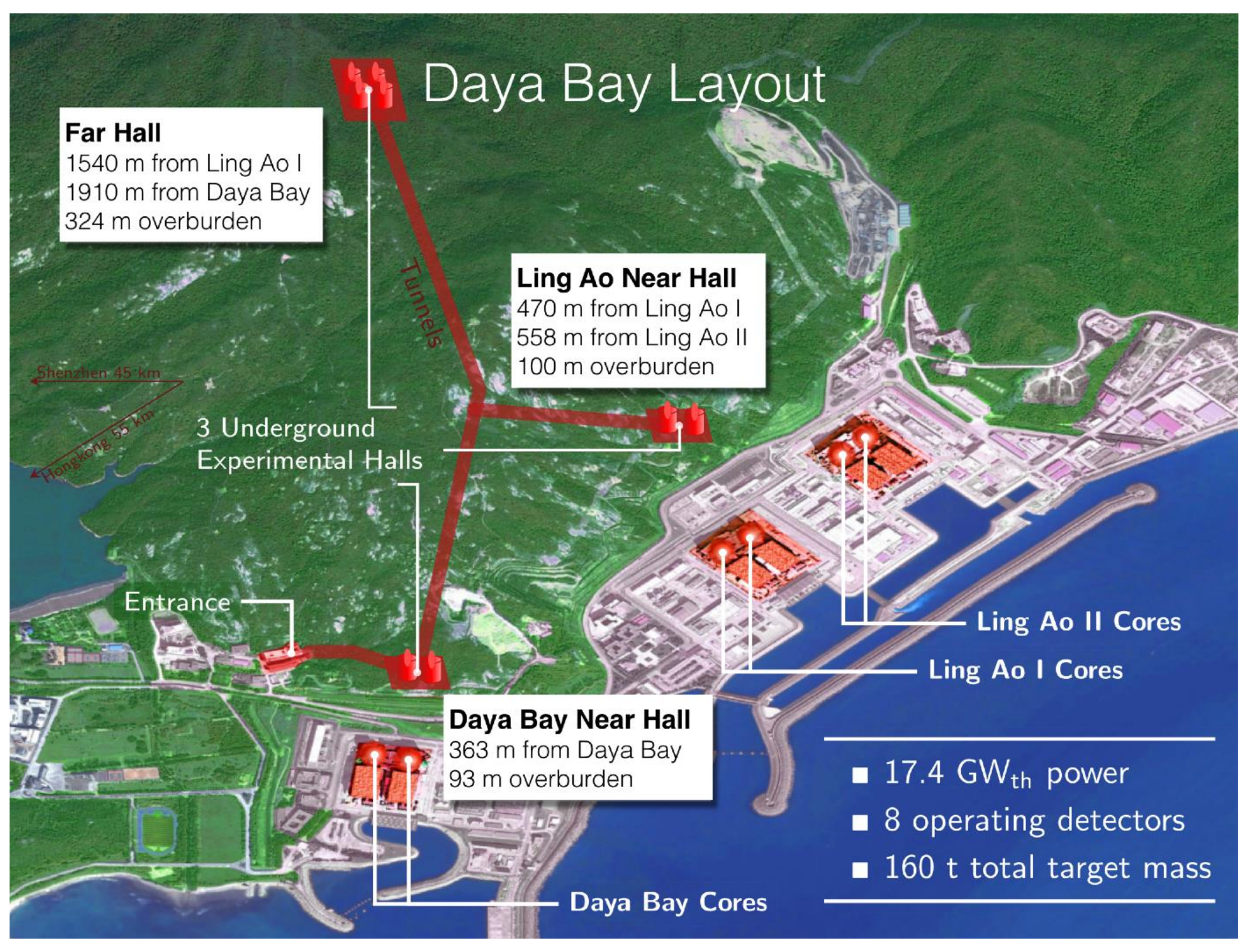
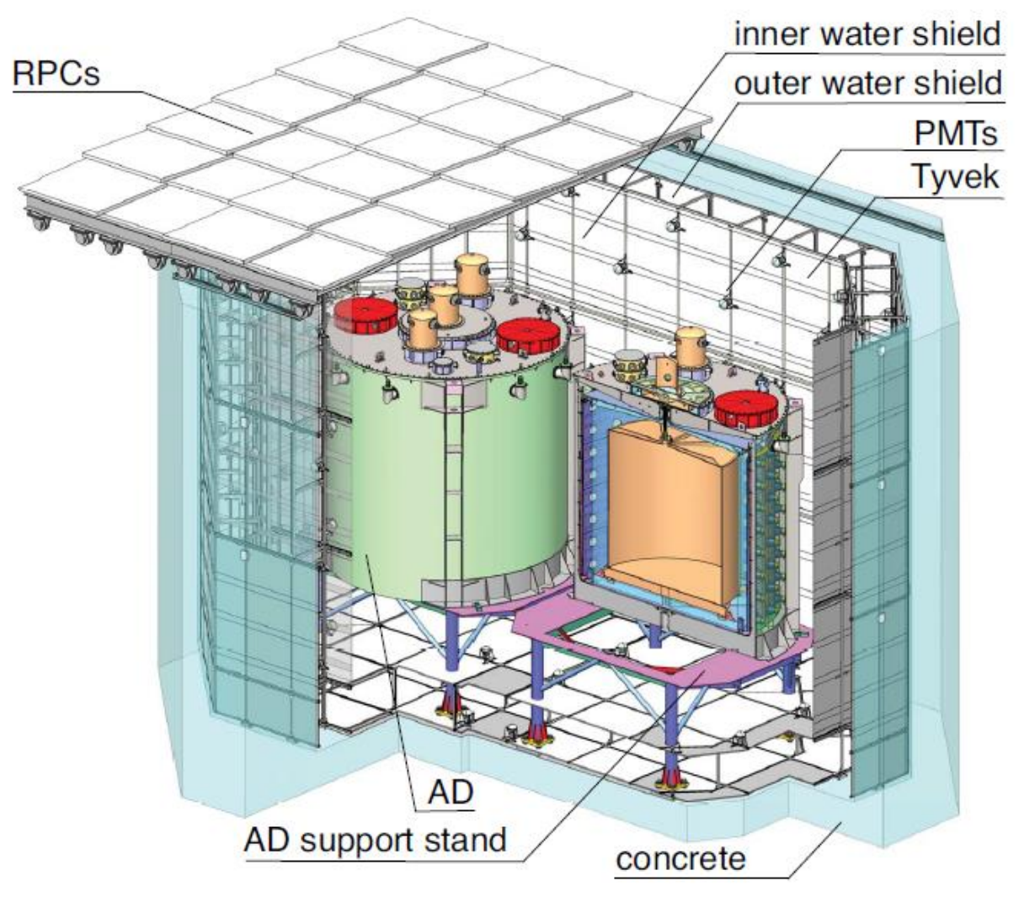
Spectral measurement of electron antineutrino disappearance via neutron capture on hydrogen at Daya Bay

Qun Wu (Shandong University), on behalf of the Daya Bay Collaboration

The Daya Bay Reactor Neutrino Experiment

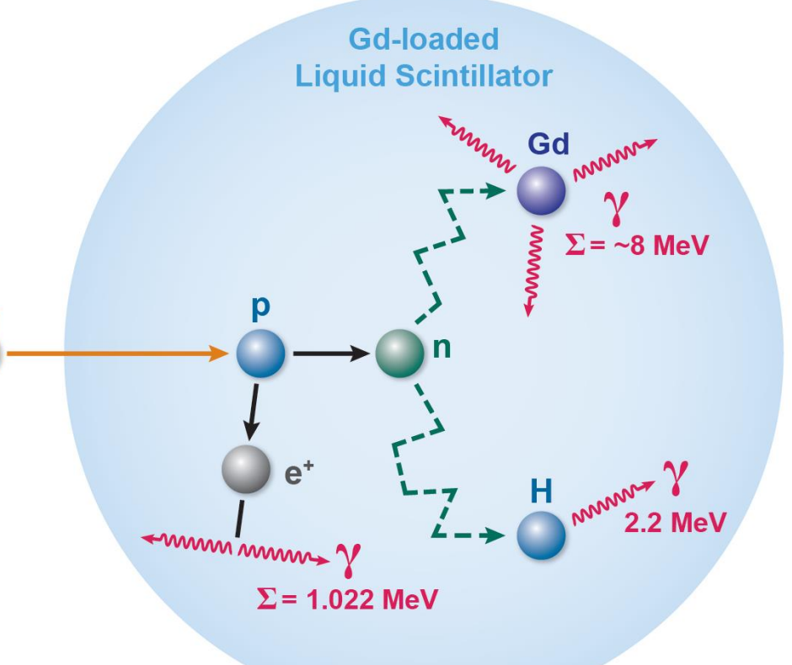




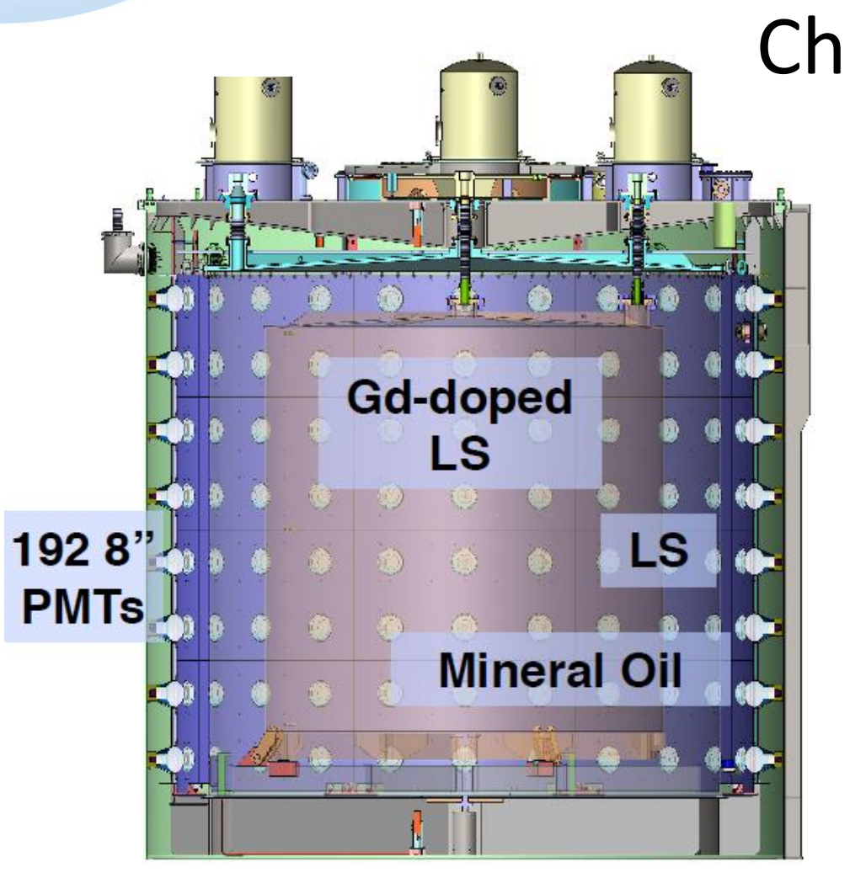
$$P_{\overline{\nu}_e\to\overline{\nu}_e} \approx 1-\sin^2 2\theta_{13}\sin^2\frac{1.267\Delta m^2_{ee}L}{E}-\cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\frac{1.267\Delta m^2_{21}L}{E}$$

$$\Delta m^2_{ee}\approx\cos^2\theta_{12}\,|\Delta m^2_{31}|+\sin^2\theta_{12}|\Delta m^2_{32}|\,,\quad |\Delta m^2_{32}|\approx|\Delta m^2_{ee}|\pm 5.2\times10^{-5}\mathrm{eV}^2 \text{ for NH (-) /IH(+)}$$

A relative rate + shape measurement using Inverse Beta Decays (IBDs) tagged by neutron capture on Gd (nGd) provides the world's most precise measurement of $\sin^2 2\theta_{13}$ and Δm^2_{ee}. *Phys. Rev. D* ***95****, 072006 (2017)*

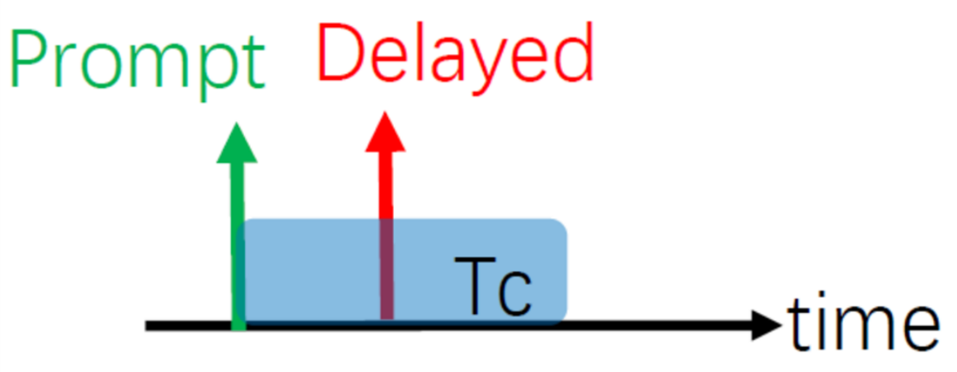


Inverse Beta Decay tagged via neutron capture on hydrogen (nH IBDs)



Merit:
- Independent data sample with comparable statistics (targets: GdLS, LS, Acrylic components)
- Largely different systematics

Challenges:
- Large contamination from accidental coincidences
- Sizeable energy leakage



Signal Selection:
- Flasher cut/Muon Veto
- Multiplicity in coincidence window (T_c) = 2

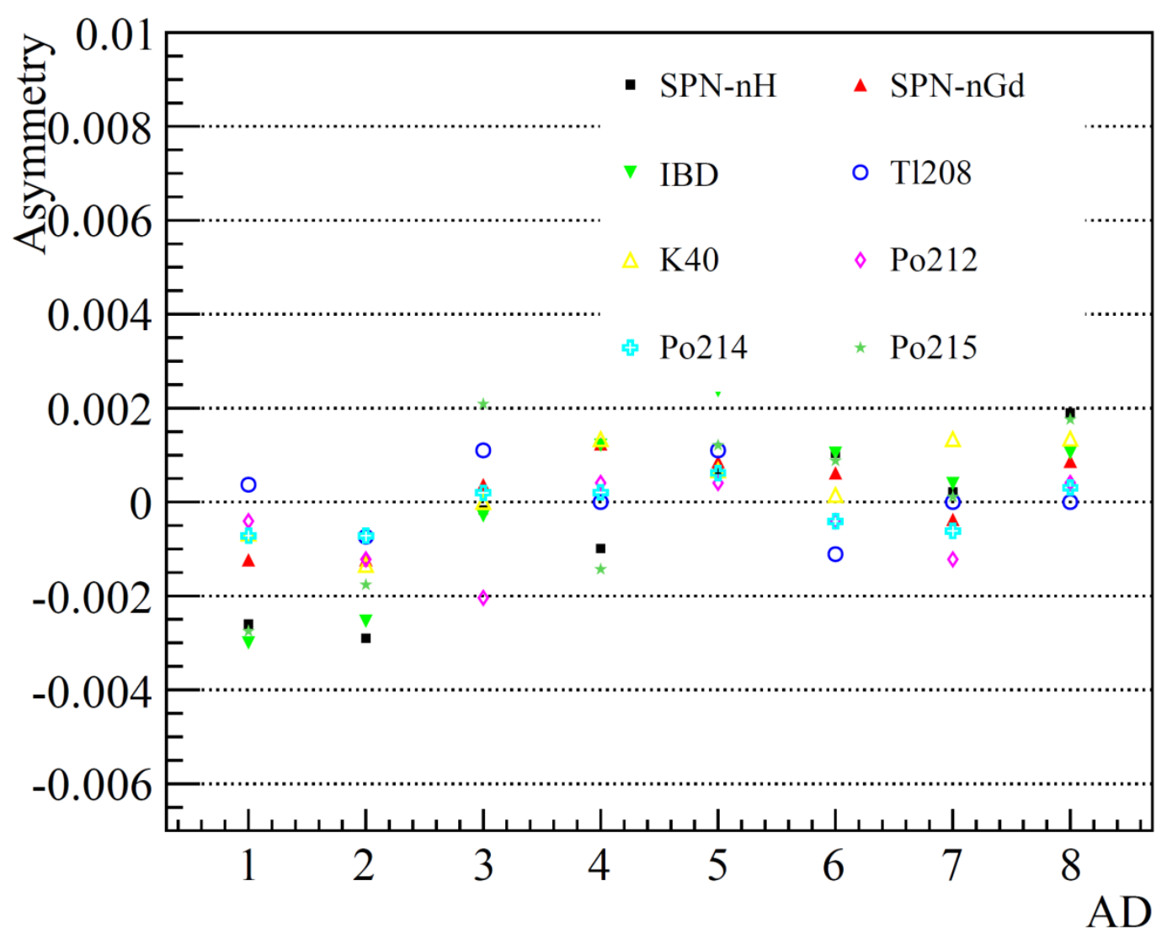
$1.5 < E_p < 12$ MeV; $\mu-3\sigma < E_d < \mu+3\sigma$;
$1\ \mu s < \Delta T < 400\ \mu s$; $R_{pd} < 50$ cm

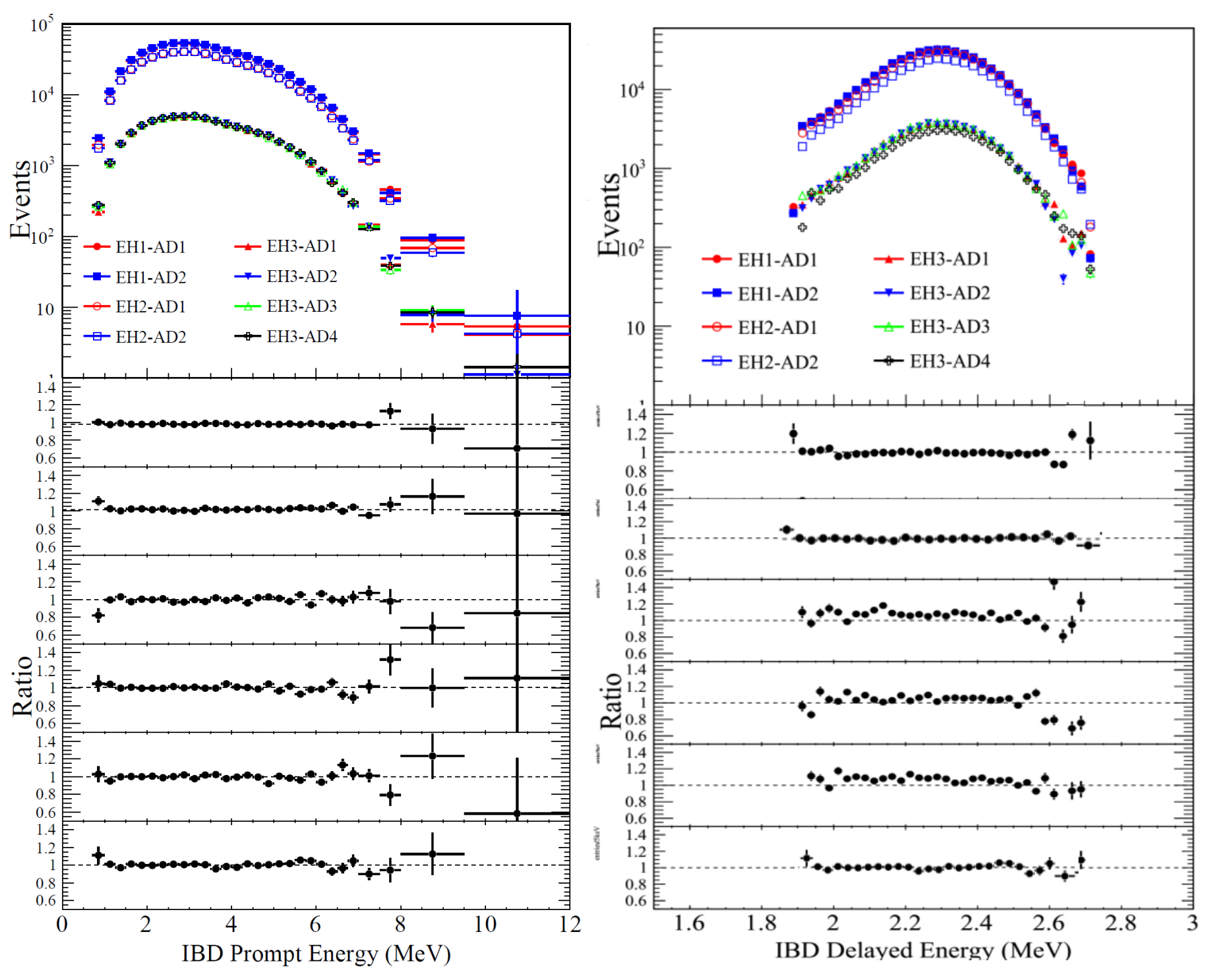
About 1.6 million events at Near sites and 0.4 million events at Far site (1230 days of data)

Backgrounds :
- Accidentals (Background/Signal: 12% @ Near site, 51%@ Far site)
- Muon-induced fast neutron; ^{9}Li/^{8}He
- Calibration source induced: Am-C

Energy Reconstruction

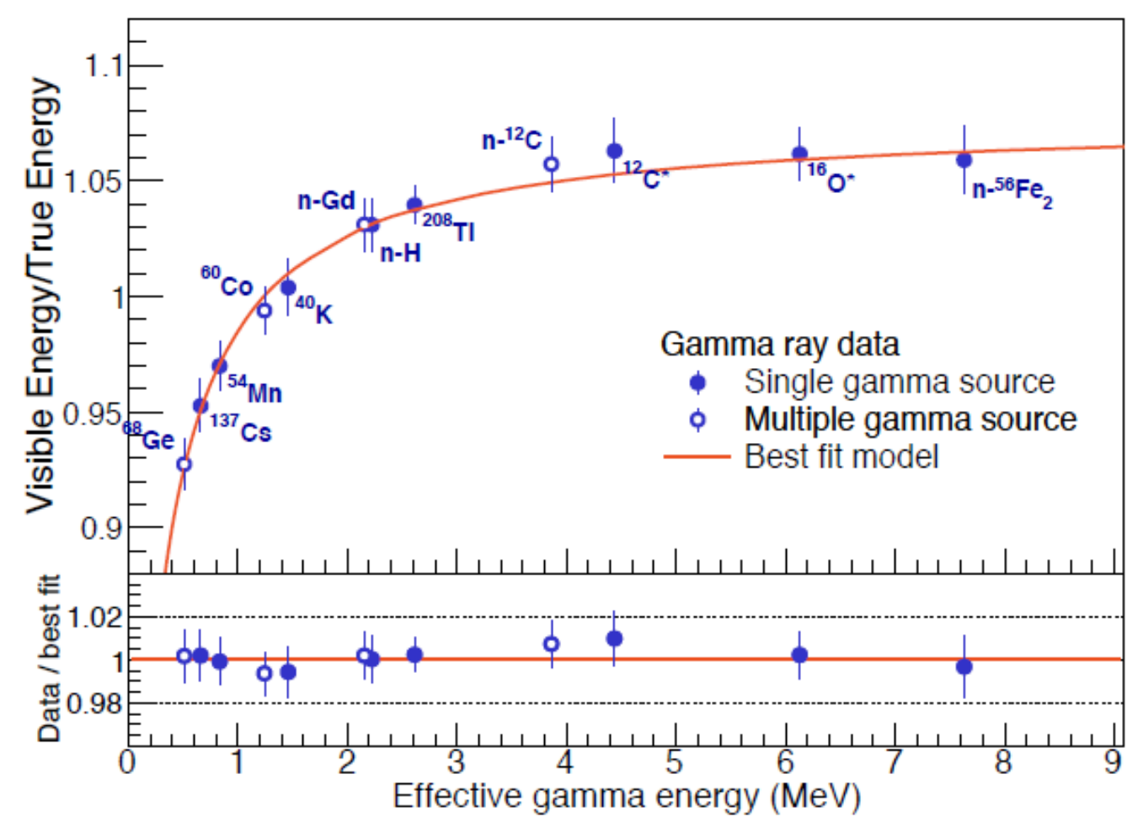
Energy scale AD-to-AD differences:
- Various calibration references
- Relative energy scale uncertainty:
  - < 0.2% for nGd
  - < 0.4% for nH

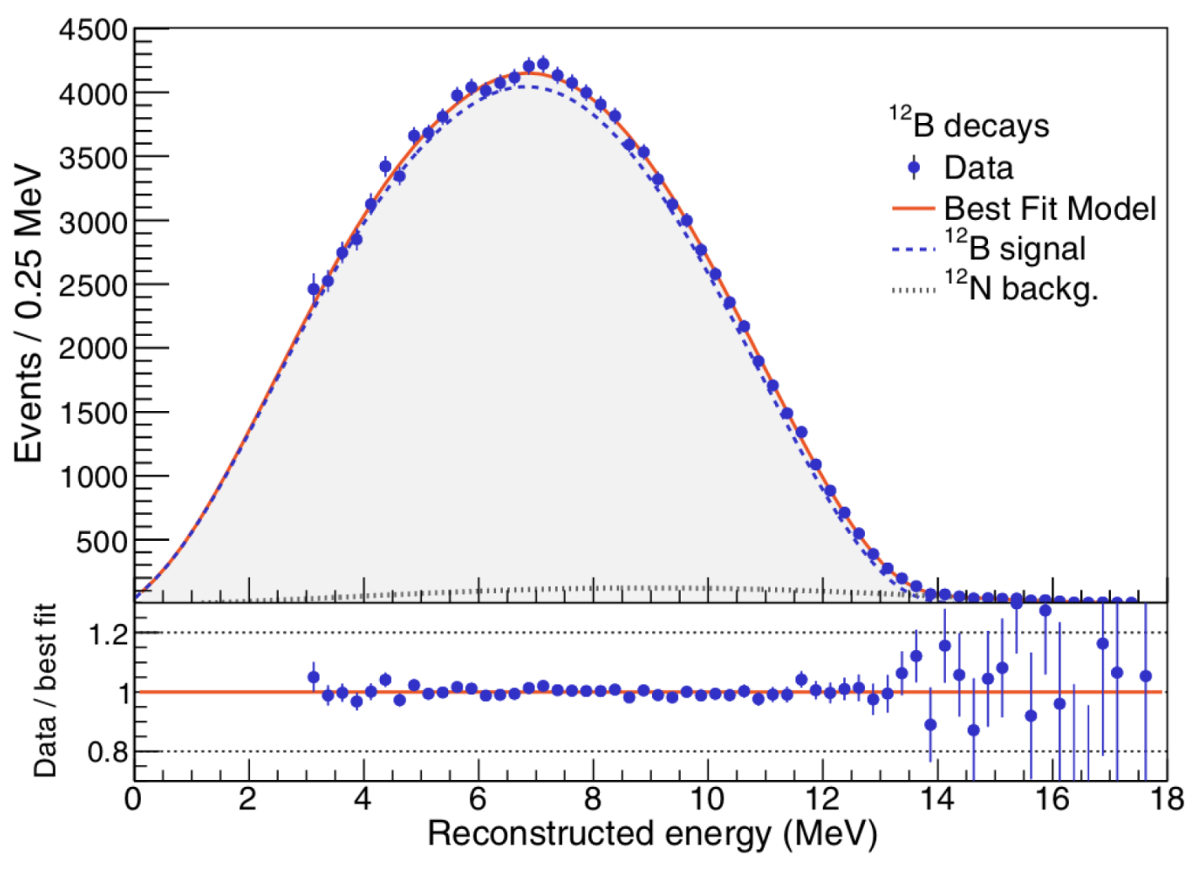




Side-by-Side Comparison

Mapping between the reconstructed and true energy for nGd





From Energy Model for nGd to nH

nGd: *Phys. Rev. D* ***95****, 072006 (2017)*

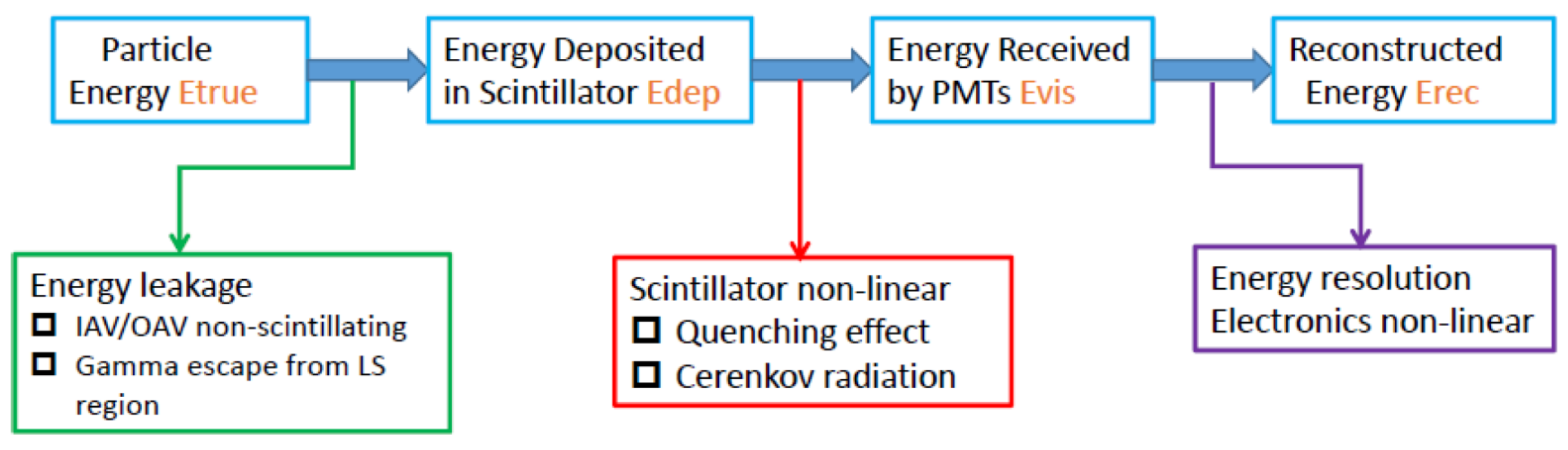
- $$\frac{E_{\rm rec}}{E_{\rm true}}=f_{\rm scint}(E_{\rm true})\cdot f_{\rm electronics}(E_{\rm vis})$$

$$f_{\rm scint}(E_{\rm true})=\frac{E_{\rm vis}}{E_{\rm true}}=\beta_{\rm vis}[f_q(E_{\rm true},k_B)+k_C f_C(E_{\rm true})]$$

$$f_{\rm electronics}(E_{\rm vis})=\frac{E_{\rm rec}}{E_{\rm vis}}=\beta_{\rm rec}\left[1+\alpha\exp\left(-\frac{E_{\rm vis}}{\tau}\right)\right]$$

- Includes the nonlinearity from LS and readout electronics
- Parameters obtained from various ϒ peaks and continuous ^{12}B β-spectrum

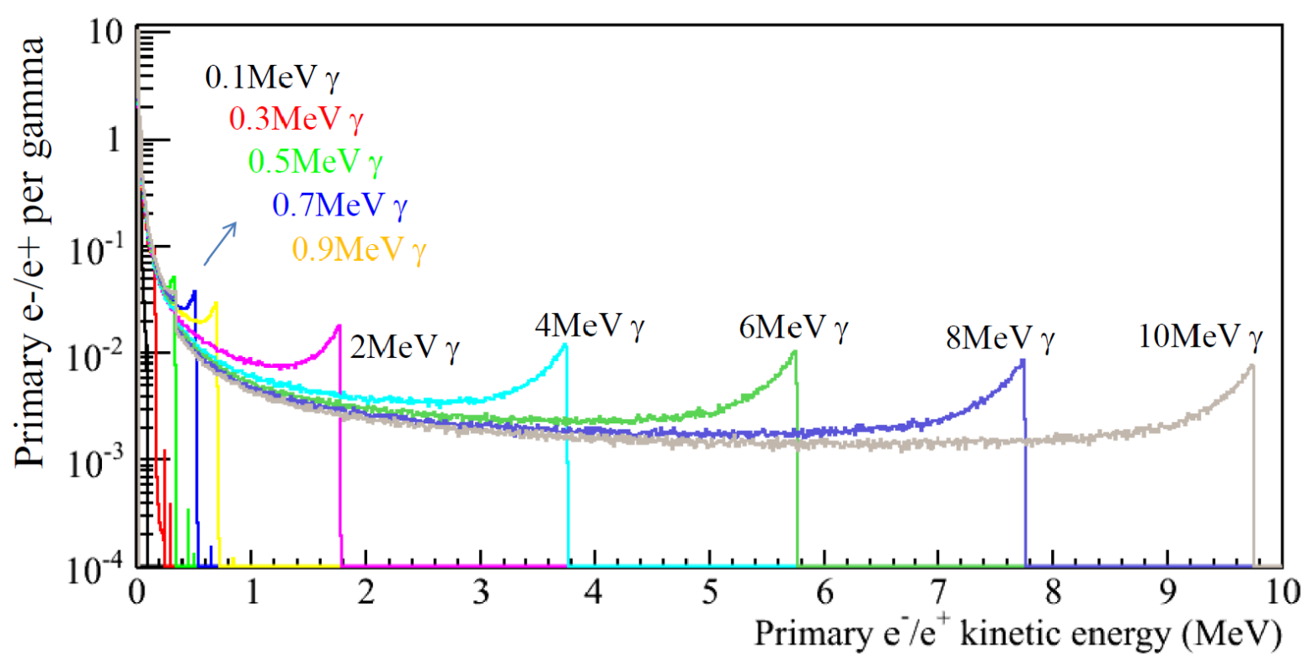
- nH : More energy leakage mainly for IBDs generated in LS and acrylic components
  - Trace e^+ (from IBD) kinematic energy deposition process using Geant4-based MC
  - Obtain the visible energy for each step during the lifetime of e^+
  - For annihilation γ's, apply the gamma-scintillator nonlinearity curve
  - Sum over the visible energy and apply the electronics nonlinearity curve to get the reconstructed energy


Particle Energy Etrue → Energy Deposited in Scintillator Edep → Energy Received by PMTs Evis → Reconstructed Energy Erec

Energy leakage
☐ IAV/OAV non-scintillating
☐ Gamma escape from LS region

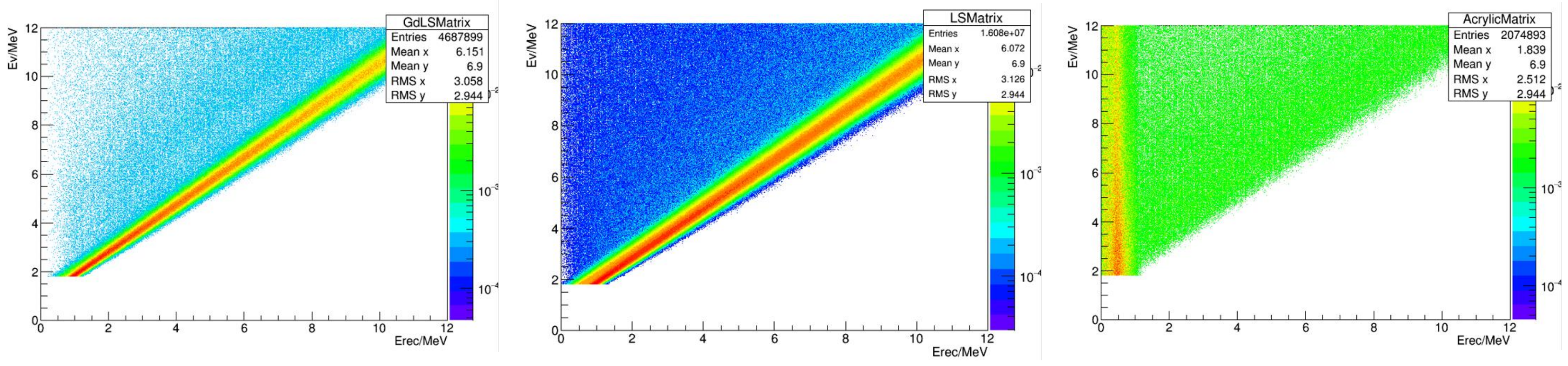
Scintillator non-linear
☐ Quenching effect
☐ Cerenkov radiation

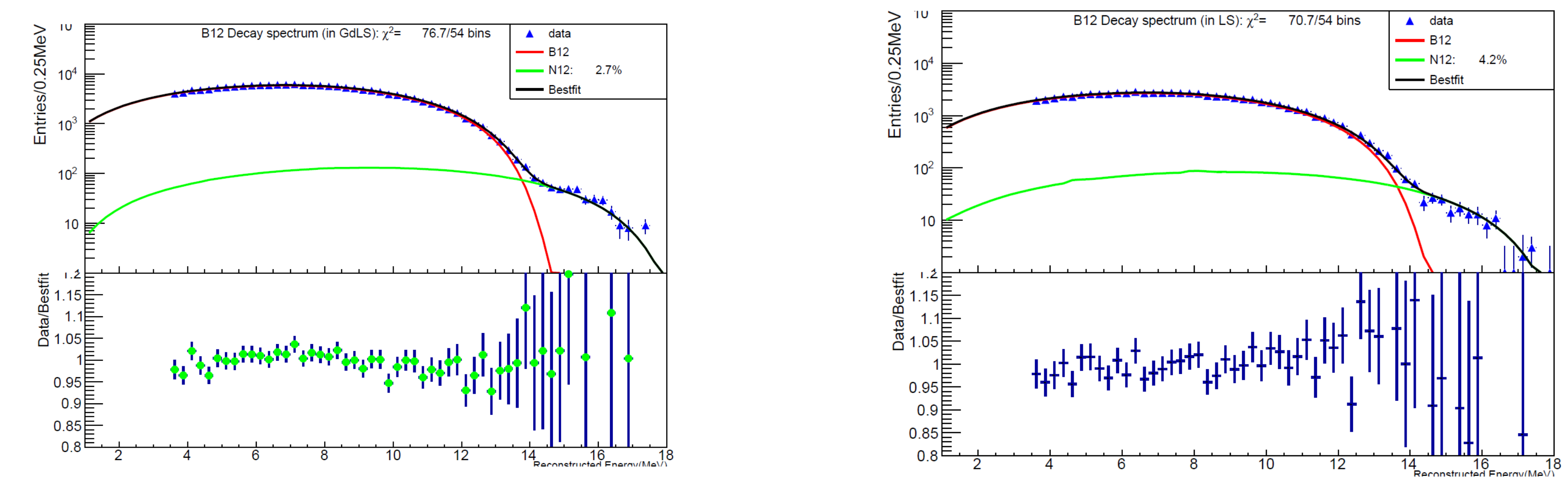
Energy resolution
Electronics non-linear



A detailed study on energy responses of scintillator detectors can be found in Nucl. Instrum. Methods **A890** (2018) 133-141

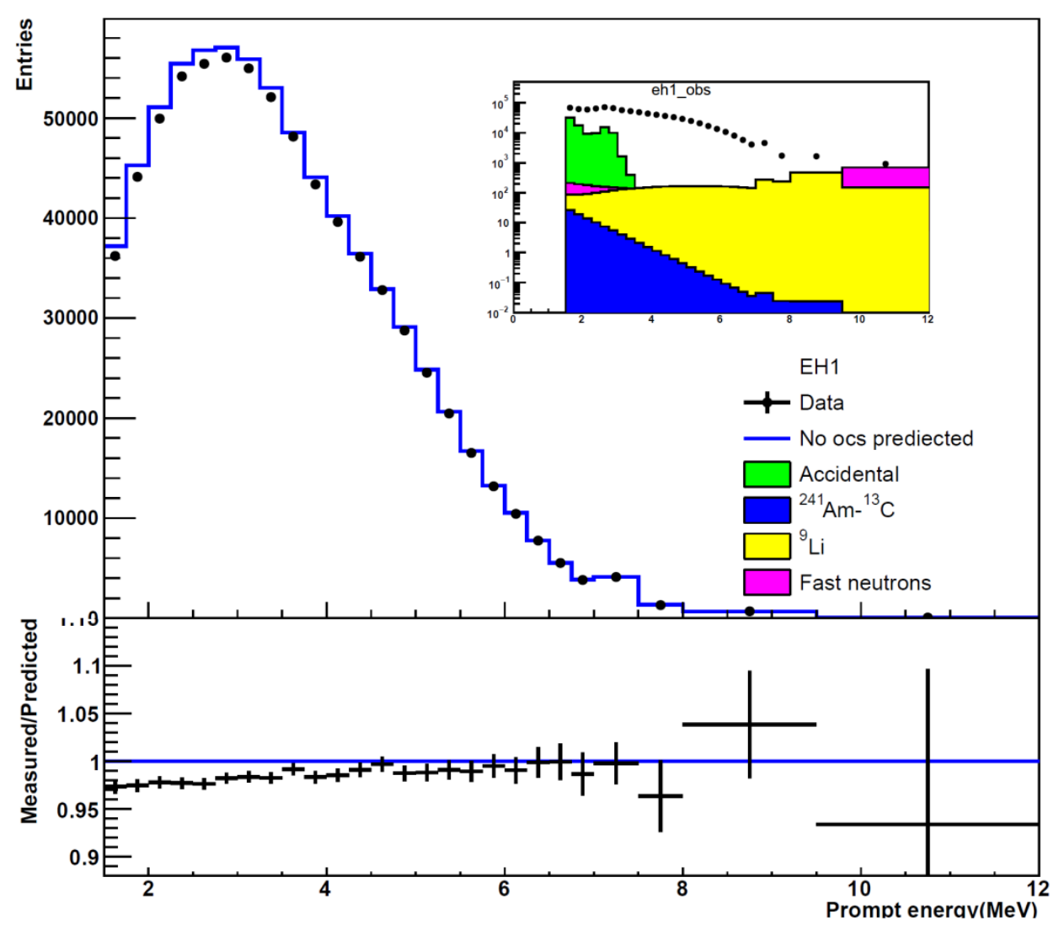
Energy model for nH IBDs

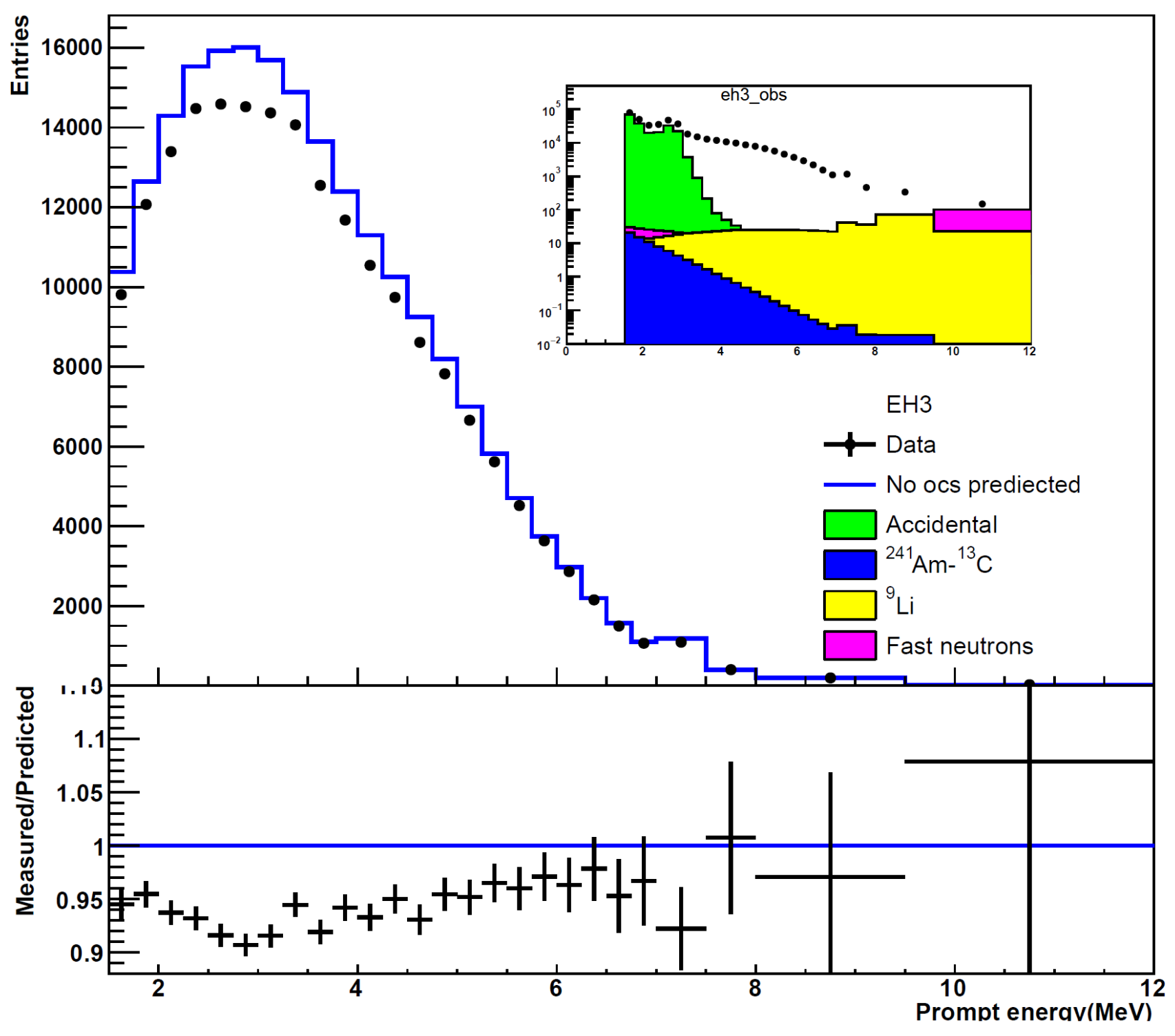


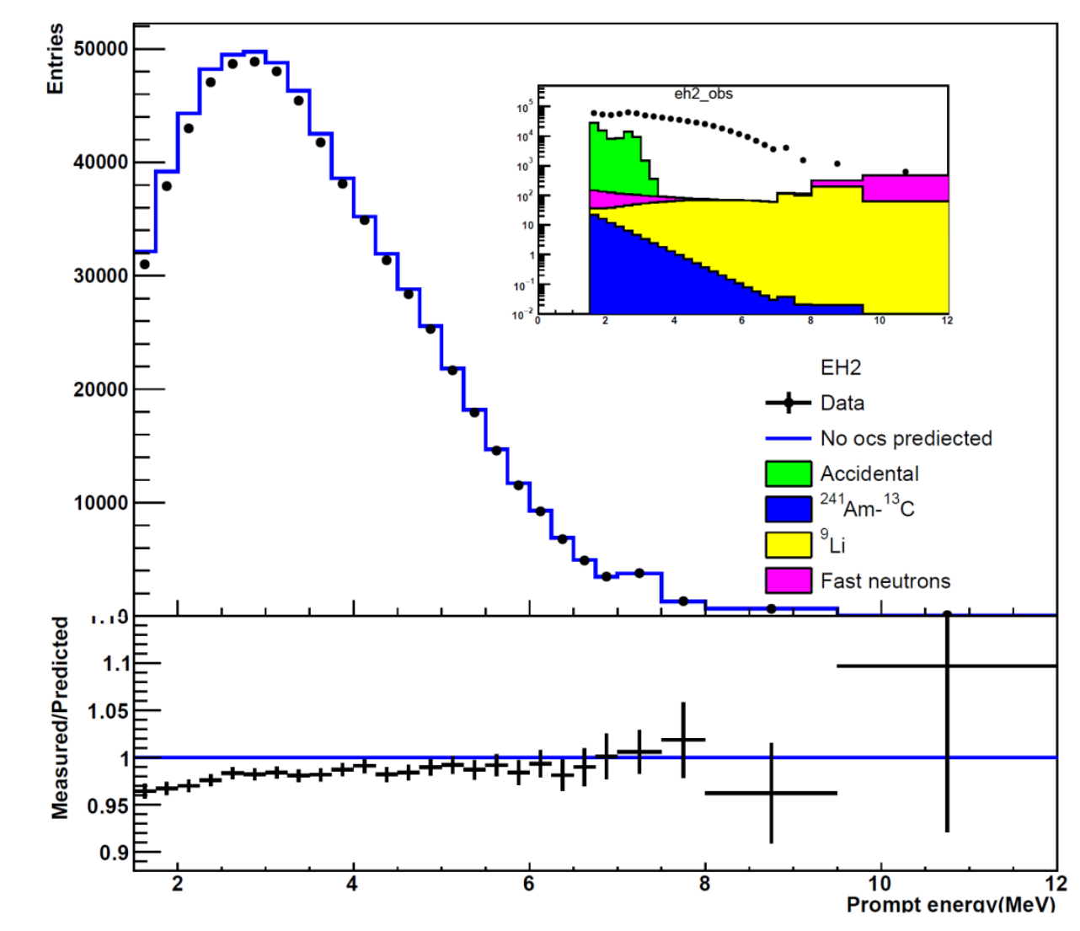


Energy model validation
- Agrees with nGd model for IBDs reconstructed in GdLS region
- Prediction of ^{12}B β-spectrum agrees with data for GdLS and LS region
- Agrees with an independent energy model considering secondary particle generation in gamma-energy-deposition process

Comparison between measured and expected positron spectrum (assuming no oscillation)







- Clear neutrino disappearance is present, and is energy and baseline dependent
- Results based on rate and spectral information will be released soon

NEUTRINO 2018 – XXVIII INTERNATIONAL CONFERENCE ON NEUTRINO PHYSICS AND ASTROPHYSICS JUNE 4-9, 2018 HEIDELBERG