Search for θ_{13} at the Daya Bay Neutrino Experiment

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Outline

- Neutrino oscillation and the search for θ_{13}
- The Daya Bay neutrino experiment
  - The design of the Daya Bay experiment
  - The simulation and the systematic budget
  - Timeline and current status
- Conclusions

Continue the Neutrino Exploration

$$U_{PMNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmospheric & long-baseline accelerator experiments

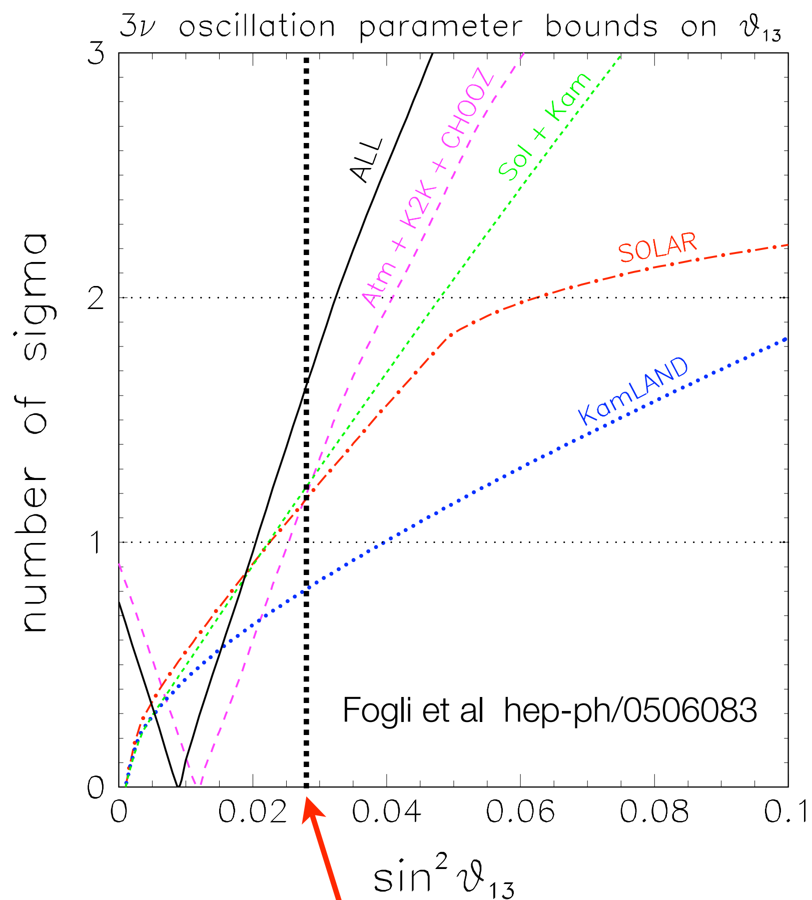
?

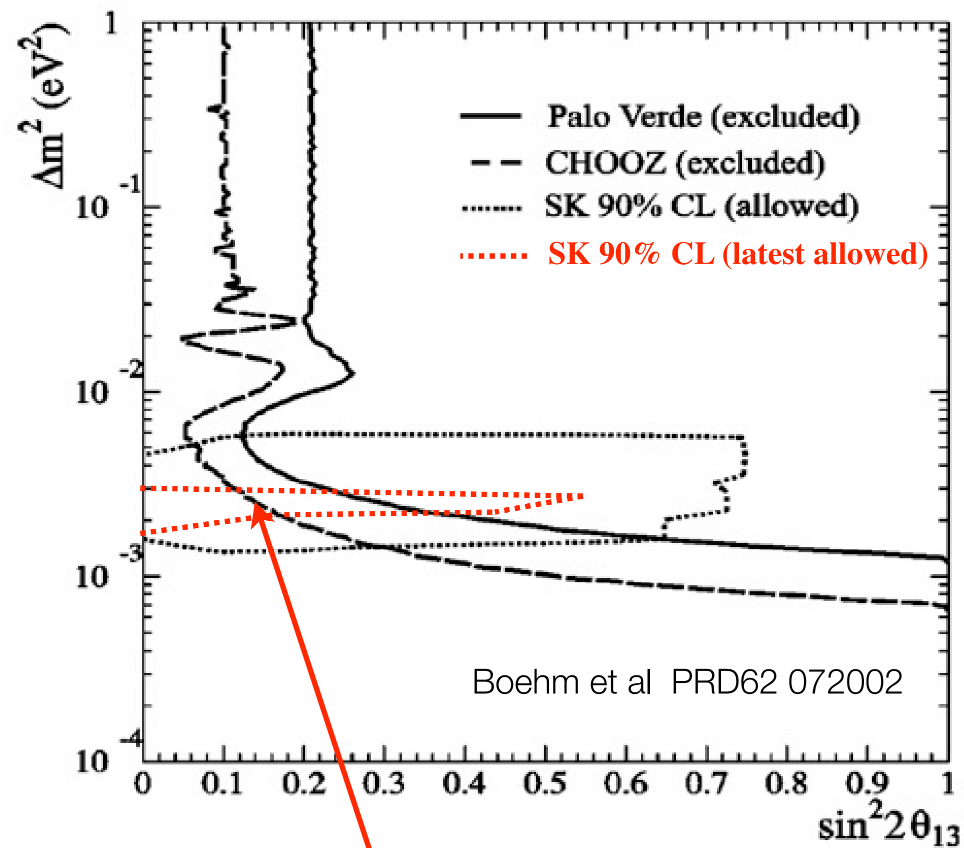
solar & long-baseline reactor experiments

- θ_{13} is the gateway to the lepton CP-V. Its value is crucial for the planning of the next generation appearance experiments for CP
- Two ways to measure θ_{13}
  - Short-baseline reactor experiments: $P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right)$
  - Long-baseline appearance experiments:

$$P_{\nu_\mu \to \nu_e} = \left|\sin\theta_{23}\sin 2\theta_{13}\left(\frac{\Delta_{31}}{\Delta_{31} - aL}\right)\sin(\Delta_{31} - aL)e^{-i(\Delta_{32}+\delta_{CP})} + \cos\theta_{23}\sin 2\theta_{12}\left(\frac{\Delta_{21}}{aL}\right)\sin(aL)\right|^2$$

Current Limits on θ_{13}





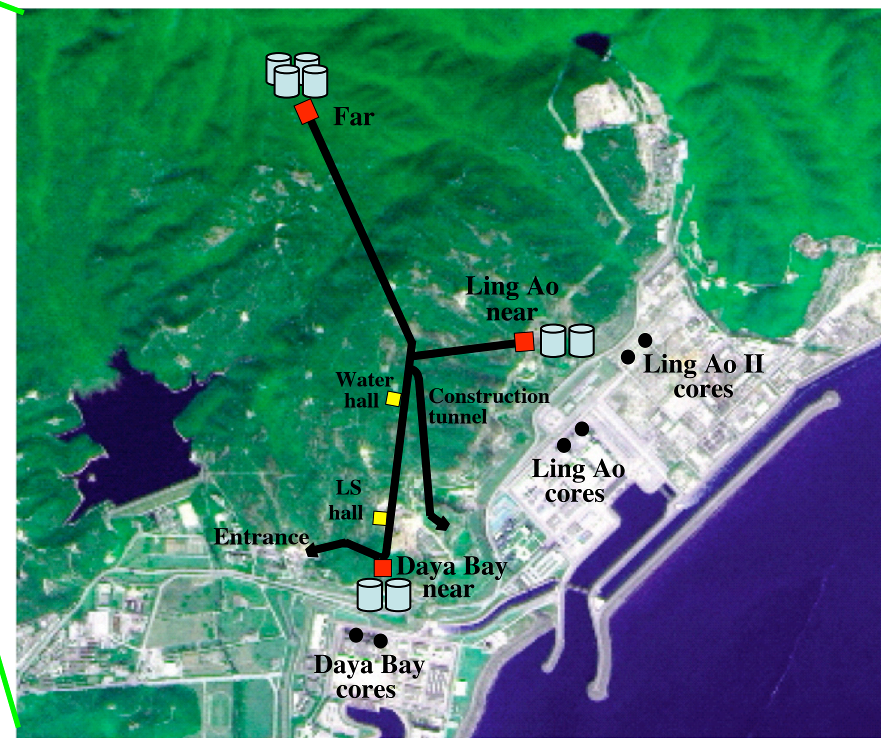
Global Fit: $\sin^2 2\theta_{13} < 0.12$ @ 90% C.L.

Direct Search: $\sin^2 2\theta_{13} < 0.17$ @ 90% C.L.

The Daya Bay Neutrino Experiment

The Daya Bay Reactor Power Plant
Southern China, 50 km from Hong Kong

2 near-sites + 1 far-site
8 identical 20t detectors
To reach ~0.01 in $\sin^2 2\theta_{13}$



How to Achieve High Sensitivity?

- Increase statistics
  - powerful sources, large detectors, high detection efficiency
- Strengthen the signal
  - optimize the baselines
- Reduce systematic uncertainties
  - reactor related: using near-far detector arrangement
  - detector related: using “identical” detectors
- Suppress backgrounds
  - go deeper underground
  - both passive and active veto systems

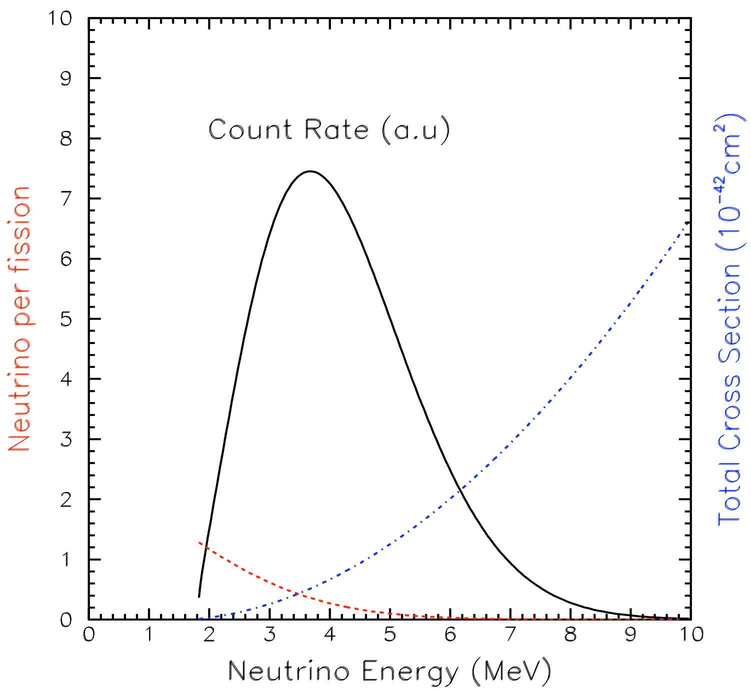
Antineutrino Detection

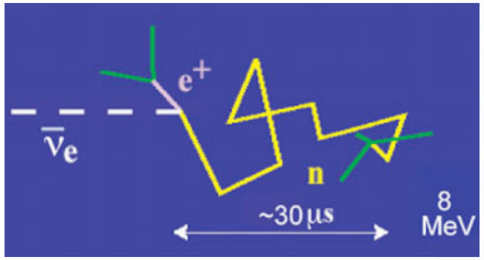
0.1% Gd doped liquid scintillator as target

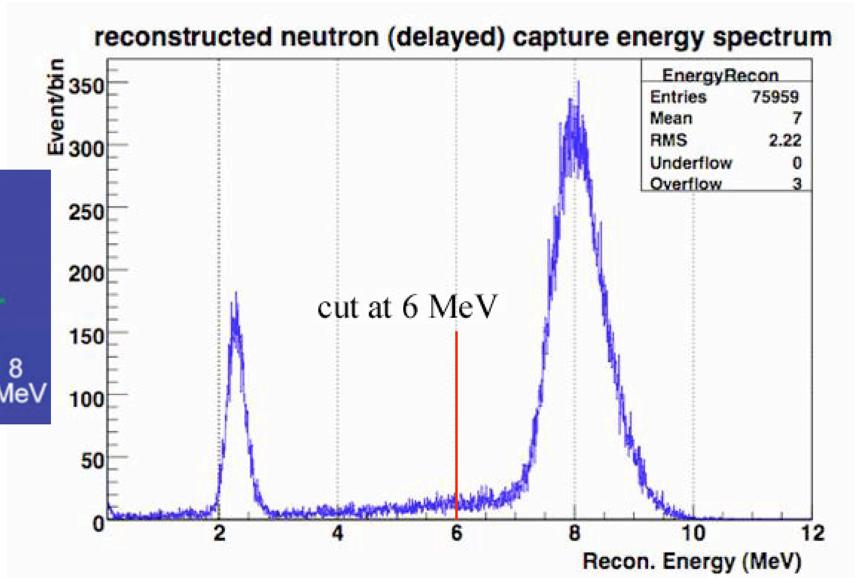
$$\bar{\nu}_e + p \rightarrow e^+ + n \xrightarrow{0.3b} n + p \rightarrow D + \gamma(2.2\,\mathrm{MeV})$$

$$n \xrightarrow{50{,}000b} n + Gd \rightarrow Gd^* \rightarrow Gd + \gamma(\sim 8\,\mathrm{MeV})$$

$$E_{\bar{\nu}_e} \approx E_{e^+} + m_n - m_p$$





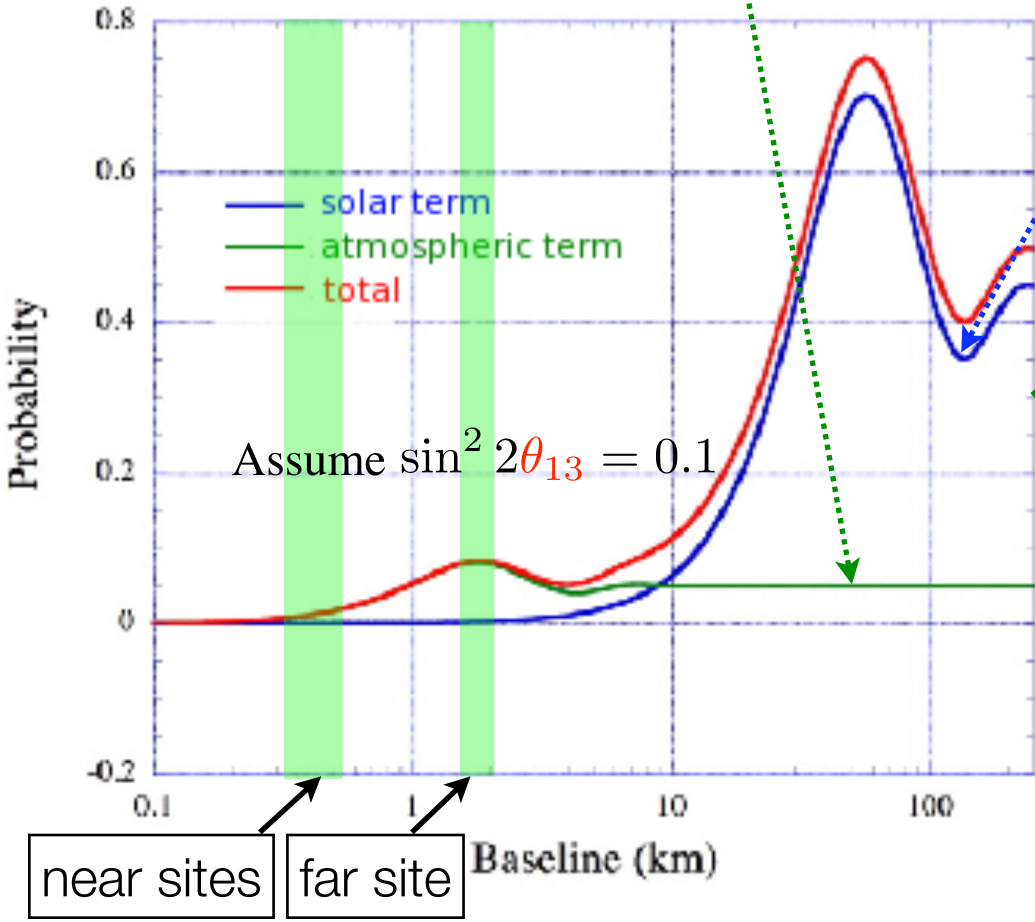


Delayed 8 MeV gamma

- background suppression
- well-defined target zone

Baselines of the Daya Bay Experiment

$$P_{\bar{\nu}_e \to \bar{\nu}_x} = \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$



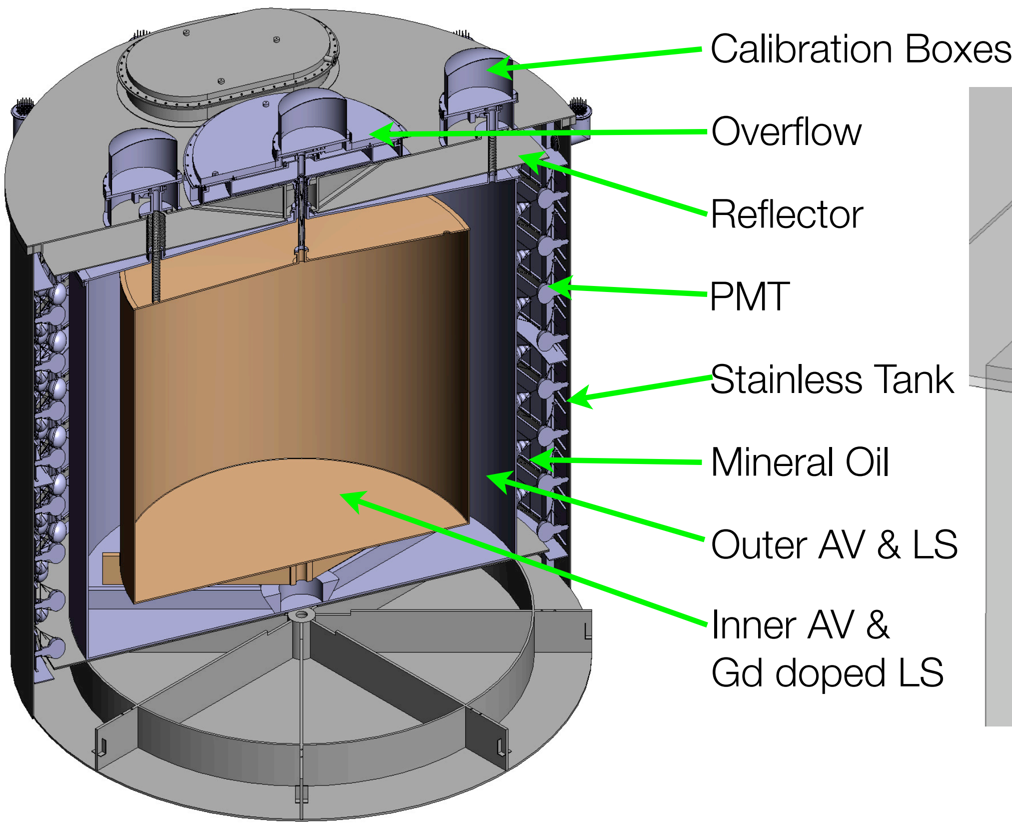
Baselines

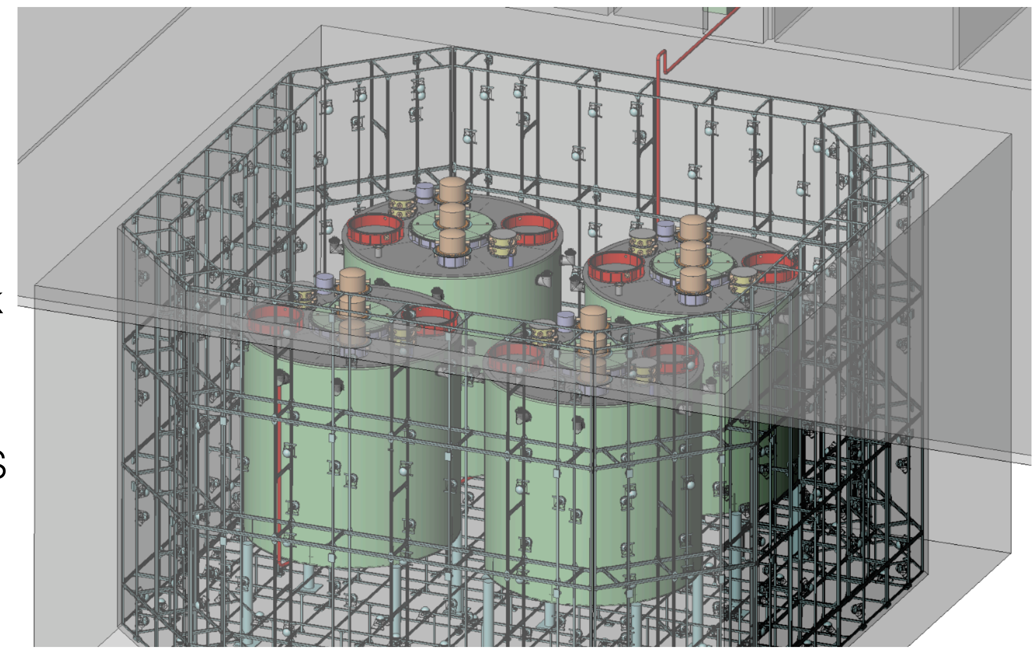
	DYB Site (m)	LA Site (m)	Far Site (m)
DYB	363	1347	1985
LA	857	481	1618
LA II	1307	526	1613

Expected number of IBD events

	DYB Site	LA Site	Far Site
IBD Evts (/day/det)	930	760	90

The Design of the Detectors

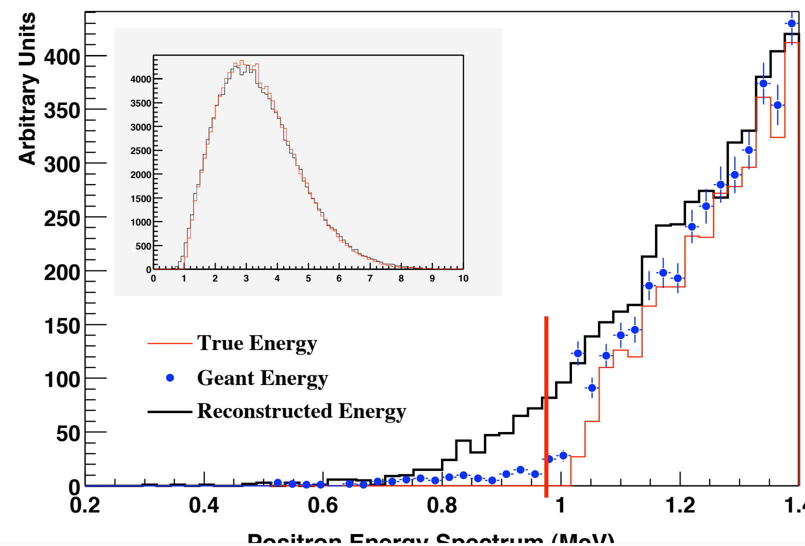




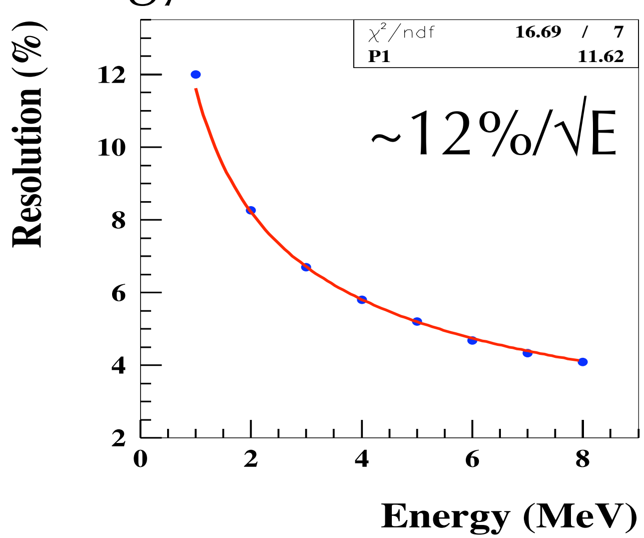
- 3-zone design: Gd-LS, LS & mineral oil
- 20 t target mass: 0.1% Gd doped LS
- 192 PMTs+ top/bottom reflectors
- submerged in water Cherenkov/RPC veto

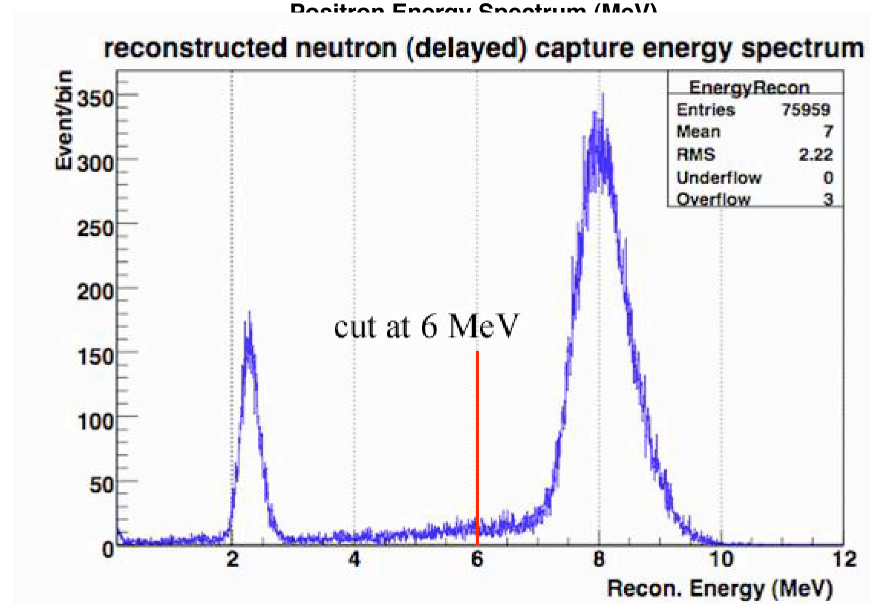
Detector Performance Simulation

- Detector simulation with GEANT4
- Detection efficiency
  - 1 MeV cut for prompt positrons >99%
  - 6 MeV cut for delayed neutrons ~91%



- Energy resolution





Detector Systematic Uncertainty Control

Some examples:

- Acrylic vessels and liquid scintillator
  - manufactured and filled in pairs with a common storage tank
- Target mass
  - load cells to measure the target mass to 0.1%
  - flow meter during filling 0.1%
  - overflow tank liquid level monitoring with ultrasonic devices
- Energy calibration to reach relative uncertainty 0.1%
  - automated calibration: ^{68}Ge(positron), ^{252}Cf(neutron) & LED
  - being practiced on the prototype: ^{133}Ba(0.356 MeV), ^{137}Cs(0.662 MeV), ^{60}Co(1.17+1.33 MeV), ^{22}Na(1.022+1.275 MeV), Pu-C(6.13 MeV), ^{252}Cf(neutron)

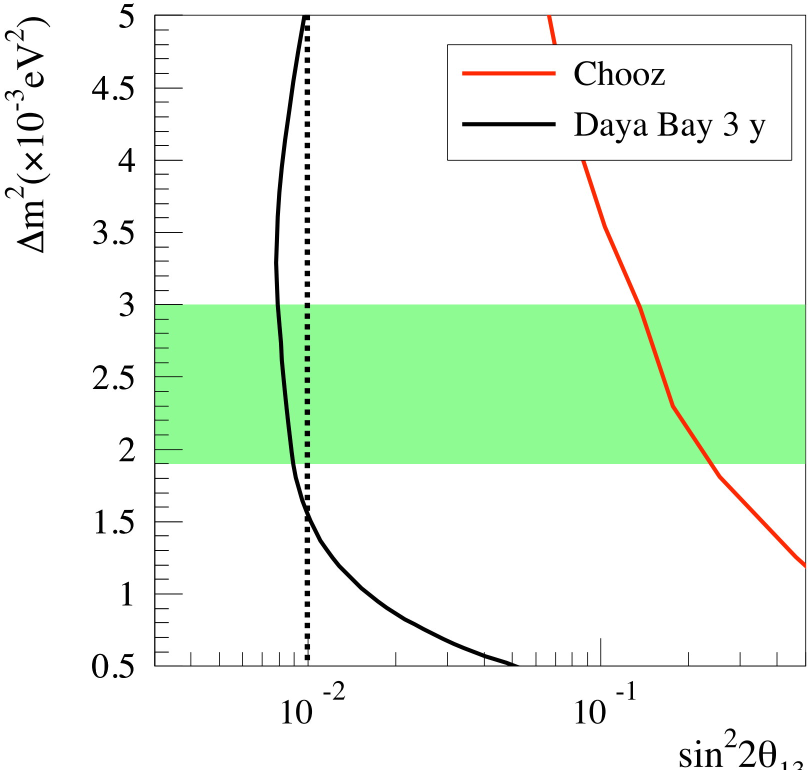
The Systematic Summary

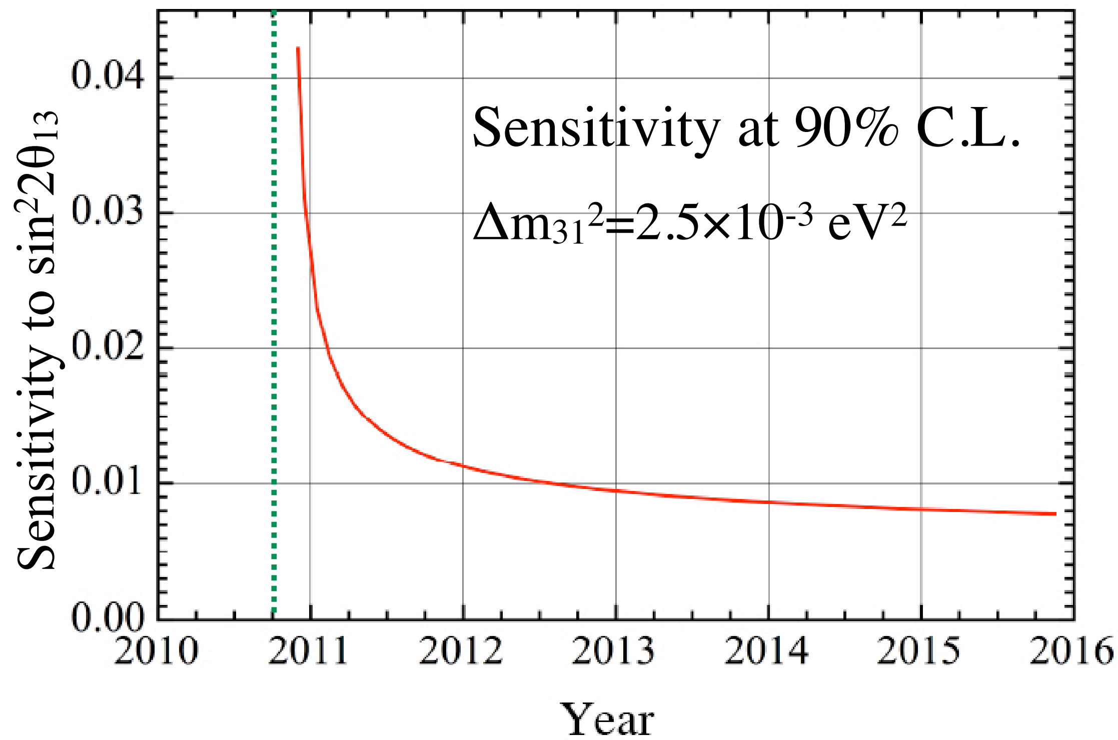
Detector Uncertainty Sources		Baseline	Goal	Chooz Experience
Number of protons		0.3%	0.1%	0.8%
Detector Efficiency	Energy cut	0.2%	0.1%	0.8%
	H/Gd ratio	0.1%	0.1%	1.0%
	Time cut	0.1%	0.03%	0.4%
	Neutron Multiplicity	0.05%	0.05%	0.5%
	Trigger	0.01%	0.01%	0.01%
	Live time	<0.01%	<0.01%	<0.01%
Total uncertainty		0.38%	0.18%	1.7%

Two detector relative uncertainty (Baseline 0.38%, Goal 0.18%)

One detector absolute uncertainty (Chooz 1.7%)

The Daya Bay Sensitivity





$$\chi^2 = \min_{\gamma} \sum_{A=1}^{8} \sum_{i=1}^{N_{bins}} \frac{\left[M_i^A - T_i^A\left(1+\alpha_c+\sum_r \omega_r^A \alpha_r + \beta_i + \varepsilon_D + \varepsilon_d^A\right) - \eta_f^A F_i^A - \eta_n^A N_i^A - \eta_s^A S_i^A\right]^2}{T_i^A + (\sigma_{b2b} T_i^A)^2}$$

$$+ \frac{\alpha_c^2}{\sigma_c^2} + \sum_r \frac{\alpha_r^2}{\sigma_r^2} + \sum_{i=1}^{N_{bins}} \frac{\beta_i^2}{\sigma_{\rm shp}^2} + \frac{\varepsilon_D^2}{\sigma_D^2} + \sum_{A=1}^{8}\left[\left(\frac{\varepsilon_d^A}{\sigma_d}\right)^2 + \left(\frac{\eta_f^A}{\sigma_f^A}\right)^2 + \left(\frac{\eta_n^A}{\sigma_n^A}\right)^2 + \left(\frac{\eta_s^A}{\sigma_s^A}\right)^2\right]$$

The Daya Bay Schedule

- Daya Bay in construction (CD2/3a review passed in Jan 2008)
- Feb 19, 2008 civil construction first blast
- Mar 15, 2008 surface assembling building construction started
- Oct 2009, the two Daya Bay near hall detectors start data taking
- June 2010, all detectors in place, data taking with the full Daya Bay
- Then we tell you θ_{13}!

Conclusions

- θ_{13} is the gateway to CP-V physics in lepton sector. Its value is crucial for the planning of next generation neutrino experiments for CP-V measurements.

- The Daya Bay neutrino experiment is designed to reach sensitivity of ~0.01 in $\sin^2 2\theta_{13}$. It is the most sensitive reactor neutrino experiment in construction.

- The full Daya Bay neutrino experiment will start data taking in June 2010.

The Daya Bay Collaboration

Asia	America	Europe	Total
17 institutions 125 members	14 institutions 73 members	3 institutions 9 members	207 collaborators

More Systematic Uncertainties

Reactor Systematic Uncertainty	Value
reactor-related correlated uncertainty	2%
reactor-related uncorrelated uncertainty	2%
shape uncertainty of the neutrino spectra	2%

Background Types	B/S Value		
	DYB	LA	Far
the uncertainty of the accidental background events	<0.2%	<0.2%	<0.1%
the uncertainty of the fast neutrons induced by cosmic muons	0.1%	0.1%	0.1%
the uncertainty of the background events induced by $^{8}He/^{9}Li$	0.3%	0.2%	0.2%

Daya Bay Discovery Potential