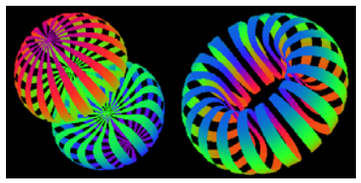
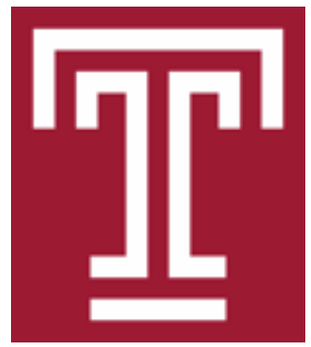


Nuclear Physics Symposium: Exploring the Heart of Matter

Chicago, September 26-27, 2014



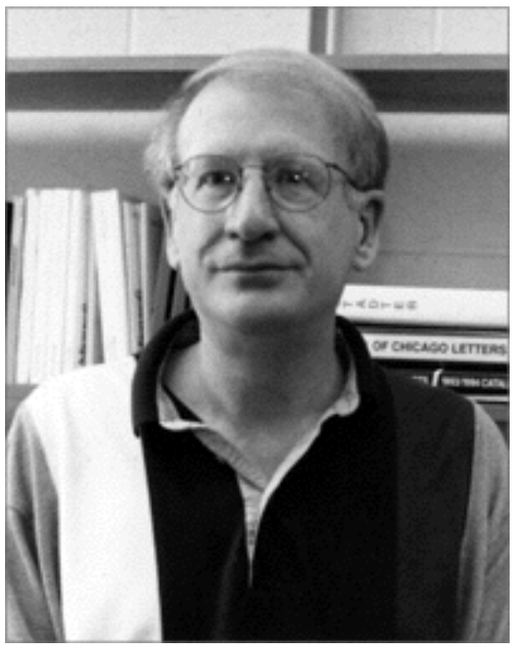
"Neutrino Oscillations"

Jim Napolitano, Temple University

My Neutrino Oscillations and Roy

E645 @LAMPF

~1982



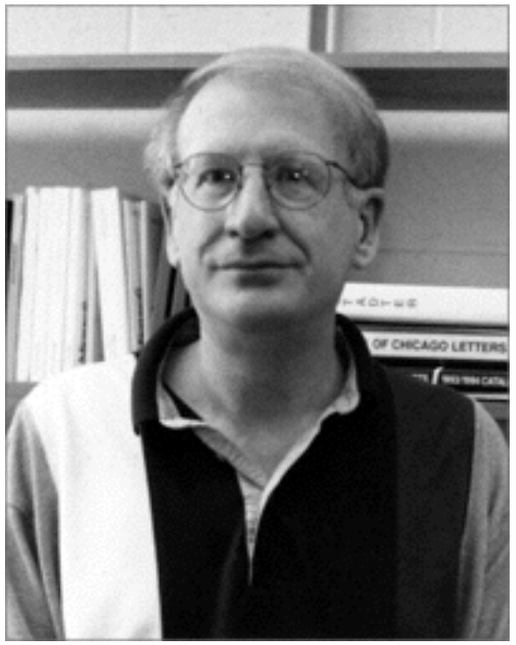
~2012

My Neutrino Oscillations and Roy

E645 @LAMPF

"Say, Jim, maybe you would like to measure something that isn't zero?"

~1982



~2012

My Neutrino Oscillations and Roy

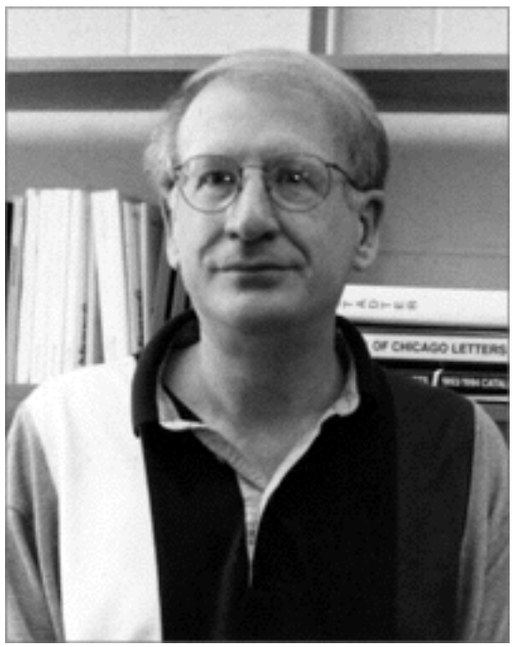
E645 @LAMPF

"Say, Jim, maybe you would like to measure something that isn't zero?"

Daya Bay

PROSPECT

~1982



~2012

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GUNS MADE HIM FREE... GOLD KEPT HIM FREE!
THE TALL TEXAN
starring
LLOYD BRIDGES·LEE J. COBB
MARIE WINDSOR·LUTHER ADLER

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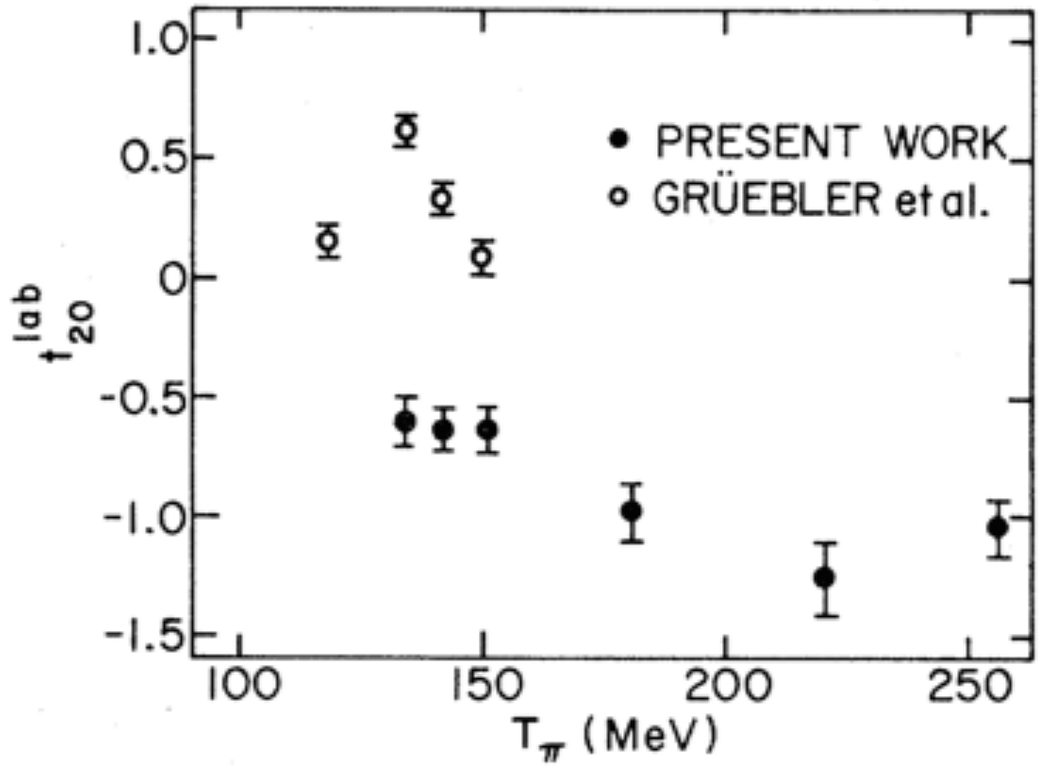
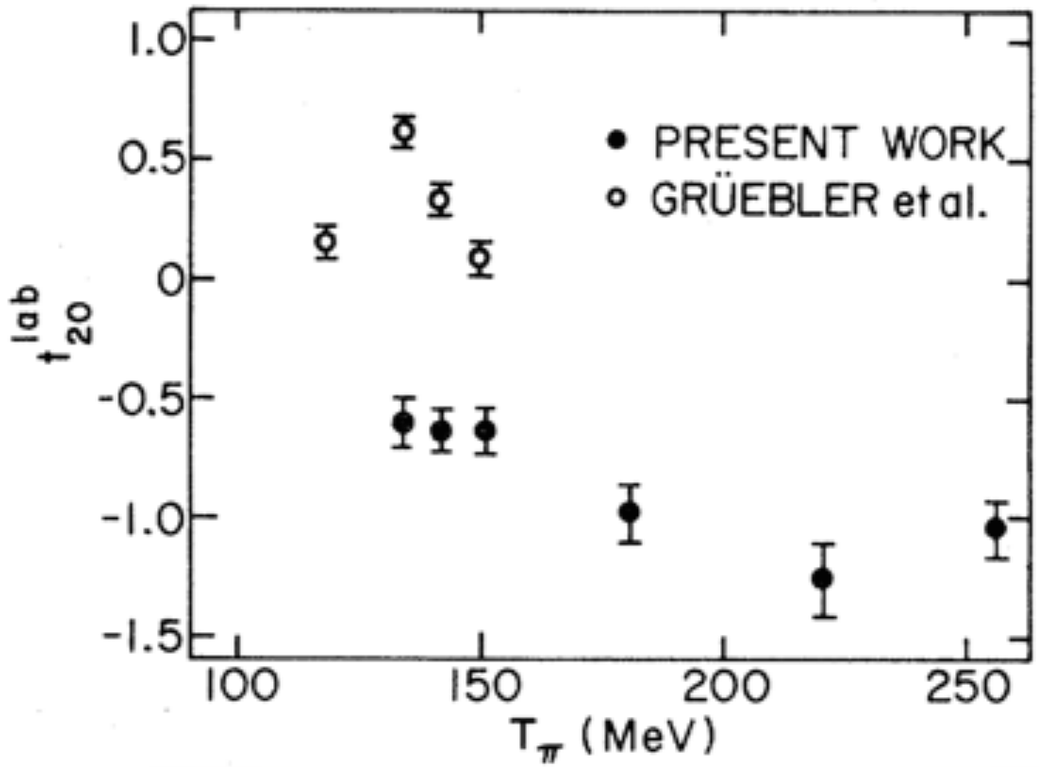
LLOYD BRIDGES

Roy: The Hero of T20



Roy: The Hero of T20



Siberia and Moscow

I hear there are subversives in Novosibirsk?

Siberia and Moscow

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Siberia and Moscow

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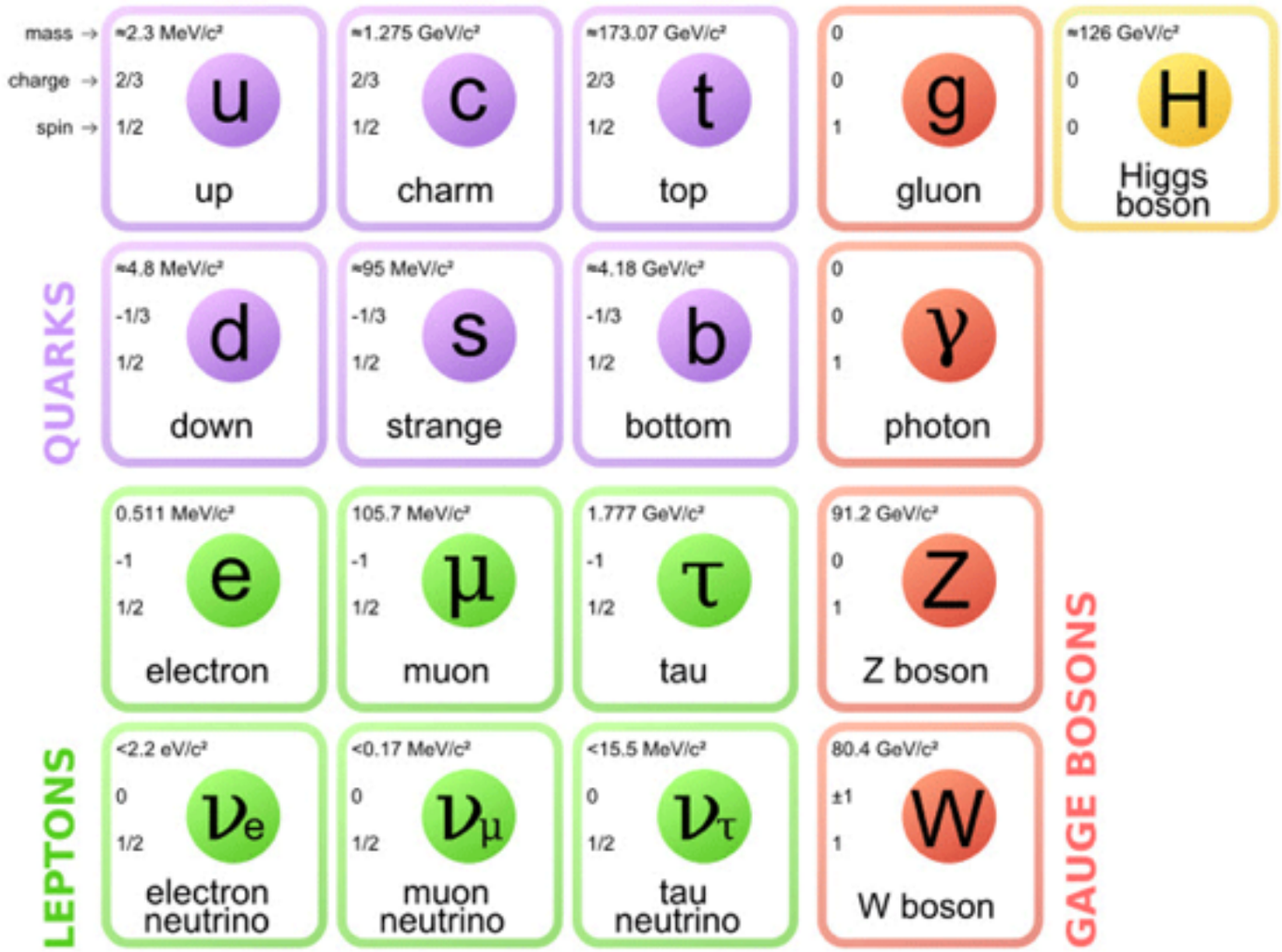
Neutrino Oscillations

Past, Present, and Future

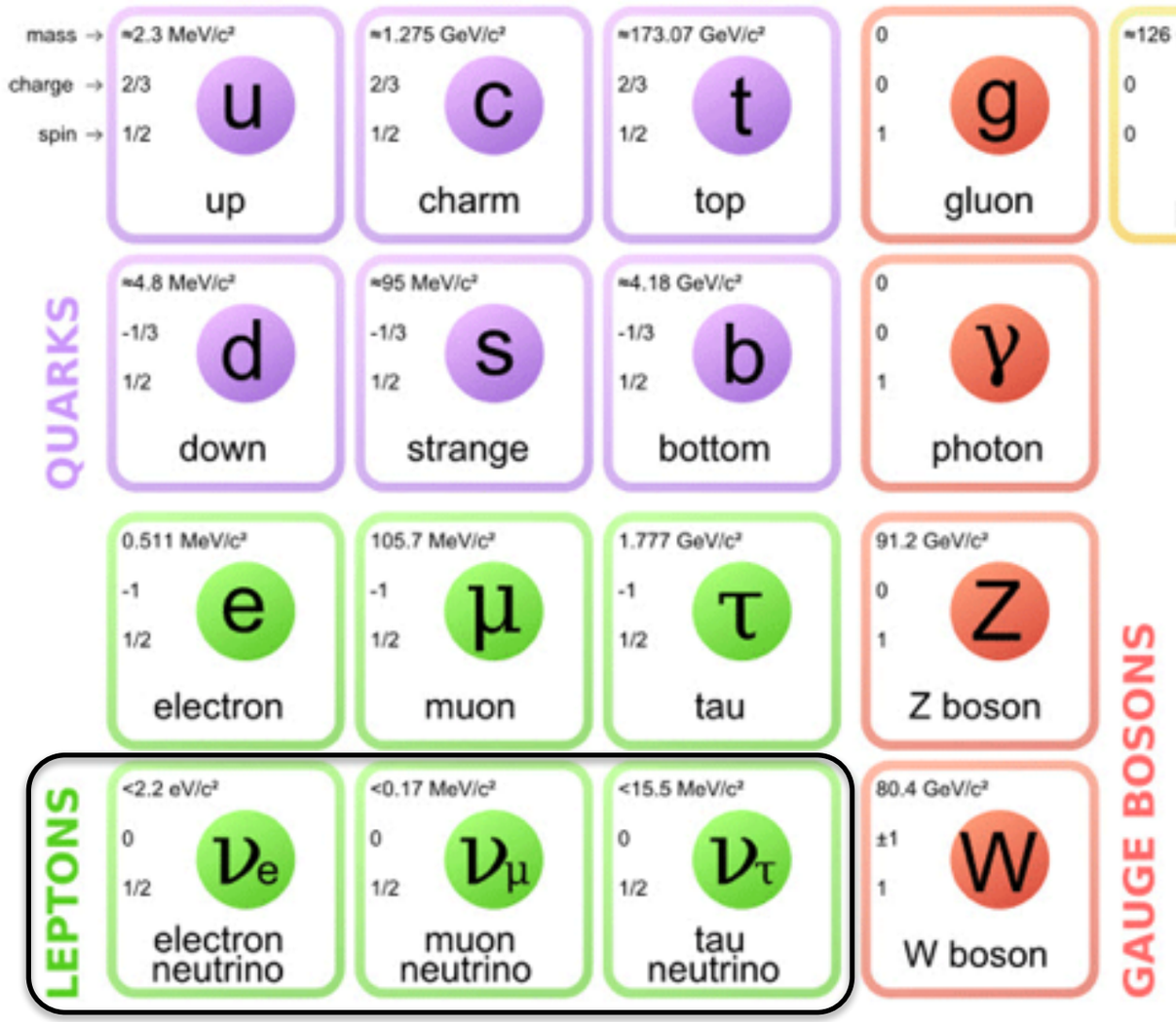
Neutrino Mixing

The Standard Model



Neutrino Mixing

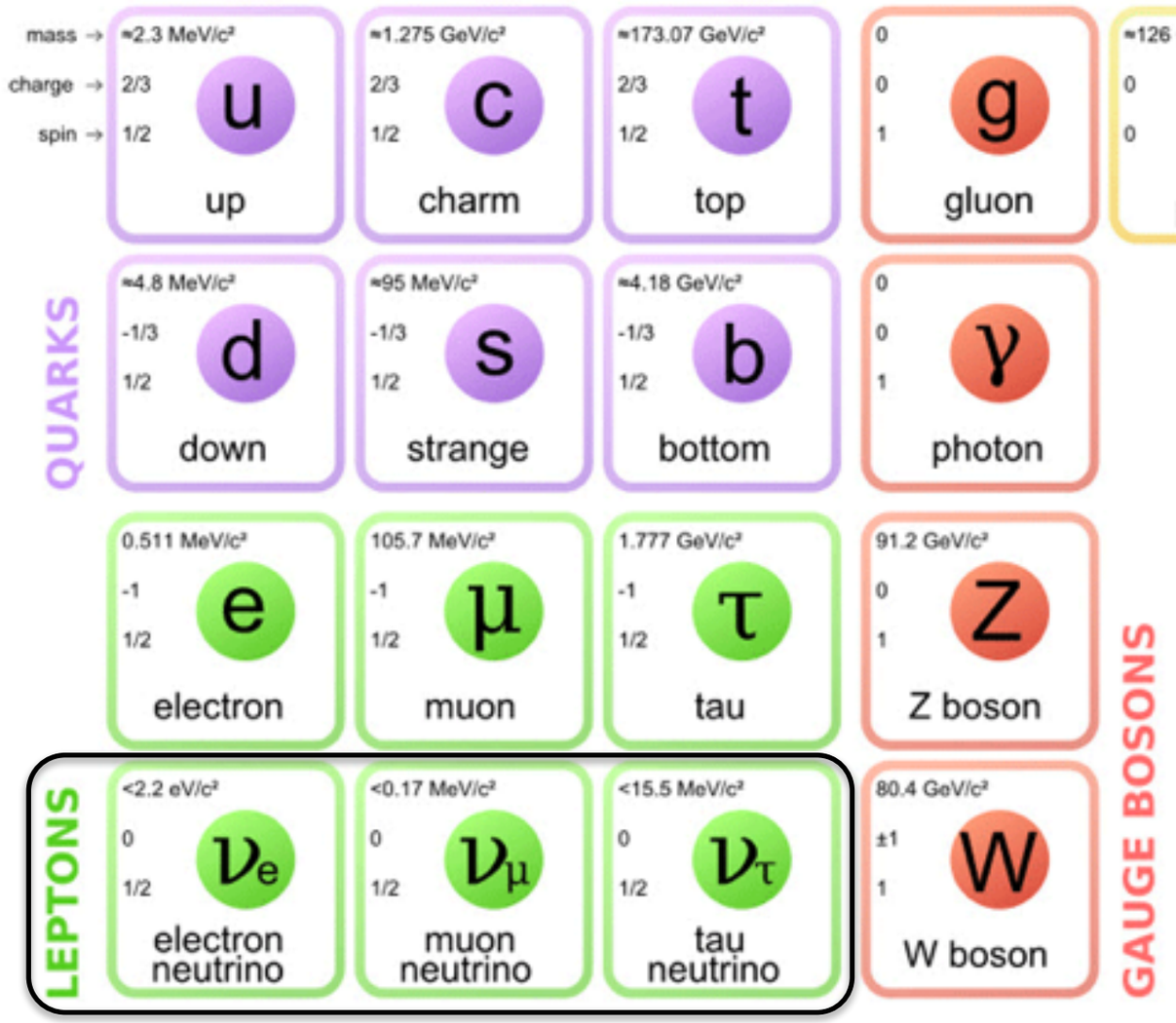
The Standard Model



Weak Eigenstates:
Is that all there is?

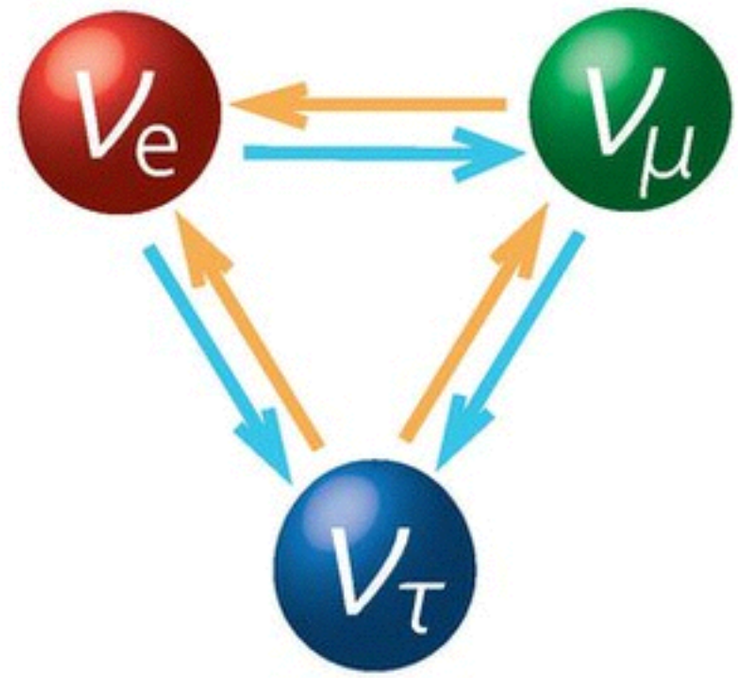
Neutrino Mixing

The Standard Model



Weak Eigenstates:
Is that all there is?

If not, then the neutrinos can mix!



Unitary mass matrix described by <u>three angles</u> and a <u>phase</u>.

Neutrino Oscillations

Interference between “mass eigenstates”

Three generations ⇒ Complicated expressions!

But in the end, it boils down to the following:

“Disappear” *“Appear”*

$$P(\nu_\alpha \to \nu_\alpha) = 1 - P(\nu_\alpha \to \nu_\beta)$$

$$= 1 - \sin^2 2\theta \sin^2 \left[1.27\ \Delta m^2(\mathrm{eV})^2\ \frac{L}{E}\left(\frac{\mathrm{m}}{\mathrm{MeV}}\right)\right]$$

Neutrino Oscillations

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Mixing angle

Difference in the squares of the masses

Neutrino Oscillations

Interference between "mass eigenstates"

Three generations ⇒ Complicated expressions!

But in the end, it boils down to the following:

Tune energy (E) and baseline (L) to optimize sensitivity to generations.

"Disappear" *"Appear"*

$$P(\nu_\alpha \to \nu_\alpha) = 1 - P(\nu_\alpha \to \nu_\beta)$$

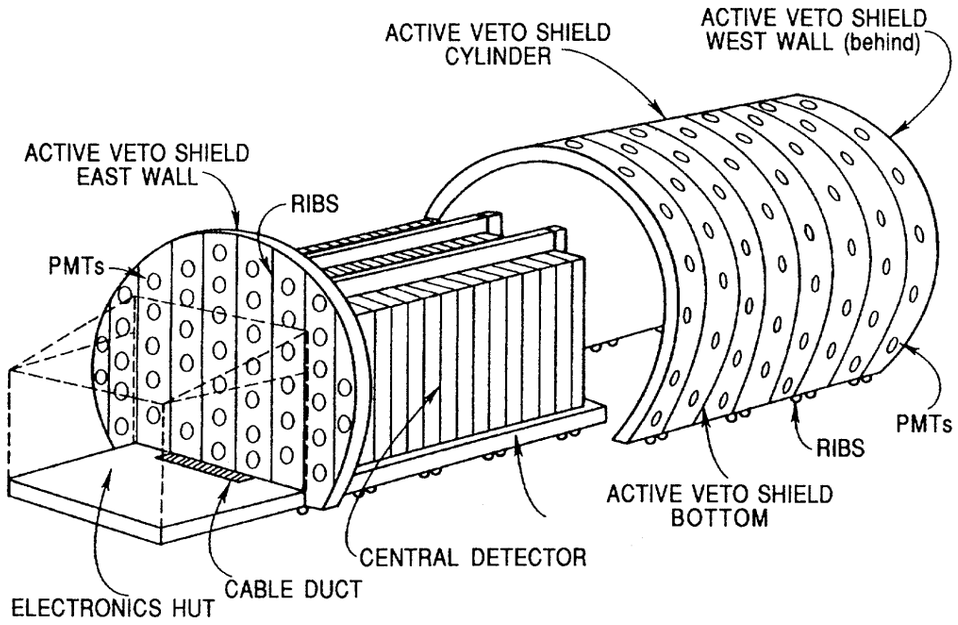
$$= 1 - \sin^2 2\theta \sin^2 \left[1.27 \Delta m^2 (\mathrm{eV})^2 \frac{L}{E} \left(\frac{\mathrm{m}}{\mathrm{MeV}} \right) \right]$$

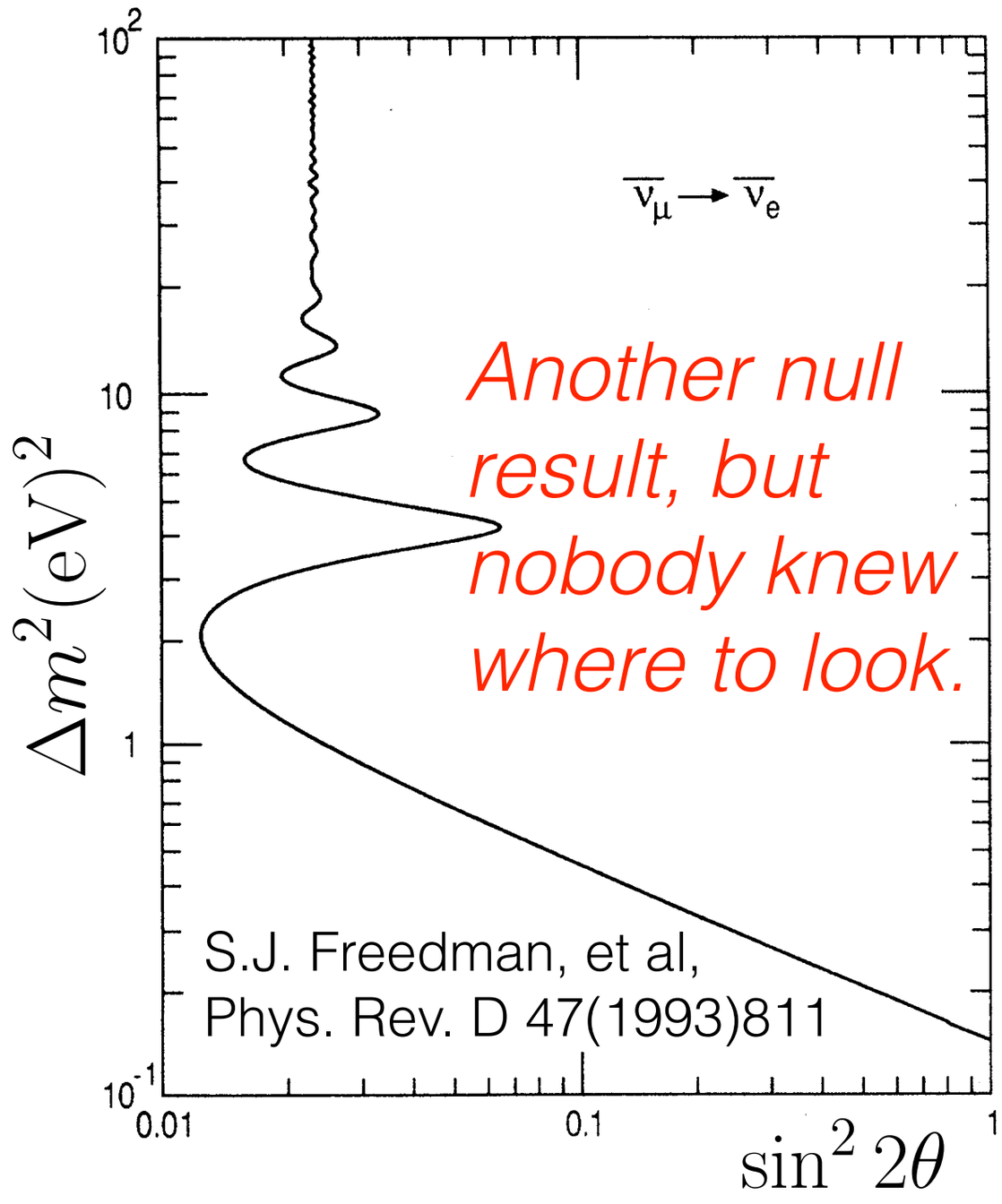
Mixing angle

Difference in the squares of the masses

E645 at LAMPF

Search for $\nu_\mu \rightarrow \nu_e$ Appearance





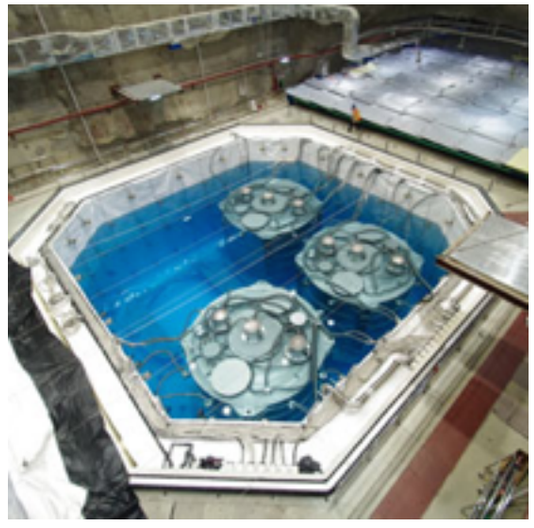
Daya Bay

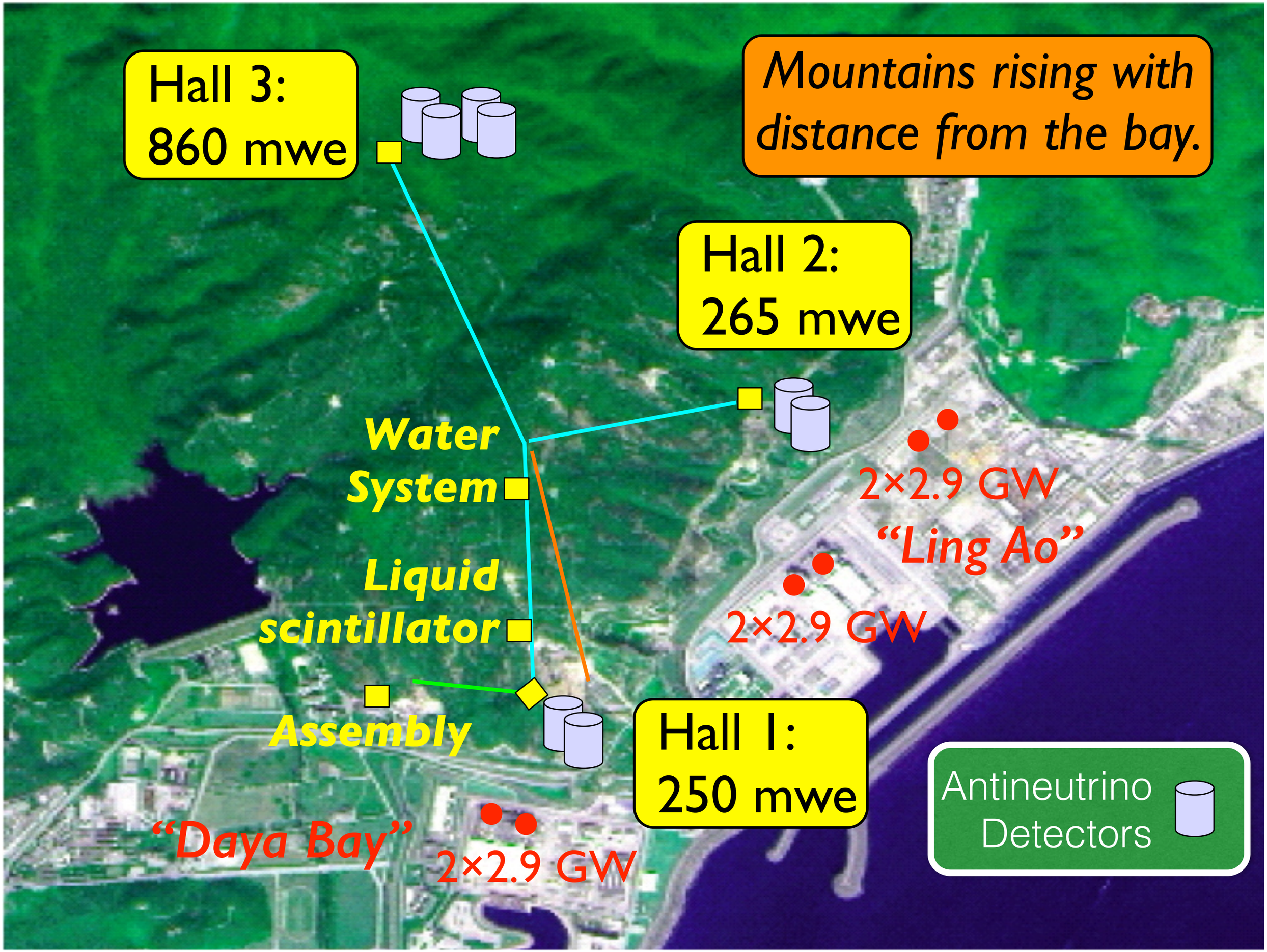
Fast Forward 25 Years: Neutrino Mixing Occurs!

However, the mixing angle θ_{13} remains unknown.

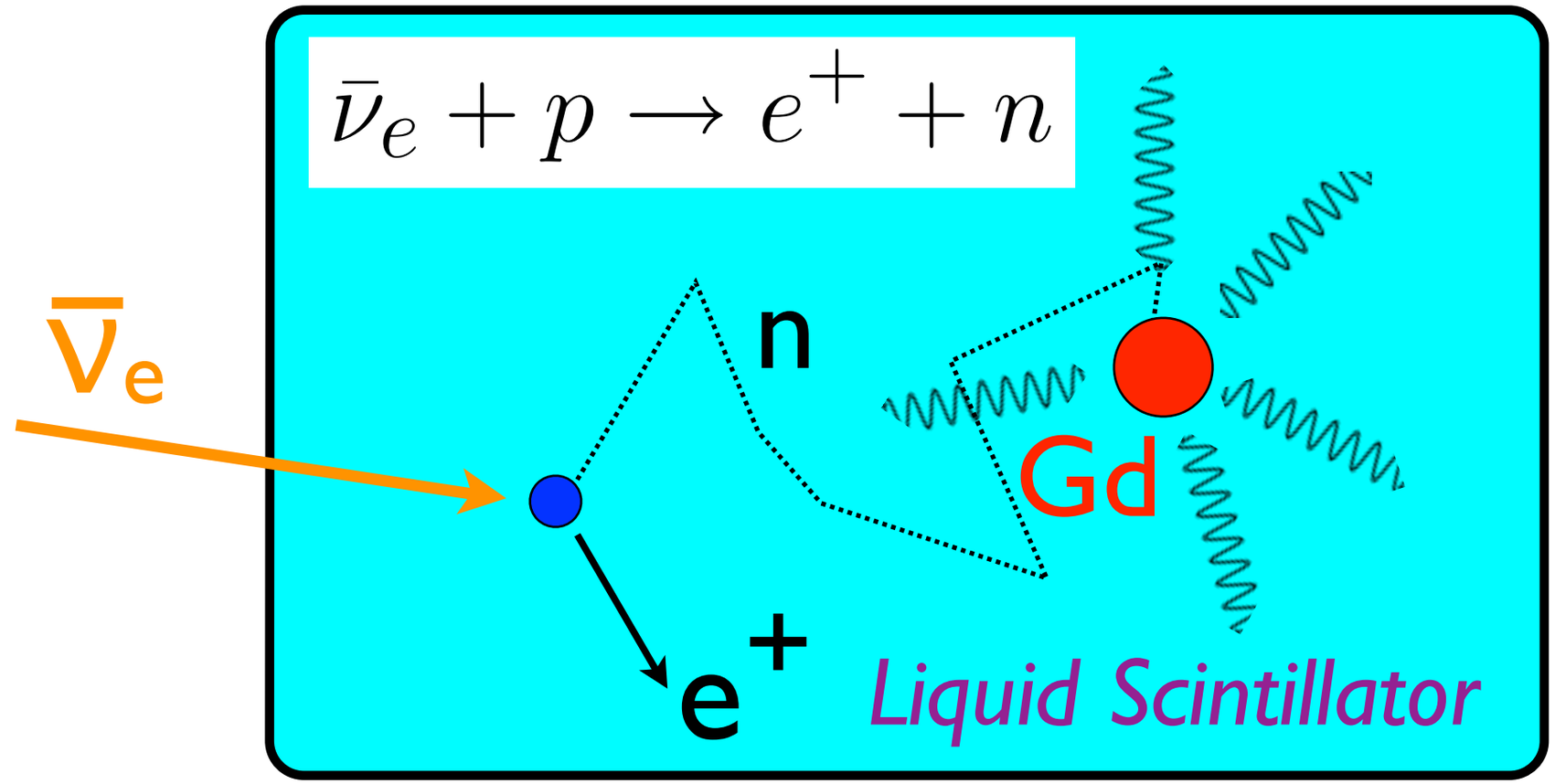
Limits from prior experiments say that θ_{13} is "small".

The world mounts three disappearance experiments at nuclear power plants close to the optimum baseline.



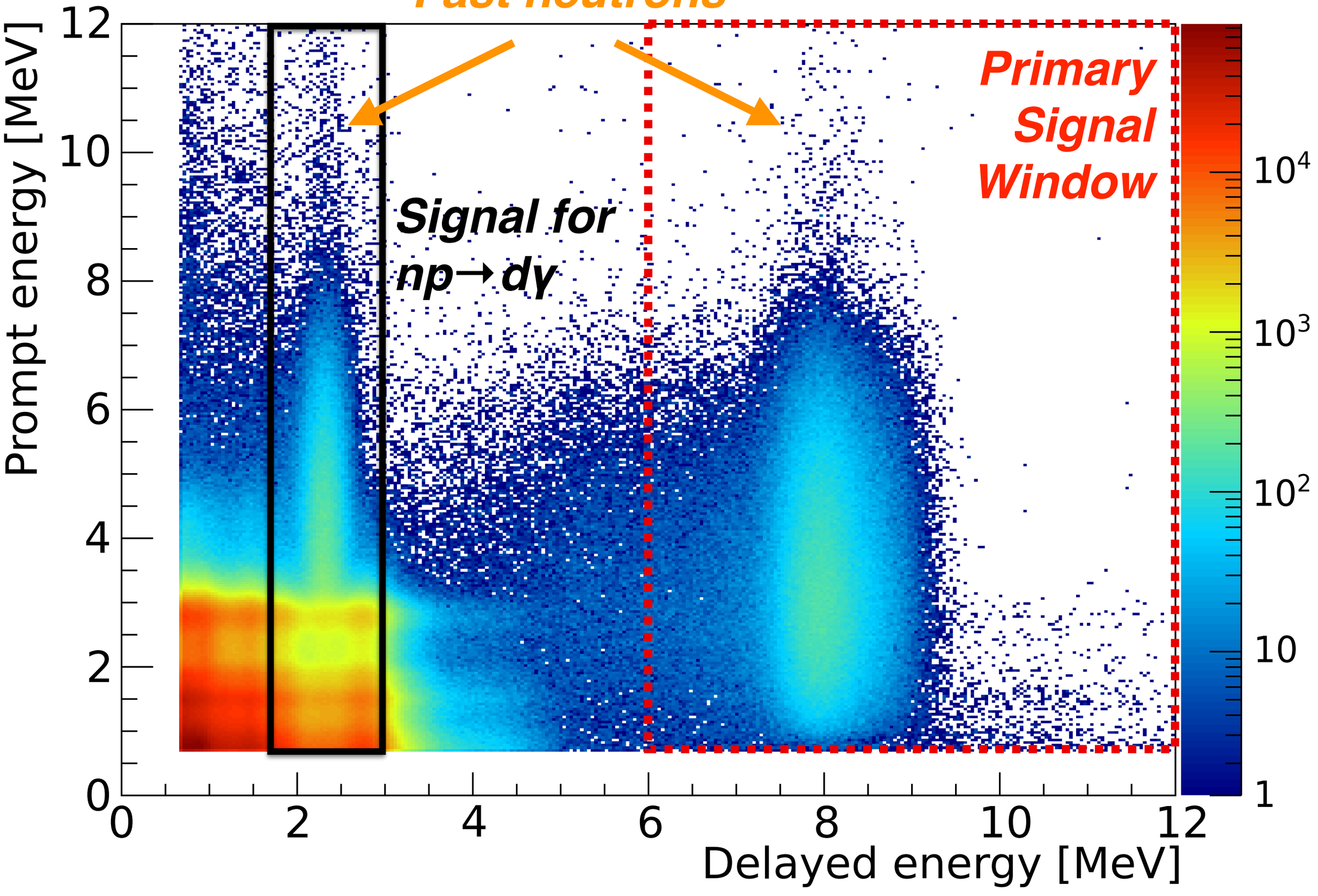

Hall 3:
860 mwe
Mountains rising with distance from the bay.
Hall 2:
265 mwe
Water
System
Liquid
scintillator
Assembly
2×2.9 GW
"Ling Ao"
2×2.9 GW
"Daya Bay"
2×2.9 GW
Hall 1:
250 mwe
Antineutrino
Detectors

Detecting Electron Antineutrinos

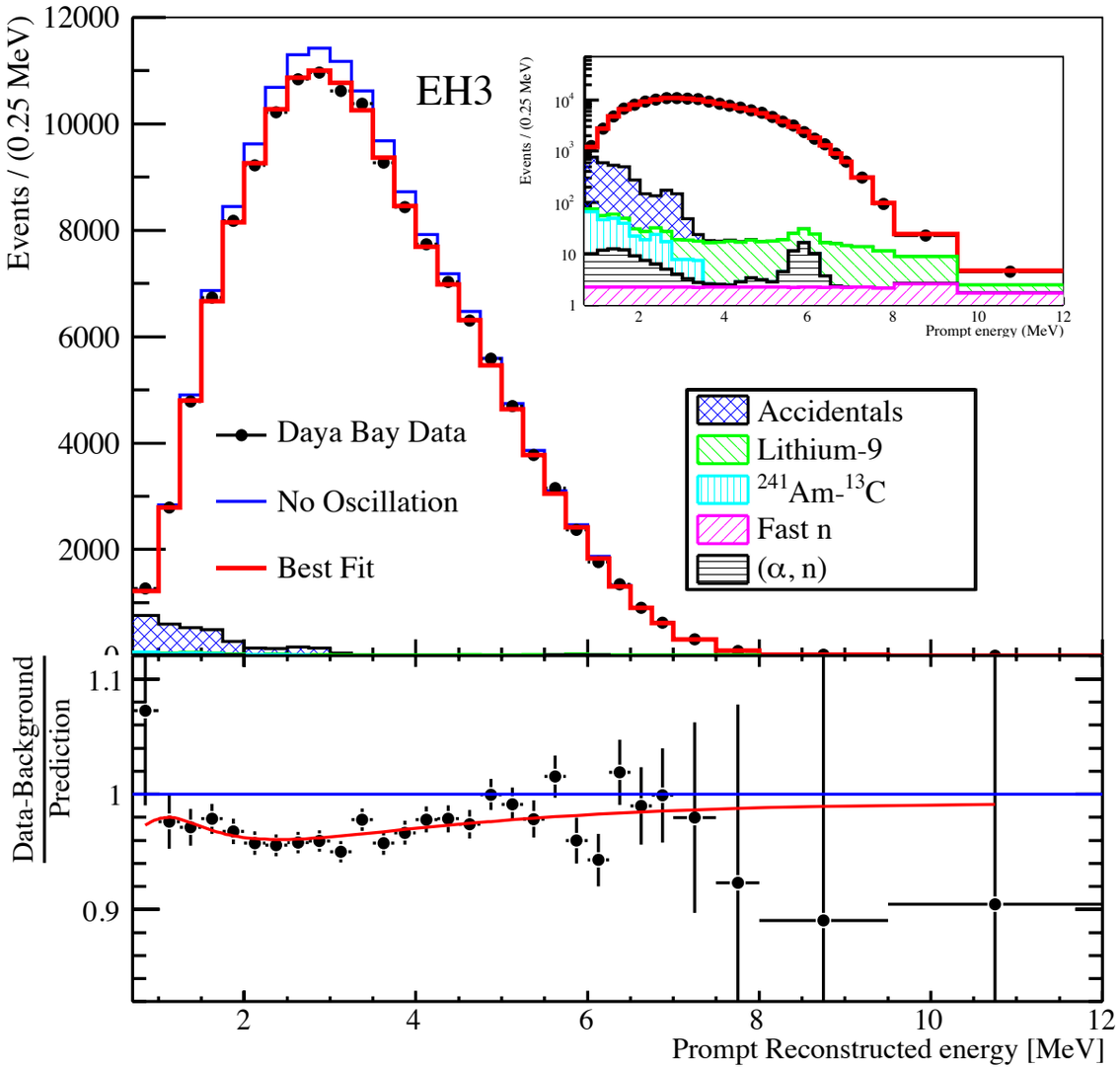


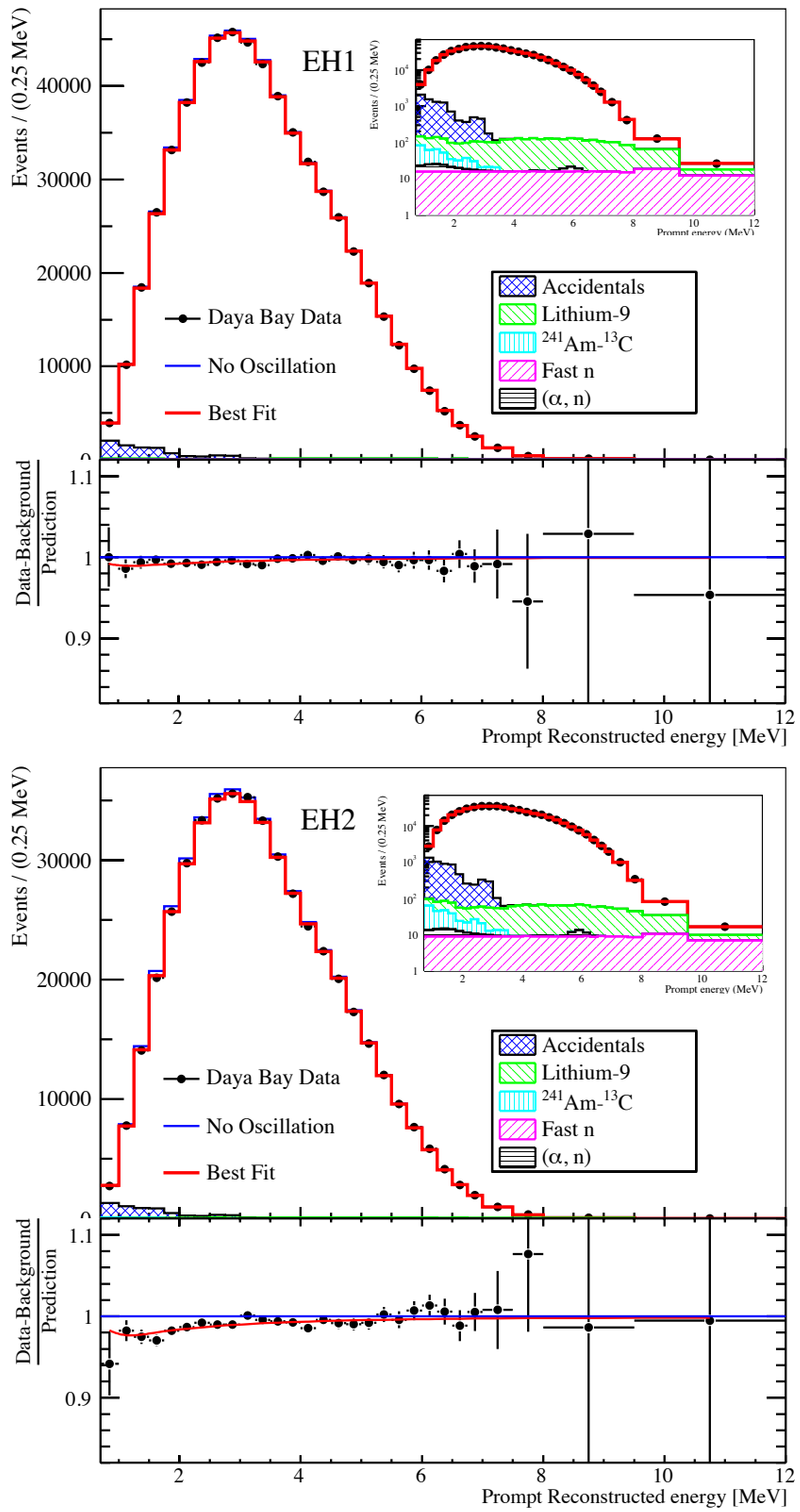
Prompt signal from e^+ gives primary energy signal

Delayed signal from Gd capture fights background


Fast neutrons
Primary Signal Window
Signal for np→dγ
Prompt energy [MeV]
Delayed energy [MeV]
0
2
4
6
8
10
12
1
10
10²
10³
10⁴

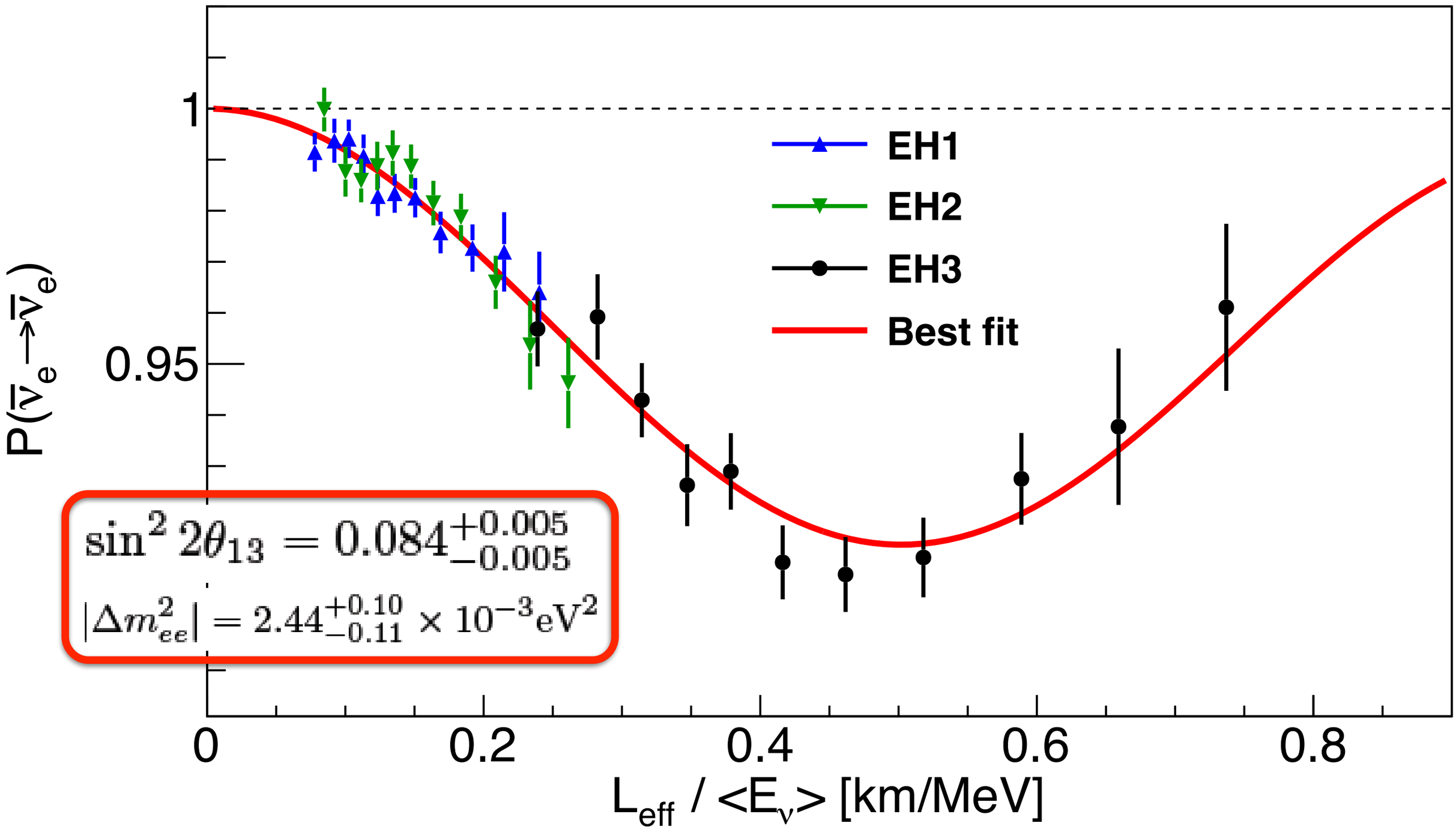
Neutrino Energy Spectra



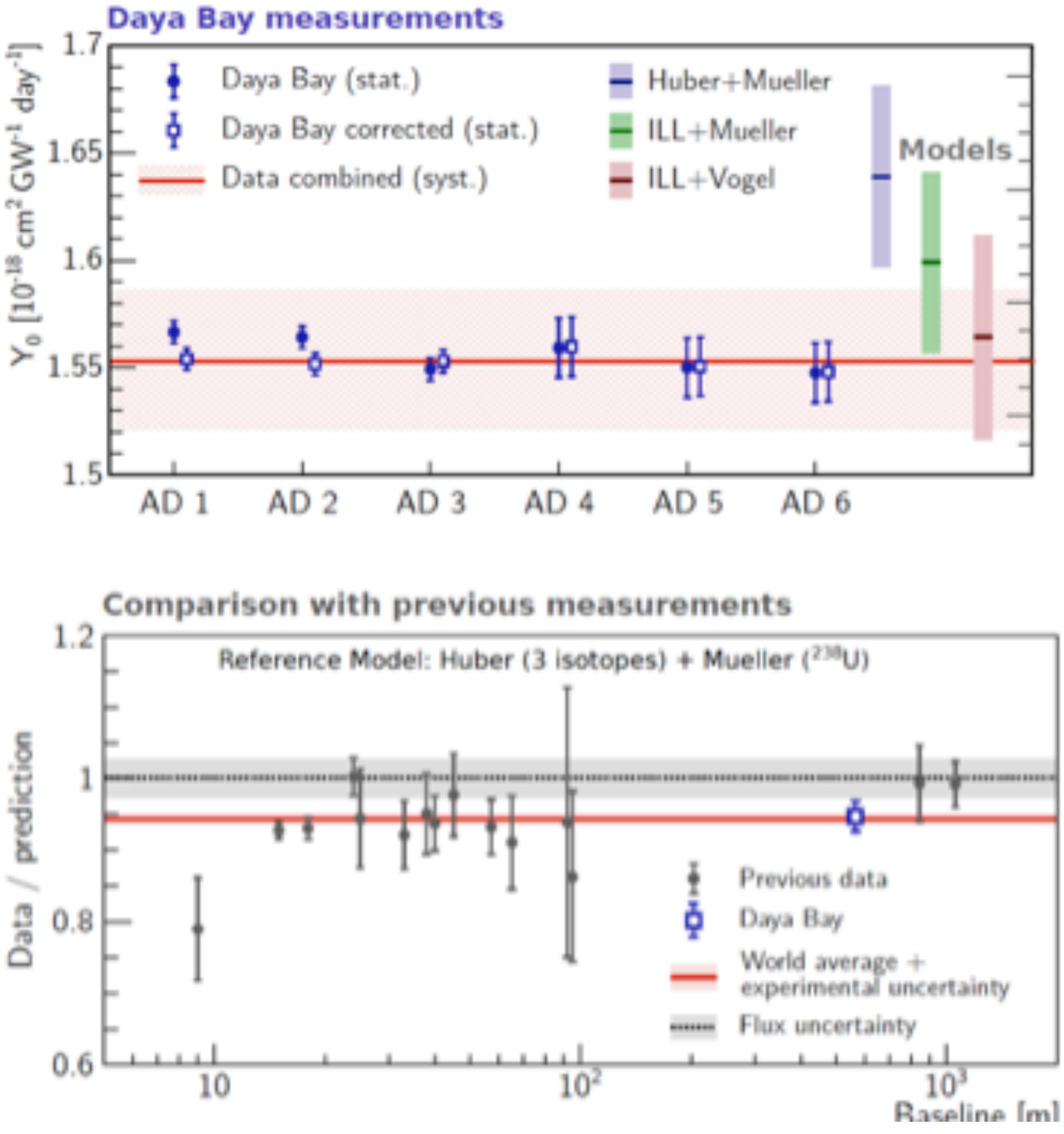


Spectral distortions are consistent with neutrino oscillations.

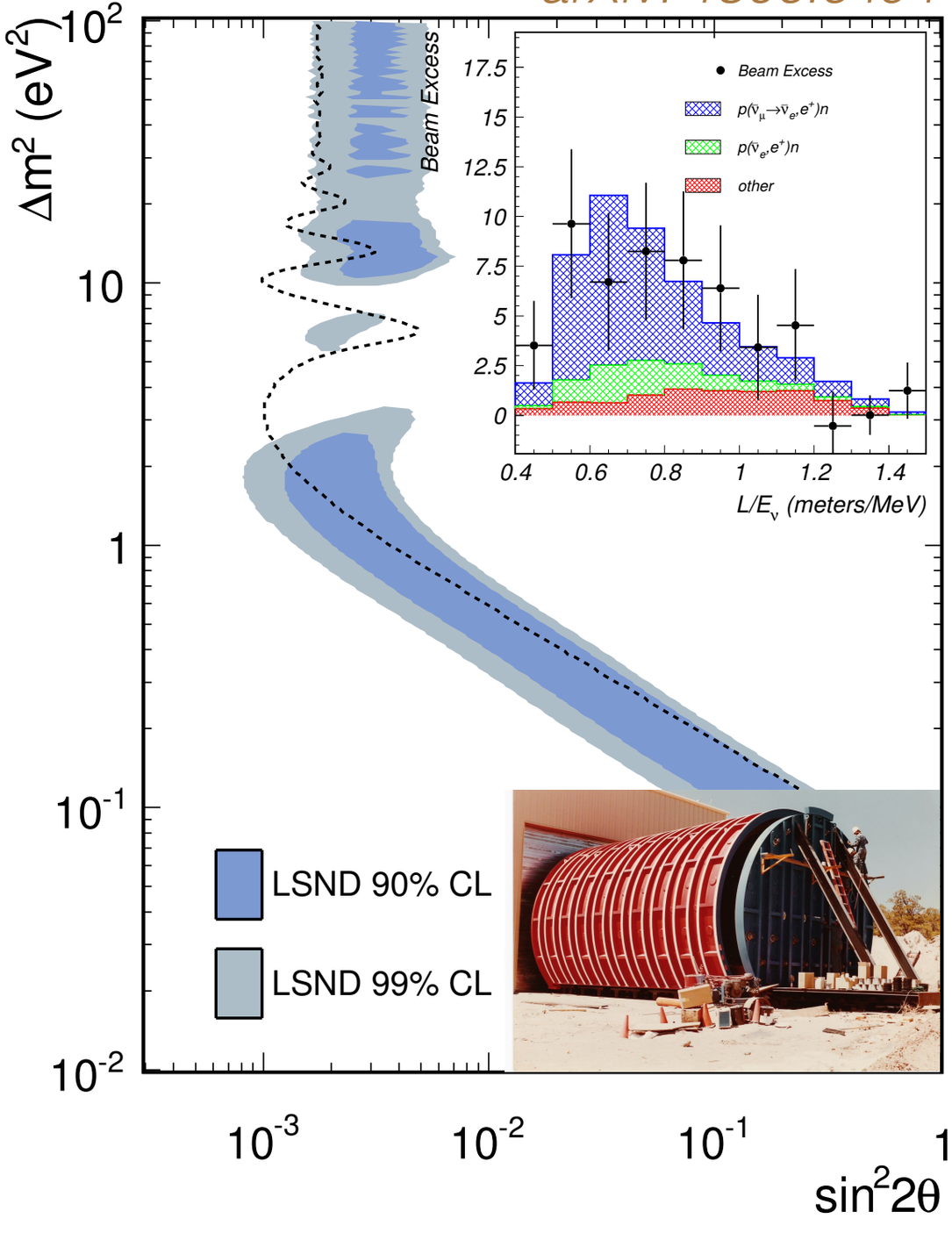
Neutrino Oscillations!



“Sterile” Neutrinos?



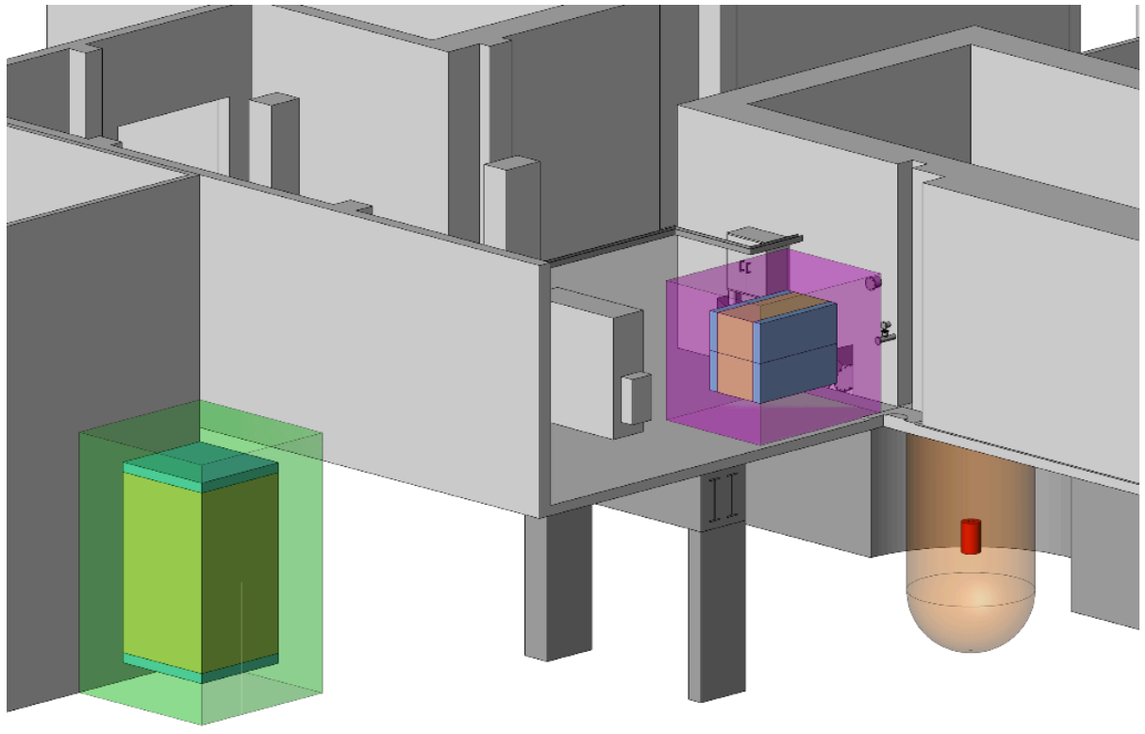
PRD 64(2001)112007
arXiv: 1306.6494



PROSPECT @ HFIR

Precision Measurement Very Close to the Reactor

arXiv:1307.2859



http://prospect.yale.edu

Neutrino detectors near to and far from a compact and well-understood research nuclear reactor core.

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Precision Measurement Very Close to the Reactor

arXiv:1307.2859

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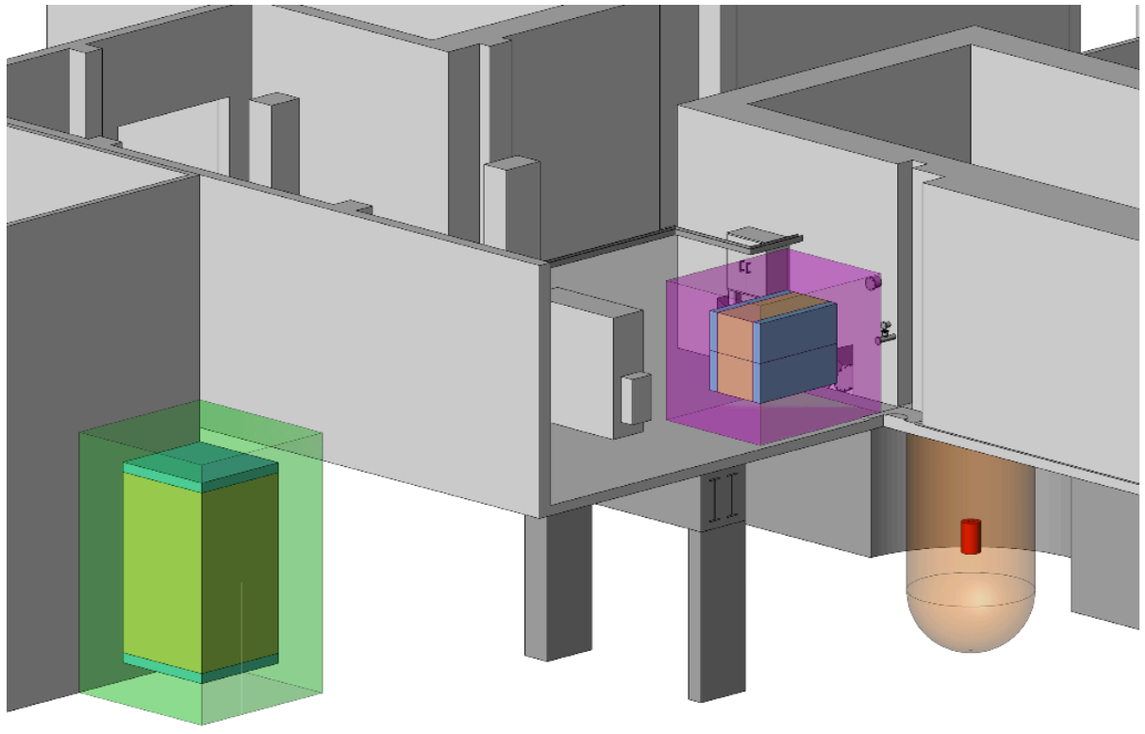
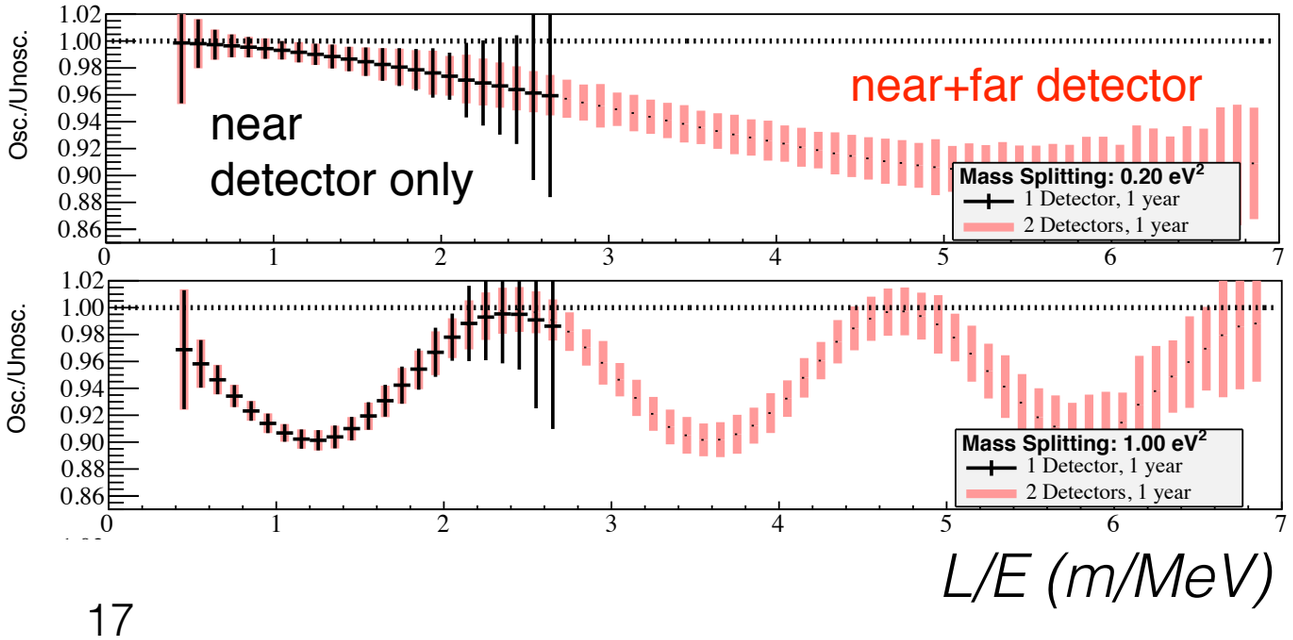


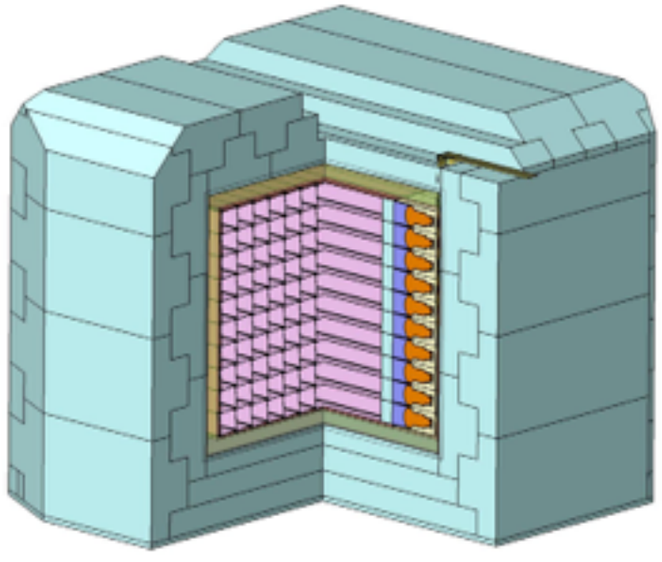
Neutrino detectors near to and far from a compact and well-understood research nuclear reactor core.

Combination of detectors so oscillation observed over wide range of Δm^2.



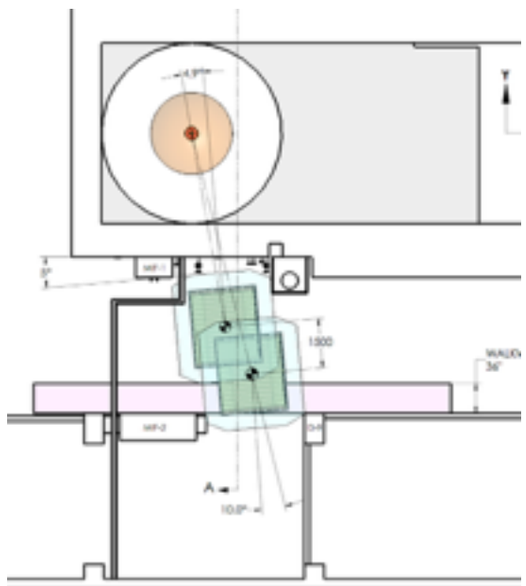
Near Detector *Sensitivity*

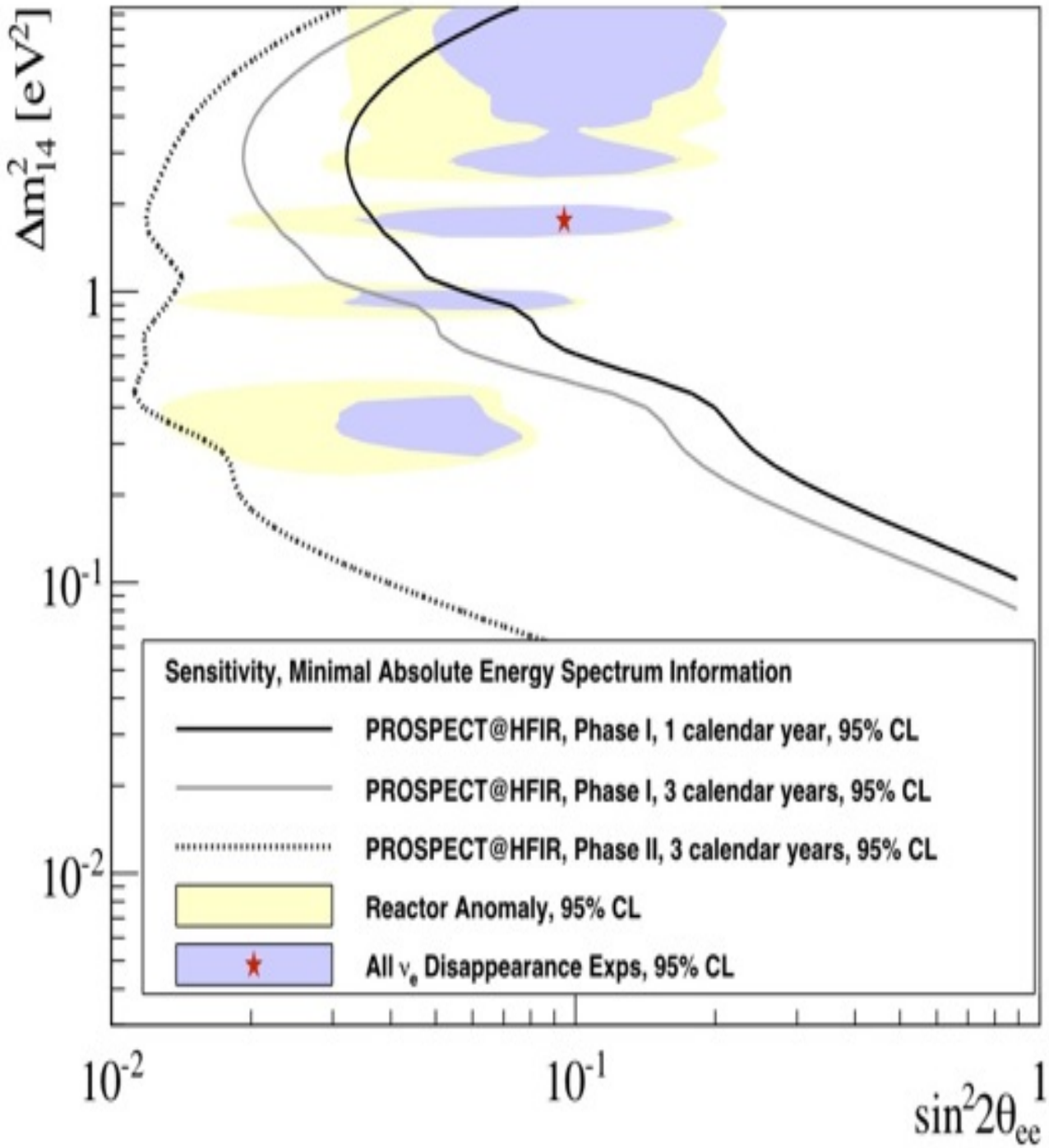
≈2.5 Tons



Floor plan at HIFR

< 10m to reactor core





Other Overlaps with Roy

Neutron cross sections

A.B. Smith, R. Holt, J. Whalen,
Argonne National Laboratory Report, ANL/NDM-43, 1978

"I began life as a neutron physicist. I am still a believer in the integral fast reactor (IFR)…"

$^{16}O(\gamma,\alpha)^{12}C$

(See talk tomorrow by Claudio Ugalde.)

Always a wide range of interests, always encouraging to young people, always a pleasure.

Congratulations, Roy!

… and many thanks to the organizers.