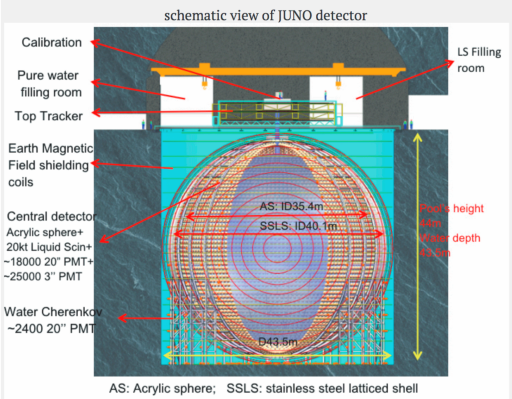
Energy and Vertex Reconstruction in JUNO

Guihong Huang on behalf of JUNO collaboration

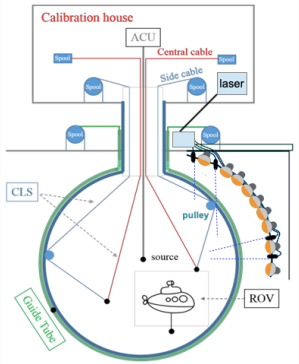
The neutrino event reconstruction goal of the JUNO experiment is to achieve the ceiling performance of the detector for reaching an energy resolution of $\sim 3\,\%/\sqrt{E}$. Which is crucial for the determination of the neutrino mass ordering with the reactor neutrinos energy spectrum. This poster proposes an energy and vertex reconstruction method that combines the charge and time information of the PMTs. This method gives a baseline of the energy and vertex reconstruction.

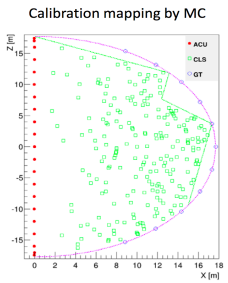
The JUNO experiment



- A multi-purpose observatory for determining the neutrino mass ordering, precisely measuring $sin^2 2\theta_{12}, \Delta m^2_{21}, \Delta m^2_{31}$, studying the solar neutrinos, supernova neutrinos, diffuse supernova neutrino background, etc. [1]
- $3\,\%/\sqrt{E(MeV)}$ unprecedented energy resolution
  - Total light level ~1200 pe / MeV
  - Attenuation length > 20 m @ 430 nm
  - Photocathode coverage ~75%
  - PMT detection efficiency > 27%

Calibration system





266 calibration positions:
ACU: 21; CLS: 219; GT: 26

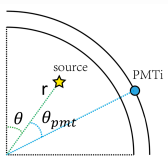
- Four complementary systems
  - Automated Calibration Unit (ACU) deploys radioactive and laser (1 ns, keV-TeV range) sources along the central axis
  - 2D: Cable Loop System (CLS) to scan vertical planes
  - 2D: Guide Tube to scan the outer surface of the central detector (where the CLS cannot reach)
  - 3D: Remotely Operated Vehicle (ROV) operating inside the LS to scan the full volume

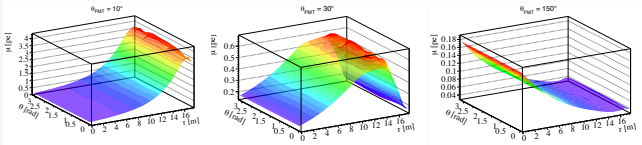
Construction of the nPE map

Goal: The expected light level per unit visible energy of PMTs μ_0

Challenge: The calibration positions of ACU + CLS are limited and are not axis-like deployed

Solution: Apply the cubic spline interpolation to construct the 3-D nPE map $\mu_0(r, \theta, \theta_{pmt})$





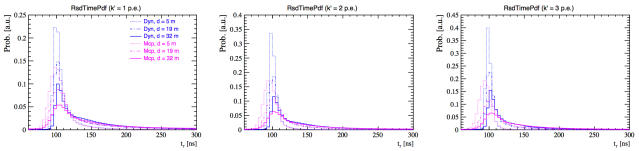
The 3-D nPE map constructed from ACU+CLS n-H

Construction of the residual time pdfs

Goal: The pdfs of $t_r = t_h - t_f - t_d - t_0$ measured by PMTs $P_T(t_r|k, d)$

Challenges: $P_T(t_r|k, d)$ is related to k; The interaction time (t0) of every calibration event is difficult to retrieve;...

Solutions: Adopt k' from nPE recognition; Use large enough bin width (4 ns) → The peak time of the scintillator light pulse can be set as t0.



The residual time pdfs constructed from ACU+CLS n-H

Charge and time combining maximum likelihood estimation

The likelihood function of QMLE is constructed as Eq. 1. Which can give a robust energy and vertex with the charge information only. The likelihood function of the time based maximum likelihood estimation (TMLE) is constructed as Eq. 2. which can optimize the theta and phi angle. The likelihood function of the charge and time combining likelihood maximum estimation (QTMLE) is constructed as Eq. 3 in order to optimize the energy and vertex resolution.

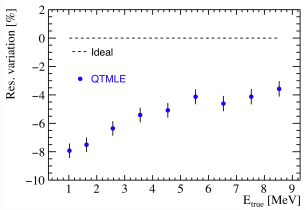
$$\mathscr{L}(q_1, q_2, \ldots, q_N | \mathbf{r}, E) = \prod_{unhit} e^{-\mu_j} \prod_{hit} \left(\sum_{k=1}^{+\infty} \frac{e^{-\mu_i} \mu_i^k}{k!} P(q_i|k) \right). \quad (1)$$

$$\mathscr{L}(t_{1,r}, t_{2,r}, \ldots, t_{N,r}; k'_1, k'_2, \ldots, k'_N | \mathbf{r}, t_0) = \prod_{hit} P_T(t_{i,r}|d_i, k'_i, t_0). \quad (2)$$

$$\mathscr{L}(q_1, q_2, \ldots, q_N; t_{1,r}, t_{2,r}, \ldots, t_{N,r}; k'_1, k'_2, \ldots, k'_N | \mathbf{r}, E, t_0) = \prod_{unhit} e^{-\mu_j} \prod_{hit} \left(\left(\sum_{k=1}^{+\infty} \frac{e^{-\mu_i} \mu_i^k}{k!} P(q_i|k) \right) P_T(t_{i,r}|d_i, k'_i, t_0) \right). \quad (3)$$

Reconstruction performance

For the full chain Monte Carlo simulation uniform positron data samples, the reconstructed energy non-uniformity is < 1% inside fiducial volume and most of the effects of the charge smearing, dark noise and vertex resolution on the energy resolution have been handled.



Conclusion and outlook

The charge information is of great use to fit the radius in the marginal area while the time information is of great use to constraint the radius in the center area and the angles in the whole detector. The QTMLE combined the charge and time information can optimize the energy resolution at low energy range. However, the impact of the dark noise, charge smearing and vertex resolution on the energy resolution need further studies.

Reference

- [1] JUNO collaboration, J. Phys.G 43(2016) 030401[arXiv:157.5613].

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