Bonnie Fleming
NuFACT
July 25, 2012

Nu Anomalies at Short Baseline

- Interesting hints from short baseline oscillation experiments
- Future experiments to address results
  - MicroBooNE and LAr1
  - European program

For many years we've been working to understand neutrinos and the many open questions and worldwide program to address these…

- •Neutrinos have mix and have mass – YES!
- •How do they get their mass?
- •Can the universe predict their mass?
- •What is the nature of the neutrino?
- •What is the ordering of the neutrino masses?
- •Are there sterile neutrinos? (Short Baselines)
- •Do neutrinos violate CP? (Long Baselines)

This past year in neutrino physics:

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

Hints from Experiments

- •LSND anomaly
- •MiniBooNE anomalies
- •Reactor Anomaly
- •Gallex and Sage data

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

- •Decay at Rest sources (SNS)
- •Reactor and Source experiments
- •Accelerator experiments

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

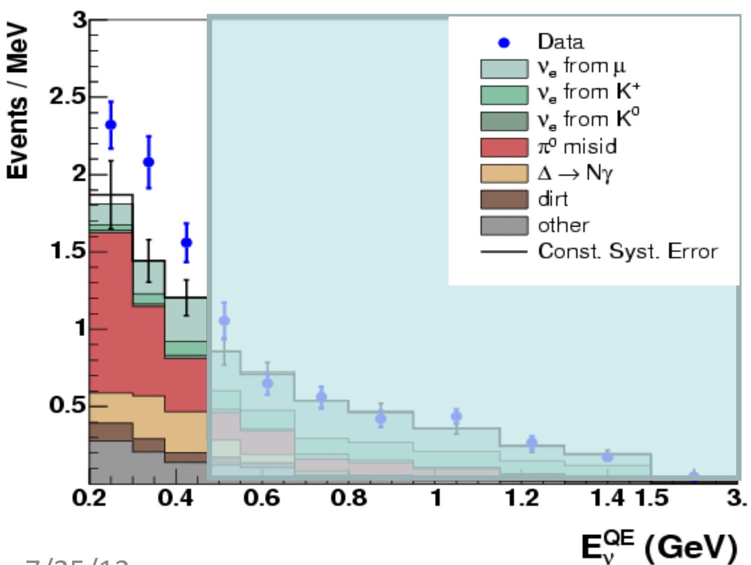
MiniBooNE Neutrino Oscillation Results

A.A. Aguilar-Arevalo et al., PRL 102, 101802 (2009)

Excess of events observed at lower energy:
128.8 ± 20.4 ± 38.3 (3.0σ)

Shape not consistent with simple 2ν oscillations

Magnitude consistent with LSND



Anomaly Mediated Neutrino-Photon Interactions at Finite Baryon Density: Jeffrey A. Harvey, Christopher T. Hill, & Richard J. Hill, arXiv:0708.1281

CP-Violation 3+2 Model: Maltoni & Schwetz, arXiv:0705.0107; T. Goldman, G. J. Stephenson Jr., B. H. J. McKellar, Phys. Rev. D75 (2007) 091301.

Extra Dimensions 3+1 Model: Pas, Pakvasa, & Weiler, Phys. Rev. D72 (2005) 095017

Lorentz Violation: Katori, Kostelecky, & Tayloe, Phys. Rev. D74 (2006) 105009

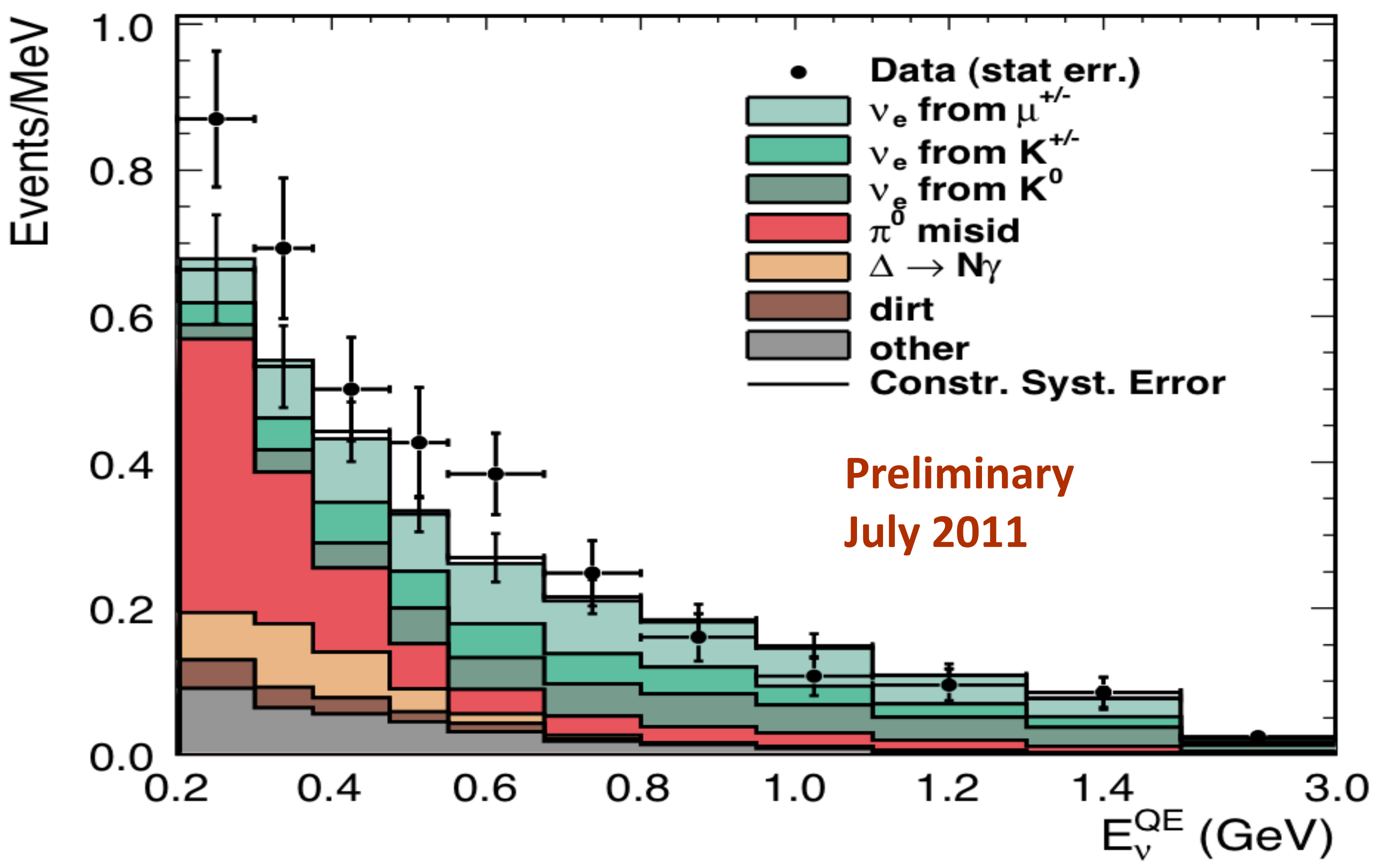
CPT Violation 3+1 Model: Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303

New Gauge Boson with Sterile Neutrinos: Ann E. Nelson & Jonathan Walsh, arXiv: 0711.1363

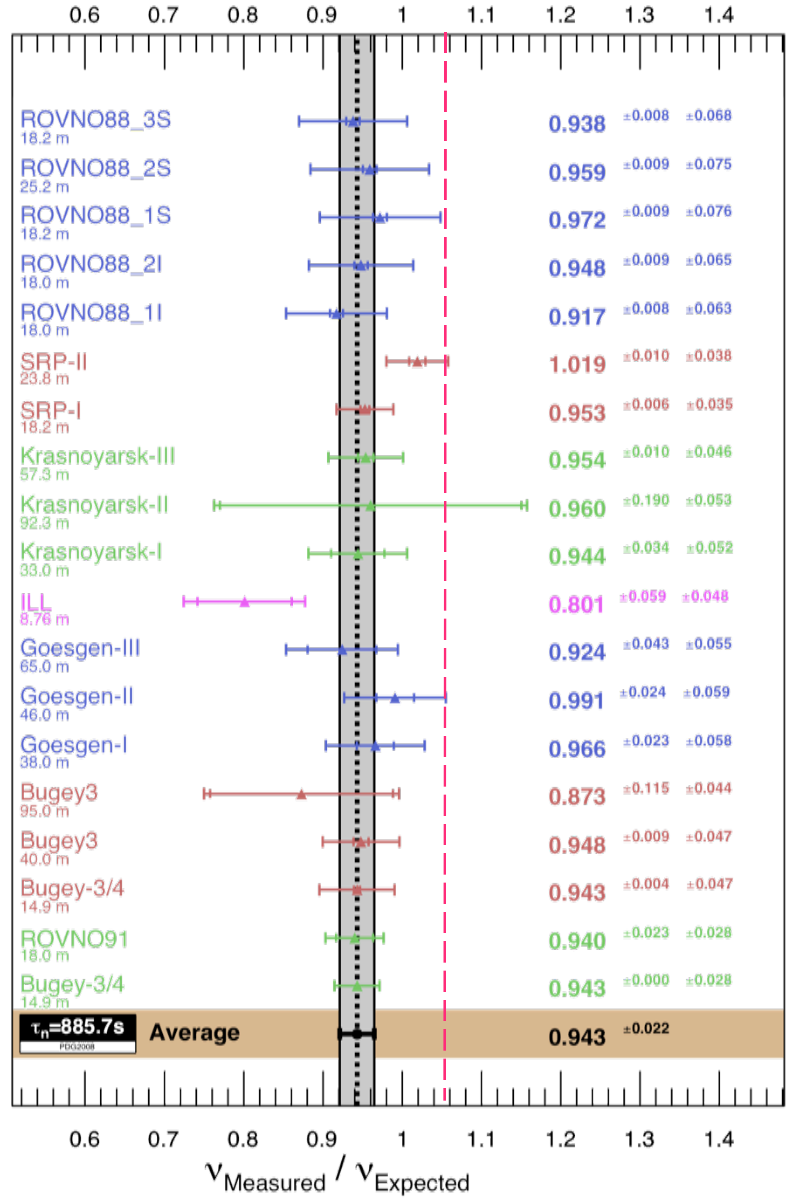
MiniBooNE Antineutrino Oscillation Results

update of A. A. Aguilar-Arevalo, Phys. Rev. Lett. 105, 181801 (2010)

- 8.58E20 POT (~50% more data than published and new K+ constraint from SciBooNE)
- Excess = 57.7+-18.8+/-22.4 (200-3000 MeV)



The reactor antineutrino anomaly



- **New Reactor antineutrino Spectra**
  - Net 3% upward shift in energy-averaged fluxes
  - Phys. Rev. C83, 054615, 2011

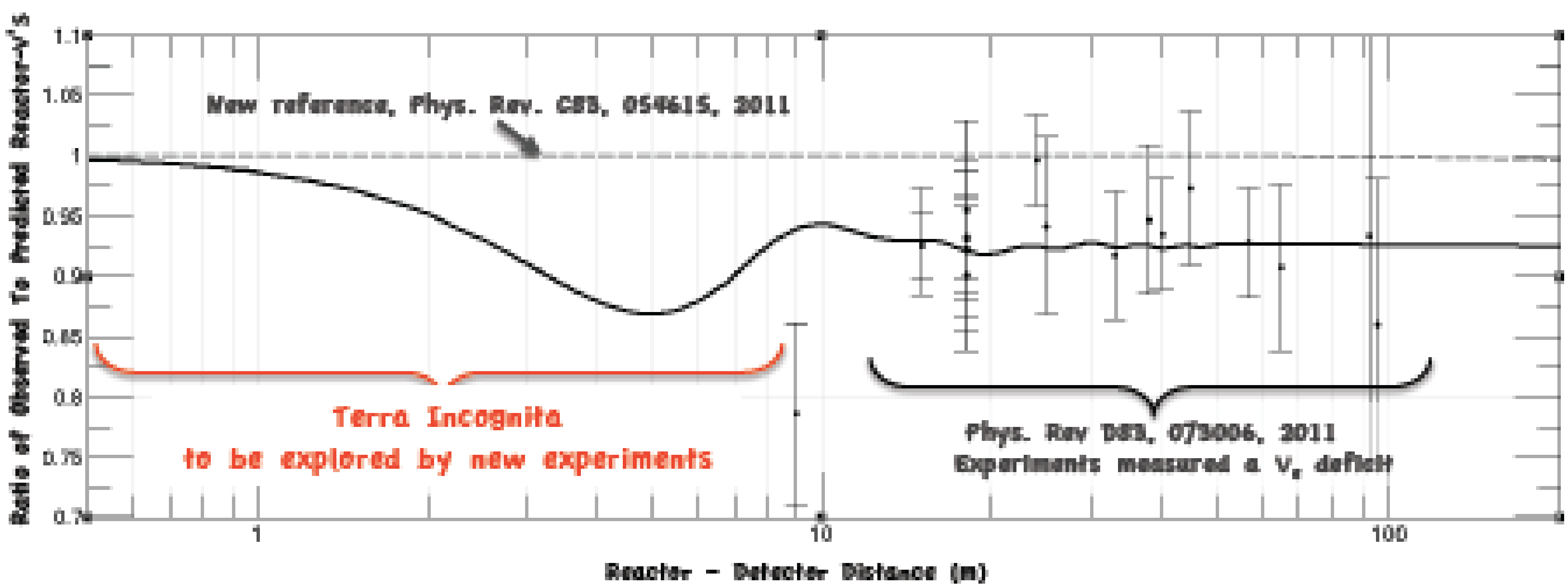
- **Recent re-analysis of 19 reactor neutrino results**
  - Neutron life time correction & Off-equilibrium effects
  - Phys. Rev. D83, 073006, 2011
  - **μ = 0.943±0.023** (2.5 sigma effect)

- **At least three alternatives:**
  - Wrong prediction of ν-spectra ?
  - Bias in all experiments ?
  - New physics at short baselines: Mixing with 4th ν-state

Improved reactor neutrino spectra

- Re-evaluation of IBD cross sections (neutron lifetime updated)
- Include long lived radioisotopes in reactors

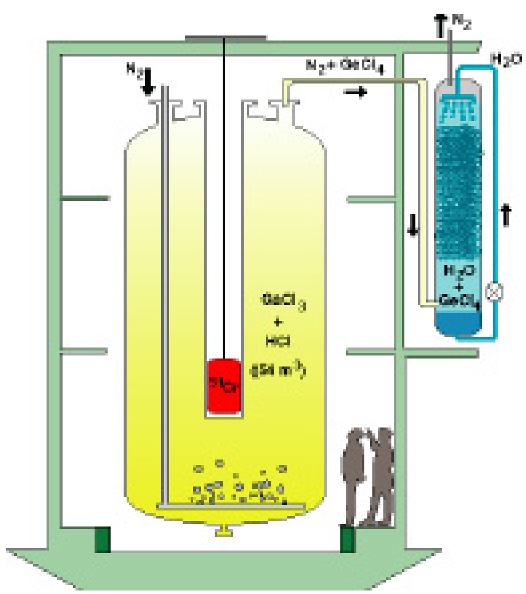
Observed/Predicted averaged event ratio = 0.927 ± 0.023 (~3 σ)

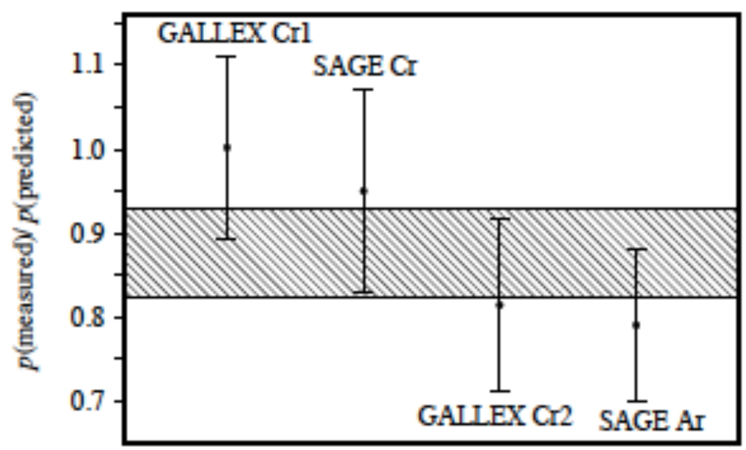


T. Lasserre

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)



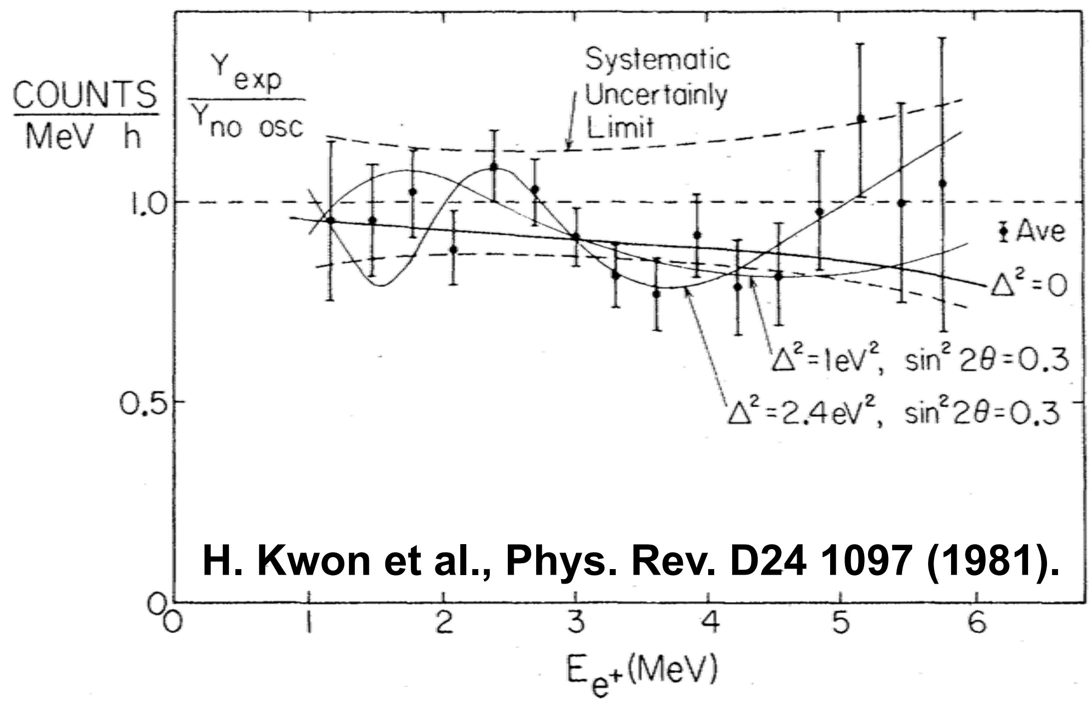


R=0.86+-0.05
(observed/predicted rate)

The 1981 ILL Grenoble neutrino experiment

- **ILL Reactor : pure ^{235}U ; Compact core ; Detector at 8.8 m**

- Reanalysis in 1995 by part of the collaboration to account for overestimation of flux at ILL reactor by 10%... Affects the rate only



H. Kwon et al., Phys. Rev. D24 1097 (1981).

- Large errors, but a striking pattern is seen by eye ?

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

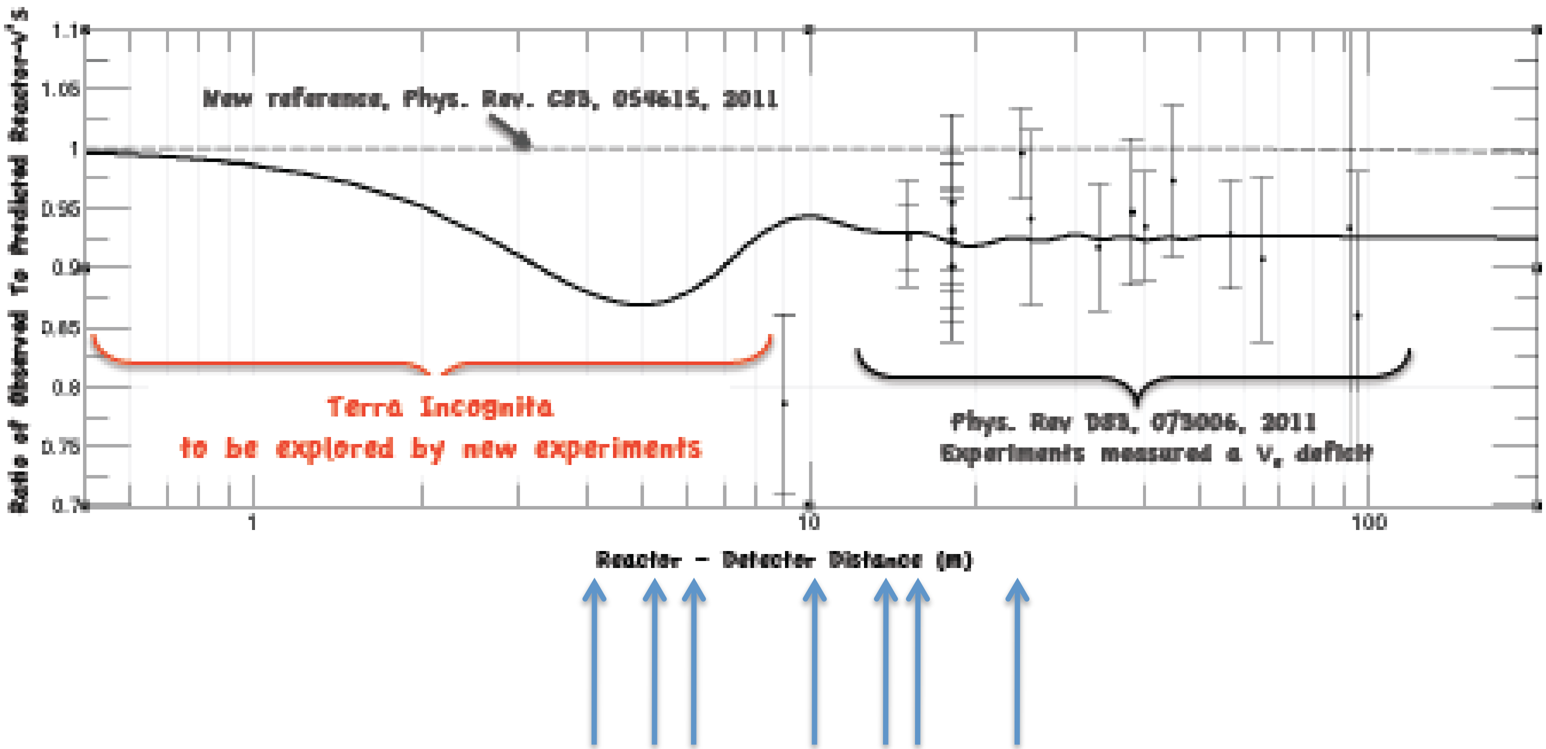
Anomaly	Type	Channel	Significace
LSND	DAR	vbar CC	3.8σ
MiniBooNE	SBL Accelerator	ν CC	3.0σ
MiniBooNE	SBL Accelerator	vbar CC	1.7σ
Gallium/Sage	Source –e capture	ν CC	2.7σ
Reactor	Beta-decay	vbar	3.0σ

- 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

Pursue both…

Reactor experiments to search for sterile neutrino….

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

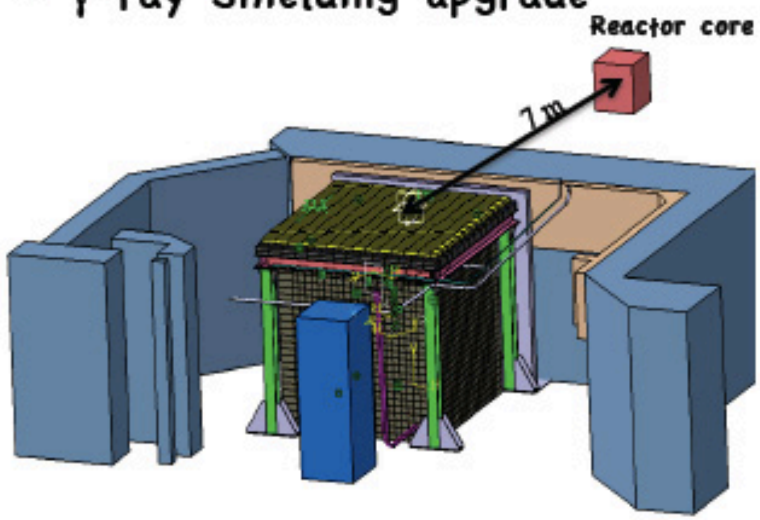


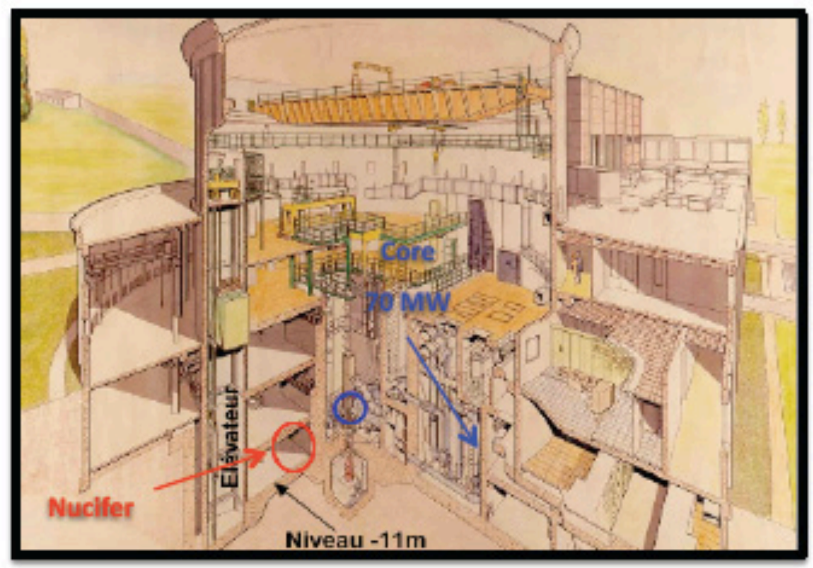
Reactor experiments probe "Terra Incognita"
and look for indication of oscillations……

Nucifer, Osiris (Saclay)

- First goal: Non Proliferation: P_{th} & Fuel Composition U/Pu
- **Osiris Site in Saclay**
  - 70 MW Research reactor, size: 57x57x60 cm
  - Detector Size : 1.2x0.7m (850l)
  - Shallow Depth: 5 m.w.e
  - <L>=7.0±0.3 m → highgamma ray flux

  } challenging environment
- **Status: start taking data - Commissioning**
  - Scintillator upgrade
  - γ-ray Shielding upgrade





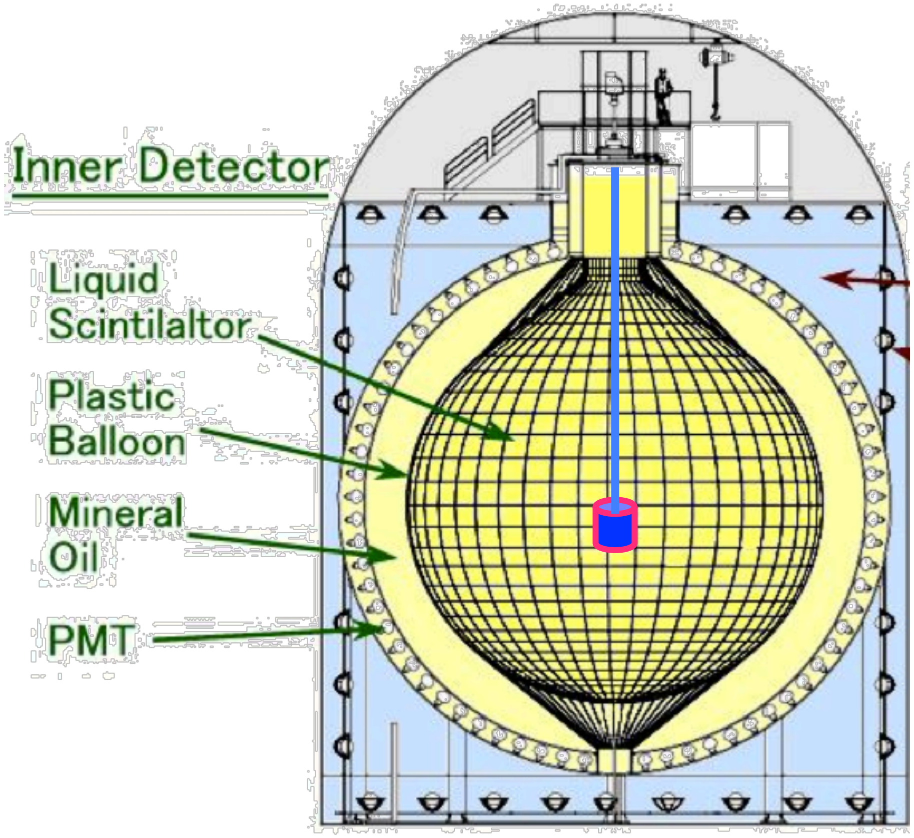
Th. Lasserre - CERN - 05/2012

Source Experiments

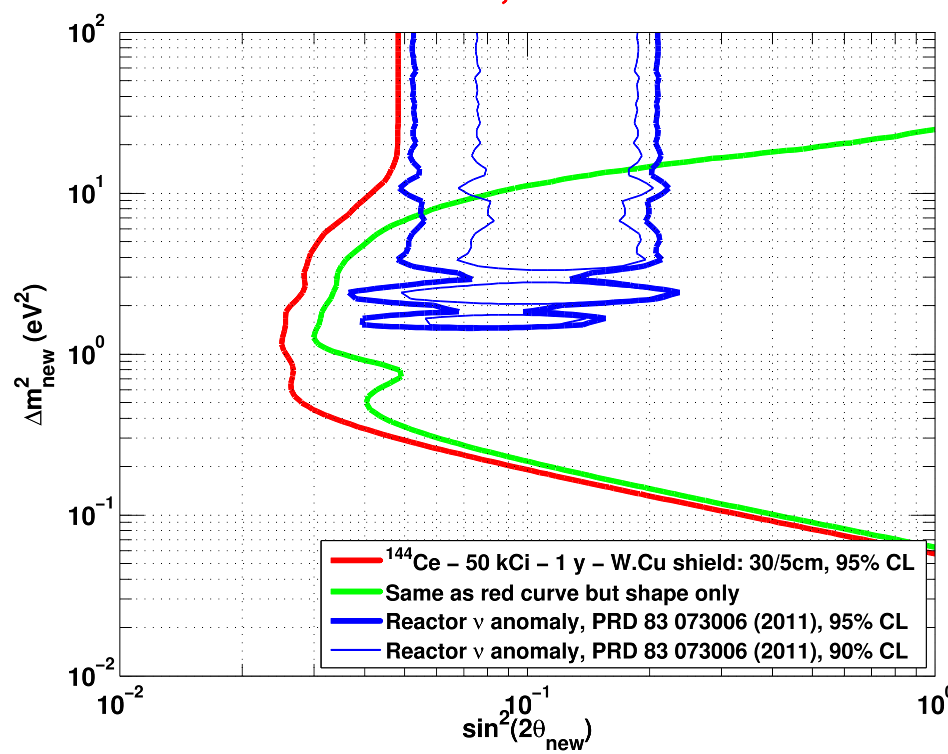
Species	Source	Experiment	Status
ν_e	^{51}Cr	Baksan	Proposal
ν_e	^{51}Cr	LENS	Proposal
ν_e	^{51}Cr	Borexino	Proposal
ν_e	^{51}Cr	SNO+	Proposal
ν_e	^{37}Ar	Richochet	Proposal
$\bar{\nu}_e$	^{144}Ce	CeLAND	Proposal
$\bar{\nu}_e$	^{144}Ce	Daya-Bay	Proposal

A ^{144}Ce kCi Anti-neutrino Source Experiment

- A 50 kCi anti-ν source (10 g of ^{144}Ce) in the middle of a large LS detector
- Inside a thick 35 cm W-Cu shielding → background free
- Energy-dependent oscillating pattern in event spatial distribution



M. Cribier, M Fechner, T. Lasserre, et al. arXiv:1107.2335, 95%CL contours

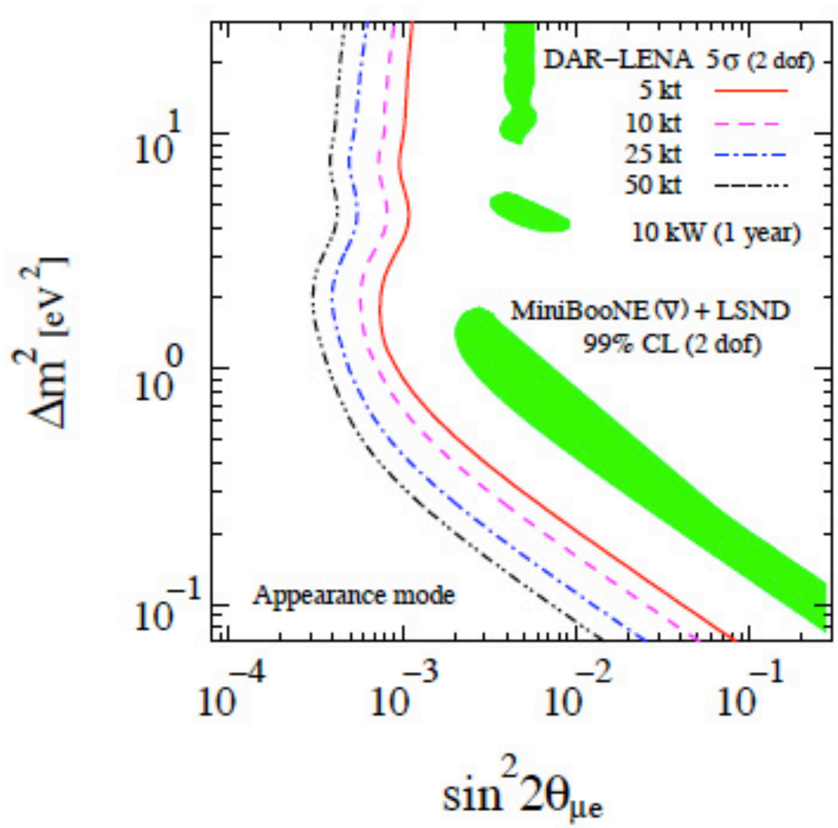


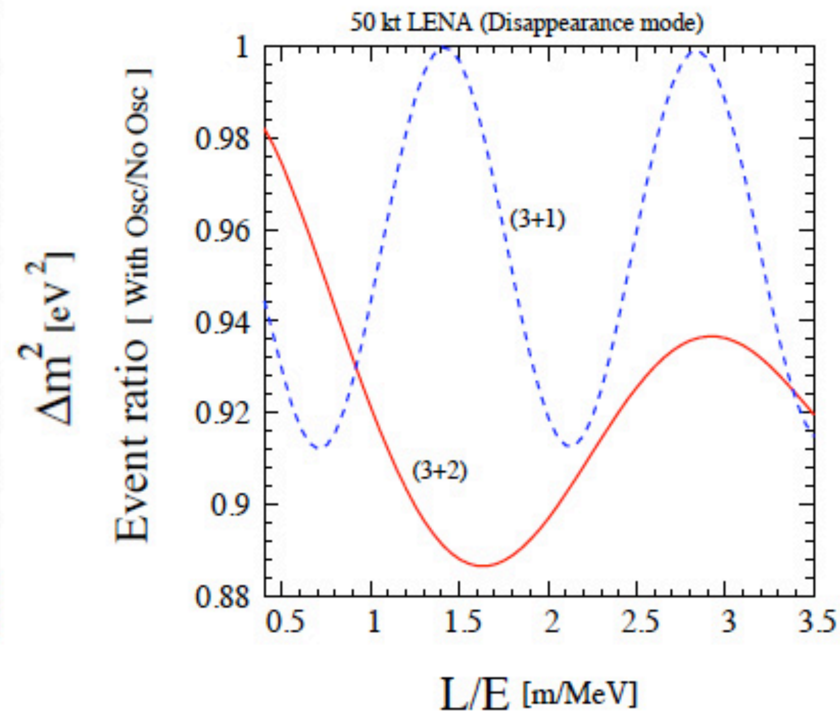
Detectors which could be used for this idea include Kamland, SNO+, or Borexino…

OscSNS

- Spallation neutron source at ORNL
- 1GeV protons on Hg target (1.4MW)
- Free source of neutrinos
- Well understood flux of neutrinos
- Can repeat the LSND measurement at ~5 sigma in one year!

Stopped DAR cyclotron beam to look for oscillations (both electron anti-neutrino appearance and electron neutrino disappearance) over meters using liquid scintillator based detectors (NOvA or LENA)





See variations in L/E in the detector
Differentiate between sterile neutrino models

arXiv:1105.4984 [hep-ph]

Accelerator based experiments:

At FNAL:

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

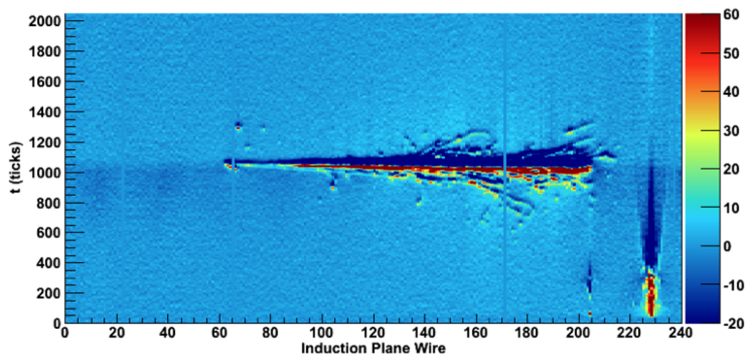
At CERN

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

The MicroBooNE experiment

Capability to resolve particle interactions: reduce backgrounds, identify and improve signal

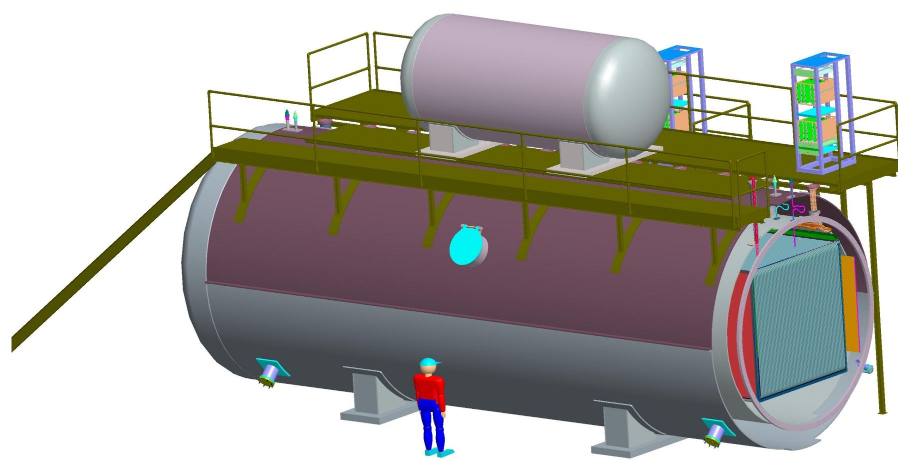
Liquid Argon Time Projection Chamber



Use topology and dE/dx to differentiate electrons (signal) from gammas (background) indistinguishable in Cerenkov imaging detectors

Electron neutrino candidate from ArgoNeuT

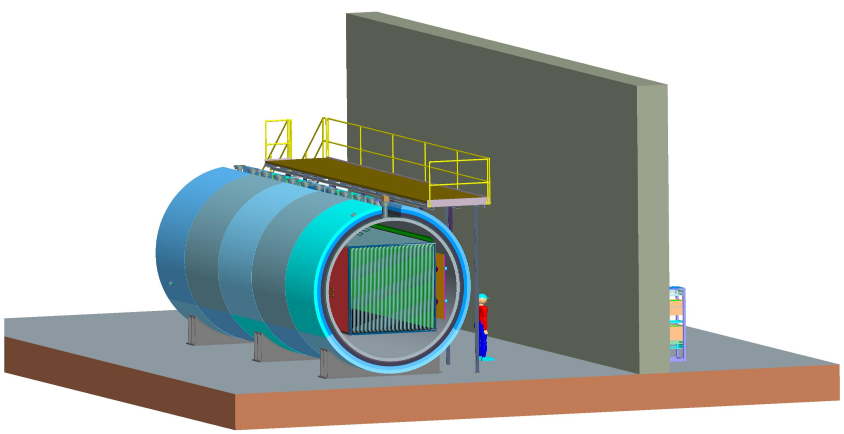
LArTPC detector to address the MiniBooNE low energy excess and measure a suite of low energy neutrino cross sections



Physics and Development Goals

MicroBooNE Physics

- MiniBooNE low energy excess
- Suite of low energy cross section measurements

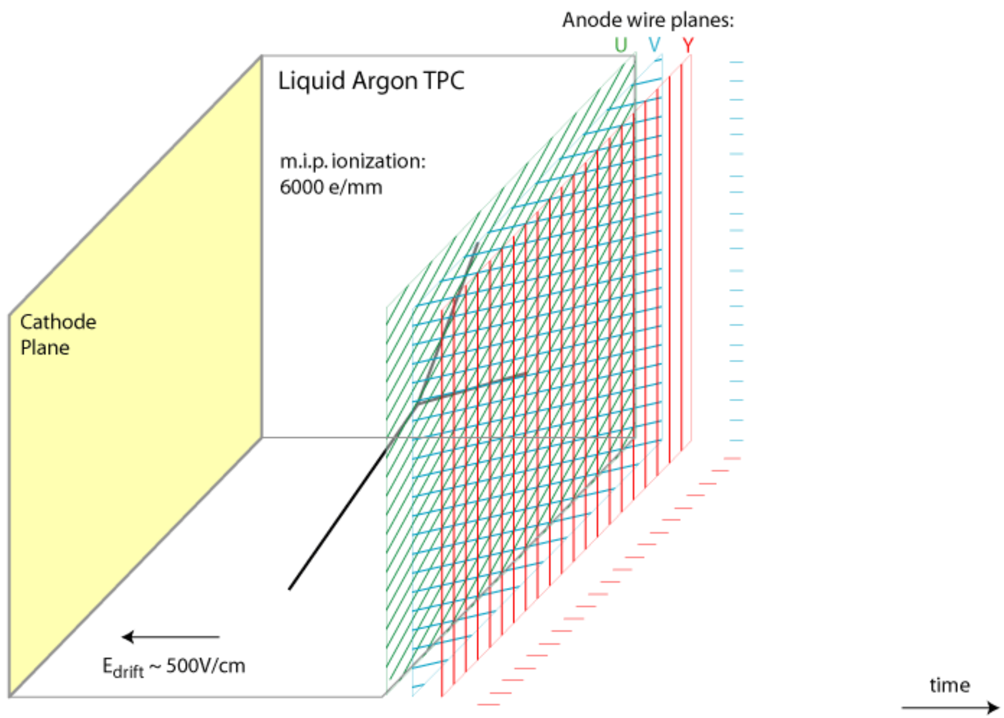


MicroBooNE LAr TPC Development Goals

- Demonstrate photon – electron identification
- Develop cold electronics
  - Implementation of cold CMOS electronics in Liquid Argon
- Purity: Test of GAr purge in large, fully instrumented vessel
- Refine sensitivity estimates for next generation detectors
- Test ability to run on/near surface for proton decay
- Develop tools for analysis
- Develop cost scaling model for larger detectors

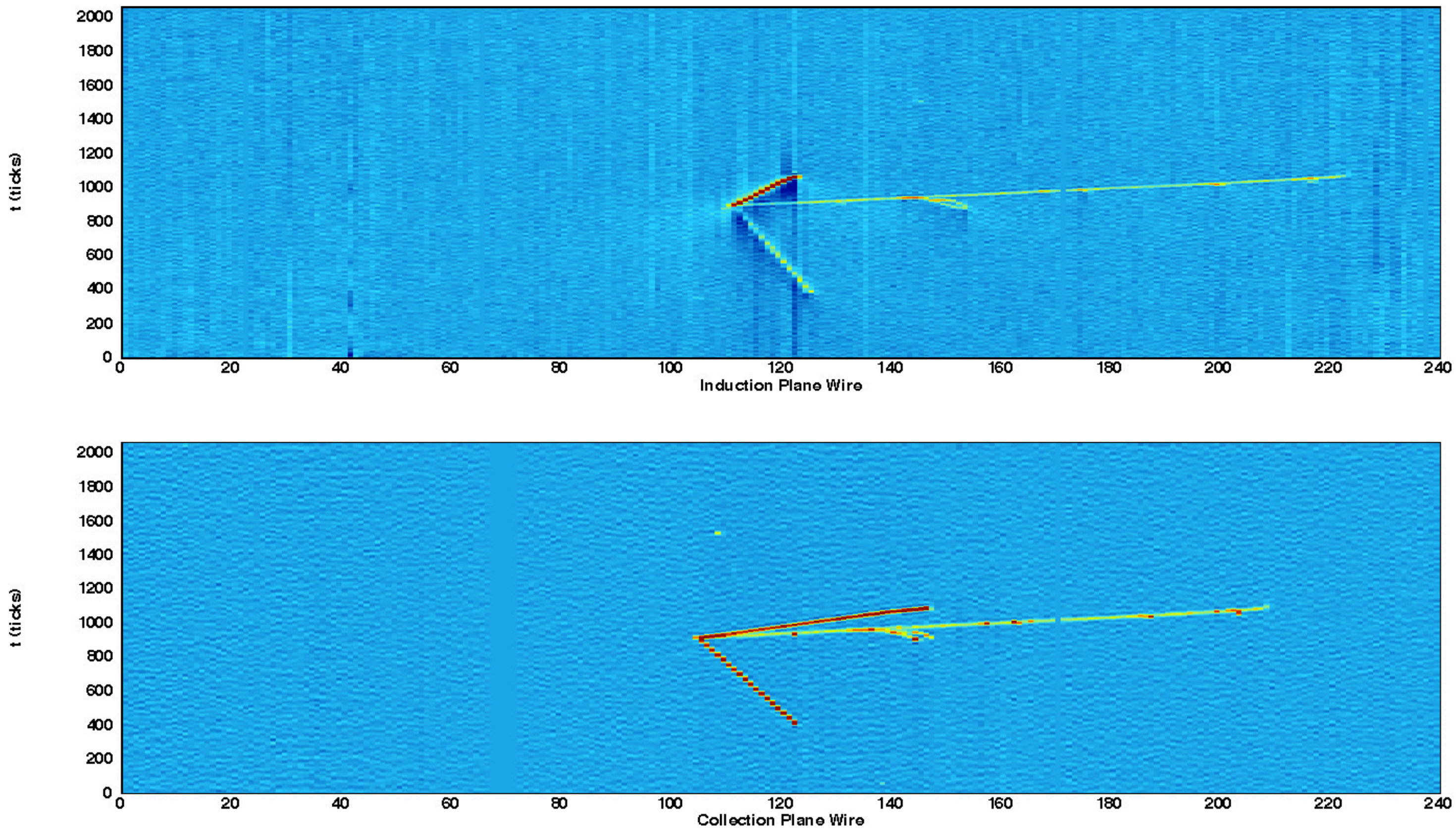
General Description: LArTPCs

- Passing charged particles ionize Argon
- Electric fields drift electrons meters to wire chamber planes
- Induction/Collection planes image charge, record dE/dx

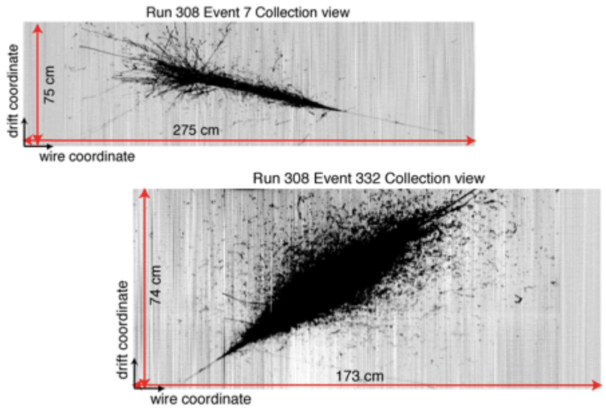


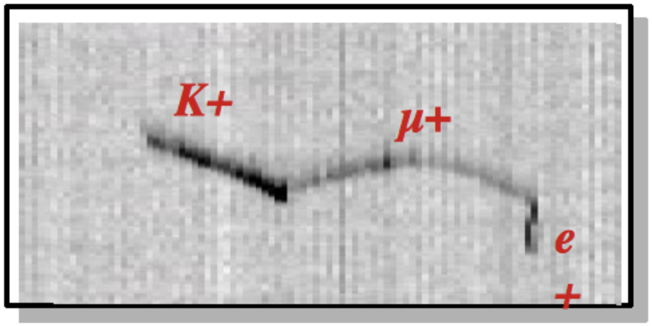
General Description: LArTPCs

ArgoNeuT candidate neutrino interactions

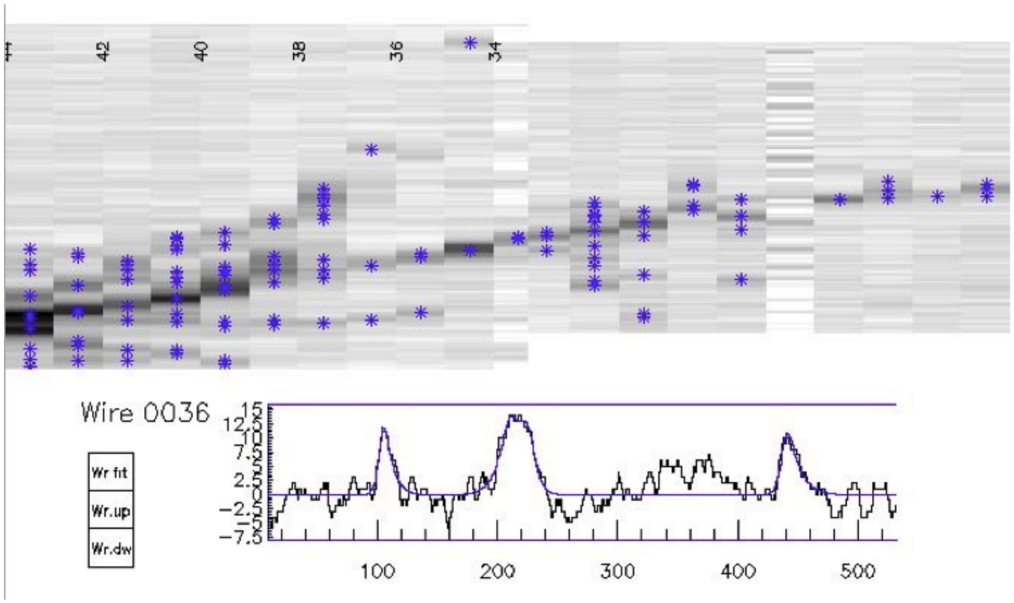


Particles in LArTPCs





T300 data from ICARUS test run 2001



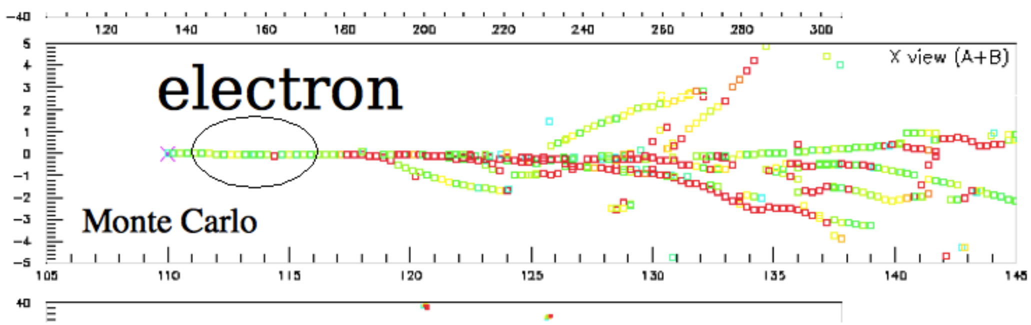
Hadronic shower from Yale TPC run, April 2007

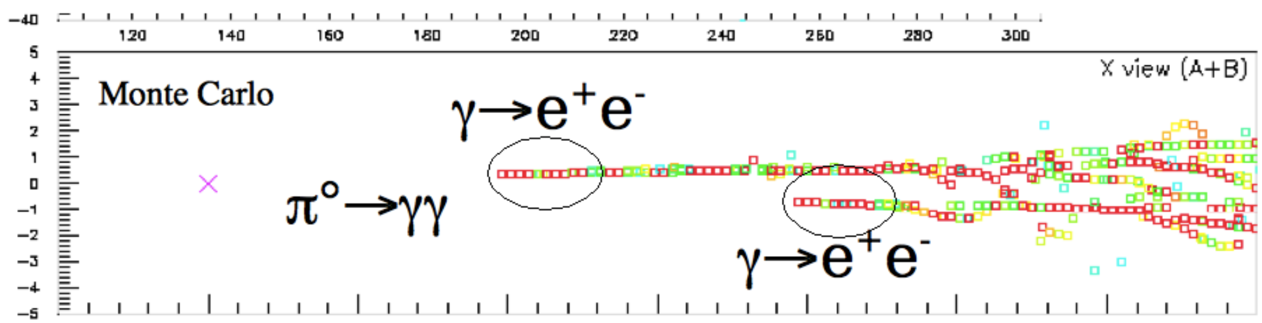
Achieve 80-90% efficiency for electron neutrino interactions

→ Use topology to differentiate event classes

LArTPCs image events and collect charge
Separates electrons from backgrounds with → γs
do e/γ separation via dE/dx

look in first couple cm of track before shower begins





Where electrons deposit
1 MIP = green
(MIP = minimum ionizing particle)

$\gamma \to e^+e^-$ deposit
2 MIPs = red

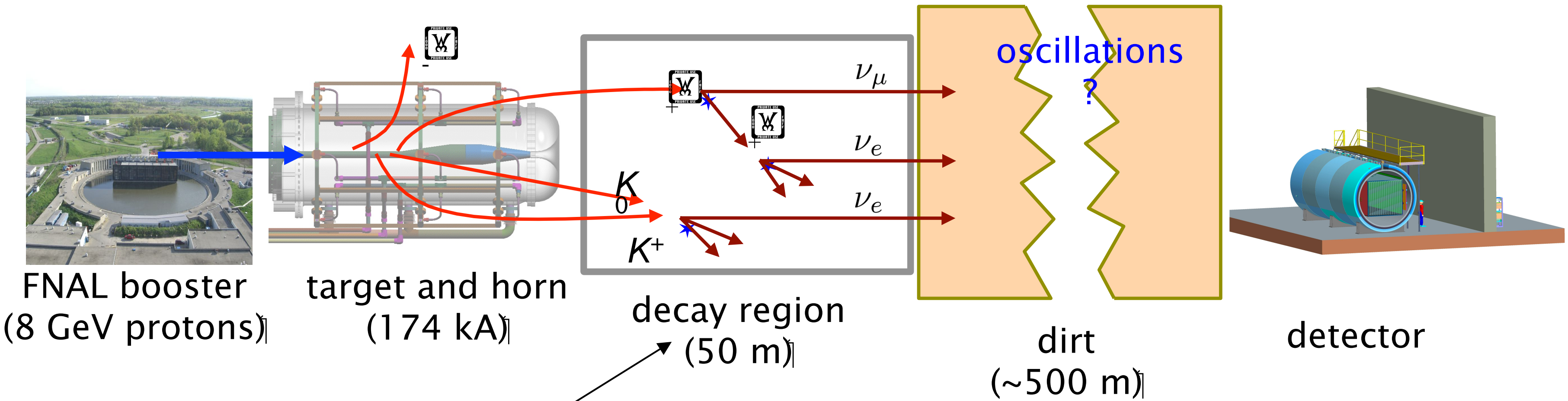
Collaboration

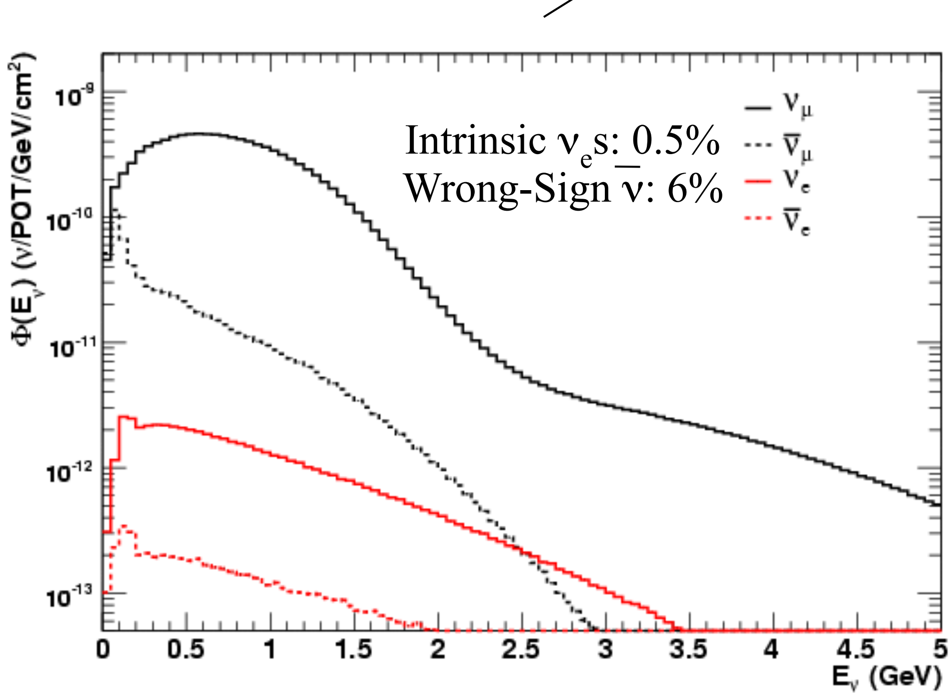
- *Brookhaven Lab*: H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowiecki, J. Mead, V. Radeka, S. Rescia, J. Sondericker, C. Thorn, B. Yu
- *Columbia University*: L. Camilleri, R. Carr, G. Cheng, G. Karagiorgi, C. Mariani, B. Seligman, M. Shaevitz, B. Willis**, B. Sippach, C. Chi
- *FermiLab*: B. Baller, C. James, H. Jostlein, S. Pordes, G. Rameika, J. Raaf, B. Rebel, R. Schmitt, D. Schmitz, J. Wu, G. Zeller*
- *Kansas State University*: T. Bolton, G. Horton-Smith, D. McKee
- *Los Alamos Lab*: G. Garvey, J. Gonzales, B. Louis, C. Mauger, G. Mills, Z. Pavlovic, R. Van de Water, H. White
- *Massachusetts Institute of Technology*: W. Barletta, L. Bugel, J. Conrad, C. Ignarra, B. Jones, T. Katori, T. Smidt, A. Prakash
- *Michigan State University*: C. Bromberg, D. Edmunds
- *Princeton University*: K. McDonald, C. Lu, Q. He
- *St. Marys*: P. Nienaber
- *Syracuse University: M. Soderberg*
- *University of Bern: A. Ereditato, I. Kreslo, M. Weber*
- *University of Cincinnati*: R. Johnson
- *University of Texas at Austin*: S. Kopp, K. Lang
- *Yale University*: C. Brasco, F. Cavanna, E. Church, B. T. Fleming*, R. Guenette, K. Partyka, A. Szelc, E. Klein, J. Lozier, O. Palmara

14 institutions
~75 collaborators
NSF funded/DOE funded

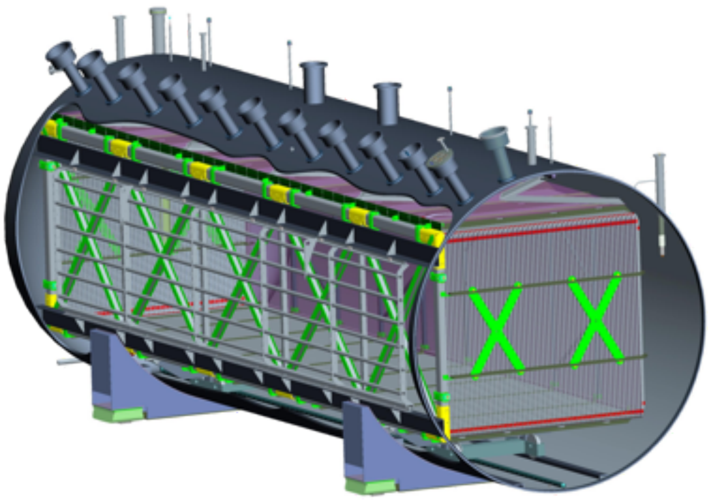
*=Spokespersons

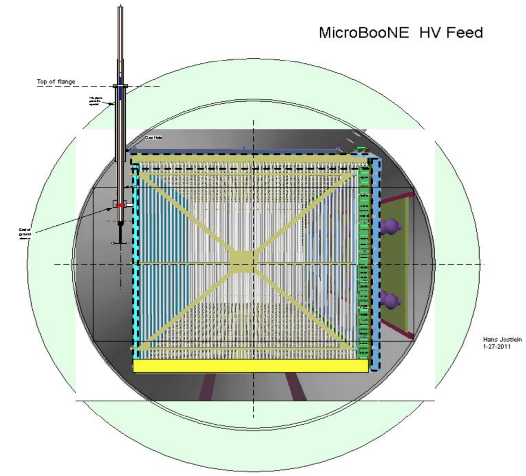
MicroBooNE:

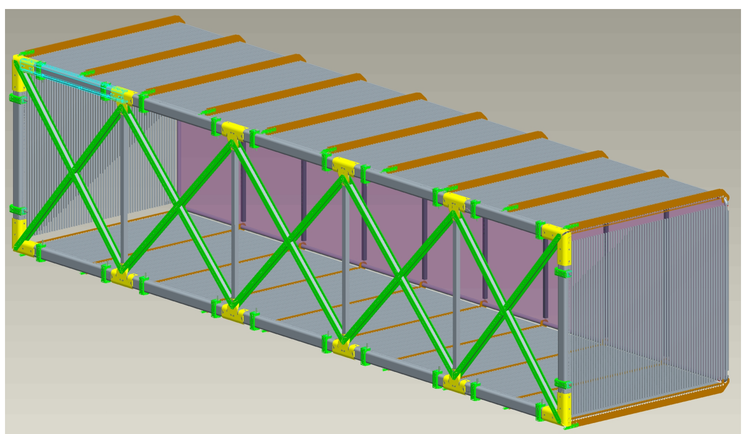




- •Detector positioned in (nearly) the same place as MiniBooNE
- •Observe same neutrino flux in which MiniBooNE observed the low energy excess
- •Differentiate excess as electrons or photons







Field cage, anode and cathode planes

- Beam on view of TPC.
- Ionization electrons drifted to beam right through wire chamber planes
- HV on cathode plane at beam left

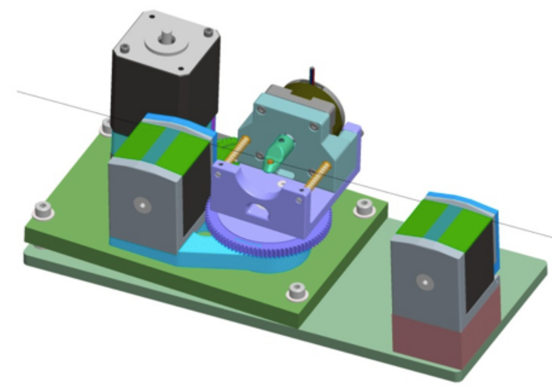
Liquid Argon Test Facility at Fermilab

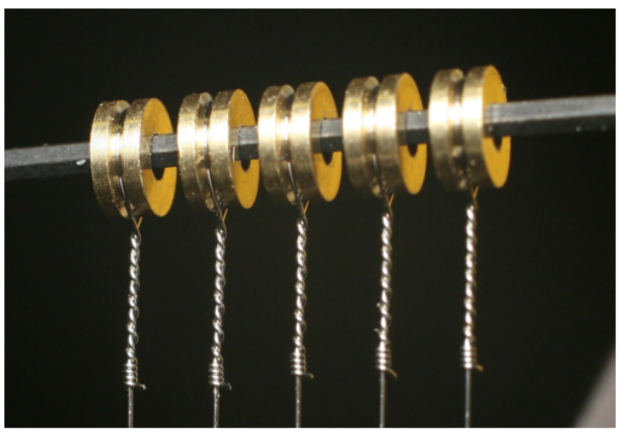
Beginning of March
Beginning of May

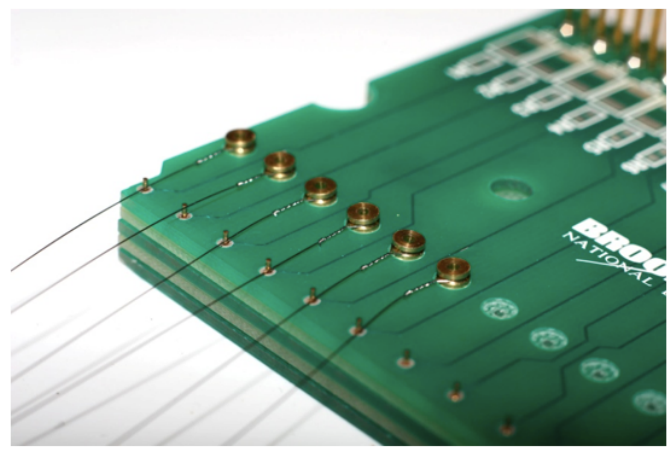
Three wire planes (U,V,Y) readout ionization electrons

- 3mm wire pitch
- Y: vertical, U,V: +/- 60 degrees to Y
- Nominal wire length: Y: 2.5m, U,V: 5m
- 3456 Y wires, 2400 each U,V wires
- Wire material is stainless steel coated with copper and a gold flash: high breakload, low resistance.
- Wire attachment via ferrule attached to wire carrier boards
- Fully automated wire winding machine

Rotating head of the winding machine

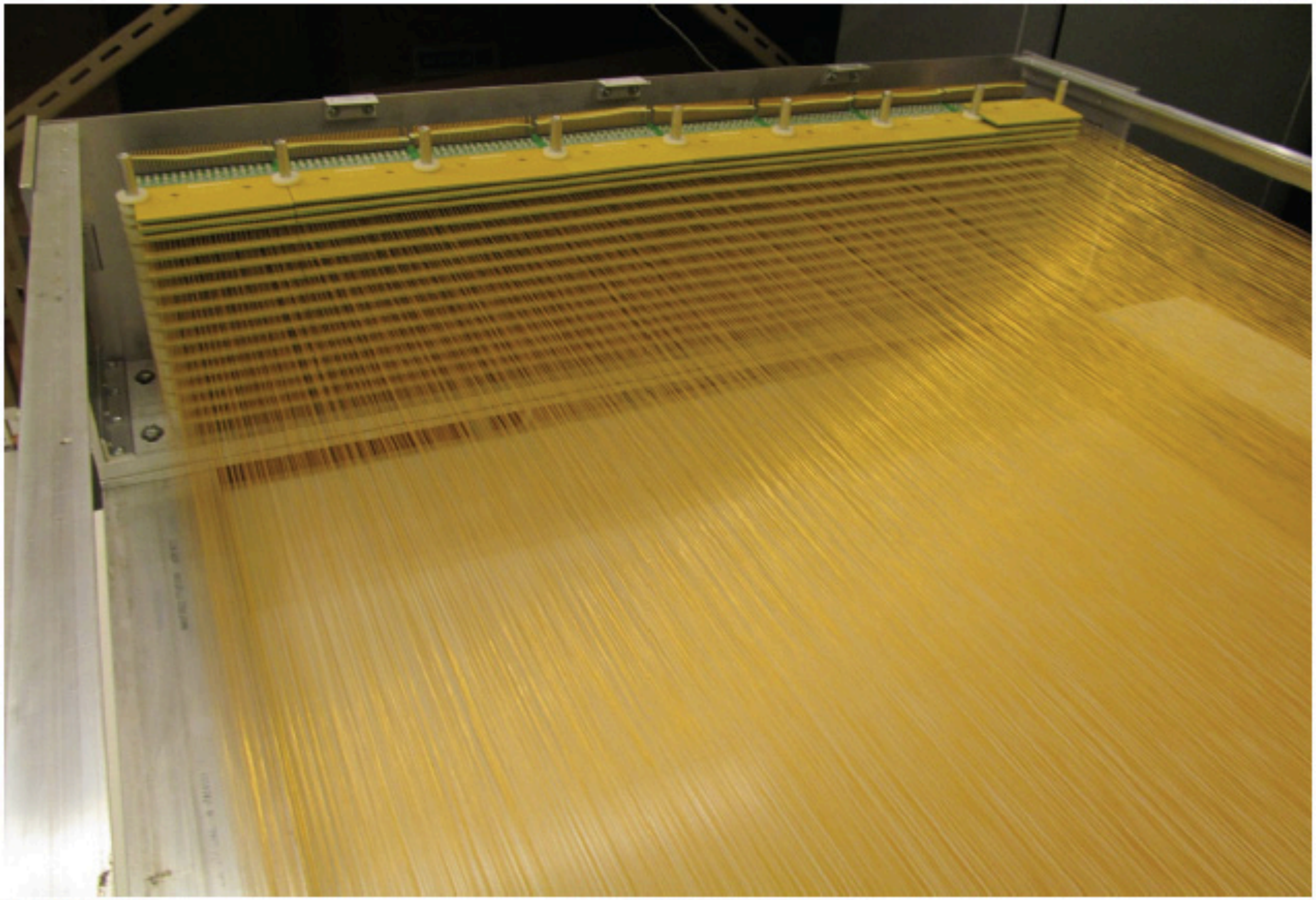






R. Guenette

Wires at Syracuse



R. Guenette

Wire winding machine at Yale

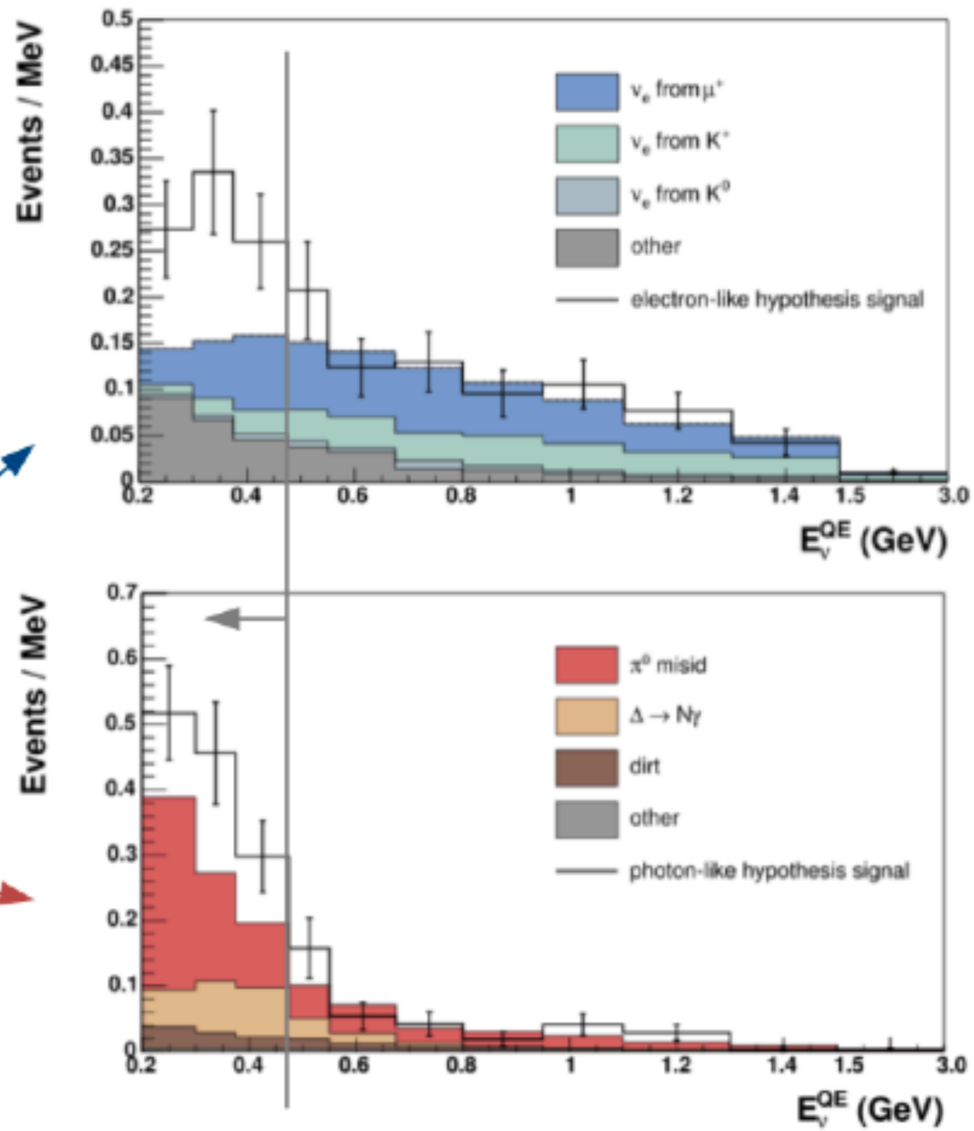
MicroBooNE at 470m on the BNB

MicroBooNE sensitivity to low energy excess:

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

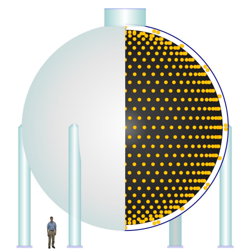
Electron-like hypothesis:
36.8 excess events
41.6 background events
5.7σ stat. significance

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



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:

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

A longer term program of short baseline oscillation physics at Fermilab

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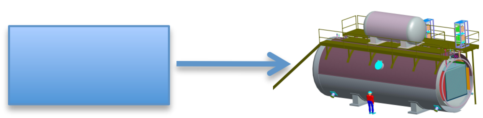
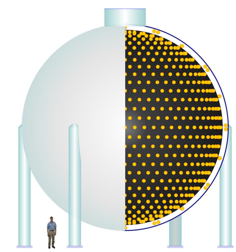
Now •Phase 0: Continued running of MiniBooNE in anti-neutrino mode

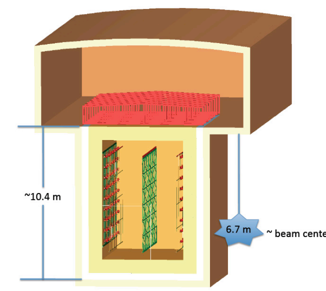
2013 •Phase 1: MicroBooNE run in neutrino mode to address low energy excess

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…

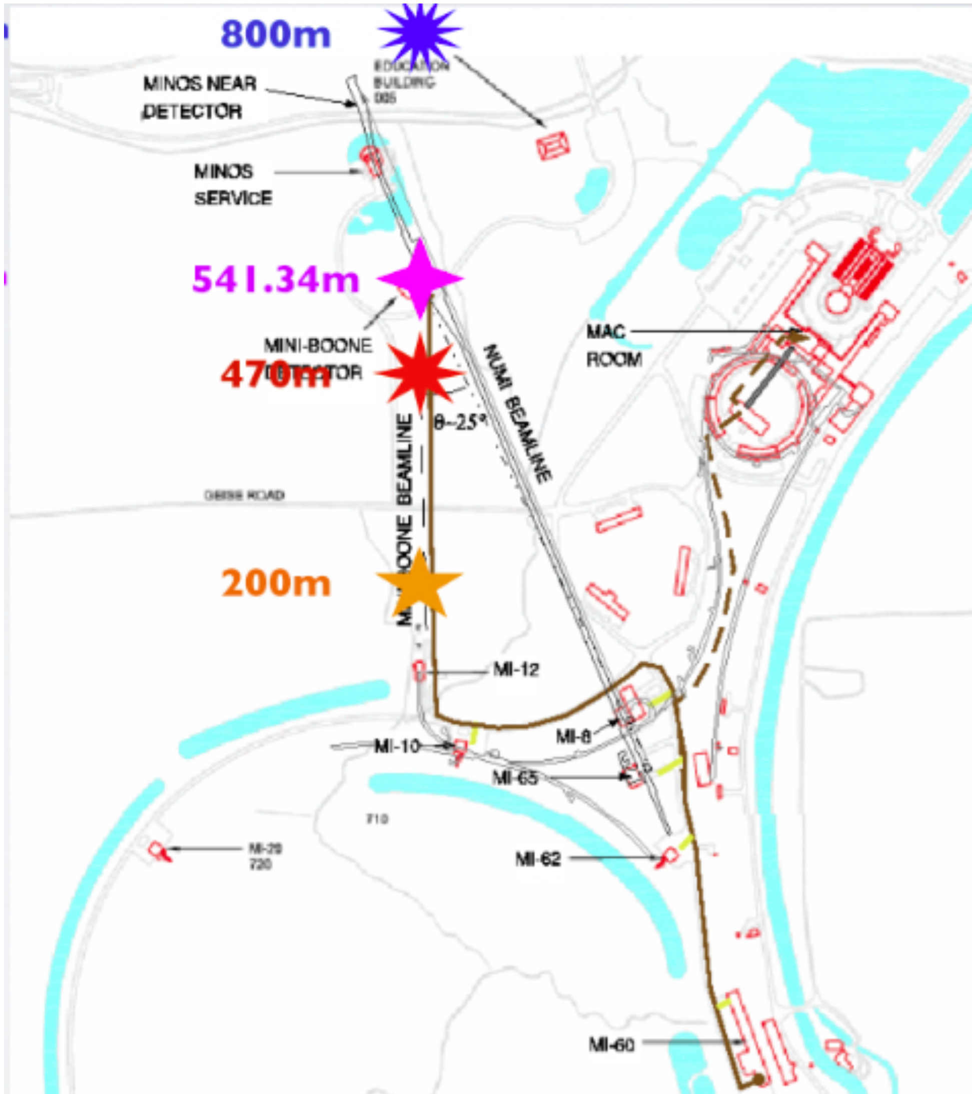
Example:

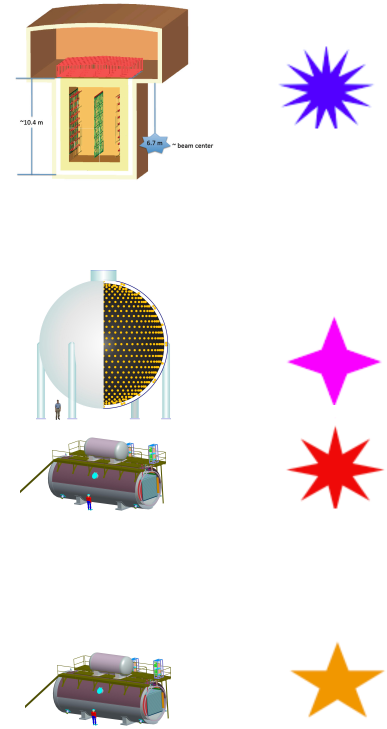
Now •Phase 0: Continued running of MiniBooNE in anti-neutrino mode

2013 •Phase 1: MicroBooNE run in neutrino mode to address low energy excess

201? •Phase 2: Near/Far comparison: MicroBooNE (at 200m) and Large 1kton scale LArTPC address anti-neutrino results (at 700m)

Program on Booster Neutrino Beamline





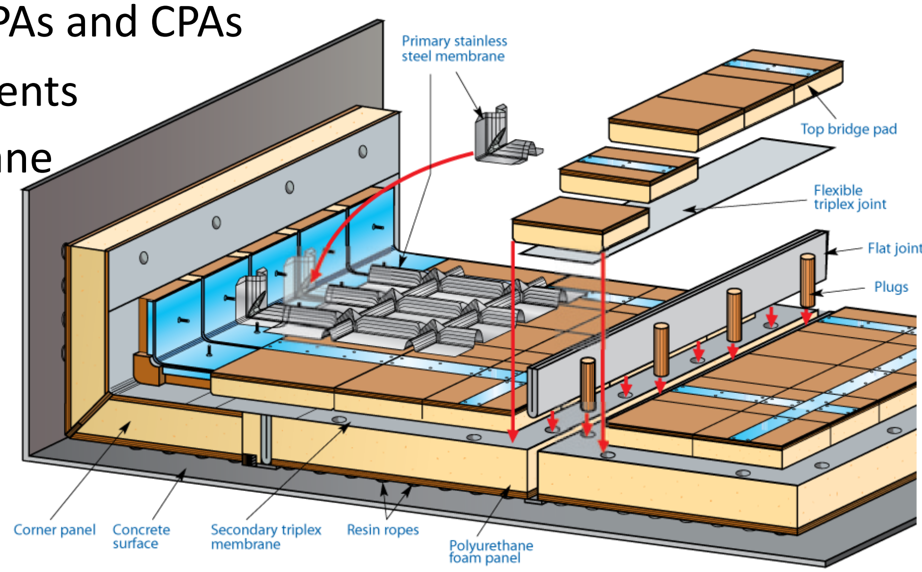
Neutrino Source

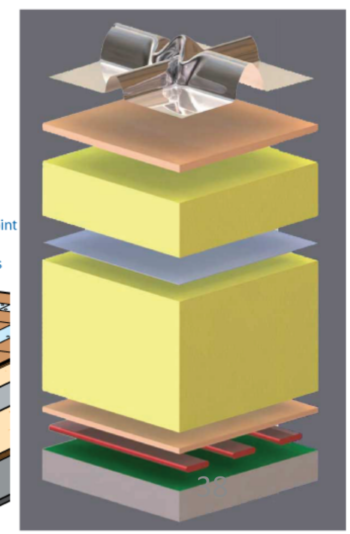
Could also use NUMI Beam at short baselines – LArTPC detectors at 1km(NOvA near detector site) and a new site at about 1.6km

1Kton LAr detector

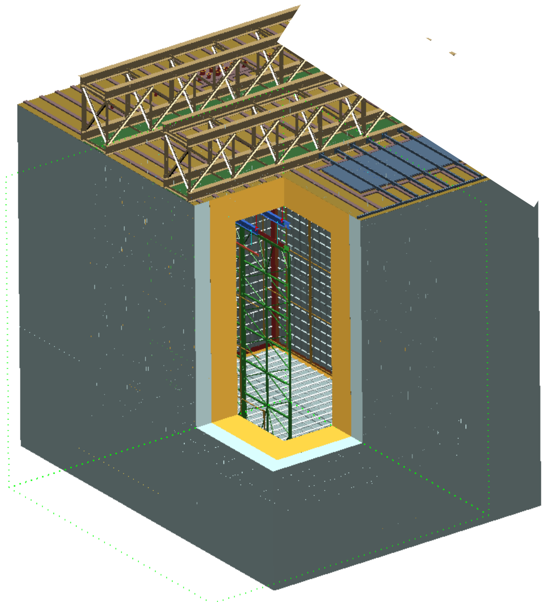
- This 1kton detector will address the anti-neutrino anomalies and serve as an engineering prototype for long baseline program
- The present design is a TPC constructed of an array of modular units:
  - Anode Plane Assemblies (APAs 2.5m wide, 7m high and 10cm thick), which contain the wires and scintillation 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.

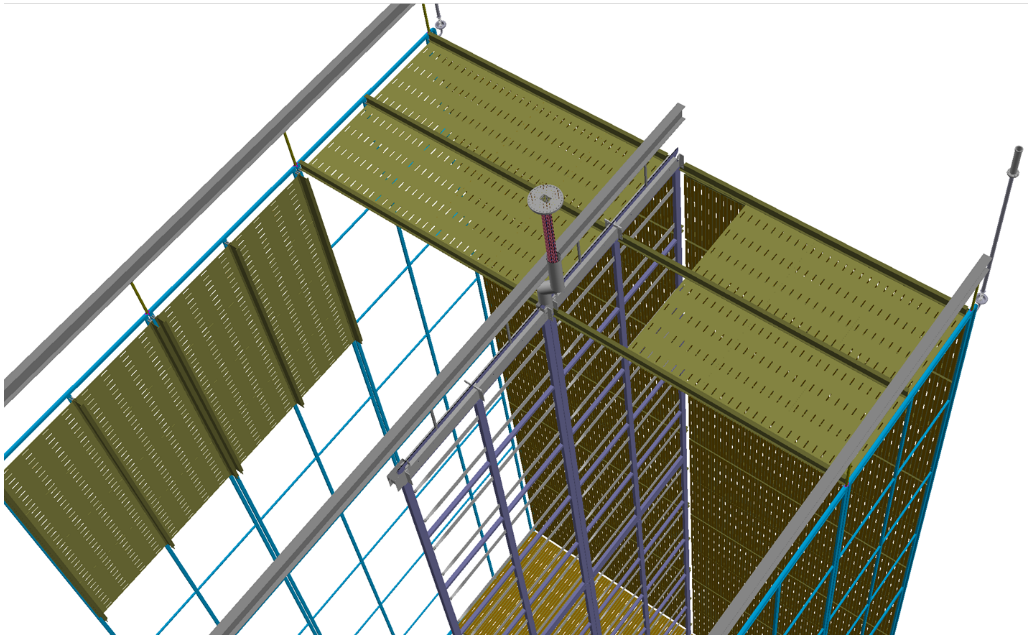




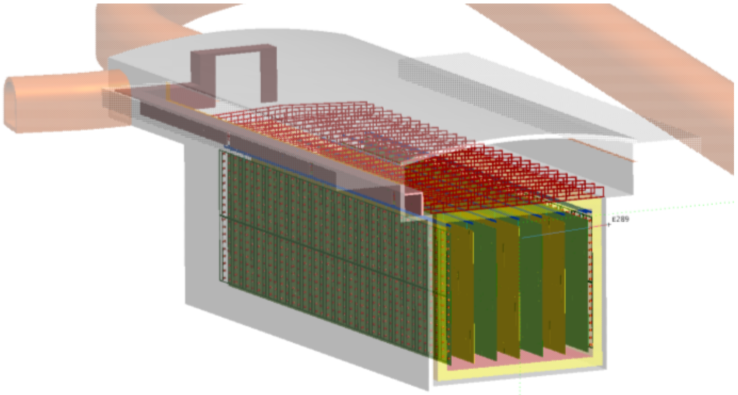
1Kton LAr detector



Membrane cryostat dimensions:
~10m in width, ~11m in height
and ~16m in length



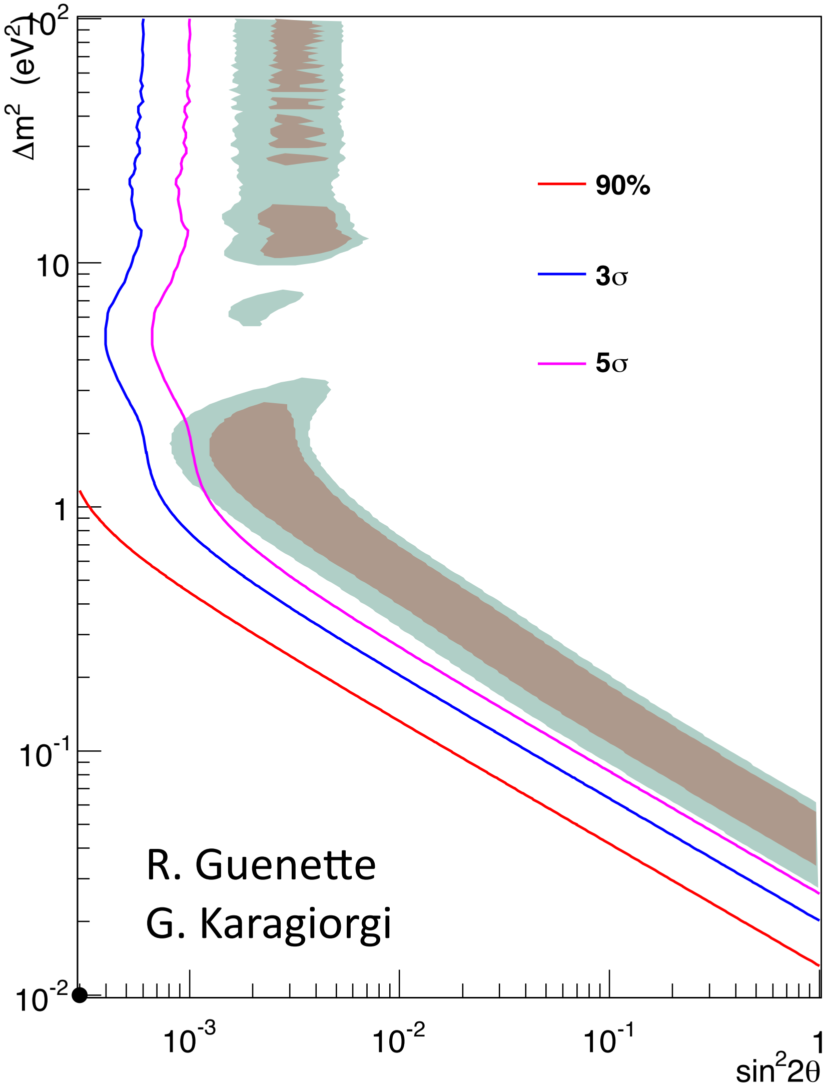
Arrangement of APAs, CPAs, and field cage panels



In addition to the physics program, LAr1 will have a development program serving as the engineering prototype for LArTPCs for long baseline CP Violation Searches (e.g.: LBNE).

LAr1 sensitivity* to MiniBooNE anti-neutrino anomalies

Reference configuration: MicroBooNE at 200m and LAr1 at 700m

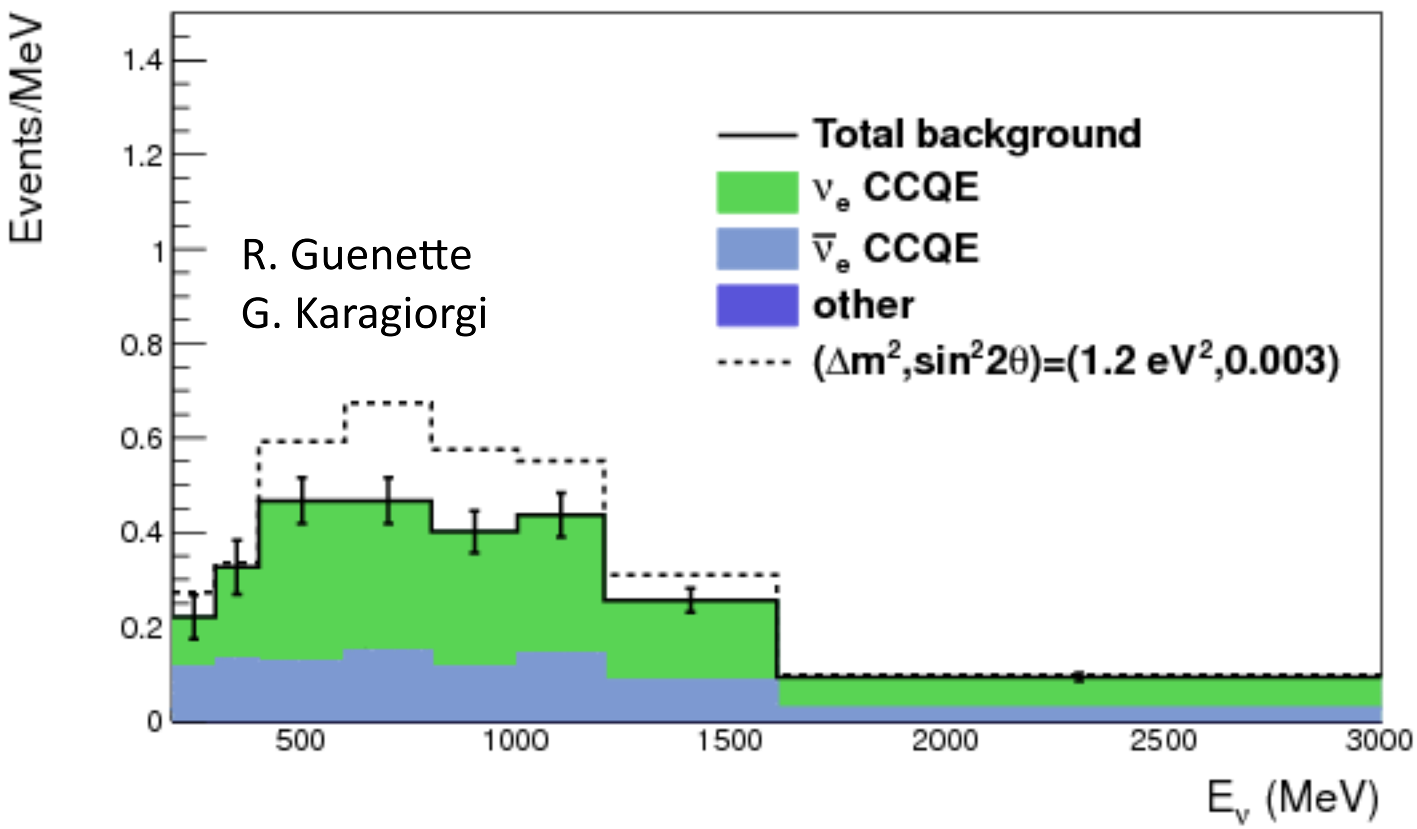


3-5 years with present running conditions

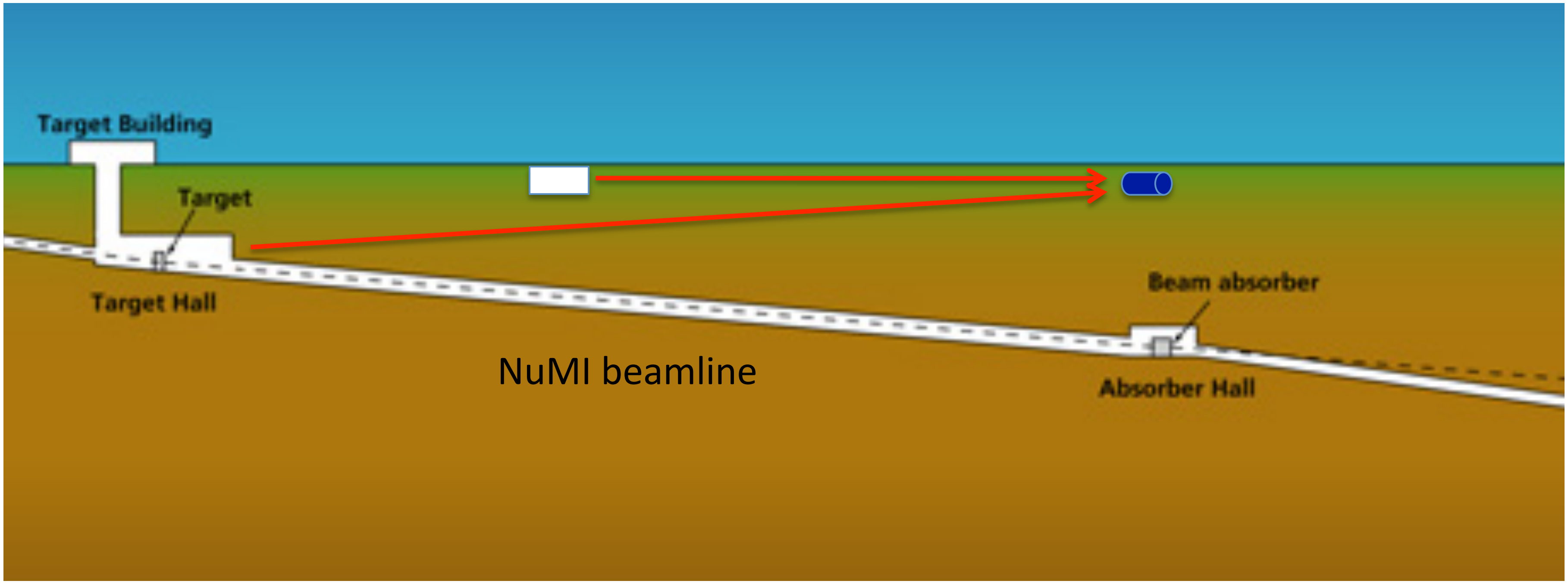
Fiducial volumes assumed for MicroBooNE and Lar1 are 61t and 695t respectively.

* 3+1 neutrino model

Example event excess over background
Total sample of ν_μ interactions = ~150k

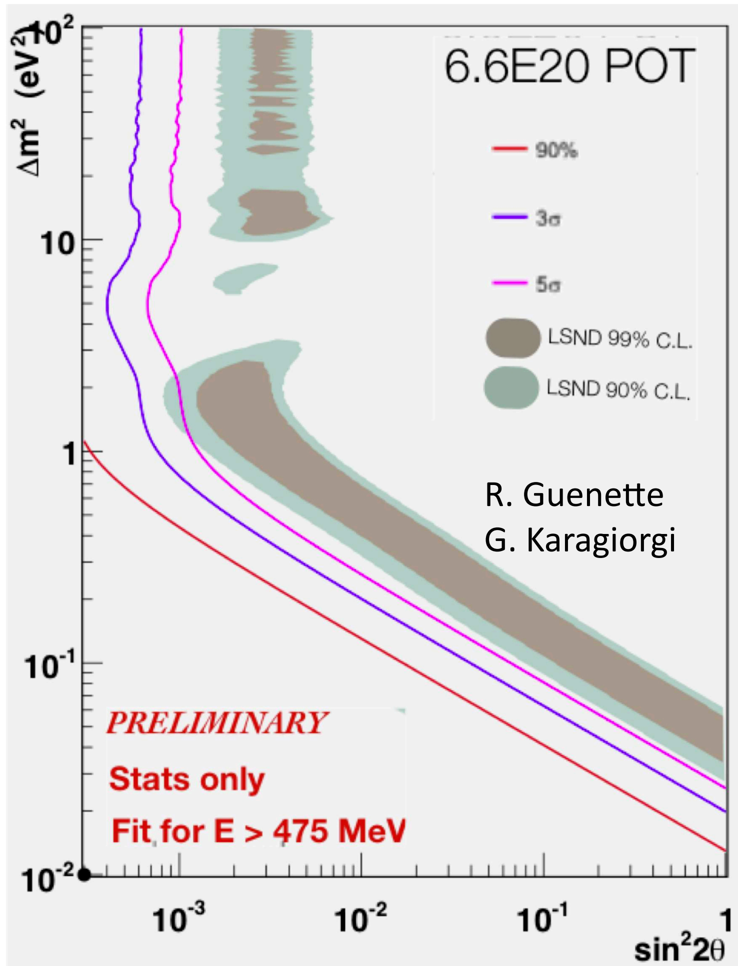


MicroBooNE "sees" both the Booster Neutrino Beam and an off-axis component of the NuMI beam



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

MicroBooNE + LAr1 can also probe neutrino mode oscillations…



Accelerator based experiments:

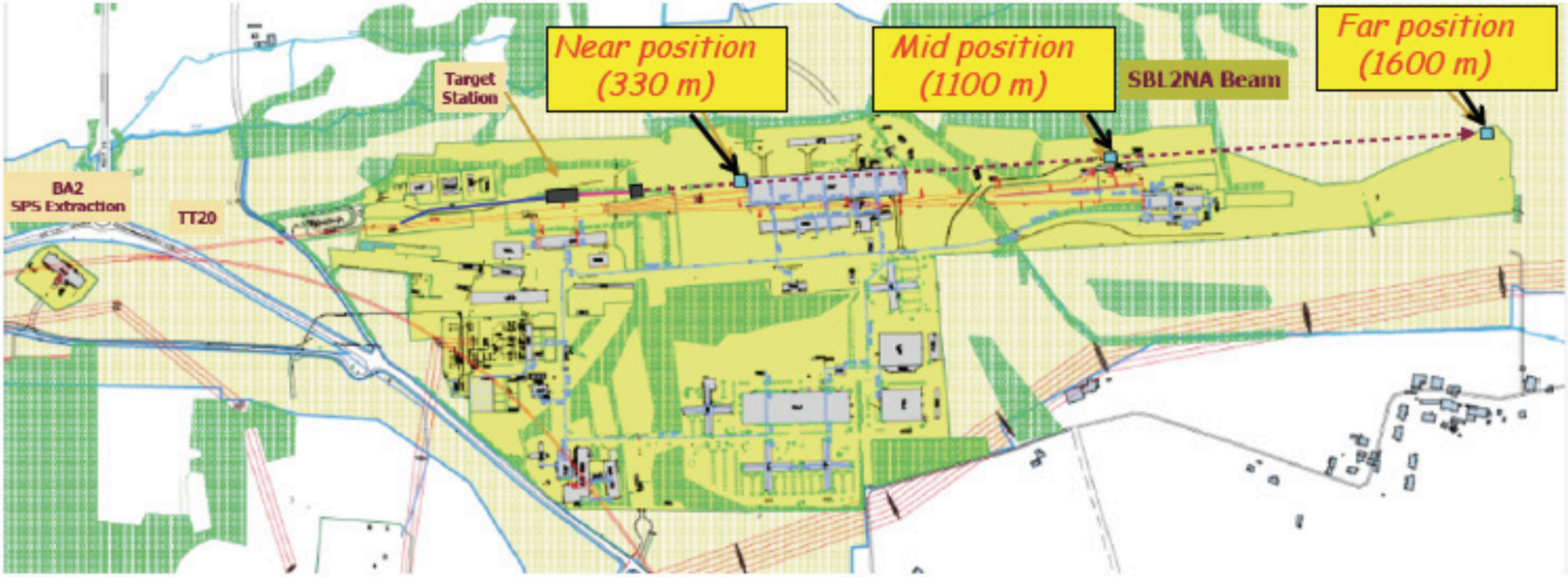
At FNAL:

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

At CERN

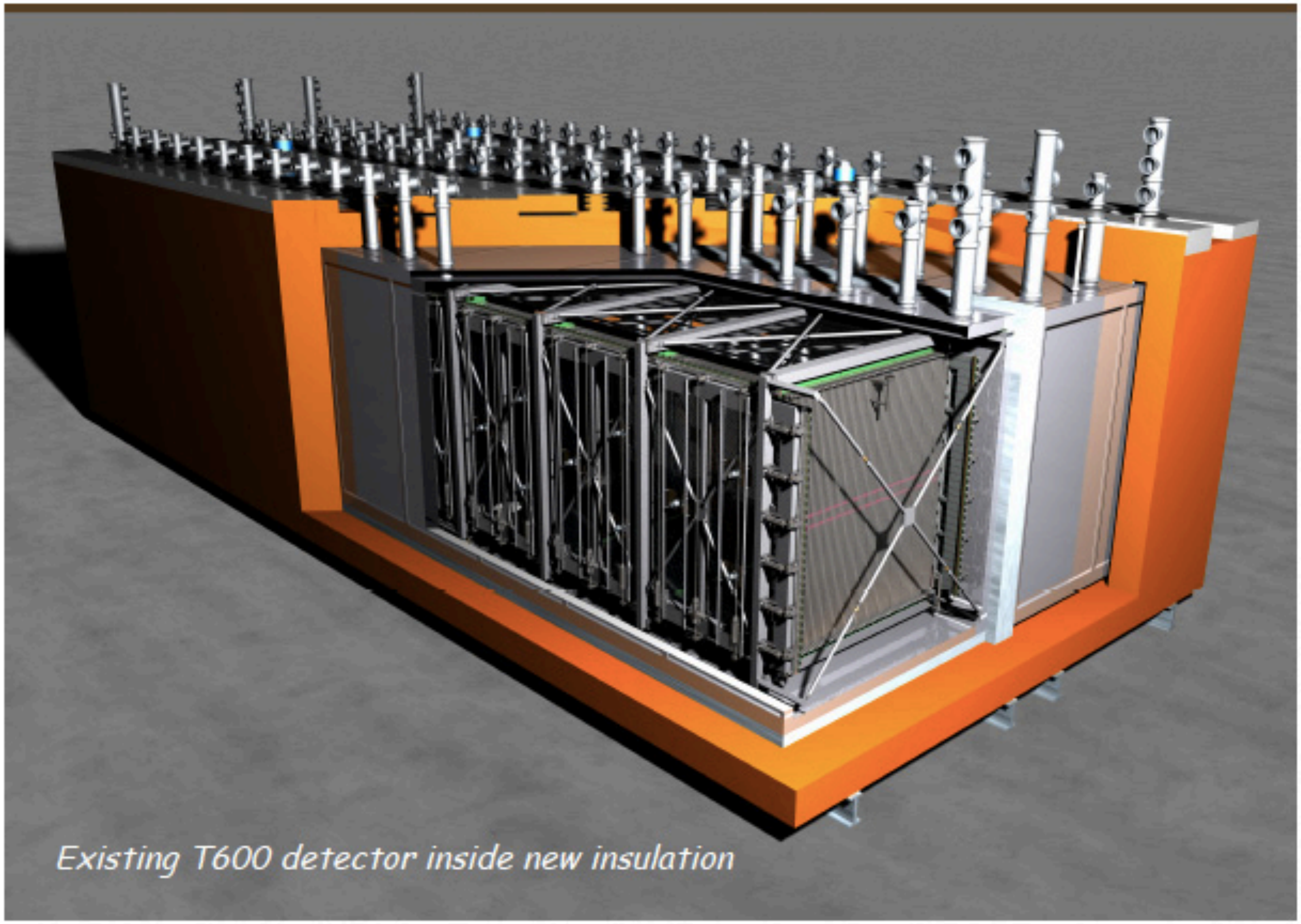
- CERN SPS: two-three detector expt in North Area (proposal)

New Neutrino Facility in the CERN North Area

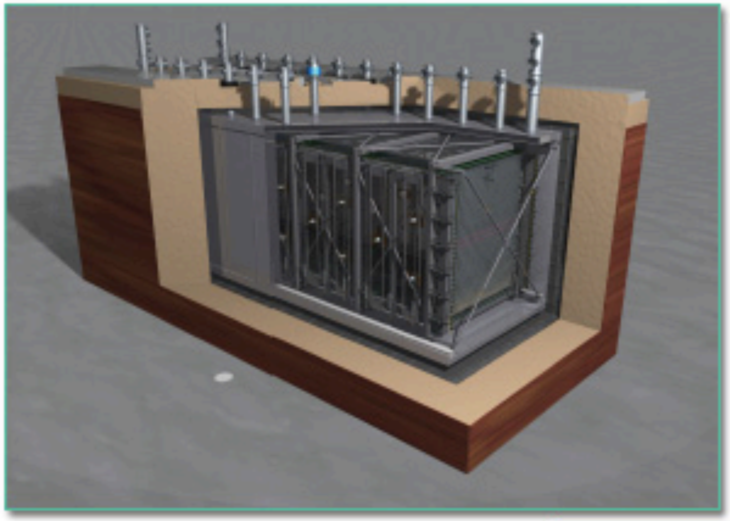


100 GeV primary beam fast extracted from SPS; target station next to TCC2; decay pipe l =100m, ø = 3m; beam dump: 15m of Fe with graphite core, followed by μ stations.
Neutrino beam angle: pointing upwards; at -3m in the far detector ~5mrad slope.

T600 layout in the CERN-SPS

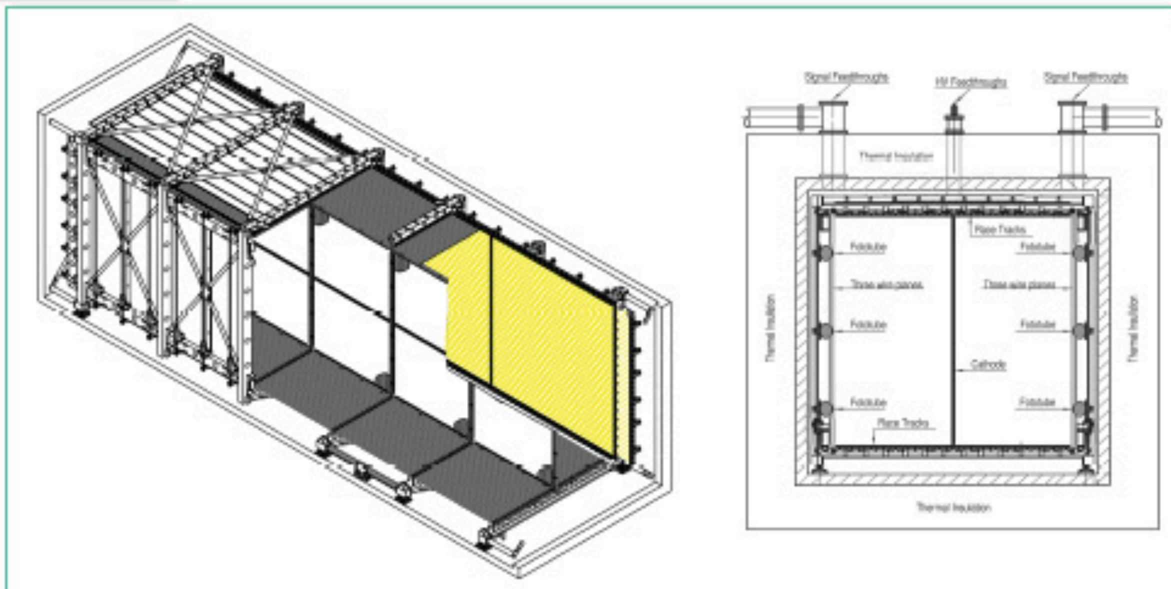


New T150 LAr-TPC



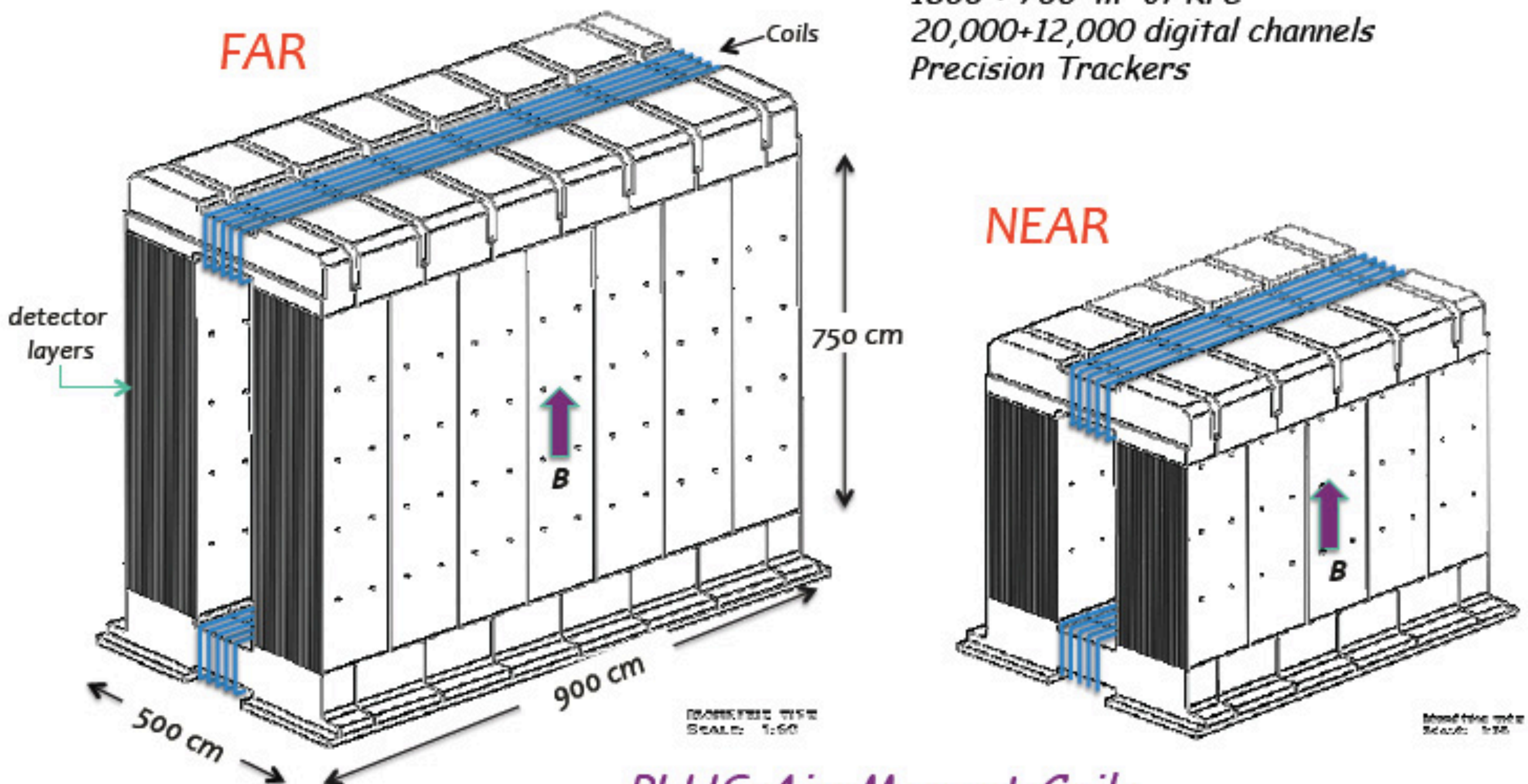
The present design of the T600 is extended to the basic structure of the T150 module. The module contains a high precision, high stability stainless steel structure independent of the container that supports two wire chambers, with three read-out planes each, the field shaping electrodes and one cathode,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



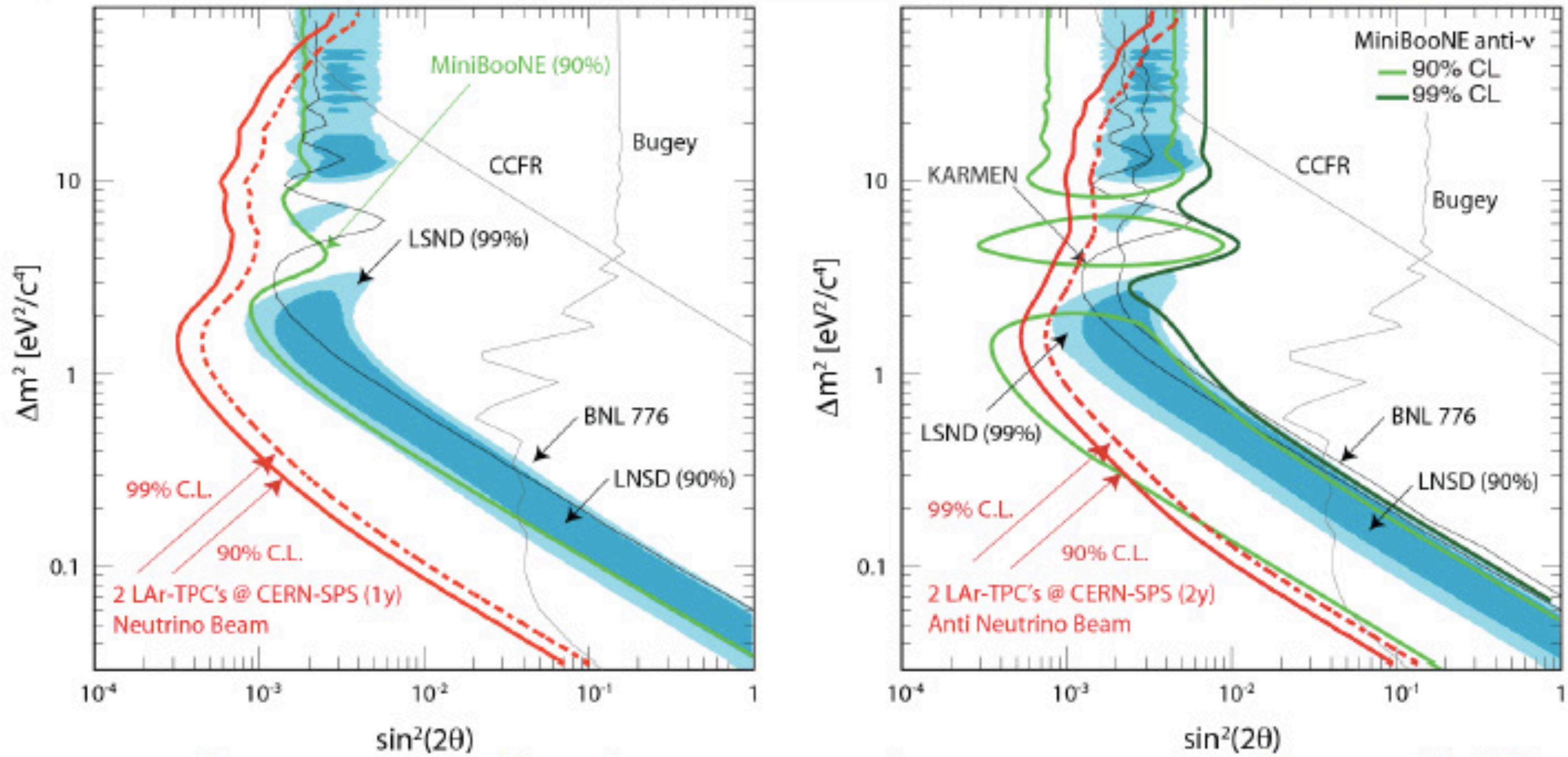
NESSiE Iron Spectrometers

1800 + 700 m² of RPC
20,000+12,000 digital channels
Precision Trackers



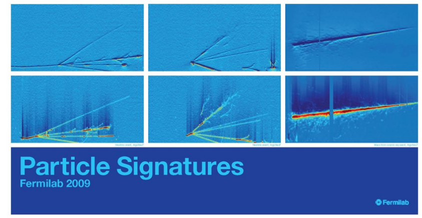
PLUS Air-Magnet Coils

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.

Summary



A number of interesting experimental hints at Short Baselines…

Many ideas on how to address these anomalies – with a handful of those ideas presented here

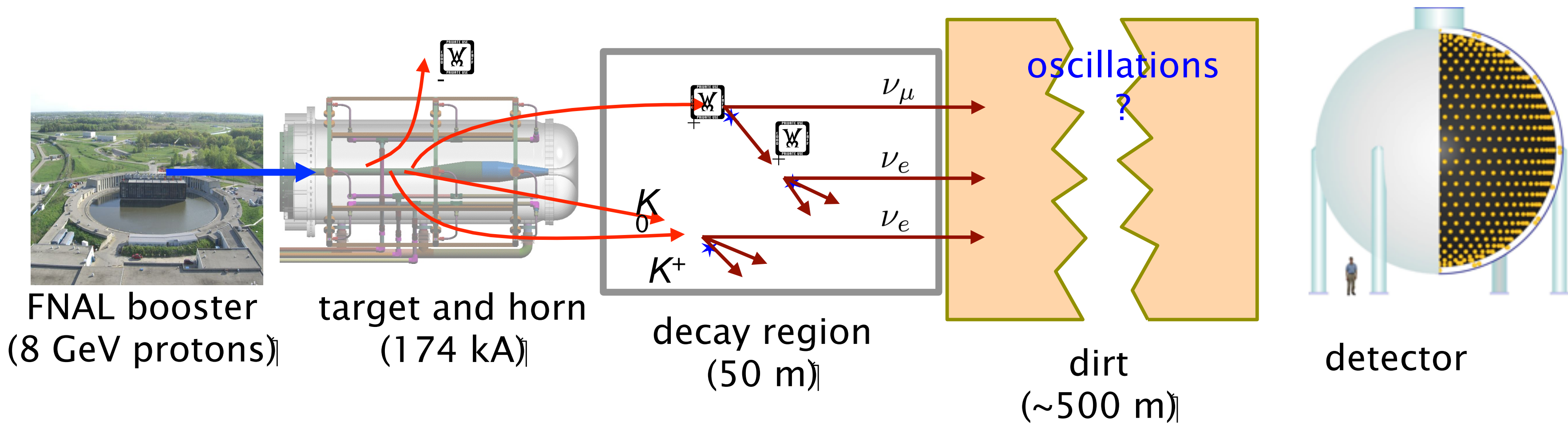
Are these hints of Sterile neutrinos or other new physics?

+

???

Backups

MiniBooNE:

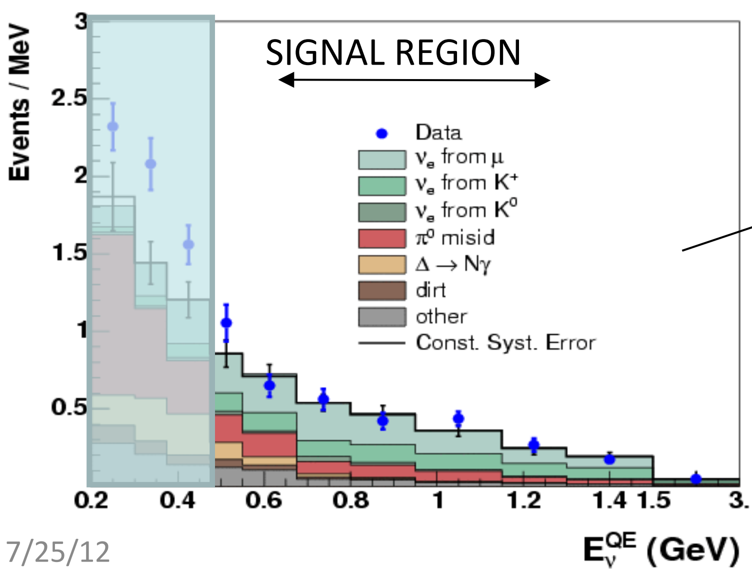


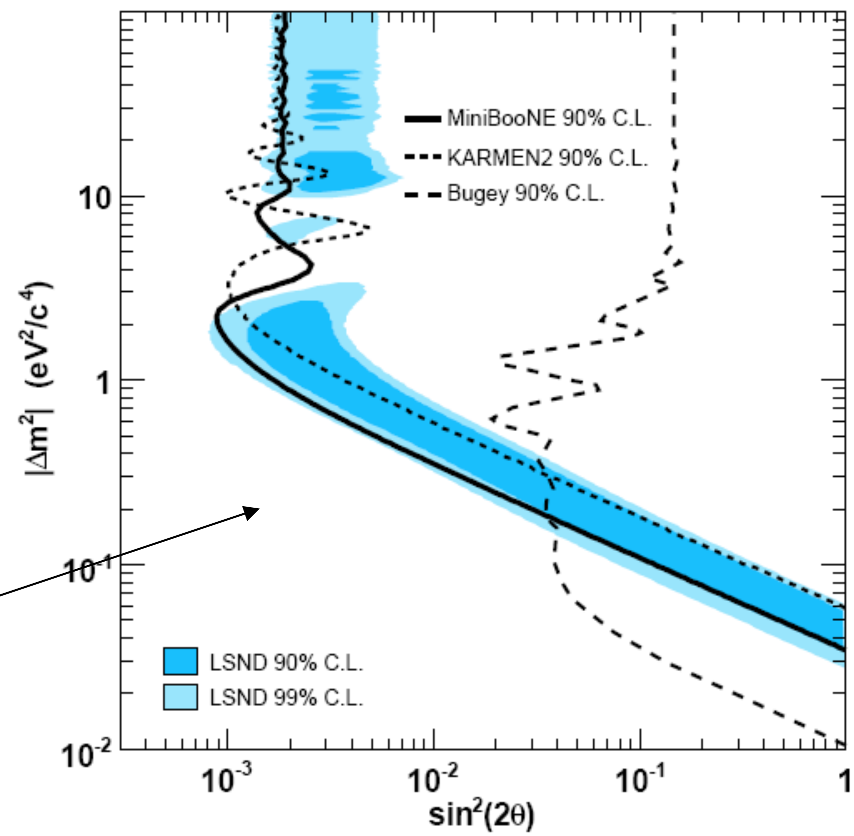
- Mini Booster Neutrino Experiment to look for electron neutrino appearance in a primarily muon neutrino beam
- Neutrino beam created using protons from the Fermilab Booster
- Muon neutrinos travel ~500m to detector
- Detector: 12m in diameter lined with 1500 Photo Multiplier tubes looking for Cerenkov signature of electron vs. muon neutrinos

MiniBooNE Neutrino Oscillation Results

A.A. Aguilar-Arevalo et al., PRL 102, 101802 (2009)

- 6.46e20 POT
- No excess of events at higher energy (E>475 MeV)
- Ruled out simple 2ν oscillations as LSND explanation (assuming no CP violation)

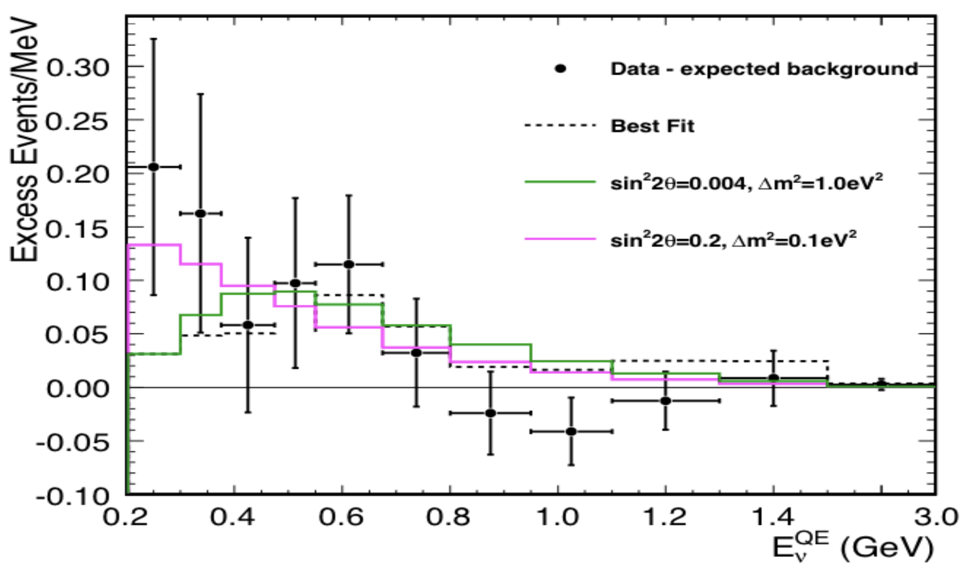


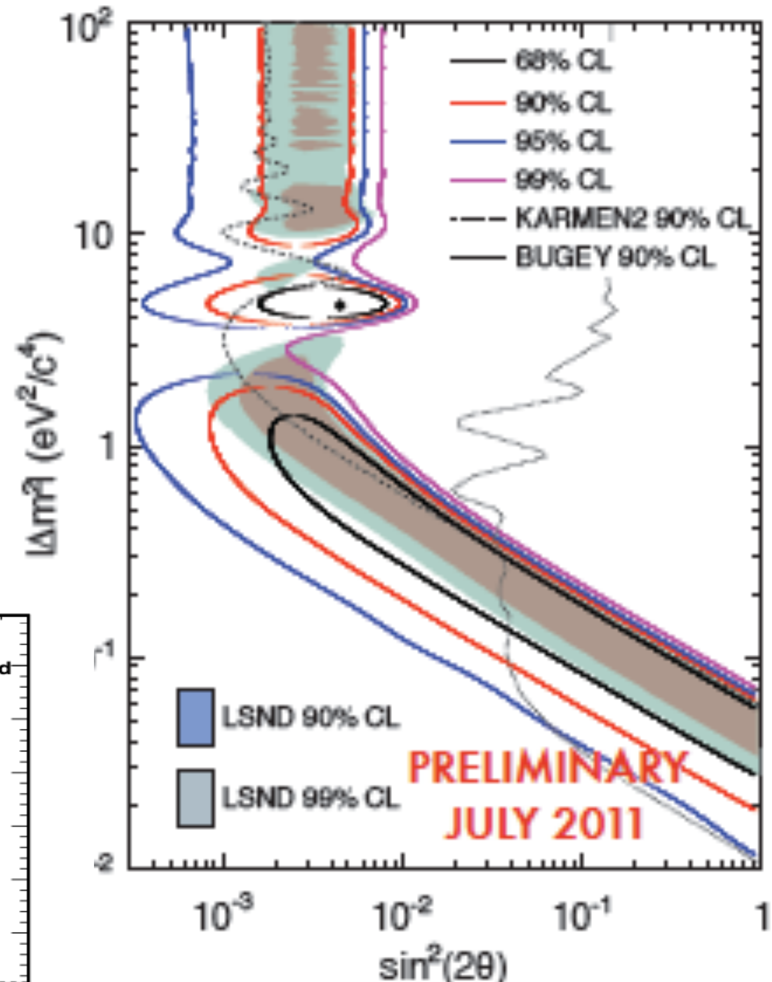


Phys. Rev. Lett. 98, 231801 (2007)

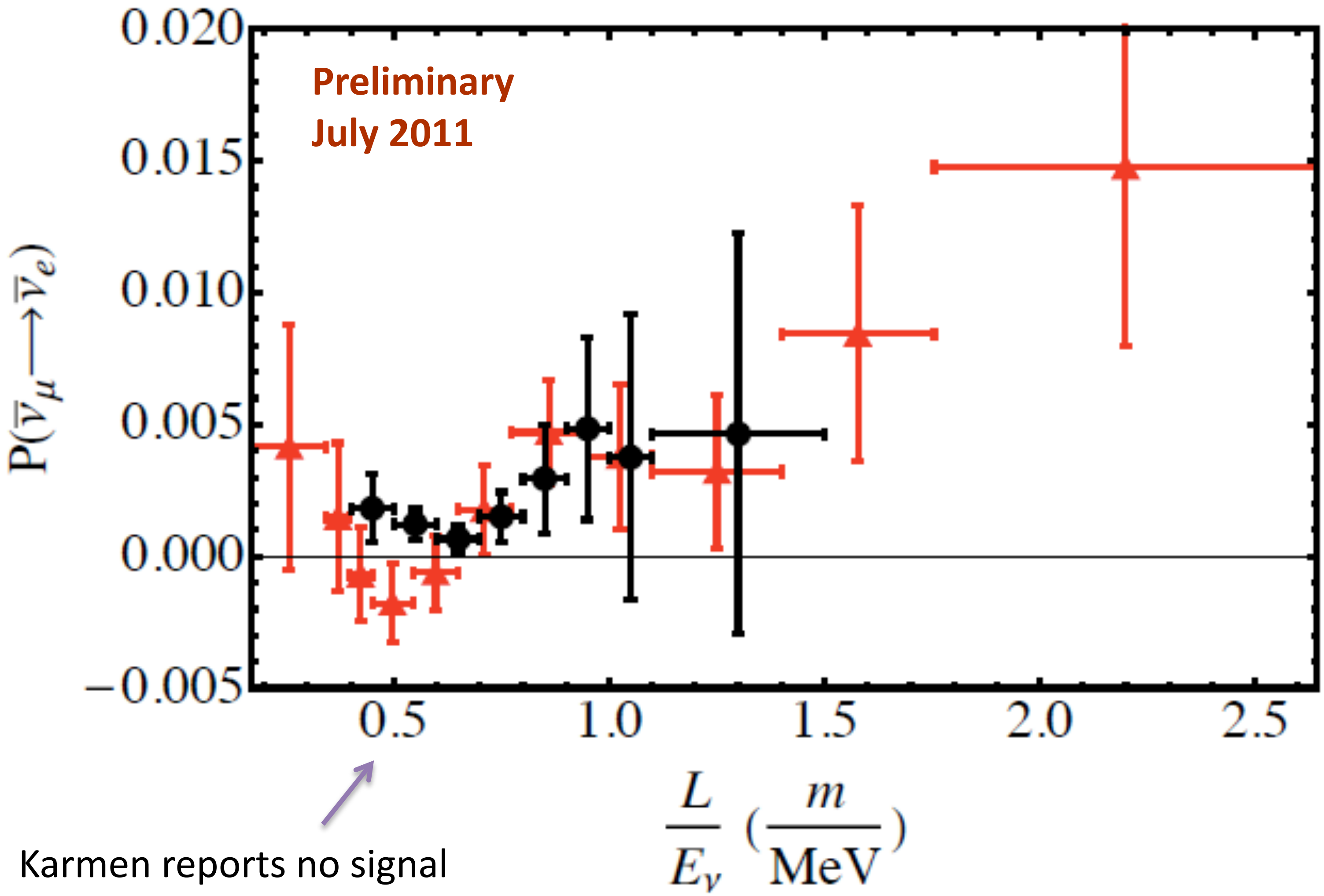
Oscillation interpretation

- 8.58E20 POT
- Oscillations favored over background on hypotheses at 97.6% CL (model dependent)
- No assumption made about low energy excess





L/E Comparison
of LSND & MiniBooNE Antineutrino mode



Karmen reports no signal around L/E ~ 0.5