Neutron source-based event reconstruction in the JUNO detector

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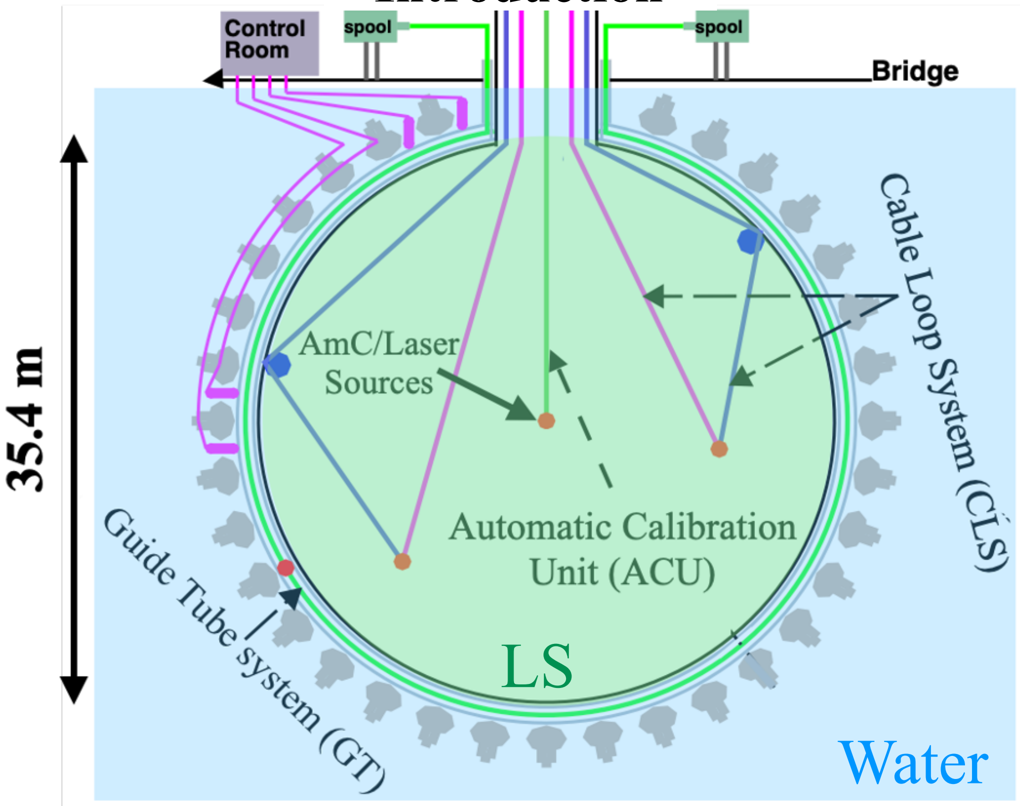
Abstract

This poster presents vertex and energy reconstruction algorithms in the JUNO detector, which are developed based on neutron source and laser calibration events. The performances of the two algorithms are evaluated with the JUNO detector simulation. The vertex reconstruction bias has been estimated to be within 4 cm, and the resolution for positrons with E_{kin}=0 MeV has been evaluated to be about 9 cm. As for the energy reconstruction performance, the non-uniform bias is estimated to be less than 0.5%.

Introduction



- JUNO is 20 kton liquid scintillator detector in Jiangmen, China.
- Expected to start the physics run in 2024.
- Aim to determine the neutrino mass ordering with reactor neutrinos.
  - $\bar{\nu}_e + p \rightarrow e^+ + n$
- 17,612 20-inch PMTs & 25,600 3-inch PMTs are being installed.
- Various calibration source deployment systems.

Vertex & Energy Reconstruction Algorithms

$$L = \prod_j^{\text{Unhit}} P_j^q(\text{unhit}|\mu_j^{\text{exp}}) \prod_i^{\text{Hit}} P_i^q(Q_i^{\text{obs}}|\mu_i^{\text{exp}}) P_i^t(t_{i,\text{residual}}|R, \theta_{i,\text{PMT}}, Q_i^{\text{obs}}, \text{Total Charge}),$$

$t_{i,\text{residual}} = t_{i,\text{first hit time}} - \text{T.O.F.}(x,y,z) - t_0,$

$t_{i,\text{first hit time}}$: First photon detection at the ith PMT,

μ_i^{exp} : Expected charge at the ith PMT,

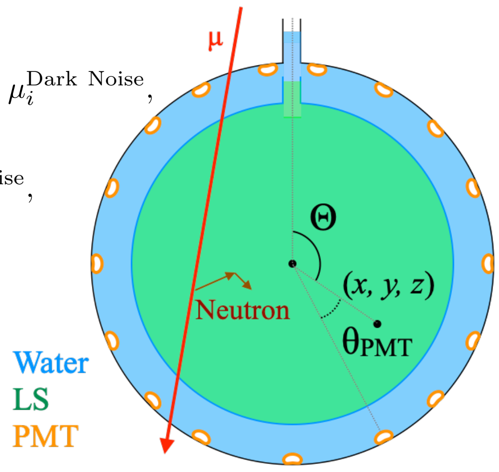
for vertex reconstruction,

$\mu_i^{\text{exp}} = \mu_{i,0}^{\text{exp}}(R, \Theta, \theta_{i,\text{PMT}}) \times \text{Total Charge} + \mu_i^{\text{Dark Noise}},$

for energy reconstruction,

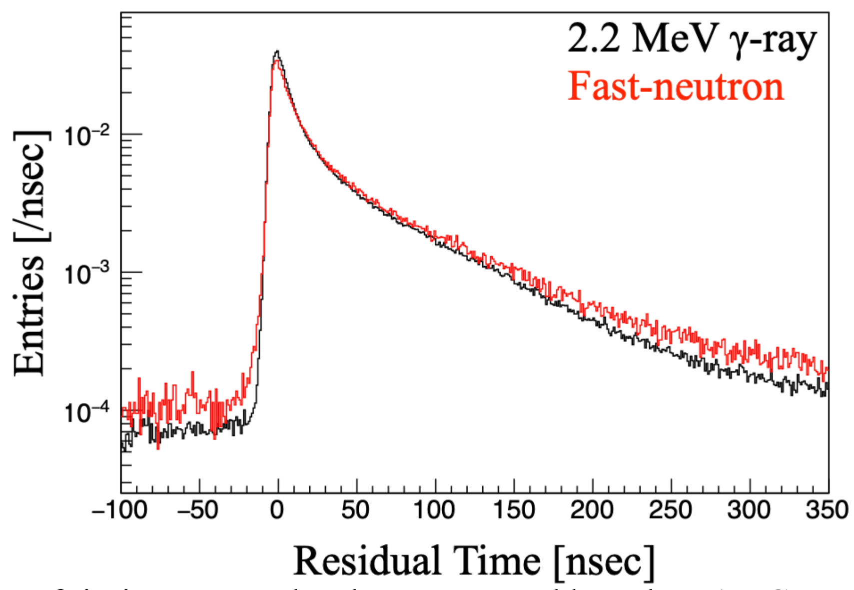
$\mu_i^{\text{exp}} = \mu_{i,0}^{\text{exp}}(R, \Theta, \theta_{i,\text{PMT}}) \times E_{\text{vis}} + \mu_i^{\text{Dark Noise}},$

Q_i^{obs} : Observed charge at the ith PMT.

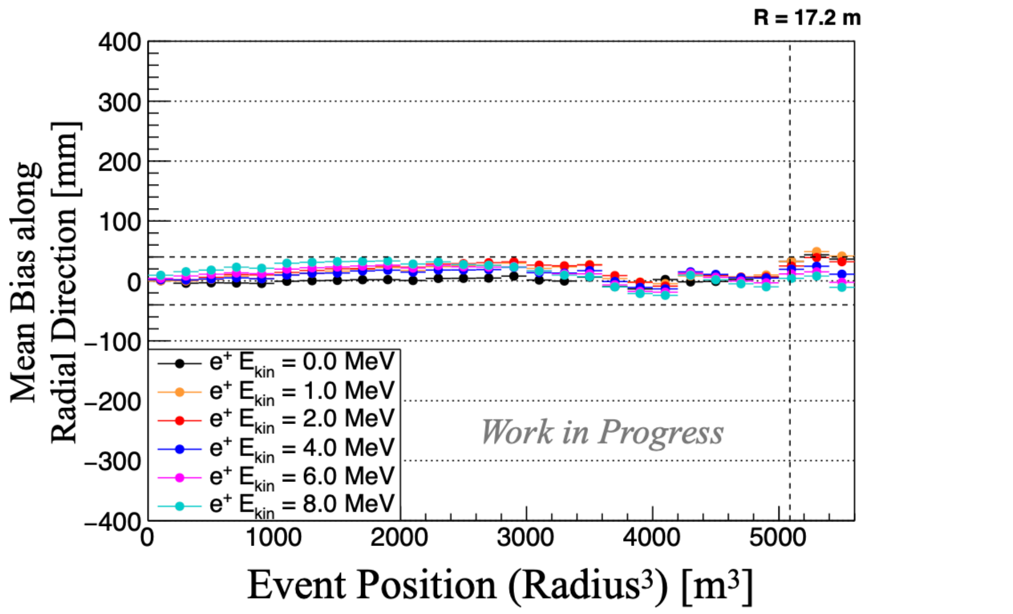


- Search for the event vertex position (*x, y, z*) which maximizes the likelihood (*L*).
- After the vertex reconstruction, the event energy is reconstructed by maximizing the charge PDF (P^q) part of the likelihood.
- Probability density functions (P^q and P^t, P.D.F.) and charge map (μ^{exp}) are obtained by radioactive neutron source ($^{241}Am^{13}C$), cosmogenic neutron, and laser calibration events.
- Various intensity laser events are used to characterize the PMT charge distribution (P.D.F.).

Inputs for the Algorithms & Performances

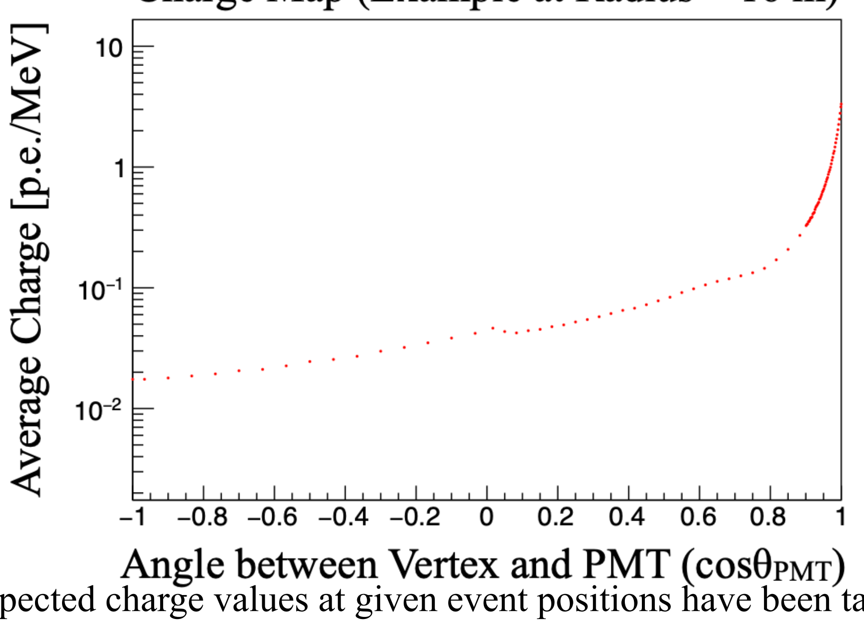


- A set of timing P.D.F.s has been prepared based on AmC neutron source events generated along the central axis of the detector.
- Use events from 2.2 MeV γ-ray from neutron captures on hydrogen.

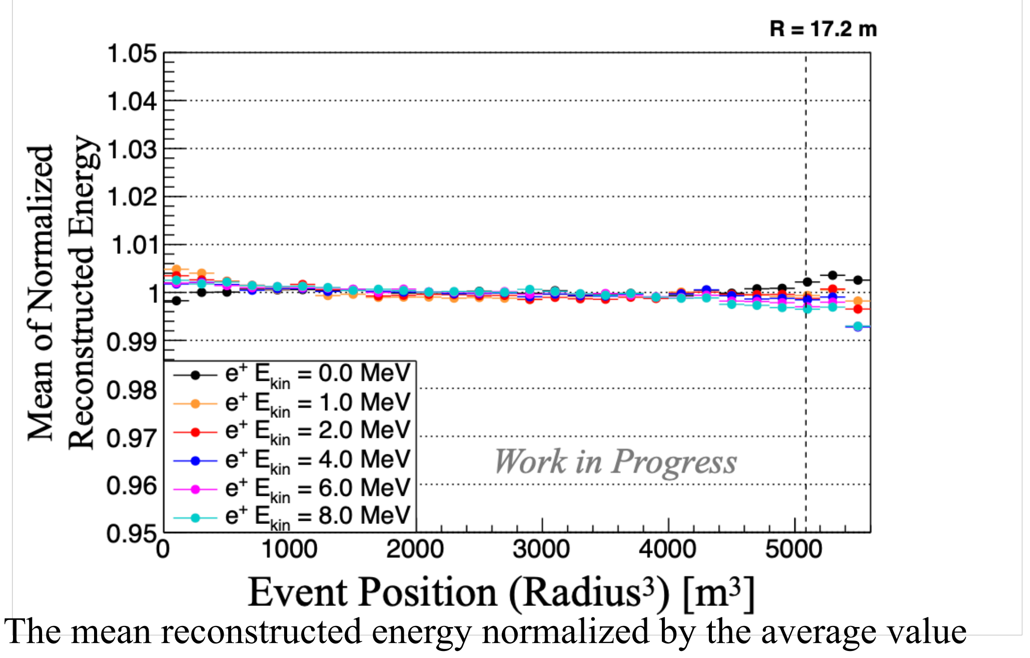


- Mean value of the difference between reconstructed and true radius is less than 4 cm within the JUNO fiducial volume (Radius<17.2 m).
- The resolution for positions with E_{kin}=0 MeV is ~9 cm.

Charge Map (Example at Radius ~ 16 m)



- Expected charge values at given event positions have been tabulated using uniformly distributed (cosmogenic) neutron samples.
- More bins where charge value changes rapidly.



- The mean reconstructed energy normalized by the average value within the fiducial volume. Its non-uniformity is kept within 0.5%.
- The resolution for positions with E_{kin}=0 MeV is ~3.05%.

References: [1]. arXiv:2011.06405 about the JUNO calibration strategy. [2]. arXiv:2211.16768 about the existing JUNO event reconstruction tool.