The Short-Baseline Neutrino (SBN) Physics Program at Fermilab

David Schmitz

(on behalf of the SBN Collaborations: ICARUS/WA104, MicroBooNE, and SBND)
Quick SBN Overview

SBN Physics Goals & Sensitivities

SBN Program Status

Summary
The Three LArTPC SBN Program

A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

\[ \langle L_{\nu} \rangle \sim 600 \text{ m} \]
\[ \langle E_{\nu} \rangle \sim \frac{700 \text{ MeV}}{1 \text{ km/GeV}} \]

<table>
<thead>
<tr>
<th>Detector</th>
<th>Distance from BNB Target</th>
<th>Active LAr Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBND</td>
<td>110 m</td>
<td>112 ton</td>
</tr>
<tr>
<td>MicroBooNE</td>
<td>470 m</td>
<td>87 ton</td>
</tr>
<tr>
<td>ICARUS</td>
<td>600 m</td>
<td>476 ton</td>
</tr>
</tbody>
</table>

David Schmitz, UChicago
The SBN Collaborations (July 2016)

Proposal submitted jointly by ICARUS-WA104, MicroBooNE and LAr1-ND (now SBND) Collaborations
218 authors from 22 US and 23 non-US institutions

Argonne National Lab, USA
Brookhaven National Lab, USA
CERN, Switzerland
Colorado State University, USA
Fermi National Lab, USA
INFN Sez. di Catania and University, Catania, Italy
INFN GSSI, L’Aquila, Italy
INFN LNGS, Assergi (AQ), Italy
INFN Sez. di Milano Bicocca, Milano, Italy
INFN Sez. di Napoli, Napoli, Italy
INFN Sez. di Padova and University, Padova, Italy
INFN Sez. di Pavia and University, Pavia, Italy
H. Niewodniczanski Inst. of Nucl. Phys.,
   Polish Academy of Science, Krakow, Poland
Institute for Nuclear Research (INR),
   Institute of Physics, University of Silesia,
   Katowice, Poland
Inst. for Radio-Electronics,
   Warsaw University of Technology, Warsaw, Poland
Los Alamos National Lab, USA
National Centre for Nuclear Research, Warsaw, Poland
University of Pittsburgh, USA
Russian Academy of Science, Moscow, Russia
SLAC, USA
Texas University at Arlington, USA
University of Bern, Switzerland
Brookhaven National Lab, USA
University of Cambridge, UK
University of Campinas – UNICAMP, Brazil
CERN, Switzerland
University of Chicago, USA
Columbia University, USA
Federal University of ABC – UFABC, Brazil
Federal University of Alfenas – UFAL, Brazil
Fermi National Laboratory, USA
Illinois Institute of Technology, USA
Indiana University, USA
Kansas State University, USA
Lancaster University, UK
University of Liverpool, UK
Los Alamos National Lab, USA
University of Manchester, UK
University of Michigan, USA
MIT, USA
University of Oxford, USA
University of Pittsburgh, USA
Pacific Northwest National Laboratory, USA
Princeton University, USA
Saint Mary’s University of Minnesota, USA
SLAC, USA
Syracuse University, USA
University of Texas at Arlington, USA
Tubitak Space Tech. Research Inst., Turkey
Virginia Tech, USA
Yale University, USA

SBN Program has continued to grow: now 27 US and 26 non-US institutions
Quick SBN Overview

SBN Physics Goals & Sensitivities

SBN Program Status

Summary
Physics Beyond the 3-ν SM?

- Experimental anomalies ranging in significance (2.8-3.8σ) have been reported over the past 20 years from a variety of experiments studying neutrinos at baselines less than 1 km.

- Common interpretation is as evidence for one or more additional, mostly "sterile" neutrino states driving oscillations at $\Delta m_{\text{new}}^2 \approx 1 \text{ eV}^2$ and a relatively small $\sin^2(2\theta_{\text{new}})$.

Confirmation of the sterile neutrino hypothesis would be a major discovery, opening a window onto a particle sector not accessible through SM interactions.

A definitive null result would settle a long-standing open question in neutrino physics with possible implications for future 3-ν oscillation experiments.
Examples of 3+1 Global Fits

**P(ν_μ → ν_e) more than 10x smaller than for LBL at θ_{13}**

Certainly very sensitive experiments are needed!

| (Δm^2_{41}, sin^2 2θ_{μe}) = (1.6 eV^2, 0.0014) |

Global best-fit:

**ν_μ → ν_e appearance**

**ν_e disappearance**

**ν_μ disappearance**

New fits including IceCube ν_μ and ν_μ disappearance results

Original LSND result still most significant signal


Original LSND result still most significant signal

David Schmitz, UChicago

The SBN Program at Fermilab - Neutrino 2016
SBN will apply the advantages of the LArTPC technology and *multiple detectors at different baselines* to the question of high-$\Delta m^2$ *sterile neutrino oscillations* to definitively test currently allowed oscillation parameter regions at $\geq 5\sigma$.

Science Goals of the SBN Program

- Increase statistics of signal
- Control systematics

Neutrino Energy: 700 MeV

- $\Delta m^2 = 1.60 \text{ eV}^2$
- $\sin^2(2\theta) = 0.0014$

Neutrino Energy: 700 MeV

- $\Delta m^2 = 0.43 \text{ eV}^2$
- $\sin^2(2\theta) = 0.013$

Detector Location: 600 m

- $\Delta m^2 = 1.60 \text{ eV}^2$
- $\sin^2(2\theta) = 0.0014$

Detector Location: 600 m

- $\Delta m^2 = 0.43 \text{ eV}^2$
- $\sin^2(2\theta) = 0.013$
Science Goals of the SBN Program

- Study $\nu$-Argon interaction physics using millions of events from both the Booster and Main Injector neutrino beams at Fermilab.

**NuMI**

- **off-axis @ ICARUS**

**DUNE**

- $2^{nd}$ max
- $1^{st}$ max

**SBND**

- $1.5 \times 10^6 \nu_\mu$ CC/year
- $12 \times 10^3 \nu_e$ CC/year

**ICARUS**

- $10^5$ NuMI off-axis events/year
- many at the DUNE $1^{st}$ osc. max

High statistics, precision measurements of neutrino+Ar cross sections in the relevant energy range will help reach systematics goals in LBNF-DUNE.

See Matt Toups’ talk for MicroBooNE details and status.
Science Goals of the SBN Program

- Study $\nu$-Argon interaction physics using millions of events from both the Booster and Main Injector neutrino beams at Fermilab

**DUNE: 2$^{nd}$ max**

**SBND: 1.5$\times 10^6$ $\nu_\mu$ CC/year**

**SBND: 12$\times 10^3$ $\nu_e$ CC/year**

**SBND records a MicroBooNE three-year dataset in ~2 months!**

*High event rate allows study of even rare interaction channels*

- coherent scattering
- strange production
- neutrino-electron scattering

**Charged Current Coherent Pion Expectations (GENIE estimate, rounded)**

<table>
<thead>
<tr>
<th></th>
<th>1 Month</th>
<th>1 Year</th>
<th>3 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC Coherent</td>
<td>500</td>
<td>6,300</td>
<td>19,000</td>
</tr>
</tbody>
</table>

**SBND Hyperon Production Expectations (CC + NC) (GENIE Expectations)**

<table>
<thead>
<tr>
<th></th>
<th>1 Month</th>
<th>1 Year</th>
<th>3 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda^0$ Production</td>
<td>200</td>
<td>2,600</td>
<td>8,000</td>
</tr>
<tr>
<td>$\Sigma^+$ Production</td>
<td>125</td>
<td>1,500</td>
<td>4,500</td>
</tr>
</tbody>
</table>
Correlations between detectors (same beam and detection technique) allow for cancelations in systematic uncertainties on backgrounds.

Analysis utilizes available advanced simulation tools to quantify the correlations:

- GEANT4 simulation of Booster Neutrino Beam fluxes based on dedicated hadron production data [Phys. Rev. D79, 072002 (2009)]
- GENIE neutrino event generator

Event rates strongly correlated, as expected. Similar for $\nu_\mu$.
Cosmogenic Backgrounds

- The challenge at the surface: 1000x longer charge drift time than the beam spill time!

<table>
<thead>
<tr>
<th>Detector</th>
<th>Neutrino interaction every N spills</th>
<th>Cosmic muon in beam spill time every N spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBND</td>
<td>25</td>
<td>300</td>
</tr>
<tr>
<td>MicroBooNE</td>
<td>800</td>
<td>200</td>
</tr>
<tr>
<td>ICARUS-T300</td>
<td>500</td>
<td>100</td>
</tr>
</tbody>
</table>
Mitigation of Cosmogenic Backgrounds

- **3m of concrete overburden** \(\rightarrow\) Near 100% reduction of primaries other than muons with only few percent increase in secondaries.

- This leaves **photons generated near the TPC by cosmic \(\mu\)** as the main cosmogenic background for \(\nu_e\) appearance search.

- Multi-step mitigation strategy:
  - External cosmic ray tracker systems to tag cosmic muons near the detectors
  - Internal photon detection systems with good time and spatial resolution for 1-to-1 matching of scintillation and ionization signals in the detectors
  - Further rejection possible with sufficient scintillation time resolution by exploiting bunched structure of the Booster proton beam (2 ns bunches every 19 ns)
SBN $\nu_\mu \rightarrow \nu_e$ Oscillation Sensitivity

$\Delta m^2 (eV^2)$ vs $\sin^2 2\theta_{\mu e}$

- 90% CL
- 3$\sigma$ CL
- 5$\sigma$ CL

- T600, 6.6e+20 POT (600m)
- MicroBooNE, 1.32e+21 POT (470m)
- SBND, 6.6e+20 POT (100m)

$\nu_\mu$ mode, CC Events
Reconstructed Energy
80% $\nu_e$ Efficiency
Stat., X-Sec., Flux, Cosmics, Dirt
$\nu_e$ Only Fit

5$\sigma$

- SBND
- MicroBooNE
- ICARUS T600
Importance of $\nu_\mu$ Disappearance at SBN

- Oscillation formulas in a simple 3+1 model:

  \[ P^{3+1}_{\nu_\mu \rightarrow \nu_\mu} = 1 - \sin^2 2\theta_{\mu\mu} \sin^2 \left( \frac{\Delta m_{41}^2 L}{4E_\nu} \right) \]

  \[ P^{3+1}_{\nu_\mu \rightarrow \nu_e} = \sin^2 2\theta_{\mu e} \sin^2 \left( \frac{\Delta m_{41}^2 L}{4E_\nu} \right) \]

  \[ \sin^2 2\theta_{\mu e} = 4|U_{\mu 4}|^2|U_{e 4}|^2 \]

  \[ \sin^2 2\theta_{\mu\mu} = 4|U_{\mu 4}|^2(1 - |U_{\mu 4}|^2) \]

- $\nu_e$ appearance cannot occur in SBN without $\nu_\mu$ disappearance
  - Critical aspect of SBN that is ONLY enabled with multiple detectors

- Non-zero $U_{e4}$ also implies some amount of $\nu_e$ disappearance and the BNB is not a pure beam
  \[ \sin^2 2\theta_{ee} = 4|U_{e 4}|^2(1 - |U_{e 4}|^2) \]

  - Again, $\nu_\mu$ disappearance an important handle

  - Direct $\nu_e$ disappearance searches being pursued using reactors and radioactive sources provide valuable complementary input to the sterile neutrino puzzle
SBN $\nu_\mu \rightarrow \nu_x$ Oscillation Sensitivity

$\Delta m^2 = 1.1 \text{ eV}^2$

$\Delta m^2 = 0.44 \text{ eV}^2$

Near Det

Far Det

SBND (6.6 $\times 10^{20}$ POT)

MicroBooNE (1.3 $\times 10^{21}$ POT) and T600 (6.6 $\times 10^{20}$ POT)
Quick SBN Overview

SBN Physics Goals & Sensitivities

SBN Program Status

Summary
Broke ground on the Far Detector building in July 2015

Ready for installation end of 2016
Broke ground on the Near Detector building in early 2016

Also completed end 2016/early 2017
The SBN Far Detector – The ICARUS-T600

- ICARUS is the largest existing LArTPC in the world
  - Completed a successful three-year physics run in CNGS neutrino beam at Gran Sasso Laboratory 2010-2012
  - Currently at CERN being overhauled and prepared for transport to Fermilab
ICARUS Refurbishment Activities

- ICARUS overhaul is to update technology and prepare for surface operation at FNAL
  - New thermal insulation and cold vessel construction
  - Maintenance and partial replacement of cryogenic and purification systems
ICARUS Refurbishment Activities

- ICARUS overhaul is to update technology and prepare for surface operation at FNAL
  - Improved planarity of TPC cathode
  - Enlarged PMT system with improved electronics for surface operation

Flattened cathode will improve event imaging and reconstruction, e.g. for measuring track momentum by multiple coulomb scattering

360 8” PMTs (90 per chamber) coated with TPB wave-length shifter ~9 p.e./MeV at cathode

New shields to prevent induction of PMT signals on the TPC wires

Neutrino 2016 Poster: “Performance Study of the New Light Detection System for the ICARUS T600 Detector” by Andrea Falcone

Neutrino 2016 Poster: “TPB Thickness and Quantum Efficiency Measurements for the NEW ICARUS T600 Light Detection System in the SBN Project” by Maura Spanu
ICARUS Refurbishment Activities

- ICARUS overhaul is to update technology and prepare for surface operation at FNAL
  - Updated TPC electronics

  - From 595 to 10 liters!

  - No need to change basic architecture, but only adopt more modern components to improve performance

  - Both analogue and digital electronics directly on the flanges

  - Ongoing tests at LArTPC facilities at CERN and INFN-LNL, significant improvement on the Induction wire planes is obtained

- ICARUS at Gran Sasso

- ICARUS at FNAL
SBND will be a new LArTPC

- Build upon experience and apply lessons learned from MicroBooNE and other detectors at FNAL and elsewhere
- Common design elements to ICARUS and the DUNE single phase far detector and protoDUNE-SP

The Short-Baseline Near Detector (SBND)
SBND: Detector Design Elements

- Modular TPC construction as in DUNE-SP

**Field Cage:** roll-formed metal profiles installed in panels (16). Some are removable for detector access. Similar to protoDUNE-SP design.

**Anode Plane Assemblies:** 4.1 x 2.5 m wire plane frames (4) tiled to create two drift regions

**HV & Cathode:** SS tubing frames with mesh panels
SBND: Detector Design Elements

SBND will have unprecedented scintillation photon yield in a neutrino LArTPC

- Primary scintillation detection system uses 144 TPB coated 8” PMTs, same model as in ICARUS
  - ~15 p.e./MeV at cathode

- Scintillation detection R&D being pursued with acrylic light-guides & SiPM based readout system (DUNE)
  - Investigating possible further enhancement with reflective foils coated in wave-length shifter installed on the cathode plane. *Simulations indicate much improved uniformity of collection efficiency across the drift volume.*

- SBND an excellent platform for R&D possibilities as well

Neutrino 2016 Poster: "Light Detection System Simulations for SBND" by Diego Garcia-Gamez
Front-end electronics with cold ADC and multi-plexing
- 11k channels → 4 feed-throughs (MicroBooNE = 8.2k → 11 feed-throughs)
- Co-development with protoDUNE

Readout, DAQ and triggering development

Nearly $4\pi$ coverage bi-layered external cosmic ray tracker system
SBND: TPC Construction Has Begun

Wire plane frames in production

HV feed-through prototype

Cathode plane mesh prototype

Wiring procedures prototyping

Neutrino 2016 Poster: "SBND: Status of the Fermilab Short-Baseline Near Detector" by Nicola McConkey
Quick SBN Overview

SBN Physics Goals & Sensitivities

SBN Program Status

Summary
The SBN Program @ Fermilab: Summary

- Three international collaborations have come together to form the SBN Program at Fermilab to:
  - Explore the anomalous hints of new physics in the neutrino sector with coverage of the LSND allowed oscillation parameters in neutrinos at $>5\sigma$
  - Study $\nu$-Ar interactions with high precision in an important energy range
  - Further develop the LArTPC technology and help build expertise of the global neutrino physics community working toward DUNE

- SBN program has made significant progress in 2015-2016
  - MicroBooNE is operating now with high intensity beam
  - Civil construction at Fermilab well along at both new sites
  - ICARUS-T600 refurbishment progressing well; on schedule for delivery in 2017
  - SBND TPC is in final design phase, construction of components has begun; assembly in 2017; installation in 2018

Well on our way to an exciting SBN physics program!
• **MONDAY**
  *P1.024:* “Electron Diffusion Measurements in the ICARUS T600 Detector” by Marta Torti, Pavia  
  *P1.085:* “TPB Thickness and QE Measurements for the New ICARUS-T600 Light Det. System in the SBN Project” by Maura Spanu, Pavia  
  *P1.086:* “Performance Study of the New Light Detection System for the ICARUS T600 Detector” by Andrea Falcone, UT Arlington  
  *P1.087:* “Signal Processing in the MicroBooNE LAr TPC” by Craig Thorn, BNL  
  *P1.088:* “Light Detection System Simulations for SBND” by Diego Garcia-Gamez, Manchester

• **TUESDAY**
  *P2.054:* “MeV Sterile Neutrino Decays at the Fermilab SBN Complex” by Mark Ross-Lonergan, Durham  
  *P2.076:* “The Fermilab Short-Baseline Neutrino Program” by David Schmitz, Chicago  
  *P2.077:* “Model Uncertainties at MicroBooNE” by Marco Del Tutto, Oxford  
  *P2.079:* “Vertex Reconstruction Algorithm Development for the MicroBooNE Single Photon Event Search” by Robert Murrells, Manchester  
  *P2.086:* “SBND: Status of the Fermilab Short-Baseline Near Detector” by Nicola McConkey, Sheffield

• **WEDNESDAY**
  *P3.068:* “Michel Electron Reconstruction with the MicroBooNE LArTPC” by David Caratelli, Columbia  
  *P3.069:* “Analyzing LArTPC Images with Deep Learning” by Kazu Terao, Columbia  
  *P3.070:* “The Reconstruction of Neutral Pions in MicroBooNE” by Ariana Hackenburg, Yale  
  *P3.071:* “Physics Program of the Short-Baseline Near Detector (SBND)” by Dominic Brailsford, Lancaster  
  *P3.075:* “Novel Sterile Neutrino Oscillation Search Utilizing a Stopped Kaon Source and the SBN Program” by Joseph Zennamo, Chicago
Extras
SBN Program Timeline

- **MicroBooNE:**
  - Running now with excellent beam rates!

- **ICARUS:**
  - Overhauling of ICARUS modules completed and ready for transport in early 2017
  - Installation on the beamline at Fermilab in 2017
  - Commissioning and operations in 2018

- **SBND:**
  - Finalizing SBND detector system designs now. Production of first components started in 2016 and is ongoing.
  - TPC assembly at Fermilab to begin in 2017, install into cryostat 2018
  - Begin commissioning late 2018, operations in 2019

- **Physics:**
  - Sensitivities all based on 6.6e20 POT in the BNB (nominal three years running), limited naturally by exposure in the far detectors
  - SBND records the MicroBooNE three-year data set in ~2 months
At the January 2014 meeting of the Fermilab Physics Advisory Committee (PAC), two new proposals were put forward:

- **P-1052: ICARUS@FNAL**: Existing ICARUS-T600 LArTPC plus a near detector in the Fermilab Booster Neutrino Beam (BNB)
- **P-1053: LAr1-ND**: Near detector to MicroBooNE to be followed by 1kton scale far detector in the future, “LAr1”.

“The PAC encourages the [groups] to work together to formulate a common Short-Baseline Neutrino Experimental program for FNAL”

Submitted to the PAC in **January 2015**


Submitted jointly by ICARUS-WA104, MicroBooNE and LAr1-ND (now SBND) Collaborations

218 authors from 22 US and 23 non-US institutions
Science Goals of the SBN Program

1. Directly follow-up on the **MiniBooNE neutrino anomaly** by utilizing the LArTPC technology to determine the composition of the observed excess as electrons or photons

2. Apply the advantages of the LArTPC technology and multiple detectors at different baselines to the question of high-$\Delta m^2$ **sterile neutrino oscillations** and definitively test currently allowed oscillation parameter regions at $\geq 5\sigma$
   - Add a near detector to measure the unoscillated ($\text{flux} \times \text{cross section}$) and reduce significantly the systematic uncertainties in oscillation searches
   - Increase the fiducial mass at the far site to reduce statistical uncertainties on a potential signal

3. Study **$\nu$-Argon interaction physics using millions of events** from both the Booster and Main Injector neutrino beams at Fermilab

4. Further **develop the LArTPC technology** toward the aim of applying it at very large scales for long-baseline physics in DUNE
Liquid Argon TPCs: Operating Principle

- Neutrino+Ar → final state charged particles
- Propagating charged particles ionize the argon
- Electric field drifts free electrons few meters to wire chamber planes (~1.6 mm/μs at 500 V/cm)
- Induction/Collection planes image charge, record dE/dx
- Argon purity of prime importance to avoid signal attenuation

![Diagram of Liquid Argon TPC]

Electric field drifts free electrons few meters to wire chamber planes (~1.6 mm/μs at 500 V/cm), so drift time is 1-2 milliseconds.

![Graph of Neutrino interaction in the ArgoNeuT LArTPC at Fermilab]

Neutrino interaction in the ArgoNeuT LArTPC at Fermilab.
Liquid Argon TPC

Active Volume

Drift Electrons

Around 100 kV

Liquid Argon Time Projection Chamber
Electron/Gamma ID in LArTPCs

Electron
\[ \gamma \rightarrow e^+ + e^- \]

ArgoNeuT Preliminary

Distance from start

Energy Deposited, dE/dx [MeV/cm]
Recall a primary physics goal of MicroBooNE is to directly follow-up on the **MiniBooNE neutrino anomaly** by utilizing the LArTPC technology (fully active calorimeter) to determine the composition of the observed excess as electrons or photons.

**MiniBooNE (Cherenkov Detector)**

See talk by Matt Toups
Scintillation Light in LArTPCs

- Ionized LAr creates large amounts of scintillation light as well
  - ~40k photons/MeV at 0 electric field

- Valuable for fast-timing information

- The problem is that the light is at 128 nm (VUV)
  - Shift the light from UV to Visible, typically using Tetraphenyl Butadiene (TPB)
Backgrounds & Oscillation Signals in SBN

- **Electron neutrino CC interactions**
  - $\pi \rightarrow \mu \rightarrow \nu_e$
  - $K^+ \rightarrow \nu_e$
  - $K^0 \rightarrow \nu_e$

- **Sample appearance signal**

- **Photon-induced e.m. shower backgrounds**
  - NC misIDs
  - $\nu_\mu$ CC misIDs

  - “Dirt” Backgrounds: beam-related but out-of-detector interactions
  - Cosmogenic photon sources
Other Beam Related Backgrounds

- **“Dirt” backgrounds**
  - Beam-induced backgrounds that sneak into the active volume from outside

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**Applied a tight 25cm FV buffer to keep this background limited**
Mitigation of Cosmogenic Backgrounds

External CR trackers identify potentially contaminated beam spills (1.6µs window)
ID ~95% of cosmic µ, reject few % of beam triggers

Off-beam triggers can be used to measure the cosmic background to high precision so small systematic uncertainties - all about statistics
Plots on following three slides indicate the sensitivity contour that touches the left side of the 99% CL allowed region for the original LSND data as a function of $\Delta m^2_{41}$. 
Impact of Three Detectors

Sensitivity to 3+1 $\nu$ signal along the LSND 99% CL

- Full SBN Program
- SBND + T600
- SBND + MicroBooNE
Impact of Cosmics

Sensitivity to 3+1 $\nu$ signal along the LSND 99% CL

- Full SBN Program
- SBN, Topological Cosmic ID Only

$\sqrt{\Delta \chi^2}$ vs. $\Delta m^2$ (eV$^2$)
Impact of Additional Beam Statistics

Sensitivity to 3+1 $\nu$ signal along the LSND 99% CL

- Nominal SBN Statistics
- 2.0x SBN Statistics
- 1.5x SBN Statistics

$\Delta m^2$ (eV$^2$)
SBND: Detector Design Elements

- Membrane cryostat (35ton, WA105, protoDUNE, DUNE)

“mobile” cryostat lid plate

“fixed” cryostat lid plate

TPC hangs from cryostat lid

Outer mechanical support. Membrane cryostat built inside.

WA105 @ CERN
SBND: Detector Design Elements

- UV calibration laser system
  - 4 UV lasers similar to type deployed in MicroBooNE
  - ~100% coverage of TPC volumes using corner ports and steerable mirrors (prototype ongoing)

Straight tracks in the TPC enable field mapping and purity measurements
SBND Photon Detection

With PMTs only and a 70% transparent cathode

With PMTs and cathode covered with TPB coated reflector foils

Neutrino 2016 Poster: "Light Detection System Simulations for SBND" by Diego Garcia-Gamez
The Booster Neutrino Beam

Energy (GeV)

0.0 0.5 1.0 1.5 2.0 2.5 3.0

POT

$6 \times 10^2 / 50 \text{MeV/m}$

MicroBooNE

$10^{-5}$
$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$

$\Phi(\nu)$ MicroBooNE

$/$50MeV/2$m^2$/10^6POT

$\nu_\mu$
$\\bar{\nu}_\mu$
$\nu_e$
$\\bar{\nu}_e$

0.5% $\nu_e$ content

700 MeV peak energy

beam near the surface, parallel to South Dakota (LBNE)

to South Dakota (LBNE)

NuMI beam (MINOS, NovA)

to Minnesota

Main Injector and Recycler

Tevatron Ring (decommissioned)

fixed target

booster neutrino beam

muon campus

linac

booster

test beam
Booster Neutrino Beam Improvements

- Far detector statistics are key to $\nu_e$ appearance sensitivity
  - $(\text{Detector mass}) \times (\text{Neutrino flux}) \times (\text{Time})$

- Possible BNB upgrade paths:
  1. Increase focusing efficiency of target/horn system
     - Optimize horn length, inner conductor, and current
  2. Increase rate at which horn system is capable of running
     - Booster can operate at 15 Hz, existing horn at 5 Hz (limited by mechanical integrity and power supply)

- Detailed study carried out by design team at FNAL; conclusion: gains up to $\sim 1.8 \times$ in event rate possible with longer horn design and upgraded power supply
Look for electron anti-neutrinos in a beam with well-predicted fluxes and small electron anti-neutrino background

$\bar{\nu}_e$ detection via inverse-beta-decay: $\bar{\nu}_e + p \rightarrow e^+ + n$
(coincidence signal)

800 MeV proton beam from LANSCE accelerator

Beam produced by decays at rest is precisely known

blue histogram is oscillation best fit to excess

neutron captures to produce a 2.2 MeV gamma
MiniBooNE (2003-2014)

- MiniBooNE was a Cherenkov detector
- Single electron indistinguishable from single gamma
- 800 ton liquid scintillator detector
- 540 m from the beam target
Many global analyses that incorporate the positive and null results available
- Kopp et al.
- Conrad et al.
- Giunti et al.
- others

Positive signals in $\nu_\mu \rightarrow \nu_e$ appearance and $\nu_e$ disappearance (neutrinos and antineutrinos)

No evidence for $\nu_\mu$ disappearance

To definitively confirm or refute this 1 eV sterile neutrino interpretation is the primary physics goal of the SBN Program
SBND ↔ DUNE

- SBND design based on technologies/solutions similar to those planned for DUNE

Development of photon detection technologies
Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.