Neutrino Experiments:
Present, Plans, and ν Ideas

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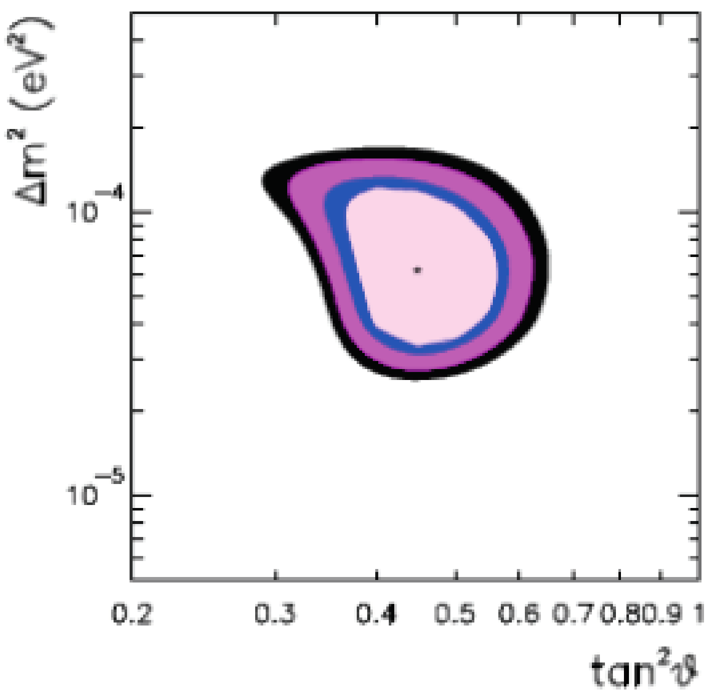
Columbia University
Pheno 2008

We have a fully self-consistent model
for how neutrinos behave:

They interact via only the weak interaction.
They have mass
They mix
… and therefore they oscillate

This model is predictive!

Allowed region for
solar neutrino oscillation
measurements,



fit by Gonzalez-Garcia

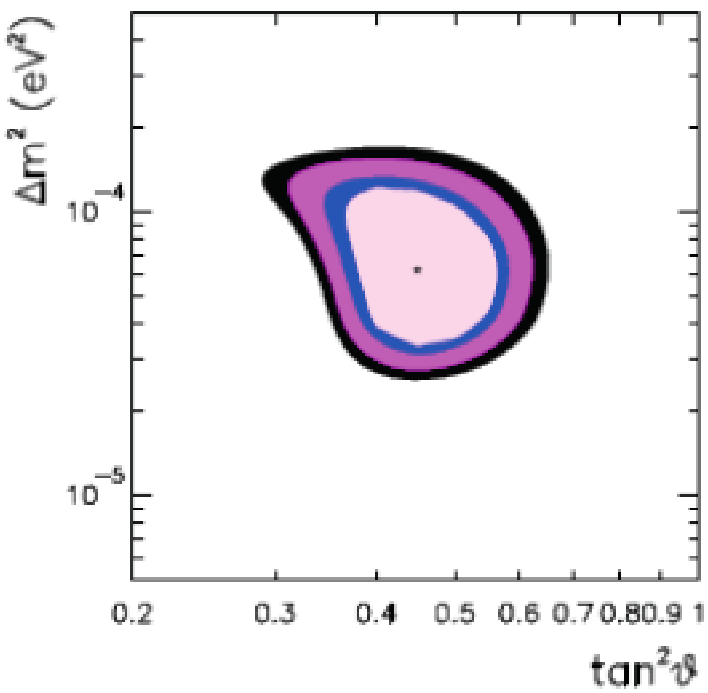
if this is due to $\nu_e \rightarrow \nu_{other}$

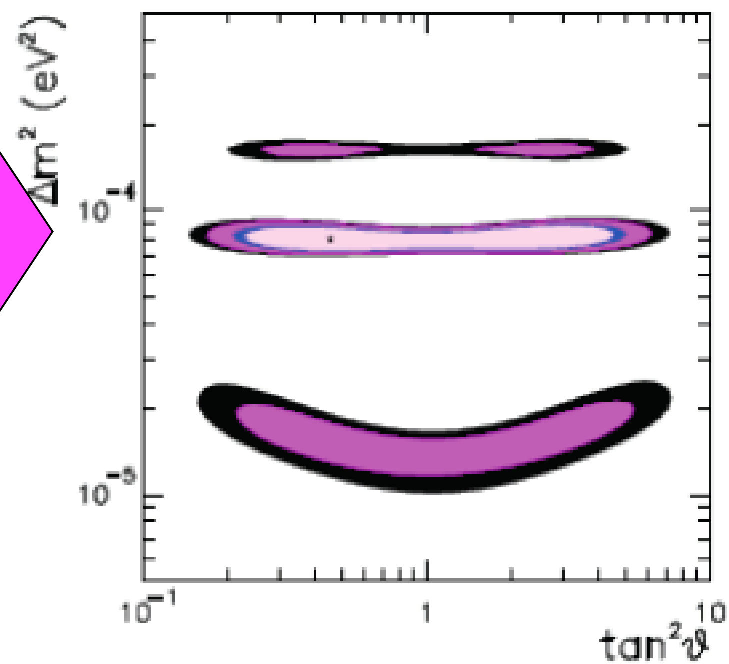
then $\bar{\nu}_e \rightarrow \bar{\nu}_{other}$
should be observable
with the same wavelength

This model is predictive!

Allowed region for solar neutrino oscillation measurements,

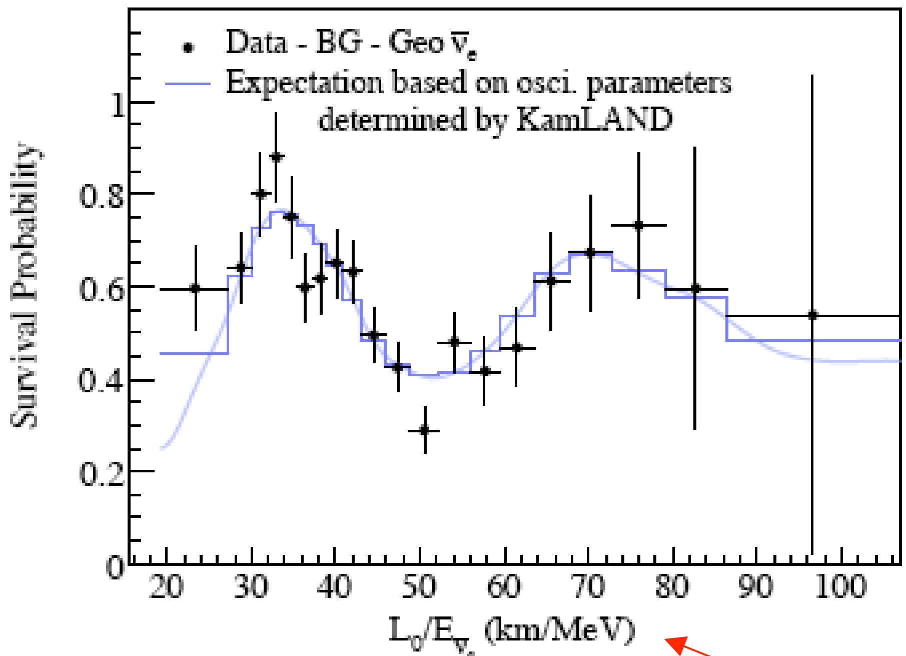
Allowed region for the Kamland reactor $\bar{\nu}_e \rightarrow \bar{\nu}_{other}$ Experiment!





fits by Gonzalez-Garcia

The result from the Kamland reactor experiment
also shows the L/E dependence one expects from oscillations!



$$P_{Osc} = \sin^2 2\theta \sin^2\left(1.27\Delta m^2 L/E\right)$$

arXiv:0801.4589

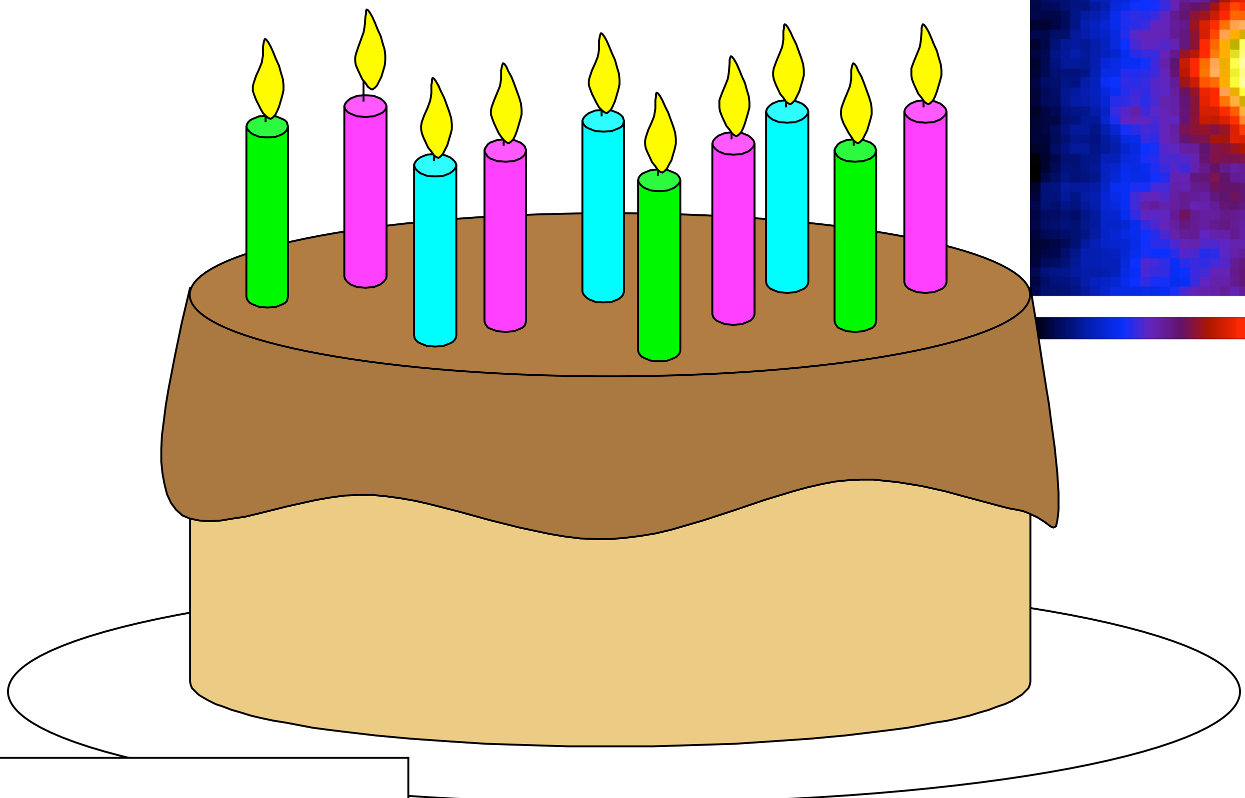
This is an amazing place to be,
considering where we were only 10 years ago.

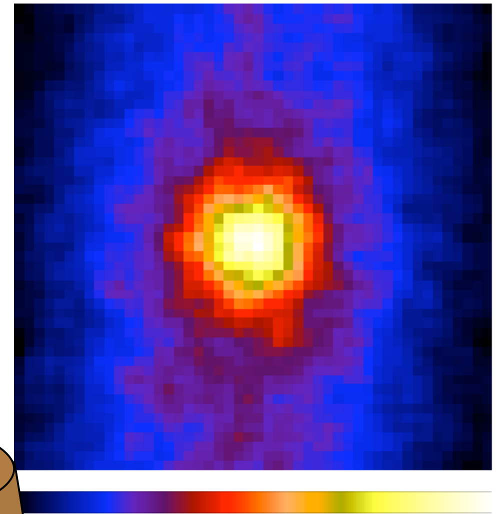
"neutrinos don't have mass, the SM says so!"

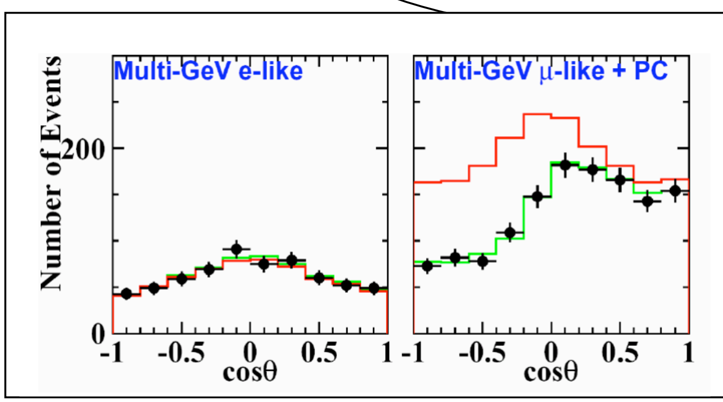
"But if they did have mass, then the natural scale is $\Delta m^2 \sim 10 - 100$ eV^2 In order to explain dark matter"

"And the oscillation mixing angles must be small because it must be like the quark mixing angles"

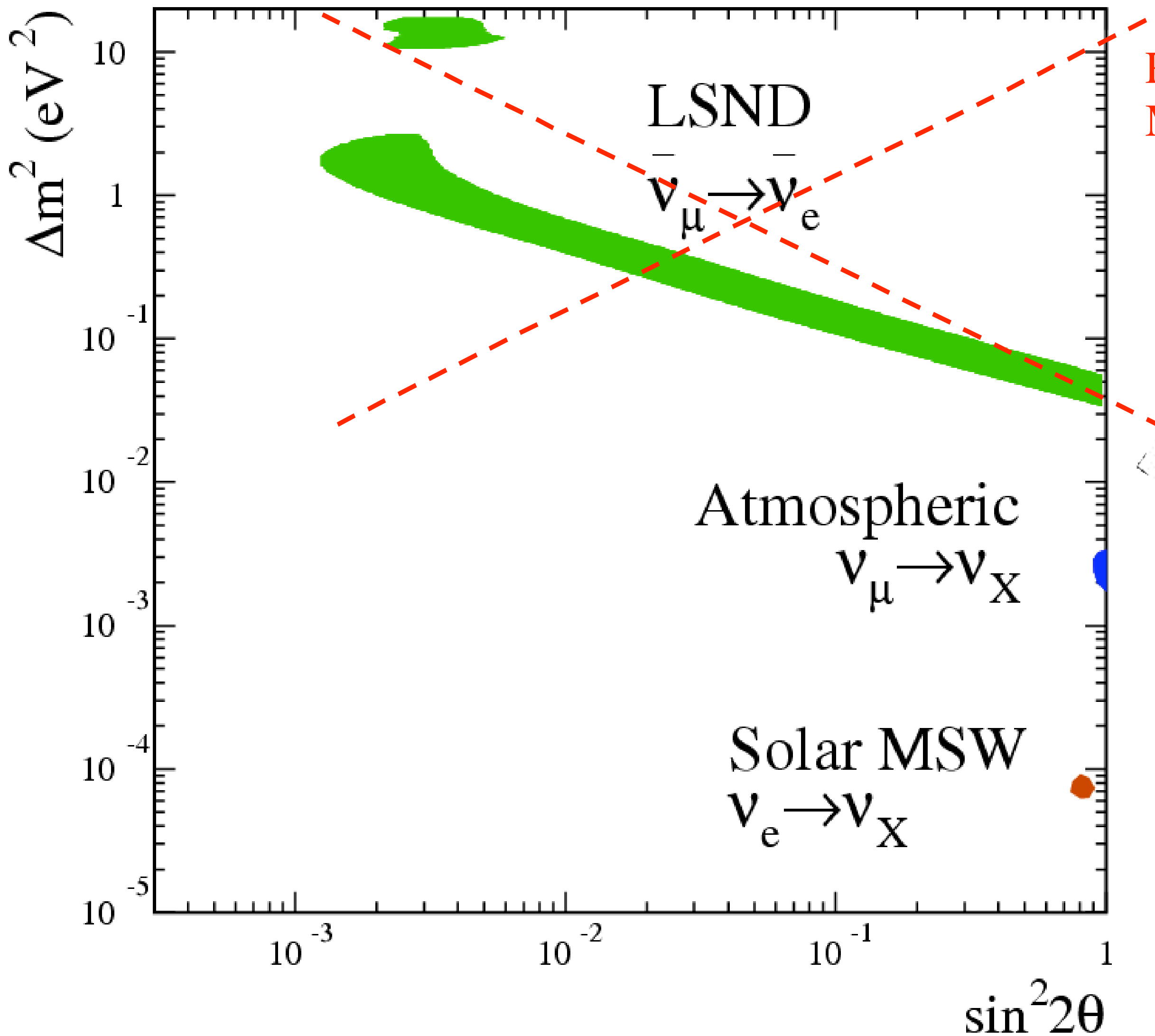
Happy 10th Anniversary
Super-K!



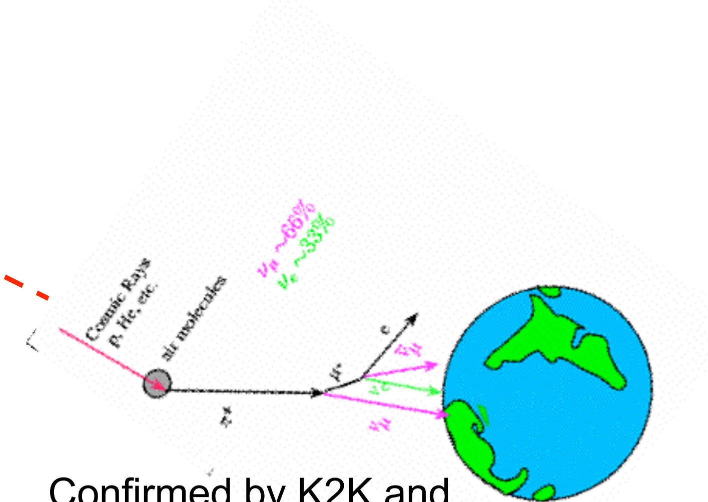




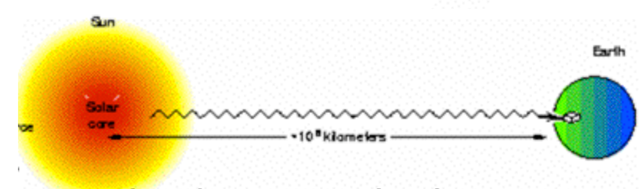
What we have learned since about oscillations...



Ruled out by
MiniBooNE in ν-mode



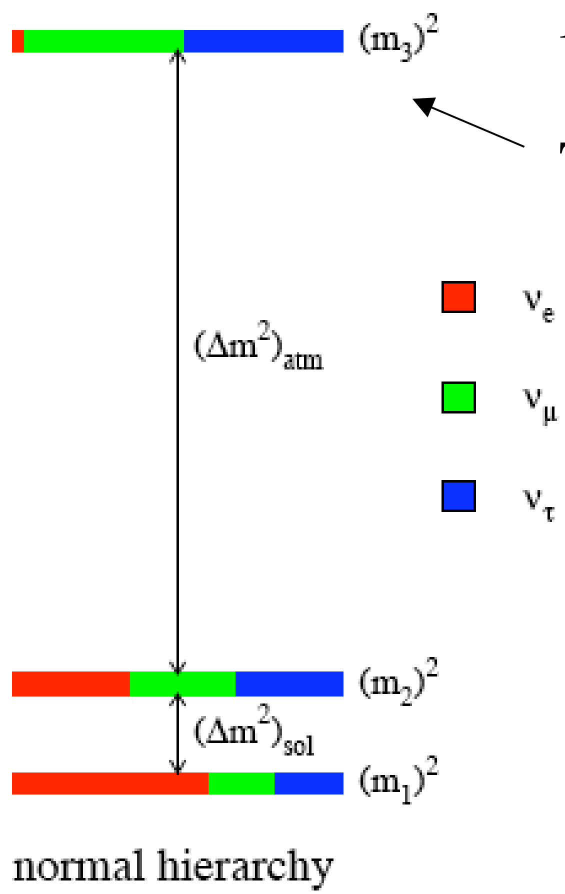
Confirmed by K2K and
Minos accelerator neutrino exps



Confirmed by SNO and
by Kamland
reactor neutrino exp

Our Model

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



BUT *mysteries* remain….

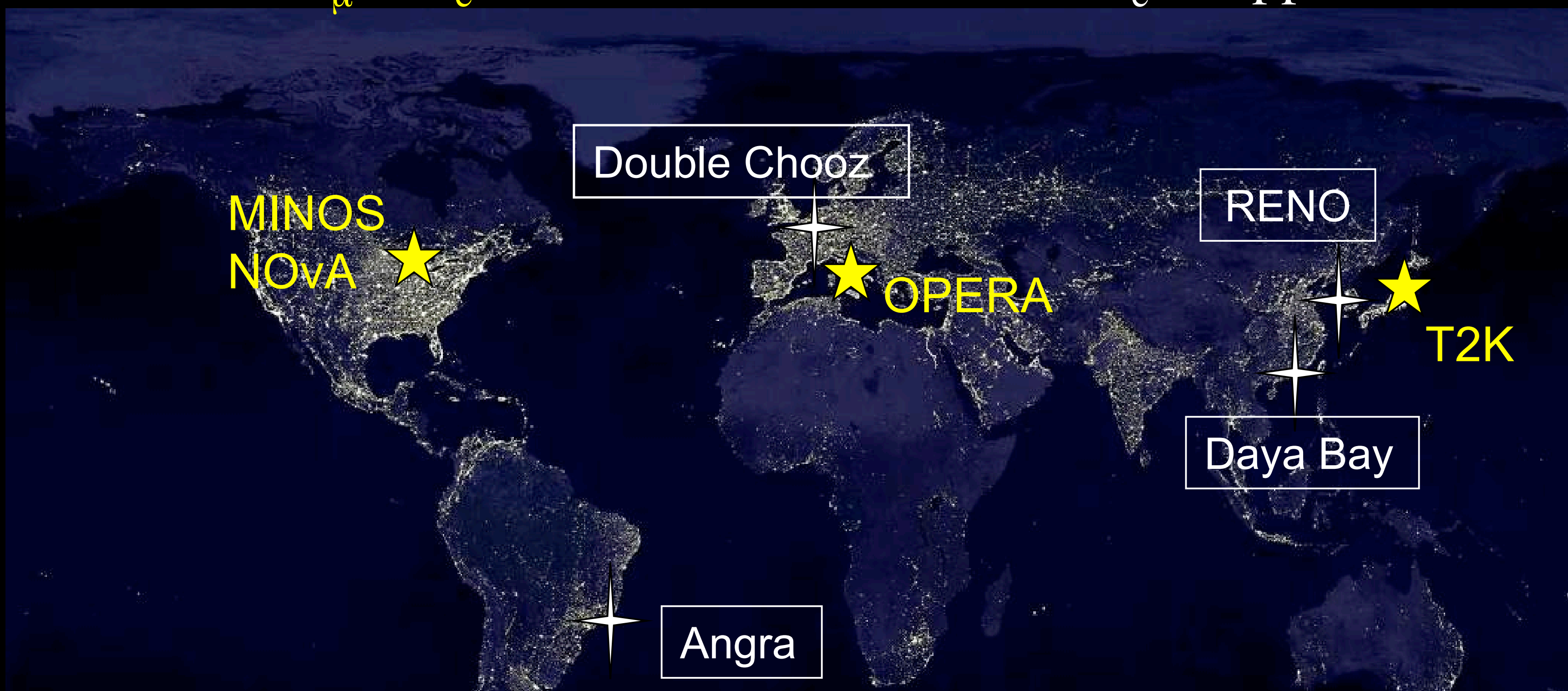
These center on ν_3

Question 1:
Is there any ν_e content?
or
What's the value of θ_{13}?

The Frenzy to Find θ_{13} is ON!!!!

★ = beam based, $\nu_\mu \rightarrow \nu_e$

✦ = reactor based, $\bar{\nu}_e$ disappearance



The value of θ_{13}

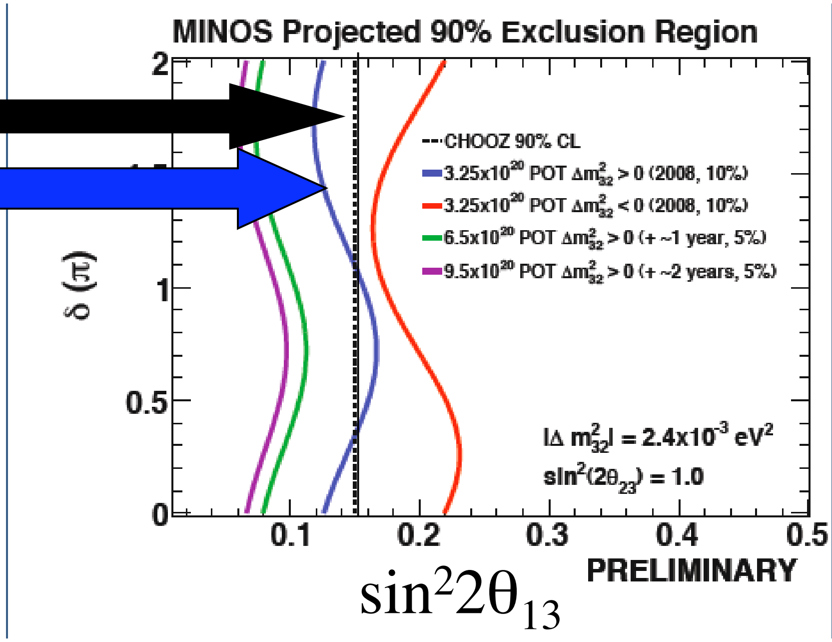
…may indicate new physics if it is small.

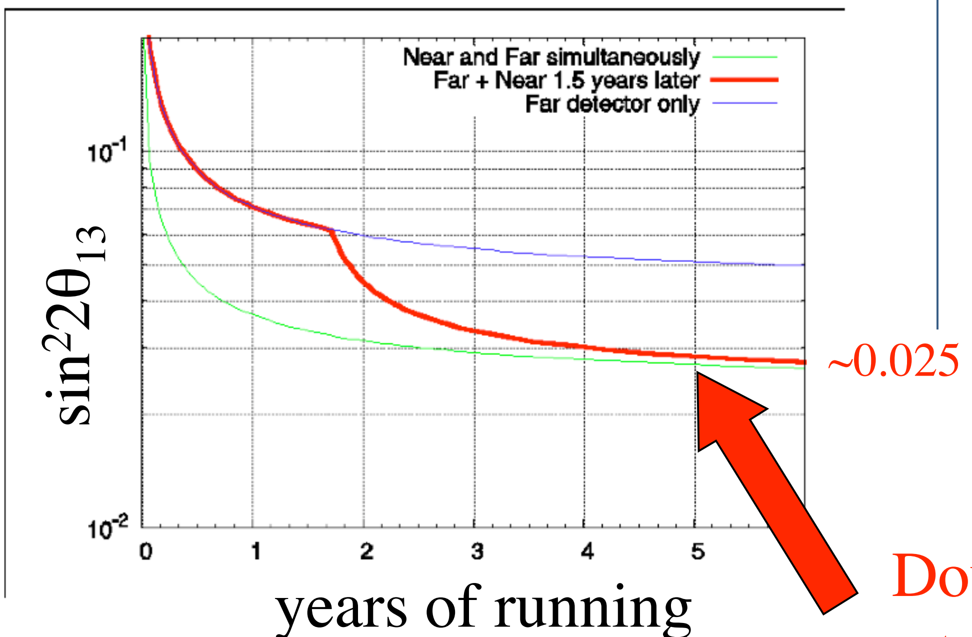
…opens the door to search for CP violation if it is large

The timeline for discovery….

We are here ($\sin^2 2\theta_{13}$~0.15)

Minos' results -- **this summer**!



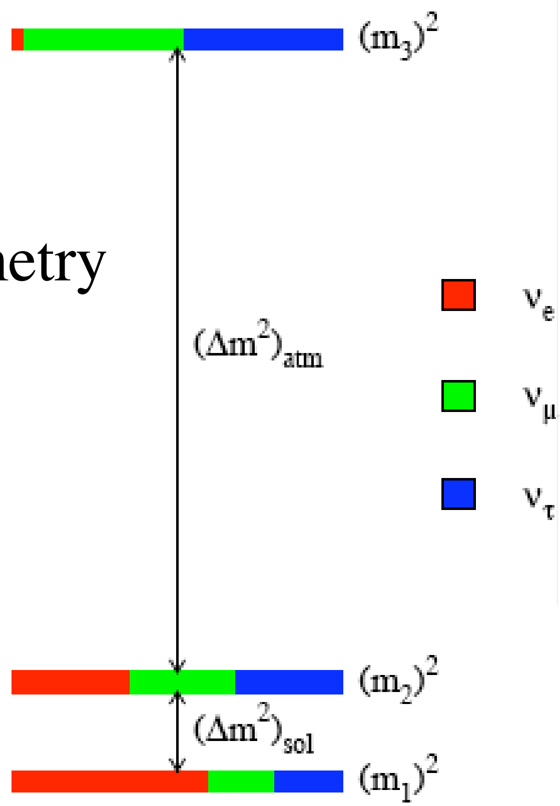


Double Chooz, **starting next year**, extending a factor of 5 to ~0.025

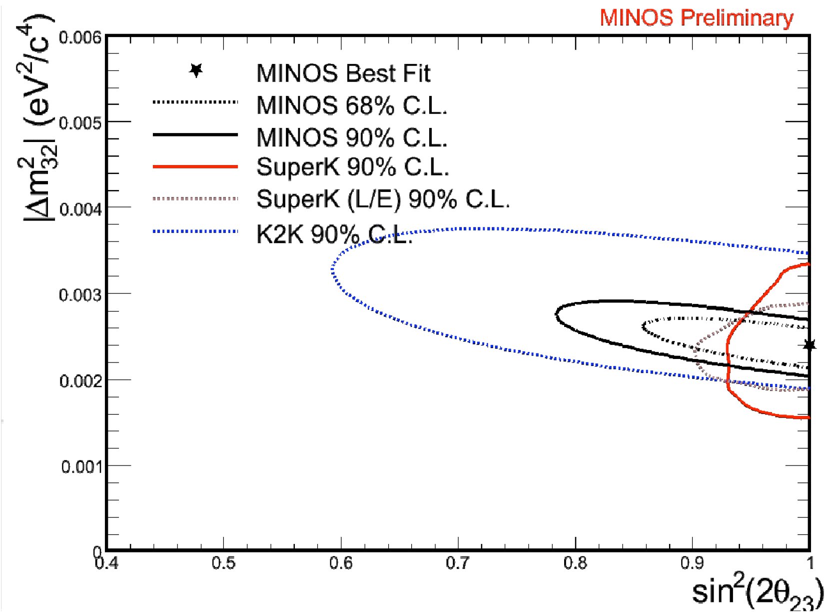
Daya Bay, extending another factor of >2 to ~0.01, **starting 2010**

Question 2: Are we seeing maximal mixing between ν_μ and ν_τ in ν_3?

Is there a μ and τ symmetry at the highest E scales ???



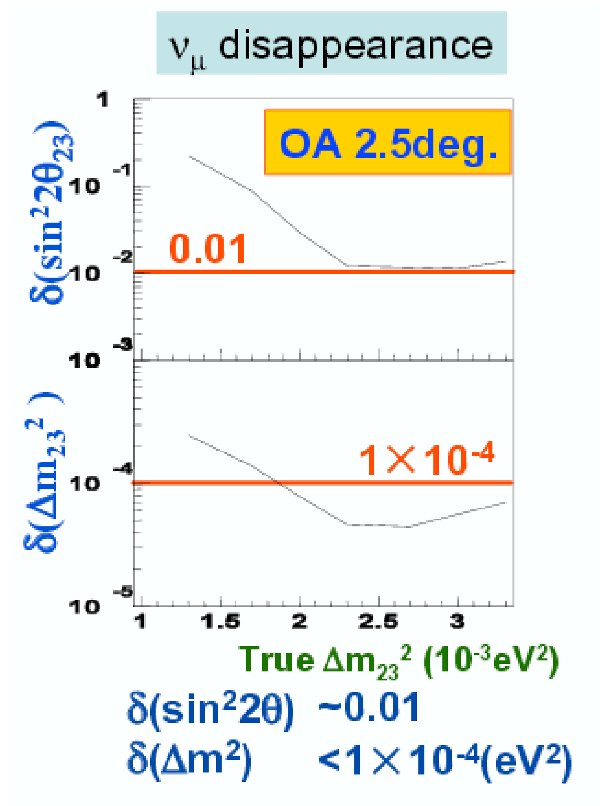
normal hierarchy



The new direction that ν physics is pointing is really unexpected!

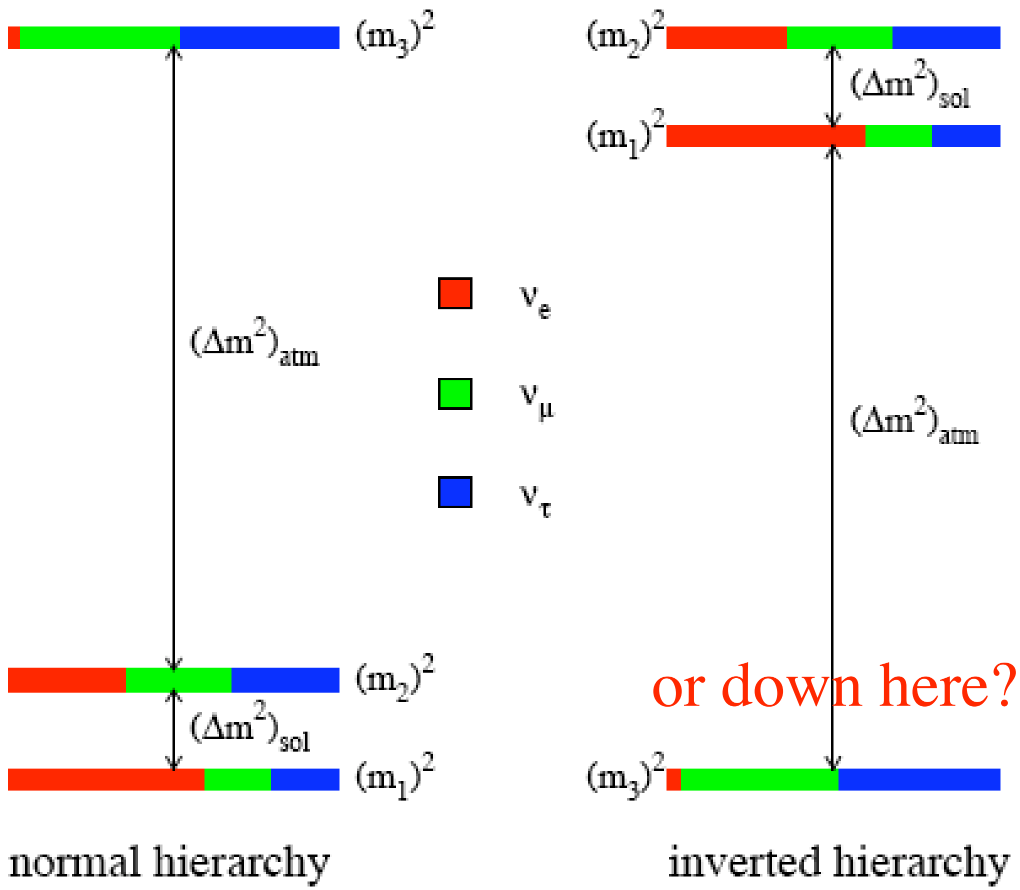
T2K will squeeze down further on the $\nu_\mu - \nu_\tau$ mixing angle

Expected to turn on in 2009



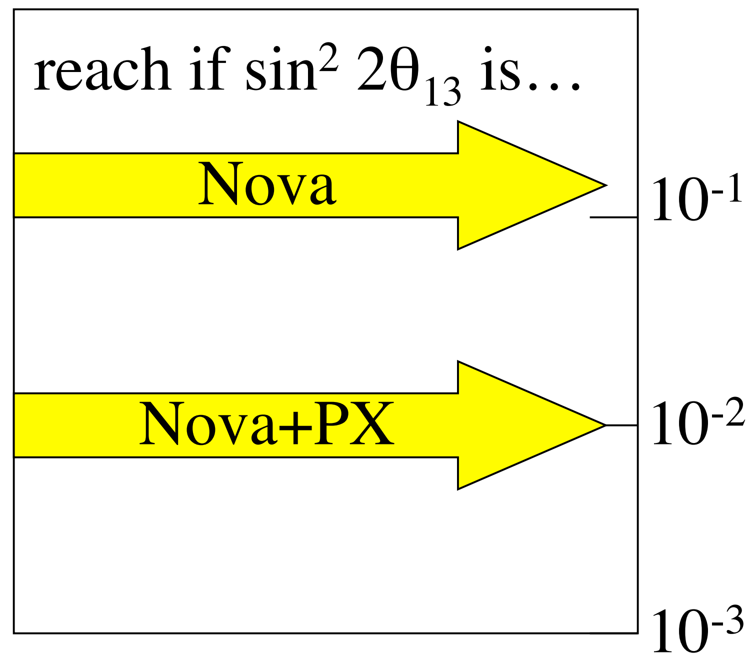
After 5 years of running…

Question 3:
Is ν_3 up here?



or down here?

i.e. can we identify the mass hierarchy at 95% CL??



assuming no CP violation

Life is much more complicated with ~~CP~~ !!

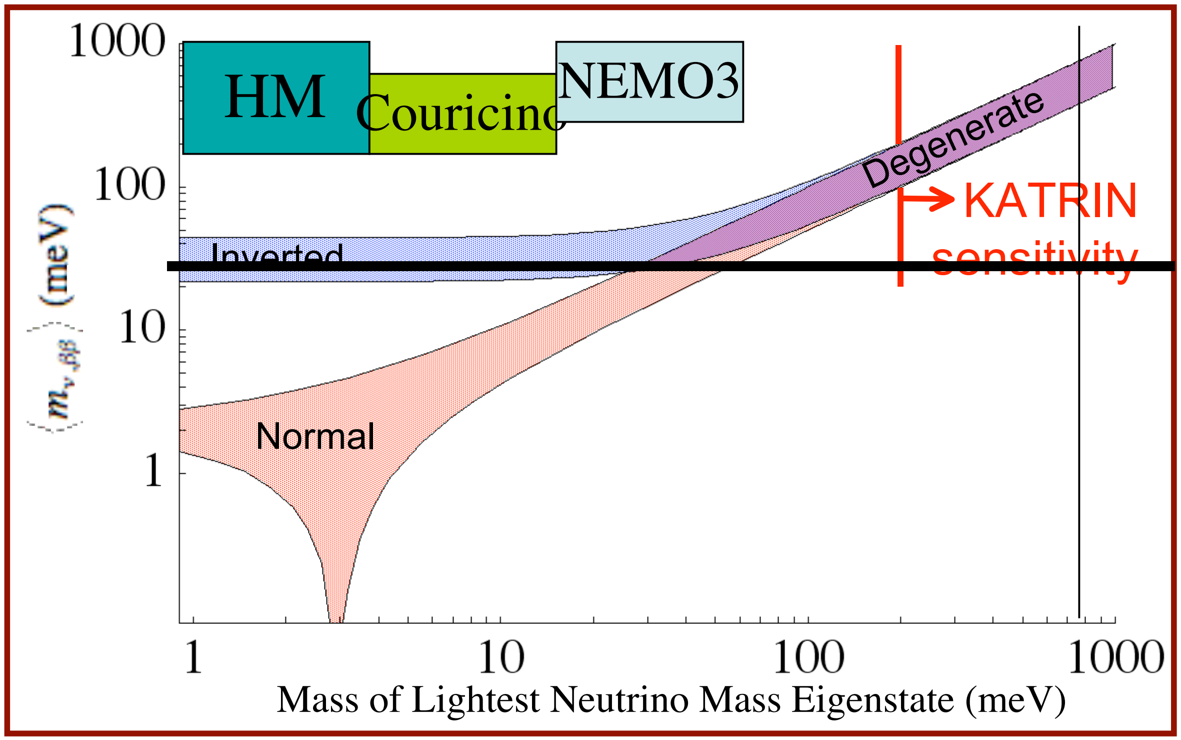
And at the same time….

Question 4: what is the absolute mass of ν_3 ? (and ν_1 and ν_2 too!)

Question 5: is that coming from a Majorana mass term?

Current limits:

Mass measured from $0\nu\beta\beta$ decay



Level we should reach by 2015

Bottom line: while there are mysteries, the model works well

Neutrino and LHC Physicists have a lot in common…

Darn it! Nearly everything seems to work!

But the patterns…!?!
the odd parameter values…?!?
the missing pieces…!?!
They must be telling us *something*.
There must be something more!

In fact, we have been on this path for a while!

This was the program sketched out
in the 2004 APS Neutrino Study…

And so it is reasonable to ask….

What else is ν?

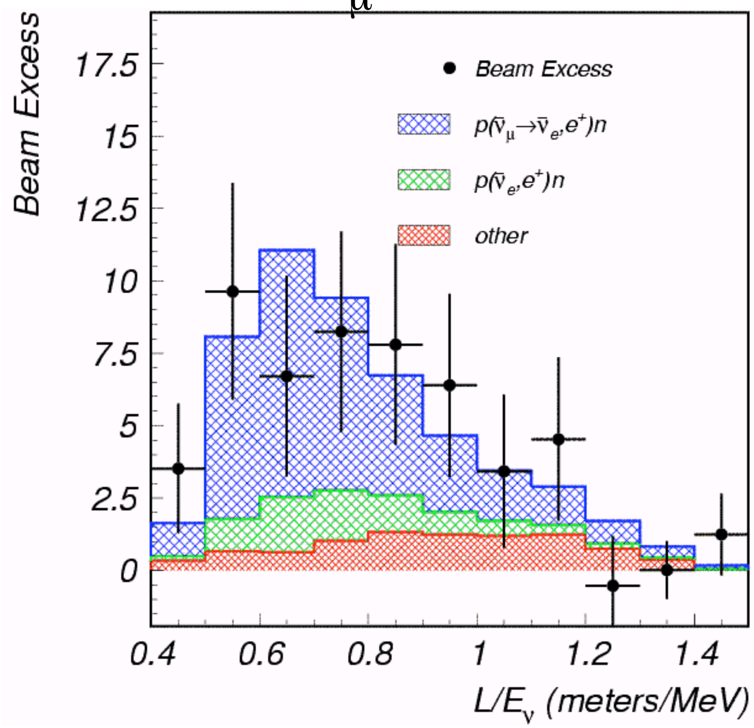
Two new ideas for Neutrino Physics in the US:

MicroBooNE
A Tev-based Neutrino Program

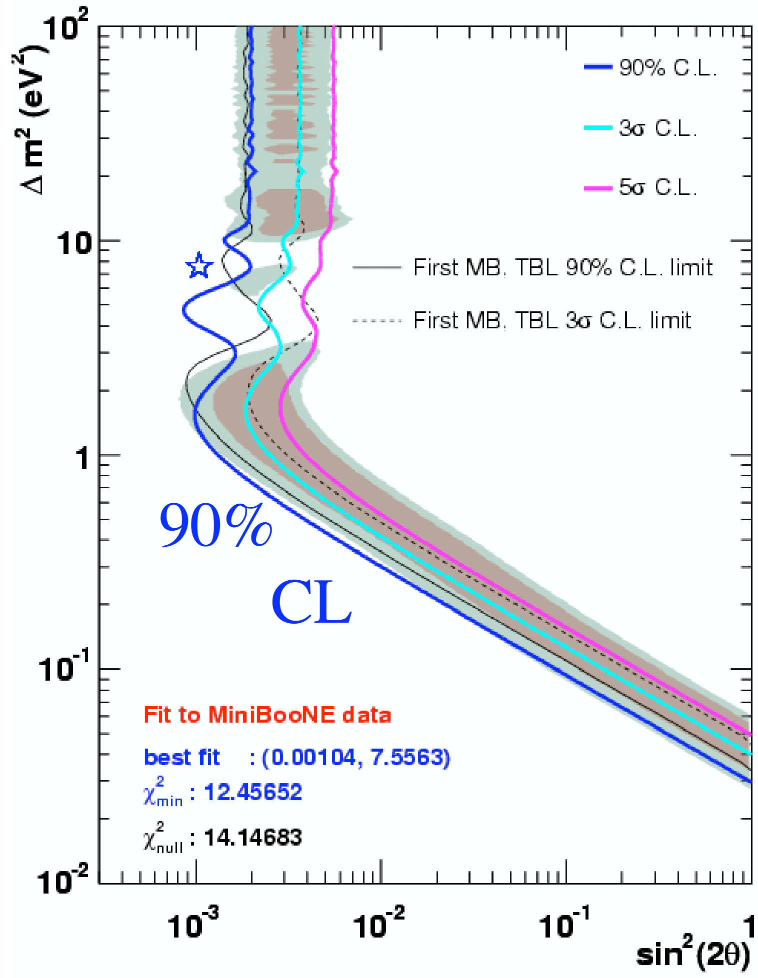
MicroBooNE

MicroBooNE is prompted by MiniBooNE is prompted by the LSND result…

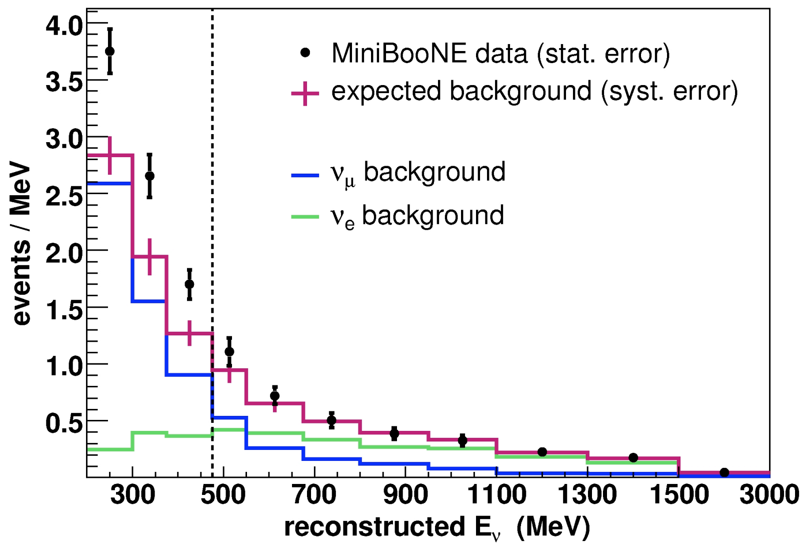
An excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam…



Consistent with high Δm^2 2 neutrino oscillations



In a search with E_ν>475 MeV MiniBooNE did not confirm this interpretation of LSND

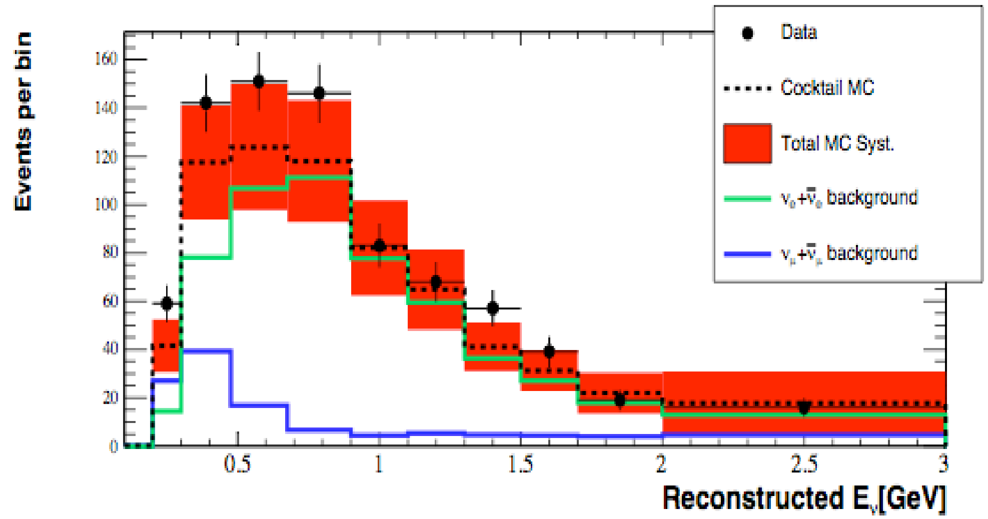


But an ~3σ excess of events was observed below 475 MeV

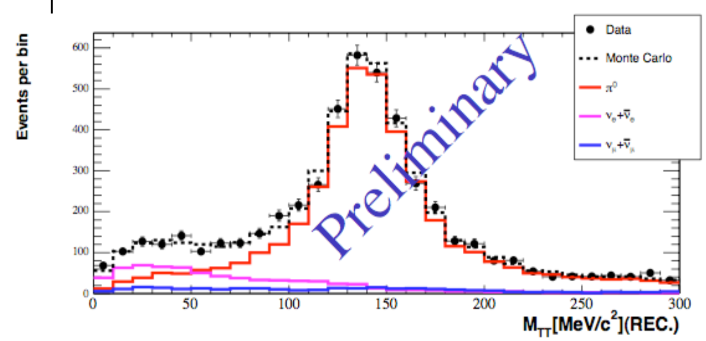
An update with improved analysis cuts will be presented at Neutrino 2008 in May

E_ν^{QE} [MeV]	200-300	300-475	475-1250
total background	284±25	274±21	358±35
ν_e intrinsic	26	67	229
ν_μ induced	258	207	129
NC π^0	115	76	62
NC Δ_Nγ	20	51	20
Dirt	99	50	17
other	24	30	30
Data	375±19	369±19	380±19
Data-MC	91±31	95±28	22±40

The NuMI Beam in MiniBooNE shows a similar but less significant excess.



E_ν^{QE} [MeV]	200-900	900-3000
total background	401±66	261±50
ν_e intrinsic	311	231
ν_μ induced	90	30
NC π^0	30	25
NC Δ_Nγ	14	1
Dirt	35	1
other	11	3
Data	498±22	285±17
Data-MC	97±70	24±53
Significance	1.40 σ	0.45 σ

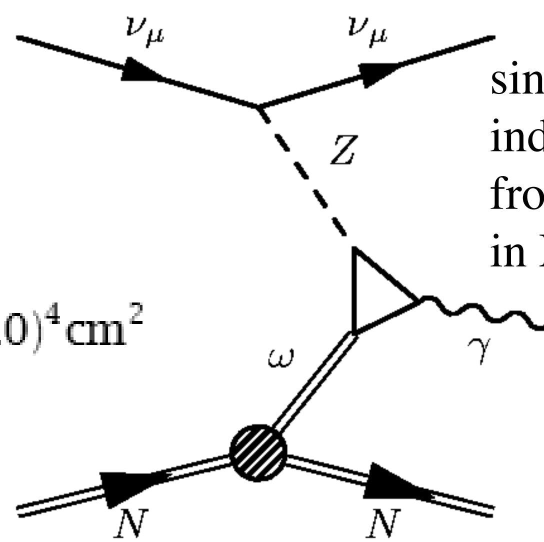


Again, π^0 and ν_e agreement with test samples was excellent

So what is it? A new possibility, just calculated

Anomaly-mediated photon production

$$\sigma = \frac{\alpha g_\omega^4 G_F^2 E_\nu^6}{480 \pi^6 m_\omega^4} \simeq 2.2 \times 10^{-41} (E_\nu/\mathrm{GeV})^6 (g_\omega/10.0)^4 \mathrm{cm}^2$$



single photon is indistinguishable from an electron in MiniBoNE

if $g_\omega \sim 10$, and E_ν were 700 MeV
this would produce a 115 event excess…
About the right level….

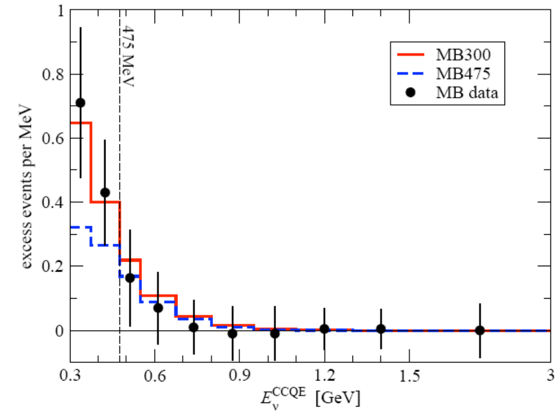
but does not account for form factor which cuts off the E^6 rise.
and will the angular distribution match?

More studies to do!

Examples of New Physics Explanations:

A new light vector boson with B-L coupling

(Nelson, Walsh, Phys.Rev. D77 03301, 2008)

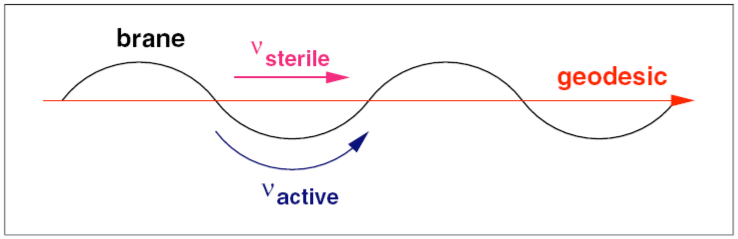


Sterile neutrinos with CP violation

(Maltoni, Schwetz, Phys.Rev. D76 093005, 2007)

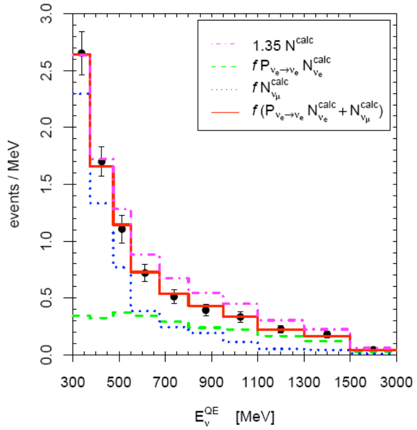
Sterile neutrino short-cuts in extra dimensions

(Päs, Pakvasa, Weiler, Phys.Rev. D72 095017, 2005)



Electron neutrino disappearance, inspired by the deficit seen in the Ga expts source calibrations

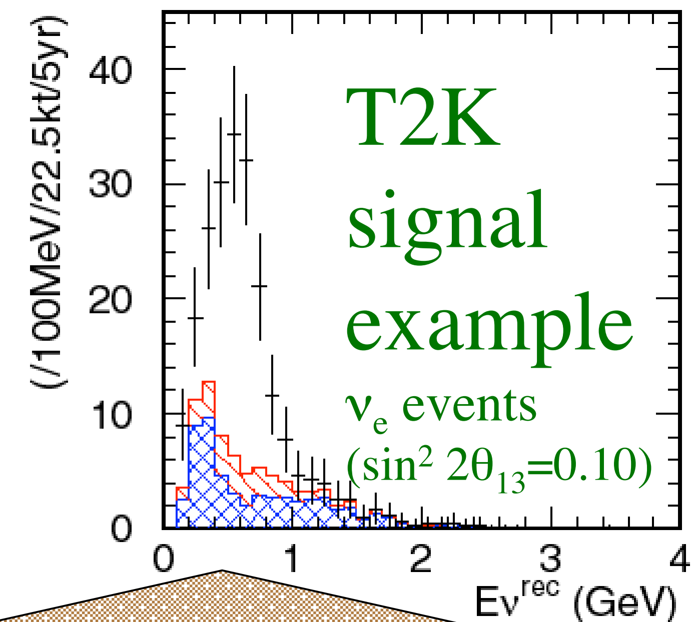
(Giunti and Laveder, hep-ph 0707.4593)



Etc.

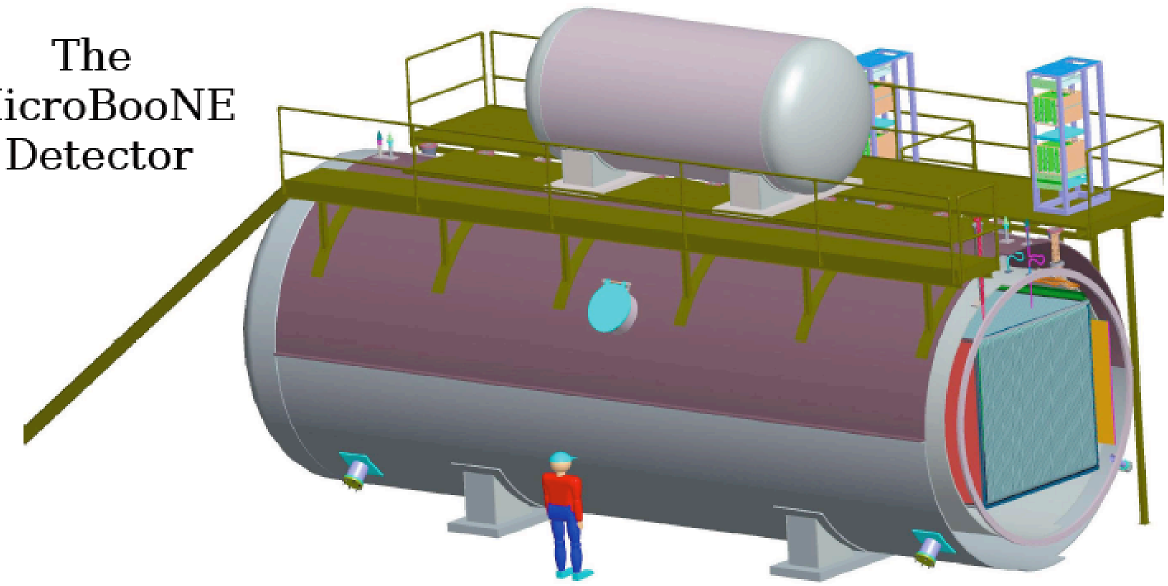
Whatever the cause, we need to understand it

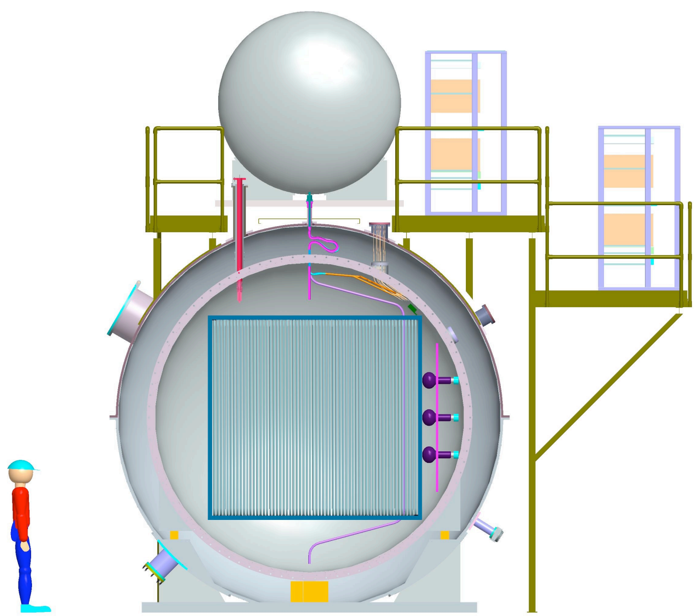
T2K's beam is the <u>same energy</u> as MiniBooNE beam and the Super K <u>detector is very similar</u>!



There is likely to be an ~100 event background right here!

The MicroBooNE Detector



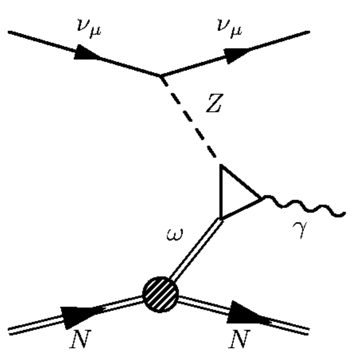


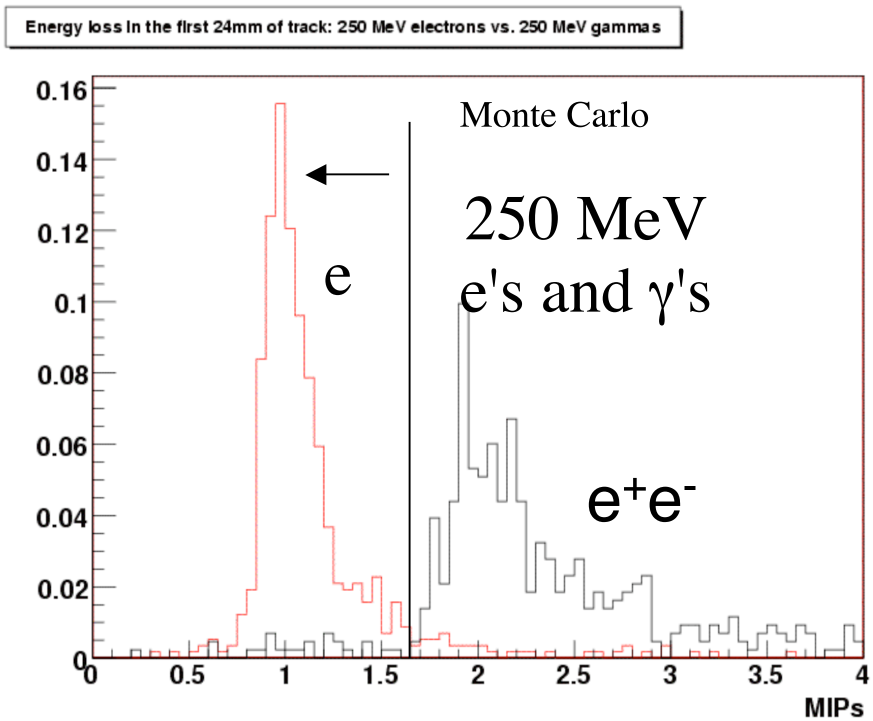
Introducing MicroBooNE…

A 70 ton LAr detector, running in the Booster Beam

Proposal under consideration at Fermilab

LAr has the capability to differentiate between single photon sources





And electron-like ($\nu_\mu \rightarrow \nu_e$) sources

- 3+2 with CP Violation
- a new interaction with B-L coupling
- etc.

Why do MicroBooNE?

- To investigate the low energy excess
- To measure cross sections
- To advance our experience with LAr TPCs

MicroBooNE could be the first LArTPC to produce cutting edge physics results

A Tevatron-based Neutrino Program

A Brief History…

The idea has been around for some time,

The call from the Steering Committee for "near term experiments that can be supported by an evolution of the Fermilab accelerator complex" caused the idea to gel.

The concept was endorsed by the Steering Committee:

[An] experiment with an 800 GeV proton beam would impose approximately a five percent tax on NuMI for both Project X and SNuMI. Proton-source upgrades, particularly Project X, make possible a stronger neutrino-science program.

FNAL Steering Group seeks input from HEP community

Director Pier Oddone has charged Deputy Director Young-Kee Kim to lead a Steering Group to develop a strategic roadmap for the accelerator-based HEP physics program at Fermilab (see Director's Corner, Fermilab Today, April 17, 2007). The roadmap will outline discovery opportunities during the period before ILC construction can begin, while supporting the international R&D and engineering design for as early a start of the ILC as possible. The Steering Group, consisting of members of the US HEP community and Laboratory staff, will report to Director Oddone by August 1.

The Steering Group would like to solicit input from the HEP community as widely as possible. As part of this effort, Kim has been meeting with collaborations of experiments at Fermilab, will give a report on the Steering group's work at the Fermilab and SLAC Users Meetings on June 6 and June 7, respectively, and will conduct Town Hall meetings on the same days. To provide input, please email Kim a note or a letter with your thoughts.

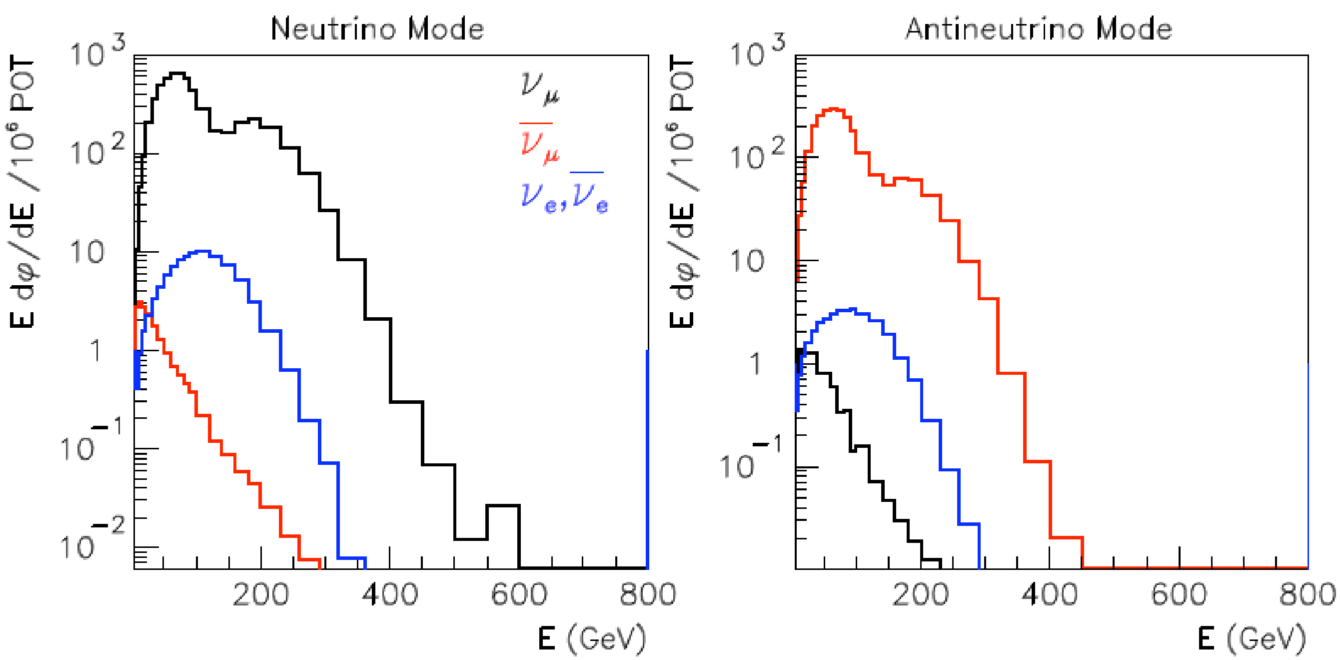
The Steering Group would also like to hear ideas from the community on near-term experiments that can be supported by an evolution of the Fermilab accelerator complex. If you have suggestions, please write up a single-page sketch consisting of the physics case, back-of-envelope discussion of accelerator requirements, and a brief detector description. Please send your input by Monday, June 11.

You can find the charge, membership and activities of the Steering Group here.

The 800 GeV Neutrino Program can provide two beams…

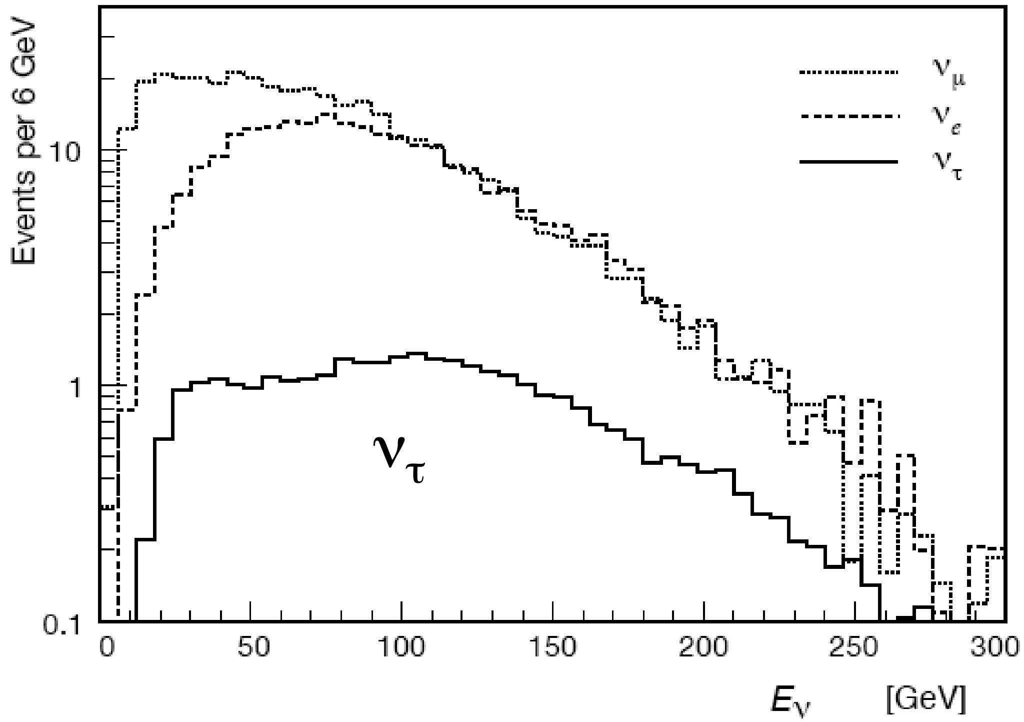
Beam 1: A NuTeV-style Flux (used by NuSOnG)

Uniquely high energy, and low background,
produced using a sign-selected quad-train



Beam 2: A DoNuT (Discovery of the Nu Tau)-style Flux

A beam dump flux:

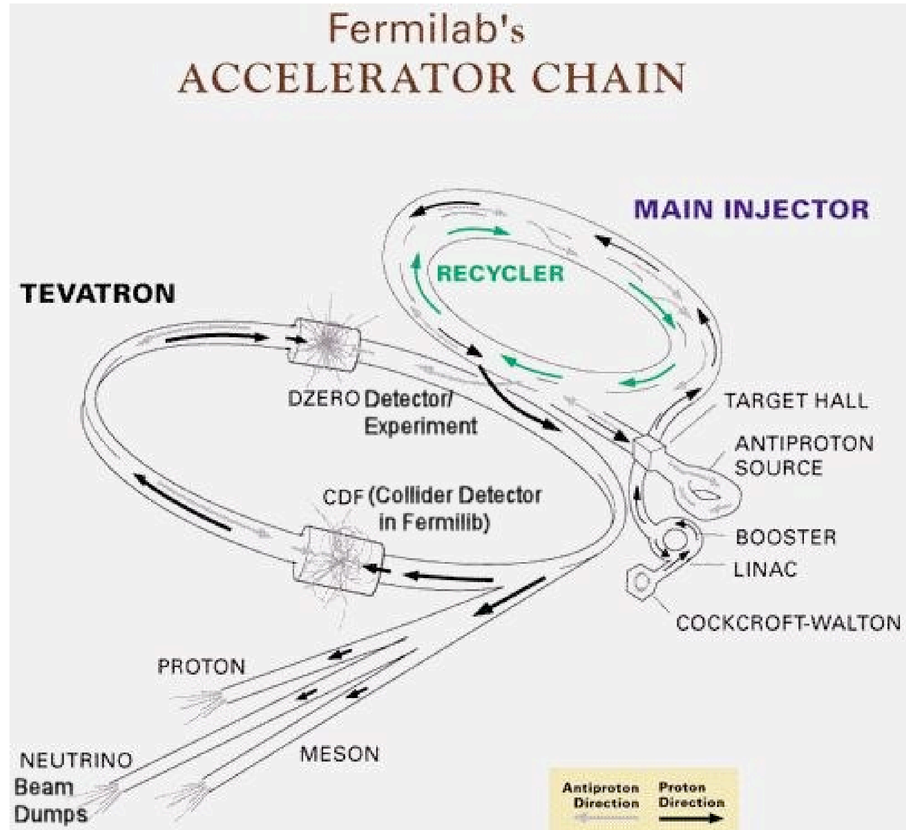


Uniquely enriched in ν_τ's which are above threshold for CCQE

5×10^{19} POT/year

5× the number of protons per fill,
1.5 × faster cycle time
66% uptime per year

$18M/year to run



Two useful publicly-available memos:

http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2222
http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2849

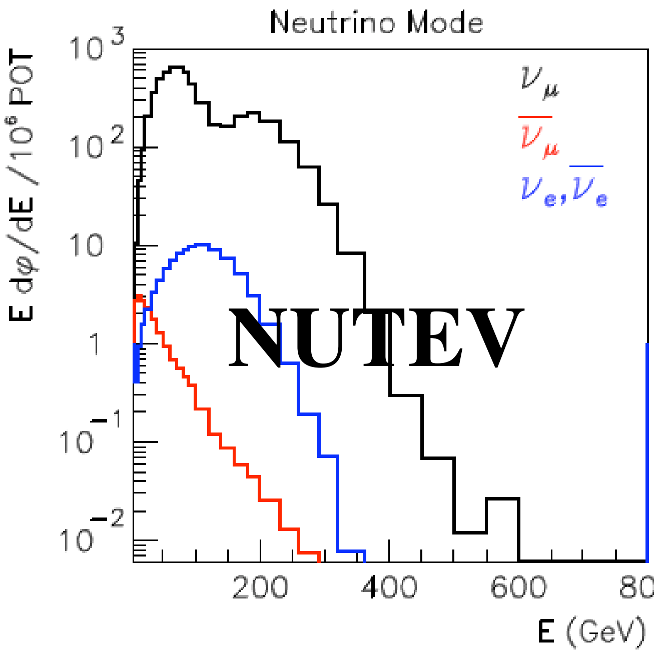
A suite of interesting experiments:

- NuSOnG
- A small ν_τ experiment to obtain ×100 DoNuT statistics
- A large (~5kt) magnetized LAr detector for 1E6 ν_τ events and neutrino factory measurements
- A small dedicated search for neutrissimos (moderately-heavy neutral heavy leptons)
- A high resolution neutrino scattering experiment to study charm and QCD (HiResMuNu)

None of these experiments can be done anywhere else.

This program is unique to Fermilab.

NuSOnG: Neutrino Scattering On Glass



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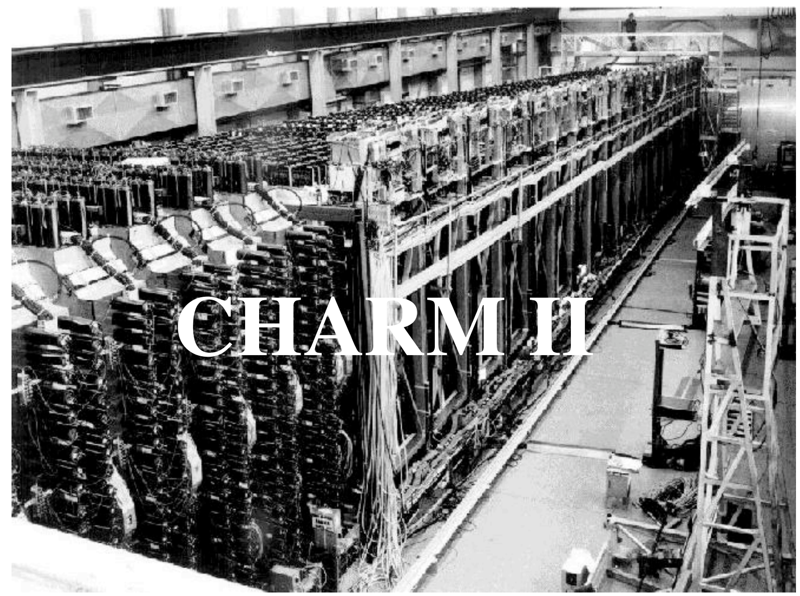


High energy,
very pure beam
(×20 POT)

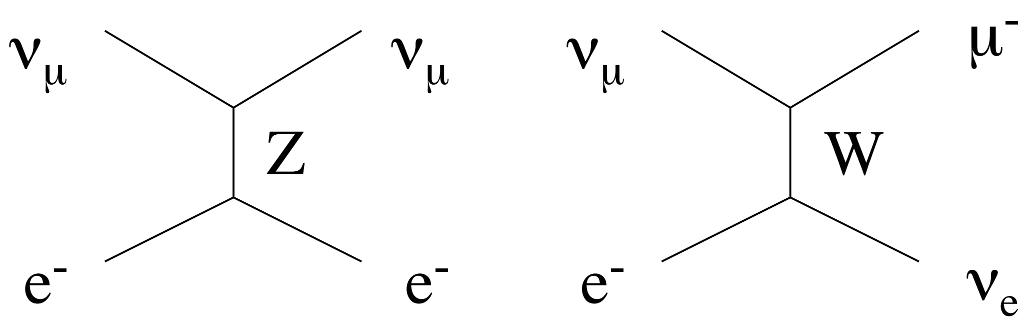
Fine-grained,
massive detector
(×6 mass)

1.5E20 POT in ν , 0.5E20 POT in $\bar{\nu}$

Very high statistics!

600M	ν_μ CC Deep Inelastic Scattering
190M	ν_μ NC Deep Inelastic Scattering
75k	ν_μ electron NC elastic scatters
700k	ν_μ electron CC quasielastic scatters (IMD)
33M	$\bar{\nu}_\mu$ CC Deep Inelastic Scattering
12M	$\bar{\nu}_\mu$ NC Deep Inelastic Scattering
7k	$\bar{\nu}_\mu$ electron NC elastic scatters
0k	$\bar{\nu}_\mu$ electron CC quasielastic scatters

A unique opportunity for these channels!

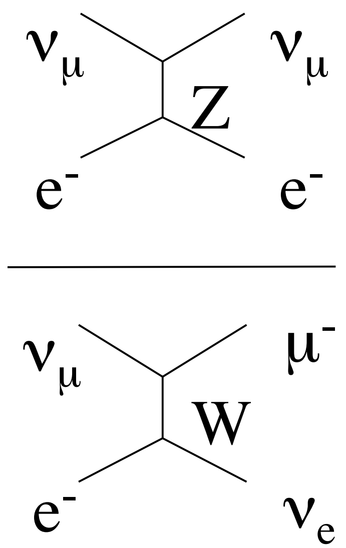


As many thesis topics as I can type in 5 minutes…

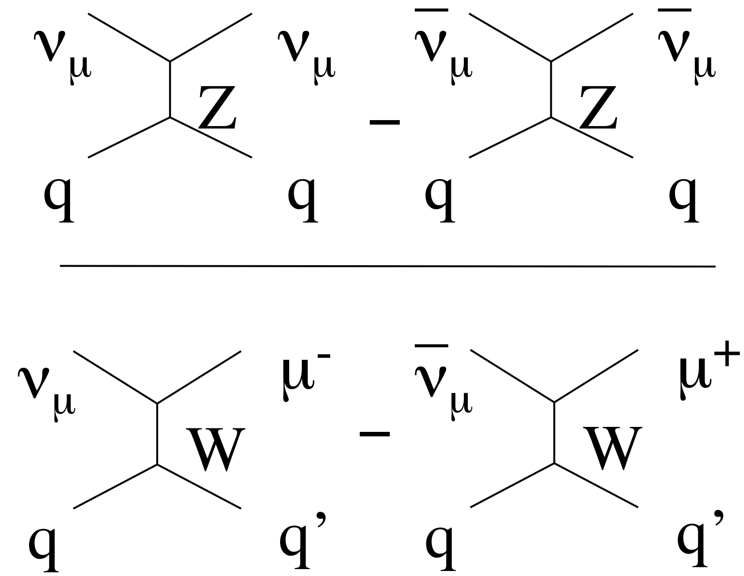
1. **The weak mixing angle measure from neutrino-electron scattering**
2. **The weak mixing angle measured from neutrino-quark scattering**
3. **New physics limits probed through coupling to the Z**
4. **New physics limits from the inverse muon decay cross section**
5. **Cross section measurement of neutrino and antineutrino electron scattering**
6. **A search for $N \rightarrow \mu\mu\nu$ decay in the 5 GeV mass range**
7. **Searches for light mass neutrissimos**
8. **ν_μ disappearance at very high Δm^2**
9. **A search for evidence of nonunitarity of the 3 neutrino matrix**
10. **A search for neutral heavy leptons in the 5 GeV mass range**
11. **Constraints on muonic photons**
12. **Measurement of the CCQE cross section at high energy**
13. **Measurement of the NCπ0 cross section at high energy**
14. **A study of the transition from single pion to DIS production at high energy**
15. **Measurement of F_2 and xF_3 at very high statistics**
16. **Comparisons of F_2 on nuclear targets from low to high x**
17. **High precision measurement of R from neutrino scattering**
18. **Constraint on isospin violation from ΔxF_3**
19. **Charm production in the emulsion target and a measure of B_c**
20. **Measurement of the strange sea and Δs from dimuon production**
21. **Measurement of the charm sea from wrong-sign single muon production in DIS**
22. **Neutrino vs antineutrino nuclear effects**

Electroweak Measurements:

New!



Purely leptonic



NuTeV-style
“Paschos-Wolfenstein”

Expected errors
0.7% conservative,
0.4% best case

0.4% conservative
0.2% best case

Our quoted physics case is based on the conservative estimates

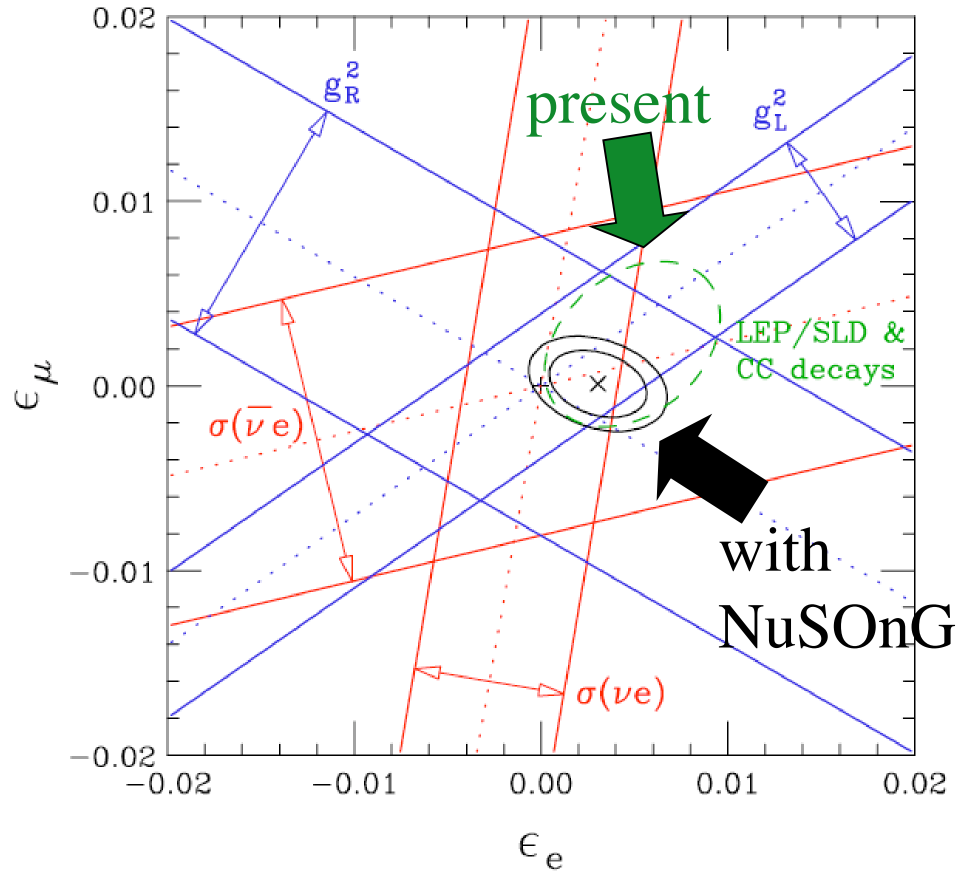
Terascale Physics Opportunities at a High Statistics, High Energy Neutrino Scattering Experiment: NuSOnG

http://arxiv.org/abs/0803.0354

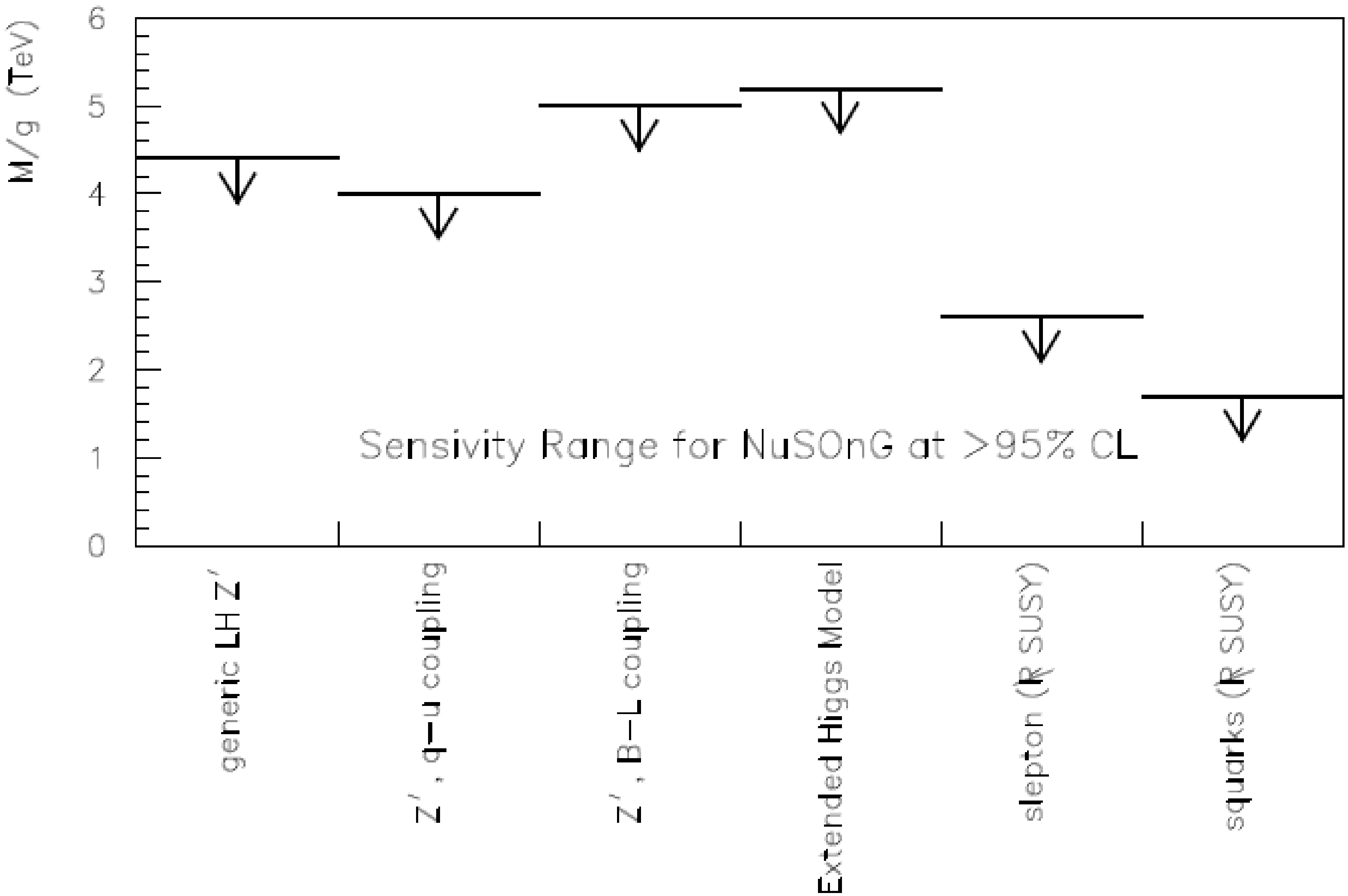
Mass scale reach of 1 to 7 TeV depending on model,

Unique access to
certain new physics,
e.g. non-universal couplings

Complementary info
to LHC can help
identify new physics



NuSOnG in the Context of Specific "Typical" Models



Z-prime   Extended Higgs   SUSY

A final thought in closing

These new experiments need support from you.

Frankly put, the US accelerator program is facing dark days.
And this affects everyone, **whether you work here or LHC**

What we need is a different kind of thinking…

We need to develop ideas which:

- Will build on existing infrastructure
- Are not too costly
- Can be implemented quickly -- within 5-10 years!
- DO INTERESTING, UNIQUE PHYSICS

The Phenomenology Community
can be leaders on this!

Neutrino experiments are a great place to start.

And great way to start developing new ideas
is to attend the exciting neutrino talks TODAY!

Neutrino Experiments

Contribution List | Time Table

Monday, 28 April 2008

14:00

[115] Neutrino Properties from Neutrino Telescopes
by Ms. Irina MOCIOIU (Pennsylvania State University)
(TBD: 14:00 - 14:15)

[123] Direct Searches for New Physics at NuSOnG and Other Neutrino Experiments
by Ms. Georgia KARAGIORGI (Columbia University)
(TBD: 14:15 - 14:30)

[124] The Terascale Physics Reach of NuSOnG
by Prof. William LOINAZ (Amherst College)
(TBD: 14:30 - 14:45)

[126] Global Lorentz Violation Model for Neutrino Oscillation with MiniBooNE
by Mr. Teppei KATORI (Indiana University)
(TBD: 14:45 - 15:00)

15:00

[127] NC pi0 Production in the MiniBooNE Antineutrino Data
by Ms. Van NGUYEN (Columbia University)
(TBD: 15:00 - 15:15)

[128] Multi-Beam Strategy for Low Energy Neutrino-Nucleus Cross-Sections
by Mr. Rainer SCHIEL (University of Kansas)
(TBD: 15:15 - 15:30)

[129] Constraints on Non-Standard Interactions of the Neutrinos using Borexino
by Mr. Yee KAO (Virginia Tech)
(TBD: 15:30 - 15:45)

[130] The Daya Bay Neutrino Experiment
by Dr. Wei WANG (University of Wisconsin)
(TBD: 15:45 - 16:00)

Neutrino Models

Contribution List | Time Table

Monday, 28 April 2008

16:00

[157] Interaction of Dirac and Majorana Neutrinos with Weak Gravitational Fields
by Mr. Arun THALAPILLIL (University of Chicago)
(TBD: 16:30 - 16:45)

[159] Small Neutrino Masses in a TeV Scale Seesaw Model with a Z'
by Prof. Mu-Chun CHEN (UC Irvine)
(TBD: 16:45 - 17:00)

17:00

[161] TriMinimal Parametrization of the Neutrino Mixing Matrix
by Prof. Tom WEILER (Vanderbilt University)
(TBD: 17:00 - 17:15)

[163] Precision Measurement of Neutrino Oscillation Parameters with KamLAND
by Dr. Daniel DWYER (Caltech)
(TBD: 17:15 - 17:30)

[167] Minimal Neutrinoless Double Beta-Decay Rates from Approximate Flavor Symmetries
by Mr. James JENKINS (Northwestern University)
(TBD: 17:30 - 17:45)

[169] The Search for Neutrinoless Double Beta Decay with the CUORE Experiment
by Dr. Samuele SANGIORGIO (University of Wisconsin)
(TBD: 17:45 - 18:00)

18:00

[170] Implications of Electroweak-Scale Right-Handed Neutrinos
by Prof. P. Q. HUNG (University of Virginia)
(TBD: 18:00 - 18:15)