PROCEEDINGS OF SCIENCE

FNAL SBN Program status

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The Short Baseline Neutrino Program at Fermilab aims at timely delivering a rich and compelling physics opportunity, including the ability to perform the most sensitive search to date for sterile neutrinos at the eV mass-splitting-scale through both appearance and disappearance oscillation channels.

It consists of the three liquid argon TPC detectors SBND, MicroBooNE and ICARUS, exposed to the Booster Neutrino Beamline (BNB) at different baselines. The current status and perspectives of the program and each detectors are hereby presented.

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1. Introduction

The Short Baseline Neutrino Program (SBN) was proposed to the Fermilab Physics Advisory Committee (PAC) in 2015 [1] for definitively solving the "puzzling picture" of neutrino oscillations over short baseline, that results from several anomalous experimental results over the last 20 years that do not fit into the standard landscape of 3-flavour neutrino mixing (**Table 1**).

Independent observations of disappearance of $\overline{\nu}_e$ from nearby nuclear reactors [2], disappearance of ν_e from intense calibration sources in solar ν experiments [3] and appearance of $\nu_e/\overline{\nu}_e$ in $\nu_\mu/\overline{\nu}_\mu$ beams at particle accelerators [4][5] are possibly explained by nonstandard "sterile" neutrino state(s) driving oscillations at $\Delta m^2_{new} \approx 1\ eV^2$ and relatively small $\sin^2(2\vartheta_{new})$, although no model so far has been successful in fitting all experimental results at once.

Experiment	Type	Channel	Significance
LSND	DAR accelerator	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8 σ
MiniBooNE	SBL accelerator	$\nu_\mu \rightarrow \nu_e$	4.5 σ
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8 σ
GALLEX/SAGE	Source – e capture	ν_e disappearance	2.8 σ
Reactors	β decay	$\bar{\nu}_e$ disappearance	3.0 σ

Table 1. *Summary of experimental anomalies in short baseline neutrino oscillation experiments.*

The SBN Program has the unique possibility to address both ν_e appearance and ν_μ disappearance at the same time by exploiting the very well characterized FNAL Booster ν beamline (BNB) and three detectors based on the same liquid argon TPC technique (**Figure 1**).

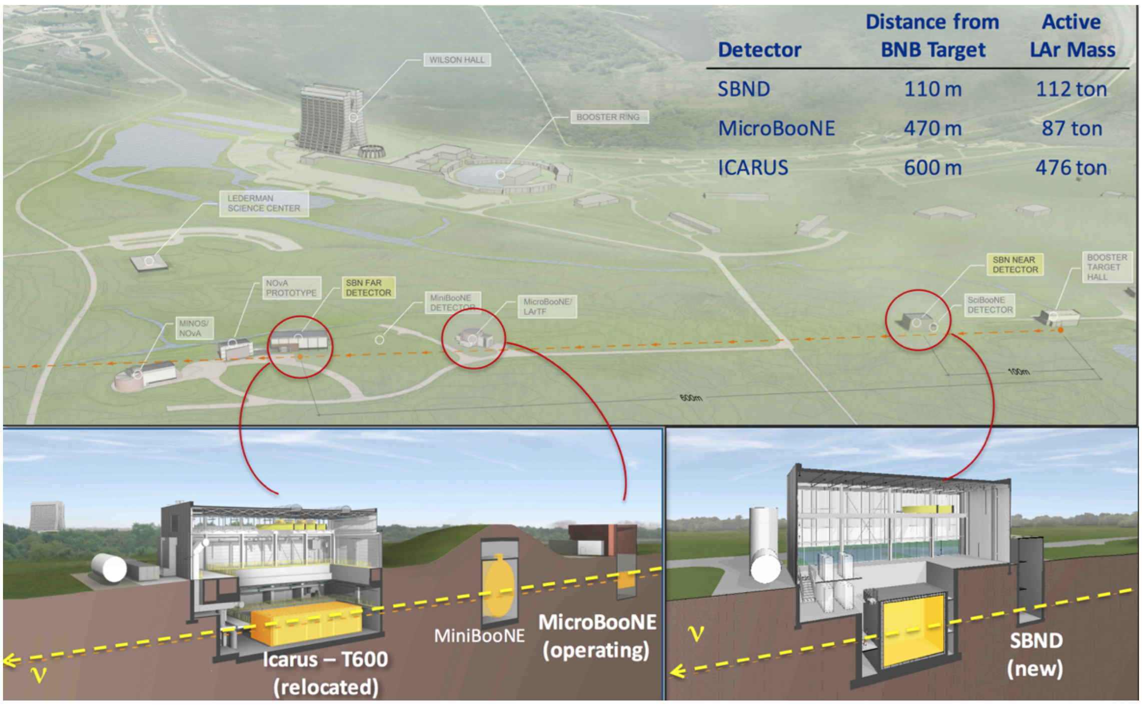

Figure 1*. Layout of the SBN Program at Fermilab, with positions and masses of the constituent detectors.*

2. Physics reach of the SBN Program

SBN has a staged physics program, consisting in:

- understanding the nature of the MiniBooNE "low energy" excess anomaly, using the MicroBooNE detector by itself (Phase I).
- searching for short baseline oscillations both in appearance and disappearance channels, by adding the SBND and ICARUS near and far detectors (Phase II).

Sample event spectra of charge-current electron neutrino events expected at the three detectors in Phase II, with the signal corresponding to the best fit (Δm^2_{new}, $\sin^2(2\vartheta_{new})$) point from reference [6], are shown in **Figure 2**.

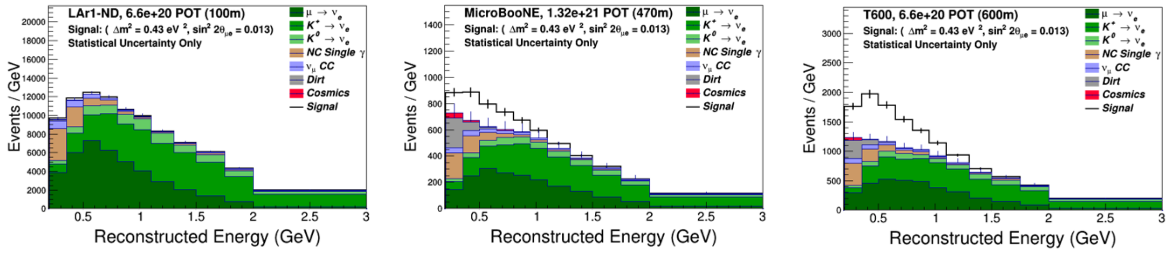

Figure 2. *Simulated event spectra for ν_e-CC events at the three SBN detectors*

Leveraging the MiniBooNE expertise in simulating BNB neutrino fluxes and partial cancelations in systematic uncertainty ensured by correlations between detectors (same beam and experimental technique), the LSND 99% C.L. region will be covered at ~ 5 σ level and sensitivity to ν_μ disappearance will be extended by one order of magnitude beyond present limits in 3 years of data taking with positive focusing of the BNB, i.e. with a primarily ν_μ beam (**Figure 3**).

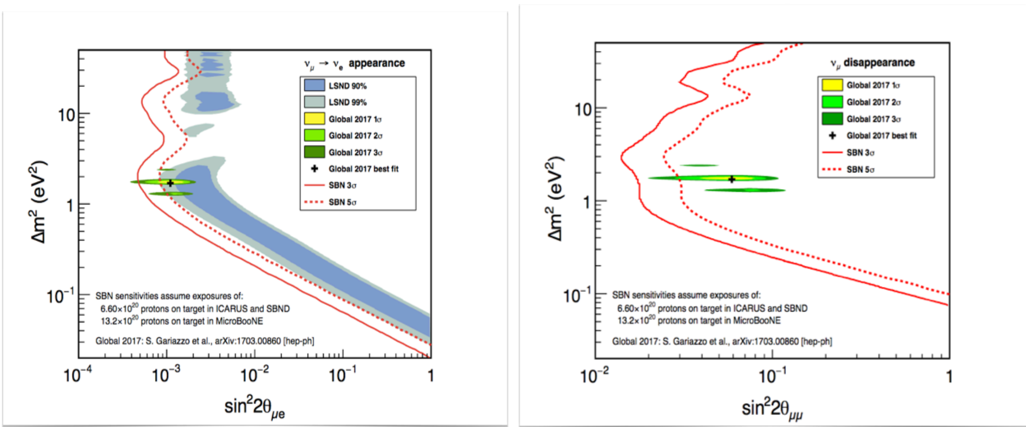

Figure 3. *Expected sensitivities of the SBN Program in ν_e appearance (left) and ν_μ disappearance (right). A recent global best fit point S. Gariazzo et al., arXiv:1703.00860 [hep-ph] (2017). is shown as a reference.*

While pursuing its main physics goal, the SBN Program will also lay the ground for the future by further developing the LAr-TPC detector technology and by measuring cross sections of neutrinos on argon at energies relevant to the Deep Underground Neutrino Experiment (DUNE), which will expose multi-kiloton scale liquid argon TPC detector to a high-intensity long baseline neutrino beam to investigate primarily CP violation in the leptonic sector [7].

3. The SBN detectors

The liquid argon time projection chamber (LAr-TPC) detector technology [8] was chosen for the three detectors in the SBN Program because of its excellent spatial resolution and calorimetry, which allows for efficient separation of electron and photon signals based on topology and energy deposition and therefore identification of ν_e-CC signal over backgrounds, especially ν-NC with single photon production. The working principle of this technology is sketched in **Figure 4**.

All detectors are surrounded by palisades of cosmic ray tagger (CRT), i.e. plastic counters for detecting particles entering from outside hence facilitating discrimination of cosmic-ray induced backgrounds.

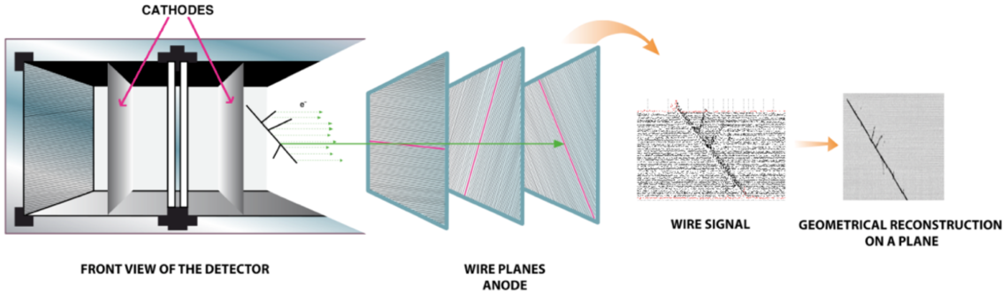

Figure 4. *Schematic representation of the working principle of a LAr-TPC detector*

1.1 Phase I: MicroBooNE

MicroBooNE, located at 470 m from target, consists of a single TPC with 2.5 m maximum drift, for a total active mass of 87 t. It is in steady operations since October 2015 and has so far collected almost 10^{21} protons on target.

Great progress in understanding detector effects (electronics noise, space charge, recombination, diffusion, etc) and on automated event reconstruction enabled first results on ν_μ-CC inclusive differential cross section and CC π^0 total cross section (**Figure 5**).

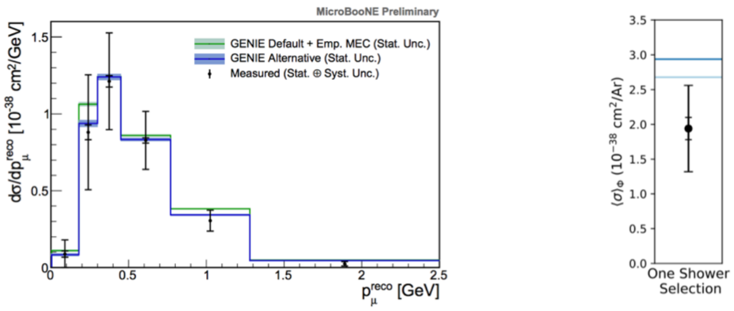

Figure 5. *Left: ν_μ-CC inclusive differential cross section on argon as a function of the reconstructed μ momentum. Right: measured total flux integrated ν_μ charged current single π^0 cross section. Results are compared with MC expectations based on the default and an alternative GENIE models.*

1.2 Phase II: SBND + ICARUS

SBND, located at 110 m from target, is made of 2 TPCs with 2 m maximum drift distance, for an overall active mass of 112 t.

It will characterize the neutrino beam before the onset of oscillations, addressing one of the dominant systematic uncertainties, and it will collect the largest data sample of neutrino-Ar interactions in the world in foreseeable future (~ $1.5\text{x}10^6$ ν_μ-CC and ~12000 ν_e-CC per year).

Civil construction of the facilities is completed, and assembly of the detector components started at Fermilab in summer 2018 (**Figure 6**, left). Data taking is expected to begin in 2020.

ICARUS-T600, located at 600 m from the source, consists of 4 TPCs with 1.5 m maximum drift, for a total active mass of 476 t.

Given its large mass and far location, it will provide high sensitivity to BNB oscillated neutrinos. It will also collect ~ 10^5 NuMI off-axis events/year, allowing for cross section studies in an energy region of interest for both first and second DUNE oscillation peaks.

The detector, refurbished at CERN after previous operations in Italy in 2010-2013 [9], was finally put in its final position at Fermilab in August 2018 (**Figure 6**, right), and is presently undergoing the final phases of installation of external cryogenic components and readout electronics. Data taking is anticipated to start in 2019.

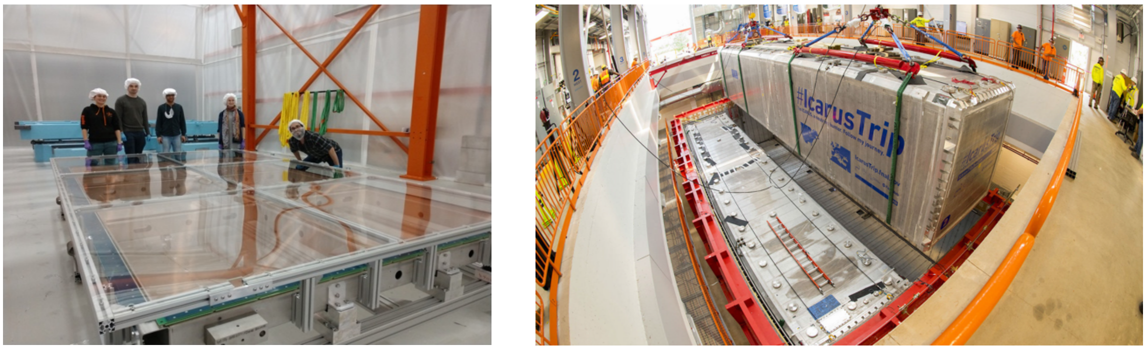

Figure 6. *Left: the first Anode Plane Assembly (APA) of the SBND detector in the clean room at Fermilab. Right: Rigging of the cold vessels of the ICARUS detector inside the warm box.*

4. Conclusive remarks

The SBN Program at Fermilab is well on its way to an exiting search for neutrino oscillations over short baseline addressing the sterile neutrino puzzle.

Alongside the study of both ν_e appearance and ν_μ disappearance effects, it will also give the unique opportunity to make high precision measurements of ν-Ar cross sections while developing the LAr-TPC technology and building expertise in preparation for DUNE.

References

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