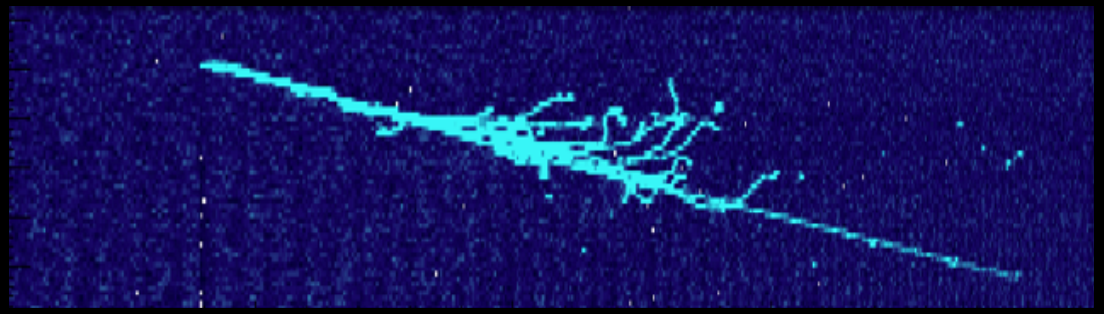
The Fermilab short baseline neutrino oscillation program



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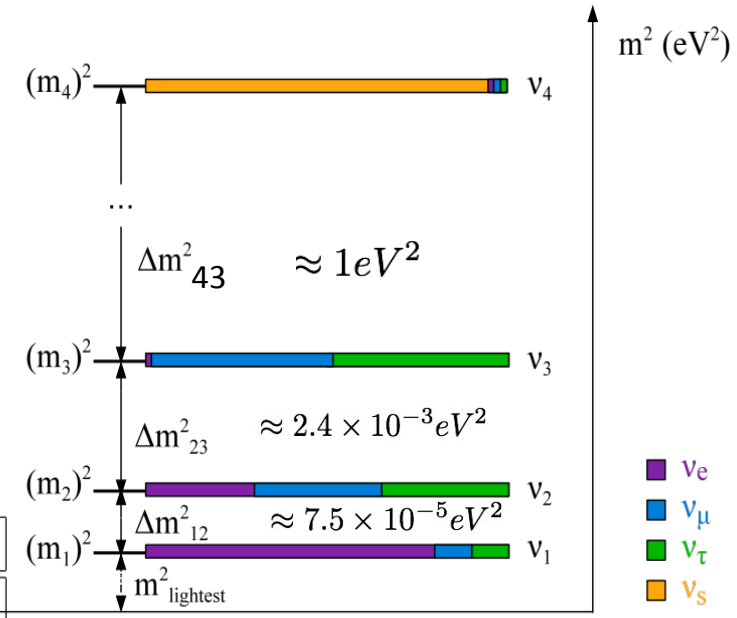
LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

The physics case

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



Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \to \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

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
- ν_μ and ν_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.

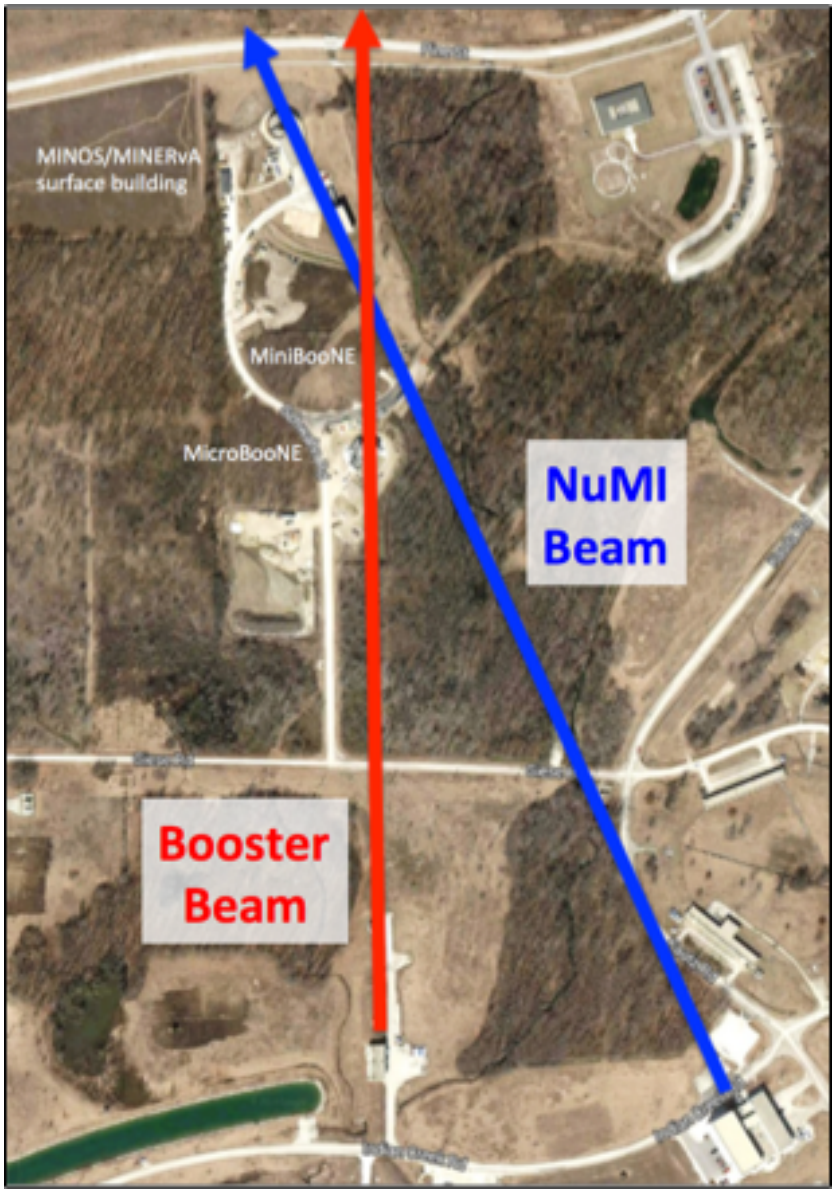
Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international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

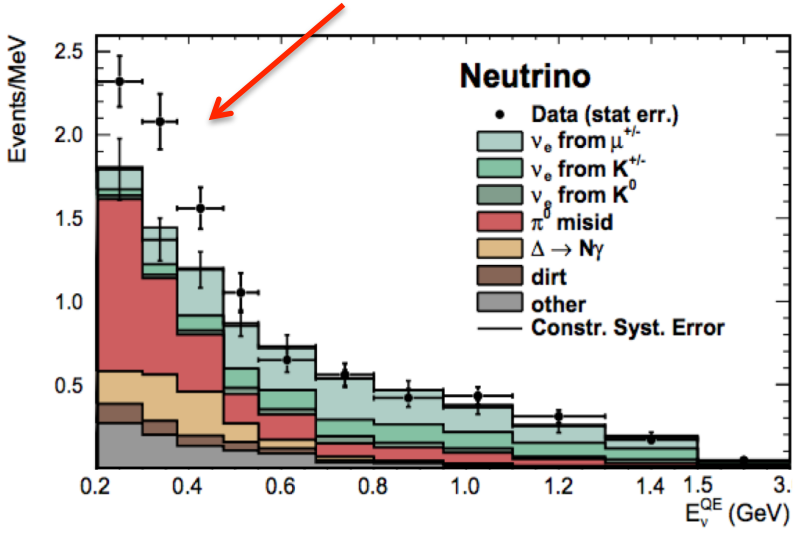
The first phase of the next generation SBN Program begins soon with MicroBooNE coming online later this year!

June 23, 2014

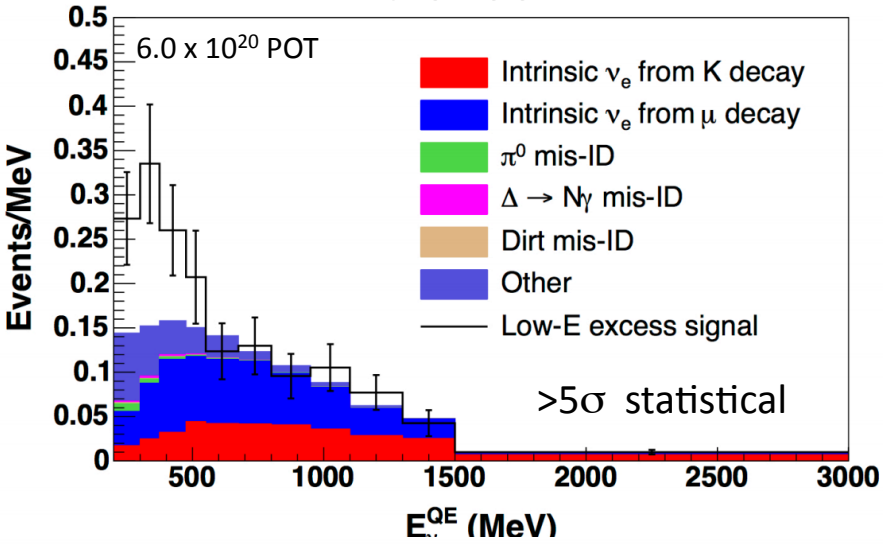
MicroBooNE and the MiniBooNE "Low-Energy Excess"

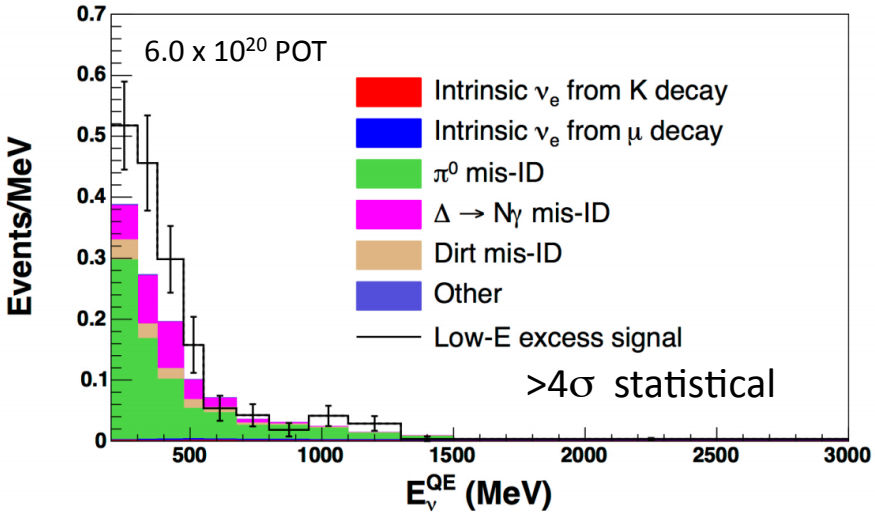
MicroBooNE will investigate if **the excess events seen by MiniBooNE are electrons or photons**

MiniBooNE



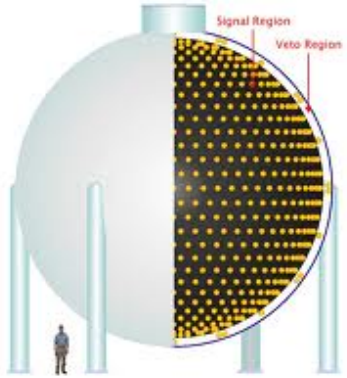
MicroBooNE

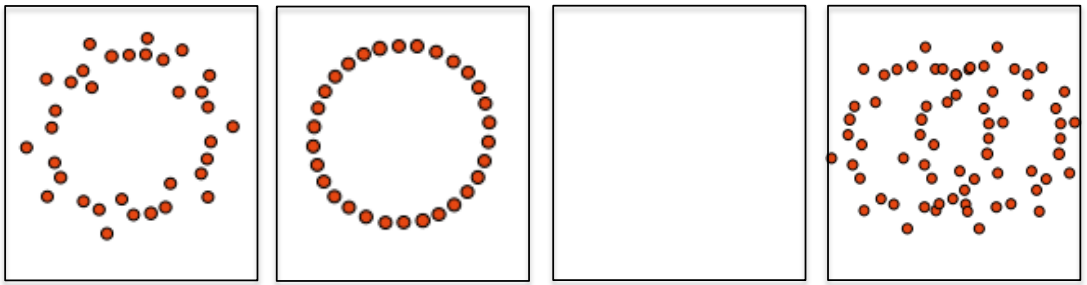




Address the LSND/MiniBooNE signal with LAr TPCs

MiniBooNE

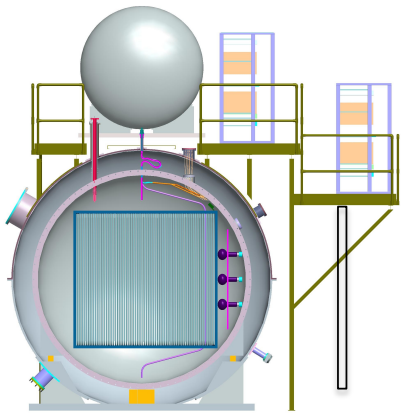


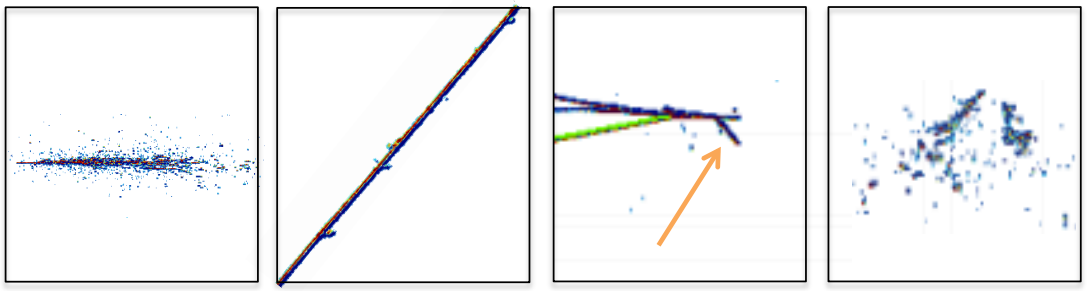


Electron, Photon | Muon | Proton | $\pi^0 \rightarrow \gamma + \gamma$

(Cherenkov Detector)

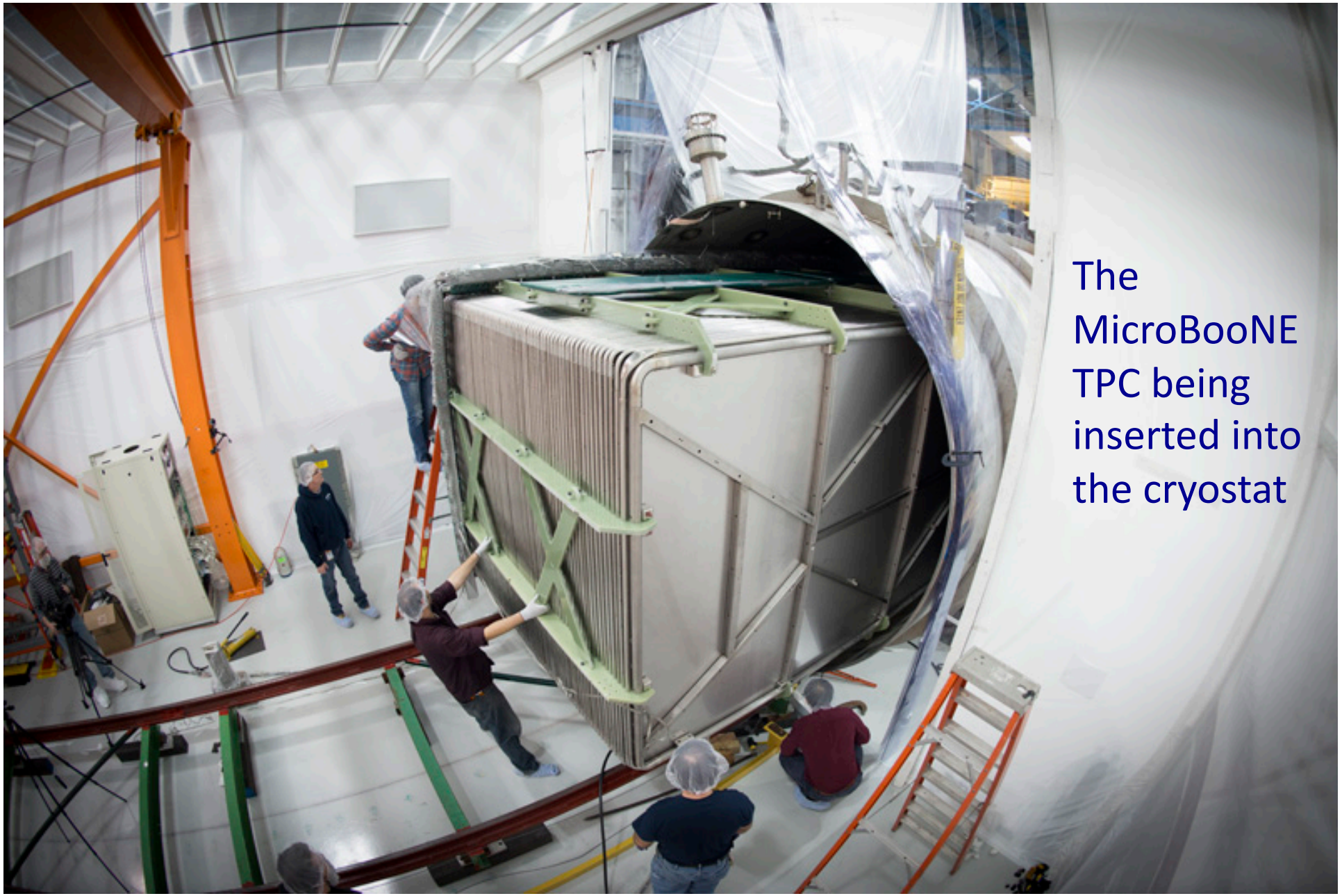
MicroBooNE





Electron, Photon | Muon | Proton | $\pi^0 \rightarrow \gamma + \gamma$

(LArTPC)



The MicroBooNE TPC being inserted into the cryostat

MicroBooNE Collaboration + project team

Brookhaven: M. Bishai, H. Chen, K. Chen, S. Duffin, J. Farrell, F. Lanni, Y. Li, D. Lissauer, G. Mahler, D. Makowiecki, J. Mead, X. Qian, V. Radeka, S. Rescia, A. Ruga, J. Sondericker, C. Thorn, B. Yu, C. Zhang

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

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MIT: W. Barletta, L. Bugel, G. Collin, J. Conrad, C. Ignarra, B. Jones, J. Moon, M. Moulai, J. Spitz, M. Toups, T. Wongjirad

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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. Dytman, 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

University of Bern: A. Ereditato, D. Goeldi, I. Kreslo, M. Luethi, C. Rudolf von Rohr, T. Strauss, M. Weber

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. Szelc

3 countries
23 institutions
136 collaborators
31 postdocs
24 grad students

*spokespeople, +project manager

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:

P-1053: LAr1-ND http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/LAr1ND_Proposal.pdf

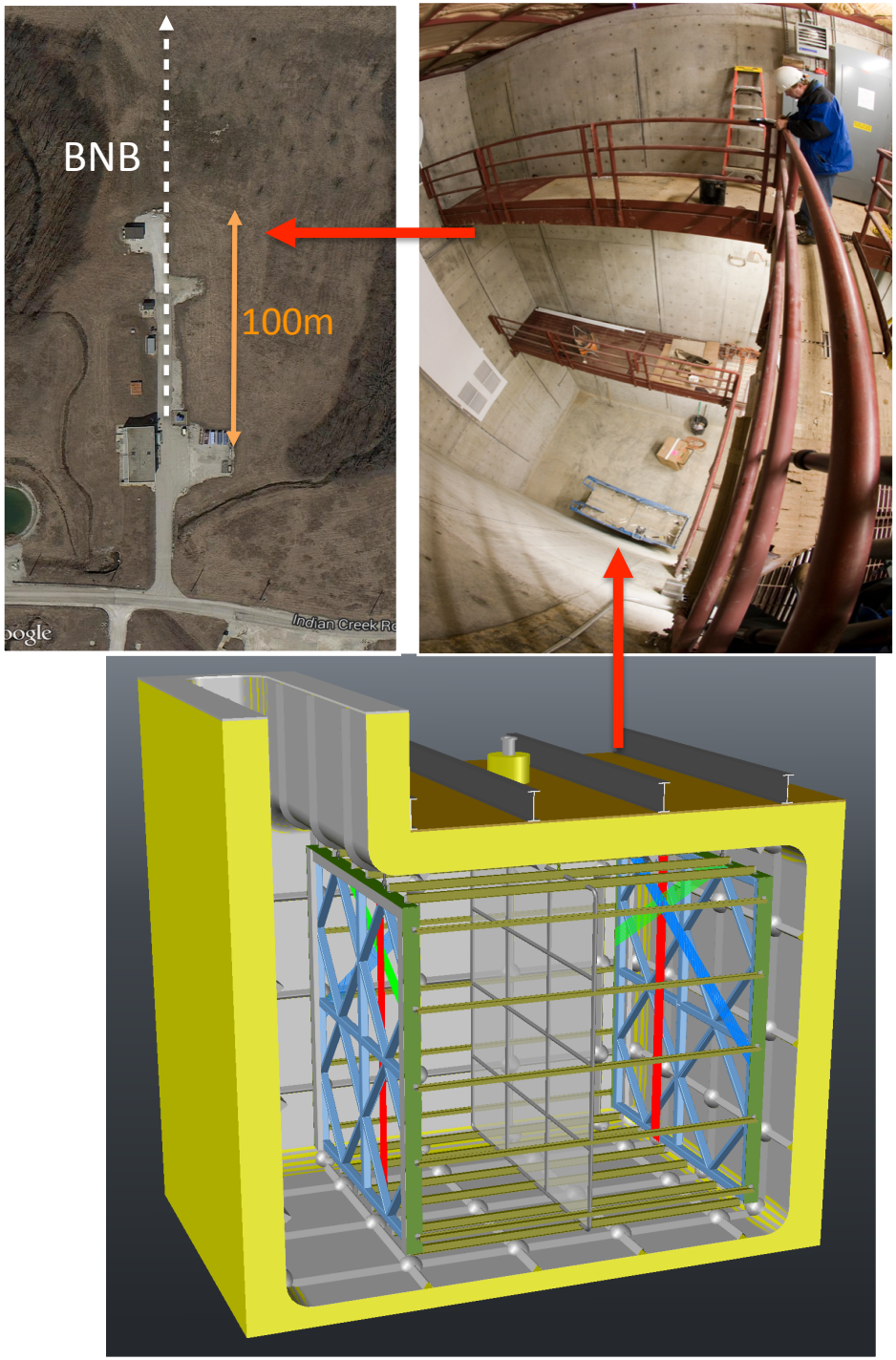
Realizing the importance of a near detector to measure the unoscillated fluxes and the physics program enabled in a first phase with a ND + MicroBooNE, LAr1-ND was proposed as the next phase in the SBN program.

P-1052: ICARUS@FNAL http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/ICARUS.pdf

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 ν-Ar cross sections
- *O*(1M ν_μ and 6000 ν_e events/year)



LAr1-ND Collaboration

C. Adams[1], C. Andreopoulos[2], J. Asaadi[3], B. Baller[4], M. Bishai[5], L. Bugel[6], L. Camilleri[7], F. Cavanna[1], H. Chen[5], E. Church[1], D. Cianci[8], G. Collin[6], J.M. Conrad[6], G. De Geronimo[5], A. Ereditato[9], J. Evans[10], B. Fleming[1], W.M. Foreman[8], G. Garvey[11], R. Guenette[12], J. Ho[8], C.M. Ignarra[6], C. James[4], C.M. Jen[13], B.J.P. Jones[6], L.M. Kalousis[13], G. Karagiorgi[7], W. Ketchum[11], I. Kreslo[9], V.A. Kudryavtsev[14], D. Lissauer[5], W.C. Louis[11], C. Mariani[13], K. Mavrokoridis[2], N. McCauley[2], G.B. Mills[11], Z. Moss[6], S. Mufson[15], M. Nessi[16], J. Nowak[17], O. Palamara*[1], Z. Pavlovic[11], X. Qian[5], L. Qiuguang[11], V. Radeka[5], R. Rameika[4], C. Rudolf von Rohr[9], D.W. Schmitz*[8], M. Shaevitz[7], M. Soderberg[3], S. Söldner-Rembold[10], J. Spitz[6], N. Spooner[14], T. Strauss[9], A.M. Szelc[1], C.E. Taylor[11], K. Terao[7], L. Thompson[14], M. Thomson[18], C. Thorn[5], M. Toups[6], C. Touramanis[2], R.G. Van De Water[11], M. Weber[9], D. Whittington[15], B. Yu[5], G. Zeller[4], and J. Zennamo[8]

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*Spokespeople

10 US institutions

- 3 DOE National Laboratories
- 6 NSF institutions

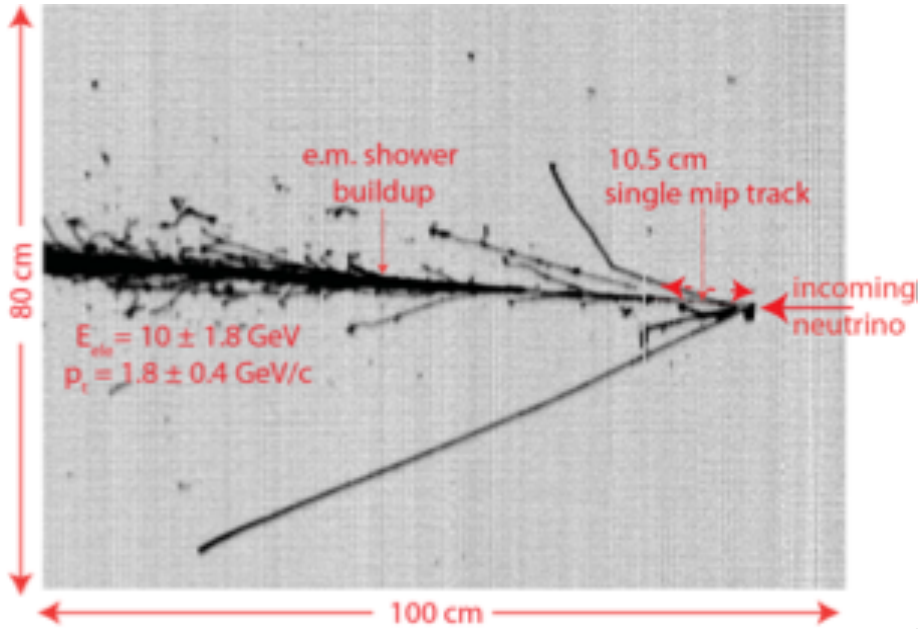
8 European institutions

- 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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INFN, LNGS, Assergi (AQ), Italy [1)], INFN, Sezione di Padova, 35131 Padova, Italy [2)], Dipartimento di Fisica, Università di Padova, 35131 Padova, Italy [3)], INFN, Sezione di Catania, Catania, Italy [5)], INFN, Laboratori Nazionali di Frascati (LNF), 00044 Frascati (Roma), Italy [6)], Dipartimento di Fisica, Università di Pavia, 27100 Pavia, Italy [7)], INFN, Sezione di Pavia, 27100 Pavia, Italy [8)], INFN, Sezione di Milano Bicocca, Dipartimento di Fisica G. Occhialini, 20126 Milano, Italy [9)], The H. Niewodniczanski Institute of Nuclear Physics, Polish Academy of Science, Kraków, Poland [10)], Department of Physics and Astronomy, University of California, Los Angeles, USA [11)], INFN, Sezione di Napoli, Dipartimento di Scienze Fisiche, Università Federico II, 80126 Napoli, Italy [12)], INR-RAS, Moscow, Russia [13)], CERN, Geneva , Switzerland [14)], Institute of Physics, University of Silesia, Katowice, Poland [15)], National Center for Nuclear Research, Warszawa, Poland [16)], Los Alamos National Laboratory, New Mexico, USA [17)], Institute for Radioelectronics, Warsaw University of Technology, Warsaw, Poland [18)], GSSI, L'Aquila (AQ), Italy [19)] , INFN, Sezione di Milano, 20133 Milano, Italy [20)]

SBN program development

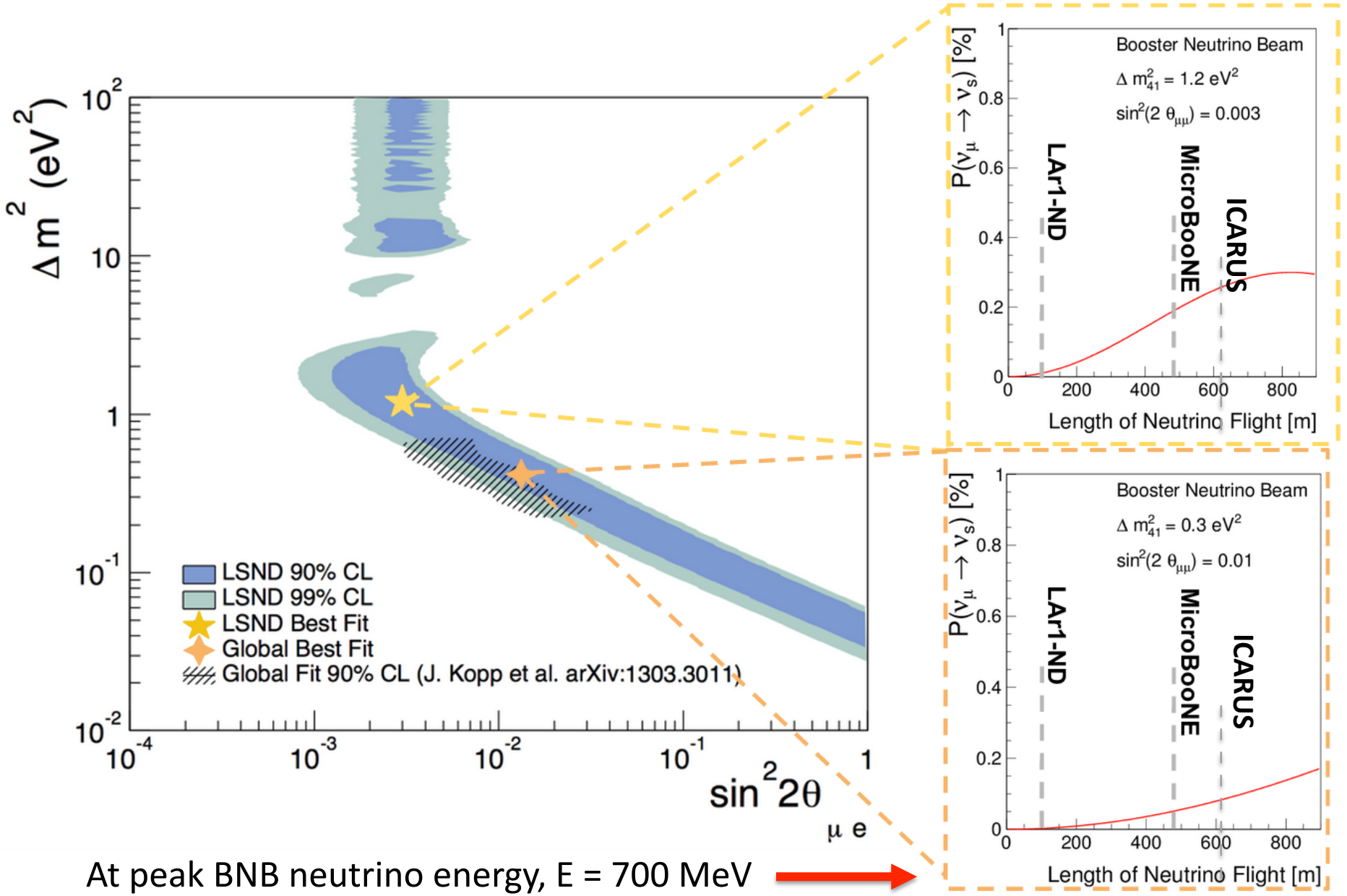
- Members of LAr1-ND, MicroBooNE and ICARUS, representatives from Fermilab, INFN and CERN, have been working together to develop a coherent SBN program on the BNB.
- Coordinator (Peter Wilson, FNAL) to work with contacts from the three detectors to assess cost, schedule and requirements.
- International 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.

SBN program optimization

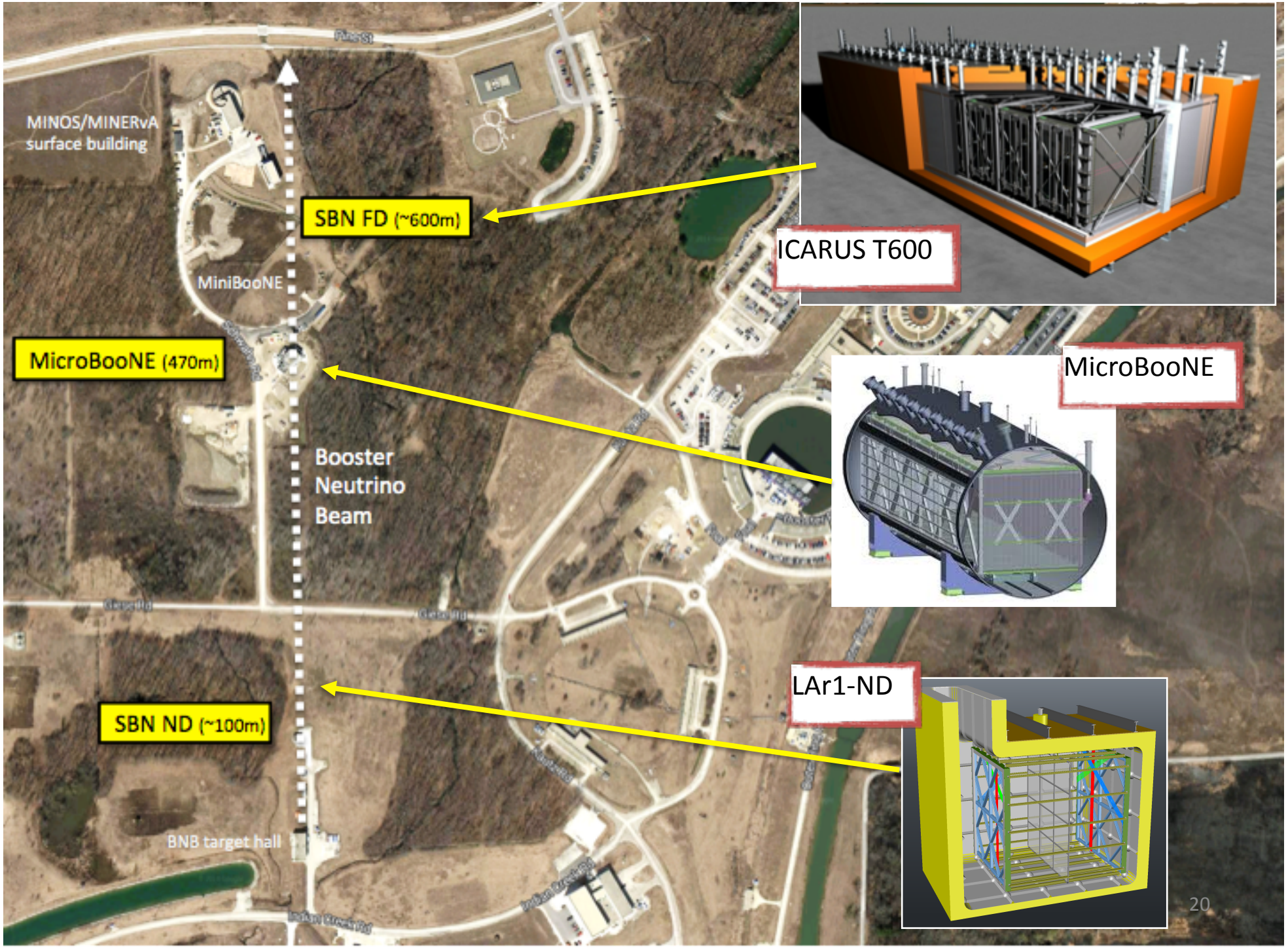
Four Working Groups active on:

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

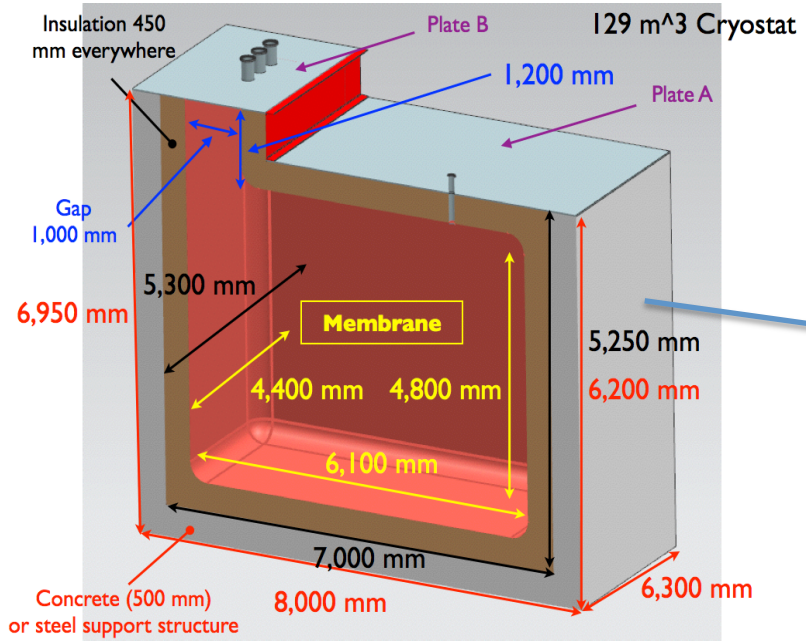
Neutrino oscillations in the BNB

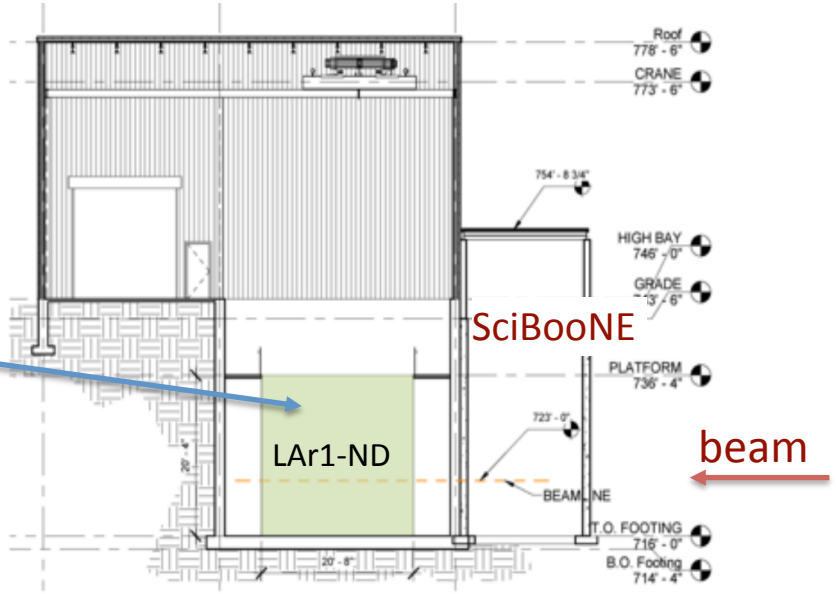


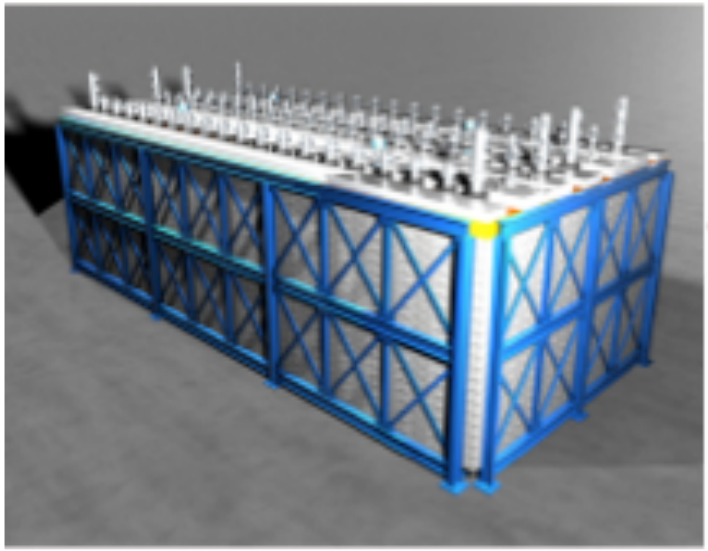
At peak BNB neutrino energy, E = 700 MeV


MINOS/MINERvA
surface building
SBN FD (~600m)
MiniBooNE
MicroBooNE (470m)
Booster
Neutrino
Beam
SBN ND (~100m)
BNB target hall
ICARUS T600
MicroBooNE
LAr1-ND

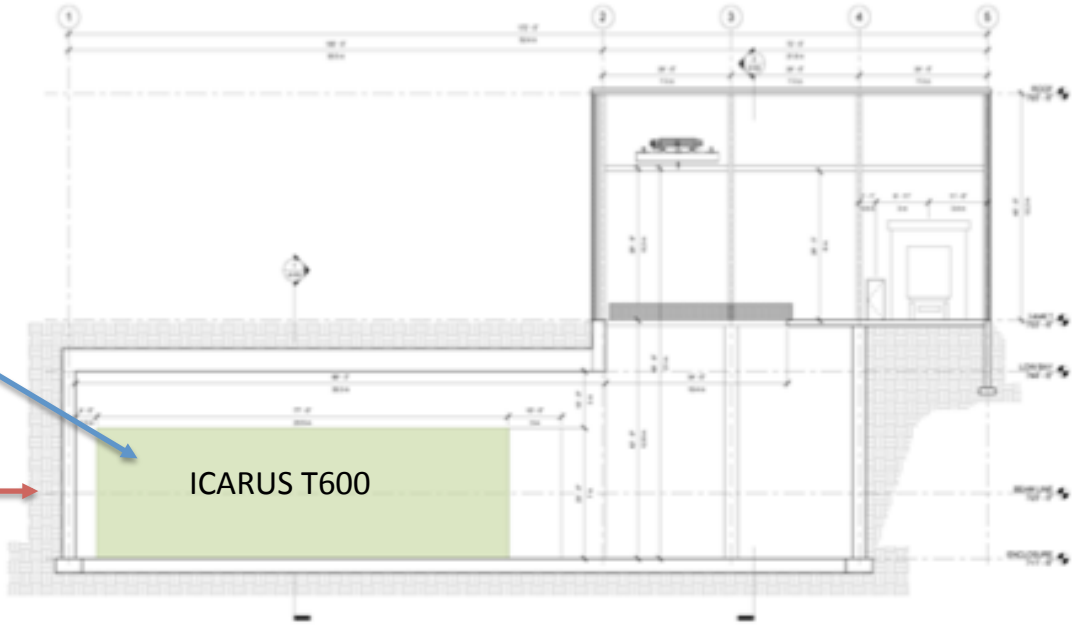
SBN facilities



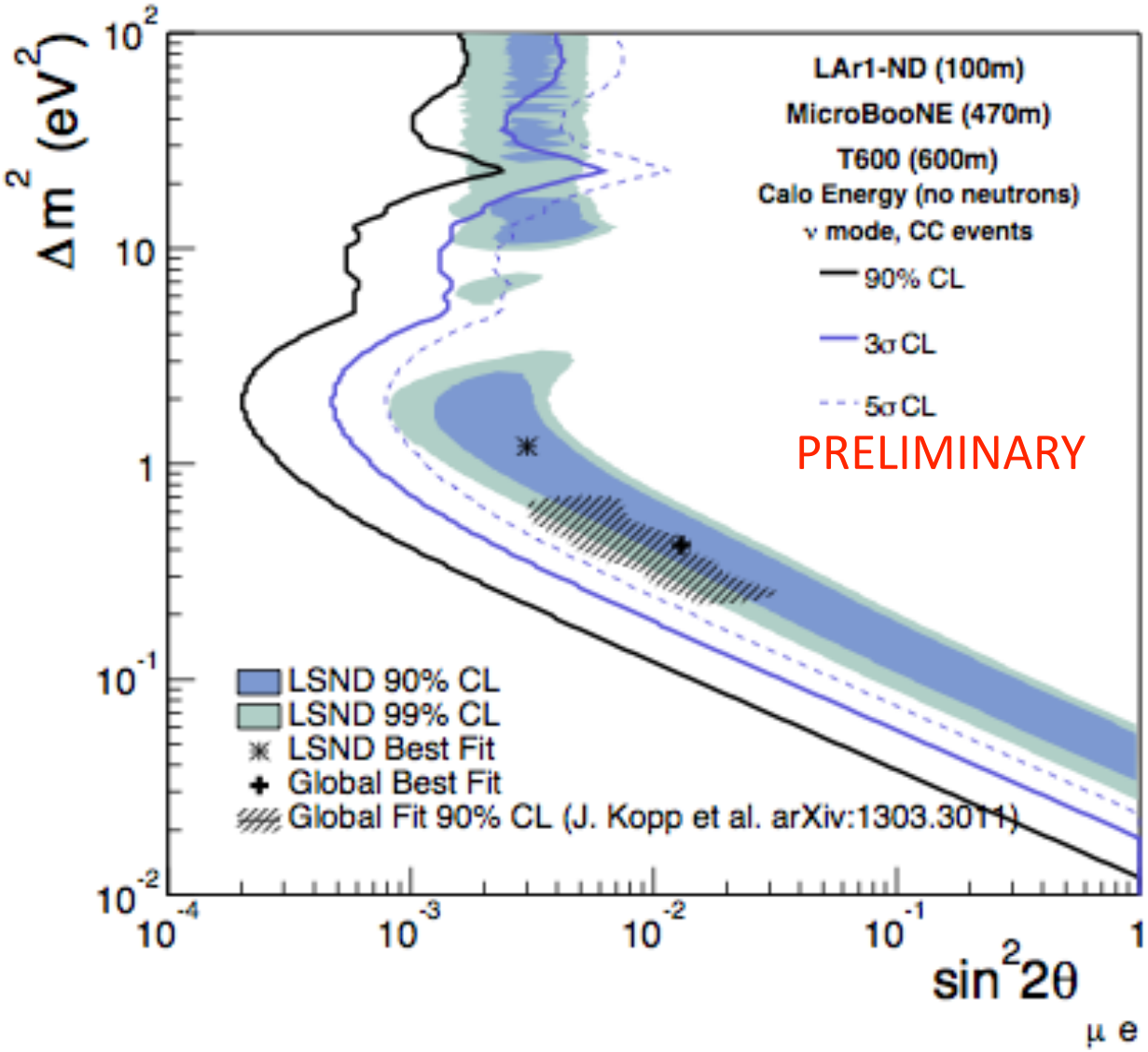




beam



$\nu_\mu \rightarrow \nu_e$ appearance sensitivity



6.6×10^{20} p.o.t. exposure

- 80% ν_e CC ID efficiency
- Beam-related backgrounds only
- Possible cosmogenic backgrounds not included

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

High Level Milestones

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

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!