Status of the The Daya Bay Experiment

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on behalf of the Daya Bay Collaboration

Japan-US seminar on Double Beta Decay and Neutrinos, Hawai'i, October 11-13, 2009

Obligatory neutrino matrix slide

$|\nu_f\rangle = \sum_i U^*_{fi}|\nu_i\rangle$ Interaction eigenstates $\neq$Mass eigenstates

$c_{ij} \equiv \cos\theta_{ij}$, $s_{ij} \equiv \sin\theta_{ij}$

$$U_{if} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} K_{0\nu\beta\beta}$$

$\theta_{23} \approx 45^\circ$
Atmospheric ν
Accelerator ν

$\theta_{13} < 10^\circ$
Short-baseline Reactor ν
Future accelerator ν

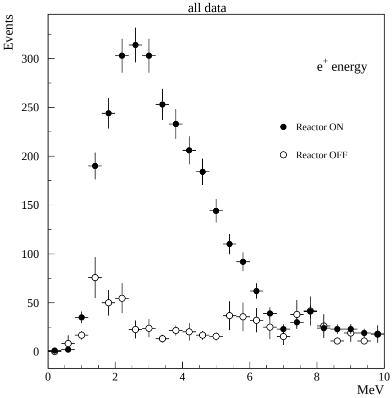
$\theta_{12} \approx 35^\circ$
Solar ν
Long-baseline Reactor ν

Daya Bay design sensitivity: $\sin^2 2\theta_{13} < 0.01$ (90%CL)

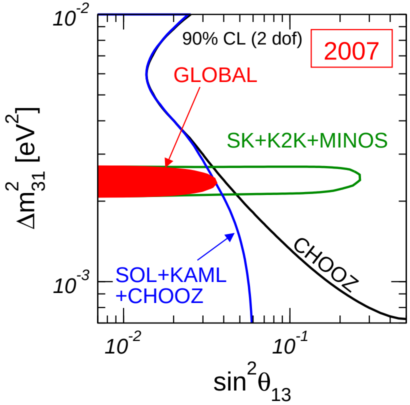
Short-baseline Reactor $\bar{\nu}_e$ is a disappearance experiment:

$$\mathcal{P}(\bar{\nu}_e \to \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2(1.27\Delta m^2_{31} L/E)$$

Chooz: Best experimental limit on θ_{13}

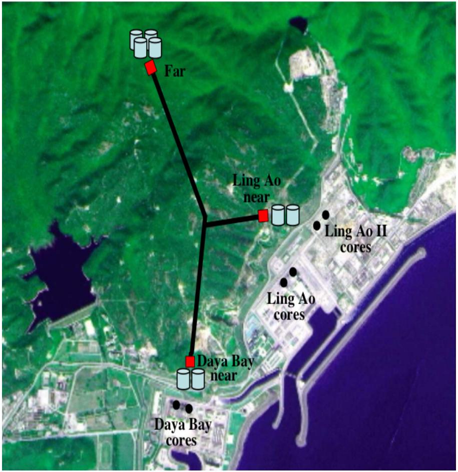


5 ton target exposed to 2 reactors, total thermal power 8.5 GW, 1 km baseline
Phys.Lett.B**466** (1999) 415



Recent global ν analysis
`arXiv:0710.5027`

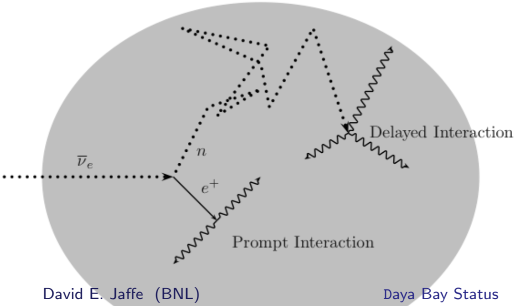
Getting to $\sin^2 2\theta_{13} < 0.01$

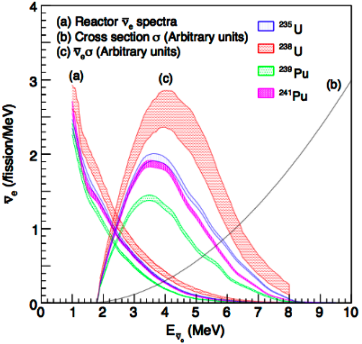


- *Increase statistics:* 4× 20 ton target at far site, 11.6 $\mathrm{GW_{th}}$ (17.4 $\mathrm{GW_{th}}$ in 2011). $1\ \mathrm{GW_{th}} = 2 \times 10^{20} \bar{\nu}_e/\mathrm{s}$
- *Suppress cosmogenic background:* Go deeper.
- *Reduce systematic uncertainties:* Deploy "identical" near/far detector pairs.
- *Optimize baseline*

$\bar{\nu}_e$ detection method

- Inverse-beta decay: $\bar{\nu}_e p \rightarrow e^+ n$
- Target: 0.1% Gd-loaded Liquid Scintillator
  $nGd \rightarrow Gd^* \rightarrow Gd + \gamma s(8\ \mathrm{MeV})$
- $\sim 30\mu s$ mean neutron capture time
- Delayed coincidence provides powerful background rejection



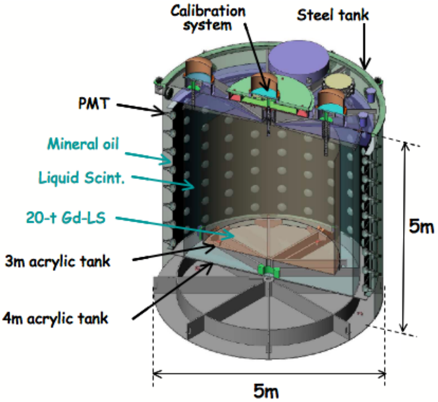


Reactor anti-neutrino spectrum

arXiv:physics/0607126

Anti-neutrino Detectors (ADs)

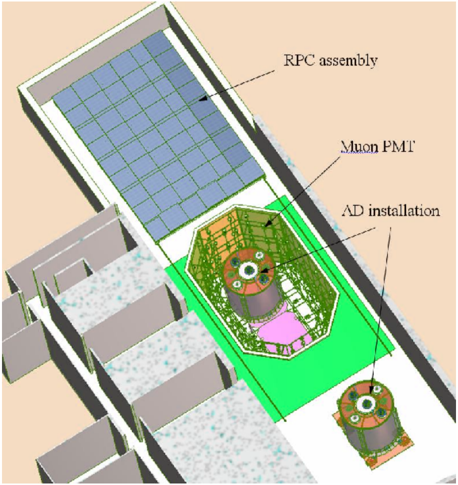
- 8 identical detectors: Reduce systematic uncertainties
- Each detector 3 nested cylinders:
  1. Inner: 20t GdLS [a] (d=3m)
  2. Mid: 20t LS [b] (d=4m)
  3. Outer: 40t mineral oil (d=5m
- 192 8-inch PMTs/detector
- Top/bottom reflectors
- Provides $12\%/\sqrt{E(\mathrm{MeV})}$ energy resolution



[a] GdLS=Gd-loaded Liquid Scintillator
[b] LS=Liquid Scintillator

More details in Dan Dwyer's presentation

Cosmic veto and shielding



- Multiple muon veto detectors
- Water Čerenkov
  - ADs submerged in water ($\geq$ 2.5m shielding)
  - Inner/Outer regions optically separated by Tyvek sheets
  - 8-inch PMTs on frames (289/near, 384/far site)
- RPC: Provides independent veto above water pool

More details in Qing He's presentation

Reducing systematic uncertainties

Detector Uncertainty Source		Baseline	Goal	Chooz Experience
Number of protons		0.3%	0.1%	0.8%
Detection Efficiency	Energy cuts	0.2%	0.1%	0.8%
	H/Gd ratio	0.1%	0.1%	1.0%
	Time cut	0.1%	0.03%	0.4%
	Neutron mult.	0.05%	0.05%	0.5%
	Trigger	0.01%	0.01%	0.01%
	Live time	$< 0.01\%$	$< 0.01\%$	$< 0.01\%$
Total Uncertainty		0.38%	0.18%	1.7%
		Two detector **relative** uncertainty		One detector **absolute** uncertainty

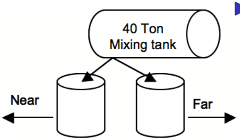
Requirements on systematic uncertainties

$$\frac{N_\mathrm{f}}{N_\mathrm{n}} = \left(\frac{N_\mathrm{p,f}}{N_\mathrm{p,n}}\right)\left(\frac{L_\mathrm{f}}{L_\mathrm{n}}\right)^2\left(\frac{\epsilon_\mathrm{f}}{\epsilon_\mathrm{n}}\right)\frac{\mathcal{P}(L_\mathrm{f}, E; \sin^2 2\theta_{13})}{\mathcal{P}(L_\mathrm{n}, E; \sin^2 2\theta_{13})}$$

Measured ratio of rates

Number of protons

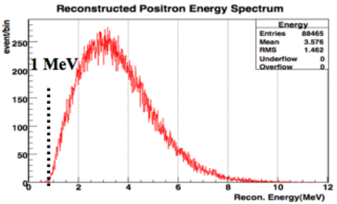
Efficiency ratio

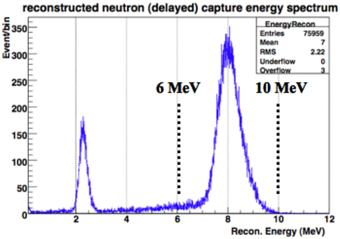


- Attain $\leq 0.3\%$ on proton ratio by monitoring filling mass with load cells(accuracy $< 0.02\%$) and Coriolis mass flowmeters(accuracy $< 0.1\%$). Fill ADs in pairs.
- Attain $\leq 0.2\%$ on efficiency ratio with calibration

More details on calibration system in Kim Boddy's presentation

Detector efficiency





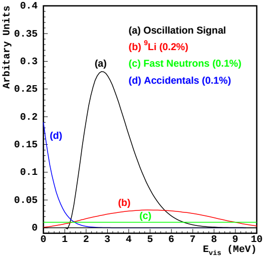
Simulation: Achieving 0.2% eff'y systematic, implies knowing e^+ threshold to 2% (easy) and relative neutron threshold to 1% (more difficult)

- Positron energy cuts at 1 & 8 MeV. Calibrate e^+ threshold with ^{68}Ge source.
- Neutron capture energy cut at 6 MeV. Calibrate with spallation nGd capture over full fiducial volume + weekly deployment of AmC source on 3 vertical axes.

Background processes and rates

Background due to natural radioactivity & cosmic ray interactions

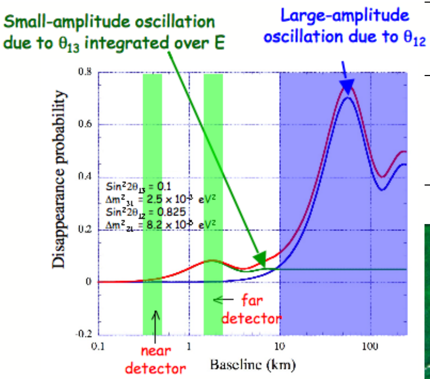
1. Muon interactions in the LS produce $^{9}\mathrm{Li}/^{8}\mathrm{He}$. A β^-, *n* emitter with Q=13 MeV, τ=0.178s. Expect bkgd/signal ∼0.003. Can be measured with data (NIMA**564**(2005)081801).
2. Muon interactions outside AD in water and rock produce "fast" neutrons that interact in GdLS, LS. Expect bkgd/signal ∼0.001. Can estimate rate from data and simulation.
3. Accidental coincidences of radioactive background with cosmogenic background. Expect bkgd/signal ∼0.01. Calculable from observed singles rates.



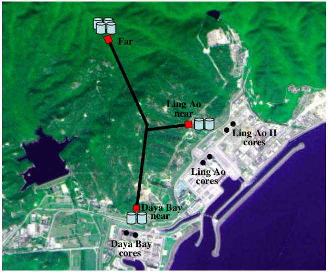
Oscillation signal for $\sin^2 2\theta_{13} = 0.01$

Optimize baseline

$$1-\mathcal{P}(\bar{\nu}_e \rightarrow \bar{\nu}_e) = \sin^2 2\theta_{13} \sin^2 \frac{1.27\Delta m^2_{31} L}{E} - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \frac{1.27\Delta m^2_{21} L}{E}$$

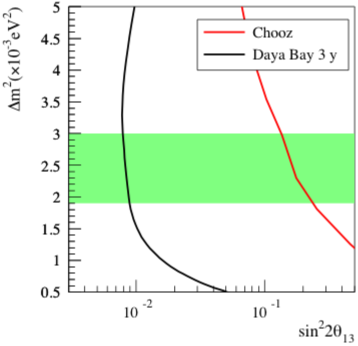


(meters)	Expt'l site		
Reactors	DyB	LA	Far
DayaBay	363	1348	1986
LingAo I	857	481	1618
LingAo II	1307	526	1613
Overburden	98	112	355

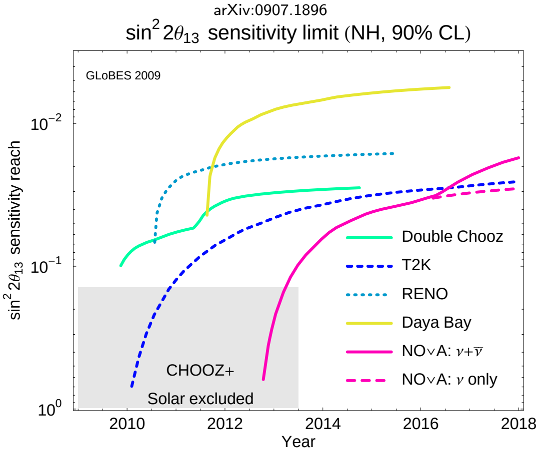


Expected sensitivity

90% CL limit on $\sin^2 2\theta_{13}$ assuming baseline systematics

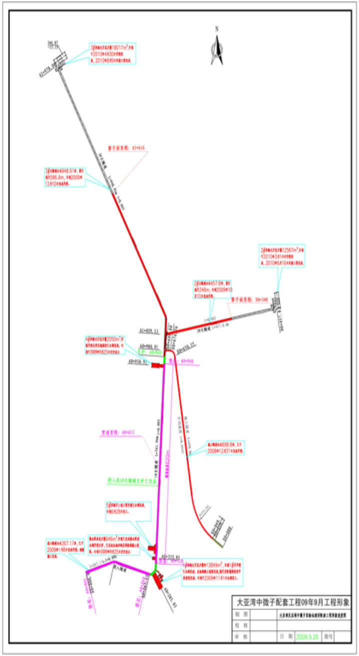


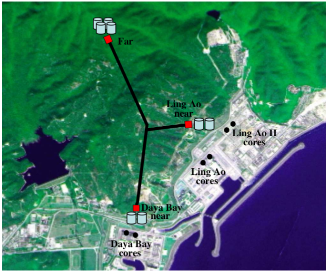
3 years of data



Sensitivity comparison

Civil construction





Excavated, paved and lighted tunnel

Milestones and Assembly

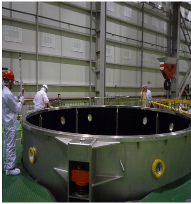
Oct 07 Ground breaking

Spring 08 CD3 review completed

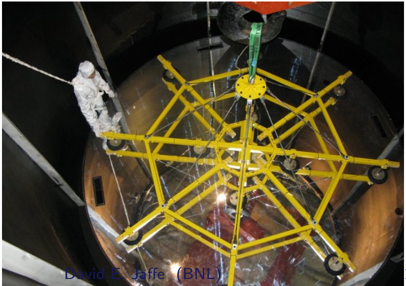
Mar 09 Surface Assembly Building occupied

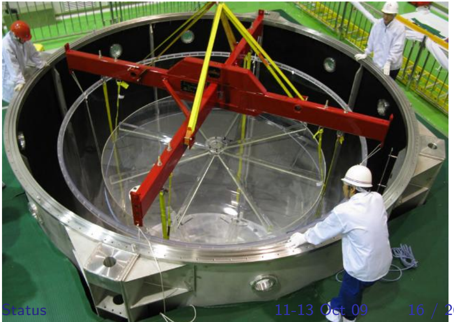
Summer 10 Daya Bay near hall ready for data

Summer 11 All 3 halls ready for data

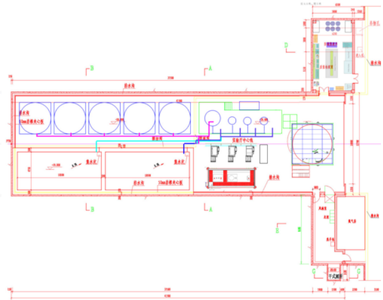


Antineutrino detector test assembly





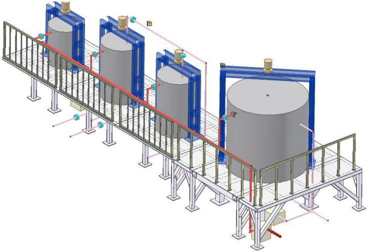
Liquid-filling hall status



Gd – Liquid Scintillator test production

Require 200 ton 0.1% gadolinium-loaded liquid scintillator (Gd-LS).

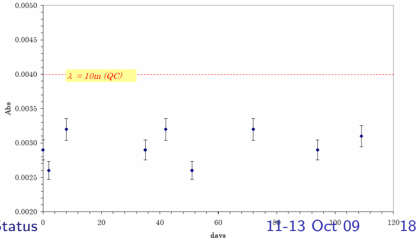
4 ton test batch 2009/03



0.1% Gd-LS in 5000L tank.

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

At right: Gd-LS absorption stable for 120 days and $\lambda > 10$m



The last slide

- The Daya Bay Reactor Anti-neutrino Experiment will provide the most accurate measurement of $\sin^2 2\theta_{13}$ in the next few years.
- Civil construction and detector fabrication is progressing.

Stay tuned for the following Daya Bay presentations:

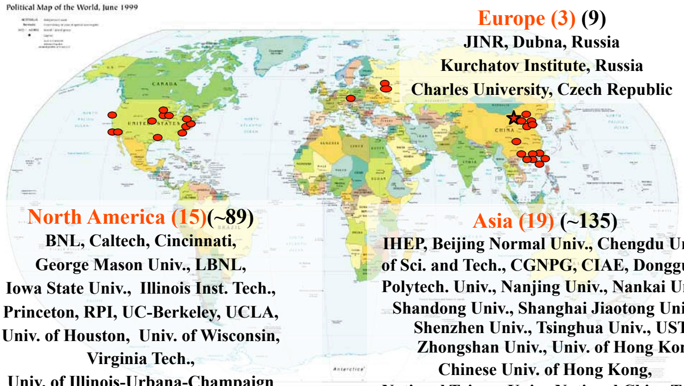
Calibration System	K. Boddy
Anti-neutrino Detector -Testing and Commissioning	D. Dwyer
Muon System	Q. He

Many thanks to my Daya Bay colleagues in helping prepare these slides.

Extra

The Daya Bay Collaboration

The Daya Bay Collaboration



Europe (3) (9)
JINR, Dubna, Russia
Kurchatov Institute, Russia
Charles University, Czech Republic

North America (15)(~89)
BNL, Caltech, Cincinnati, 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 (19) (~135)
IHEP, Beijing Normal Univ., Chengdu Univ. of Sci. and Tech., CGNPG, CIAE, Dongguan Polytech. Univ., Nanjing Univ., Nankai Univ., Shandong Univ., Shanghai Jiaotong 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.

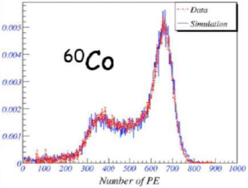
~ 233 collaborators

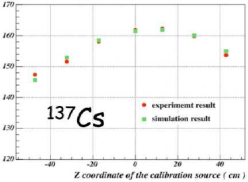
2

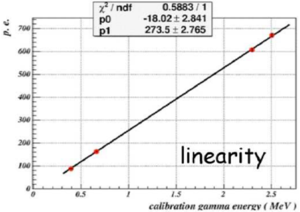
Prototype Antineutrino Detector Performance

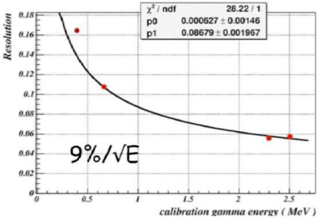
2-zone Prototype at IHEP

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



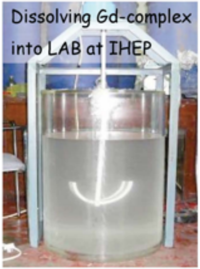


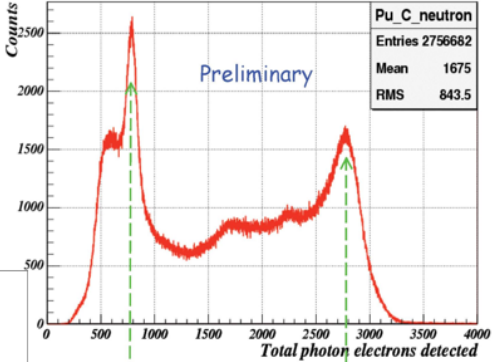




Prototype filled with 0.1% GdLS

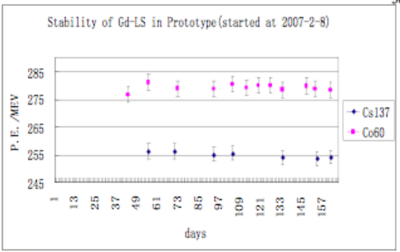
IHEP Prototype Filled With 0.1% Gd-LS





2.2 MeV
(neutron captured
by proton)

8 MeV
(neutron captured
by Gd)



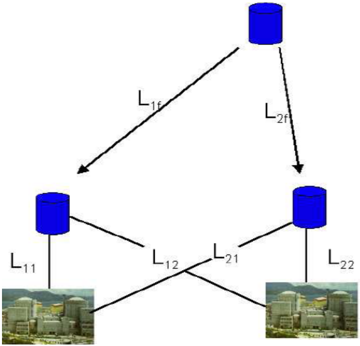
Daya Bay

Cancellation of Flux Uncertainty with Multiple Reactors

Q: Cancellation $\bar{\nu}_e$ flux uncertainty with multiple reactor sites?

A: Deweight the oversampled cores by a factor α:

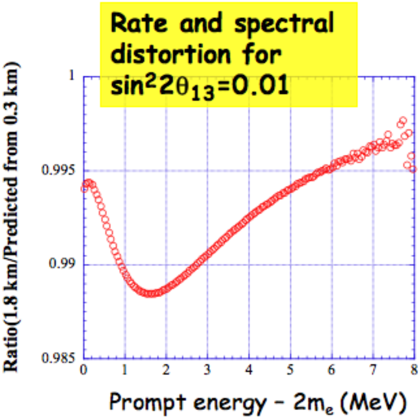
$$\mathrm{Ratio} = \alpha \frac{\mathrm{Near1}}{Far} + \frac{Near2}{Far}$$

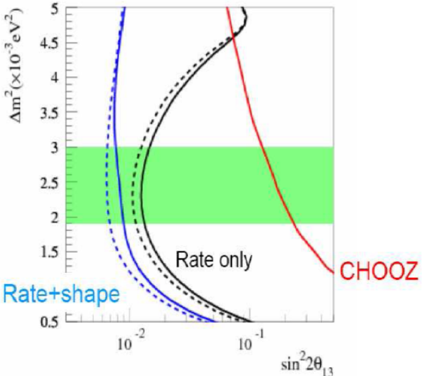


$$\alpha = \frac{(L_{22}^2 L_{1F}^2)^{-1} - (L_{21}^2 L_{2F}^2)^{-1}}{(L_{11}^2 L_{2F}^2)^{-1} - (L_{12}^2 L_{1F}^2)^{-1}}$$

For 4(6) cores, $\alpha = 0.34(0.39)$ and 2% reactor flux uncertainty is reduced to 0.035% (0.1%). Slightly more complicated expression if flux/reactor differs.

Sensitivity of rate and shape analyses





3 years Daya Bay running
Solid: 0.38% baseline syst. unc.
Dashed: 0.18% goal syst. unc.