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Neutron source-based event reconstruction in JUNO

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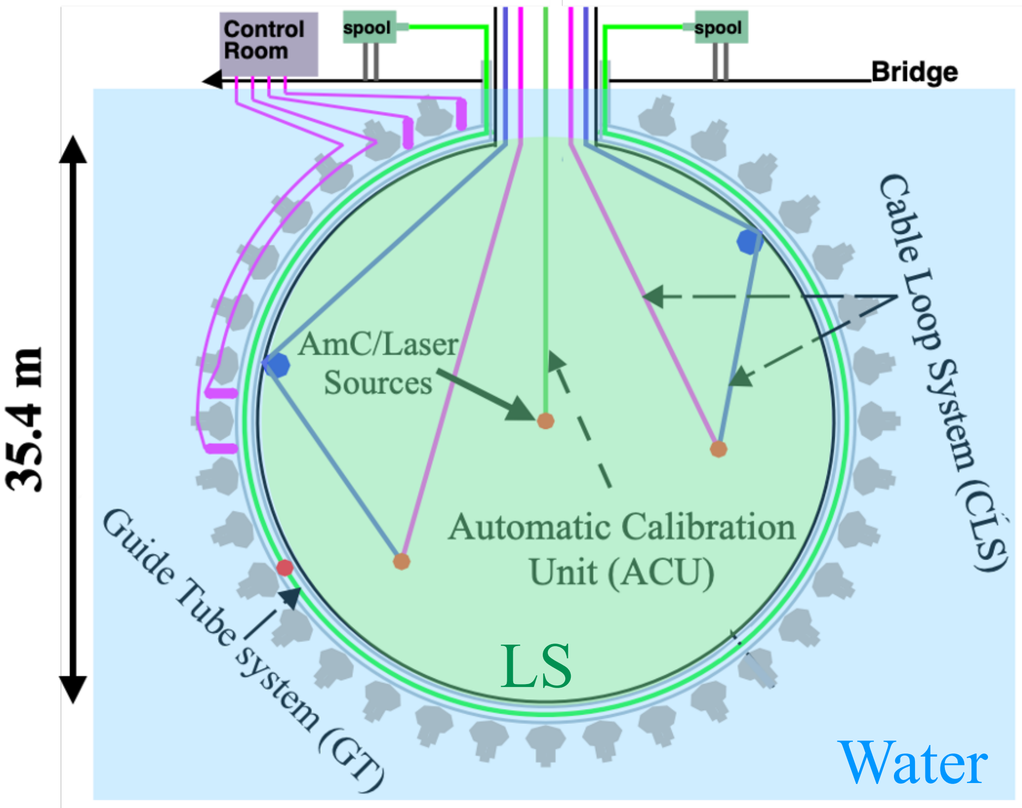
Introduction



- JUNO will be a 20 kton liquid scintillator detector in Jiangmen, China.
- Expected to start the physics run in 2025.
- The primary experimental goal is to determine the neutrino mass ordering with reactor neutrinos.
  - $\bar{\nu}_e + p \rightarrow e^+ + n$ (Inverse Beta Decay, IBD)
- 17,612 20-inch PMTs & 25,600 3-inch PMTs are being installed.
- Various calibration source deployment systems will be equipped.
- The event reconstruction is crucial:
  - define fiducial volume, IBD event selection, precise energy measurement, etc.

Event Reconstruction Algorithms

Vertex Reconstruction Likelihood

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

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

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

Timing PDF (P^t)
Charge Map (μ)
Charge PDF (P^q)

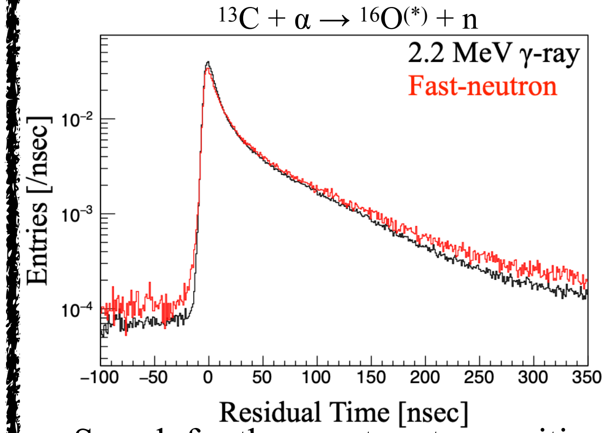
Energy Reconstruction Likelihood

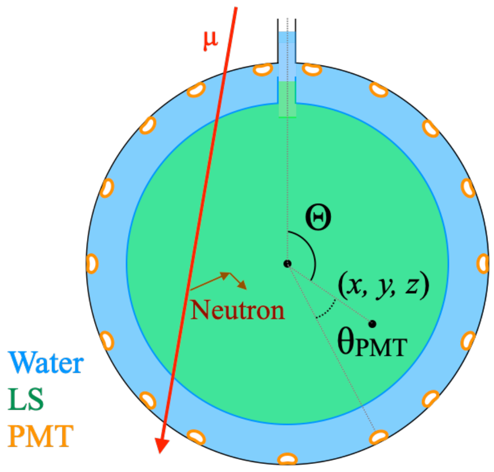
$$L = \prod_{j}^{\text{Unhit}} P_j^q(\text{unhit}|\mu_j^{\text{exp}}) \prod_{i}^{\text{Hit}} P_i^q(Q_i^{\text{obs}}|\mu_i^{\text{exp}})$$

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

Timing PDF from ^{241}Am^{13}C Sample

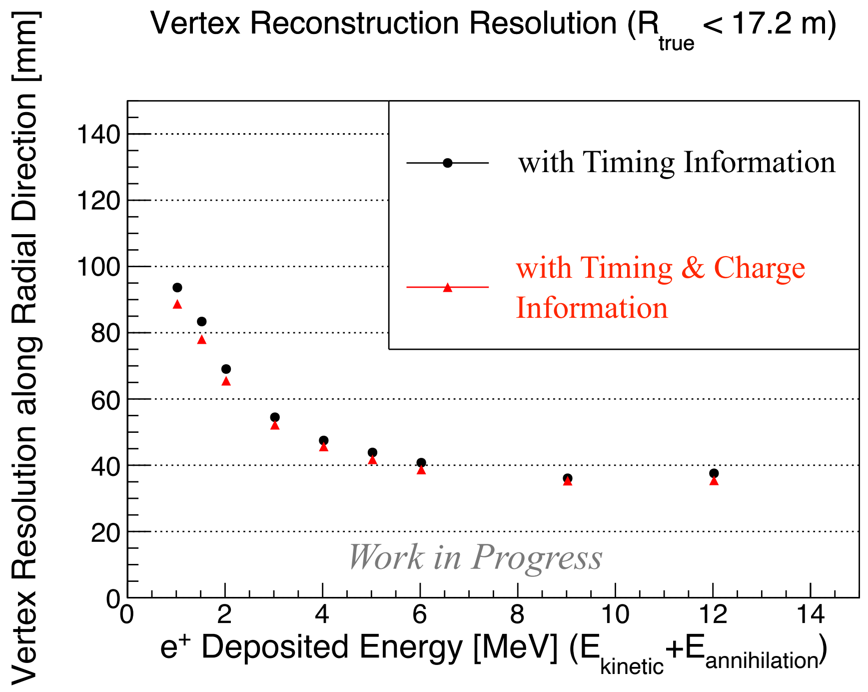
$^{13}C + \alpha \rightarrow {}^{16}O^{(*)} + n$



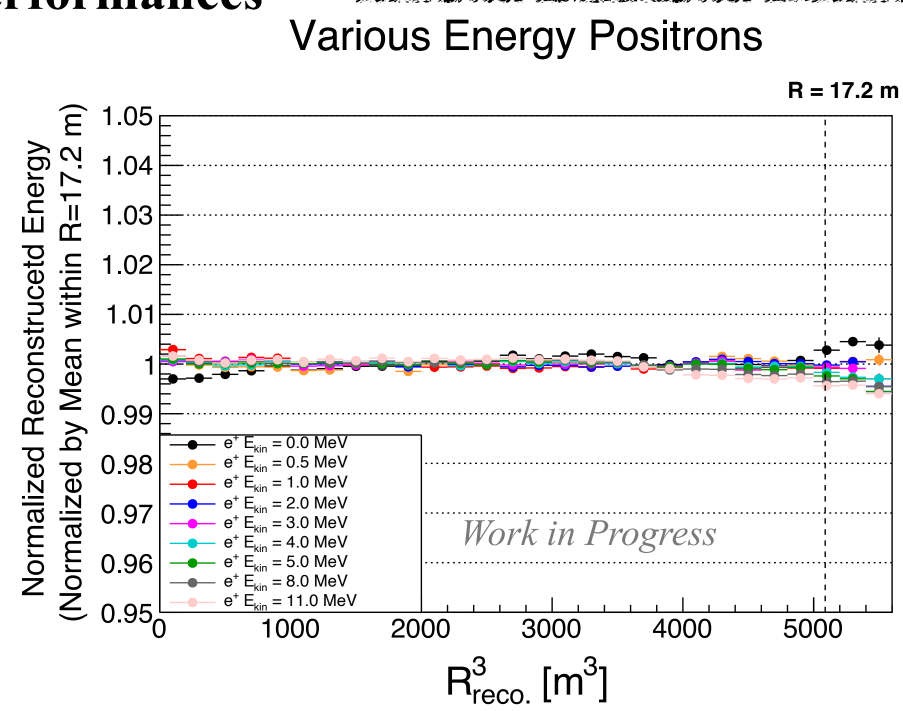


- Search for the event vertex position (x, y, z) which maximizes the likelihood (L) involving both time & charge information.
- After the vertex reconstruction, the event energy is reconstructed by maximizing the charge PDF (P^q) part of the likelihood.
- Probability density functions (P^q and P^t, P.D.F.) 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.).

Reconstruction Performances

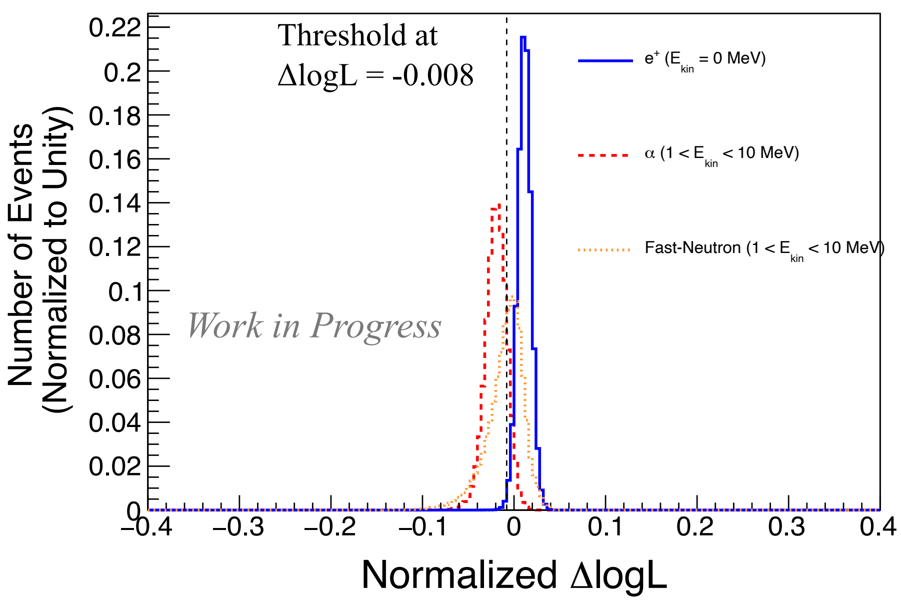


- ~9 cm for e^+ with $E_{\text{kin}} = 0$ MeV.
- Charge information improves the performance.



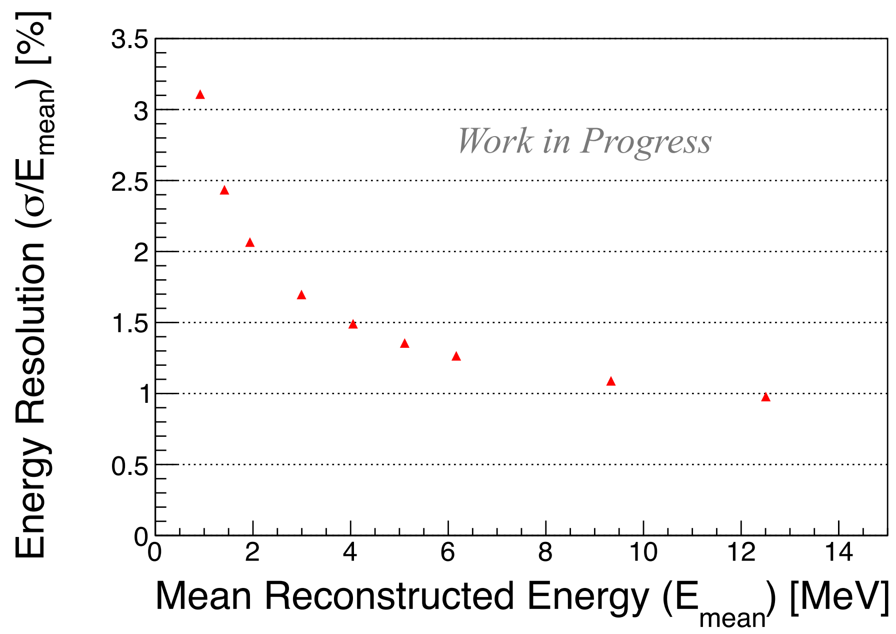
- The reconstructed energy uniformity is kept within 0.5%.
- Working in the entire IBD energy range.

Particle Identification



- Remove 80% of alpha and 45% of fast-neutron.
- Keep 99% of e^+ signals.

Energy Resolution (σ/E_{mean}) ($R_{\text{reco.}} < 17.2$ m)



- ~3% energy resolution for e^+ with $E_{\text{kin}} = 0$ MeV.