Cosmic Muon Track Reconstruction in JUNO

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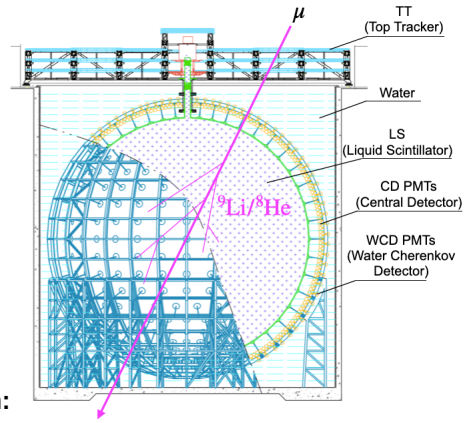
Motivation

JUNO: 20-kton liquid scintillator detector determining the Neutrino Mass Ordering (NMO).

- **^{9}Li/^{8}He Background:** Cosmic-muon-produced ^{9}Li/^{8}He isotopes mimic the Inverse Beta Decay (IBD) signal, limiting this physics sensitivity.
- **Muon Reconstruction:**
  - **CD & WCD:** Provide independent or joint muon track reconstruction for detector-wide veto strategies.
  - **TT:** Provides high-precision tracks (0.2° angular resolution) as an external reference, despite limited coverage.



Muon Reconstruction methods

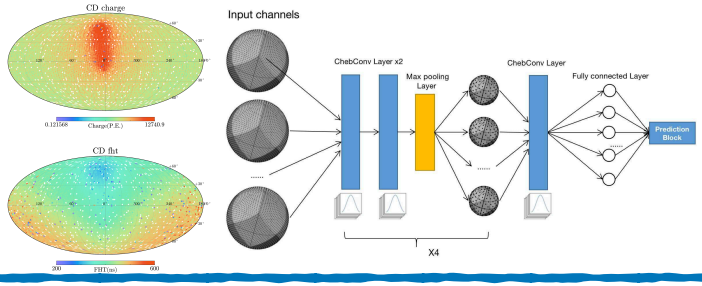
Traditional methods

- **Charge-based**
  - WCD charge cluster
- **Timing-based**
  - Joint CD & WCD χ^2 minimization of FHT(First Hit Time) residuals

Edwin

(**E**vent reconstruction based on **D**eep-learning and **W**aveform **IN**formation) [2]

- HEALPix-based spherical GNN with rotation-equivariant graph convolutions
- Extracts spatial features from PMT waveforms
- Data-driven training with TT reference tracks



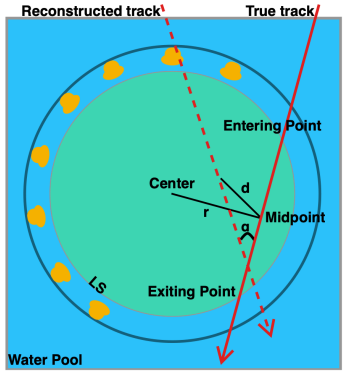
Amber

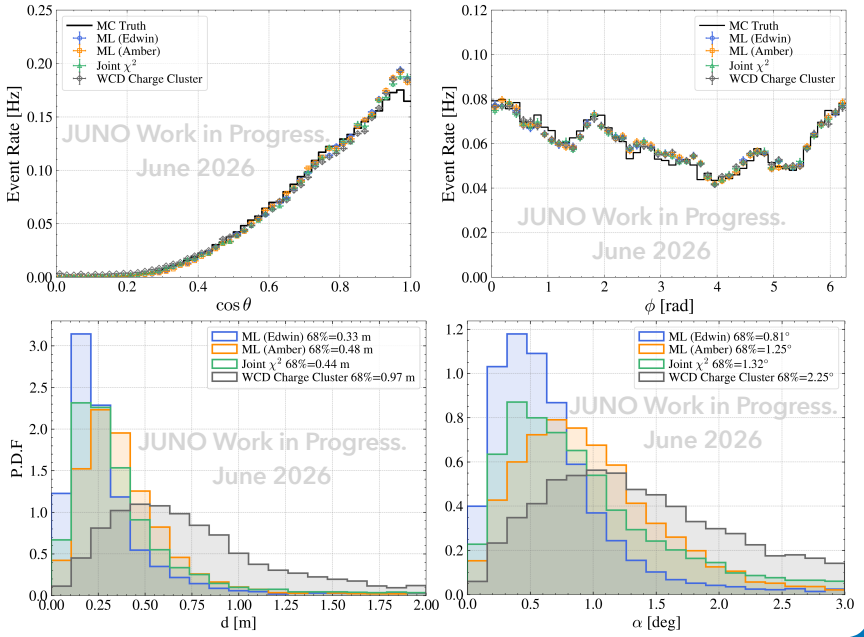
(**A**ttention **M**echanism-**B**ased **E**vent **R**econstructor)

- Transformer-based model
- Data-driven training with TT reference tracks

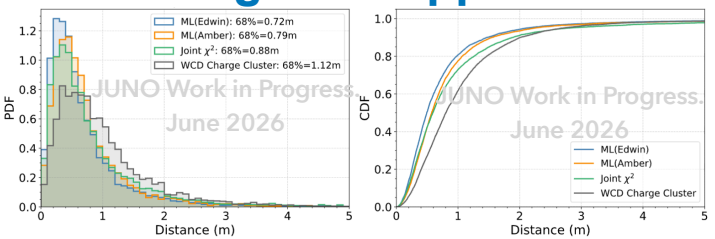
Reconstruction performance

- **Angular Spectra:** The reconstructed direction
- **TT Reference Tracks Comparison:** Common benchmark for evaluating angular and spatial reconstruction residuals.
- Good agreement among independent reconstruction frameworks





Cosmogenic suppression



- **Physics Benchmark:** Muon–SPN (SPallation Neutron) distance distributions within a 2 ms time window.
- **Cosmogenic Background Rejection:** Provides direct guidance for veto optimization and background suppression.

Summary

- Independent traditional and machine learning approaches establish a robust and validated muon tracking capability for JUNO.
- Muon–SPN correlations provide direct guidance for optimizing cosmogenic ^{9}Li/^{8}He background suppression.

[1] Abusleme A, Adam T, Adamowicz K, et al. Initial performance results of the JUNO detector[J]. Chinese Physics C, 2026, 50(4): 043001.
[2] Zekun Yang et al. "First attempt of directionality reconstruction for atmospheric neutrinos in a large homogeneous liquid scintillator detector". Phys. Rev. D 109.5 (2024)