

Reactor Neutrino Results

Jun Cao

Institute of High Energy Physics



**36th International Conference
on High Energy Physics**

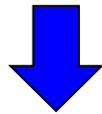
4 – 11 July 2012

Melbourne Convention and Exhibition Centre

Neutrino Mixing

In a 3- ν framework

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



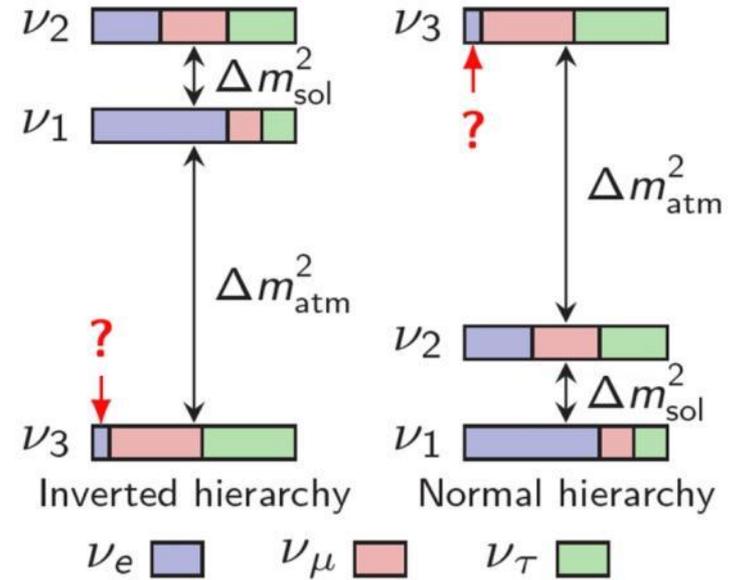
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & e^{-i\delta} & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\rho} & 0 & 0 \\ 0 & e^{i\sigma} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\theta_{23} \sim 45^\circ$
Atmospheric
Accelerator

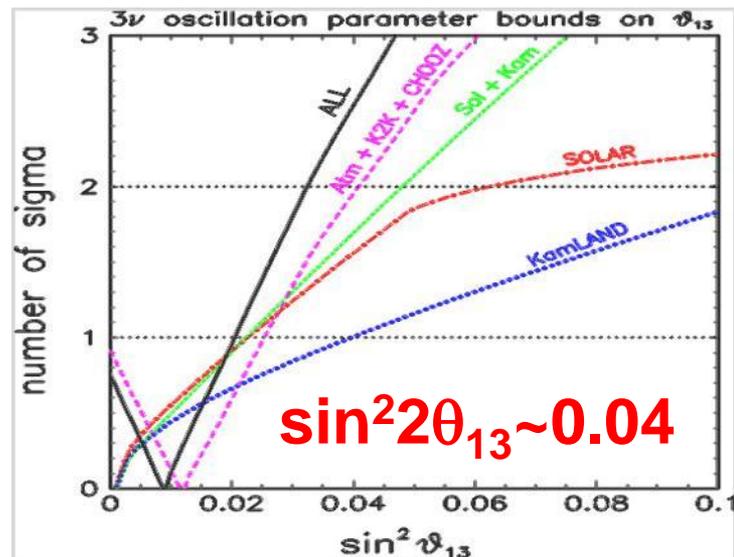
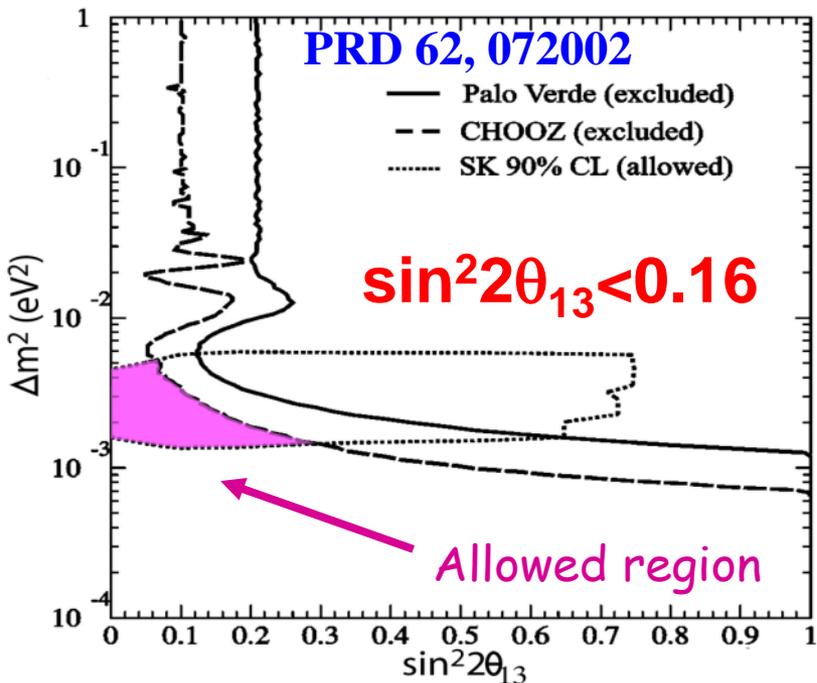
$\theta_{13} = ?$
Reactor
Accelerator

$\theta_{12} \sim 34^\circ$
Solar
Reactor

$0\nu\beta\beta$

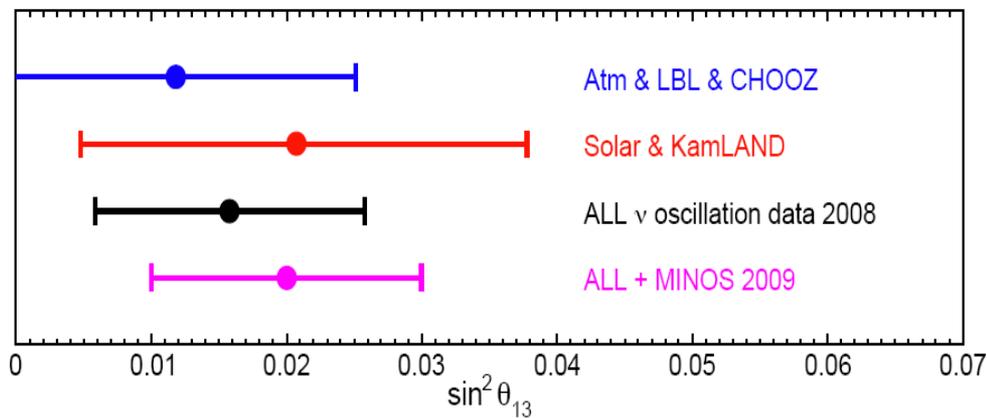
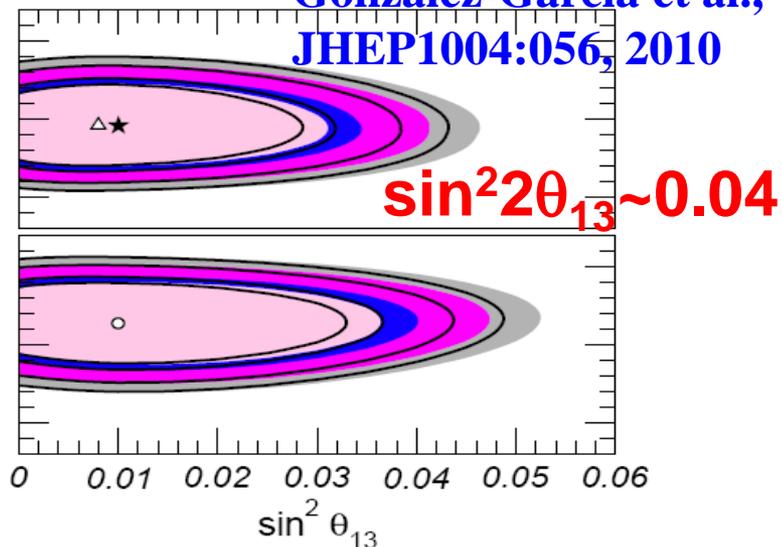


How large is θ_{13} ?



Fogli et al., hep-ph/0506307

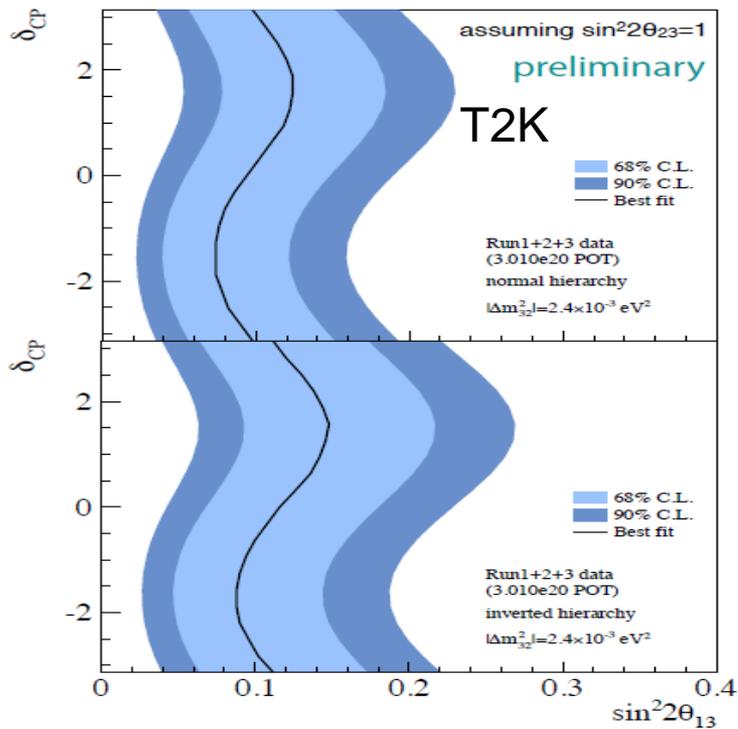
Gonzalez-Garcia et al.,
JHEP1004:056, 2010



$\sin^2 2\theta_{13} \sim 0.08$, non-zero 2σ

Fogli et al., J.Phys.Conf.Ser.203:012103 (2010)

How to measure θ_{13}



Accelerator (appearance)

Related with CPV and matter effect

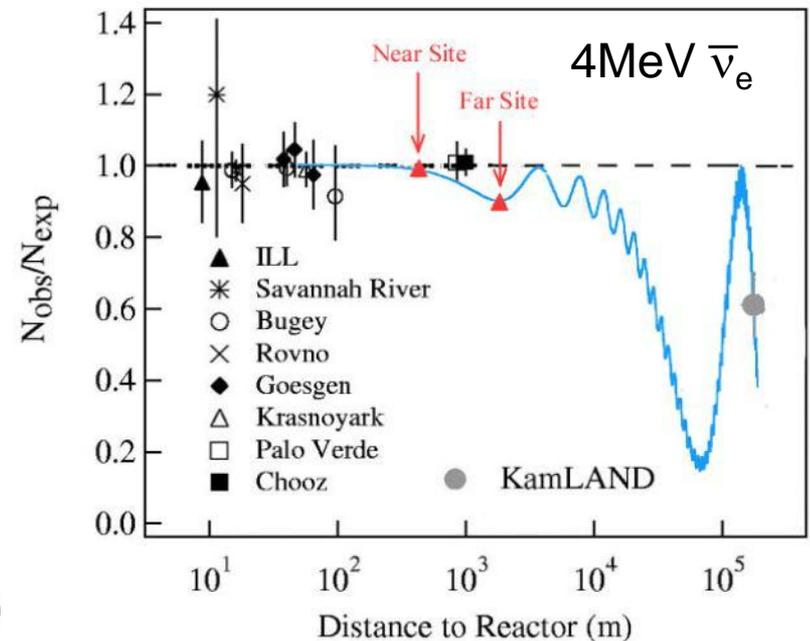
$$P_{\nu_{\mu} \rightarrow \nu_e} = \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2 \left(\Delta m_{31}^2 L / 4E \right) + (\text{CPV term}) + (\text{matter term}) + \dots$$

Reactor (disappearance)

Clean in physics, only related to θ_{13}

Precision measurement

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e} \approx 1 - \sin^2 2\theta_{13} \sin^2 \left(\Delta m_{31}^2 L / 4E \right) - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \left(\Delta m_{21}^2 L / 4E \right)$$



Precision Measurement at Reactors

Major sources of uncertainties:

- ◆ Reactor related ~2%
- ◆ Detector related ~2%
- ◆ Background 1~3%

Lessons from past experience:

- ◆ CHOOZ: Good Gd-LS
- ◆ Palo Verde: Better shielding
- ◆ KamLAND: No fiducial cut

Near-far relative measurement
Mikaelyan and Sinev, hep-ex/9908047

| Parameter | Error | Near-far |
|-----------------------------|--------------|------------------|
| Reaction cross section | 1.9 % | 0 |
| Energy released per fission | 0.6 % | 0 |
| Reactor power | 0.7 % | ~0.1% |
| Number of protons | 0.8 % | < 0.3% |
| Detection efficiency | 1.5 % | 0.2~0.6% |
| CHOOZ Combined | 2.7 % | < 0.6% |

Proposed Reactor Experiments

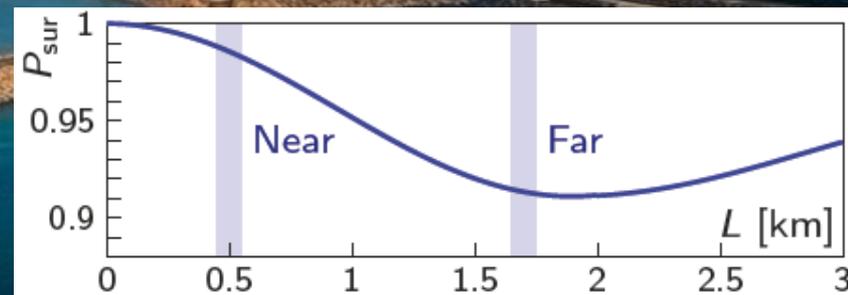
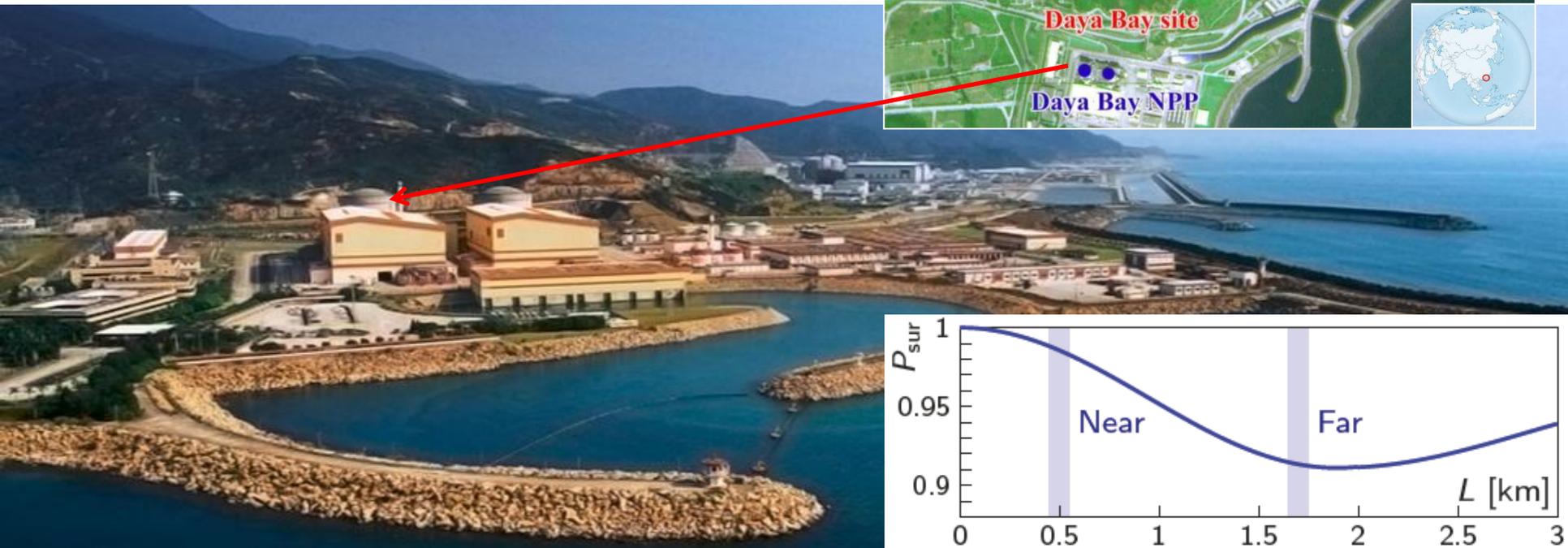
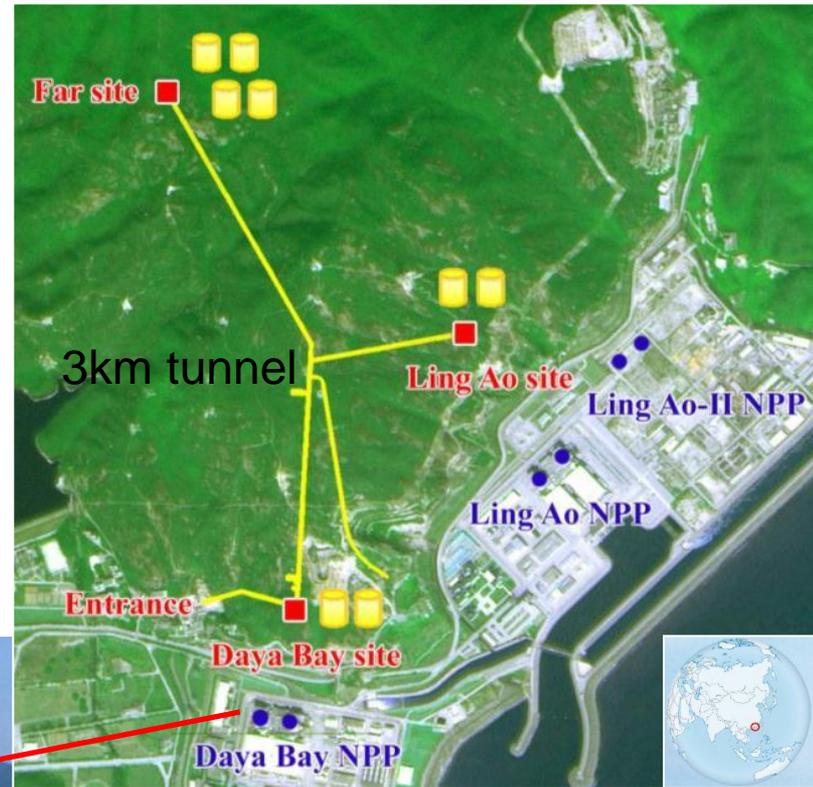


8 proposals, most in 2003 (3 on-going)

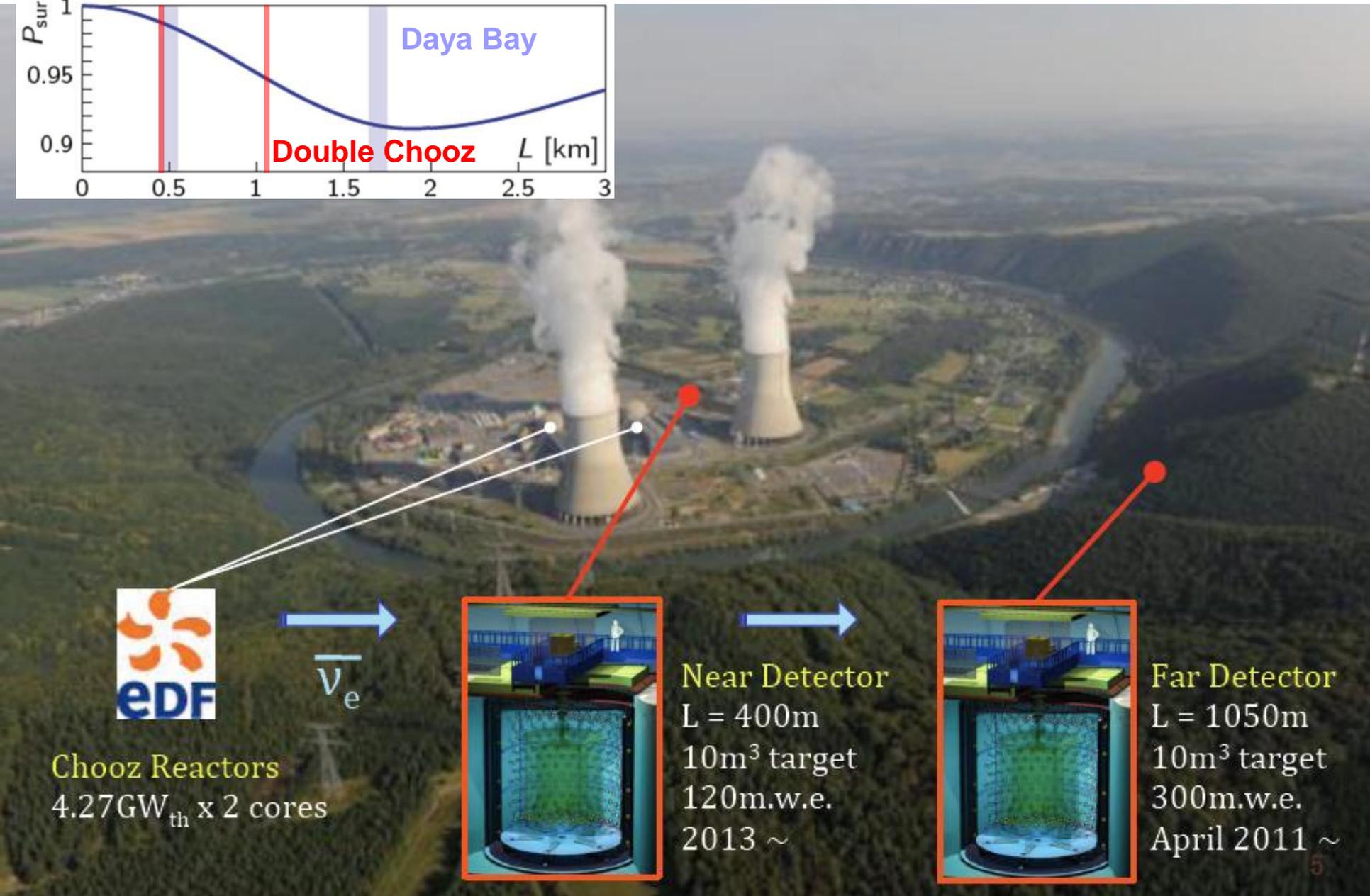
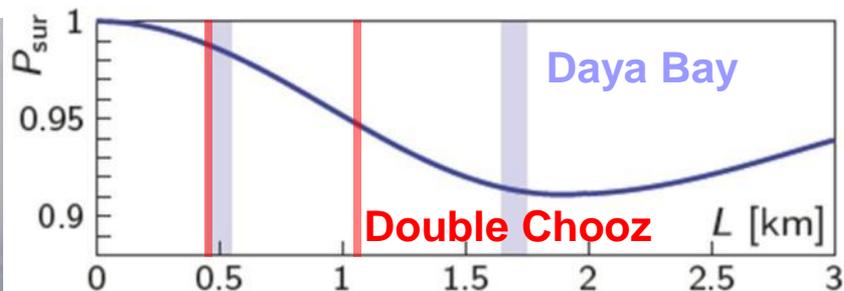
- Fundamental parameter
- Gateway to ν -CPV and Mass Hierachy measurements
- Less expensive

The Daya Bay Experiment

- 6 reactor cores, 17.4 GW_{th}
- Relative measurement
 - 2 near sites, 1 far site
- Multiple detector modules
- Good cosmic shielding
 - 250 m.w.e @ near sites
 - 860 m.w.e @ far site
- Redundancy



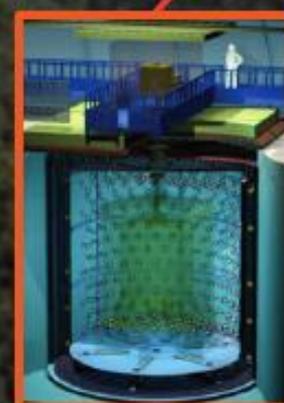
Double Chooz



Chooz Reactors
4.27GW_{th} x 2 cores



Near Detector
L = 400m
10m³ target
120m.w.e.
2013 ~



Far Detector
L = 1050m
10m³ target
300m.w.e.
April 2011 ~

RENO

16t, 120 MWE

6 cores
16.5 GW

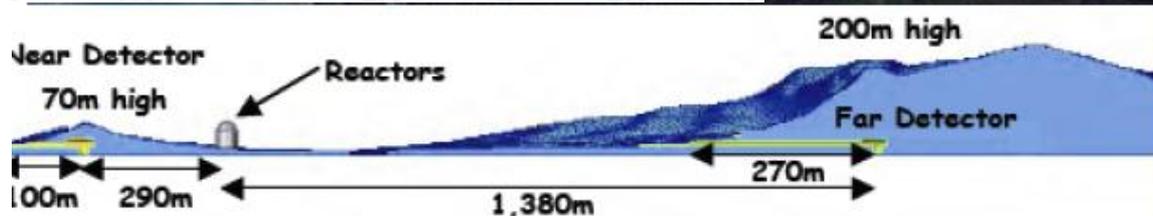
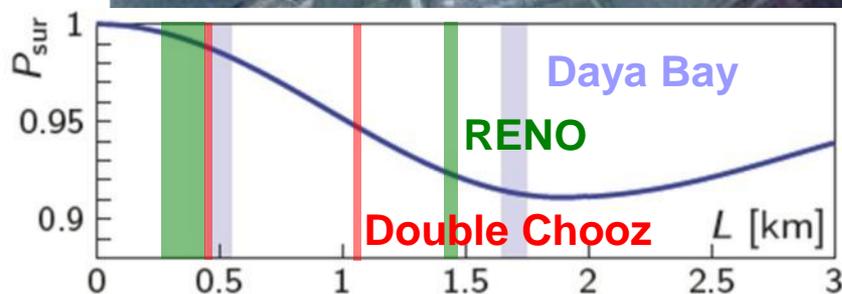
Near Detector

290m

1380m

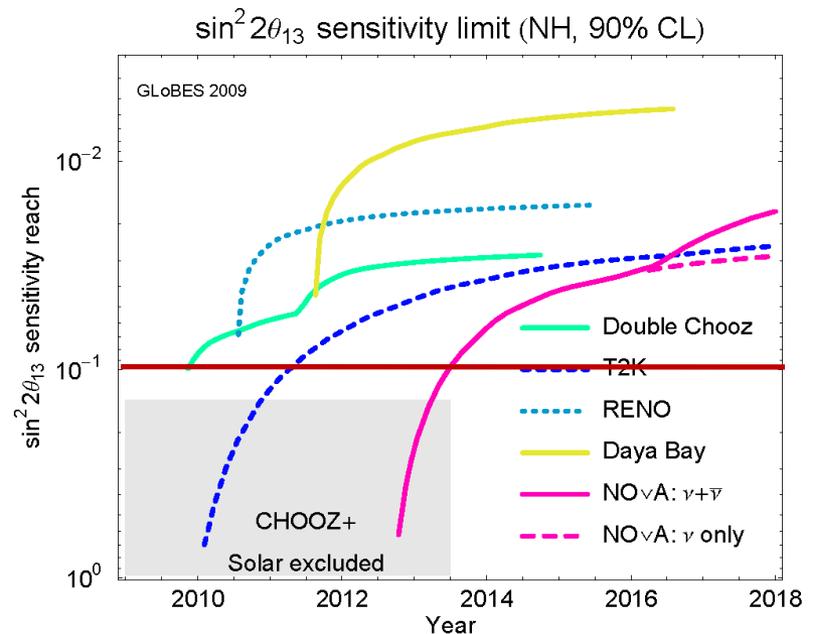
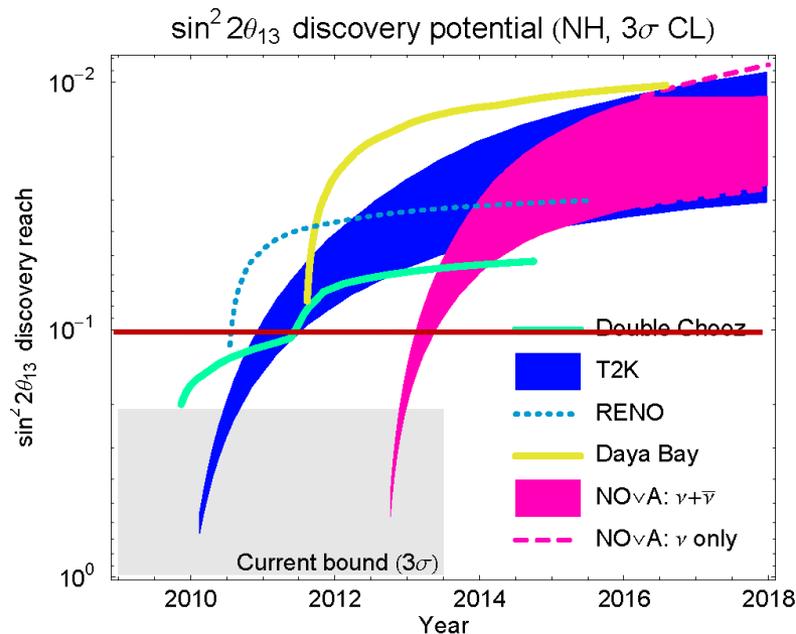
Far Detector

16t, 450 MWE



Three on-going experiments

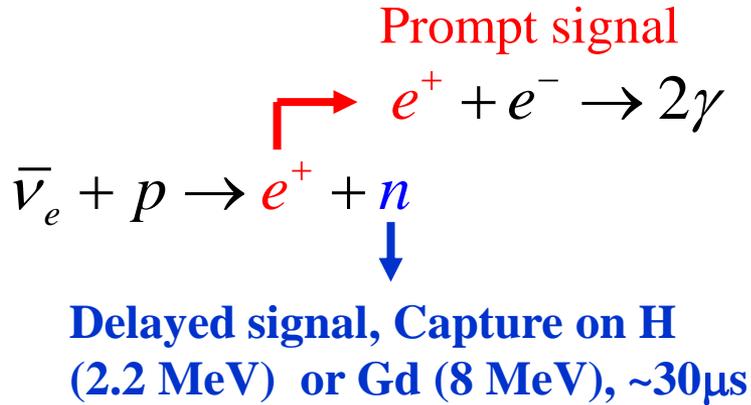
| Experiment | Power (GW) | Detector(t) Near/Far | Overburden (m.w.e.) Near/Far | Sensitivity (3y,90%CL) |
|--------------|------------|----------------------|------------------------------|------------------------|
| Daya Bay | 17.4 | 40 / 80 | 250 / 860 | ~ 0.008 |
| Double Chooz | 8.5 | 8 / 8 | 120 / 300 | ~ 0.03 |
| RENO | 16.5 | 16 / 16 | 120 / 450 | ~ 0.02 |



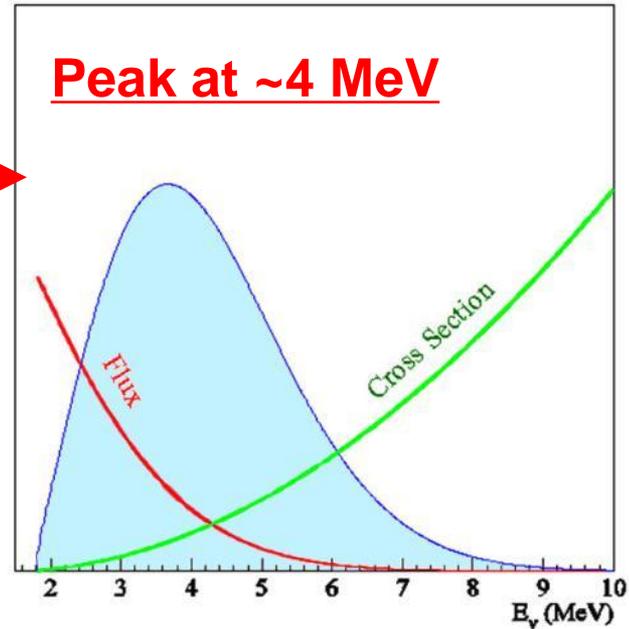
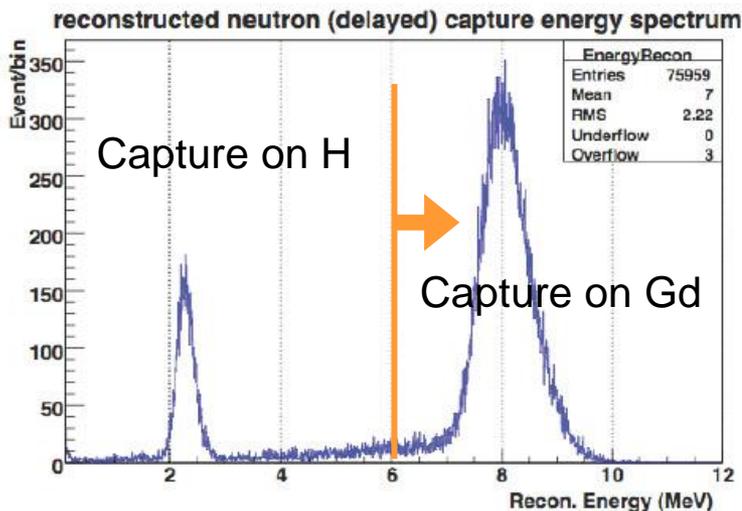
Huber et al. JHEP 0911:044, 2009

Detecting Reactor Antineutrino

Inverse beta decay



0.1% Gd by weight



Major backgrounds:

- ◆ **Cosmogenic neutron/isotopes**
 - ⇒ $^8\text{He}/^9\text{Li}$
 - ⇒ **fast neutron**
- ◆ **Ambient radioactivity**
 - ⇒ **accidental coincidence**

Similar Detector Design

Water

- Shield radioactivity and cosmogenic neutron
- Cherekov detector for muon

RPC or Plastic scintillator

⇒ muon veto

Three-zone neutrino detector

⇒ Target: Gd-loaded LS

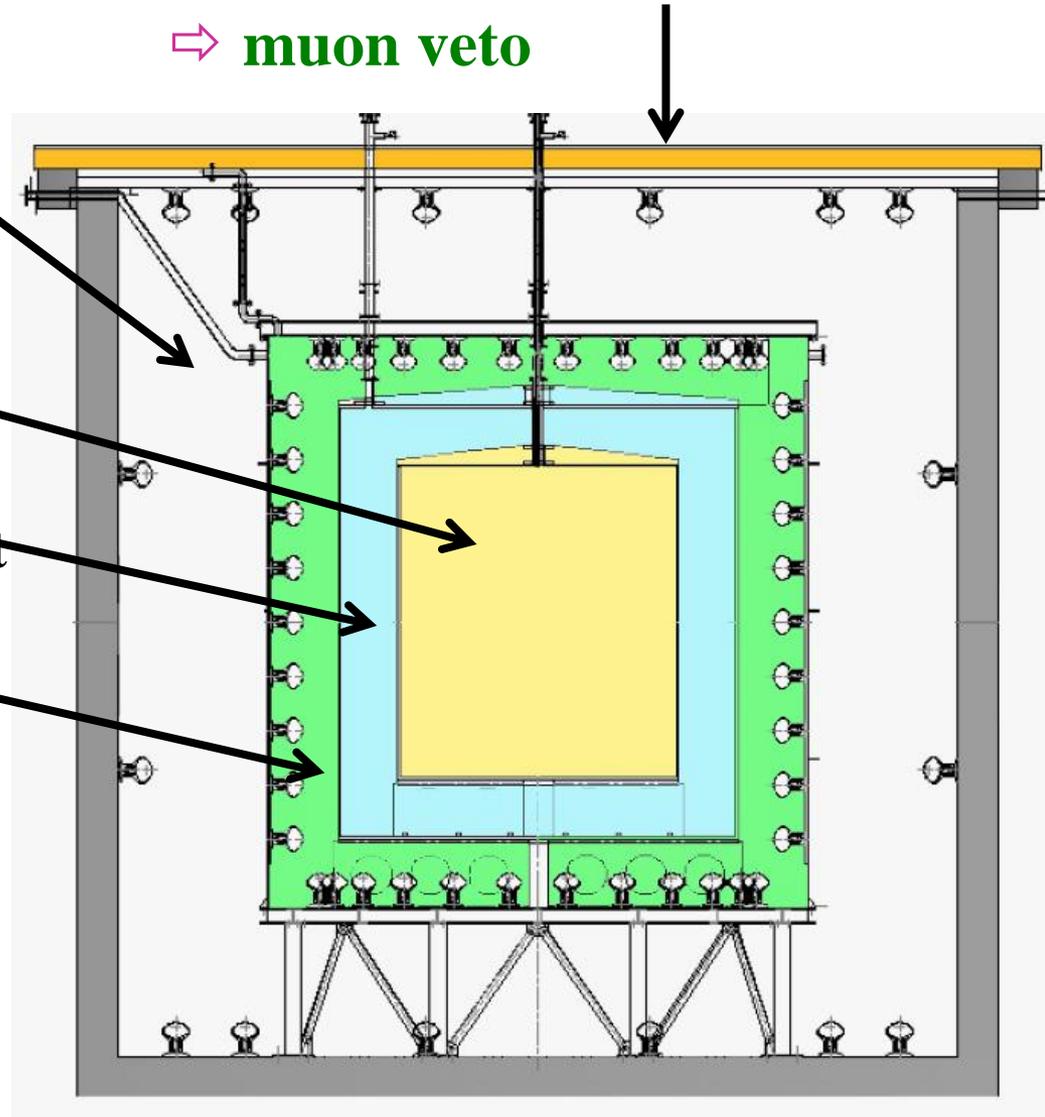
- 8-20 t for neutrino

⇒ γ -catcher: normal LS

- 20-30 t for energy containment

⇒ Buffer shielding: oil

- 40-100 t for shielding



Similar Detector Design

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- Shield radioactivity and cosmogenic neutron
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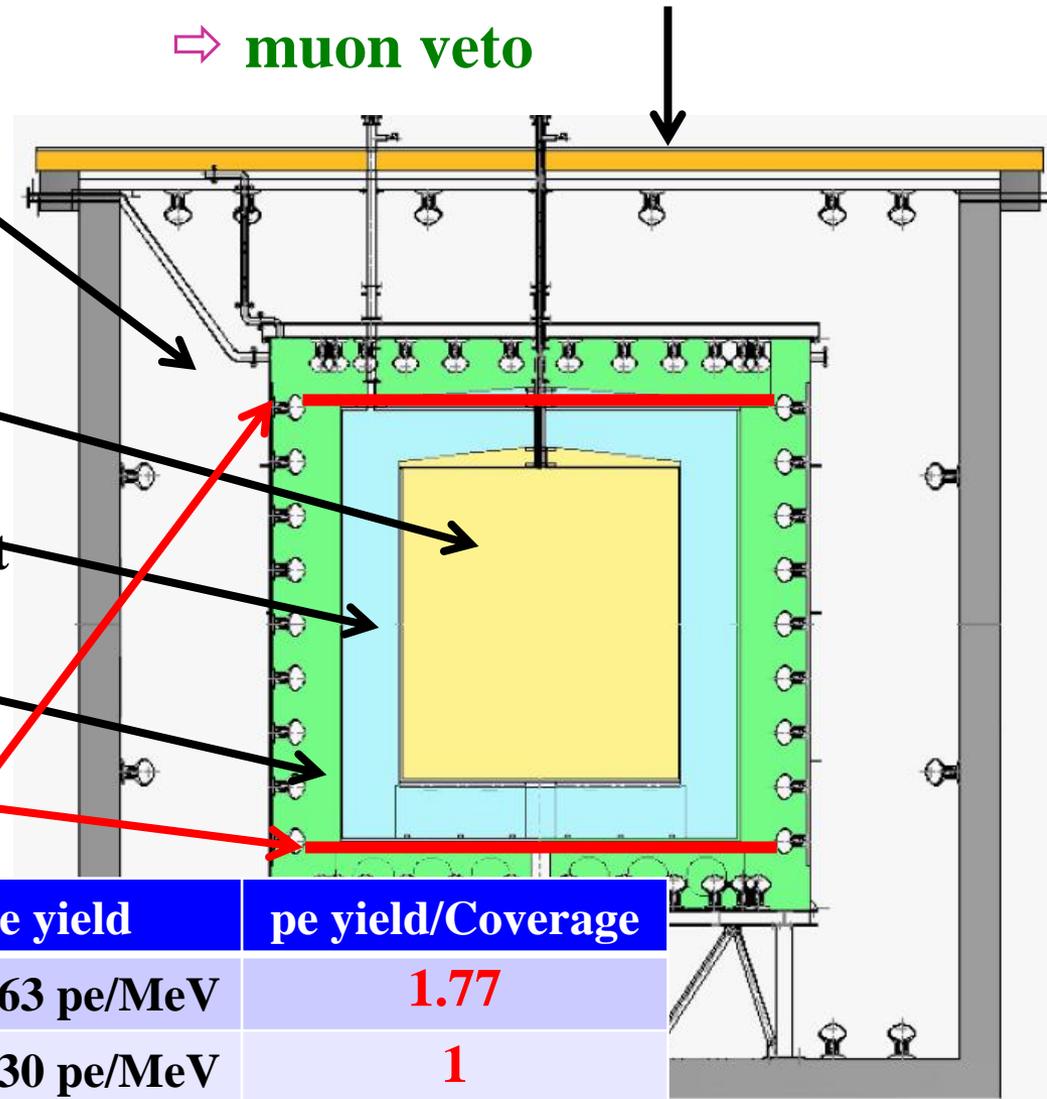
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⇒ Buffer shielding: oil

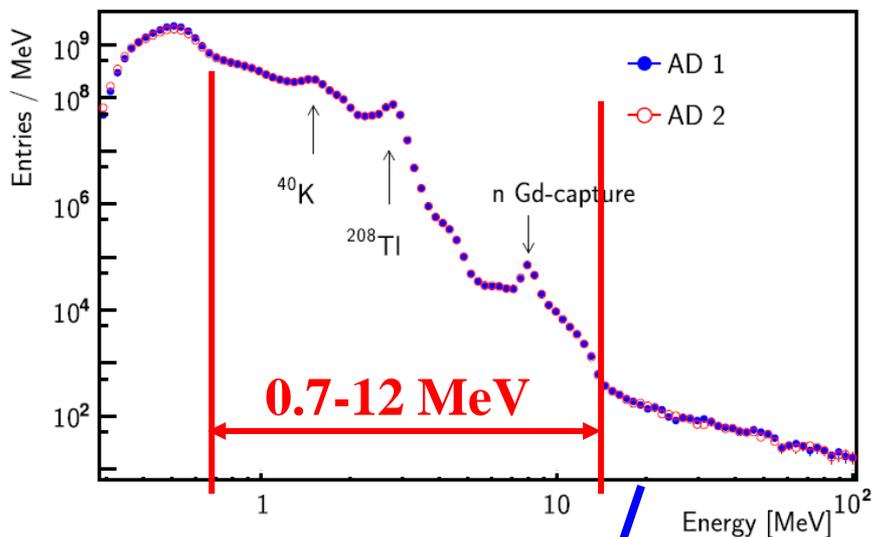
- 40-100 t for shielding

Daya Bay Reflective panels

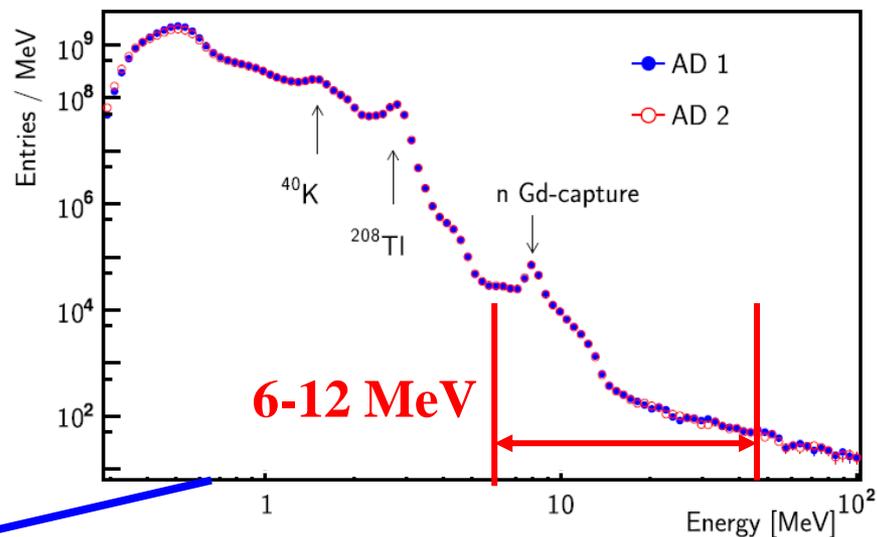


| | PMT | Coverage | pe yield | pe yield/Coverage |
|--------------|---------|----------|------------|-------------------|
| Daya Bay | 192 8" | ~6% | 163 pe/MeV | 1.77 |
| RENO | 354 10" | ~15% | 230 pe/MeV | 1 |
| Double Chooz | 390 10" | ~16% | 200 pe/MeV | 0.81 |

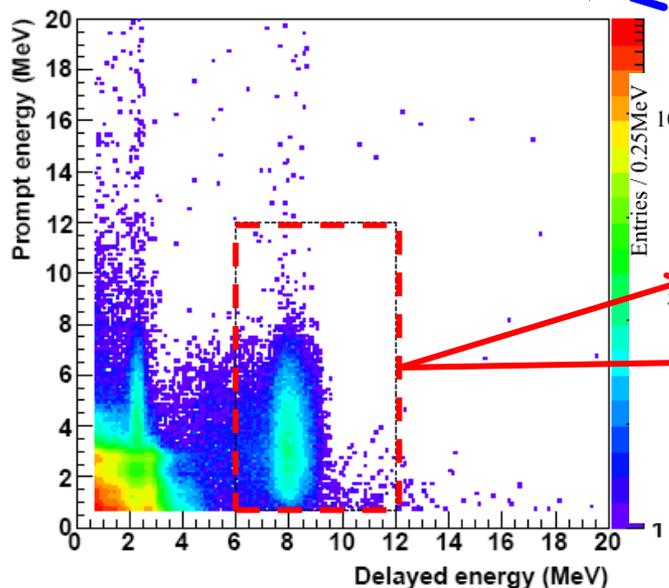
Neutrino Selections



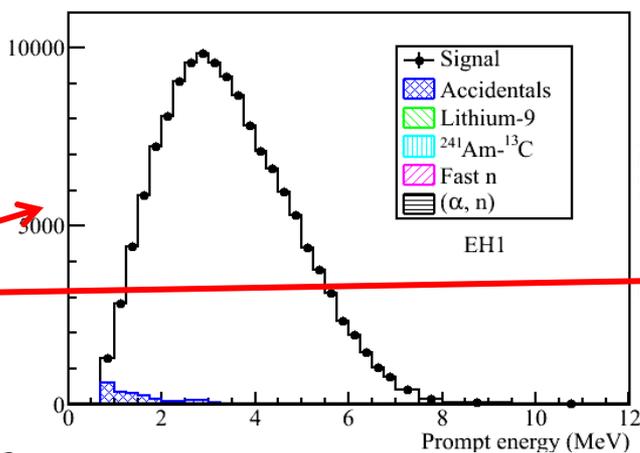
Prompt candidate



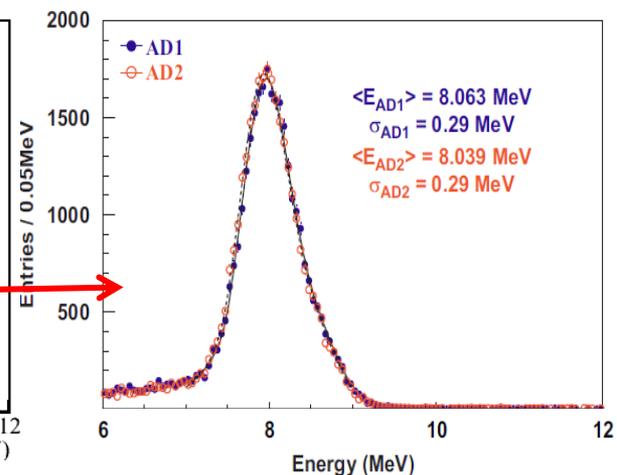
Delayed candidate



Correlated Events in 1-200 μ s

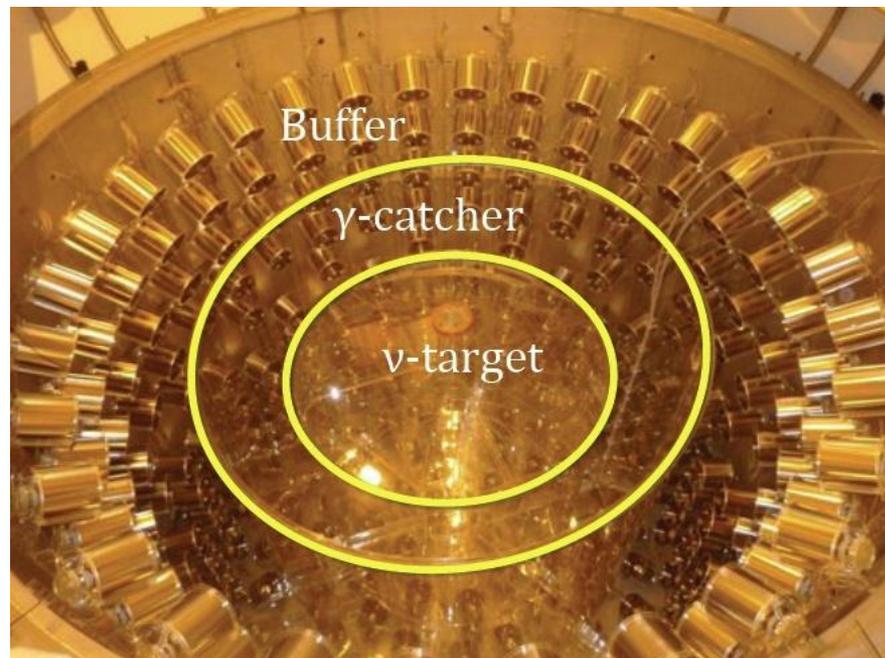


**Reactor Neutrinos
(Prompt)**



Neutrons (Delayed)

Double Chooz Results



- ◆ Far detector starts data taking at the beginning of 2011
- ◆ First results in Nov. 2011 based on 85.6 days of data

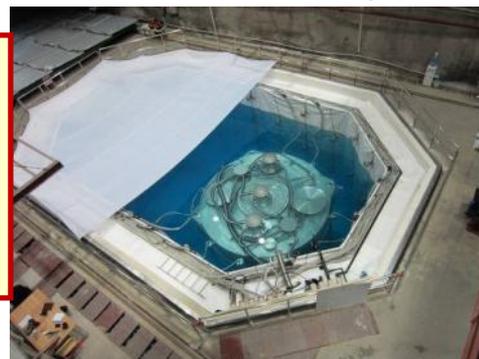
$\sin^2 2\theta_{13} = 0.086 \pm 0.041(\text{Stat}) \pm 0.030(\text{Syst}), 1.7\sigma$ for non-zero θ_{13}

- ◆ Updated results on Jun.4, 2012, based on 228 days of data

$\sin^2 2\theta_{13} = 0.109 \pm 0.030(\text{Stat}) \pm 0.025(\text{Syst}), 3.1\sigma$ for non-zero θ_{13}

Daya Bay Results

2011-11-5



L3
L4

Ling Ao-II NPP

L1
L2

Ling Ao NPP

2011-8-15



EH1

AD1 AD2

D1
D2

Daya Bay NPP

Mar.8, 2012, with 55 day data

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

5.2 σ for non-zero θ_{13}

2011-12-24



EH2

AD3

EH3

AD6 AD4
AD5

2011-8-15

2011-8-15

Jun.4, 2012, with 139 day data

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

7.7 σ for non-zero θ_{13}

RENO



- ◆ Data taking started on Aug. 11, 2011
- ◆ First physics results based on 228 days data taking (up to Mar. 25, 2012) released on April 3, 2012, revised on April 8, 2012:

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(\text{Stat}) \pm 0.019(\text{Syst}), \quad 4.9\sigma \text{ for non-zero } \theta_{13}$$

Backgrounds

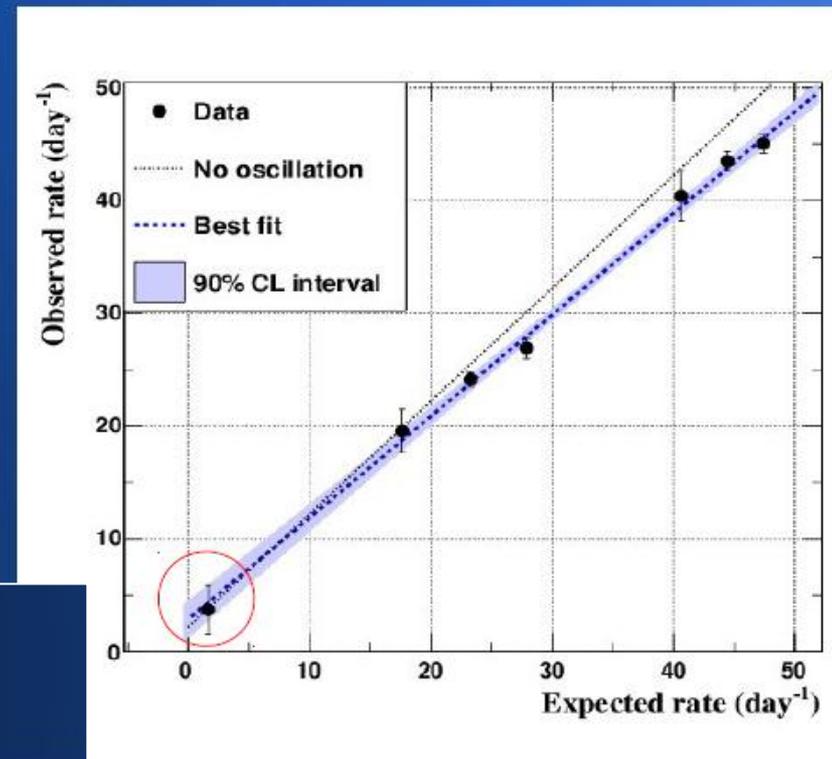
| | Daya Bay | | RENO | | Double Chooz |
|---|----------|-------|-------|-------|--------------|
| | Near | Far | Near | Far | Far |
| Accidentals (B/S) | 1.4% | 4.0% | 0.56% | 0.93% | 0.6% |
| $\Delta B/B$ (data/statistics) | 1.0% | 1.4% | 1.4% | 4.4% | 0.8% |
| Fast neutrons (B/S) | 0.1% | 0.06% |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

Backgrounds at Double Chooz: Reactor-off

- live-time with both reactors off: 0.84 day
 - Total background rate = **2.2 event/day** (two events)
- Consistent with estimation:
 - **2.2 ± 0.6 event/day**
- Best fit to expected rate: 
 - **2.9 ± 1.1 event/day**
- 7.53 more days with off-off data:
 - Analysis ongoing...

• Background rate: 1.0 ± 0.4 events/day

• Expected: 1.7 ± 0.3 events/day



Efficiencies and Systematics

Uncorr: Data
Corr.: MC+data

| | Daya Bay | | RENO | | Double Chooz |
|---------------------------|-------------|-------------|-------------|-------------|-----------------------|
| | Corr. | Uncorr. | Corr. | Uncorr. | Corr \oplus 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% |

Functional Identical Detectors

- ◆ **Why systematics is so small?** c.f. An et al. NIM. A 685 (2012) 78
 - ⇒ **Idea of "identical detectors" throughout the procedures of design / fabrication / assembly / filling.**
 - ⇒ **For example: Inner Acrylic Vessel, designed $D=3120\pm 5$ mm**
 - Variation of D by geometry survey=**1.7mm**, Var. of volume: 0.17%
 - Target mass var. by load cell measurement during filling: 0.19%

| Diameter | IAV1 | IAV2 | IAV3 | IAV4 | IAV5 | IAV6 |
|----------------|---------|---------|---------|---------|---------|---------|
| Surveyed(mm) | 3123.12 | 3121.71 | 3121.77 | 3119.65 | 3125.11 | 3121.56 |
| Variation (mm) | 1.3 | 2.0 | 2.3 | 1.8 | 1.5 | 2.3 |

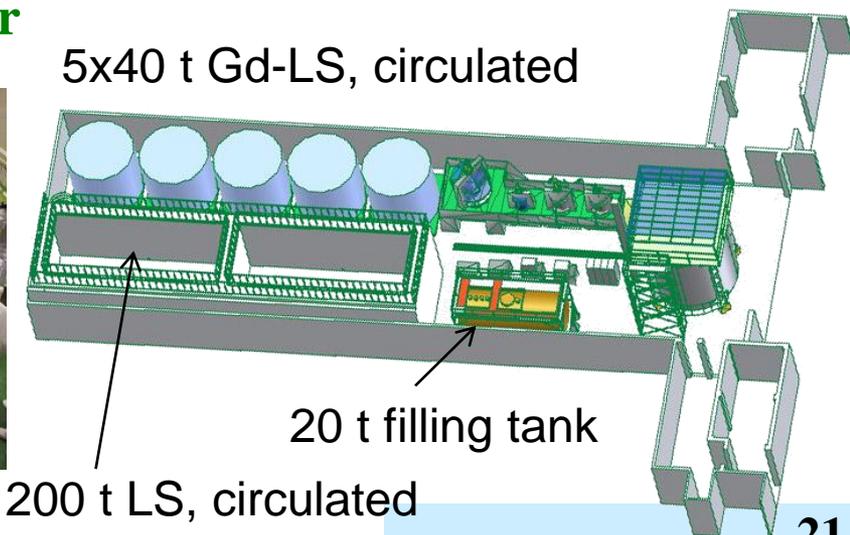
⇒ **"Same batch" of liquid scintillator**



4-m AV in pairs

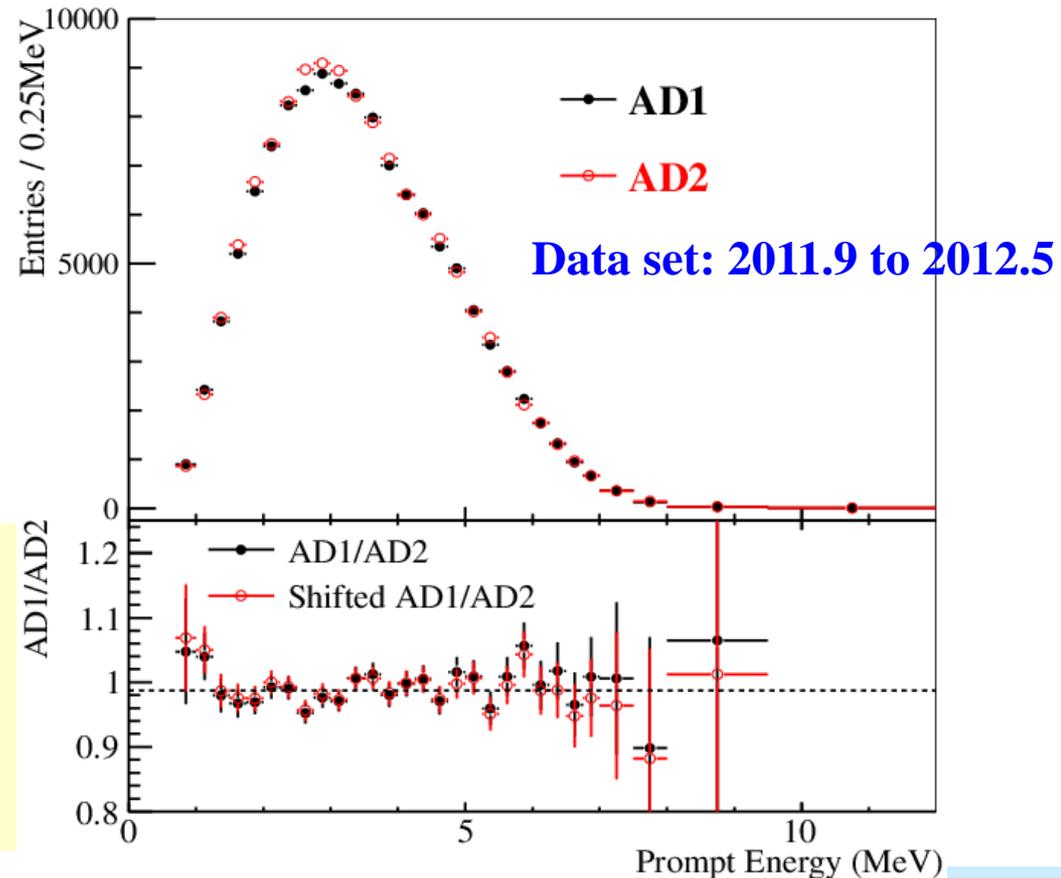
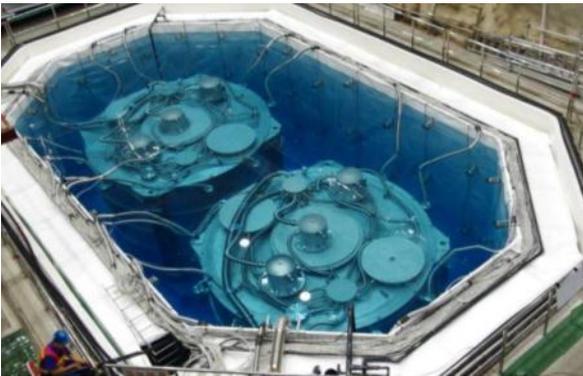


Assembly in pairs



Systematic Error at Daya Bay: Side-by-side Comparison

- ◆ Expected ratio of neutrino events: $R(AD1/AD2) = 0.982$
⇒ The ratio is not 1 because of target mass, baseline, etc.
- ◆ Measured ratio: $0.987 \pm 0.004(\text{stat}) \pm 0.003(\text{syst})$

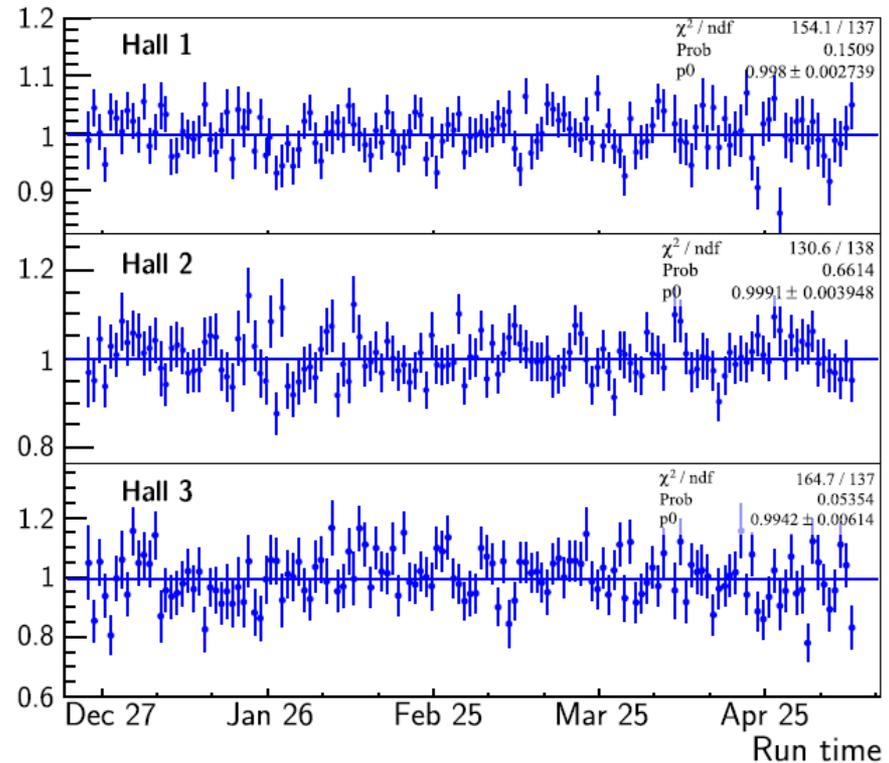
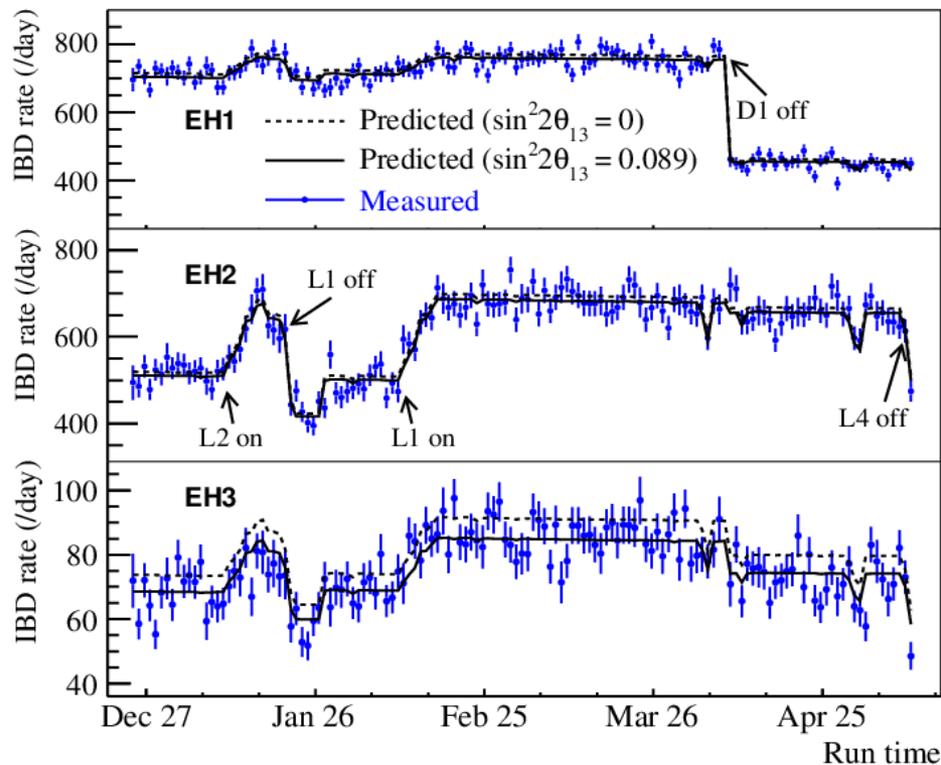


This check shows that syst. are under control, and will eventually "*measure*" the syst. error

Reactor Flux Uncertainty

| | Daya Bay | | RENO | | Double Chooz |
|---|----------|---------|-------|---------|---------------|
| | Corr. | Uncorr. | Corr. | Uncorr. | Corr.⊕Uncorr. |
| 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% |
| Thermal power | | 0.5% | | 0.5% | 0.5% |
| Fission fraction | | 0.6% | | 0.7% | 0.9% |
| Spent fuel | | 0.3% | | | |
| Total Corr. | 3% | | 2.0% | | 1.8% |
| Total Uncorr. of a core | | 0.8% | | 0.9% | |
| n/f reduction factor | | 5% | | 23% | |
| Final Uncertainty | | 0.04% | | 0.21% | 1.8% |

Daily Rate: Evidence of Deficit

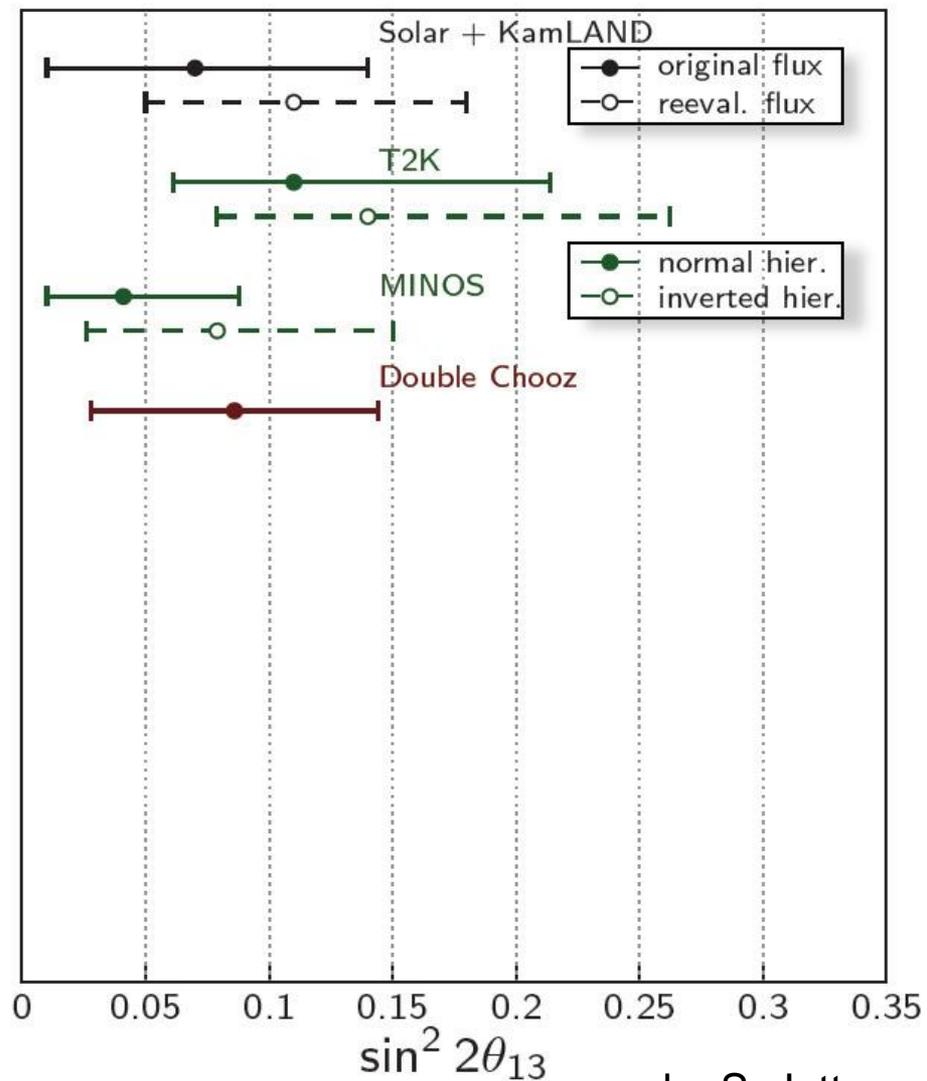
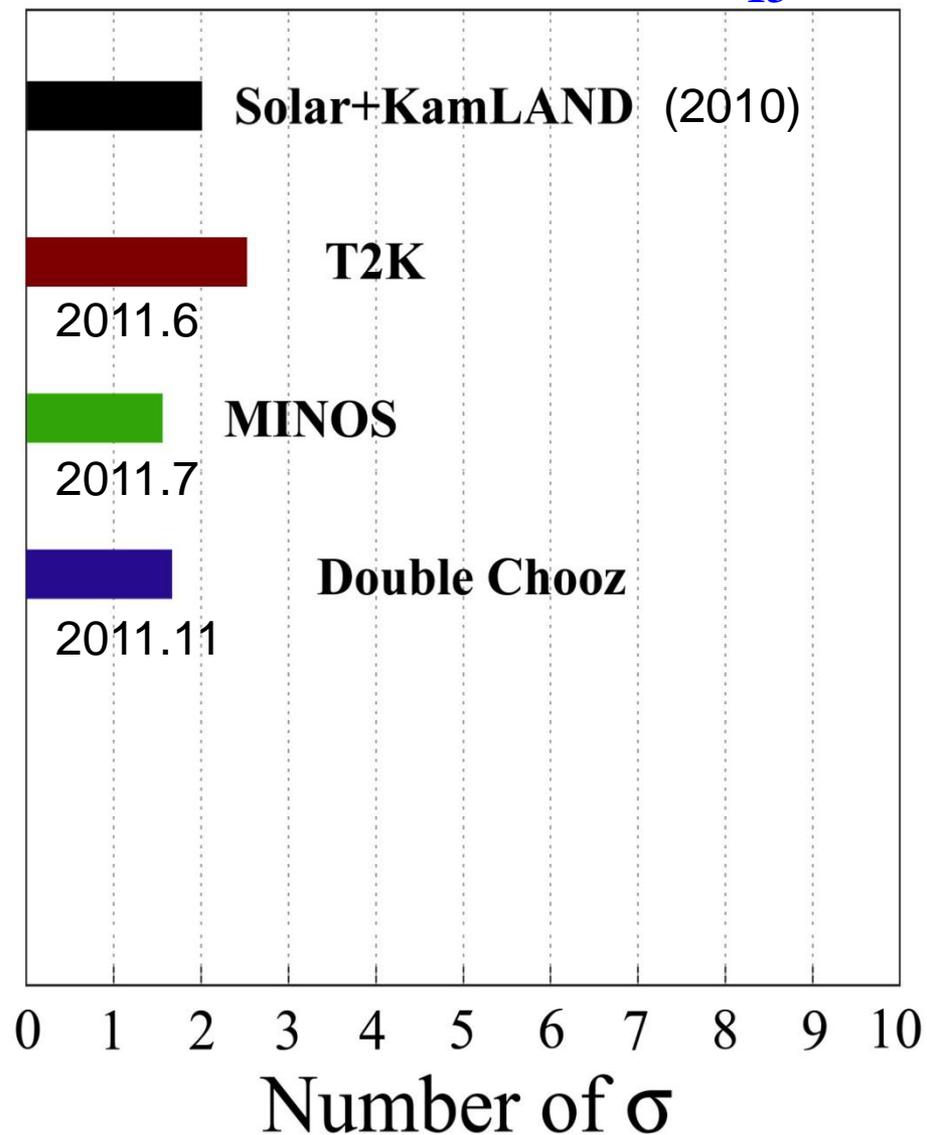


Predictions are absolute, multiplied by a global normalization factor from the fitting.

(to account for the absolute ν flux and absolute detection eff. uncertainty)

Global Picture

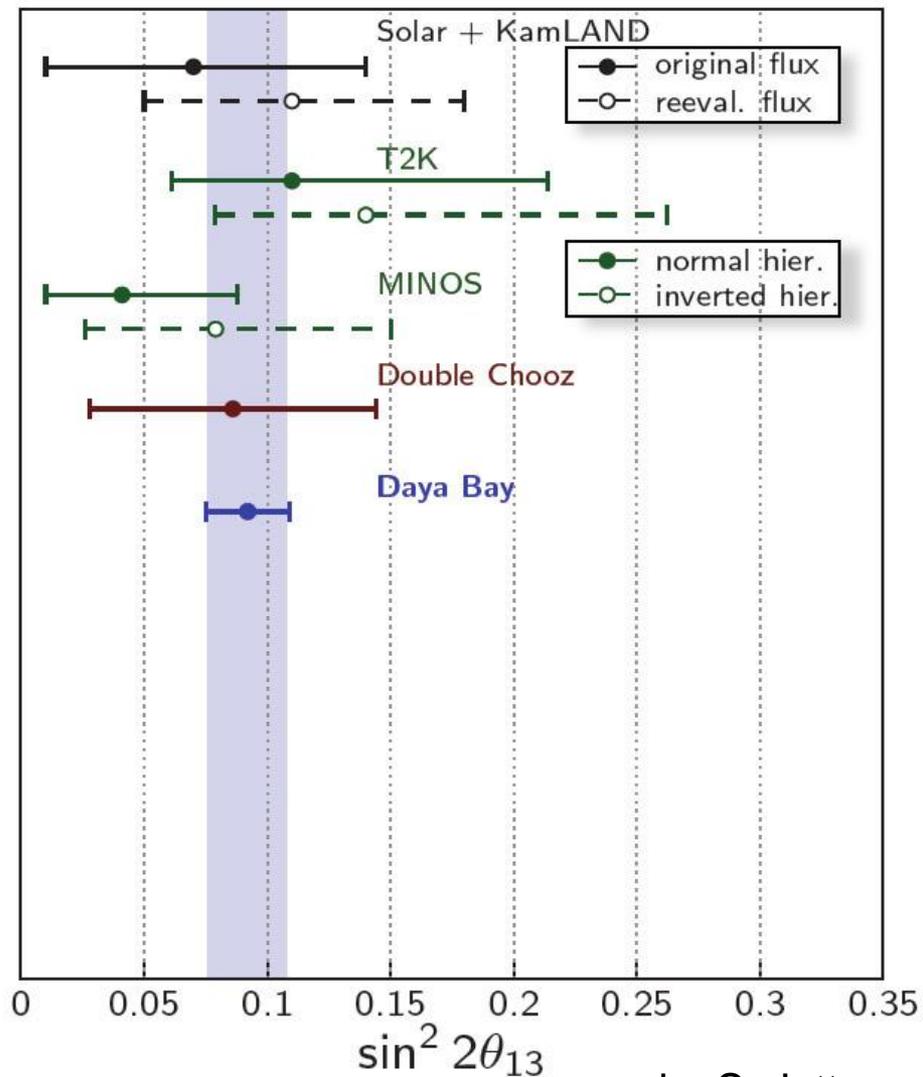
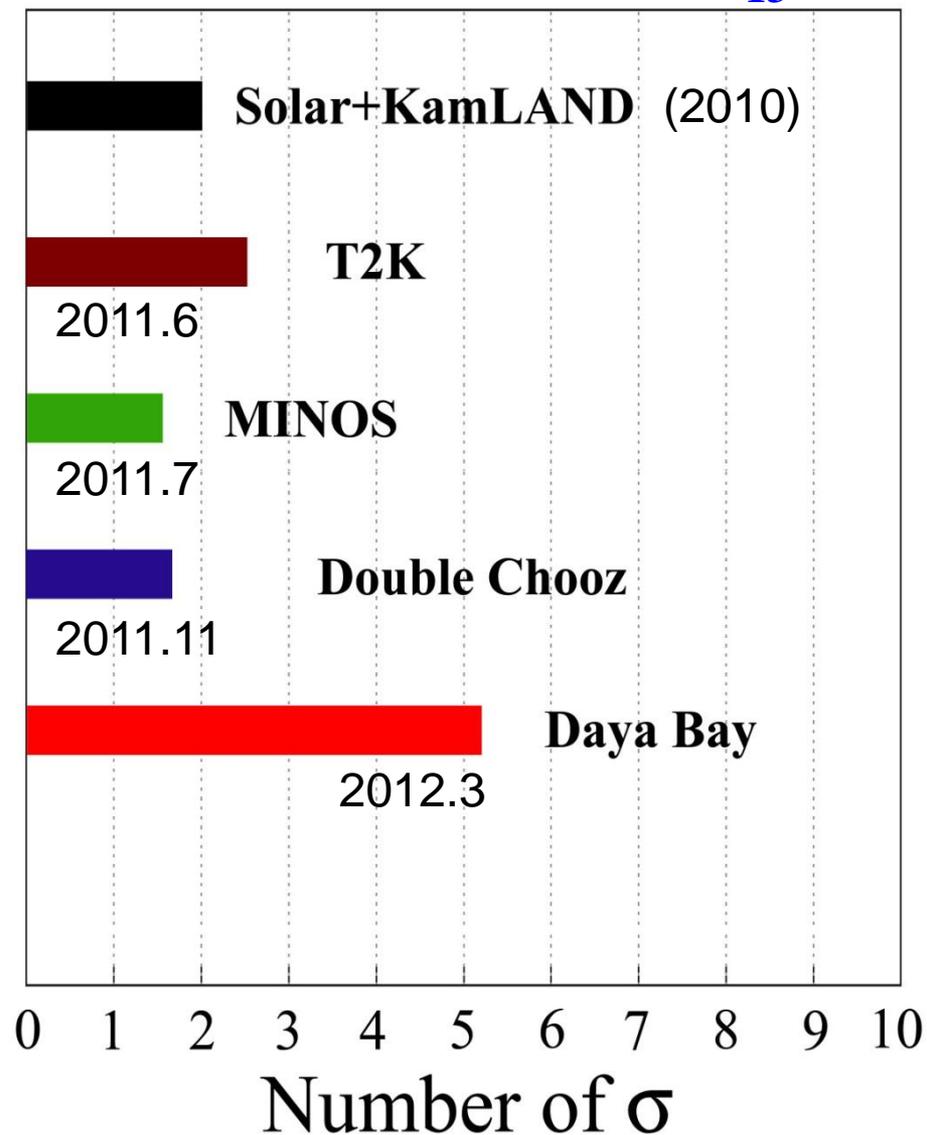
Exclusion of non-zero θ_{13}



by S. Jetter

Global Picture

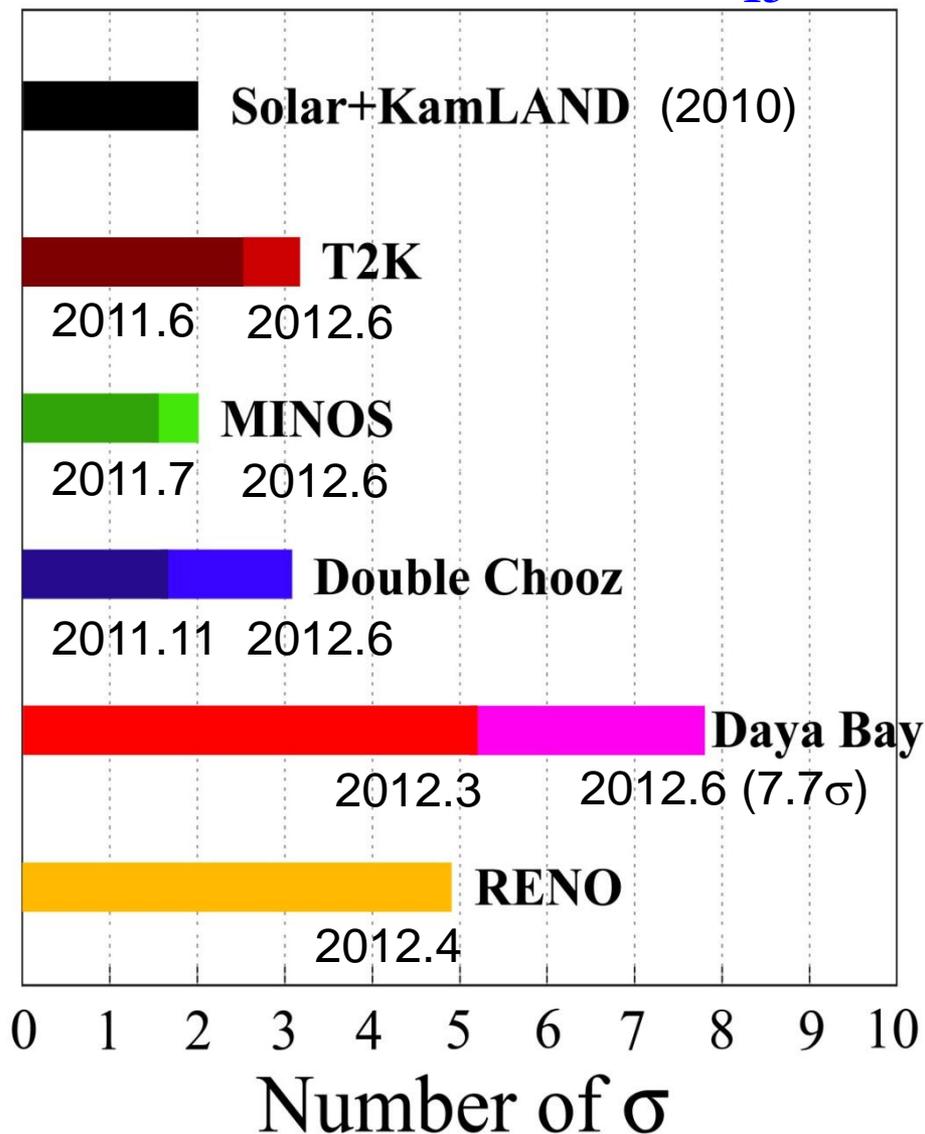
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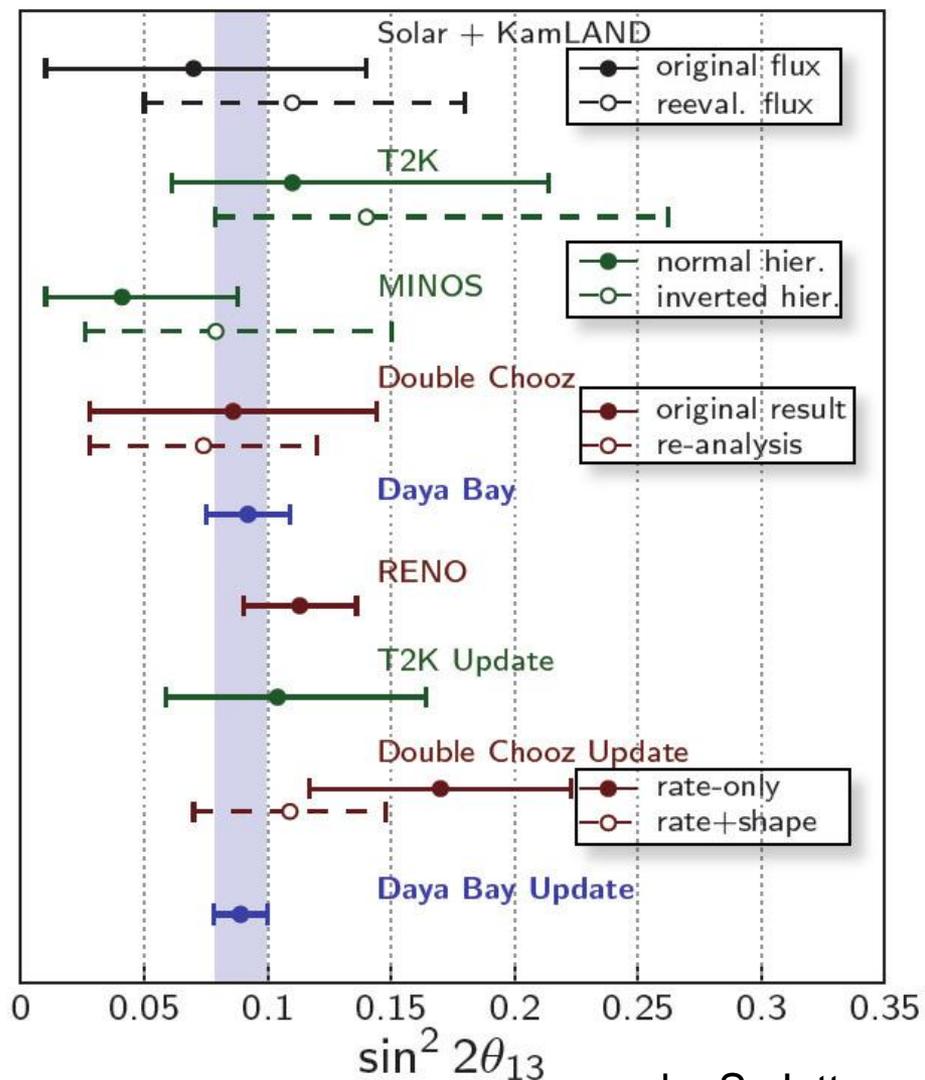
by S. Jetter

Global Picture

Exclusion of non-zero θ_{13}



A consistent picture



by S. Jetter

Future

◆ Daya Bay

- ⇒ Installation of remaining two detectors this summer
- ⇒ Full data taking this fall
- ⇒ Current precision of $\sin^2 2\theta_{13}$ 12.5%, 3 year: 4-5%

◆ RENO

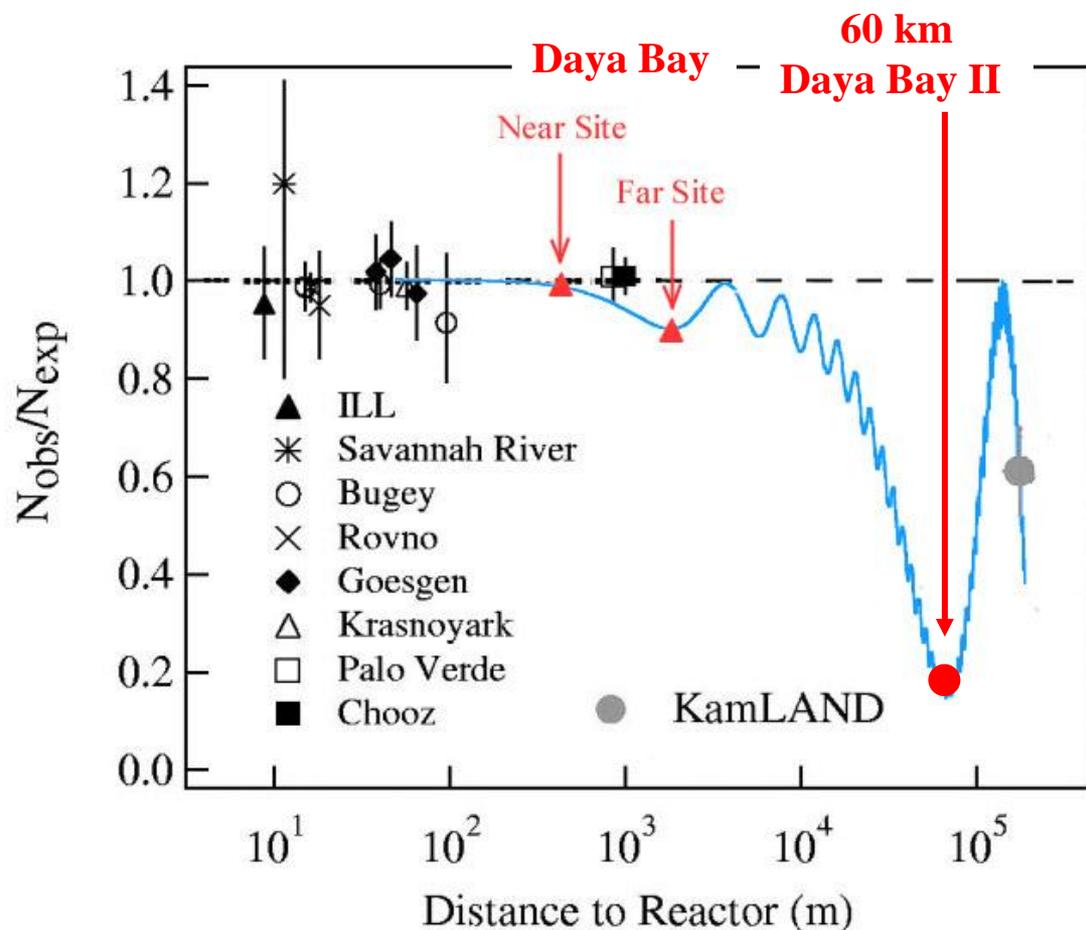
- ⇒ Continue data taking
- ⇒ 3 year precision of $\sin^2 2\theta_{13}$: ~10%

◆ Double Chooz

- ⇒ Near site detector installation underway
- ⇒ Full data taking (by the end of) next year
- ⇒ 3 year precision of $\sin^2 2\theta_{13}$: ~15%

◆ Direct measurement Δm^2_{31} , Reactor ν spectrum, Reactor ν anomaly, cosmogenic n/isotope yield, non-standard interaction, ...

Next Step: Daya Bay-II Experiment



◆ 20 kton LS detector

◆ $3\%/\sqrt{E}$ resolution

◆ Rich physics

⇒ Mass hierarchy

⇒ Precision measurement
of 4 oscillation
parameters to $<1\%$

⇒ Supernovae neutrino

⇒ Geoneutrino

⇒ Sterile neutrino

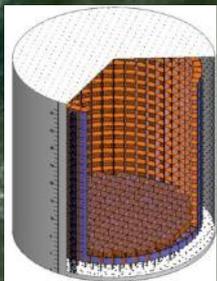
⇒ Atmospheric neutrinos

⇒ 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

An Ideal Location

Overburden >1500 MWE



DYBB 候选

128.9 km

58 km

58 km

DYB

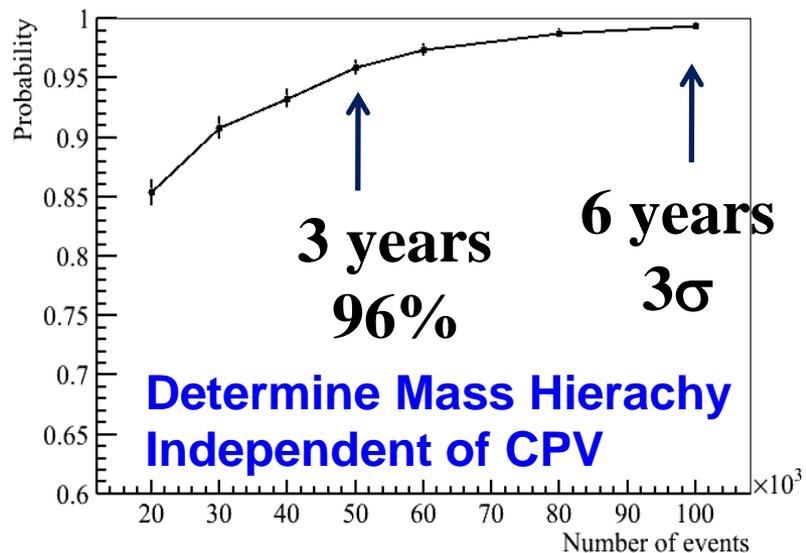
Daya Bay NPP
6x2.9GW

惠州

Huizhou NPP
planned 6x2.9GW

陆丰

Lufeng NPP
planned 6x2.9GW

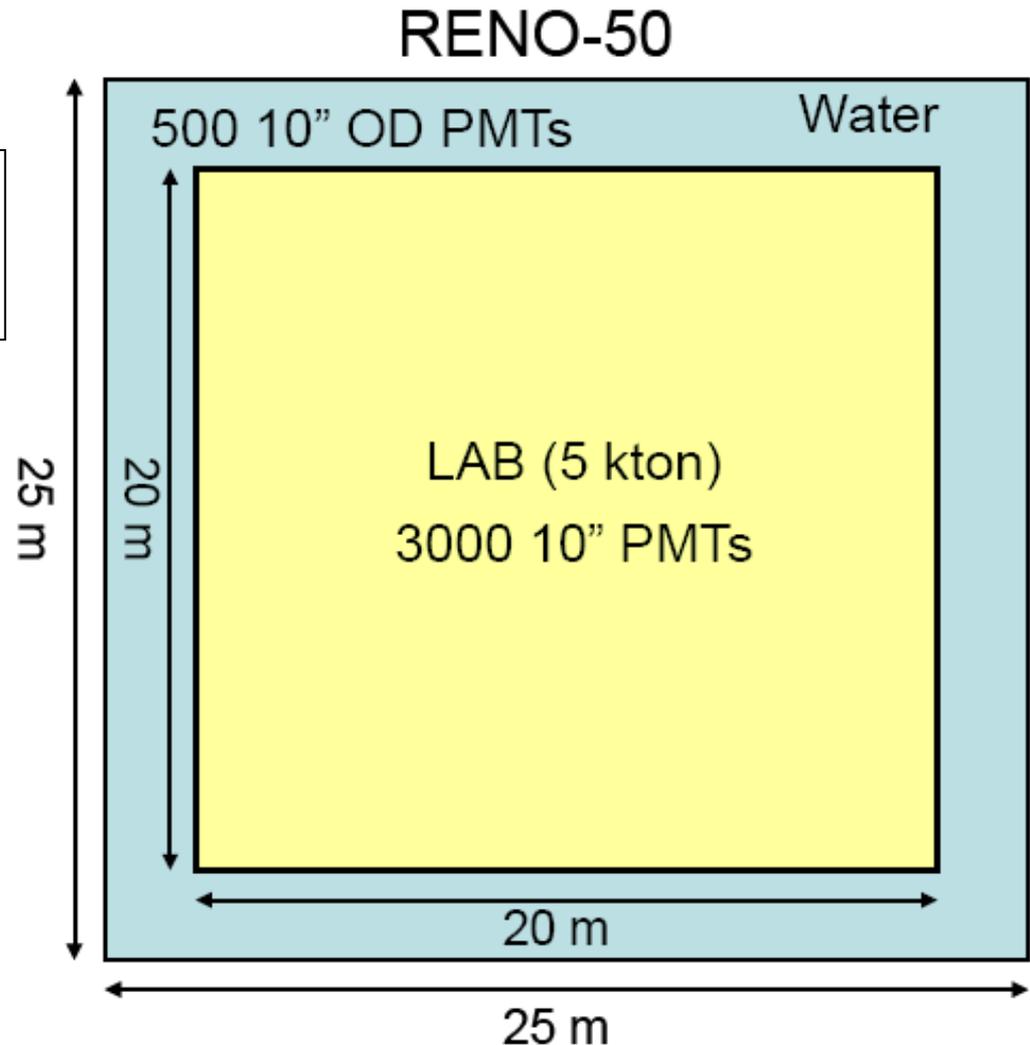


RENO-50

- 5000 tons ultra-low-radioactivity Liquid Scintillation Detector

$$\frac{\delta \sin^2 \theta_{12}}{\sin^2 \theta_{12}} \sim 1.0\%(1\sigma) \text{ in a year}$$

- **Mass Hierachy**
- **Solar neutrino**
- **Geoneutrino**
- **Supernovae**
- **T2K beam**
- **exotic**



Summary

- ◆ Daya Bay experiment discovered the new oscillation and proved θ_{13} is quite large.
 - ⇒ We can measure the MH and CPV in our lifetime!
- ◆ Six results from 3 reactor exp., 2 accelerator exp., and fit from solar+KamLAND are consistent.
- ◆ Precision on $\sin^2 2\theta_{13}$ will be improved to 4-5%
- ◆ As the most powerful man-made neutrino source, reactor neutrinos will continue to play an important role:
 - ⇒ Mass hierarchy
 - ⇒ Precision measurement of mixing parameters up to $< 1\%$ level → unitarity test of the mixing matrix
 - ⇒ Sterile neutrinos, Neutrino magnetic moments

Thanks !

Reference

◆ Daya Bay

- ⇒ F.P. An et al., Daya Bay Coll., “A side-by-side comparison of Daya Bay anti-neutrino detectors”, arXiv: 1202.6181[physics.ins-det], Nucl. Inst. and Meth. A 685 (2012), pp. 78-97
- ⇒ F.P. An et al., Daya Bay Coll., “Observation of electron anti-neutrino disappearance at Daya Bay”, arXiv: 1203.1669[hep-ex], Phys. Rev. Lett. 108, 171803 (2012)
- ⇒ D. Dwyer, Talk at Neutrino 2012, Kyoto, June 4, 2012
- ⇒ **L.J. Wen, Talk at ICHEP 2012, Melbourne, July 5, 2012.**

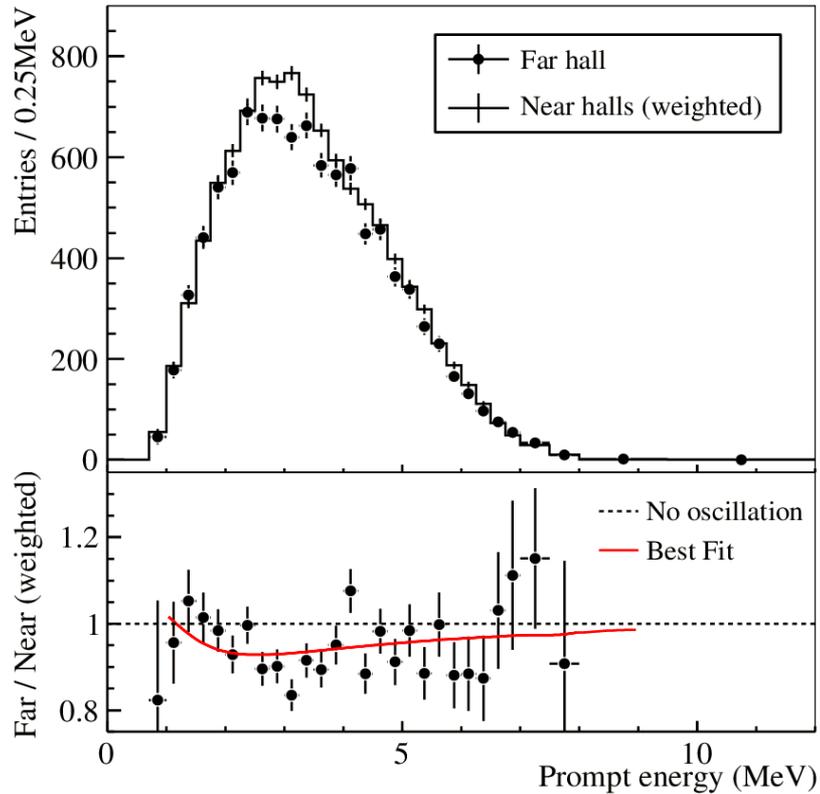
◆ Double Chooz

- ⇒ Y. Abe et al., Double Chooz Collaboration, “Indication for the disappearance of reactor electron antineutrinos in the Double Chooz experiment.”, Phys.Rev.Lett. 108 (2012) 131801
- ⇒ M. Ishitsuka, Talk at Neutrino 2012, Kyoto, June 4, 2012
- ⇒ **Pau Novella, Talk at ICHEP 2012, Melbourne, July 5, 2012.**

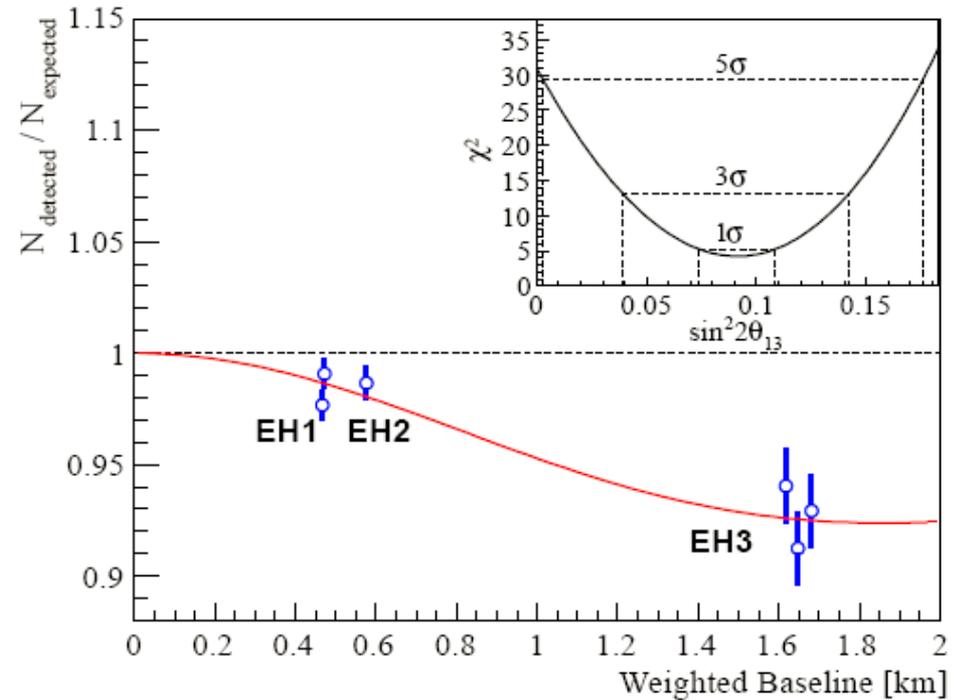
◆ RENO

- ⇒ J.K. Ahn et al., RENO Collaboration, “Observation of Reactor Electron Anti-Neutrino Disappearance in the RENO Experiment”, Phys.Rev.Lett. 108 (2012) 191802

Discovery of a non-zero value of θ_{13} (2012.3)



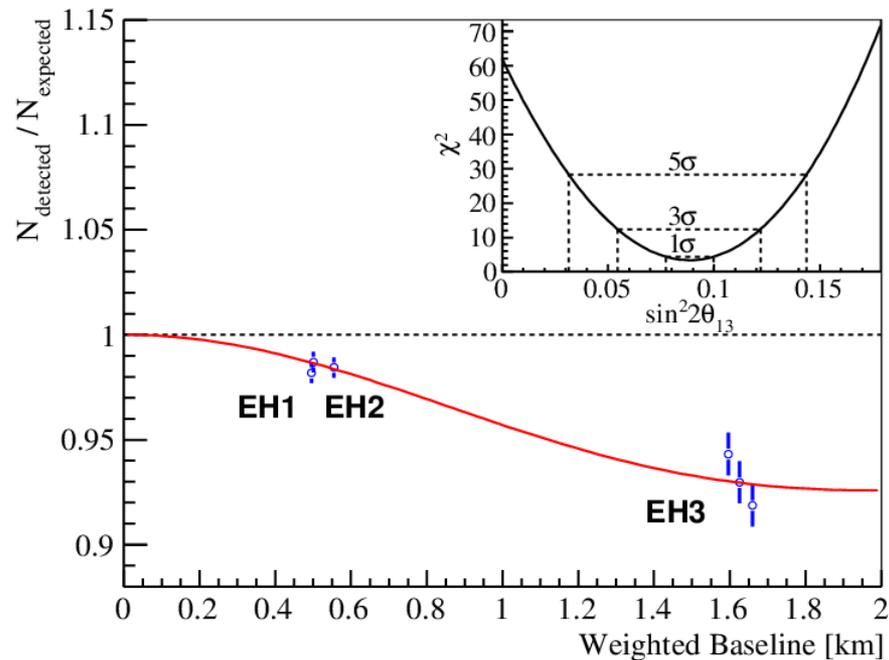
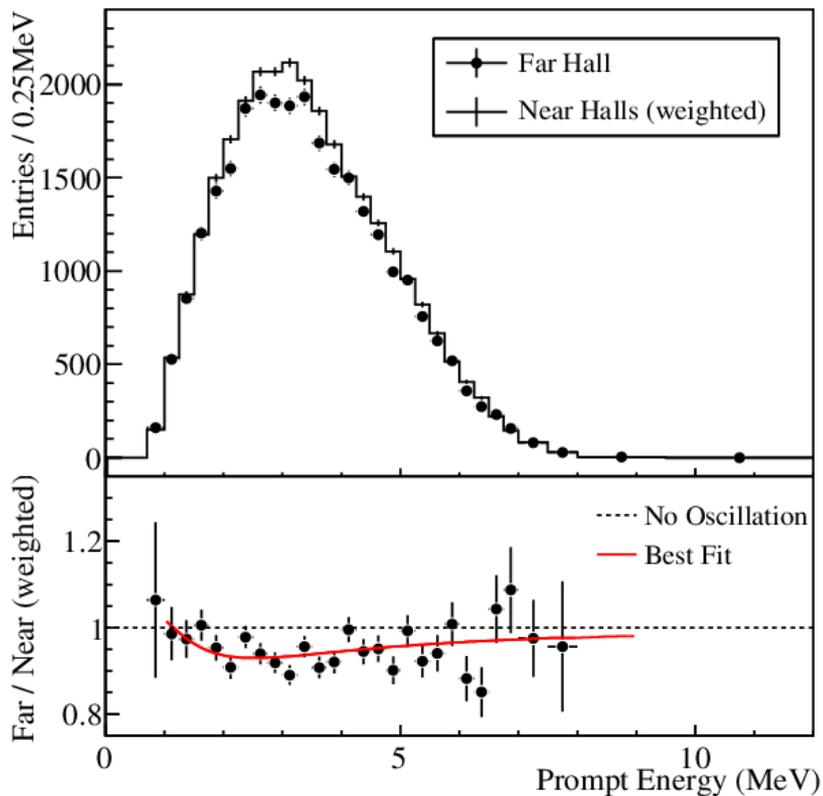
$$R = 0.940 \pm 0.011 \text{ (stat)} \pm 0.004 \text{ (syst)}$$



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

A clear observation of far site deficit with the first 55 days' data.
5.2 σ for non-zero value of θ_{13}

Daya Bay Improved Results (2012.6)

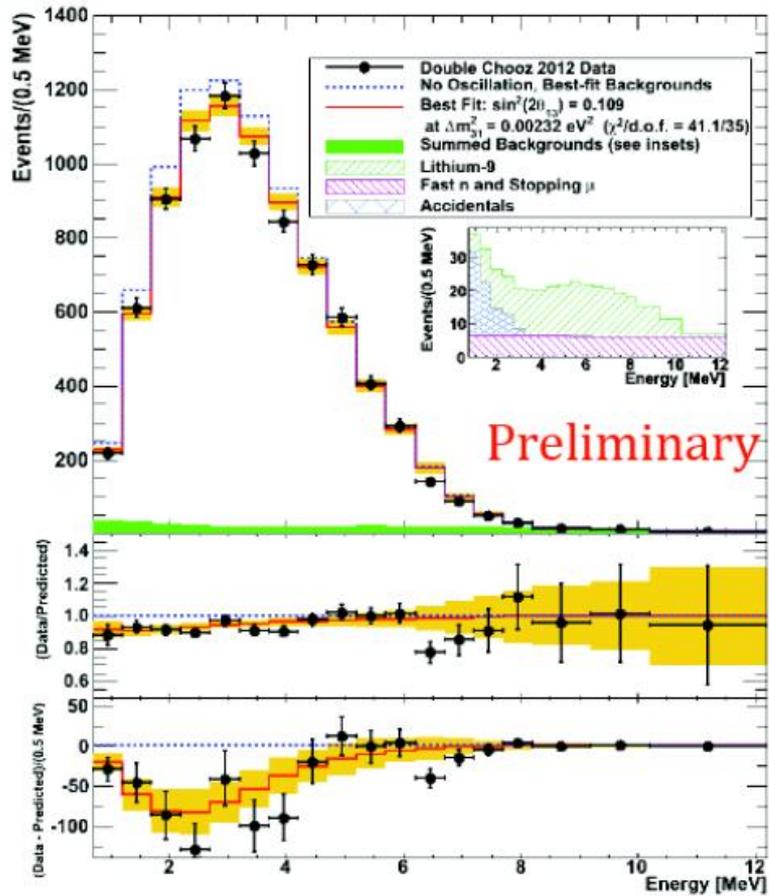


$$R = 0.944 \pm 0.007 \text{ (stat)} \pm 0.003 \text{ (syst)}$$

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

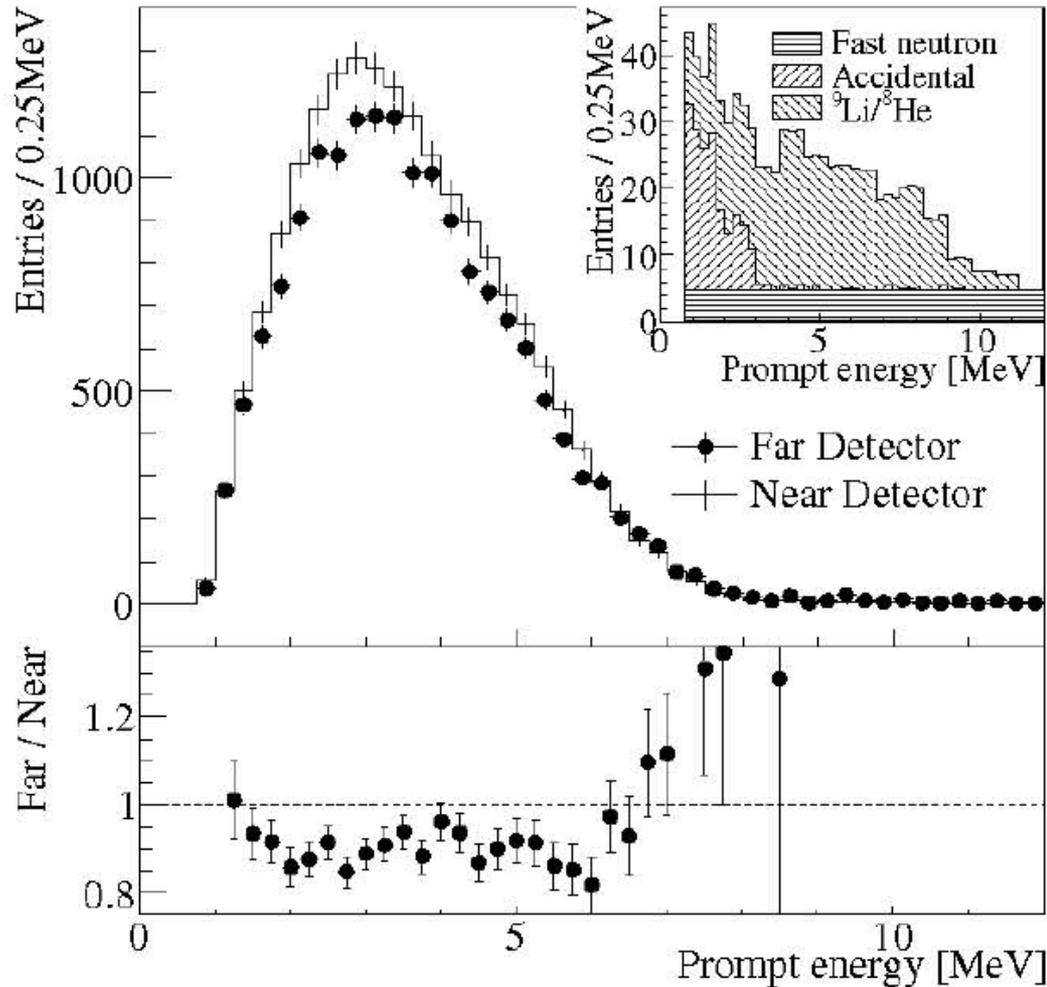
**With 2.5x more statistics, an improved measurement to θ_{13}
7.7 σ for non-zero value of θ_{13}**

Oscillation Results



- Rate only:
- $\sin^2(2\theta_{13}) = 0.170 \pm 0.035(\text{stat}) \pm 0.040(\text{syst})$
- Rate+Shape:
- $\sin^2(2\theta_{13}) = 0.109 \pm 0.030(\text{stat}) \pm 0.025(\text{syst})$
- $\chi^2/\text{dof} = 41/35$
- $\sin^2(2\theta_{13}) = 0$ excluded at 99.9% (3.1σ)
(frequentist study)

RENO Results (2012.4)



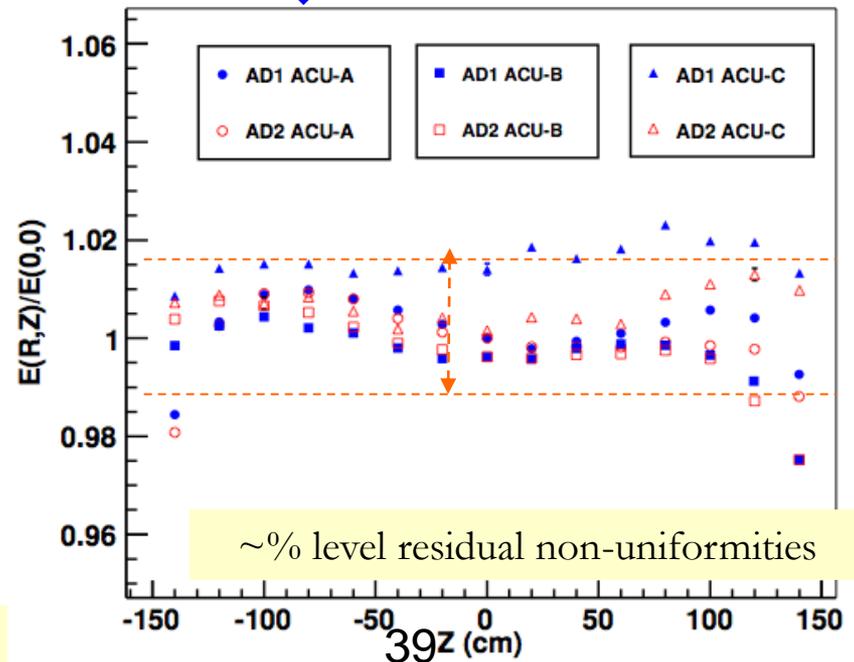
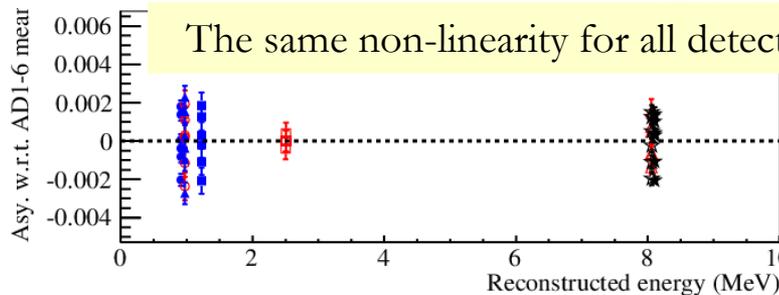
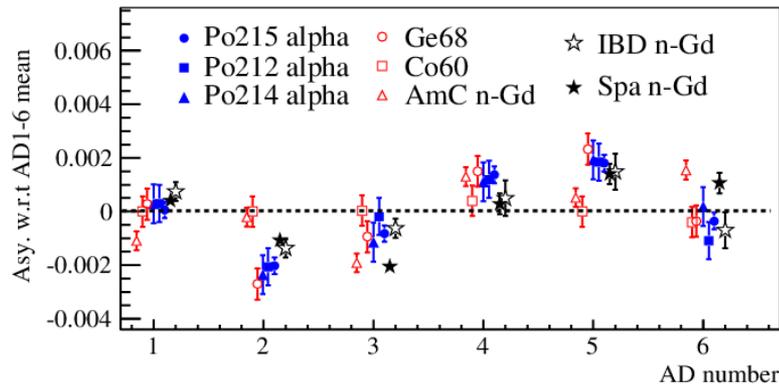
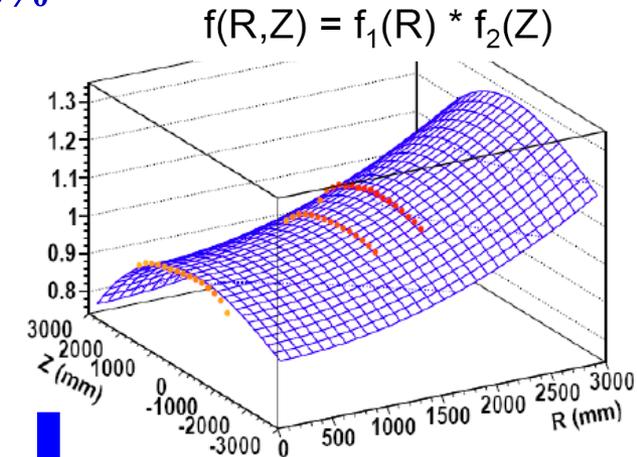
$$R = 0.920 \pm 0.009(\text{stat}) \pm 0.014(\text{syst})$$

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(\text{stat}) \pm 0.019(\text{syst})$$

4.9 σ for non-zero value of θ_{13}

Energy calibration & reconstruction

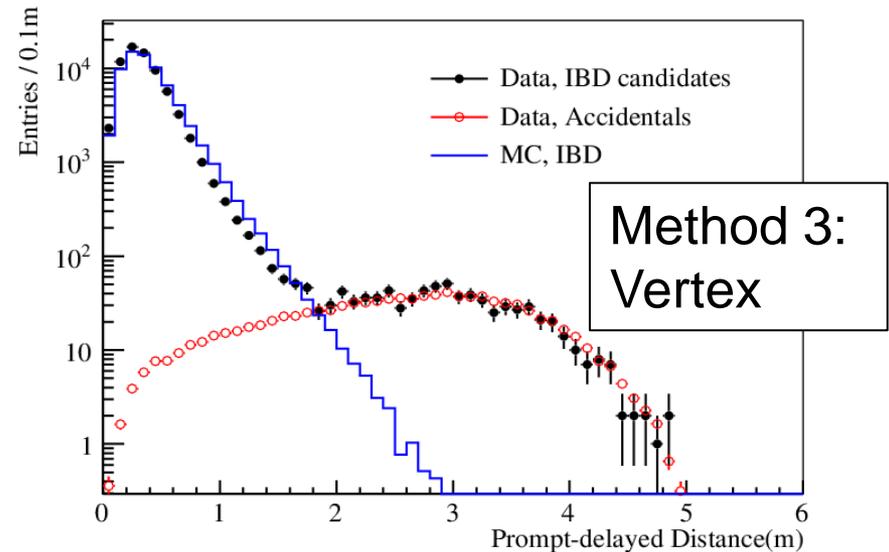
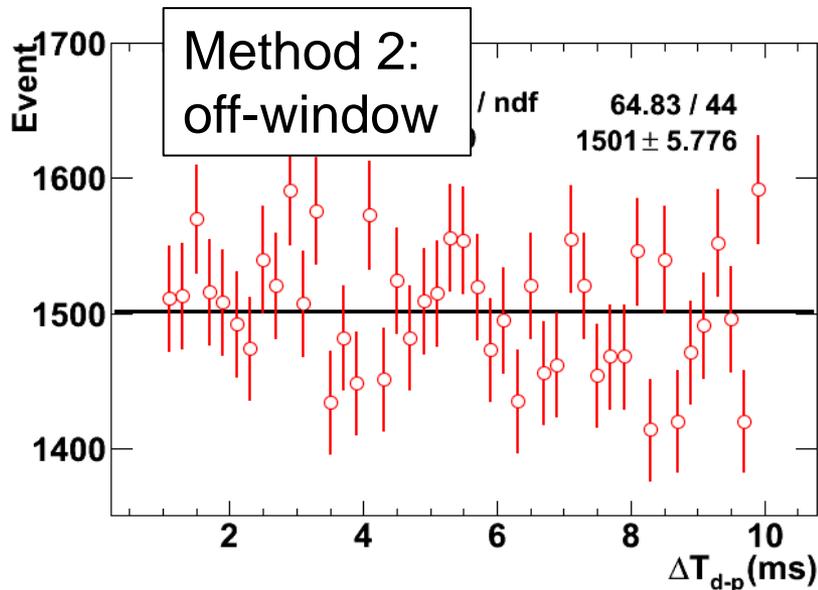
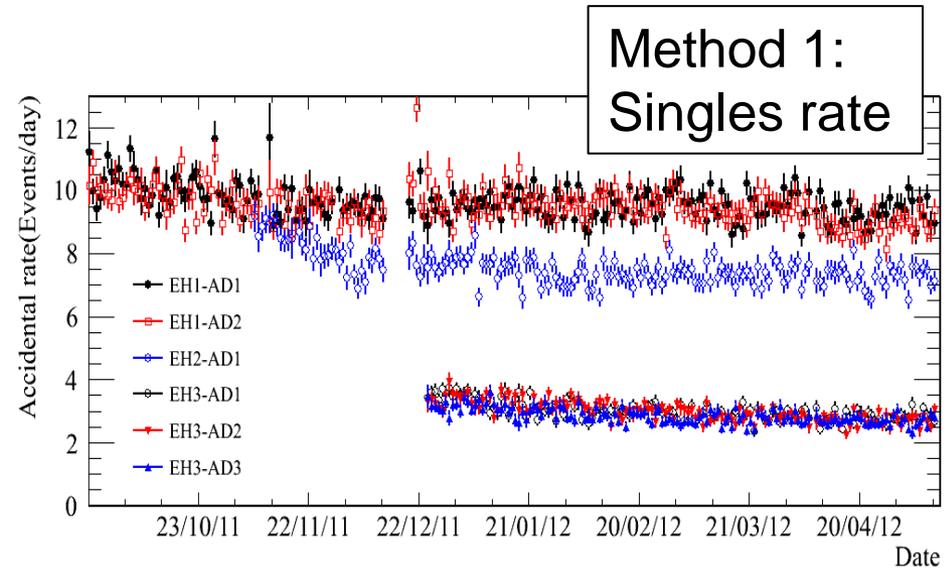
- Low-intensity LED \rightarrow PMT gains are stable to 0.3%
- ^{60}Co at the detector center \rightarrow raw energies
 - Correct small (0.2%) time dependence
- ^{60}Co at different positions in detector
 - Correct spatial dependence . Common correction for all the ADs
- Calibrate energy scale using neutron capture peak



\rightarrow 0.12% efficiency difference among detectors

Backgrounds: Accidentals

- Two signals accidentally satisfied the anti-neutrino event selection criteria
- ◆ **Calculation:** use the rate of prompt- and delayed-signals



B/S @ EH1/2 ~ 1.4%, B/S @ EH3 ~ 4.0%

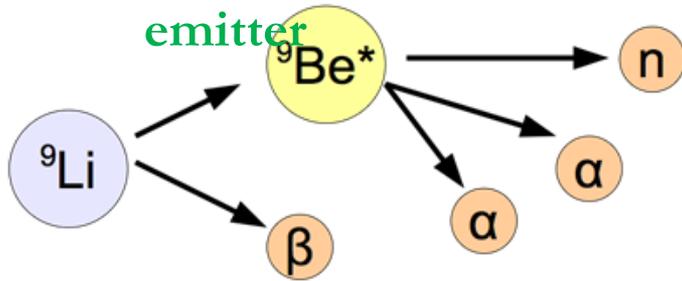
$\Delta B/B \sim 1\%$

Backgrounds: ${}^9\text{Li}/{}^8\text{He}$

◆ Cosmic μ produced ${}^9\text{Li}/{}^8\text{He}$ in LS

β -decay + neutron

emitter



• Measurement:

- Time-since-last-muon fit method

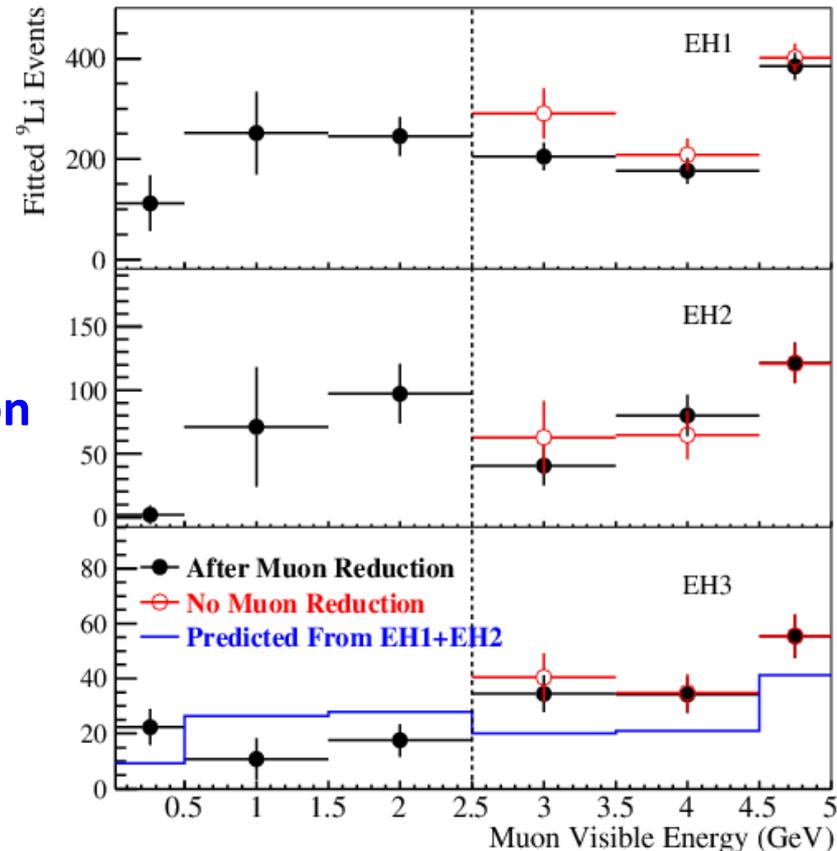
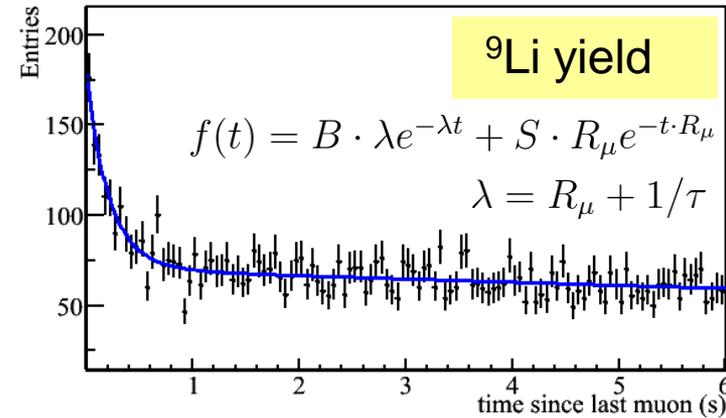
B/S uncertainty:
$$\sigma_b = \frac{1}{\sqrt{N}} \cdot \sqrt{(1 + \tau R_\mu)^2 - 1}$$

- Improve the precision by preparing muon samples w/ and w/o followed neutrons
- Set a lower limit \Rightarrow Muons with small visible energy also produce ${}^9\text{Li}/{}^8\text{He}$

B/S @ EH1/2 \sim 0.4%, B/S @ EH3 \sim 0.3%

$\Delta\text{B}/\text{B} \sim 50\%$

${}^9\text{Li}/{}^8\text{He}$ Fit



Backgrounds: Fast neutrons

Method I:

Relax the $E_p < 12\text{MeV}$ criterion. Extrapolation into the (0.7 MeV, 12.0 MeV) region gave an estimate for the residual fast-neutron background.

Method II:

Use water pool to determine the spectra of fast neutron, and estimate the residual fast neutron background and water pool inefficiency

$$n_f = n_f^{iws} \cdot (1 - \epsilon_{iws}) + n_f^{ows} \cdot (1 - \epsilon_{ows}) + n_f^{rock}$$

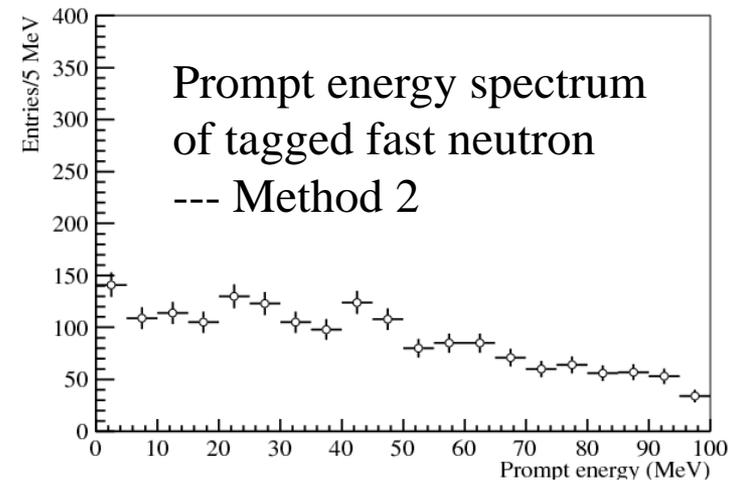
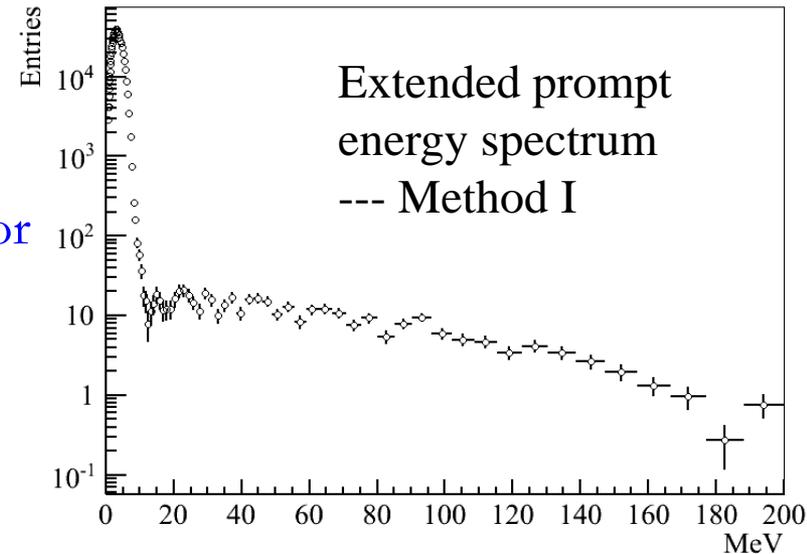
↙
↙

efficiency of IWS muon
efficiency of OWS ONLY muons

Results are consistent

B/S @ EH1/2 ~ 0.12%, B/S @ EH3 ~ 0.07%

$\Delta B/B \sim 40\%$

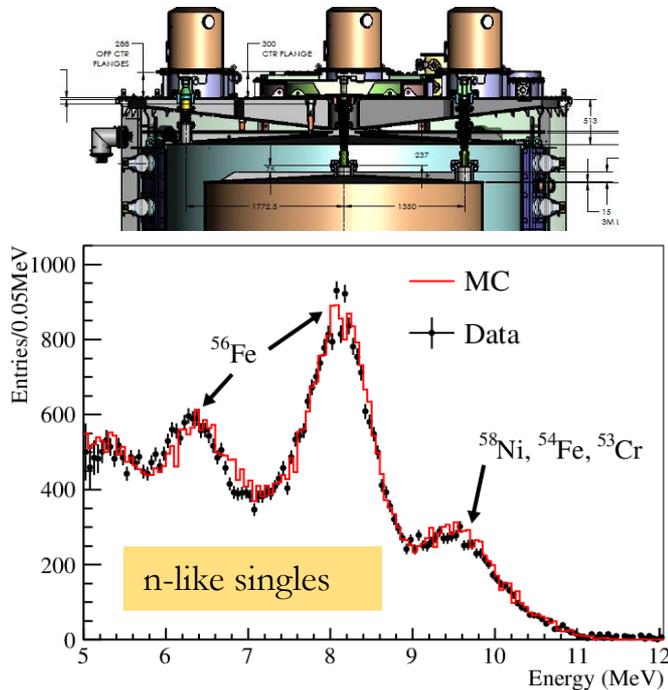


Backgrounds: ^{241}Am - ^{13}C source & $^{13}\text{C}(\alpha,n)^{16}\text{O}$

◆ Correlated backgrounds from ^{241}Am - ^{13}C source inside ACUs :

- ⇒ Neutron inelastic scattering with ^{56}Fe + neutron capture on ^{57}Fe
- ⇒ Simulation shows that correlated background is 0.2 events/day/AD

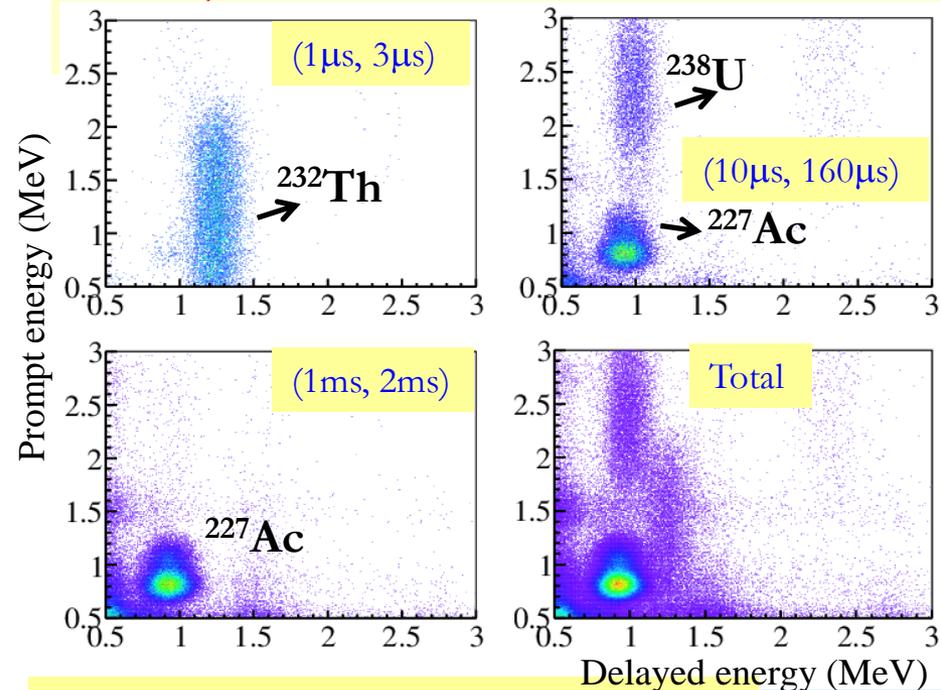
B/S @ EH1/2 ~ 0.03%, B/S @ EH3 ~ 0.3%, $\Delta\text{B/B} \sim 100\%$



◆ $^{13}\text{C}(\alpha,n)^{16}\text{O}$ correlated backgrounds

- ⇒ Identified α sources (^{238}U , ^{232}Th , ^{227}Ac , ^{210}Po) and rates from cascade decays and spatial distribution
- ⇒ Calculate backgrounds from α rate + (α,n) cross sections

B/S @ EH1/2 ~ 0.01%, B/S @ EH3 ~ 0.05%, $\Delta\text{B/B} \sim 50\%$



Time correlations of the cascade decays