The Short-Baseline Neutrino Program at Fermilab: Input to the European Particle Physics Strategy Update 2018-2020

The SBN Program

The Short-Baseline Neutrino program (SBN) will have world-leading sensitivity to resolve a set of existing anomalies in neutrino physics and test the possibility of sterile neutrino driven oscillations at the 1 eV/c^2 mass scale. SBN's superb sensitivity to sterile neutrino oscillations is enabled by the combination of three functionally-identical Liquid-Argon Time Projection Chamber (LArTPC) detectors positioned along the same neutrino beam at Fermilab. SBN also allows for an extensive neutrino cross-section measurement program on argon, and offers unique opportunities for a variety of exotic searches for new sub-GeV dark matter candidates. The SBN program is benefiting from major contributions from European institutions, funding agencies, and CERN, and the European community's continued significant participation is critical to the program's success. Data-taking with all detectors is expected from 2020, with peak physics exploitation in the period 2021-2024.

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Most neutrino processes to date are described by oscillations between the three known active flavours. However, a series of statistically-significant anomalous results calls for unknown phenomena or new physics. They are a) the LSND anomaly (appearance at $\sim$3.8σ level of $\sim$50 MeV $\bar{\nu}_e$'s in a $\bar{\nu}_\mu$ beam from muon decay at rest), b) the MiniBooNE anomaly (appearance at $\sim$4.7σ level of $\sim$1 GeV $\nu_e(\bar{\nu}_e)$'s in a $\nu_\mu(\bar{\nu}_\mu)$ beam from pion decay in flight), c) the reactor anomaly (disappearance at $\sim$3.0σ level of few-MeV $\bar{\nu}_e$'s produced in reactor cores), and d) the Gallium anomaly (disappearance at $\sim$2.7σ level of sub-MeV ν_e's produced by radioactive sources). These results, all of which appear at a neutrino baseline to energy ratio of about 1 m/MeV, can be interpreted as large-Δm^2 oscillation, requiring the addition of a new sterile neutrino state with a mass around 1 eV/c^2. The existence of such gauge neutrino singlets is well motivated and is a natural consequence of a non-zero neutrino mass. There is no a priori scale for the mass of these gauge singlets and one (or more) could well be in the 1 eV/c^2 scale. On the other hand, the interpretation of the above anomalies in terms of light sterile neutrinos is in tension with several other measurements. Given the significance of the potential observation of a sterile neutrino and the impact that such a discovery may have on CP invariance violation searches, performing a definitive experimental test that can settle the issue of a light sterile neutrino is one of the main scientific priorities in neutrino physics.

The Short-Baseline Neutrino program (SBN) is a phased world-class experimental program in the Booster neutrino beam at Fermilab. The facility was designed to reach a $>$5σ sensitivity test of the currently allowed oscillation parameter region. Its superb sensitivity to electron-neutrino appearance characterized by a mixing parameter $\sin^2 2\theta_{\mu e} \approx 10^{-3}$ is enabled by the combination of three functionally-identical Liquid-Argon Time Projection Chamber (LArTPC) detectors, with excellent imaging capabilities, positioned at different baselines in the same neutrino beam: SBND (112 ton active mass) at a distance of 110 m from the neutrino production target, MicroBooNE (89 ton) at a distance of 470 m, and ICARUS (476 ton) at a baseline of 600 m. The multi-detector configuration also allows a sensitive search for muon-neutrino disappearance in the same experiment, a powerful cross-check of any new physics interpretation of an observed signal in the electron channel.

In addition to its unique oscillation physics potential, the SBN complex will allow for an extensive neutrino cross-section measurement program. In fact, the difficulties in modelling neutrino-nucleus interactions in a kinematic area that spans the boundary between the non-perturbative and perturbative regimes and where the impulse approximation breaks down are broadly recognized. Recent high-statistics experiments (MiniBooNE, MINERvA, T2K) have performed several detailed measurements of neutrino-nucleus interactions, mainly for inclusive and low-multiplicity (no-pion and single-pion) exclusive channels. A rather confusing picture emerges from the data and tensions persist between the measurements. Current theoretical models and Monte Carlo simulations do not provide a consistent description of all available measurements. The impact on oscillation studies from this lack of detailed understanding of neutrino interactions is severe and well understood. As a consequence of the unprecedented statistics and imaging capabilities, the SBN program will bring a generational advance in neutrino interaction studies. SBN measurements will underpin the early physics exploitation in DUNE and mitigate the risks associated with the insufficient understanding of neutrino interaction physics. The importance of this cannot be overstated: The SBN program is the *only source* of neutrino-argon data until the start of the DUNE data-taking operations! Finally, the SBN detectors offer unique opportunities for exotic searches, in particular by probing Vector, Neutrino and Higgs portal models via the direct production and detection of sub-GeV dark matter candidates.

CERN and many European groups are making substantial contributions towards realizing the huge physics potential of the SBN program. Both ICARUS detector modules were refurbished at CERN, as part of the CERN Neutrino Platform program in collaboration with INFN. This refurbishment included the design and fabrication of new aluminum cryostats and the installation of new photomultiplier tubes. New ICARUS TPC electronics has been provided by the Italian INFN, while each of CERN and INFN are contributing to the far detector cosmic ray tagger (CRT). INFN supplies part of the ICARUS data acquisition (DAQ) system, whereas both CERN and INFN contribute substantially in the cryogenics and in the integration and installation of the detector. For the near detector, the Swiss Bern group, who pioneered the use of CRT and laser calibration techniques in MicroBooNE, are providing such systems, whereas the U.K. groups took a leading role in the TPC design and fabrication, building the cathode plane assemblies (CPAs) and two of the four anode plane assemblies (APAs). The U.K. also provided one of the two SBND high-voltage feedthroughs. Finally, CERN is taking a leading role in the design and construction of the near detector cryostat with INFN and Fermilab each making substantial contributions. CERN is also contributing substantially to the cryogenic systems.

The design, construction, and operation of the SBN detectors offers valuable experience to the researchers involved and is providing important opportunities for development of the liquid argon TPC technology. The near detector, for example, is a modular design, along the lines of the DUNE single-phase far detectors, and is being built by many European and US groups that will contribute to DUNE construction in the future. The SBN detectors are also opportunities to develop and test many elements of a large liquid-argon detector, such as cryostat design, photon detection techniques, and detector readout electronics. The long-term stable operation and analysis of data from all the SBN detectors will provide valuable lessons and experience for the community, as is already being seen with the operation of MicroBooNE.

Substantial advances are also being made in the organization of the overall analysis effort, with close coordination between the different SBN collaborations. A common simulation, data reconstruction and analysis chain has already been set up. Work is currently ongoing for producing the first end-to-end SBN oscillation sensitivity calculation by exploiting the full SBN detector simulation and reconstruction tools. European groups that harbour a substantial expertise and experience in the physics exploitation of modern neutrino experiments are playing a leading role in this effort with major responsibilities across the whole program.

The SBN project is on track to commence its physics data-taking operations with all LArTPC detectors by the end of 2020. The MicroBooNE detector has been taking data for the past three years and has collected data for an exposure in excess of 10^{21} protons-on-target. The ICARUS detector will be filled with liquid argon in summer 2019 and begin physics data-taking with an operational CRT and all shielding in place by early 2020. SBND will be ready to fill with argon during summer 2020 with the start of operations expected by the end of 2020. Sensitivity projections for oscillation searches are based on around three years of data collection with the far detector. Studies of neutrino-argon scattering in SBN can begin immediately after the start of data-taking in both detectors, with the near detector, in particular, accumulating $\mathscr{O}(10^5)$ Booster neutrino beam interactions per month. In addition to the primary flux from the Booster beam, the ICARUS detector will record $\mathscr{O}(10^5)$ off-axis events per year from the NuMI beam, with much of the flux in the energy range of interest to the DUNE long-baseline neutrino programme.

We believe that the continued strong support from CERN and Europe to the SBN program in the near term is an essential component of achieving the physics goals of SBN and of establishing the European neutrino community as leaders in the forthcoming enterprise of DUNE/LBNF, the major, long-term effort of the European and international neutrino community.