The Daya Bay Reactor Neutrino Experiment

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on behalf of the Daya Bay Collaboration

Neutrino Champagne 2009

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The Daya Bay Nuclear Power Plant

- Located in Guangdong Province, China about 1 hour from Hong Kong
- 4 Reactors with 11.6 GW thermal power going to 6 reactor with 17.4 GW_{th} in early 2011
- Among the most powerful NPP in the world
- Mountainous terrain is well suited for shielding underground detectors
- The utility company (China Guangdong Nuclear Power Group) has joined the collaboration

Daya Bay Design Principles

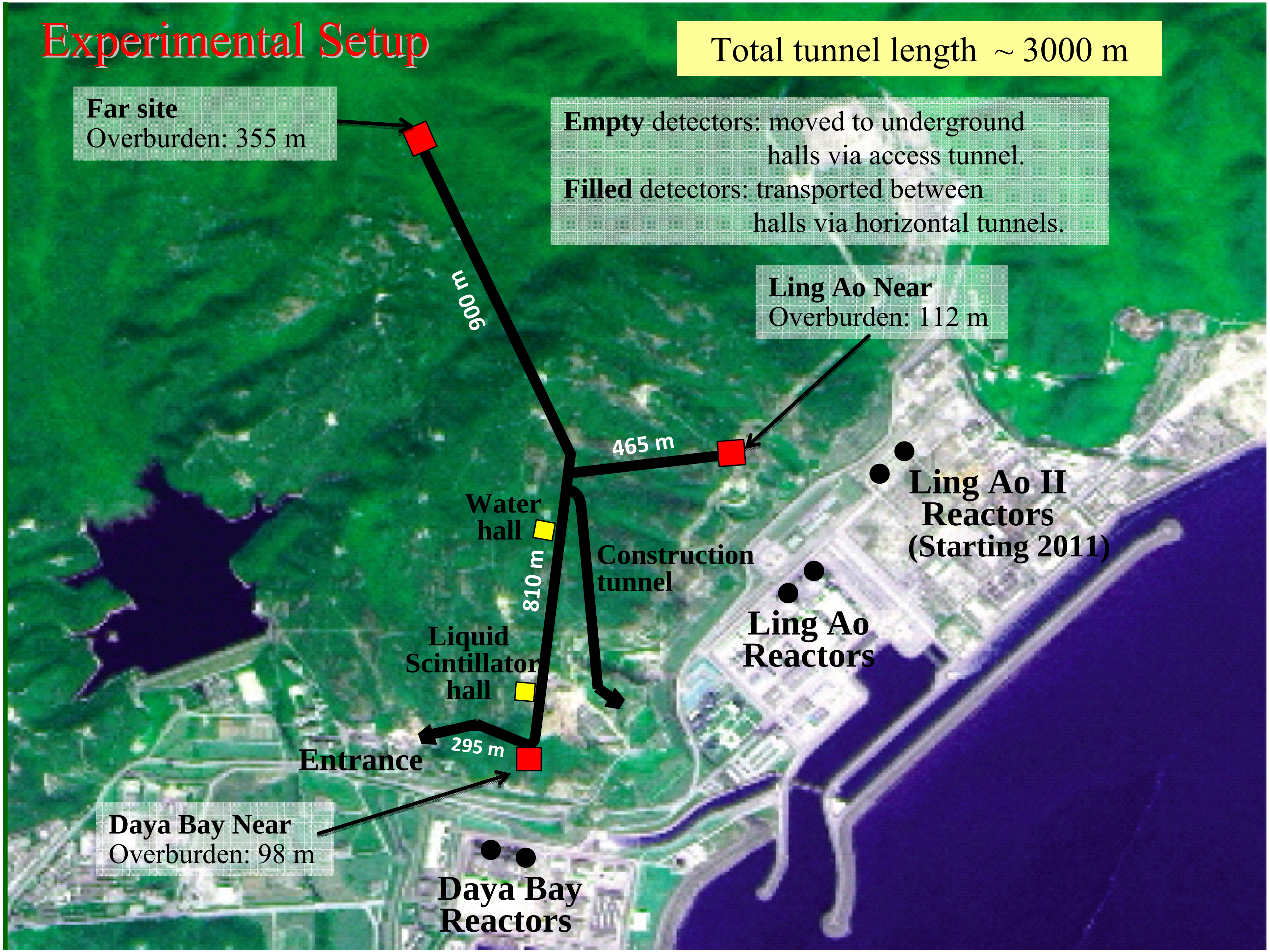
Identical near and far detectors cancel many systematic error.

Multiple modules boost statistics while reducing systematic errors with multiple independent measurements and direct comparisons of detector counting rates in a common ν flux.

Three zone detector design eliminates the need for spatial cuts which can introduce systematic uncertainies.

Shielding from cosmic rays and natural radioactivity reduces background rates and provides measurable handles on remaining background.

Movable detectors allows for concurrent civil and detector construction, early detector commissioning at the near site, and possible cross calibration between near and far detectors to further reduce systematic errors.

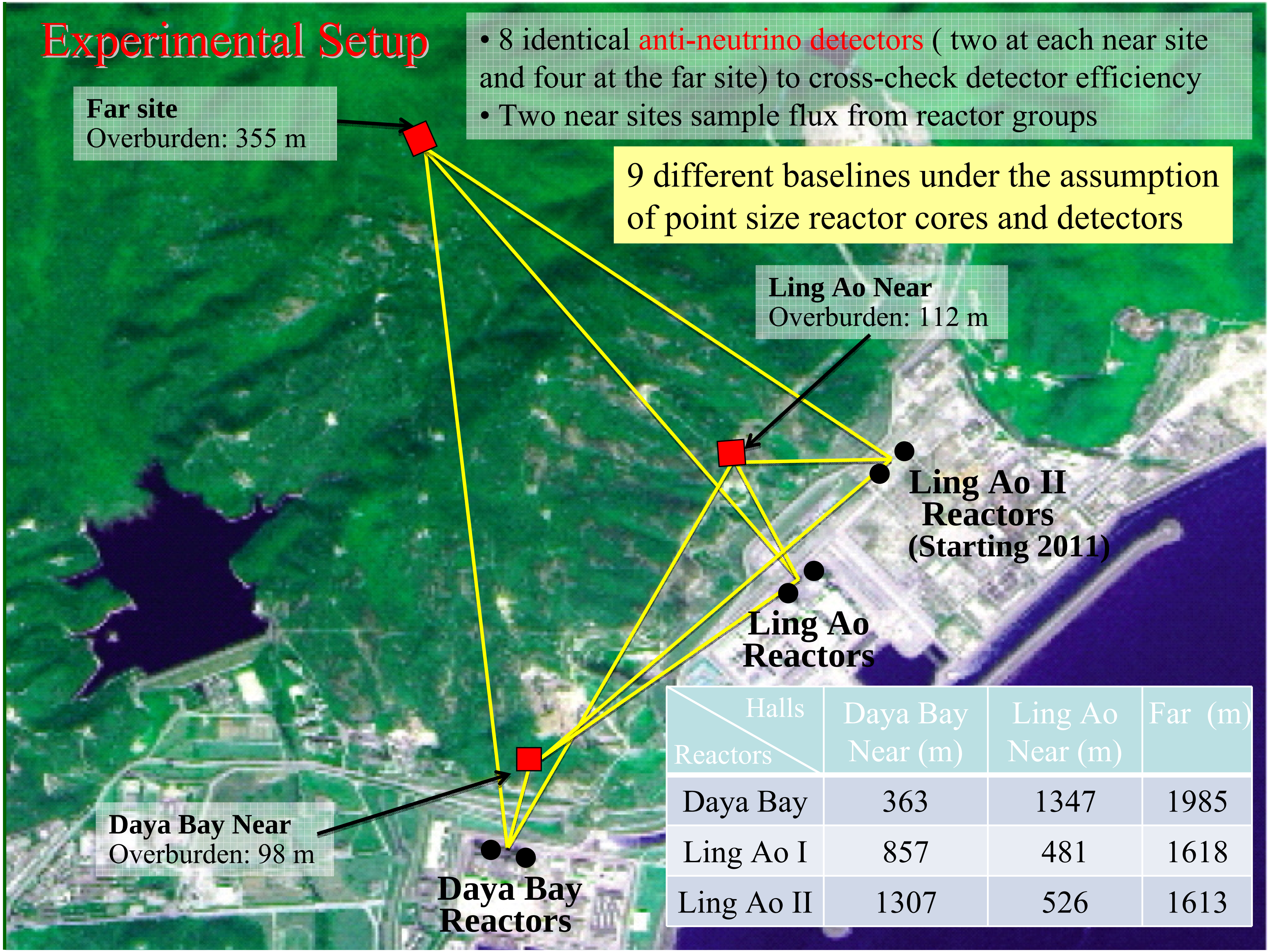


Experimental Setup
Total tunnel length ~ 3000 m
Far site
Overburden: 355 m
Empty detectors: moved to underground halls via access tunnel.
Filled detectors: transported between halls via horizontal tunnels.
Ling Ao Near
Overburden: 112 m
900 m
465 m
Ling Ao II Reactors (Starting 2011)
Water hall
810 m
Construction tunnel
Ling Ao Reactors
Liquid Scintillator hall
295 m
Entrance
Daya Bay Near
Overburden: 98 m
Daya Bay Reactors

Experimental Setup

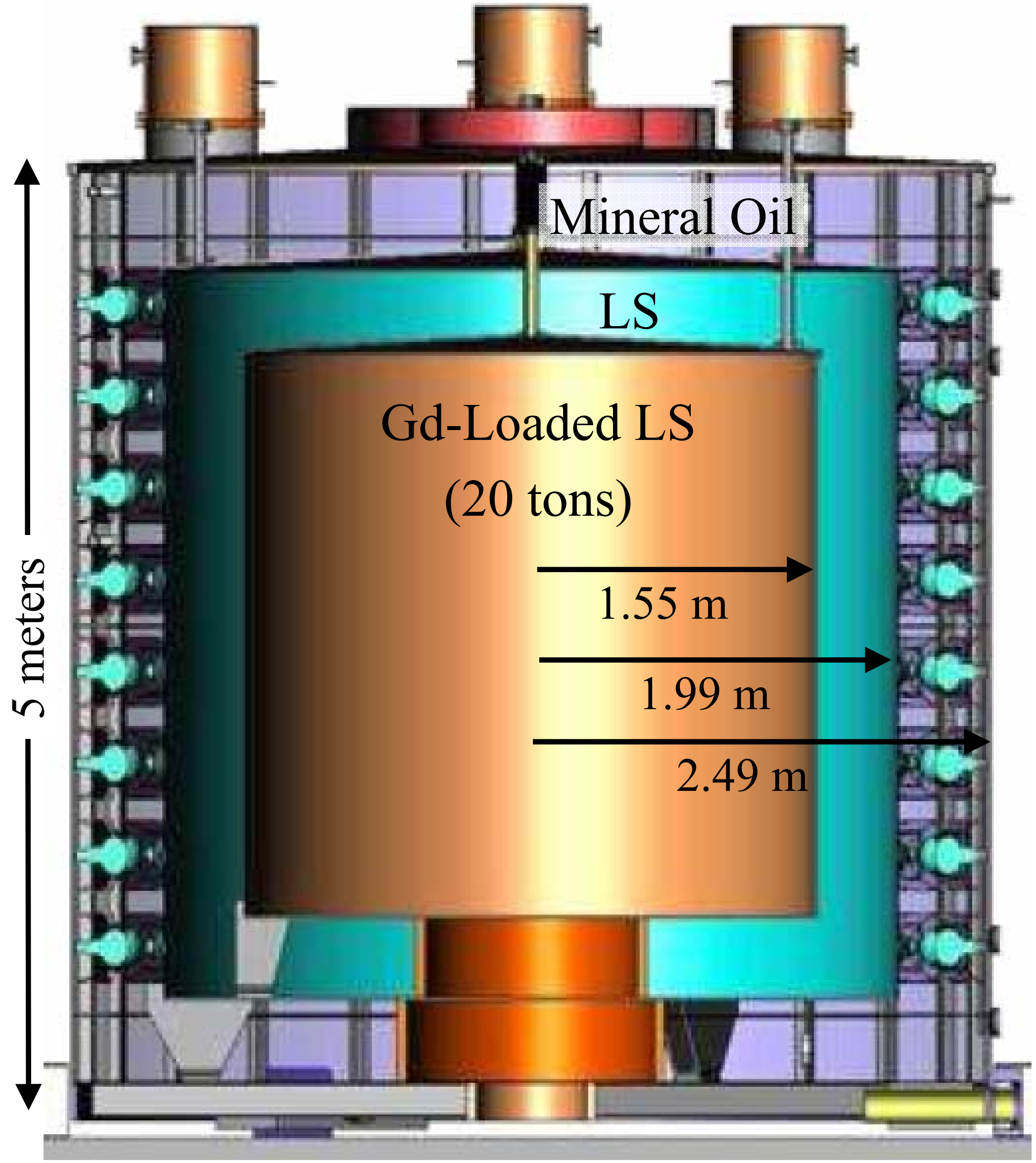
- 8 identical anti-neutrino detectors (two at each near site and four at the far site) to cross-check detector efficiency
- Two near sites sample flux from reactor groups

9 different baselines under the assumption of point size reactor cores and detectors



Reactors \ Halls	Daya Bay Near (m)	Ling Ao Near (m)	Far (m)
Daya Bay	363	1347	1985
Ling Ao I	857	481	1618
Ling Ao II	1307	526	1613

The Daya Bay Detector Design



There are 8 antineutrino detectors in all

Three zone, cylindrical design
- 0.1% wt Gd-Loaded LS target
- LS gamma catcher
- Mineral oil buffer

Reflectors at top and bottom

196 PMT's arrayed around the barrel of the cylinder

5 meter total diameter

Designed to sit in a pool of ultrapure water

For more information on the liquid scintillator see the poster by Qi Ming

Water Shield and Muon Tagging System

The water pool shields the detectors from energetic γ-rays from the decay chains of ^{238}U, ^{232}Th and ^{40}K in surrounding the rock

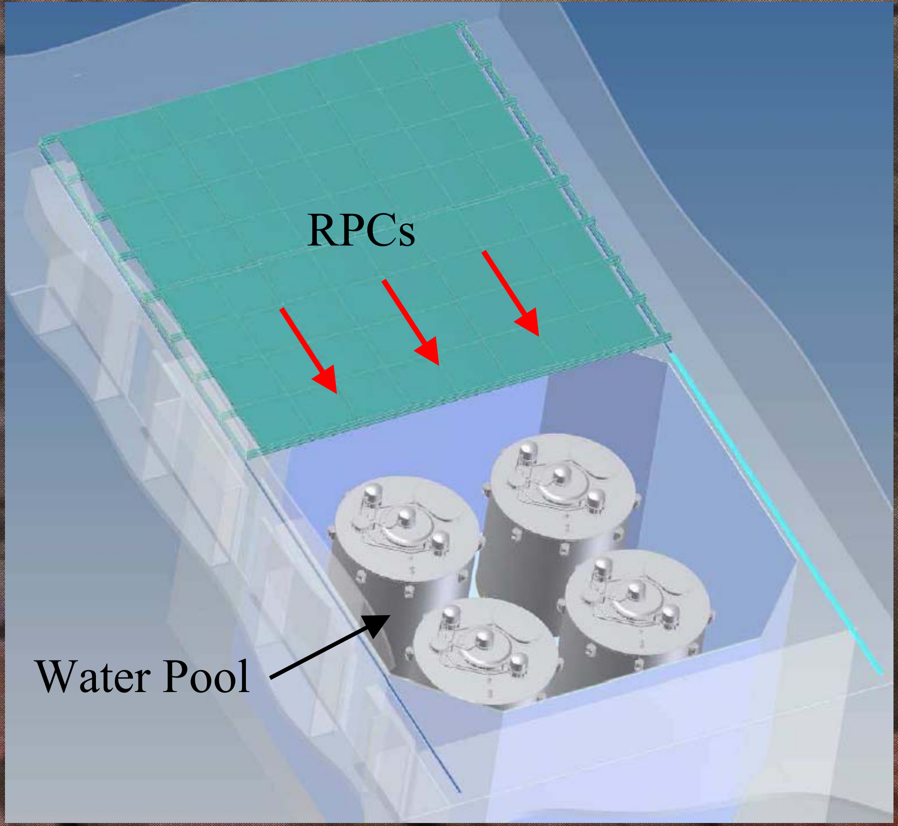
It also detects the Čerenkov light produced by cosmic ray muons which pass near the detectors

The pool is lined with white Tyvek and sparsely populated with PMTs

The pool is optically separated into two zones (inner and outer)

The top is covered with 4 layers of RPC

The two zones allow a better measurement of efficiency



Minimum 2.5 m water shielding in all directions.

Measuring $\sin^2 2\theta_{13}$

The measurement is a ultimately a ratio of observed inverse β-decay events in near and far detectors in initially one, but ultimately many energy bins (sampling a broad range of oscillation phases).

$$\frac{N_f}{N_n}$$

Proton Number Ratio

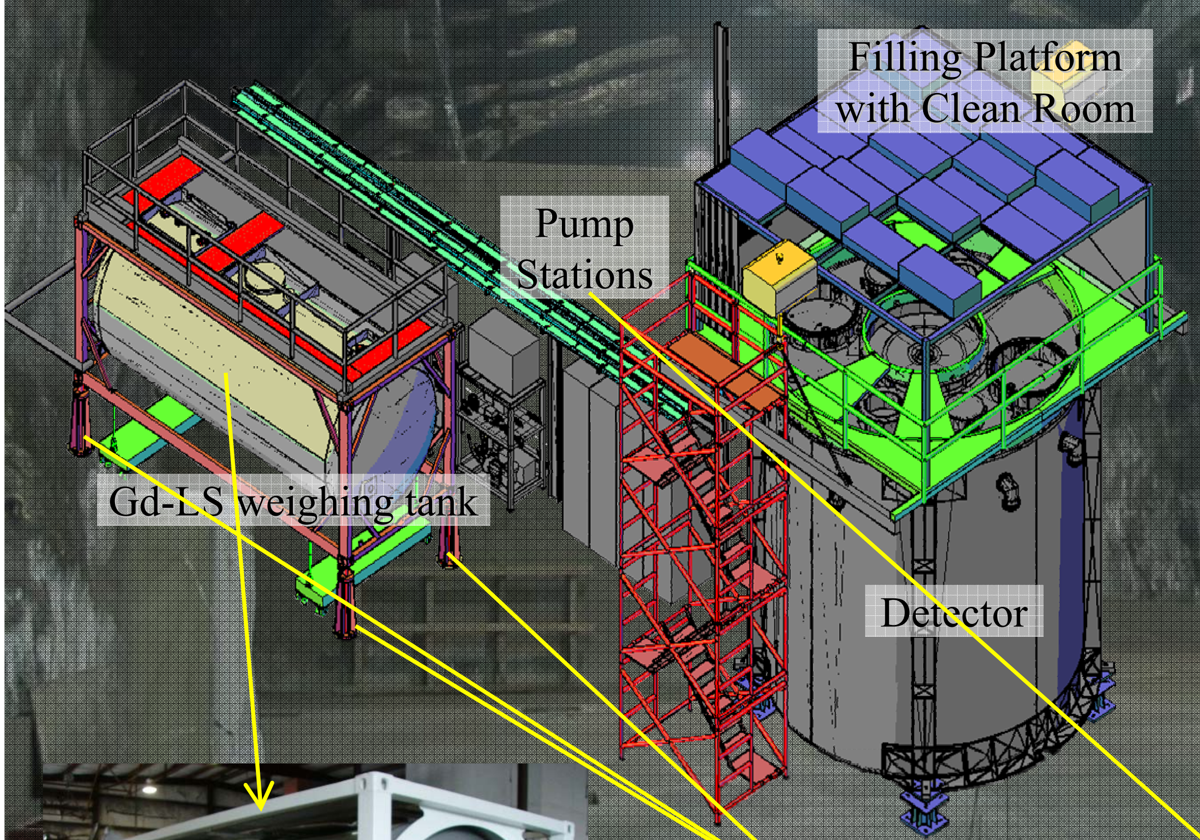
↓

$\pm 0.3\%$

$\sin^2 2\theta_{13}$

Controlling the Proton Ratio Systematic Error

The final step in building the detectors is to fill the three zones.

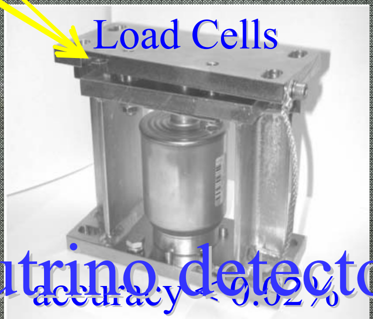


Detectors are filled underground.

Detectors will be filled in pairs (one far, one near) from common scintillator and mineral oil batches.

Mixed fluid weights are carefully measured throughout the filling.

As are fluid flow rates.



The antineutrino detector filling hall

Measuring $\sin^2 2\theta_{13}$

The measurement is a ultimately a ratio of observed inverse β-decay events in near and far detectors in initially one, but ultimately many energy bins (sampling a broad range of oscillation phases).

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

Proton Number Ratio → $\pm 0.3\%$

Ratio of Detector Efficiencies → Calibration → $\pm 0.2\%$

$\sin^2 2\theta_{13}$

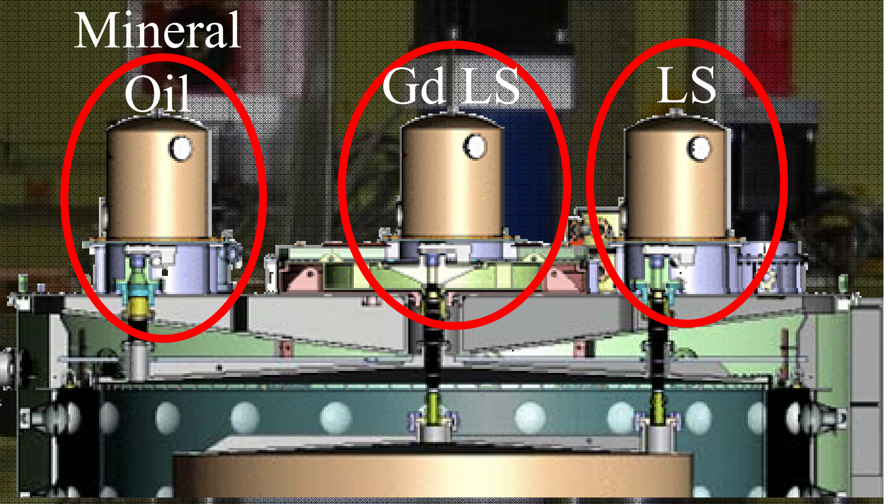
Calibration System

Automated calibration system with routine weekly deployment of sources

LED light sources for monitoring optical properties

Stopped e^+ and n sources give fixed energies for energy calibration

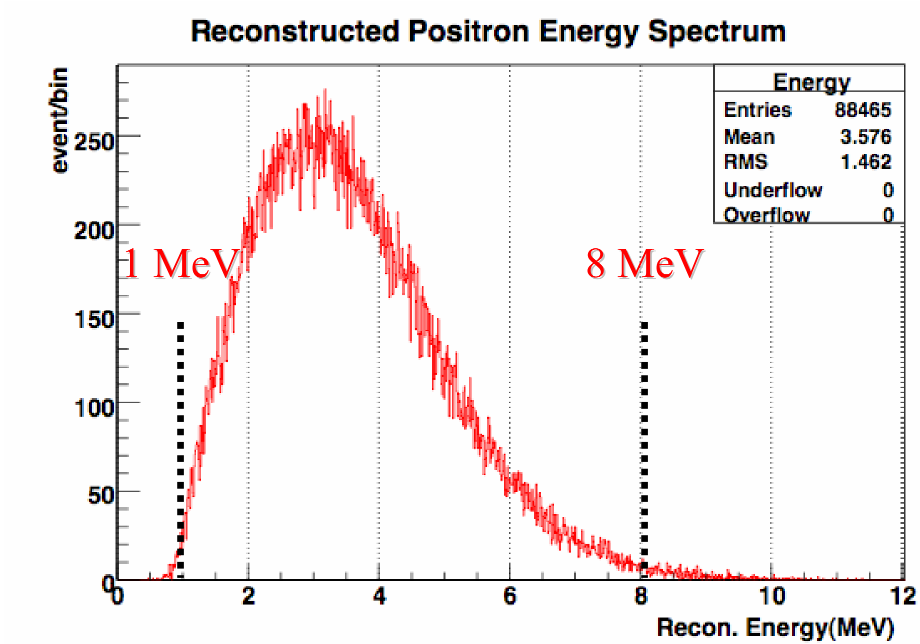
- ^{68}Ge source
- Am-^{13}C + ^{60}Co source
- LED diffuser ball



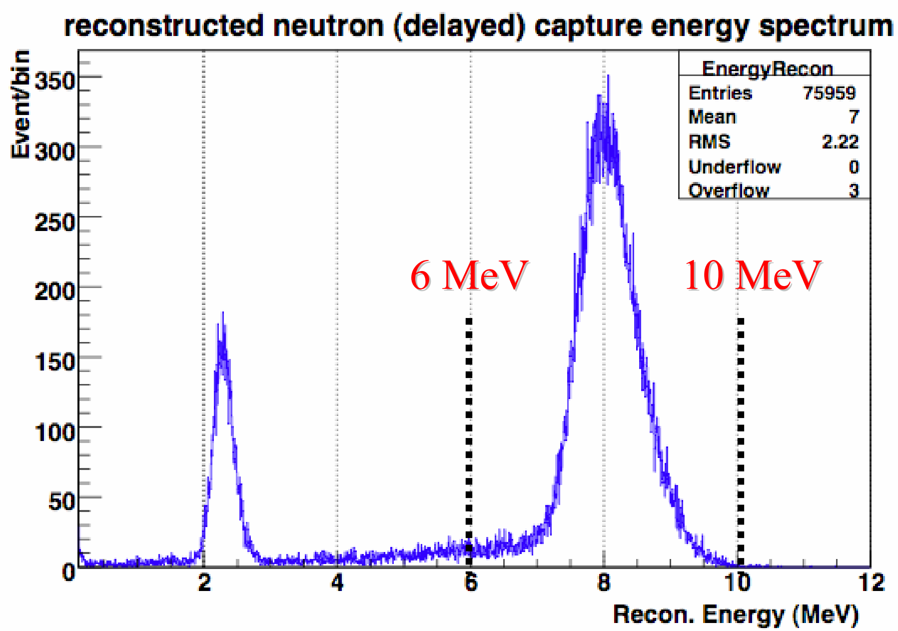
Calibration units which remotely insert a range of calibration devices along a vertical axis in each of the three zones.

Efficiency and Energy Calibrations

Prompt Energy Signal



Delayed Energy Signal



Stopped positron signal from the ^{68}Ge source (2×0.511 MeV) gives us the inverse β-decay positron energy threshold

Neutrons (Am-^{13}C and tagged spallation) gives us a 2.2 MeV signal (in the positron energy range) and 8 MeV from Gd neutron capture

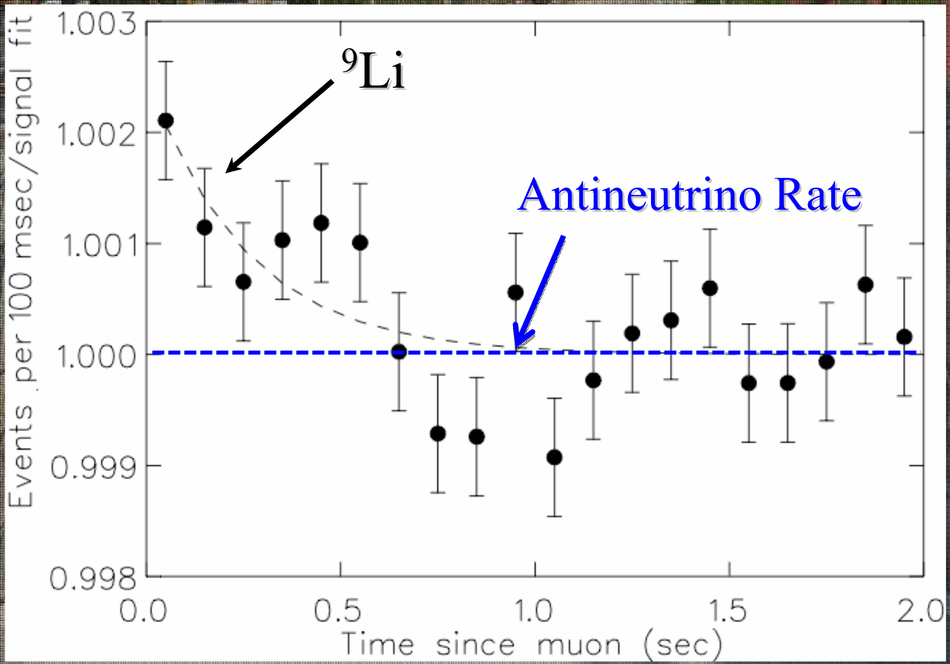
With a 1 MeV cut for prompt positrons:
>99% efficiency with negligible uncertainty

With a 6 MeV cut for delayed neutrons:
~78% efficiency with 0.22% relative uncertainty

Backgrounds

Fast neutron — fast neutron enters detector, creates prompt signal, thermalizes, and is captured.

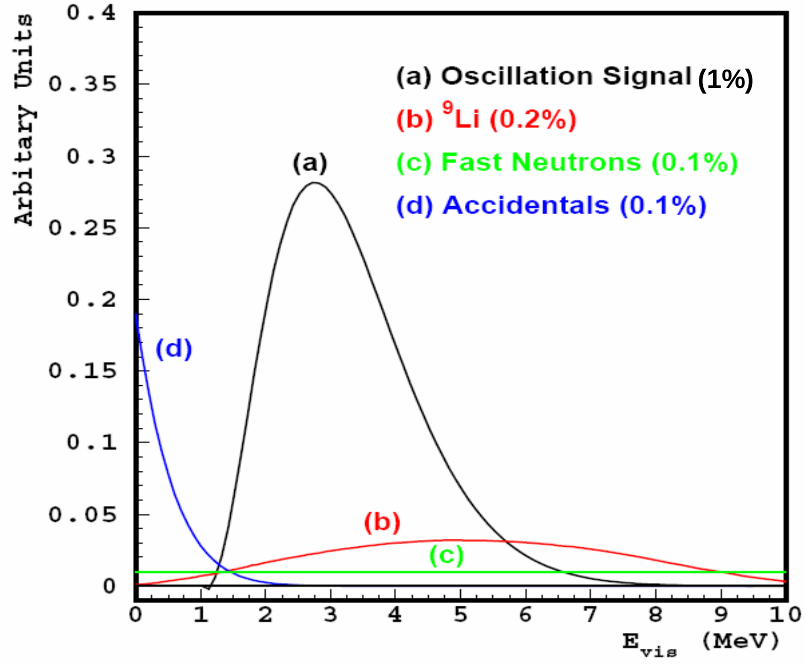
Correlated decays — β+n decays of ^{9}Li and ^{8}He produced in the antineutrino detector by spallation of μ on ^{12}C.



Random coincidence — two unrelated events that happen close together in space and time.

Portal to the underground halls which provide from 250 to 925 meters water equivalent shielding

Signal to Background



After all filters the background rates are small compared to a disappearance due to oscillations with $\sin^2 2\theta_{13}$ of 1%.

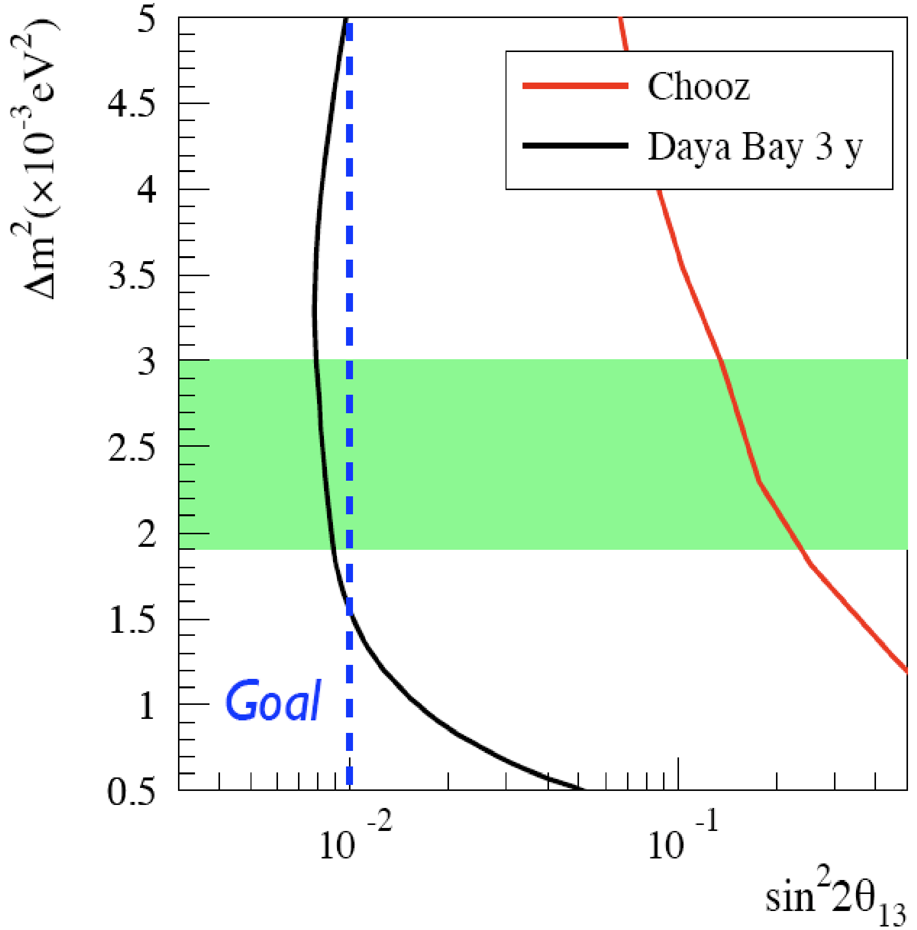
In addition, each background has a characteristic and distinct energy spectrum.

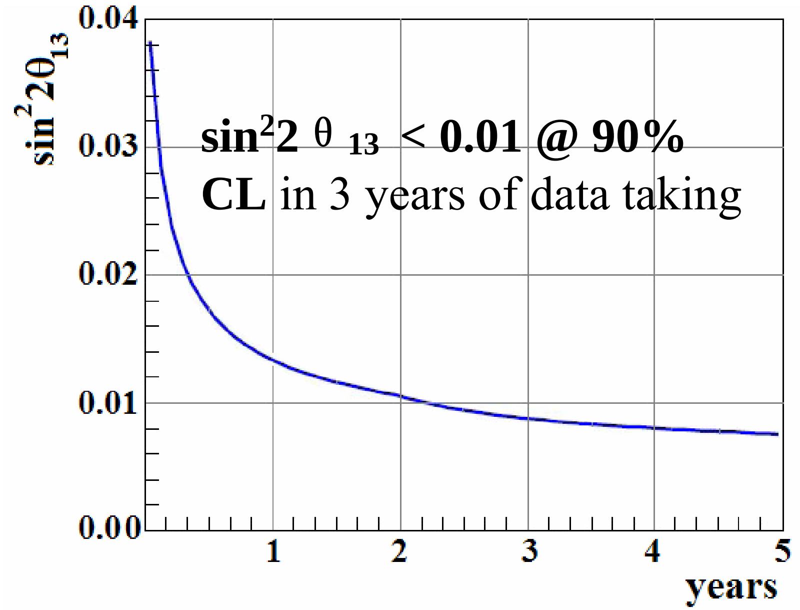
		DYB site	LA site	far site
(a)	Antineutrino rate (/day/module)	840	740	90
	Natural radiation (singles) (Hz)	<50	<50	<50
	Single neutron (/day/module)	18	12	1.5
	β-emission isotopes (/day/module)	210	141	14.6
(d)	Accidental/Signal	<0.2%	<0.2%	<0.1%
(c)	Fast neutron/Signal	0.1%	0.1%	0.1%
(b)	^{8}He^{9}Li/Signal	0.3%	0.2%	0.2%

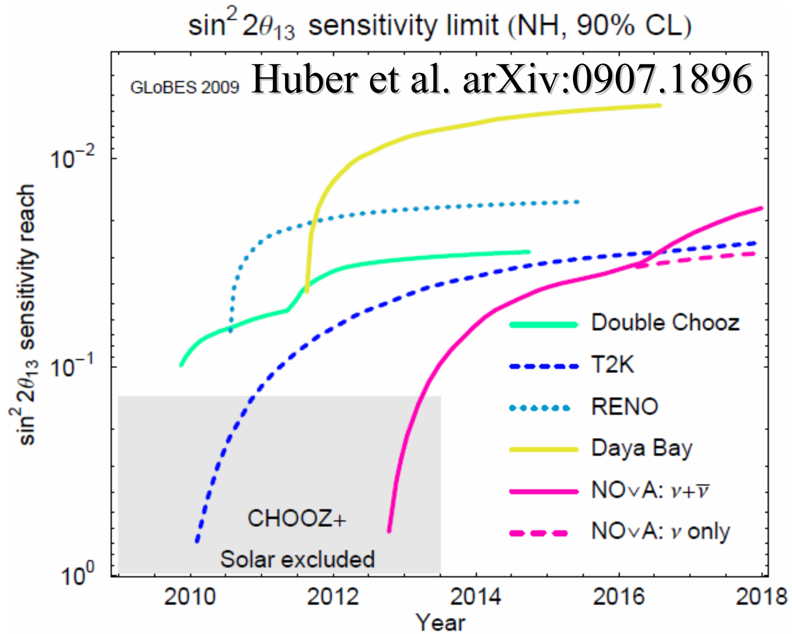
Systematic and Statistical Errors

Source of Uncertainty		Chooz	Daya Bay (*relative*)		
		(*absolute*)	Baseline	Goal	Goal w/Swapping
Number of 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%
Background (per detector)		0.85%	<0.4%	<0.4%	<0.4%
Neutrino Flux		2.7%	0.13%	0.13%	0.13%
Signal Statistics		1.8%	0.2%	0.2%	0.2%
Sensitivity to $\sin^2 2\theta_{13}$ (at 90% CL)		~13%	0.8%	0.7%	0.6%

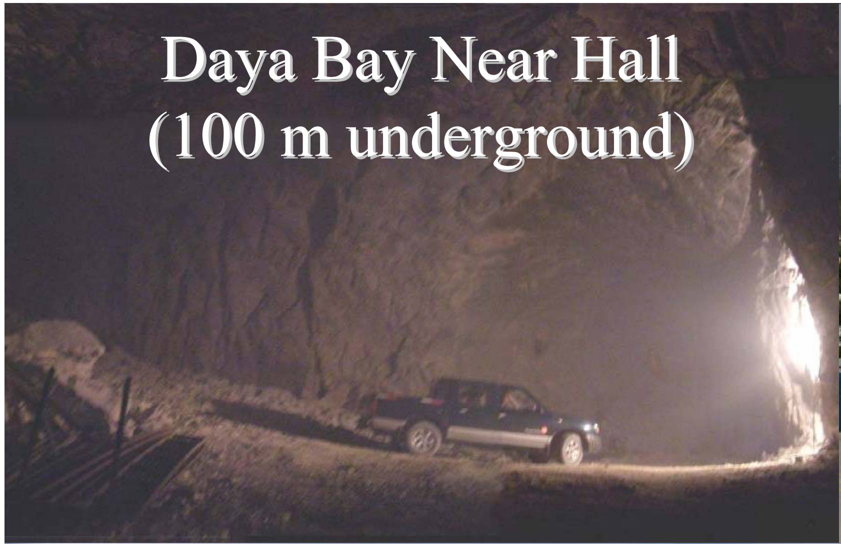
Sensitivity





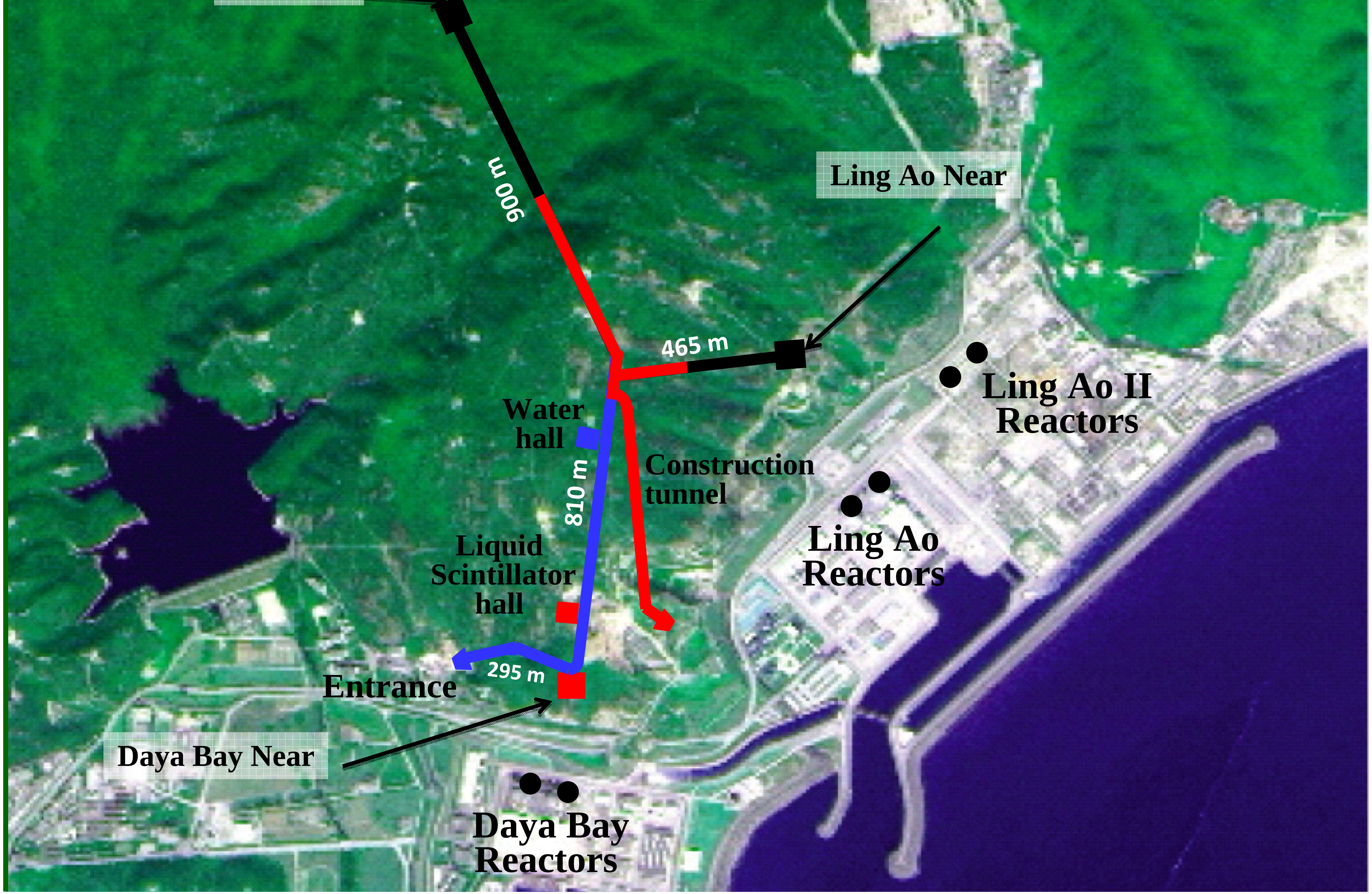


Status: Civil Construction



Status: Civil Construction

As of late September…

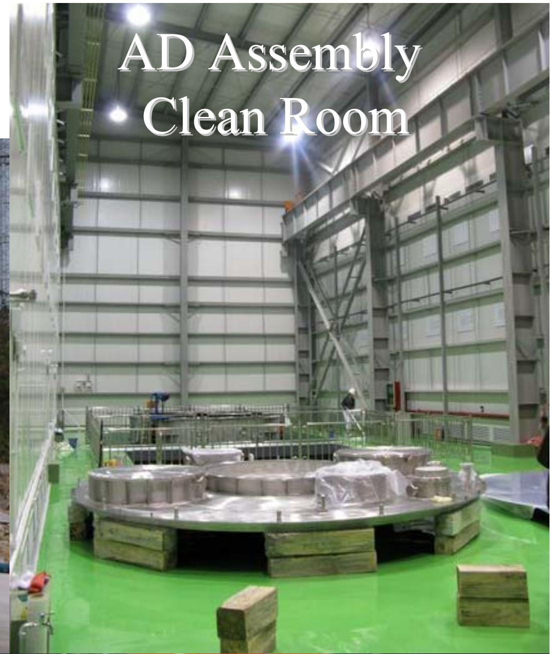


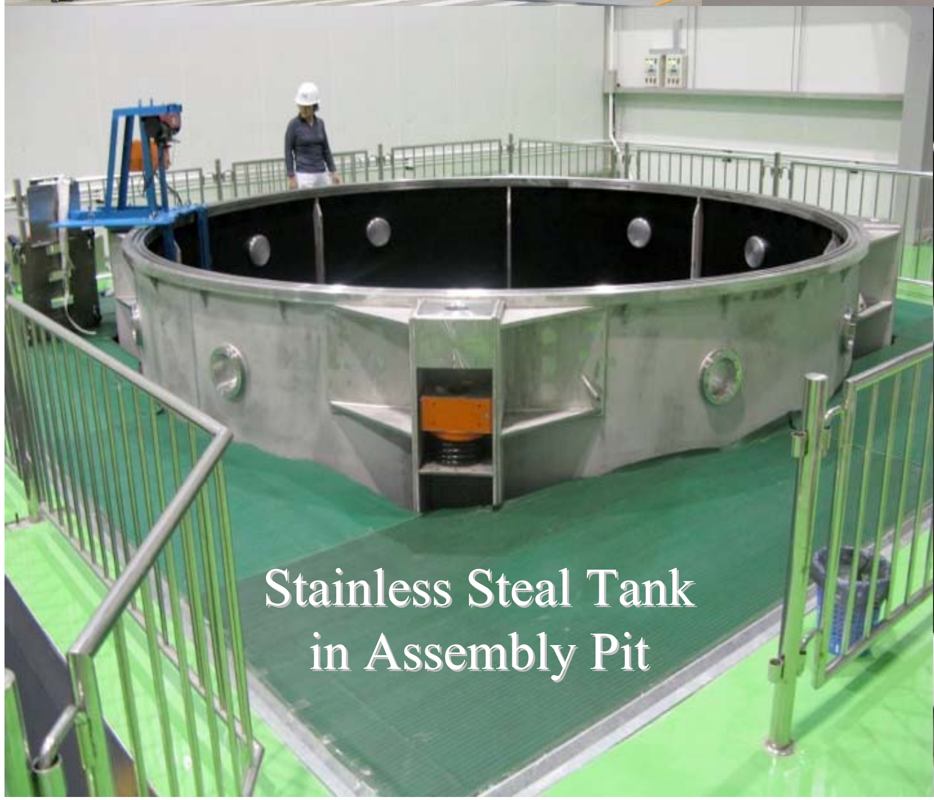
Status: Experimental Components

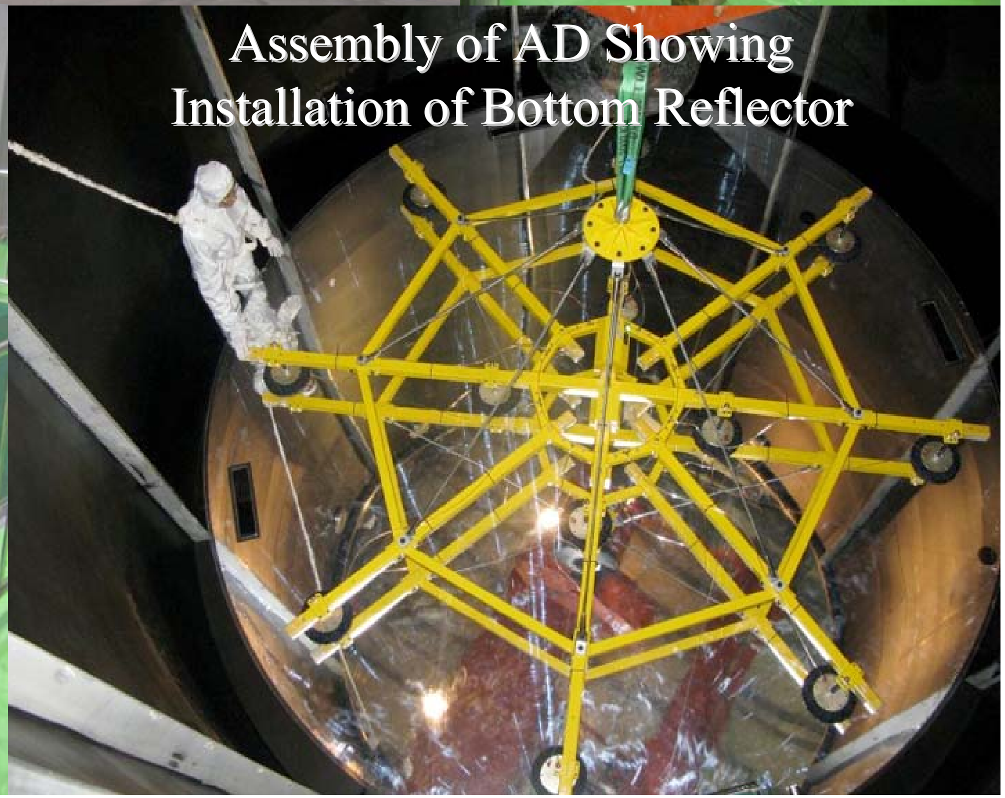
Status: Detector Assembly


Delivery of 4 m Acrylic Vessel


SS Tank Delivery


AD Assembly
Clean Room


Stainless Steal Tank
in Assembly Pit


Assembly of AD Showing
Installation of Bottom Reflector

Project Schedule

- October 2007: Ground Breaking
- Spring 2008: CD3 review completed
- March 2009: Surface Assembly Building occupancy
- Summer 2010: Daya Bay Near Hall ready for data taking
- Summer 2011: All near and far halls ready for data taking

Three years of data taking to reach sensitivity goal.

The Daya Bay Collaboration

Europe.:

Charles U., JINR, Kurchatov Institute

Asia:

Beijing Normal, Chengdu U. of Tech., CGNPE, CIAE, CUHK, Dongguan Polytech, IHEP Beijing, Nankai, Nanjing, National Chiao-Tung U., National Taiwan U., National United U., Shangdong U., SJTU, Shenzhen U., Tsinghua U., HKU, USTC, Zhongshan U.

U.S.:

BNL, Caltech, Cincinnati, George Mason, Houston, IIT, Iowa State, LBNL, Princeton, RPI, UC Berkeley UCLA, UIUC, Virginia Tech, Wisconsin