Daya Bay

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and
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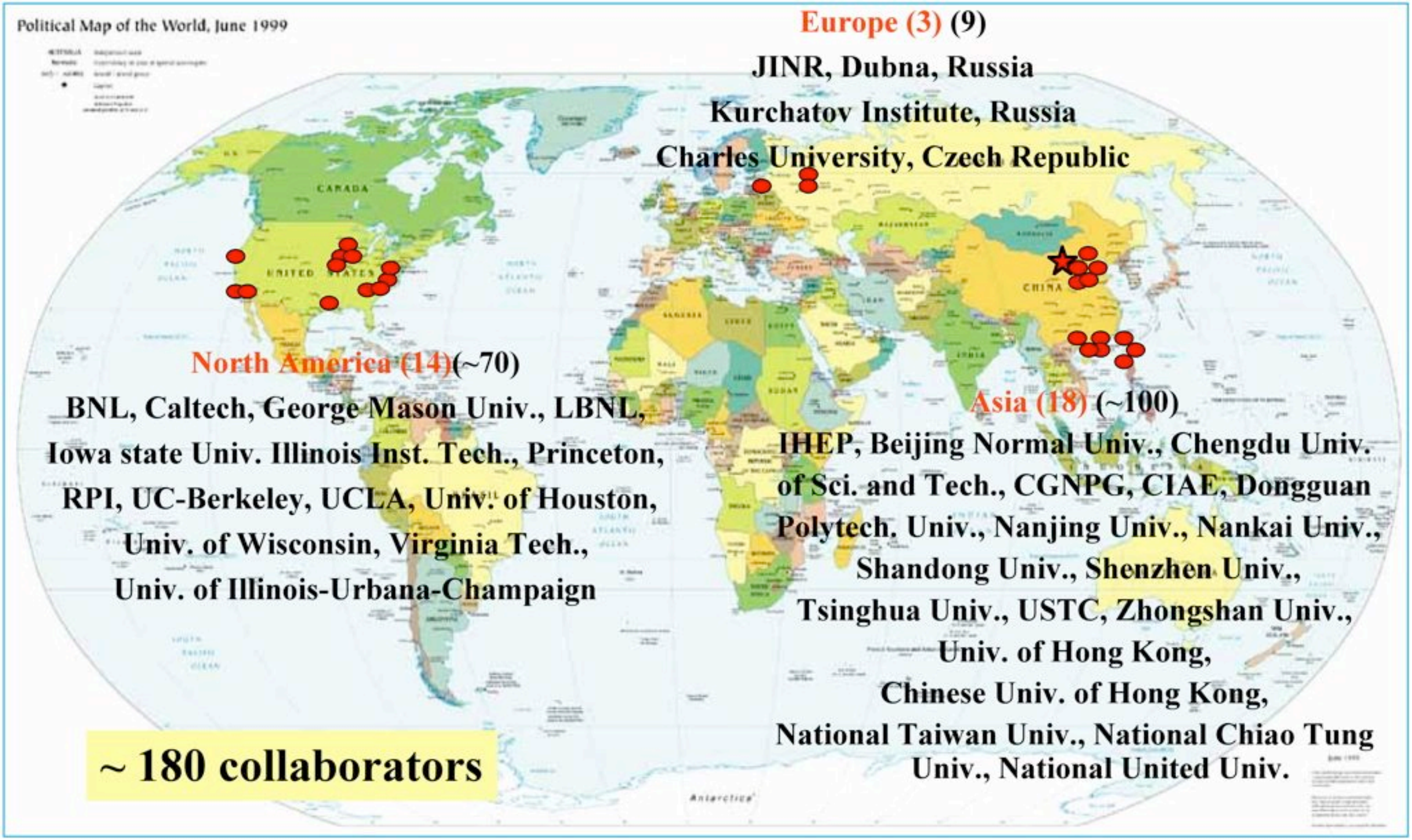
For
The Daya Bay Collaboration

GDR Neutrino at Universite Victor Segalen Bordeaux 2, France, 25 October, 2007

Daya Bay Collaboration

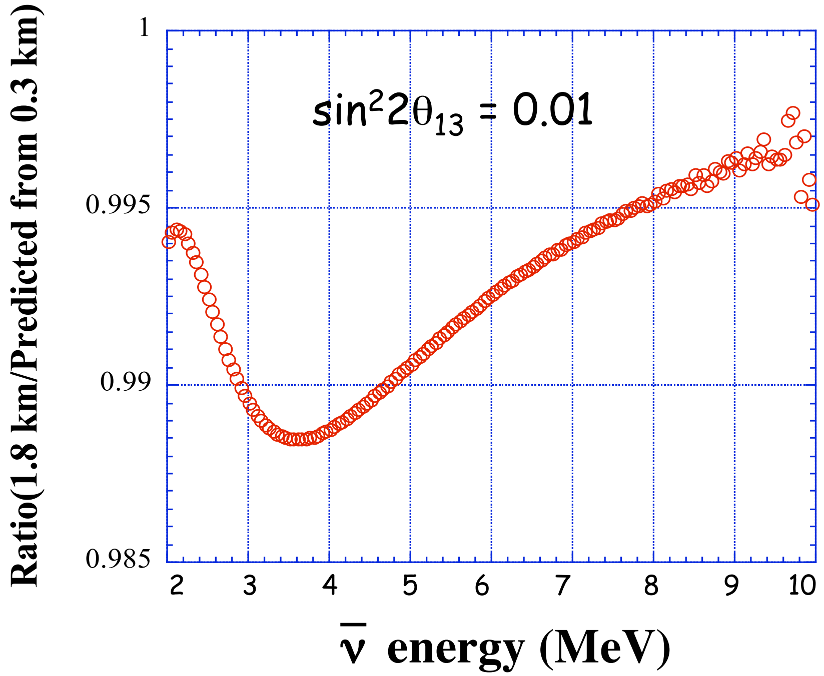



12-14 Jan, 2007 at HKU

Daya Bay: Goal And Approach

- Recommendation of the APS Neutrino Study Group:
  - *An expeditiously deployed multidetector reactor experiment with sensitivity to $\bar{\nu}_e$ disappearance down to $\sin^2 2\theta_{13} = 0.01$, an order of magnitude below present limits.*
- 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 Reach A Precision of 0.01 in Daya Bay?

- **Increase statistics:**
  - Use powerful nuclear reactors
  - Utilize large target mass, hence large detectors
  - Long running time
- **Suppress background:**
  - Go deep underground to gain overburden for reducing cosmogenic background
  - Use active shield around the target
- **Reduce systematic uncertainties:**
  - Reactor-related:
    - Near and far detectors to minimize reactor-related errors
    - Optimize baseline for best sensitivity and smaller residual reactor-related errors
  - Detector-related:
    - Use "Identical" pairs of detectors to do ***relative*** measurement
    - Comprehensive program in calibration/monitoring of detectors
    - Interchange near and far detectors (optional)


55 km
DAYA WAN
MIRS BAY
DEEP BAY
TOLO HARBOUR
SHENZHEN
HONG KONG
KOWLOON
YANTIAN
FUTIAN
LUOHU
BAO'AN
NANSHAN
LO WU
FANLING
TAI PO
SHA TIN
TSUEN WAN
TUEN MUN
YUEN LONG
TIN SHUI WAI
SAI KUNG
TSEUNG KWAN O
MA ON SHAN
TAI MO SHAN
TUNG CHUNG
Lantau Island
LANTAU PEAK
VICTORIA PEAK
Hong Kong Island
Aberdeen
Stanley
Lamma Island
Dapeng
Nan'ao
QINIANG SHAN
Gangkou Liedao
Xi Zhou
Chi Zhou
Dalajia
Dasanmen
Xiaosanmen Dao
Kuichong
Meisha
Yantian Port
Shatoujiao
Sha Tau Kok
Man Kam To
Crooked Island
Crescent Island
Double Island
Ping Chau
Shekou Port
Shekou
Mawan Port
Chiwan Port
Xiaochan Dao
Dachan Dao
Neilingding Dao
Lung Kwu Chau
Castle Peak
The Brothers
Ma Wan
Tsing Yi
Kwai Chung Port
Chek Lap Kok
Peng Chau
Hei Ling Chau
Mui Wo
Tai O
Shek Kwu Chau
Cheung Chau
Siu A Chau
Soko Islands
Tai A Chau
Niutou Dao
Guishan
Guishan Dao
Dazhi Zhou
Xiaozhi Zhou
Kau Sai Chau
Town Island
Jin Island
Basalt Island
Ninepin Group
Tung Lung Chau
Waglan Island
Po Toi Islands
Po Toi
Beaufort Island
Sung Kong
URMSTON ROAD
LANTAU CHANNEL
WEST LAMMA CHANNEL
EAST LAMMA CHANNEL
TATHONG CHANNEL
Boundary of Special Administrative Region
LEGEND
Railway
Main road
Secondary road
Built-up area / Cultivation
Airport / Major port
Power station
Peak (in metres)
Contours (vertical interval 200 metres with supplementary contour at 100 metres)
Sea depth in metres
Series AR/18/IRS
Edition 7 2002
Survey and Mapping Office, Lands Department
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The Daya Bay Nuclear Power Complex

- 12th most powerful in the world (11.6 GW_{th})
- One of the top five most powerful by 2011 (17.4 GW_{th})
- Adjacent to mountain, easy to construct tunnels to reach underground labs with sufficient overburden to suppress cosmic rays

Ling Ao NPP: 2 × 2.9 GW_{th}

Ling Ao II NPP: 2 × 2.9 GW_{th}
Ready by 2010-2011

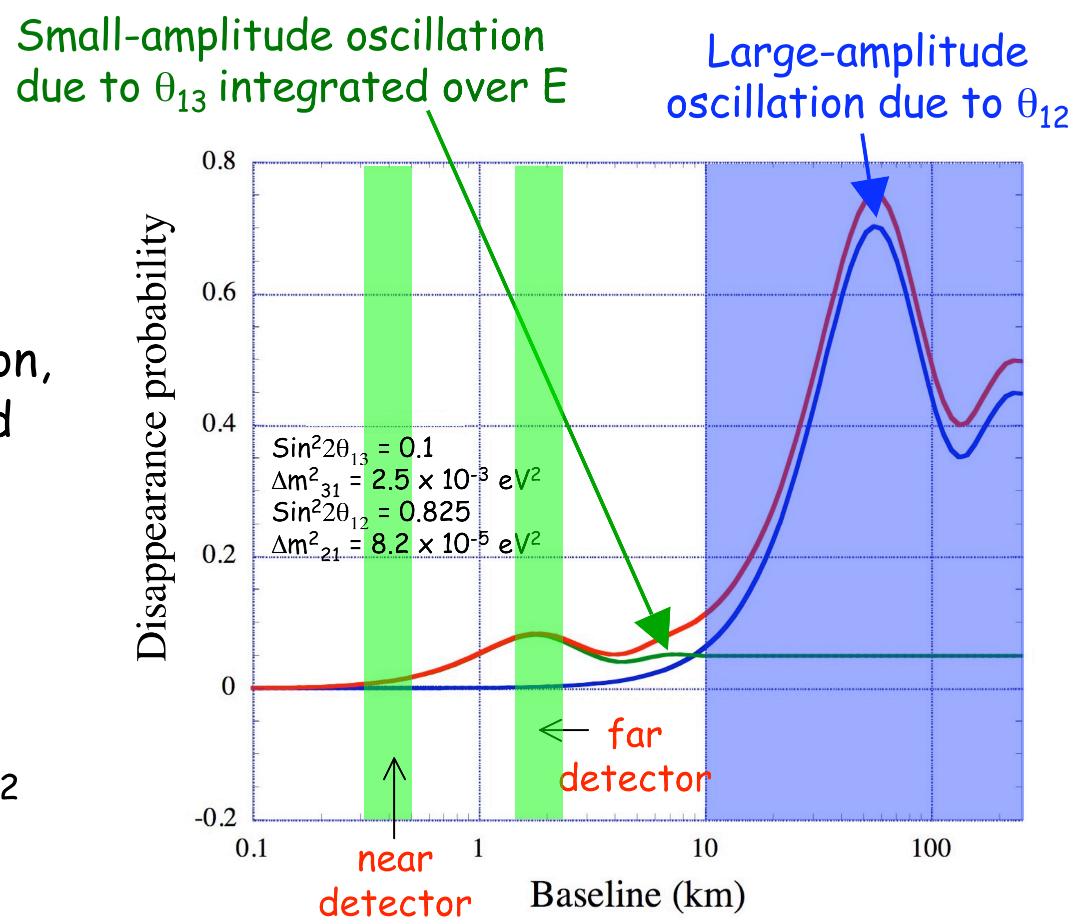
Where To Place The Detectors ?

- Since reactor $\bar{\nu}_e$ are low-energy, it is a disappearance experiment:

$$P(\bar{\nu}_e \to x) \approx \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E}\right)$$

- Place near detector(s) close to reactor(s) to measure flux and spectrum of $\bar{\nu}_e$ for normalization, hence reducing reactor-related systematic

- Position a far detector near the first oscillation maximum to get the highest sensitivity, and also be less affected by θ_{12}

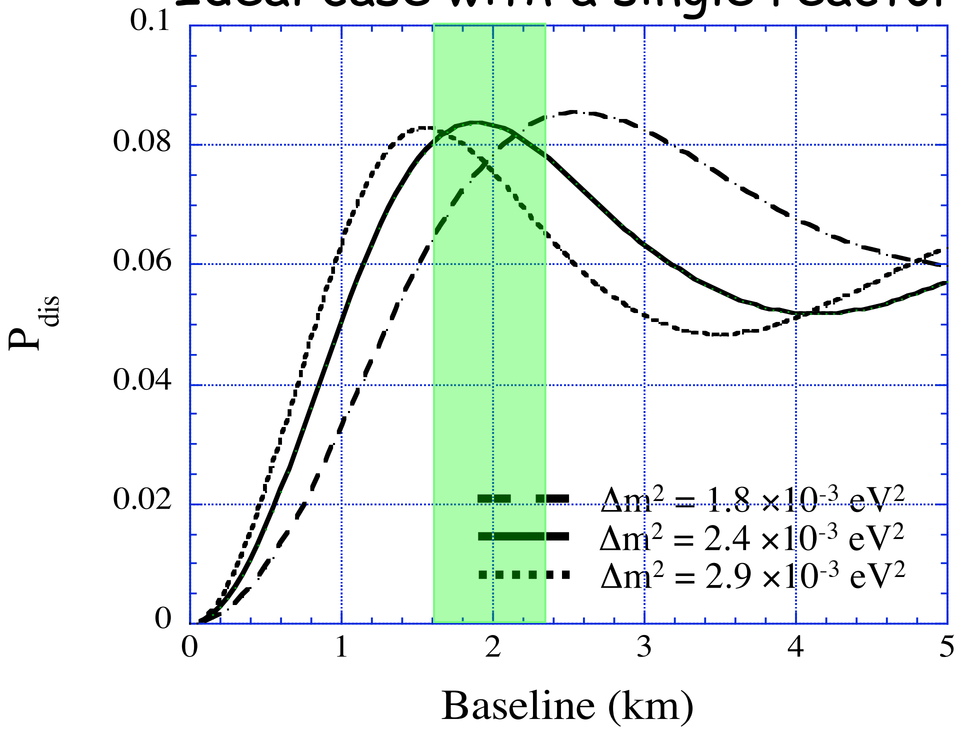


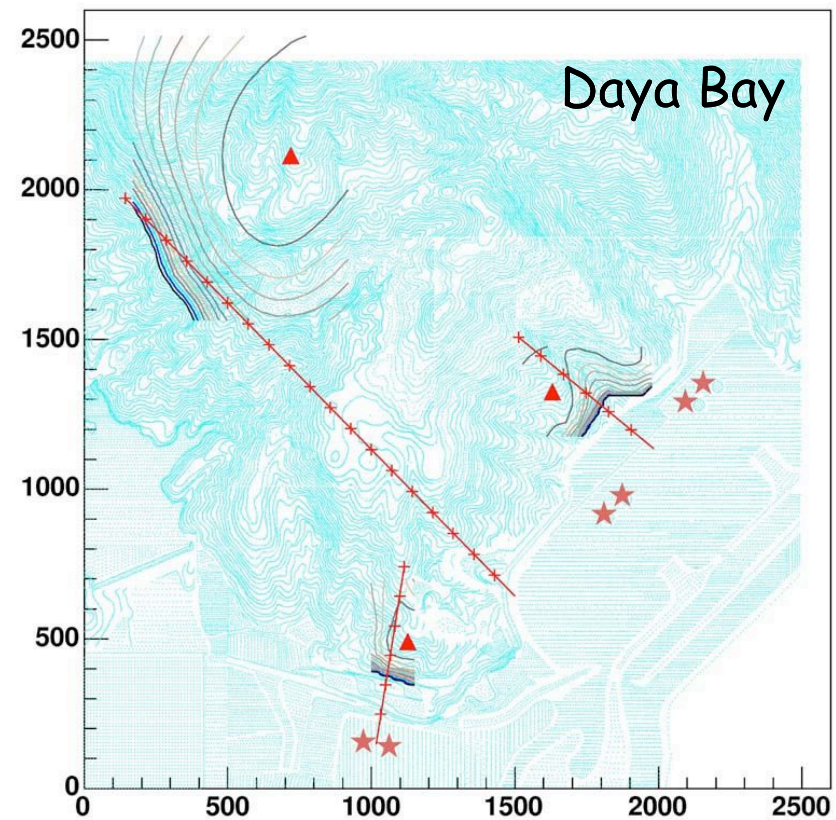
Baseline optimization and site selection

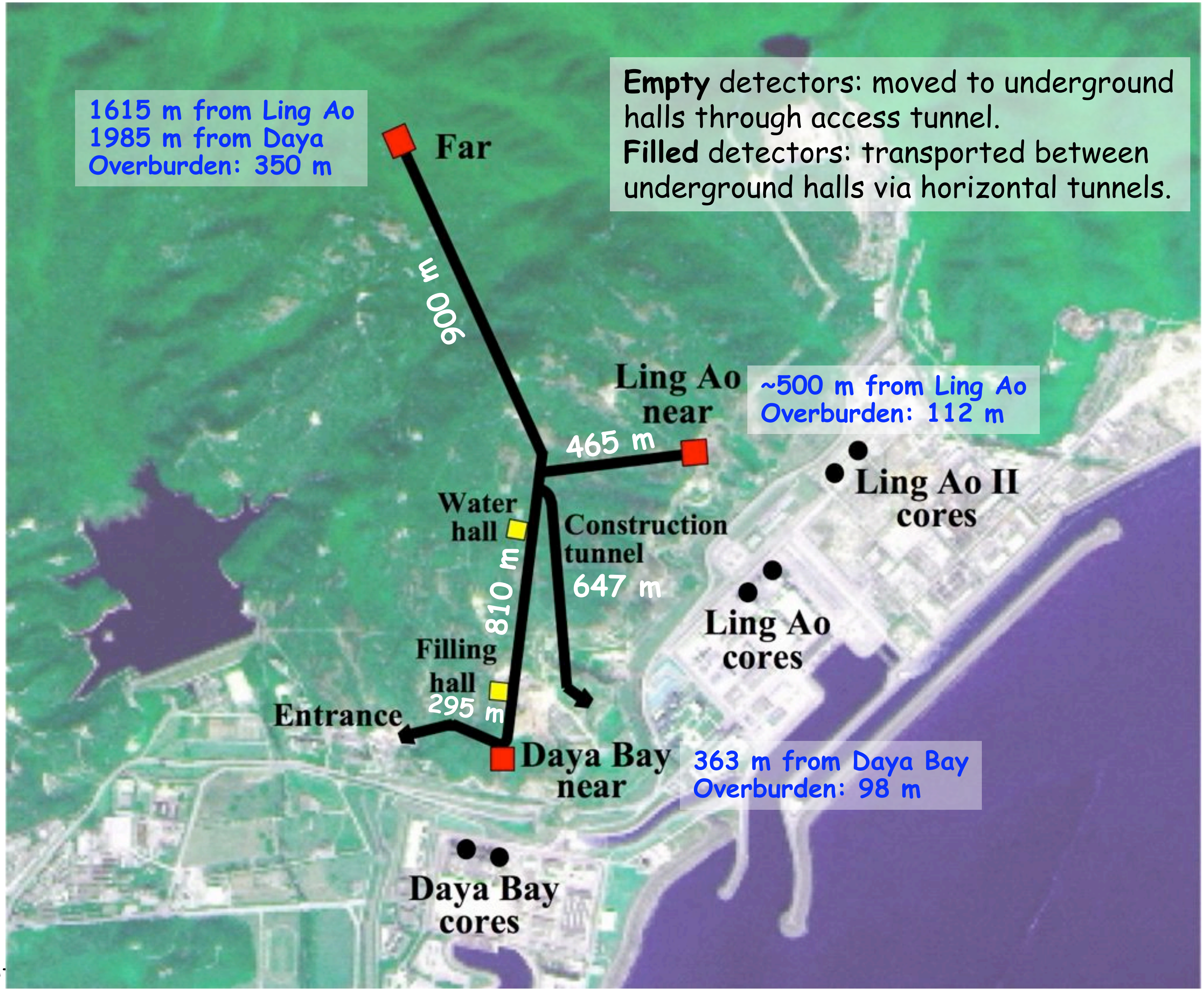
Inputs to the process:

- Flux and energy spectrum of reactor antineutrino
- Systematic uncertainties of reactors and detectors
- Ambient background and uncertainties
- Position-dependent rates and spectra of cosmogenic neutrons and ^9Li

Ideal case with a single reactor

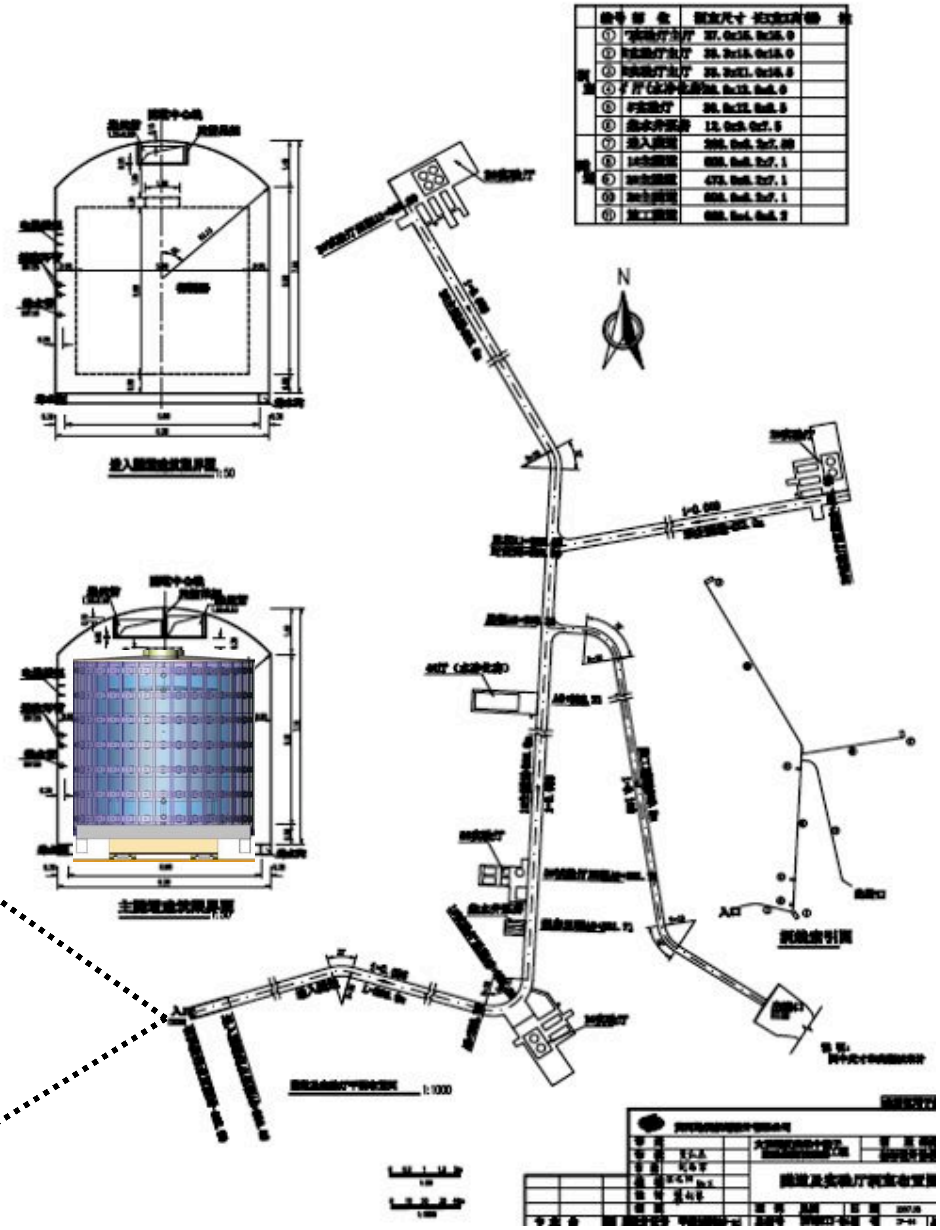





Empty detectors: moved to underground halls through access tunnel.
Filled detectors: transported between underground halls via horizontal tunnels.
1615 m from Ling Ao
1985 m from Daya
Overburden: 350 m
Far
900 m
Ling Ao near
~500 m from Ling Ao
Overburden: 112 m
465 m
Ling Ao II cores
Water hall
Construction tunnel
647 m
810 m
Ling Ao cores
Filling hall
295 m
Entrance
Daya Bay near
363 m from Daya Bay
Overburden: 98 m
Daya Bay cores

Civil Construction

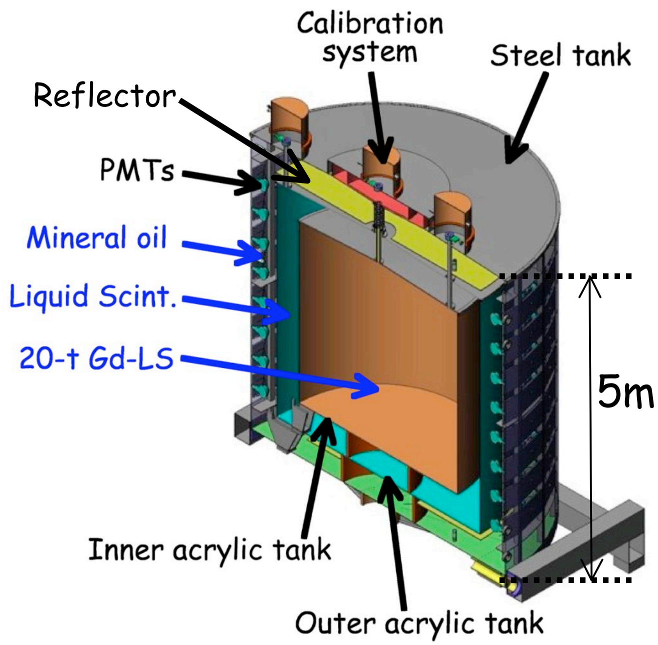
- Total tunnel length is about 3100 m
- Estimated total construction cost is ~$11 M
- Construction has begun this month
- First experimental hall is available after 13 months
- Construction time is ~22 months

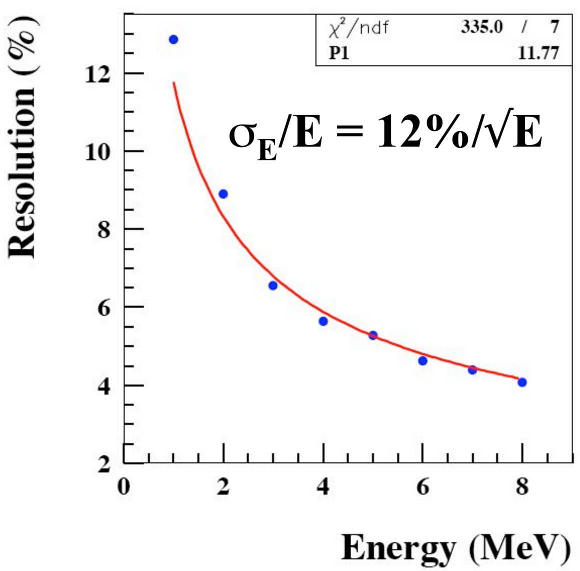


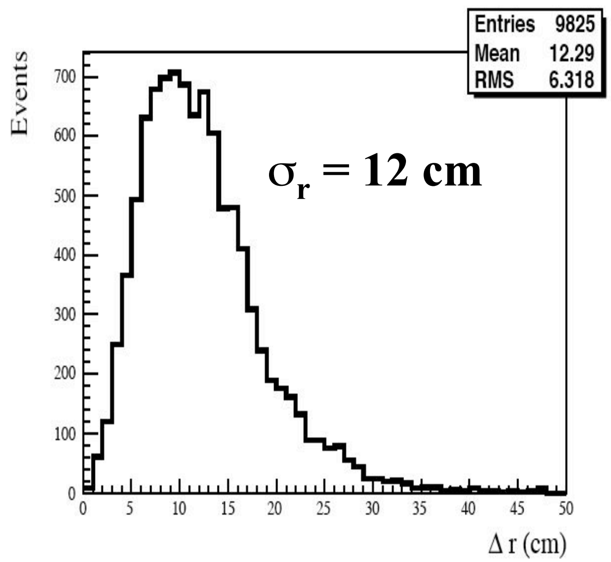
Antineutrino Detectors

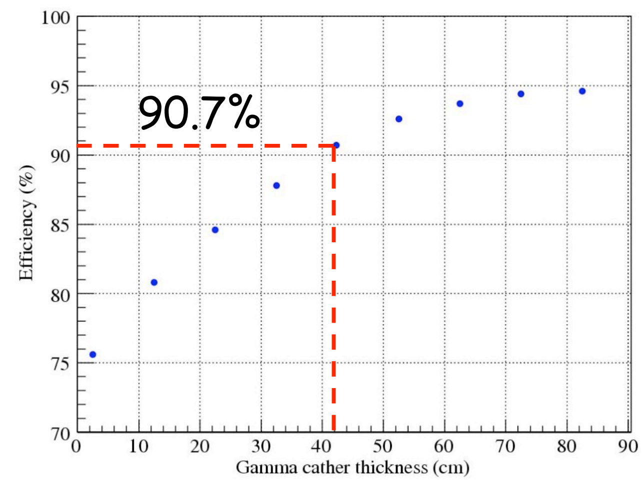
- Three-zone cylindrical detector design
  - Target: 20 T (0.1% Gd-LS), radius = 1.55 m
  - Gamma catcher: 20 T (LS), thickness = 0.42 m
  - Buffer : 40 T (mineral oil) , thickness = 0.48 m
- Low-background 8" PMT: 192
- Reflectors at top and bottom
- Photocathode coverage:

  5.6 % → 12% (with reflectors)





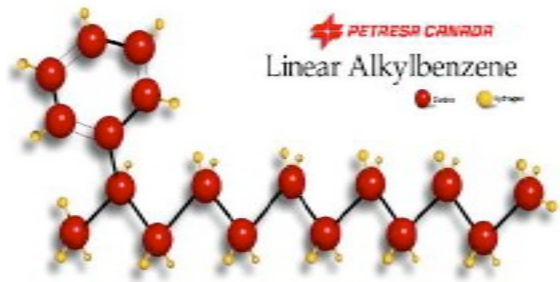




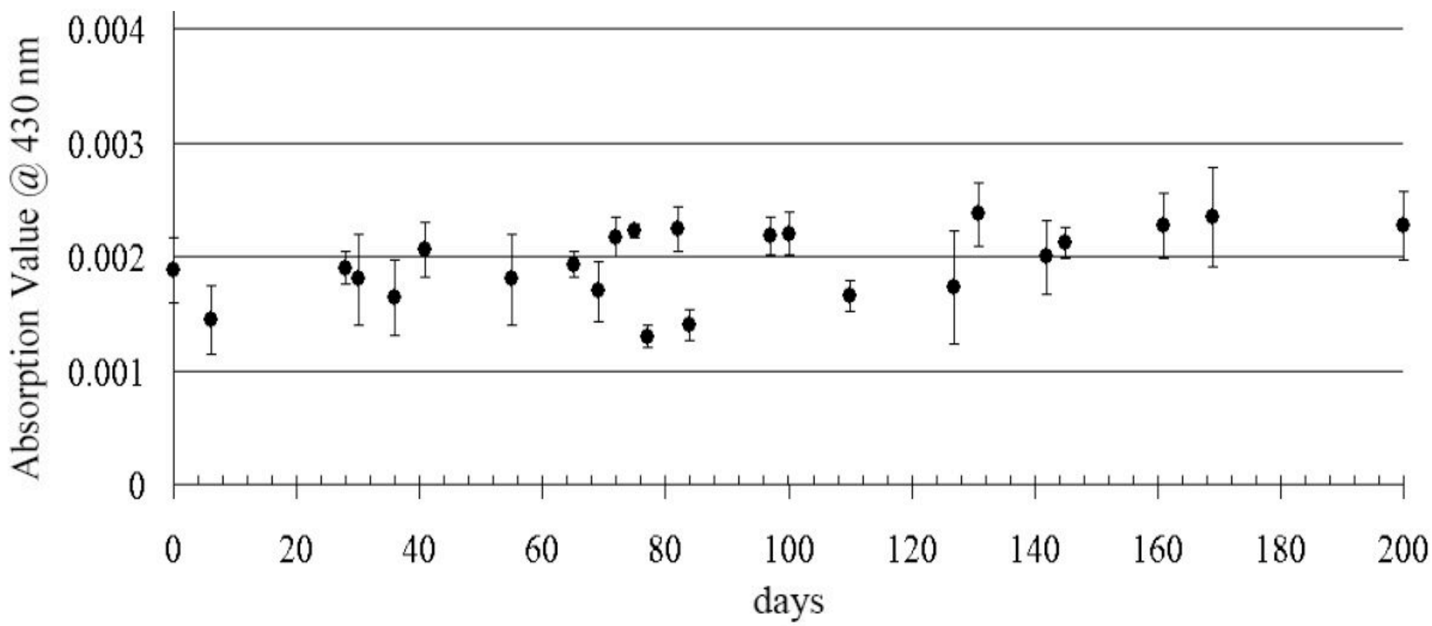
- Eight 'identical' detector modules

Gd-Liquid Scintillator

- Use LAB (Linear Alkyl Benzene):
  - high light yield, ~50% of anthracene
  - long attenuation length, > 10 m @ 430 nm
  - high flash point, ~130 °C
  - no EH&S issues
  - compatible with many plastics
  - cheap (raw material for making detergent)

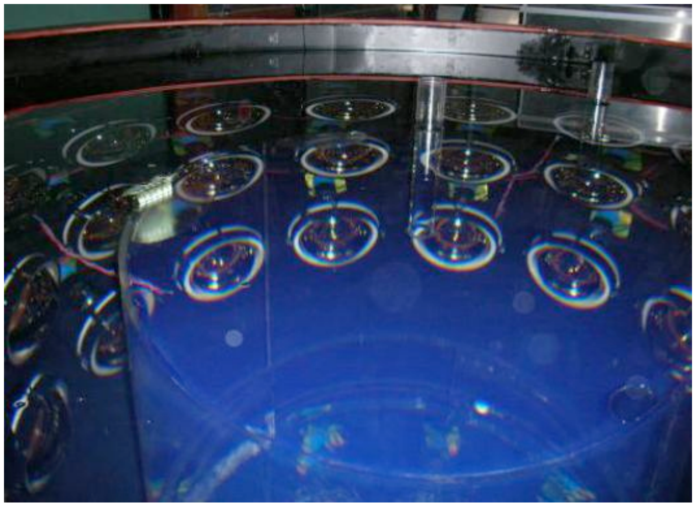


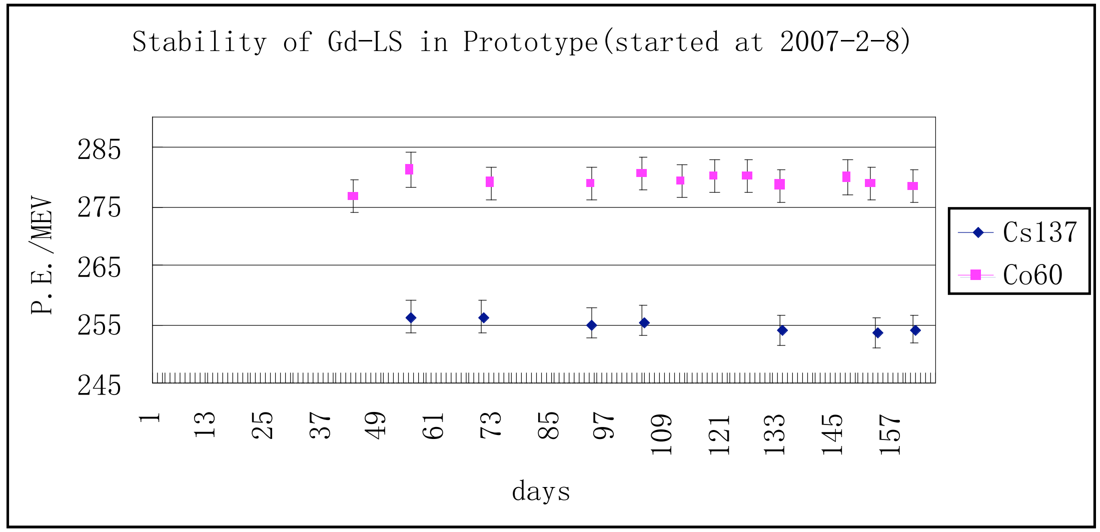
- 0.1% Gd-LAB with 3 g/l PPO and 15 mg/l Bis-MSB

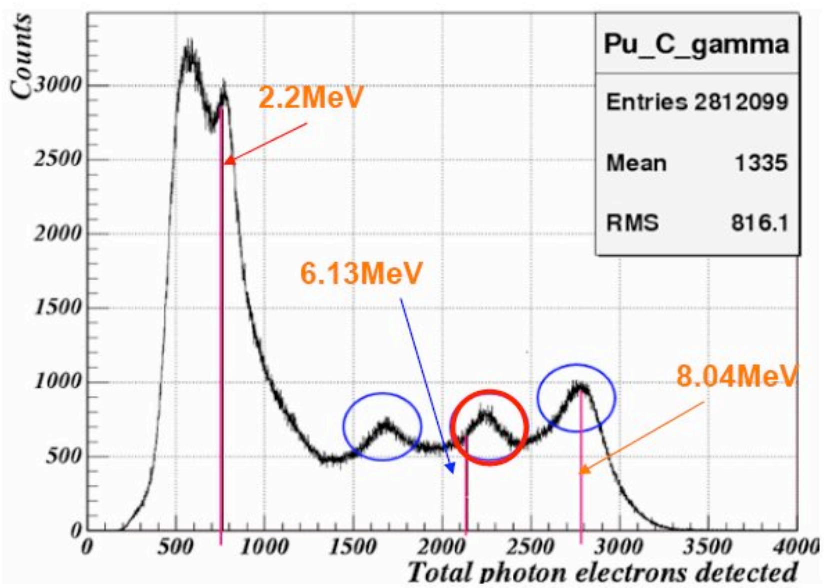


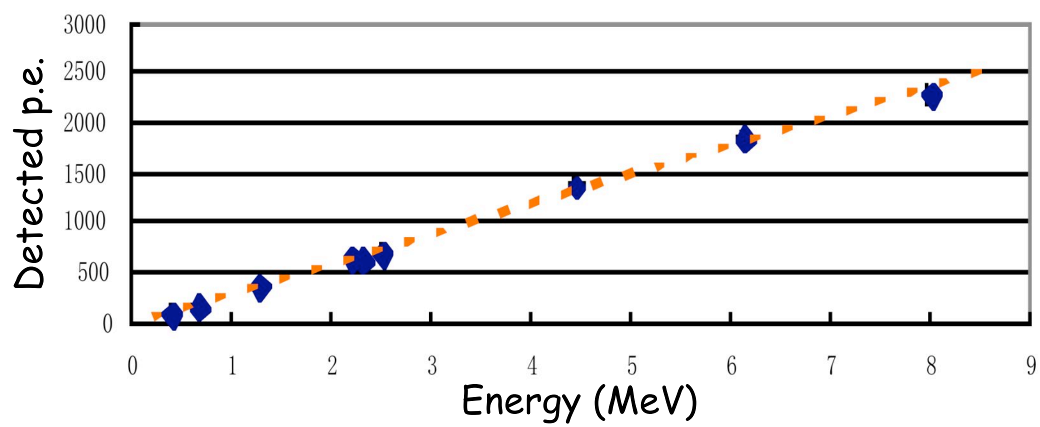
2-zone Prototype at IHEP

- 0.5 ton Gd-LS (it was unloaded LS for more than a year)
- 45 8" PMTs with reflectors at the top and bottom

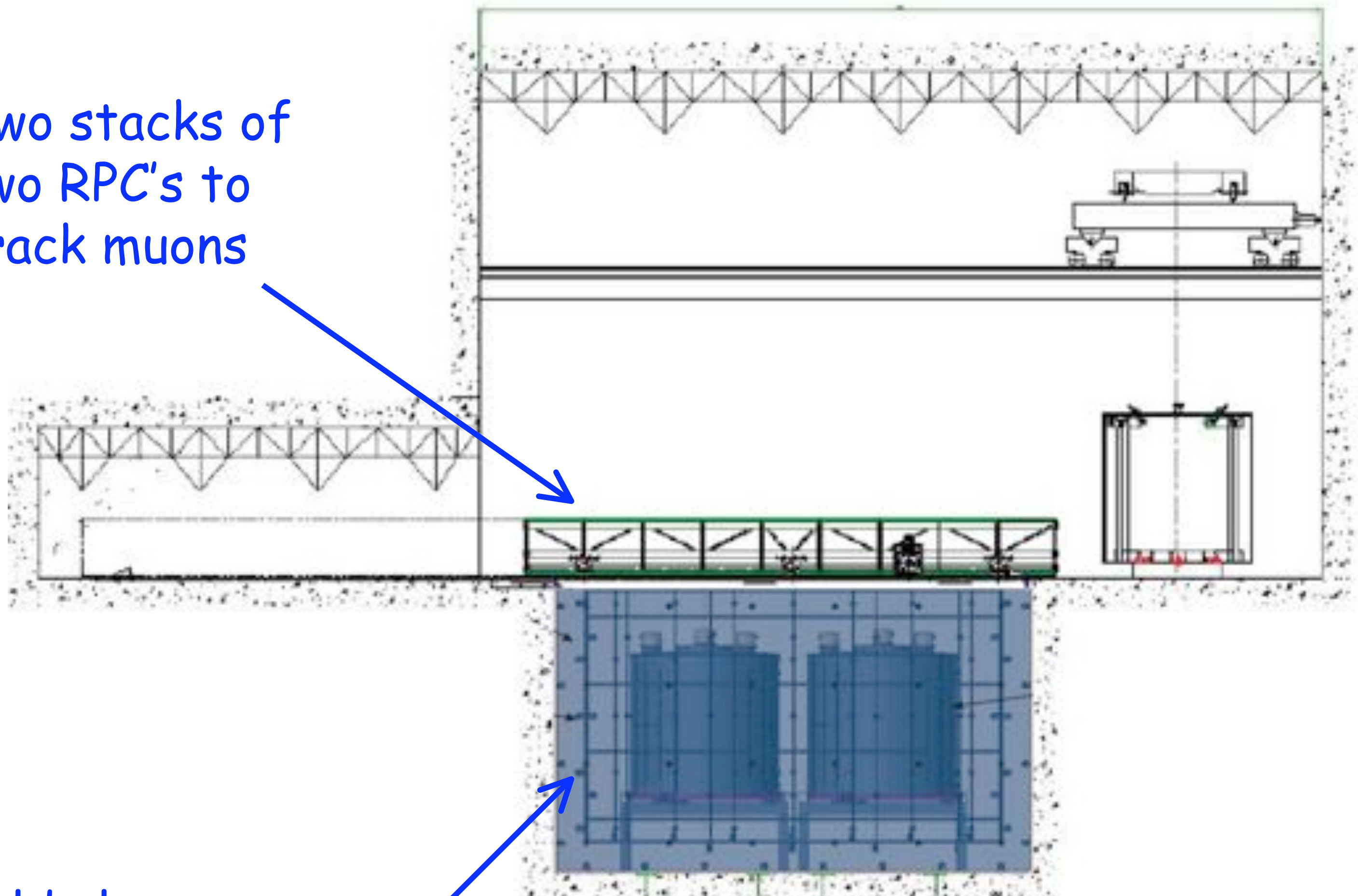








An Example of the Muon System



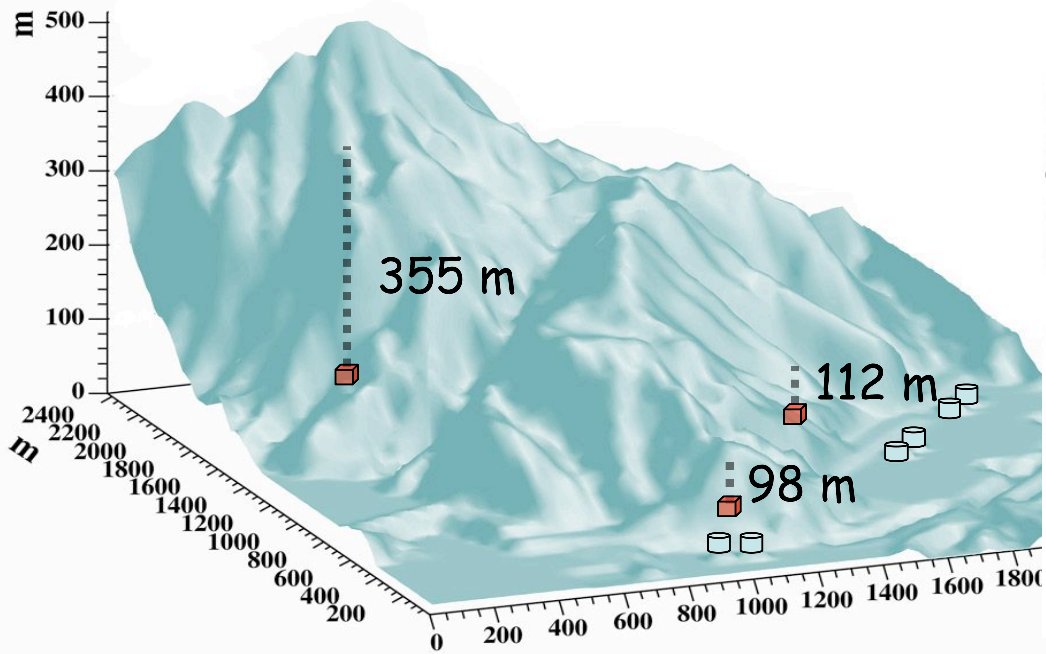
Two stacks of two RPC's to track muons

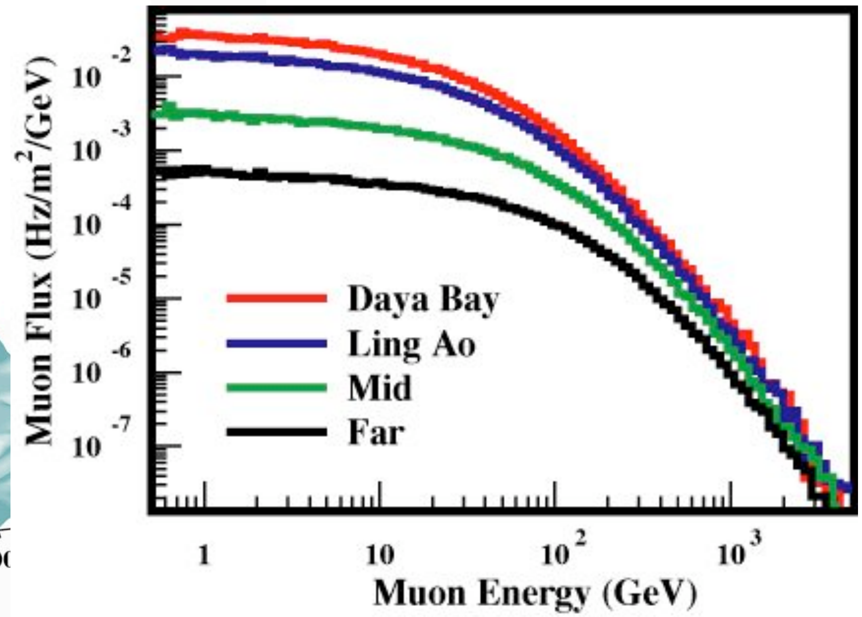
Water shield also serves as Cherenkov counter for tagging muons

- Combined efficiency of Cherenkov and tracker > 99.5% with error measured to better than 0.25%

Cosmic-ray Muon

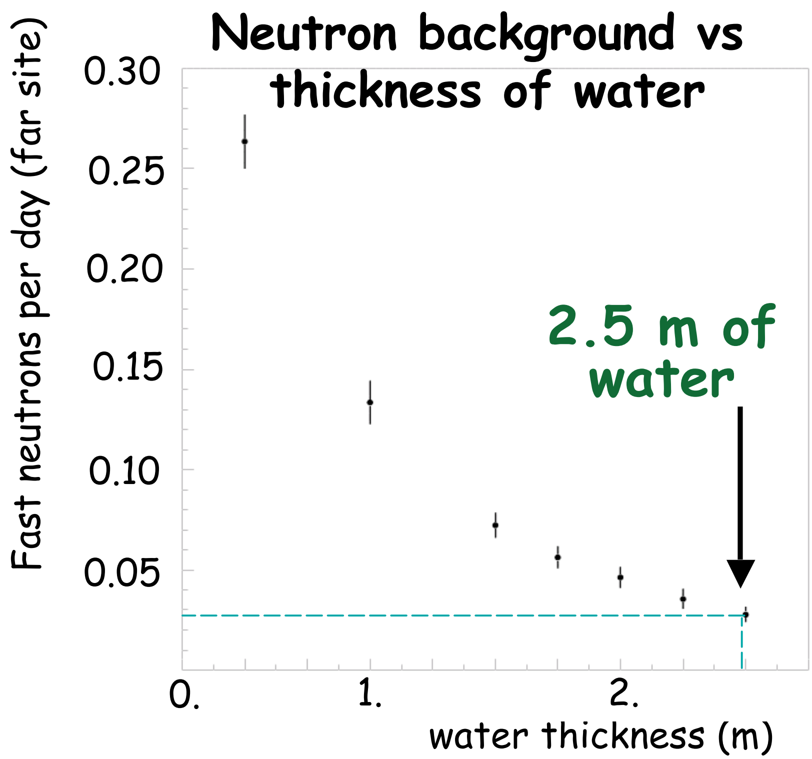
- Use a modified Gaisser parametrization for cosmic-ray flux at surface
- Apply MUSIC and mountain profile to estimate muon intensity & energy

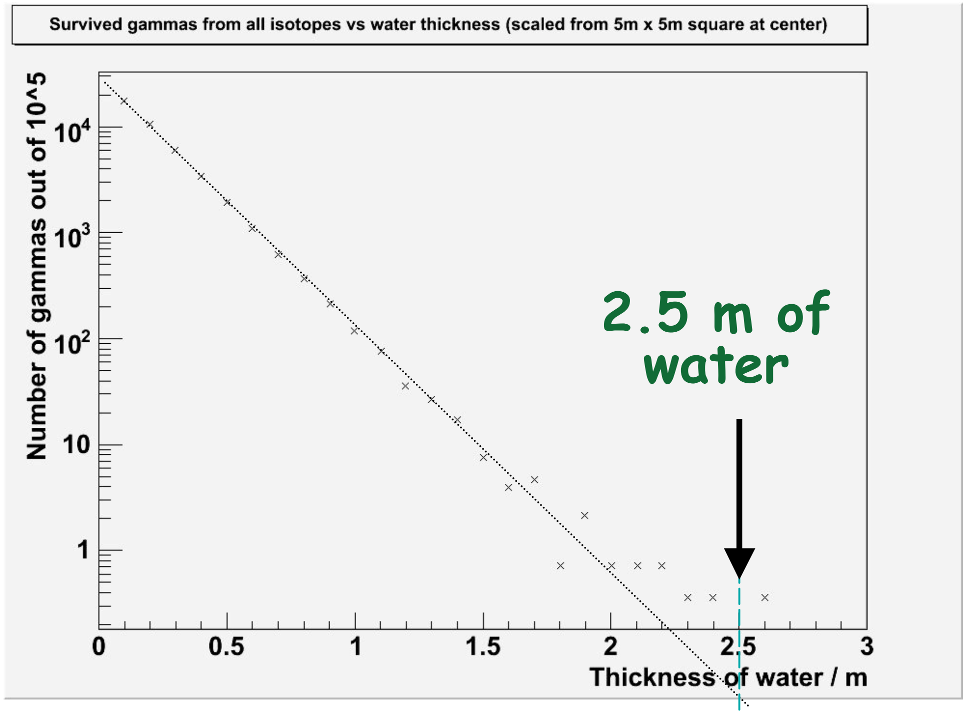




	DYB	LingAo	Far
Overburden (m)	98	112	355
Muon intensity (Hz/m²)	1.16	0.73	0.041
Mean Energy (GeV)	55	60	138

Shielding Antineutrino Detectors

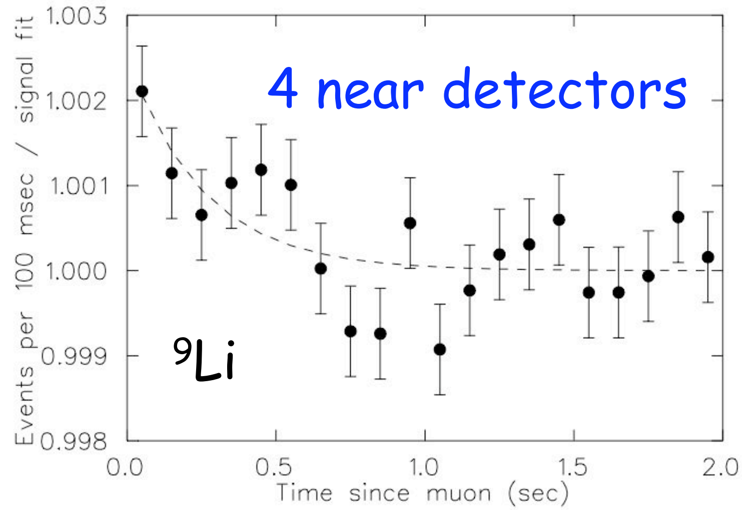




- Detector modules enclosed by 2.5 m of water to shield energetic neutrons produced by cosmic-ray muons and gamma-rays from the surrounding rock

Background

- Uncorrelated background:
  Sources: U/Th/K/Rn/neutron
  Single gamma rate @ 0.9MeV < 50Hz/module
  Single neutron rate < 1000/day/module
- Correlated backgrounds: $n \propto E_\mu^{0.75}$
  Fast Neutrons: double coincidence
  ^{8}He/^{9}Li: beta-neutron emitting decays
- All these background events can be measured and corrected



Per module	Daya Bay Near	Ling Ao Near	Far Hall
Baseline (m)	363	481 from Ling Ao 526 from Ling Ao II	1985 from Daya Bay 1615 from Ling Ao's
Overburden (m)	98	112	350
Radioactivity (Hz)	<50	<50	<50
Muon rate (Hz)	36	22	1.2
Antineutrino Signal (events/day)	930	760	90
Accidental Background/Signal (%)	<0.2	<0.2	<0.1
Fast neutron Background/Signal (%)	0.1	0.1	0.1
^{8}He+^{9}Li Background/Signal (%)	0.3	0.2	0.2

Systematic Uncertainties

- Reactor-related:

Near detectors really help !

Number of cores	α	σ_ρ(power)	σ_ρ(location)	σ_ρ(total)
4	0.338	0.035%	0.08%	0.087%
6	0.392	0.097%	0.08%	0.126%

- Detector-related:

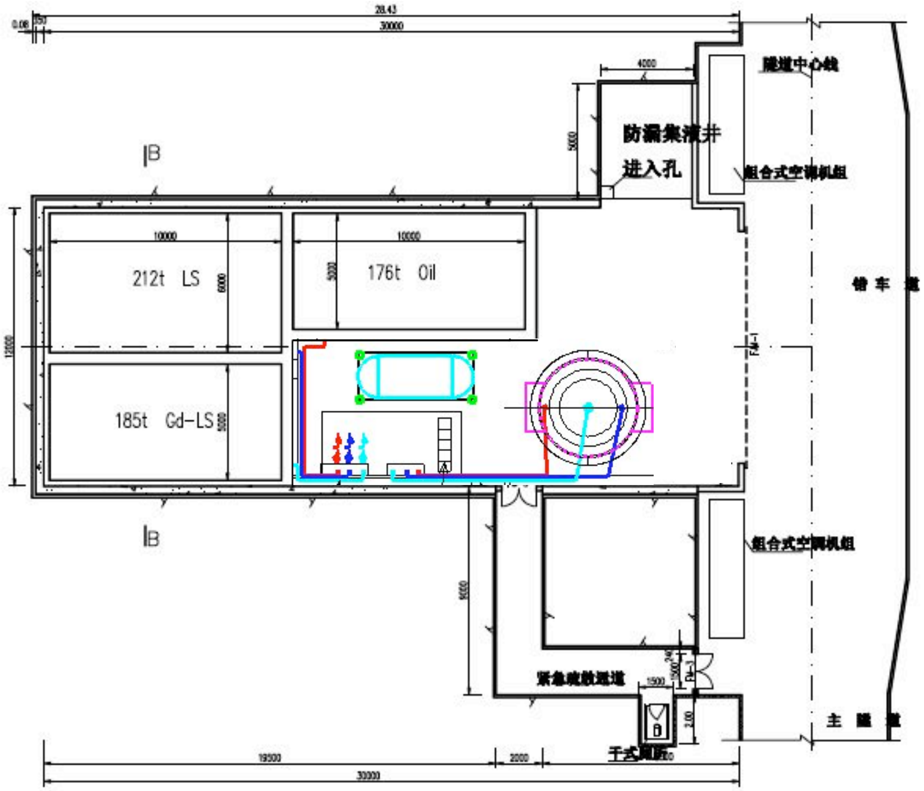
Source of uncertainty		Chooz *(absolute)*	Daya Bay *(relative)*		
			Baseline	Goal	Goal w/Swapping
# protons	H/C ratio	0.8	0.2	0.1	0
	Mass	-	0.2	0.02	0.006
Detector Efficiency	Energy cuts	0.8	0.2	0.1	0.1
	Position cuts	0.32	0.0	0.0	0.0
	Time cuts	0.4	0.1	0.03	0.03
	H/Gd ratio	1.0	0.1	0.1	0.0
	n multiplicity	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 detector-related uncertainty		1.7%	0.38%	0.18%	0.12%

anticipated

with R&D

Controlling Target Mass & Composition

- Use one batch of 400-t pure LAB to prepare the scintillators stored in two underground tanks
- Fill two detectors sequentially at a time underground with controls of load cells (0.008% accuracy), Coriolis mass flow meters (reproducible at 0.1%), and volume flow meters (good to 0.02%), as well as temperature monitoring :

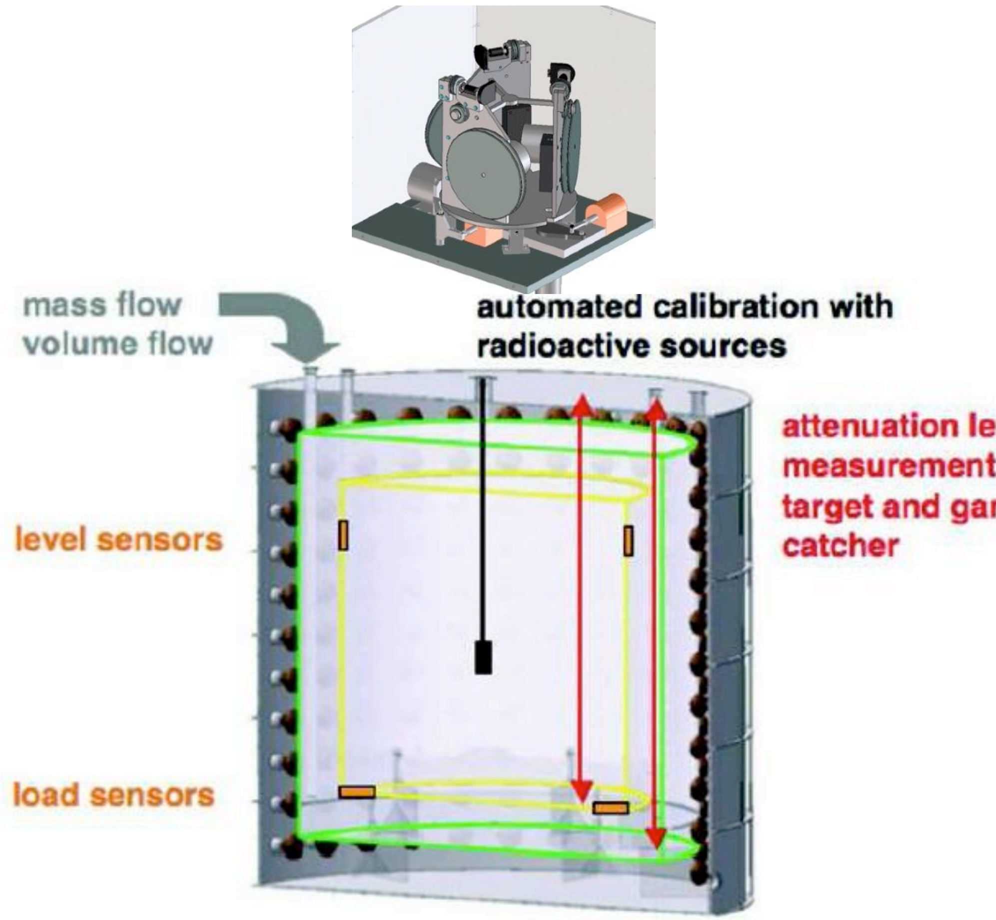


Gd-LS: 25 kl ISO tank

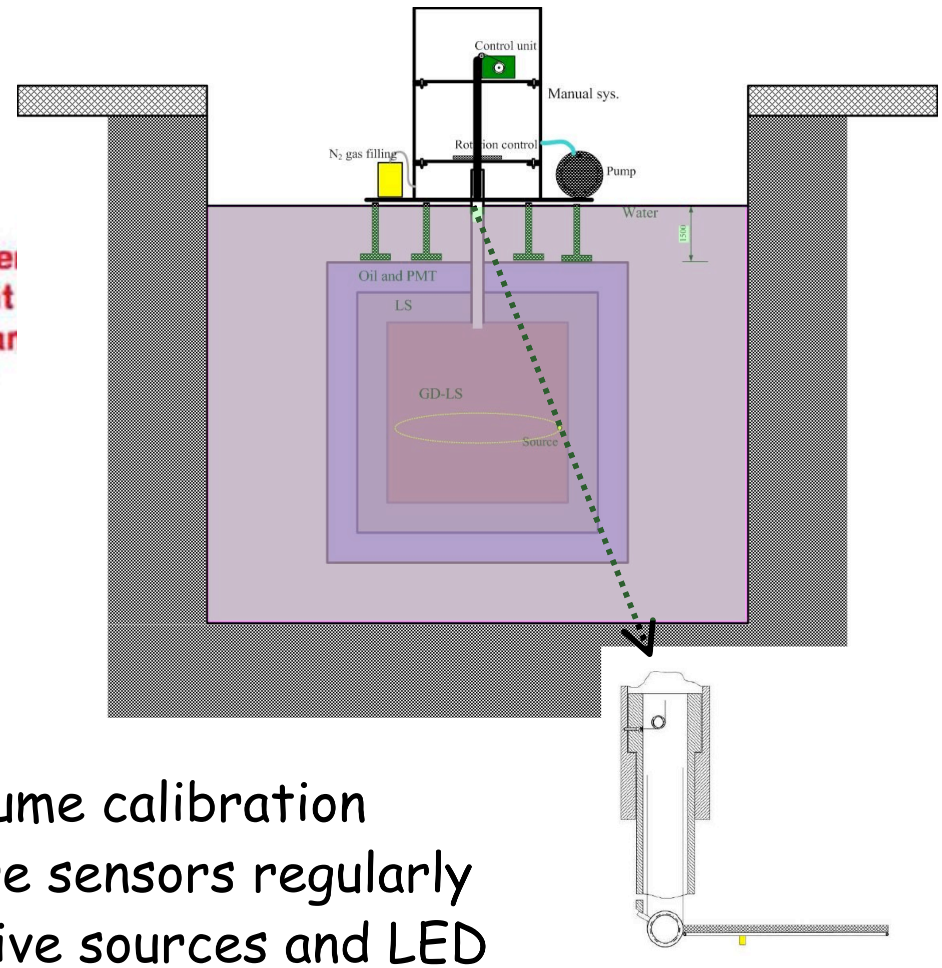
LS: Coriolis mass flow meters, $\Delta\rho < 10^{-3}$

load cell ($\Delta m/m < 0.005\%)_{mea}$

Calibration And Monitoring

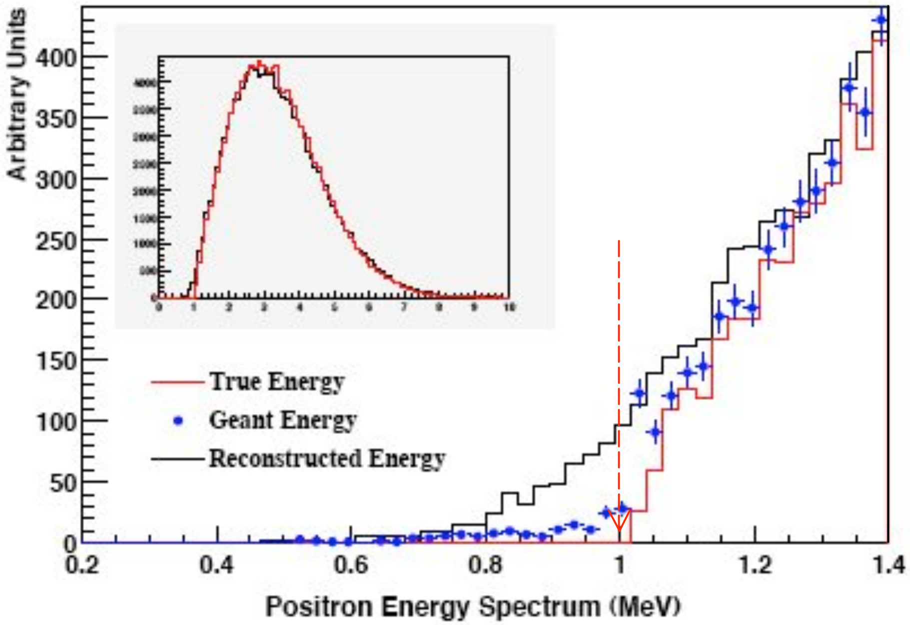


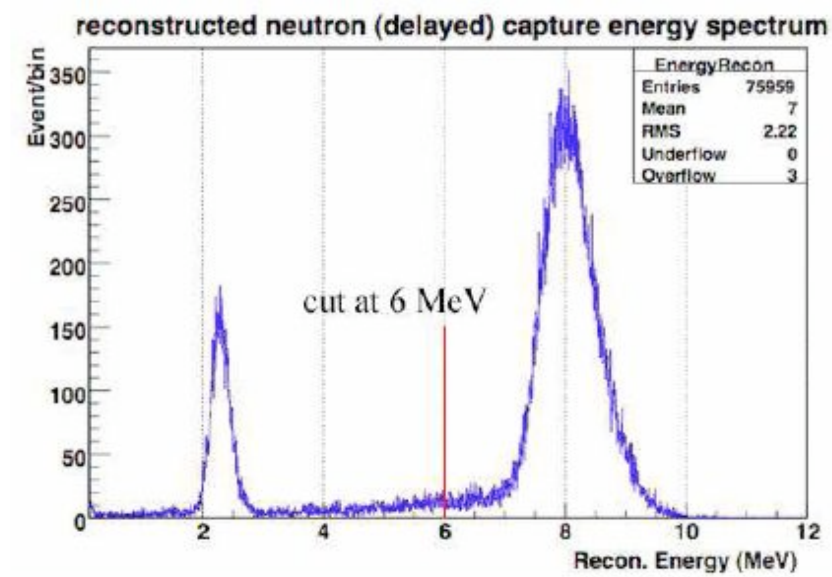
Manual calibration



- Use a manual system to do full-volume calibration
- Monitor level, load and temperature sensors regularly
- Frequent calibration with radioactive sources and LED along vertical axes with an automated calibration system

Calibrating Energy Cuts





- Routine calibration with
  - ^{68}Ge: e^+ annihilation yields two 0.511 MeV γ's
  - ^{60}Co: 2.6 MeV in γ's
  - ^{238}Pu-^{13}C (α-n source):

$$\alpha\,(^{238}\mathrm{Pu}) + {}^{13}\mathrm{C} \rightarrow {}^{17}\mathrm{O}$$

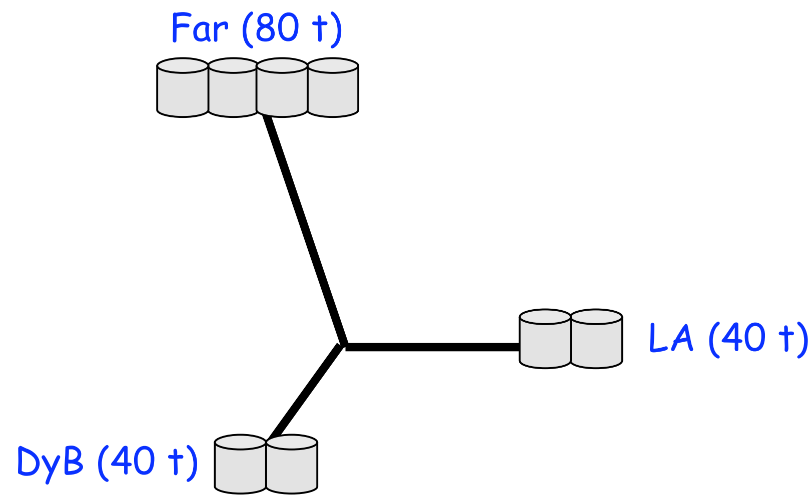
~ 5.48 MeV

$\rightarrow {}^{16}\mathrm{O} + n$

$\rightarrow {}^{16}\mathrm{O}^* + n$

$\rightarrow {}^{16}\mathrm{O} + \gamma$ (6.13 MeV)

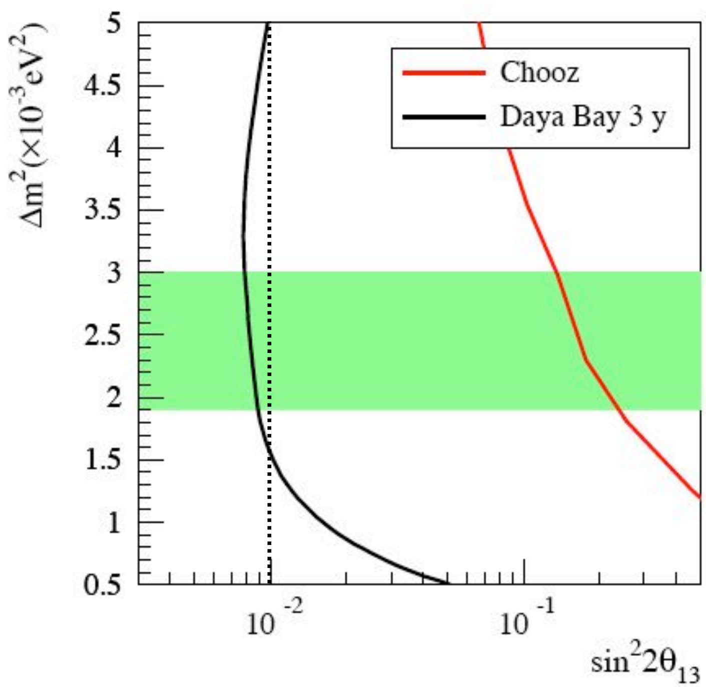
Sensitivity of Daya Bay



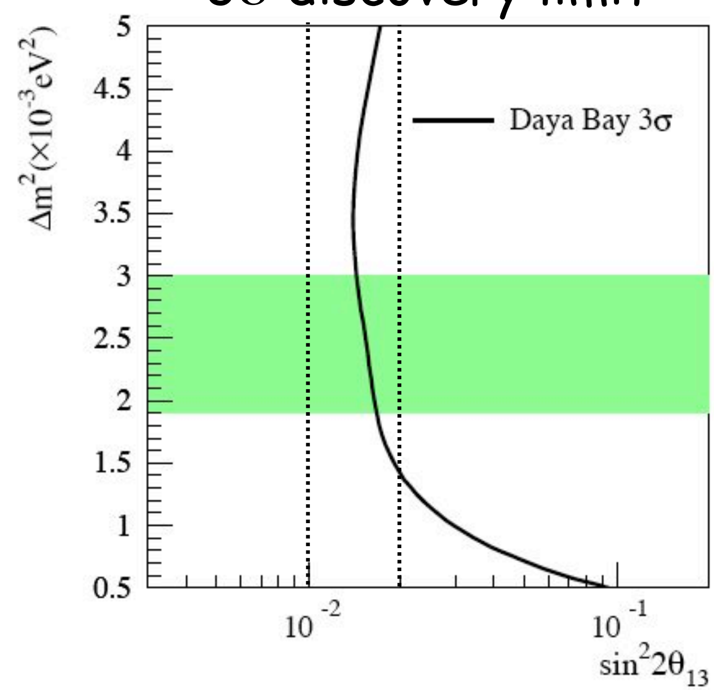
- Use rate and spectral shape
- input relative detector syst. error of 0.38%/detector

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

90% confidence level



3σ discovery limit



Milestones

- US CD-1 review — Apr 07
- Chinese 3-year project funding began to flow — Apr 07
- Start civil construction — Oct 07
- Groundbreaking ceremony — Oct 13,2007

- US CD-2/3a review — Jan 08
- Commission of 2 detectors at Daya Bay Hall — Sept 09
- Begin data taking with 8 detectors in final configuration — Oct 10

Summary

- Daya Bay will reach a sensitivity of ≤ 0.01 for $\sin^2 2\theta_{13}$
- Detailed design of detectors is nearly complete !!
- Received commitment from Chinese funding agencies
- On track of getting CD2/3a approval in January 2008
- Civil construction has begun:
  - Groundbreaking on Oct 13, 2007
  - Daya Bay Hall beneficial occupancy in 2008

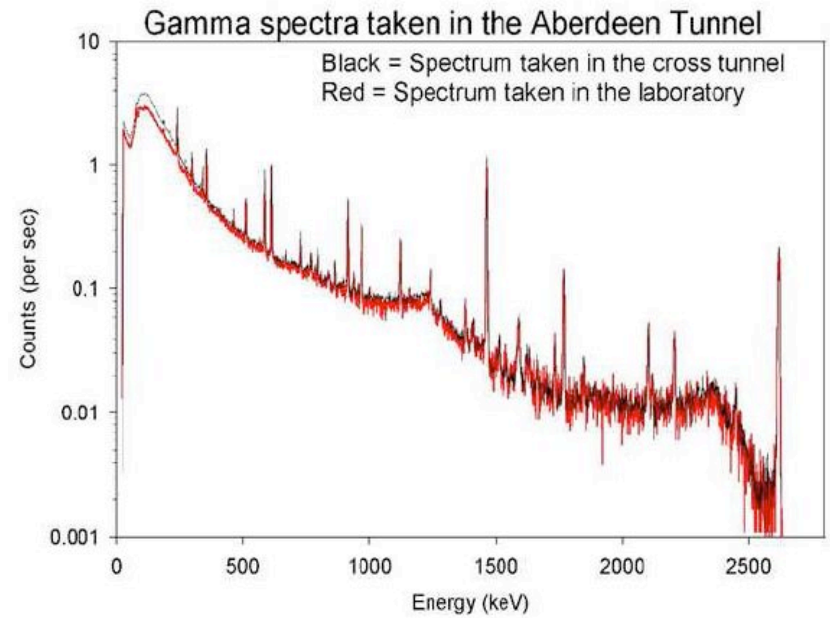
    First data with two detectors in Daya Bay Hall in 2009
  - Ling Ao Hall and Far Hall beneficial occupancy in 2009

    Data taking with all detectors in 2010
- Daya Bay is sailing forwards

Merci !

Aberdeen Tunnel Experiment (Hong Kong)

For studying cosmic muons, spallation neutrons, and gamma background



similar overburden/geology between Aberdeen and Daya Bay

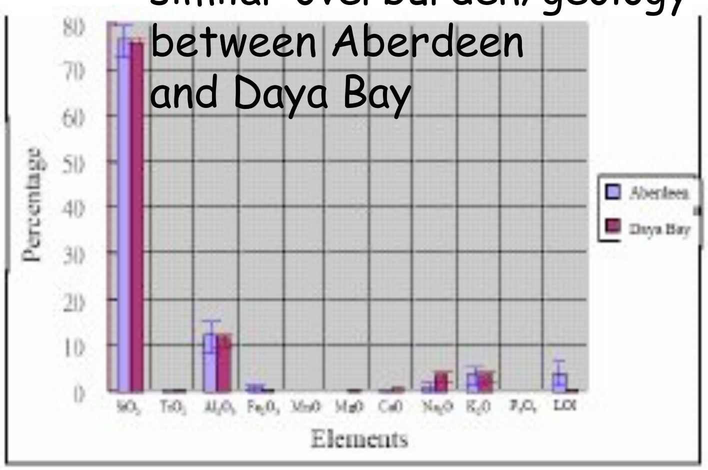


Fig. 1 A comparison of rock compositions at Daya Bay and Aberdeen