Daya Bay Reactor Neutrino Experiment

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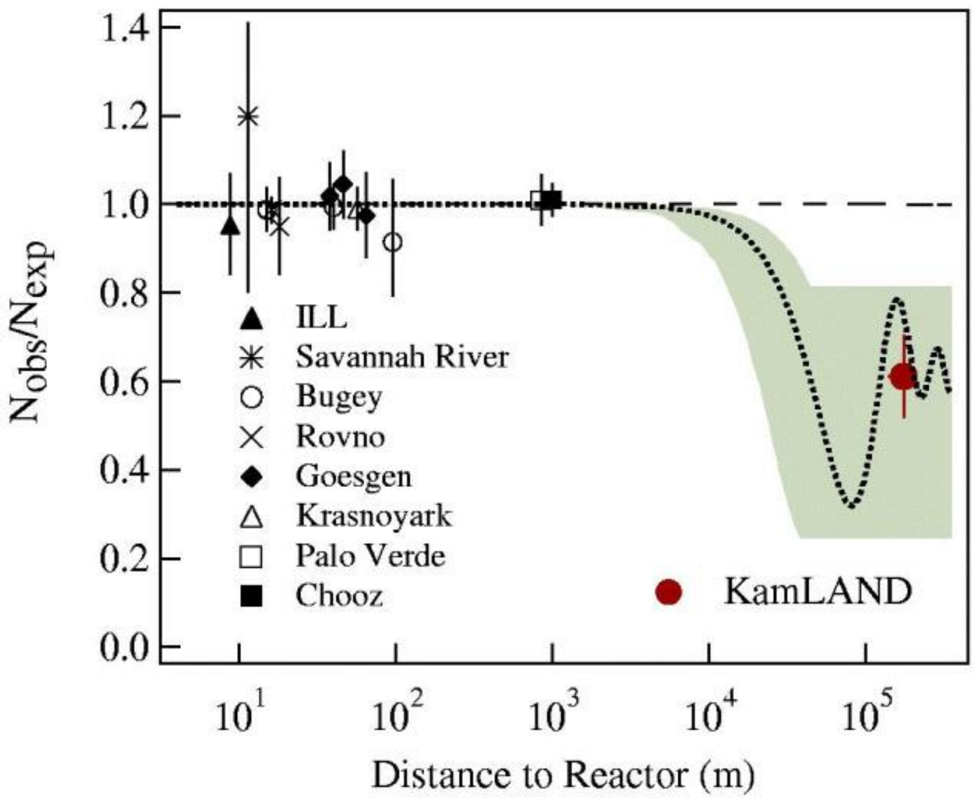
Past Reactor Neutrino Experiments

Reactor anti-neutrino experiments have played a critical role in the 50-year-long history of neutrinos.

- **The first neutrino observation in 1956 by Reines and Cowan.**
- **Determination of the upper limit of mixing angle theta13 to $\sin^2 2\theta_{13}<0.17$ (Chooz, Palo Verde)**
- **The first observation of reactor anti-neutrino disappearance at KamLAND in 2003.**



Now reactor neutrino experiments become prominent again for measuring mixing angle θ_{13} precisely.

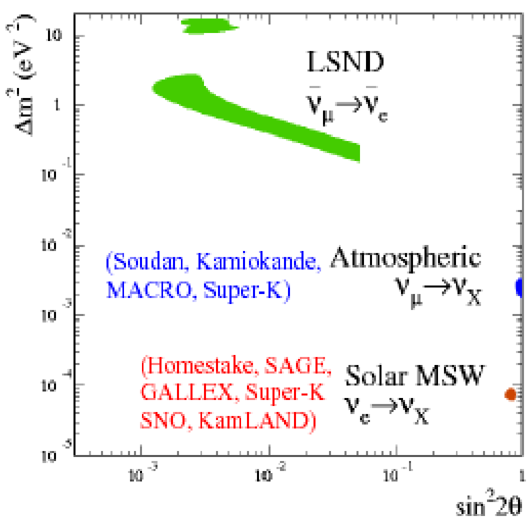
Neutrino Oscillation

Since 1998, we believe that neutrino can oscillate. non-zero mass + mixing

Neutrino Mixing: PMNS Matrix

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

Atmospheric, K2K, MINOS, T2K, etc.	Reactor Accelerator	Solar KamLAND
$\theta_{23} \sim 45^{o}$	$\theta_{13} < 12^{o}$	$\theta_{12} \sim 30^{o}$

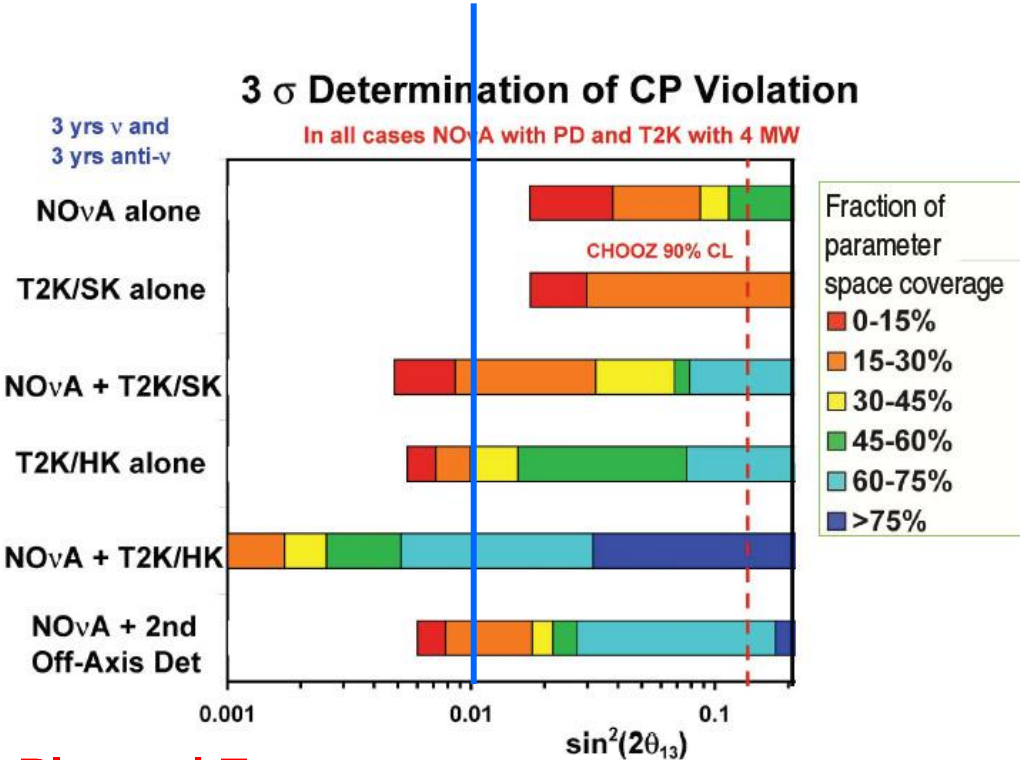


Known: $|\Delta m^2_{32}|$, $\sin^2 2\theta_{23}$, Δm^2_{21}, $\sin^2 2\theta_{12}$

Unkown: $\sin^2 2\theta_{13}$, δ_{CP}, Sign of Δm^2_{32}

Sterile Neutrino: Yes? No? Yes? Yes? ???

Measuring $\sin^2 2\theta_{13}$ to 0.01



Planned Exp.

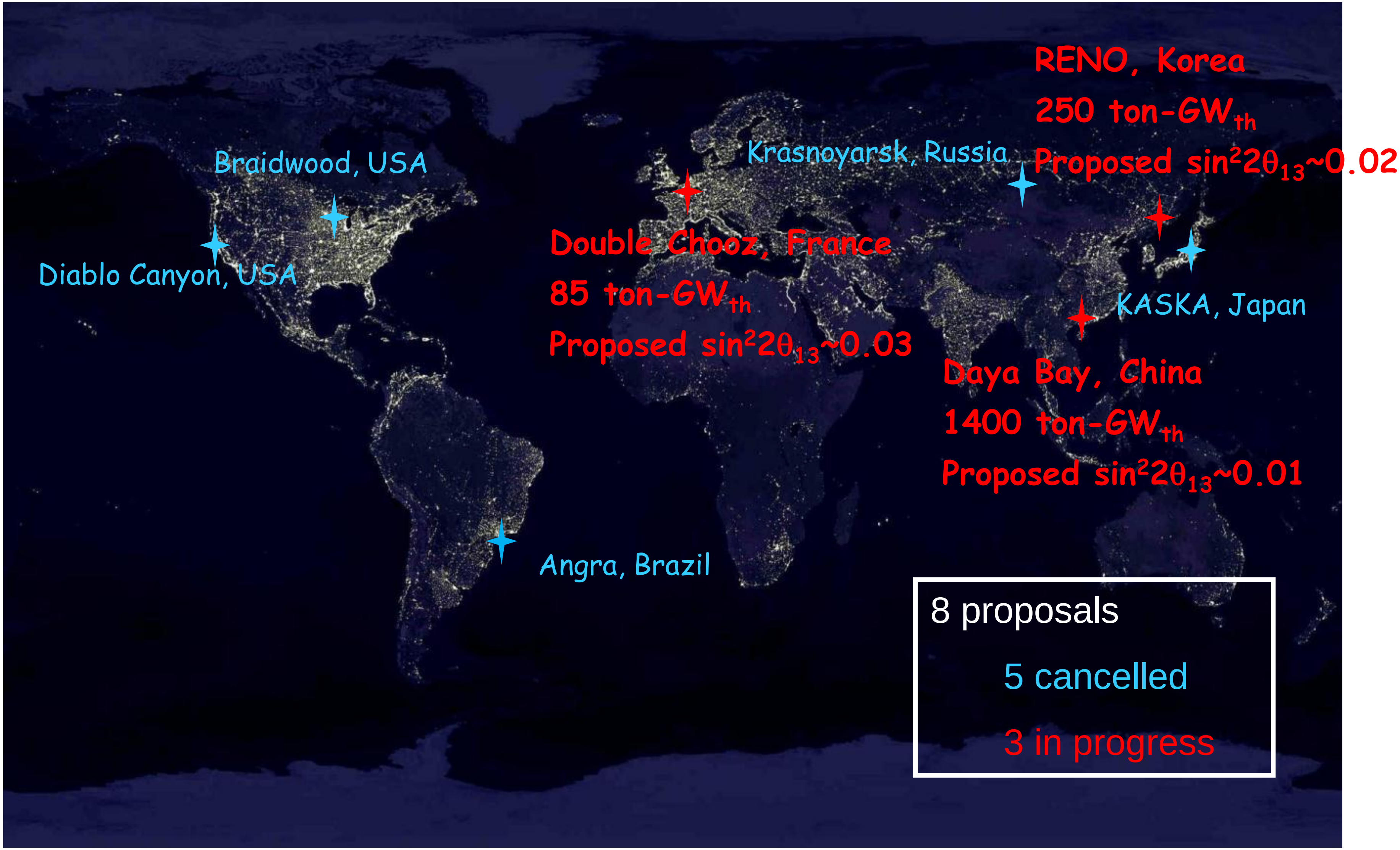
If $\sin^2 2\theta_{13}<0.01$, long baseline (LBL) experiments with conventional beam have little chance to determine the CP violation.

Measuring $\sin^2 2\theta_{13}$ to 0.01 will provide a roadmap for the future LBL experiments.

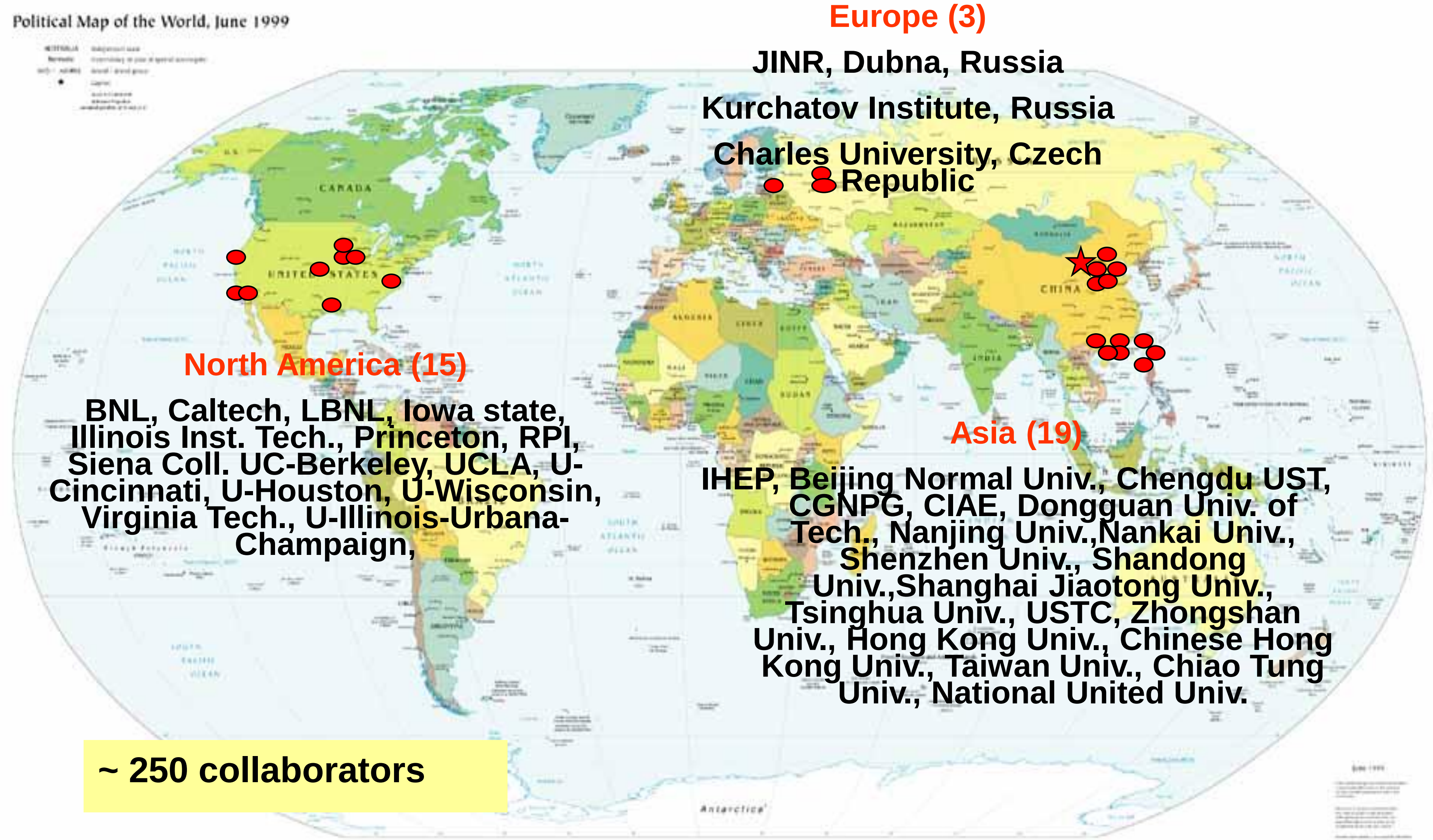
"We recommend, as a high priority, …, An expeditiously deployed multi-detector reactor experiment with sensitivity to $\bar{\nu}_e$ disappearance down to $\sin^2 2\theta_{13}=0.01$"

---- APS Neutrino Study, 2004

Proposals for measuring θ_{13} at reactors



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)

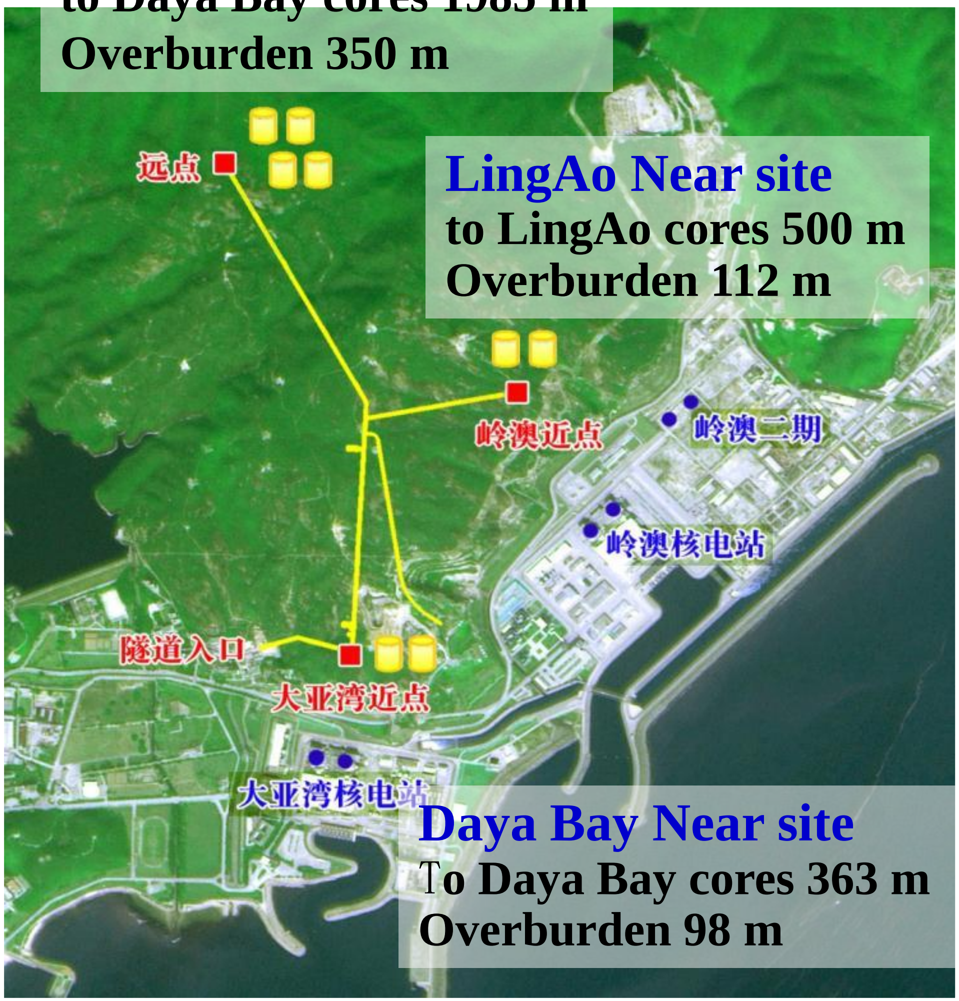
IHEP, Beijing Normal Univ., Chengdu UST, CGNPG, CIAE, Dongguan Univ. of Tech., Nanjing Univ.,Nankai Univ., Shenzhen Univ., Shandong Univ.,Shanghai Jiaotong Univ., Tsinghua Univ., USTC, Zhongshan Univ., Hong Kong Univ., Chinese Hong Kong Univ., Taiwan Univ., Chiao Tung Univ., National United Univ.

~ 250 collaborators

Daya Bay and Ling Ao Nuclear Power Plant

Layout

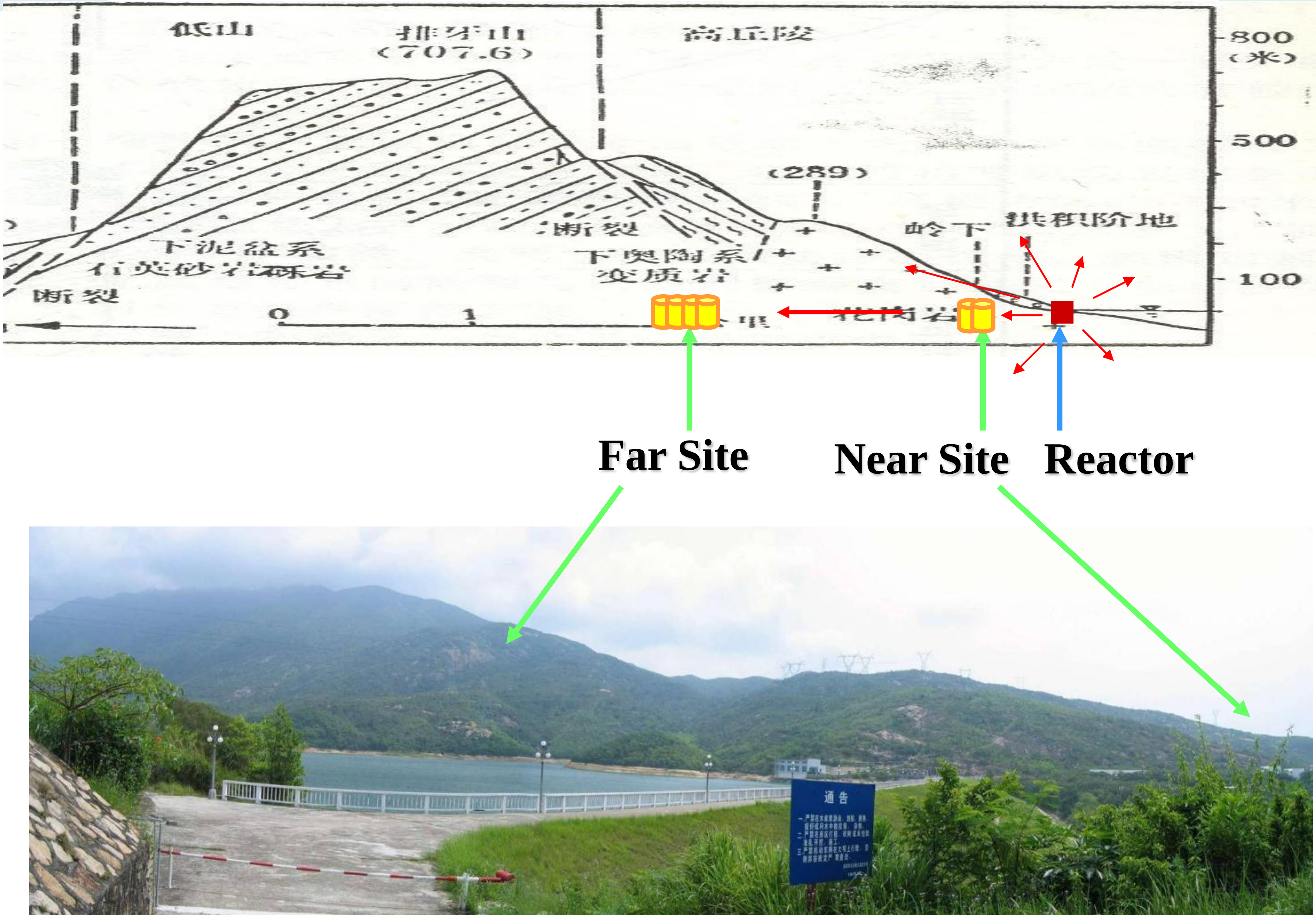
Far site
to LingAo cores 1615 m
to Daya Bay cores 1985 m
Overburden 350 m



LingAo Near site
to LingAo cores 500 m
Overburden 112 m

Daya Bay Near site
To Daya Bay cores 363 m
Overburden 98 m

- 3 experimental Hall connected with horizontal tunnel.
- 8 antineutrino Detectors (AD)
- Oscillation singal
  - neutrino rate deficit
  - energy spectrum distortion
- Near-far relative measurements
  - Cancel reactor errors (3%)
- Identical ADs
  - Cancel detector errors (2%)
- Enough Overburden
  - reduce cosmogenic backgrounds
- Larger, better detector



低山
排牙山
(707.6)
高丘陵
800
(米)
500
100
(289)
断裂
下泥盆系
石英砂岩砾岩
下奥陶系
变质岩
岭下
洪积阶地
花岗岩
断裂
0
1
公里
Far Site
Near Site
Reactor
通告

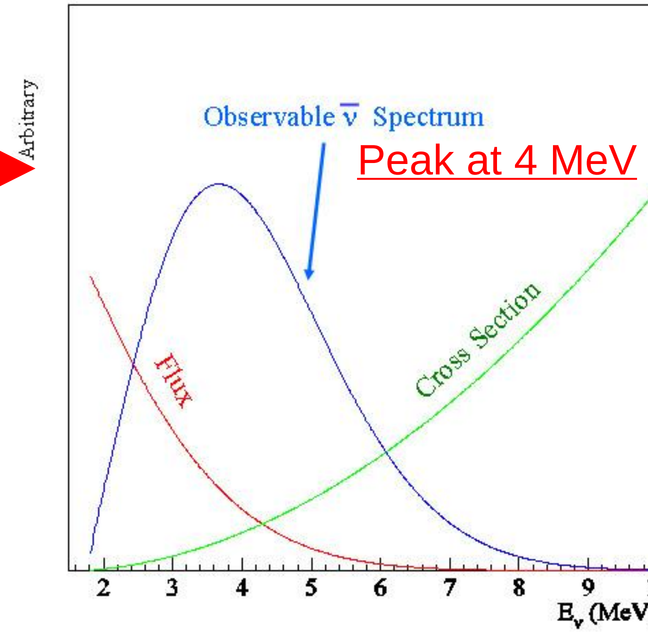
Signal and Backgrounds in detector

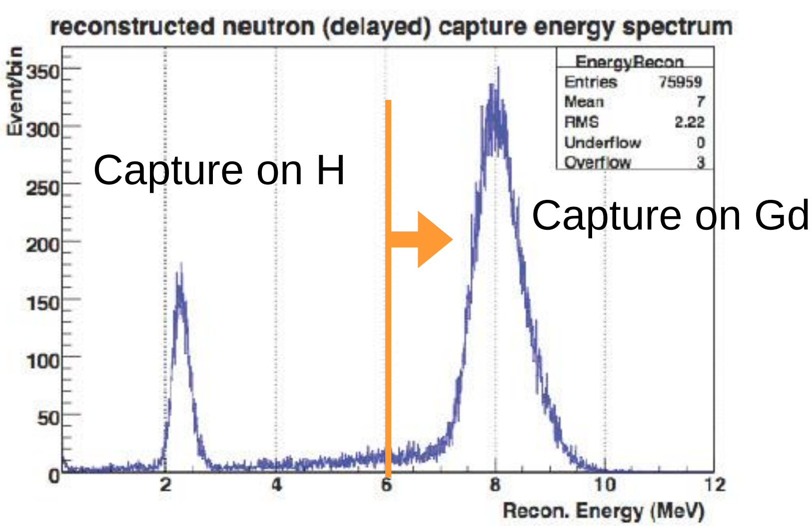
Prompt signal

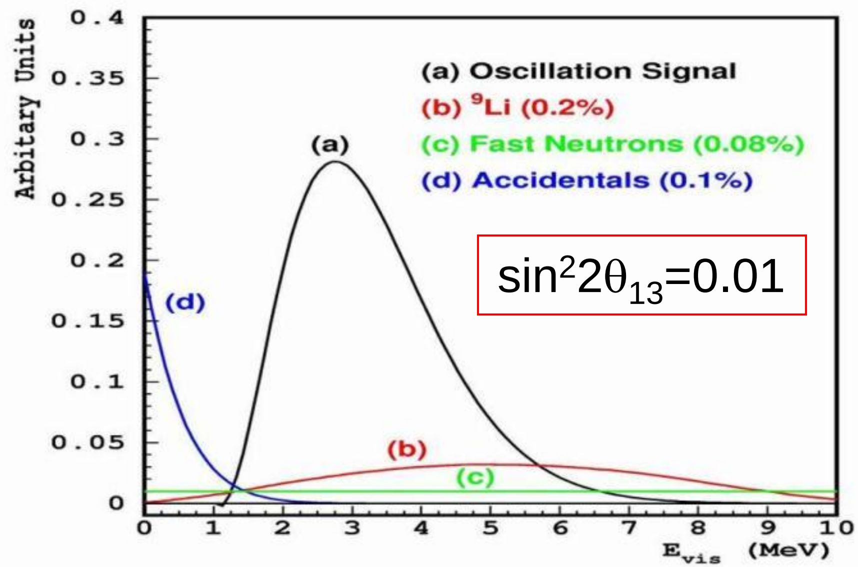
$$e^+ + e^- \rightarrow 2\gamma$$

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

Capture on H or Gd,
Delayed signal, 2.2, 8 MeV





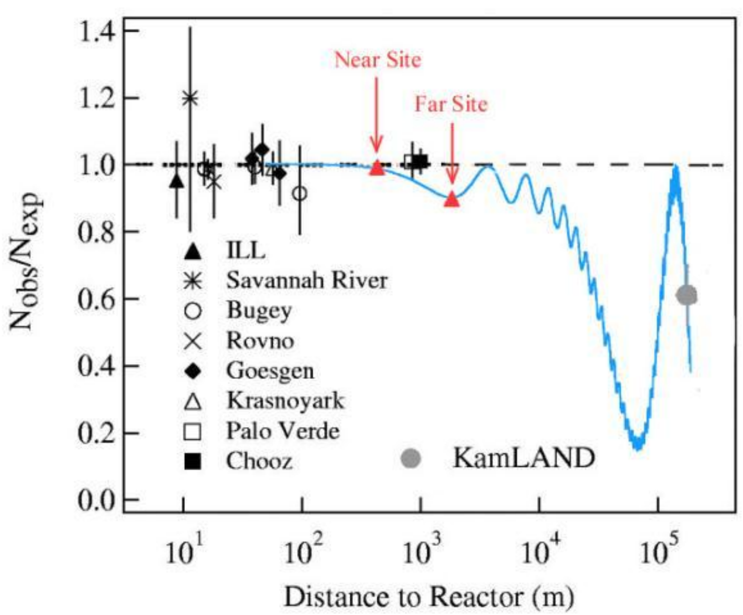


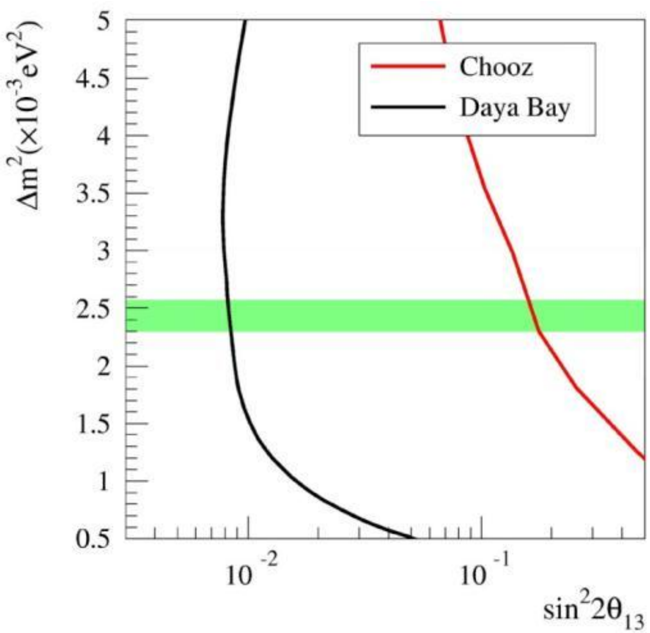
Past Results

- Chooz: R=1.01±2.8%(stat) ±2.7%(syst), $\sin^2 2\theta_{13} < 0.17$
- Chooz: bad Gd-LS
- Palo Verde: shallow site, large background

Improve the precision by an order

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





How to improve precision by an order?

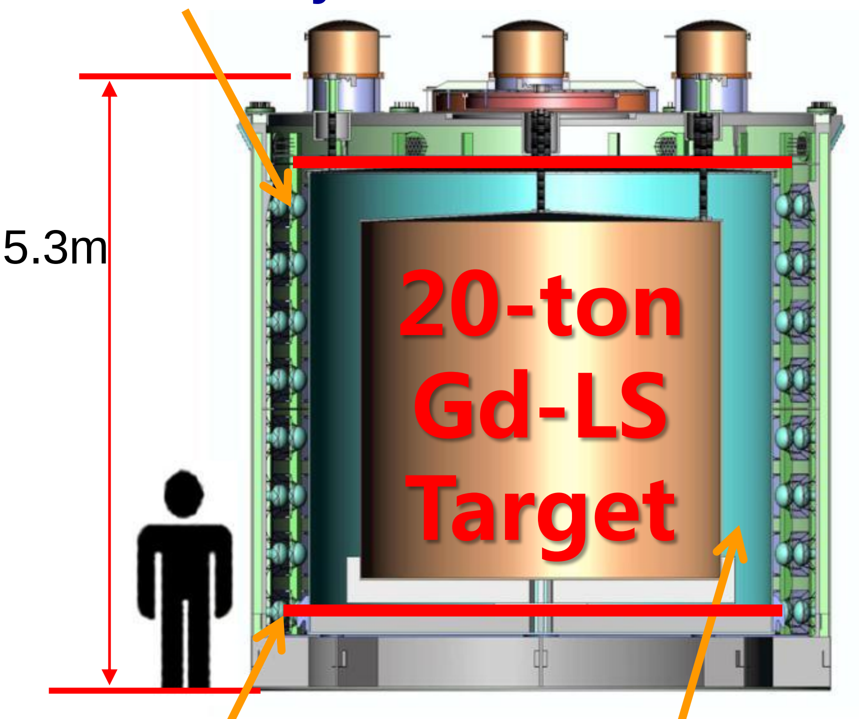
- Large statistics (Powerful reactors, Large detector)
  - Chooz: 14 t.GW.y, statistical error 3%
  - Double Chooz: 214, RENO: 830, Daya Bay: 4176
  - Statistical error in 3 years: 0.2%
- Reduce backgrounds (Overburden, Low-background detectors)
  - Chooz, Double Chooz: 300 mwe，大亚湾：940 mwe
- Reduce Systematic error
  - Identical detectors, Near-far relative measurements

Uncertainties	Reactor	Detector	Backgrounds
Chooz	3%	1.7%	?
Daya Bay	0.1%	0.4%	<0.3%

Detectors

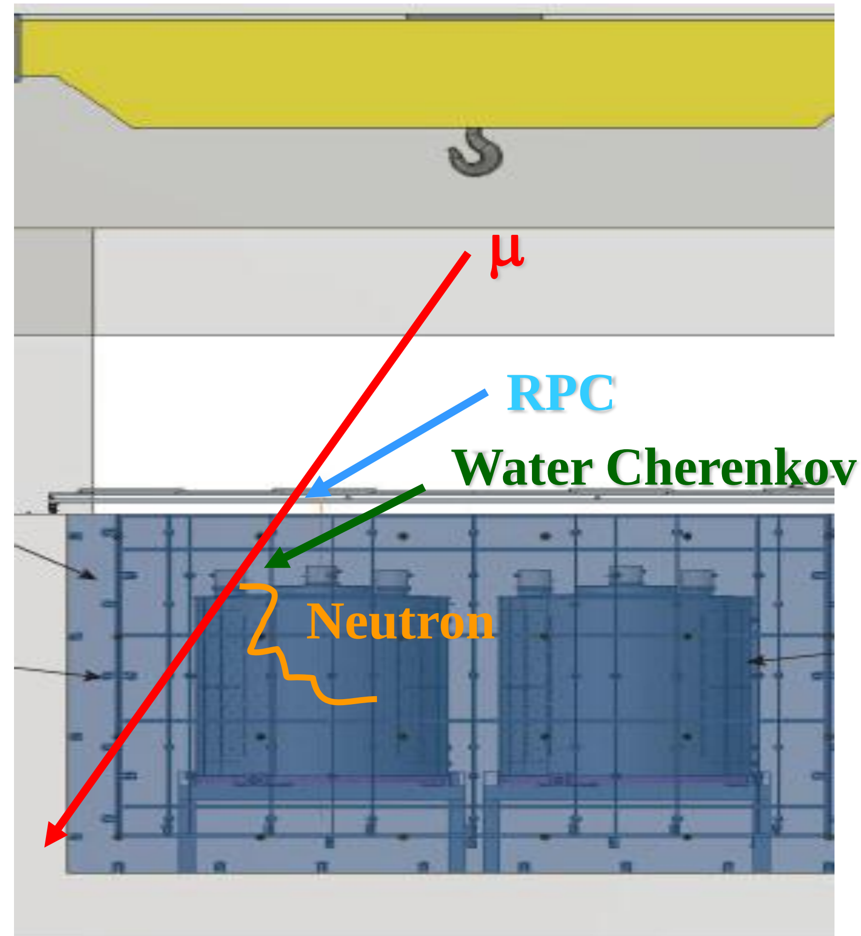
3 layers separated by Acrylic Vessels

Mineral Oil: 50cm thick, shielding radioactivity from PMT and Steel



192 PMTs

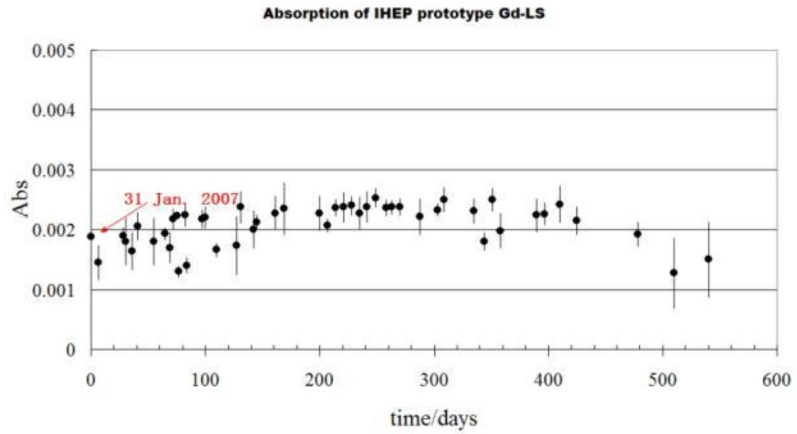
LS: 45cm thick, improve neutron energy measurement.

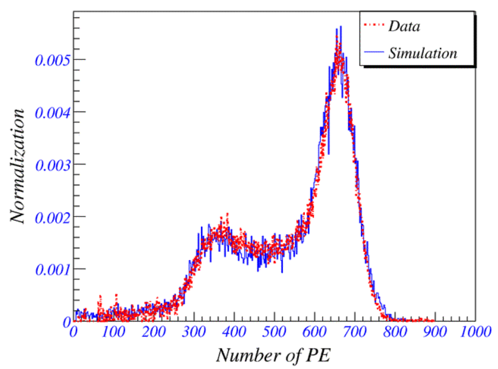


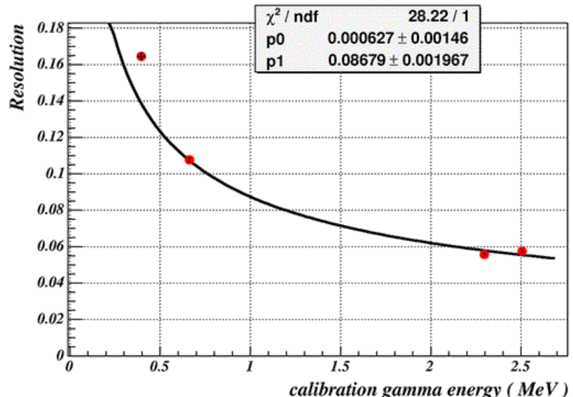
- **Water shields radioactivity and neutron**
- **Two layer water Cherenkov detector**
- **RPC**
- **Combined eff. 99.5%+-0.25%**

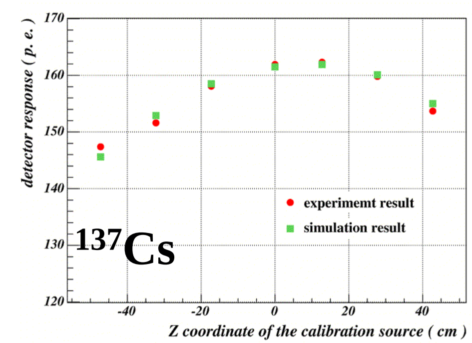
Prototype studies

- **Motivation**
  - Validate the design principle
  - Test technical details of tanks
  - Test Gd-LS
  - Test calibration and Pu-C source
- **Achievements**
  - Energy response & MC Comparison
  - Reconstruction algorithm
  - Neutron response & Pu-C source
  - Effects of reflectors
  - Gd-LS

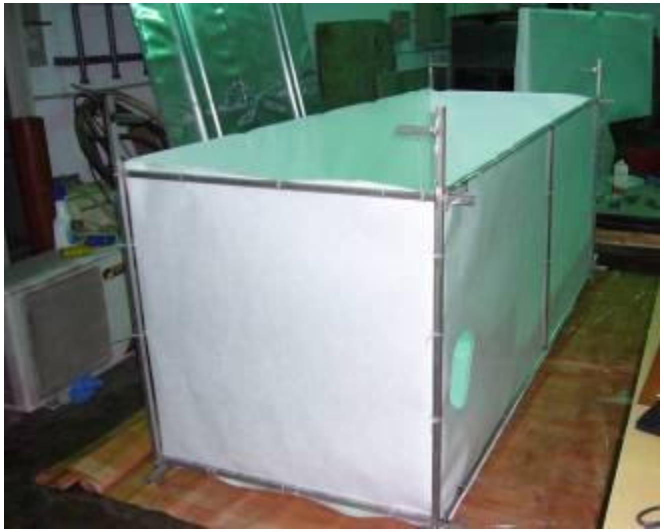


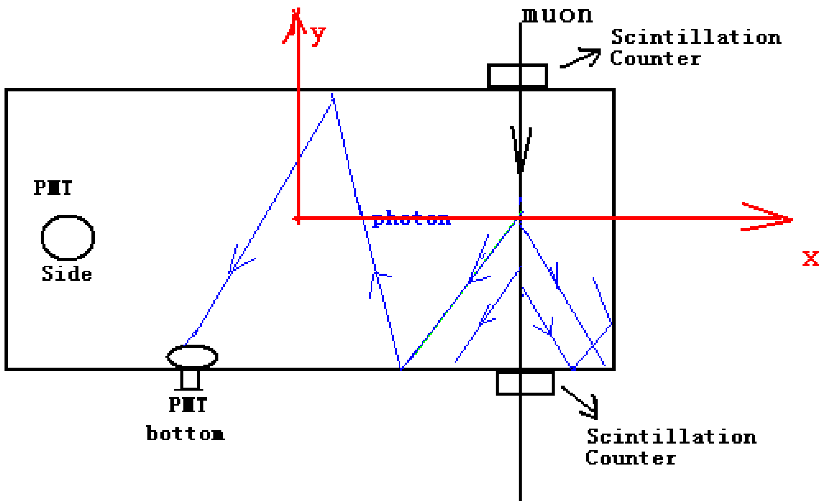


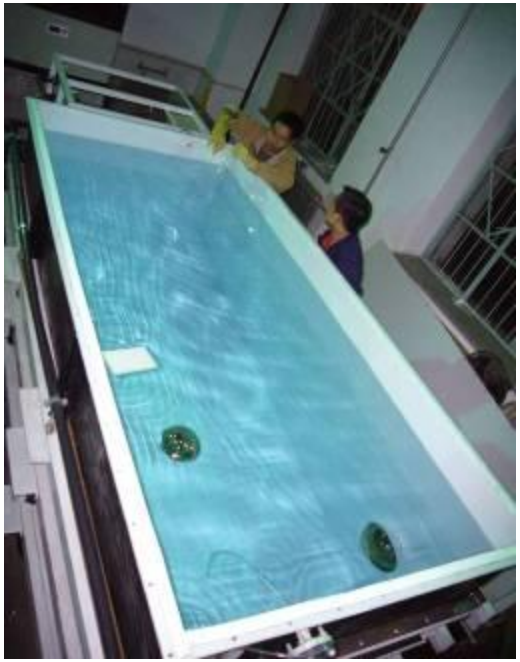




Water detector: R&D with a prototype







- Compatibility tests of materials in water
- Established a water circulation model ➔ purification system design
- MC modeling for light transport & light collection

Backgrounds

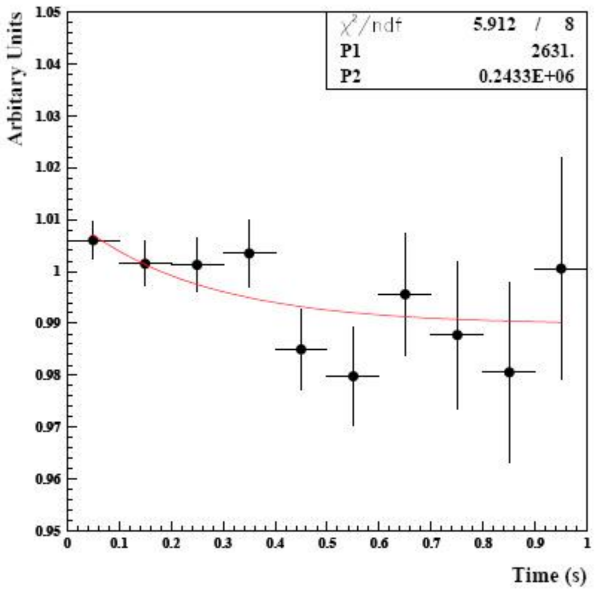
- $^{9}Li/^{8}He$ (correlated background, B/S estimated to 0.3%)
  - ⇨ Cosmogenic long-lived isotopes, β-n cascade, mimic neutrino signal
- "Fast Neutron" background (correlated background, B/S estimated to 0.1-0.2%)
  - ⇨ Cosmic μ produce high energy neutrons. Neutron recoil signal mimic the prompt signal. Thermalized neutron form the delayed signal.
  - ⇨ Neutron capture on C, O, etc, emit high energy neutron.
- Occidental coincidence background (B/S estimated 1%, error 0.1%)
  - ⇨ Prompt signal (single rate <50 Hz)
    - ✓ Radioactivity (PMT, rock, steel tank, LS, etc)
    - ✓ Cosmogenic isotopes
  - ⇨ Delayed signal (<200/day)
    - ✓ single neutron: Cosmic μ produces neutrons, without recoil signal.
    - ✓ cosmogenic long-lived isotopes (e.g. $^{12}B/^{12}N$)
    - ✓ Other events in 6-10 MeV (e.g. Michel's electron, corner-cutting muons)

Measuring He8/Li9 in-situ

Time since last muon

$$\sigma_{est} = \frac{1}{\sqrt{N}} \sqrt{(1+\tau R_\mu)^2 - 1}$$

L.J. Wen et. al. NIM A 564 (2006) 471



3 years' data →

0.36% error at DYB site

0.27% at LA near site

0.10% at the far site

The unknown is ^{9}Li cross section. Combine DYB and LA site

Measure to 0.2%, irrelevant to B/S ratio

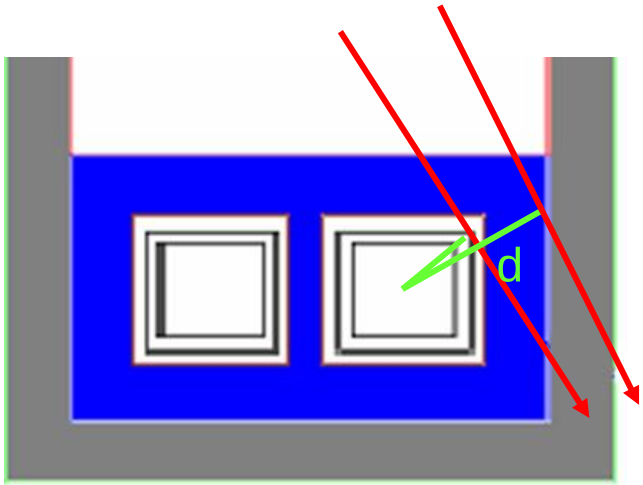
Measuring fast neutron in-situ

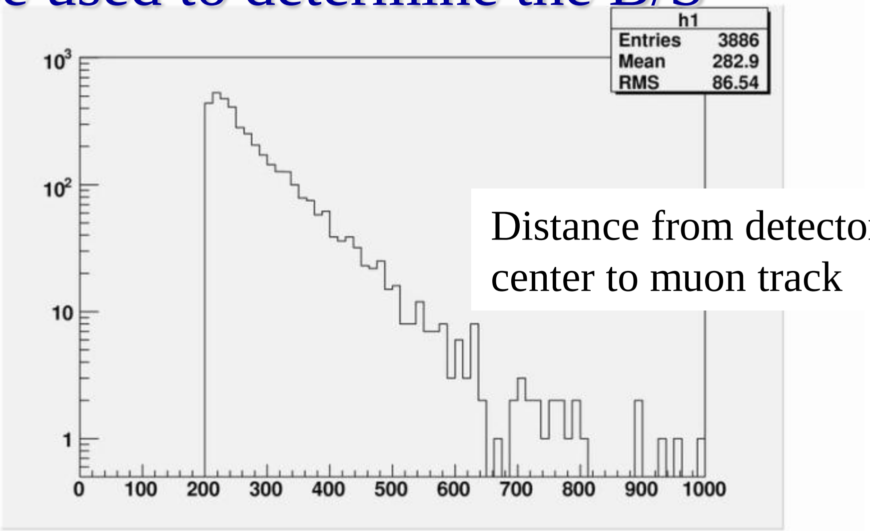
The most uncertain backgrounds. Simulation B/S ~ 0.1%.

Depends on veto eff.

	DYB	LA	Far
Fast neutron (/day/module)	0.6	0.4	0.04
Fast neutron/Signal	**~0.1%**	**~0.1%**	**~0.1%**

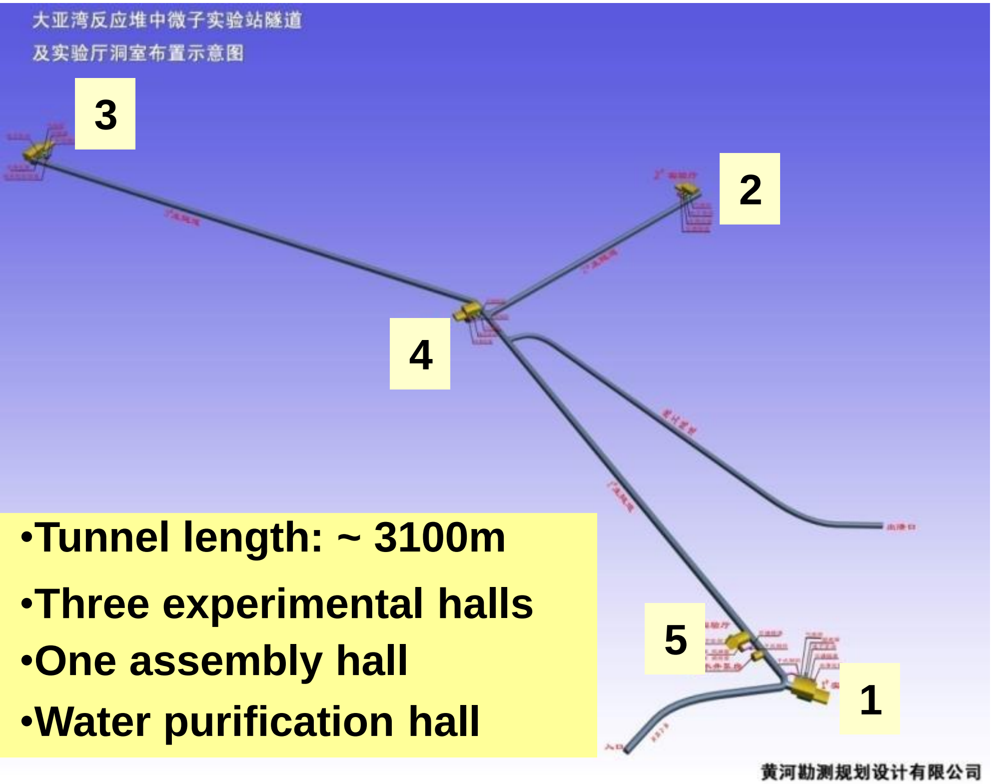
Tagged fast neutrons (by detecting the parent muons) will be 50 times of untagged ones. Can be used to determine the B/S





Could be measured in-site to ~0.1%

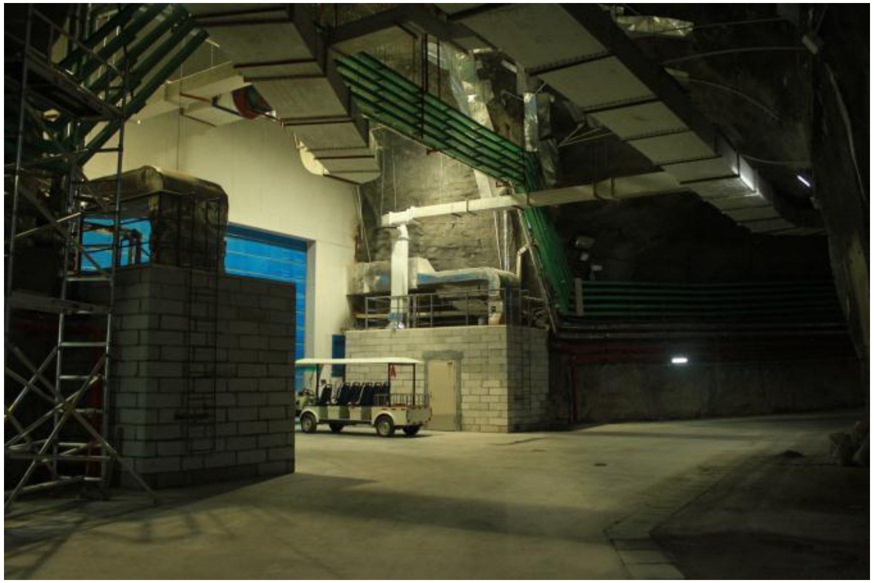
Civil construction

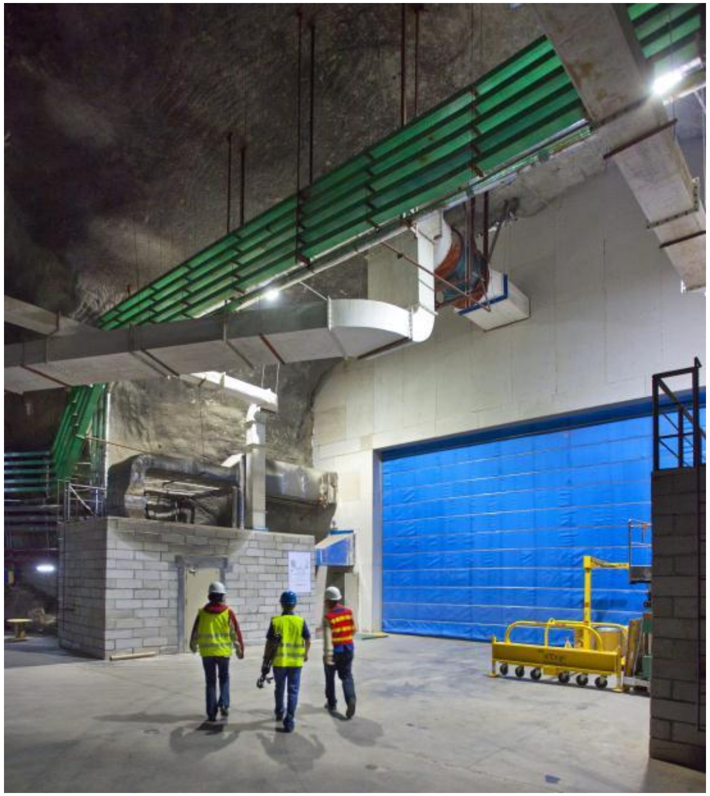


- Tunnel length: ~ 3100m
- Three experimental halls
- One assembly hall
- Water purification hall

- All blasting safely completed, no one exceeded vibration limit (0.007g)
- Hall 1, 4, 5 completed last year
- Hall 2 completed last month
- Hall 3 to be completed this summer

Civil construction

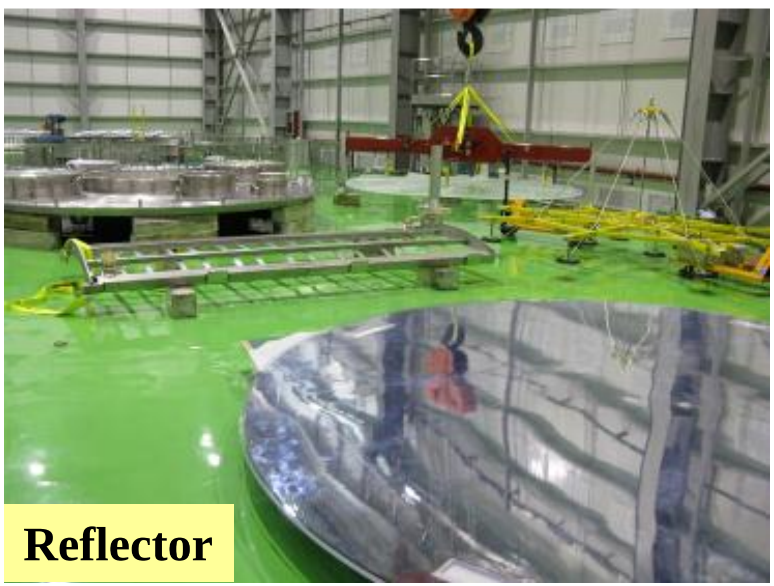




Detector Component Production


Stainless steel vessel

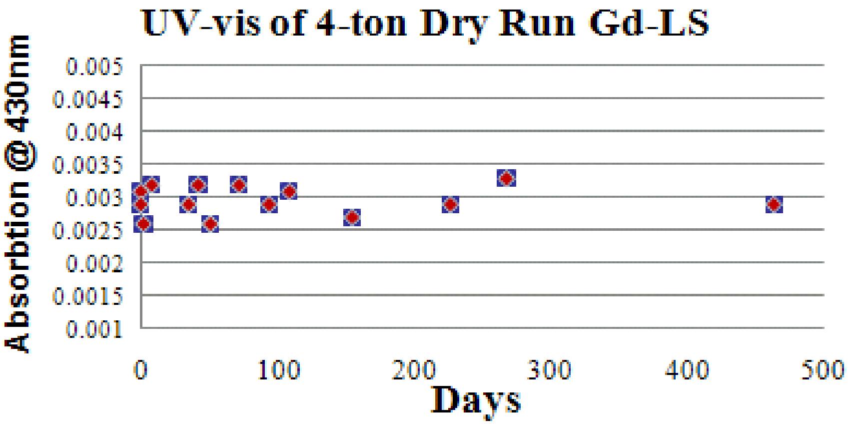

4m Acrylic vessel


Reflector


3m acrylic vessel

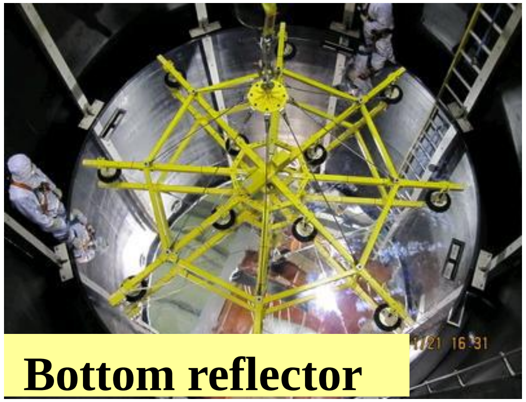
Liquid Scintillator Production

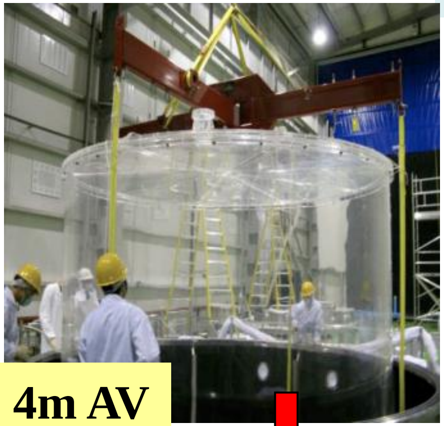
- What we need:
  - 185t Gd-LS, ~180t LS, ~320t oil
- Equipment designed, manufactured and tested at IHEP
- 4-ton Gd-LS test run successful: good quality up to now and aging test showing good stability
- Gd-LS production completed and stored in Hall 5
- LS production almost finished
- AD Filling will start next month

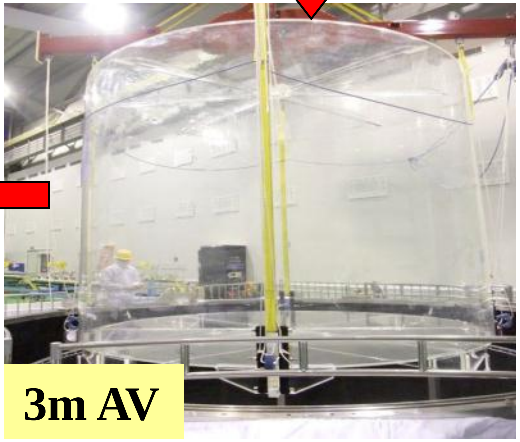


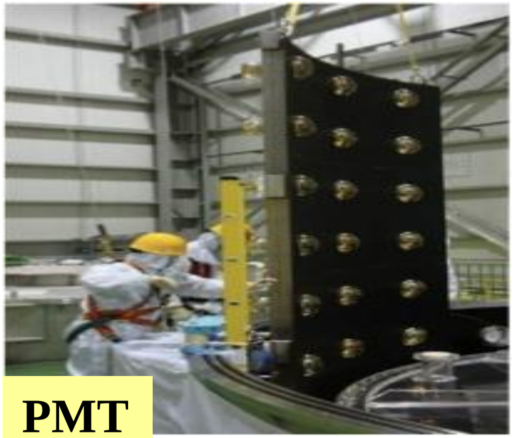
AD assembly

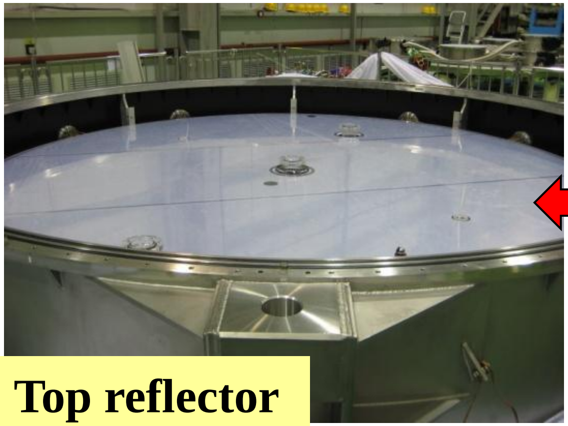

SSV


Bottom reflector

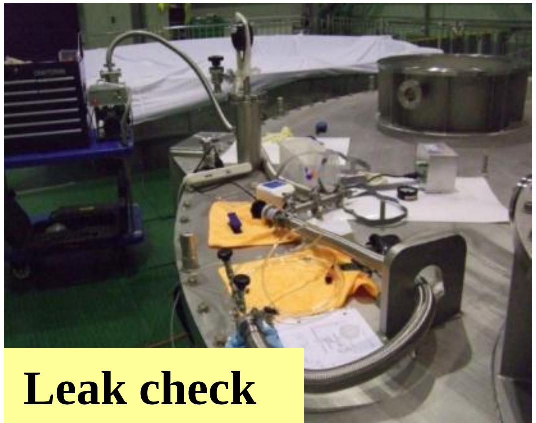

4m AV


3m AV


PMT


Top reflector


SSV lid

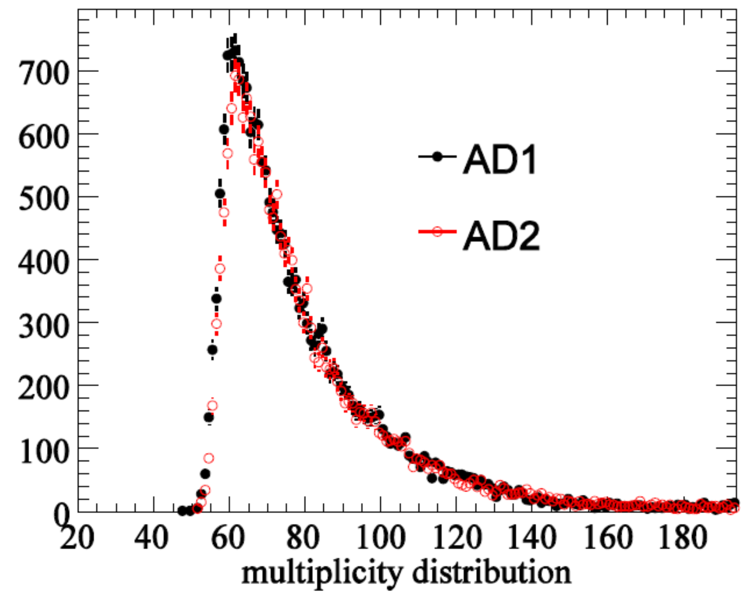

Leak check

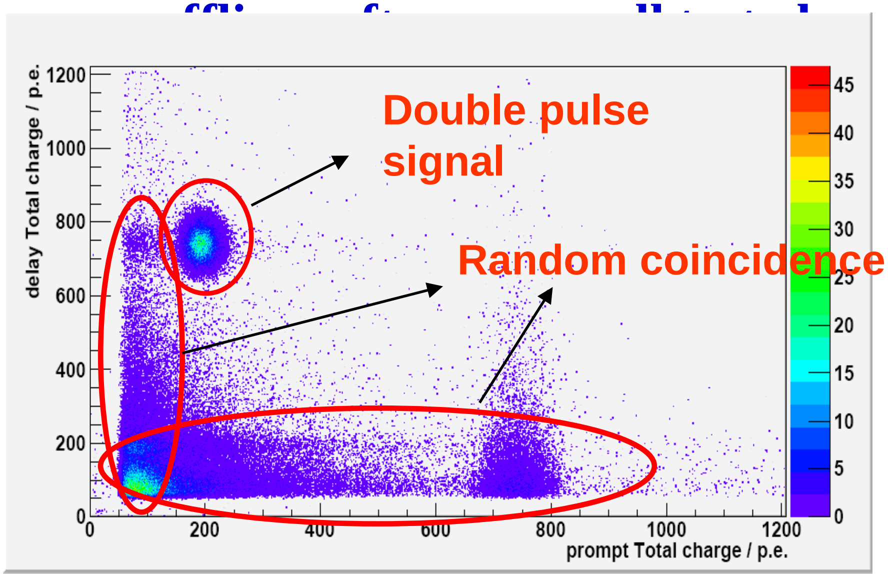

ACU

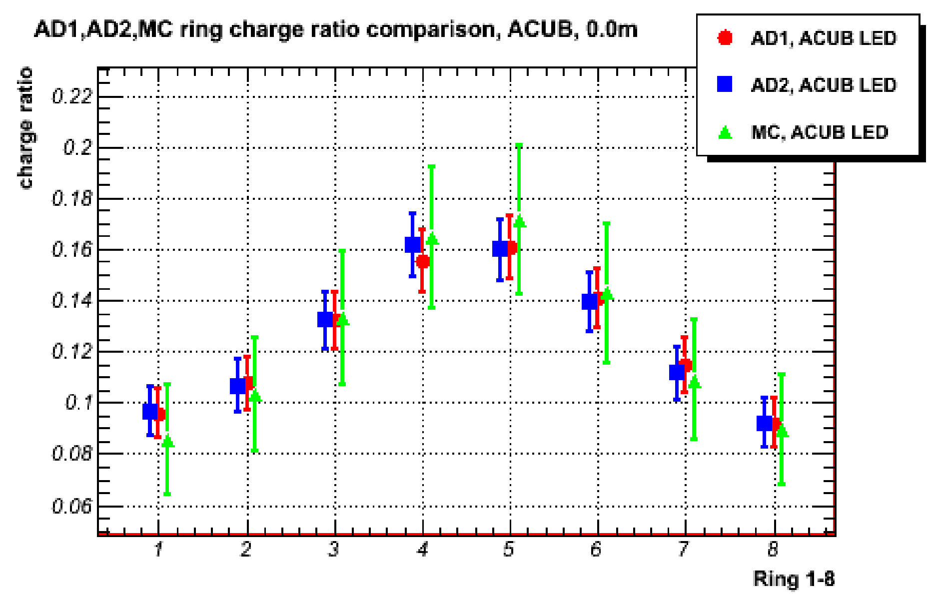
Two completed ADs

AD Dry-run

- Complete test of assembled ADs with final electronics, trigger and DAQ
- Results show that:
  - ⇨ Both ADs are fully functional
  - ⇨ Their response to LED & cosmic-rays agrees with MC expectations
  - ⇨ Two ADs are identical
  - ⇨ Electronics, trigger, DAQ and

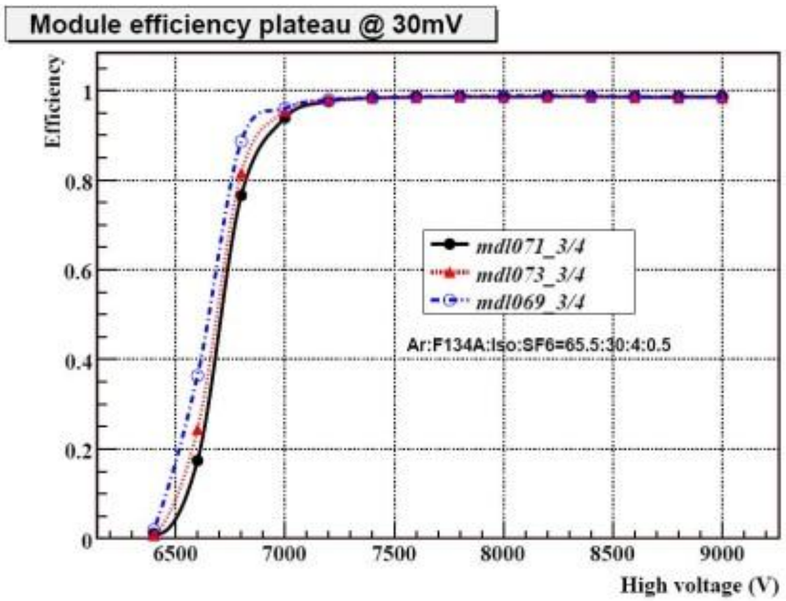






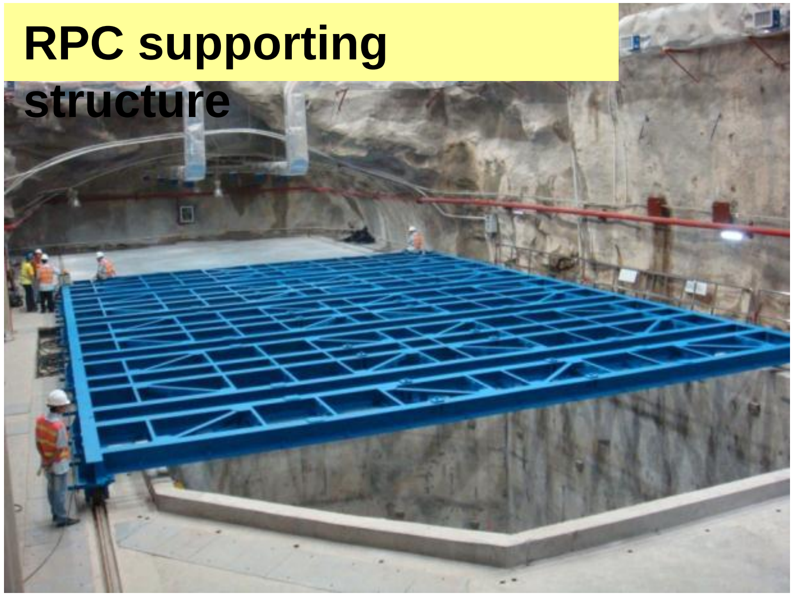
RPC production & assembly

- Each module consists of 4 layers of bare chambers made of bakelite without linseed oil(BESIII-type)
- RPC bare chamber testing shows good performance
- Module assembly almost finished
- 2/3 modules shipped to Daya Bay



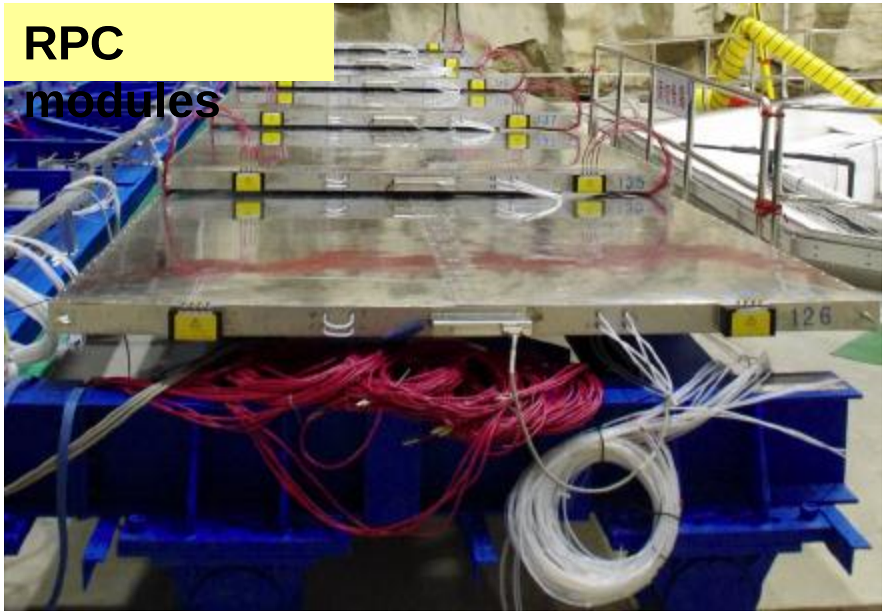
RPC installation

RPC supporting structure

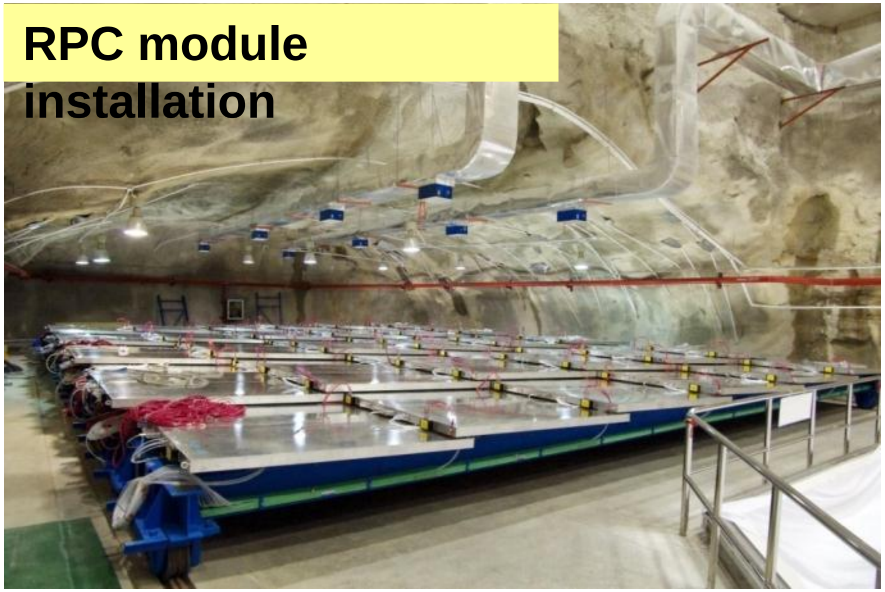


Gas system

RPC modules



RPC module installation

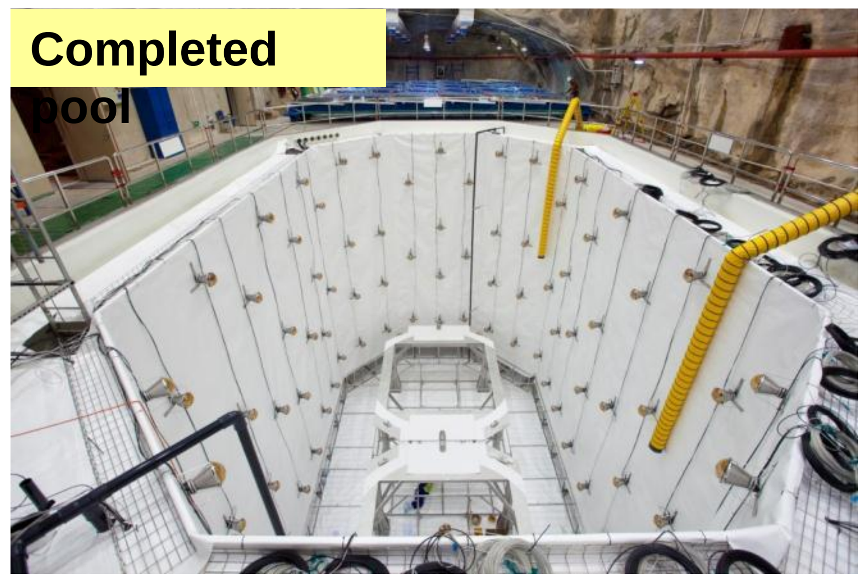


Water Cerenkov detector installation

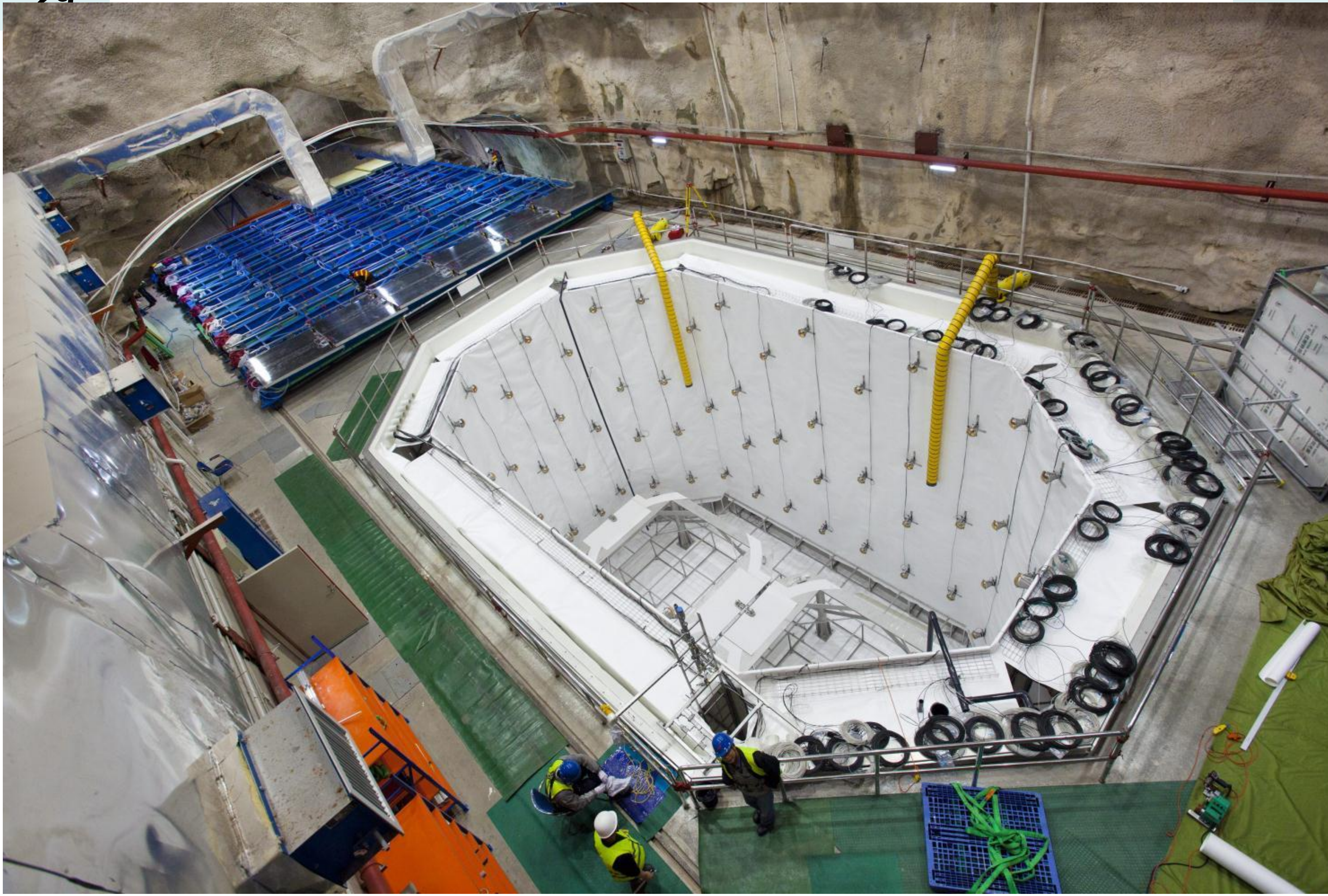
PermeFlax Painting

PMT supporting structure

Tyvek barrier



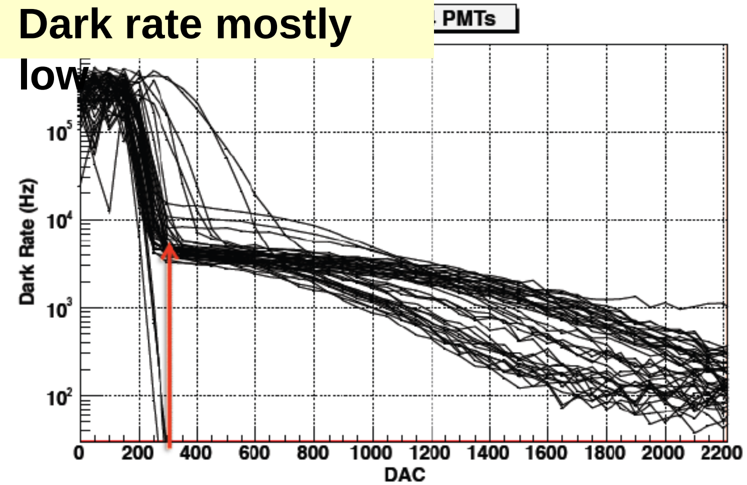
Completed pool



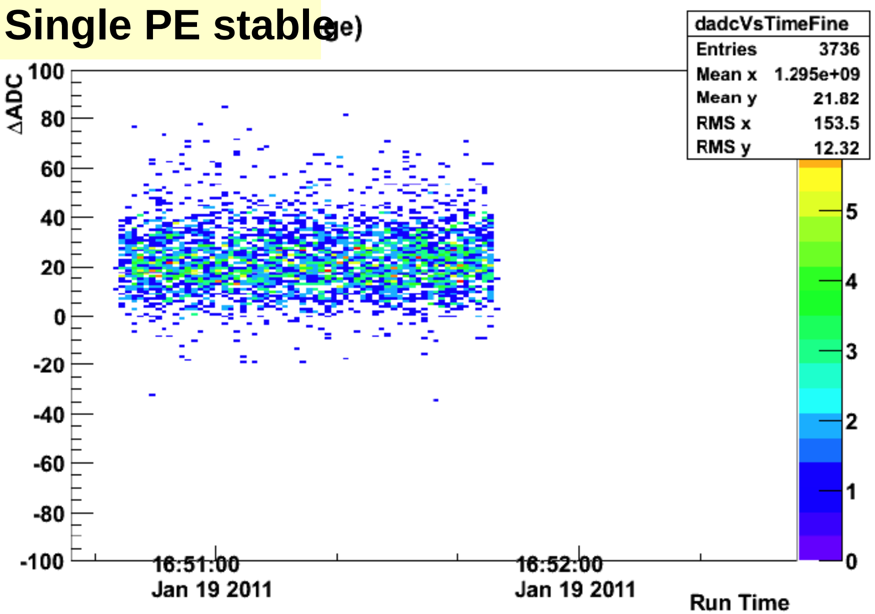
Muon Dry-run

- Test of all installed PMTs
  - All PMTs and LEDs functional
  - PMT performance within expectations
  - No grounding problems

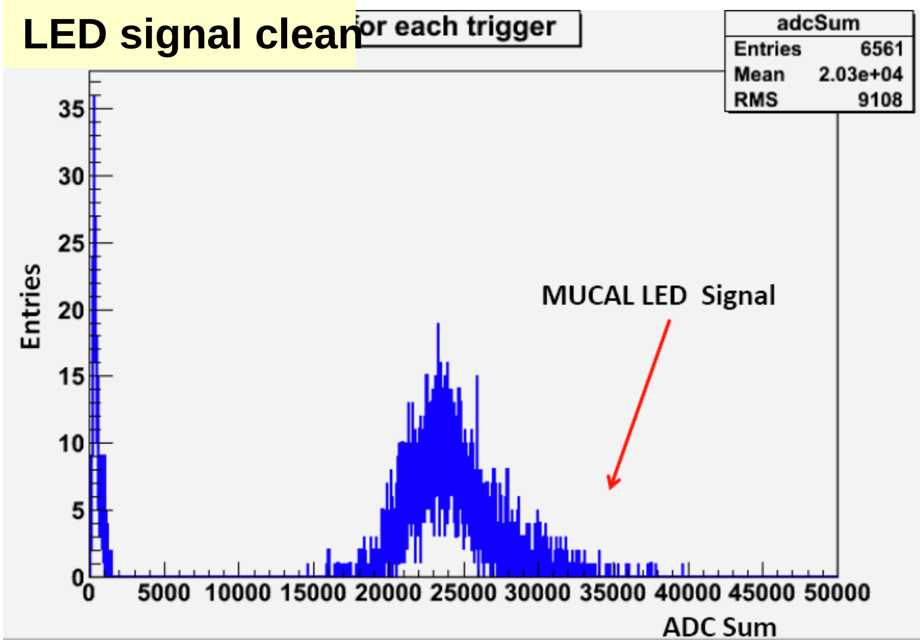
Dark rate mostly low



Single PE stable

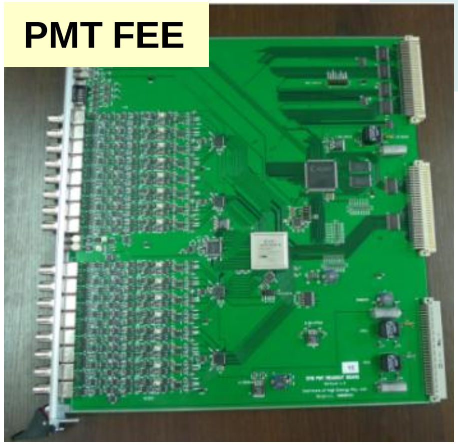


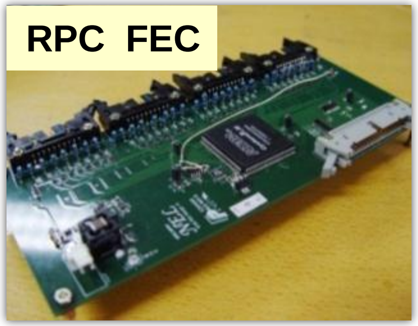
LED signal clean

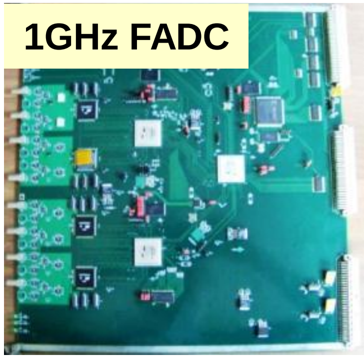


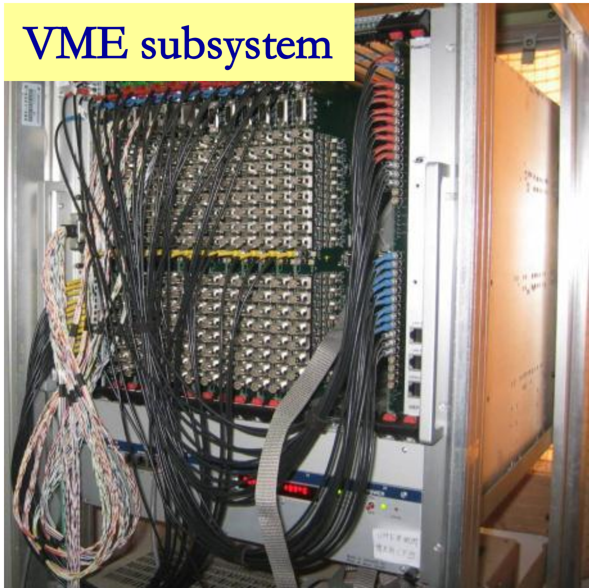
Electronics, Trigger, and DAQ

- PMT readout electronics(IHEP)
  - ⇨ Fully tested during dry run
  - ⇨ Ready for Hall 1 AD & muon-veto
- RPC readout electronics(USTC)
  - ⇨ All components ready for Hall 1
  - ⇨ Testing with trigger & DAQ underway
- Trigger(Tsinghua)
  - ⇨ Fully tested with FEE
- DAQ software(IHEP+many)
  - ⇨ Successful integration test with FEEs, trigger and DAQ
  - ⇨ Successful Online/offline integration test
  - ⇨ Ready for hall 1 data taking

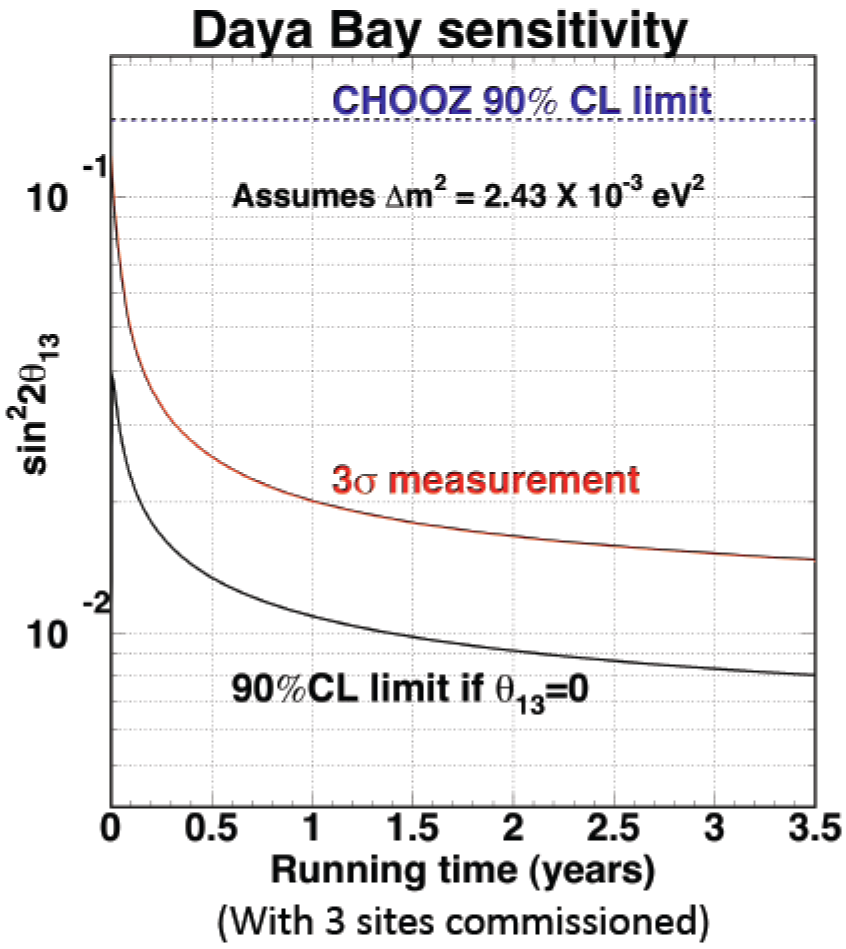








Schedule



- **2011 Autumn**
  - **Daya Bay near site only**
- **2012 Autumn**
  - **Full operation**

Full Operation

Thanks!