Recent results of the Daya Bay Experiment

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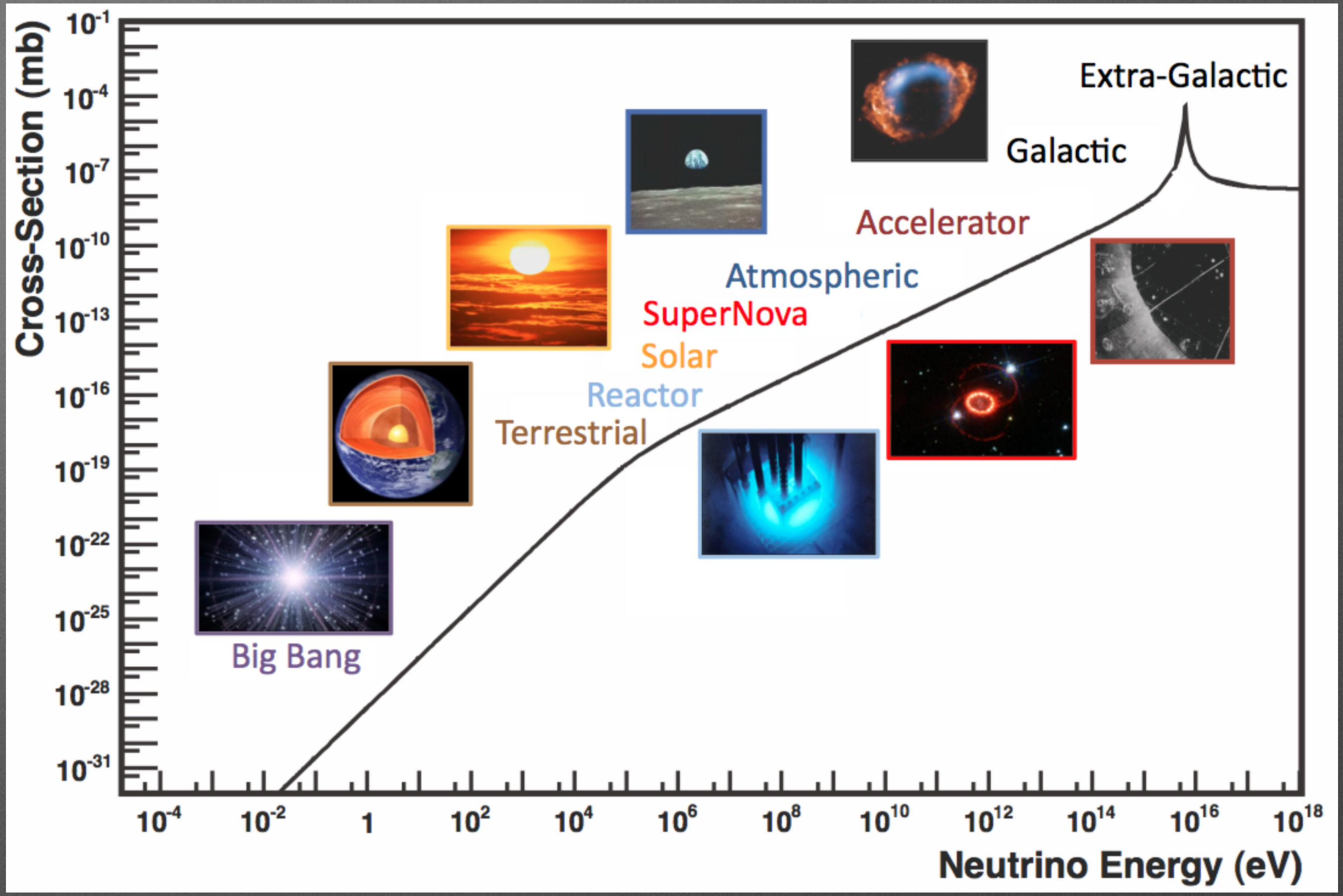
On behalf of the Daya Bay collaboration

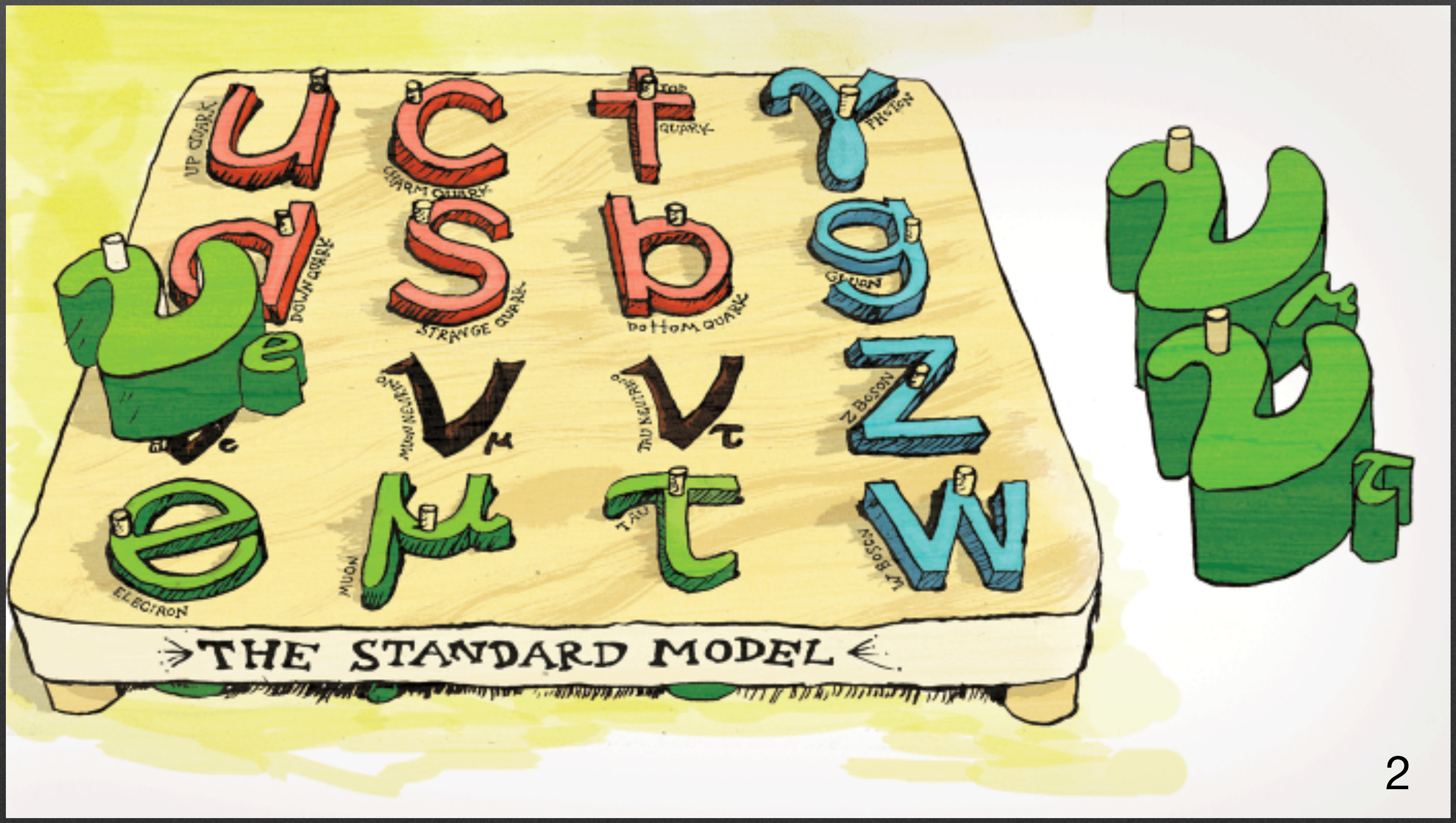
HEP 2016, Valparaiso, Chile

Neutrinos in Nature

- We can find neutrinos everywhere.
- 65 billion of neutrinos through your fingernail every second!!
- They are the second most abundant particle in the universe.
- They are the “misfits” of the Standard Model .



We must understand them!!



Neutrino Oscillation
(in a nutshell)

Torn between identities – tau-, electron- or myon-neutrino?

Neutrino Oscillations:

$$|\nu_\alpha\rangle = \sum_{k=1}^{3} U^*_{\alpha k}\,|\nu_k\rangle \qquad \alpha = e, \mu, \tau$$

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta_{\mathrm{CP}}} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta_{\mathrm{CP}}} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta_{\mathrm{CP}}} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta_{\mathrm{CP}}} & c_{13}c_{23} \end{pmatrix}$$

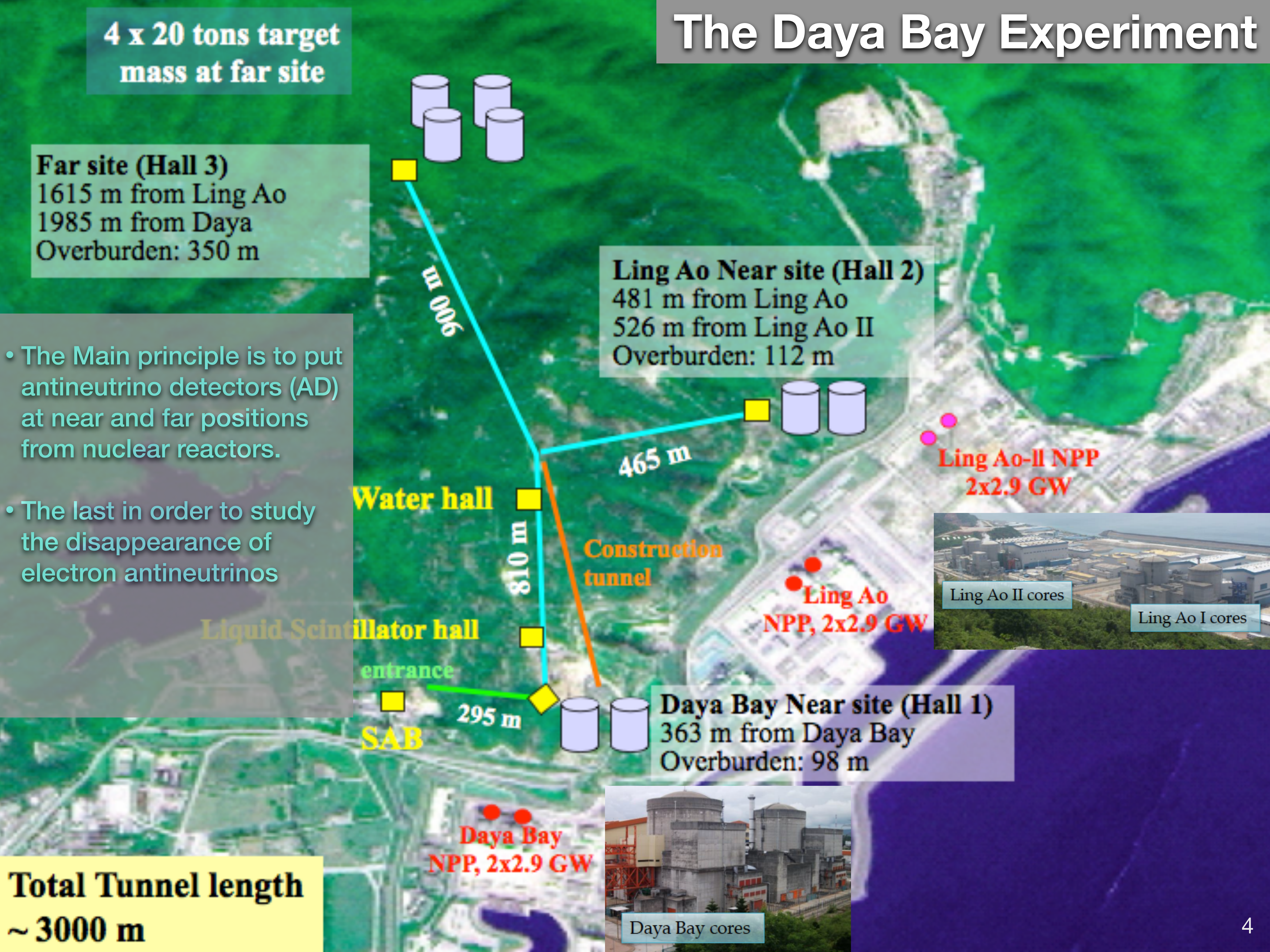
$$\boxed{P(\overline{\nu}_e \to \overline{\nu}_e) = 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(1.267\,\frac{\Delta m^2_{21}L}{E}\right) - \sin^2 2\theta_{13}\sin^2\left(\frac{1.267\Delta m^2_{ee}L}{E}\right)}$$

$$\left|\Delta m^2_{ee}\right| \simeq \left|\Delta m^2_{32}\right| \pm 5.21\times 10^{-5}\mathrm{eV}^2$$

The Daya Bay Experiment

- The Main principle is to put antineutrino detectors (AD) at near and far positions from nuclear reactors.

- The last in order to study the disappearance of electron antineutrinos



4 x 20 tons target mass at far site

Far site (Hall 3)
1615 m from Ling Ao
1985 m from Daya
Overburden: 350 m

Ling Ao Near site (Hall 2)
481 m from Ling Ao
526 m from Ling Ao II
Overburden: 112 m

Daya Bay Near site (Hall 1)
363 m from Daya Bay
Overburden: 98 m

Total Tunnel length ~ 3000 m

A Powerful Neutrino Source at an Ideal Location

Mountains shield detectors from ~~cosmic ray~~ background

cosmic particles

Daya Bay NPP 2 2.9 GW$_{\text{th}}$

Ling Ao I NPP 2 2.9 GW$_{\text{th}}$

Ling Ao II NPP 2 2.9 GW$_{\text{th}}$

Entrance to Daya Bay experiment tunnels

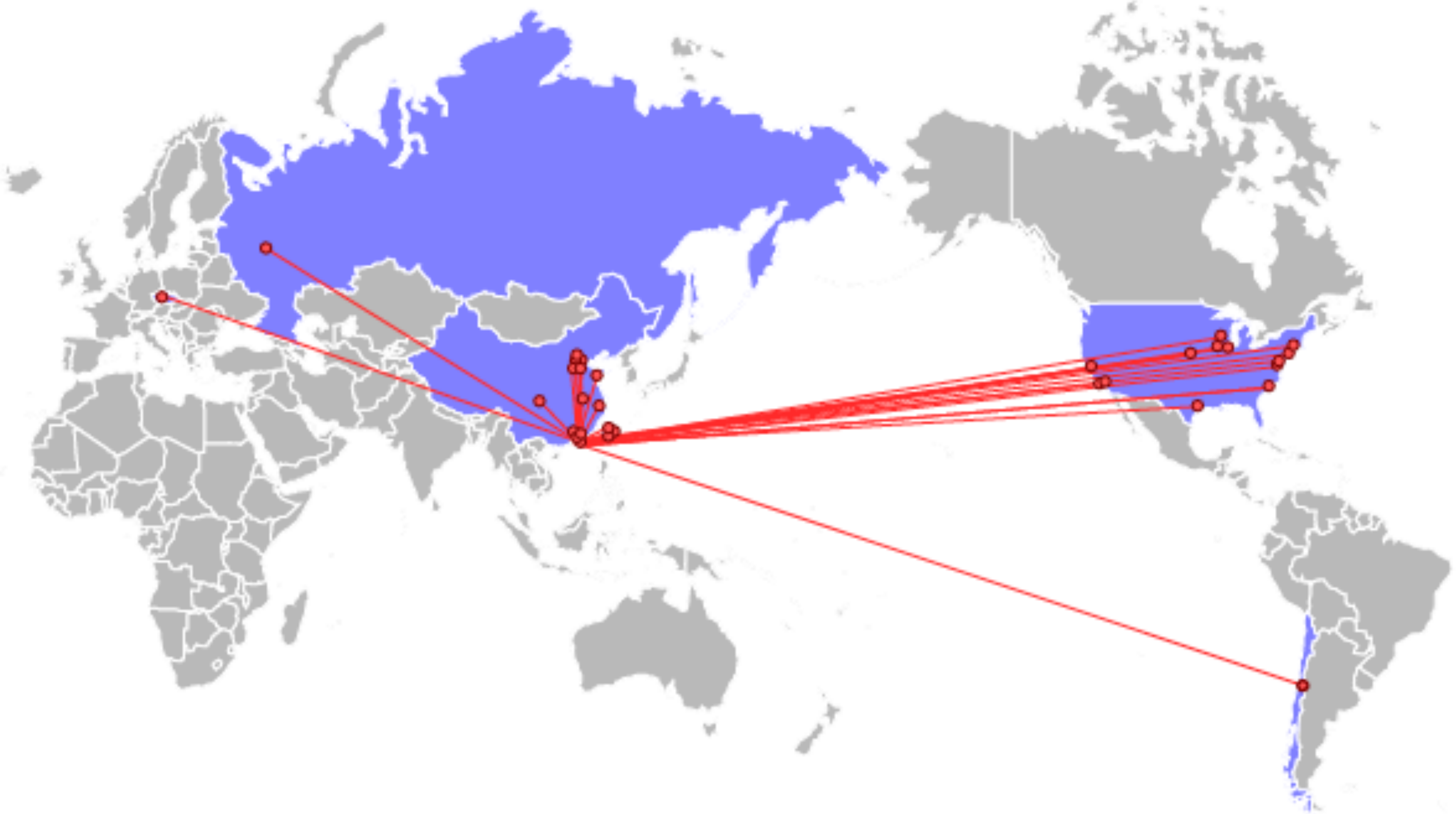
Among the top 5 most powerful reactor complexes in the world, 6 cores produce 17.4 GW$_{\text{th}}$ power, 35 x 10^{20} neutrinos per second

The Daya Bay Collaboration

~230 Collaborators

Asia (21)

Beijing Normal Univ., CGNPG, CIAE, Dongguan Polytechnic, ECUST, IHEP, Nanjing Univ., Nankai Univ., NCEPU, Shandong Univ., Shanghai Jiao Tong Univ., Shenzhen Univ., Tsinghua Univ., USTC, Xian Jiaotong Univ., Zhongshan Univ., Chinese Univ. of Hong Kong, Univ. of Hong Kong, National Chiao Tung Univ., National Taiwan Univ., National United



North America (17)

Brookhaven Natl Lab, CalTech, Illinois Institute of Technology, Iowa State, Lawrence Berkeley Natl Lab, Princeton, Rensselaer Polytechnic, Siena College, UC Berkeley, UCLA, Univ. of Cincinnati, Univ. of Houston, UIUC, Univ. of Wisconsin, Virginia Tech, William & Mary, Yale

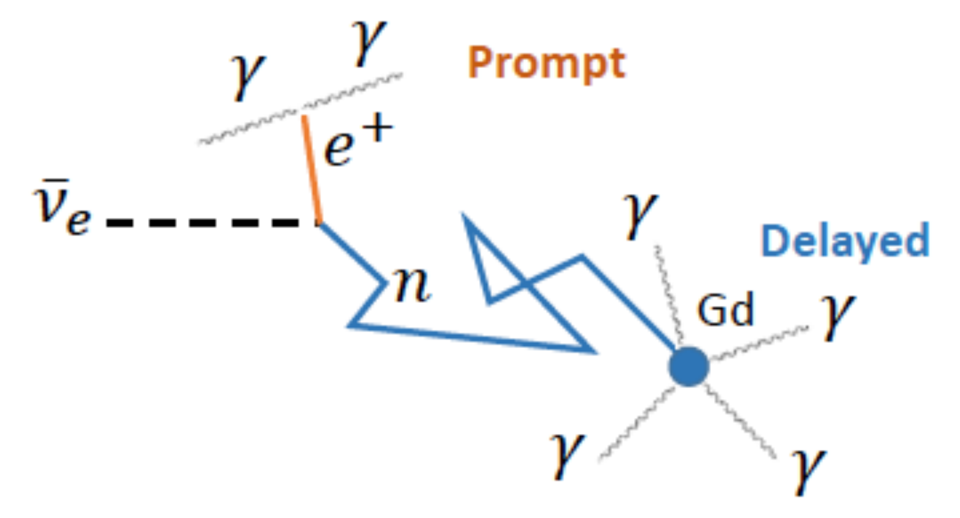
Europe (2)

Charles University, JINR Dubna

South America(1)

Catholic University of Chile

Electron antineutrino detection



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

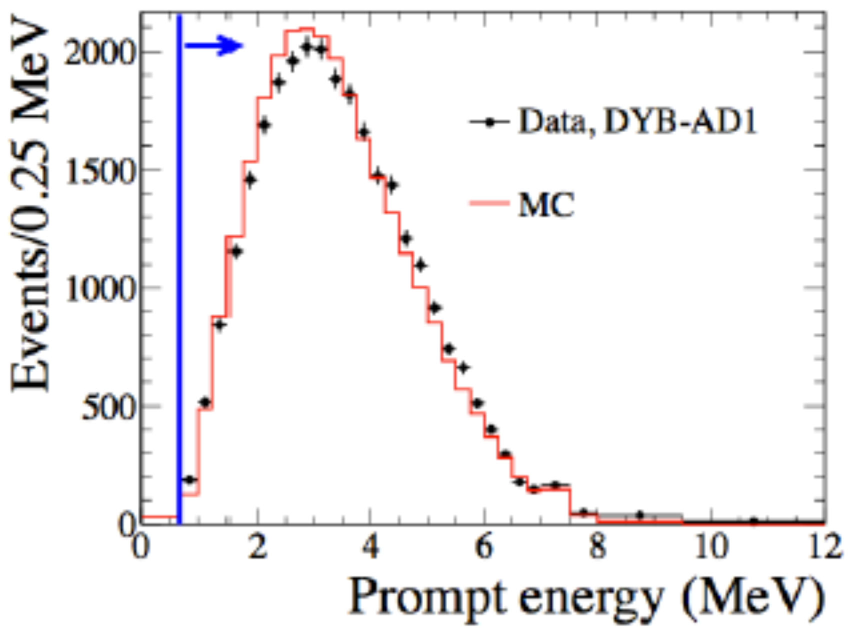
≈180μs $n + p \rightarrow D + \gamma(2.2\ \mathrm{MeV})$

≈30μs $n + Gd \rightarrow Gd^* \rightarrow Gd + \gamma' s(8\ \mathrm{MeV})$

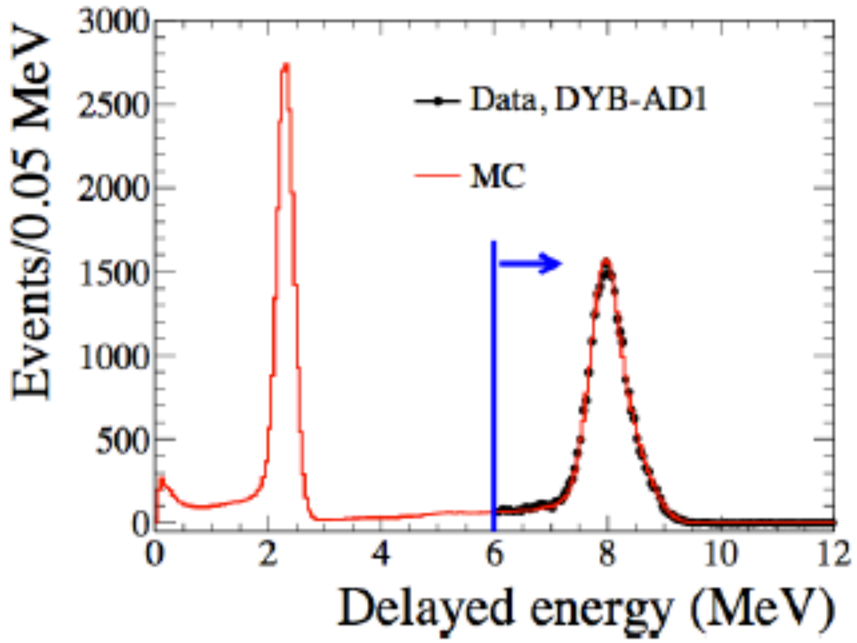
n capture on H or Gd

Antineutrino detection via inverse beta decay (IBD)

Prompt Energy Signal



Delayed Energy Signal



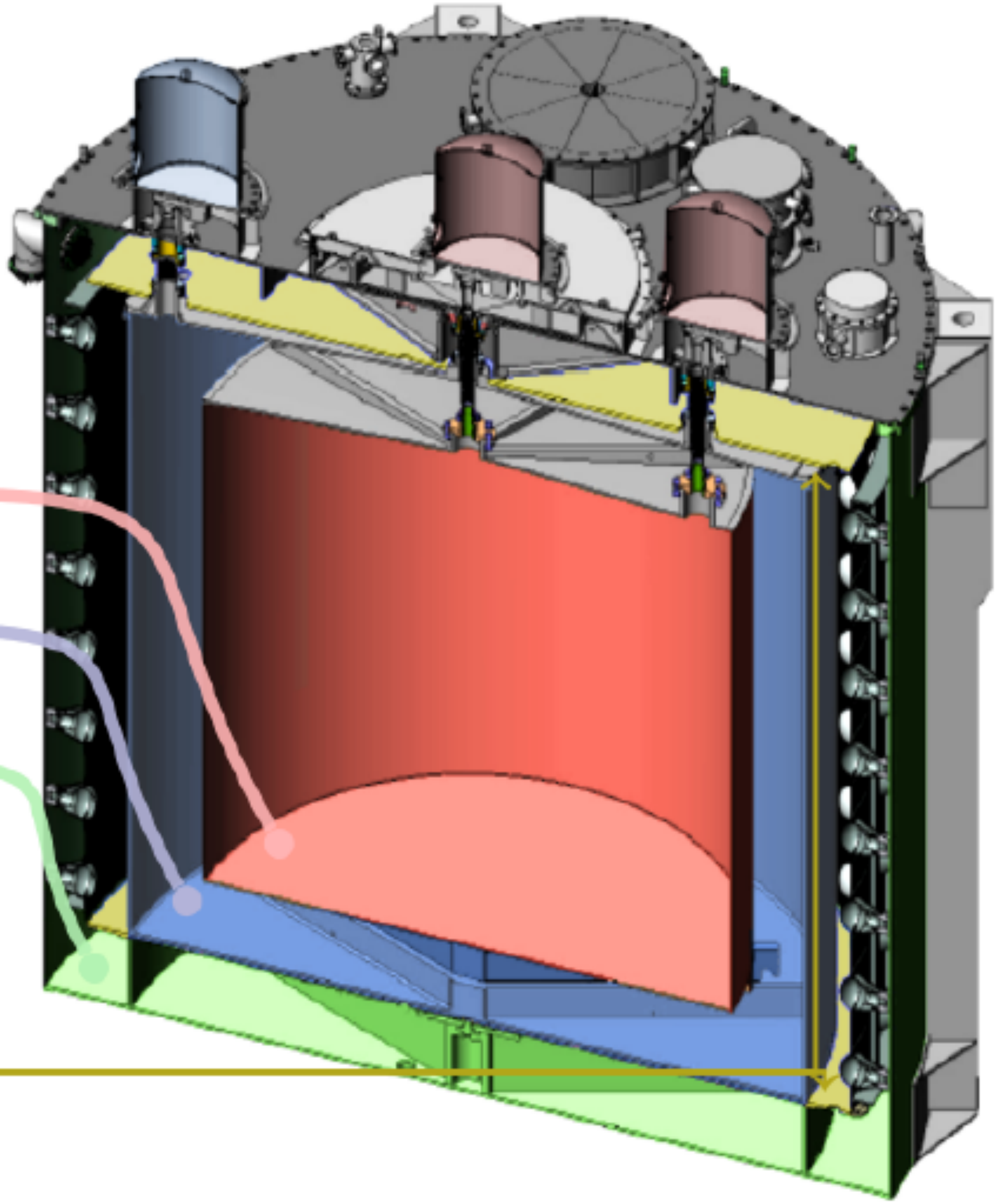
Antineutrino detector (AD) Design

8 functionally identical detectors reduce systematic uncertainties

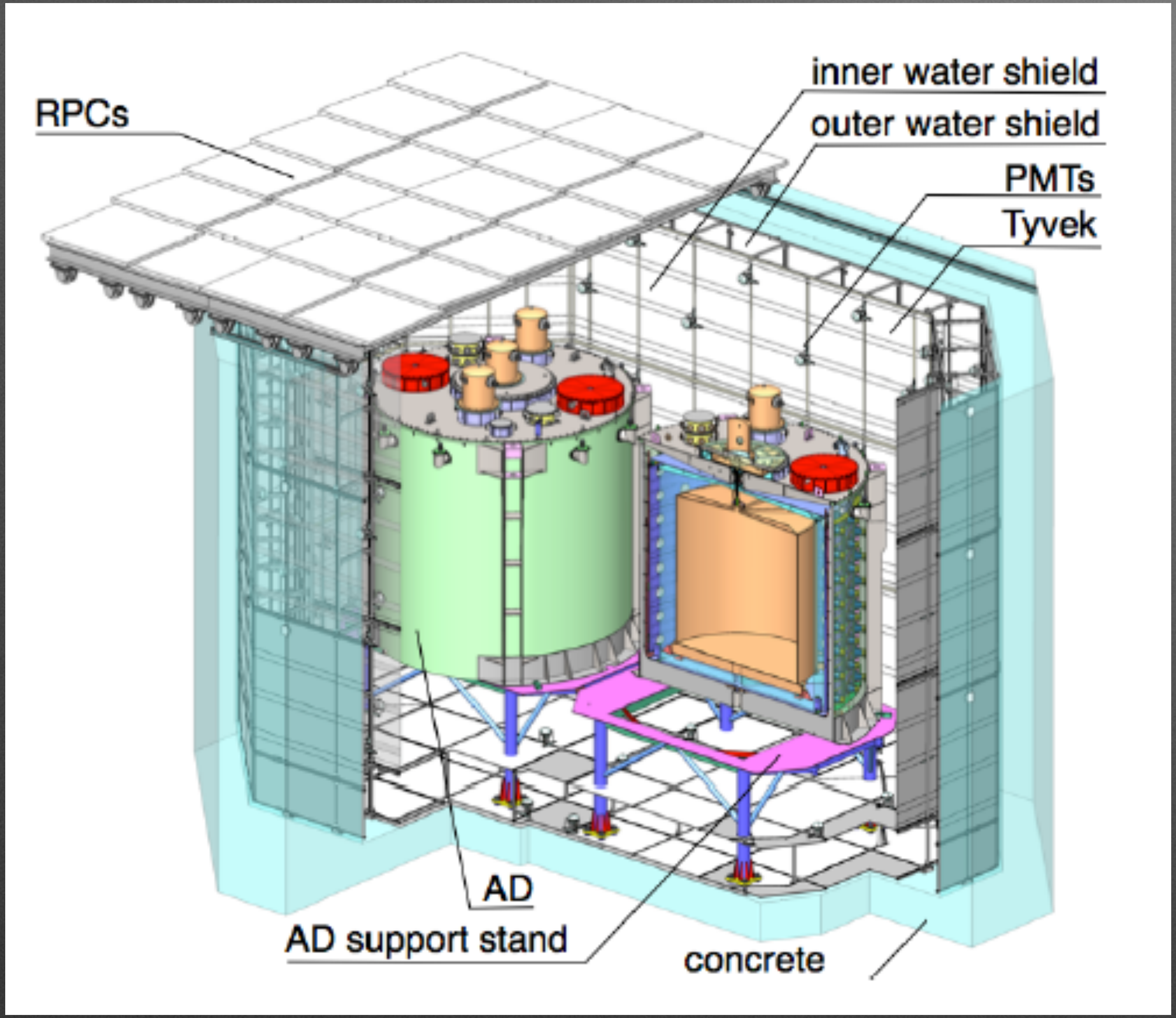
	3 zone cylindrical vessels		
	Liquid	Mass	Function
Inner acrylic	Gd-doped liquid scint.	20 t	Antineutrino target
Outer acrylic	Liquid scintillator	20 t	Gamma catcher
Stainless steel	Mineral oil	40 t	Radiation shielding

192 8 inch PMTs in each detector

Top and bottom reflectors increase light yield and flatten detector response



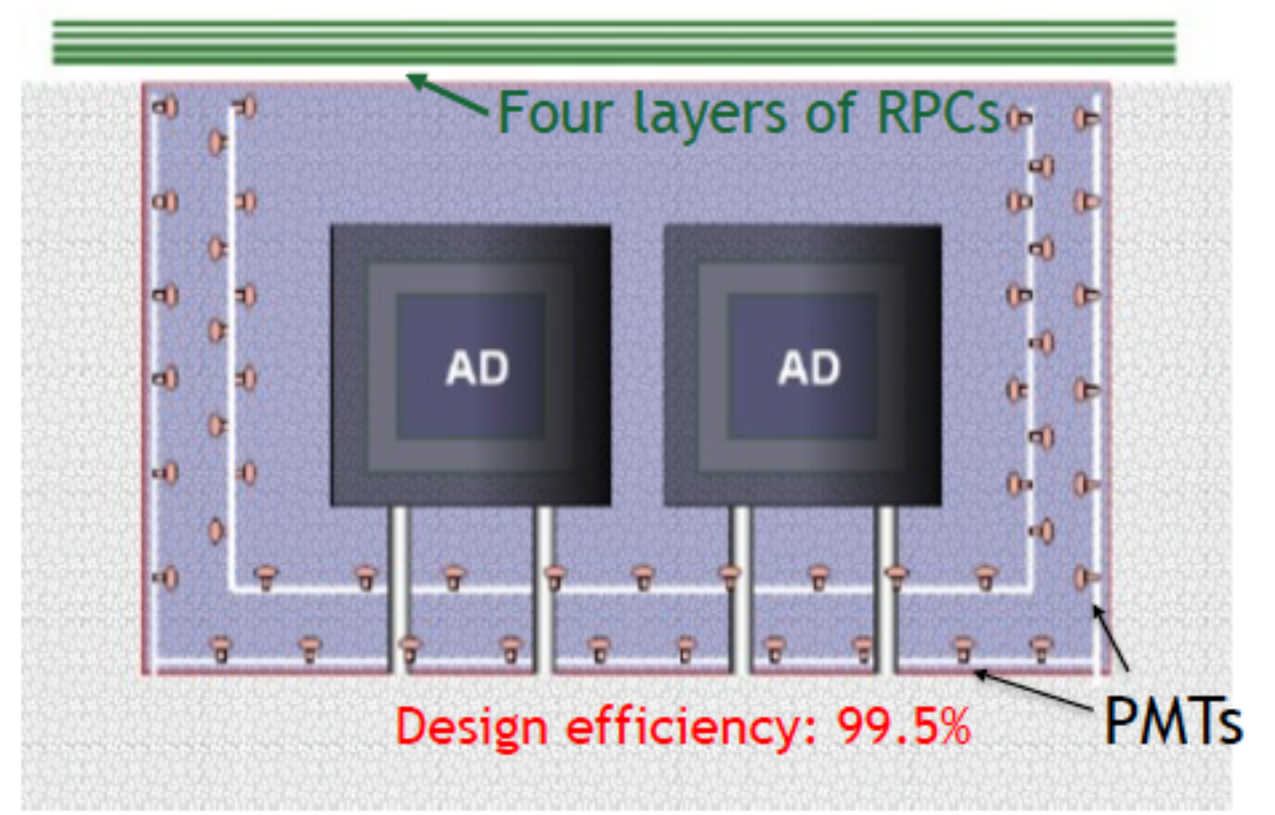
Muon veto system



The ADs are immersed in water pools in order to:

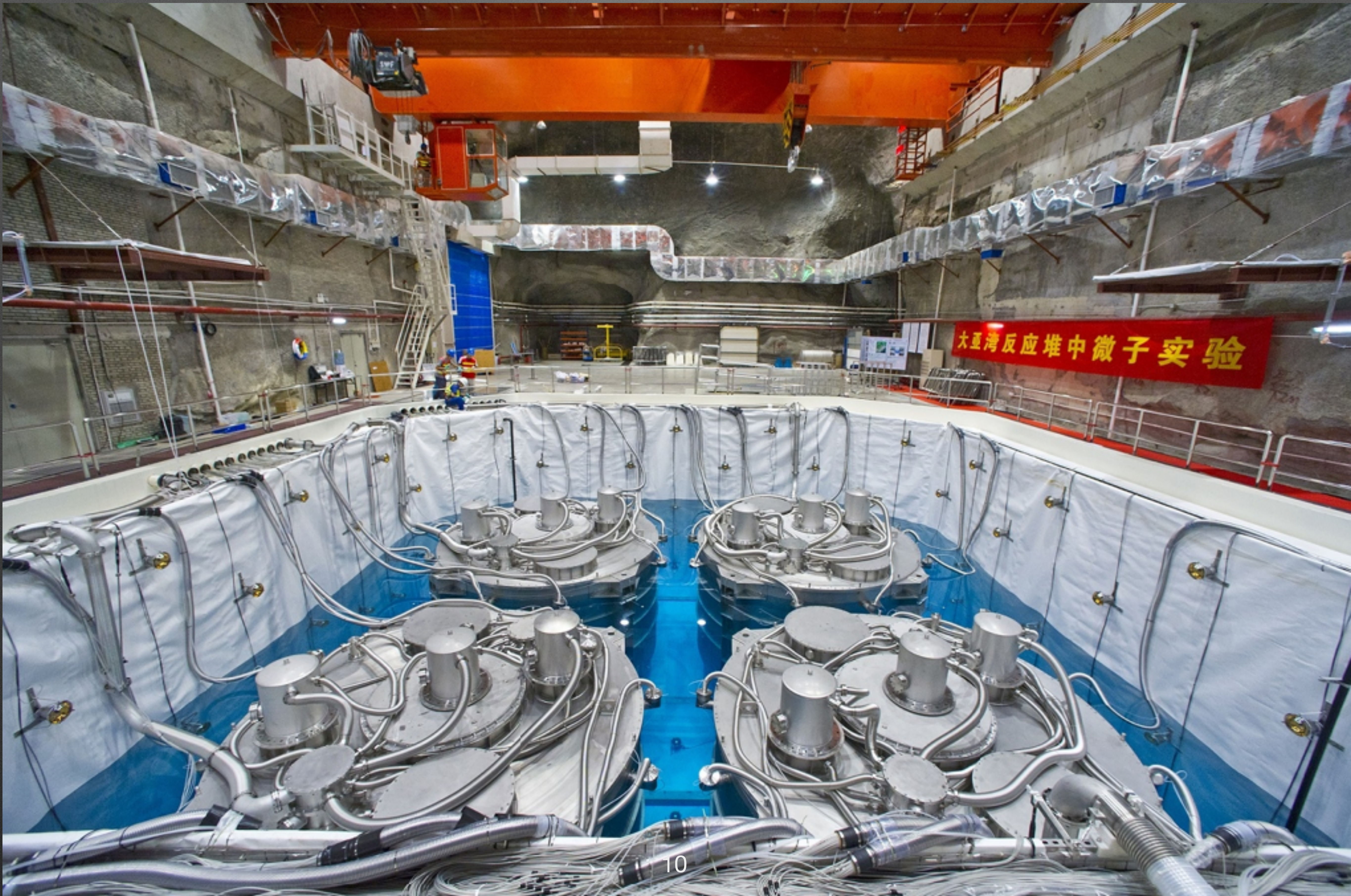
- Shield the detectors from ambient radioactivity and neutrons produced by cosmic-rays muons.
- Be a Cherenkov detector to tag cosmic rays muons.

The pools are covered with a four-layer RPC retractable roof to further increase the cosmic-ray muon tagging efficiency.



Design efficiency: 99.5%

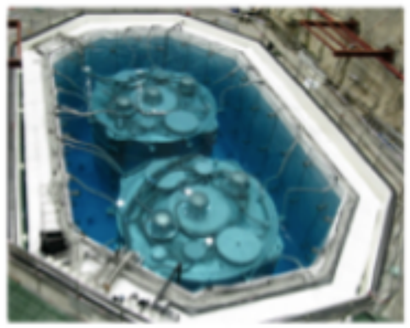
EH3 Far Hall

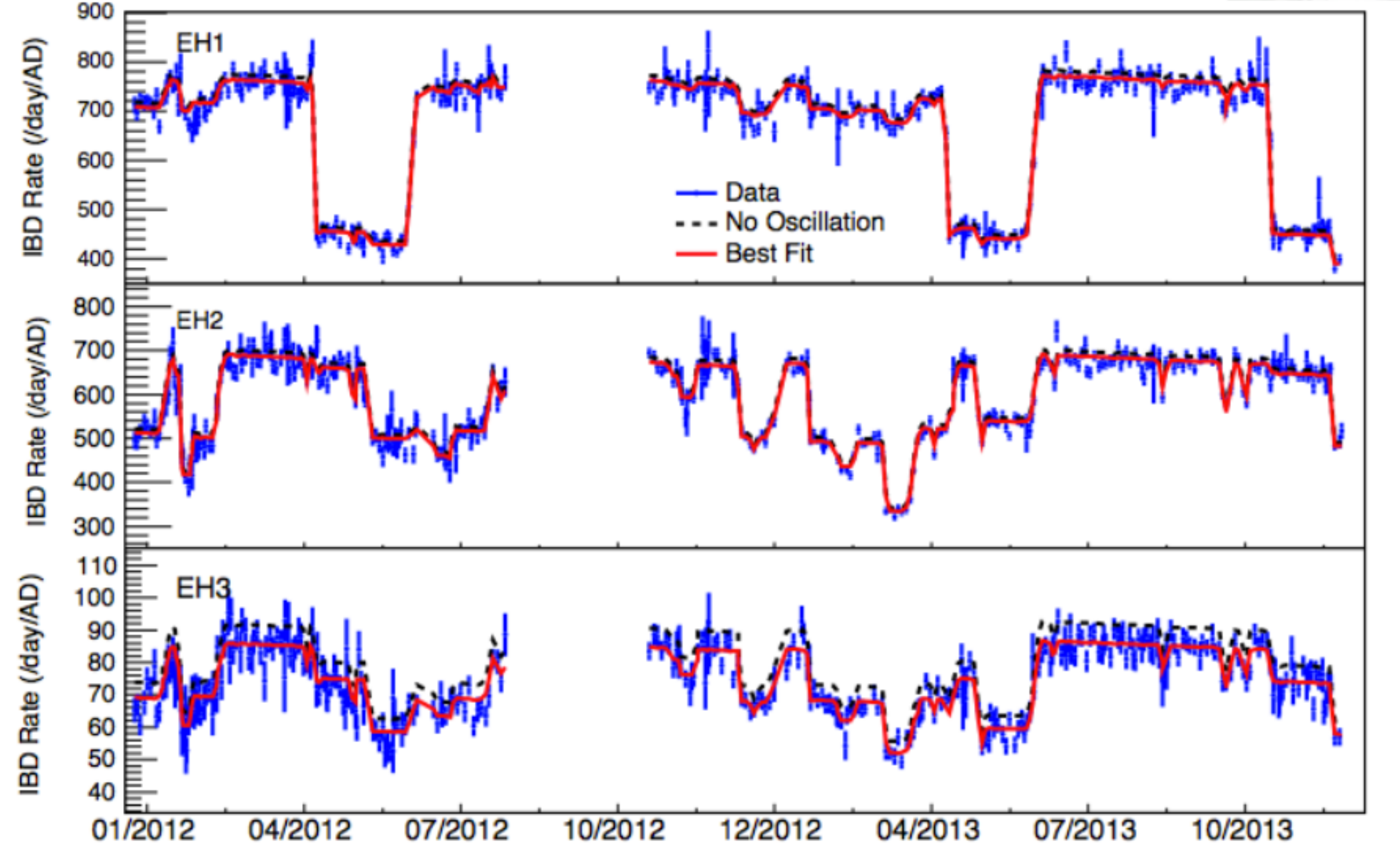


Reactor electron antineutrino flux detected

$\bar{\nu}_e$

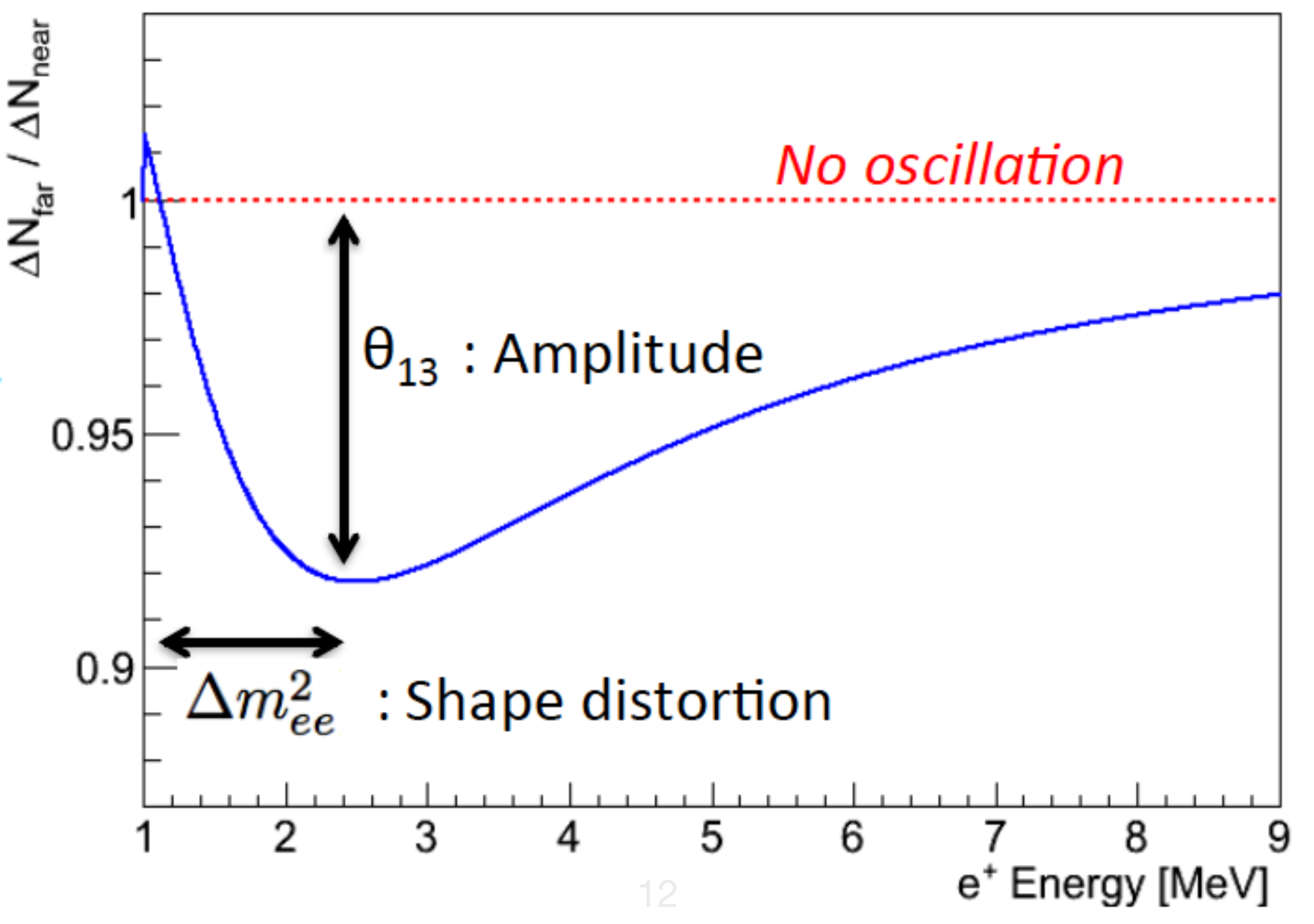
621 days





Spectral antineutrino measurement

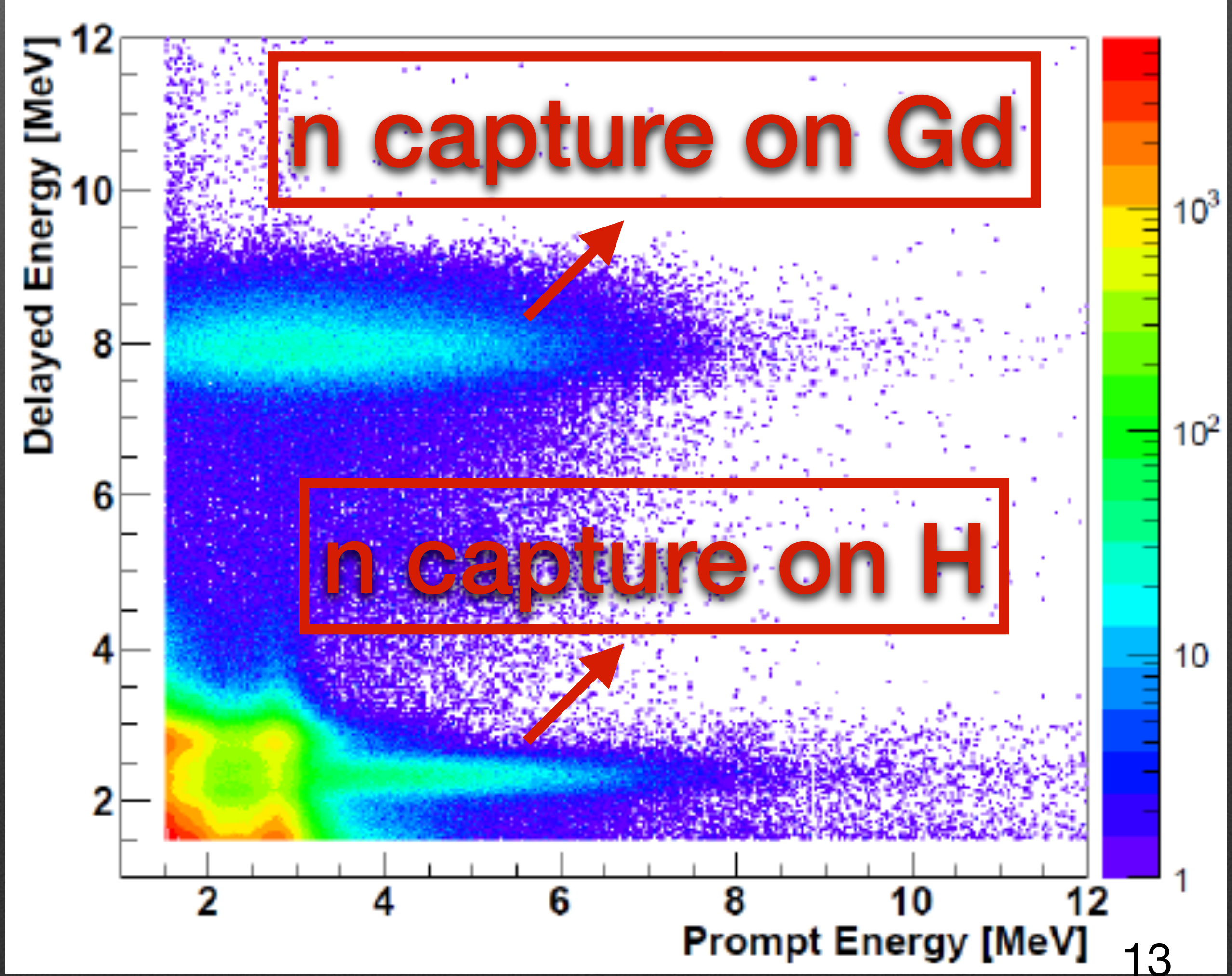
- Neutrinos oscillation with distance and energy.
- If one compare the detected neutrinos in the near hall compared with the detected neutrinos in the far hall and correcting by 1/L^2, one expect more neutrinos in the near hall
- “comparing the near and far energy distributions with perfect statistics one expects something like this due to oscillations:



Antineutrino candidates selection

Selection as follows:

- Muon Veto
- PMT flashers removed
- Prompt energy cut: 0.7 MeV<Ep<12 MeV
- Delayed energy cut: 6 MeV<Ep<12 MeV
- Coincidence time cut: 1μs< Δt<200μs
- Multiplicity cut

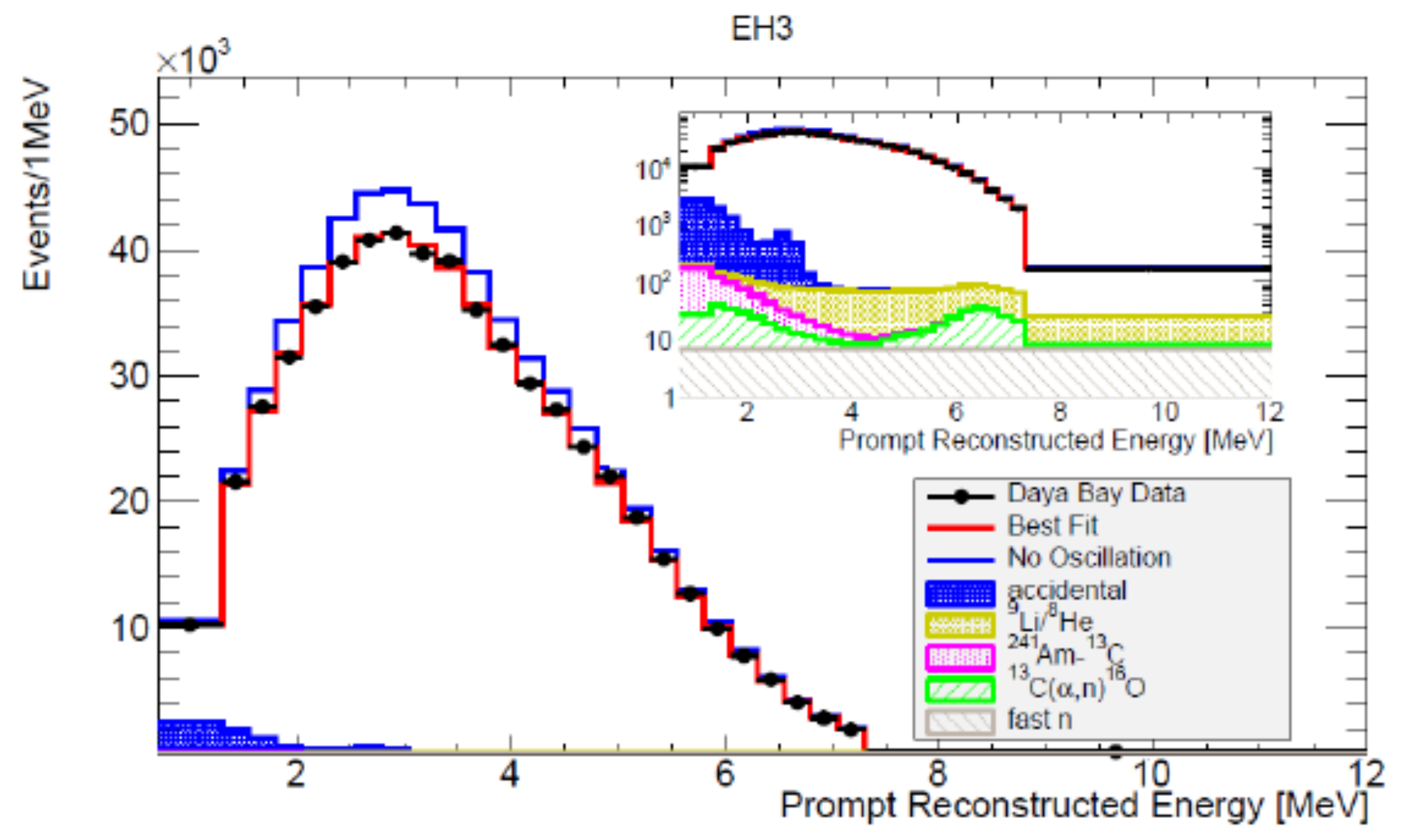


Background composition

Background	Near	Far	Uncertainty	Method	Improvement
Accidentals	1.4%	2.3%	Negligible	Statistically calculated from uncorrelated singles	Extend to larger data set
^{9}Li/^{8}He	0.4%	0.4%	~50%	Measure with after-muon events	Extend to larger data set
Fast neutron	0.1%	0.1%	~30%	Measured from RPC+OWS tagged muon events	Model independent measurement
AmC source	0.03%	0.2%	~50%	MC benchmarked with single gamma and strong AmC source, also studied with a stronger external source placed on AD	Two sources are taken out in Far site ADs
Alpha-n	0.01%	0.1%	~50%	Calculated from measured radioactivity	Reassess systematics

Background composition

The accidentals are the largest contributor to the background



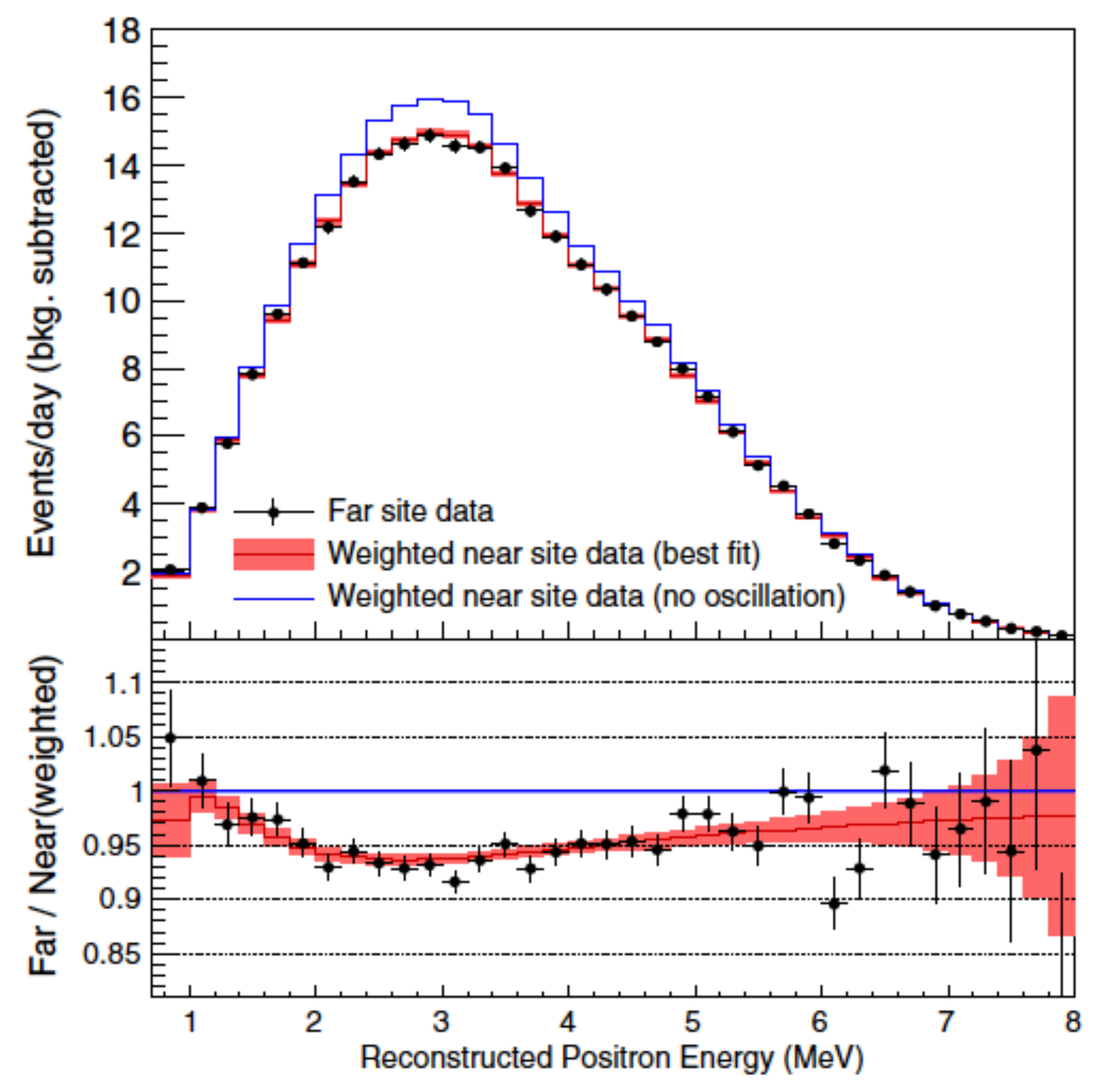
Antineutrino Oscillation Results

$$\sin^2 2\theta_{13} = 0.084^{+0.005}_{-0.005}$$

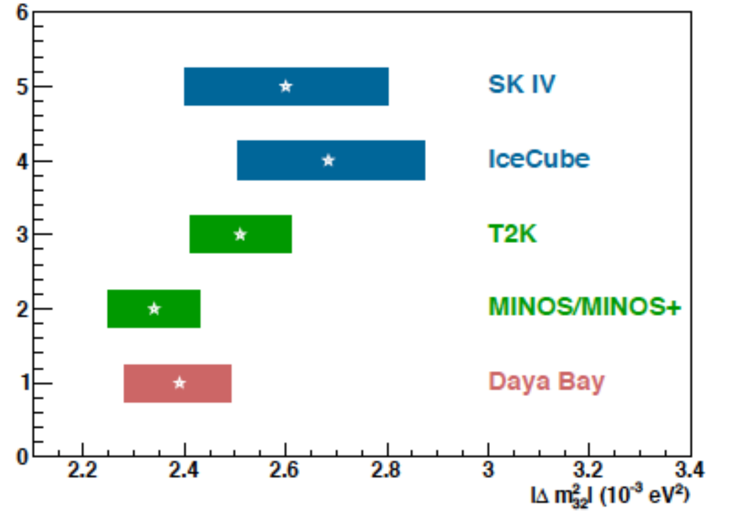
$$|\Delta m^2_{ee}| = 2.44^{+0.10}_{-0.11} \times 10^{-3}\mathrm{eV}^2$$

$$\chi^2/NDF = 134.7/146$$

- We do a relative analysis where we predict the far spectra from the near spectra
- The most precise measurement in the world, roughly 6% precision.
- Measurement in Δm^2_{ee}, consistent and of comparable precision to muon neutrino disappearance channel.



Neutrino 2014



PRL 115, 111802 (2015)

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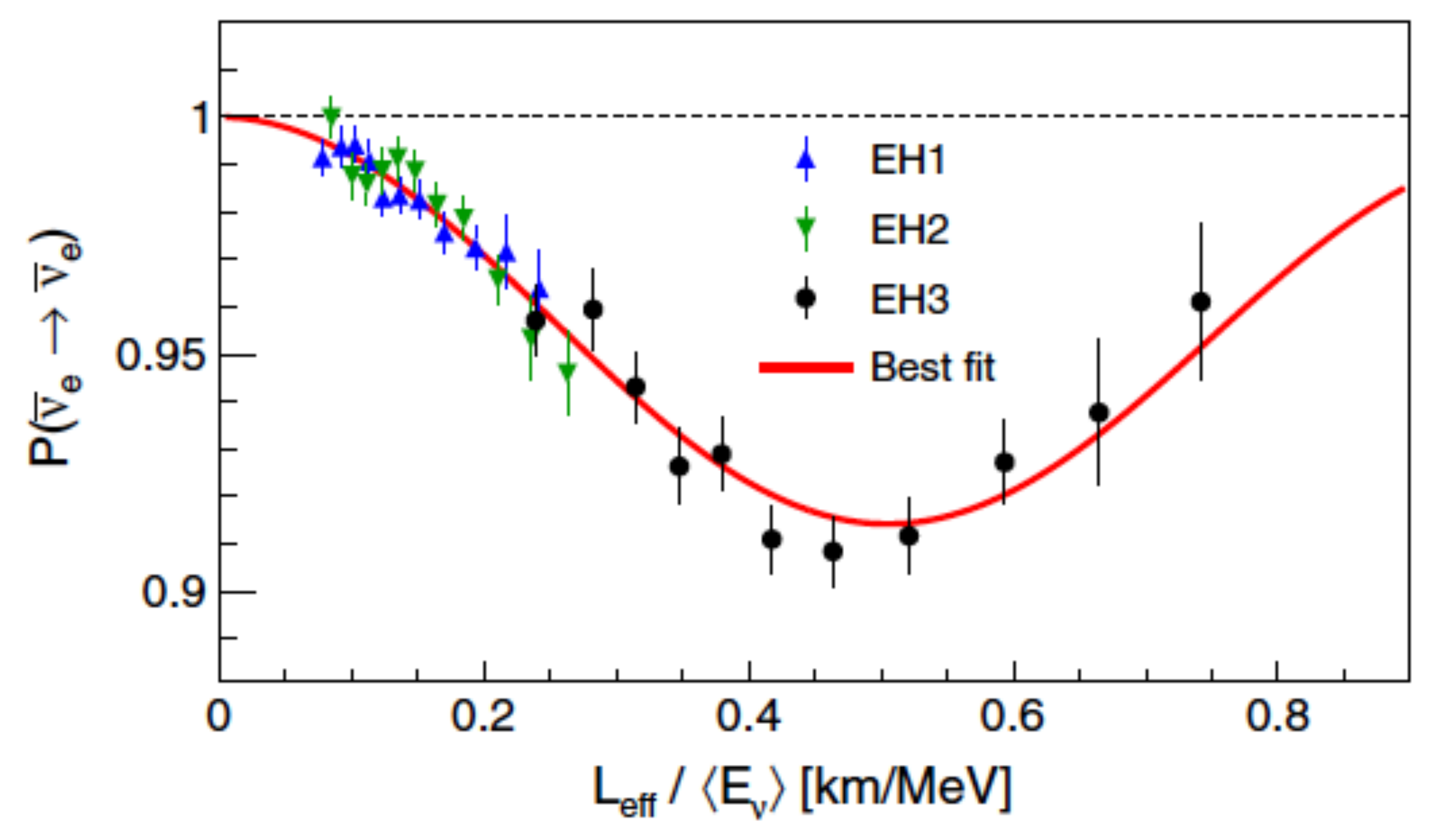
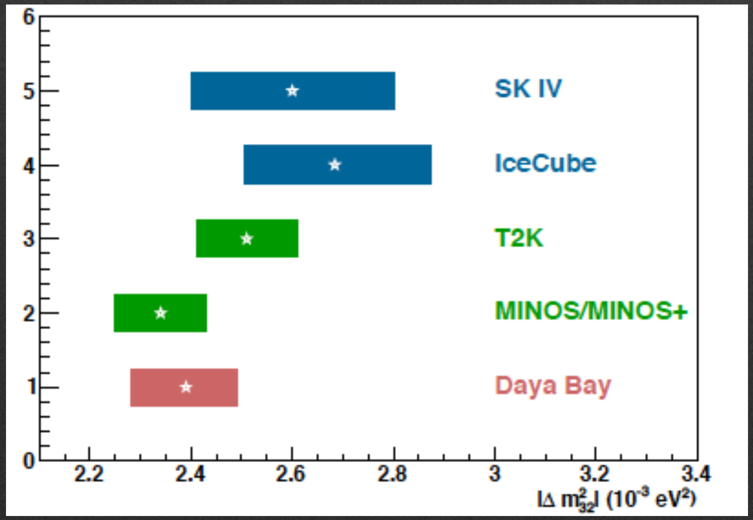


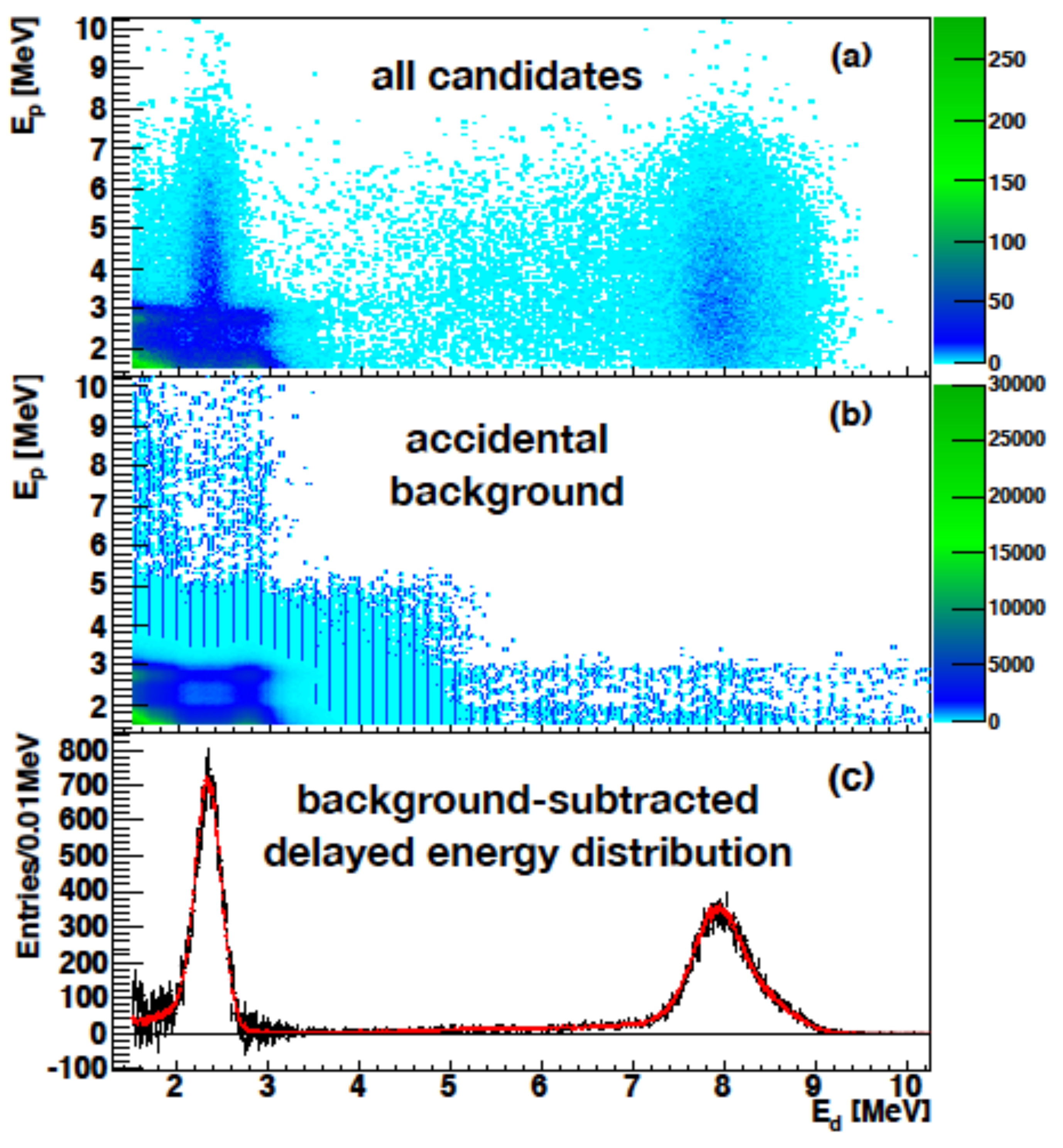
Neutrino 2014



PRL 115, 111802 (2015)

$\text{Sin}^2(2\vartheta_{13})$ from nH capture

- Statistically independent sample
- High accidental background due to longer capture time and lower delayed energy
- Strategy: raise prompt energy cut (> 1.5 MeV) and prompt to delay distance cut (0.5m)



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- Statistically independent sample
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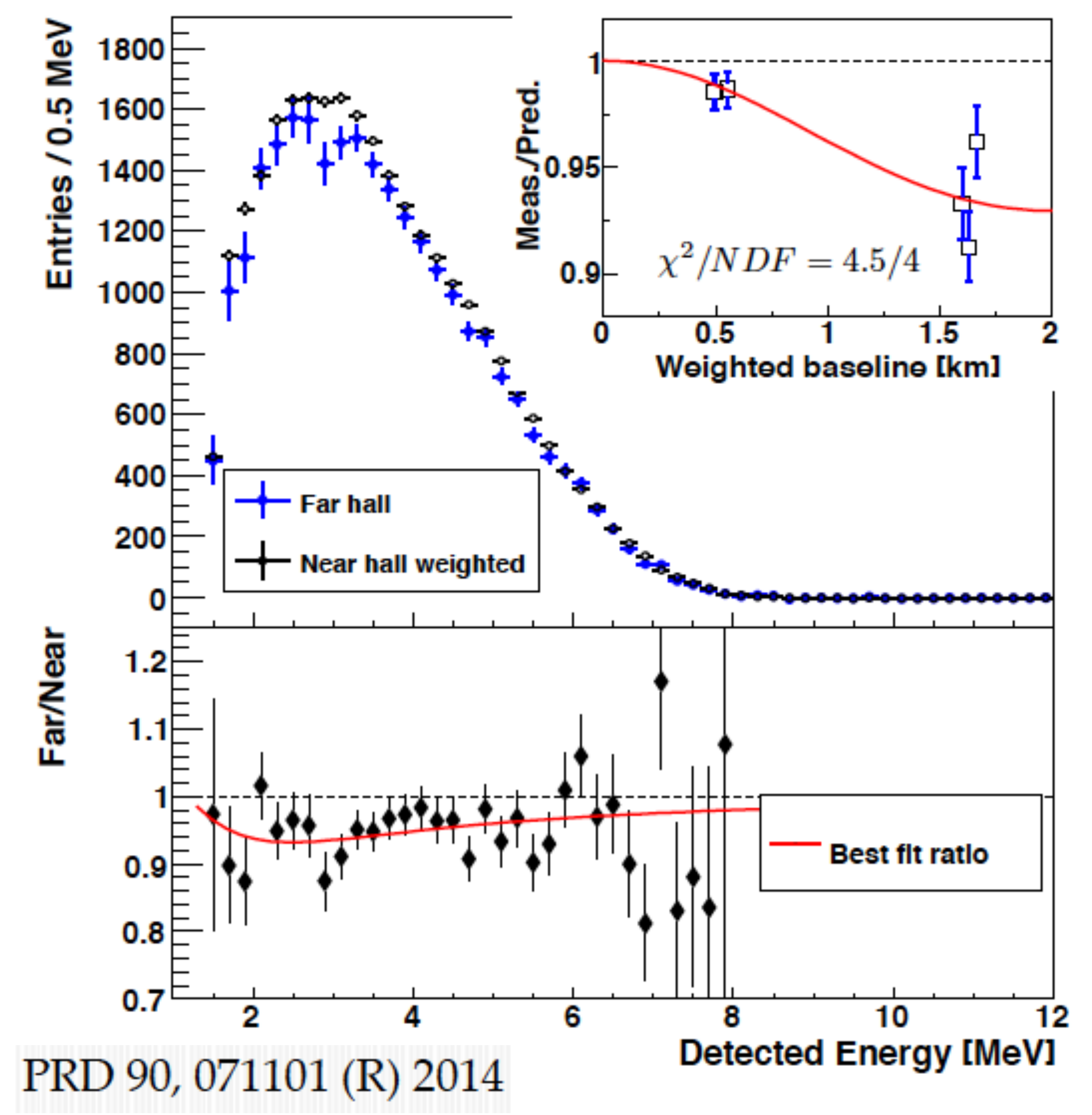
- Oscillation analysis of rate deficit using first 217 days of data acquired with 6 ADs

$\sin^2(2\vartheta_{13})=0.083 \pm 0.018$



PRD 90, 071101 (R) 2014

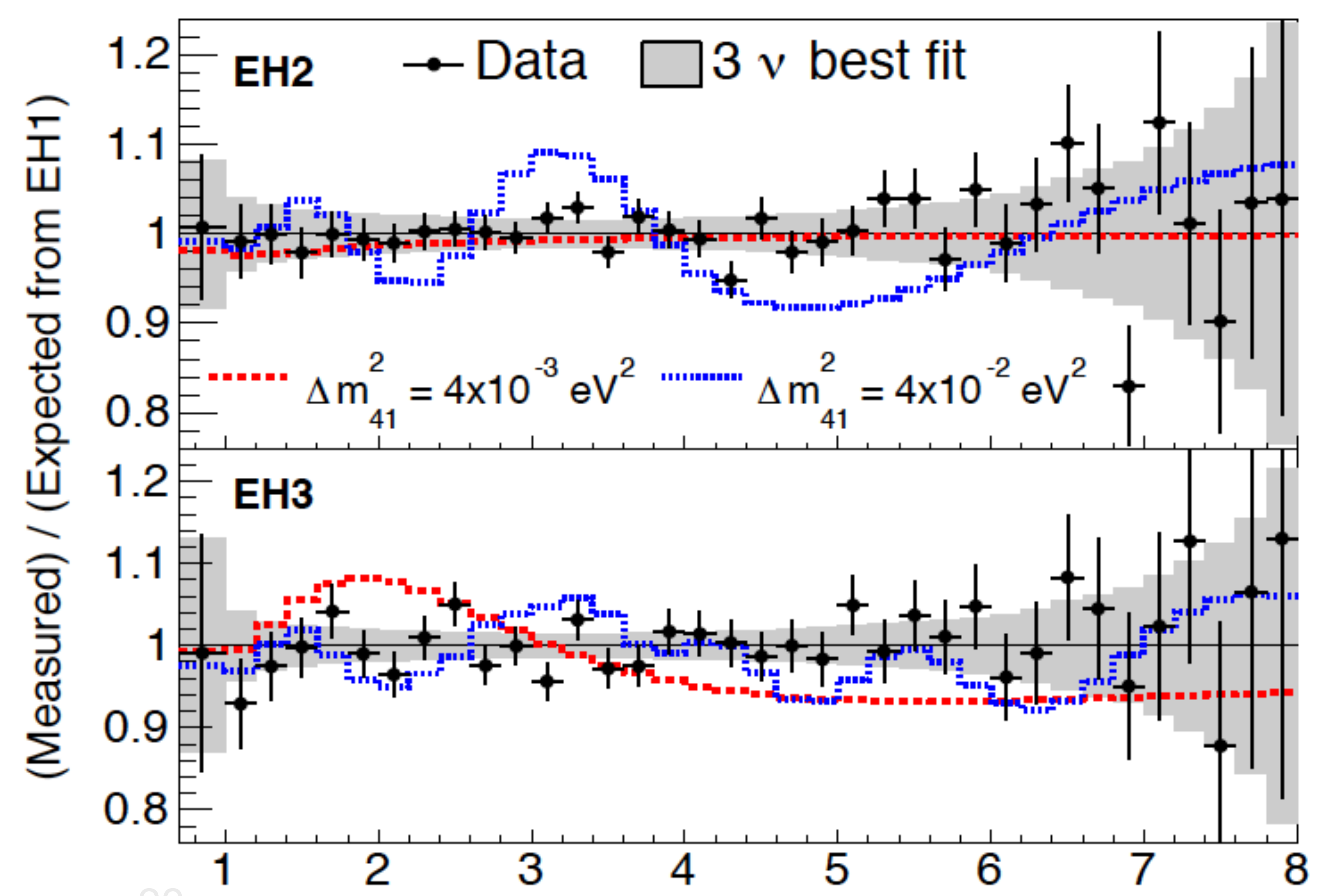
Sterile neutrinos ϑ_{14}

Sterile neutrinos could resolve some of the outstanding puzzles in cosmology and neutrino physics.

- The existence of sterile neutrino will modify the oscillation probability formula:

$$P(\bar{\nu}_e \to \bar{\nu}_e) \simeq 1 - \cos^4\theta_{14}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{ee}L}{4E_\nu}\right) - \boxed{\sin^2 2\theta_{14}}\sin^2\left(\frac{\boxed{\Delta m^2_{41}}L}{4E_\nu}\right)$$

- Looking for an additional spectral distortion with a frequency different from the one due to the atmospheric mass splitting between different sites.

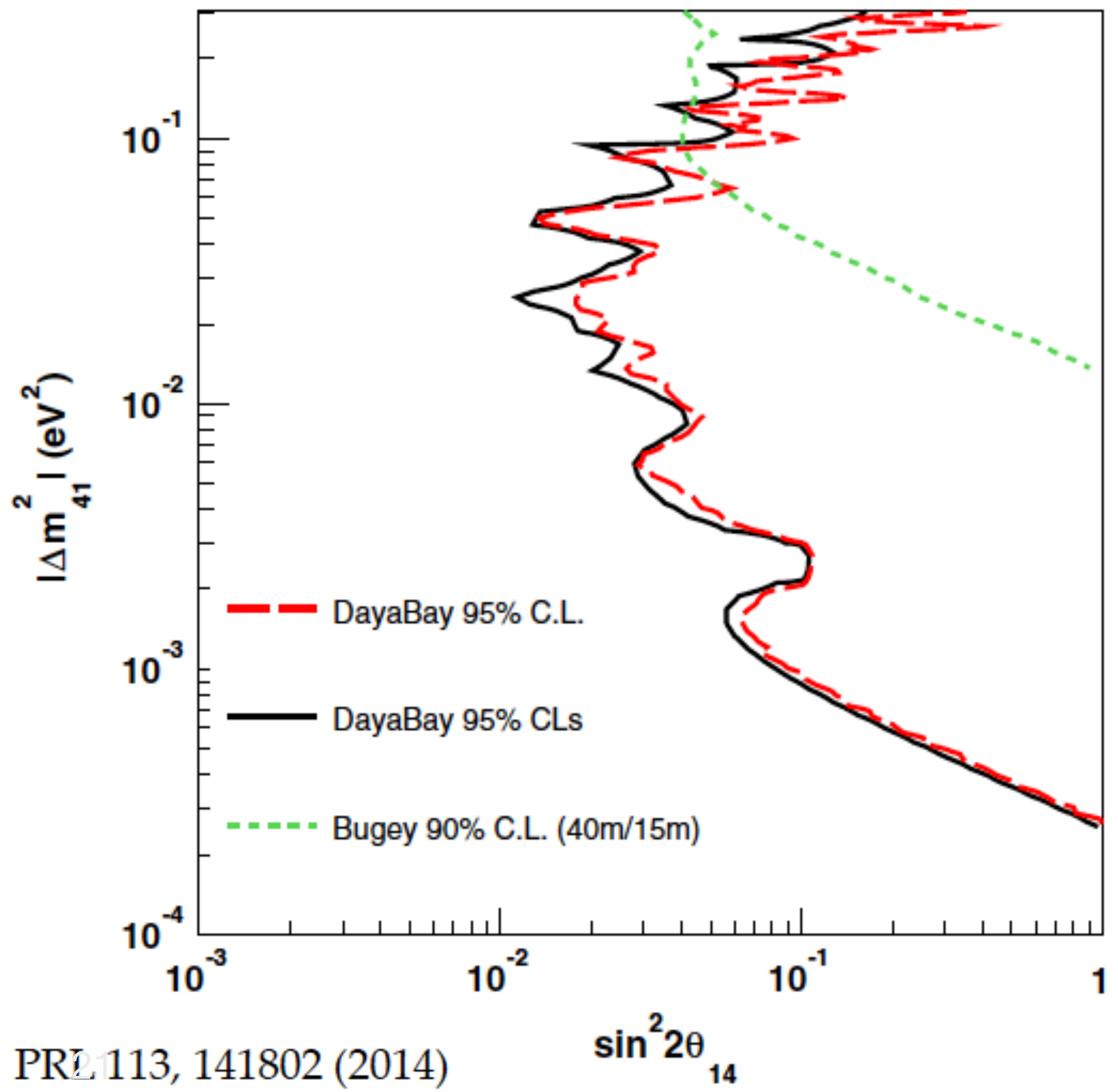


PRL 113, 141802 (2014)

Sterile neutrinos ϑ_{14}

Results:

- Two different statistical methods to set contours and they agree.
- This results was obtained using first 217 days of data acquired with 6 ADs
- Daya Bay's multiple baselines allow us to set limits in the range of $\Delta m^2_{14} \sim 0.001\text{-}0.1$ not explored previously



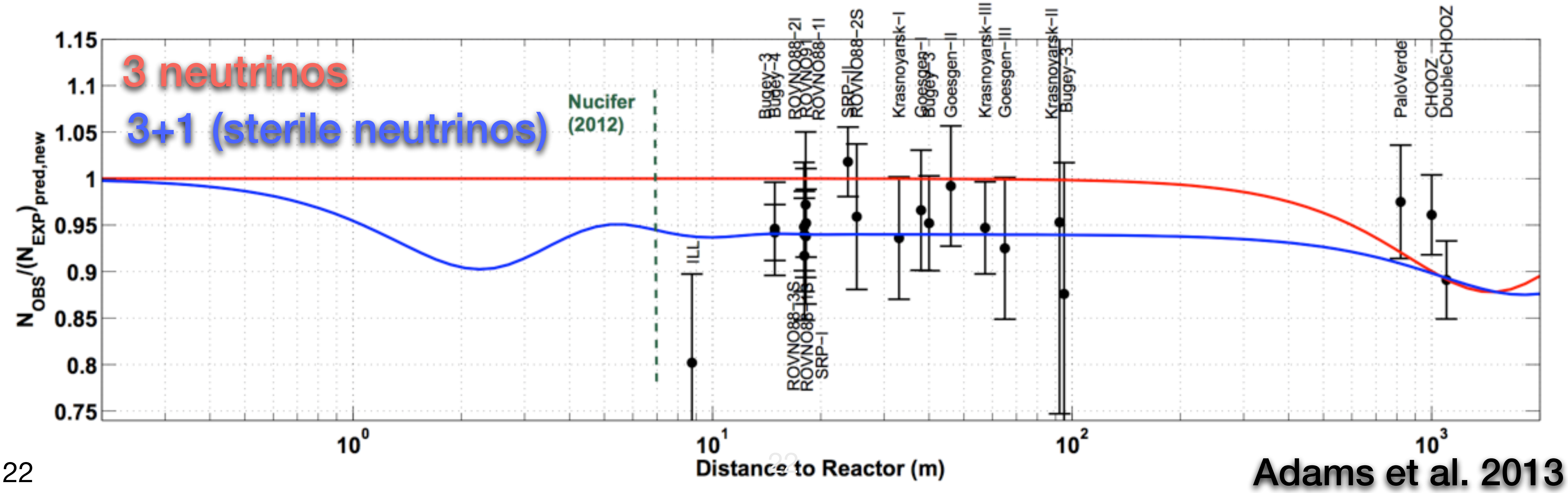
PRL 113, 141802 (2014)

Reactor antineutrino anomaly

- The reactor antineutrino anomaly, refers to the antineutrino deficit compared with the up to date theoretical predictions (Huber+Mueller).

- Among the possibilities to explain the anomaly are:

1) Error in neutrino flux prediction
2) Bias in all experiments (unlikely)
3) New physics, sterile neutrinos involved

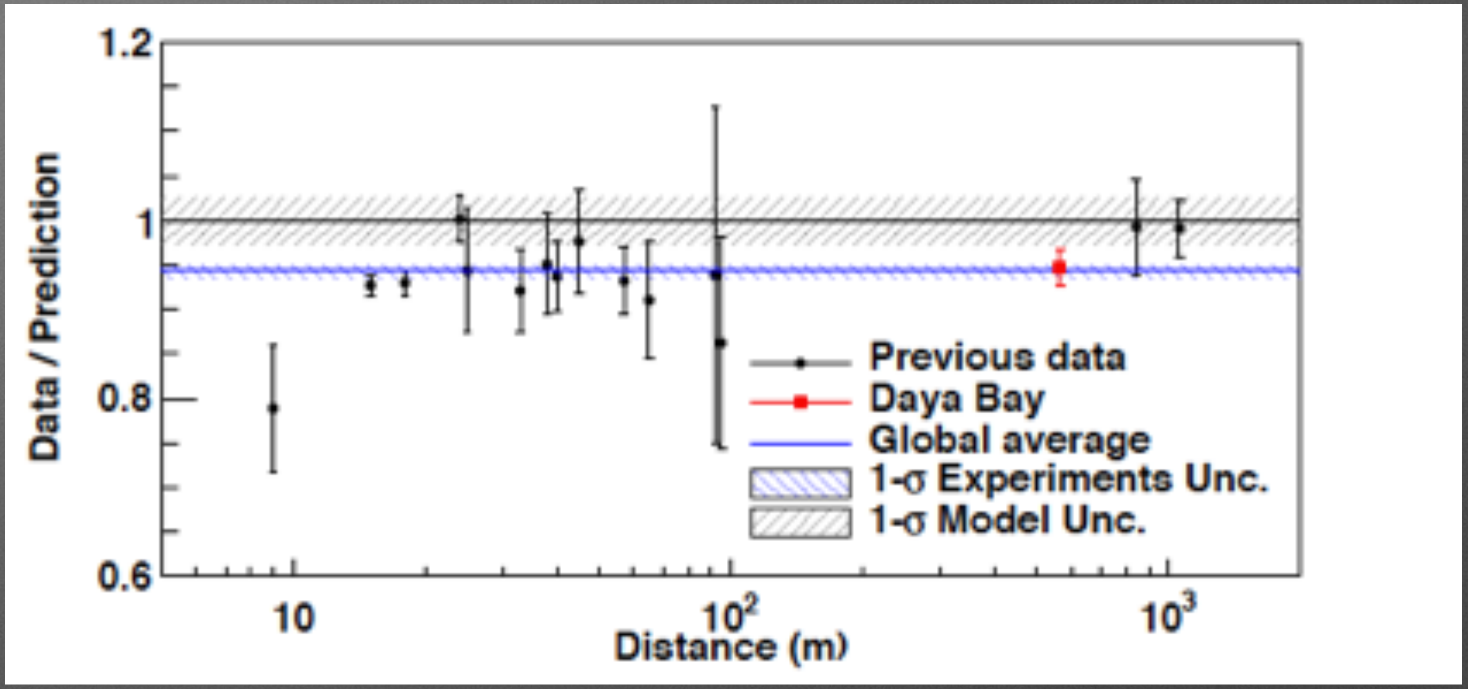


Adams et al. 2013

Reactor antineutrino anomaly

The Daya Bay measured IBD candidates flux, agree with previous short baseline experiments:

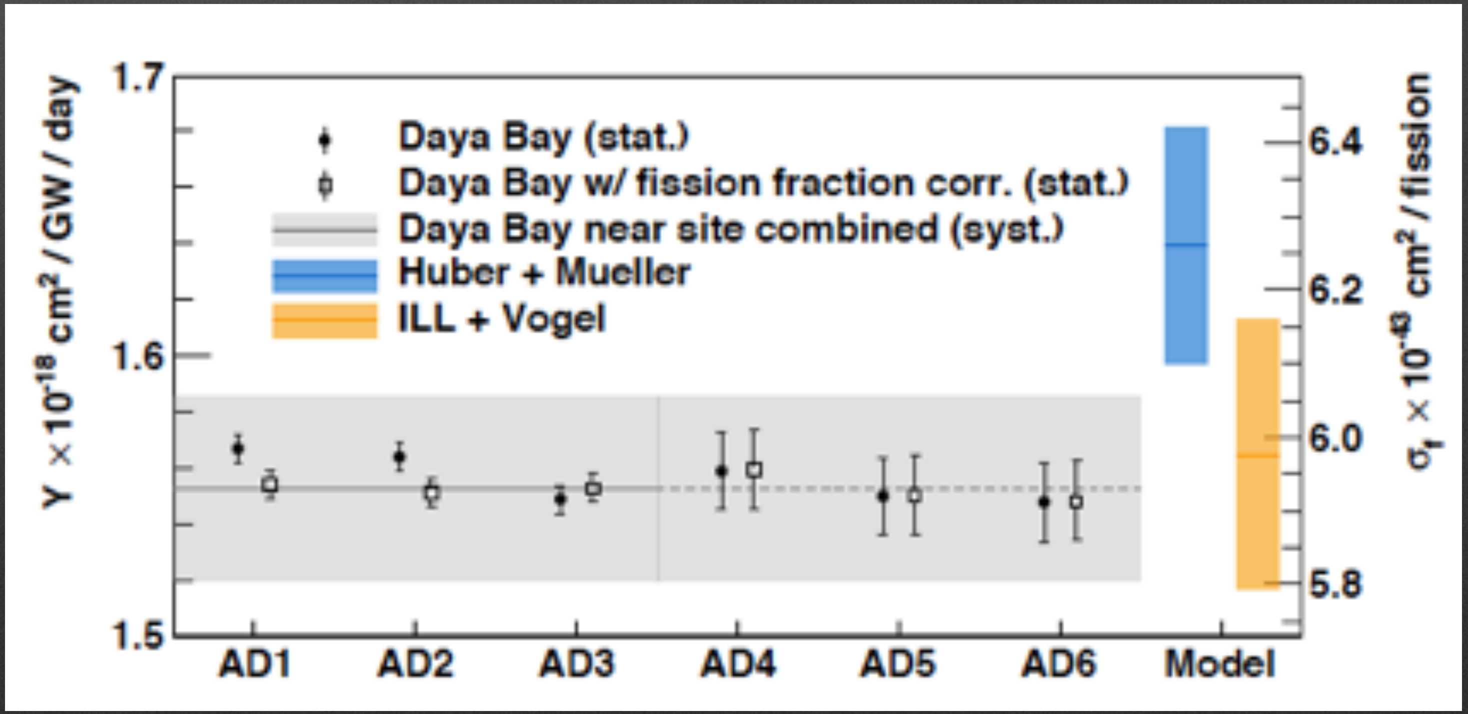
Data/Prediction = 0.947 ± 0.022 (Huber+Mueller)



The average IBD yield (Y) in the three near AD is:

$Y=(1.55 \pm 0.04)10^{-18}$ [cm^2/GW/day]

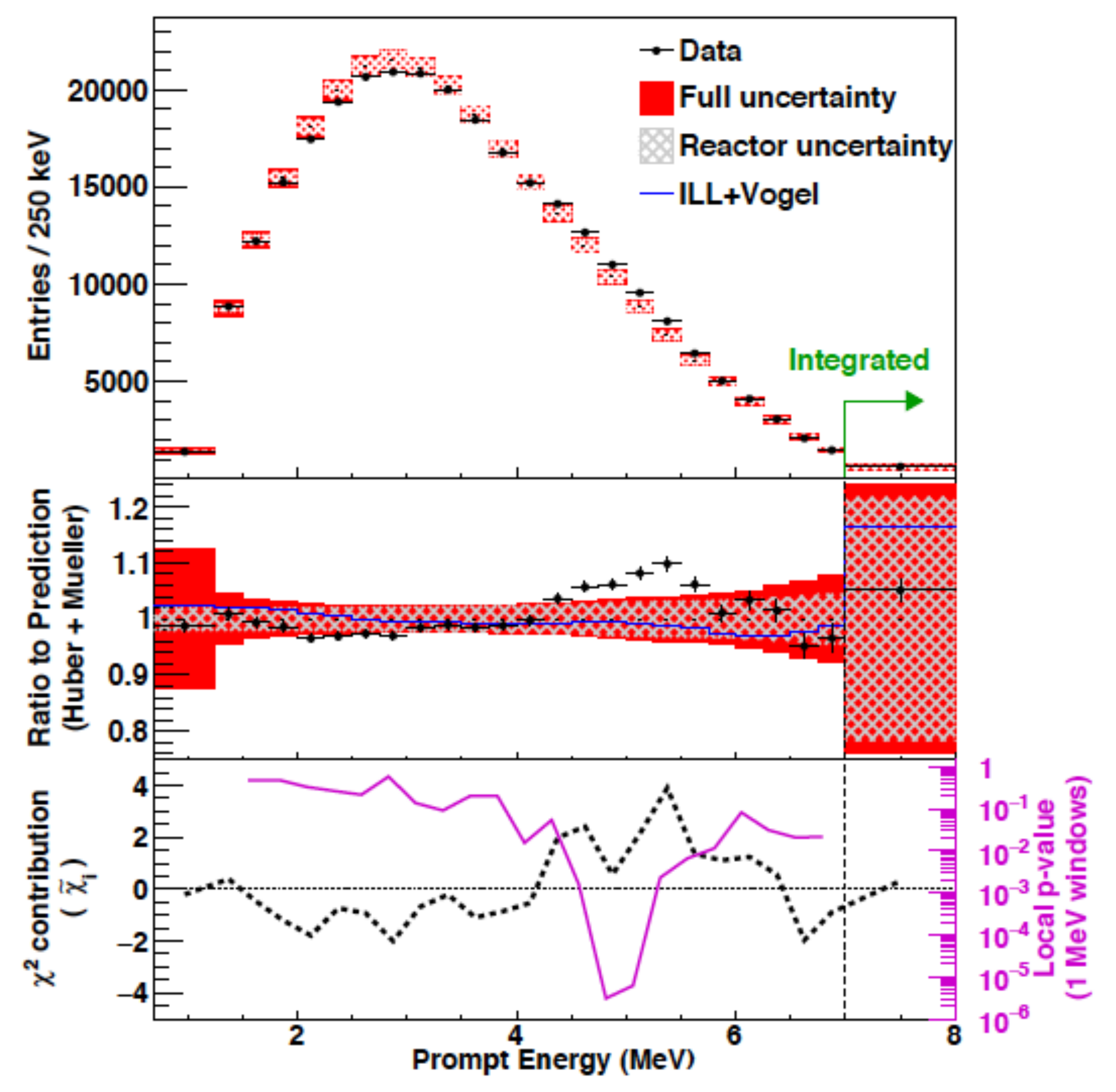
$\sigma_f=(5.92 \pm 0.14)10^{-18}$ [cm^2/fission]



Spectral shape from reactor antineutrinos

- Daya Bay measured positron spectra of IBD events in three near ADs. The Daya Bay measured positron spectra of IBD events from three near ADs are combined and compared with predictions.

- Daya Bay observes a 2.6σ discrepancy in the 0.7-12MeV range (4.4σ in the 4-6MeV range)



Daya Bay Future

- Daya Bay is still collecting data in order to increment the precision in $\sin^2(2\vartheta_{13})$ measurement (3%-4%).
- Precision determination of the energy spectrum.
- Tracking the reactor anomaly.
- Supernova online trigger system in Daya Bay running and in the near future will join to SNEWS.
- New physics explorations, like sterile neutrinos among others.

Conclusions

- Daya Bay reached the unseen 6% precision on $\sin^2(2\vartheta_{13})$ with 612 days of data taking.

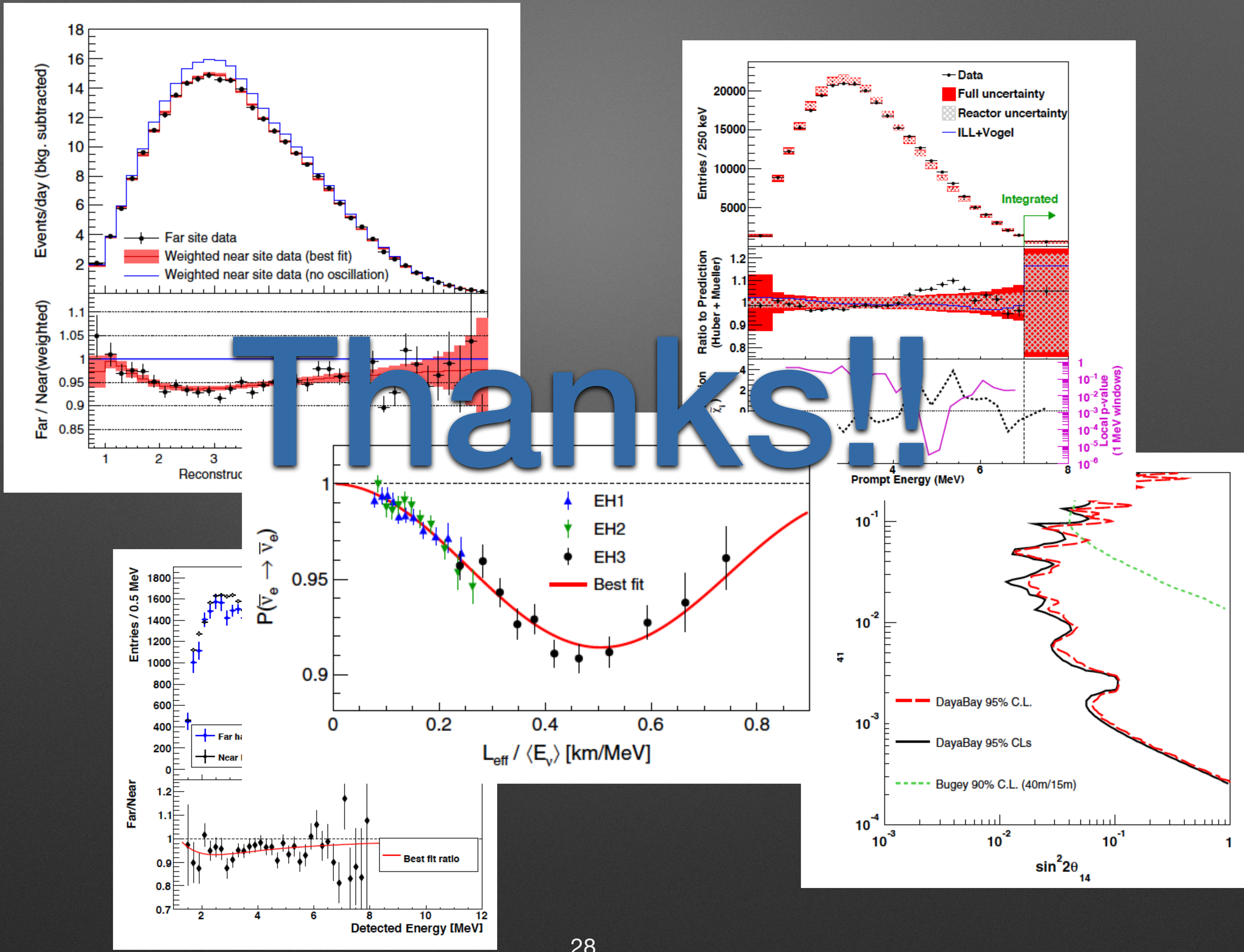
- An independent measurement of $\sin^2(2\vartheta_{13})$ using n-captures on H using first 217 days of data acquired with 6 ADs.

Conclusions

- Daya Bay has searched in the unexplored Δm^2_{14} = 0.001-0.1 eV^2 for sterile neutrino, setting the most stringent limits in this area.

- Daya Bay observes the ~6% discrepancy between the absolute reactor antineutrino flux prediction and measurement from the reactor antineutrino anomaly, which is consistent with past world average and also observes a ~4.0 σ discrepancy in the 4-6 MeV prompt energy region when comparing the predicted vs. the expected spectral shapes

Thanks!!


Events/day (bkg. subtracted)
Far site data
Weighted near site data (best fit)
Weighted near site data (no oscillation)
Far / Near(weighted)
Reconstruc
Entries / 250 keV
Data
Full uncertainty
Reactor uncertainty
ILL+Vogel
Integrated
Ratio to Prediction (Huber + Mueller)
Local p-value (1 MeV windows)
Prompt Energy (MeV)
$P(\overline{\nu}_e \rightarrow \overline{\nu}_e)$
EH1
EH2
EH3
Best fit
$L_{eff} / \langle E_\nu \rangle$ [km/MeV]
Entries / 0.5 MeV
Far ha
Near l
Far/Near
Best fit ratio
Detected Energy [MeV]
DayaBay 95% C.L.
DayaBay 95% CLs
Bugey 90% C.L. (40m/15m)
$\sin^2 2\theta_{14}$