The Daya Bay Reactor Neutrino Oscillation Experiment

Measurement of θ_{13} Mixing Parameter

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Outline

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Motivation

$$\underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\theta_{23}\approx 45^\circ \text{ Atmospheric } \nu \text{ Accelerator } \nu} \times \underbrace{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix}}_{\theta_{13}<10^\circ \text{ Short-baseline Reactor } \nu \text{ Future accelerator } \nu} \times \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\theta_{12}\approx 35^\circ \text{ Solar } \nu \text{ Long-baseline Reactor } \nu}$$

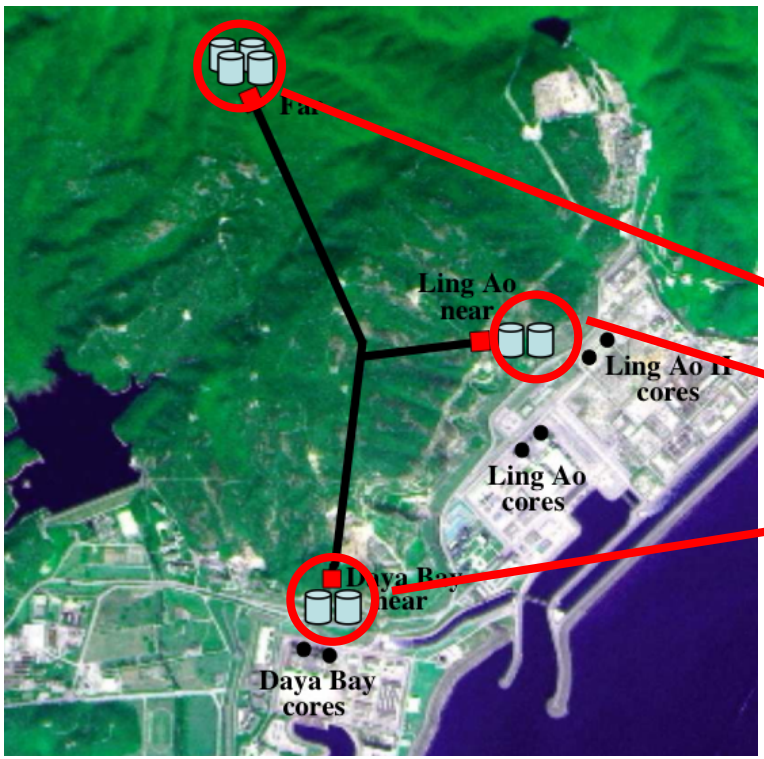
- Meassure θ_{13} with sensitivity of $\sin^2 2\theta_{13} < 0.01$ at 90% C.L.
- Currently known to be $\sin^2 2\theta_{13} < 0.19$ at 90% C.L. from the Chooz Reactor Neutrino Experiment in France
- Importance:
  - Is it possible to measure CP violation from neutrino oscillations: $P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) = \sin(2\theta_{12})\sin(2\theta_{23})\cos^2(\theta_{13})\sin(2\theta_{13})\sin\delta$
  - Mass hierarchy: $m_2 < m_3$ or $m_2 > m_3$
  - Help discriminate among theoretical models of mixing matrix

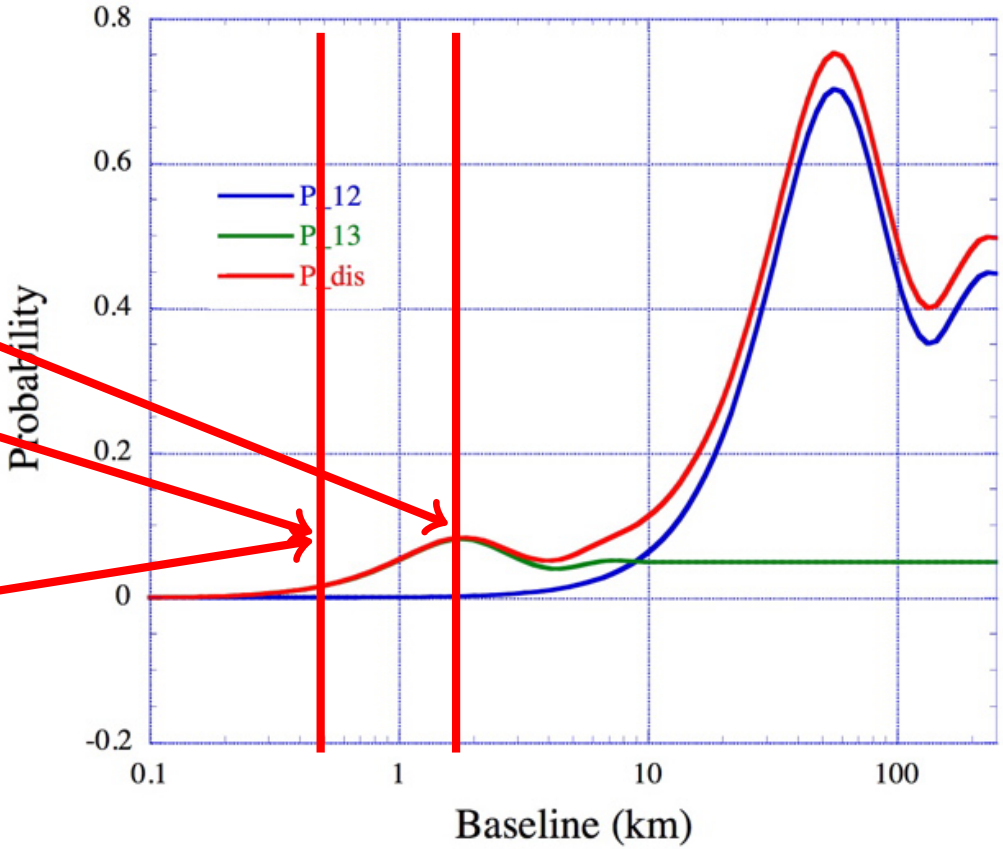
Location


RUSSIA
Lake Baikal
KAZAKHSTAN
Lake Baikhash
MONGOLIA
Harbin
Urumqi
Shenyang
KYRGYSTAN
Great Wall
Qinhuangdao
TAJIKISTAN
CHINA
BEIJING
Tianjin
KUNLUN MTNS
Qingdao
Lanzhou
Zhengzhou
Xi'an
Nanjing
PAKISTAN
KARAKORAM
HIMALAYAS
TIBET
Shigatse
Chengdu
Wuhan
Lhasa
NEPAL
Mt Everest
Chongqing
Yangtze
BHUTAN
INDIA
BANGLADESH
Guangzhou
Macau
Hong Ko
BURMA
(MYANMAR)
VIETNAM
INDIA
PACIFIC
BAY OF
BENGAL
LAOS
THAILAND
Hainan Dao
400 km
400 miles
km
mi
5
10
15
4
8
Tiantangwei
Longgang
Guanlan
Pingshan
Aotou
Shiyan
GUANGDONG
Niudipu
Longhua
Henggang
Buji
Kuiyong
Dapeng
Daya Bay
Nantou
Yantian
Xin'an
Shenzhen
Sha Tau Kok
Shatoujiao
Tai Pang Wan
Zhujiang Kou
Jiujie
Pak Shek Au
Man Uk Pin
Tong O
Tung Wan
Fanling
Lai Tau Shek
Cheung Wo
Shekou
San Tin
San Wai
Shuen Wan
Ting Kok
22° 30'
San Hing Tsuen
Hau Hoi Wan
Yung Shue Au
Kau Lau Wan
Yuen Long
Lin Fa Tei
Tai Po
Wu Lei Kiu
XIAOSANMEN DAO
Wu Kwai Sha
Tuen Mun
HONG KONG SAR (CHINA)
Wong Yi Chau
Sam Shing Hui
Tsuen Wan
Sai Kung
Sha Tsiu
Pak A
Pik Uk
Fu Tau Pun Chau
Sham Wan
Cheung Sha Wan
Kai Tak International Airport
Tsuen
Pa Tau Kwu
Kowloon
Yau Tong
Wo Sheung Au
KENNEDY TOWN
HAPPY VALLEY
TAI YUE SHAN
Sunset Peak
Victoria Peak 554 m (1818 ft)
Hong Kong
Tai O
Mount Collinson
Tong Fuk
Yi O San Tsuen
Stanley Mount
South China Sea
Fa Peng
Mount Stenhouse
Siu A Chau Tsuen
©2003 Microsoft Corp.
114°
114° 30'
MapPoint

On Site Layout

- 3 sites at different distances — 2x Near (2x2 detectors), 1xFar (4 detectors)





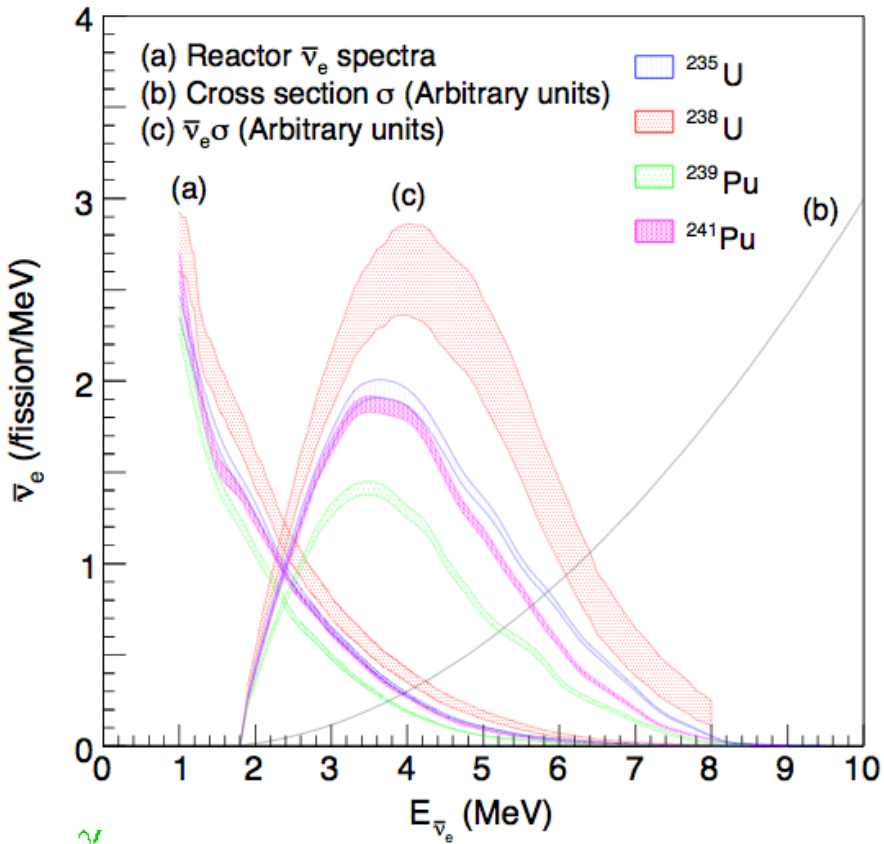
Distance from detectors to reactor cores in meters

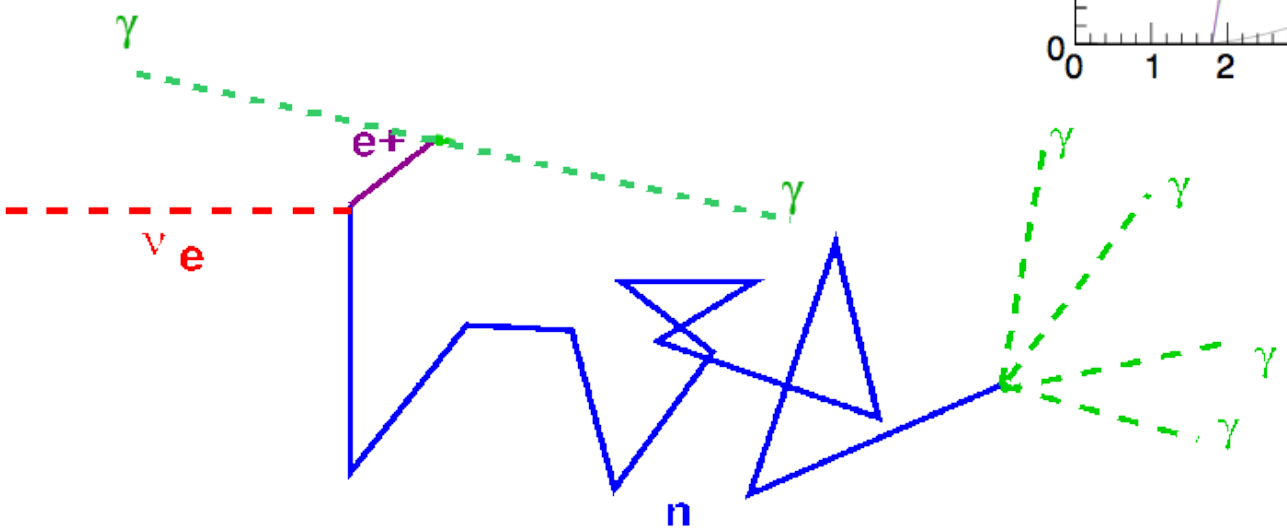
Reactors	Experimental site		
	DyB	LA	Far
DayaBay	363	1348	1986
LingAo I	857	481	1618
LingAo II	1307	526	1613
Overburden	98	112	355

Reactor Thermal Output: 11.6 GW now, 17.4 GW in 2011

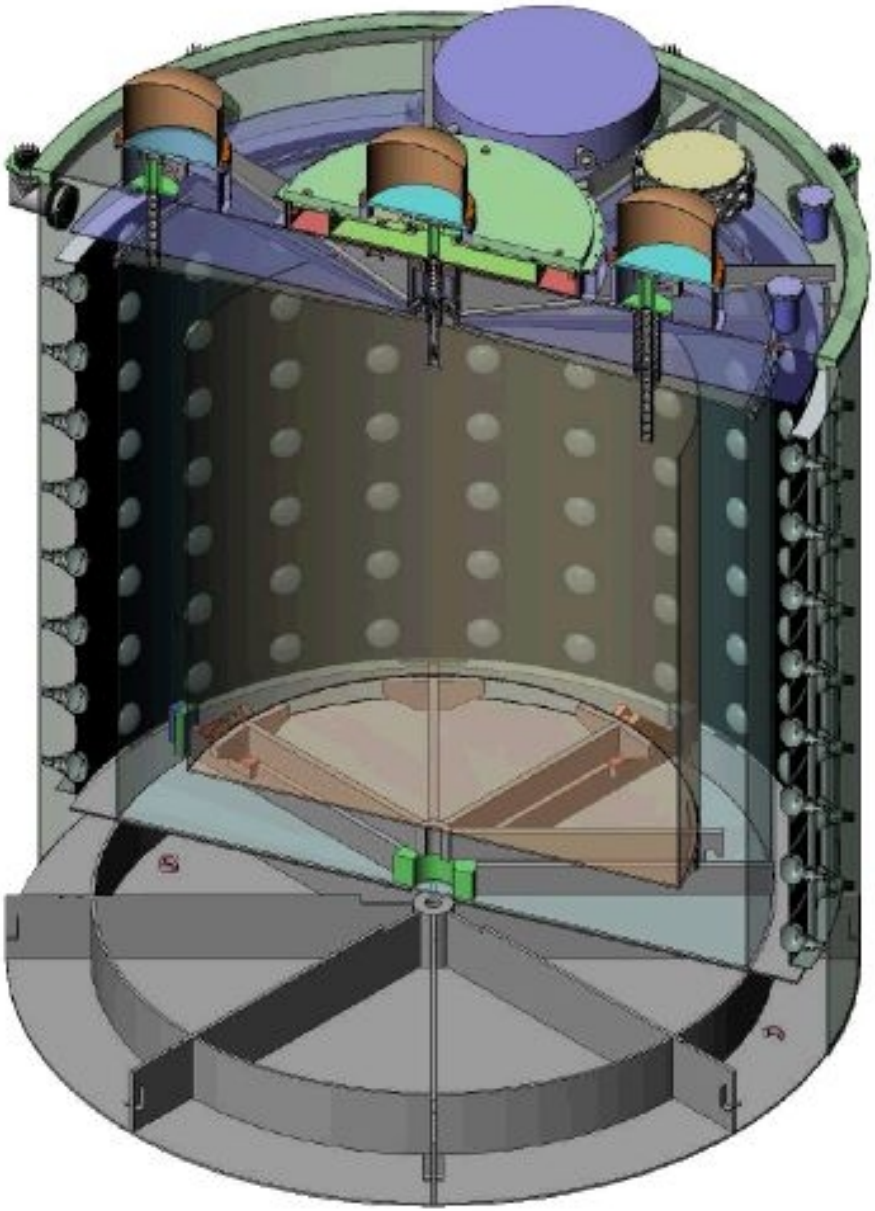
$\bar{\nu}_e$ Detection Method

- Inverse β-decay :
  $\bar{\nu}_e + p \rightarrow e^+ + n$
- Trigger on 2-fold coincidence:
  - Prompt signal from e^+
  - Delayed signal from n capture on Gadolinium $\approx 30\mu$s
- Detector with Gd doped Liquid Scintillator (LS)



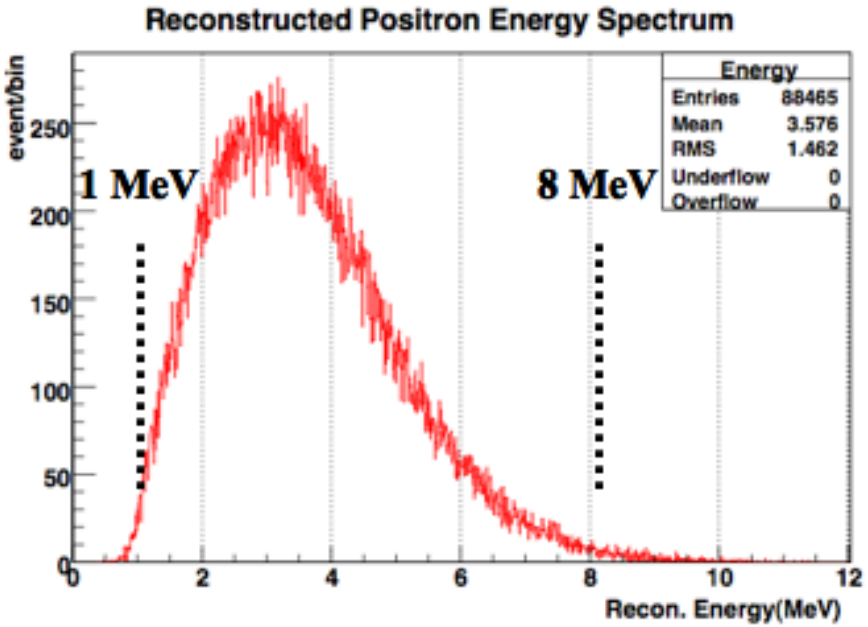


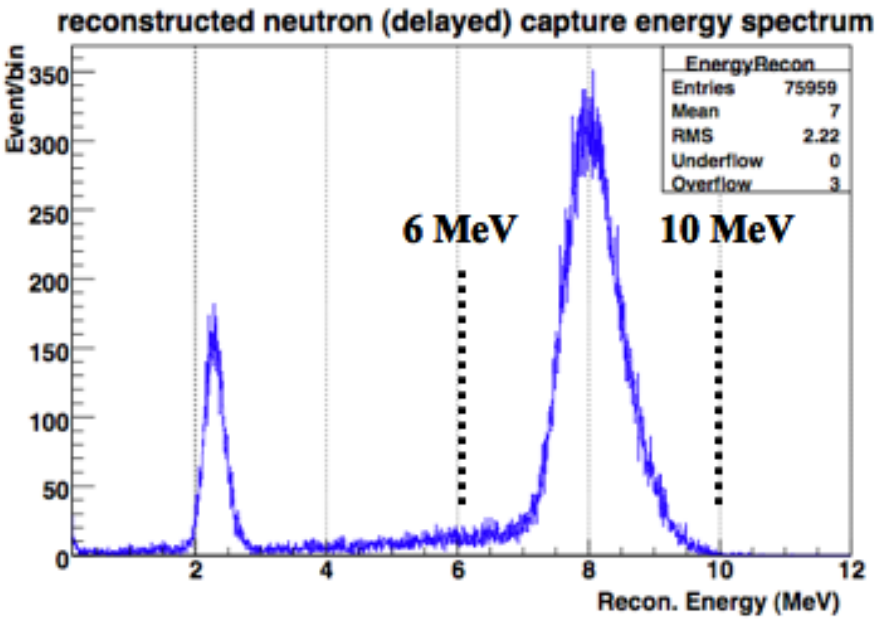
Detector



- Cylindrical 3-Zone Structure separated by acrylic vessels
  - Target: Inner 20t GdLS (0.1% of Gd, d=3m)
  - γ-catcher: Mid 20t LS (d=4m, ≈42cm thick)
  - Oil Buffer: Outer 40t mineral oil (d=5m, ≈49cm thick)
- 192 8-inch PMTs
- $12\%/E(\mathrm{MeV})$ energy resolution
- Reflectors on top and bottom

Signals





Site	Signal/day/module
Daya Bay	840
Ling Ao	760
Far Site	90

- Positron energy cuts at 1 – 8 MeV
- Neutron capture energy cut at 6 MeV
- Time cut 0.3 – 200μs

Systematic Uncertainties

Detector related uncertainty

Source of uncertainty		Detector Systematic Uncertainties	
		Conservative	Goal
# protons		0.3	0.1
Detector Efficiency	Energy cuts	0.2	0.1
	Time cuts	0.1	0.03
	H/Gd ratio	0.1	0.1
	n multiplicity	0.05	0.05
	Trigger	0.01	0.01
	Live time	<0.01	<0.01
Total		0.38%	0.18%

Reactor related uncertainty

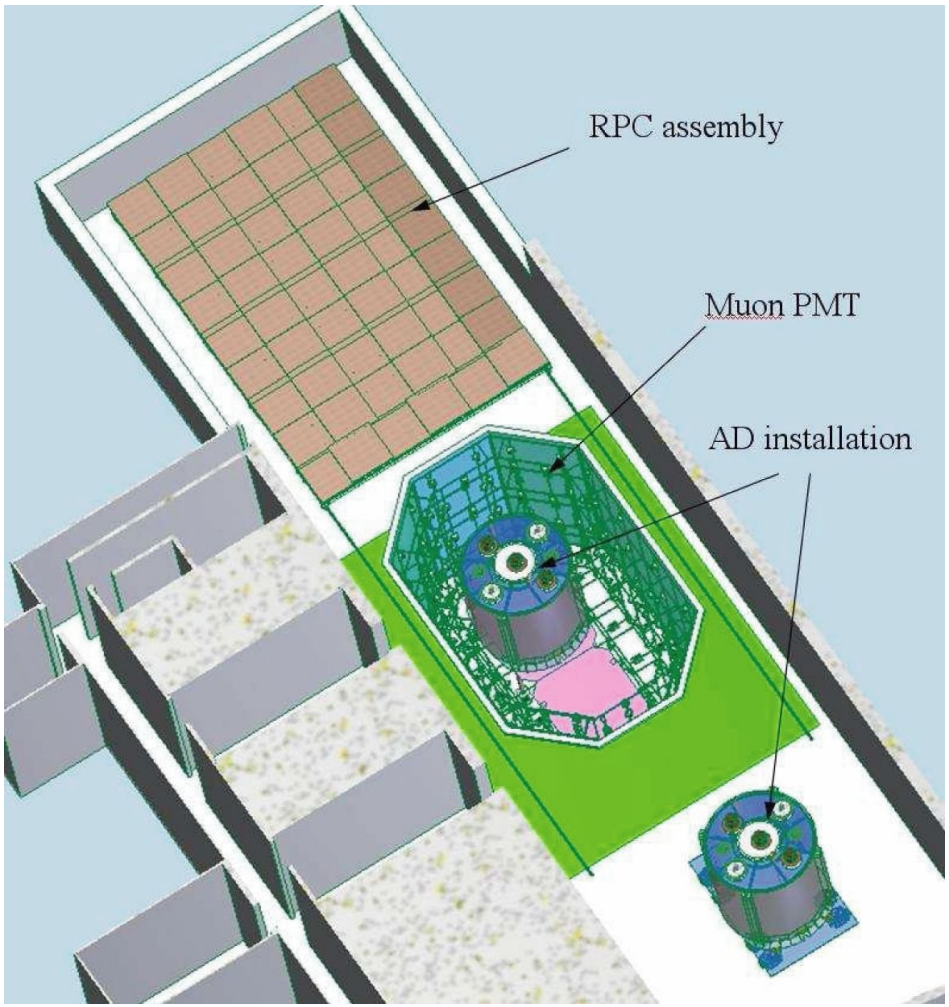
Number of cores	Power	Location	Total
4	0.035%	0.08%	0.087%
6	0.097%	0.08%	0.126%

Backgrounds

- Accidental coincidence of uncorrelated signals — natural radioactivity
- Correlated signals from fast neutrons — spallation processes of muons in surrounding rock
- β–delayed neutron decays of $^{9}\mathrm{Li}$ and $^{8}\mathrm{He}$ — products of muonic showers

	DYB	LA	Far
Fast n/signal	0.1%	0.1%	0.1%
$^{9}\mathrm{Li}$, $^{8}\mathrm{He}$/signal	0.3%	0.2%	0.2%
Accidentals/signal	$<$0.2%	$<$0.2%	$<$0.1%

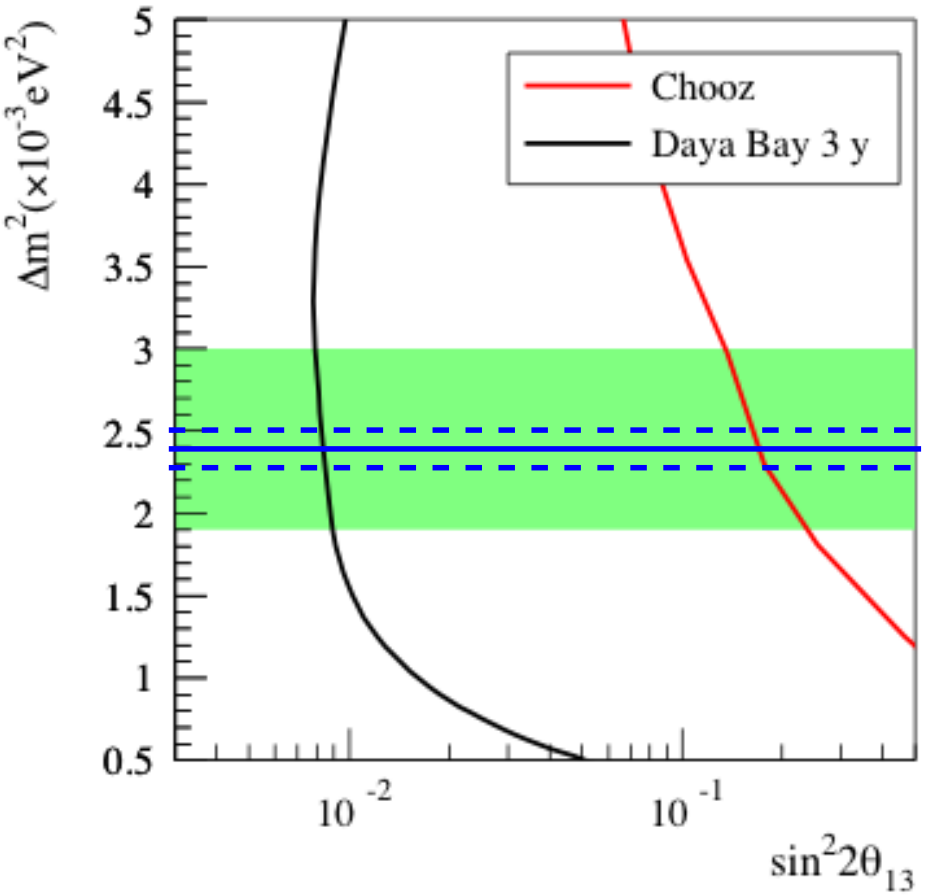
Muon veto system

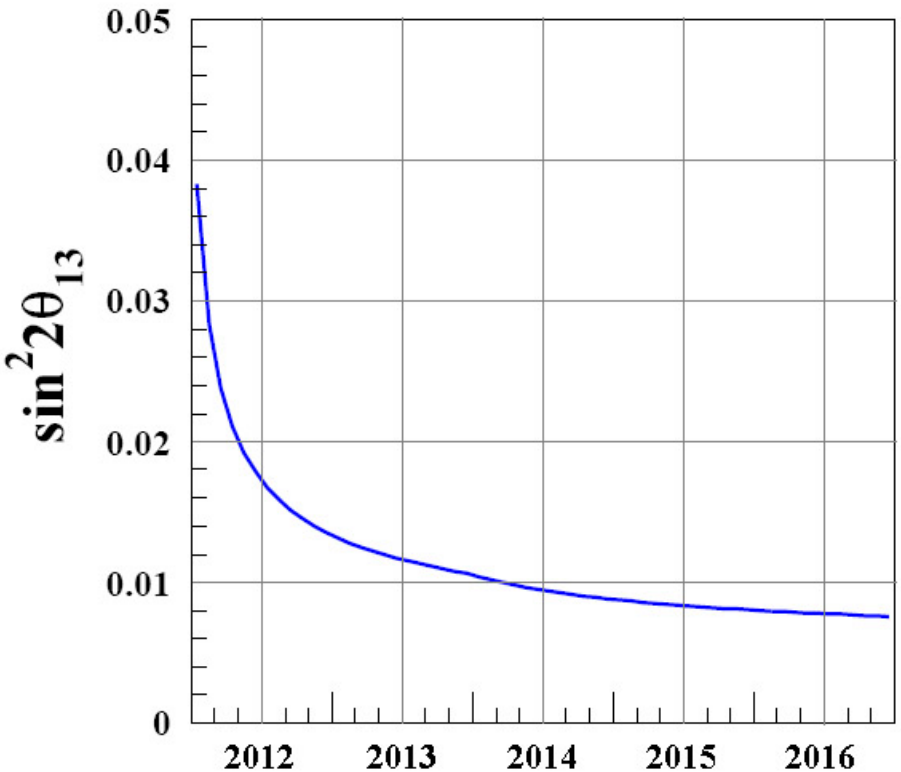


- Multiple muon veto detectors
- Water Čerenkov
  - ADs submerged in water, provide $\geq$ 2.5m shielding against radioactivity
  - Inner/Outer regions optically separated
  - 8-inch PMTs on frames (289/near, 384/far site)
- RPC—Resistive Plate Chamber
  - 4 layers in modules
  - Layer of modules covers water pool
  - Provides independent veto system
- Combined efficiency of both systems $>$ 99.5%

Sensitivity

- 90% C.L. after 3 years of data taking assuming baseline systematics, compared to Chooz results





$\Delta m^2 = 0.0025\ eV^2$

- Green band is 90% C.L. limits from atmospheric neutrino experiments
- Best fit and 1σ errors from MINOS
  ref. arXiv:0808.2016v2

Status

- Excavation continues, more than 1,700m of tunnels excavated
- Prototype detector assembled with 4m acrylic vessel and PMT support ladders

Schedule

- October 2007: Ground breaking
- Spring 2008: CD 3 reviews completed
- Upcomming months: First AD complete, "dry run" test starts
- Summer 2010: Daya Bay Near Hall ready for data
- Summer 2011: Far Hall ready for data

Collaboration

Region	Institutions	Members
China	13	102
Czech	1	4
Hong Kong, China	2	15
Russia	2	5
Taiwan, China	3	13
USA	14	88
Sum	35	227

Backup slides

Systematic Uncertainties

Source of uncertainty		Chooz (absolute)	Daya Bay (relative)		
			Conservative	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 uncertainty (detector-related)		1.7%	0.38%	0.18%	0.12%