Daya Bay Reactor Neutrino Experiment

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On behalf of the Daya Bay Collaboration

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Institute of High Energy Physics

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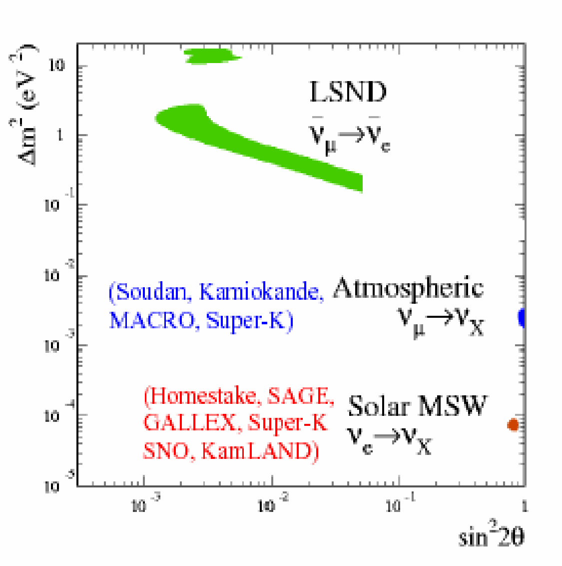
Neutrino Oscillation

Neutrino Mixing: PMNS Matrix

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

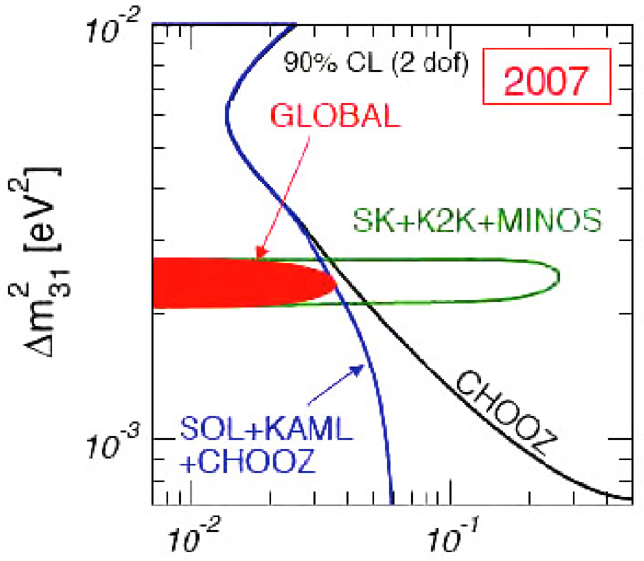
Atmospheric, K2K, MINOS, T2K, etc.	Reactor Accelerator	Solar KamLAND
$\theta_{23} \sim 45^o$	$\theta_{13} < 12^o$	$\theta_{12} \sim 30^o$



Known: $|\Delta m^2_{32}|$, $\sin^2 2\theta_{23}$, Δm^2_{21}, $\sin^2 2\theta_{12}$

Unknown: $\sin^2 2\theta_{13}$, δ_{CP}, Sign of Δm^2_{32}

Measuring θ_{13} at reactors



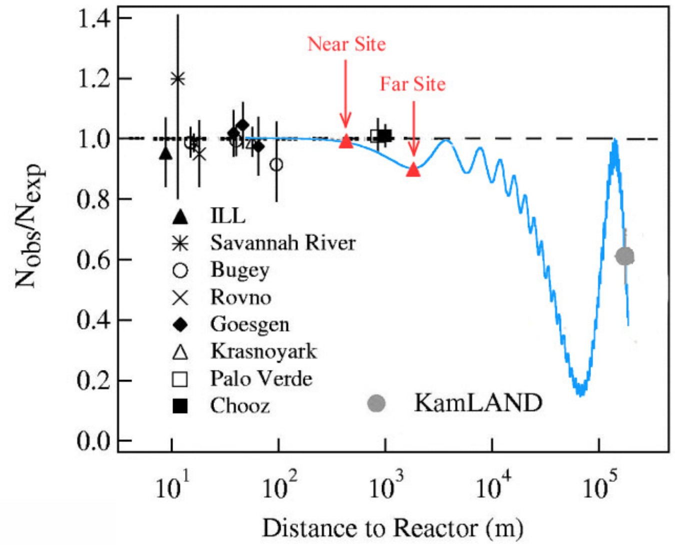
arXiv:0710.5027

Reactor ($\bar{\nu}_e$ disappearance)

Clean in physics, only related to θ_{13}

Cheaper and faster

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)$$

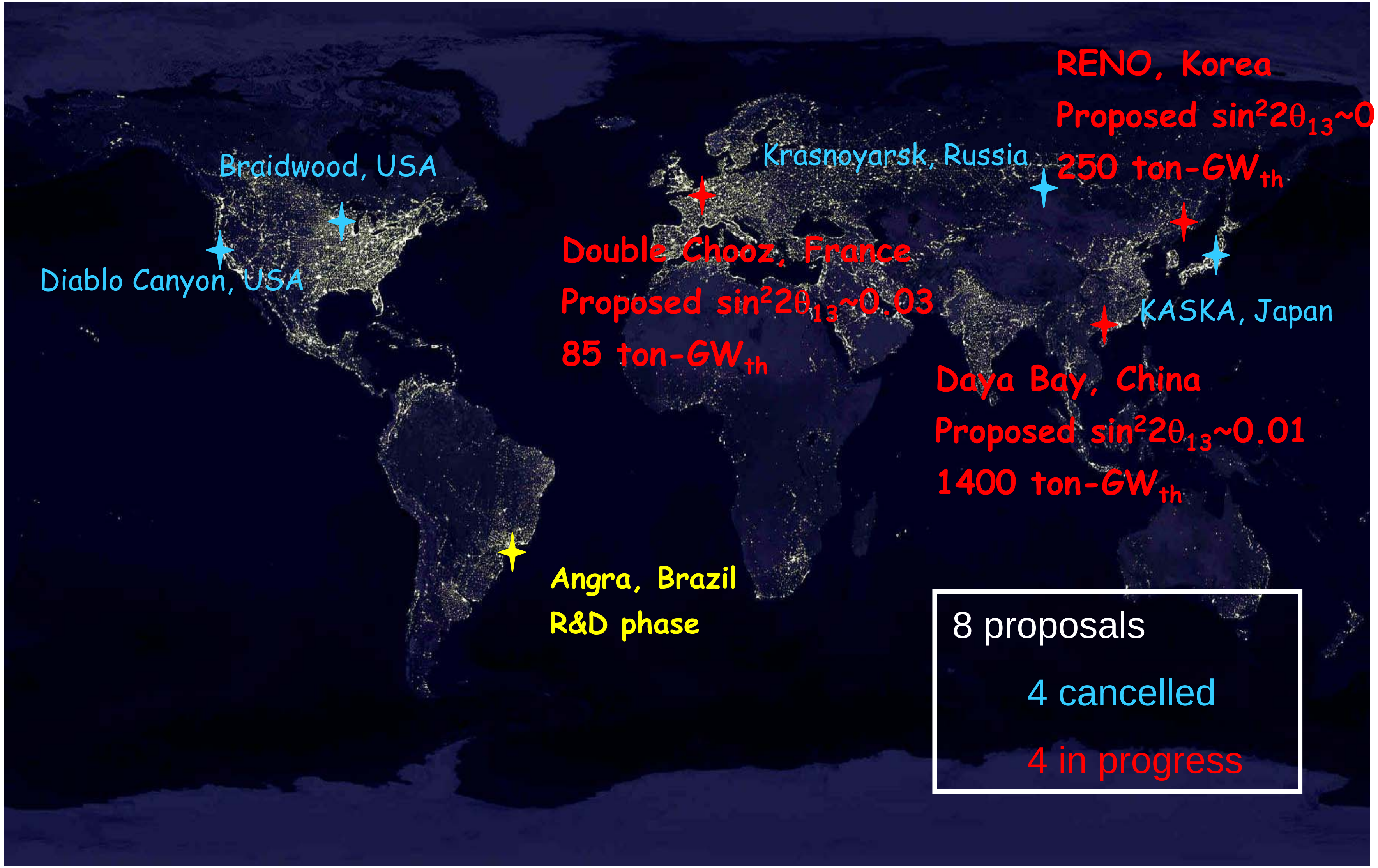


Accelerator (ν_e appearance)

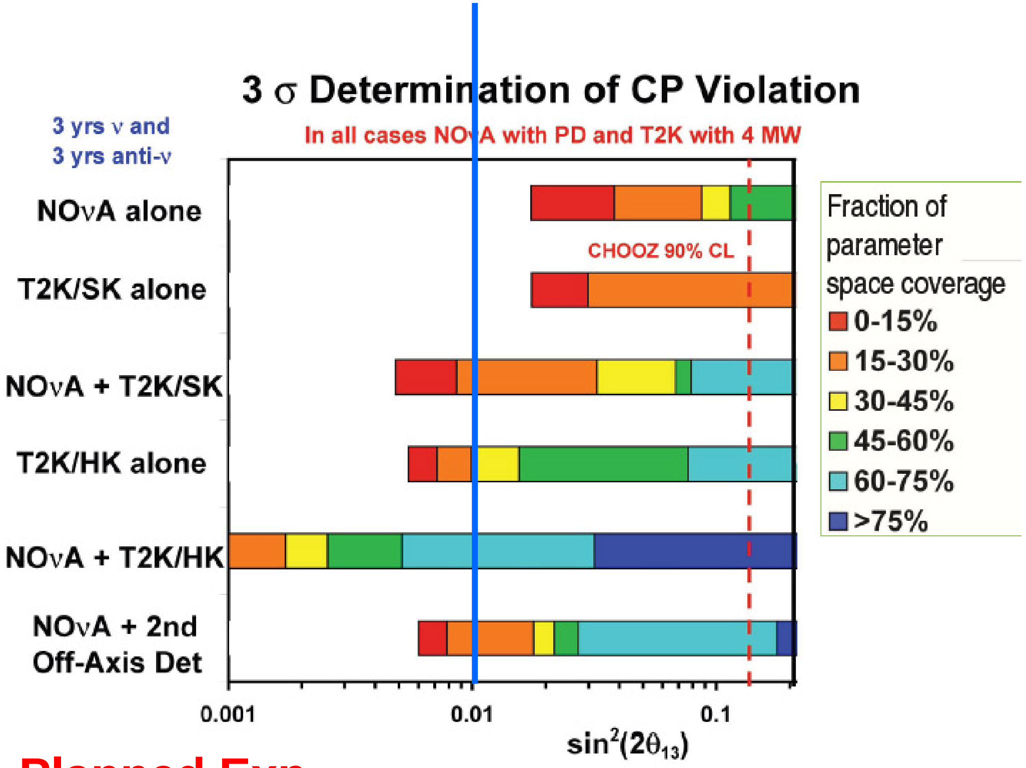
Related to CP phase, θ_{13}, and mass hierarchy

$$\begin{aligned} P(\nu_\mu \to \nu_e) = {} & 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2\Delta_{31} \\ & + 8c_{13}^2 s_{13} s_{23} c_{23} s_{12} c_{12} \sin\Delta_{31} [\cos\Delta_{32} \cos\delta - \sin\Delta_{32} \sin\delta] \sin\Delta_{21} \\ & - 8c_{13}^2 s_{13}^2 s_{23}^2 s_{12}^2 \cos\Delta_{32} \sin\Delta_{31} \sin\Delta_{21} \\ & + 4c_{13}^2 s_{12}^2 [c_{12}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta] \sin^2\Delta_{21} \\ & - 8c_{13}^2 s_{13}^2 s_{23}^2 (1 - 2s_{13}^2) \frac{aL}{4E_\nu} \sin\Delta_{31} \left[\cos\Delta_{32} - \frac{\sin\Delta_{31}}{\Delta_{31}}\right] . \end{aligned}$$

Proposals for measuring θ_{13} at reactors



Measuring $\sin^2 2\theta_{13}$ to 0.01



Planned Exp.

If $\sin^2 2\theta_{13}$<0.01, long baseline (LBL) experiments with conventional beam have little chance to determine the CP violation.

Measuring $\sin^2 2\theta_{13}$ to 0.01 will provide a roadmap for the future LBL experiments.

"We recommend, as a high priority, …, An expeditiously deployed multi-detector reactor experiment with sensitivity to $\bar{\nu}_e$ disappearance down to $\sin^2 2\theta_{13}$=0.01"

---- APS Neutrino Study, 2004

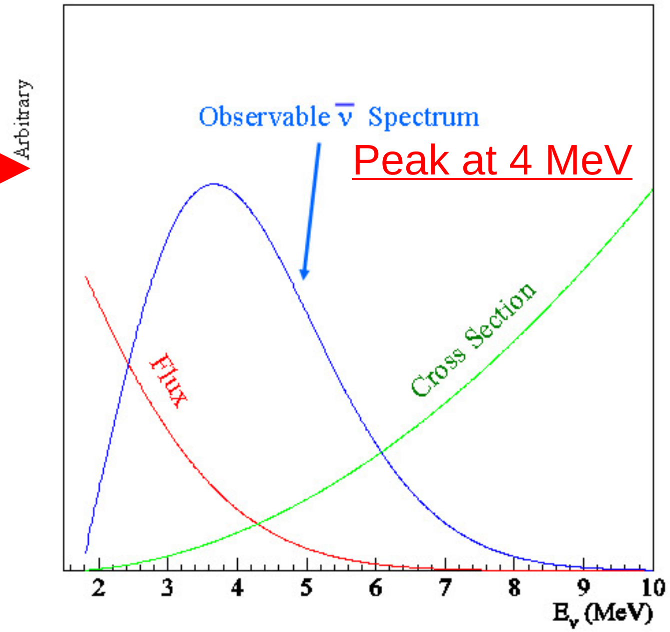
Signal and Backgrounds in detector

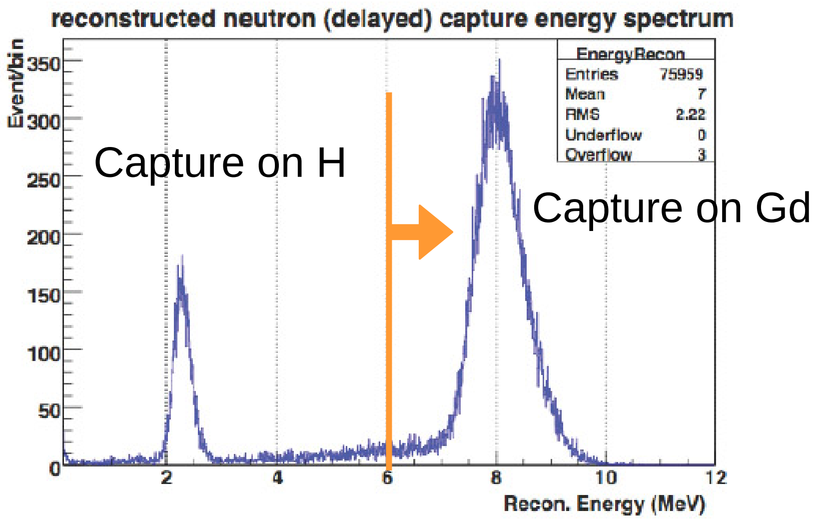
Prompt signal

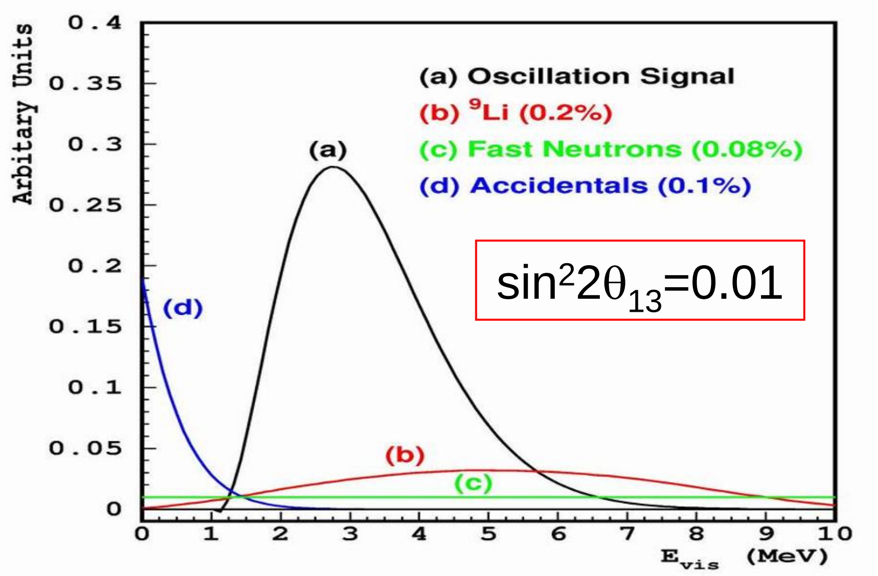
$$e^{+} + e^{-} \rightarrow 2\gamma$$

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

Capture on H or Gd,
Delayed signal, 2.2, 8 MeV





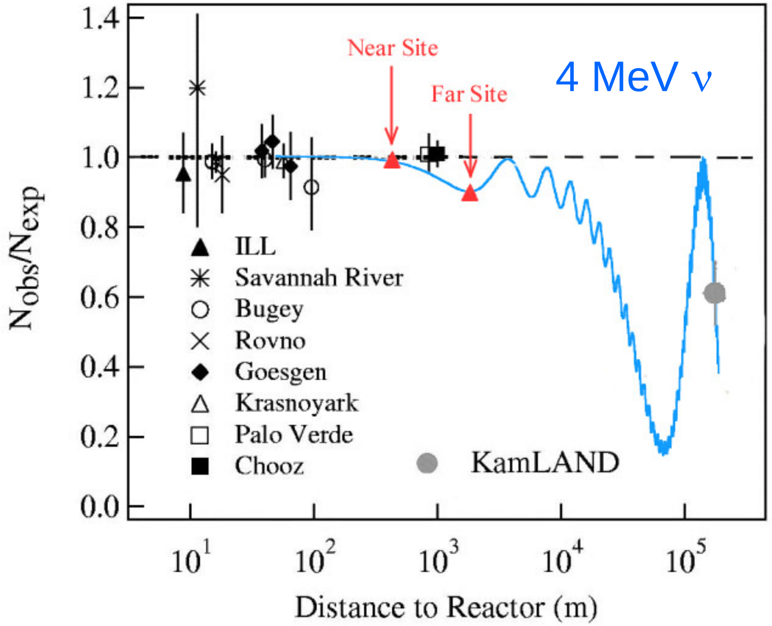


How to measure $\sin^2 2\theta_{13}$ to 0.01

CHOOZ: R=1.01±2.8%(stat) ±2.7%(syst), $\sin^2 2\theta_{13}<0.17$

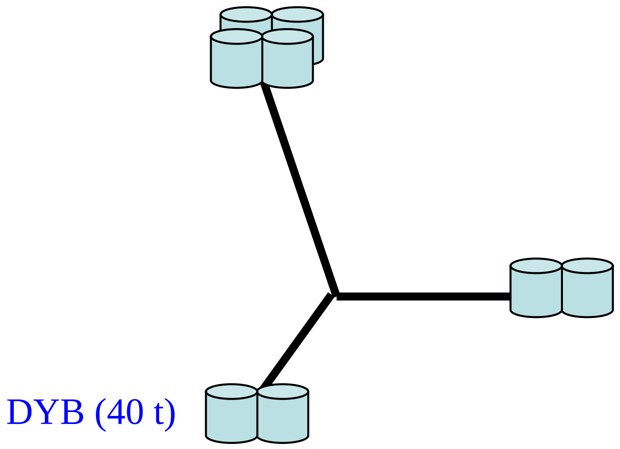
Higher statistics
- 40 ton-GW → 1400 ton-GW at Daya Bay
- Statistical error 0.2% in 3 years.

Lessons from past experience:
- Need near and far detectors
- Chooz: Good Gd-LS
- Palo Verde: Go deeper, good muon system
- KamLAND: No fiducial cut, lower threshold



Parameter	Error	Daya Bay, Relative measurement
Reaction cross section	1.9 %	Cancel out, Near/far
Number of protons	0.8 %	Reduced to <0.3%, filling tank with load cell
Detection efficiency	1.5 %	Reduced to ~0.2%, 3-layer detector
Reactor power	0.7 %	Reduced to ~0.1%, Near/far
Energy released per fission	0.6 %	Cancel out, Near/far
Chooz Combined	2.7 %	

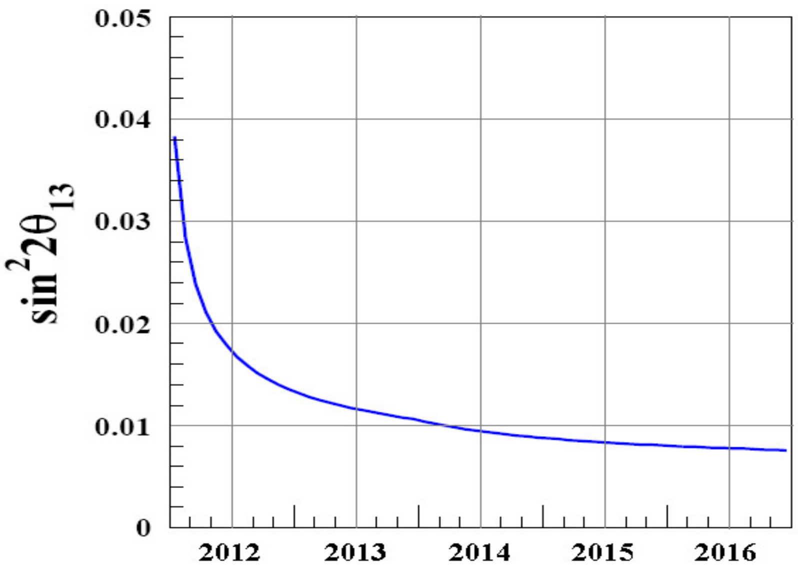
Sensitivity of Daya Bay

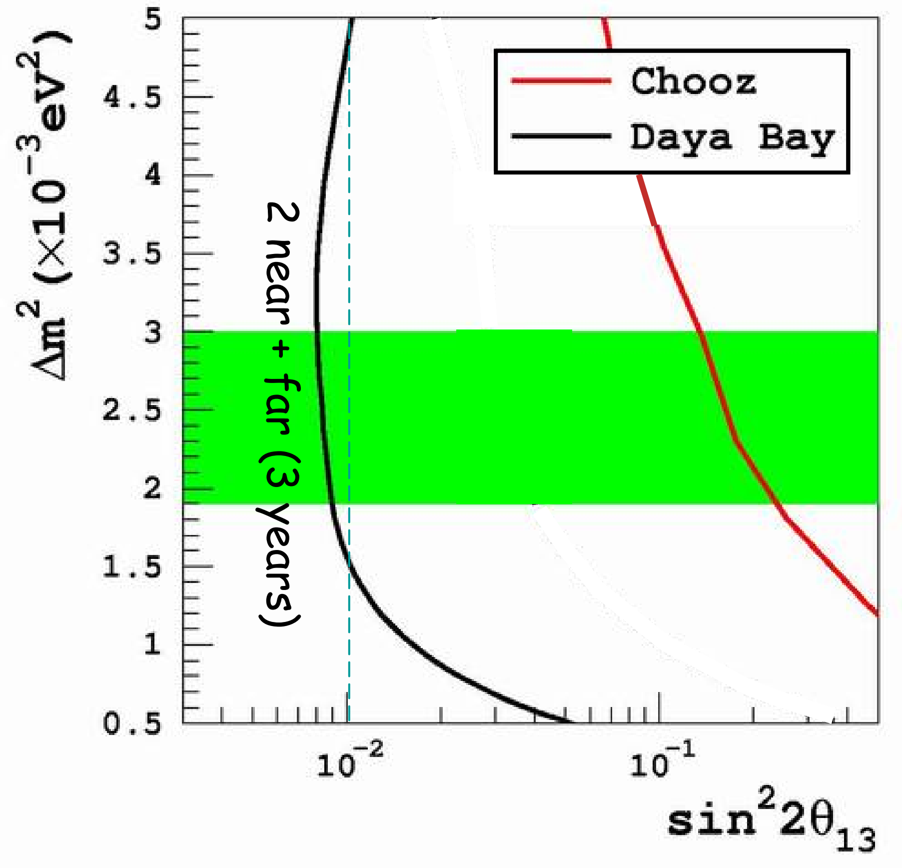


Goal: $\sin^2 2\theta_{13} < 0.01$

- Use rate and spectral shape
- input relative detector syst. error of 0.38%/detector

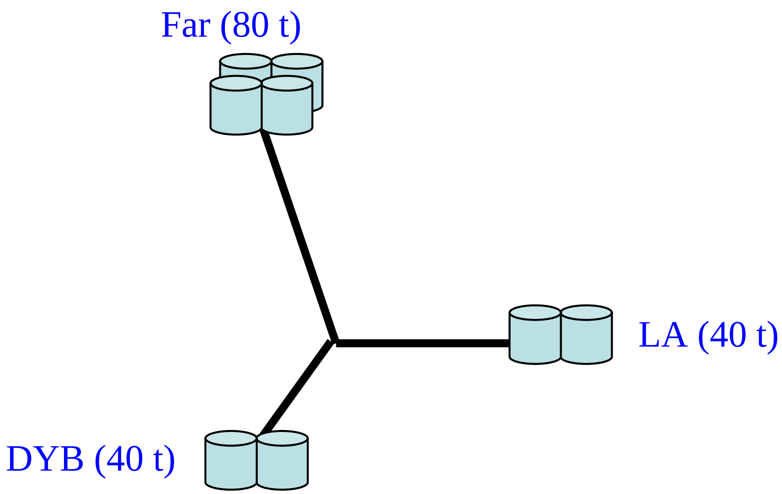
90% confidence level



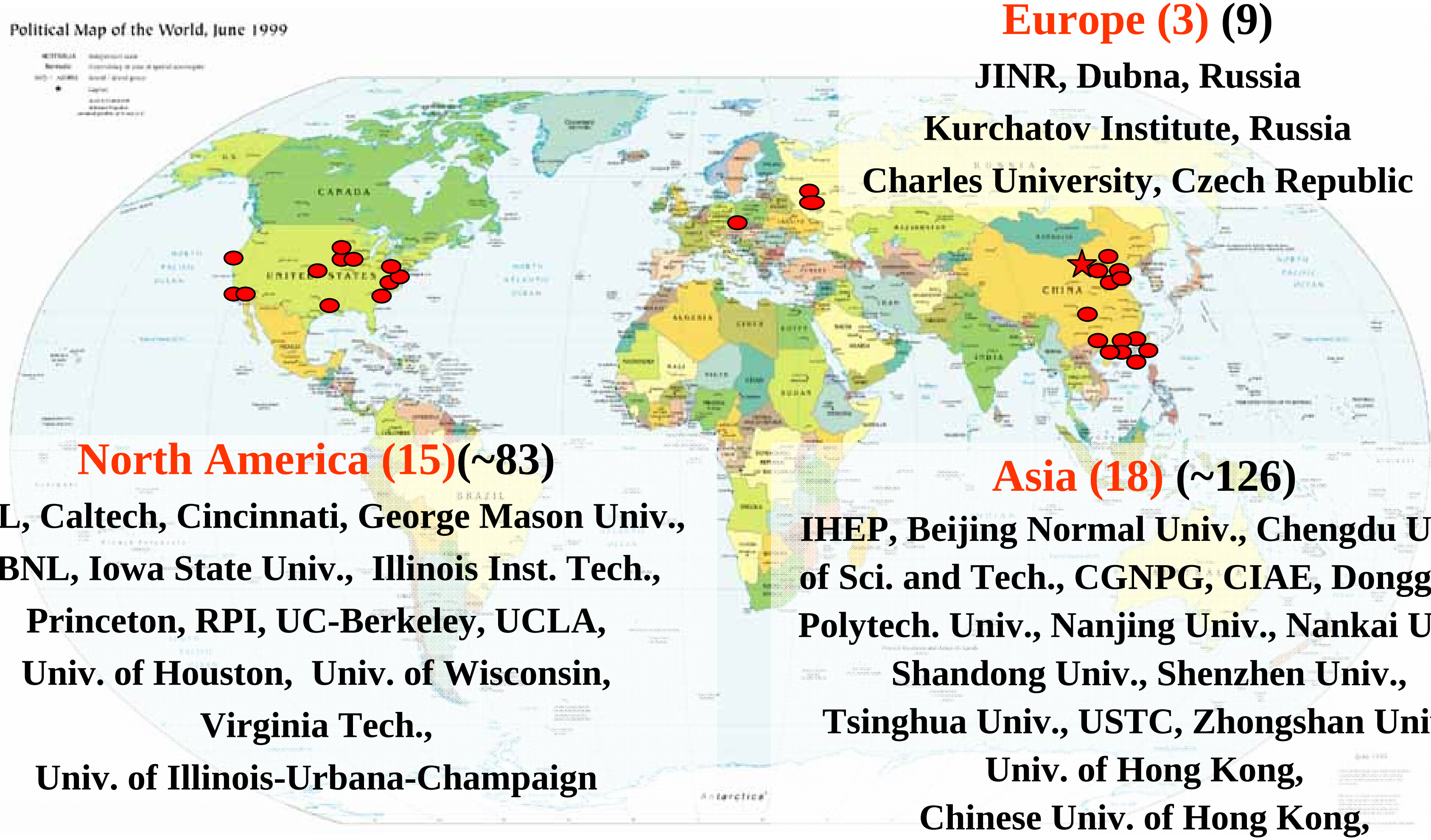


Redundancy

- Measuring $\sin^2 2\theta_{13}$ to 0.01 need to control systematic errors very well.
- We believe that the relative (near/far) detector systematic error could be lowered to 0.38%, with near/far cancellation and improved detector design.
- **Side-by-side calibration**: Event rates and spectra in two detectors at the same near site can be compared → How IDENTICAL our detectors are?
- **Detector swapping**: Daya Bay antineutrino detectors are designed to be MOVABLE. All detectors are assembled and filled with liquids at the same place. Detectors at the near sites and the far site can be swapped, although not necessary to reach our designed sensitivity, to cross check the sensitivity and further reduce the systematic errors.



The Daya Bay Collaboration



Europe (3) (9)

JINR, Dubna, Russia
Kurchatov Institute, Russia
Charles University, Czech Republic

North America (15)(~83)

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 (18) (~126)

IHEP, Beijing Normal Univ., Chengdu Univ. of Sci. and Tech., CGNPG, CIAE, Dongguan Polytech. Univ., Nanjing Univ., Nankai Univ., Shandong 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.

~ 218 collaborators

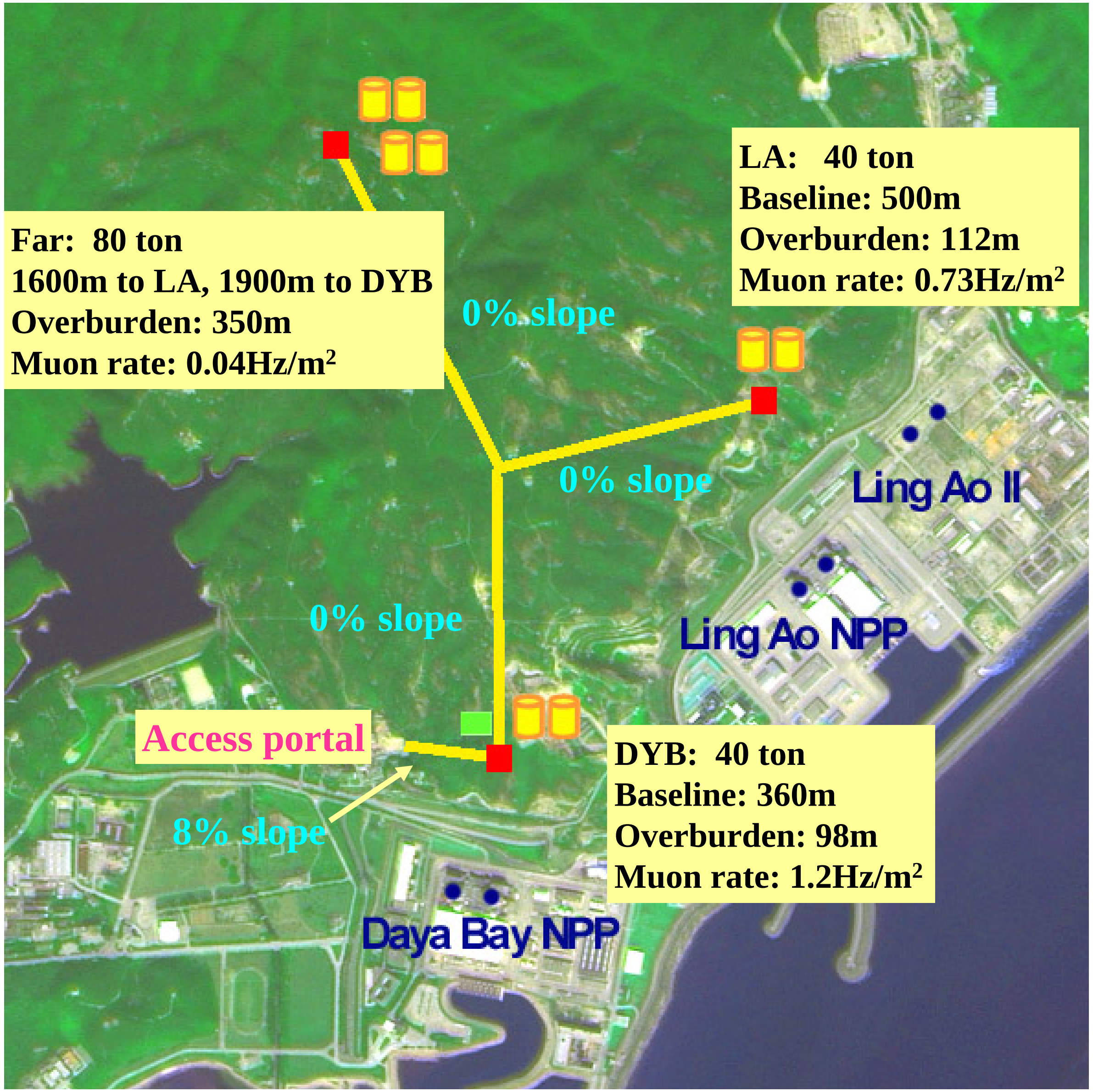
The Daya Bay site

- Transportation convenient.
  60 km to Hong Kong,
  50 km to Shen Zhen.
  A seaport in the Power Plant.
- Adjacent to high hill, ideal for underground labs.
- In the future …
  1000m high mountains at ~60km distance. Possibly to launch a intermediate-baseline experiment for mass hierarchy and precision θ_{12} measurements.
  Phys.Rev.D78:111103,2008,
  [arXiv:0807.3203];
  [arXiv:0901.2976]

Daya Bay and Ling Ao Nuclear Power Plant

Daya Bay

Goal: $\sin^2 2\theta_{13} < 0.01$ @ 90% CL in 3 years. Site: Shen Zhen, China



Power Plant
- 4 cores 11.6 GW
- 6 cores 17.4 GW from 2011

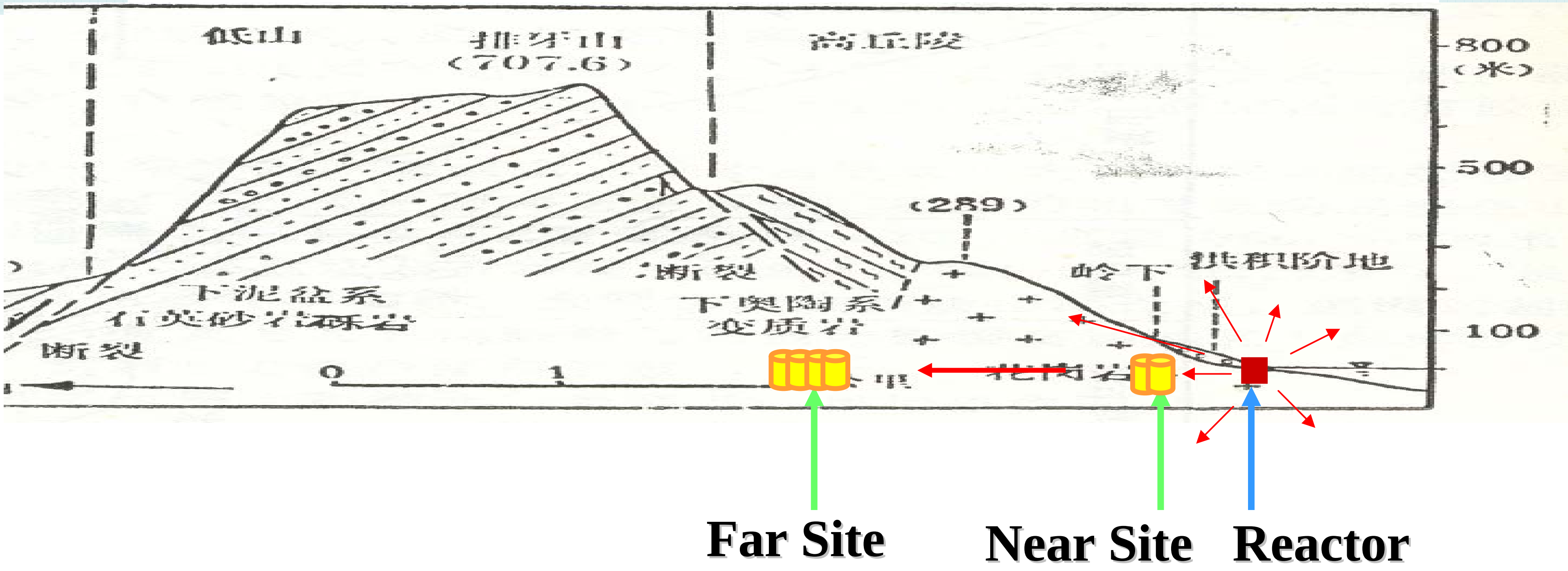
Three experimental halls
- Multiple detectors at each site
- Side-by-side calibration

Horizontal Tunnel
- Total length 3200 m

Movable Detector
- All detectors filled at the filling hall, w/ the same batch of Gd-LS, w/ a reference tank

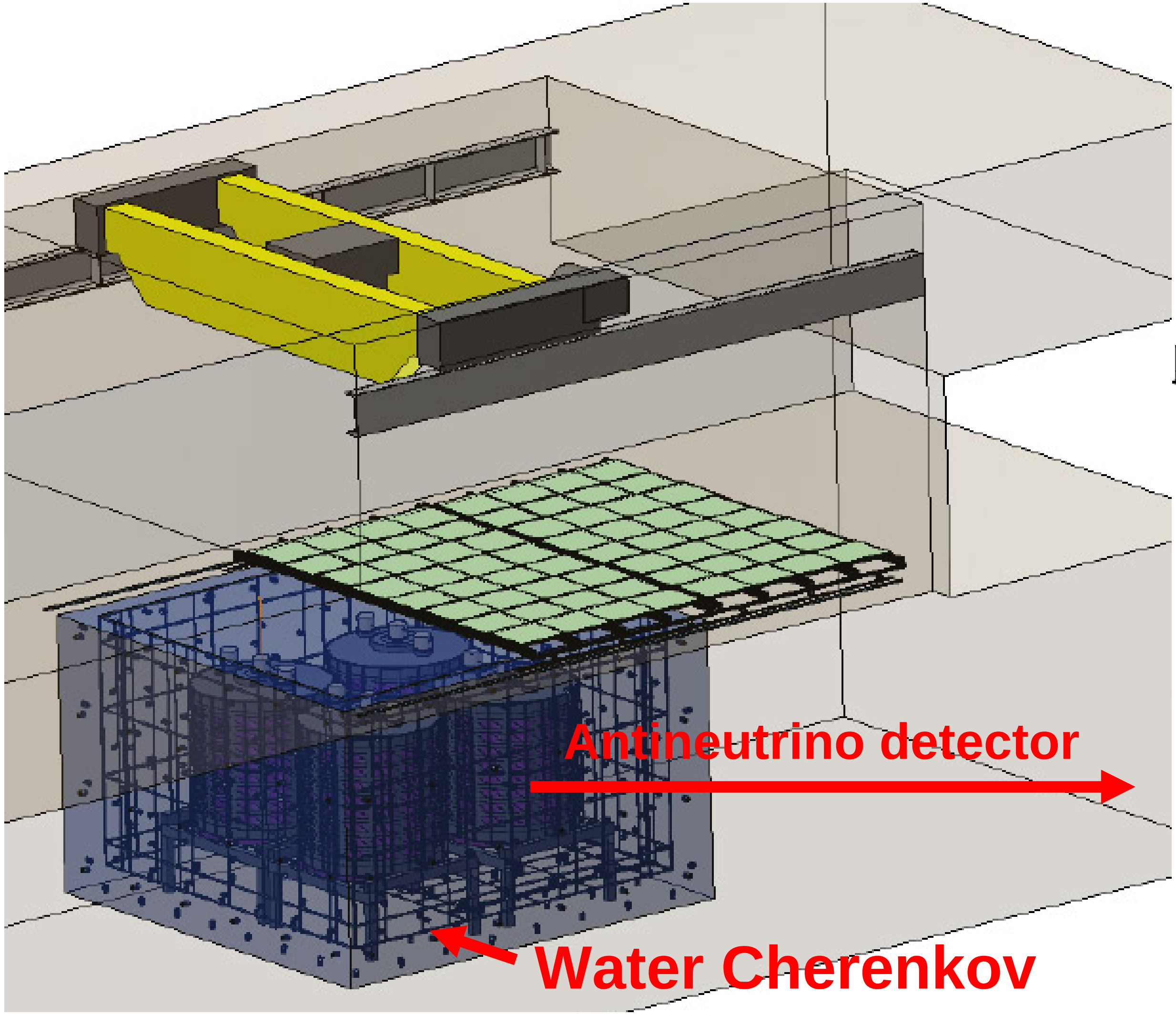
Event Rate:
- ~1200/day Near
- ~350/day Far

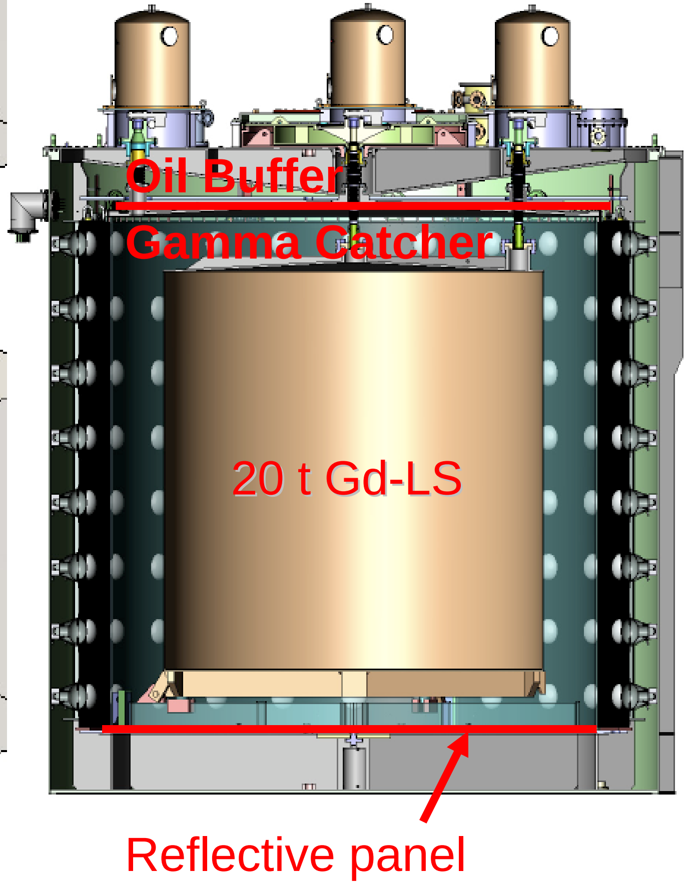
Backgrounds
- B/S ~0.4% Near
- B/S ~0.2% Far


低山
排牙山
(707.6)
高丘陵
800
(米)
500
(289)
100
岭下
洪积阶地
断裂
下泥盆系
石英砂岩砾岩
下奥陶系
变质岩
0
1
Far Site
Near Site
Reactor


通告

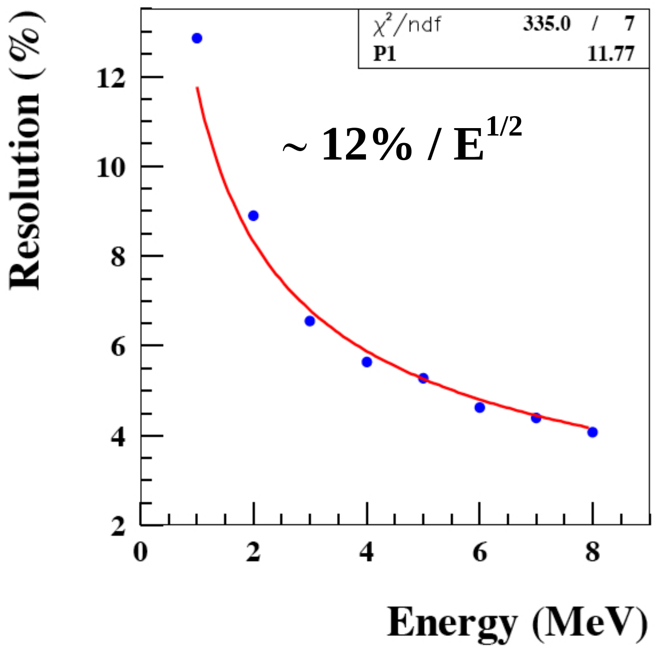
Daya Bay Detectors

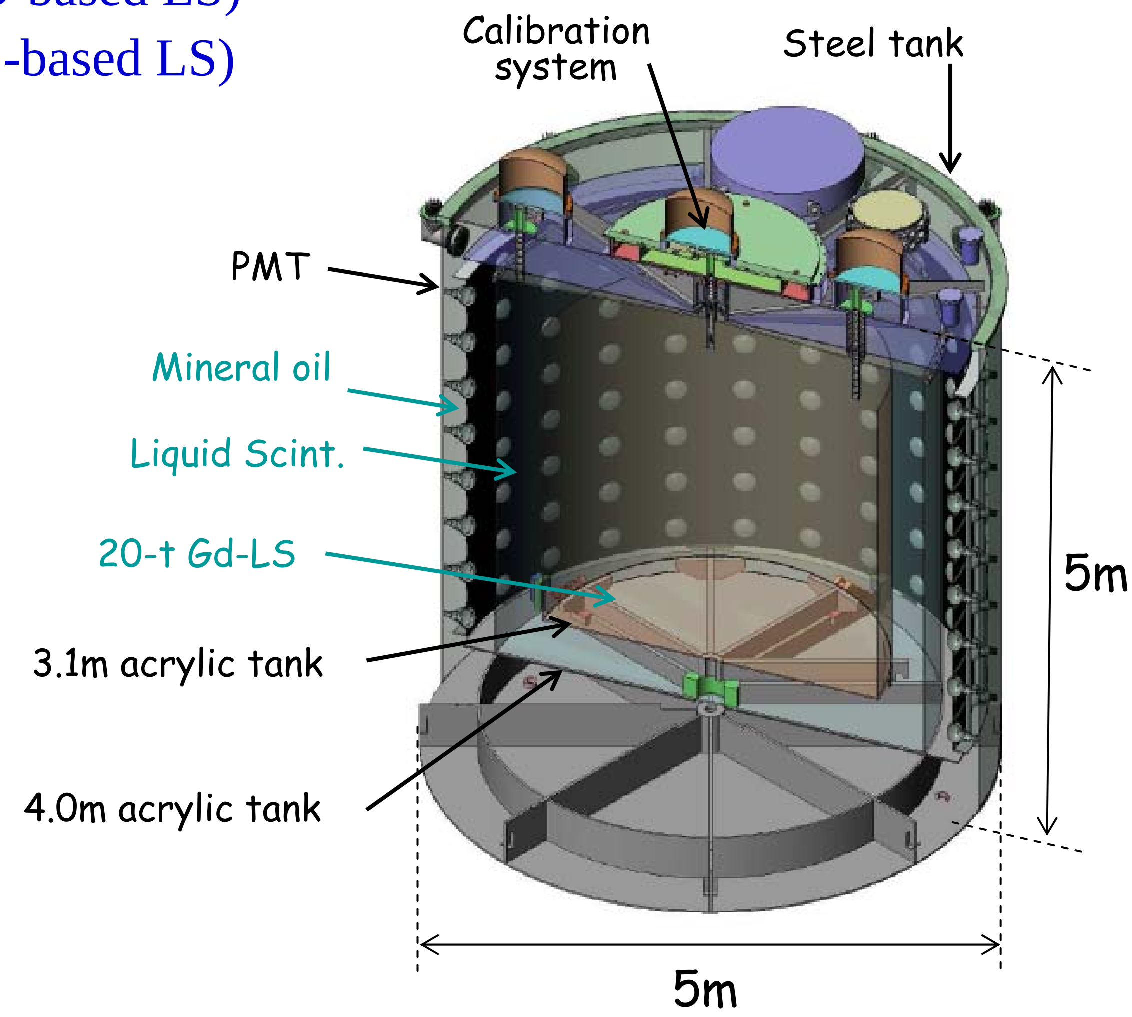




Antineutrino Detectors

- Three-zone cylindrical detector design
  - ⇨ Target: 20 t (0.1% Gd LAB-based LS)
  - ⇨ Gamma catcher: 20 t (LAB-based LS)
  - ⇨ Buffer : 40 t (mineral oil)
- Low-background 8" PMT: 192
- Reflectors at top and bottom

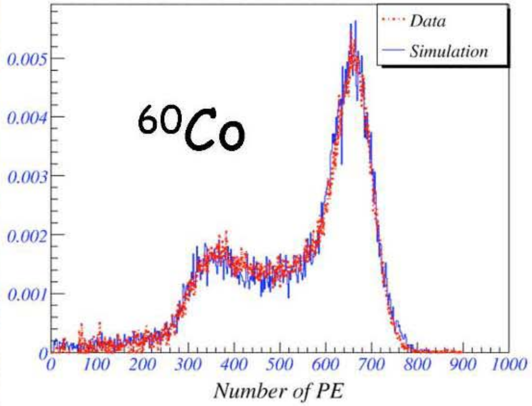


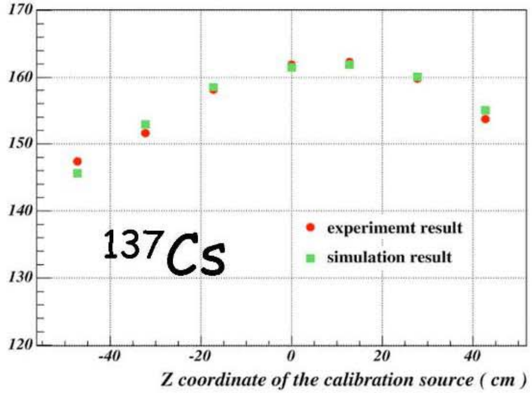


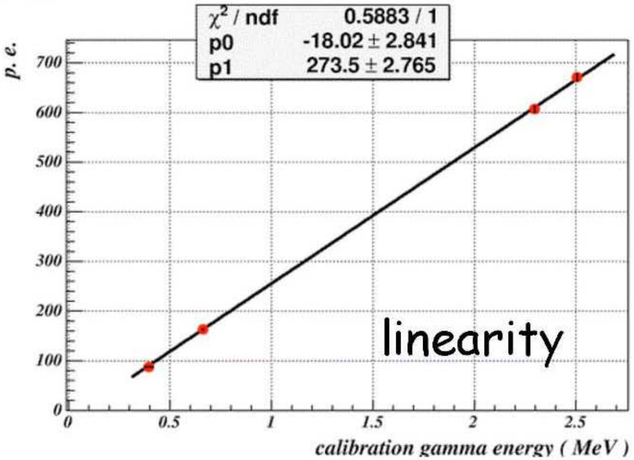
2-zone Prototype at IHEP

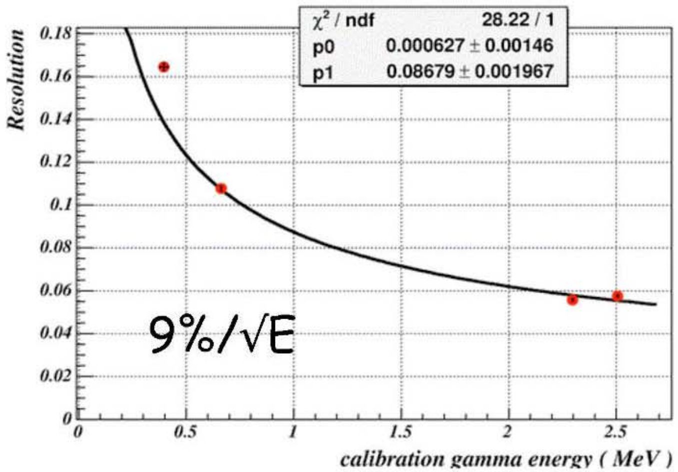
- 0.5 ton unloaded LS
- 45 8" PMTs with reflecting top and bottom

Phase-I, started in 2006, ended in Jan. 2007







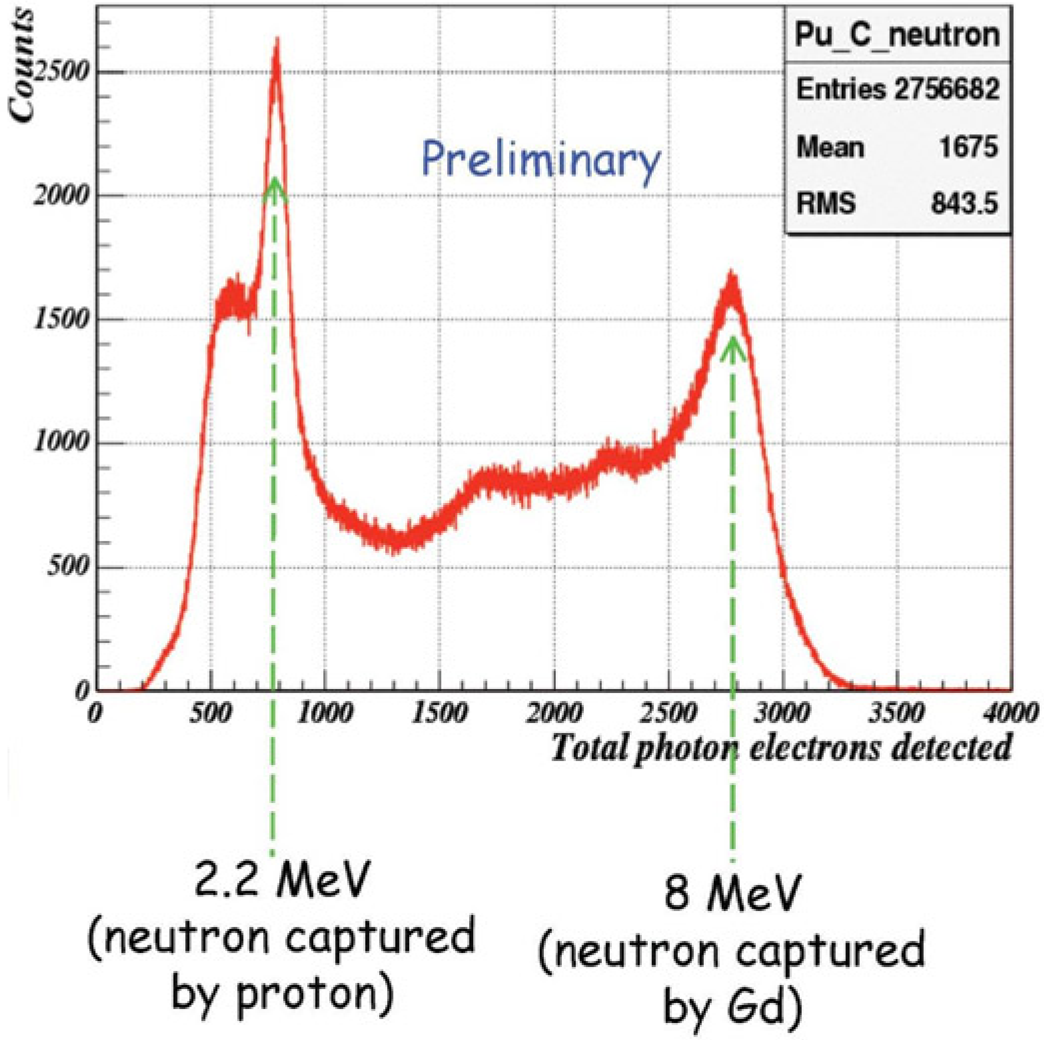


IHEP Prototype filled with 0.1% Gd-LS

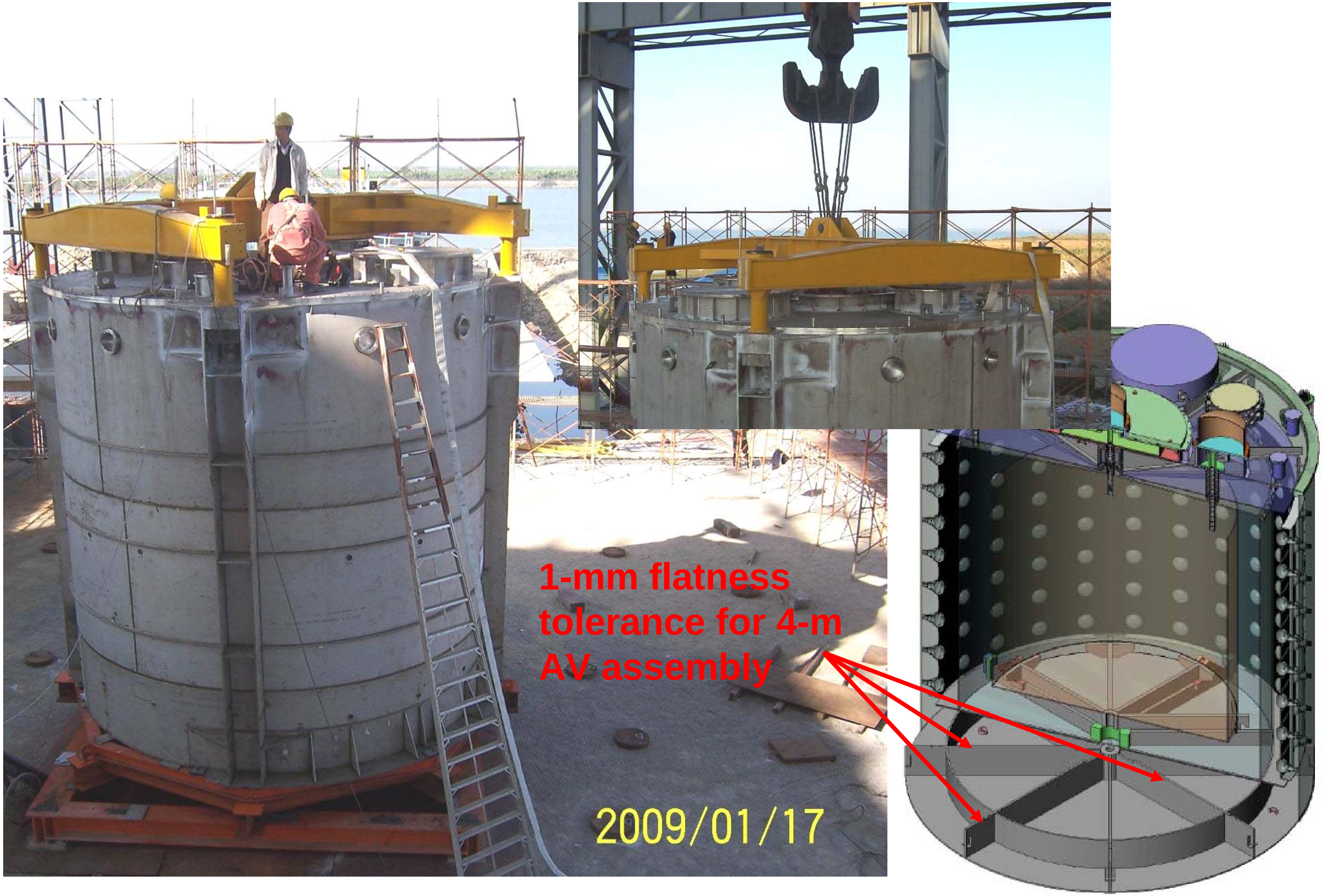
Gd-TMHA complex synthesis

Phase-II, filled with half-ton 0.1% Gd-LS, started in Jan. 2007 and keep running until now.

The prototype is also used for the FEE and Trigger boards testing.



Stainless Steel Tank Fabrication

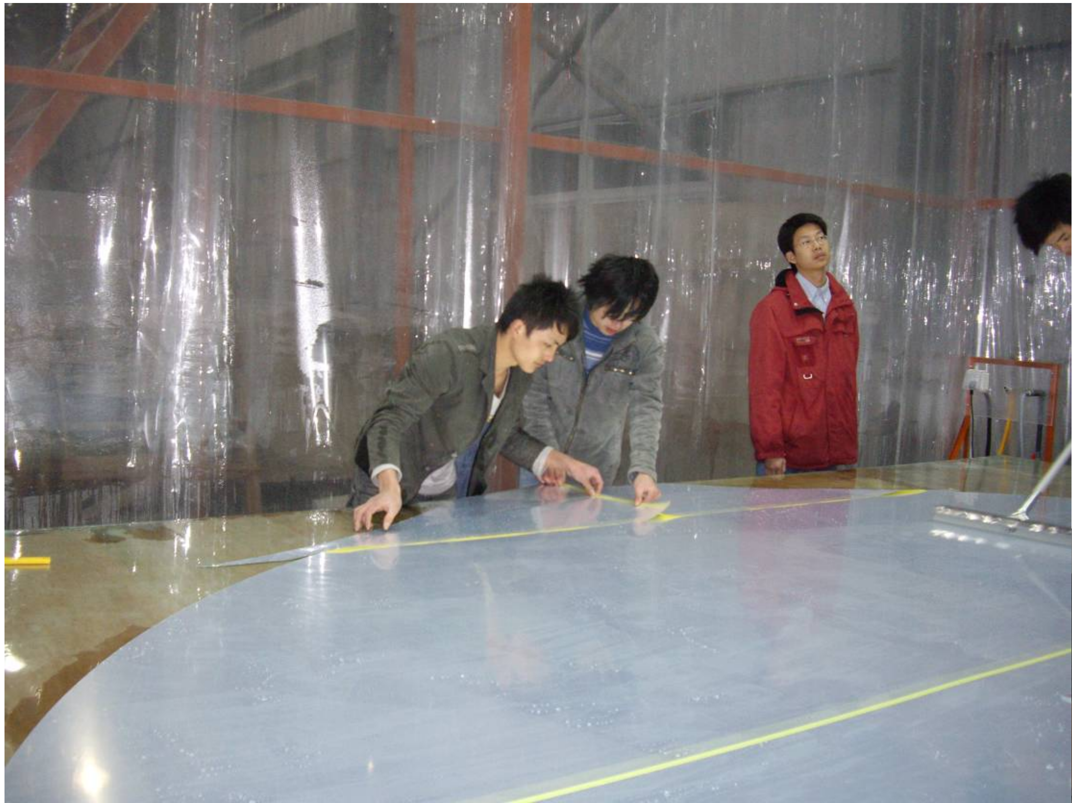


Acrylic Vessels

4-m AV in US

3-m AV in Taiwan

Reflective Panels

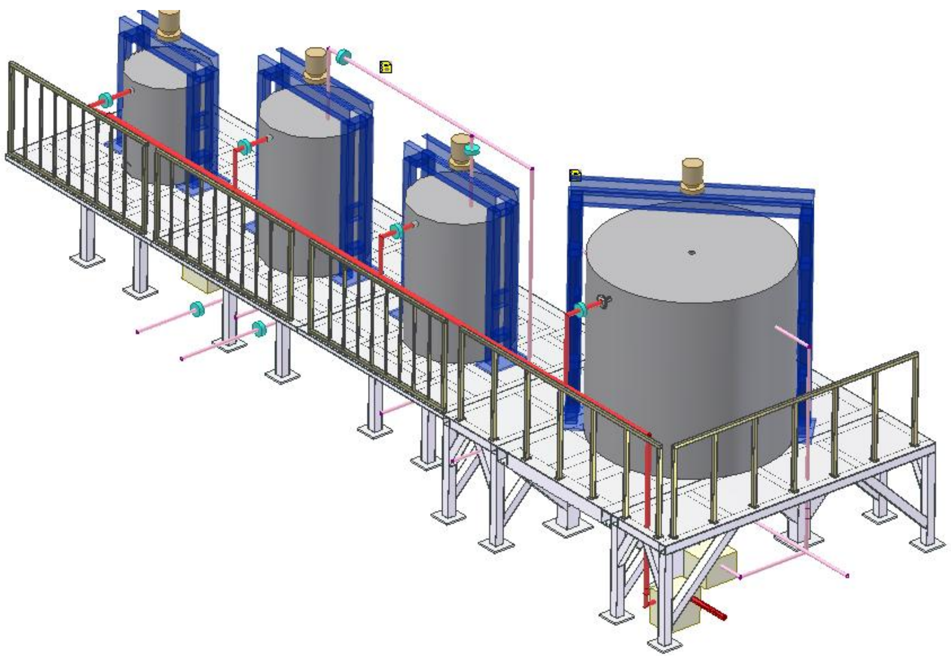


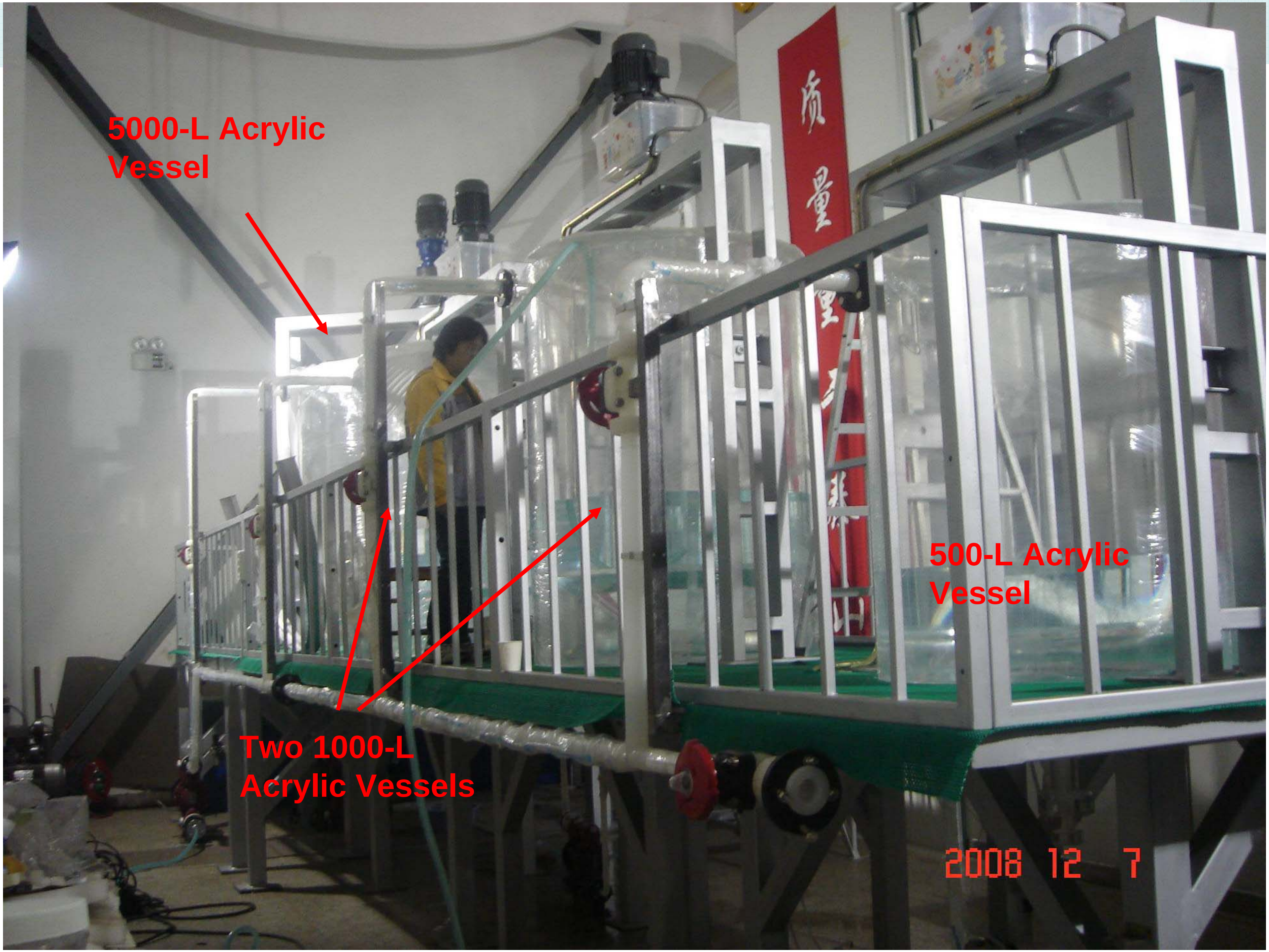
Lifting structure testing

Stick the ESR® high reflectivity film on to the acrylic panel

Gd-LS

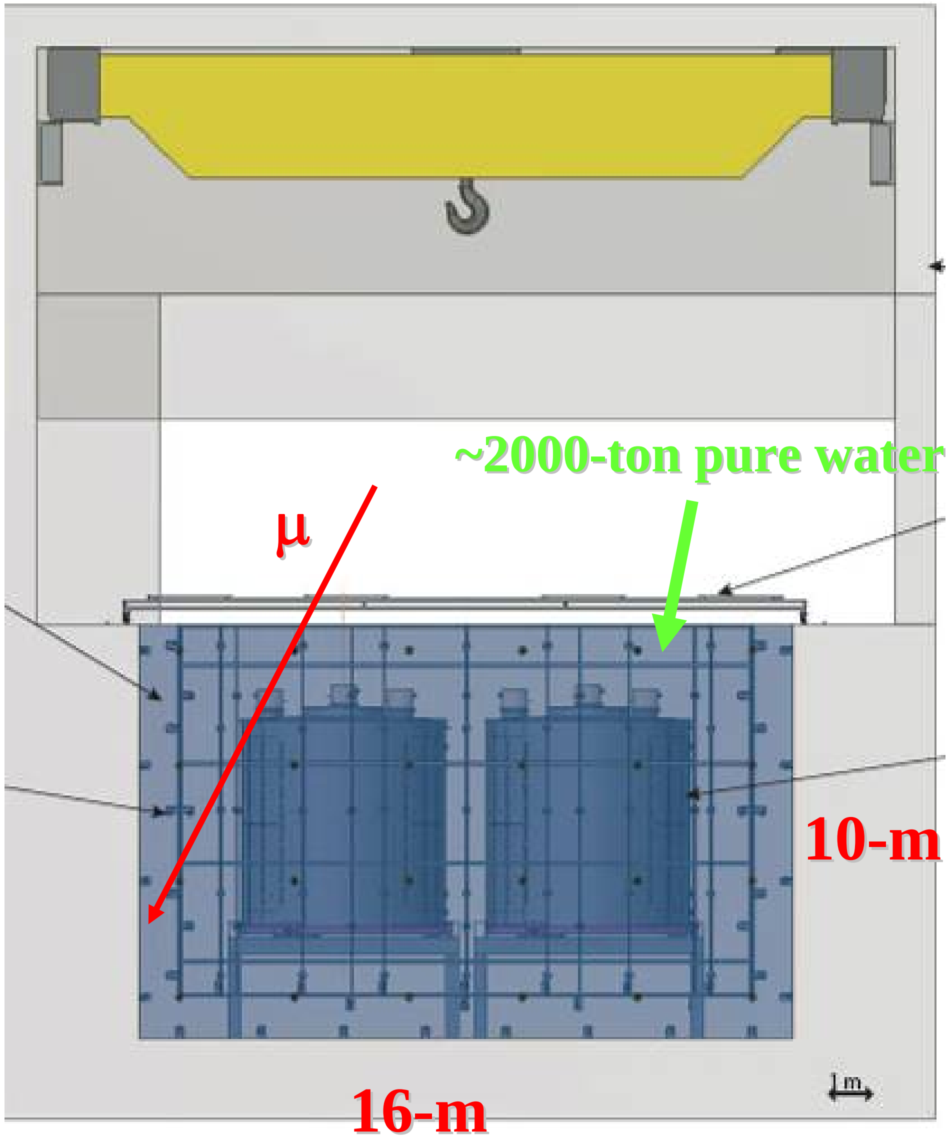
- Daya Bay experiment will use 200 ton normal liquid scintillator and 200 ton 0.1% gadolinium-loaded liquid scintillator (Gd-LS) .
  Gd-TMHA + LAB + 3g/L PPO + 15mg/L bis-MSB
- The stability of the Gd-LS has been tested for two years with IHEP prototype detector (half ton Gd-LS) and high temperature aging tests in lab.
- All Gd-LS will be produced as one batch on-site, to ensure IDENTICAL detectors. The mixing equipment has been tested at IHEP and will be re-assembled on-site.
- 4-ton production is going on.



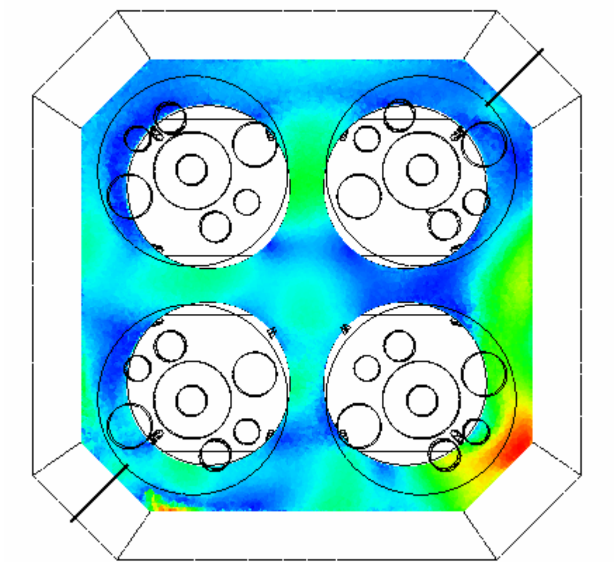


5000-L Acrylic Vessel
质量
500-L Acrylic Vessel
Two 1000-L Acrylic Vessels
2008 12 7

Muon System

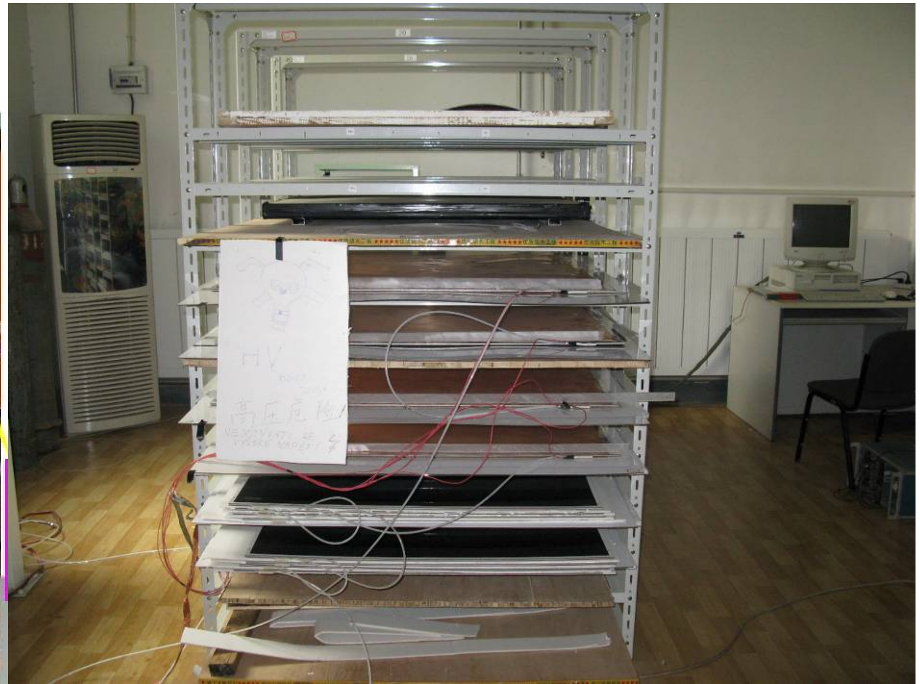


- 2.5m thick water shielding to AD in all directions.
- Two-layer water cherenkov
  - Cross check
  - Measuring fast-neutron backgrounds
- Covered w/ 4-layer RPC on top.
- The combined muon efficiency ~ 99.5%.



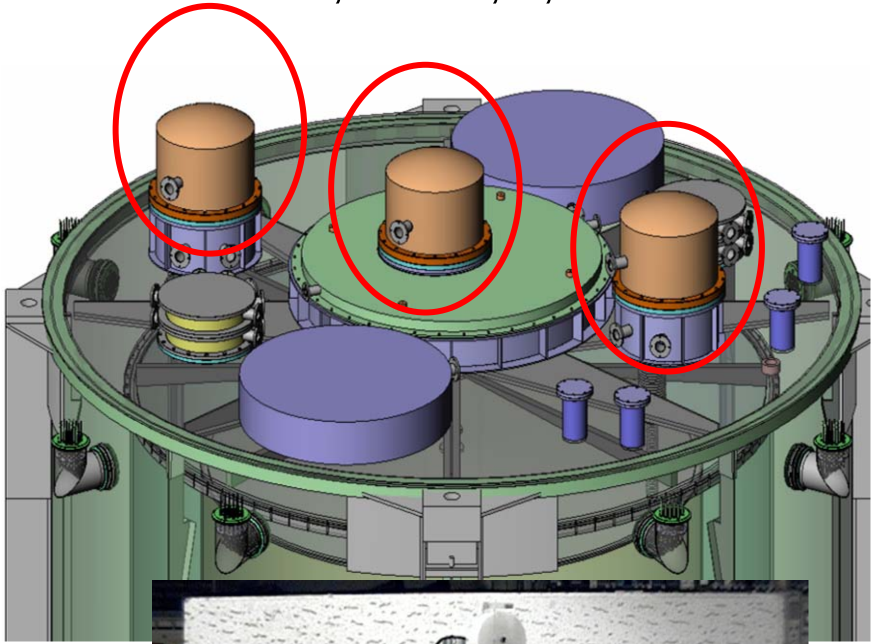
RPC Assembly

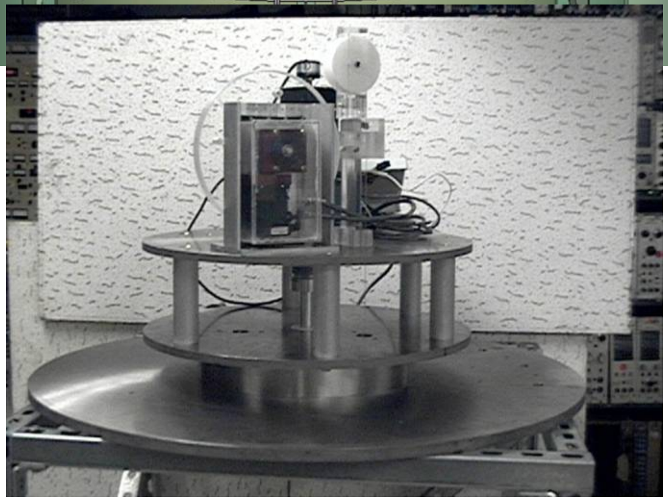
RPC module delivering table, which can lift the module to the height on module rack. Gas system is behind the module rack.

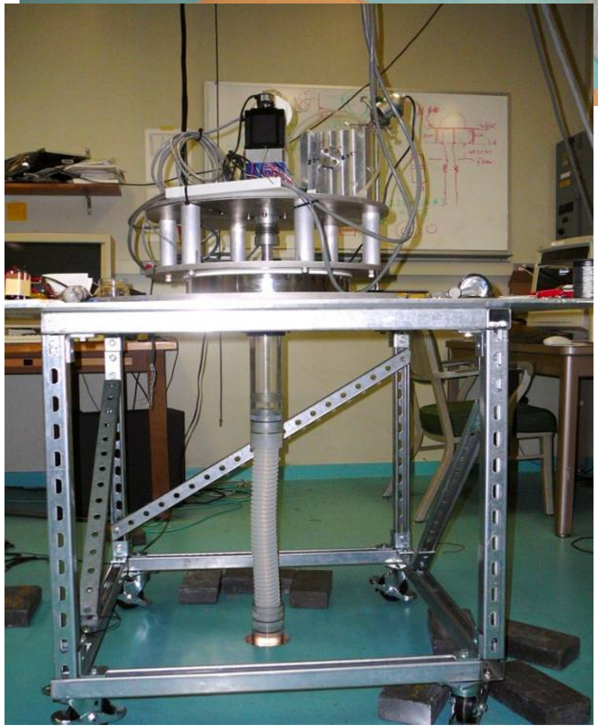


Calibration System

- Assembly at Caltech
- Ge-68, Co-60, n, LED

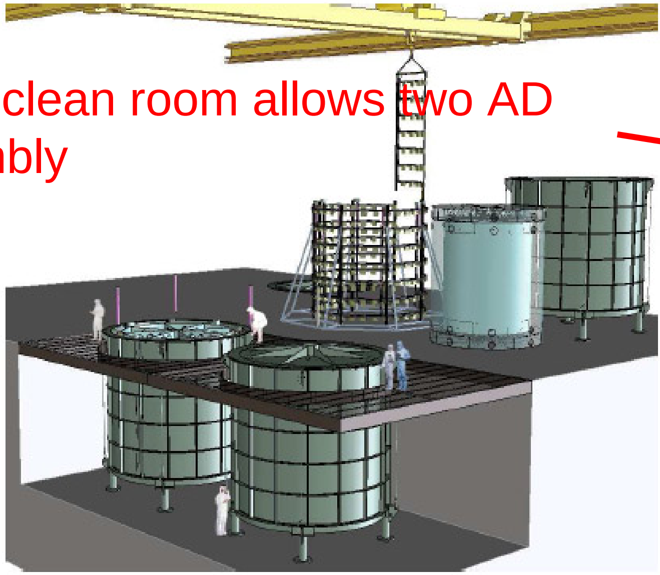






Civil Construction

Large clean room allows two AD assembly

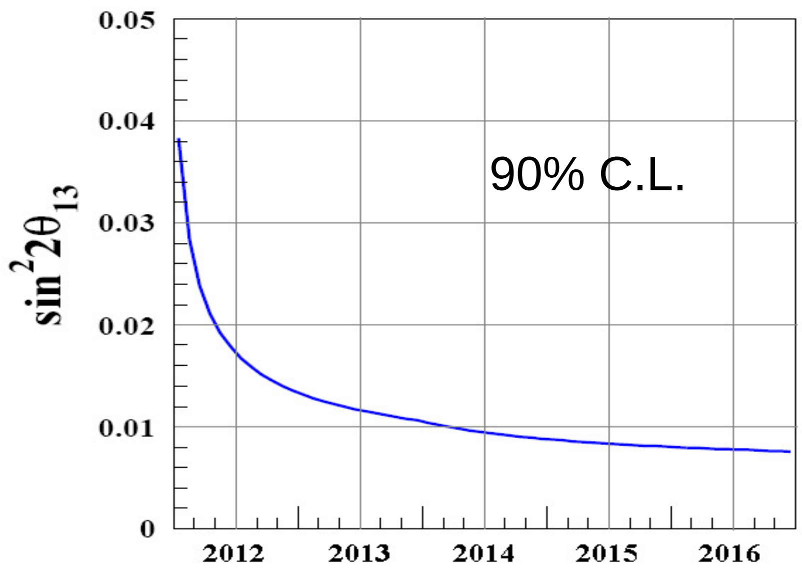


Civil Construction

Tentative Schedule

- October 2007, Ground Breaking
- March 2009, Surface Assembly Building Occupancy
  - ⇨ Antineutrino detector (AD) test assembly
- Summer 2009, Daya Bay Near Hall Occupancy
- Fall 2009, the first AD complete, Dry-run test starts
- Summer 2010, Daya Bay Near Hall Ready for Data
- Summer 2011, Far Hall Ready for Data

- Three years' data taking reach full sensitivity.



Thanks!