SBND Shower Reconstruction with SPINE

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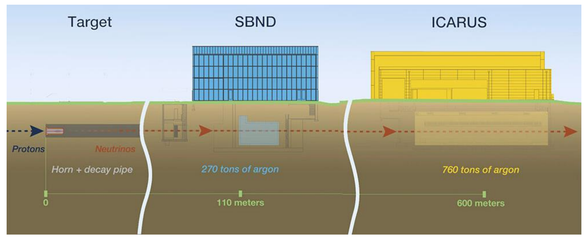
SBND

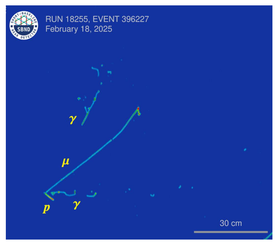
The Short-Baseline Near Detector (SBND) is one of the three detectors in the Short-Baseline Neutrino (SBN) Program, aiming to probe short-baseline neutrino oscillation anomalies.

- Features use of a Liquid Argon Time Projection Chamber (LArTPC) → Clear event topology and high-resolution event reconstruction.
- Located 110 m from the Booster Neutrino Beam (BNB) target at Fermilab → World's largest ν-Ar dataset.
- Taking high-quality data since December 2024.



Event display:

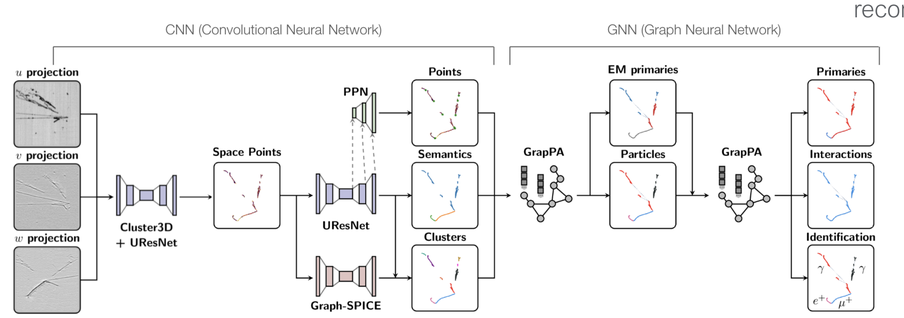
- Tracks:
  - Muons,
  - Pions,
  - Protons
- Showers:
  - Electrons,
  - Photons

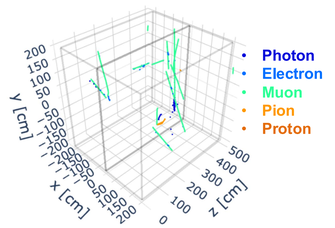


SPINE Reconstruction Chain

Scalable Particle Imaging with Neural Embeddings (SPINE) is a machine learning (ML)–based reconstruction framework for particle imaging detectors.

- CNN: Space points → Fragments
- GNN: Fragments → Particles → Interactions
- Post-processing stage: Kinematic reconstruction, calibrations, etc.





↑ 3D event display (colored by particle species).

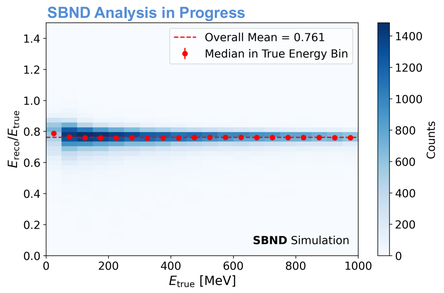
Shower Energy Reconstruction

Unlike tracks, whose energy can be reconstructed using the length of the track in the detector, shower energy must be measured calorimetrically and necessitates an additional calibration to account for sub-threshold charge lost below the noise floor.

$$E_{\text{shower}} = W_i \cdot C_{\text{calo}} \cdot C_{\text{adj}} \cdot \frac{1}{R} \cdot \sum_Q e^{\frac{t_{\text{drift}}}{\tau}} Q$$

E_{shower}	W_i	C_{calo}	C_{adj}	R	Q
[MeV]	[MeV / e^-]	[e^- / ADC]			[ADC]
		Calorimetric constant (TPC gain)		Recombination factor	Deposited charge

Work function for Ar | Shower adjustment factor | Electron lifetime correction



← Determination of the shower adjustment factor using SBND Monte Carlo simulation through comparing reconstructed shower energy to true shower energy. The extracted factor is computed to be 1.000/0.761 = 1.314.

- **Neutral pions:**
  - Decay into two photons with an opening angle.
  - π^0 mass is known (~134.98 MeV)

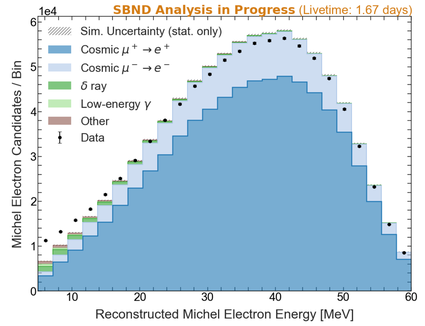
    → The invariant mass is a standard candle for shower energy reconstruction and calibration.

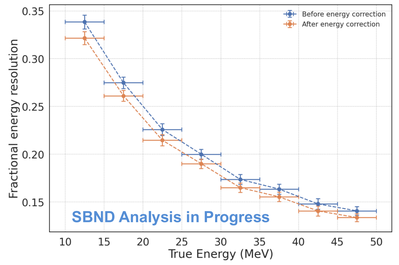
$$\pi^0 \to \gamma + \gamma \qquad m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

Shower Selections

- **Michel electrons:**
  - Produced by cosmic-ray muons that stop and decay inside the detector.
  - Energy spectrum is well-modelled → Characterize detector response to low-energy electrons.

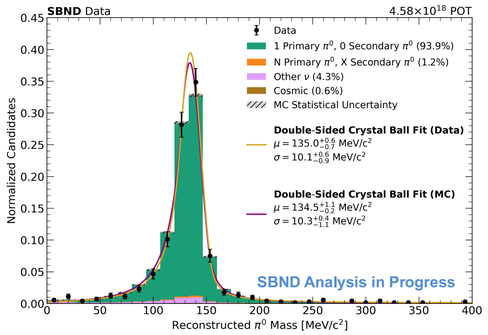
↓ MC-data agreement of the reconstructed Michel electron energy spectrum.

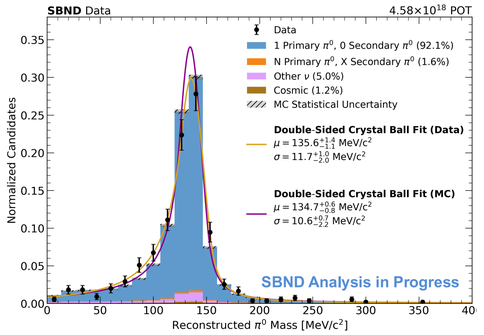




↑ A 5% increase in C_{adj} was introduced to compensate for a residual energy-scale bias observed in Michel electron reconstruction.

↓ MC-data agreement of the reconstructed π^0 mass for the SBND ν_μ CC (left) and NC (right) π^0 selection.





↓ Shower energy resolution from reconstructed photon showers in SBND ν_μ CC π^0 MC, shown as a function of true photon energy.