Physics Colloquium at U. Hawaii, Manoa
21 April 2011

Secrets of the Ghostly Neutrino

What we know, Hints at New Phenomena, and What's Up at UH

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University of Hawaii, Manoa

With Many thanks to UH Neutrino Colleagues:
P. Gorham, J. Kumar, S. Matsuno, A. McDonald, J. Murillo, S. Pakvasa,
M. Rosen, M. Sakai, S. Smith, G. Varner, and more....
+ slides from T. Lasserre, R. Raffelt, T. Schwetz

"Talking to the neighbors"

"A modest proposal for an interstellar communications network"
Economist, 7 April 2011

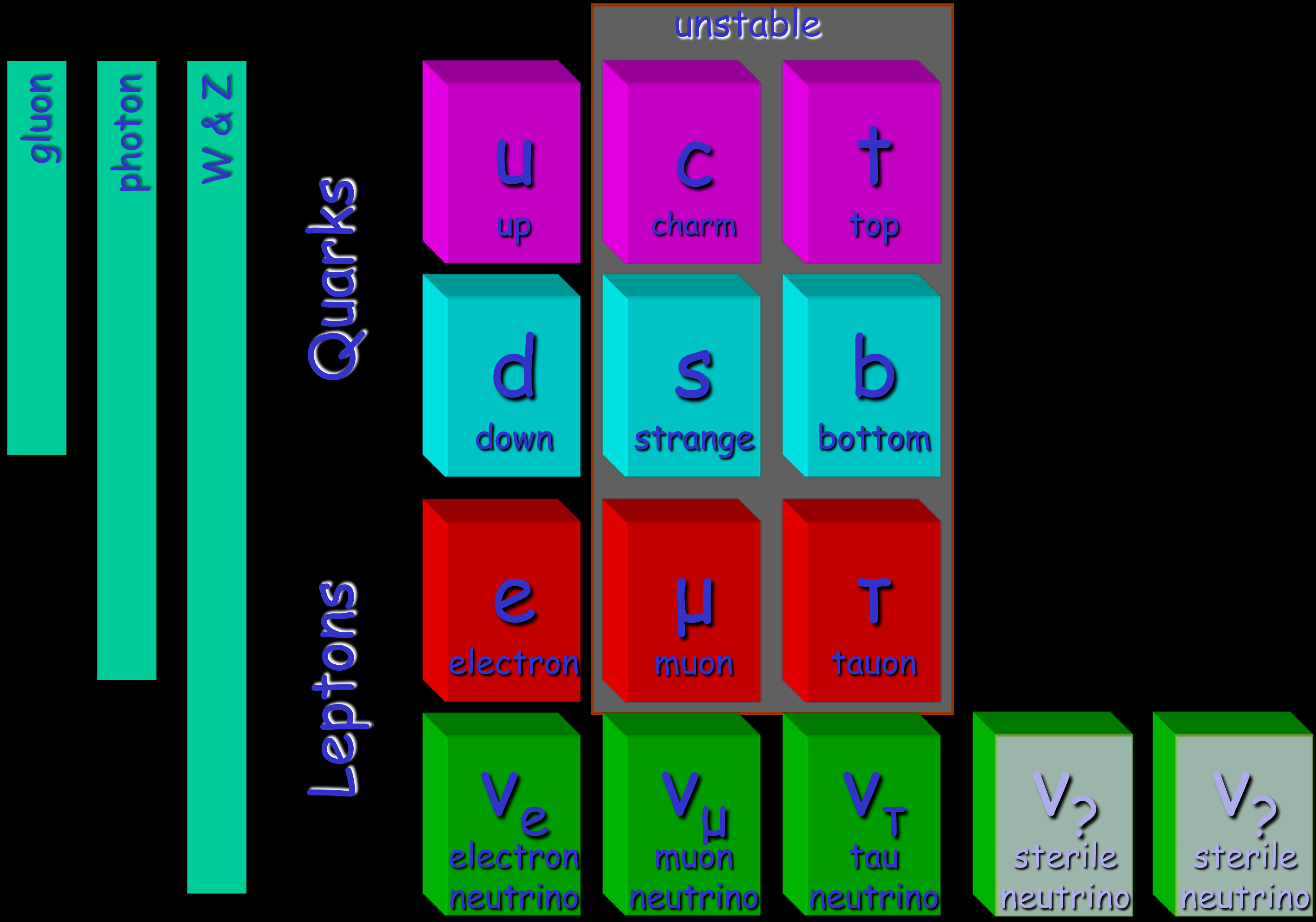
Not what this talk is about….

http://www.economist.com/PrinterFriendly.cfm?story_id=18526871

Breakfast Nus?

Neutrino Contents about
0.000000000000000000002 kCal

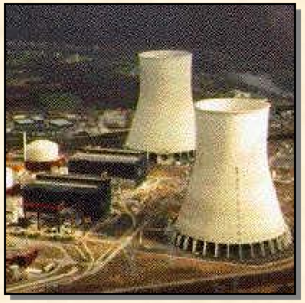
Thanks Joshua Murillo



unstable
gluon
photon
W & Z
Quarks
Leptons
u
up
c
charm
t
top
d
down
s
strange
b
bottom
e
electron
μ
muon
τ
tauon
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
$\nu_?$
sterile neutrino
$\nu_?$
sterile neutrino

Where do Neutrinos come from?

✓ Nuclear Reactors
(power stations, ships)

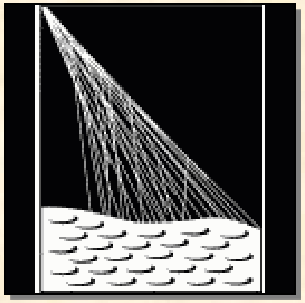


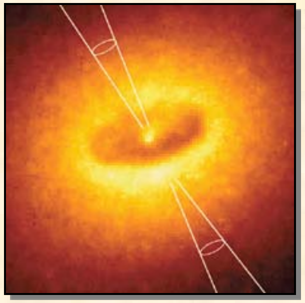
Sun ✓

✓ Particle Accelerator

Supernovae
(star collapse)
SN 1987A ✓

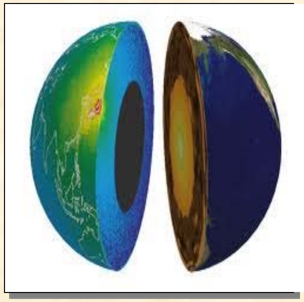
✓ Earth's Atmosphere
(Cosmic Rays)





Astrophysical
Accelerators
Soon ?

✓ Bulk Earth
(U/Th Radioactivity)



Big Bang
(here 330 ν/cm³)
Indirect Evidence

What do we know well about neutrinos?

- No electric charge.
- Little or no electric/magnetic dipole moment.
- Essentially point particles.
- Very small mass compared to other fermions.
- Participates only in SM weak interaction.
- Falls under gravity (SN1987A).
- Produced in only left-handed helicity state (nubar = right)
- Come in three flavors, e, mu and tau
- Lepton number is conserved
- No known lifetime (but…).
- Has nothing to decay to amongst known particle zoo (but nu-> nu OK)
- SM processes produce neutrinos as superposition of mass states
- Mass states' relative phases change with flight time, producing morphing between interaction states.
- Three mass states explains all accepted data, but room for new things.
- *Almost* surely we are living in a bath of undetectable ~600nu/cm^3 left from Big Bang, which travel ~300km/s.

Unanswered Neutrino Questions

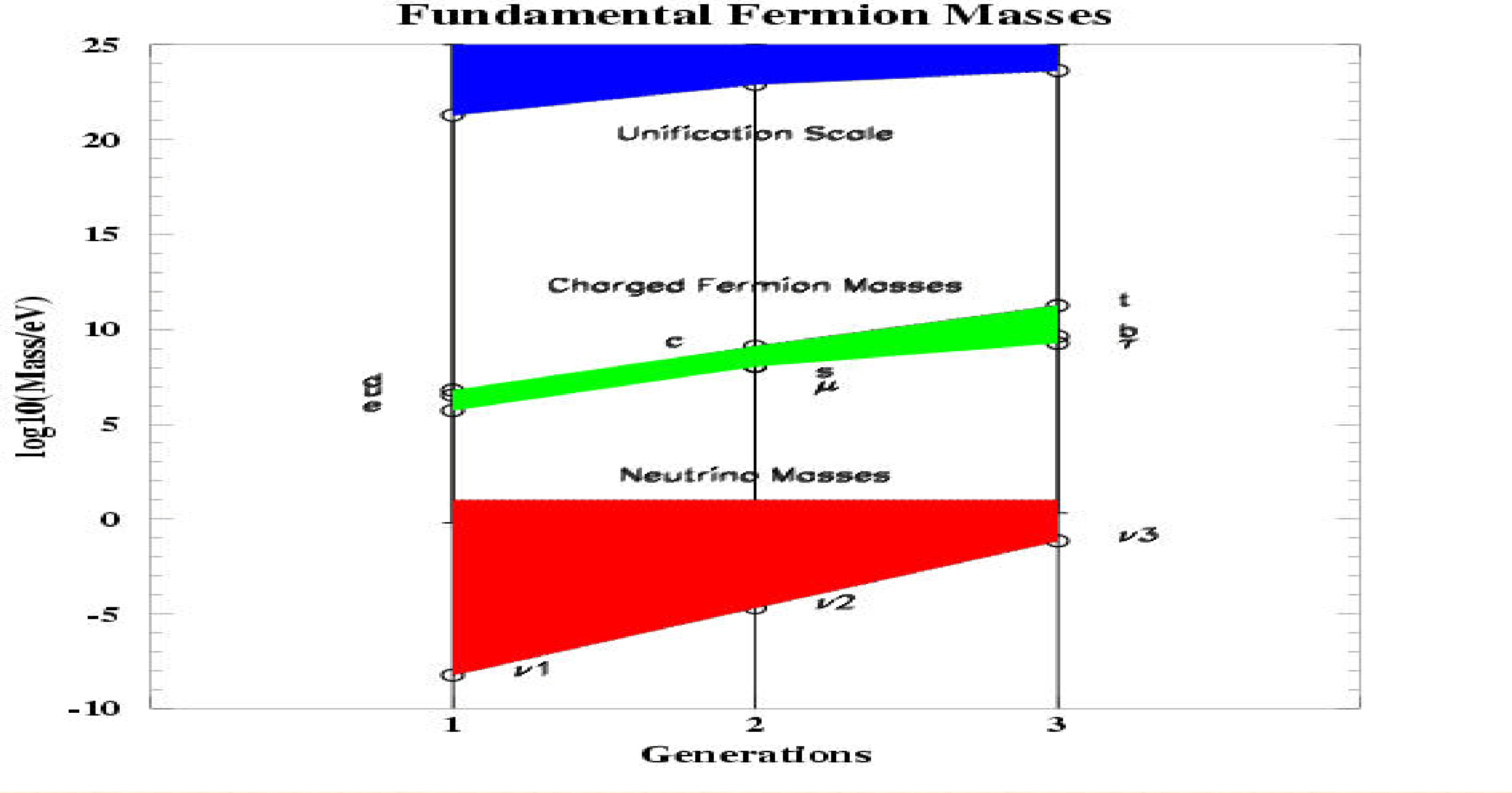
1) Who needed them anyway? Only uncharged fundamental fermion.
2) Why are masses so small?
3) What is the absolute mass scale?
4) What is the mass order?
5) Why is mixing matrix so different from quarks?
6) What is theta_13? Is mixing tri-bimax?
7) Is there CP violation as with quarks?
8) Are there heavy (TeV - GUT scale) right handed neutrinos?
9) Are neutrinos Majorana or Dirac particles?
10) Are there any light (eV scale) sterile neutrinos?

We have no guidance from a unified theory…
almost all prior theory guesses/biases were wrong…

It is an experimentalists game.

Neutrinos as Key To Grand Unification?

Fermion Mass Puzzle

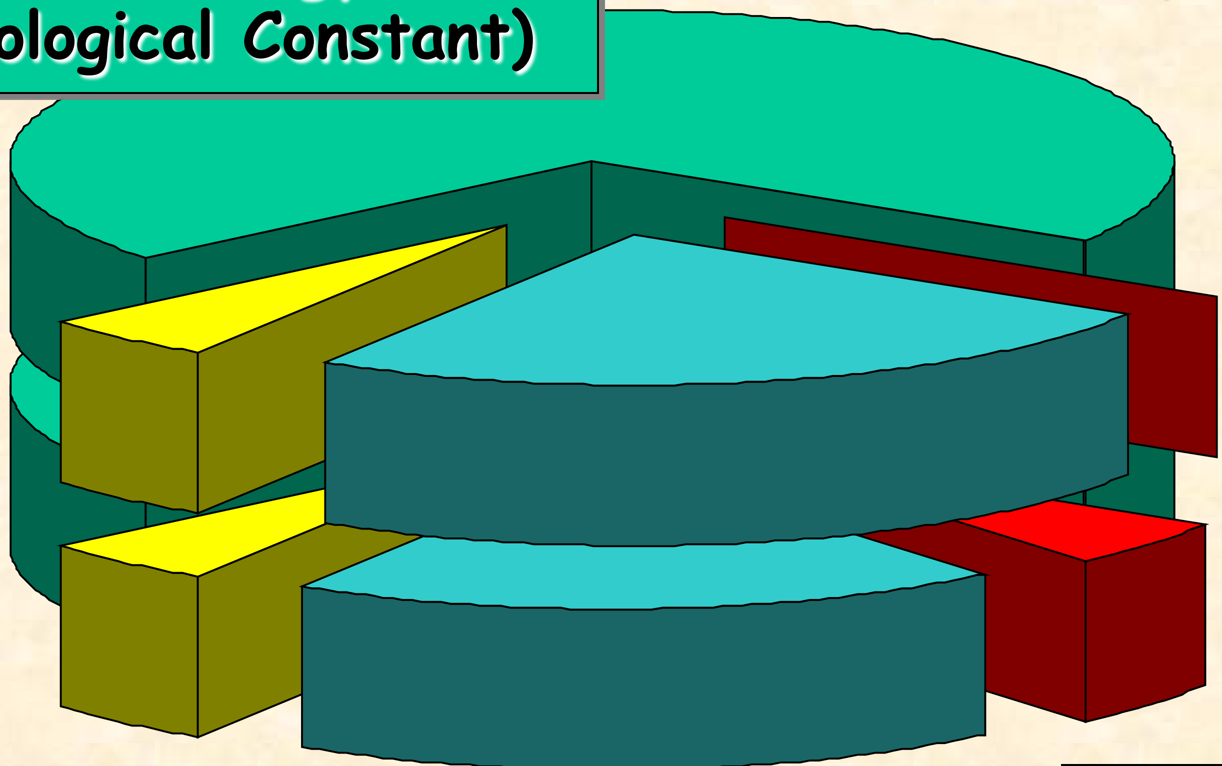


CP and CPT Violation Possible in ν Sector: Could be Key?

Matter Inventory of the Universe

Dark Energy
(Cosmological Constant)

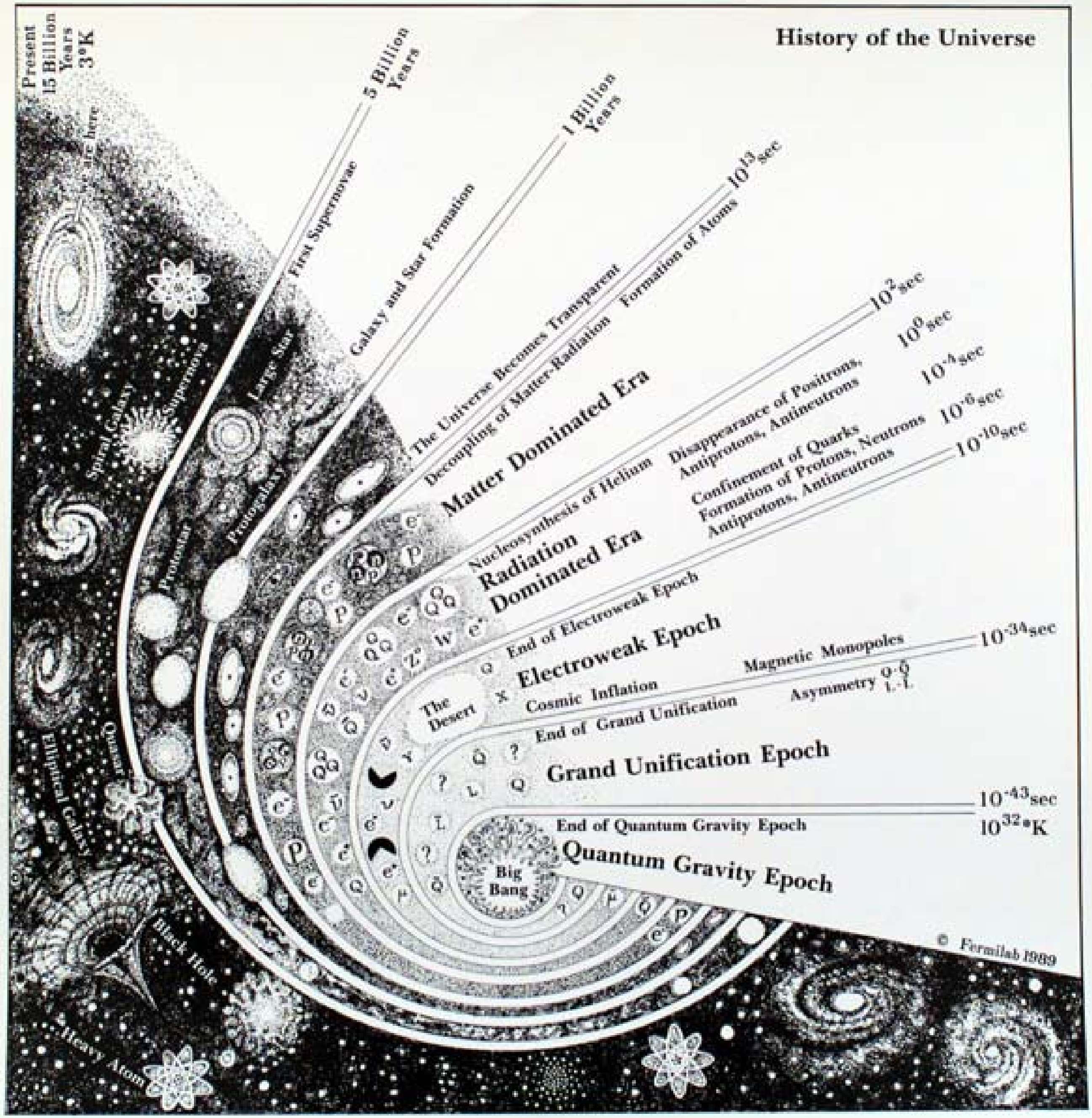
Copernicus^{n}!



Normal Matter
(of which ca.
10% luminous)

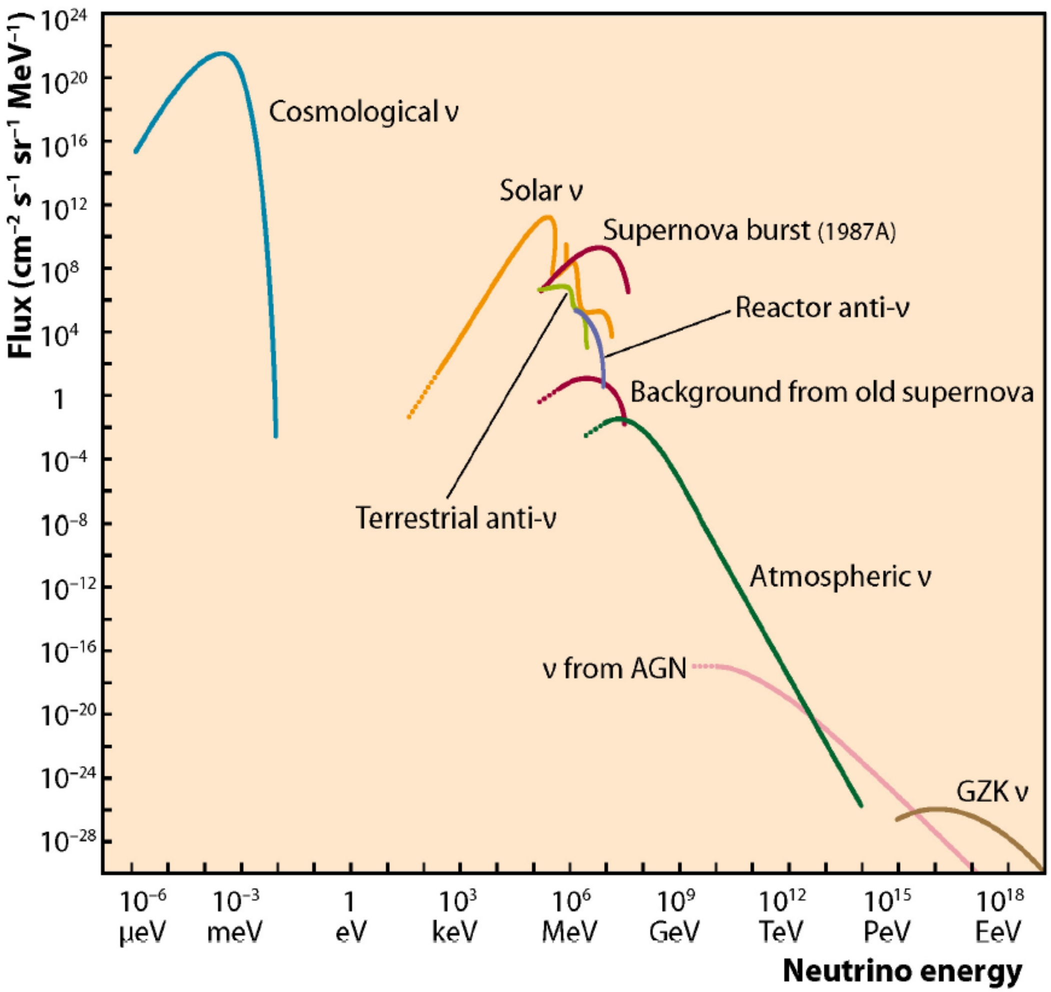
Dark
Matter

Neutrinos
min. 0.1%
max. 6%



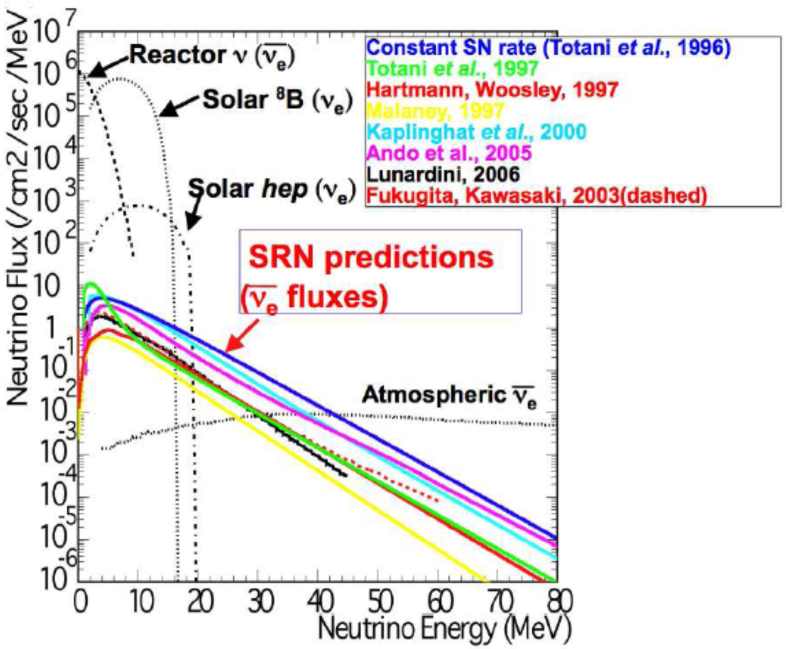
Neutrinos may play crucial role in the genesis of excess matter over anti-matter in the universe.

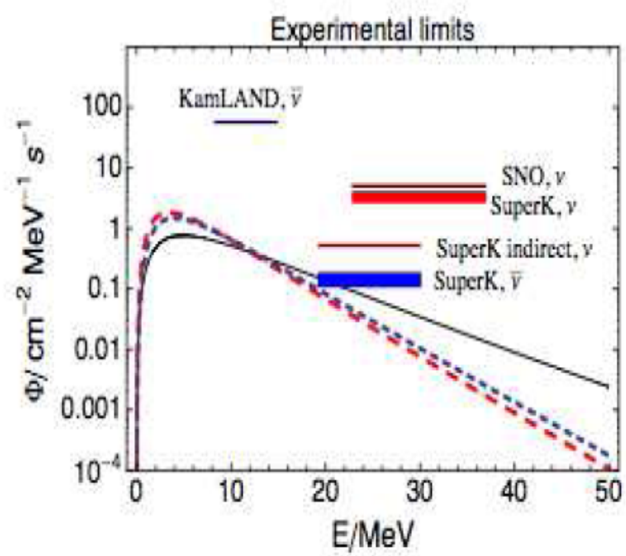
… and vast lands are to be explored:
one should be open to unexpected results.



A synoptic view of neutrino fluxes. (from ASPERA roadmap)

Neutrinos from All Earlier Supernovae





Reference Configuration	Expected Annual SRN Signal (events/year)	Expected Annual Background (events/year)	Years of LBNE Data Needed for a 3.0-σ Signal Assuming Maximum/Minimum SRN Flux
300kt WCD 30%	5 – 52	320	1.3/144
300kt WCD 30% + Gd	13 – 74	64	0.13/0.9
100kt WCD + 100kt WCD-Gd + 17kt LAr	5 – 39	114	0.35/3
100kt WCD-Gd + 34 kt LAr	4 – 27	21	0.32/3

New Window on Universe? Expect Surprises

Telescope	User	date	Intended Use	Actual use
Optical	Galileo	1608	Navigation	Moons of Jupiter
Optical	Hubble	1929	Nebulae	Expanding Universe
Radio	Jansky	1932	Noise	Radio galaxies
Micro-wave	Penzias, Wilson	1965	Radio-galaxies, noise	3K cosmic background
X-ray	Giacconi ...	1965	Sun, moon	neutron stars accreting binaries
Radio	Hewish, Bell	1967	Ionosphere	Pulsars
γ-rays	military	1960?	Thermonuclear explosions	Gamma ray bursts
Water-Cherenkov	IMB, Kamioka	1987	Nucleon Decay	ν's from SN1987A
Water-Cherenkov	SuperK	1998	Nucleon Decay	$\nu_\mu \leftrightarrow \nu_\tau$ mixing ν mass
Solar Neutrino	Homestake, SuperK, SNO	2001	Solar Burning	ν_e Oscillations

Some Neutrino Experimental Peculiarities

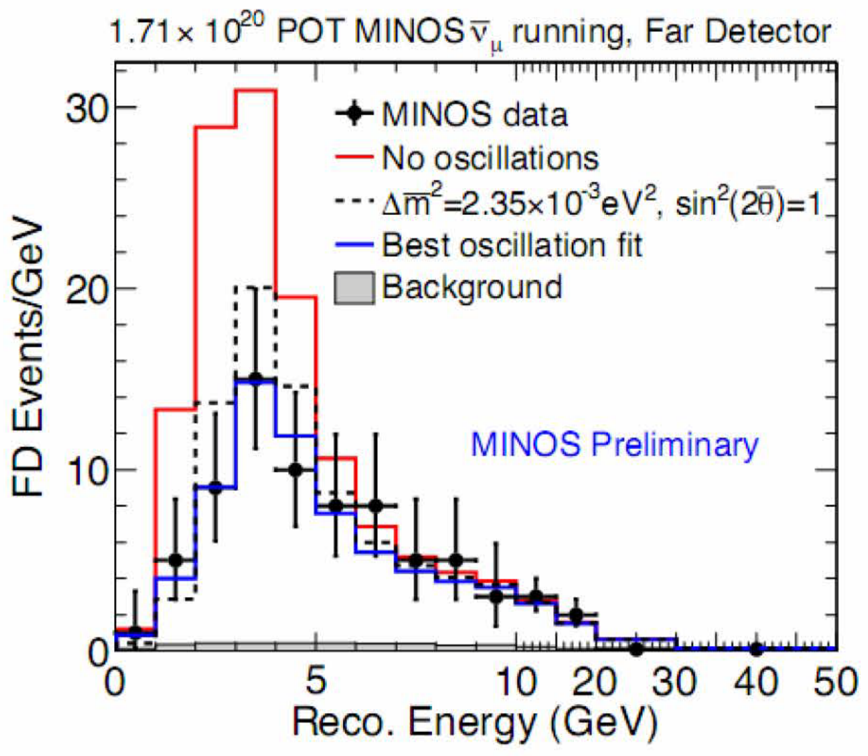
1) Flux calcs always under-predict observed rate both at accelerators, reactors and from atmospheric cosmic ray interactions. (Known but may be boring, or not?)
2) SN1987A events pointed too well…. Need another SN
3) Where are the very high energy cosmic neutrinos? (Another talk)
4) MINOS finds apparent CPT violation hints in two different runs

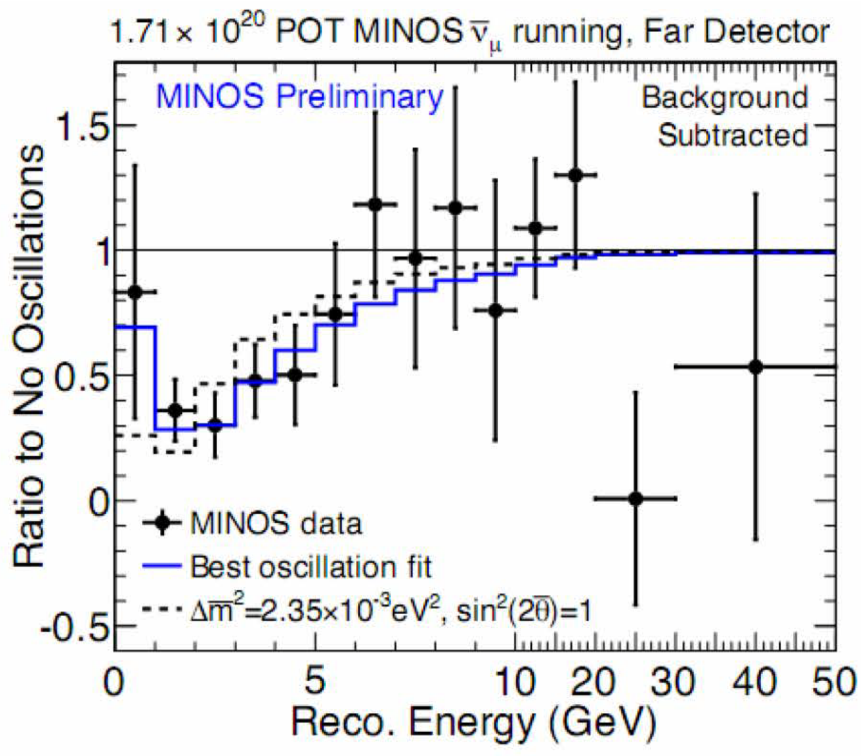
5) LSND anomaly… nu_e appear from stopped pion target
6) MiniBOONE… unexplained bumps in both nu and antinu runs, but not at same E
7) Revised reactor neutrino flux calcs exceed measurements taken over many years in experiments from 10-2000 m distance.
8) Solar Gallium experiments radioactive source calibrations came out a little low in 4 trials
9) Cosmological neutrino counting coming in high by +1 or +2

Will talk a little about 5-9 today

A couple of comments on the MINOS CPT? results

MINOS $\bar{\nu}_\mu$ result





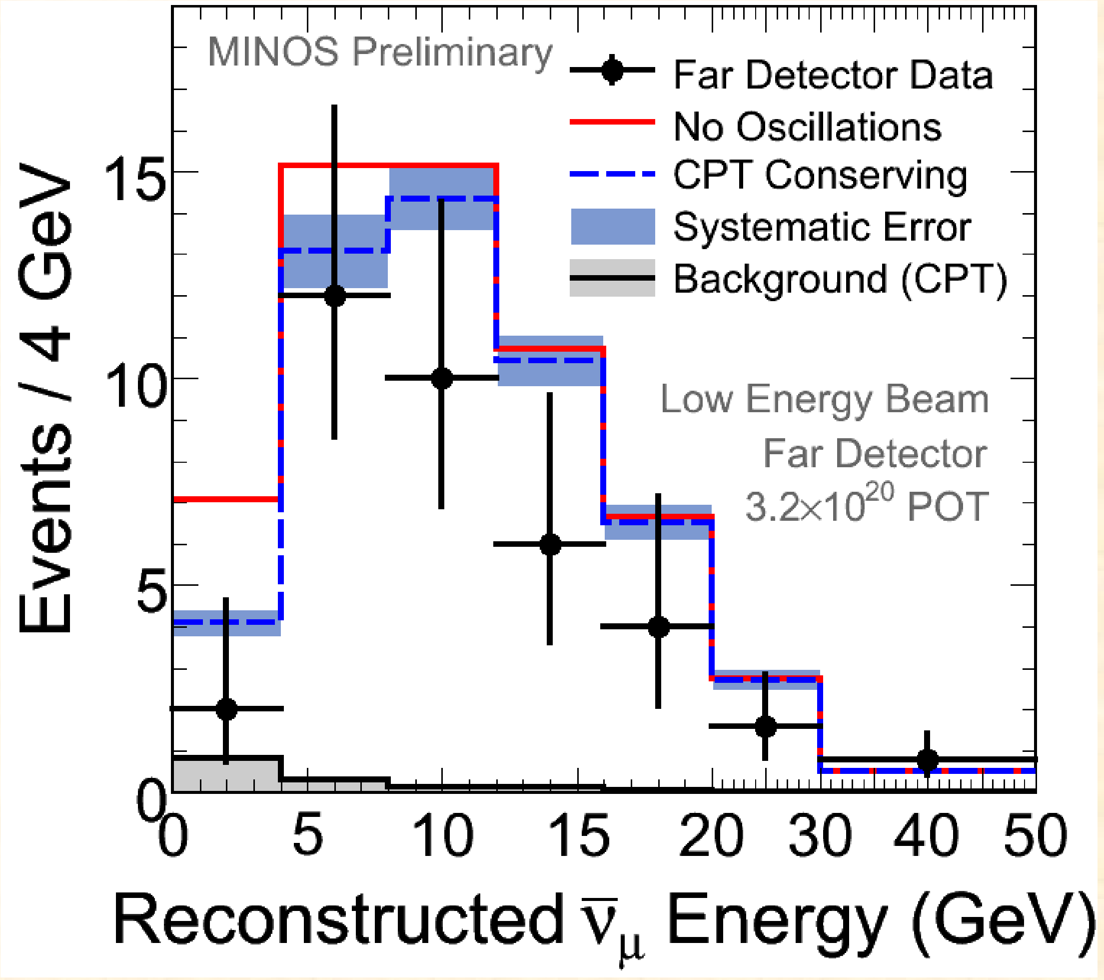
- Expected (no osc.): 155 events
- Observed: 97 events

- No oscillation is disfavored at 6.3σ

Danko NNN2010

Far Detector Spectrum – Wrong Sign Muons

- Observe **42 events** in the Far detector
- First direct observation of $\bar{\nu}_\mu$ in an accelerator long-baseline experiment
  - Predicted events with CPT conserving oscillations:
    - 58.3 ± 7.6 (stat.) ± 3.6 (syst.)
  - Predicted events with null oscillations:
    - 64.6 ± 8.0 (stat.) ± 3.9 (syst.)



Jeff Hartnell, Fermilab May 2009

$\bar{\nu}_\mu$ versus ν_μ

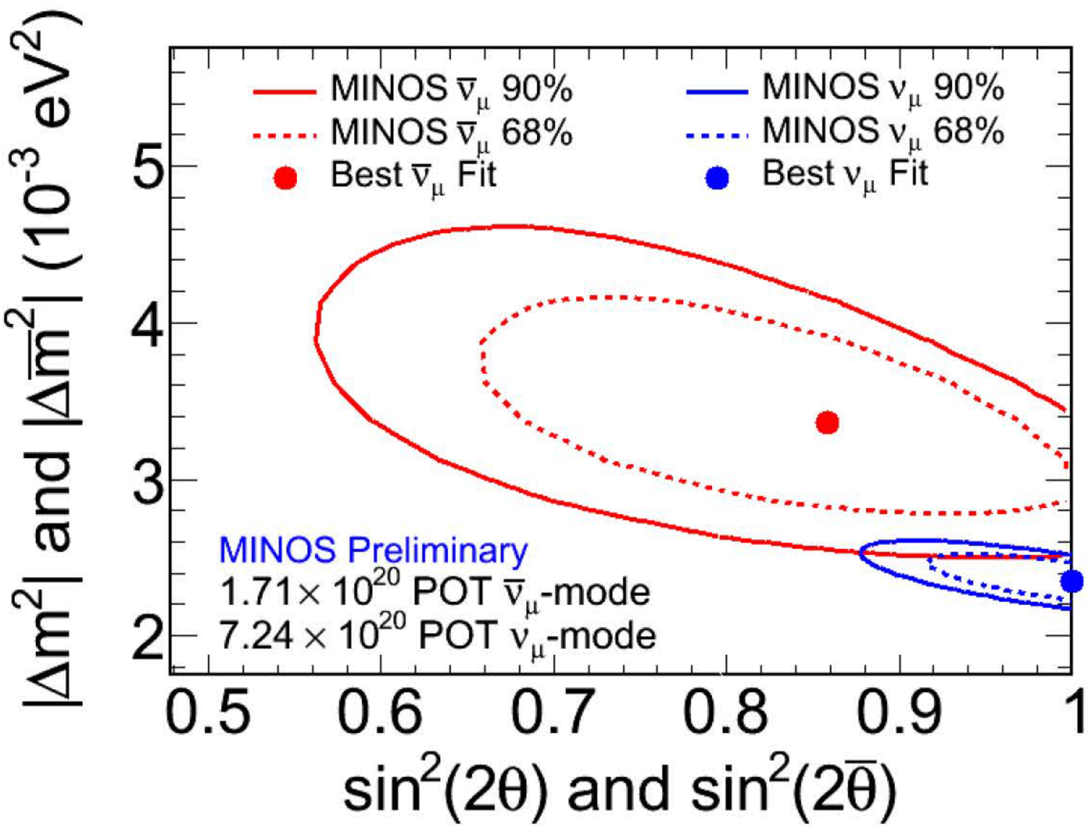
$$|\overline{\Delta m^2}| = 3.36^{+0.45}_{-0.40} \times 10^{-3} \mathrm{eV}^2$$

$$\sin^2(2\bar{\theta}) = 0.86 \pm 0.11$$

$$|\Delta m^2| = 2.35^{+0.11}_{-0.08} \times 10^{-3} \mathrm{eV}^2$$

$$\sin^2(2\theta) > 0.91 \text{ (90\% C.L.)}$$

- ~2σ inconsistency
- more antineutrino running is under way to improve nu-bar measurement



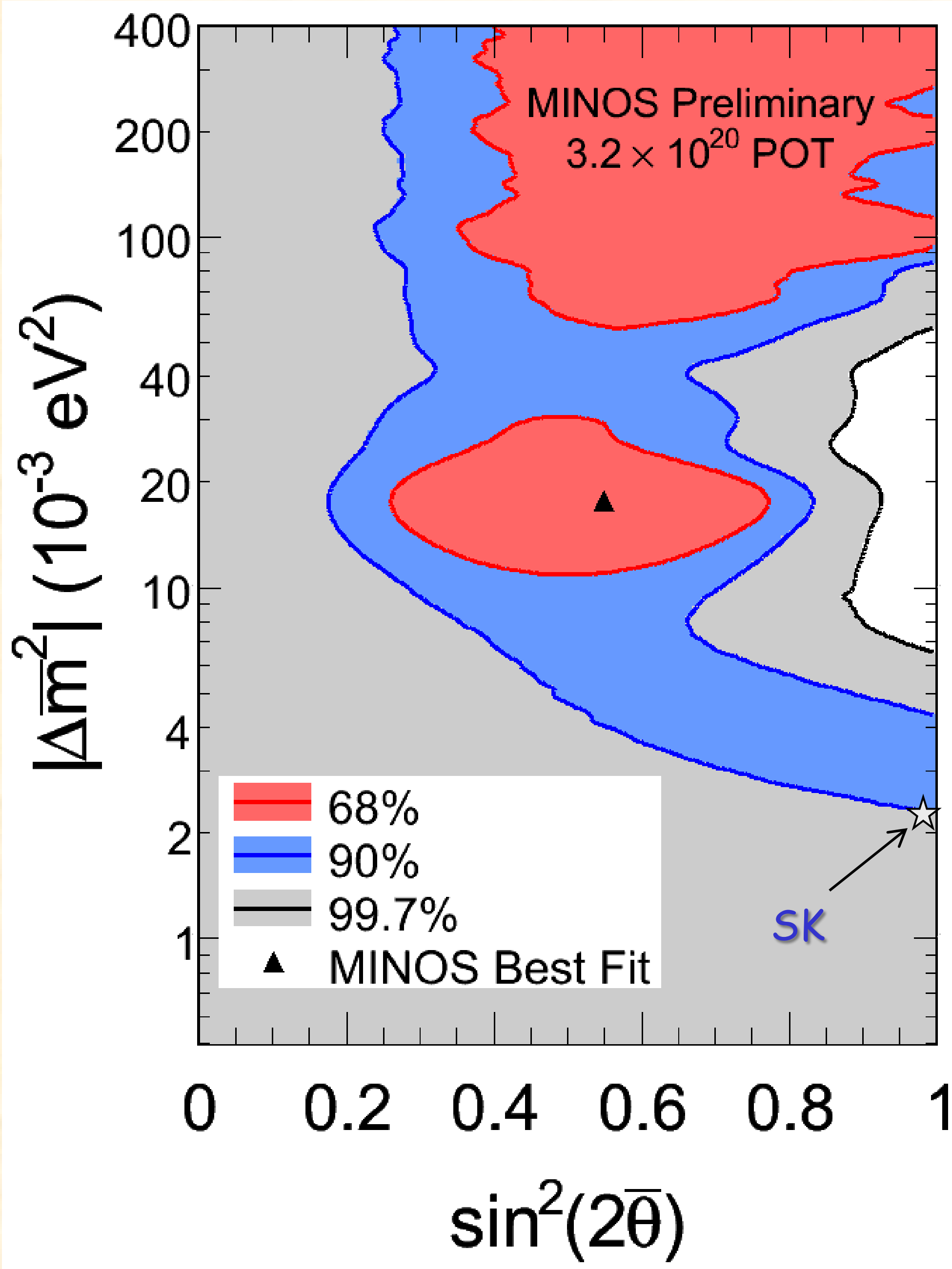
MINOS

Danko NNN2010

Wrong sign Allowed Region

- Contours obtained using Feldman-Cousins technique, including systematics
- Null oscillation hypothesis excluded at 99%
- CPT conserving point from the MINOS neutrino analysis is within 90% contour
- $\bar{\nu}_\mu$ best fit is at high value, due to deficit at high energy
- Unshaded region around maximal mixing is excluded at 99.7% C.L.

jgl conclusion..
Some internal problems in MINOS

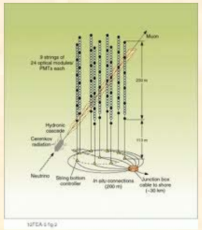


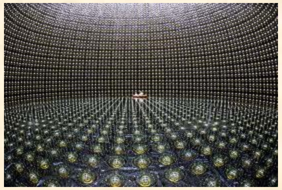
Step back…

- Overview of UH Neutrino work
- Quick historical tour
- Small tutorial on oscillations

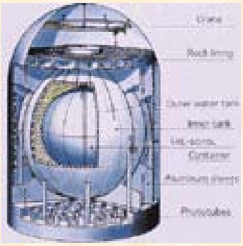
UH Neutrino Group Projects

Past
- Beginning Neutrino Astronomy (Workshops, DUMAND)
- IMB (first Hints at Neutrino Oscillations 1983, SN1987A observed in neutrinos)
- Neutrino Phenomenology and Astrophysics
- K2K (confirmation of oscillations with accelerator)
- Forte′ (terrestrial radio pulses seen from space)
- GLUE (radio pulses from moon)

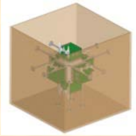




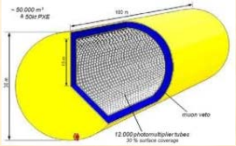
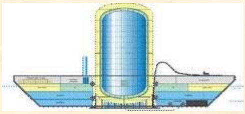
Present
- Super-Kamiokande (discovery of neutrino oscillations)
- KamLAND (electron neutrino oscillations from reactors)
- Radio Detection Studies (mechanisms, at accelerators, lab)
- [ASHRA (Nitrogen Fluorescence Air Shower, Mauna Loa)]
- ANITA (radio neutrino detection from balloon in Antarctic)
- miniTimeCube
- Reactor Monitoring
- ARA (radio detection in ice at South Pole)








Future Possibilities
- Long Baseline Neutrino Detector (DUSEL, Homestake South Dakota)
- Hanohano (ocean going >10 kiloton liquid scintillation detector)
- LENA (50 kiloton, liquid scintillation detector in Europe)
- Giant version of ANITA

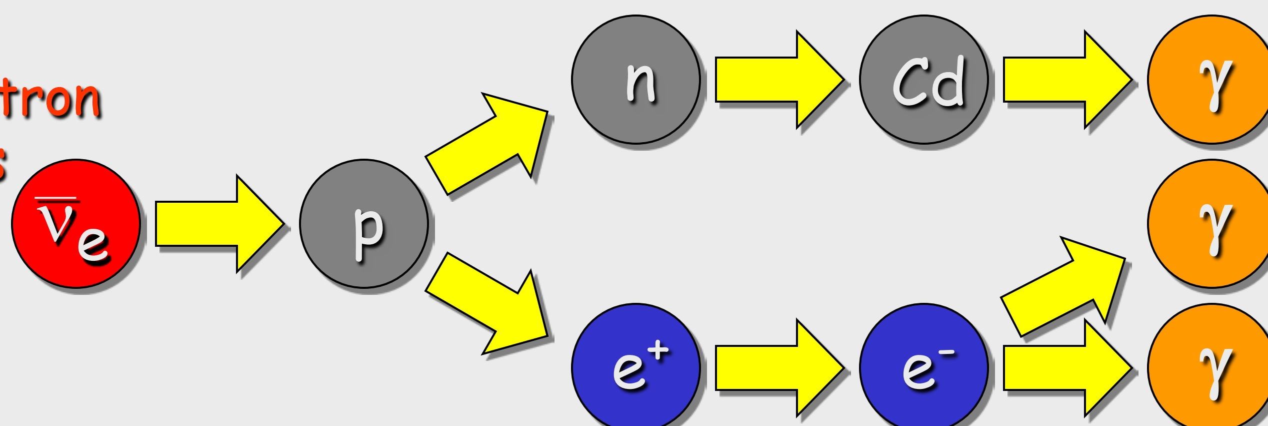



Non-Accelerator Neutrino History Survey

- Neutrinos were proposed in 1930 as solution to missing energy in beta decays.
- Said to be undetectable, but….

First Detection ! (1954 - 1956)

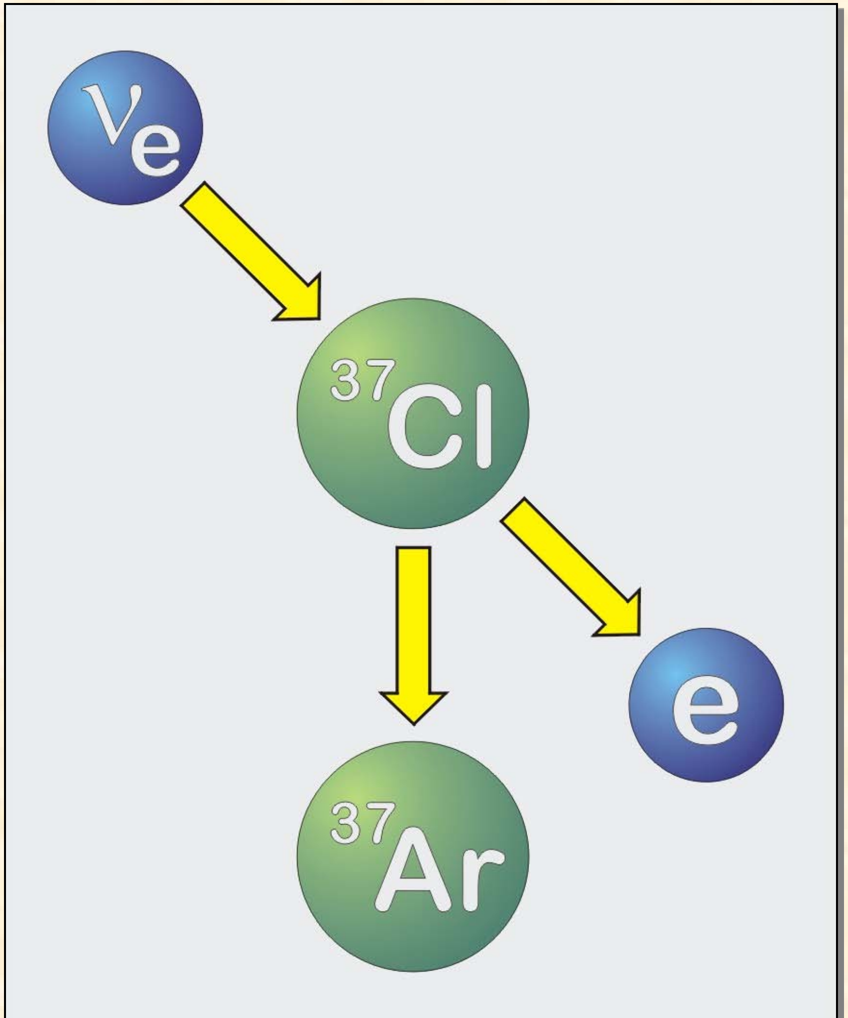
Anti-Electron Neutrinos from Hanford Nuclear Reactor

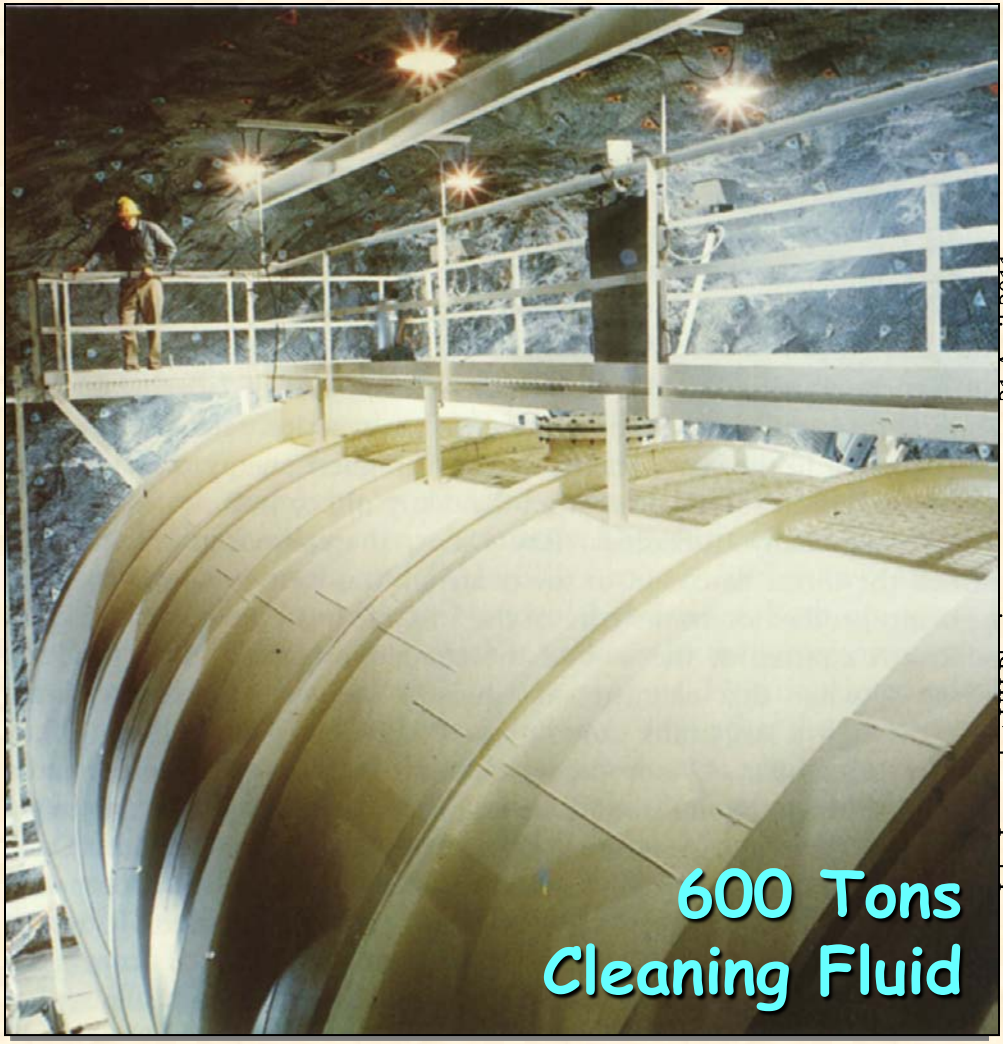


3 gamma quanta in coincidence

First Observation of Solar Neutrinos

Inverse Beta-Decay ("Neutrino Capture")





Homestake Solar-Neutrino Observatory (since ca.1967)

1980's

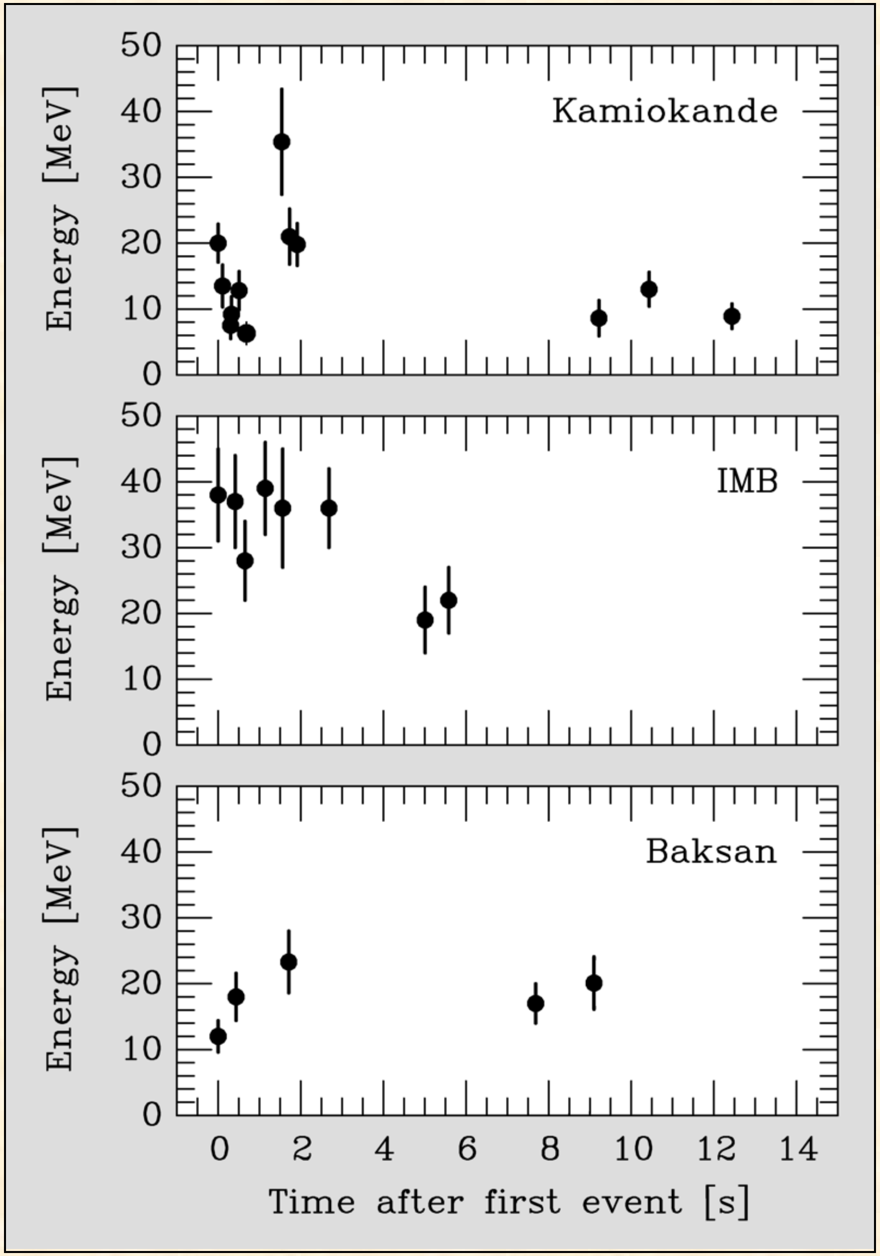
Solar neutrino experiments not seeing predicted rates…
blame game between solar modelers and experimentalists.
Theory provides a few possible explanations, including oscillations.

Underground cosmic ray neutrino detectors built to search for nucleon decay, find peculiar deficit of muon/electron neutrinos in US and Japan, but not in Europe.

Lots of confusion, finger pointing, enthusiasm, but ambiguous conclusions.

But then one great highlight, resulting in hundreds of papers:

Neutrino Signal of Supernova 1987A



Kamiokande (Japan)
Water Cherenkov detector
Clock uncertainty ±1 min

Irvine-Michigan-Brookhaven (US)
Water Cherenkov detector
Clock uncertainty ±50 ms

Baksan Scintillator Telescope
(Soviet Union)
Clock uncertainty +2/-54 s

Within clock uncertainties,
signals are contemporaneous

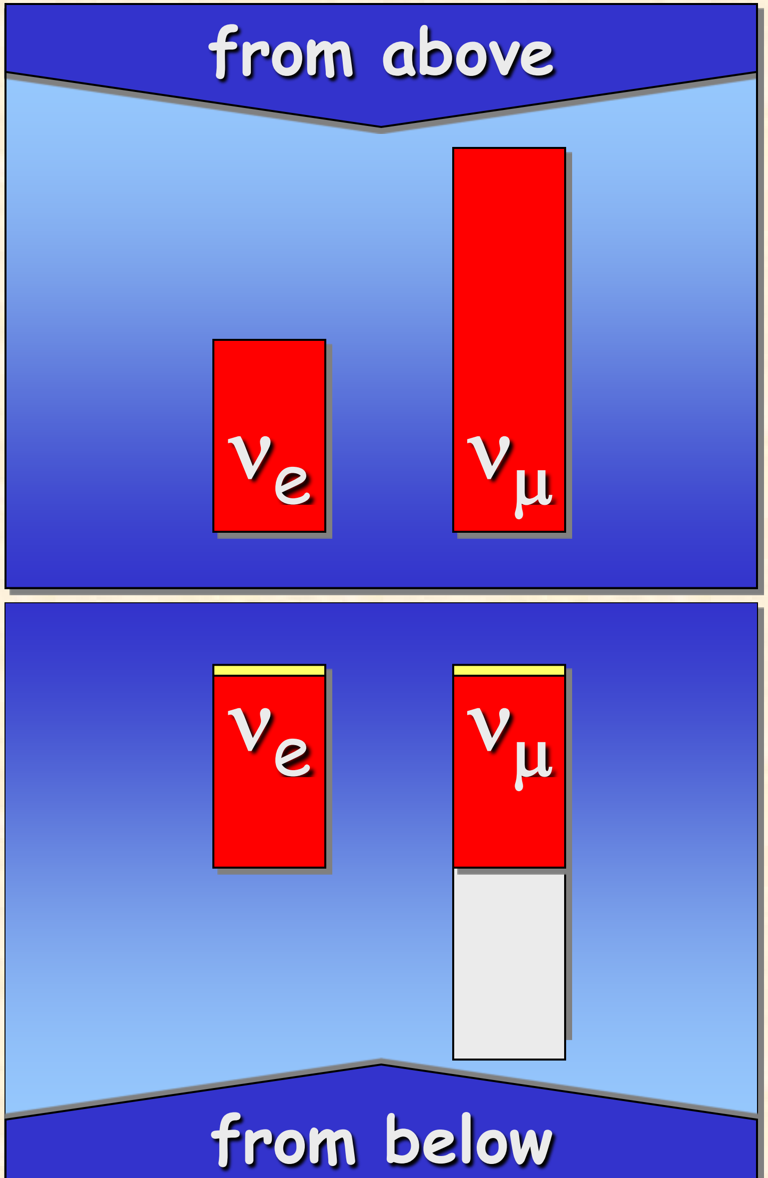
Neutrino Fever Hits in the 1990's

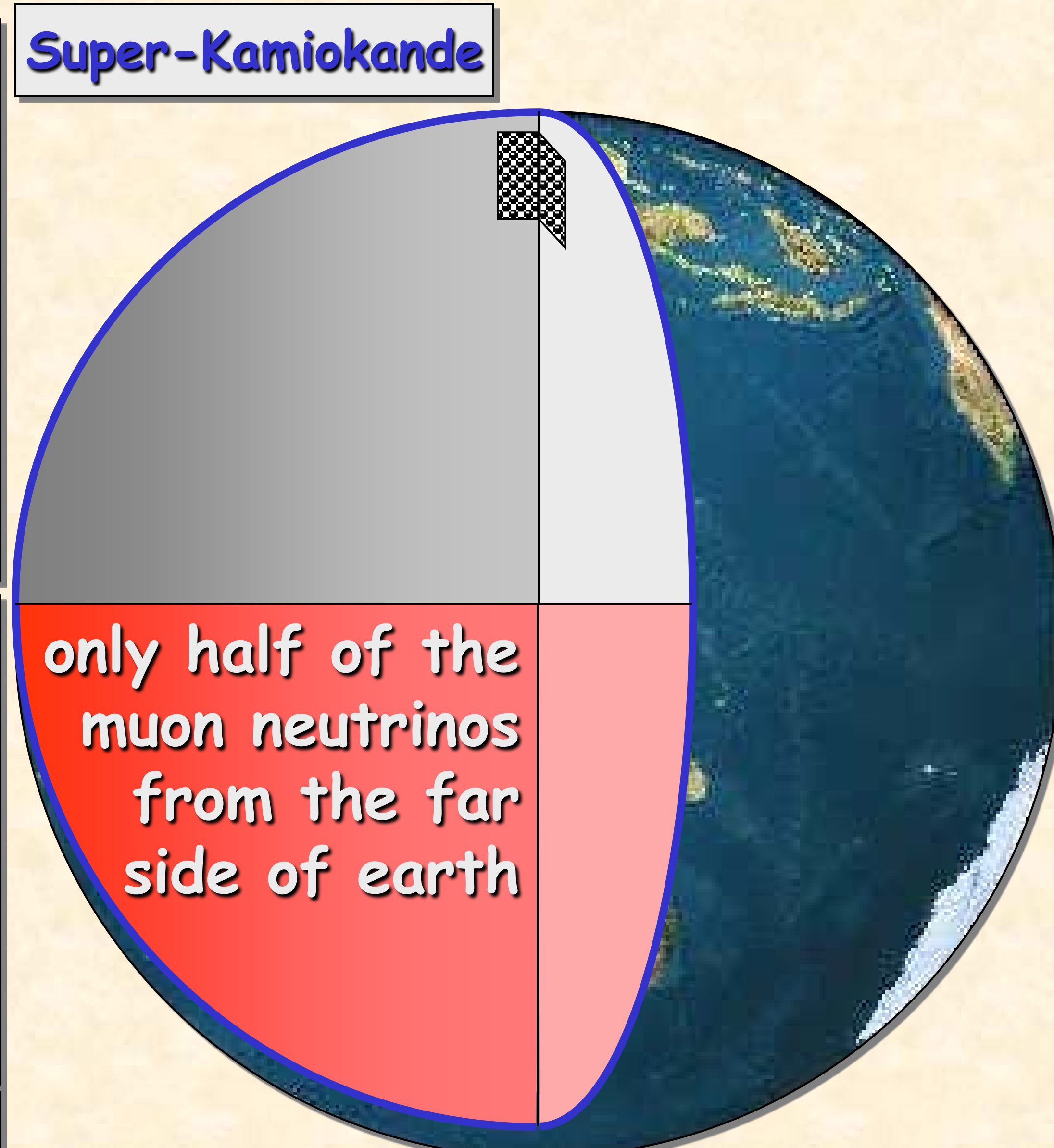
Kamiokande detects solar electron neutrinos, with directionality!

Rate is lower than models… suspicions of electron neutrino oscillations, but other solutions not ruled out.

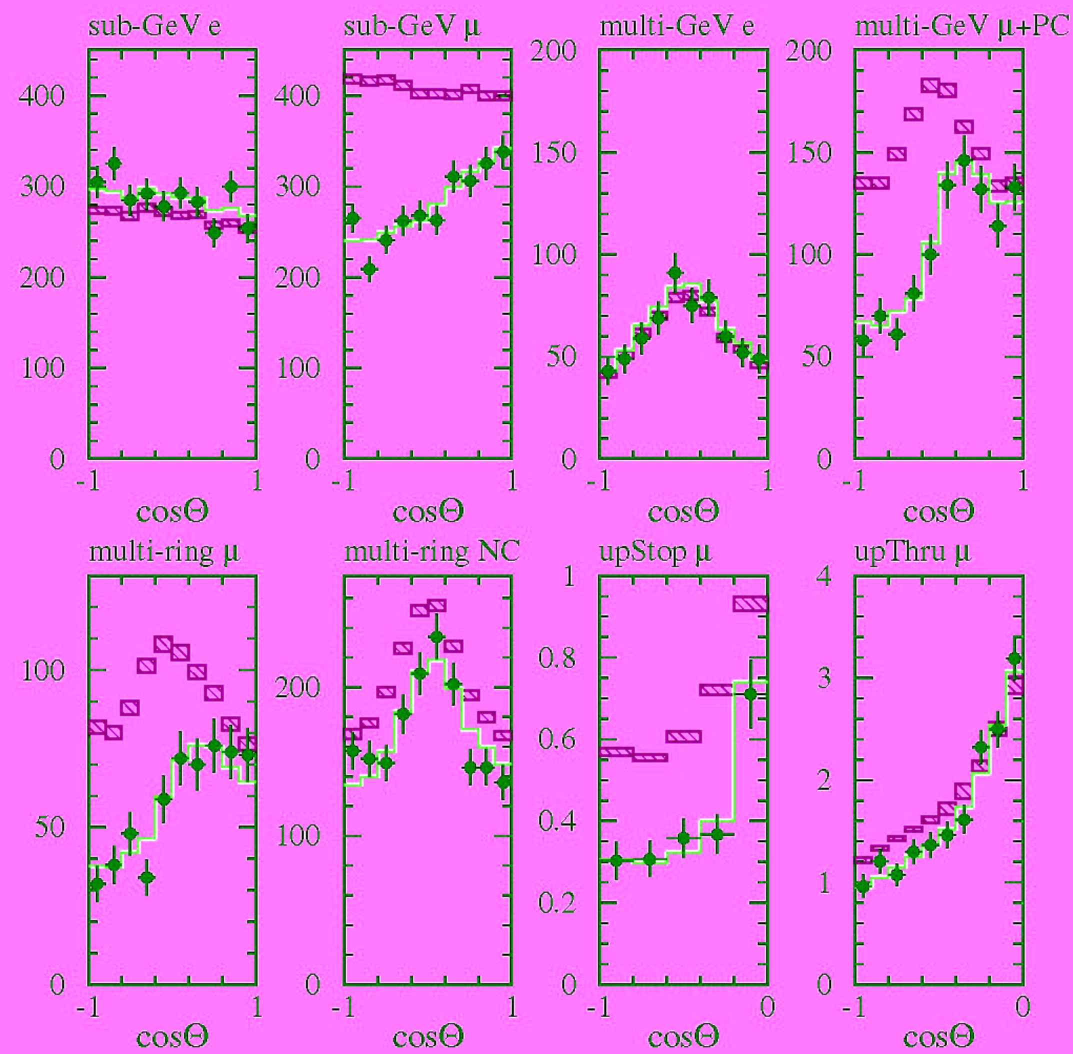
In 1996 the 50 kiloton SuperKamiokande detector starts, and by 1997 things are beginning to become clear…

Atmospheric Neutrino Anomaly





Fit to Entire Atmospheric ν Data Set



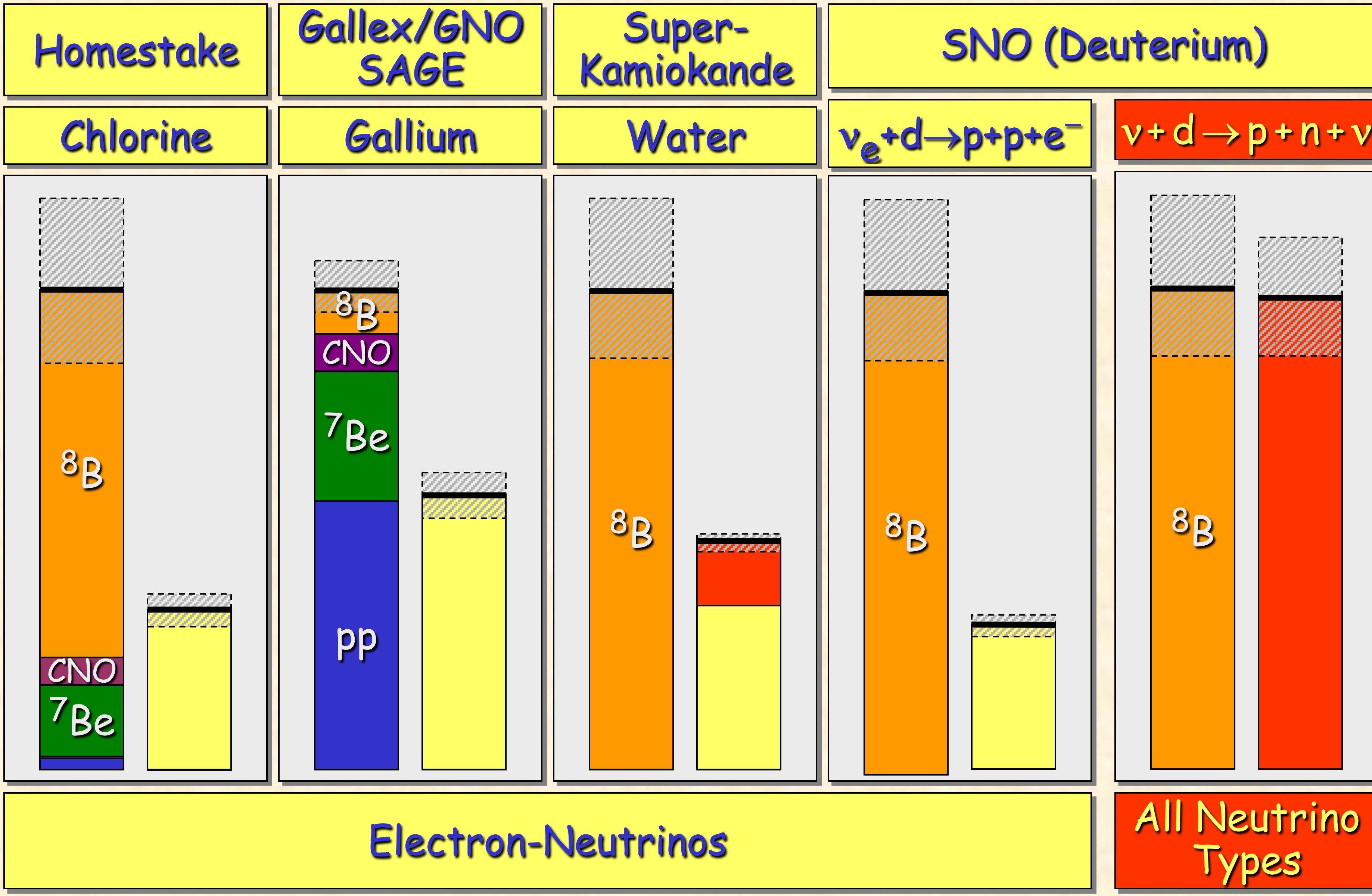
MC No-Osc

ν_μ-ν_τ

SuperK neutrino oscillations paper now most cited paper in history of experimental particle physics

Phys. Rev. Lett. 81, 1562 (1998).

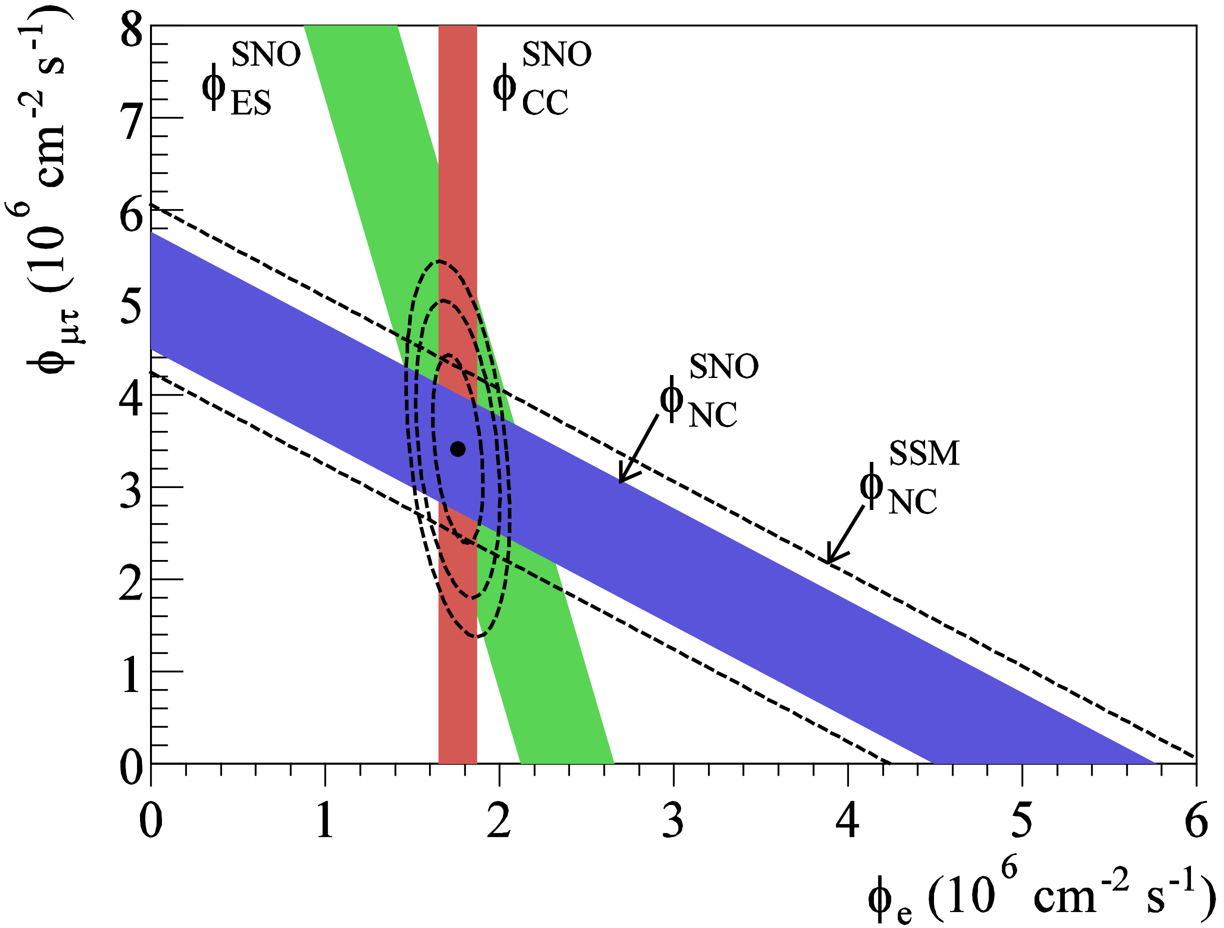
SNO Settles the Solar Neutrino Problem



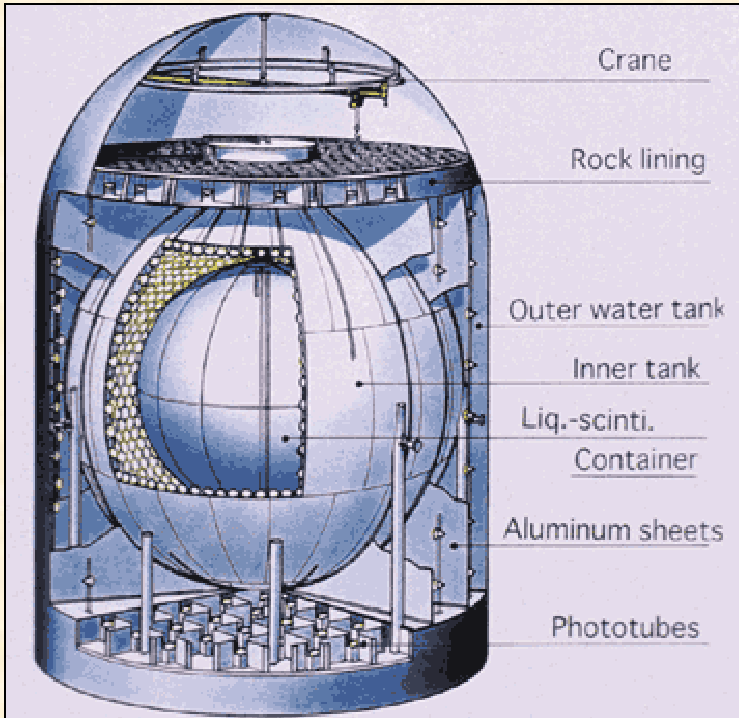
Consistency Between Measurements

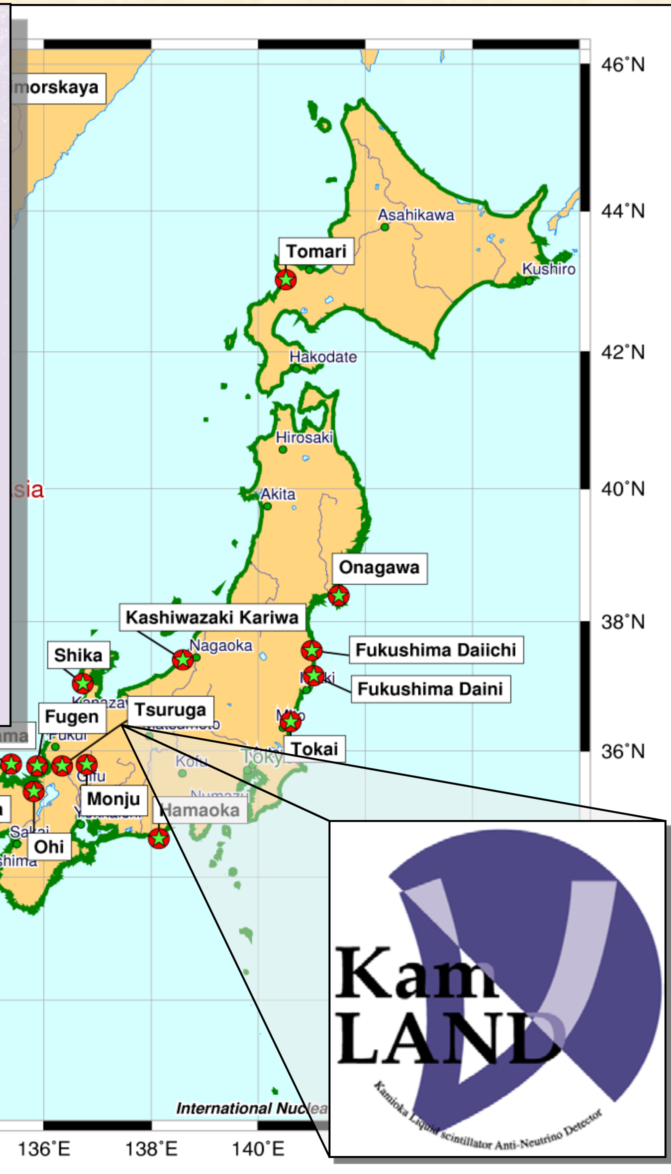
$\Phi_{ssm} = 5.05^{+1.01}_{-0.81}$ $\Phi_{sno} = 5.09^{+0.44}_{-0.43}{}^{+0.46}_{-0.43}$

$\Phi_{\mu\tau}$ is 5.3 σ from zero



KamLAND Reactor Neutrino Experiment (Japan)





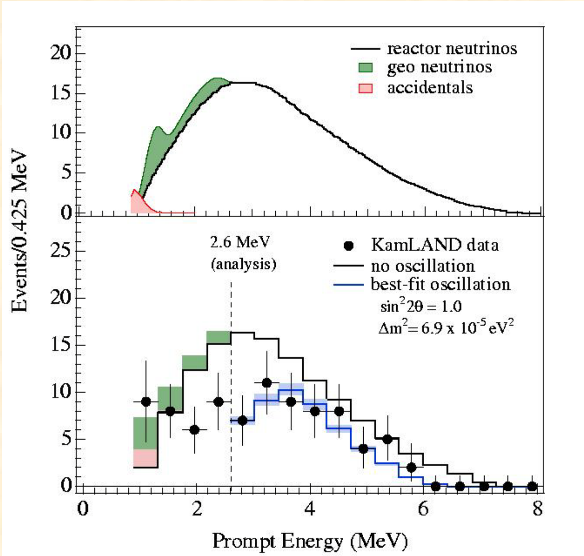
detect ν_e from >100km and observe deficit due to oscillations

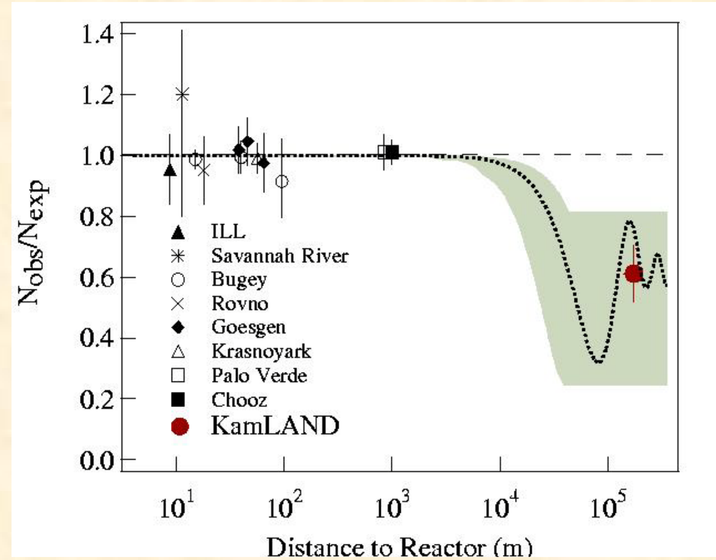
Japanese nuclear reactors 60 GW (20% world total)

- ~1 neutrino capture per day
- Taking data since Jan. '02
- Conclusive Results Fall '02.

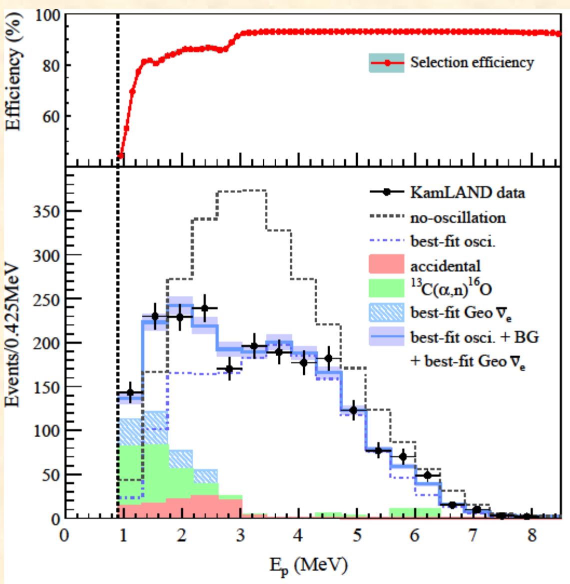
KamLAND Settles the Solar Problem

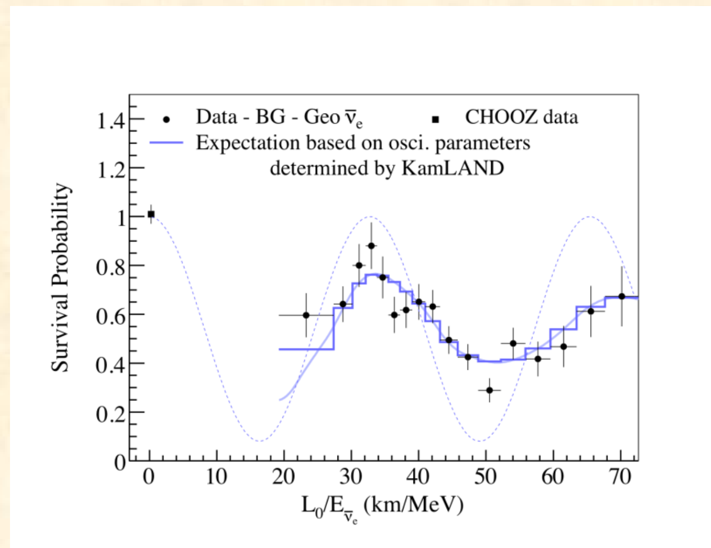
2003



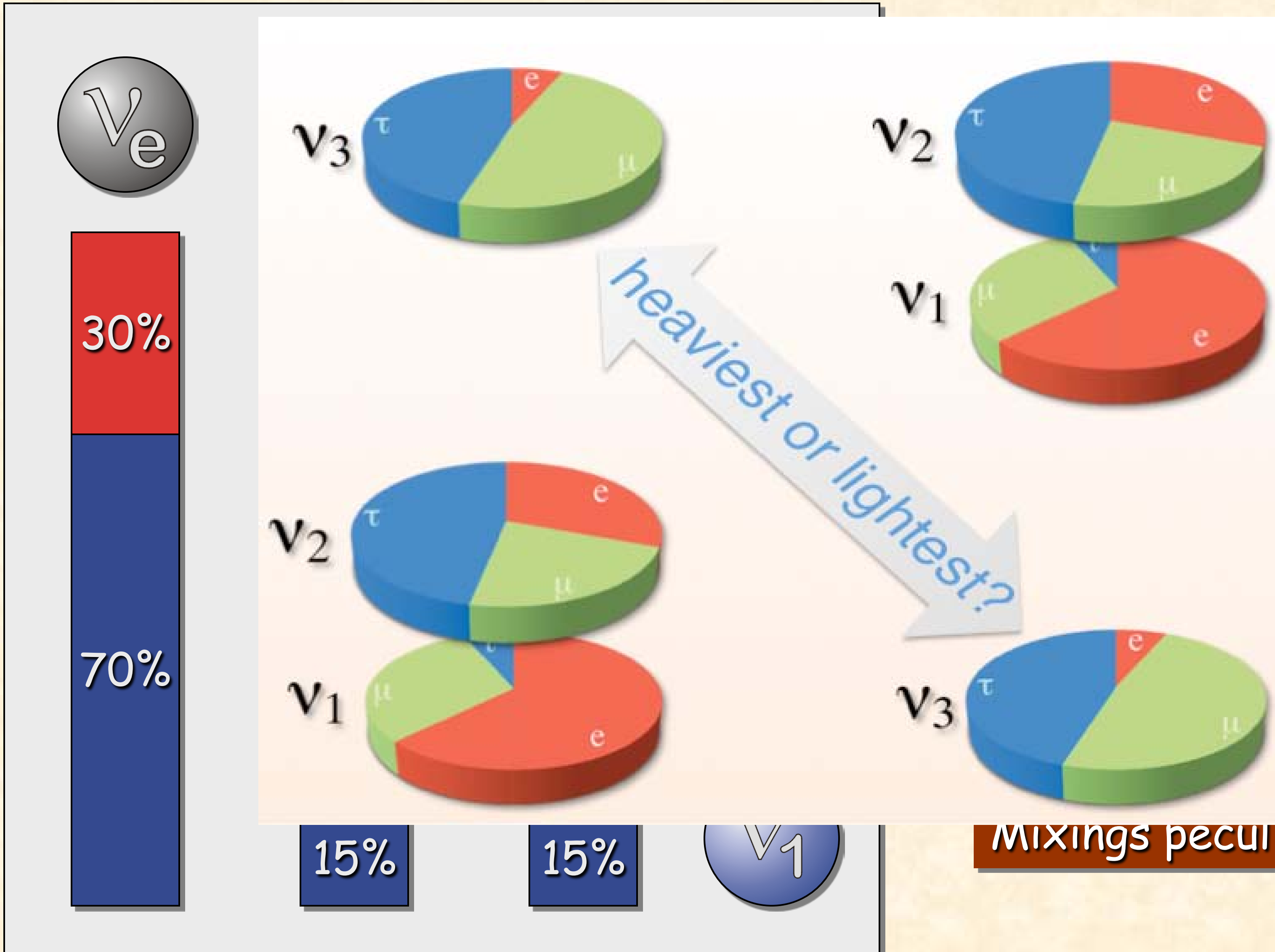


2010





Neutrino Mass and Composition



f neutrino
om
nts.

nos:
3 eV^2

$10^{-5} eV^2$

Mixings peculiarly large

Neutrino Oscillation Mixing Matrix

– U: 3 angles, 1 CP-phase + (2 Majorana phases)

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Neutrinos

$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

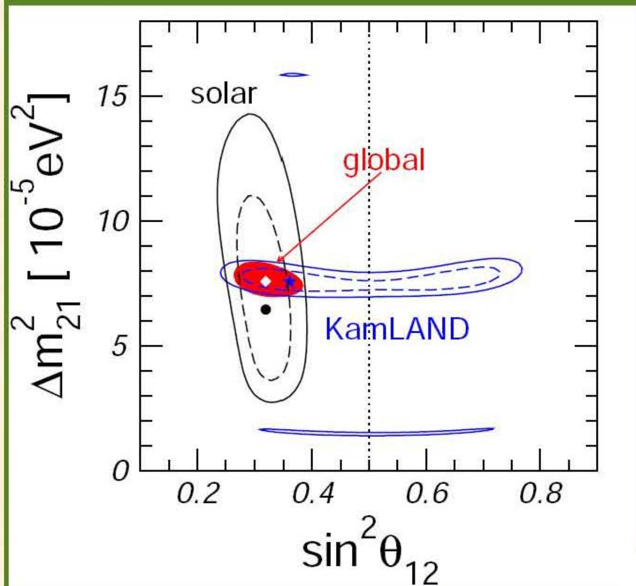
Quarks

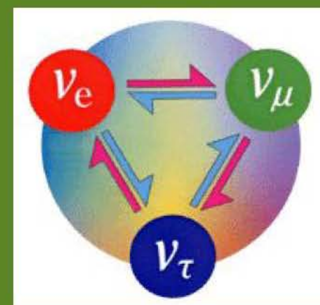
Very Different

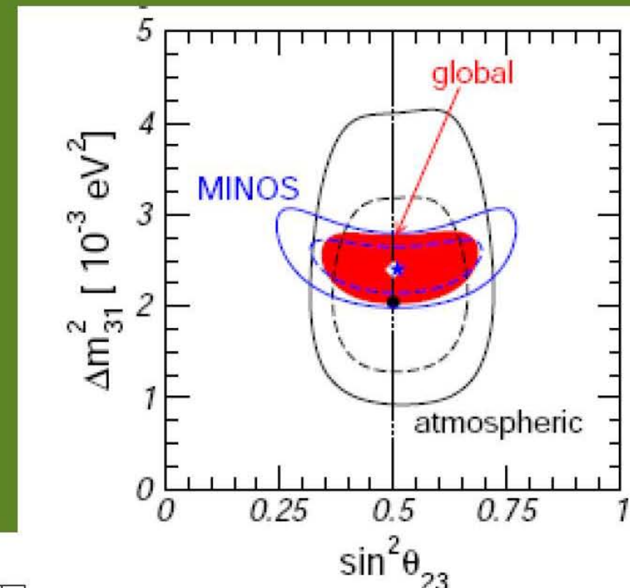
$$V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix}$$

Three Neutrinos Fits Almost all Data

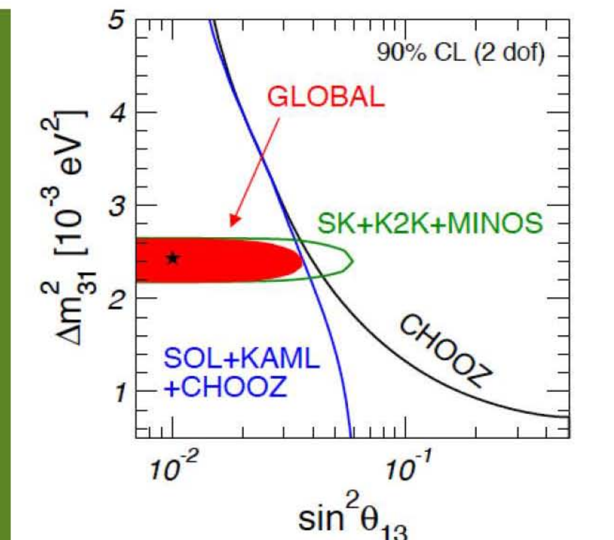
Update of Schwetz et al, NJP 10 (2008) 113011 [rev. Maltoni et al, NJP 6 (2004) 122]







Homestake, SAGE
GALLEX/GNO,
Super-K, SNO-leta, SSM
Borexino
KamLAND (180 Km)



... Super-K

K2K (250 Km)
MINOS latest app
(735 Km)

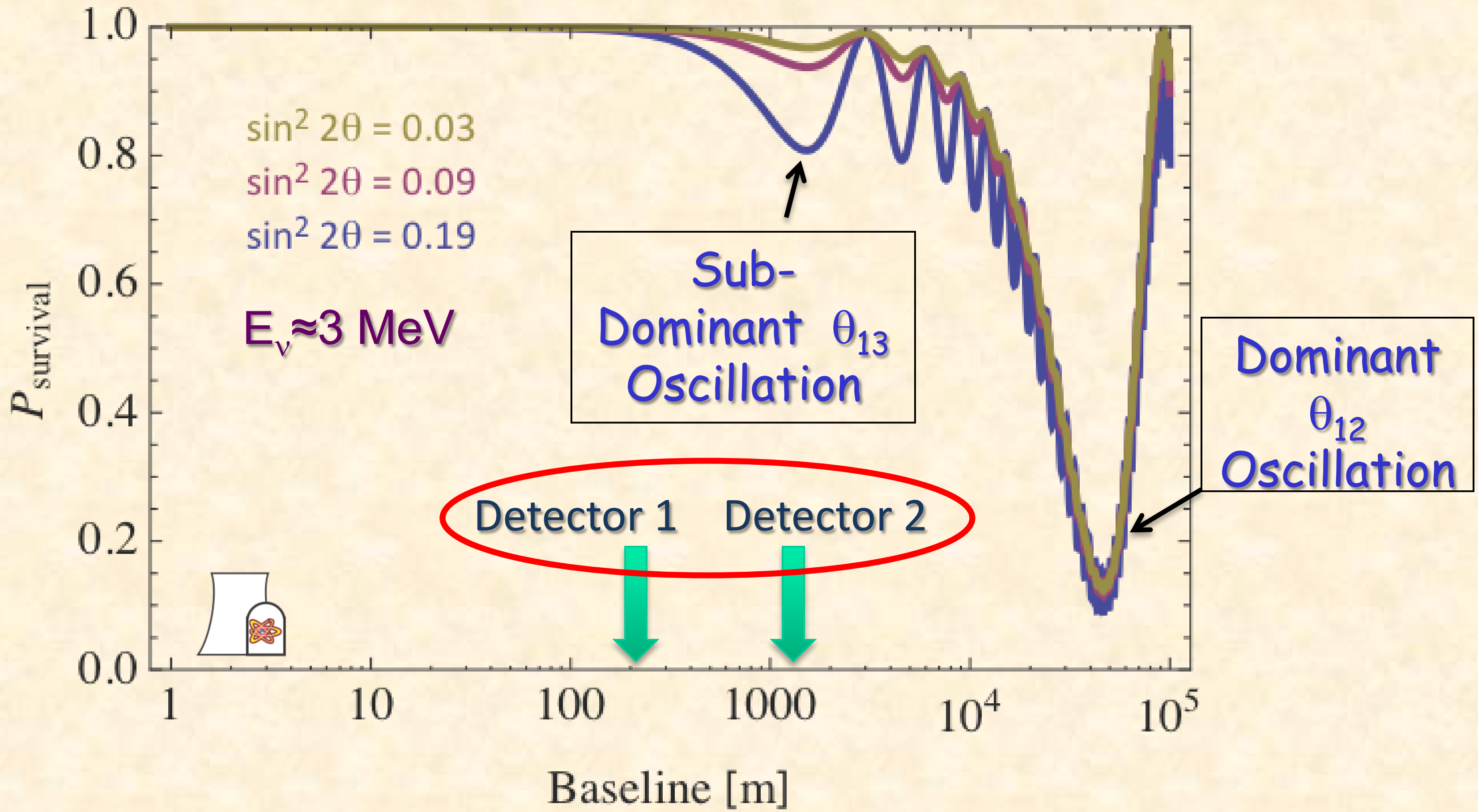
What next in Neutrino Measurements?

- For lack of time will skip exciting doings in absolute neutrino mass measure and double beta decay (now about half dozen experiments)…
- Also no comments on indirect Dark Matter measurements via neutrinos (but UH involvement here… Mich, Stefanie, Jason…
- [And Sven doing direct detection, no nus).]

- Everyone agrees 3 nu oscillations real
- Where next? Measure theta_13

Precision Reactor Experiments for θ_{13}

L. Mikaelyan, arXiv:hep-ex/0008046v2 (Krasnoyarsk)



build nearly identical detectors with nearly identical efficiency

Kearns NUFACT09

Three New Reactor Experiments Starting

- Double CHOOZ in France
- Daya Bay in China
- RENO in Korea

- DC starting with one detector now
- DB to start in a year or two
- RENO claims start in June!

Will be interesting horse race!

Now Enters the Peculiar New "Reactor Neutrino Anomaly"

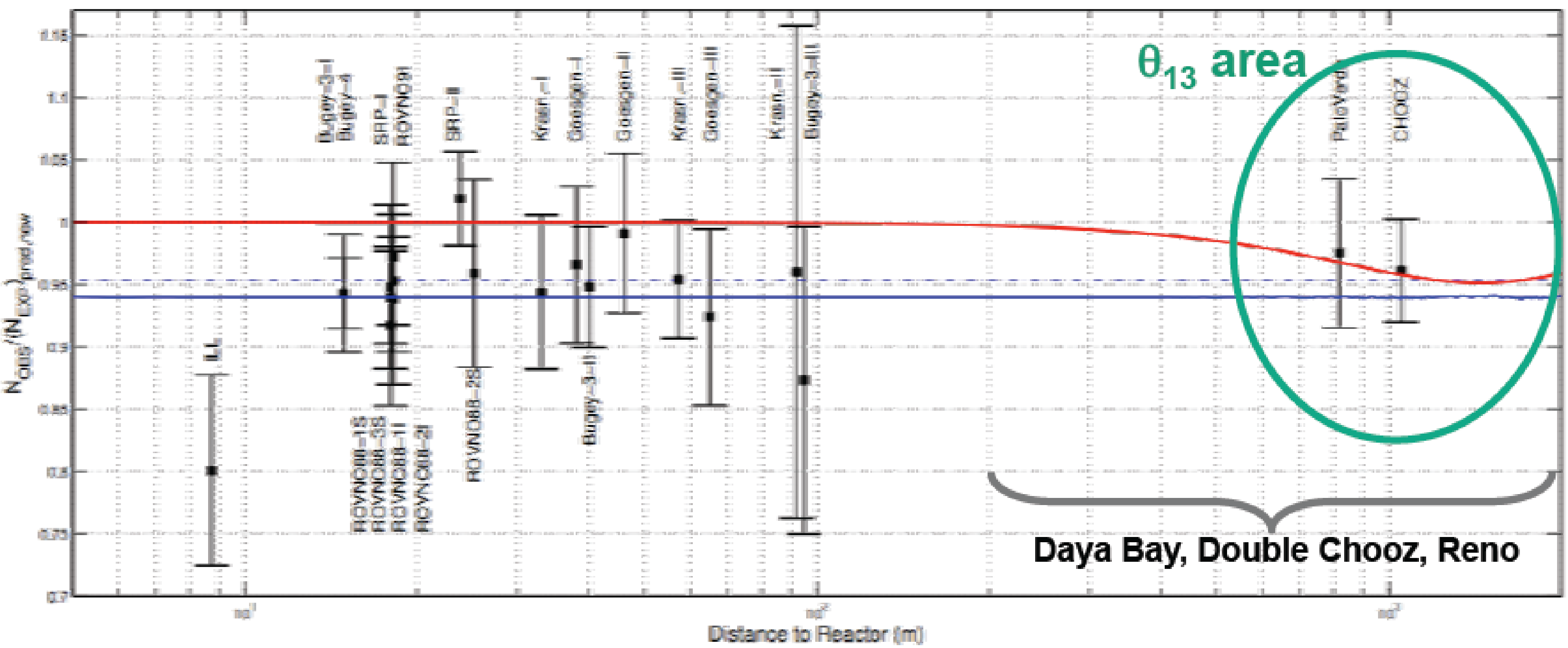
- Re-evaluation of the calculation of the neutrino flux from reactors leads French group to conclude that all earlier experiments have been observing a deficit.
- No significant objection so far from nuclear experts.
- If so, where could these be going? Possibly short range oscillations into a new fourth but "sterile" neutrino.
- Could solve some other problems…
- This could be revolutionary, and could be a key to a new domaine of matter.

New Prediction, Old Results and Implications for Θ_{13}

- The choice of normalization is crucial for reactor experiments looking for θ_{13} without near detector

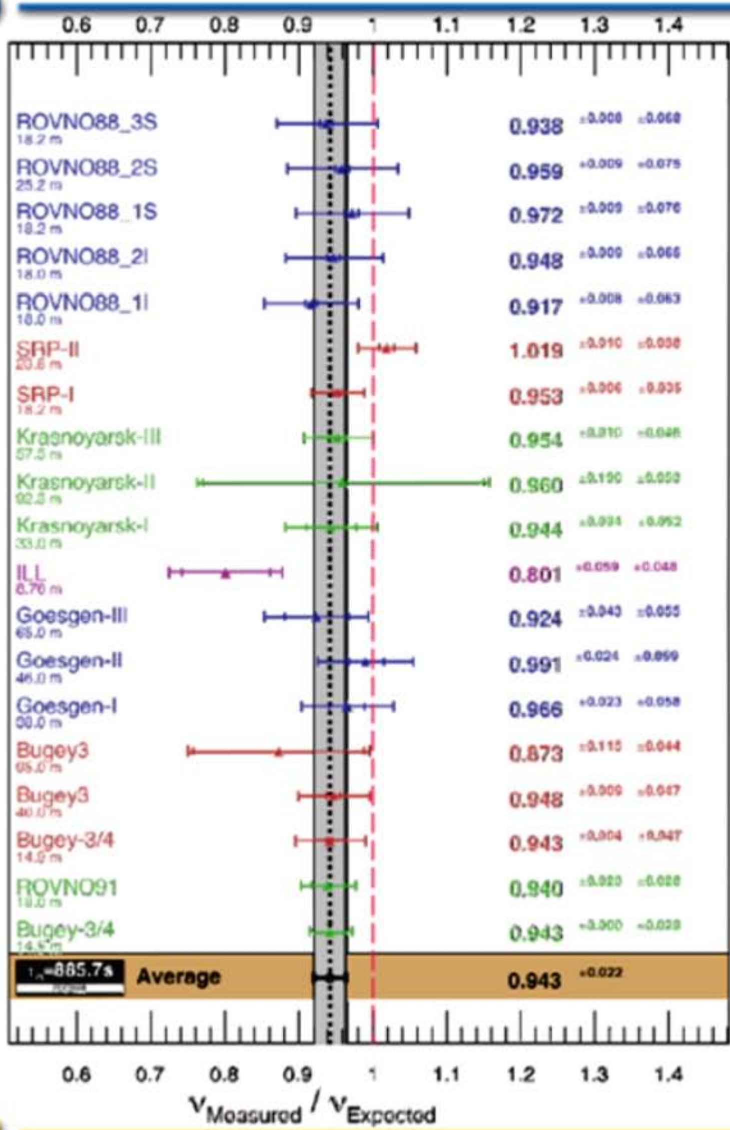
$\sigma_f^{pred,new}$: new prediction of the antineutrino fluxes

σ_f^{ano} : experimental cross section (best fitted mean averaged)



- A deficit observed at 1-2 km can either be induced by θ_{13} induced oscillation BUT also by other explanations (experimental, new ϕ, …)

The Reactor Neutrino Anomaly

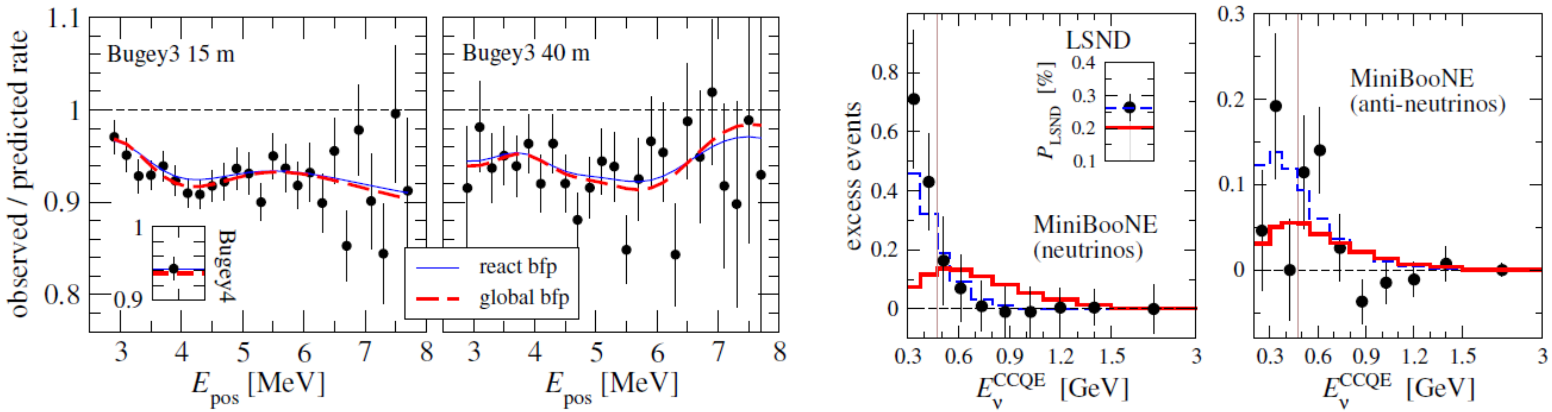


$$\chi^2 = \left(r - \vec{R}\right)^T W^{-1} \left(r - \vec{R}\right)$$

- **Best fit : μ = 0.943**
- **Uncertainty : 0.023**
- χ^2 = 19.6/19
- Deviation from unity
  - Naïve Gaussian : 99.3% C.L.
  - Toy MC: 98.6% C.L. (10^6 trials)
- No hidden covariance
  - 18% of Toy MC have χ^2_{min}<19.6

An Oscillations fit to Old and New Data

3+2 best fit point



$\Delta\chi^2$ between global bfp and app/disapp separate bfp:

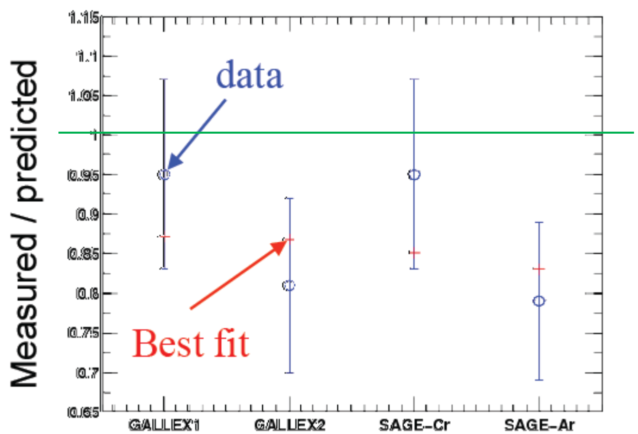
LSND	$MB\bar{\nu}$	$MB\nu$	KAR	React	CDHS	Atmos
1.2	2.9	2.5	1.5	0.9	2.4	2.3

Kopp, Maltoni, TS, 1103.xxxx

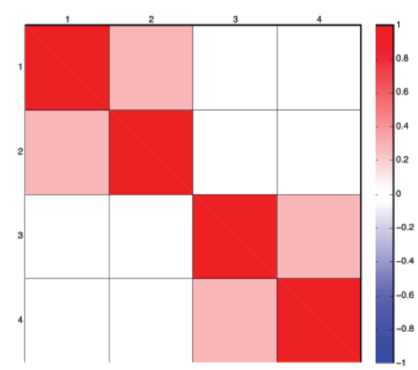
Other Possible Evidence: the Gallium Anomaly

- **4 calibration runs with intense MCi neutrino sources:**
  - 2 runs at Gallex with a ^{51}Cr source (750 keV ν_e emitter)
  - 1 run at SAGE with a ^{51}Cr source
  - 1 run at SAGE with a ^{37}Ar source (810 keV ν_e emitter)
  - **All observed a deficit of neutrino interactions compared to the expected activity. Hint of oscillation ?**

- **Our analysis for Gallex & Sage:**
  - Monte Carlo computing mean path lengths of neutrinos in Gallium tanks
  - **NEW** : Correlate the 2 Gallex runs together & the 2 SAGE runs together



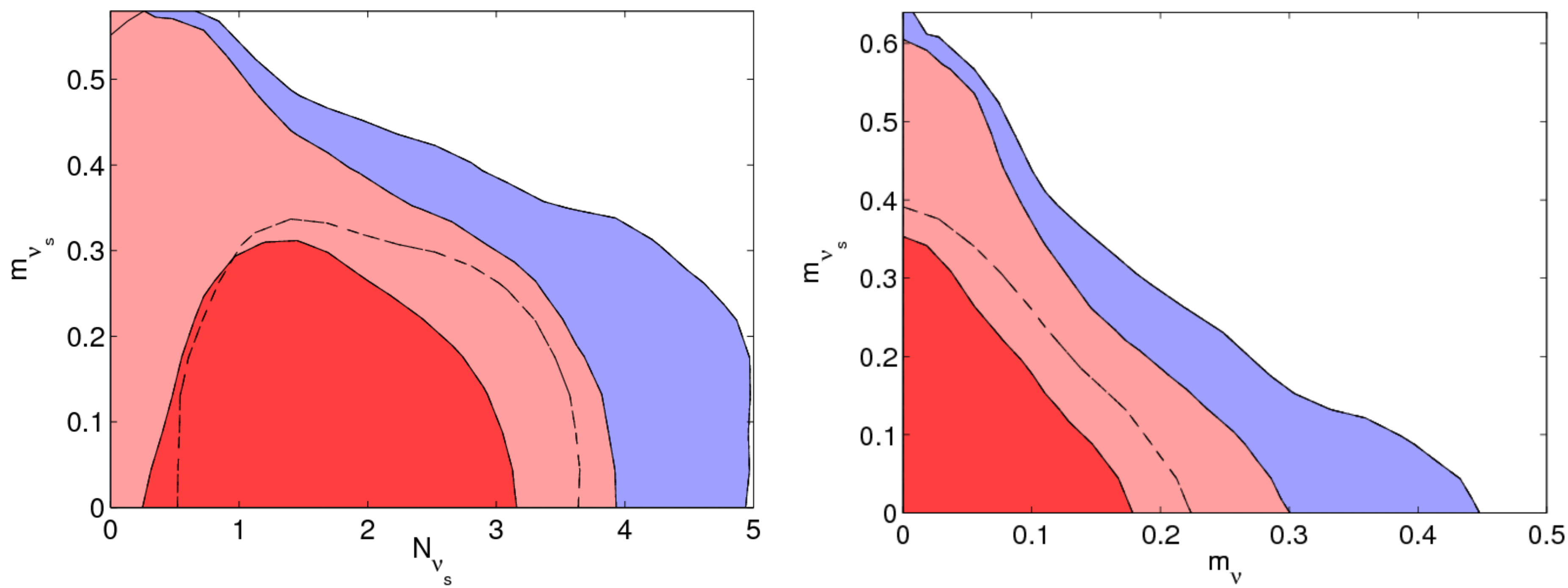
- Gallex-I
- Gallex-II
- Sage-Cr
- Sage-Ar



correlation matrix

Latest Cosmological Sterile Neutrino Analysis

Giusarma et al., 2011 http://arxiv.org/abs/1102.4774
includes masses both in active and sterile Neutrinos.



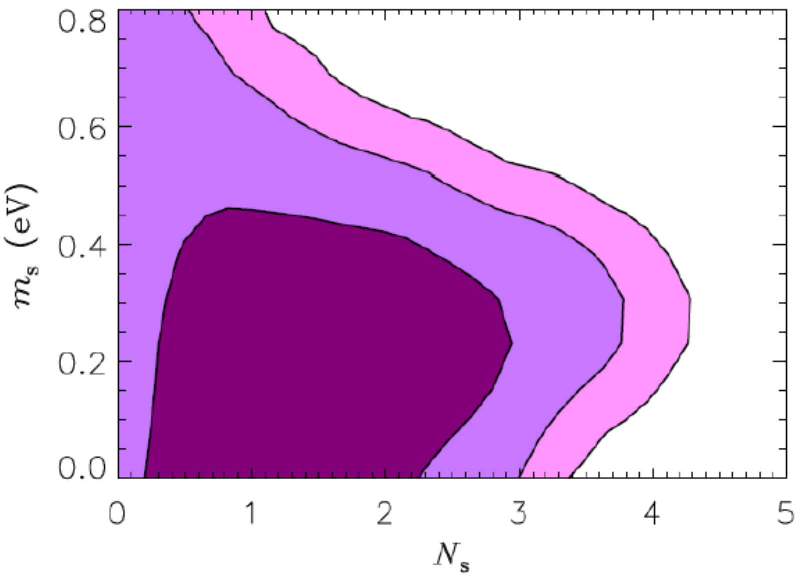
Parameter	68% CL(r1)	95% CL(r1)	68% CL (r2)	95% CL (r2)
N_{ν_s}	$0.94 - 3.16$	$0.21 - 4.63$	$0.69 - 2.53$	$0.13 - 3.56$
m_ν [eV]	$0.02 - 0.19$	< 0.36	$0.01 - 0.14$	< 0.24
m_{ν_s} [eV]	$0.04 - 0.31$	< 0.70	$0.03 - 0.30$	< 0.70

Blue: CMB+HST+SDSS
Red: CMB+HST+SDSS+SN-Ia

A. Mechiorri, NuTel 2011

Summary of Possible Signatures of Light Sterile Neutrinos

- checked solar/KamLAND fit: U_{e4}, U_{e5} similar effect as U_{e3}
- MINOS NC 1001.0336 analysis may give additional constraints
- Deficit in radioactive source experiments at Gallium exps C. Giunti
- Cosmology:



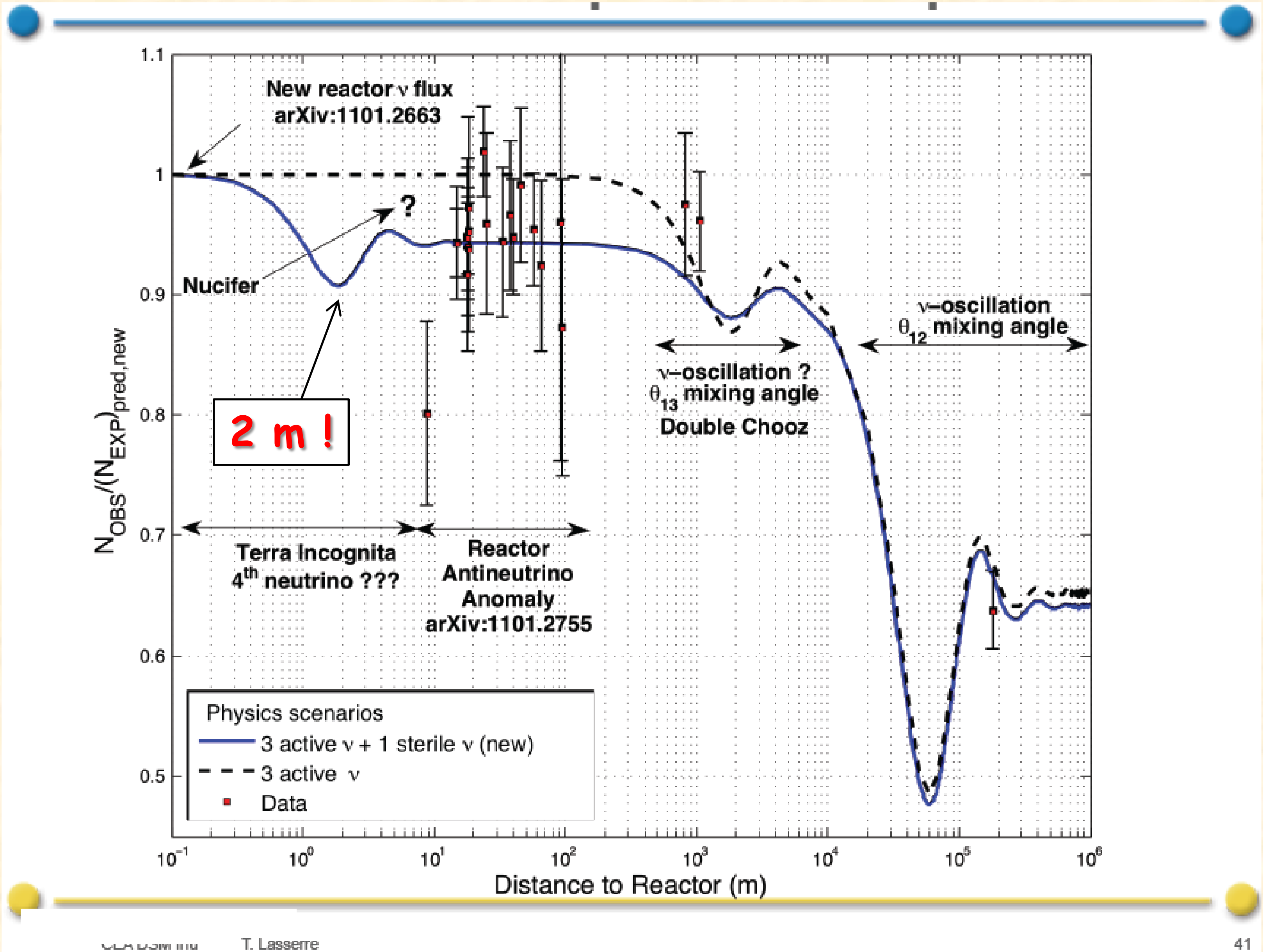
CMB, SDSS, HST

Hamann et al., 1006.5276

talk by A. Melchiorri

- BBN: $N_s < 1.2$ (95% CL) Mangano, Serpico, 1103.1261

Need for New Experiments!



Temporary Conclusions on Reactor Neutrino Anomaly

- slightly ambiguous status of θ_{13} due to new reactor fluxes: $\sin^2\theta_{13} = 0.1 - 0.3$ with hints for $\theta_{13} > 0$ at $1.8 - 3.2\sigma$
- intriguing accumulation of hints for eV-scale sterile neutrinos (LSND/MiniBooNE/reactor/Gallium)
  3+2 model with two eV-scale neutrinos gives good fit to global data

Thomas Schwetz, NuTel2011

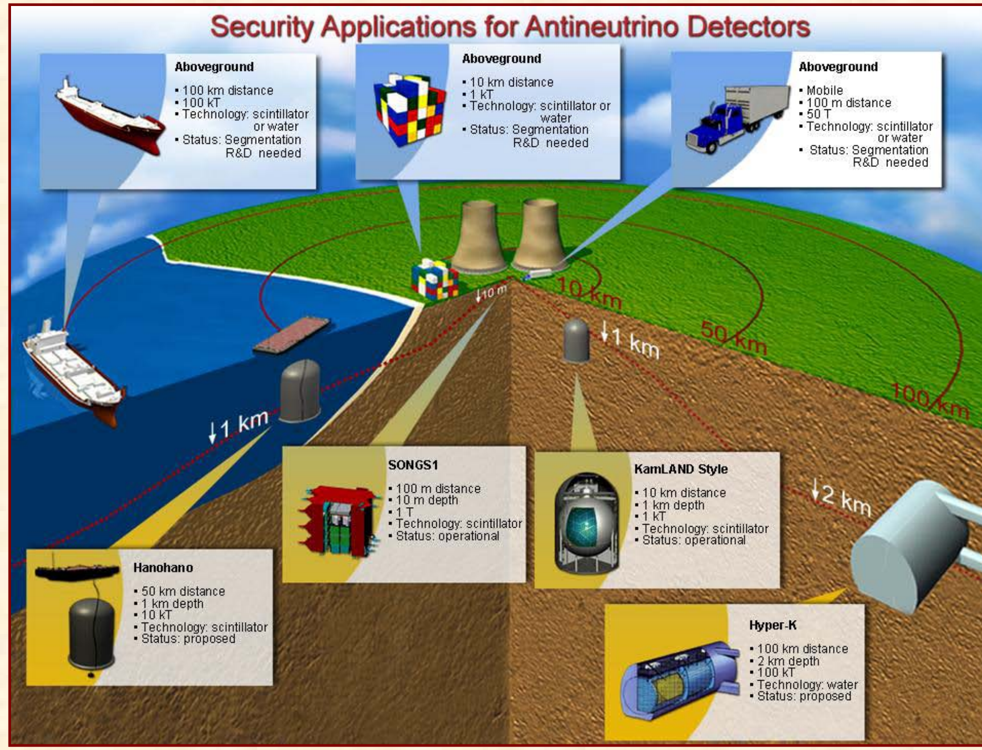
Stay tuned for a rush of proposals to untangle this shaky web!

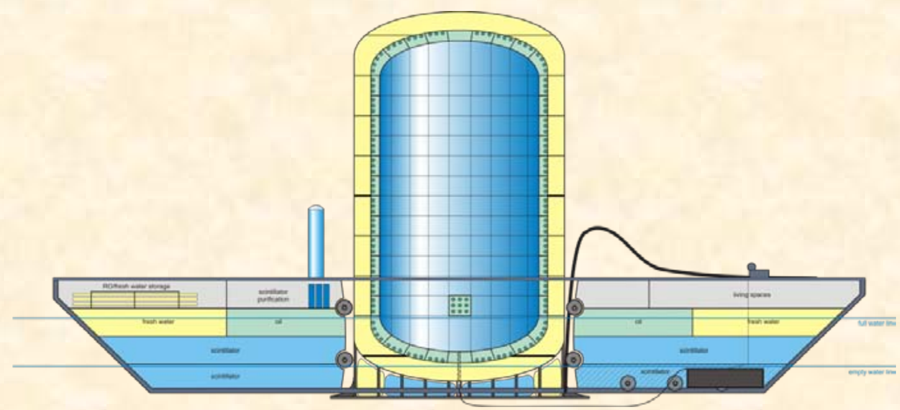
And now for something different, but related…

- We have been studying large and in some versions portable electron anti-neutrino detectors for three applications:
  - More detailed oscillations studies
  - Development of remote reactor monitoring
  - Study of geoneutrinos

Nuclear Reactor Monitoring for Anti-Proliferation

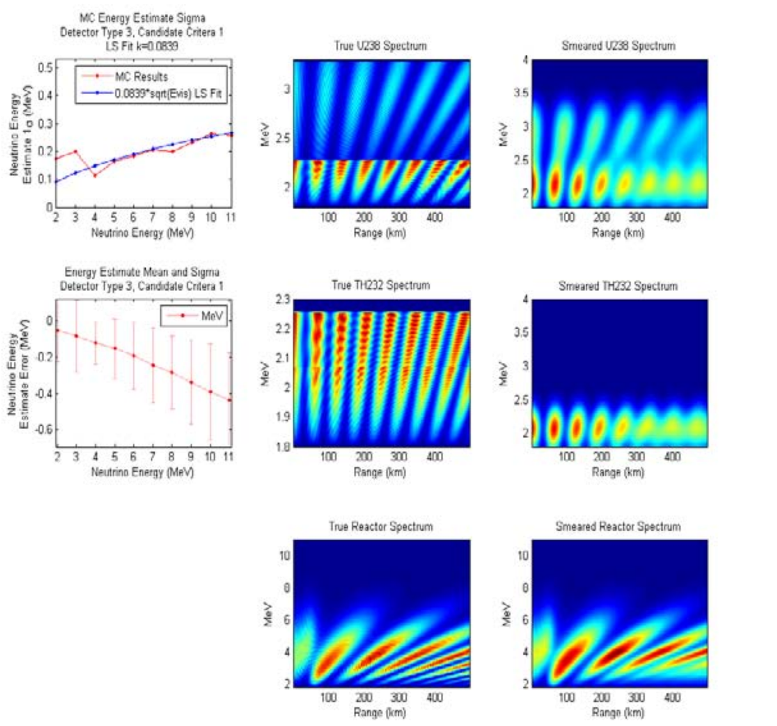
- miniTimeCube: UH building tiny portable unshielded neutrino detector which can measure useful rate near power reactor, and get some neutrino **directionality**.
- Assemble this year, take to reactor for demonstration.
- For economical construction need LAPPDs (ANL/Chicago project).
- Next version ~1m^3, able to measure reactors outside the fence from small van.
- Future: stacks of same in shipping containers.
- Reactor monitoring, but also moving towards geoneutrinos and other science.

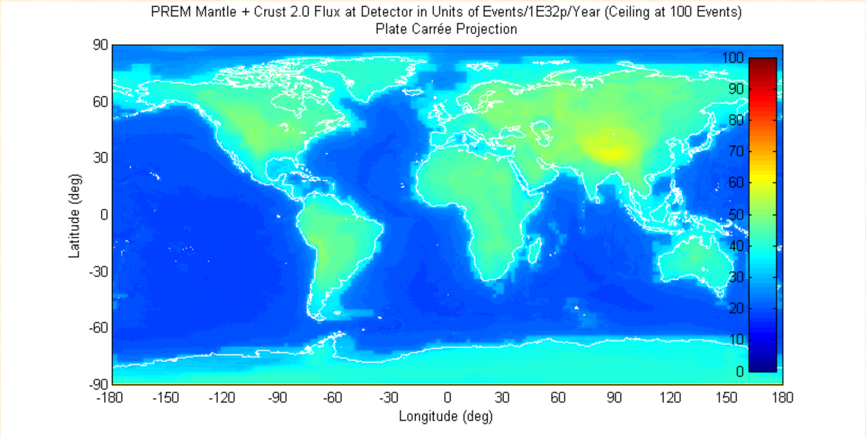


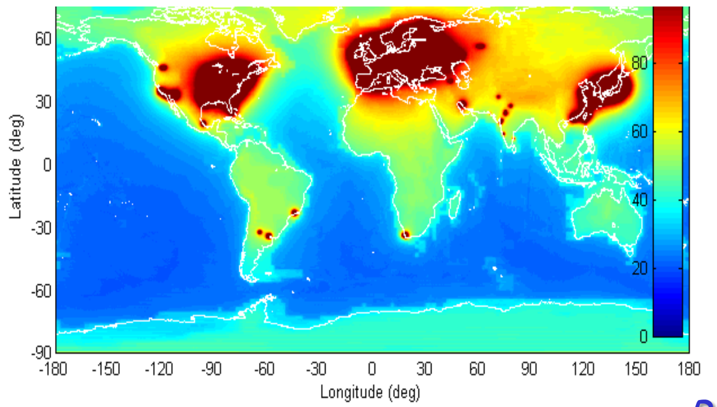


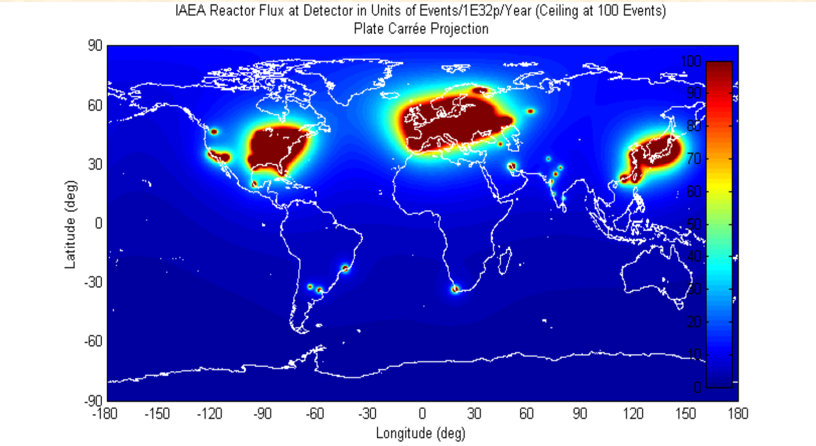
Hanohano Detector

Doing Detailed Modeling of Reactor Backgrounds



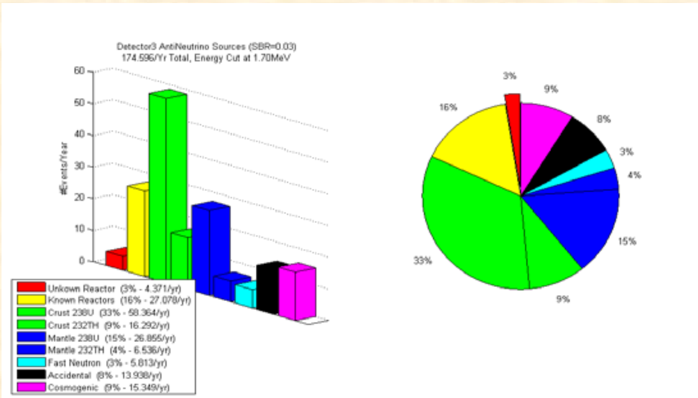




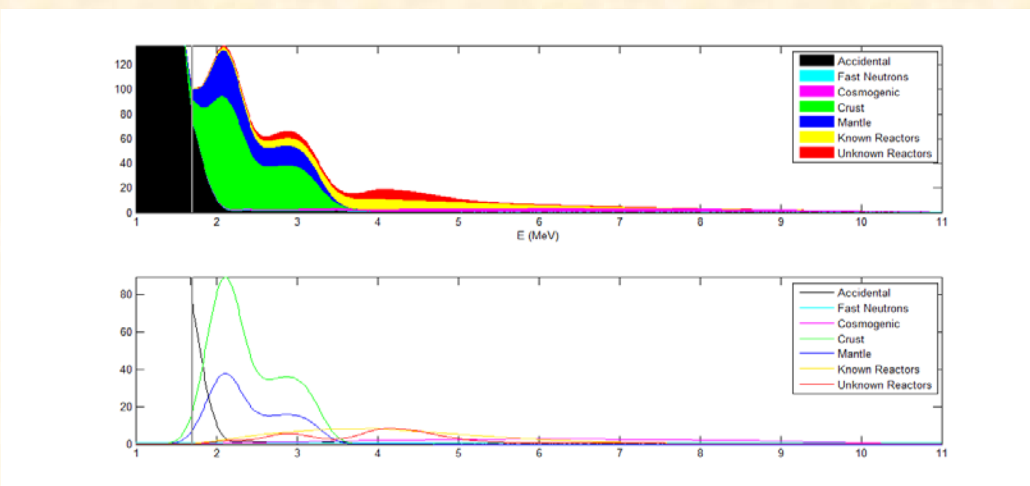


Plots from Glenn Jocher, Integrity ApplicationsInc

More on Detailed Modeling



We have a program allowing arbitrary placement of detectors, including depth and calculations of all backgrounds (based on KamLAND and Borexino experience)

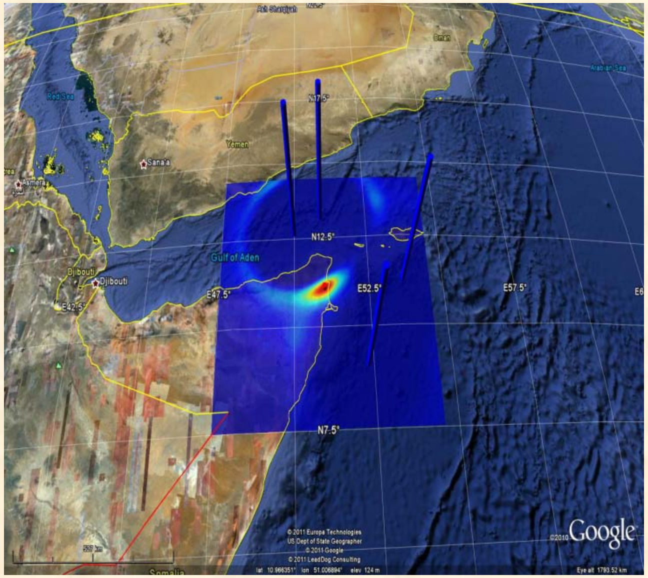


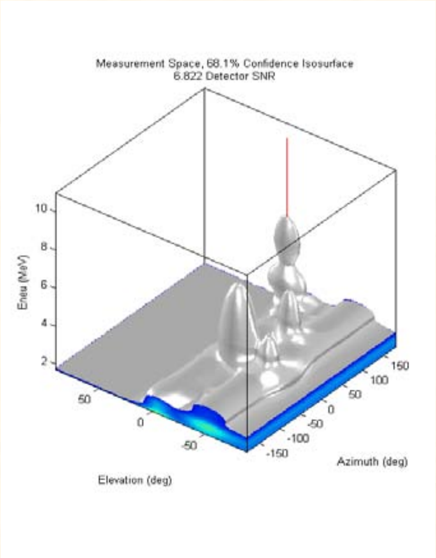
21 April 2011

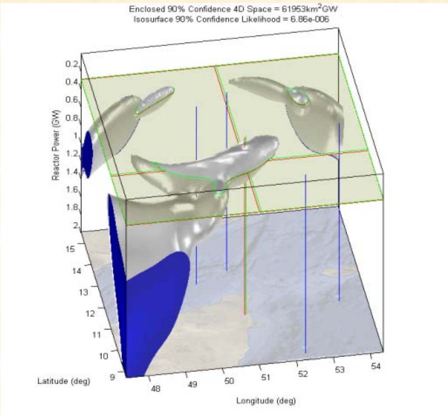
John Learned at UH Physics

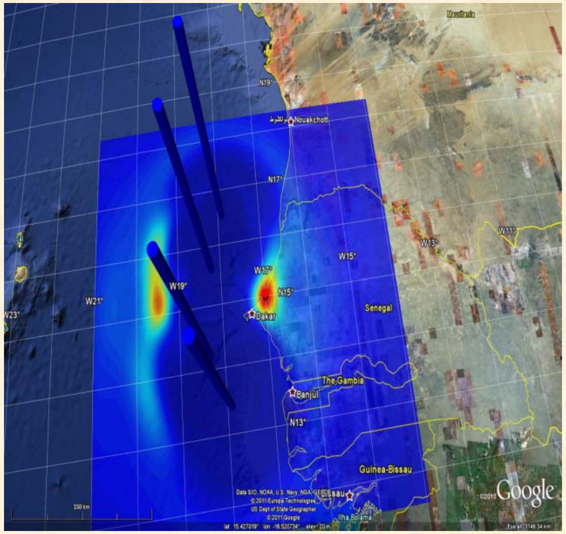
Glenn Jocher, IAI

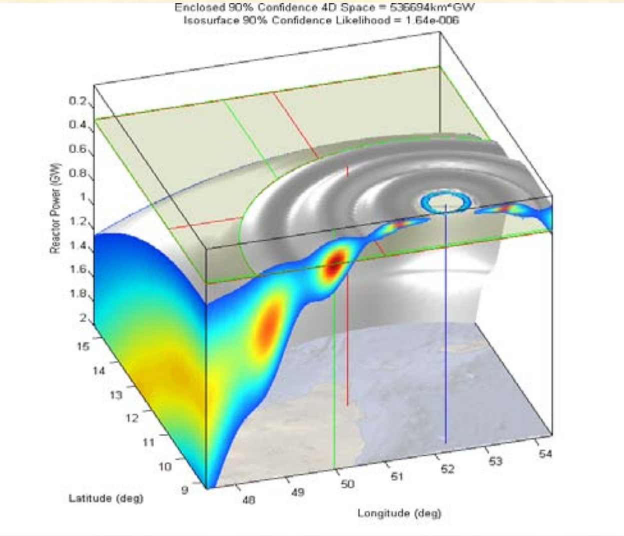
Finding and Measuring Remote Reactors











Glenn Jocher,IAI

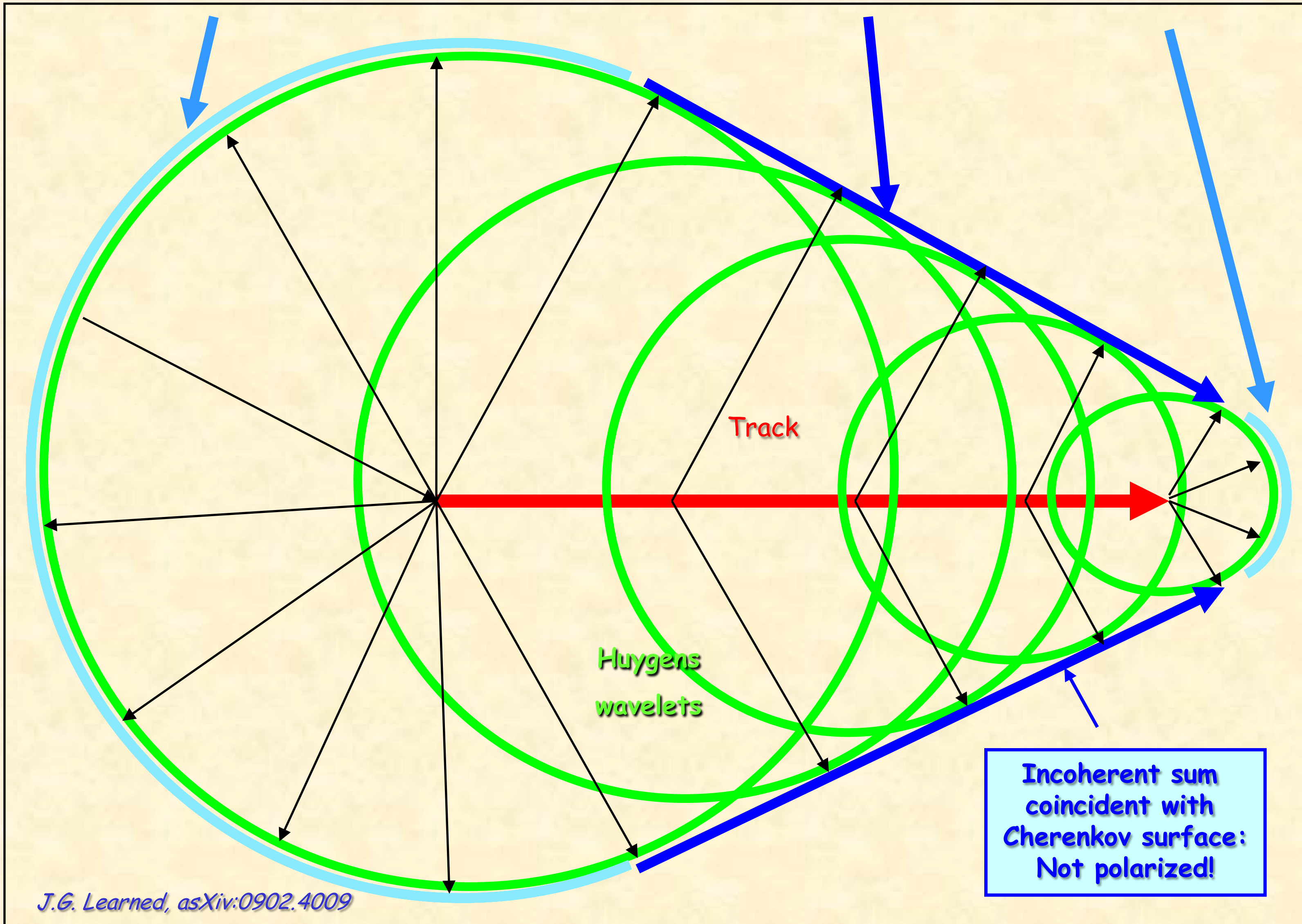
Change Gears and Talk about New Detectors

- Intro to new means of reconstructing events in liquid scintillator, where tracks radiate light isotropically
- (not like Cherenkov radiation in water as in SUperK)

2009 Realization that Liquid Scint Detector Can Reconstruct Events

First light yields topology. Now important part of LENA project proposal.

Snapshot of the Fermat Surface for a Single Muon-likeTrack



Application in 50 Kiloton LS LENA Detector

FIG. 1: Artist's view of the LENA detector.

LENA is major project proposed for Europe, probably Finland (1/3 of LAGUNA initiative)

Much nice physics to be done with such.

Major White Paper on Web shortly

Most interesting for this talk, is ability to do long baseline GeV neutrino studies Using the Fermat trick.

(Michinari Sakai working on testing with KamLAND data.)

LENA Simulation of Muon Event

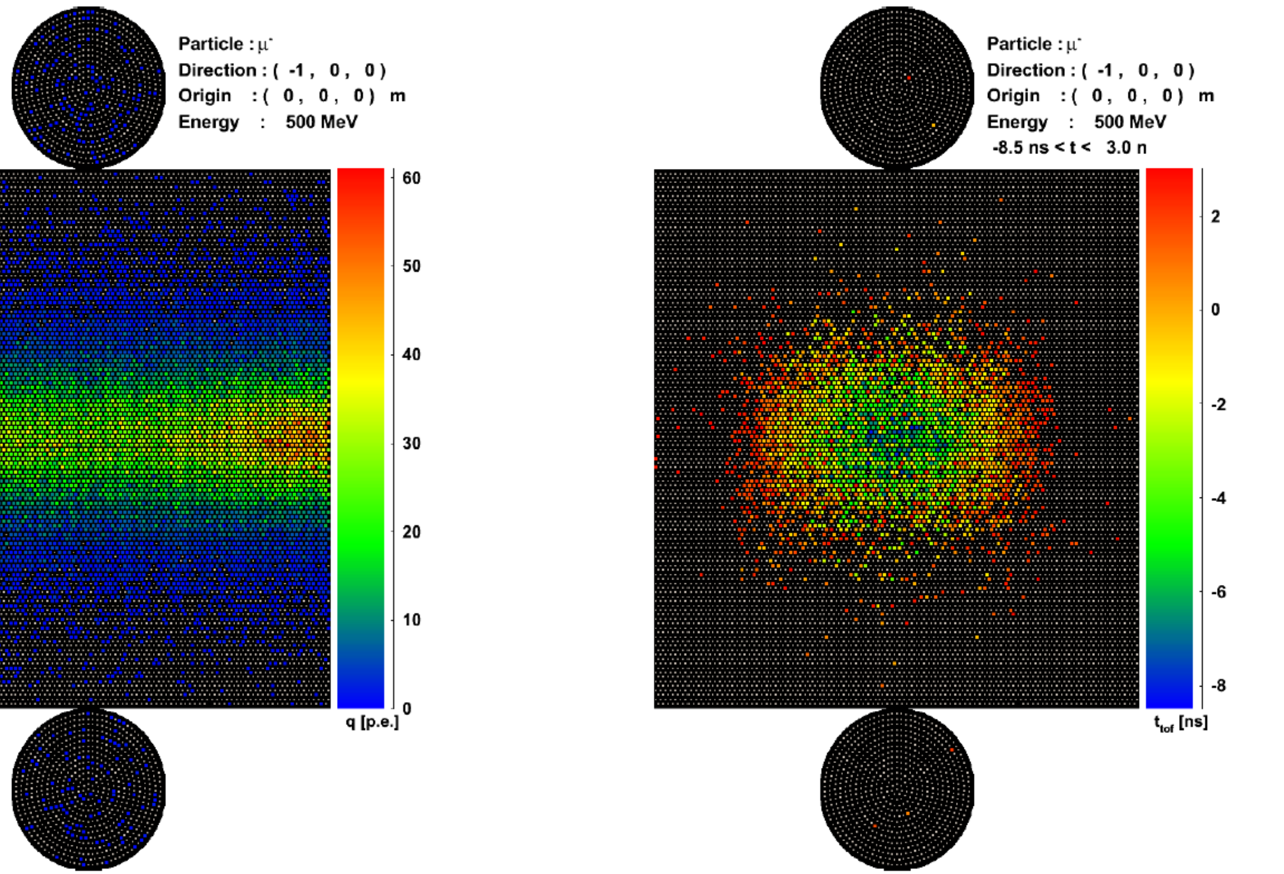


FIG. 18: A 500 MeV muon in LENA. On the left, the color coded information is the charge seen by each PMT, while the hit time of the first photon at each PMT is shown on the right, applying a time of flight correction with respect to the charge barycenter of the track.

Muons Reconstructed Very Well

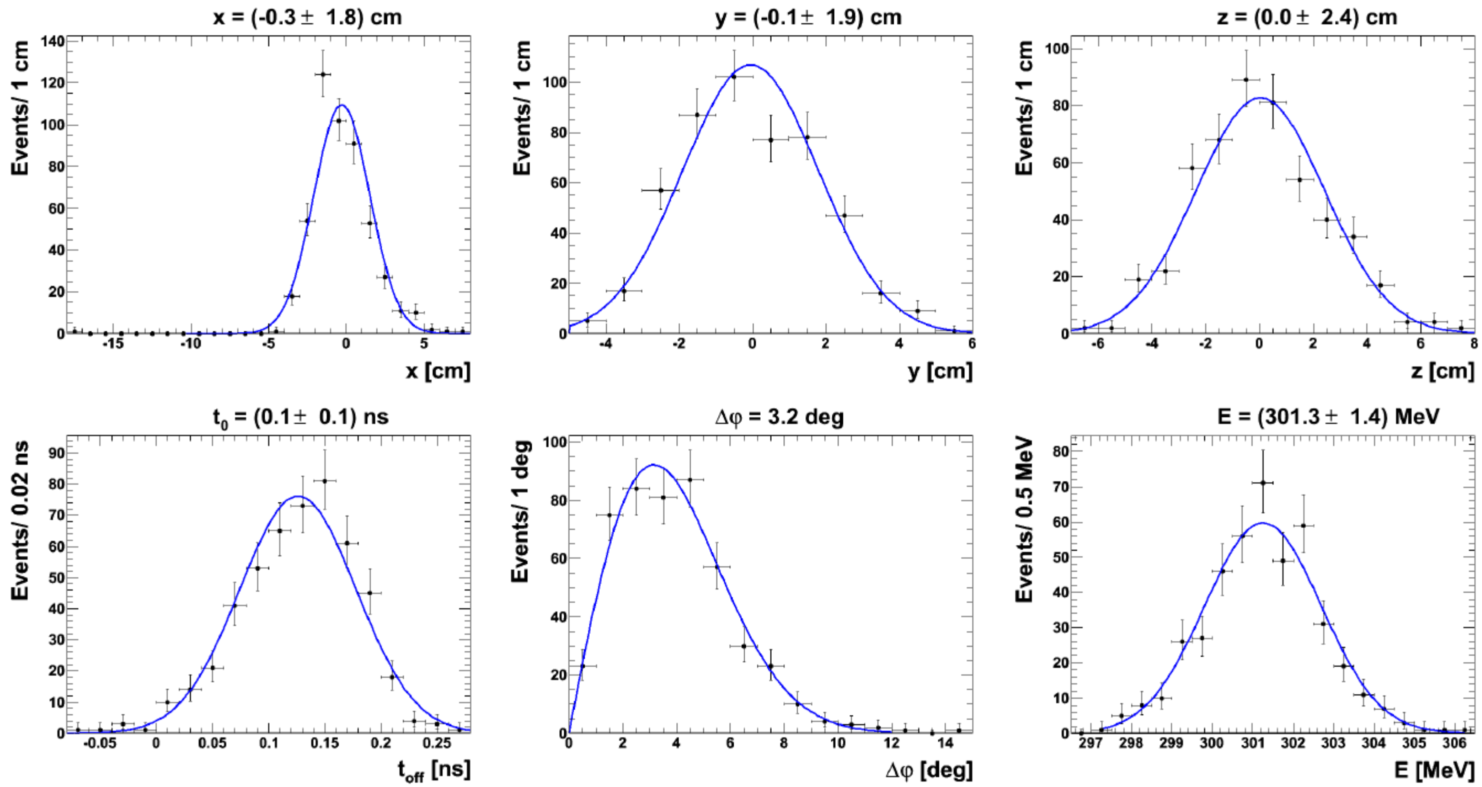
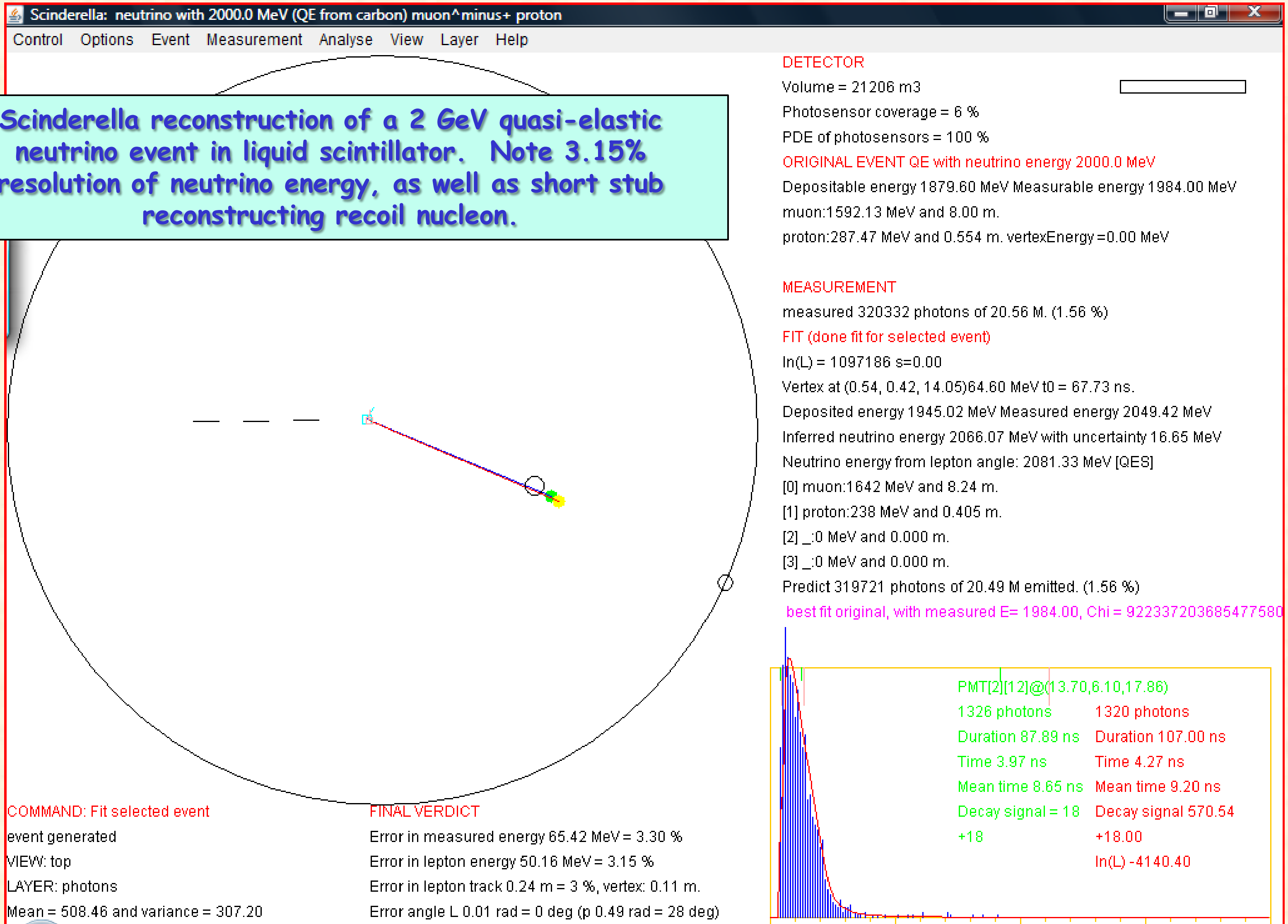


FIG. 19: Results obtained by reconstructing 300 MeV muons created in the center of the detector and traveling in negative x direction (500 events). The upper row shows the results for the start point of the track, the lower row shows the reconstructed start time (left), the angular deviation of the reconstructed track from the Monte Carlo truth (center) and the kinetic energy of the muon (right).

If one can employ the full waveforms…

Scinderella reconstruction of a 2 GeV quasi-elastic neutrino event in liquid scintillator. Note 3.15% resolution of neutrino energy, as well as short stub reconstructing recoil nucleon.



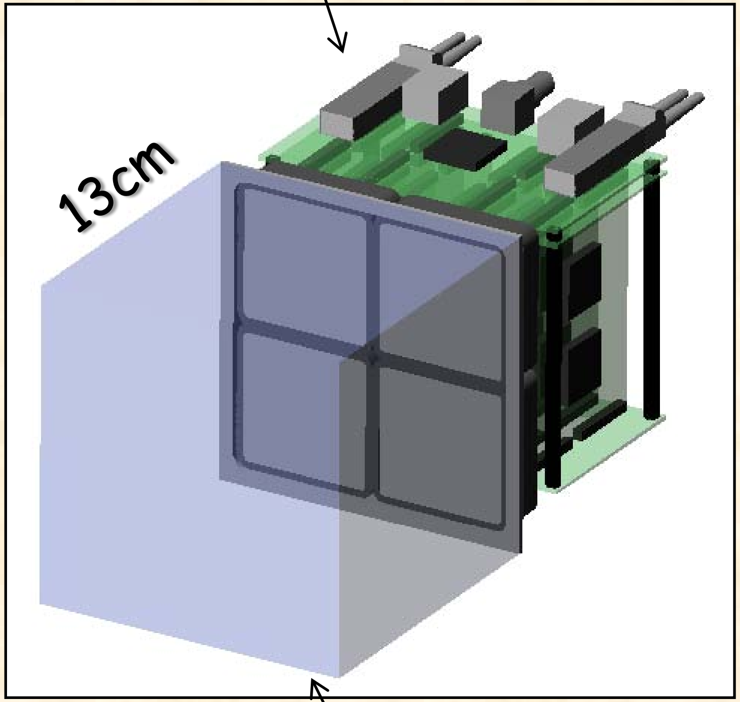
Juha Peltoniemi, arXiv:0909.4974

Back to UH for our miniTimeCube

Springboarding from this and wanting to develop a way to get directionality for electron antineutrinos we came up with a new type of detector, with time replacing optics.

Idea for Small and Directional Inverse Beta Detector

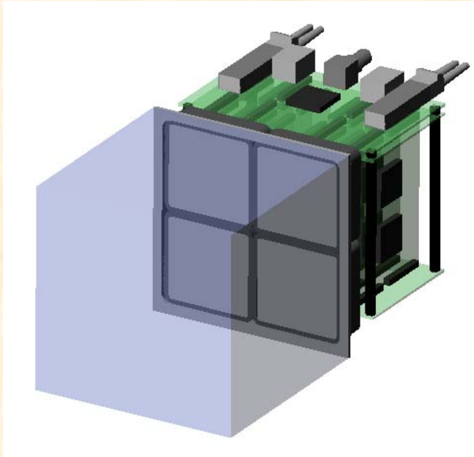
Fast digitizing electronics (x6)



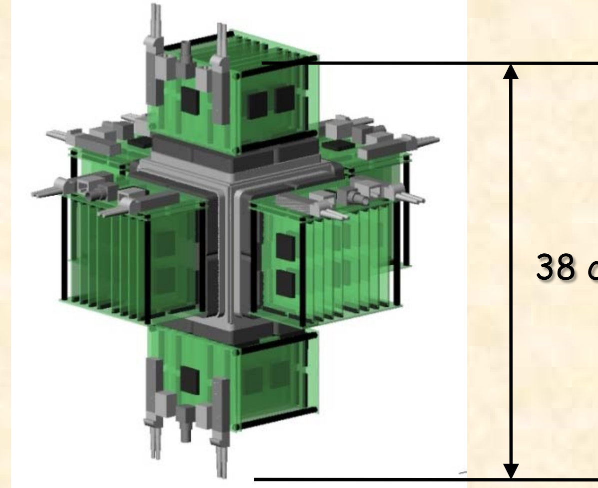
2.2 liter scintillator

- Small portable 2.2 liter scintillating cube with neutron capture doping.
- Contain positron, lose gammas
- Do imaging with fast timing, not optics (time reversal imaging).
- Get some neutrino directionality between positron origin and neutrino capture point.
- Reject noise on the fly; no shielding needed
- 4 x 6 MCP (x64 pixels each) fast (<100 ps) pixel detectors on surrounding faces
- ~10/day anti-neutrino interactions (inverse beta decay signature) from reactor.

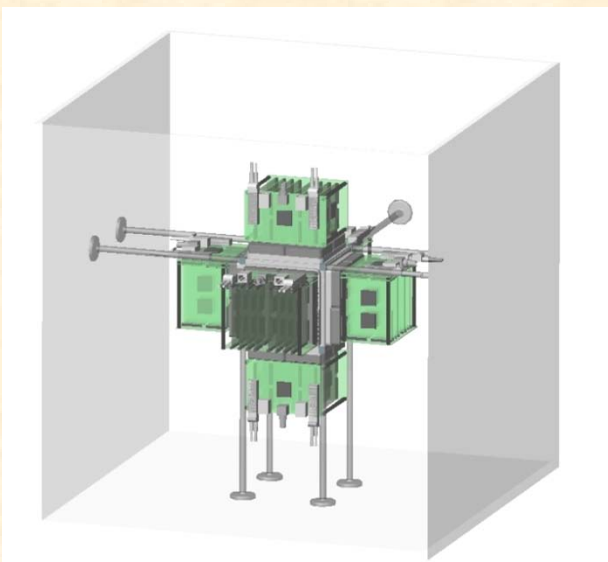
Mini Time Cube Based On 13cm^3 Boron Loaded Plastic Scintillator



MTC with read-out electronics on one face



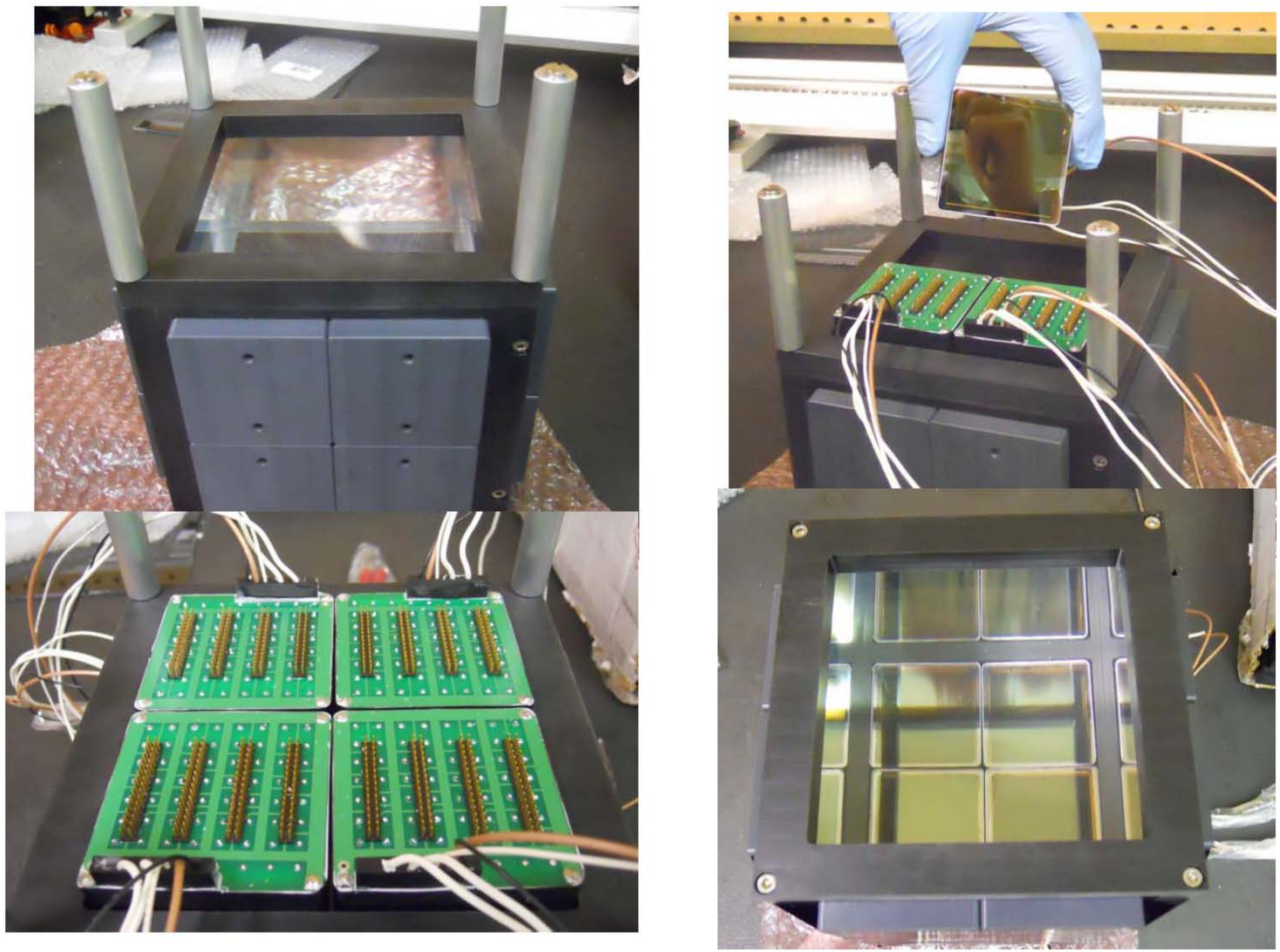
MTC fully populated with read-out UH-ID electronics



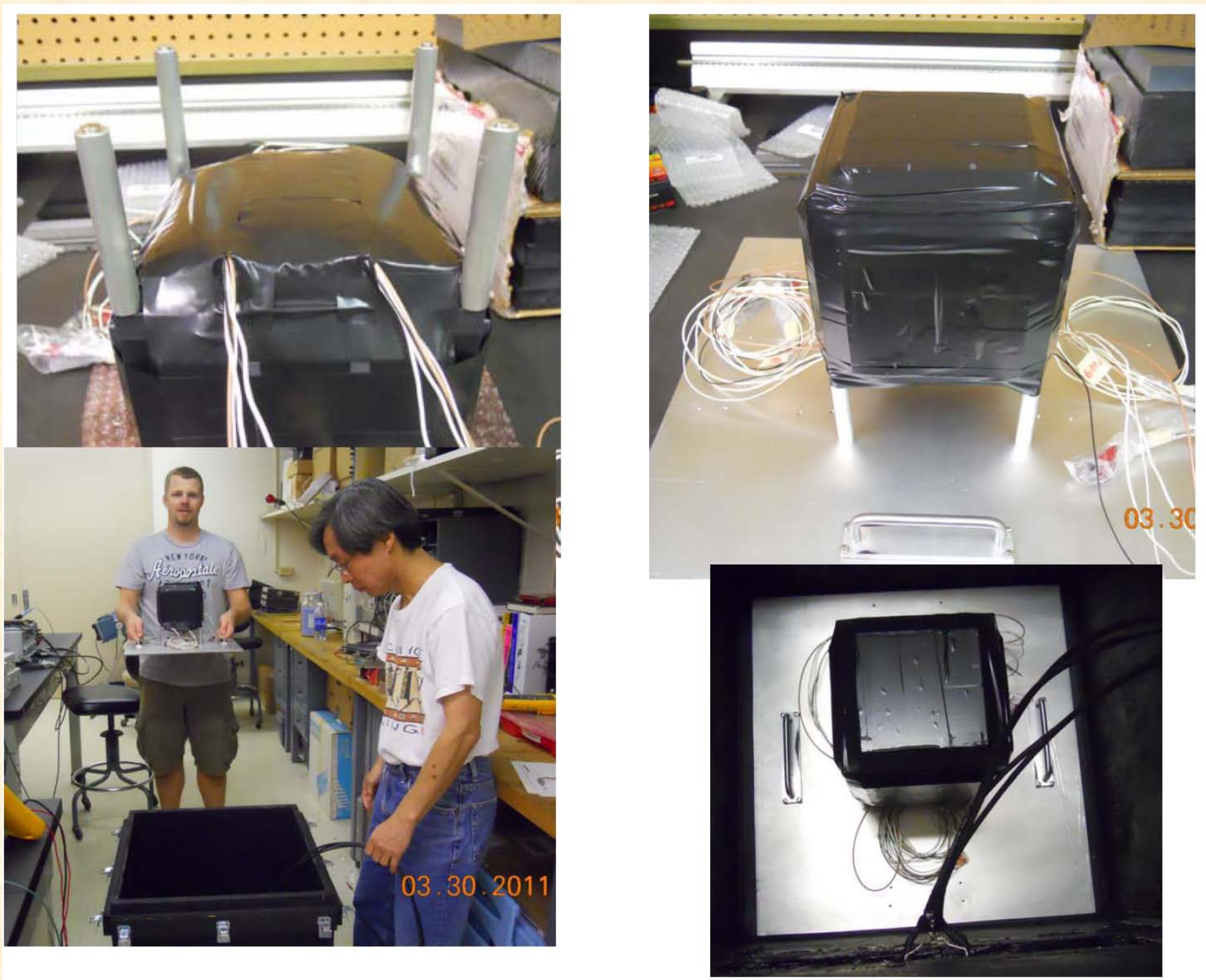
MTC within 2ft^3 enclosure

Stackable transport cases

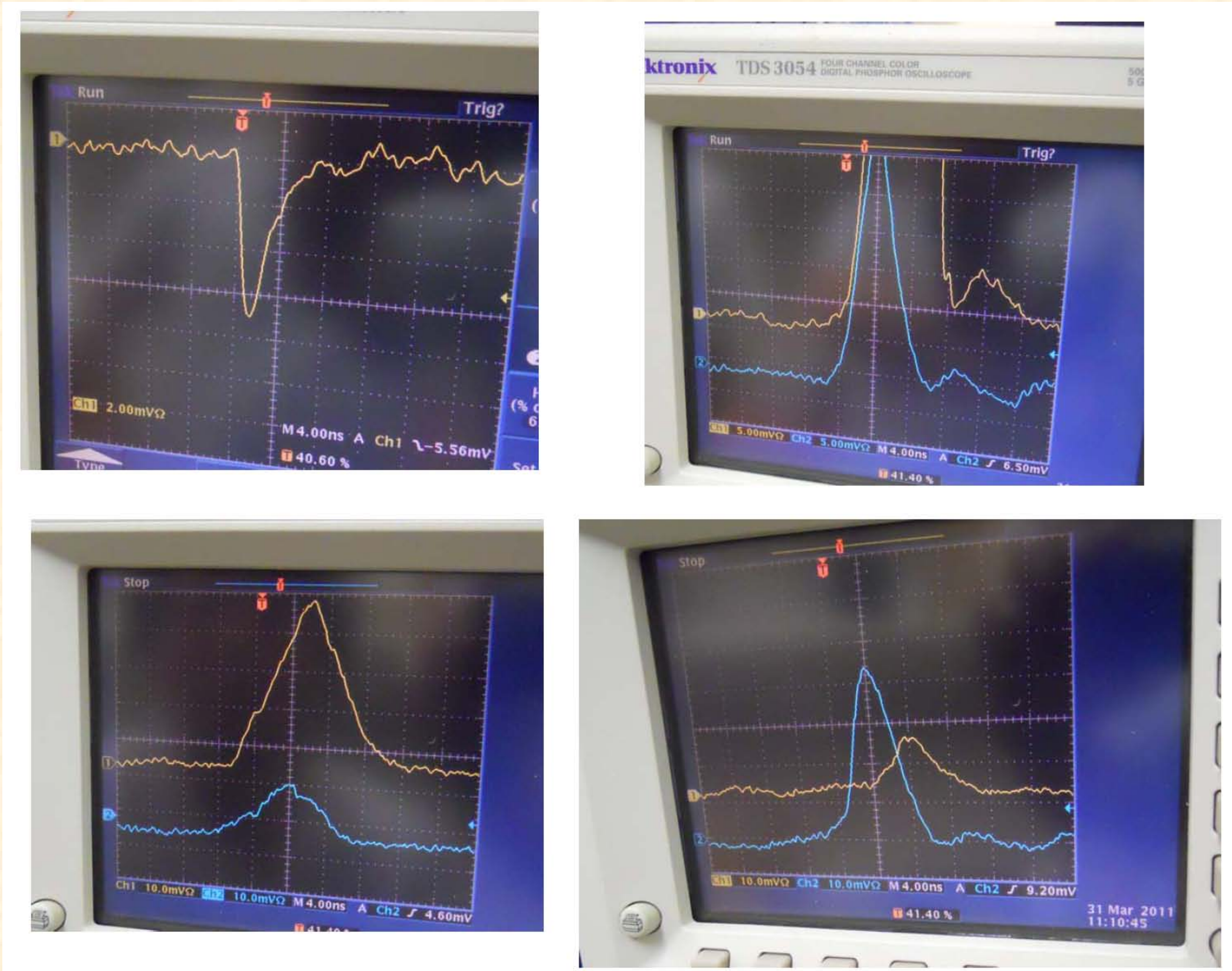
First Installation of Tubes on mTC



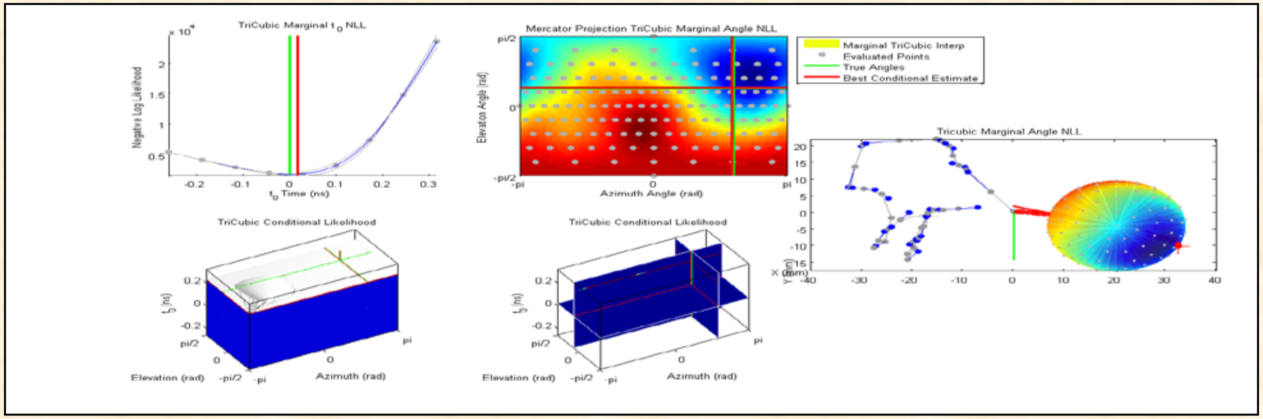
Starting Counting of Muons in Lab



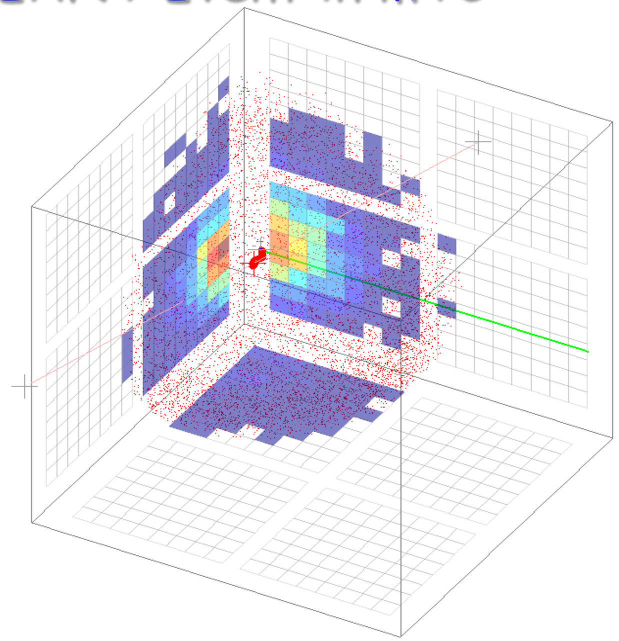
First Scope Traces



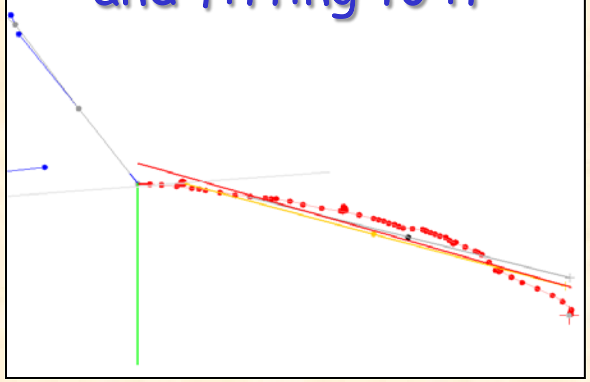
Fitting the Positron Track in mTC



GEANT Event in mTC



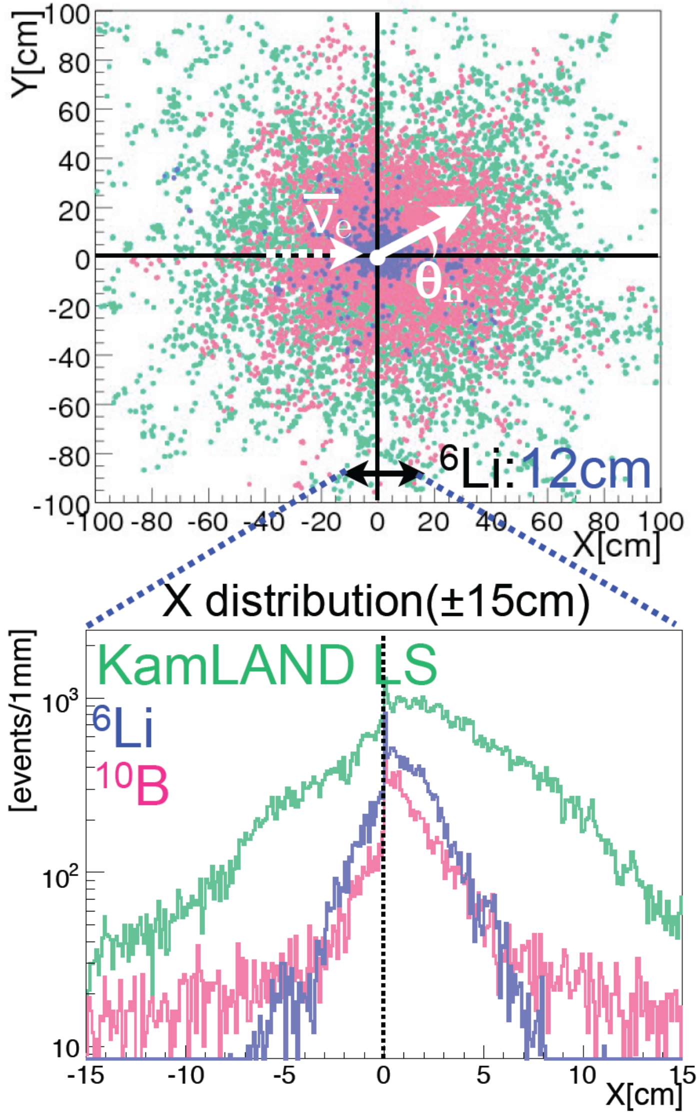
Positron track, and fitting to it



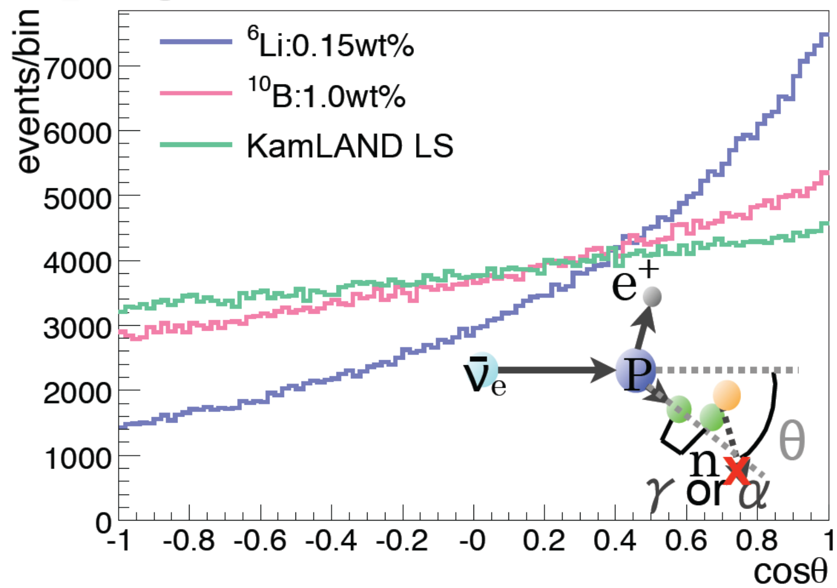
Glenn Joshcer, IAI

Angular Response Studies for KamLAND

- neutron diffuse and capture point



- angler resolution



	angler resolution Δθ	θ>45°
best ^{6}Li LS	90.1°	27.7%
^{10}B LS	114.1°	19.0%
KamLAND LS	118.6°	17.0%

… miniTimeCube will be much better

Hiroko Watnabe, RCNS

mTC Virtues, Summary

- Small size avoids gammas which smear resolution (X ~42 cm)
- Fast pixel timing (<100ps) and fast processing of waveforms rejects background in real time, resulting in
- Lack of need for shielding (unlike other detectors).
- Feasible even in high noise environment, near reactor vessel, at surface (eg. in a truck).
- Neutrino directionality via precision measure of positron production and neutron absorption locations.
- Challenges: build one and demonstrate, scale up, make more economically.
- Question under present study: Can we attack RANA with this?

Conclusion: Much Fun to be Had Untangling the Secrets of the Neutrinos

- Probably a hundred neutrino projects, large and small, underway around the world.
- This talk does no justice to the scope of the programs at accelerators, and with reactors and natural sources.
- Hopefully you get the sense of adventure as we look for the newest twists and surprises from the wiley neutrino