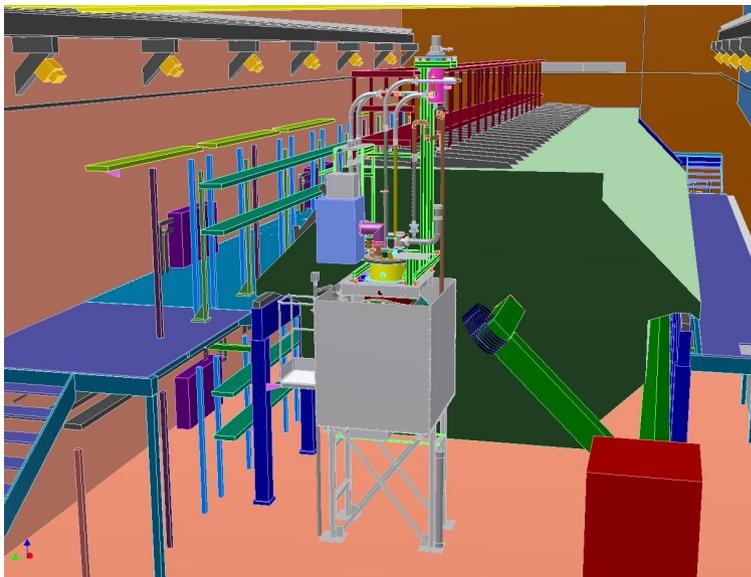
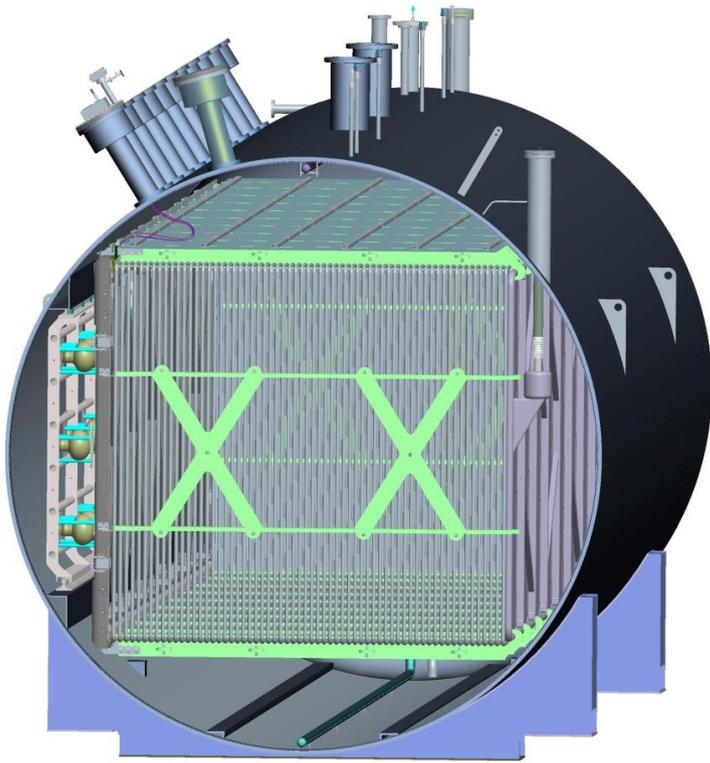


2013  
**TAUP**  
Asilomar  
September 8-13

# The MicroBooNE and ArgoNeuT Experiments

**Jonathan Asaadi**

*Syracuse University*



# Outline

- **Overview of Liquid Argon Time Projection Chambers (LArTPC's)**
- **The MicroBooNE Experiment**
  - Overview of the experiment
  - Physics motivation
  - Current status
- **The ArgoNeuT Experiment**
  - Overview of the experiment
  - Physics analysis
  - Neutral Current  $\pi^0$  studies

# LArTPC's

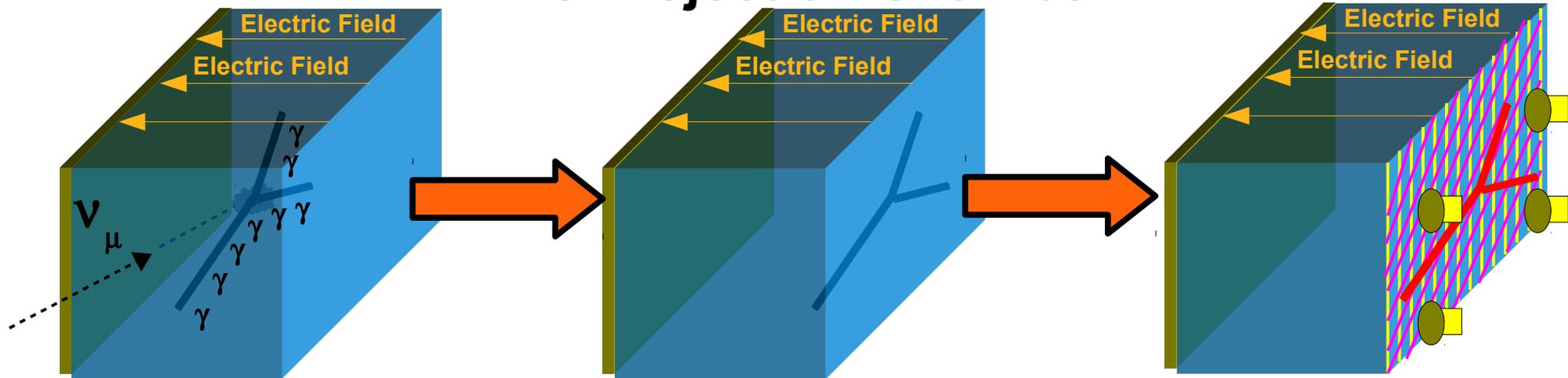
Liquid Argon is an excellent choice for neutrino detectors:

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm <sup>3</sup> ]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [ $\gamma$ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation $\lambda$ [nm]	80	78	128	150	175	

Note: This table was first produced by my boss Mitch Soderberg and if he had patented it he would have 10's of dollars because it shows up in every LAr talk I've ever seen!

- **Dense**  
*40% more dense than water*
- **Abundant**  
*1% of the atmosphere*
- **Ionizes easily**  
*55,000 electrons / cm*
- **High electron mobility**  
*Greek name means "lazy"*
- **Produces copious scintillation light**  
*Transparent to light produced*

## Time Projection Chamber



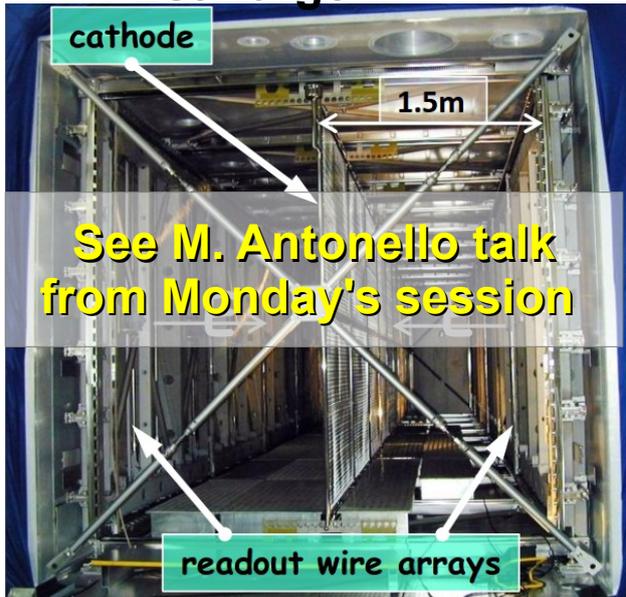
Neutrino interaction in LAr produces ionization and scintillation light

Drift the ionization charge in a uniform electric field

Read out charge and light produced using precision wires and PMT's

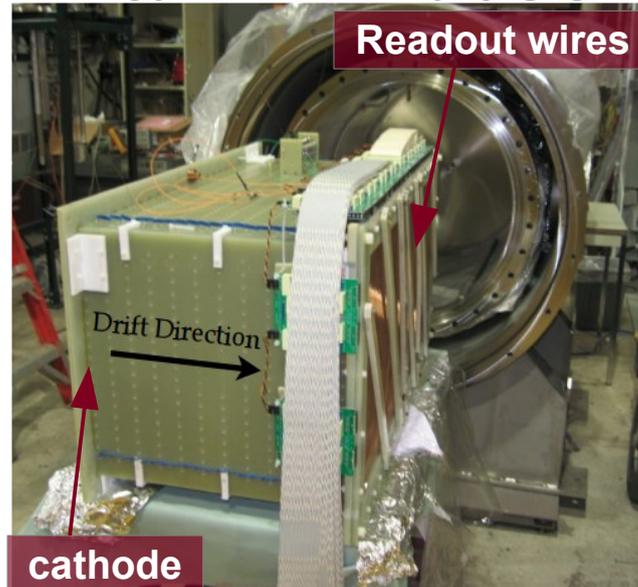
# Examples of LArTPC's

**ICARUS @ LNGS**  
First Large LArTPC



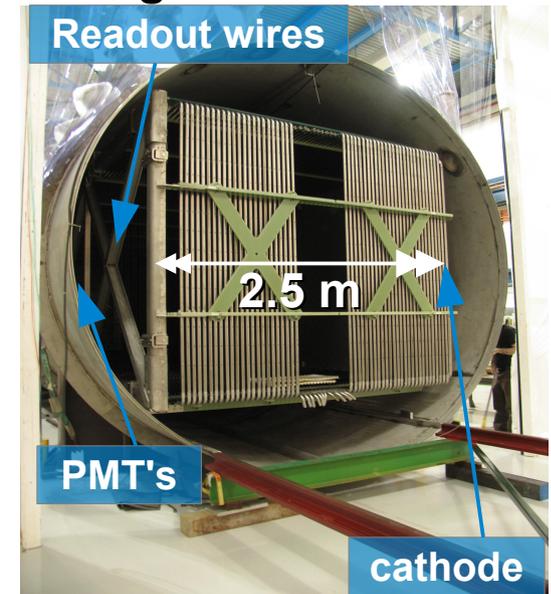
**476 tons (active mass)**  
**1.5 meter drift**  
**53,000 wires (3mm pitch)**

**ArgoNeuT @ NuMI**  
First LArTPC in the U.S.

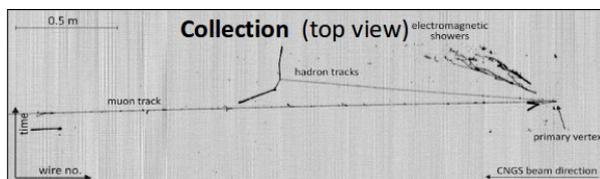


**0.26 Tons (active mass)**  
**0.47 meter drift**  
**480 wires (4mm pitch)**

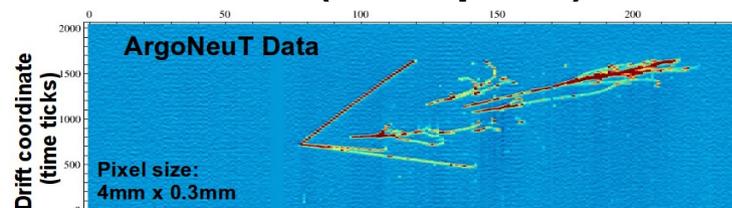
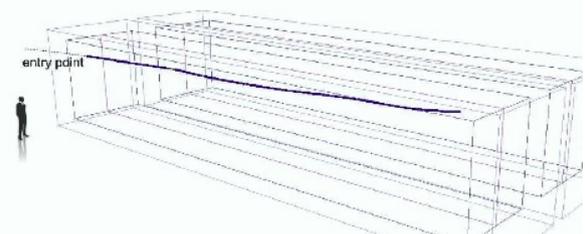
**MicroBooNE @ BNB**  
First Large LArTPC in the U.S.



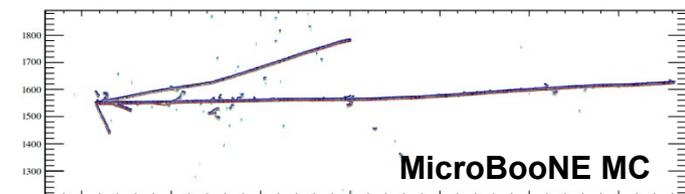
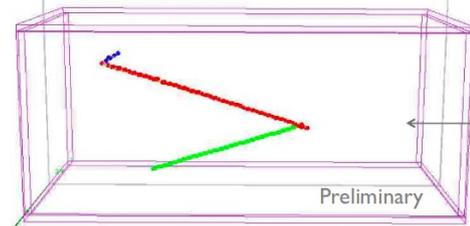
**80 tons (active mass)**  
**2.5 meter drift**  
**8256 wires (3mm pitch)**



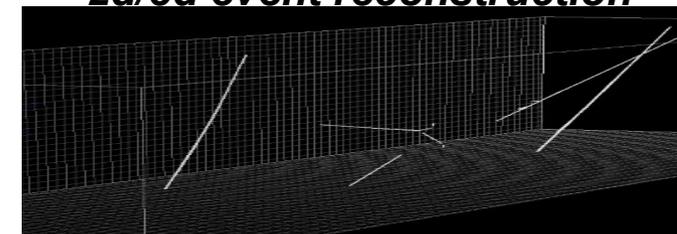
**2d/3d event reconstruction**



**2d/3d event reconstruction**

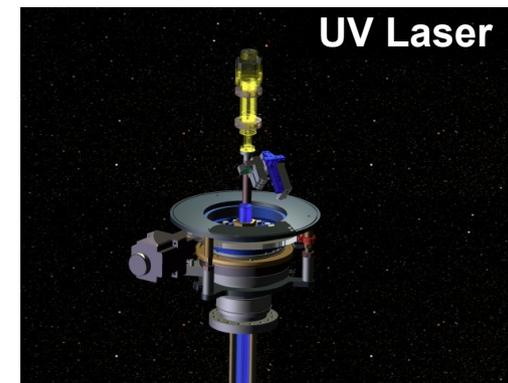
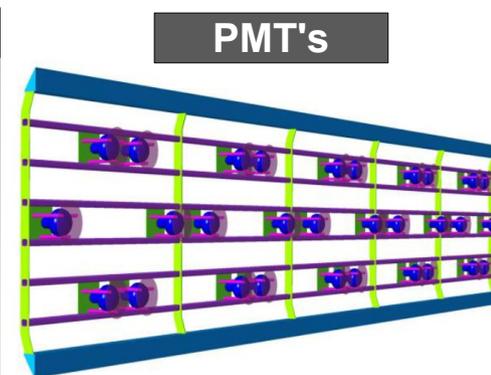
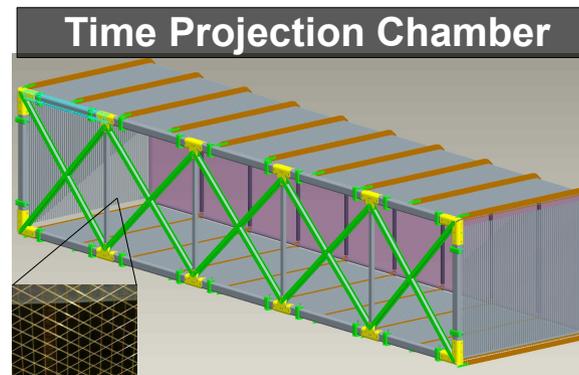
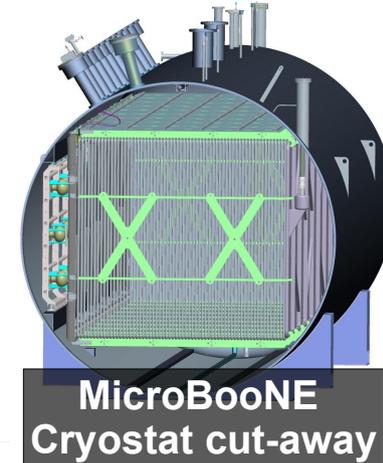
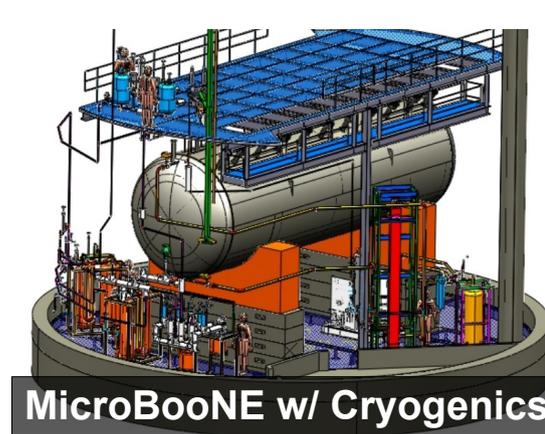


**2d/3d event reconstruction**

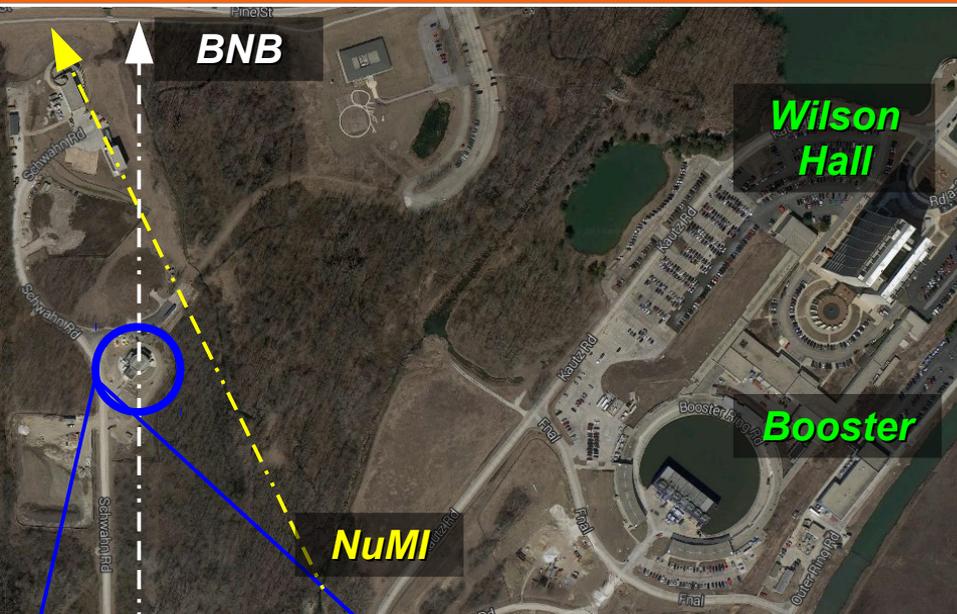


# MicroBooNE: Overview

- MicroBooNE is a 170 ton (total volume) LArTPC
- TPC Dimensions:
  - 10.3 m long x 2.3 m tall x 2.5 m wide (drift distance)
  - 80 ton active mass
- 8256 wire channels
  - 3840 Collection channels
    - Wires oriented w.r.t. the vertical
  - 4416 Induction channels
    - Wires oriented +/- 60°
- 32 8" cryogenic PMT's
  - Provides event  $t_0$  as well as cosmic ray removal
- UV Laser Calibration System



# MicroBooNE: Overview



- **MicroBooNE will be located at Fermilab's Liquid Argon Test Facility (LArTF)**

- Will see the Booster Neutrino Beam (BNB) and off-axis Neutrinos from the Main Injector (NuMI) beam

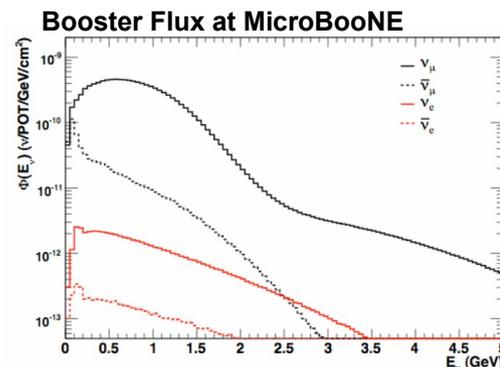
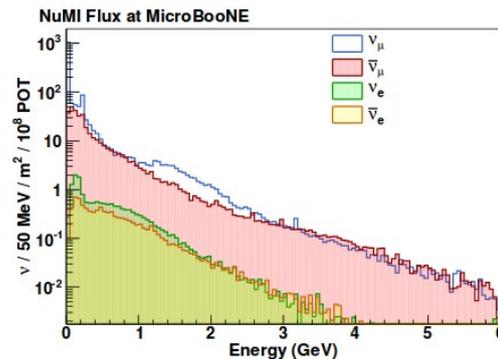
- Two beams provide both a low energy and high energy source of neutrinos

- Booster beam is created from 8 GeV protons on a beryllium target

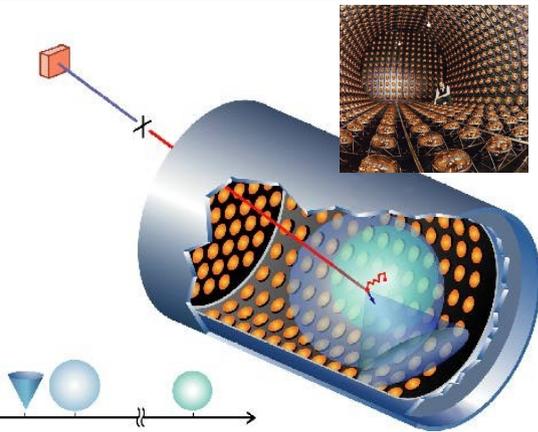
- Mean neutrino energy  $\rightarrow < 1$  GeV

- NuMI beam created from 120 GeV protons on a carbon target

- Mean neutrino energy  $\rightarrow \sim \#$  GeV



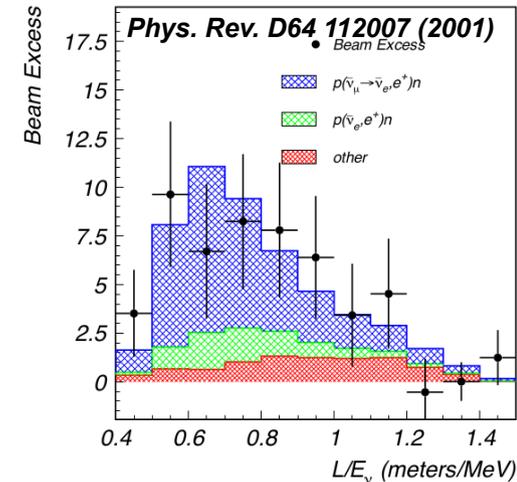
# MicroBooNE: Physics Motivation



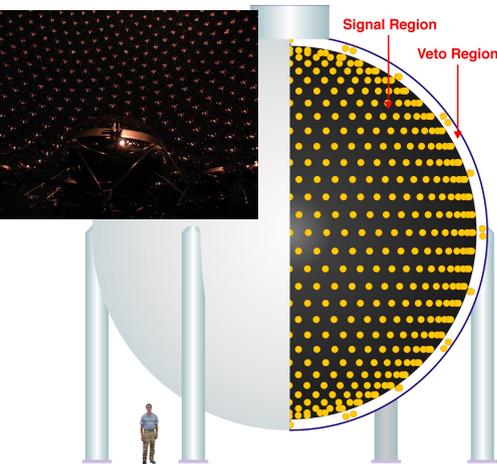
**Liquid Scintillator Neutrino Detector (LSND) observes an excess of events ( $3.8\sigma$  above background) in  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$**

**appearance search**

- Much disputed result
- Could be evidence for new physics?
- Experimental setup defined L/E

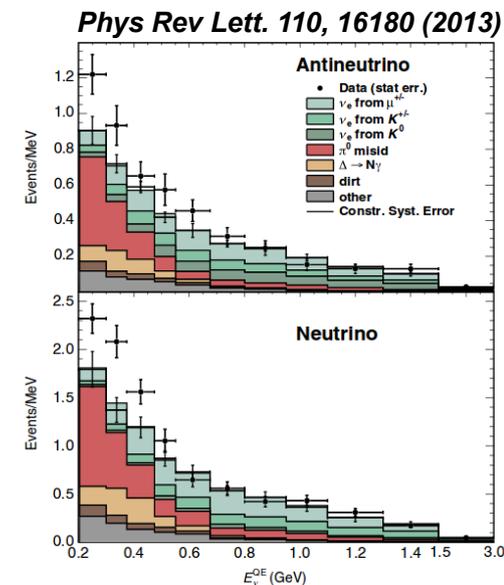


MiniBooNE Detector



**Mini-Booster Neutrino Experiment (MiniBooNE) runs at a similar L/E and sees a slightly different excess in  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$  and  $\nu_\mu \rightarrow \nu_e$  appearance search**

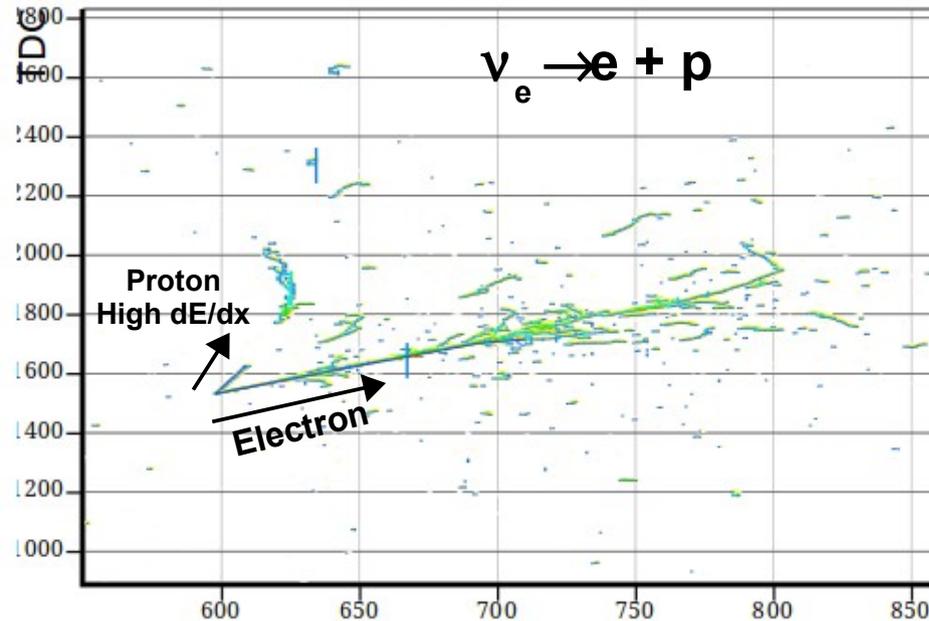
- Effect dominates at low energy
  - *Between 0.2 – 0.5 GeV*
- Insidious backgrounds dominate
  - *Tough to distinguish  $\pi^0 \rightarrow \gamma\gamma$  from  $e^-$  signature*



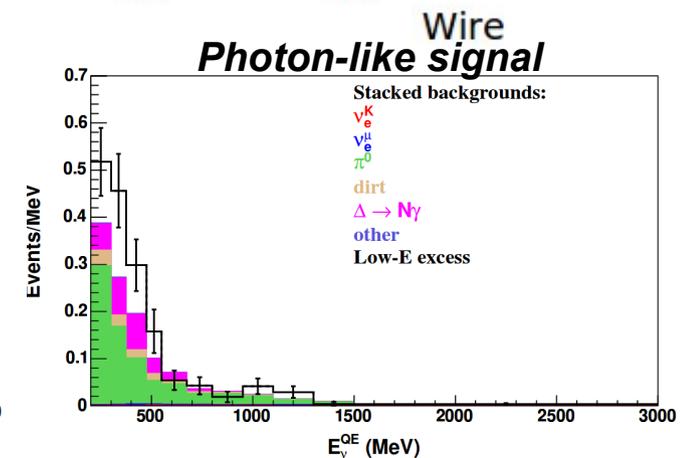
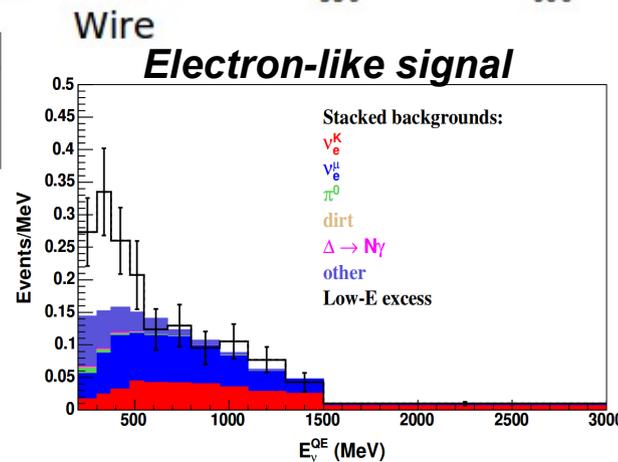
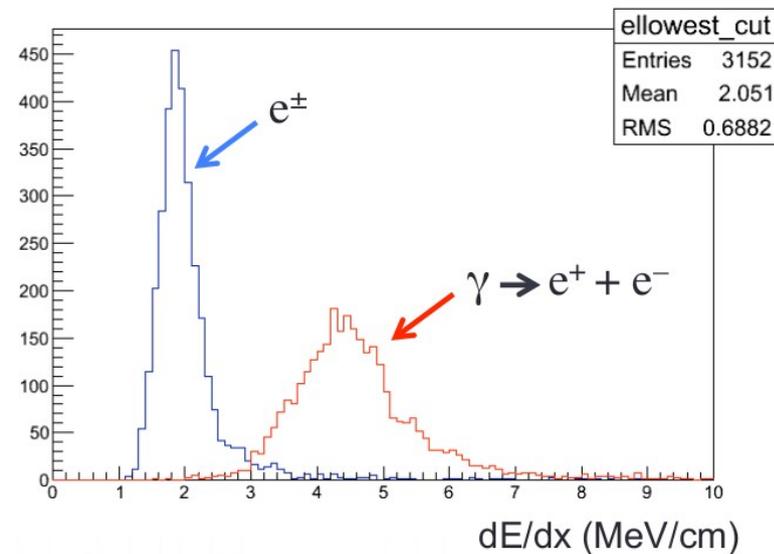
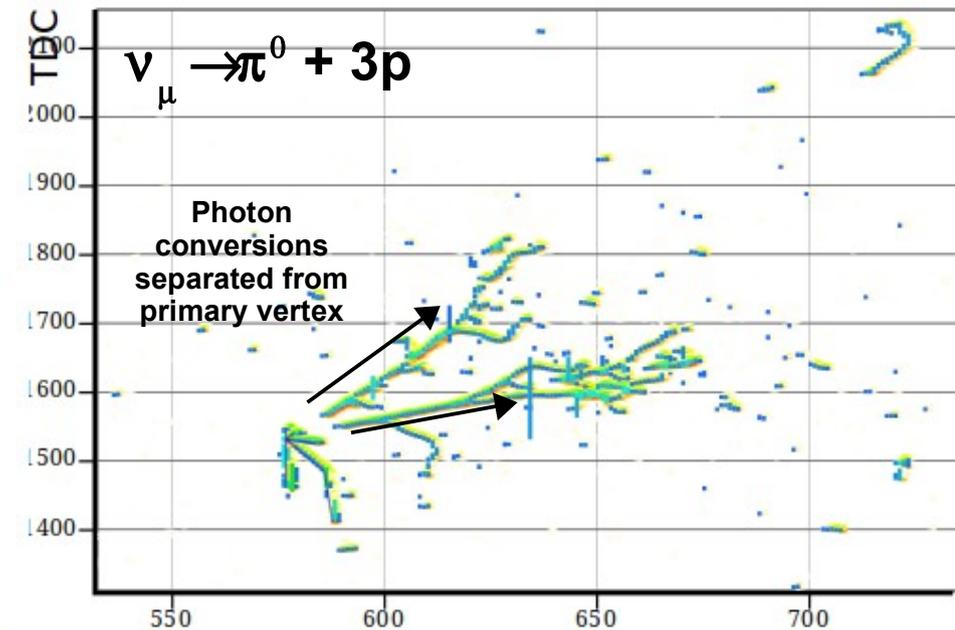
**Liquid Argon TPC's offer amazing ability to distinguish background ( $\pi^0 \rightarrow \gamma\gamma$ ) from signal ( $\nu_e$  appearance) at a variety of energy ranges and address both of these anomalies**

# MicroBooNE: Physics Motivation

MicroBooNE MC "V" View / View 1 / Plane 1



MicroBooNE MC "V" View / View 1 / Plane 1



**MicroBooNE can do more than just oscillation physics!**

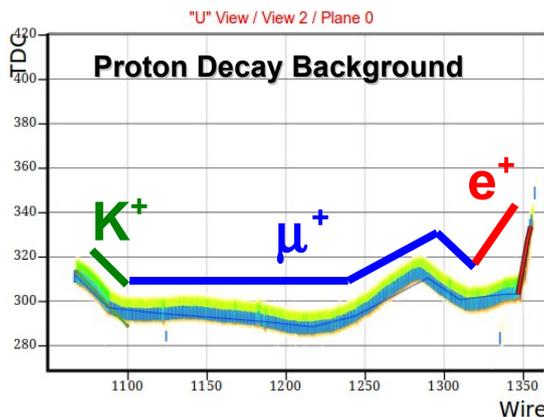
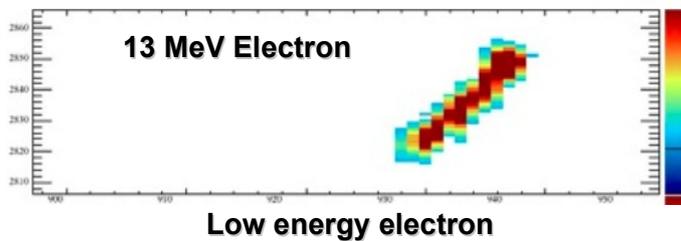
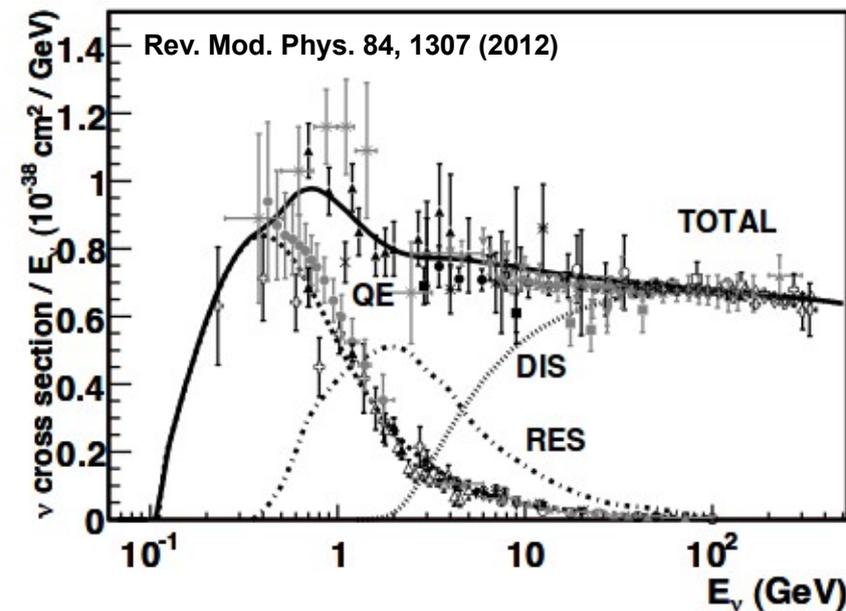
# MicroBooNE: Physics Motivation

## • Cross-section physics

- Understanding low energy cross-sections becoming crucial to many oscillation searches
  - *MicroBooNE is well situated to provide powerful insight in this region*
- Well understood cross-sections also a must for next generation long-baseline experiments
- See Tia Miceli talk about prospects of low  $Q^2$  Neutral Current cross-section measurements with MicroBooNE

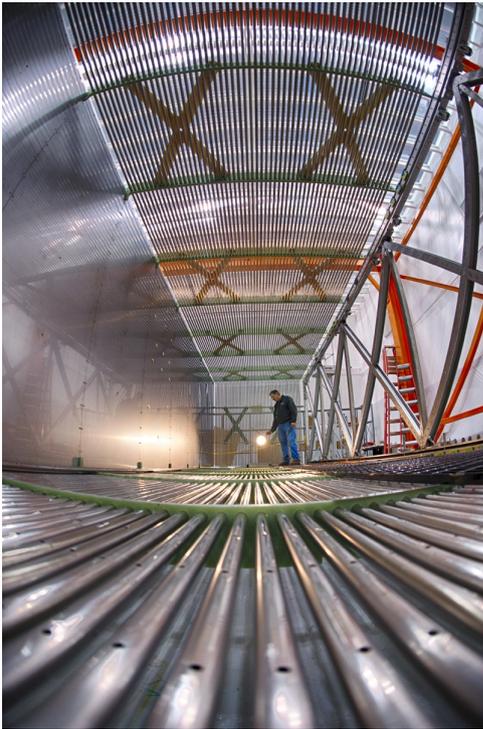
## • R&D physics

- MicroBooNE will also provide a testing ground for many physics R&D subjects
  - Supernova
    - Low energy electron reconstruction
  - Proton decay backgrounds
    - Study Kaon decays as background to “golden” channel  $p \rightarrow K^+ \nu_\mu$

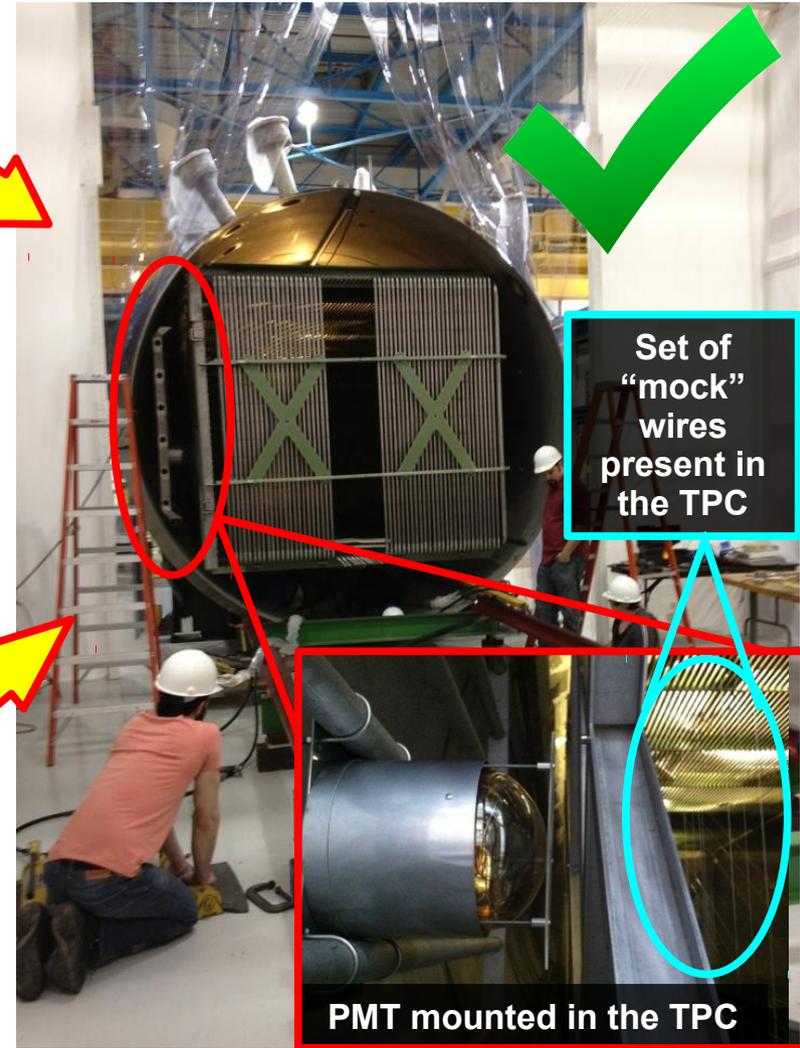


# MicroBooNE: Current Status

## TPC & Cryostat



**Major construction of the MicroBooNE TPC completed early in 2013**



Set of "mock" wires present in the TPC

PMT mounted in the TPC

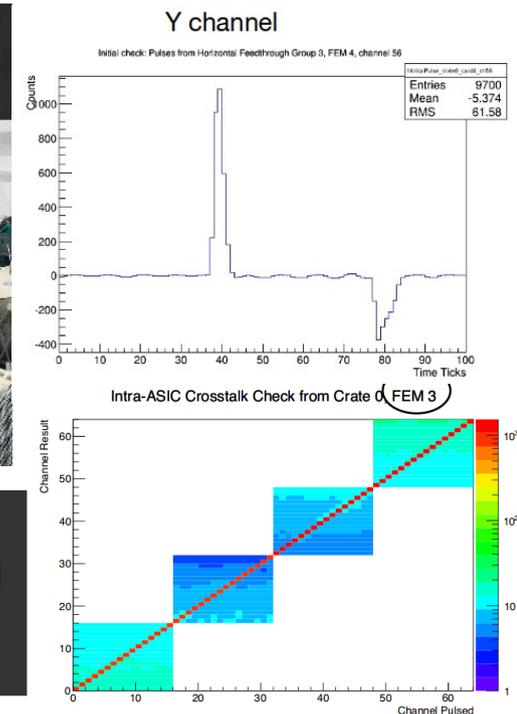
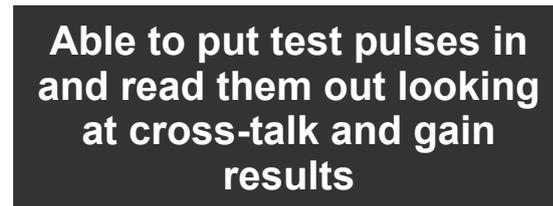
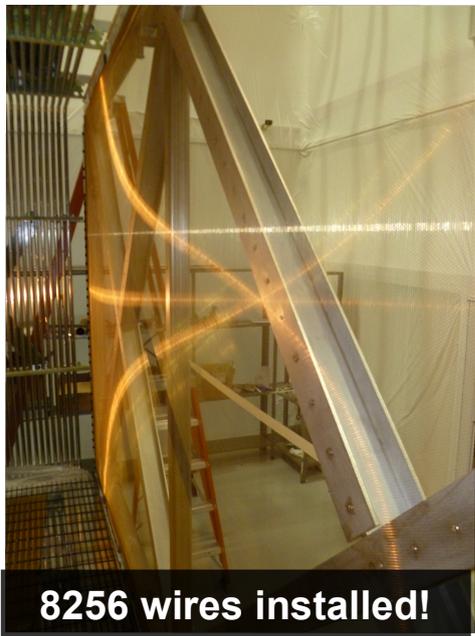
**With the arrival of the cryostat we performed a test fit of the TPC with test wires and PMT's present**



# MicroBooNE: Current Status

## Wire & Electronics Installation

Following a successful test fit, installation of the TPC wires and cold electronics was able to go forward



Preliminary tests are able to exercise the data acquisition system and verify the successful installation of all TPC wires

# MicroBooNE: Current Status

## PMT Installation



PMTs being prepared for installation



PMT cables being soldered



PMT being installed on mounting rack



Congratulations to our PMT Group



PMT flange and cables installed on the MicroBooNE cryostat



First rack installed



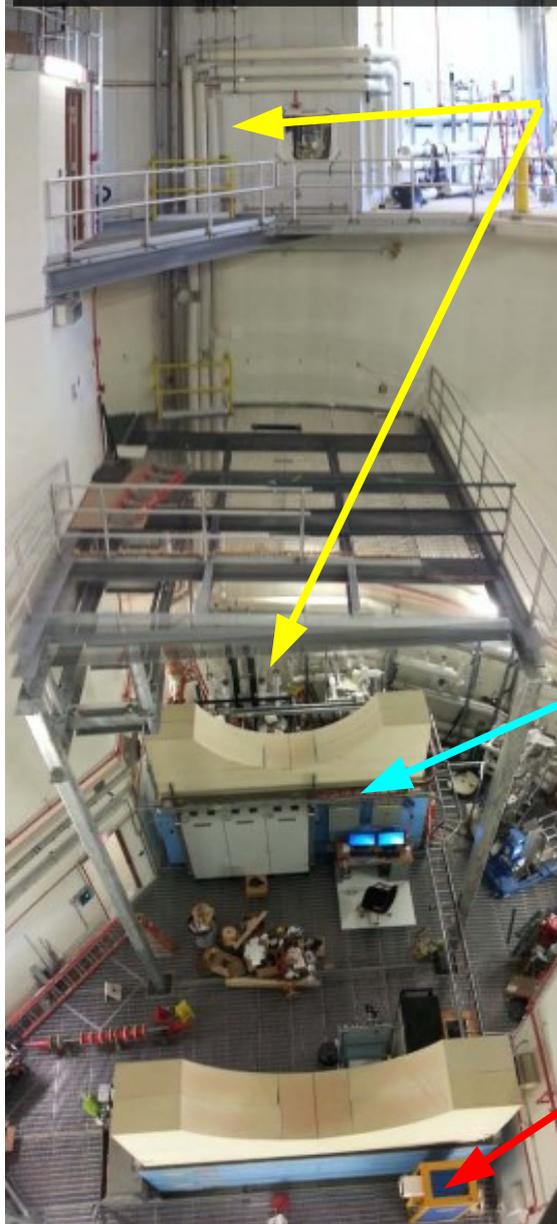
All 32 PMTs installed inside the cryostat (covered with dark bags for protection)

**First complete subsystem installed into the MicroBooNE cryostat!**

# MicroBooNE: Current Status

## Cryogenics and LArTF

Looking inside LArTF



Installation of cryogenic piping and vent lines leading into experiment cavern



Foam saddles and cryo-controllers



Physics already being done at LArTF!  
Taking cosmic ray data to measure the rate at LArTF

### Cryogenic installation proceeding at LArTF



New pristine building!

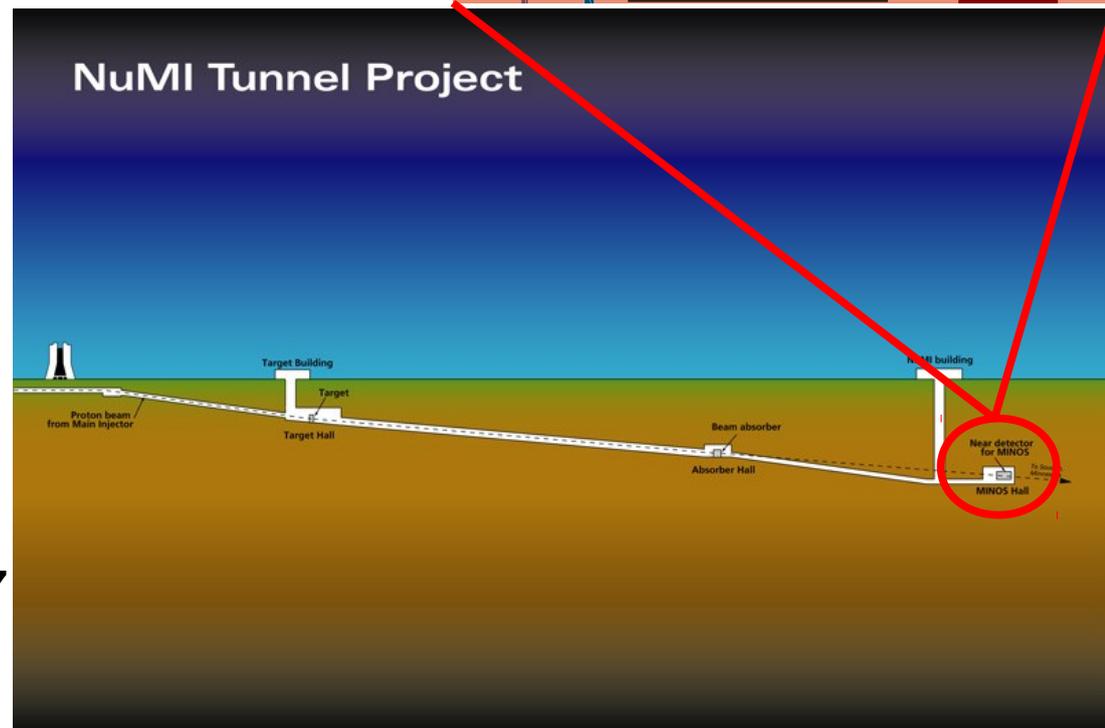
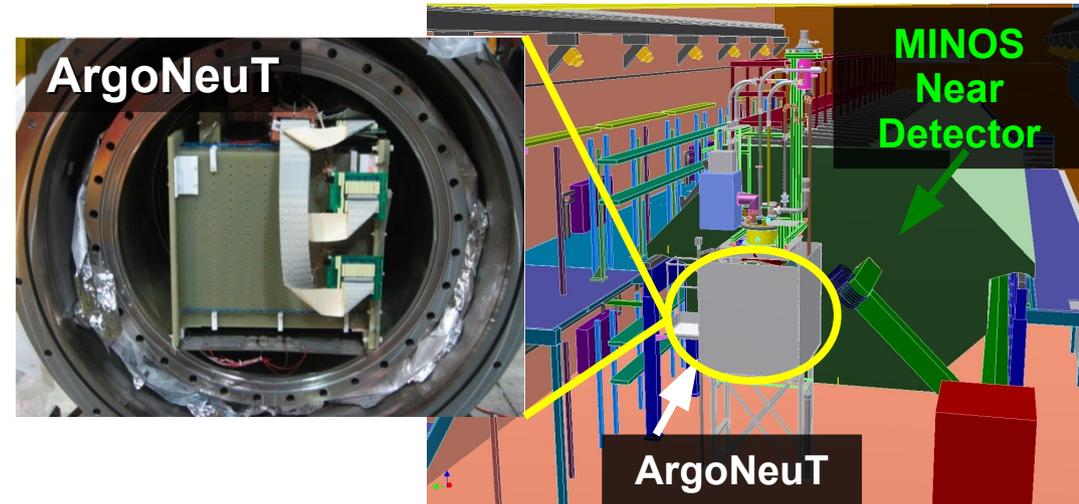


Dewars at LArTF



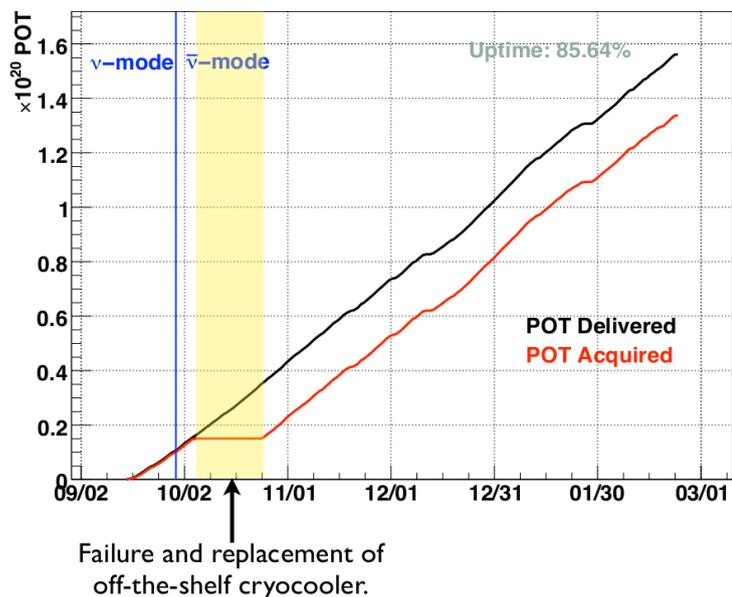
- While we are constructing MicroBooNE we are able to gain experience analyzing neutrino data thanks to ArgoNeuT!
- ArgoNeuT was the first Liquid Argon TPC in a neutrino beam in the U.S.
  - Located in the NuMI beam
  - Utilized the MINOS near detector as a muon spectrometer (sign determination)
  - 90 cm long x 40 cm tall x 47 cm wide (drift distance)

MINOS TDR: NUMI-L-337, FERMILAB-DESIGN-1998-02



# ArgoNeuT: Overview

ArgoNeuT POT delivered and accumulated



**All of these efforts inform MicroBooNE's physics program**

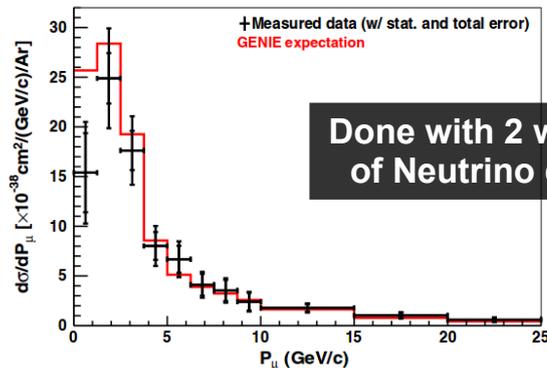
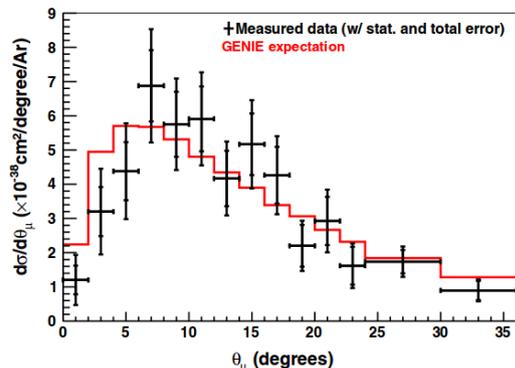
*(Not able to talk about all these analysis...just highlight a few)*

- **ArgoNeuT took data from 09/2009 – 02/2010**
  - 2 weeks in Neutrino mode ( $0.085 \times 10^{20}$  POT)
  - 4 months in Antineutrino mode ( $1.2 \times 10^{20}$  POT)
- **Collected neutrino data in the range of 0.1→20 GeV**
  - Measure  $\nu$ -Ar cross-sections
  - Study calibration of LAr detectors
  - Study nuclear effects
    - Final state interactions (FSI)
    - Short Range Correlation (SRC)
  - Develop automated reconstruction techniques

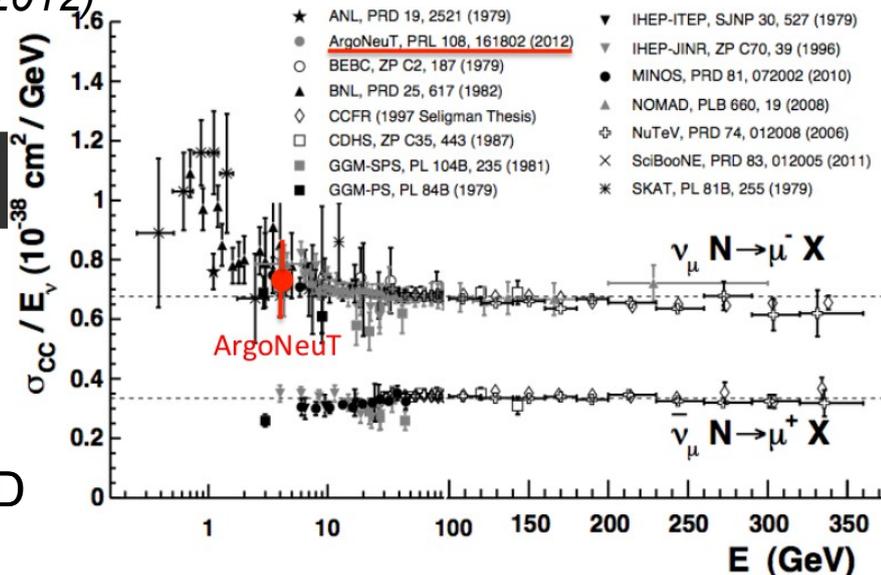
# ArgoNeuT: Physics Analysis

## Inclusive $\nu_\mu$ Charged Current Differential Cross-section

PRL 108, 161802 (2012)



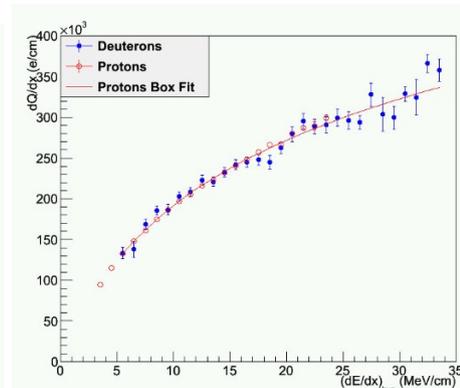
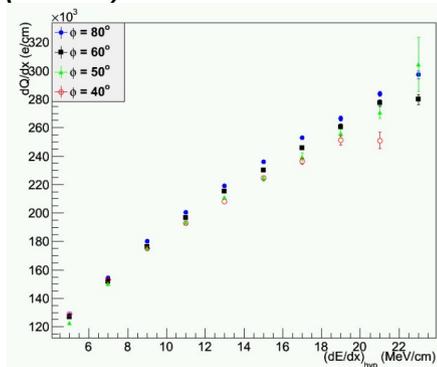
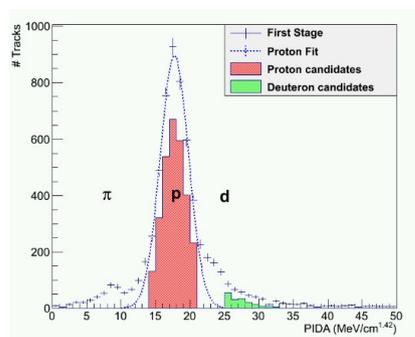
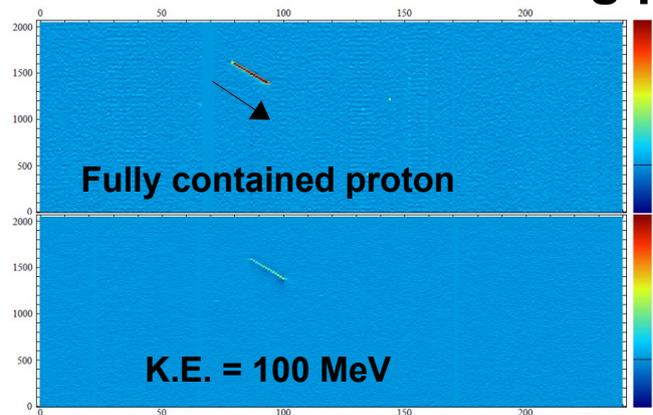
Done with 2 weeks  
of Neutrino data



Look for an interaction vertex in the fiducial volume  
Reconstruct a track which is matched to the MINOS ND  
Use MINOS for sign determination (choose  $\mu^-$ )

## A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC

JINST 8, P08005 (2013)



Study the electron-ion recombination effects using contained proton/deuteron samples found in ArgoNeuT

Results are consistent with those from ICARUS and extend the  $dE/dX$  range

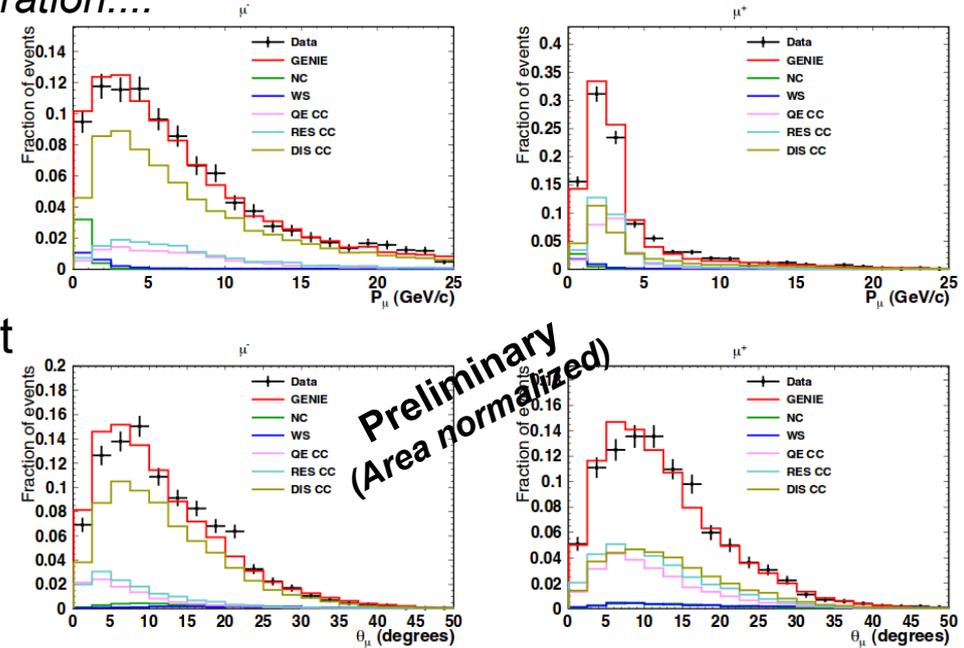
# ArgoNeuT: Ongoing Analysis

## Inclusive $\bar{\nu}_\mu$ Charged Current Differential Cross-section

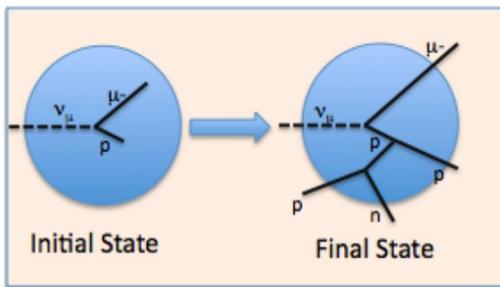
Paper in preparation....

### Measurement using Antineutrino Data

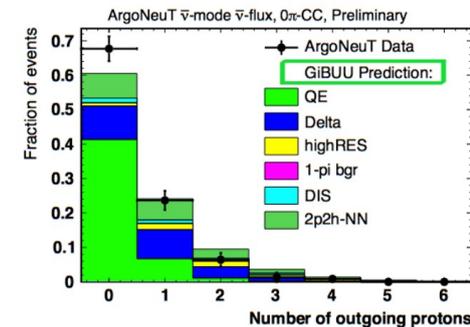
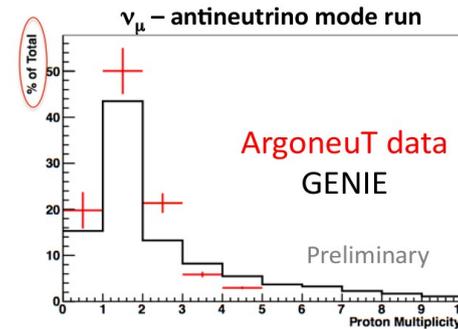
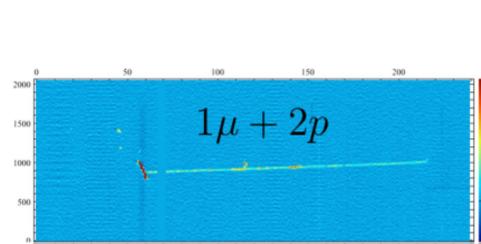
- Similar measurement to what was done using the neutrino data
- 8 times that data in Antineutrino mode
- Beam composition allows for  $\bar{\nu}_\mu$  &  $\nu_\mu$  measurement
- Use MINOS for sign determination (distinguish  $\mu^+$  &  $\mu^-$ )



## Study of Nuclear Final State Interactions (FSI)

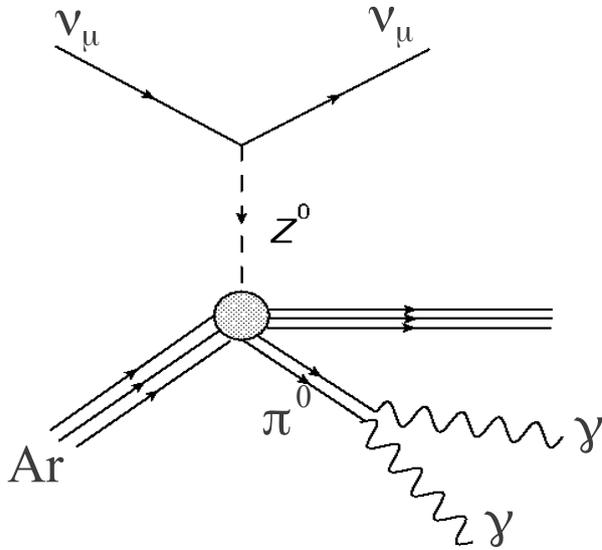


Nuclear effects play a interesting role in  $\nu$ -Nucleus scattering



LAr is excellently suited to study proton multiplicity in quasi-elastic events and compare to various FSI models

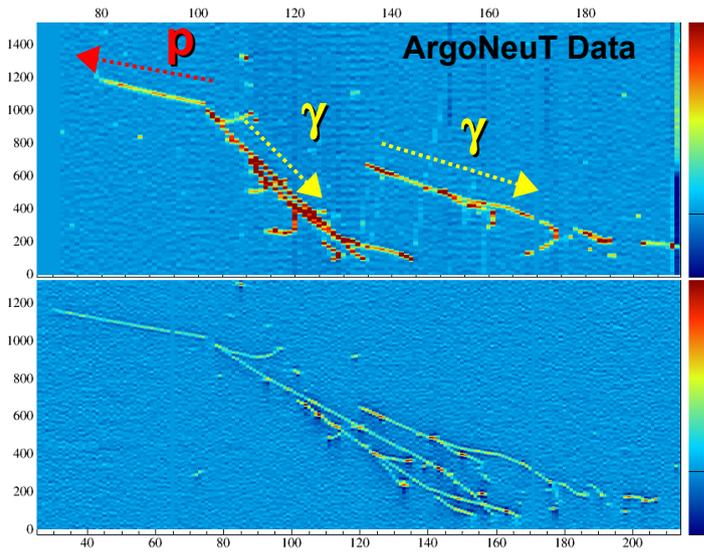
# ArgoNeuT: Neutral Current $\pi^0$ analysis



An interesting, and particularly important, channel for both oscillation searches and cross-section measurements comes from neutral current  $\pi^0$  production.

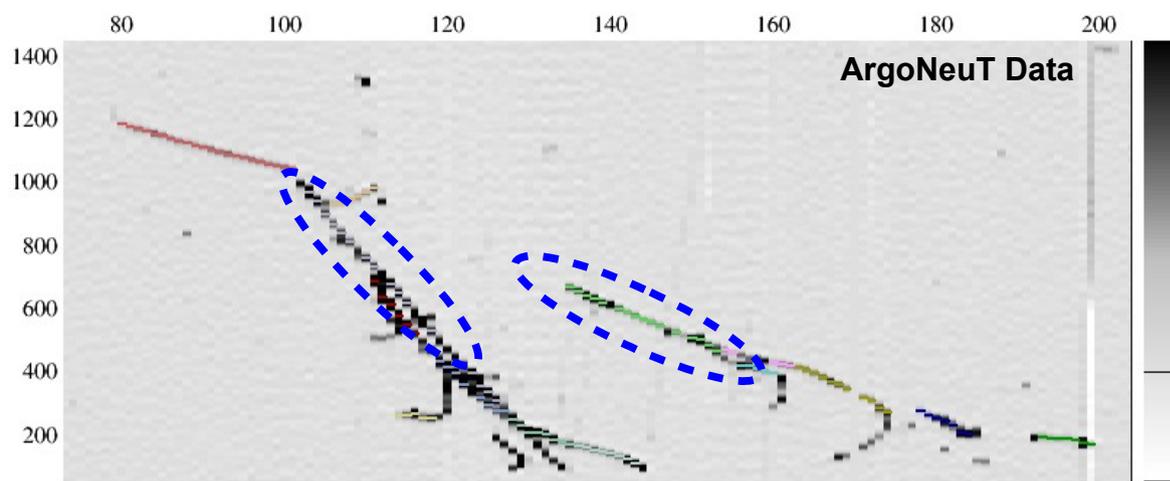
- Particularly insidious background for  $\nu_e$  appearance searches
- Notoriously difficult topology to reconstruct

The ArgoNeuT detector is too small to contain the majority of photon showers produced from  $\pi^0$ 's



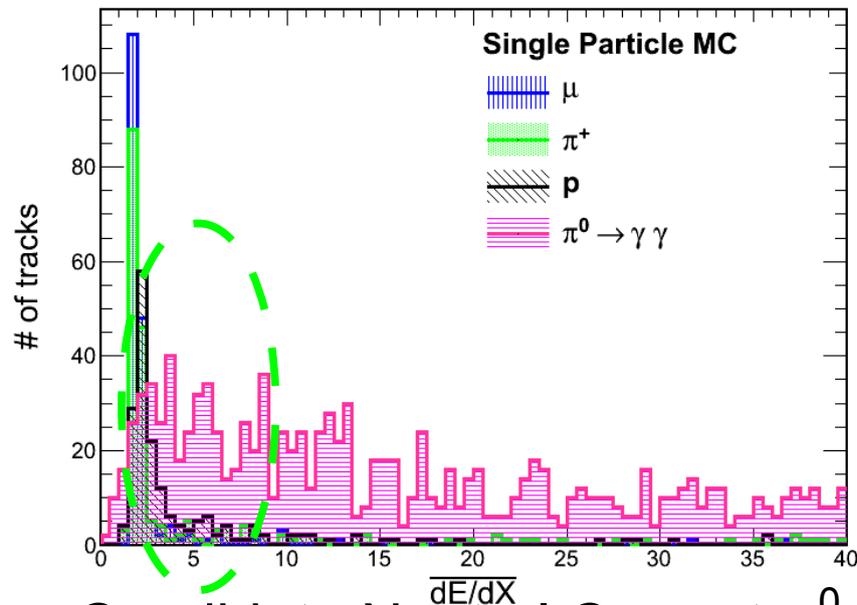
- However, it may still be possible to utilize this data and look for NC  $\pi^0$  production
- Select a sample of events likely to be neutral current
  - Require no track matched to MINOS ND
  - Require at least to clusters of energy found in each view
  - Require a reconstructed vertex in the detector
  - ...

# ArgoNeuT: Neutral Current $\pi^0$ analysis

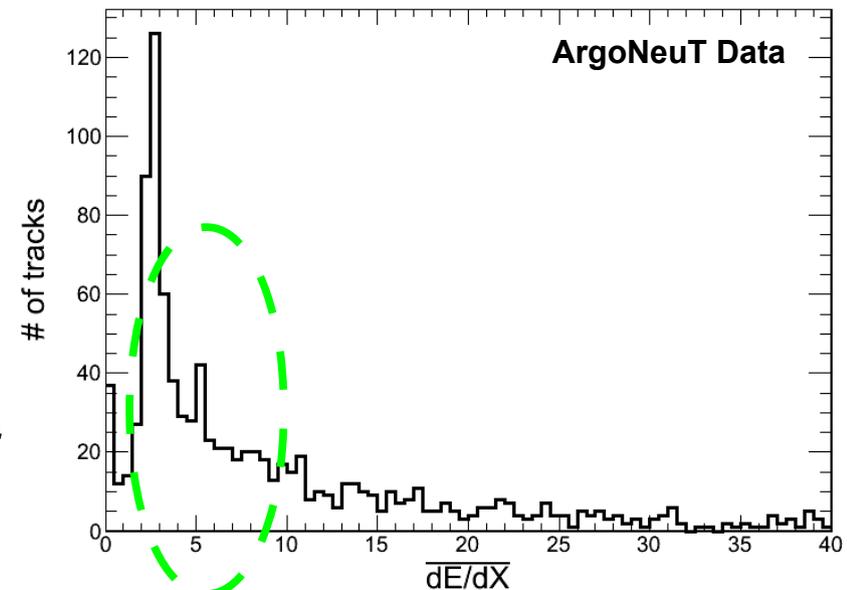


Break the clusters into smaller “track-like” segments and reconstruct the shower’s “track-segments” and analyze the  $dE/dX$  profile of the track segments

v Data



Looking at the  $dE/dX$  of these “track-segments” in MC and data show early promise of potential event discrimination



Candidate Neutral Current  $\pi^0$  events should have two highly ionizing “track-segments” pointed back to a common point (the event vertex)

**Studies continue to reconstruct these events...**

# Conclusions

- **Liquid Argon Time Projection Chambers continue to provide insight into neutrino interactions with “bubble chamber-like” granularity**
- **MicroBooNE is the next of the LAr experiments to come online in 2014**
  - Installation of all the MicroBooNE subsystems continues to make progress
  - The first complete subsystem was just installed into the cryostat
- **Data collected by the ArgoNeuT experiment provide a proving ground for the physics that can be done with LArTPC's**
  - Many analysis already published and more coming in the months ahead.

**Thank you very much  
for your attention!**





# **Backup Slides**