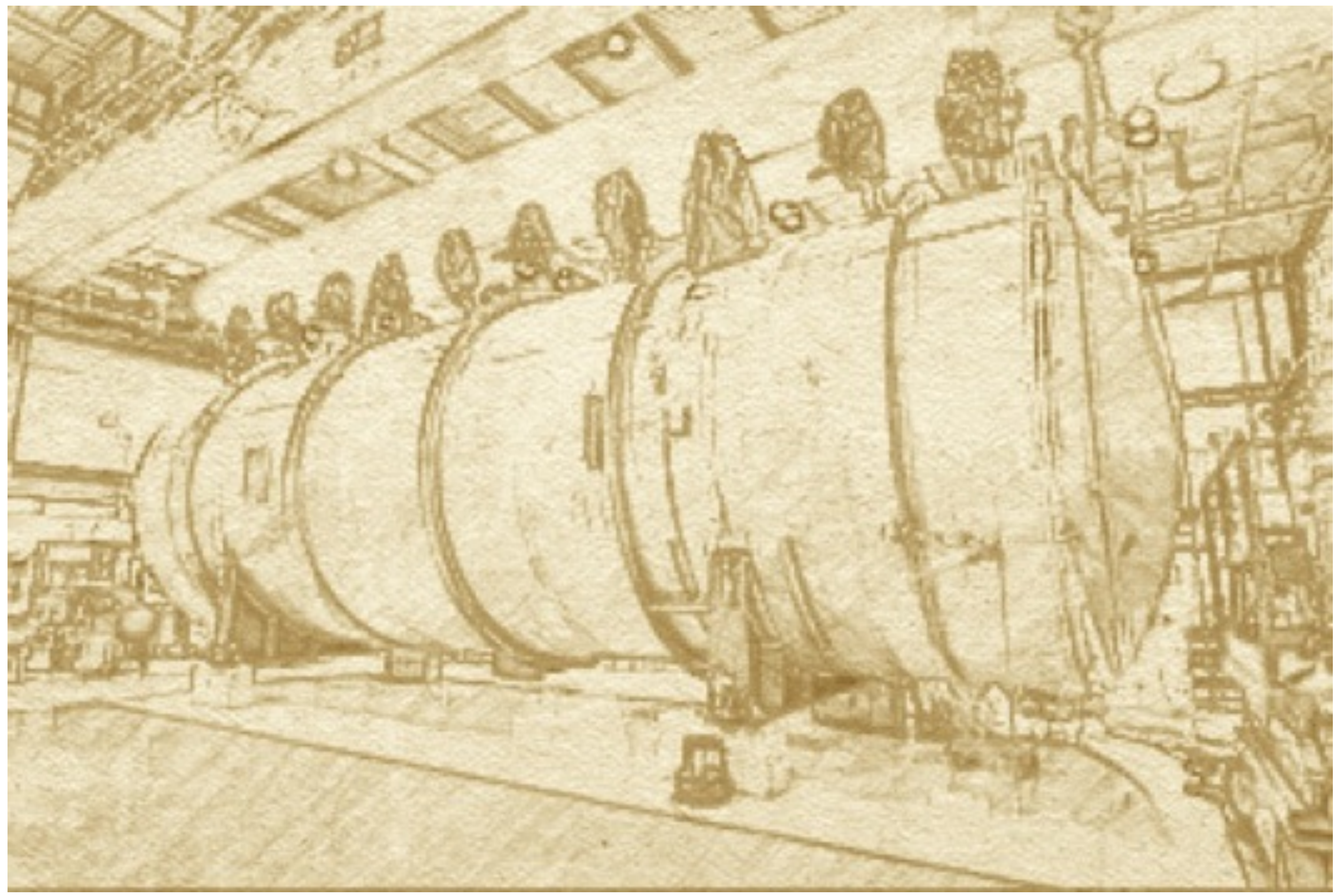
Status of the ArgoNeuT and MicroBooNE Experiments



Mitch Soderberg
on behalf of the ArgoNeuT and MicroBooNE collaborations
Recontres du Vietnam Flavour Conference

Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) are imaging detectors that offer exceptional capabilities for studying neutrinos.

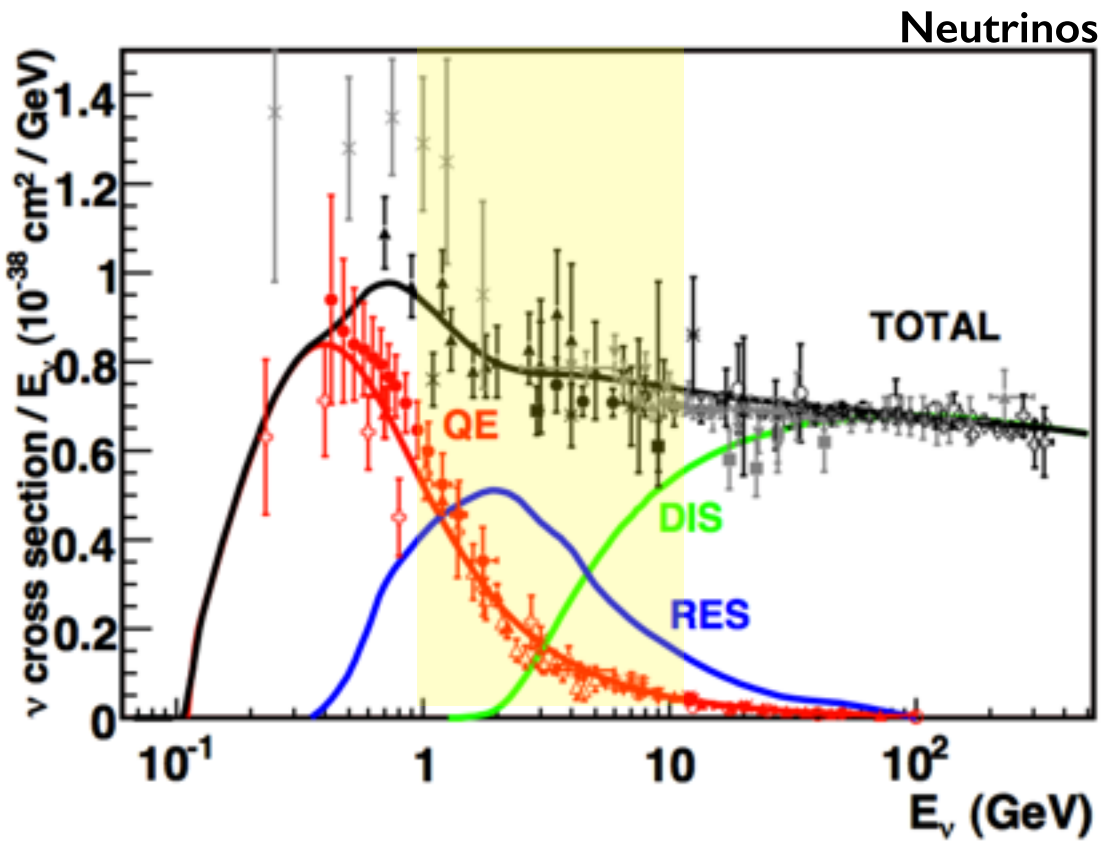
- I will give a brief overview of recent LArTPC activities in the U.S., focusing on the ArgoNeuT and MicroBooNE experiments at Fermilab.

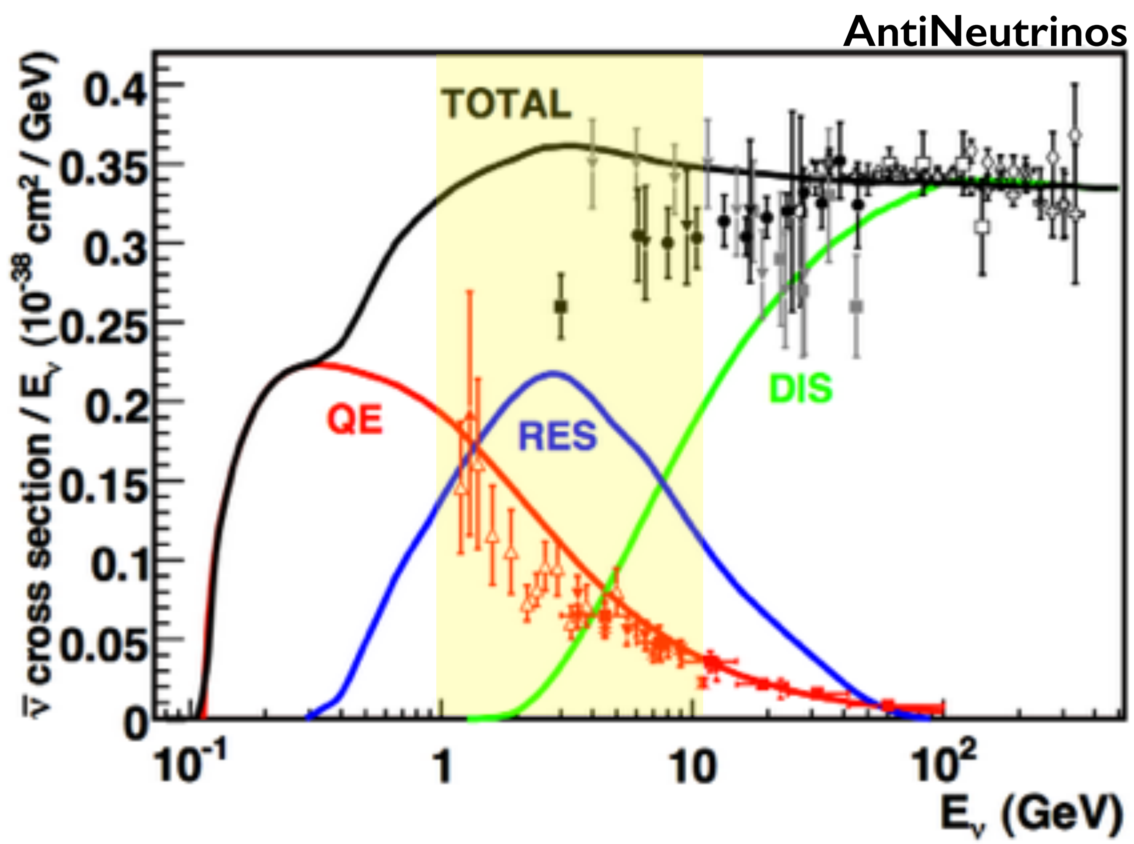
- These near-term activities are helping to bring the LArTPC technology to maturity for use in future long-baseline and short-baseline programs.

Neutrino Interactions

- Neutrino experiments that will search for CP-violation are operating in an energy-regime where several competing processes are active.

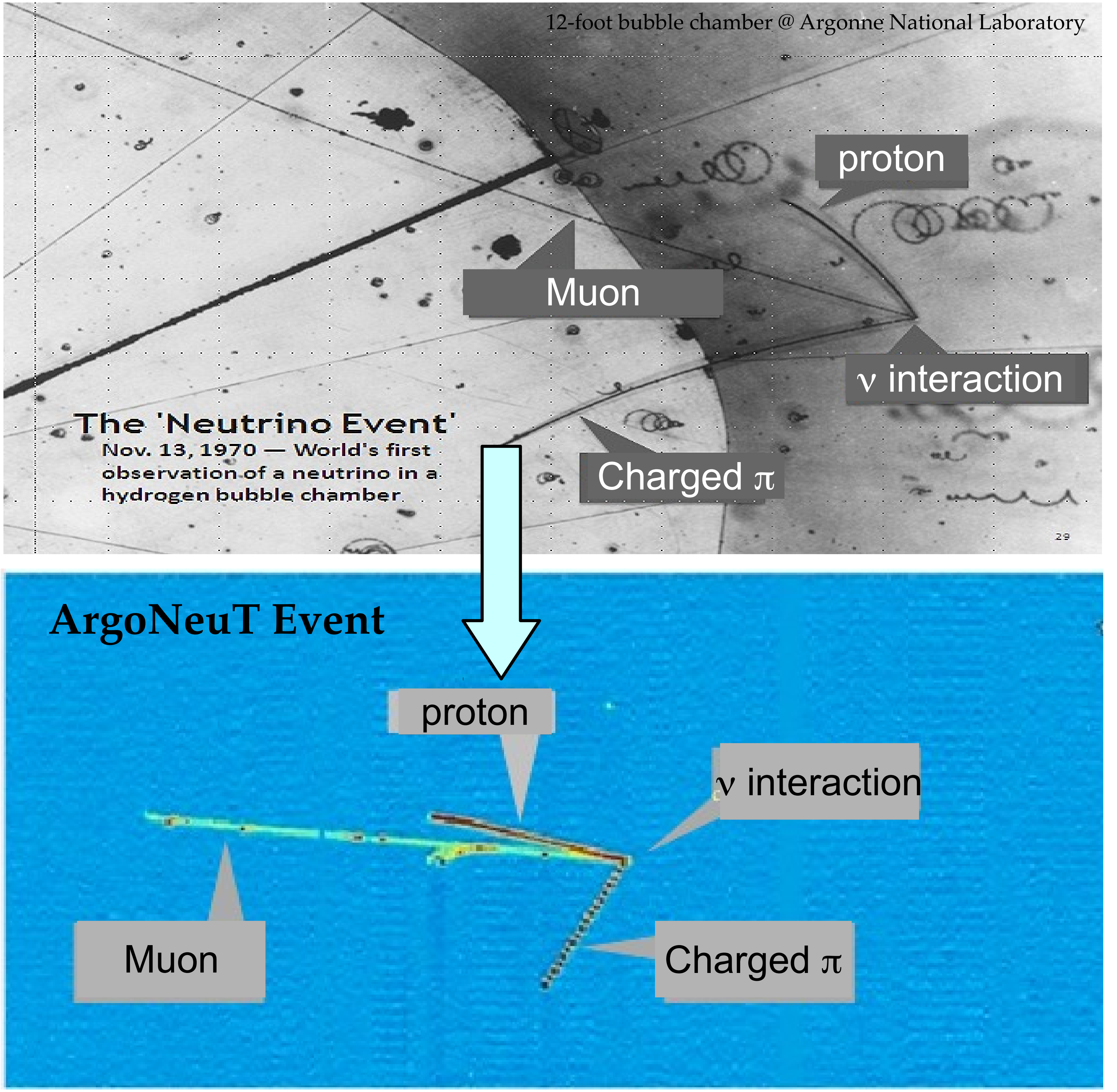
- Nuclear targets in these experiments (*e.g.* - Carbon, Argon, Oxygen, etc…) introduce complications that can skew picture of observed interactions.



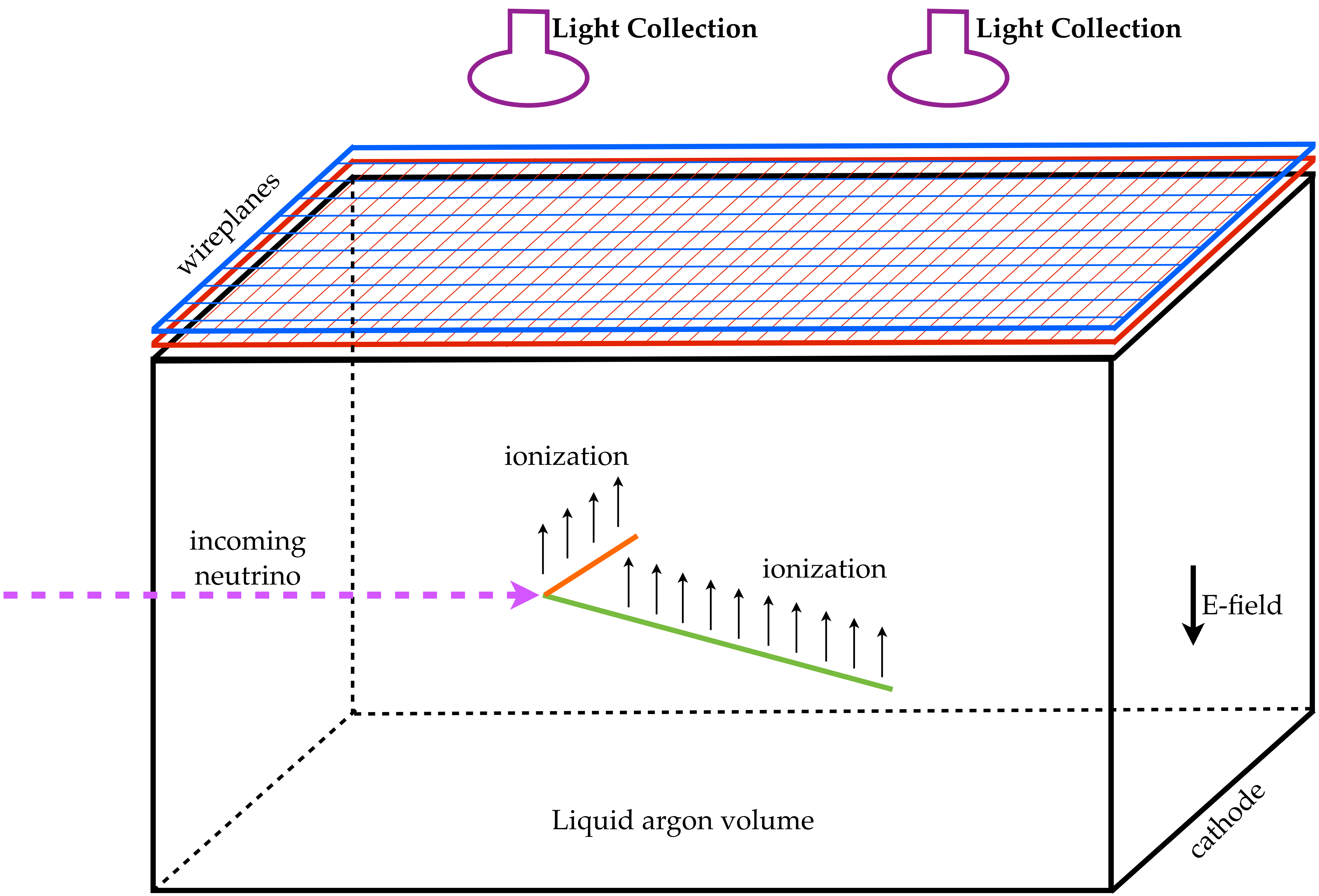


Why Liquid Argon for Neutrinos?

- Bubble chamber quality images combined with calorimetry.
- Scalable to largest sizes necessary for neutrino CP-violation searches .

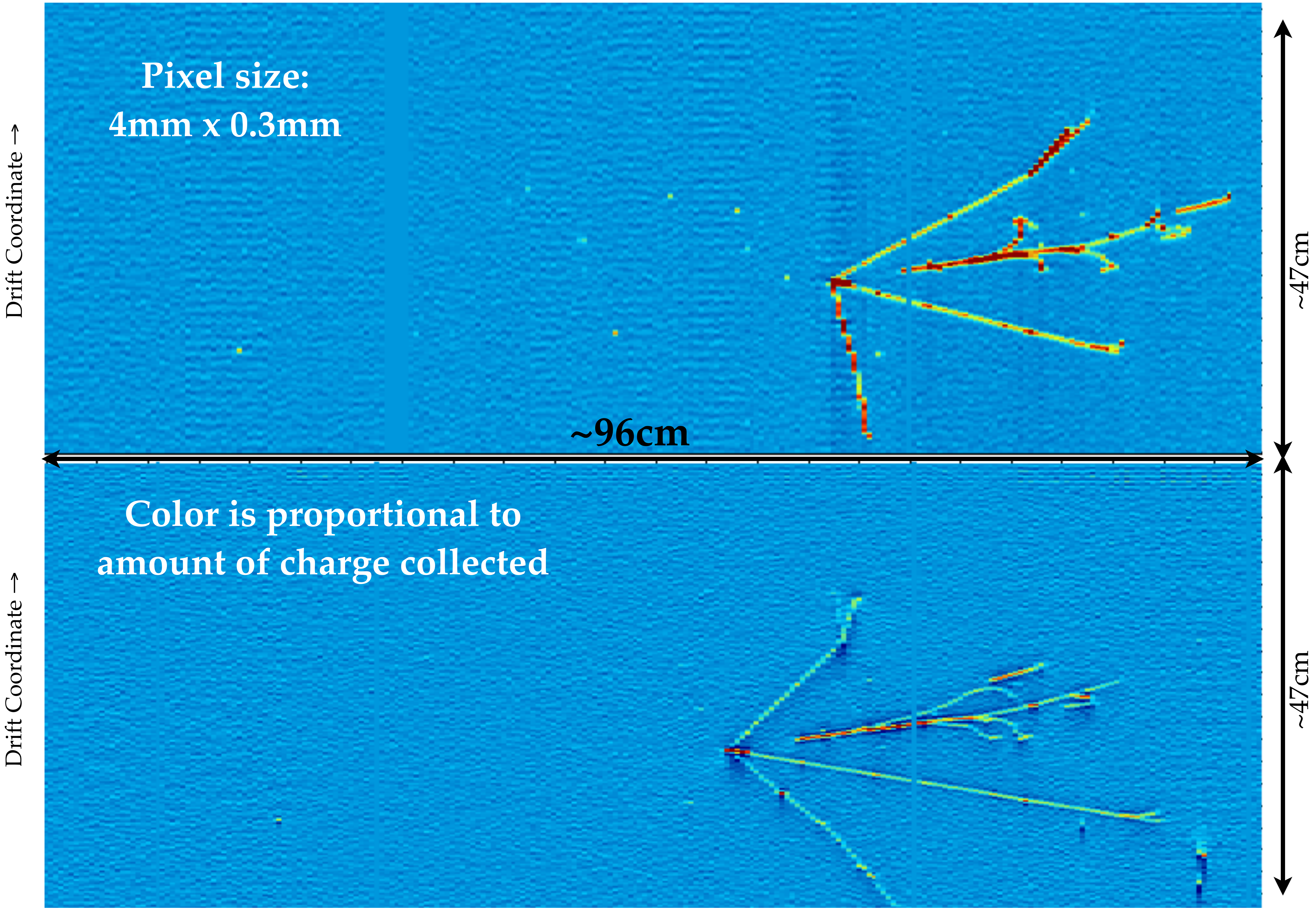


Liquid Argon Neutrino Detectors



Refs
1.) *Liquid-argon ionization chambers as total-absorption detectors*, W. Willis and V. Radeka, Nuclear Instruments and Methods 120 (1974), no. 2, 221-236.
2.) *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

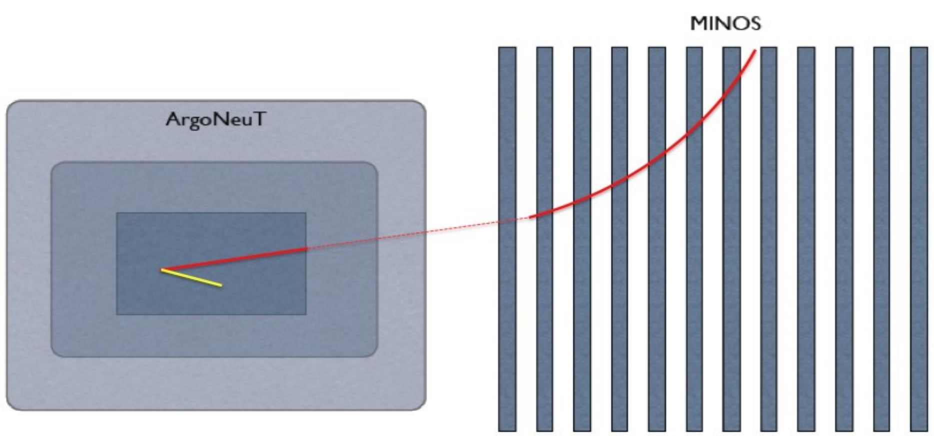
Neutrino Interaction in ArgoNeuT



ArgoNeuT

- LArTPC operated in Fermilab's NuMI neutrino beam.
- Located upstream of MINOS near detector, which provides muon reconstruction and sign selection.
- Collected 1.35×10^{20} Protons on Target (POT).

Cryostat Volume	500 Liters
TPC Volume	175 Liters (90cm x 40cm x 47.5cm)
# Electronic Channels	480
Electronics Style (Temp.)	JFET (293 K)
Wire Pitch (Plane Separation)	4 mm (4 mm)
Electric Field	500 V/cm
Max. Drift Length (Time)	0.5 m (330 μs)
Wire Properties	0.15mm diameter BeCu

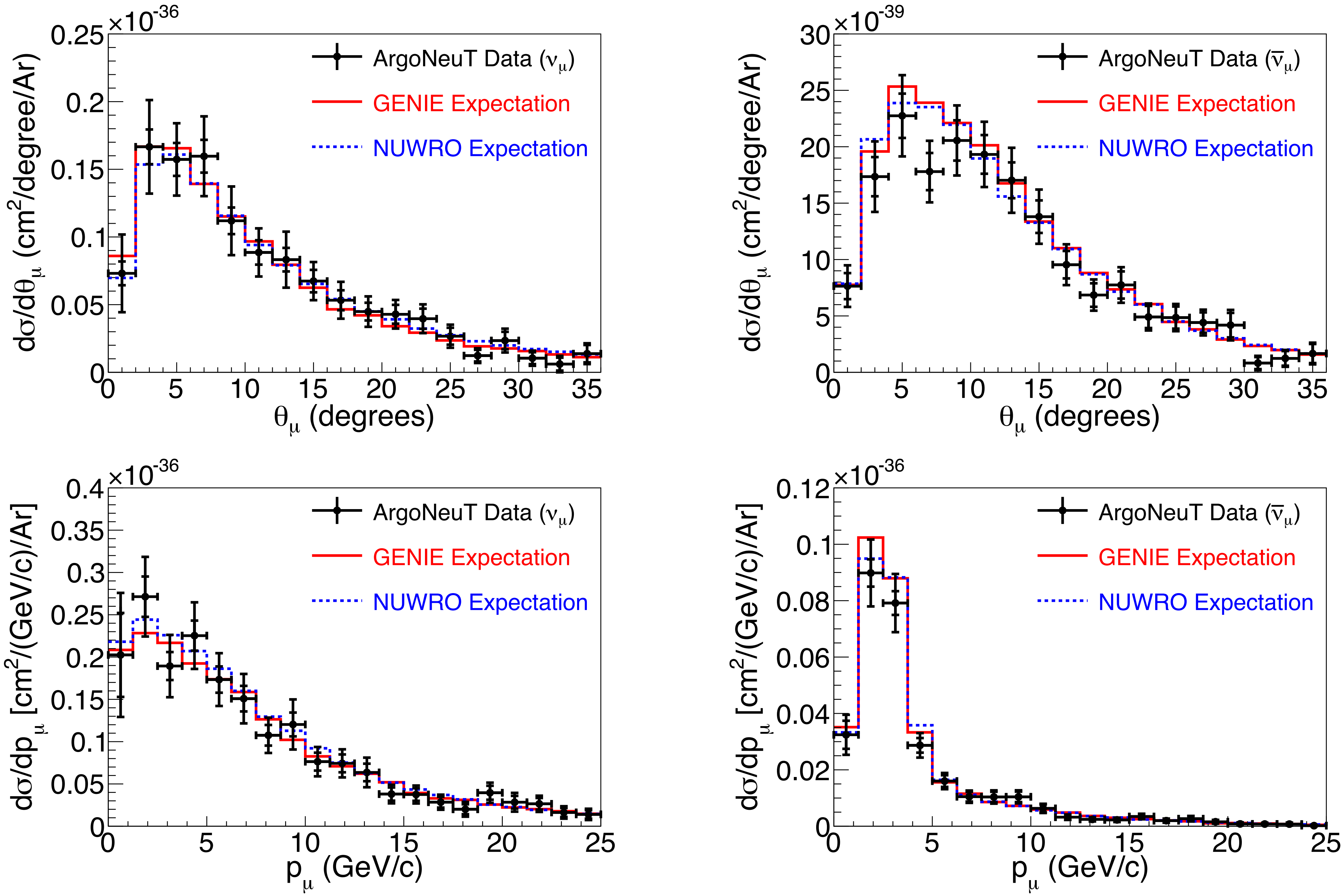


ArgoNeuT in the NuMI Tunnel

Refs:
1.) *The ArgoNeuT detector in the NuMI low-energy beam line at Fermilab*, C. Anderson et al., JINST 7 P10019, Oct. 2012, arXiv:1205.6747

ArgoNeuT: Physics

- "Standard candle" measure of inclusive charged-current cross-sections have been performed using both antineutrinos and neutrinos. First time ever on argon target.
- Helps establish performance of our evolving reconstruction tools.



Refs:
1.) *Measurements of Inclusive Muon Neutrino and Antineutrino Charged Current Differential Cross Sections on Argon in the NuMI Antineutrino Beam*, R. Acciarri et al, Phys. Rev. D 89, 112003 (2014)

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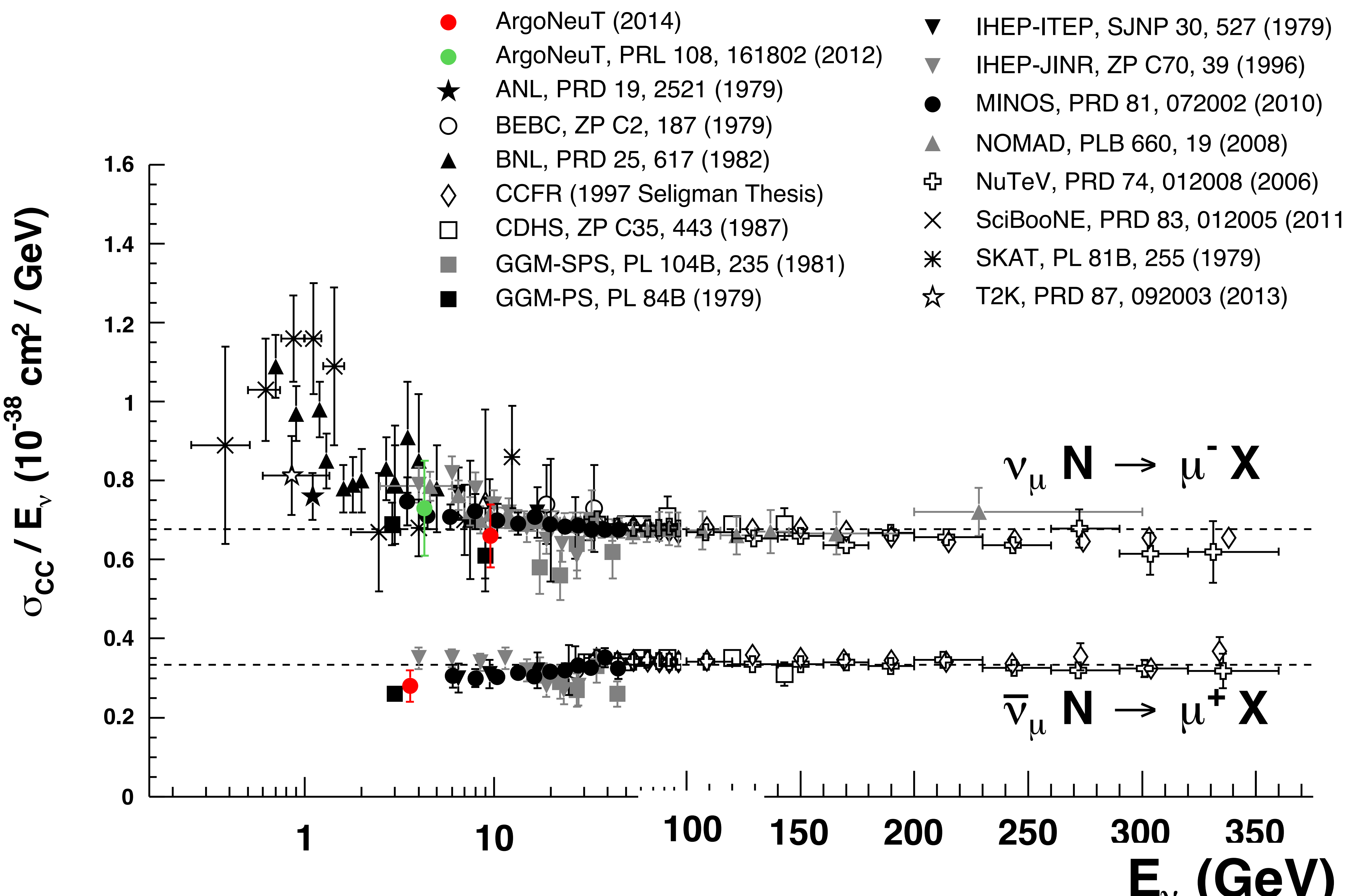

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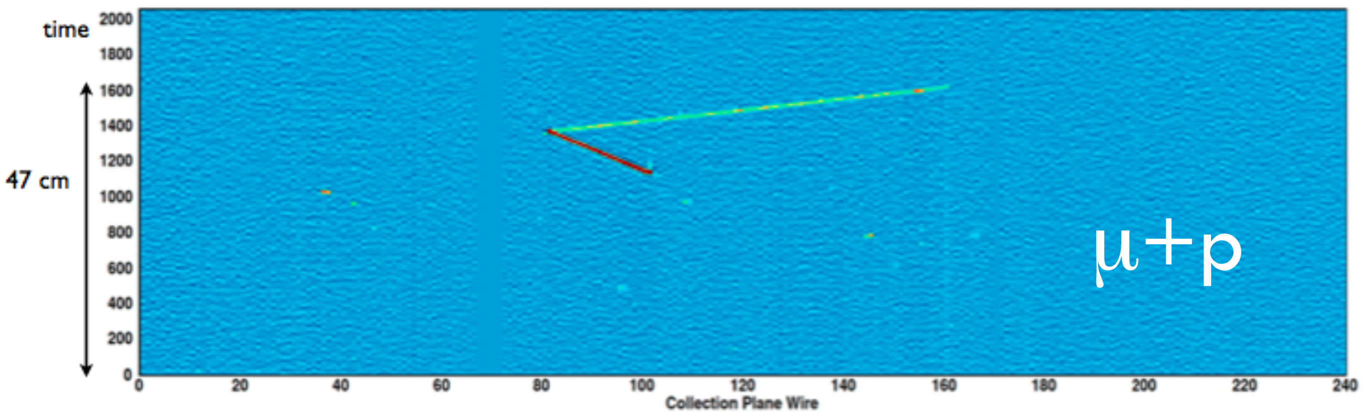
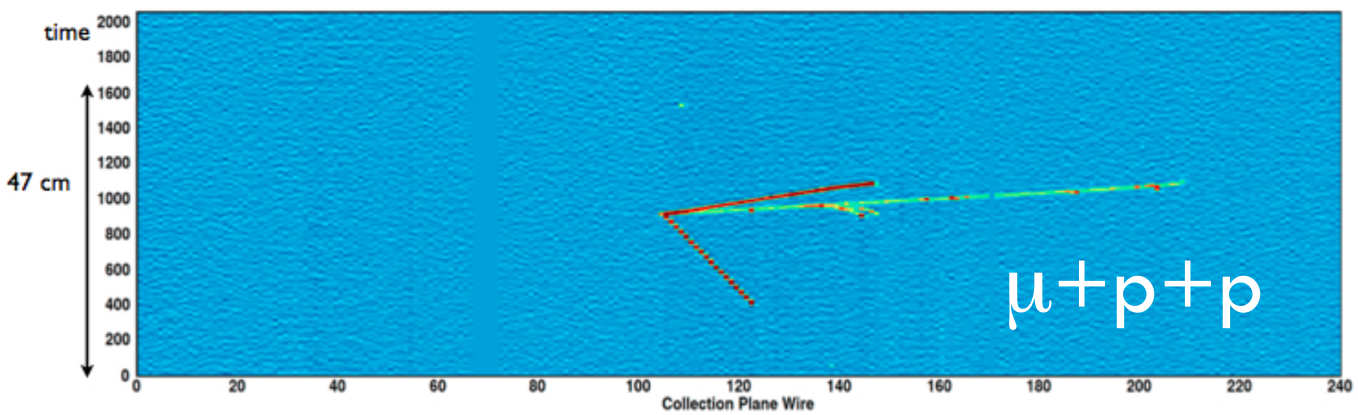
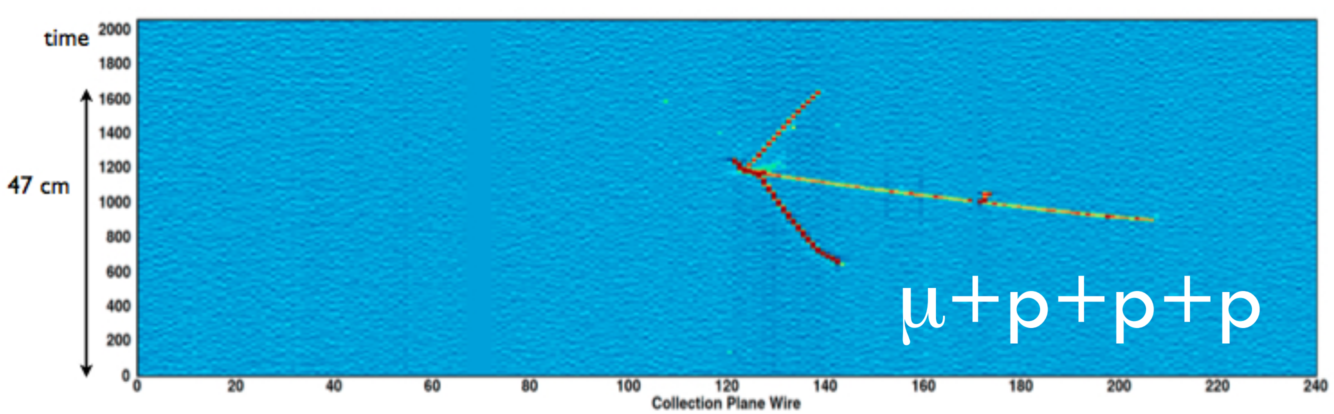
Multiplicity of protons in charged-current events with 0 pions in final state can help tune nuclear modeling.







Refs:
1.) *The detection of back-to-back proton pairs in Charged-Current neutrino interactions with the ArgoNeuT detector in the NuMI low energy beam line*, R. Acciarri et al, Phys. Rev. D 90, 012008 (2014)
2.) *First Measurement of Neutrino and Antineutrino Coherent Charged Pion Production on Argon*, R. Acciarri et al, paper in progress

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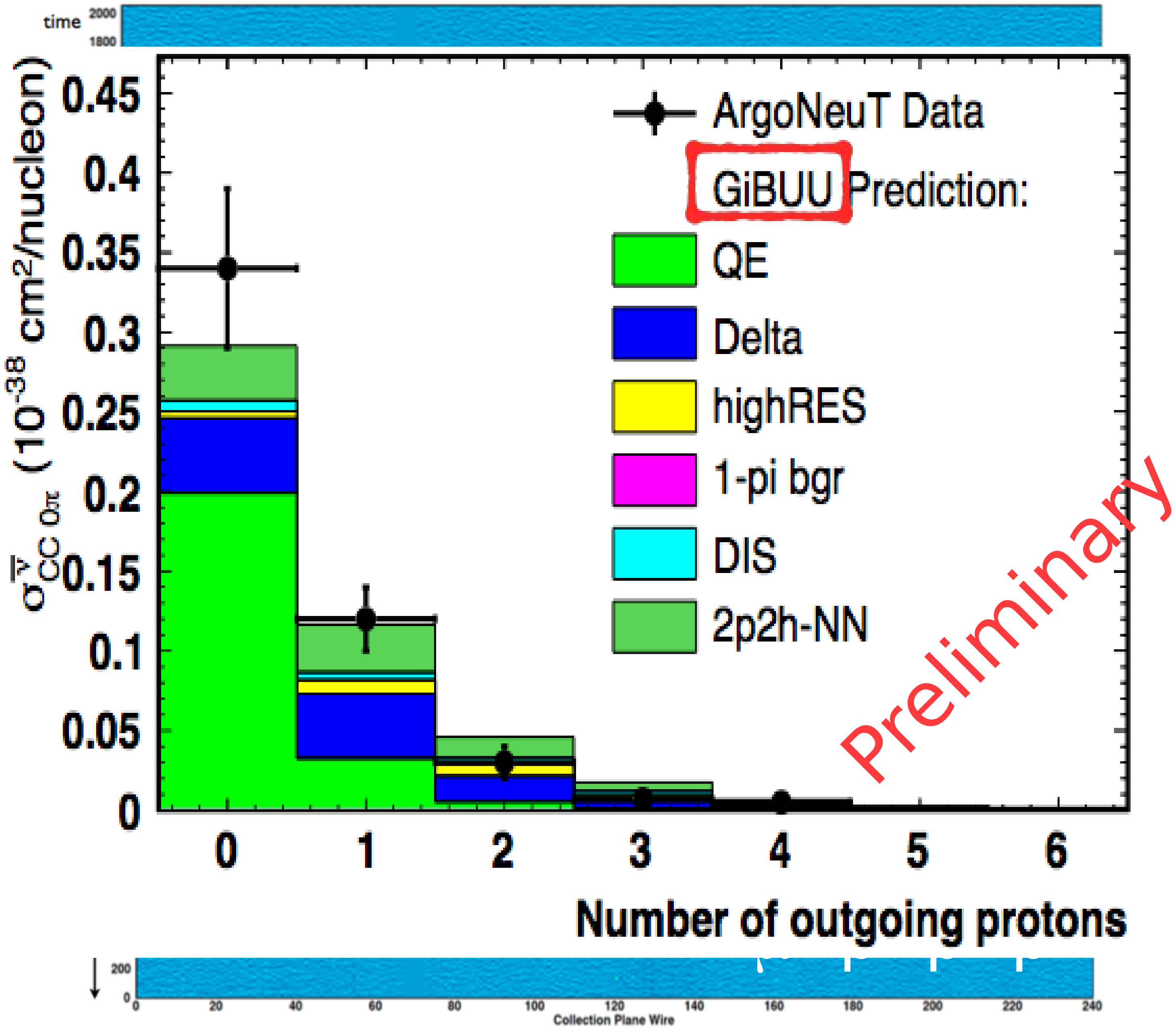

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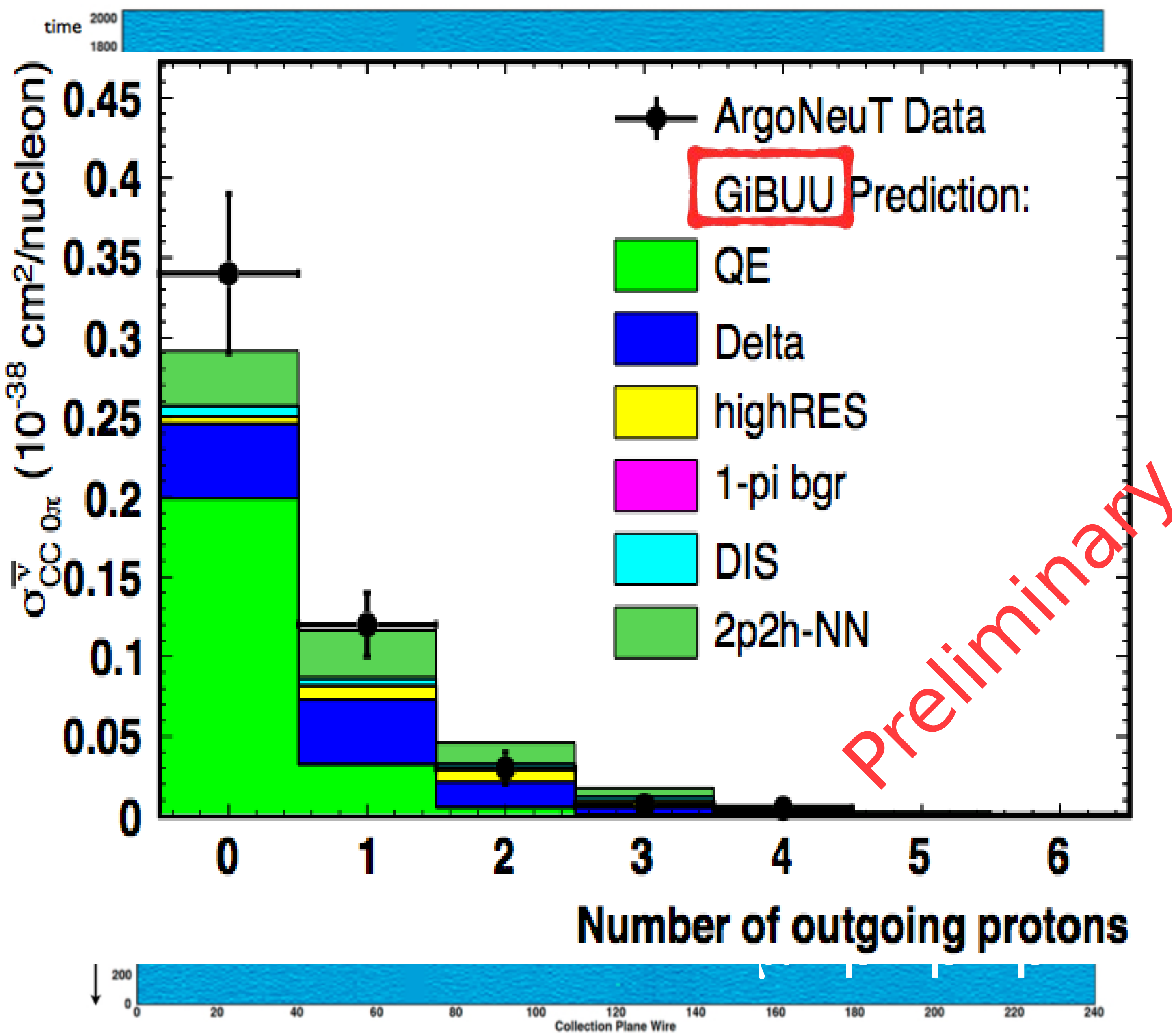
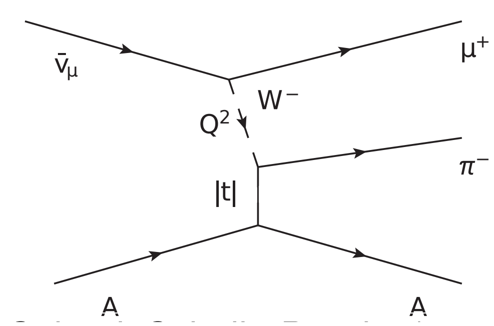
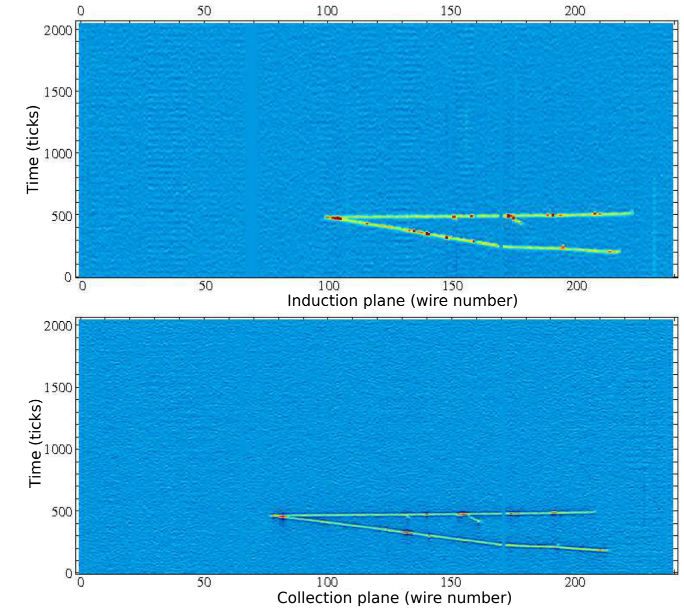
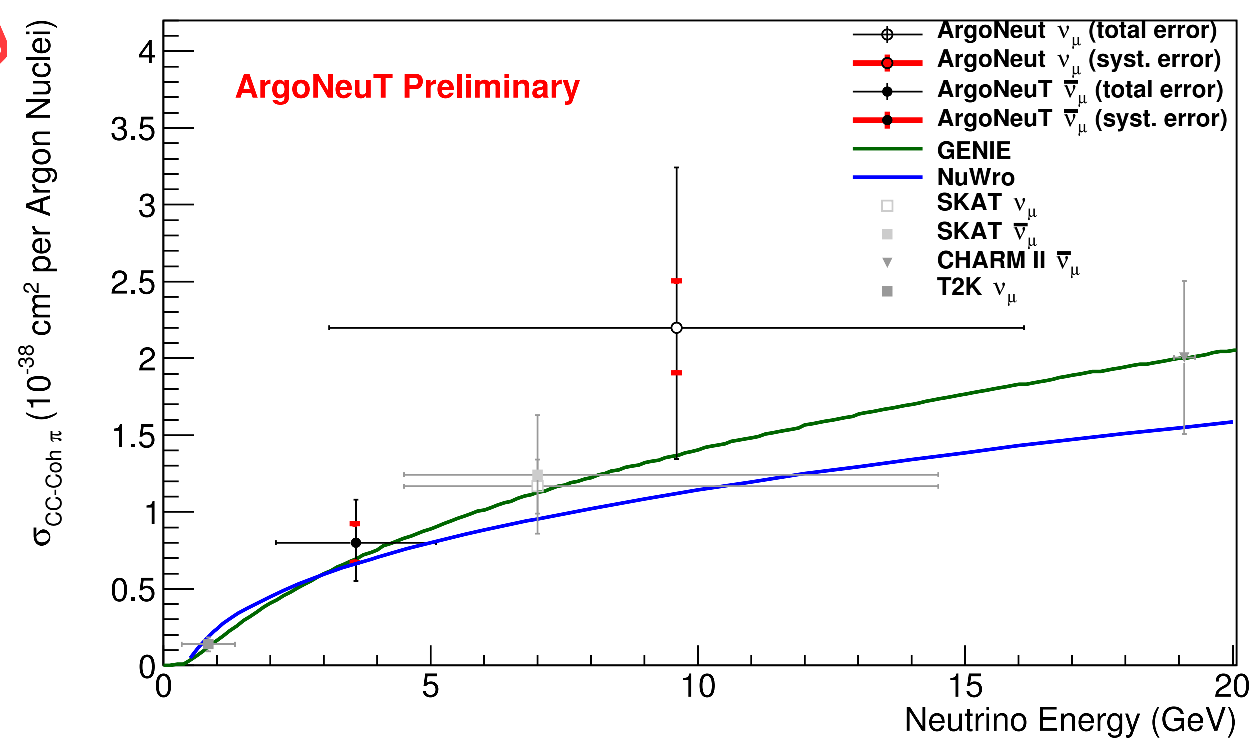


First measurement of charged-current coherent pion production on argon target.







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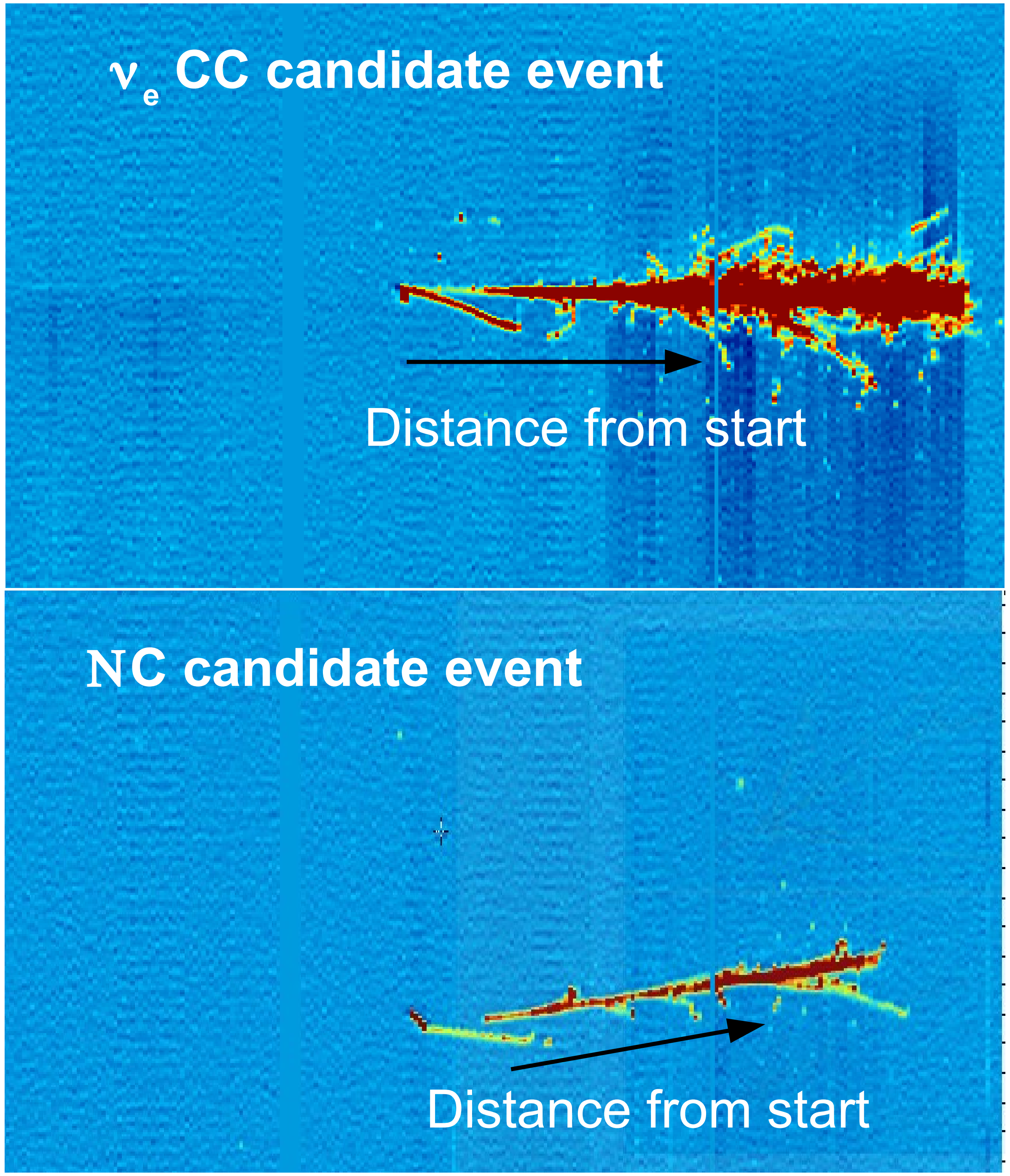
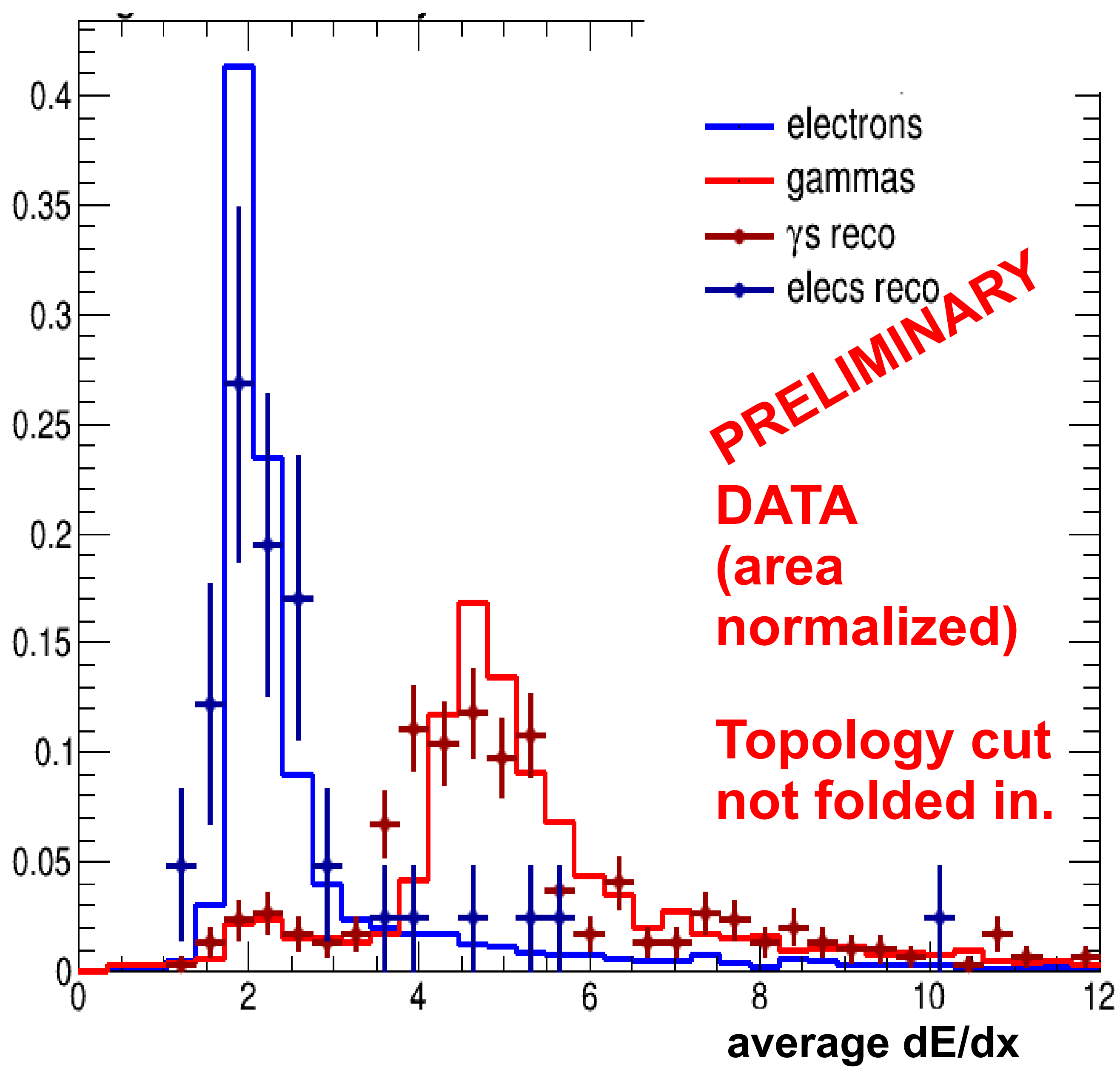
2.) *First Measurement of Neutrino and Antineutrino Coherent Charged Pion Production on Argon*, R. Acciarri et al, paper in progress

ArgoNeuT: Physics

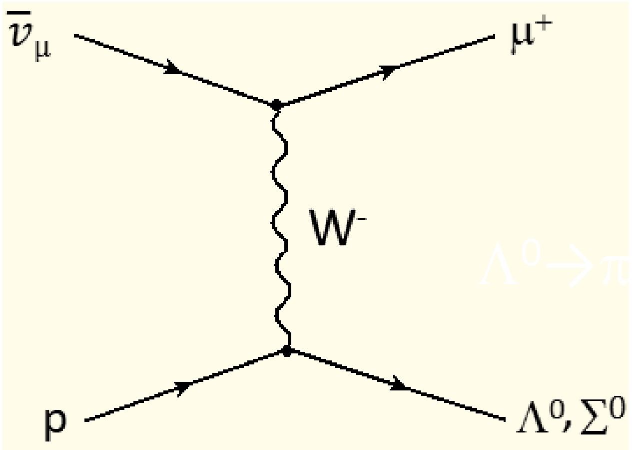
- Particle ID of electrons vs. photons relies on ability to see displaced vertices, and to reconstruct energy at beginning of shower.
- ArgoNeuT is developing this technique using a small data sample.



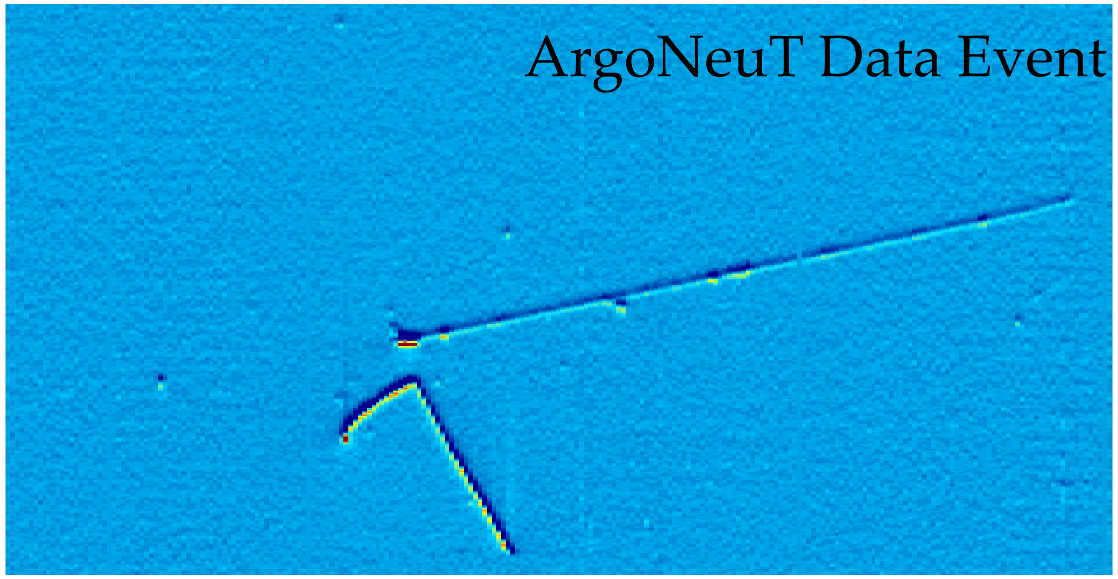


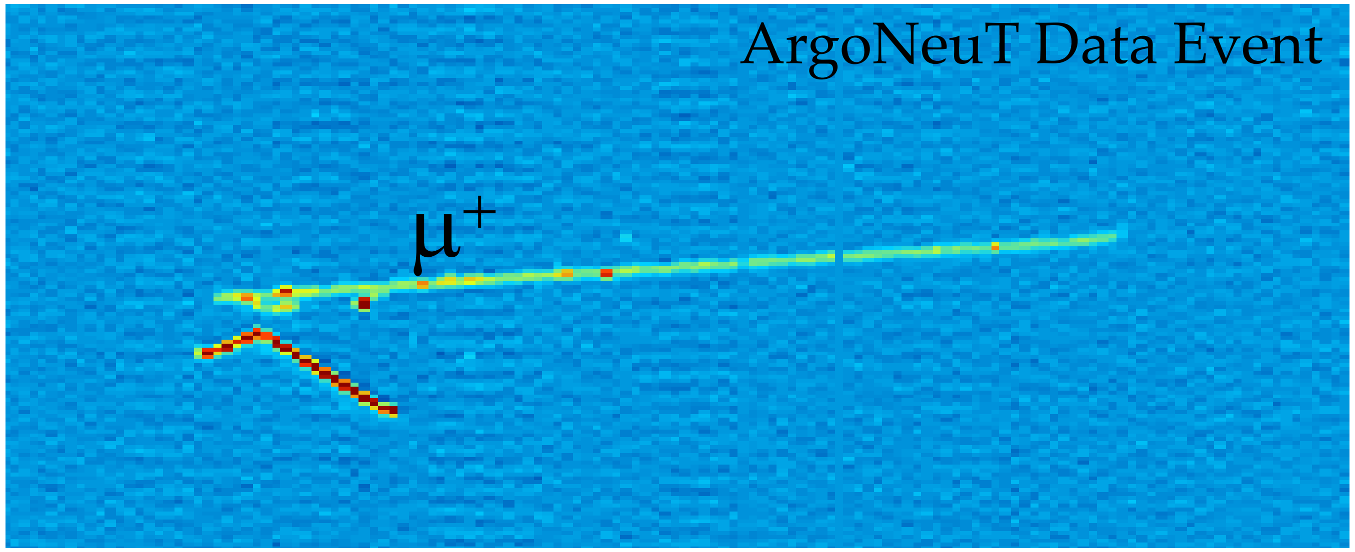
ArgoNeuT: Physics

- Excellent resolution allows direct measurement of Hyperon production in neutrino interactions.
- Due to ArgoNeuT's small size, statistics are very limited and containment is a problem, but several candidates are observed.



$\Lambda^0 \rightarrow \pi^+ + p$

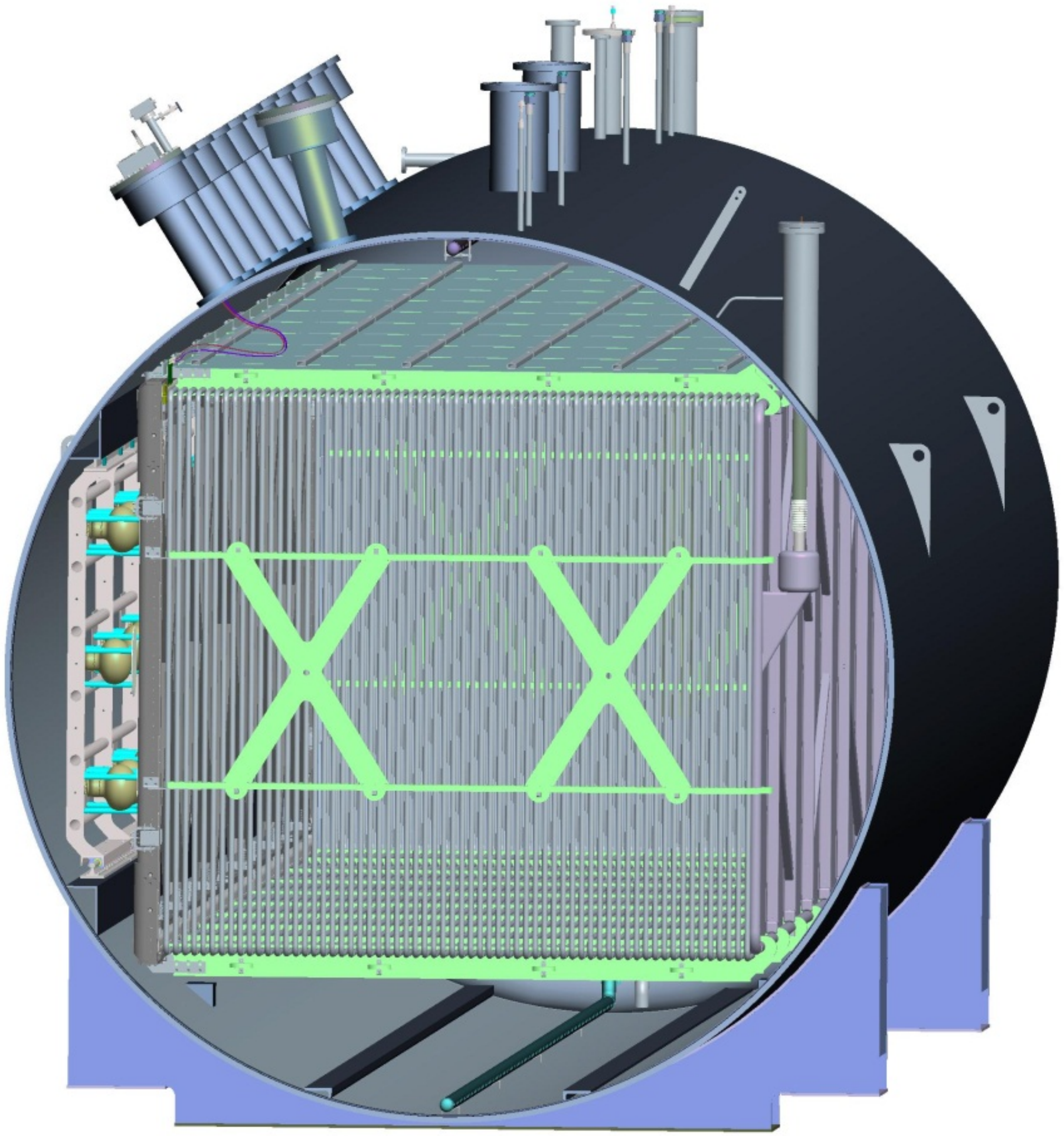




The MicroBooNE Experiment

- MicroBooNE will operate in the Booster neutrino beam at Fermilab.
- Combines physics with hardware R&D necessary for the evolution of LArTPCs.
  - MiniBooNE low-energy excess
  - Low-Energy (<1 GeV) neutrino cross-sections
  - Cold Electronics (preamplifiers in liquid)
  - Long drift (2.5m)
  - Purity without evacuation.

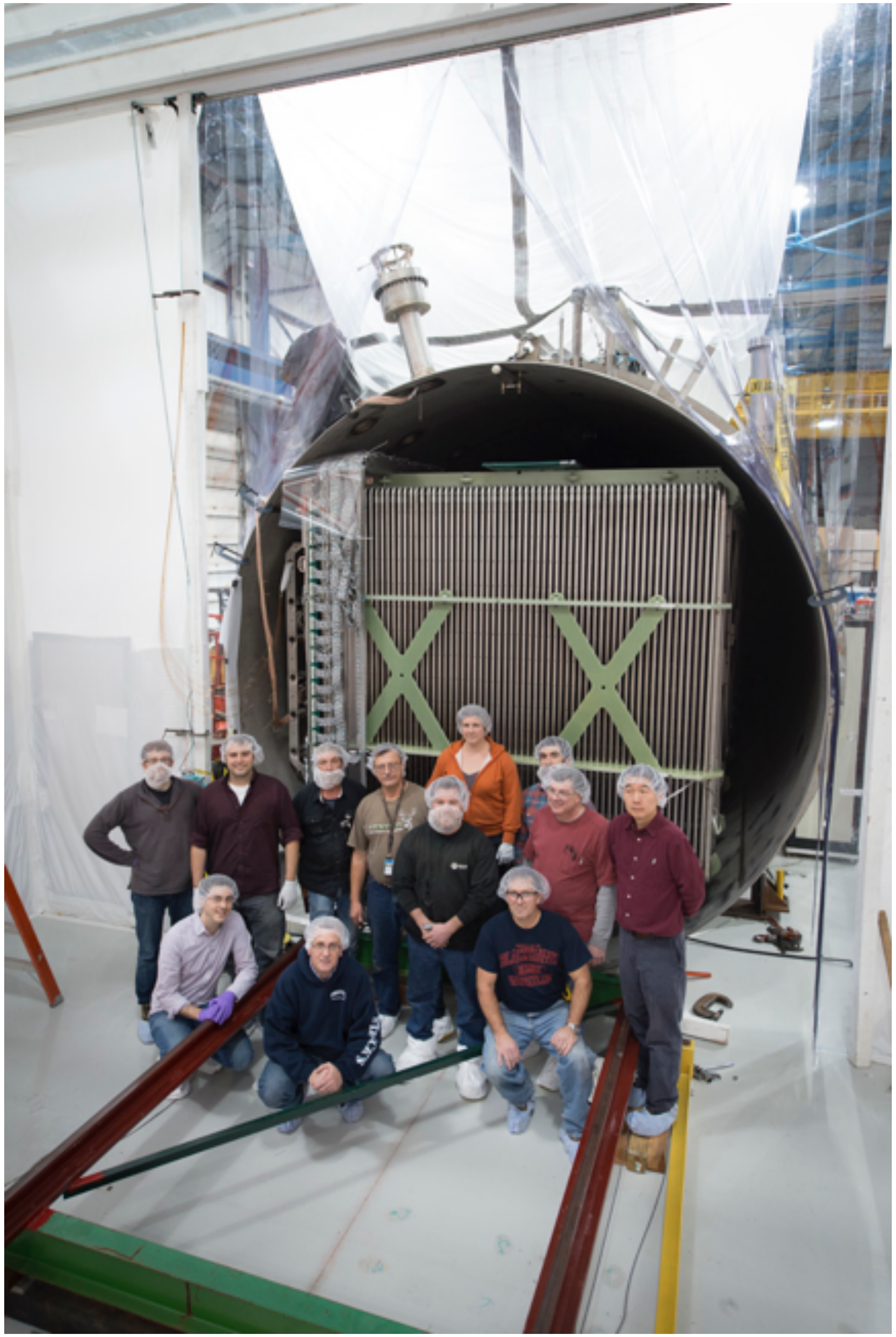
Cryostat Volume	150 Tons
TPC Volume (l x w x h)	89 Tons (10.4m x 2.5m x 2.3m)
# Electronic Channels	8256
Electronics Style (Temp.)	CMOS (87 K)
Wire Pitch (Plane Separation)	3 mm (3mm)
Max. Drift Length (Time)	2.5m (1.5ms)
Wire Properties	0.15mm diameter SS, Cu/Au
Light Collection	30 8" Hamamatsu PMTs



MicroBooNE Experiment

Refs:
1.) *Proposal for a New Experiment Using the Booster and NuMI Neutrino Beamlines*, H. Chen et al., FERMILAB-PROPOSAL-0974

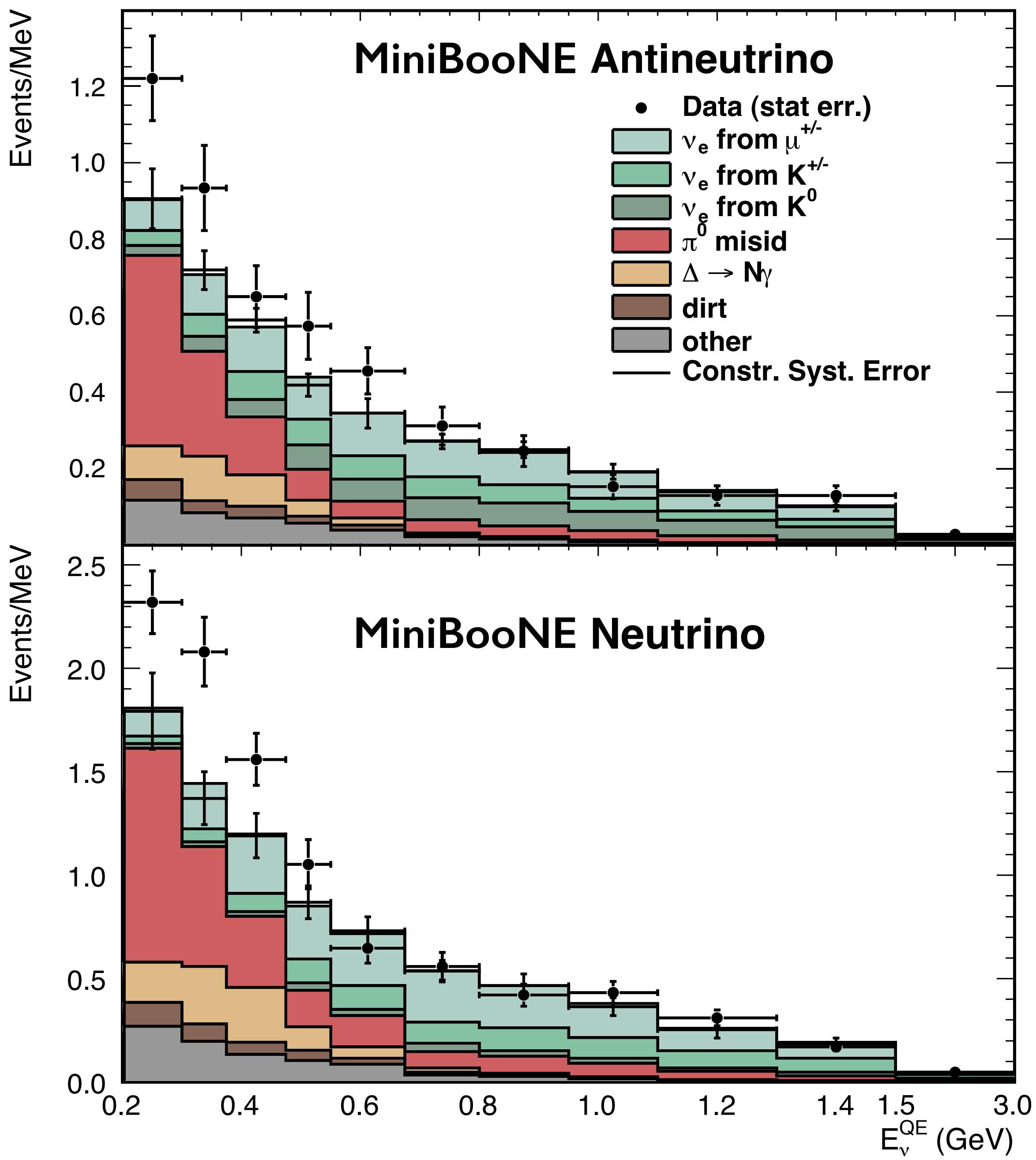
MicroBooNE Construction



MicroBooNE Installation: June 2014

MicroBooNE: Physics

- Address the "low energy excess" seen by the MiniBooNE experiment.
  - MiniBooNE is a Cerenkov detector that looks for ν_e appearance from a beam of ν_μ
  - Does MicroBooNE confirm the excess?
  - If confirmed, is the excess due to an electron-like or gamma-like process?



MiniBooNE ν_e

Appearance Result Excess

AntiNeutrino: 78.4±28.5 events (200-1250 MeV)

Neutrino: 162.0±47.8 events (200-475 MeV)

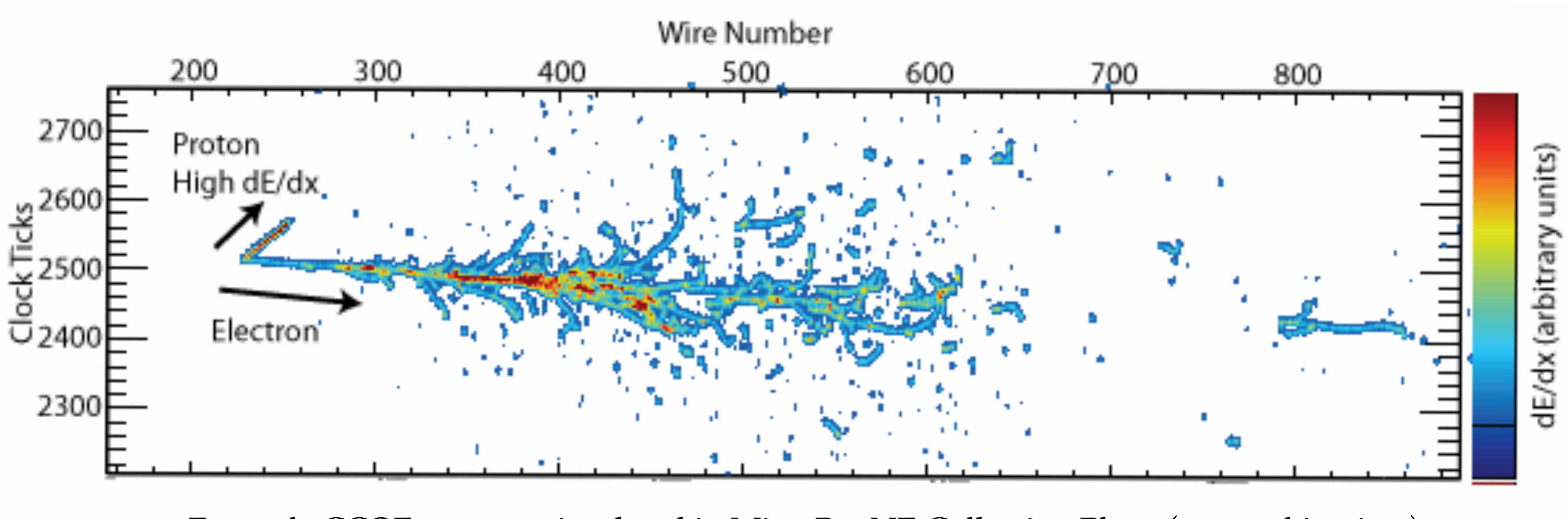
Refs:

1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)

2.) *Improved Search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillations in the MiniBooNE Experiment* MiniBooNE Collaboration, Phys. Rev. Lett. 110, 161801 (2013)

MicroBooNE: Physics

- Prove effectiveness of electron/gamma separation technique (*e.g.* - using dE/dX information), and exploit to characterize any observed MiniBooNE-like "low-E" excess signals.
- Low Energy Neutrino Cross-Section Measurements: CCQE, NC π^o, $\Delta \rightarrow N\gamma$, etc...
- Study backgrounds relevant for Proton Decay searches in larger detectors (*e.g.* - Kaon production), and develop SuperNova analysis capabilities.
- Probe the Strange Quark content of Proton.
- Continue development of automated reconstruction (building on ArgoNeuT's effort).



Example CCQE ν_e event simulated in MicroBooNE Collection Plane (zoomed in view)

Conclusions

- LArTPCs are powerful detectors for studying neutrinos.
- Tremendous ongoing progress in development of LArTPC technology, driven by “small” efforts like ArgoNeuT and MicroBooNE.
- Next few years should be very exciting as MicroBooNE come online.
- Informed by these ongoing activities, future massive (~kiloTon) LArTPCs offer potential for discovering CP-violation in neutrino sector, and short-baseline experiments will search for sterile neutrinos.

Thank you!

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University of Bern

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Imperial College London

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Gran Sasso National Laboratory

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Kansas State University

C. Bromberg, D. Edmunds, P. Laurens, B. Page
Michigan State University

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Syracuse University

K. Lang, R. Mehdiyev
The University of Texas at Austin

C. Adams, E. Church, B. Fleming, E. Klein, K. Partyka, J.Spitz, A. Szelc
Yale University

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B. Lundberg, A. Marchionni, S. Pordes, J. Raaf, G. Rameika+, B. Rebel, A. Schukraft, S. Wolbers, T. Yang, G.P. Zeller*

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Saint Mary's University of Minnesota: P. Nienaber

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Syracuse University: J. Asaadi, J. Esquivel, M. Soderberg

University of Texas at Austin: S. Cao, J. Huang, K. Lang, R. Mehdiyev

University of Bern, Switzerland: A. Ereditato, D. Goeldi, I. Kreslo, M. Luethi, C. Rudolf von Rohr, T. Strauss, M. Weber

INFN, Italy: F. Cavanna, O. Palamara *(currently at Yale)*

Virginia Tech: M. Jen, L. Kalousis, C. Mariani

Yale University: C. Adams, E. Church, B. Fleming*, E. Gramellini, A. Hackenburg, B. Russell, A. Szelc

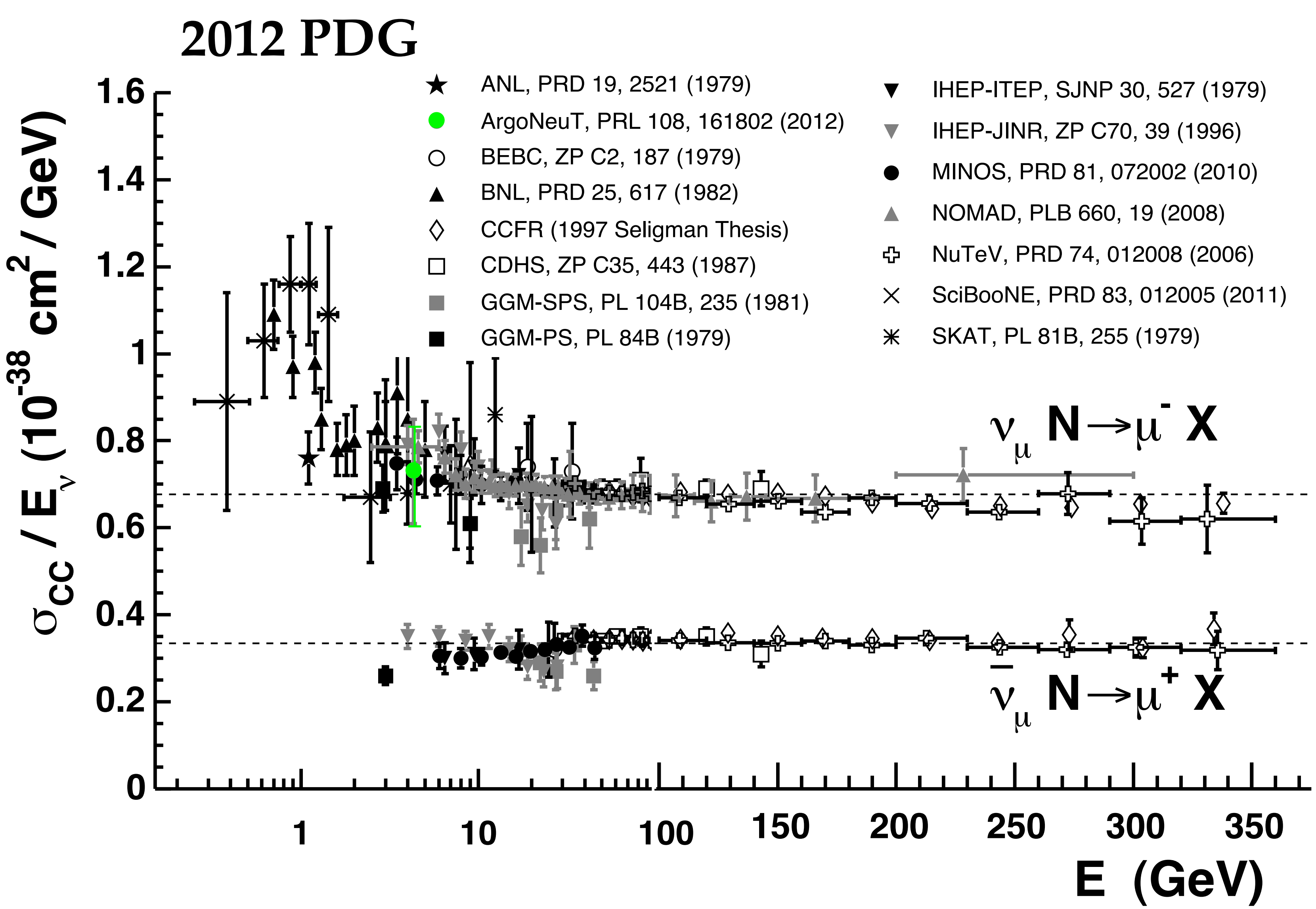
Back-Up Slides

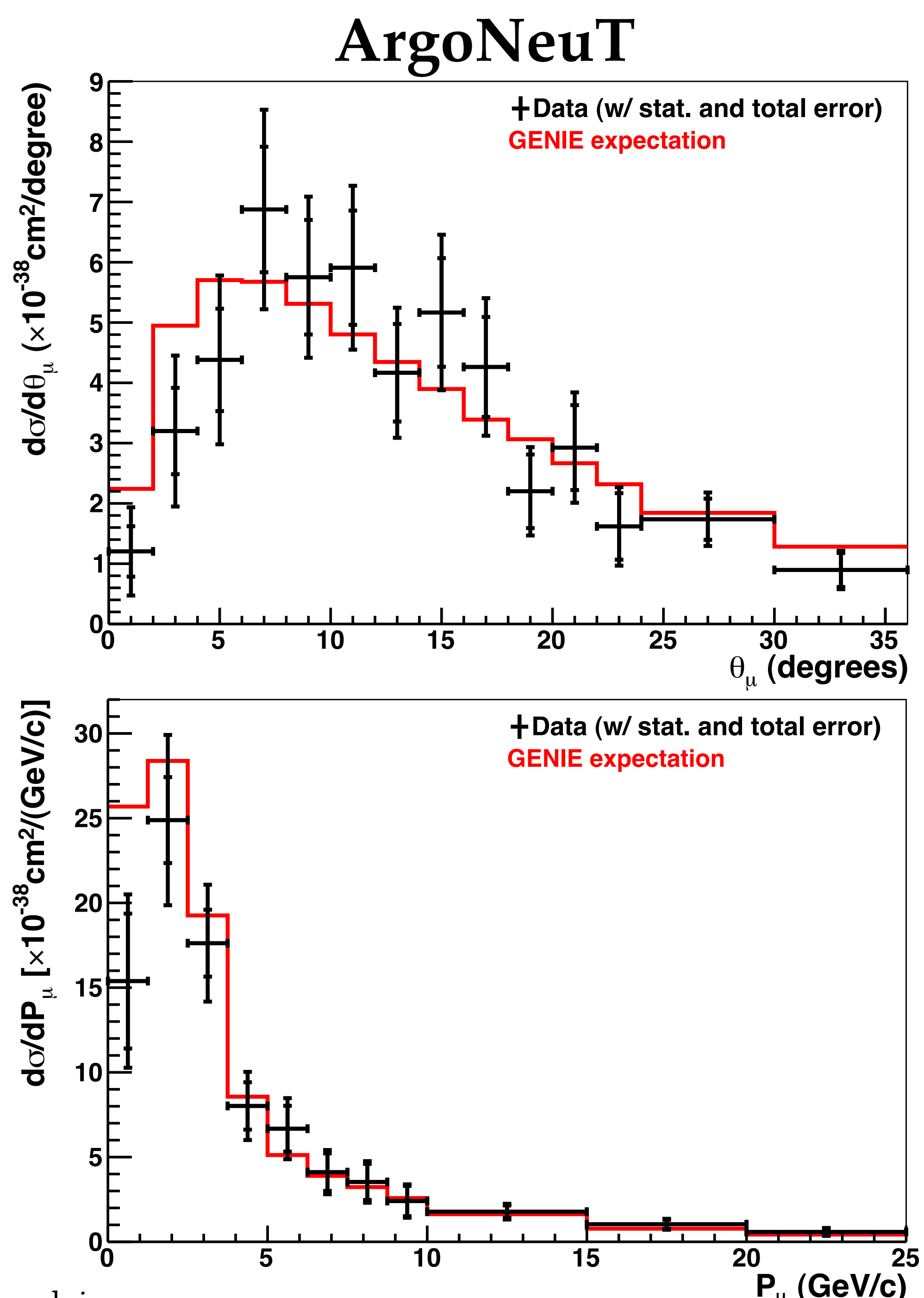
Why Noble Liquids for Neutrinos?

- Abundant ionization electrons and scintillation light can both be used for detection.
- If liquids are highly purified (<0.1ppb), ionization can be drifted over long distances.
- Excellent dielectric properties accommodate very large voltages.
- Noble liquids are dense, so they make a good target for neutrinos.
- Argon is relatively cheap and easy to obtain (1% of atmosphere).
- Drawbacks?...no free protons...nuclear effects.

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120	165	373
Density [g/cm	0.125	1.2	1.4	2.4	3	1
Radiation Length [cm]	755.2	24	14	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3	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	

ArgoNeuT: Physics





Inclusive CC cross-section

- First Results: Using **2 weeks** of neutrino-mode data (8.5×10^{18} POT), the differential cross-section for inclusive charged-current muon neutrino production was measured.
- Analysis Selection:
  - Track originating within ArgoNeuT fiducial region.
  - Match to corresponding track in MINOS near detector.
  - MINOS track is negatively charged.

$$\frac{\partial\sigma(u_i)}{\partial u} = \frac{N_{\text{measured},i} - N_{\text{background},i}}{\Delta u_i \ \epsilon_i \ N_{\text{targ}} \ \Phi}$$

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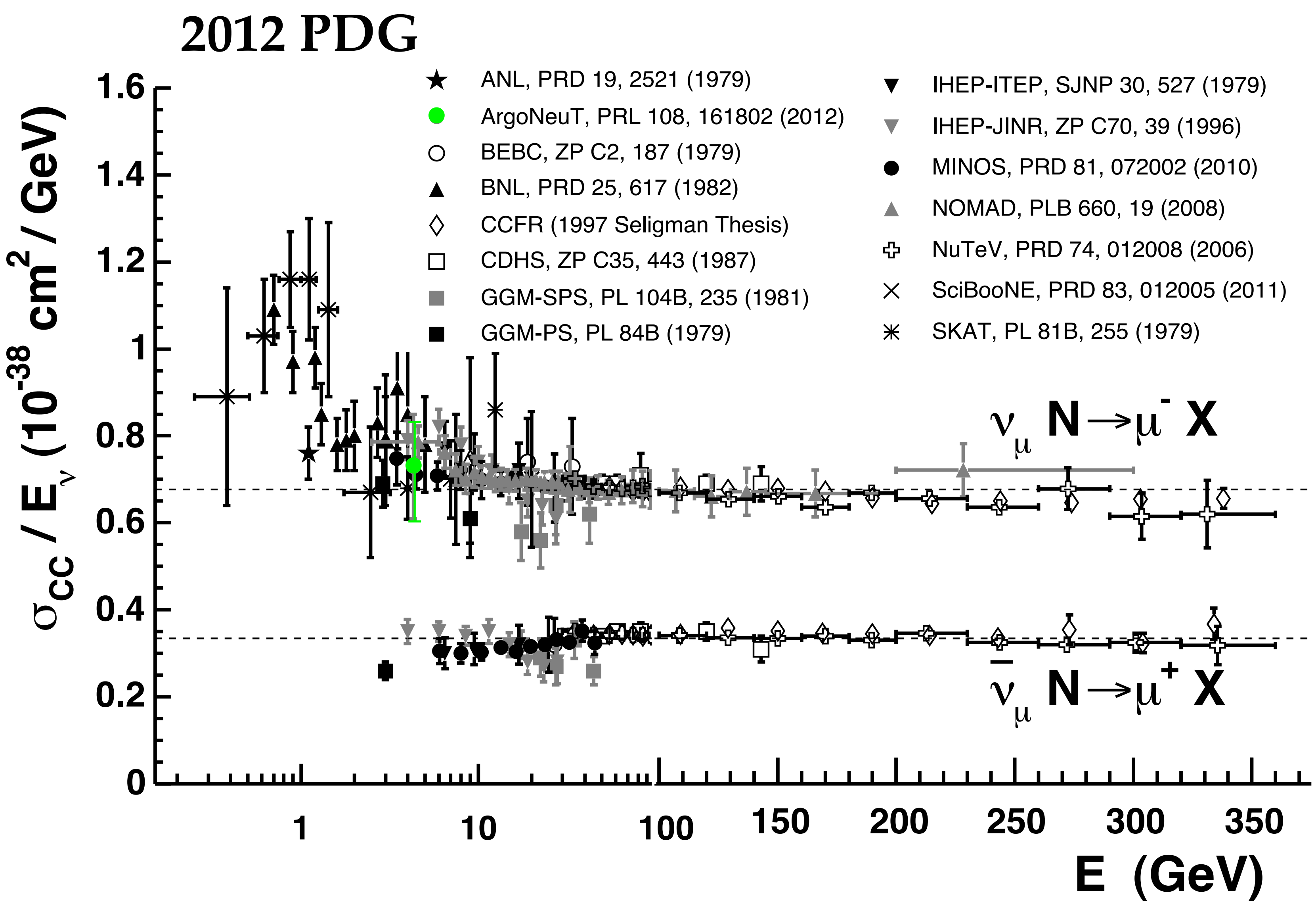

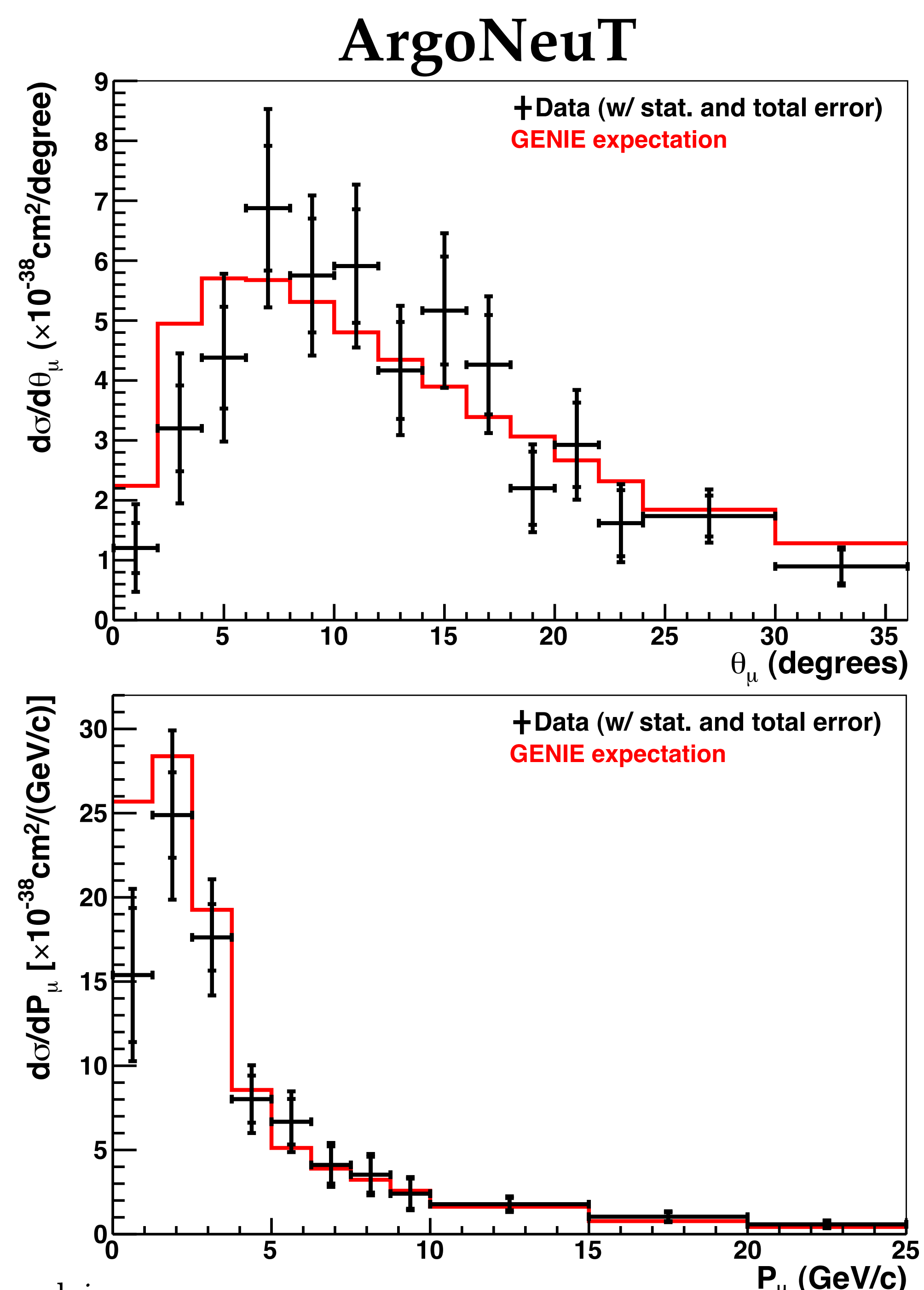

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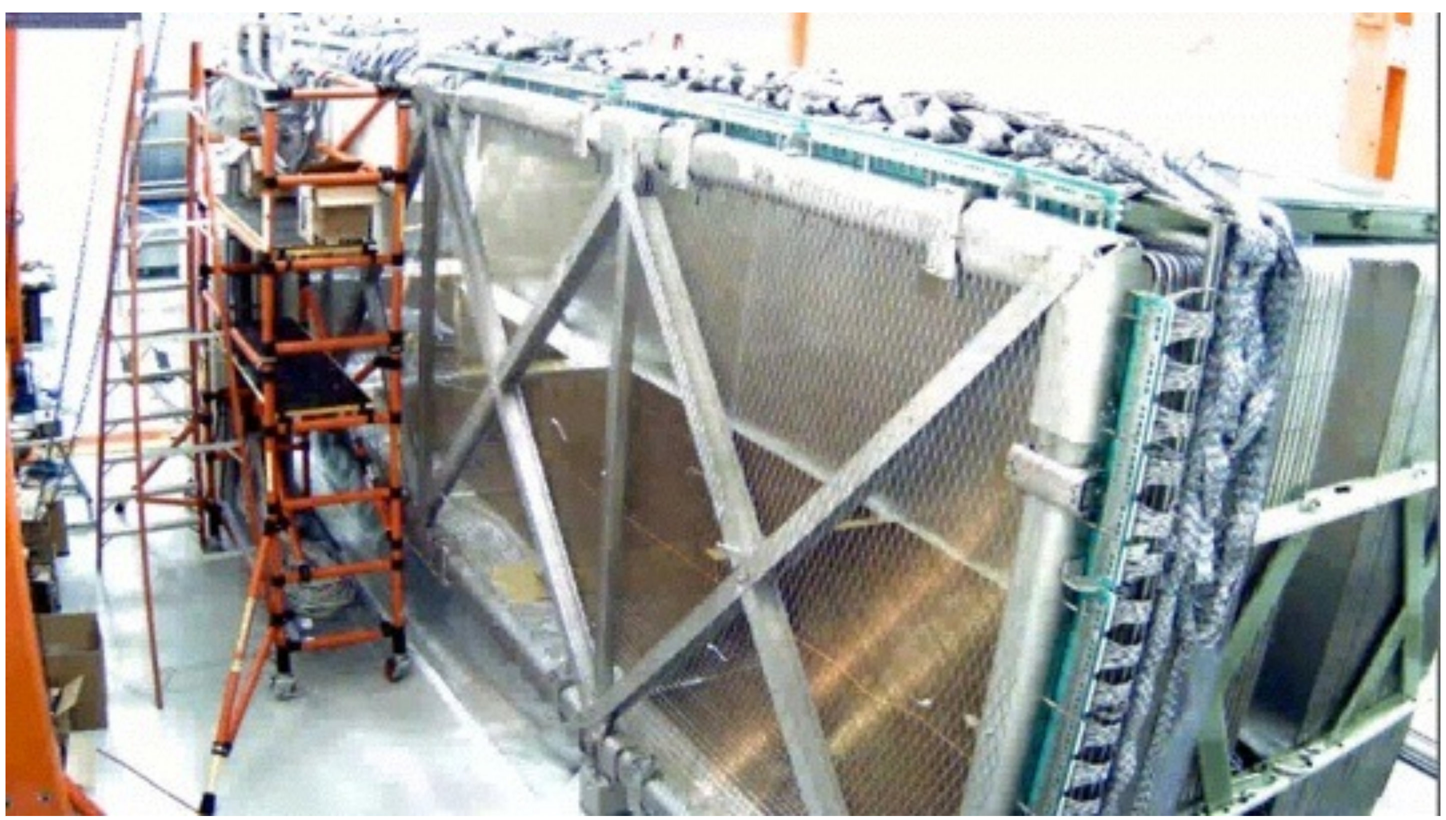

MicroBooNE TPC (Nov. 2013)

TPC Wires