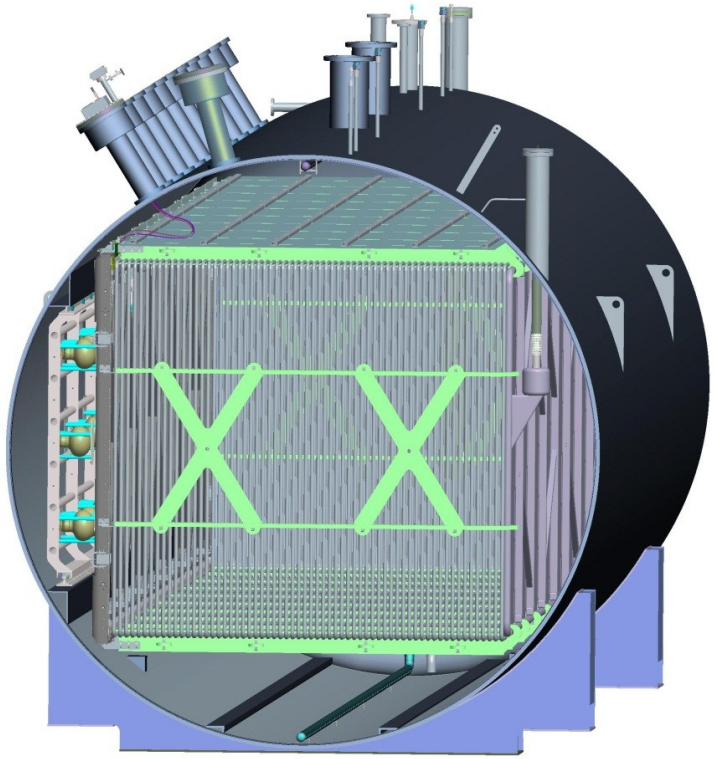
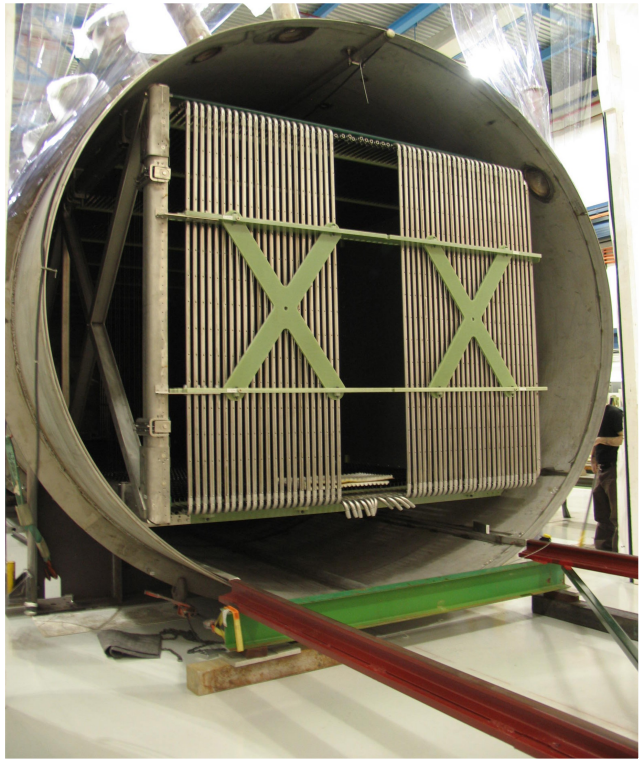


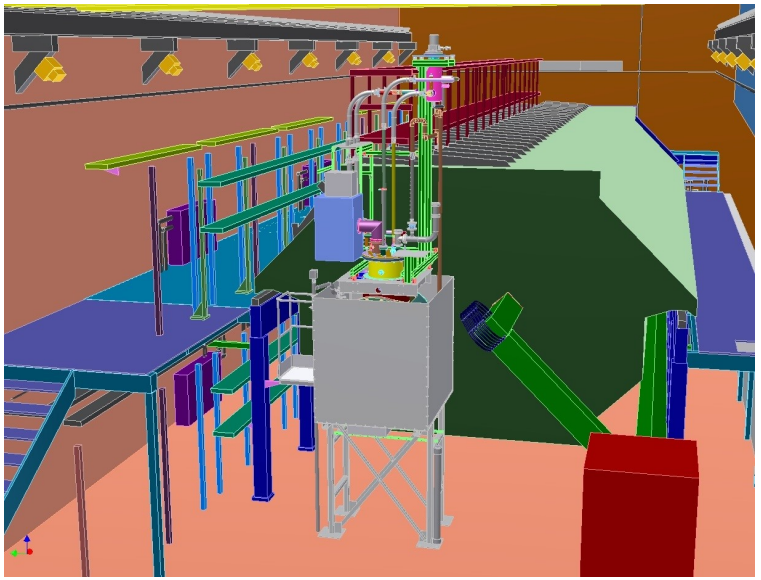


2013
TAUP
Asilomar
September 8-13

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 π^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^3]	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 [γ/MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [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

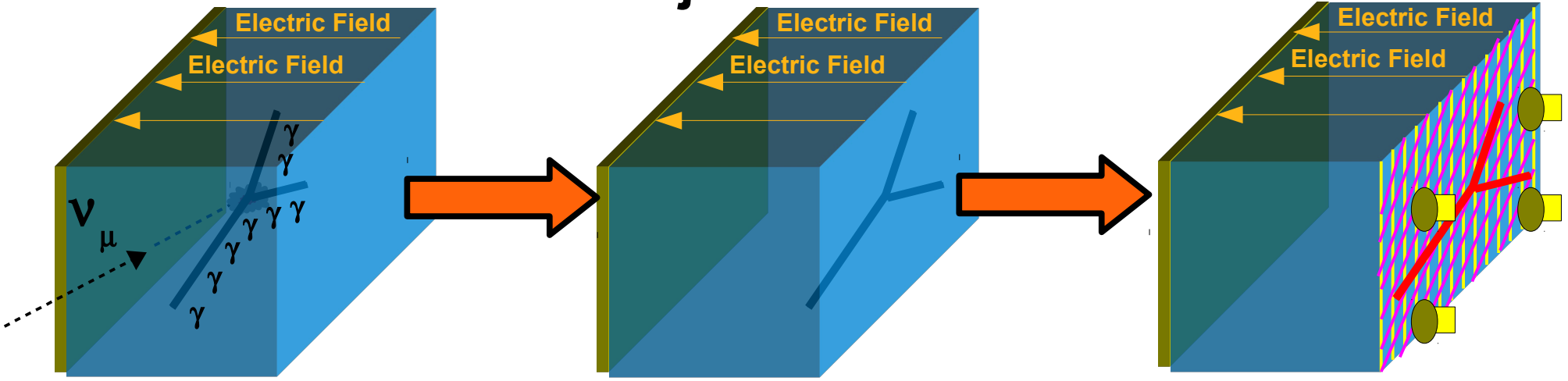
→ **Abundant**
1% of the atmosphere

→ **Ionizes easily**
55,000 electrons / cm

→ **High electron lifetime**
Greek name means "lazy"

→ **Produces copious scintillation light**
Transparent to light produced

Time Projection Chamber



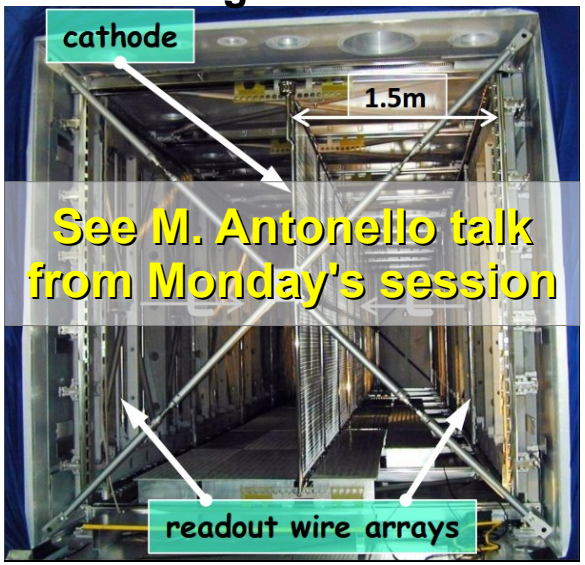
Neutrino interaction in LAr produces ionization and scintillation light

Drift the ionization charge in a uniform electric field

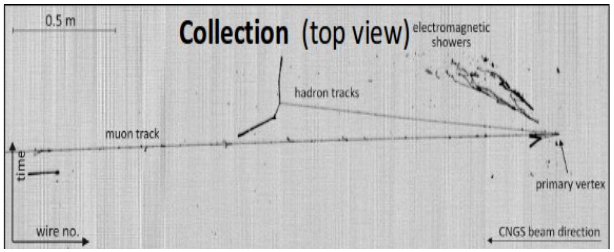
Read out charge and light produced using precision wires and PMT's

Examples of LArTPC's

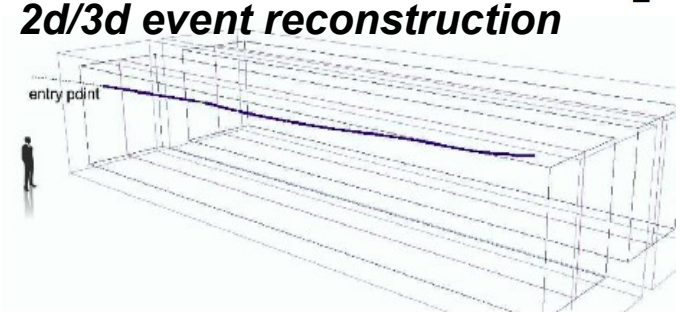
ICARUS @ CNGS
First Large LArTPC



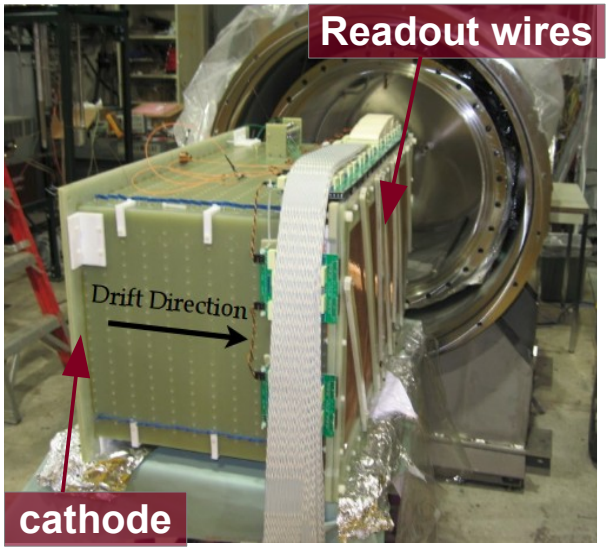
476 tons (active mass)
1.5 meter drift
53,000 wires (3mm pitch)



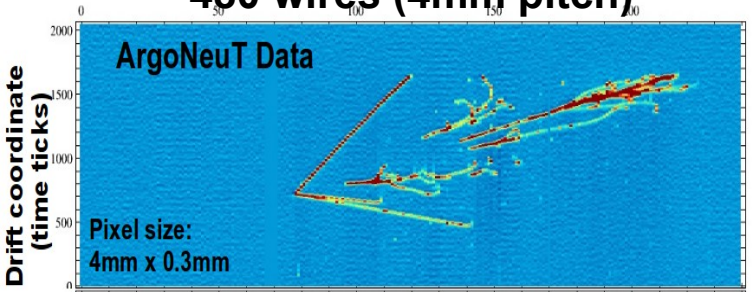
2d/3d event reconstruction



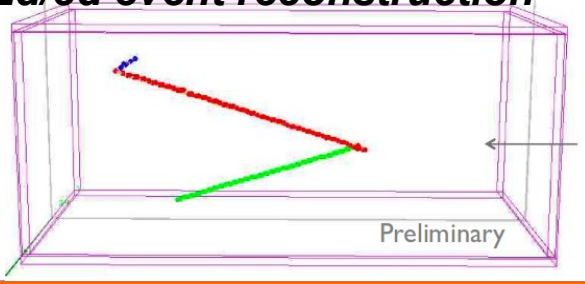
ArgoNeuT @ NuMI
First LArTPC in the U.S.



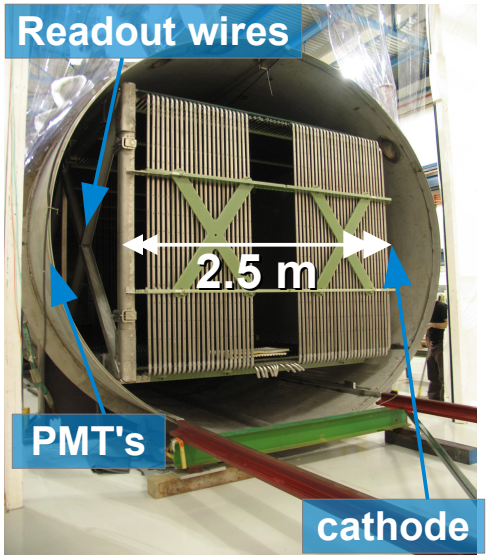
0.26 Tons (active mass)
0.47 meter drift
480 wires (4mm pitch)



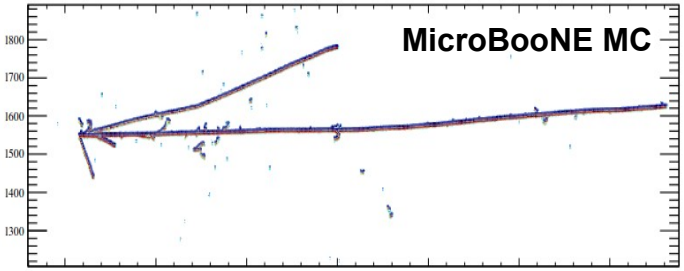
2d/3d event reconstruction



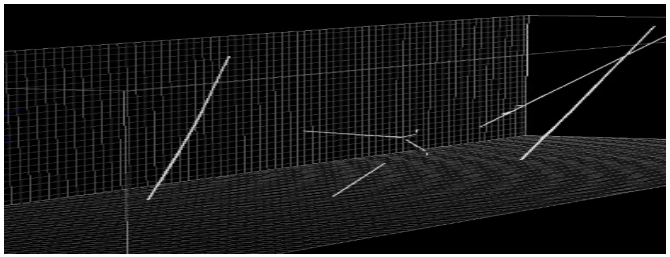
MicroBooNE @ BNB
First Large LArTPC in the U.S.



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

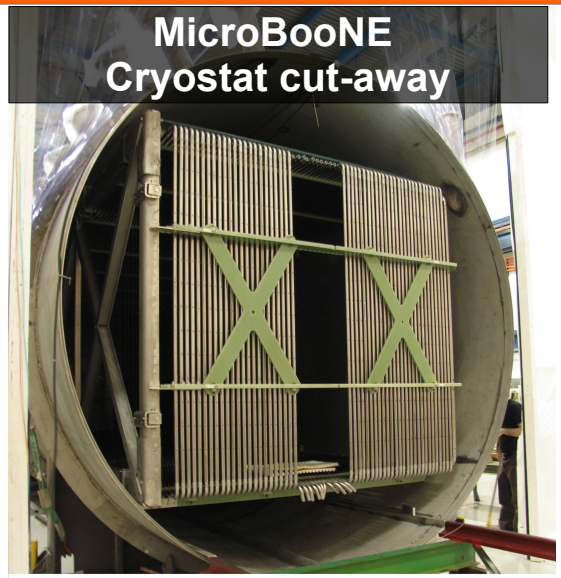


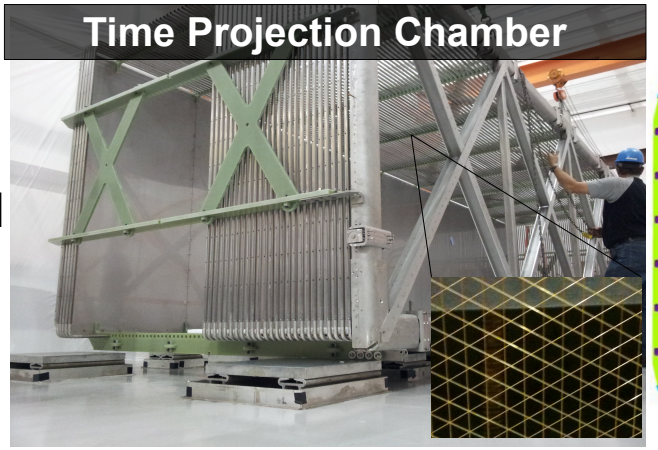
2d/3d event reconstruction

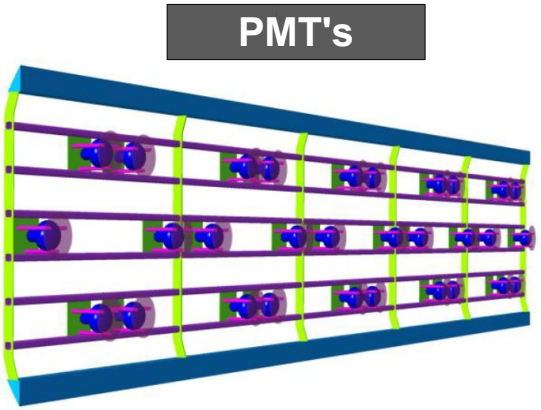


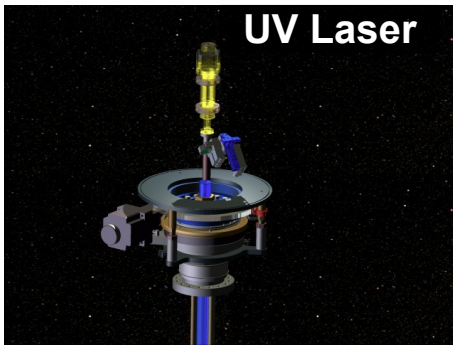
MicroBooNE: Overview

- **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**
  - 3456 Collection channels
    - Wires oriented w.r.t. the vertical
  - 4800 Induction channels
    - Wires oriented +/- 60^0
- **32 8" cryogenic PMT's**
  - Provides event t_0 as well as cosmic ray removal
- **UV Laser Calibration System**

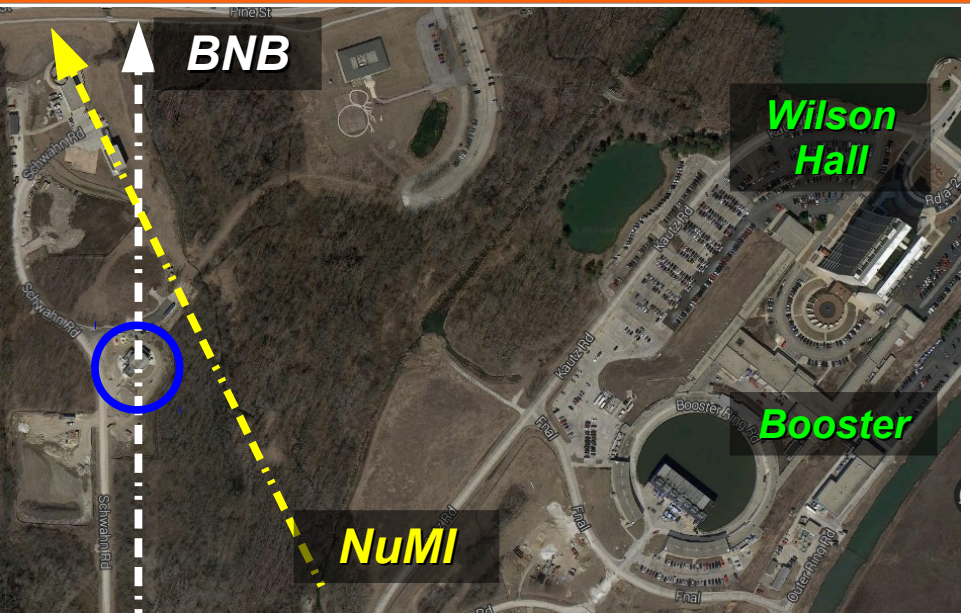






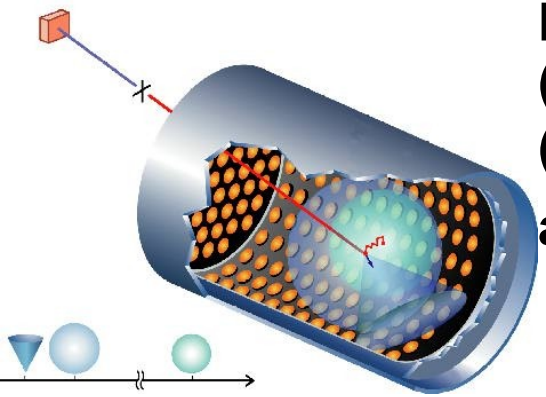


MicroBooNE: Overview



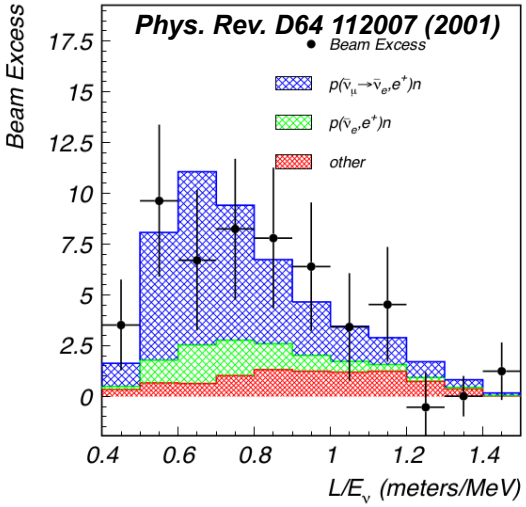
- **MicroBooNE will be located at Fermilab's Liquid Argon Test Facility (LArTF)**
  - Will see the Booster Neutrino Beam (BNB) and off-axis Neutrinos from the Main Injector (NuMI) beam
  - Two beams provide both a low energy and high energy source of neutrinos
    - Booster beam is created from 8 GeV protons on a beryllium target
      - Mean neutrino energy → < 1 GeV
    - NuMI beam created from 120 GeV protons on a carbon target
      - Mean neutrino energy → ~ # GeV

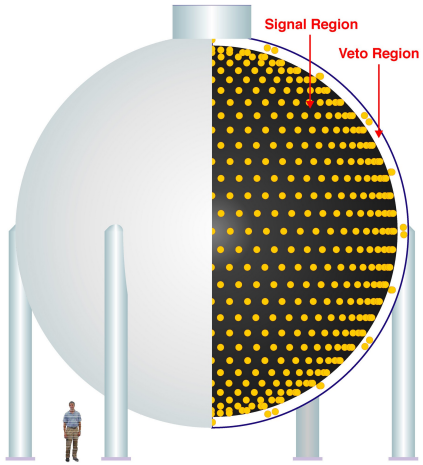
MicroBooNE: Physics Motivation



Liquid Scintillator Neutrino Detector (LSND) observes an excess of events (3.8σ above background) in $\nu_\mu \rightarrow \nu_e$ appearance search

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



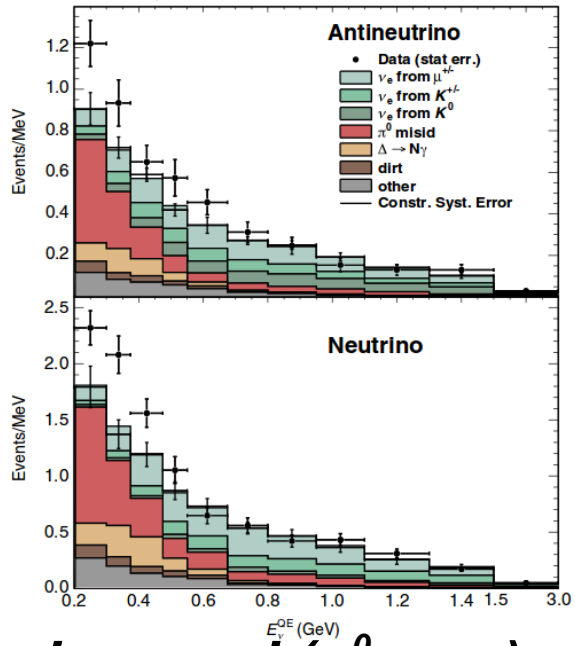


Mini-Booster Neutrino Experiment (MiniBooNE) runs at a similar L/E and sees a slightly different excess in $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_e$ appearance search

→ Effect dominates at low energy
- *Between 0.2 – 0.5 GeV*

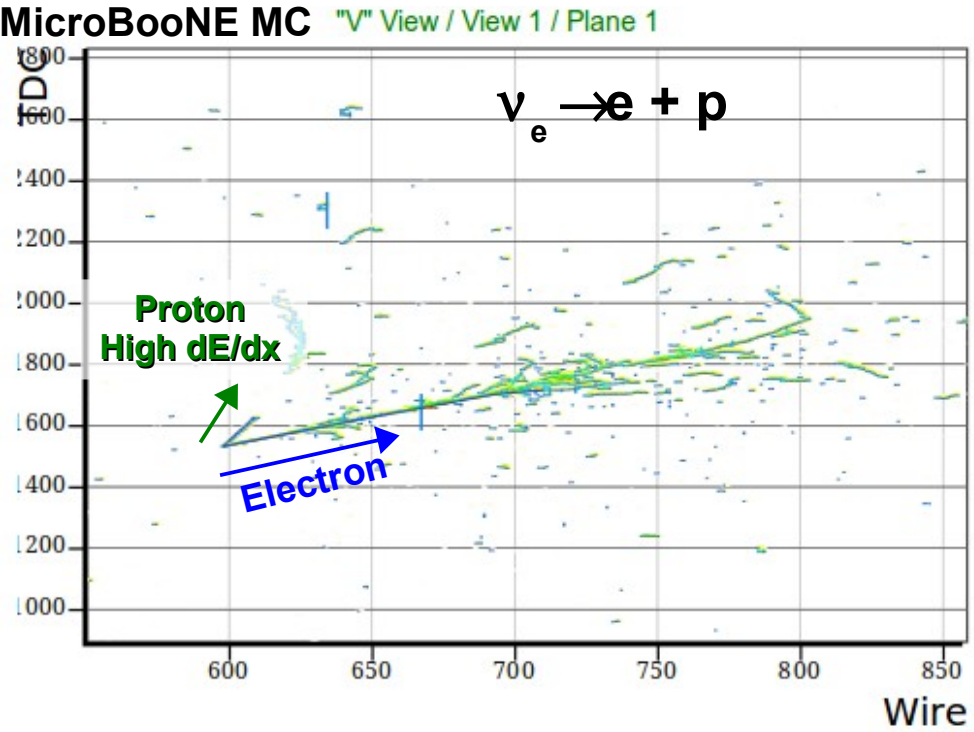
→ Insidious backgrounds dominate
→ *Tough to distinguish $\pi^0 \rightarrow \gamma\gamma$ from e^- signature*

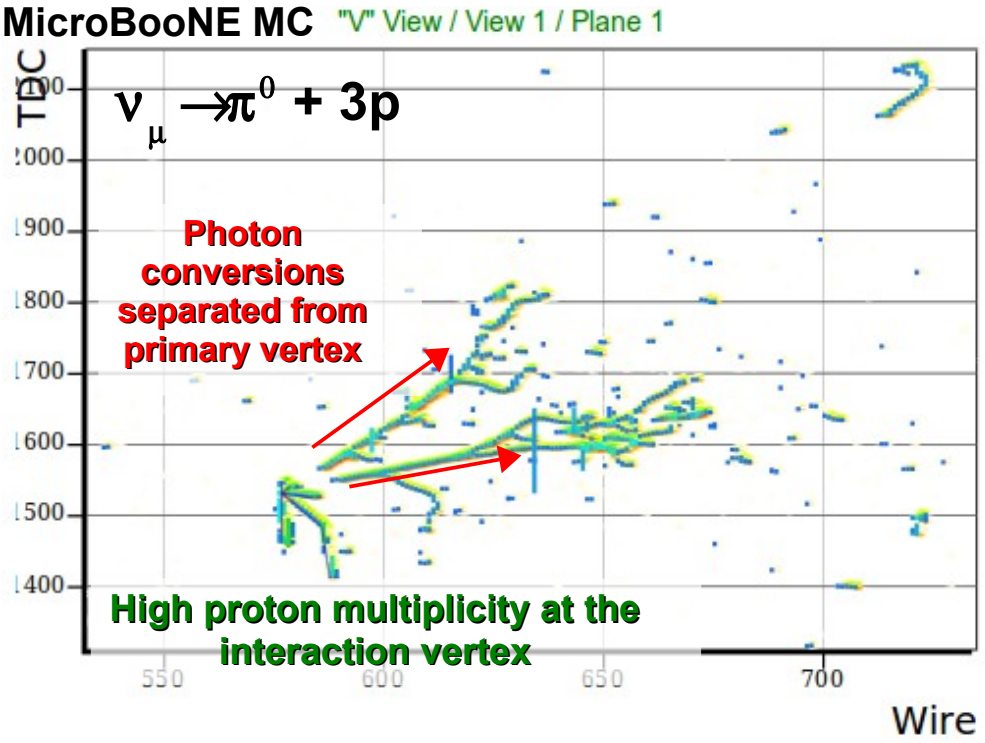
Phys Rev Lett. 110, 16180 (2013)

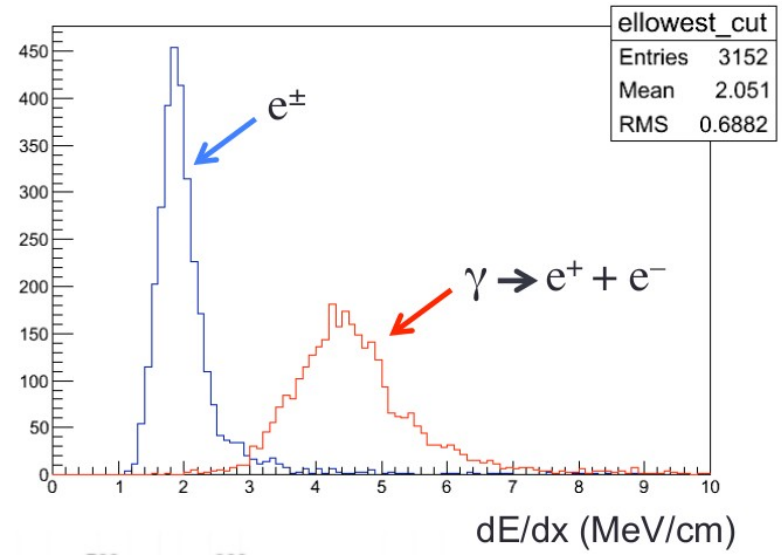


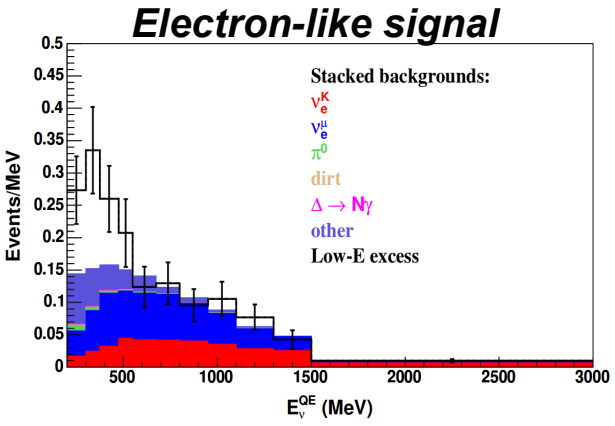
Liquid Argon TPC's offer the ability to distinguish background ($\pi^0 \rightarrow \gamma\gamma$) from signal ($\nu_e$ appearance) and address both of these anomalies

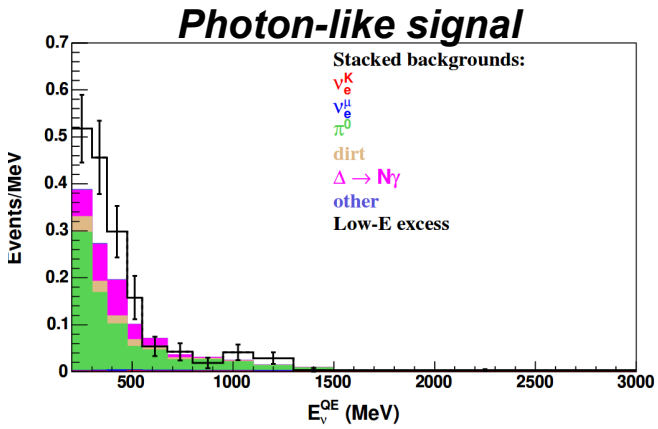
MicroBooNE: Physics Motivation





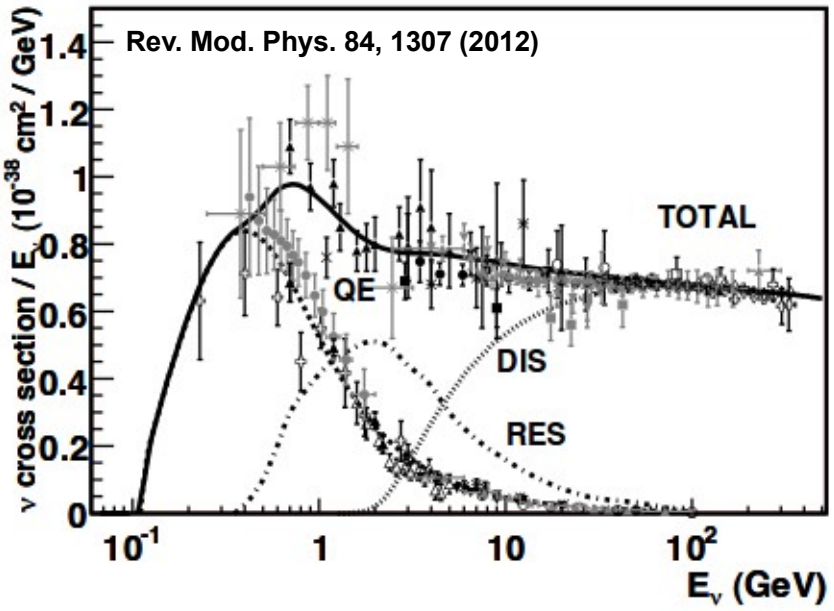


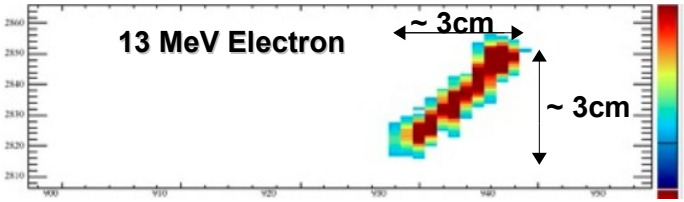




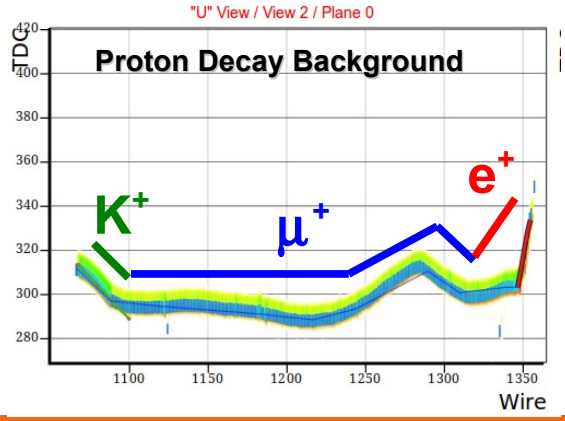
MicroBooNE can do more than just oscillation physics!

MicroBooNE: Physics Motivation





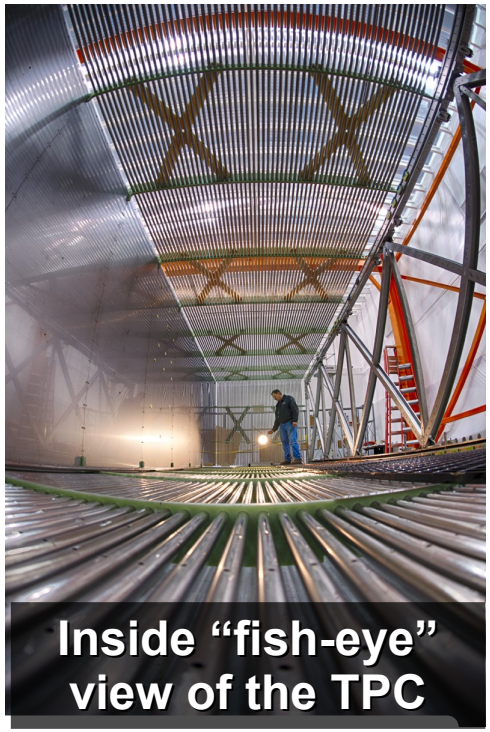
Low energy electron



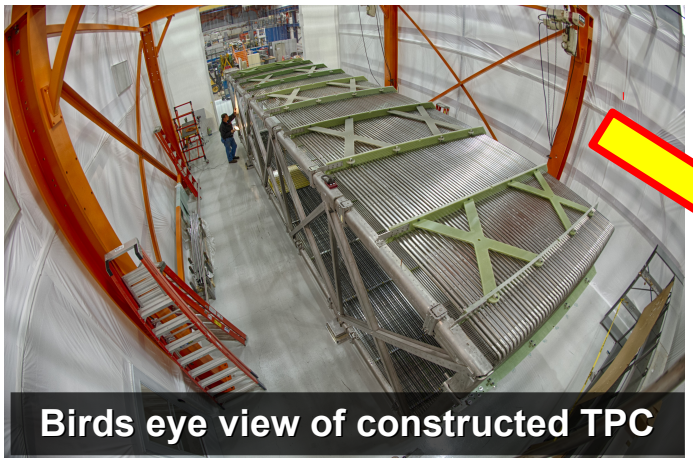
- **Cross-section physics**
  - Understanding low energy cross-sections crucial to many oscillation searches
    - *MicroBooNE will provide powerful insight*
    - *E.g. nuclear models of final state interactions* ***(See ArgoNeuT analysis later in this talk)***
  - Well understood cross-sections also 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



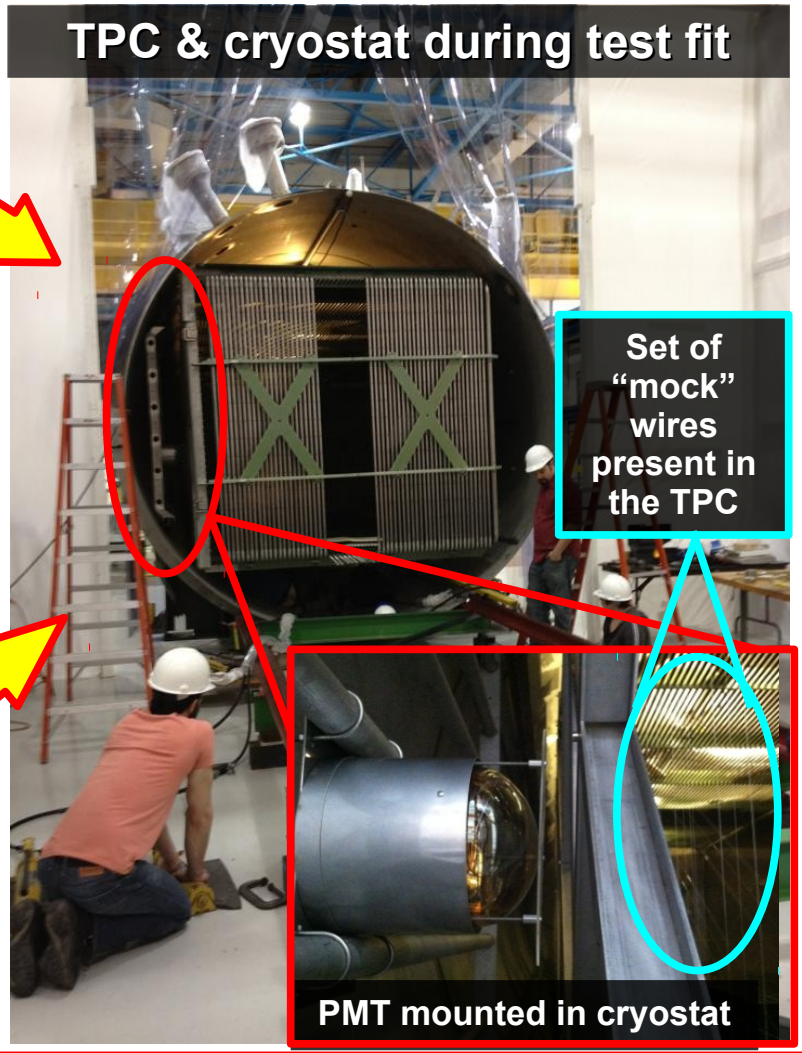
Inside "fish-eye" view of the TPC



Birds eye view of constructed TPC

Major construction of the MicroBooNE TPC completed early in 2013

TPC & cryostat during test fit



Set of "mock" wires present in the TPC

PMT mounted in cryostat

MicroBooNE cryostat arriving at Fermilab

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

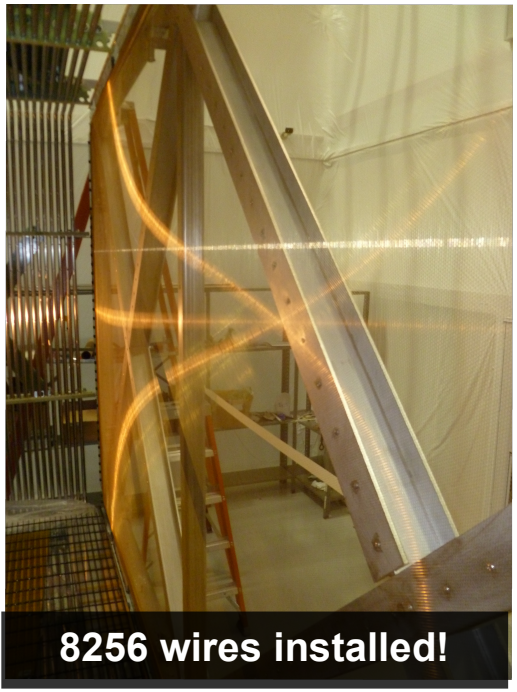
MicroBooNE: Current Status

Wire & Electronics Installation

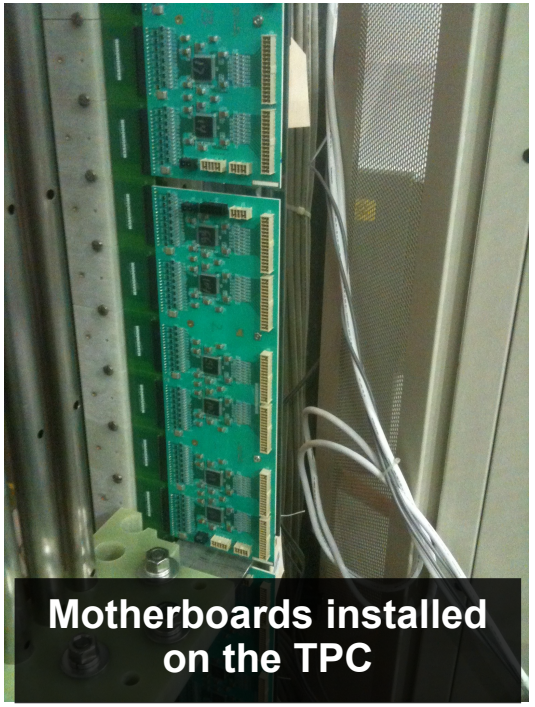
Following a successful test fit, installation of the TPC wires and cold electronics was able to go forward

Wire installation team

View of wires being installed



8256 wires installed!



Motherboards installed on the TPC

Able to test one complete feedthrough at a time

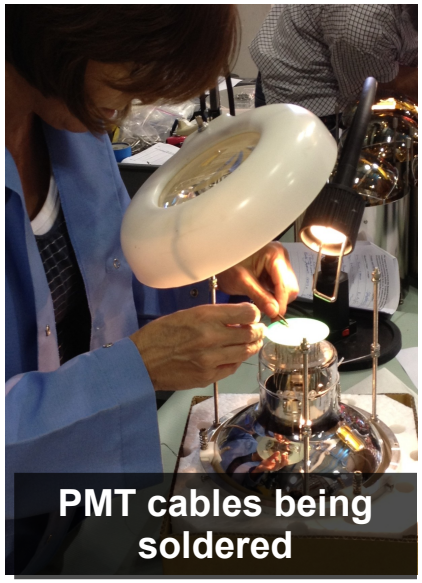
Read pulses in and out looking at cross-talk and gain results

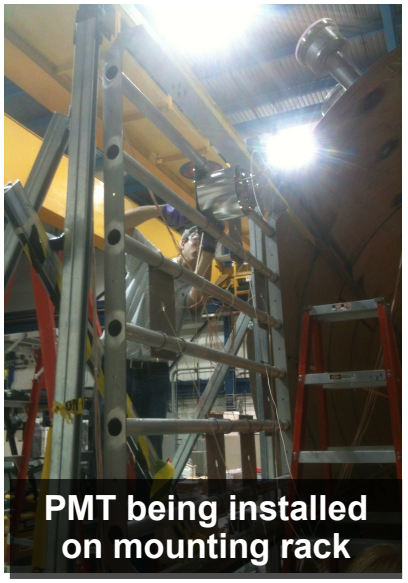
Preliminary tests are able to exercise the data acquisition system and verify the successful installation of all TPC wires

MicroBooNE: Current Status

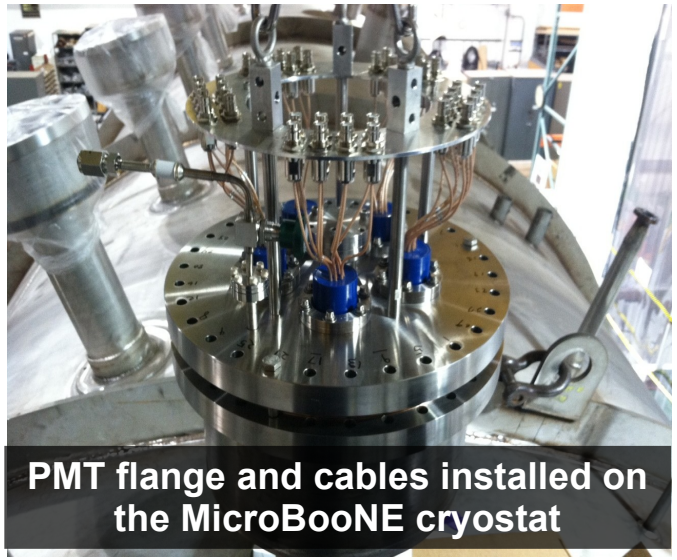
PMT Installation


PMTs being prepared for installation


PMT cables being soldered


PMT being installed on mounting rack


The PMT Group


PMT flange and cables installed on the MicroBooNE cryostat

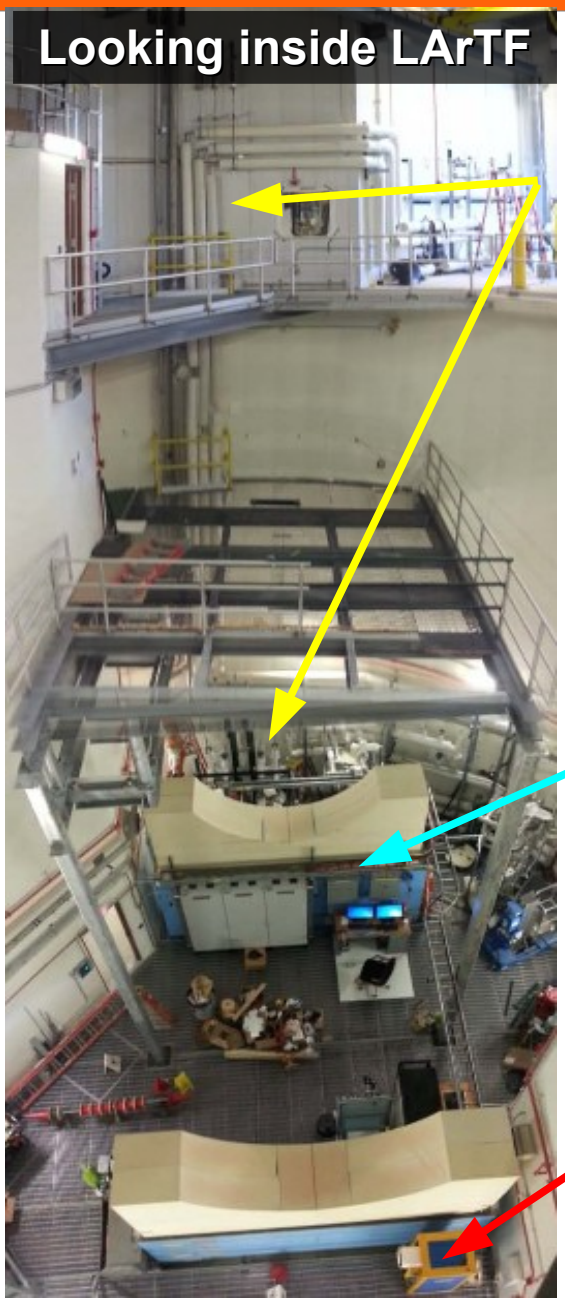

First rack installed


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

First complete subsystem installed in the cryostat!

MicroBooNE: Current Status

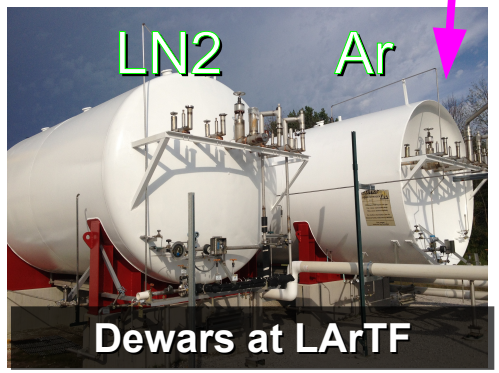
Cryogenics and LArTF



Installation of cryogenic piping and vent lines leading into experiment cavern

Cryogenic installation proceeding at LArTF

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

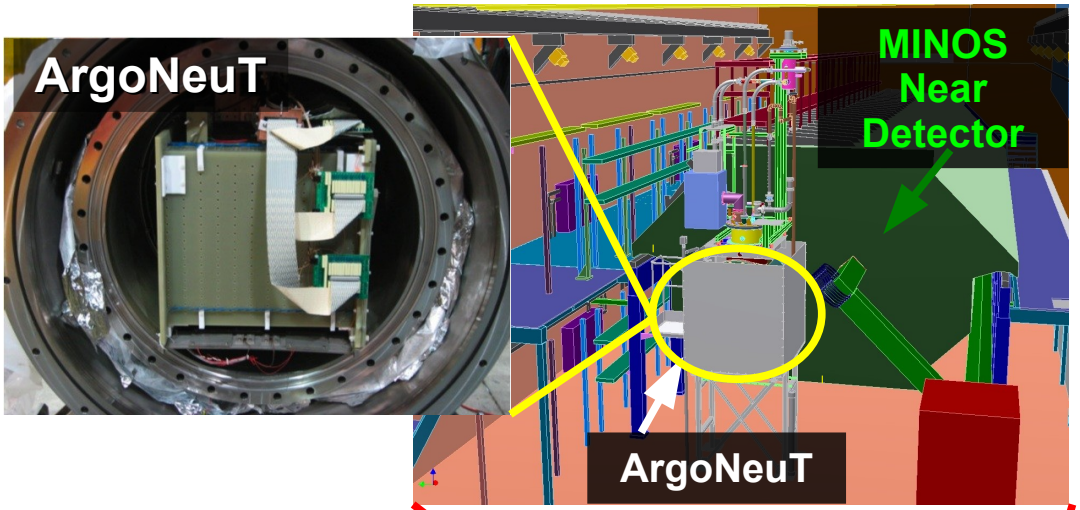


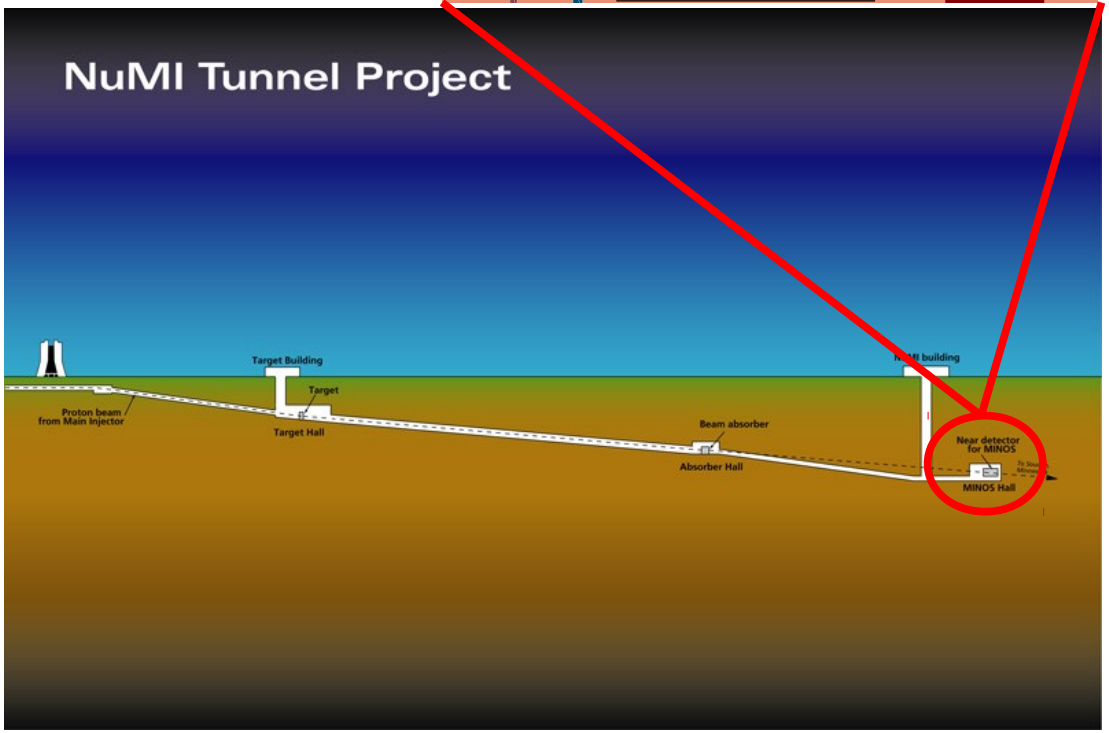
ArgoNeuT
(Argon Neutrino Teststand)

ArgoNeuT

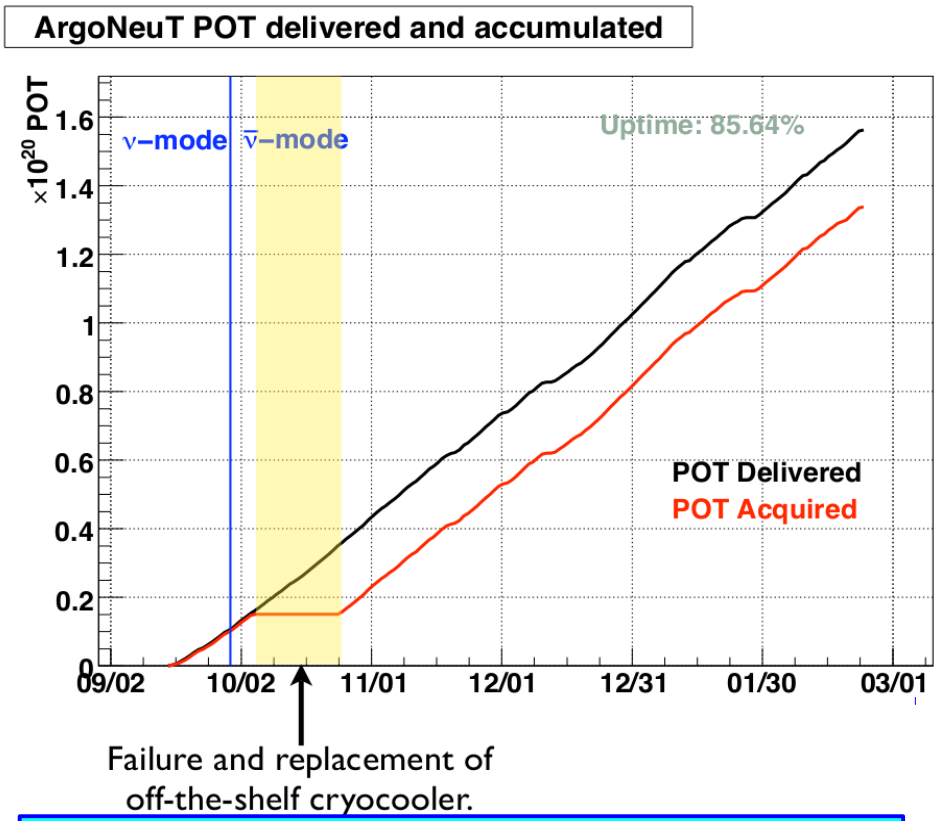
- **While we are constructing MicroBooNE we are able to gain experience analyzing neutrino data thanks to ArgoNeuT!**
- **ArgoNeuT was the first Liquid Argon TPC in a neutrino beam in the U.S.**
  - Located in the NuMI beam
  - Utilized the MINOS near detector as a muon spectrometer (sign & momentum 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



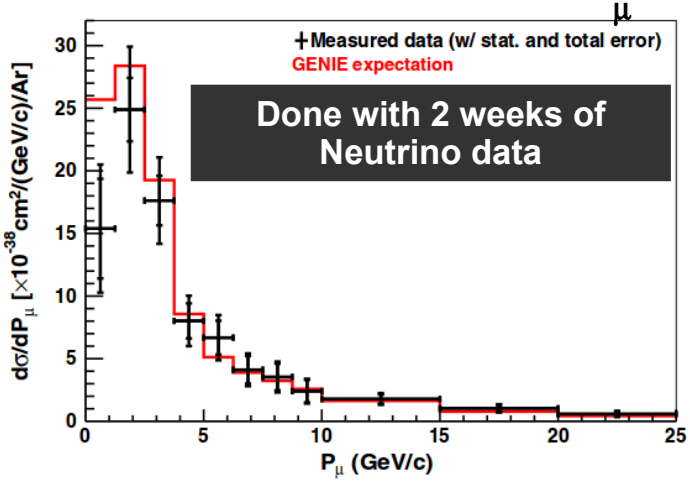
- **ArgoNeuT took data from 09/2009 – 02/2010**
  - 2 weeks in Neutrino mode (0.085 x10^{20} POT)
  - 4 months in Antineutrino mode (1.2 x 10^{20} POT)
- **Collected neutrino data in the range of 0.1→20 GeV**
  - Measure ν-Ar cross-sections
  - Study calibration of LAr detectors
  - Study nuclear effects
    - Final state interactions (FSI)
    - Nucleon/Nucleon Correlation
  - Develop automated reconstruction techniques

All of these efforts inform MicroBooNE's physics program

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

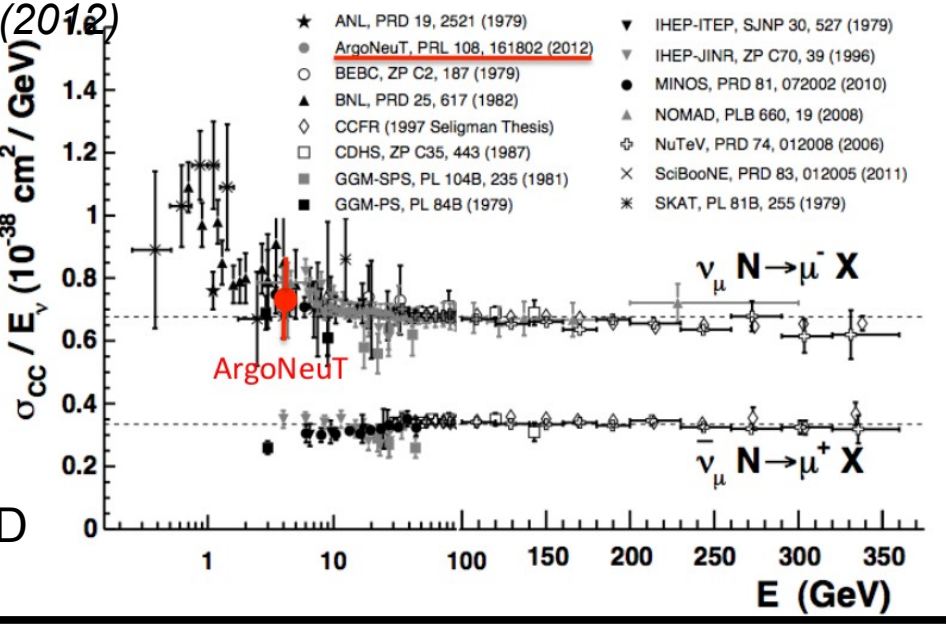
ArgoNeuT: Physics Analysis

Inclusive ν_μ Charged Current Differential Cross-section



PRL 108, 161802 (2012)

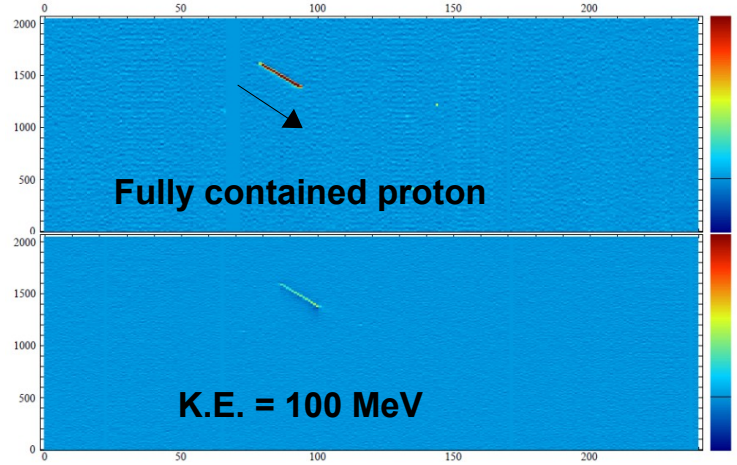
First neutrino cross-section measured on Argon!

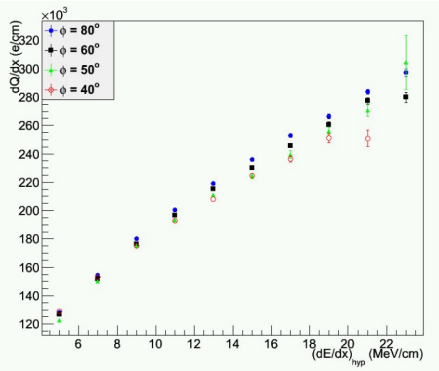


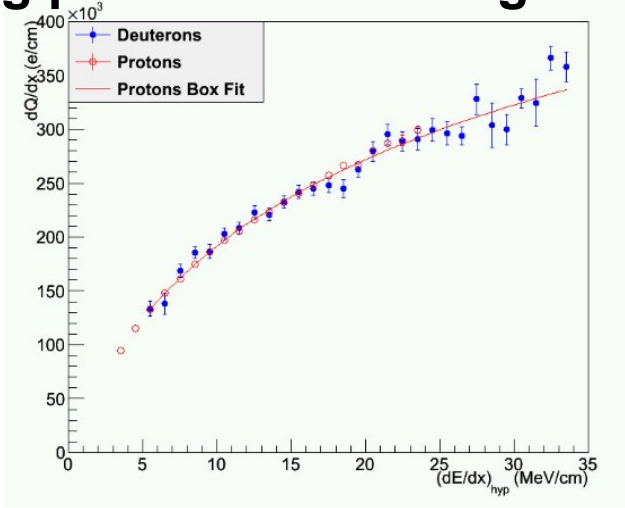
Look for an interaction vertex in the fiducial volume
Reconstruct a track which is matched to the MINOS ND
Use MINOS for sign determination (choose μ^-)

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

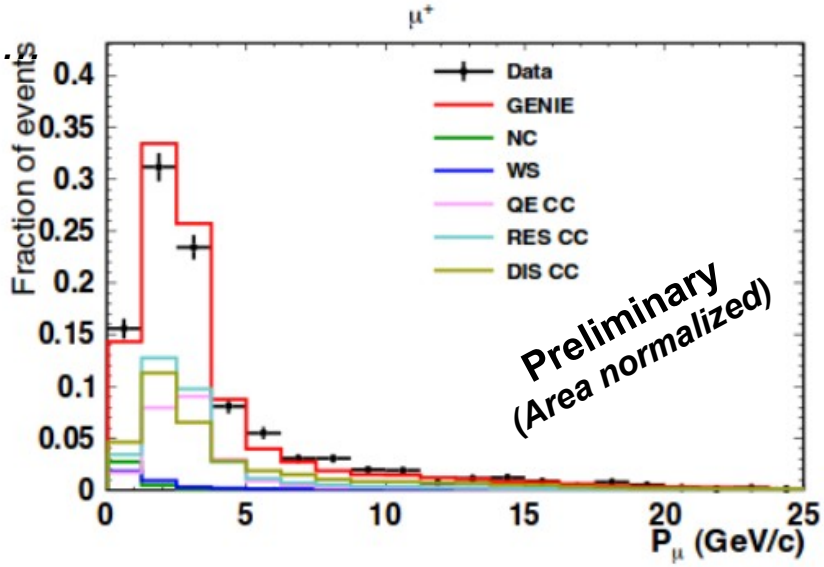
ArgoNeuT: Ongoing Analysis

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

Paper in preparation...

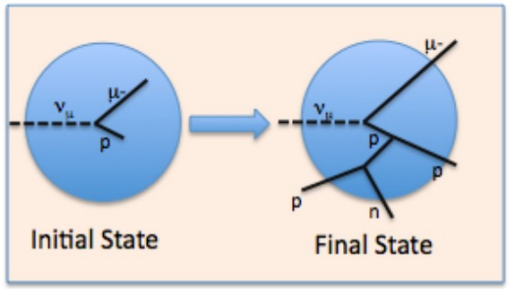
Measurement using Antineutrino Data

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

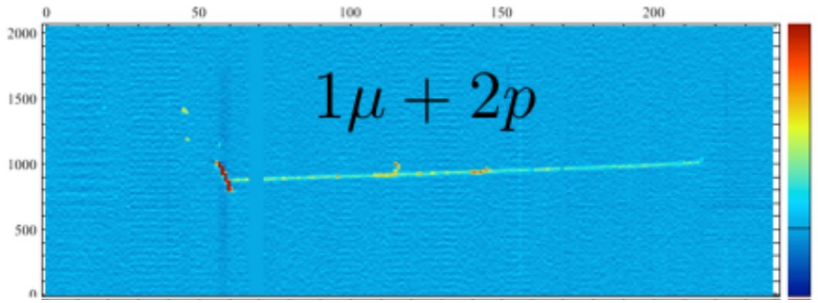


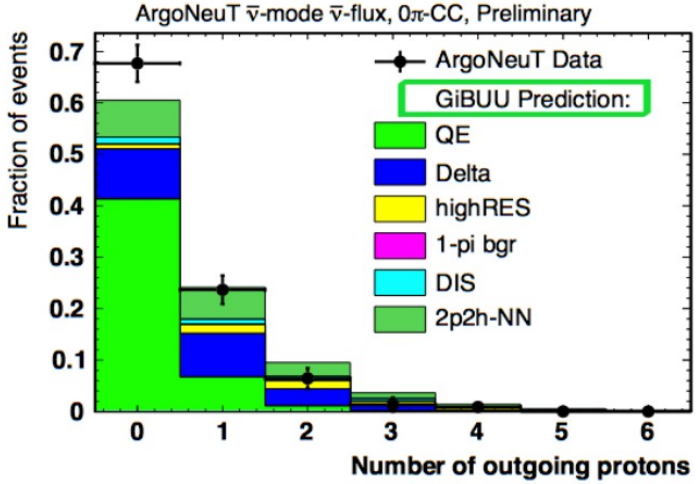
Study of Nuclear Final State Interactions (FSI)

Paper in preparation....



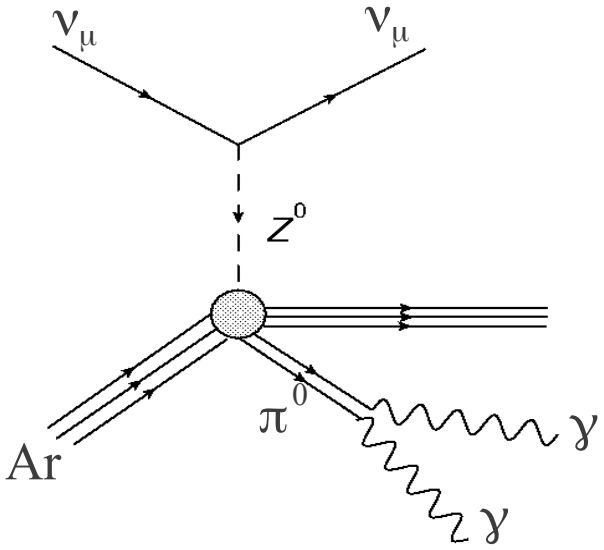
Nuclear effects play a interesting role in ν-Nucleus scattering





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

ArgoNeuT: Neutral Current π^0 analysis

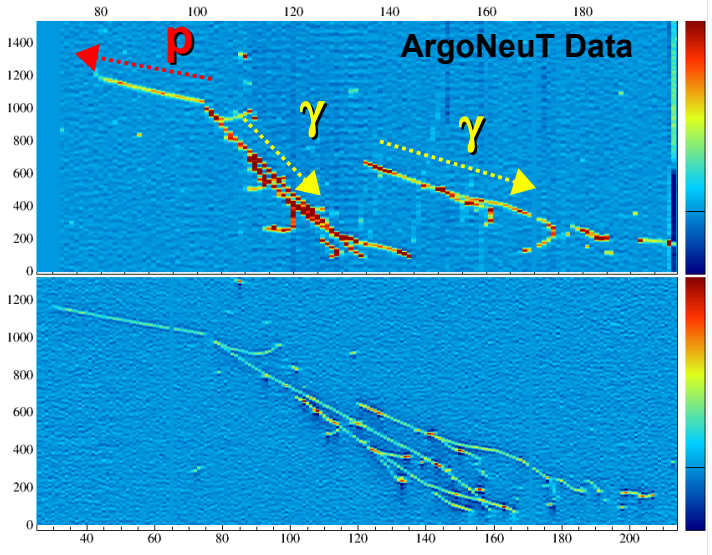


An interesting, and particularly important, channel for both oscillation searches and cross-section measurements comes from neutral current π^0 production.

→ Particularly insidious background for ν_e appearance searches

→ Notoriously difficult topology to reconstruct

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



→ However, it may still be possible to utilize the this data and look for NC π^0 production

→ Select a sample of events likely to be neutral current

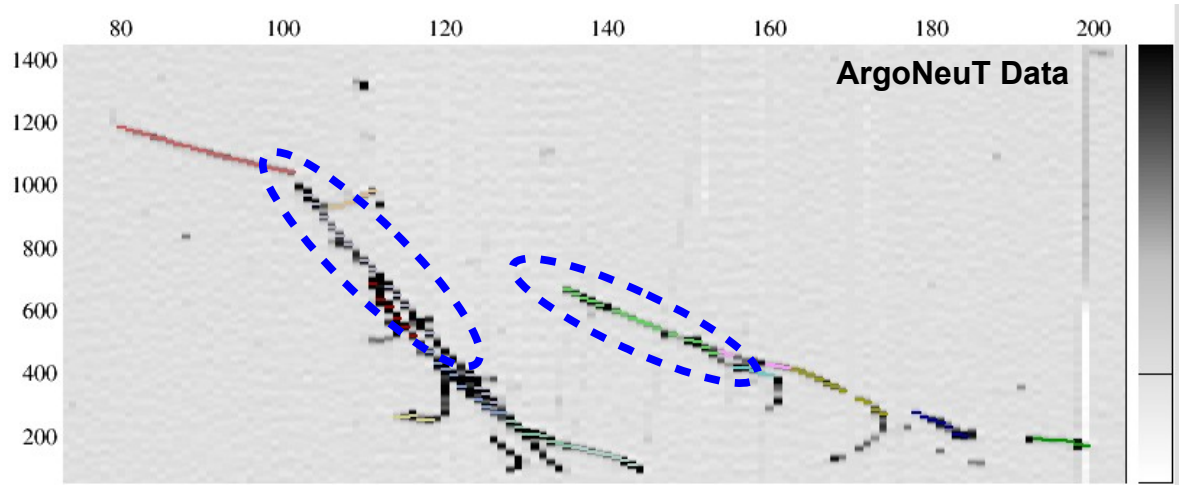
→ **Require no track matched to MINOS ND**

→ **Require at least to clusters of energy found In each view**

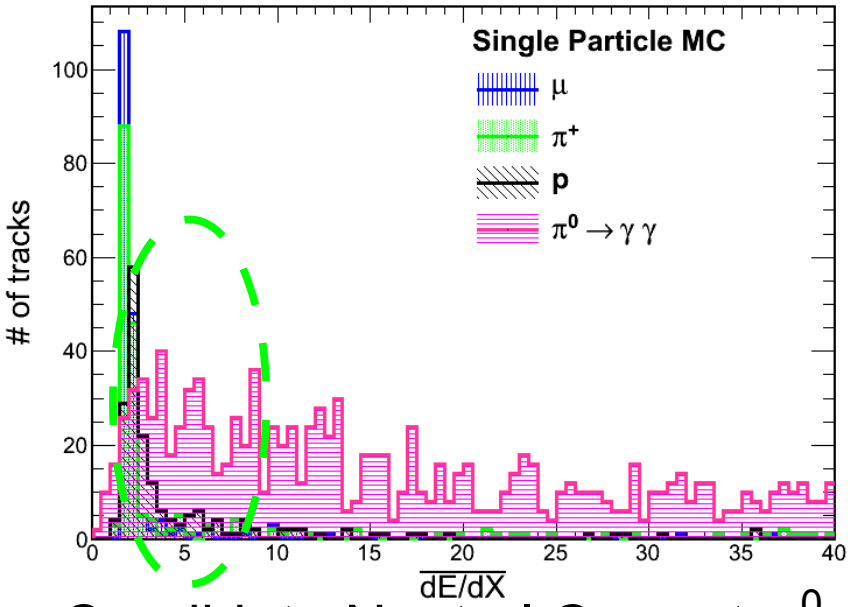
→ **Require a reconstructed vertex in the detector**

→ **...**

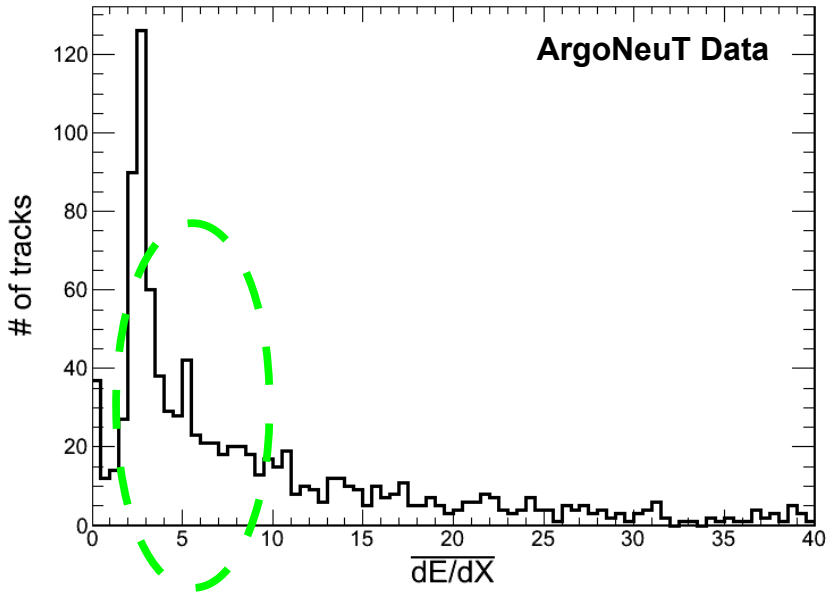
ArgoNeuT: Neutral Current π^0 analysis



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



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



Candidate Neutral Current π^0 events should have <u>two highly ionizing "track-segments" pointed back to a common point</u> (the event vertex)

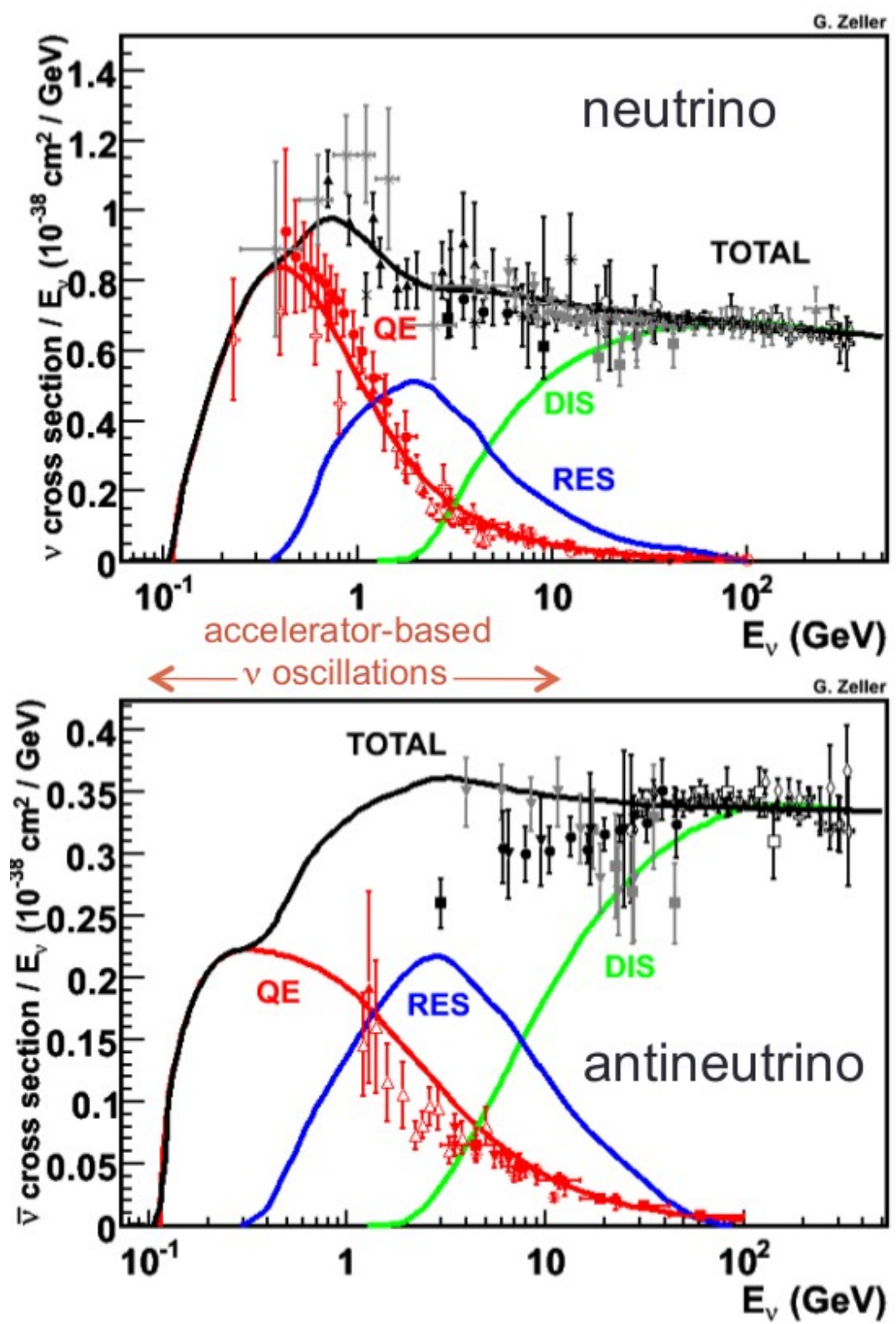
Studies continue to reconstruct these events...

Conclusions

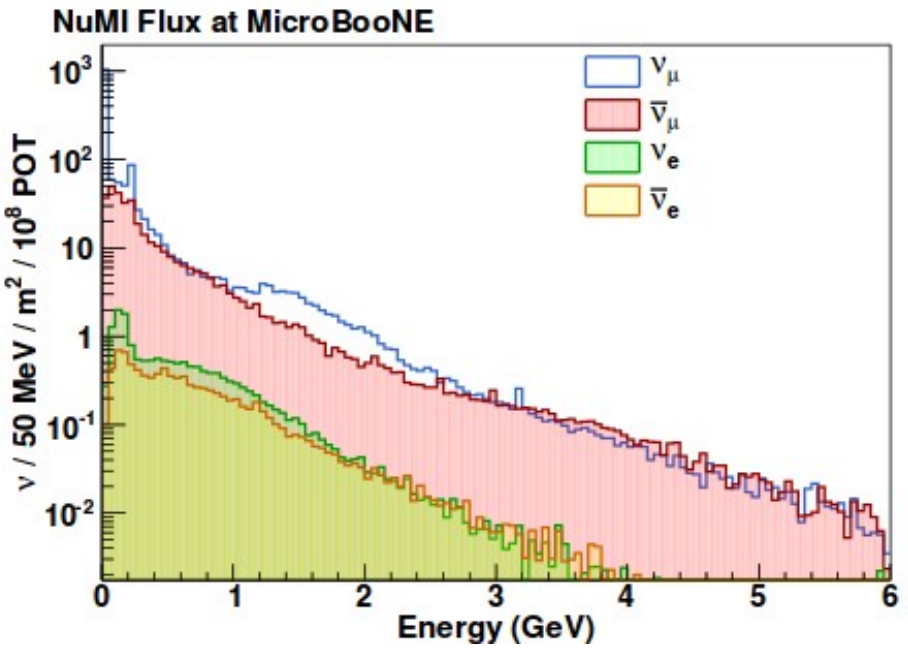
- **Liquid Argon Time Projection Chambers continue to provide insight into neutrino interactions with "bubble chamber-like" quality**
- **MicroBooNE is the next of the LAr experiments to come online in 2014**
  - Installation of all the MicroBooNE subsystems continues to make progress
  - The first complete 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 published and more coming in the months ahead.

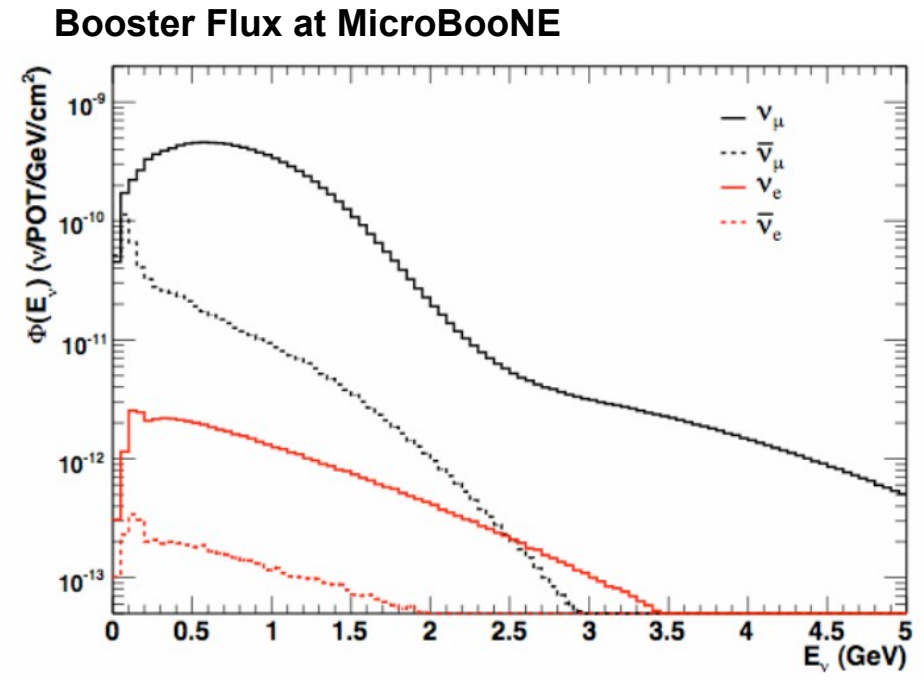

Thank you very much
for your attention!

Backup Slides


G. Zeller
neutrino
TOTAL
QE
DIS
RES
ν cross section / E_ν (10^-38 cm^2 / GeV)
E_ν (GeV)
accelerator-based
ν oscillations
G. Zeller
TOTAL
QE
RES
DIS
antineutrino
ν̄ cross section / E_ν (10^-38 cm^2 / GeV)
E_ν (GeV)

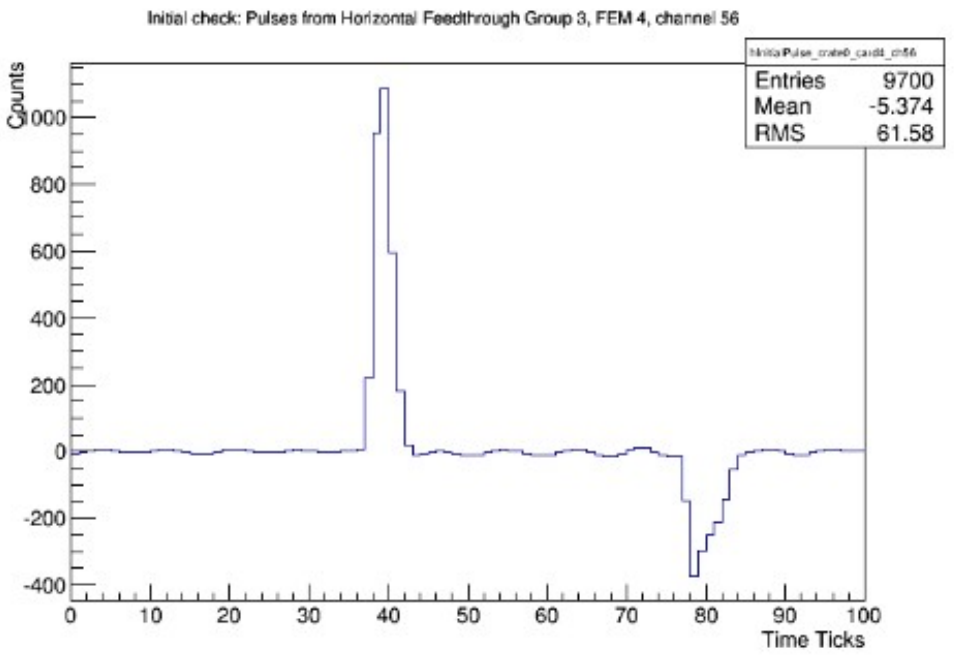
NuMI and BNB Flux

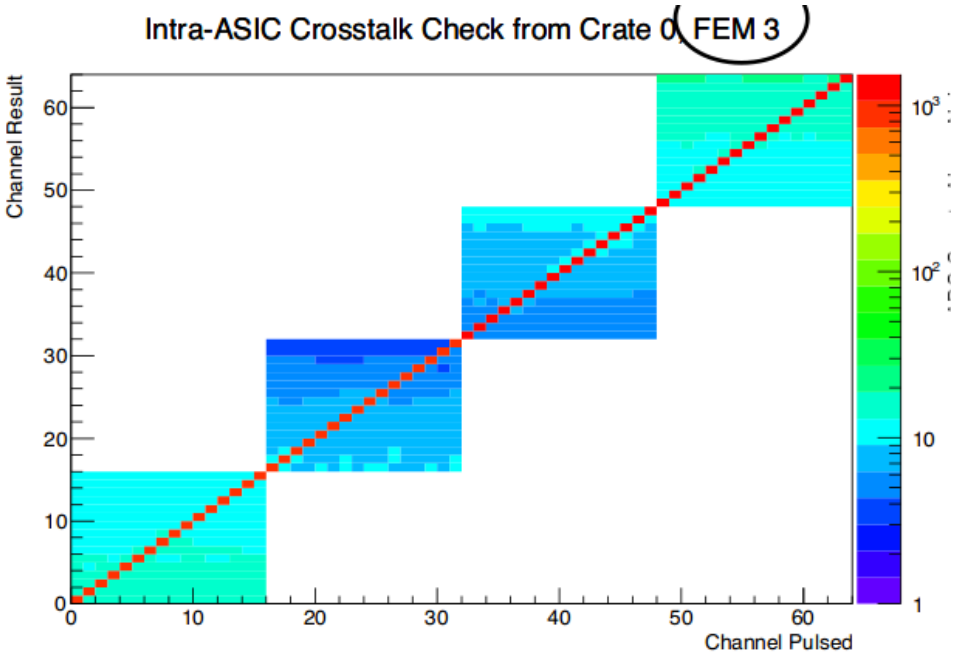




Test pulses and cross-talk tests done on wires

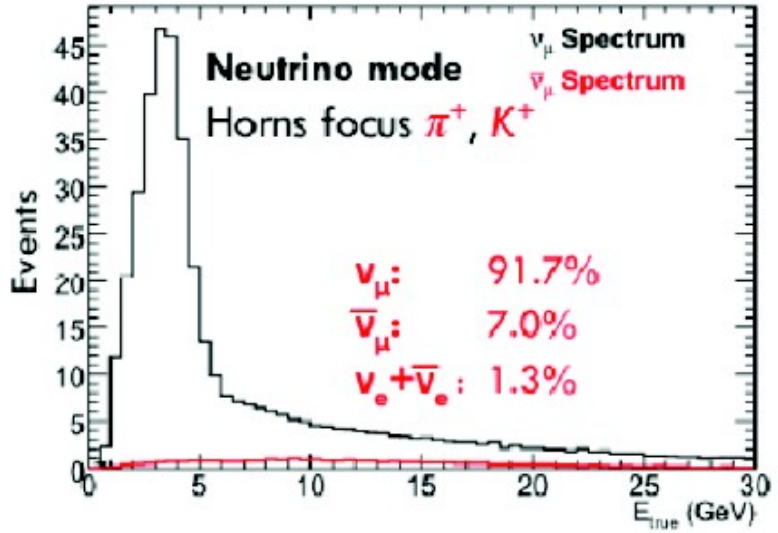
Y channel



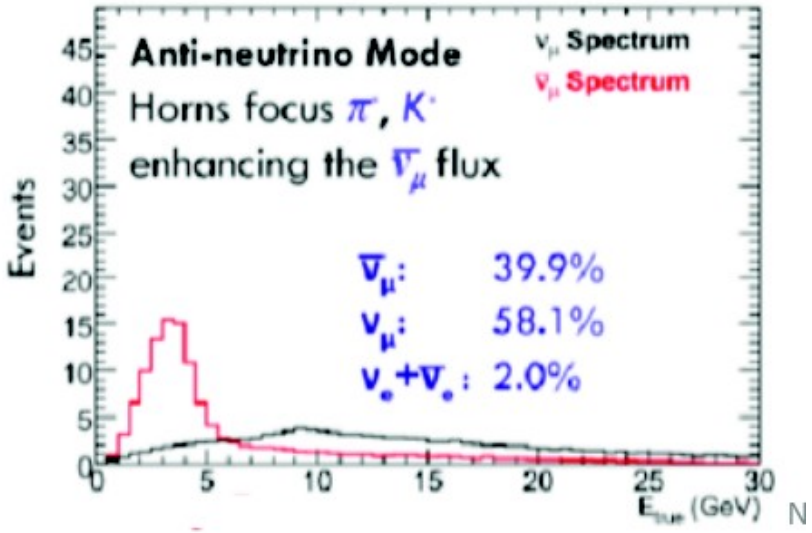


NUMI spectrum in ArgoNeuT

ν-mode (2 weeks): 0.085e20 POT



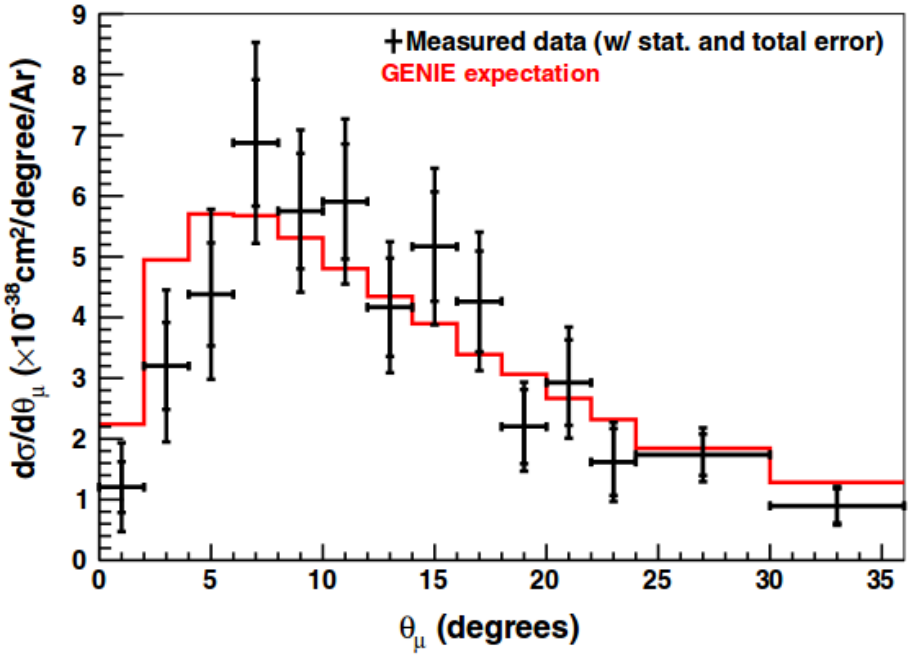
$\bar{\nu}$-mode (5 months): 1.2e20 POT



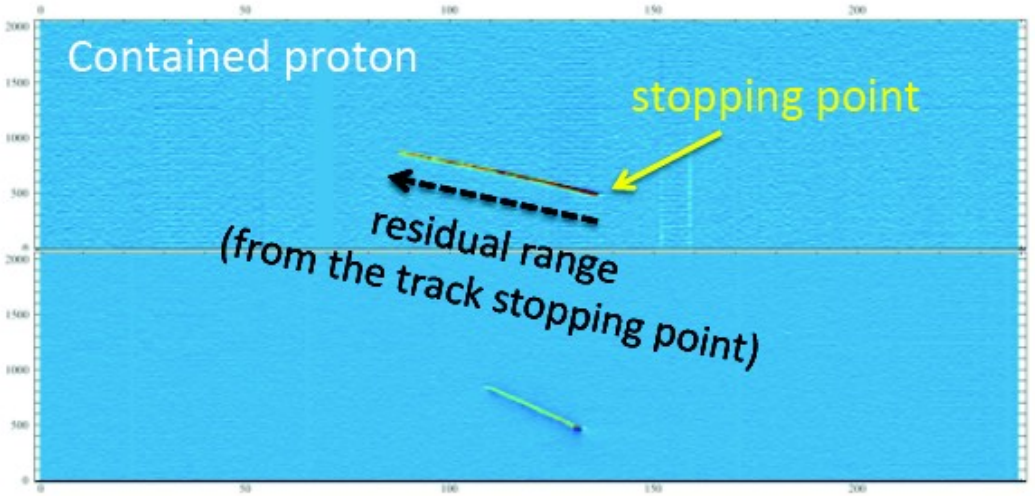
N

Inclusive ν_μ Charged Current Differential Cross-section

PRL 108, 161802 (2012)



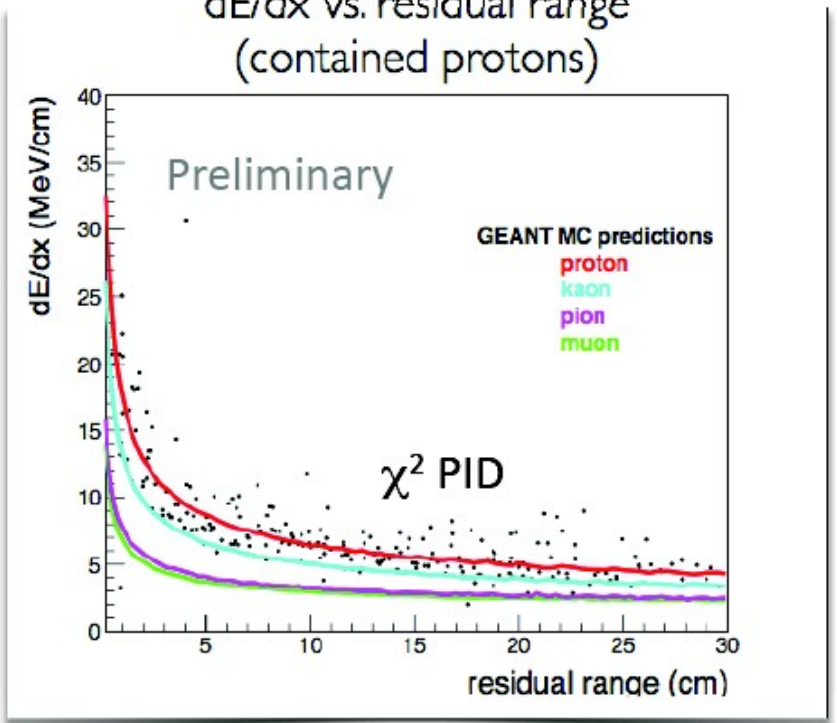
Calorimetric ParticleID



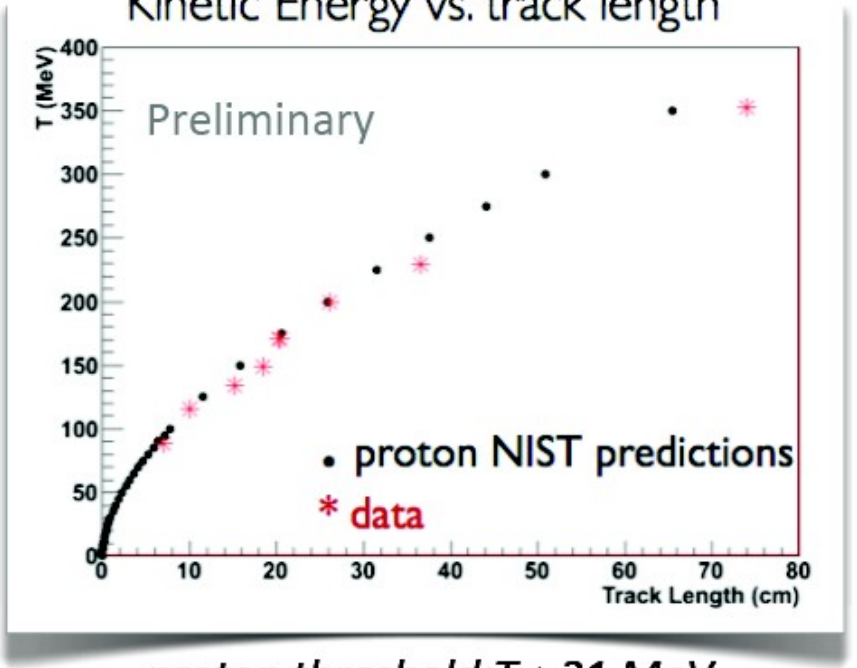
- Measurement of:
  - dE/dx vs. residual range along the track
  - kinetic energy vs. track length

Slide from Tingjun Yang @ NuFact 2013

dE/dx vs. residual range
(contained protons)



Kinetic Energy vs. track length



proton threshold:T_p>21 MeV

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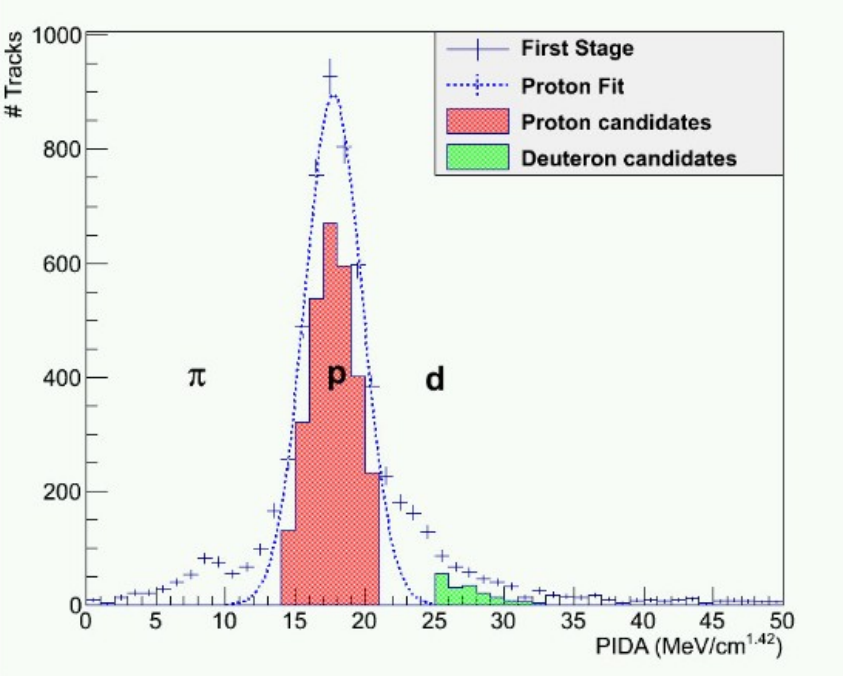
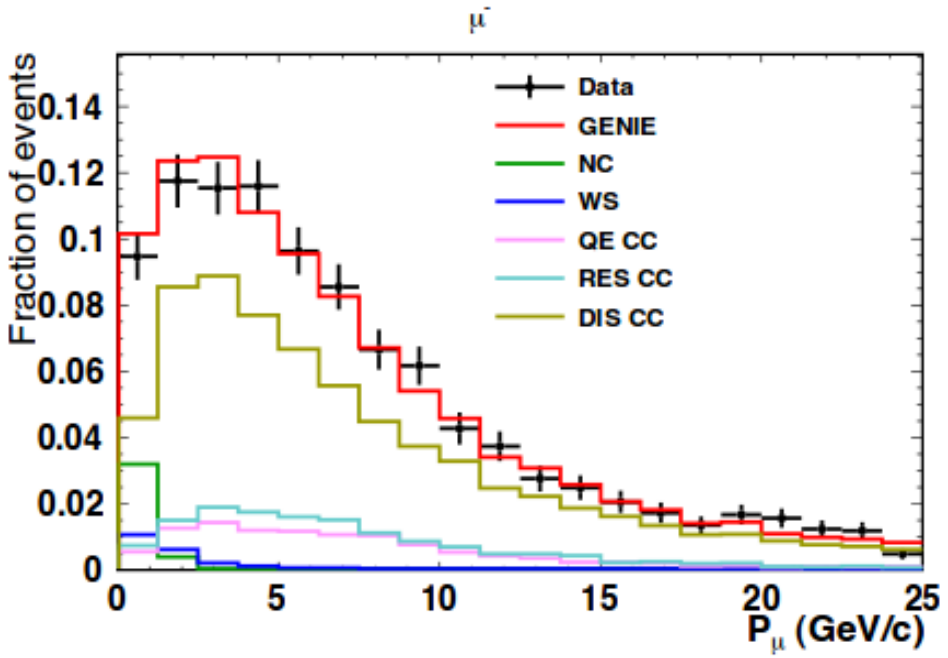
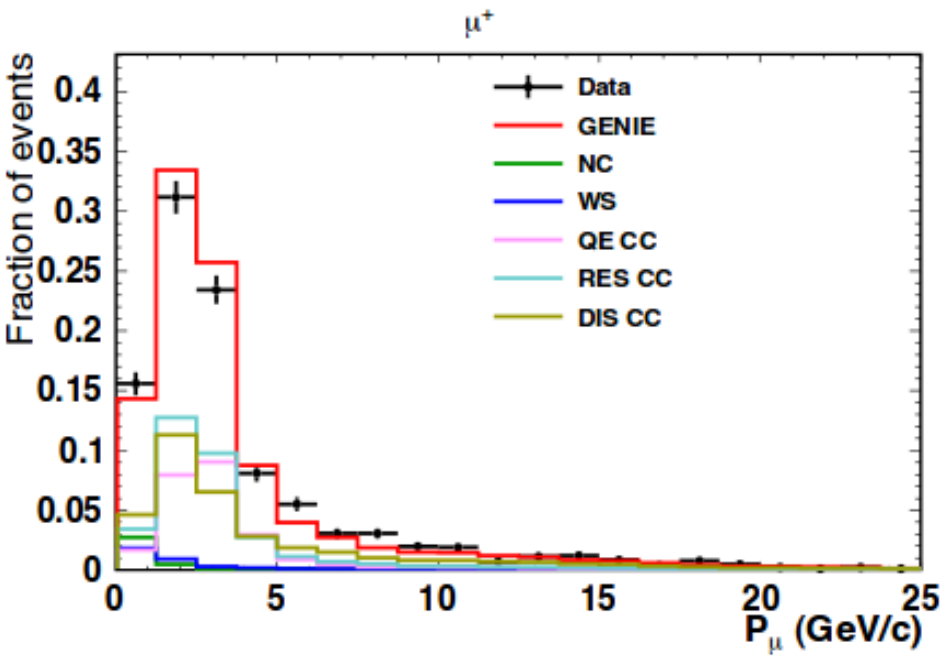
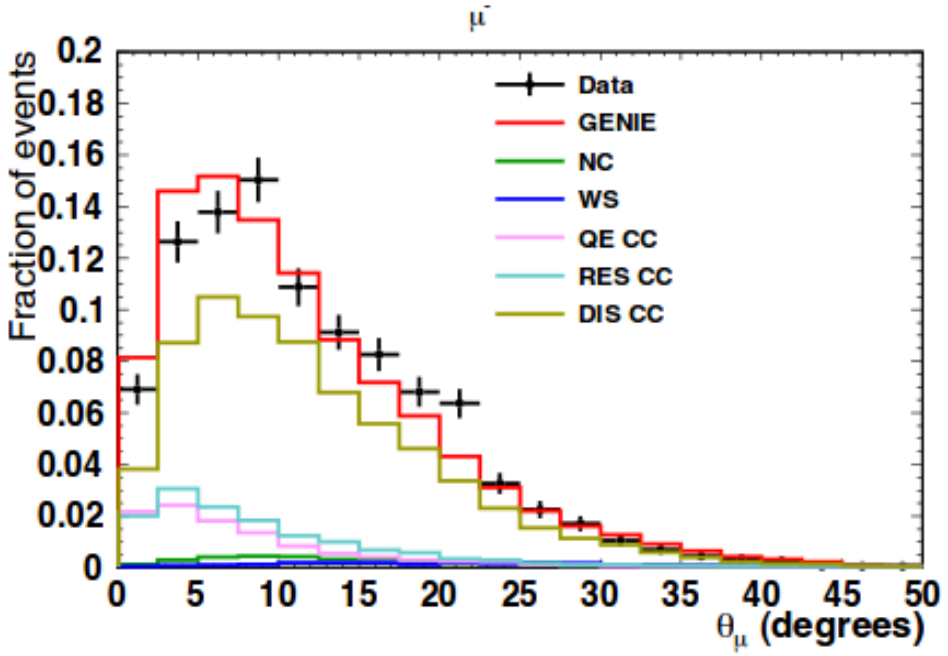
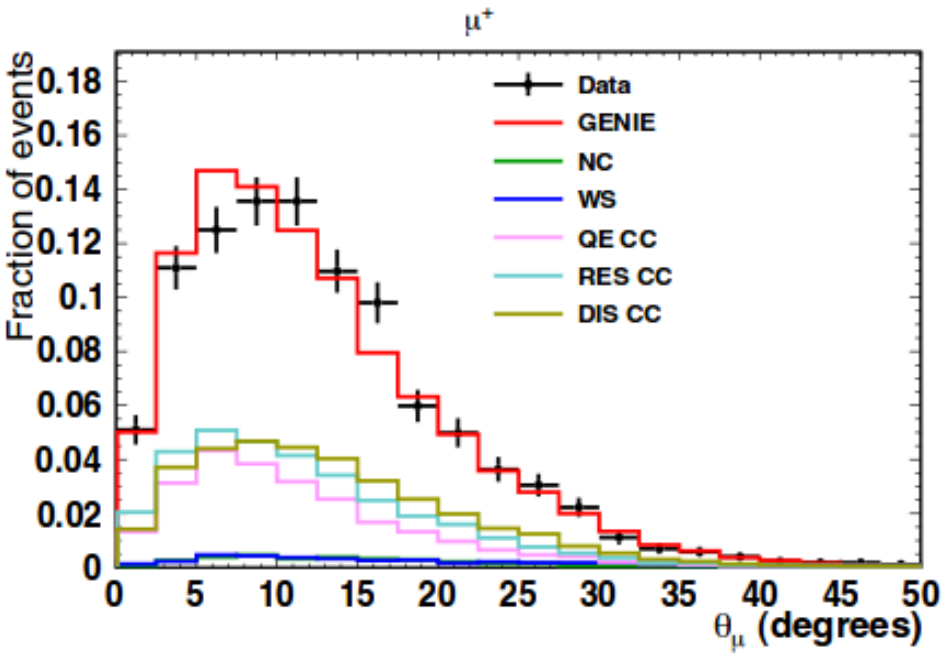


Inclusive $\bar{\nu}_\mu$ Charged Current Differential Cross-section

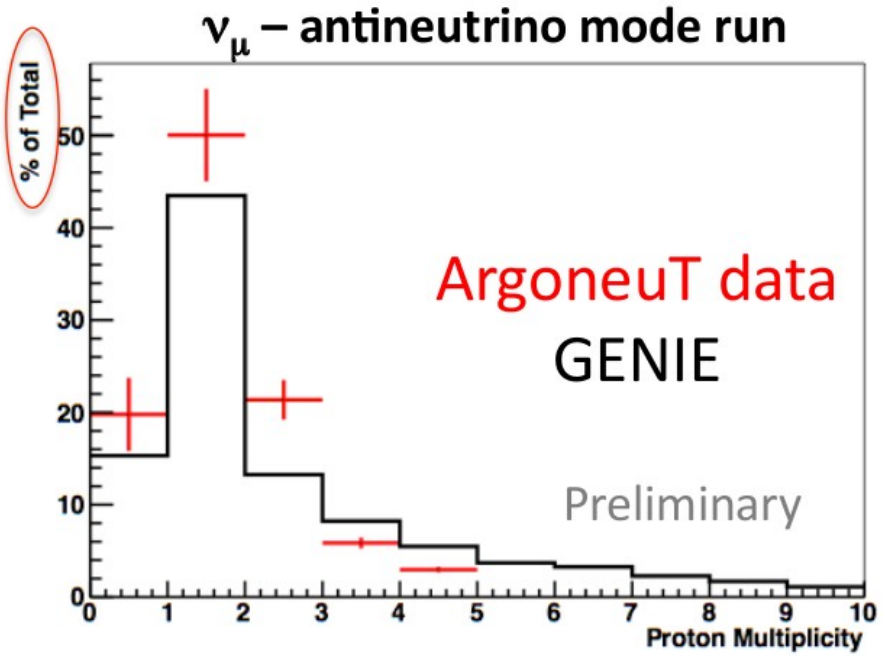


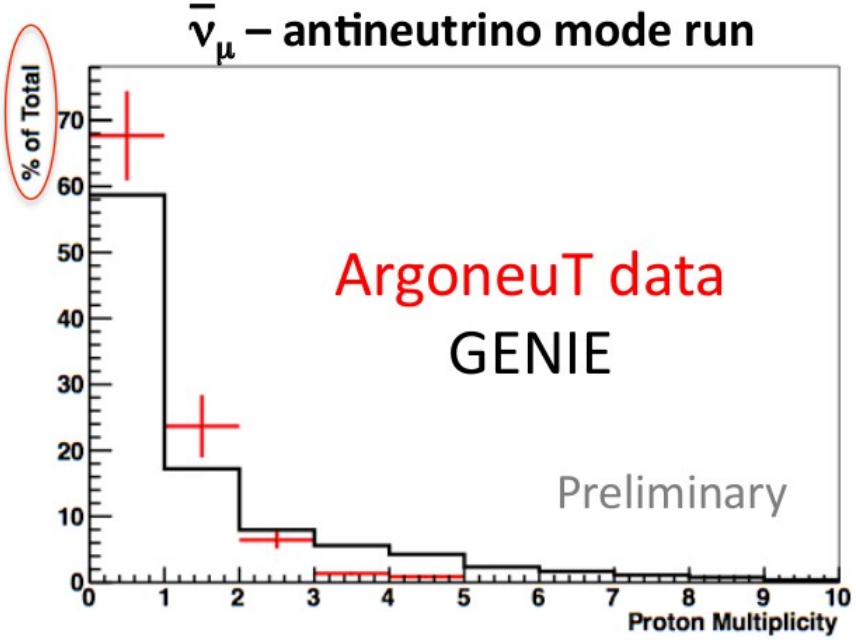




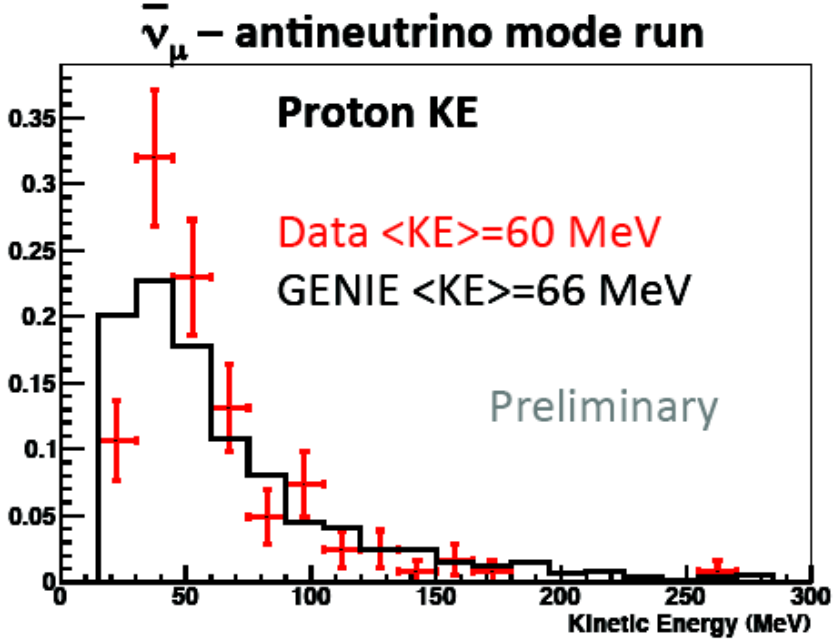


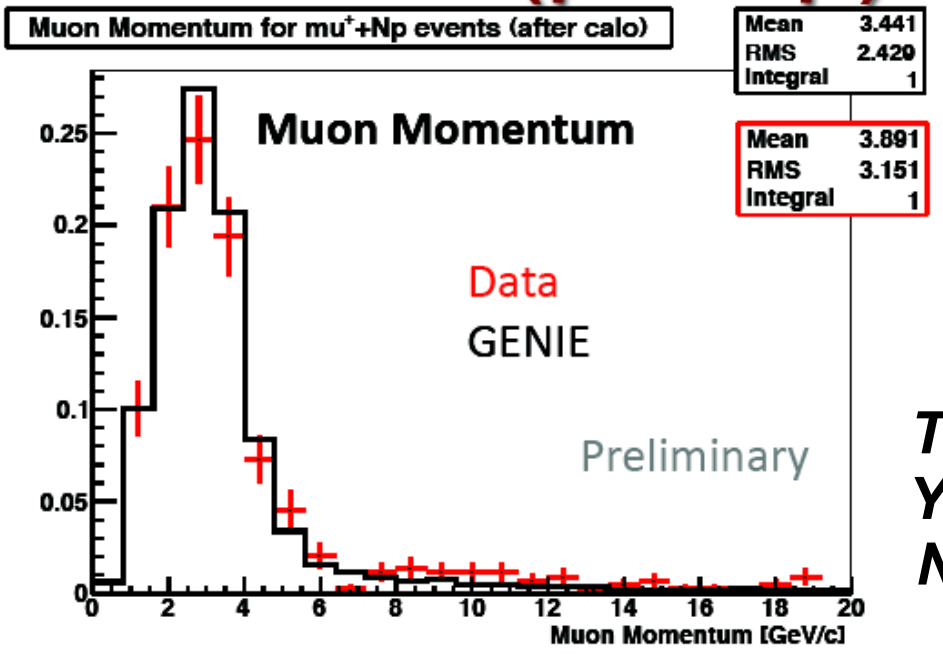
Study of Nuclear Final State Interactions (FSI)





Kinematics Reconstruction (μ^++Np)





Slide from Tingjun Yang @ NuFact 2013

- Neutrino Energy $E_\nu = E_\mu + \Sigma T_p$
- No just muon information, model independent
- Other kinematic quantity reconstruction (Q^2 etc.) in progress