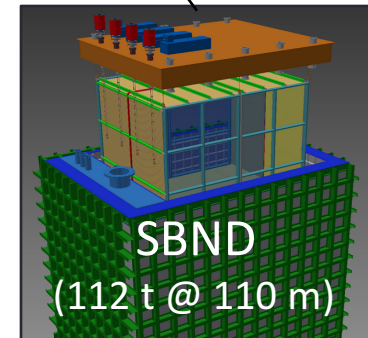
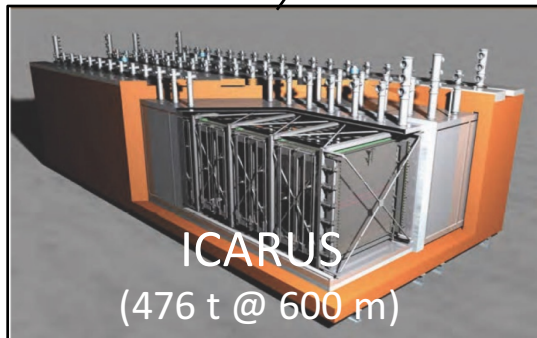
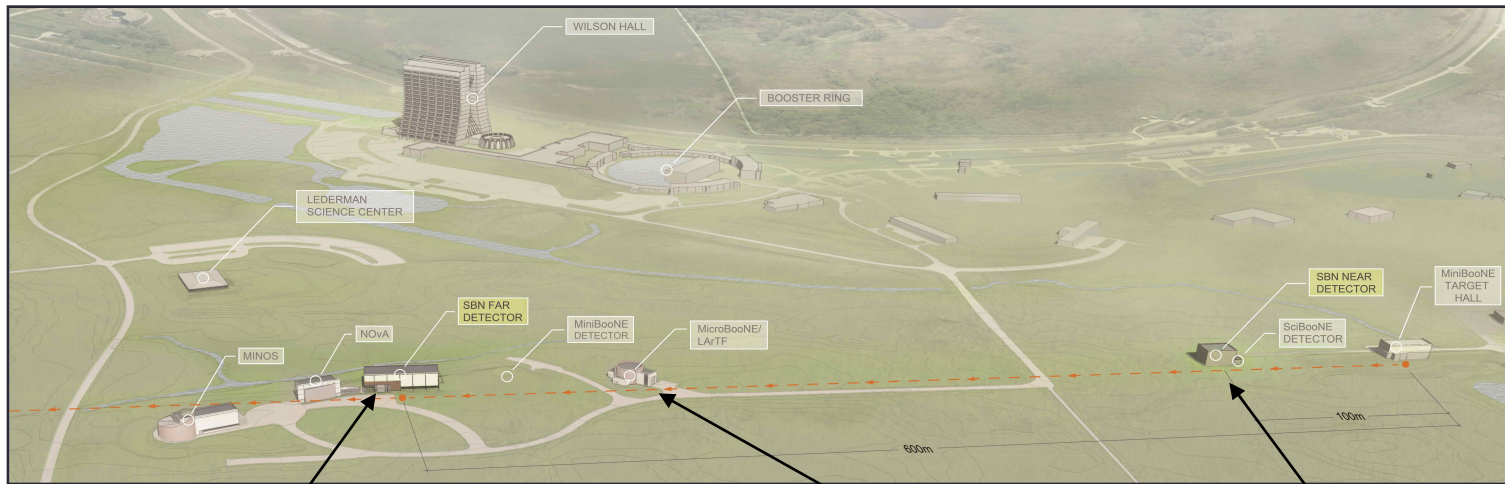


SBN – A THREE DETECTOR SHORT-BASELINE NEUTRINO OSCILLATION PROGRAM AT FERMILAB

The Fermilab PAC assessment

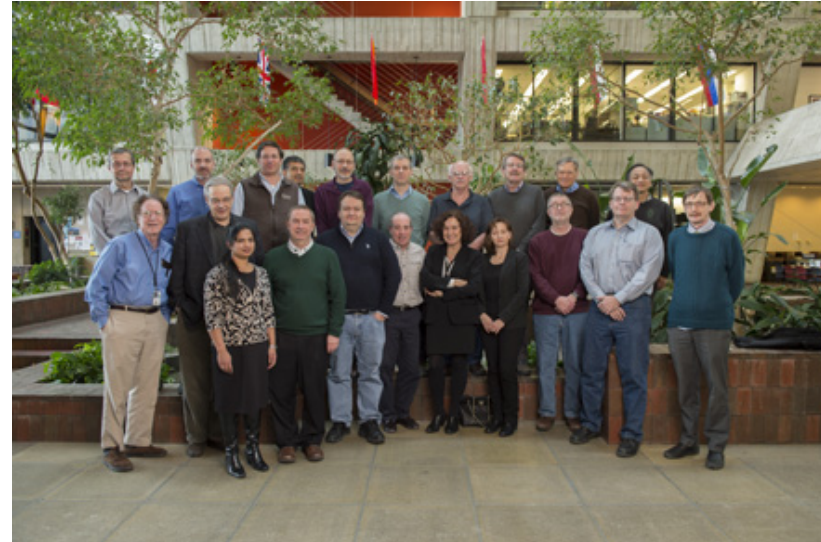


Background about the FNAL PAC

- The Committee consists of members from the particle physics community appointed by the Fermilab Director.
 - It gives advice to the Director about the optimization of the ongoing experimental program, and about plans for the future program.
 - It reviews proposals for new experiments at Fermilab
- The steps along the road to a running experiment at FNAL include:
 - Scientists who would like to carry out an experiment at Fermilab submit a formal research proposal to the Laboratory Director
 - “Stage 1 Approval” recommendation by the PAC to the Director
 - If the director accepts that advice, laboratory resources are released to undertake initial studies of technical feasibility and to evaluate if the experiment fits within the laboratory’s capabilities.
 - Approval initiates the process of drafting a Technical Scope of Work (TSW) agreement between the laboratory and the experiment’s proponents.
 - Following a detailed evaluation, the proposal is supplemented to include preliminary engineering, detector design, beamline characterization, budget formulation, and institutional contributions.
 - The proposal is then resubmitted to the PAC for possible “Stage II” approval. For projects greater than \$10M in capital equipment, Stage II approval by the PAC and agreement by the Director signals that the experiment is ready to proceed to the CD-0 stage.

Membership of the PAC

- [Roger Blandford](#), Stanford (term expires 2015)
- [Edward Blucher](#), University of Chicago (term expires 2017)
- [Daniela Bortoletto](#), University of Oxford (term expires 2016), Chair
- [Raymond \(Chip\) Brock](#), Michigan State (term expires, 2015)
- [Estia Eichten](#), Fermilab (term expires 2016)
- [Cristiano Galbiati](#), Princeton University (term expires 2017)
- [Giorgio Gratta](#), Stanford (term expires 2016)
- [Salman Habib](#), ANL (term expires 2017)
- [Josh Klein](#), University of Pennsylvania (term expires 2017)
- [David MacFarlane](#), SLAC (term expires 2018)
- [Silvia Pascoli](#), University of Durham (term expires 2017)
- [Maria Spiropulu](#), Caltech (term expires 2018)
- [Hiro Tanaka](#), University of Toronto (term expires 2017)
- [Yifang Wang](#), IHEP (term expires (term expires 2017)
- [David Lee Wark](#), RAL/Oxford (term expires 2017)
- [Taku Yamanaka](#), Osaka (term expires 2016)
- [Stephen Geer](#), Secretary
- [Hema Ramamoorthi](#), Program Planning Office



SBN PAC History

- January 2014
 - ICARUS and LAr1-ND proposals. PAC requested experiments formulate a coherent (SBN) program, including both near and far detectors, and MicroBooNE in the SBN@FNAL.
- July 2014 (post P5 report)
 - First report from SBN Task Force, includes ICARUS, LAr1-ND, MicroBooNE, and has planned contributions from CERN & INFN. Significant step in aligning SBN with P5 recommendations
- January 2015
 - The three collaborations presented a common LOI (<http://arxiv.org/abs/1503.01520>). PAC granted Stage-1 approval for ICARUS, LAr1-ND (now SBN-ND), and MicroBooNE running in the SBN@FNAL.
- June 2015
 - Recommended a plan for coordinating analysis programs as part of input for Stage-2 approval consideration.

P5 Recommendations

- The Particle Physics Prioritization Panel (P5) recommended a near-term, world-leading short-baseline experimental neutrino program with strong participation by the domestic and international neutrino physics communities working toward LBNF:
 - P5 Recommendation #12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.
 - P5 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.

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context



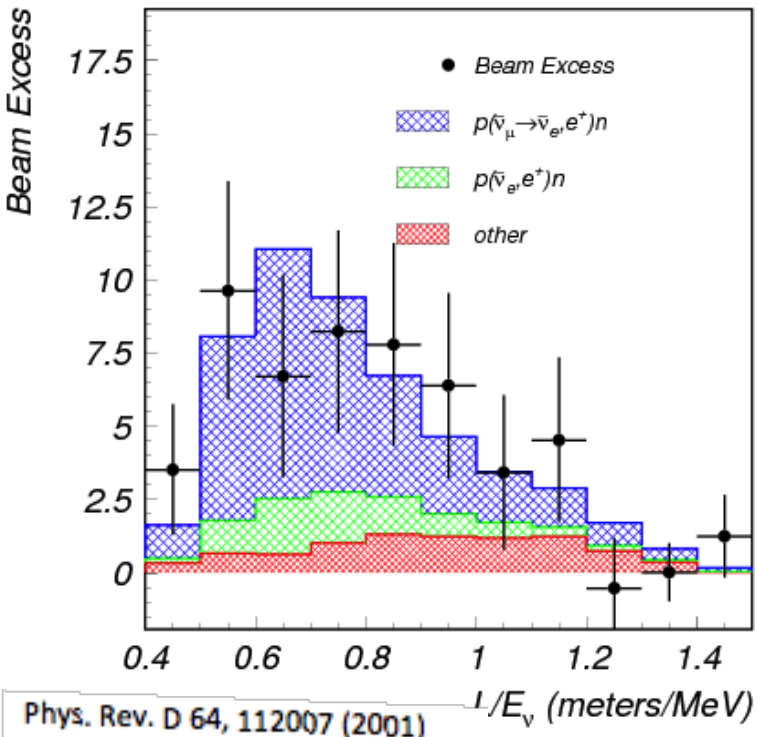
Report of the Particle Physics Project Prioritization Panel (P5)

May 2014

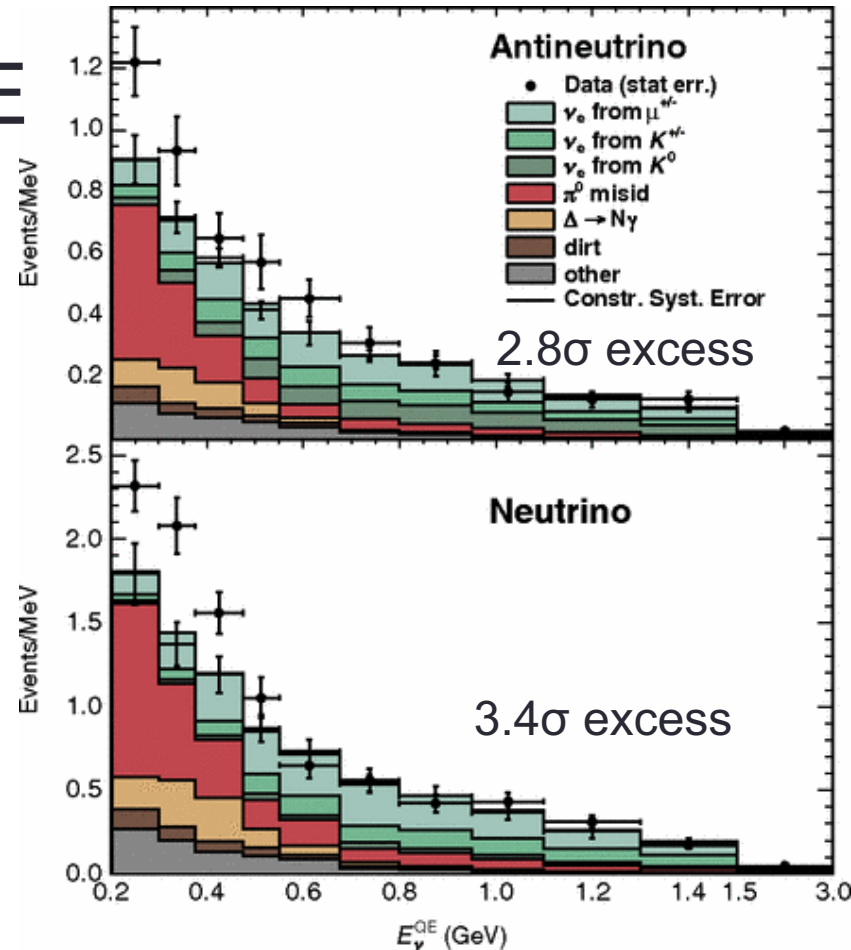
Anomalies, Light Sterile Neutrinos ?

Data inconsistent with $S\nu M$					
Appearance			Disappearance		
LSND	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\sim 4\sigma$	Reactor	$\bar{\nu}_e \rightarrow \bar{\nu}_X$	$\sim 3\sigma$
MiniBooNE	$\nu_\mu \rightarrow \nu_e$	$\lesssim 3\sigma$	Gallium	$\nu_e \rightarrow \nu_X$	$\sim 3\sigma$

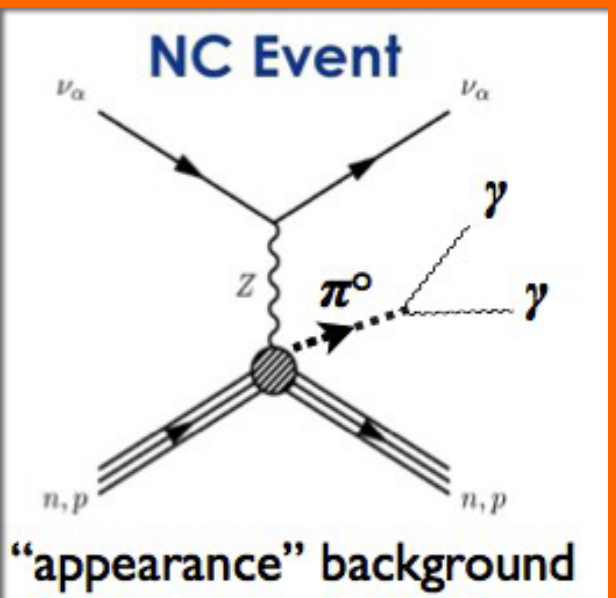
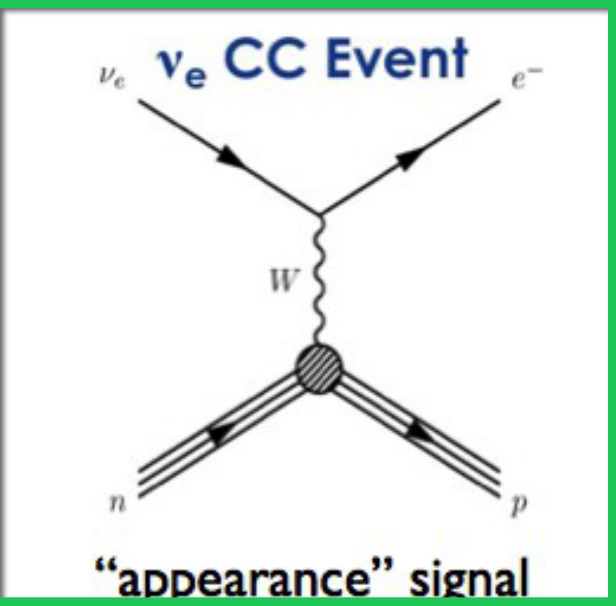
LSND



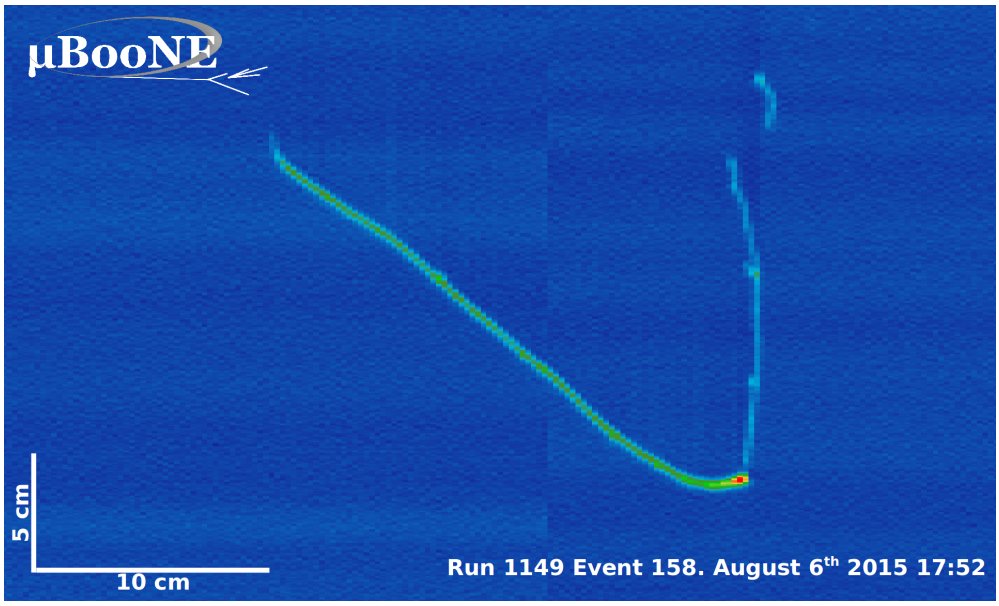
MiniBooNE

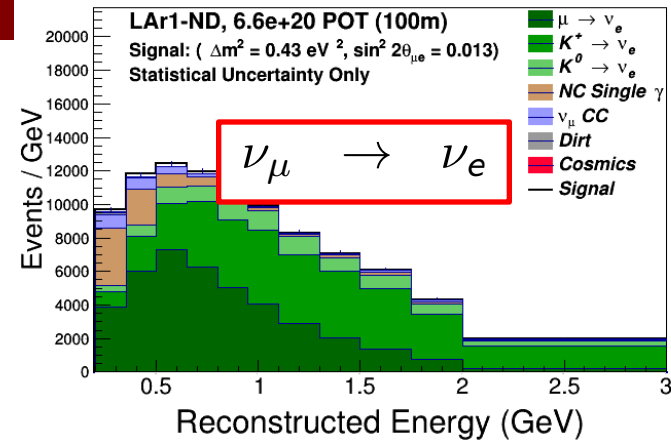


MicroBooNE



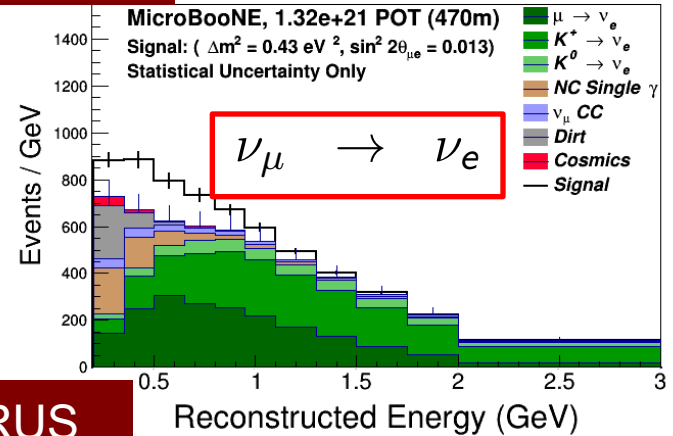
- MicroBooNE (CD0-September 2009, CD4-Completion September 2015)
 - Investigates the MiniBooNE low-energy excess by providing e-/ γ discrimination using LarTPC
 - Serves as a stepping stone towards future much larger LArTPC detectors
 - Fosters the development of fully automated reconstruction software for LArTPCs





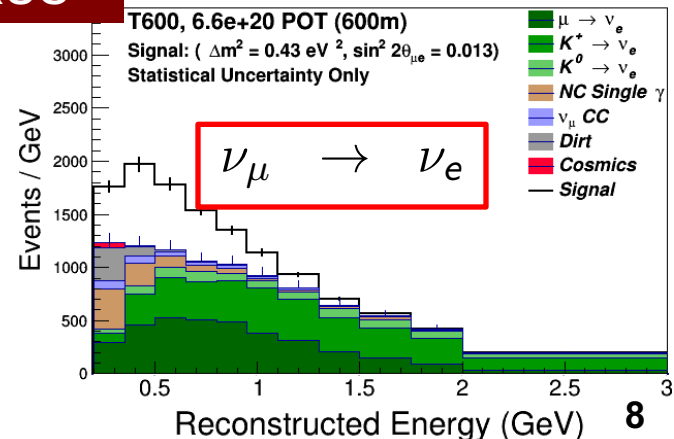
- SBND based on current DUNE-type technology allows:
 - High statistics studies of ν -Ar interactions
 - Characterization of the beam before oscillation
 - Understanding of systematic uncertainties
 - Another step in the development of the LArTPC technology for LBNF

MicroBooNE



- MicroBooNE: largest LAr TPC built in the US.
- ICARUS: the first and largest LAr TPC ever built. Undergoing refurbishment at CERN and prepped for transport to FNAL.
 - Large mass gives good ν_e rate

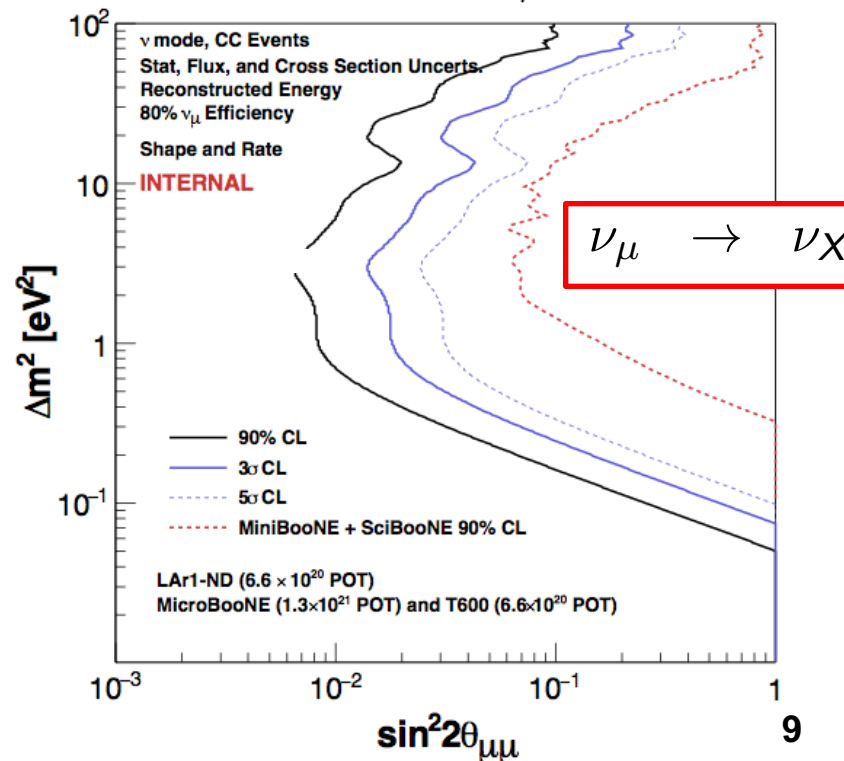
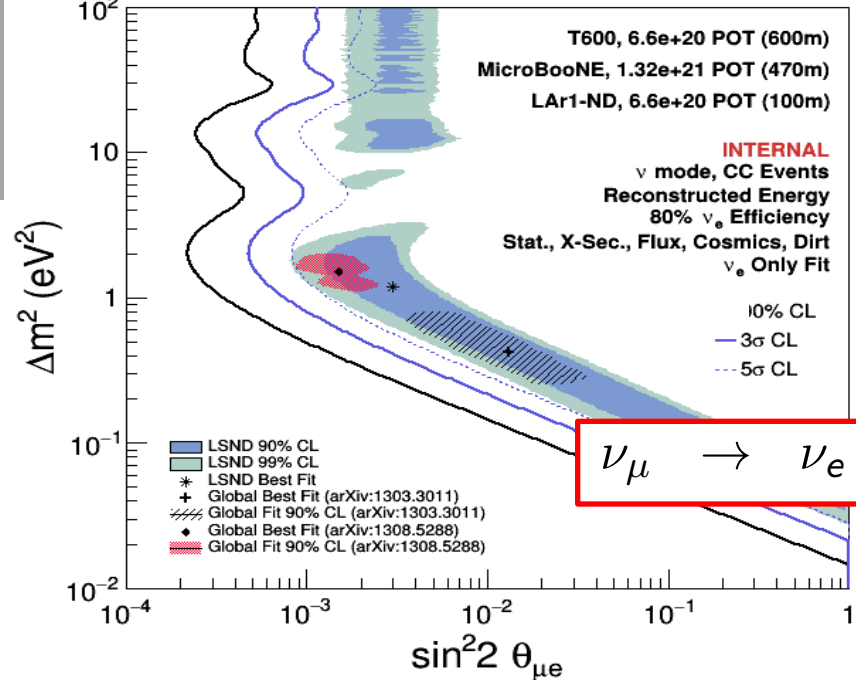
ICARUS



- The large mass far detector and the use of LAr for all detectors is key to reducing statistical and systematic uncertainties in the oscillation searches

SBN Physics

- Oscillation sensitivity was evaluated jointly by SBND(LAr1-ND), MicroBooNe, and ICARUS ([arXiv:1503.01520](https://arxiv.org/abs/1503.01520), SNB LOI)
- SBN@FNAL is sensitive to oscillations at Δm^2 (0.1-10 eV²) both in ν_e appearance and ν_μ disappearance
- Robustly address backgrounds and uncertainties:
 - ν_e contamination in the beam
 - Photons produced by neutral current interactions
 - Neutrino interactions in the earth or experimental hall surrounding the detectors
 - Backgrounds produced by cosmic rays
 - Neutrino beam and neutrino-argon cross section systematics and detector-to-detector correlations included in sensitivity analysis
- Region of interest for sterile ν is covered at 5 σ level.



PAC Feedback January 2015



- The SBN LOI was presented to the PAC which found that:
 - The SBN program as described in the LOI is fully aligned with the P5 recommendations
 - The contributions from CERN, INFN, NSF, STFC, SNSF (secured after the meeting) and the significant participation from European institutions brings significant international components to the program
- The Committee was impressed with the remarkable progress achieved by the SBND, MicroBooNe, ICARUS guided by the SBN Task Force. This included :
 - Understanding the implementation of the combined program of the three detectors
 - Producing a robust estimate of the sensitivity of the proposed program which included the detailed evaluation of neutrino flux and interaction modeling uncertainties, and backgrounds arising from cosmic rays and other sources.
- The committee encouraged the Laboratory to consider either extending the task force or forming a similar oversight group to ensure continued coordination between the collaborations until more formal memoranda of understanding are established.

PAC Feedback January 2015 II

- The PAC commented that before a CDR/Stage 2 the lab should provide:
 - Full cost and resource estimate for possible beam improvements to the upstream optics, installation of beam line instrumentation, and potential changes to the horn configuration.
- The PAC encouraged the three experiments to develop an integrated “work breakdown structure” to facilitate coordination since:
 - Common engineering and technical resources are needed from FNAL
 - There is overlap in membership, particularly between SBND and MicroBooNE.
 - Coordination and planning is required to ensure that resources are deployed effectively.
- The PAC encouraged the collaborations to develop a strategy of cross calibrations to demonstrate that relative acceptances for the various event types can be understood at **the 1% level**. There are challenges due to:
 - The deployment of three substantially different LAr TPCs
 - Large differences in neutrino flux at each detector.
 - The nature of the sought-after physics, which changes the active neutrino flux at each detector, leaving potentially no “standard candles” in the beam itself.
- The collaborations, particularly MicroBooNE, which will confront data soon, should integrate the reconstruction and event classification algorithms into the sensitivity studies and/or demonstrate their current capabilities.

PAC Recommendation January 2015

- *The Committee recommends Stage 1 approval for the SBN program, which incorporates LAr1ND and ICARUS with MicroBooNE towards a coherent SBN program. We recommend that the Laboratory provide the necessary engineering and technical resources to allow the program to move forward expeditiously, and to understand the scope of the Booster Neutrino Beamline modifications and improvements*

- At the meeting we received:
 - A status report from the MicroBooNE experiment
 - An overview of the progress on the SBN program
 - A description of the possible upgrades to the Booster Neutrino Beam.
- The committee congratulated the MicroBooNE collaboration on:
 - Achieving CD-4 and starting liquid argon filling (now completed).
 - Handling well the unexpected development of noisy channels
 - Developing a strong plan for commissioning and calibrating the detector.
 - Demonstrating progress on event reconstruction
- The Committee recommended that the Laboratory continues:
 - Monitoring progress on achieving automated event reconstruction
 - Providing relevant resources and expertise towards catalyzing this effort, since it is critical to quickly demonstrate the capabilities of the LArTPC technology.
- The committee requested that at the next PAC meeting, the MicroBooNE collaboration present a sensitivity study that:
 - Includes available existing reconstruction
 - Demonstrates the required rejection of backgrounds (such as those from π^0 s).
 - Compares key metrics in efficiency, particle identification, resolutions, background suppression, etc. relative to those assumed in the initial sensitivity estimates.
 - Evaluates the need for external cosmic veto trackers in MicroBooNE since the rejection of cosmic rays may not work as well for low energy neutrino events.

- The PAC reaffirms that the SBN program:
 - Is a critical part of the development of the LArTPC program leading up to DUNE
 - Has the sensitivity to confirm or rule out the outstanding anomalous results seen by LSND and MiniBooNE
 - Is very well aligned with the program outlined by P5.
- The PAC was pleased that:
 - Significant progress has been made on the SBND and ICARUS buildings.
 - Impressive technical progress, from the preparations for the arrival of ICARUS to the design work on the SBND TPC, photon, and counter systems.
 - The critical support from DOE, NSF, CERN, INFN, STFC, and SNSF.
- The PAC is concerned about:
 - The slow progress on coordinating the analysis across the three experiments, which is critical to the success of the SBN program. A common analysis will benefit from early on common decisions on:
 - Data formats
 - Common flux generators
 - Blind analysis schemes
 - The overlap of the collaboration membership between MicroBooNE and SBND is high. As MicroBooNE begins focusing on data analysis, there is the danger that progress towards a unified SBN program will lag.
 - The SBN schedule is very aggressive and there is little flexibility

PAC Feedback & Recommendation

June 2015

- The Committee believes that as part of the Stage 2 approval, a plan for coordinating the analysis programs across all three experiments is needed.
- The Committee believes that upgrade paths for BNB are a promising way of extending the reach of the SBN program and supports the continued study of this upgrade in coordination with the experimental collaborations
 - MicroBooNE and ICARUS are likely to be statistically limited. A gain in neutrino flux of 50-70% would be an important improvement.
- *The PAC recommends that the LBNC appoints a SBN subcommittee which oversees and advises the Laboratory on coordination among the MicroBooNE, SBND and ICARUS collaborations and other LAr detectors at FNAL and at CERN both from the technical and physics points of view. The same subcommittee should also monitor the knowledge exchange and coordination of efforts between the SBN and LBN programs. (Done)*

Enhancing the collaboration between SBN & DUNE

- First joint SBND-DUNE workshop on Sept. 2, 2015 focused on detector hardware including cold electronics, anode plane assemblies, field cage design, and photon detection systems
 - Goal was to share current detector designs and explore possibilities for direct SBND/DUNE collaboration on future development.
 - Timescales of SBND and proto-DUNE (the engineering prototype for DUNE to be operated in a test beam at CERN) are concurrent. Benefits to both SBND and DUNE in exploiting similarities/synergies.
- SBN-DUNE DAQ and readout electronics workshop on Nov 20, 2015 at Fermilab (<https://indico.fnal.gov/conferenceDisplay.py?confId=10599>)
 - Common DAQ solutions for the SBN detectors could be advantageous and are being actively discussed.
- A new SBN Task Force for finalizing the design choices on cosmic background mitigation has been convened with the charge to deliver a report by February 2016.
 - Common technical solutions could be beneficial to multiple detectors.
- Future workshops will be organized to focus on event reconstruction, and connections between the physics programs of SBND and DUNE.

Software Development/Collaboration

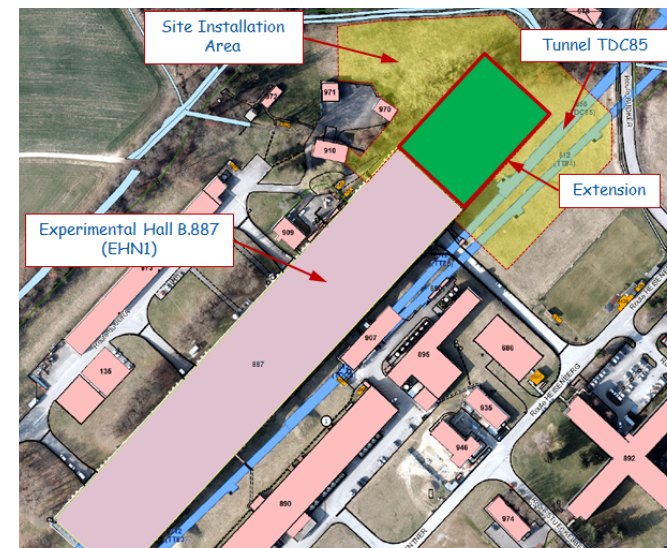
- LArSoft provides a common infrastructure for sharing physics code across Liquid Argon TPC experiments.
- An ICARUS reconstruction workshop at CERN in July included LArSoft experts from Fermilab and reconstruction developers from MicroBooNE.
- The LArSoft Steering Group organizes monthly meetings involving SBN, LArIAT, and DUNE representatives.
- A workshop in October involving all the stakeholders provided a forum to:
 - Assess the current status of LAr event reconstruction including efficiencies, resolutions, validations, challenges, etc.
 - Define the LArSoft requirements in terms of capabilities, design, performance, and solutions to support LAr TPC experiments over the next decade.

Other Important Steps

- SBN Director's Progress Review on Dec 15-17 at Fermilab. This will be a coordinated review of both SBND and ICARUS designs, cost, and schedule.
- The FNAL PAC at its January meeting expects to consider:
 - MicroBooNE update
 - A new report on the BNB upgrade path
 - Stage 2 approval for the SBN program
 - A report from the Scientific Computing Division focusing on the support for the neutrino program

Conclusions

- The PAC believes that the combination of three LAr experiments, described in the SBN LOI, **will definitively address the LSND hint for sterile neutrinos at the 5σ level**, thereby meeting the P5 recommendation
- The SBN@FNAL program has made major advances in 2015.
- The PAC continues to urge close coordination between the three experiments and has recommended steps to increase scrutiny of the SBN program
- The PAC is impressed by the FNAL and international efforts
- The new facilities at CERN are critical to the refurbishment of ICARUS and will play an important role in the future neutrino program for LBNF



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• BACKUP

Status of Neutrino Initiatives Presented to the FNAL PAC

INITIATIVE		Last Action	RESULT / COMMENTS
1032	MiniBooNE-DM	Jan 2014	Stage-2 / data taking completed
1033	MiniBooNE+	Jan 2014	Rejected
1051	CHIPS R&D	Jan 2014	Approved for 1 year R&D
1052	SBN /ICARUS	Jan 2015	Stage 1
1053	SBN / SBN-ND	Jan 2015	Stage 1
	SBN / MicroBooNE	Jan 2015	Stage 1
1057	NESSiE	Jan 2015	Rejected
1060	CAPTAIN-BNB	June 2015	Deferred (until after 1061)
1061	CAPTAIN-MINERvA	June 2015	Stage 1
1063	ANNIE	Jan 2015	Stage 1 / proceed with Phase-1

NOTE: Testbeam initiatives, which are not considered by the PAC, are not listed.

Status of Initiatives Presented to the FNAL PAC

INITIATIVE		Last Action	RESULT / COMMENTS
1032	MiniBooNE-DM	Jan 2014	Stage-2 / data taking completed
1033	MiniBooNE+	Jan 2014	Rejected
1039	Polarized-DY	Jun 2013	Stage-1 / contingent on NP funds
1051	CHIPS R&D	Jan 2014	Approved for 1 year R&D
1052	SBN /ICARUS	Jan 2015	Stage 1
1053	SBN / SBN-ND	Jan 2015	Stage 1
	SBN / MicroBooNE	Jan 2015	Stage 1
1057	NESSiE	Jan 2015	Rejected
1060	CAPTAIN-BNB	June 2015	Deferred (until after 1061)
1061	CAPTAIN-MINERvA	June 2015	Stage 1
1063	ANNIE	Jan 2015	Stage 1 / proceed with Phase-1
1067	SeaQuest Dark Photon	June 2015	Approved for 1 st phase (in preparation for full proposal)

NOTE: Testbeam initiatives, which are not considered by the PAC, are not listed.