The Daya Bay Reactor Neutrino Experiment

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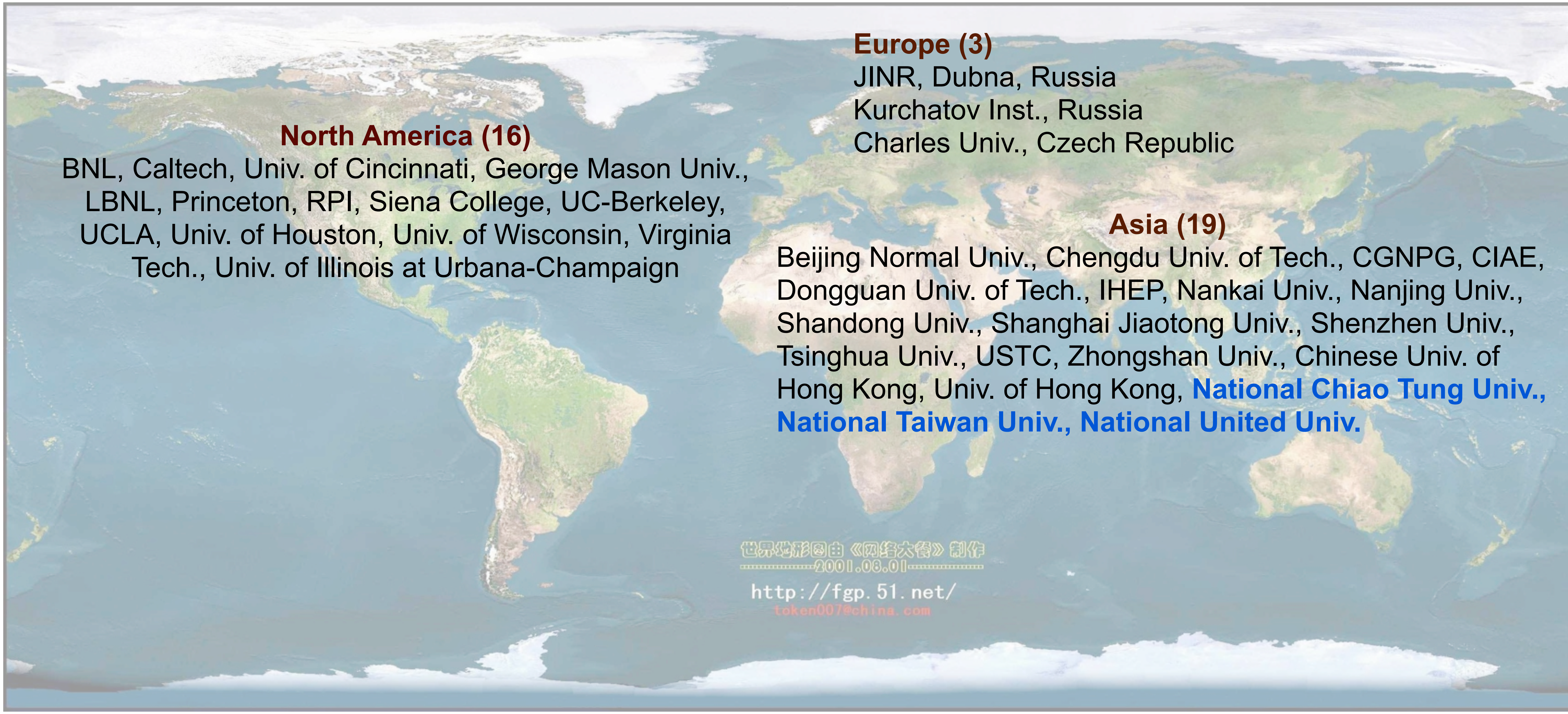
Daya Bay Collaborators



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JINR, Dubna, Russia
Kurchatov Inst., Russia
Charles Univ., Czech Republic

North America (16)
BNL, Caltech, Univ. of Cincinnati, George Mason Univ., LBNL, Princeton, RPI, Siena College, UC-Berkeley, UCLA, Univ. of Houston, Univ. of Wisconsin, Virginia Tech., Univ. of Illinois at Urbana-Champaign

Asia (19)
Beijing Normal Univ., Chengdu Univ. of Tech., CGNPG, CIAE, Dongguan Univ. of Tech., IHEP, Nankai Univ., Nanjing Univ., Shandong Univ., Shanghai Jiaotong Univ., Shenzhen Univ., Tsinghua Univ., USTC, Zhongshan Univ., Chinese Univ. of Hong Kong, Univ. of Hong Kong, **National Chiao Tung Univ., National Taiwan Univ., National United Univ.**

Outline

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- Design Considerations
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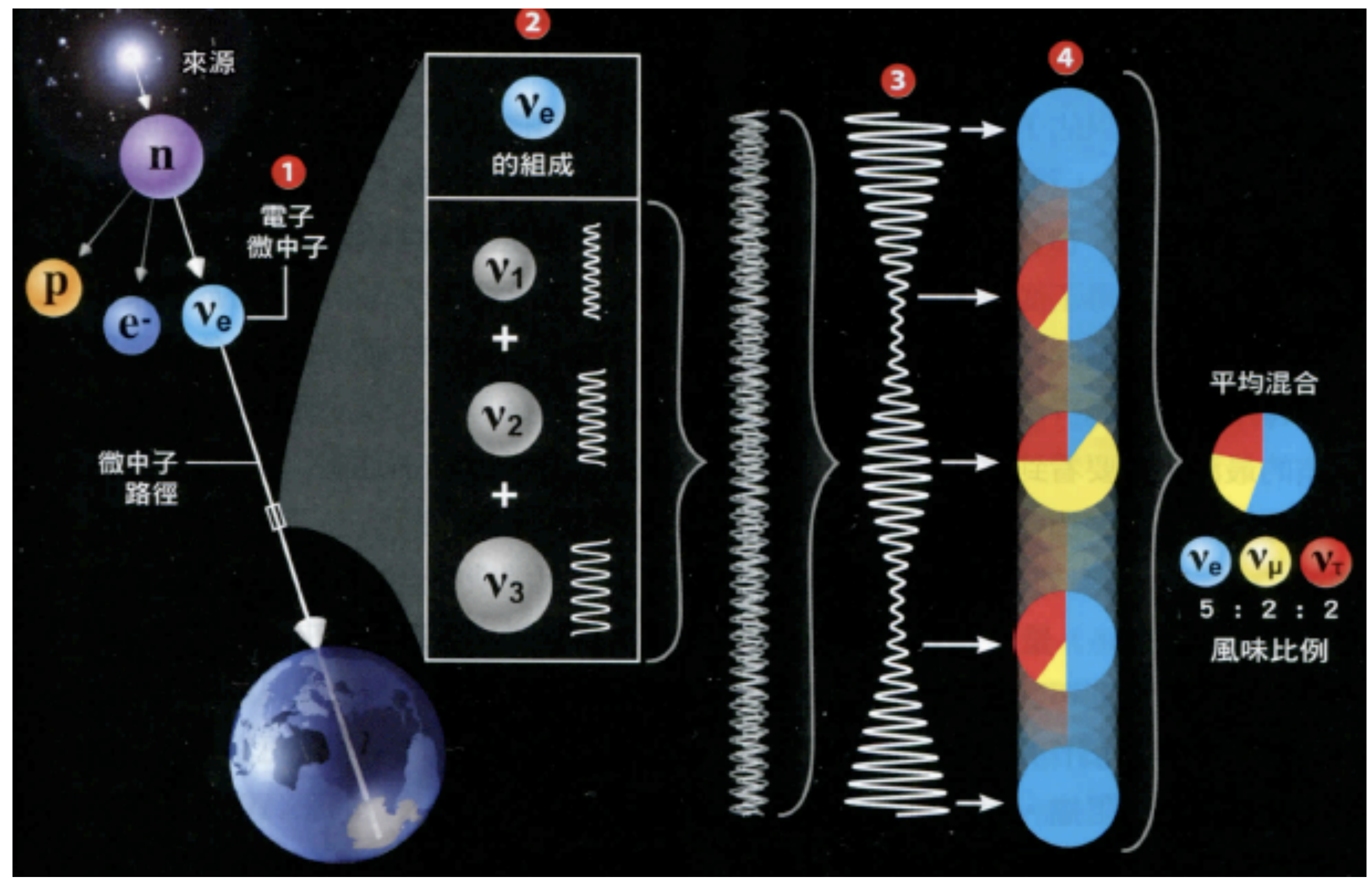
A brief introduction to neutrino oscillation

Бруно Понтекорво

Bruno Pontecorvo -

First suggestion that neutrinos can "mix" (change from one type to another). This require massive neutrinos.



$$\nu_\alpha = U \nu_i$$

ν_α : weak eigenstates; α = e, μ, τ.
ν_i : mass eigenstates; i = 1, 2, 3.
U : 3x3 PMNS unitary matrix.

A brief introduction to neutrino oscillation

PMNS(Pontecorvo–Maki–Nakagawa–Sakat) Matrix U =

$$\underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Solar, reactor}} \underbrace{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{12} \end{pmatrix}}_{\text{reactor and accelerator}} \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\text{Atmospheric, accelerator}} \underbrace{\begin{pmatrix} e^{i\delta_1} & 0 & 0 \\ 0 & e^{i\delta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{0\nu\beta\beta}$$

$\theta_{12} \sim 32°$

$\theta_{23} \sim 45°$

Motivation

The role of θ_{13} :

1. Complete basic model of neutrino oscillations.

PMNS(Pontecorvo–Maki–Nakagawa–Sakat) Matrix U =

$$\underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Solar, reactor}} \underbrace{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{12} \end{pmatrix}}_{\text{reactor and accelerator}} \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\text{Atmospheric, accelerator}} \underbrace{\begin{pmatrix} e^{i\delta_1} & 0 & 0 \\ 0 & e^{i\delta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{0\nu\beta\beta}$$

2. If θ_{13} between 0.01~0.03 => determine CP phase δ_{CP}.

3. The mass hierarchy depends on the size of θ_{13}.

※ Our goal: to determine the unknown neutrino mixing angle θ_{13} with a sensitivity of 0.01 or better in $sin^2 2\theta_{13}$.

Neutrino Detection

Inverse beta decay reaction

- **Prompt-delayed coincidence**

$$\overline{\nu_e} + p \rightarrow e^+ + n$$

Neutrino Detection

Inverse beta decay reaction

- **Prompt-delayed coincidence**

Prompt signal

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

$$\overline{\nu_e} + p \rightarrow e^+ + n$$

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

Delayed signal

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

Neutrino Detection

Inverse beta decay reaction

- **Prompt-delayed coincidence**

Prompt signal

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

$$\overline{\nu_e} + p \rightarrow e^+ + n$$

~28 μs

$$n + Gd \rightarrow Gd^* \rightarrow Gd + \gamma(8\ MeV)$$ 49,000 b

Delayed signal

$$n + p \rightarrow D + \gamma\ (2.2\ MeV)$$ 0.3 b

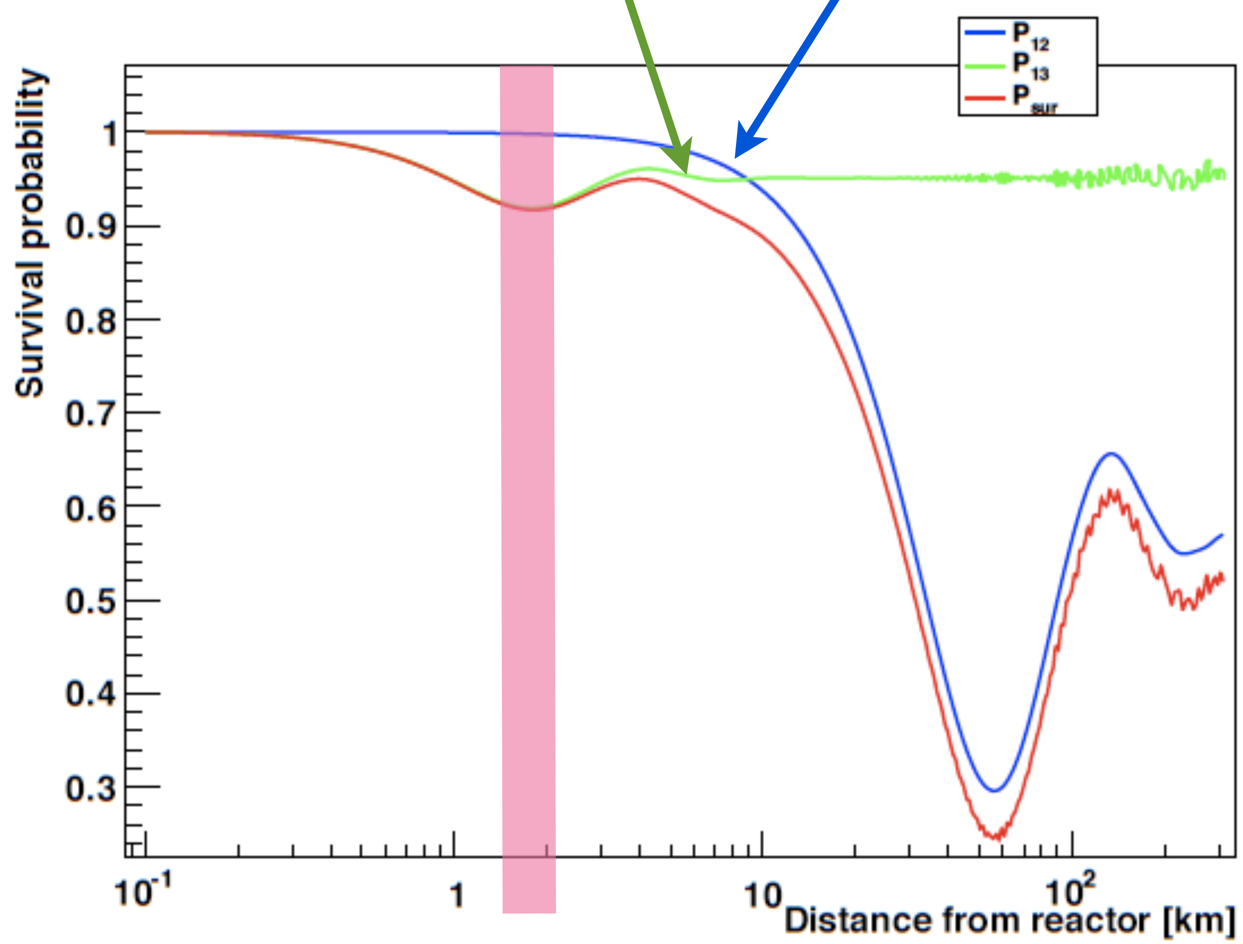
- **Why Gd?**
  - neutron capture delayed signal is far from natural radioactivity.
  - Large capture cross section
  - Short capture time

A powerful neutrino source

- By 2011, the 2nd most powerful complexes in the world (17.4 GW_{th}).
- Adjacent to mountains, easy to construct labs with sufficient overburden to suppress cosmogenic backgrounds

Optimized Baseline

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



$E_\nu \in [1.8, 8]$ MeV

$\sin^2 2\theta_{13} = 0.1$

$\theta_{12} = 34^\circ$

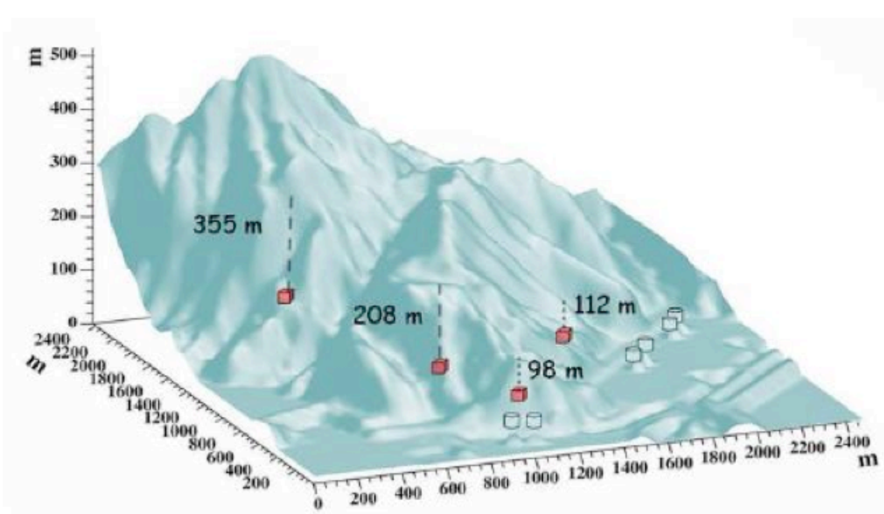
$\Delta m^2_{13} = 2.5 \times 10^{-3}$ eV^2

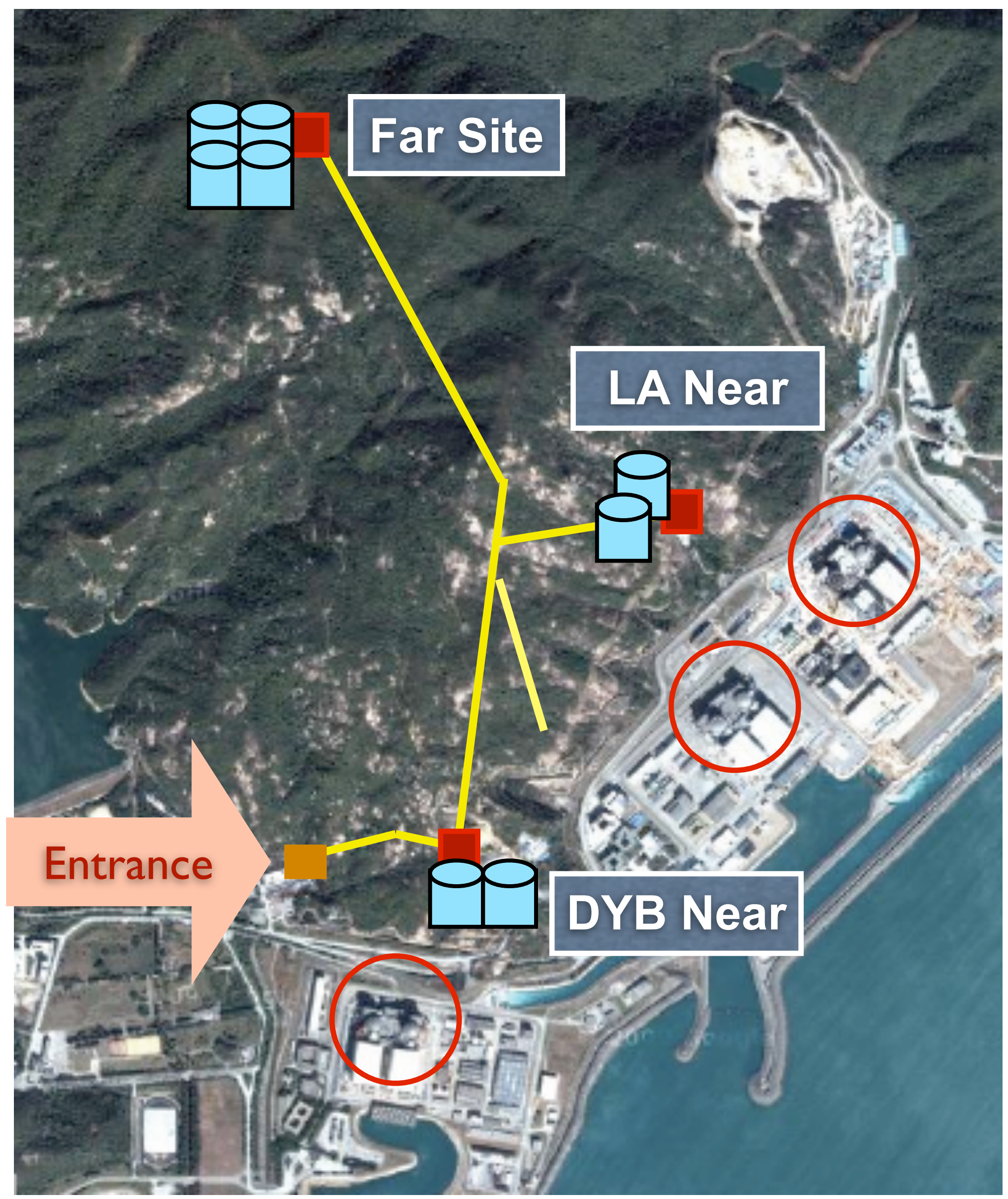
$\Delta m^2_{21} = 7.9 \times 10^{-5}$ eV^2

Experimental Layout

- **Three experimental halls** Multiple detectors at each site
- **Movable Detector** All detectors are filled with the same batch of Gd-LS

Far: 80 ton
1600m to LA, 1900m to DYB
Overburden: 355m
Muon rate: 0.04Hz/m²





LA: 40 ton
Baseline: 500m
Overburden: 112m
Muon rate: 0.73Hz/m²

DYB: 40 ton
Baseline: 360m
Overburden: 98m
Muon rate: 1.2Hz/m²

Method of Measurement

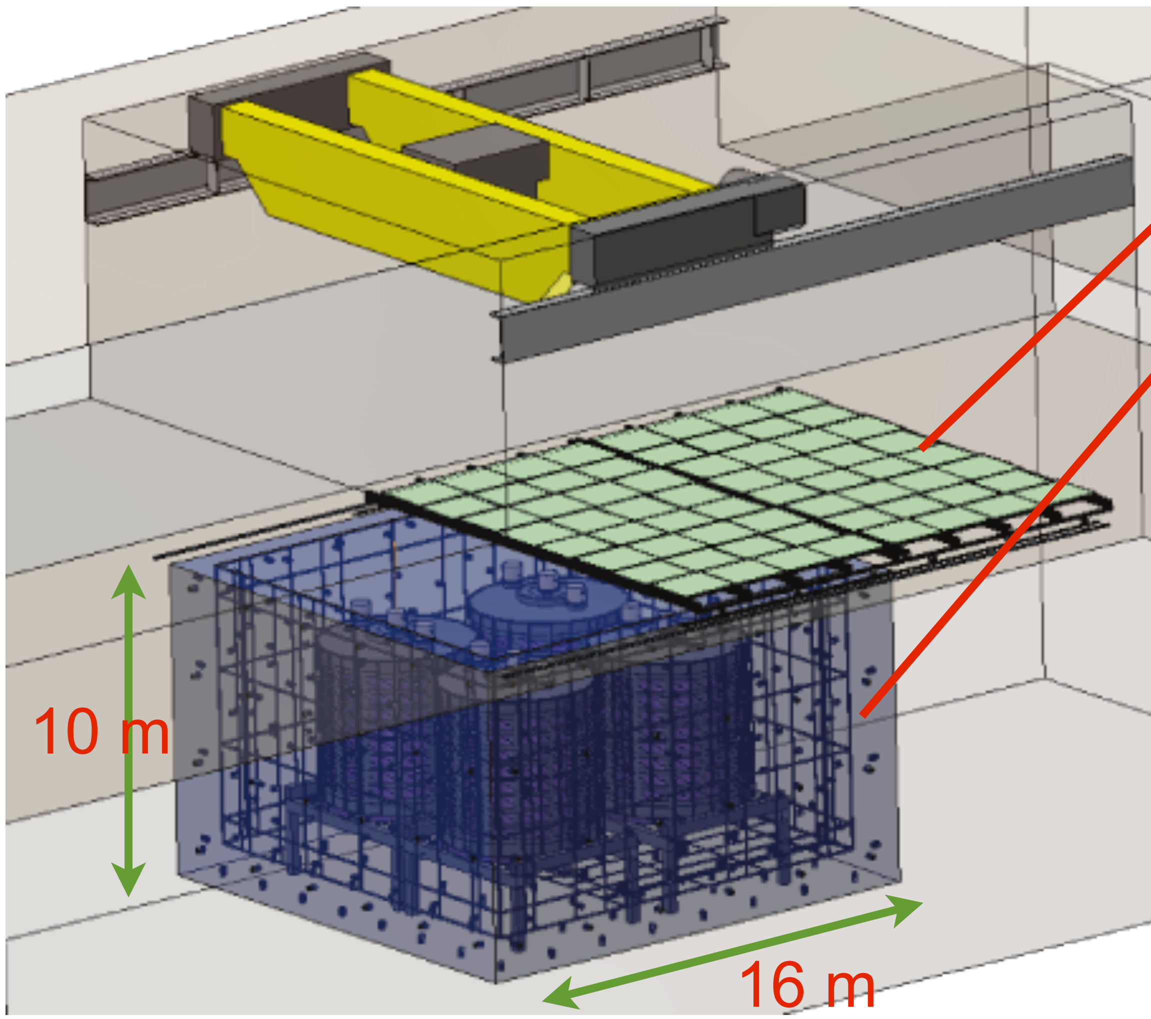
- The detection concept: sample the reactor anti-neutrino flux in the near and far locations, and look for evidence of disappearance.

$$\frac{N_{\rm f}}{N_{\rm n}} = \left(\frac{N_{\rm p,f}}{N_{\rm p,n}}\right)\left(\frac{L_{\rm n}}{L_{\rm f}}\right)^2\left(\frac{\epsilon_{\rm f}}{\epsilon_{\rm n}}\right)\left[\frac{P_{\rm sur}(E,L_{\rm f})}{P_{\rm sur}(E,L_{\rm n})}\right]$$

- Measured ratio of rates
- Detector mass ratio (number of protons) – comes from mass measurements
- Detector efficiency ratio – comes from calibration systems
- $\mathrm{Sin}^2(2\theta_{13})$

Daya Bay Detectors

Far site experimental hall



Muon Veto System

- 4-layer RPCs
- Water Cherenkov Detector
  - 2.5m thick water to shield backgrounds from neutrons and γ's from rock
  - 2-zone (Inner water and Outer water) separated by reflective Tyvek.

Anti-neutrino detector

※ The water detector + the RPC roof achieve a very high muon veto efficiency:

$$\varepsilon_{combined} > (99.5 \pm 0.25)\%$$

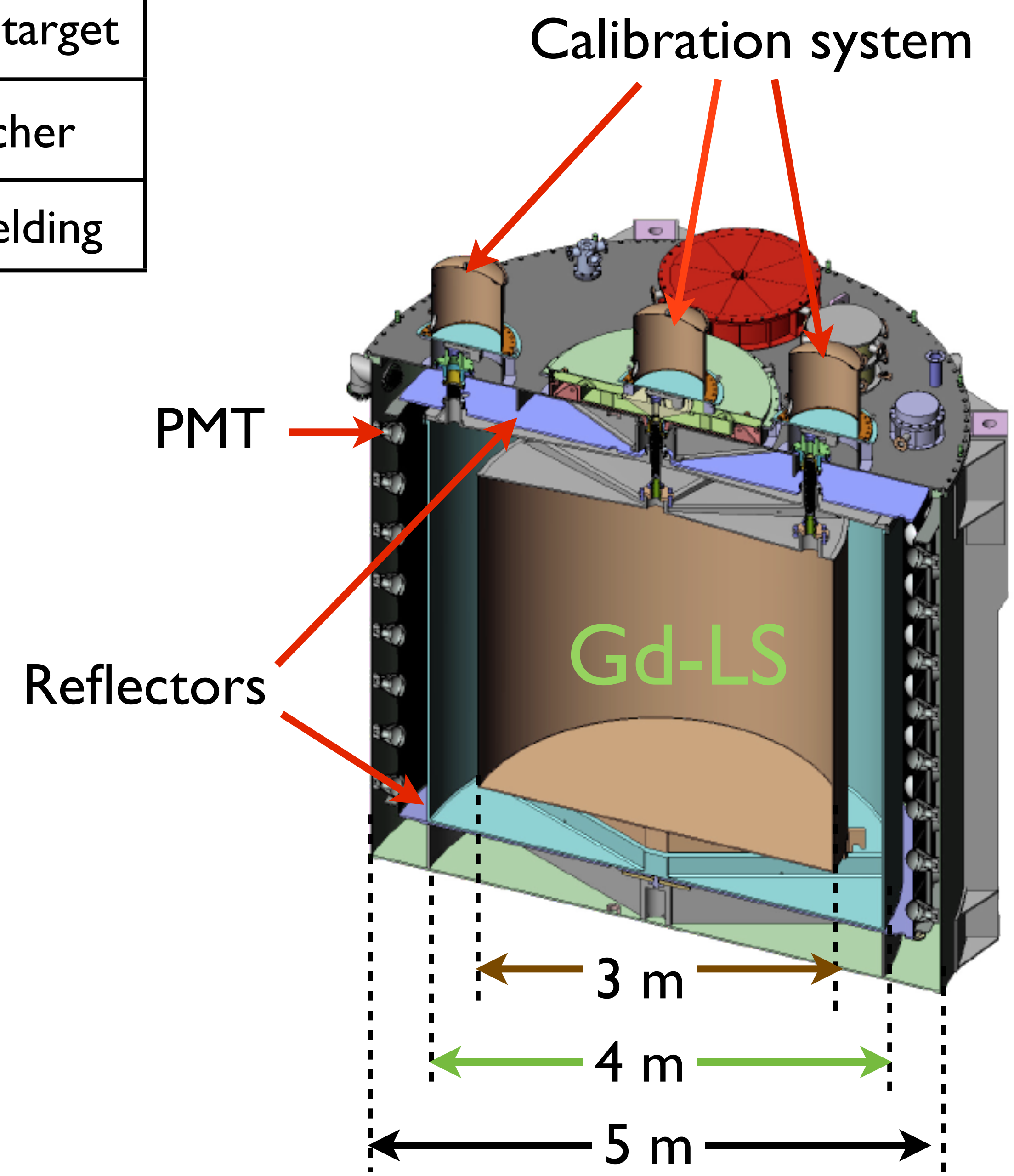
Anti-neutrino Detectors

- 3 Zone detector:

Zone	Liquid	Purpose
Inner AV (3m)	Gd-doped LS	Anti-neutrino target
Outer AV (4m)	LS	Gamma catcher
SSV (5m)	Mineral Oil	Radiation shielding

- 192 8" PMTs in mineral oil buffer.
- 20 ton Gd doped LS
- Top/bottom reflectors.
- Automatic calibration units (ACU).

AV: Acrylic Vessel
SSV : Stainless steel vessel
LS : Liquid Scintillator



Gd-doped Liquid Scintillator

- **Requirements on Gd-LS**
  - Long stability (experiment running time: 3-5 years)
  - Good transparency, attenuation length > 10 m
  - High light yield (50% Anthracene)
  - Low radioactivity, compatible with acrylic

- **Daya Bay Gd-LS recipe**
  - Solvent: LAB (Linear Alkyl Benzene)
  - Fluor: PPO (3g/L), bis-MSB (15 mg/L)
  - 0.1% Gd

Gd-doped Liquid Scintillator

PMT

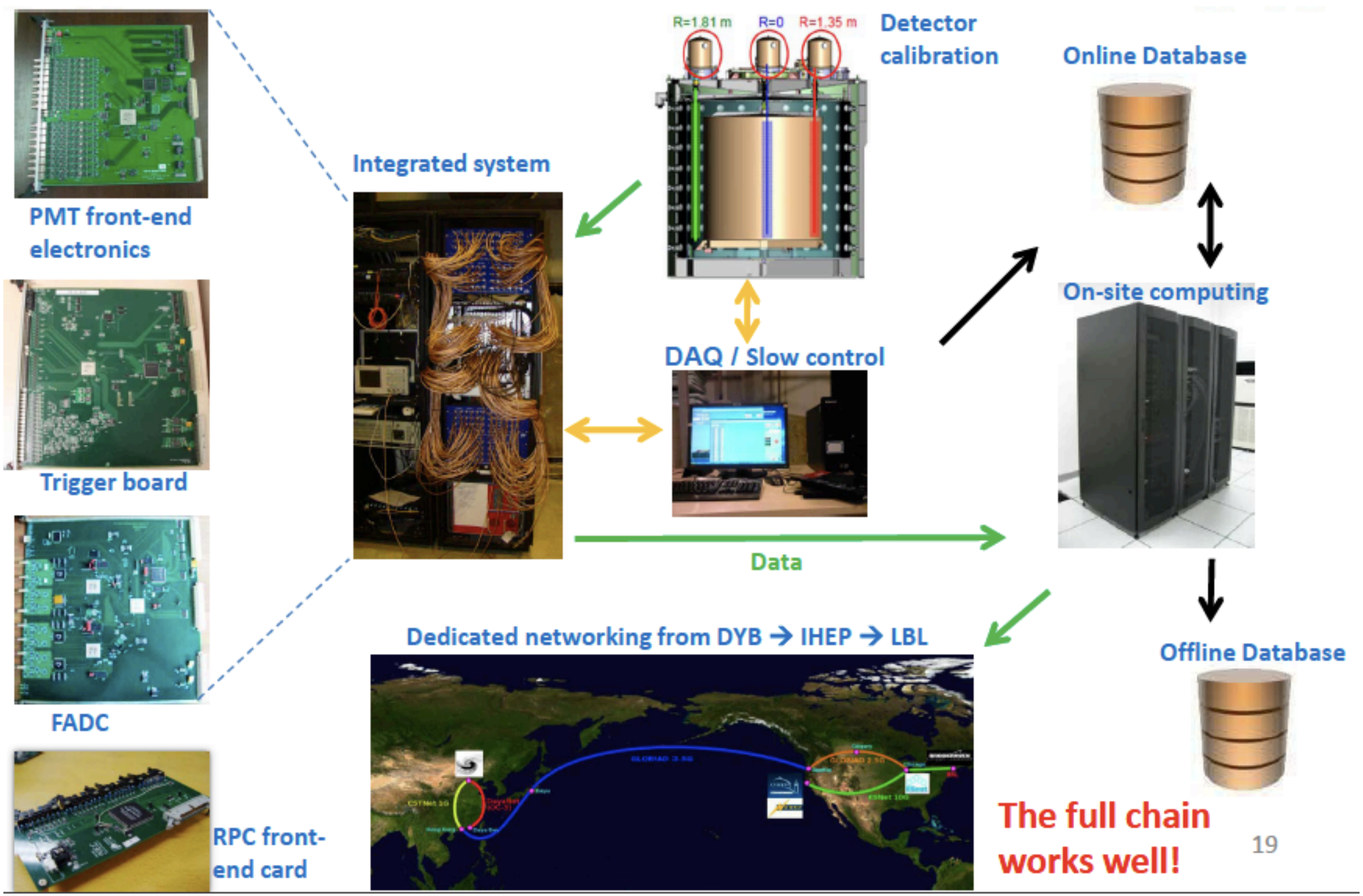
Photomultiplier Tube (PMT)

- 192 8” PMTs in each AD; 960 8” PMTs in water pool (total)
- Hamamatsu R5912 low radioactive glass PMT

High Voltage System

- CAEN SY1527LC Mainframe
- 1934A HV modules

Electronics, Trigger, DAQ & Offline



Design Considerations

- **Identical near and far detectors** to cancel reactor-related errors
- **Multiple modules** for reducing detector-related errors and cross checks
- **Three-zone detector modules** to reduce detector-related errors
- **Overburden and shielding** to reduce bakgrounds
- **Multiple muon detectors** for reducing background and cross checks
- **Movable detectors** for swapping

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

High statistics

- 17.4 GW NPP at Daya Bay, 80 ton target

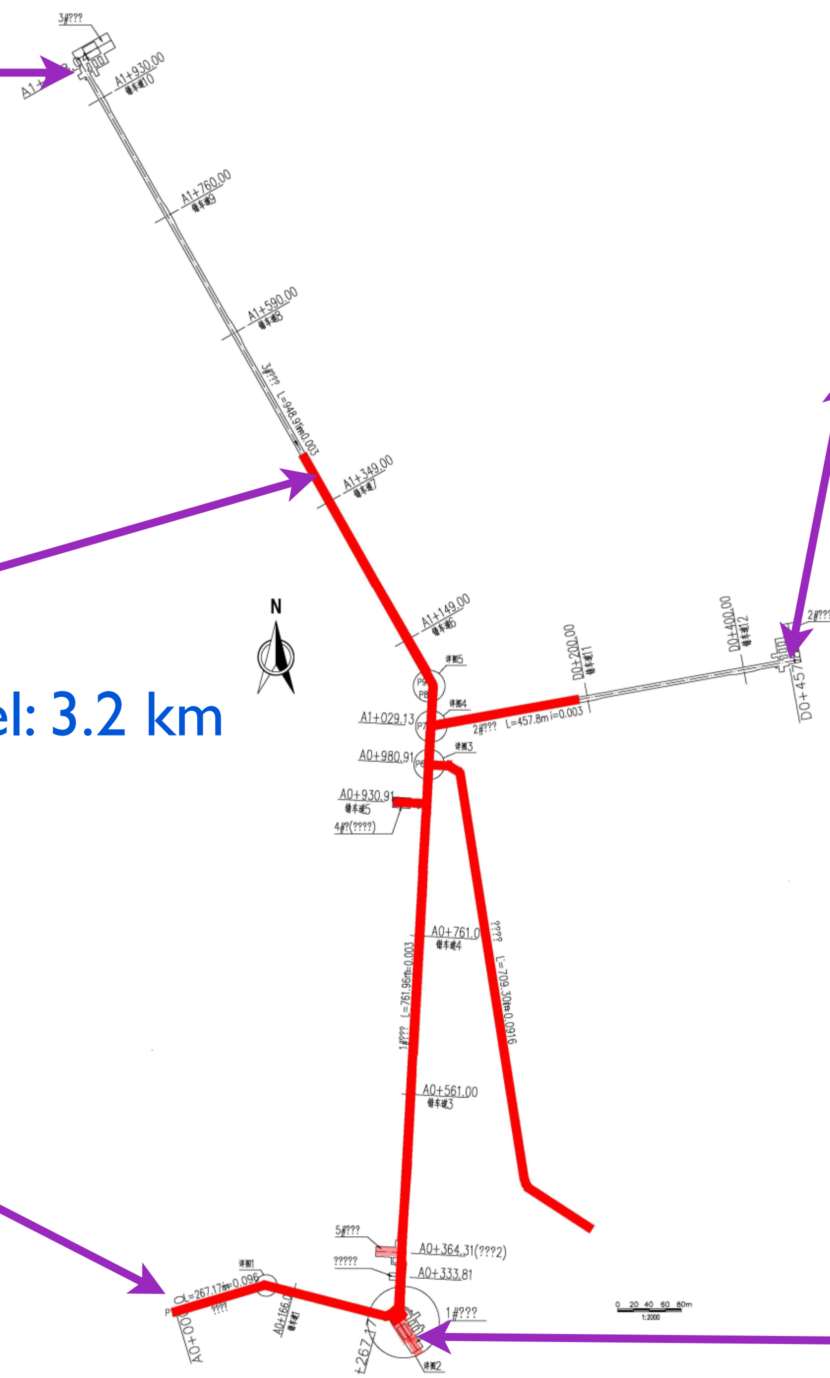
  → statistical error 0.2% in 3 years

Uncertainties	Past experiments	Daya Bay
Reactor power	~1%	Reduce to < 0.13%, Near/Far cancellation
Fission rate	~2%	
Spectrum	~0.3%	Near/Far cancellation
Backgrounds	1~3%	< 0.2% (correlated), < 0.1% (uncorrelated)
Target mass & H/C	1~2%	< 0.3%, filling tank with load cell
Efficiency	2~3%	< 0.2%, 3-zone detector

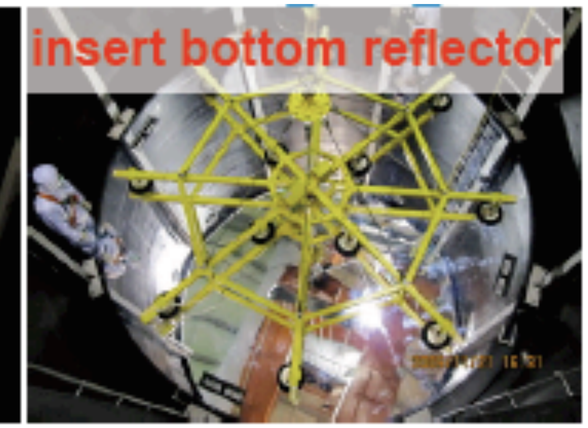
Status - civil

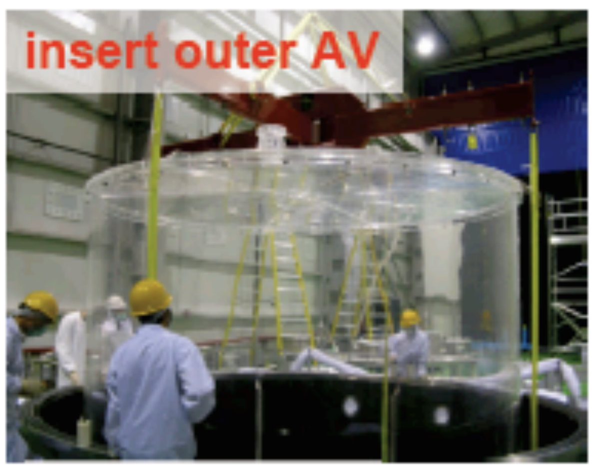
Tunnel: 3.2 km

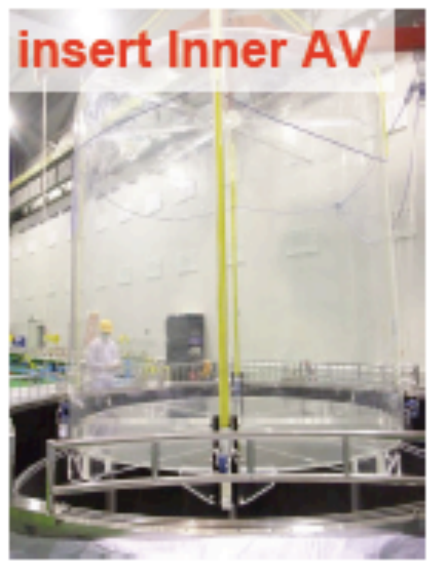
Surface assembly building

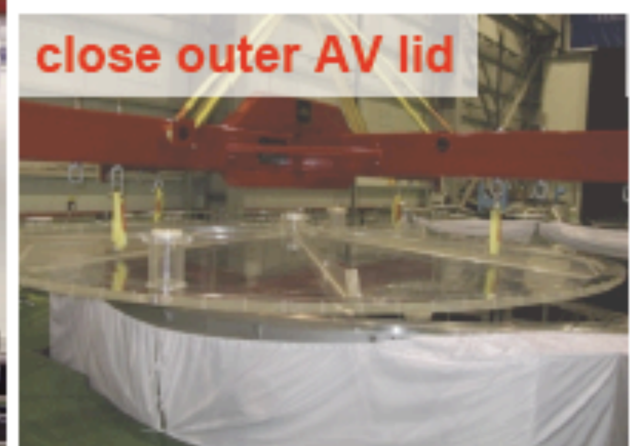


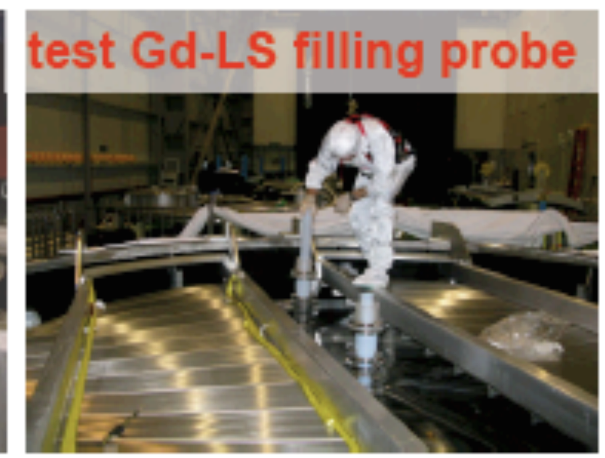
Status - Detector Assembly

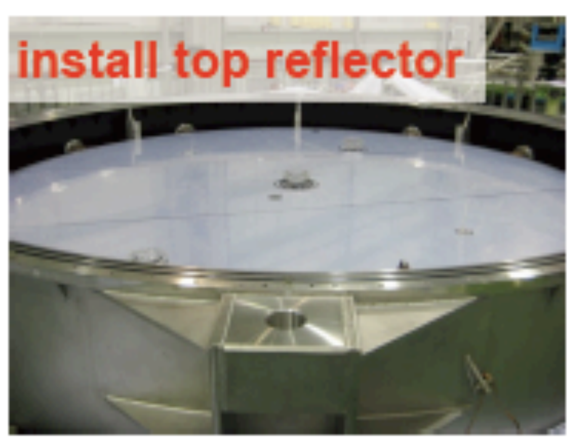












Schedule

- October 2007, Ground Breaking
- March 2009, Surface assembly building ready
- October 2010, first AD pair complete, Dry-Run tests finished
- October 2010, Daya Bay Near Hall Occupancy

◎ We are going to fill in the Gd-LS

◎ Daya Bay Hall ready by Fall 2011

◎ Ling Ao and Far Halls ready by Fall 2012

Thank you!