- Niigata U.
- Osaka U.
- Princeton U.
- U. Sydney
- Tohoku U.
- U. Tokyo
- Tokyo Inst. Tech.
- Tokyo Metropolitan U.
- U. Tsukuba
- Vienna

~300 members
Detector

Belle Detector

- SC solenoid 1.5T
- CsI(Tl) 16\(X_0\)
- TOF counter
- 8GeV \(e^-\)
- 3.5GeV \(e^+\)
- Aerogel Cherenkov cnt. \(n=1.015\sim1.030\)
- Tracking + \(dE/dx\) small cell + He/C\(_2\)H\(_5\)
- Si vtx. det.
- 3 lyr. DSSD
- \(\mu/\bar{K}_L\) detection
- 14/15 lyr. RPC+Fe
- 4layer + scCDC

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SVD 2.0 Upgrade

- Larger angular acceptance.
- Increase of number of layers 3 to 4.
- Smaller radius of inner-most layer (3cm → 2cm). (smaller r of BP also)
- Radiation tolerant (20 Mrad) readout chip (VA1TA).
Ladders

Forward

Backward

L#1

L#2

L#3

L#4
Mounting completed Feb. 13

The last Ladder!
Installation

Kirika Level 1.5 Trigger

SVD2 installation  19-Aug-2003

Cabling finished   1-Sept.-2003
Proper-time difference ($\Delta t$)

$e^-: 8.0 \text{ GeV}$

$e^+: 3.5 \text{ GeV}$

$\gamma(4S)$

$\beta\gamma \sim 0.425$

$B_{\text{tag}}$

$\Delta z \approx c\beta\gamma \tau_B \sim 200 \mu m$

$\frac{\Delta z}{c \beta\gamma} = \Delta t$

Flavor tag

resolution
Example Event

Rare decay: $B^0 \rightarrow \pi^+\pi^-$
Many Important Results!

- Discovery (w/BaBar) of CP-violation in the B-system
  - Expected, but large and clean
  - CP-violation in Kaon system tiny
- Recent first observation in \( B \rightarrow \pi \pi \)
  - Detector working well, but already starting to think of the future
  - Incremental Detector improvements
  - Seriously higher luminosity needed to probe non Standard-model effects – upgrade of accelerator and detector

>70 papers in last 2+ years & more pending
Belle Mission

- Observation of CP violation in B decays
  - Achieved in 2001
- Observation of direct CP violation in B decays and other parameters of CKM matrix
  - by 2006 with the gradual improvement of KEKB
- Explore New Physics beyond the Standard Model
  - off-diagonal elements (e.g. study of SUSY breaking)
  - need much higher luminosity

Our Focus Now
Study of Hadron Systematics Using the Belle TOF System

M. Jones
University of Hawaii, Honolulu, Hawaii, USA

Abstract
The Belle TOF system gives a time resolution of about 100 ps for high-momentum muons in dimuon events but 115 ps for pions and kaons in hadron events. This note examines various effects responsible for the poorer resolution for hadrons. Three effects are found to bias time: hitting near gaps between TOF counters, tracks with inconsistent predicted and calculated z positions, and tracks for which adjacent TOF counters have hits.

PACS numbers:
Core part ~100 ps
But tails!!!
RMS ~150 ps

FIG. 15: TOF resolution versus momentum for negative pions (squares) and muons (circles) in 2-photon events. The pions are from 4-pion final states in exp. 17 runs 800-937. Muons are from dimuon final states in exp. 19 runs 1000-1599. For comparison, the resolutions for pions in HadronC events from exp. 23 runs 552-699 are shown as diamonds. The resolution values are from Gaussian fits to Az distributions.
Why Such A Variance???

- **Intrinsic Performance:**
  - Tough to get
  - Beam tests don’t require sustained operation
  - Hadronic Calibration!
    - Very important – details omitted due to space limitations
    - Much work, no fundamental understanding
    - Velocity dependent (dE/dx?) fudge
    - Systematic, so no SQRT(2)
    - May be TWC technique dependent
  - Sad history of underperformance:
    - CLEO, CPLEAR, BESII, ...
  - Error Budget!!

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**Graph:**

- **Beam:** negative 2.0 [GeV/c]
- **Time resolution [ps]**
- **Z [cm]**
- **3cmTOF**
- **5cmTOF**
Time Walk Correction

- Reasonable functional form
  - But as background increases...

- Many ideas: e.g. direct digitization at high speed?

Peter Grach studies
Limitations

DIRC + MDC

BaBar
Looks like BaBar does better.

Belle
TOP Counter

- Looks good, though Time-of-Propagation depends on photon wavelength
Cherenkov Ring folding

To measure $X$ instead of $\Phi$

The ring image can be obtained in TOP vs. $X_{\text{true}}$

CCT is limit as $X \to \text{small}$

Not so different from DIRC partial ring reconstruction
Electronics – scenarios

- Bar TOP
  - ~5mm pos. resolution: 40 Ch/counter
  - *200 counters = 1440 channels
  - Multi-hit (hidden cost) >1440 channels

- Butterfly TOP
  - ~200 counters = 1440 channels
  - ~1mm pos. resolution: 40 Ch/counter
  - *~100 counters: few 100k channels

- Focusing DIRC
  - ~few mm x few mm: few kCh/counter
  - *~100 counters: few 100k channels
  - ~1mm pos. resolution: 200 Ch/counter
  - *180 counters = 36,000 channels
Time Stretcher Module

- Designed with LRS
  - R&D 100 Award

- 16 Channels/1 per DC
- Stretch factor 20x
- RF clock Reference

VIPA Standard Module
MTS1 Silicon (1)
MTS$_1$ Silicon (2)

Completely differential signal routing
Evaluation Board

MTS1 chip

CPLD (programmable logic)

TTL-LVDS translator

Bottom view
MTS1 Timing Residuals

RMS ~ 51ps
σ ~ 49ps

- However, this value includes the (large) system jitter
NTS32

- Better test system
- 32-channels for beam testing prototypes
Occupancy issues

Pixel for $R < 3\text{ cm}$
Pipeline for $R < 10\text{ cm}$

Trigger simulation study desirable

Large ambiguity even with dedicated simulation. Need to be conservative.
Pixel Detector

- Seppo working on new board (APT1)
- Test SNR vs. frame rate, etc.
- New chip (CAP1, CAP2)
Continuous Acquisition Pixel

- Conceptually Simple
  - Analog reset, sample & then sample continuously
  - Row-wise analog shift out as fast as possible:
    - Consider 22.5μm pitch output w/ 4:1 AMUX
    - 100MSa/s output (e.g. 8-bit ADC on output)
    - 10μs for 1k columns (# row independent)
    - Possibility of passing signals through to allow joining to form ladders

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CAP Concept

• **Automatic CDS**
  – When receive L1 trigger:
    * sift data in sync pipe and provide the difference in value for orbit with trigger and preceding orbit
  – Analog reset
    • If can reset once every 100 orbits, 1% “deadtime”
    • $1\mu s$ “reset” and $10\mu s$ to obtain a baseline sample
    • Possibly even less, depending upon dynamic range and background
    • Can build “intelligence” into reset
      - When starting to saturate
      - L1 busy
    • Minimization of leakage current important
    • Relatively simple to fabricate
CAP1 Prototype

- TSMC 0.35mm Process

- High speed framing:
  - Target 10µs latency
  - Pipelined readout

Oct. 6 Submission – Today!

“slow” RO resolution ~ 2µm

Column Ctrl Logic

132x48 (22.5µm² pixels)

~6k pixels
New Devices

- Characterize process, noise measurements
High Luminosity!

At $L = 10^{35} \text{ cm}^{-2}/\text{s}$:

- Pipelined readout:
  128k channels equiv., 40MHz x 2bytes

  - $10 \text{Tera-bytes per second!}$ (10,000 CDs per second)

  ↓

- Global Decision logic trigger: 10kHz
- FIFO: 128k channels equiv., 16 bytes

  - $20 \text{ Giga-bytes per second!}$ (200 GbE links)

  ↓

- COPPER, online Farm

  - $200 \text{ Mega-bytes per second!}$ (max. data rate to tape)
Common Electronics

- COPPER (COmmon Pipelined Platform for Electronics Readout)
- Card ~ crate – aid in data reduction
- On board data reduction
CuEval FINESSE

- Front-end INstrumentation Entity for Sub-detector Specific Electronics

- Dual 128kB RAM
- 480 Mbps USB2.0
- COPPER Interface

Hardware “ready” – Bin working on firmware
ANITA

ANTARCTIC IMPULSIVE TRANSIENT ANTENNA

A LONG DURATION BALLOON MISSION TO CONSTRAIN THE ORIGIN OF THE HIGHEST ENERGY PARTICLES IN THE UNIVERSE

UNIVERSITY OF HAWAII AT MANOA

UCIrvine
University of California, Irvine

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The Flux Problem

- At $E > 10^{21}$...
- Life is tough

$$\iiint_{r, \phi, \theta} d\theta d\phi d\theta$$
Antarctic Impulsive Transient Antenna (ANITA)

- **ANITA Goal:** Pathfinding mission for GZK neutrinos
- **NASA SR&T funded since October 2002, launch in 2006**
ANITA concept

Antarctic Ice at f<1GHz, T<-20C:

- Lossless RF transmission
- Minimal scattering
- largest homogenous, RF-transmissive solid mass in the world

~700km to horizon
observed area: ~1.5 M square km
ANITA Payload

Simulated pulse—multiple antennas

- ANITA antennas view ~2π sr with 60 deg overlapping beams
- Beam intensity gradiometry, interferometry, polarimetry used to determine pulse direction & thus original neutrino track orientation
STRAW2 Chip

Self-Triggered Recorder Analog Waveform (STRAW)

16 Channels of 256 deep SCA buckets
Optimized for RF input Microstrip 50Ω
Target input Bandwidth: >700MHz
Record length: 128-256ns

Die: ~2.5mm²

Self-Triggering:
- LL and HL (adj.) for each channel
- Multiplicity trigger for LL hits

On-chip ADC:
12-bit, >2MSPS

Sampling Rate:
1-3GSa/s (adj.)

Sampling Rates
~8GSa/s possible w/ 0.25µm process

External option:
MUXed Analog out

Under Test
STRAW2 Evaluation

- Adjustable: 0.6 – 3.4 GSa/s
- 256 samples (70 – 300ns)

- RF signal input
RF Response

- Sub-ns transient ping: <= 100ps leading edge
RF Response (2)

- Low Power! (250mW/16 channels == < 20mW/channel @ 3.3 GSa/s)

STRAW3 target: f3dB ~ 1.2GHz

STRAW2 already useable for NaCl applications
TOF Counter Test

TOF Counter, FM-PMT

Further testing this summer (Quarknet High-school Teacher), no conclusions yet [manpower limited – balloon application]

STRAW2 chip sampling @ 3.3 Gsa/s

@ 3.3 Gsa/s, 15 samples on 5ns risetime leading edge
ANITA-lite (prototype)

RF test flight in December – equipment to Texas in July
ANITA-lite as-built Configuration

- Electronics integration into pressure housing
- Antenna arrangement
- Instrument housing under TIGER
- Housing, hard drive, veto antenna
- Redundant fast-recovery USB harddrive (8GB)

A team effort! Hawaii dominated
ANITA-lite hang test team

• From left: Jim Kennedy (UH), David Saltzberg (UCLA), David Ridley (UH), John Clem (Bartol), Marc Rosen (UH), Jason Link (UH), Peter Gorham (UH), Kurt Liewer (JPL), Jim Beatty (PSU)
• Not shown: M. Duvernois (UM), D. Cowen (PSU), G. Varner (UH), C. Hebert (UH)
Antenna testing and development

- Anechoic test chamber
- Up to 400 lb embedded salt stack

- PCB antenna development
  - Muon test chamber
  - SLAC T460
Horn Antenna Prototype

Quad-ridge horn Prototype
Cosmic-ray Radio Testbed

Testbed goals:
• Detect first Askaryan signals of cosmic origin
  – Use (rare) multi-TeV muon or single hadron showers
  – Scintillation counter trigger provides particle tag
  – 48 channel digitization via time-multiplexing
• Development of large-scale DAQ needed for full-scale detector
  – ~200 total antenna signals present
Operational since August 2002
  – Data analysis difficult

• Foreground: electronics rack & cable delay
• Background: salt chamber with amplifiers

DALI upgrade – cPCI STRAW2 acq. card
Natural Salt Domes: Potential PeV-EeV Neutrino Detectors

- Natural salt can be extremely low RF loss:
  ~ as radio clear as Antarctic ice
- ~2.4 times as dense
- typical salt dome: 50-100 km³ water equivalent in top ~3km

Qeshm Island, Hormuz strait, Iran, 7km diameter salt dome

Caprock visible from space

Isacksen salt dome, Elf Ringnes Island, Canada 8 by 5km
GEISER

- Gigabit Ethernet Instrumentation for SalSA Electronic Readout
- Senior student project
- Prototype of real system – what better way to gain experience
  - Use commercial network equipment (hubs and routers) to form trigger
  - If works, may actually be deployed

http://www2.hawaii.edu/~ridley/
PC Board

Jim: assy – improved functionality

Greg: continue high quality
Testing

STRAW2

- Sample Clock
  - Set VCO voltage (1.65 V)

- Input DC offset
  - 633 mV
For further information

- Projects continually evolving
- If any further questions, can look at later
- Will visit lab:
  - Details may be difficult to understand
  - Don’t be afraid to ask

http://www.phys.hawaii.edu/~idlab