Bonnie Fleming
PAC Aspen, Summer 2012
June 19, 2012

A Letter of Intent for a Neutrino Oscillation Experiment on the Booster Neutrino Beamline: LAr1

- Motivation for LAr1: Interesting hints from short baseline oscillation experiments suggest BSM Physics
- Future program to address these at Fermilab: MicroBooNE and

LAr1: 1kton fiducial volume LArTPC

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•Developing short baseline oscillation anomalies suggest new physics in neutrino sector (sterile neutrino(s)?) – generate lots of attention…

Hints from Experiments

- •LSND anomaly
- •MiniBooNE anomalies (recent updates!)
- •Reactor Anomaly
- •Gallex and Sage data

Where to address these? *Two different philosophies….*

- •Decay at Rest sources
- •Reactor and Source experiments
- •Conventional Accelerator experiments

LAr1

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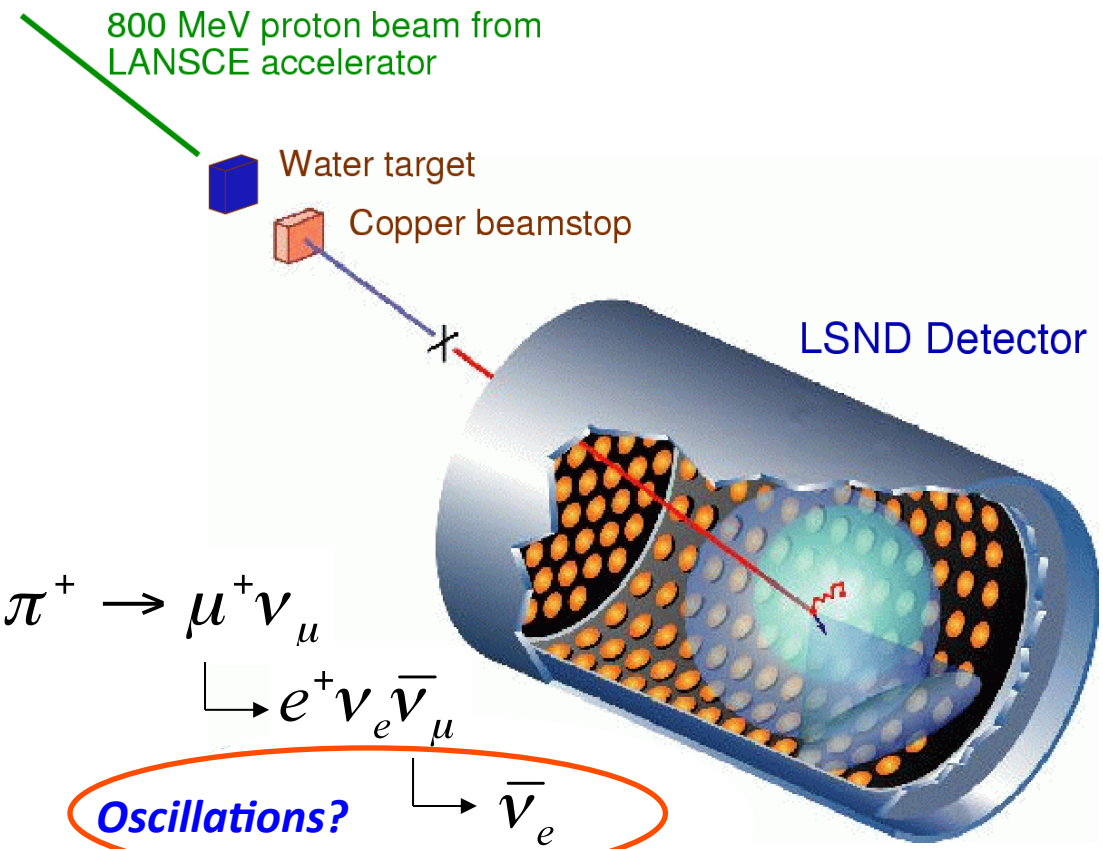
The LSND Anomaly



$$\pi^+ \rightarrow \mu^+ \nu_\mu$$

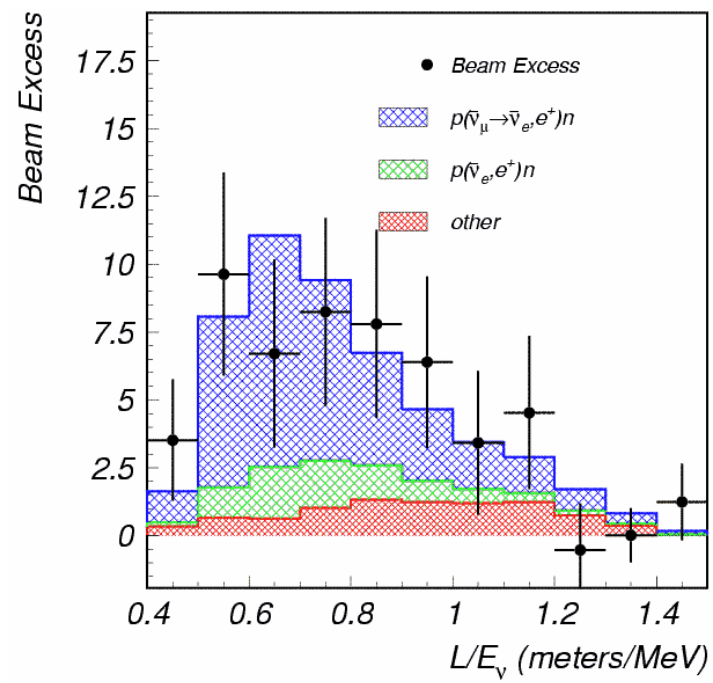
$$\hookrightarrow e^+ \nu_e \bar{\nu}_\mu$$

$$\hookrightarrow \bar{\nu}_e$$

Oscillations?

Signal: $\bar{\nu}_e \rightarrow e^+ n$

$\hookrightarrow$ n p $\rightarrow$ d γ(2.2MeV)



Saw an excess of $\bar{\nu}_e$:
87.9 ± 22.4 ± 6.0 events.

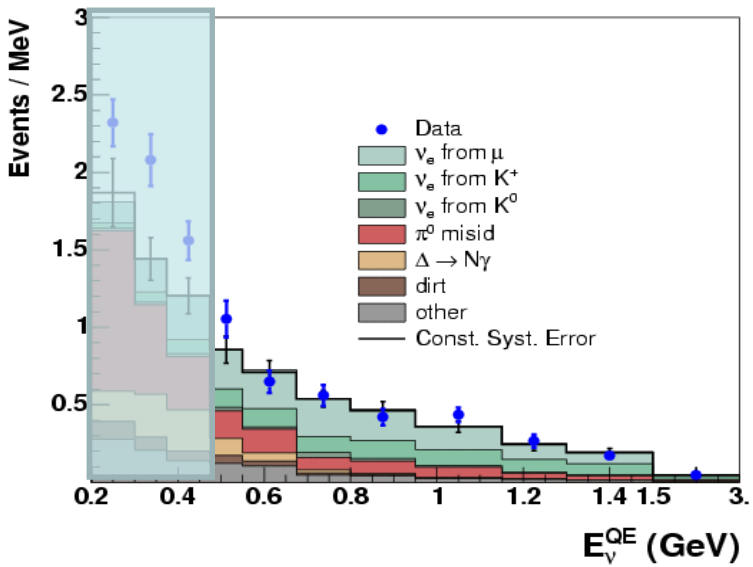
With an oscillation probability of (0.264 ± 0.067 ± 0.045)%.

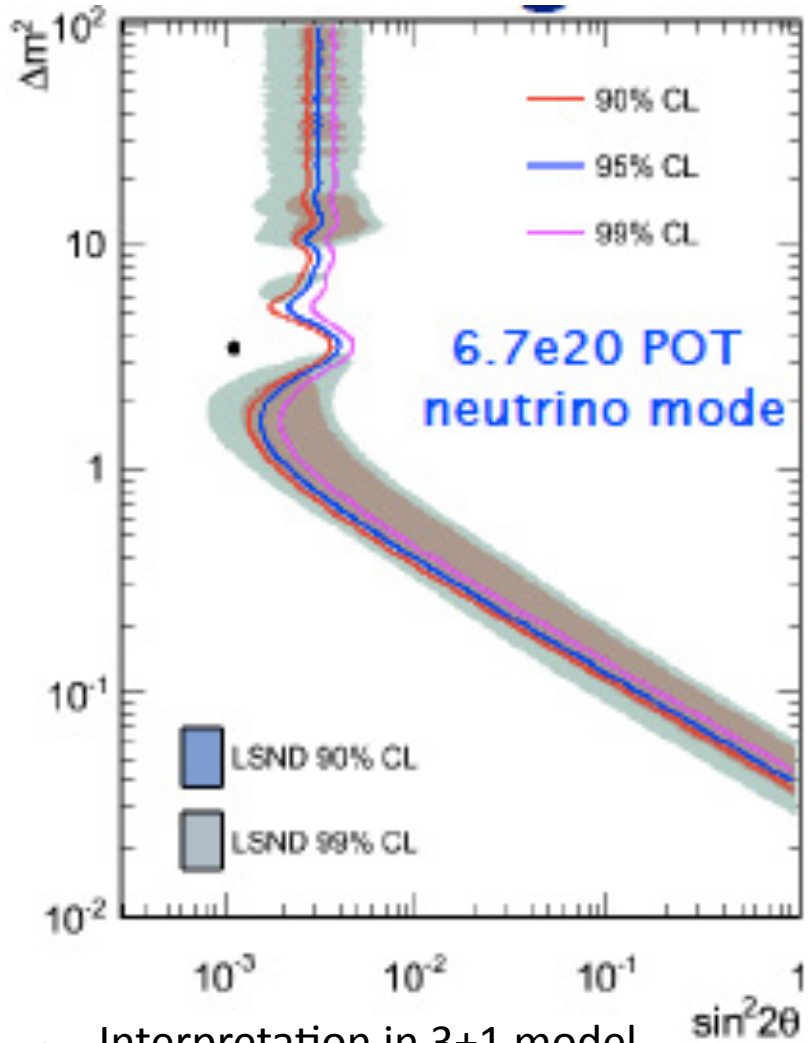
3.8 σ evidence for oscillation.

MiniBooNE Neutrino Oscillation Results

New results presented at Neutrino 2012

- 6.46e20 POT
- Fit E=475-1250 MeV



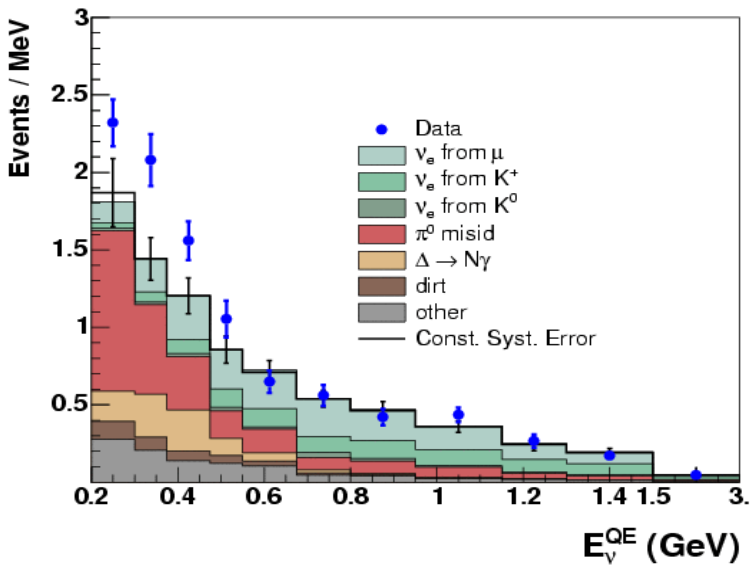


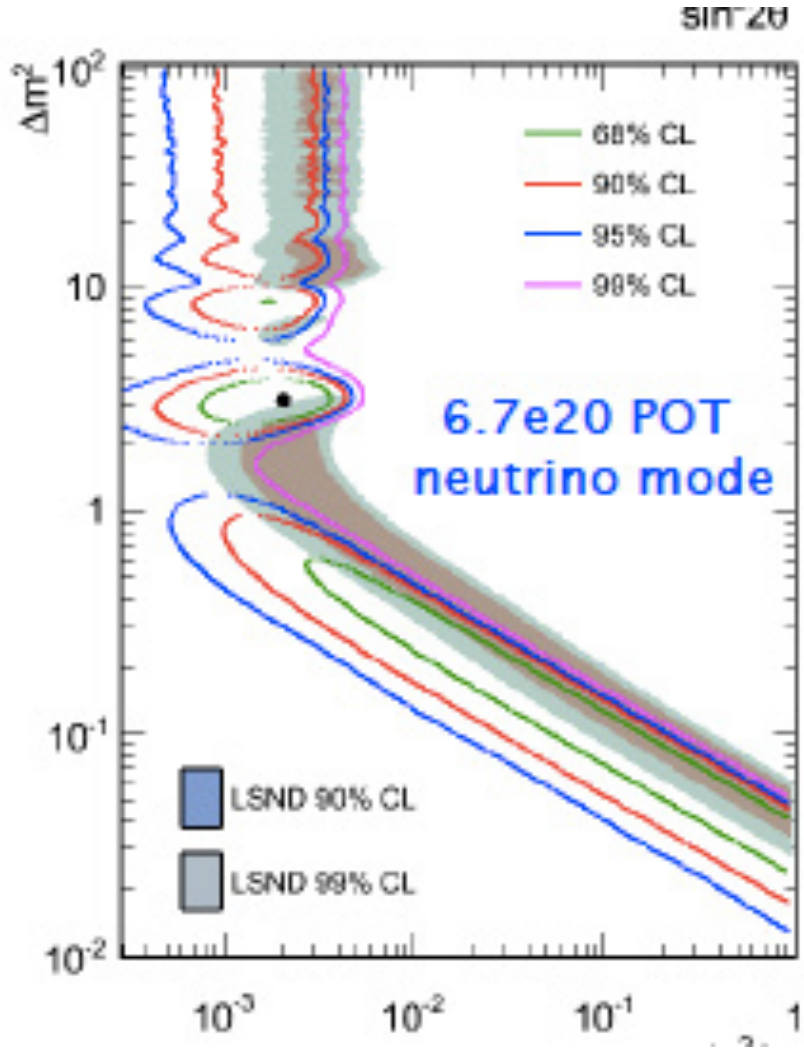
- Interpretation in 3+1 model

MiniBooNE Neutrino Oscillation Results

New results presented at Neutrino 2012

- 6.46e20 POT
- 161.8 ± 28.1 ± 40.1 (3.3σ)
- Fit E=200-1250 MeV

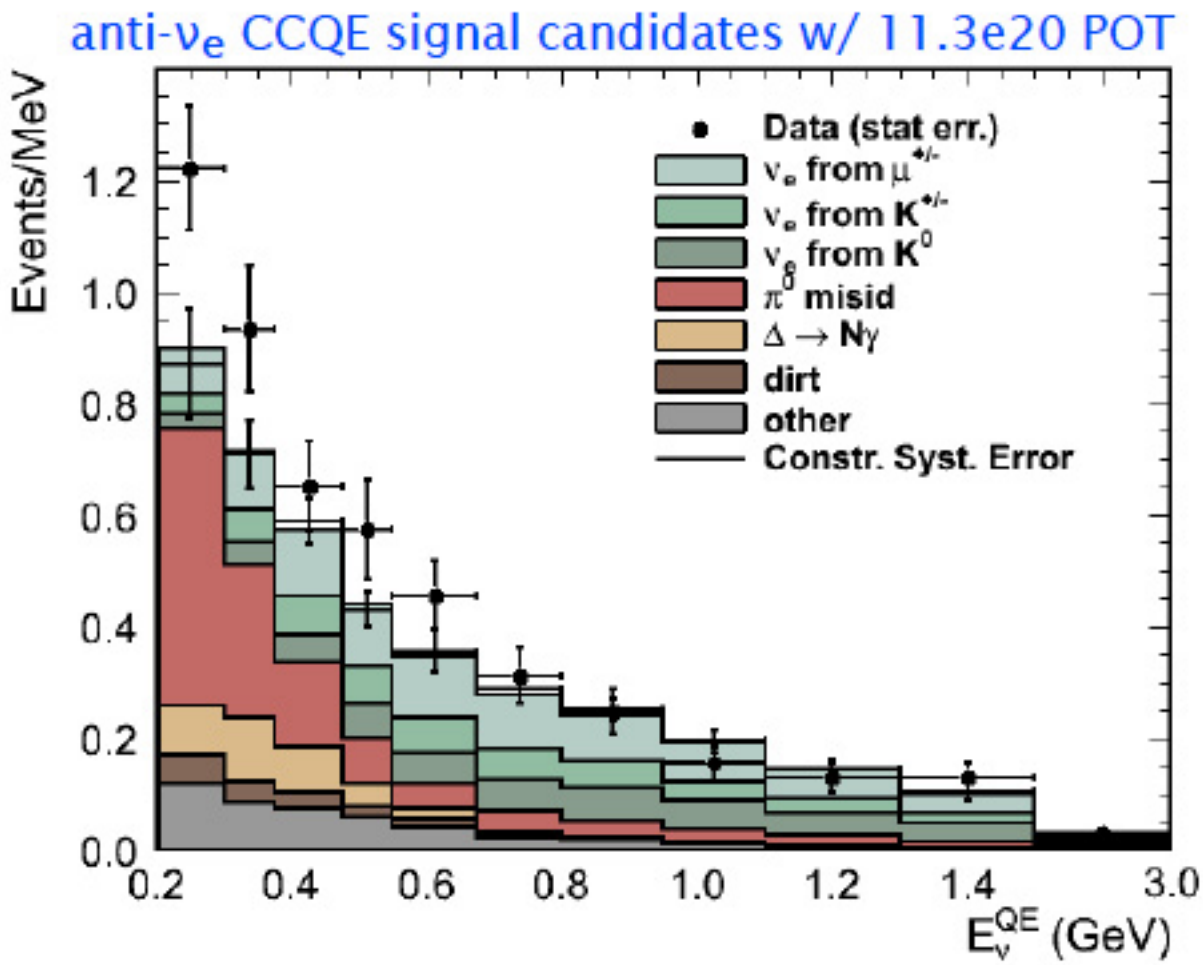




Most significance comes from low energy region

MiniBooNE Antineutrino Oscillation Results

New results presented at Neutrino 2012



With Full data set:
Anti-neutrino mode
Now more consistent with neutrino mode data

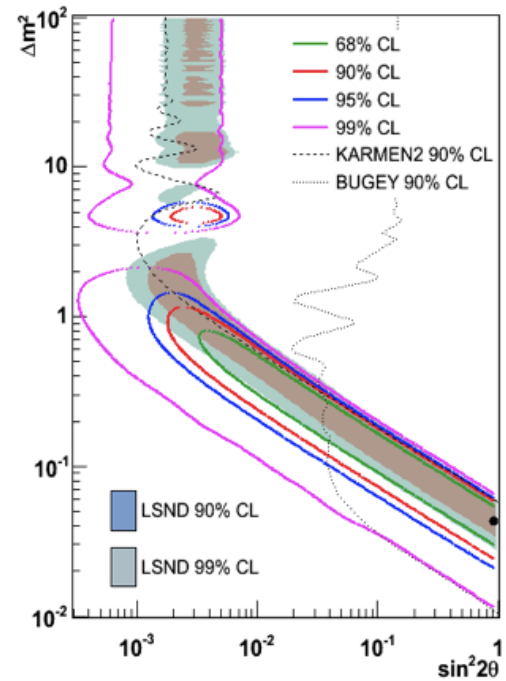
$78.4 \pm 20.0 \pm 23.4$ events

E=200-1250 MeV
2.5σ

Allowed region: $\bar{\nu}$ mode

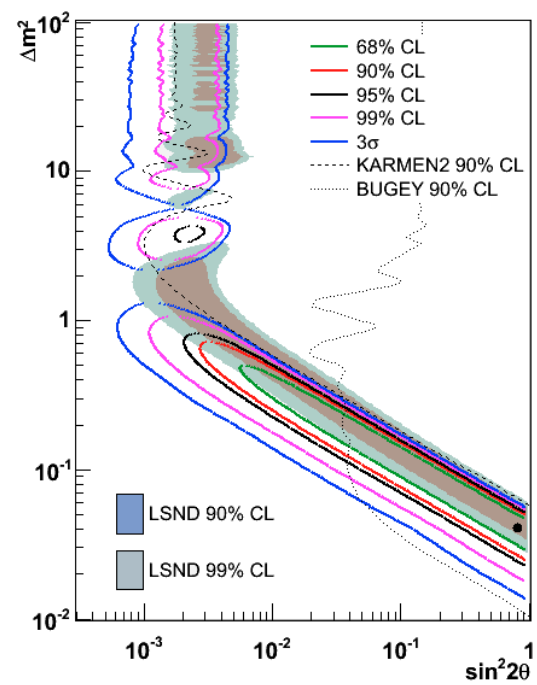
- 11.3E20 POT
- 2.5σ excess from E=200-1250 MeV

Changes from previous analysis:
•Double the statistics
•Using samples to constrain errors: $\bar{\nu}$ CCQE, NCπ^o, Dirt enhanced
•An improved insitu measurement of wrong sign contamination
•New SciBooNE constraint on intrinsic ν_e from K+
•….

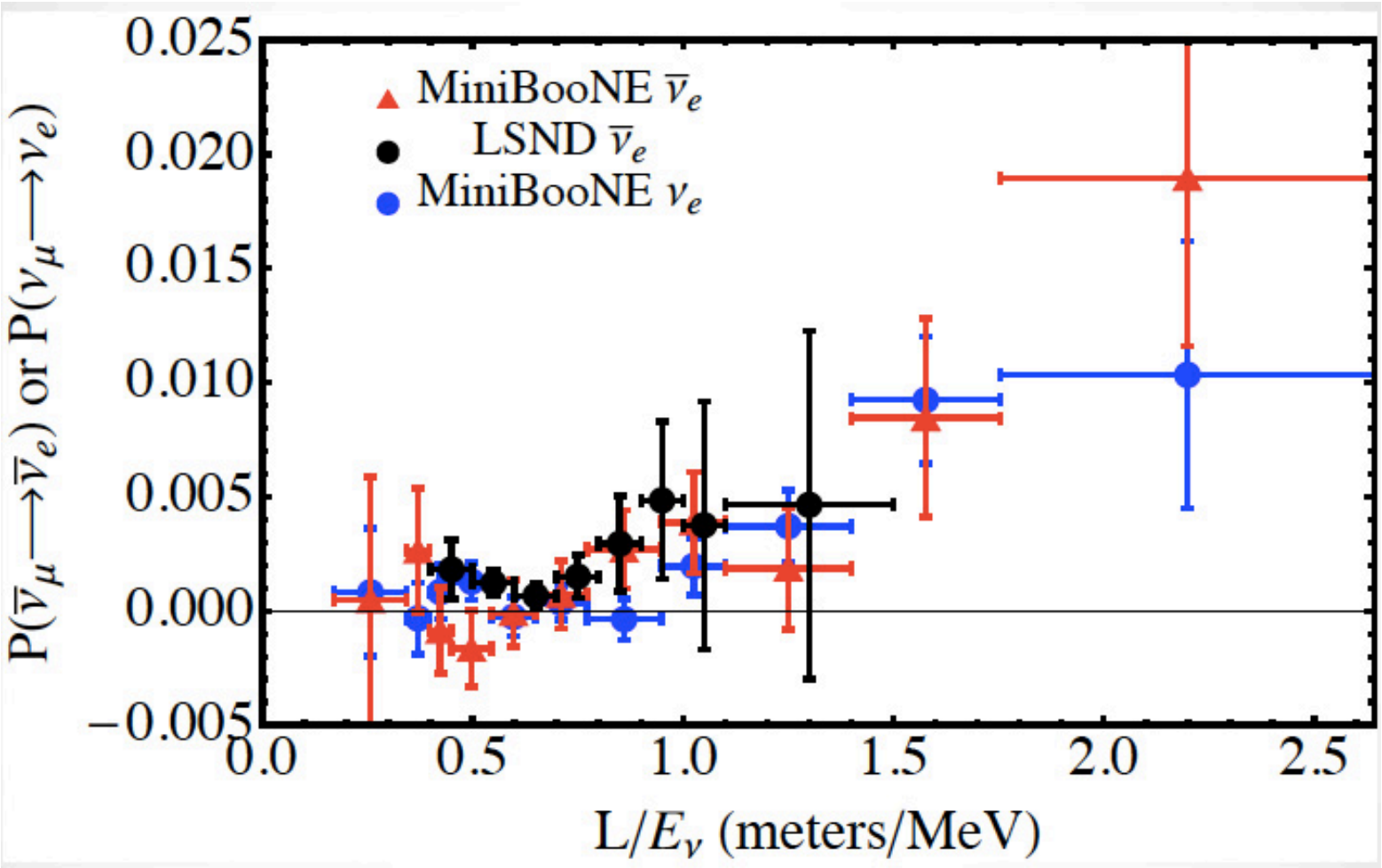


Combined $\nu + \bar{\nu}$ analysis

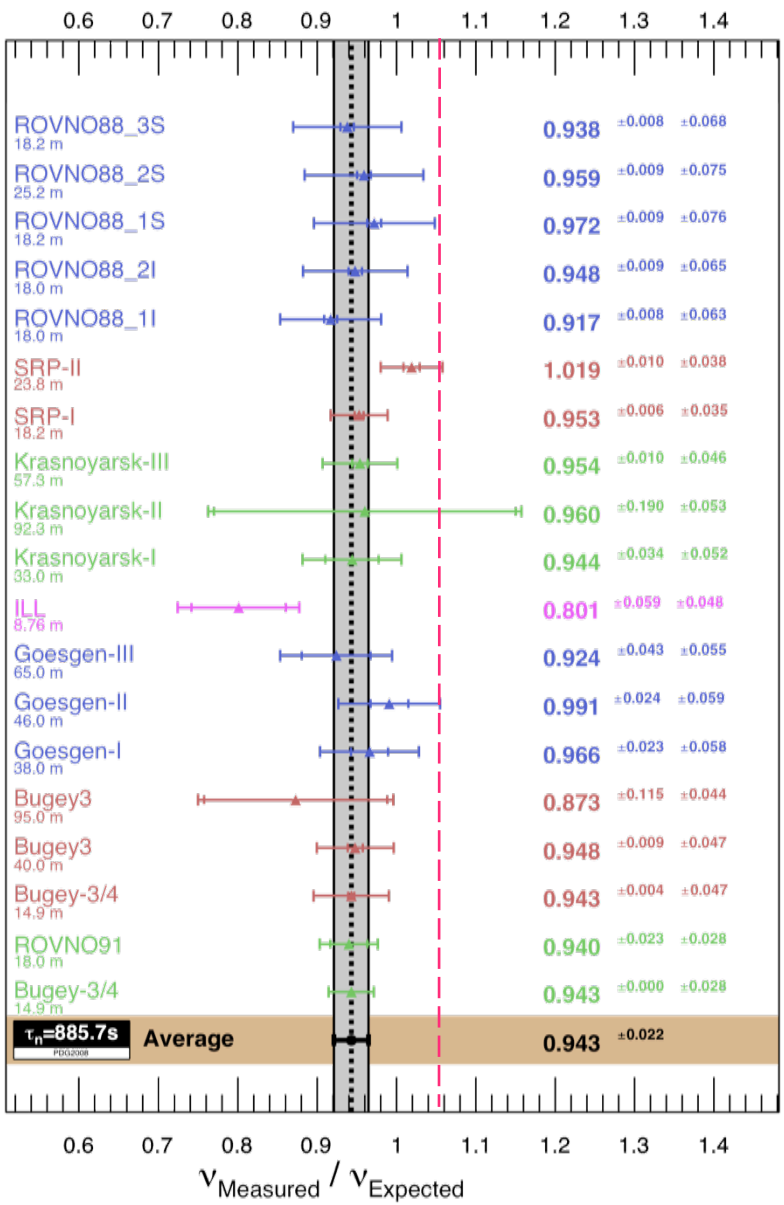
•Excess (200-1250): 240 ± 34.5 ± 52.6 (3.8 σ)
•Best fit preferred over null at 3.6 σ



L/E Comparison of LSND & MiniBooNE $\bar{\nu}_e$ and ν_e data



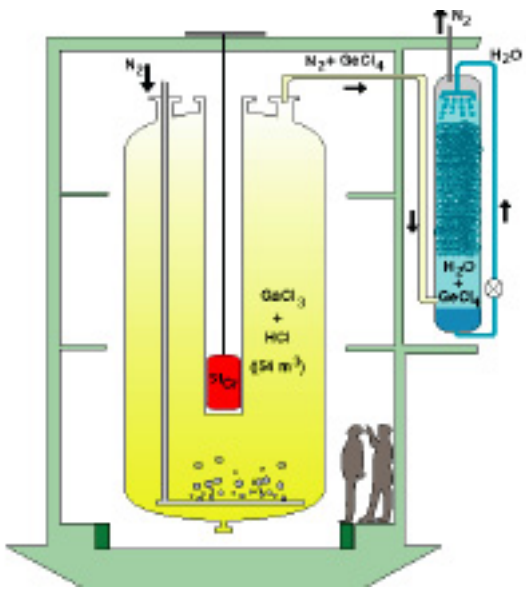
The reactor antineutrino anomaly

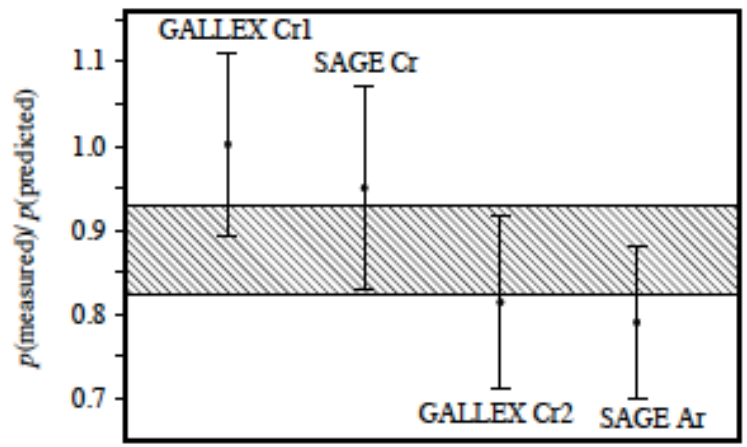


- **New Reactor antineutrino Spectra**
  - Net 3% upward shift in energy-averaged fluxes
  - Adds to 3% shift upwards
  - Phys. Rev. C83, 054615, 2011
- **Recent re-analysis of 19 reactor neutrino results**
  - Neutron life time correction & Off-equilibrium effects
  - Phys. Rev. D83, 073006, 2011
  - **μ = 0.943±0.023** (2.7-3 sigma effect)

Radioactive Neutrino Sources

- Neutrinos detected through radiochemical counting of Ge nuclei: $^{71}Ga+\nu_e \rightarrow ^{71}Ge+e^-$
- GALLEX and SAGE calibration runs with intense MCi sources (ν_e)

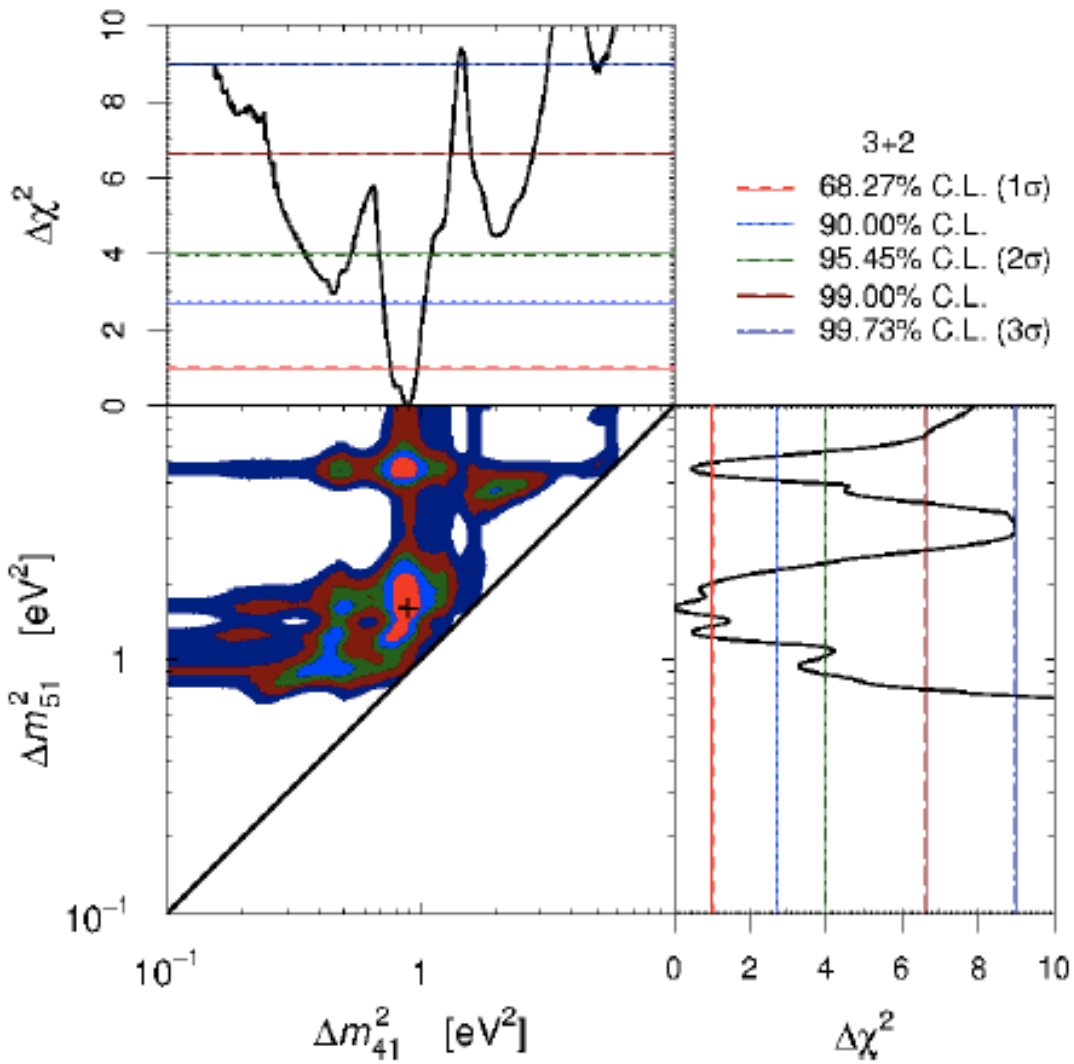




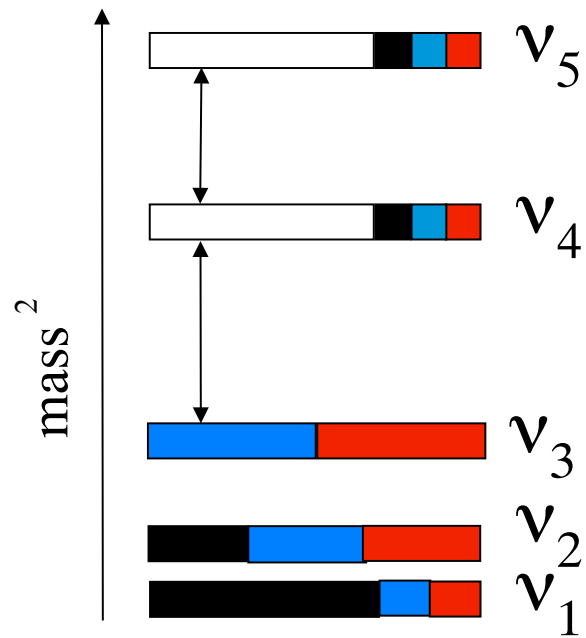
R=0.86+-0.05
(observed/predicted rate)

Global 3+2 Fit to World Neutrino & Antineutrino Data

Giunti & Laveder, arXiv:1107.1452



- $\nu_\mu \rightarrow \nu_e \neq \bar{\nu}_\mu \rightarrow \bar{\nu}_e$



However, in 3+2 models there is some tension between neutrino & antineutrino data and appearance and disappearance experiments.

Story of Short Baseline Oscillations coming together…..
How can we confirm/rule out these signals?

Anomaly	Type	Channel	Significance
LSND	DAR	νbar CC	3.8σ
MiniBooNE	SBL Accelerator	ν CC	3.0σ
MiniBooNE	SBL Accelerator	νbar CC	2.5σ
Gallium/Sage	Source –e capture	ν CC	2.7σ
Reactor	Beta-decay	νbar	3.0σ

3.8σ

- Two philosophies:
  - Test exactly what has been seen with a more sensitive experiment
  - Look for "smoking gun" oscillation wiggles over very short baselines but the right L/E

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LAr1

Growing interest in hints, many conferences, papers, and new ideas on how to address them

Reactor experiments address anomalies

Proposal	Reactor	Baseline	Status
Nucifer (Saclay)	Osiris 70MW	7	Taking Data
Stereo (Genoble)	ILL 50 MW	10	Proposal
SCRAAM (CA)	San-Onofre 3 GW	24	Proposal
NIST (US)	NCNR 20 MW	4-11	Proposal
NEUTRINO4	SM3 100 MW	6-12	Proposal
SCRAAM (Idaho)	ATR 150 MW	12	Proposal
DANSS (Russia)	KNPP 3 GW	14	Fabrication

Source Experiments to address anomalies

Species	Source	Experiment	Status
ν_e	^{51}Cr	Baksan	Proposal
ν_e	^{51}Cr	LENS	Proposal
ν_e	^{51}Cr	Borexino	Proposal
ν_e	^{51}Cr	SNO+	Proposal
ν_e	^{37}Ar	Richochet	Proposal
$\bar{\nu}_e$	^{144}Ce	CeLAND	Proposal
$\bar{\nu}_e$	^{144}Ce	Daya-Bay	Proposal

Accelerator based experiments:

At Fermilab

- MicroBooNE (under construction)
- *LAr1: two detector follow on to MicroBooNE (LoI)*

At CERN

- CERN SPS: two-three detector experiment in North Area (proposal)

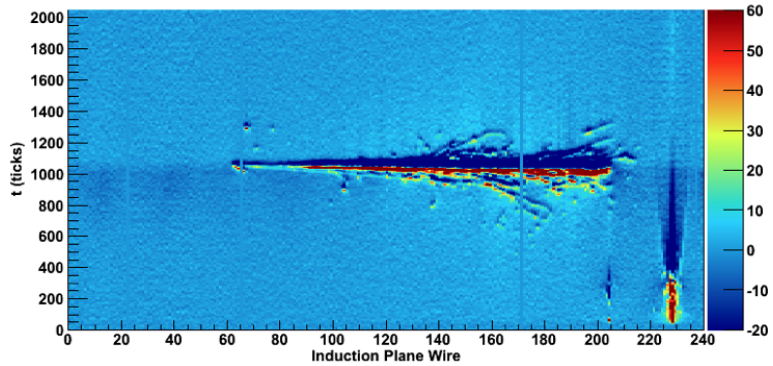
Recent "European Strategy on Neutrino Physics" @ CERN
Lots of interest in reviving neutrino physics in Europe both at long and short baselines.

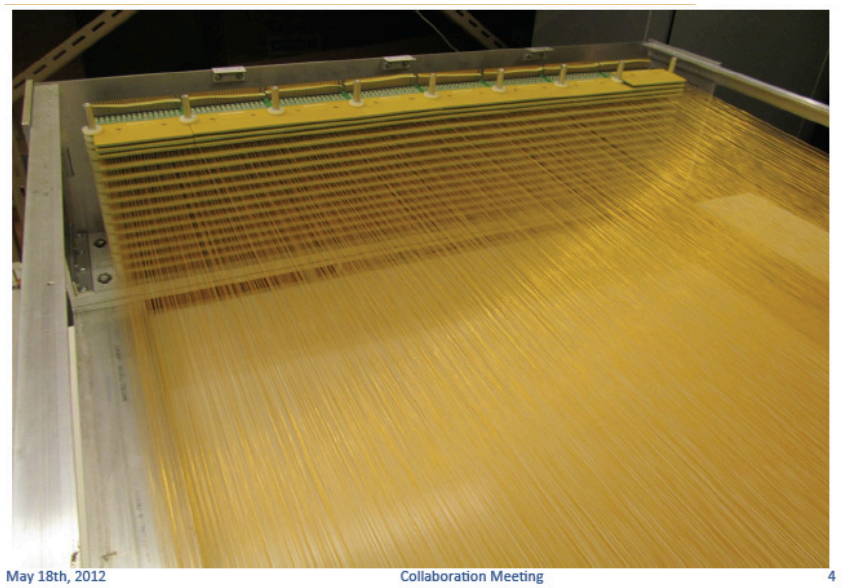
The MicroBooNE experiment

Liquid Argon Time Projection Chamber

LArTPC detector to address the MiniBooNE low energy excess and measure a suite of low energy neutrino cross sections
LArTPC development

- Spring 2012: DOE CD3b, Stage II approval
- Data taking 2014, 6.6E20 POT in ν mode





Wire stringing nearly complete

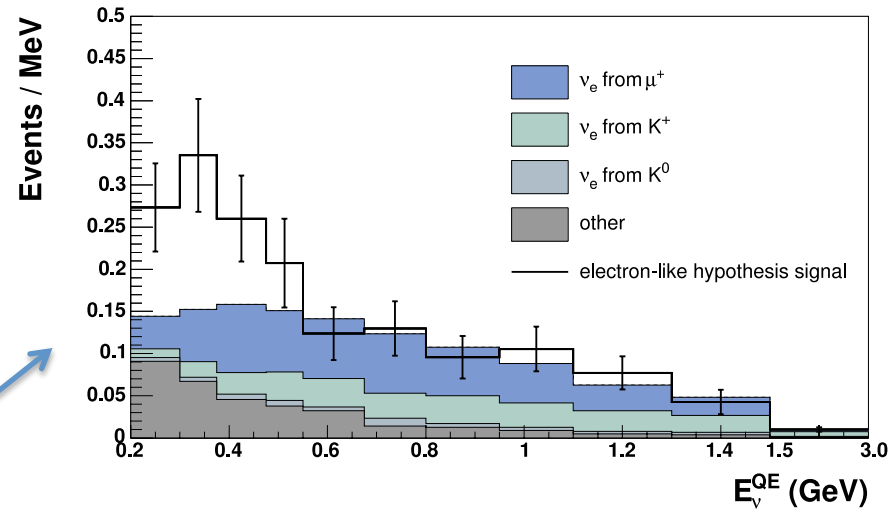
MicroBooNE at 470m on the BNB

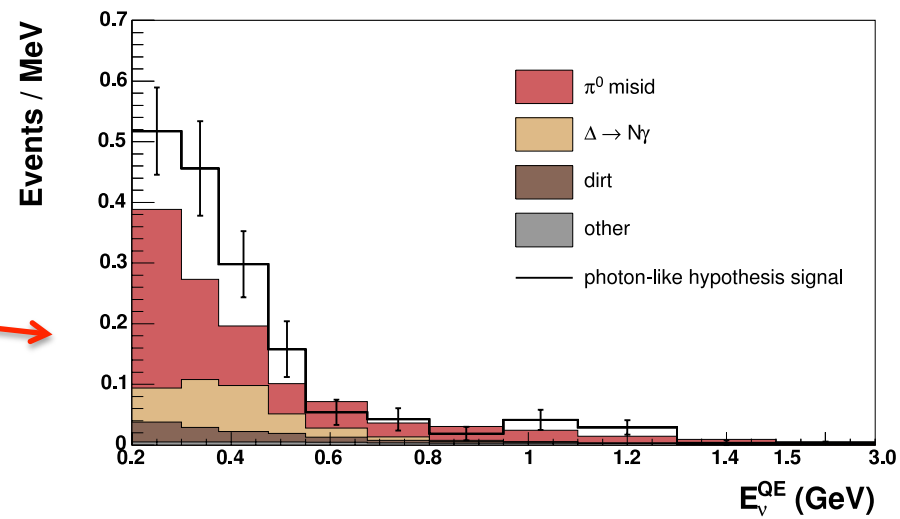
MicroBooNE sensitivity to low energy excess:

(neutrino running,
70 ton fiducial volume,
x2 higher PID efficiency than MiniBooNE,
3% mis-ID,
6.0e20 POT)

Electron-like hypothesis:
36.8 excess events
41.6 background events
5.7σ stat. significance

Photon-like hypothesis:
36.8 excess events
78.9 background events
4.1σ stat. significance





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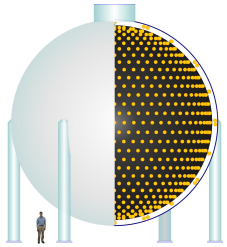
A longer term program of short baseline oscillation physics at Fermilab

Booster
Neutrino Beam
Source



MiniBooNE/MicroBooNE team studying physics potential of phased program to address this physics. -- Work in progress…

Example:

2012 •Phase 0: Continued running of MiniBooNE in anti-neutrino mode

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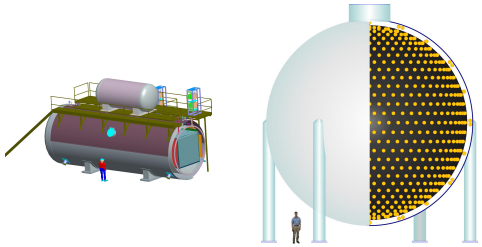

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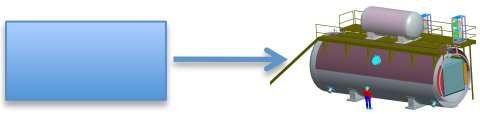

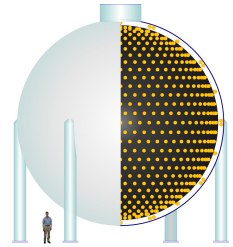

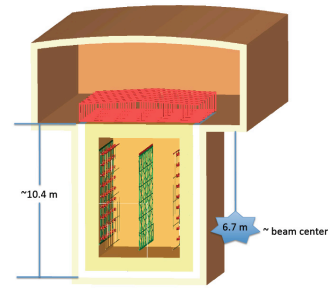

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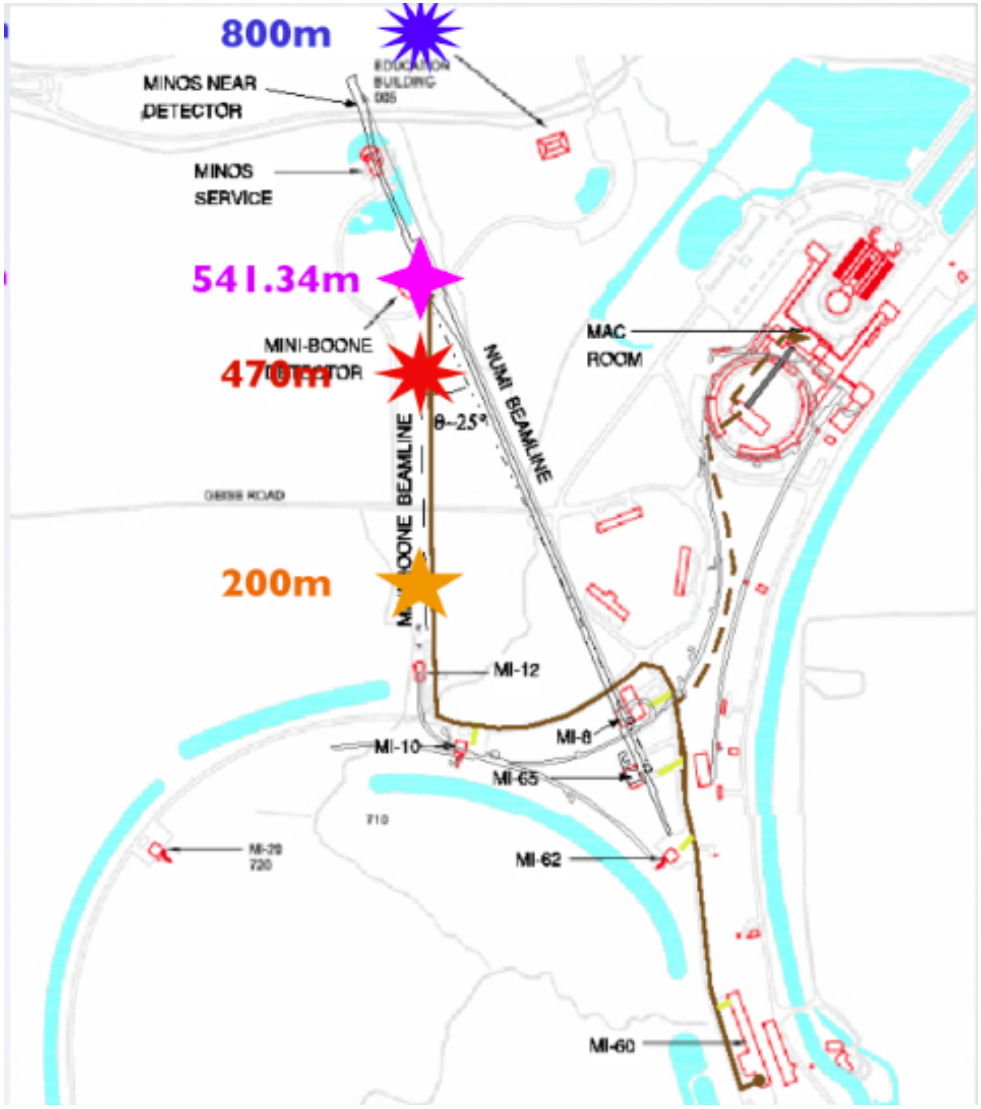
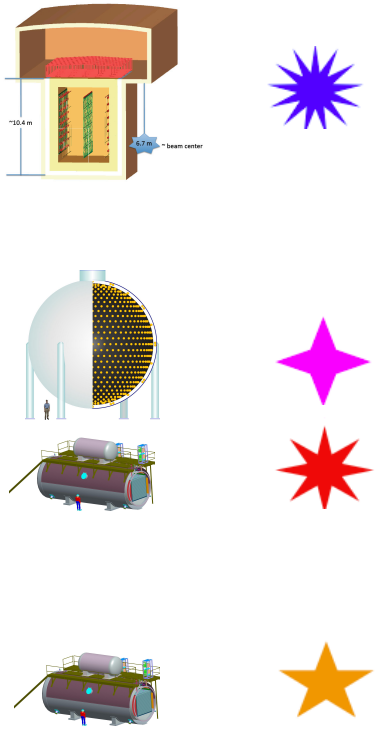
2014 •Phase 1: MicroBooNE run in neutrino mode to address low energy excess

201? •Phase 2: Near/Far comparison: MicroBooNE (near detector) and Large 1kton scale LArTPC address anti-neutrino results (far detector)

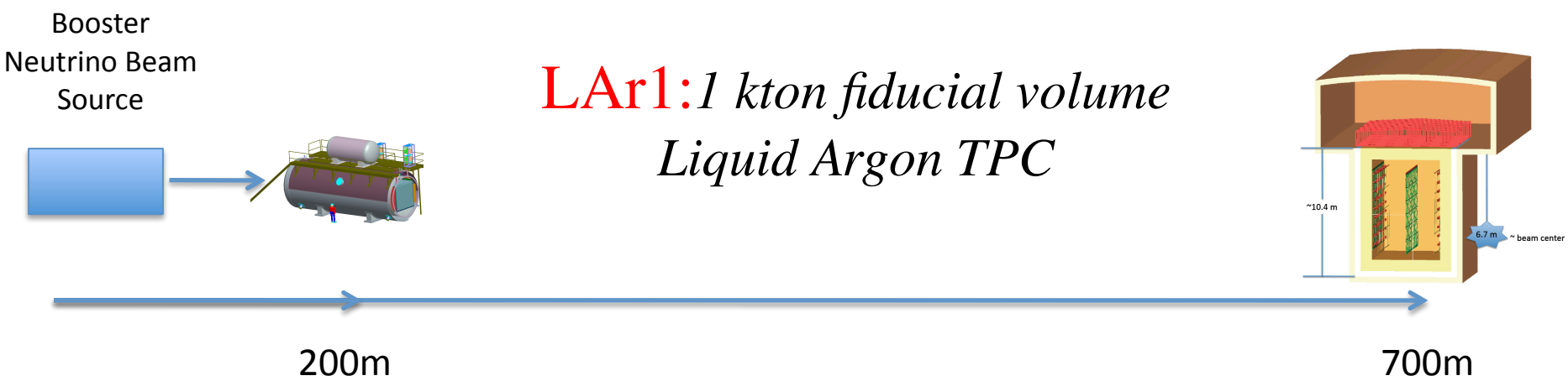
Program on Booster Neutrino Beamline





Neutrino Source

Considered a number of different locations to take advantage of Booster Neutrino Beam and NuMI beam



- Located at 700m on the Booster Neutrino Beamline
- MicroBooNE, moved to 200m, serves as its near detector
- $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance search: Near/Far Comparison
- 10E20 POT on BNB
- Can also extend reach in $\nu_\mu \rightarrow \nu_e$ appearance
- Physics program is complementary to other programs on site (MicroBooNE, MINOS+)

Combines physics program with development towards LBL experiments: LBNE

H. Chen, C. Thorn, D. Lissauer, V. Radeka, B. Yu, G. Mahler, S. Rescia, S. Duffin, Y. Li
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D. Kaleko, G. Karagiorgi, B. Seligman, M. Shaevitz, B. Willis
Columbia University

B. Baller, H. Greenlee, J. Raaf, R. Rameika, G. Zeller
Fermi National Accelerator Laboratory

M. Messier, S. Mufson, J. Musser, J. Urheim
Indiana University

W. Huelsnitz, W.C. Louis, G.B.Mills, Z. Pavlovic, R.G. Van De Water
Los Alamos National Laboratory

L. Bugel, J. Conrad, T. Katori, C. Ignarra, B. Jones, M. Toups
Massachusetts Institute of Technology

Kirk McDonald
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Virginia Tech

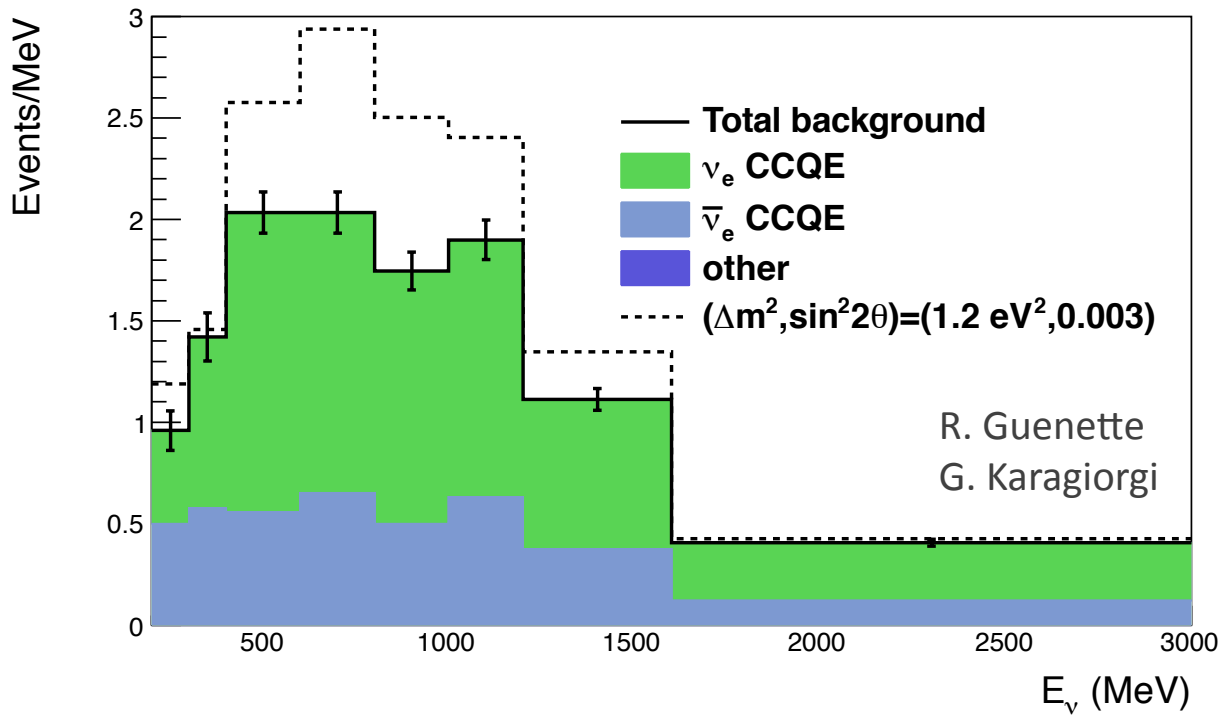
J. Assadi, M. Soderberg
Syracuse University

M. Marshak
University of Minnesota

F. Cavanna, E. Church, B.T. Fleming, R. Guenette, O. Palamara, K. Partyka, A. Szelc
Yale University

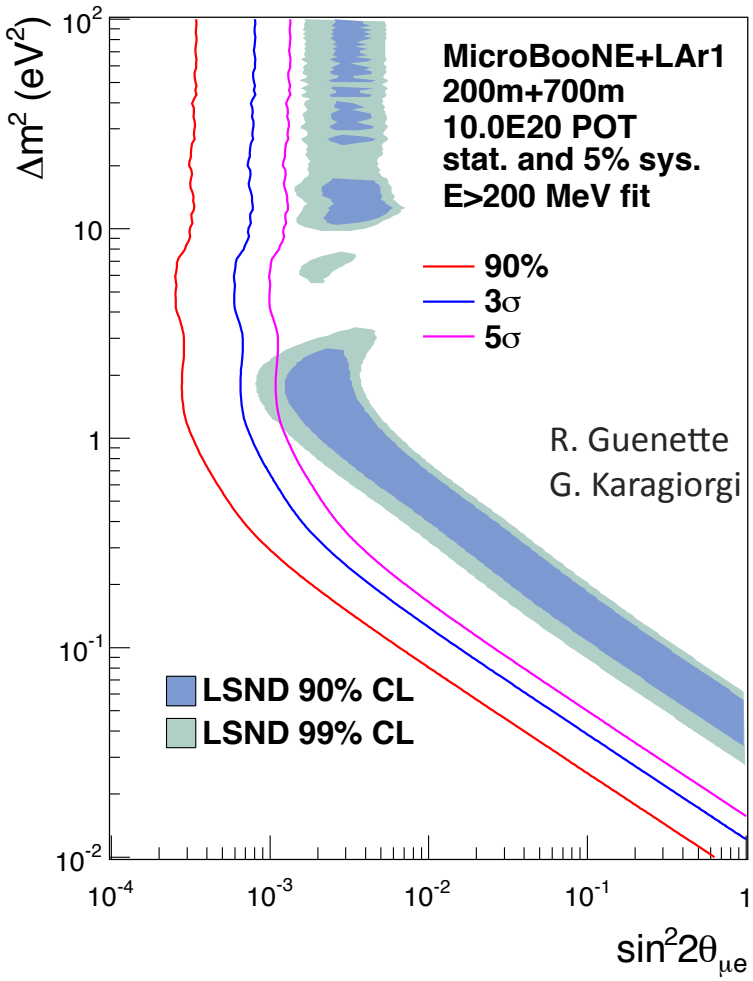
Expected event rates

Intrinsic ν_e	Intrinsic $\bar{\nu}_e$	LSND Best Fit $\nu+\bar{\nu}$	ν_μ	$\bar{\nu}_\mu$
200-3000 MeV	200-3000 MeV	200-3000 MeV	200-2000 MeV	200-3000 MeV
1,895	894	257+434	130,126	217,059



LAr1 sensitivity* to MiniBooNE anti-neutrino anomaly

MicroBooNE at 200m and LAr1 at 700m

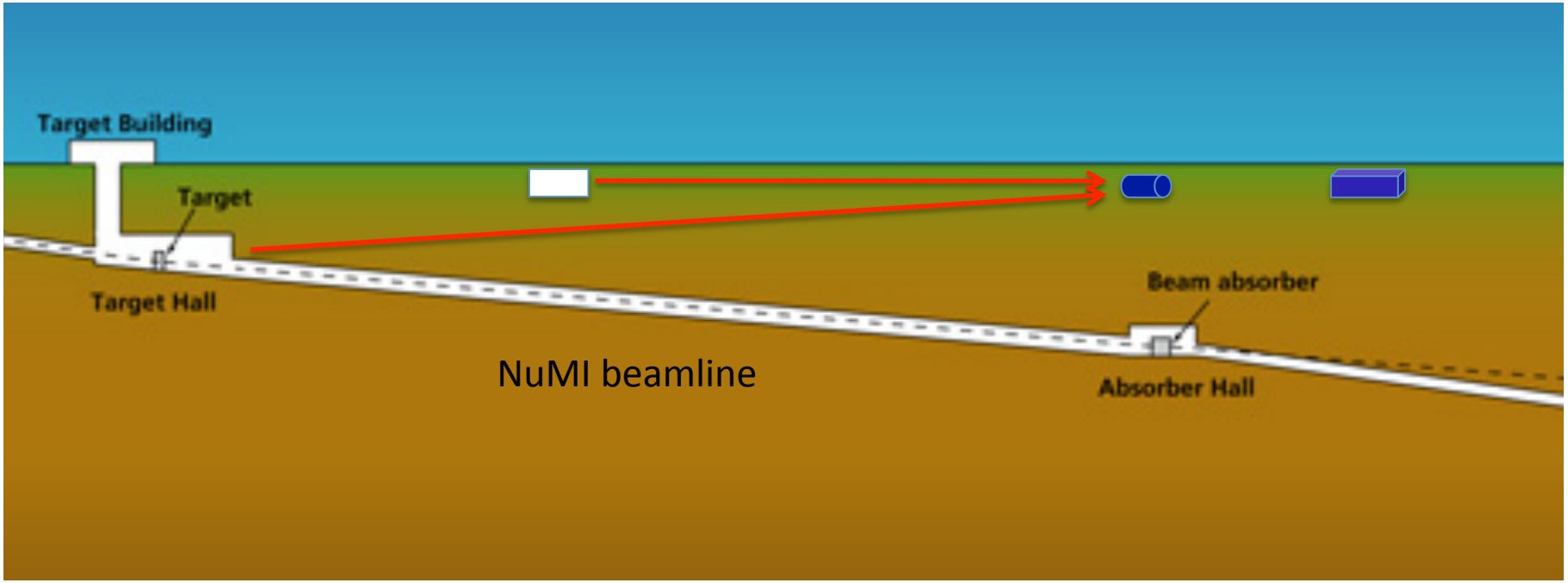


10.0E20 POT: ~5 years with present running conditions

Fiducial volumes assumed for MicroBooNE and LAr1 are 61t and ~1kton respectively.

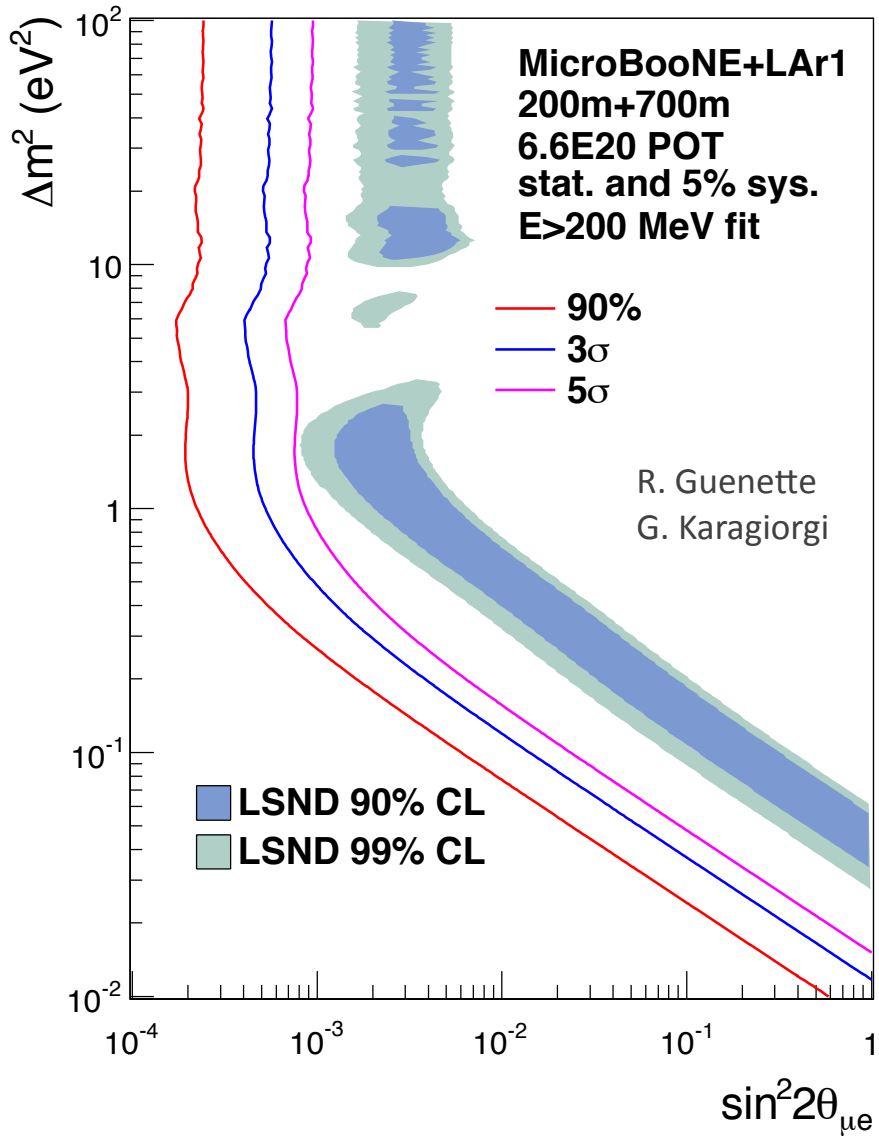
* 3+1 neutrino model

LAr1 + MicroBooNE will "see" both the Booster Neutrino Beam and an off-axis component of the NuMI beam



In addition to $\bar{\nu}_e$ appearance – can also look for NC disappearance, $\bar{\nu}_\mu$ disappearance….

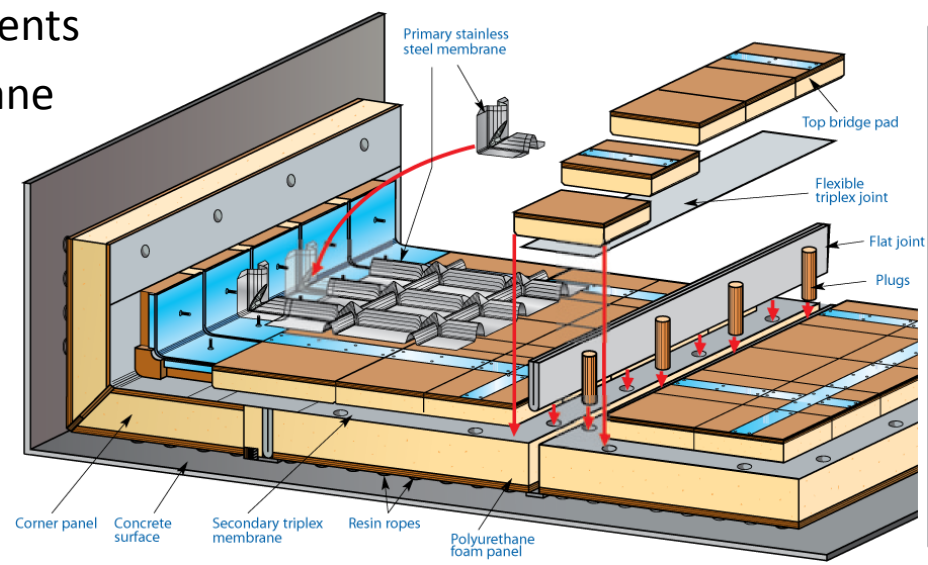
MicroBooNE + LAr1 can also probe neutrino mode oscillations…

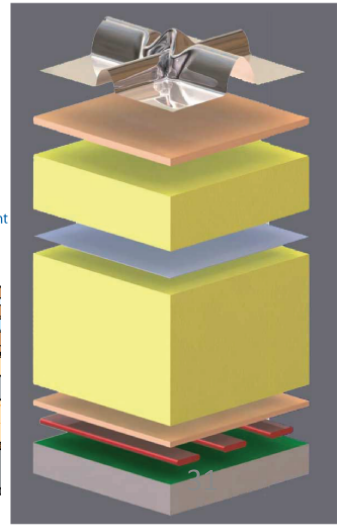


Conceptual Design

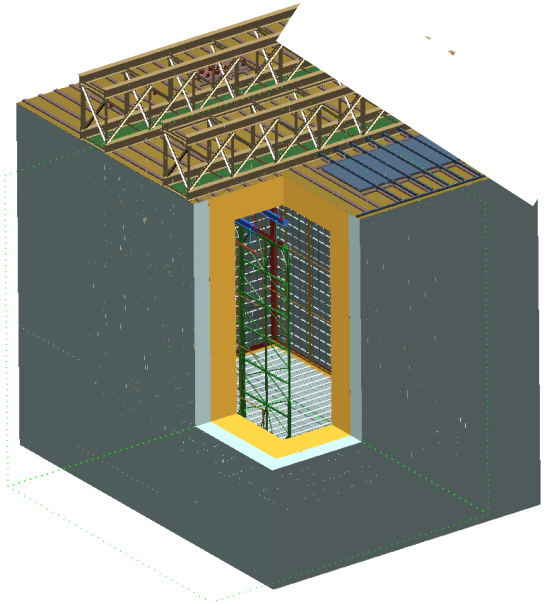
- The conceptual design for LAr1 is the design of the engineering prototype for LBNE
- The present design is a TPC constructed of an array of modular units:
  - Anode Plane Assemblies (APAs 2.5m wide, 7m high and 10cm thick), which contain the wires and scintillation light detection system and instrumented with cold electronics
  - Cathode Plane Assemblies (CPAs 2.5m wide and 7m high), which provide the high voltage electrode to create the drift field
  - Field Cage Panels which shape the uniform electric field of 500 V/cm between the APAs and CPAs

All the active detector elements are arrayed inside a membrane style cryostat and immersed in ultra-high purity LAr, maintained by the cryogenic system.

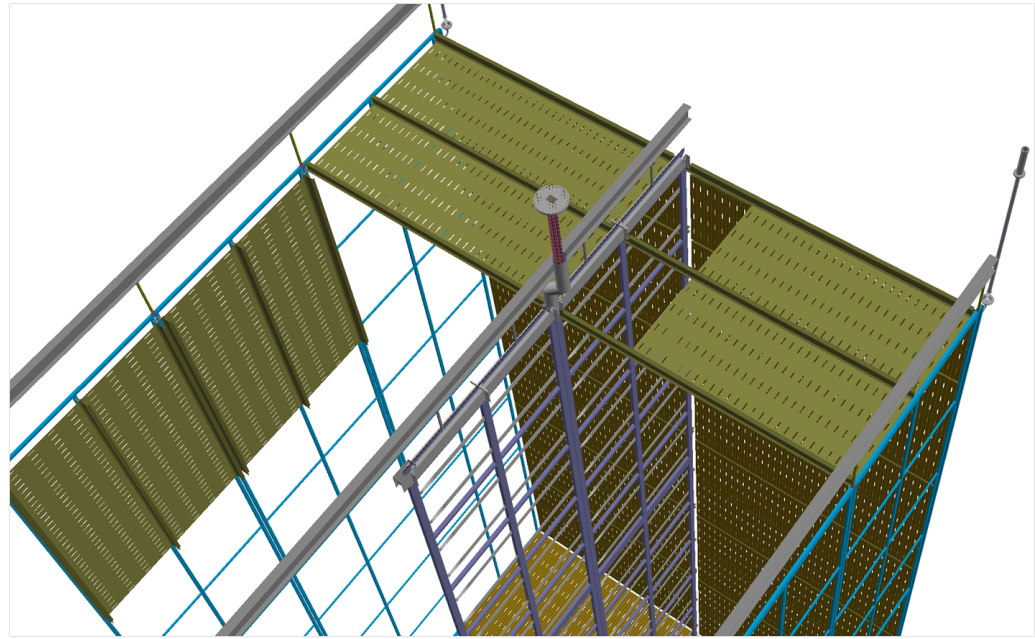




1Kton LAr detector

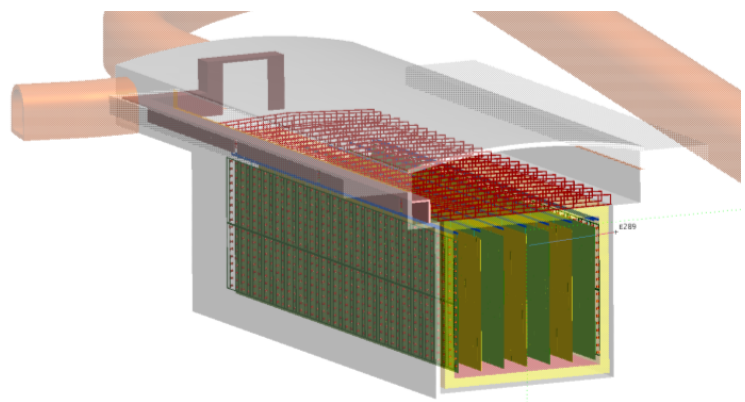


Membrane Cryostat



Arrangement of APAs, CPAs, and field cage panels

In addition to the physics program, LAr1 will have a development program serving as the engineering prototype for LArTPCs for long baseline oscillation searches (eg: LBNE)



Fermilab Program

While each of the SBL anomalies taken by themselves are 2-4σ anomalies, together they suggest something interesting happening at short baselines!

This has drawn a lot of interest in the community in many conferences, workshops, and reports
"Light Sterile Neutrinos: A White Paper"
Fermilab Short Baseline Task Force Report

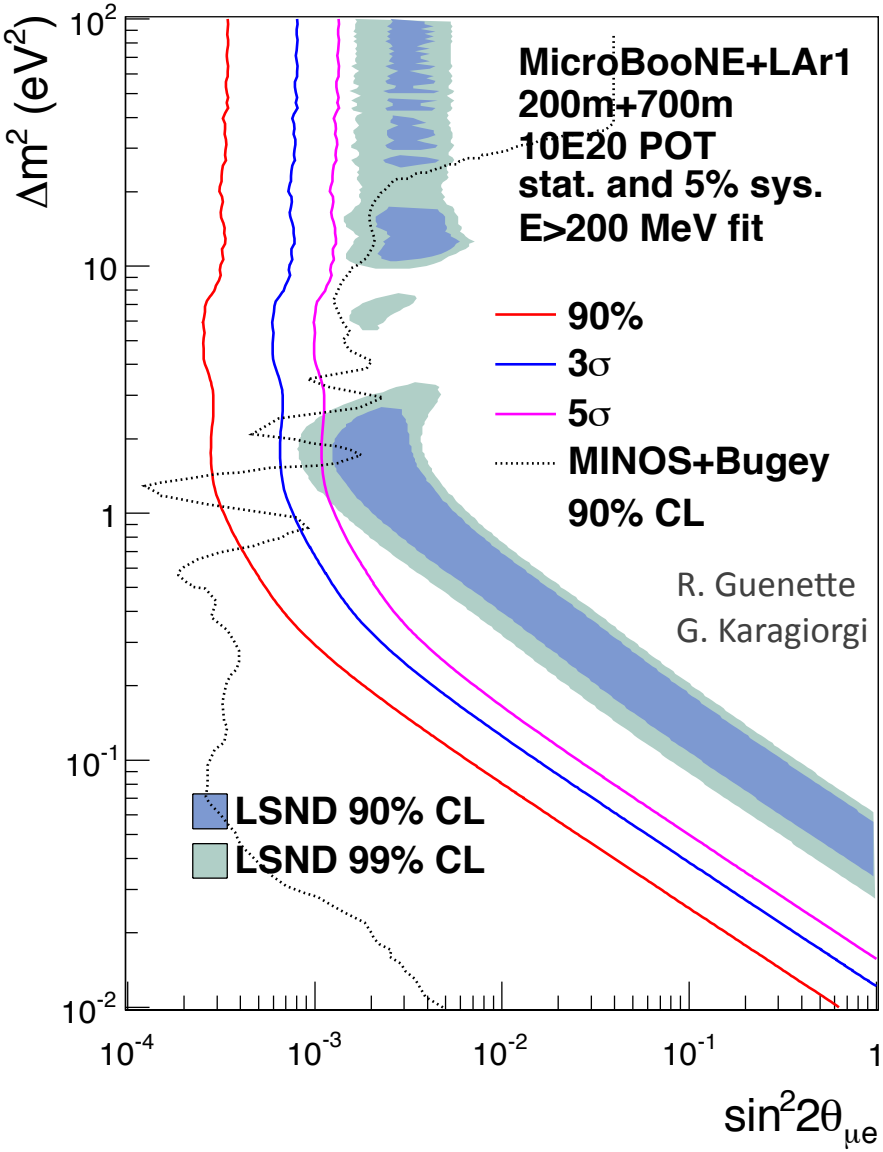
With MicroBooNE, and MINOS+ Fermilab will be the first to begin to explore these anomalies – search for sterile neutrinos…

Summary

LAr1 will definitively address the MiniBooNE anti-neutrino anomaly, combined with the results of MicroBooNE, Fermilab will have the answer, perhaps discovery, to this puzzle.

We ask the PAC to strongly recommend that we proceed to the Proposal Stage

Backup slides



Combination of LAr1 and MINOS+

LAr1 does best at high Δm^2 and MINO+ does best at low Δm^2

Combined – Fermilab definitively addresses and cross checks the short baseline anomalies!

Accelerator based experiments:

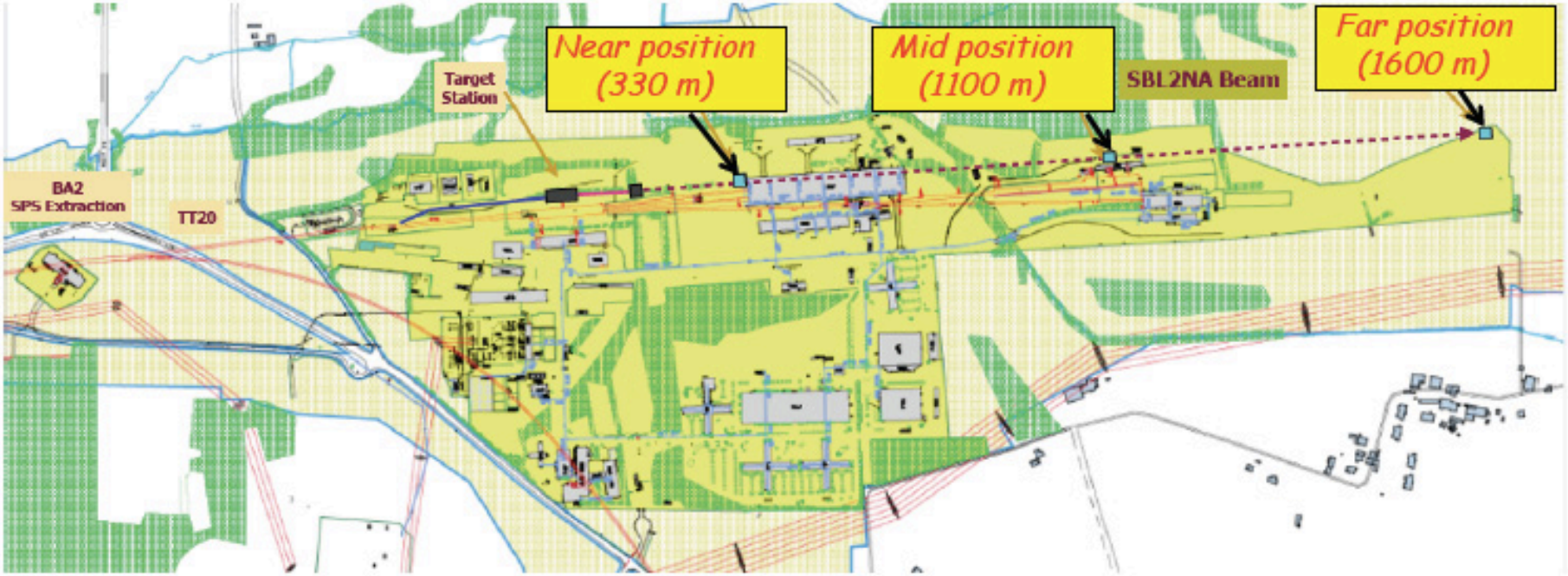
At FNAL:

- MicroBooNE (under construction)
- LAr1: two detector follow on to MicroBooNE (proposal)

At CERN

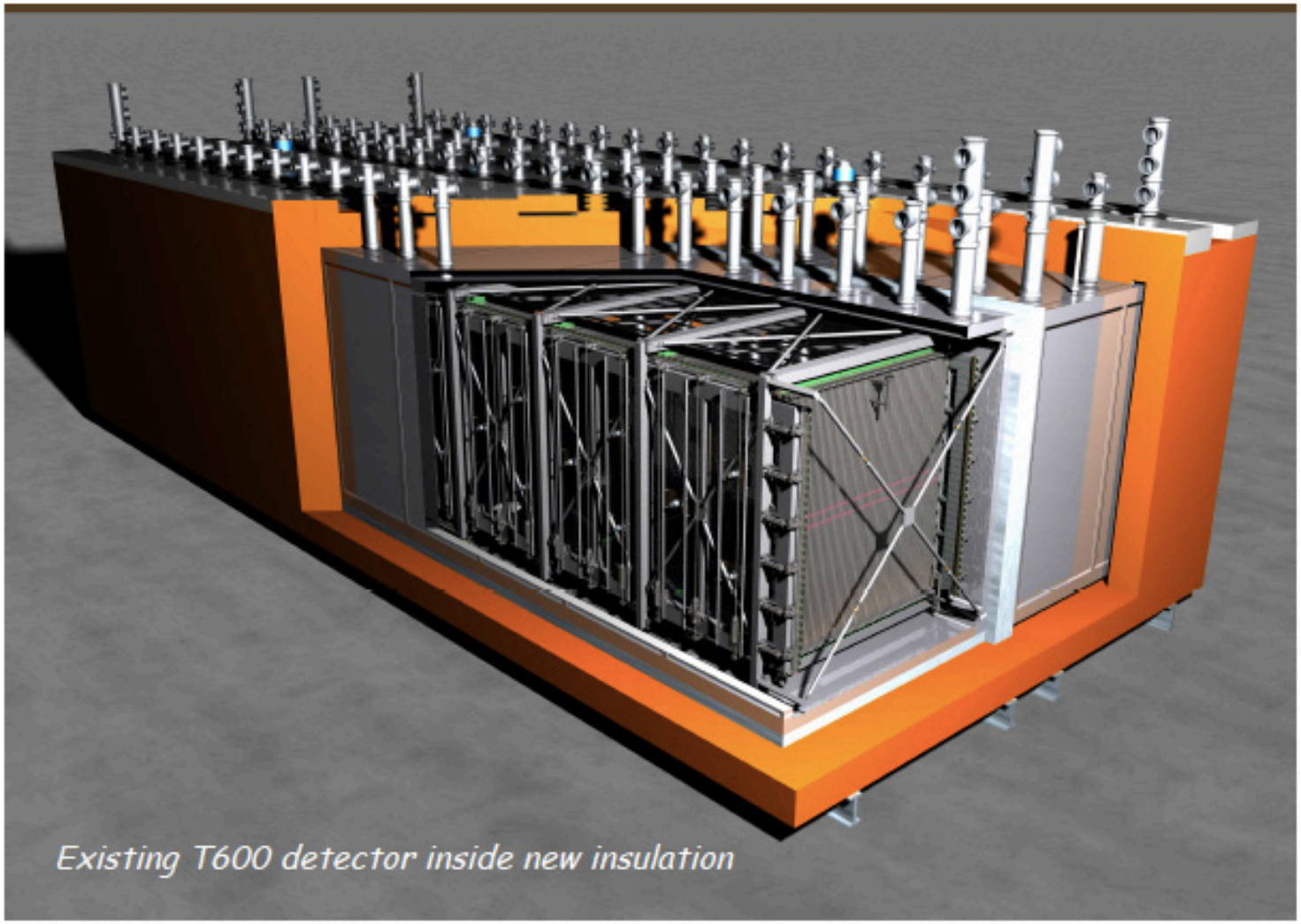
- CERN SPS: two-three detector expt in North Area (proposal)

New Neutrino Facility in the CERN North Area

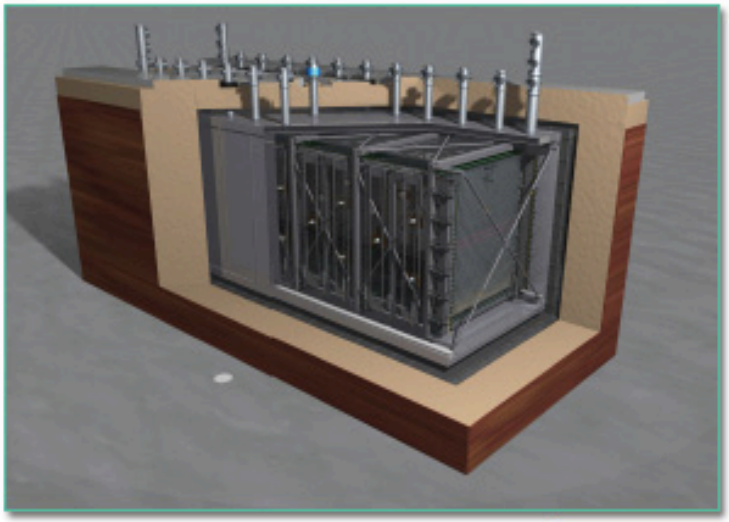


100 GeV primary beam fast extracted from SPS; target station next to TCC2; decay pipe l =100m, ø = 3m; beam dump: 15m of Fe with graphite core, followed by μ stations.
Neutrino beam angle: pointing upwards; at -3m in the far detector ~5mrad slope.

T600 layout in the CERN-SPS

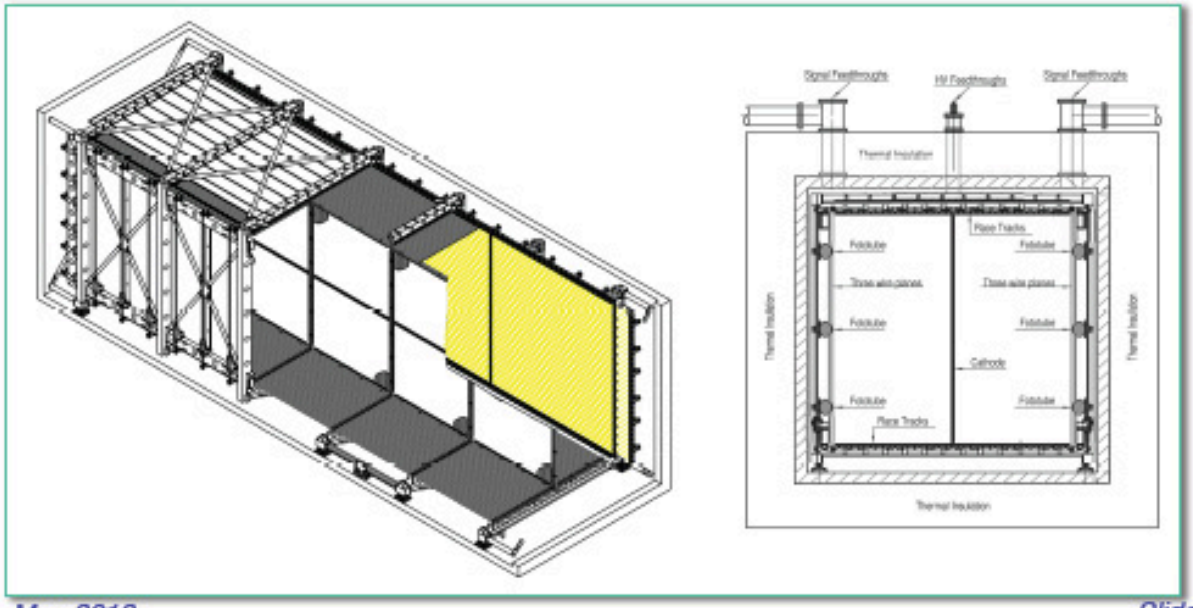


New T150 LAr-TPC

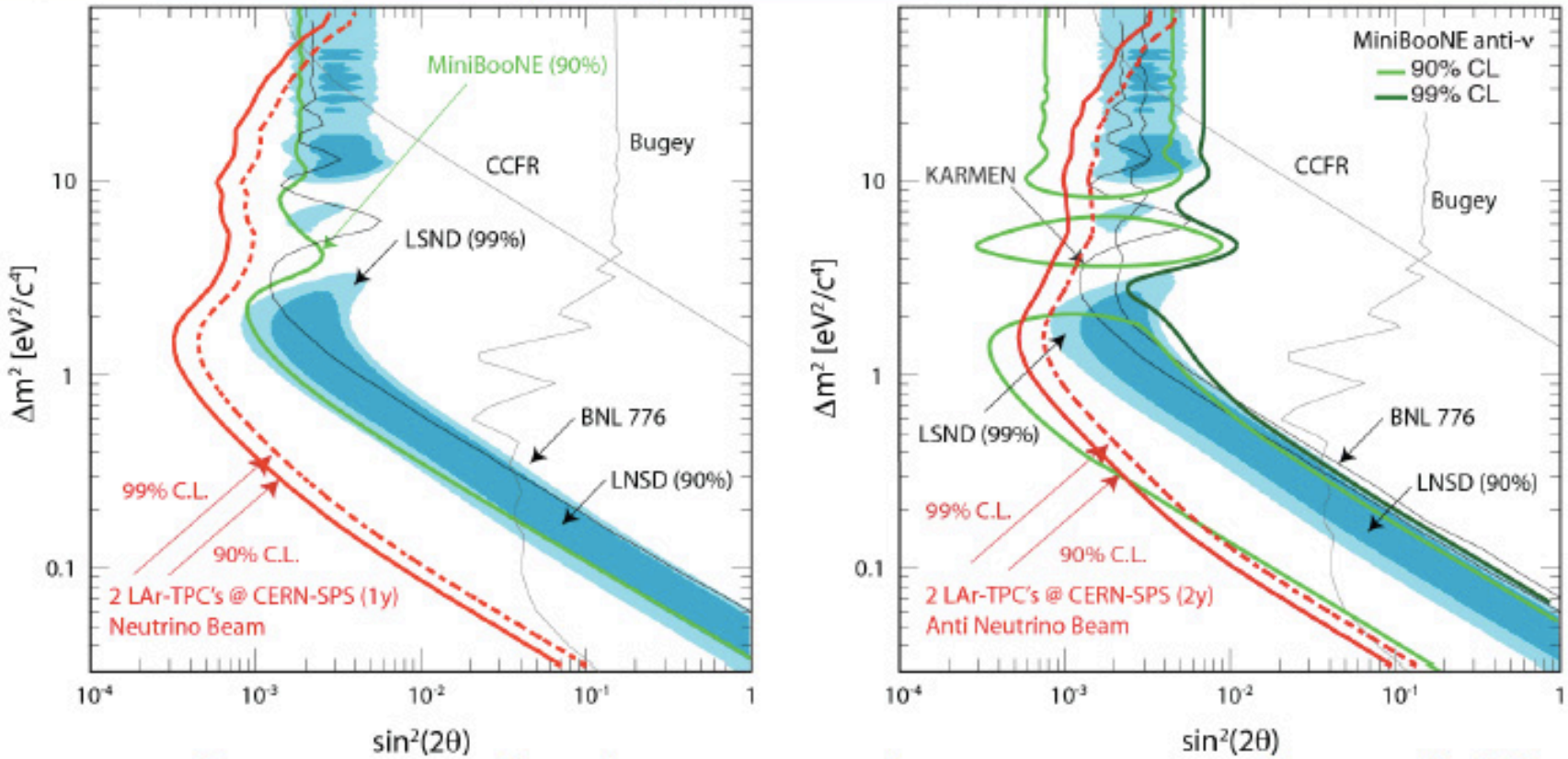


The present design of the T600 is extended to the basic structure of the T150 module. The module contains a high precision, high stability stainless steel structure independent of the container that supports two wire chambers, with three read-out planes each, the field shaping electrodes and one cathode, separating the two 1.5 m drift regions.

Most of the solutions already successfully adopted for the T600 at LNGS will be used. Existing equipment will be conveniently re-used (wiring tables, cleaning tools, etc.).



Comparing LSND sensitivities



Expected sensitivity for the proposed experiment: ν_μ beam (left) and anti-ν_μ (right) for 4.5 10^{19} pot (1 year) and 9.0 10^{19} pot (2 years) respectively. LSND allowed region is fully explored in both cases.