MICROBOONE PHYSICS

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Outline

- The detector and beam
  - —MicroBooNE TPC
  - —Booster and NuMI beams at Fermilab
- Oscillation physics
  - —Shed light on the MiniBooNE low energy excess
- Low energy neutrino cross sections
- Non-accelerator topics
  - —Supernova neutrino detection
  - —Proton decay backgrounds

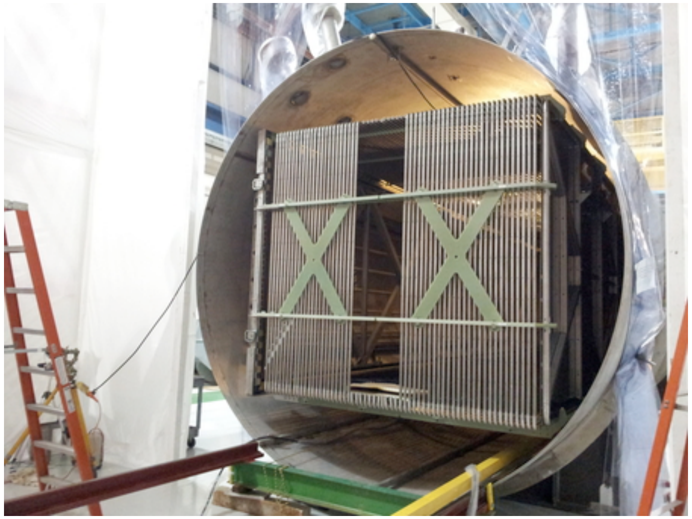
MicroBooNE Detector

- 60 ton fiducial volume (of 170 tons total) liquid Argon TPC
- TPC consists of 3 planes of wires; vertical Y, ±60° from Y for U and V
- Array of 32 PMTs sit behind TPC wires
- Purification system capable of achieving < 100 ppt O_2 and < 1 ppm N_2
- Ready for neutrino data in 2014

See talk by Sarah Lockwitz in the Accelerators, Detectors, and Computing Session

MicroBooNE Detector

- MicroBooNE has several R&D goals
  - —Cold frontend electronics which will reside inside the vessel
  - —2.5 m drift distance across the TPC, longest done in a beam experiment
  - —Gas purge of cryostat instead of vessel evacuation



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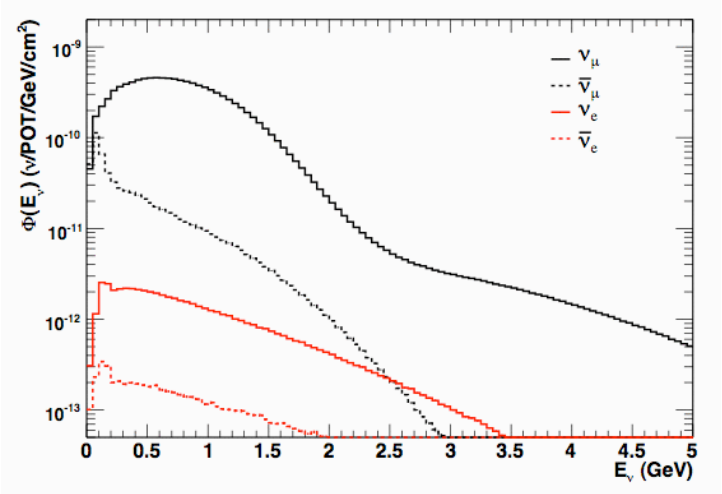
The Booster Neutrino Beam

- Driven by 8 GeV protons hitting a beryllium target for a mean neutrino energy of 0.8 GeV
- Will provide MicroBooNE with similar L/E (oscillation parameter experiments set) to that of MiniBooNE
- Well known beam, already run for a decade, will lead to a few quick results

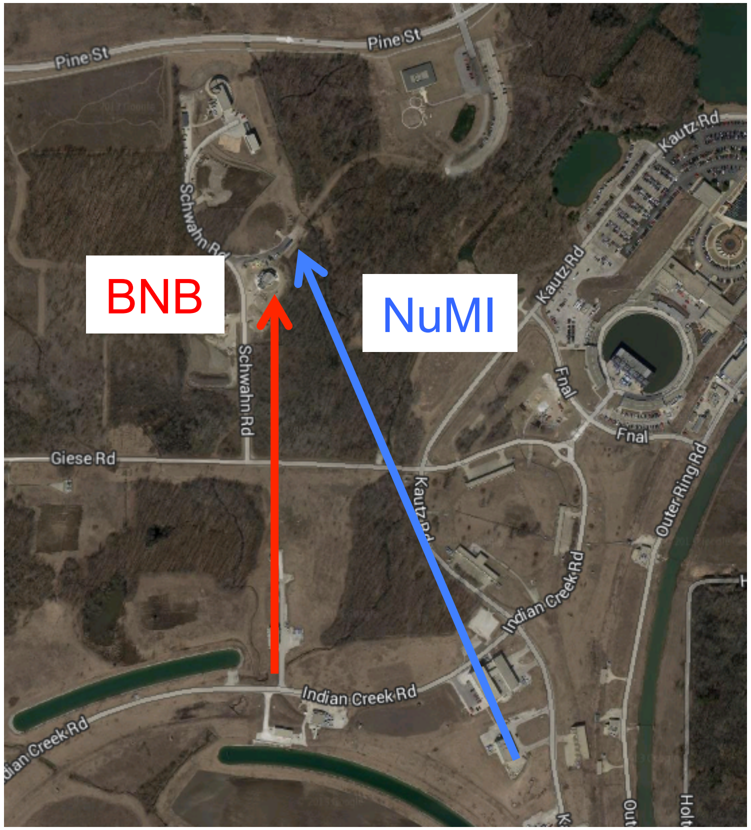


The NuMI Beam

- MicroBooNE will also be getting beam from FNAL's Main Injector neutrino beam
- 120 GeV protons are directed onto a carbon target, produces an off-axis beam for MicroBooNE, potentially useful for NOvA

	BNB	NuMI
Total	143,000	60,000
υ_μ CCQE	66,000	25,000
NC π^0	8,000	3,000
υ_e CCQE	400	1,000
POT	6×10^{20}	8×10^{20}

POT – protons on target
CCQE – charged current quasielastic



Oscillation physics

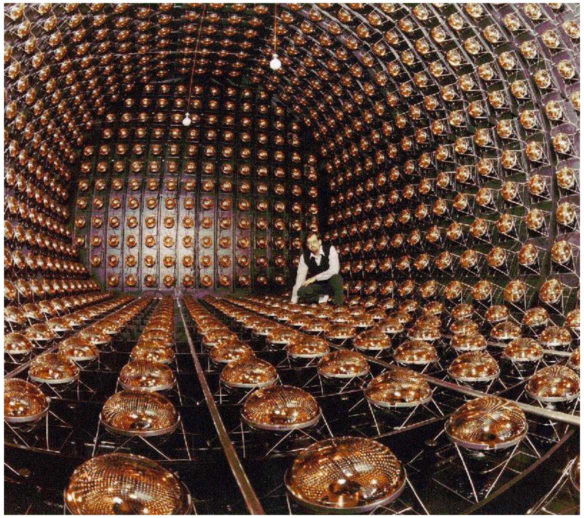
LSND Anomaly

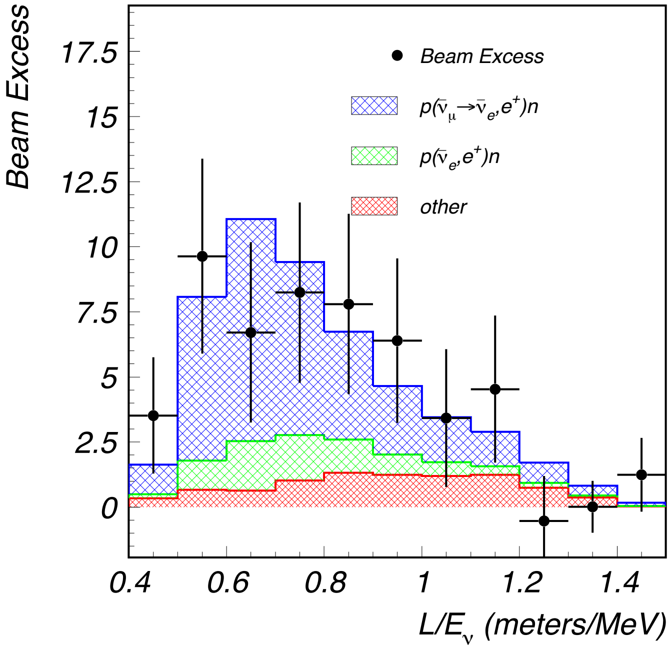
- The motivation for MicroBooNE begins with LSND
- LSND observed a $\bar{\nu}_e$ appearance signal in a $\bar{\nu}_\mu$ beam
- Excess of 87.9 ± 23.2, for 3.8σ

$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27L\Delta m^2}{E}\right)$$

$$= 0.245 \pm 0.081\%$$

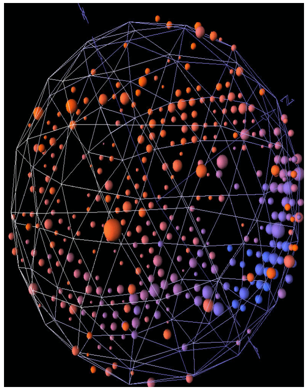
L/E – defined by experimental setup
θ – mixing angle
Δm^2 – oscillation frequency



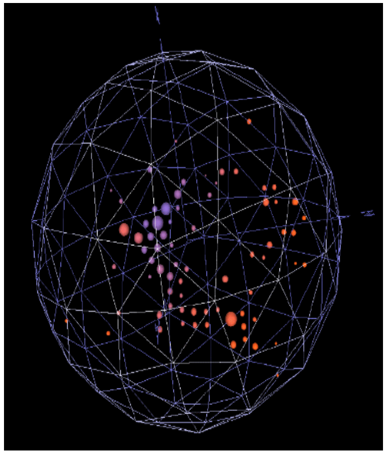


From LSND to MiniBooNE

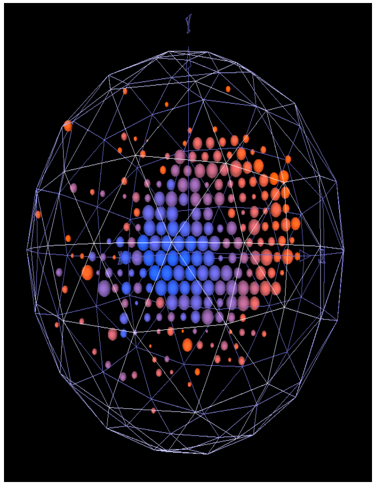
- MiniBooNE, a mineral oil based Cherenkov detector, was designed to observe or refute the LSND
- Looked for ν_e in a ν_μ beam off of the Booster Neutrino Beam
- MiniBooNE, like all Cherenkov detectors, had trouble distinguishing π^0 to $\gamma\gamma$ (background) from a single electron (signal)



$\nu_\mu n \rightarrow \nu_\mu n \pi^0 (\pi^0 \rightarrow \gamma\gamma)$

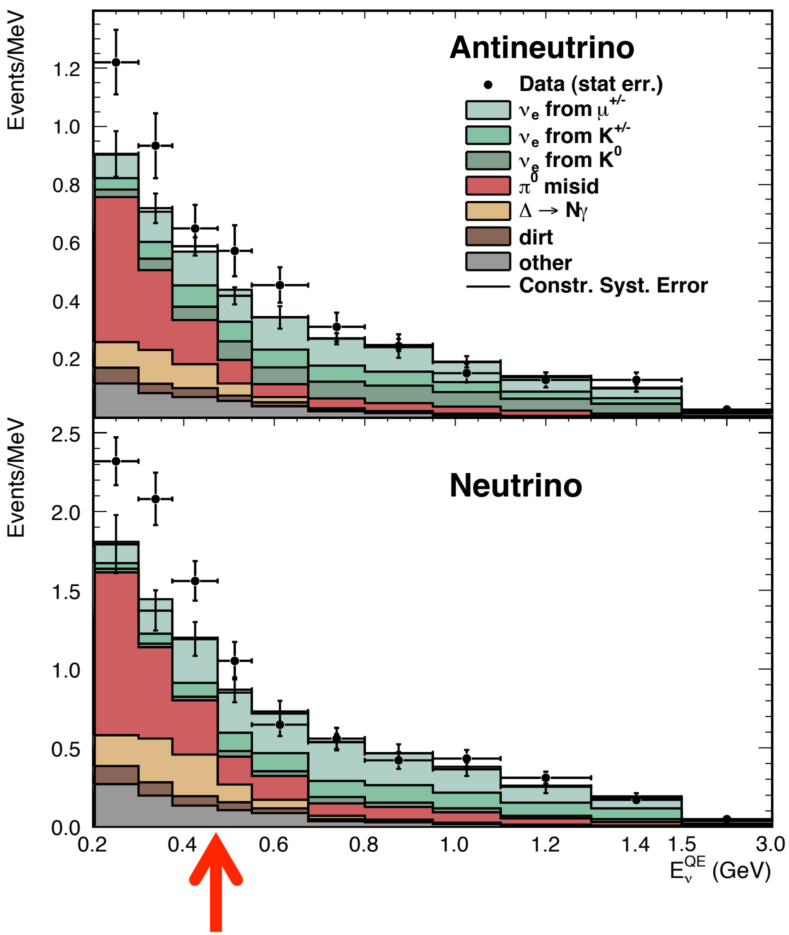


$\nu_e n \rightarrow e^- p$



$\nu_\mu n \rightarrow \mu^- p$

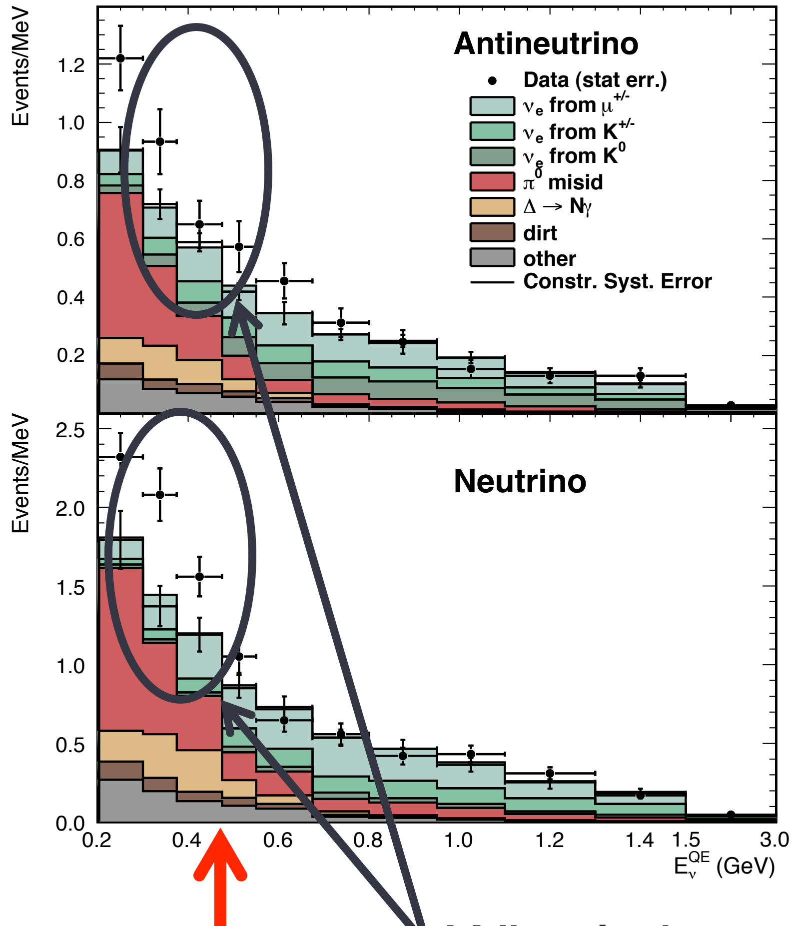
MiniBooNE low energy excess



0.475 GeV cut

- MiniBooNE carried out the oscillation analysis, applying a cut on neutrino energies below 0.475 GeV
- See arXiv:1303.2588 [hep-ex] for details

MiniBooNE low energy excess



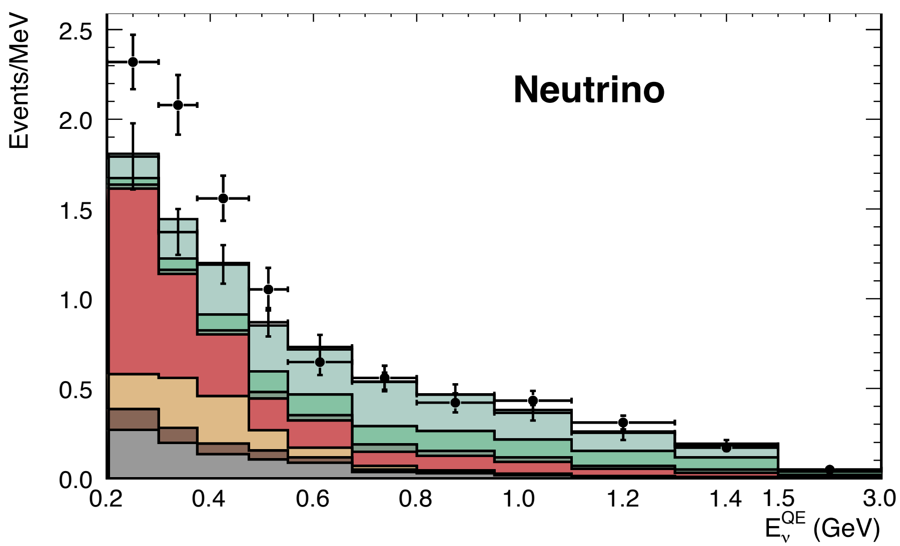
0.475 GeV cut

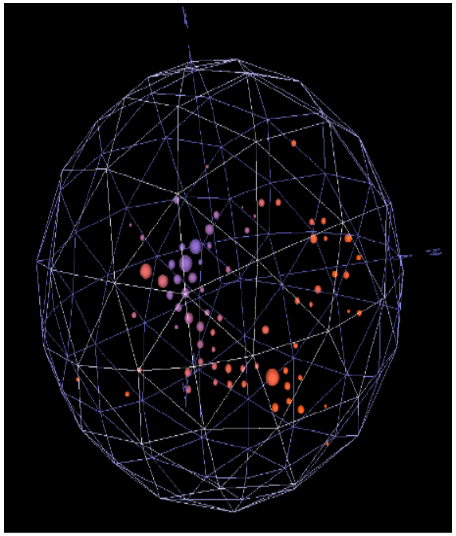
What's happening here?

- MiniBooNE carried out the oscillation analysis, applying a cut on neutrino energies below 0.475 GeV
- See arXiv:1303.2588 [hep-ex] for details

MiniBooNE Excess

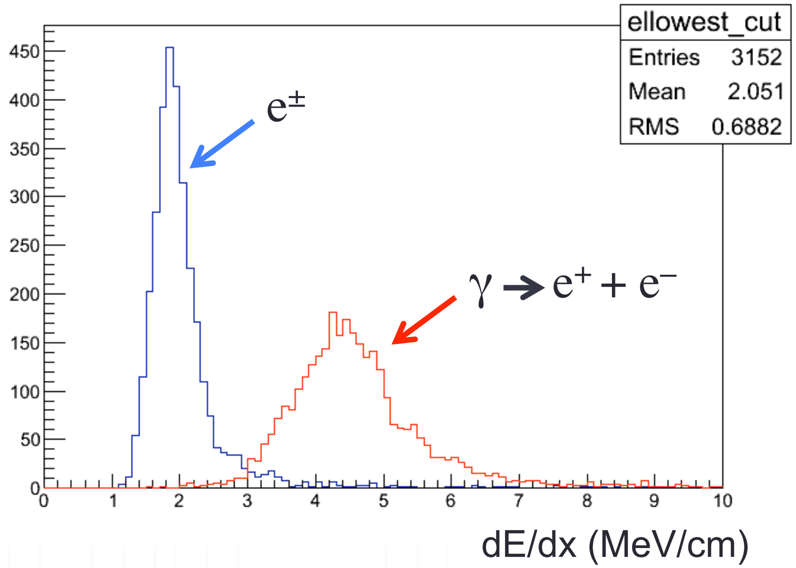
- MiniBooNE sees an excess in neutrino and antineutrino modes, 240.0 ± 62.9 events for 3.8σ
- Excesses appear in the region 0.2-0.475 GeV, where NC π^0 and processes producing a single photon dominate
- Problem is, a photon looks just like an electron!

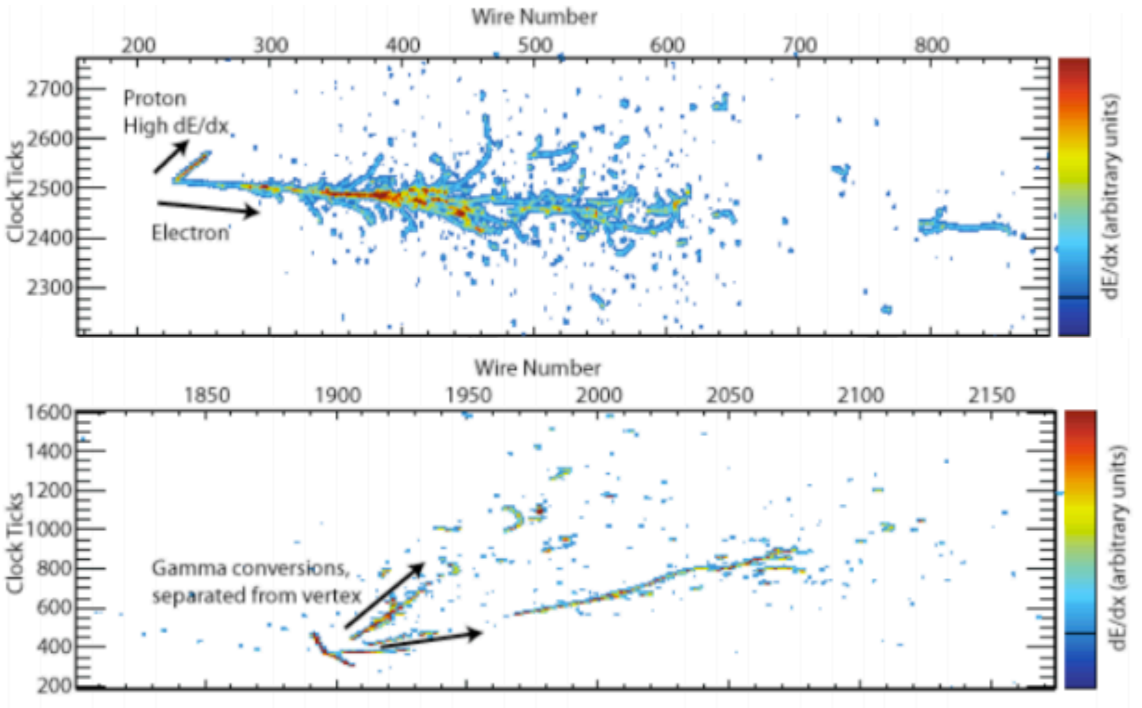




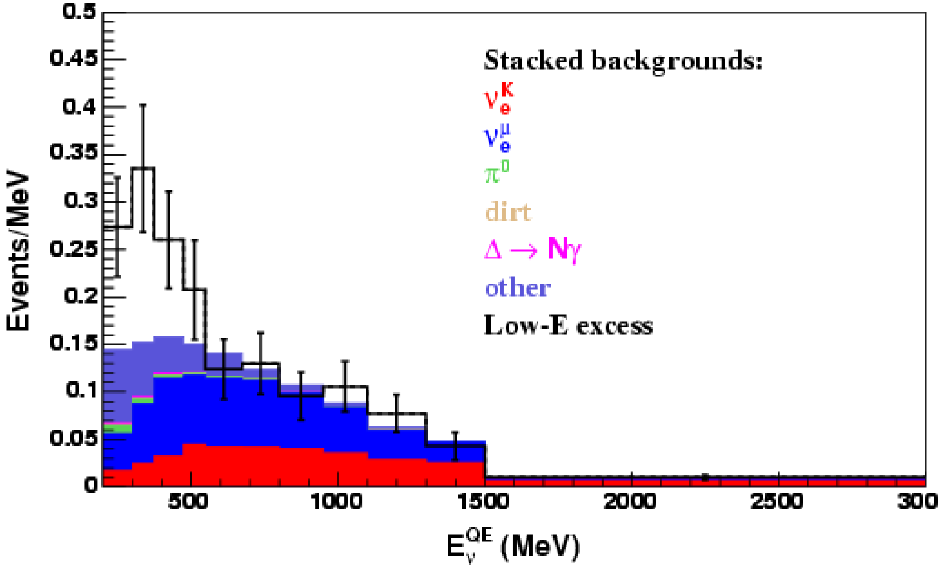
MicroBooNE

LArTPCs are excellent for distinguishing electrons from photons using dE/dx and event topologies

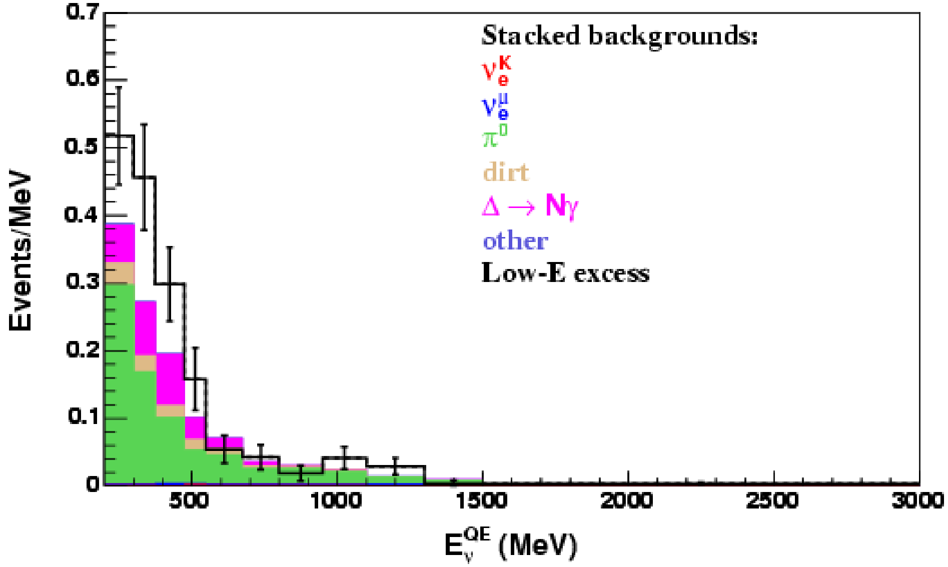




MicroBooNE Oscillation Analysis



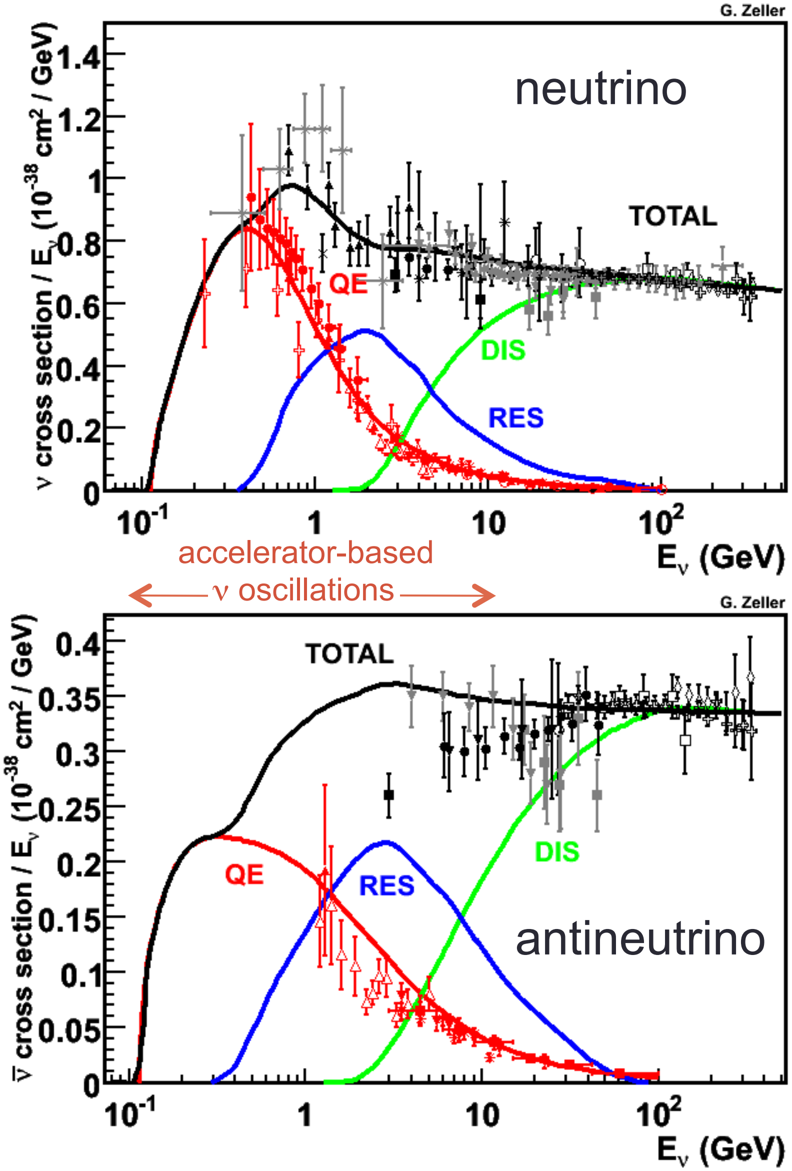
Optimized to find electron-like signal



Optimized to find photon-like signal

Cross section physics

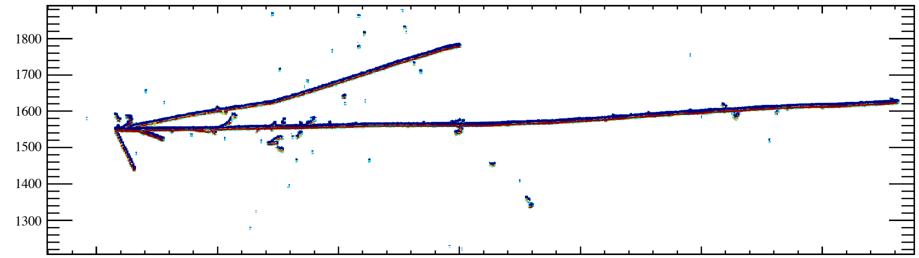
Neutrino Cross Sections



- Has recently received a lot of attention, crucial for ν oscillations
- ν cross sections are historically not well known in the energy range we care about
- Nuclear effects are far more complex than we originally thought, forcing a dramatic change in our thinking recently
- In the 1 GeV range, driven by results from MiniBooNE, MicroBooNE will probe the exact same energy region with a more capable detector

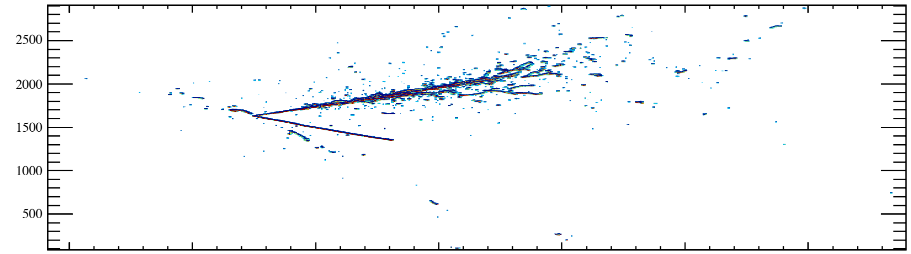
Cross sections in MicroBooNE

- MicroBooNE will make the first ν cross section measurements in argon at ~1 GeV
  - —LArTPC provides phenomenal resolution for position and momentum
  - —Possible to reconstruct complicated topologies
  - —Able to see protons with kinetic energies as low as 20 MeV
  - —High statistics will make measurements systematically limited
- After ~10 years of operation, FNAL neutrino Booster beam has a well characterized flux which will allow expeditious results from MicroBooNE (Phys. Rev. D79, 072002 (2009))



$$\nu_\mu + {}^{40}\mathrm{Ar} \rightarrow \mu^- + p + p + n + p$$

simulated neutrino interactions in MicroBooNE



$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + p + p + \pi^0 + p$$

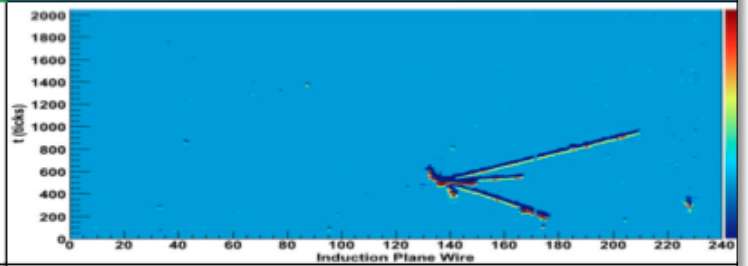
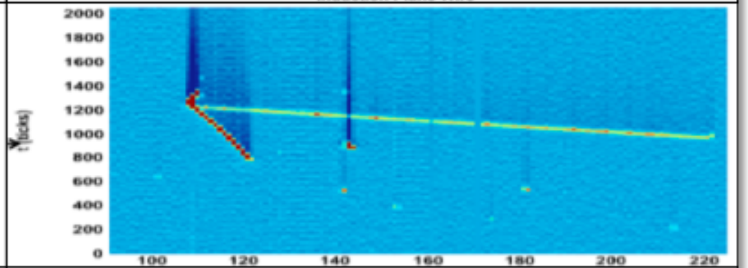
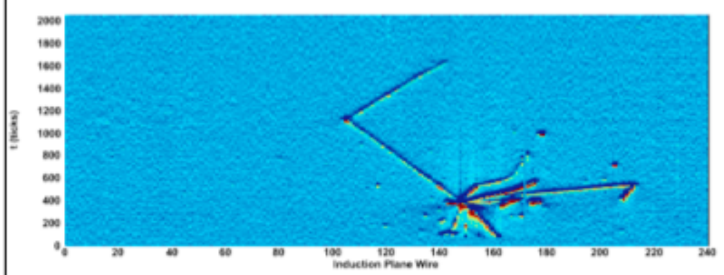
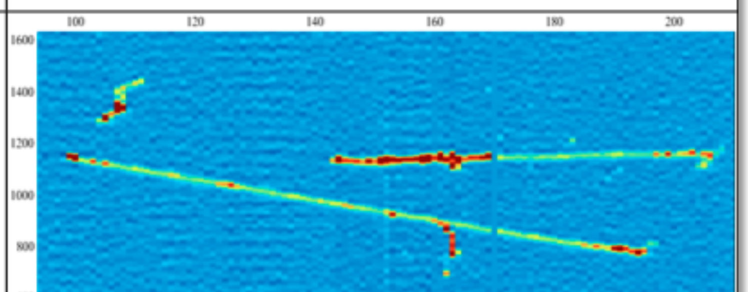
Expected Statistics

production mode	# events
CC QE ($\nu_\mu n \rightarrow \mu^- p$)	60,161
NC elastic ($\nu_\mu N \rightarrow \nu_\mu N$)	19,409
CC resonant π^+ ($\nu_\mu N \rightarrow \mu^- N \pi^+$)	25,149
CC resonant π^0 ($\nu_\mu n \rightarrow \mu^- p \pi^0$)	6,994
NC resonant π^0 ($\nu_\mu N \rightarrow \nu_\mu N \pi^0$)	7,388
NC resonant $\pi^\pm$ ($\nu_\mu N \rightarrow \nu_\mu N' \pi^\pm$)	4,796
CC DIS ($\nu_\mu N \rightarrow \mu^- X$, $W > 2$ GeV)	1,229
NC DIS ($\nu_\mu N \rightarrow \nu_\mu X$, $W > 2$ GeV)	456
NC coherent π^0 ($\nu_\mu A \rightarrow \nu_\mu A \pi^0$)	1,694
CC coherent π^+ ($\nu_\mu A \rightarrow \mu^- A \pi^+$)	2,626
NC kaon ($\nu_\mu N \rightarrow \nu_\mu K X$)	39
CC kaon ($\nu_\mu N \rightarrow \mu^- K X$)	117
other ν_μ	3,678
total ν_μ CC	98,849
total ν_μ NC+CC	133,580
ν_e QE	326
ν_e CC	657

MicroBooNE will more precisely examine the final states produced in these neutrino interactions by exploiting the capabilities of LAr and building off of the experience gained in **MiniBooNE** (same flux) and **ArgoNeuT** (same detector technology)

(rates assuming 6.6 $\times 10^{20}$ POT)

A Few Examples

CC processes	Example of Topologies from ArgoNeuT data
$\nu_\mu + Ar \rightarrow 1\mu + X$ (ν_μ-CC inclusive Cross Section)	
$\nu_\mu + Ar \rightarrow 1\mu + 0\,\pi + (n_p\, \boldsymbol{p} + n_n\, \boldsymbol{n})$ $[n_p, n_n = 0, \text{ or } 1, \text{ or } 2]$ (ν_μ-"0-pion" CC Cross Section)	
$\nu_\mu + Ar \rightarrow 1\mu + 1\,\pi^\pm + (n_p\, \boldsymbol{p} + n_n\, \boldsymbol{n})$ $[n_p, n_n = 0, \text{ or } 1, \text{ or } 2]$ (ν_μ-"1-$\pi^\pm$" CC Cross Section)	
$\nu_\mu + Ar \rightarrow 1\mu + 1\,\pi^0 + (n_p\, \boldsymbol{p} + n_n\, \boldsymbol{n})$ $[n_p, n_n = 0, \text{ or } 1, \text{ or } 2]$ (ν_μ-"1-π^0" CC Cross Section)	

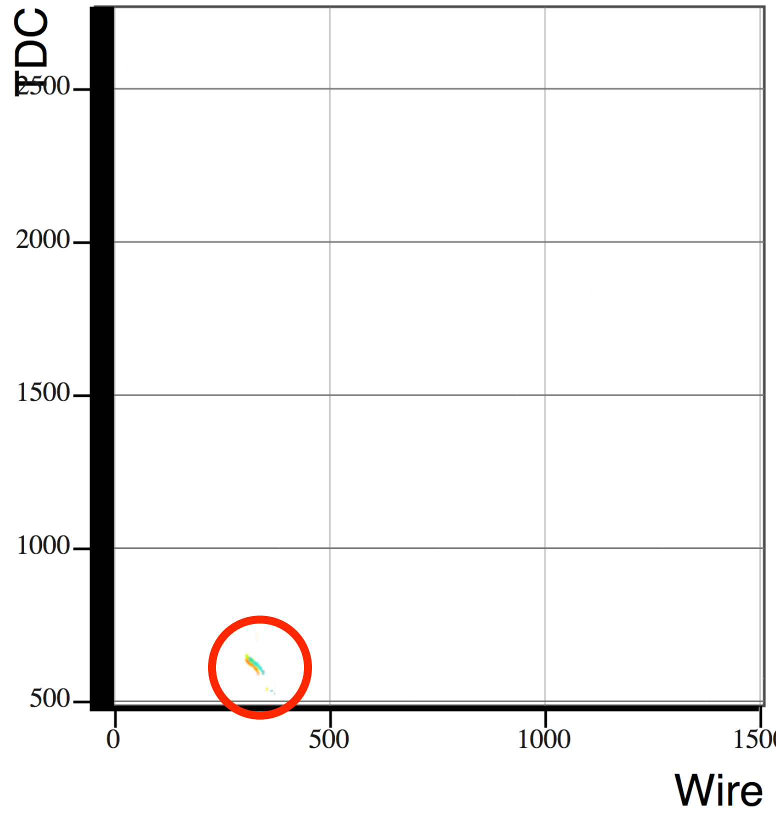
Examples of event topologies MicroBooNE will measure

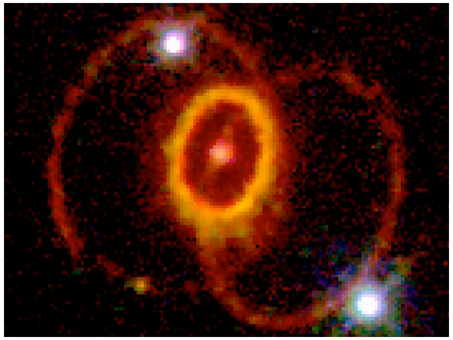
(event displays are actual data from ArgoNeuT)

Non-accelerator topics

Supernova Neutrinos

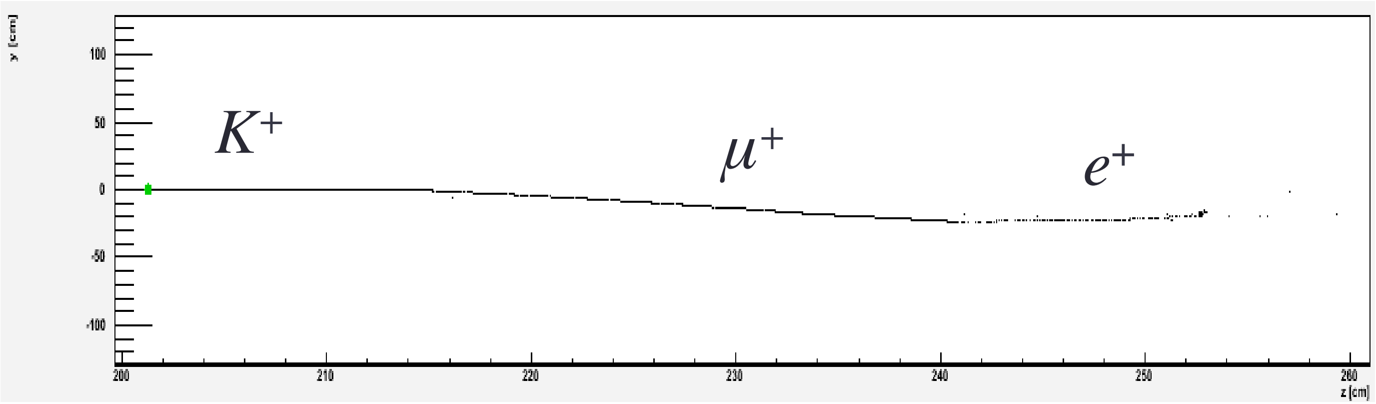
- Supernova neutrinos will be observable through data buffering and a trigger from SNEWS
- MicroBooNE would see 10-20 neutrino from a galactic supernova
- 20 neutrinos total (from all detectors in the world) were observed from 1987a





Proton decay backgrounds

- Many GUTs predict the proton decay of $p^+ \rightarrow K^+ \nu$
- MicroBooNE is too small to be sensitive to proton decay, multi-kiloton, underground LArTPCs will be
- However, we can begin studying backgrounds for the decay $p^+ \rightarrow K^+ \nu$
- Possible to distinguish K from p using dE/dx



Summary

- We have several physics goals
  - —Determine the origin of the MiniBooNE low energy excess
  - —Measure a suite of low energy neutrino cross sections
  - —Supernova neutrinos
  - —Proton decay background studies
- MicroBooNE will begin taking data in 2014
- Stay tuned!

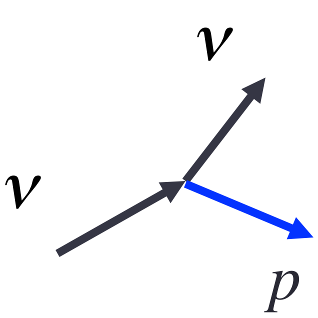
Backup

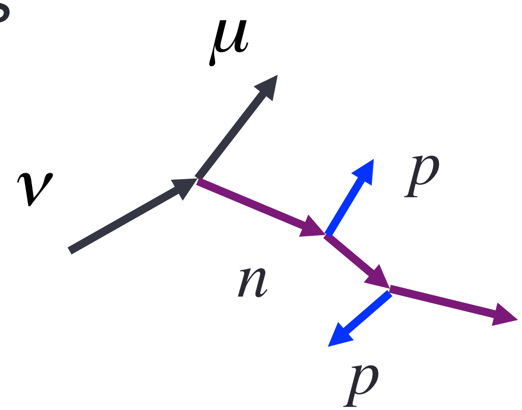
Proton ΔS

- MicroBooNE will have sensitivity to ΔS, fraction of proton spin carried by the strange quark

$$R_{NC/CC} = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)}$$

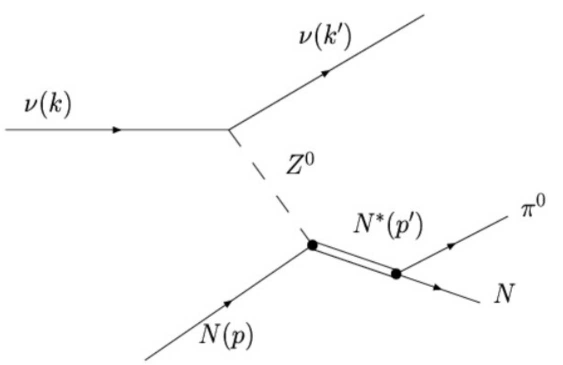
- Potential to shed light on proton spin
- Useful for spin-dependent WIMP measurements
- Helpful for modeling LAr events





Coherent pion production

- MicroBooNE's detector capabilities make searching for coherent pion production feasible
- Coherent production has two standout features
  - —Lack of debris from nuclear breakup (coherent production leaves nucleus intact)
  - —Forward going lepton and pion in the final state



vs.