Antineutrino Detector of Dayabay Reactor Neutrino Experiment

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On Behalf of the DayaBay Collaboration

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Outline

- Motivation and design of DYB reactor experiment
  - $\sin^2 2\theta_{13}$ sensitivity to 0.01
  - Key designs to fulfill the goals
- Design and structure of AD
  - Large statistics
  - Nested 3-zones structure
  - Small relative systematic error
  - Construction
- Summary

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.
$\theta_{23} \sim 45^o$

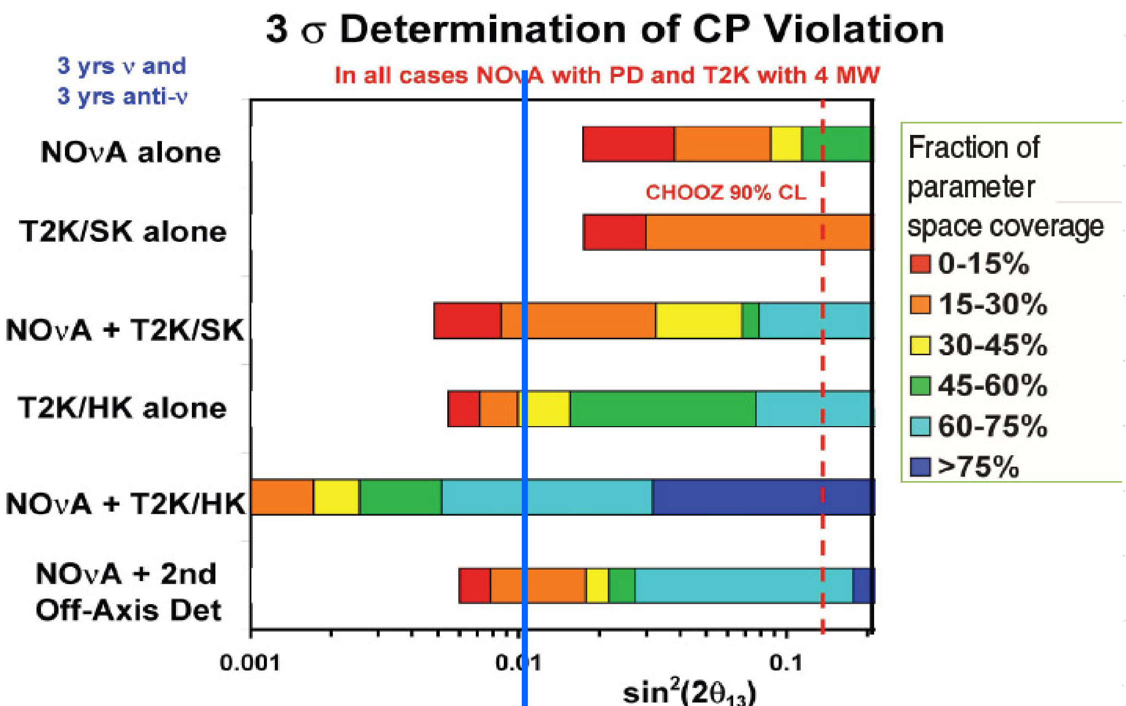
Reactor
Accelerator
$\theta_{13} < 12^o$

Solar
KamLAND
$\theta_{12} \sim 30^o$

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 $\sin^2 2\theta_{13}$ to sensitivity of 0.01



Planned Exp.

If $\sin^2 2\theta_{13} < 0.01$, long baseline (LBL) experiments with conventional beam face more difficulties 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

Measuring θ_{13} at reactors

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

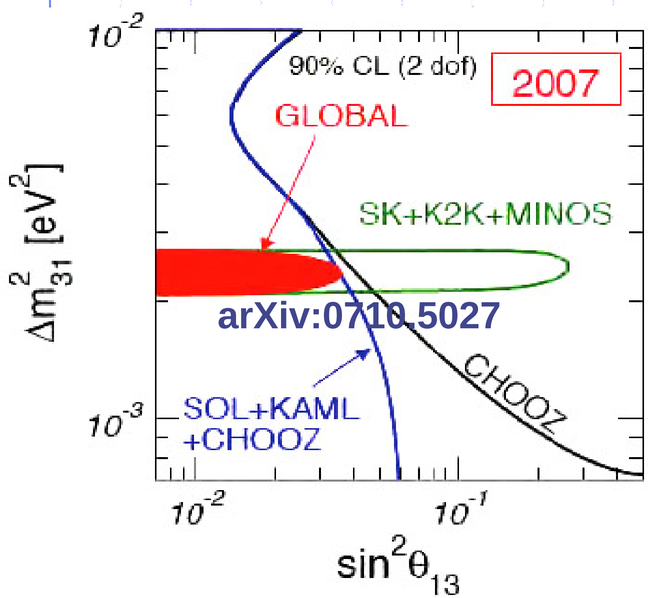
- Clean in physics
- Cheaper and faster

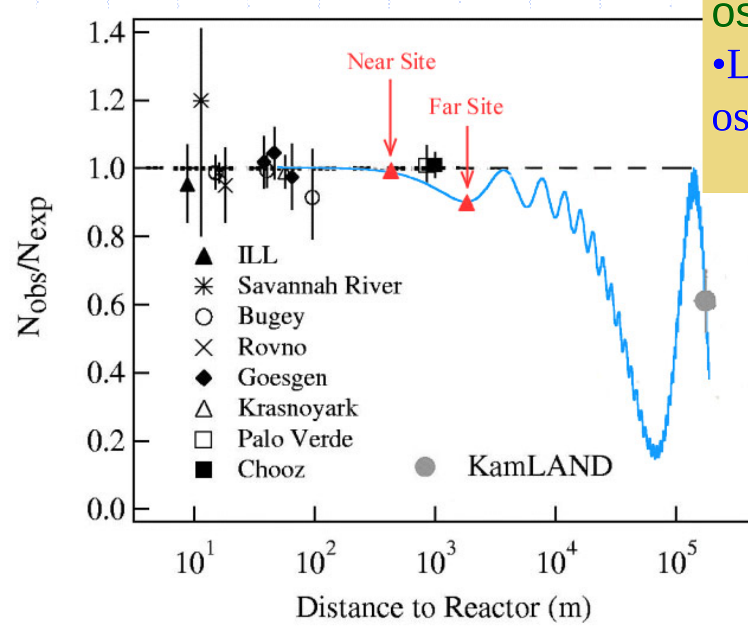
$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)$$

Accelerator (ν_e appearance)

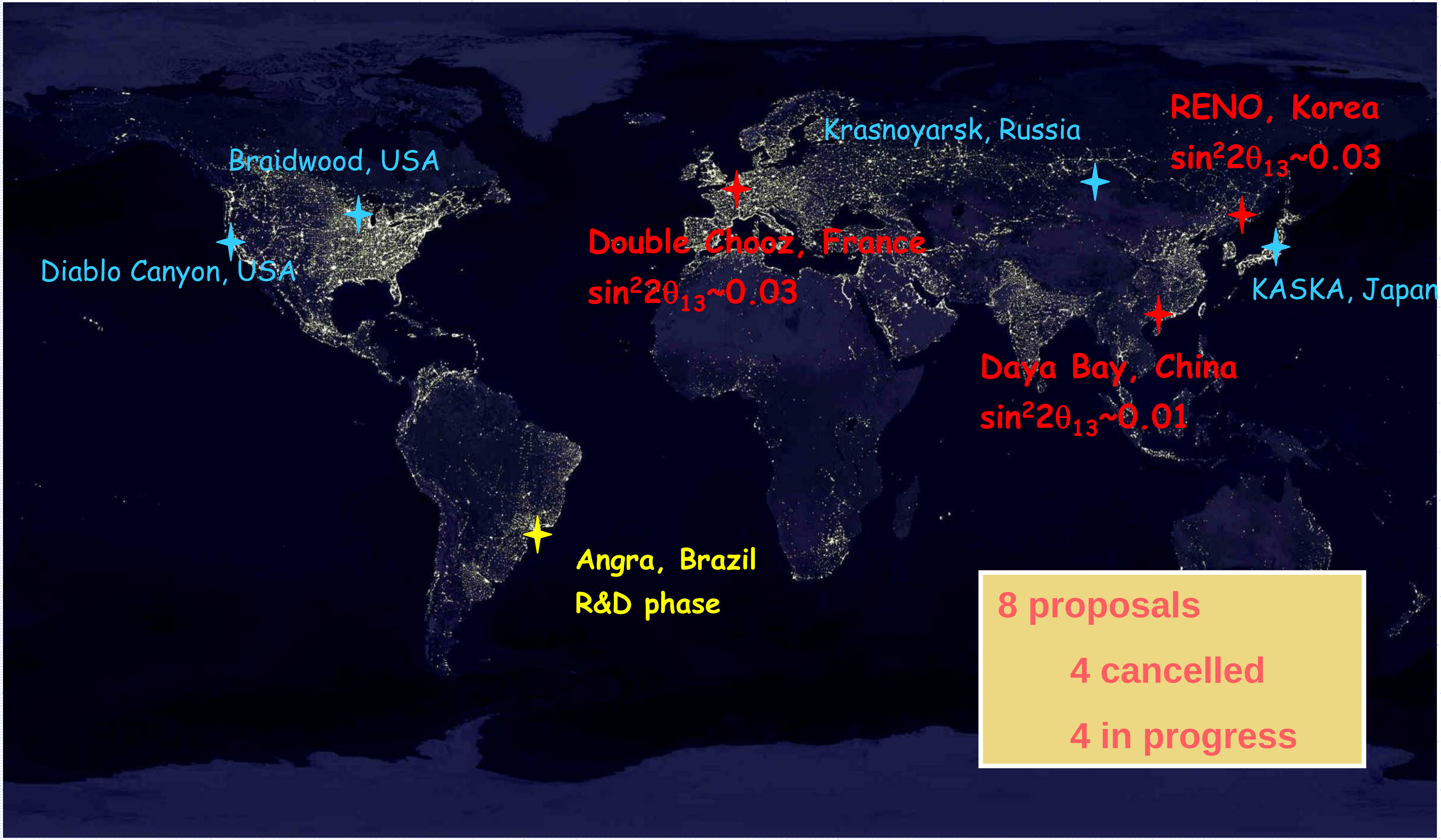
Related with CP phase, θ_{13}, and mass hierarchy

- Small-amplitude oscillation due to θ_{13}
- Large-amplitude oscillation due to θ_{12}





Proposals for measuring θ_{13} at reactors

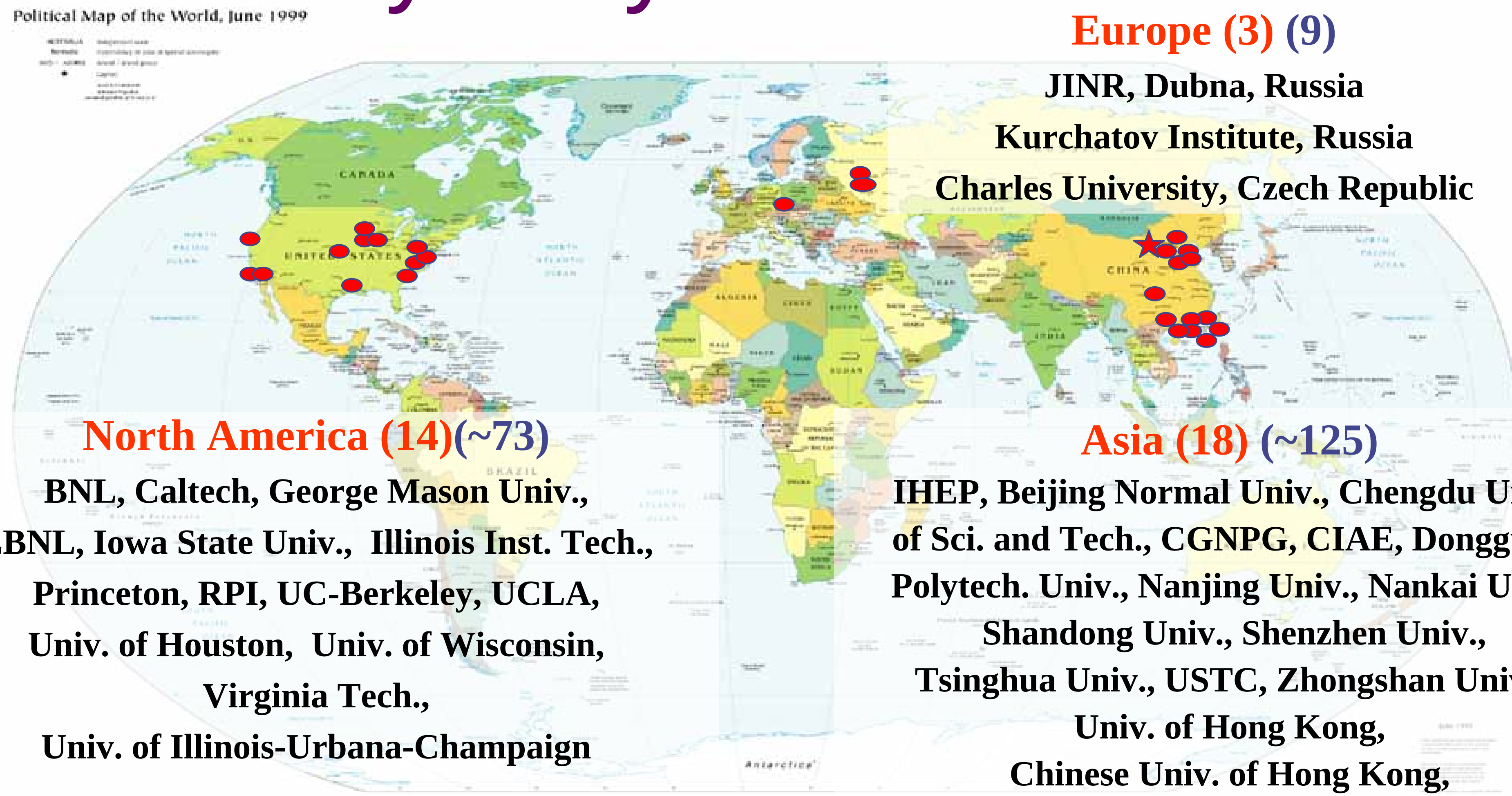


8 proposals

4 cancelled

4 in progress

The Daya Bay Collaboration



Europe (3) (9)

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

North America (14)(~73)

BNL, Caltech, 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) (~125)

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.

~ 207 collaborators

DayaBay and LingAo NPP

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

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

How to measure $\sin^2 2\theta_{13}$ to 0.01 of sensitivity—(1) High Statistics

- Integrated Luminosity: proportional to
  Power of reactor X Mass of target X Years
- For far site detectors, in 3 years: the IL of the three experiments is respectively: 250, 4200, 1038 (GW·T·Y)
- Statistical error is only 0.2% in 3 years, about 350 events/day.

Table Comparison of three experiments

Experiment	Power (GW)	Baseline near/far(m)	Target mass near/far(t)	Overburden (MWE)	Sensitivity (90%C.L.)
Double Chooz	8.4	150/1050	10/10	60/300	0.03
Dayabay	17.4	400/1800	40/80	300/1000	0.01
RENO	17.3	150/1500	20/20	230/675	0.03

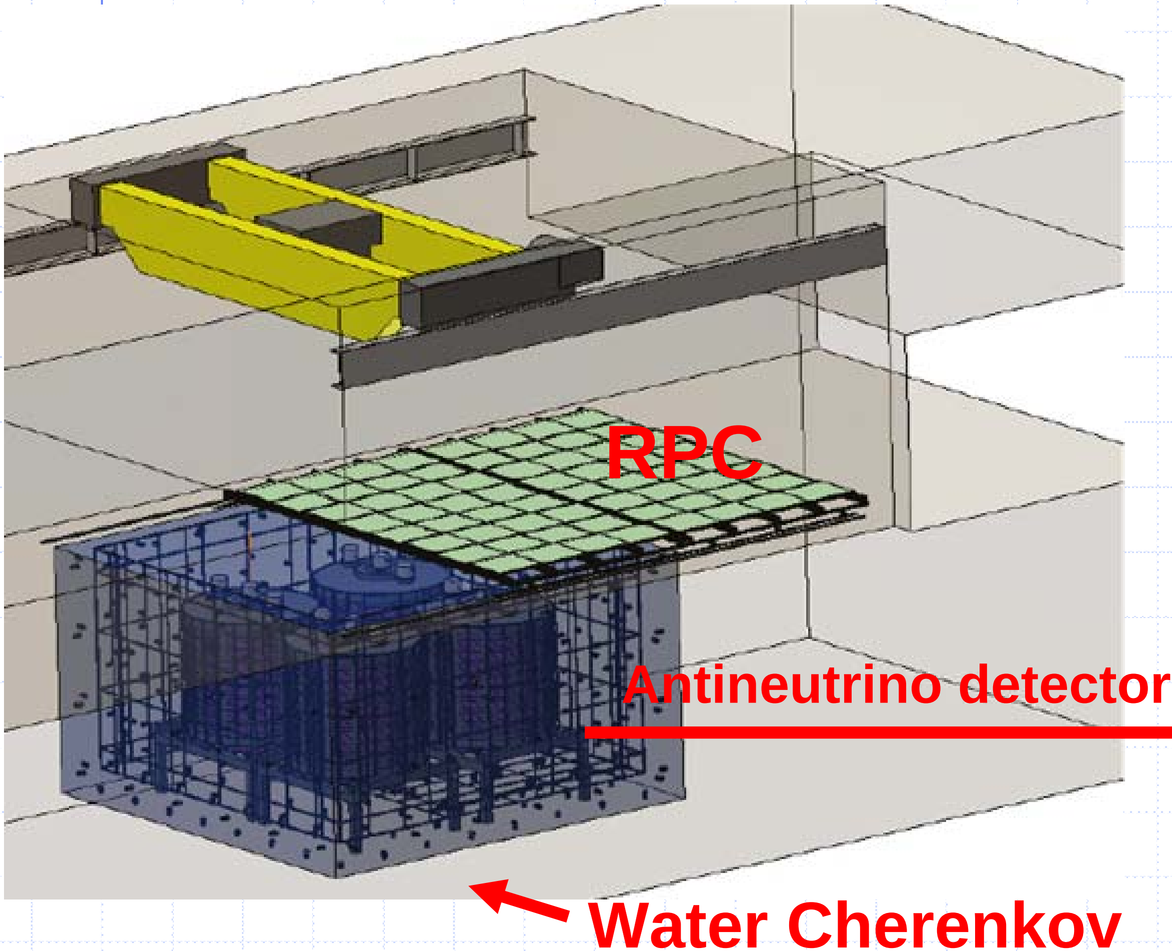
How to measure $\sin^2 2\theta_{13}$ to 0.01 of sensitivity—(2) Systematic error

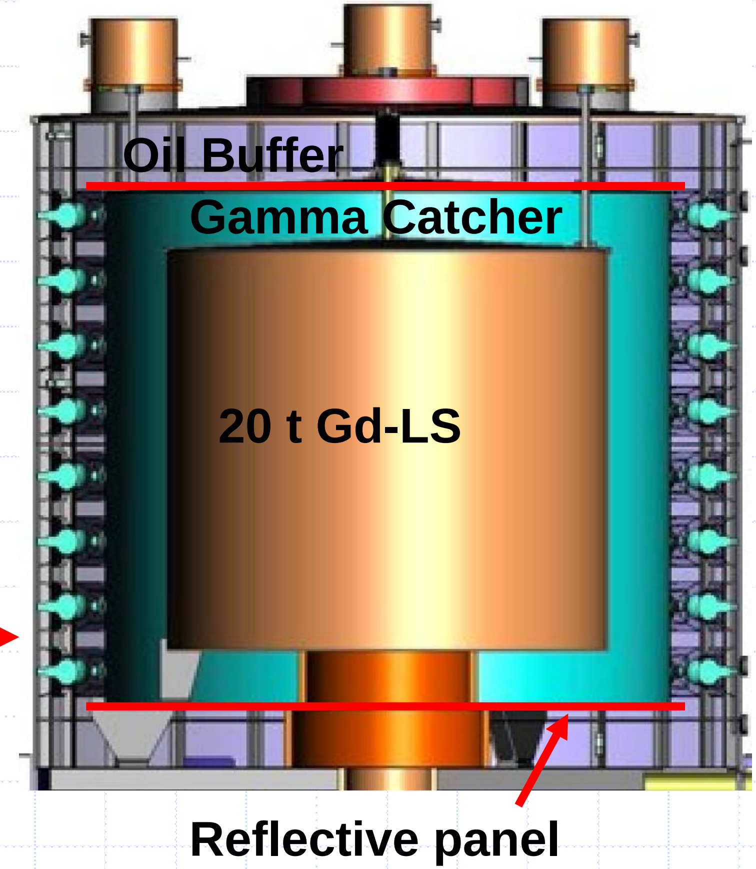
- Near and far detectors, check the reactor power
- Good and stable Gd-LS
- Background: Go deeper, good muon system
- Lower threshold
- Identical detectors: can be swapped to subtract the non-correlated error, like protons' number and efficiencies.

Source of uncertainty		Chooz (*absolute*)	Daya Bay (*relative*) Baseline	Goal	Goal w/Swapping
# protons		0.8	0.3	0.1	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%

Daya Bay Detectors

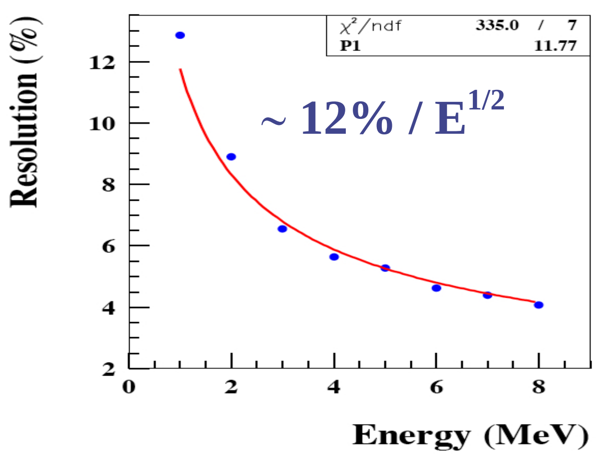
Two veto detectors,
Totally reject 99.5% cosmic ray
• RPC,
•Water Cherenkov

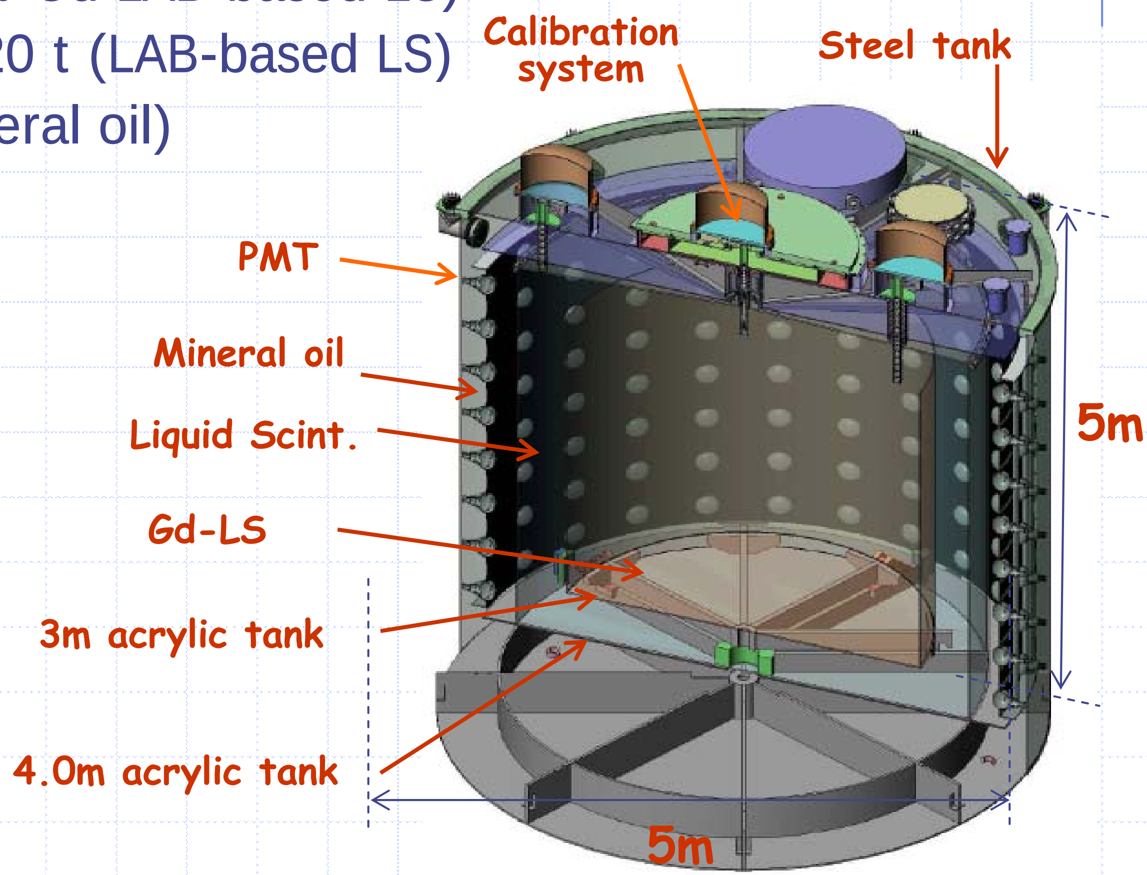




Deployment of Antineutrino Detector (AD)

- Three-zone nested cylindrical detector design
  - Target: 3m AV, 20 t (0.1% Gd LAB-based LS)
  - Gamma catcher: 4m AV, 20 t (LAB-based LS)
  - Buffer :5m SSV, 40 t (mineral oil)
- Low-background 8” PMT: 192
- Reflectors at top and bottom





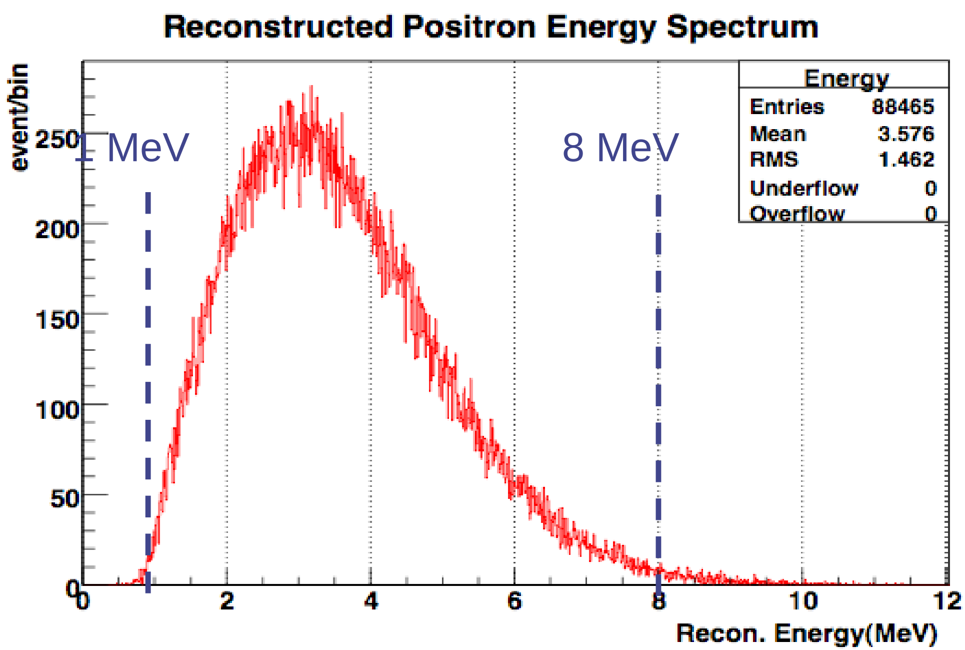
Antineutrino Detection principle

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

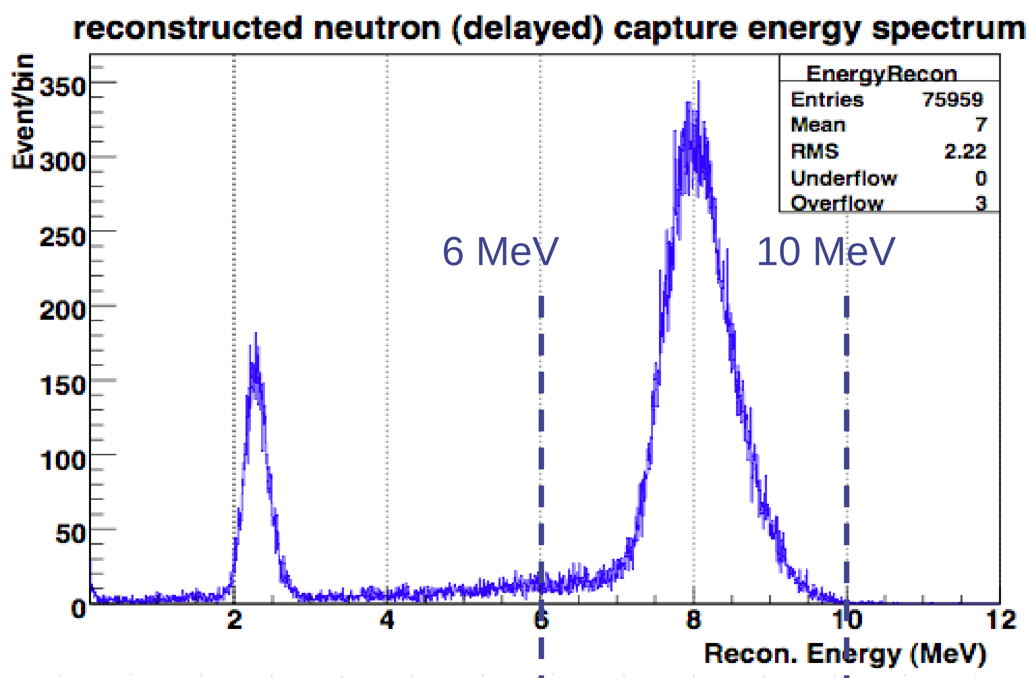
0.3 b $\rightarrow$ + p $\rightarrow$ D + γ (2.2 MeV) (delayed)

49,000 b $\rightarrow$ + Gd $\rightarrow$ Gd* $\rightarrow$ Gd + γ's (8 MeV) (delayed)

Prompt Energy Signal

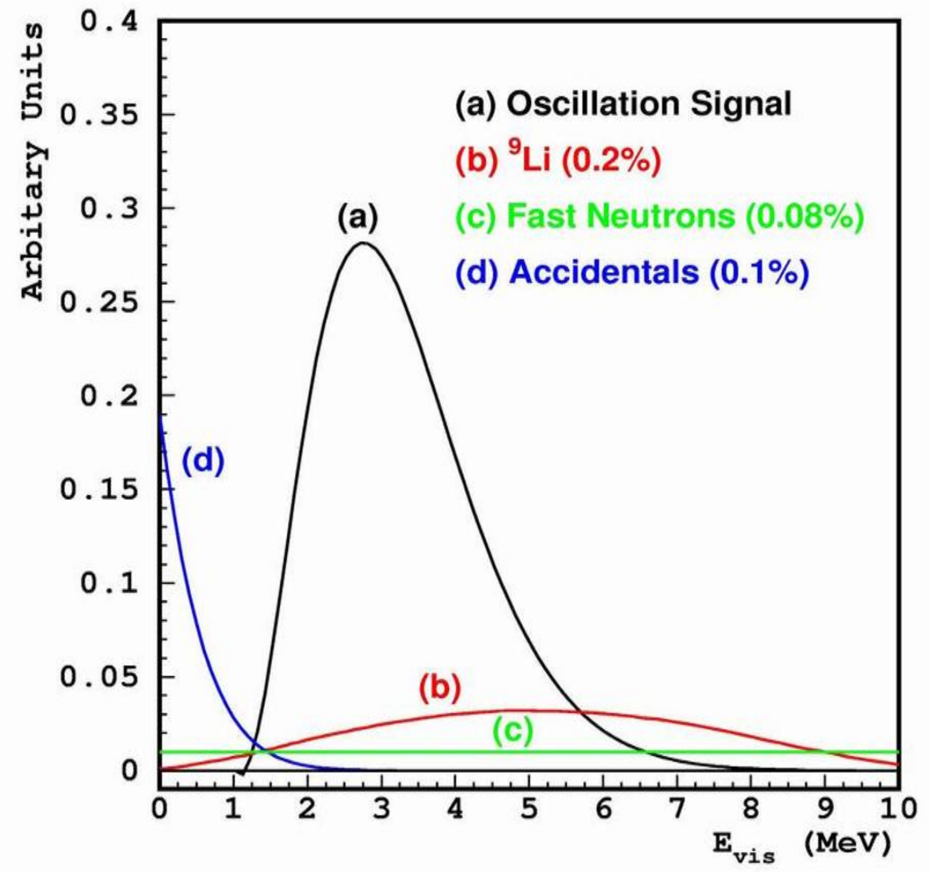


Delayed Energy Signal



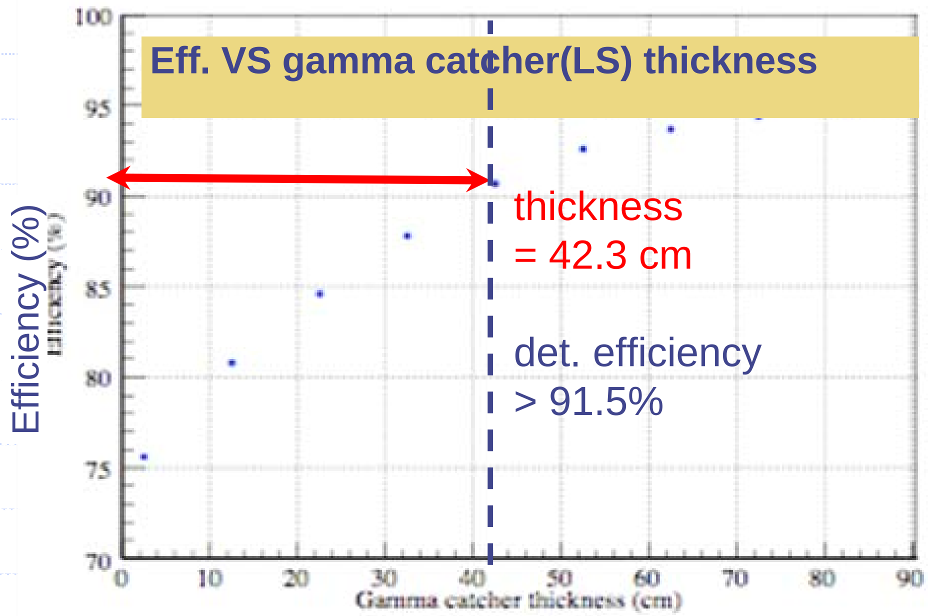
Signal and background

- ID
  - No position reconstruction
  - Time windows for two prompt and delayed signals:
  - Energy cuts
- BG
  - **^{8}He and ^{9}Li:** generated by cosmic ray, decays to βand n
  - **Fast Neutrons:** generated by cosmic ray, proton hit out give prompt signal, and slow neutron give delayed signal
  - **Occidentals:** natural radiation give prompt signal, cosmogenic neutron or β ray give delayed signal

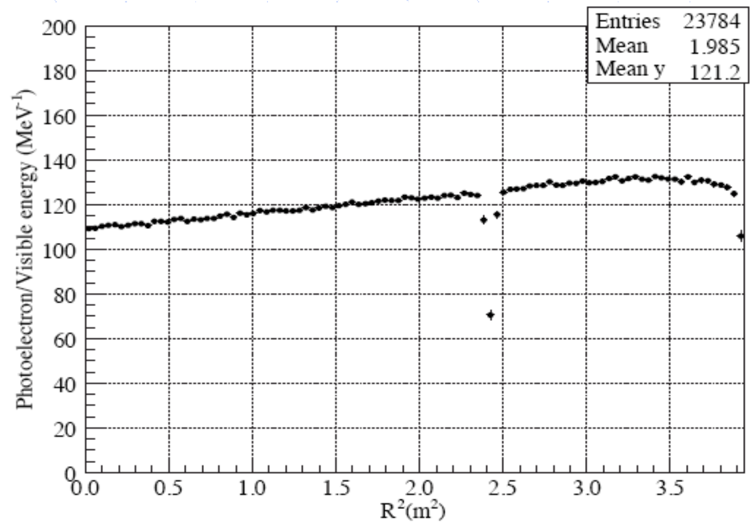


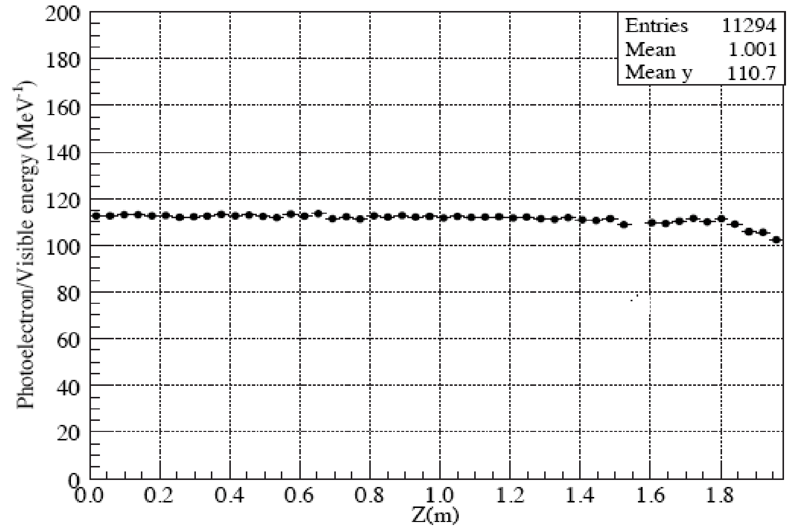
Simulation on AD

- GEANT4-based simulations
- Idealized 3-zone detector plus reflectors
- Developing realistic geometry in simulations



Uniformity of PE in R and Z direction

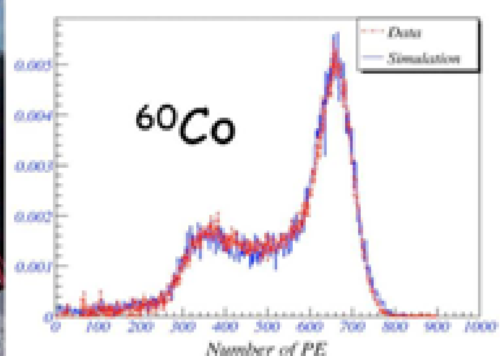


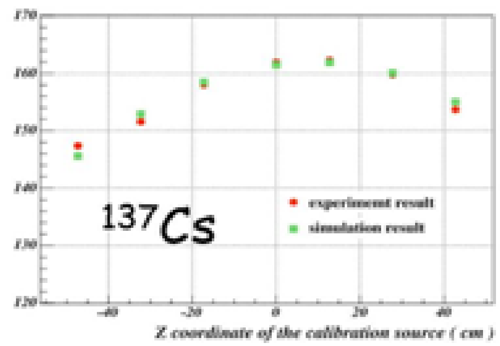


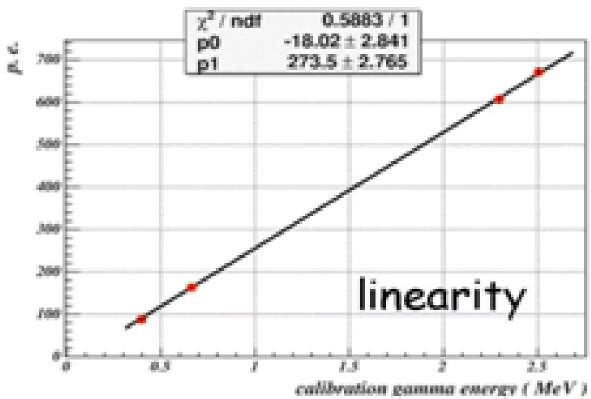
Prototype test (1)

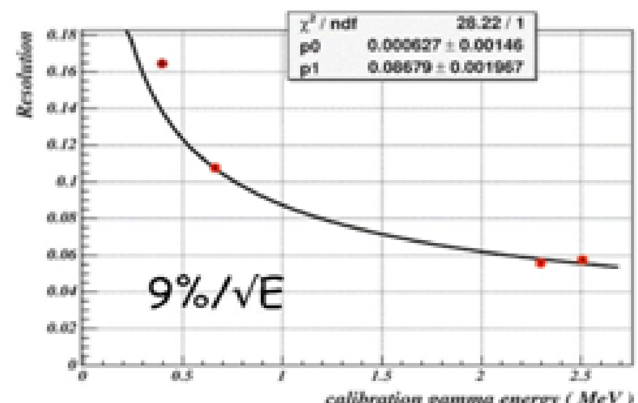
- 0.5 ton unloaded LS
- 45 8" PMTs with reflecting top and bottom

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





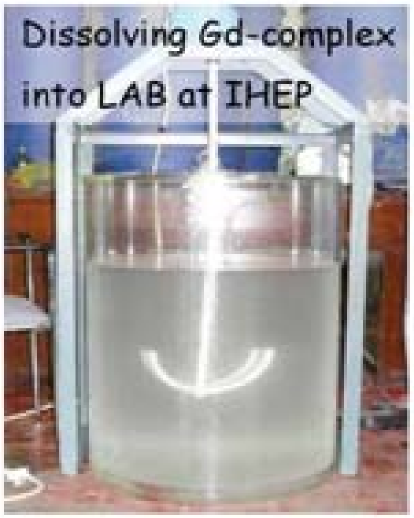




Kam-Biu Luk

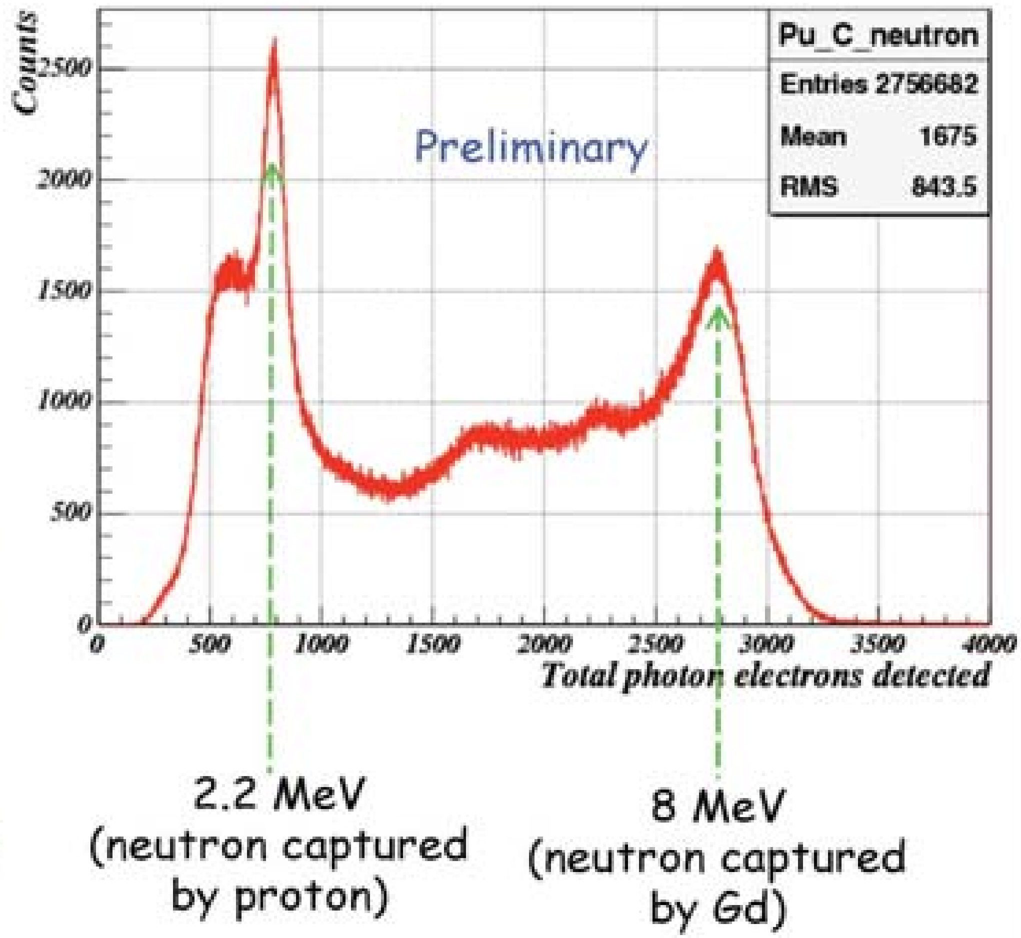
Daya Bay

Prototype test (2)



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.

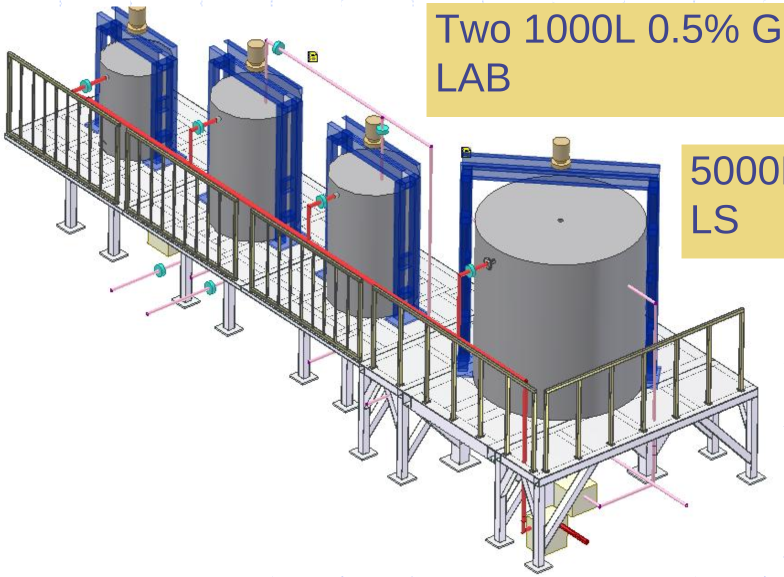


Gd-Liquid Scintillator Test Production

500L fluor-LAB

Two 1000L 0.5% Gd-LAB

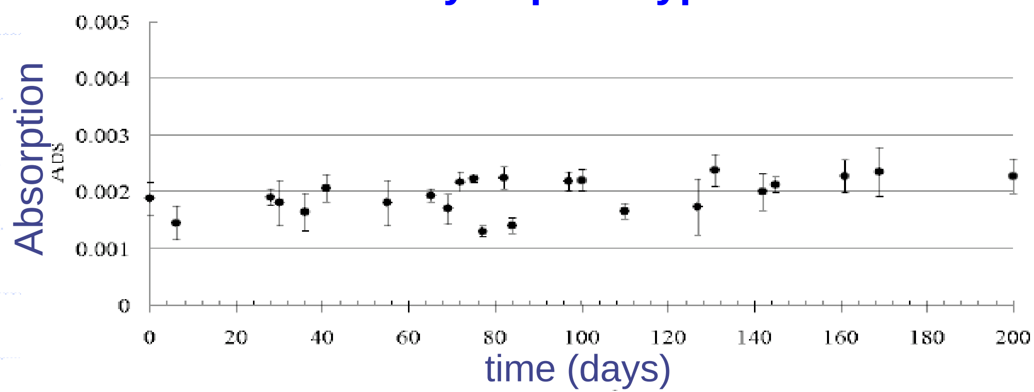
5000L 0.1% Gd-LS



0.1% Gd-LS in 5000L tank

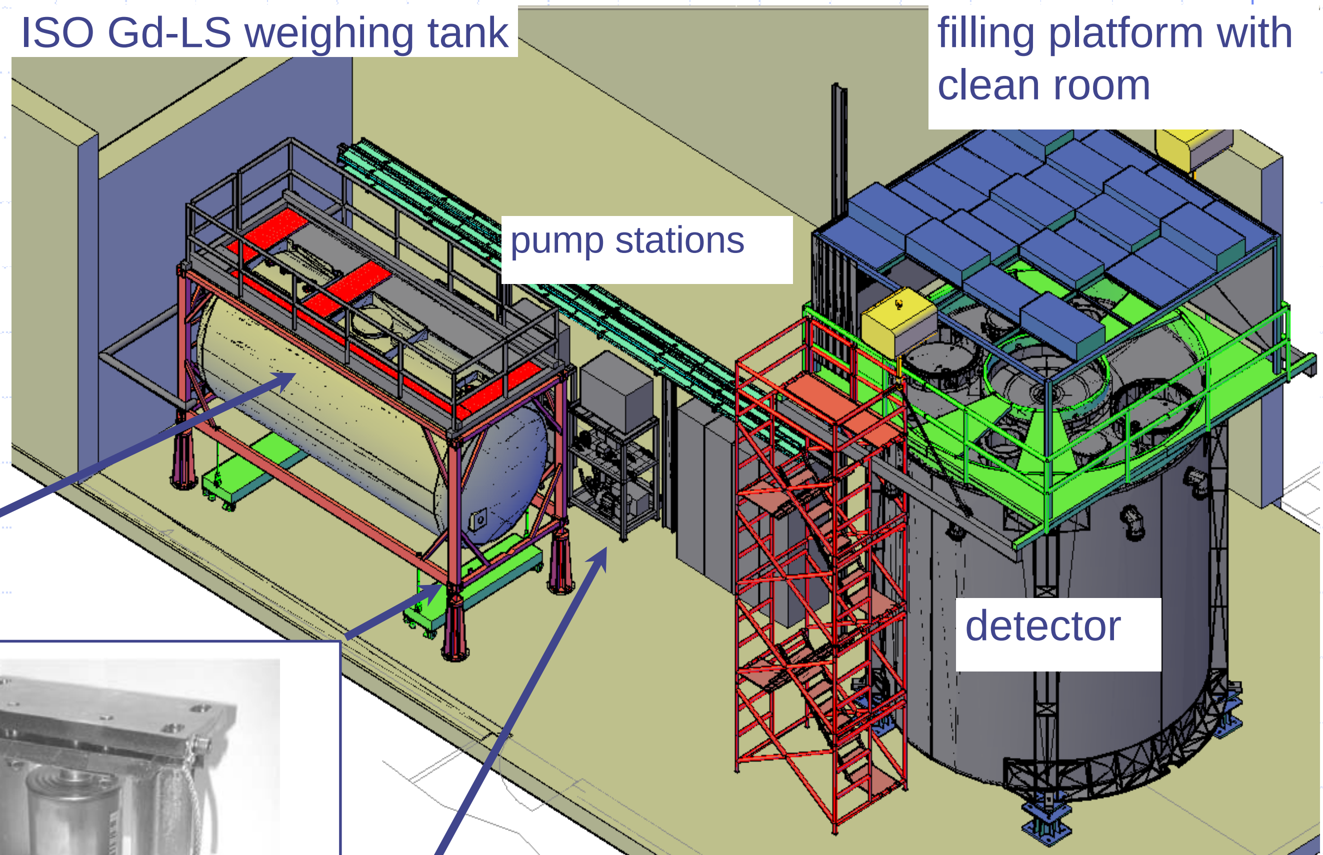
Gd-LS will be produced in multiple batches but mixed in reservoir on-site, to ensure identical detectors.

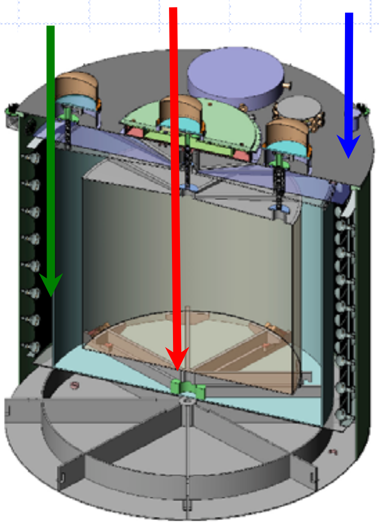
Gd-LS stability in prototype



Target Mass Measurement

20-ton, teflon-lined ISO tank

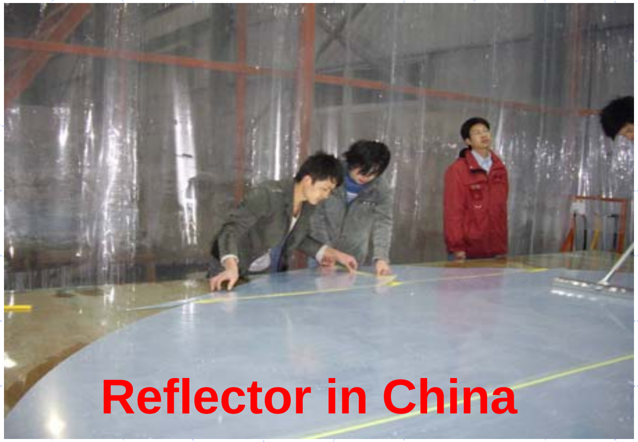




load cell
accuracy < 0.02%

Coriolis mass flow meters
< 0.1%

AD components

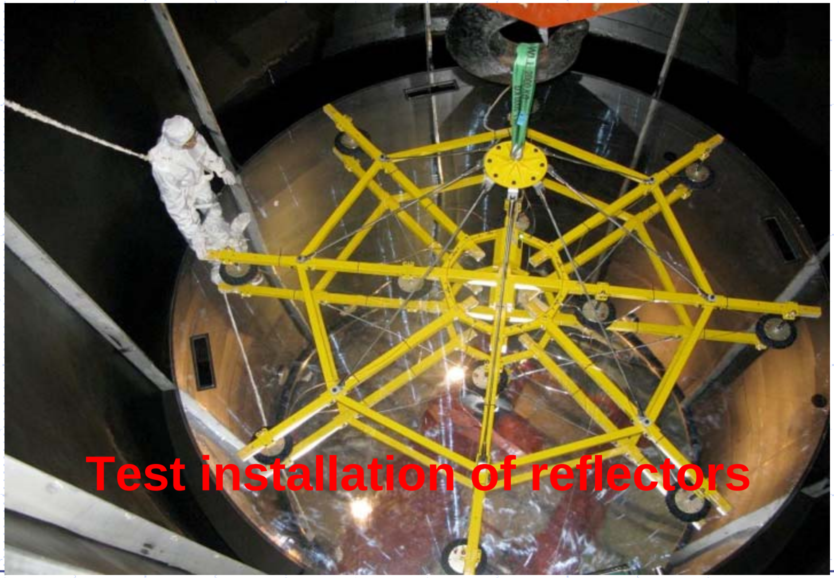

Reflector in China


1st SSV arriving at Dayabay


3m AV in Taiwan


4m AV in US

Test Assembly



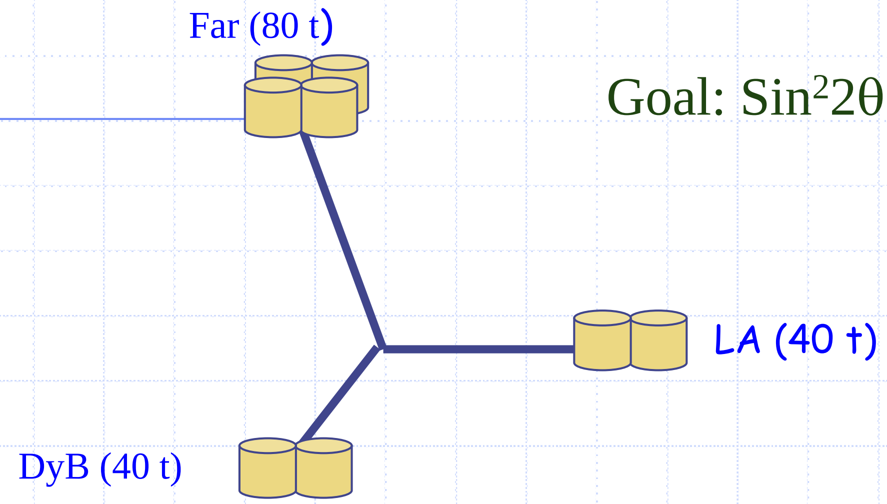
Civil construction

Summary

- Daya Bay experiment is designed to measure $\sin^2 2\theta_{13}$ to a sensitivity of <0.01 at 90% CL in 3 years of data taking. It is the most sensitive reactor θ_{13} experiment under construction.
- Special characters:
  - High powerful reactor and Relative big target mass, give low statistical error
  - Mountains around are useful to reduce the BG
  - 3-zone nested detector design of AD allows observation of antineutrino signal without position and fiducial cuts.
  - AD Relative detector systematic error < 0.38%.
- Civil and detector construction are progressing. Data taking at near site will begin in 2010.

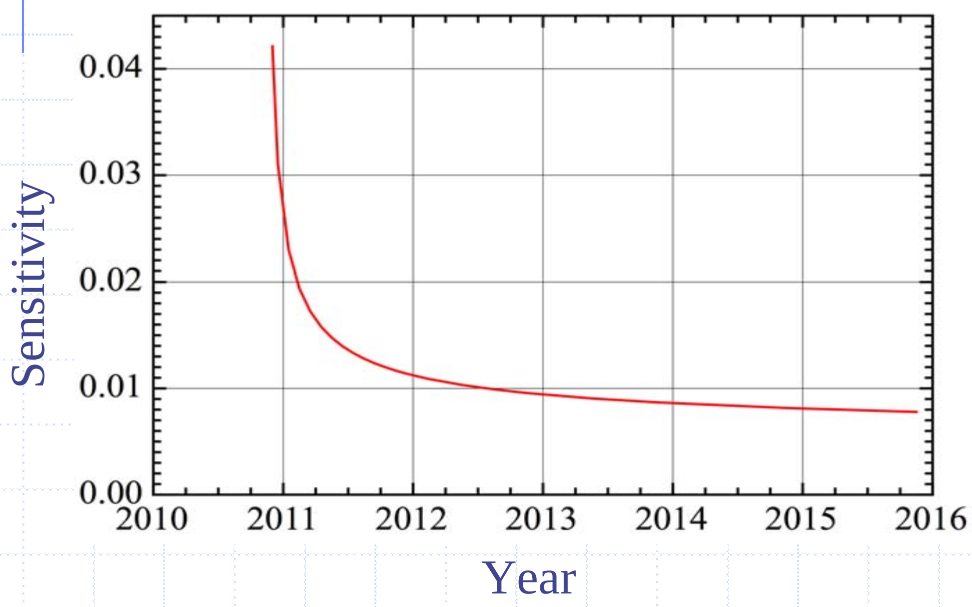
Thank you for your attention !

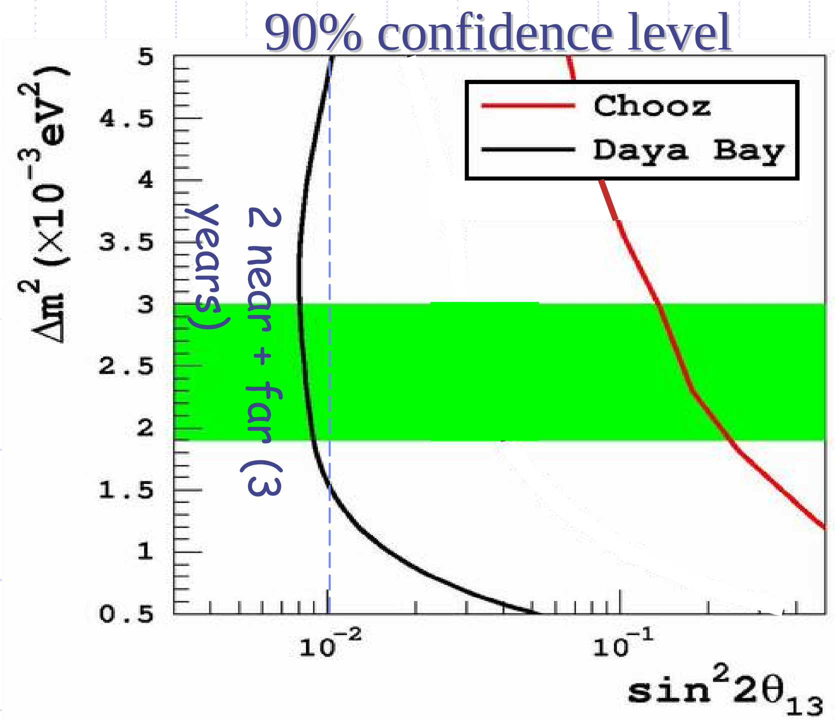
Sensitivity of Daya Bay



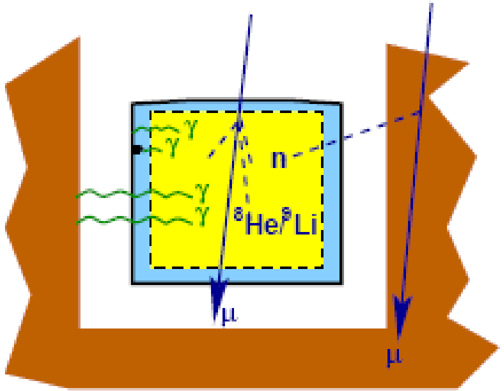
Goal: $\sin^2 2\theta_{13} < 0.01$

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





Background sources in the AD



Using a modified Gaisser parameterization and the DYB mountain profile the cosmic ray rates are:

	DYB	LA	Far
Overburden (m)	98	112	355
Muon intensity (Hz/m^2)	1.16	0.73	0.041
Mean Energy (GeV)	55	60	138

Source	Type	Rate/20T module (DYB/LA/FAR)
Rock	U/Th/K $\gamma > 1$ MeV	$\mathcal{O}$(MHz) w/o shielding!
SS vessel and welds	U/Th/K/Co	$\sim$ 20 Hz
PMT glass R5912	U/Th/k	$\sim$ 12 Hz
Cosmic muons	^{12}B/^{12}N β only	396/267/28
Cosmic muons	^{8}He/^{9}Li β-n	3.7/2.5/0.26
Cosmic muons	fast neutrons (2 subevents)	depends on shielding
Cosmic muons	neutrons (1 subevent)	depends on shielding

GOAL: Use a thick water shield to reduce neutron and rock γ bkgds

The He^8/Li^9 background

He^8/Li^9 generated by showers from cosmic muons in the AD LS:

$$^{9}Li \rightarrow \underbrace{e^-}_{\text{prompt}} + \bar{\nu}_e + ^{9}Be^* \rightarrow ^{8}Be + \underbrace{n}_{\text{delayed n-capture}}$$

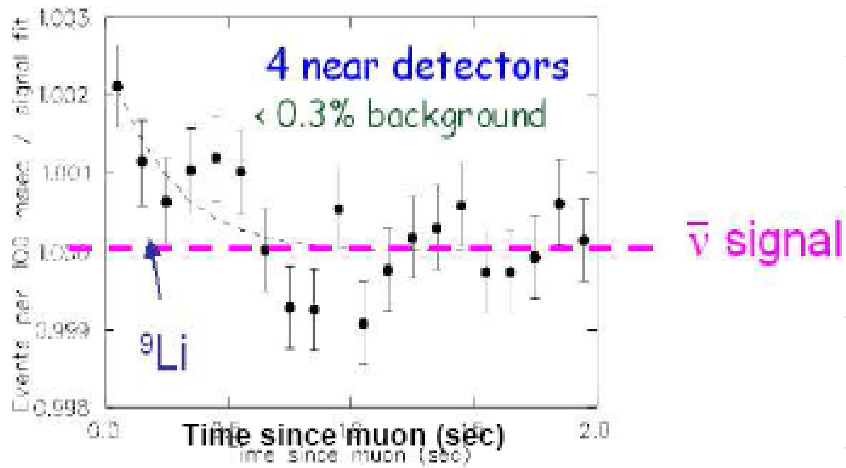
Q= 13 MeV, $\tau = 178$ msec $\Rightarrow$ poor spatial correlation with μ track.

Computed rates (Hagner et. al.) events/module/day:

	DYB	LA	Far
$\bar{\nu}_e$ IBD	840	740	90
$^{9}\mathrm{Li} + ^{8}\mathrm{He}$	3.7	2.5	0.26

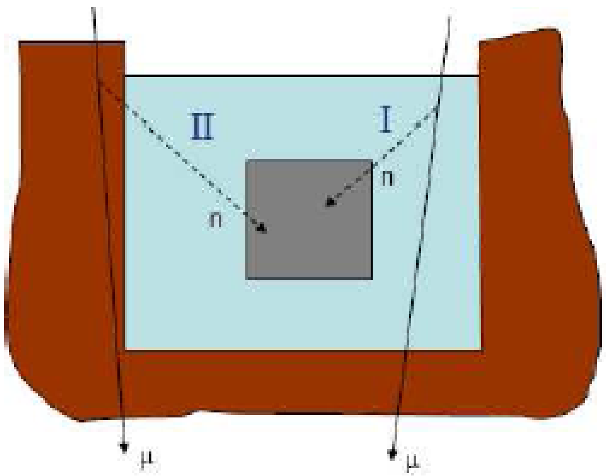
But it can be measured ! $\longrightarrow$

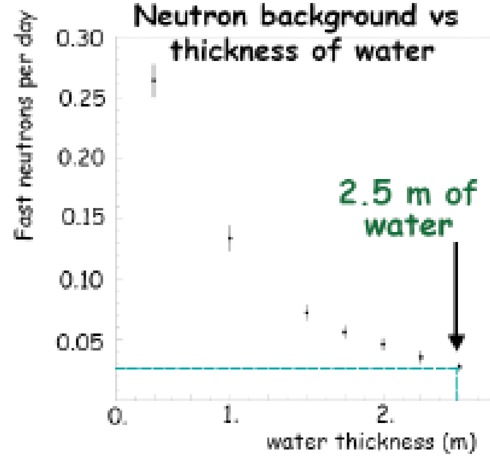
$B/S \approx 0.3\%$



Fast Neutron Background

$$n_{\rm fast} + p/n \rightarrow \underbrace{p/n}_{prompt} + \underbrace{n^*}_{delayed}$$





Fast neutron simulation results assuming active water shield with 99.5% muon tagging eff (events/day/20T module) :

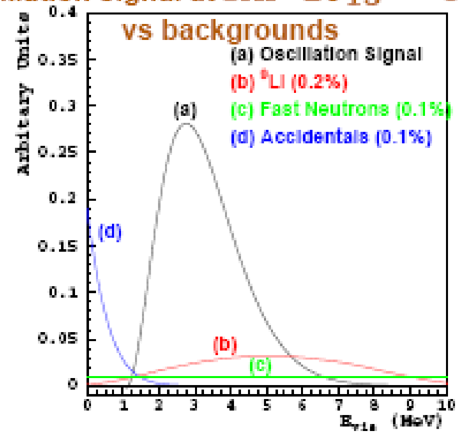
	I: From untagged μ	II:Rock neutrons	II:Total/Signal
DYB	0.10	0.5	6×10^{-4}
LA	0.07	0.35	6×10^{-4}
Far	0.01	0.03	4×10^{-4}

Accidental background rates

Prompt: $\gamma > $ 1MeV from radioactivity $\sim$ 40Hz/AD module with shielding

Delayed:: 1) untagged single neutron capture 2) cosmogenic beta emmiters (6-10MeV, mostly ^{12}B/^{12}N) 3)U/Th $\longrightarrow$ O, Si $(\alpha, n, \gamma[6-10\ \mathrm{MeV}])$

Oscillation signal at $\sin^2 2\theta_{13} = 0.01$ vs backgrounds



	DYB	LA	Far
Signal rates	840/day	740/day	90/day
1) neutrons (singles)	18/day	12/day	1.5/day
2) βs (singles)	210/day	141/day	14.6/day
3) $\alpha, n\gamma$ (singles)	$<$10/day	$<$10/day	$<$10/day
Coinc rate	2.3/day	1.3/day	0.26/day
B/S	$\sim 3 \times 10^{-3}$	$\sim 2 \times 10^{-3}$	$\sim 3 \times 10^{-3}$

Untagged background rates are tiny and subtractable