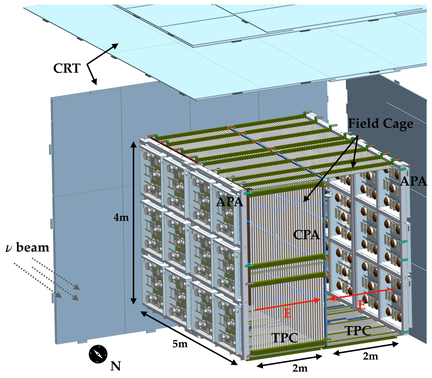
Timing reconstruction utilising multiple detection subsystems at the Short-Baseline Near Detector experiment

Annalea Corallo & Nguyễn Vũ Chi Lan on behalf of the SBND collaboration

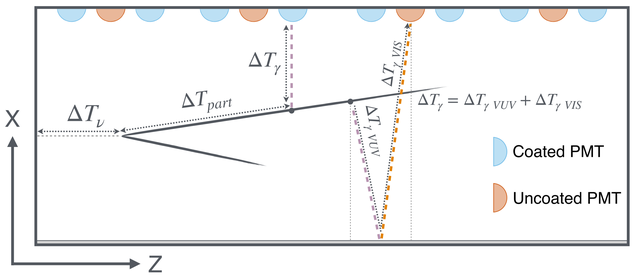
annalea.corallo@fe.infn.it | vclnguyen@ucsb.edu

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

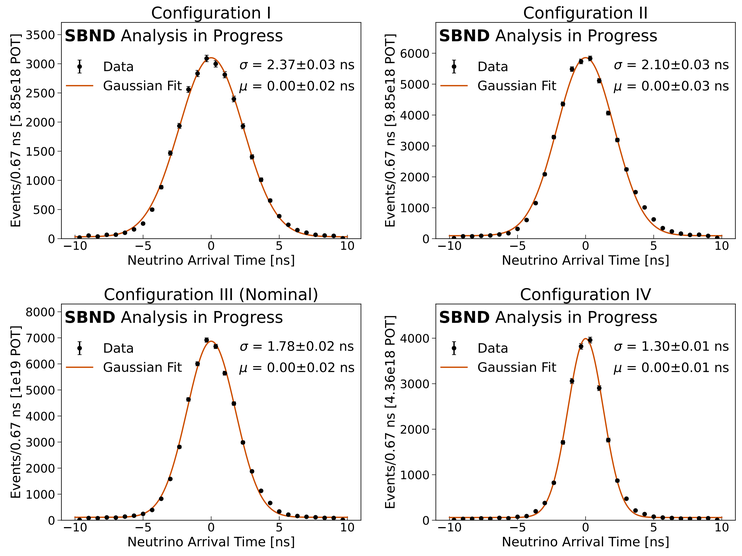


- PMT and charge signals are matched by minimising the distance between the two weighted centres.
- PMT & charge signals enable correction for the photon Time-of-Flight (ToF), ΔT_γ, from the scintillation location to PMTs.
- Charge signals enable correction for the daughter particle ToF, ΔT_{part}, and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

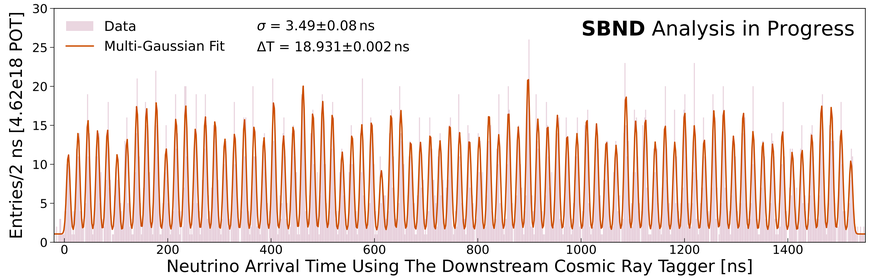
3. Probing Various Booster Neutrino Beam Configurations

- 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

↓

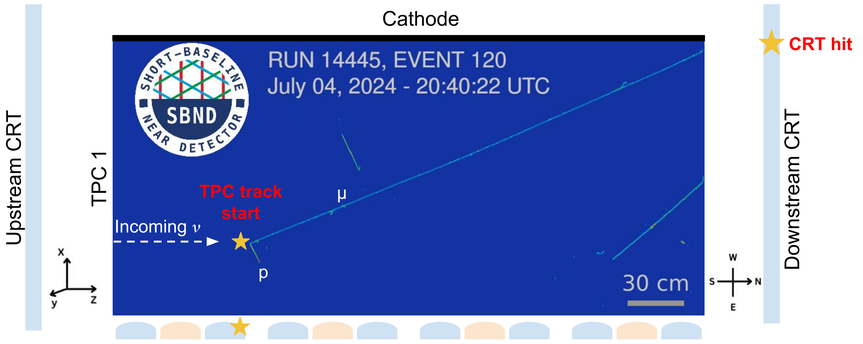
Track start/end (furthest from CRT signals)

↓

Earliest PMT signals > 20 PE near track start/end

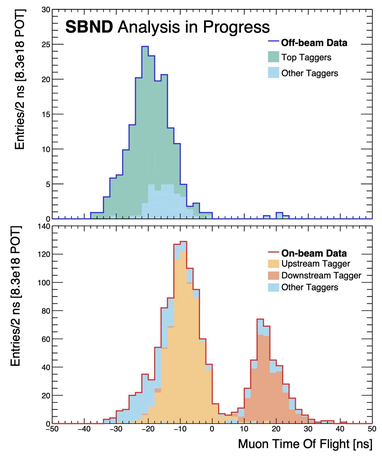
↓

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 $\mathcal{O}$(few ns) resolution, enabling neutrino identification through time-of-flight.**



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