Observation of Electron Anti-neutrino Disappearance at Daya Bay

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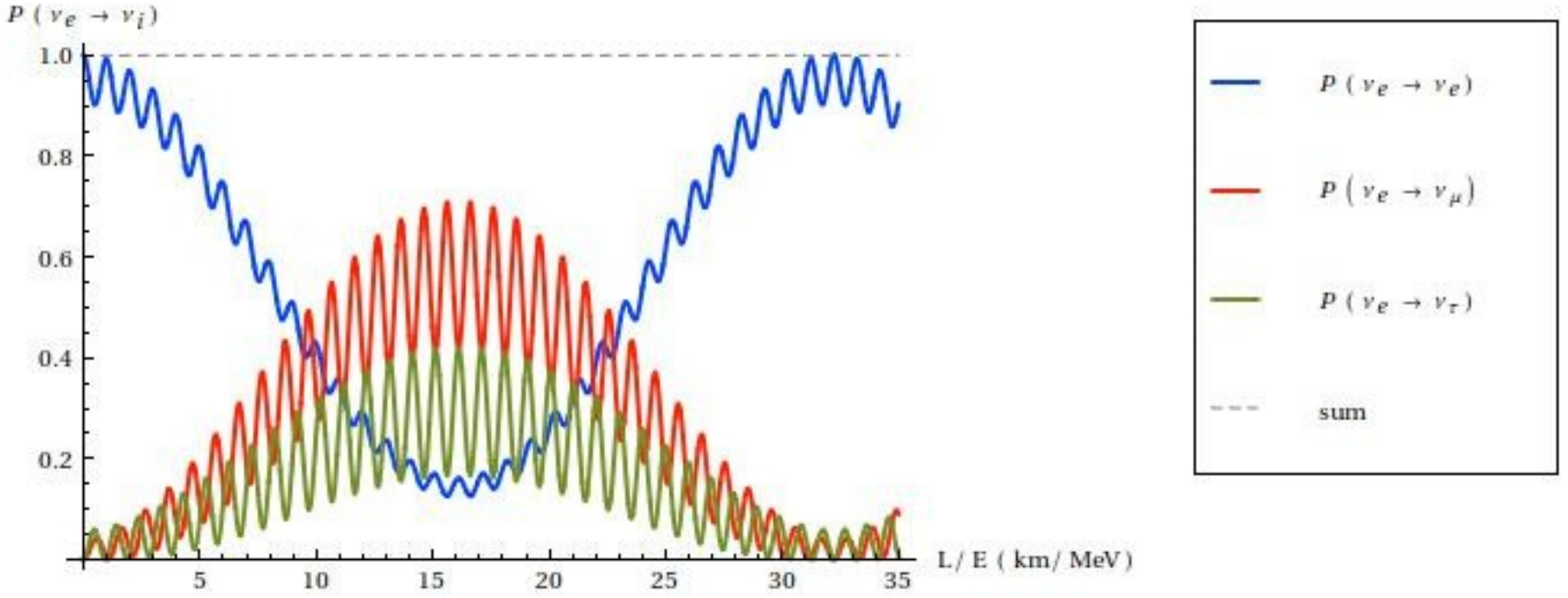
December 5, 2017

Neutrino Oscillation



$\bar{\nu}_e$ From nuclear reaction in nuclear power plant

$$P_{\text{sur}} \approx 1 - \sin^2 2\theta_{13} \sin^2(1.267 \Delta m^2_{31} L/E),$$

Pontecorvo Maki – Nakagawa – Sakata Matrix

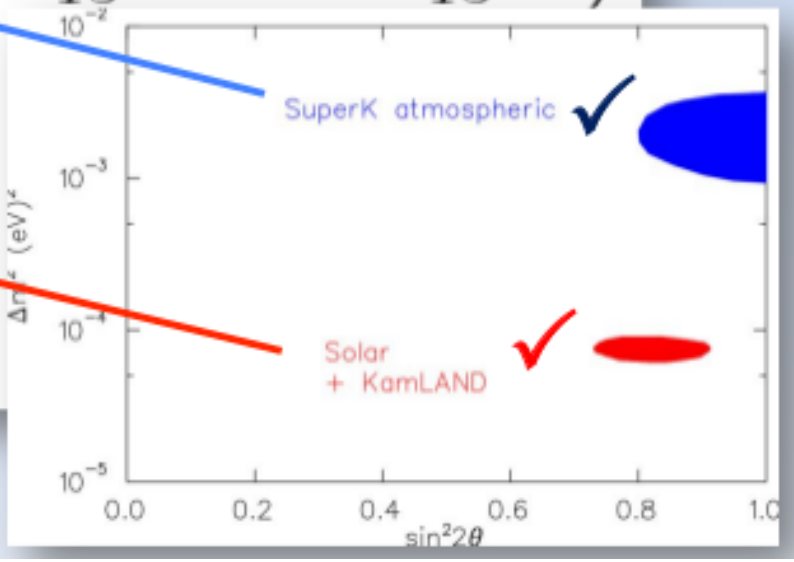
$$U_{PMNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

Gateway to CP Violation!

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

CP violation

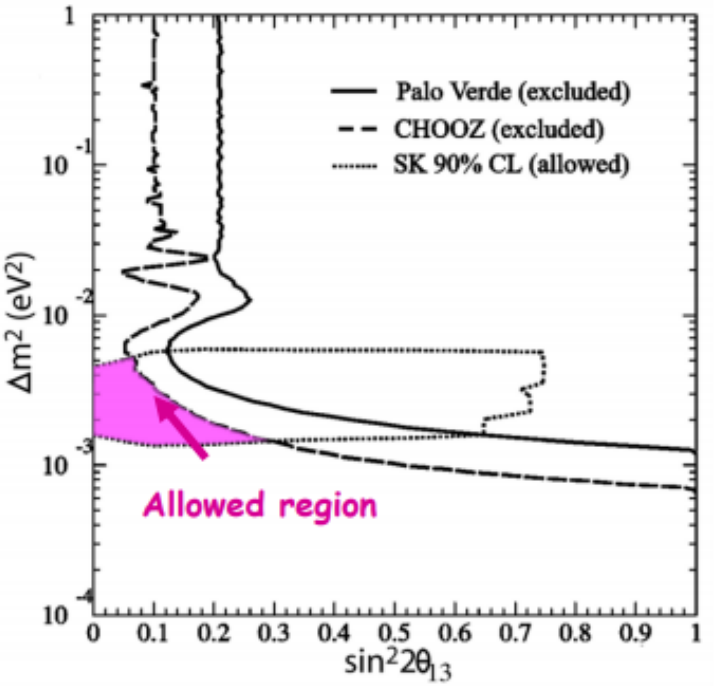
$$\times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} .$$



Direct Searches in the Past

- **Palo Verde & Chooz: no signal**

$\mathrm{Sin}^2 2\theta_{13} < 0.12$ @ 90%C.L.
if $\Delta M^2_{23} = 0.0024\ \mathrm{eV}^2$



- **T2K: 2.5 σ over bkg**

$0.03 < \mathrm{Sin}^2 2\theta_{13} < 0.28$ @ 90%C.L. for NH
$0.04 < \mathrm{Sin}^2 2\theta_{13} < 0.34$ @ 90%C.L. for IH

- **Minos: 1.7 σ over bkg**

$0 < \mathrm{Sin}^2 2\theta_{13} < 0.12$ @ 90%C.L. NH
$0 < \mathrm{Sin}^2 2\theta_{13} < 0.19$ @ 90%C.L. IH

- **Double Chooz: 1.7 σ**

$\sin^2 2\theta_{13} = 0.086 \pm 0.041(\mathrm{stat}) \pm 0.030(\mathrm{sys})$

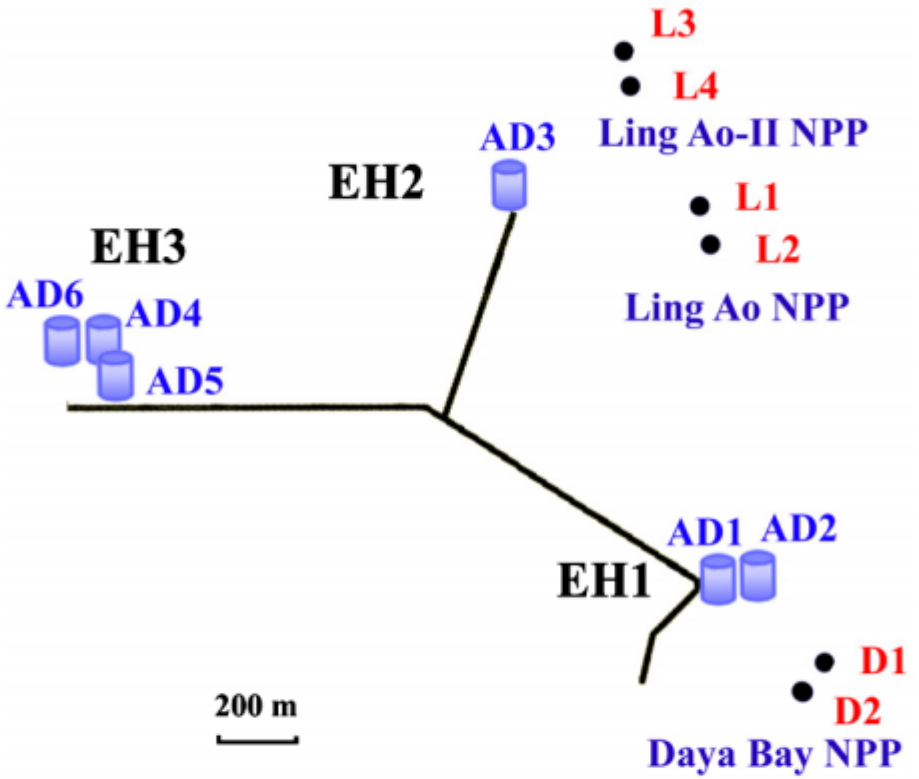
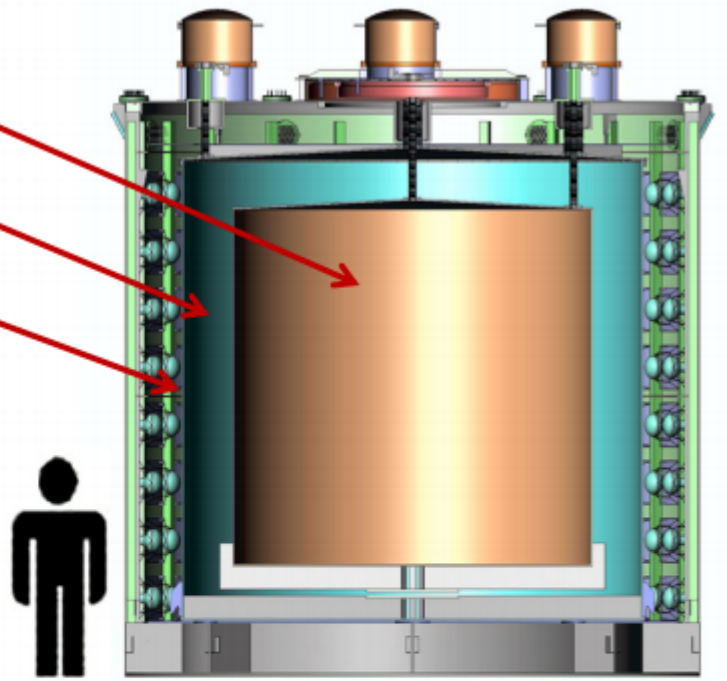
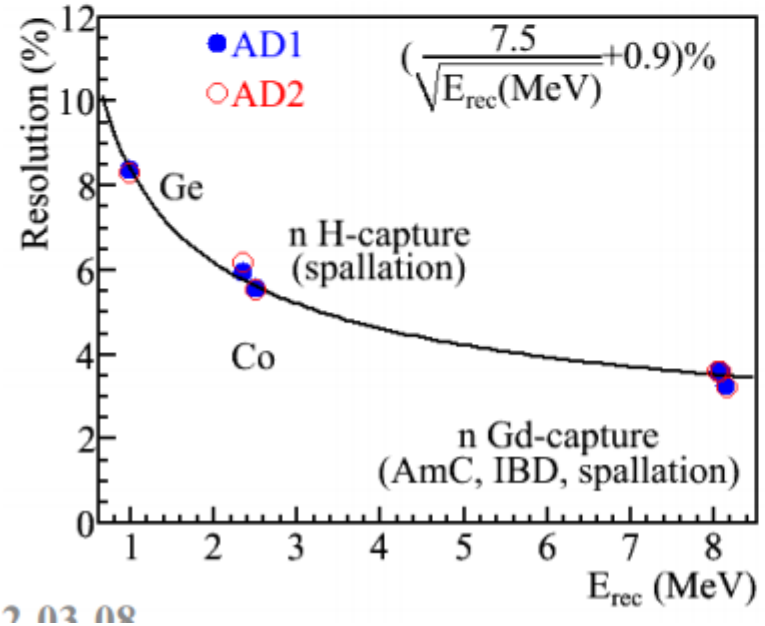


FIG. 1 (color online). Layout of the Daya Bay experiment. The dots represent reactors, labeled as D1, D2, L1, L2, L3, and L4. Six ADs, AD1–AD6, are installed in three EHs.

Anti-neutrino Detector (AD)

- **Three zones modular structure:**
  - **I. target: Gd-loaded scintillator**
  - **II. γ-catcher: normal scintillator**
  - **III. buffer shielding: oil**
- **192 8” PMTs/module**
- **Two optical reflectors at the top and the bottom, Photocathode coverage increased from 5.6% to 12%**





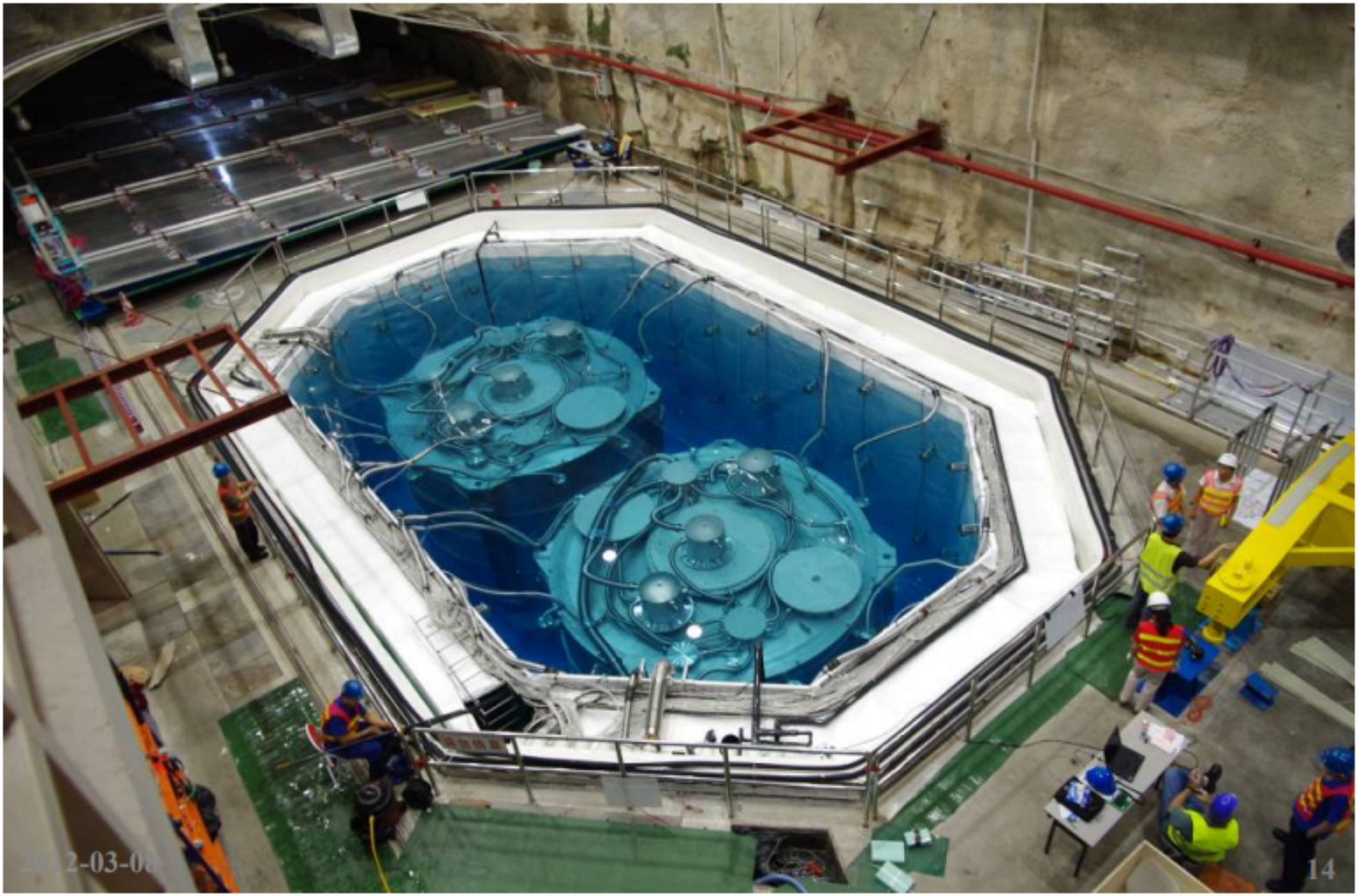
Target: 20 t, 1.6m

γ-catcher: 20t, 45cm

Buffer: 40t, 45cm

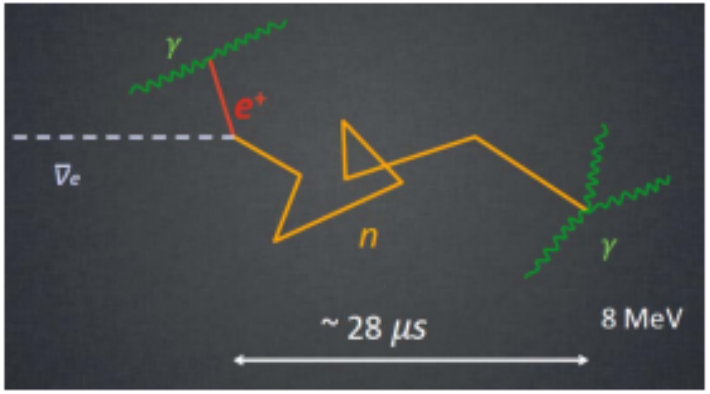
Total weight: ~110 t

Two ADs Installed in Hall 1



Neutrino Detection: Gd-loaded Liquid Scintillator

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

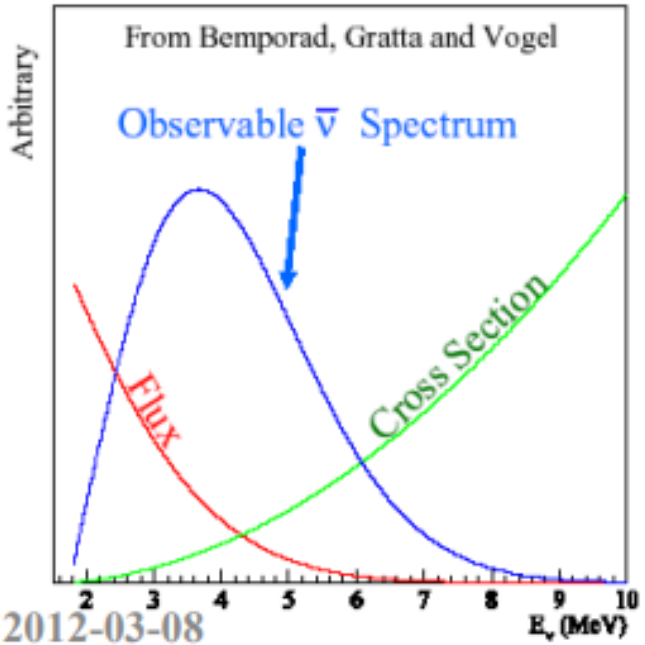


$\tau \approx 28\ \mu s$(0.1% Gd)

$$n + p \rightarrow d + \gamma\ (2.2\ MeV)$$

$$n + Gd \rightarrow Gd^* + \gamma\ (8\ MeV)$$

Neutrino Event: coincidence in time, space and energy



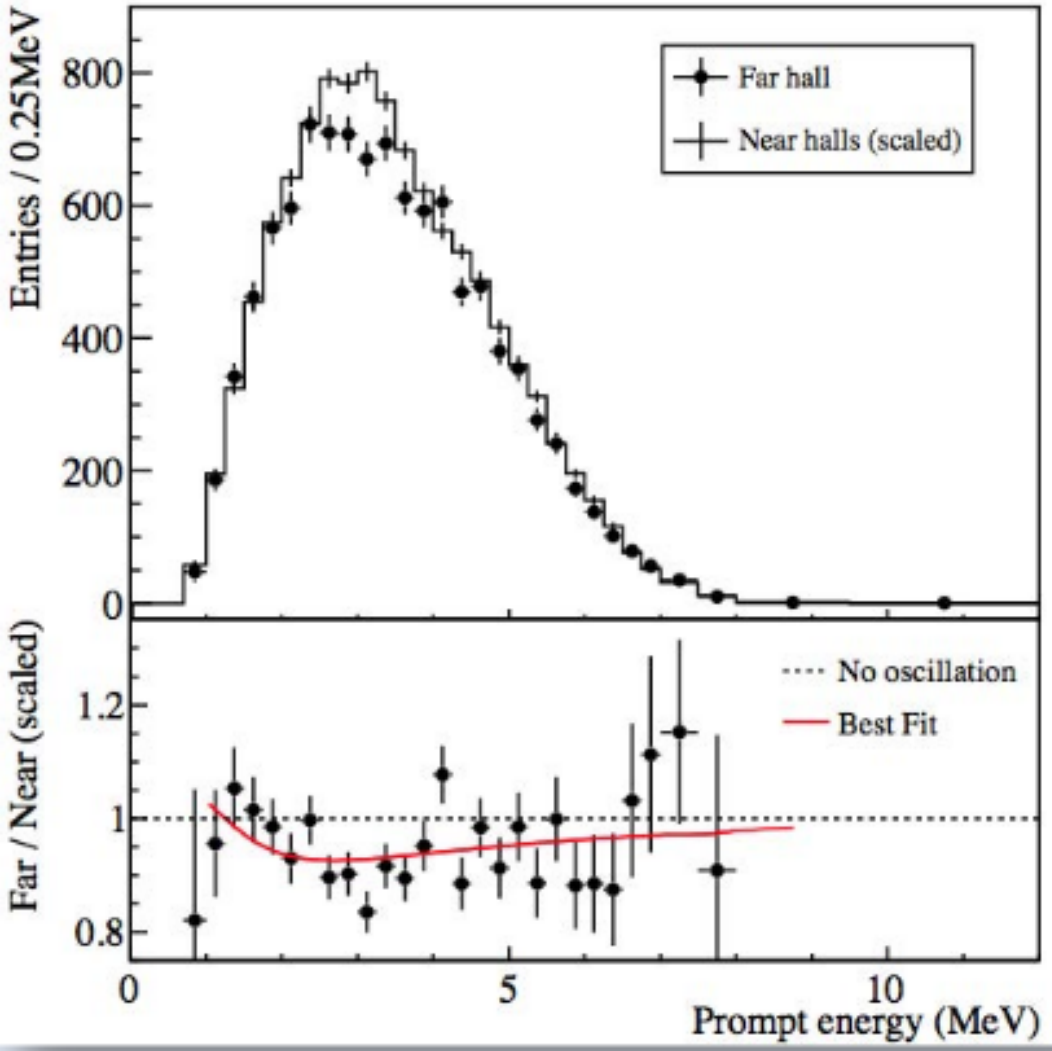
Neutrino energy:

$$E_{\bar{\nu}} \cong T_{e^+} + T_n + (M_n - M_p) + m_{e^+}$$

10-40 keV *1.8 MeV:* Threshold

March 2012: θ_{13} Surprise!

Compare measured rates and spectra



$$R = \frac{Far_{measured}}{Far_{expected}} = \frac{M_4 + M_5 + M_6}{\sum_{i=4}^{6}(\alpha_i(M_1 + M_2) + \beta_i M_3)}$$

M_n are the measured rates in each detector. Weights α_i,β_i are determined from baselines and reactor fluxes.

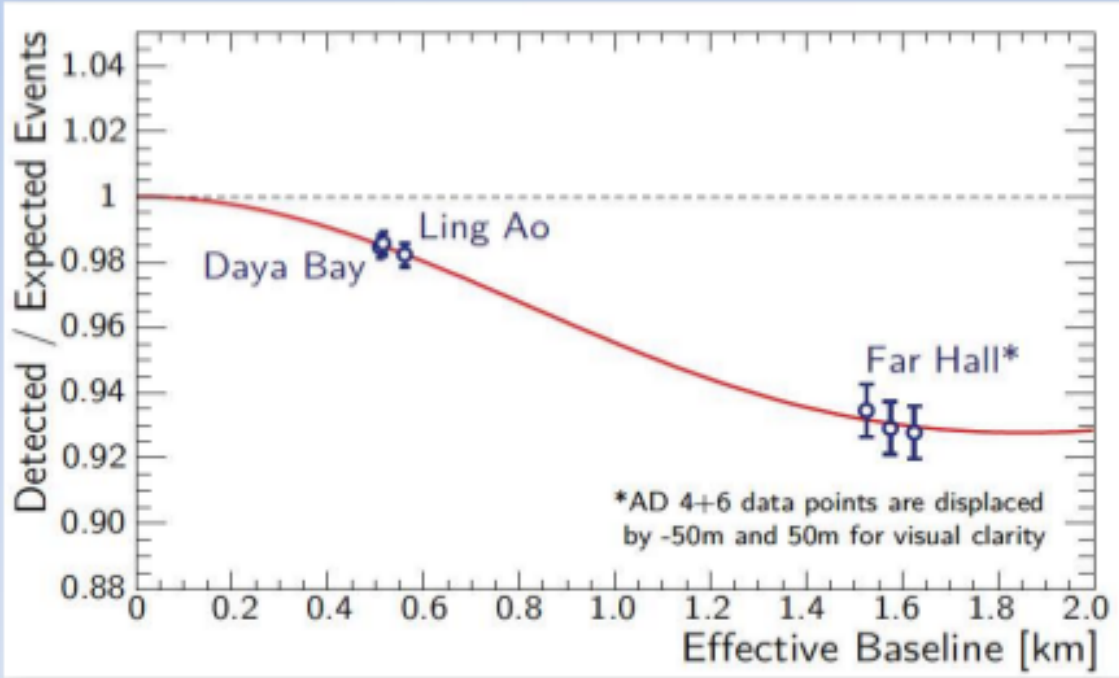
R = 0.940 ± 0.011 (stat) ± 0.004 (syst)

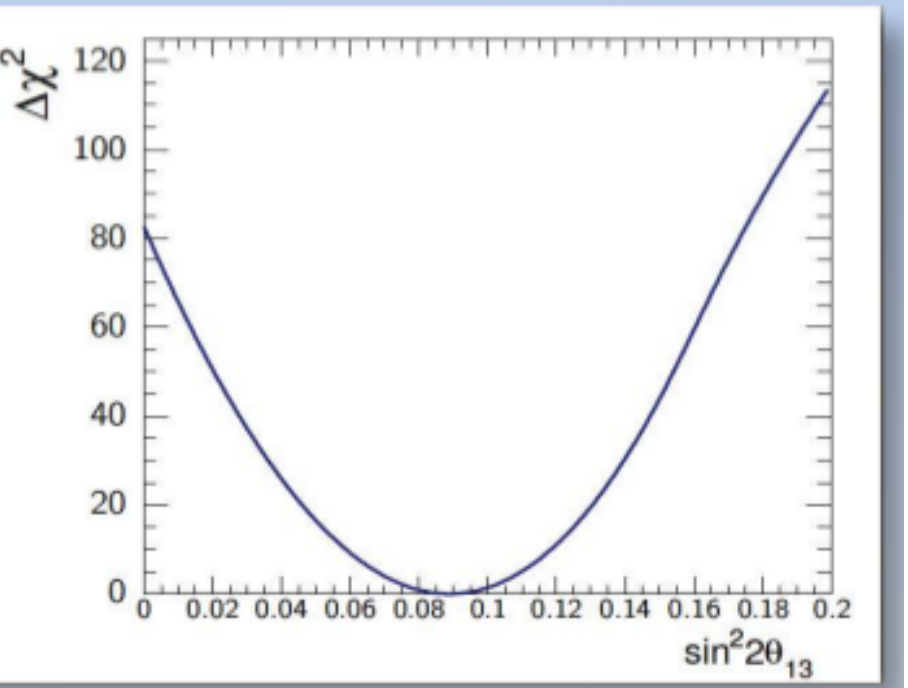
Clear observation of far site deficit!

Spectral distortion consistent with oscillation.

July 2013: Updated result

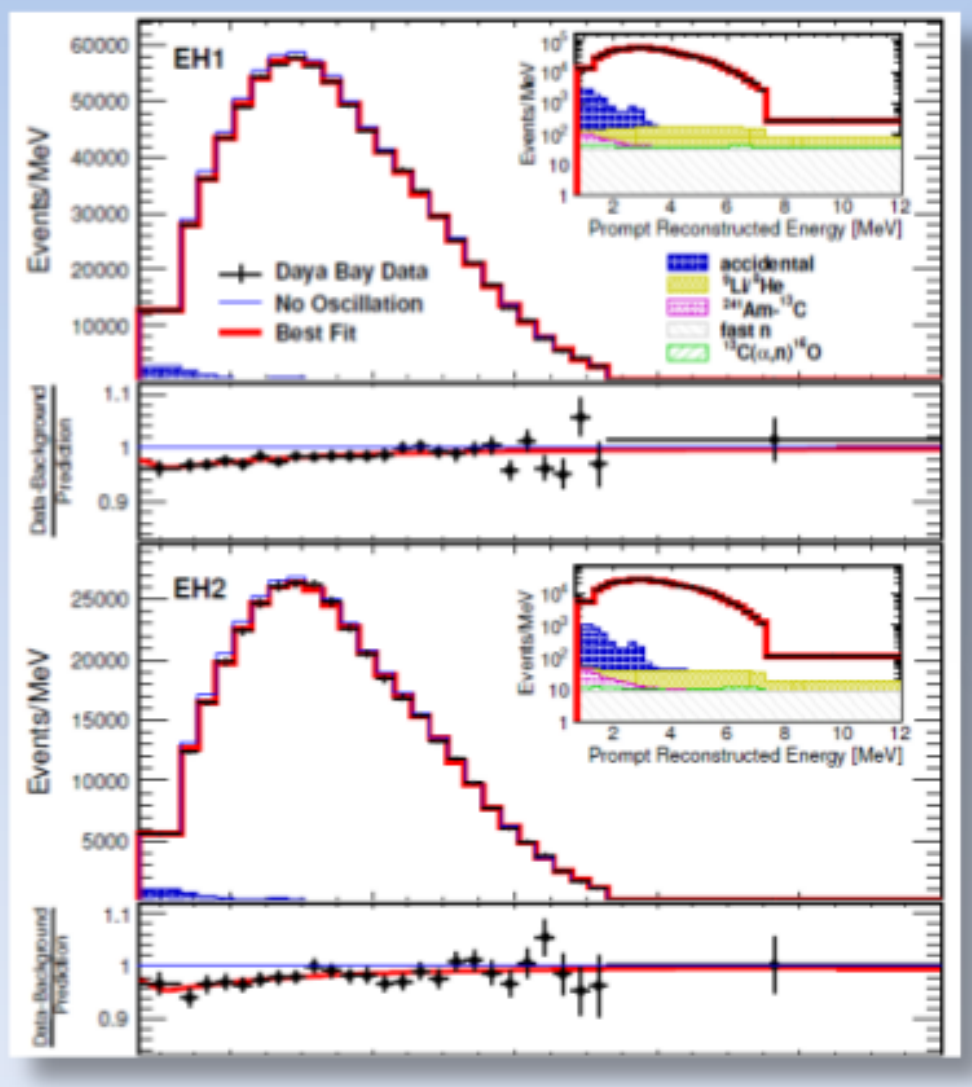
Rate only analysis:

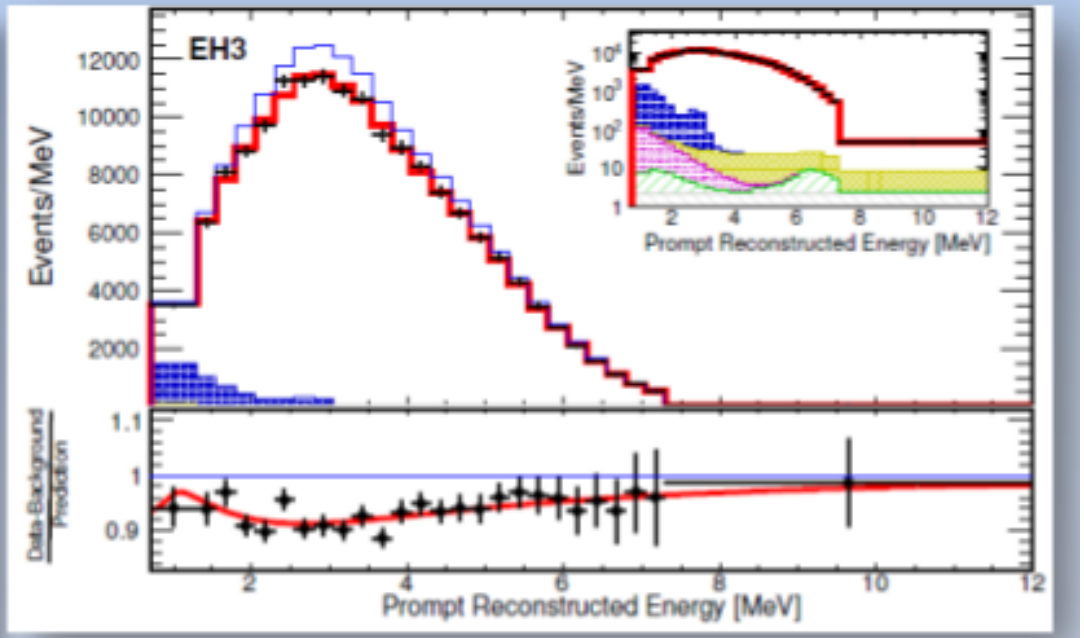




$\sin^2 2\theta_{13} = 0.089 \pm 0.009$

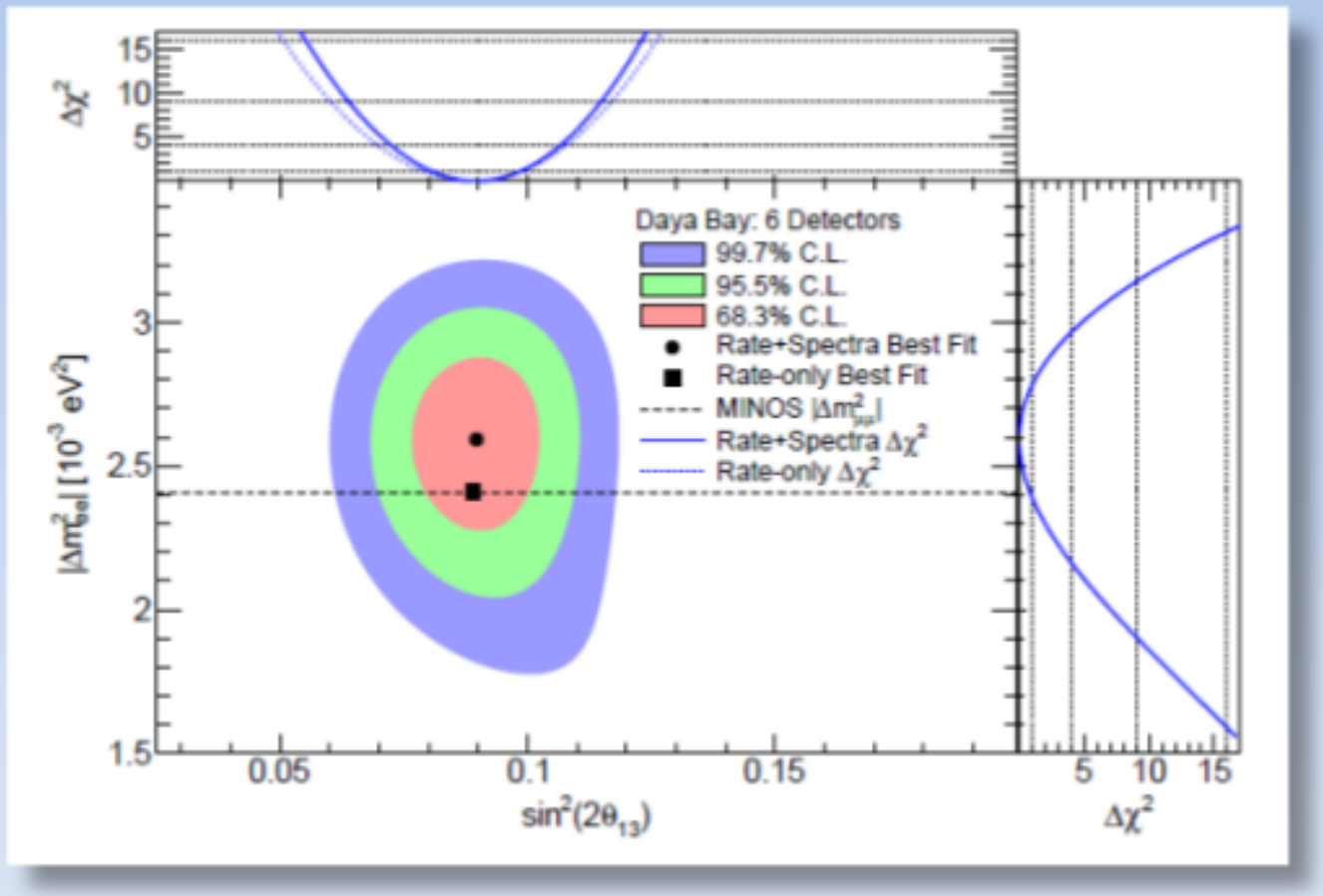
Energy Spectrum Distortion





- Clear difference at far site
- Consistent with oscillations

Rate + Shape Analysis



$$\sin^2 2\theta_{13} = 0.090^{+0.008}_{-0.009} \qquad \chi^2/N_{DOF} = 162.7/153$$

$$|\Delta m^2_{ee}| = 2.59^{+0.19}_{-0.20} \times 10^{-3}\ \text{eV}^2$$

Thank you !