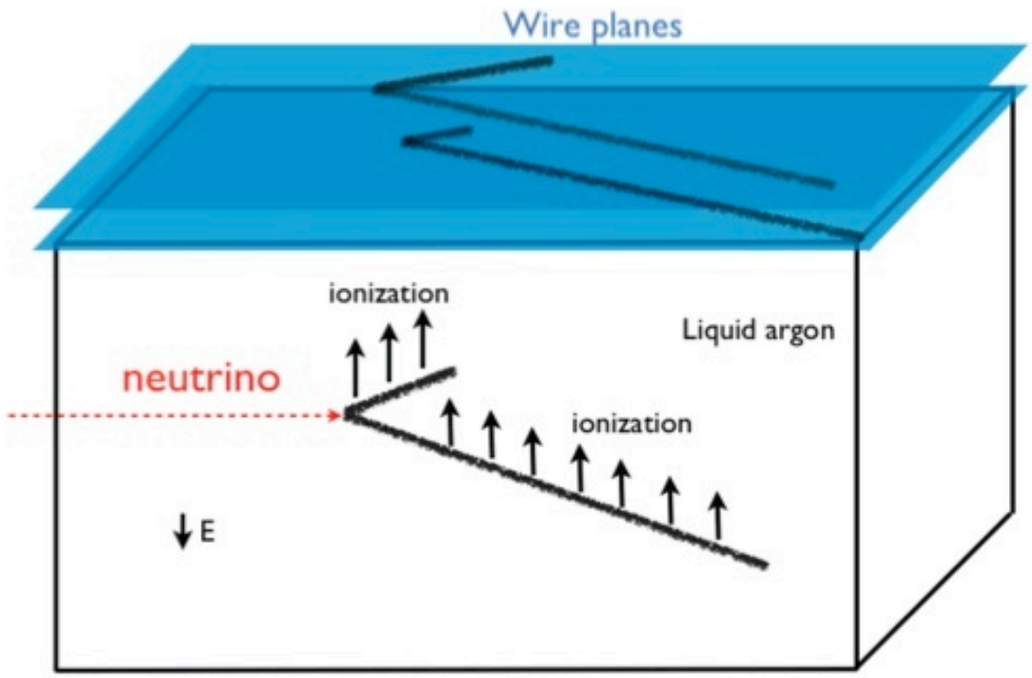
Mitch Soderberg
Fermilab Short Baseline Workshop

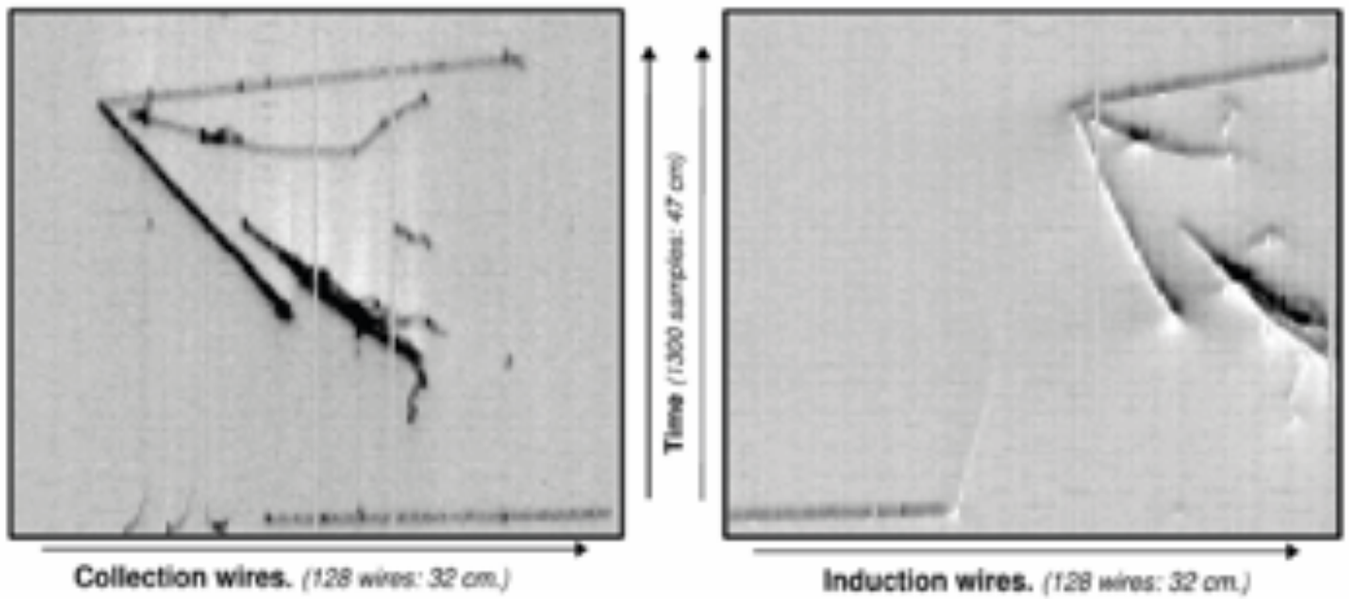
Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) are being developed to study neutrino interactions, particularly for use as a far-detector in a long-baseline experiment.
- These detectors also have great potential for short-baseline studies where they are well suited to make precision measurements of neutrino interactions, which will help improve knowledge of neutrino oscillations.
- In this talk I will show how the LArTPC technique is used on the ArgoNeuT project, and discuss some of the work ongoing to extract physics measurements from data.

Liquid Argon Neutrino Detectors

- Neutrino interactions in the TPC produce charged particles that ionize the argon as they travel.
- Ionization is drifted along E-field to wireplanes, consisting of wires spaced ~millimeters apart.
- Location of wires within a plane provides position measurements...multiple planes give independent views.
- Timing of wire pulse information is combined with known drift speed to determine drift-direction coordinate.





Images from ICARUS* 50-liter TPC.

*Pioneering LArTPC work done by the ICARUS collaboration. See talk by Francesco Pietropaolo on Sat.

Refs:

1.) *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

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 unavoidable.

Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm³]	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	

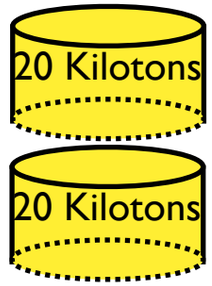
Liquid Argon Efforts at Fermilab

Development focused on scaling LArTPCs to sizes necessary for long-baseline experiment.

Materials / Electronics Test Stand

L.A.P.D.

LBNE



100% R&D

2007-

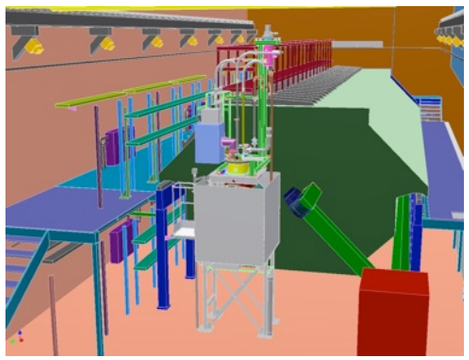
2008-

2011

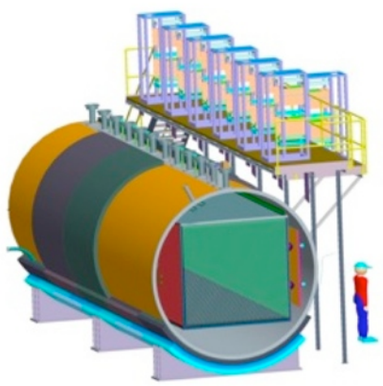
2013

20??

100% Physics



ArgoNeuT



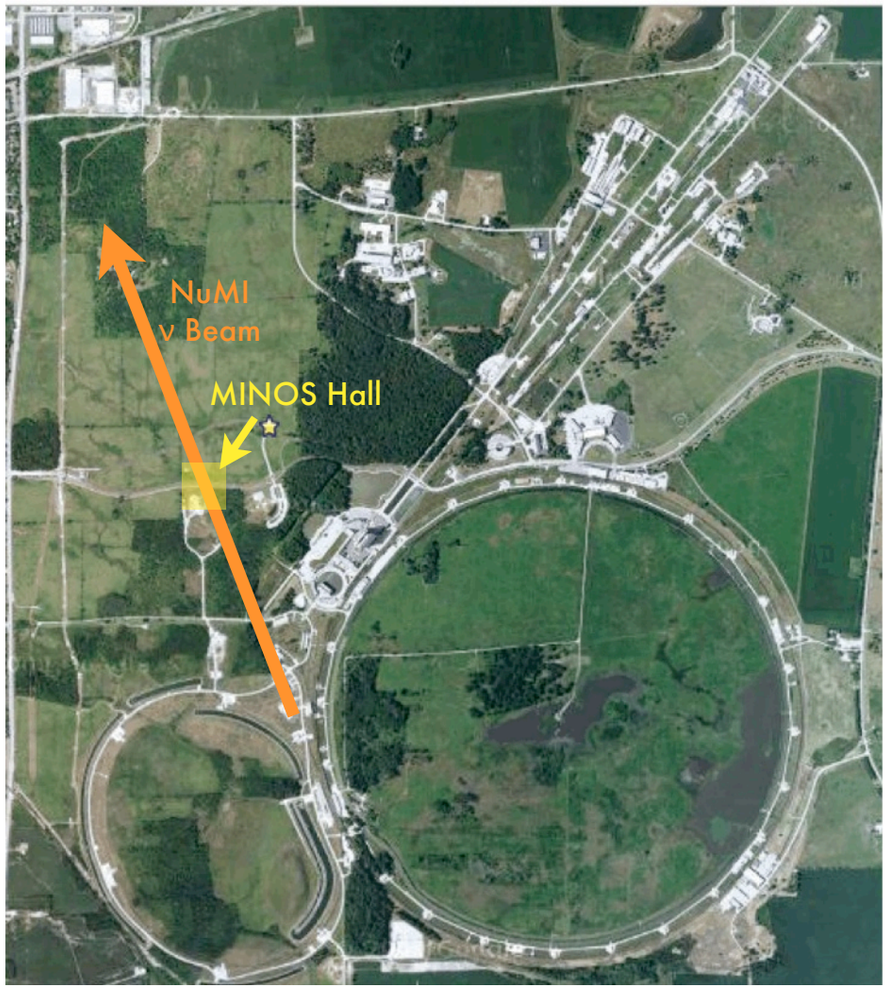
MicroBooNE

Highly relevant for short-baseline physics...see talk by Roxanne Guennette on Sat.

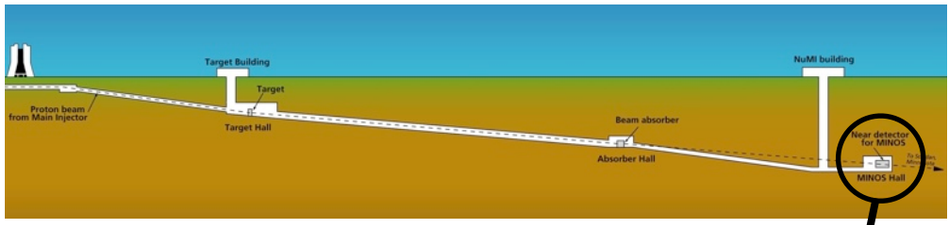
Refs:
1.) *A Regnerable Filter for Liquid Argon Purification* Curioni et al, NIM A605:306-311 (2009)
2.) *A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water* Andrews et al, NIM A608:251-258 (2009)

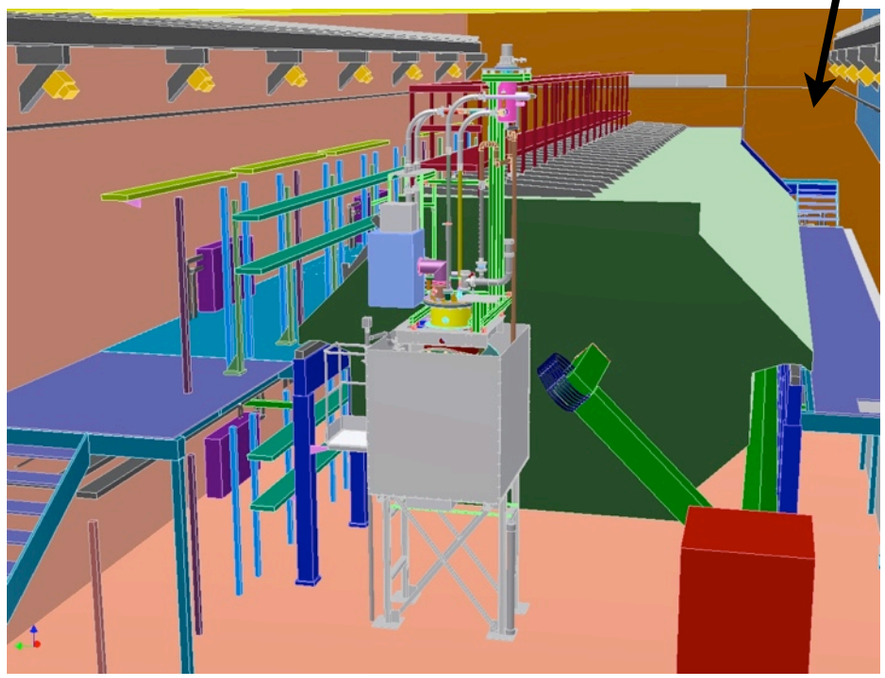
The ArgoNeuT Project

- ArgoNeuT (a.k.a. - Fermilab T962) deployed a ~175 liter LArTPC in a neutrino beam.
- Operated in NuMI beam, upstream of MINOS near detector (to aid in muon reconstruction).
- ArgoNeuT Goals:
  - Gain experience building/running LArTPCs.
  - Accumulate neutrino/antineutrino events (1st time in the U.S., 1st time ever in a low-E beam).
  - Develop simulation/reconstruction tools for LArTPCs and make comparisons with data.



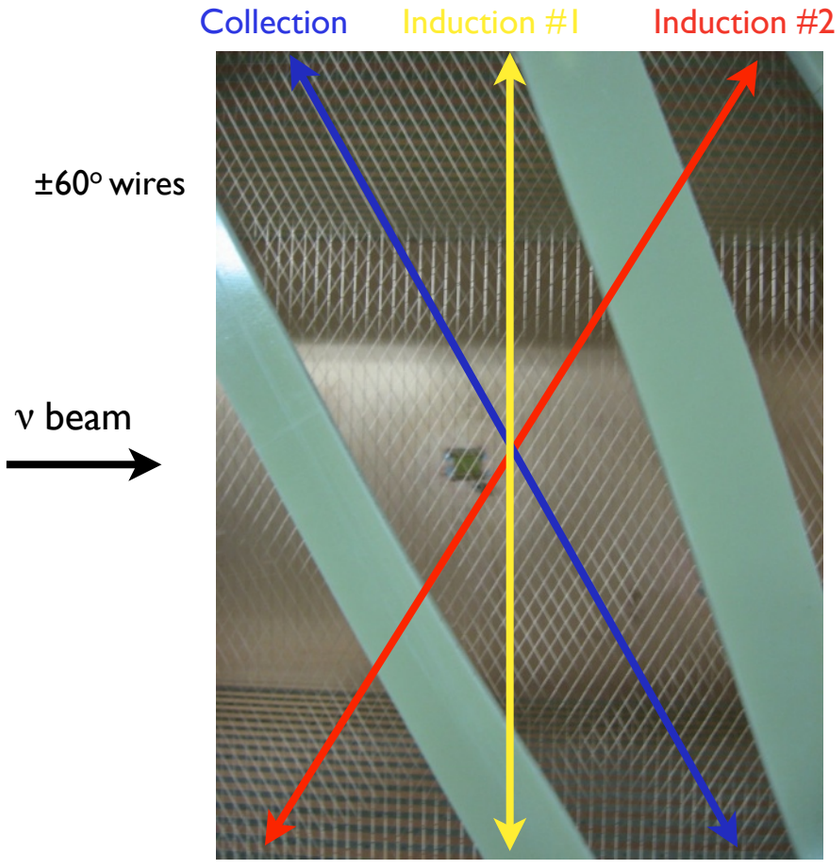
NuMI Beam at Fermilab



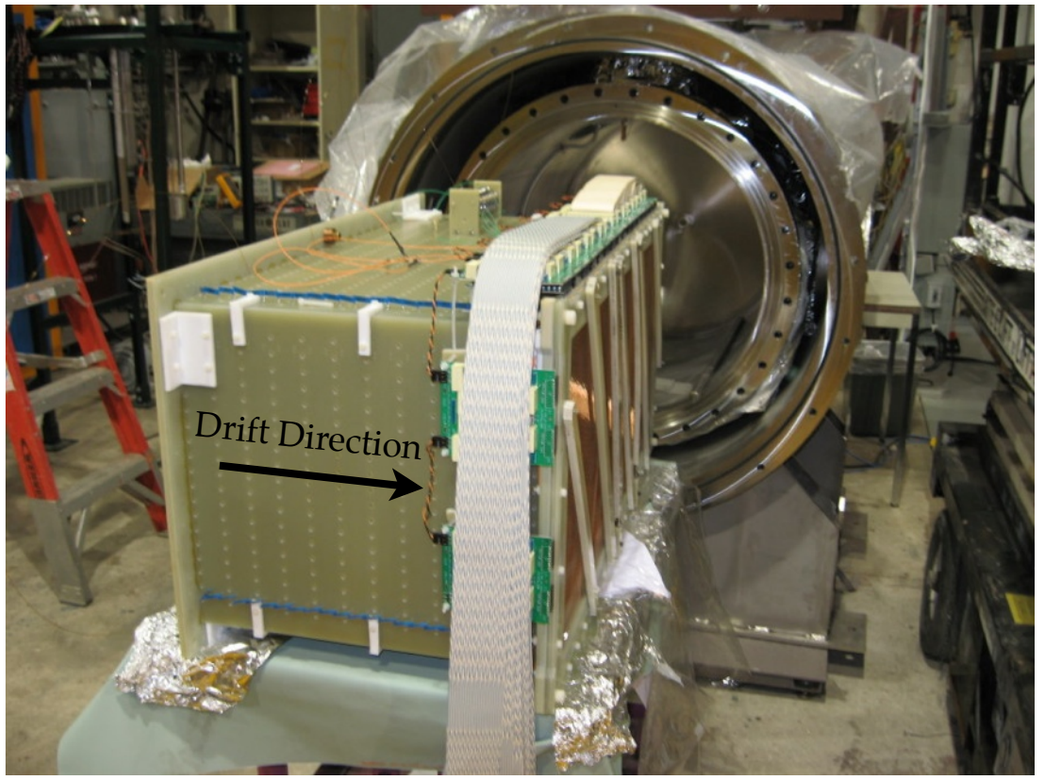


Schematic of ArgoNeuT in MINOS Hall at Fermilab

ArgoNeuT Detector Details



Wire Orientations

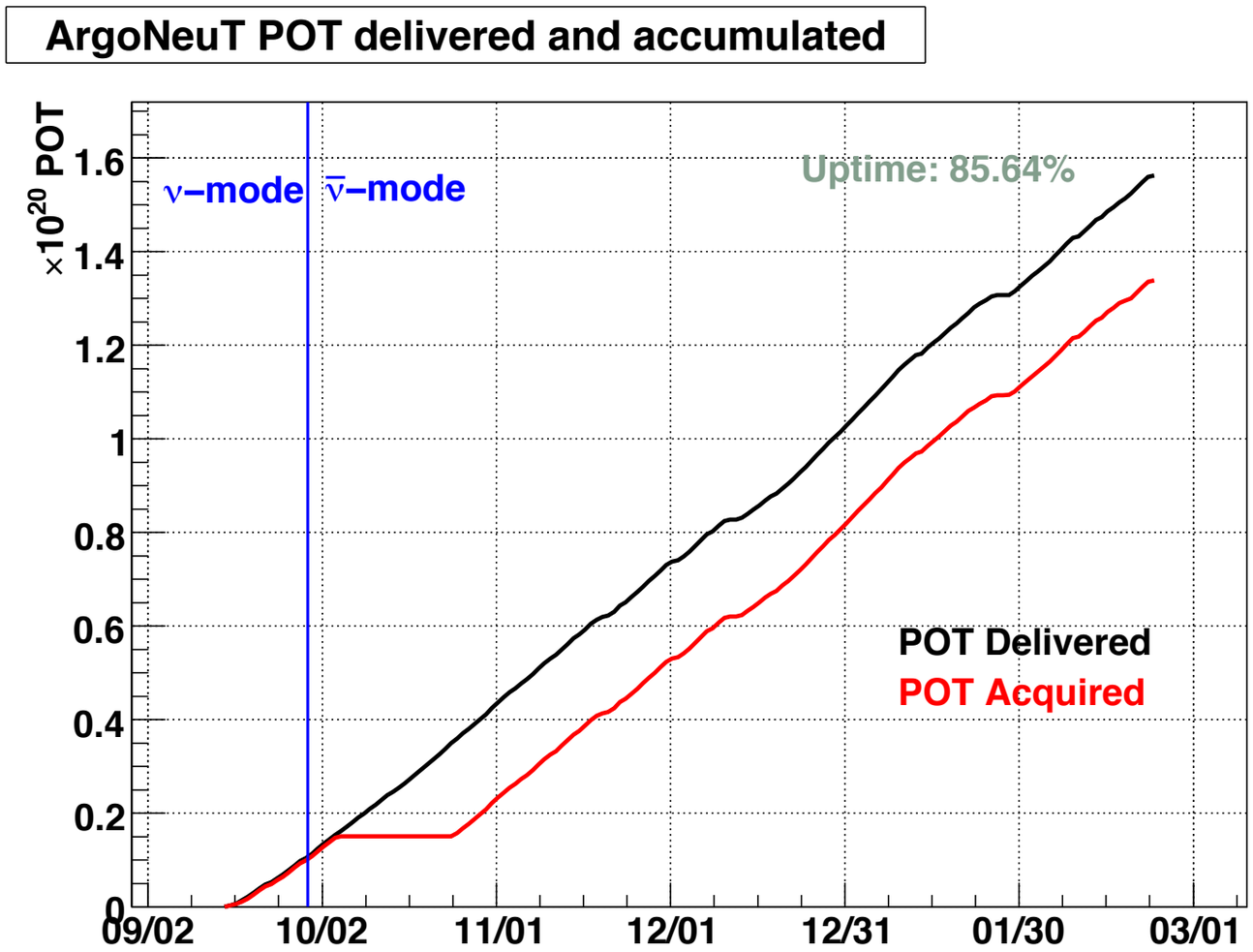


TPC outside vacuum-jacketed cryostat

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# 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 Beamline

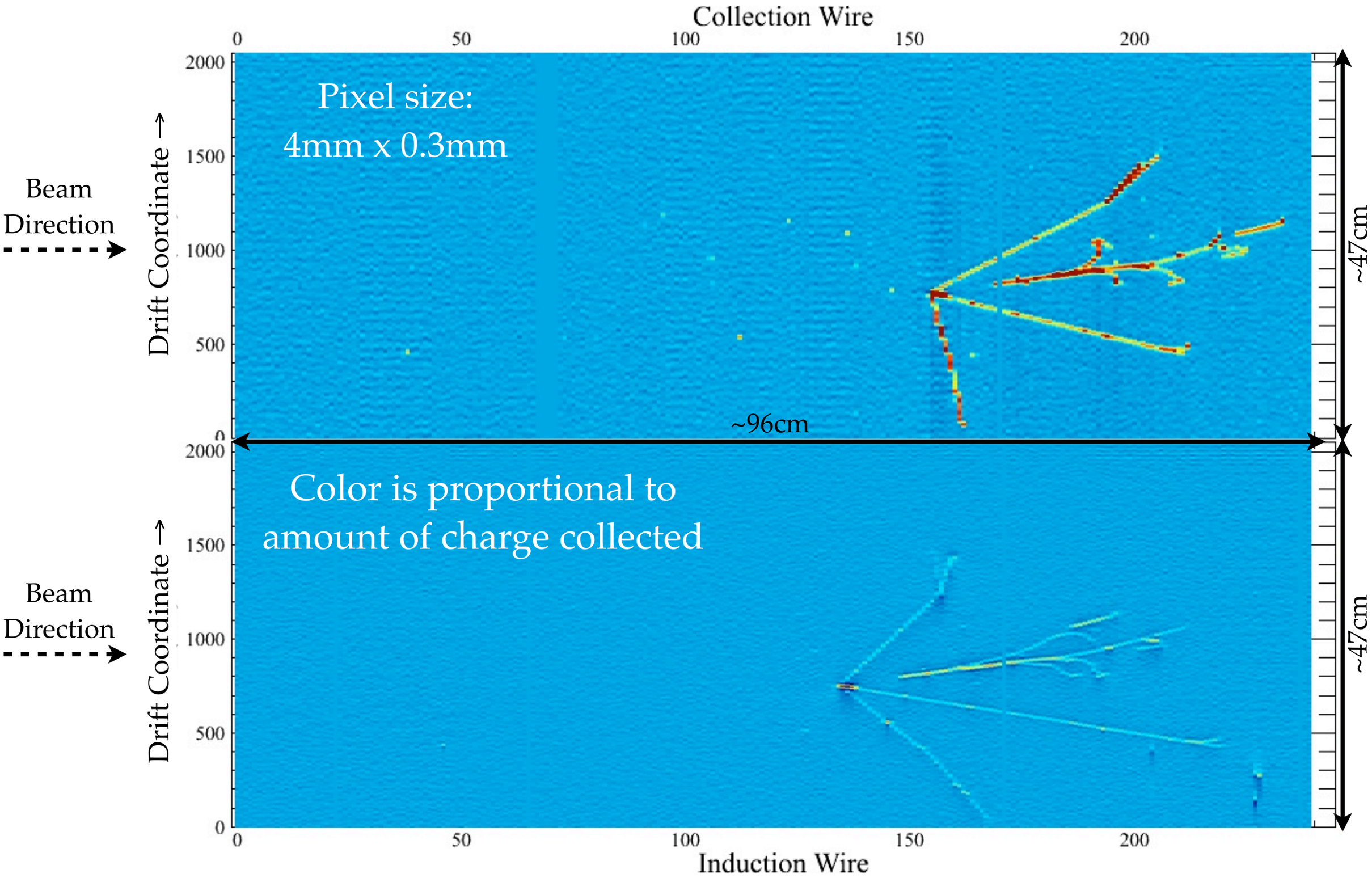
- Physics run lasted from Sept. 2009 through Feb. 22, 2010, mostly in antineutrino mode.
- Accumulated ~1.35E20 Protons On Target (P.O.T.).
- Now focusing on developing tools to analyze data and extract physics results.



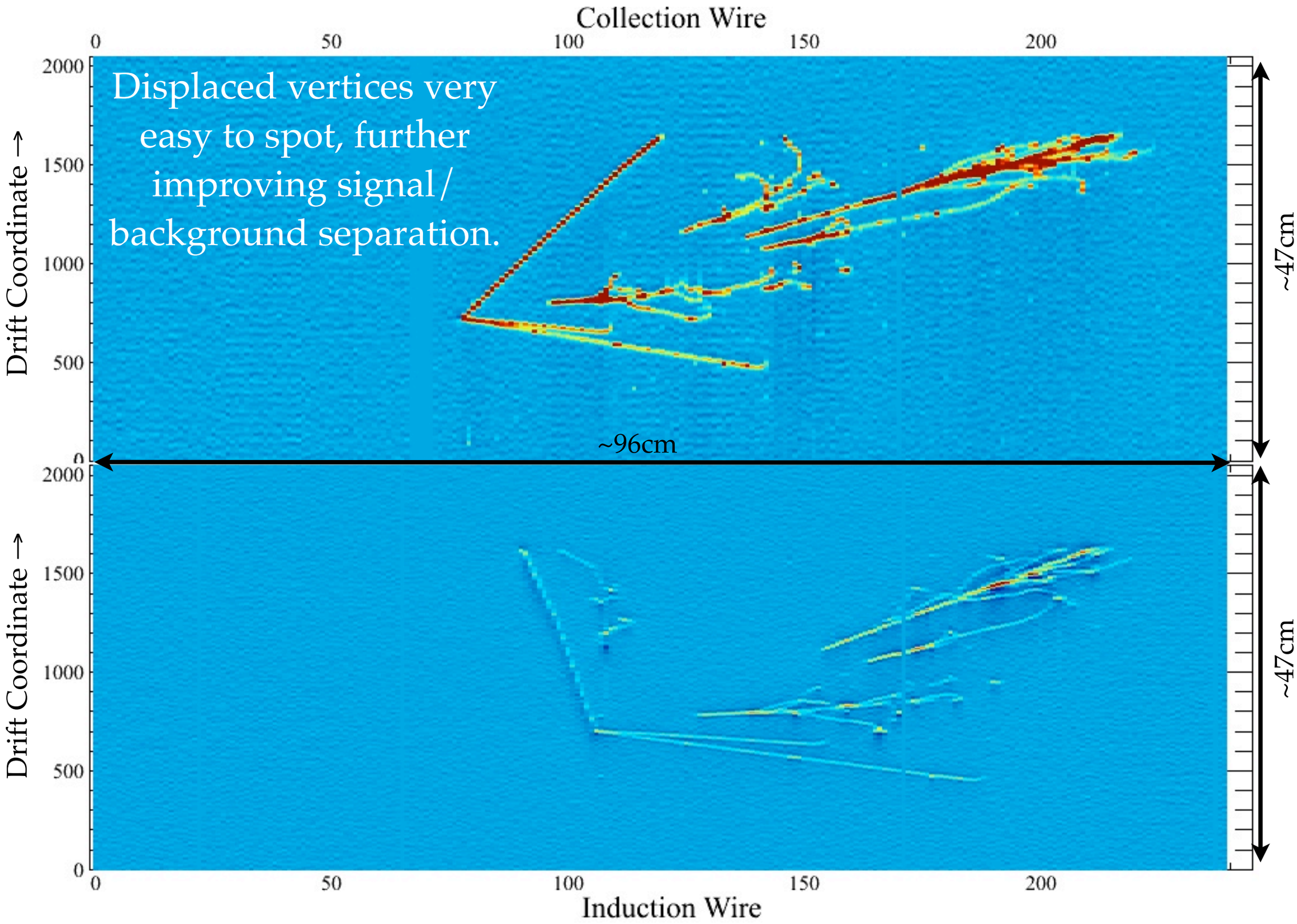
Note: Uptime would have been ~99% without downtime caused by cryocooler failure.

ArgoNeuT in the MINOS Hall

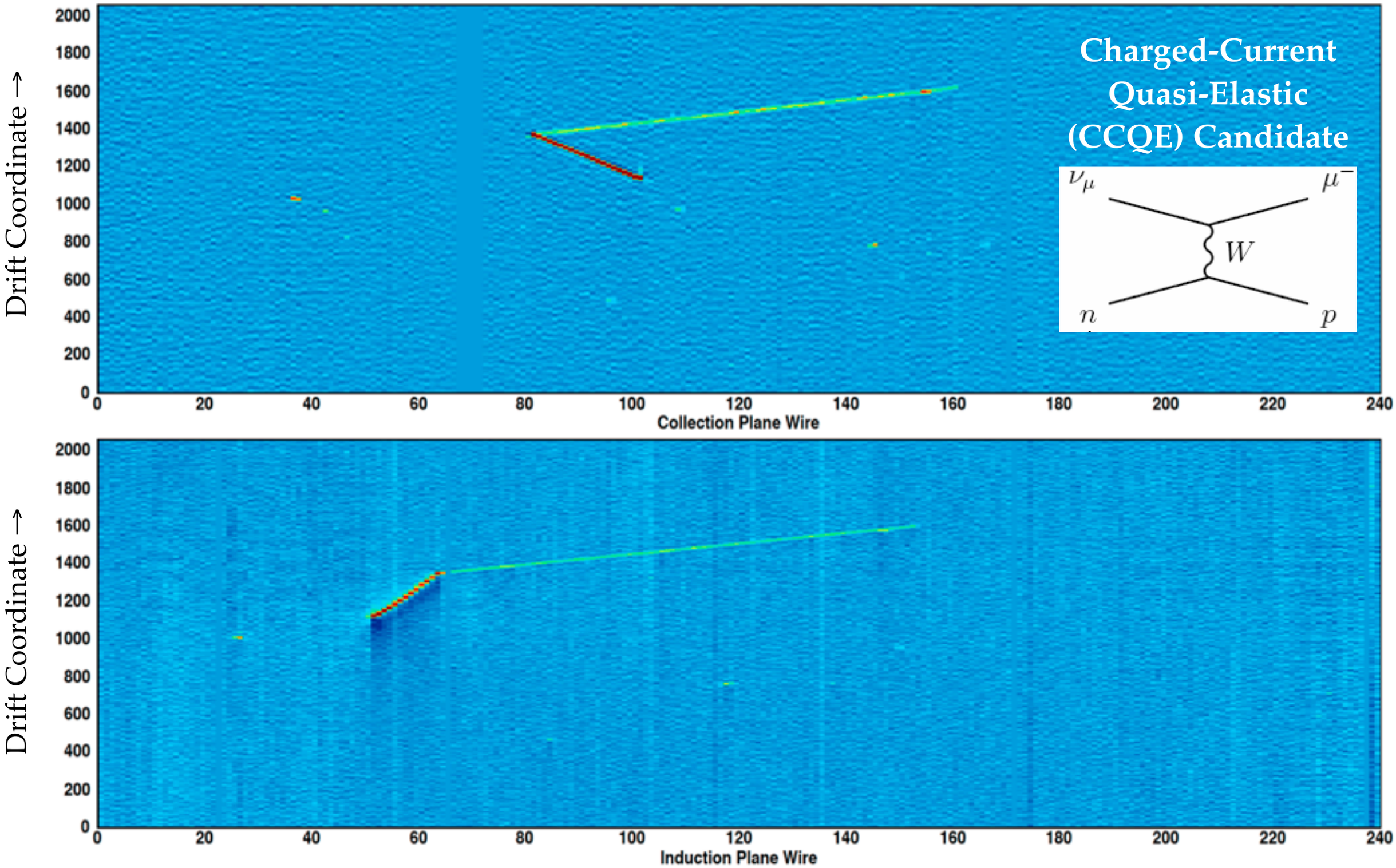
ArgoNeuT Event



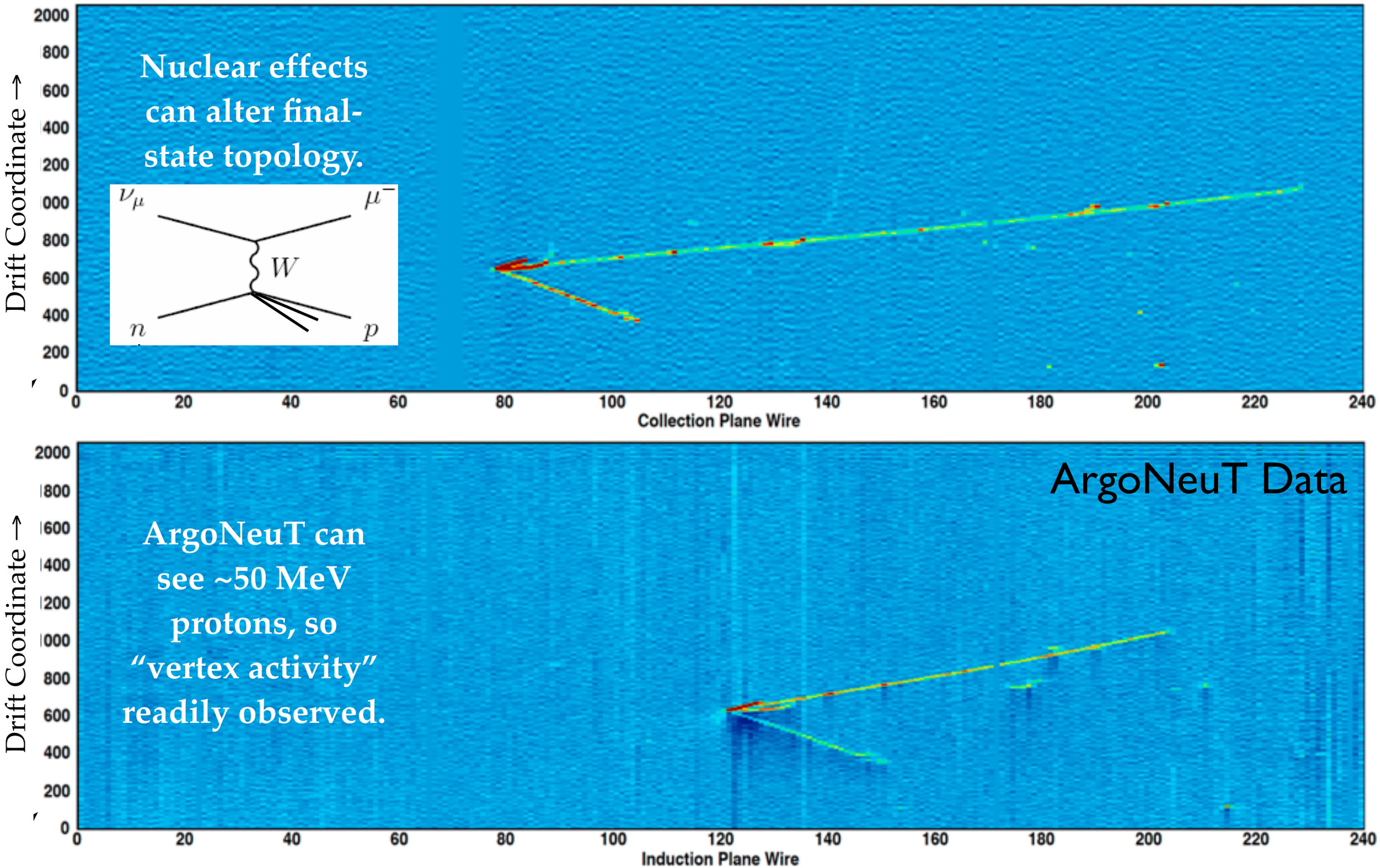
ArgoNeuT Event



ArgoNeuT Event

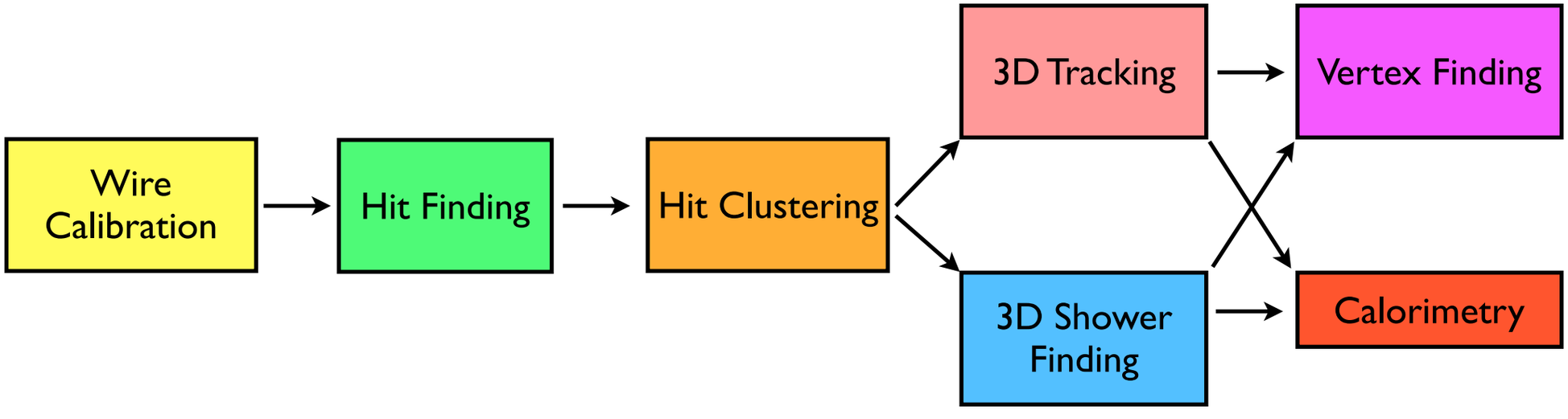


ArgoNeuT Event

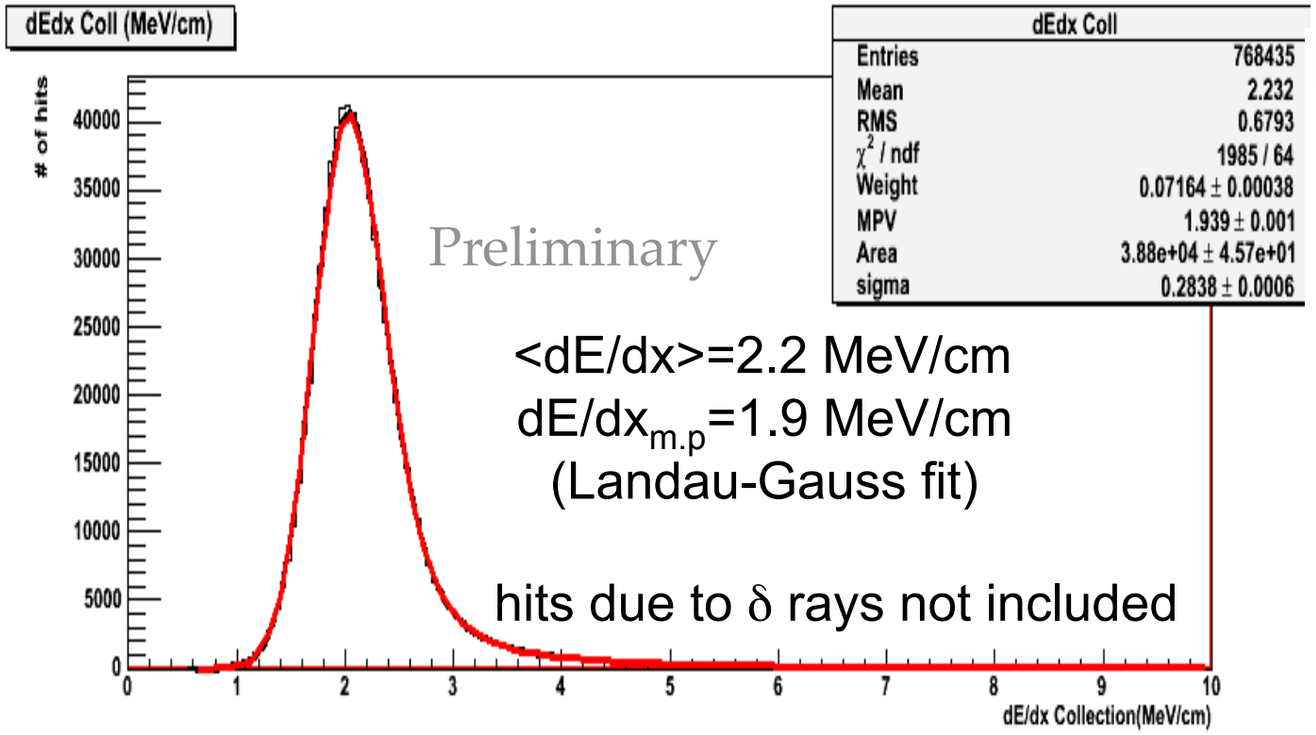


LArTPC Reconstruction

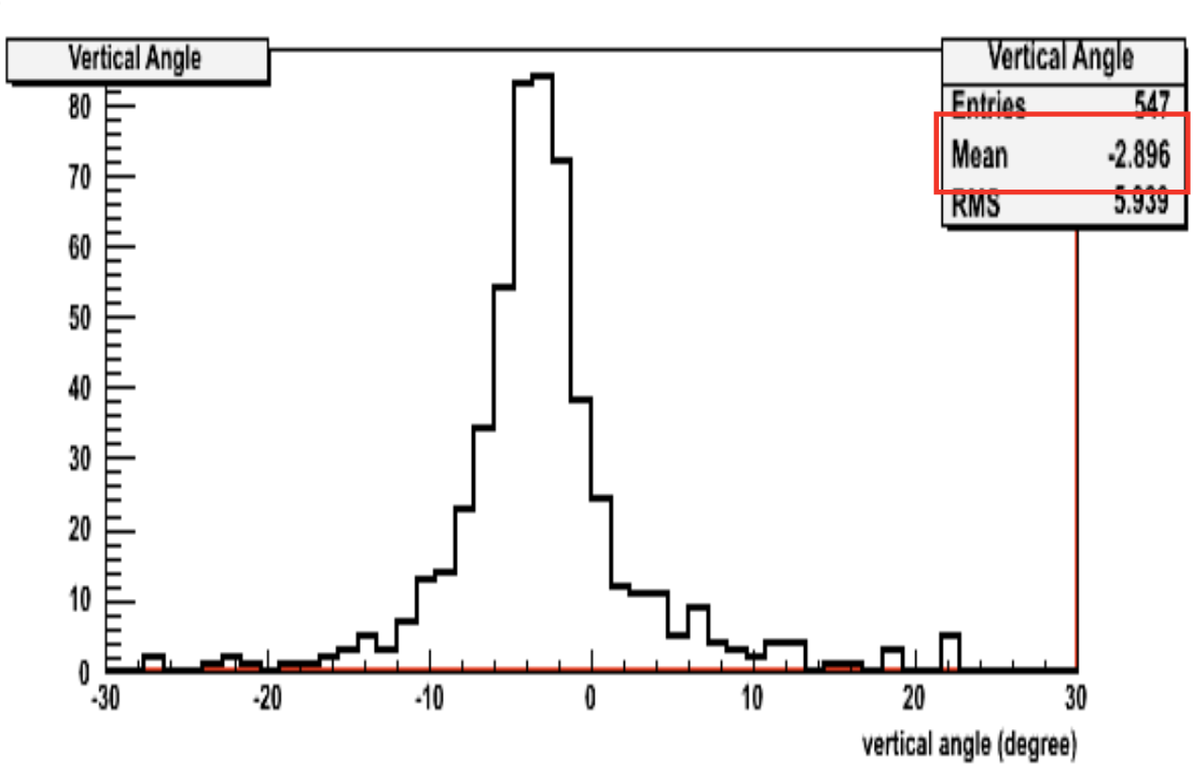
Reconstruction Chain for LArTPC Data



Using ArgoNeuT data we have made great strides in developing a full reconstruction/ simulation chain.

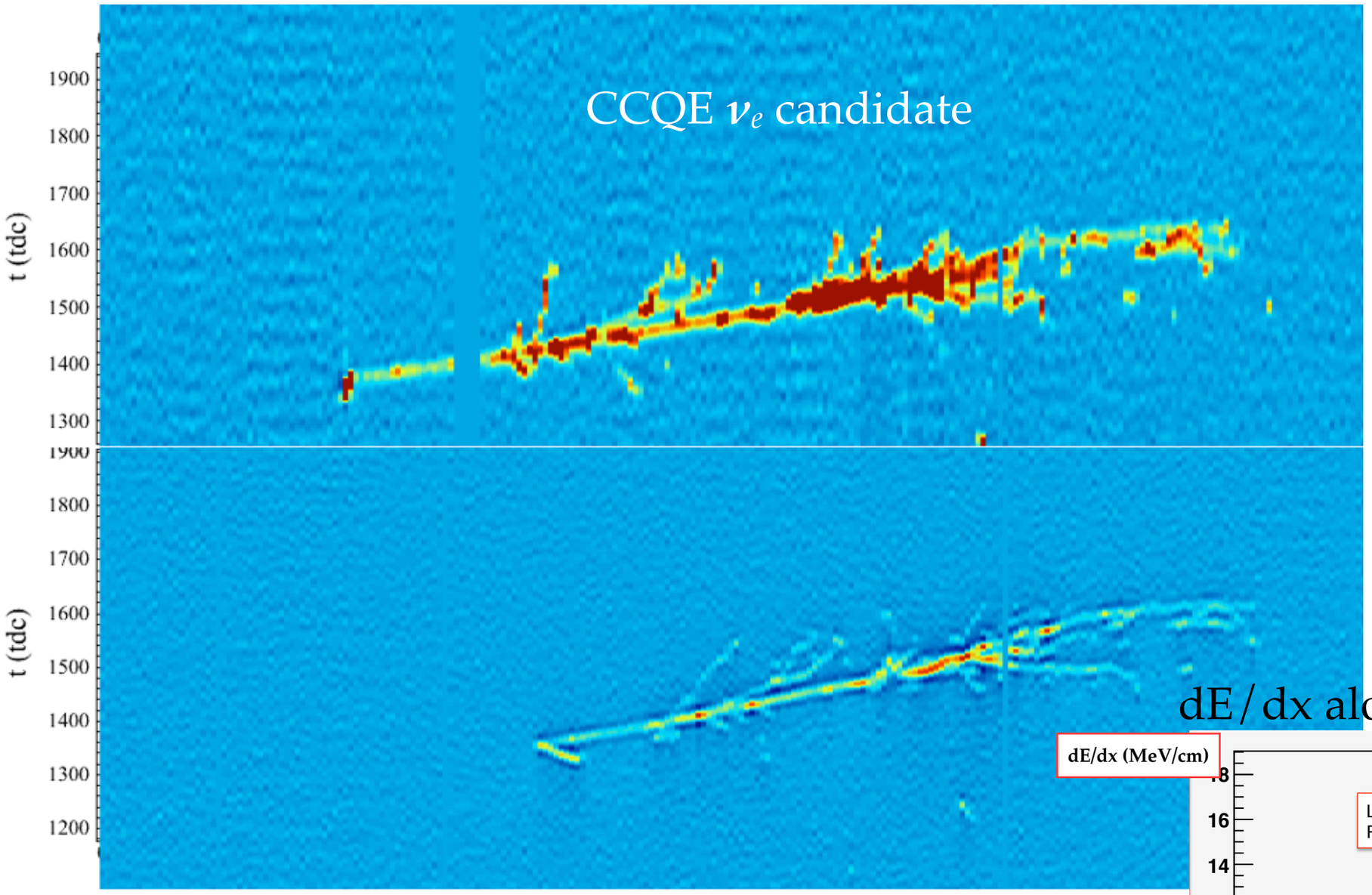


dE/dx distribution for ~1000s of muons.

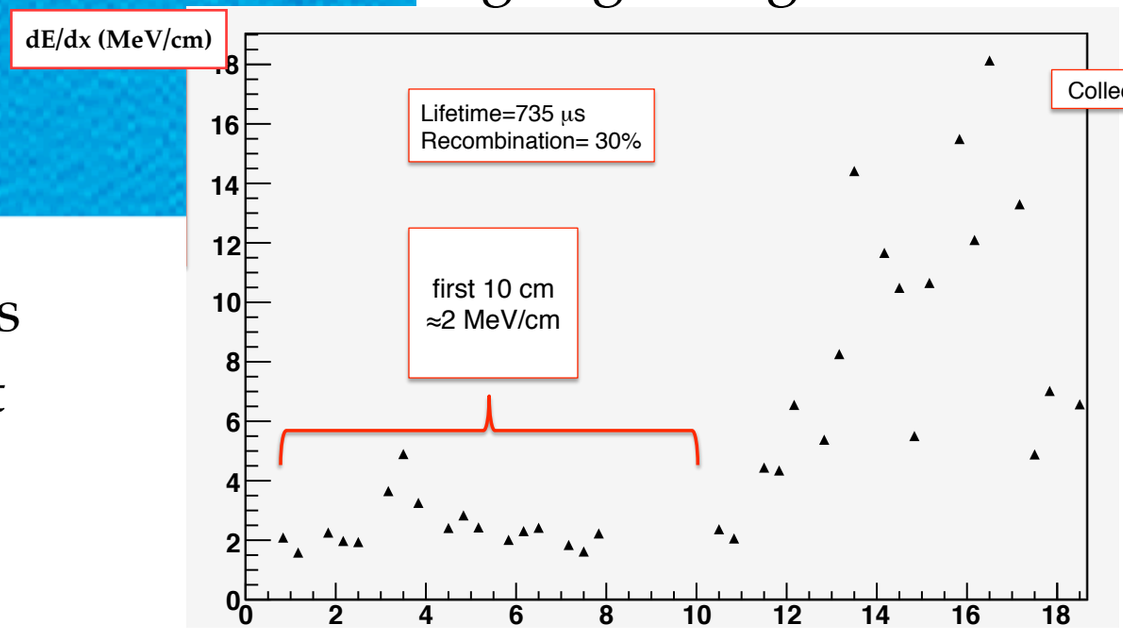


Vertical Angle distribution.
NuMI Beam is at -3º

LArTPC Reconstruction

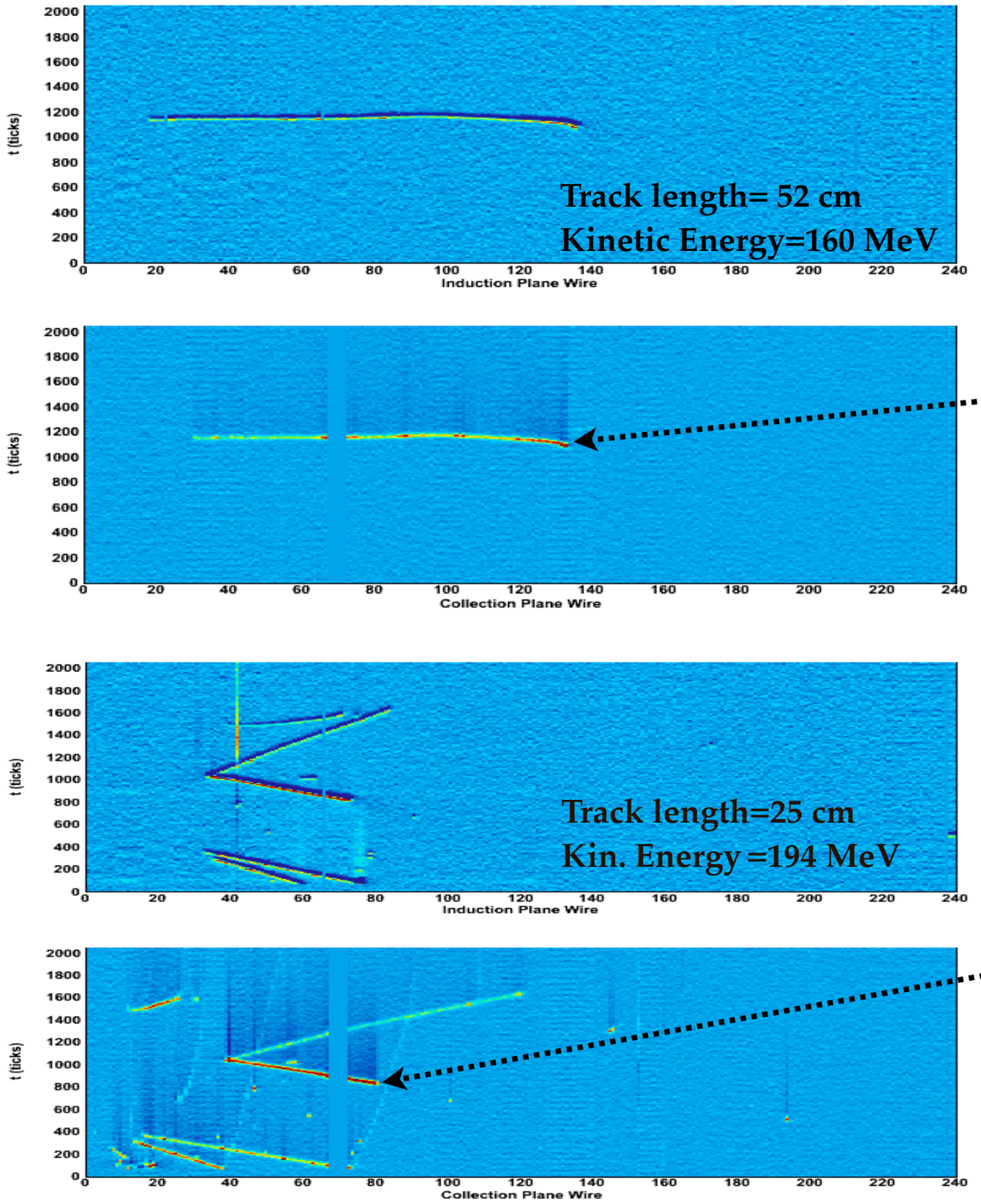


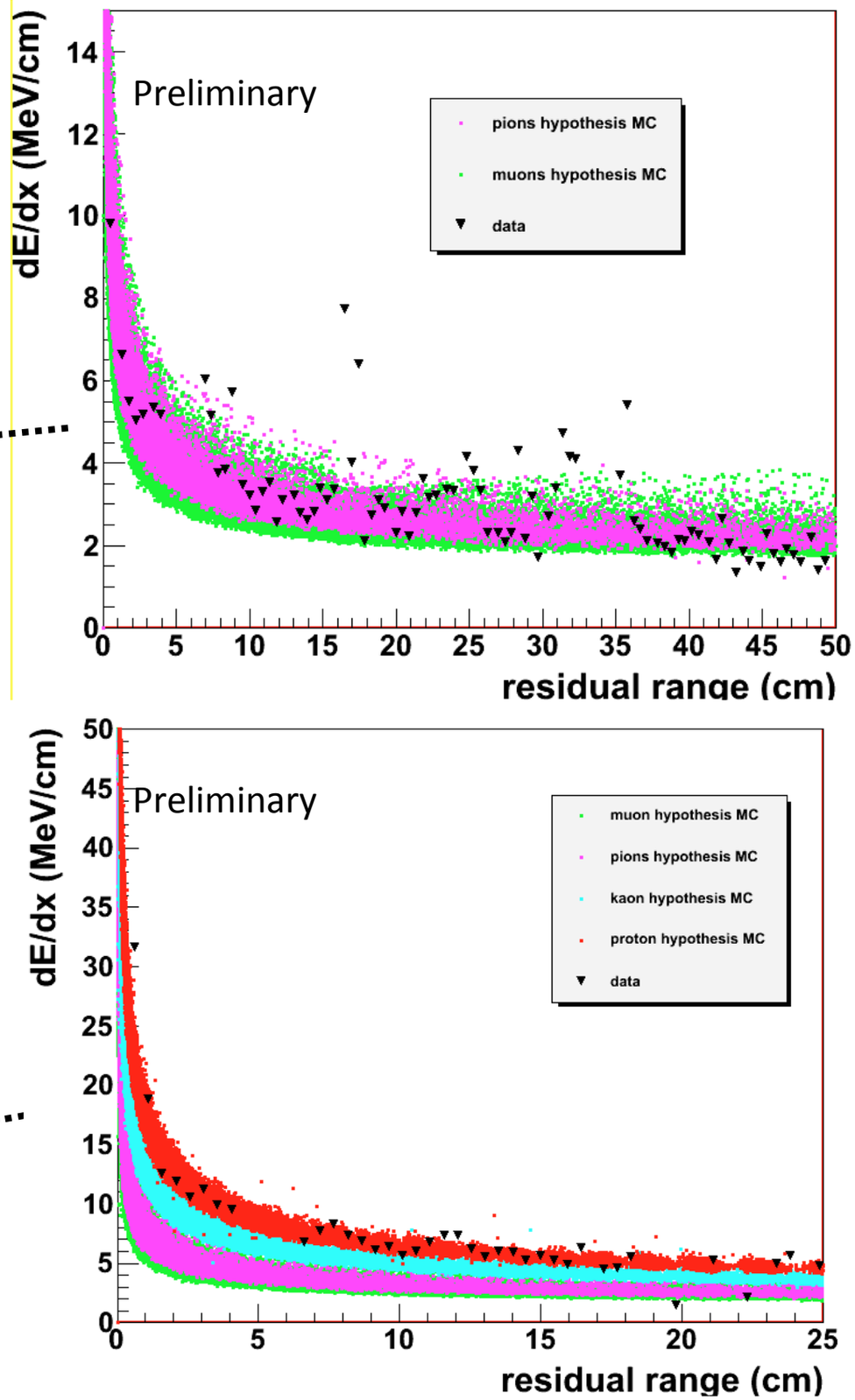
dE/dx along beginning of shower.



Starting to have tools to reconstruct showers in 3D and calculate dE/dx...very important step towards determining true signal/ background capabilities for LArTPCs.

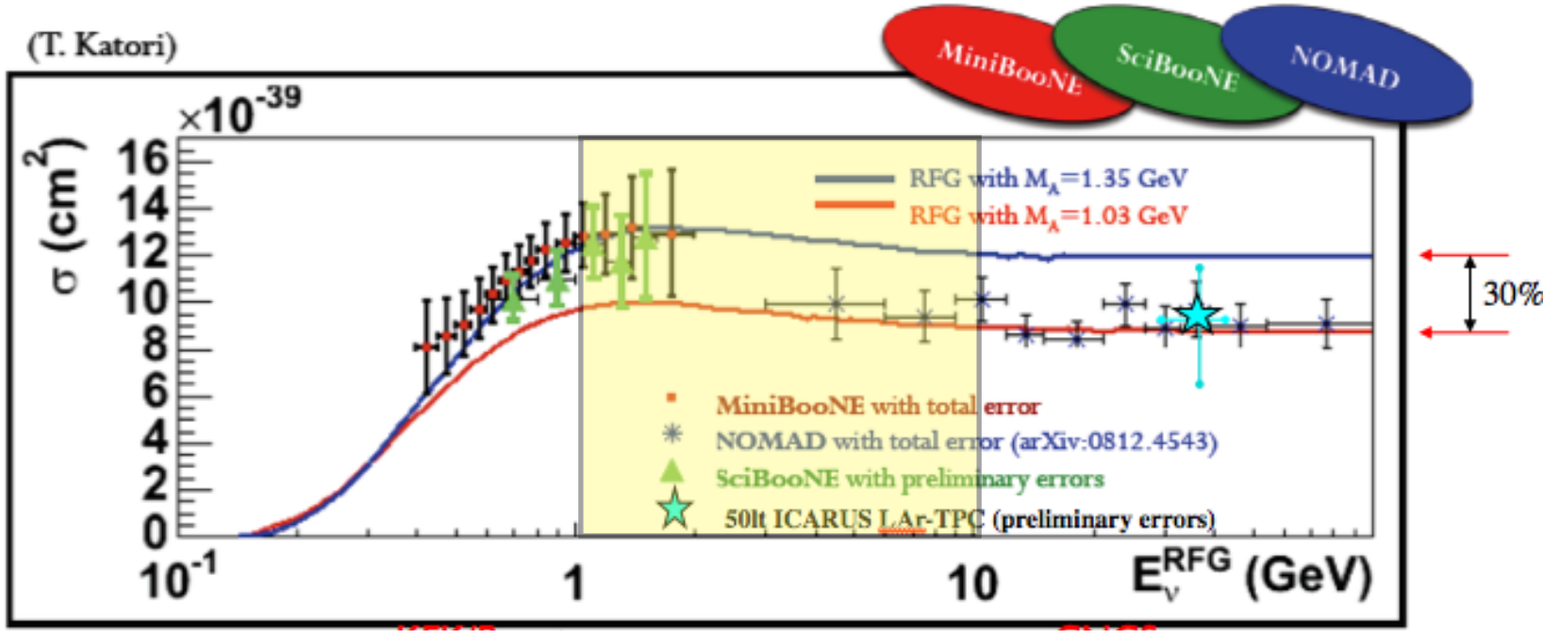
Calorimetry

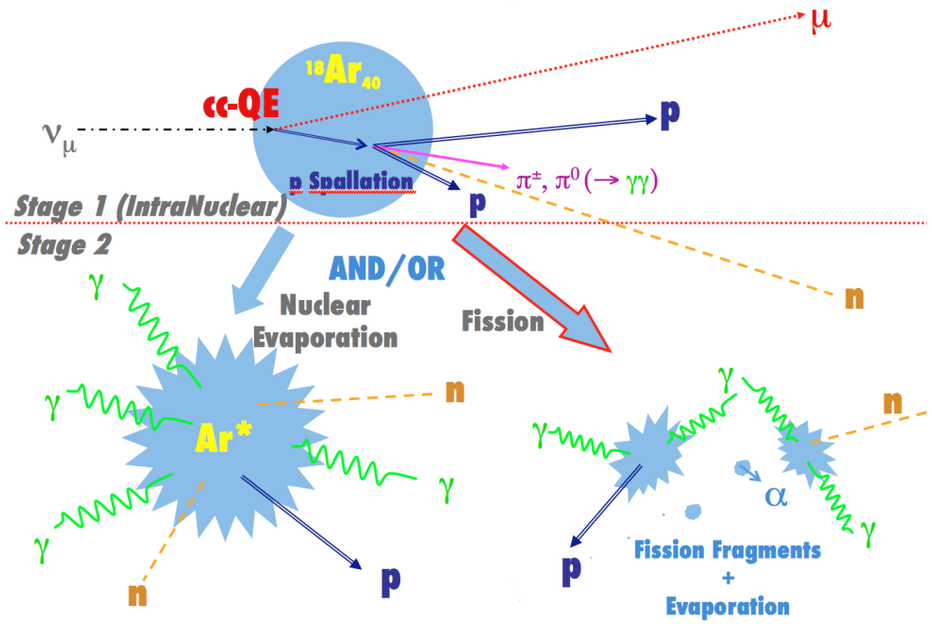




LArTPCs and Short-Baseline Physics

- Excellent ability to distinguish electrons from photons, reducing the NC background.
- ~mm wire-spacing allows very short (low-energy) tracks to be observed.
- CCQE cross-section in the few-GeV region is subject of much interest.
  - recent MiniBooNE and NOMAD measurements differ by ~30%
  - definition of "CCQE" is ambiguous due to various nuclear effects.
  - fine-grained LArTPC will have excellent capability to analyze extra vertex activity.





- ***proton Spallation*** (intranuclear interactions with **p** and **n** emission ...but also **$\pi^{\pm}$, π^{0}**)
- ***Nuclear evaporation*** (lower kin.en. **p** and **n**)
- (and/or) ***Fission*** (nuclear fragments, α's,..)
- ***Nuclear de-excitation*** with **γ** emission

ArgoNeuT Physics Prospects

- Using ArgoNeuT's low-energy threshold (~50MeV) and tracking capabilities, we will include vertex activity and measure cross-sections for CCQE-like (anti)neutrino events from 1-5 GeV.
  - small statistics for CCQE, but there is hope (ICARUS 50-liter made a measurement with ~80 events).
  - Fully contain about ~40% of protons in CCQE events in neutrino mode (and very high % of muons enter MINOS).
- Our initial focus is on analyzing the ~2 weeks of neutrino-mode data, studying "inclusive" CC sample and making MC/Data comparisons (should have soon).

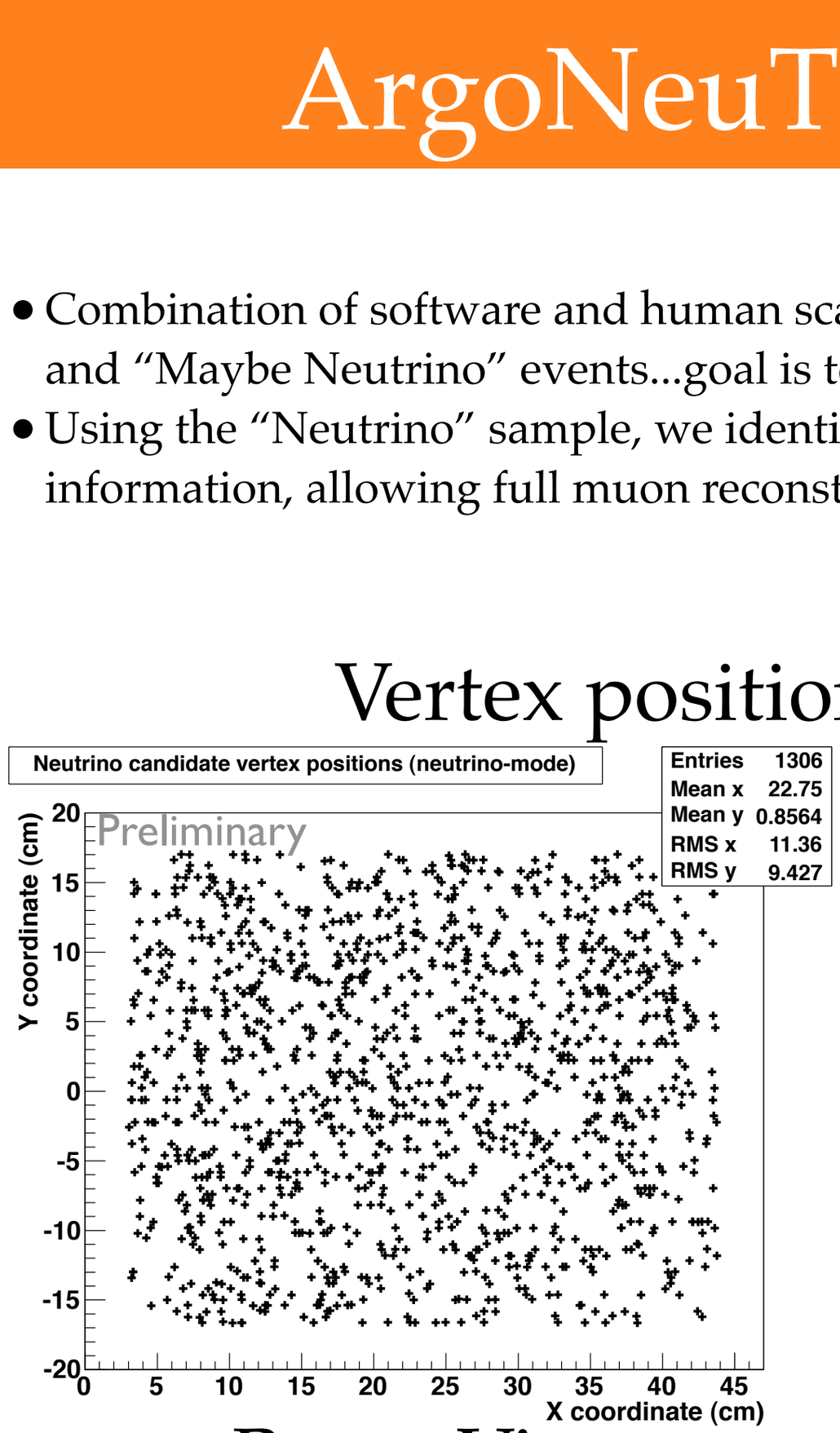
Reaction	#events in AV (~1.35E20 POT)
ν_μ CC	~6600
$\overline{\nu}_\mu$ CC	~4900
ν_μ CCQE	~600
ν_e CC	~130

Expected event sample in ArgoNeuT

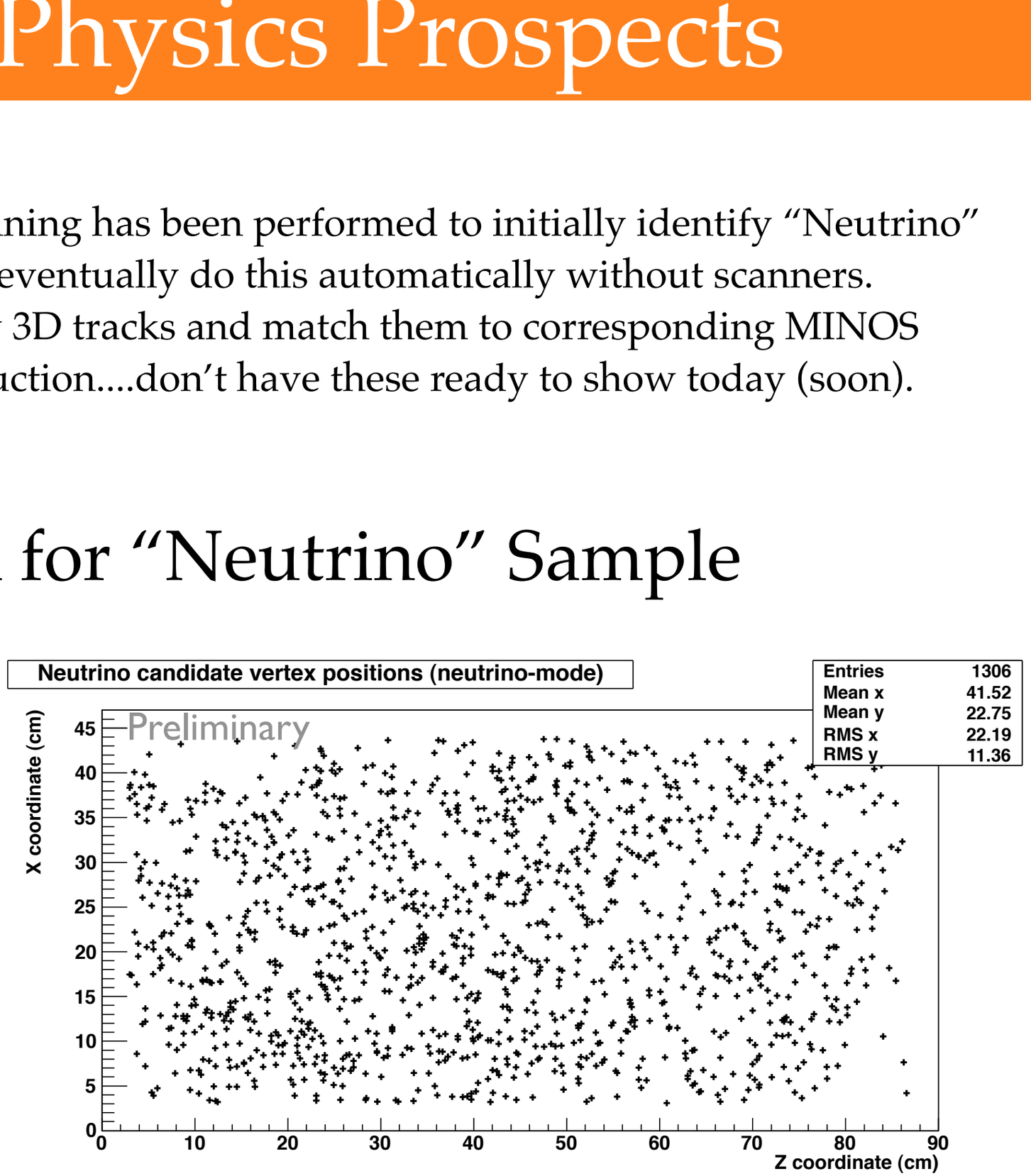
ArgoNeuT Physics Prospects

- Combination of software and human scanning has been performed to initially identify “Neutrino” and “Maybe Neutrino” events...goal is to eventually do this automatically without scanners.
- Using the “Neutrino” sample, we identify 3D tracks and match them to corresponding MINOS information, allowing full muon reconstruction....don’t have these ready to show today (soon).

Vertex position for “Neutrino” Sample



Beam View



Top View

Conclusions

- LArTPCs are very attractive technology for neutrino physics due to combination of scalability and precision tracking/calorimetry.
- ArgoNeuT is a 175-liter LArTPC that ran in the NuMI beam at Fermilab.
- Tools/techniques developed to analyze ArgoNeuT data will benefit future LArTPCs.
- We expect first results analyzing charged-current inclusive sample later this summer.

ArgoNeuT Collaboration

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