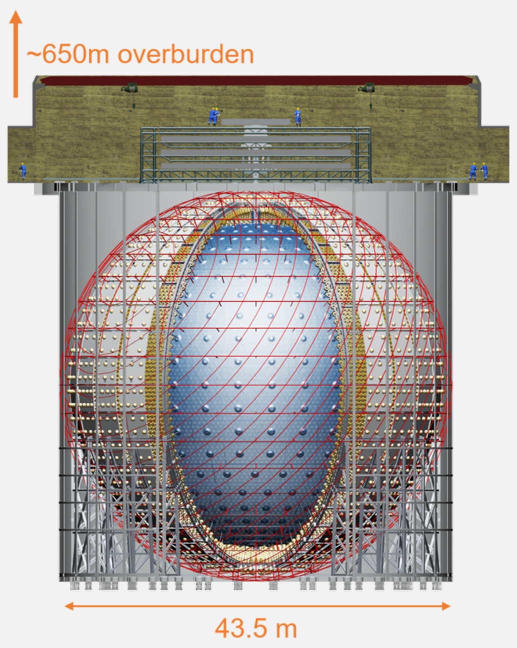
Overview of the event reconstruction in JUNO

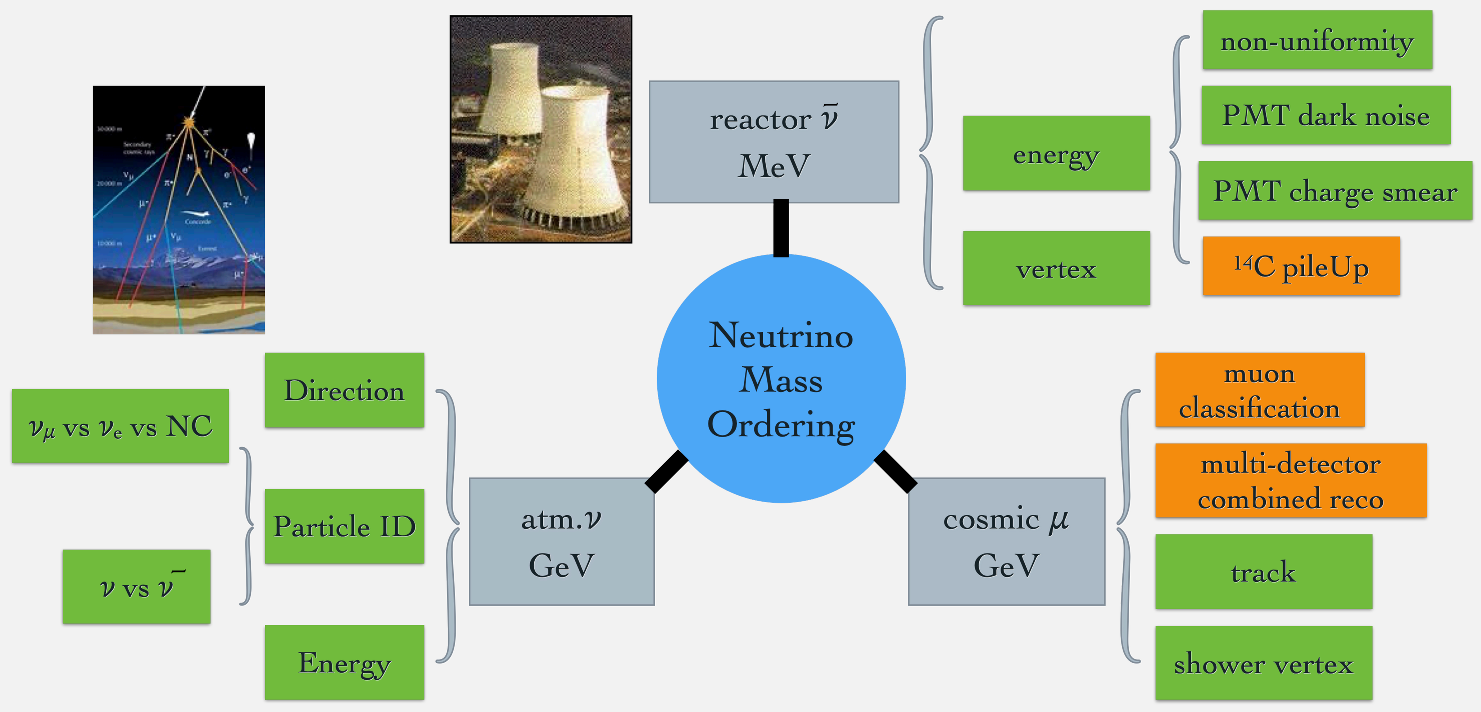
Wuming Luo (Institute of High Energy Physics)
On behalf of JUNO

1 JUNO Experiment



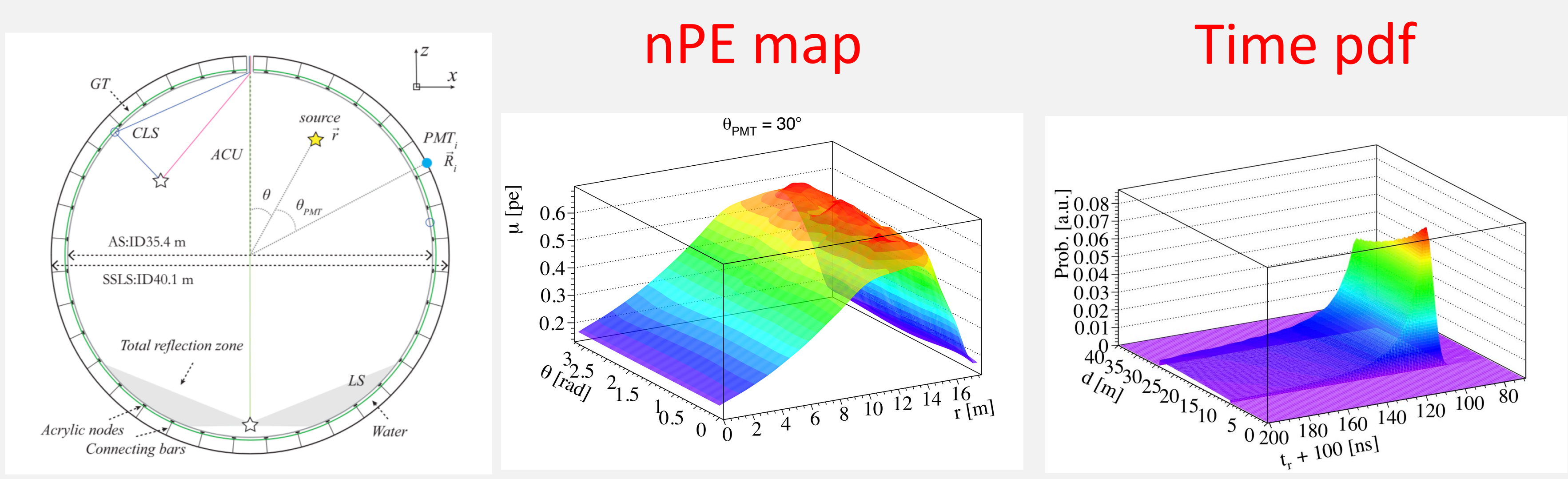
- World's largest liquid-scintillator detector.
- Central Detector: 20kton LS, 17'612 20" PMTs and 25'600 3" PMTs.
- Unprecedented energy resolution 3%@1MeV
- Main physics goal: determination of neutrino mass ordering (NMO).

2 Reconstruction at JUNO



3 Reconstruction for Reactor Neutrinos

- Step1: use calibration data to construct the expected number of PhotoElectron(nPE) and time(T) response of PMTs
- Step2: build a likelihood function with observed charge(Q)&T
- Step3: simultaneously reconstruct E and $\mathbf{r}$



4 Combined Likelihood Estimation

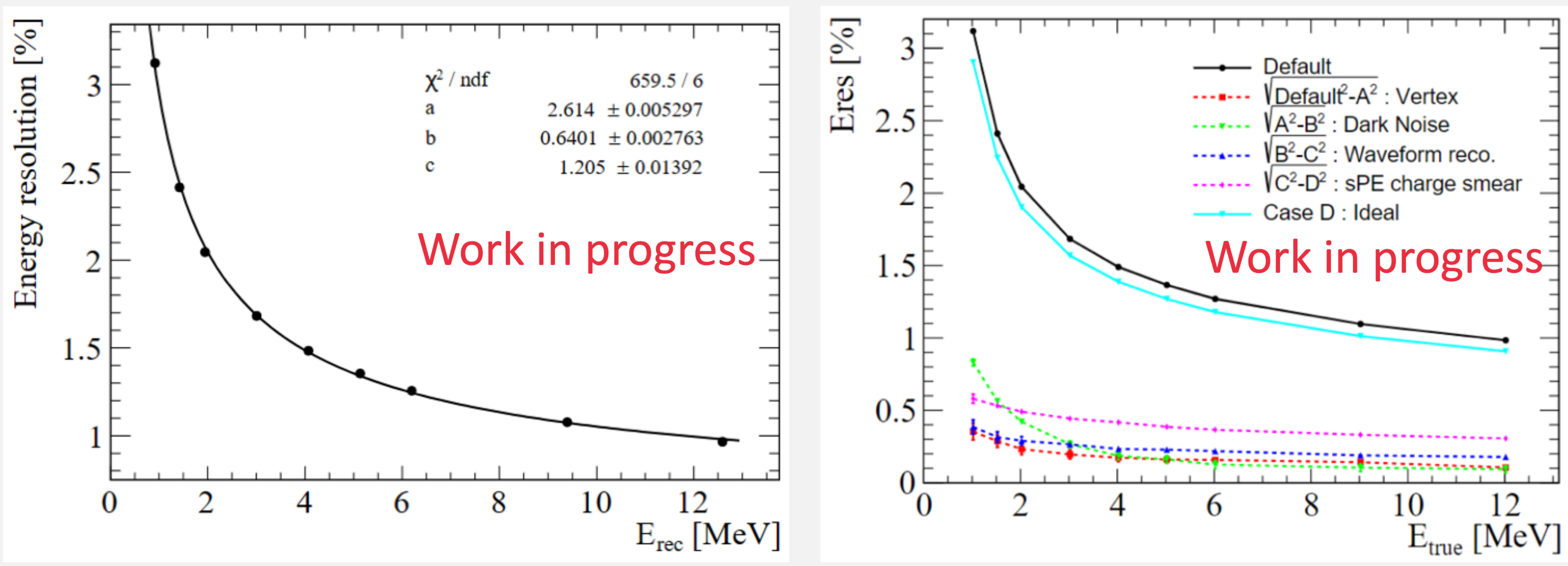
The likelihood function is constructed as the following equation to reconstruct the vertex and energy, where $\mu_i = \hat{\mu}_i E + \mu_i^d$. The expectation inputs are nPE map $\hat{\mu}$, time pdf P_T and charge pdf $P_Q(q\,|\,k)$ constructed from calibration data. The observation inputs are hit charge $\{q_i\}$ and residual hit time $\{t_{i,r}\}$ of PMTs. For small PMTs, only their hit states are used.

$$\mathscr{L}(q_1, q_2, \ldots, q_N; t_{1,r}, t_{2,r}, \ldots, t_{N,r} | \mathbf{r}, E, t_0) =$$

$$\prod_{unhit} e^{-\mu_j} \prod_{LPMT\ hit} \left(\left(\sum_{k=1}^{+\infty} \frac{e^{-\mu_i}\mu_i^k}{k!} P_Q(q_i|k) \right) P_T(t_{i,r}|r, d_i, \mu_i^l, \mu_i^d, t_0) \right) \prod_{SPMT\ hit} (1 - e^{-\mu_i}).$$

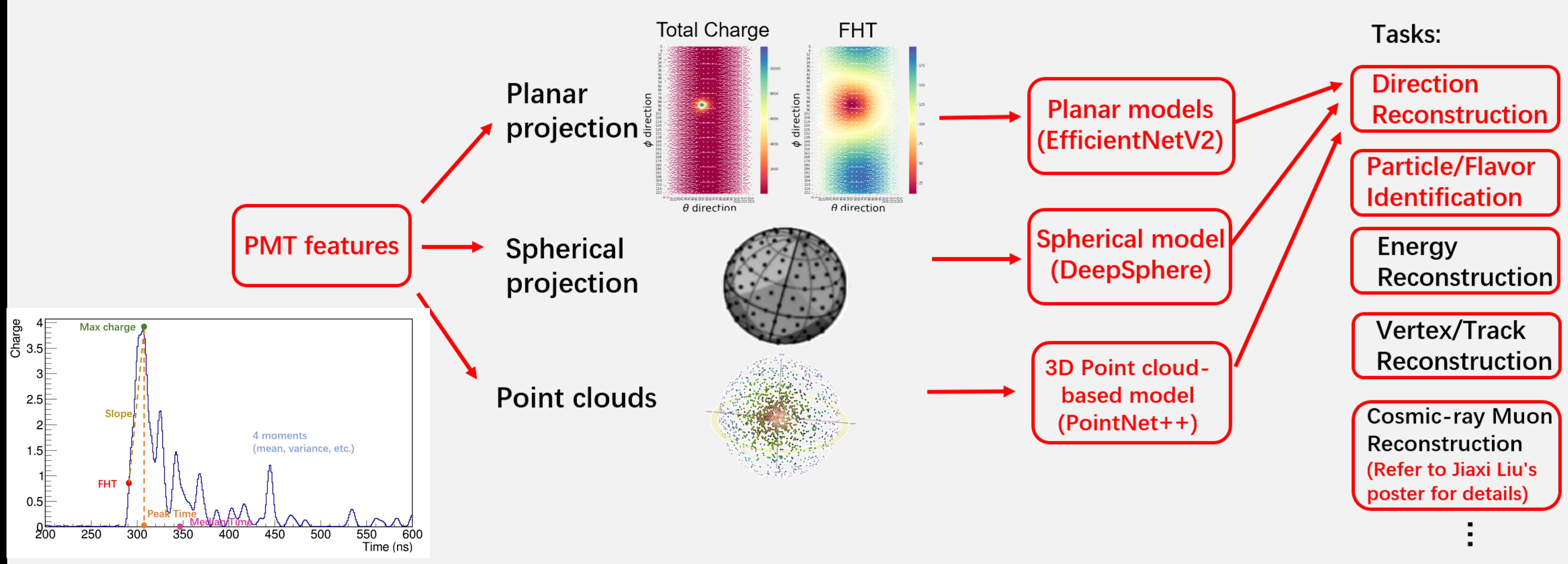
5 Energy Resolution Performance

- Latest predicted energy resolution 2.95%@1MeV
- Decomposition of the energy resolution



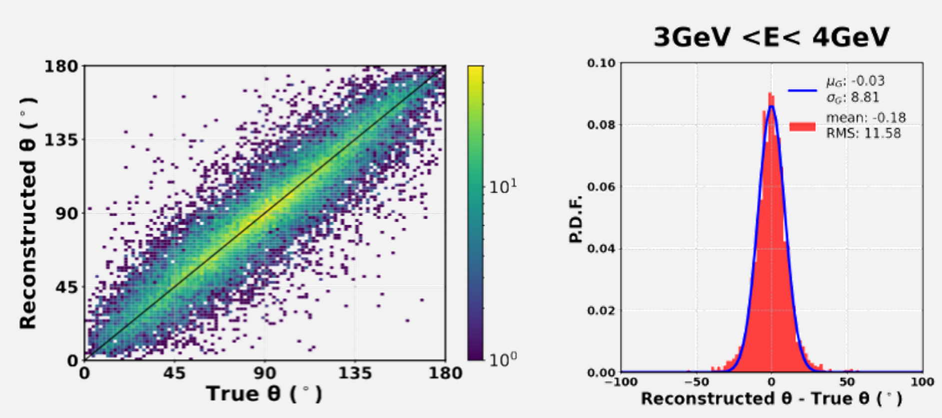
6 Reconstruction for Atm. Neutrinos

Combining the waveform features of all PMTs forms a spherical point cloud signal, upon which different types of models have been explored.

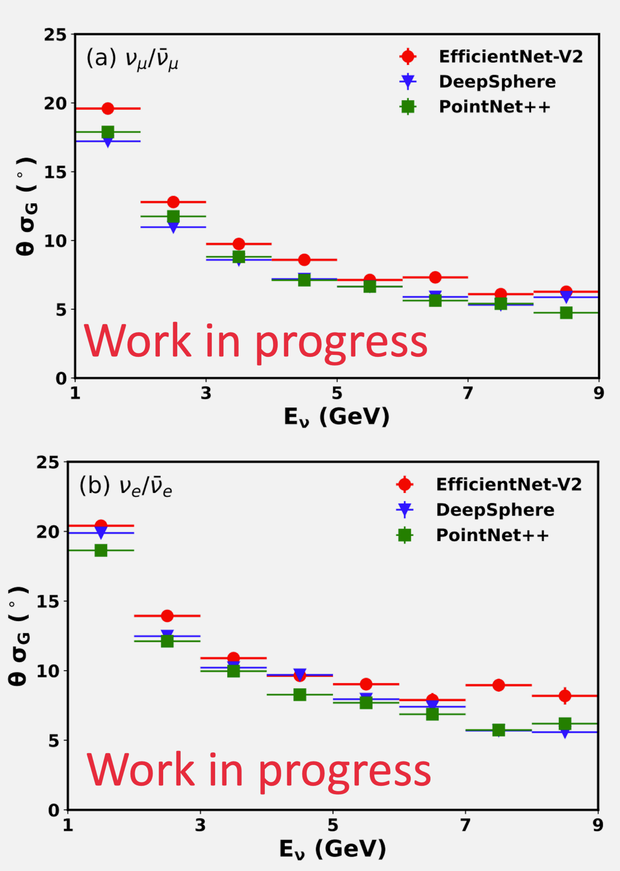


7 Direction Reconstruction Performance

Zenith angle (θ) reconstruction performance presented as an example.



2D distribution of Reconstructed θ VS True θ in all energies, and 1D distribution of Reconstructed θ - True θ in [3,4]GeV ($\nu_\mu/\bar{\nu}_\mu$ events, PointNet++ result as example)



8 Summary

- Reconstruction at JUNO is crucial and challenging
  - High precision vertex and energy for reactor neutrinos
  - Direction and PID for atmospheric neutrinos
- Data-driven likelihood-based reconstruction method has been developed for reactor neutrinos
  - Simultaneous Vertex and Energy reco.
  - Using both charge and time information of PMTs
- A Machine Learning based reconstruction method has been developed for atmospheric neutrinos
  - Multi-purpose: directionality, PID, Energy etc.
  - Promising preliminary results

References

1. Guihong Huang et al, Improving the energy uniformity for large liquid scintillator detectors, Nucl.Instrum.Meth.A 1001 (2021) 165287
2. JUNO Collaboration, JUNO physics and detector, Prog.Part.Nucl.Phys. 123 (2022) 103927
3. GuiHong Huang et al, Data-driven simultaneous vertex and energy reconstruction for large liquid scintillator detectors, Nucl.Sci.Tech. 34 (2023) 6, 83