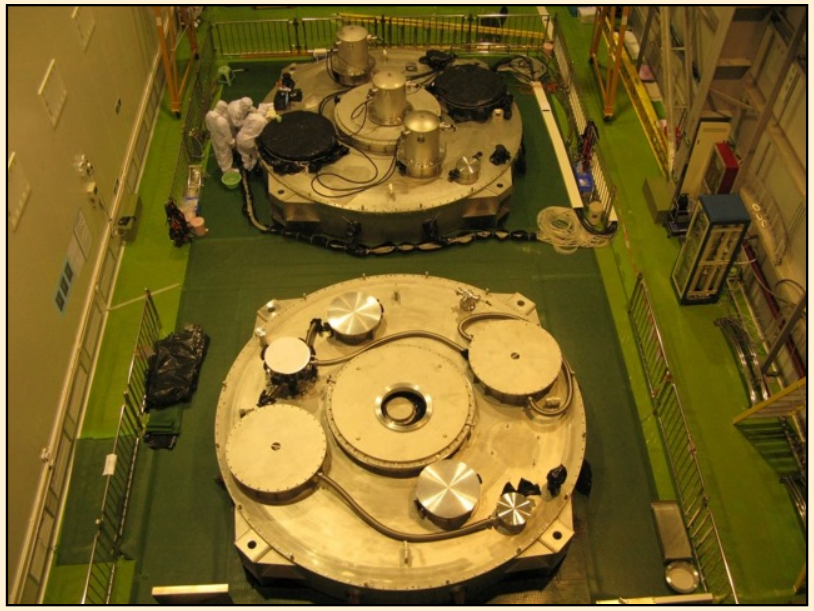
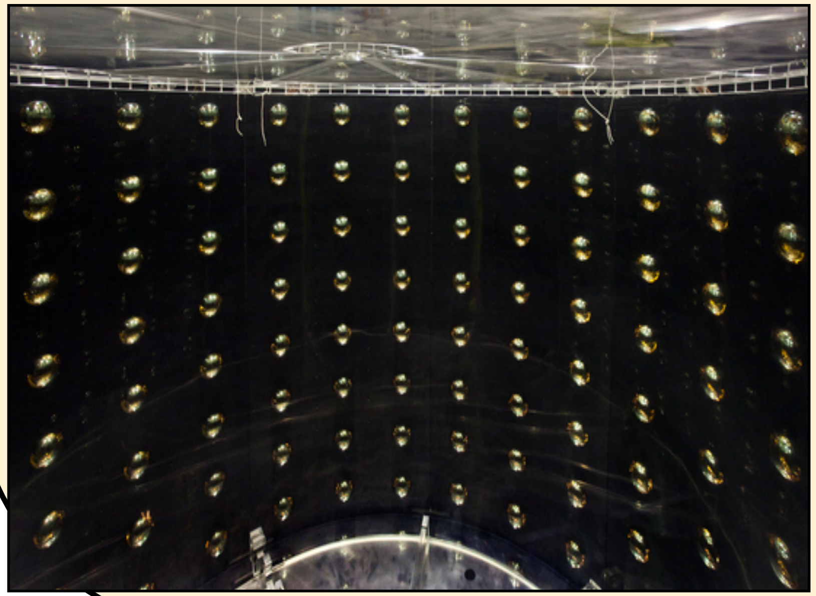
The Daya Bay Reactor Antineutrino Experiment and Prospects for θ_{13}

Michael McFarlane, on behalf of the Daya Bay collaboration





http://dayabay.ihep.ac.cn

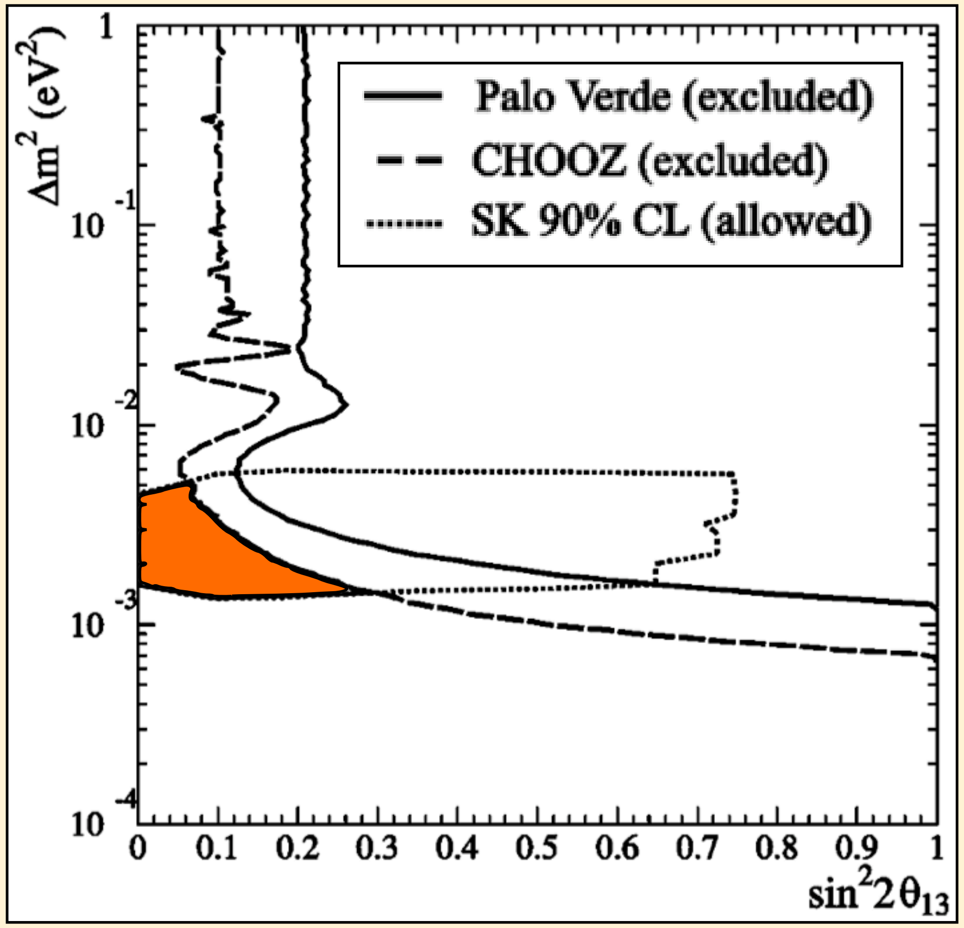
Neutrino Oscillations

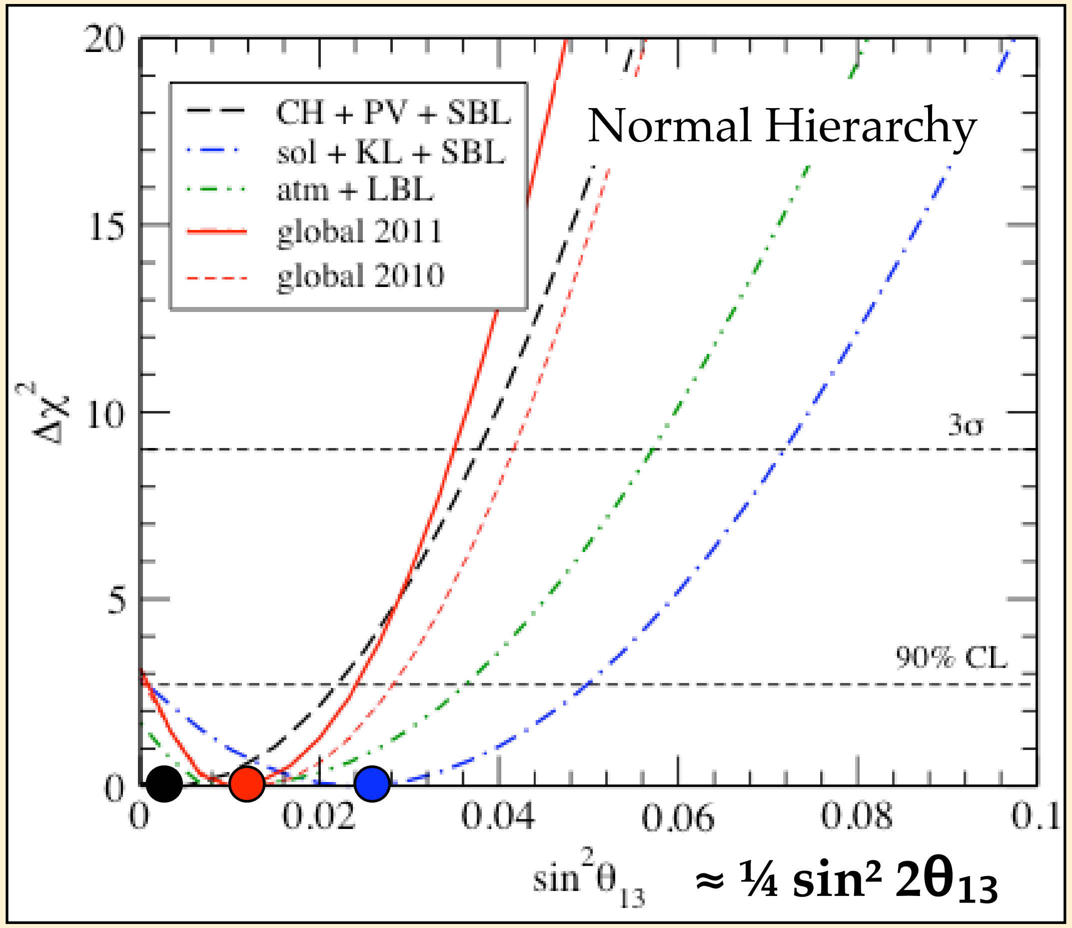
Neutrino Mixing:

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix} \begin{pmatrix}\cos\theta_{13} & 0 & e^{-i\delta}\sin\theta_{13}\\ 0 & 1 & 0\\ -e^{i\delta}\sin\theta_{13} & 0 & \cos\theta_{13}\end{pmatrix} \begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix} \begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Consequence for Reactor Antineutrinos:

$$P\,(\overline{\nu}_e \rightarrow \overline{\nu}_e) = 1 - \sin^2 2\,\theta_{13}\,\sin^2\left(1.27\,\Delta m^2_{13}\,L\,/\,E\right)\ \{\mathrm{km},\ \mathrm{MeV}\}$$





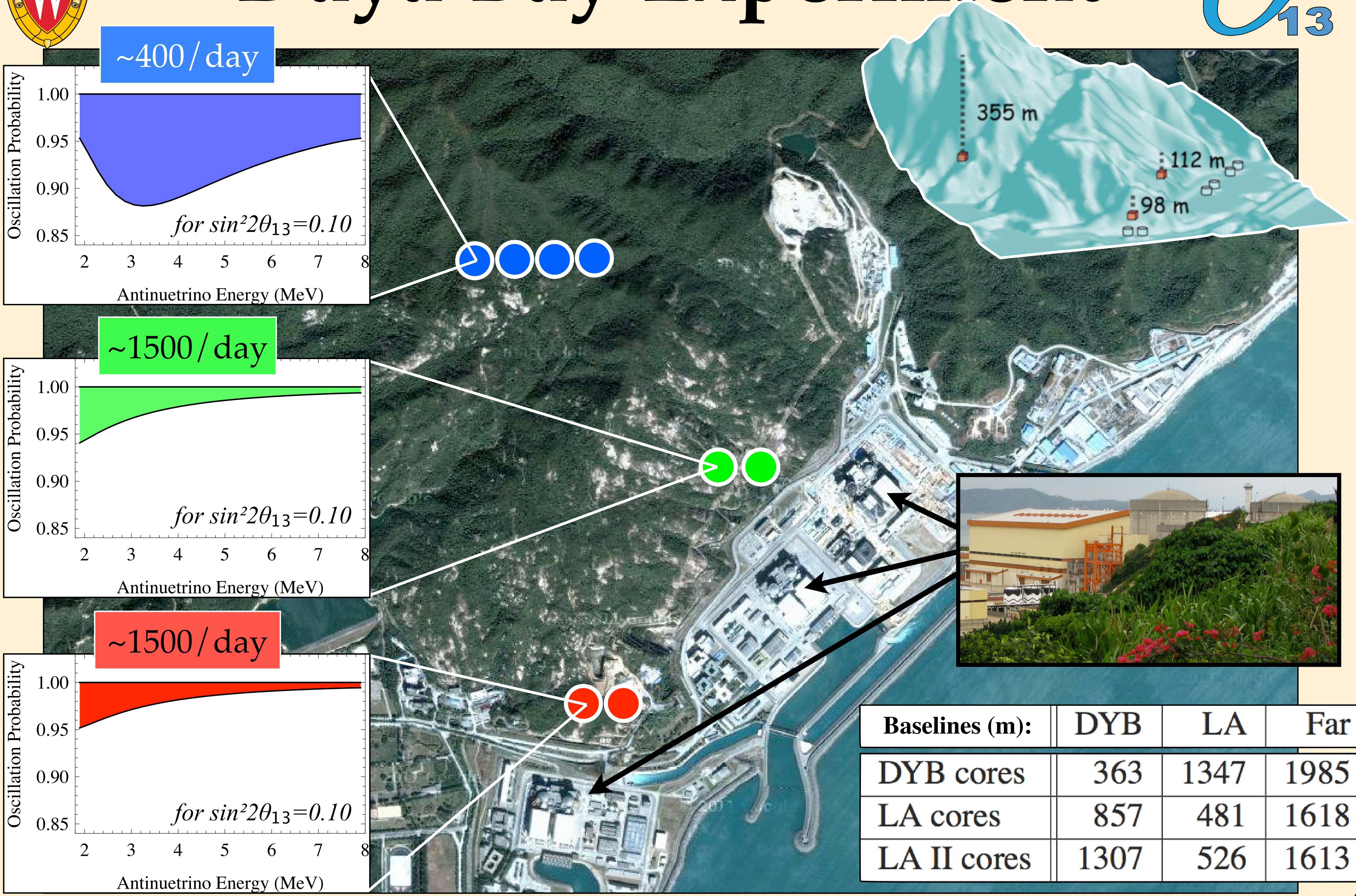
$\sin^2 2\theta_{13} < 0.15$ @ 90% C.L.

Interesting hints!

Phys.Lett. B466 (1999) 415-430

http://arxiv.org/abs/1103.0734

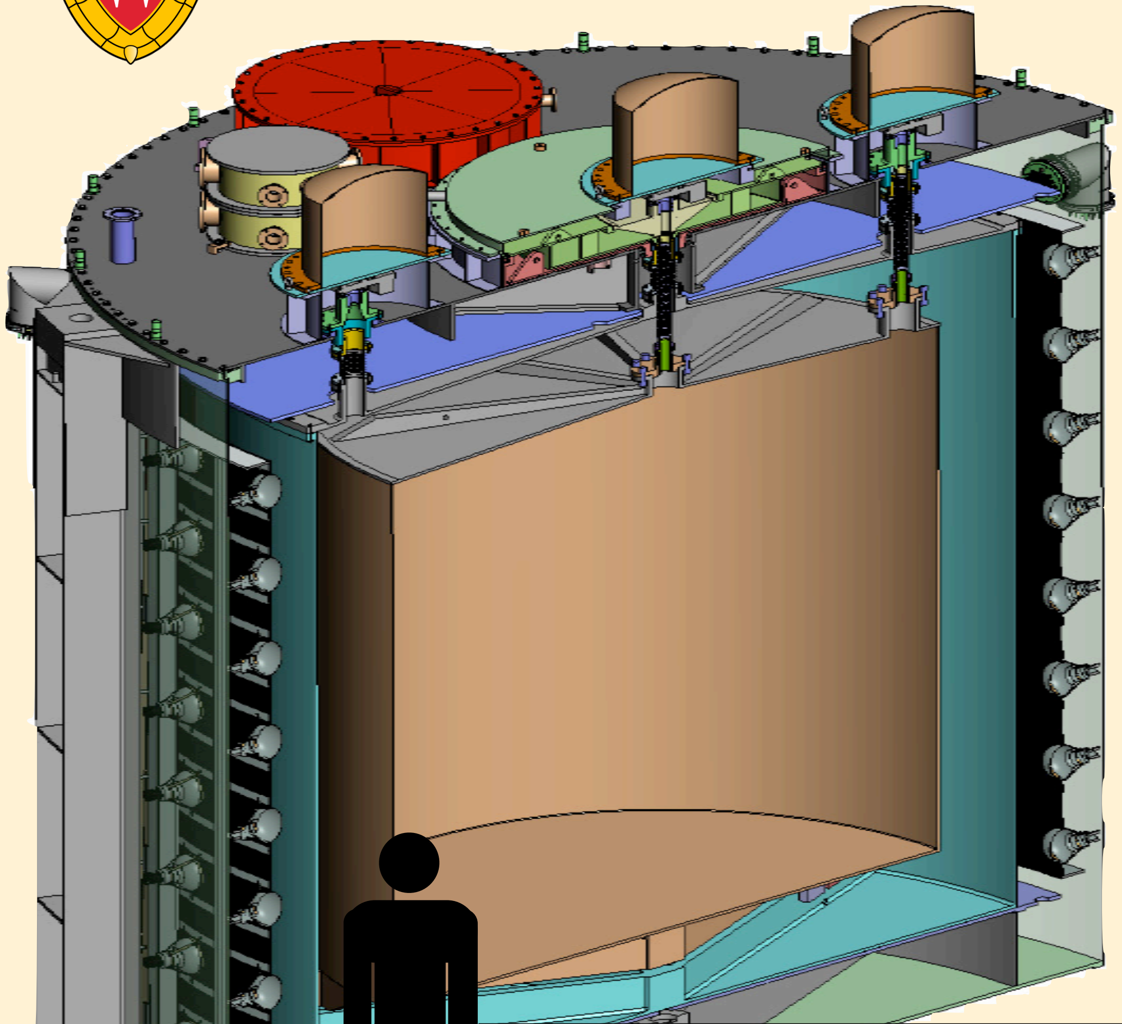
Daya Bay Experiment



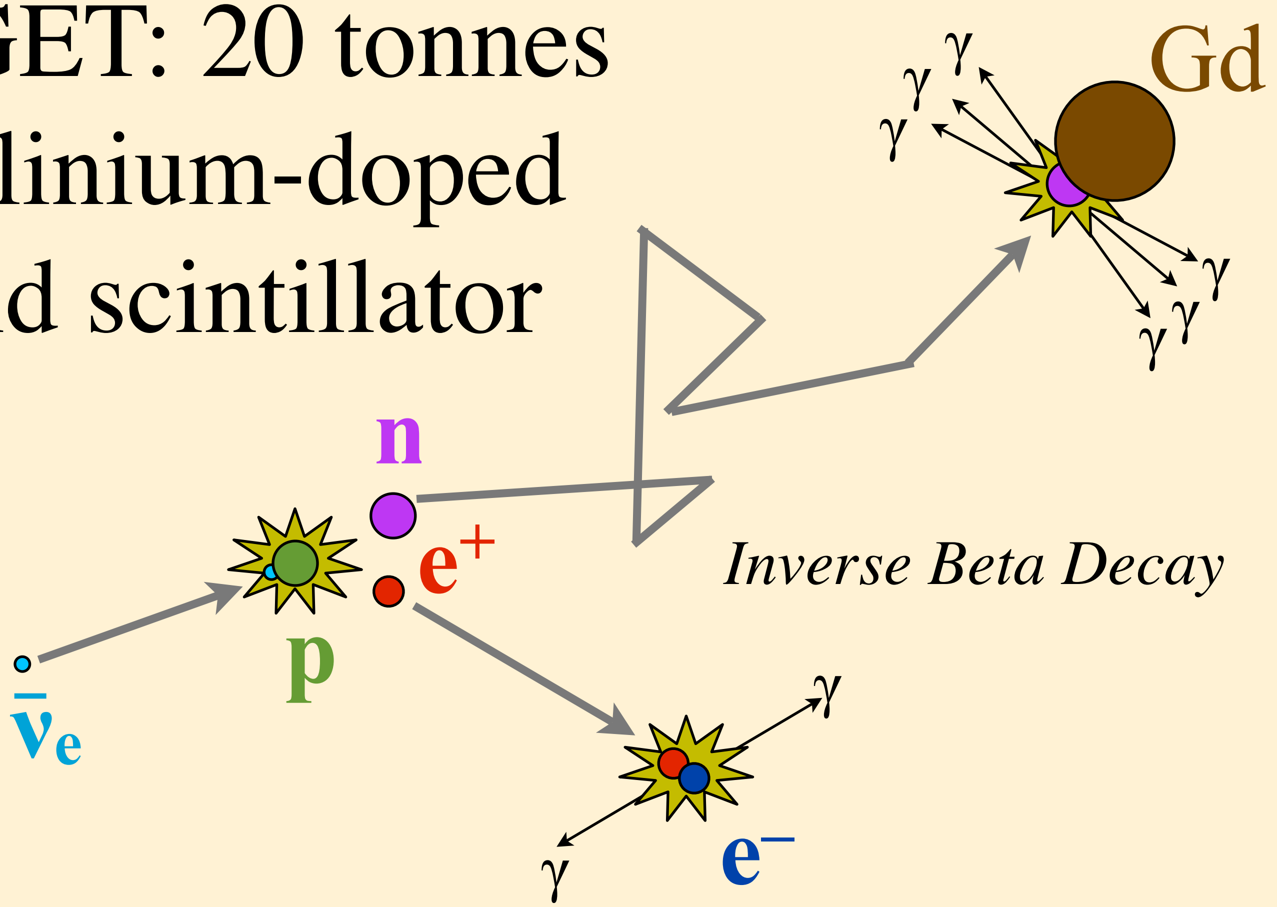
Baselines (m):	DYB	LA	Far
DYB cores	363	1347	1985
LA cores	857	481	1618
LA II cores	1307	526	1613

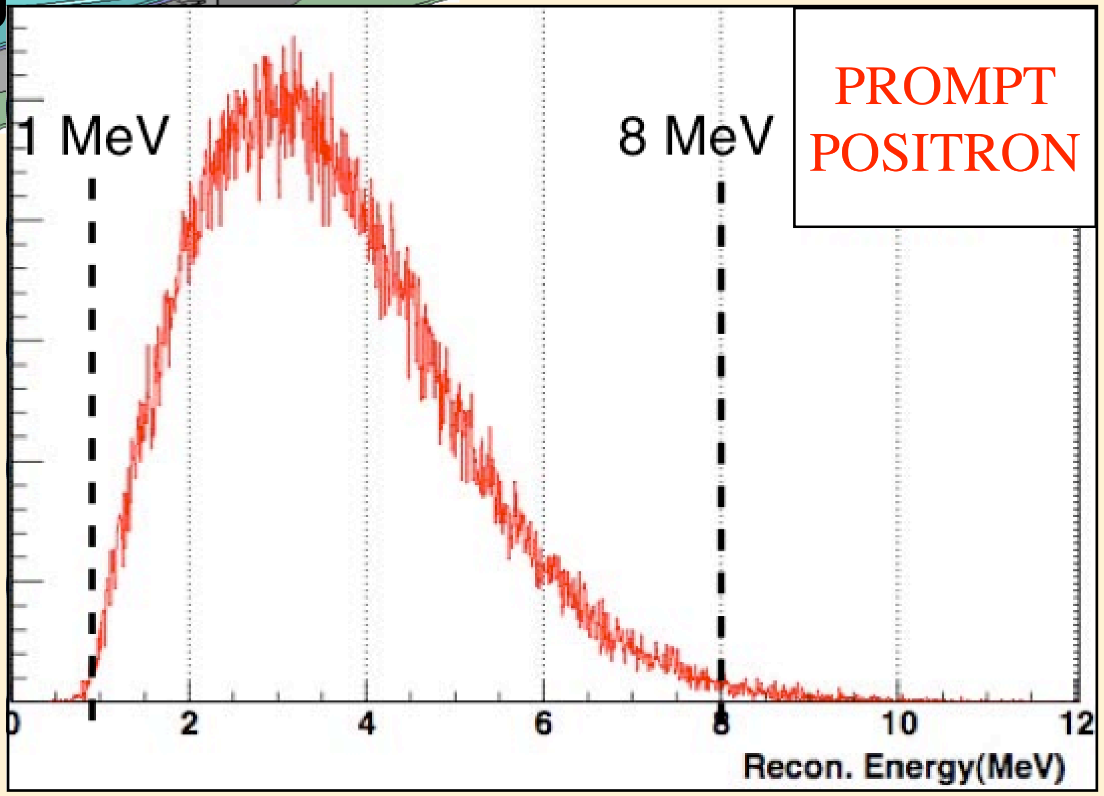
Signals: (1) Reduction in events, (2) Spectral distortion

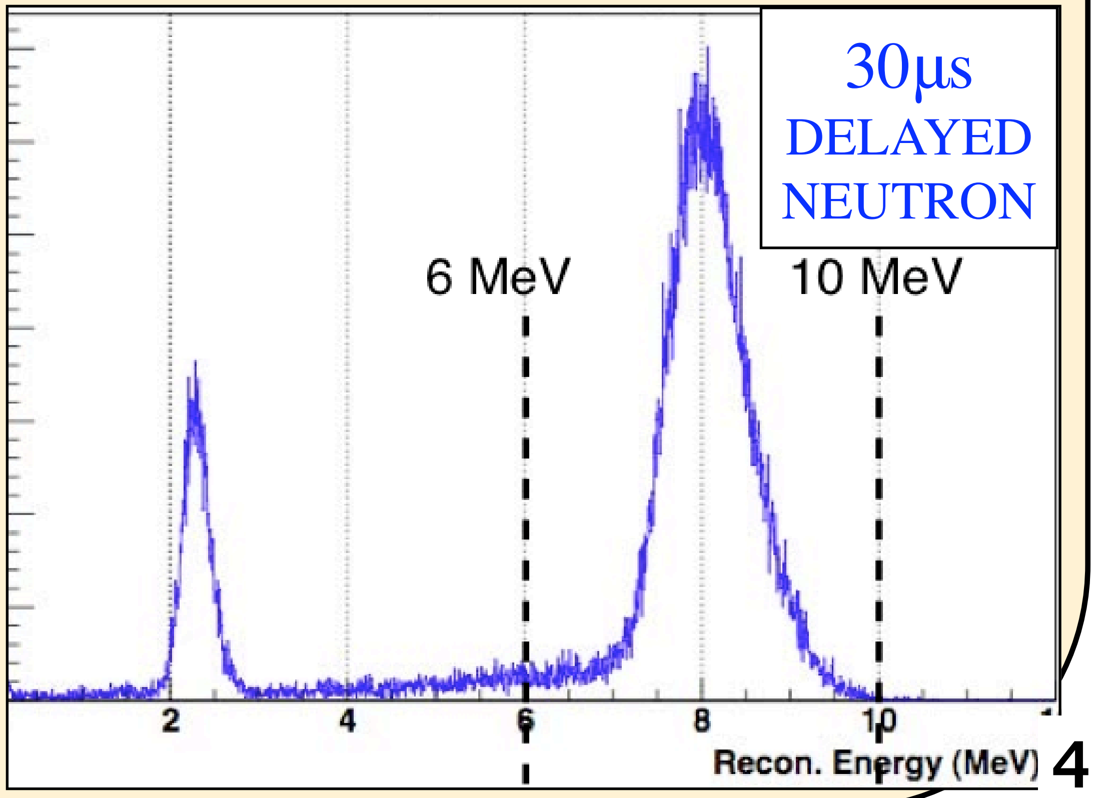
Detection Principle



TARGET: 20 tonnes
gadolinium-doped
liquid scintillator

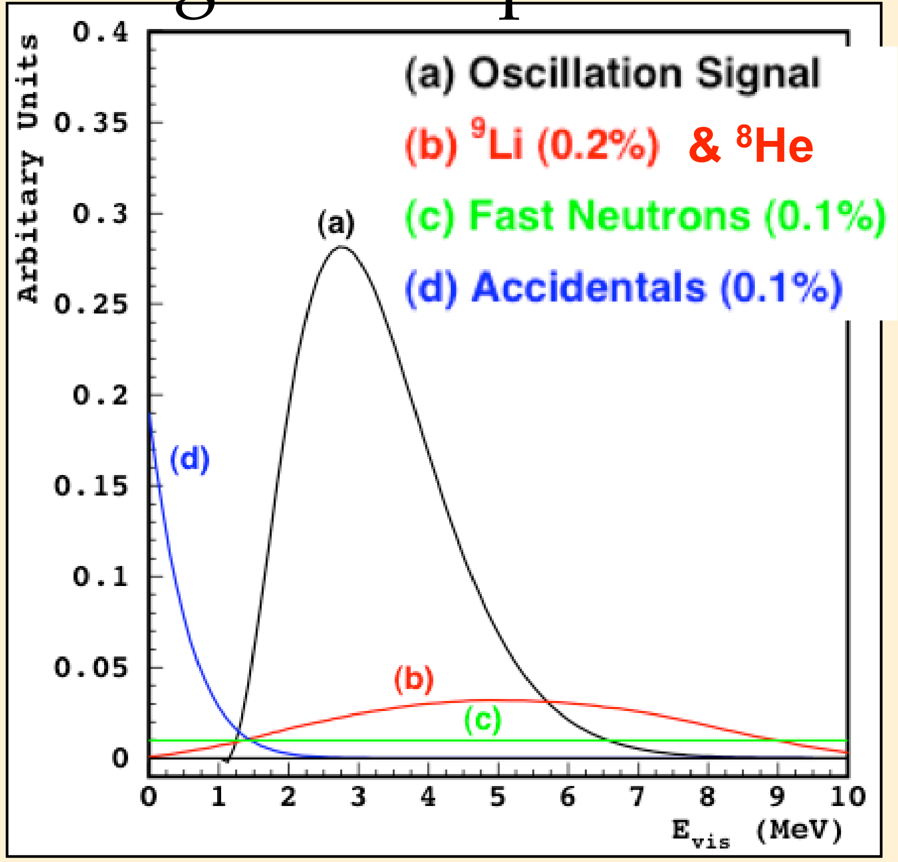






Backgrounds

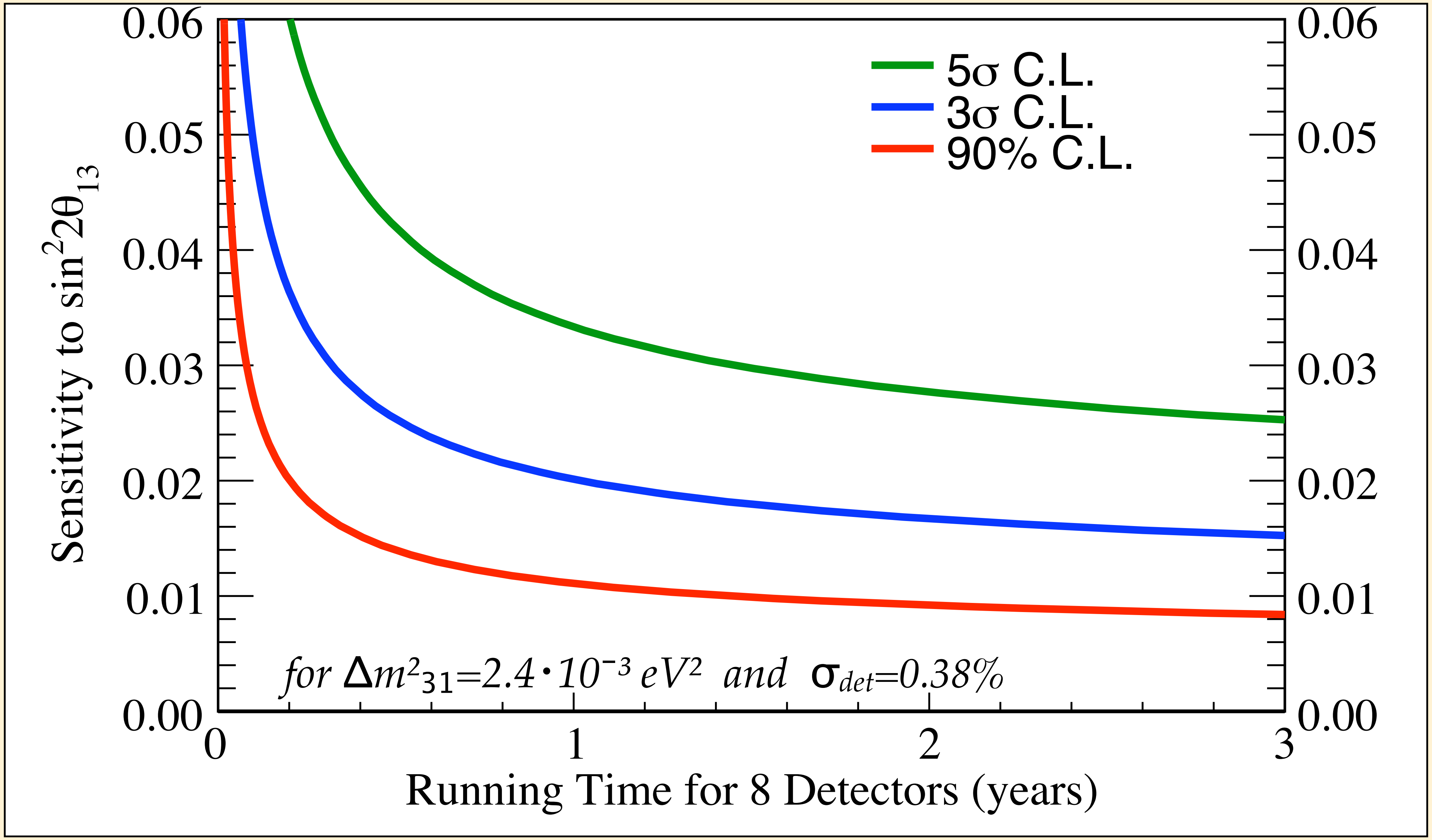
Background Spectra:



Bkg:Signal ≤ 0.3% per background per site.

http://arxiv.org/abs/hep-ex/0701029	Daya Bay Near	Ling Ao Near	Far Hall
Radioactivity (Hz)	<50	<50	<50
Muon rate (Hz)	36	22	1.2
Antineutrino Signal (events/day)	840	740	90
Accidental Background/Signal (%)	<0.2	<0.2	<0.1
Fast neutron Background/Signal (%)	0.1	0.1	0.1
^{8}He+^{9}Li Background/Signal (%)	0.3	0.2	0.2

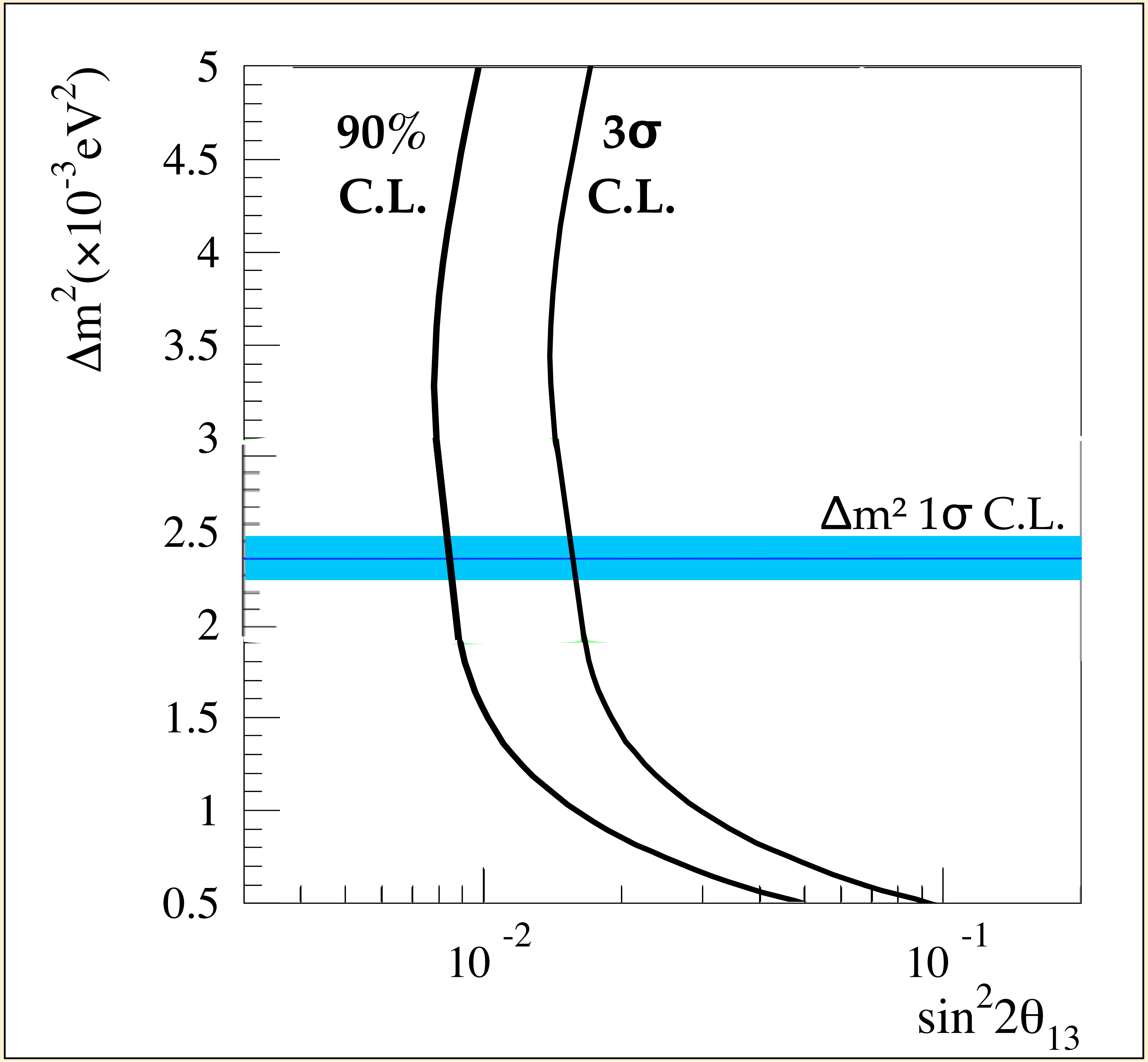
Confidence Versus Time



90% CL	3σ CL	5σ CL
0.008	0.015	0.025

We use **GLoBES** release 3.1.2.0

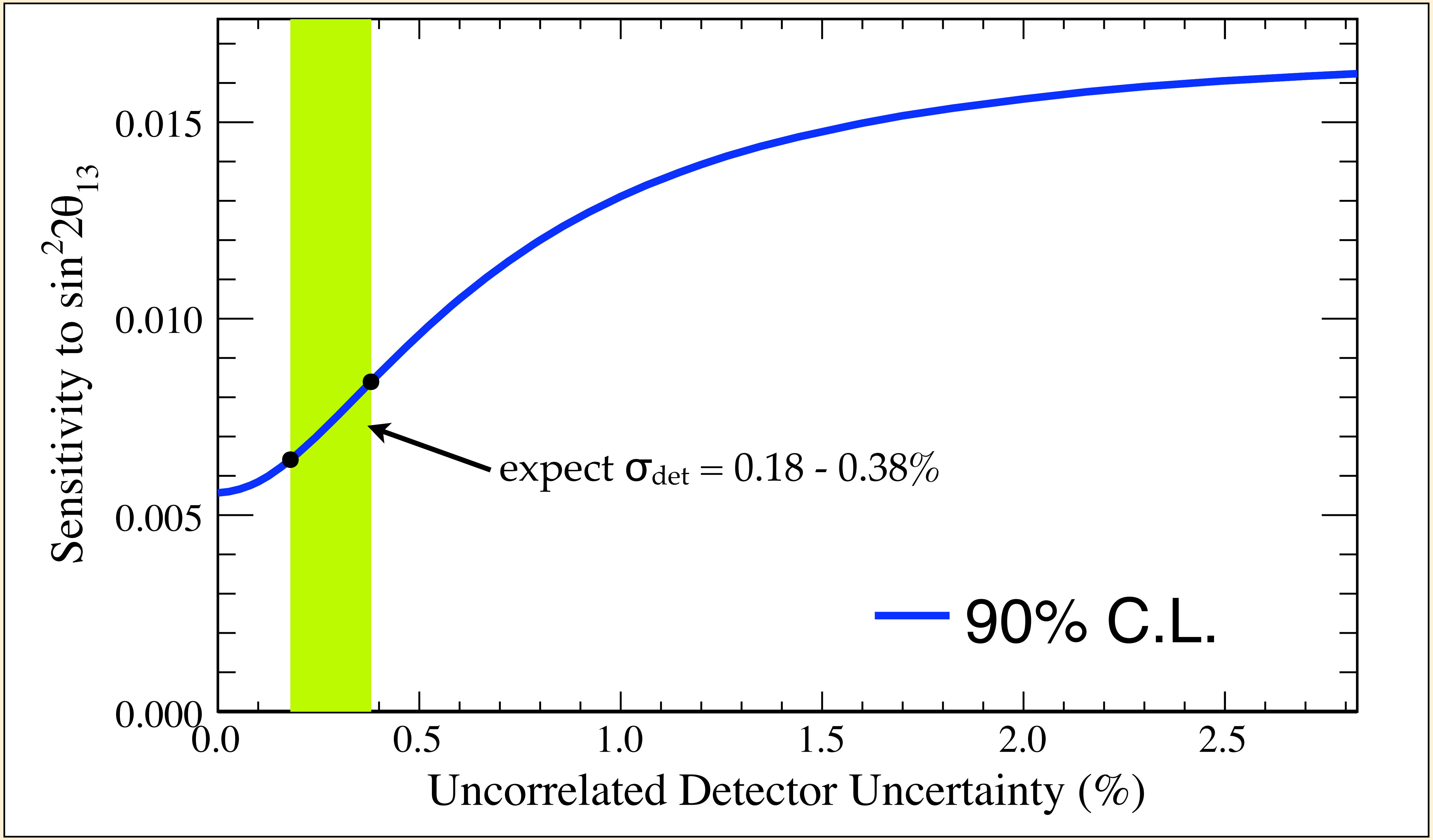
Sensitivity Versus Δm^2_{31}



Daya Bay sensitivity has very little dependence on Δm^2_{31}

http://arxiv.org/abs/hep-ex/0701029 http://arxiv.org/abs/0808.2016

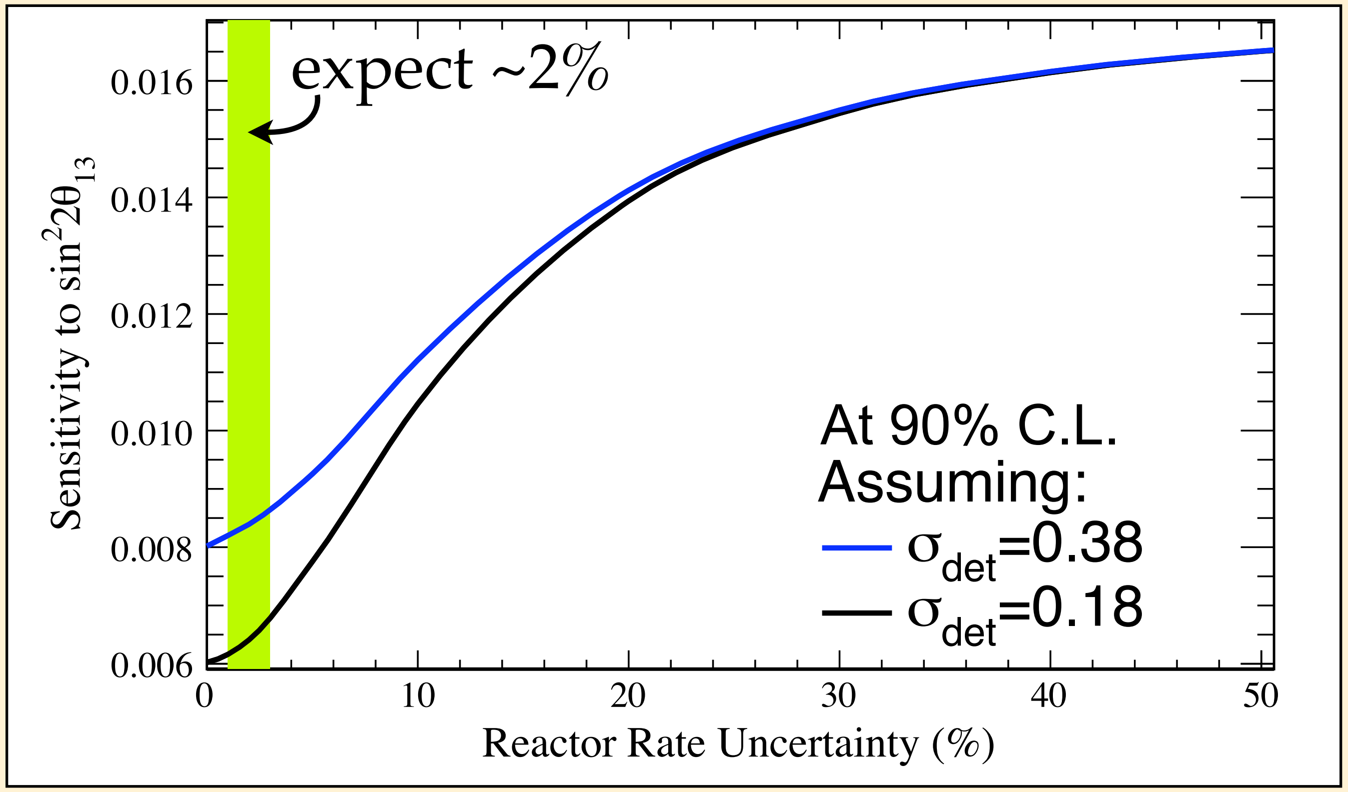
Detector Systematic



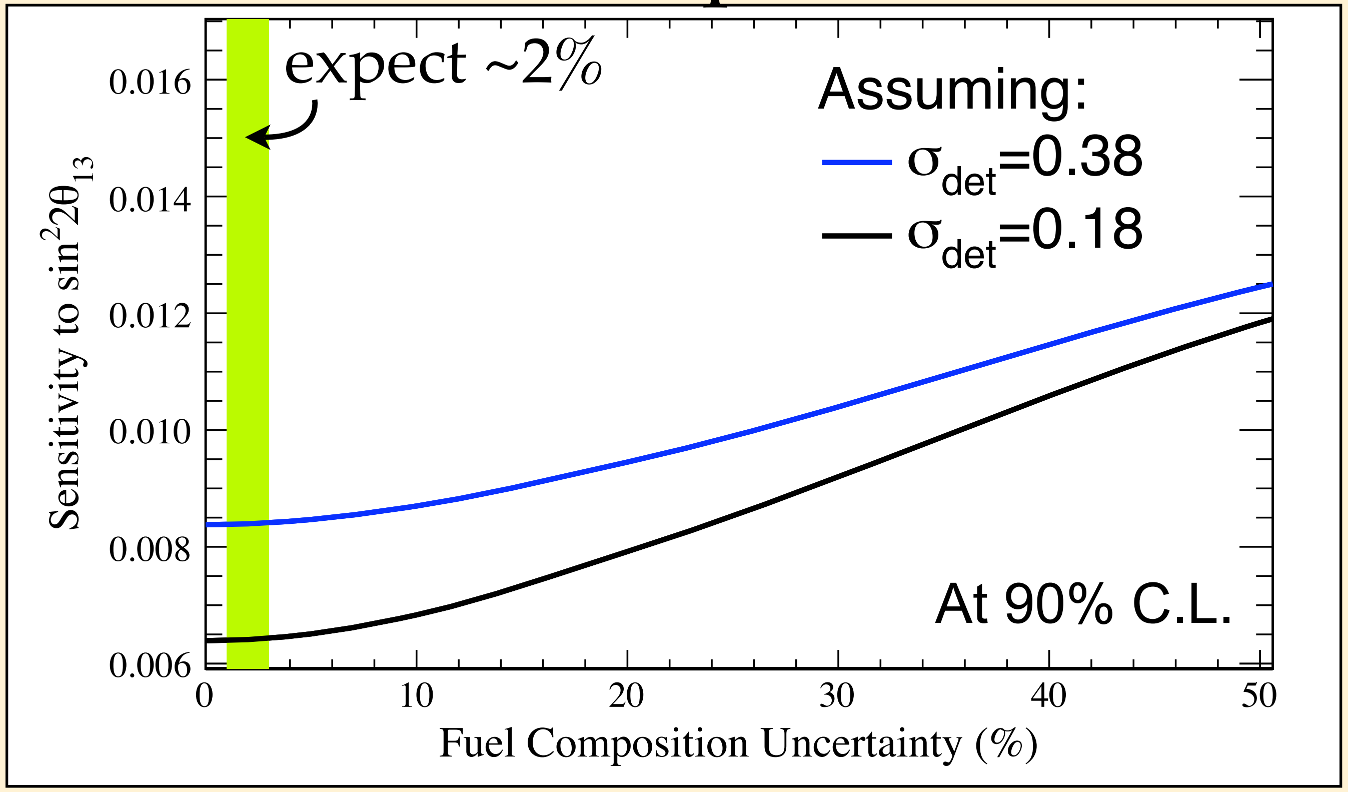
Most important systematic! Determines how ‘identical’ our detectors are. It is minimized by identical construction, filling, low background materials

Reactor Uncertainties

Reactor Flux:



Fuel Composition:



- ▶ We expect about 2% uncertainties on uncorrelated reactor flux and fuel composition.
- ▶ Sensitivity still good in large limit
- ▶ Reactor company is collaborator

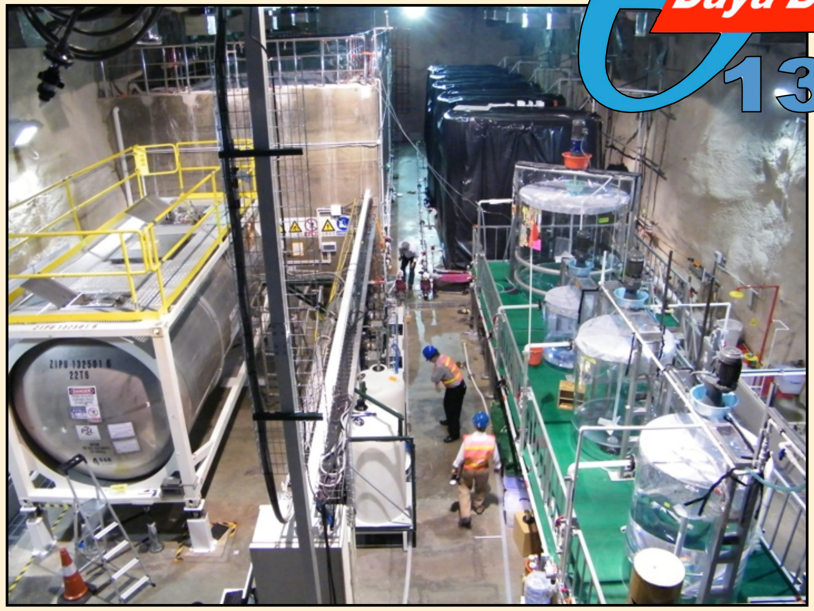
Summary

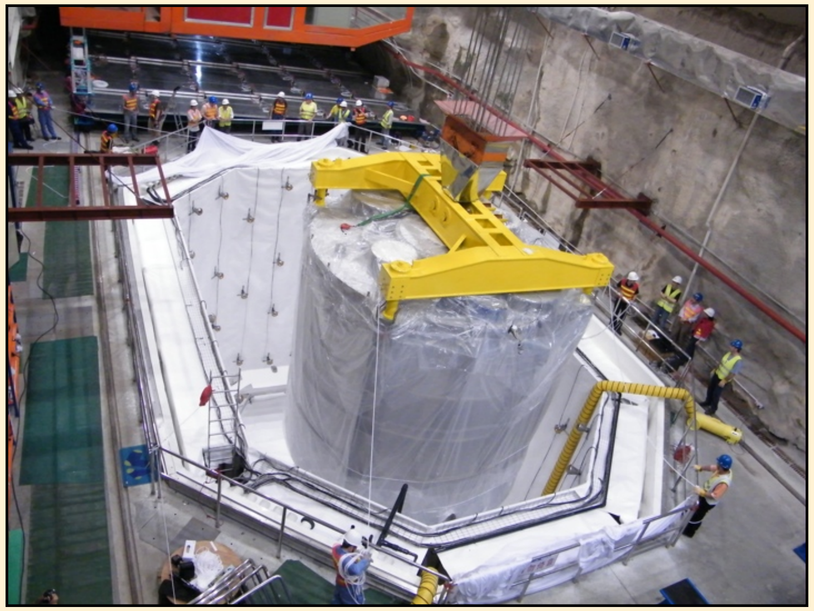
▶ Daya Bay has a sensitivity to $\sin^2 2\theta_{13} = 0.01$ and 3σ discovery at 0.015.

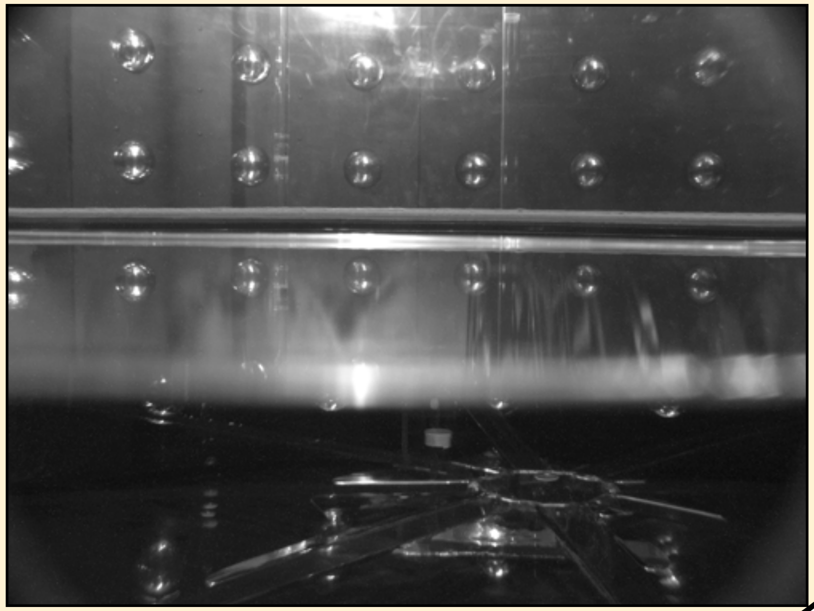
▶ Near:Far detector deployment, and rate + spectrum handles, make Daya Bay resilient to systematics

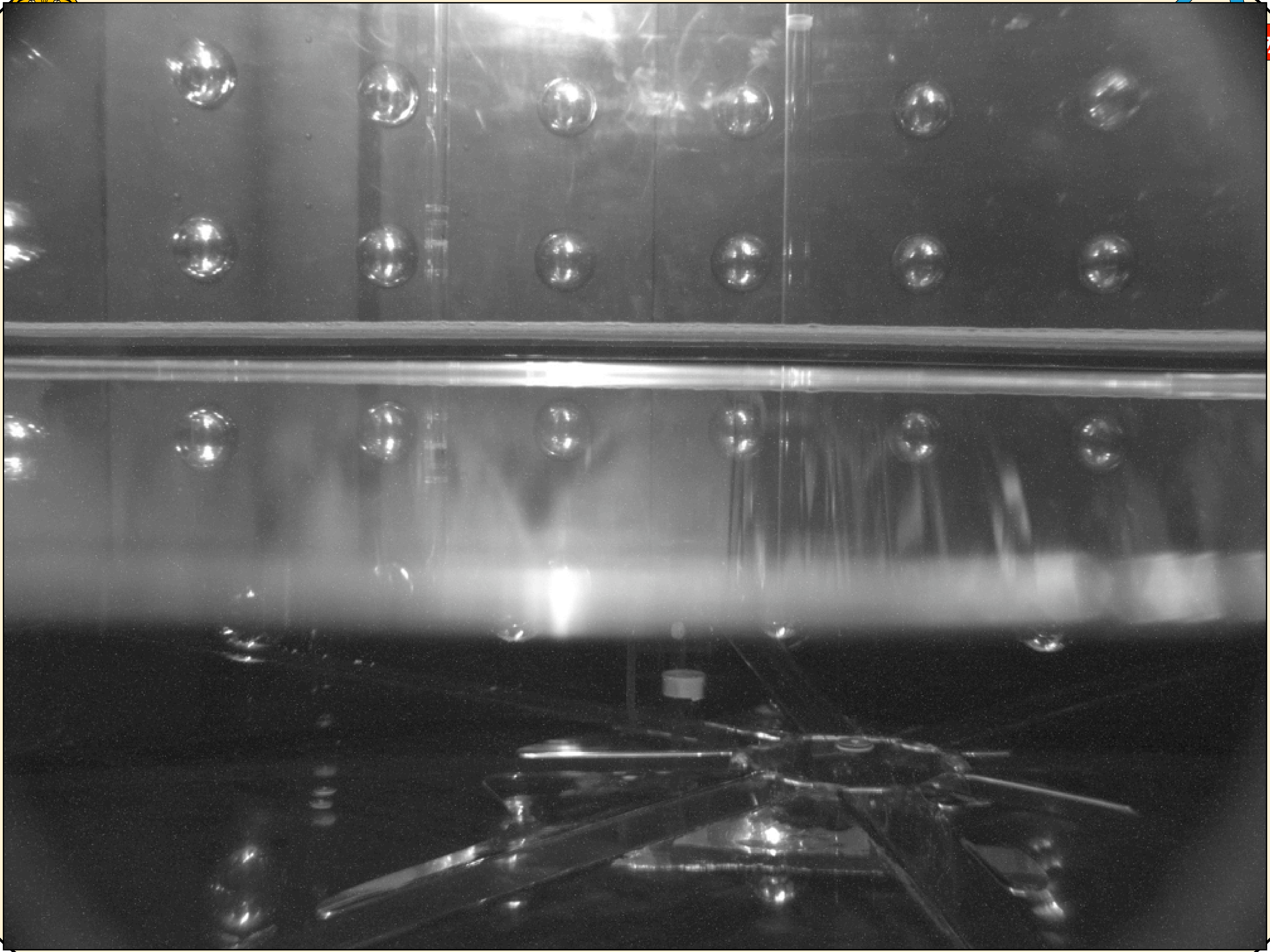
▶ First two detectors take data this summer!

▶ All 8 detectors starting Fall 2012.









Additional Content

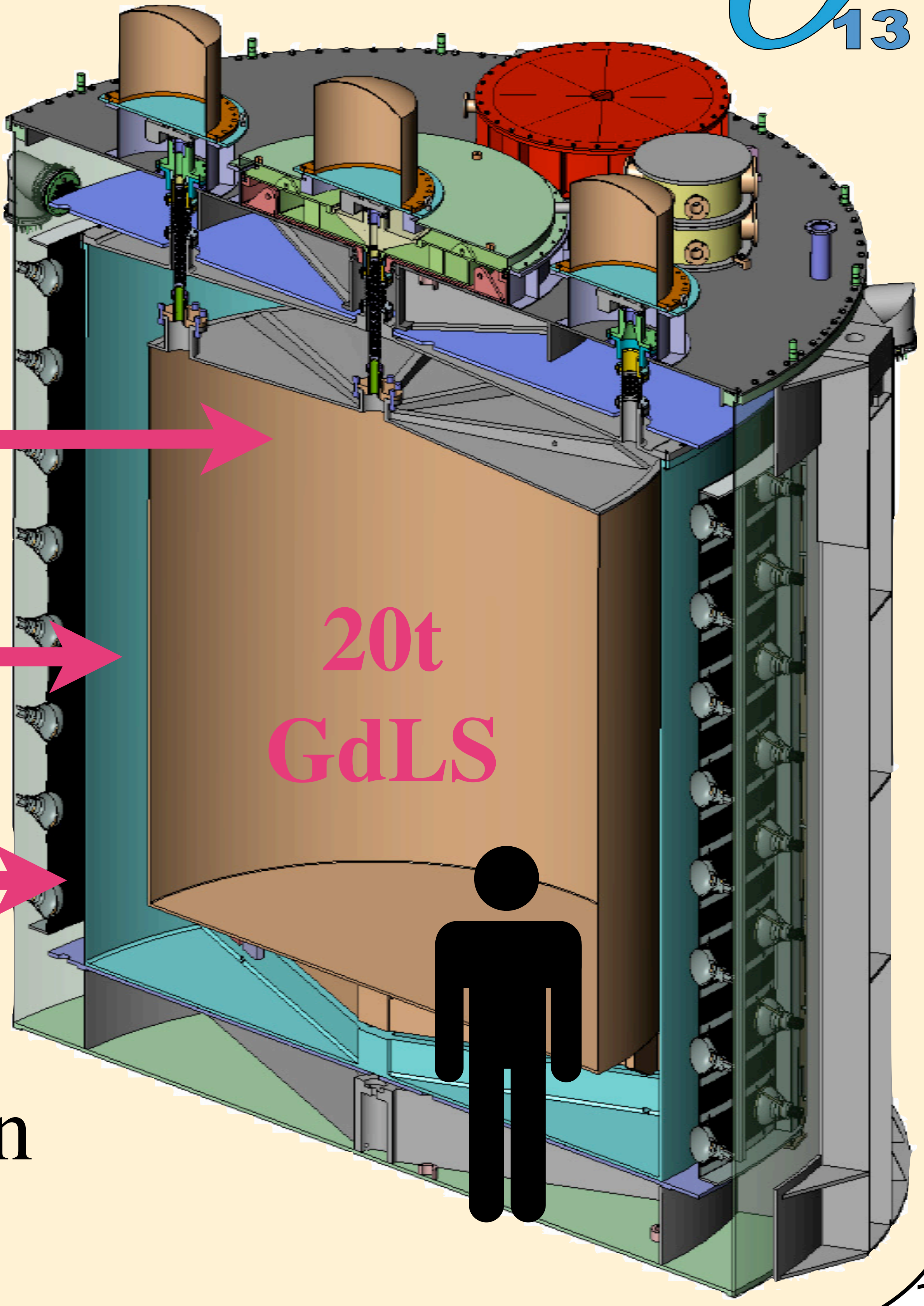
Antineutrino Detectors

Three liquid volumes:

▶0.1% Gadolinium-doped liquid scintillator– *target region*

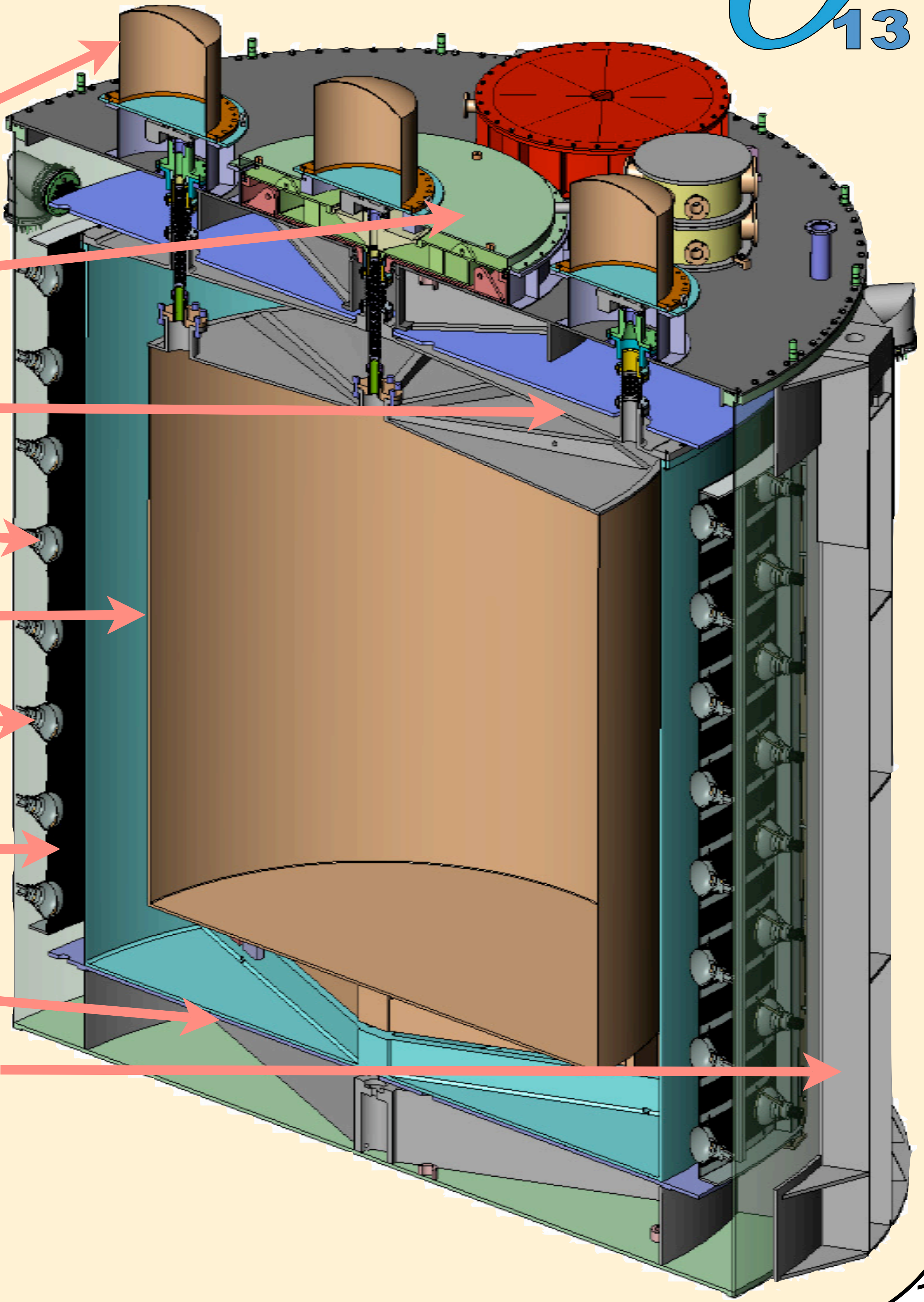
▶Liquid Scintillator– *light collection*

▶Mineral Oil– *PMT buffer*



No position reconstruction or fiducial cuts needed

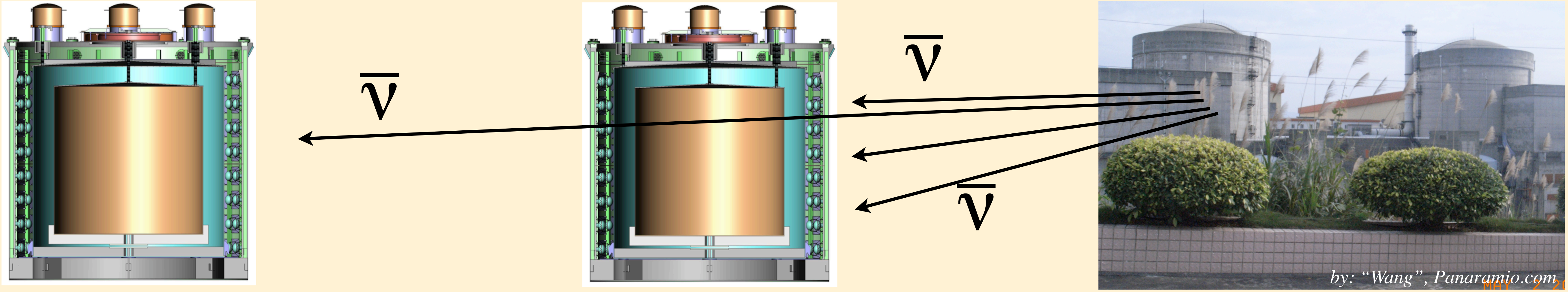
Antineutrino Detectors



- ▶Calibration system
- ▶Overflow system
- ▶Reflector
- ▶192 PMTs
- ▶3m acrylic vessel
- ▶4m acrylic vessel
- ▶Radial absorber
- ▶Reflector
- ▶5m stainless steel tank

Detector Pairing

“Identical” detector pairs mitigate systematic uncertainties



by: “Wang”, Panaramio.com

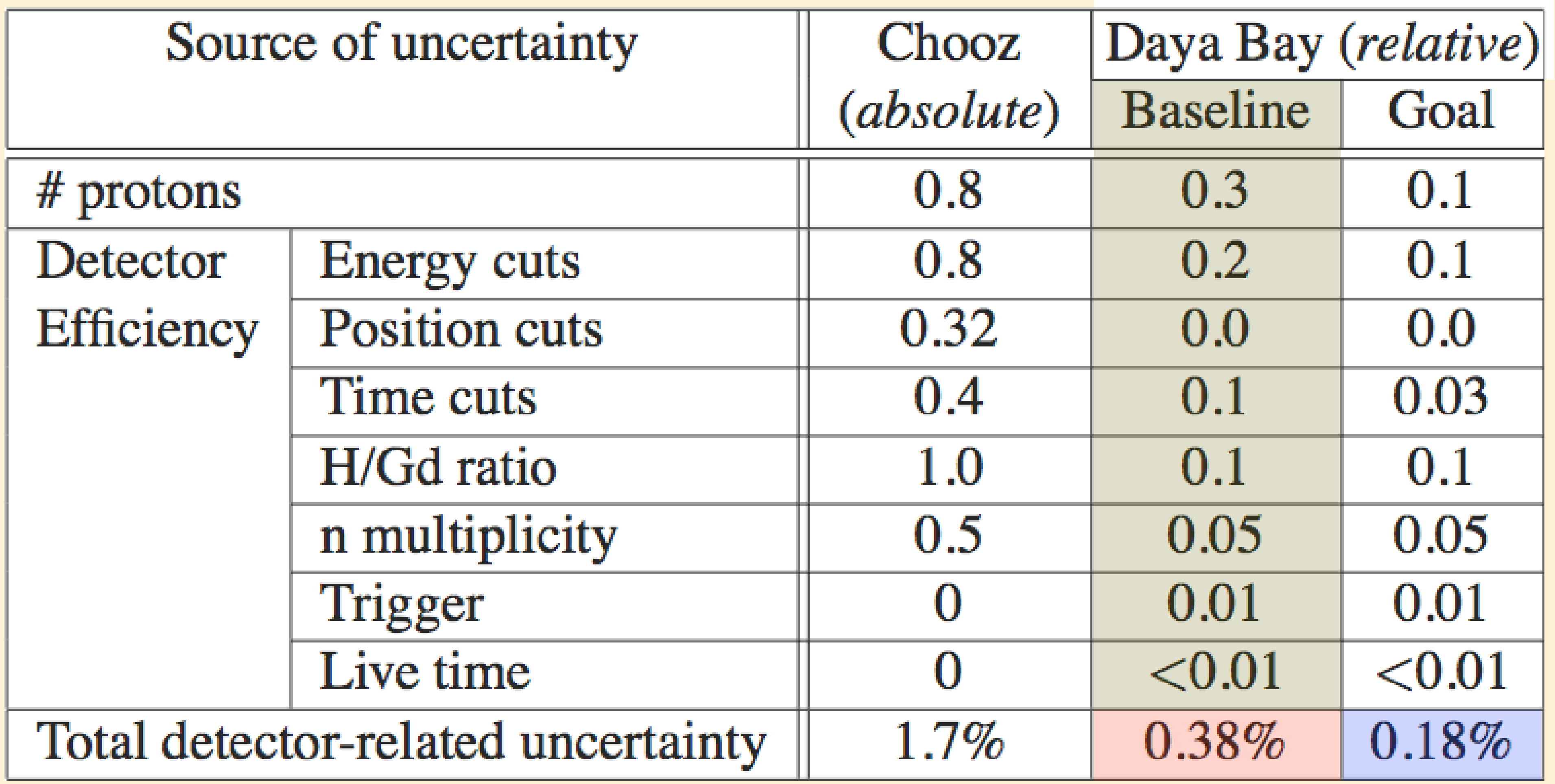
Detectors are deployed in near-far pairs

$$\frac{N_{\mathrm{f}}}{N_{\mathrm{n}}} = \left(\frac{N_{\mathrm{p,f}}}{N_{\mathrm{p,n}}}\right)\left(\frac{L_{\mathrm{n}}}{L_{\mathrm{f}}}\right)^2\left(\frac{\epsilon_{\mathrm{f}}}{\epsilon_{\mathrm{n}}}\right)\left[\frac{P_{\mathrm{sur}}(E,L_{\mathrm{f}})}{P_{\mathrm{sur}}(E,L_{\mathrm{n}})}\right]$$

$$\sin^2 2\theta_{13} \approx \frac{1}{\sin^2\left(\Delta m^2_{31} L/E\right)}\left[1 - \epsilon_r\left(\frac{N_{\mathrm{f}}}{N_{\mathrm{n}}}\right)\left(\frac{L_{\mathrm{f}}}{L_{\mathrm{n}}}\right)^2\right]$$

Detector Systematics

Correlated detector systematic cancels.
Uncorrelated detector systematic does not



Source of uncertainty		Chooz (*absolute*)	Daya Bay (*relative*) Baseline	Goal
# protons		0.8	0.3	0.1
Detector Efficiency	Energy cuts	0.8	0.2	0.1
	Position cuts	0.32	0.0	0.0
	Time cuts	0.4	0.1	0.03
	H/Gd ratio	1.0	0.1	0.1
	n multiplicity	0.5	0.05	0.05
	Trigger	0	0.01	0.01
	Live time	0	<0.01	<0.01
Total detector-related uncertainty		1.7%	0.38%	0.18%

Expect 0.38% with existing techniques, 0.18% with R+D

Correlated reactor systematic cancels.
Uncorrelated cancels by 94% for 6 reactors

Daya Bay Model

$$\chi^2(\theta_{13}, \Delta m^2_{31}|\vec{\eta}) = \sum_{d=1}^{D}\sum_{b=1}^{B}\frac{\left(f_b^d(\vec{\eta}) - o_b^d\right)^2}{o_b^d + (o_b^d\sigma_{\mathrm{b2b}})^2} + \left(\frac{\eta_{\mathrm{N}}}{\sigma_{\mathrm{N}}}\right)^2 + \sum_{b=1}^{B}\left(\frac{\eta^b_{\mathrm{shape}}}{\sigma^b_{\mathrm{shape}}}\right)^2 + \sum_{d=1}^{D}\left[\left(\frac{\eta^d_{\mathrm{det}}}{\sigma^d_{\mathrm{det}}}\right)^2 + \left(\frac{\eta^d_{\mathrm{scale}}}{\sigma^d_{\mathrm{scale}}}\right)^2\right] + \ldots$$

$$\begin{aligned} f_b^d(\vec{\eta}) &= \left(1 + \eta_{\mathrm{N}} + \eta^d_{\mathrm{det}} + \eta^b_{\mathrm{shape}}\right)\sum_{c=1}^{C}\left(1 + \eta^c_{\mathrm{core}}\right)\left(n^{d,b}_{c,\iota=1} + \sum_{\iota=2}^{I}\left(1 + \eta_{c,\iota}\right) n^{d,b}_{c,\iota}\right) \\ &+ \left(1 + \eta^d_{\mathrm{acc}}\right) a_b^d + \left(1 + \eta^d_{\mathrm{fast}}\right) m_b^d + \left(1 + \eta^d_{\mathrm{iso}}\right) S_b^d\,. \end{aligned}$$

Category	**Uncertainty**	**Value (%)**
Detector	Rate normalization	0.38-0.18
	Energy Resolution	$12\%/\sqrt{E}$
	Energy scale	2
	Bin-to-bin	0.3
Reactor	Flux	2
	Fuel composition	2
	Spectrum	2
Site	Backgrounds	0.3
Global	Global correlated	2.8

http://arxiv.org/abs/1103.0734

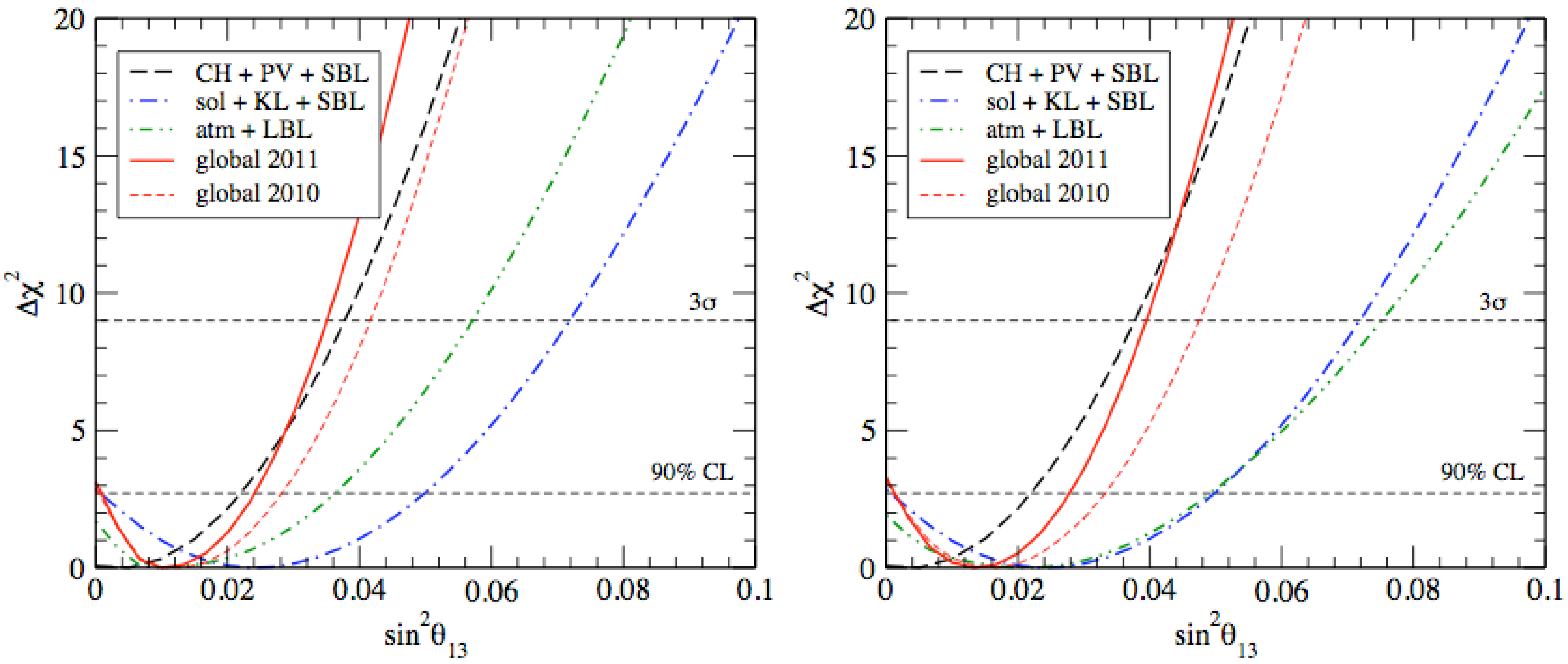


Figure 9. Constraint on $\sin^2\theta_{13}$ from different data sets, shown for NH (left) and IH (right). The curves labeled "CH+PV+SBL" include the Chooz, Palo Verde and the short-baseline reactor experiments, "solar+KL+SBL" include solar, KamLAND and short-baseline reactor data, and "atm + LBL" include Super-K atmospheric data, MINOS (disappearance and appearance), and K2K. The results from our previous 2010 analysis are also shown for comparison.