Results from Daya Bay Experiment

Bedřich Roskovec
Charles University in Prague
on behalf of the Daya Bay Collaboration

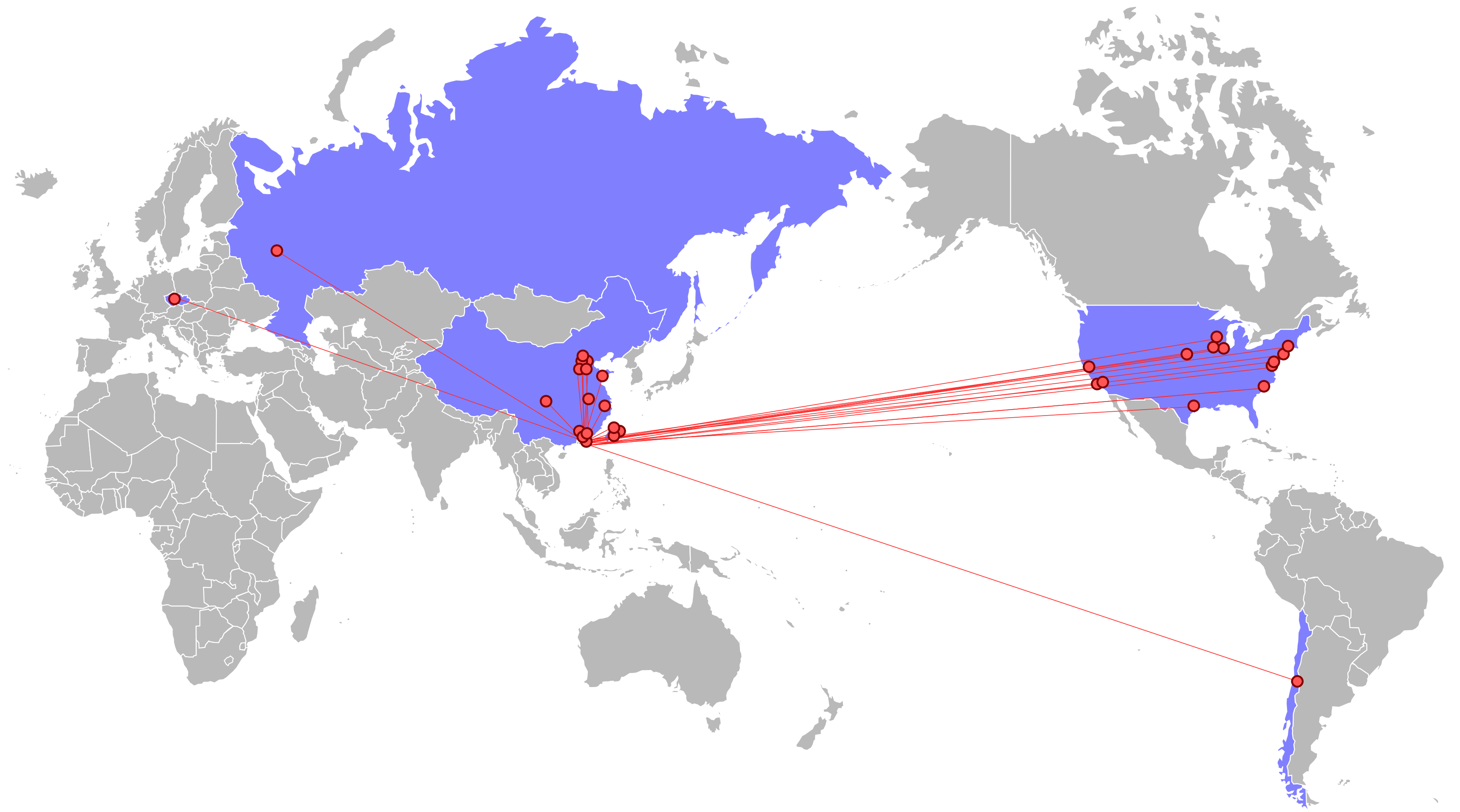
Outline

- Day Bay Experiment
- Measurement of neutrino oscillation parameters in three-neutrino framework
- Search for light sterile neutrinos
- Measurement of reactor antineutrino energy spectrum and absolute flux

Data Bay Experiment collaboration

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

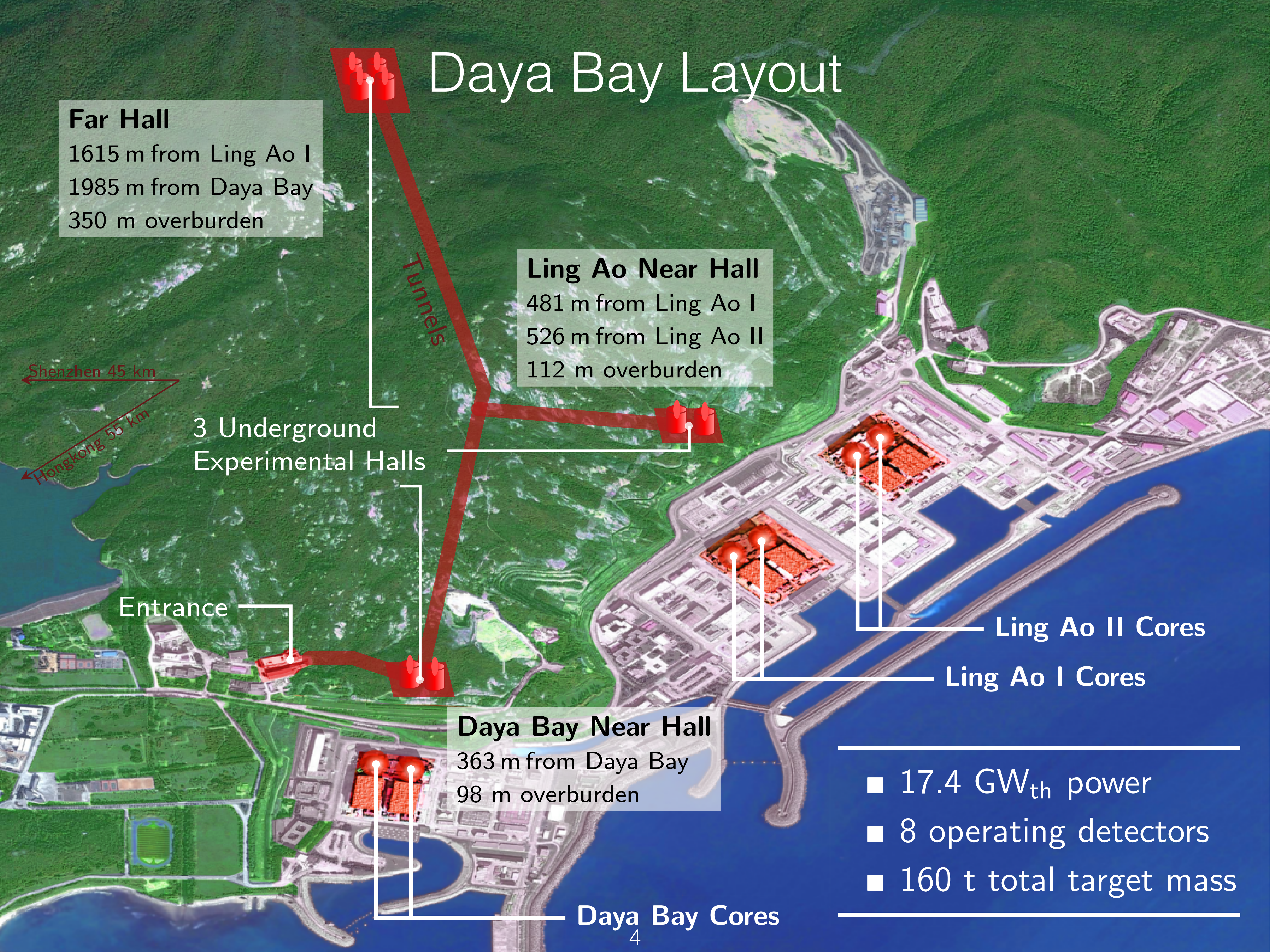
Europe (2)

Charles University, JINR Dubna

South America(1)

Catholic University of Chile

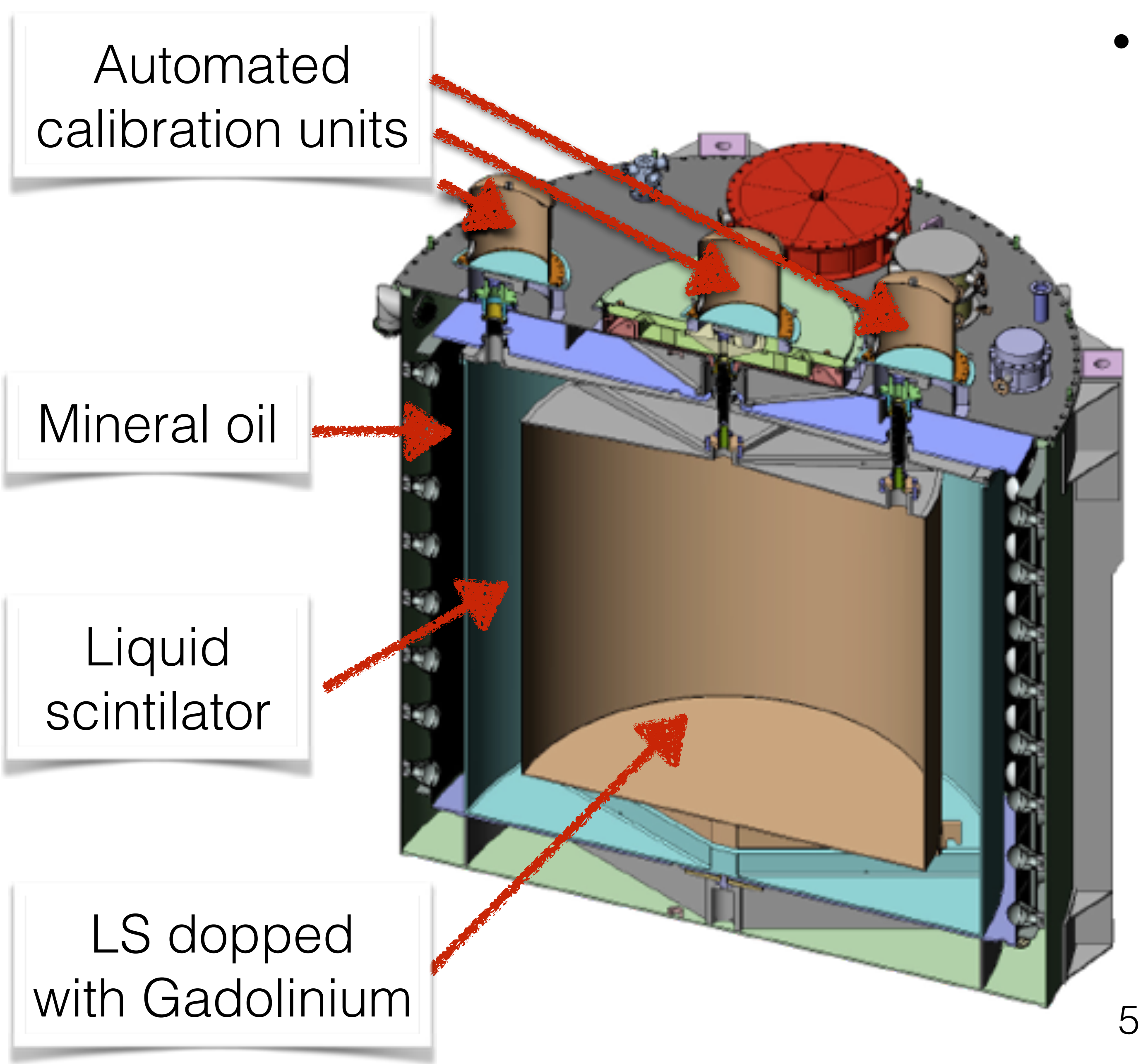
Daya Bay Layout

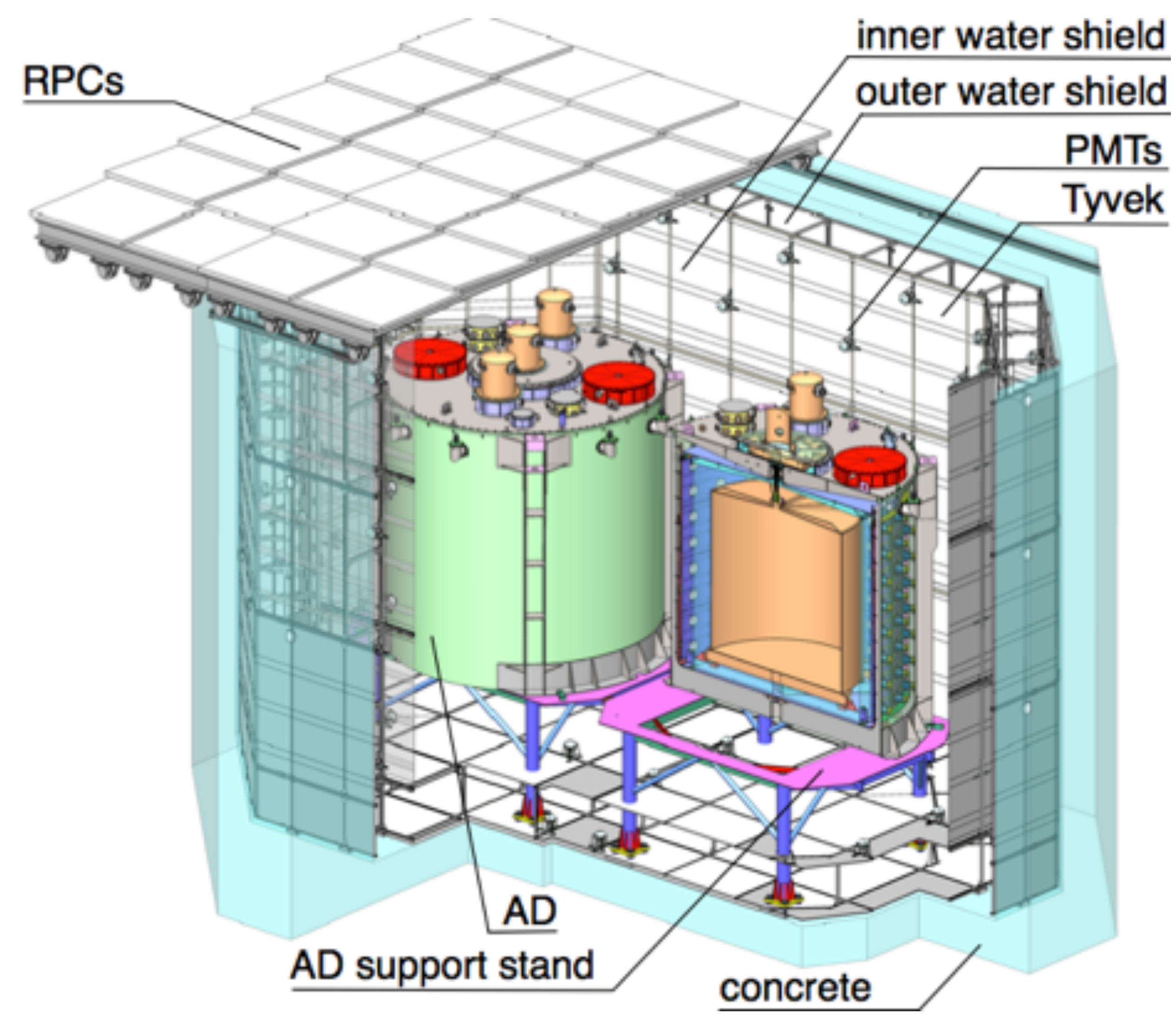


Antineutrino detector and muon tagging system

- Antineutrino detector
  - 3 separated regions - GdLS, LS, MO
  - 182x8" PMT
  - 3 ACUs with radioactive sources for weekly energy calibration

- Muon tagging system
  - ADs submerged in the water pool - passive shielding (n,γ) and active muon detector
  - Inner and outer optically separated regions of the pool - two independent water Čerenkov detectors
  - 4-layer resistive plate chamber array





Antineutrino candidate selection

Coincidence

Inverse beta decay:

prompt signal

delayed signal

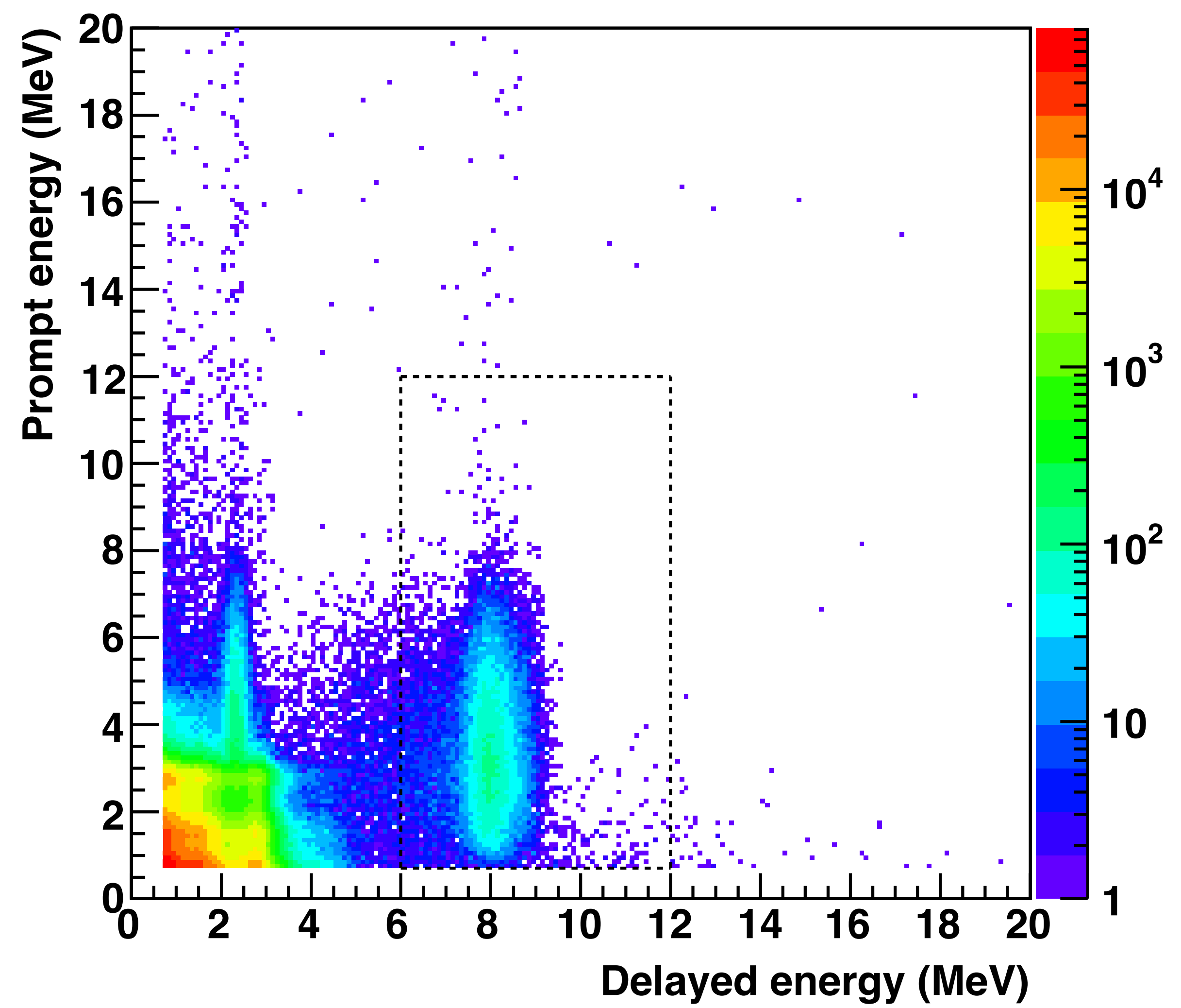
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

$$30\ \mu s \rightsquigarrow n + Gd \rightarrow Gd^* \rightarrow Gd + \gamma s\ (8\ \mathrm{MeV})$$

$$200\ \mu s \rightsquigarrow n + H \rightarrow D + \gamma\ (2.22\ \mathrm{MeV})$$

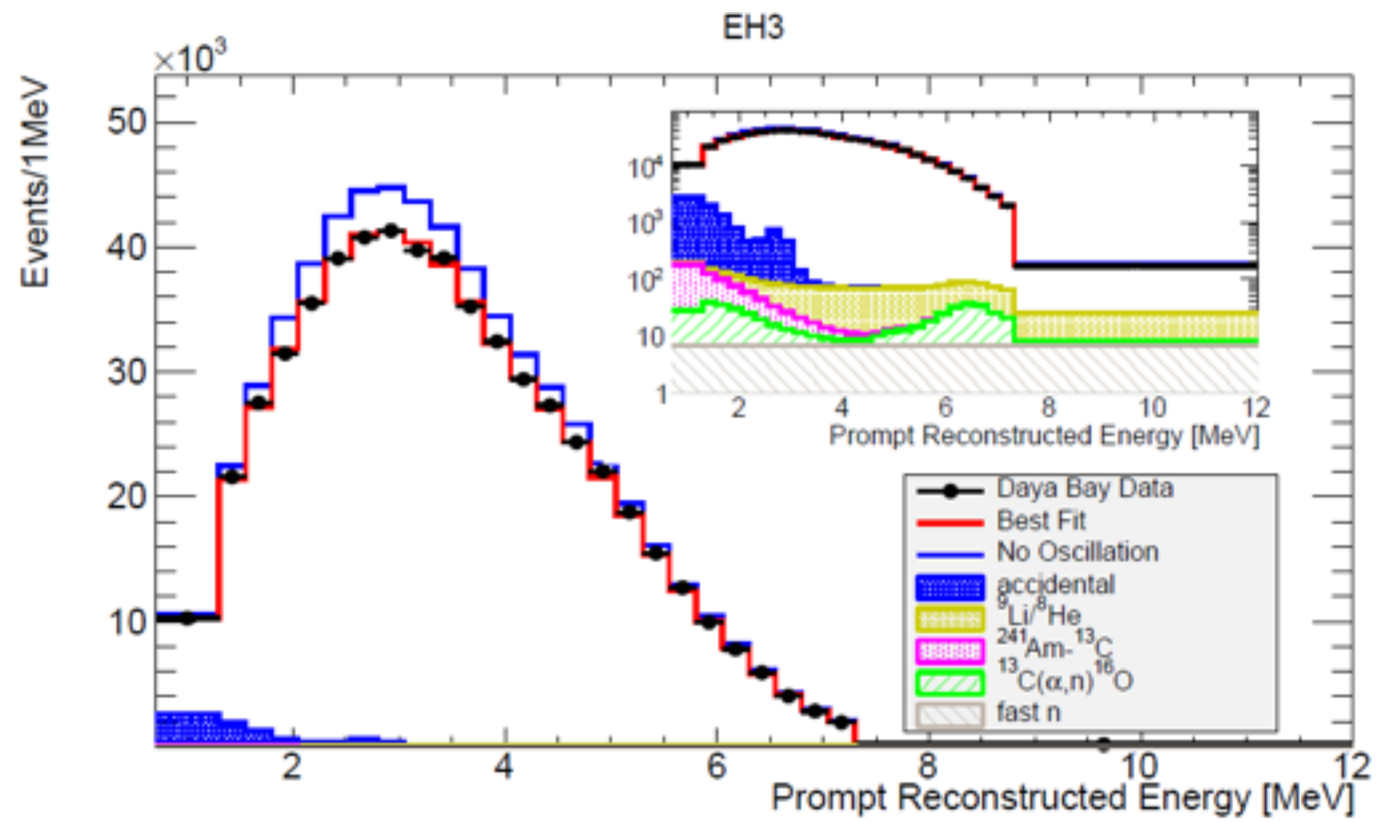
IBD selection

- Remove flashing PMT events
- Prompt energy cut: 0.7 MeV<E_p<12 MeV
- Delayed energy cut: 6 MeV<E_p<12 MeV
- Coincidence time: 1 μs<dt<200 μs
- Selection of isolated prompt-delayed pair
- Veto after tagged muon for the background reduction



Backgrounds

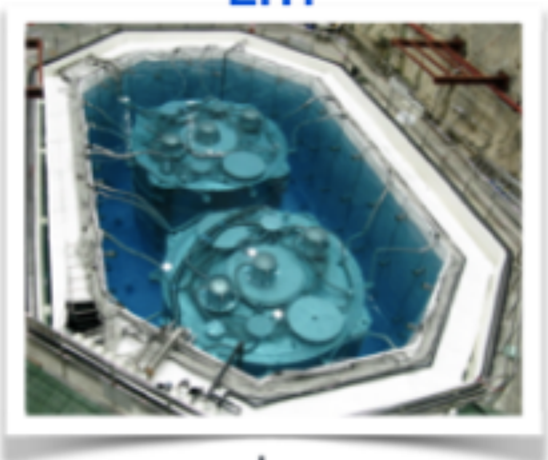
- Background at Daya Bay
  - Low background experiment with ~3% at Far Hall
  - Precise measurement - background systematic uncertainties well under control
- Uncorrelated
  - **Accidental coincidence** of two independent events which pass the selection criteria
- Correlated
  - **^{9}Li/^{8}He** -Unstable spallation products induced by cosmic muons
  - **Fast neutrons** - Induced by cosmic muons
  - **^{241}Am-^{13}C** - Correlated signal from calibration source in ACUs
  - **^{13}C(α,n)^{16}O** - Signal induced by α interacting on carbon atoms



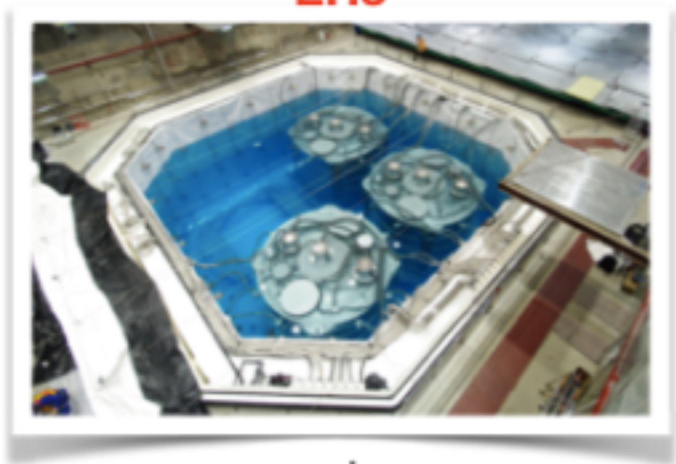
Background	Near	Far	Uncertainty
Accidentals	1.4%	2.3%	negligible
^{9}Li/^{8}He	0.4%	0.4%	50%
^{241}Am-^{13}C	0.03%	0.2%	50%
Fast n	0.1%	0.1%	30%
^{13}C(α,n)^{16}O	0.01%	0.1%	50%

Timeline of the Daya Bay

EH1



EH3



EH3

Aug. 2011

Dec. 2011

Aug. 2012

6 AD Data Taking

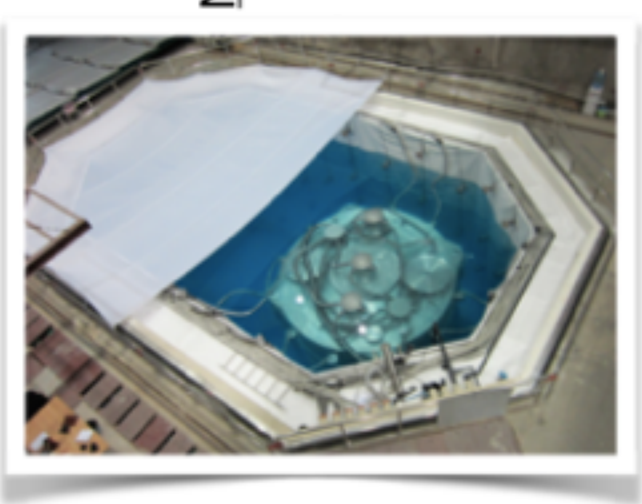
8 AD Data Taking

Nov. 2011

2011/12-2012/07

Aug. 2012

2012/10-now



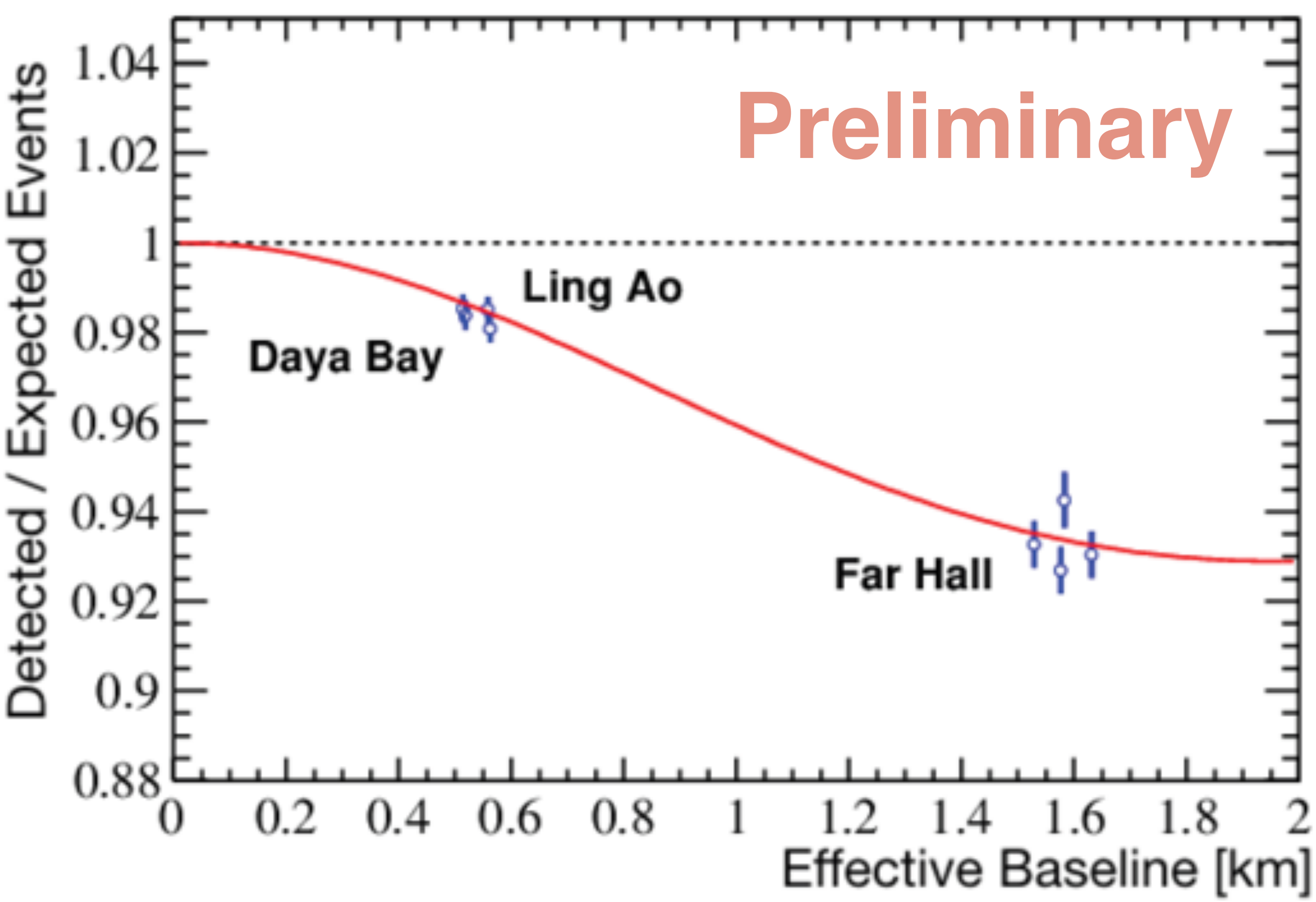
EH2

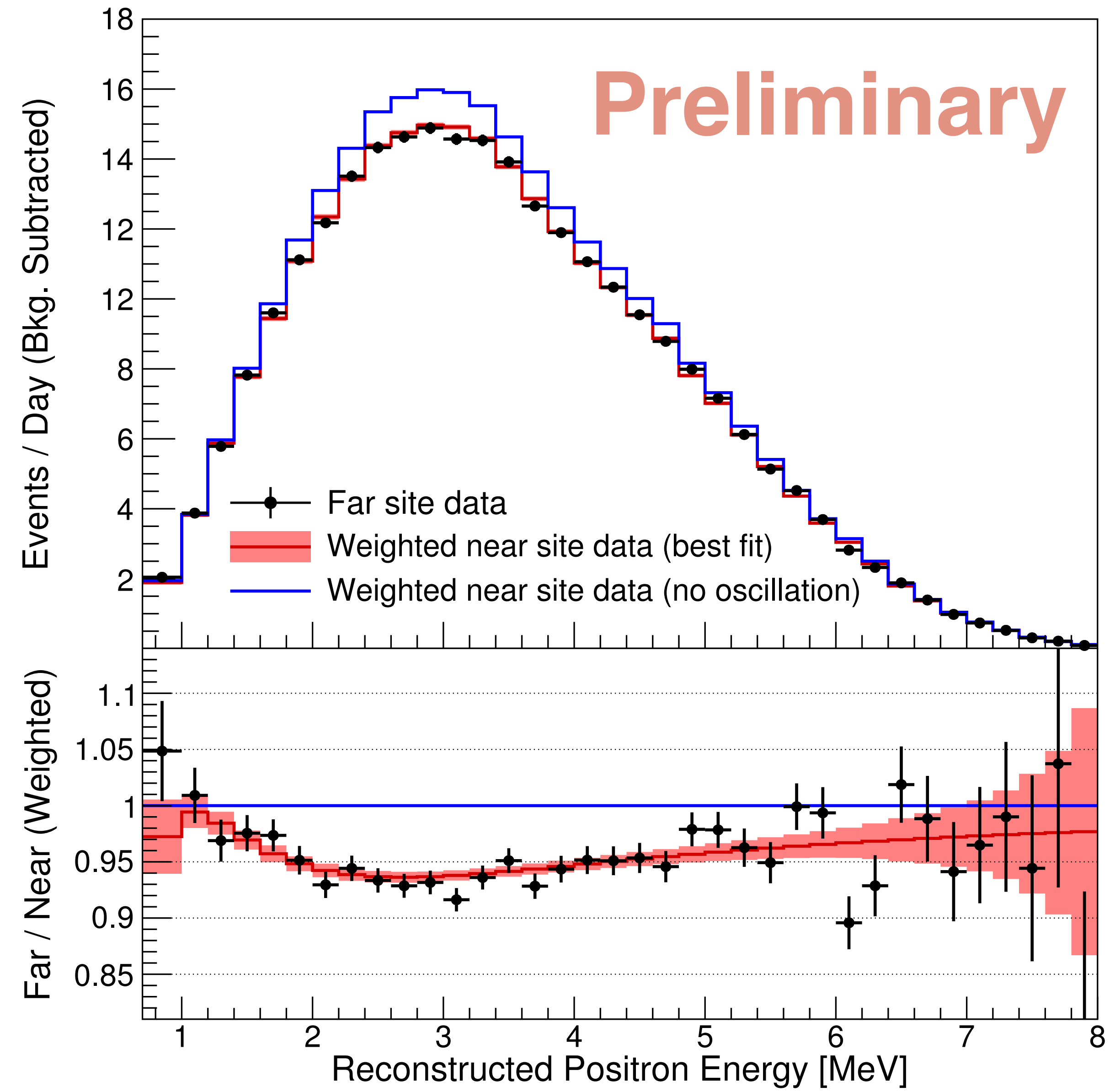
EH2

3-neutrino oscillation analysis

- Survival probability formula:

$$P(\bar{\nu}_e \to \bar{\nu}_e) \simeq 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\frac{\Delta m^2_{21}L}{4E} - \sin^2 2\theta_{13}\sin^2\frac{\Delta m^2_{ee}L}{4E}$$





Observed deficit consistent with neutrino oscillation scenario

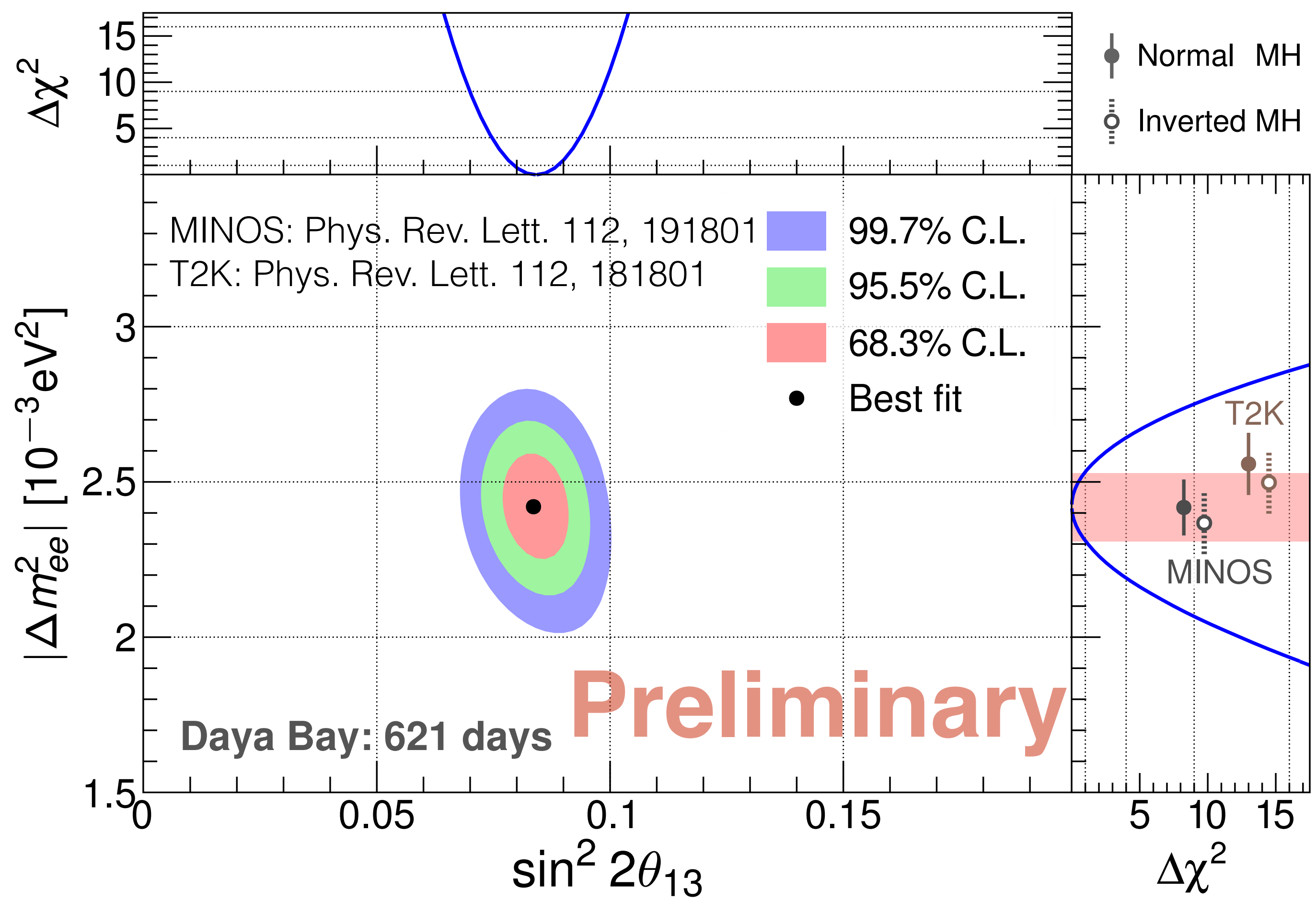
Result of the oscillation parameters

- Best fit:

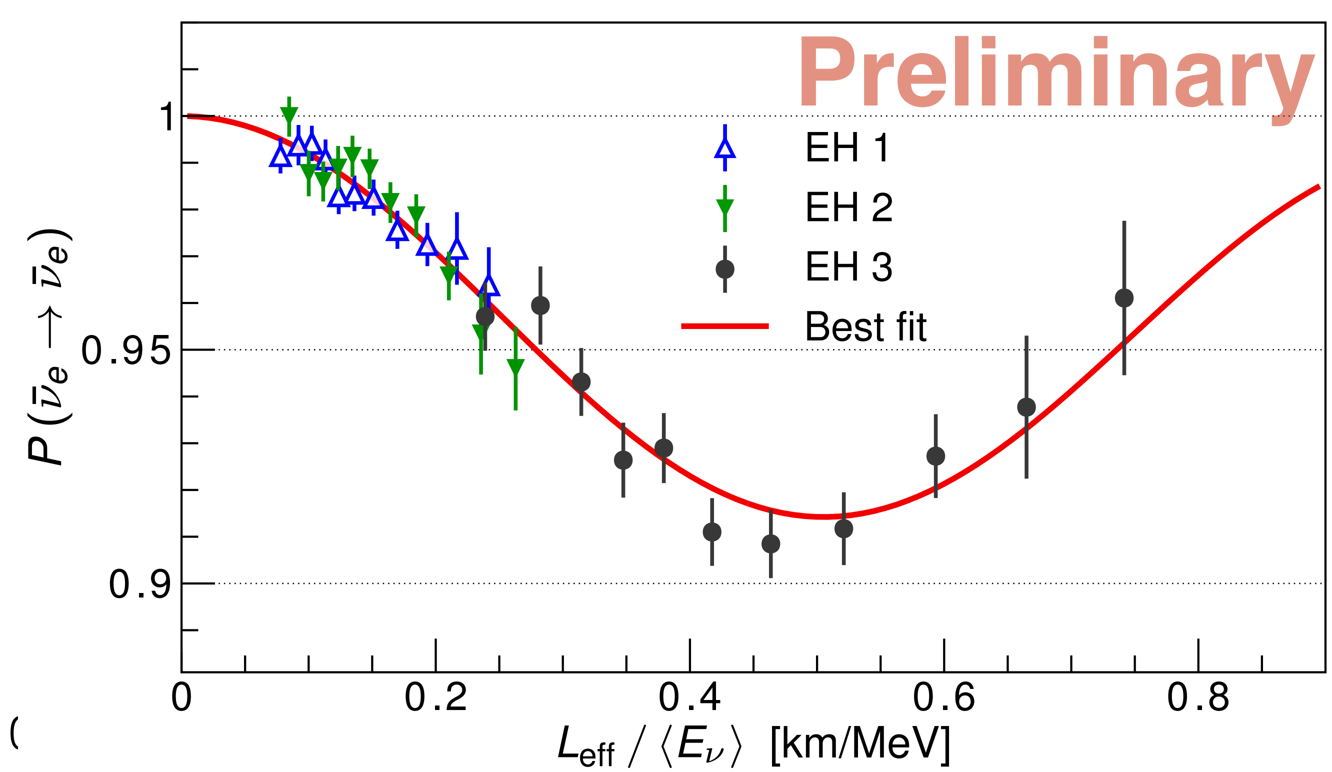
$$\sin^2 2\theta_{13} = 0.084 \pm 0.005$$

$$|\Delta m^2_{ee}| = 2.42 \pm 0.011 \times 10^{-3}\ \mathrm{eV}^2$$

$$\chi^2/NDF = 134.6/146$$



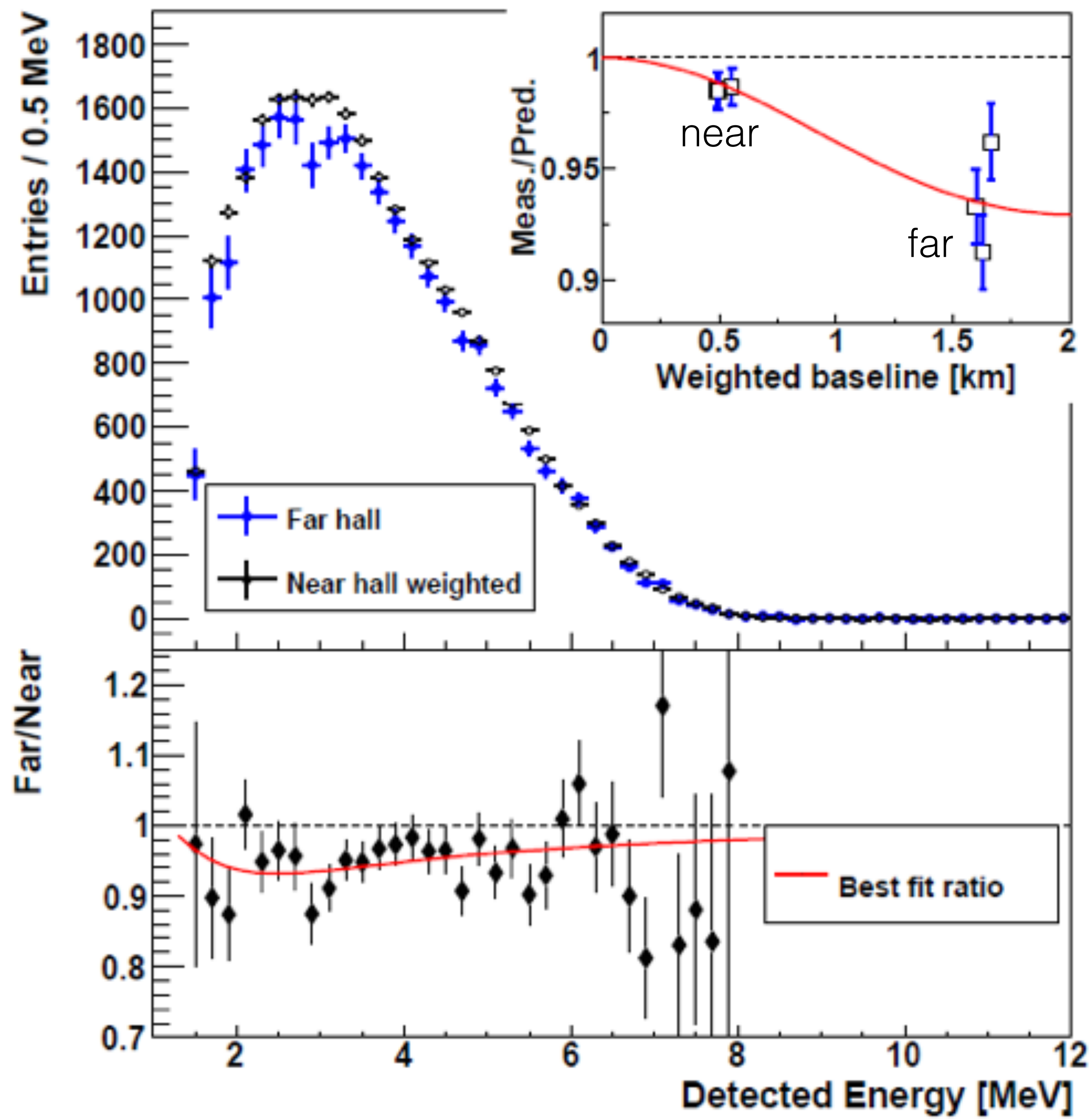
- $\sin^2 2\theta_{13}$ measurement
  - Most precise measurement up to date
  - Precision 6%→3% by the end of 2017
  - Crucial measurement for experiments searching for CP-violation in lepton sector
- $|\Delta m^2_{ee}|$ measurement
  - Comparable precision with long baseline accelerator experiments
  - Consistent result



Results of nH analysis

- Key information about nH analysis
  - Rate analysis based on 6 AD data taking
  - Independent measurement of θ_{13} due to largely different systematics from nGd
  - Higher statistics due to additional 20 t of LS as a target mass
  - More accidental background mainly caused by lower delayed signal energy and longer capture time

- Differences in selection
  - Coincidence time: 1 μs<dt<400 μs
  - Prompt energy cut: 1.5 MeV<E_p<12 MeV
  - Delayed energy cut: ±3σ around nH peak
  - Distance cut: dR<0.5 m



- Best fit:

$$\sin^2 2\theta_{13} = 0.083 \pm 0.018$$

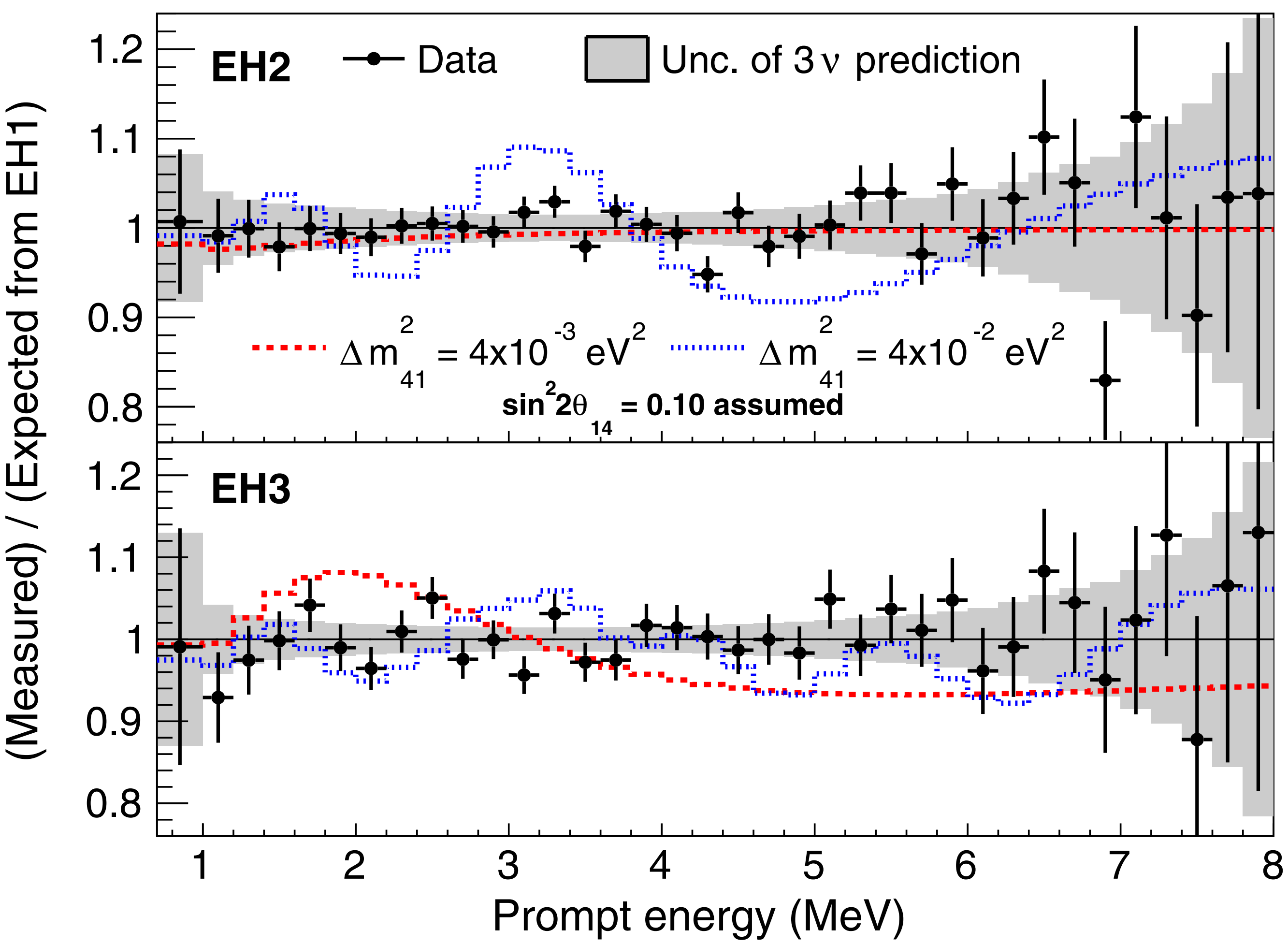
$$\chi^2/NDF = 4.5/4$$

Phys. Rev. D 90, 071101 (2014)

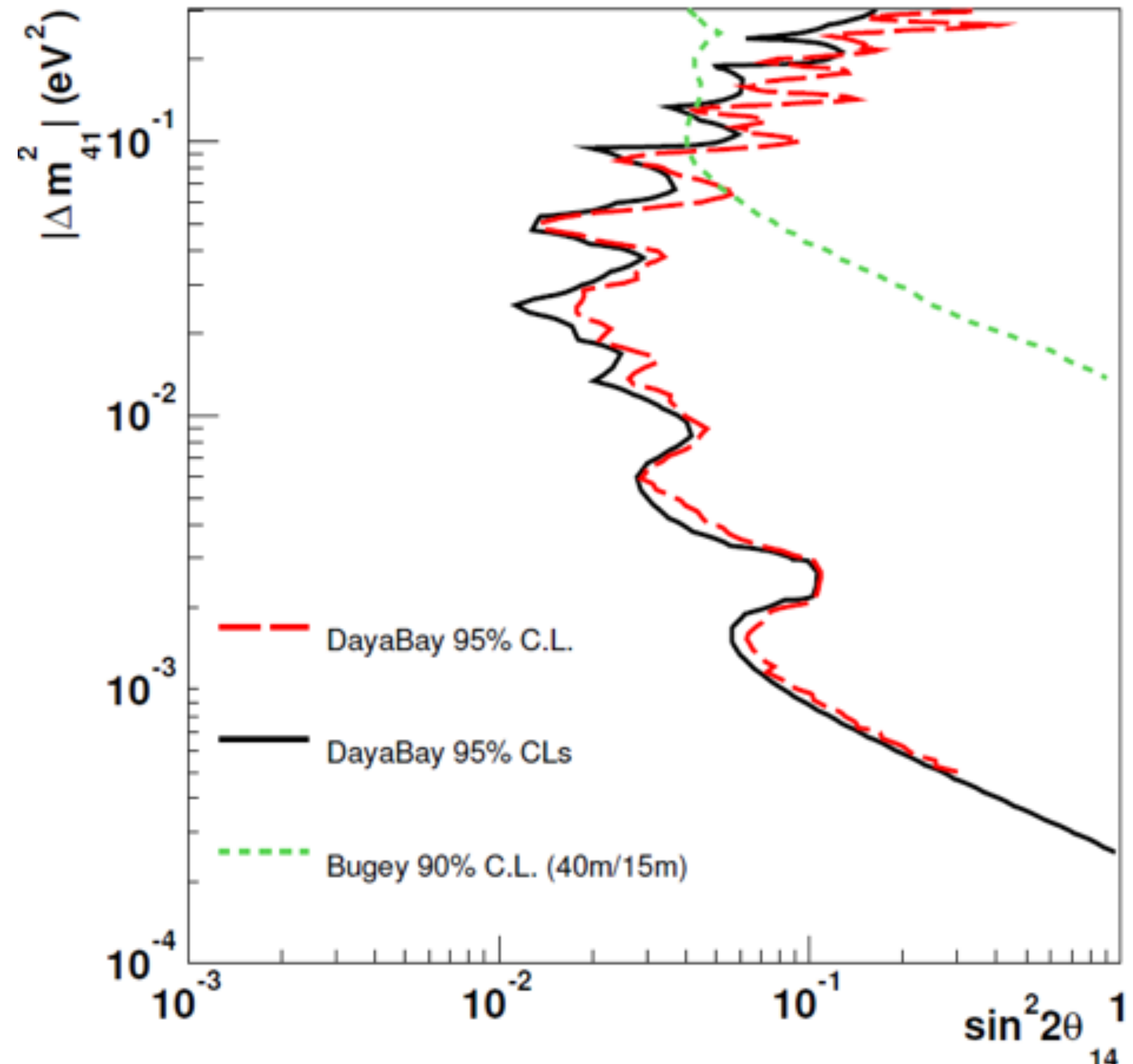
Light sterile neutrino search results

- Survival probability formula:

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



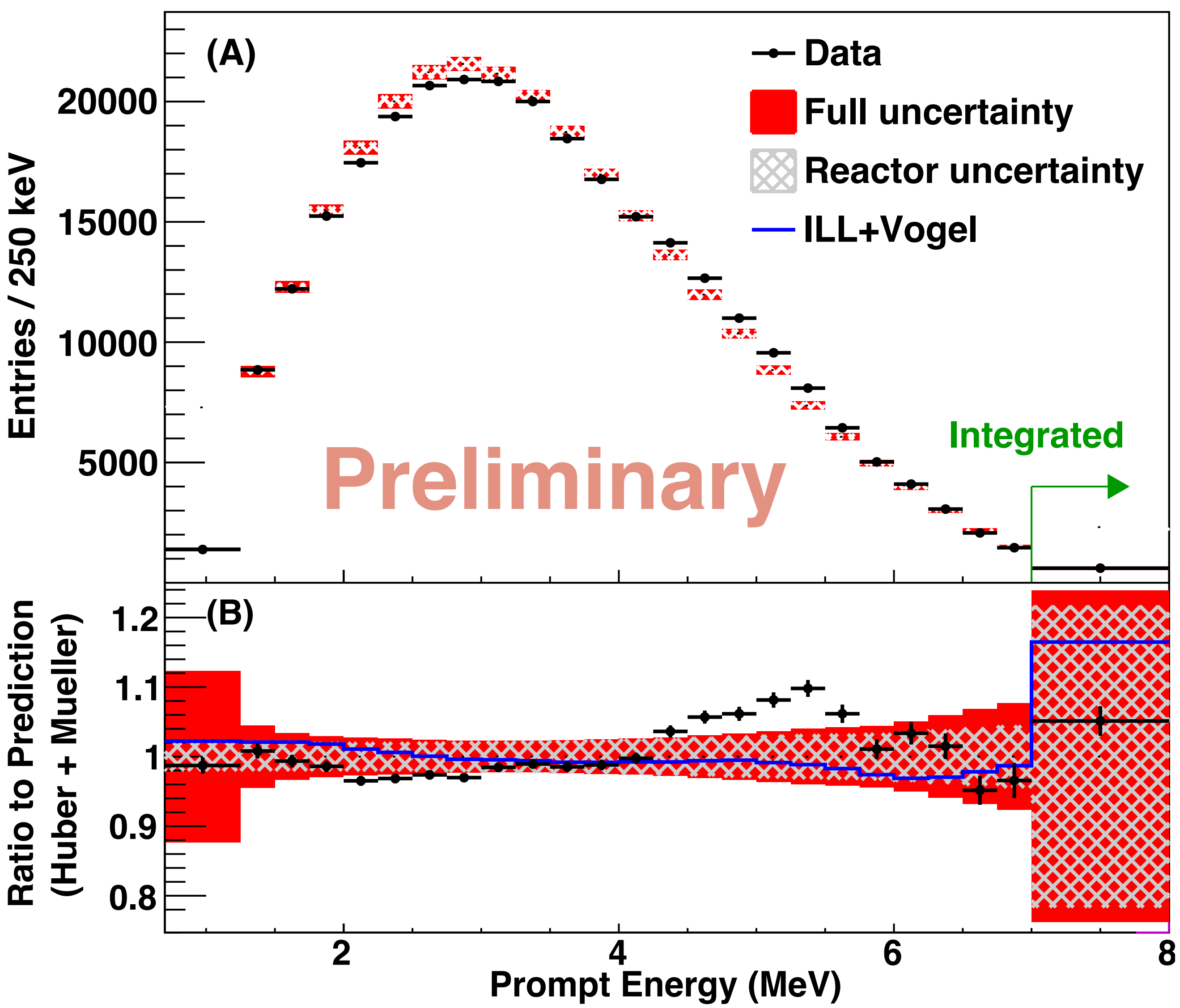
Phys. Rev. Lett. 113, 141802 (2014)



- Results:
  - No hint of light sterile neutrino observed
  - Most stringent limit for $|\Delta m^2_{41}|<0.1$ eV^2
  - Joint analysis with MINOS in progress

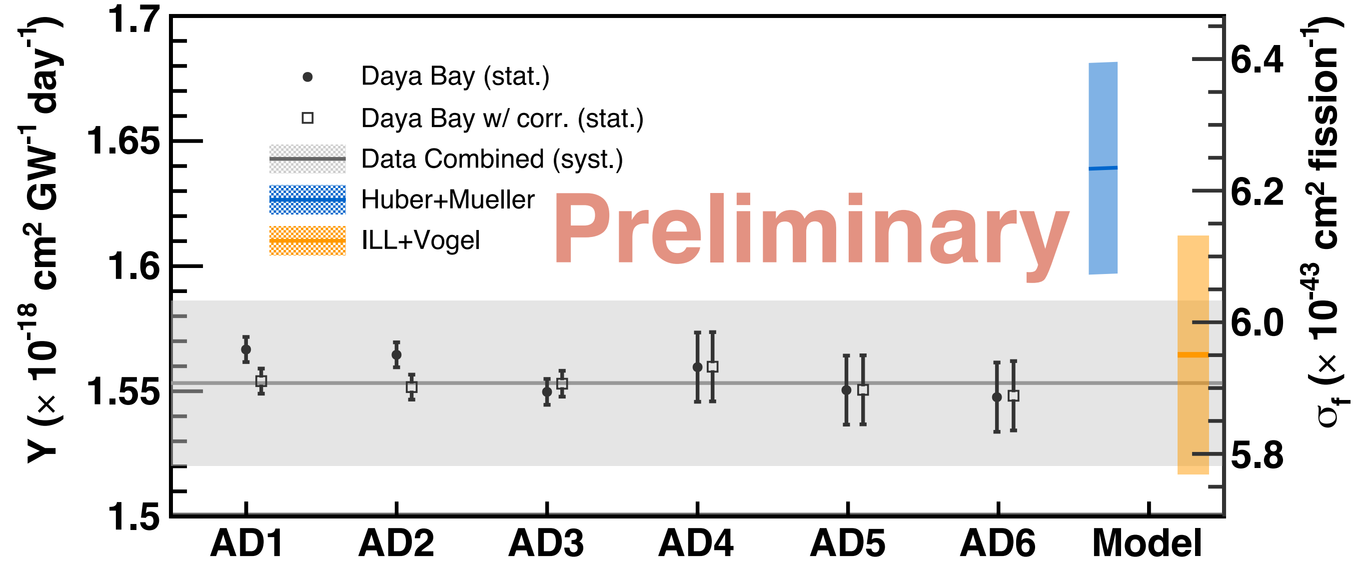
Reactor antineutrino energy spectrum and absolute flux

Spectral shape

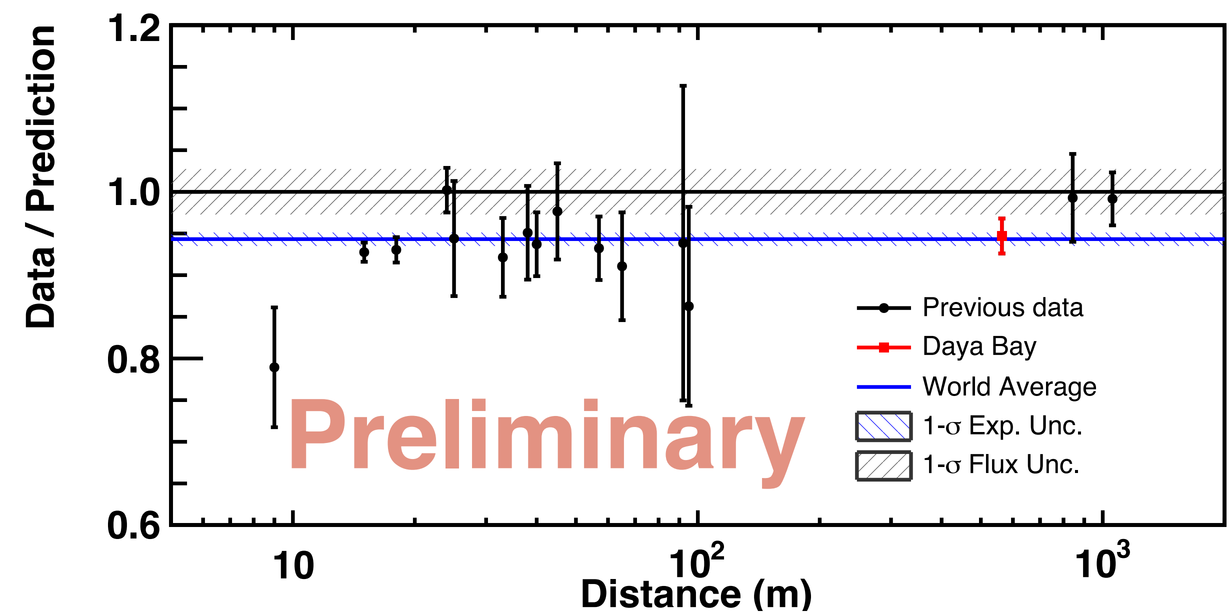


- Measurement inconsistent with the traditional predictions based on β- spectrum conversion

Absolute flux



- Data lower than the prediction models
  - Huber+Mueller: 0.947±0.022
  - ILL+Vogel: 0.992±0.023



- Consistent with previous experiments

Summary

- Data Bay Experiment provided
  - Most precise measurement of $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ with comparable precision to the accelerator experiments

$$\sin^2 2\theta_{13} = 0.084 \pm 0.005$$

$$|\Delta m^2_{ee}| = 2.42 \pm 0.011 \times 10^{-3}\ \mathrm{eV}^2$$

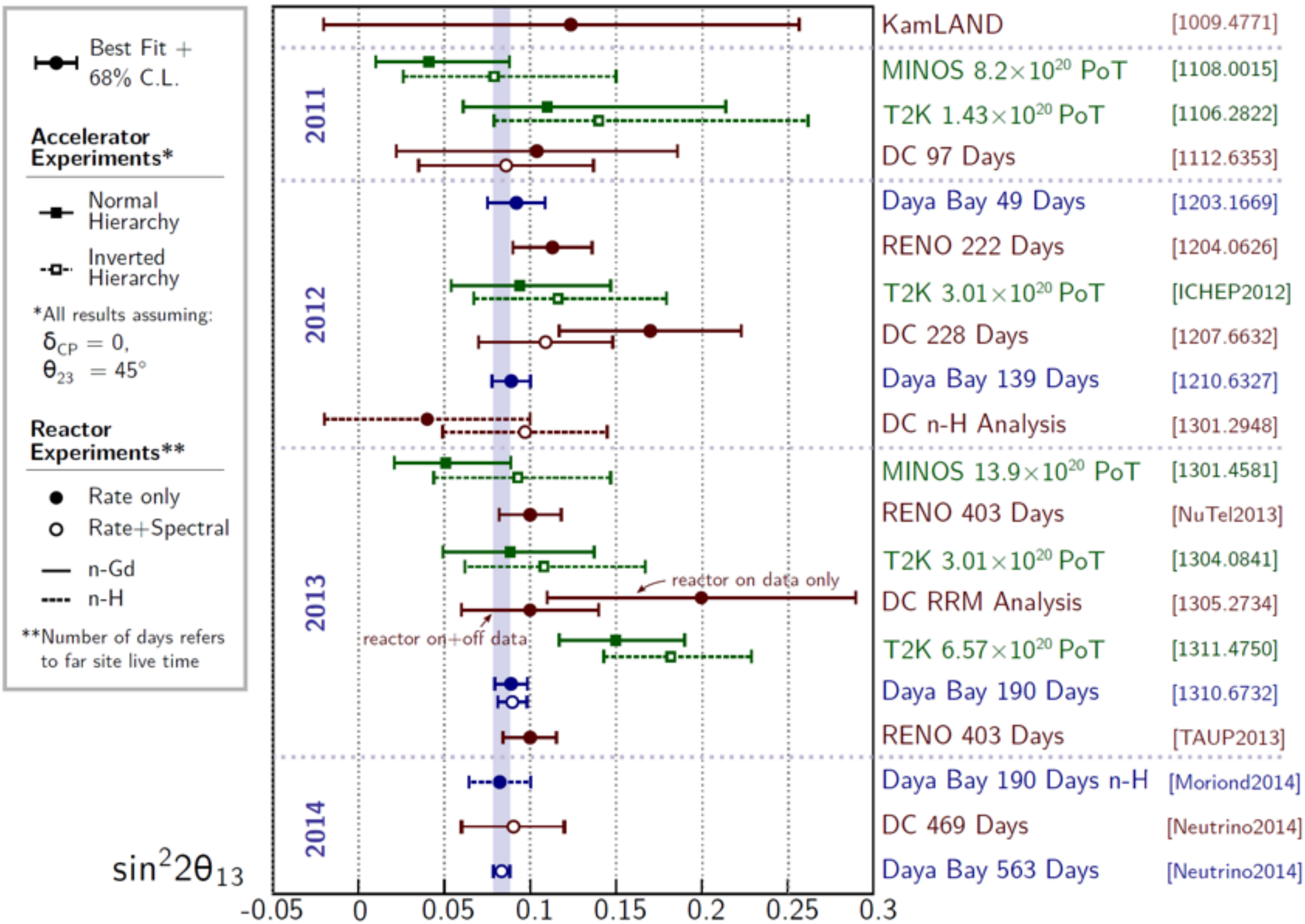
  - Independent measurement $\sin^2 2\theta_{13}$ using neutron capture on hydrogen

$$\sin^2 2\theta_{13} = 0.083 \pm 0.018$$

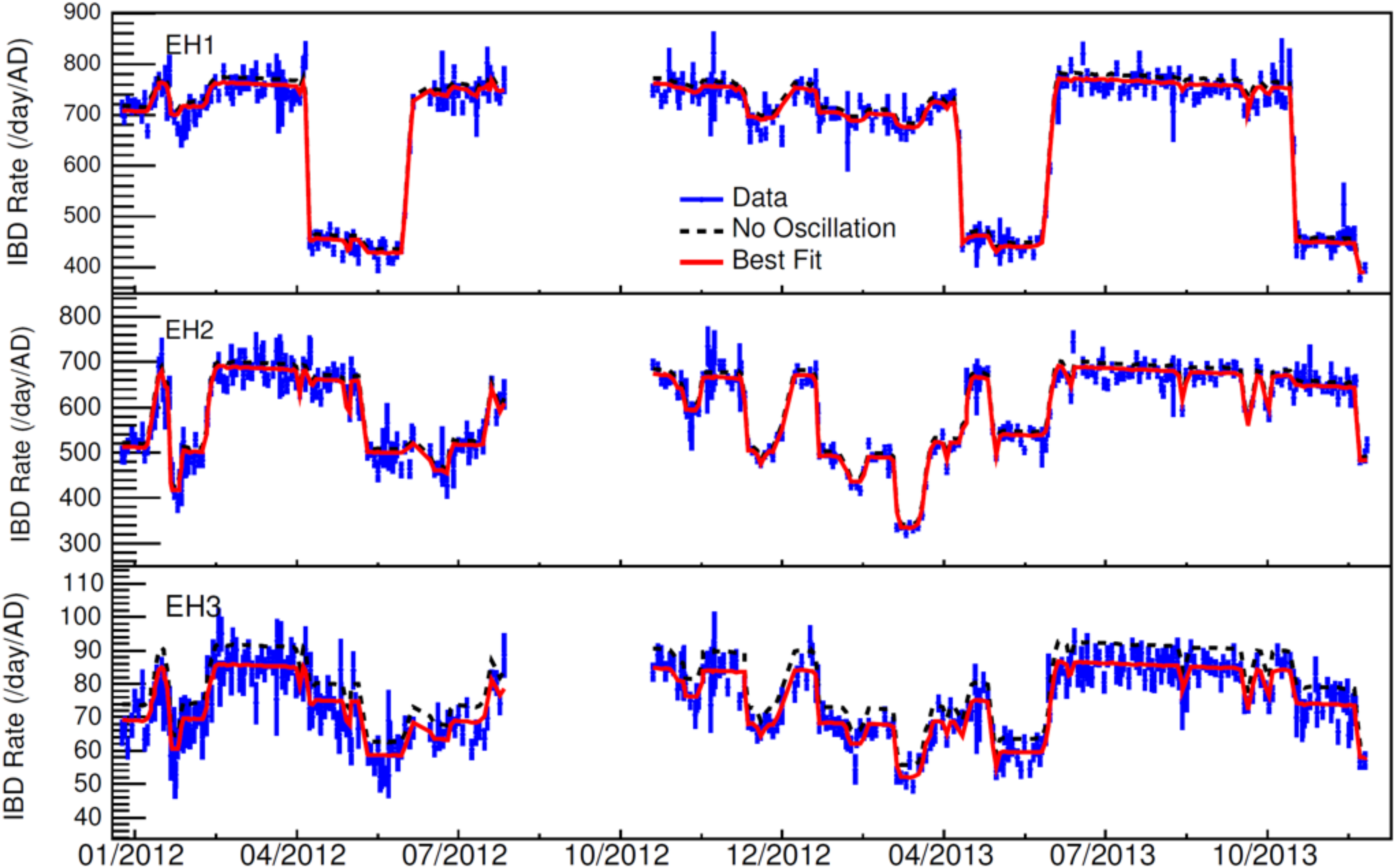
  - Most stringent limit for neutrino mixing to light sterile neutrino for new mass squared splitting $|\Delta m^2_{41}| < 0.1\ \mathrm{eV}^2$
  - Reactor antineutrino spectrum inconsistent with traditional predictions
  - Reactor antineutrino flux consistent with other experiments but inconsistent with predictions

Backup slides

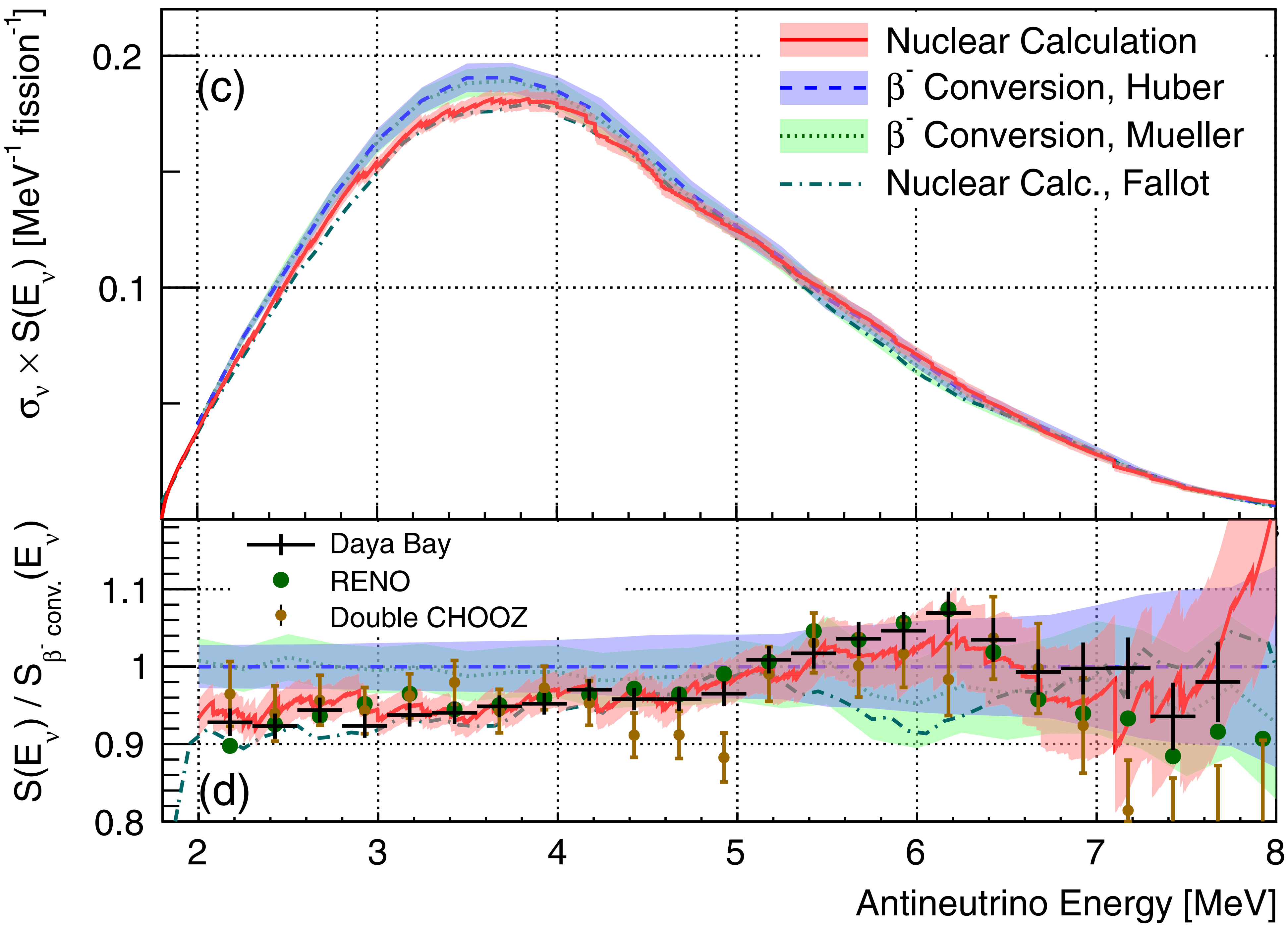
Evolution of the $\sin^2 2\theta_{13}$ value



Reactor power correlated with detected IBD rate



Ab initio calculation of reactor antineutrino energy spectrum



D.Dwyer, T.Langford: Phys. Rev. Lett. 114, 012502 (2015)