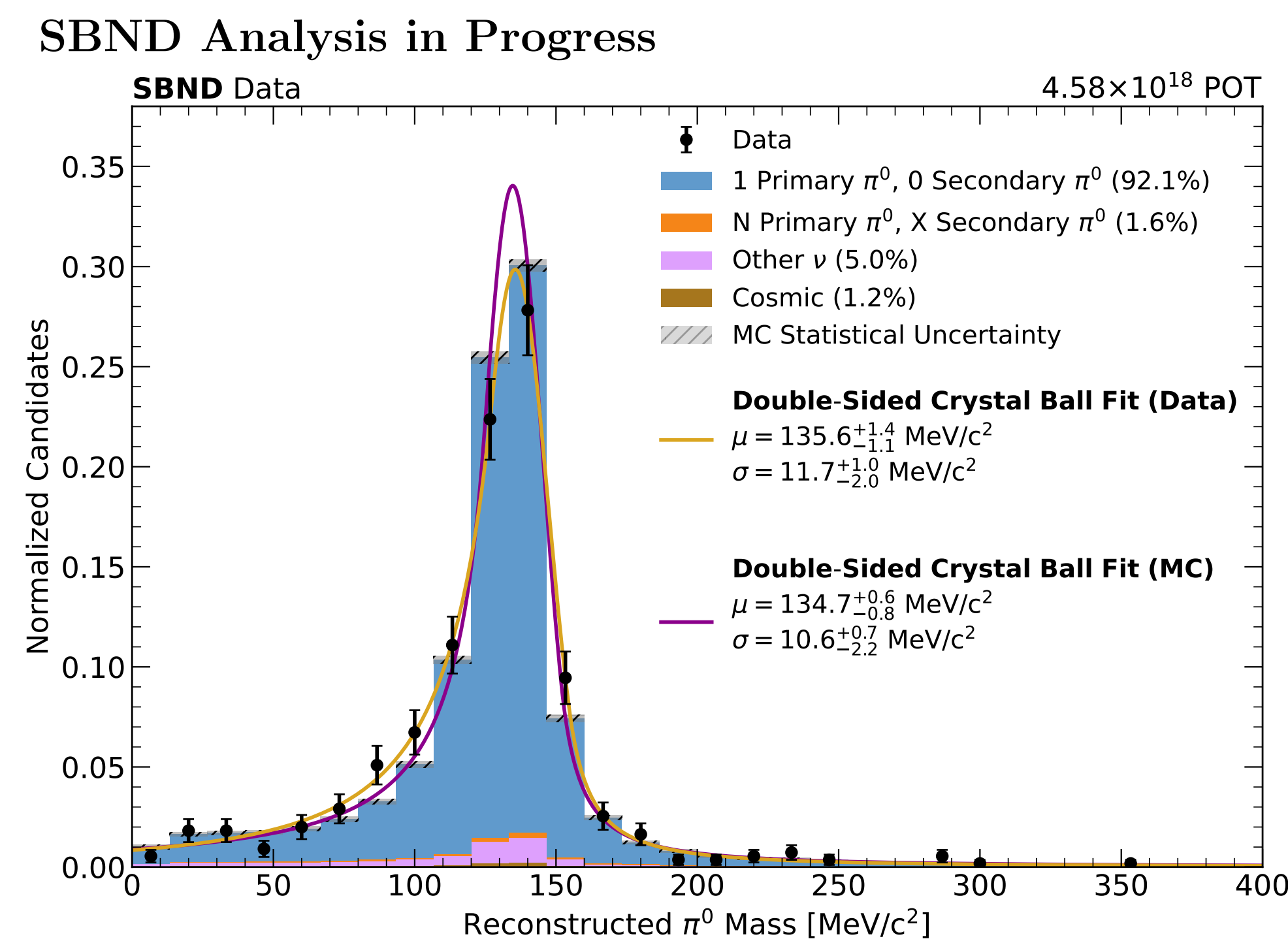


Introduction & Motivation

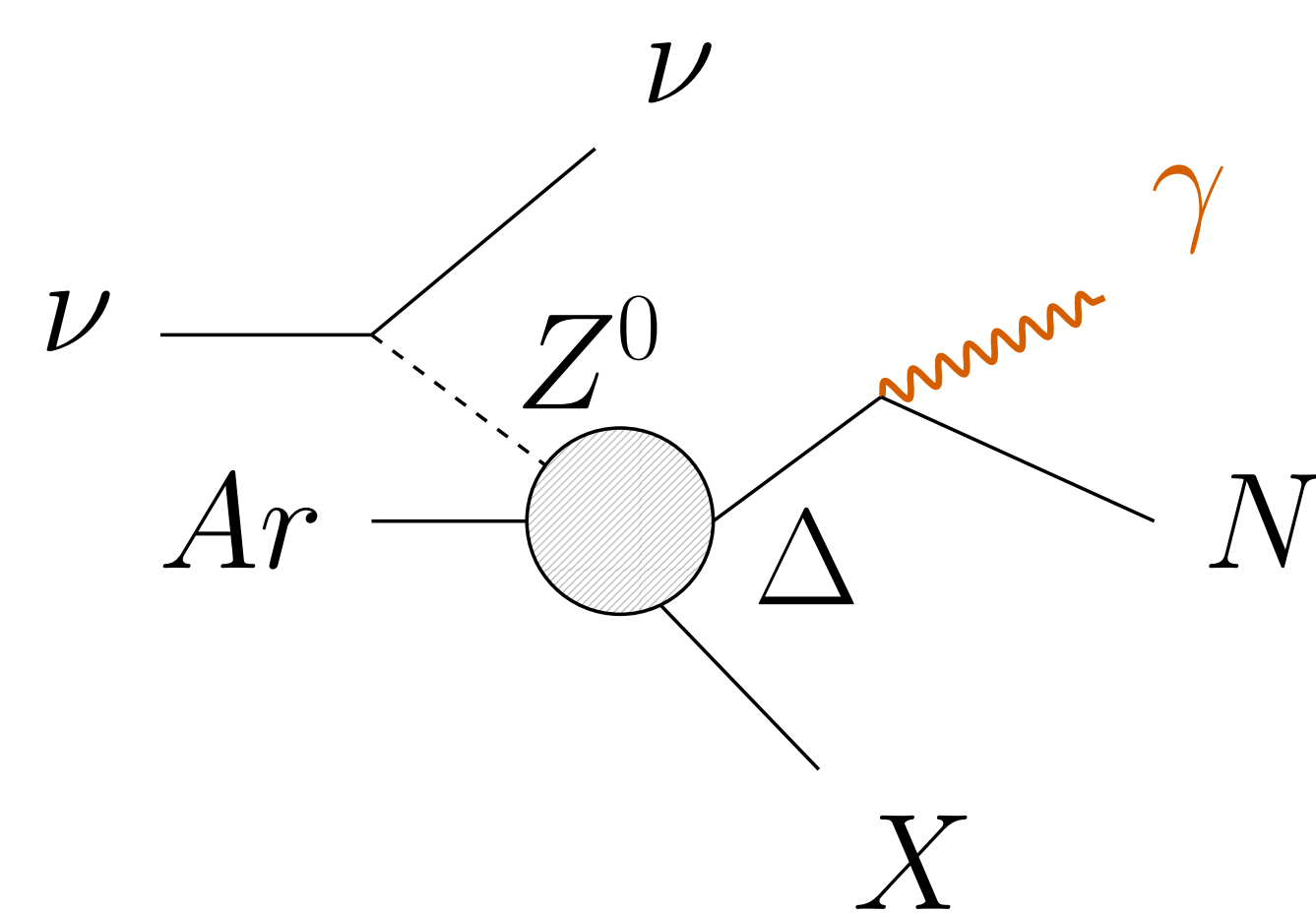
- SBND is a 112-ton liquid-argon TPC at Fermilab – the near detector of the Short-Baseline Neutrino Program.
- Reconstruction and selection of photon/electron electromagnetic (EM) showers underpins oscillation, cross-section, and rare-process measurements; photon final states probe BSM physics including the MiniBooNE low-energy excess [1].
- Built on SPINE [2] (Scalable Particle Imaging with Neural Embeddings) – an end-to-end, machine-learning reconstruction giving a full particle-level interaction hierarchy (Particle Identification Score (PID), vertex, kinematics). One chain serves many analyses, enabling a scalable physics program.
- Two complementary event selection efforts: $NC \pi^0$ (high-statistics benchmark) and $NC \Delta \rightarrow N \gamma$ (rare, single photon final state).

Benchmark: $NC \pi^0$ Photon Calibration

$NC \pi^0$ control samples give a data-driven validation of photon reconstruction and the calibration of the EM energy scale: the reconstructed π^0 mass, fit with a double-sided Crystal Ball, shows data/MC agreement at the true π^0 mass ($\approx 135 \text{ MeV}/c^2$), with an energy resolution of $\approx 7\%$ ($\sigma \approx 10 \text{ MeV}$).



Searching for $NC \Delta(1232) \rightarrow N \gamma$

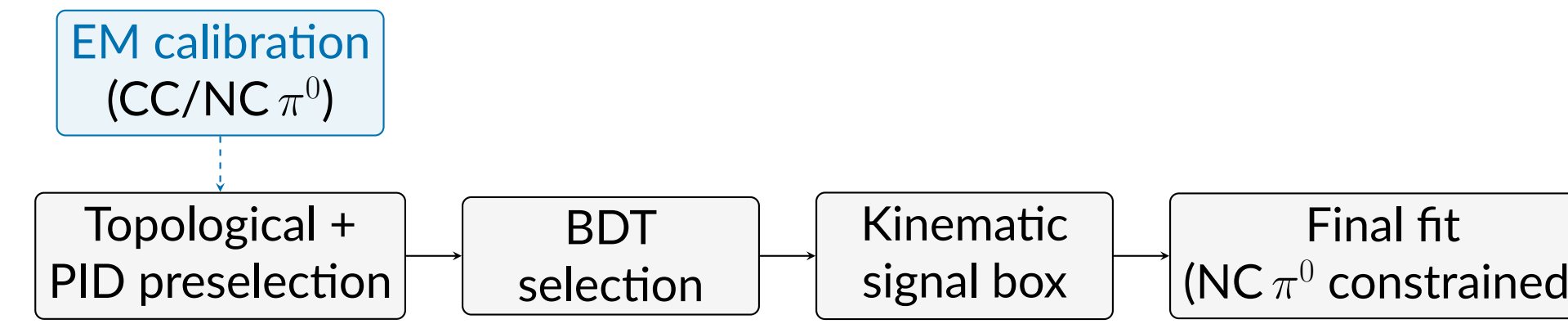


We search for NC resonant $\Delta(1232)$ production and radiative decay:

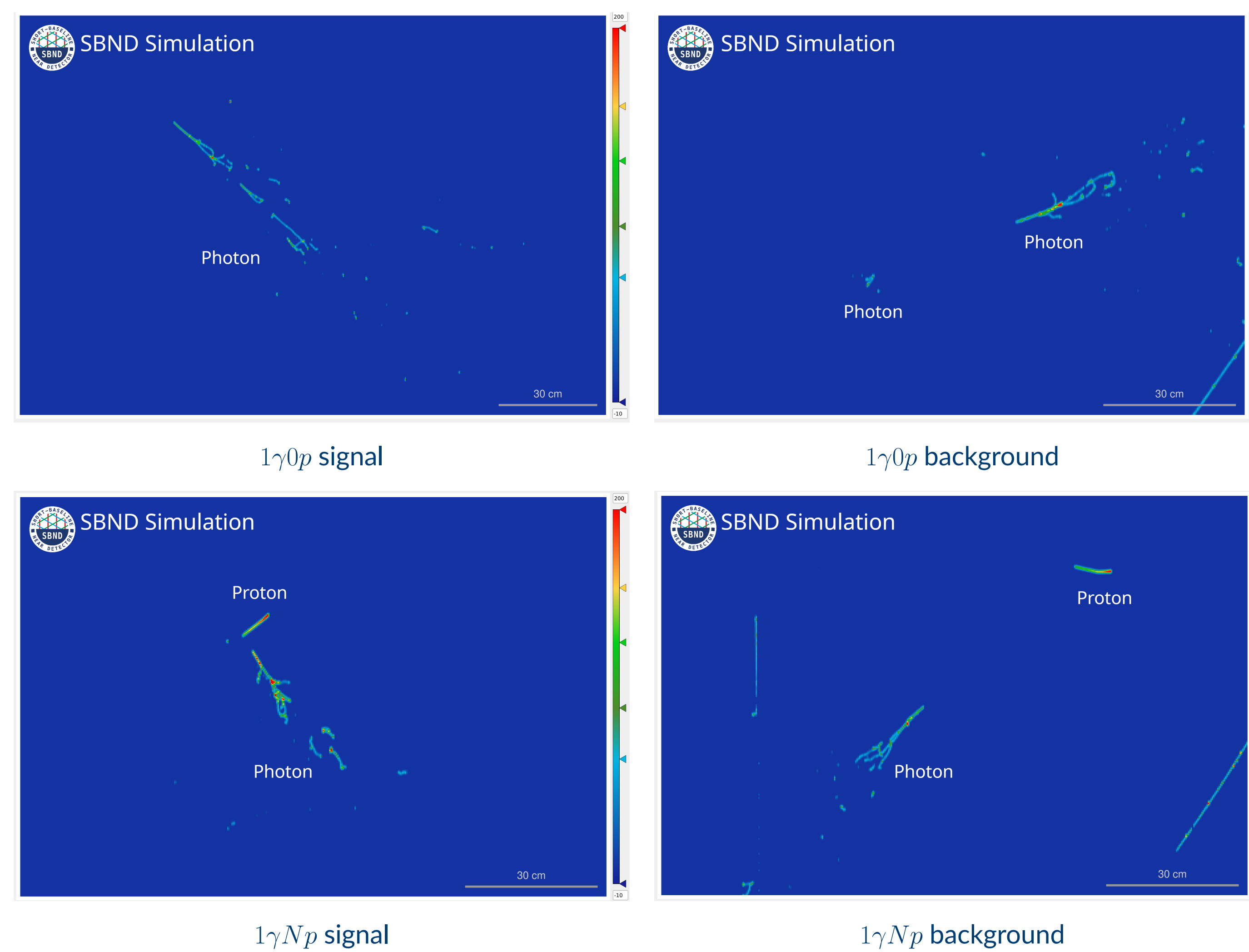
$$\nu + Ar \rightarrow \nu + \Delta(1232) \rightarrow \nu + N \gamma$$

- A rare process; previously probed by T2K, NOMAD, and MicroBooNE [3, 4], relevant to the MiniBooNE low-energy excess.
- Signal: $NC \Delta(1232)$ with exactly one photon and no $e/\mu/\pi^\pm$ ($E_k > 25 \text{ MeV}$), contained in the fiducial volume. SBND expects $\mathcal{O}(10^3)$ signal events for $\sim 6 \times 10^{20}$ POT (Run 1).
- Two exclusive channels by proton multiplicity ($E_k > 50 \text{ MeV}$): $1\gamma 0p$ (no protons) and $1\gamma Np$ ($N \geq 1$).

Analysis Strategy



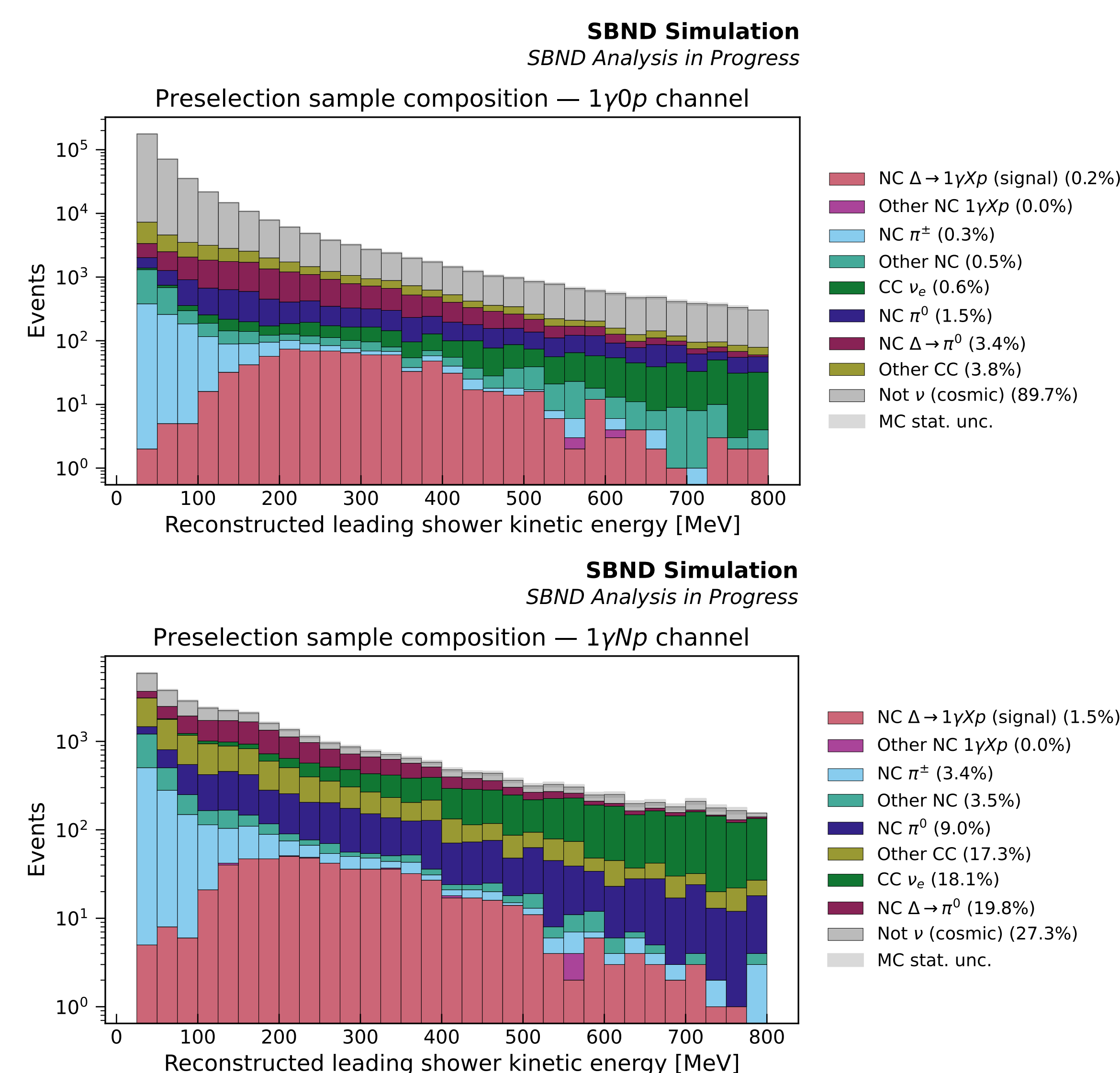
Examples of Selected NC Delta Radiative Decay Events



Left: $NC \Delta \rightarrow N \gamma$ signal (a single photon shower, plus a proton track for $1\gamma Np$). Right: $NC \Delta \rightarrow \pi^0$ background – a π^0 decay photon is lost, leaving a single-shower topology that mimics the signal.

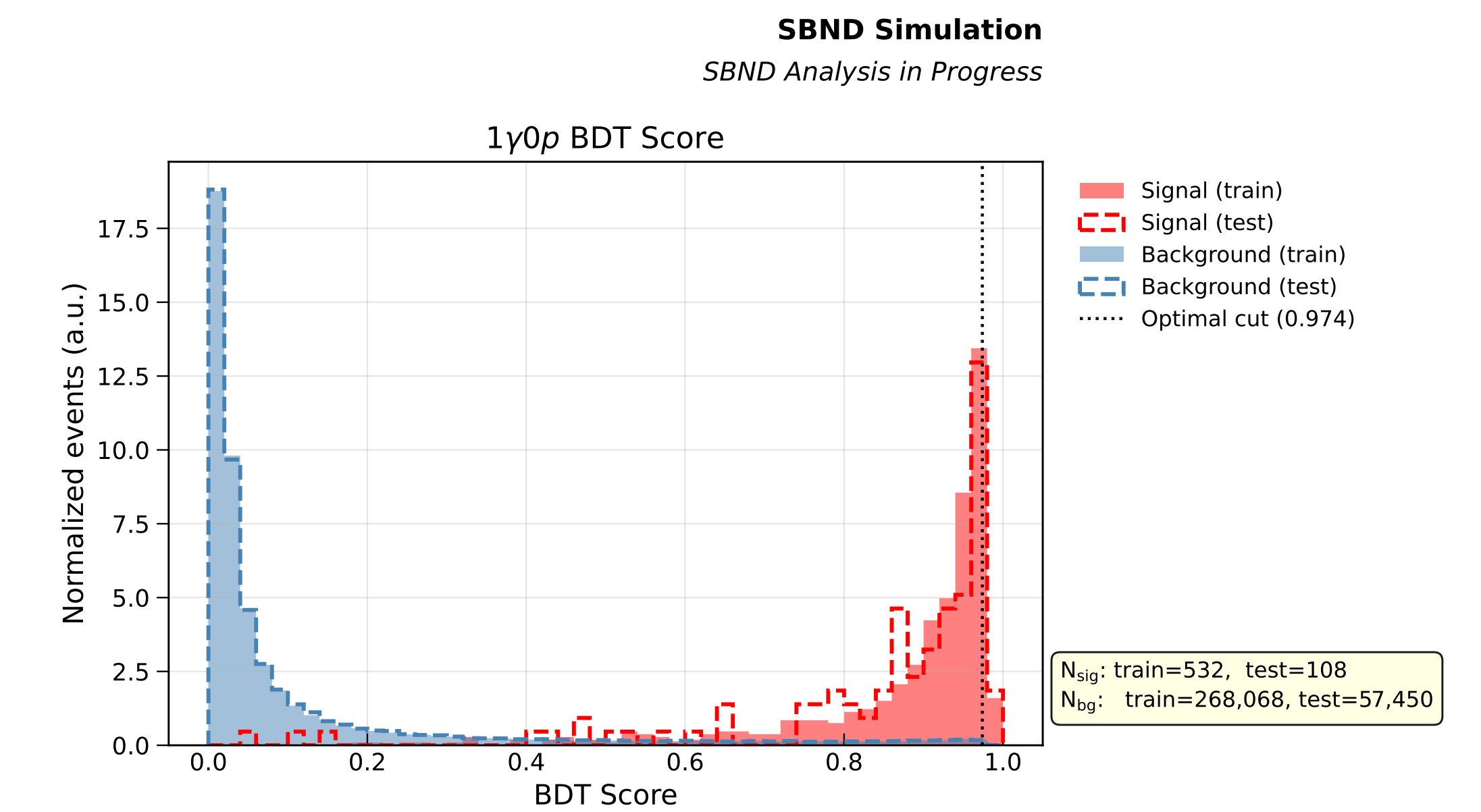
Preselection

A topology + PID preselection keeps exactly one reconstructed shower (no μ/π^\pm), contained in the fiducial volume. The sample is dominated by cosmics and $NC \pi^0$ events with one lost π^0 photon – motivating a multivariate selection.



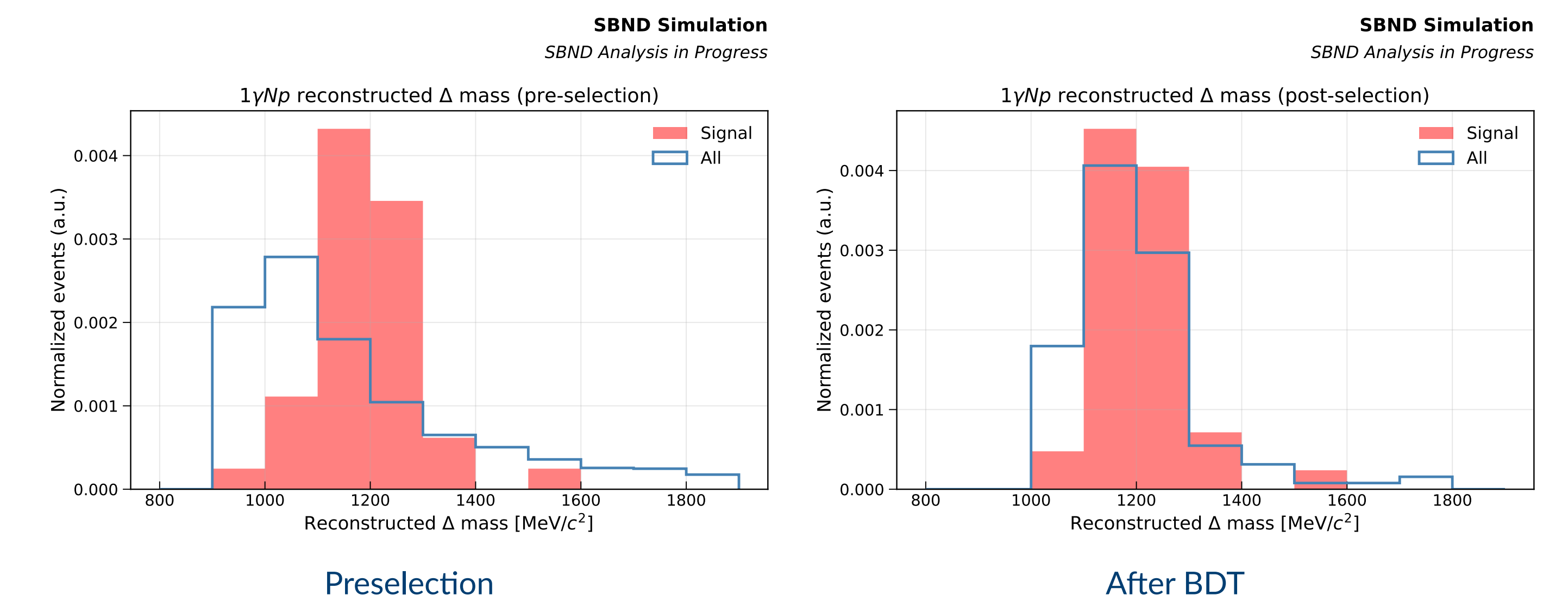
BDT Postselection

A per-channel XGBoost BDT separates $NC \Delta \rightarrow N \gamma$ signal from all backgrounds ($S/\sqrt{S+B}$ -optimised cut). The BDT withholds kinematic variables for a later signal-box fit, reaching ROC-AUC up to 0.97. Key discriminating variables: SPINE primary/photon scores (network confidence the shower is primary and is a γ), shower directional spread, shower start position, and subleading shower KE (flags $\pi^0 \rightarrow \gamma \gamma$ backgrounds in $1\gamma Np$).



Reconstructed $\Delta(1232)$ Mass

After the BDT, the reconstructed Δ mass (the invariant mass of the γ + leading p system in $1\gamma Np$) is enriched in signal and peaks near the nominal $\Delta(1232)$ mass of $1232 \text{ MeV}/c^2$.



Summary & Outlook

- SPINE shower reconstruction enables a diverse photon-final-state program at SBND which can exploit benchmark selections such as $NC \pi^0$ to validate photon reconstruction and the EM energy scale.
- SPINE-reconstructed π^0 invariant mass gives an energy resolution of $\approx 7\%$ ($\sigma \approx 10 \text{ MeV}$) at the π^0 mass.
- SBND's high flux enables a possible first measurement of the SM-predicted process $NC \Delta \rightarrow N \gamma$. A dedicated search is in progress; a preliminary selection chain shows promising results.

References

- A. A. Aguilar-Arevalo et al. "Updated MiniBooNE neutrino oscillation results with increased data and new background studies". In: *Phys. Rev. D* 103 (5 Mar. 2021), p. 052002.
- Francois Drielsma et al. *Scalable, End-to-End, Deep-Learning-Based Data Reconstruction Chain for Particle Imaging Detectors*. 2021. arXiv: 2102.01033 [hep-ex].
- P. Abratenko et al. "Search for Neutrino-Induced Neutral-Current Δ Radiative Decay in MicroBooNE and a First Test of the MiniBooNE Low Energy Excess under a Single-Photon Hypothesis". In: *Phys. Rev. Lett.* 128 (11 Mar. 2022), p. 111801.
- P. Abratenko et al. "Enhanced search for neutral current Δ radiative single-photon production in MicroBooNE". In: *Phys. Rev. D* 112 (9 Nov. 2025), p. L091101.

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