Daya Bay Neutrino Experiment

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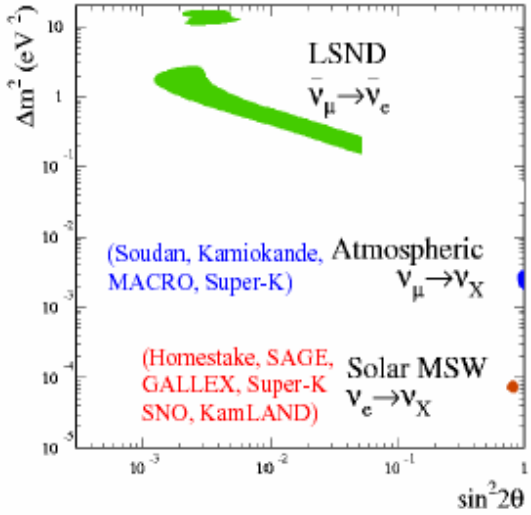
Neutrino Oscillation

Neutrino Mixing: PMNS Matrix

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

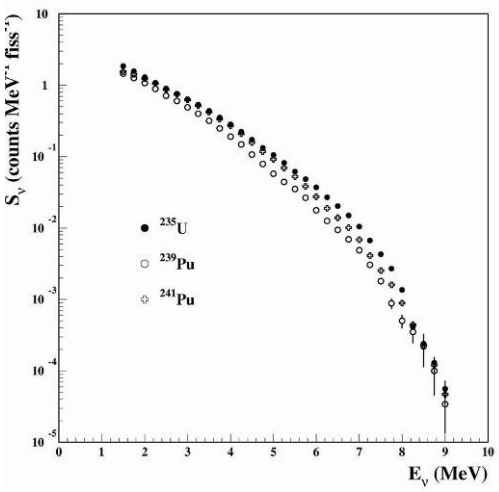
Atmospheric | Reactor and LBL | Solar



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

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

Reactor Neutrino

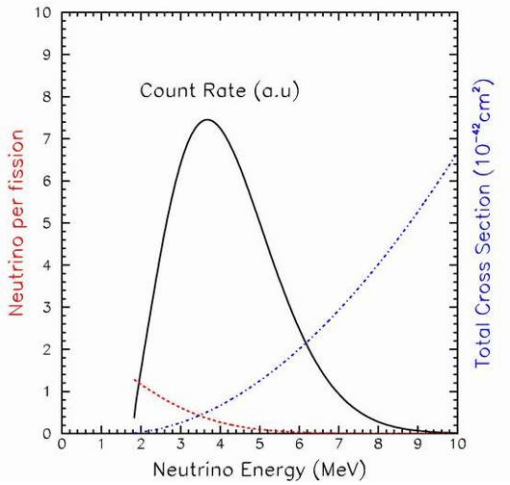


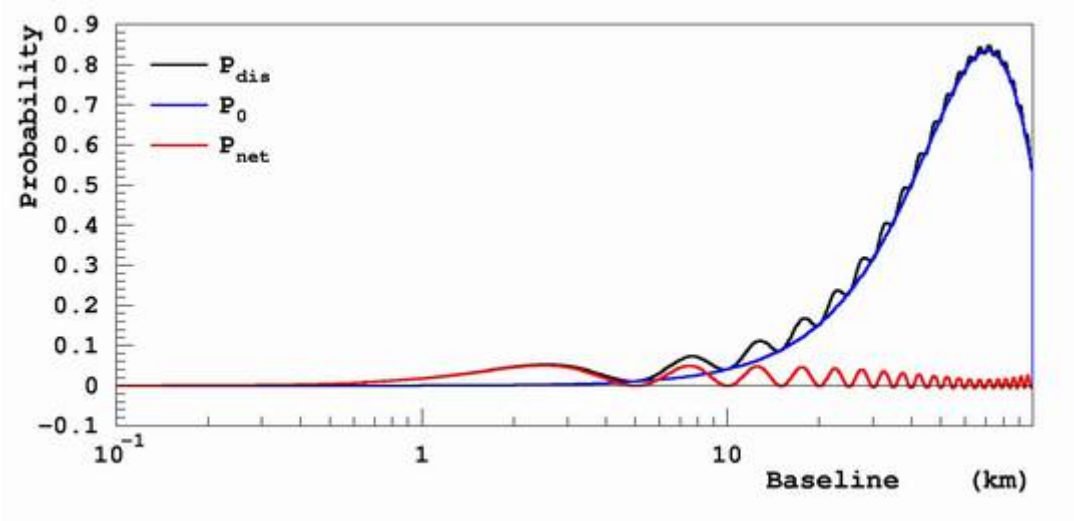
Prompt signal

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

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

Capture on H, or Gd, Cd, etc.
Delayed signal

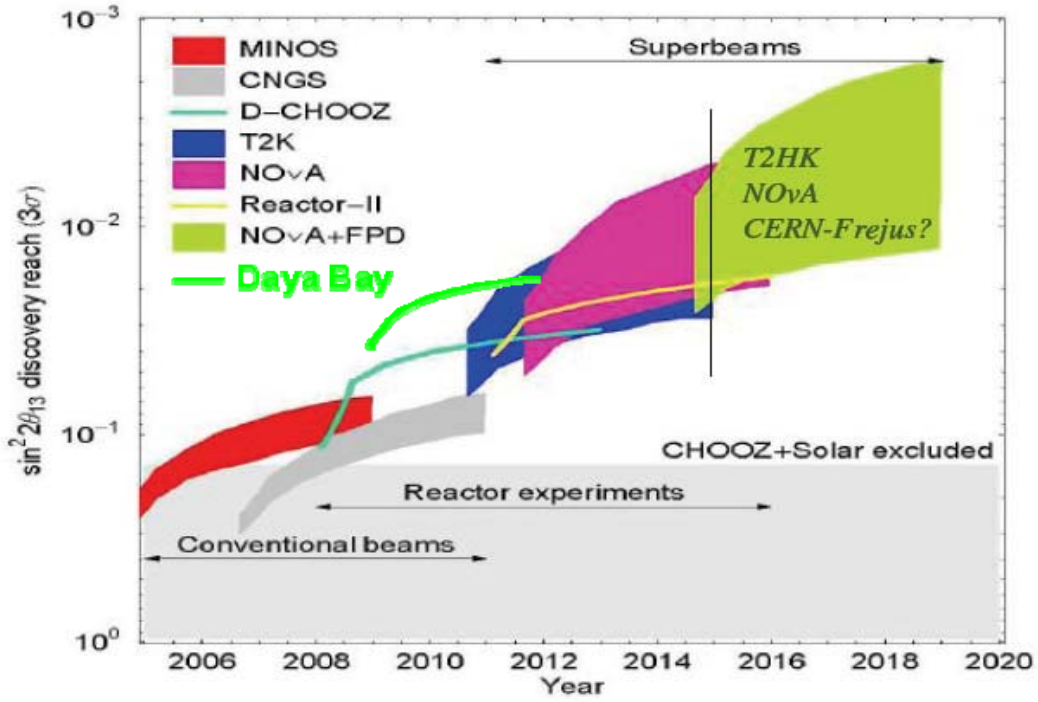




θ_{12}: ~ 55km

θ_{13}: ~ 2km

Physics Goal



Beta beam → 1e-4 ?

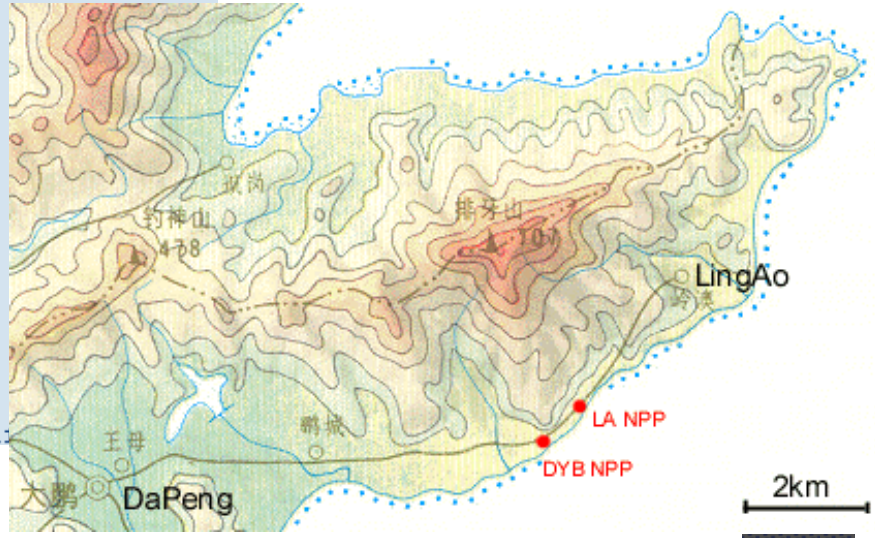
Reactor Neutrino:

- Fast, Cheap, and Clean!
- Mature technique, Chooz, Palo Verde, KamLAND
- but challenging on controlling systematics.

The proposed **Daya Bay Experiment** will measure $\sin^2 2\theta_{13}$ to 0.01 or better at 90% C.L. in a three-year run (2001).

And a direct measurement of Δm^2_{31}

Location of Daya Bay



Two metropolises

- Hong Kong 55 km

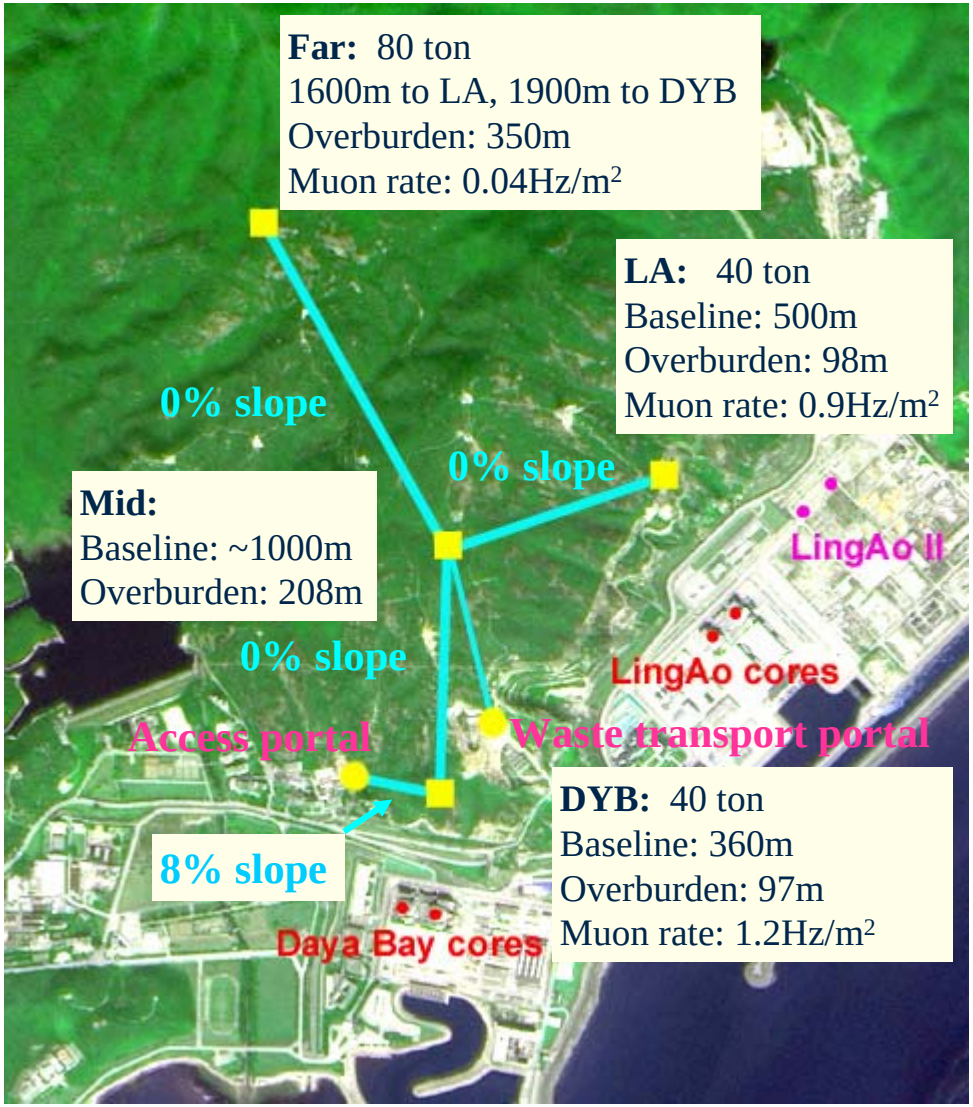
  θ_{12} maximum

- ShenZhen 45 km

The Site


LingAo II NPP 2.9GW×2
Under construction (2010)
Daya Bay NPP 2.9GW×2
LingAo NPP 2.9GW×2

Tunnel Layout



Horizontal tunnel

Approved by Power Plant

Total Tunnel length

~ 3200 m

Detector swapping

cancels most detector systematic error.
Residual error ~ 0.2%

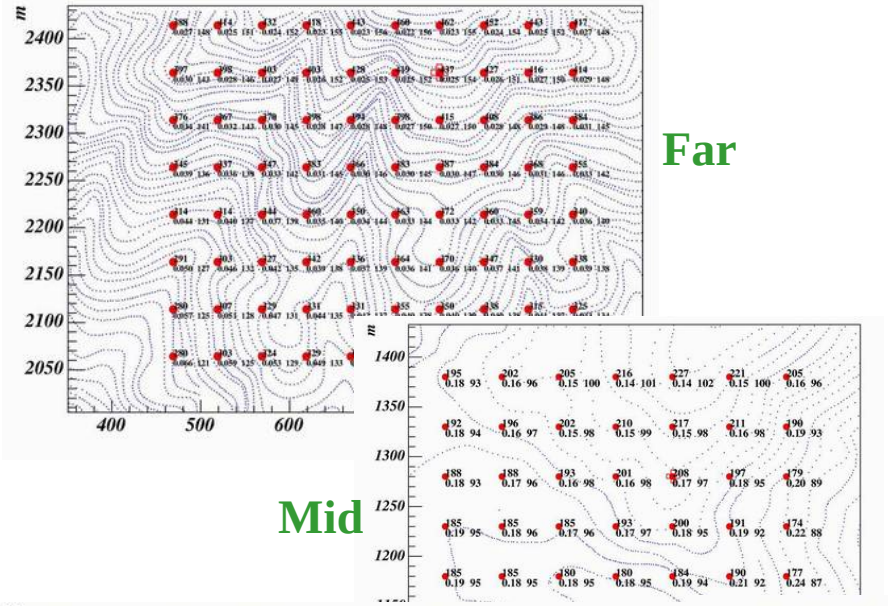
Backgrounds

B/S of DYB,LA ~ 0.5%
B/S of Far ~ 0.2%

Site Survey

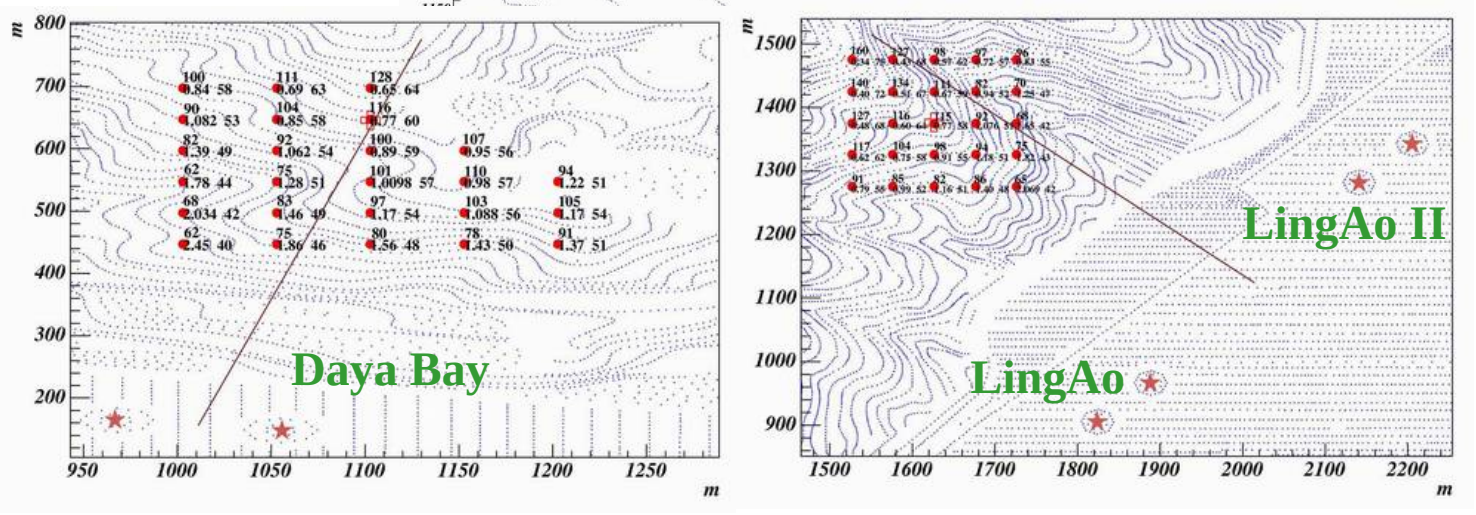
Topography: Completed
Geological Survey: Completed
Geological Physical Survey: Completed
Bore-Hole Drilling: Oct.~Dec.

Muon Simulation



MUSIC simulation

	DYB	LA	Mid	Far
Elevation (m)	97	98	208	347
Flux (Hz/m^2)	1.2	0.94	0.17	0.045
Mean Energy (GeV)	55	55	97	136



Rock density
2.6 g/cm^3

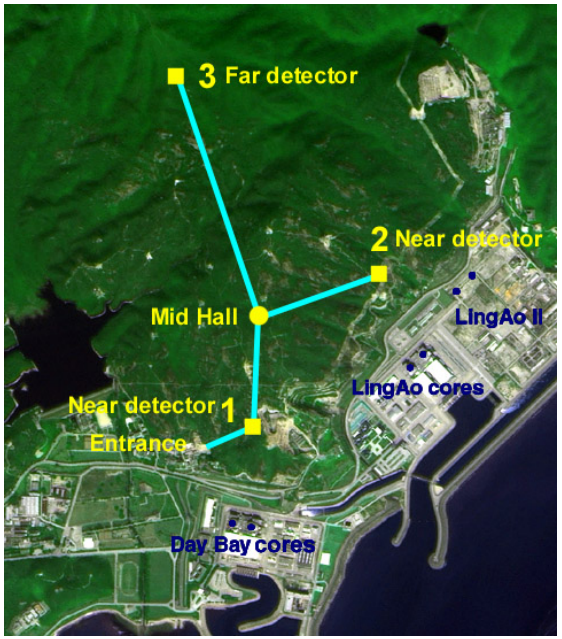
A Versatile Site

Fast measurement:

One near site + mid site

Sensitivity ~ 0.03 in a one year run

40 ton/site, reactor error 0.7%



Full operation: (Goal)

- **Two near sites + Far site** ($\sin^2 2\theta_{13} < 0.01$)
- Mid site + Far site ($\sin^2 2\theta_{13} \sim 0.01$)
- Two near sites + Mid site + Far site ($\sin^2 2\theta_{13} < 0.01$)

Different systematics

Detector

Vertical, cylindrical modules

- Easy to fabricate
- Easy to calibrate
- Size limited by tunnel cross section
- Multiple modules to control systematics and gain enough statistics.

Three-layer structure:

I. target: Gd-loaded scintillator, 20 ton

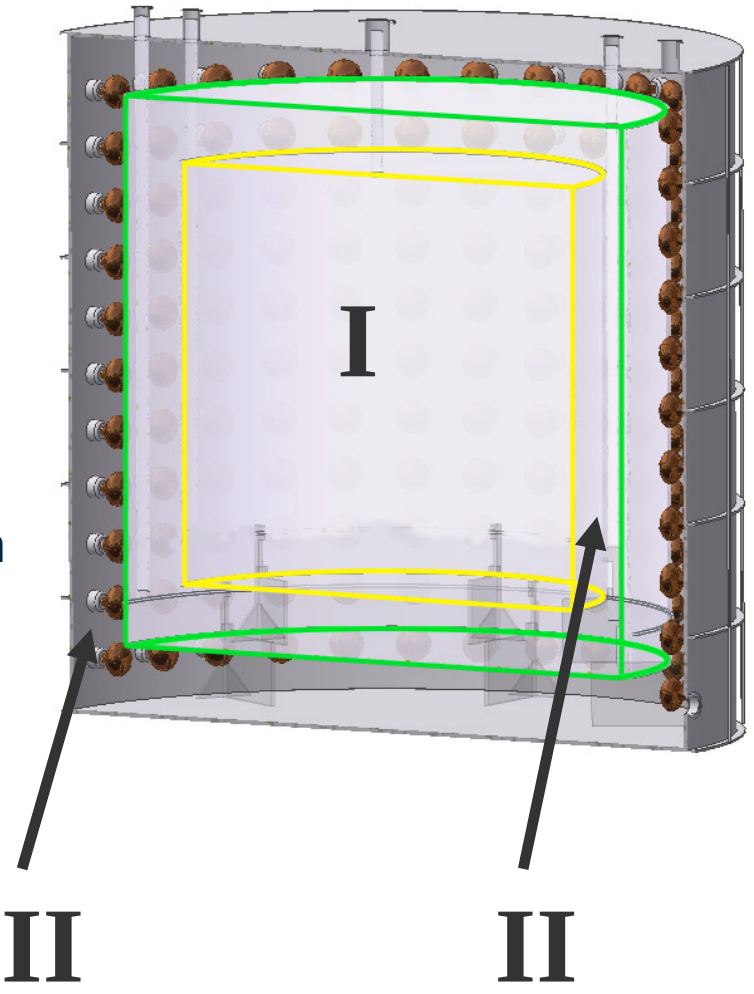
II. gamma catcher: normal scintillator, 45cm

III. Buffer shielding: mineral oil, ~45cm

Possibly with reflection on top and bottom

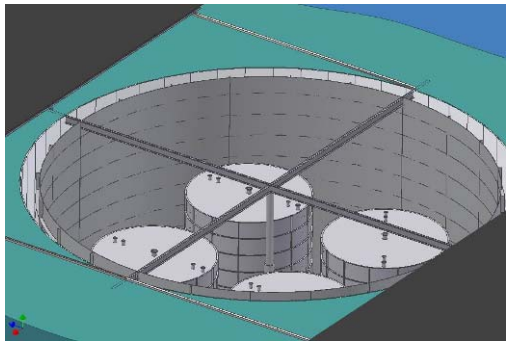
~200 8”PMTs mounted in oil

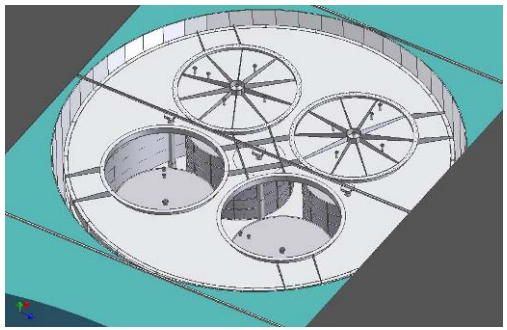
$$\frac{\sigma}{E} \sim \frac{14\%}{\sqrt{E(\mathrm{MeV})}}, \quad \sigma_{\mathrm{vertex}} = 14\mathrm{cm}$$

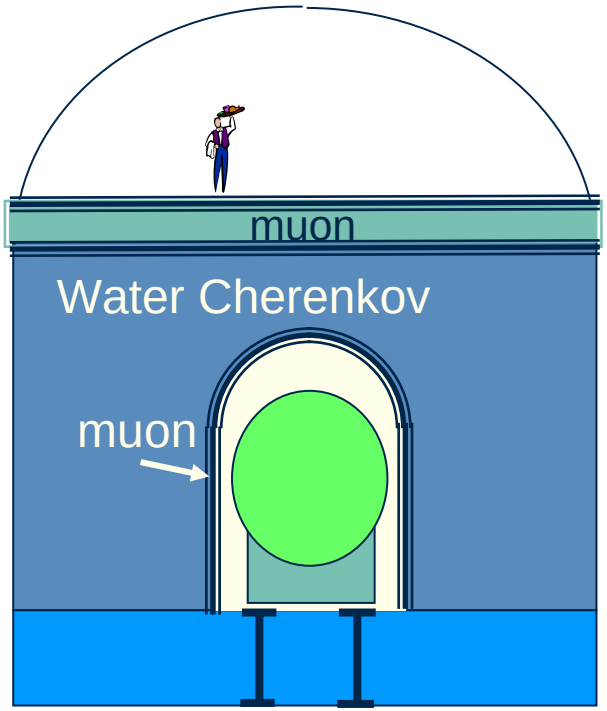


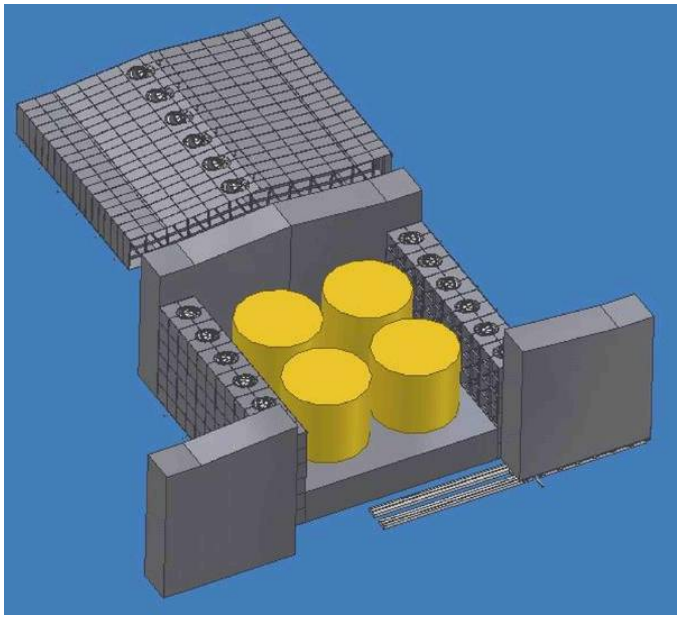
Veto

- **2m+ water shielding (**neutron produced in rock and gammas**)**
- Water cherenkov detector
- Another muon veto (plastic scintillator or RPC) outside the water shielding.
  > 99.5% efficiency.

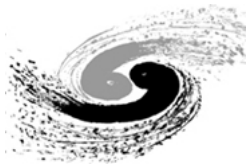








Background



	Near Site	Far Site
Radioactivity (Hz)	<50	<50
Accidentals B/S	<0.05%	<0.05%
Fast Neutron backgrounds B/S	0.15%	0.1%
^{8}He/^{9}Li B/S	0.55%	0.25%

Radioactivity: PMT glass, Rock, Radon in the air, etc

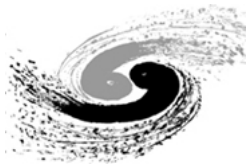
Neutron Singles and Fast neutron backgrounds

- ✓ Neutrons produced in rock and water shielding (99.5% veto efficiencey)

Cosmogenic isotopes ^{8}He/^{9}Li

- ✓ Cross section measured at CERN (Hagner et. al.)
- ✓ Can be measured in-situ, even for near detector with muon rate ~ 10 Hz.
- ✓ The above number is before shower muon cut.

Systematics



Systematic errors	Chooz	Daya Bay
Reaction Cross Section	1.9%	0, near-far cancellation
Energy released per fission	0.6%	0, near-far cancellation
Reactor Power	0.7%	0.06%, near-far cancellation
Number of Protons	0.8%	0, detector swapping
Detection efficiency	1.5%	~0.2%, fewer cuts, detector swapping
Total	2.75%	~0.2%

No Vertex cut.

Residual detection error is dominated by the **neutron energy cut** at 6 MeV, arises mainly from energy scale uncertainties. It is ~0.2%, suppose 1% energy scale error at 6 MeV.

Positron energy cut negligible.

Residual systematic error: ~ 0.2%

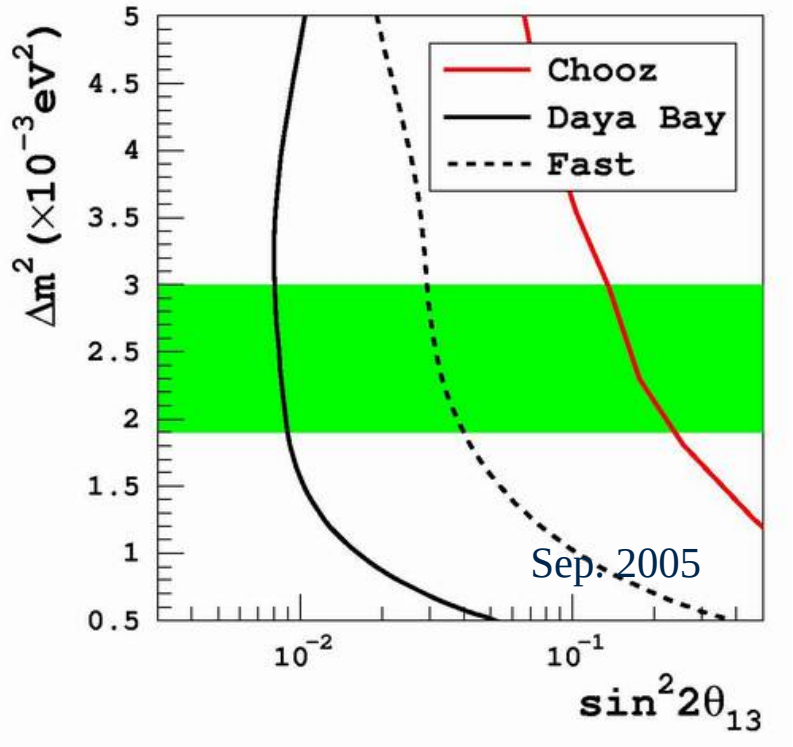
Statistical Error (3 years): 0.2%

Backgrounds: B/S ~ 0.6%

Sensitivity

- DYB detector
  - ✓ baseline 360m
  - ✓ 40 ton
  - ✓ B/S ~0.5%
- LA detector
  - ✓ baseline 500m
  - ✓ 40 ton
  - ✓ B/S ~0.5%
- Far detector
  - ✓ 1900m to DYB cores
  - ✓ 1600m to LA cores
  - ✓ 80 ton
  - ✓ B/S ~0.2%
- Three-year run (2009-2011)
  - ✓ 0.2% statistical error
- Detector residual error 0.2%

90% confidence level



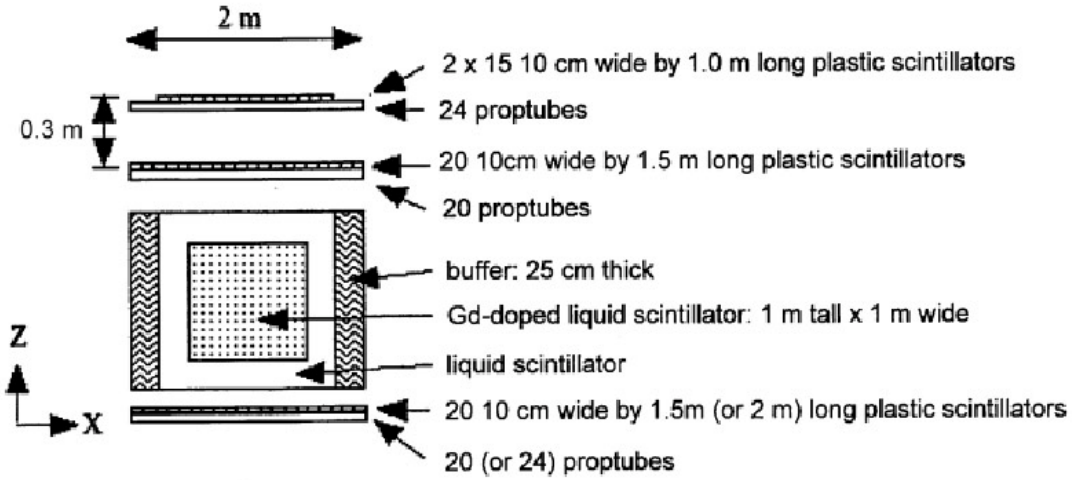
IHEP Detector Prototype

2-layer cylindric detector, 0.5 ton Gd-doped LS surrounded by 5 ton oil, 45 PMTs.

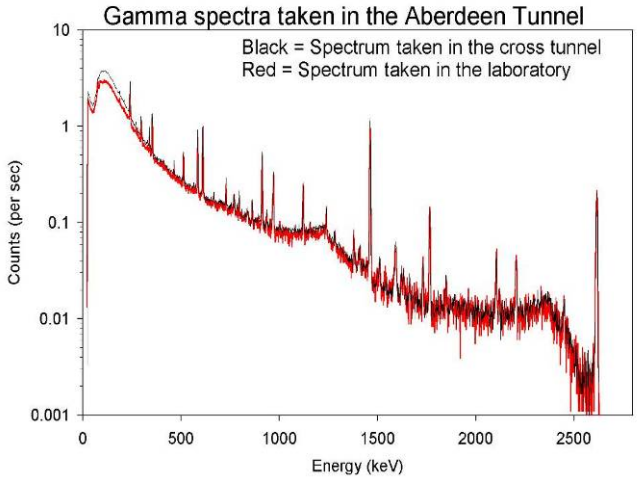
Mounting PMT now.

Aberdeen Tunnel Exp.

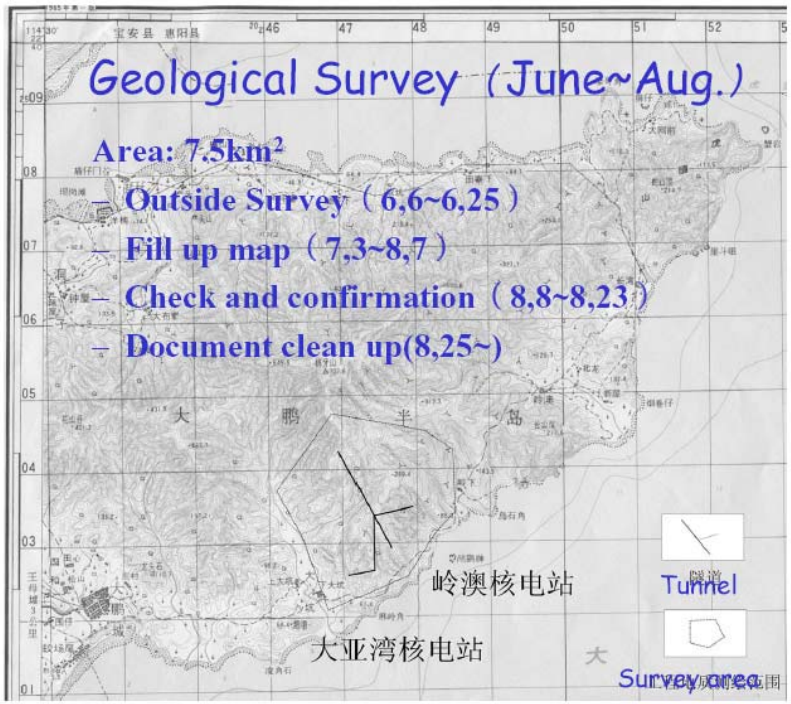
- Hong Kong University & Chinese University of Hong Kong.
  Started in Jun. 2005
- ~ 240m Overburden
- To study cosmic muon, neutron production, possibly cosmogenic isotopes.



Similar rock as Daya Bay

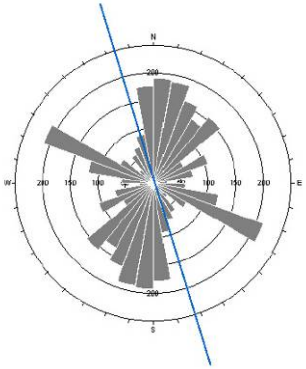


Geological Survey



- Topography Survey, done
- Geological Survey, done
- Geological Physical Survey, done
  - High Resolution electric resistance
  - seismic reflection
  - Micro gravity measurement
- Bore hole drilling, Oct.~Dec.

Orientation Statistics of Joints



Our tunnel is slightly away the direction of joints