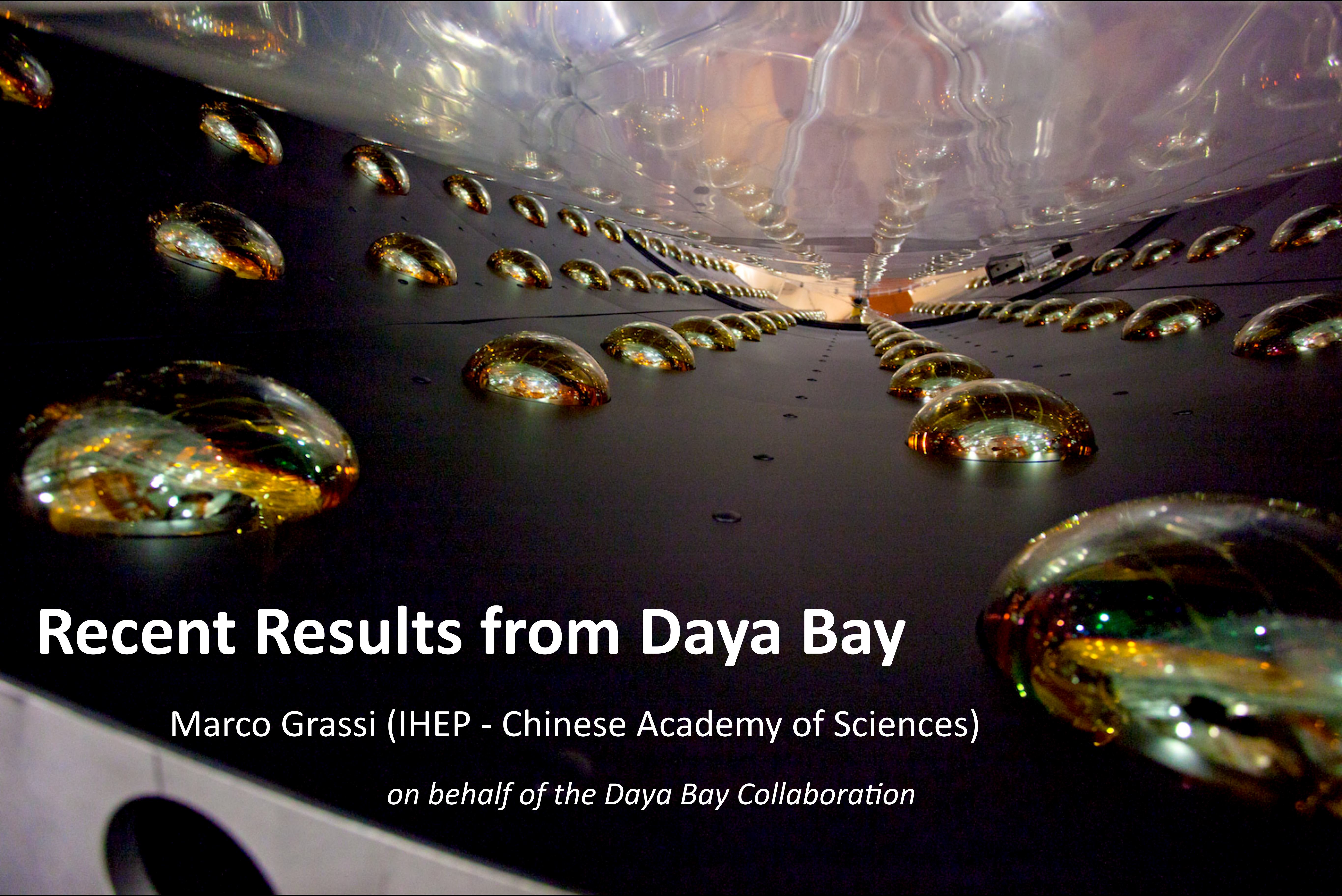
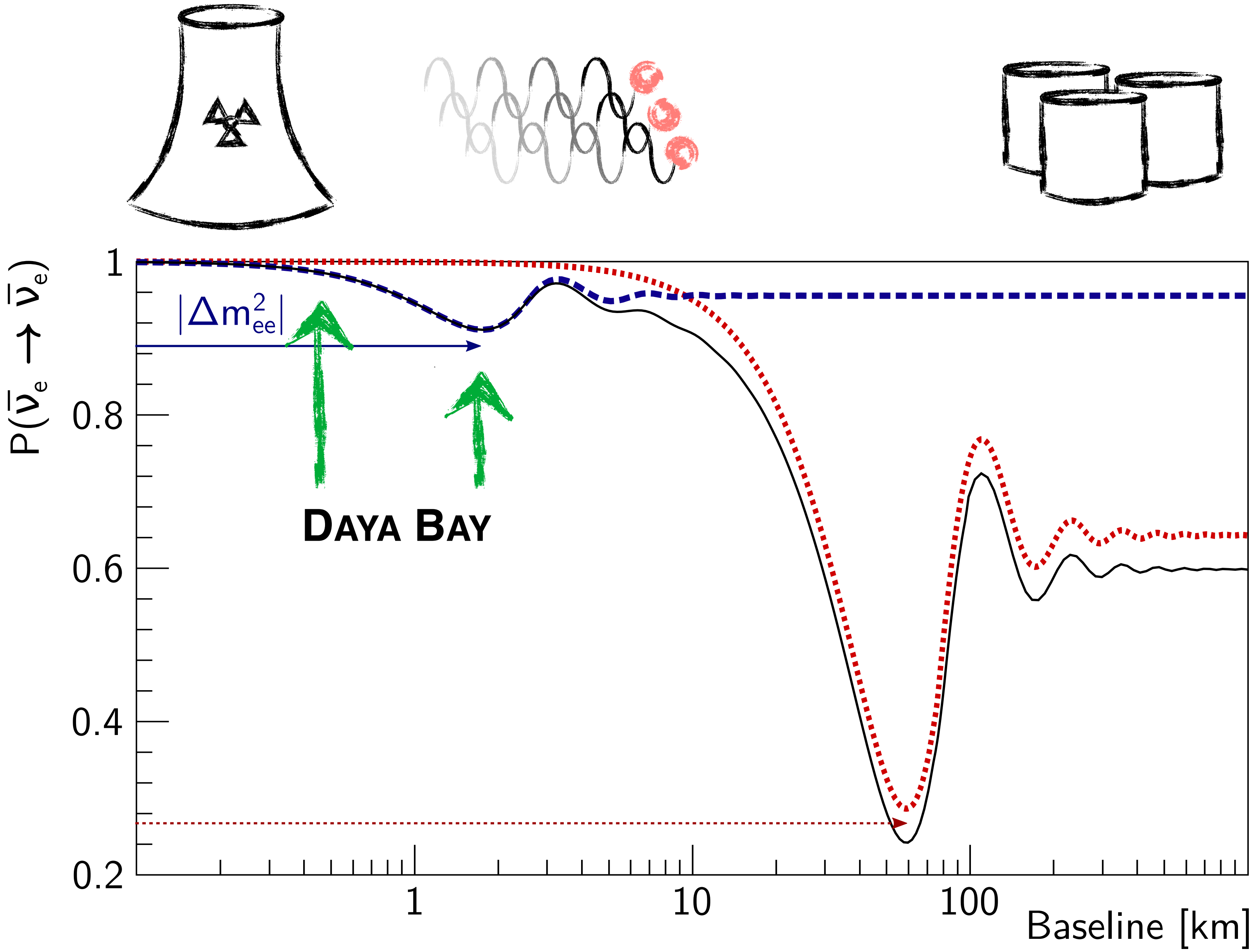


Recent Results from Daya Bay

Marco Grassi (IHEP - Chinese Academy of Sciences)

on behalf of the Daya Bay Collaboration

DYB Aims at Detecting Reactor Antineutrino to…

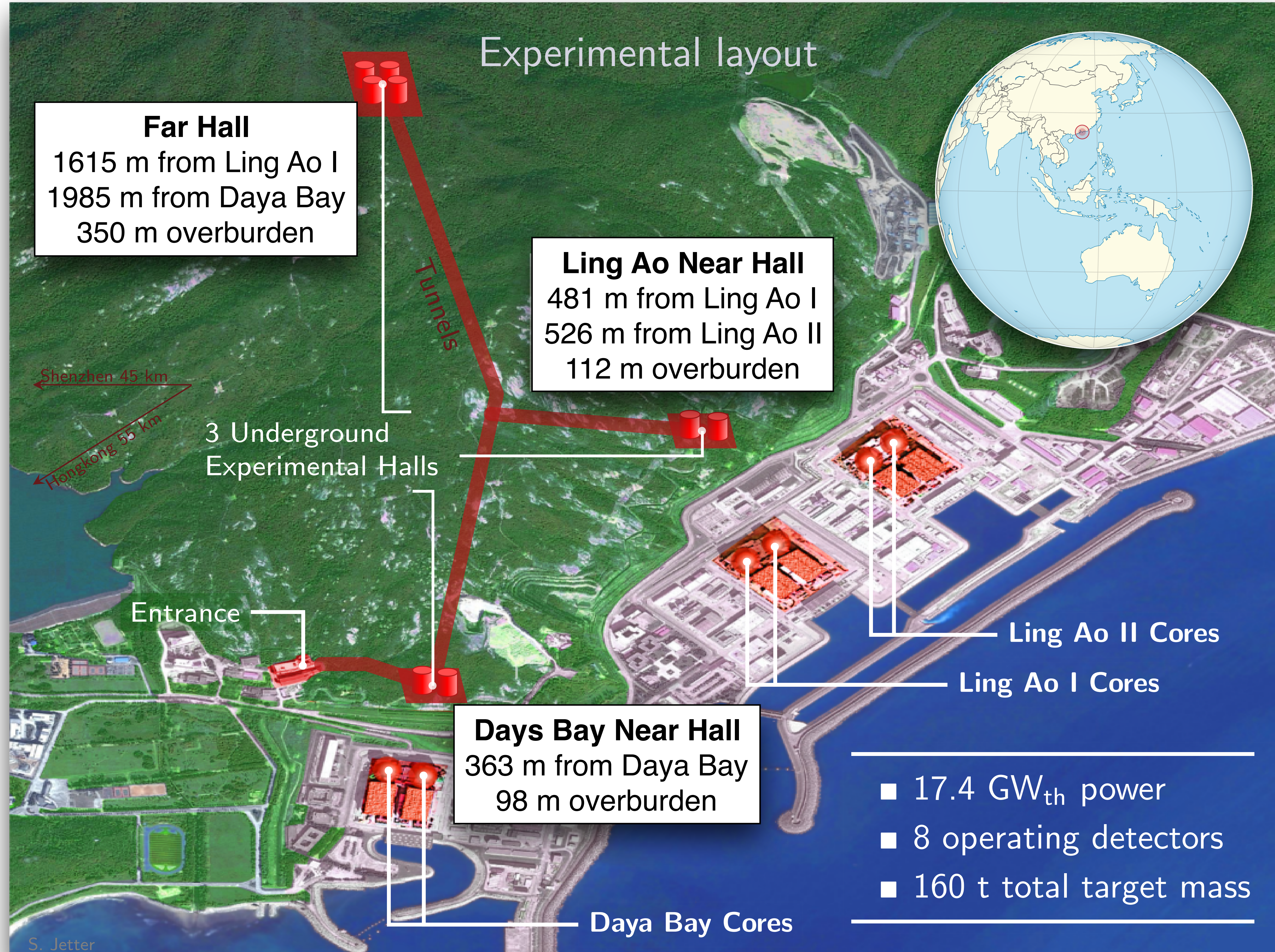


Determine θ_{13} & mass splitting by measuring disappearance of antineutrinos at ~2km

Measure reactor antineutrino flux and spectrum

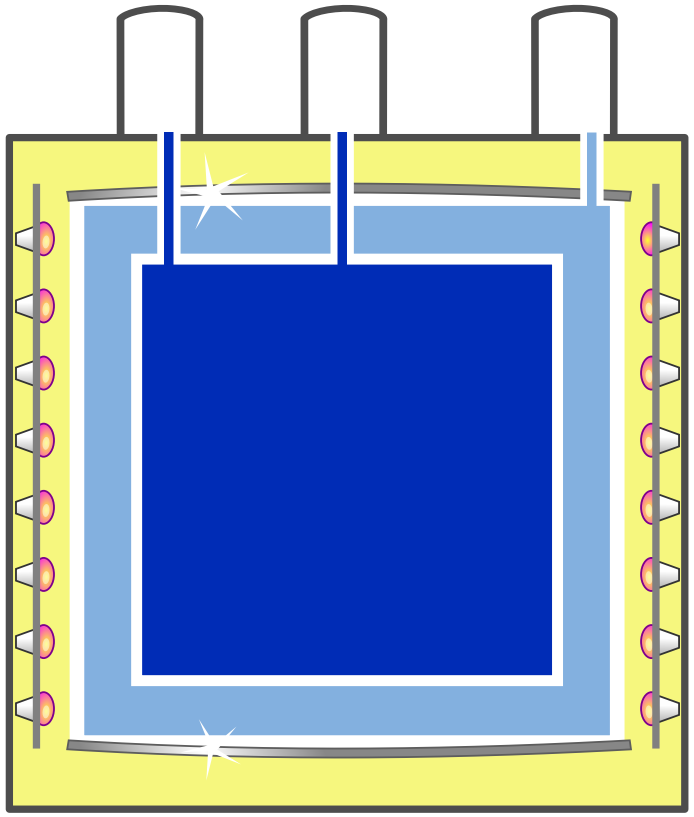
Search for Physics Beyond Standard Model

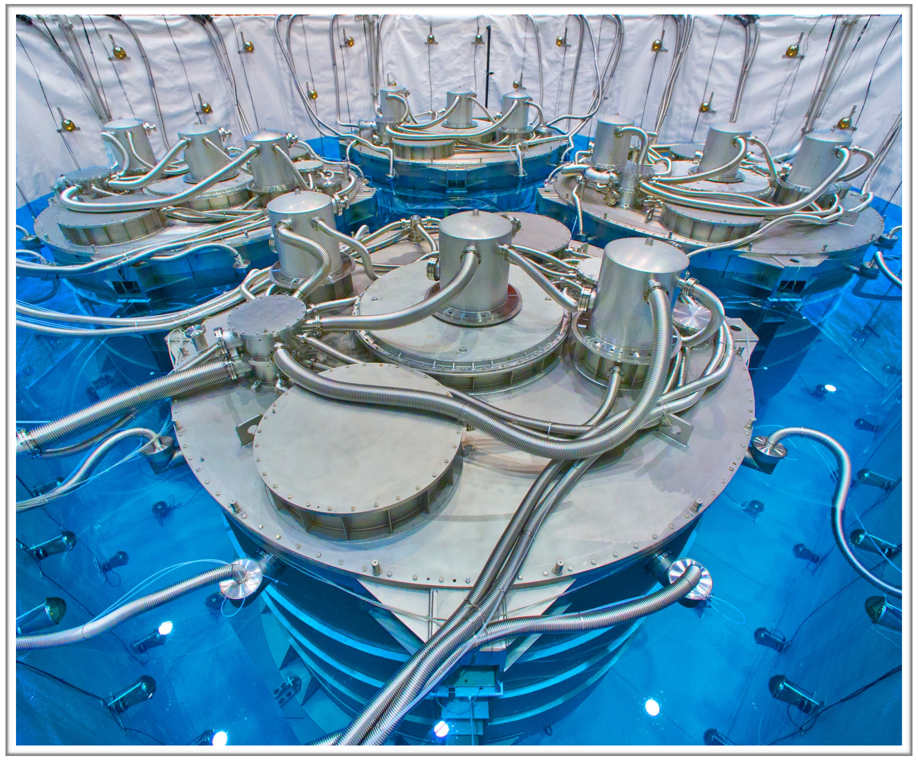
Eight Detectors in Three Underground Halls



- 17.4 GW_{th} power
- 8 operating detectors
- 160 t total target mass

Eight Identical Antineutrino Detectors (ADs)





Antineutrino Detector composed of 3 nested vessels

- filled with 0.1% Gd-doped liquid scintillator (LS)
- filled with undoped scintillator
- filled with mineral oil

ADs are immersed in a water Cherenkov detector (bkg moderator & muon veto)

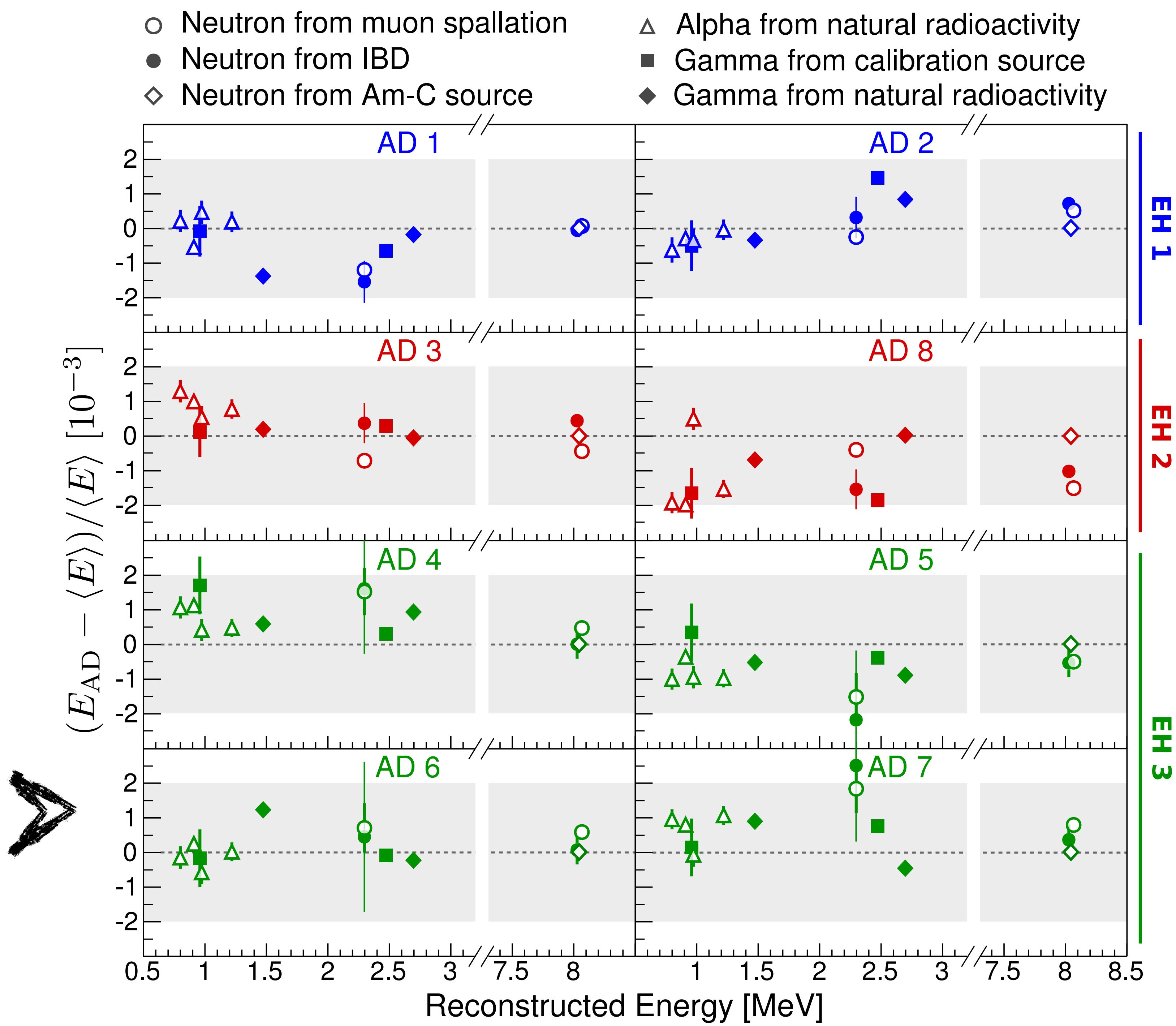
How identical are the ADs?

Eight Identical Antineutrino Detectors (ADs)

Energy scale calibrated using neutrons at the detector center

Time variation and position dependence corrected using gamma source

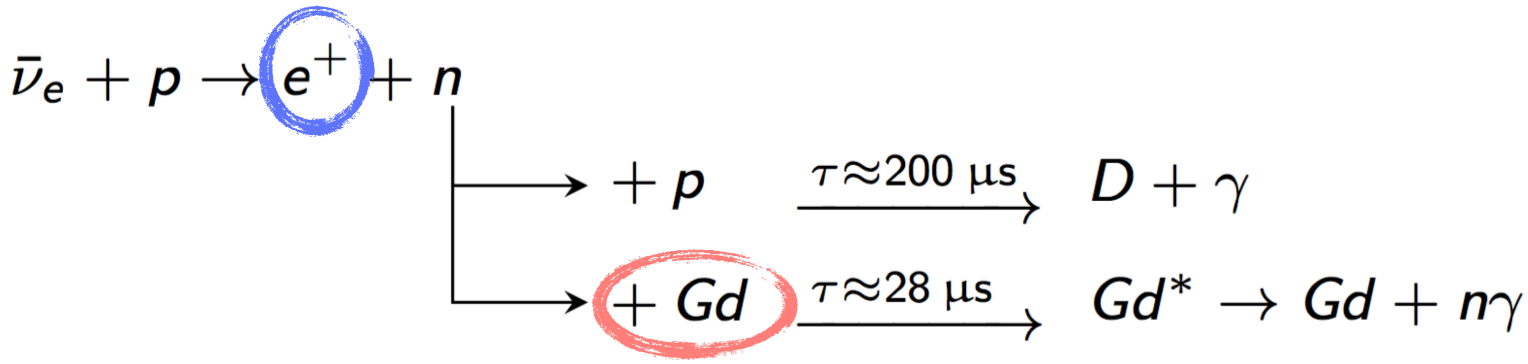
Multiple sources with different spatial distributions to validate uncertainty on energy scale



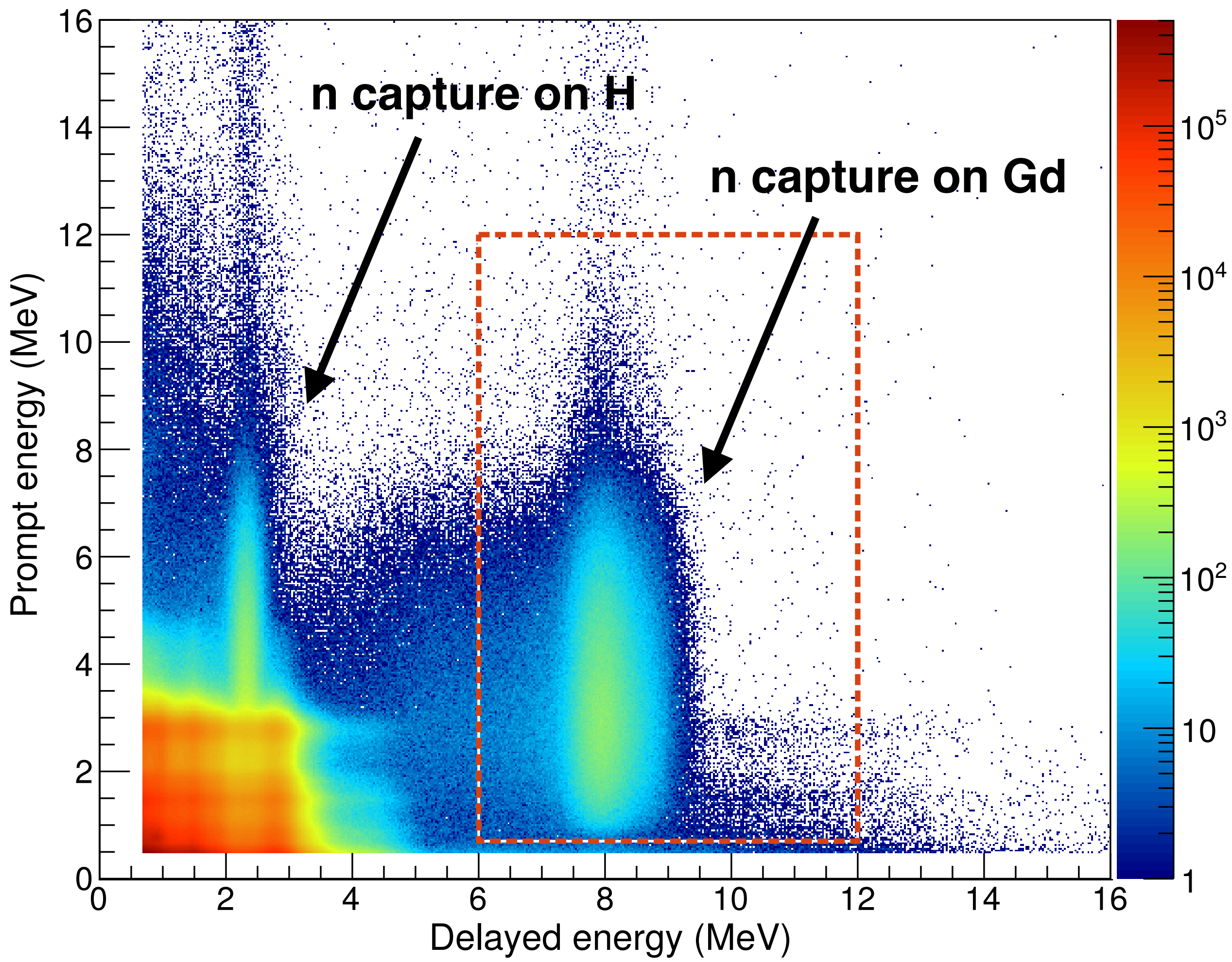
Less than 0.2% variation in reconstructed energy between detectors

Selection of Antineutrino Candidates (Signal)

Inverse Beta Decay (IBD) Reaction



Experimental signature: **prompt+delayed coincidence**



Selection Criteria:

0.7 MeV < E_{PROMPT} < 12 MeV

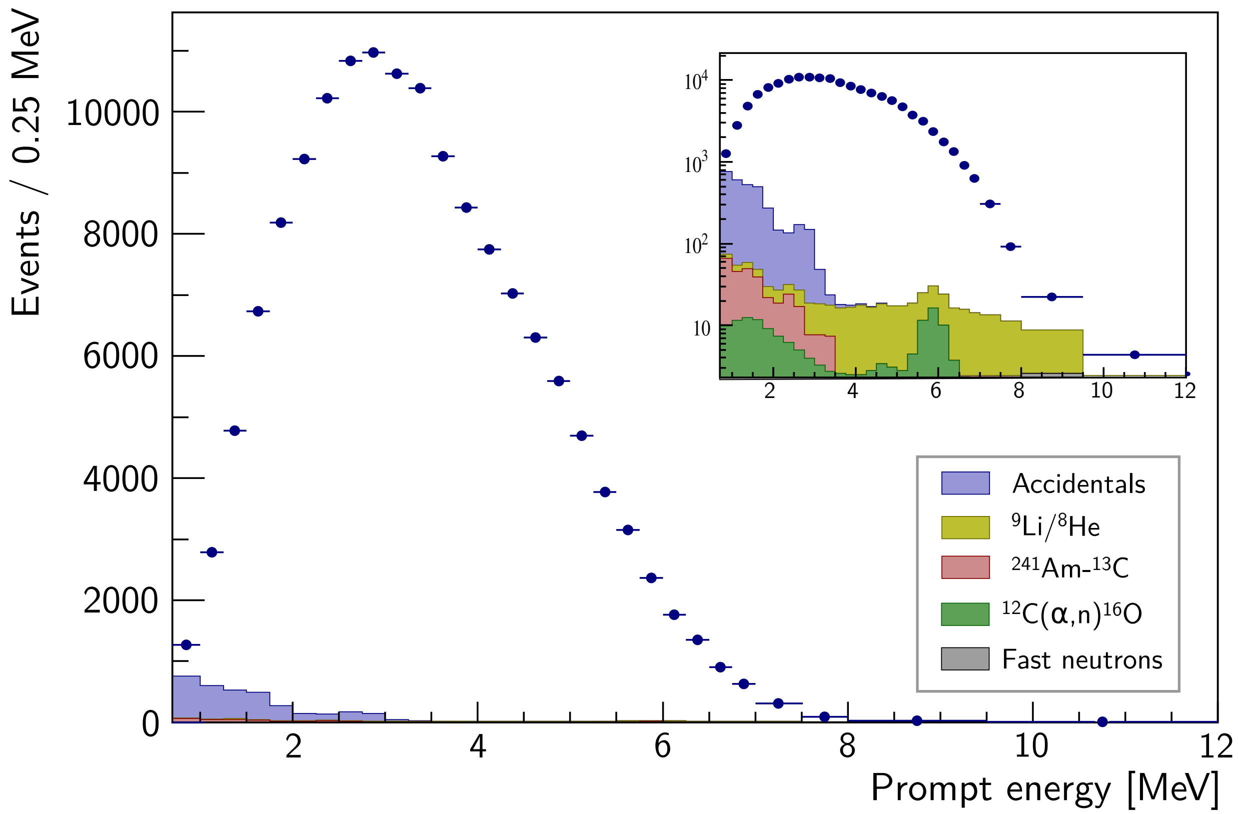
6 MeV < $E_{DELAYED}$ < 12 MeV

1 μs < $(t_D - t_P)$ < 200 μs

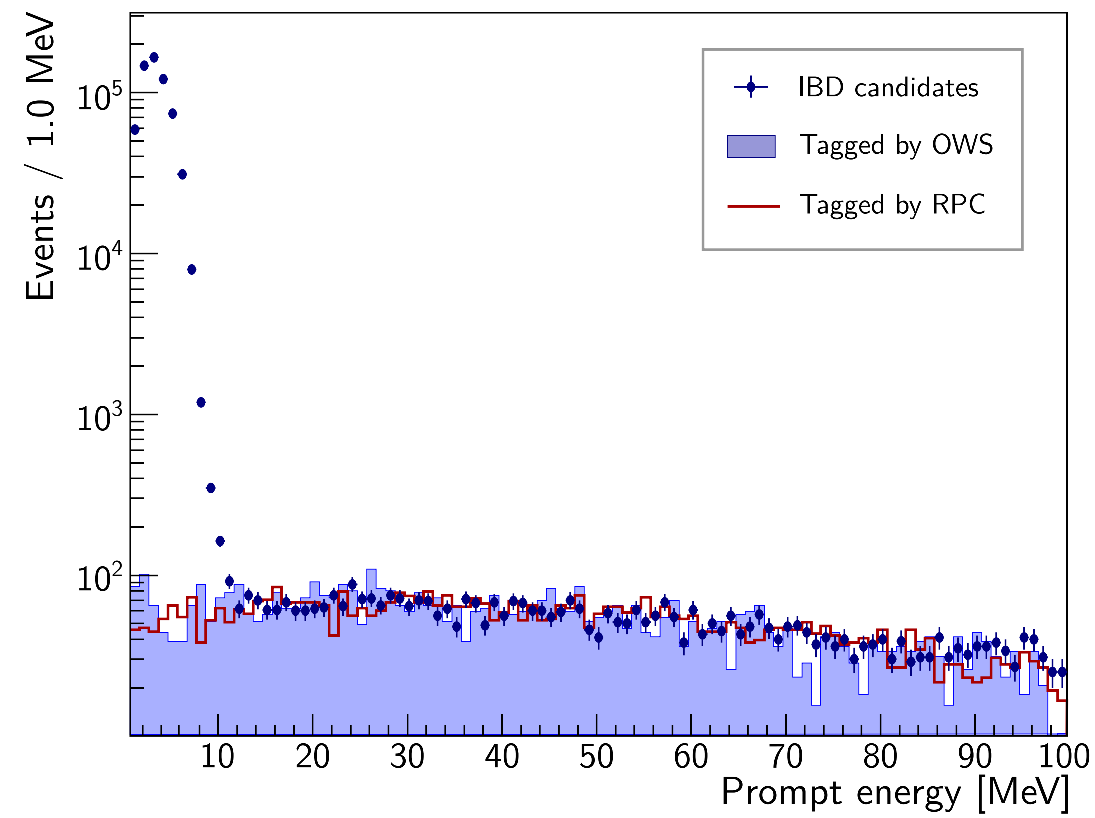
Muon veto to suppress cosmogenic bkg

Backgrounds

Far hall IBD spectrum



Daya Bay near hall fast n spectrum

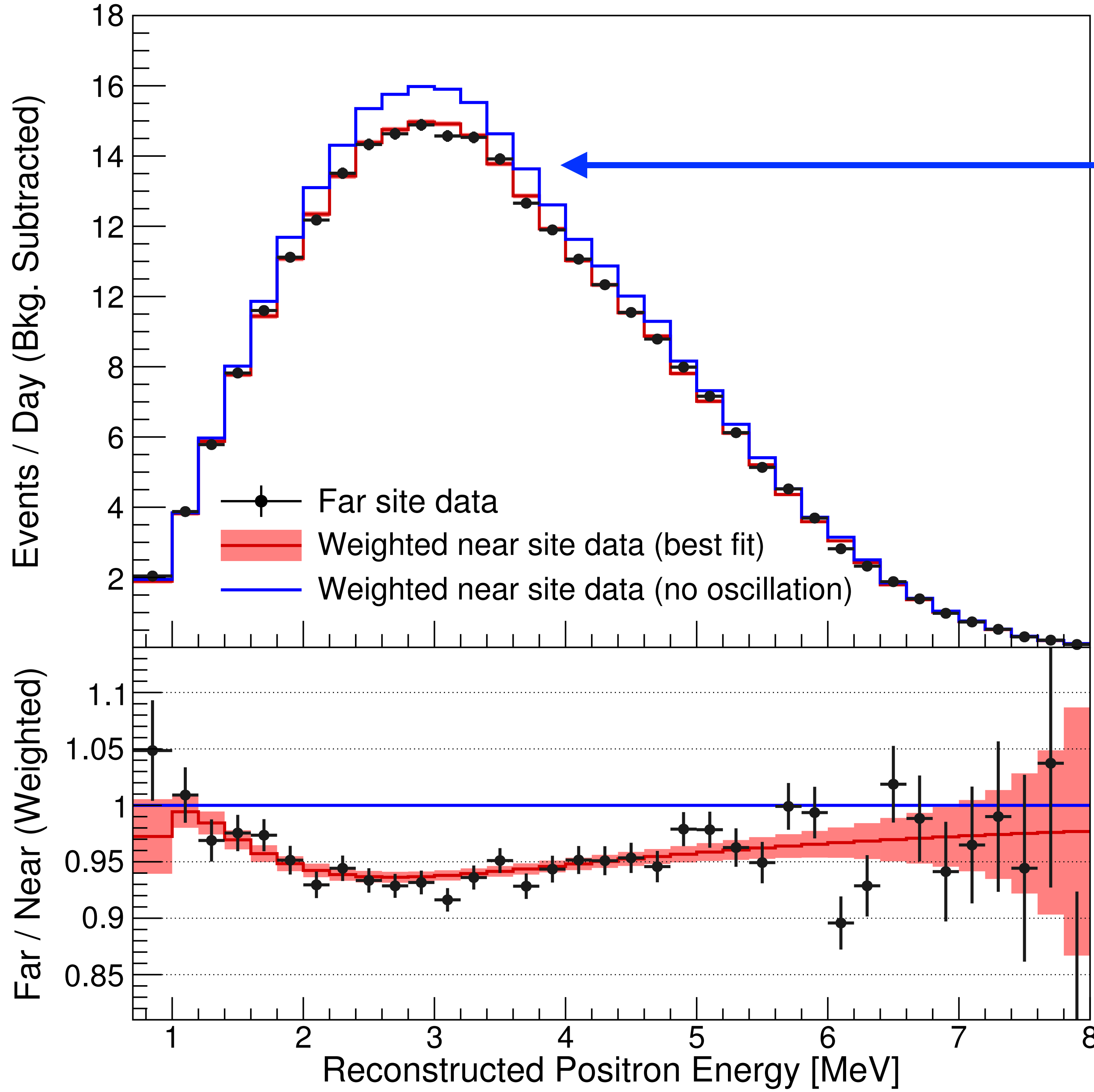


Background	Near	Far	Uncertainty	Method
Accidentals	1.4%	2.3%	~1%	Computed statistically from uncorrelated singles
^{9}Li / ^{8}He	0.4%	0.4%	~50%	Measured with after-muon events
^{241}Am-^{13}C	0.1%	0.1%	~50%	MC tuned to single gamma and strong Am-C source
Fast Neutrons	0.03%	0.2%	~50%	Measured with tagged muon events
$^{13}C(\alpha,n)^{16}O$	0.01%	0.1%	~50%	Calculated from measured radioactivity

Antineutrino Oscillation Spectrum

PRL 115, 111802 (2015)

Total Exposure: $6.9 \cdot 10^5$ GW_{th}-ton-days ▶ more than **150k IBD candidates** at far site



◀ Reco **positron spectrum** at far site

Compared w/ expectation based on near-site measurements assuming no oscillation

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

$|\Delta m^2_{ee}| = (2.42 \pm 0.11) \cdot 10^{-3}\ eV^2$

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

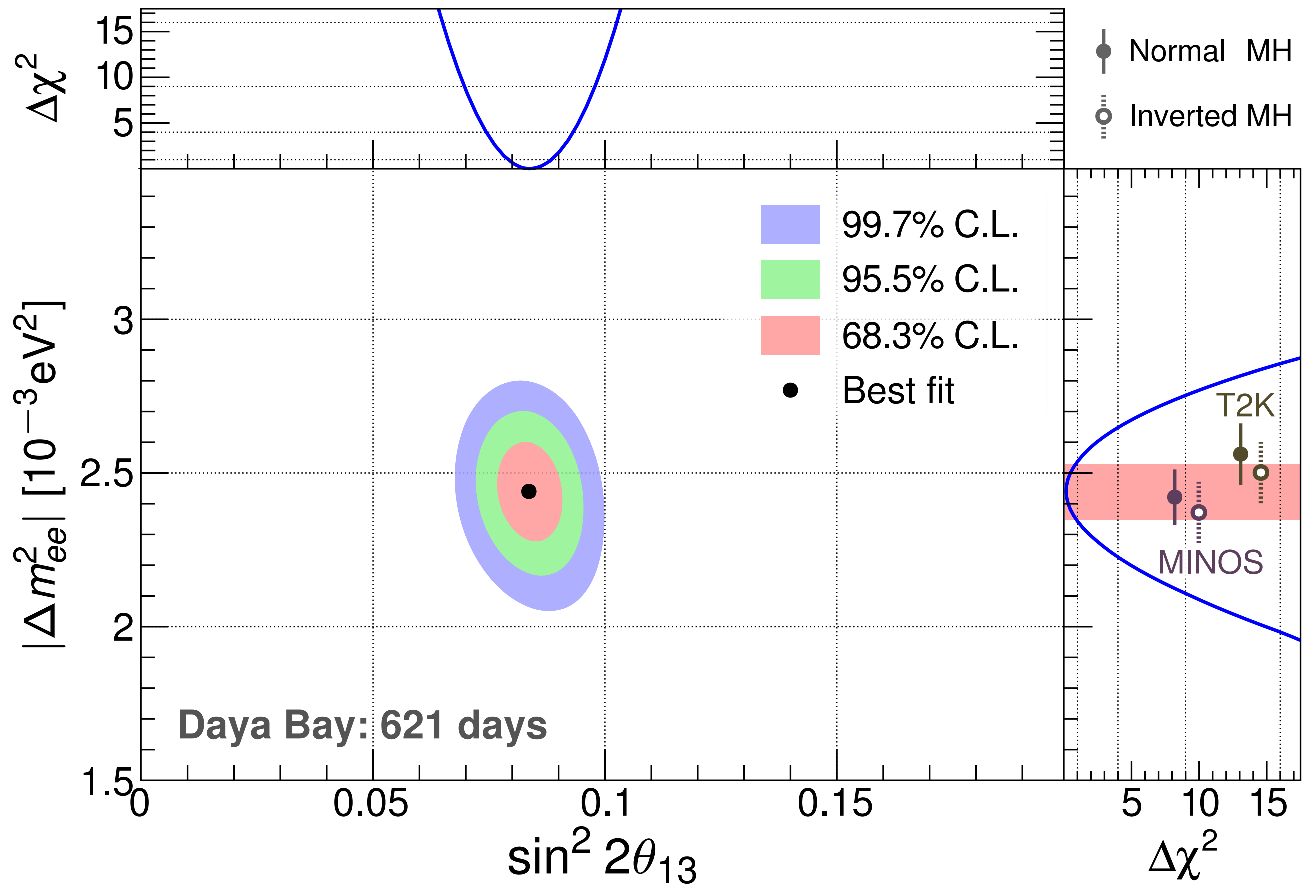
$|\Delta m^2_{32}|$ (NH) $= (2.37 \pm 0.11) \cdot 10^{-3}\ eV^2$

$|\Delta m^2_{32}|$ (IH) $= (2.47 \pm 0.11) \cdot 10^{-3}\ eV^2$

Uncertainties dominated by **statistics**

Antineutrino Oscillation Spectrum

PRL 115, 111802 (2015)



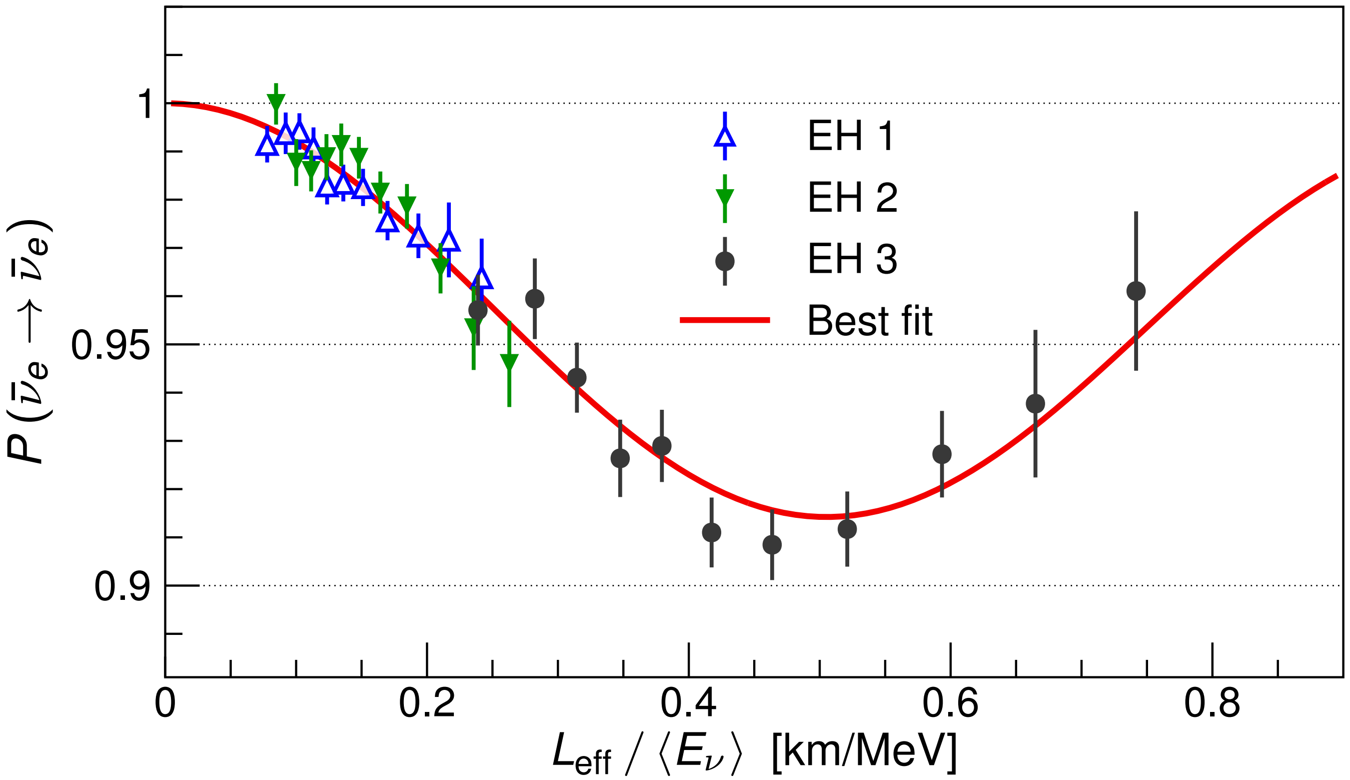
Mass Splitting

consistent & competitive precision

with

ν_μ disappearance measurements

(MINOS, T2K)



Electron Antineutrino Survival Prob

Effective baseline takes into account multiple detectors / multiple cores

Independent θ_{13} Measurement via n Capture on H

PRD 90, 071101(R) (2014)

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

$$n + p \xrightarrow{\tau \approx 200\ \mu s} D + \gamma$$

$$n + Gd \xrightarrow{\tau \approx 28\ \mu s} Gd^* \rightarrow Gd + n\gamma$$

nH IBD Candidates: pros and cons

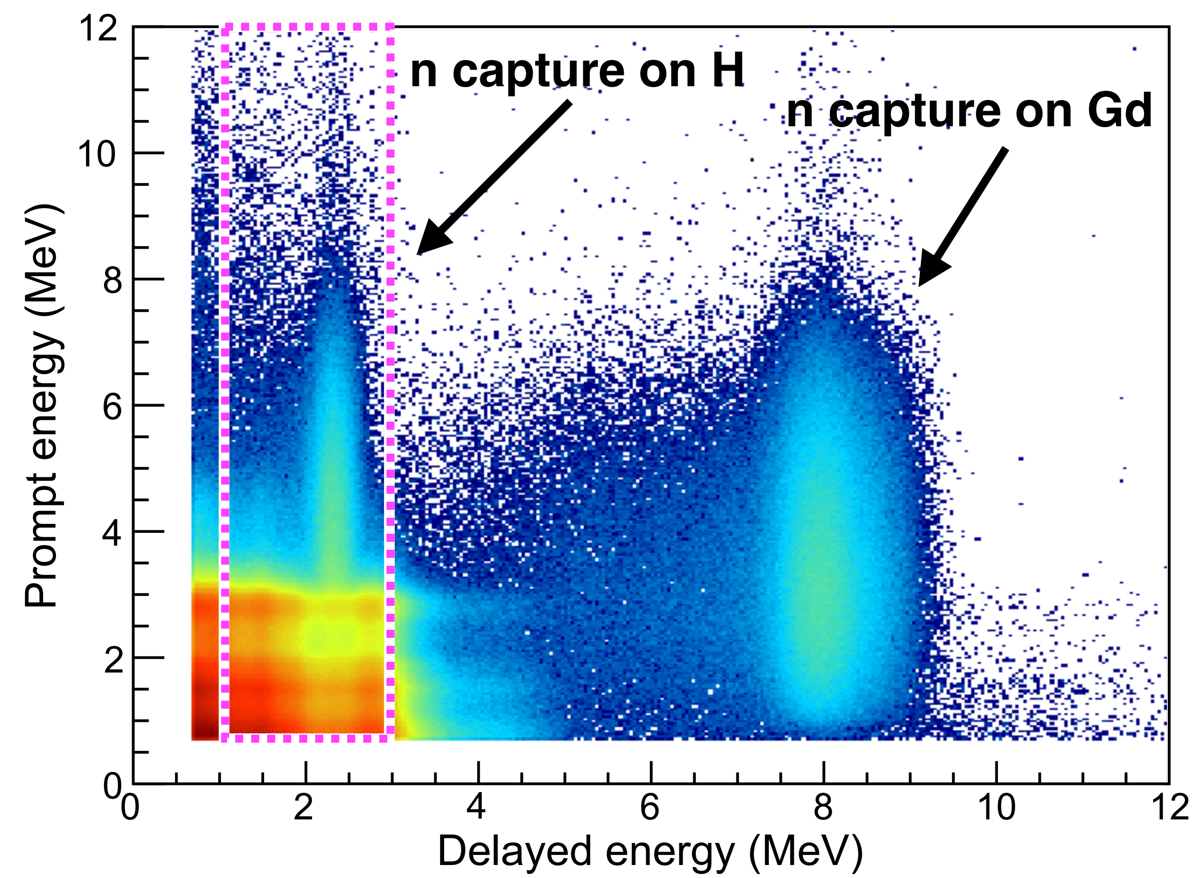
Large sample, stat. independent from nGd

Different systematics wrt nGd analysis

High accidental background from longer capture time and lower delayed energy

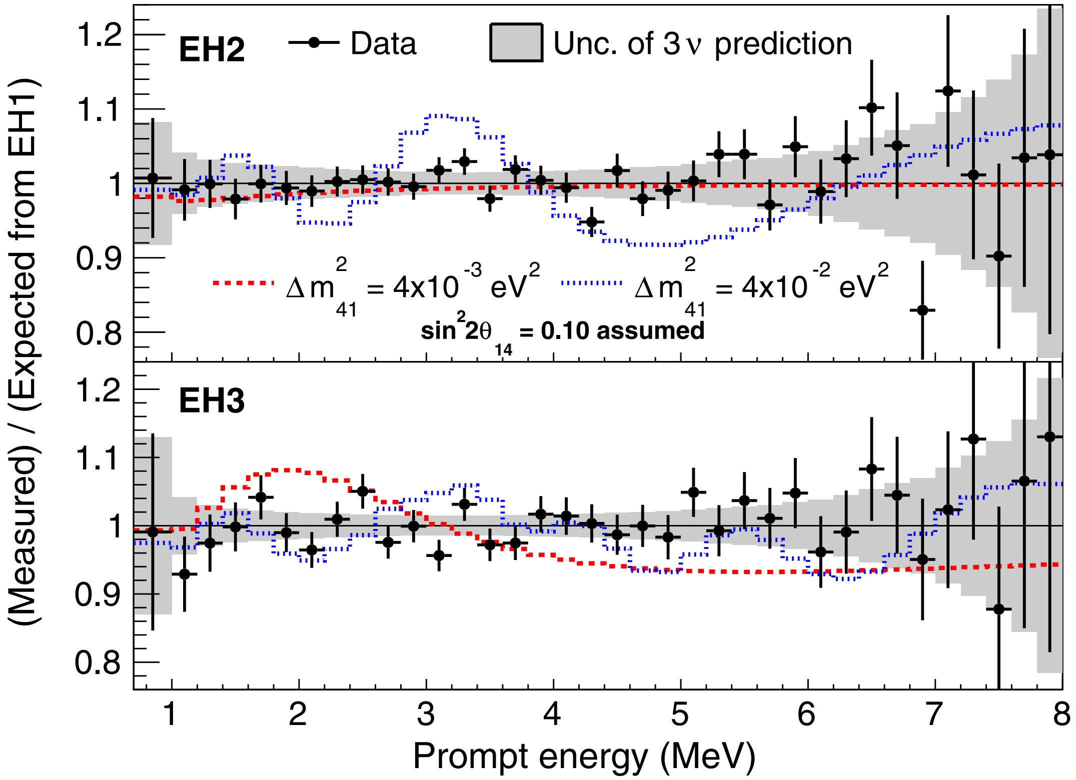
Rate-only Result (217 days of data)

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



Search for Sterile Neutrinos

PRL 113, 141802 (2014)



Sterile: not participating in V-A interactions

Appealing non-baryonic DM candidate

Experimental signature:

Modification of active-neutrino oscillation

New mixing params: θ_{14} Δm_{14}

DYB's unique configuration allows to scan Δm_{14}

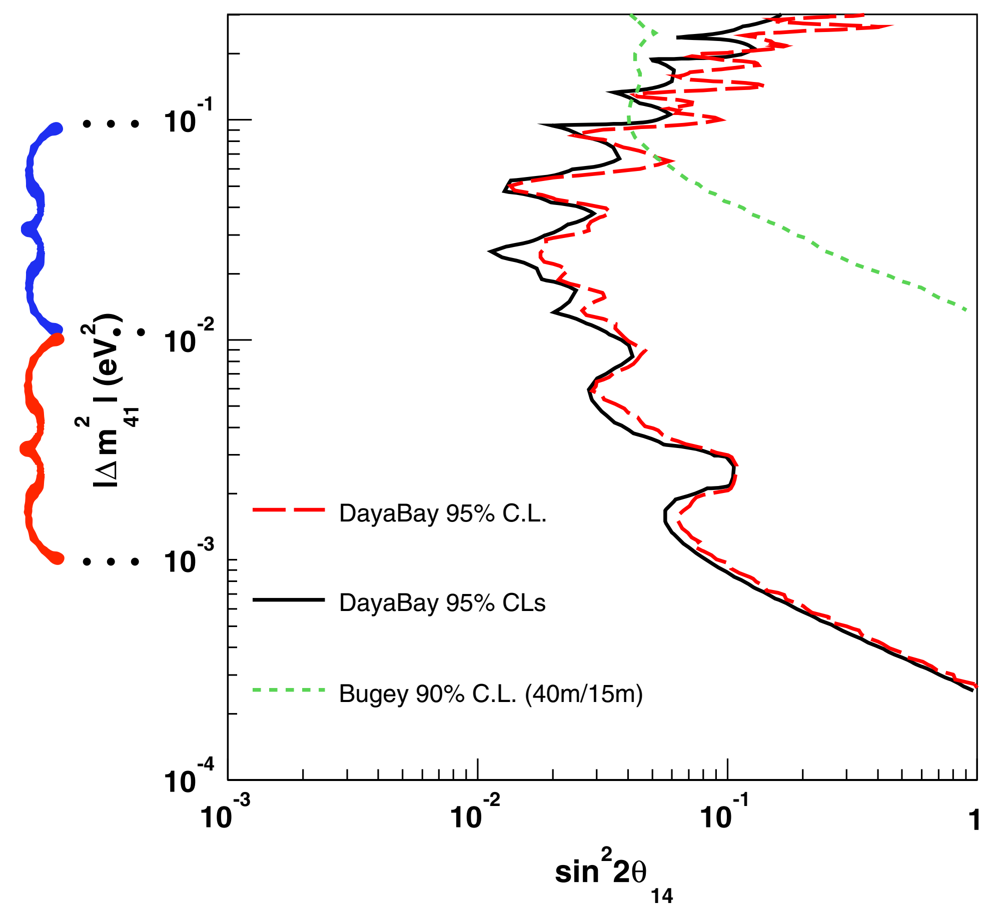
Few **hundred** meter baseline

Relative measurement between near halls

~2 **thousand** meter baseline

Comparison between near and far halls

World's best limit on θ_{14} in $|\Delta m_{14}|^2 < 0.1$ region



Reactor Antineutrino Flux

1508.04233 (PRL Accep.)

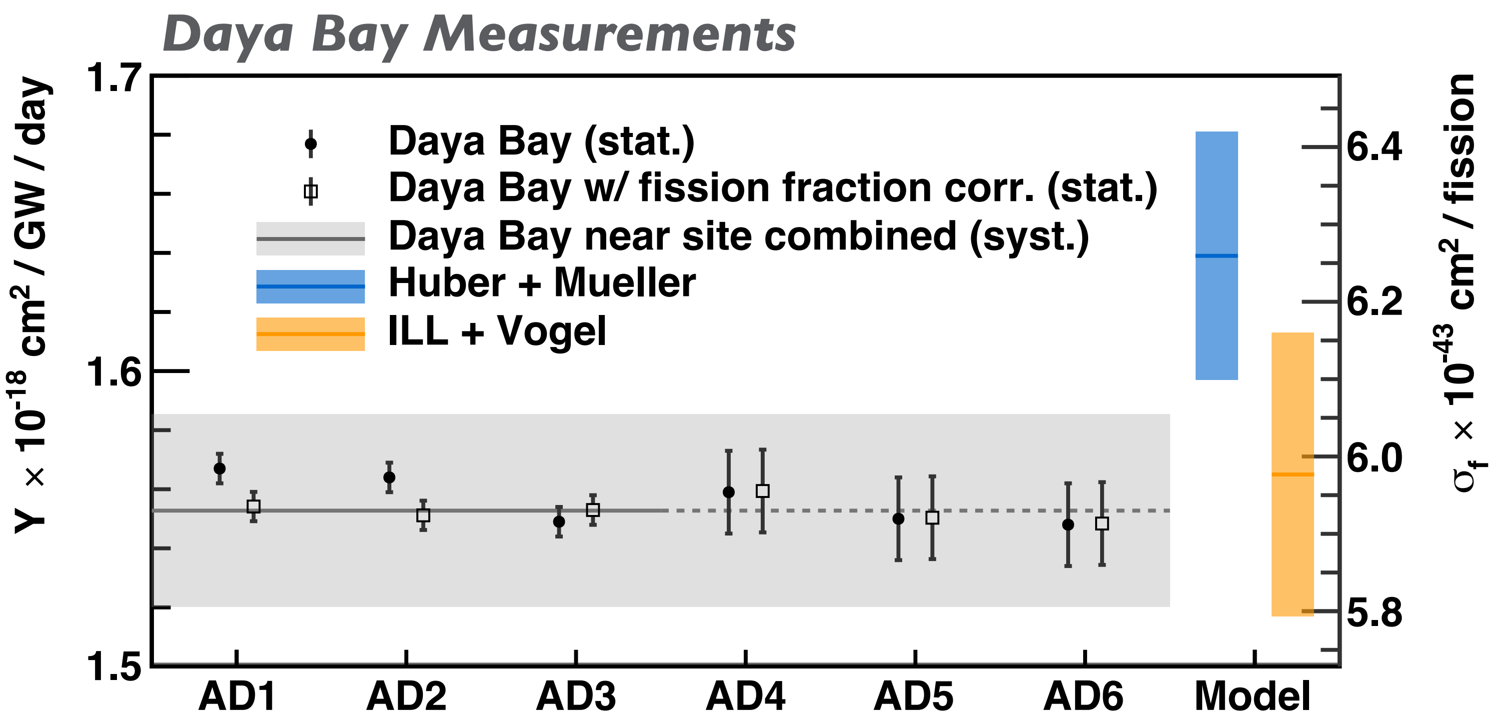
Measure $\bar{\nu}$ flux from reactors

Average IBD yields in 3 Near ADs

Ratio Data/Prediction

R (Huber+Muller) = 0.946 ± 0.022

R(ILL+Vogel) = 0.991 ± 0.023



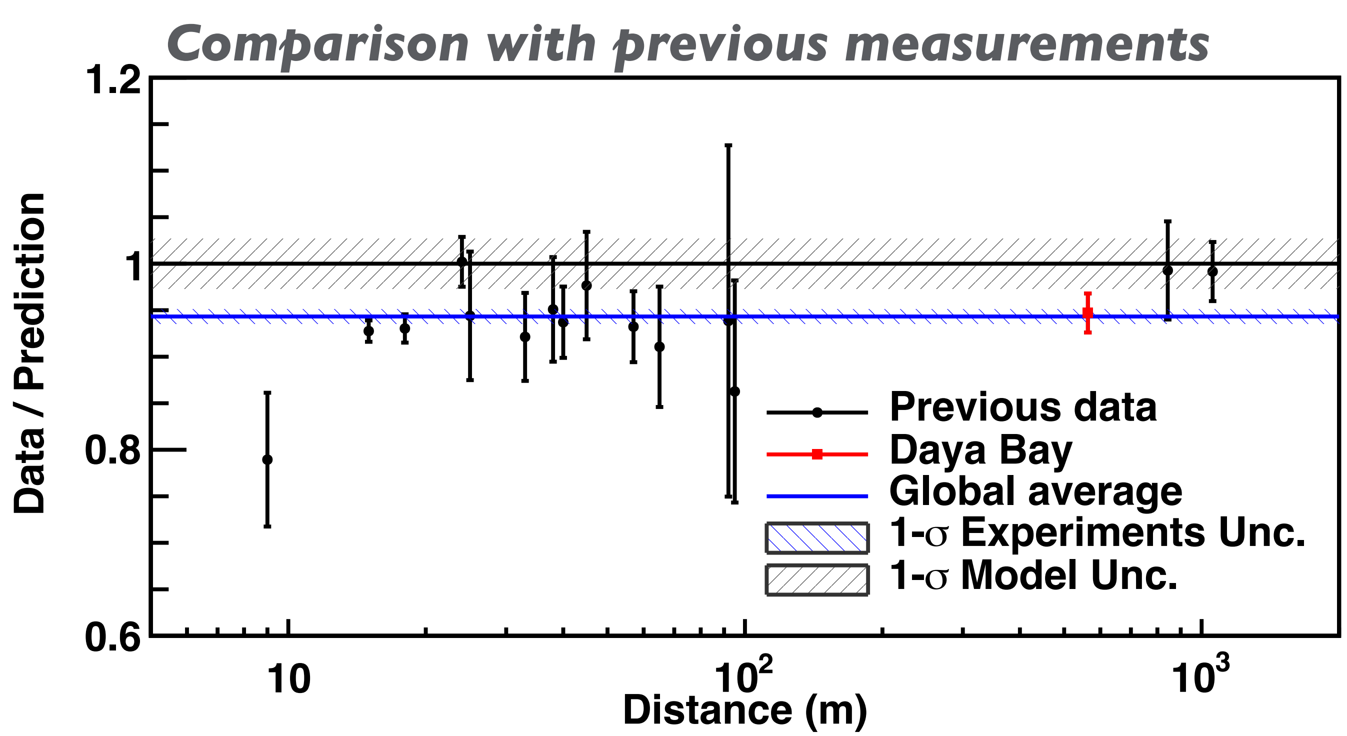
Rate vs reactor distance

Normalised to Huber+Muller

DYB data consistent with existing "**reactor anomaly**"

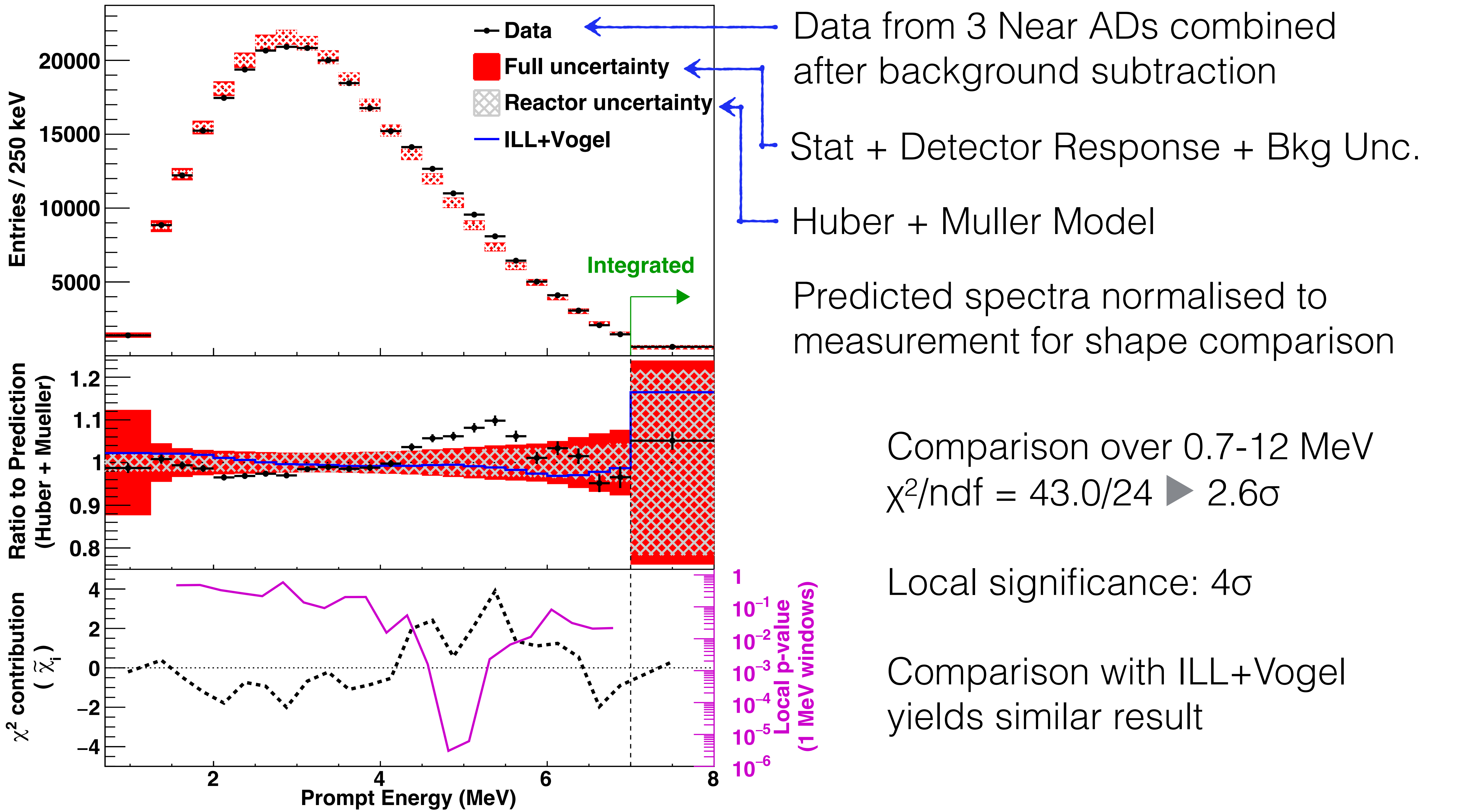
Global Fit

0.943 ± 0.008 (exp) ± 0.025 (model)



Antineutrino Prompt Energy Spectrum

1508.04233 (PRL Accep.)



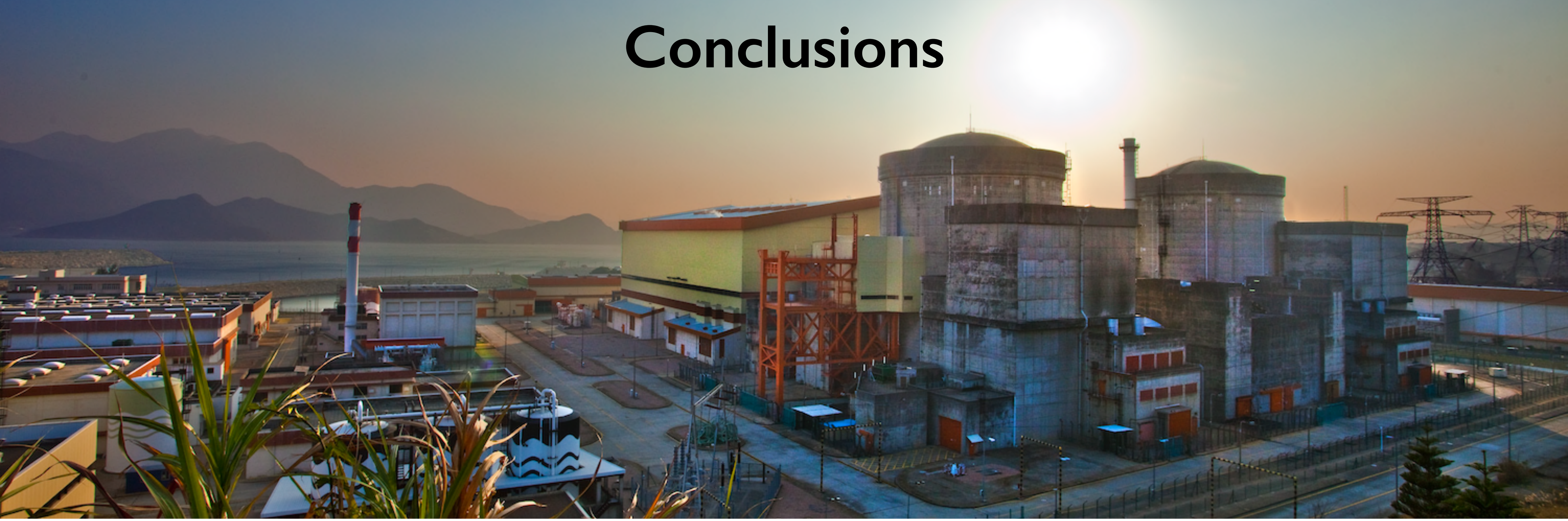
Predicted spectra normalised to measurement for shape comparison

Comparison over 0.7-12 MeV
χ^2/ndf = 43.0/24 ▶ 2.6σ

Local significance: 4σ

Comparison with ILL+Vogel yields similar result

Conclusions



Huge reactor antineutrino sample (1.2M IBDs) allowed Daya Bay Experiment to:

Deliver the world's best measurement of $\sin^2(2\theta_{13})$

Determine Δm^2_{ee} with precision competitive to neutrino-beam experiments

Set best limit on sterile neutrino in the case of mass splitting smaller than 0.1 eV^2

Confirm the existence of a spectral distortion in the reactor antineutrino spectrum

New data release (2x more statistics) expected in Summer 2016!

Backup

Independent θ_{13} Measurement via n Capture on H

PRD 90, 071101(R) (2014)

nH IBD Candidates: pros and cons

Large sample, stat. independent from nGd

Different systematics wrt nGd analysis

High accidental background from longer capture time and lower delayed energy

nH Analysis Strategy

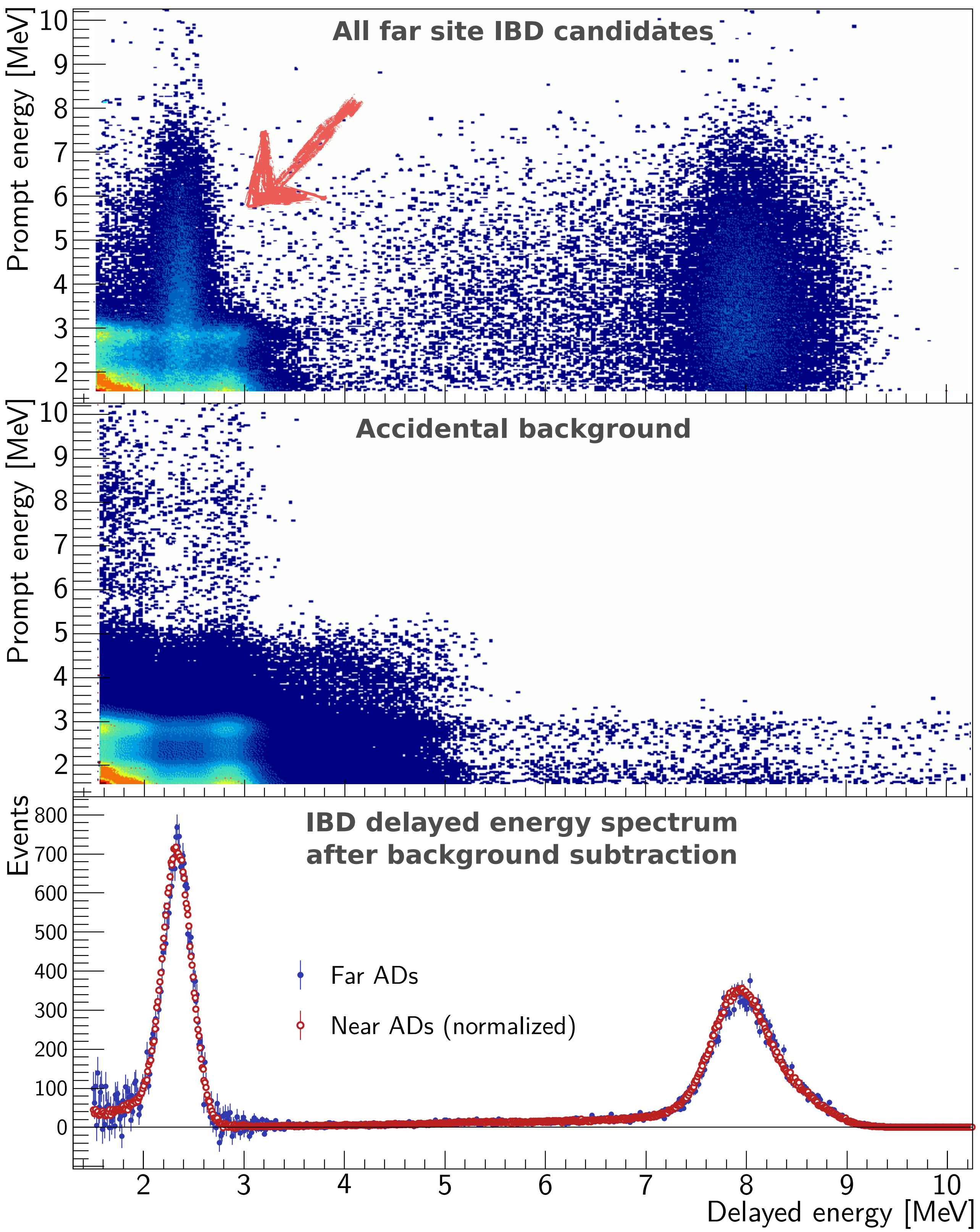
Prompt Energy cut raised to 1.5 MeV

50 cm vertex correlation cut applied

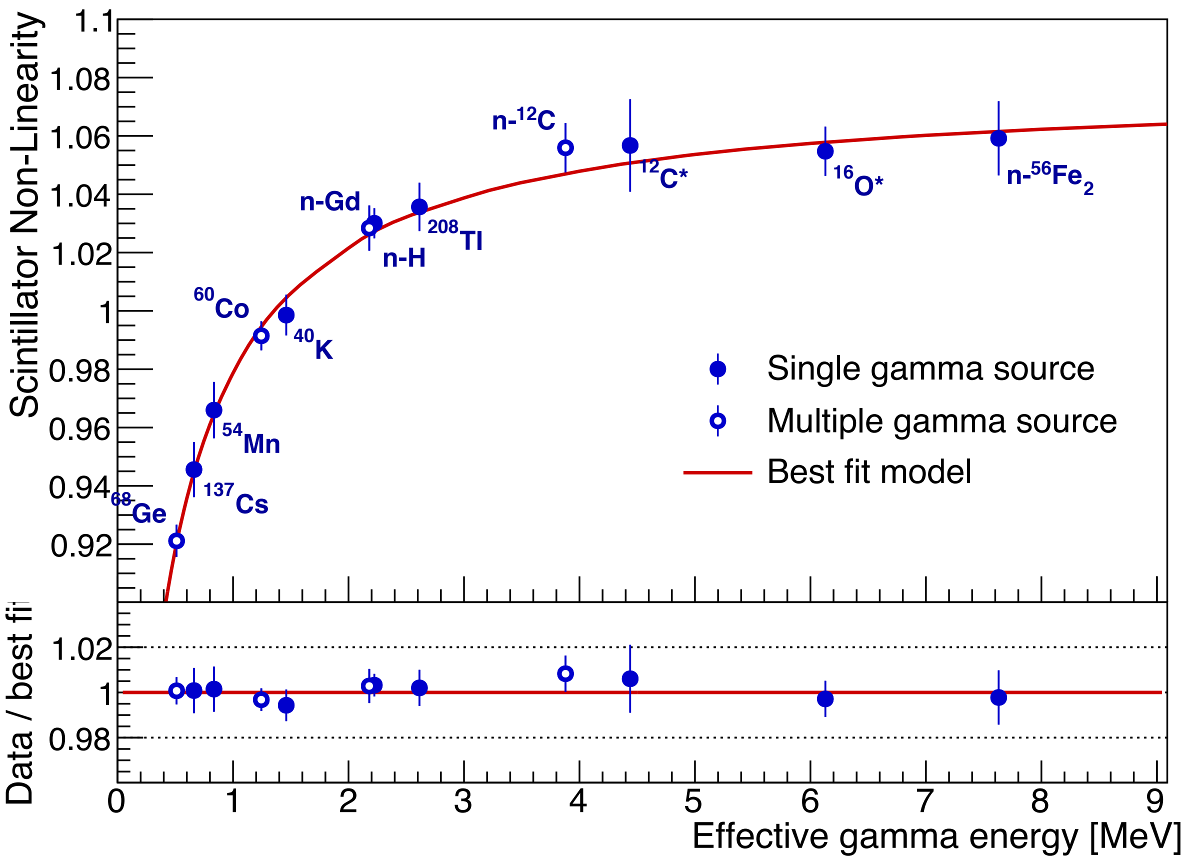
Residual accidental bkg evaluated w/ event mixing technique and statistically subtracted

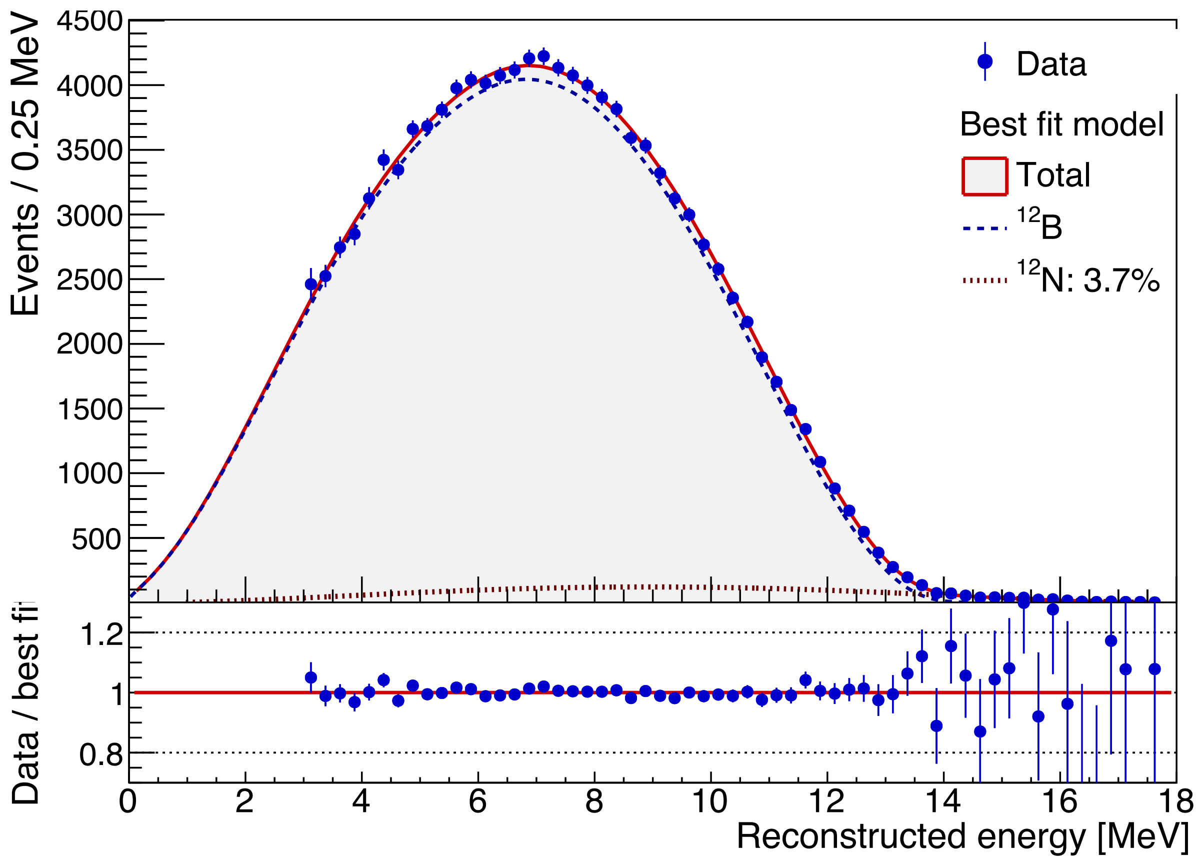
Rate-only Result (217 days of data)

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



Energy Response Model





Non-linear (NL) energy response originated from:

- particle-dependent NL light yield of LS
- charge-dependent NL in the PMT readout electronics

Model parameters computed with unconstrained χ^2 fit to calibration datasets:

- 12 gamma lines from both deployed and naturally occurring sources
- β decay spectrum of ^{12}B produced by muon spallation inside the Gd-LS volume

Resulting uncertainty in absolute energy scale < 1%

Positron Response Model

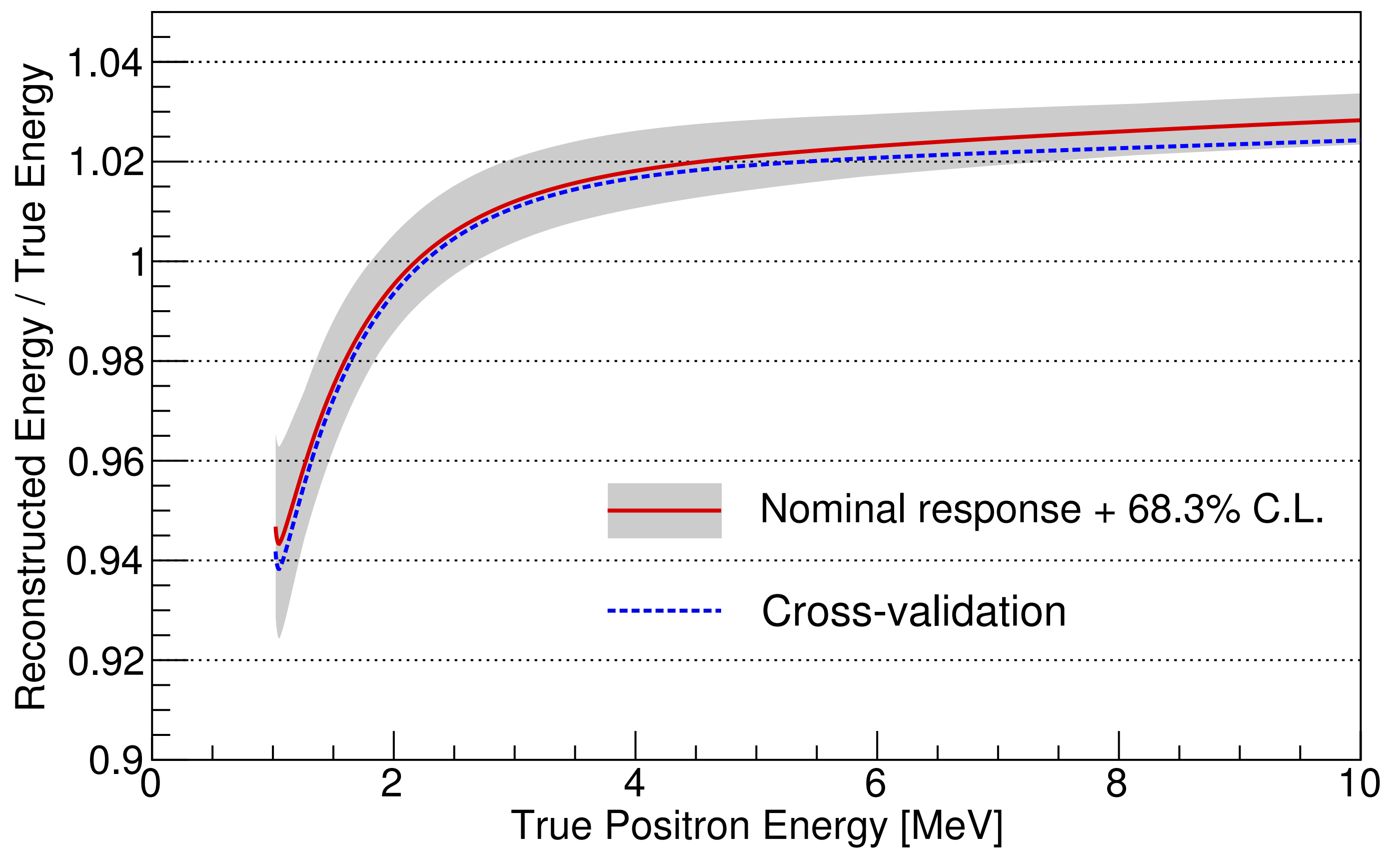
Uncertainty band obtained using other response functions consistent with fitted calibration data within 68% C.L.

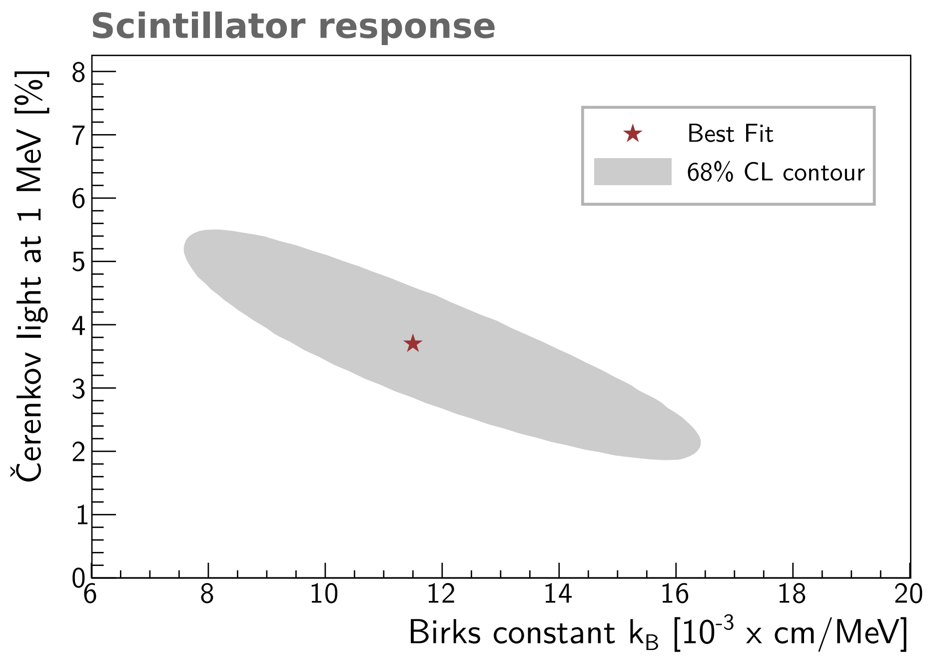
Resulting unc. in absolute energy scale <1%

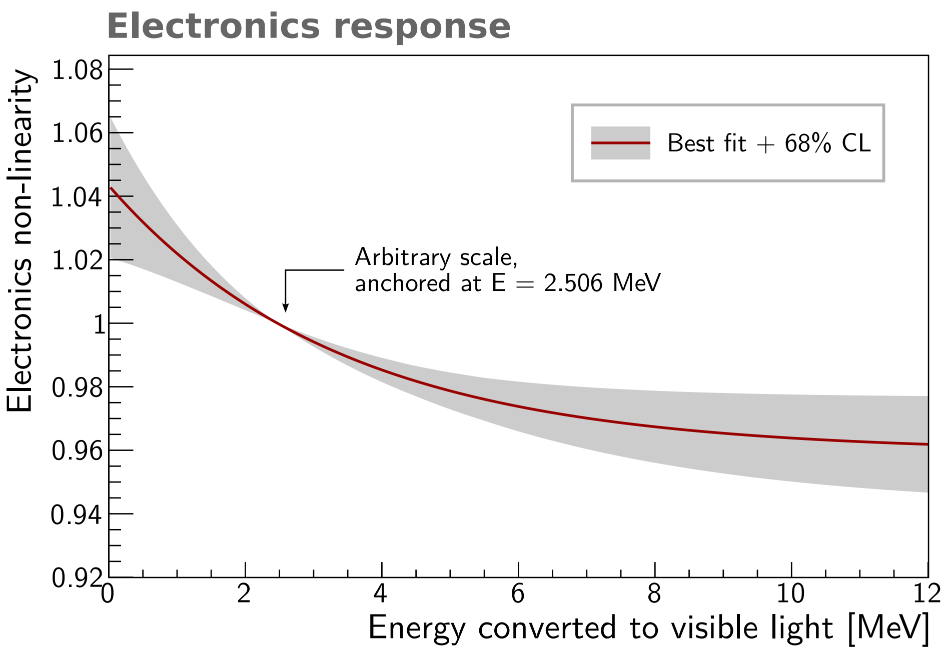
Cross-check: response computed using:

53 MeV cutoff in the Michel electron spectrum from muon decay at rest

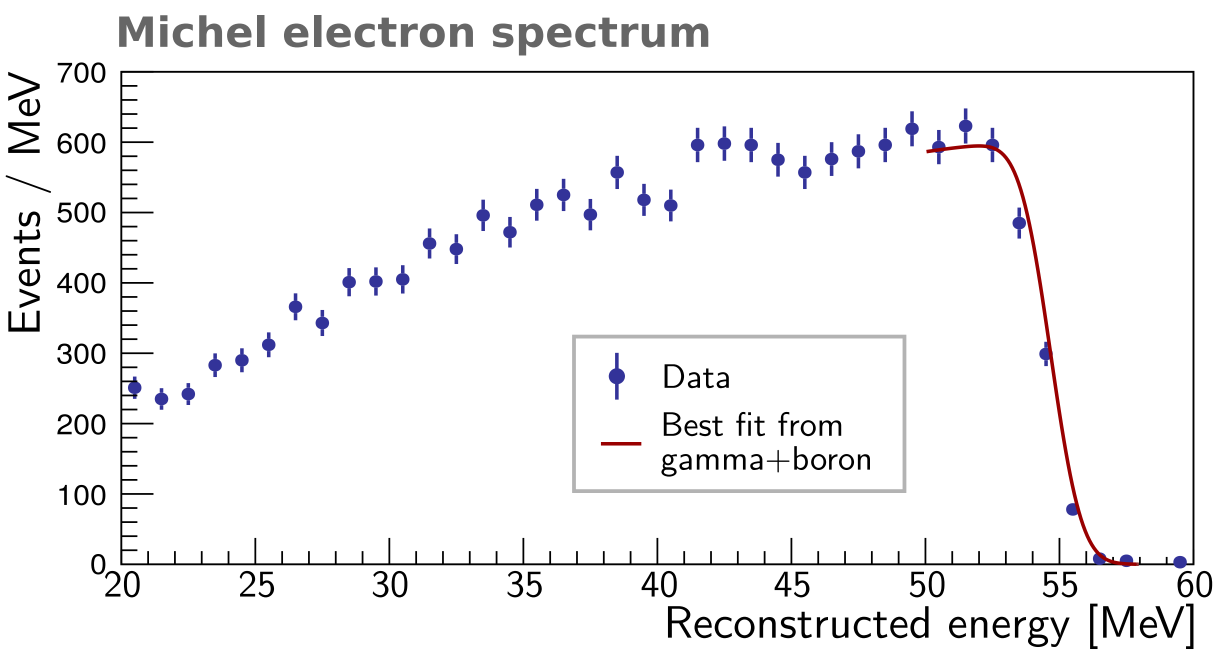
$\beta+\gamma$ spectra from natural Bi and Tl decays

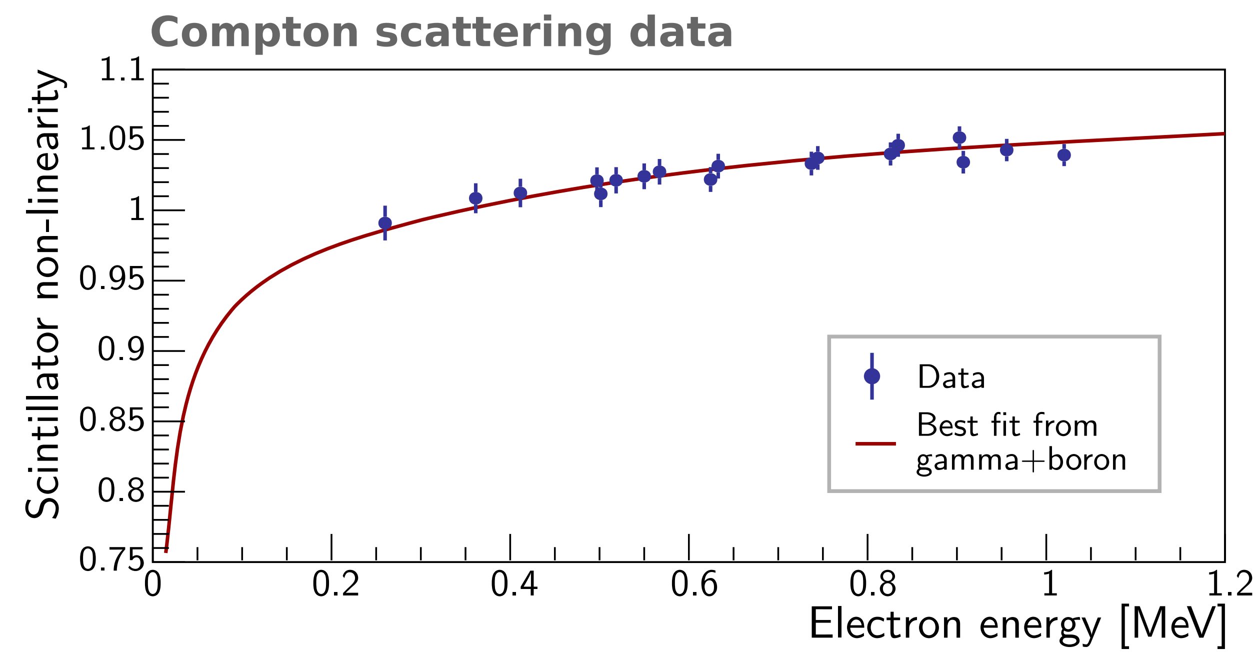


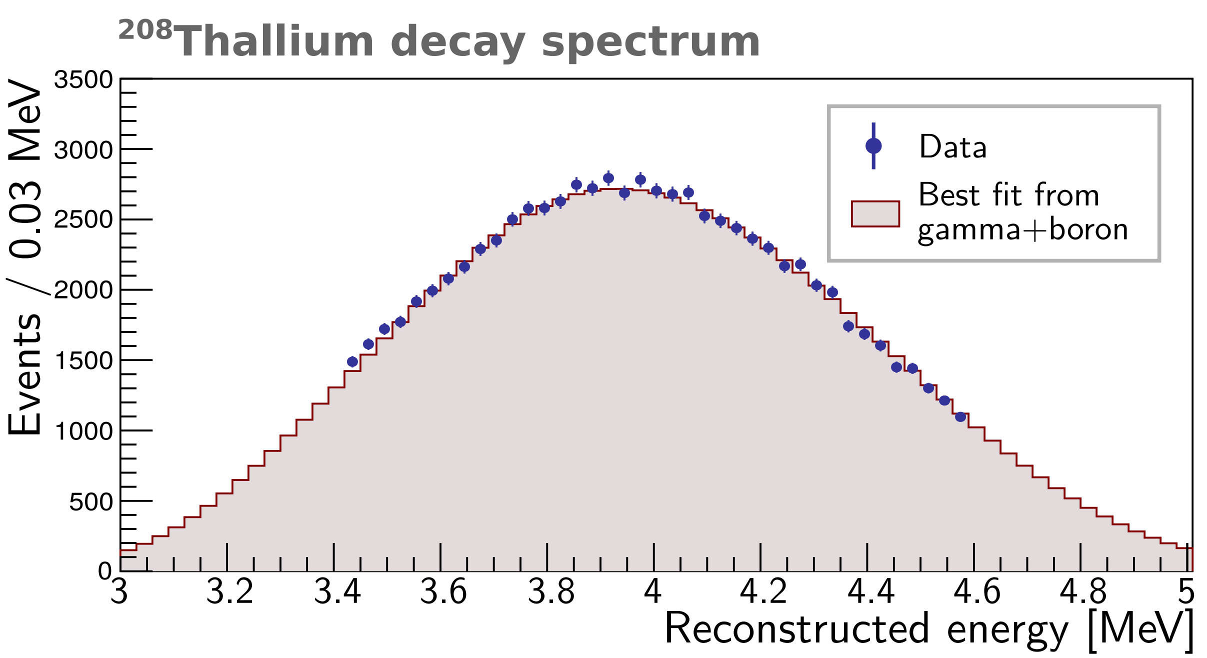


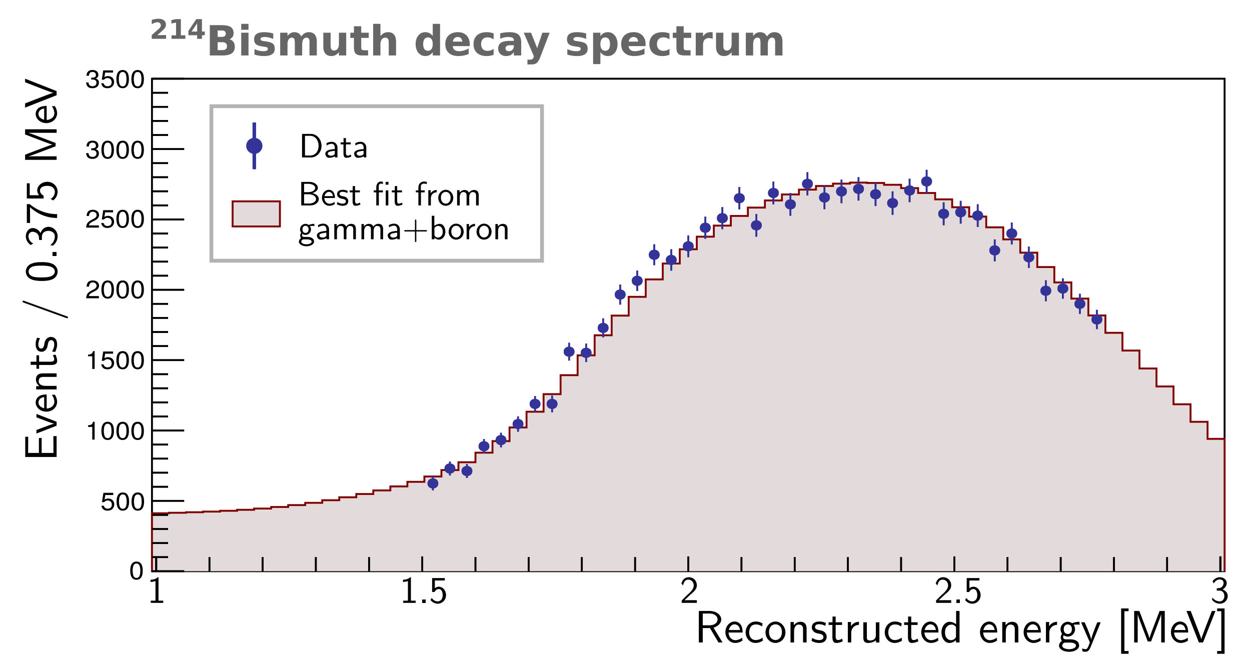


Response Model Validation









Summary of Signal and Backgrounds

	EH1		EH2		EH3			
	AD1	AD2	AD3	AD8	AD4	AD5	AD6	AD7
IBD candidates	304459	309354	287098	190046	40956	41203	40677	27419
DAQ live time(days)	565.436	565.436	568.03	378.407	562.451	562.451	562.451	372.685
ε_μ	0.8248	0.8218	0.8575	0.8577	0.9811	0.9811	0.9808	0.9811
ε_m	0.9744	0.9748	0.9758	0.9756	0.9756	0.9754	0.9751	0.9758
Accidentals(per day)	8.92 ± 0.09	8.94 ± 0.09	6.76 ± 0.07	6.86 ± 0.07	1.70 ± 0.02	1.59 ± 0.02	1.57 ± 0.02	1.26 ± 0.01
Fast neutron(per AD per day)	0.78 ± 0.12		0.54 ± 0.19		0.05 ± 0.01			
^{9}Li/^{8}He(per AD per day)	2.8 ± 1.5		1.7 ± 0.9		0.27 ± 0.14			
Am-C correlated 6-AD(per day)	0.27 ± 0.12	0.25 ± 0.11	0.27 ± 0.12		0.22 ± 0.10	0.21 ± 0.10	0.21 ± 0.09	
Am-C correlated 8-AD(per day)	0.20 ± 0.09	0.21 ± 0.10	0.18 ± 0.08	0.22 ± 0.10	0.06 ± 0.03	0.04 ± 0.02	0.04 ± 0.02	0.07 ± 0.03
^{13}C(α, n)^{16}O(per day)	0.08 ± 0.04	0.07 ± 0.04	0.05 ± 0.03	0.07 ± 0.04	0.05 ± 0.03	0.05 ± 0.03	0.05 ± 0.03	0.05 ± 0.03
IBD rate(per day)	657.18 ± 1.94	670.14 ± 1.95	594.78 ± 1.46	590.81 ± 1.66	73.90 ± 0.41	74.49 ± 0.41	73.58 ± 0.40	75.15 ± 0.49

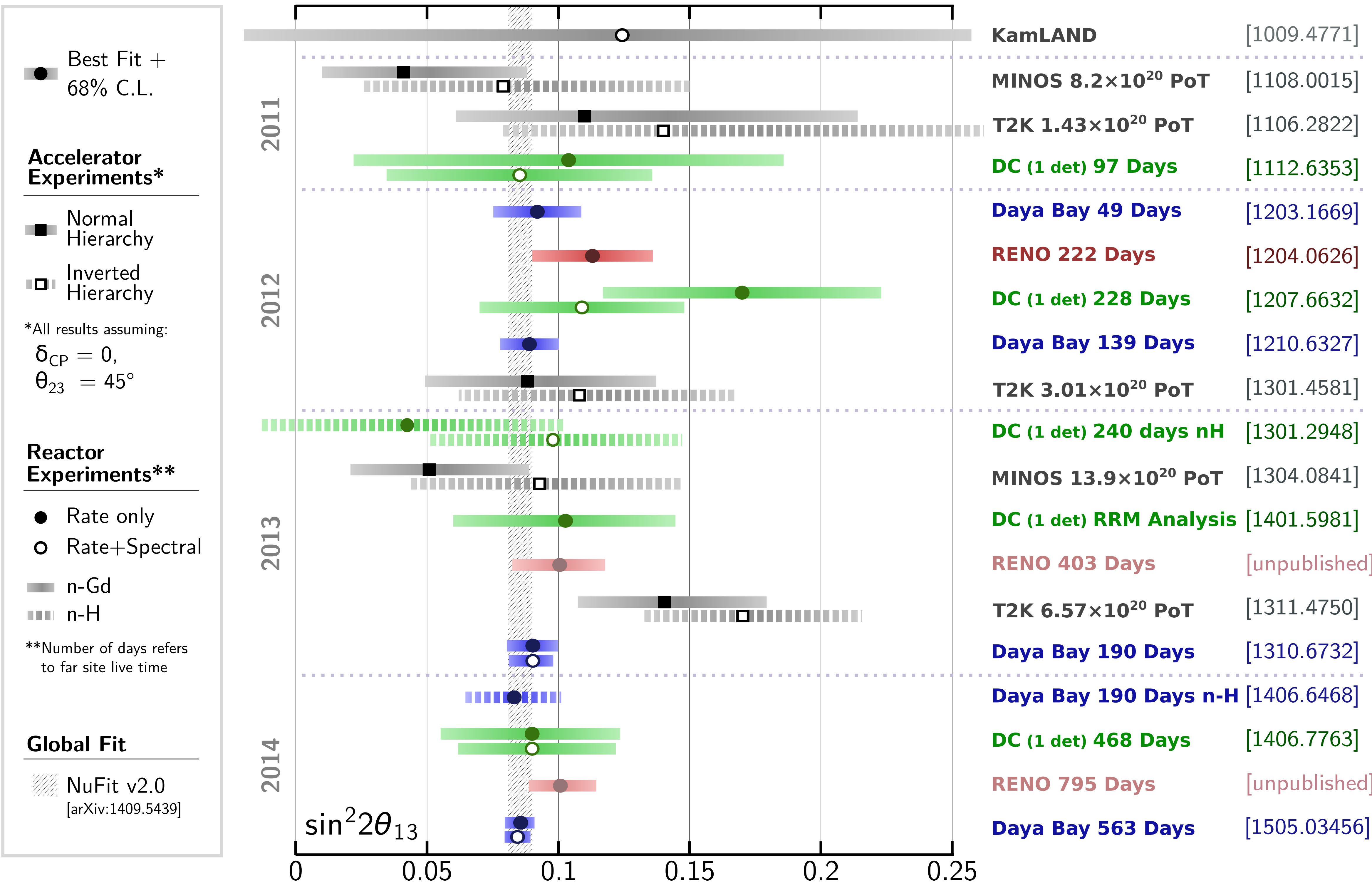
^{13}C(α,n) ^{16}O

α from natural radioactivity may interact with a nucleus and emit a neutron.

α come from ^{238}U, ^{232}Th, and ^{210}Po decay chains (in the case of Gd-LS also from ^{227}Ac)

The nucleus ^{13}C is a natural component of carbon, commonly found in LS.

History of $\sin^2(2\theta_{13})$



Reactor Models

Two fissile antineutrino spectrum models

1) ILL + Vogel

ILL model of ^{235}U, ^{239}Pu, ^{241}Pu — Phys. Lett. B 118, 162 (1982); Phys. Lett. B 160, 325 (1985); Phys. Lett. B 218, 365 (1989)

Vogel's theoretical model of ^{238}U — Phys. Rev. C 24, 1543 (1981)

2) Huber + Muller

- Huber's model of ^{235}U, ^{239}Pu and ^{241}Pu — Phys. Rev. C 84, 024617 (2011)
- Muller's model of ^{238}U — Phys. Rev. C 83, 054615 (2011)

→ Chosen as reference because of improved treatment of beta-to-antineutrino conversions

Muon Veto

Muon veto to suppress cosmogenic bkg

Muon crossing Water Pool only: veto 0.6ms

Muon crossing AD {
- 20 MeV<E<2.5 GeV: veto 1ms
- E>2.5 GeV: veto 1s