Future Short-Baseline Neutrino Experiments

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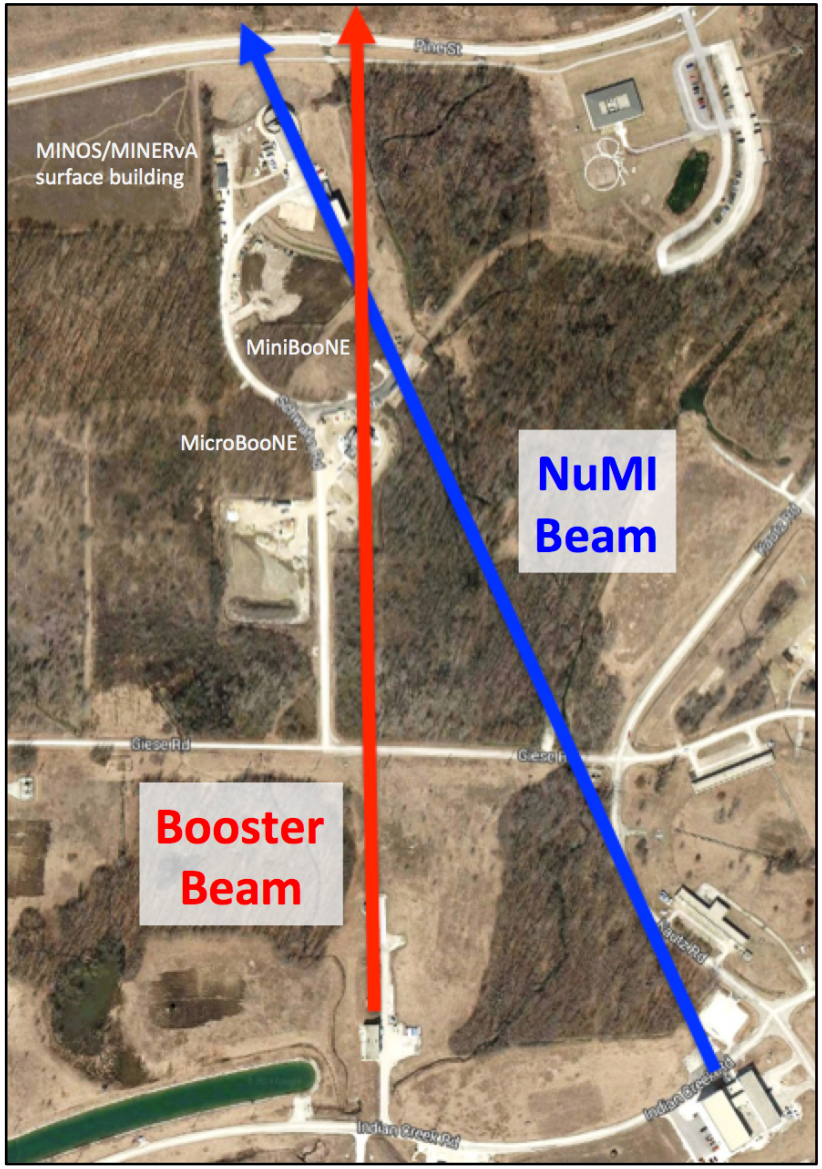
Outline

- Why a Short-Baseline Neutrino (SBN) Program at Fermilab
- A little history: recent proposals to expand the SBN program, address anomalies, and search for sterile neutrinos
- The plan moving forward to build a world-leading accelerator-based short-baseline neutrino oscillation program on the FNAL Booster Neutrino Beam

BNB Short-Baseline Neutrino Program

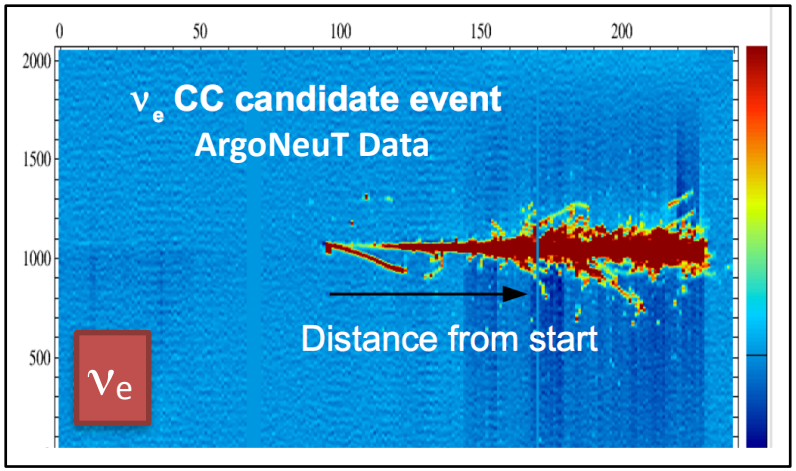
Fermilab makes an ideal host for a next generation short-baseline neutrino oscillation experimental program

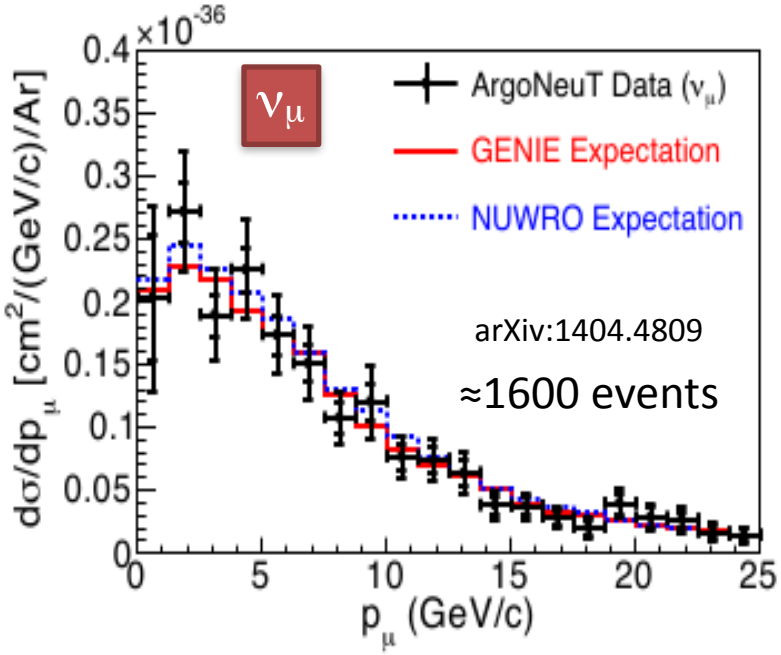
- SBN Program builds upon existing capabilities and infrastructure, such as the Booster Neutrino Beam (BNB)
  - The NuMI Beam is deep and aimed down toward Minnesota, but the BNB is shallow (~10 m detector hall depth at all baselines)
  - BNB neutrino fluxes are well understood due to dedicated hadron production data (the HARP experiment @ CERN) and 10+ years of study by MiniBooNE and SciBooNE



Synergy with the Long-Baseline Program

- SBN Program has important synergies with on-going lab efforts and the future long-baseline neutrino program
  - Continued development of the Liquid Argon TPC technology for neutrino physics. SBN experiments offer a great opportunity for use of mid-scale detectors which will see large neutrino exposures.
    - LArTPC technology development and prototyping
    - Development and validation of LArTPC event reconstruction with large ν_μ and ν_e data sets
    - Measure important ν-Ar cross sections in GeV energy range
    - Demonstrate sensitive $\nu_\mu \rightarrow \nu_e$ appearance and disappearance oscillation measurements with LAr detectors



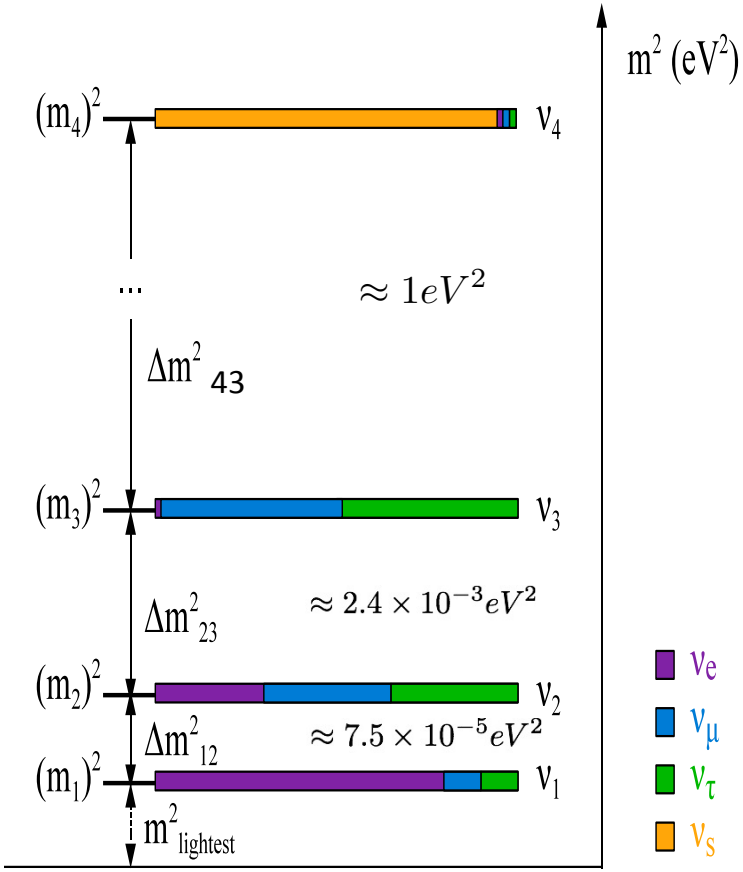


Expands the Laboratory's Science Program

- SBN Program expands the science reach of the world-class neutrino physics program here at Fermilab
  - While each of these measurements alone lack the significance to claim a discovery, together they could be hinting at important 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

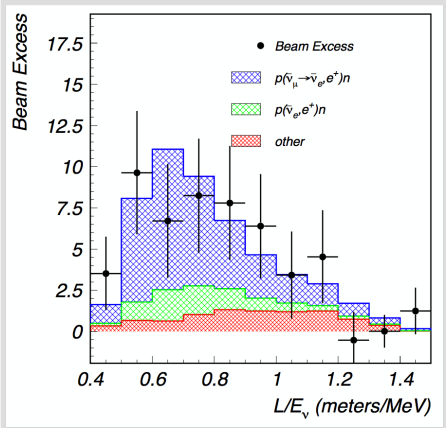
K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)



One thing is certain…

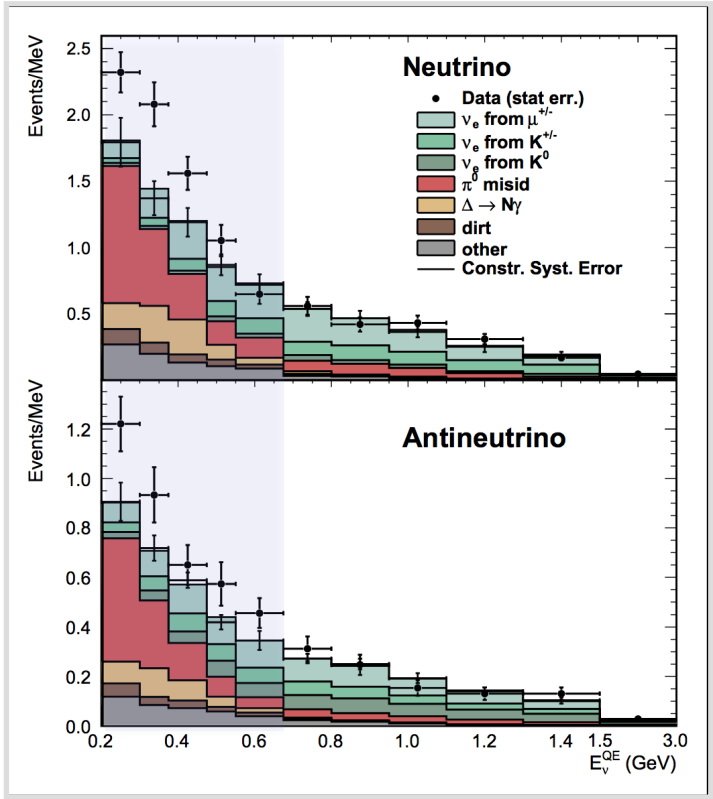
The discovery of a light sterile neutrino would be monumental for particle physics as well as cosmology

Accelerator-Based Anomalies



LSND

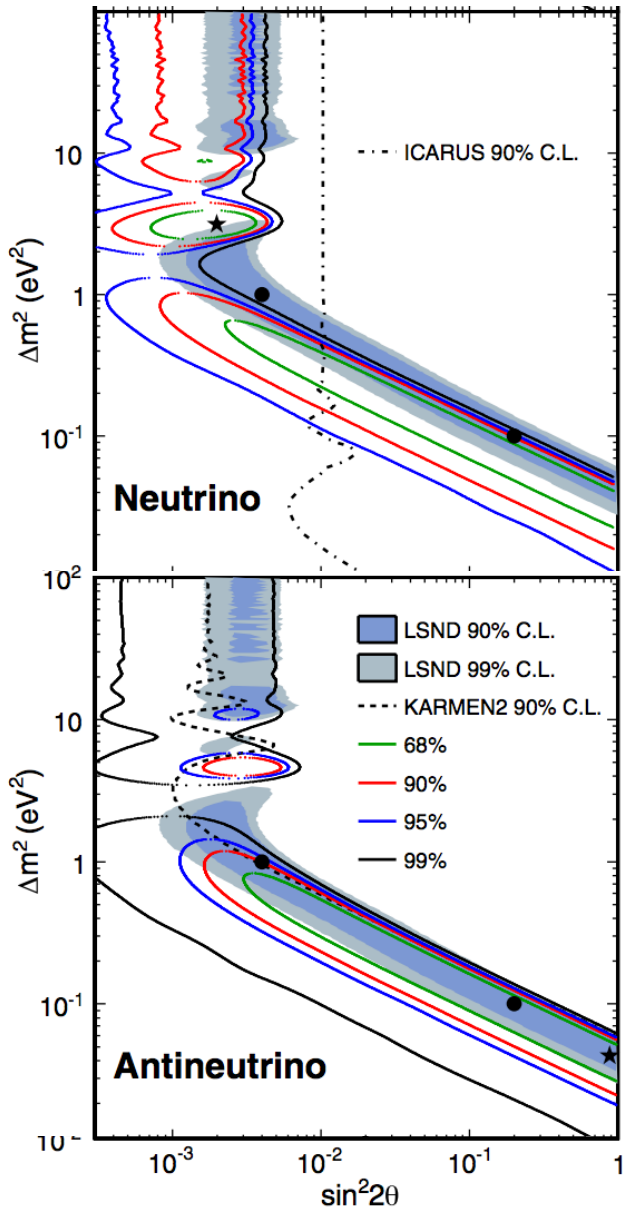
$\bar{\nu}_\mu \to \bar{\nu}_e ?$



$\nu_\mu \to \nu_e ?$

MiniBooNE

$\bar{\nu}_\mu \to \bar{\nu}_e ?$



P5 Report Recommendations

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

Project/Activity	Scenario A	Scenario B	Scenario C	ν					
Short Baseline Neutrino Portfolio	Y	Y	Y		✓				I

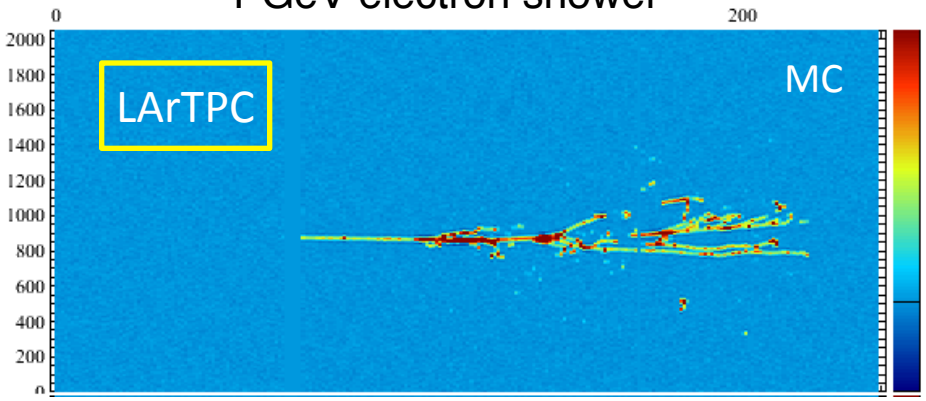
Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international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

π Decay-In-Flight Experiments

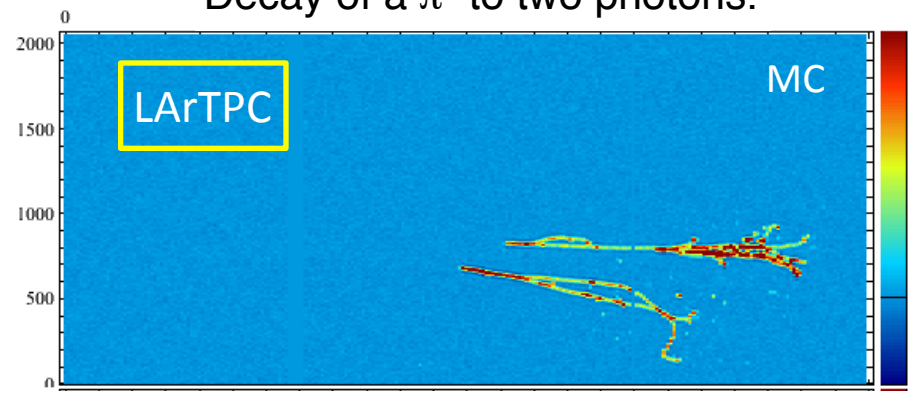
- DIF beam provides a rich oscillations program with a single facility:
  - $\nu_\mu \rightarrow \nu_e$ appearance
  - ν_μ and ν_e disappearance
  - both neutrinos and antineutrinos possible
  - CC and NC interactions
- Anomalies exist here (MiniBooNE neutrino and antineutrino) and these need to be addressed
- However:
  - Need detectors that can <u>distinguish electrons from photons</u> in order to reduce key backgrounds
  - <u>Multiple detectors</u> at different baseline are key for reducing systematic uncertainties

Electron/Photon Separation with LArTPCs

1 GeV electron shower

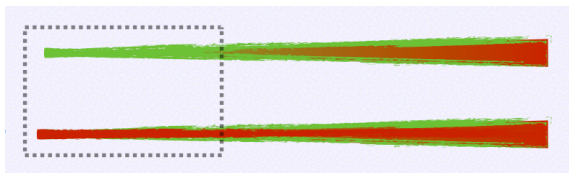


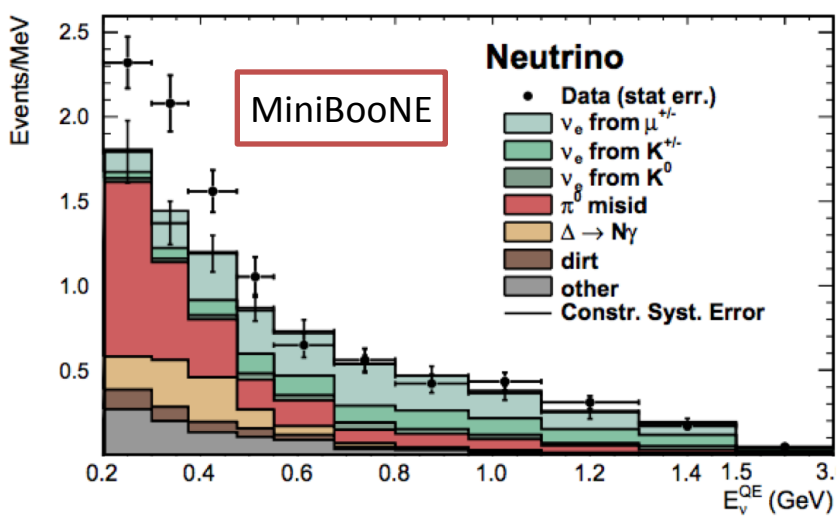
Decay of a π^0 to two photons.

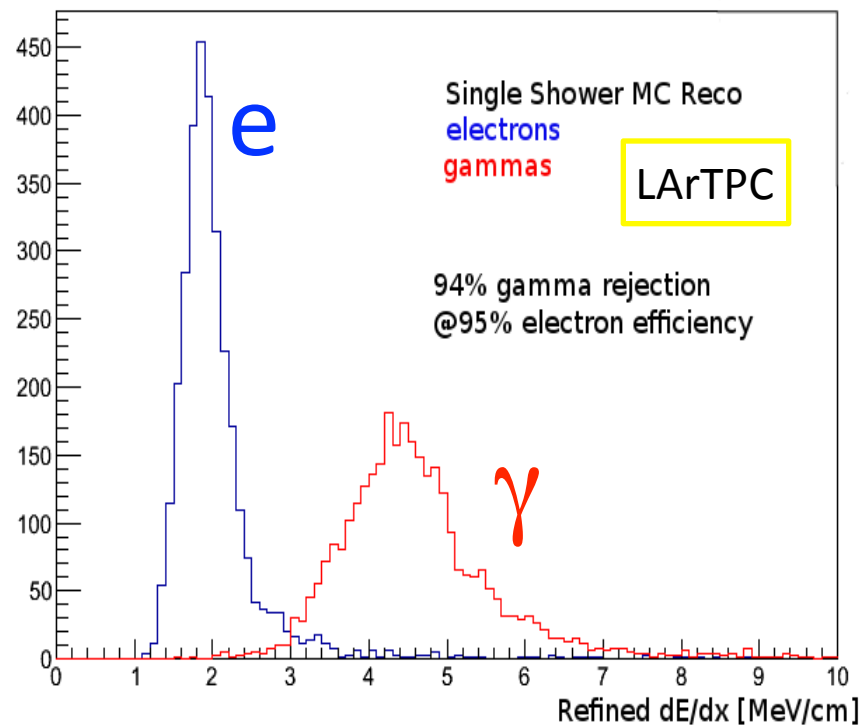


Electron

$$\gamma \rightarrow e^+ + e^-$$



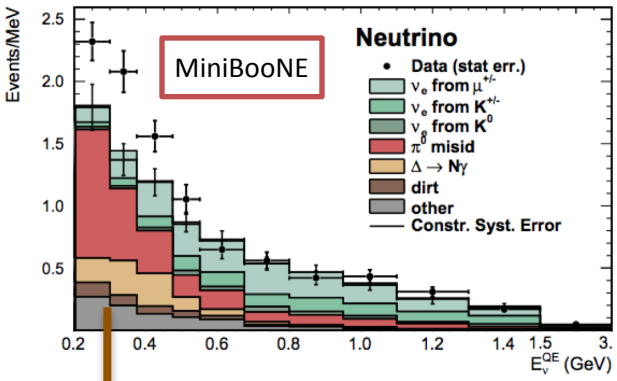


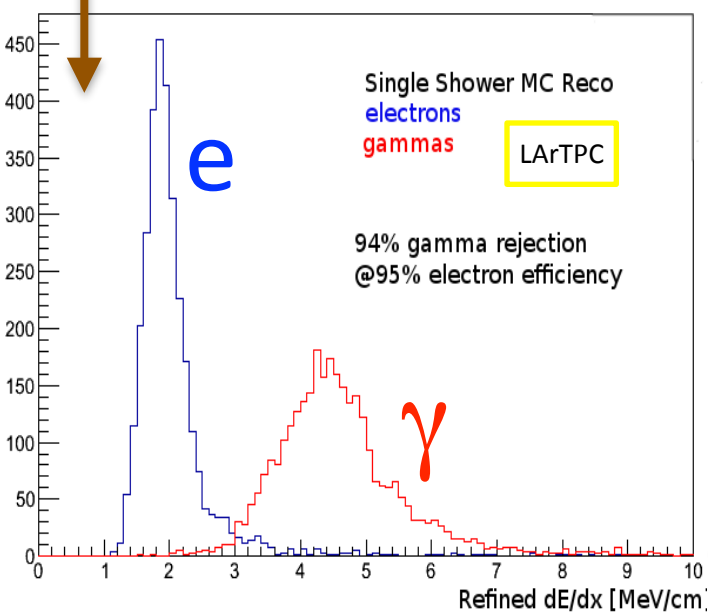


MicroBooNE

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

MicroBooNE and the MiniBooNE Excess

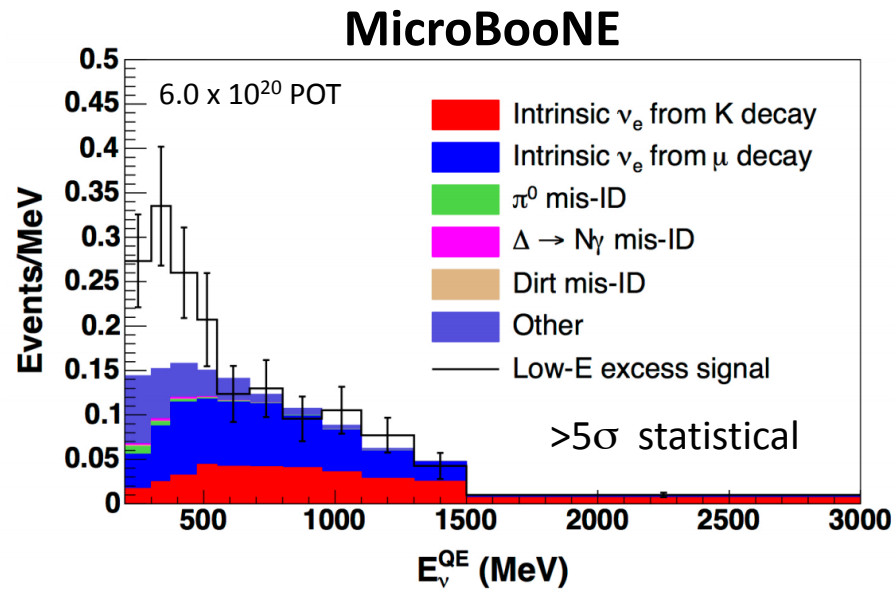


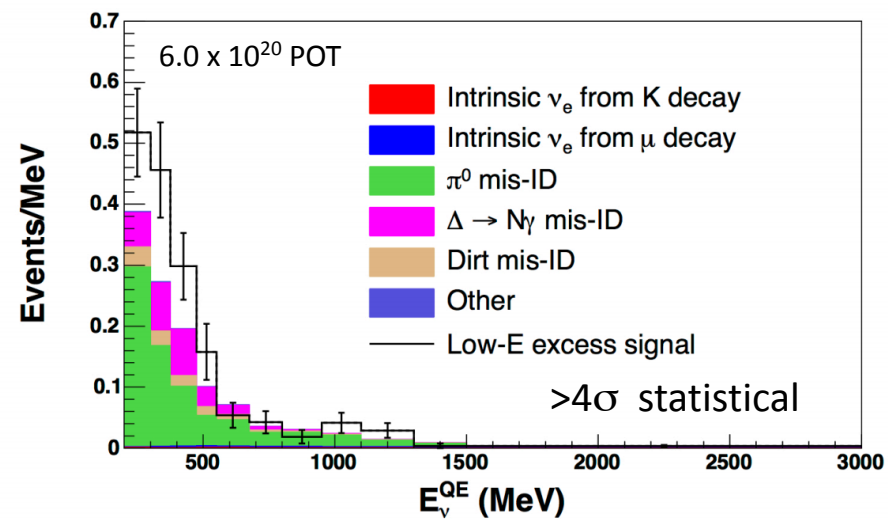


electrons

OR...?

photons





MicroBooNE can investigate a critical piece of the puzzle: **are the excess events seen by MiniBooNE <u>electrons</u> or <u>photons</u>?**

Some Recent History

- MicroBooNE was not designed to explore the complete sterile neutrino oscillation parameter space on its own
- Summer 2012, an LOI was submitted to the Fermilab PAC for the “LAr1” project. This was a 1-kton FV LArTPC, based on designs for LBNE, to serve as a second detector along with MicroBooNE. Estimated cost was $80M.

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  - 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.

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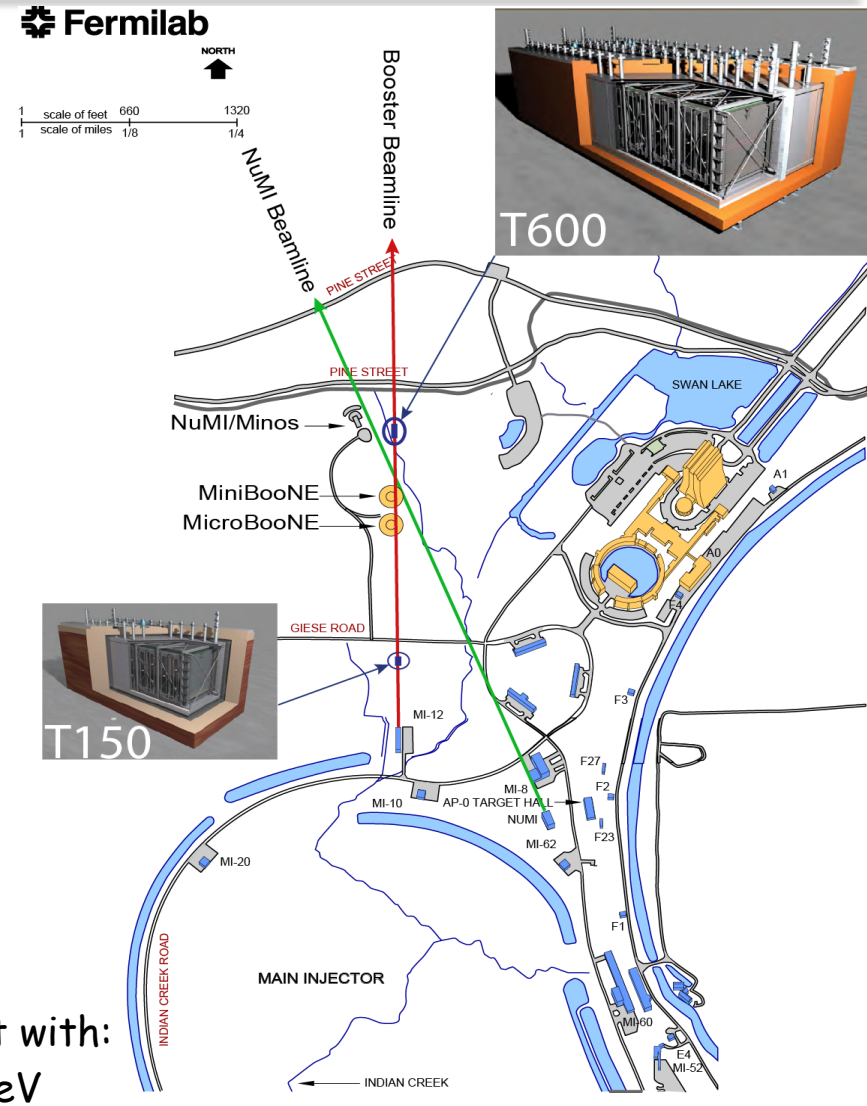
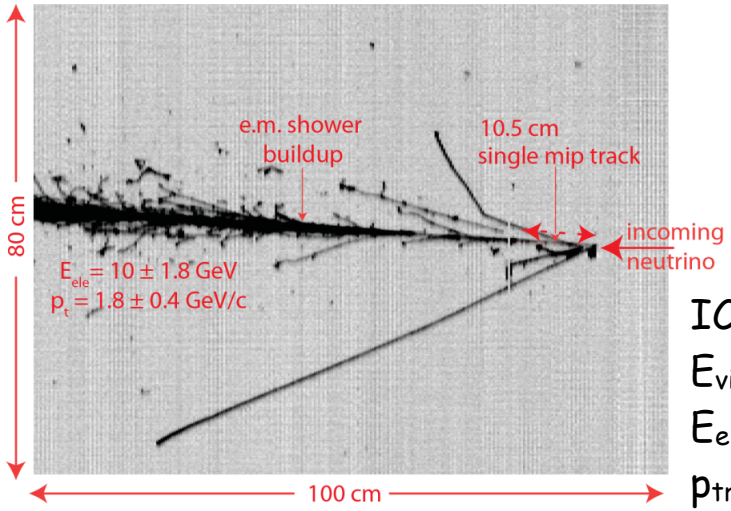
  - P-1052: ICARUS@FNAL http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/ICARUS.pdf
    - Was proposed to relocate the updated existing ICARUS T600 LArTPC detector (~450-ton FV) to the BNB and to construct a new one-fourth scale detector based on the same design to serve as a near detector for oscillation searches.

ICARUS@FNAL Proposal

- ICARUS T600 detector to be located along the BNB at ~700 m from the target
- A new T150 detector based on the ICARUS design to be located at about 150±50 m from the target
- T600 would also receive ν's from the off-axis NuMI neutrino beam peaked at ~2 GeV with an enriched ν_e flux
- The dual presence of T600 and new T150 would extend the information coming from MicroBooNE





ICARUS data event with:

$E_{visible}$ = 11.5 ± 1.8 GeV

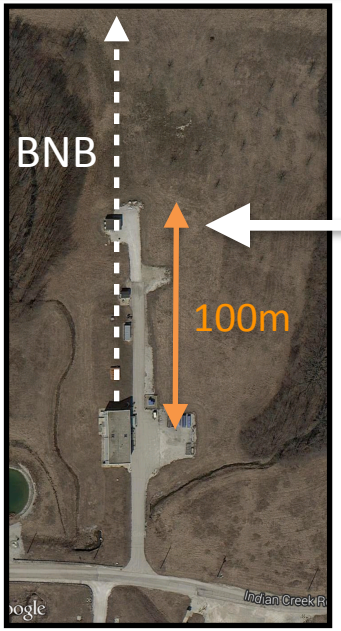
$E_{electron}$ = 10 ± 1.8 GeV

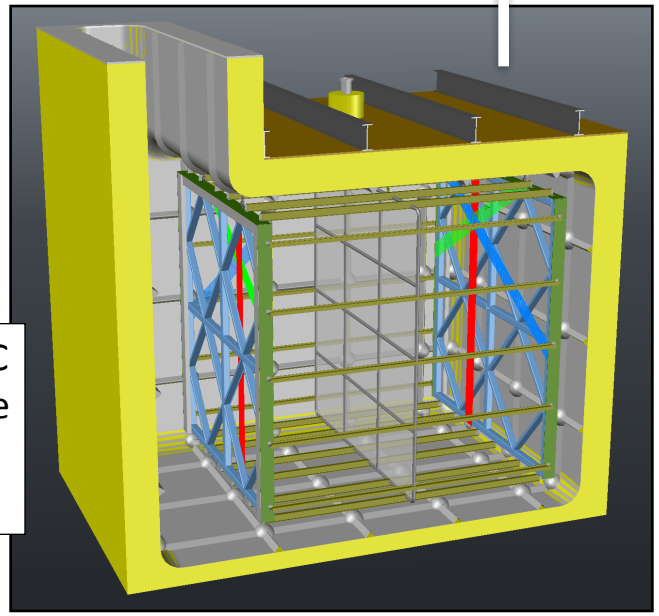
$p_{transverse}$ = 1.8 ± 0.4 GeV/c

http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/PAC_presentation.jan2014.F.pptx

LAr1-ND Proposal

- LAr1-ND detector design approach:
  - utilize as many design elements developed for the LBNE Far Detector as feasible
  - implement technology that builds upon experience from the T600, MicroBooNE and the 35-ton membrane cryostat prototype
  - control project cost by reusing the empty SciBooNE detector hall at 100 m on the BNB
- LAr-ND would provide high-statistics measurement of the intrinsic BNB content, enabling sensitive oscillation searches in combination with downstream detectors
- Together with MicroBooNE, provide a complete interpretation of the MiniBooNE excess. Photons or electrons? Intrinsic to the beam or appearing?
- Valuable "physics R&D" such as reconstruction development and GeV ν-Ar cross sections.
  ~1M ν_μ events per year, 6,000 ν_e per year!





82 ton TPC membrane cryostat design

http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/LAr1ND_PAC_2014_01_23_v3.pdf

SBN Program Development

- Since the January PAC, proponents of the LAr1-ND and ICARUS proposals, members of the MicroBooNE collaboration, as well as representatives from Fermilab, INFN and CERN, have been working together to develop plans for a coherent SBN program on the BNB.
  - An international team* is currently leading the preparation of a joint proposal to be submitted to the PAC for their next meeting in July.
  - This proposal will include physics sensitivities for a multi-LArTPC detector program with a LAr1-ND type near detector at 100-150m, MicroBooNE at 470m, and the ICARUS T600 detector at 600m along the BNB.
  - Three day workshop at FNAL in April with several members from each group
    - Workshop included also the NESSIE collaboration who have proposed a muon spectrometer-based addition to the SBN experimental program at FNAL (arXiv:1404.2521)

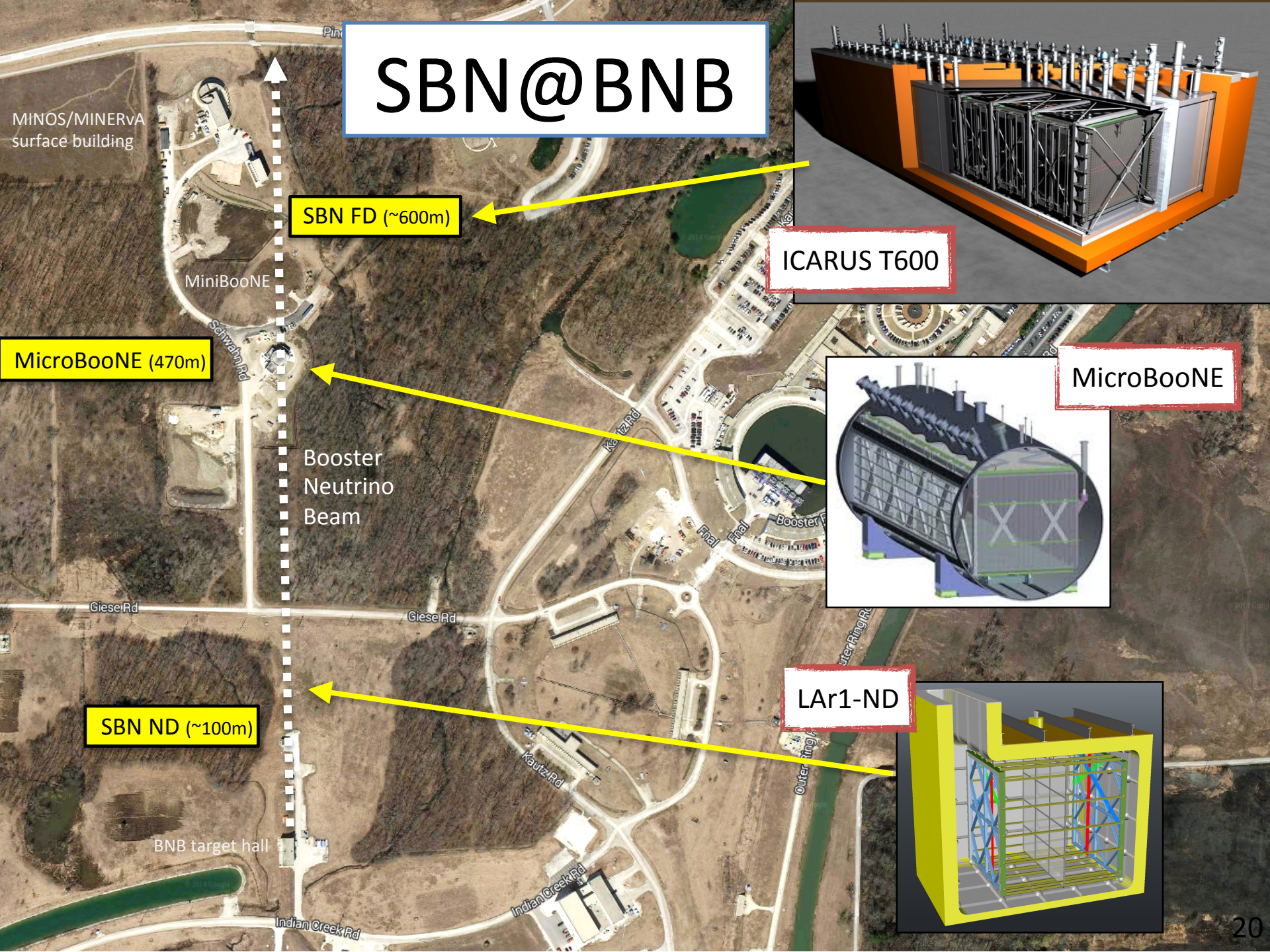
*A. Guglielmi (INFN Padova/ICARUS), M. Nessi (CERN), D. Schmitz (Chicago/LAr1-ND), G. Zeller (FNAL/MicroBooNE), and FNAL SBN Coordinator P. Wilson (FNAL SBN)

SBN Program Optimization

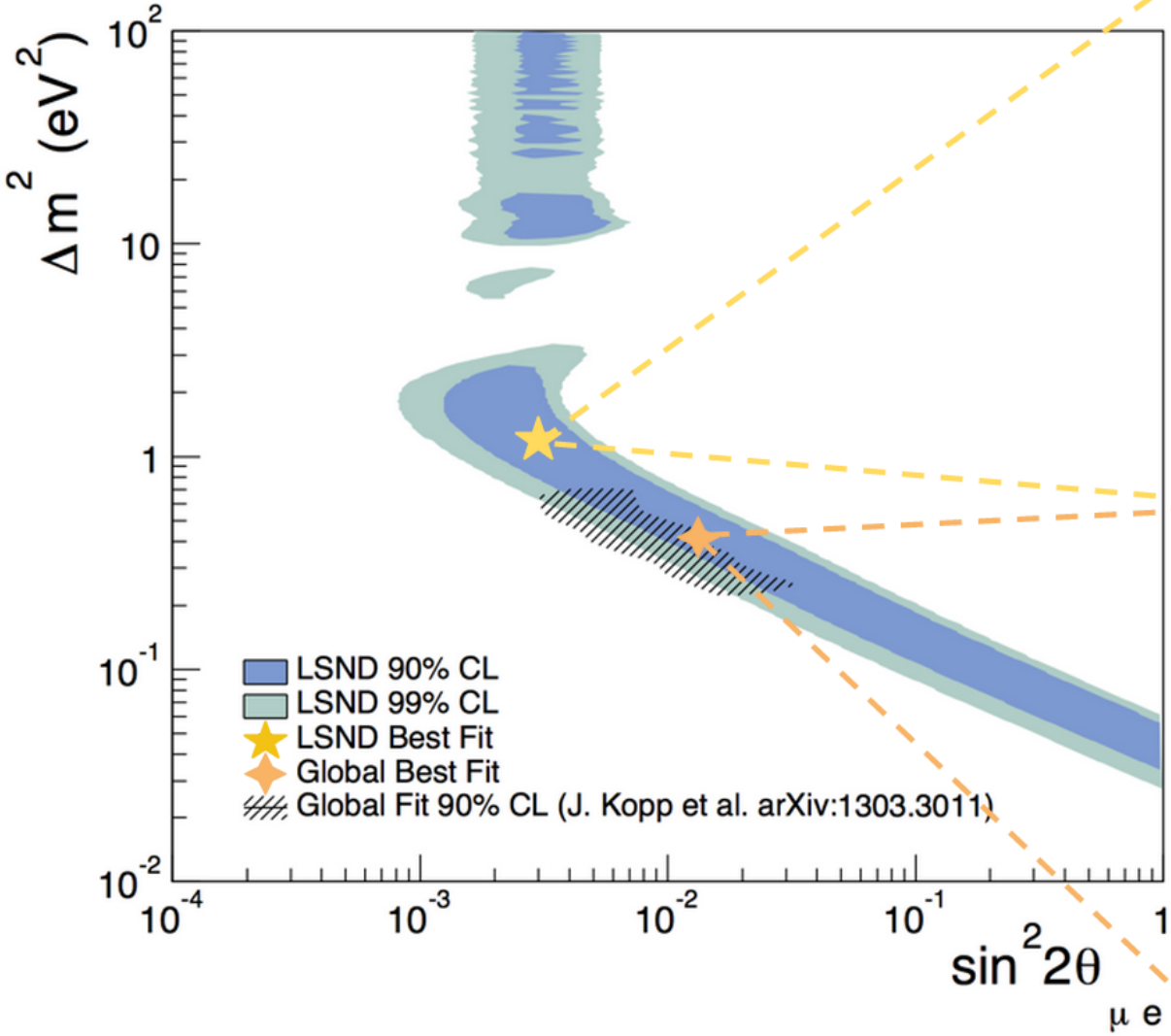
- Feeding into the proposal are the on-going efforts of Working Groups with broad participation among the institutions and collaborations. Their charges are to address specific, key questions relating to the optimization of the experimental configuration.

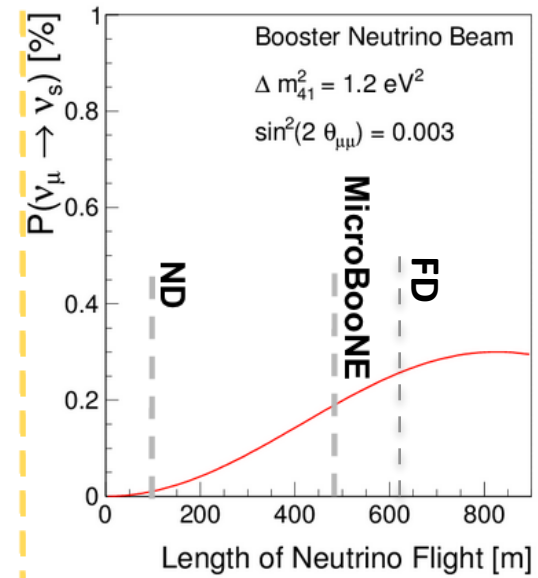
1. Cosmic backgrounds
   - Impact of cosmic muons, neutrons and photons for surface detectors
2. Neutrino Flux and Systematics
   - Optimization of ND location, FD on-axis vs on surface
3. Detector Buildings and Siting
   - Cost and scheduling
4. Cryostat and Cryogenic Systems

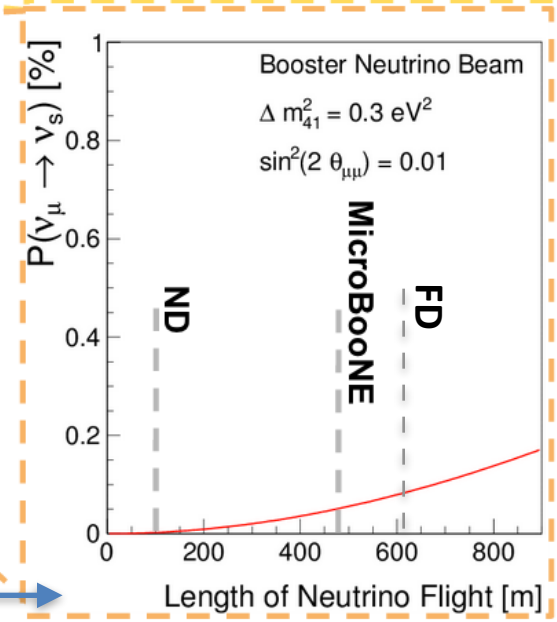
SBN@BNB


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

Sterile Neutrino Oscillations on the BNB

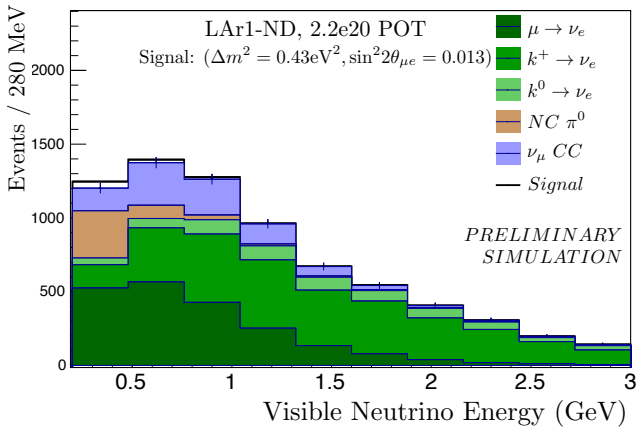




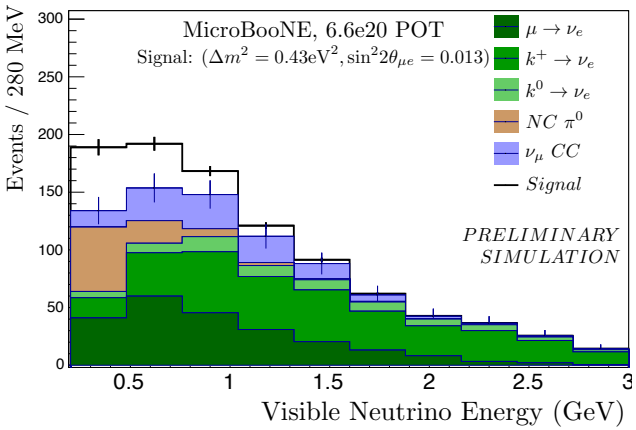


At peak BNB neutrino energy, E = 700 MeV

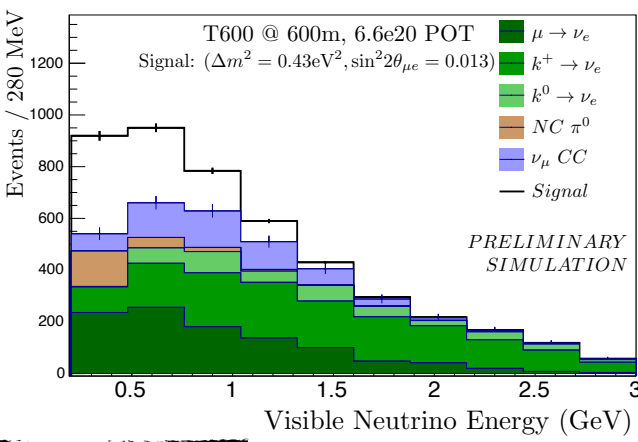
ND @ 100 m



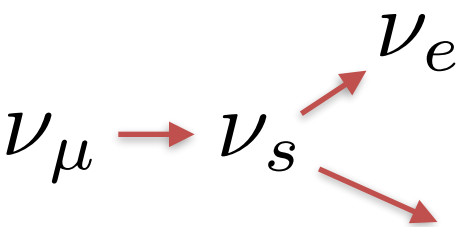
MicroBooNE @ 470 m



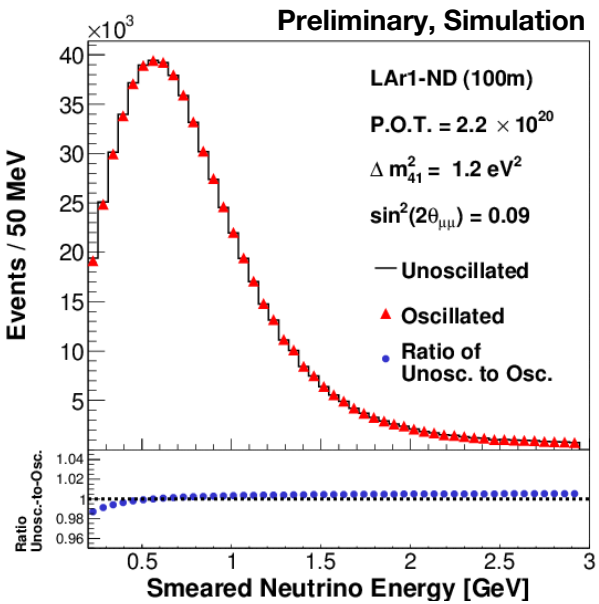
ICARUS T600 @ 600 m

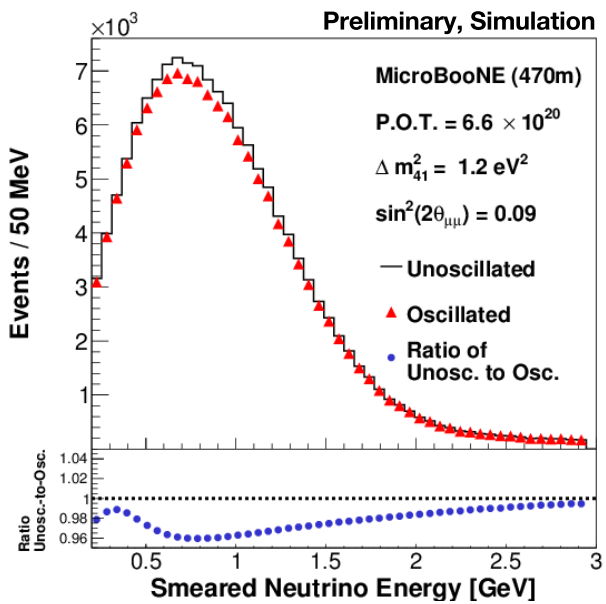


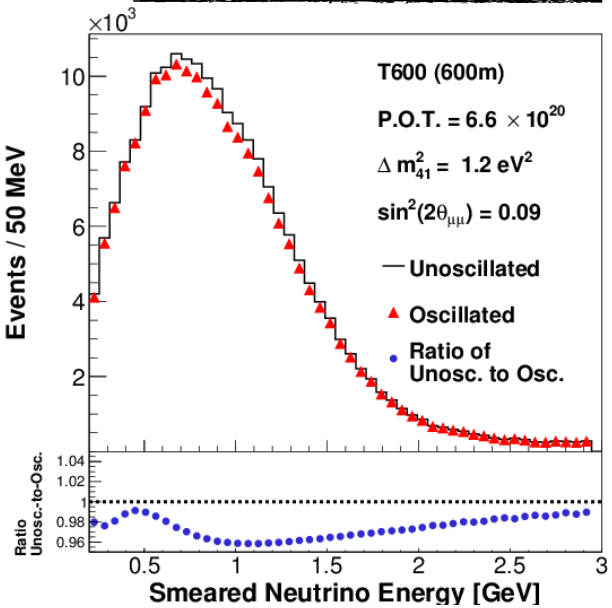
ν_e Appearance



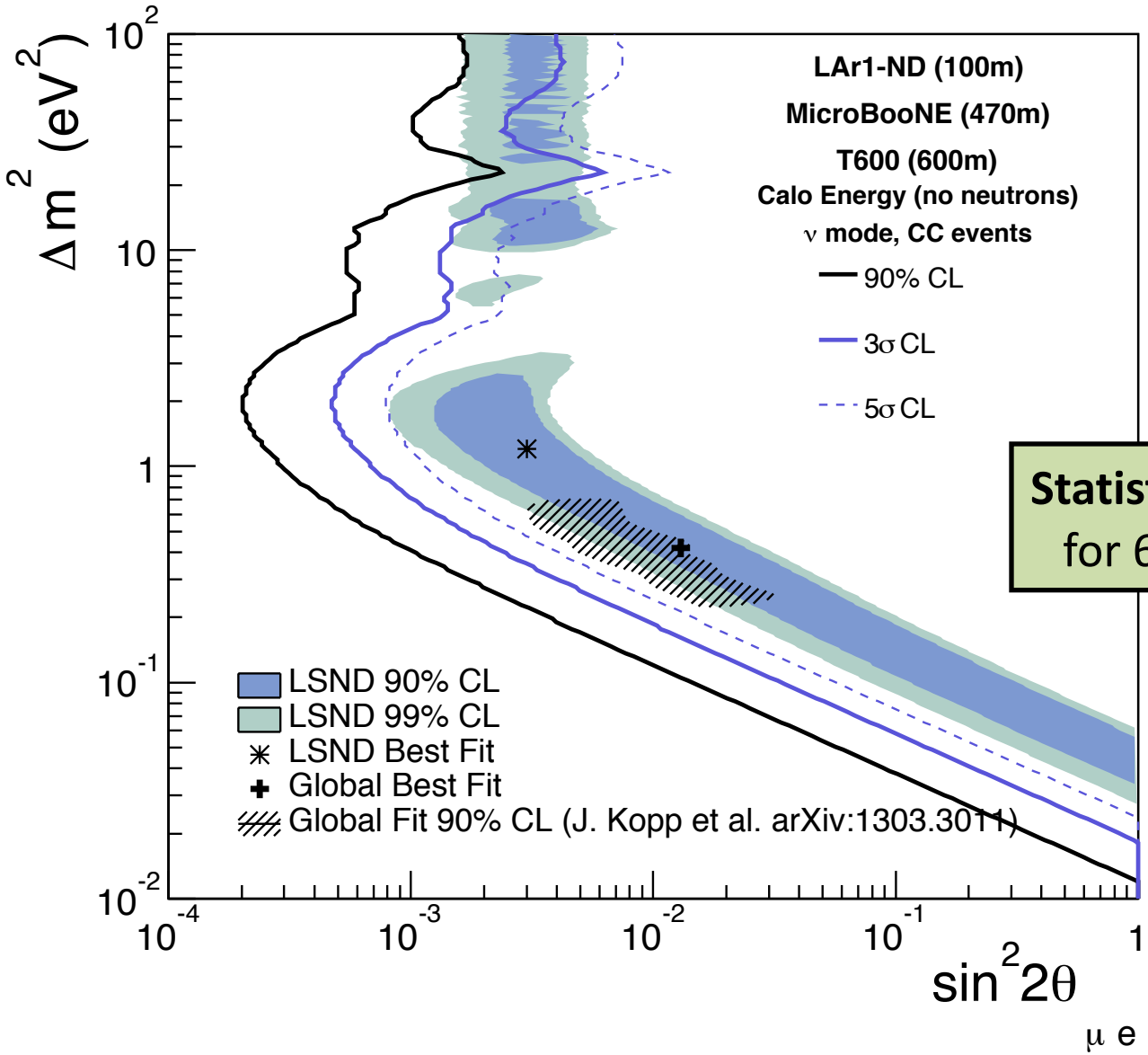
ν_μ Disappearance

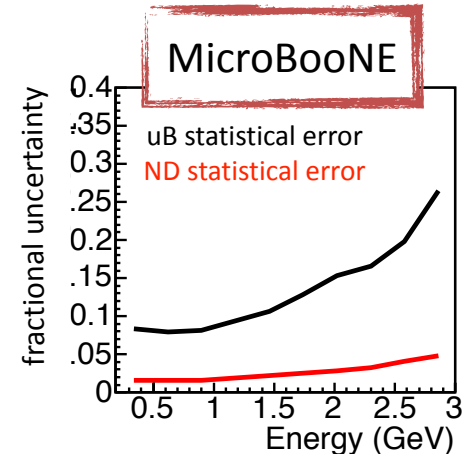




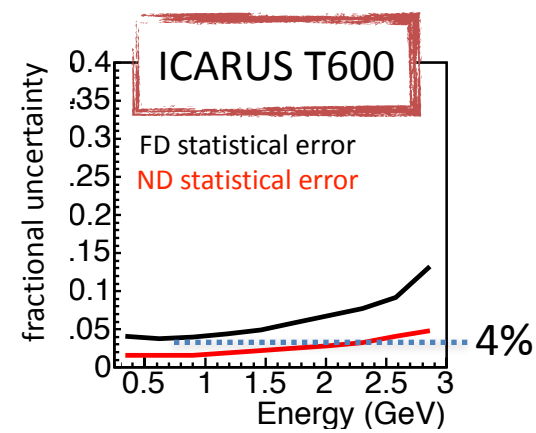


$\nu_\mu \rightarrow \nu_e$ Appearance





Statistical Uncertainty Limit for 6.6e20 POT exposure



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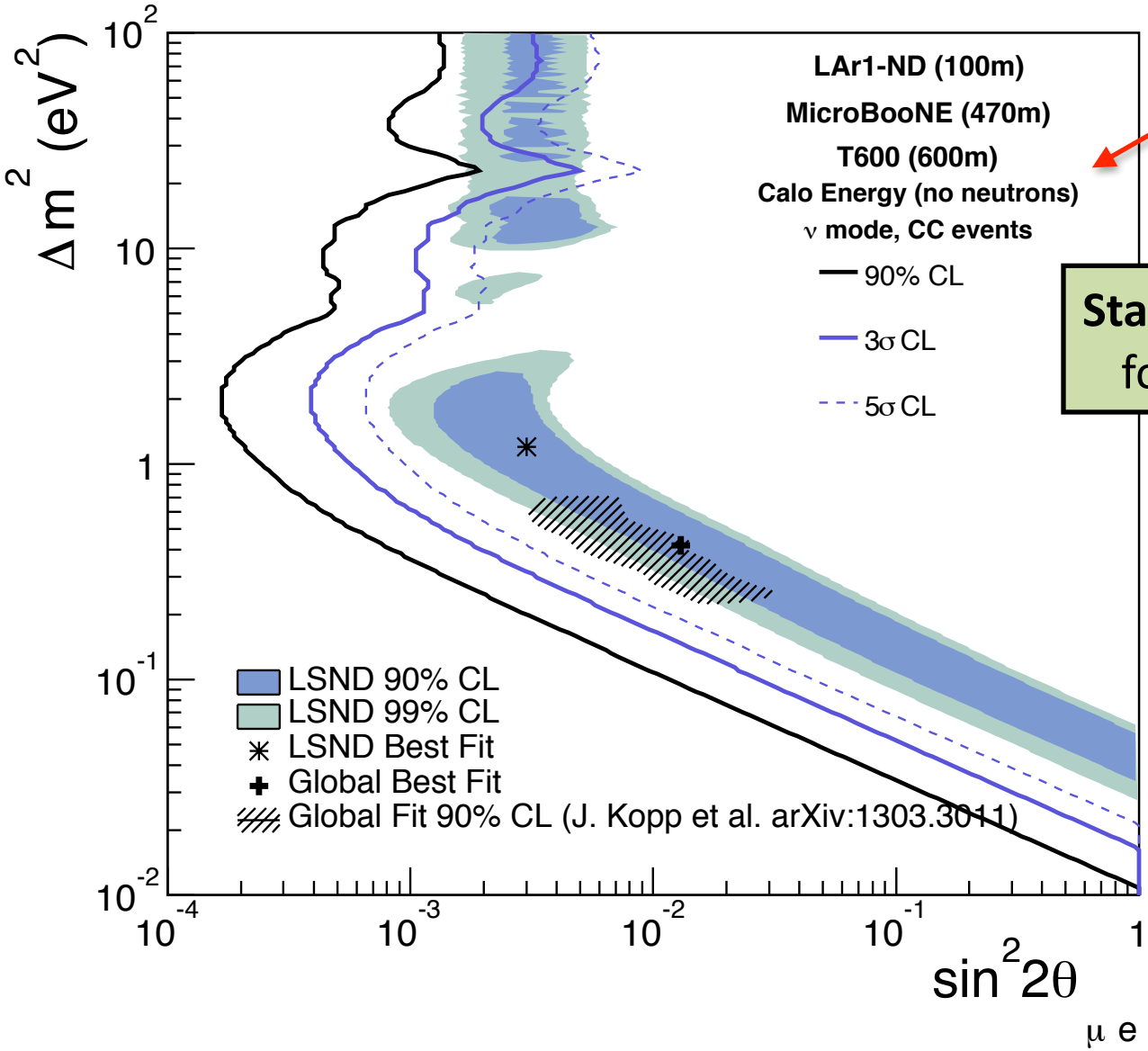


Impact of increased exposure by 50%

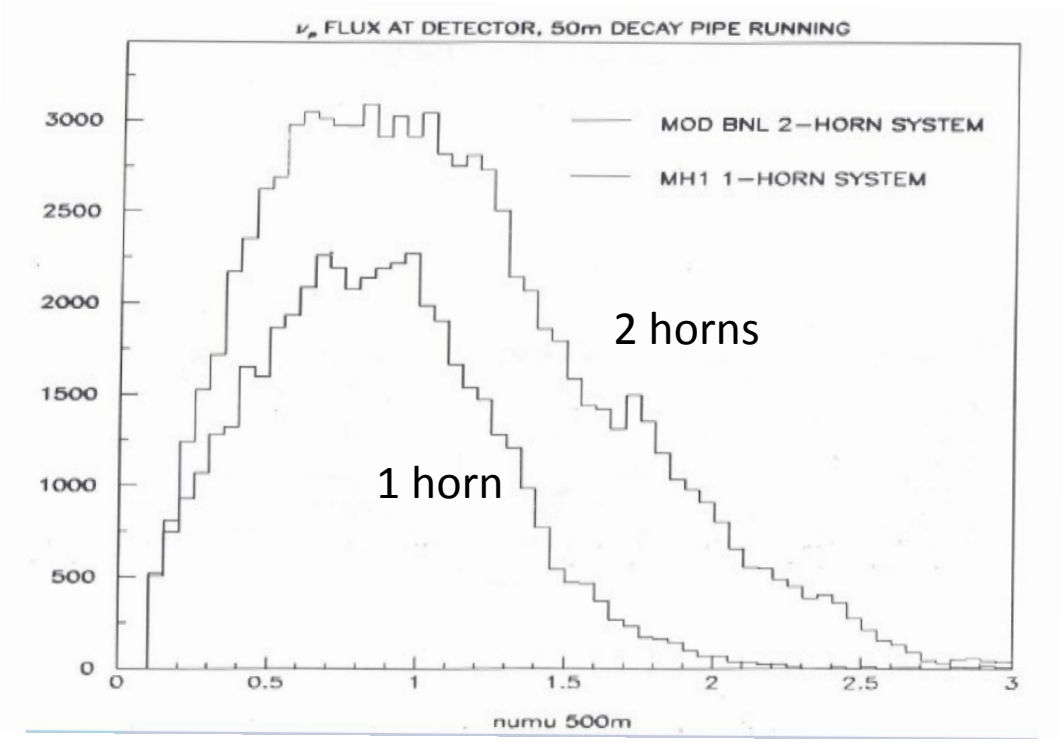
Statistical Uncertainty Limit for 10e20 POT exposure

Projecting integrated POT onto a time axis is clearly important and depends on proton economics after ~2018.

PIP-I/PIP-II goals very valuable to success of this program!

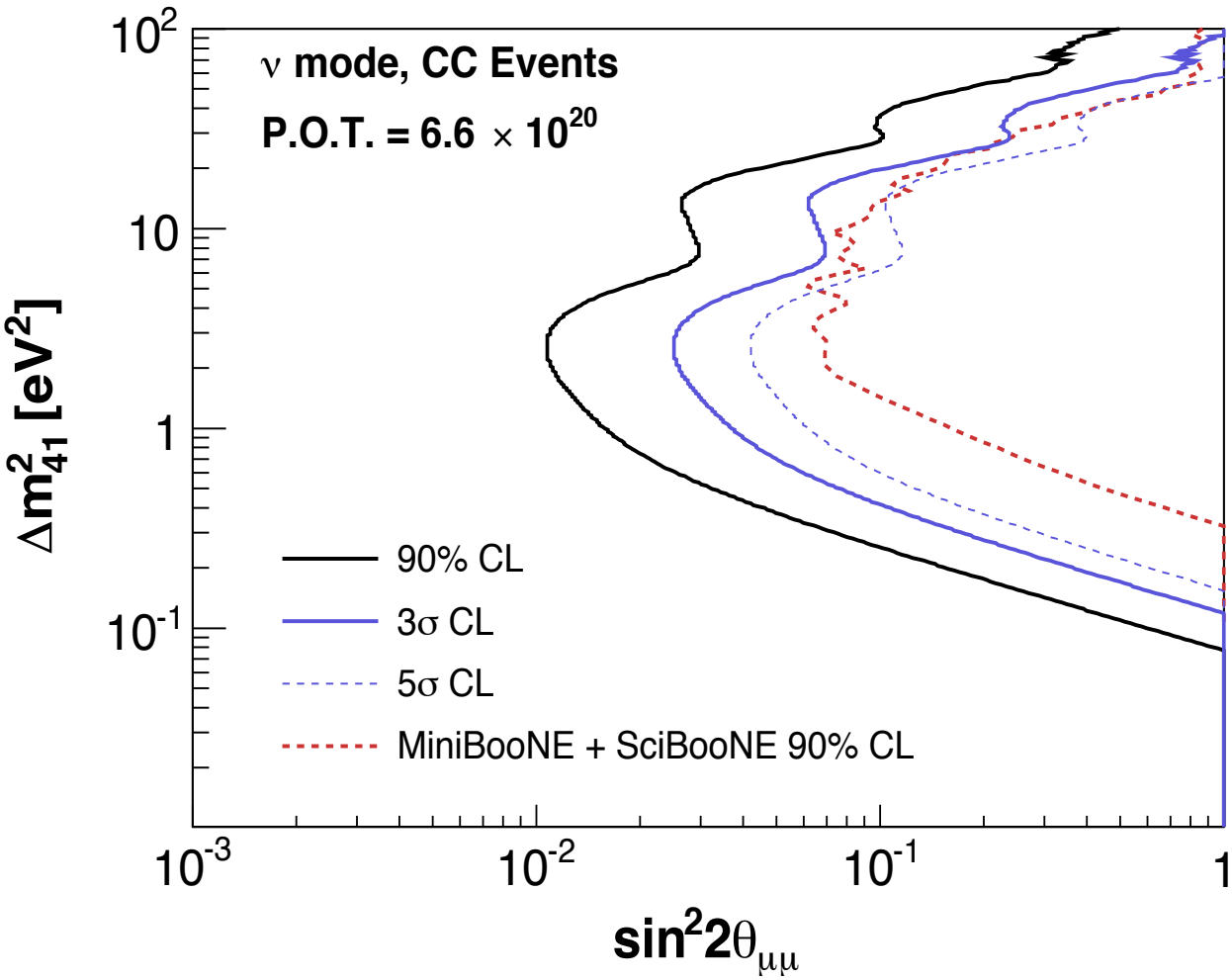
Make Every Proton Count

- Possible BNB upgrades:
  - New inner conductor design?
  - New target design?
  - Deploy 25m absorber?
  - 2nd focusing horn?



- Beamline was optimized for MiniBooNE in 1990s
  - Neutrino detector technology matters (S/B is the metric)
  - Available hadron production data (from HARP expt.) means pion production off the target now better understood. Re-optimize focusing?

ν_μ Disappearance



ν_μ disappearance not a statistics limited search. Here shown with a 4% systematic uncertainty on the near to far extrapolation.

Previous limit at high Δm^2 limited by near and far detectors being different technologies

Summary

- Fermilab is well positioned to play a key role in resolving the existing hints for new physics happening at short-baseline
- A discovery would be revolutionary
- A short-baseline program additionally provides opportunities for important physics measurements and detector R&D toward the future neutrino program
- Such a program has been strongly endorsed by the recent P5 Report
- An international group is currently developing a proposal to build a world-leading program here at Fermilab, utilizing the existing BNB. An optimization of this program, integrating recent proposals by the ICARUS and LAr1-ND collaborations, is under development for the summer PAC next month.

LAr1-ND Collaboration

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- 3 DOE National Laboratories
- 6 NSF institutions

7 European institutions

- 5 UK institutions
- 1 Swiss institution
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Most also LBNE collaborators.

MicroBooNE Collaboration

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total team (collaboration + project):
- 3 countries
- 23 institutions
- 134 collaborators (includes project team)

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