Highlights from the Daya Bay Neutrino Experiment

Zhe Wang

Tsinghua University

(On behalf of the Daya Bay Collaboration)

Presentation at ICNFP on Sep. 5, 2013

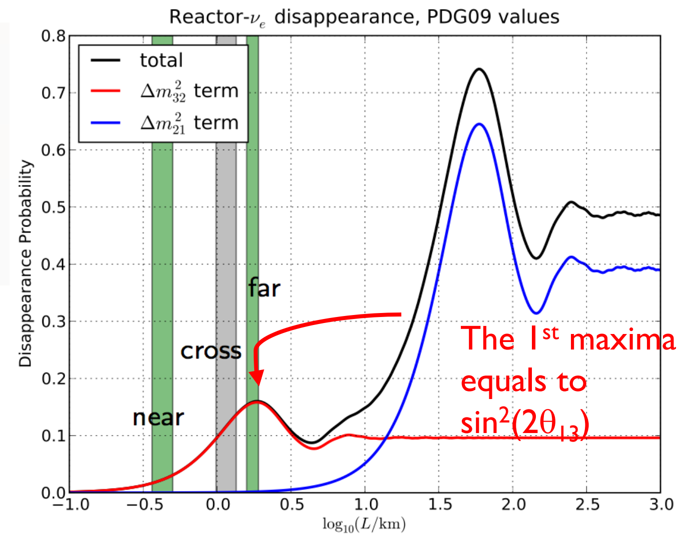
Measurement Method

Detection of anti-electron-neutrino

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

$\rightarrow + p \rightarrow D + \gamma\ (2.2\ MeV)$ (200 μs)

$\rightarrow + Gd \rightarrow Gd^* \rightarrow Gd + \gamma\text{'s}\ (8\ MeV)$ (30 μs)



Extraction of θ_{13}

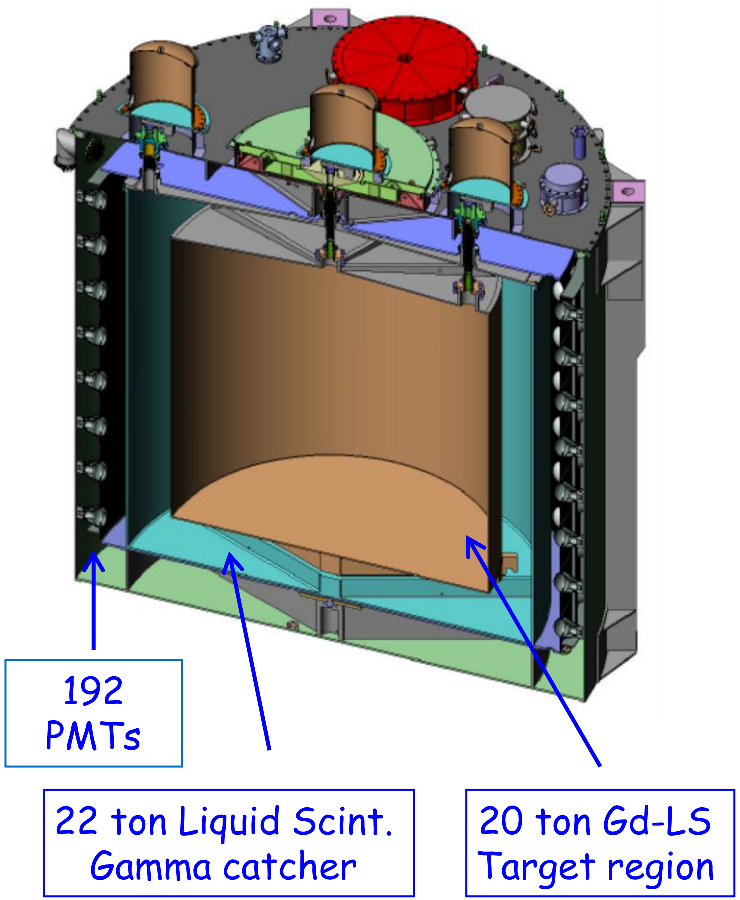
1. Mixing angle θ_{13} governs overall size of $\bar{\nu}_e$ deficit
2. Effective mass squared difference $|\Delta m^2_{ee}|$ determines deficit dependence on L/E

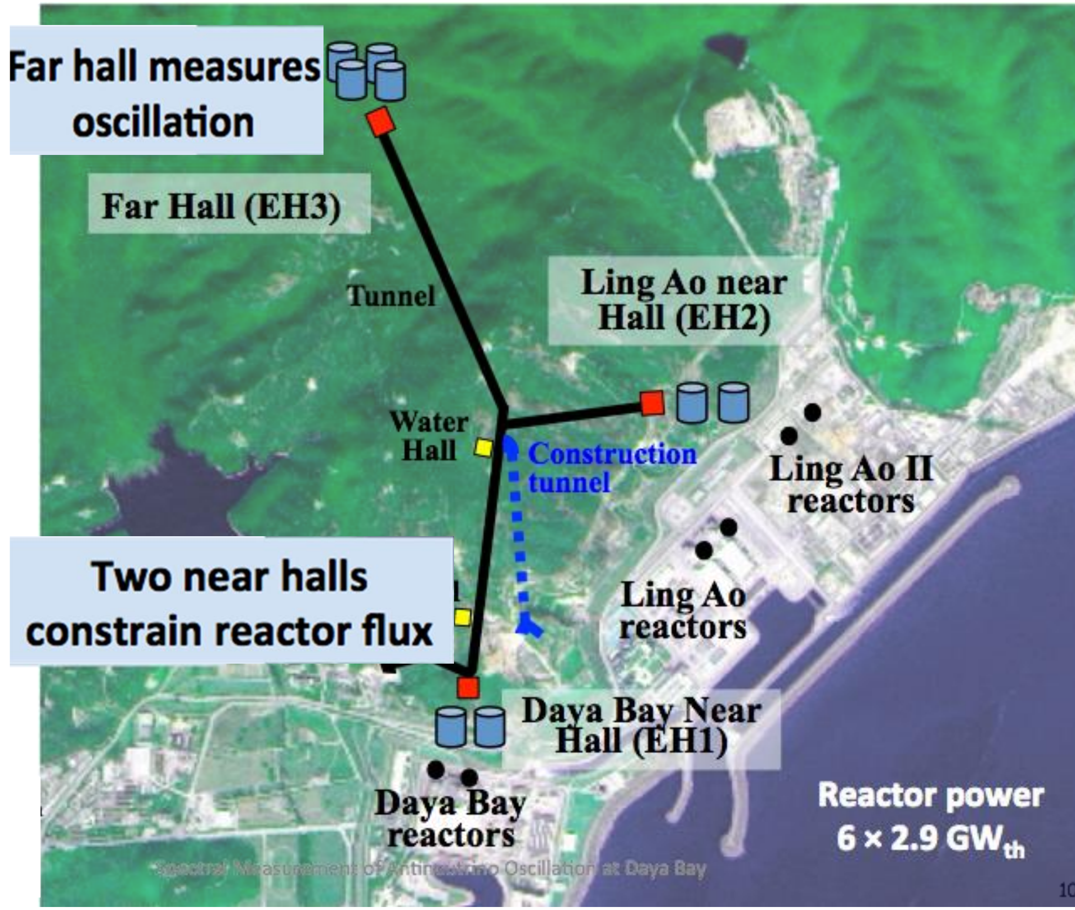
Short Baseline — Long Baseline

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e} = 1 - \sin^2 2\theta_{13} \sin^2\left(\Delta m^2_{ee} \frac{L}{4E}\right) - \sin^2 2\theta_{12} \cos^4\theta_{13} \sin^2\left(\Delta m^2_{21} \frac{L}{4E}\right)$$

$$\sin^2(\Delta m^2_{ee} \tfrac{L}{4E}) \equiv \cos^2\theta_{12} \sin^2(\Delta m^2_{31} \tfrac{L}{4E}) + \sin^2\theta_{12} \sin^2(\Delta m^2_{32} \tfrac{L}{4E})$$

The Daya Bay Experiment





Experiment Status and Data Taking

Two detector comparison [1202.6181]

- 90 days of data, Daya Bay near only
- NIM A **685** (2012), 78-97

First oscillation analysis [1203:1669]

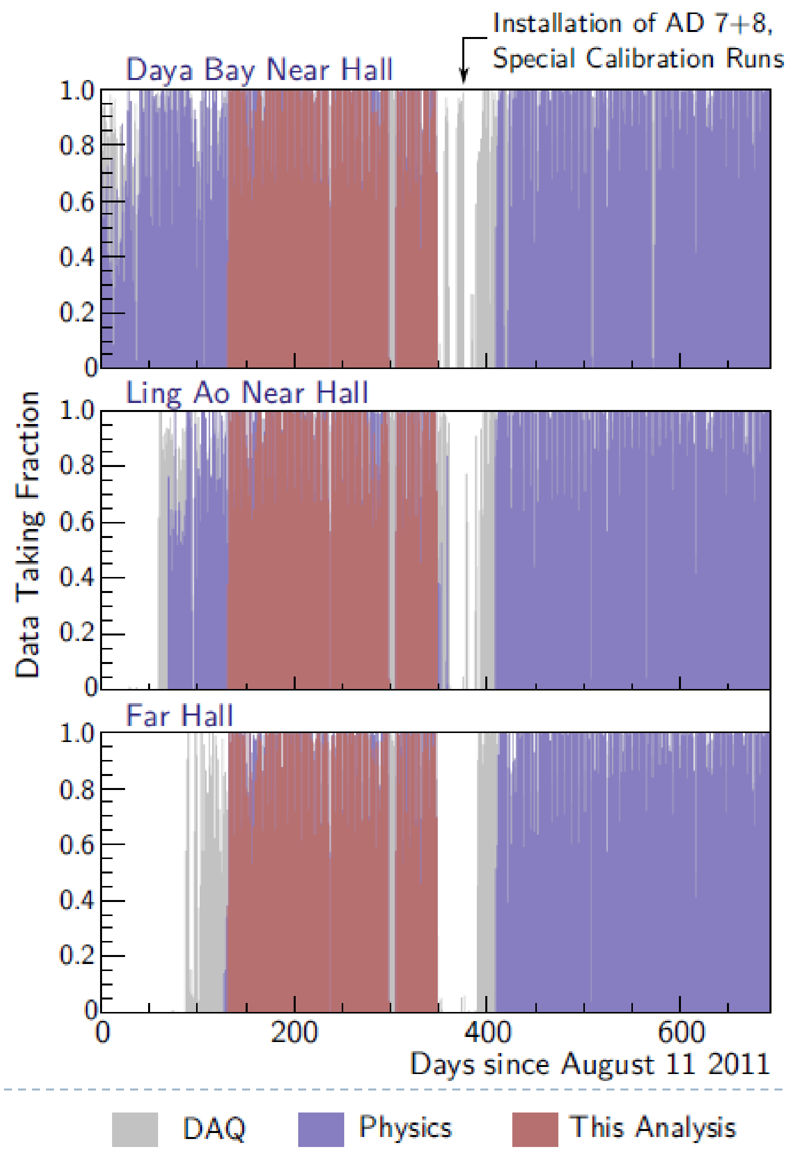
- 55 days of data, 6 ADs near+far
- PRL **108** (2012), 171803

Improved oscillation analysis [1210.6327]

- 139 days of data, 6 ADs near+far
- CPC **37** (2013), 011001

Spectral Analysis

- 217 days complete 6 AD period
- 55% more statistics than CPC result



Signal and Background Summary

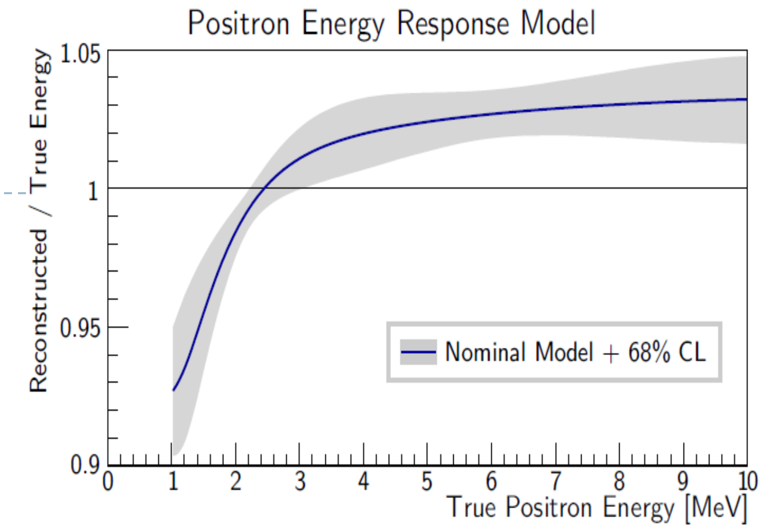
	Near Halls			Far Hall		
	AD1	AD2	AD3	AD4	AD5	AD6
IBD candidates	101290	102519	92912	13964	13894	13731
DAQ live time (day)	191.001		189.645	189.779		
Efficiency	0.7957	0.7927	0.8282	0.9577	0.9568	0.9566
Accidentals (/day/AD)*	9.54±0.03	9.36±0.03	7.44±0.02	2.96±0.01	2.92±0.01	2.87±0.01
Fast neutron (/day/AD)*	0.92±0.46		0.62±0.31	0.04±0.02		
^{8}He/^{9}Li (/day/AD)*	2.40±0.86		1.20±0.63	0.22±0.06		
Am-C corr. (/day/AD)*	0.26±0.12					
^{13}C(α, n)^{16}O (/day/AD)*	0.08±0.04	0.07±0.04	0.05±0.03	0.04±0.02	0.04±0.02	0.04±0.02
IBD rate (/day/AD)*	**653.30 ± 2.31**	**664.15 ± 2.33**	**581.97 ± 2.07**	**73.31 ± 0.66**	**73.03 ± 0.66**	**72.20 ± 0.66**

* Corrected for the efficiency of the muon veto and multiplicity cuts

Collected more than 300k antineutrino interactions

- Consistent rates for side-by-side detectors
- Uncertainties still dominated by statistics

Detector Energy Response



Particle Energy E_{true}

↓

Energy Deposited in Scintillator E_{dep}

↓

Energy Converted to Visible Light E_{vis}

↓

Reconstructed Energy E_{rec}

Energy Losses in Acrylic

Acrylic vessels non-scintillating

- Induce shape distortion
- Correction from MC

Scintillator Response

- Quenching effects
- Cherenkov radiation

Energy Resolution

- Light production
- Light collection
- PMT/electronics response

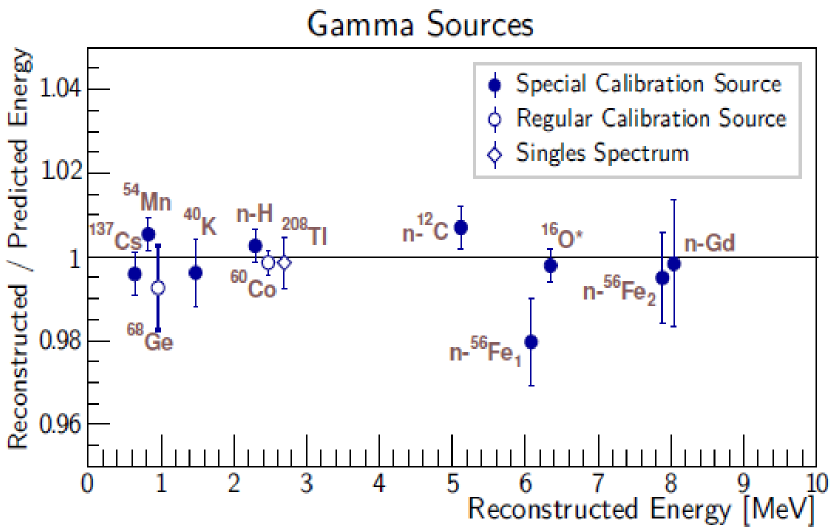
Readout Electronics

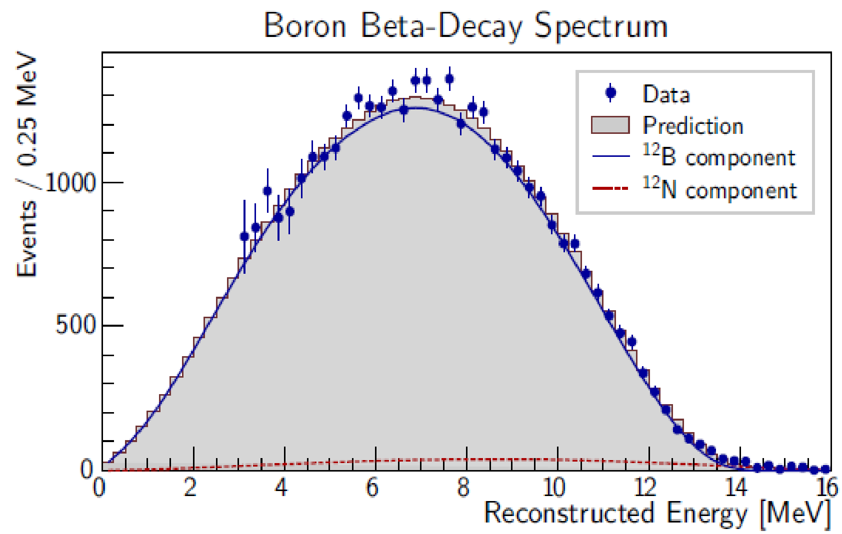
- Charge collection efficiency decreases with visible light

Model maps reconstructed energy E_{rec} to true kinetic energy E_{true}

- Minimal impact on oscillation measurement
- Crucial for measurement of reactor spectra

Constraining Models For Non-linear Response





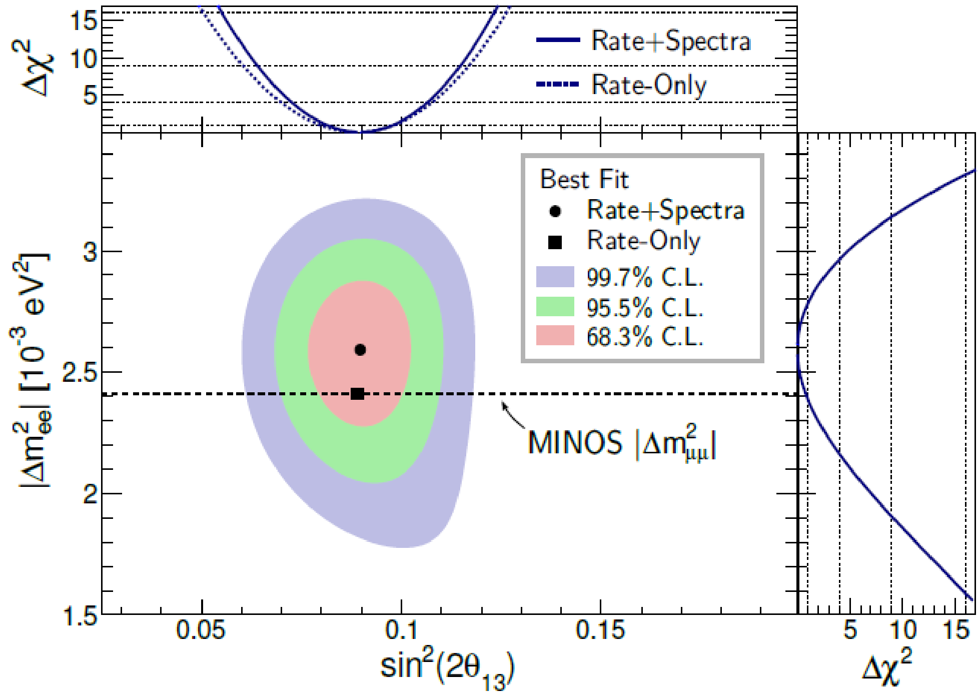
Full detector calibration data

1. Monoenergetic gamma lines from various sources
   - Radioactive calibration sources, employed regularly: ^{68}Ge, ^{60}Co, ^{241}Am-^{13}C and during special calibration periods: ^{137}Cs, ^{54}Mn, ^{40}K, ^{241}Am-^{9}Be, Pu-^{13}C
   - Singles and correlated spectra in regular physics runs (^{40}K, ^{208}Tl, n capture on H)
2. Continuous spectrum from ^{12}B produced by muon spallation inside the scintillator

Standalone measurements

- Scintillator quenching measurements using neutron beams and Compton e$^-$
- Calibration of readout electronics with flash ADC

Rate+Shape Fit Result



$\sin^2 2\theta_{13} = 0.090^{+0.008}_{-0.009}$

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

$\chi^2/NDF = 162.7/153$

Rate + Shape

$\sin^2 2\theta_{13} = 0.108 \pm 0.028$

$|\Delta m^2_{ee}| = 2.55^{+0.21}_{-0.18} \times 10^{-3} (eV^2)$

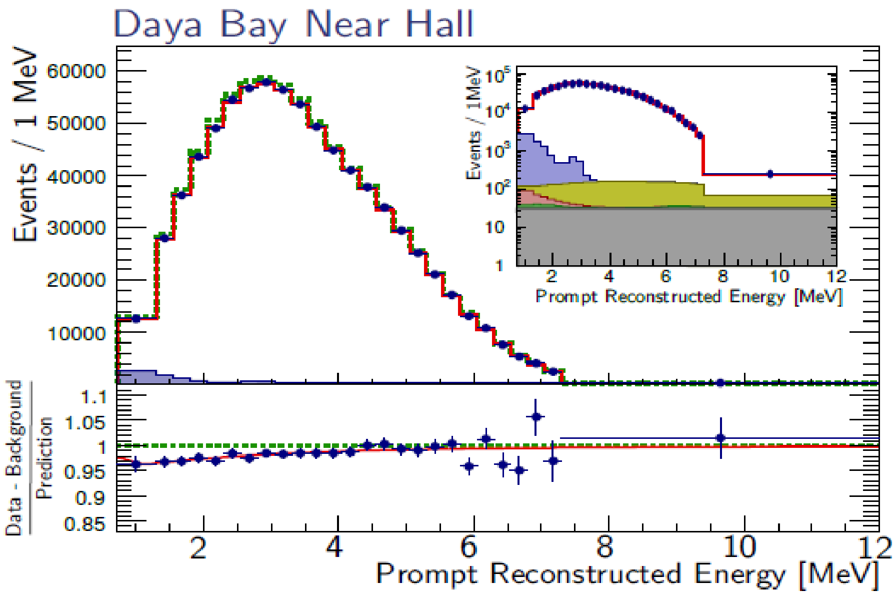
$\chi^2/NDF = 161.2/148$

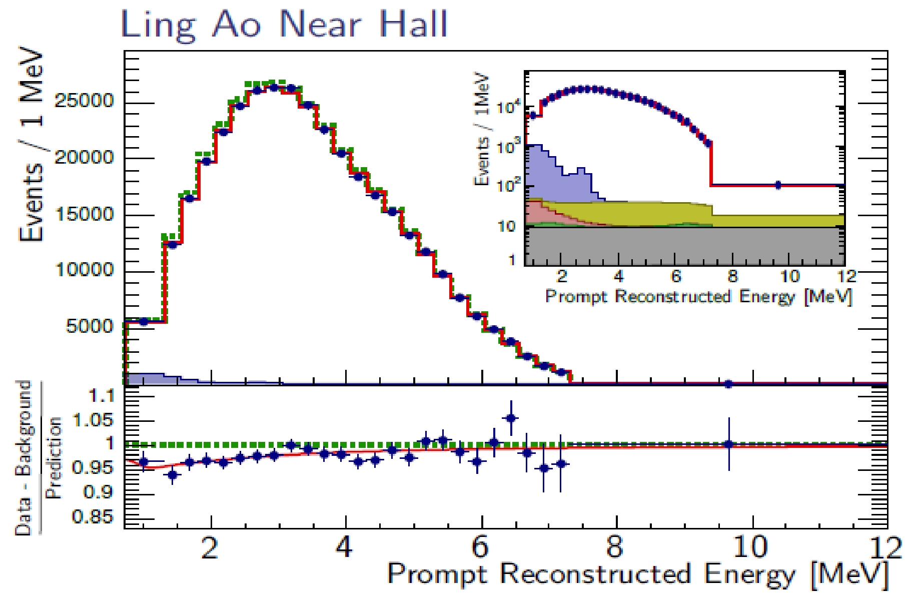
Shape only fit

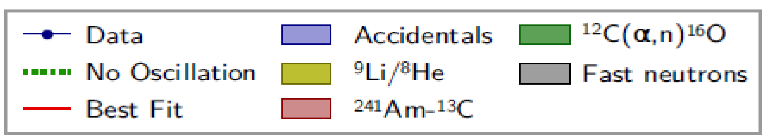
Strong confirmation of oscillation-interpretation of observed $\bar{\nu}_e$ deficit

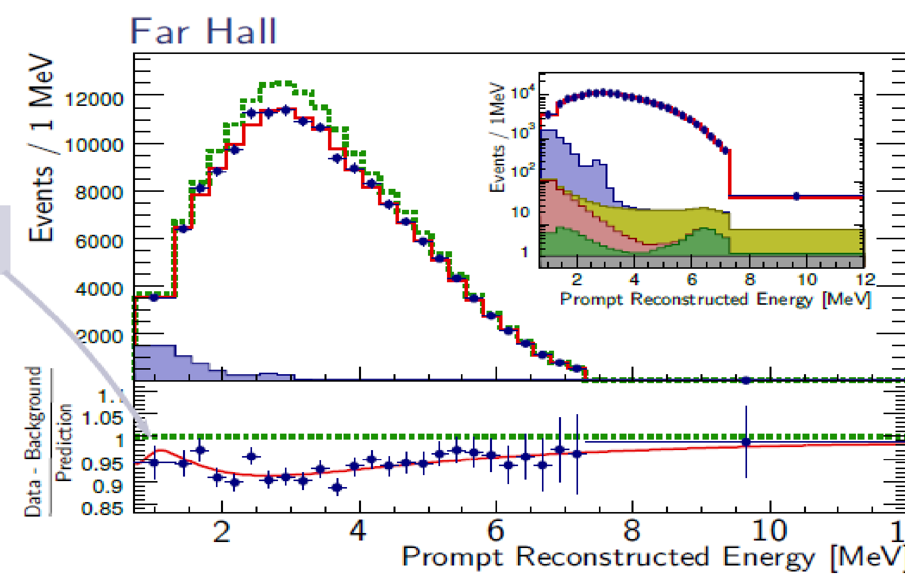
	Normal MH Δm^2_{32} [10^{-3}eV^2]	Inverted MH Δm^2_{32} [10^{-3}eV^2]
From Daya Bay Δm^2_{ee}	$2.54^{+0.19}_{-0.20}$	$-2.64^{+0.19}_{-0.20}$
From MINOS $\Delta m^2_{\mu\mu}$ [João, NuFact2013]	$2.37^{+0.09}_{-0.09}$	$-2.41^{+0.12}_{-0.09}$

IBD Spectrum at Three Sites







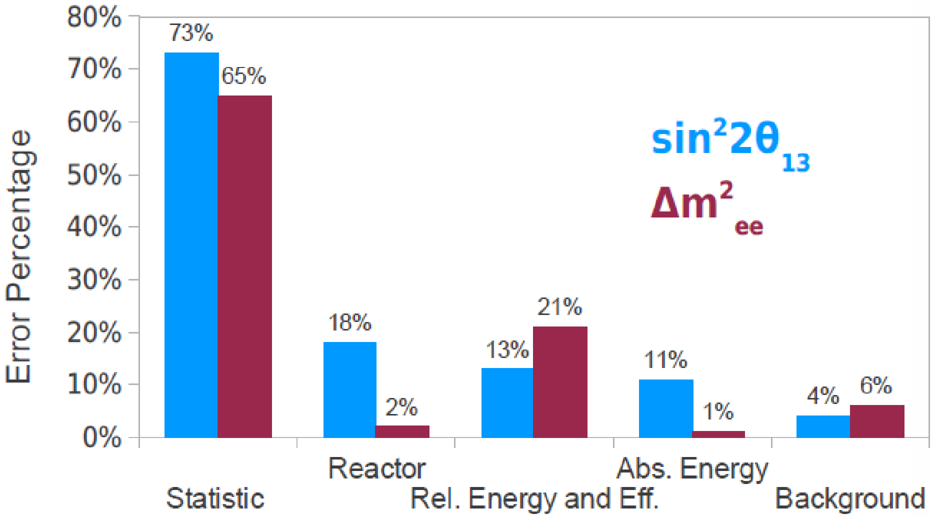


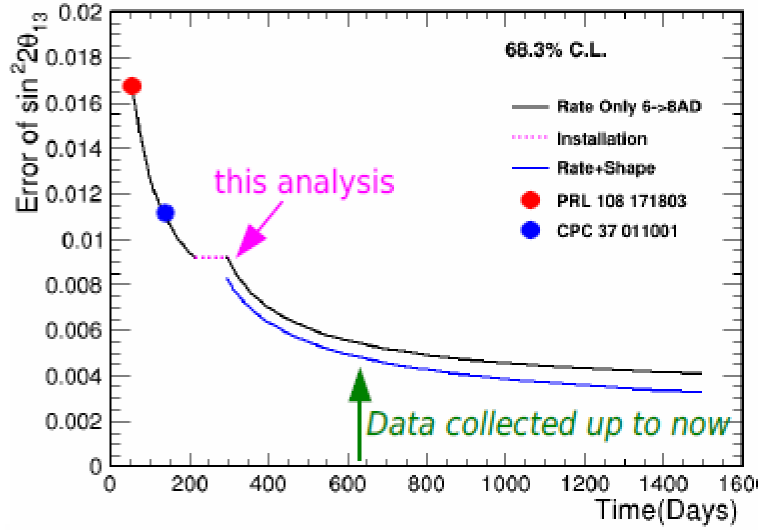
Shape distortion from energy losses in acrylic

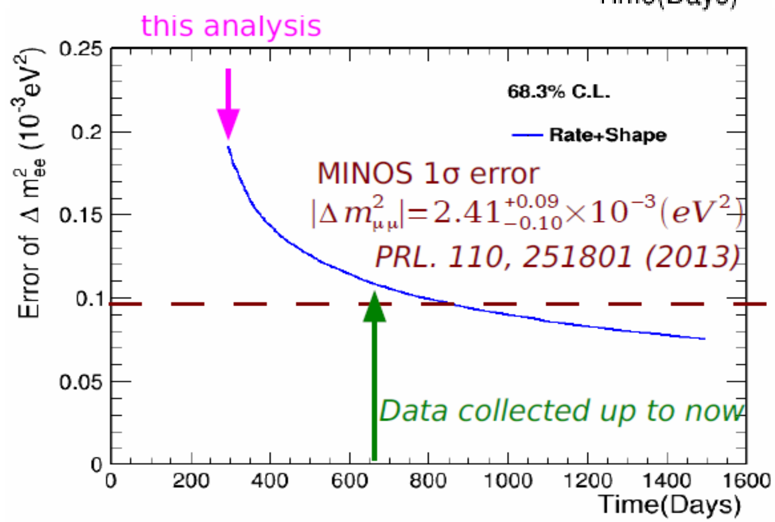
Spectral distortion consistent with oscillation

- Both background and predicted no-oscillation spectra from best fit
- Statistical errors only

Systematic and Prospect







- **Current error is dominated by the statistical uncertainty**
- **Dominant systematic uncertainty is from absolute and relative energy efficiency, reactor model.**

Probing θ_{13} with Hydrogen Neutron Capture Signal

Benefit:

- Largely independent oscillation measurement
- Improve overall sensitivity
- Improve understanding about detector and reactor

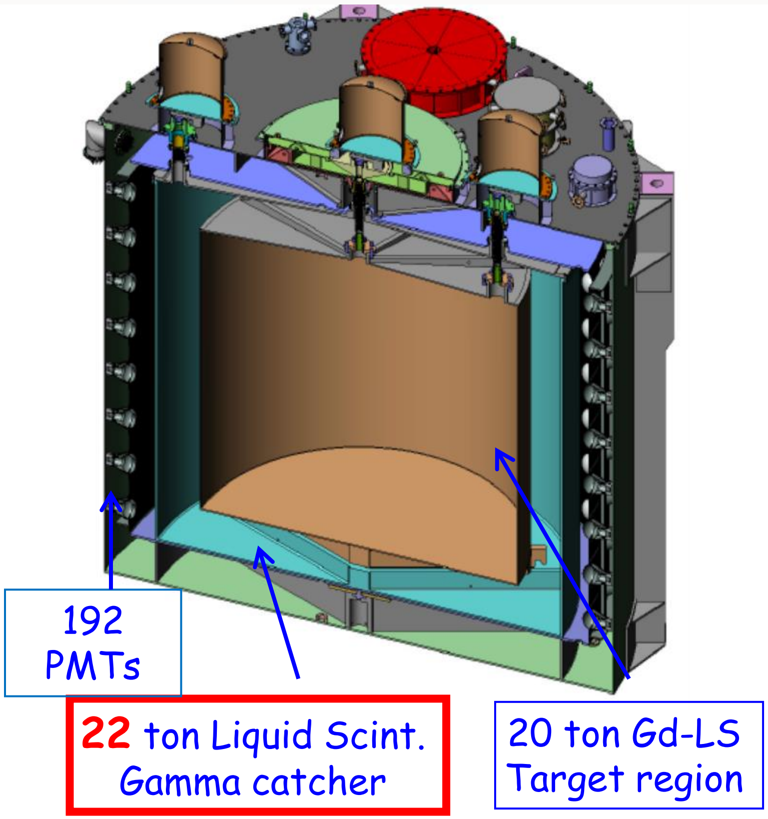
Challenge:

- High <u>accidental</u> background; long capture time: ~200 μs; Large energy leakage
- New or tight cuts: <u>distance</u>, timing and energy ==> New systematic
- Different background situation

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

$$\rightarrow + p \rightarrow D + \gamma\ (2.2\ MeV)$$

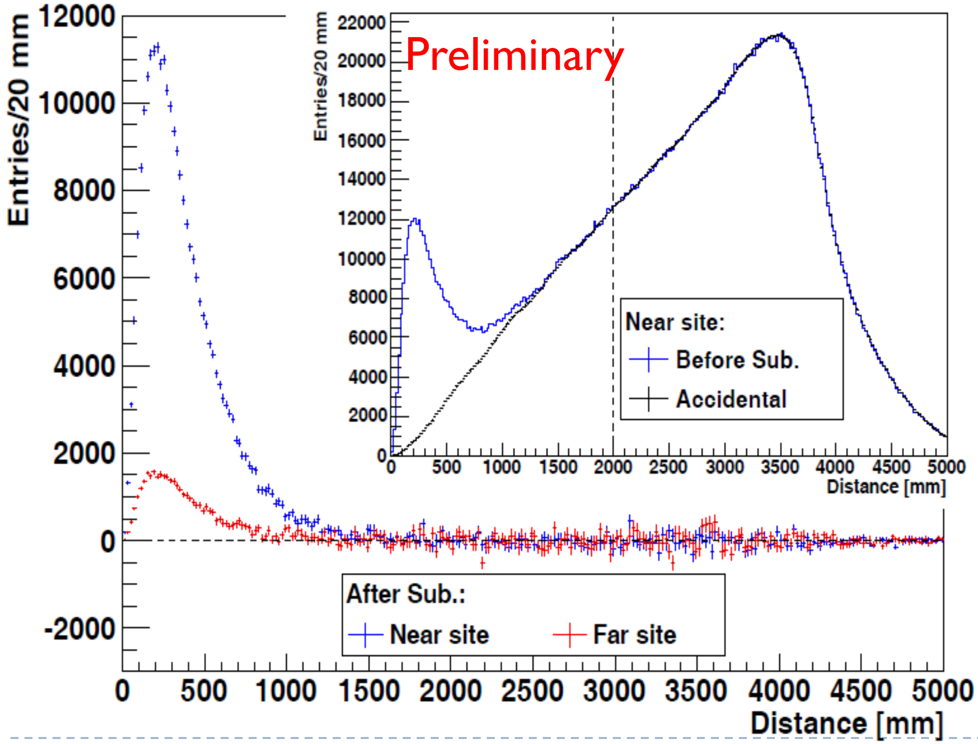
$$\rightarrow + Gd \rightarrow Gd^* \rightarrow Gd + \gamma\text{'s}\ (8\ MeV)$$



Accidental Background Suppression

Accidental Spectrum Prediction:

- Select single event (isolated in time) and randomly combined to predict accidental spectrum
- The spectrum is normalized according to run time and selection efficiency arXiv:1301.5085 (2013)



Distance

- Distance between the reconstructed prompt and delayed vertexes
- Accidental background tends to have large distance (powerful cut)
- Can be complex to understand its uncorrelated uncertainty
- But it turns out the efficiency and systematic can directly studied with real data.

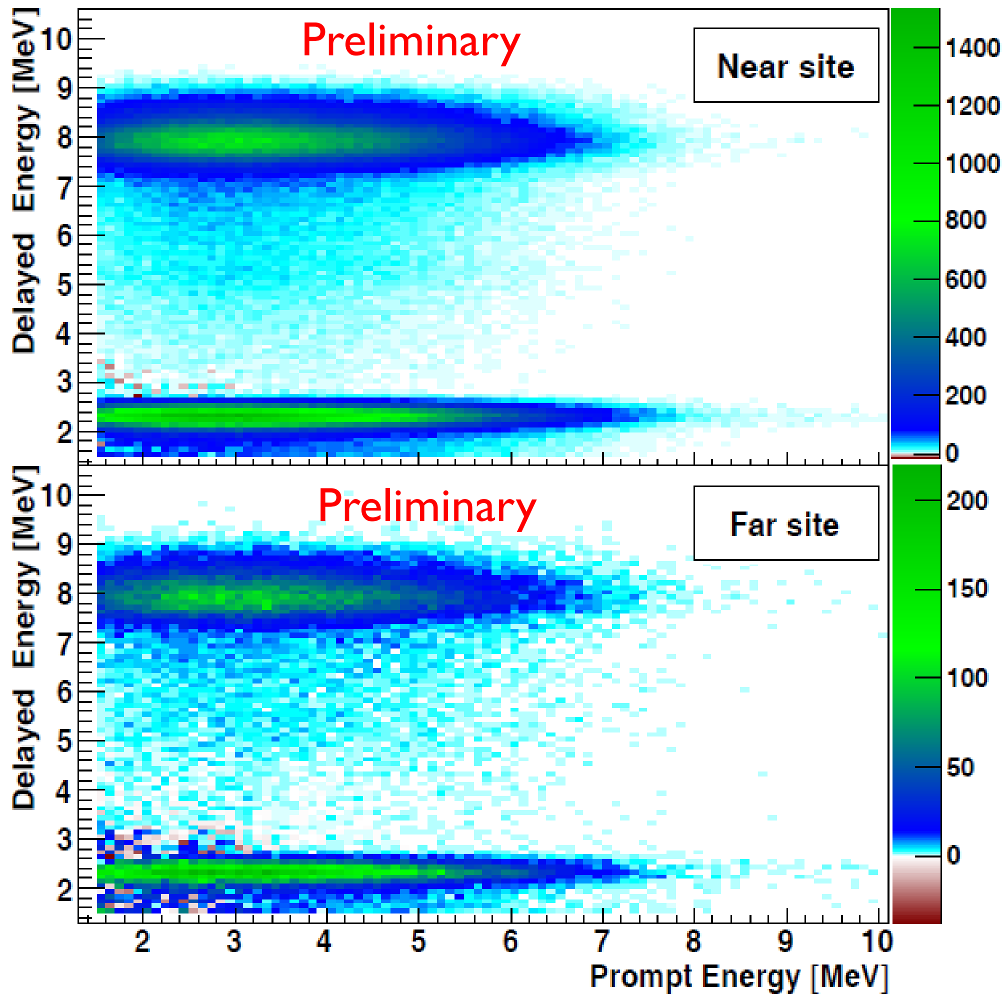
Correlated Event Distribution

All correlated events:

- **Accidental Background statistical subtracted (Largest background and irreducible statistical error)**

- **The long distance events (>2m) can also be used for accidental background validation.**

- **Still include correlated background: Li9, Fast neutron, AmC.**



The hydrogen neutron capture signal is seen.

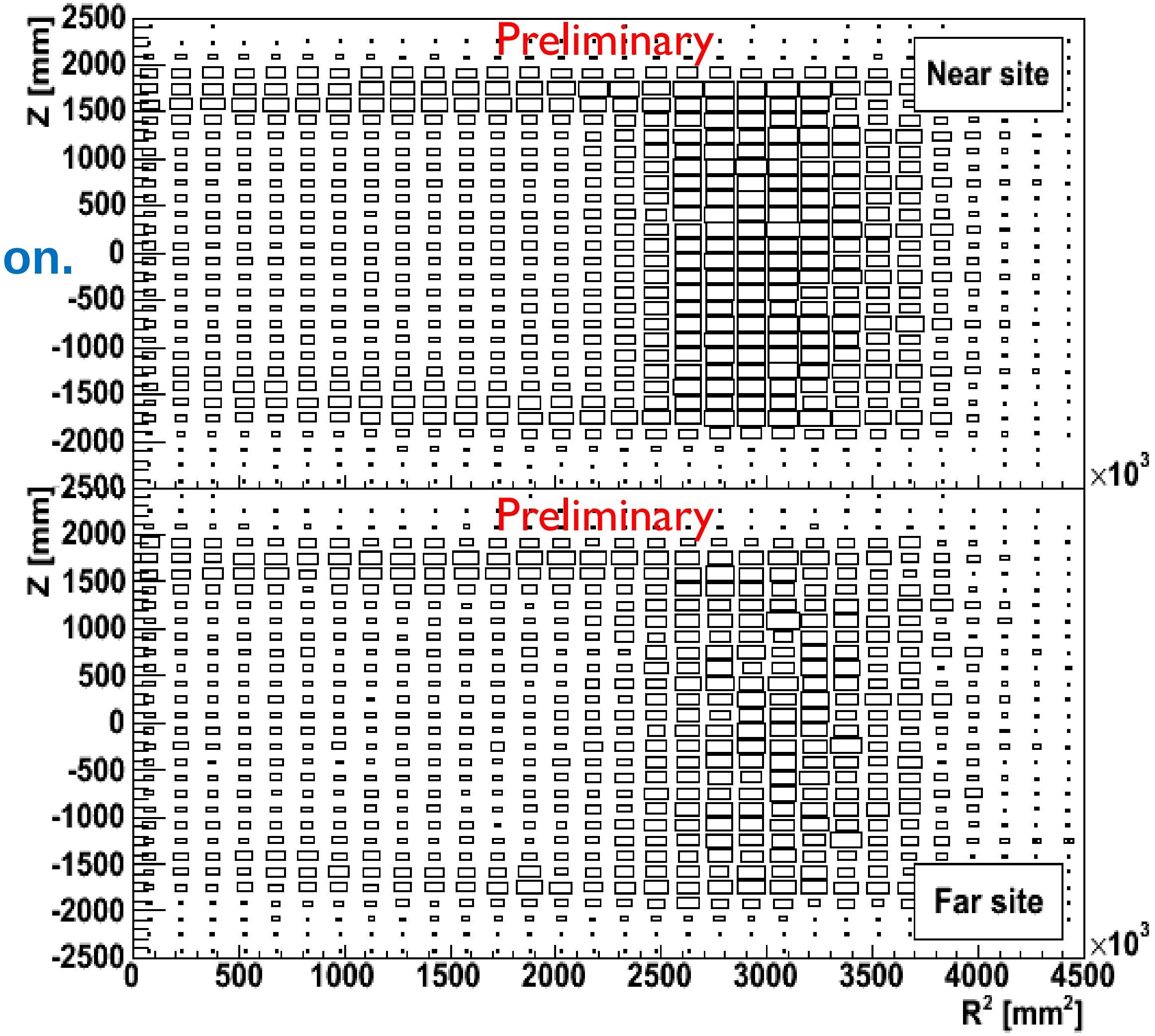
Hydrogen Capture Sample Vertex Distribution

For the 2.2 MeV band:

- Most of them is in the LS region. Agree with expectation.
- Some are from the GdLS region. In GdLS ~16% is captured on H.

Hydrogen neutron capture sample is selected.

Other systematic and background studies are in progress.



Supernova Trigger Status and Plan

An online trigger for 8-AD simultaneous IBD rate increase is added.

Function	Performance	Specific Feature
IBD selection, Combination, Control the false alarm rate	Entire design works smooth and effective.	Low Energy Threshold: Online 2(8)MeV Offline 0.7MeV
Access Database, Email Alert, DAQ status cross check, Auto error report & daily report	Workload to DAQ: extra 8% for physics run (0.4% data taking time) And 70% CPU @1kHz(500Hz IBD)	Better Energy Resolution 0.3MeV@10MeV
…… (Being added)	Time Latency from trigger to alarm ~10s	Time Accuracy (GPS)
		Online Detection Probability > 94% within Milky Way
		Equivalent Target Mass ~0.7kt @ 0.01Hz bkg

Future: Offline validation (~40min latency) and join SNEWS

Summary

With 6-AD rate+shape analysis:

$$\sin^2 2\theta_{13} = 0.090^{+0.008}_{-0.009}$$

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

Expect more from Daya Bay

- **8 detectors and more than 2 years data**
- **Absolute reactor flux to address reactor anomaly**
- **Hydrogen neutron capture result**

Thank you for your attention!