Progress of JUNO-TAO

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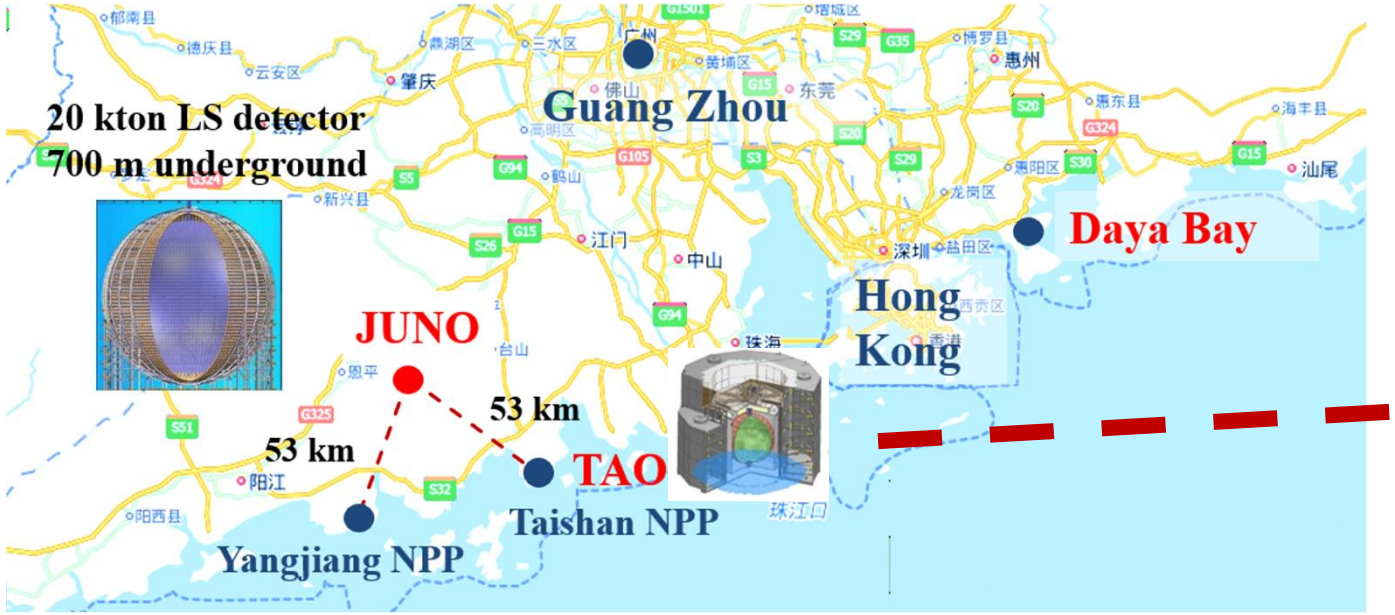
On behalf of JUNO Collaboration

2026.7.15

JUNO-TAO

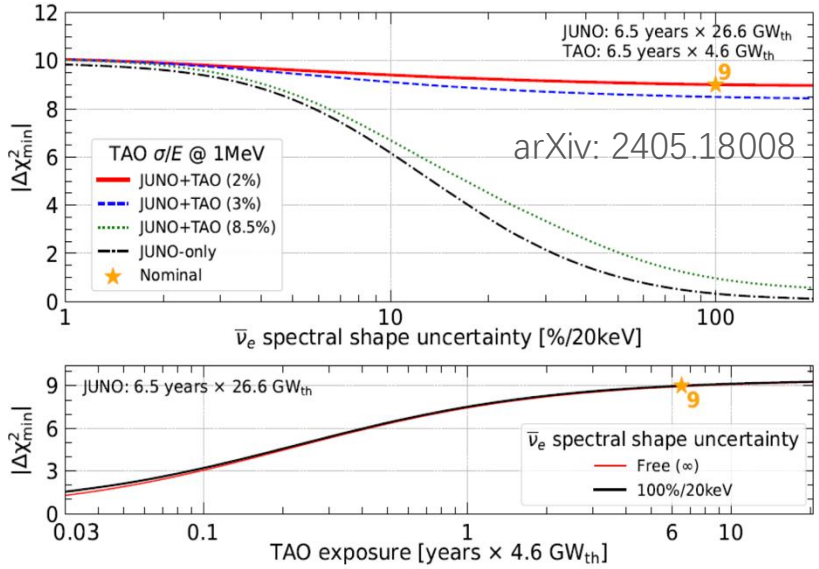


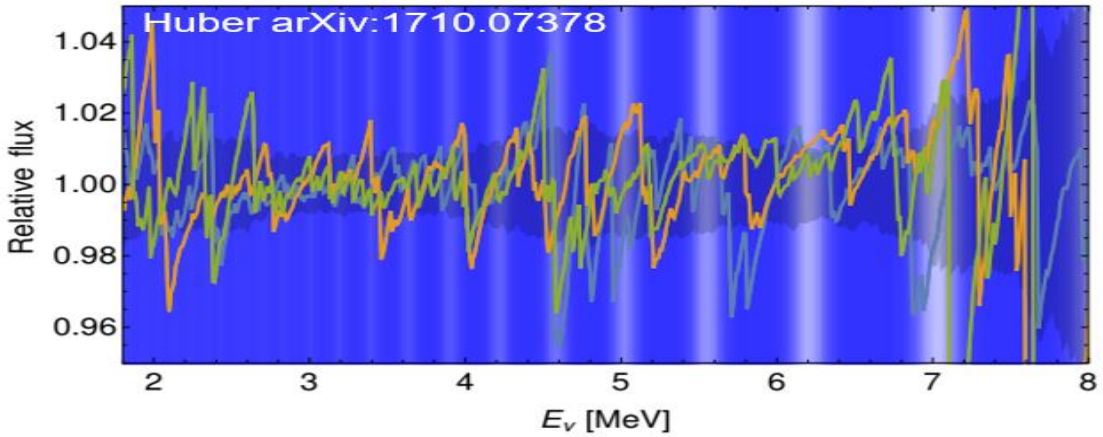
- A satellite experiment of JUNO
- **43.2 m** away from Unit 1

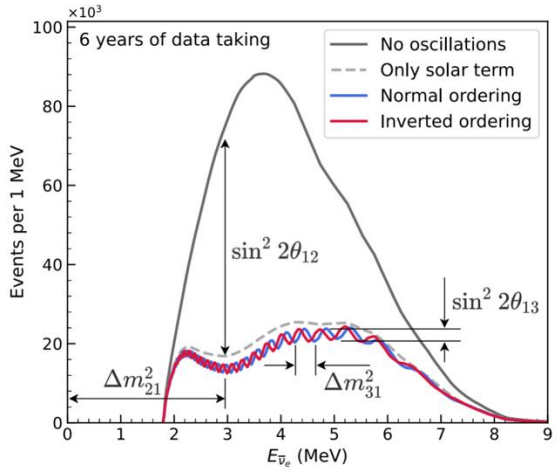
TAO Motivation

1. Provide a reference spectrum for JUNO

- TAO can help to remove the model dependence by measuring **fine structures** in neutrino energy spectrum
- The energy resolution of TAO must be equal or better than JUNO $(3\%/\sqrt{E})$



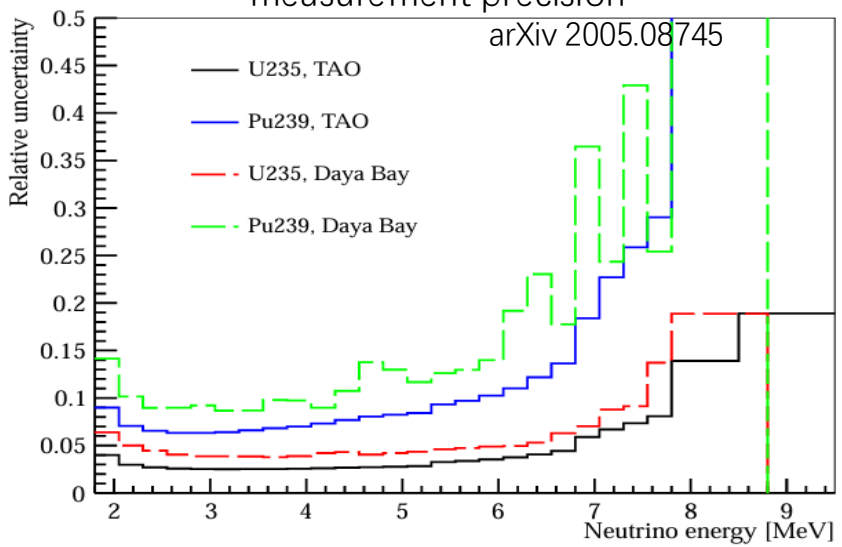




TAO Motivation

2. Provide a benchmark measurement for nuclear database
   - $2\%/\sqrt{E}$
   - Reactor spectral shape precision ~ 1% in 2-5 MeV
3. Measuring isotopic neutrino spectra, reactor monitoring, spent nuclear fuel & sterile neutrino

Expected U/Pu neutrino spectrum measurement precision



Innovation

To get higher light yield

Use SiPM

PDE:
~50% (JUNO ~30%)
Coverage:
~85% (JUNO ~78%)

High dark count rate! (~100k Hz/mm²)

Cool down to -50 °C

DCR:
50 Hz/mm²

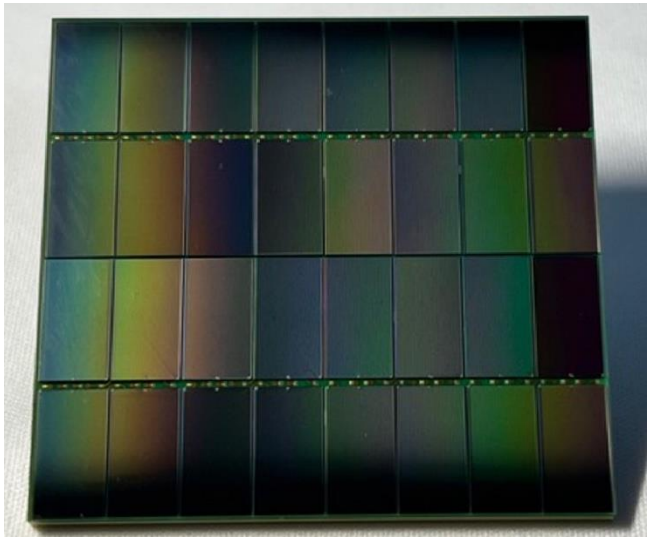
Liquid Scintillator untransparent

New LS recipe

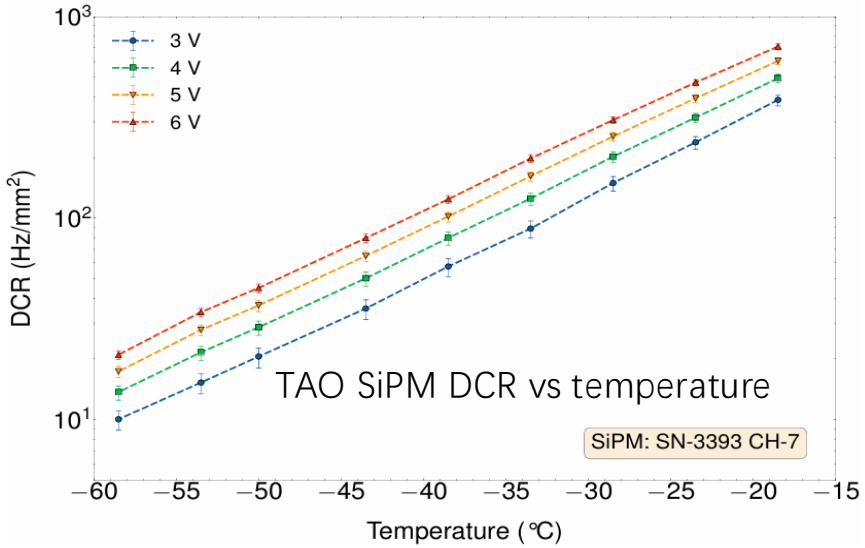
Cosolvent &
Low water content

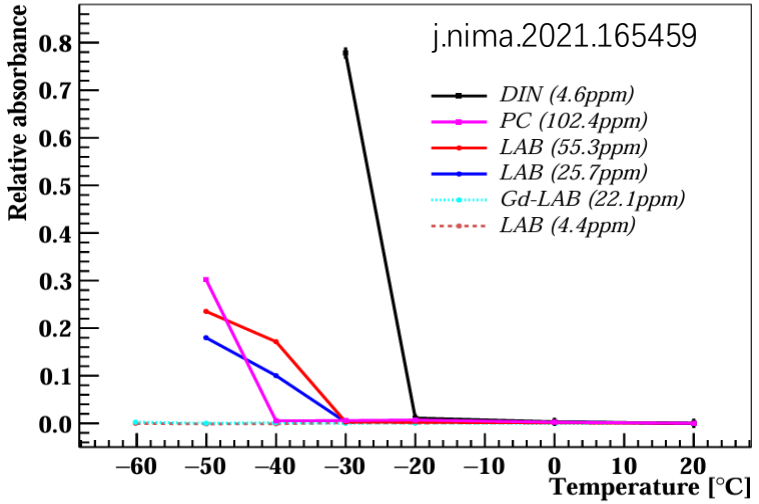
Done!

4500 PE/MeV (~2.6× JUNO)
→ σstat = 1.5%

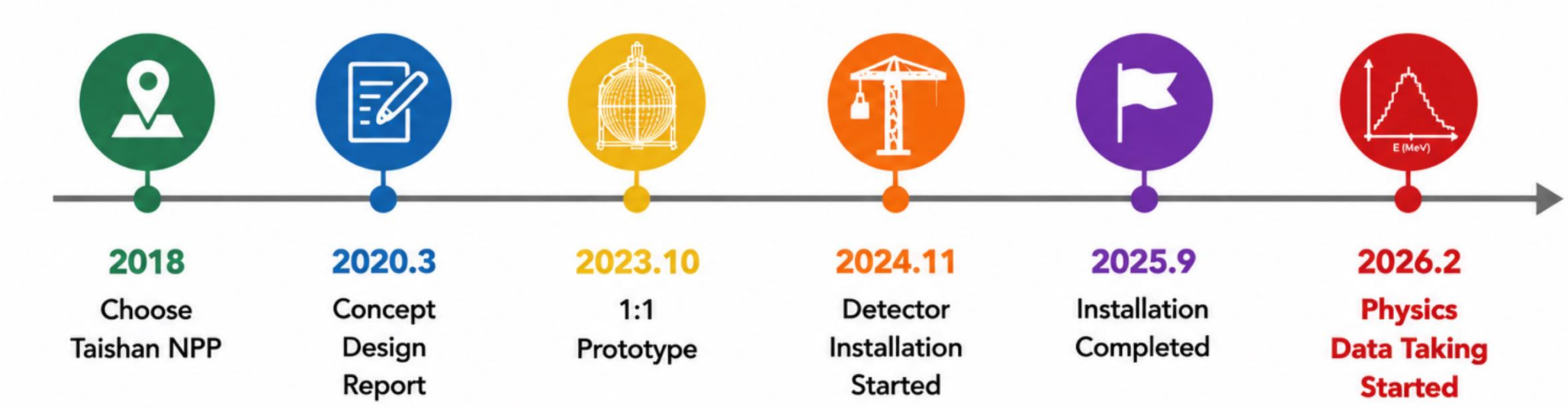


TAO SiPM





TAO: From Design to Physics Data Taking




TAO Conceptual Design Report

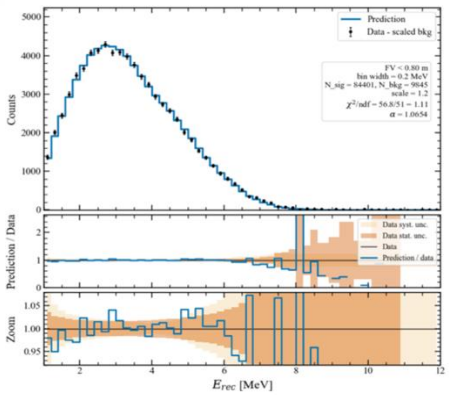
A Precision Measurement of the Reactor Antineutrino Spectrum with Sub-percent Energy Resolution

The JUNO Collaboration

May 17, 2020

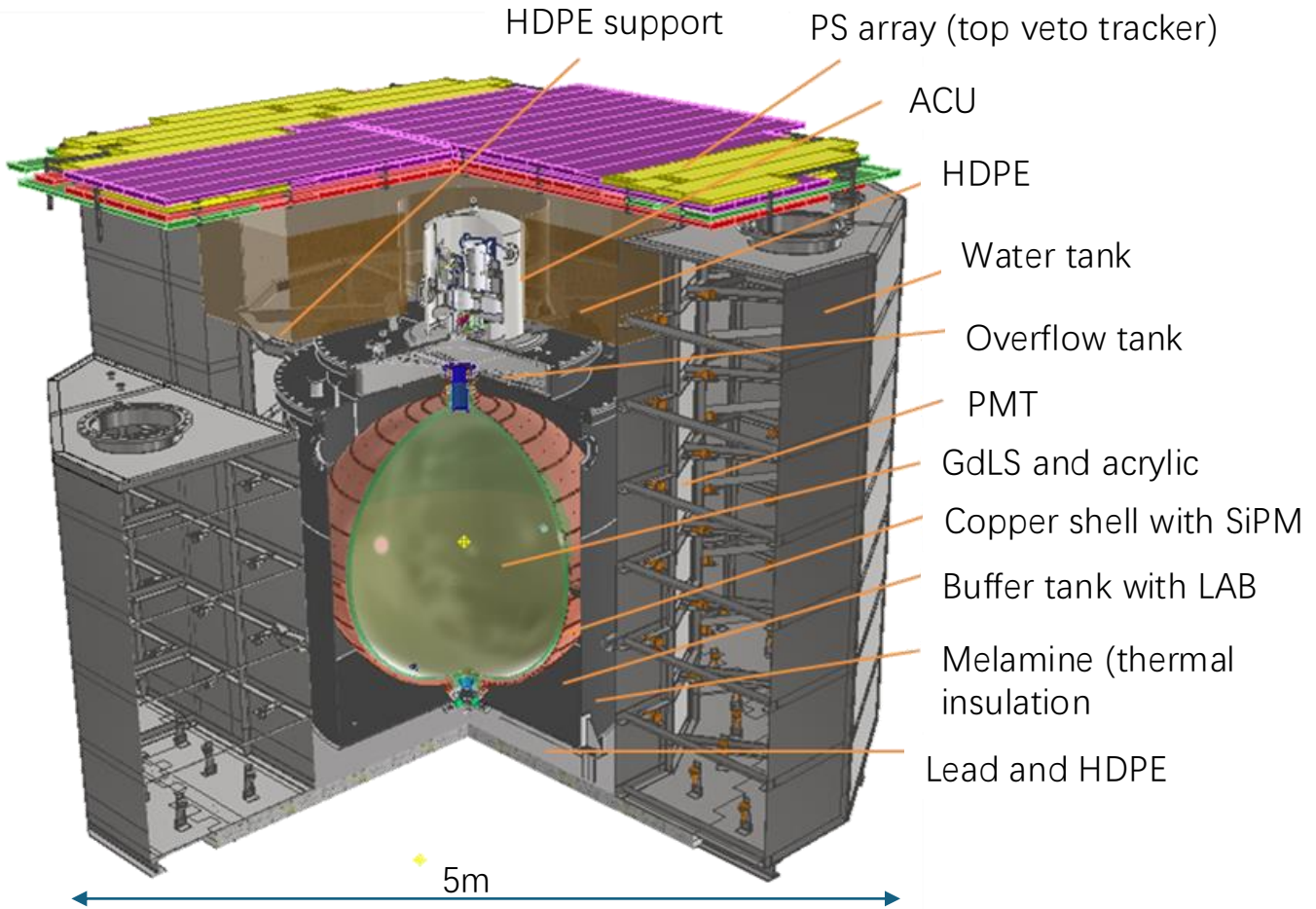
Abstract

The Taishan Antineutrino Observatory (TAO, also known as JUNO-TAO) is a satellite experiment of the Jiangmen Underground Neutrino Observatory (JUNO). A ton-level liquid scintillator detector will be placed at ~ 30 m from a core of the Taishan Nuclear Power Plant. The reactor antineutrino spectrum will be measured with sub-percent energy resolution, to provide a reference spectrum for future reactor neutrino experiments, and to provide a benchmark measurement to test nuclear databases. A spherical acrylic vessel containing 2.8 ton gadolinium-doped liquid scintillator will be viewed by 10 m^2 Silicon Photomultipliers (SiPMs) of > 50% photon detection efficiency with almost full coverage. The photoelectron yield is about 4500 per MeV, an order higher than any existing large-scale liquid scintillator detectors. The detector operates at -50°C to lower the dark noise of SiPMs to an acceptable level. The detector will measure about 2000 reactor antineutrinos per day, and is designed to be well shielded from cosmogenic backgrounds and ambient radioactivities to have a ~ 10% background-to-signal ratio. The experiment is expected to start operation in 2022.



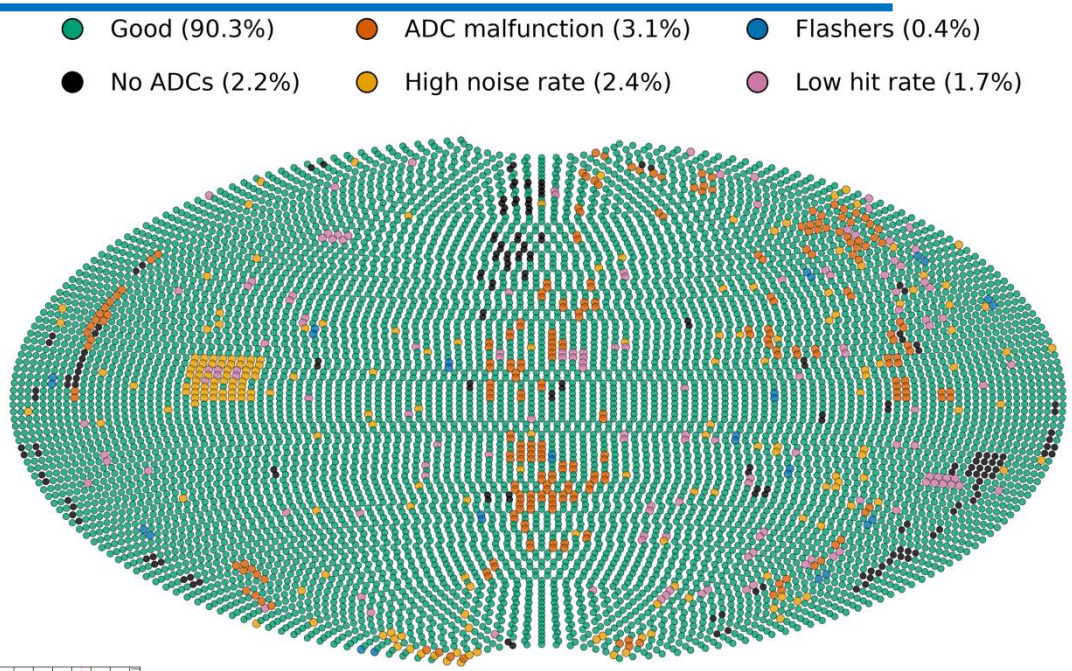
Detector Design

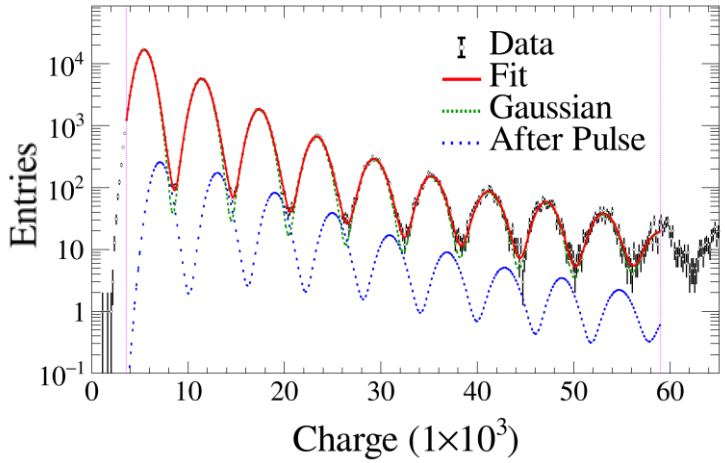
- **Central detector (CD)**
  - **2.8 t GdLS** in an acrylic vessel (Ø = 1.8m)
  - **10 m^2 SiPM** on a copper shell
  - Tank filled with buffer **LAB**
  - Automated Calibration Unit (**ACU**) (from Daya Bay) & Cable Loop System (**CLS**)
- **2 veto detectors**
  - 3 water Cerenkov detectors
  - 4 layers of plastic scintillator (PS) bars

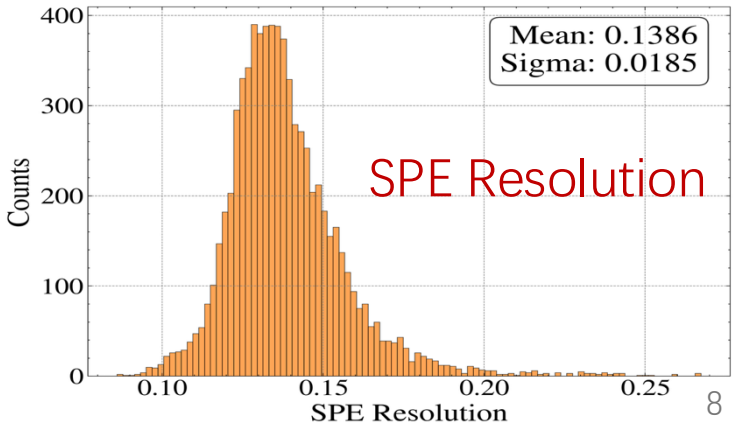


Detector Performance: SiPM

- **90% good channel**
  - Total channel number: 8048
- **SiPM over voltage V_{ov}: 3.5 V**
- **Gain:** 6000 ± 130 LSB, **uniformity ~2%, stability: ~0.1%**
- **Single photo-electron (SPE) resolution**: ~**14%** (15% in CDR)
- **DCR**: ~**50 Hz/mm^2** (100 Hz/mm^2 in CDR)
- **PDE**: ~50% (SiPM QA/QC**), uniformity ~5%**
- **Cross-talk**: ~25% (preliminary)
- **After-pulse**: < 5% (SiPM QA/QC)

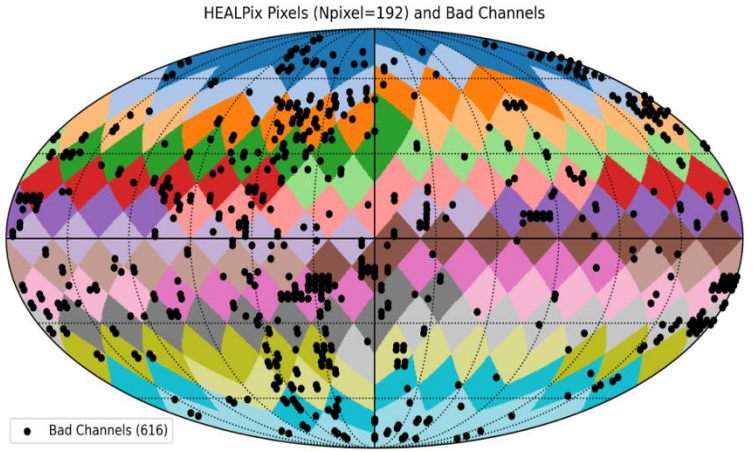


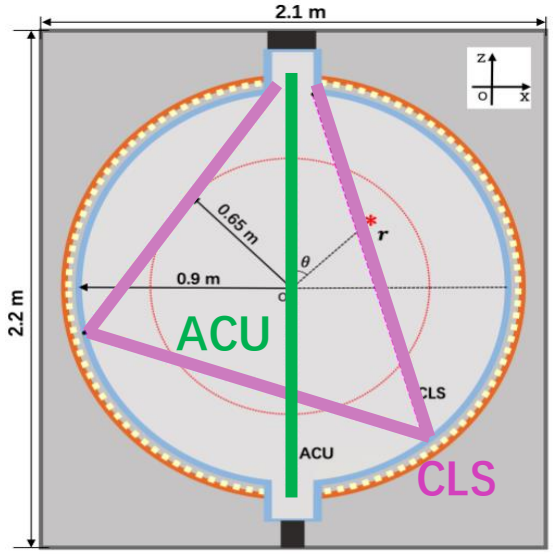


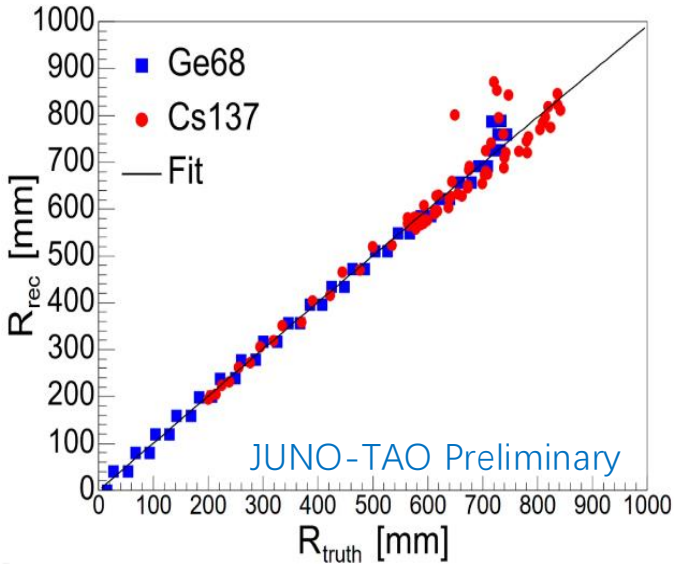


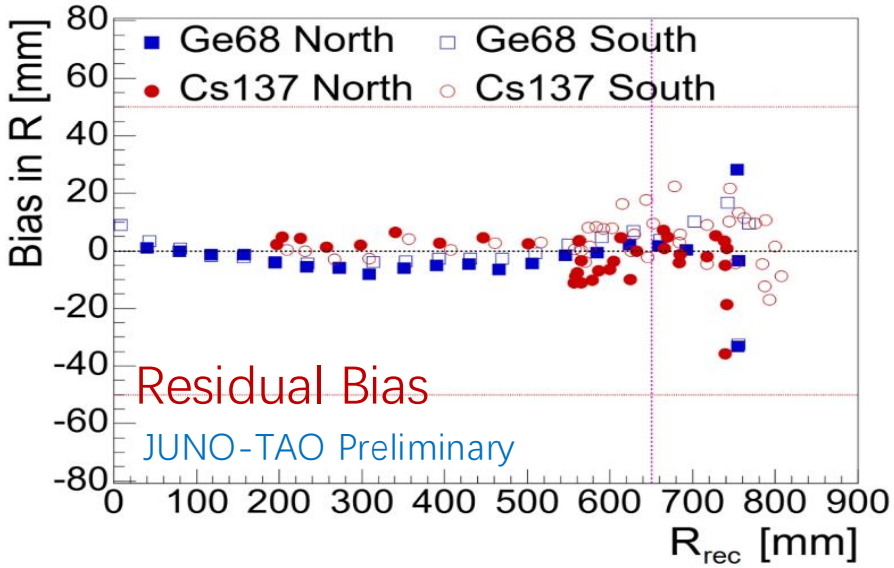
Vertex Reconstruction

- **Charge center method**
- **Procedure**:
  1) group channels to restore spherical symmetry
  2) calculate charge center
  3) correct R bias (ACU/CLS data in different positions)
- **Performance**: bias **10 (40)** mm near R = **650 (800)**









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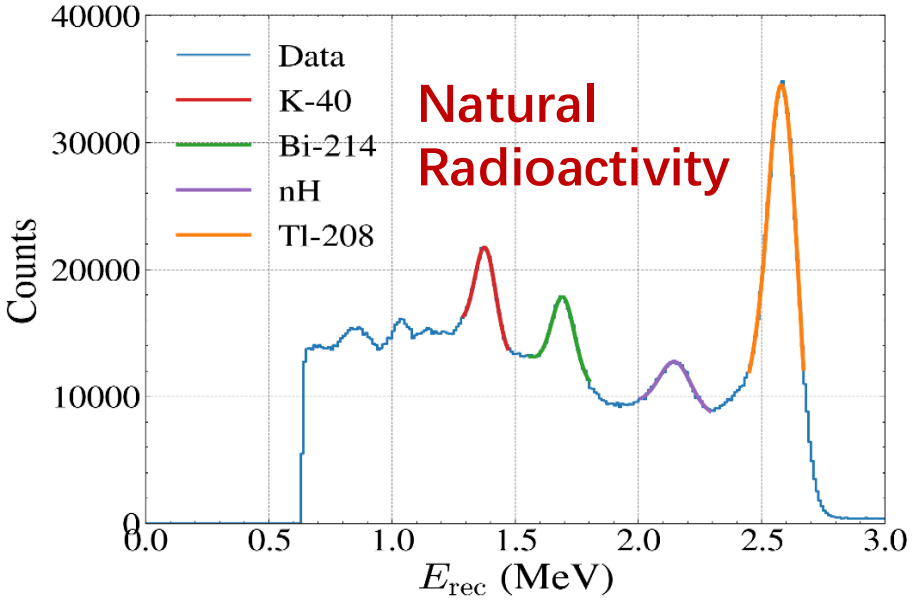
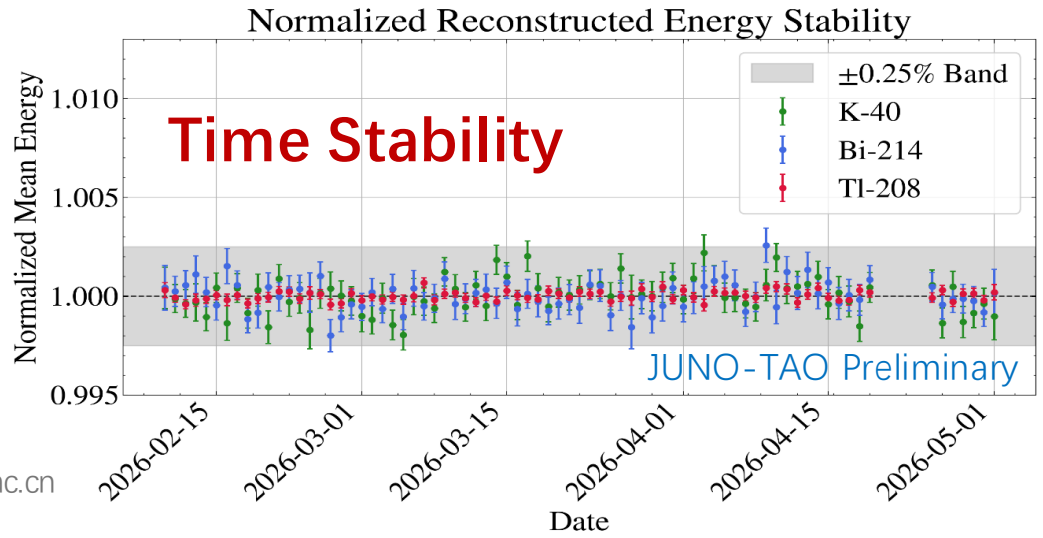
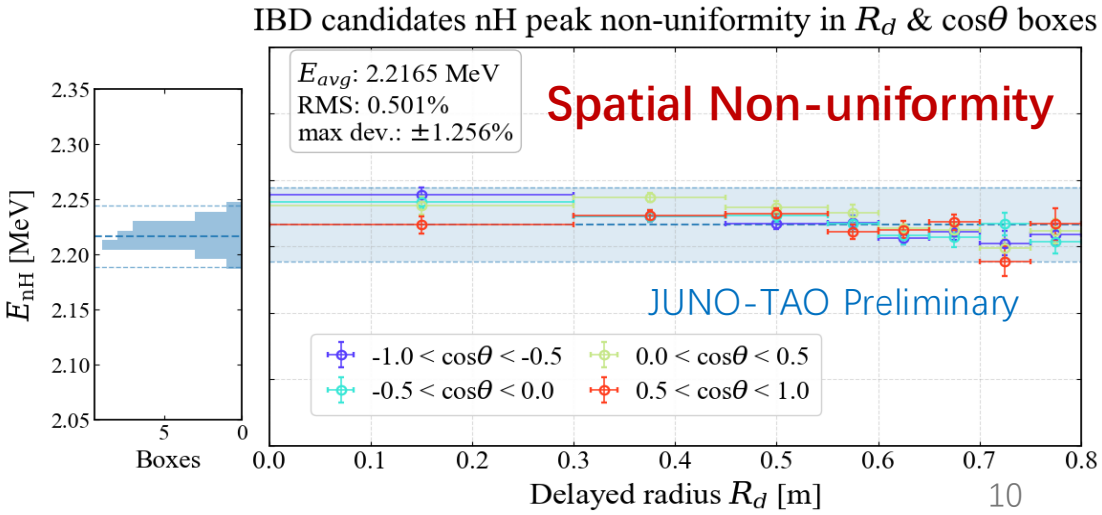
Energy Reconstruction

- **Procedure**:
  1) PE counting in channel; 2) PE sum in event;
  3) non-uniformity correction (calibration data and Tl-208);
  4) time variation correction (Tl-208);
  5) fix energy scale (nH peak @2.223 MeV)
- **Energy scale performance**:
  - Time stability **< 0.25%** (natural radioactive events)
  - Non-uniformity **0.6%** (IBD nH events)

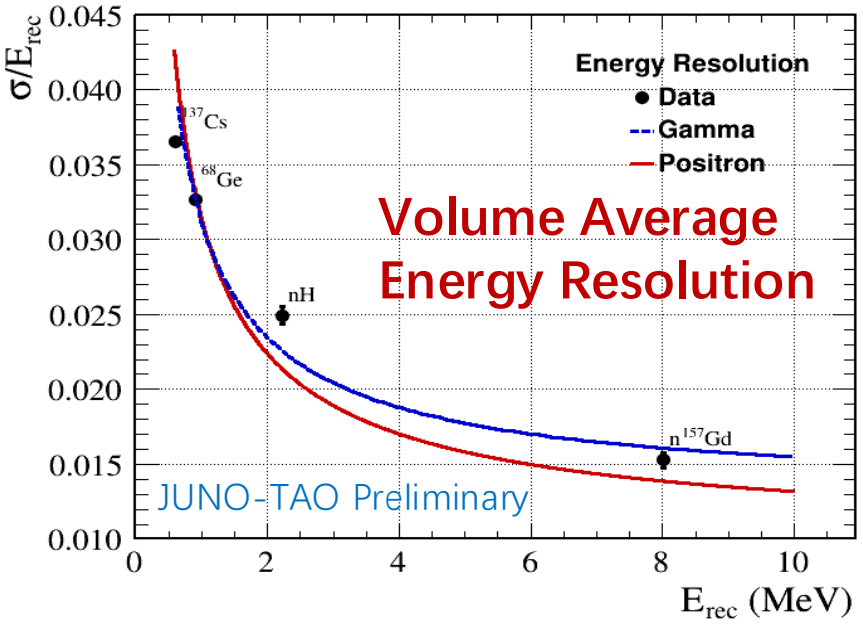


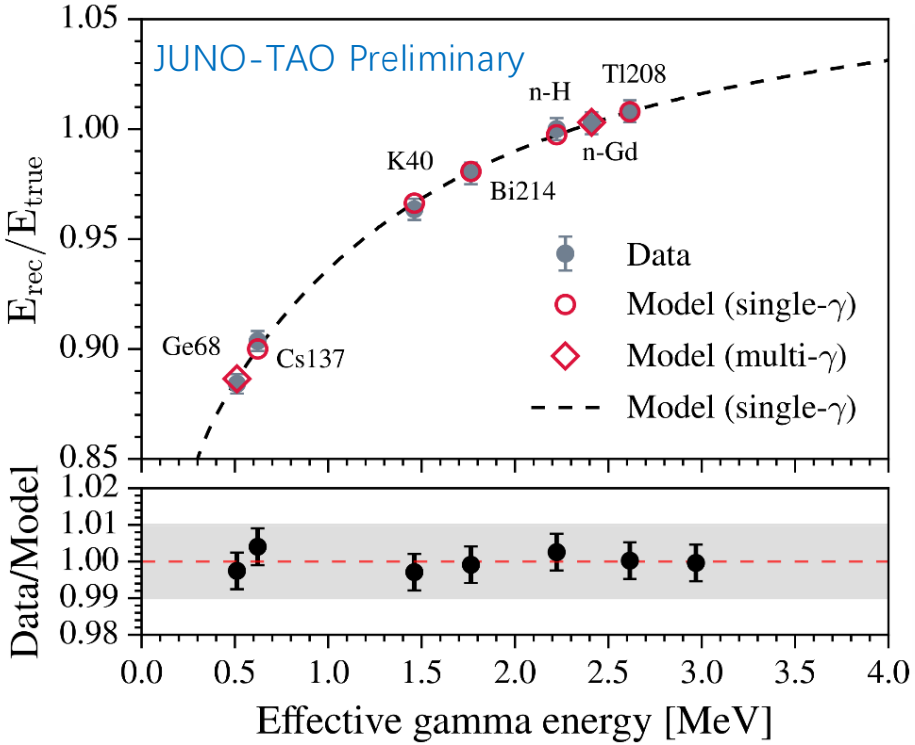


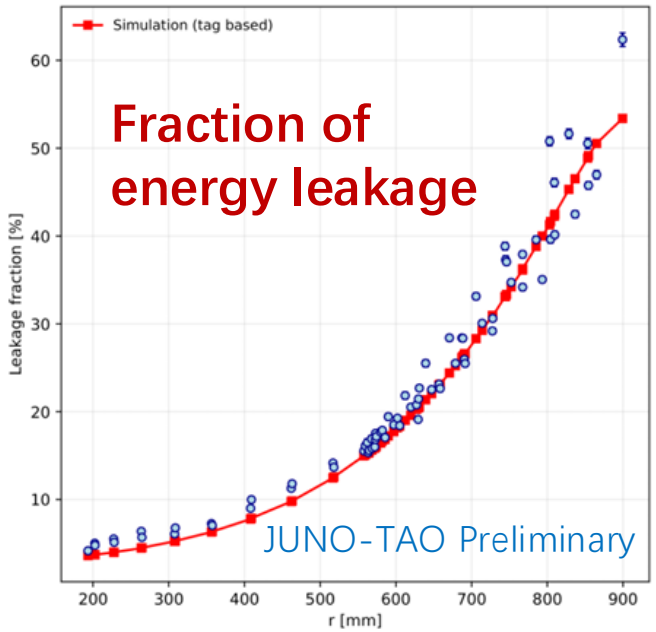


Detector Response

- **Energy resolution：** Ge-68 @R = 0: **2.82% @1MeV**
- **Energy nonlinearity:** Uncertainty: ~1–2%
- **Energy leakage:** Modeled with MC and validated with calibration data

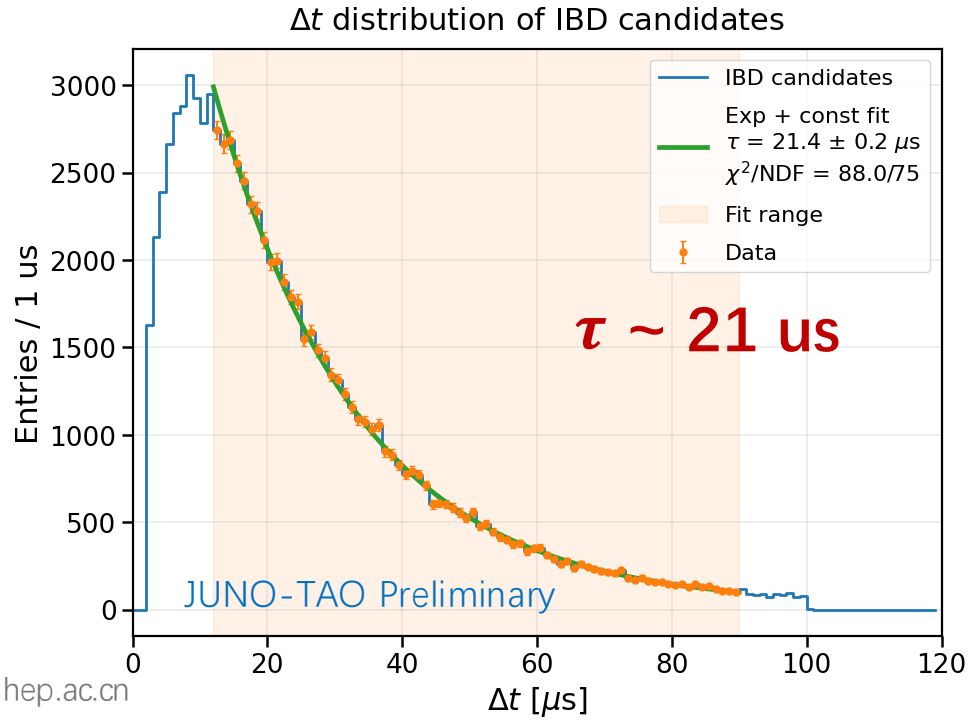


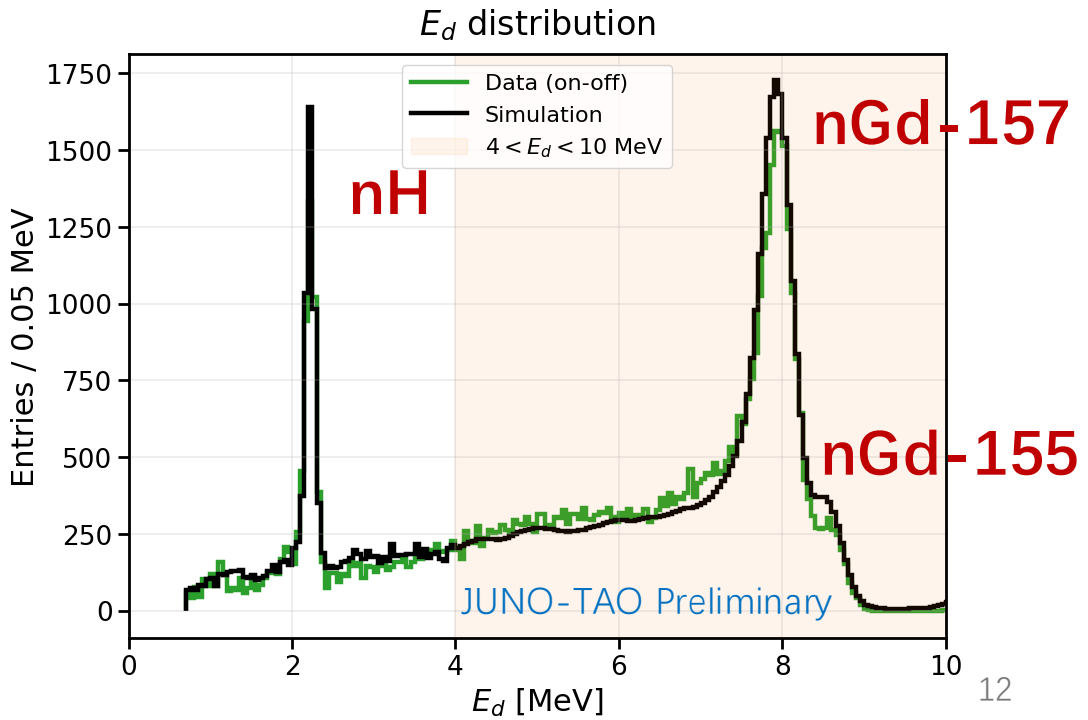




IBD Selection

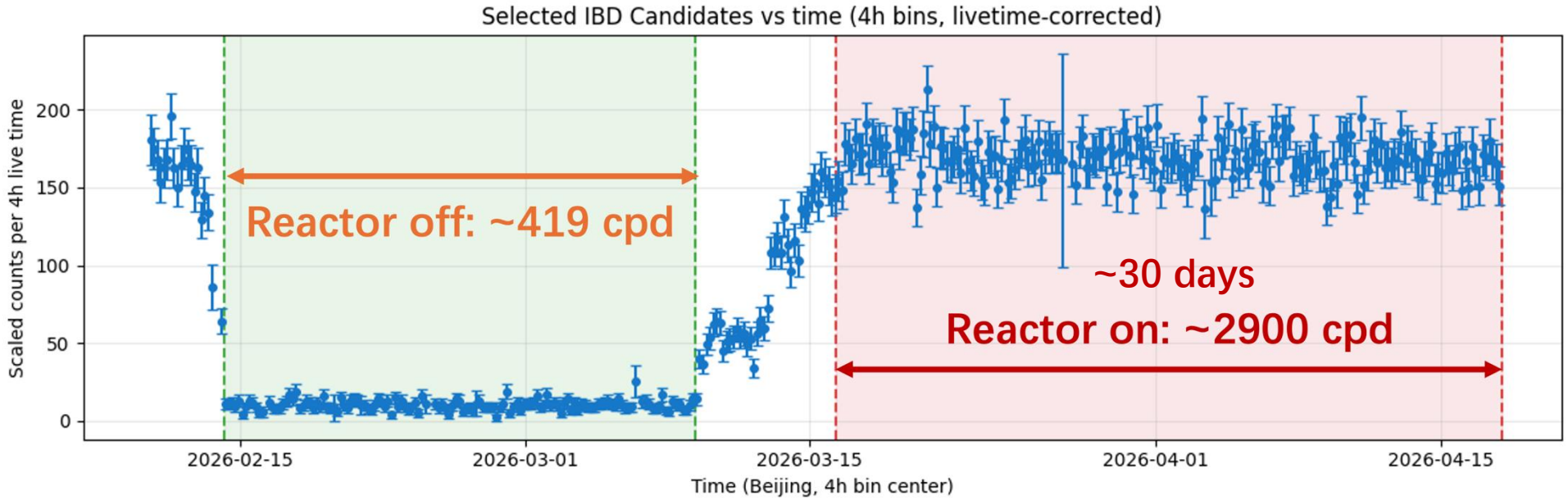
- **Time**: ΔT(prompt, delayed) in (2, 100) us time window, veto events in (0,100) us after muon
- **Space**: ΔR(prompt, delayed) < 500 mm, R(prompt) < 800 mm (Fiducial Volume Cut)
- **Energy**: E(delayed) in (4,10) MeV
- **Total efficiency**: 46.6 ± 5.0 %, **systematics**: FV cut on R(prompt), energy cut on E(delayed)





IBD Signal Rate

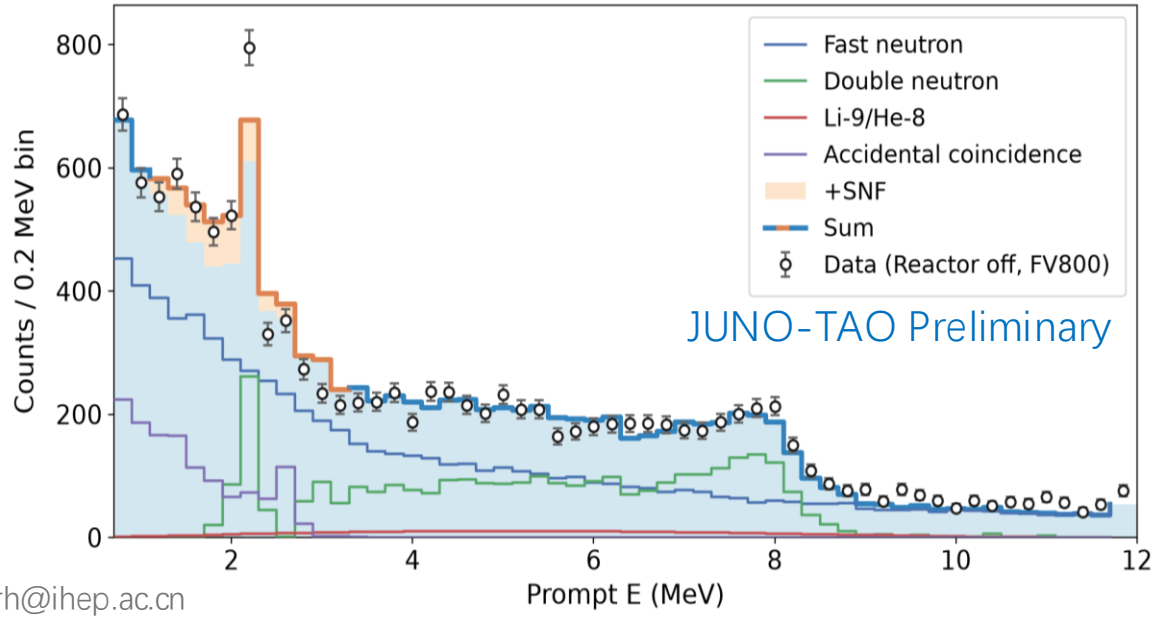
- **Observed IBD signal rate**: ~2500/day, from reactor-on data minus (scaled) reactor-off data.
- **S:B = 6:1 w/o PSD (pulse shape discrimination)**
  - Really good for shallow overburden experiment
  - could be improved in future



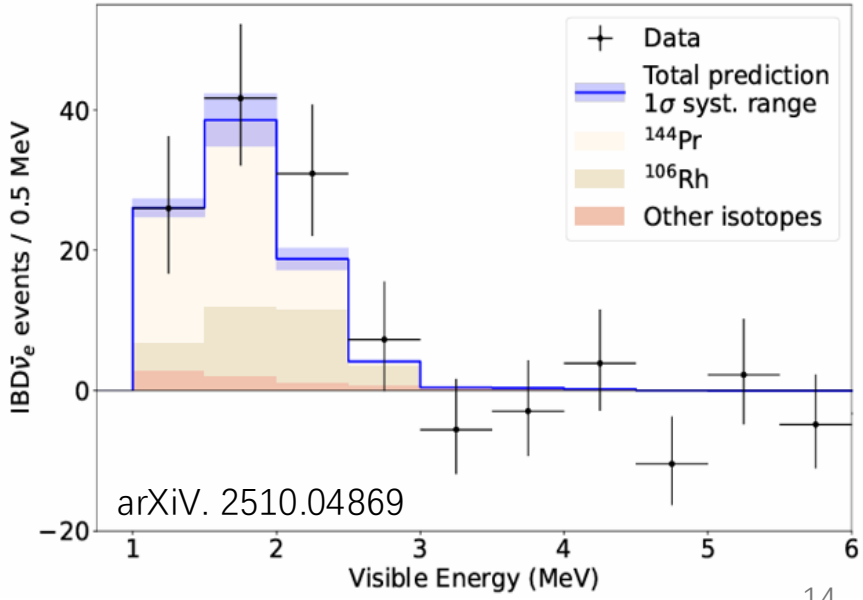
Reactor-off Spectrum & SNF

- **Direct measurement of background**
- **Direct measurement of spent nuclear fuel (SNF) neutrino**
  - Background: date-driven estimation except for Li-9/He-8, can be further suppressed
  - Unit 2 shutdown makes SNF neutrino signal more clear

TAO Reactor-off Data

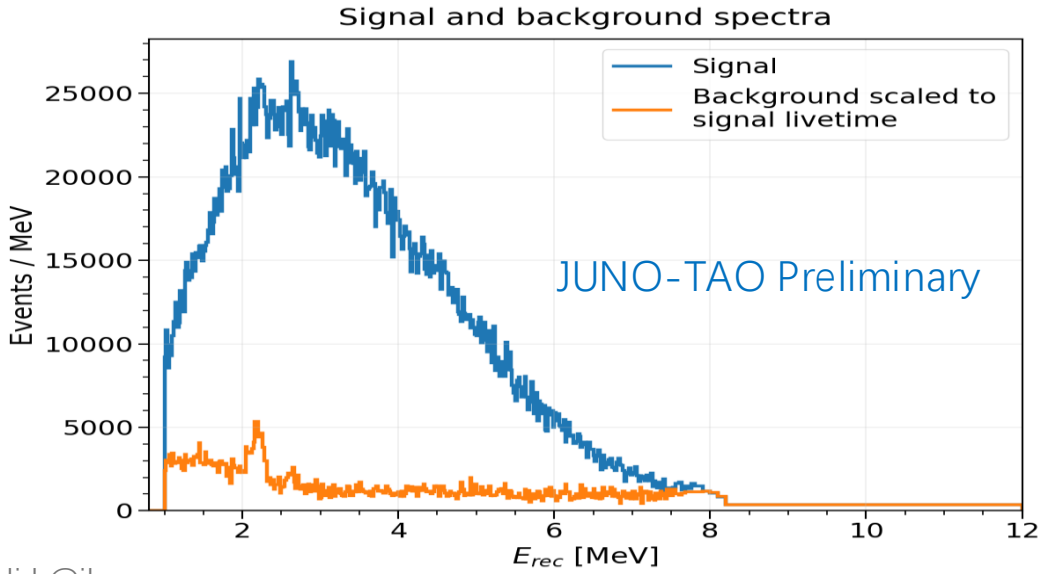


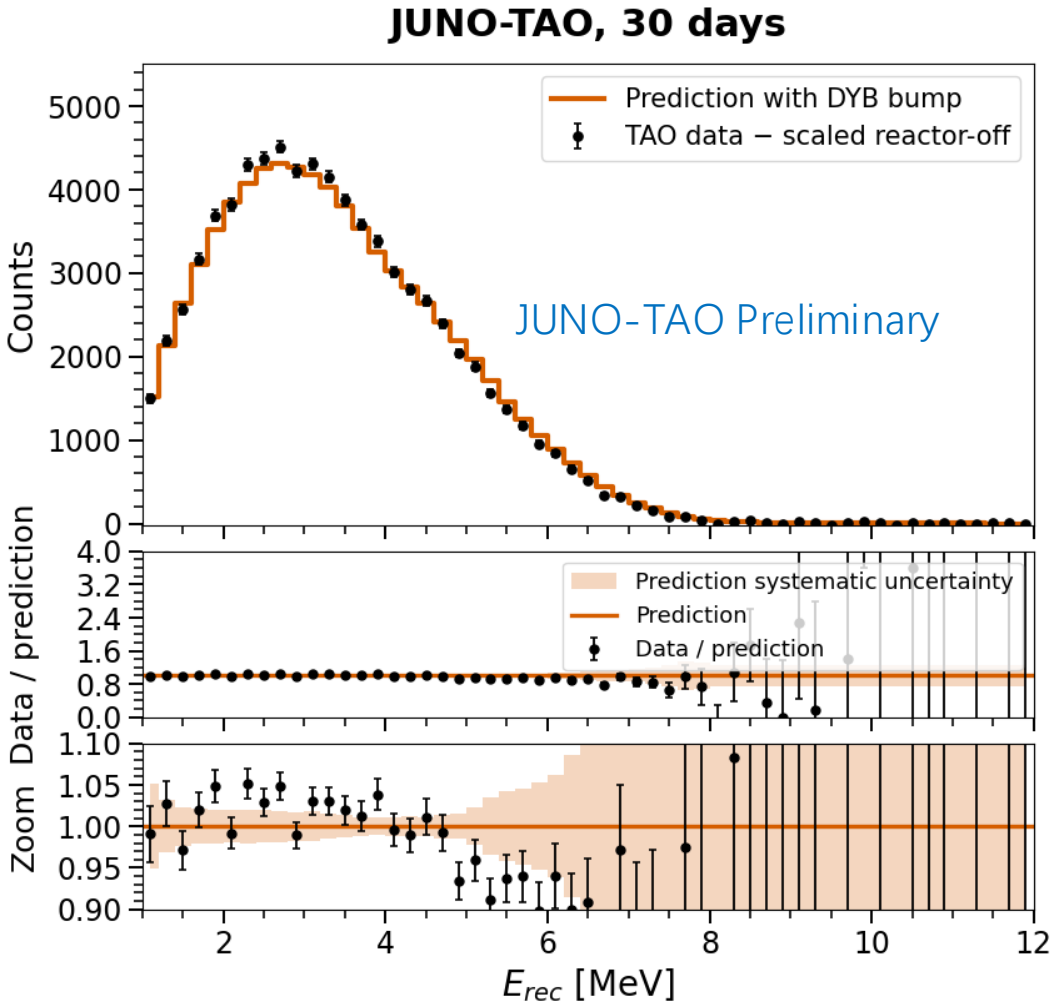
SNF neutrino observed by Double Chooz



Event Energy Spectrum

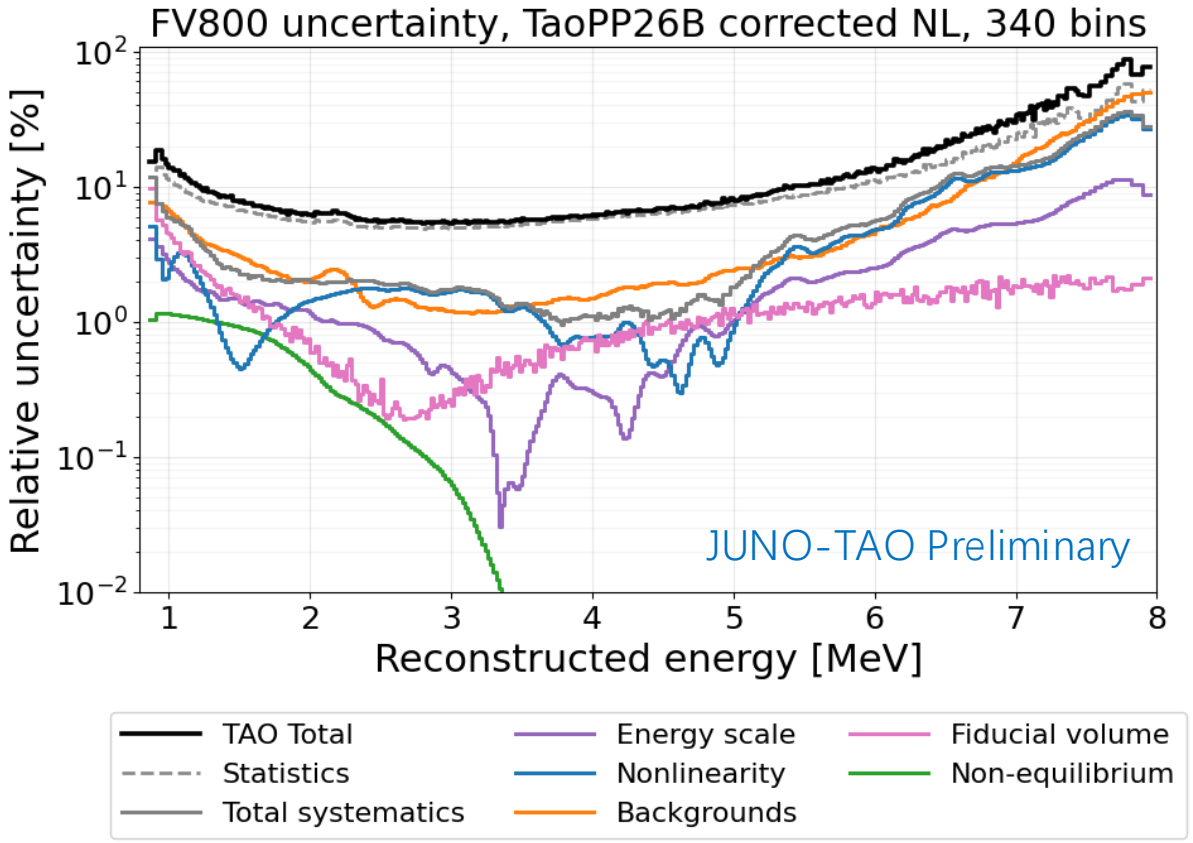
- **Prediction**: Huber-Mueller model (PRC, 83:054615, 2011, PRC, 84:024617, 2011) + Daya Bay correction (PRL 123(11):111801, 2019) + non-equillibrium correction, convoluted with TAO detector response
- **Results**: good data/prediction agreement, small difference in high energy tail





Spectrum Shape Uncertainty

- **Statistical uncertainty dominates**, with 1 month data and 20 keV bin
- **Systematics**: energy non-linearity and background subtraction



Summary

- TAO detector is constructed and in stable operation since **Feb. 10th, 2026**
- World leading energy resolution **2.8% @Ge-68**, further improvements expected
- Excellent background control, further background suppression expected
- Preliminary IBD analysis with 1 month data, good data/prediction agreement
  - spectrum used in JUNO physics analysis

Thanks!

Detector Assembling