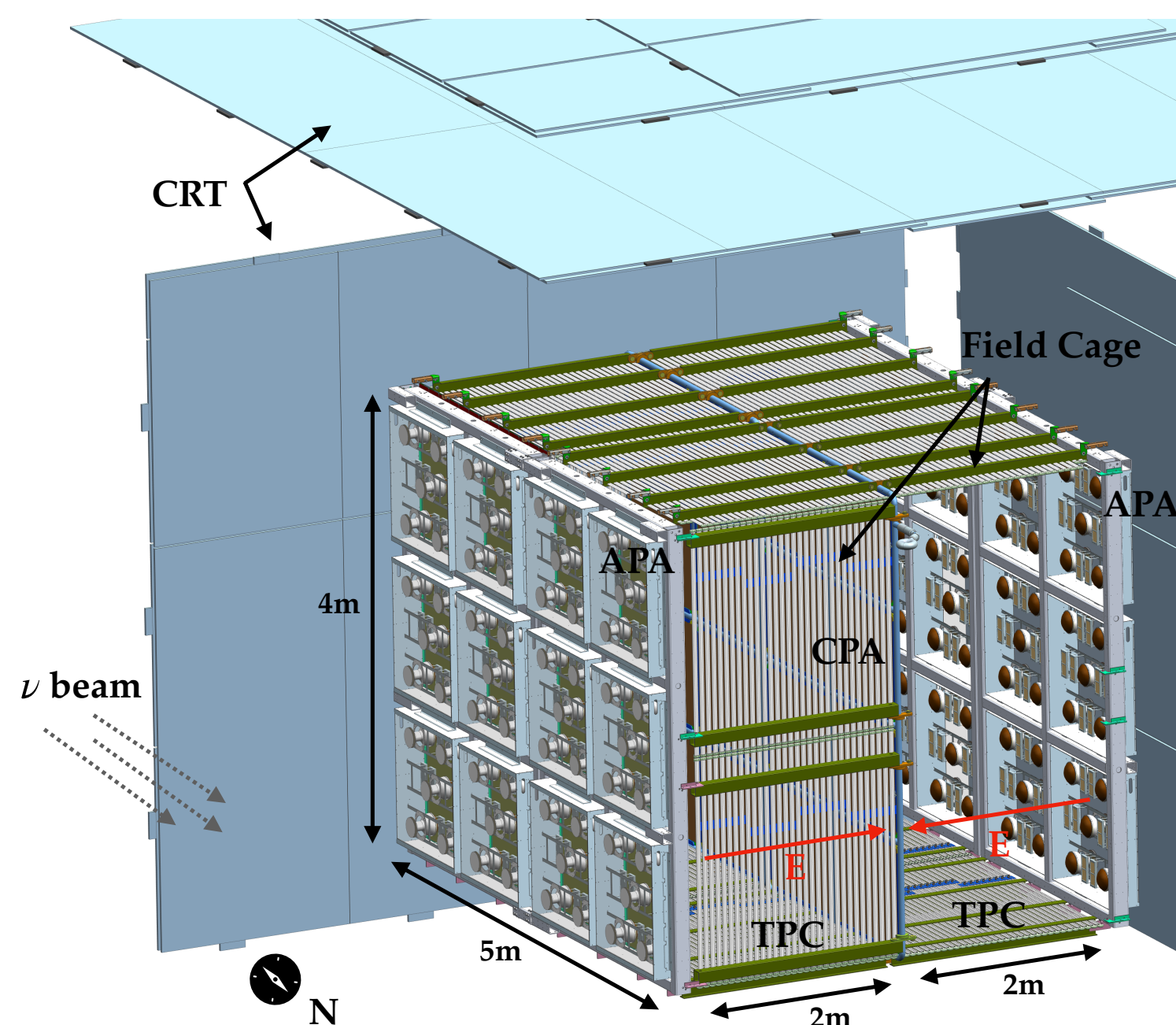


Timing reconstruction utilising multiple detection subsystems at the Short-Baseline Near Detector experiment



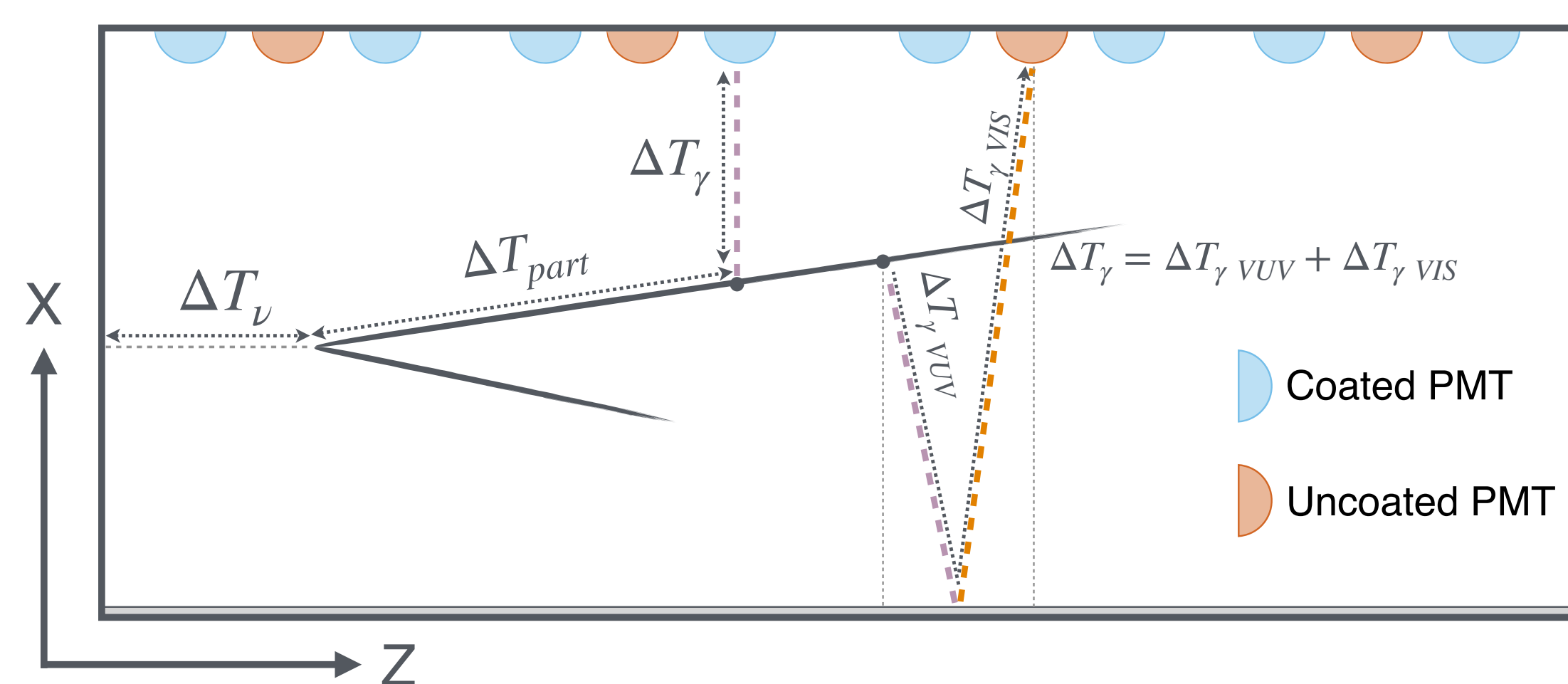
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1. The Short-Baseline Near Detector (SBND)



- SBND is a **Liquid Argon Time Projection Chamber (LArTPC)** of 112 t active volume.
- Anode planes are made up of **3 wire planes** oriented at distinct angles to enable 3D charge reconstruction.
- Photon detection subsystems include 120 TPB-coated/uncoated **PhotoMultiplier Tubes (PMTs)**, 192 **XARAPUCAs**, and **TPB-coated reflective foils** at the cathode to detect VUV and wavelength-shifted visible scintillation photons.
- 7 Cosmic Ray Taggers (CRTs)**, made up of perpendicular plastic scintillators, surround the TPCs to tag cosmic muons.

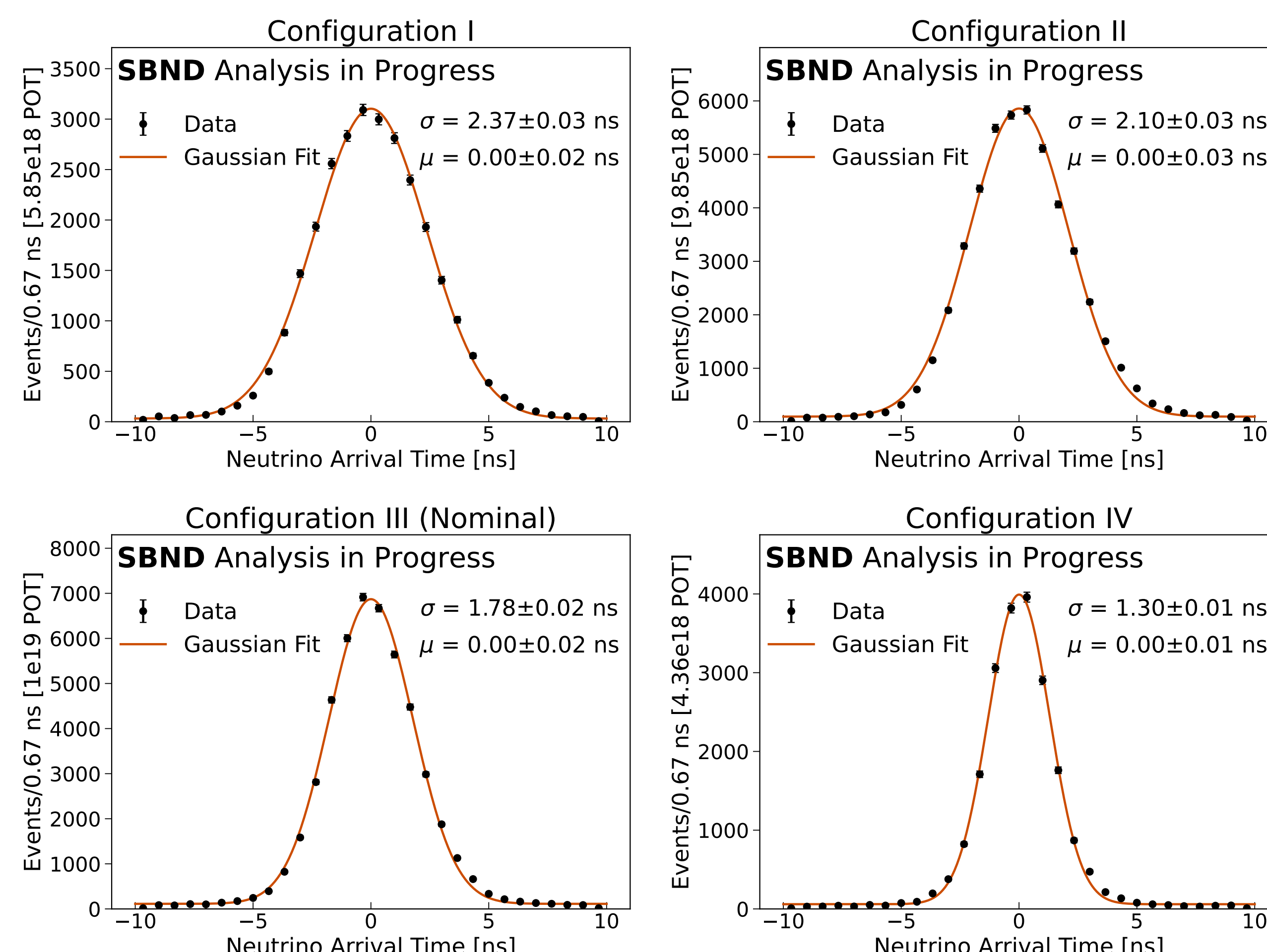
2. Timing Reconstruction Utilising Light and Charge



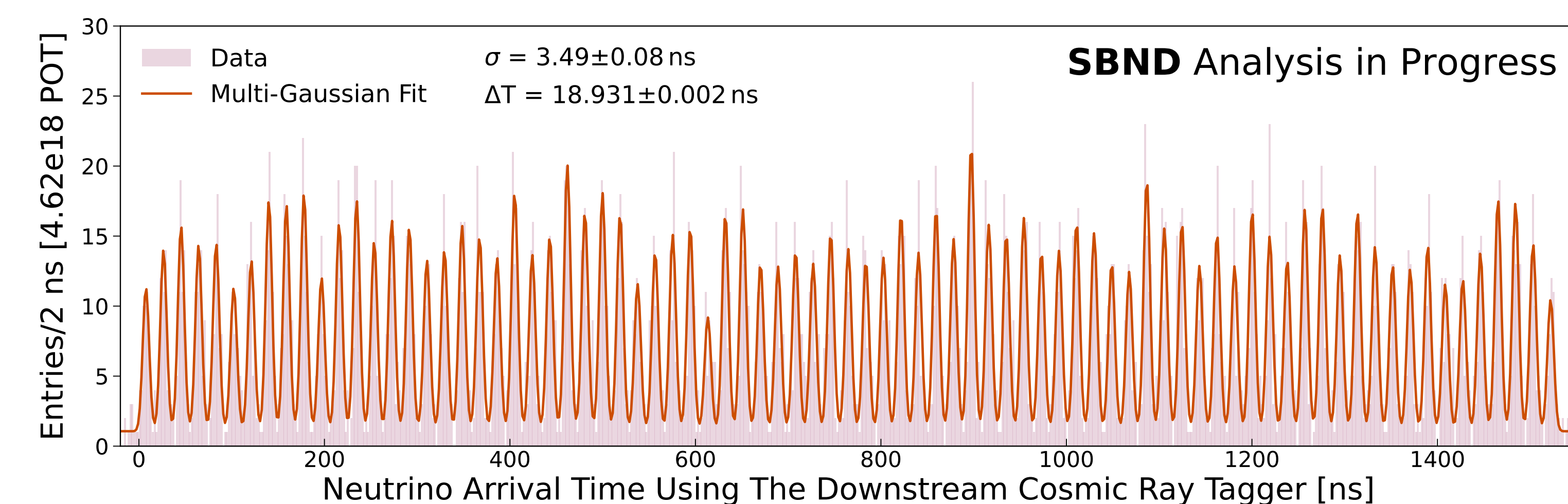
- PMT and charge signals are matched by minimising the distance between the two weighted centres.
- PMT & charge signals enable correction for the photon Time-of-Flight (ToF), ΔT_γ , from the scintillation location to PMTs.
- Charge signals enable correction for the daughter particle ToF, ΔT_{part} , and the neutrino ToF, ΔT_ν .
- Combining light and charge enables ns-level reconstruction of neutrino interaction timing.**

3. Probing Various Booster Neutrino Beam Configurations

- The detector timing resolution σ_D utilising light and charge was evaluated by reconstructing the Booster Neutrino Beam (BNB) timing structure, consisting of 81 Gaussian bunches.
- BNB configuration I, II, III (nominal) and IV bunch widths are reported to be $\mathcal{O}(2.1 \text{ ns})$, $\mathcal{O}(1.7 \text{ ns})$, $\mathcal{O}(1.3 \text{ ns})$ and $\mathcal{O}(0.8 \text{ ns})$.
- An upper limit is set on the detector timing resolution utilising light & charge:**
 $\sigma_D \leq 1.30 \text{ ns}$



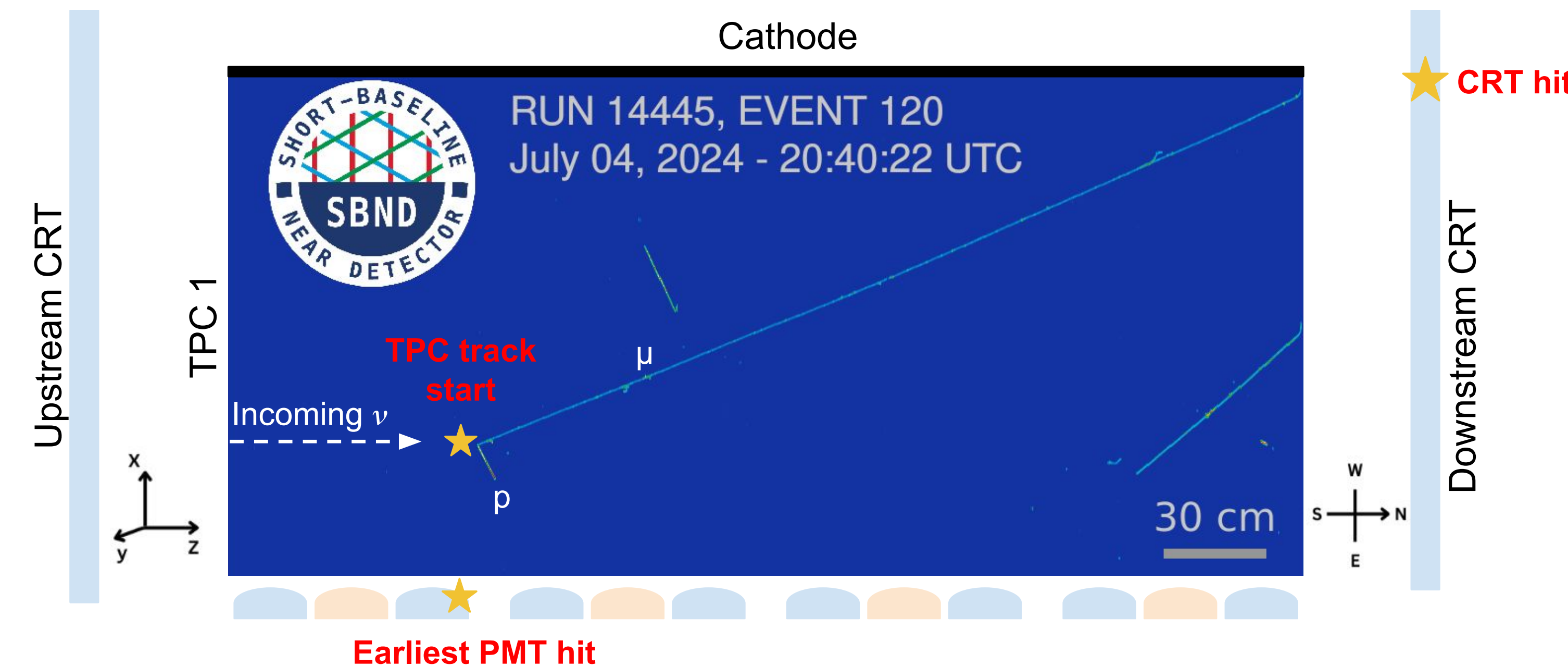
4. Booster Neutrino Beam Reconstruction Utilising Cosmic Ray Taggers



- The downstream CRT is exposed to a high flux of exiting muons from neutrino interactions inside the TPCs.
- For the BNB configuration I $\mathcal{O}(2.1 \text{ ns})$, CRT signals resolved with $\sigma_{\text{CRT}} = 3.49 \text{ ns}$.**

5. Selecting Muons for Time-of-Flight Calculation

- CRT signals within the beam spill
- CRT, charge & PMT signals matched in the same TPC
- Track start/end (furthest from CRT signals)
- Earliest PMT signals $> 20 \text{ PE}$ near track start/end
- Muon ToF = $t_{\text{CRT}} - t_{\text{PMT}}$



6. Muon Time-of-Flight Application

- Left peak — entering muons:** CRT signals precede scintillation light in the TPCs.
 - Off-beam: Cosmic muons from above pass through top CRTs.
 - On-beam: Muons from charged current ν_μ interactions in the dirt in front of the detector cross the upstream CRT.
- Right peak — exiting muons:** Scintillation light precedes the muon reaching the CRTs.
 - On-beam: Muons from charged current ν_μ interactions inside the TPCs exit through the downstream CRT.
- SBND's CRT-PMT timing achieves $\mathcal{O}(\text{few ns})$ resolution, enabling neutrino identification through time-of-flight.**

