Status of the Daya Bay Experiment

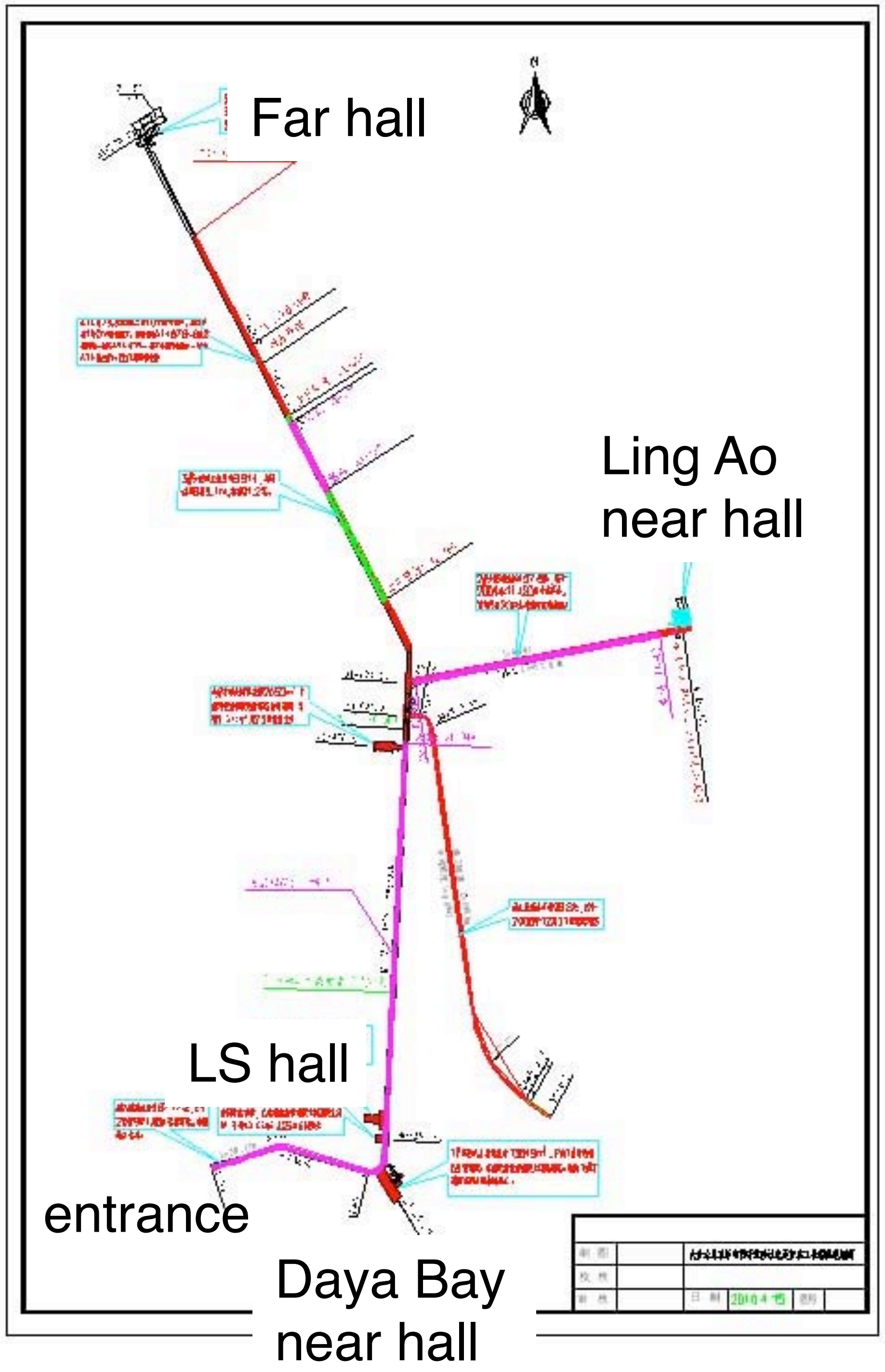
Chao Zhang
BNL

on behalf of the Daya Bay collaboration

INFO11, 7/18/2011

Where is Daya Bay?

Daya Bay Underground Laboratory



Daya Bay Collaboration

Europe (3)

JINR, Dubna, Russia

Kurchatov Institute, Russia

Charles University, Czech Republic

North America (15)

BNL, Caltech, LBNL, Iowa state, Illinois Inst. Tech., Princeton, RPI, Siena Coll. UC-Berkeley, UCLA, U-Cincinnati, U-Houston, U-Wisconsin, Virginia Tech., U-Illinois-Urbana-Champaign,

Asia (19)

IHEP, Beijing Normal Univ., Chengdu UST, CGNPG, CIAE, Dongguan Univ. of Tech., Nanjing Univ.,Nankai Univ., Shenzhen Univ., Shandong Univ.,Shanghai Jiaotong Univ., Tsinghua Univ., USTC, Zhongshan Univ., Hong Kong Univ., Chinese Hong Kong Univ., Taiwan Univ., Chiao Tung Univ., National United Univ.

~250 collaborators

The Goal: θ_{13}

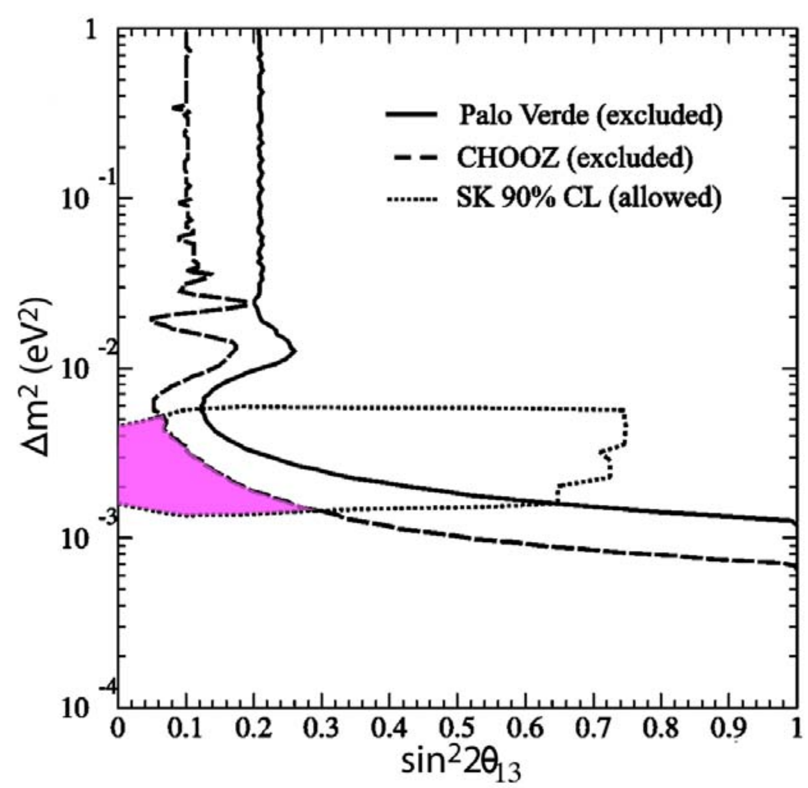
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{\mathrm{PMNS}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Neutrino Oscillation

$$\downarrow$$

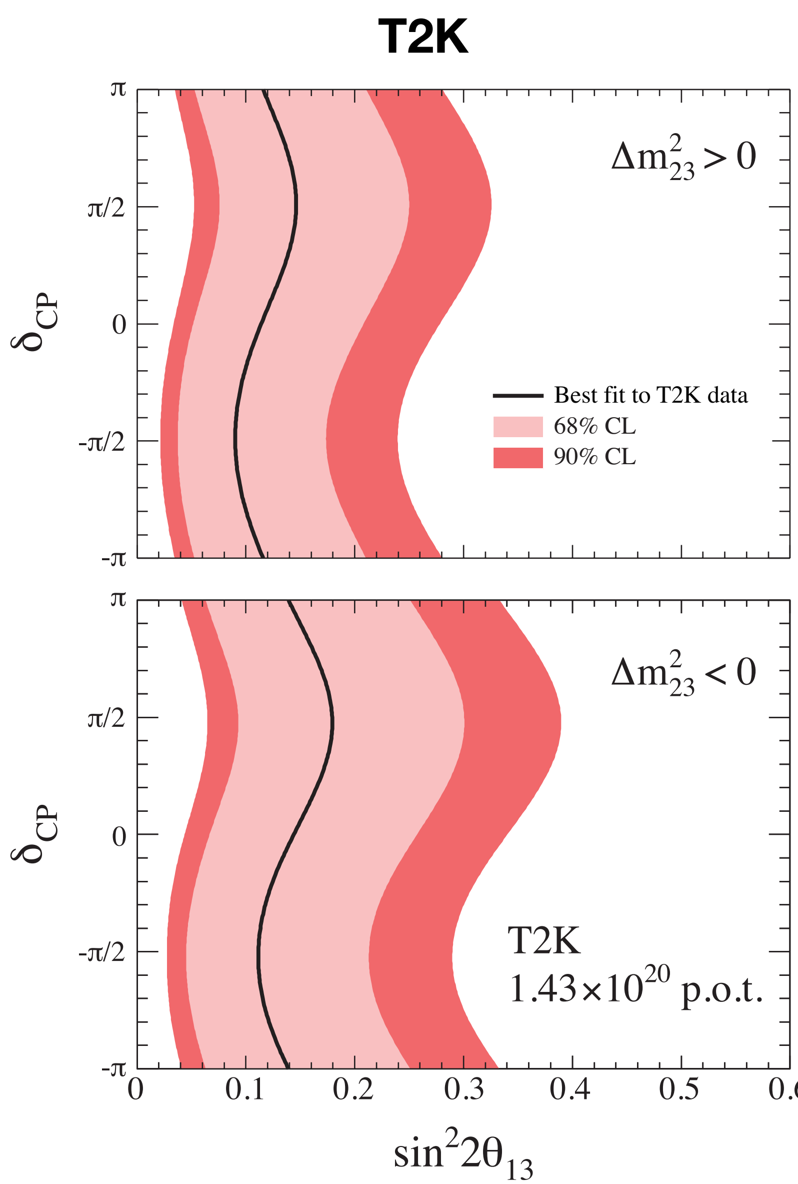
$$\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{-i\alpha_1/2} & 0 \\ 0 & 0 & e^{-i\alpha_2/2} \end{pmatrix}$$

- The only unknown mixing angle
- Tiny θ_{13} = Nightmare for CP violation hunters

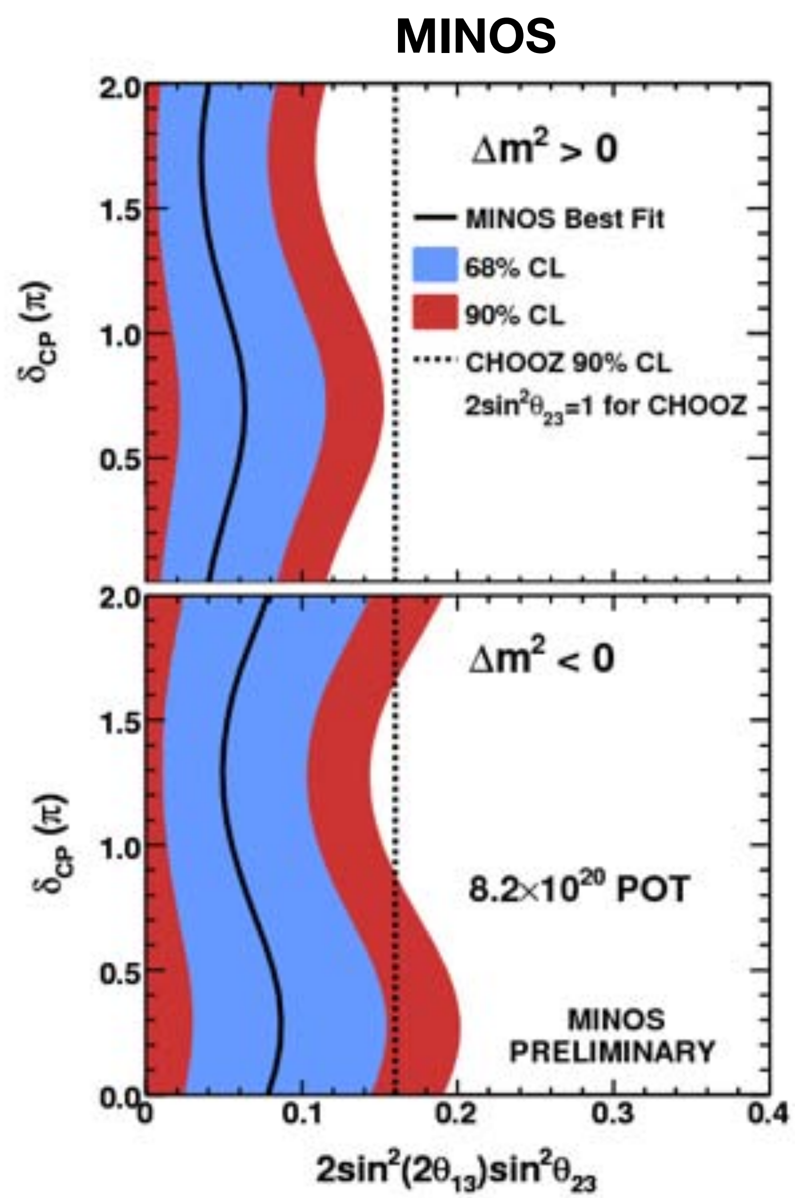


$\sin^2 2\theta_{13} < 0.15$ @90% C.L. (CHOOZ)

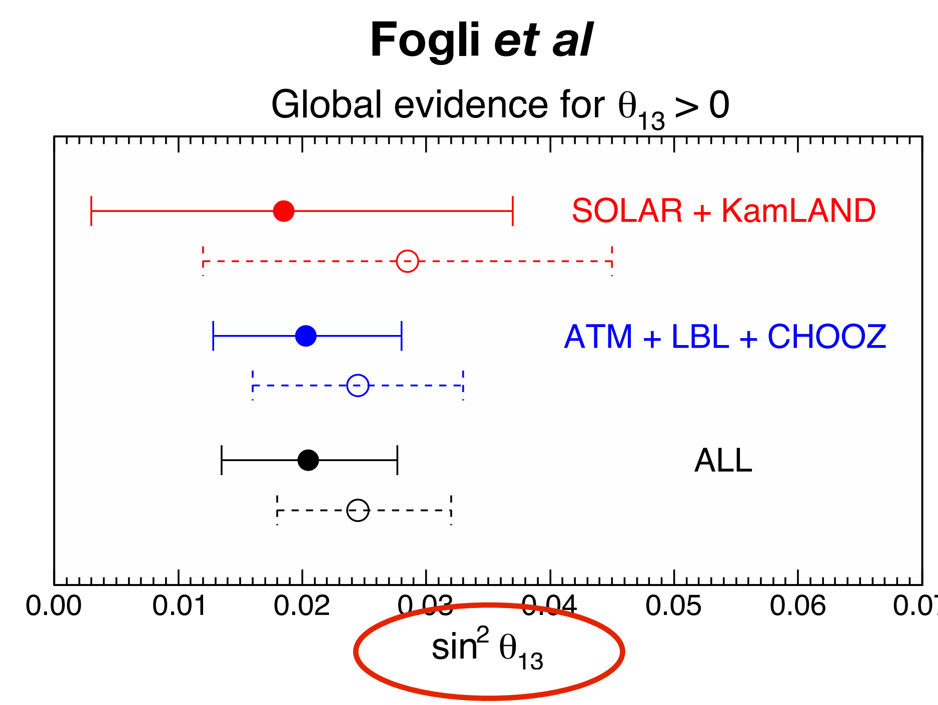
Recent Hint of θ_{13}



arXiv:1106.3133



http://www-numi.fnal.gov/pr_plots



arXiv:1106.6028

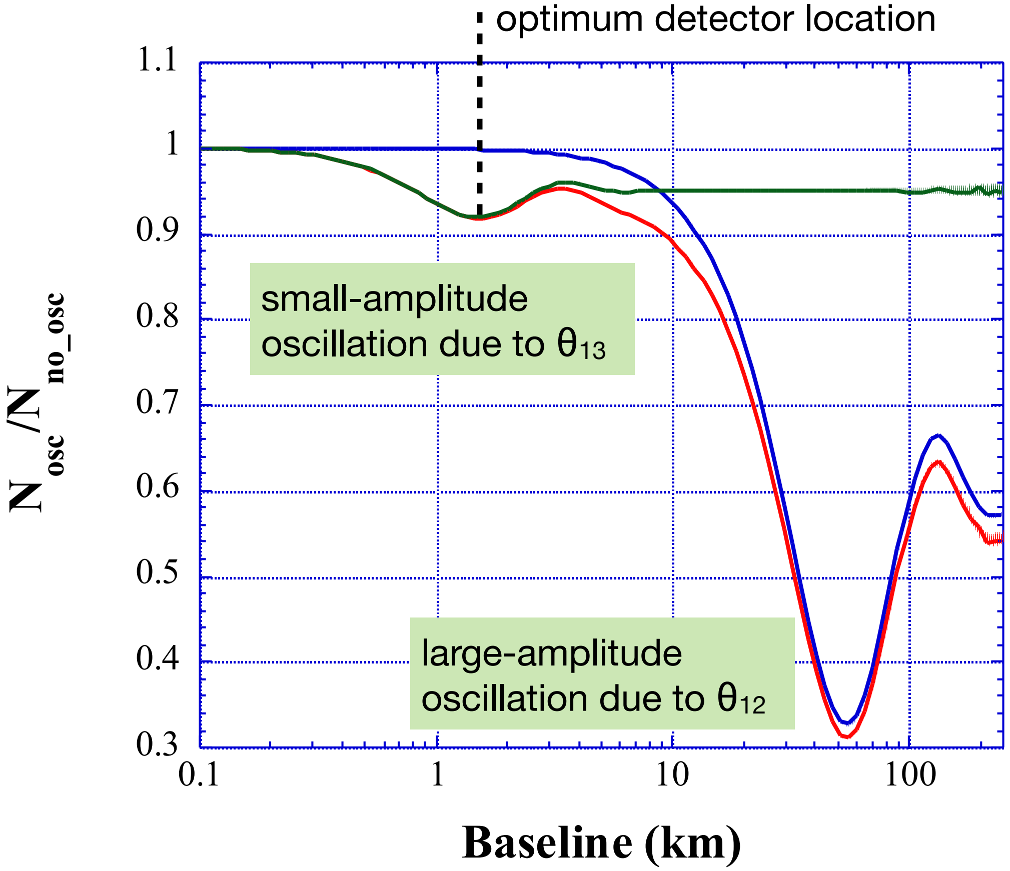
Daya Bay's goal:

$\sin^2 2\theta_{13} < 0.01$ @ 90% C.L. in 3 years of data taking

Reactor v.s. Accelerator

Nuclear Reactor

- pure $\bar{\nu}_e$ source
- 6 $\bar{\nu}_e$ / fission
- 2 x 10^{20} $\bar{\nu}_e$ / sec / GW_{th}



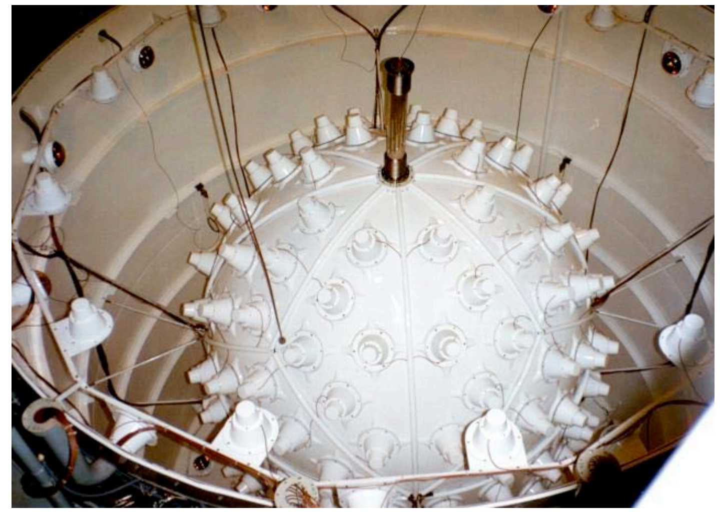
$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}{}^2 L}{4E_\nu}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}{}^2 L}{4E_\nu}\right)$$

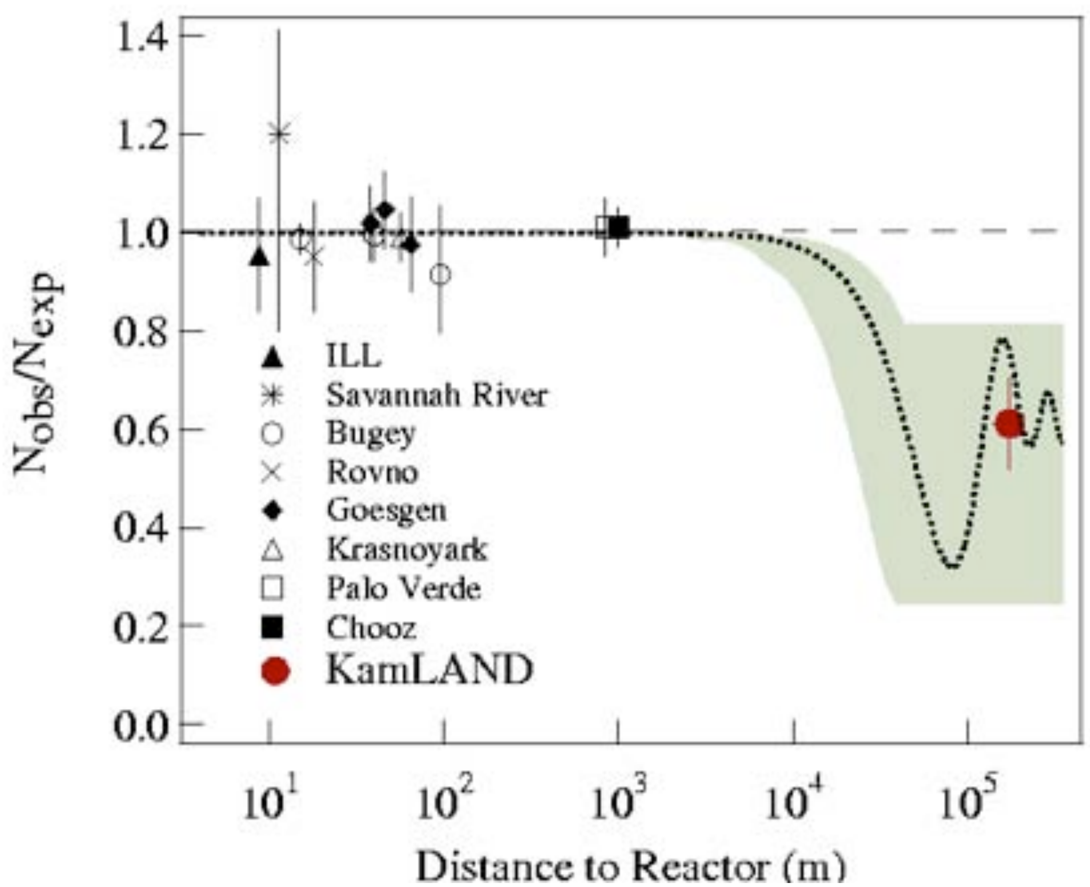
$\Delta m^2 \sim 10^{-3}\ \mathrm{eV}^2$
E ~ MeV
$\Rightarrow$ L ~ 1 km

- Clean signal
- no CP violation
- negligible matter effects
- Free neutrinos!

Reactor Neutrinos Have Long Been Our Friends

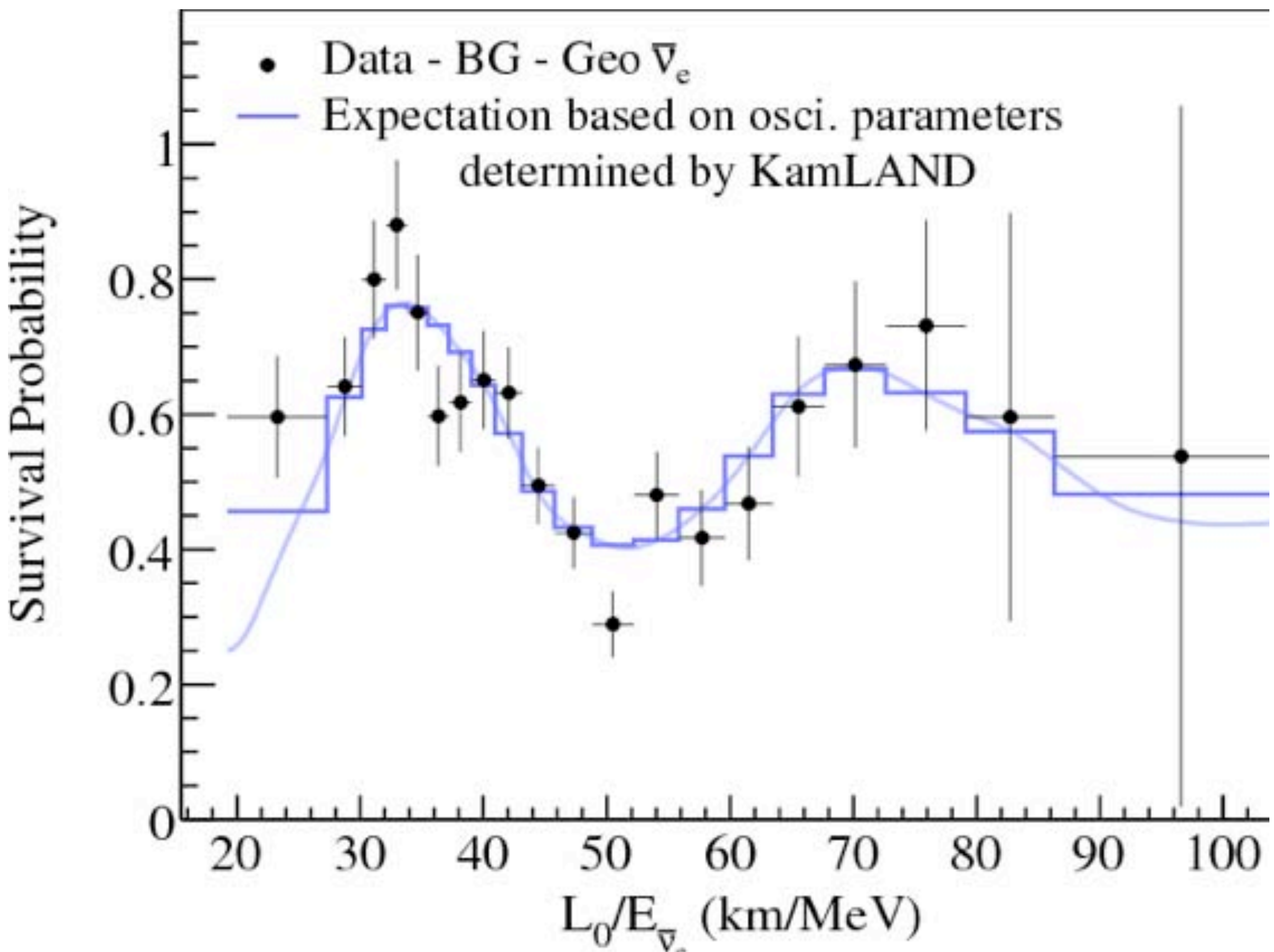
Fred Reines (?) working at a neutrino detector (circa 1953)





PRL 90 (2003) 021802

Reactor Neutrino ‘Oscillation’



PRL 100 (2008), 221803

$$P_{e,e} = 1 - sin^2 2\theta_{12} sin^2(1.27\Delta m^2_{12} L/E)$$

Reactor Neutrinos are ‘Well Understood’

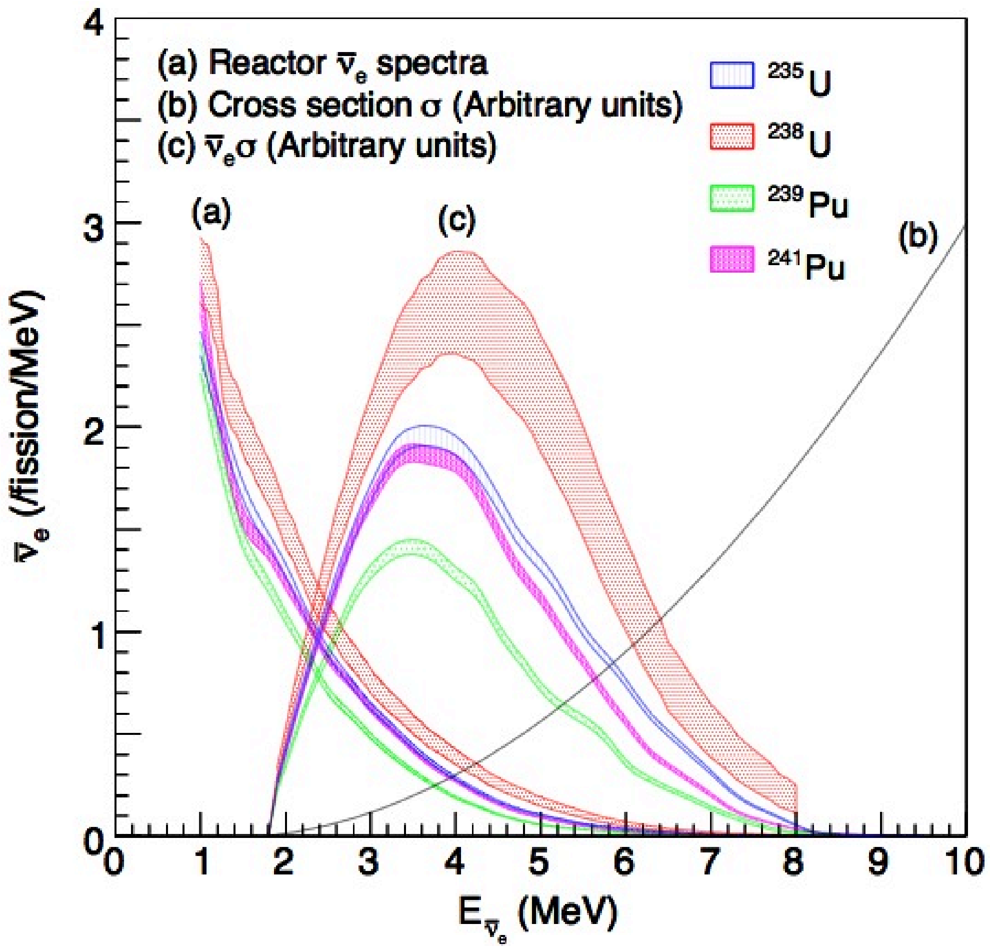
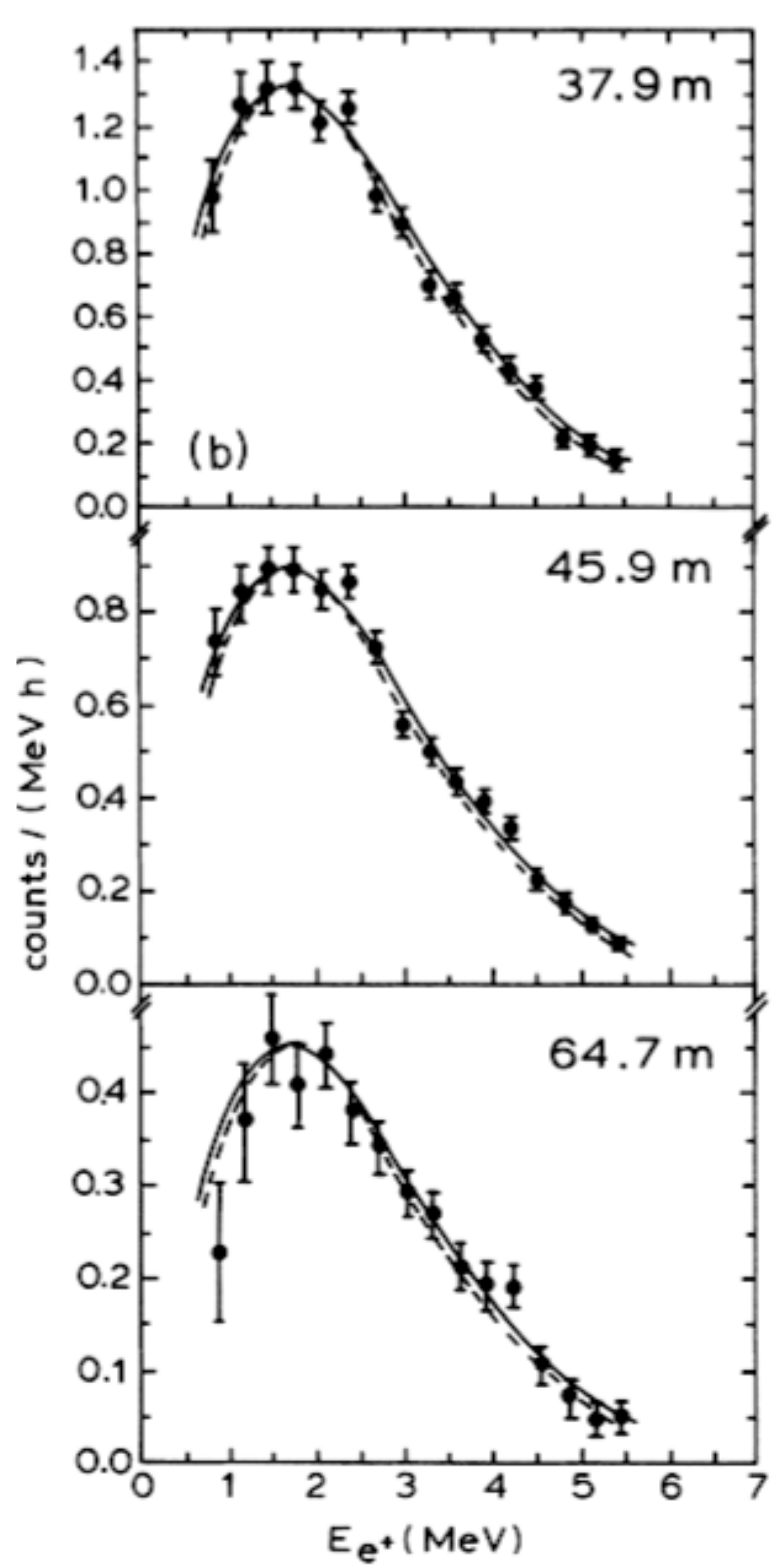


TABLE I. Estimated systematic uncertainties relevant for the neutrino oscillation parameters Δm^2_{21} and θ_{12}.

	Detector-related (%)		Reactor-related (%)	
Δm^2_{21}	Energy scale	1.9	$\bar{\nu}_e$-spectra [7]	0.6
Event rate	Fiducial volume	1.8	$\bar{\nu}_e$-spectra	2.4
	Energy threshold	1.5	Reactor power	2.1
	Efficiency	0.6	Fuel composition	1.0
	Cross section	0.2	Long-lived nuclei	0.3

KamLAND, PRL 100 (2008), 221803

Gösgen Measured Reactor Spectrum



Phys. Rev. D 34, 2621-2636 (1986)

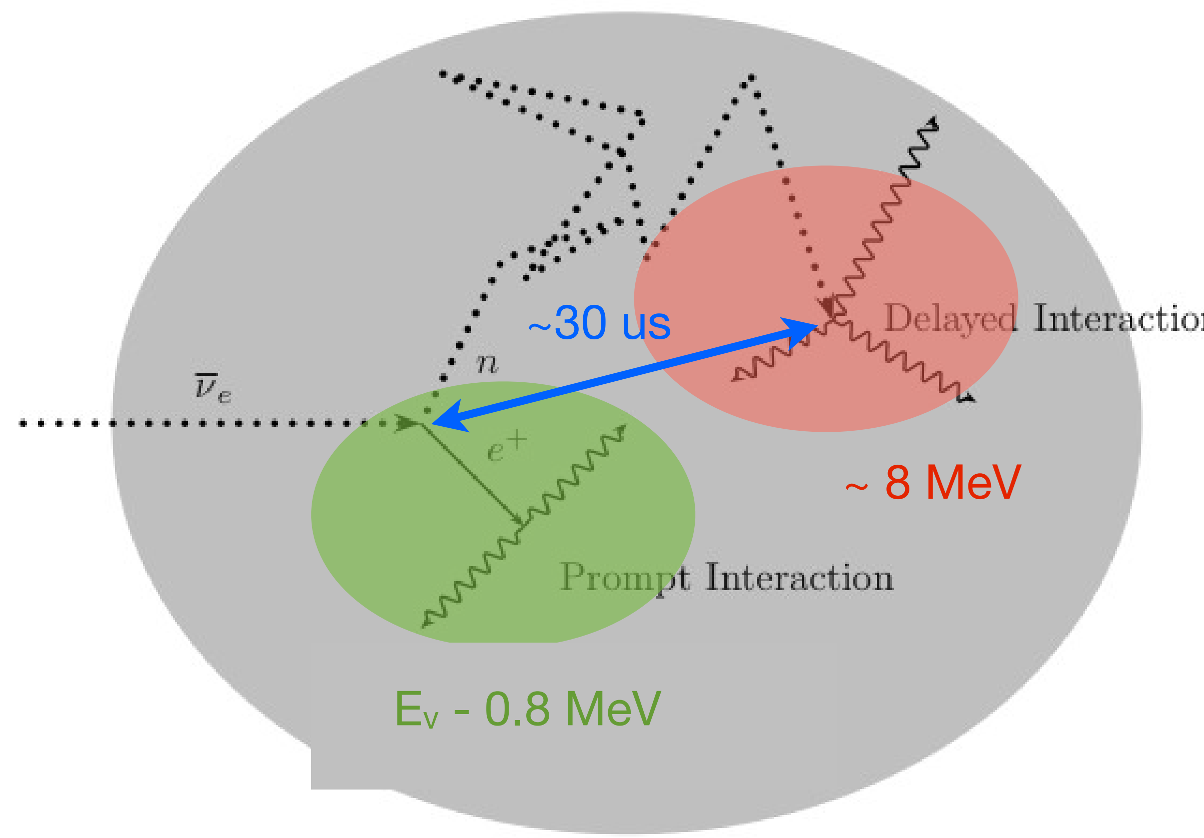
Anti-neutrino Detection is ‘Well Understood’

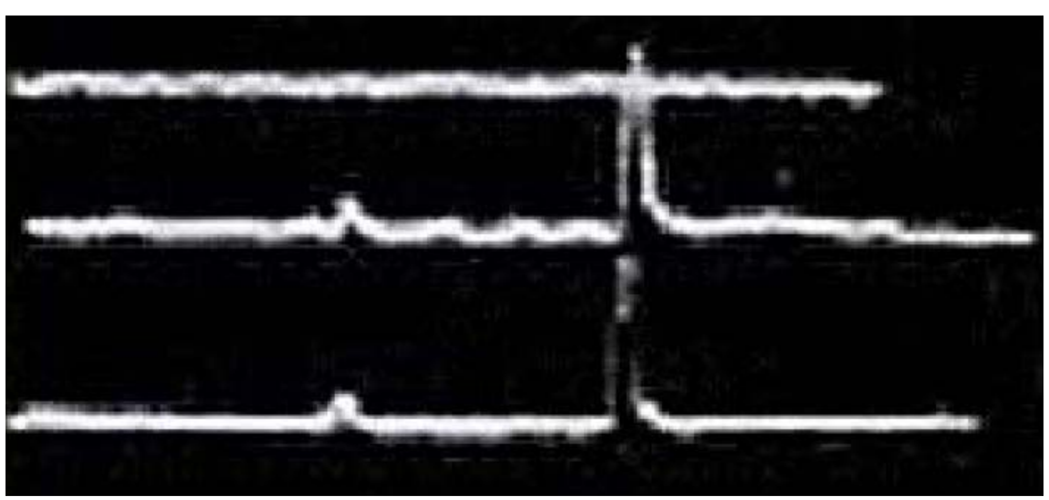
Inverse Beta Decay

- $E_{threshold}$ = 1.8 MeV
- Dominant process at low energy
- ‘Large’ cross section $\sigma \sim 10^{-42}$ cm^2
- Distinctive coincidence signature in a large liquid scintillator detector

$$\bar{\nu}_e + p \rightarrow \boxed{e^+} + n$$

$$\mathrm{n} + {}^{A}\mathrm{Gd} \rightarrow {}^{A+1}\mathrm{Gd} + \boxed{\gamma' s}$$





Cowan & Reines, Savannah River 1956

Three Games in Town

	Thermal Power (GW)	Mass (Tons)	Near		Far		δ_{SYST} (%)
			Dist (m)	Depth (mwe)	Dist (m)	Depth (mwe)	
Double Chooz	8.5	2×10	400	115	1050	300	0.6
RENO	16.4	2×16	290	130	1380	460	0.5
Daya Bay	17.4	8×20	363 & 481	260	1985 & 1613	910	> 0.2 < 0.4

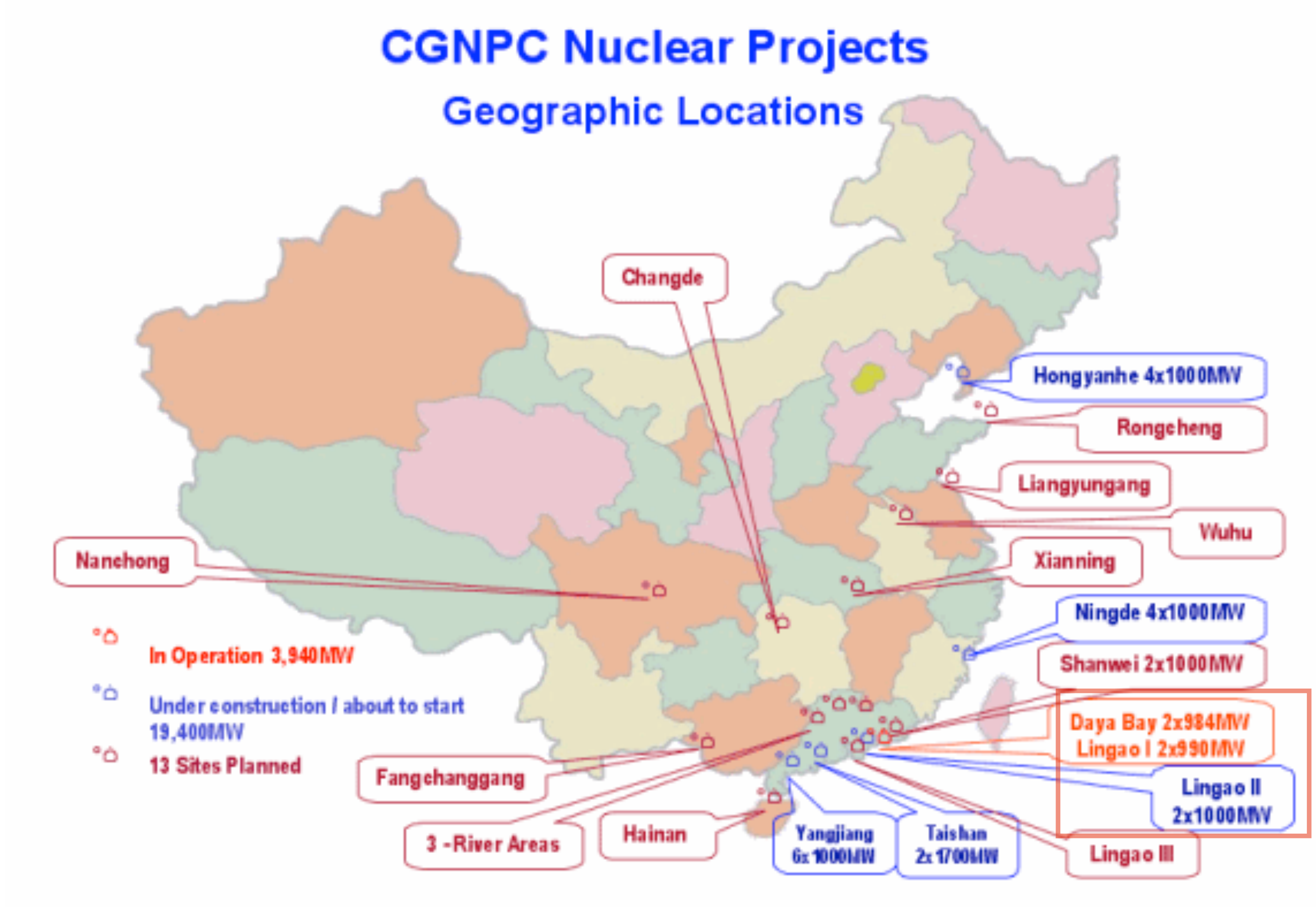
Daya Bay is larger, deeper, and has better systematics

Aim: precision measurement of θ_{13} to $\sin^2 2\theta_{13} < 0.01$

How to achieve 0.01?

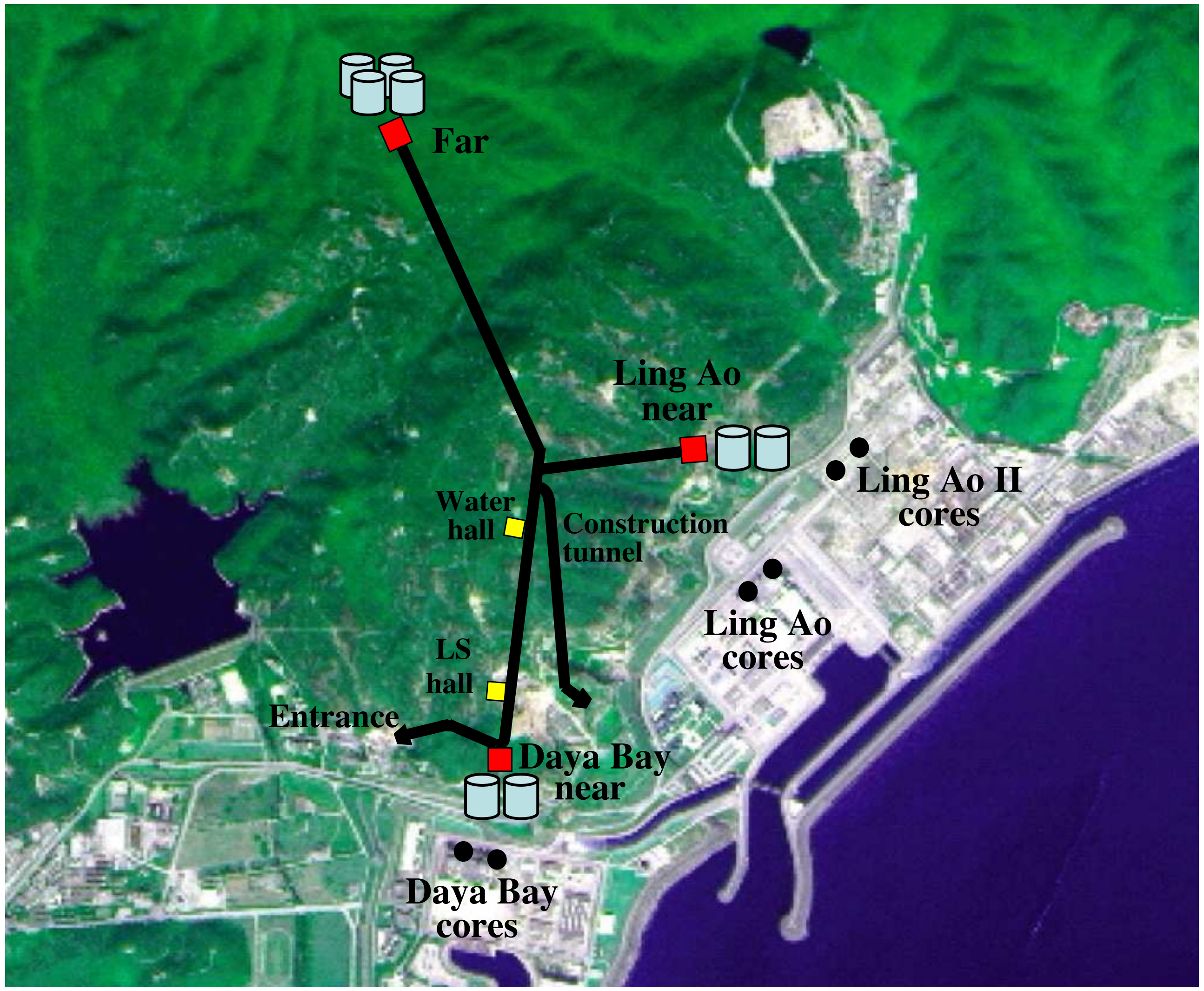
- Increase Statistics: Powerful Nuclear reactor + Large target mass
- Reduce Systematic Uncertainties
    - Reactor Related
        - Optimize baseline for the best sensitivity
        - Near and far detectors to minimize reactor-related uncertainties
    - Detector Related
        - ‘Identical’ pairs of detectors to do relative measurement
        - Comprehensive detector calibration
        - Interchange near and far detectors (optional)
    - Background Related
        - Deep underground to reduce cosmic induced backgrounds
        - Active and passive shielding

Nuclear Power Plants in China



- 13 reactor cores in operation, many under construction
- ~10GW electric, ~2% of total electric power
- Increase to ~6% by 2020

Sites and Reactors



- Three reactor complex, each with 2 cores, 17.4 GWth in total
- Two near sites to sample flux from reactor groups
- Four detectors (80T) at Far site to increase statistics
- Multiple detectors per site to cross-check detector efficiency

Baseline

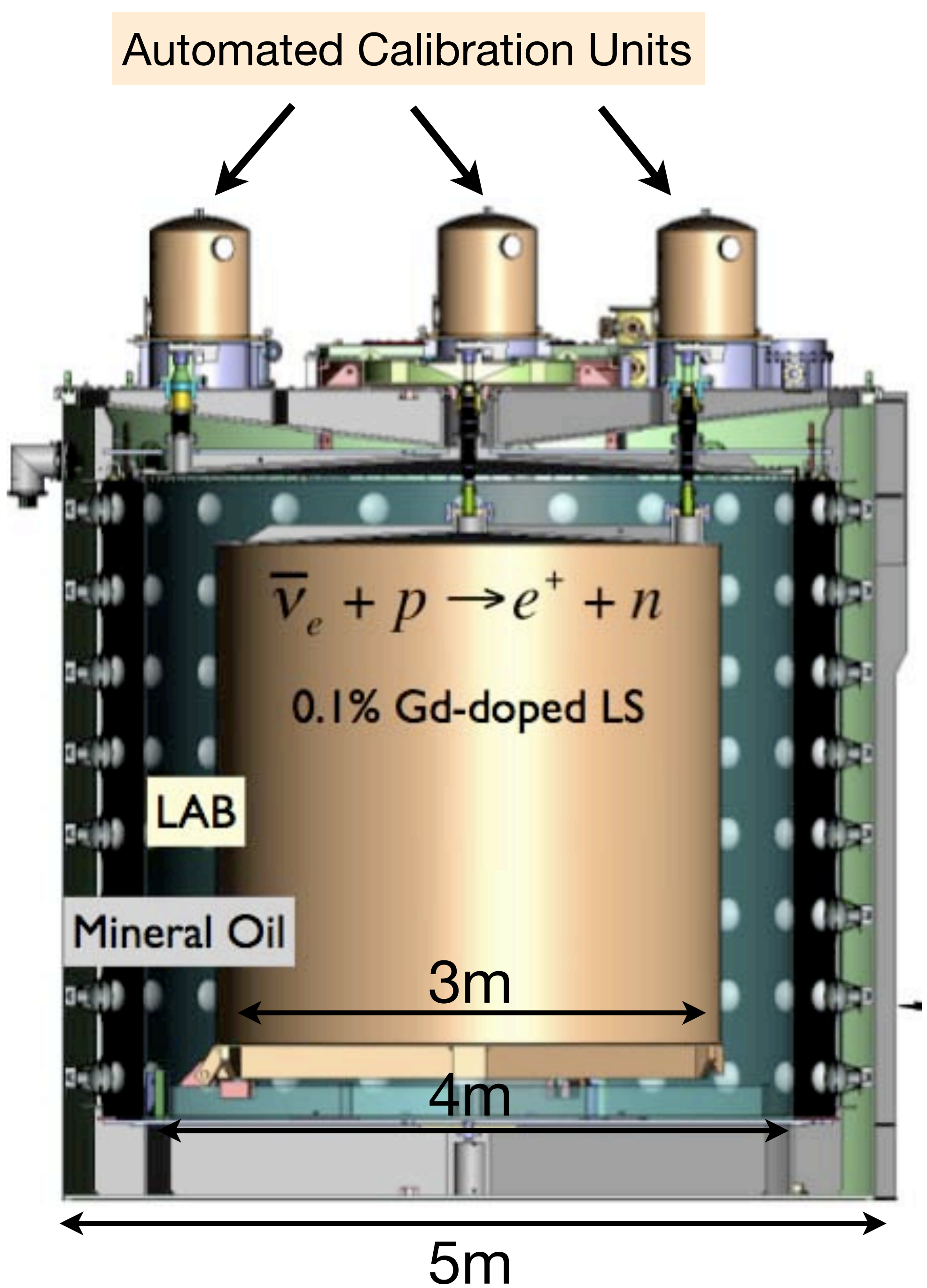
	DYB	LA	Far
DYB cores	363	1347	1985
LA cores	857	481	1618
LA II cores	1307	526	1613

Anti-neutrino Event Rate

Daya Bay near site	930
Ling Ao near site	760
Far site	90

events/day per 20 ton module

Anti-Neutrino Detector



8 ‘identical’ detectors:
- 2@near site x 2, 4@far site
- Build and fill in pairs

Each detector has 3 nested zones separated by Acrylic Vessels:
- Inner: 20 tons Gd-doped LS (target mass)
- Mid: 20 tons LS (gamma catcher)
- Outer: 40 tons mineral oil (buffer)

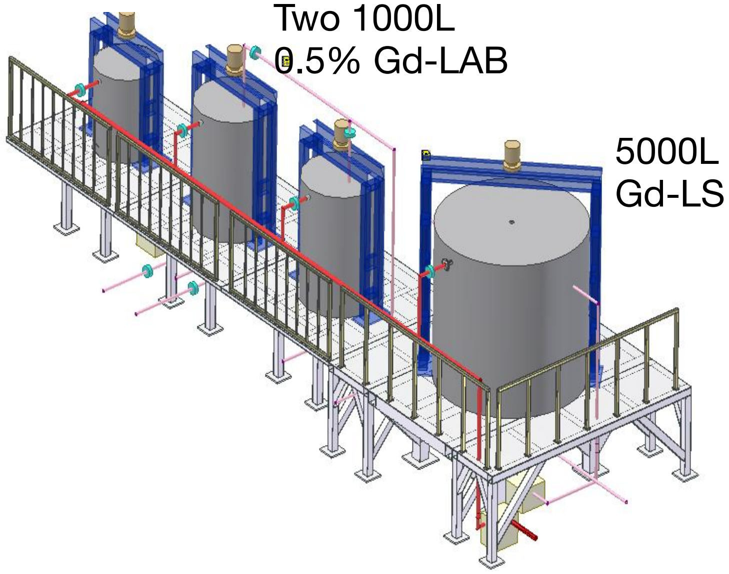
Each detector has:
- 192 8-inch Photomultipliers
- Optical reflectors at top/bottom of cylinder
- 12%/√E energy resolution

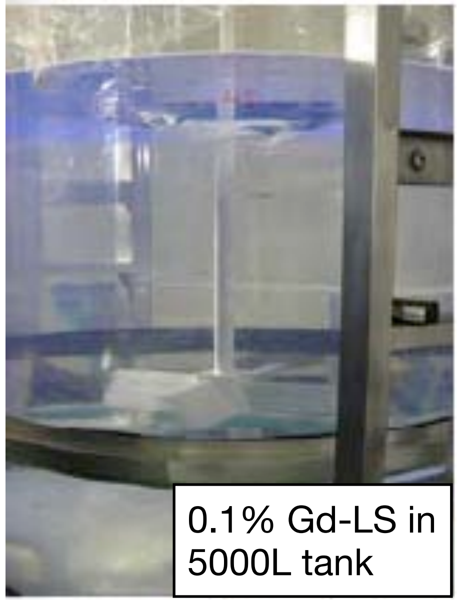
Gd-LS defines the target volume
No fiducial volume cut required

Gd-Loaded Liquid Scintillator

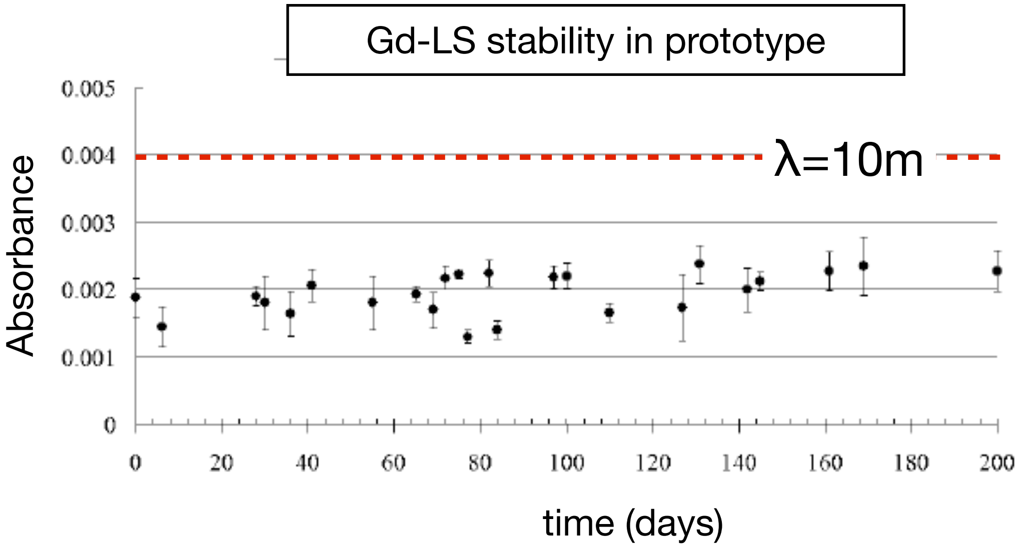
Daya Bay experiments uses 185 ton 0.1% gadolinium-loaded liquid scintillator (Gd-LS)

Gd-TMHA + LAB + 3g/L PPO + 15mg/L bis-MSB



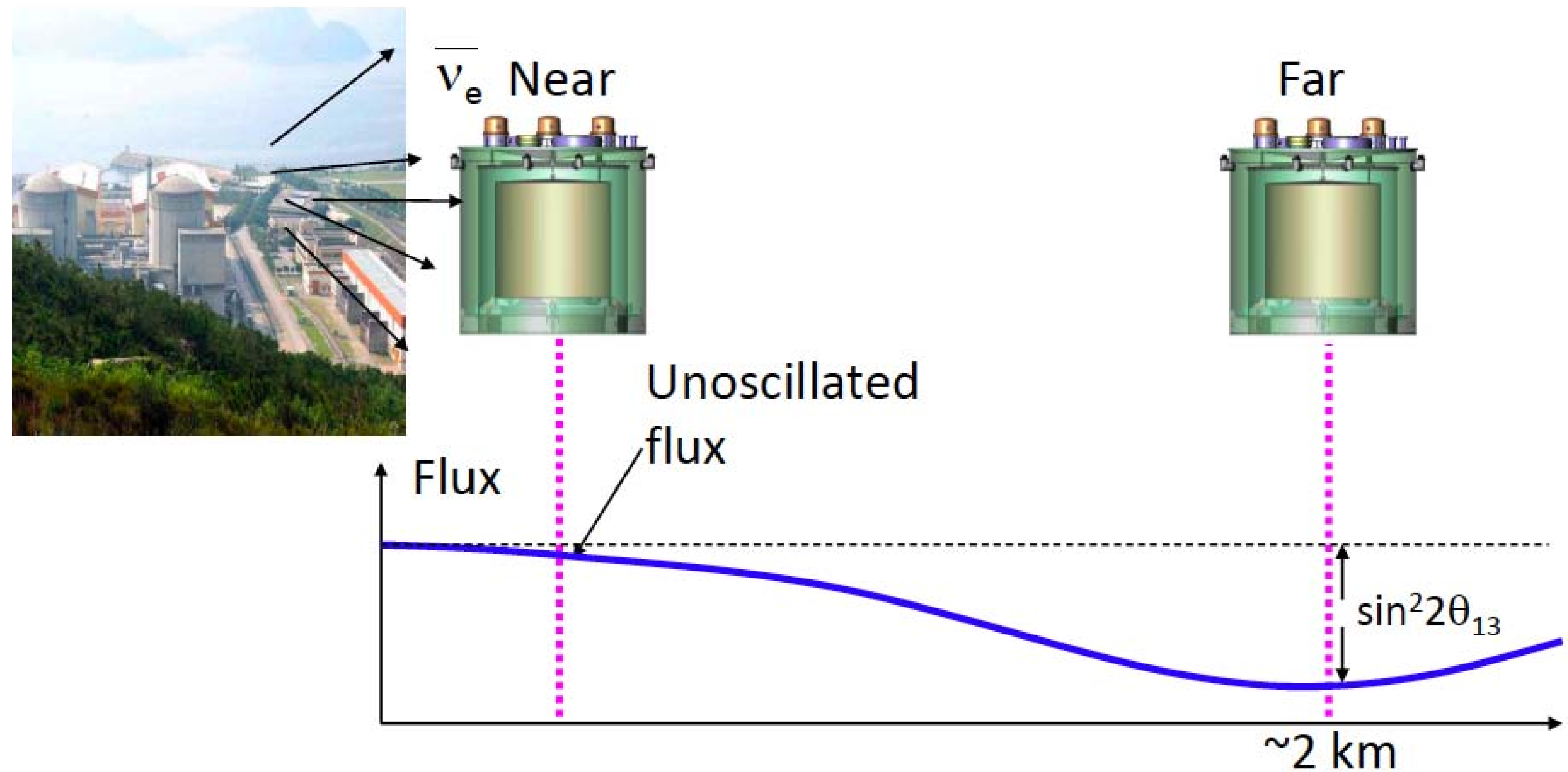


Gd-LS are produced in multiple batches but mixed in reservoir on-site to ensure identical detectors



Near/Far Measurements

- Largest systematic uncertainties form reactor flux/spectra
- Near/Far measurements to cancel

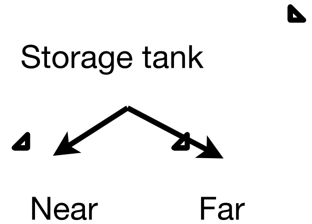


$$\frac{N_{\rm f}}{N_{\rm n}} = \left(\frac{N_{\rm p,f}}{N_{\rm p,n}}\right)\left(\frac{L_{\rm n}}{L_{\rm f}}\right)^2\left(\frac{\epsilon_{\rm f}}{\epsilon_{\rm n}}\right)\left[\frac{P_{\rm sur}(E,L_{\rm f})}{P_{\rm sur}(E,L_{\rm n})}\right]$$

Ratio of Neutrinos

Proton Ratio

0.3%



+ flow & mass measurement

Detector Efficiency

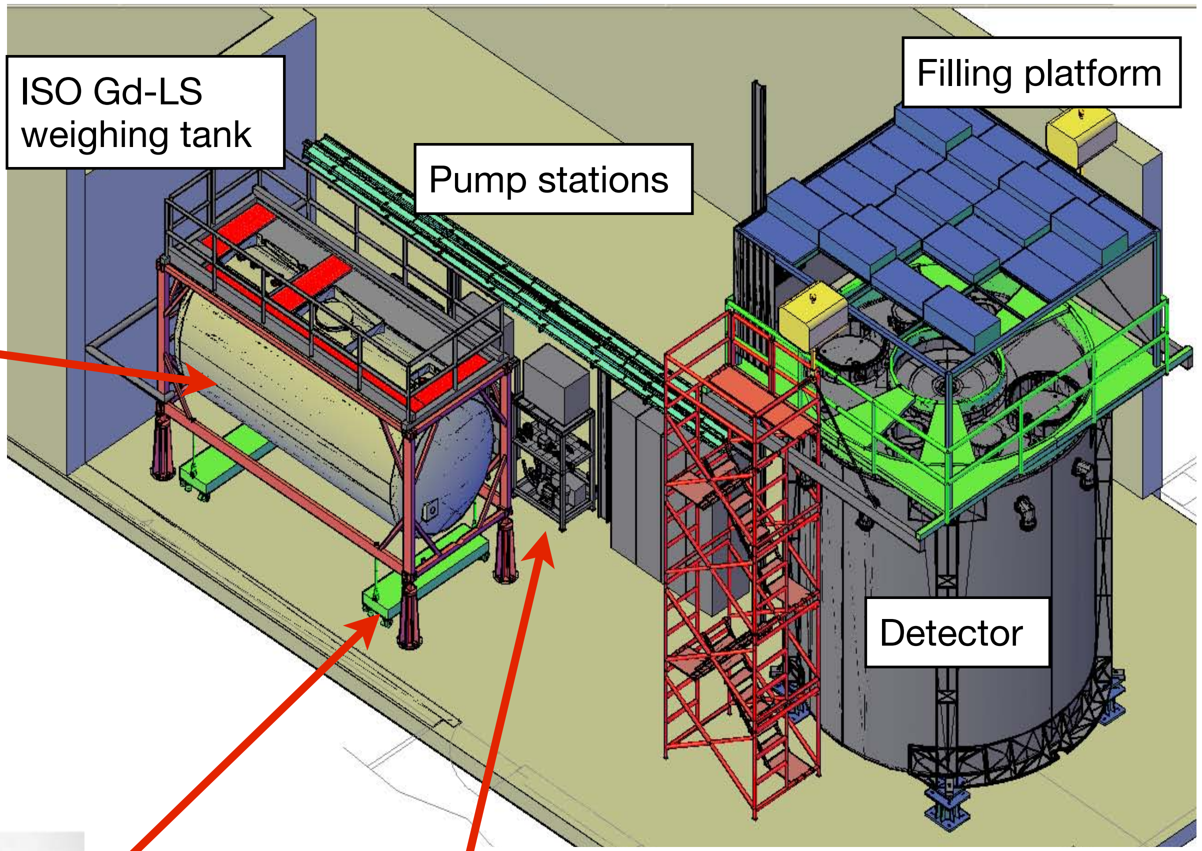
0.2%

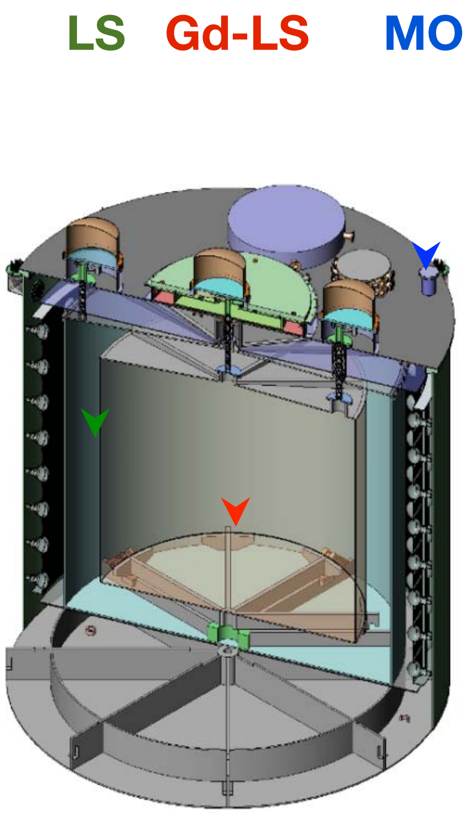
Identical AD + Calibration

Survival Probability (Theta13)

Target Mass Measurement

20-ton, teflon-lined ISO tank

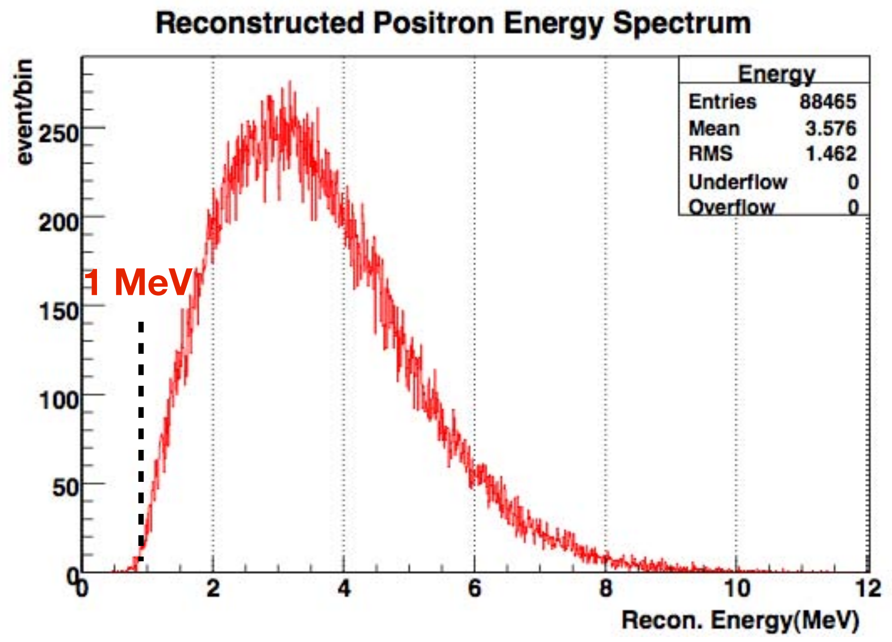


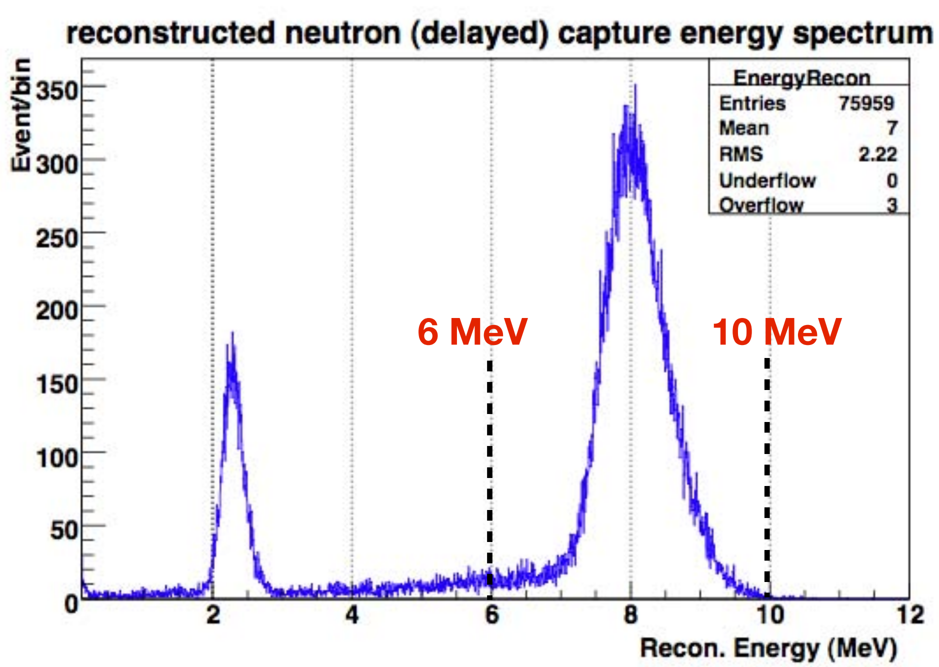


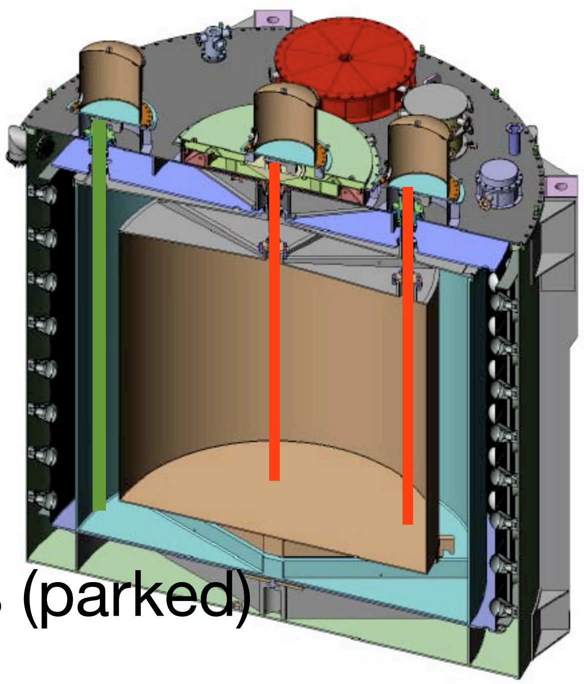
Load cell
accuracy < 0.02%

Coriolis mass flowmeters
accuracy < 0.1%

Energy Calibration







- 3 ACUs / detector
  - Central Gd-LS
  - Edge Gd-LS
  - LS (gamma catcher)
- Each ACU has three sources (parked)
  - ^{68}Ge (e+ threshold)
  - ^{241}Am^{13}C (n threshold) +^{60}Co (2.5MeV)
  - LED (timing)
- Simultaneous, automated weekly deployment
- Spallation neutrons (10^4/day/detector @Near, 10^3/day/detector @Far) for full volume check

0.2% detector efficiency means 2% at e^+ threshold and 1% at neutron threshold

Muon Veto System

Multiple muon veto detectors

Water Cherenkov

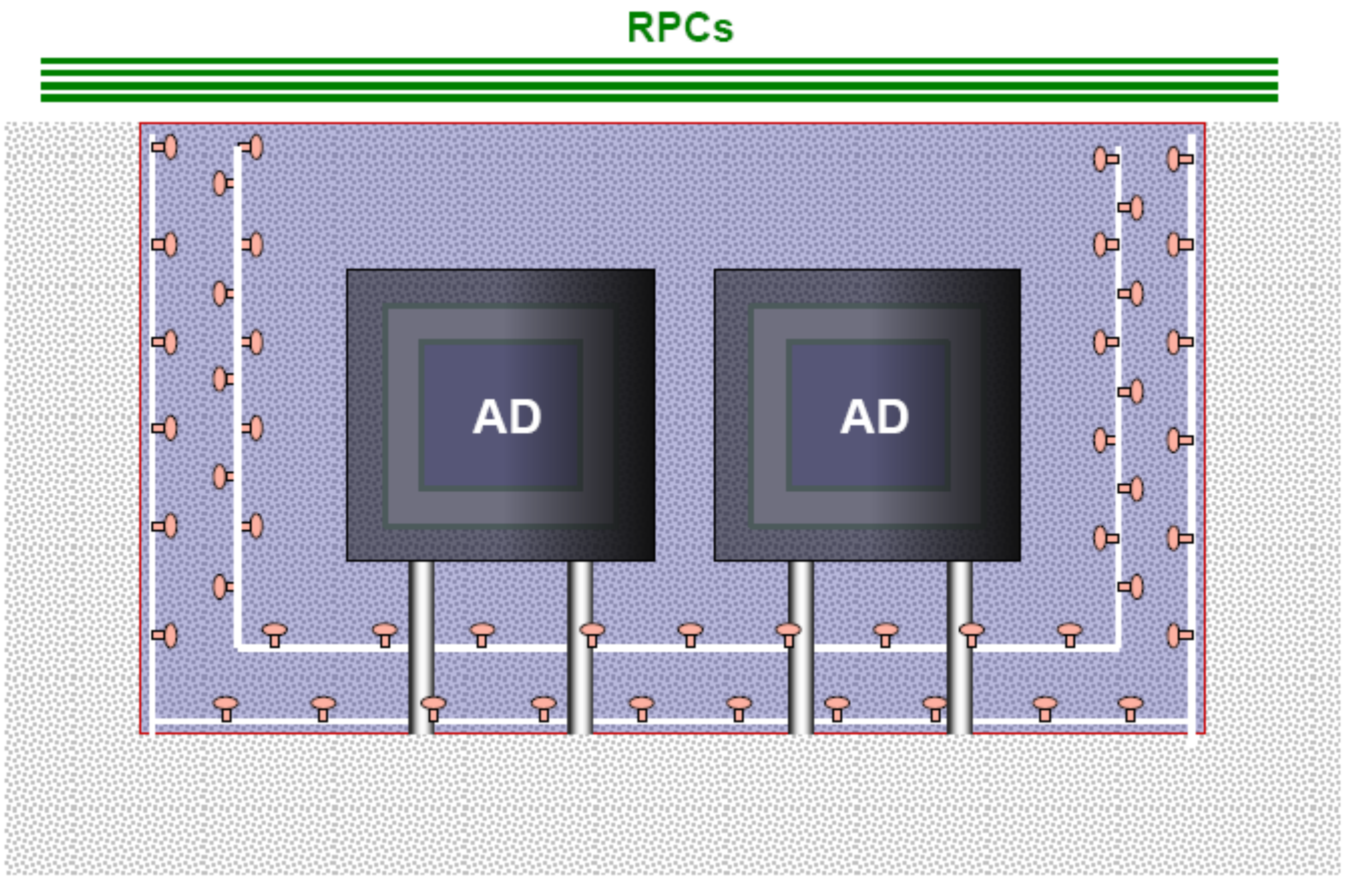
- Detectors submerged in water, passive shielding against neutrons and gammas

- Optically separated by Tyvek sheets into inner / outer region for cross-check

- 8-inch PMTs mounted on frames, 288 @Near, 384 @Far

RPC

- Independent muon tagging
- Retractable roof above pool



	DYB site	LA site	Far site
Vertical overburden (m)	98	112	355
Muon Flux (Hz/m^2)	1.16	0.73	0.041
Muon Mean Energy (GeV)	55	60	138

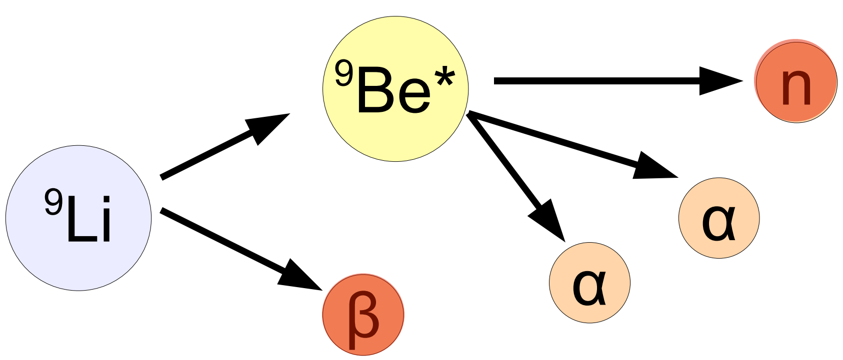
arXiv:hep-ex/0701029v1 (TDR)

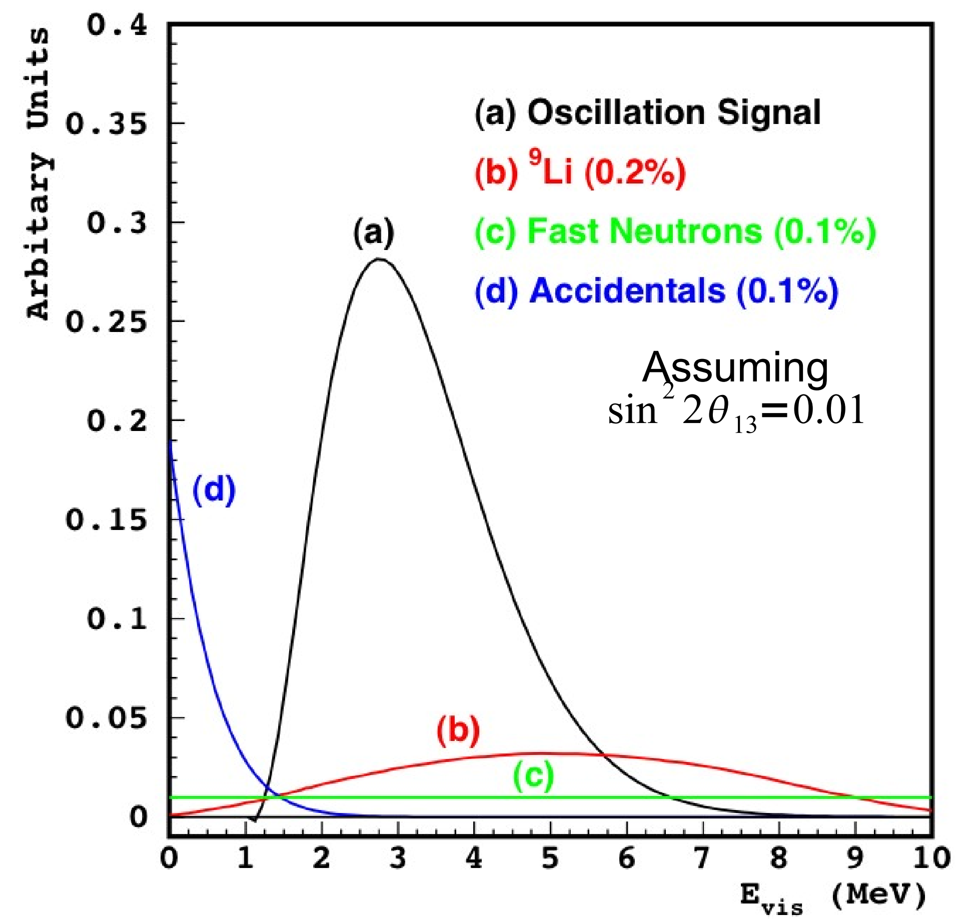
Redundant veto system = highly efficient muon rejection

$\varepsilon > (99.5 +/- 0.25)\%$

Backgrounds

- Accidentals
  - Two uncorrelated events mimic prompt + delayed signal
- Fast neutrons
  - proton recoil (prompt) + neutron capture (delayed)
- ^{9}Li / ^{8}He
  - beta decay (prompt) + neutron capture (delayed)

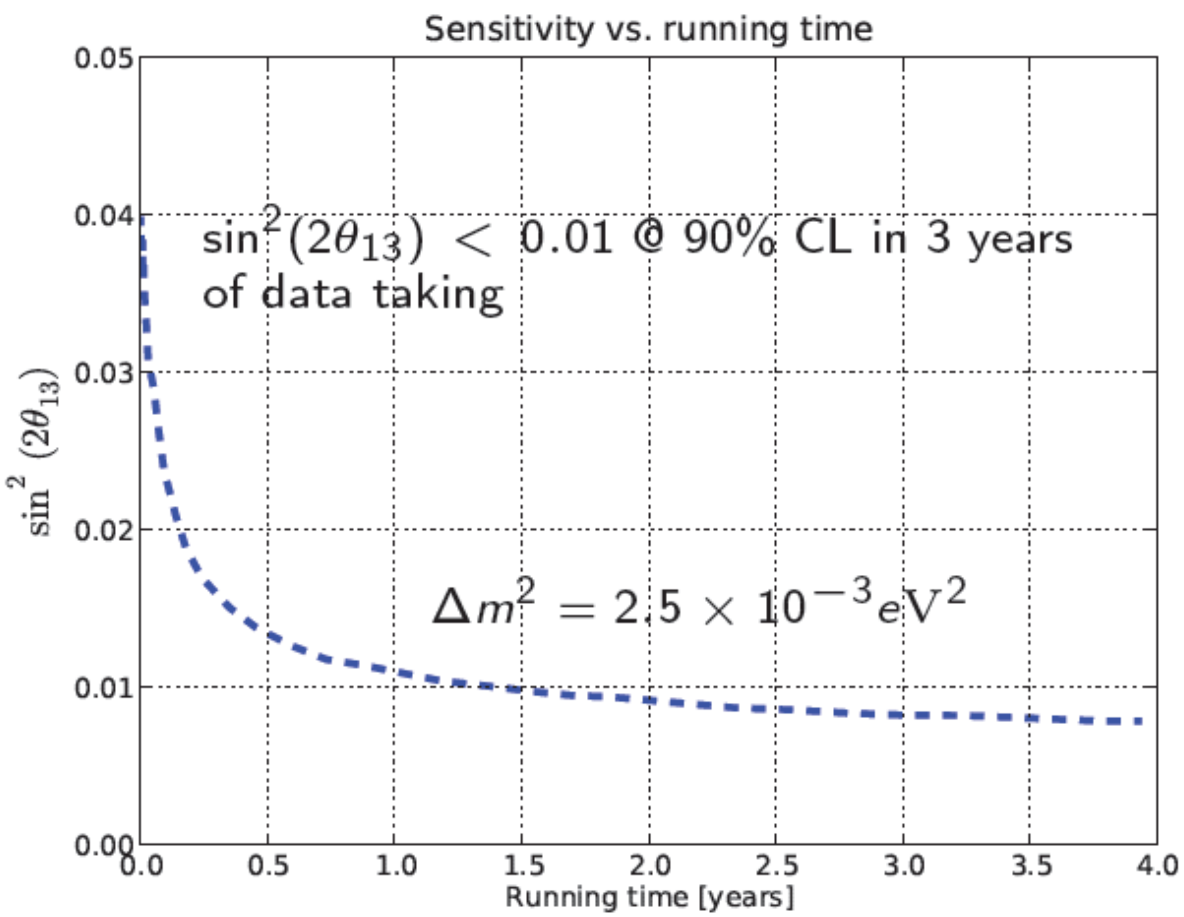


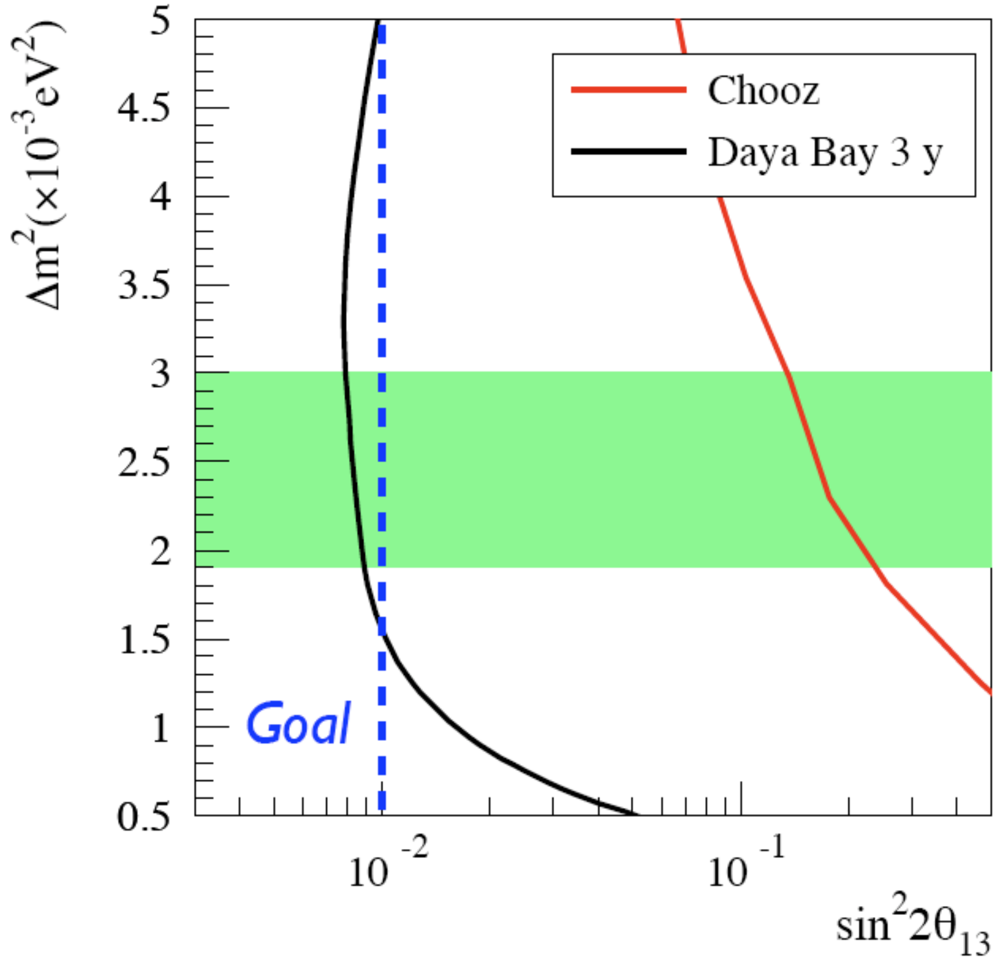


	DYB site	LA site	far site
Antineutrino rate (/day/module)	930	760	90
Natural radiation (Hz)	<50	<50	<50
Single neutron (/day/module)	18	12	1.5
β-emission isotopes (/day/module)	210	141	14.6
Accidental/Signal	<0.2%	<0.2%	<0.1%
Fast neutron/Signal	0.1%	0.1%	0.1%
^{8}He^{9}Li/Signal	0.3%	0.2%	0.2%

arXiv:hep-ex/0701029v1 (TDR)

Sensitivity





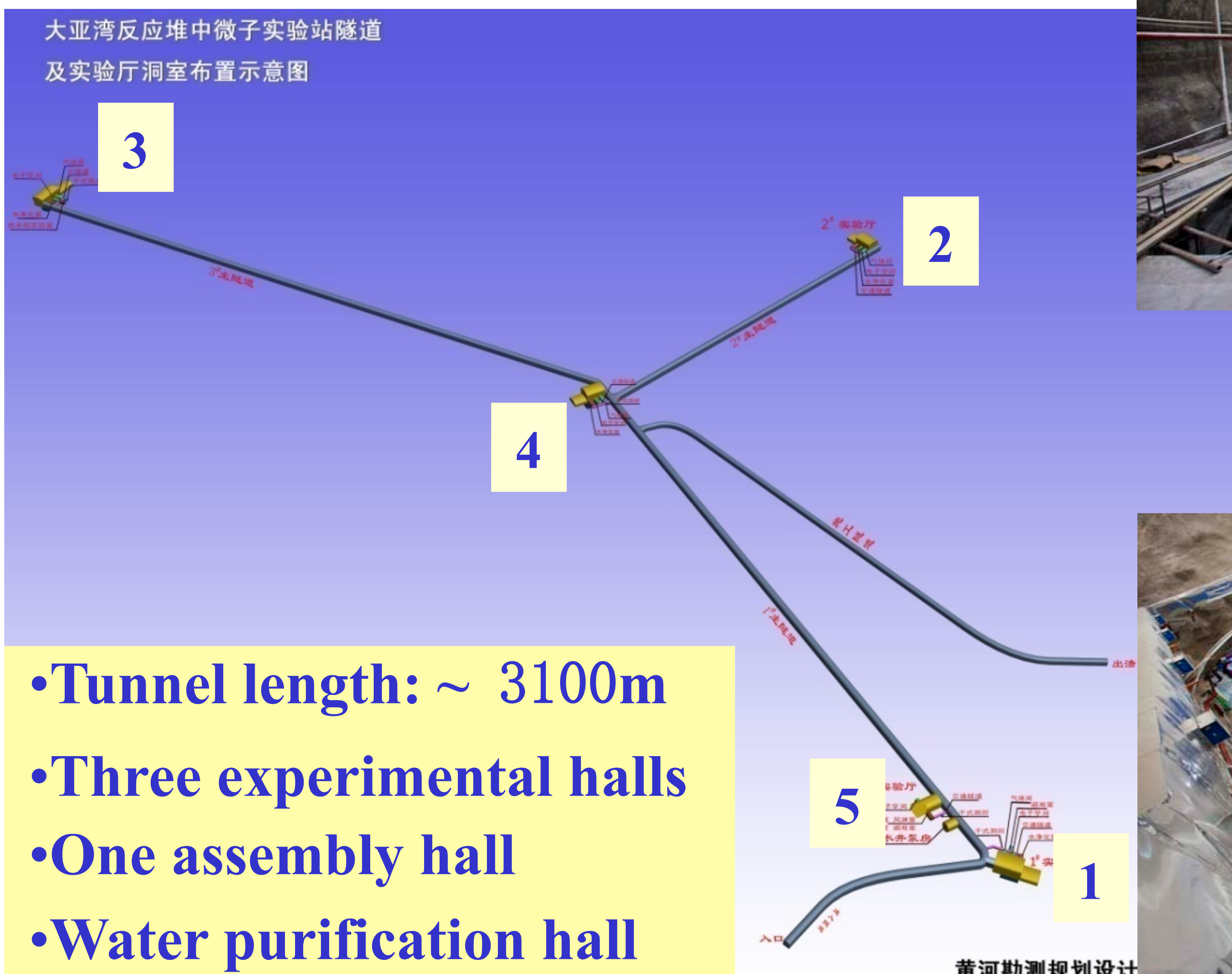
$\sin^2 2\theta_{13} < 0.01$ @ 90% C.L. in 3 years of data taking

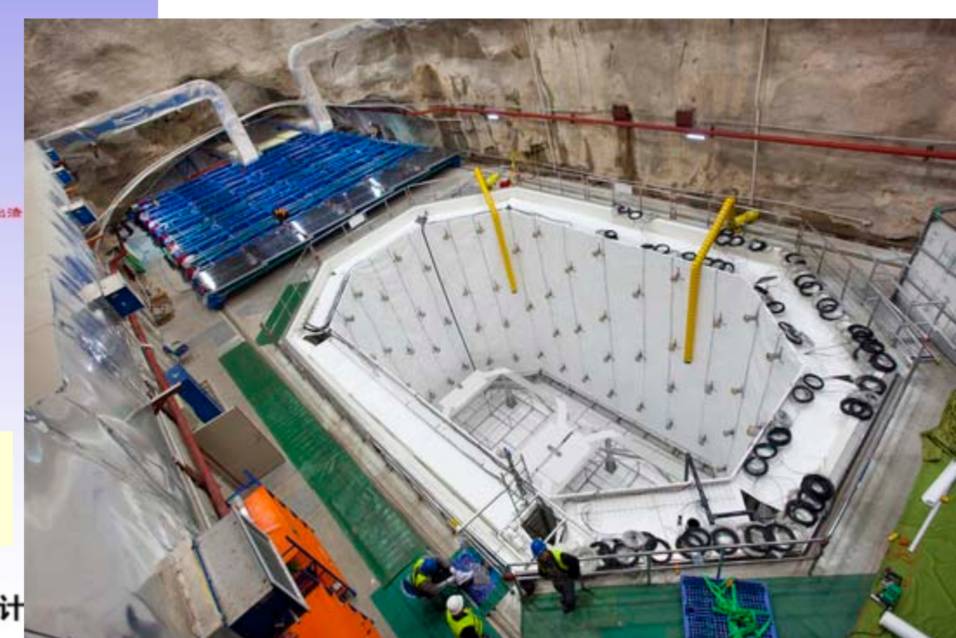
- Summer 2011 start physics data taking with near site
- Summer 2012 start data taking with full experiment

Daya Bay Status

Civil Construction

- Experimental (Near) Hall 1, 2 finished
- Experimental (Far) Hall 3 finishing this summer

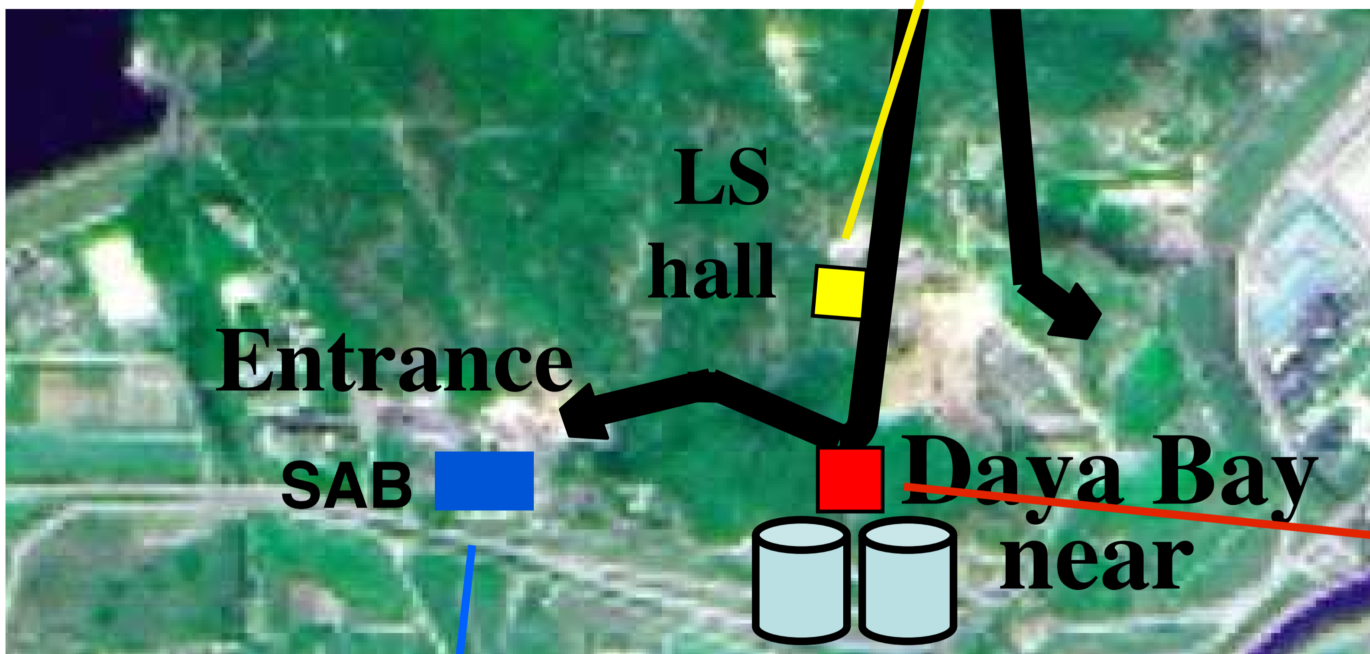




- Tunnel length: ~ 3100m
- Three experimental halls
- One assembly hall
- Water purification hall

A Busy Past Year

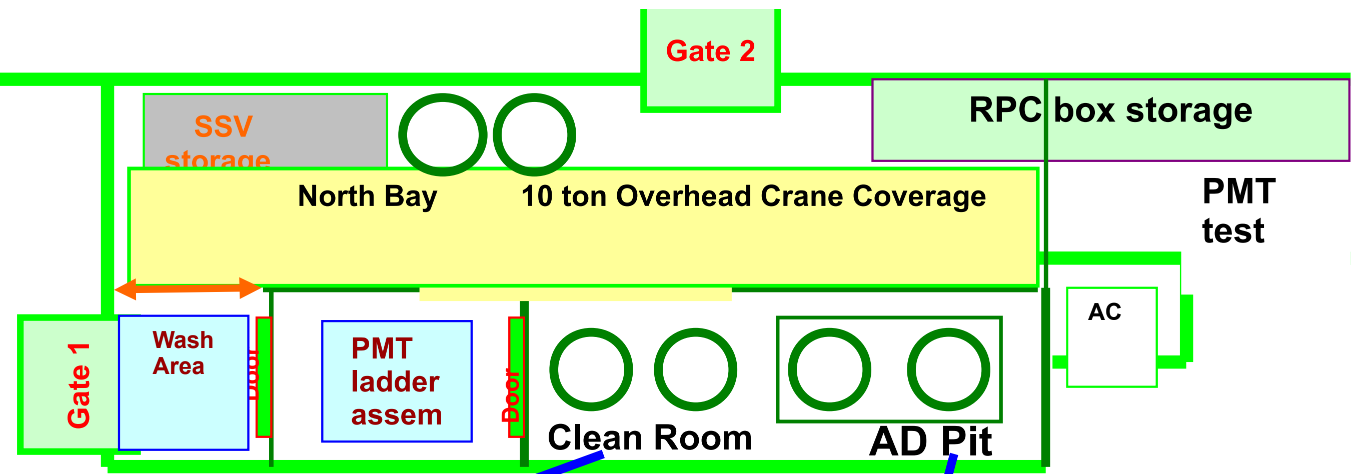
- Transport underground
- Fill with scintillator

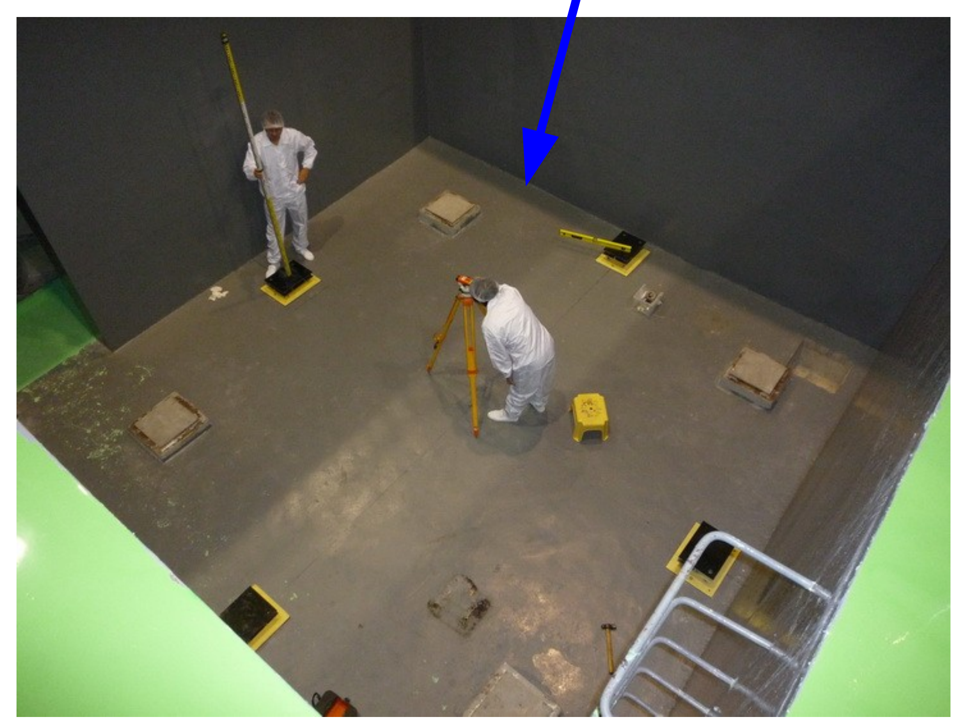


- Install Muon system
- Install filled ADs
- Begin data taking

- Assemble ADs above ground
- Test assembled ADs

Surface Assembly Building

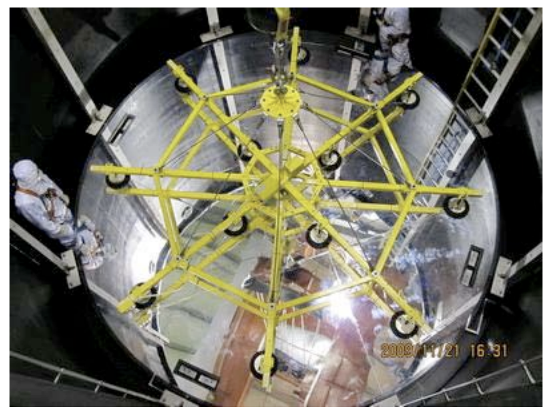




Anti-Neutrino Detector Assembly

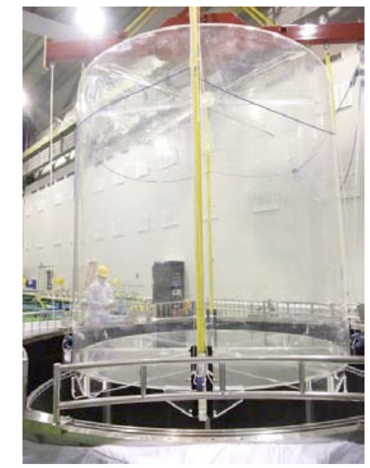
- AD #1-4 are fulling assembled

Stainless Steel Vessel (SSV) in assembly pit



Install Lower reflector

4m Acrylic Vessel (AV)

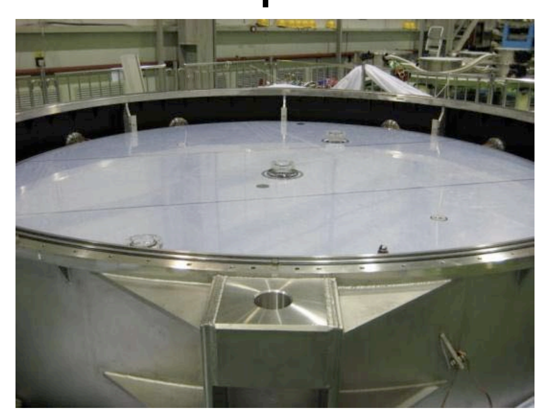


Lower 3m AV

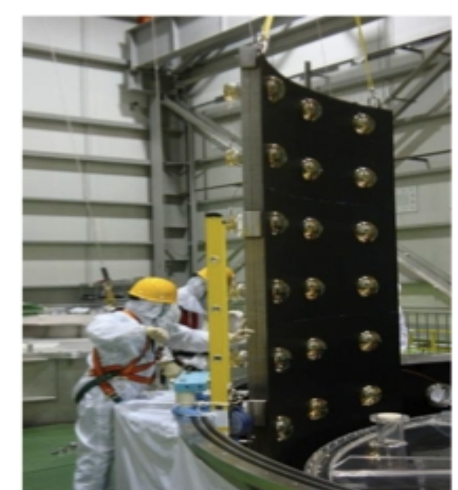
Install Calibration Units

Close SSV Lid

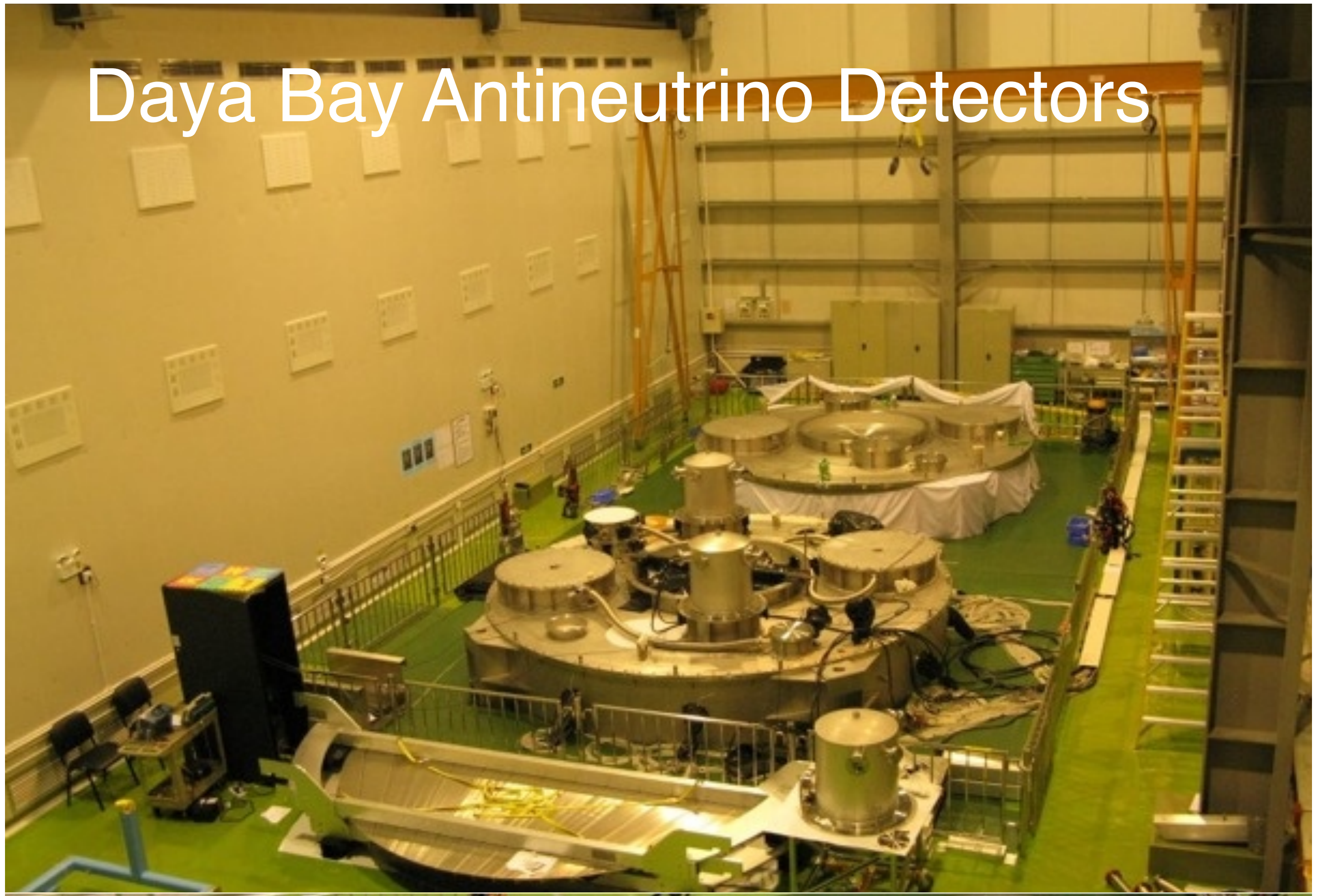
Install Top reflector

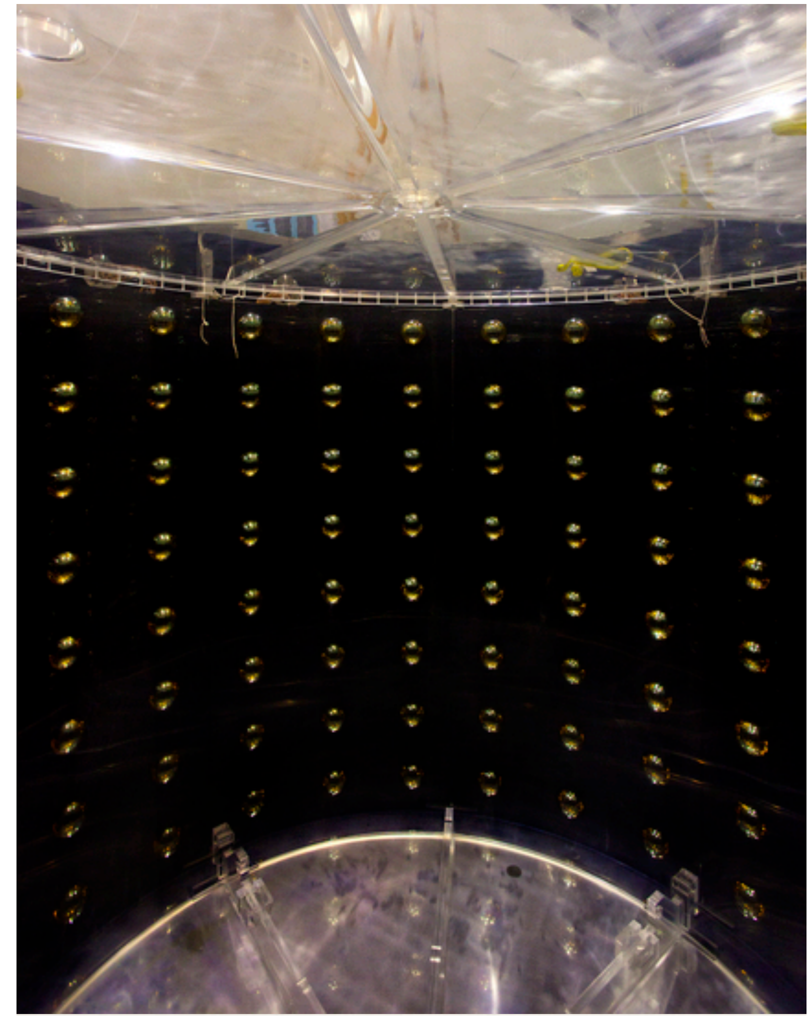


Install PMT Ladders



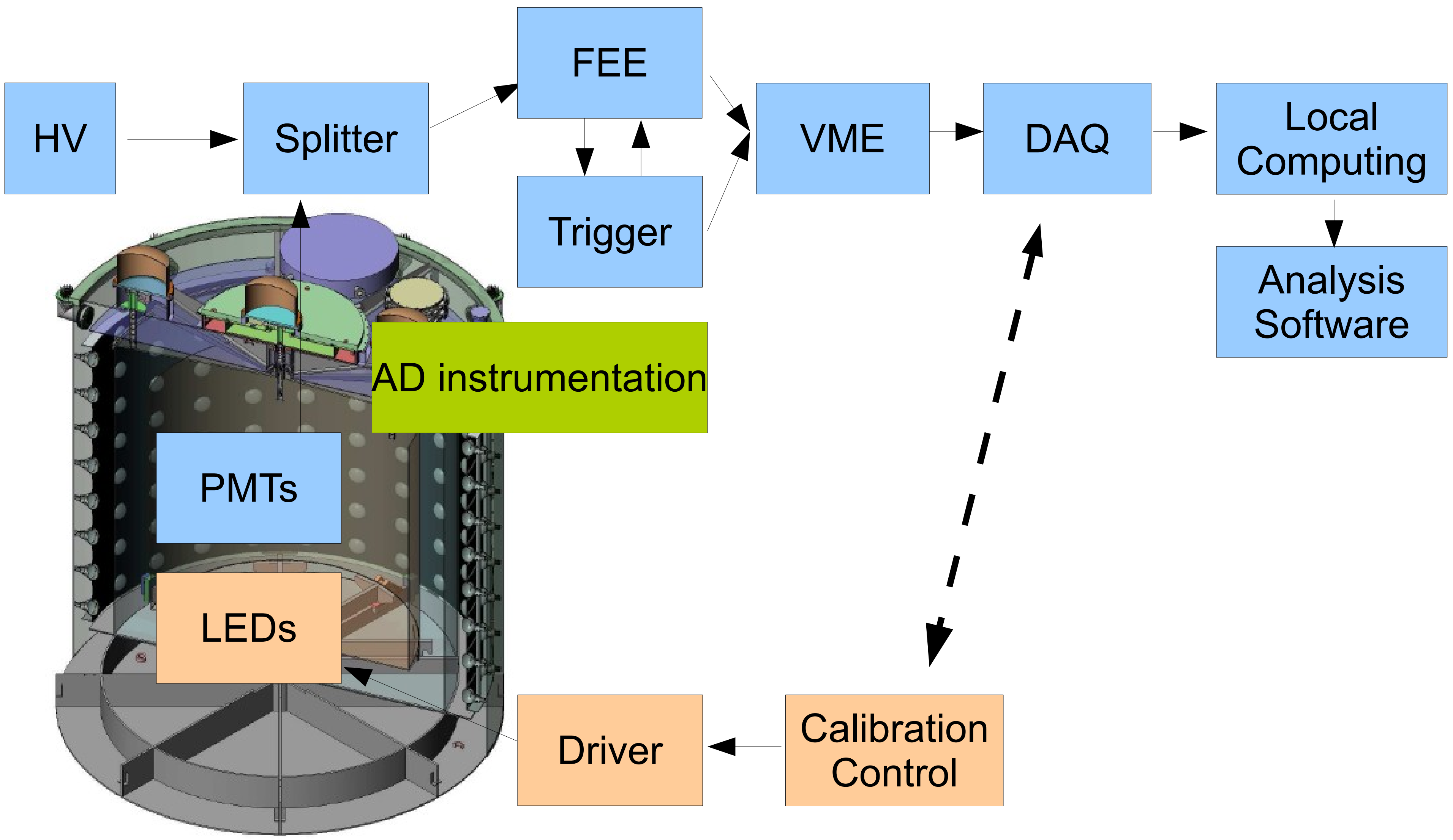
More Pictures of the AD





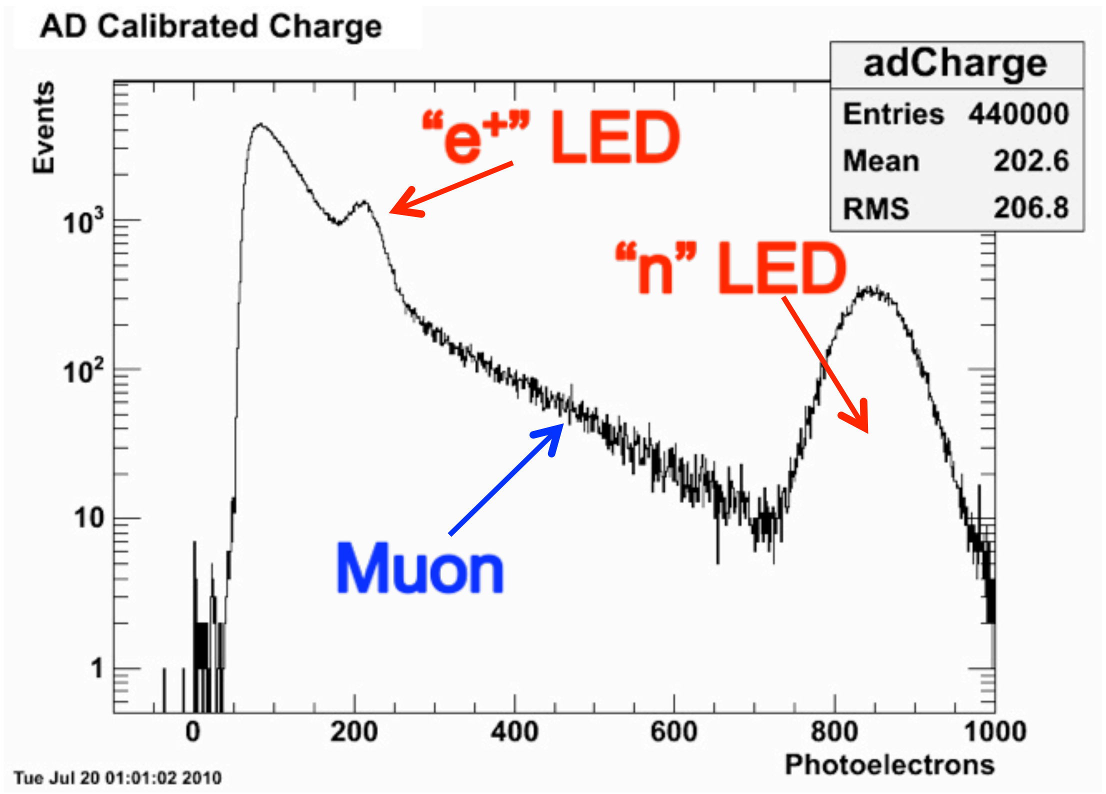
AD Dry Run

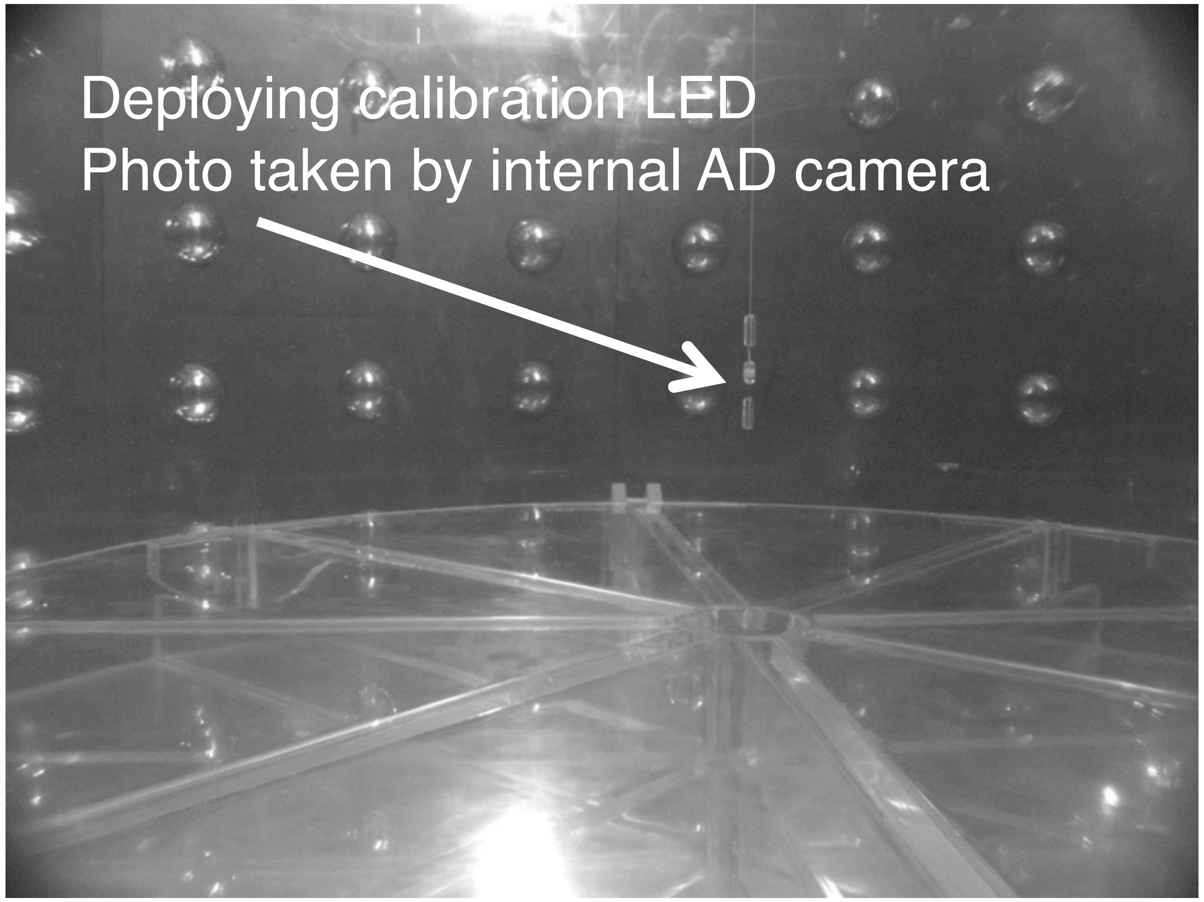
- Integrated Test of the complete AD system before moving to underground for filling

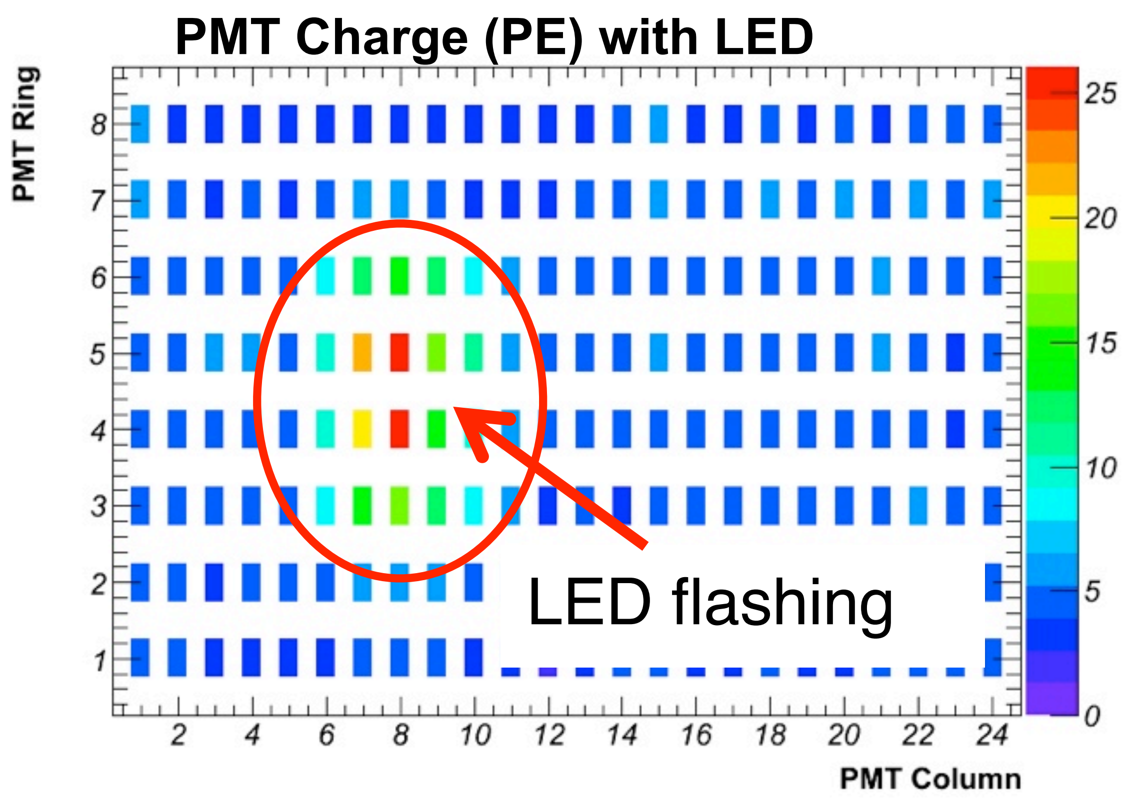


AD Dry Run

- First AD Data
  - Double-pulsed LED to mimic antineutrino interaction
  - Dry run in assembly building (above ground). Can see muon events

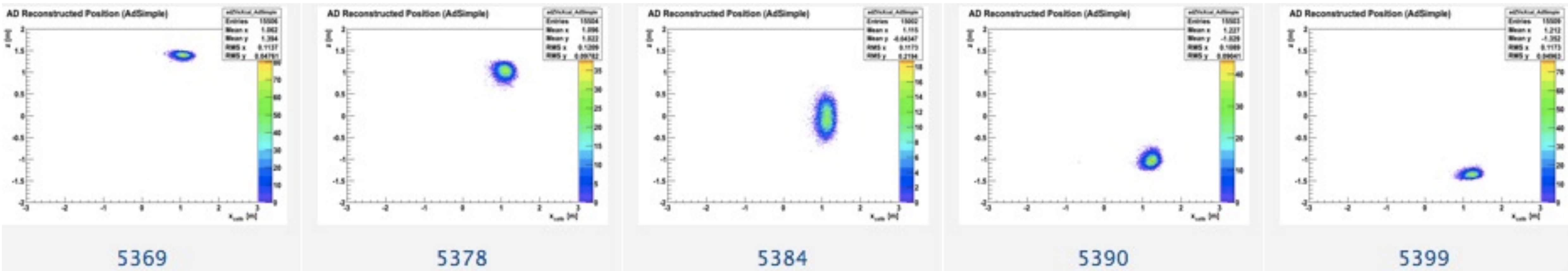




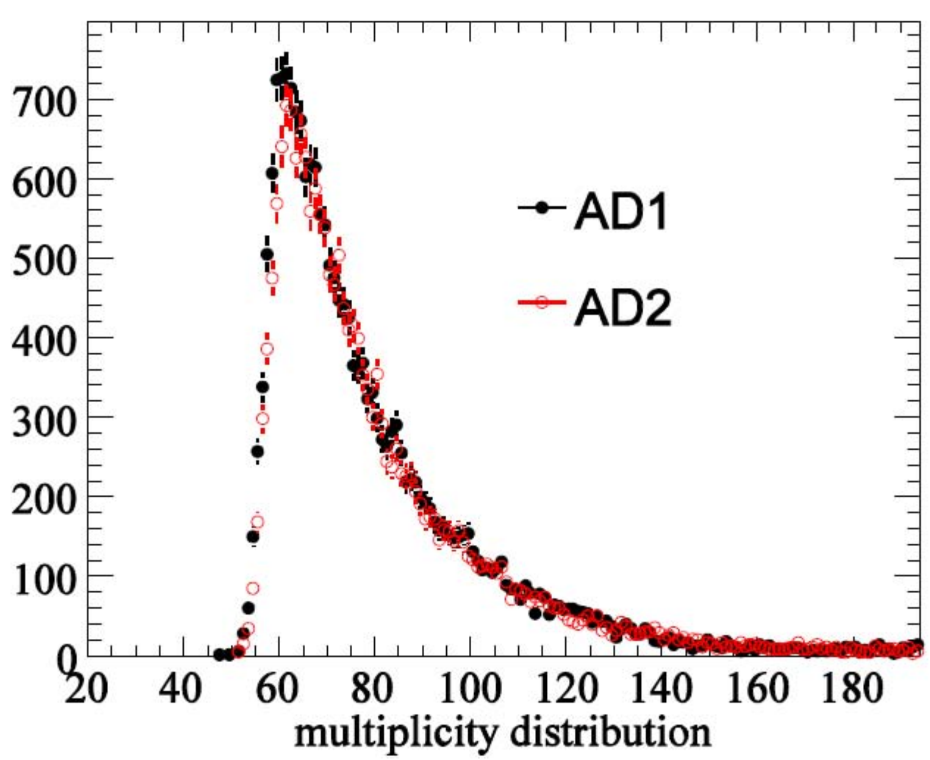


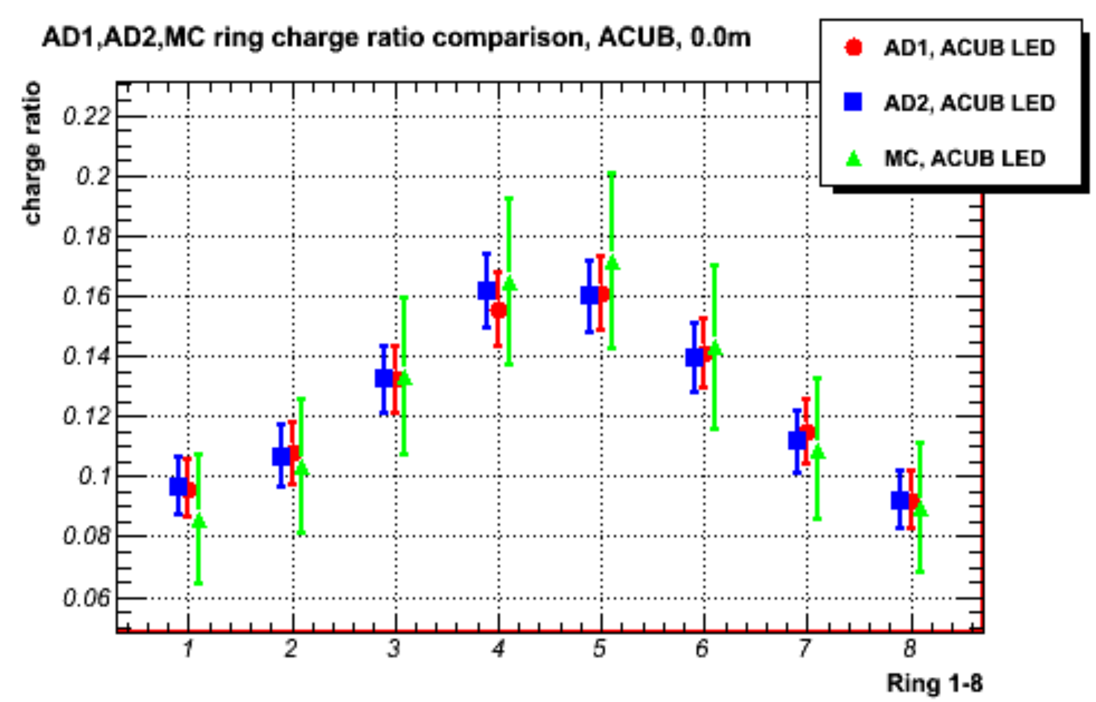
AD Dry Run

Reconstructed Vertex of Off-axis LED Deployments



AD1 & AD2 Comparison

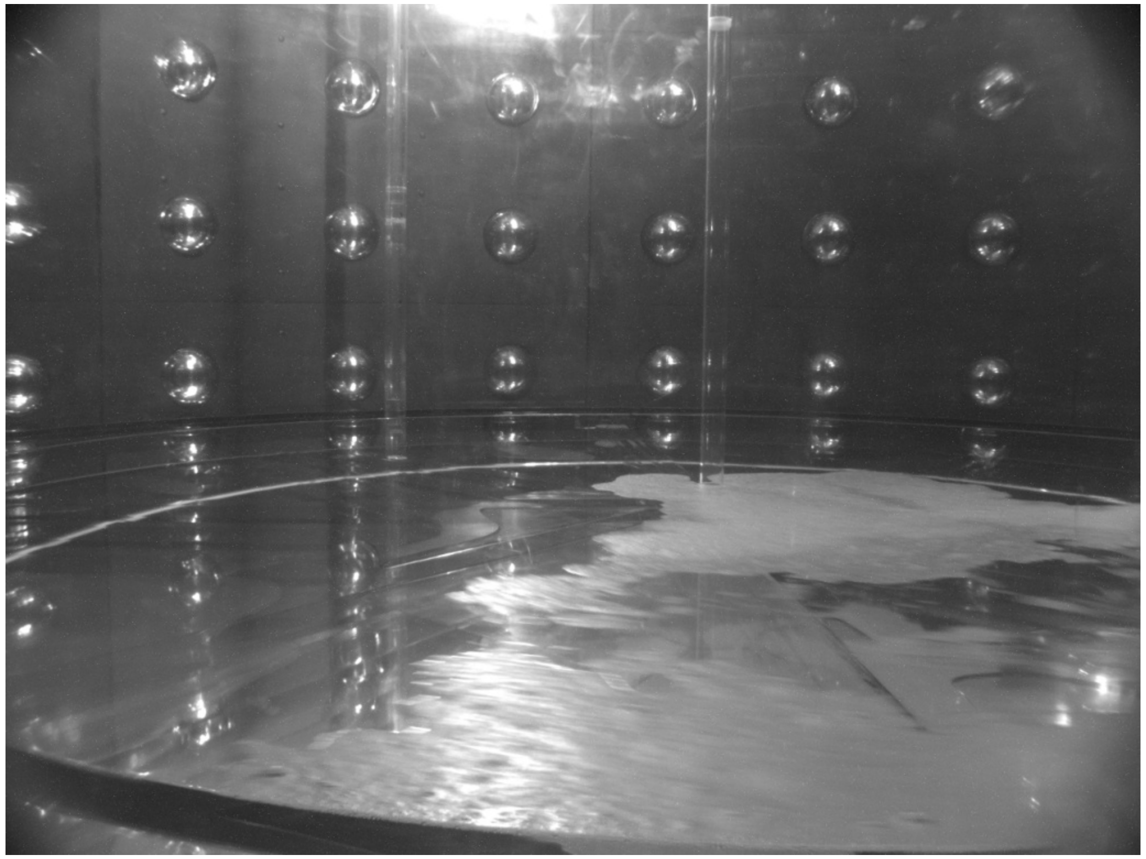


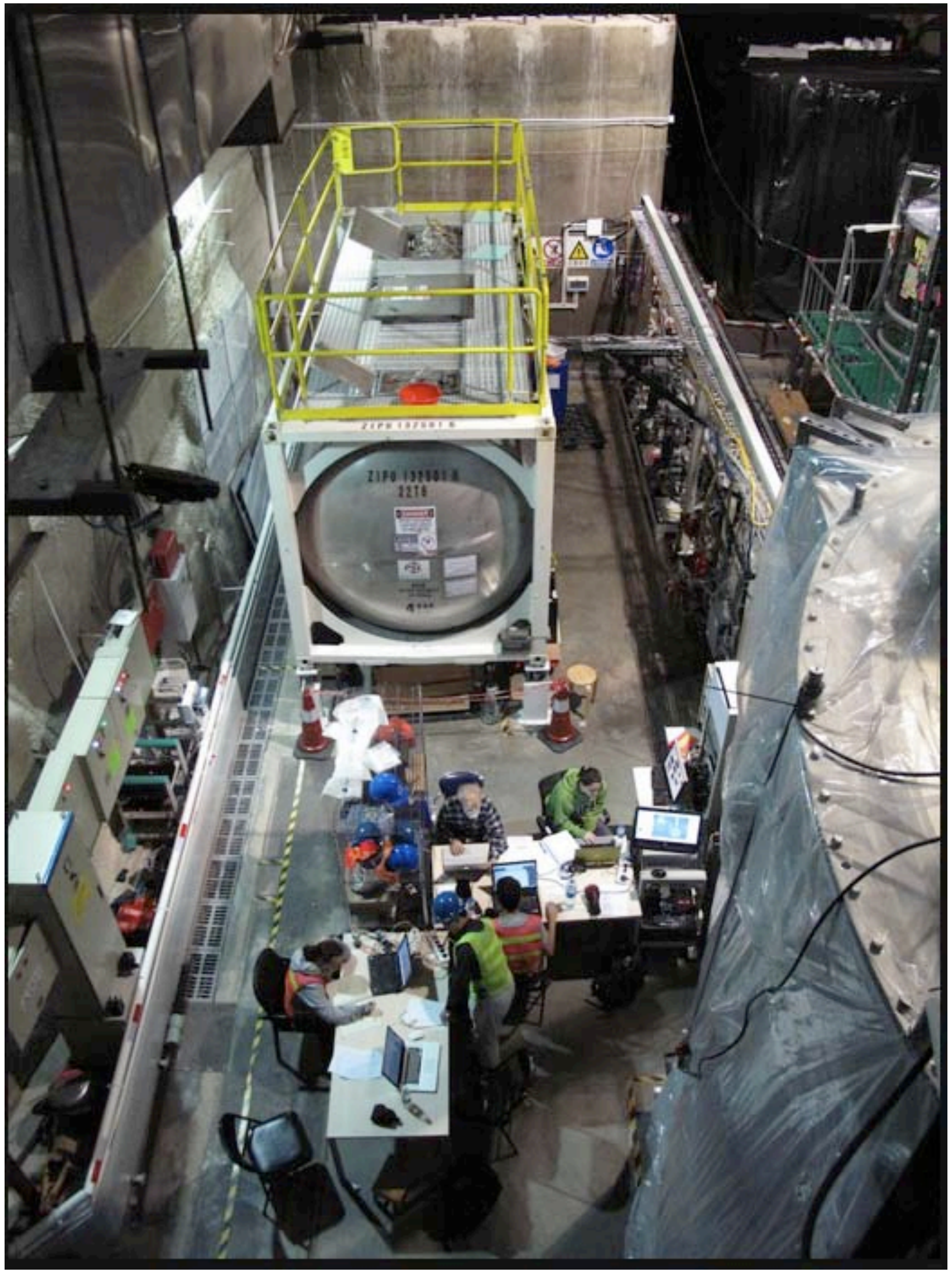


AD Transporting

AD Filling

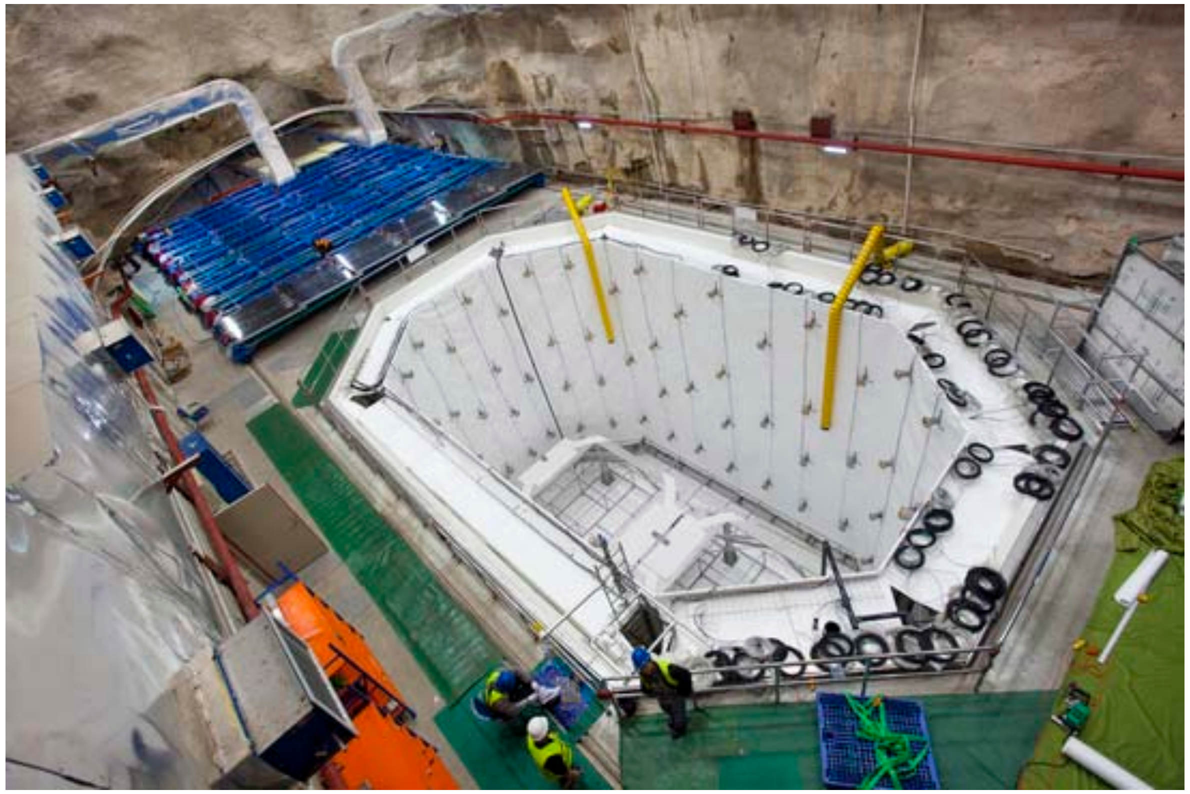
- AD #1 and #2 successfully filled
  - Precision mass measurement
  - Liquid level monitor
  - Temperature control

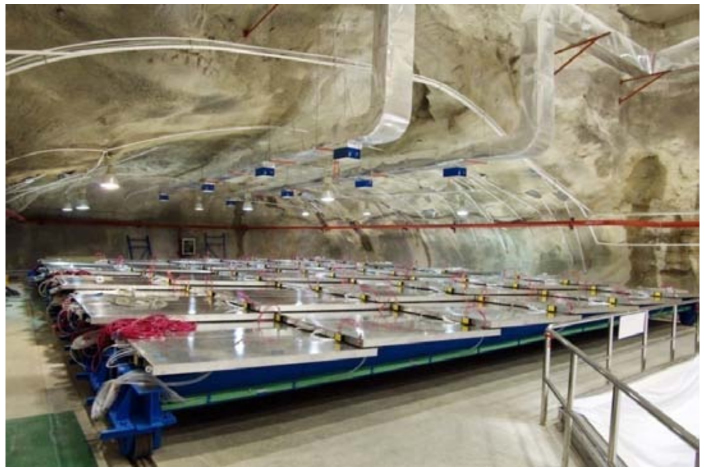




Muon System Installation

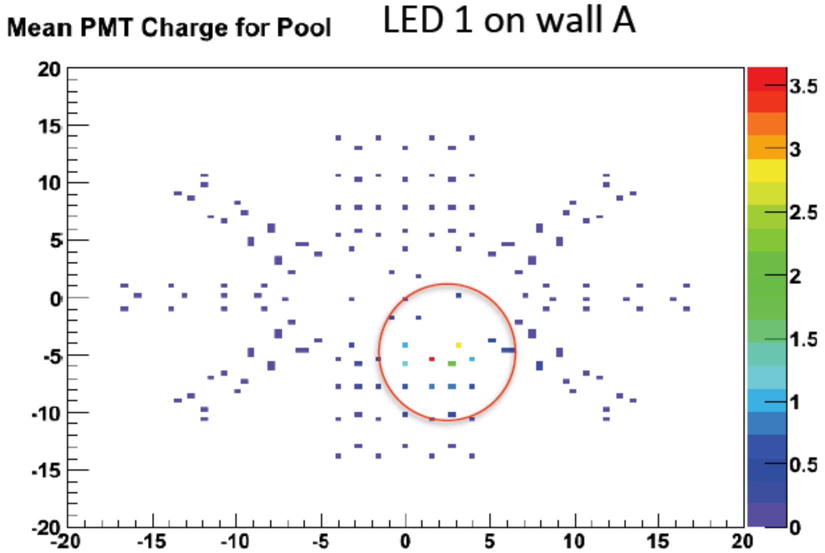
- Muon System Status (EH1)
  - All 288 PMTs installed
  - RPC modules installed
  - Pool dry run finished with good performance





Fully installed RPC

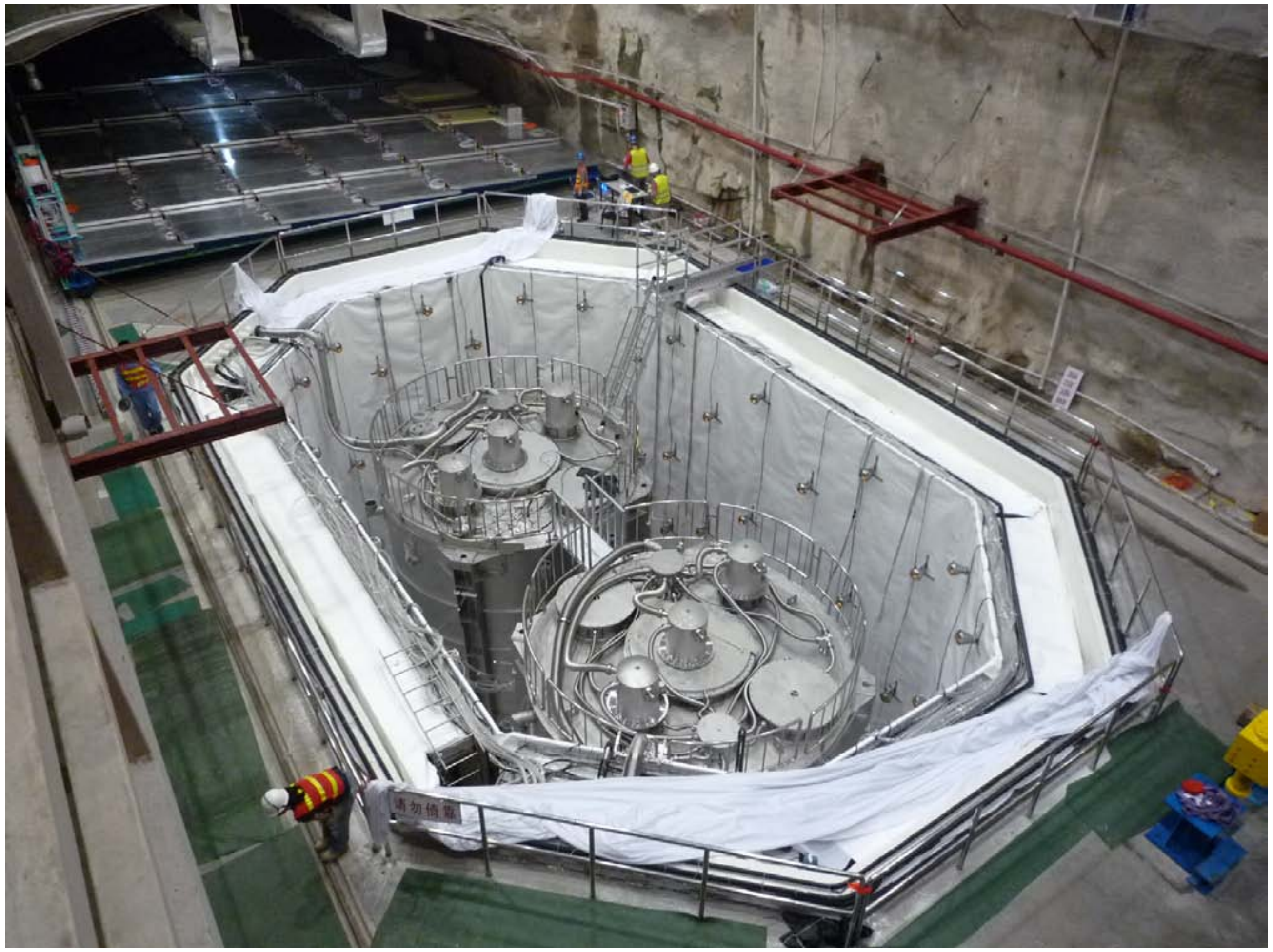
Pool divided by Tyvek into inner and outer regions

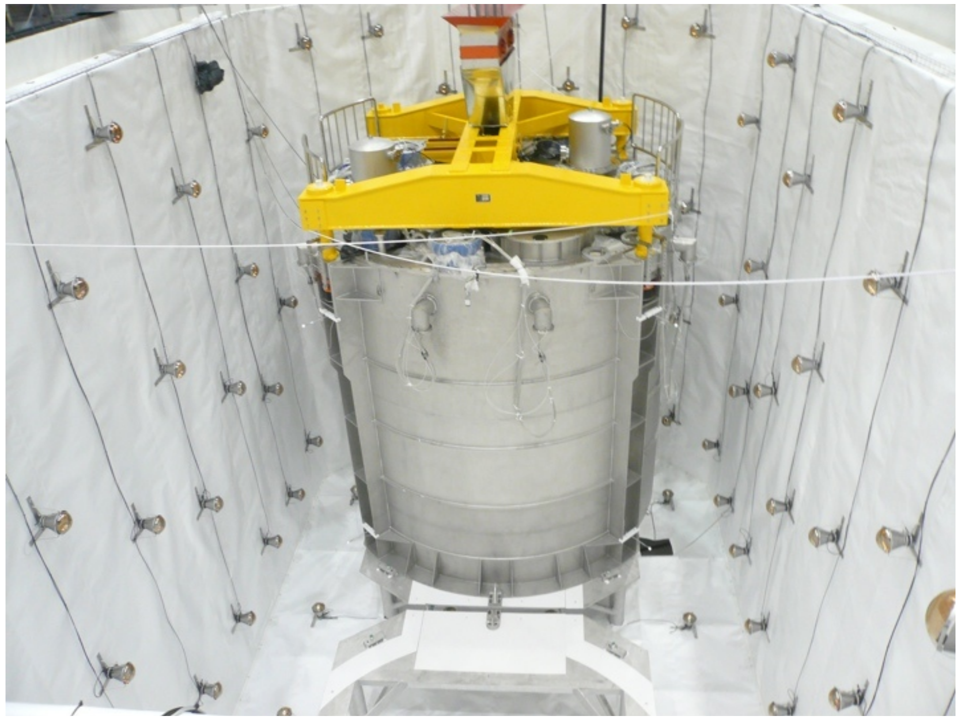


calibration LED flashing

Move AD into the Pool

- Daya Bay Near Site (EH1) Status
  - AD #1 and #2 are in the pool
  - Taking AD data with dry pool
  - Water fill in August





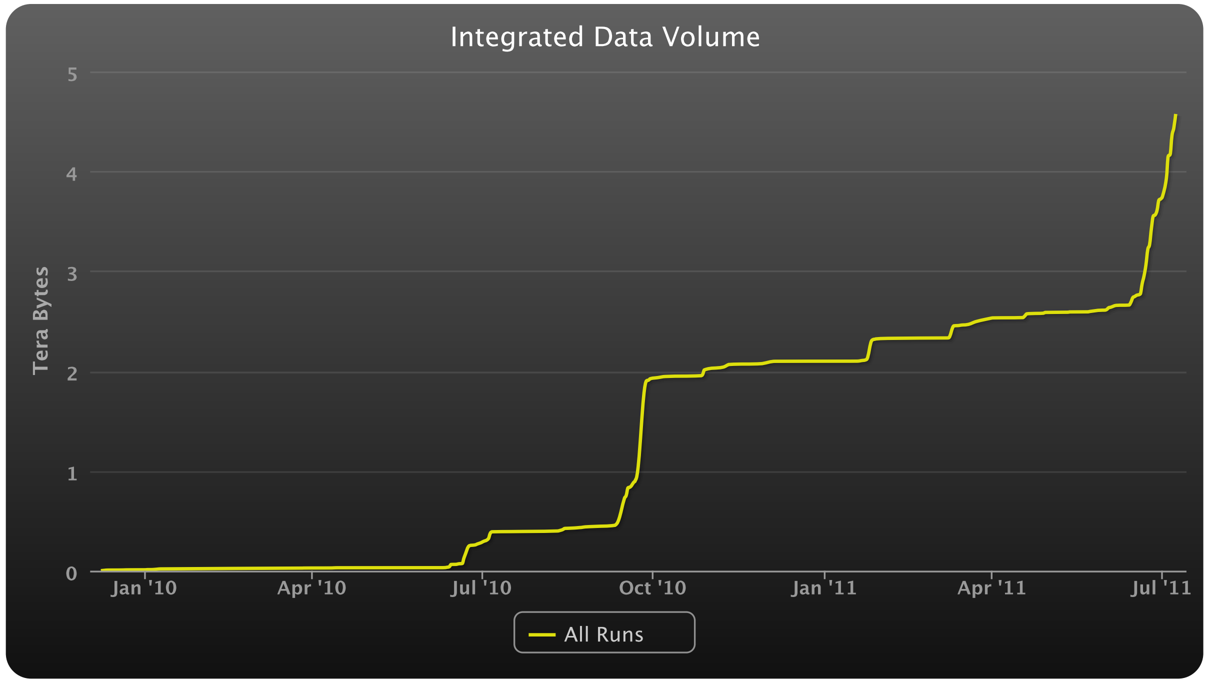
Summary

- Daya Bay experiment is designed to measure the unknown mixing angle θ_{13} to a great precision: $\sin^2 2\theta_{13} < 0.01$ @ 90% C.L.

- Smooth progress
  - Two ADs for Hall 1 (Daya Bay near) fully completed
  - Muon system for Hall 1 completed. Water pool fill in August
  - Hall 1 physics data taking soon

- Toward full experiment
  - Hall 2 (Ling Ao near) installation started
  - Hall 3 (Far) installation after this summer
  - Full Data taking next summer (2012)

Exciting time as rapidly increasing data coming!



Detector Related Systematics

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

arXiv:hep-ex/0701029v1 **(TDR)**

- Baseline: achievable through proven methods
- Goal: with additional calibration and analysis efforts
- Swapping: potential improvement by swapping near/far detectors

Most systematic uncertainties reduced through detector design