



The Daya Bay Experiment to Measure θ_{13}

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UC Berkeley & LBNL

On behalf of the Daya Bay Collaboration

*Presented at the Erice School/Workshop on "Neutrinos in
Cosmology, in Astro, in Particle and in Nuclear Physics"
Erice/Sicily/Italy, September 21, 2009*

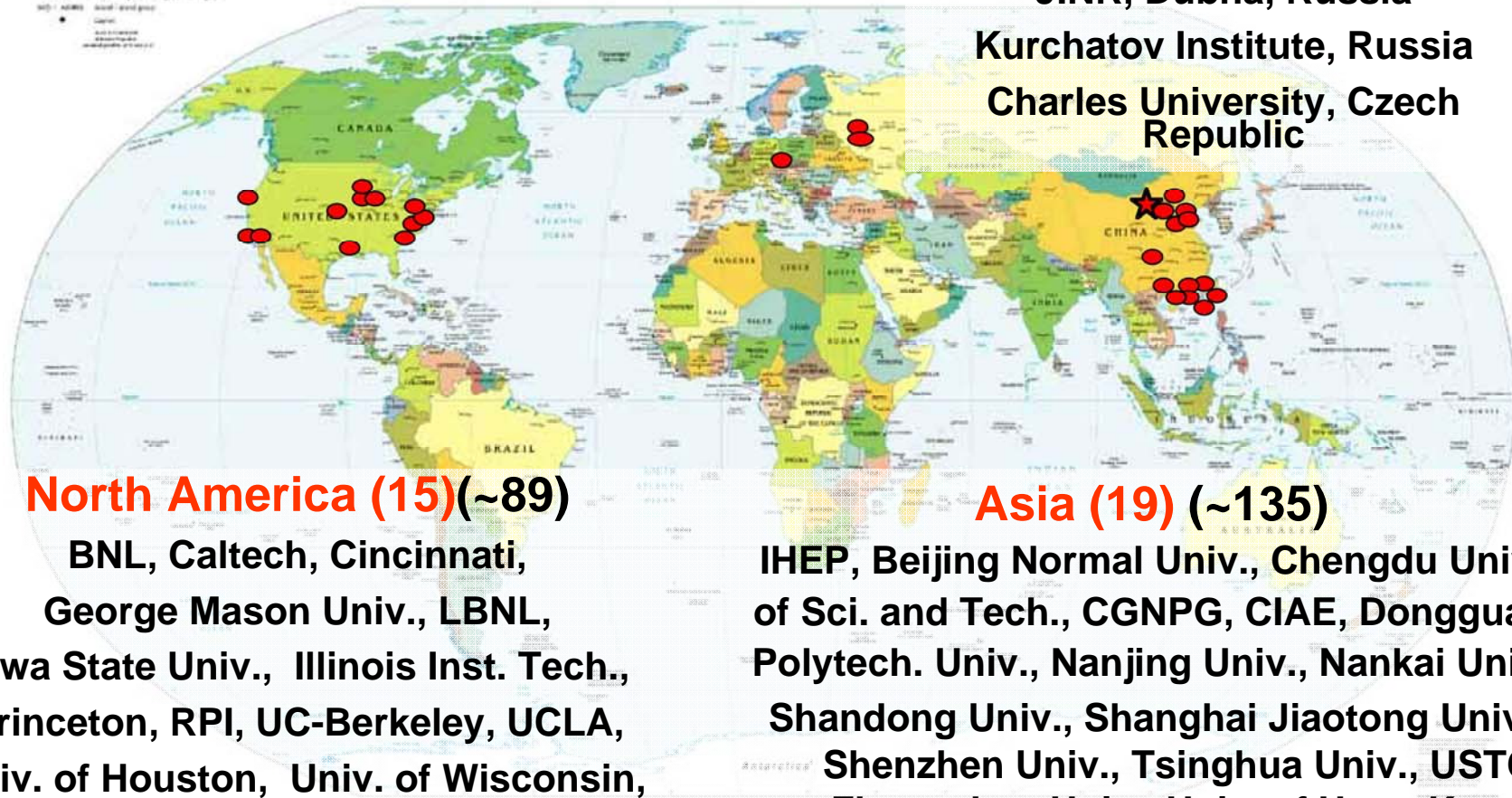


Outline

- Overview
- Physics
- Detector
- Backgrounds
- Calibration
- Schedule

The Daya Bay Collaboration

Political Map of the World, June 1999



Europe (3) (9)

JINR, Dubna, Russia

Kurchatov Institute, Russia

Charles University, Czech Republic

North America (15)(~89)

BNL, Caltech, Cincinnati,

George Mason Univ., LBNL,

Iowa State Univ., Illinois Inst. Tech.,

Princeton, RPI, UC-Berkeley, UCLA,

Univ. of Houston, Univ. of Wisconsin,

Virginia Tech.,

Univ. of Illinois-Urbana-Champaign

Asia (19) (~135)

IHEP, Beijing Normal Univ., Chengdu Univ.

of Sci. and Tech., CGNPG, CIAE, Dongguan

Polytech. Univ., Nanjing Univ., Nankai Univ.,

Shandong Univ., Shanghai Jiaotong Univ.,

Shenzhen Univ., Tsinghua Univ., USTC,

Zhongshan Univ., Univ. of Hong Kong,

Chinese Univ. of Hong Kong,

National Taiwan Univ., National Chiao Tung

Univ., National United Univ.

~ 233 collaborators

Location of the Daya Bay Nuclear Power Plant



The Daya Bay Nuclear Power Plant

1 GW_{th} generates 2×10^{20} $\bar{\nu}_e$ per sec



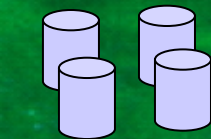
- 12th most powerful in the world (**11.6 GW**)
- Top five most powerful by 2011 (**17.4 GW**)
- Adjacent to mountain, easy to construct tunnels to reach underground labs with sufficient overburden to suppress cosmic rays

Daya Bay Layout

4 x 20 tons target
mass at far site

Far site

1615 m from Ling Ao
1985 m from Daya
Overburden: 350 m



1006 m

Ling Ao Near site

~500 m from Ling Ao
Overburden: 112 m

465 m



Ling Ao-II NPP
(under construction)
2x2.9 GW in 2010

Water hall

810 m

Construction
tunnel

Filling hall

entrance

295 m



Daya Bay Near site

363 m from Daya Bay
Overburden: 98 m

Ling Ao
NPP, 2x2.9 GW

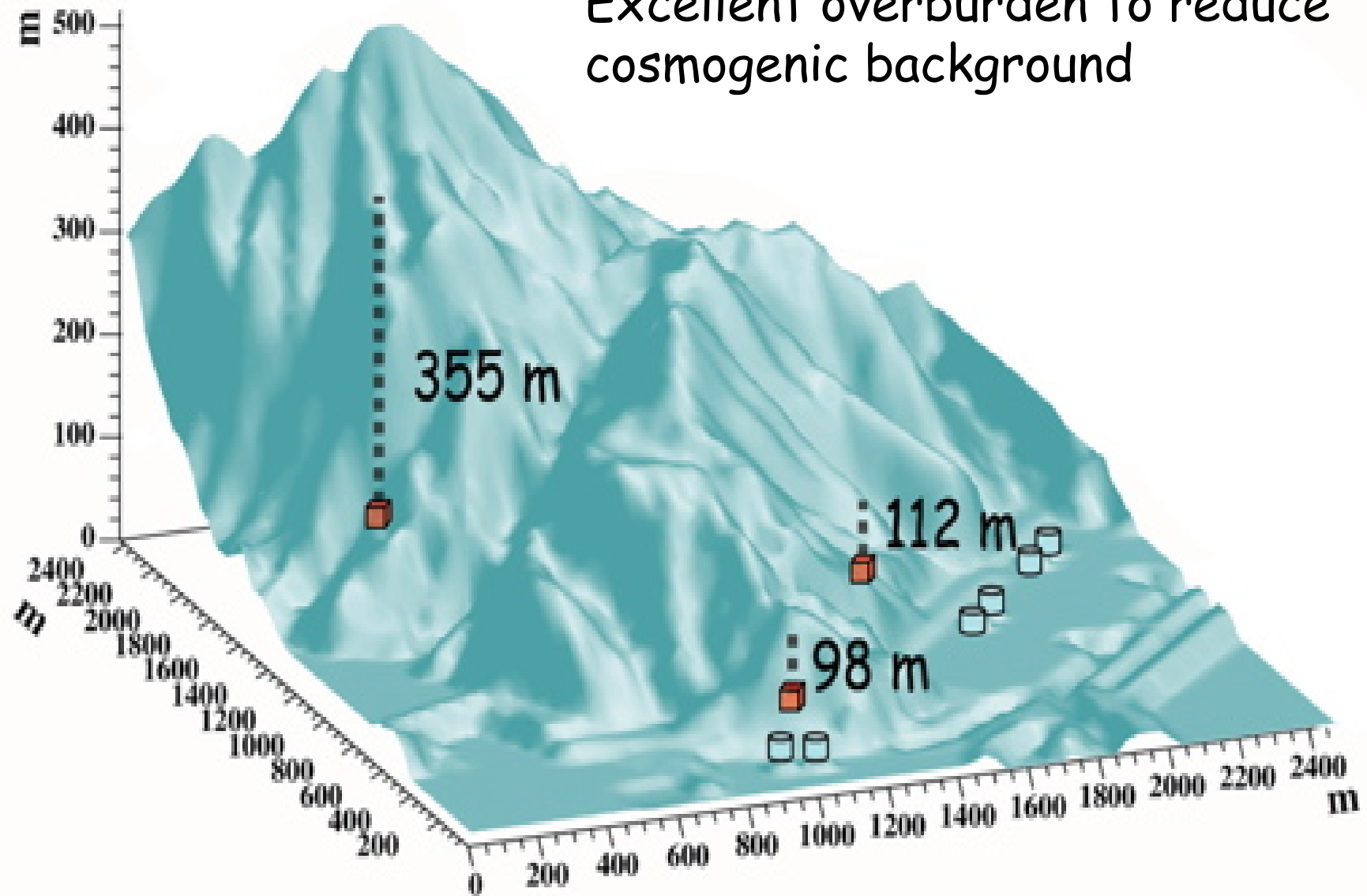
Daya Bay
NPP, 2x2.9 GW

Horizontal Tunnel

Total length 3200 m

Topography

Excellent overburden to reduce cosmogenic background



1000

As of July 09

The map shows the proposed rail alignment for the New York City Subway. The route starts at the existing line (dashed black line) and follows a new alignment (solid red line) through the area. Key stations and points along the alignment include:

- Station 1 (top left)
- Station 2 (top left)
- Station 3 (top left)
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- Station 98 (top left)
- Station 99 (top left)
- Station 100 (top left)

The map also includes a scale bar and a north arrow.

Ling Ao Hall

Daya Bay Near Hall

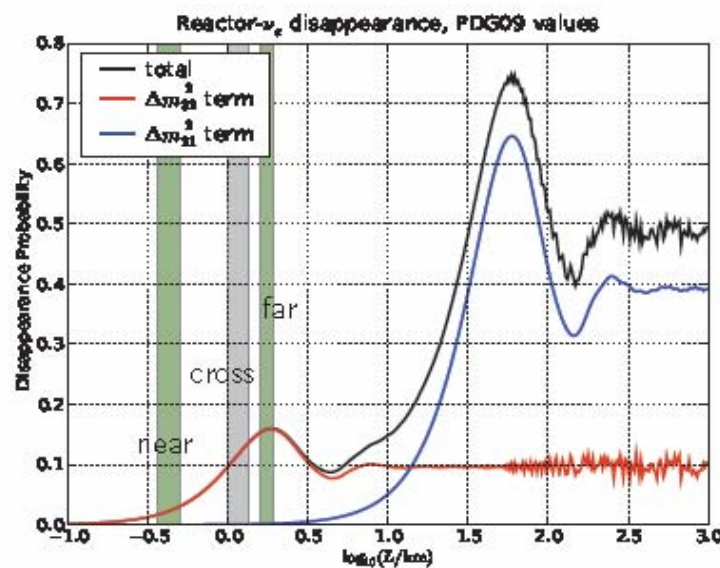
Construction Tunnel

Position Sensitivity

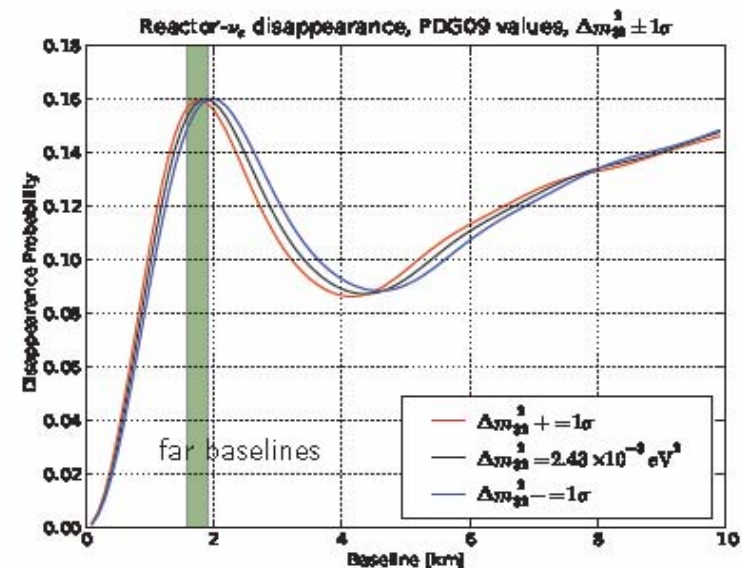
Positioning for $\bar{\nu}_e$ Disappearance

For $\Delta m_{32}^2 \gg \Delta m_{21}^2$:

$$P(\nu_e \rightarrow \nu_e) \approx \sin^2(2\theta_{13}) \sin^2\left(\frac{\Delta m_{32}^2 L}{4E}\right) + \sin^2(2\theta_{12}) \cos^4(\theta_{13}) \sin^2\left(\frac{\Delta m_{21}^2 L}{4E}\right)$$



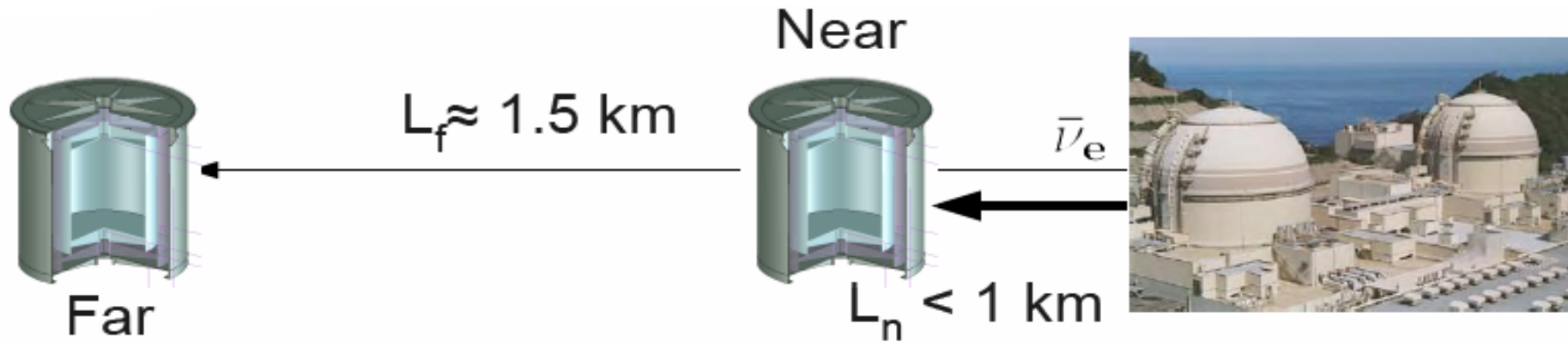
Maximizing sensitivity to θ_{13} .



Robust against changing Δm_{32}^2 .

Probabilities smeared over reactor- $\bar{\nu}$ interaction spectrum.

Method



$$\frac{N_{far}}{N_{near}} = \left(\frac{N_{P.far}}{N_{P.near}} \right) \left(\frac{L_{near}}{L_{far}} \right)^2 \left(\frac{\epsilon_{far}}{\epsilon_{near}} \right) \left(\frac{P_{surv}(E, L_{far})}{P_{surv}(E, L_{near})} \right)$$

Measured
ratio of
Rates

Proton
Number
Ratio

Detector
Efficiency
Ratio

Filling Gd-LS and
Mass measurement

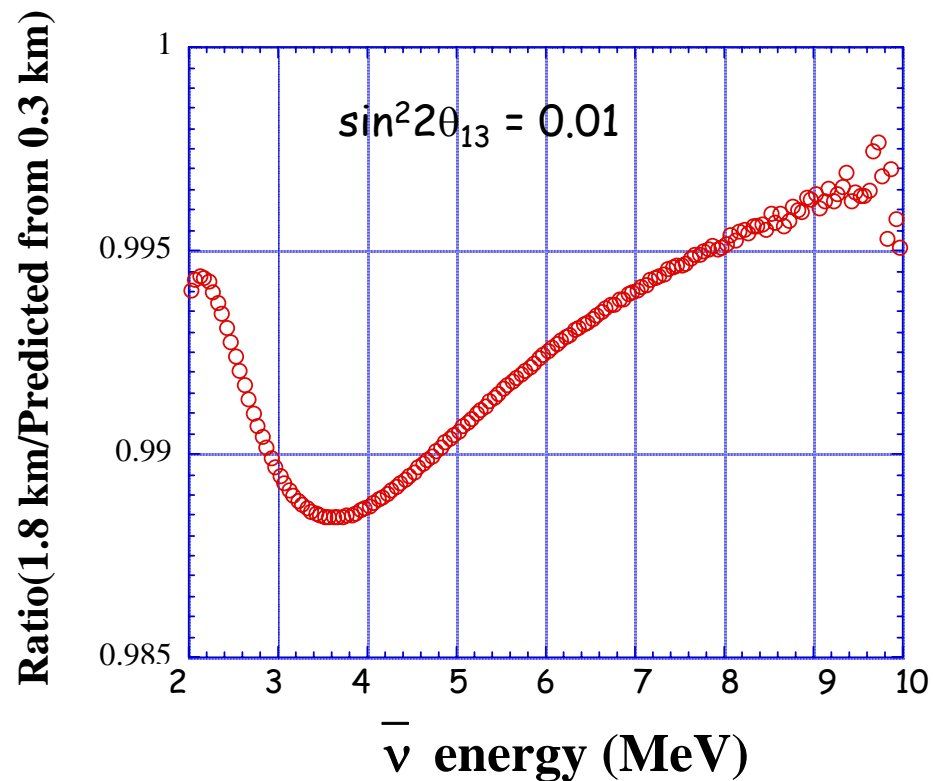
Calibration Systems

$\sin^2 2\theta_{13}$



Daya Bay: Goal and Approach

- Utilize the Daya Bay nuclear power complex to:
 - determine $\sin^2 2\theta_{13}$ with a sensitivity of 0.01
 - by measuring deficit in $\bar{\nu}_e$ rate and spectral distortion.



How to measure $\sin^2 2\theta_{13}$ to 0.01

Reduce systematic uncertainties:

■ **Reactor-related:**

- Optimize baseline for best sensitivity and lowest residual errors
- Near and far detectors to minimize reactor-related errors

■ **Detector-related:**

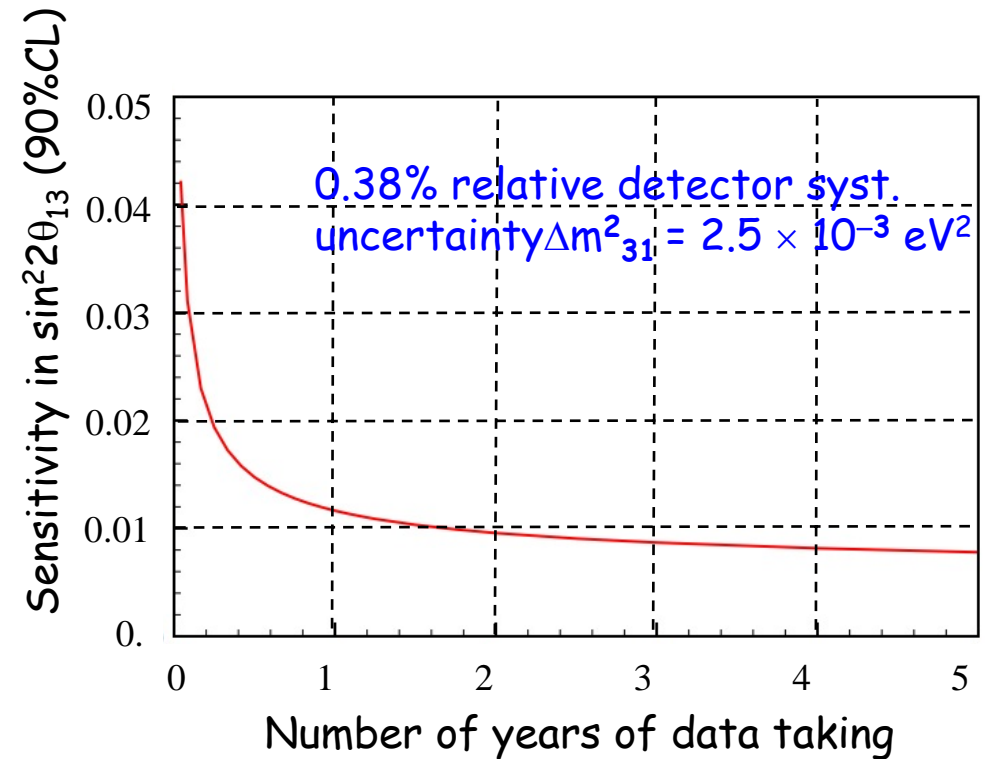
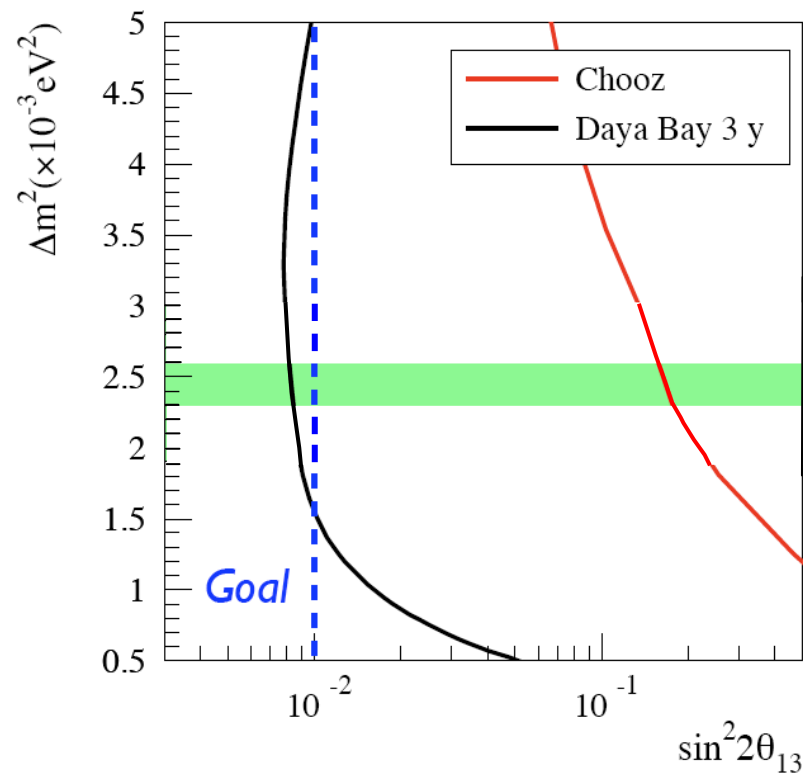
- Use “Identical” pairs of detectors to do relative measurement
 - Fill all detectors with same batch of Gd-LS.
- Comprehensive program in calibration/monitoring
 - Side-by-side calibration

■ **Background-related**

- Go as deep as possible to reduce cosmic-induced backgrounds
- Enough active and passive shielding
 - B/S ~0.4% Near
 - B/S ~0.2% Far

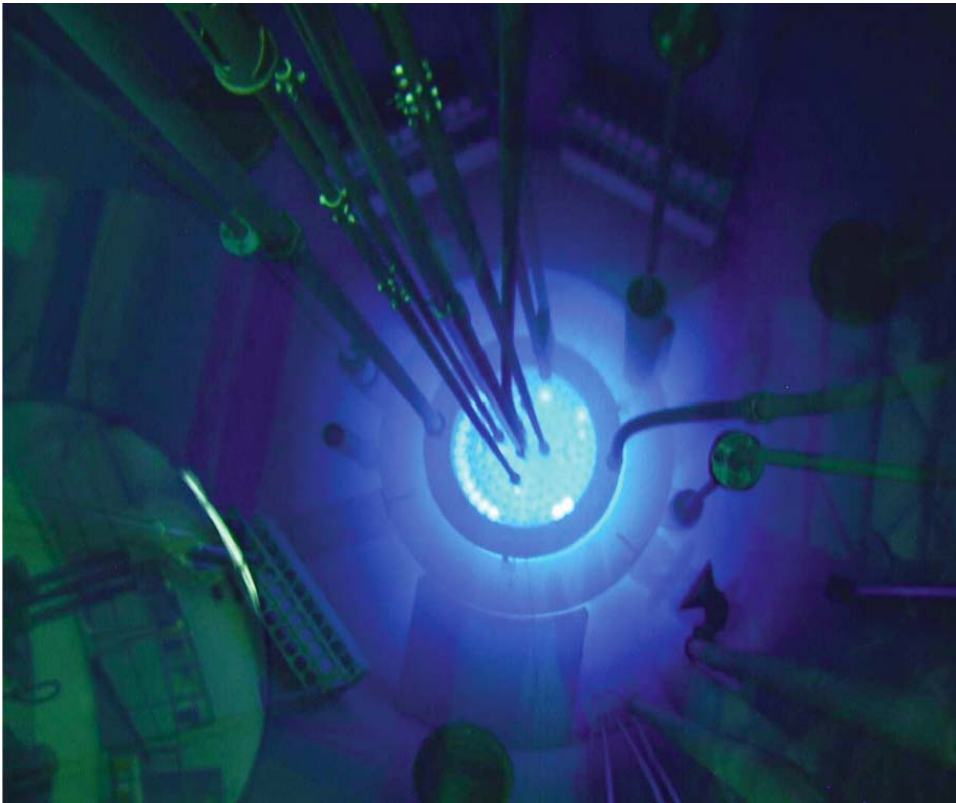
Sensitivity of Daya Bay

$\sin^2 2\theta_{13} < 0.01$ @ 90% CL in 3 years of data taking

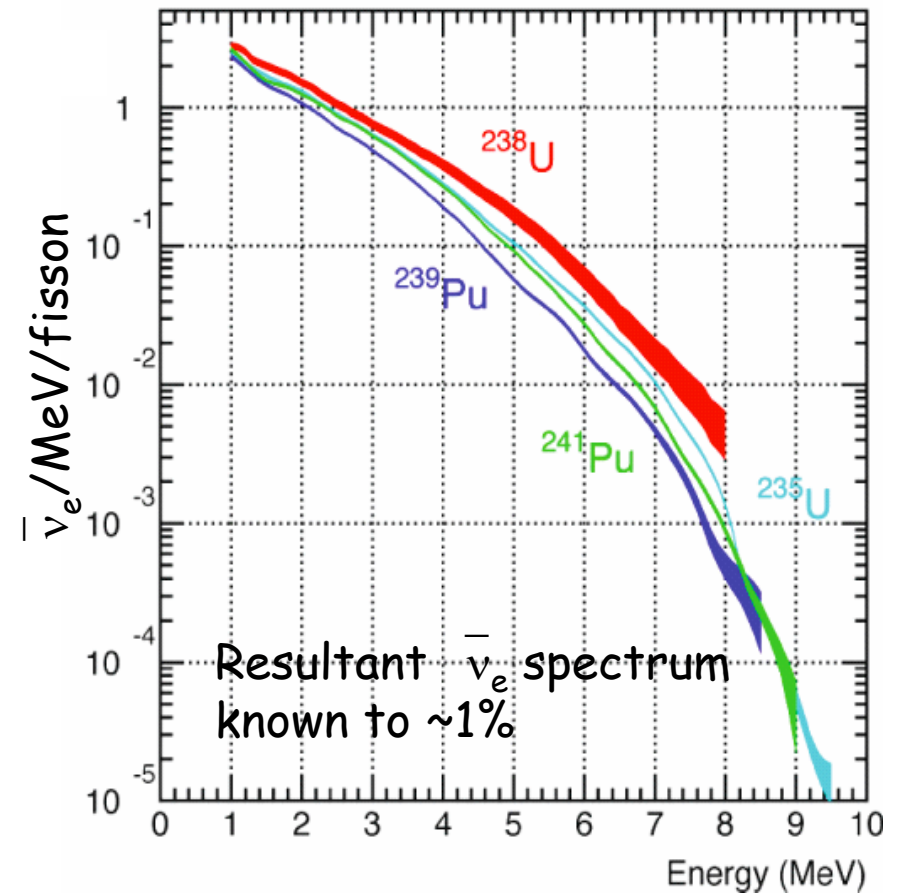


Reactor $\bar{\nu}_e$

- Fission processes in nuclear reactors produce a huge number of low-energy $\bar{\nu}_e$

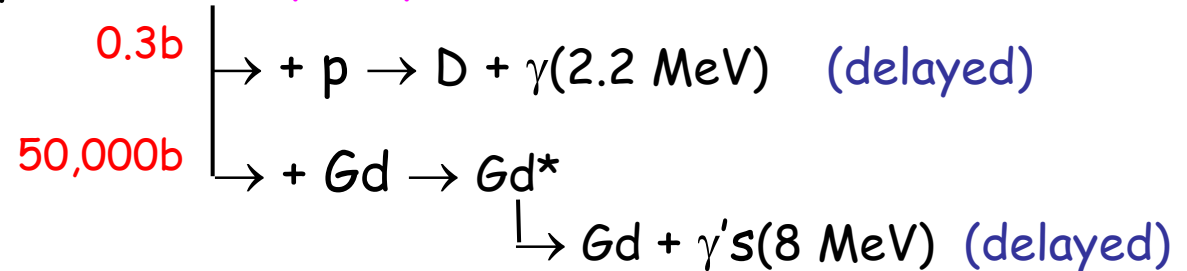
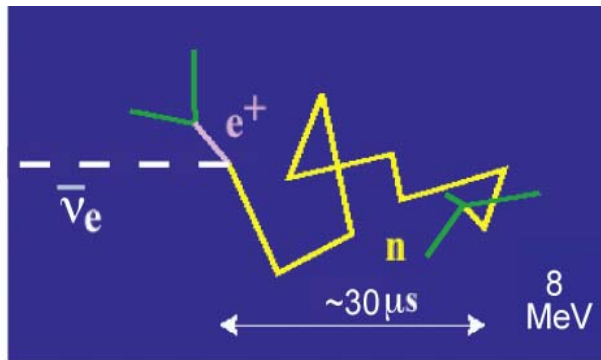
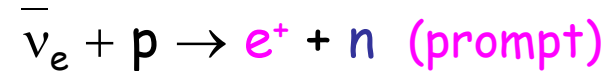


3 GW_{th} generates 6×10^{20} $\bar{\nu}_e$ per sec



Detecting $\bar{\nu}_e$ in liquid scintillator

- Detect **inverse β -decay** reaction in 0.1% Gd-doped liquid scintillator:



- Time- and energy-tagged signal is a good tool to suppress background events.

- Energy of $\bar{\nu}_e$ is given by:

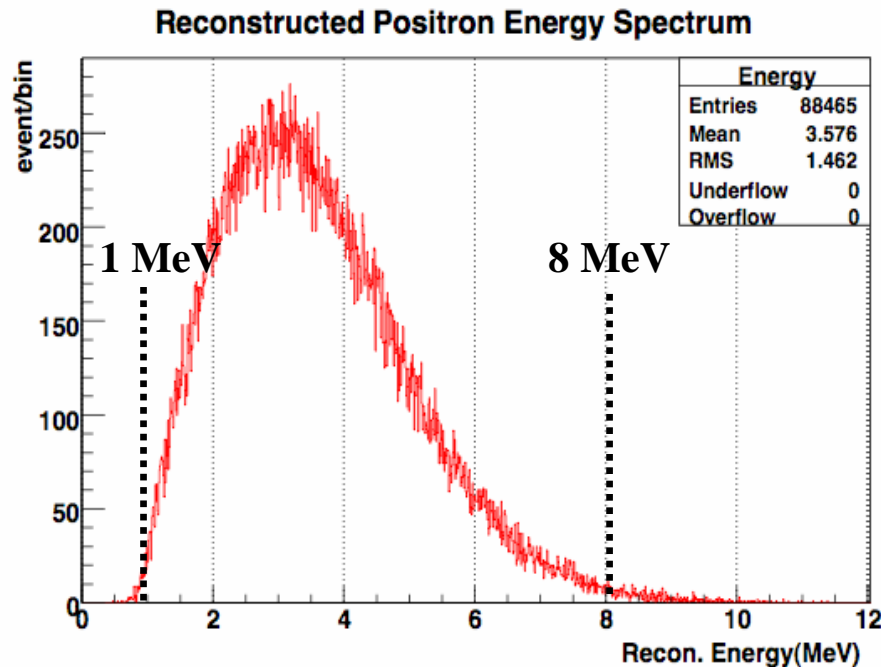
$$E_{\bar{\nu}} \approx T_{e^+} + T_n + (m_n - m_p) + m_{e^+} \approx T_{e^+} + 1.8 \text{ MeV}$$

10-40 keV

Detection of $\bar{\nu}_e$

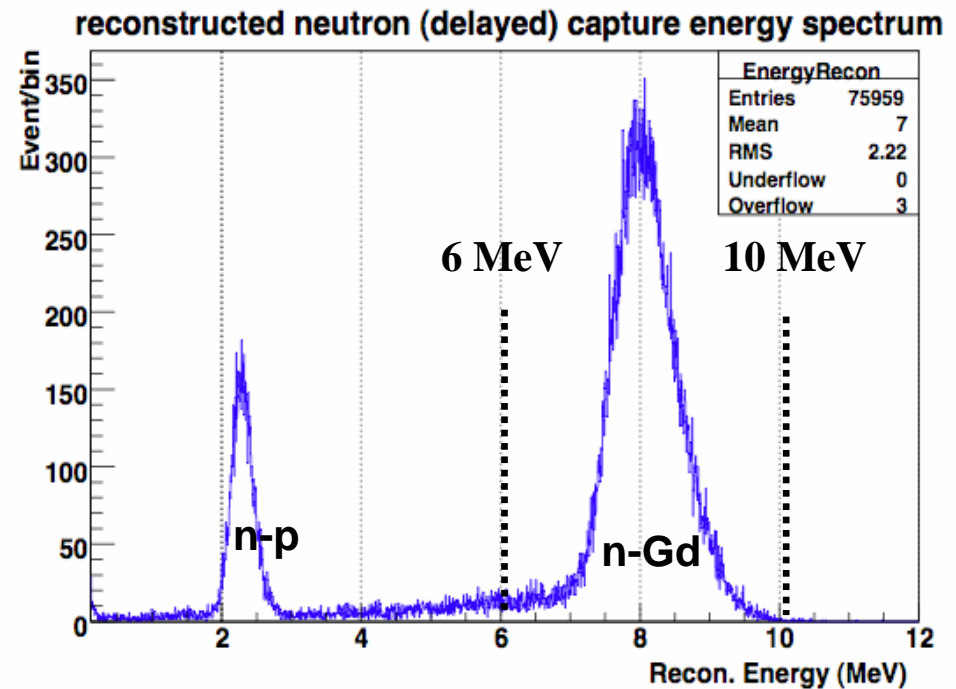
Inverse β -decay in Gd-doped liquid scintillator:

Prompt Energy Signal



- E_{e^+} (“prompt”) $\in [1, 8]$ MeV
- $E_{n\text{-cap}}$ (“delayed”) $\in [6, 10]$ MeV
- $t_{\text{delayed}} - t_{\text{prompt}} \in [0.3, 200]$ μs

Delayed Energy Signal



Coincidence of prompt positron and delayed neutron signals helps to suppress background events

Expected Antineutrino Rates

(Per Day per Module)

<u>Site</u>	<u>Rate</u>
DYB	840
LA	740
Far	90

Systematic Uncertainty Control

- Acrylic vessels and liquid scintillator
 - manufactured and filled in pairs with a common storage tank
- Target mass
 - load cells to measure the target mass to 0.1%
 - flow meter during filling 0.1%
 - overflow tank liquid level monitoring with ultrasonic devices
- Energy calibration to reach relative uncertainty 0.1%
 - automated calibration: ^{68}Ge (positron), ^{252}Cf (neutron) & LED
 - being practiced on the prototype: ^{133}Ba (0.356 MeV), ^{137}Cs (0.662 MeV), ^{60}Co (1.17+1.33 MeV), ^{22}Na (1.022+1.275 MeV), Pu-C(6.13 MeV), ^{252}Cf (neutron)

Sources of Uncertainty

Detector Uncertainty Source		Baseline	Goal	Chooz Experience
Number of protons		0.3%	0.1%	0.8%
Detection Efficiency	Energy cuts	0.2%	0.1%	0.8%
	H/Gd ratio	0.1%	0.1%	1.0%
	Time cut	0.1%	0.03%	0.4%
	Neutron mult.	0.05%	0.05%	0.5%
	Trigger	0.01%	0.01%	0.01%
	Live time	< 0.01%	< 0.01%	< 0.01%
Total Uncertainty		0.38%	0.18%	1.7%
		Two detector relative uncertainty		One detector absolute uncertainty

Backgrounds

Backgrounds

Backgrounds arise from cosmic- μ s:

Accidental coincidence :

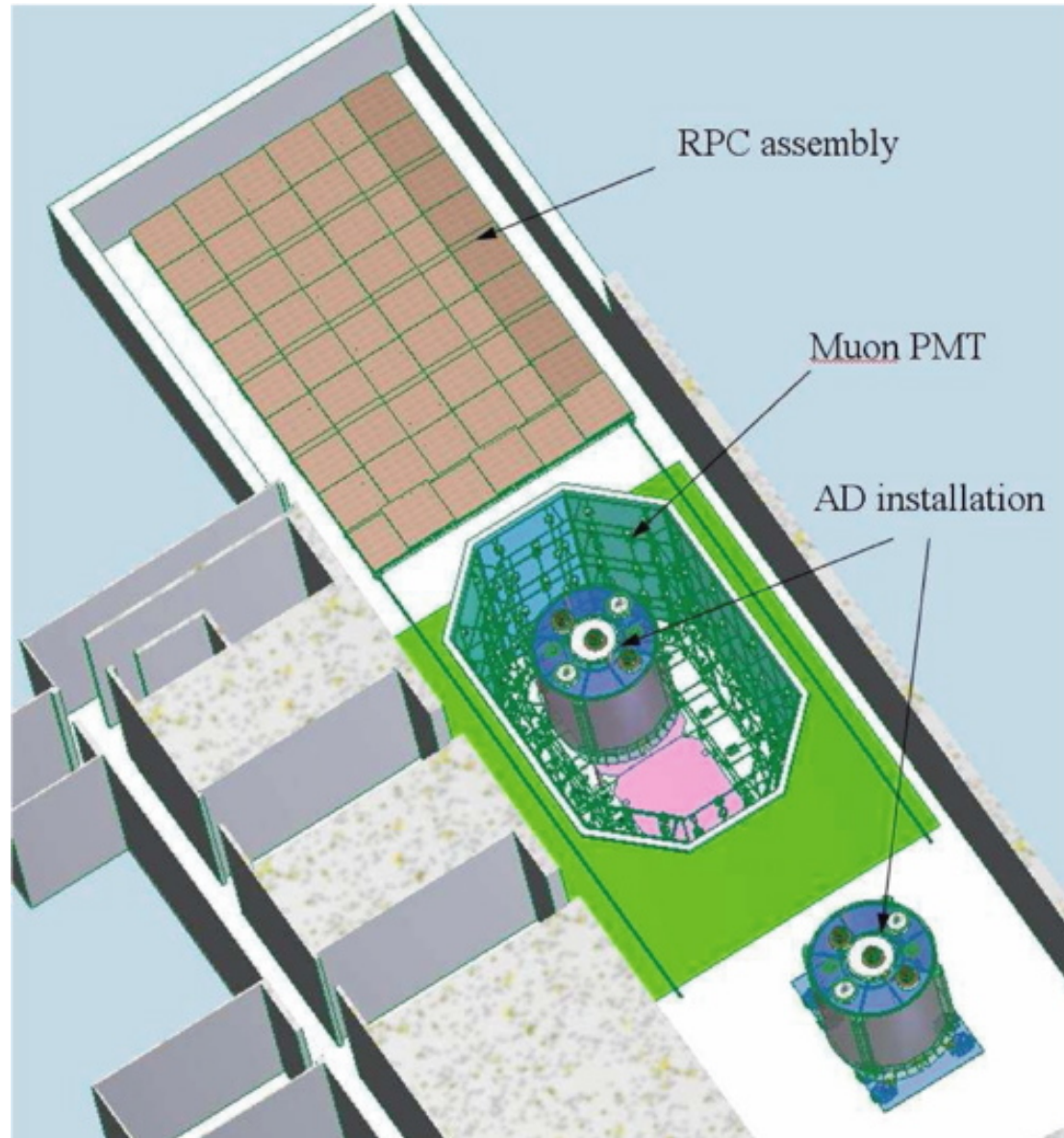
- natural radioactivity + neutrons from cosmic- μ .

Correlated events :

- Fast cosmogenic neutrons (recoil proton + n-capture),
- β +n decays of cosmogenic produced ^9Li and ^8He .
- Measurable by μ -tagging.

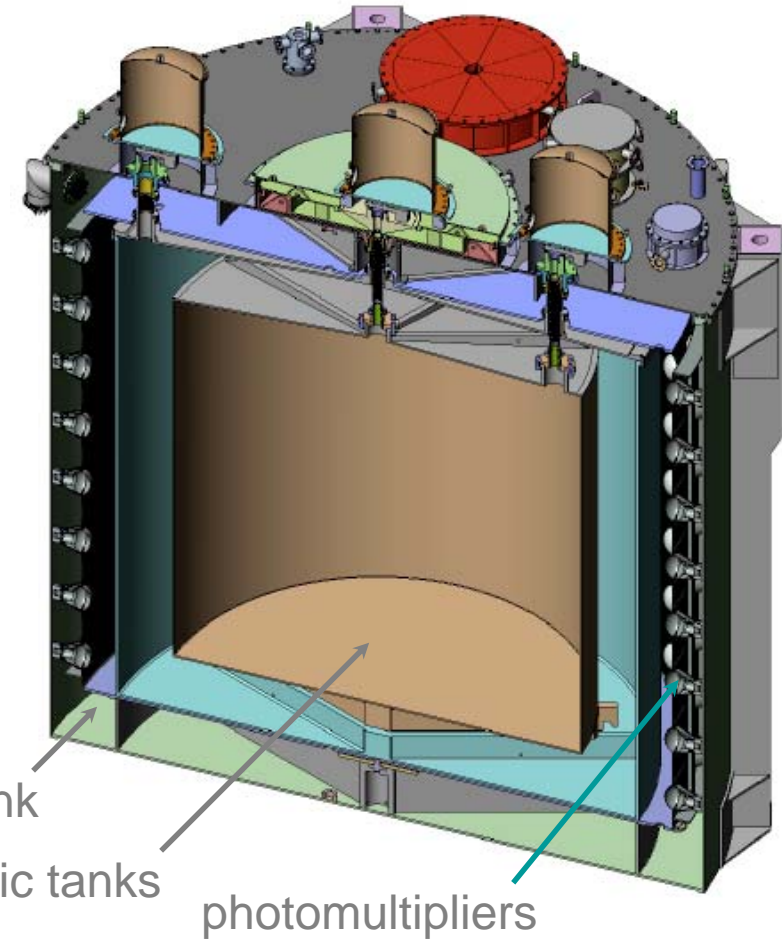
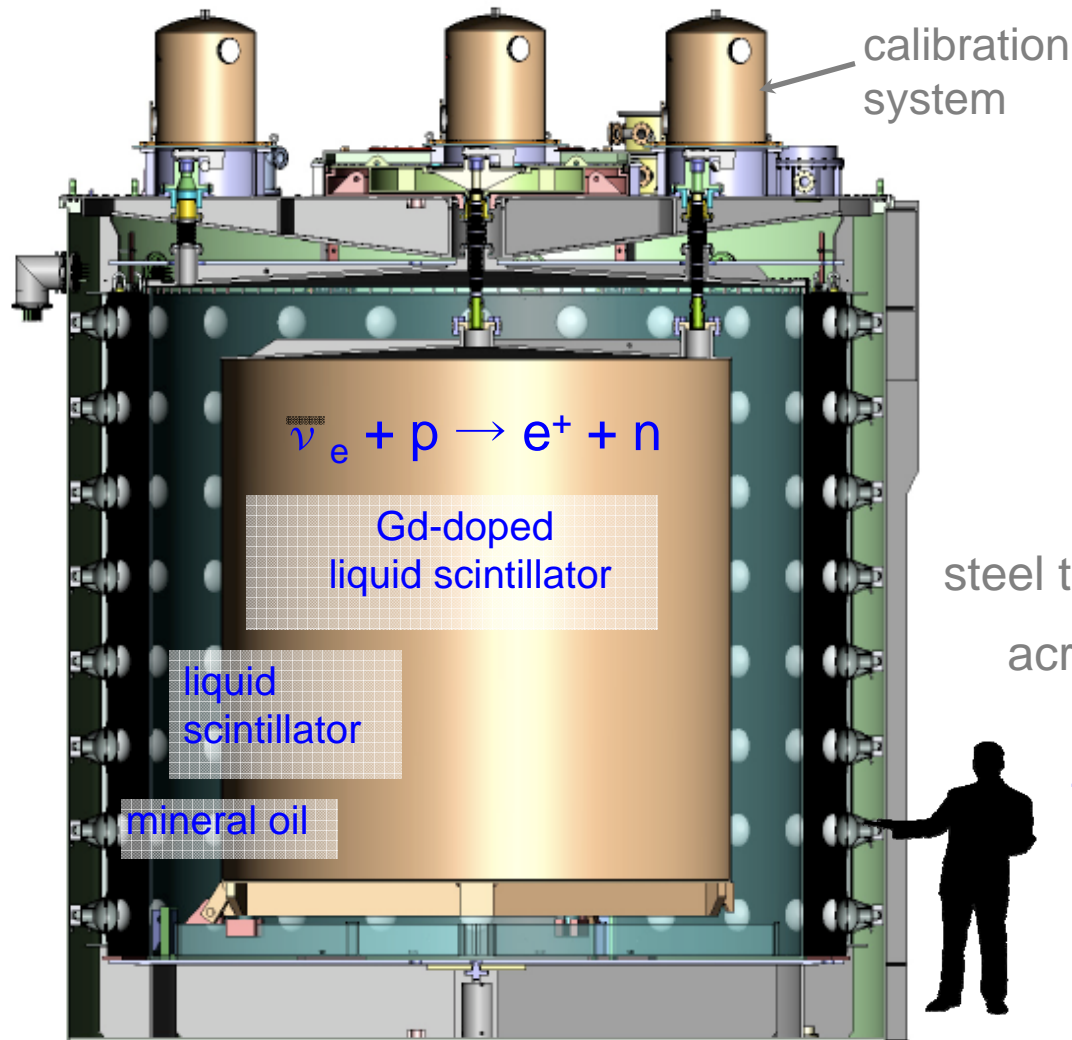
	Daya Bay Near	Ling Ao Near	Far Hall
Radioactivity (Hz)	<50	<50	<50
Muon rate / AD (Hz)	36	22	1.2
$\bar{\nu}_e$ -Signal (events/day)	840	740	90
Accidental B/S (%)	<0.2	<0.2	<0.1
Fast neutron B/S (%)	0.1	0.1	0.1
$^8\text{He}+^9\text{Li}$ B/S (%)	0.3	0.2	0.2

Layout in DBY Hall



Daya Bay Antineutrino Detector

- 8 “identical”, 3-zone detectors



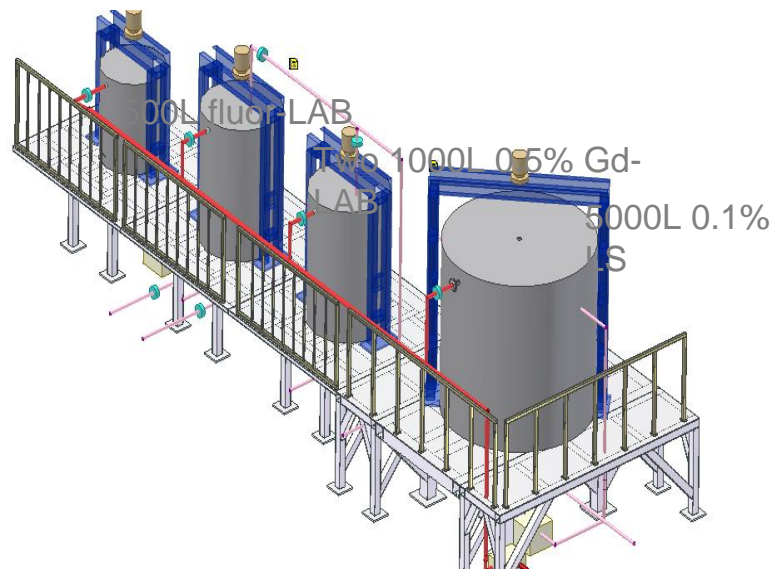
target mass: 20t per detector
 detector mass: ~ 110t
 photosensors: 192 PMTs
 energy resolution: 12%/ \sqrt{E}

Gd-Liquid Scintillator Test Production

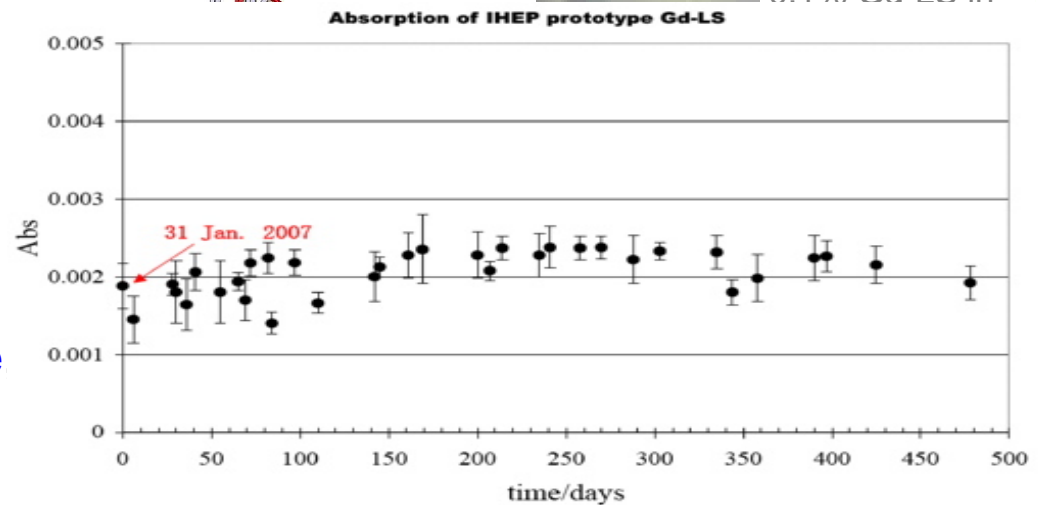
Daya Bay experiment uses 200 ton 0.1% gadolinium-loaded liquid scintillator (Gd-LS). Gd-TMHA + LAB + 3g/L PPO + 15mg/L bis-MSB



4-ton test batch production in April 2009.



0.1% Gd-LS in

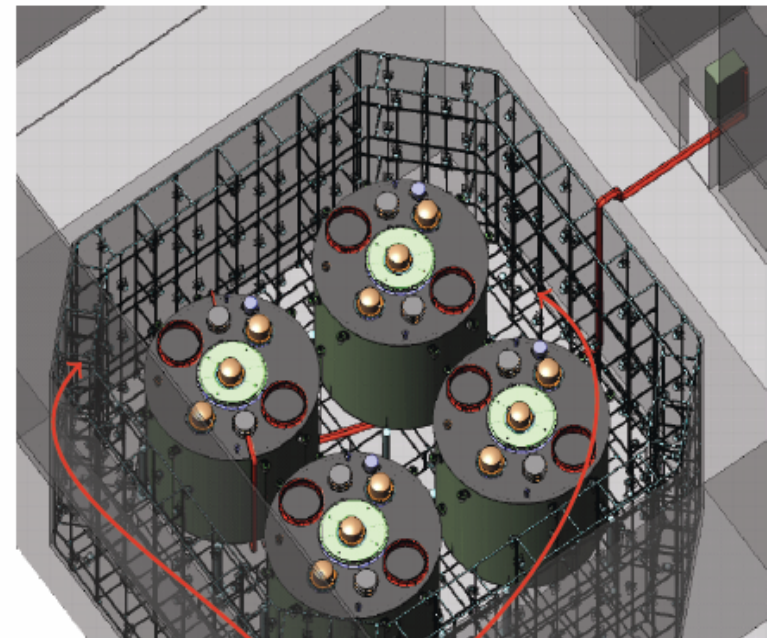


Water Cherenkov Detector to Tag Muons

Muon Veto Detectors

Efficiencies to tag all muons and muons leading to activity in ADs

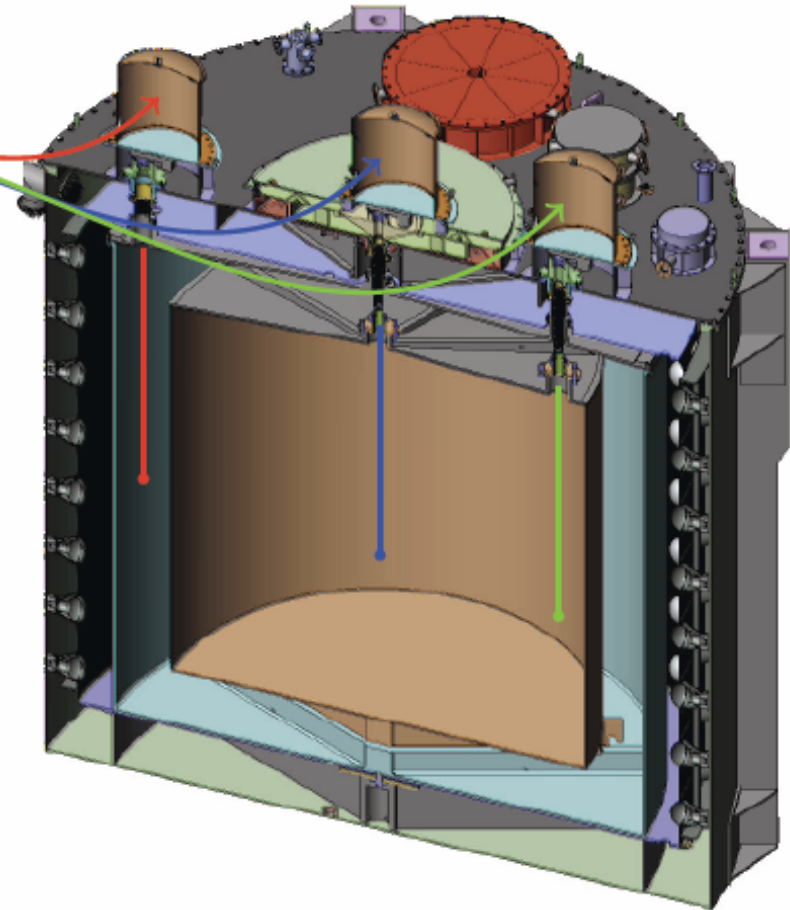
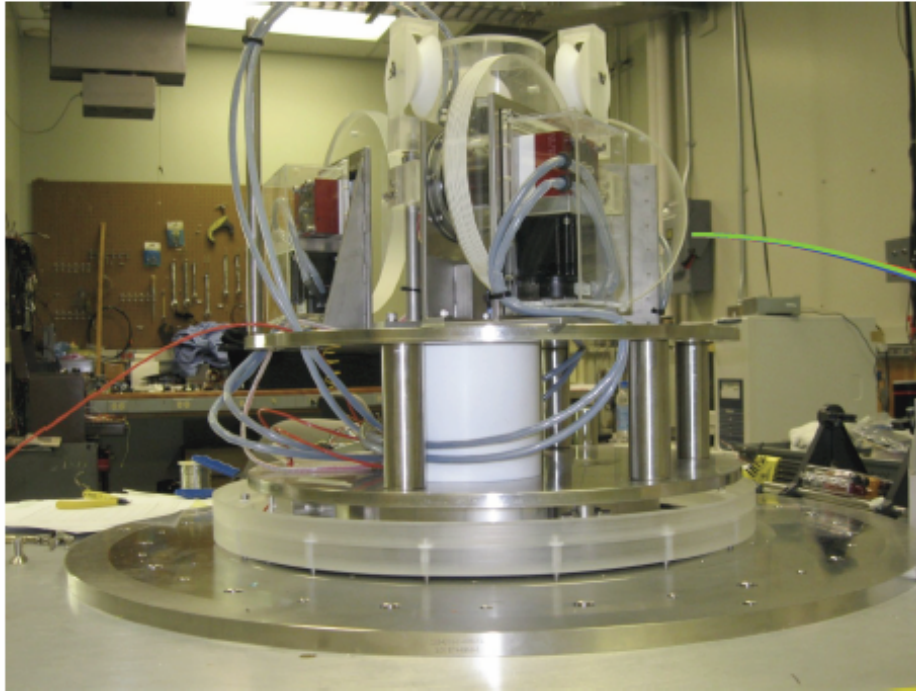
- Overall veto efficiency goal $99.5\% \pm 0.25\%$.
- OWS+IWS alone $> 99\%$ eff for μ in IWS or AD.
- Less eff. for μ in OWS or rock
 - less likely to make bkg
- Ongoing studies of ineff. μ :
 - fast neutrons
 - radioactive isotopes production (^9Li , ^8He)
 - challenging to obtain enough simulation statistics (1 min sim = 1 CPU-month).



1m thick Outer (OWS) & 1.5 m thick Inner (IWS) Water Shields separated by Tyvek curtain.

Muon rate (Hz)	DB	LA	Far
per AD module	36	22	1.2

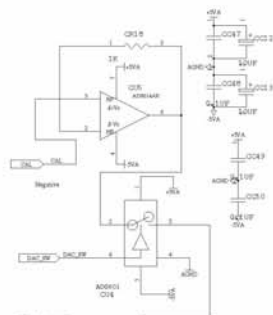
Calibration



- 3 automatic calibration units / AD.
 - LS & on-/off-axis GdLS
- LEDs monitoring optical properties
- Radioactive sources fix energy
- Additional “free” spallation neutrons

Front End Electronics

FAST ANALOG CIRCUIT for Analog Trigger



INPUT STAGE

SHAPING & ADC CIRCUIT for Charge Measurement

THRESHOLD CIRCUIT for Multiplicity Trigger

FEE ANALOG CIRCUITS

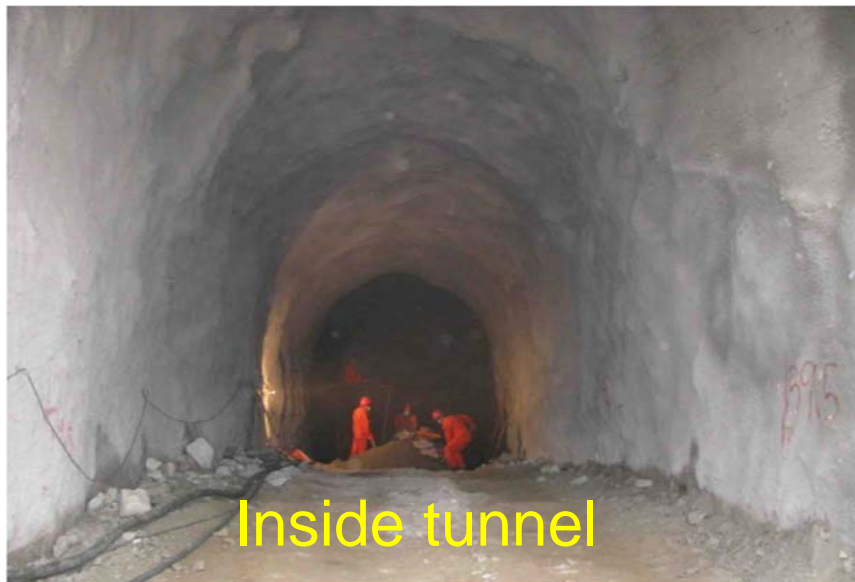
Civil Construction



Entrance



Surface Assembly Bldg 2009/02/18



Inside tunnel



Control Room 2009/02/18

Tunnel Construction Status



Pool Excavation in DBY Hall - Aug 09



Main Tunnels Join - June 09

Detector Assembly



Stainless steel tank in China



3-m acrylic vessel in Taiwan



4-m vessel in the U.S.



SS Tank delivery



Delivery of 4m AV



Stainless steel tank in SAB

AD Components



4-meter acrylic vessel arrives



Unpacked 4-m acrylic vessel

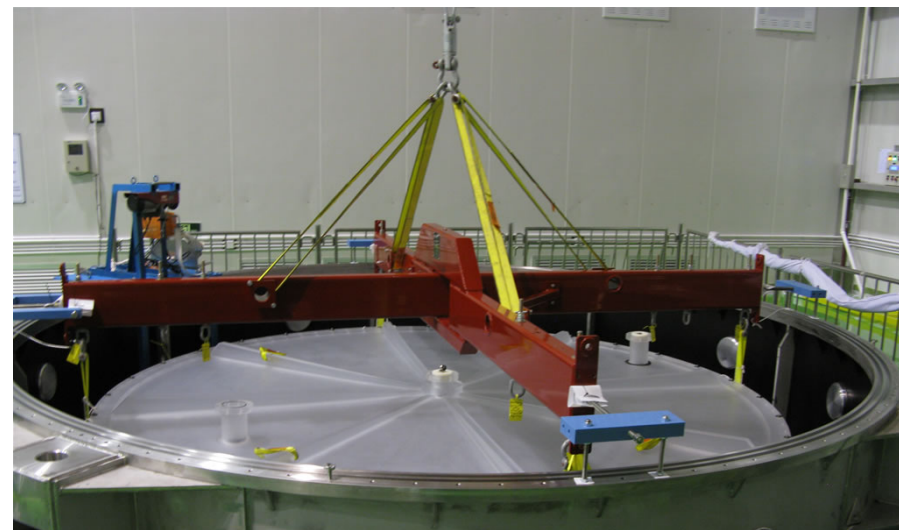
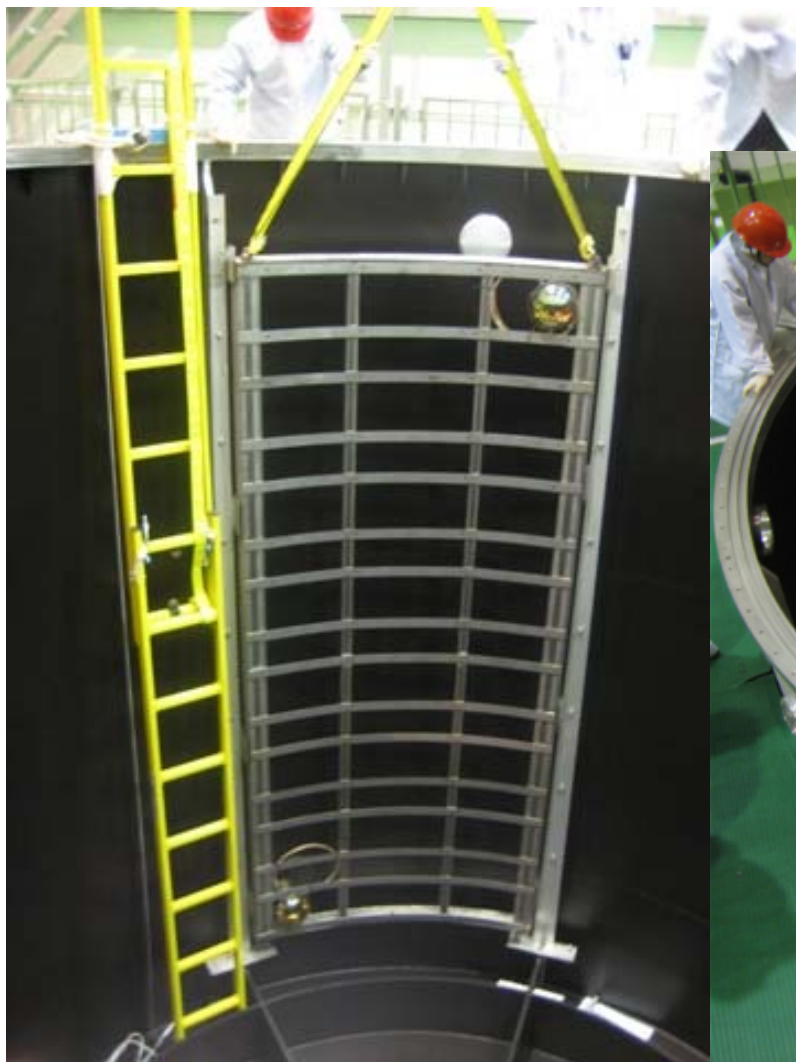


PMT Ladder



Mounting of non-reflecting panels
on ladder

AD Assembly



Schedule

- 2003-2007: Proposal, R&D, engineering design etc.
- October 2007: Ground Breaking
- March 2009: Surface Assembly Building occupancy
- Fall 2010: Daya Bay Near Hall ready for data taking
- Fall 2011: All near and far halls ready for data taking

Three years' data taking to reach full sensitivity.

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Thank You !