Bonnie Fleming
NNN 2014
November 4th, 2014

ArgoNeuT/MicroBooNE

What have we learned with ArgoNeuT?

Where are we going? MicroBooNE and the SBL program at FNAL

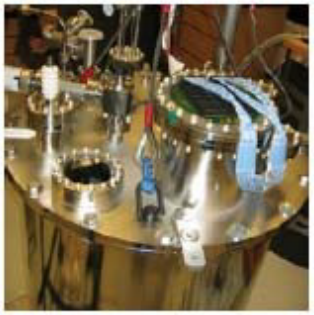
From NNN2009 – US based program then…..

Liquid-Argon Time Projection Chambers

Status of R&D Program in the US

The first TPCs in the United States:

Yale TPC



Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

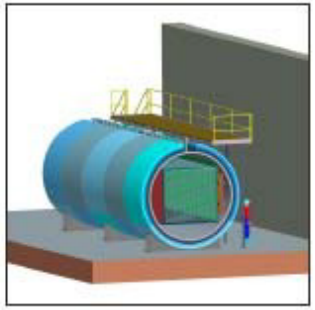
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

MicroBooNE



Location: Fermilab
Active volume: 0.1 kton
Start of construction: 2010

Test stands to improve liquid-argon technology:

Luke

Location: Fermilab
Purpose: materials test station
Operational: since 2008

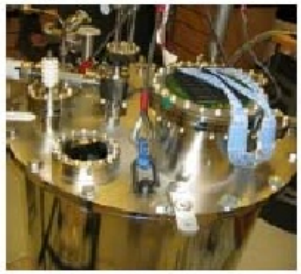
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

From A Szelc talk, Neutrino 2014

US based program now…..

Yale TPC



Location: Yale University
Active volume: 0.002 ton
operational: 2007

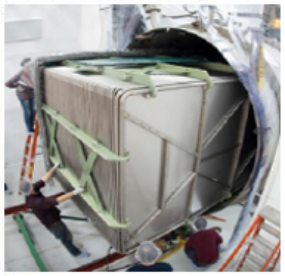
Bo

Location: Fermilab
Active volume: 0.02 ton
operational 2008

ArgoNeuT

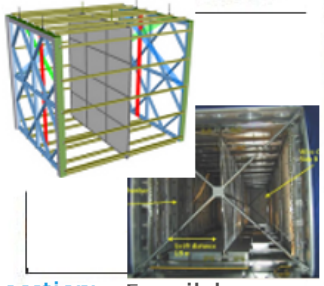
Location: Fermilab
Active volume: 0.3 ton
operational: 2008
First neutrinos: June 2009

MicroBooNE



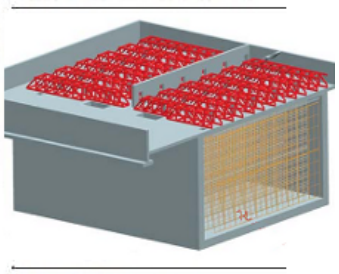
Location Fermilab
Active volume: 0.1 kton
Operational: 2015

SBN @ FNAL



Location: Fermilab
Active volume: 0.1 + 0.6 kton
Construction start: 2017

LBNE



Location: Homestake
Active volume: 35 kton
Construction start 202?

Luke

Location: Fermilab
Purpose: materials test st
Operational: since 2008

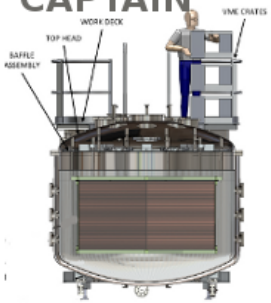
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2011

LArIAT

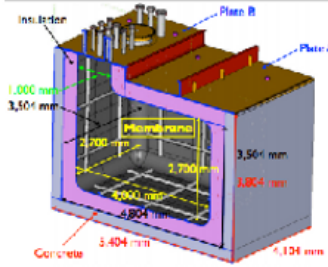
Location: Fermilab
Purpose: LArTPC calibration
Operational: 2014 (phase 1)

CAPTAIN



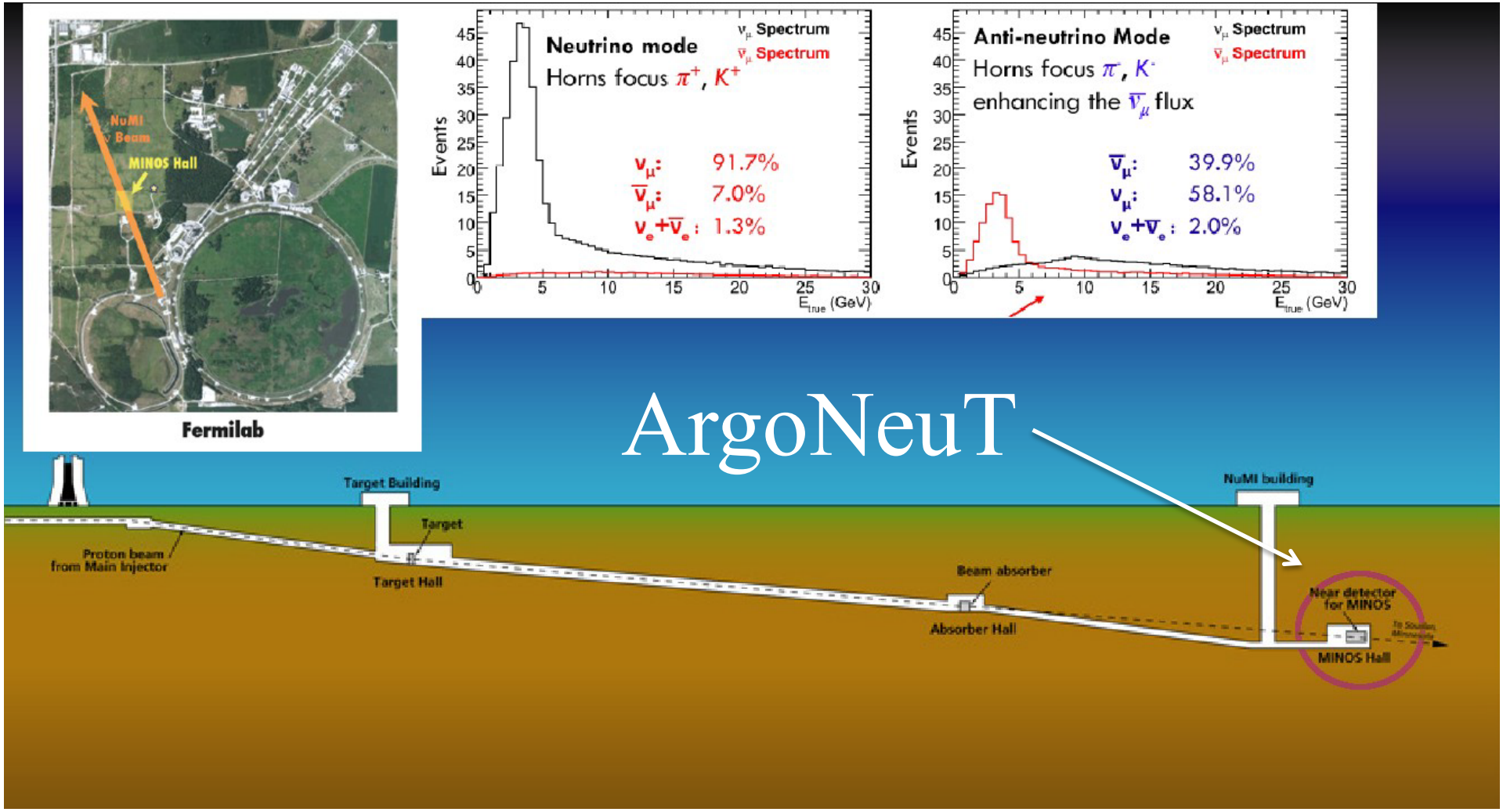
Location: LANL
Purpose: LArTPC calibration
Operational: 2014

LBNE 35 Ton



Location: Fermilab
Purpose: purity demo
Operational: 2013

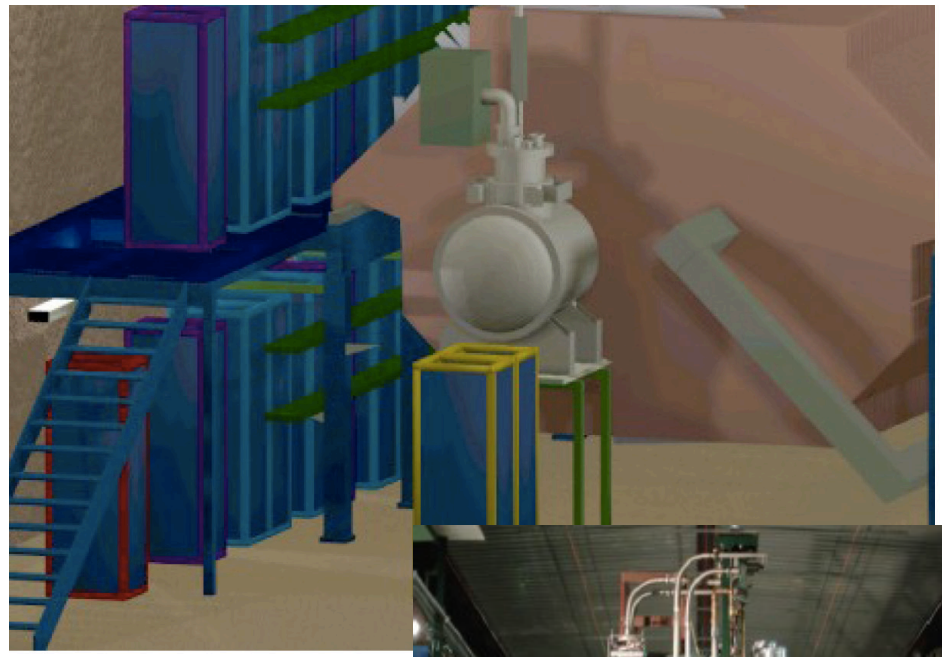
Just the US based program



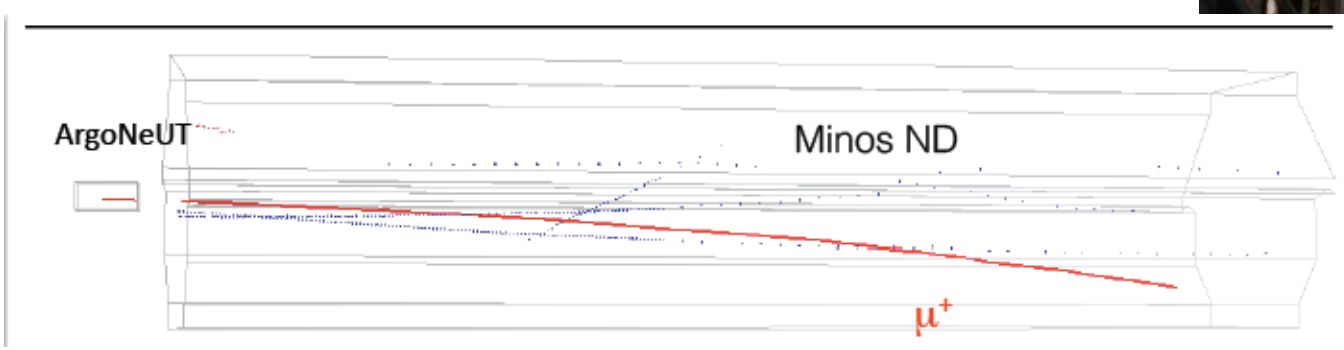
- Originally proposed as a pure R&D experiment
  - Gain experience with LArTPC detection technique
  - Develop ideas for massive underground TPCs
  - See neutrino Interactions

ArgoNeuT

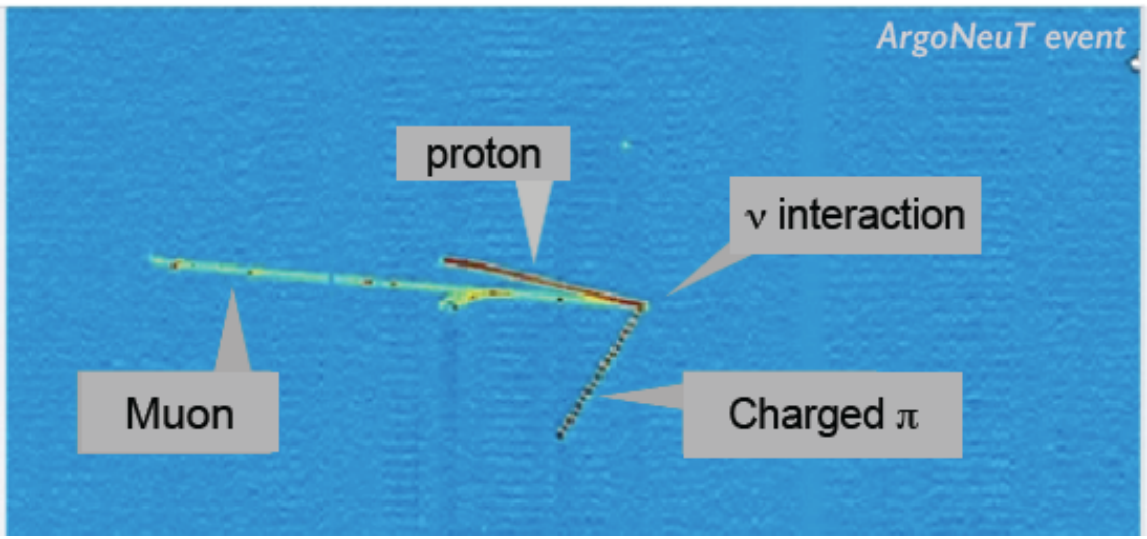
- 0.3 ton LArTPC
- 0.5m x 0.5 m x 1m TPC
- 4mm wire pitch
- Warm electronics – 4MHz sampling rate
- Ran in NuMI beam from 2009-2010



- 1.35 x 10^{20} POT mostly in anti-neutrino mode
- Collected ~10k neutrino interactions (1-10 GeV)
  - Anti-neutrino mode – 5 months (significant wrong sign fraction…)
  - Neutrino mode run – 2 weeks

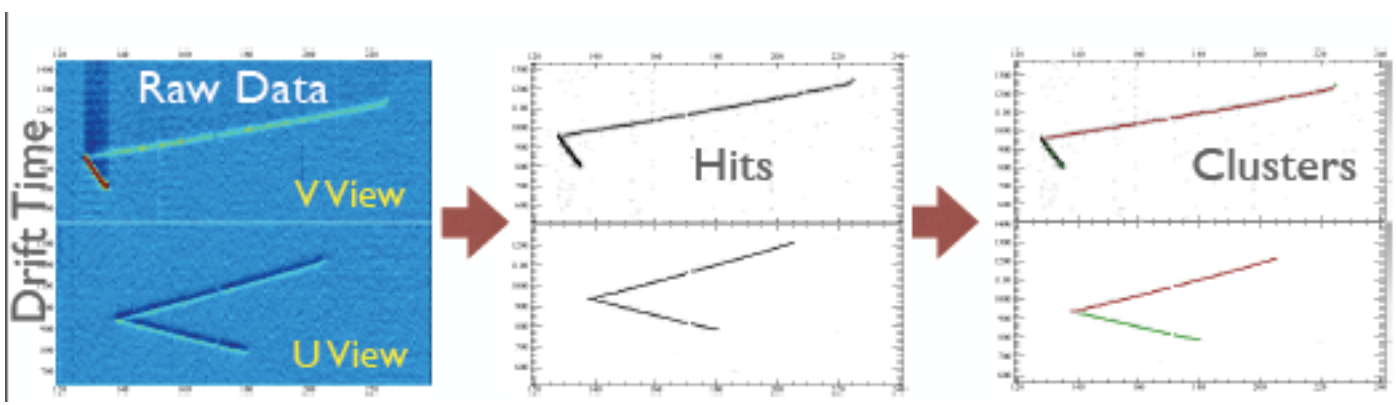


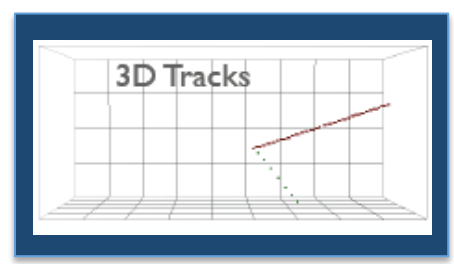
Development of Reconstruction and simulation software (LArSoft) to analyze data (see G. Petrillo's talk)



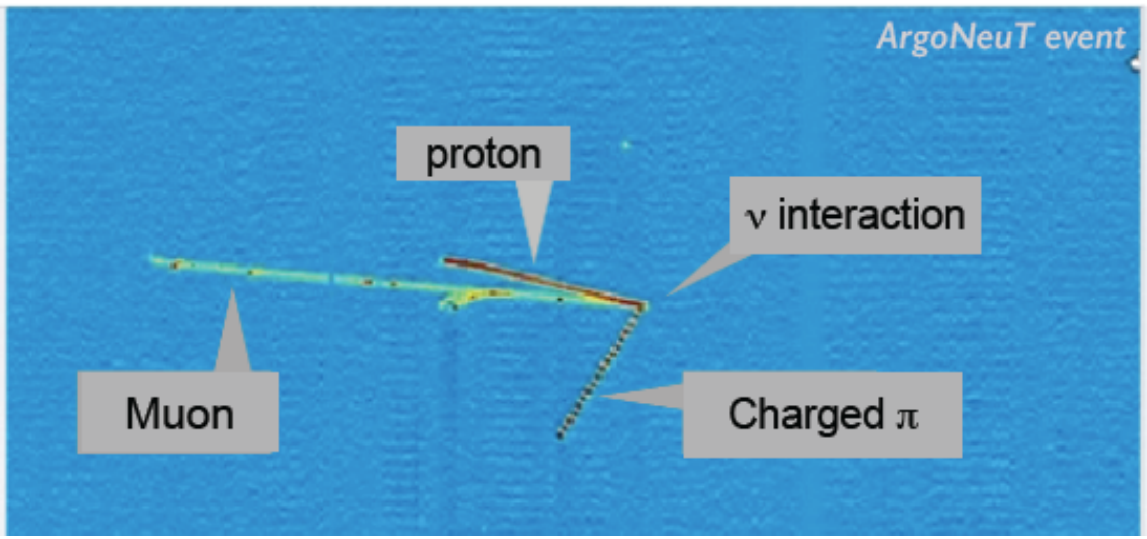
- Vertex activity
  - Calorimetry
  - Multiple tracks/ particle ID
- Outgoing particle tracking
- Showering events

Physics analysis
Tools along the way…





Development of Reconstruction and simulation software (LArSoft) to analyze data



- Vertex activity
  - Calorimetry
  - Multiple tracks/ particle ID
- Outgoing particle tracking
- Showering events
- Tools along the way…

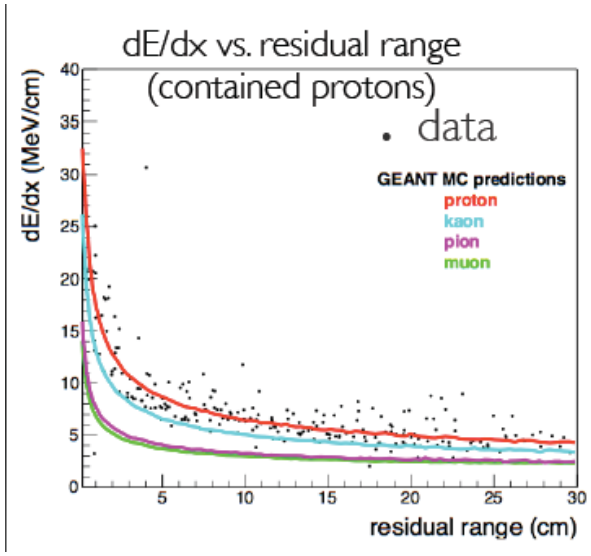
Move from classifying events by interaction type (quasi-elastic, resonant, ….)

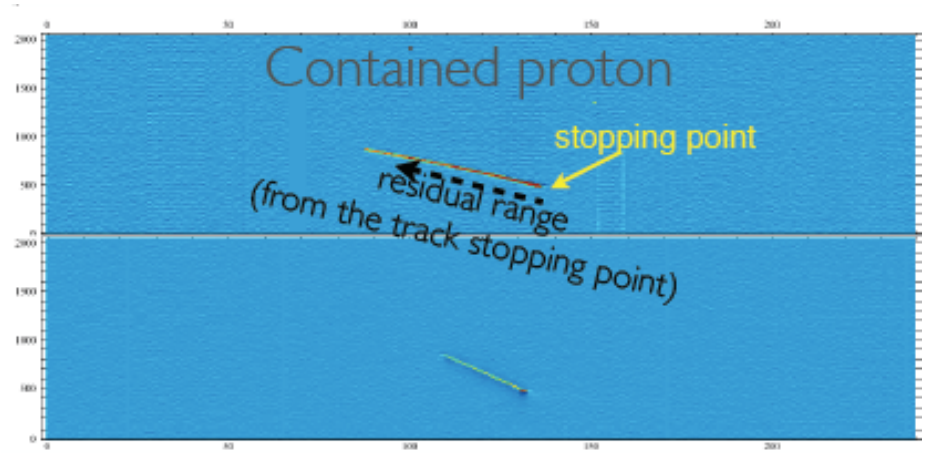
Identification by topology (0 proton, 1 proton, 2 proton…)

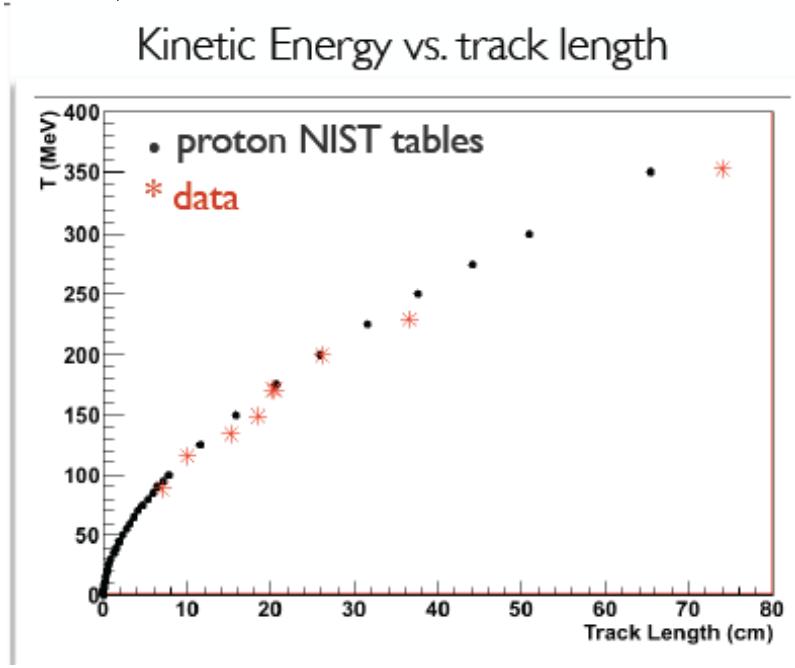
Opens up new window onto neutrino-nucleus scattering

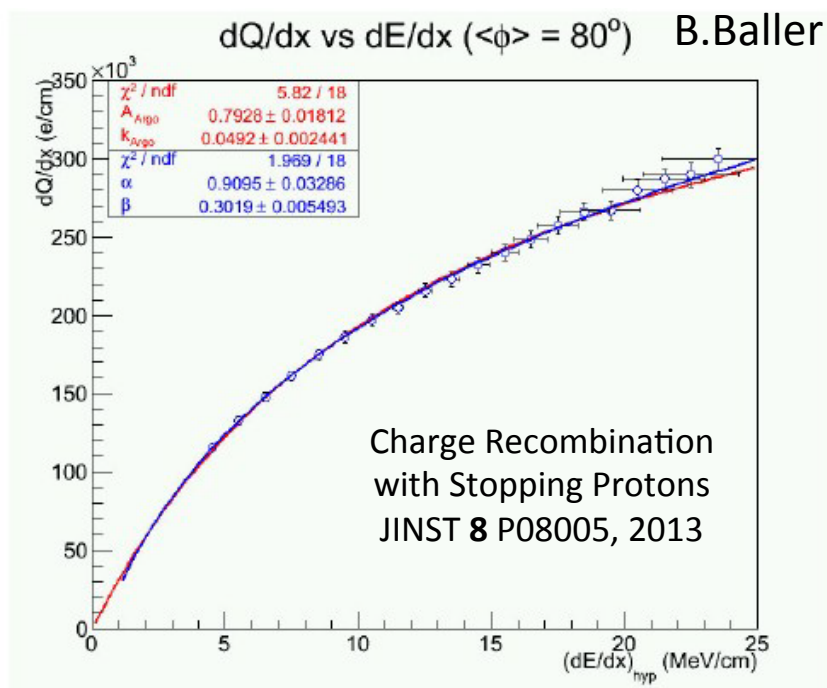
Calorimetric Reconstruction and particle ID:

Identify proton through energy loss over range

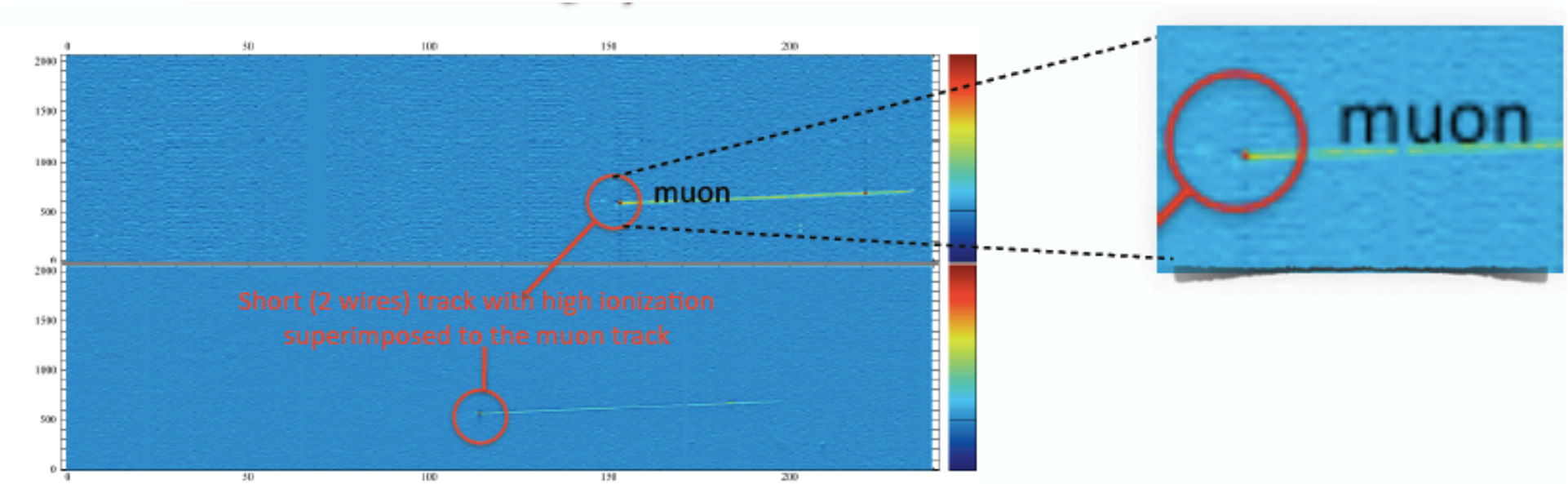








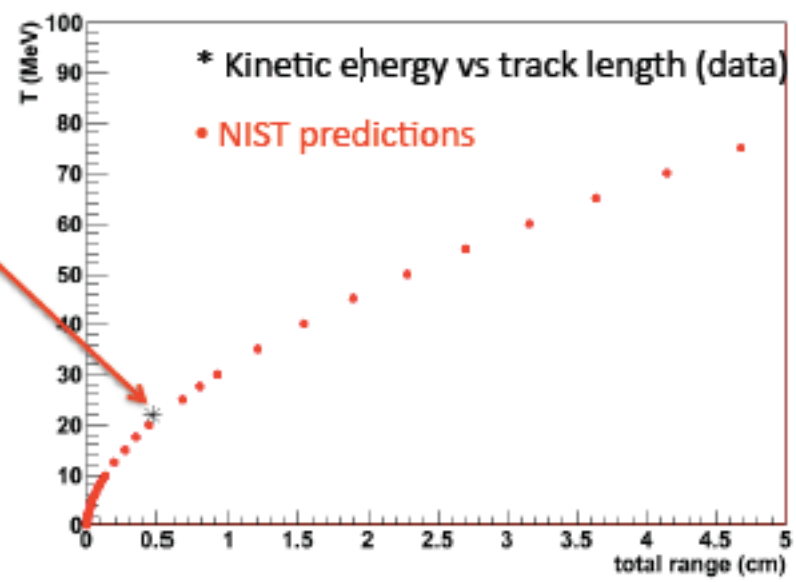
Low energy proton reconstruction



The short track behaves like proton

Length=0.5 cm

T_p=22±3 MeV

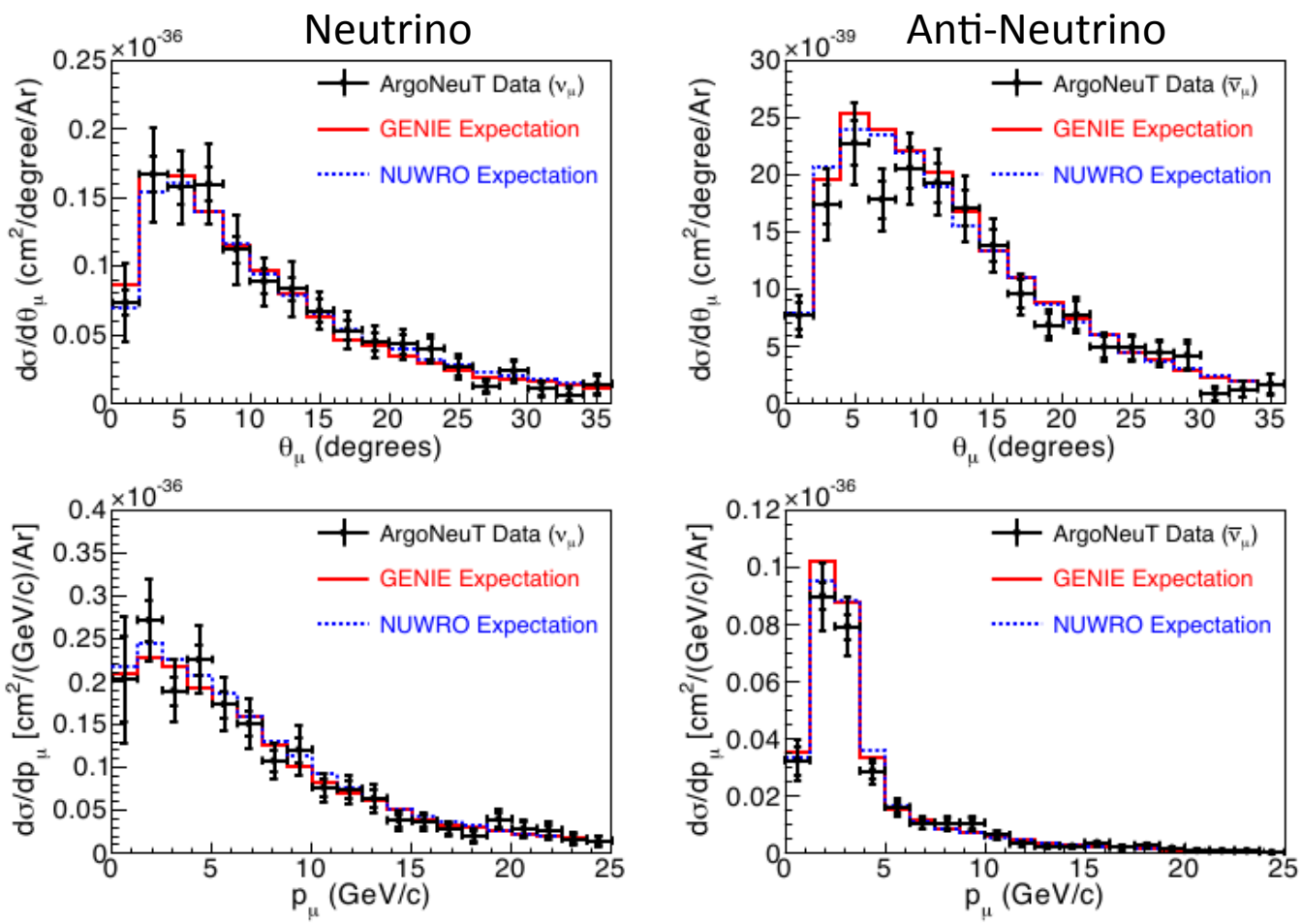


Sets ArgoNeuT proton threshold ID:
21 MeV Kinetic Energy

O. Palamara

Physics Results!

ν_μ and $\bar{\nu}_\mu$ charged current inclusive measurement
Topology: Outgoing Muon tagged by sign



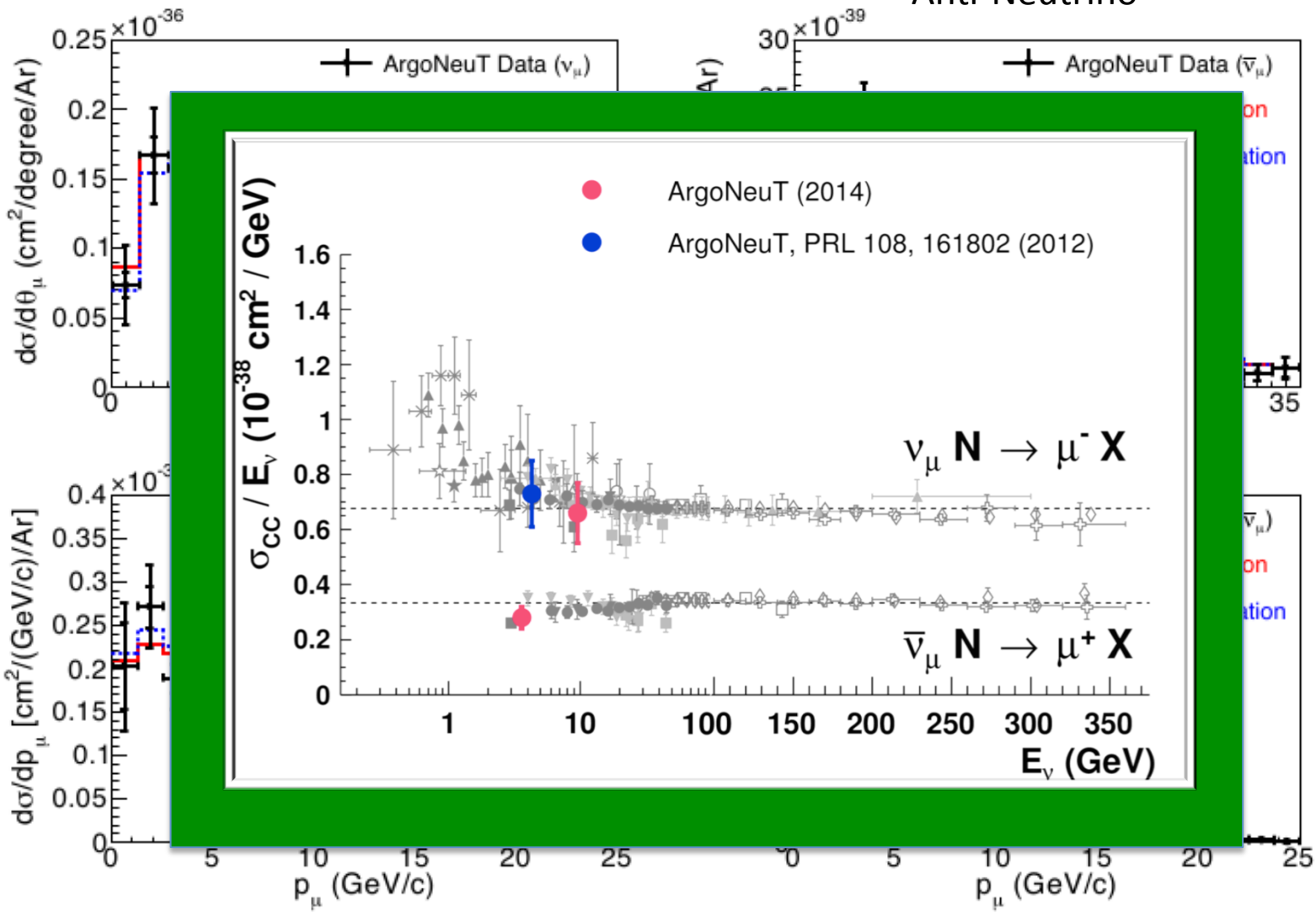
Neutrino CC inlcusive: PRL **108**, 161802 (2012) arXiv:1111.0103 (J. Sptiz)
Neutrino and Anti-Neutrin CC Inclusive: PRD**89**, 112003 (2014) (E. Church/T. Yang)

ν_μ and $\overline{\nu}_\mu$ charged current inclusive measurement

Topology: Outgoing Muon tagged by sign

Neutrino

Anti-Neutrino



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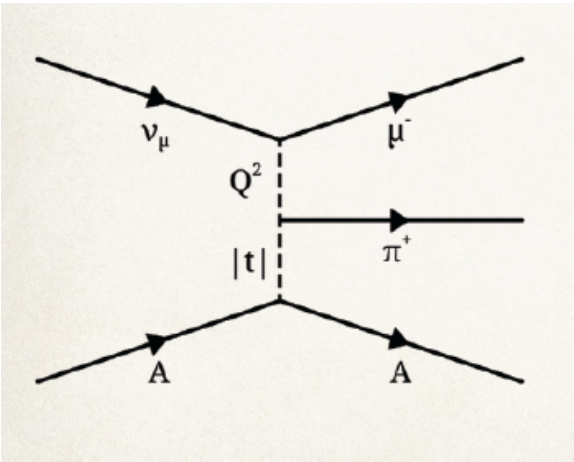
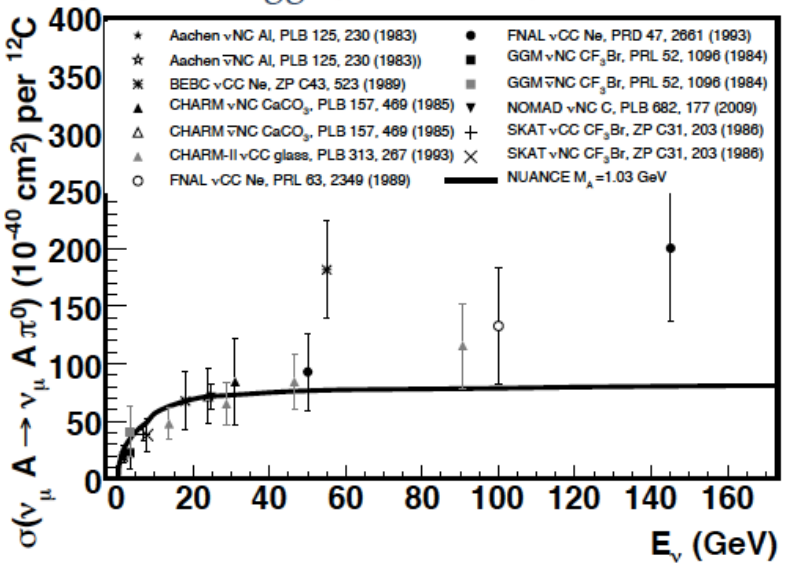
CC Coherent Pion Production

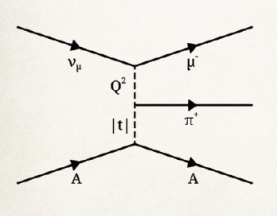


J.A. Formaggio, G.P. Zeller, arXiv:1305.7513

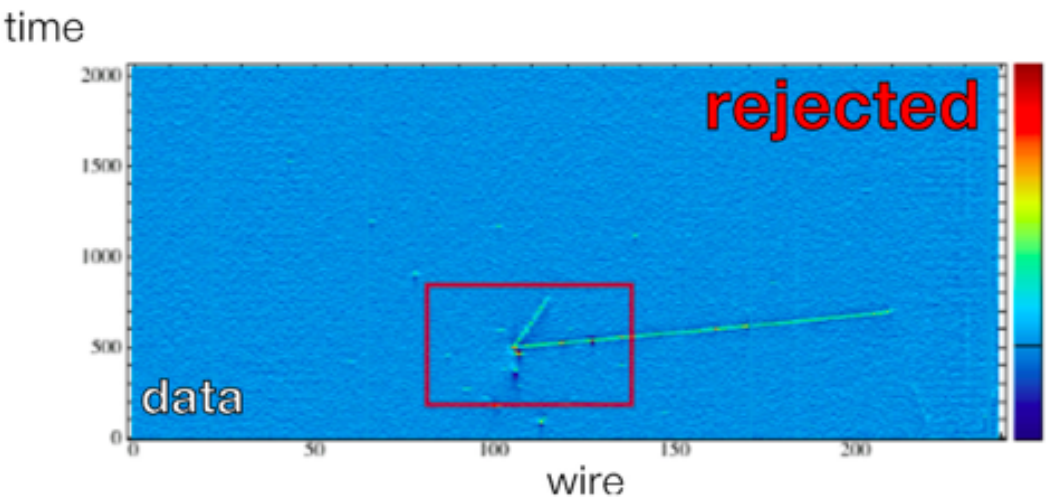


Neutrino scatters coherently off entire nucleus

- Small momentum transfer -> Forward going lepton and pion in final state
- No visible recoil
- Identify event by event instead of through Q^2 shape

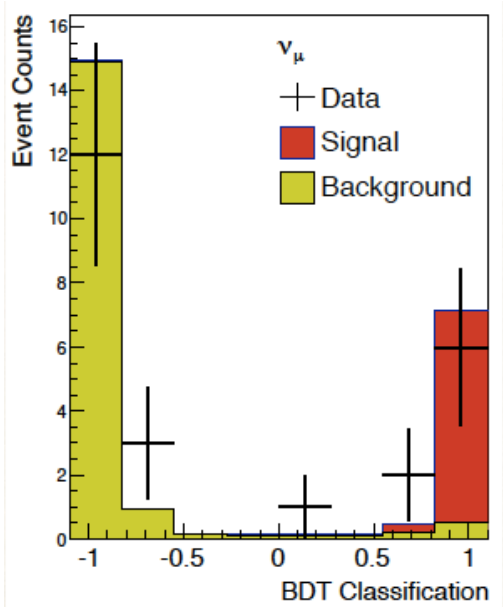


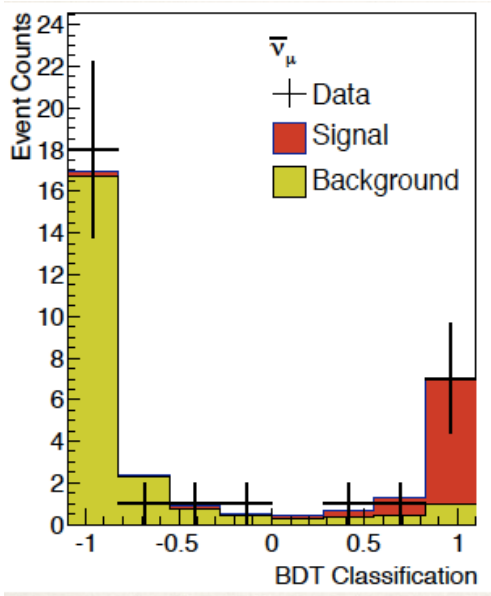
CC Coherent Pion Production



ArgoNeuT Analysis

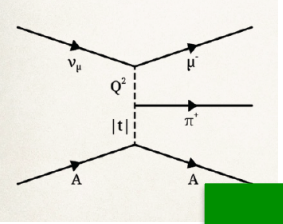
- Characterize events by single muon track and single pion track
- No vertex activity
- Boosted Decision Tree to separate signal from background



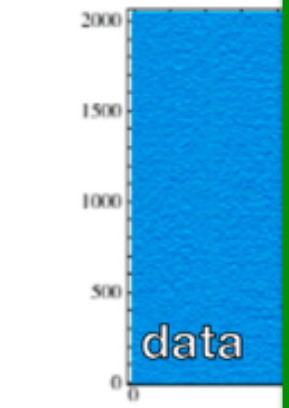


CC Coherent Pion Production

T. Yang
E. Santos

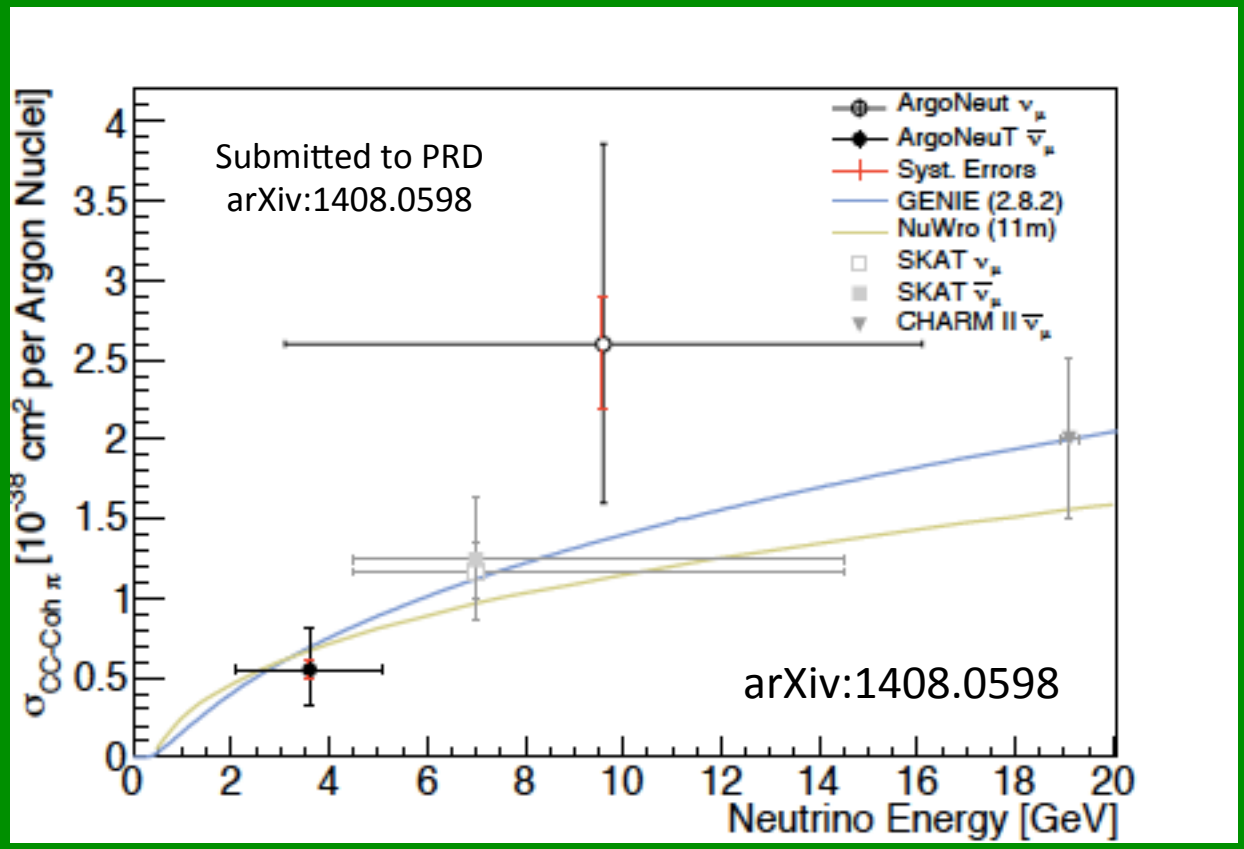


time



single
pion

to

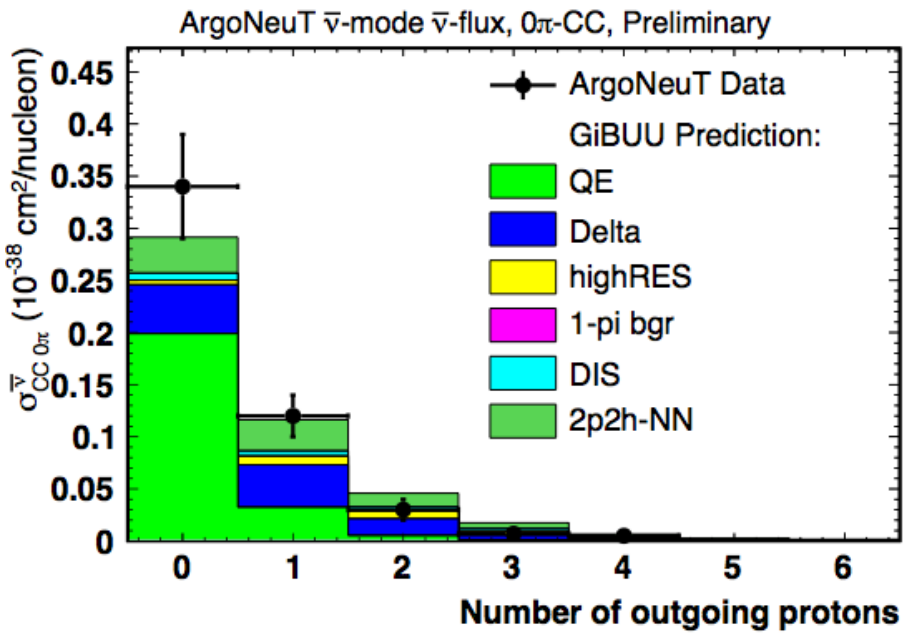


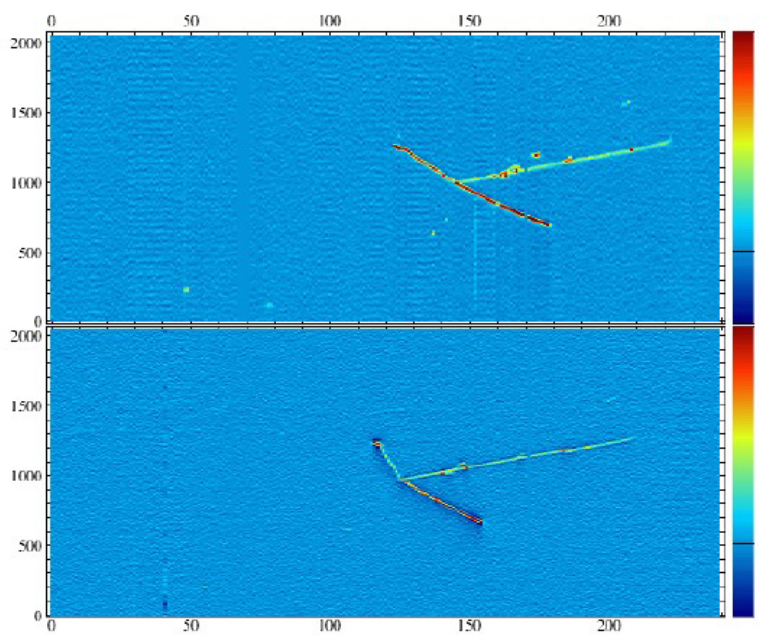
$$\langle \sigma_{\bar{\nu}_\mu} \rangle = \left(5.5^{+2.6}_{-2.1}(stat)^{+0.6}_{-0.7}(syst)\right) \times 10^{-39} cm^2$$

$$\langle \sigma_{\nu_\mu} \rangle = \left(2.6^{+1.2}_{-1.0}(stat)^{+0.3}_{-0.4}(syst)\right) \times 10^{-38} cm^2$$

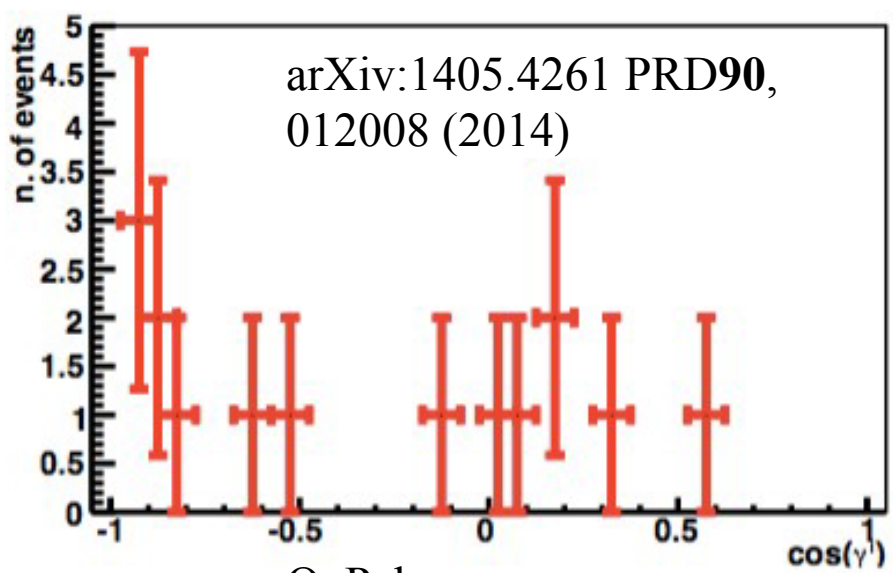
Observing proton multiplicities

1. Measure cross sections as a function of proton multiplicity
2. Observed back to back proton pairs – possible mechanism is CC RES pion-less reactions involving pre-existing SRC np pairs.





Example: 2 proton pair events: "Hammer events"

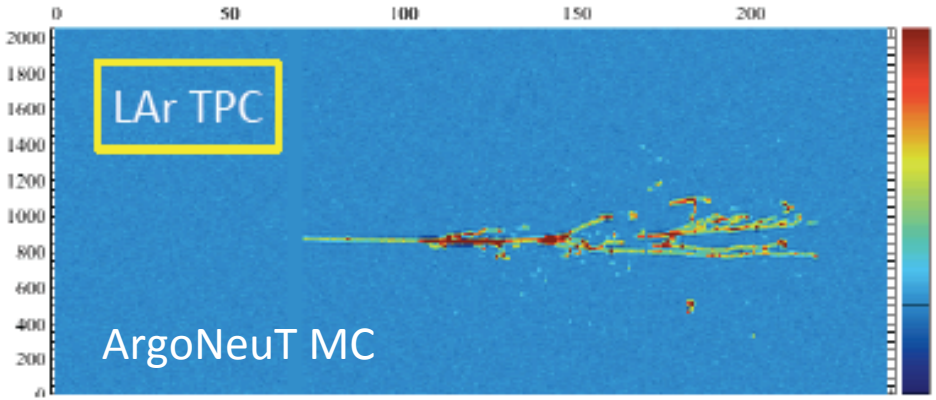


arXiv:1405.4261 PRD**90**, 012008 (2014)

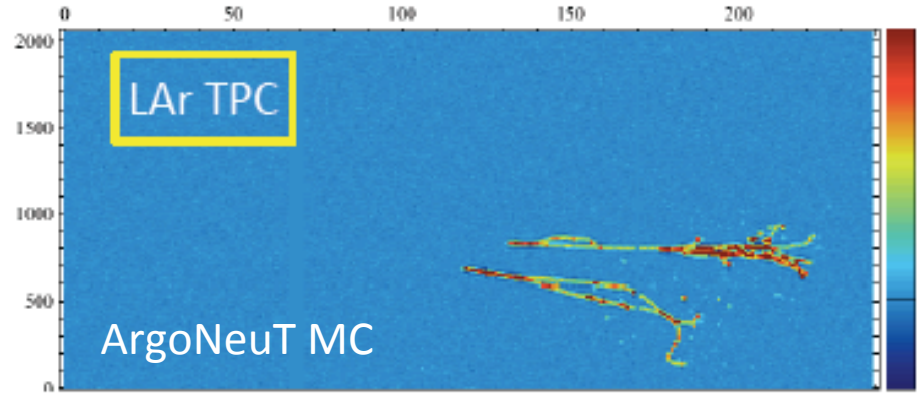
O. Palamara

Electron/photon Separation with LAr TPCs

1 GeV electron shower



Decay of a 1 GeV π^0 to two photons.

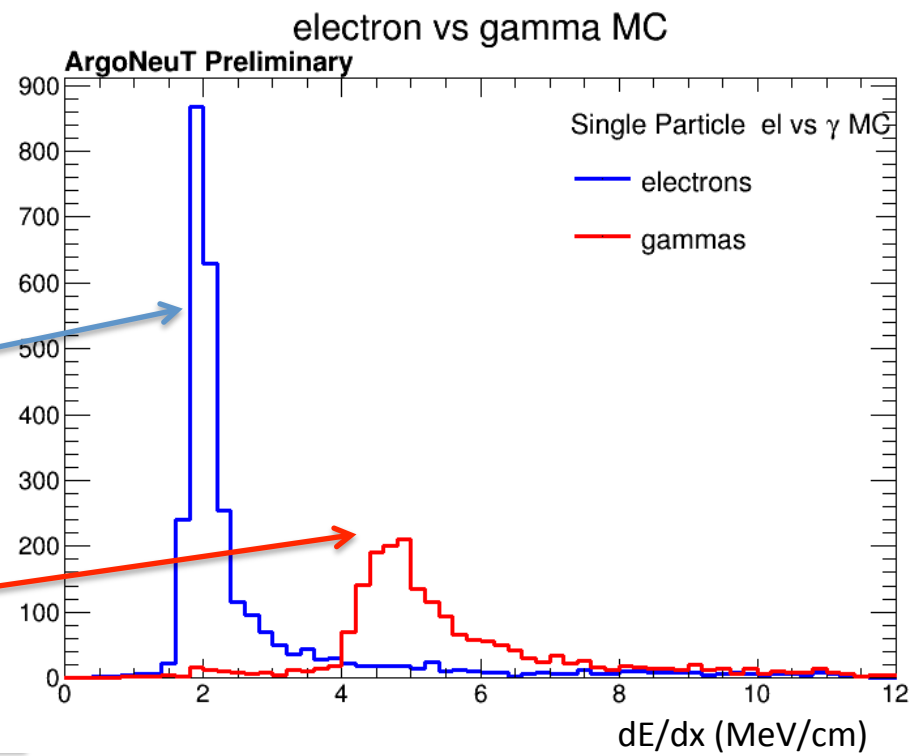


Beautiful images of events to use topology to differentiate event classes

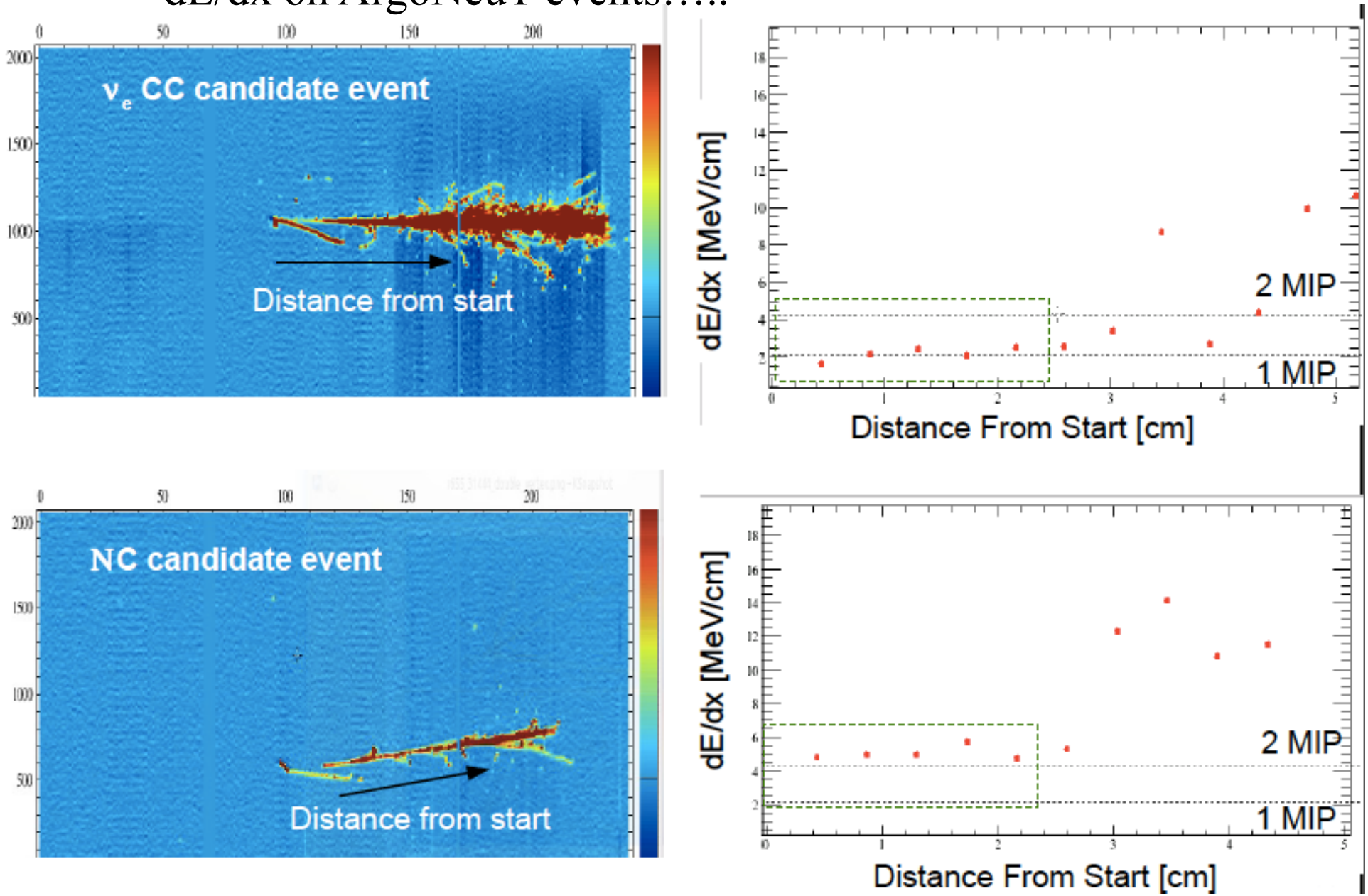
Take advantage of calorimetry to tag electrons vs gammas using dE/dx before electromagnetic shower evolves

Electron

Converted γ: e^+e^-



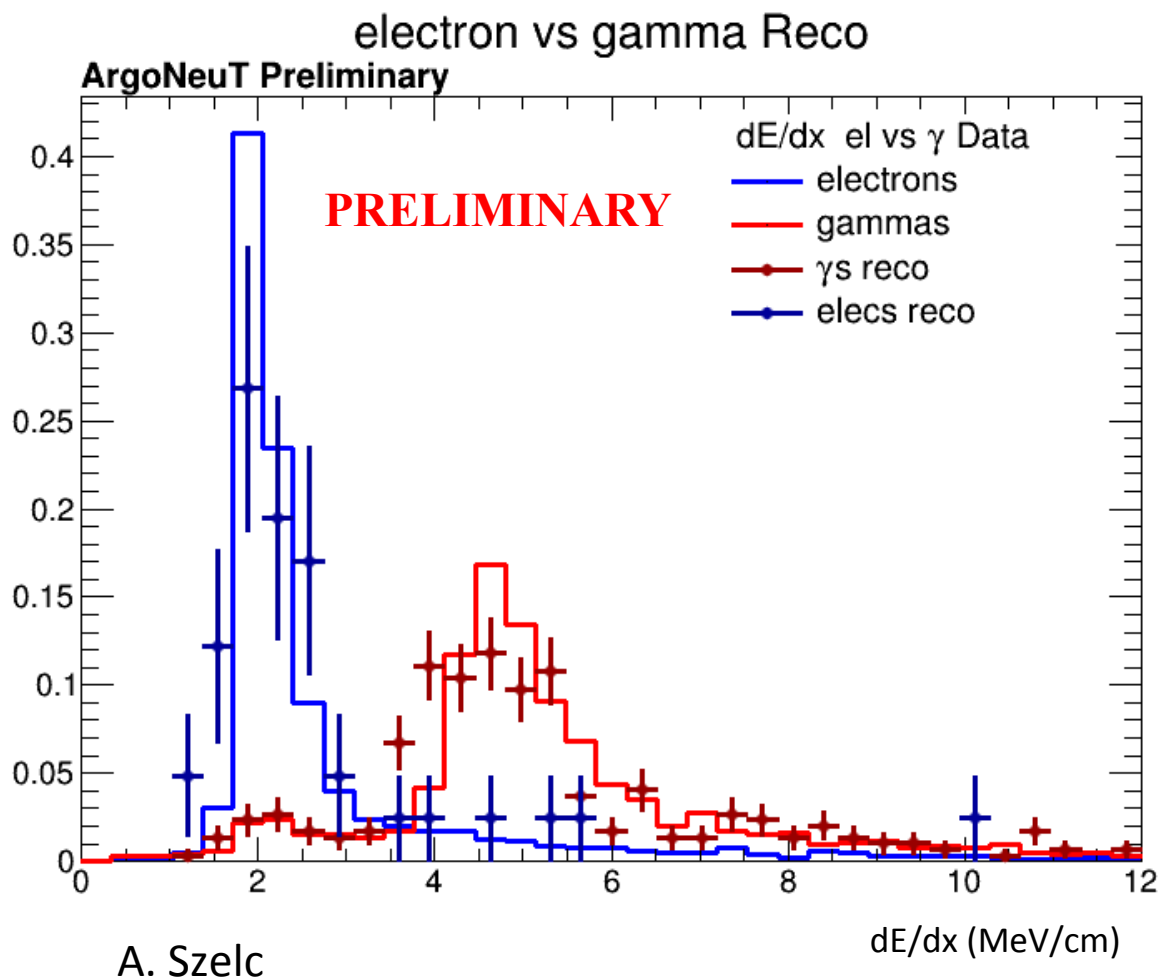
dE/dx on ArgoNeuT events…..



From A. Szelc

dE/dx separation confirmed with data!

- Gammas defined as EM showers detached from visible vertex
- Electrons defined as EM showers with visible vertex and no gap
- Electron events require no track matched to MINOs

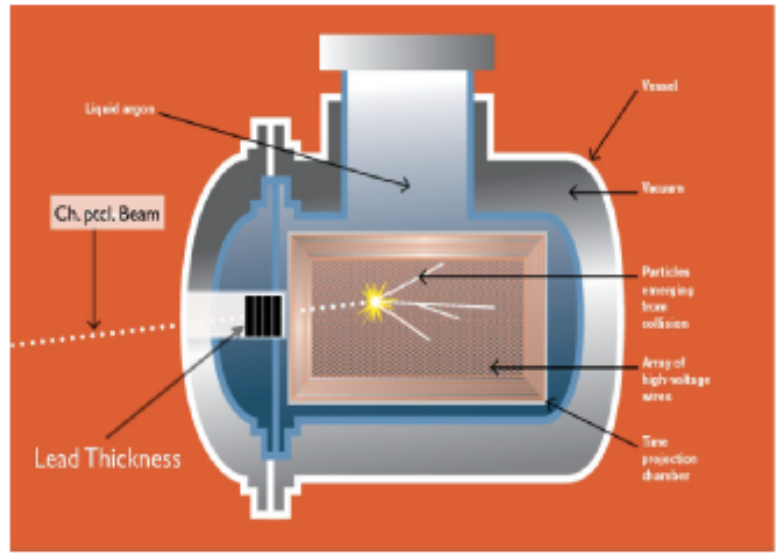


A. Szelc

ArgoNeuT becomes LArIAT

LArIAT: Liquid Argon in a Test Beam

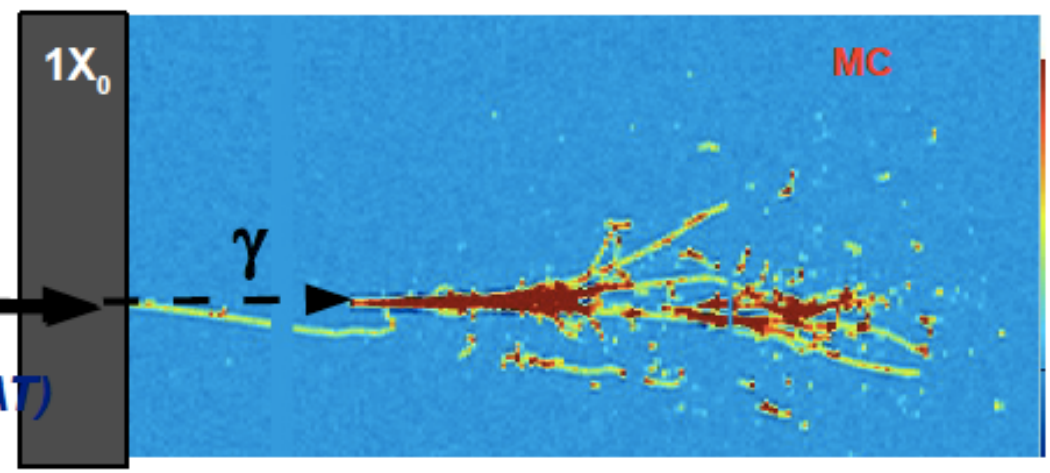
- Modified ArgoNeuT detector deployed in the FNAL test beam
- Known particle species, for example electrons…..

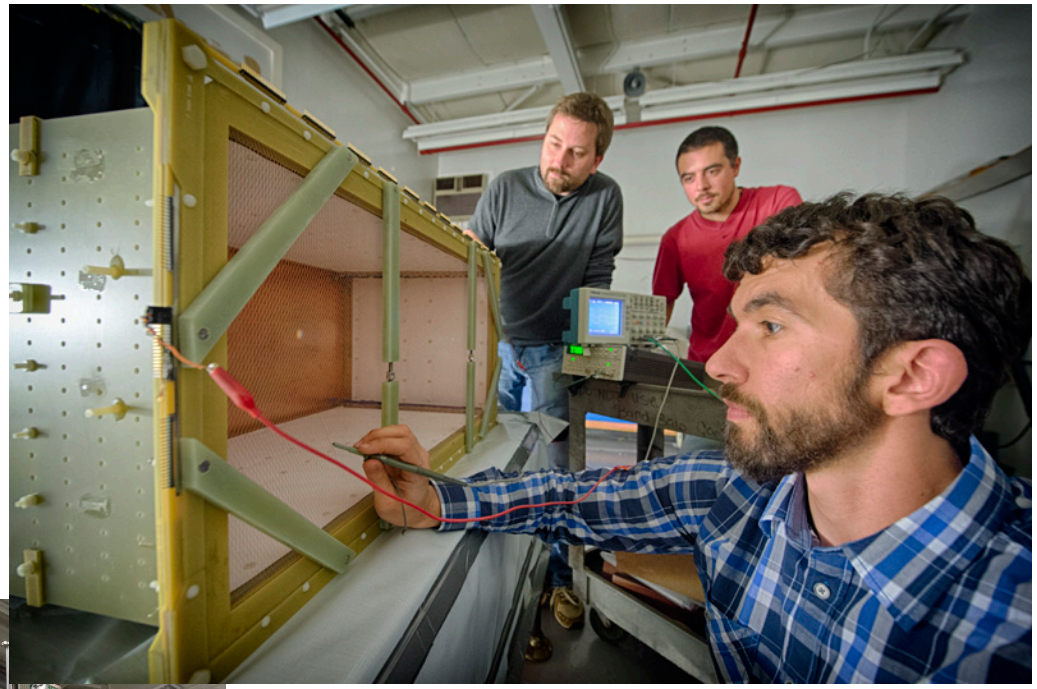


Electrons are found in tertiary beam. Photons generated via brehmsstrahlung in $1X_0$ pre-shower disk.

Do not need shower containment

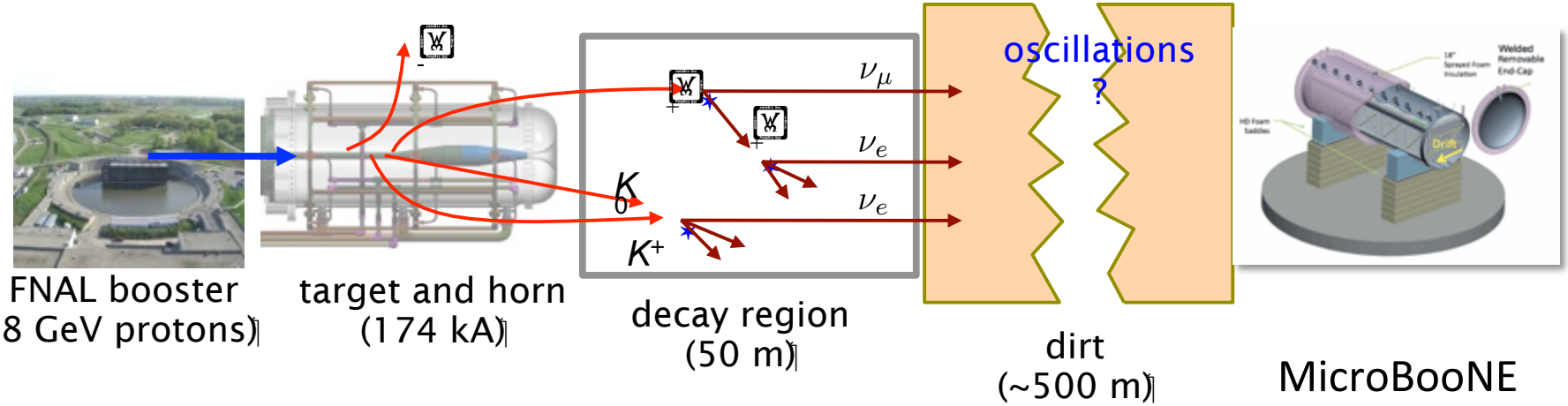
(This is only a small part of the Physics we will measure with LArIAT)





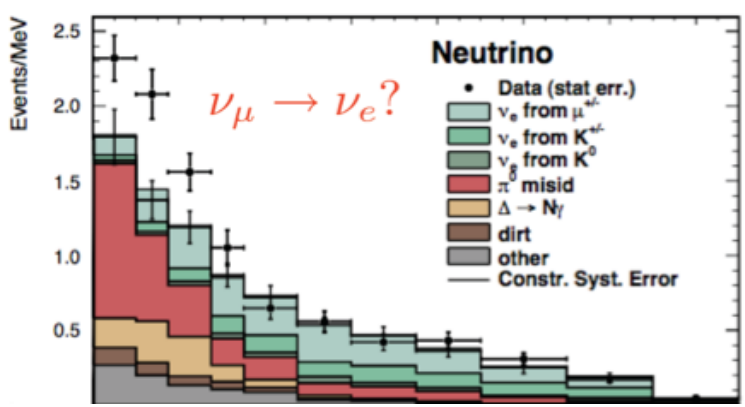
ArgoNeuT becomes LArIAT

The MicroBooNE Experiment



:

- Test exactly what has been seen in MiniBooNE with a more sensitive experiment – address the Short Baseline Anomalies!



Differentiate signal ν_es from background single photons so that it is 5 sigma significant but ~x10 smaller than MiniBooNE

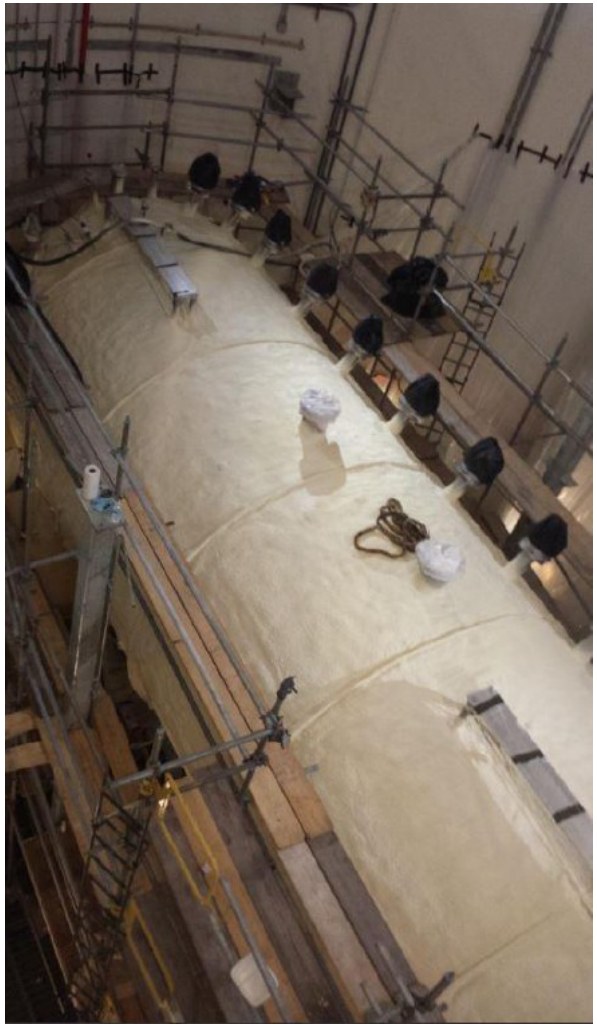
Fermilab *Today*

December 20th, 2013

MicroBooNE installs time projection chamber inside vessel, prepares for move

Completed Detector moved to LArTF this summer

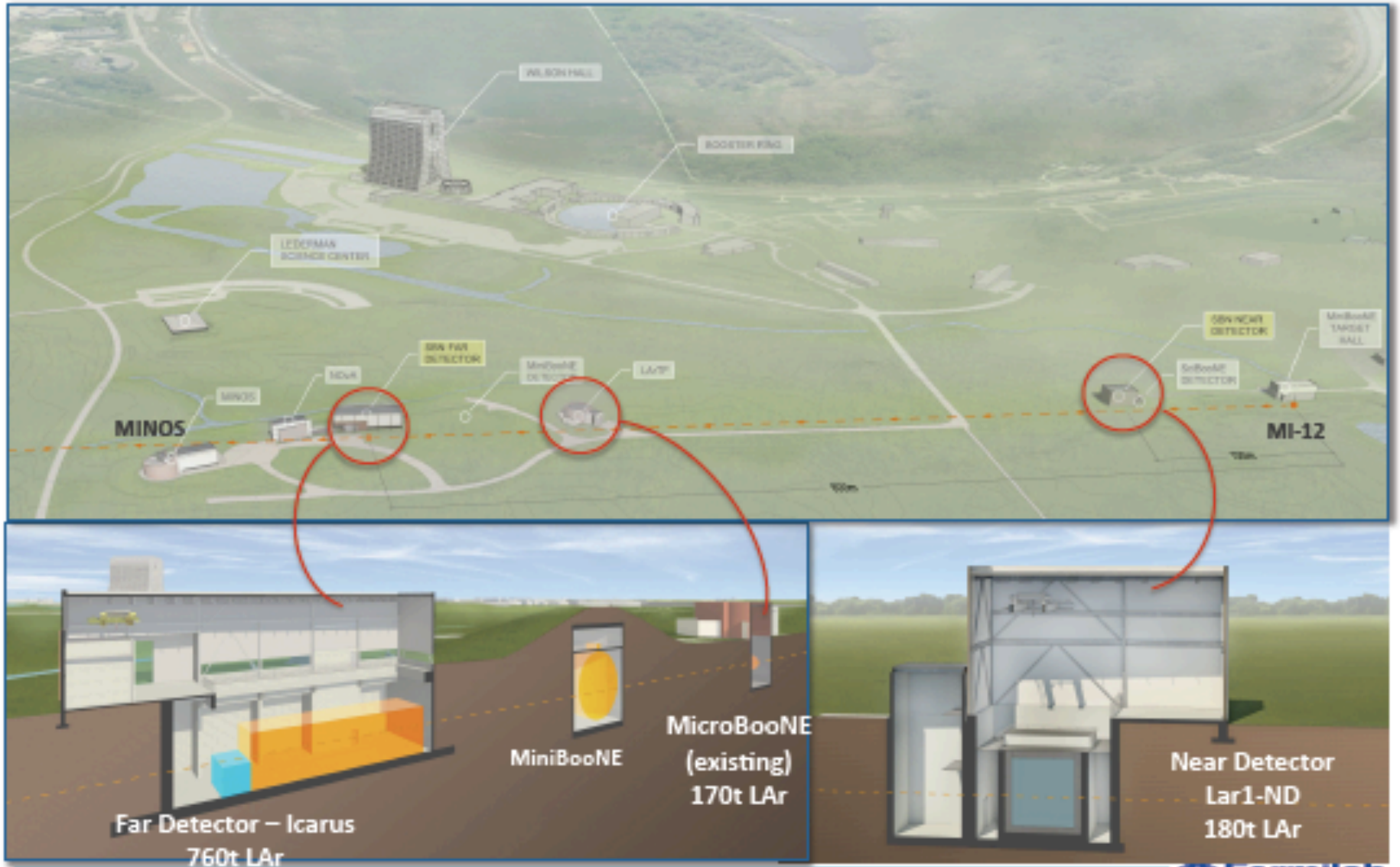
Final Installation underway, Commissioning has begun, LAr fill scheduled for January



Detector insulated, in place in LArTF

Electronics racks being installed in October

SBN Program Layout



Summary

- ArgoNeuT produced first published cross section measurements on Argon (with several more papers in preparation) and several technical papers

  7 papers in 2 years(!)
- LArIAT is ArgoNeuT modified and in a test beam to begin data taking next year
- MicroBooNE will begin data taking next year
  - Low energy excess observed by MicroBooNE
  - Suite of precision neutrino cross section measurements!
- Short Baseline program at FNAL beyond MicroBooNE includes LAr1-ND and ICARUS