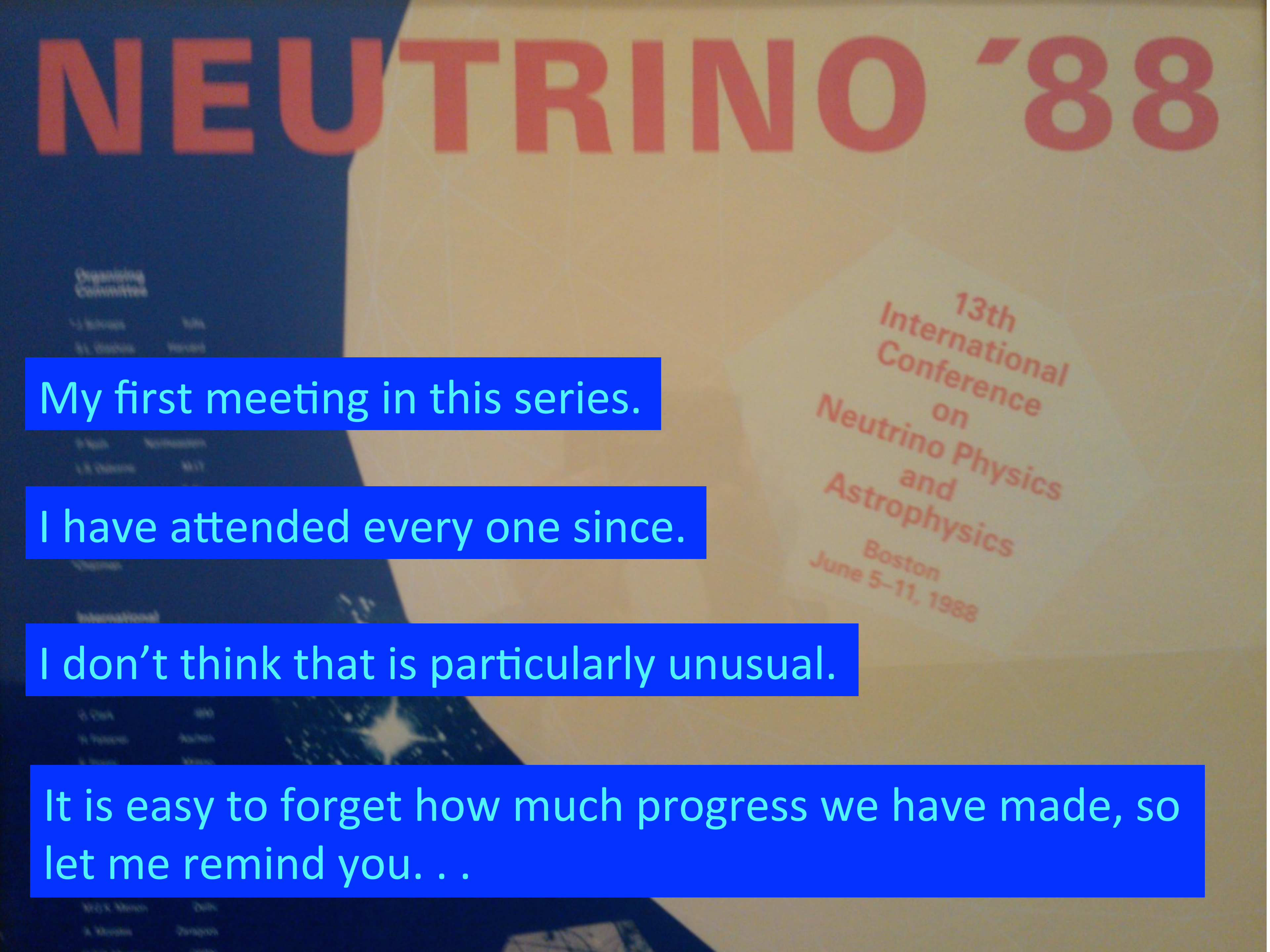
Experimental Perspectives After Neutrinos 2014 (Not a Summary!)

Dave Wark
University of Oxford/STFC Rutherford Appleton Laboratory

June 7th, 2014



My first meeting in this series.

I have attended every one since.

I don't think that is particularly unusual.

It is easy to forget how much progress we have made, so let me remind you. . .

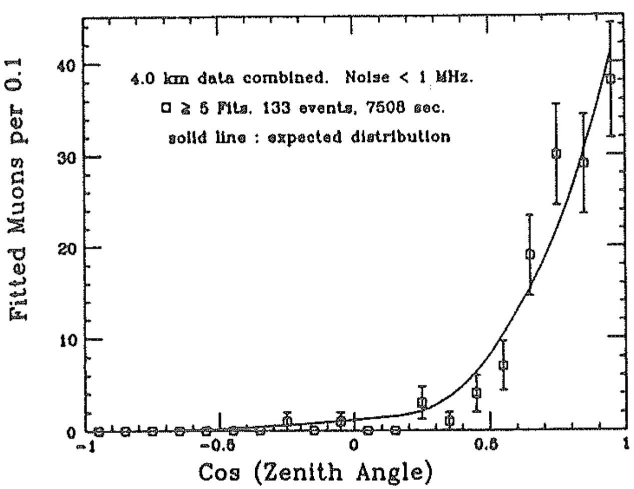

NEUTRINO '88
What we knew then. . .
NEUTRINO2014
XXVI International Conference on Neutrino Physics and Astrophysics
What we know now. . .
June 2-7, 2014, Boston, U.S.A.
NEUTRINO 2040
June 4-9, 2040, Boston U.S.N.A.
What we hope to learn. . . .
XXXIX International Conference on
Neutrino Physics and Astrophysics

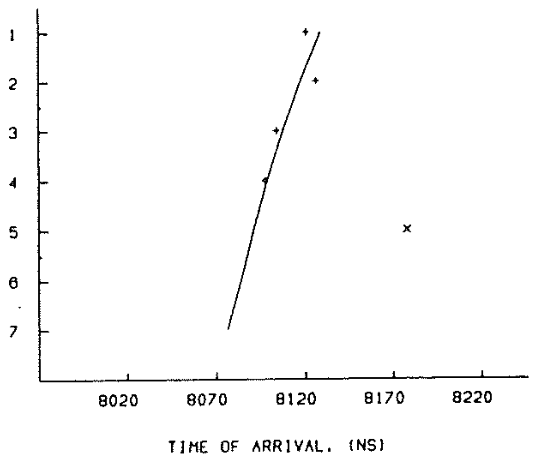
High Energy ν Astronomy

DUMAND: PROGRESS AND STATUS

V.J. Stenger
Department of Physics and Astronomy, University of Hawaii
Honolulu, Hawaii

For the DUMAND Collaboration:
U. Hawaii, U. Tokyo Institute for Cosmic Ray Research,
U. California at Irvine, Vanderbilt U., U. Wisconsin,
Purdue U., U. Bern, CalTech, and Scripps
Institution for Oceanography.
(The Universities of Aachen and Kiel have
joined in the Stage II proposal.)





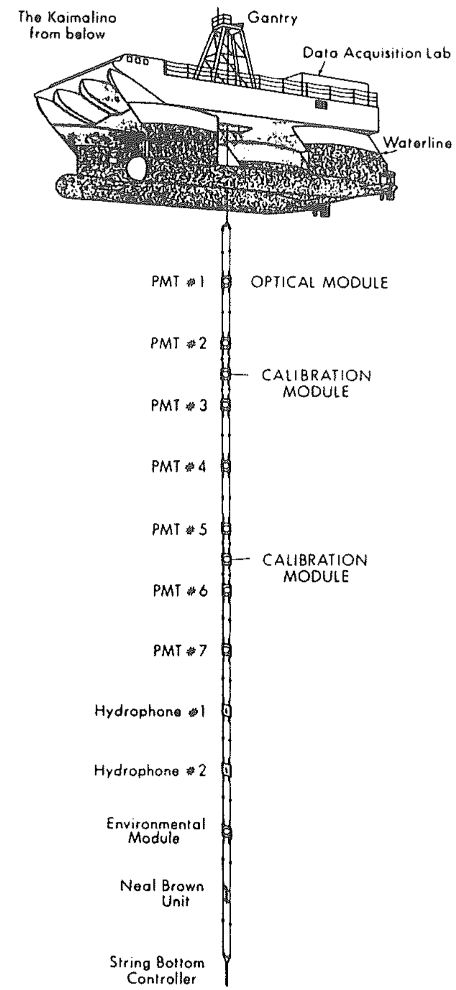


Fig. 1. The DUMAND Short Prototype String. Seven optical modules (PMT) and ancillary equipment are spaced 5.18 m apart along a vertical cable deployed from the center well of the highly stable vessel Kaimalino.

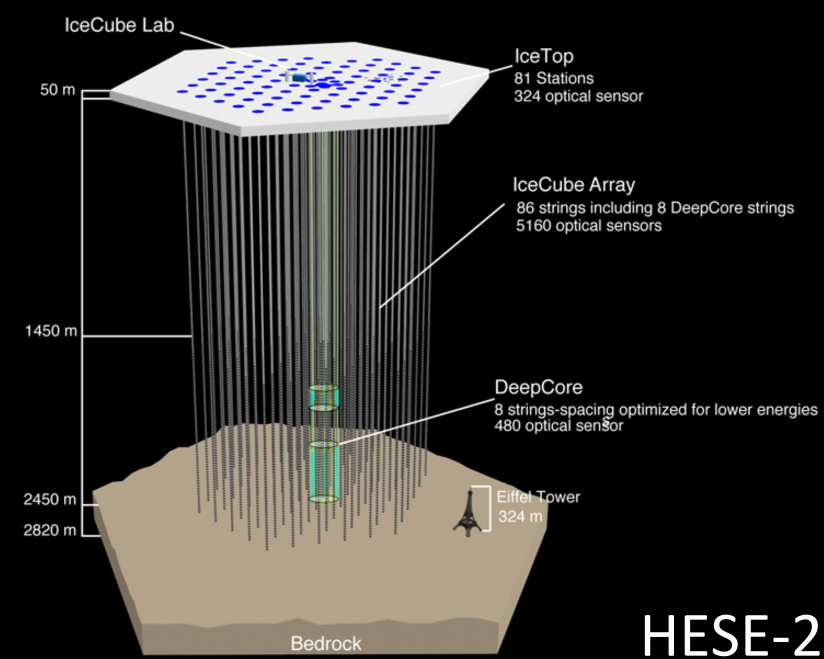
NEUTRINO2014

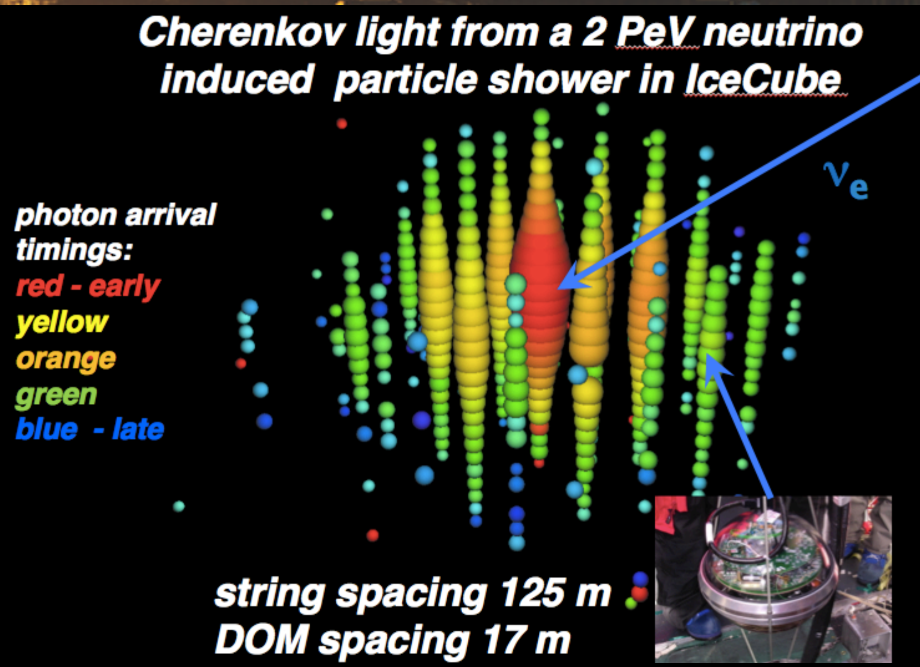
XXVI International Conference on Neutrino Physics and Astrophysics

June 2-7, 2014, Boston, U.S.A.

High Energy ν Astronomy

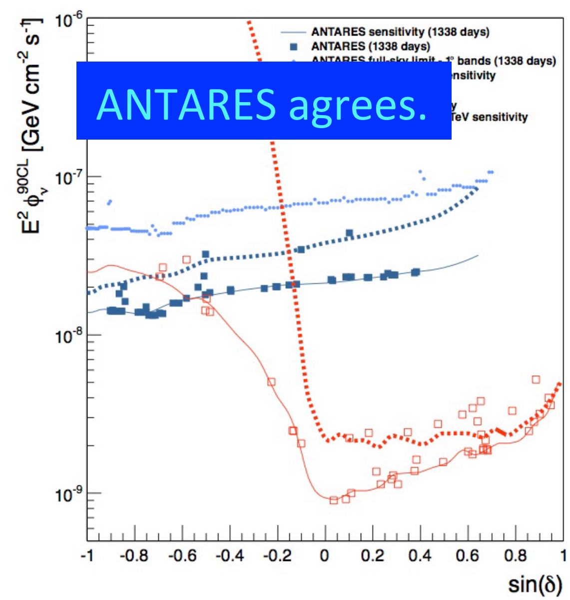
IceCube gets more events!

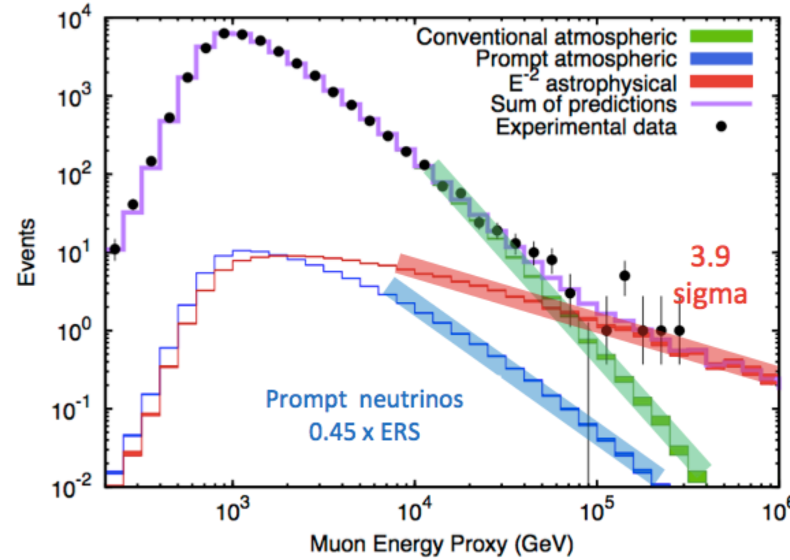


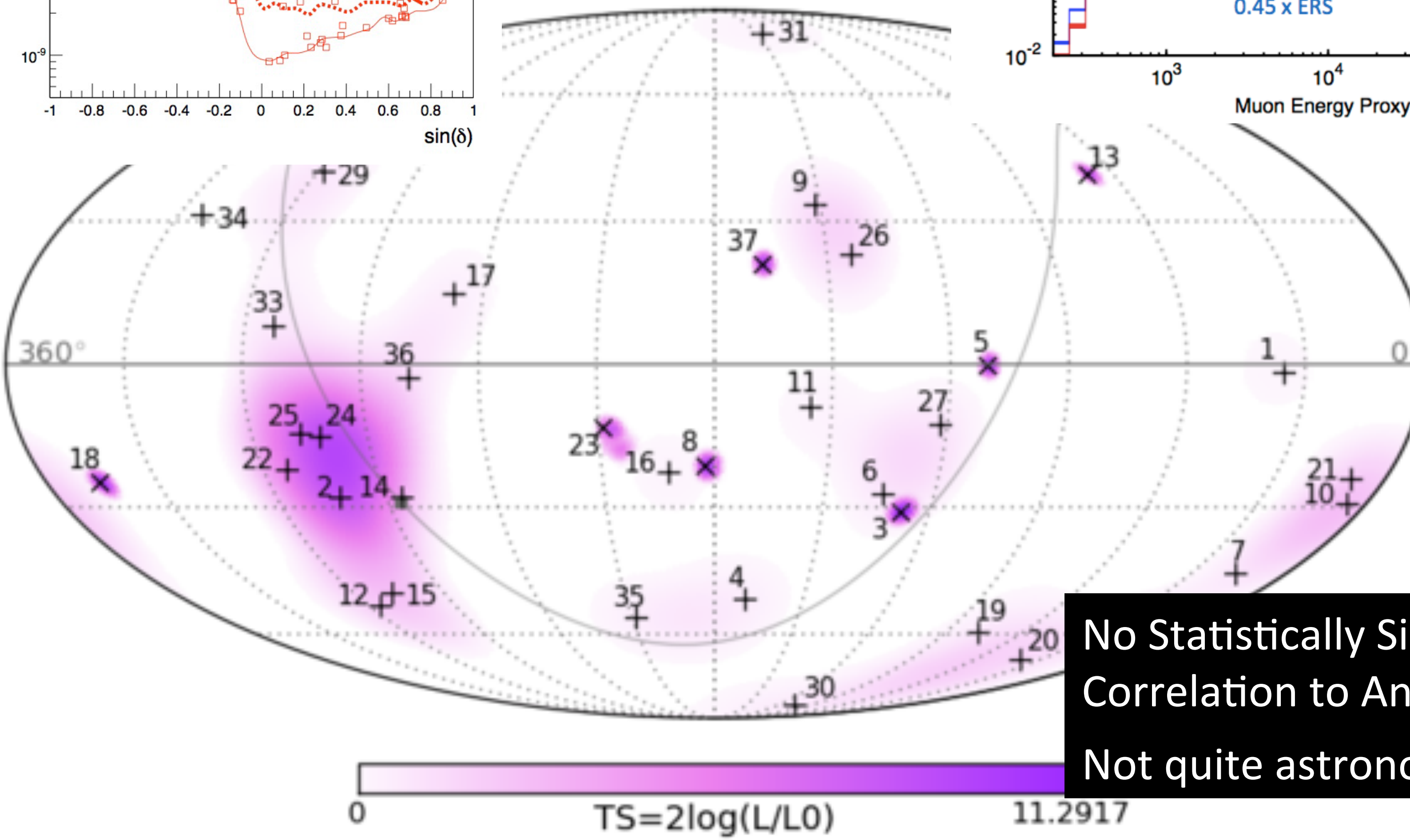


HESE-2 (IC79 + IC86-1 + IC86-2): 37 events on a background expectation of 15

ANTARES agrees.

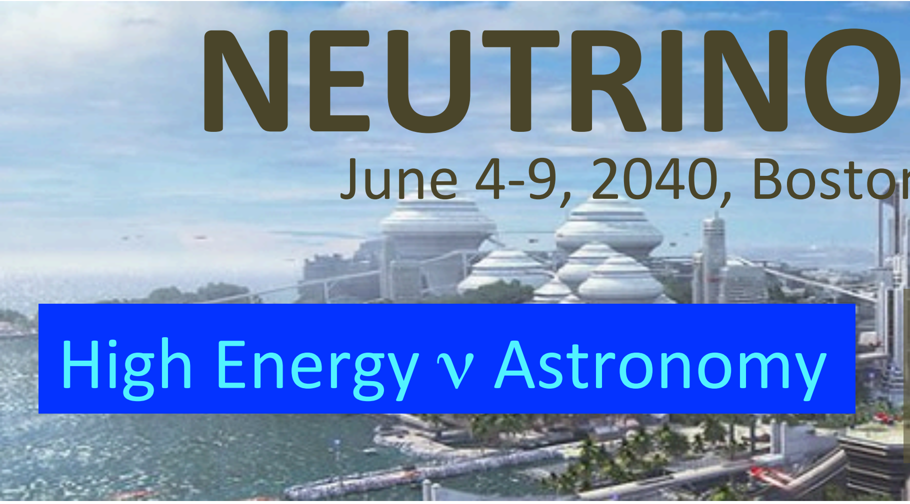






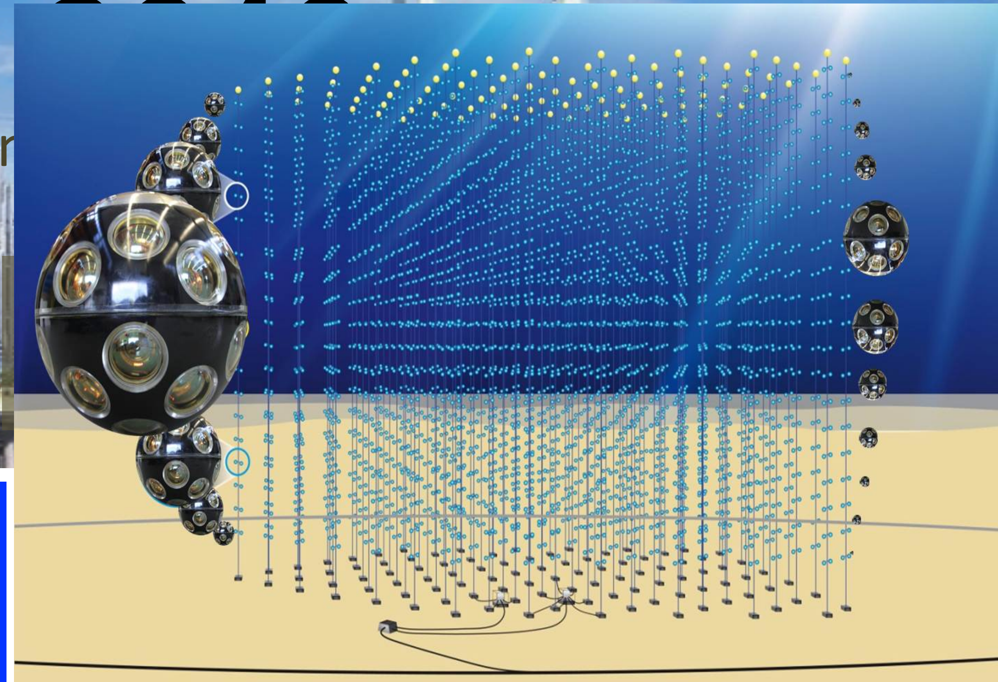
No Statistically Significant Correlation to Anything!

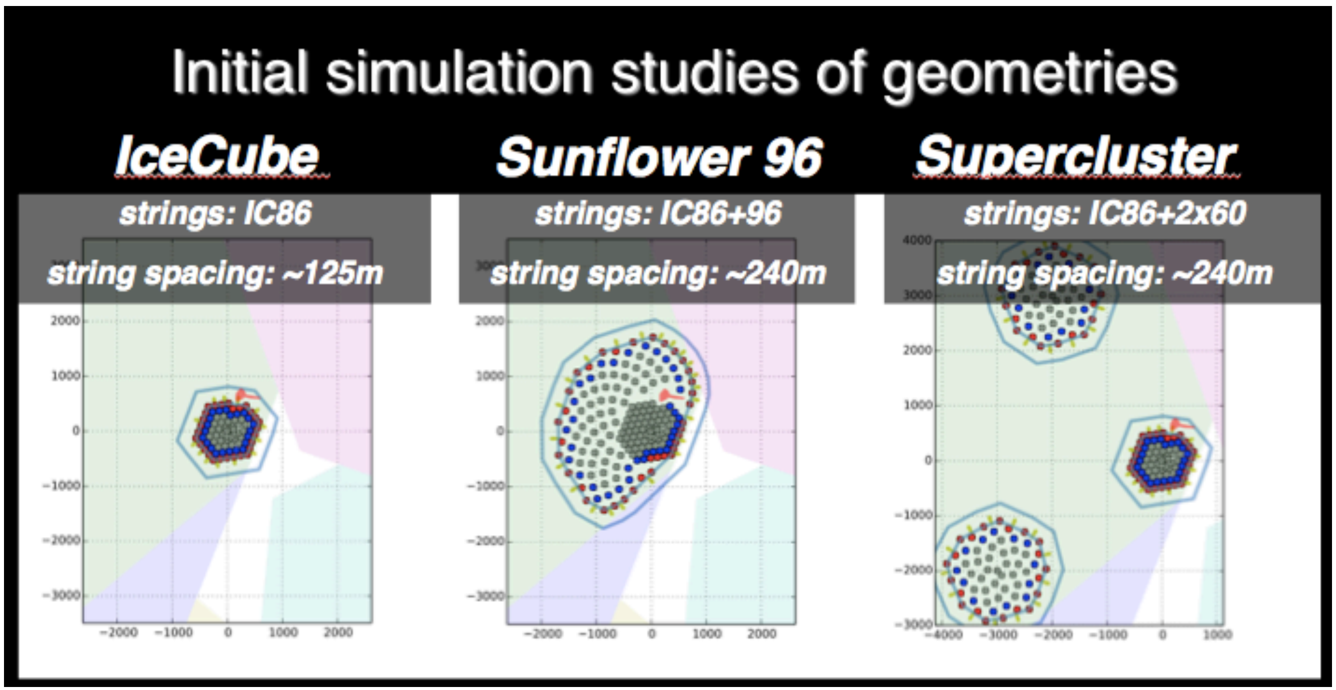
Not quite astronomy yet. . .

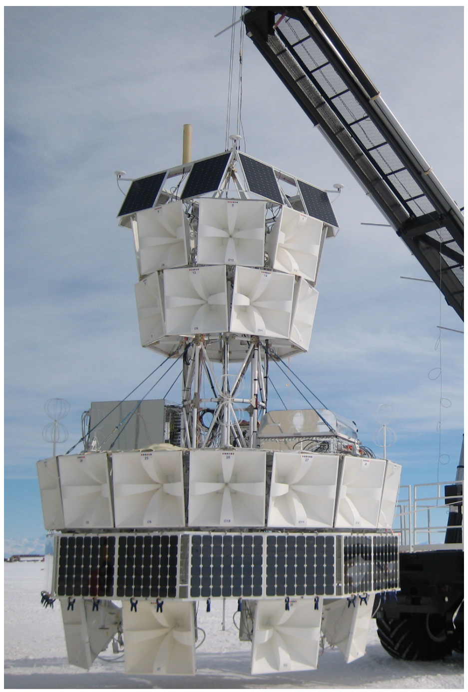


High Energy ν Astronomy

By 2040 this should be old news
and ν astronomy should just be
astronomy – assuming we see sources!







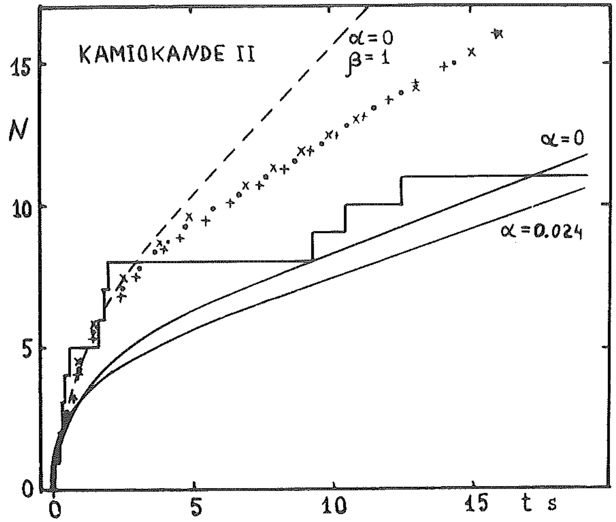
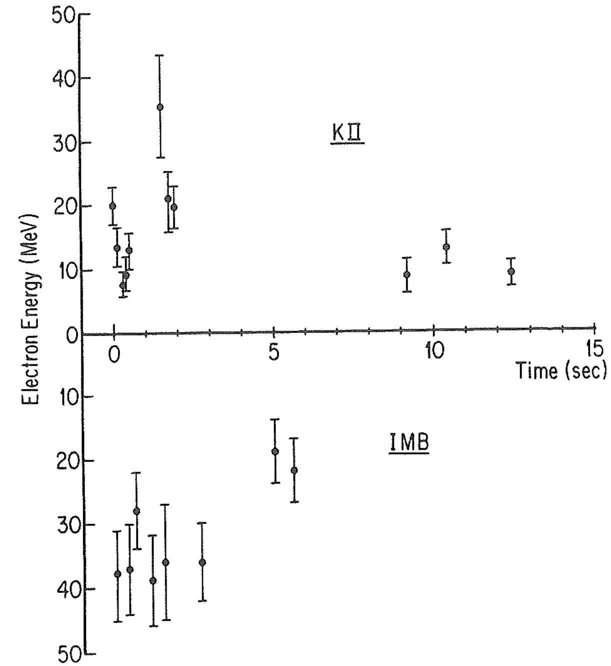


Fig.2. A comparison of the time behaviour of the number of the $\tilde{\nu}_e$-events from SN 1987A in the KII detector[18) – the stepped line with the theoretical predictions.



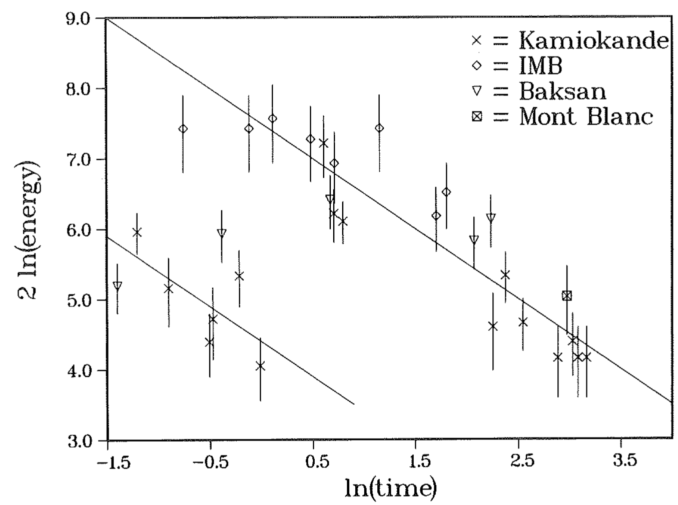


Fig. 4. Log-log plot of neutrino arrival time against neutrino energy. The upper line corresponds to a neutrino mass of 26 eV and the lower one 6 eV.

5. Neutrinos from Supernovae

Chairs: T. Walker and D. Kiss

*Review of neutrinos from SN1987a
L.R. Sulak

*Theoretical review of neutrinos from SN1987a
J.N. Bahcall

10 seconds that shook the world
A. Burrows 142

The neutrino radiation of collapsing stellar cores and the neutrino burst detected from SN1987a
D.K. Nadyozhin 165

*Mind boggling news from supernova SN1987a
A. DeRujula

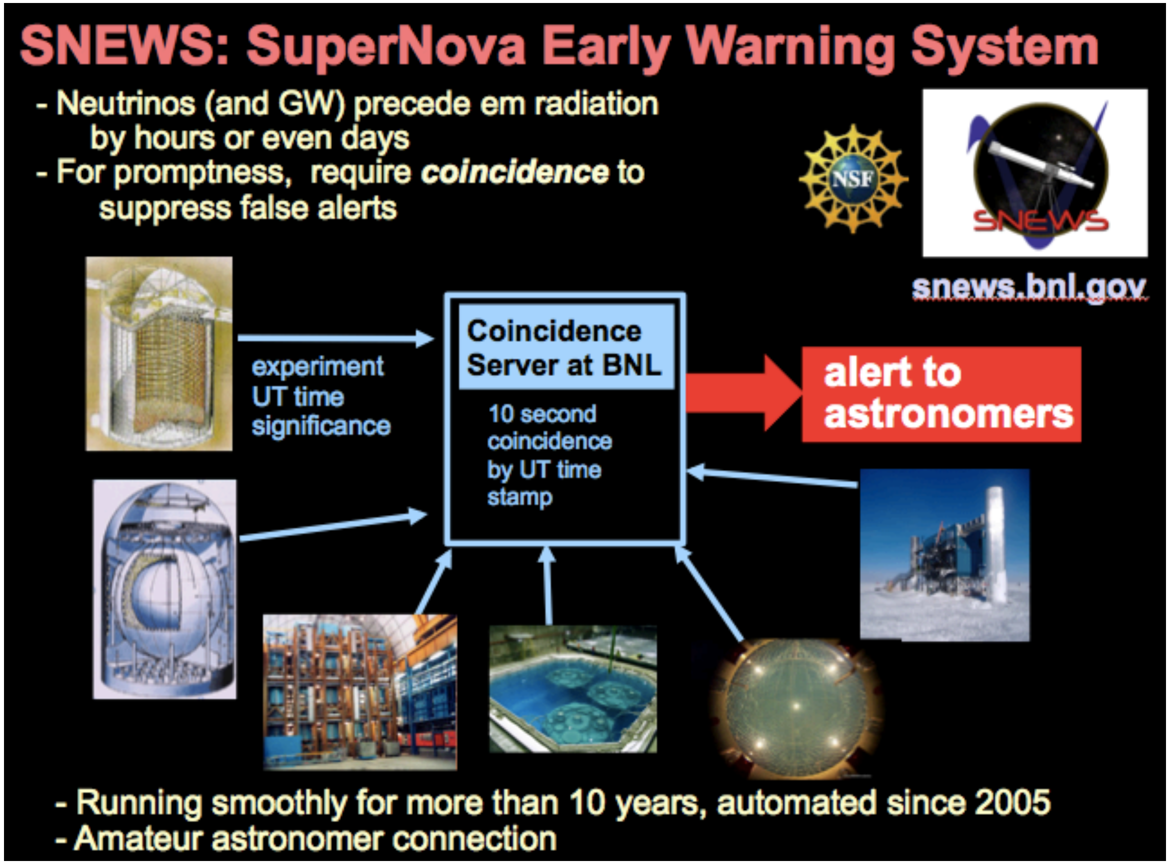
*Neutrinos from supernovae and the sun: Comments and summary
H. Bethe

Supernovae ν

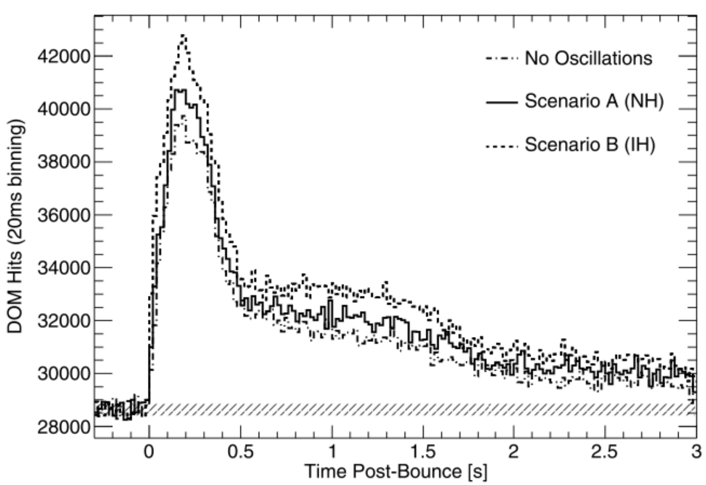
Still waiting. . .

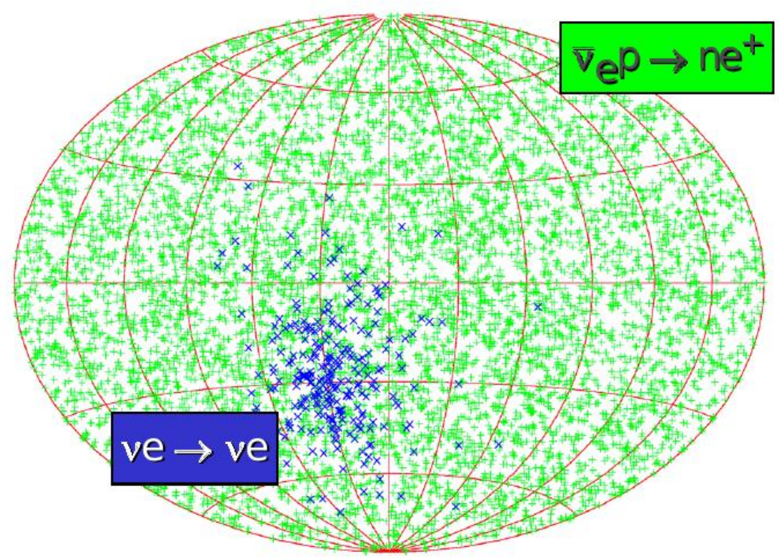
. . . but not passively.

We must be ready!!!



In his summary talk to Neutrinos 88,
Lev Okun predicted a SN in 2003 ± 15 years,
so in 2040 we will still be mining the data
from SN 2018a.





Kinematic ν Mass Measurements

STATUS OF THE ITEP NEUTRINO MASS MEASUREMENT FROM ^{3}H BETA SPECTRUM

V. Lubimov

Institute of Theoretical and Experimental Physics,

Moscow, USSR

$$M_{\nu} = 26 {}^{+6}_{-5} \text{ eV}$$

$$17 < M_{\nu} < 40 \text{ eV}$$

R. G. H. Robertson

Physics Division, Los Alamos National Laboratory,

Los Alamos, NM 87545, U. S. A.

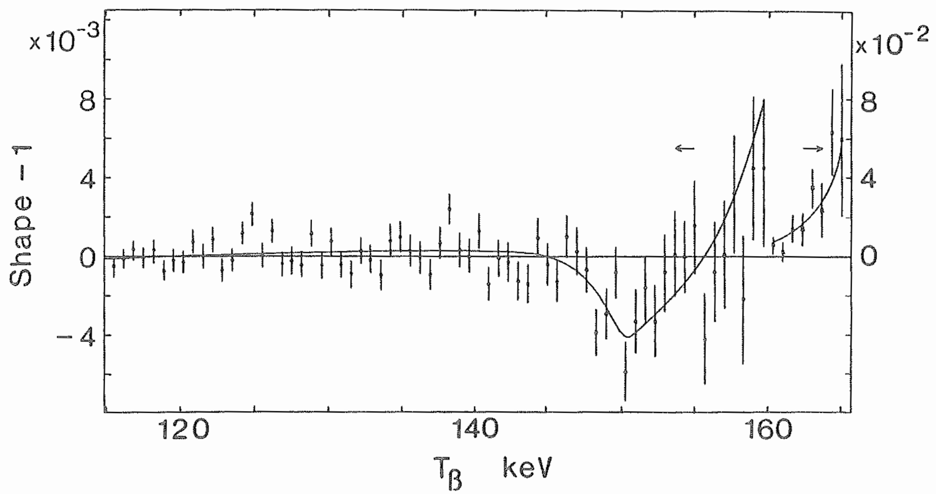
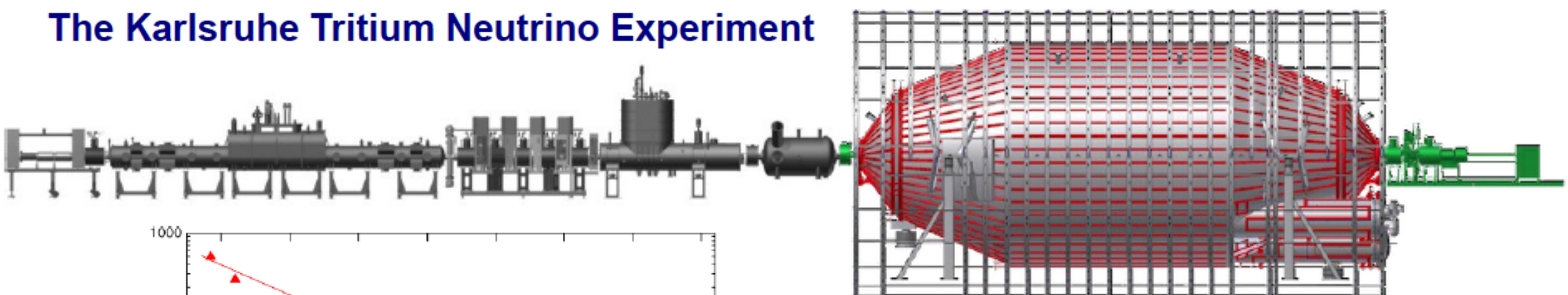
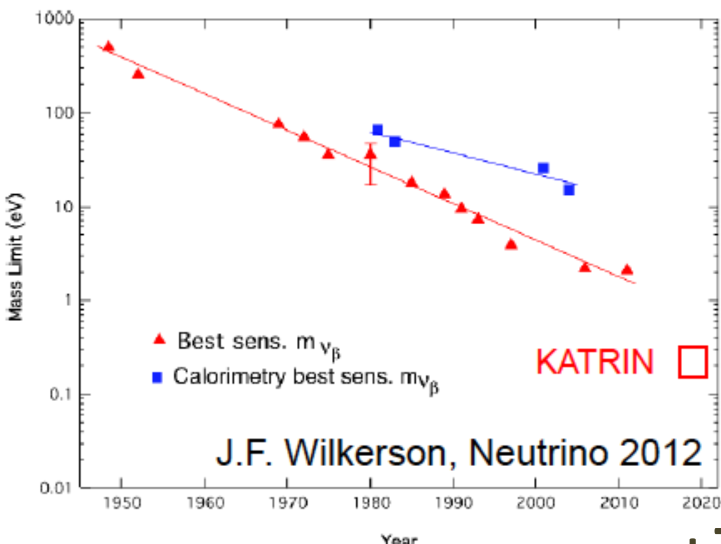


Fig. 3. Data of Simpson and Hime (ref. 5) on the β decay of ^{35}S. Residuals are shown relative to a straight line (the expected shape for zero neutrino masses) and a curved line (the expected shape if there is a 1% admixture of a 17-keV neutrino).

Kinematic ν Mass Measurements

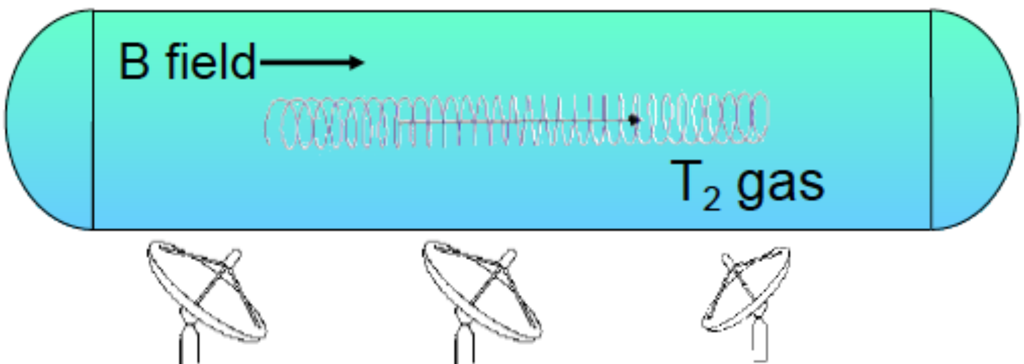




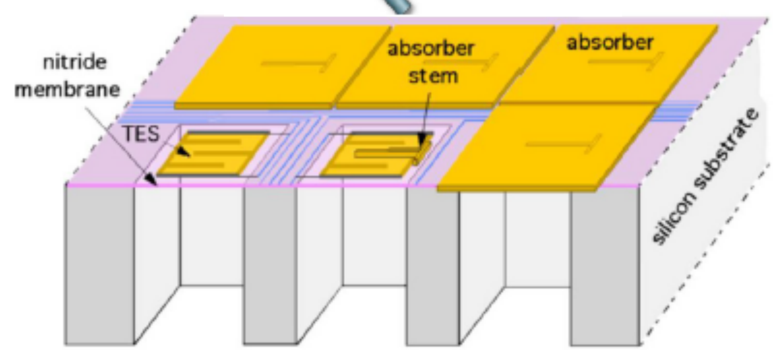
+TOF?

Kinematic ν Mass Measurements

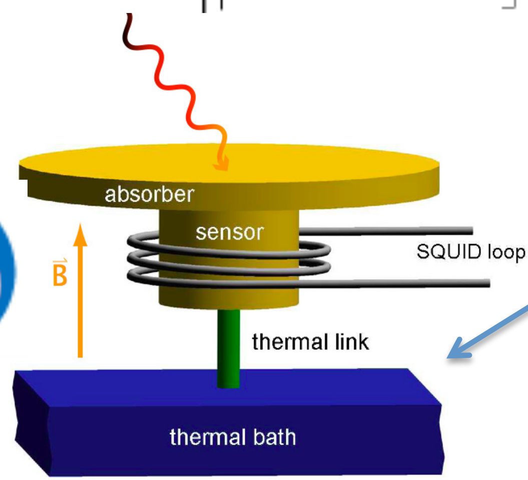
Project 8



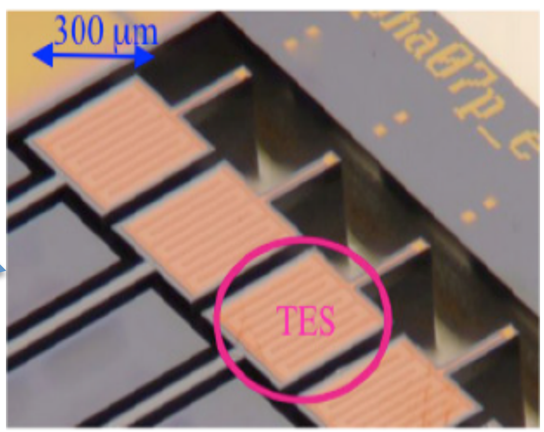
HOLMES



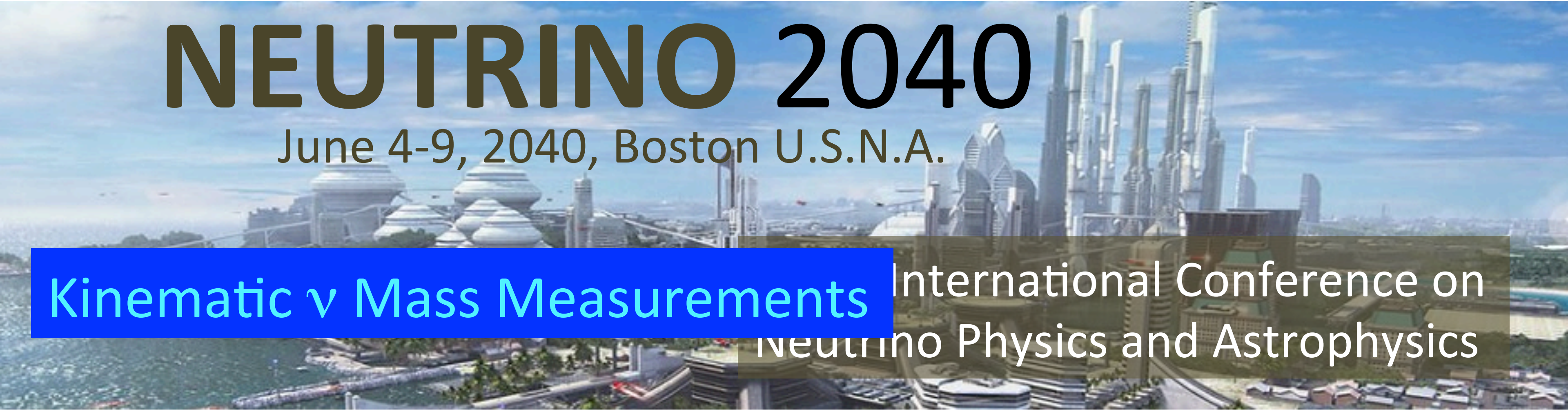
ECHo



^{163}Ho



LANL: Detectors



Kinematic ν Mass Measurements

Should be long since done and dusted by 2040, but who knows what new ideas will come along?

Cosmological ν

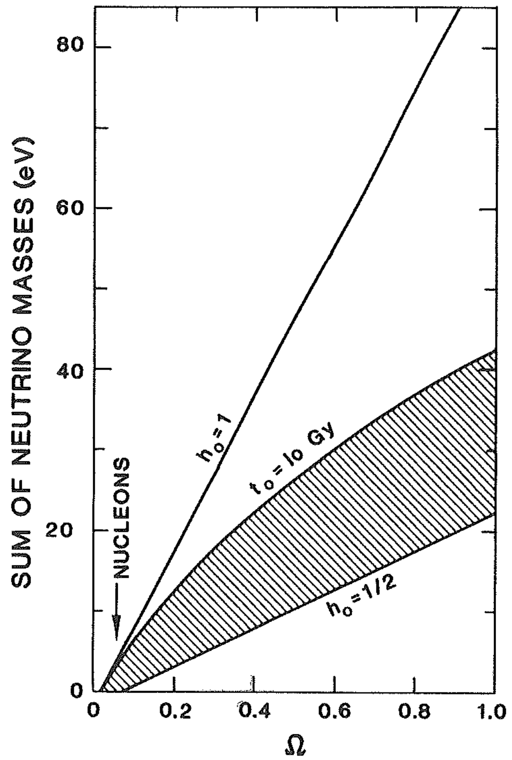
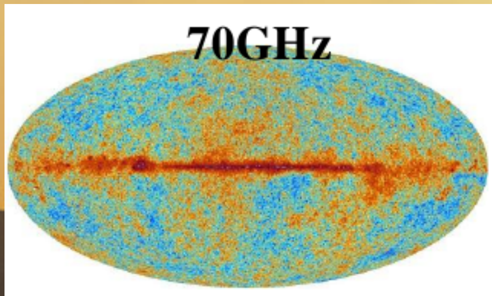
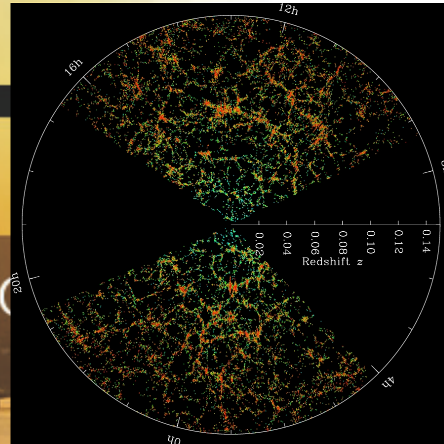


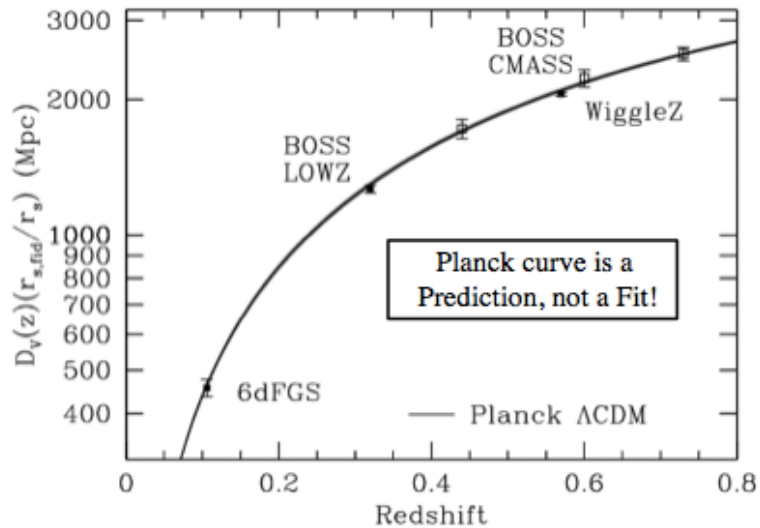
Fig.1 Allowed region (shaded) for neutrino mass, in the absence of other sources of dark matter.

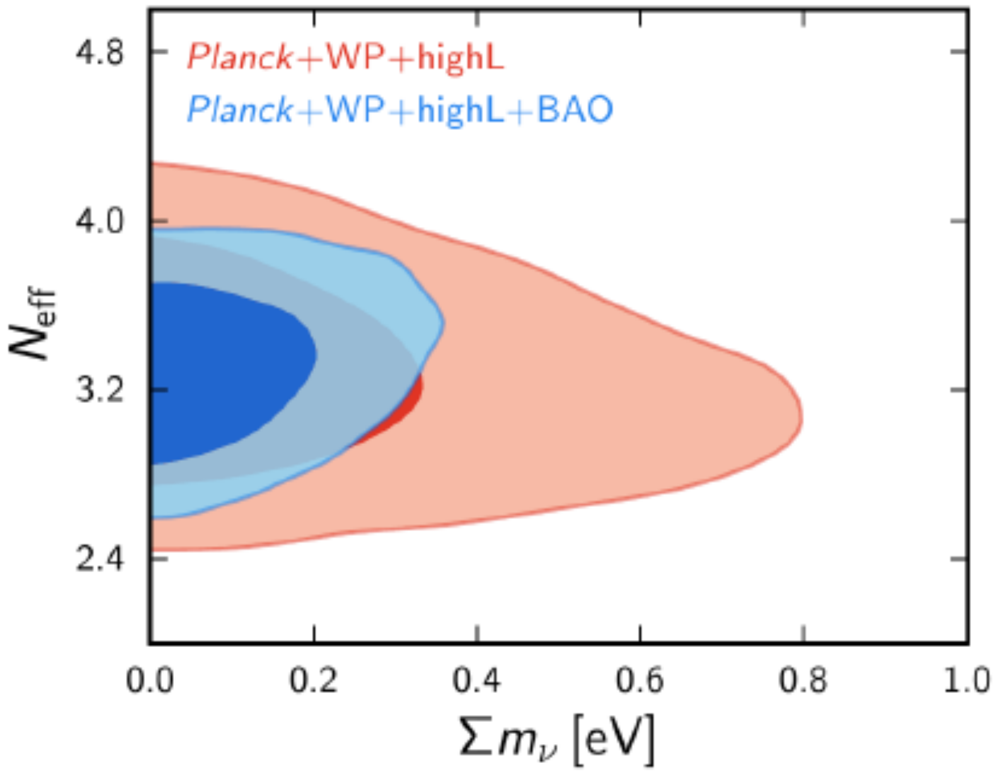
Many mentions in the conference of ~25 eV neutrinos as the Dark Matter

Cosmological ν









- The current observational situation is … unsettled.
- Planck predicts a relatively high amplitude.
- Several data sets (clusters, galaxy lensing, and RSD) suggest lower values.
- Planck weak lensing itself gives a higher value.
- Current errors are 0.1-0.15 eV (rms). Central values can reach 0.4 eV, or be down around 0.

Cosmological data is rare and precious stuff
for determining the properties of the early Universe.
We shouldn't waste it measuring ν properties.
ν properties should be inputs to cosmology,
not outputs. That statement is (to me) independent
of the quality of the cosmological data.

ββ decay

DOUBLE BETA DECAY: YESTERDAY, TODAY, TOMORROW

Ettore Fiorini
Dipartimento di Fisica dell'Universita' di Milano
Istituto Nazionale di Fisica Nucleare, Sezione di Milano

TABLE II: RECENT RESULTS OF THE SOURCE DETECTOR EXPERIMENTS (years)

GROUP		TECHNIQUE	T(0ν)	T(2ν)	T(major)
Irvine[11-12]	^{82}Se	T.P.C.	>1.1 10^{22}	$1.1^{+.8}_{-.3}$ 10^{20}	>7.3 10^{20}
Kiev[13]	^{96}Zr	Scintill.	>6.5 10^{19}	-	-
Osaka[14]	^{100}Mo	Solid S.D.	>1.9 10^{20}	>2.5 10^{17}	>1.9 10^{19}
Irvine[15]	"	T.P.C.	>1.9 10^{19}	>6.8 10^{17}	>7.5 10^{18}
LBL+M.H.+N.M.[16]	"	Solid S.D.	-	> 4 10^{18}	>2.1 10^{21}
Kiev[17]	"	Scintill.	>2.1 10^{21}	-	-
Moscow[18]	"	"	> 4 10^{20}	>6.2 10^{18}	>2.8 10^{19}
Kiev[19]	^{130}Te	"	>1.2 10^{21}	-	-
Moscow[18]	^{150}Nd	"	>1.7 10^{21}	>1.8 10^{19}	> 1 10^{20}

STATUS OF ββ-DECAY EXPERIMENTS IN THE YEAR OF THE REINES FEST

F.T. Avignone, III
Department of Physics and Astronomy, University of South Carolina, Columbia, South Carolina 29208
R.L. Brodzinski, J.H. Reeves, and H.S. Miley
Pacific Northwest Laboratory[(a)], Richland, Washington 99352

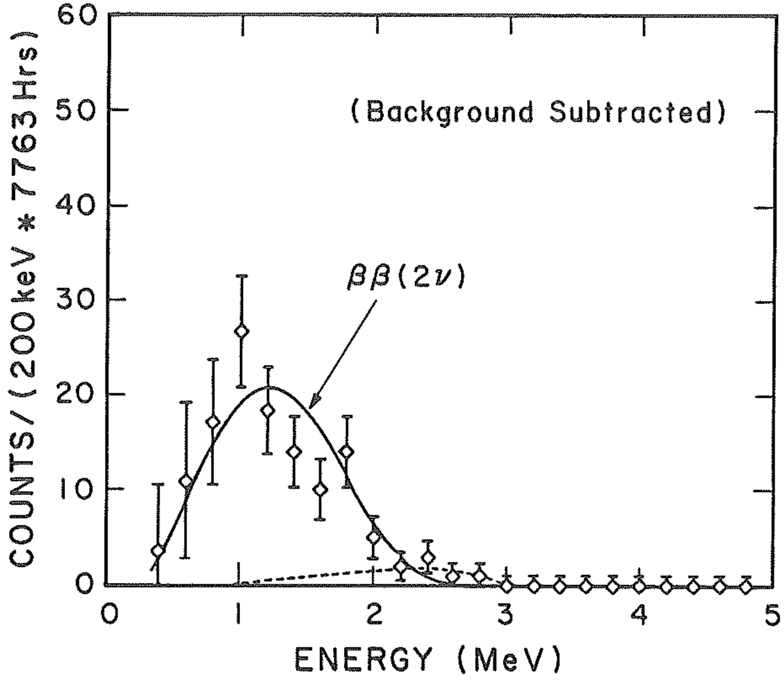
TABLE I. Double-beta decay half-lives (years) from selected experiments.

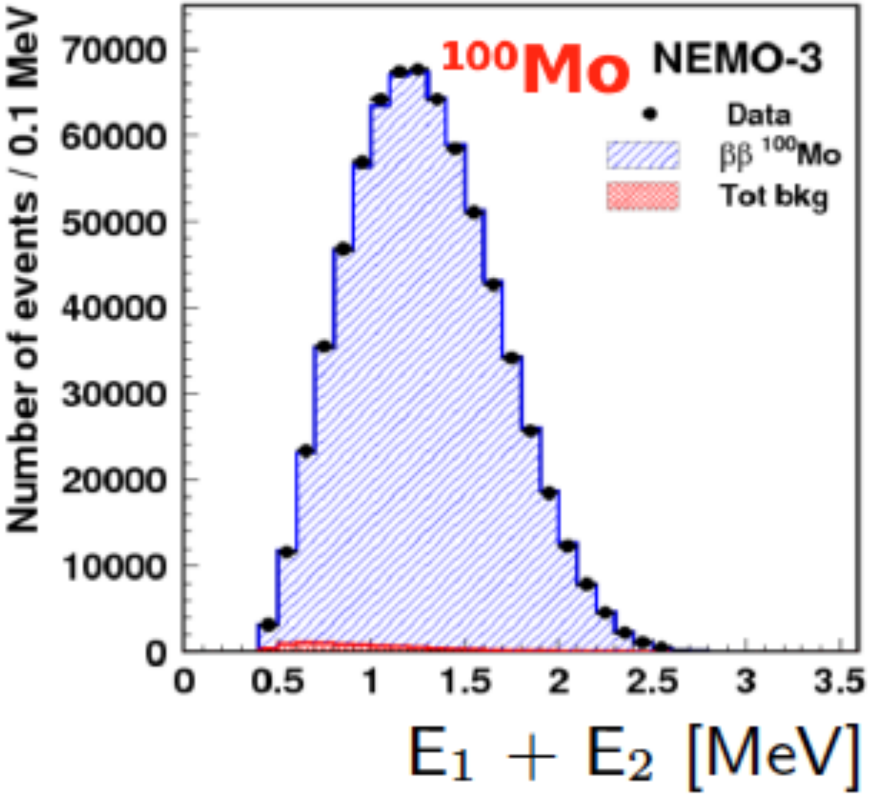
Experiment	Isotope	$T^{0\nu}_{1/2}(0^+\rightarrow 0^+)$	$T^{0\nu,M}_{1/2}(0^+\rightarrow 0^+)$	$T^{0\nu}_{1/2}(0^+\rightarrow 2^+)$	$T^{2\nu}_{1/2}$
UCSB/LBL	^{76}Ge	>7 x 10^{23}*	>1.4 x 10^{21}		
CALTECH/ NEUCHATEL/ SIN	^{76}Ge	>3 x 10^{23}	>1 x 10^{21}	>3.4 x 10^{22}	>5 x 10^{20}
FREJUS	^{76}Ge	>6 x 10^{22}	---	>6 x 10^{22}	---
GUELPH/ QUEENS	^{76}Ge	>1.6 x 10^{23}	---	---	---
PNL/USC	^{76}Ge	>3 x 10^{23}	>2 x 10^{21}		>1.0 x 10^{21}
ITEP/YEREVAN	^{76}Ge	>7 x 10^{23}**	>4 x 10^{21}	---	(7.5^{+5}_{-2}) x 10^{20}
OSAKA	^{100}Mo	>1.6 x 10^{20}	>6 x 10^{18}	---	>2.6 x 10^{17}
LBL/ MT. HOLYOKE/ UNM	^{100}Mo	---	>3.3 x 10^{20}	---	>3.8 x 10^{18}
BAKSAN	^{136}Xe	>3.3 x 10^{21}	>1.9 x 10^{20}	>1.5 x 10^{21}	>7.8 x 10^{19}
BAKSAN	^{100}Mo	>4.4 x 10^{20}	>2.8 x 10^{19}	>2.0 x 10^{20}	>6.2 x 10^{18}
MILANO	^{136}Xe	>2.0 x 10^{21}	>6 x 10^{20}	---	---
BAKSAN	^{150}Nd	>1.7 x 10^{21}	>1 x 10^{20}	>1.1 x 10^{21}	>1.8 x 10^{19}

*This result is based on statistical fluctuations alone. A maximum likelihood analysis yields 1.3 x 10^{24} y.
**A different analysis of the data yielding $T^{0\nu}$>4.7 x 10^{23} y is discussed in the text.

ββ decay

^{82}Se 2νββ decay in the Irvine TPC

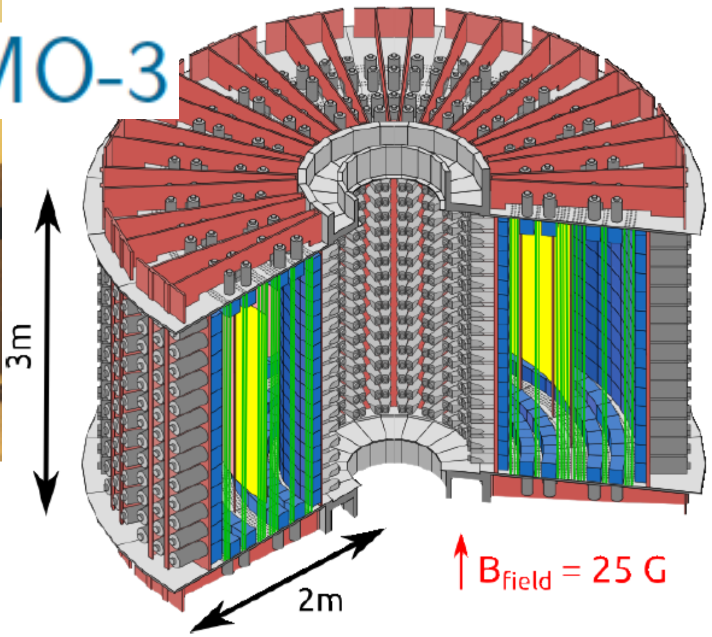




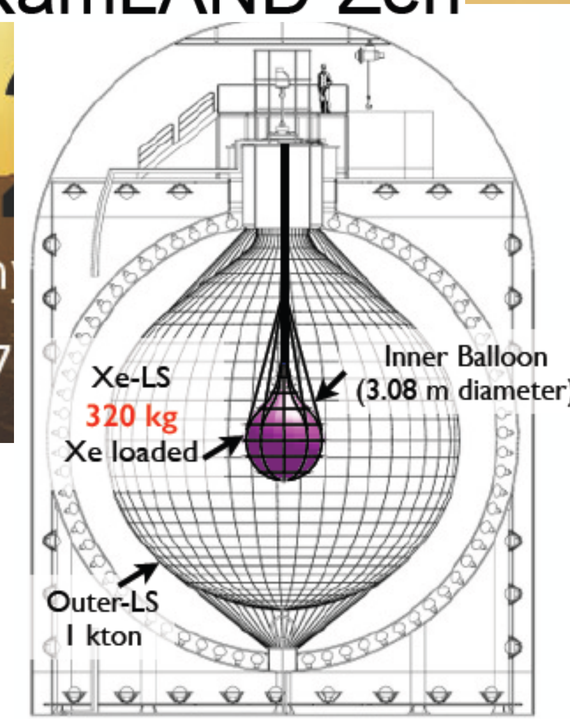
$\sim$700 000 $2\nu2\beta$ events collected

$\beta\beta$ decay

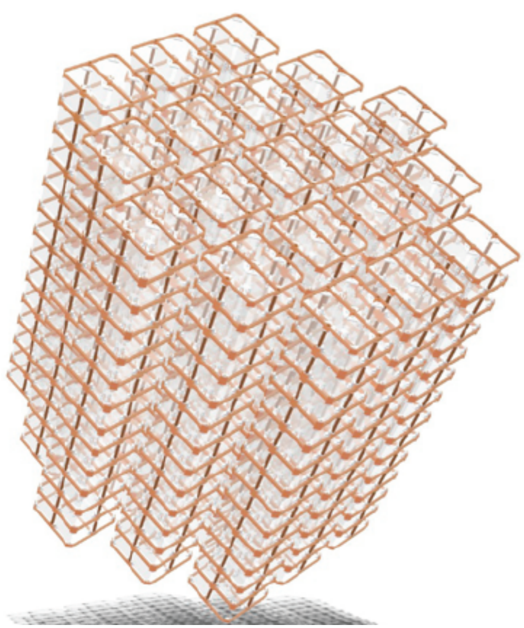
NEMO-3



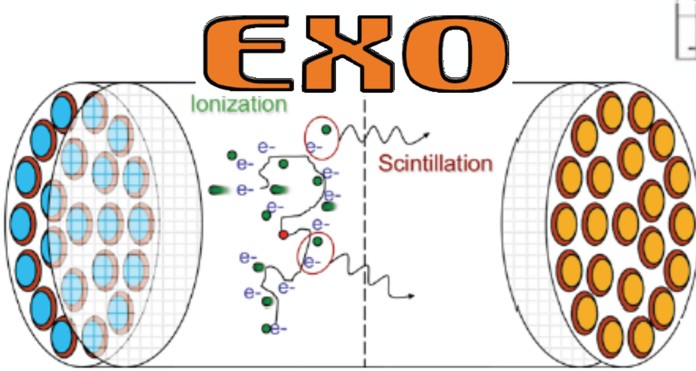
KamLAND-Zen

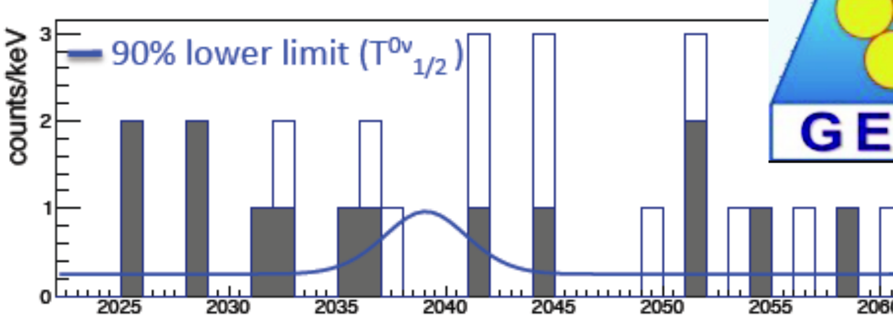


CUORE @ LNGS



EXO





$\beta\beta$

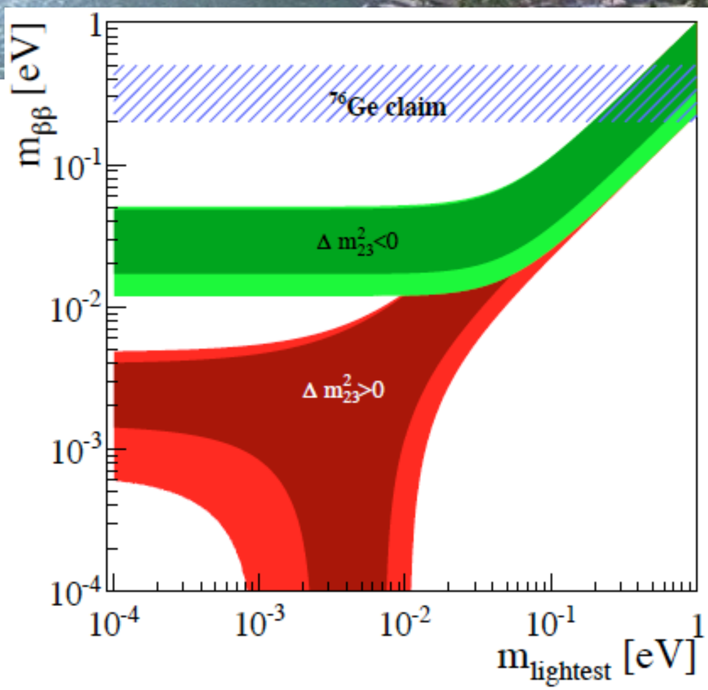
GERDA

NEUTRINO 2040

June 4-9, 2040, Boston U.S.N.A.

XXXIX International Conference on Neutrino Physics and Astrophysics

ββ decay



We are here.

By 2025, we hope to ~~eliminate~~ demonstrate Majorana neutrinos in the inverted hierarchy.

0νββ decay?	Mass Hierarchy: NH	Mass Hierarchy: IH
No	?	✔
Yes	✔✔	✔

We would need a bigger experiment, so we should make sure we do the R&D to be ready.

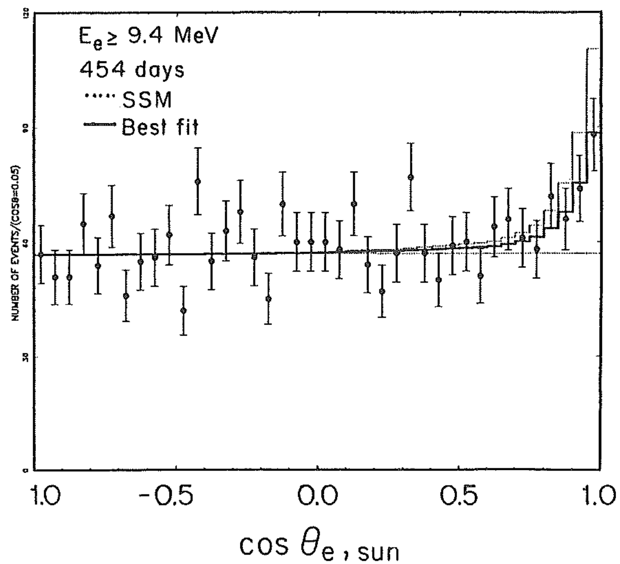
Solar ν

Many talks: Davis, Bahcall, Smirnov, Wolfenstein, Gavrin, Hampel,. . .

A. K. Mann

Department of Physics

University of Pennsylvania, Philadelphia, PA



$$\frac{{}^{37}\text{Cl Radiochem. Detector (1987)}}{\text{SSM}} = 0.53 \pm 20\%,$$

which is to be compared with the Kamiokande-II result

$$\frac{\text{KAM-II Water Cerenkov Detector (1987)}}{\text{SSM}} = 0.5 \pm 33\%$$

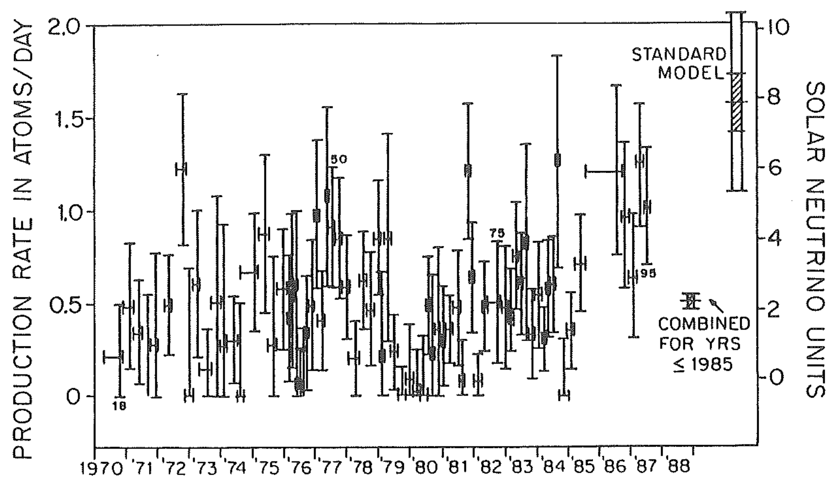
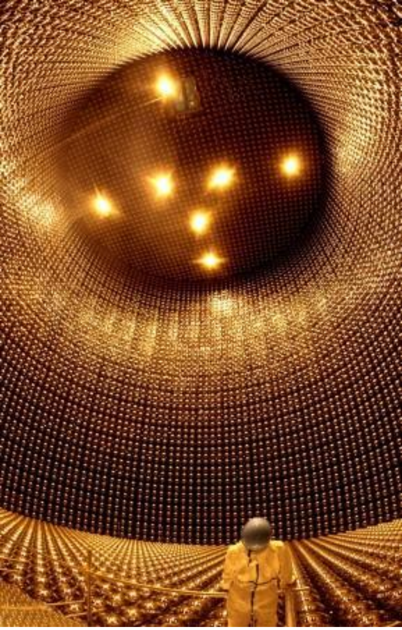
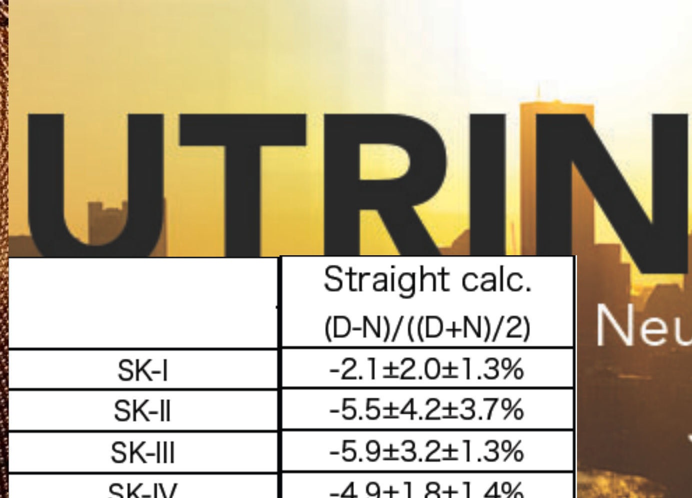
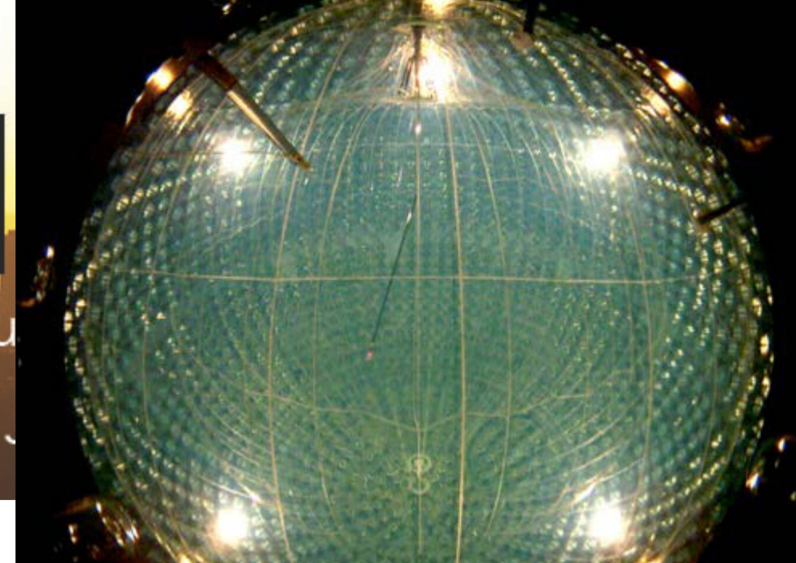


Fig. 4

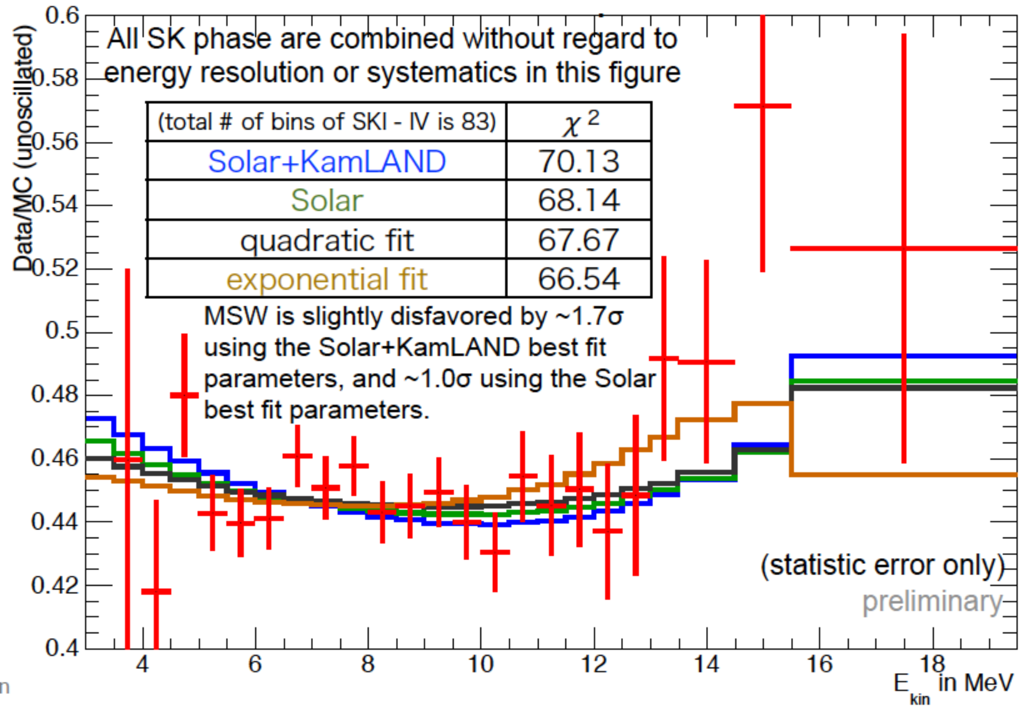


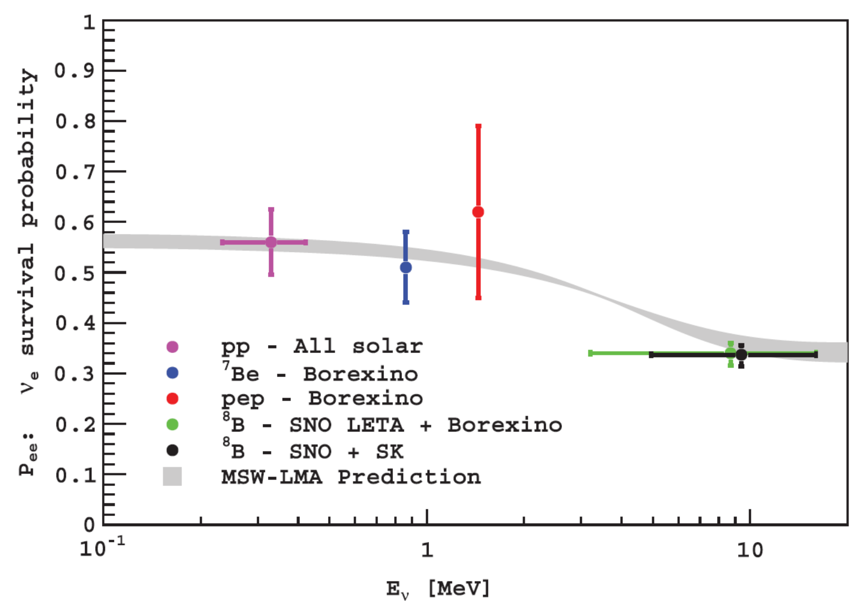


	Straight calc. (D-N)/((D+N)/2)
SK-I	-2.1±2.0±1.3%
SK-II	-5.5±4.2±3.7%
SK-III	-5.9±3.2±1.3%
SK-IV	-4.9±1.8±1.4%
combined	-4.1±1.2±0.8%
non-zero significance	2.8 σ



Th< 9 10^{-19} g/g 95% C.L.
U < 8 10^{-20} g/g 95% C.L.
Kr< 7.1 cpd/100 tons 95% C.L.





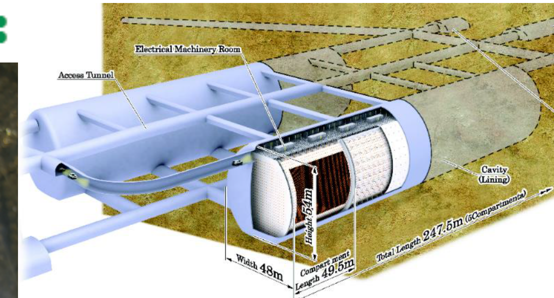
NEUTRINO 20

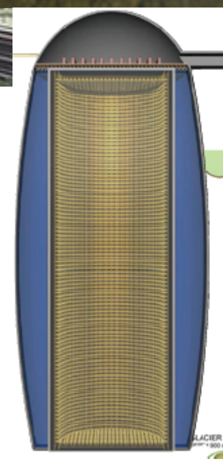
June 4-9, 20

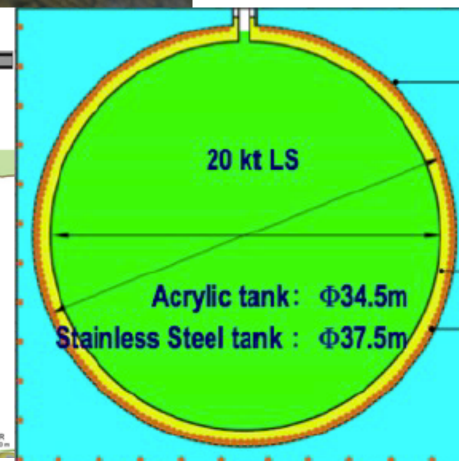
Solar ν

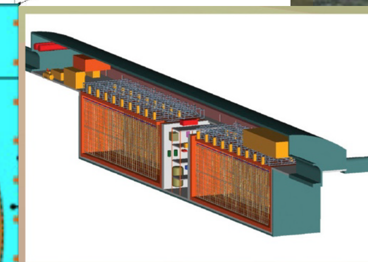
Liquid xenon (XMASS, LZ):

Liquid neon (CLEAN):









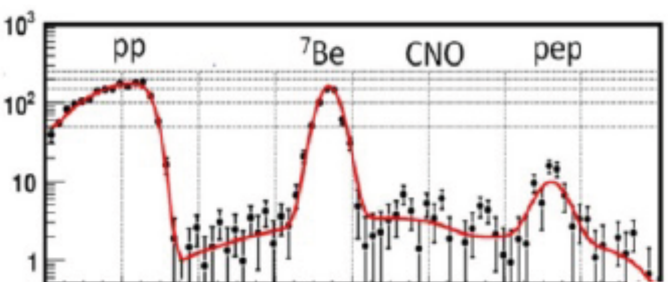
Many reasons to try to do more:

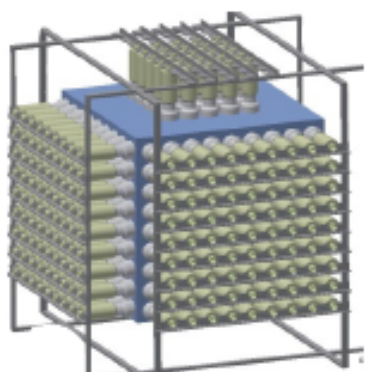
- Map out MSW transition.
- Look for new physics.
- See all solar ν branches.

Dedicated experiment?:

$$\nu_e + {}^{115}In \longrightarrow {}^{115}Sn^* + \beta^-$$

$$\tau = 4.76\mu s \hookrightarrow \gamma(115\text{keV}) + \gamma(497\text{keV}) + {}^{115}\text{Sn}$$

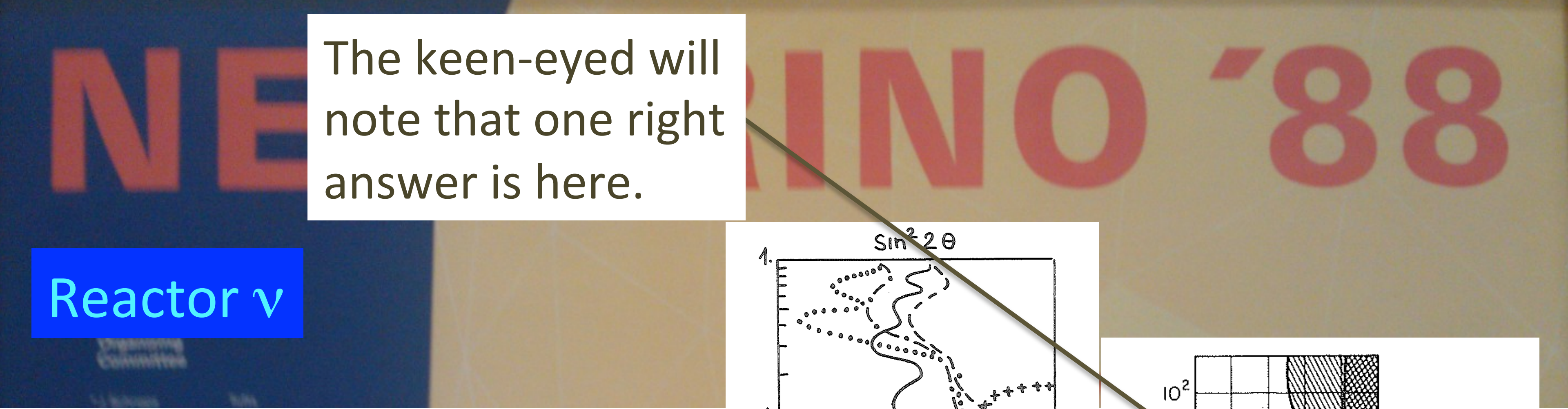




2.10. Indium-Scintillation Detector

^{115}In is a potential real time pp-neutrino detector using e^--γ coincidence[17] since the threshold for $^{115}\text{In}(\nu_e,e^-)^{115m}\text{Sn} \xrightarrow[3\mu s]{\gamma} {}^{115}\text{Sn}$ is 128 keV only.

Unfortunately, background problems at such low energy are insurmountable because ^{115}In itself is radioactive. However, this may be different if one refrains from aiming at pp-ν-detection. With a threshold of ~600 keV, it could be the best experiment to detect ^{7}Be-neutrinos (SSM: 116 SNU from ^{7}Be, only 14.4 SNU from ^{8}B)[3]. Presently, a working group is looking into the feasibility of such an experiment.

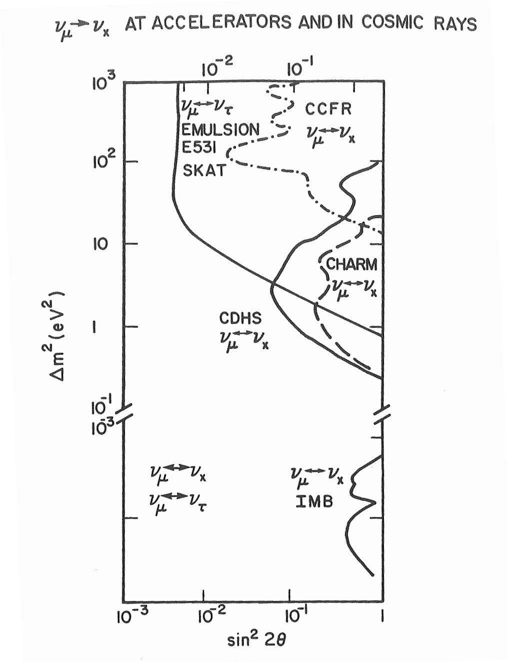


The keen-eyed will note that one right answer is here.

Reactor ν

Neutrino oscillations at reactors

J.Bouchez
Département de Physique des Particules Elémentaires
CEN-Saclay, 91191 Gif-sur-Yvette Cedex, France



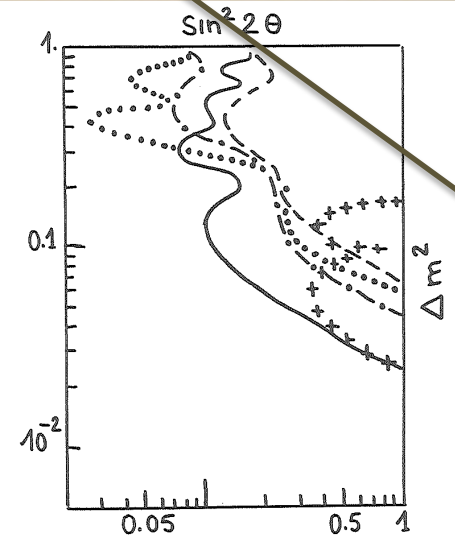
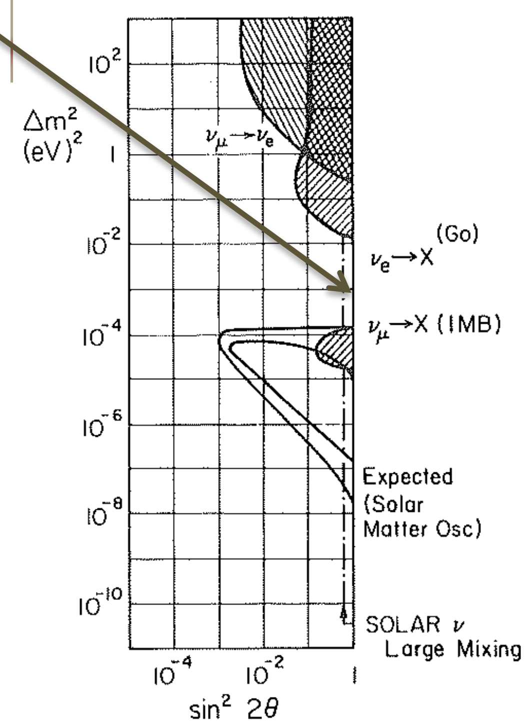


Figure 4: Exclusion plot on oscillation parameters $sin^2 2\theta$ and $\Delta m^2 (eV^2)$.
Continuous curve: Gösgen [12] 90% CL
dotted curve: Savannah River [13] 95% CL
dashed curve: Bugey 2 [15] 95%CL
dashed-dotted curve: Rovno [18] 90% CL
++++ curve: Moscow [20] 95% CL

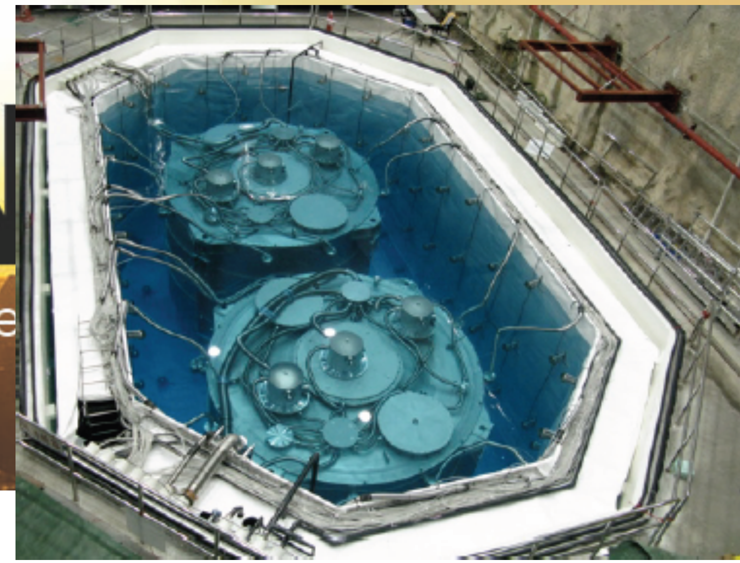


NEUTRINO PHYSICS WITH REACTORS

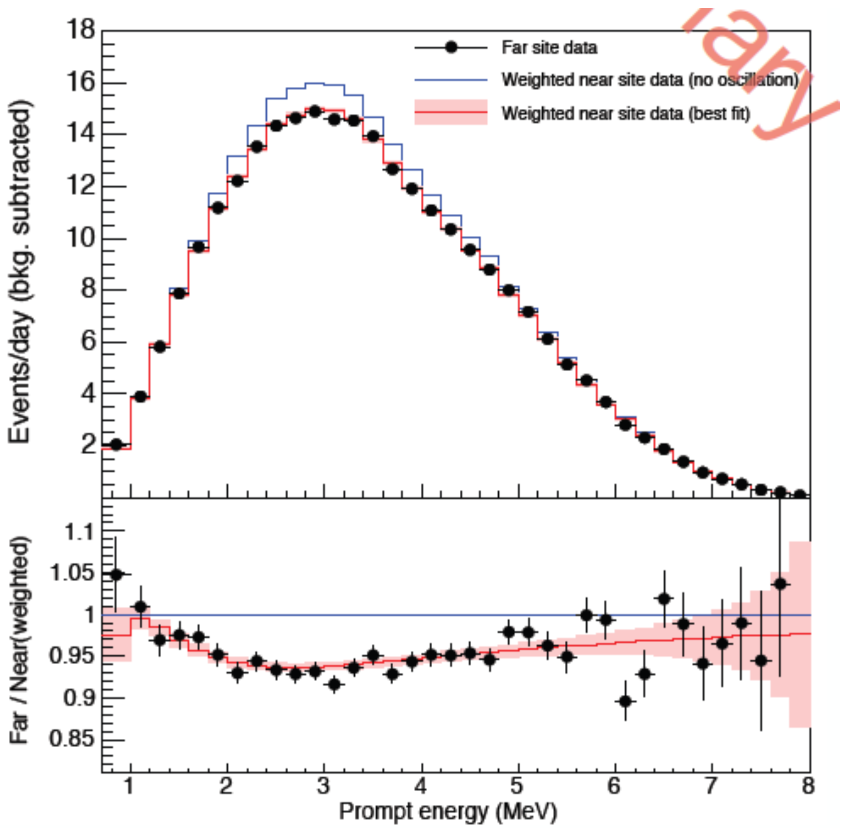
Felix Boehm

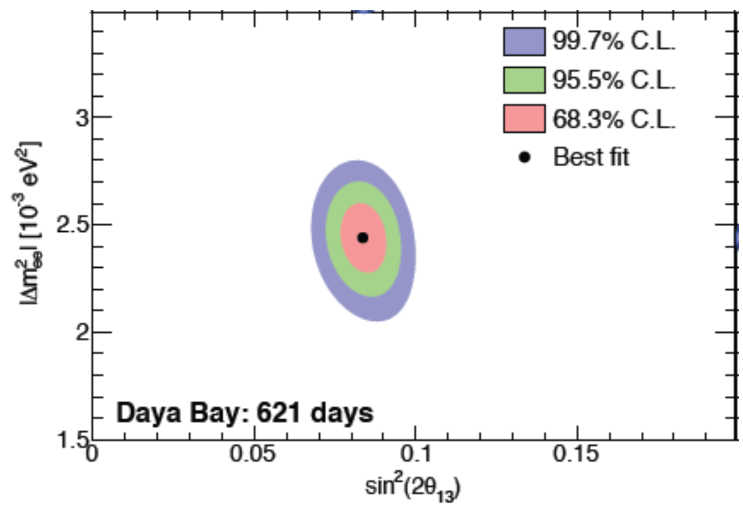
California Institute of Technology
Pasadena, Ca 91125

Fig. 9. Exclusion plot for neutrino oscillations from various experiments.



Daya Bay with 8 detectors, many improvements. . .



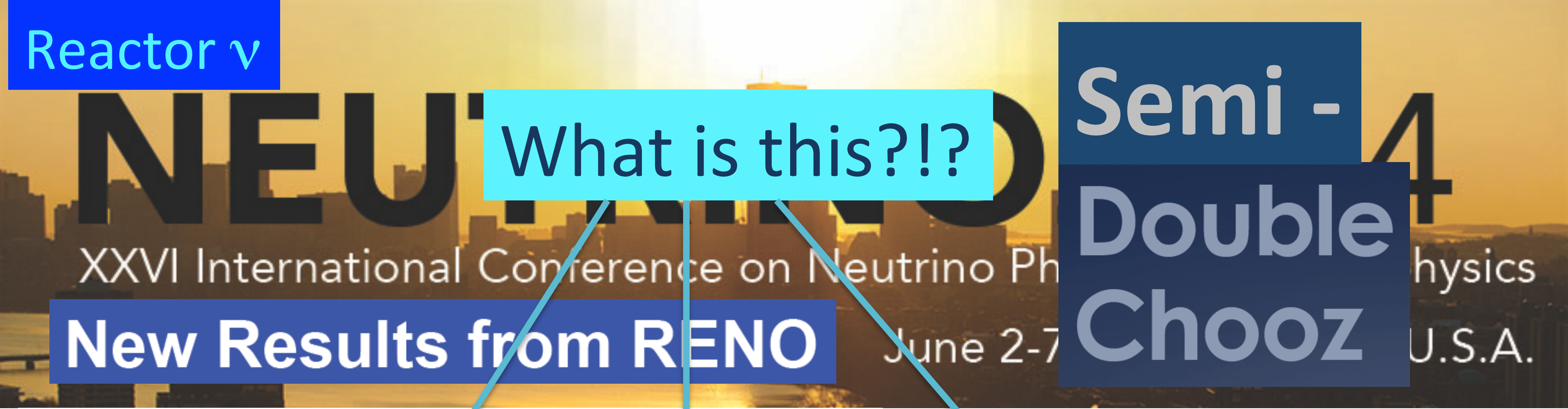


$$\sin^2 2\theta_{13} = 0.084^{+0.005}_{-0.005}$$

$$|\Delta m^2_{ee}| = 2.44^{+0.10}_{-0.11} \times 10^{-3}\mathrm{eV}^2$$

$$\chi^2/NDF = 134.7/146$$

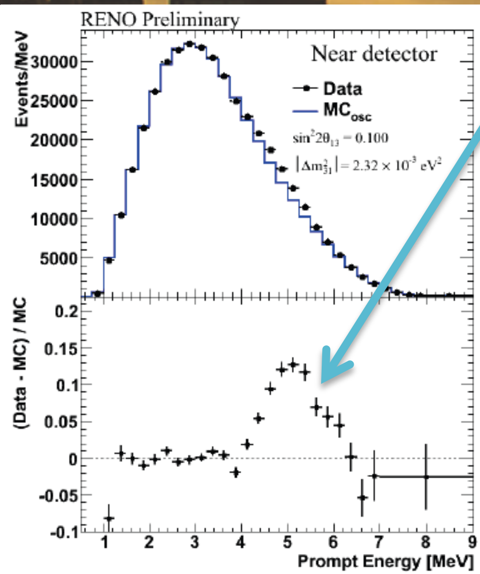
Reactor ν

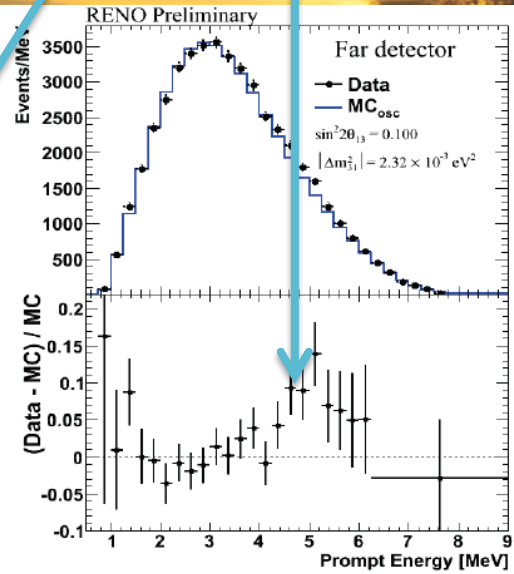


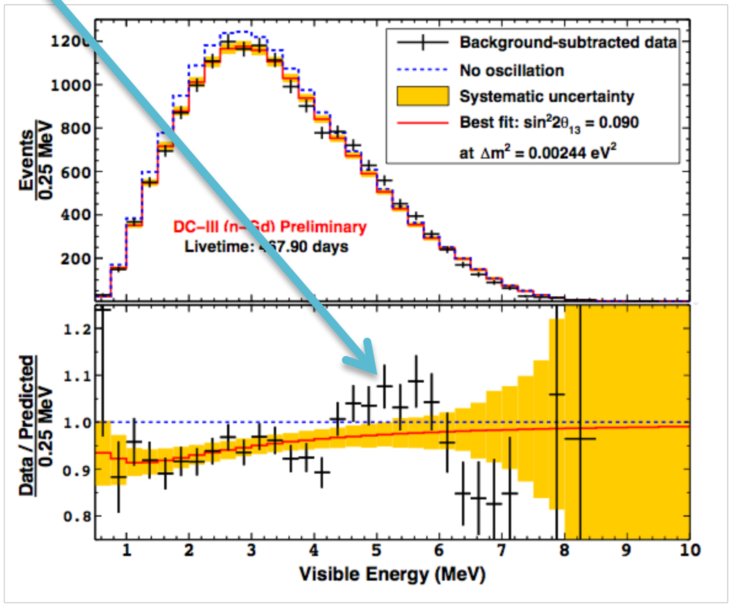
What is this?!?

Semi - Double Chooz

New Results from RENO







Rate only analysis →

Preliminary result

C data set (~800 days)

$\sin^2(2\,\theta_{13}) = 0.101 \pm 0.008\ (\text{stat.}) \pm 0.010\ (\text{sys.})$

Rate + shape analysis →

$\sin^2(2\,\theta_{13}) = (0.09 \pm 0.03)$

$(\chi^2/\text{n.d.f.} = 51.4/40)$

background substracted

The field benefits greatly from 3 exps!

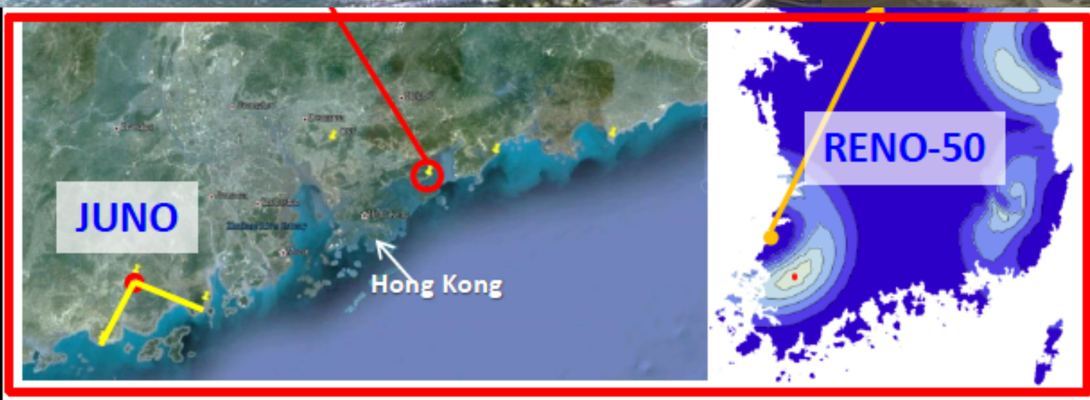
NEUTRINO 2040

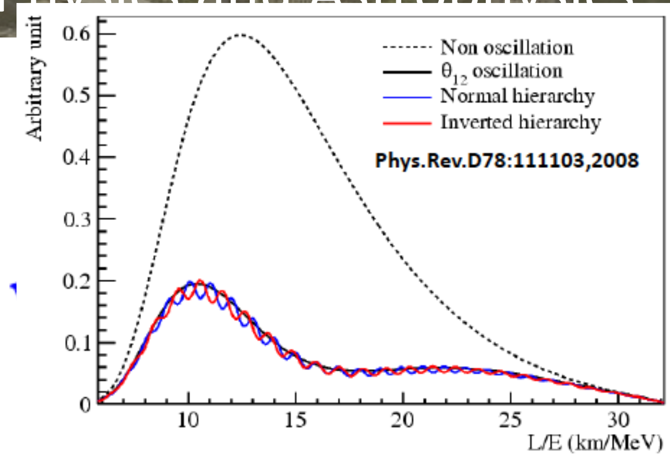
June 4-9, 2040, Boston U.S.N.A.

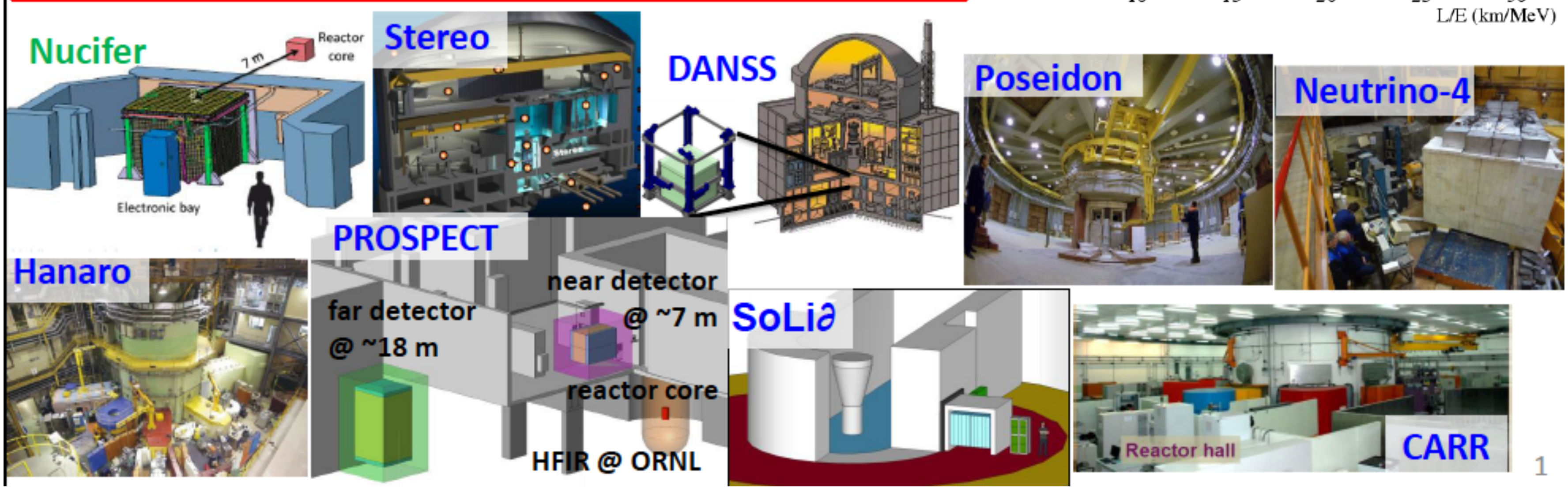
Reactor ν

Liangjian Wen

...national Conference on Neutrino Physics and Astrophysics







Atmospheric ν

Review of Atmospheric Neutrino Phenomena in Underground Nucleon Decay Detectors

A. SUZUKI

National Laboratory for High Energy Physics (KEK)
Tsukuba, Ibaraki, 305, Japan

Fig. 2

Momentum distributions for: Kamiokande (a) electron -like events and (b) muon-like events. The last momentum bin sums all events with their momenta larger than 1100 MeV/c. The histograms show the distributions expected from atmospheric neutrino interactions.

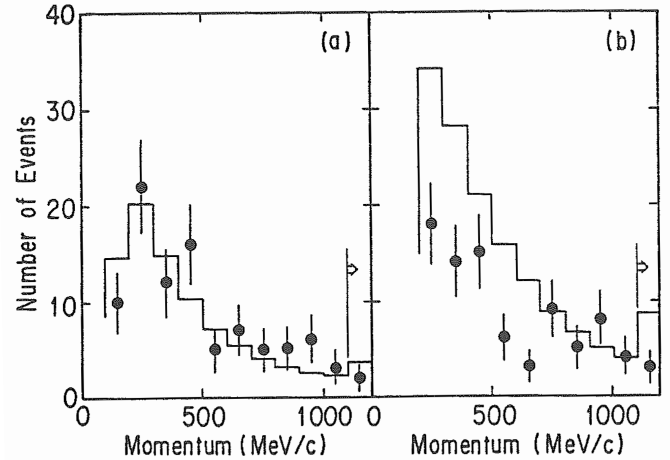
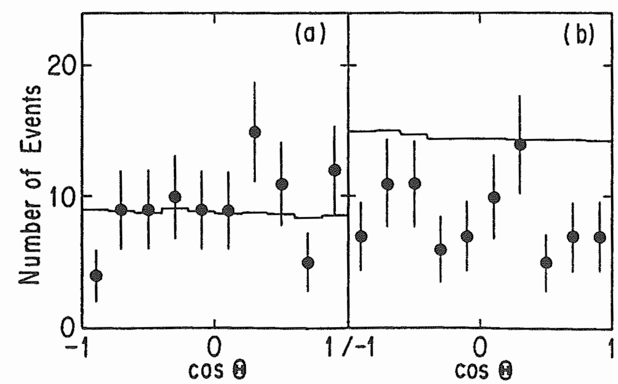
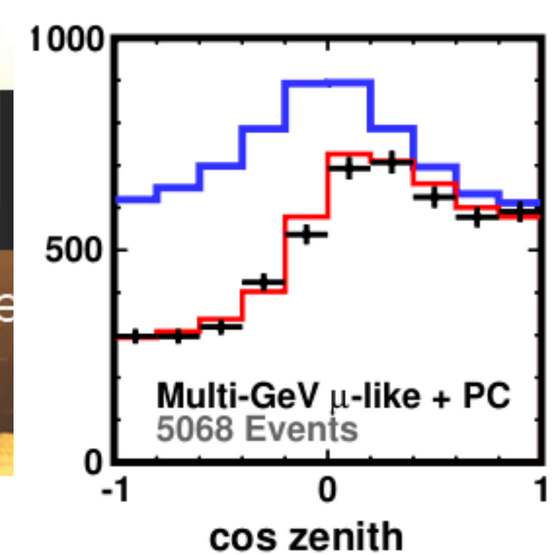


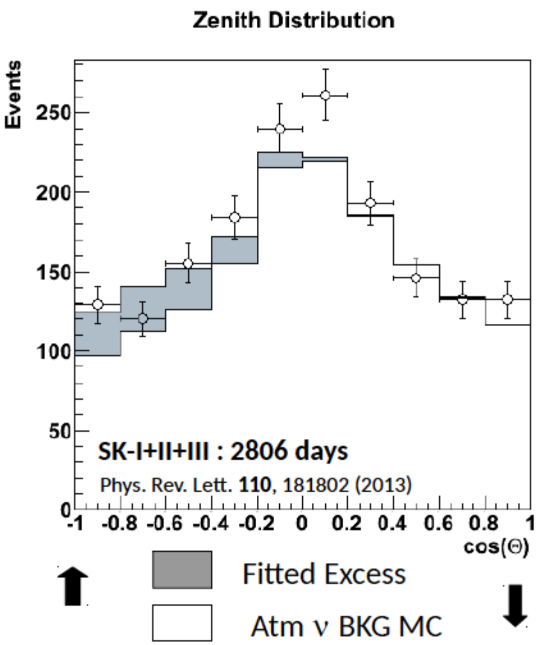
Fig. 3

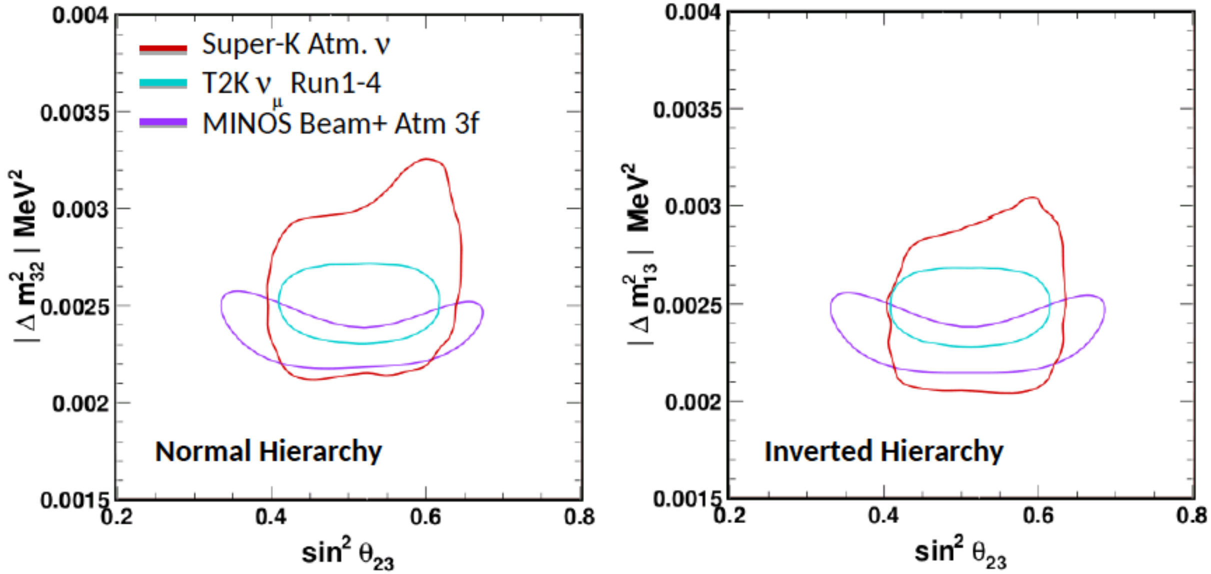
Zenith angle distributions for: Kamiokande (a) electron -like events and (b) muon-like events. cosΘ=1 corresponds to downward-going events. The histograms show the distributions expected from atmospheric neutrino interactions.



Super K Atmospheric ν





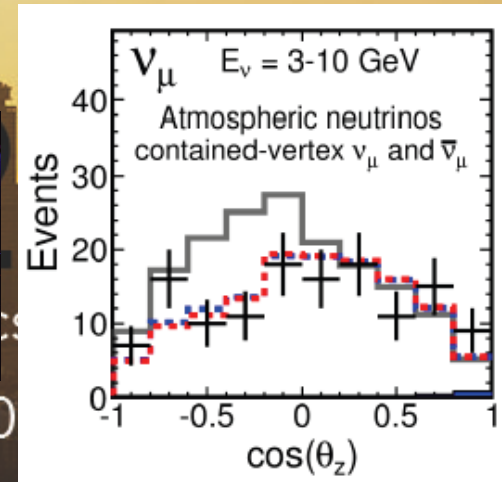


This corresponds to

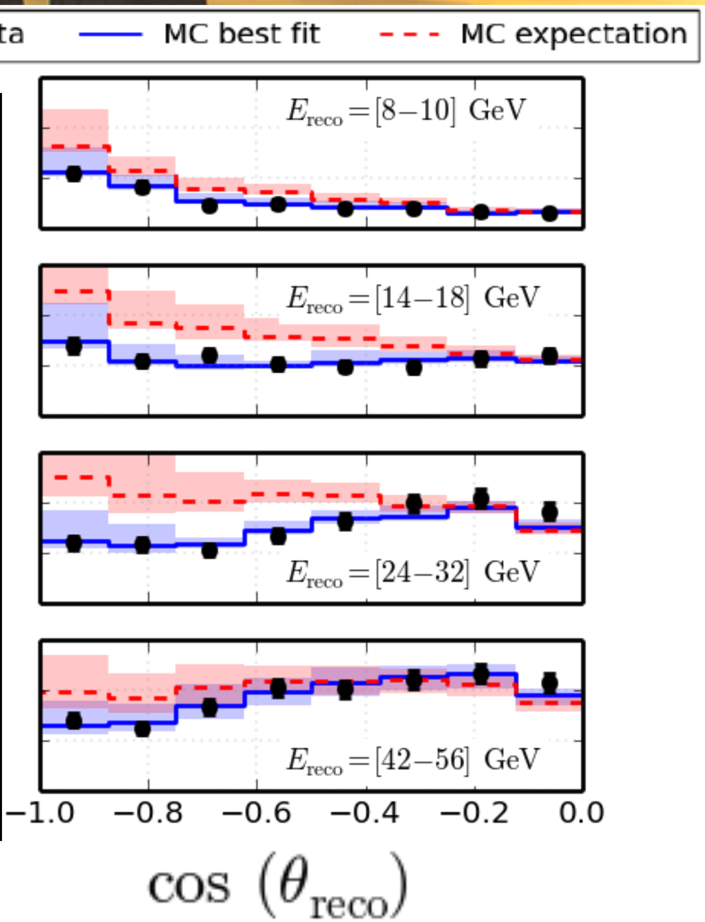
180.1 ±44.3 (stat) +17.8-15.2 (sys) events, a

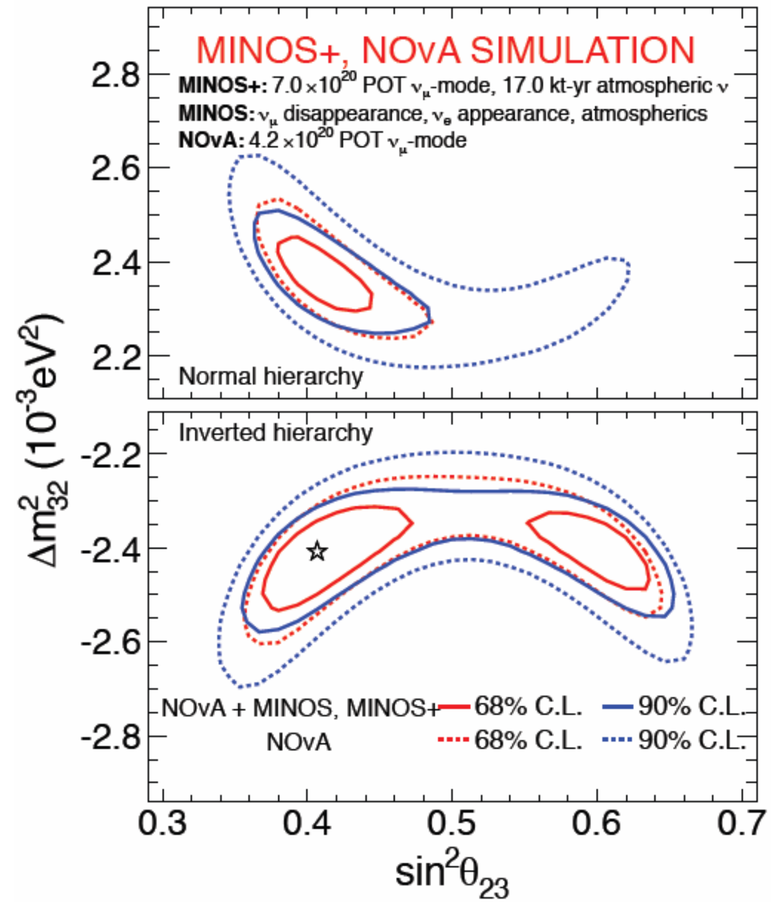
3.8 σ excess (Expected 2.7 σ significance)

Atmospheric ν

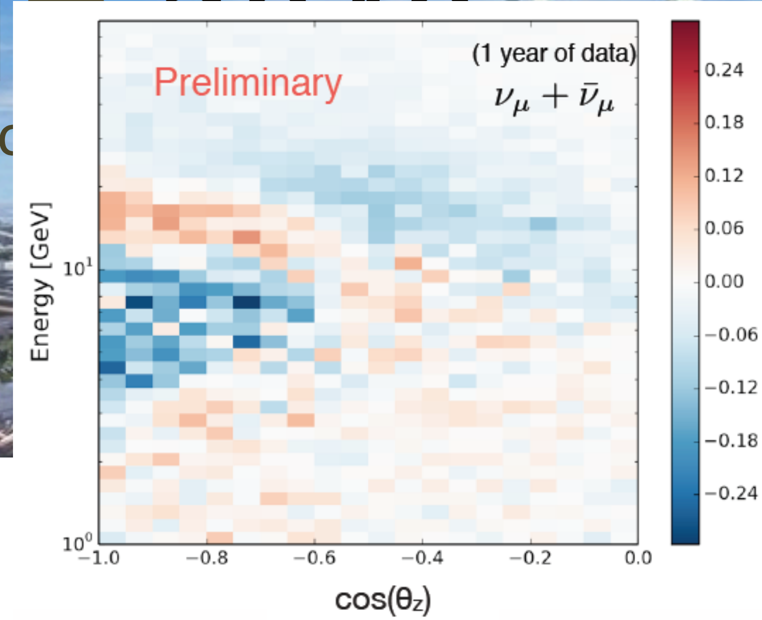


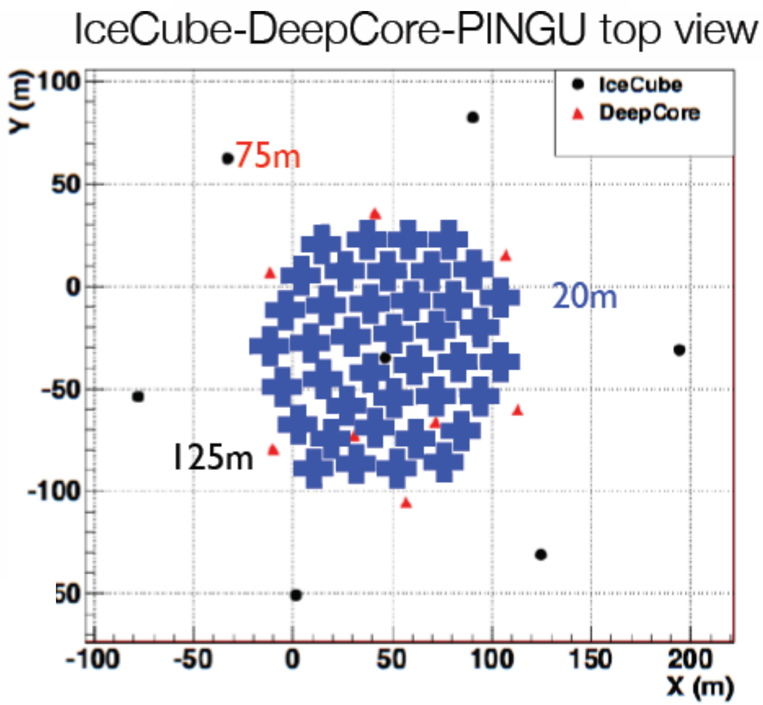
IceCube/DeepCore

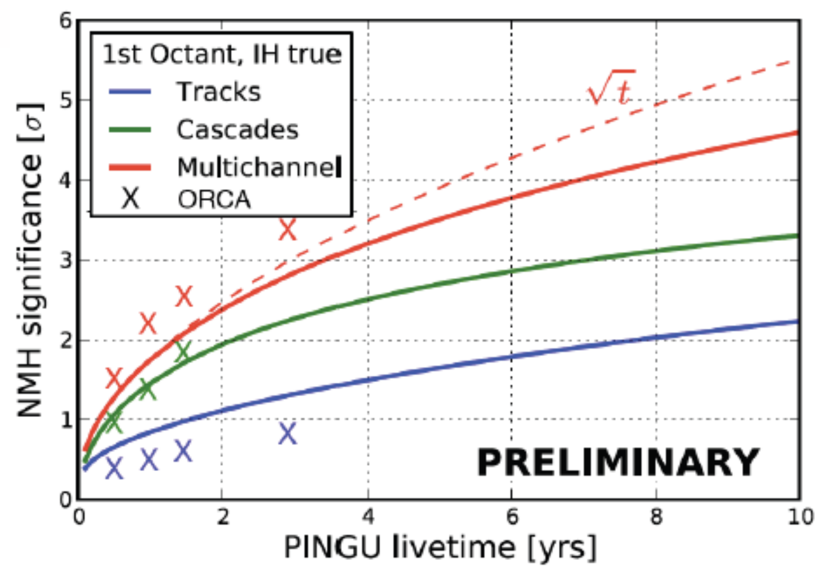


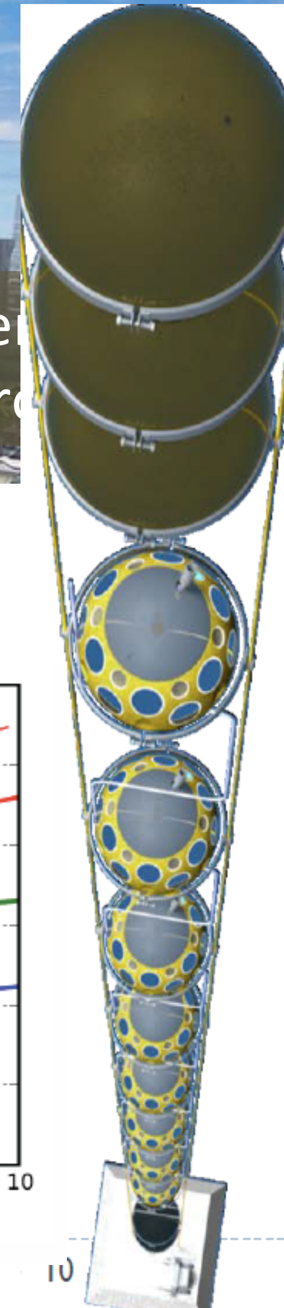


Atmospheric ν





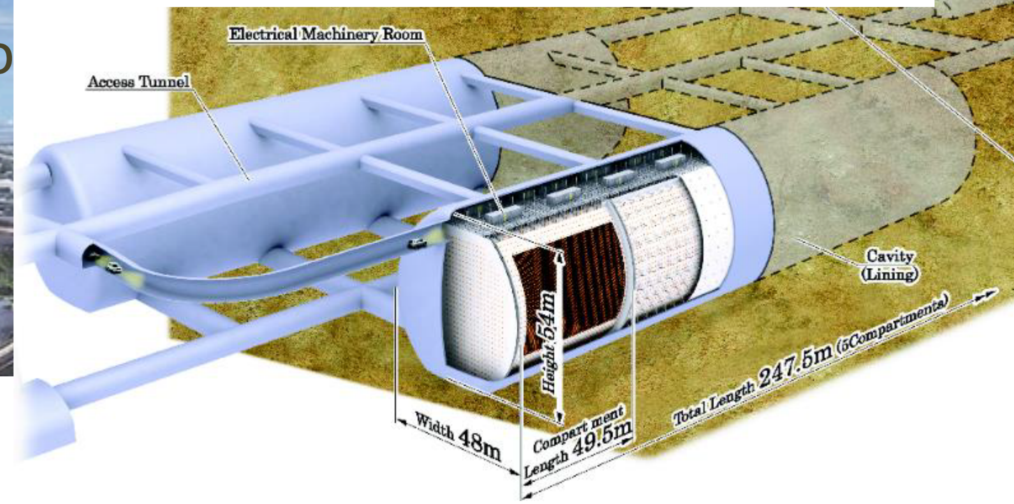


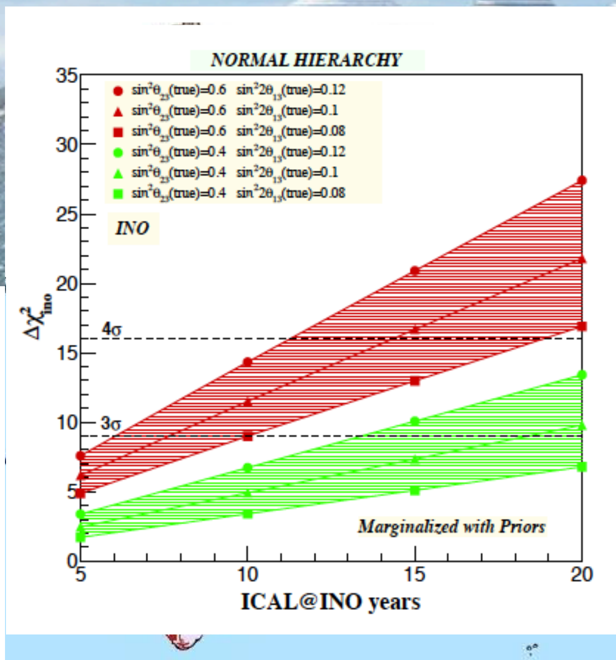


ORCA

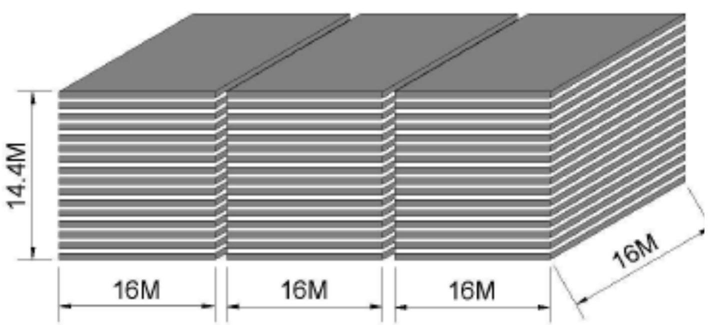
Atmospheric ν

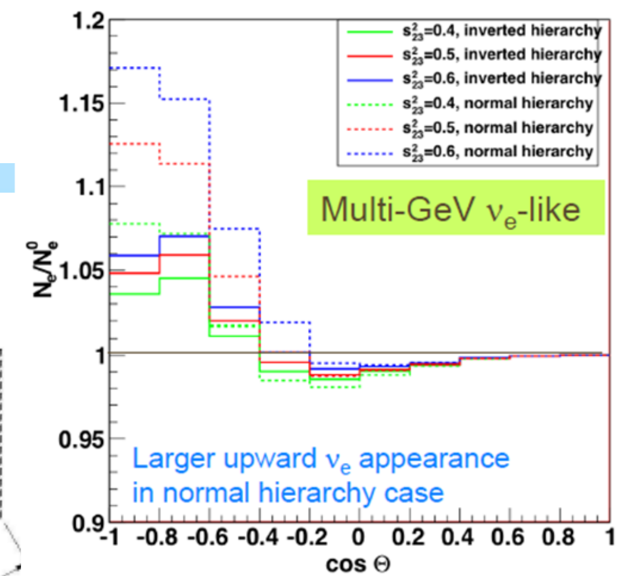
Hyper-Kamiokande

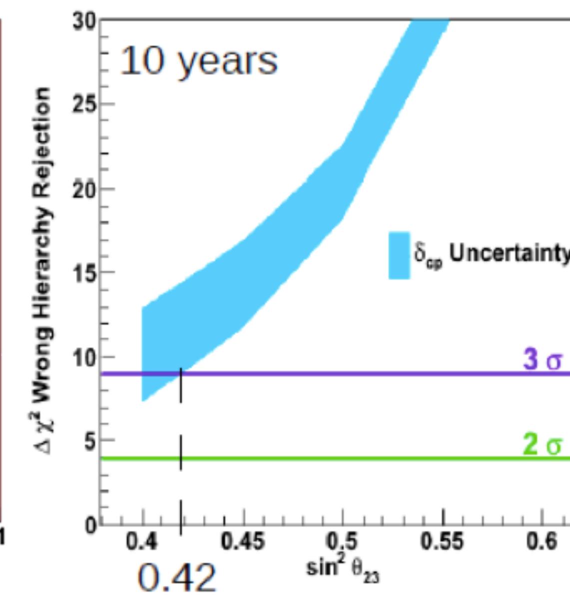




ICAL@INO







The UCI Liquid Argon TPC Program

presented by
Steven D. Biller
University of California, Irvine

Long Baseline ν Oscillations

I couldn't find a word about doing a long-baseline experiment.

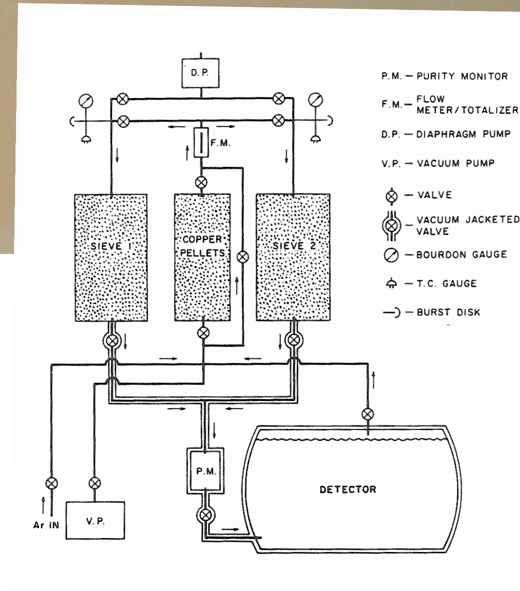


Figure 1 : Components of large-scale purification system.

ICARUS LIQUID ARGON IMAGING CHAMBER:
A NOVEL DETECTOR TECHNOLOGY

Presented by
Alessandra Ciocio

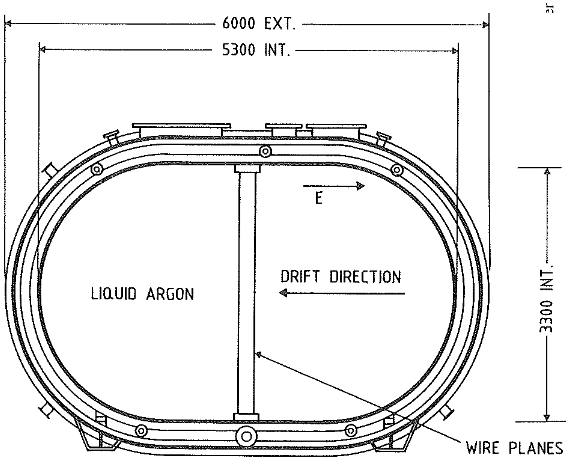
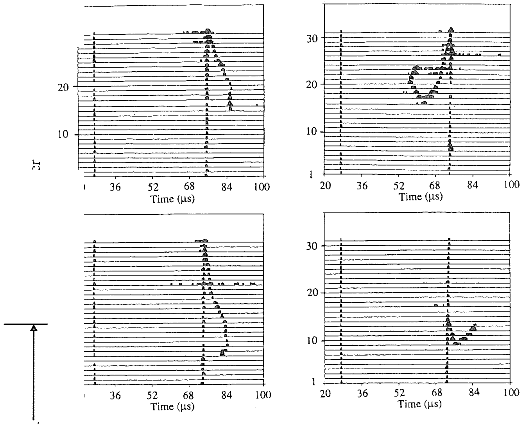


Figure 7.— Cross section of the 210 m^3 ICARUS I dewar



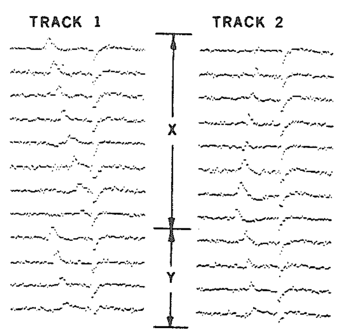
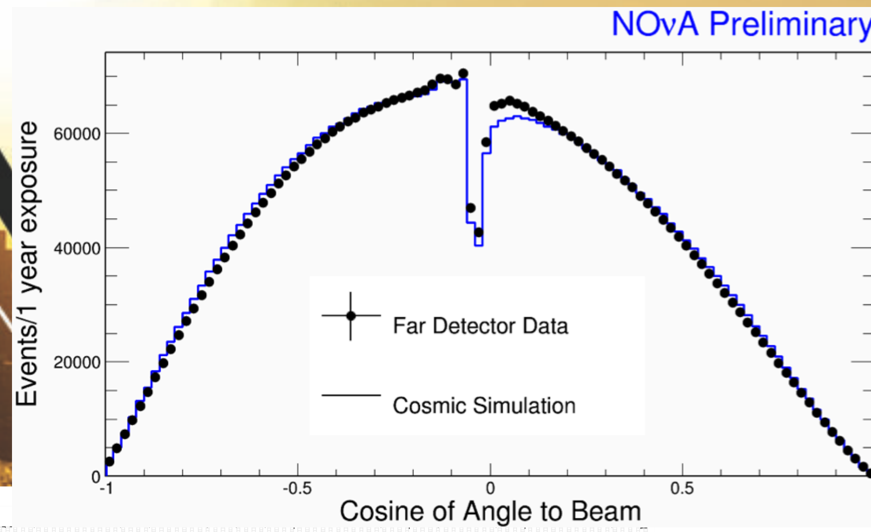
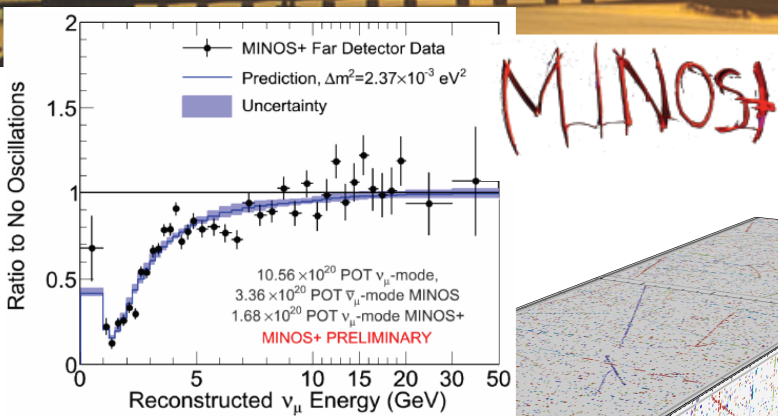


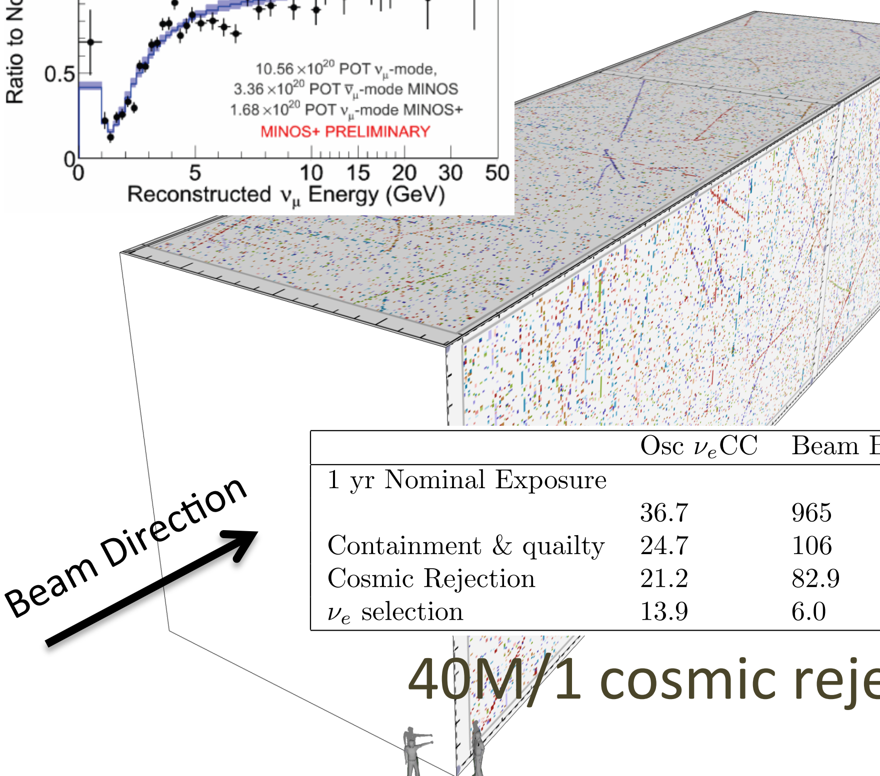
Figure 3 : Two examples of 3-dimensional tracks showing the signals on 8 X and 4 Y coordinates digitized at 1 MHz. The amplitudes of the negative calibration pulses correspond to 1.5 fc of charge.

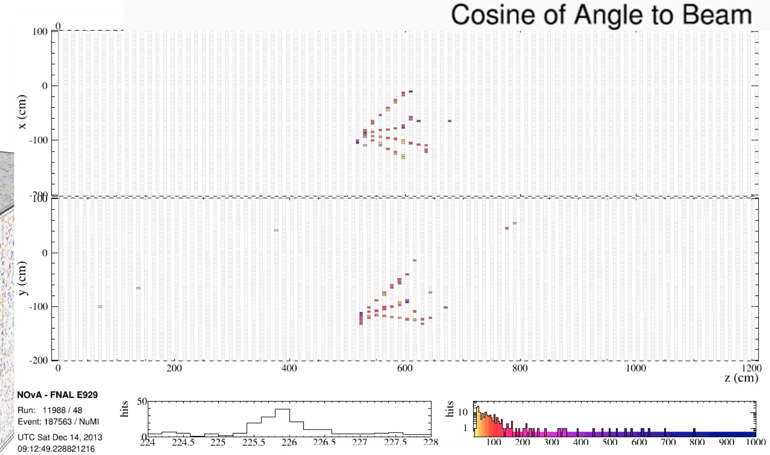
Long Baseline ν Oscillations

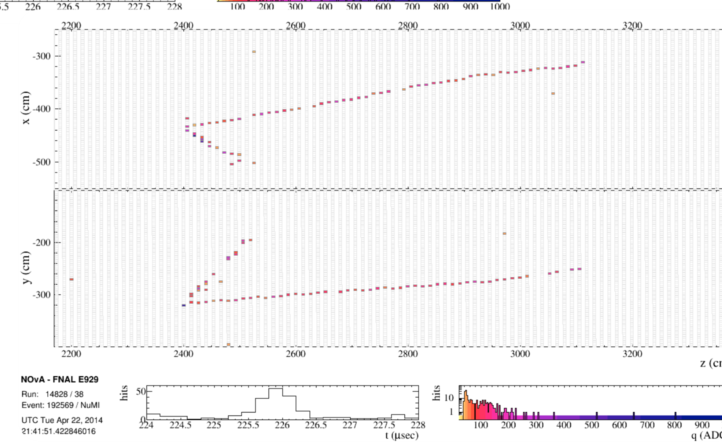
The NOνA Experiment







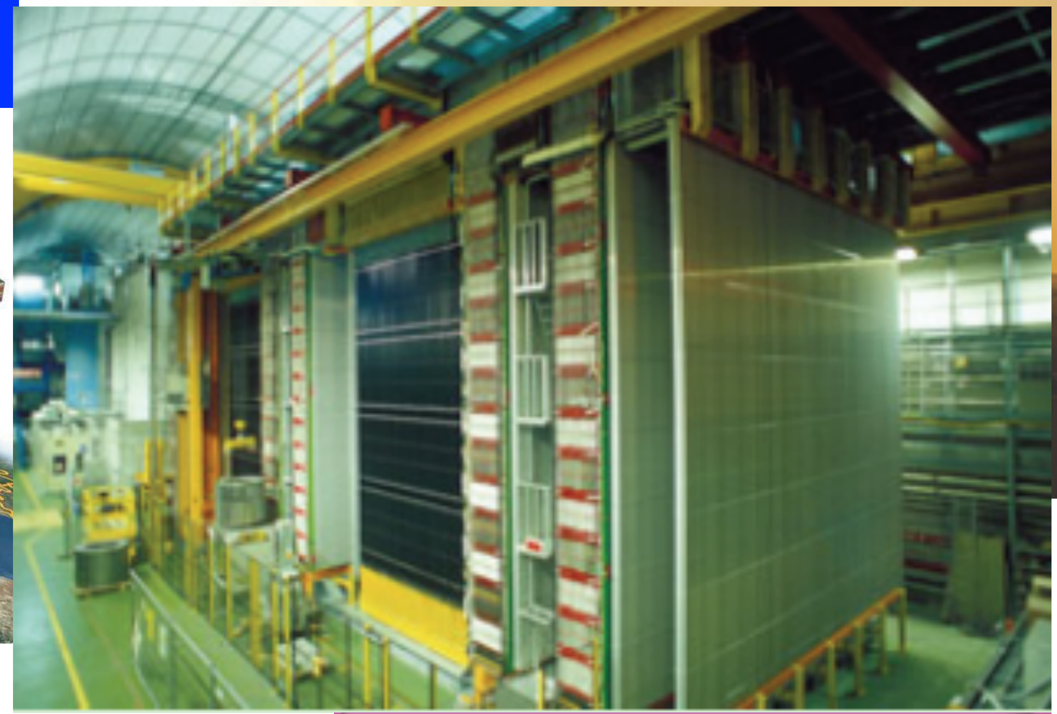




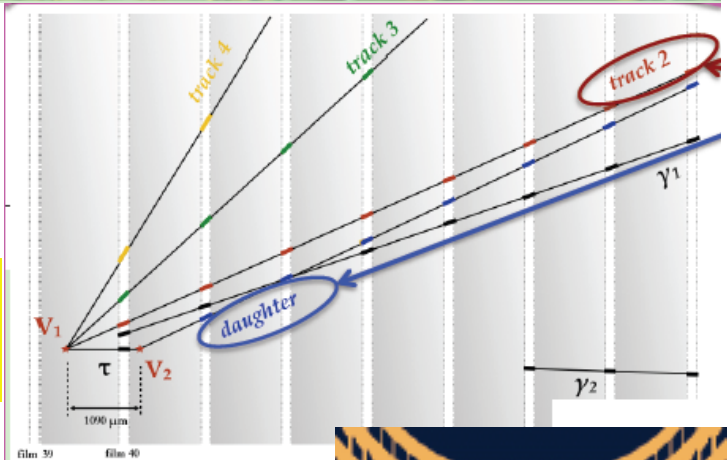
	Osc ν_eCC	Beam Bkg	Cosmic Bkg
1 yr Nominal Exposure			
	36.7	965	19M
Containment & quailty	24.7	106	55k
Cosmic Rejection	21.2	82.9	834
ν_e selection	13.9	6.0	0.46

40M/1 cosmic rejection!

Long Baseline ν Oscillations

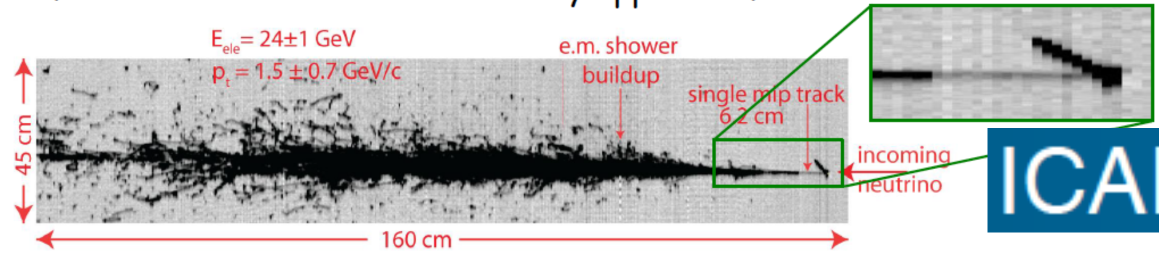


Decay channel	Expected signal $\Delta m_{23}^2 = 2.32$ meV^2	Total background	Observed
$\tau \to h$	0.4 ± 0.08	0.033 ± 0.006	2
$\tau \to 3h$	0.57 ± 0.11	0.155 ± 0.03	1
$\tau \to \mu$	0.52 ± 0.1	0.018 ± 0.007	1
$\tau \to e$	0.61 ± 0.12	0.027 ± 0.005	0
Total	2.1 ± 0.42	0.23 ± 0.04	4



no oscillation excluded at 4.2 σ CL

- The evolution of the actual dE/dx from a single track to an e.m. shower for the electron shower is clearly apparent from individual wires.

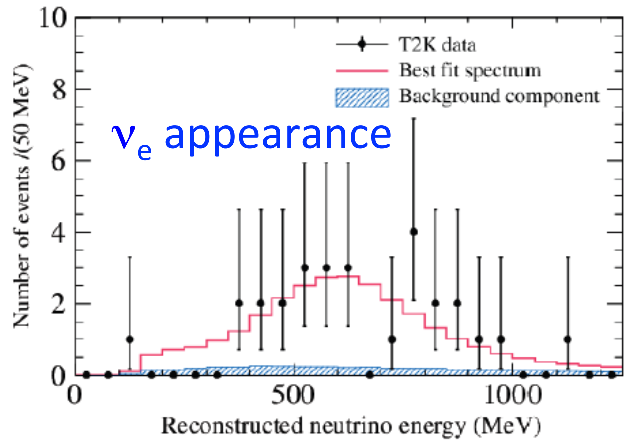


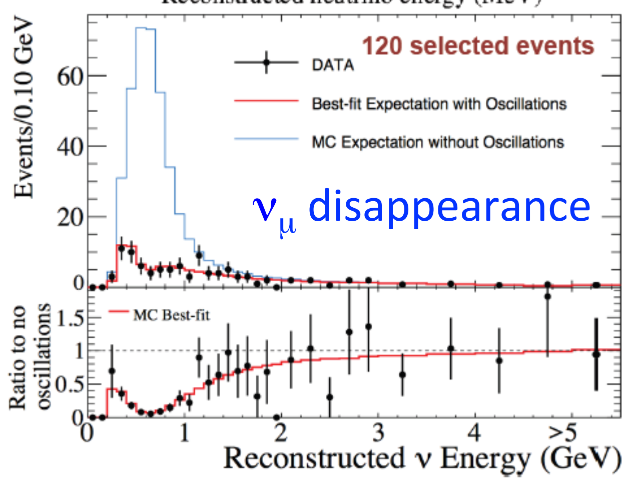
ICARUS

OPERA

Long Baseline ν Oscillations

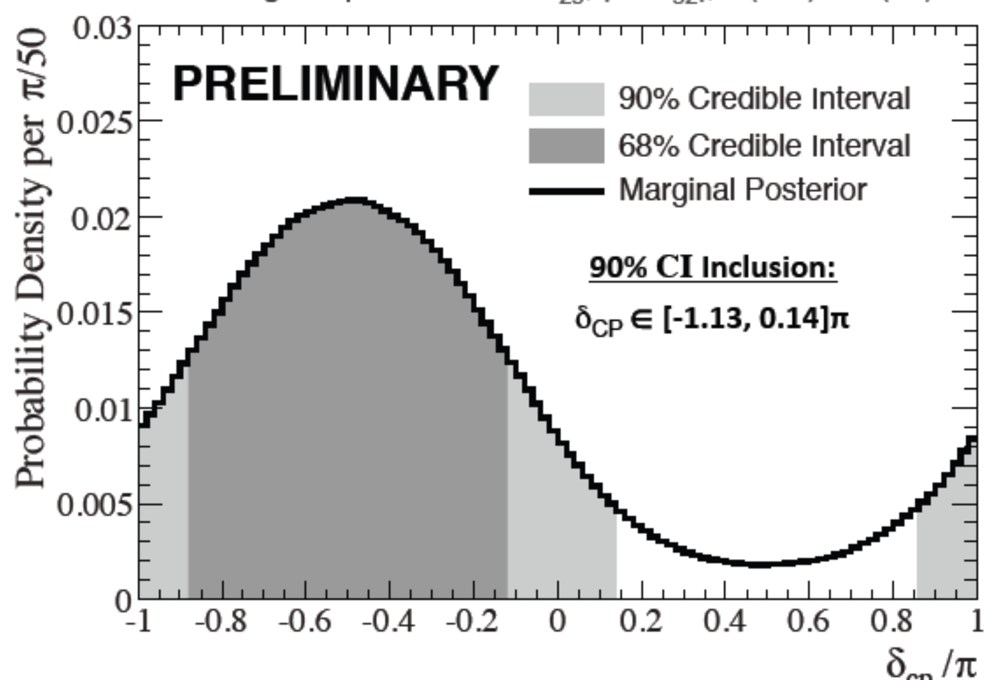
The T2K Experiment



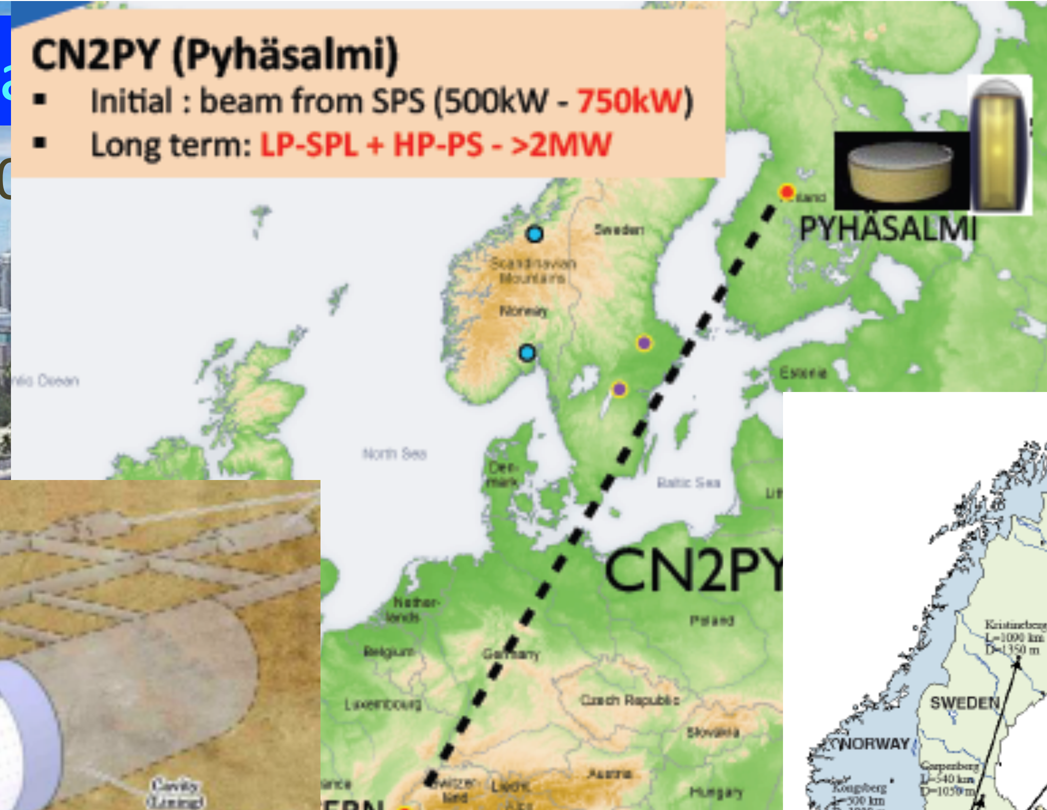


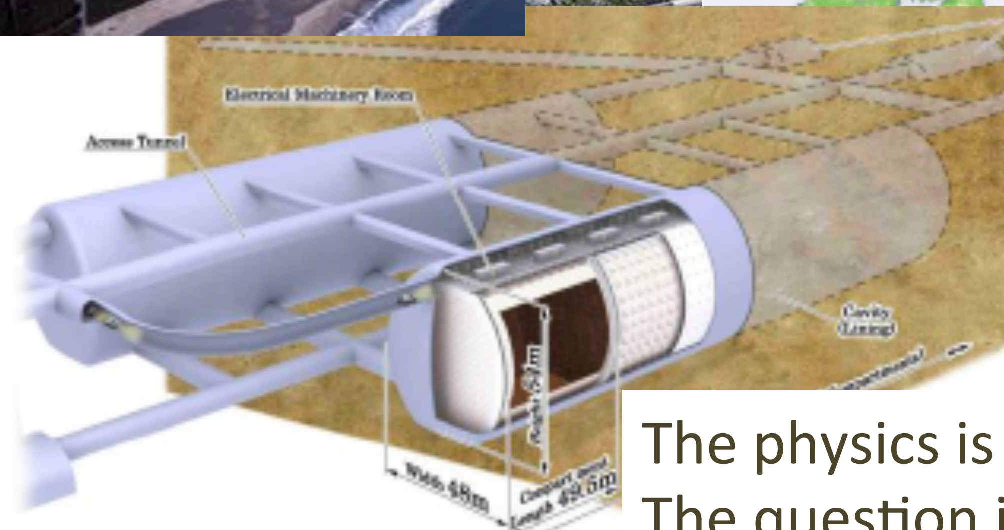
T2K Joint $\nu_\mu + \nu_e$ Bayesian Analysis

Assuming flat priors for $\sin^2\theta_{23}$, $|\Delta m^2_{32}|$; P(NH) = P(IH) 0.5



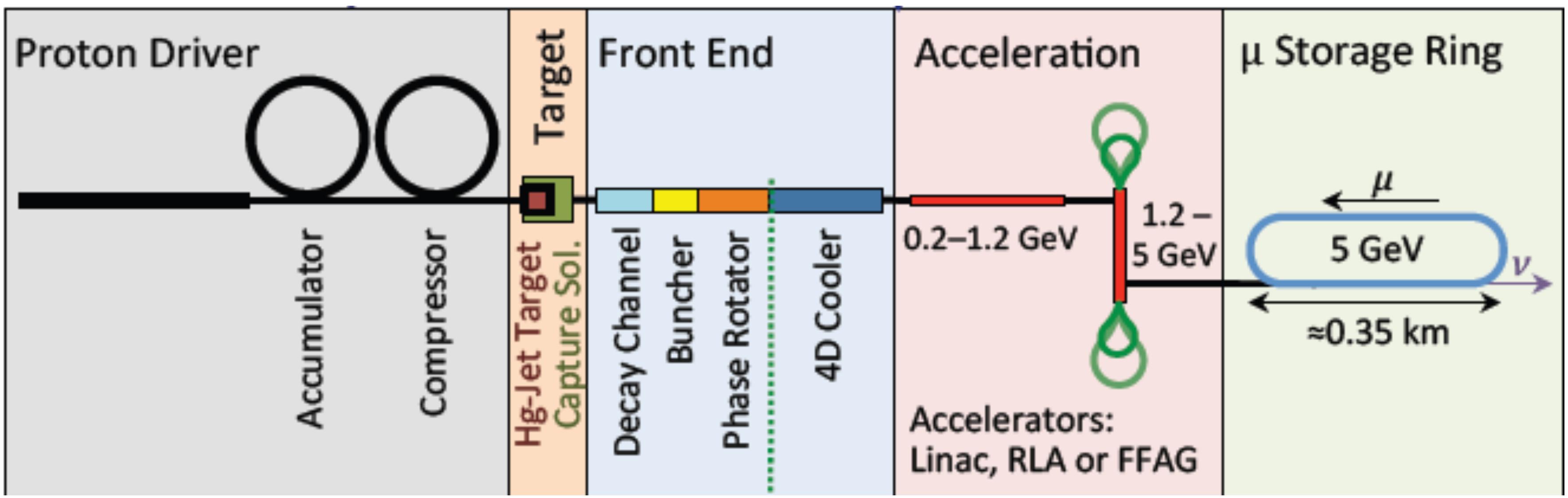
Long Baseline ν Oscilla





The physics is compelling,
The question is which to build?

Long Baseline ν Oscillations



If we want to reach accuracy in mixing parameters comparable to the CKM, we will need a NF, and if we want one of those, we must be working now.

ν interactions and hadron production

6. Neutrino Interactions at Accelerators

Chairs: H.H. Bingham and D.R.O. Morrison

A new method to investigate the nuclear effect in leptonic interactions
T. Kitagaki 176

Review of nucleon structure functions
F.E. Taylor 184

The parton distributions in nuclei and in polarized nucleons
F.E. Close 199

Review of multilepton production
W.H. Smith 215

Tests of PCAC and coherent production on nuclei
P. Marage 231

Hadron production in high energy neutrino and antineutrino collisions
N. Schmitz 243

Rare processes in $\nu_\mu - N$ interactions
S.R. Mishra 259

8. Neutrino Interactions at Accelerators II

Chair: T. Kitagaki

Recent results of the SKAT neutrino bubble chamber experiment
R. Nahnhauer 366

Determination of $sin^2\theta_W$ by muon neutrino and antineutrino scattering by electrons
M.V. Diwan 375

Results from $\nu_e - e^-$ elastic scattering at LAMPF
R.C. Allen 385

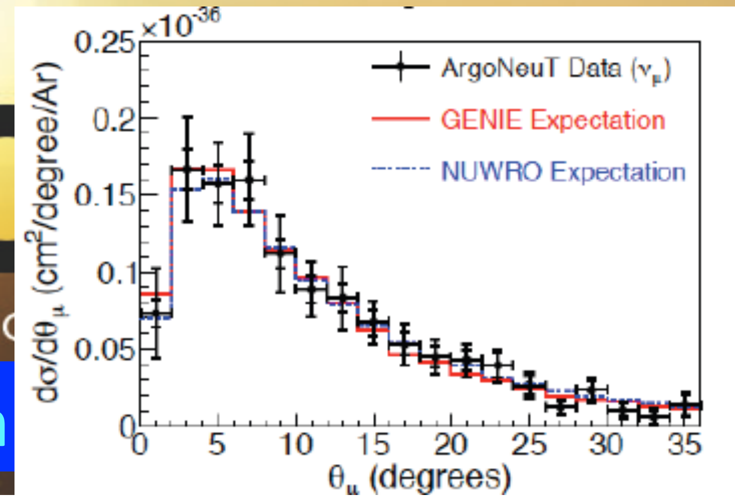
$\nu_\mu - \nu_e$ universality in charged-current neutrino interactions
S. Manly 391

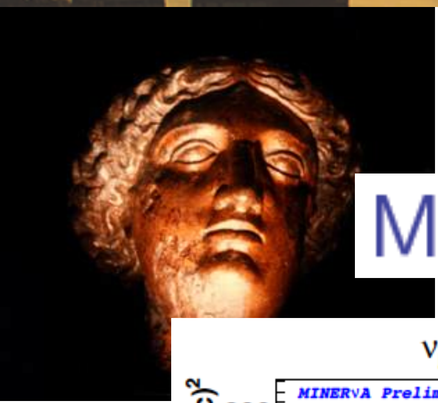
First results from the CHARM II experiment
A. Staude 397

Neutral weak current phenomena
K. Winter 403

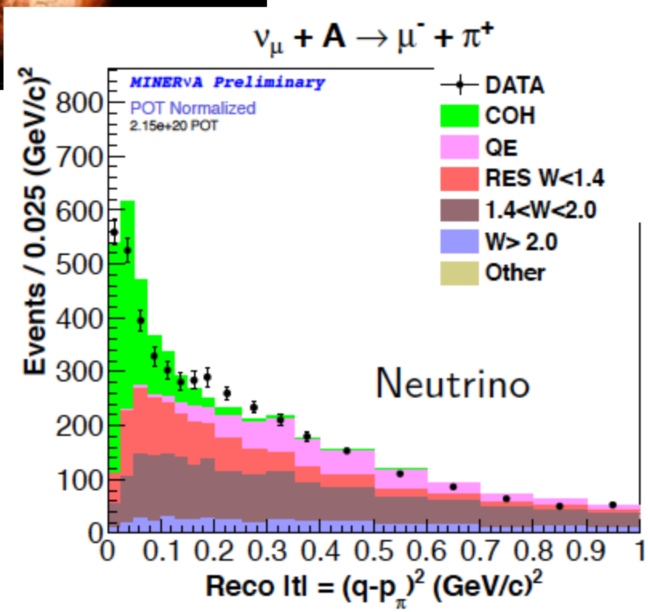
A study of deep inelastic processes with muons and tagged neutrinos at the Serpukhov accelerator
I.A. Savin 421

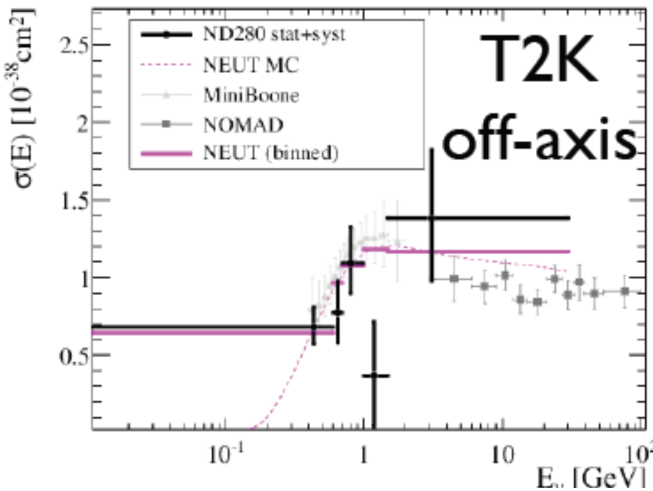
ν interactions and hadron production





MINERνA





MIPP

NA49

SHINE NA61

We need νStorm.

NEUTRINO 2040

June 4-9, 2040, Boston U.S.N.A.

national Conference on
Neutrino Physics and Astrophysics

ν interactions and hadron production

- I think we as a community need a clearer plan on how we are going to make progress here, and in particular, I think we need to recruit more theorists into this area.

Sterile ν

NEW LIMITS ON $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ OSCILLATIONS

Presented by
T.Y. Ling
The Ohio State University

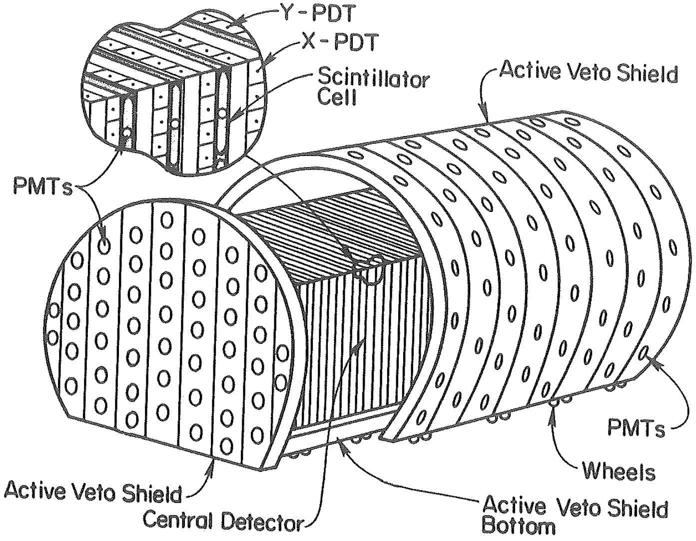


Figure 1 Isometric view of the detector and the cosmic-ray veto shield.

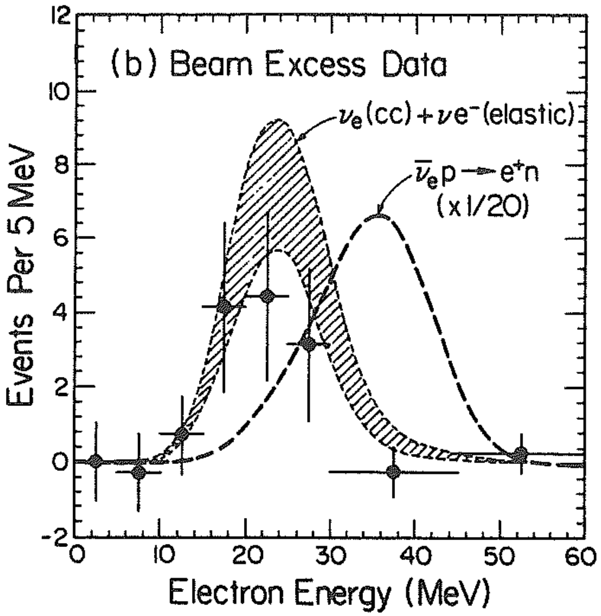


Figure 5 Visible energy distribution for the Beam-Excess electrons. The shaded band is the expected electron spectrum for ν_e CC reactions and νe elastic reactions. The dashed curve shows the maximum oscillation signal, scaled down by a factor of 20.

Sterile ν

- Many hints, which you just heard again.
- Apologies to today's speakers, but I am largely going to punt on this one.
- I certainly agree that we need to sort this out one way or the other.
- I certainly applaud the large degree of complementarity that is appearing in the programme.

Yale TPC

Location: Yale University
Active volume: 0.002 ton
operational: 2007

Bo

Location: Fermilab
Active volume: 0.02 ton
operational 2008

ArgoNeuT

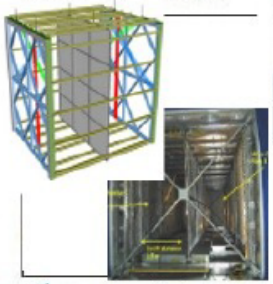
Location: Fermilab
Active volume: 0.3 ton
operational: 2008
First neutrinos: June 2009

MicroBooNE

Location Fermilab
Active volume: 0.1 kton
Operational: 2014

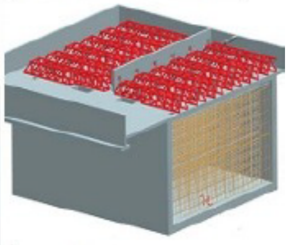
This talk

SBN @ FNAL



Location: Fermilab
Active volume: 0.05 + 0.6 kton
Construction start: 2017

LBNE



Location: Homestake
Active volume: 35 kton
Construction start 202?

Luke

Location: Fermilab
Purpose: materials test st
Operational: since 2008

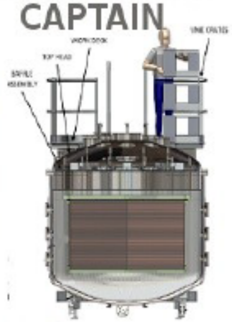
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2011

LArIAT

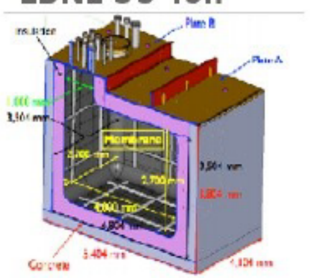
Location: Fermilab
Purpose: LArTPC calibration
Operational: 2014 (phase 1)

CAPTAIN



Location: LANL
Purpose: LArTPC calibration
Operational: 2014

LBNE 35 Ton



Location: Fermilab
Purpose: purity demo
Operational: 2013

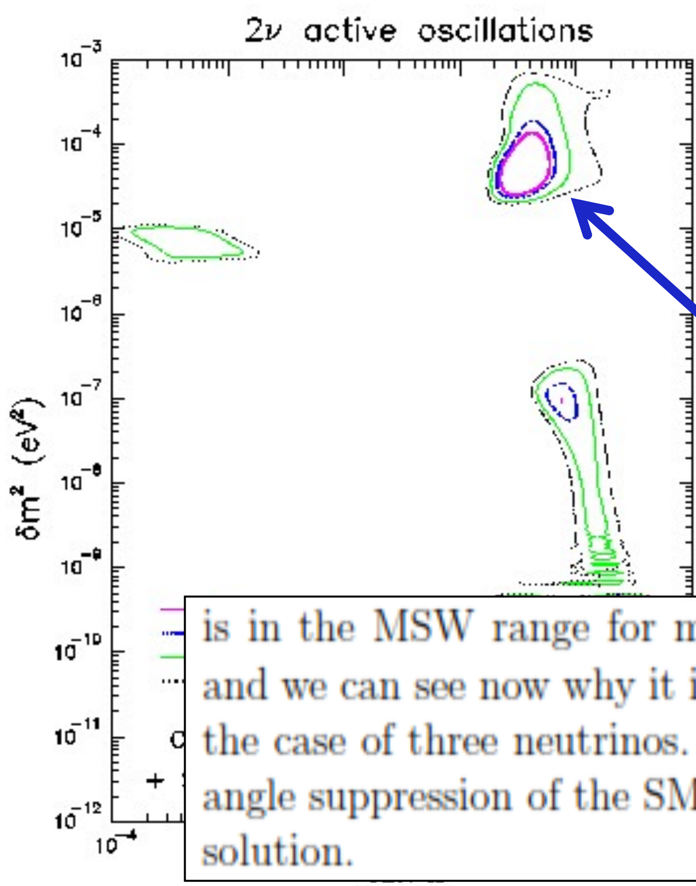
Sterile ν

- I do have one challenge for the theorists.
- How are we supposed to compare experiments when the dominant model (3+1) is already almost ruled out by experiment?
- Is there some more model-independent way to compare different experiments?

- I don’t know if it will be a routine bit of ν physics or an almost-forgotten bit of history, I just hope it isn’t still a controversy!

A couple of questions:

- How should we measure the MH?
  - Convincingly and Correctly.



CP-Violation in Neutrino Oscillations*

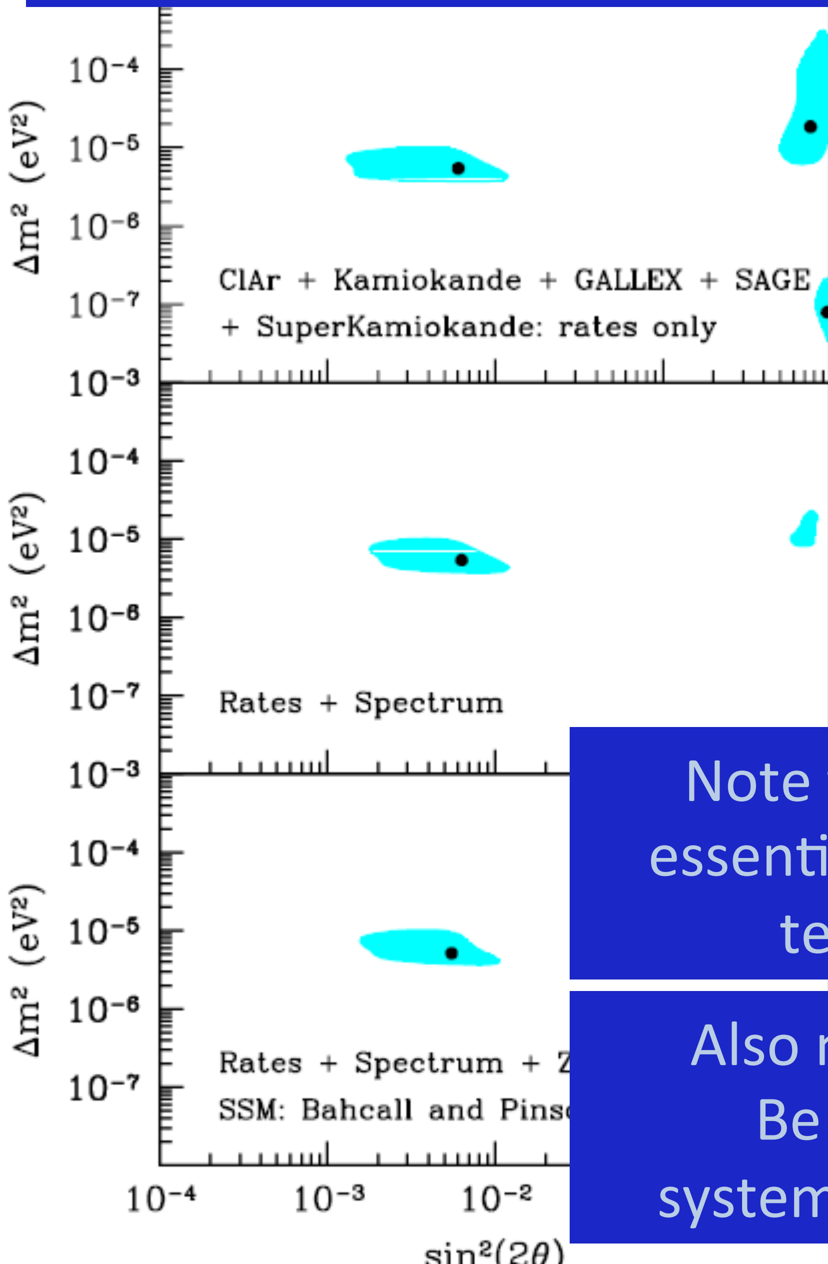
arXiv:hep-ph/9903308v3 17 Sep 1999

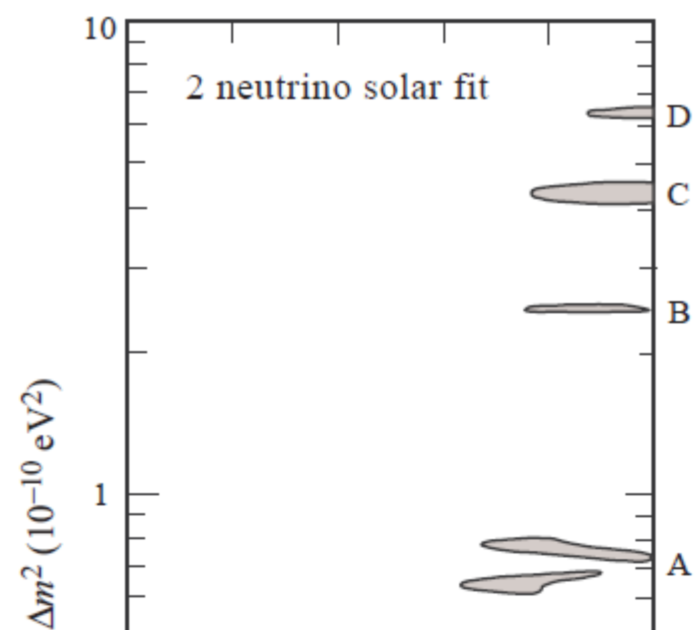
K. Dick[ab], M. Freund[c], M. Lindner[d] and A. Romanino[e]

is in the MSW range for maximal J, i.e. maximal mixing angle. This is the LMA case and we can see now why it is especially interesting from the point of CP-violating effects in the case of three neutrinos. The point is that this solution is neither affected by the small angle suppression of the SMA solution nor by the small $\Delta m^2_{\rm SUN}$ suppression of the vacuum solution.

These are 99% c.l. contours!

Using all data as of Neutrinos '98.





Note that these best fits would essentially rule out CP violation in terrestrial experiments.

Also note that they are wrong.
Be careful of global fits of systematics limited experiments!

arXiv:hep-ph/9905458v1 24 May 1999

arXiv:hep-ph/9812273v3 24 Feb 1999

A couple of questions:

- How should we measure the MH?
  - Convincingly and Correctly.
- Which project should we back to measure CP?
  - More than one of them!
  - We believe existing oscillations measurements because of multiple complementary techniques – we can do this again (accel. vs. reactor; ν vs. anti-ν, 1st vs 2nd max.) – let's make the case.

Since Neutrino 88 we have convincingly observed neutrino oscillations in atmospheric, solar, reactor, and accelerator neutrinos, and accurately measured many of the parameters. We have also seen the first high-E cosmic neutrinos, and the effects of relic neutrinos on cosmological measurables.

We still have waiting for us the MH, the octant, CP violation in neutrino oscillations, the absolute neutrino mass scale, Dirac vs. Majorana, supernovae neutrinos, possible sterile neutrinos, neutrino magnetic moments, coherent scattering, maybe even direct detection of relic neutrinos, and who knows what surprises.

One of you at the back of the room may well give the summary talk at Neutrino 2040. I am sure you will have even more progress to report, but only if as a field we work together to push everyone forward. Let's get at it!

Unfortunately I have to report that England will lose the 2040 World Cup to Gibraltar.

On penalties.