θ_{13} Quest at Daya Bay

Measurement of θ_{13} Mixing Parameter

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on behalf of Daya Bay Experiment Collaboration

Charles University in Prague

Nu HoRIzons III, February 8-10, 2010, Allahabad, India

Outline

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PMNS Matrix

$$\underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}} \times \underbrace{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix}} \times \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

$\theta_{23} \approx 45^\circ$
Atmospheric ν
Accelerator ν

$\theta_{13} < 10^\circ$
Short-baseline Reactor ν
Future accelerator ν

$\theta_{12} \approx 35^\circ$
Solar ν
Long-baseline Reactor ν

- Meassure θ_{13} with sensitivity of $\sin^2 2\theta_{13} < 0.01$[1] at 90% C.L.
- Currently known to be $\sin^2 2\theta_{13} < 0.19$ at 90% C.L. from the Chooz Reactor Neutrino Experiment in France

[1] $\sin^2\theta_{13} < 0.0025$ and $\theta_{13} < 3^\circ$

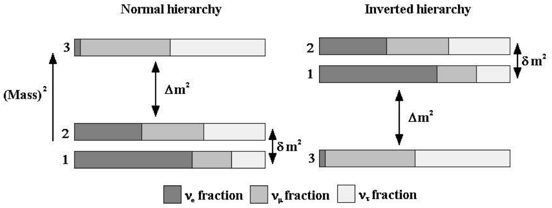
Motivation

Importance

- Step to complete basic model of ν oscillations
- Open gate to go further
- Is it possible to measure CP violation from neutrino oscillations:

$$P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) = \sin(2\theta_{12})\sin(2\theta_{23})\cos^2(\theta_{13})\sin(2\theta_{13})\sin\delta$$

- Mass hierarchy: $m_2 < m_3$ or $m_2 > m_3$

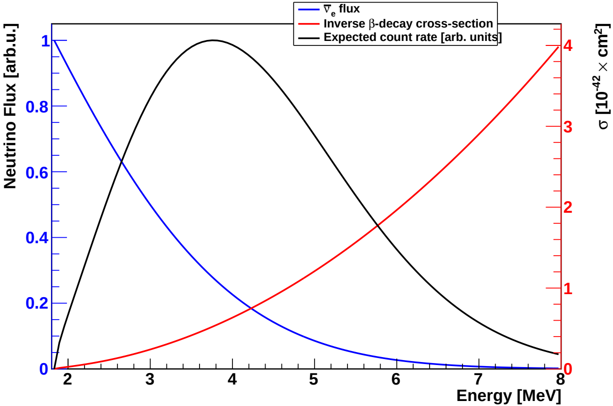


- Help discriminate among theoretical models of mixing matrix

Neutrino Oscillations

Expected Count Rate in Detector

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{13} L}{4E_\nu}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E_\nu}\right)$$



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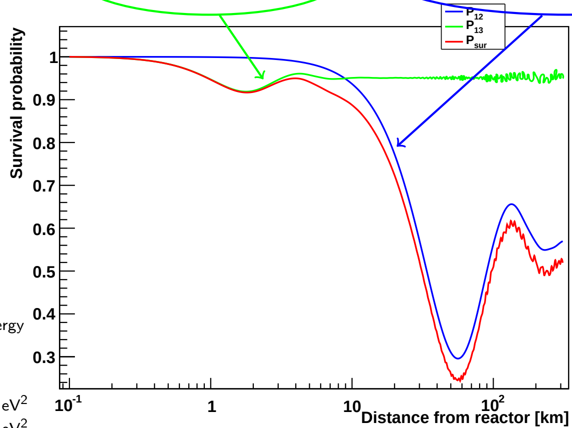


Integrated over $\bar{\nu}_e$ energy
$E_\nu \in [1.8, 8]$ MeV
$\sin^2 2\theta_{13} = 0.1$
$\theta_{12} = 34^\circ$
$\Delta m^2_{13} = 2.5 \times 10^{-3}$ eV^2
$\Delta m^2_{21} = 7.9 \times 10^{-5}$ eV^2

Outline

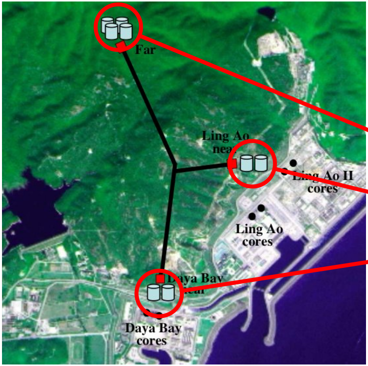
Location

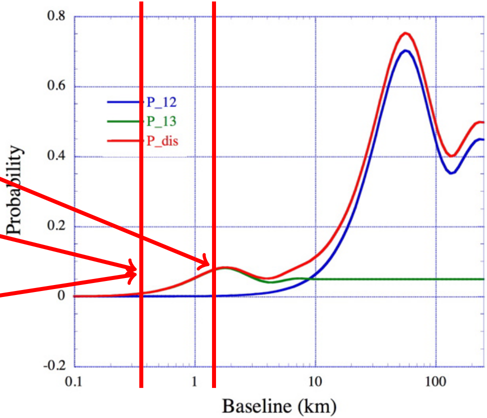
Daya Bay Nuclear Powerplant

$\sim$ 50 km from Hong Kong

On Site Layout

- 3 sites at different distances — 2x Near (2x2 detectors), 1xFar (4 detectors)





Distance from detectors to reactor cores in meters

Reactors	Experimental site		
	DyB	LA	Far
DayaBay	363	1348	1986
LingAo I	857	481	1618
LingAo II	1307	526	1613
Overburden	98	112	355

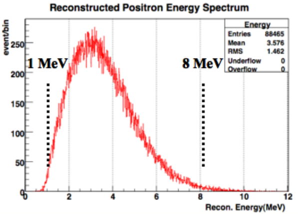
Reactor Thermal Output: 11.6 GW now, 17.4 GW in 2011

Outline

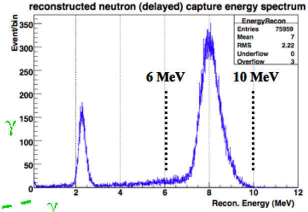
$\bar{\nu}_e$ Detection Method

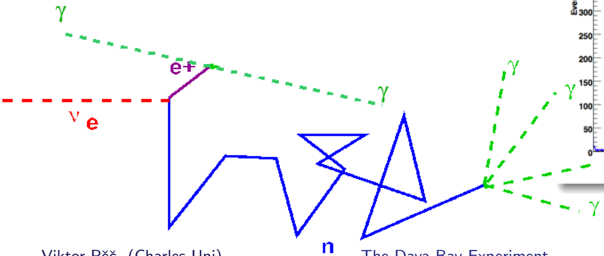
- Inverse β-decay :
  $\bar{\nu}_e + p \rightarrow e^+ + n$
- Trigger on 2-fold coincidence:
  - Prompt signal from e^+
  - Delayed signal from n capture on Gadolinium $\approx 30\mu$s
- Detector with Gd doped Liquid Scintillator (LS)

Prompt signal

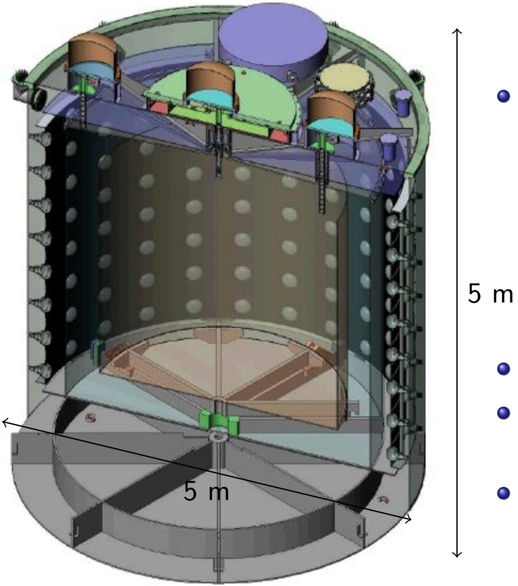


Delayed signal



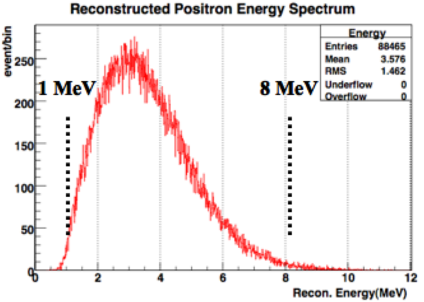


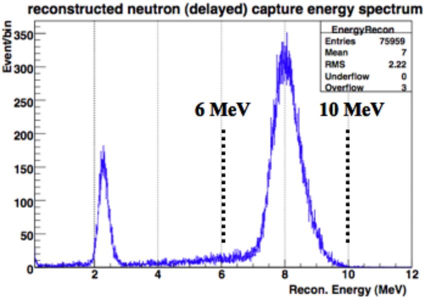
Detector



- Cylindrical 3-Zone Structure separated by acrylic vessels
  - Target: Inner 20t GdLS (0.1% of Gd, d=3m)
  - γ-catcher: Mid 20t LS (d=4m, ≈42cm thick)
  - Oil Buffer: Outer 40t mineral oil (d=5m, ≈49cm thick)
- 192 8-inch PMTs
- $12\%/\sqrt{E(\mathrm{MeV})}$ energy resolution
- Reflectors on top and bottom

Signals





Site	Signal/day/module
Daya Bay	840
Ling Ao	760
Far Site	90

- Positron energy cuts at 1 – 8 MeV
- Neutron capture energy cut at 6 MeV
- Time cut 0.3 – 200μs

Outline

Relative Measurements

$$\frac{N_f}{N_n}(E) = \frac{N_{p,f}}{N_{p,n}} \left(\frac{L_n}{L_f}\right)^2 \frac{\epsilon_f}{\epsilon_n} \frac{P(E, L_f)}{P(E, L_n)}$$

- Expected ratio of measured events for particular energy at Near and Far site
- Number of protons in target – careful measurements during filling
- Neutrino flux at distance $L \propto 1/L^2$
- Detector detection efficiencies – intensive calibration program
- Survival probabilities – sign of oscillation

Systematic Uncertainties

Detector related uncertainty

Source of uncertainty		Detector Systematic Uncertainties: Conservative	Goal
# protons		0.3	0.1
Detector Efficiency	Energy cuts	0.2	0.1
	Time cuts	0.1	0.03
	H/Gd ratio	0.1	0.1
	n multiplicity	0.05	0.05
	Trigger	0.01	0.01
	Live time	<0.01	<0.01
Total		0.38%	0.18%

Reactor related uncertainty

Number of cores	Power	Location	Total
4	0.035%	0.08%	0.087%
6	0.097%	0.08%	0.126%

Outline

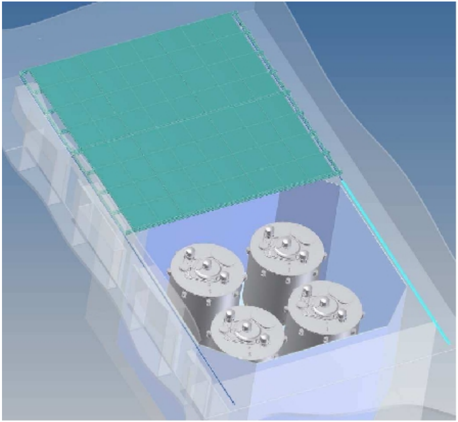
Backgrounds

- Accidental coincidence of uncorrelated signals — natural radioactivity
- Correlated signals from fast neutrons — spallation processes of muons in surrounding rock
- β–delayed neutron decays of ^{9}Li and ^{8}He — products of muonic showers

Background subtraction uncertainties

	DYB	LA	Far
Fast n/signal	0.1%	0.1%	0.1%
^{9}Li, ^{8}He/signal	0.3%	0.2%	0.2%
Accidentals/signal	$<$0.2%	$<$0.2%	$<$0.1%

Muon veto system

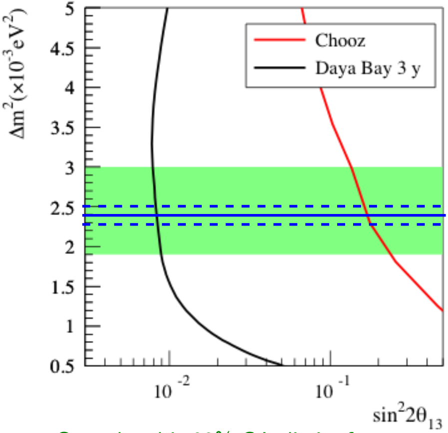


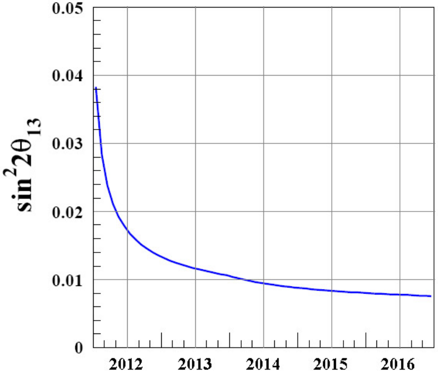
- Multiple muon veto detectors
- Water Čerenkov
  - ADs submerged in water, provide $\geq$ 2.5m shielding against radioactivity
  - Inner/Outer regions optically separated
  - 8-inch PMTs on frames (289/near, 384/far site)
- RPC—Resistive Plate Chamber
  - 4 layers in modules
  - Layer of modules covers water pool
  - Provides independent veto system
- Combined efficiency of both systems $> 99.5\%$

Outline

Sensitivity

- 90% C.L. after 3 years of data taking assuming baseline systematics, compared to Chooz results





$\Delta m^2 = 0.0025 \text{ eV}^2$

- Green band is 90% C.L. limits from atmospheric neutrino experiments
- Best fit and 1σ errors from MINOS
  ref. arXiv:0808.2016v2

Outline

Status

Excavation continues, more than 3,000 m of tunnels excavated

Status

2 experimental halls excavated

Status

First AD being assembled

Schedule

- October 2007: Ground breaking
- March 2009: Surface assembly building occupancy
- Upcoming months: Commissioning first AD - Dry run
- 2010: Daya Bay Near Hall ready for data
- 2011: Far Hall ready for data

Collaboration

Region	Institutions	Members
China	14	109
Czech	1	4
Hong Kong	2	16
Russia	2	5
Taiwan	3	13
USA	16	96
Sum	38	243

Backup slides

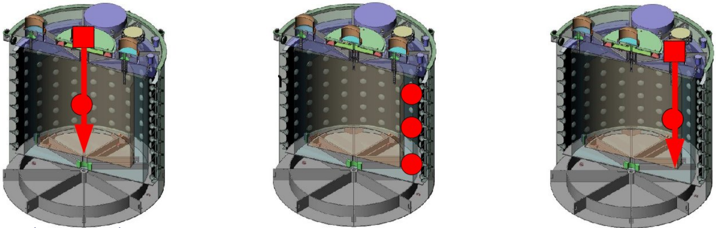
Detector Dry Run

Purpose

- PMT readout and system integration
- Coordination of calibration and DAQ
- PMT measurements
  - Timing
  - Gain
  - Peak-to-valley ratio
  - Relative efficiency

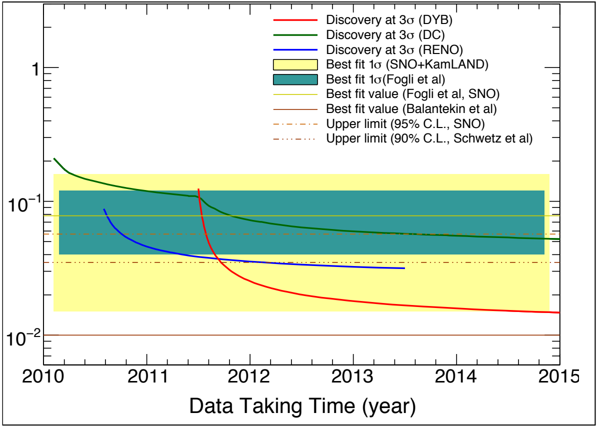
Implementation

- Assembled detector without filling (no scintillator, no mineral oil)
- Use LED sources



3σ Discovery

GLoBES models



- Analysis by C. Lewis, B. Littlejohn, M. McFarlane, W. Wang, K. Heeger from University of Wisconsin
- Models for RENO and Double Chooz from GLoBES website
- Starting dates from Huber et al (arXive: 0907.1896)

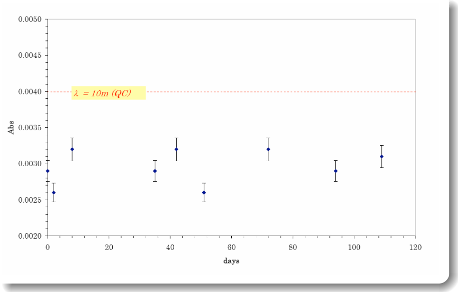
Overburden

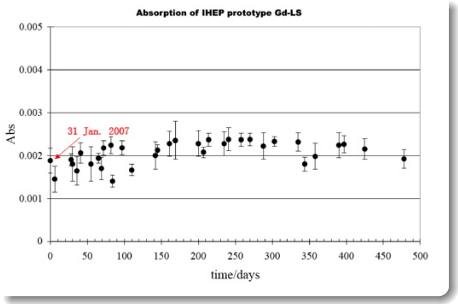
	DYB site	LA site	Far site
Vertical overburden (m)	98	112	355
Vertical overburden (m.w.e.)	255	291	910
Muon Flux (Hz/m2)	1.16	0.73	0.041
Muon Mean Energy (GeV)	55	60	138

Systematic Uncertainties

Source of uncertainty		Chooz (absolute)	Daya Bay (relative)		
			Conservative	Goal	Goal w/Swapping
# protons		0.8	0.3	0.1	0.006
Detector Efficiency	Energy cuts	0.8	0.2	0.1	0.1
	Position cuts	0.32	0.0	0.0	0.0
	Time cuts	0.4	0.1	0.03	0.03
	H/Gd ratio	1.0	0.1	0.1	0.0
	n multiplicity	0.5	0.05	0.05	0.05
	Trigger	0	0.01	0.01	0.01
	Live time	0	<0.01	<0.01	<0.01
Total uncertainty (detector-related)		1.7%	0.38%	0.18%	0.12%

Gd Liquid Scintilator Stability

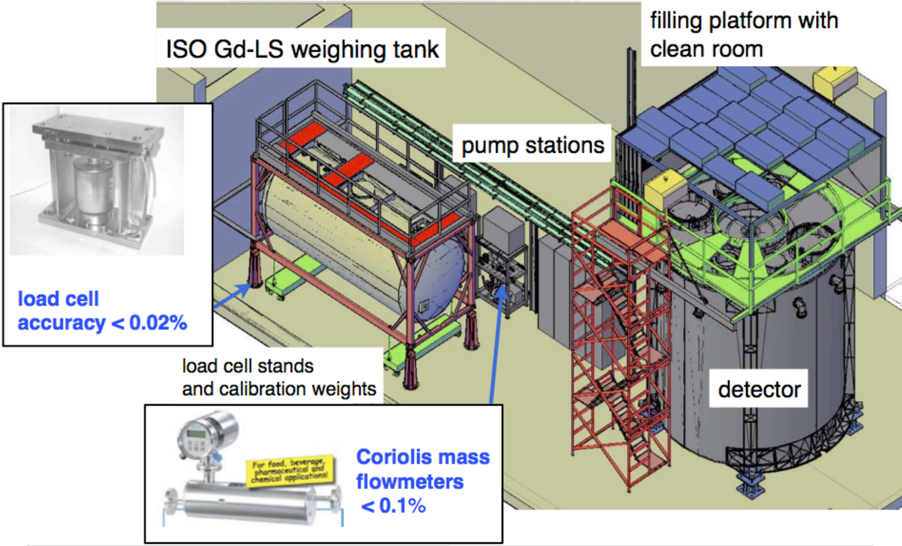




AD Calibration

- Weekly deployment of radioactive sources
  - $\beta+$ – ^{68}Ge
  - neutrons – Am/Pu-C
  - γ – ^{60}Co, ^{137}Cs
- LED diffuser balls
  - monitor optical properties of materials
  - PMT gains and timing
  - Electronics performance

AD Filling and Target Mass Measurement

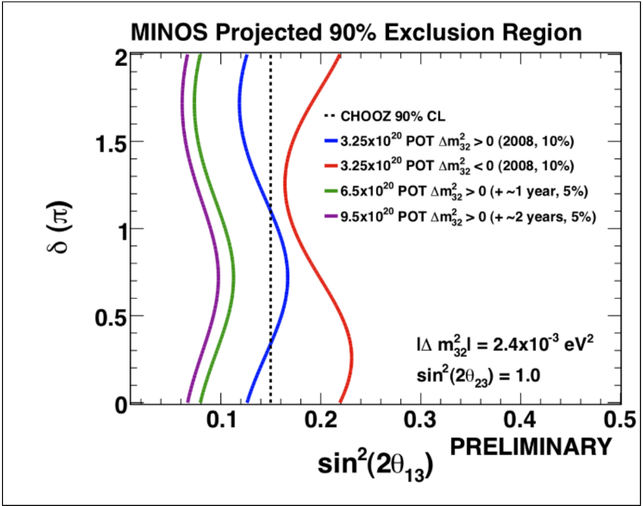


Huber et al., arxiv 0907.1896

Setup	t_ν [yr]	$t_{\bar{\nu}}$ [yr]	P_{Th} or P_{Target}	L [km]	Detector technology	m_{Det}
Double Chooz	-	3	8.6 GW	1.05	Liquid scintillator	8.3 t
Daya Bay	-	3	17.4 GW	1.7	Liquid scintillator	80 t
RENO	-	3	16.4 GW	1.4	Liquid scintillator	15.4 t
T2K	5	-	0.75 MW	295	Water Cerenkov	22.5 kt
NOνA	3	3	0.7 MW	810	TASD	15 kt

Table 1: Summary of the standard setups at their nominal luminosities.

MINOS ν_e appearance observation



From MINOS web page.