Latest Results from Daya Bay and its Future Prospects

Yifang Wang

Institute of High Energy Physics

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Daya Bay reactor neutrino experiment

- Next to the second largest reactor complex: 6 reactor cores operational, 17.4 GW_{th} in total
- Mountains near by, easy to construct a lab with enough overburden to shield cosmic-ray backgrounds

Direct Searches before Daya Bay

- **Palo Verde & Chooz: no signal**

$Sin^2 2\theta_{13} < 0.15$ @ 90%C.L. if $\Delta M^2_{23} = 0.0024\ eV^2$

- **T2K: 2.5 σ over bkg**

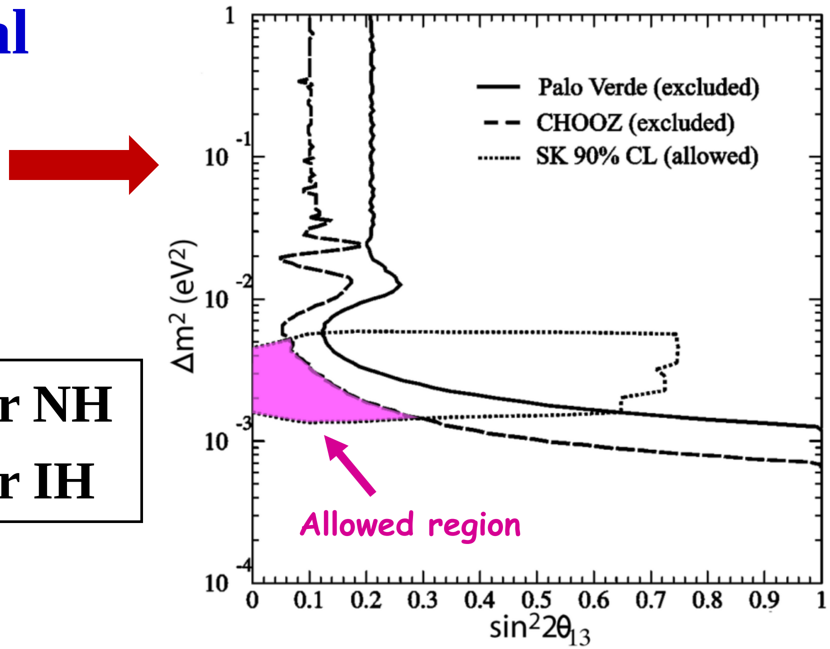
$0.03 < Sin^2 2\theta_{13} < 0.28$ @ 90%C.L. for NH
$0.04 < Sin^2 2\theta_{13} < 0.34$ @ 90%C.L. for IH

- **Minos: 1.7 σ over bkg**

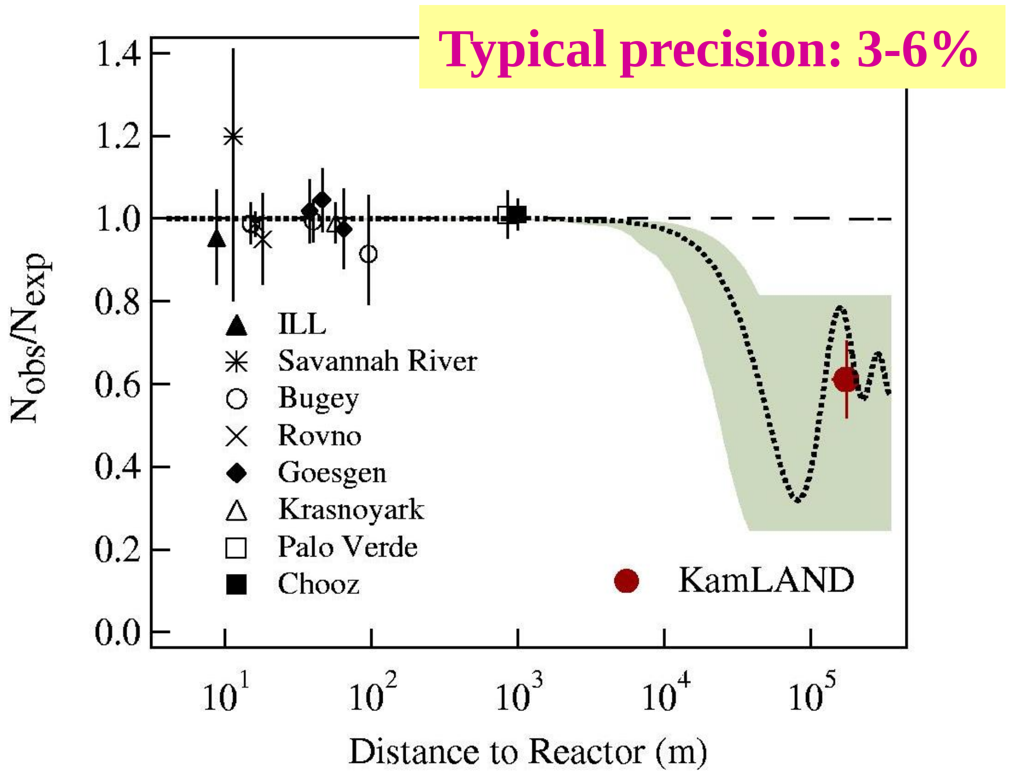
$0 < Sin^2 2\theta_{13} < 0.12$ @ 90%C.L. NH
$0 < Sin^2 2\theta_{13} < 0.19$ @ 90%C.L. IH

- **Double Chooz: 1.7 σ**

$\sin^2 2\theta_{13} = 0.086 \pm 0.041(stat) \pm 0.030(sys)$



Reactor Experiment: comparing observed/expected neutrinos

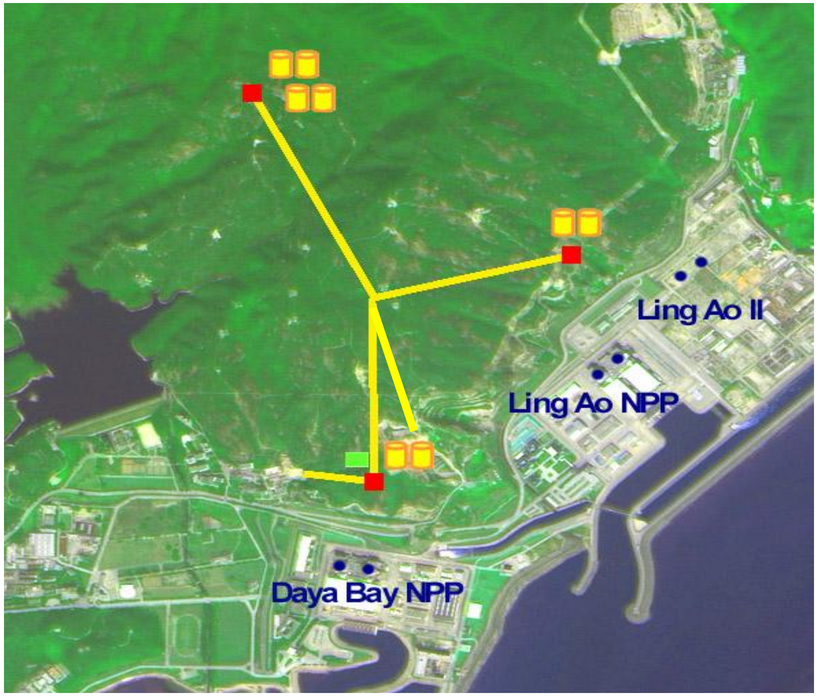


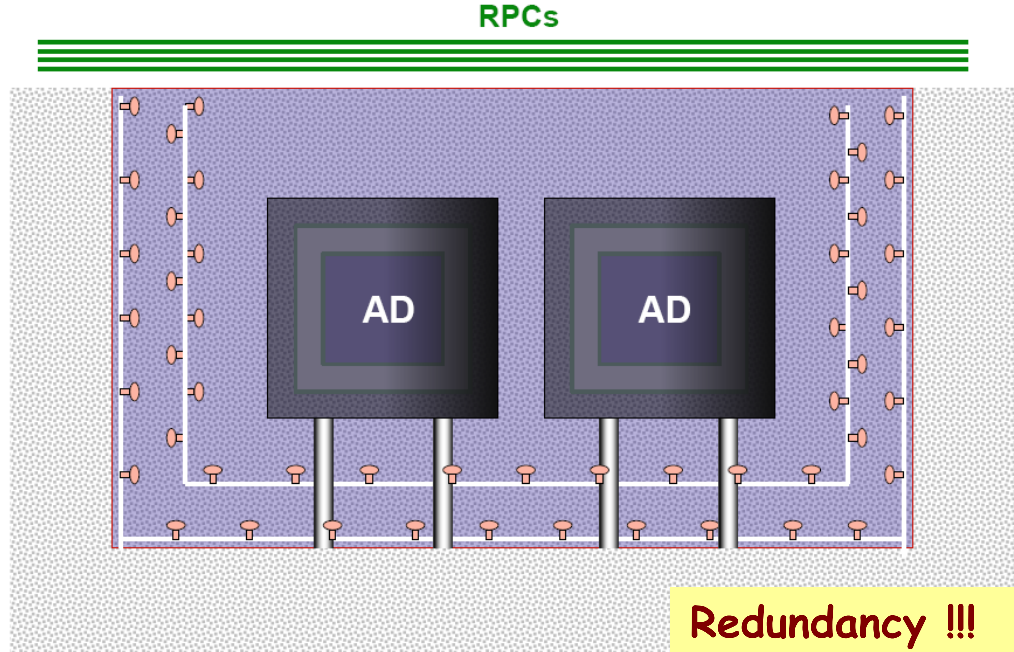
Precision of past exp.

- **Reactor power: ~ 1%**
- **Spectrum: ~ 0.3%**
- **Fission rate: 2%**
- **Backgrounds: ~1-3%**
- **Target mass: ~1-2%**
- **Efficiency: ~ 2-3%**

Our design goal: a precision of ~ 0.4%

Daya Bay Experiment: Layout



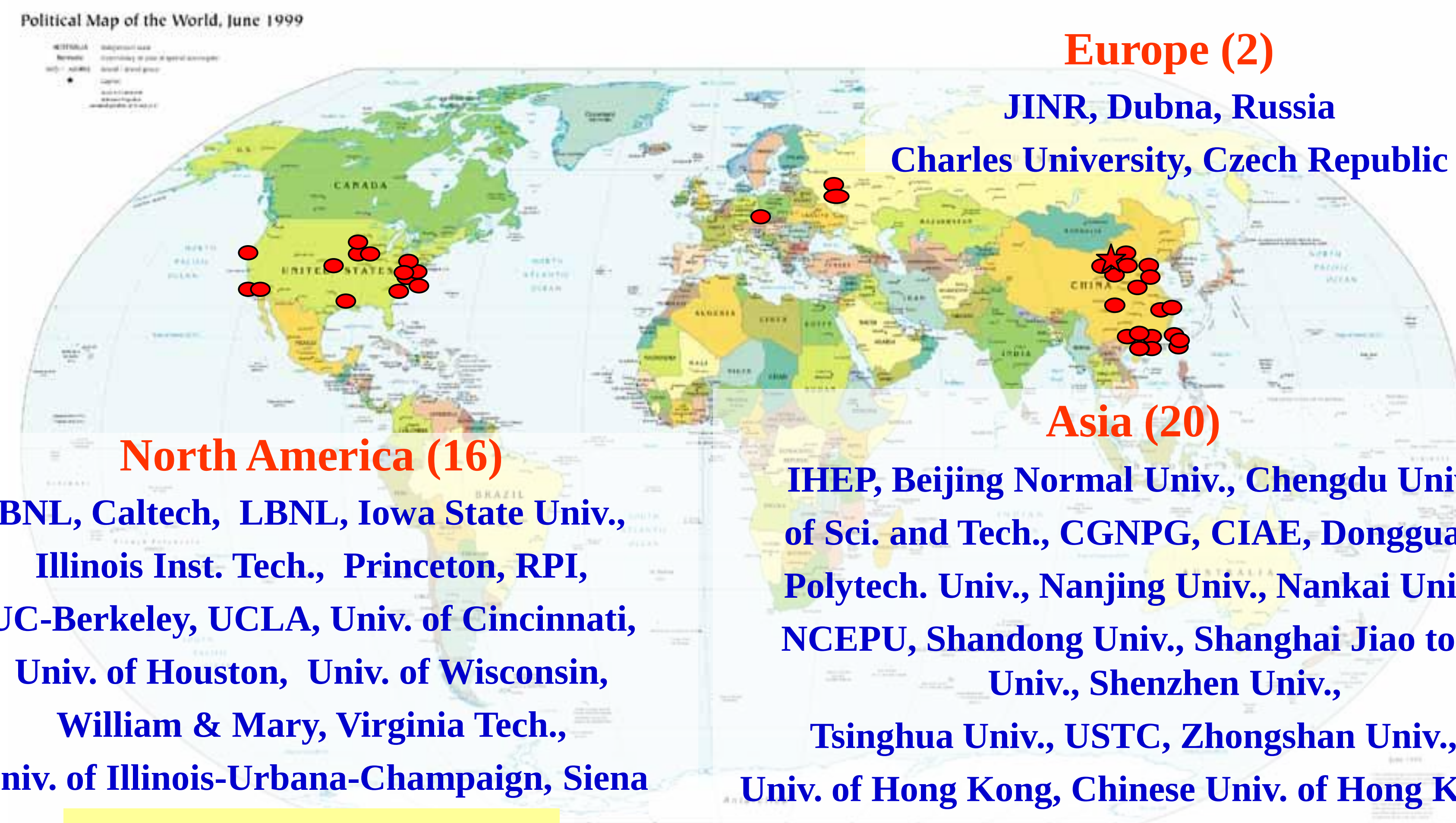


- Relative measurement to cancel Corr. Syst. Err.
  - ⇨ 2 near sites, 1 far site
- Multiple AD modules at each site to reduce Uncorr. Syst. Err.
  - ⇨ Far: 4 modules, near: 2 modules

Cross check; Reduce errors by 1/√N

- Multiple muon detectors to reduce veto eff. uncertainties
  - ⇨ Water Cherenkov: 2 layers
  - ⇨ RPC: 4 layers at the top + telescopes

The Daya Bay Collaboration



Europe (2)

JINR, Dubna, Russia

Charles University, Czech Republic

Asia (20)

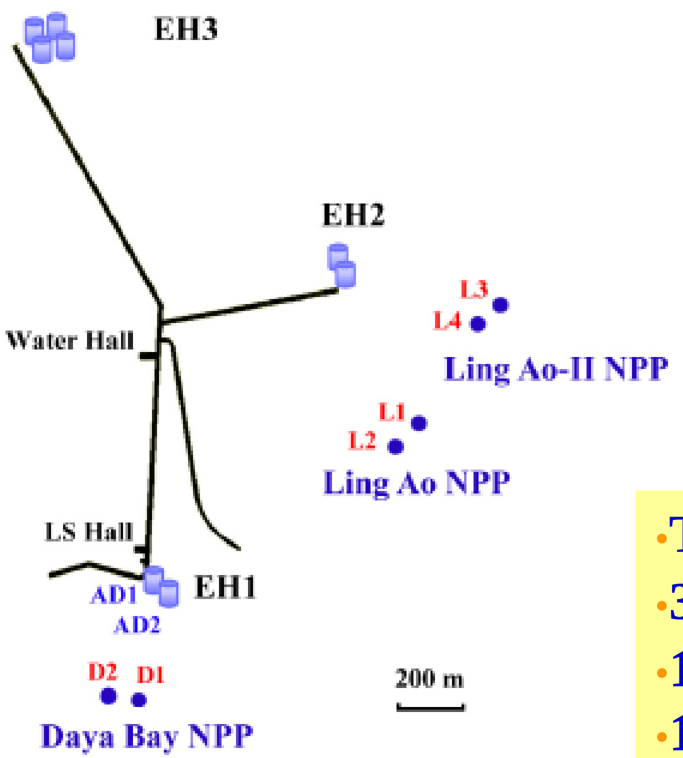
IHEP, Beijing Normal Univ., Chengdu Univ. of Sci. and Tech., CGNPG, CIAE, Dongguan Polytech. Univ., Nanjing Univ., Nankai Univ., NCEPU, Shandong Univ., Shanghai Jiao tong Univ., Shenzhen Univ., Tsinghua Univ., USTC, Zhongshan Univ., Univ. of Hong Kong, Chinese Univ. of Hong Kong, National Taiwan Univ., National Chiao Tung Univ., National United Univ.

North America (16)

BNL, Caltech, LBNL, Iowa State Univ., Illinois Inst. Tech., Princeton, RPI, UC-Berkeley, UCLA, Univ. of Cincinnati, Univ. of Houston, Univ. of Wisconsin, William & Mary, Virginia Tech., Univ. of Illinois-Urbana-Champaign, Siena

~250 Collaborators

Underground Labs



- Tunnel: ~ 3100m
- 3 Exp. hall
- 1 hall for LS
- 1 hall for water

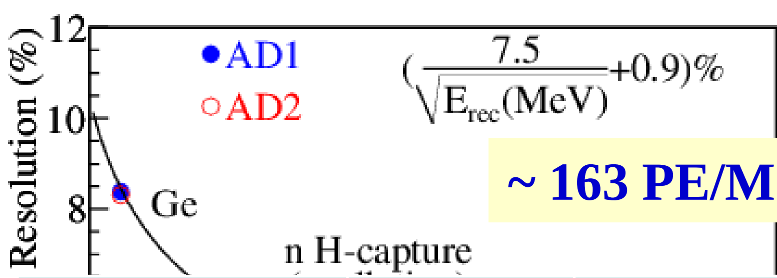
	Overburden (MWE)	R_μ (Hz/m^2)	E_μ (GeV)	D1,2 (m)	L1,2 (m)	L3,4 (m)
EH1	250	1.27	57	364	857	1307
EH2	265	0.95	58	1348	480	528
EH3	860	0.056	137	1912	1540	1548

Tunnel and Underground Lab

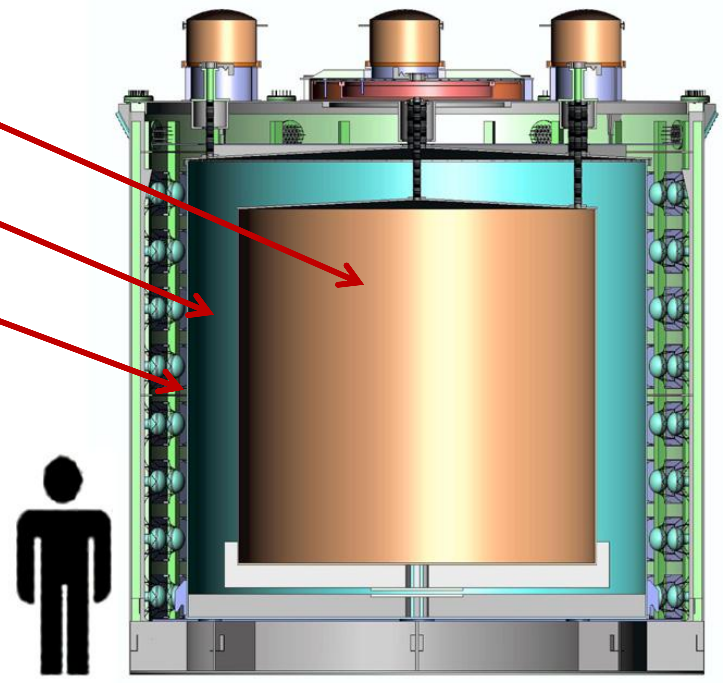
A total of ~ 3000 blasting right next reactors. No one exceeds safety limit set by National Nuclear Safety Agency（0.007g）

Anti-neutrino Detector (AD)

- **Three zones modular structure:**
  I. target: Gd-loaded scintillator
  II. γ-catcher: normal scintillator
  III. buffer shielding: oil
- **192 8" PMTs/module**
- **Two optical reflectors at the top and the bottom,** Photocathode coverage increased from 5.6% to 12%



~ 163 PE/MeV



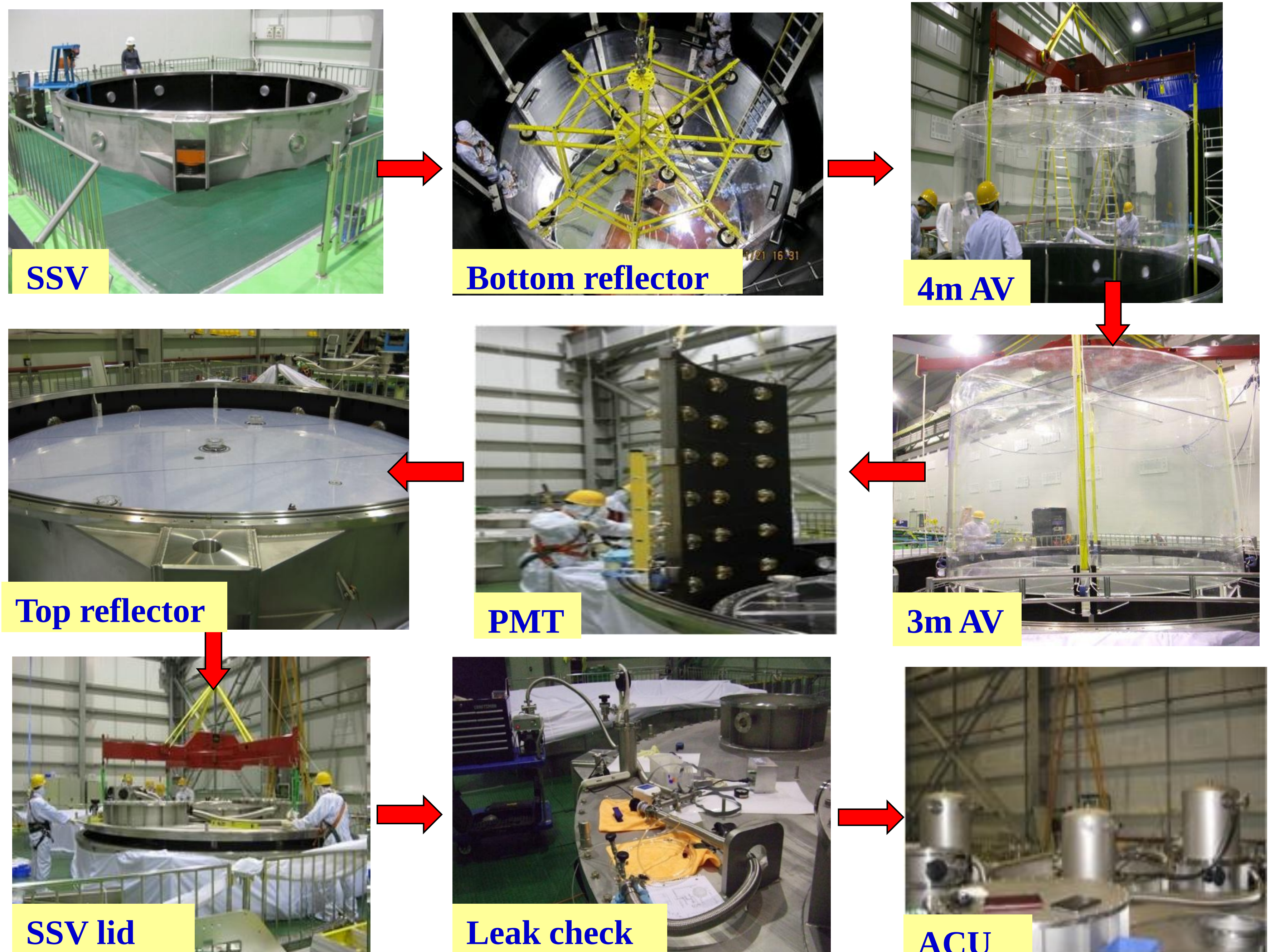
Target: 20 t, 1.6m

n

10 t

	PMT	Coverage	pe yield	pe yield/Coverage
Daya Bay	192 8"	~6%	163 pe/MeV	1.77
RENO	354 10"	~15%	230 pe/MeV	1
Double Chooz	390 10"	~16%	200 pe/MeV	0.81

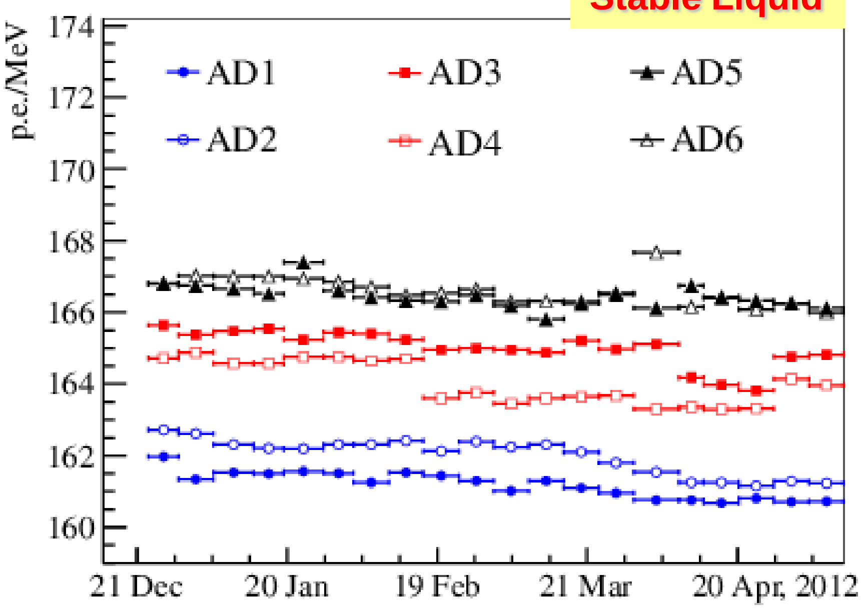
AD assembly


SSV
Bottom reflector
4m AV
3m AV
PMT
Top reflector
SSV lid
Leak check
ACU

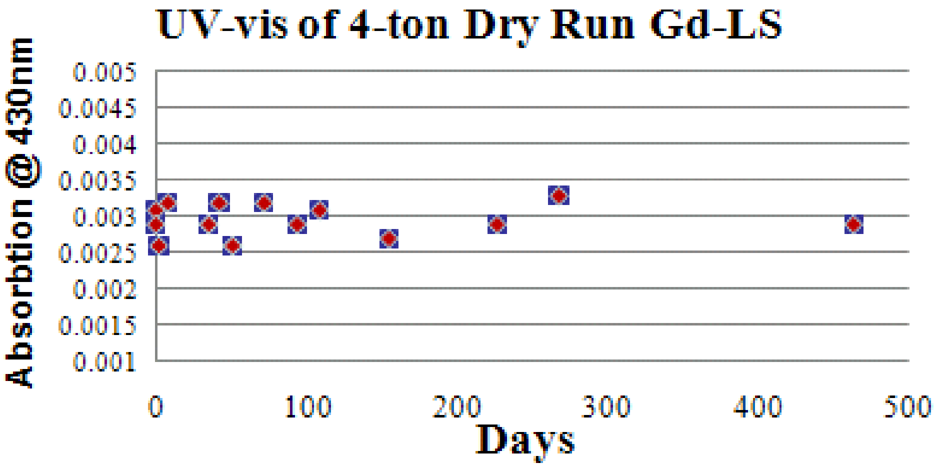
Gd-loaded Liquid Scintillator

- Liquid production, QA, storage and filling at Hall 5
  - ⇨ 185t Gd-LS, ~180t LS, ~320t oil
- LAB+Gd (TMHA)³+PPO+BisMSB
- Stable over time
  - ⇨ Light yield: ~163 PE/MeV

Stable Liquid

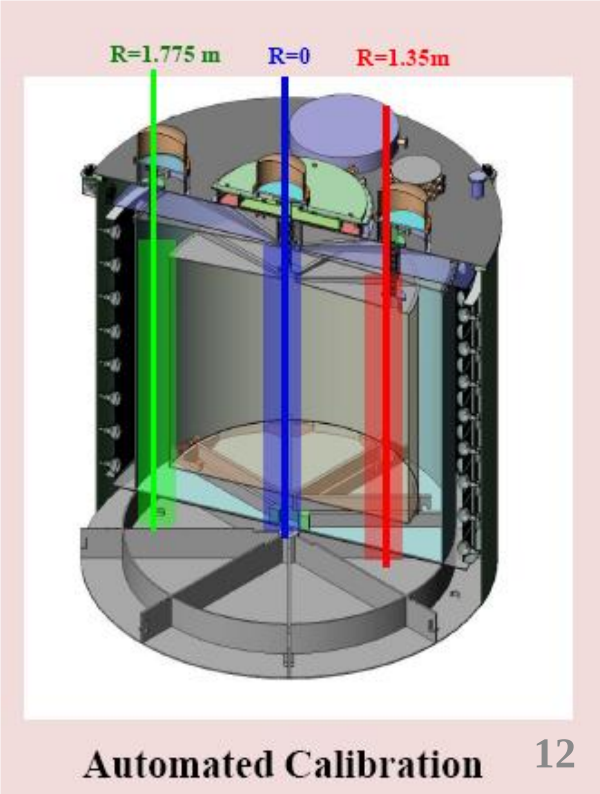


Liquid hall：LS production and filling

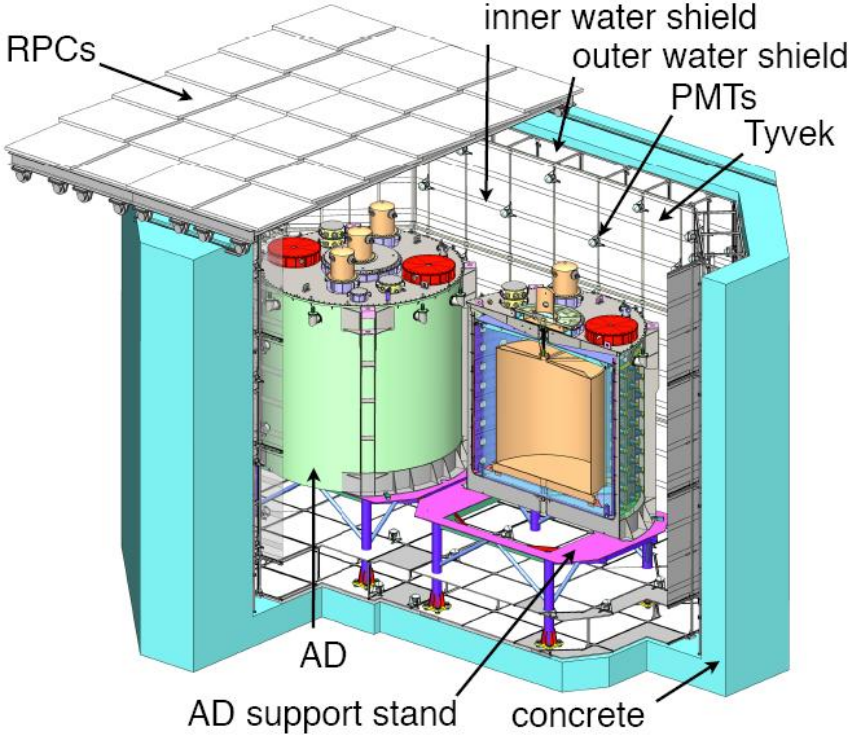


Automatic Calibration System

- **Three Z axis:**
  - One at the center
    - ✓ For time evolution, energy scale, non-linearity…
  - One at the edge
    - ✓ For efficiency, space response
  - One in the γ-catcher
    - ✓ For efficiency, space response
- **3 sources for each z axis:**
  - LED
    - ✓ for T_0, gain and relative QE
  - ^{68}Ge (2×0.511 MeV γ's)
    - ✓ for positron threshold & non-linearity…
  - ^{241}Am-^{13}C + ^{60}Co (1.17+1.33 MeV γ's)
    - ✓ For neutron capture time, …
    - ✓ For energy scale, response function, …
- **Once every week:**
  - 3 axis, 5 points in Z, 3 sources



Muon Veto Detector



Two active cosmic-muon veto's

- **Water Cerenkov: Eff.>97%**
- **RPC Muon tracker: Eff. > 88%**

- **RPCs**
  - **4 layers/module**
  - **54 modules/near hall, 81 modules/far hall**
  - **2 telescope modules/hall**
- **Water Cerenkov detector**
  - **Two layers, separated by Tyvek/PE/Tyvek film**
  - **288 8" PMTs for near halls; 384 8" PMTs for the far hall**
- **Water processing**
  - **High purity de-ionized water in pools also for shielding**
  - **First stage water production in hall 4**
  - **Local water re-circulation & purification**

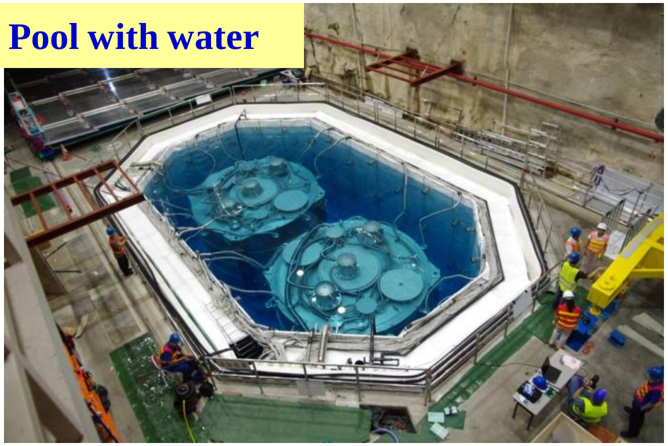
Water Cerenkov detector installation

PermaFlex painting

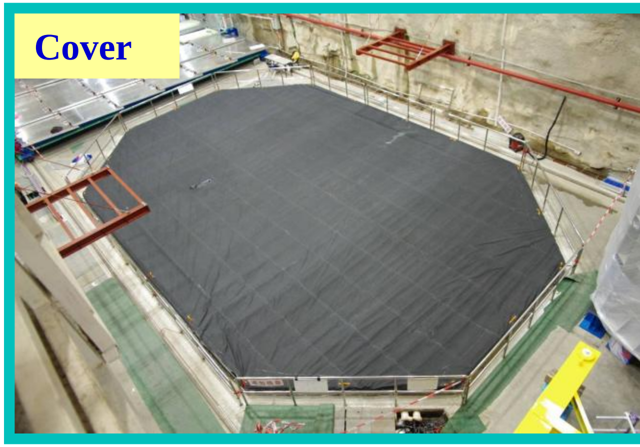
PMT frame & Tyvek

Completed pool

Install AD

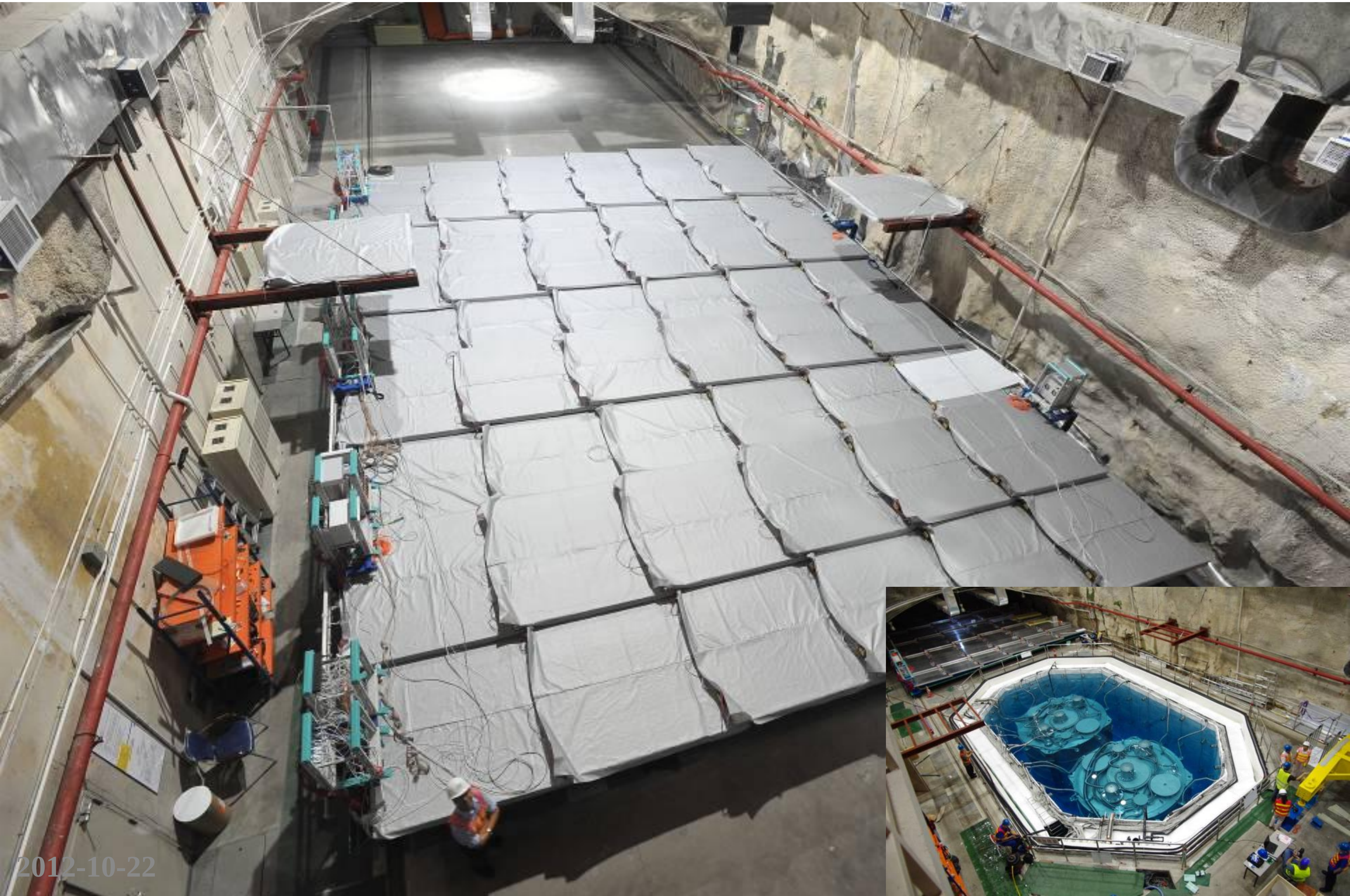


Pool with water

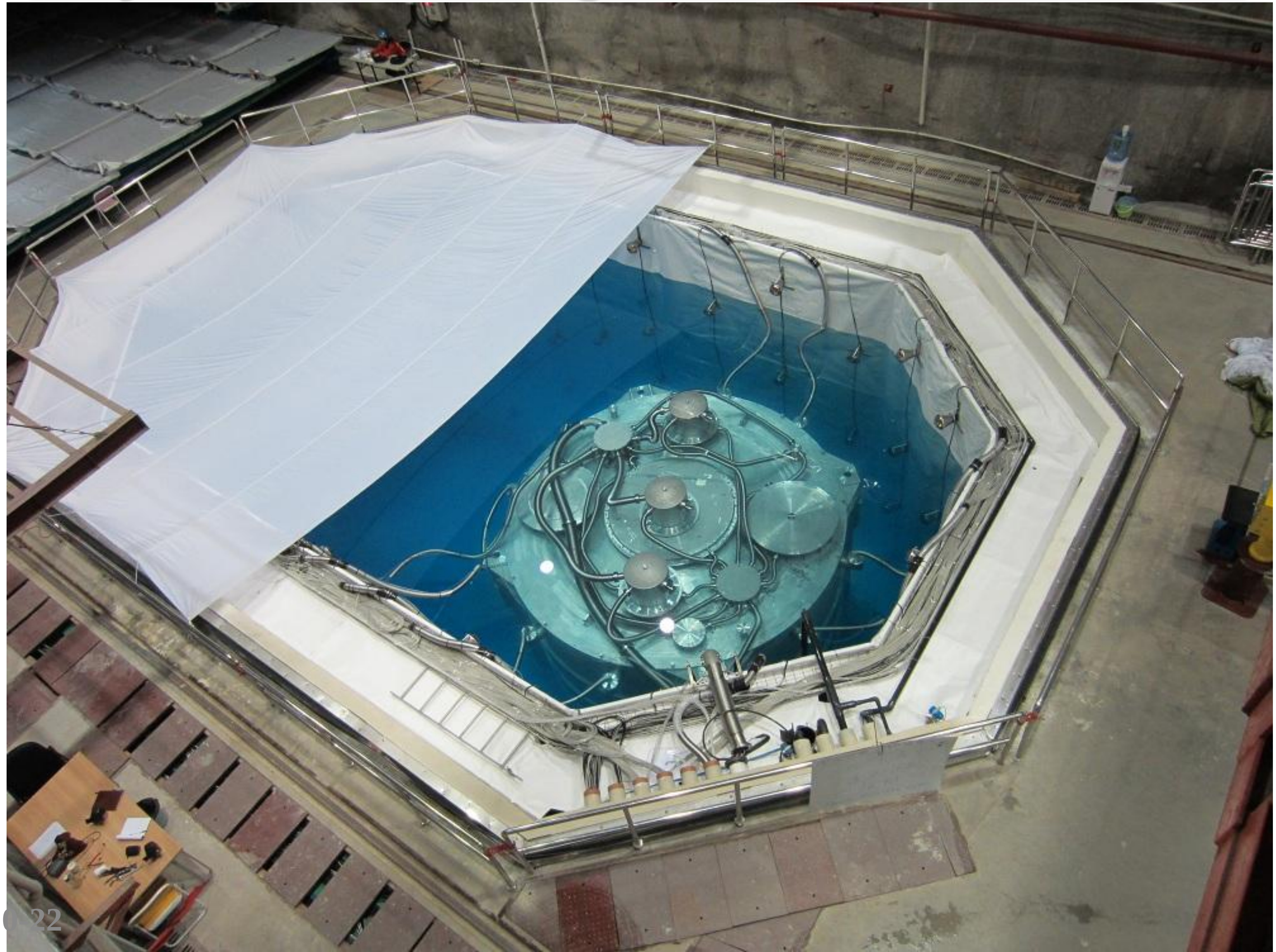


Cover

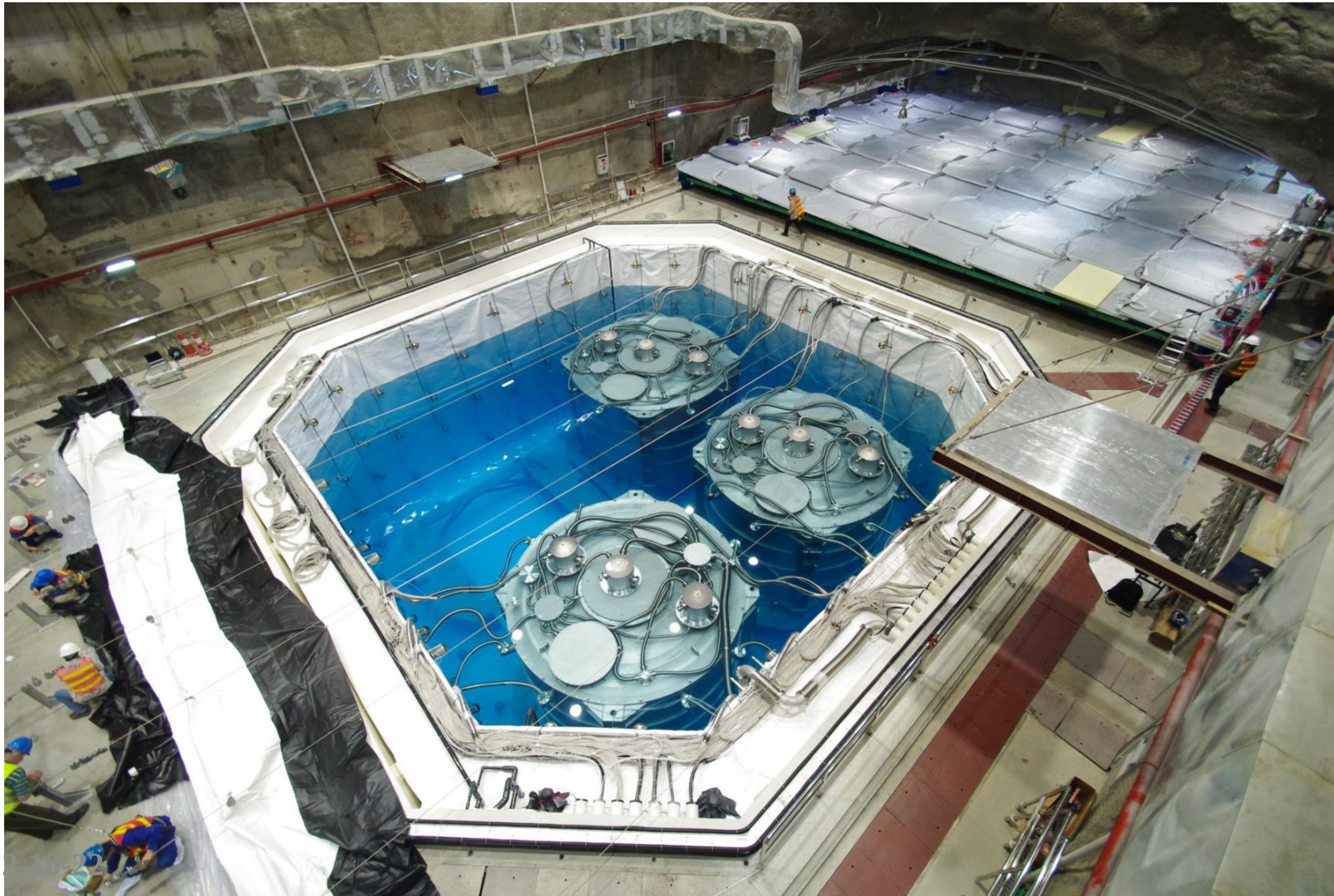
Hall 1(two ADs) Started the Operation on Aug. 15, 2011



One AD insalled in Hall 2
Physics Data Taking Started on Nov.5, 2011



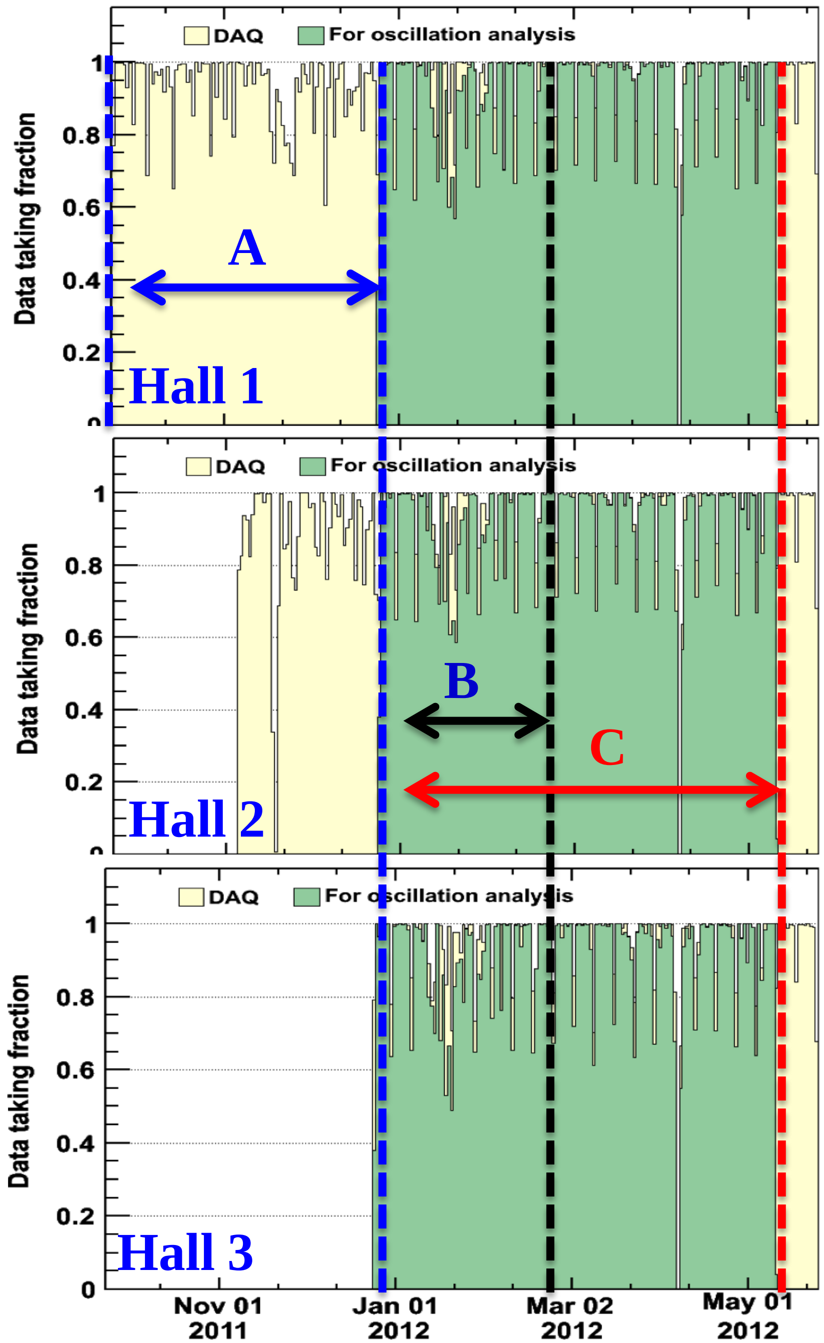
Three ADs insalled in Hall 3
Physics Data Taking Started on Dec.24, 2011



Data Set

- A→Two Detector Comparison: Sep. 23, 2011 – Dec. 23, 2011
- B→First Oscillation Result: Dec. 24, 2011 – Feb. 17, 2012
- C→Updated analysis: Dec. 24, 2011 – May 11, 2012

- DAQ eff. ~ 97%
- Eff. for physics: ~ 89%

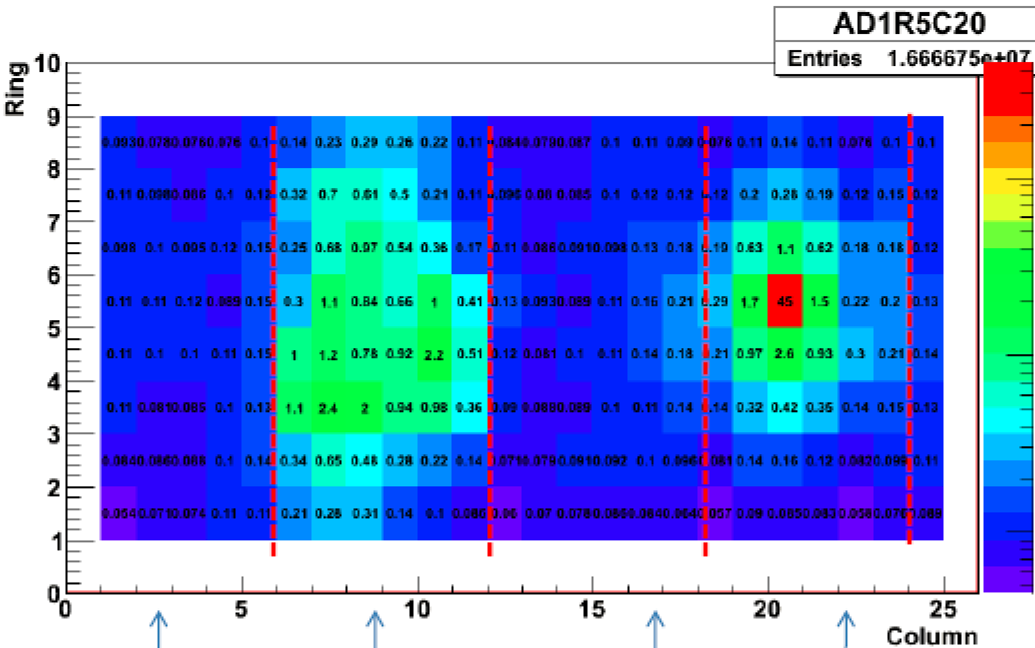


First results announced on Mar,.8， 2012:

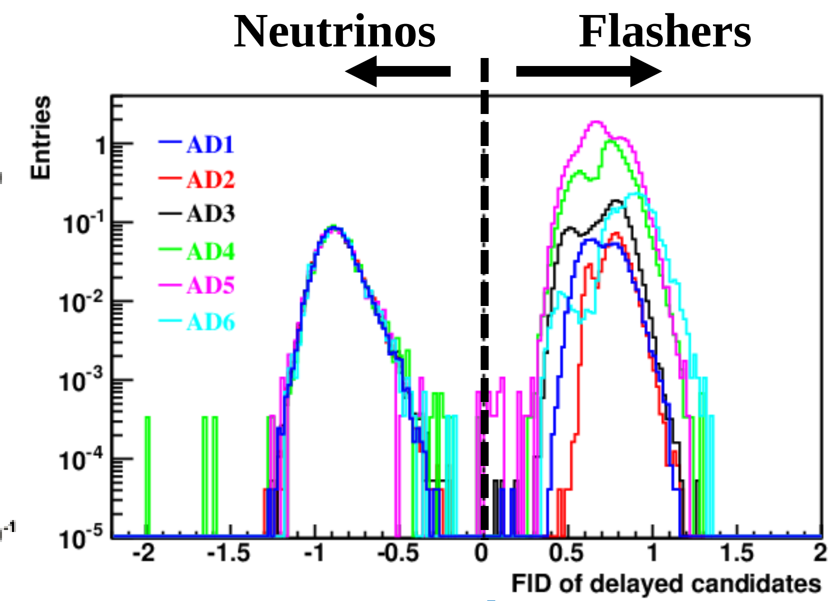
F.P. An et al., NIM. A 685(2012)78

F.P. An et al., Phys. Rev. Lett. 108, (2012) 171803

Flashers: Imperfect PMTs



Quadrant 4 Quadrant 3 Quadrant 2 Quadrant 1, where the hottest PMT locates



$$\log_{10}\left(\left(\frac{Quadrant}{1.}\right)^2 + \left(\frac{MaxQ}{0.45}\right)^2\right) < 0$$

- **Spontaneous light emission by PMT**
- **~ 5% of PMT, 5% of event**
- **Rejection: pattern of fired PMTs**
  - **Topology: a hot PMT + near-by PMTs and opposite PMTs**

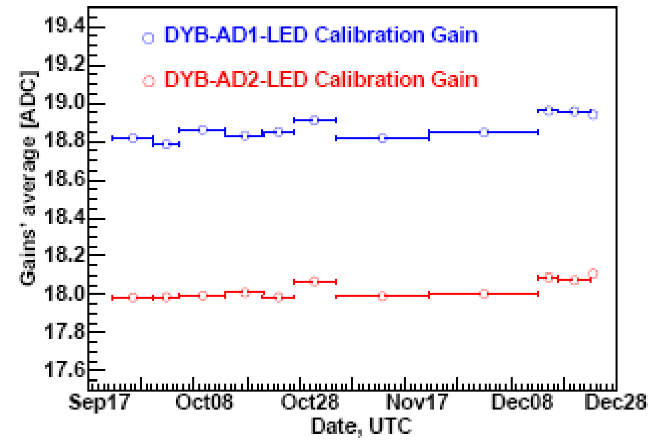
Quadrant = Q3/(Q2+Q4)

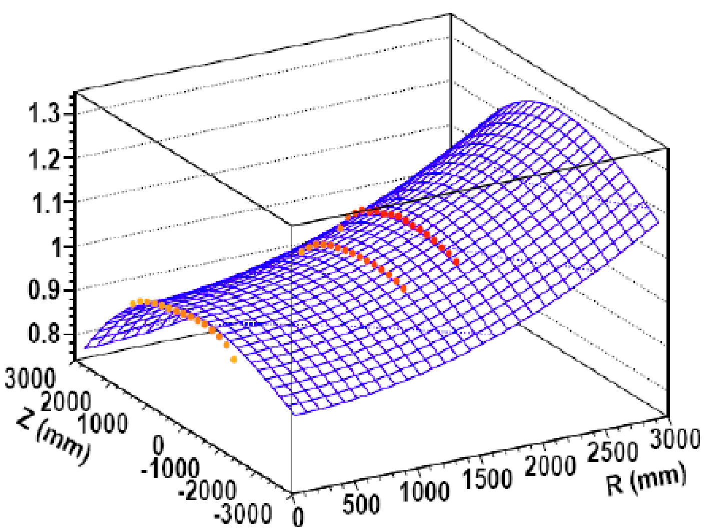
MaxQ = maxQ/sumQ

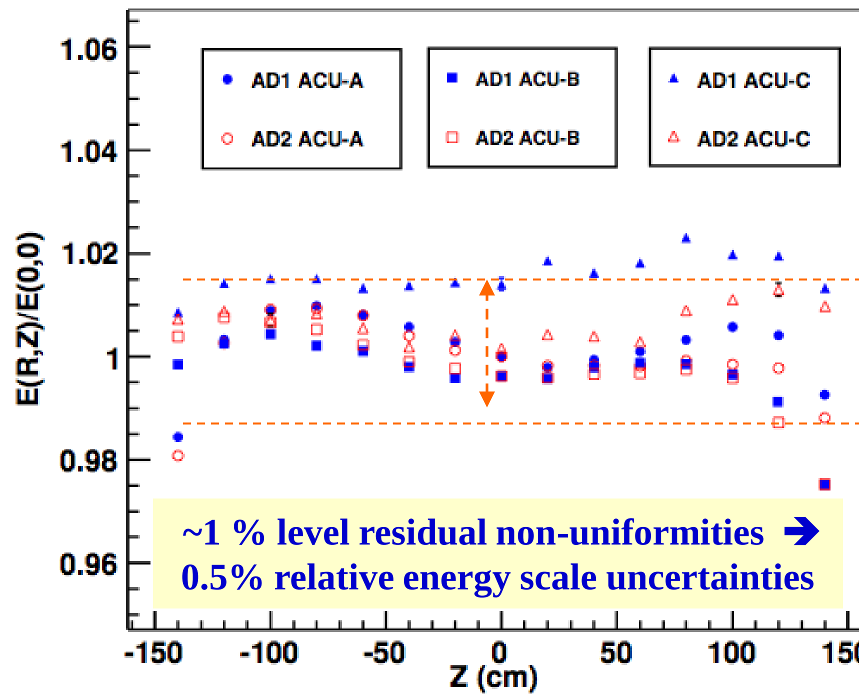
Inefficiency to neutrinos:
0.024% ± 0.006%(stat)
Contamination: < 0.01%

Event Reconstruction: Energy Calibration

- PMT gains(~1×10^7)from low-intensity LED:
  - ⇨ All three halls are kept in a temperature within $\pm1\,^{o}C$ for gain stability
- ^{60}Co at the center ➔ raw energies
  - ⇨ time dependence corrected
- ^{60}Co at different R & Z to obtain the correction function, $f(R,Z) = f_1(R) * f_2(Z)$
  - ⇨ space dependence corrected
  - ⇨ same for all the ADs

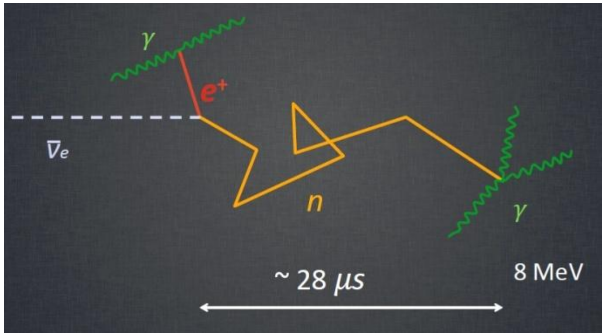






Event Signature and Backgrounds

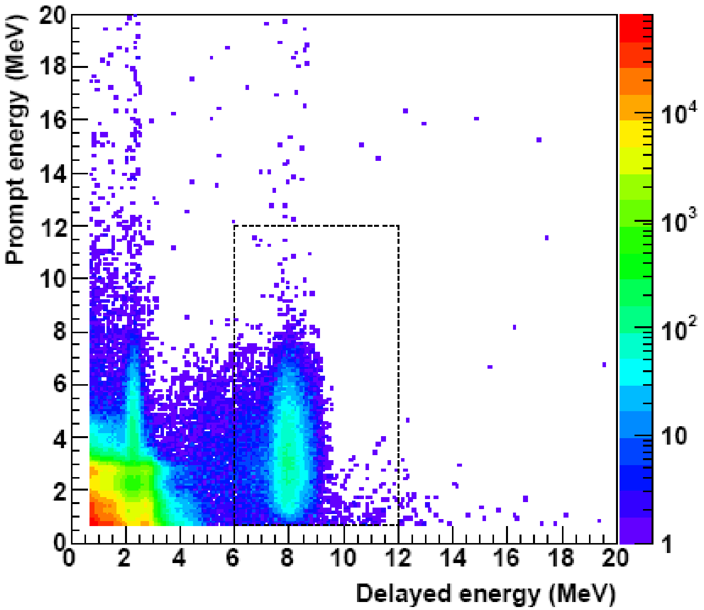
- **Signature:** $\bar{\nu}_e + p \rightarrow e^+ + n$
  - **Prompt: e^+, 1-10 MeV,**
  - **Delayed: n, 2.2 MeV@H, 8 MeV @ Gd**
  - **Capture time: 28 μs in 0.1% Gd-LS**



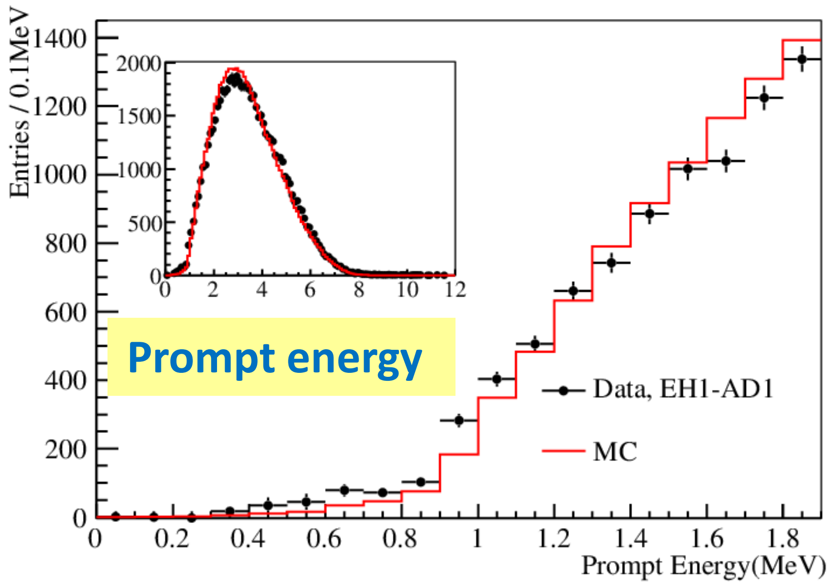
- **Backgrounds**
  - **Uncorrelated: random coincidence of γγ, γn or nn**
    - ✓ **γ from U/Th/K/Rn/Co… in LS, SS, PMT, Rock, …**
    - ✓ **n from α-n, μ-capture, μ-spallation in LS, water & rock**
  - **Correlated:**
    - ✓ **Fast neutrons: prompt—n scattering, delayed—n capture**
    - ✓ **^{8}He/^{9}Li: prompt—β decay, delayed—n capture**
    - ✓ **Am-C source: prompt—γ rays, delayed—n capture**
    - ✓ **α-n: ^{13}C(α,n)^{16}O**

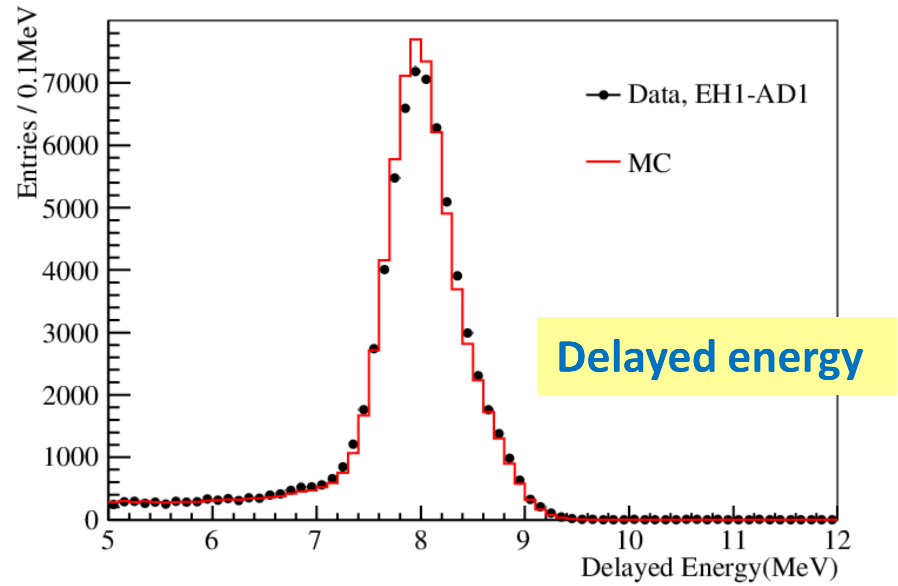
Neutrino Event Selection

- **Pre-selection**
  - **Reject Flashers**
  - **Reject Triggers within (-2 μs, 200 μs) to a tagged water pool muon**
- **Neutrino event selection**
  - **Multiplicity cut**
    - ✓ Prompt-delayed pairs within a time interval of 200 μs
    - ✓ No triggers(E > 0.7MeV) before the prompt signal and after the delayed signal by 200 μs
  - **Muon veto**
    - ✓ *1s* after an AD shower muon
    - ✓ *1ms* after an AD muon
    - ✓ *0.6ms* after an WP muon
  - **$0.7\text{MeV} < E_{prompt} < 12.0\text{MeV}$**
  - **$6.0\text{MeV} < E_{delayed} < 12.0\text{MeV}$**
  - **$1\mu s < \Delta t_{e^+\text{-}n} < 200\mu s$**

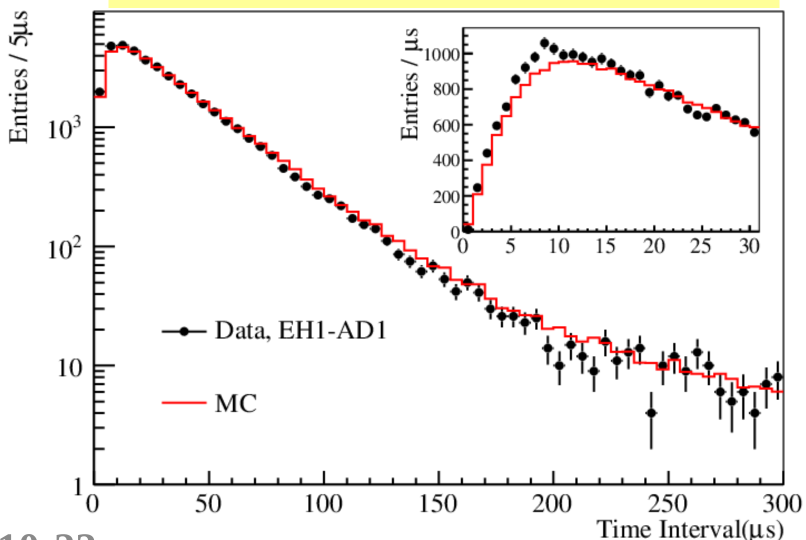


Selected Signal Events: Good Agreement with MC

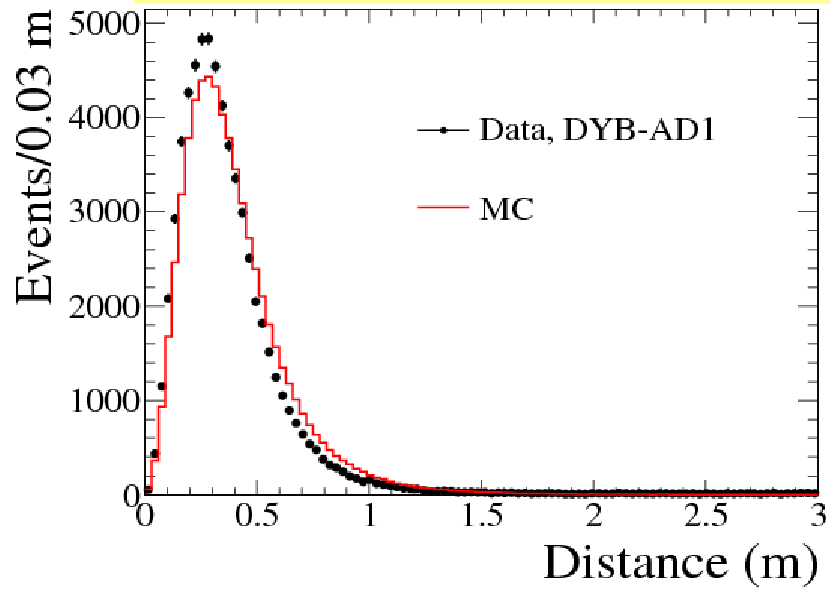




Time between prompt-delayed

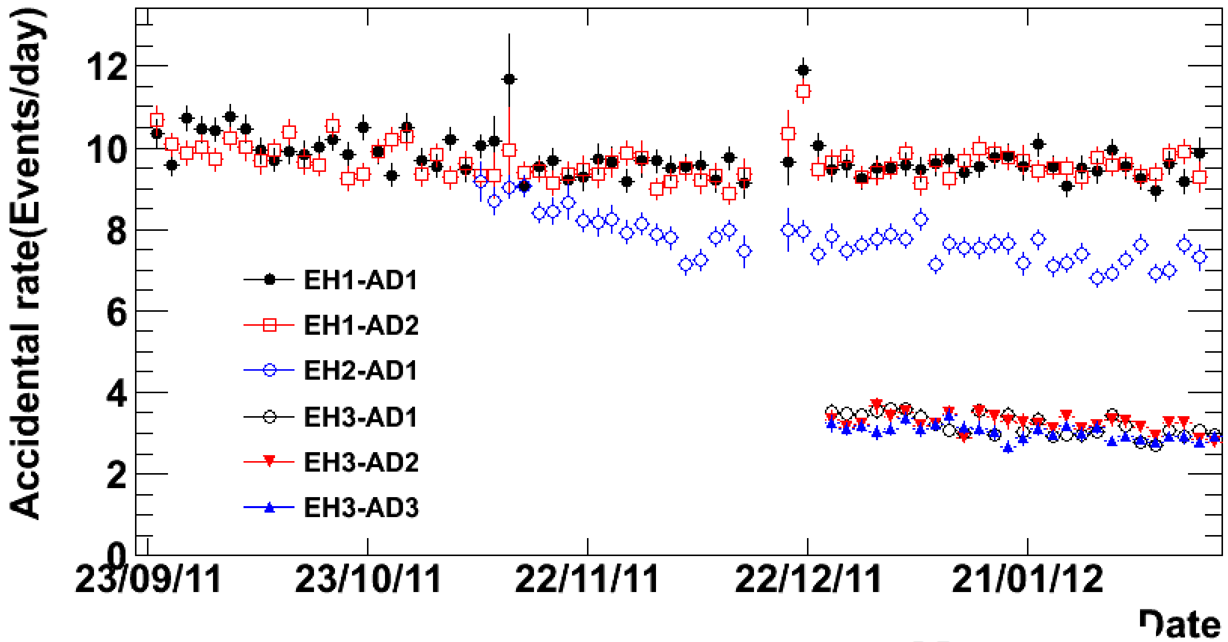


Distance between prompt-delayed



Accidental Backgrounds

- **Coincidence probability checked by**
  - Off-window
  - Distance between prompt-delay pair
- **Consistent to 1%**

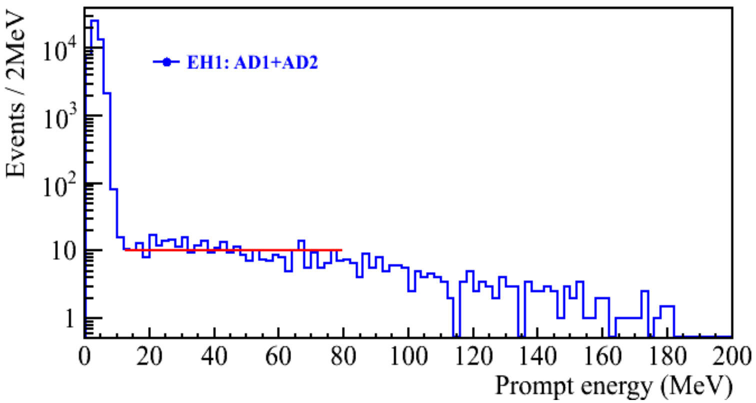


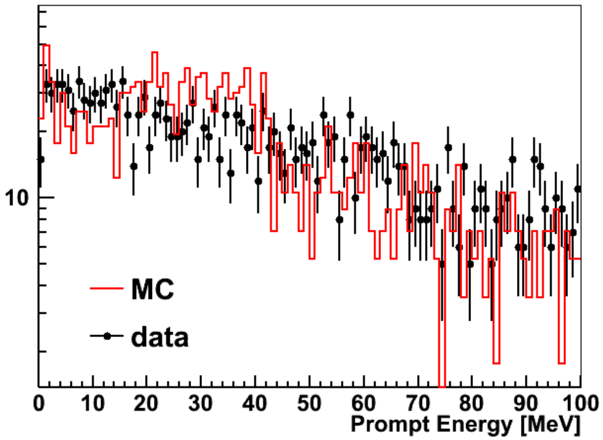
$$N_{\text{accBkg}} = \sum_i N^i_{\text{n-like singles}} \bullet \left(1 - e^{-R^i_{e^+\text{-like triggers}} \bullet 200\,\mu s}\right) \pm \frac{N_{\text{accBkg}}}{\sqrt{\sum_i N^i_{\text{n-like singles}}}}$$

	EH1-AD1	EH1-AD2	EH2-AD1	EH3-AD1	EH3-AD2	EH3-AD3
Accidental rate(/day)	9.82±0.06	9.88±0.06	7.67±0.05	3.29±0.03	3.33±0.03	3.12±0.03
B/S	1.37%	1.38%	1.44%	4.58%	4.77%	4.43%

Fast Neutrons

- Estimate from events with E >12 MeV
  - Difference of the fitting function gives systematic uncertainties
- Cross check: Sum up all neutrons from water pools & rock
  - Water pool:
    - ✓ Measure neutrons from tagged muons and compare with MC
    - ✓ Untagged neutrons estimated by using water pool inefficiencies
  - Rock: Estimate based on MC simulation





(event/day/AD)	Fast neutron	Cross checks
EH1	0.77±0.24	0.71±0.35
EH2	0.58±0.33	0.51±0.25
EH3	0.05±0.02	0.02±0.02

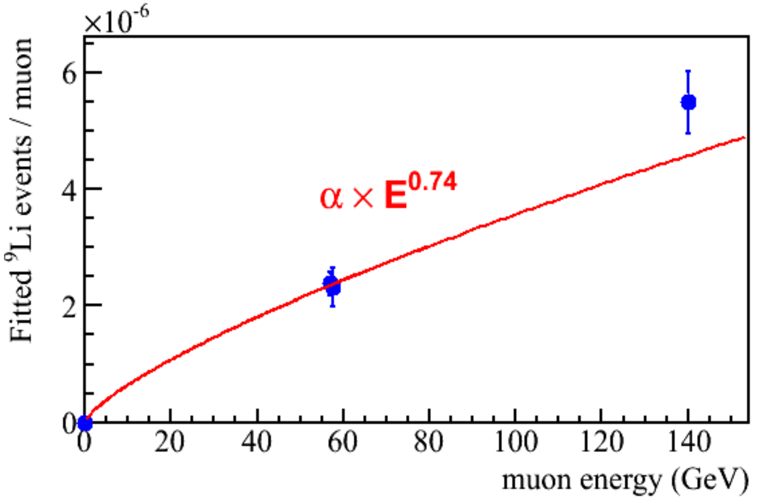
Two methods are consistent

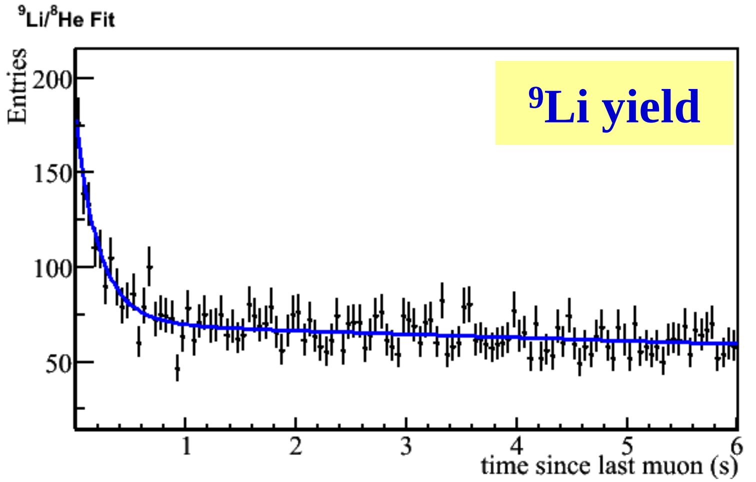
Backgrounds –^{8}He/^{9}Li

- **Cosmic μ produced ^{9}Li/^{8}He in LS**
  - **β-decay + neutron emitter**
  - **$\tau(^8$He/^{9}Li$)$ = 171.7ms/257.2ms**
  - **^{8}He/^{9}Li, Br(n) = 12%/48%, ^{9}Li dominant**
  - **Production rate follow $E_\mu^{0.74}$ power law**
- **Measurement:**
  - **Time-since-last-muon fit**

$$f(t) = B/\lambda \cdot e^{-t/\lambda} + S/T \cdot e^{-t/T}$$

  - **Improve the precision by reducing the muon rate:**
    - ✓ **Select only muons with an energy deposit >1.8MeV within a [10us, 200us] window**
    - ✓ **Issue: possible inefficiency of ^{9}Li**
  - **Results w/ and w/o the reduction is studied**





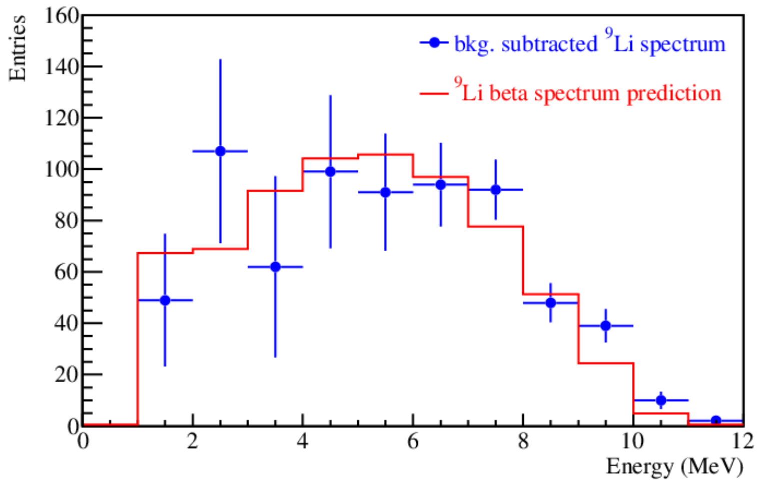
Error follows

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

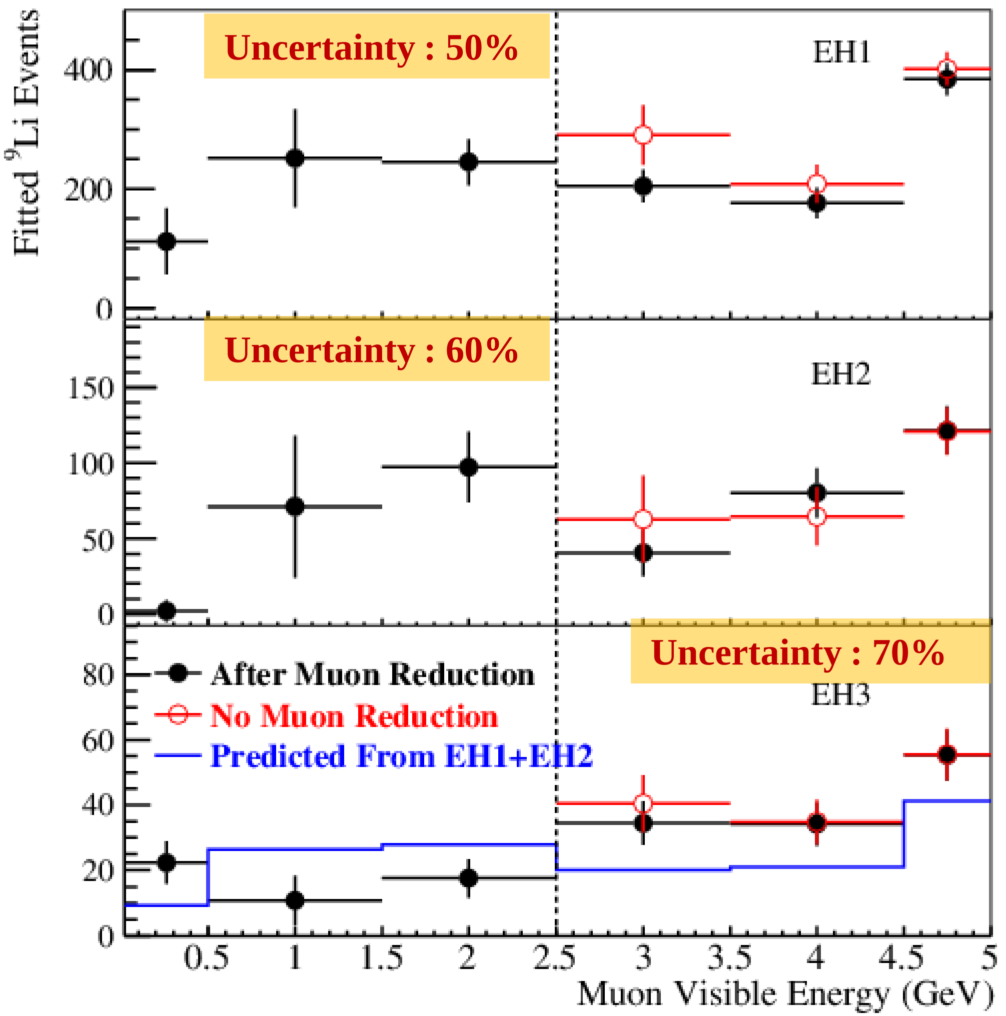
L.J. Wen et al, NIM A564 (2006)471

Measurement in EH1+EH2 & Prediction in EH3

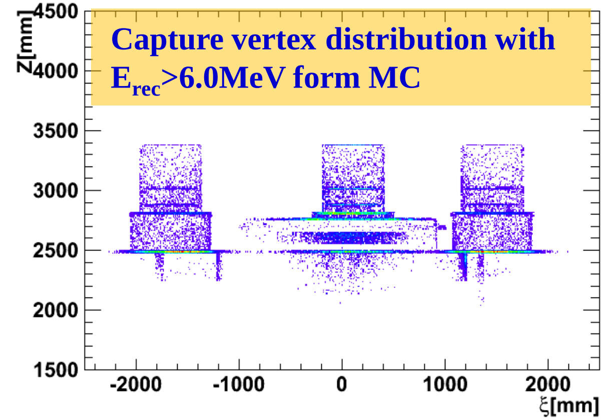
- Measurement in EH1/EH2 with good precision, but EH3 suffers from poor statistics
- Results w/ and w/o the muon reduction consistent within 10%
- Correlated ^{9}Li production ($E_\mu^{0.74}$ power law) allow us to further constraint ^{9}Li yield in EH3
- Cross check: Energy spectrum consistent with expectation

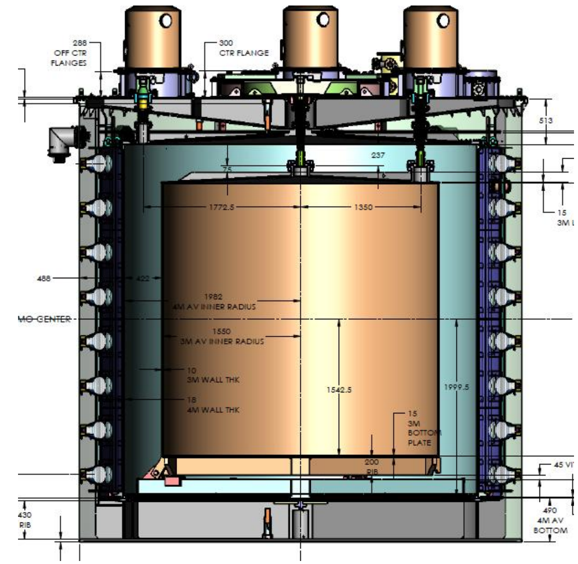


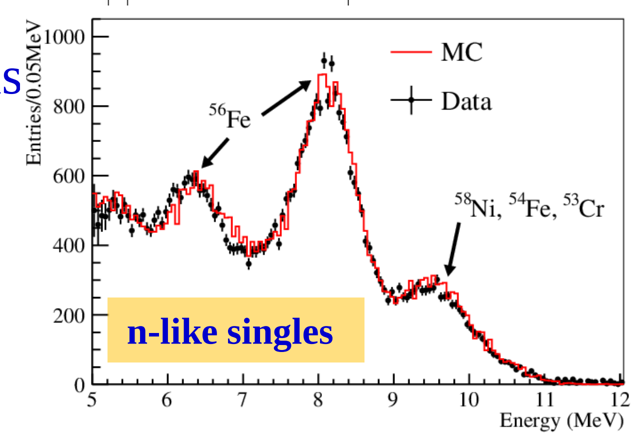
^{9}Li yield



^{241}Am-^{13}C Backgrounds







- **Uncorrelated backgrounds:**

  R = 50 Hz × 200 μs × $R_{n\text{-}like}$ (events/day/AD)

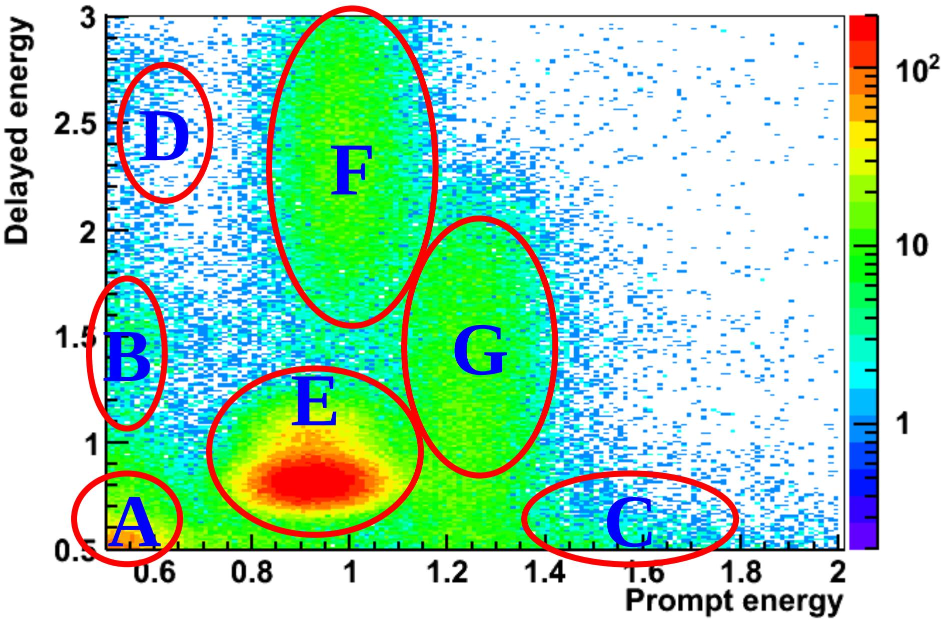
  - $R_{n\text{-}like}$ Measured to be ~230/day/AD, in consistent with MC Simulation
  - R is not a negligible amount, particularly at the far site (B/S ~ 3.17%)
  - Measured precisely together with all the other uncorrelated backgrounds

- **Correlated backgrounds:**
  - Neutron inelastic scattering with ^{56}Fe + neutron capture on ^{57}Fe
  - Simulation shows that correlated background is 0.2 events/day/AD, corresponding to a B/S ratio of 0.03% at near site, 0.3% at far site

Uncertainty: 100%

Backgrounds from $^{13}C(\alpha,n)^{16}O$

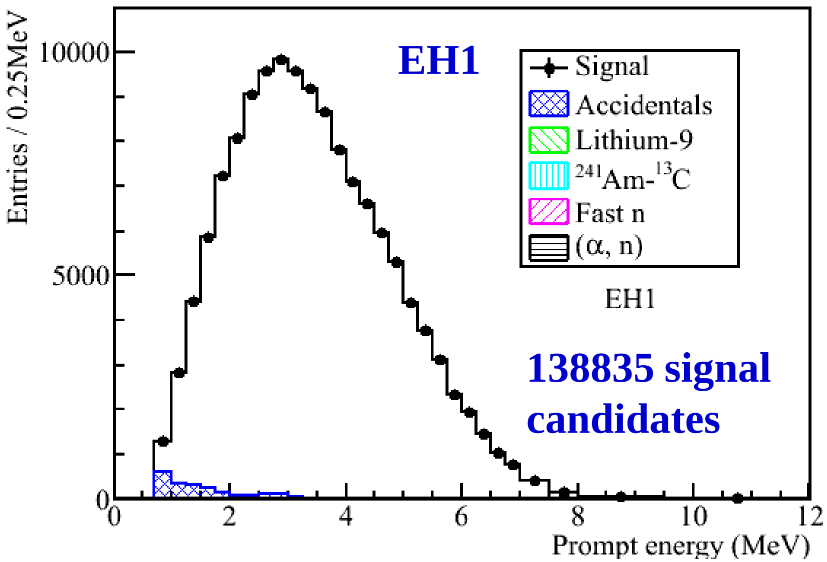
- Identify α sources: ^{238}U, ^{232}Th, ^{227}Ac, ^{210}Po,…
- Determine α rate from cascade decays
- Calculate backgrounds from α rate + (α,n) cross sections

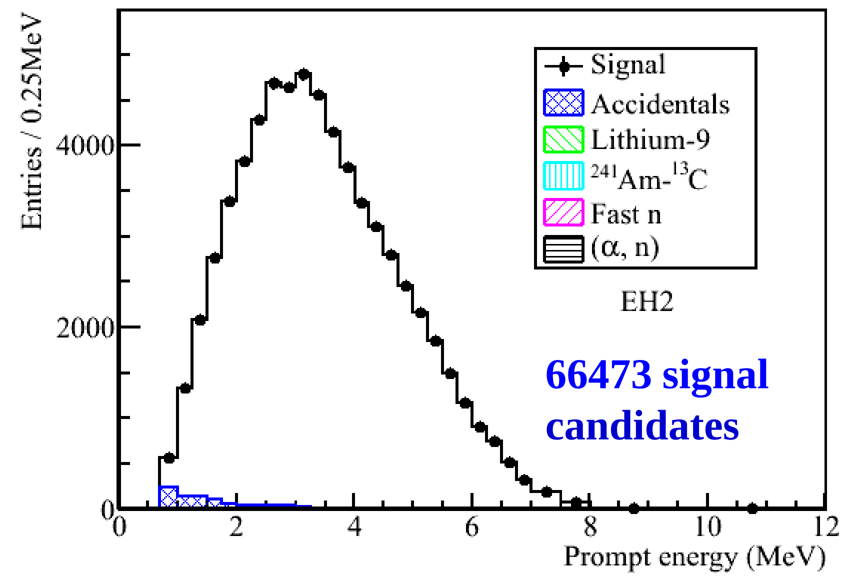


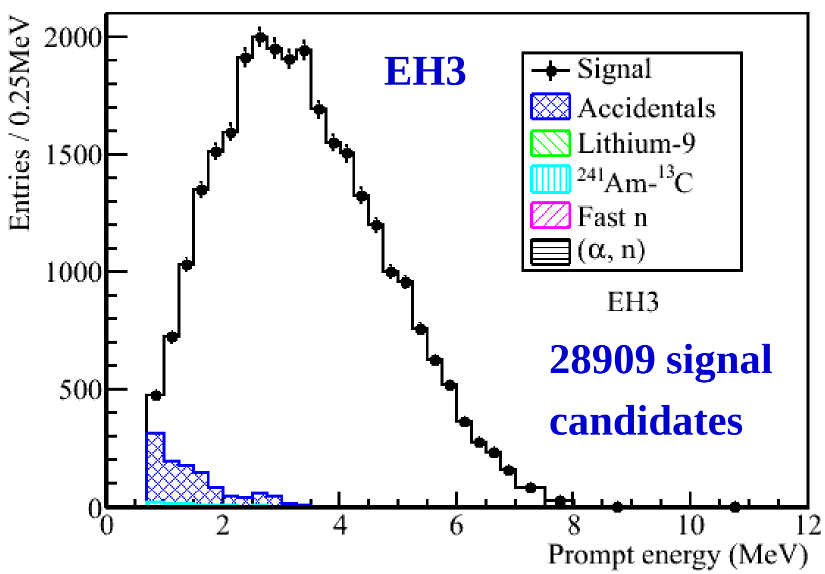
	Components	Total α rate	BG rate
Region A	Acc. Coincidence of ^{210}Po & ^{210}Po	^{210}Po: 22Hz at EH1 14Hz at EH2 5Hz at EH3	0.06/day at EH1 0.04/day at EH2 0.02/day at EH3
Region B	Acc. Coincidence of ^{210}Po & ^{40}K		
Region C	Acc. Coincidence of ^{40}K & ^{210}Po		
Region D	Acc. Coincidence of ^{208}Tl & ^{210}Po		
Region E	Cascade decay in ^{227}Ac chain	1.4 Bq	0.01/day
Region F	Cascade decay in ^{238}U chain	0.07Bq	0.001/day
Region G	Cascade decay in ^{232}Th chain	1.2Bq	0.01/day

Uncertainty: 50%

Signal+Backgound Spectrum



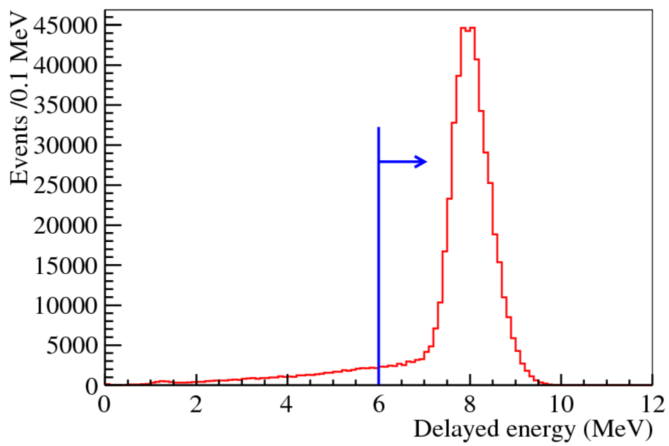


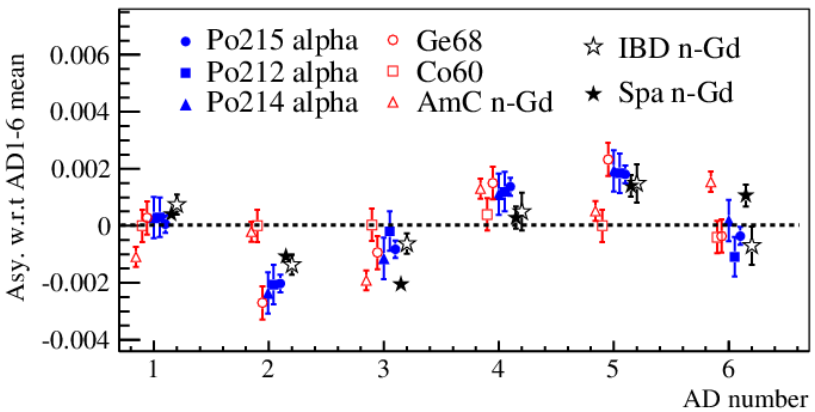


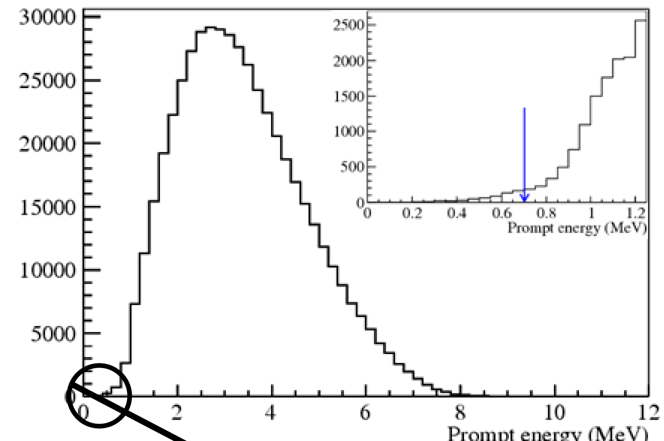
	B/S @EH1/2	B/S @EH3
Accidentals	~1.4%	~4.5%
Fast neutrons	~0.1%	~0.06%
$^8He/^9Li$	~0.4%	~0.2%
Am-C	~0.03%	~0.3%
α-n	~0.01%	~0.04%
Sum	~2%	~5%

Energy Cuts Efficiency and Systematics

- **Delayed energy cut $E_n > 6$ MeV**
  - ⇨ Energy scale uncertainty 0.5% ➔
  - ⇨ Efficiency uncertainty ~ 0.12%
- **Prompt energy cut $E_p > 0.7$ MeV**
  - ⇨ Energy scale uncertainty 2 % ➔
  - ⇨ Efficiency uncertainty ~ 0.01%

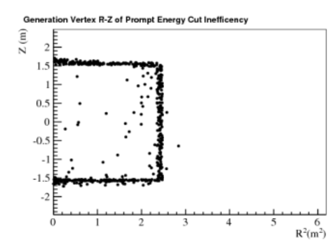




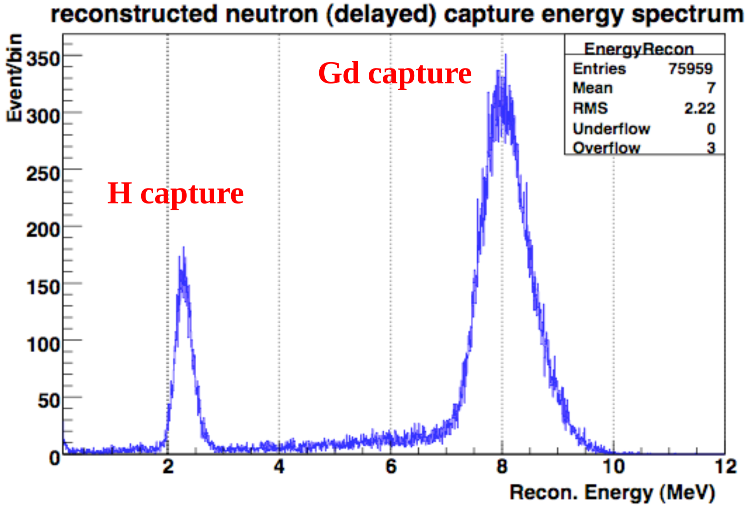


	Eff.	Corr.	Un-corr.
Delayed energy cut	90.9%	0.6%	0.12%
Prompt energy cut	99.88%	0.10%	0.01%

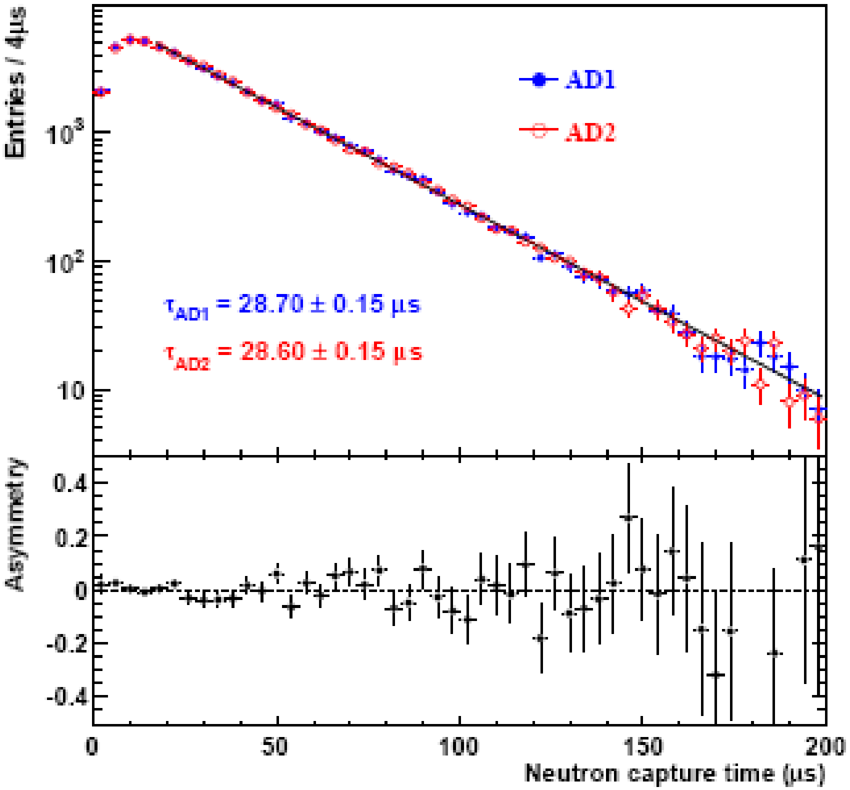
Inefficiency mainly from edges



Gd Capture Fraction: H/Gd and Systematics



Neutron capture time from Am-C

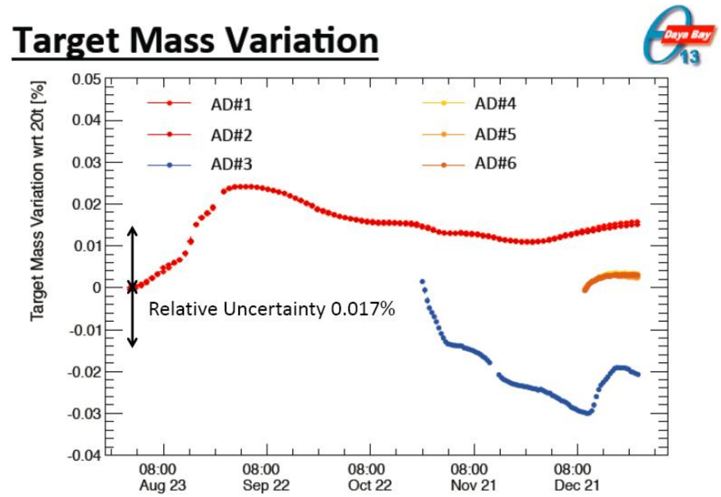


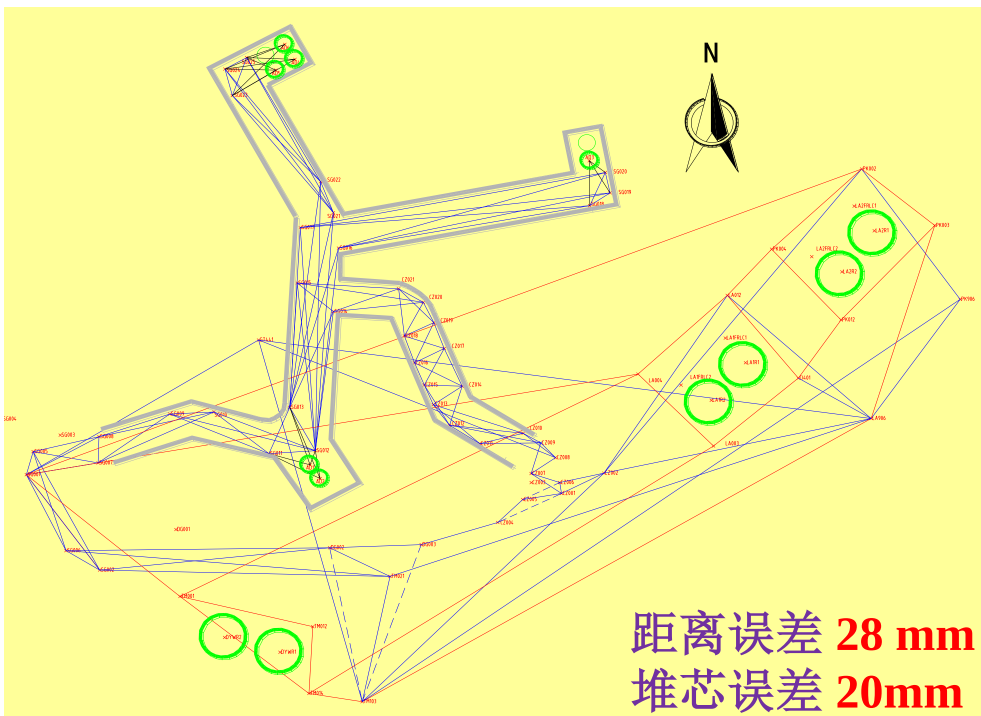
- Uncertainty is large if takes simply the ratio of area
- Relative Gd content variation 0.1% → evaluated from neutron capture time
- Geometry effect on spill-in/out 0.02% → relative differences in acrylic thickness, acrylic density and liquid density are modeled in MC

	Eff.	Corr.	Un-corr.
Gd capture ratio	83.8%	0.8%	<0.1%

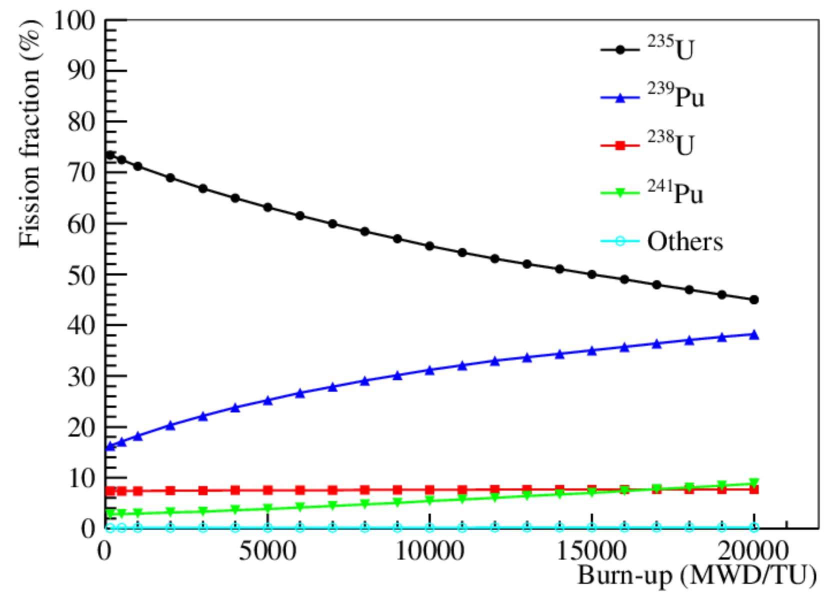
Predictions

- Baseline（ 3.5cm，~0.002%）
- Target mass（3kg，0.015%）
- Reactor neutrino flux





距离误差 28 mm
堆芯误差 20mm
总误差　35 mm



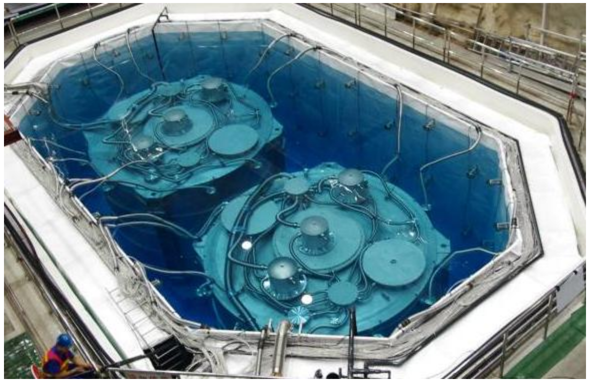
The Most Precise Neutrino Experiment

	Efficiency	Correlated	Uncorrelated
Detector			
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%		
Livetime	100.0%	0.002%	<0.01%
Combined	78.8%	1.9%	0.2%

Design: (0.18 - 0.38) %

Correlated		Uncorrelated	
Reactor			
Energy/fission	0.2%	Power	0.5%
$\overline{\nu}_e$/fission	3%	Fission fraction	0.6%
		Spent fuel	0.3%
Combined	3%	Combined	0.8%

Side-by-side Comparison



Expectation:

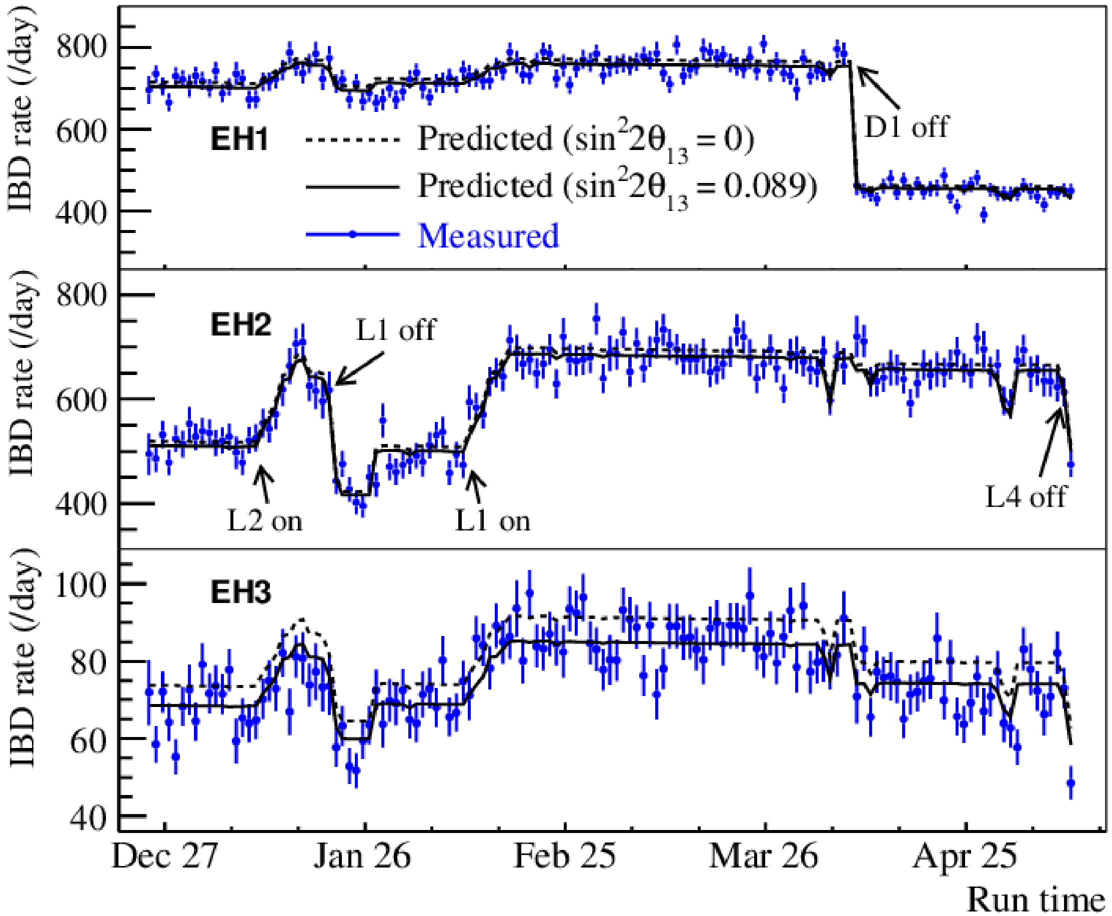
R(AD1/AD2) = 0.982

Measurement:

0.987 ± 0.004(stat) ± 0.003(syst)

Daily Neutrino Rate

- **Three halls taking data synchronously allows near-far cancellation of reactor related uncertainties**
- **Rate changes reflect the reactor on/off.**



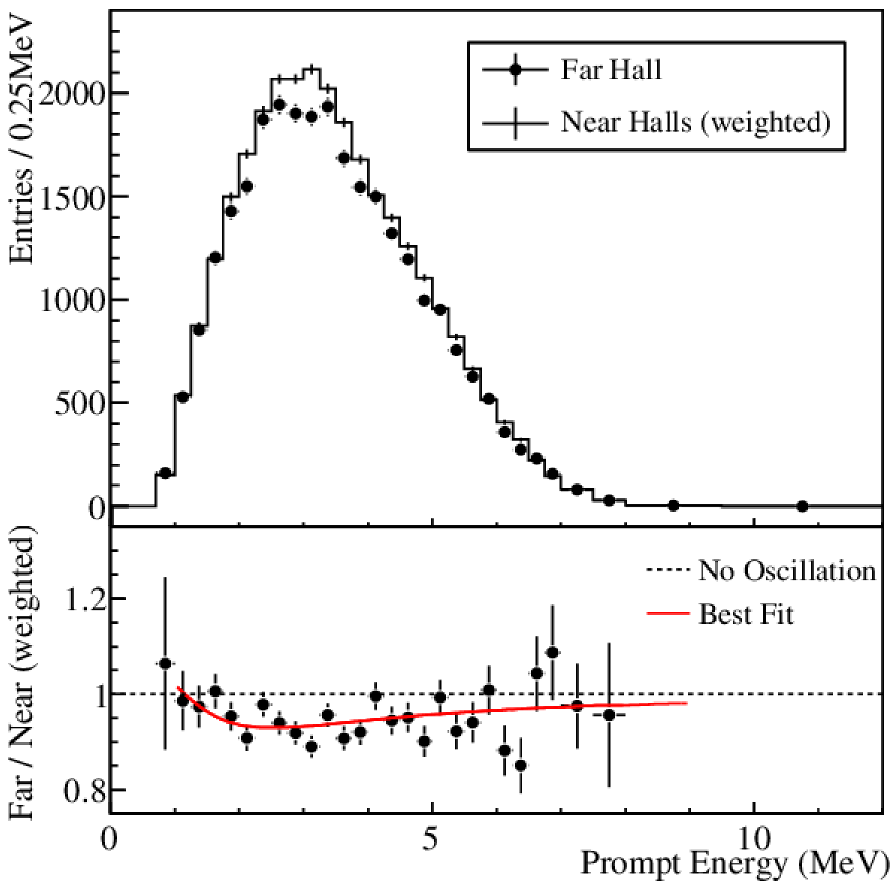
Predictions are absolute, multiplied by a normalization factor from the fitting

Electron Anti-neutrino Disappearence

Using near to predict far:

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

$$M_i = \frac{IBD_i - B_i^{Acc} - B_i^{FNeutron} - B_i^{9Li/8He} - B_i^{AmC} - B_i^{\alpha-n}}{\epsilon_i^{muon}\epsilon_i^{multi} T Mass_i}$$



Determination of α, β:

1) **Set R=1 if no oscillation**
2) **Minimize the residual reactor uncertainty**

R = 0.944 ±0.007 (stat) ±0.003 (syst)

Spectral distortion Consistent with oscillation

χ^2 Analysis

$\chi^2 = \mathrm{m}$

$+ \sum$

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

$\chi^2/\mathrm{NDF} = 3.4/4$

7.7 σ for non-zero θ_{13}

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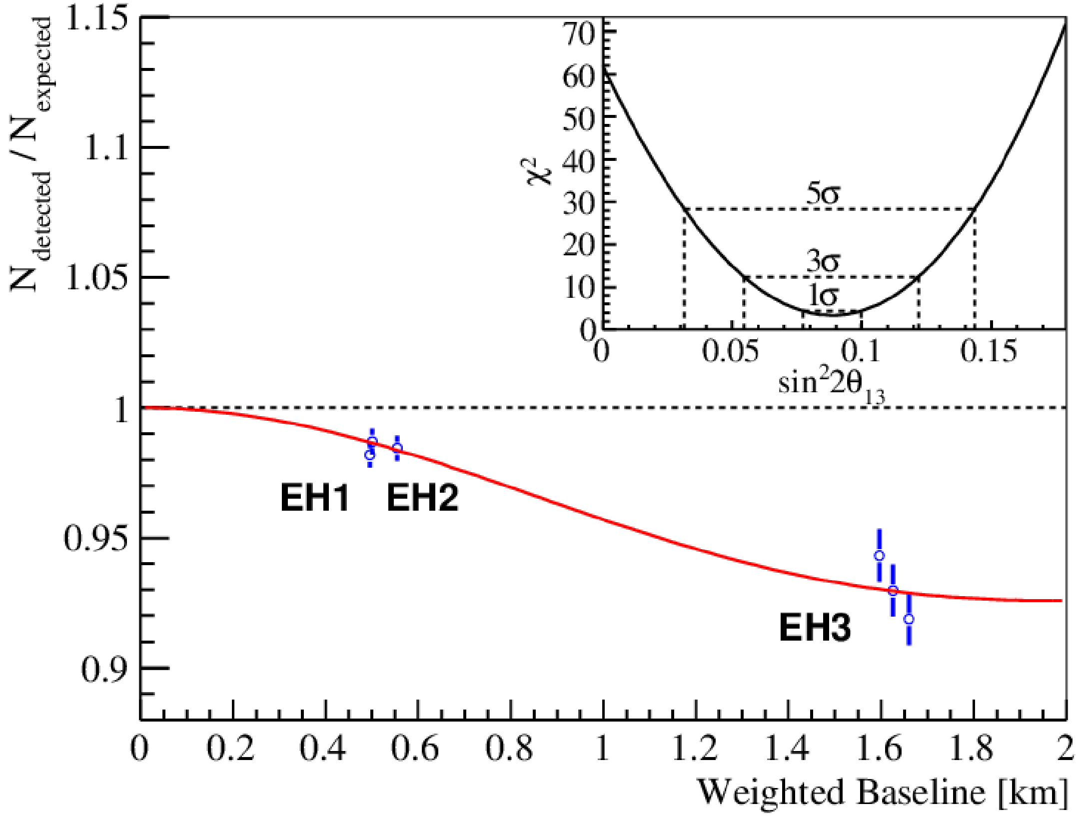
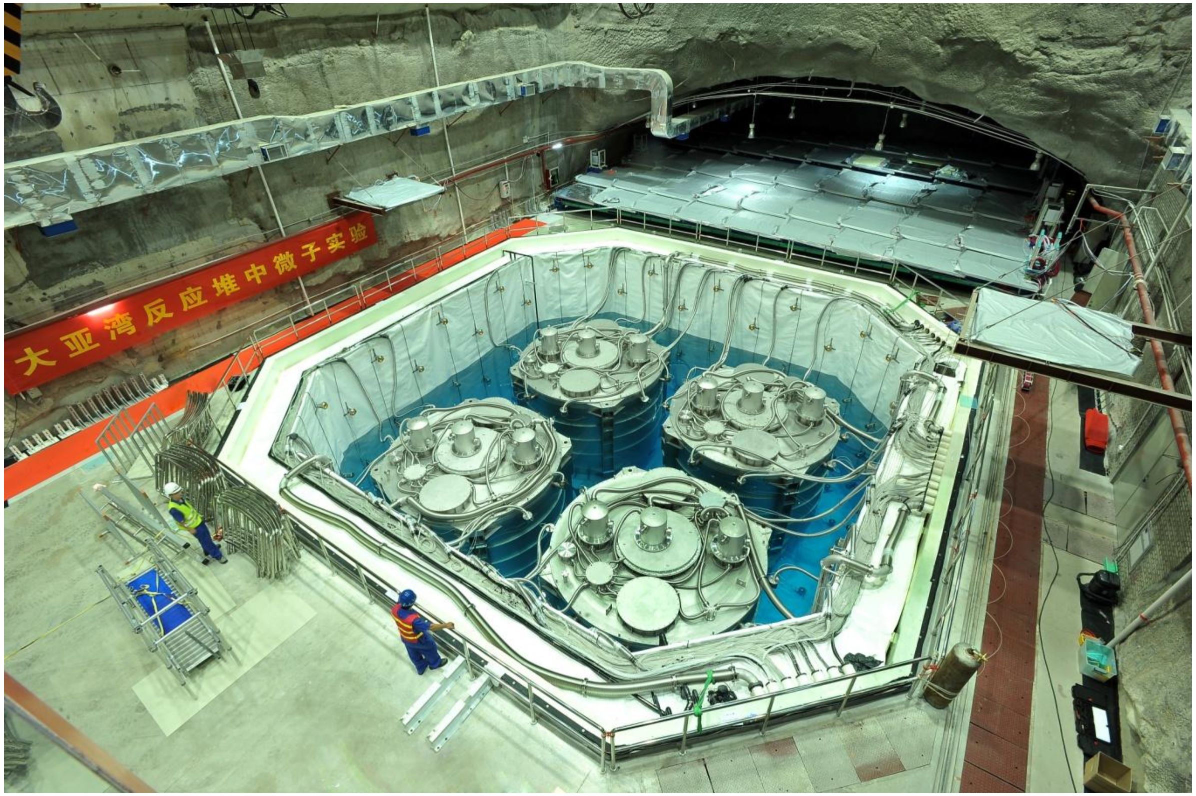


Comparison with Other Experiments

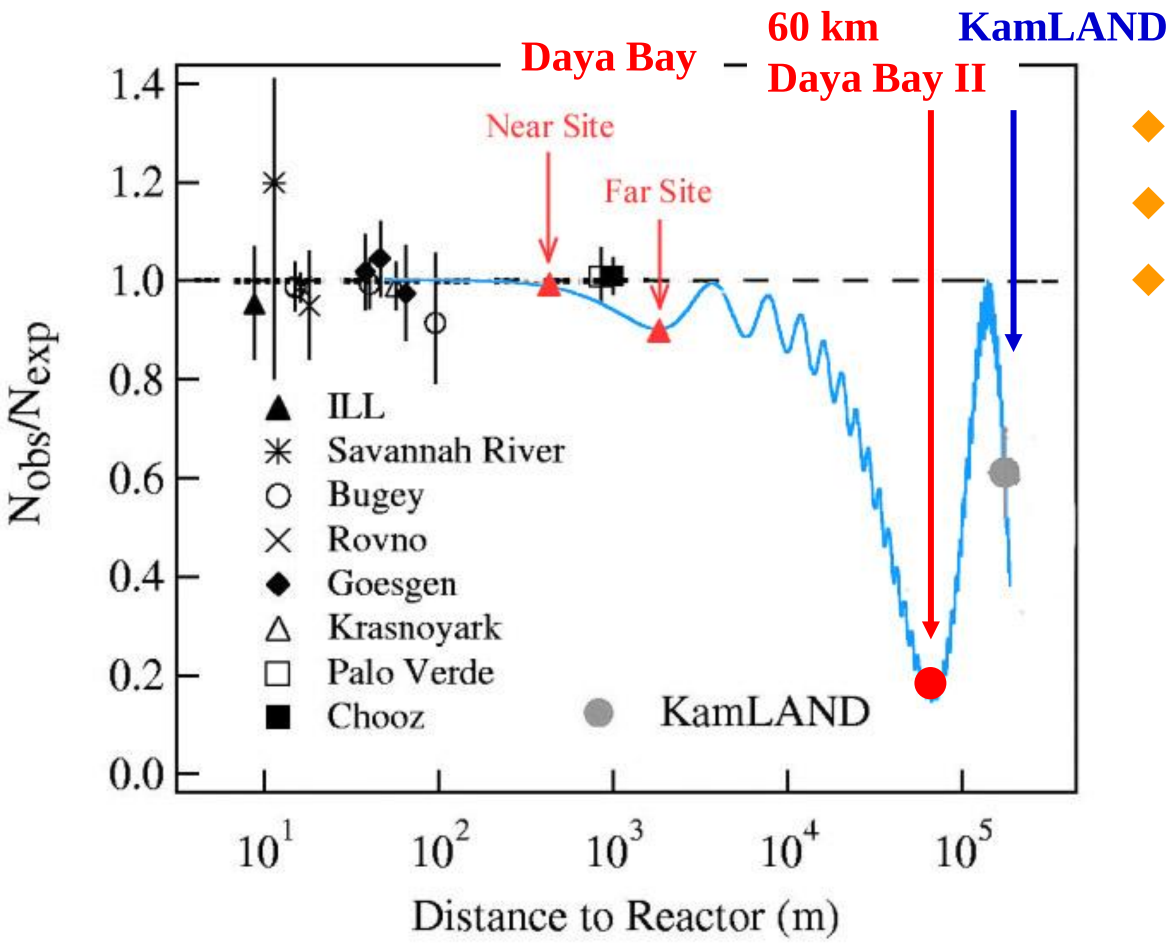
- Double Chooz Exp. completed near far construction in 2011, full operation in 2013
  - ⇨ Results in June based on far-site data, significance = 3.1 σ
  - ⇨ Expected ultimate precision： ~15%
- RENO Exp. started operation in Aug. Their first paper on April 8 confirmed our results:
  - ⇨ Significance = 4.9 σ
  - ⇨ $\sin^2 2\theta_{13} = 0.113 \pm 0.013(\text{stat.}) \pm 0.019(\text{syst.})$
  - ⇨ Expected ultimate precision： ~10%
- T2K Exp. re-started operation at the end of last year:
  - ⇨ Results in June： Significance = 3.1 σ
  - ⇨ Expected ultimate precision： ~15%
- Daya Bay Exp. updated results in June:
  - Significance = 7.7σ
  - Expected ultimate precision： ~5%

Current status and future plan

- **Summer maintenance completed**
- **Two new AD modules installed**
- **Data taking restated in Oct.**
- **Precision results in three years, $\Delta(\sin^2 2\theta_{13}) \sim 4\%$**



Next Step: Daya Bay-II Experiment

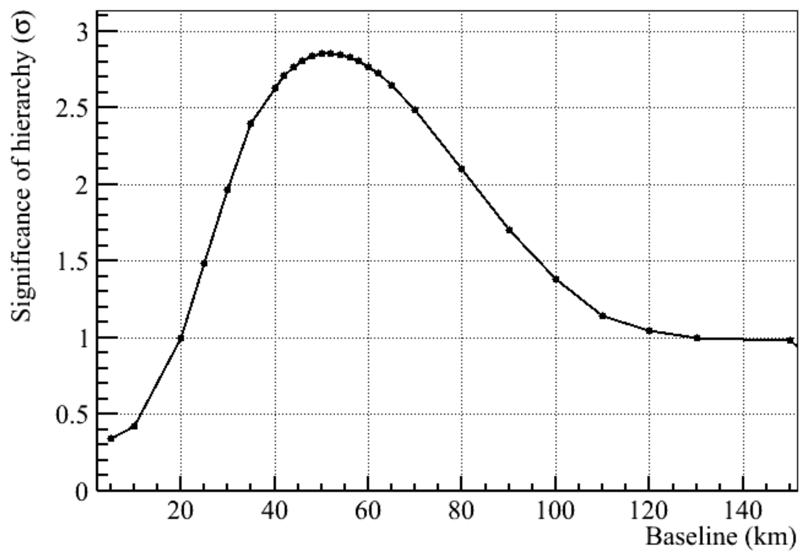


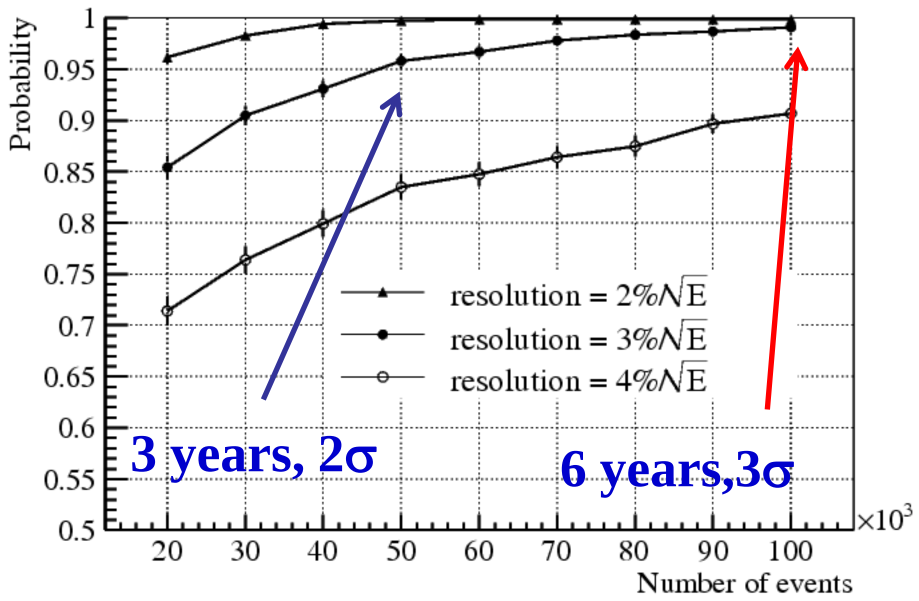
- 20 kton LS detector
- 3% energy resolution
- Rich physics possibilities
  - Mass hierarchy
  - Precision measurement of 4 mixing parameters
  - Supernovae neutrinos
  - Geoneutrinos
  - Sterile neutrinos
  - Atmospheric neutrinos
  - Exotic searches

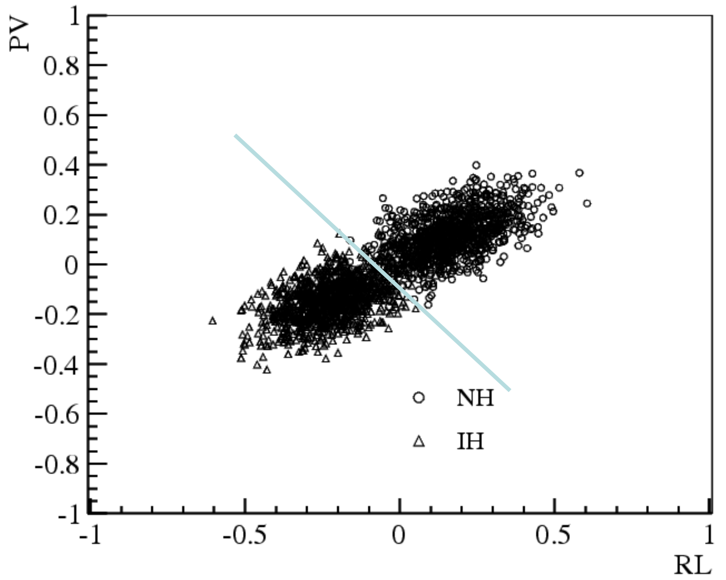
Talk by Y.F. Wang at ICFA seminar 2008, Neutel 2011; by J. Cao at Nutel 2009, NuTurn 2012 ;
Paper by L. Zhan, Y.F. Wang, J. Cao, L.J. Wen, PRD78:111103,2008; PRD79:073007,2009

Easier now with a large θ_{13}

- **New default parameters:**
  - **Detector size: 20kt**
  - **Energy resolution: 3%**
  - **Thermal power: 36 GW**
  - **Baseline 58 km**



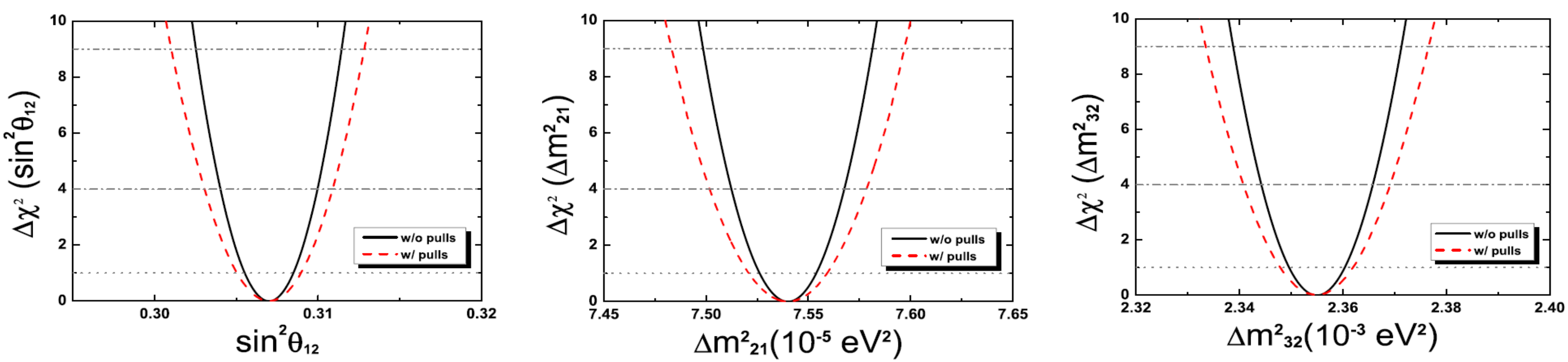




Precision Measurements

- **Fundamental to the Standard Model and beyond**
- **Probing the unitarity of U_{PMNS} to ~1% level !**

	Current	Daya Bay II
Δm^2_{12}	3%	0.26%
Δm^2_{23}	5%	0.30%
$\sin^2\theta_{12}$	6%	0.63%
$\sin^2\theta_{23}$	20%	N/A
$\sin^2\theta_{13}$	14% ➔ 4%	~ 15%



Supernova neutrinos

- Less than 20 events observed so far
- Assumptions:
  - Distance: 10 kpc (our Galaxy center)
  - Energy: 3×10^{53} erg
  - L_ν the same for all types
  - Tem. & energy

$T(\bar{\nu}_e) = 3.5$ MeV, $<E(\bar{\nu}_e)> = 11$ MeV

$T(\nu_e) = 5$ MeV, $<E(\nu_e)> = 16$ MeV

$T(\nu_x) = 8$ MeV, $<E(\nu_x)> = 25$ MeV

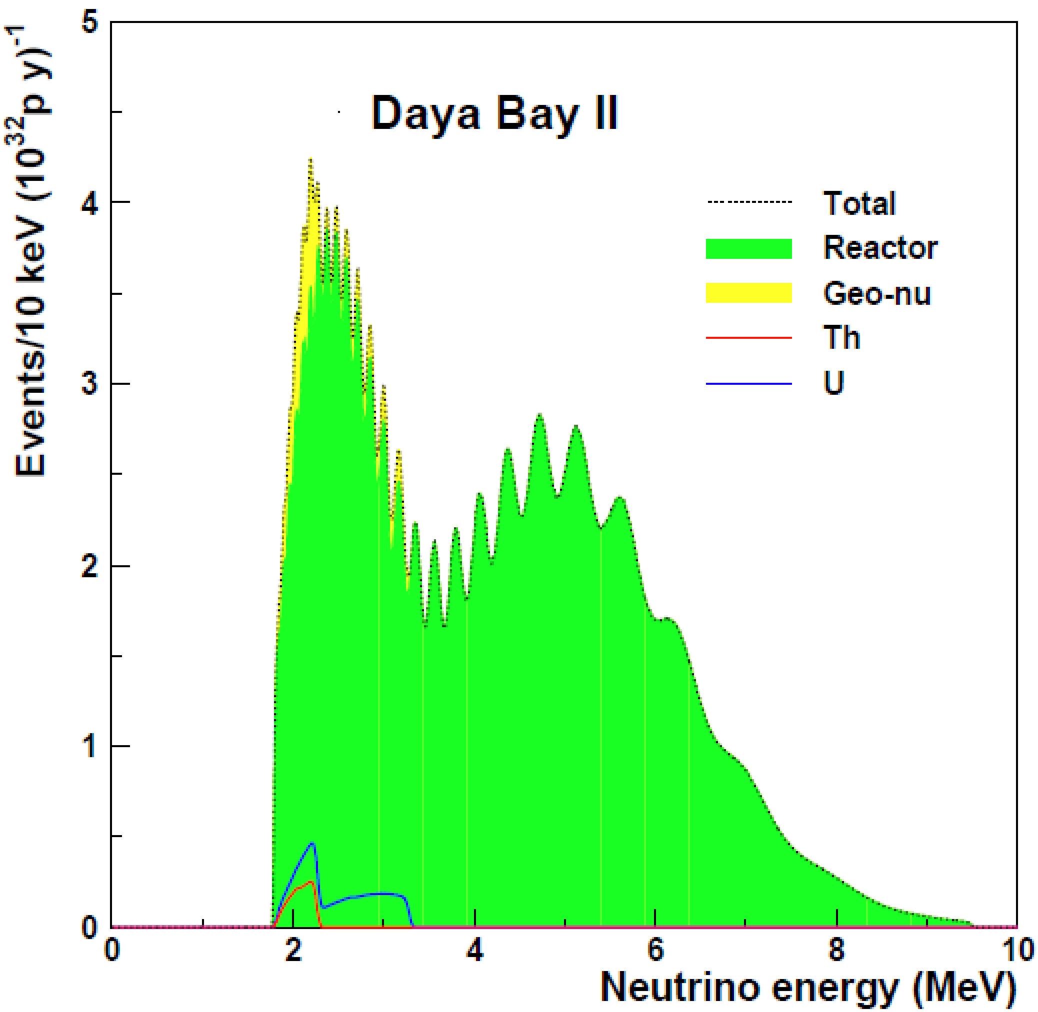
- Many types of events:
  - $\bar{\nu}_e + p \rightarrow n + e^+$, ~ 3000 correlated events
  - $\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B^* + e^+$, ~ 10-100 correlated events
  - $\nu_e + {}^{12}C \rightarrow {}^{12}N^* + e^-$, ~ 10-100 correlated events
  - $\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^*$, ~ 600 correlated events
  - $\nu_x + p \rightarrow \nu_x + p$, single events
  - $\nu_e + e^- \rightarrow \nu_e + e^-$, single events
  - $\nu_x + e^- \rightarrow \nu_x + e^-$, single events

Water Cerenkov detectors can not see these correlated events

Energy spectra & fluxes of all types of neutrinos

Geoneutrinos

- Current results:
  - KamLAND: 40.0±10.5±11.5 TNU
  - Borexino: 64±25±2 TNU
- Desire to reach an error of 3 TNU: statistically dominant
- Daya Bay II: >×10 statistics, but difficult on systematics
- Background to reactor neutrinos



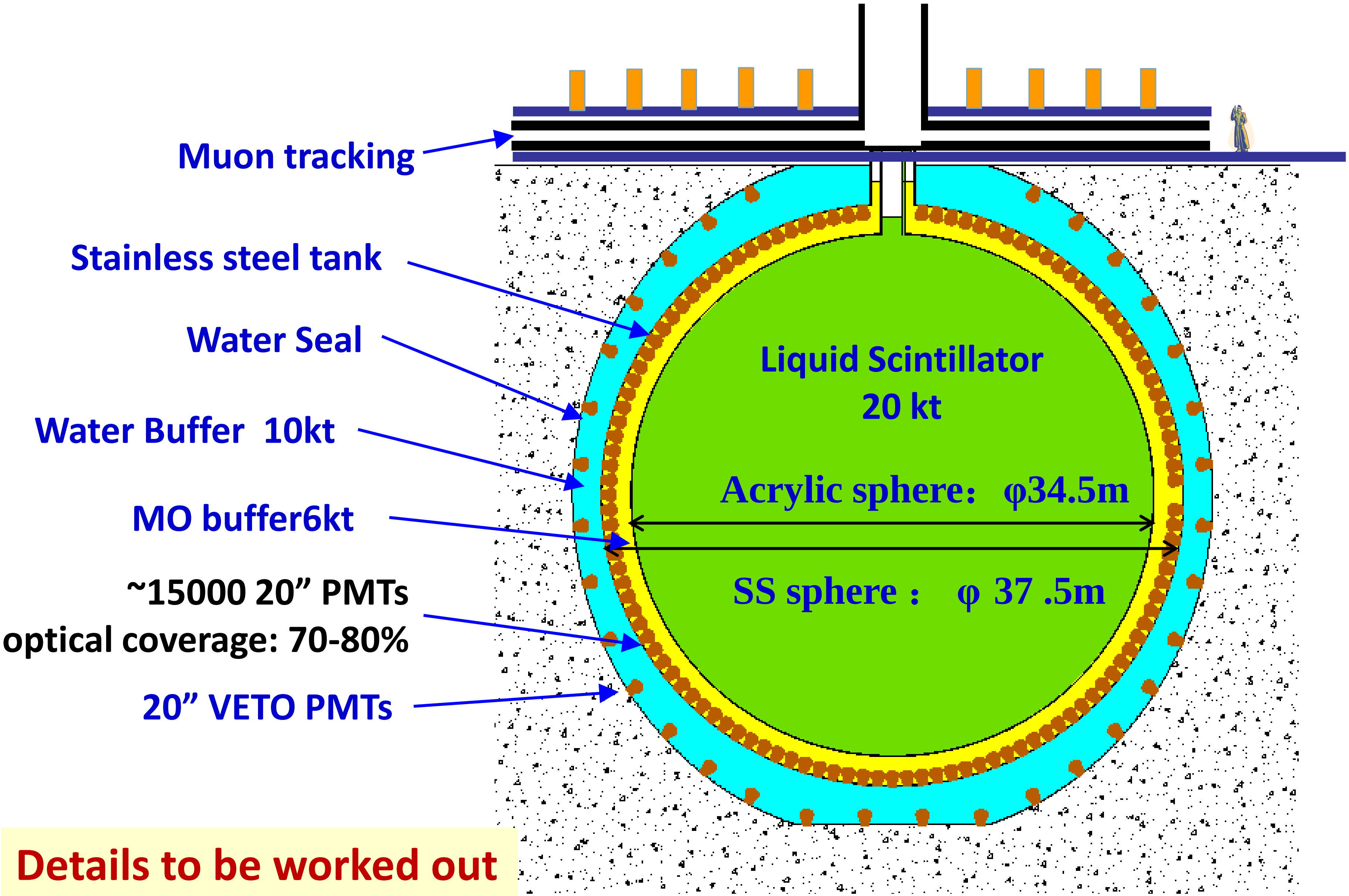
Stephen Dye

The reactors and possible site

	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

Overburden ~ 2000 MWE

Detector Concept



Details to be worked out

Technical Challenges

- **Requirements:**
  - ⇨ **Large detector: >10 kt LS**
  - ⇨ **Energy resolution: 3%/√E ➔ 1200 p.e./MeV**
- **Ongoing R&D:**
  - ⇨ **Low cost, high QE "PMT"**
  - ⇨ **Highly transparent LS: 15m ➔ 30m**

	KamLAND	Daya Bay II
LS mass	**~1 kt**	**20 kt**
Energy Resolution	**6%/√E**	**3%/√E**
Light yield	**250 p.e./MeV**	**1200 p.e./MeV**

More photons, how and how many ?

- **Highly transparent LS:**
  - ⇨ **Attenuation length/R: 15m/16m → 30m/35m ×0.9**
- **High light yield LS:**
  - ⇨ **KamLAND: 1.5g/l PPO → 5g/l PPO**

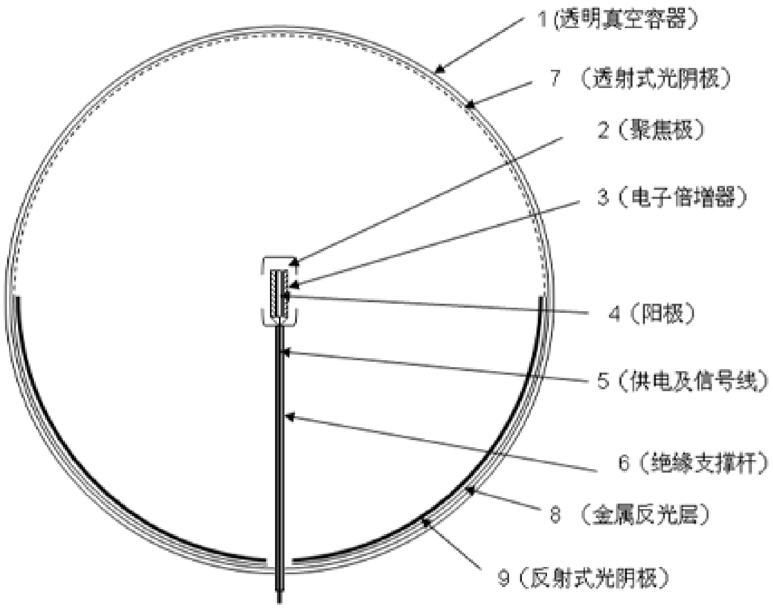
    Light Yield: 30%→ 45%; × 1.5
- **Photocathode coverage :**
  - ⇨ **KamLAND: 34% → ~ 80% × 2.3**
- **High QE "PMT":**
  - ⇨ **20" SBA PMT QE: 20% → 35% × 1.7**

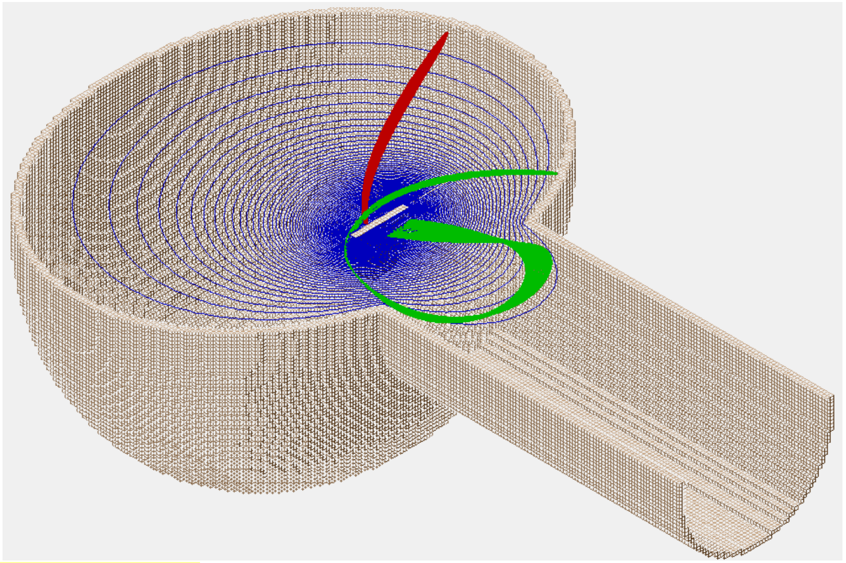
    or New PMT QE ~ 40% × 2

5.3 – 7.0 → (2.7 – 2.4)% /√E

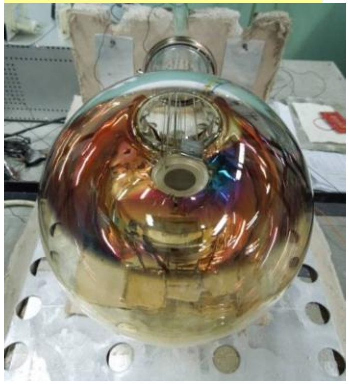
With 1% constant term & 1% neutron recoil uncertainty, we are still OK

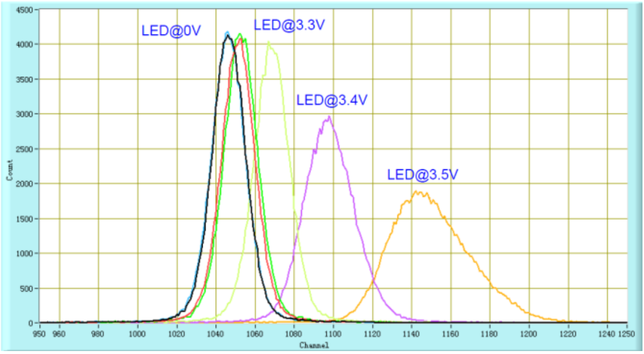
A new type of PMT: higher photon detection eff.





8” MCP-PMT





- Top: transmitted photocathode
- Bottom: reflective photocathode

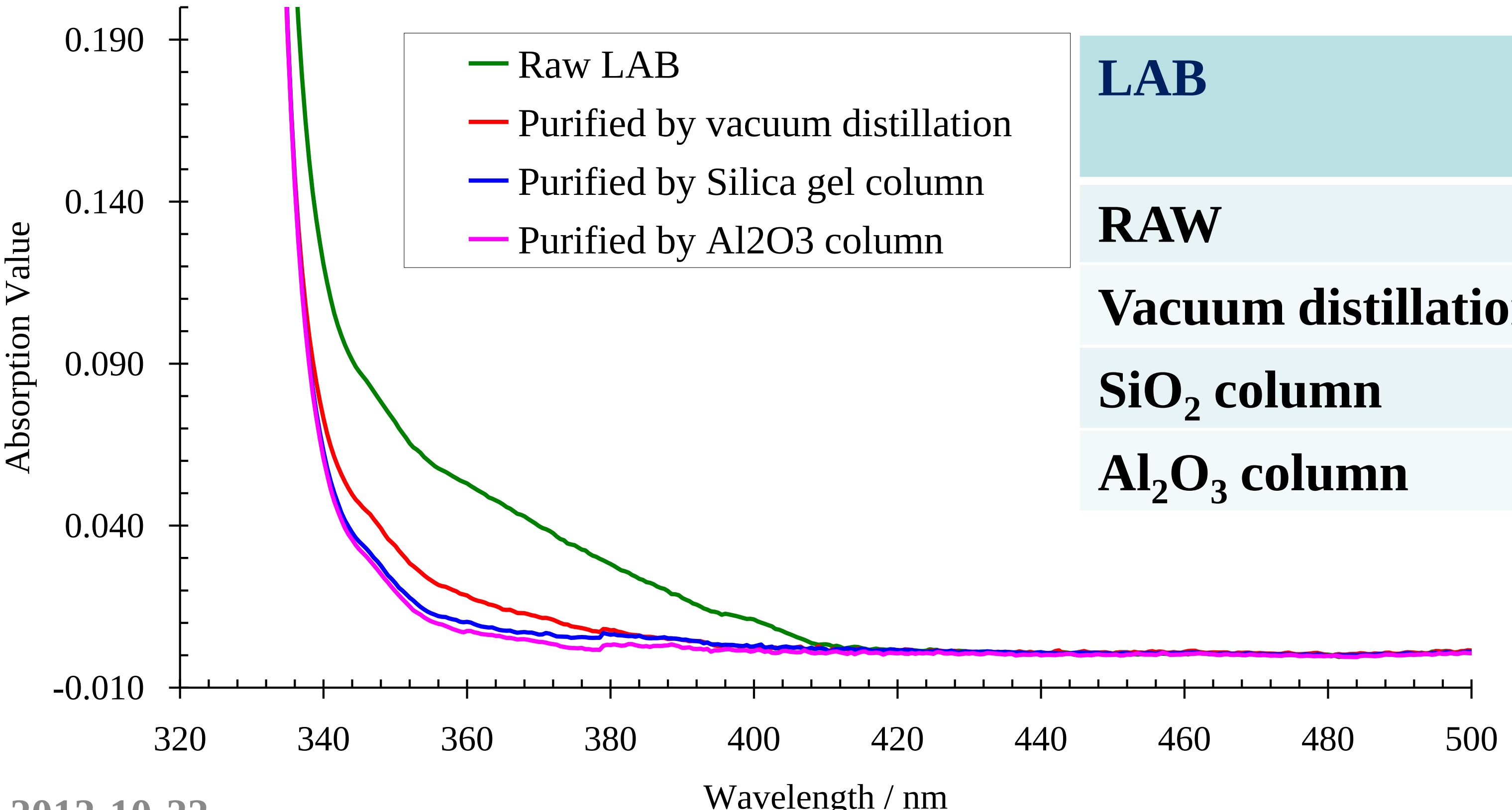
  additional QE: ~ 80%*40%
- MCP to replace Dynodes ➔ no blocking of photons

~ ×2 improvement

Prototypes

How to get transparent LS ?

- **Improve raw materials (using Dodecane instead of MO for LAB production）**
- **Improve the production process**
- **Purification**



LAB	Atte. Length @ 430 nm
RAW	14.2 m
Vacuum distillation	19.5 m
SiO_2 column	18.6 m
Al_2O_3 column	22.3 m

50

Summary

- **Electron anti-neutrino disappearance is observed at Daya Bay,**

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

  together with a spectral distortion

- **A new type of neutrino oscillation is thus discovered**

Updated Results on June. 4, 2012:

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

$\chi^2/NDF = 3.4/4$, 7.7 σ for non-zero θ_{13}

First Results on Mar. 8, 2012:

$\sin^2 2\theta_{13} = 0.092 \pm 0.016 (stat) \pm 0.005 (syst)$

$\chi^2/NDF = 4.26/4$, 5.2 σ for non-zero θ_{13}

- **Future of reactor neutrinos: Mass hierarchy**

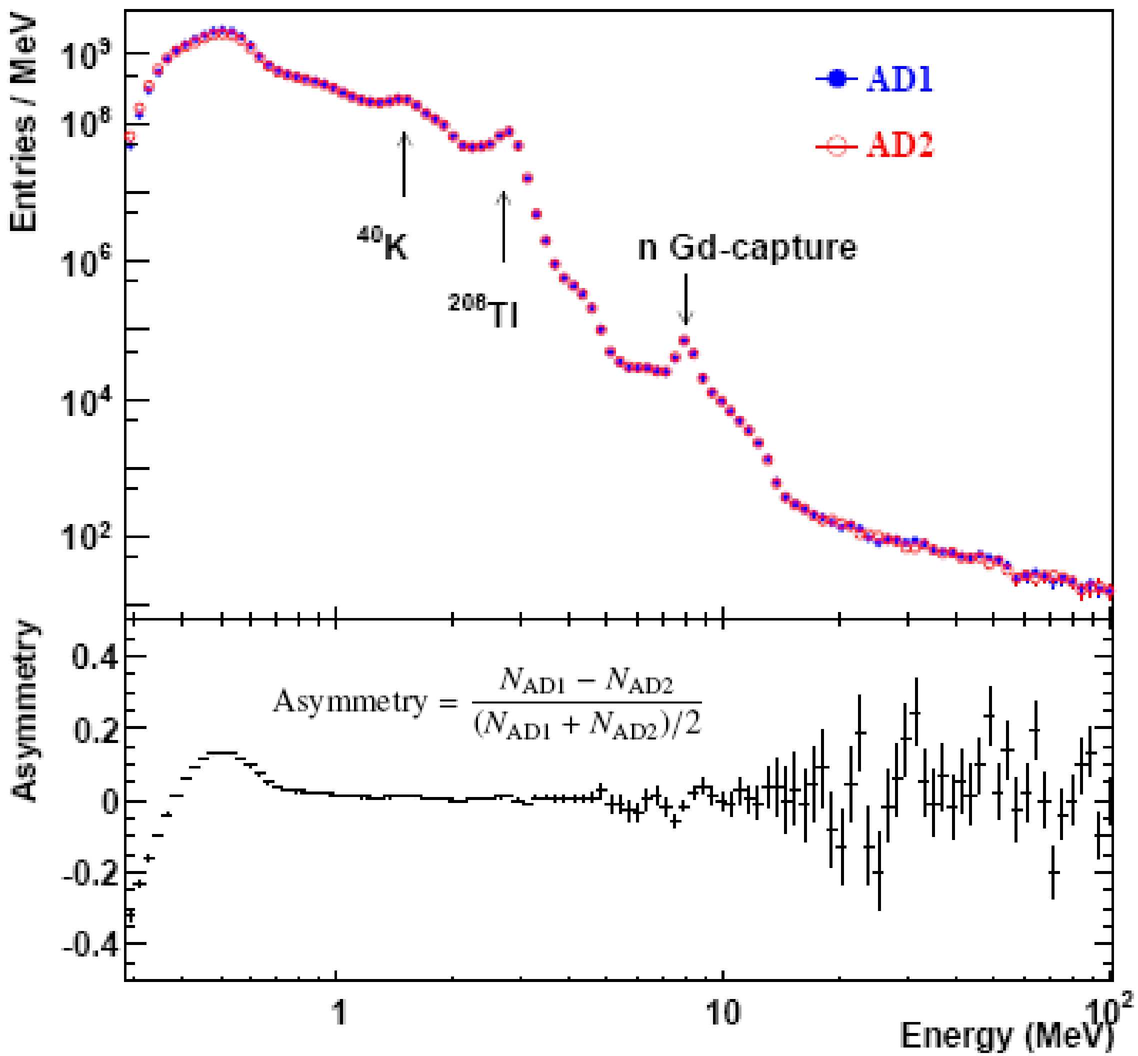
backup

Single Rate: Understood

- Design: ~50Hz above 1 MeV
- Data: ~60Hz above 0.7 MeV, ~40Hz above 1 MeV

- From sample purity and MC simulation, each of the following component contribute to singles
  - ~ 5 Hz from SSV
  - ~ 10 Hz from LS
  - ~ 25 Hz from PMT
  - ~ 5 Hz from rock

- All numbers are consistent



Backgrounds & uncertainties

	Daya Bay		Reno		Double Chooz
	Near	Far	Near	Far	Far
Accidentals (B/S)	1.4%	4.0%	0.56%	0.93%	0.6%
Uncertainty(ΔB/B)	1.0%	1.4%	1.4%	4.4%	0.8%
Fast neutrons(B/S)	0.1%	0.06%	0.64%	1.3%	1.6%
Uncertainty(ΔB/B)	31%	40%	2.6%	6.2%	30%
^{8}He/^{9}Li (B/S)	0.4%	0.3%	1.6%	3.6%	2.8%
Uncertainty (ΔB/B)	52%	55%	48%	29%	50%
α-n(B/S)	0.01%	0.05%	-	-	-
Uncertainty(ΔB/B)	50%	50%	-	-	-
Am-C(B/S)	0.03%	0.3%	-	-	-
Uncertainty (ΔB/B)	100%	100%	-	-	-
Total backgrounds(B/S)	1.9%	4.7%	2.8%	5.8%	5.0%
Total Uncertainties (Δ(B/S))	0.2%	0.35%	0.8%	1.1%	1.5%

Efficiencies and Systematics

	Daya Bay		Reno		Double Chooz
	Corr.	Uncorr.	Corr.	Uncorr.	Corr/Uncorr.
Target proton	0.47%	0.03%	0.5%	0.1%	0.3%
Flasher cut	0.01%	0.01%	0.1%	0.01%	-
Delayed energy cut	0.6%	0.12%	0.5%	0.1%	0.7%
Prompt energy cut	0.1%	0.01%	0.1%	0.01%	-
Energy response	-	-	-	-	0.3%
Trigger efficiency					<0.1%
Multiplicity cut	0.02%	<0.01%	0.06%	0.04%	-
Capture time cut	0.12%	0.01%	0.5%	0.01%	0.5%
Gd capture ratio	0.8%	<0.1%	0.7%	0.1%	0.3%
Spill-in	1.5%	0.02%	1.0%	0.03%	0.3%
livetime	0.002%	<0.01%			-
Muon veto cut	-	-	0.06%	0.04%	-
Total	1.9%	0.2%	1.5%	0.2%	1.0%

Reactor flux estimate

	Daya Bay		Reno		Double Chooz
	Corr.	Uncorr.	Corr.	Uncorr.	Corr./Uncorr.
Thermal power		0.5%		0.5%	0.5%
Fission fraction/Fuel composition		0.6%		0.7%	0.9%
Fission cross section /Bugey 4 measurement	3%		1.9%		1.4%
Reference spectra			0.5%		0.5%
IBD cross section			0.2%		0.2%
Energy per fission	0.2%		0.2%		0.2%
Baseline	0.02%		-		0.2%
Spent fuel		0.3%			
Total	3%	0.8%	2.0%	0.9%	1.8%