



Contribution ID: 119

Type: **Poster contribution**

Data-driven Charge Template Reconstruction for the TAO Liquid Scintillator Detector

Monday, August 31, 2026 6:00 PM (2 hours)

The Taishan Antineutrino Observatory (TAO) is a compact spherical liquid scintillator detector designed to achieve excellent energy resolution for precision reactor antineutrino measurements. Owing to the compact detector geometry, photon timing information provides limited discrimination for event reconstruction, motivating the development of a reconstruction algorithm based solely on the SiPM charge response.

We present a data-driven Charge Template reconstruction method that simultaneously reconstructs the event vertex and visible energy using a maximum-likelihood approach. Calibration data collected with deployed Ge-68 and Cs-137 radioactive sources are used to construct a three-dimensional detector response map describing the expected photoelectron yield as a function of event position and the relative SiPM geometry. The excellent single-photoelectron resolution of the TAO SiPM system enables reliable photoelectron counting, allowing the detector response to be modeled directly in photoelectron space while suppressing the impact of correlated electronic noise. During reconstruction, the measured SiPM charge pattern is compared with the expected response predicted by the 3D nPE map, and the event parameters are obtained through likelihood minimization. Since the detector response model is derived directly from calibration data, detector non-uniformities are naturally incorporated into the reconstruction without requiring additional position-dependent energy corrections.

The proposed method establishes a fully calibration-driven reconstruction framework for TAO and provides a robust approach for precision energy and vertex reconstruction in compact liquid scintillator detectors.

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Session Classification: Poster

Track Classification: WG6: Detector Physics