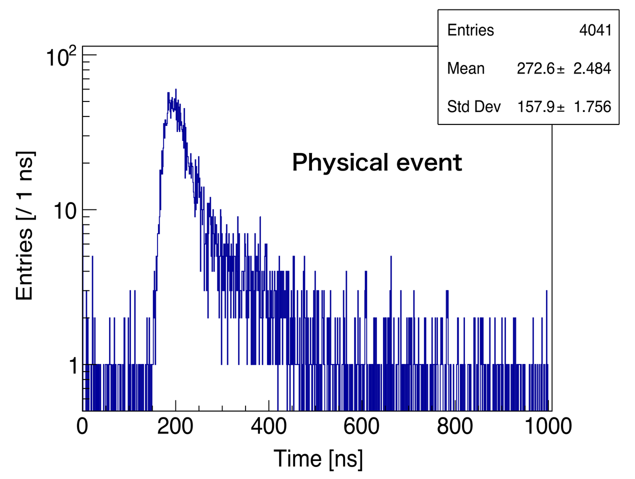
Cosmogenic Neutron Studies in JUNO

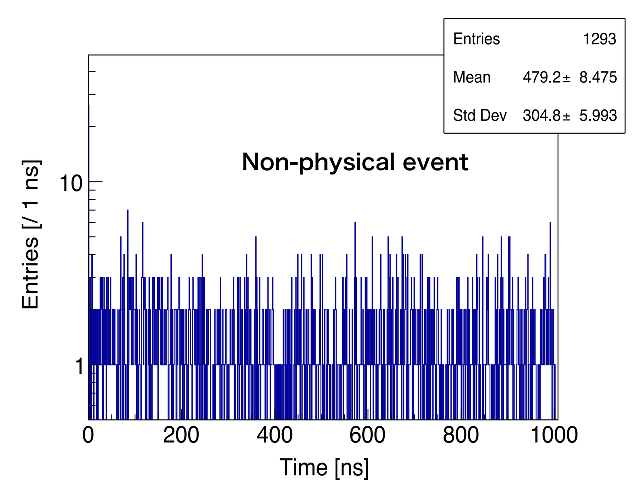
JUNO Preliminary. June 2026.
JUNO Work in Progress. June 2026.

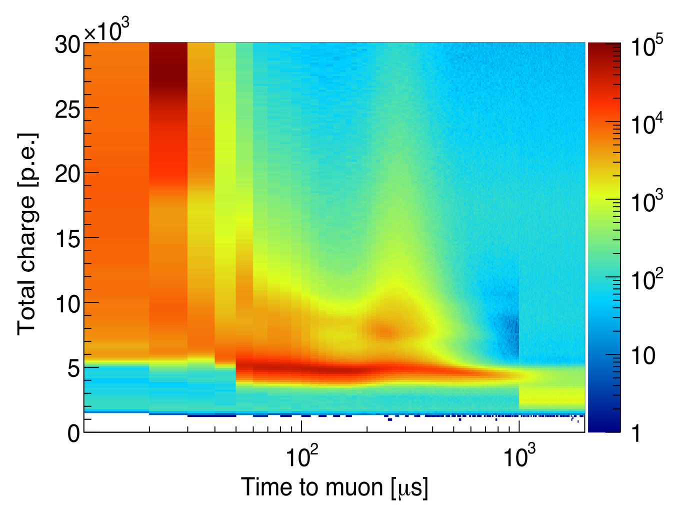
Ping Zhang
Shanghai Jiao Tong University | JUNO Collaboration
Neutrino 2026, UC Irvine

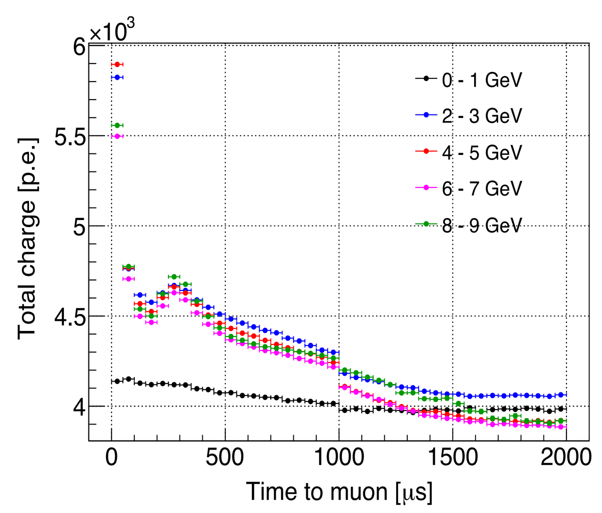
1. Neutron Event Selection for Saving Waveform in OEC

- Cosmogenic neutrons serve as natural calibration source for JUNO, enabling a three-dimensional calibration of the detector's energy response compared to existing artificial calibration systems in JUNO [1].
- The online selection of neutron events is executed in OEC (online events classification) tool, saving waveforms for more precise event reconstruction in subsequent analyses.
- High-energy muons induce intense after-pulse in the PMTs, which severely contaminates the neutron events especially within 50 μs after muon. We apply selection cuts:
  - 1.3 MeV < Energy < 3.5 MeV
  - 50 μs < Time to Muon < 2 ms





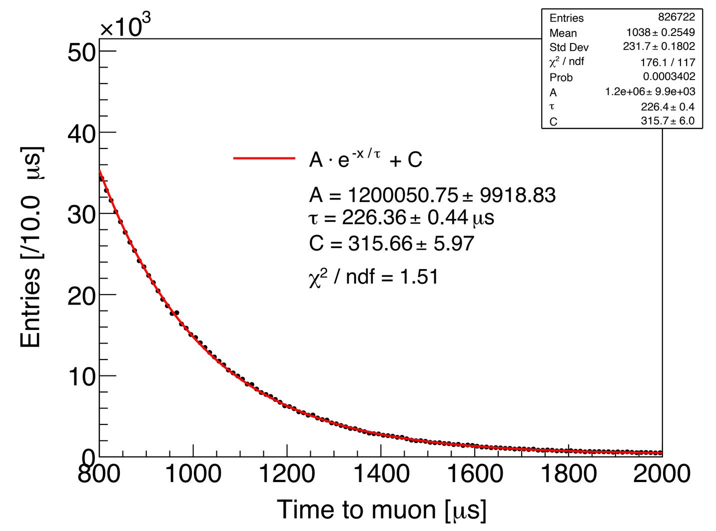


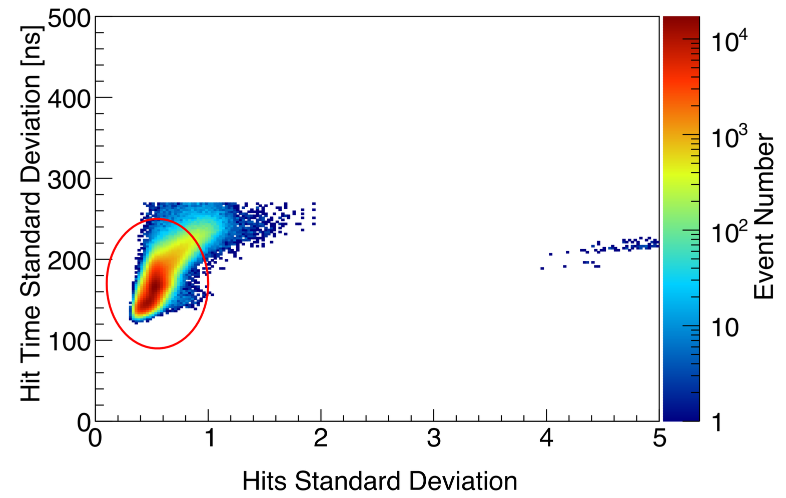


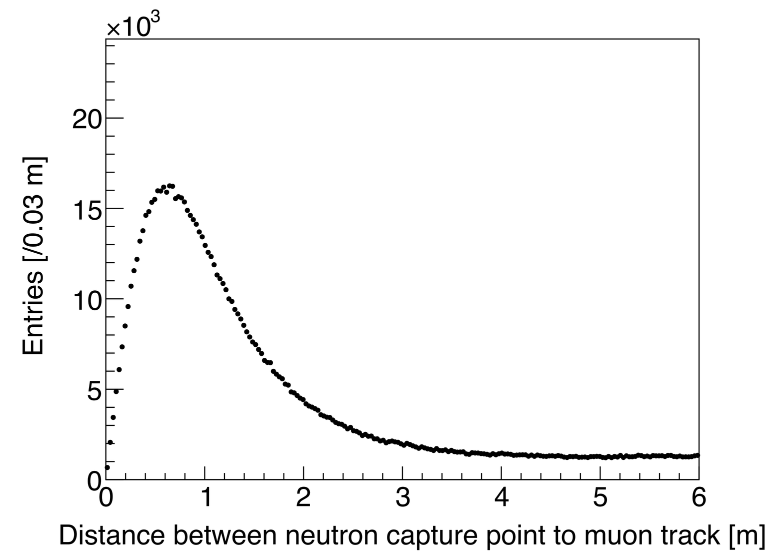
2. Neutron Selection for Calibration

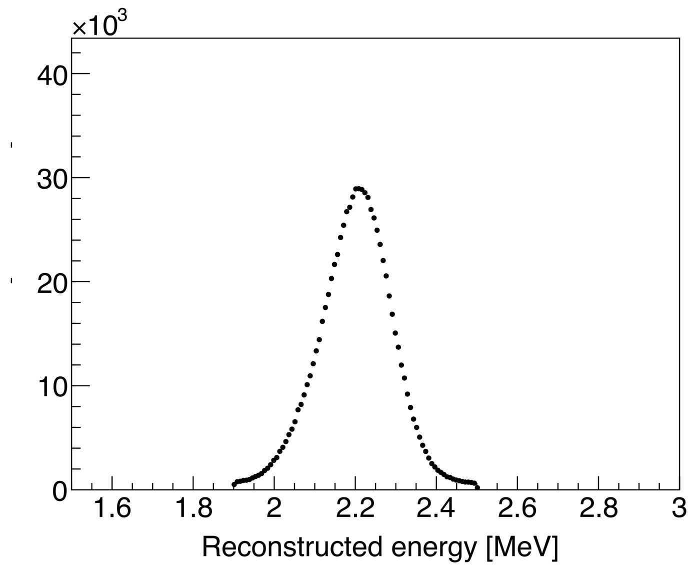
- To select pure neutron events for the calibration, we apply a late time window of [0.8 ms, 2 ms] after muon, combined with a spatial cut of [0, 4 m] to the muon track.
- Flasher and after-pulse events are also removed by applying an ellipse cut, using hits and hit time standard deviation as variables.
- The selection efficiency is only ~2% due to the late time window, selection purity is 95.4% within all liquid scintillator, and the impurity is due to the high radioactivity events rate out of the fiducial volume R > 16.5 m.

Parameter	Cuts
Energy [MeV]	[1.9, 2.5]
Time to Muon [ms]	[0.8, 2]
Distance to Muon Track [m]	[0, 4]
Flasher and Afterpulse Cut	$\left(\frac{\sigma_{hits}-0.55}{0.45}\right)^2+\left(\frac{\sigma_{hit\ time}-170}{80}\right)^2<1$



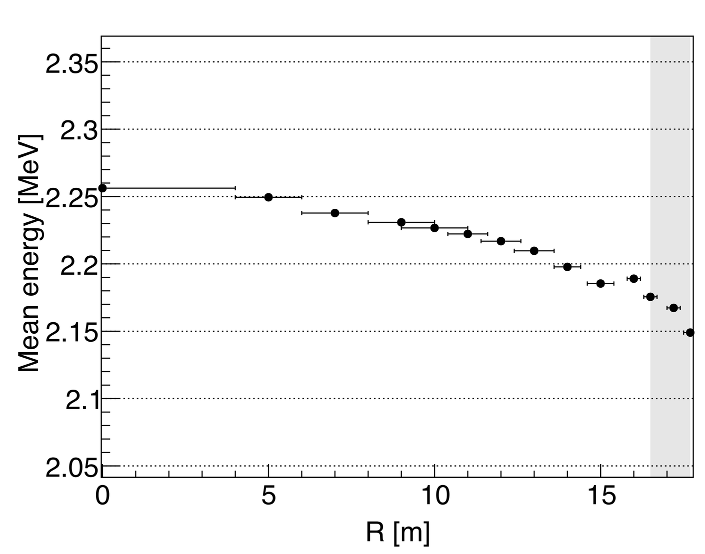


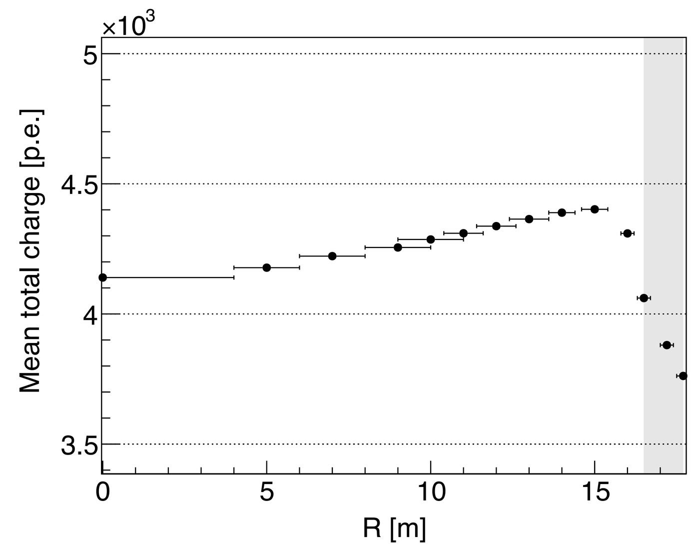




3. Position Dependence of Energy

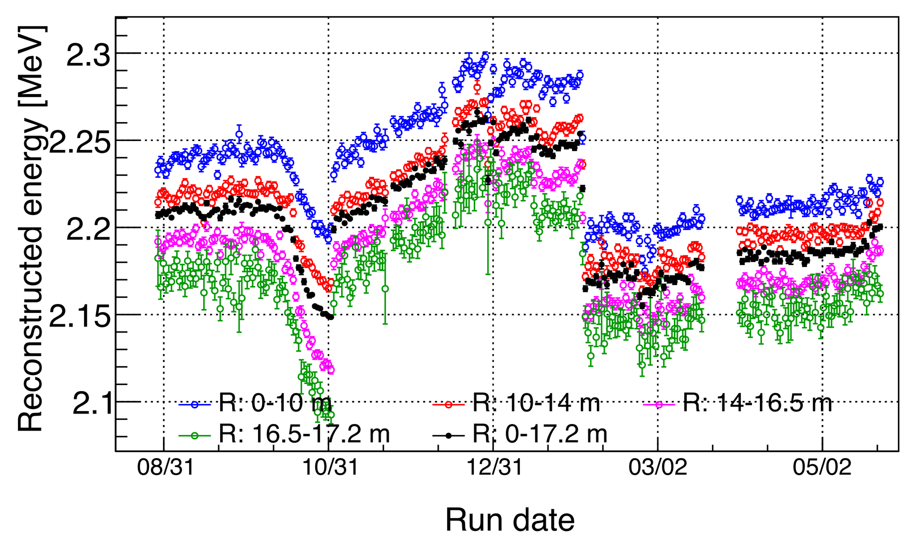
- Spatial dependence of the energy is observed for neutron events. Specifically, as the position approaches the detector center, yielding a higher muon energy deposition. This subsequently induces more pronounced PMT after-pulse effects, which lead to higher energy.

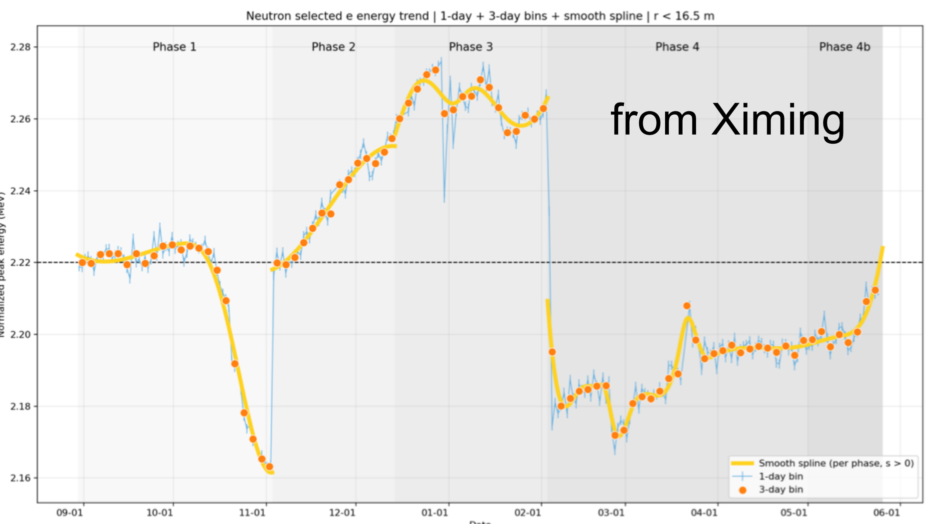




4. Energy Evolution Over the Time

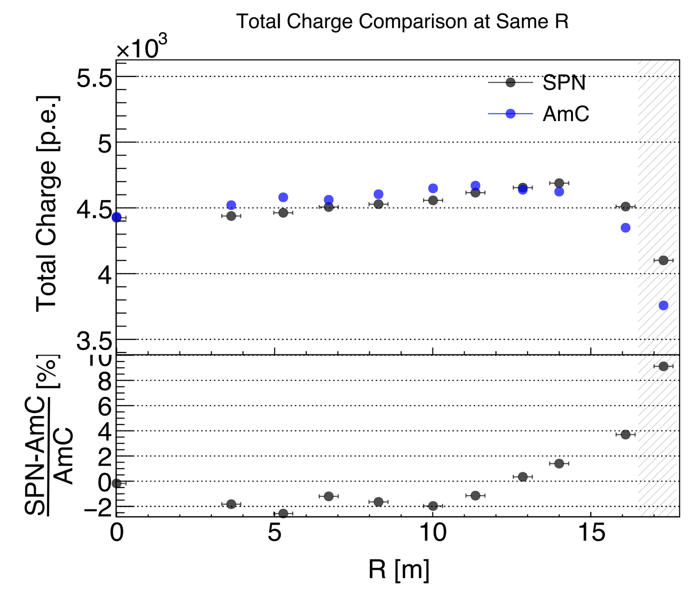
- Due to the change in the optical properties of the buffer water between the liquid scintillator and the PMTs, as well as the PMT high voltage tunning. The energy of events exhibits a noticeable evolution over the detector running time.
- By implementing a time-dependent energy correction based on cosmogenic neutron events, the root-mean-square (RMS) of the IBD delayed-signal energy in JUNO is reduced from 1.54% to 0.93%, substantially mitigating the temporal drift of the detector's energy scale.

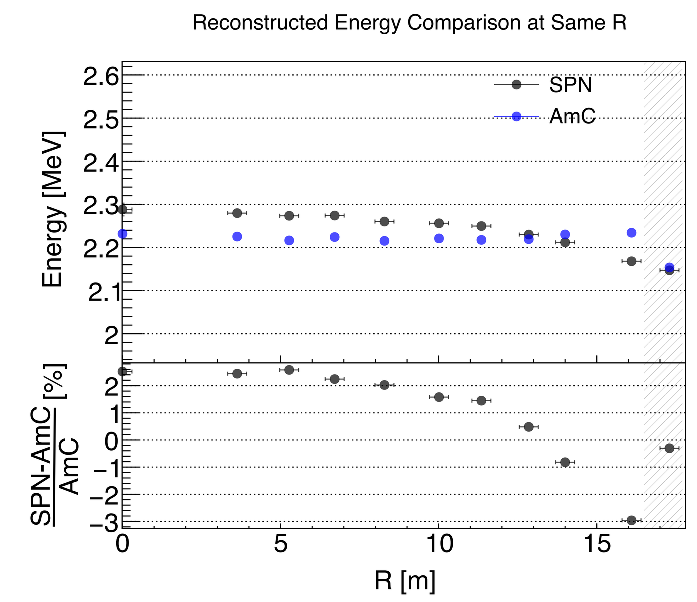


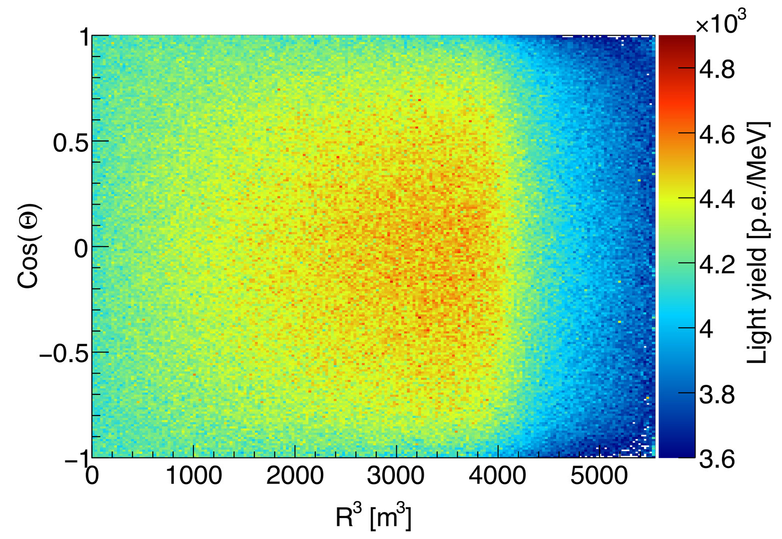


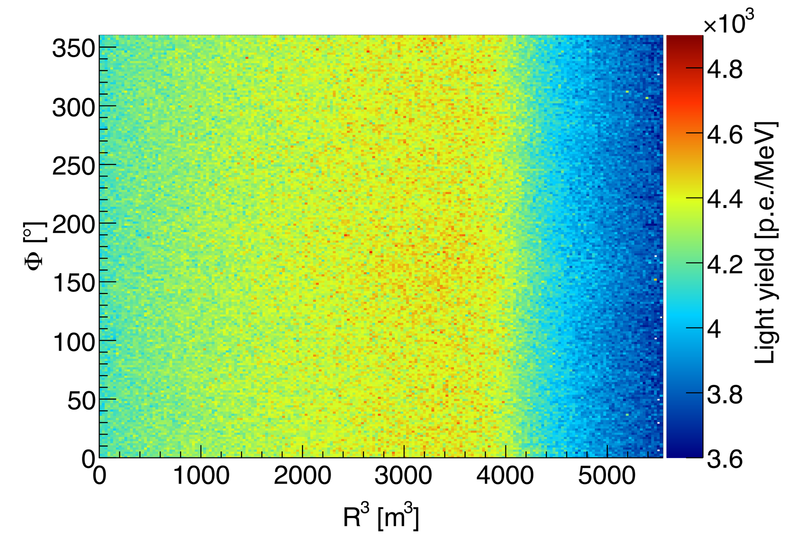
5. Neutron Light Yield

- Neutrons enable a three-dimensional calibration of the detector's light yield throughout the entire liquid scintillator volume. Compared to the artificial calibration AmC neutron source [1], the total charge difference is < 4% within the fiducial volume.









Reference

[1]. JUNO collaboration, Calibration Strategy of the JUNO Experiment, arXiv:2011.06405.