The Fermilab short baseline neutrino oscillation program

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Hints for the existence of “sterile neutrinos" ?

While each of the measurements below alone lacks the significance to claim a discovery, together they could be suggesting new physics

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Type</th>
<th>Channel</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSND</td>
<td>DAR</td>
<td>$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC</td>
<td>3.8$\sigma$</td>
</tr>
<tr>
<td>MiniBooNE</td>
<td>SBL accelerator</td>
<td>$\nu_\mu \rightarrow \nu_e$ CC</td>
<td>3.4$\sigma$</td>
</tr>
<tr>
<td>MiniBooNE</td>
<td>SBL accelerator</td>
<td>$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC</td>
<td>2.8$\sigma$</td>
</tr>
<tr>
<td>GALLEX/SAGE</td>
<td>Source - e capture</td>
<td>$\nu_e$ disappearance</td>
<td>2.8$\sigma$</td>
</tr>
<tr>
<td>Reactors</td>
<td>Beta-decay</td>
<td>$\bar{\nu}_e$ disappearance</td>
<td>3.0$\sigma$</td>
</tr>
</tbody>
</table>

Evidence for light sterile neutrinos would be a major discovery in particle physics and cosmology
π Decay-In-Flight experiments

Complementary ways to search sterile neutrinos and address existing anomalies: reactors, radioactive sources, DAR, etc.

DIF beams provide a rich oscillations program with a single facility:

- $\nu_\mu \rightarrow \nu_e$ appearance
- $\nu_\mu$ and $\nu_e$ disappearance
- both neutrino and antineutrino beams possible
- CC and NC interactions
- cross section physics over a broad range of relevant energies

However,

- Need detectors that can distinguish electrons from photons in order to reduce key backgrounds: liquid argon TPCs?
- Multiple detectors at different baselines is crucial for reducing systematic uncertainties
USA P5 report recommendations

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.

The Fermilab SBN program
Address the issue by a comprehensive $\nu \rightarrow \nu_x$ and $\nu_\mu \rightarrow \nu_e$ oscillation program (SBN)

Short-Baseline Neutrino beam at FNAL:

- The Booster Neutrino Beam (BNB) is shallow (~10 m detector hall depth at all baselines)
- Neutrino fluxes well understood due to dedicated hadron production data (CERN experiments) and >10 years experience by MiniBooNE and SciBooNE
- SBN experiments offer a great opportunity for use of mid-scale detectors, which will see large neutrino exposures; continue development of the liquid Argon TPC technology for neutrino physics
Detector technology choice: LAr TPC

- **ICARUS T600** is the first large LAr TPC having been operated at LNGS (CNGS beam) and constitutes a wealth of knowledge in the field.
- The **WA104 R&D project at CERN** (CENF) will rebuild the T600 and prepare it for beam at Fermilab.
- The **approved T-1053 (LAr1-ND) experiment at FNAL** will perform the needed R&D and develop the technical design for the LAr1-ND detector.
- The **MicroBooNE detector** (E-974) will be coming online soon and be the first of the whole program.
- The **LArIAT (T1034) experiment** will provide charged beam calibration of the LAr TPC.
- More ideas/solutions might come from the R&D being conducted in Bern (**ARGONTUBE/ARGONCUBE**).

Together, the SBN program offers a valuable and exciting opportunity for the international community who is pursuing this technology as a cornerstone in neutrino physics for the next several decades.
MicroBooNE

The first phase of the next generation SBN Program begins soon with MicroBooNE coming online later this year!

June 23, 2014
MicroBooNE and the MiniBooNE “Low-Energy Excess”

MicroBooNE will investigate if the excess events seen by MiniBooNE are electrons or photons.

A. Ereditato – NU
Address the LSND/MiniBooNE signal with LAr TPCs

MiniBooNE

- Electron, Photon
- Muon
- Proton

\[ \pi^0 \rightarrow \gamma + \gamma \]

(Cherenkov Detector)

MicroBooNE

- Electron, Photon
- Muon
- Proton

\[ \pi^0 \rightarrow \gamma + \gamma \]

(LArTPC)
The MicroBooNE TPC being inserted into the cryostat
MicroBooNE Collaboration + project team


University of Cambridge: A. Blake, J. Marshall, M. Thomson

University of Chicago: W. Foreman, J. Ho, D. Schmitz, J. Zennamo

University of Cincinnati: R. Grosso, J. St. John, R. Johnson, B. Littlejohn


Kansas State University: T. Bolton, S. Farooq, S. Gollapinni, G. Horton-Smith


Michigan State University: C. Bromberg, D. Edmunds

New Mexico State University: T. Miceli, V. Papavassiliou, S. Pate, K. Woodruff

Otterbein University: N. Tagg

University of Oxford: G. Barr, M. Bass, R. Guenette

University of Pittsburgh: S. Dyman, D. Naples, V. Paolone

Princeton University: K. McDonald, B. Sands

Saint Mary’s University of Minnesota: P. Nienaber

SLAC: M. Convery, B. Eberly, M. Graham, D. Muller, L. Rochester, Y-T. Tsai, T. Usher

Syracuse University: J. Asaadi, J. Esquivel, M. Soderberg

University of Texas at Austin: S. Cao, J. Huang, K. Lang


INFN: F. Cavanna, O. Palamara (currently at Yale)

Virginia Tech: M. Jen, L. Kalousis, C. Mariani, R. Pelkey

Yale University: C. Adams, E. Church, B. Fleming*, E. Gramellini, A. Hackenburg, B. Russell, A. Szolec

*spokespeople, + project manager

3 countries
23 institutions
136 collaborators
31 postdocs
24 grad students
Next steps towards a complete FNAL program

**MicroBooNE**: focused on understanding the MiniBooNE neutrino anomaly, not designed to explore the whole sterile neutrino oscillation parameter space on its own.

LOI submitted to the Fermilab PAC (**LAr1 project**) in 2012: 1-kton LArTPC to serve as a second (near) detector along with MicroBooNE.

January 2014: two proposals were put forward to the PAC:


Realizing the importance of a near detector to measure the unoscillated fluxes and the physics program enabled in a first phase with a ND + MicroBooNE, LAr1-ND was proposed as the next phase in the SBN program.

**P-1052: ICARUS@FNAL** [http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/ICARUS.pdf](http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/ICARUS.pdf)

Proposal to relocate an upgraded ICARUS T600 LAr TPC detector to the BNB and to construct a new one-fourth scale detector based on the same design to serve as a near detector for oscillation searches.
LAr1-ND

- LAr1-ND: LAr TPC exploiting as many design elements developed for LBNE
- High statistics measurement of intrinsic BNB content: sensitive oscillation searches in combination with downstream detectors
- With MicroBooNE, provide full interpretation of the MiniBooNE excess. Photons or electrons? Intrinsic to the beam or appearing?
- Side results: reconstruction development and GeV $\nu$-Ar cross sections
- $O(1M \nu_\mu$ and $6000 \nu_e$ events/year)
LAr1-ND Collaboration


1 Yale University, New Haven, CT
2 University of Liverpool, Liverpool, UK
3 Syracuse University, Syracuse, NY
4 Fermi National Accelerator Laboratory, Batavia, IL
5 Brookhaven National Laboratory, Upton, NY
6 Massachusetts Institute of Technology, Boston, MA
7 Columbia University, Nevis Labs, Irvington, NY
8 University of Chicago, Enrico Fermi Institute, Chicago, IL
9 University of Bern, Laboratory for High Energy Physics, Bern, Switzerland
10 University of Manchester, Manchester, UK
11 Los Alamos National Laboratory, Los Alamos, NM
12 University of Oxford, Oxford, UK
13 Center for Neutrino Physics, Virginia Tech, Blacksburg, VA
14 University of Sheffield, Sheffield, UK
15 Indiana University, Bloomington, IN
16 CERN, Geneva, Switzerland
17 Lancaster University, Lancaster, UK
18 University of Cambridge, Cambridge, UK

*Spokesperson

10 US institutions
- 3 DOE National Laboratories
- 6 NSF institutions
8 European institutions
- 6 UK institutions
- 1 Swiss institution
- CERN

11 groups also on MicroBooNE
ICARUS at FNAL

• T600 LAr TPC to be located along the BNB at ~700 m from the target

• New T150 TPC to be placed at 150±50 m from the target

• T600: also ν’s from the off-axis NuMI beam with (~2 GeV) with enriched ν_e flux

• T600 plus T150 would extend the information coming from MicroBooNE
ICARUS Collaboration


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SBN program development

• Members of LAr1-ND, MicroBooNE and ICARUS, representatives from Fermilab, INFN and CERN, have been working together to develop a coherent SBN program on the BNB.

• Coordinator (Peter Wilson, FNAL) to work with contacts from the three detectors to assess cost, schedule and requirements.

• International Task Force formed to lead the preparation of a SBN proposal to the FNAL PAC

• Proposal to include the physics sensitivities for a multi-LArTPC detector program with LAr1-ND near 100 m, MicroBooNE at 470 m, and the ICARUS T600 detector near 600 m along the BNB.
Four Working Groups active on:

1. Cosmic backgrounds
   - Impact of cosmic showers on oscillation searches
   - Mitigation strategies

2. Neutrino Flux and Systematics
   - Optimization of ND location
   - Consider optimization of the BNB for higher flux/p.o.t.

3. Detector Buildings and Siting
   - Building requirements
   - Costs and schedule

4. Cryostat and Cryogenic Systems
   - Design of cryogenics including possibility of standardized systems for both detectors
Neutrino oscillations in the BNB

At peak BNB neutrino energy, $E = 700$ MeV
SBN facilities
$\nu_\mu \rightarrow \nu_e$ appearance sensitivity

6.6x10^{20} \text{ p.o.t. exposure}

- 80% $\nu_e$ CC ID efficiency
- Beam-related backgrounds only
- Possible cosmogenic backgrounds not included

PRELIMINARY
SBN schedule

Schedule and Milestones

- Goal set of having detectors ready for data taking in Spring 2018. This is very challenging but possible.
- Detailed schedule not yet prepared, presented here is a first pass at high level milestones
  - Construction of buildings is on critical path
  - Preparation of CDR must proceed immediately to define requirements of buildings and cryogenics systems
- To achieve this schedule, the work of the Task force and WGs must continue with increased participation and cooperation in the coming months

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Date</th>
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<tbody>
<tr>
<td>Submission of a detailed SBN proposal for peer review</td>
<td>Oct 2014</td>
</tr>
<tr>
<td>Final CE requirements ready final building design</td>
<td>Nov 2014</td>
</tr>
<tr>
<td>Near detector cryostat engineering study contracted</td>
<td>Nov 2014</td>
</tr>
<tr>
<td>T600 at CERN, refurbishing starting</td>
<td>Dec 2014</td>
</tr>
<tr>
<td>Cryogenic plants proposal submitted for peer review</td>
<td>Mar 2015</td>
</tr>
<tr>
<td>LAr1-ND technical proposal submitted for peer review</td>
<td>Mar 2015</td>
</tr>
<tr>
<td>Ground breaking for far detector building</td>
<td>May 2015</td>
</tr>
<tr>
<td>Cryogenics procurement plans released and active</td>
<td>Sep 2015</td>
</tr>
<tr>
<td>Ground breaking for near detector building</td>
<td>Oct 2015</td>
</tr>
<tr>
<td>LAr1-ND cryostat procurement contract issued</td>
<td>Dec 2015</td>
</tr>
<tr>
<td>Buildings ready, utilities installation start</td>
<td>Oct 2016</td>
</tr>
<tr>
<td>Start cryostat assembly for near detector at Fermilab</td>
<td>Oct 2016</td>
</tr>
<tr>
<td>T600 ready at CERN for transport</td>
<td>Nov 2016</td>
</tr>
<tr>
<td>T600 detector arrives at Fermilab</td>
<td>Mar 2017</td>
</tr>
<tr>
<td>Start LAr1-ND detector installation</td>
<td>Apr 2017</td>
</tr>
<tr>
<td>Start cryogenic plant commissioning</td>
<td>Aug 2017</td>
</tr>
<tr>
<td>LAr1-ND and T600 installed</td>
<td>Sep 2017</td>
</tr>
<tr>
<td>Start detectors cooling and commissioning</td>
<td>Nov 2017</td>
</tr>
<tr>
<td>Start data taking with beam</td>
<td>Apr 2018</td>
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</table>
Summary

• The international SBN program at Fermilab, strongly endorsed by the P5 report, is going to play a key role in resolving the existing hints for new physics happening: sterile neutrinos

• A discovery would be a major science result (for particle physics and cosmology)

• The SBN program additionally provides supporting physics measurements and detector R&D towards the future long-baseline neutrino program (LBNF)

• Finally, the SBN program will serve as a development platform and demonstration of extremely sensitive disappearance and appearance neutrino oscillation measurements by using the LAr TPC technology
Thank you for your attention!