An Improved Measurement of Electron Antineutrino Disappearance at Daya Bay

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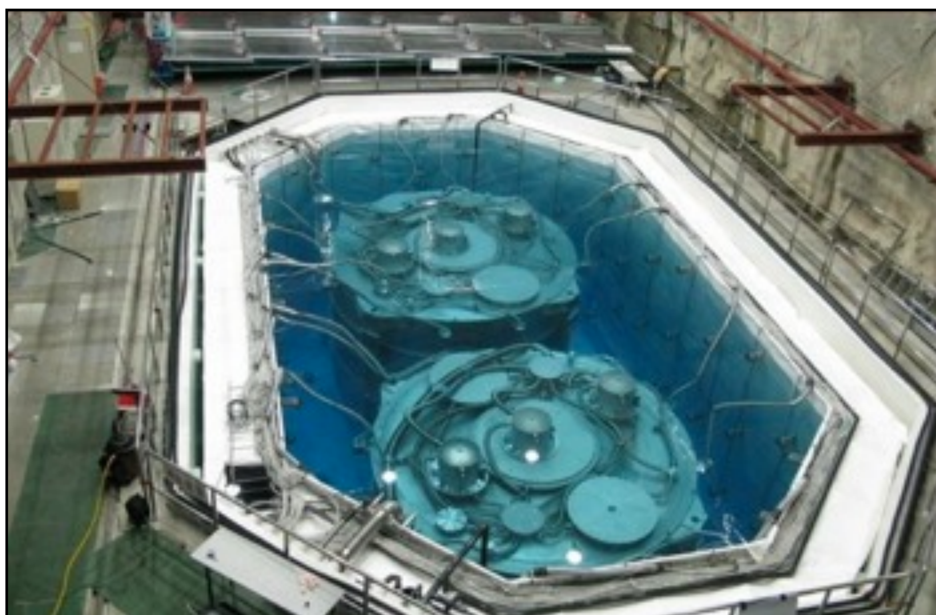
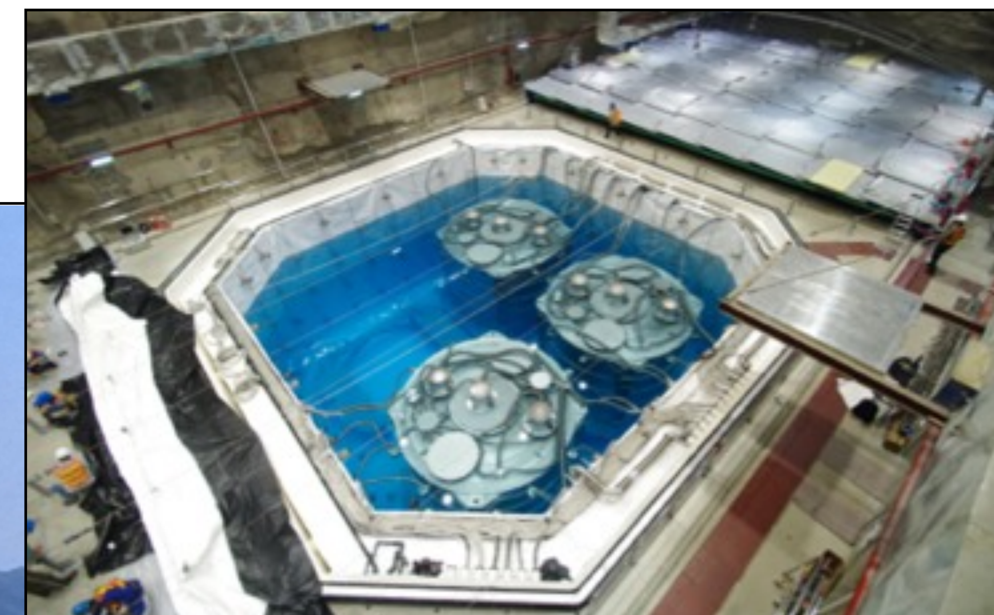
on behalf of the
Daya Bay Collaboration

6/14/2012





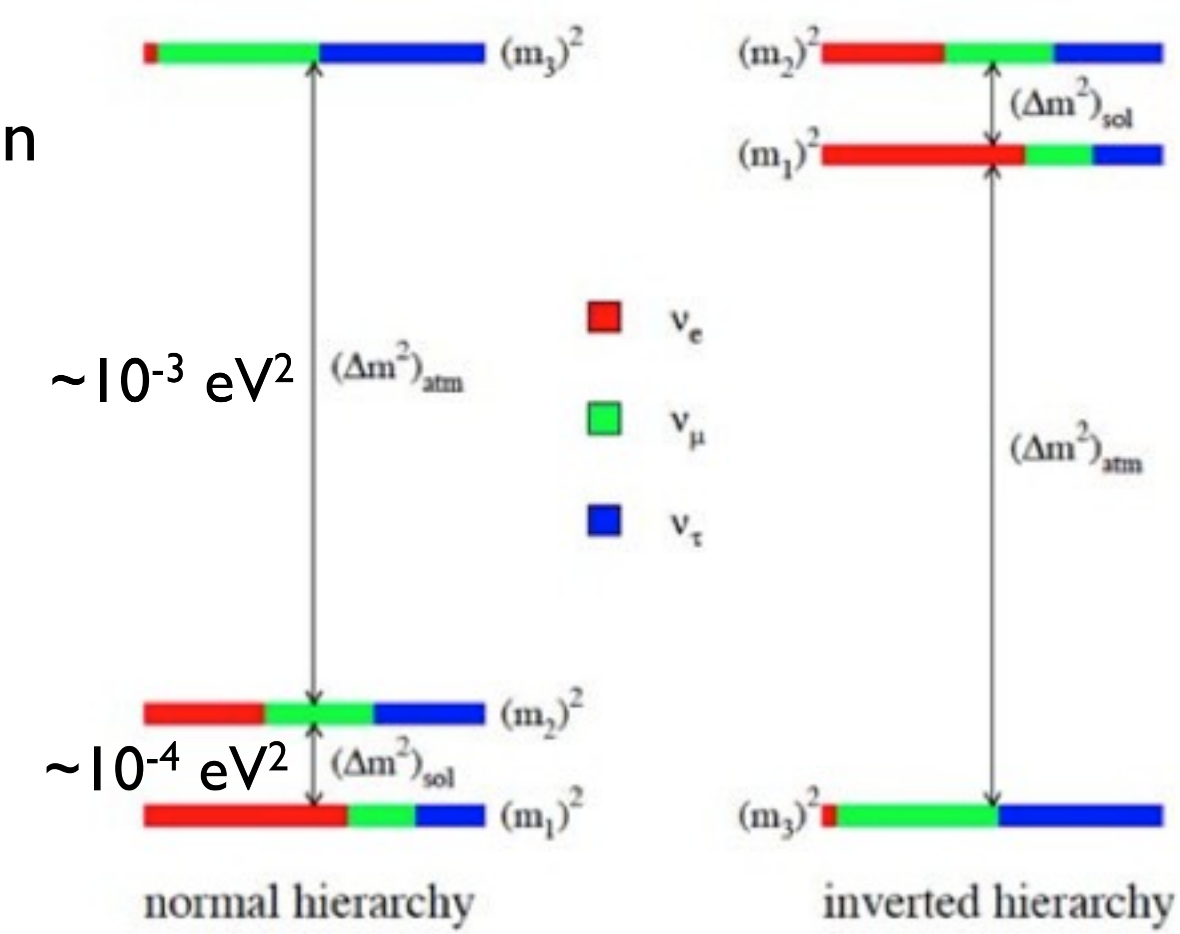
Neutrino Oscillations

- Neutrinos are not massless:
  - Flavor and mass eigenstates are different:

$c_{ij} = \cos(\theta_{ij})$;
$s_{ij} = \sin(\theta_{ij})$;

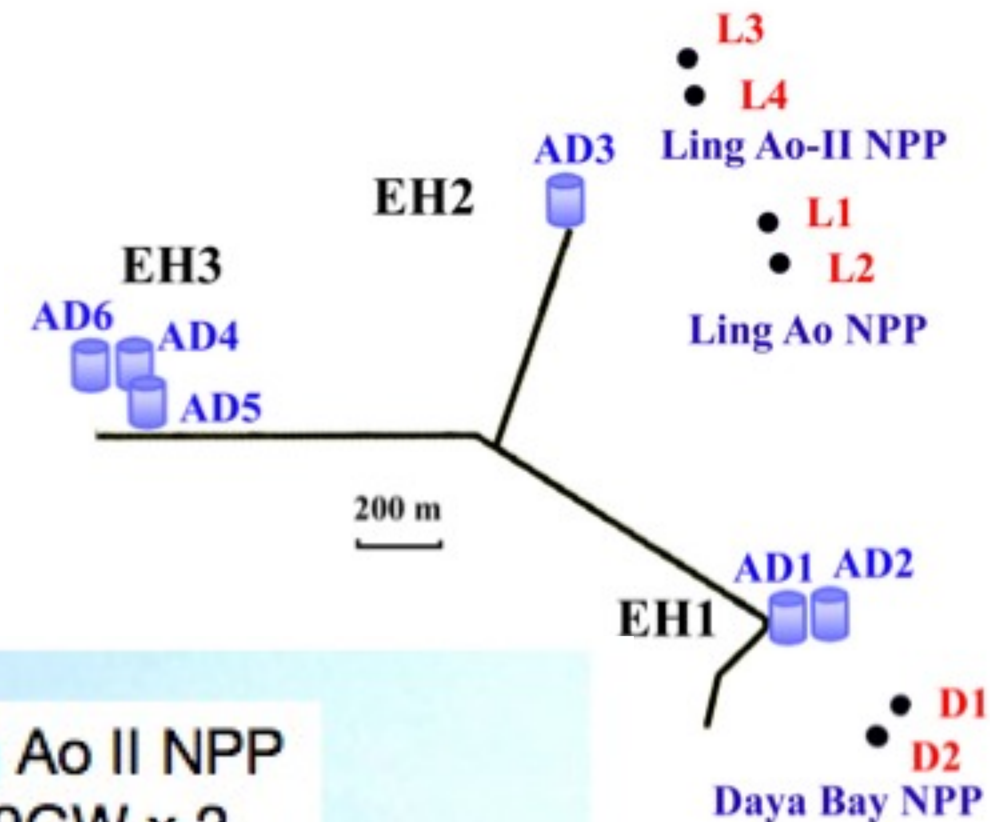
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \begin{pmatrix} e^{ia_1/2}\nu_1 \\ e^{ia_2/2}\nu_2 \\ \nu_3 \end{pmatrix}$$

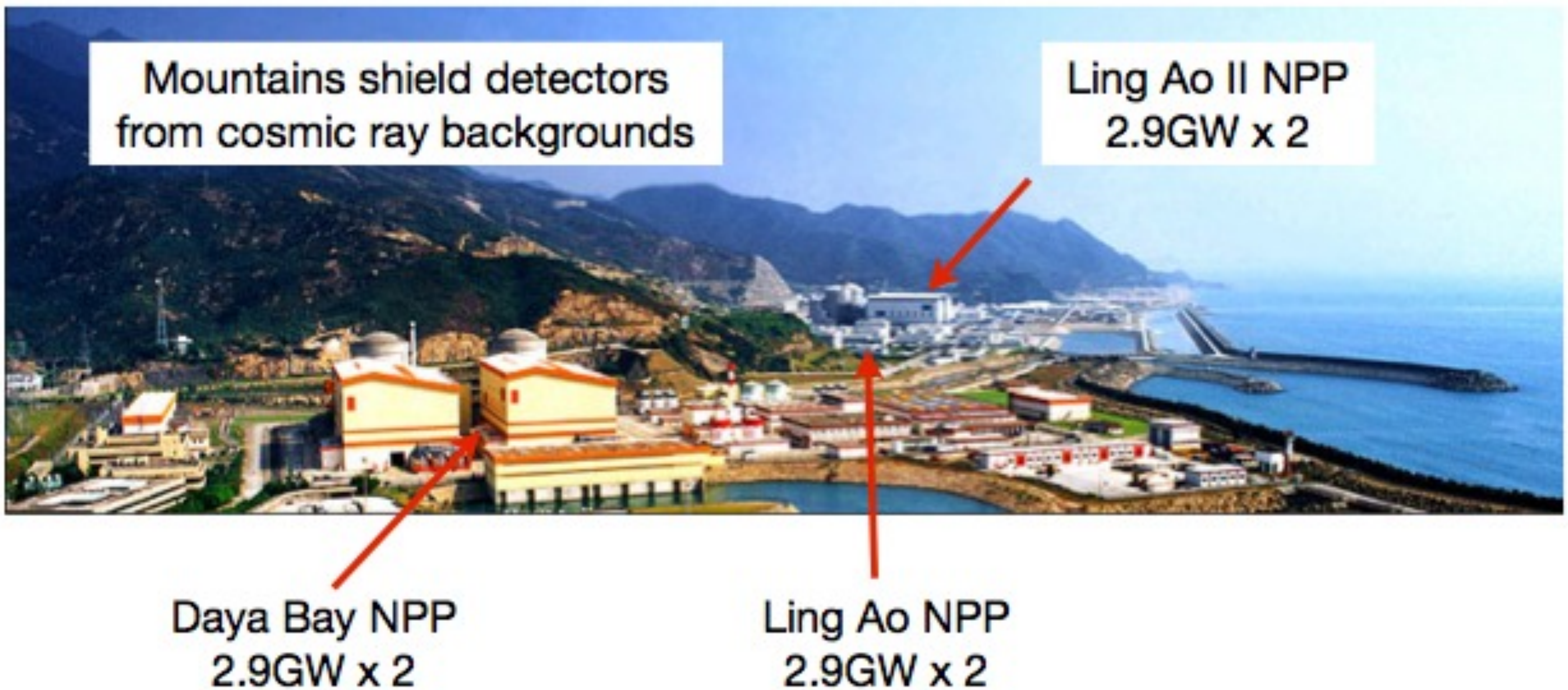
  - Leads to neutrino flavor transformation
  - Parameters governing oscillation:
    - Neutrino mass differences
    - Mixing angles
    - CP-violating phase, δ
  - Many current experiments designed to measure θ_{13}



The Daya Bay Experiment: Looking For θ_{13}

- Three reactor sites with 2 cores, 17.4 GW_{th} total
- 6 detectors at three experimental halls (EHs)
- 120 T total target mass, 60 T at far site
- Positions measured to 3cm or better!





Daya Bay: A Relative Measurement

- Near-far sites allow relative measurement:

Protons

Interaction cross-section

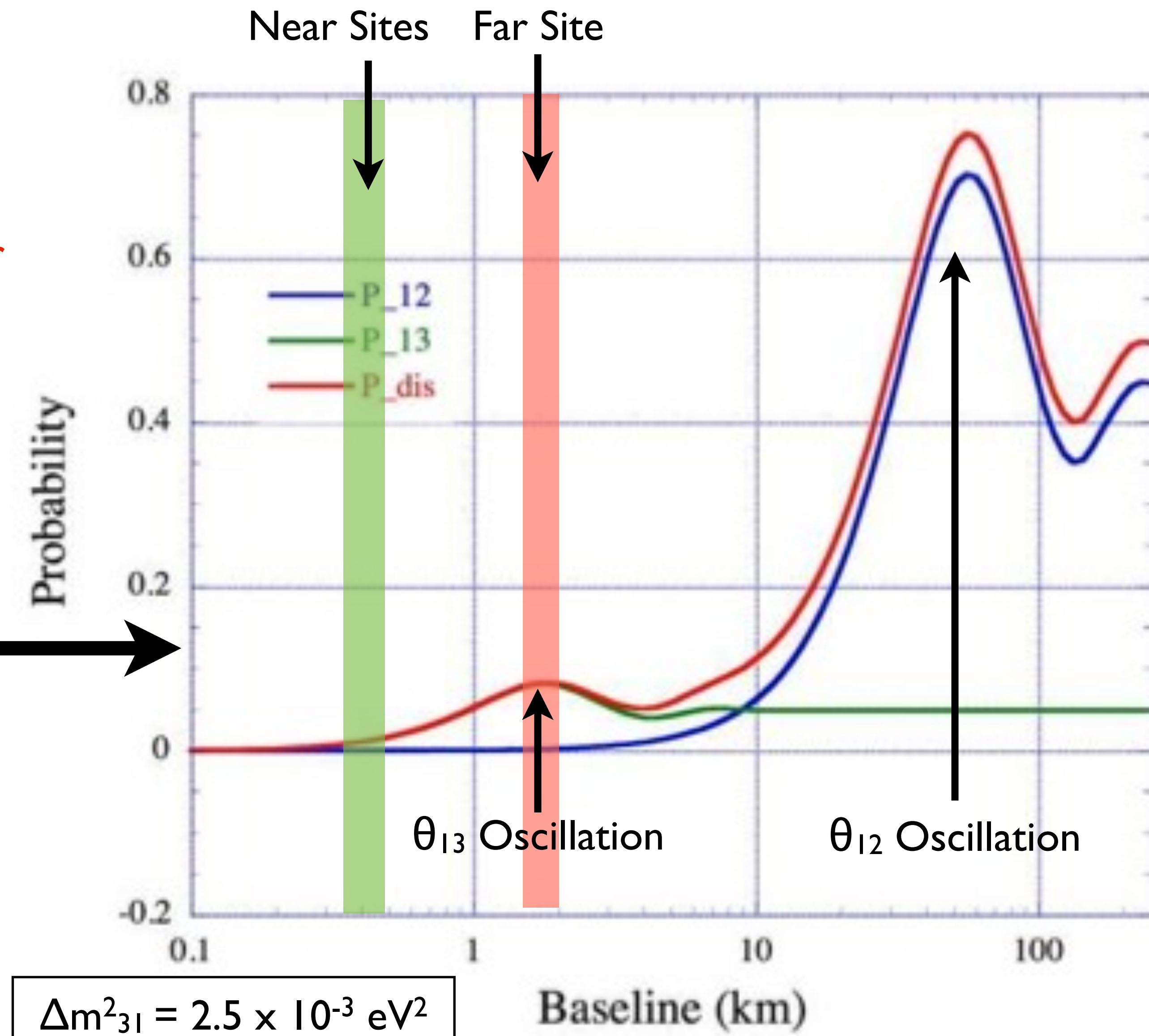
$$N_{det} = \frac{N_p}{4\pi L^2} \int \epsilon \sigma P_{sur} S dE$$

Baseline

Efficiency

Reactor spectrum, power

$$\frac{N_f}{N_n} = \left(\frac{N_{p,f}}{N_{p,n}}\right)\left(\frac{L_n}{L_f}\right)^2\left(\frac{\epsilon_f}{\epsilon_n}\right)\left[\frac{P_{sur}(E, L_f)}{P_{sur}(E, L_n)}\right]$$

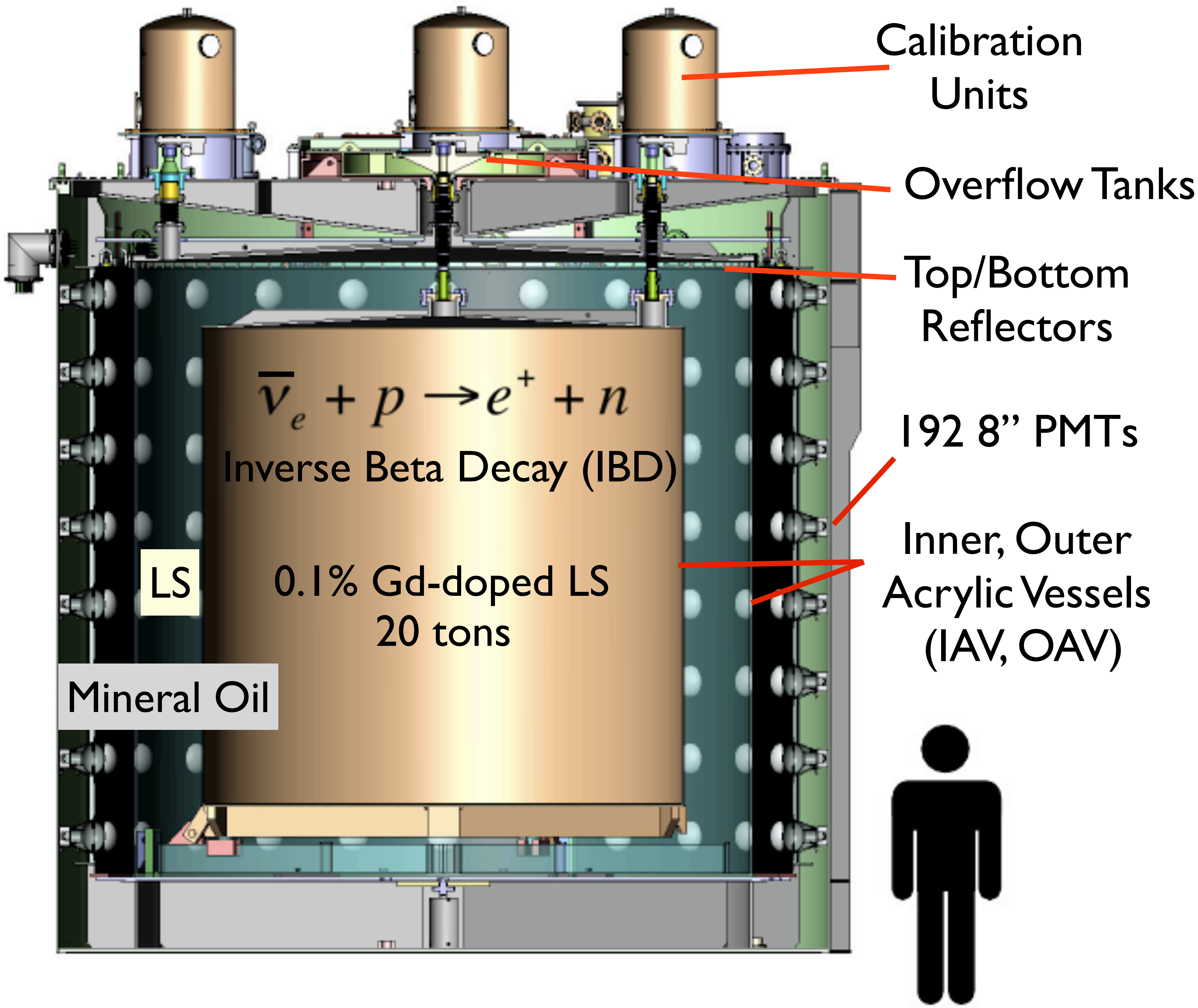


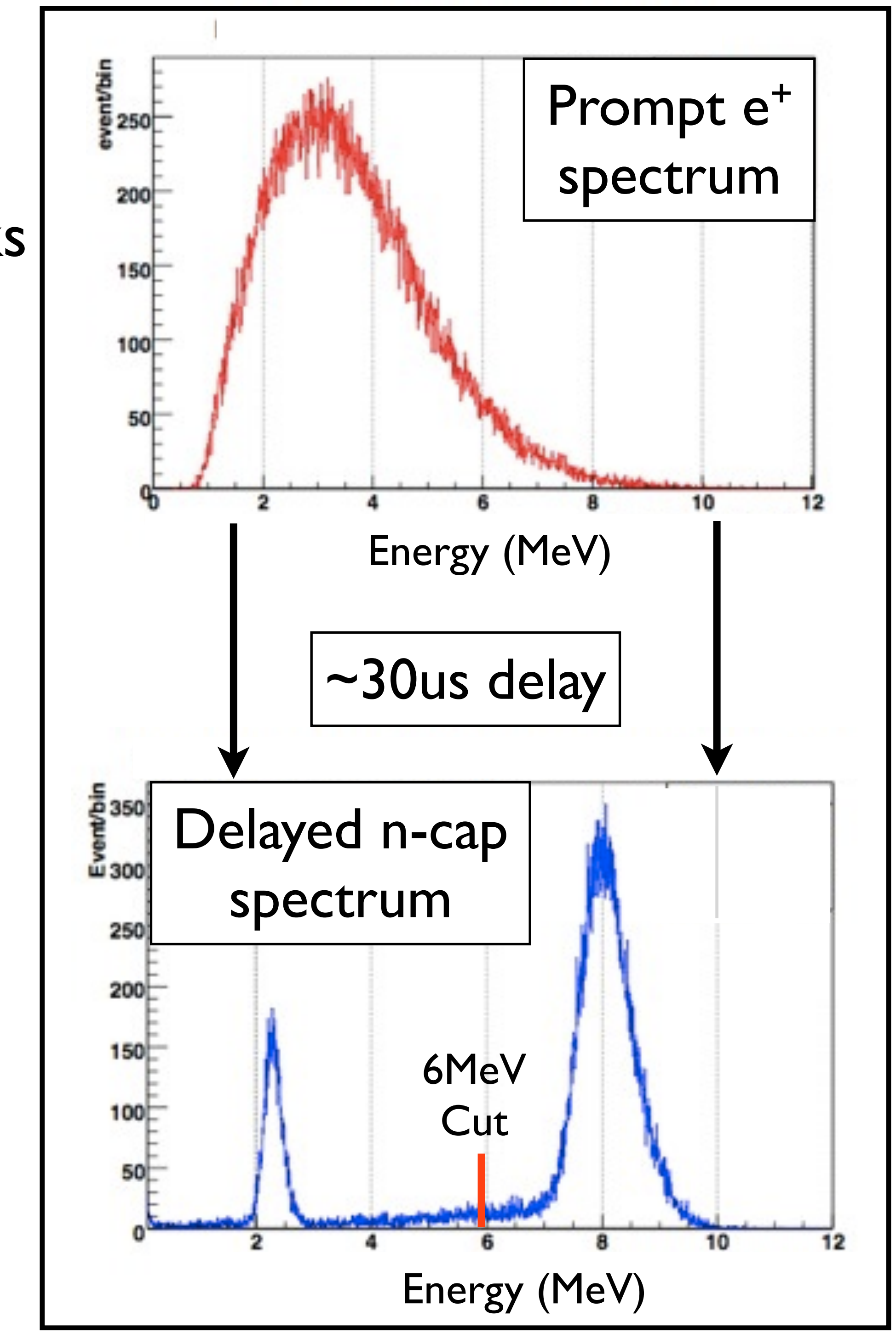
Δm^2_{31} = 2.5 x 10^{-3} eV^2
$\sin^2 2\theta_{13}$ =0.1

- Largest uncertainties cancel:
  - Reactor shape, thermal power
  - Largest detector systematics
- Baseline optimized for a θ_{13} measurement

Daya Bay $\bar{\nu}_e$ Detectors (ADs)

- A Daya Bay AD: three-zone liquid scintillator detector

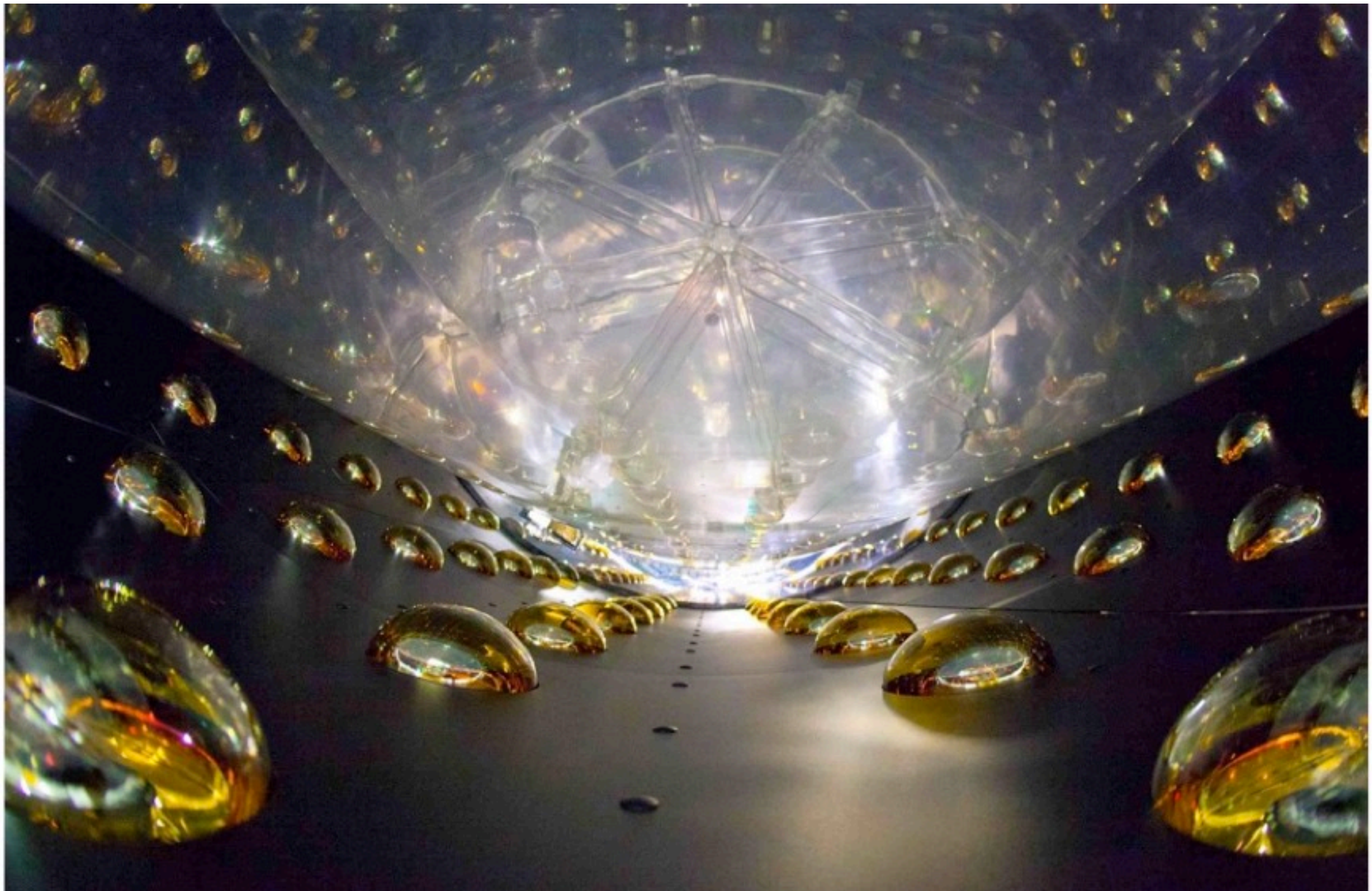




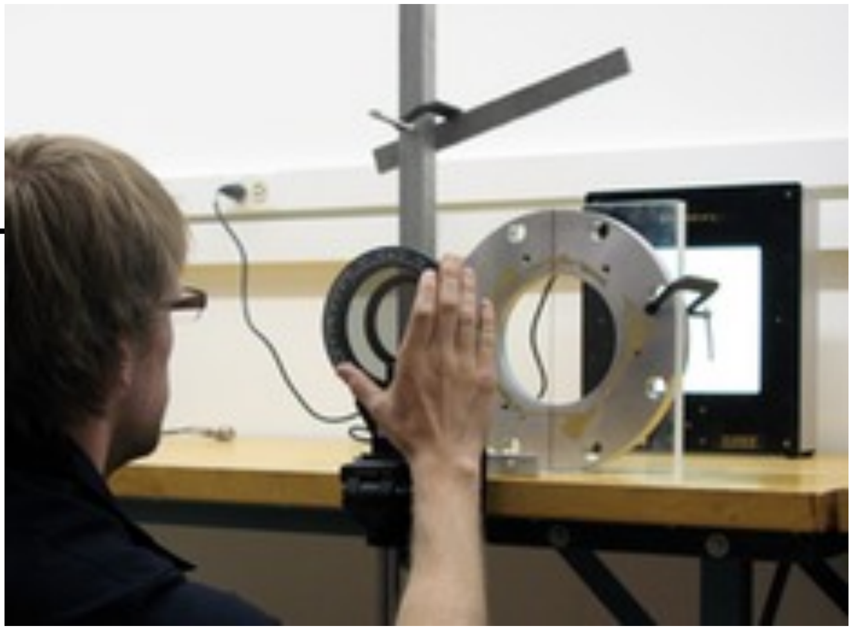
Daya Bay Monte Carlo Data

Daya Bay $\overline{\nu}_e$ Detectors (ADs)

Interior of a Daya Bay antineutrino detector



Acrylic Vessels (AVs)



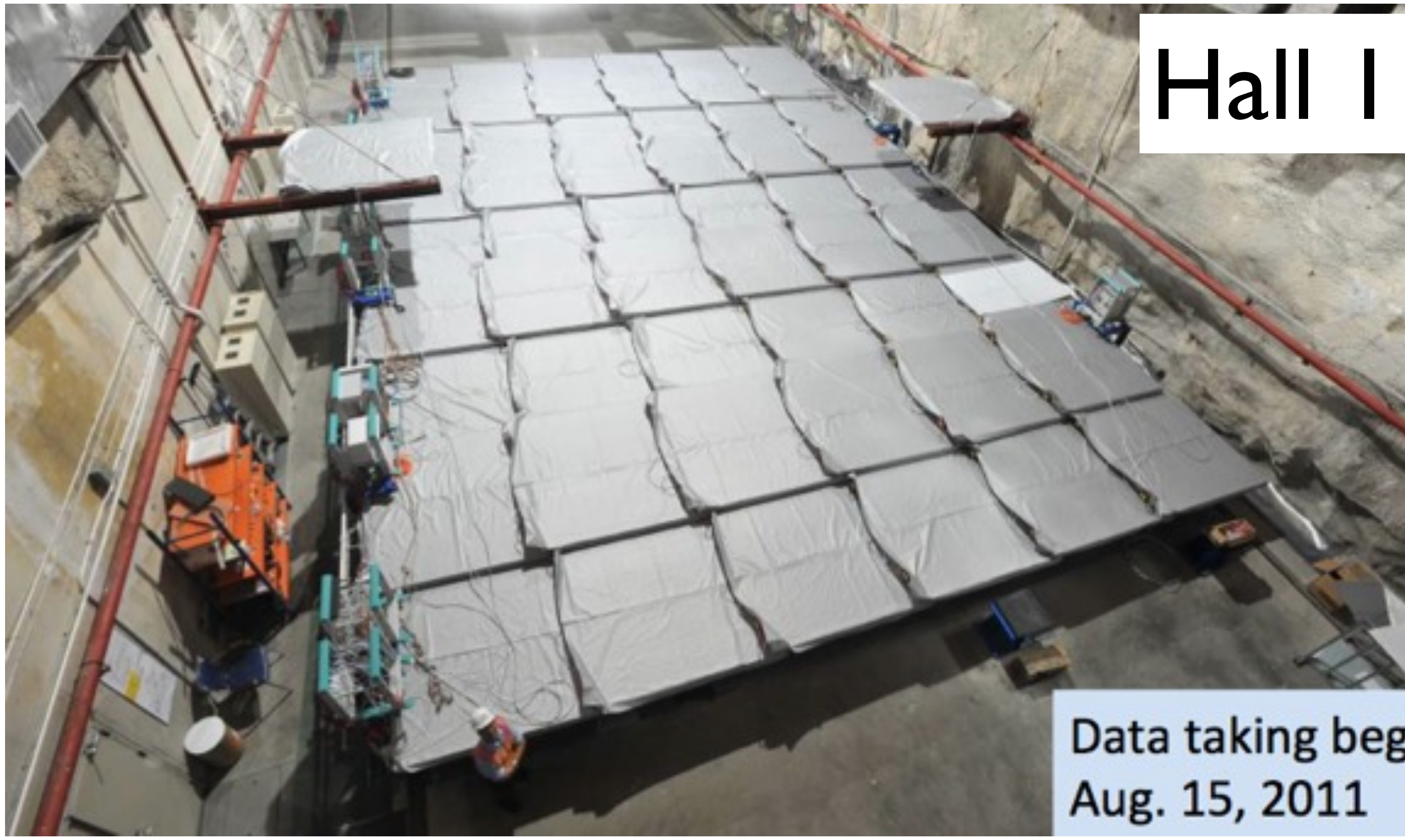
Designed AV Stress Testing System in Lab

On-site characterization measurements

AV Cleaning at Daya Bay

- Played major role in AV design, construction, assembly and characterization:
  - B.R. Littlejohn, *et. al.*, JINST **4** T09001 (2009)
  - H.R. Band, B.R. Littlejohn, *et. al.*, JINST **7** 06004 (2012)
  - M. Krohn, B.R. Littlejohn, K.M. Heeger, arXiv:1206.1944 (2012)
    Submitted to JINST

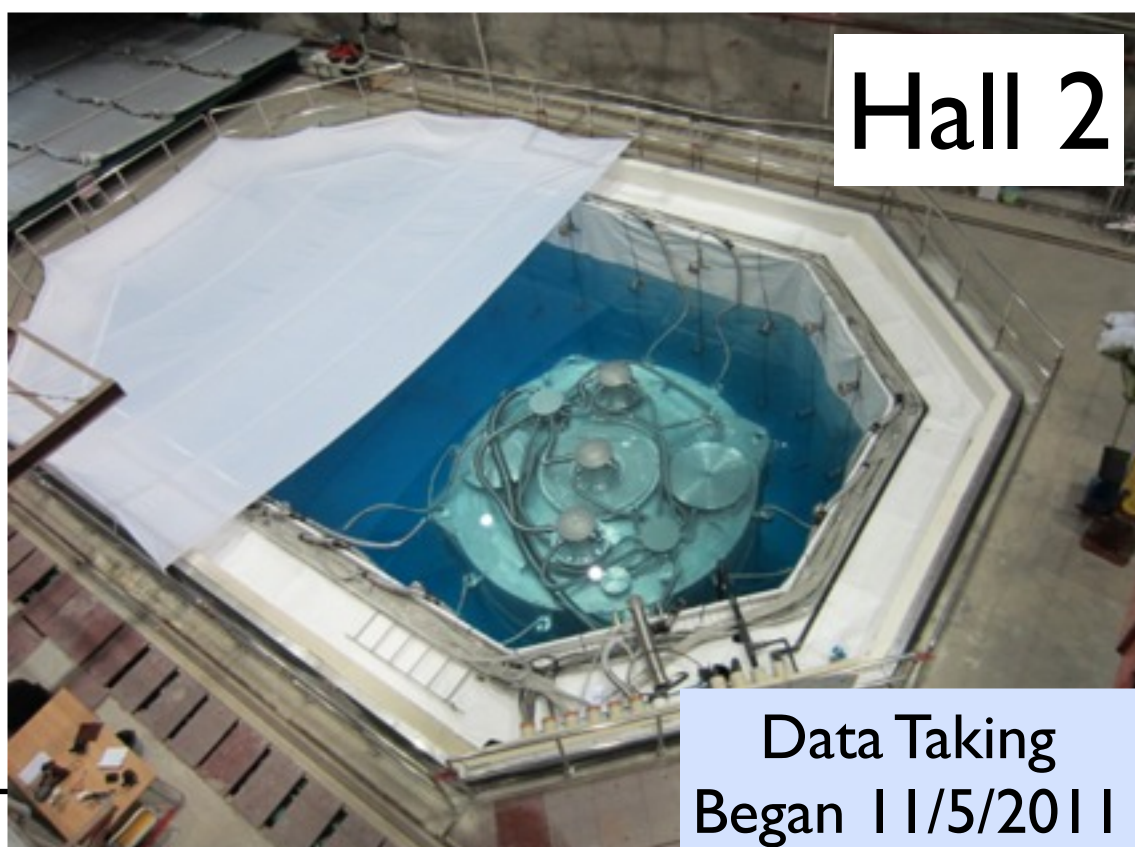
Daya Bay Detector Deployment



Hall 1

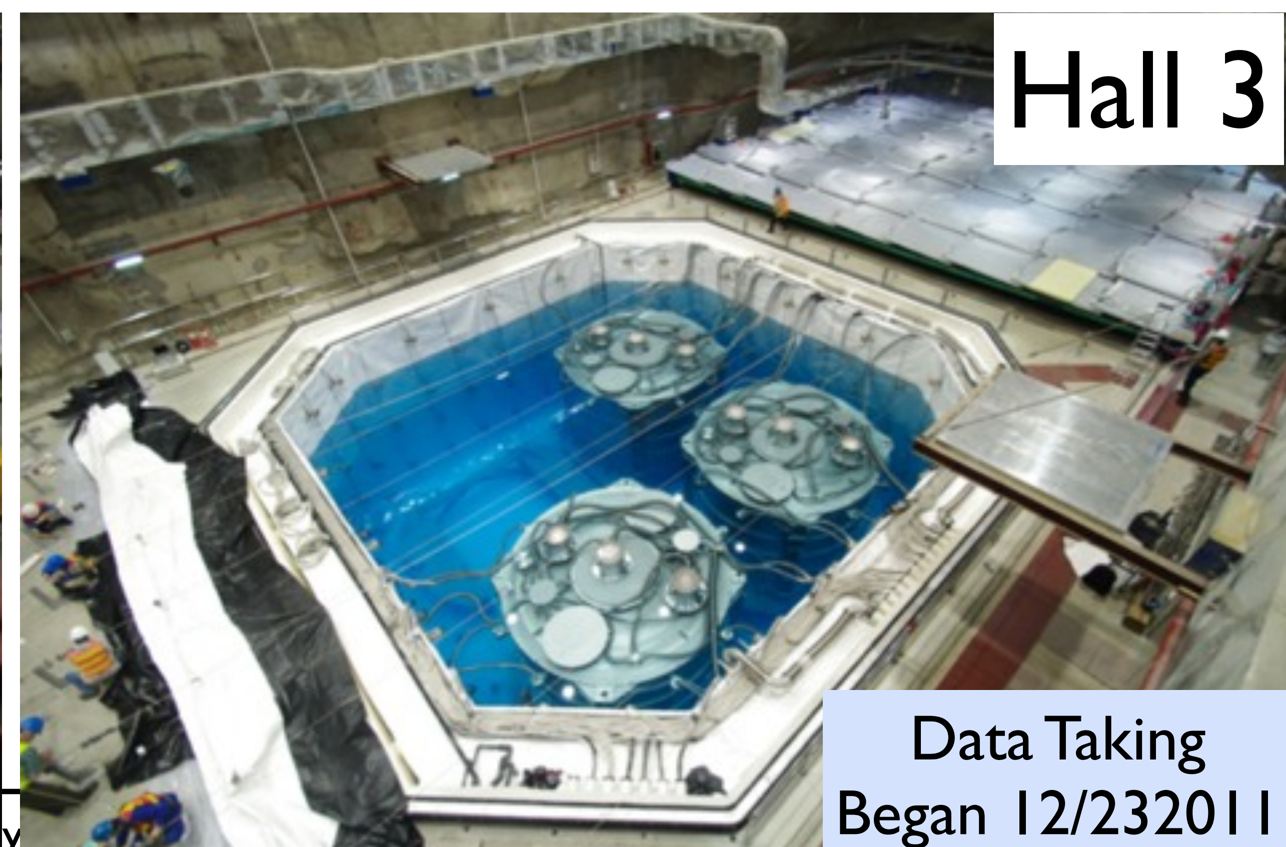
Data taking began
Aug. 15, 2011

- Detectors installed in water muon veto pool
- Resistive plate chambers installed over top for further muon veto
- All three halls running



Hall 2

Data Taking
Began 11/5/2011

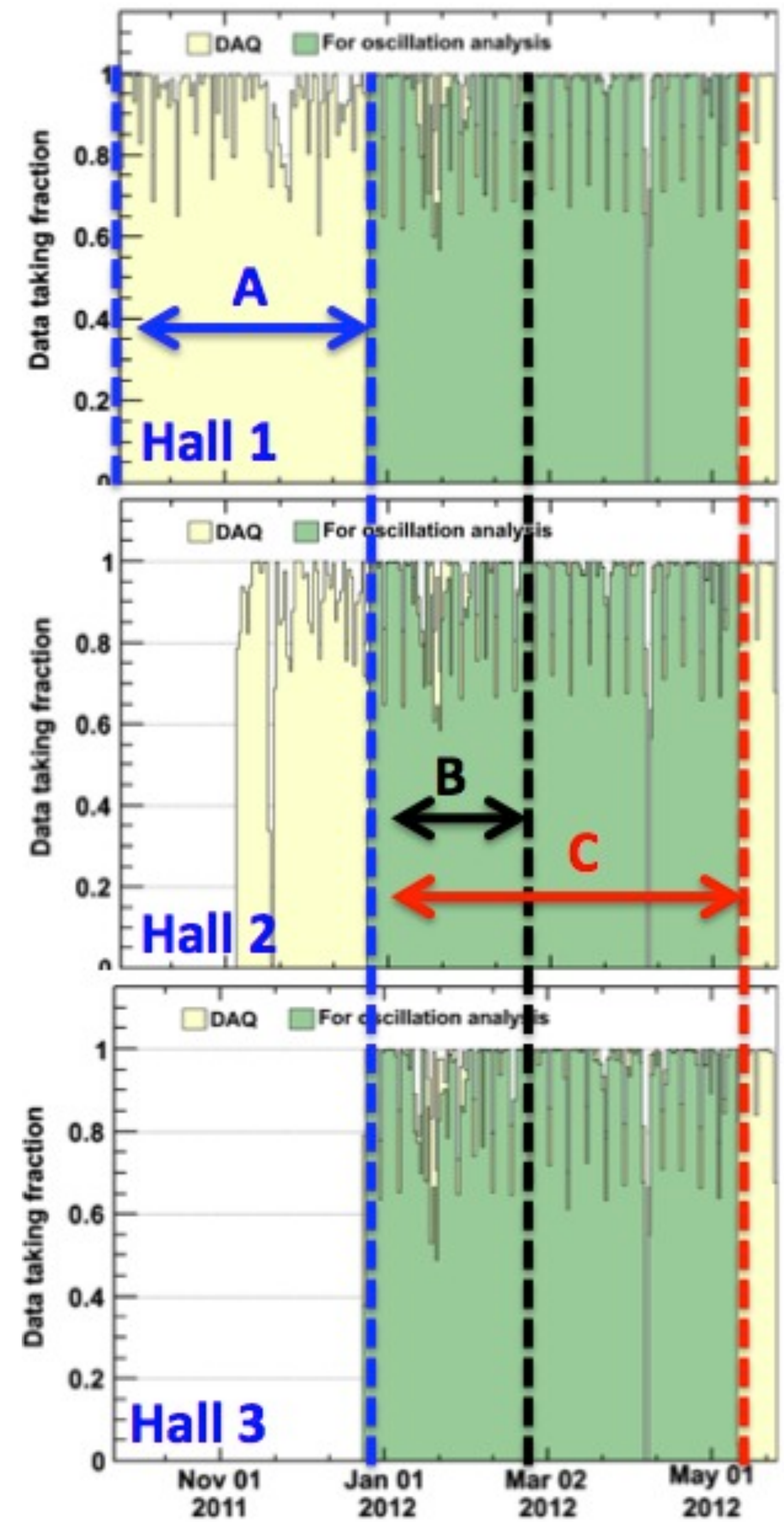


Hall 3

Data Taking
Began 12/232011

Data-Taking Periods

- A: Near-Site Comparison:
  - Sep. 23 2011 - Dec. 23, 2012
  - Side-by-side comparison of two near-site detectors
  - Demonstrated detector systematics
  - NIM **A685** 78 (2012)
- B: First Oscillation Result:
  - Dec. 24, 2011 - Feb. 17, 2012
  - All 3 halls (6ADs) operating
  - Phys. Rev. Lett **108** 171803 (2012)
- C: This Update:
  - Dec. 24, 2011 - May 11, 2012
  - More than 2.5x the previous dataset



Data Set Summary

>200k antineutrinos detected!

	AD1	AD2	AD3	AD4	AD5	AD6
Antineutrino candidates	69121	69714	66473	9788	9669	9452
DAQ live time (day)	127.5470		127.3763	126.2646		
Efficiency	0.8015	0.7986	0.8364	0.9555	0.9552	0.9547
Accidentals (/day)	9.73±0.10	9.61±0.10	7.55±0.08	3.05±0.04	3.04±0.04	2.93±0.03
Fast neutron (/day)	0.77±0.24	0.77±0.24	0.58±0.33	0.05±0.02	0.05±0.02	0.05±0.02
$^{8}He/^{9}Li$ (/day)	2.9±1.5		2.0±1.1	0.22±0.12		
Am-C corr. (/day)	0.2±0.2					
$^{13}C(\alpha, n)^{16}O$ (/day)	0.08±0.04	0.07±0.04	0.05±0.03	0.04±0.02	0.04±0.02	0.04±0.02
Antineutrino rate (/day)	**662.47 ±3.00**	**670.87 ±3.01**	**613.53 ±2.69**	**77.57 ±0.85**	**76.62 ±0.85**	**74.97 ±0.84**

Consistent neutrino event rates at all sites with low B/S

Uncertainties Summary

- Dominated by statistical uncertainty at the far site: 1%

Detector			
	Efficiency	Correlated	Uncorrelated
Target Protons		0.47%	0.03%
Flasher cut	99.98%	0.01%	0.01%
Delayed energy cut	90.9%	0.6%	0.12%
Prompt energy cut	99.88%	0.10%	0.01%
Multiplicity cut		0.02%	<0.01%
Capture time cut	98.6%	0.12%	0.01%
Gd capture ratio	83.8%	0.8%	<0.1%
Spill-in	105.0%	1.5%	0.02%
Livetime	100.0%	0.002%	<0.01%
Combined	78.8%	1.9%	0.2%

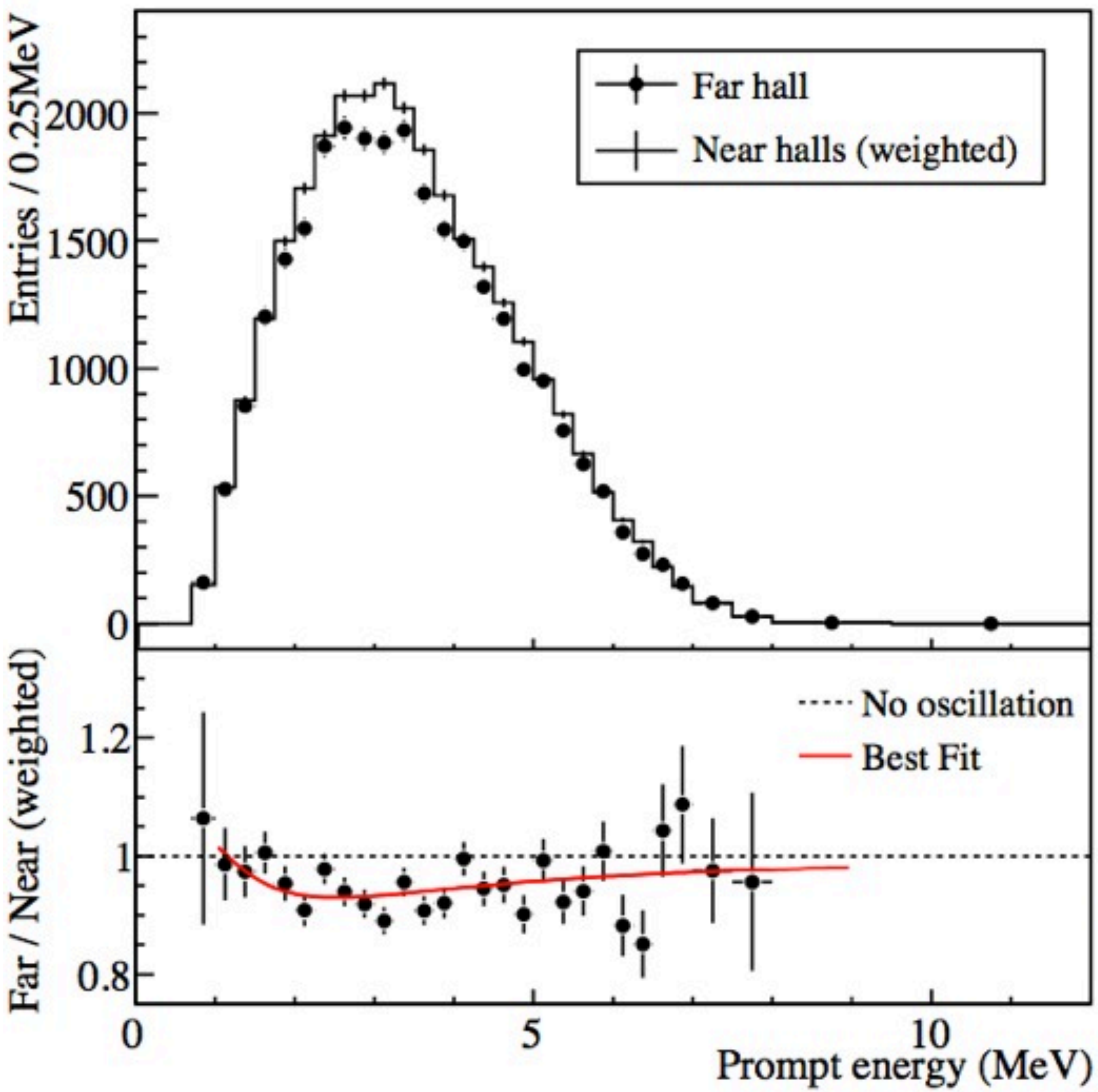
F.P. An *et al.*, PRL 108 171803 (2012)

Background Uncertainties

	Near Halls	Far Hall
Accidentals	0.02%	0.05%
$^8He/^9Li$	0.2%	0.2%
Fast Neutron	0.03%	0.05%
$^{241}Am^{12}C$ Source	0.003%	0.3%

- Reactor uncertainty contribution, near-far measurement: < 0.1%
- Baseline uncertainties: 0.02%

Near Versus Far Comparison



$$R = \frac{Far_{measured}}{Far_{expected}} = \frac{M_4 + M_5 + M_6}{\sum_{i=4}^{6}(\alpha_i(M_1 + M_2) + \beta_i M_3)}$$

M_n are the measured rates in each detector. Weights α_i,β_i are determined from baselines and reactor fluxes.

R = 0.944 ± 0.007 (stat) ± 0.003 (syst)

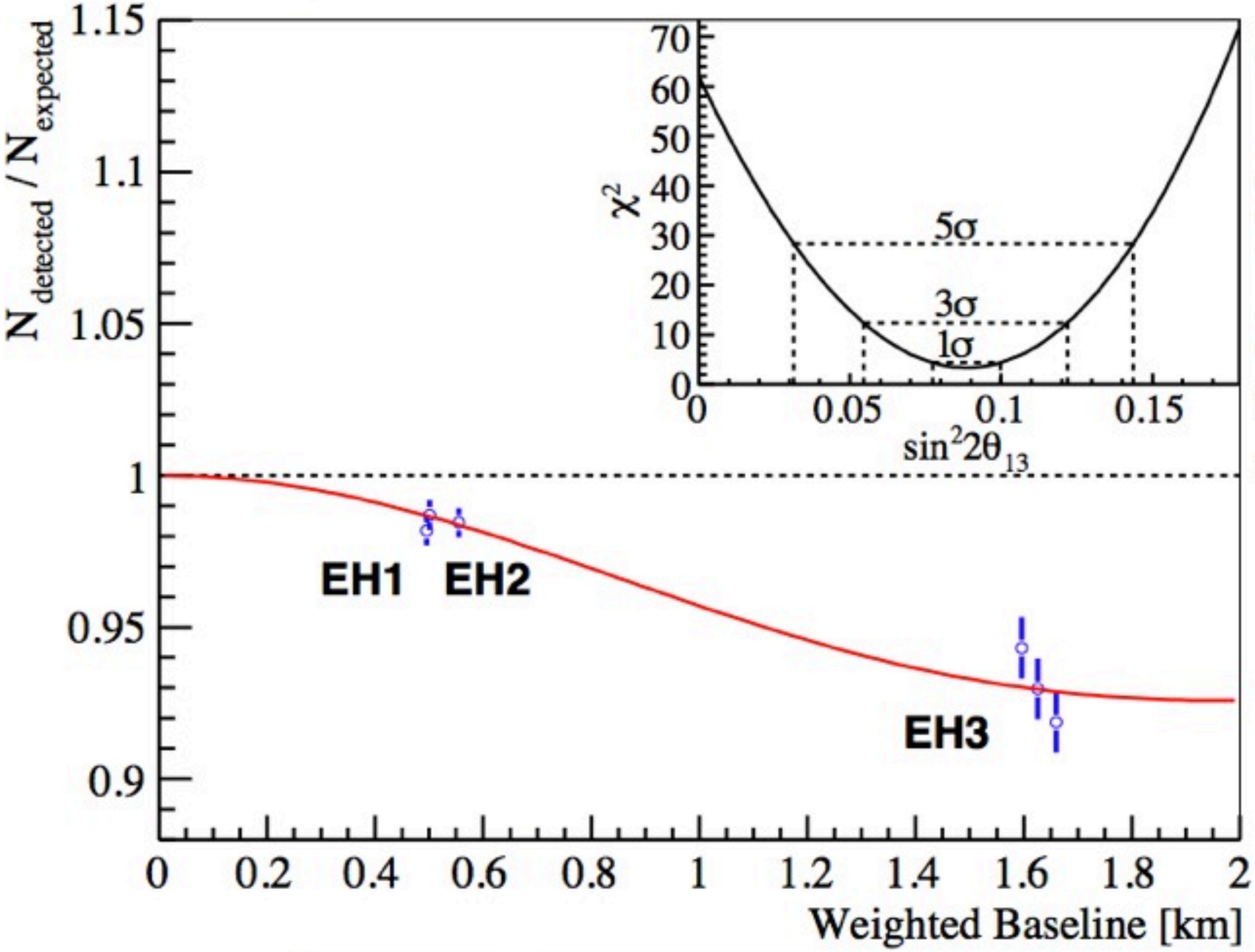
Clear observation of far site deficit.

Spectral distortion consistent with oscillation.*

* Caveat: Spectral systematics not fully studied; θ_{13} value from shape analysis is not recommended.

Rate Analysis

Estimate θ_{13} using measured rates in each detector.



Uses standard χ^2 approach.

Far vs. near relative measurement.
[Absolute rate is not constrained.]

Consistent results obtained by independent analyses, different reactor flux models.

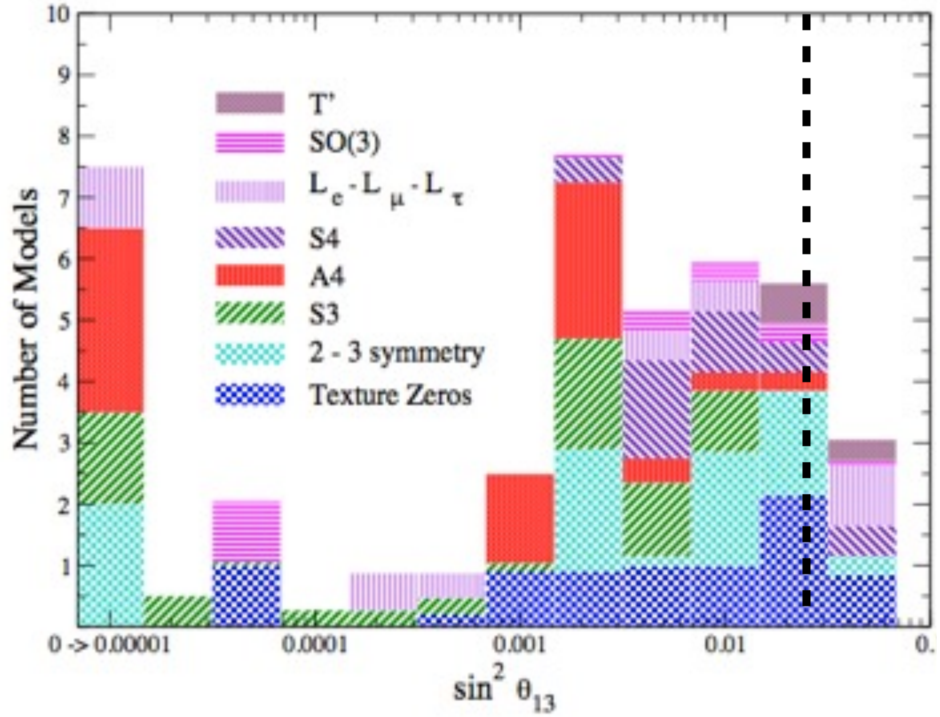
Most precise measurement of $\sin^2 2\theta_{13}$ to date.

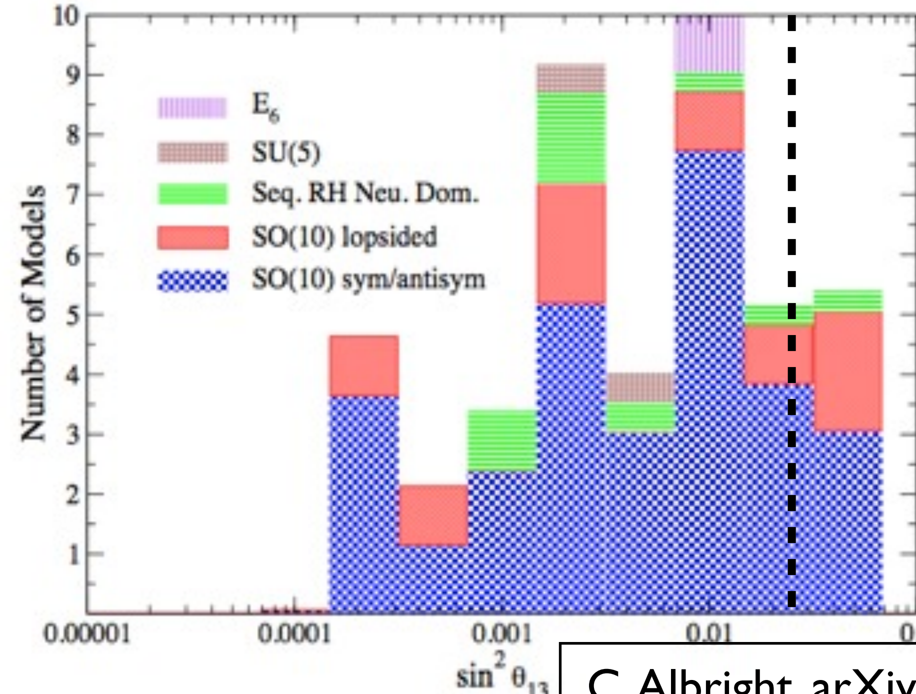
$\sin^2 2\theta_{13} = 0.089 \pm 0.010\ (\text{stat}) \pm 0.005\ (\text{syst})$

Impacts of Large θ_{13}

- Theoretical possibilities are greatly reduced, although more are surely on their way!

Flavor Symmetries

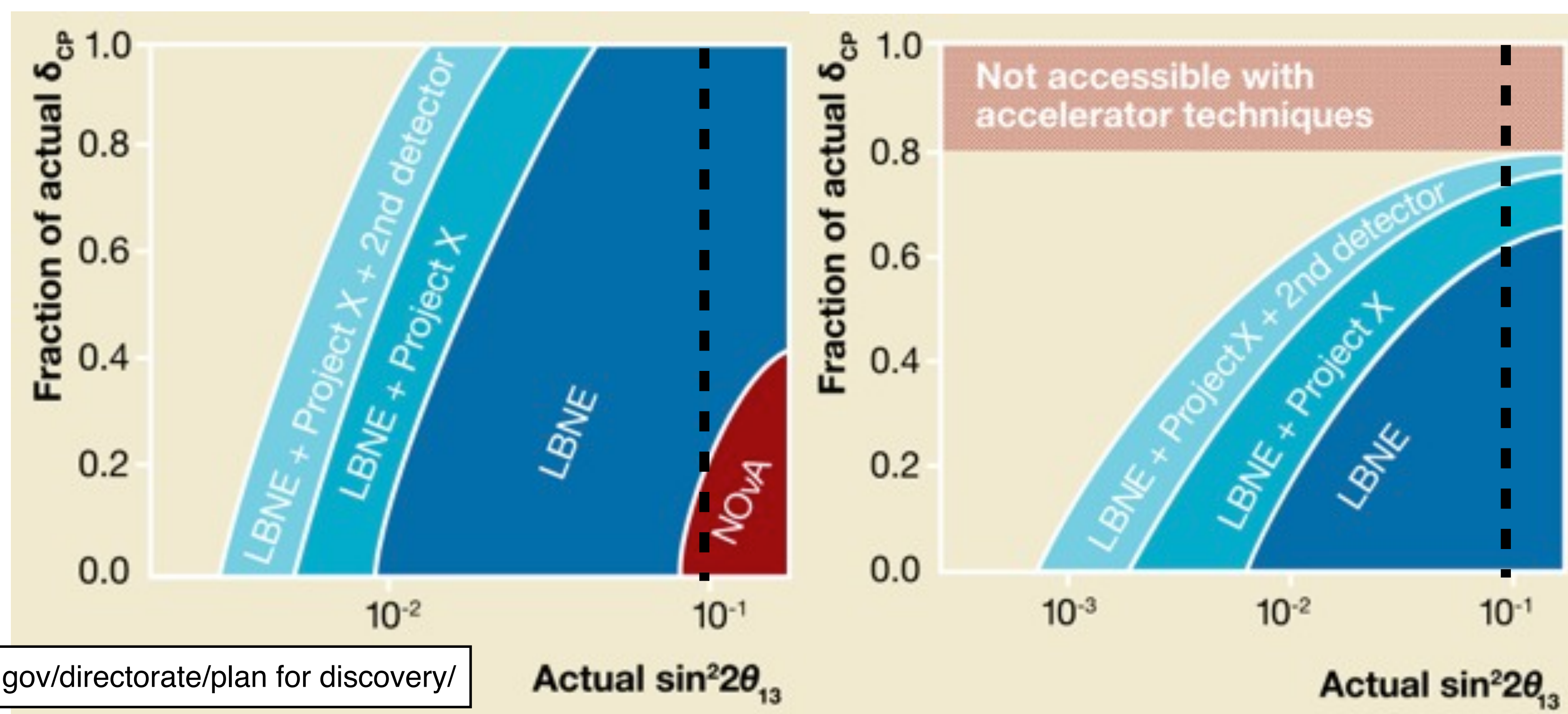




GUTs

C. Albright, arXiv:0911.2437v1 (2009)

- Prospects for mass hierarchy and δ_{cp} greatly improved at future neutrino exps.



http://www.fnal.gov/directorate/plan for discovery/

Daya Bay: θ_{13} and More

Daya Bay has measured non-zero θ_{13} to $>7\sigma$
Expect much more to come from Daya Bay!

- Primary Goals
  - Precision measurement of $\sin^2 2\theta_{13}$ measurement with extended calibration, improved analysis, and increased statistics
  - Measurement of mass-squared splitting
- Additional Science Goals
  - Measure reactor flux and spectra with largest dataset ever collected
  - Search for new non-standard antineutrino interactions, like sterile neutrinos: arXiv:1109.6036
  - Measure cosmogenic neutron and isotope production at various depths for future exps.
- Technical Studies
  - Demonstrate multi-year operation of "functionally identical detectors"
  - Verify long-term GdLS stability