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Proceeding Paper

Status of the Short-Baseline Near Detector at Fermilab †

Miquel Nebot-Guinot on behalf of the SBND Collaboration

Institute for Particle and Nuclear Physics, University of Edinburgh, Edinburgh EH8 9YL, UK; miquel.nebot@ed.ac.uk

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Abstract: The Short-Baseline Near Detector (SBND) will be one of three Liquid Argon Time Projection Chamber (LArTPC) neutrino detectors positioned along the axis of the Booster Neutrino Beam (BNB) at Fermilab, as part of the Short-Baseline Neutrino (SBN) Program. The detector is currently in the construction phase and is anticipated to begin operation in 2023. SBND is characterized by superb imaging capabilities and will record over a million neutrino interactions per year. Thanks to its unique combination of measurement resolution and statistics, SBND will carry out a rich program of neutrino interaction measurements and novel searches for physics beyond the Standard Model (BSM). It will enable the potential of the overall SBN sterile neutrino program by performing a precise characterization of the unoscillated event rate, and by constraining BNB flux and neutrino–argon cross-section systematic uncertainties. In this proceedings article, the physics reach, current status, and future prospects of SBND are discussed.

Keywords: neutrino; short-baseline oscillation; particle detectors

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1. Introduction

In recent years, some neutrino experiments have revealed anomalous results pointing towards our incomplete understanding of the full picture of neutrino physics. Particularly, evidence of an electron-like Low-Energy Excess (LEE) from neutrinos from particle accelerators at LSND [1] and MiniBooNE [2] proves the need for further testing of the short-baseline neutrino oscillation scenario. These LEE anomalies, when interpreted as neutrino oscillations, point to an extension of the three-flavor neutrino model and could be explained by the existence of at least one heavier sterile neutrino. Nevertheless, the LEE could also come from limitations intrinsic to Cherenkov detectors, which cannot discriminate electron-like from gamma-like signals. In order to definitively resolve the nature of the MiniBooNE-like signal, the Short-Baseline Neutrino (SBN) program at Fermilab was proposed [3].

2. The Short-Baseline Neutrino Program

The aim of the SBN program is to fully resolve the question of the existence of sterile neutrinos and, additionally, perform world-leading cross-section measurements and BSM searches while developing the liquid-argon neutrino technology for the future Long-Baseline Neutrino program [4]. It is a multi-detector facility located on the Booster Neutrino Beam (BNB) at Fermilab (see Figure 1), with all detectors using the same accelerator beam, nuclear target and detector technology to reduce systematic uncertainties to the percentage level. The neutrino beam—which was also used by MiniBooNE—is generated from pions decaying in flight [5] and the technology used for the three detectors is Liquid Argon Time Projection Chambers (LArTPC). MicroBooNE, located 470 m from the source close to the MiniBooNE experiment site, was the first LArTPC in BNB and used 170 t of liquid argon [6]. It finished collecting data in 2021 and is still processing its full dataset, but the first results using half of its data have already been published with no evidence of low-energy excess. However, the significance of the measurement was insufficient to rule out the sterile neutrino hypothesis [7]. The SBN far detector, ICARUS, is currently taking data at 600 m from the source using 760 t of LAr [8]. For a full oscillation analysis, a near detector is needed close to the neutrino source. The Short-Baseline Near Detector (SBND) is located 110 m from the neutrino beam source and will use 260 t of LAr. The status of its construction and commissioning is the topic of this article.

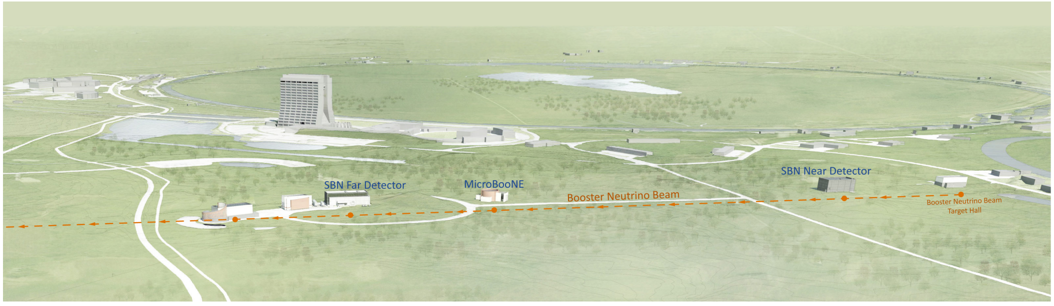

Figure 1. Fermilab map showing the locations of the three SBN detectors and the BNB [4].

Liquid Argon Time Projection Chambers

Liquid Argon Time Projection Chamber (LArTPC) detectors have become the technology of choice for many neutrino experiments due to their excellent tracking and calorimetry achieved by detecting ionization and scintillation signals produced in the argon by the products of neutrino interactions. In a LArTPC, when a charged particle interacts within the LAr in the detector, it ionizes and excites argon atoms. Ionized electrons (typically 42,000 e^-/MeV) are drifted towards a charge readout plane by a 500 V/cm electric field. The response time of the TPC is a few ms, dependent on the purity of the argon. In the meantime, the scintillation light (128 nm) produced by the de-excitation of the argon dimers (40,000 γ/MeV) is recorded by photo-detectors located behind the charge readout with a response time O(10 ns), and provides signals for timing and triggering [9]. The combination of the different charge readout planes and the timing from the optical readout provides full 3D image reconstruction. This technology is capable of identifying different species of particles, reconstructing 3D images with fine-grained information and measuring the energy deposited. All of this translates to precise neutrino vertex interaction and particle flow identification, excellent calorimetry, discrimination between charged-particle tracks and electromagnetic particle showers and, crucially, the electron–gamma distinction needed to resolve the MiniBooNE anomaly.

3. SBND Physics Program

The SBND experiment will start collecting data in 2023, with three main goals:

- It will resolve the question of the existence of the sterile neutrino by constraining the unoscillated flux as a part of the Short-Baseline Neutrino program for sterile neutrino searches. The near detector plays a fundamental role in answering whether the MiniBooNE low-energy excess is intrinsic to the BNB, or if it appears along the beam line, indicating a sterile oscillation [10];
- Likewise, SBND, with its improved particle identification and momentum resolution capabilities, and with the large number of neutrinos it will detect given its target proximity (it will be the largest sample of neutrino–argon interactions to date), will perform the most precise neutrino cross-section measurements;
- In addition, SBND will search for new physics beyond the Standard Model [11].

In more detail, the SBND cross-section program will expand the studies of neutrino–argon interactions in the GeV energy range (where nuclear effects play a major role and complicate the energy reconstruction of neutrino interactions) with unprecedented precision, a key requirement for future LArTPC neutrino experiments, using its largest-ever sample of $\nu - Ar$ interactions. It will observe 5000 ν-events per day, and 1.5 million ν_μ

CC events and 12,000 ν_e in one year (see Figure 2. Additionally, SBND's vicinity to the neutrino-bea target will allow the measurements of many rare channels such as heavy-baryon production (Δ^0, Σ^+), NC coherent single-photon production, etc., and will cover peaks of kinematic area relevant for DUNE.

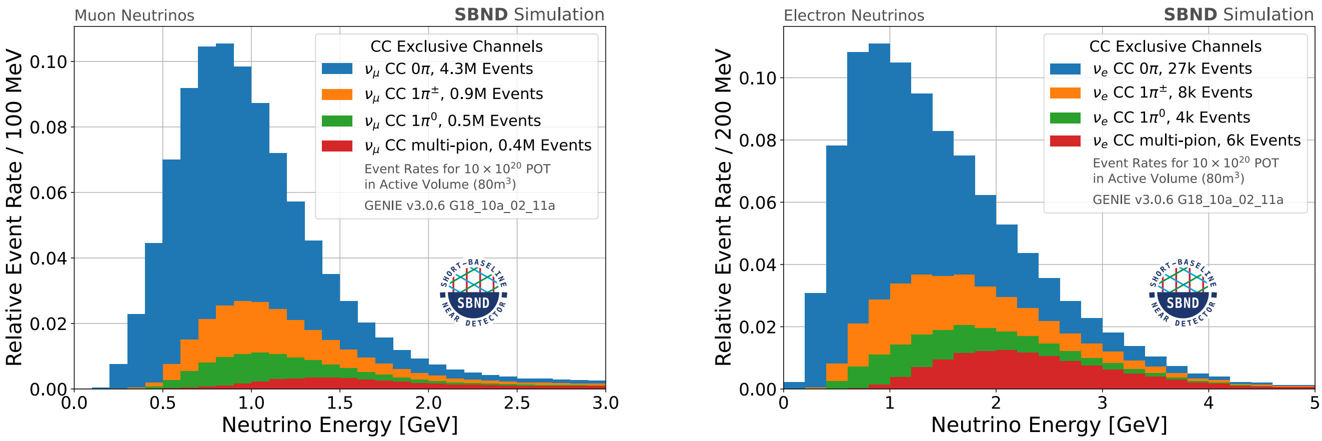

Figure 2. Number of expected muon (**left**) and electron (**right**) neutrinos in SBND during 4 years of data collection, separated by interaction channel (note the different scales).

4. The Short-Baseline Near Detector: Description and Status

The SBND is a multi-component system with three different detectors: the Time Projection Chamber (TPC), the Photon Detection System (PDS) and an external Cosmic Ray Tagger (CRT). The TPC and the PDS are inside the liquid-argon-filled cryostat.

The 4 m wide, 4 m high and 5 m long (in the beam direction) TPC is made up of an opaque cathode plane in the middle, and two sets of wired Anode Plane Assemblies (APA) on both sides, creating two separate two-meter-long drift time projection chambers (Figure 3 shows the left one). To drift the ionized electrons, a field cage surrounds each drift volume and the cathode is biased at −100 kV, providing a 500 V/cm electric field and a maximum drift time of 1.28 ms. The APAs record the drifted ionized electrons via three wire planes: one collection plane with vertical wires and two induction planes with wires at ±60° from vertical. Each APA has 11,264 wires with 3 mm wire pitch, and front-end readout electronics, installed on the frames (cold electronics). The TPC has been assembled, and was finalized in June 2022, in a separate facility inside a temporary clean room tent. It will later be moved to its final place inside the cryostat.

The Photon Detection System is a modular assembly situated behind the APAs (see Figure 4), consisting of 24 modules (12 per side) and the TPB (tetraphenyl butadiene, 127 nm to 430 nm, wavelength-shifted)-coated reflector foils on the cathode. The PDS records the scintillation light by looking inside the TPC with modules of 5 8-inch Hamamatsu R5912-mod Cryogenic PMTs and 8 X-ARAPUCAs, giving a total of 120 PMTs and 192 X-ARAPUCAs. In each module, the four corner-placed PMTs are TPB-coated, while the central ones are uncoated. Likewise, half of the X-ARAPUCA light traps (internally reflecting light cells guiding the photons towards a SiPM detector) [12] are coated with TPB and installed in pairs with uncoated ones that aim to read the cathode wavelength-shifted reflected photons. This combined system recording scintillation and reflected light provides a more uniform light yield and an excellent timing resolution. The PDS installation was finished in September 2022.

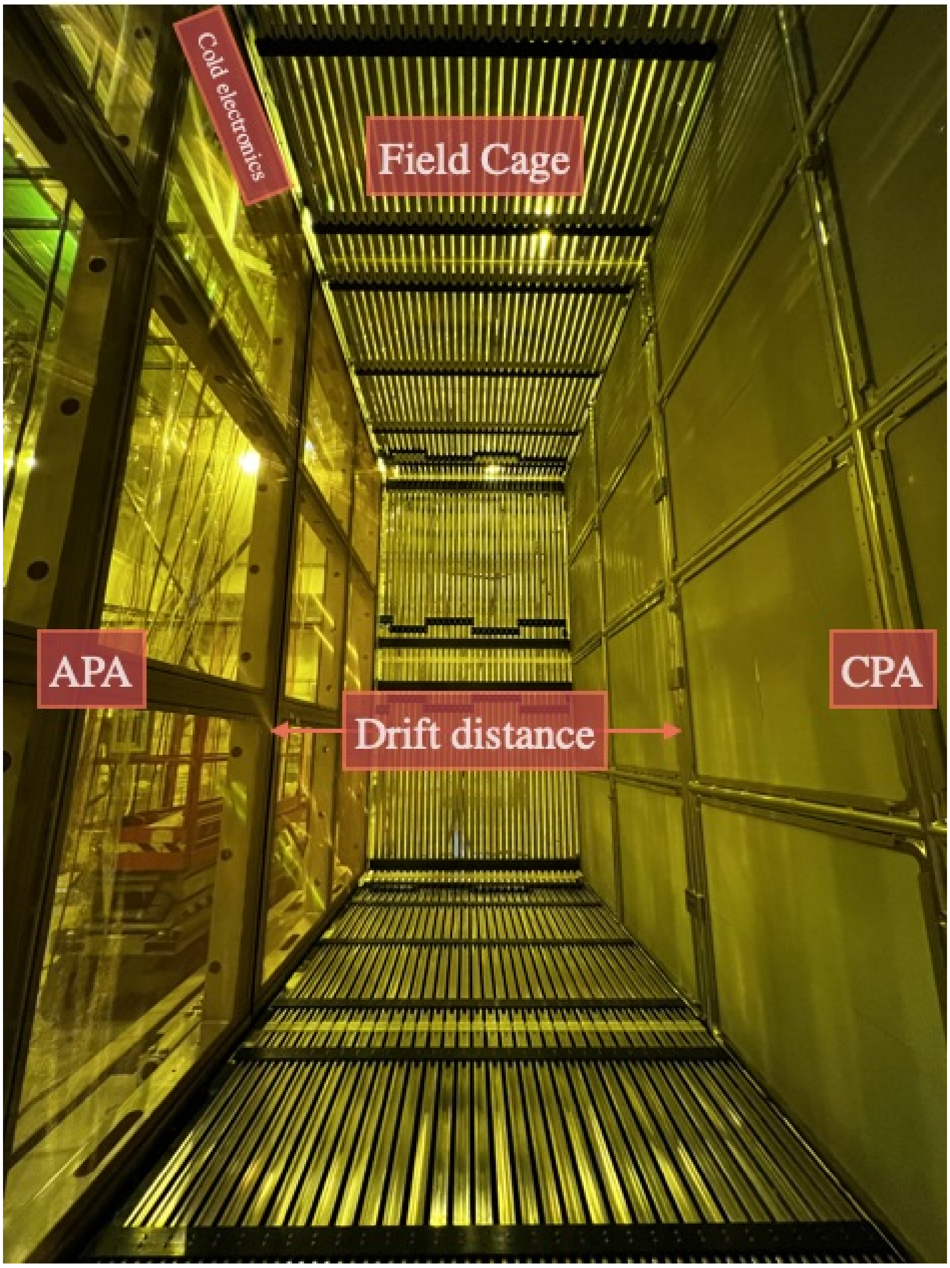

Figure 3. Picture of the assembled TPC showing the left-hand-side drift volume, with the main components labeled.

As with any surface-installed detector, SBND will be constantly bombarded with cosmic-ray-generated particles. In order to mitigate this background of cosmic rays, SBND will be equipped with a Cosmic Ray Tagger system surrounding the six sides of the detector. This full coverage will identify out-of-time tracks: entering, exiting and crossing cosmic-ray muons. The CRT system is made out of 135 single modules (1.8 m $\times$ 1.8 m and 4.5 m $\times$ 1.8 m) of extruded scintillator strips read out by SiPMs. A temporary "muon-beam telescope", consisting of CRT modules installed on the upstream and downstream walls of the SBND cryostat, enabled the DAQ and electronics for the PMTs, CRT, beam and trigger systems to be commissioned before the LAr commissioning phase. The complete CRT will be installed and integrated last, but the bottom CRT panels, below the cryostat, are already in place.

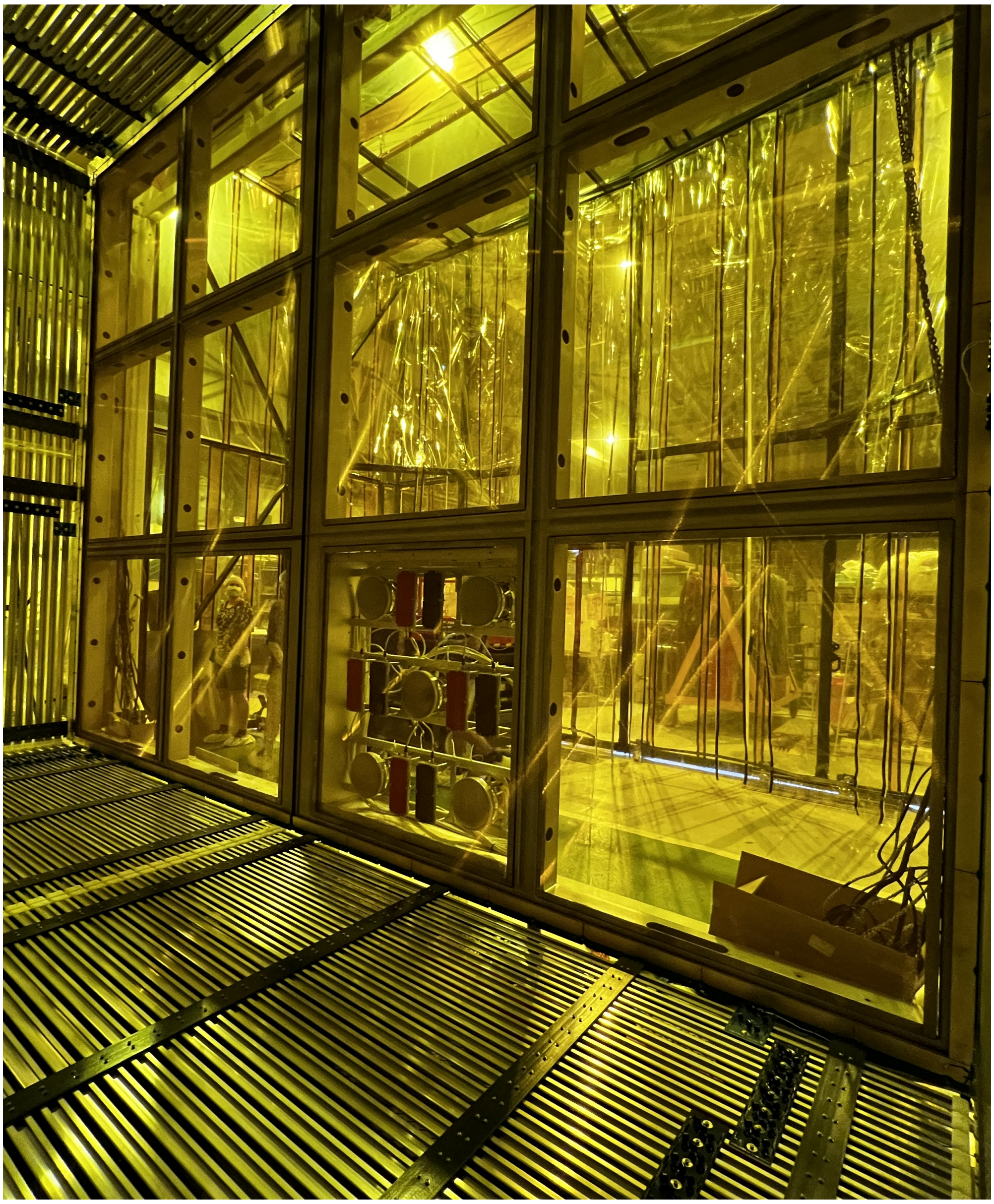

Figure 4. Picture of the right-hand-side TPC during the PDS installation, showing one of the PDS modules installed behind the APA.

The SBND liquid-argon host is a membrane type identical to that planned for the future DUNE far detectors. It consists of a stainless-steel I-beam outer cryostat of 9.3 m $\times$ 7.5 m $\times$ 7.6 m, with two layers of 40 cm insulation blocks and a secondary membrane in between. An innermost layer of corrugated stainless steel acts as the primary membrane. Its construction was finished in September 2022. The next steps in the SBND construction will be the moving and installation of the already-assembled TPC (including the PDS). This will begin its commissioning phase with cryogenic operations at the beginning of summer 2023.

5. Summary

The near detector of the Short-Baseline Neutrino program at Fermilab will play a fundamental role in constraining the unoscillated BNB flux to definitively address the MiniBooNE anomaly in sterile neutrino searches. Additionally, SBND will accumulate an unprecedented number of neutrino interactions in argon, enabling a high-precision cross-section program, as well as new physics searches. Great progress in SBND installation has been achieved, and the cryostat, TPC and PDS have already been assembled and are ready to be installed, while commissioning activities before cryogenic operations have been completed as well.

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Conflicts of Interest: The authors declare no conflict of interest.

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