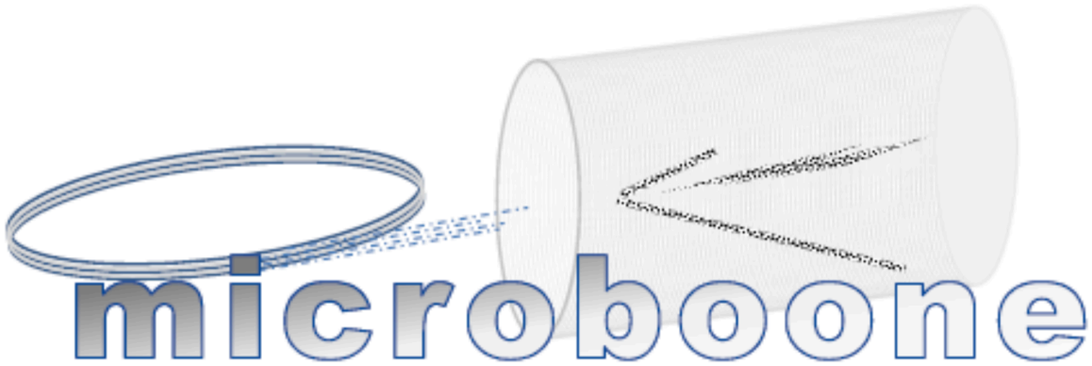


LArTPCs and neutrino detection at FNAL

Joshua Spitz
Neutrino University
FNAL, 8/12/2010

A NEWTrino?
A chameleon (w/ the ability to change "flavor")?
A lizard of some kind shaped like the Greek letter ν?

- Please send me an email (joshua.spitz@yale.edu) if you would like to learn more about LArTPC technology and/or neutrino physics.
- Above all else, we need more people working in this field.

Neutrino questions

(not a comprehensive list)

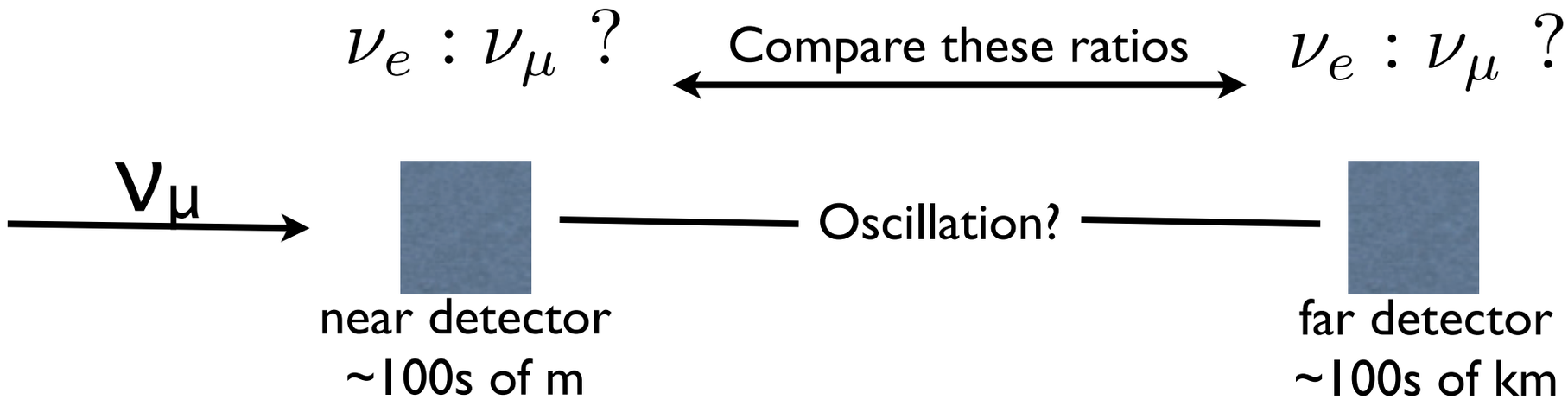
- theta13 non-zero?...delta_cp?
- supernova burst and diffuse
- relic, big-bang neutrinos
- UHE Astrophysics: AGN, GRB, and GZK neutrinos
- absolute mass
- proton lifetime
- geo-neutrinos
- solar neutrinos
- nu_tau
- sterile neutrino(s)?
- theta_23 maximal?
- majorana or dirac?
- mass hierarchy normal or inverted?
- neutrinos as dark matter?
- cross sections and nuclear physics (e.g. delta_s, M_a)
- Weinberg angle

Relevant for the talk today

Sort of relevant for the talk today

It is good that you are interested in neutrinos. There are a lot of questions that need answering!

A reminder: the conventional long-baseline technique in searching for theta_13 and delta_CP



Does nu_mu oscillate to nu_e (appearance)?

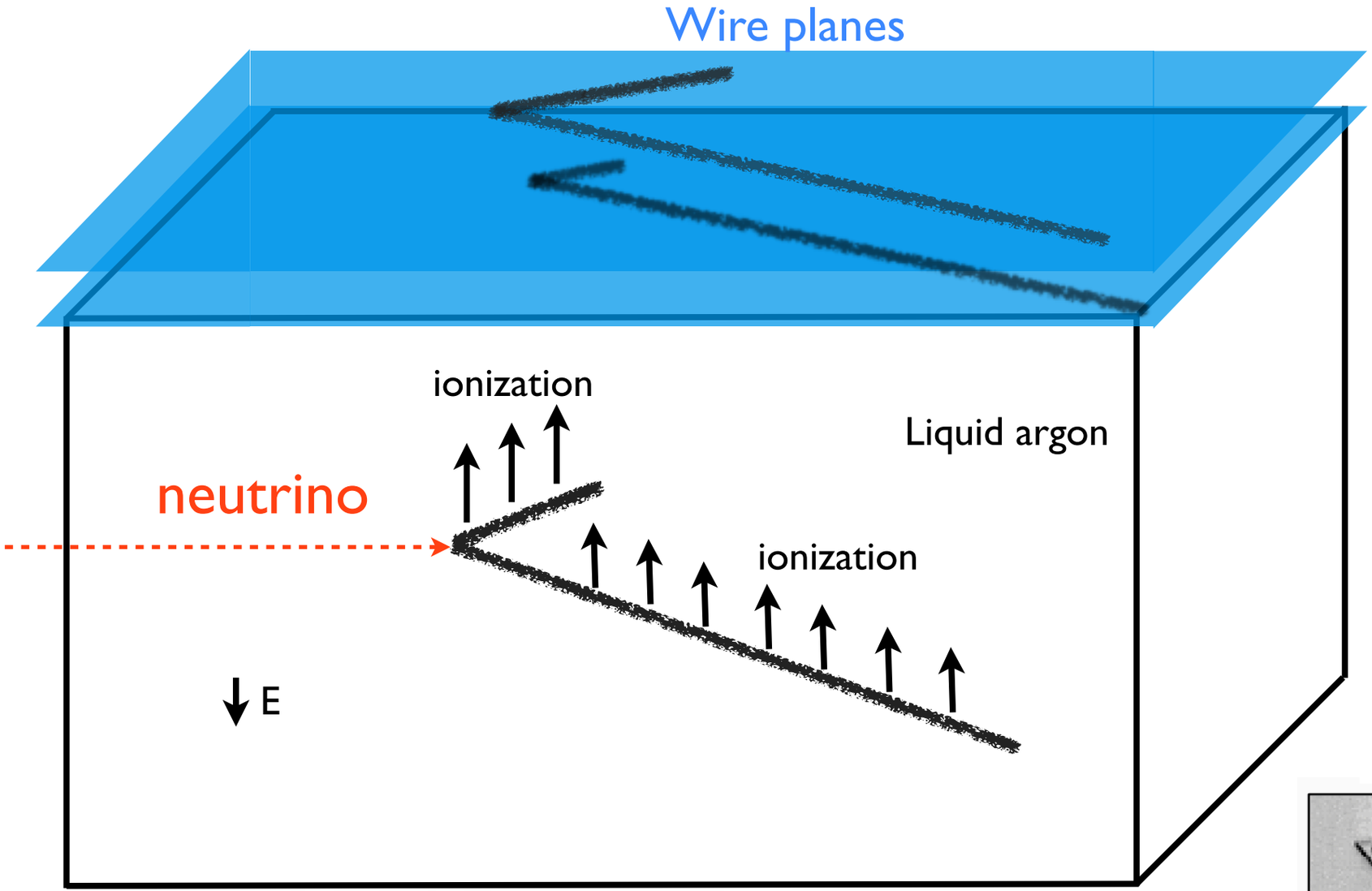
CP violation in the lepton sector? $P[\nu_\mu \to \nu_e] \neq P[\overline{\nu}_\mu \to \overline{\nu}_e]$?

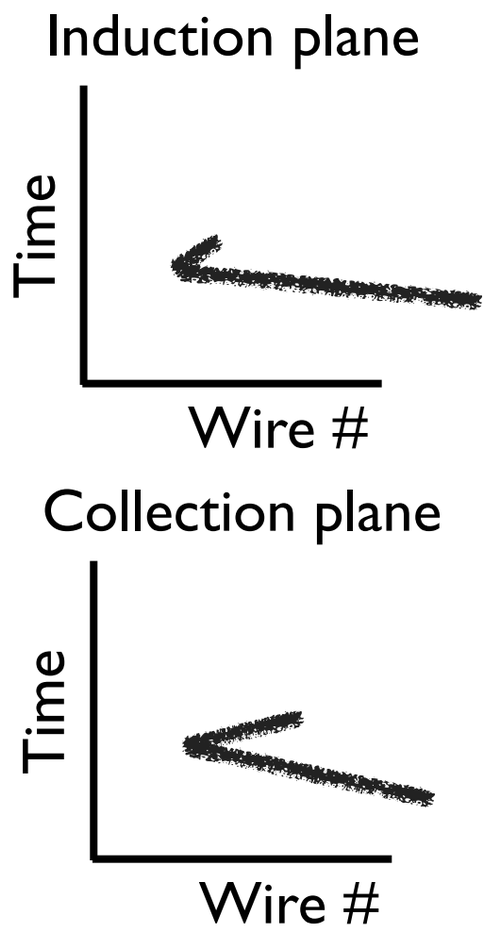
FNAL is very interested in answering these questions

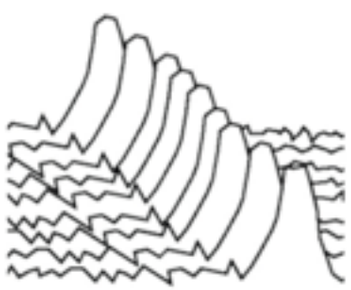
A wish list for accelerator-based neutrino oscillation physics

- Beam:
  - Intense, pure beam w/ a smartly chosen L/E
- Detector(s):
  - High resolution 3D imaging
  - Precise calorimetric reconstruction
  - Fully active
  - Homogeneous volume
  - Low energy threshold
  - Particle ID (background suppression)
  - Big (scalable)

The LArTPC concept

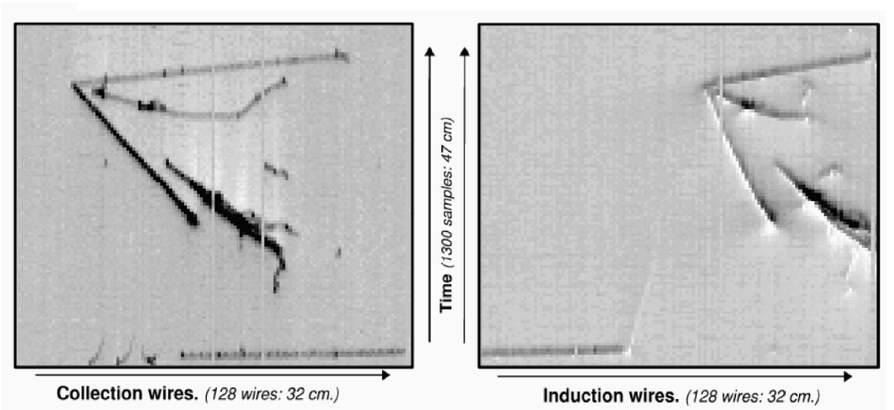






Wire pulses in time give the drift coordinate of the track

Scintillation light is also available for detection!

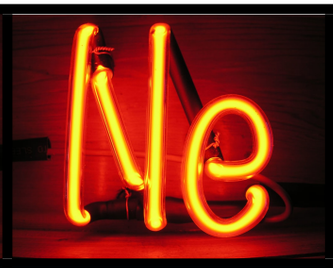
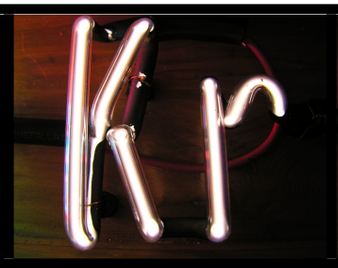


ICARUS 50 L in WANF neutrino beam

induction plane + collection plane + time = 3D image of event (w/ calorimetric info)

This concept can also be employed for direct dark matter detection!

Why argon?

						
	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	

- Large ionization and scintillation yields offer two avenues for particle detection.
- Noble liquids also offer excellent dielectric properties for high voltage.

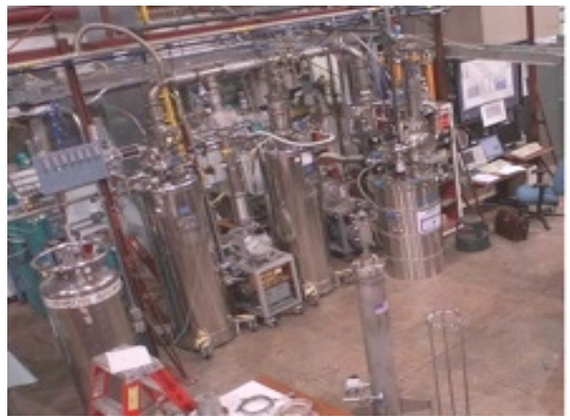
Expensive

LArTPC neutrino detection

The US LArTPC program is fast moving from R&D to physics!

- **Position resolution and topology**
  - Pixel size in ArgoNeuT = (4.0 x 0.3) mm^2.
  - 3D imaging in a homogeneous and fully active detector.
- **dE/dx**
  - Monte Carlo studies show that LArTPCs can separate electrons & gammas with >90% efficiency.
  - Vital to electron-neutrino tagging in appearance searches.
- **Low energy threshold**
  - Detection of particles with energy down to ~10 MeV.
- **Always live and scalable**

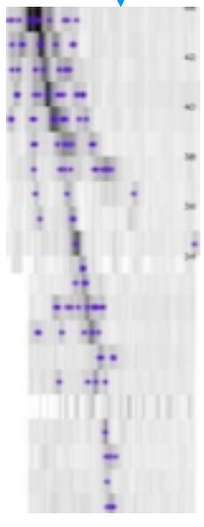
Materials Test Stand



Electronics Test Stand

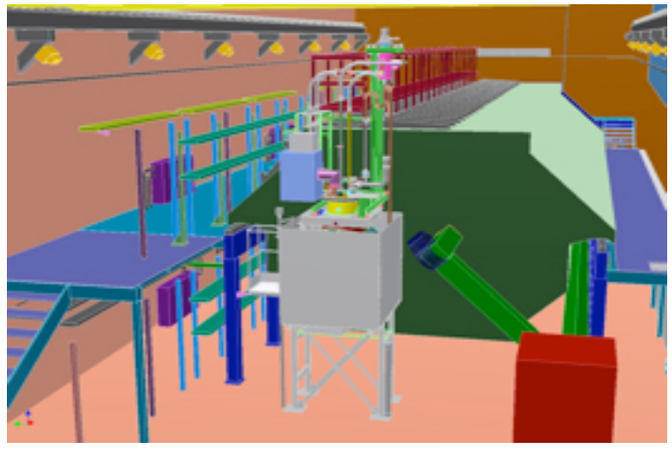
2007 — 100% R&D

2007-



Yale Tracks

2008-

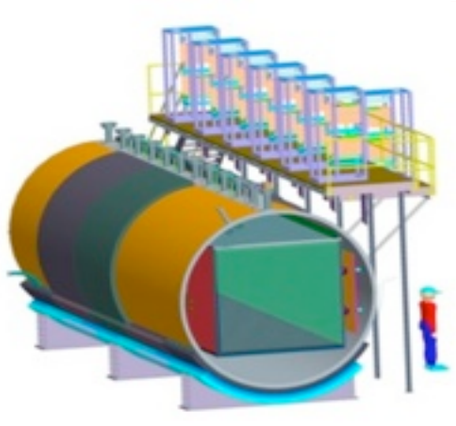


ArgoNeuT
Cross sections

2010-

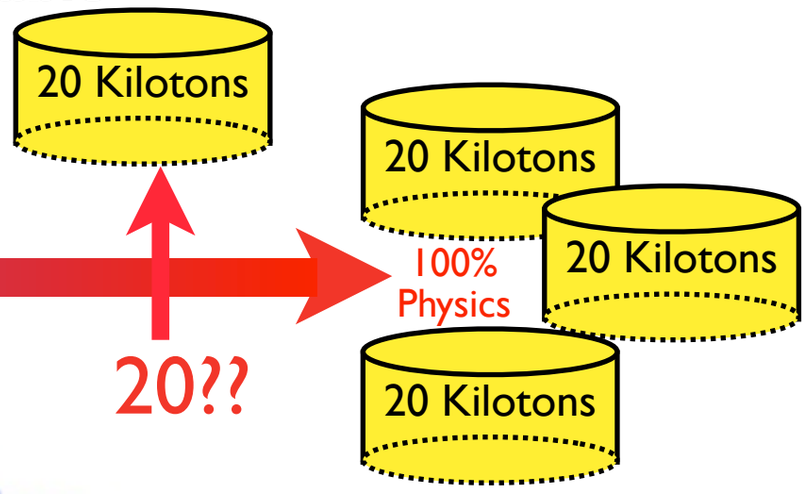
LAr Purity Demonstrator

2013-



MicroBooNE
Cross sections
MiniBooNE anomalies

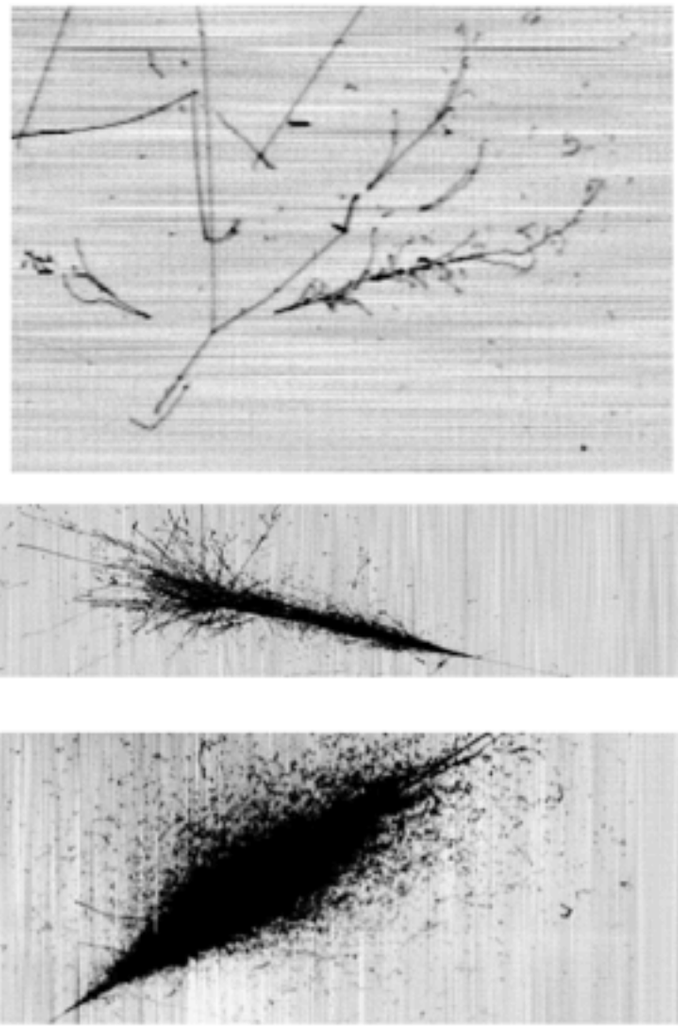
20??



LBNE
Proton decay
θ_{13} and δ_{CP}
Supernova burst
Supernova relic
Geo-neutrinos
Atmospheric ν_τ app.
Atmospheric ν_μ disapp.
...

Addressing LAr challenges

- Cryogenics and Purity
  - Insulation and cooling.
  - Achieving and maintaining purity.
  - How do detector materials affect purity?
- Safety
  - Oxygen Deficiency Hazard (ODH).
  - Relief lines in a pressurized vessel.
- Electronics
  - Signal/noise.
- Detector components
  - Cryostat, field cage, HV, wires, PMTs, purity monitor,…
- Software
  - Simulated event generation, propagation, and reconstruction.



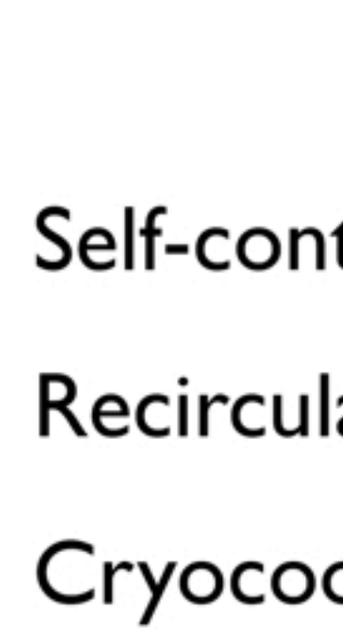
ICARUS LArTPC events

ArgoNeuT

The Cryostat

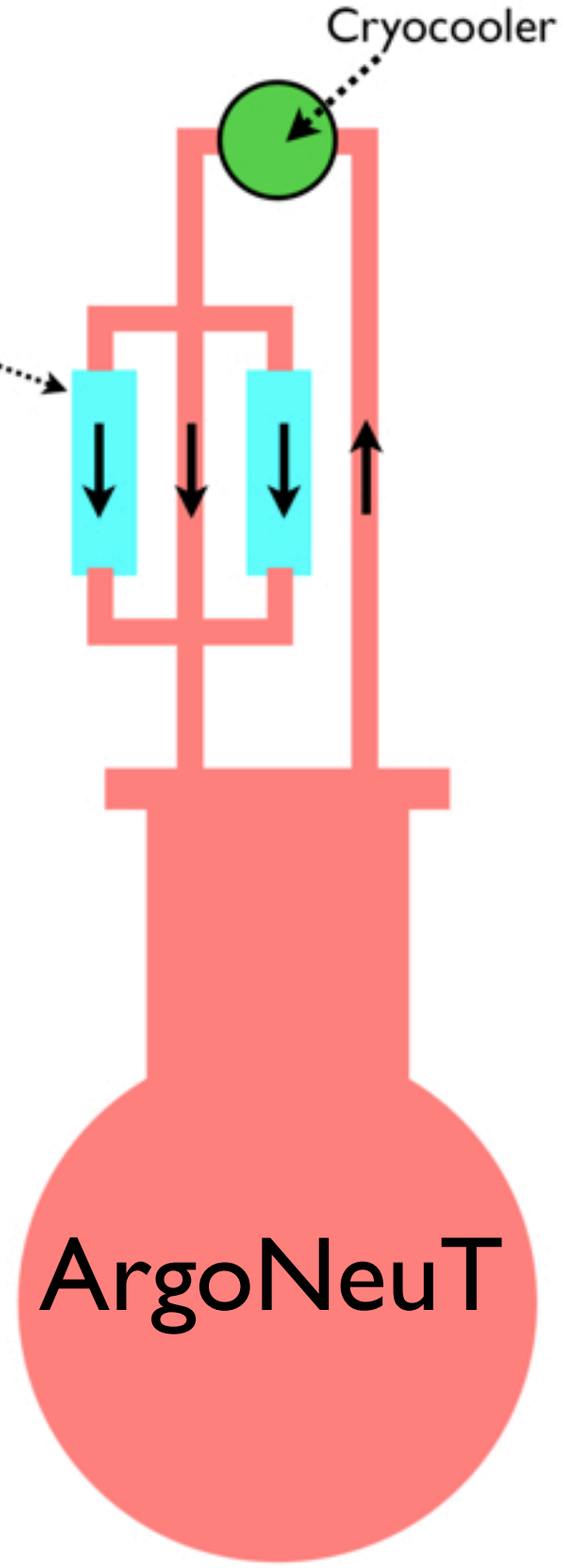
Cryo-system

- Self-contained system.
- Recirculate argon through Trigon filter.
- Cryocooler used to condense boil-off gas.
- Multiple relief paths to achieve safe running.

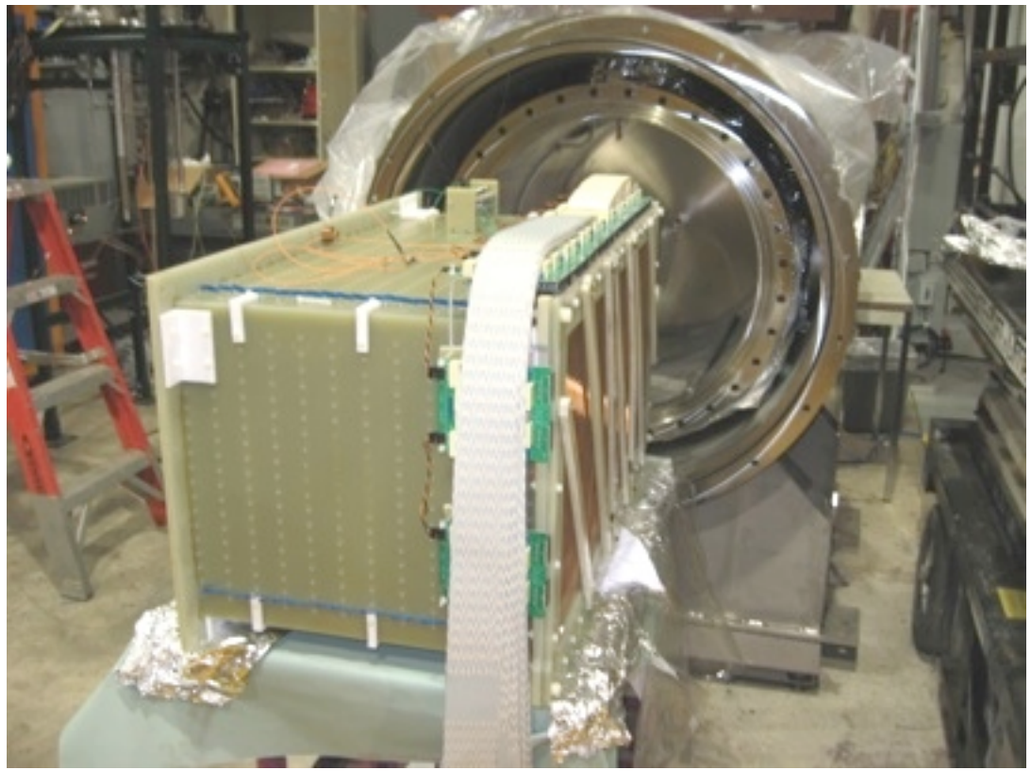


300W Cryocooler

Vacuum-Jacketed Cryostat

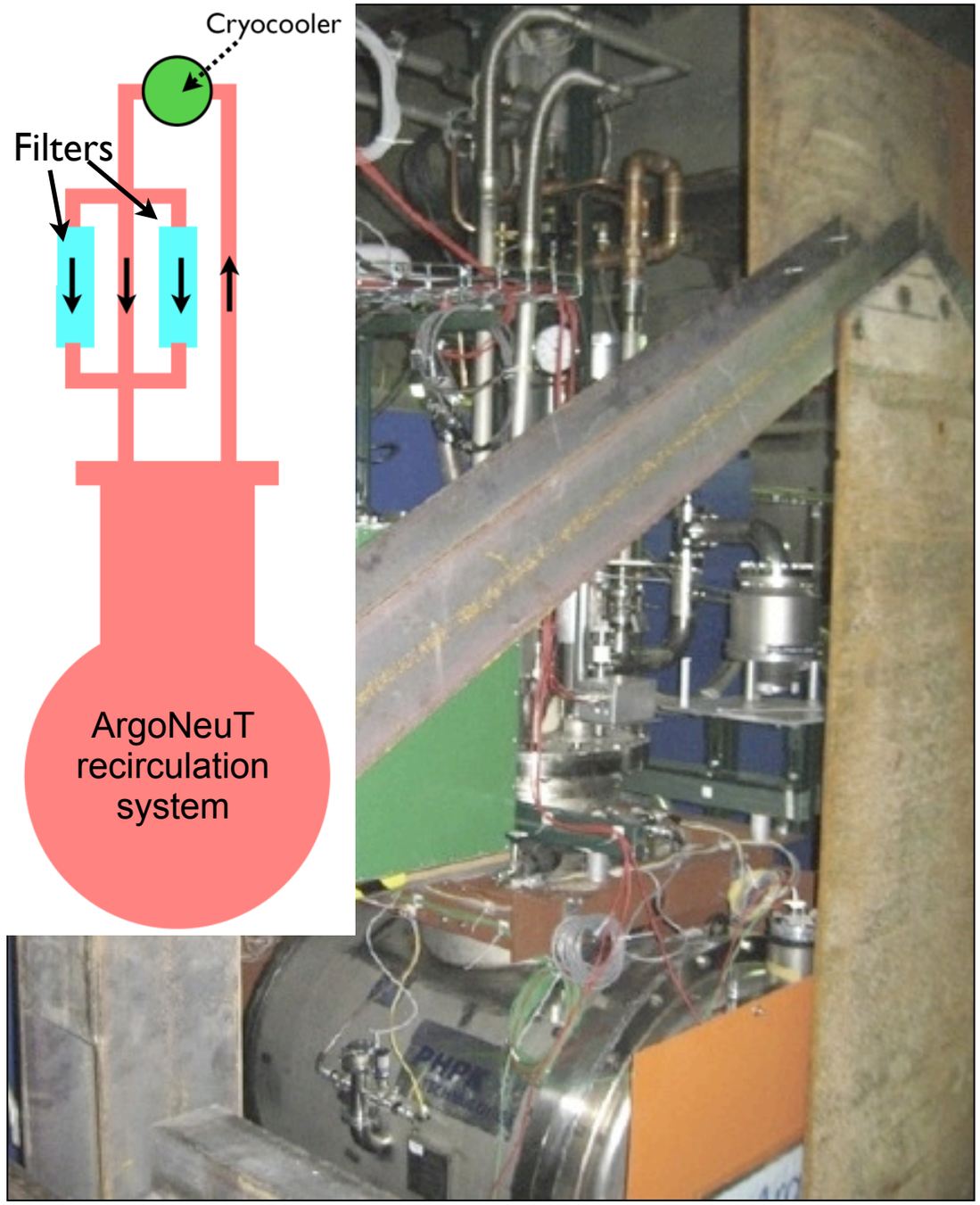


The ArgoNeuT TPC and cryostat



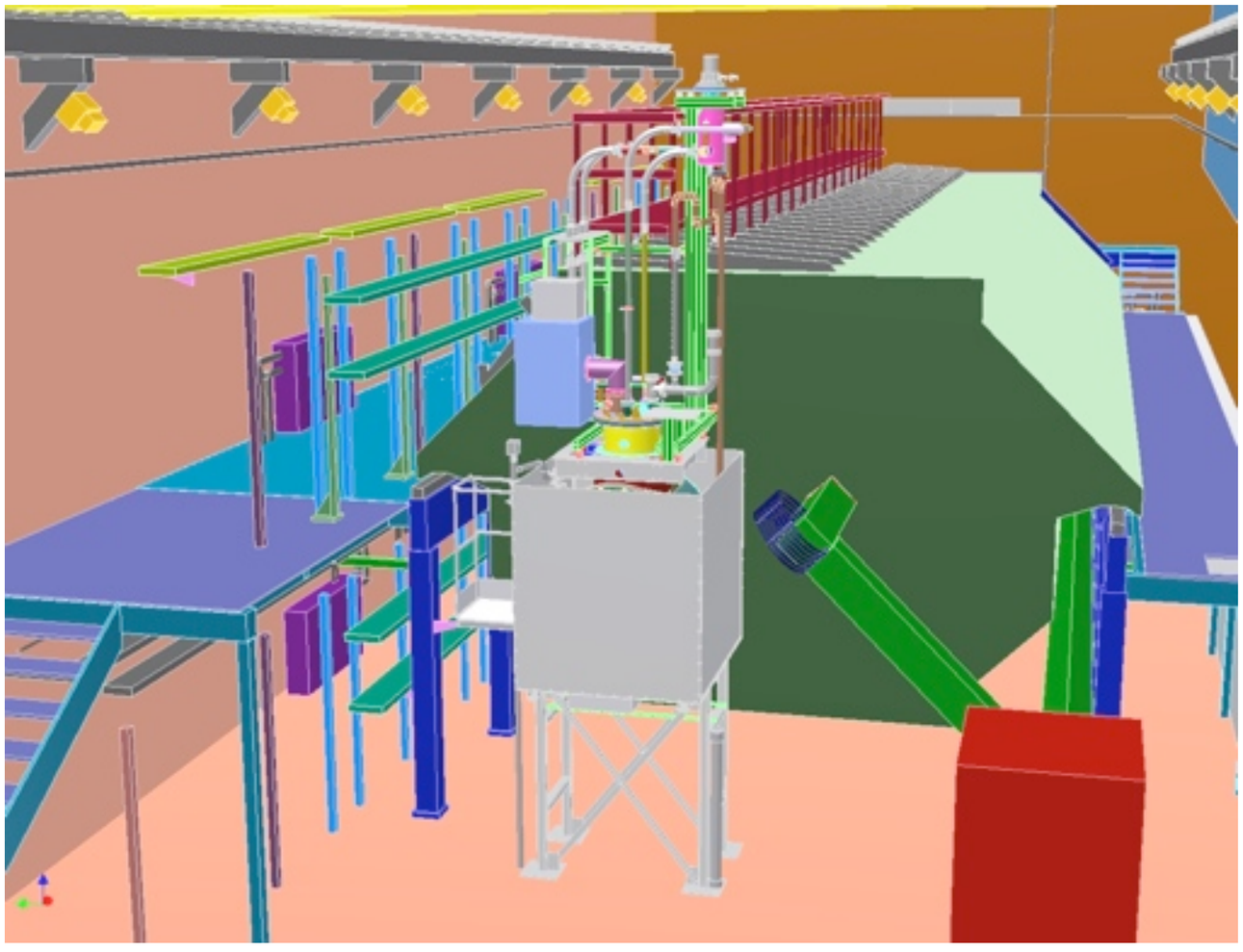
The TPC, about to enter the inner cryostat

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330μs)
Light Collection	None

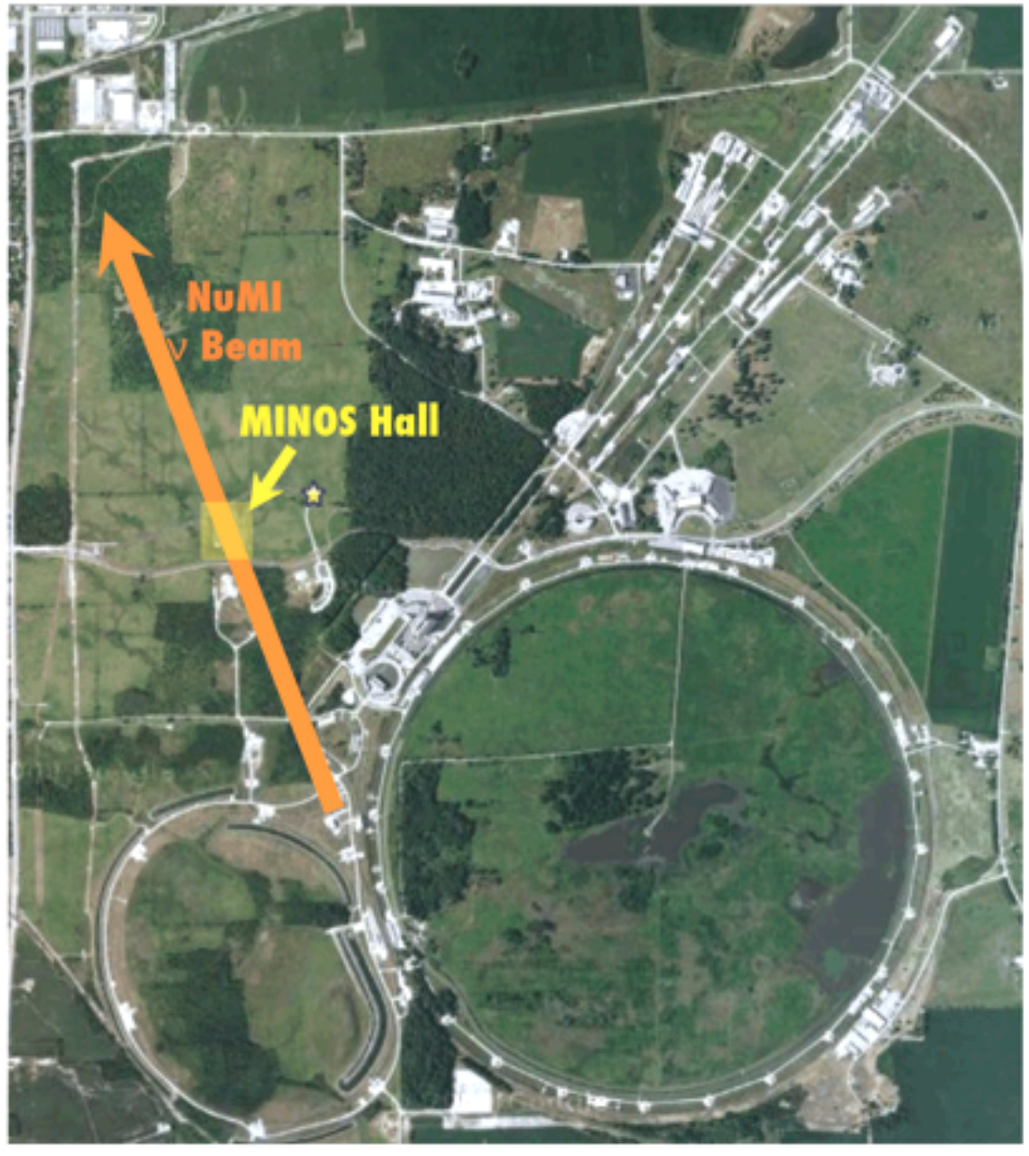


The fully-instrumented detector in the beamline

ArgoNeuT in the NuMI beam

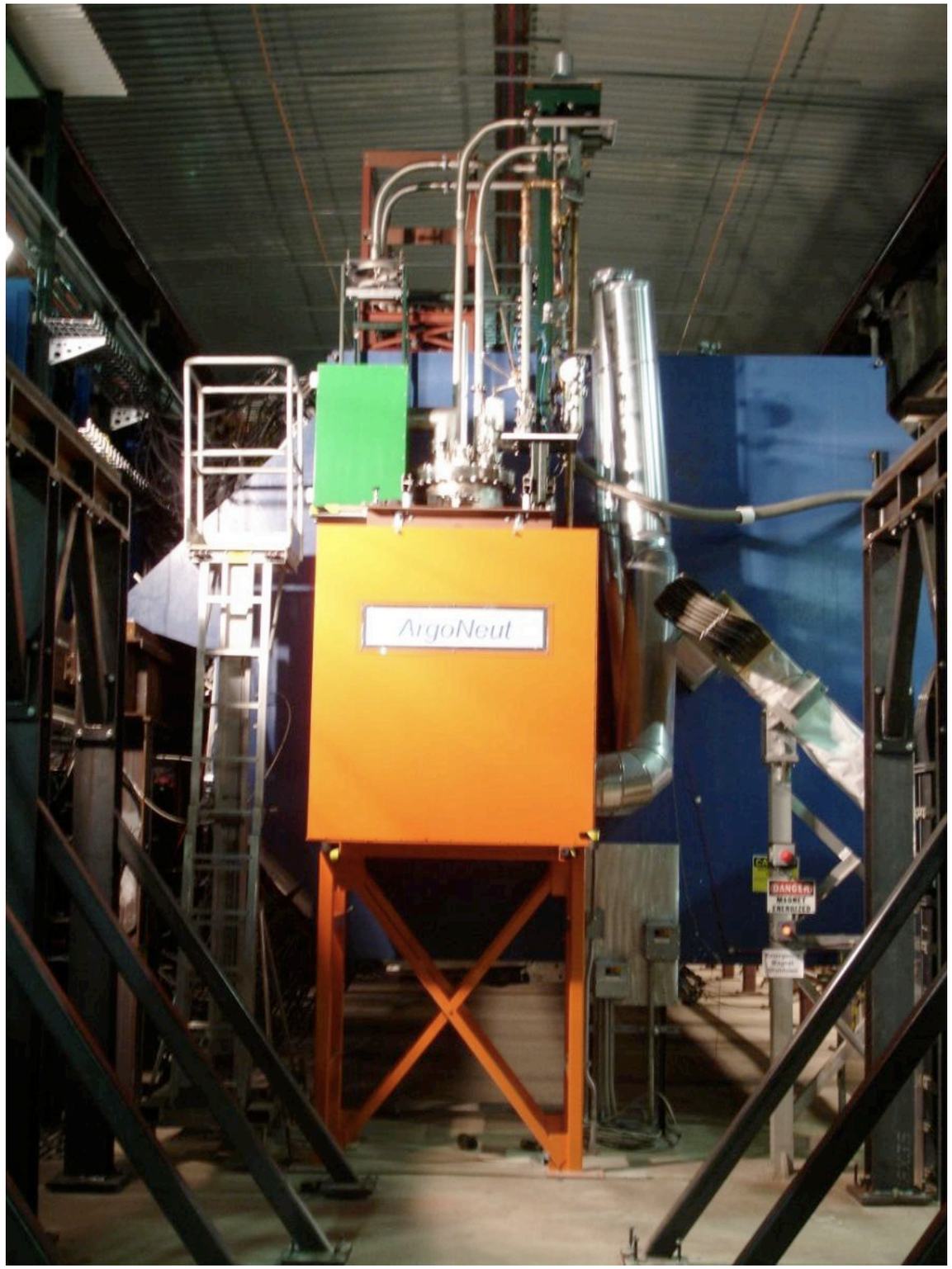


ArgoNeuT, just upstream of the MINOS near detector

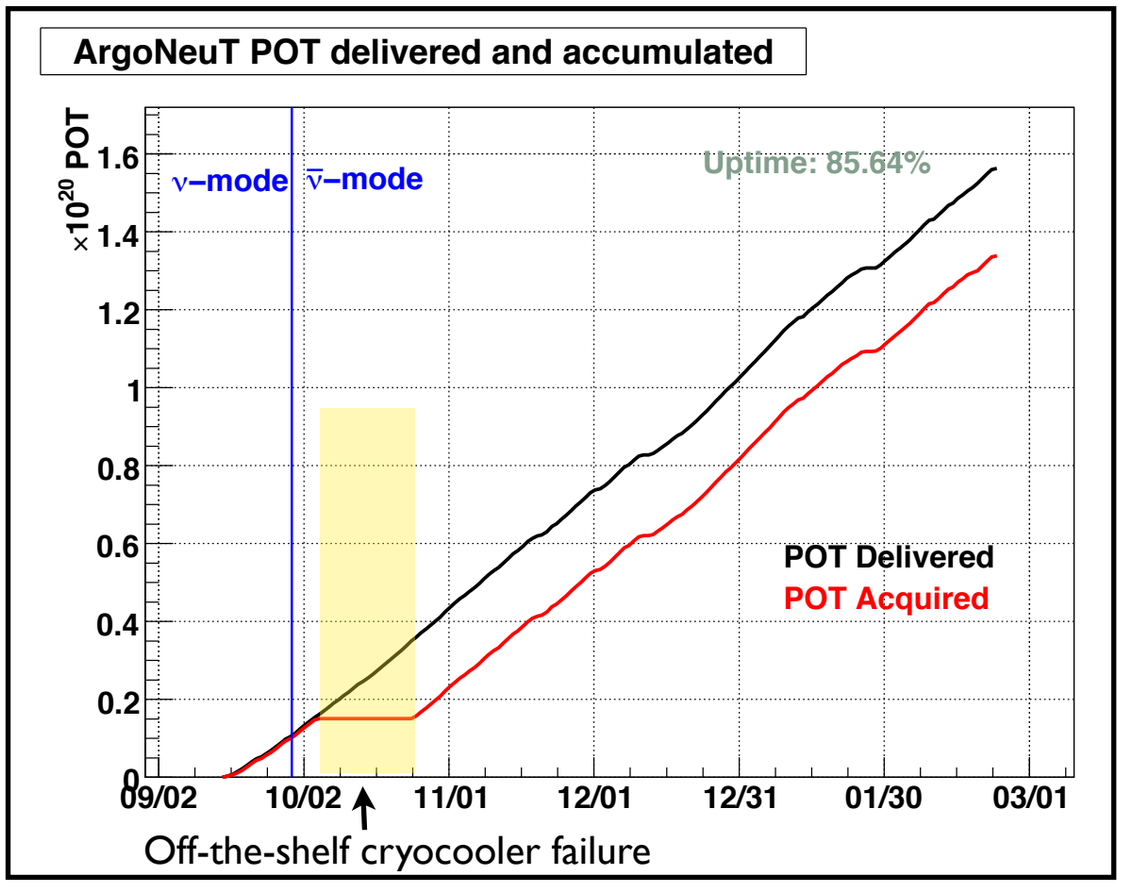


NuMI beamline at Fermilab

ArgoNeuT underground



ArgoNeuT's physics run

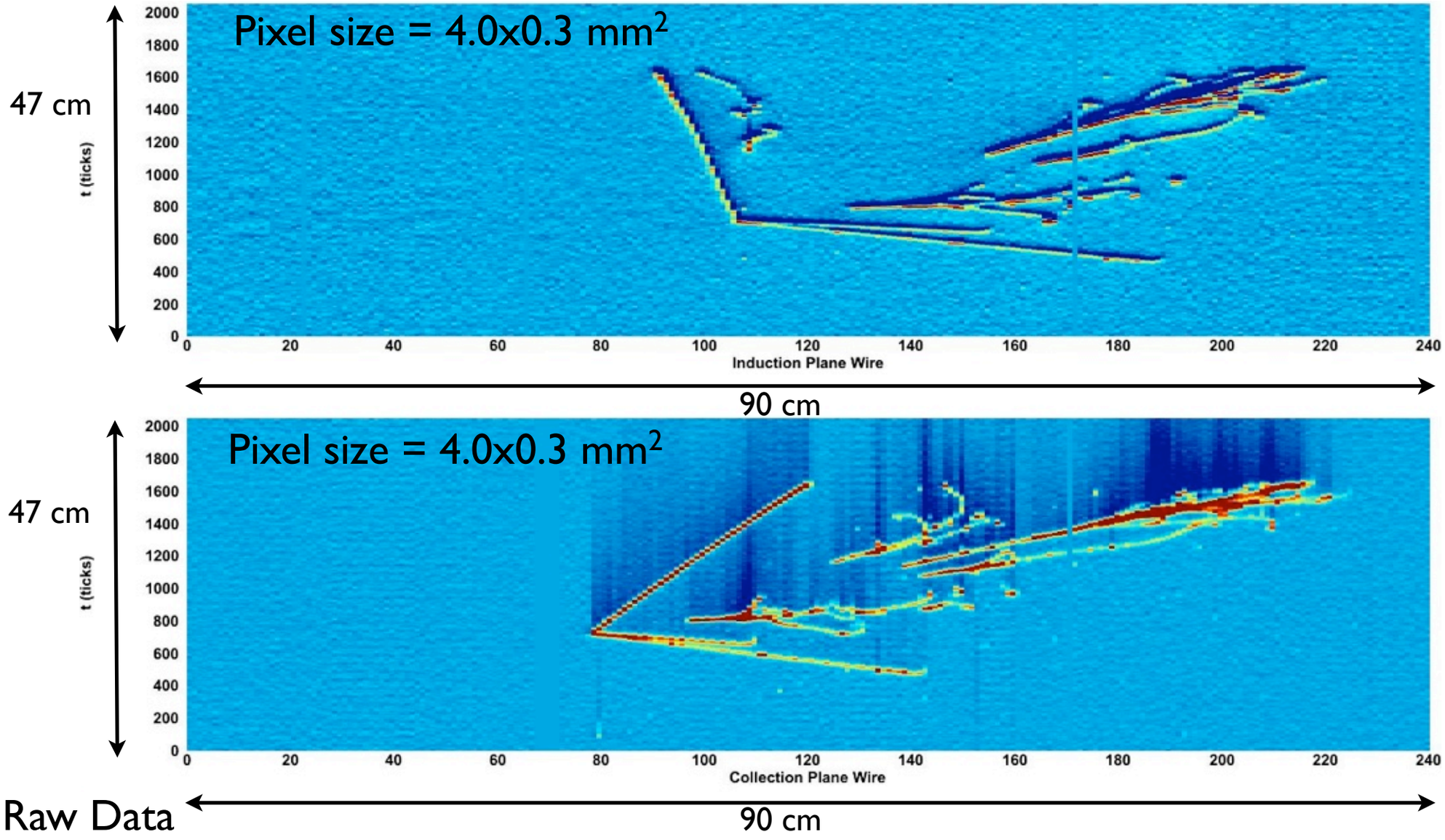


- ArgoNeuT (NSF/DOE) recently completed its phase I physics run, lasting from 9/14/2009-2/22/2010.
- Goals:
  - Multiple neutrino cross section and vertex activity characterization measurements.
    - I will focus on the "CCQE-like" cross section and vertex activity analyses in this talk.
  - dE/dx particle separation capabilities of LArTPCs will be demonstrated.
  - Developing automated reconstruction techniques, to be used for ArgoNeuT and future LArTPCs.
  - R&D for future LArTPCs.

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

- Stable, shift-free operation for >5 months!
- The first 1000s of (anti-)neutrino LArTPC events collected in a low-energy (~3 GeV) neutrino beam ever!

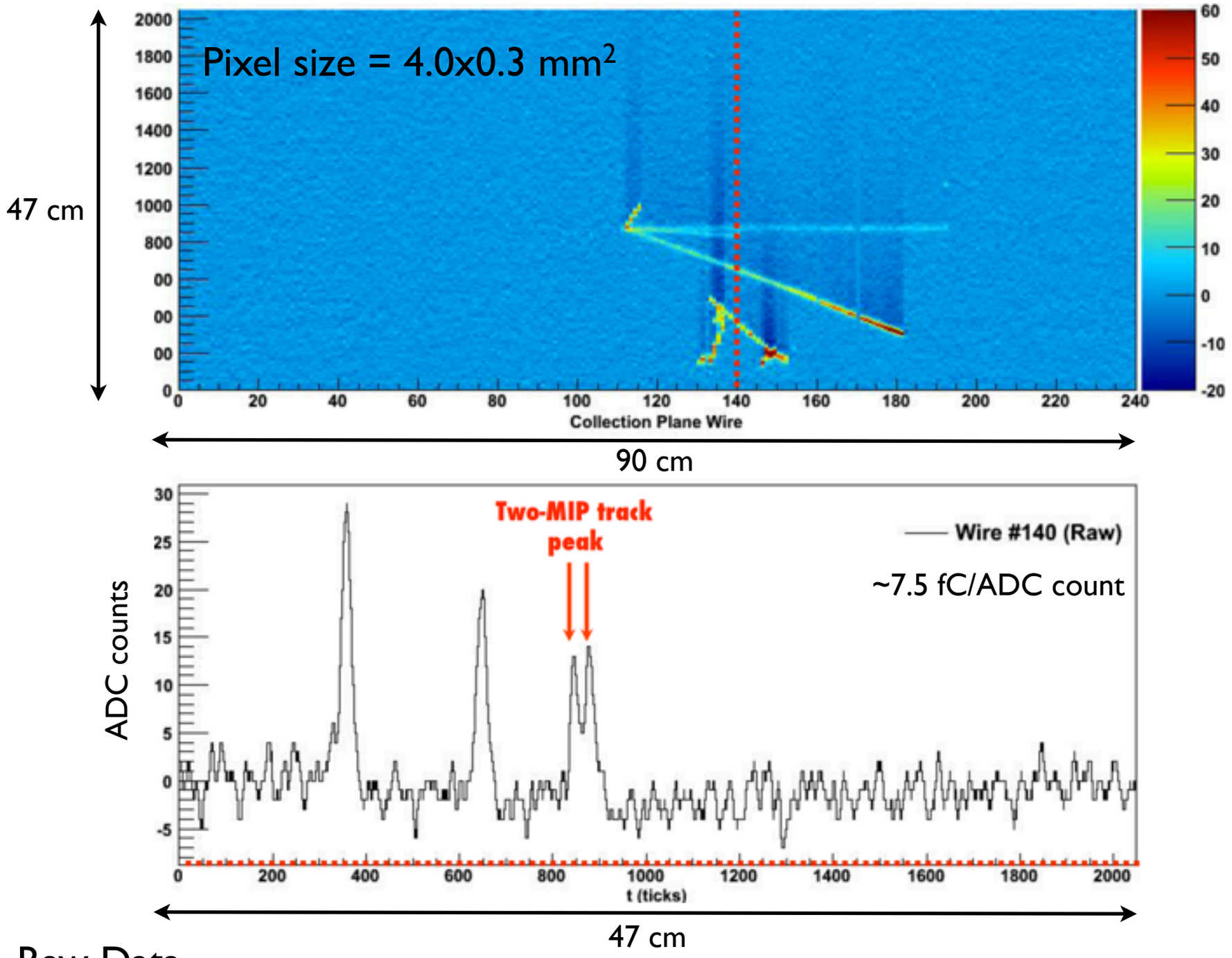
Neutrino event



A charged current neutrino DIS event with two pi0 decays.

- The detector provides two 2D-views of an event.
- The color scale is indicative of the energy deposited along the track.

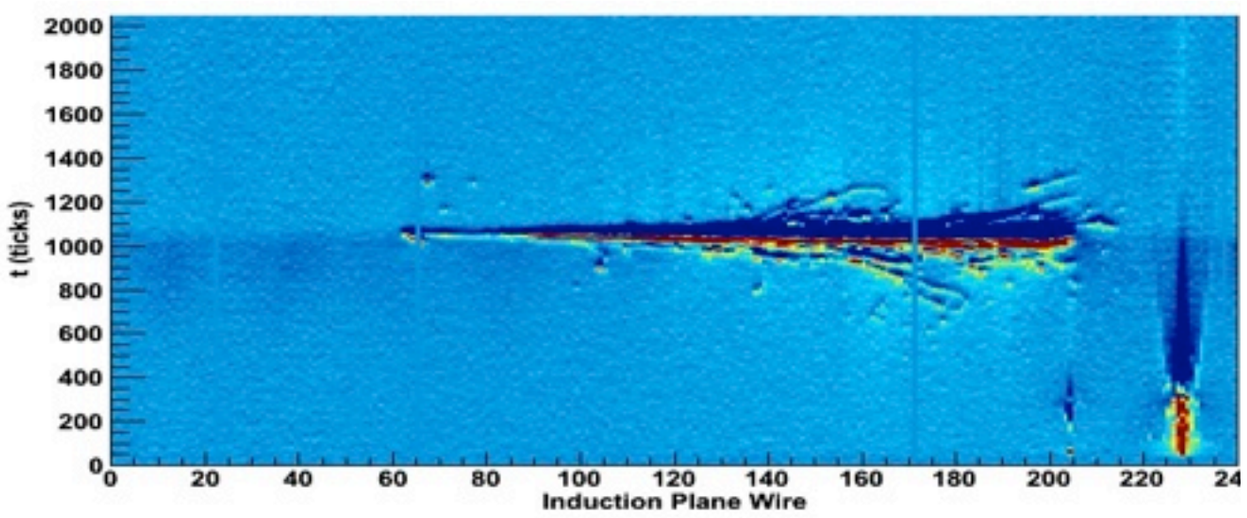
Wire pulses

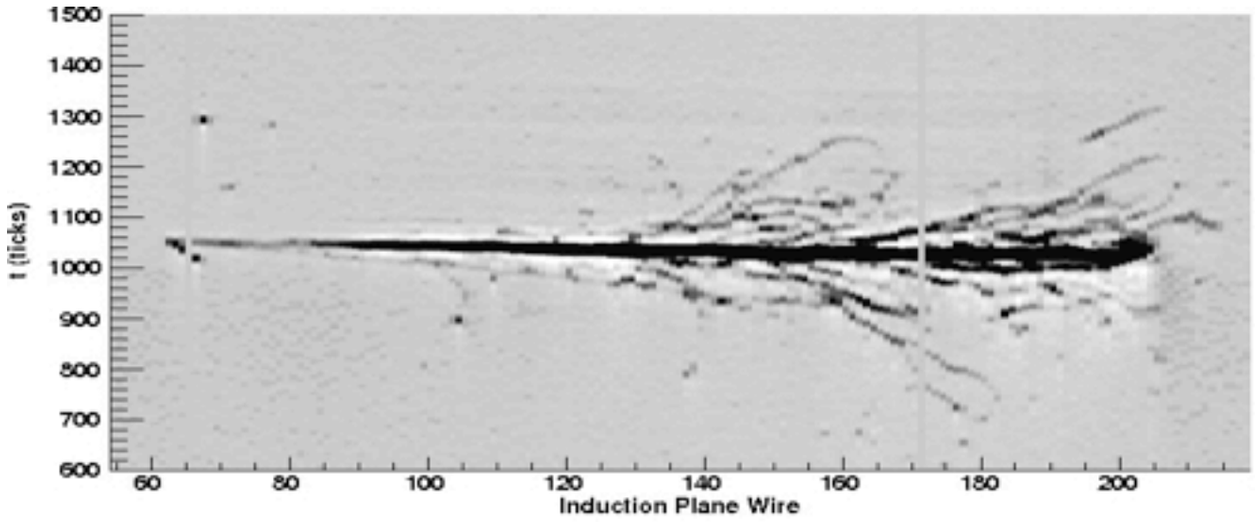


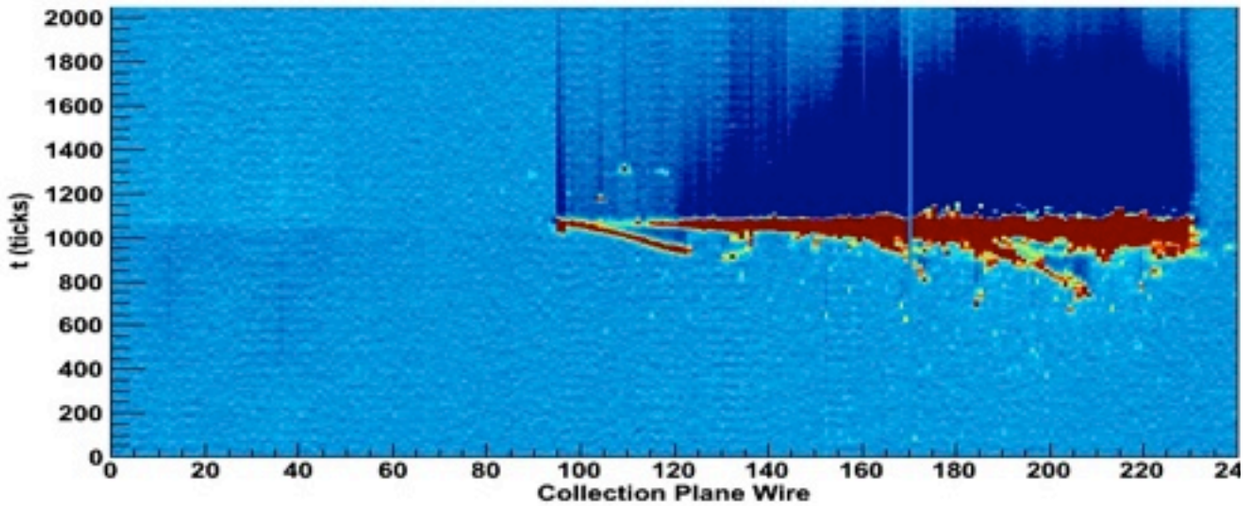
Raw Data

- The actual wire pulses can be seen here in the "wire view".

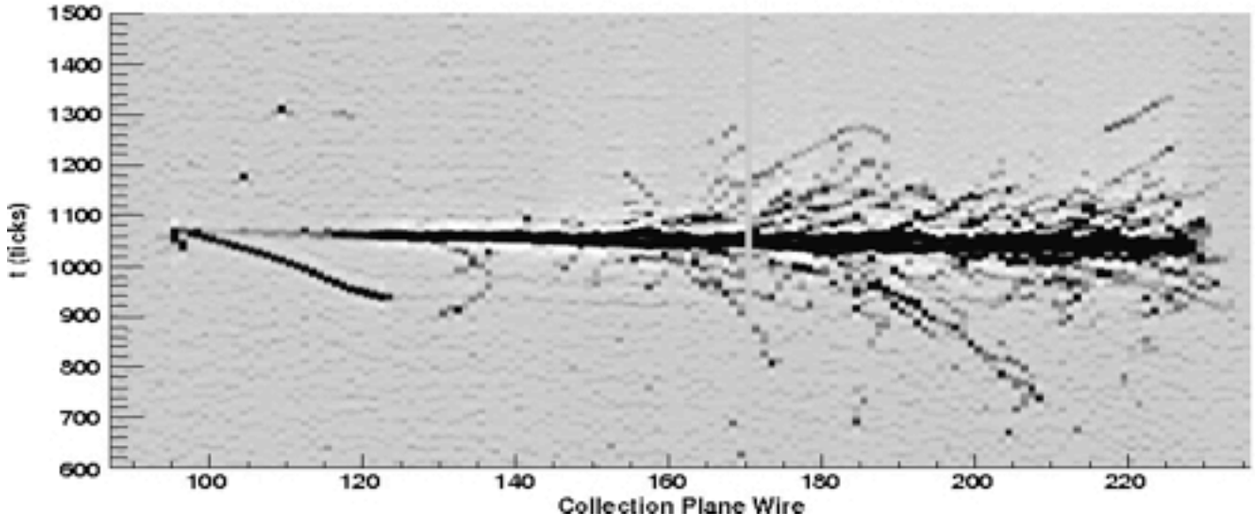
An electron-neutrino







Raw Data

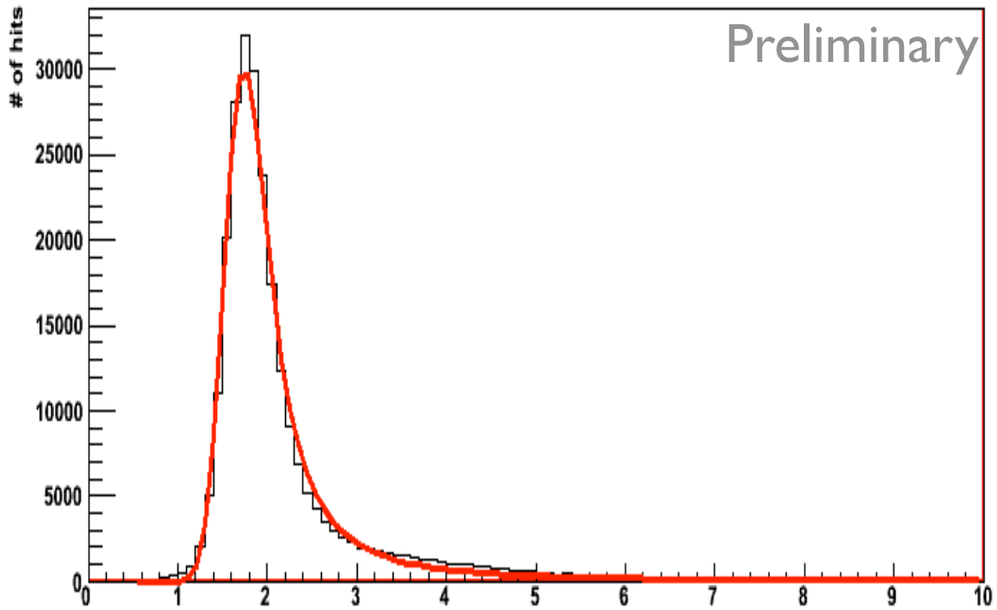


Deconvoluted Data

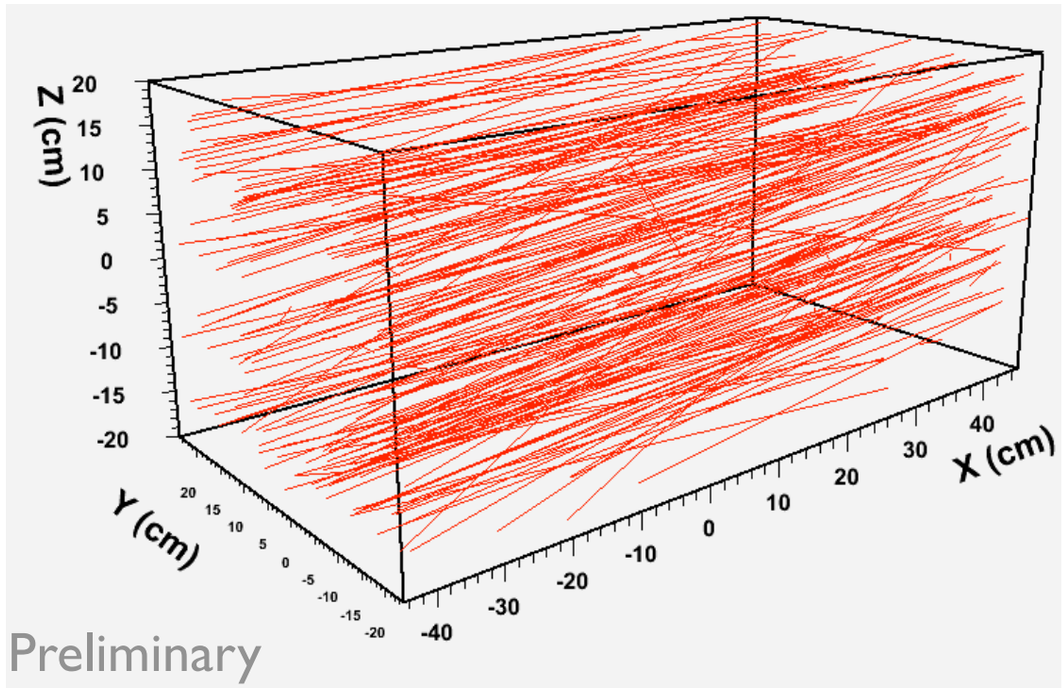
- This (beam-intrinsic) event demonstrates what a signal-like electron-neutrino event looks like to an LArTPC.
- Current and future long baseline neutrino oscillation experiments (MINOS, T2K, NoVA, LBNE, ...) search for electron-neutrino appearance in order to measure θ_{13} and δ_{CP}.

Automated reconstruction of muons

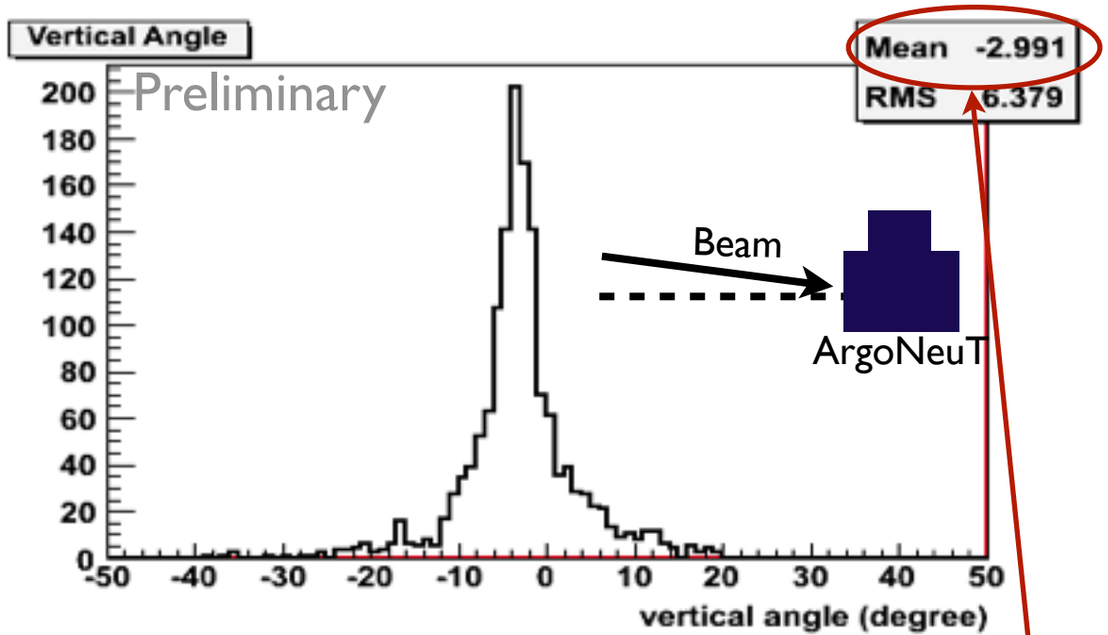
- The first step in ArgoNeuT's neutrino reconstruction algorithm is to reconstruct the muon.
- Along with calorimetry and tracking within the ArgoNeuT TPC, we are also working on matching tracks with the downstream MINOS near detector.



Muon calorimetry (dE/dx)



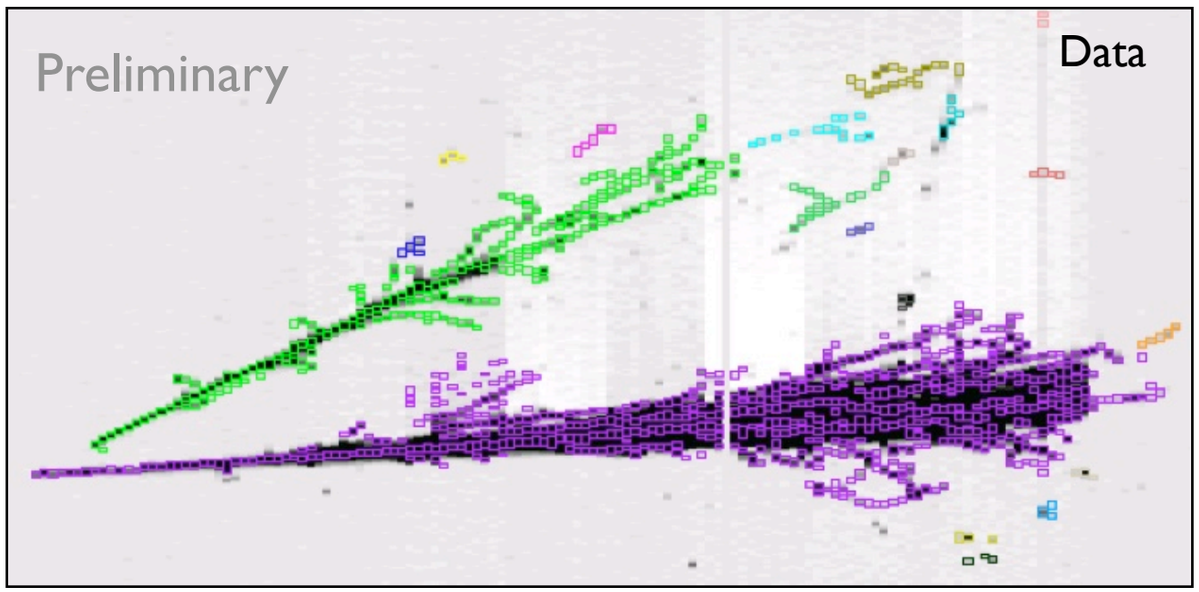
3D-reconstruction of muons



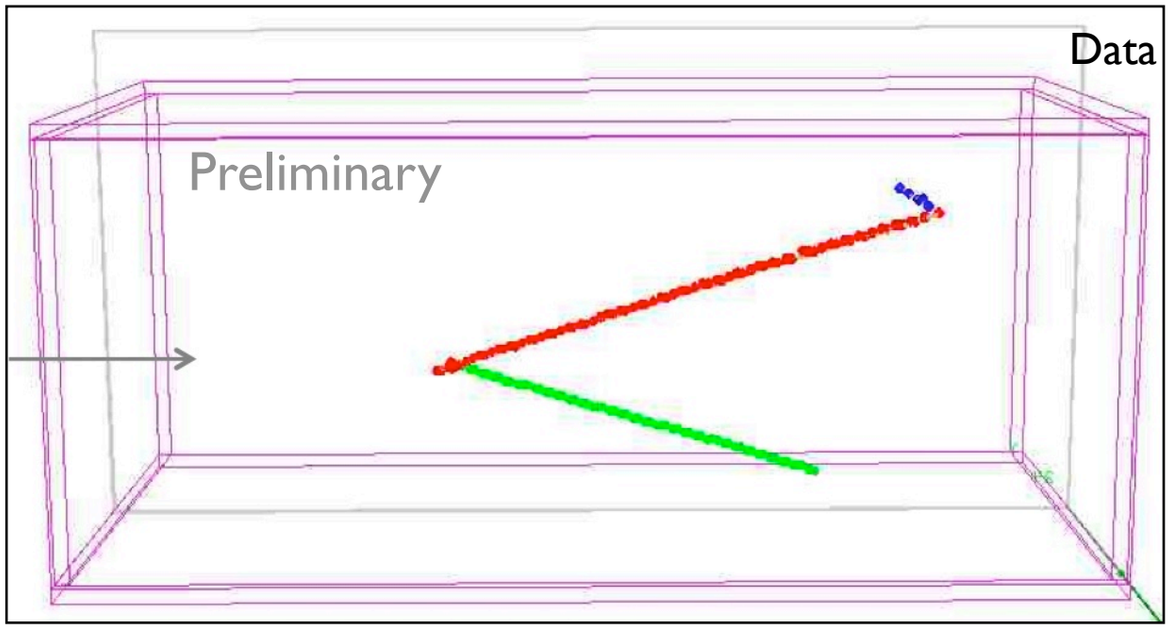
Angular distribution of muons (NuMI beam is at 3°)

Reconstructing neutrino events

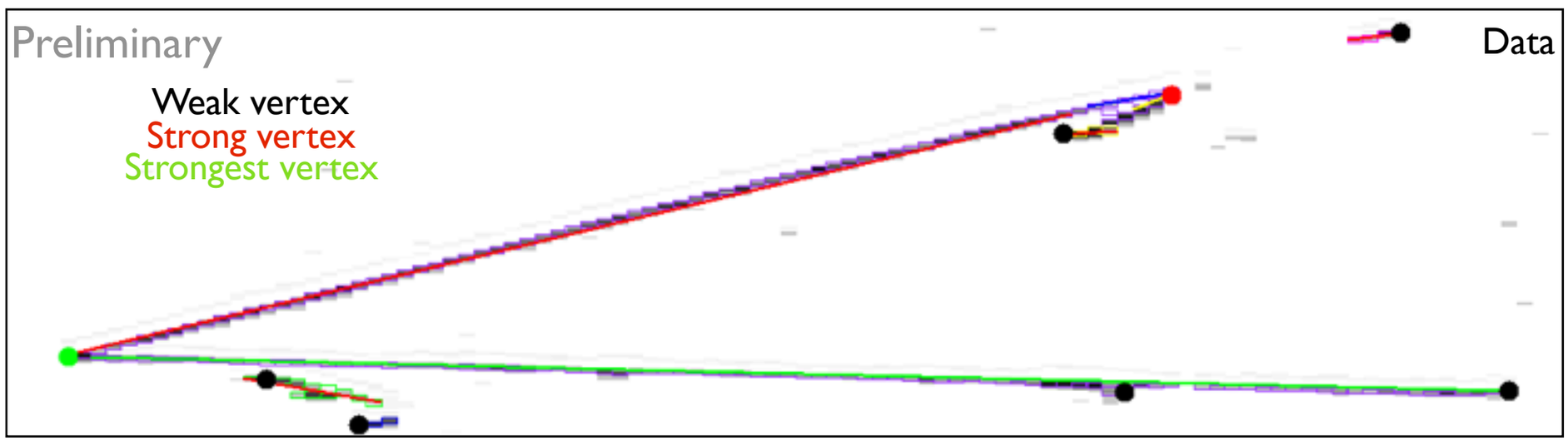
- ArgoNeuT has created an automated reconstruction framework currently capable of hit finding, calorimetry, cluster/line/vertex-finding, track fitting and 3D track matching.



Hit finding + density-based clustering.



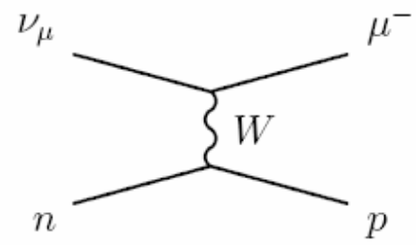
3D reconstruction



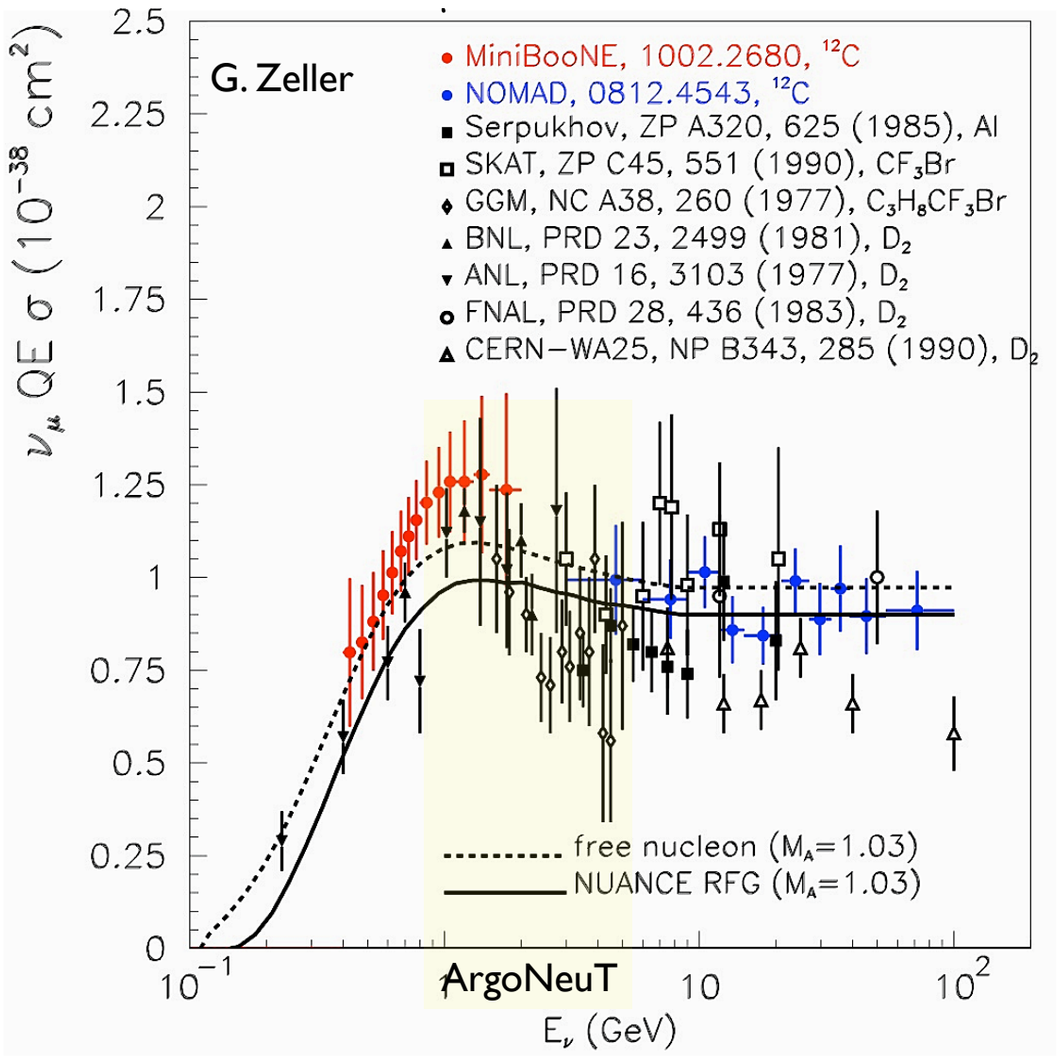
Line finding/fitting + vertex/endpoint finding

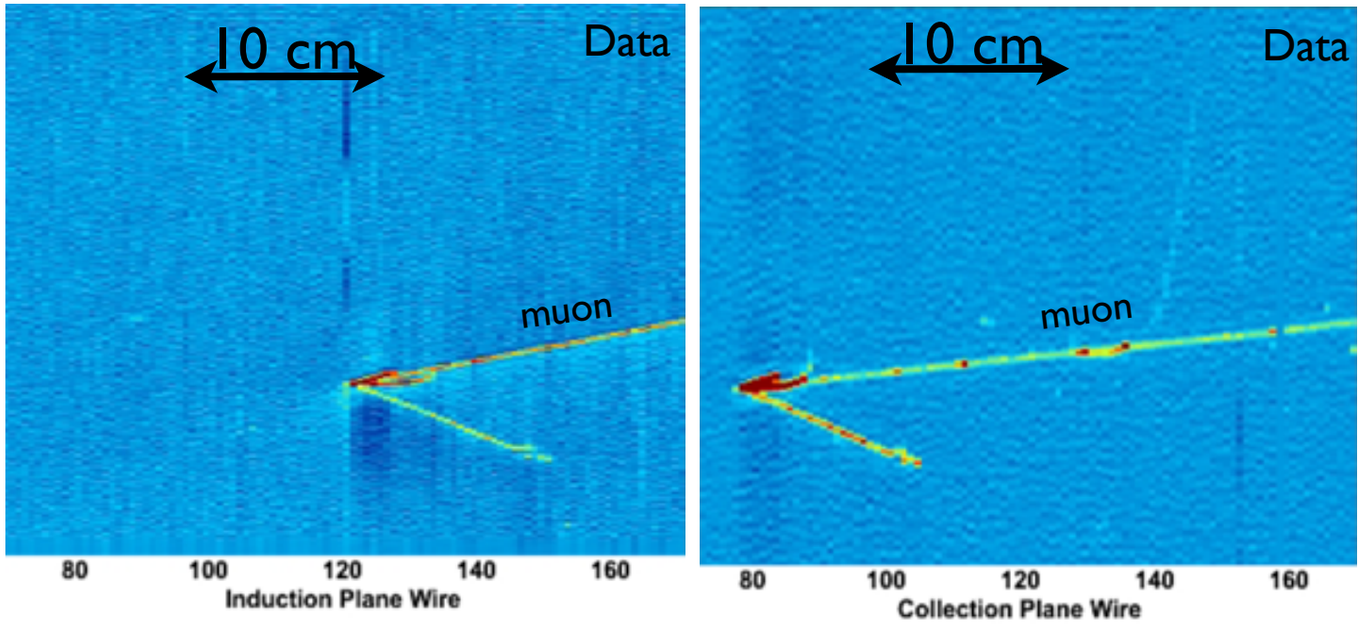
Addressing the CCQE puzzle

$$\nu_\mu \mathrm{n} \longrightarrow \mu^- \mathrm{p}$$



- The CCQE interaction is considered the "golden channel" for most GeV-scale neutrino oscillation experiments.
- However, the CCQE cross section uncertainty over most of the relevant energy range is large.For example, recent MiniBooNE and NOMAD (both ^{12}C) CCQE cross section measurements disagree by up to 30% or more.
- With mm-scale resolution and 3D imaging, ArgoNeuT will analyze the vertex activity kinematics and measure differential kinematic and total cross sections for CCQE-like (anti-)neutrino events from ~1-5 GeV.





A zoomed-in view of a CCQE-like neutrino event with vertex activity

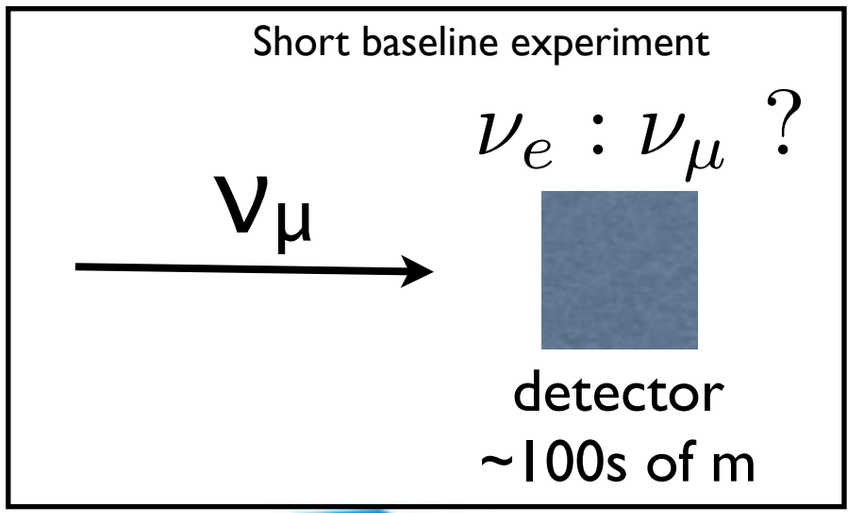
MicroBooNE

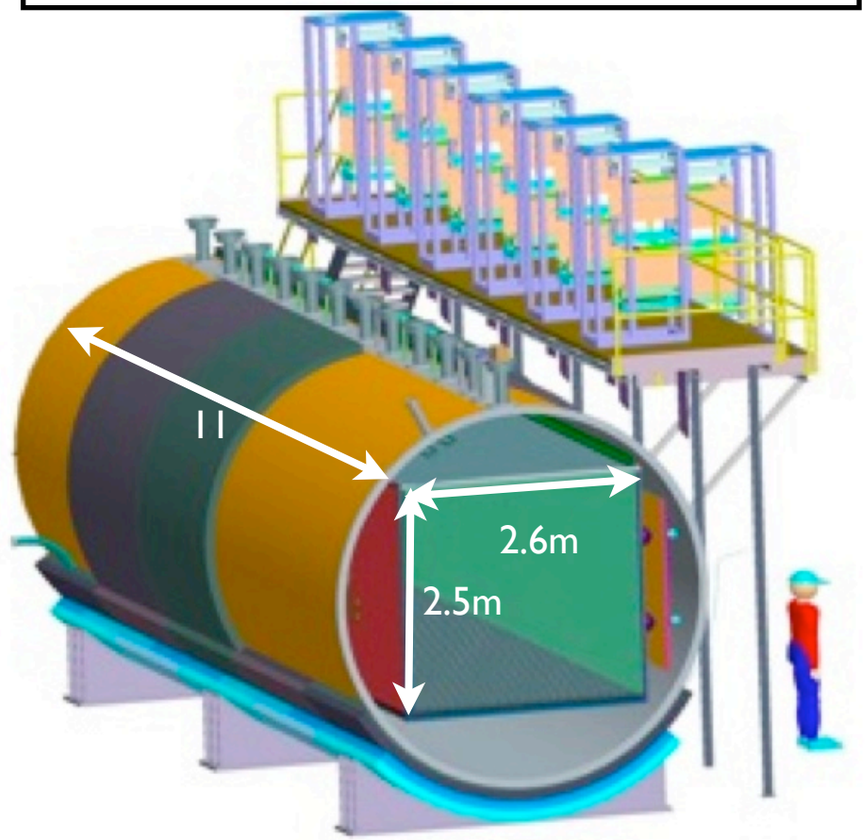
MicroBooNE

- MicroBooNE is a LArTPC-based experiment that will operate in the on-axis Booster neutrino beam and off-axis NuMI neutrino beam on the surface at Fermilab.
- Combines timely physics with hardware R&D necessary for the evolution of LArTPCs.
  - MiniBooNE low-energy excess
  - Low-Energy Cross-Sections
  - Cold Electronics
  - Long-drift operation (strict demands on LAr purity)

Cryostat Volume	150 Tons
TPC Volume	90 Tons
# Electronic Channels	~9000
Wire Pitch	3 mm
Electronics Style (Temp.)	JFET (120 K)
Max. Drift Length (Time)	2.5m (1.5ms)
Light Collection	~30 8" Hamamatsu PMTs

★Stage 1 approval from Fermilab directorate in June 2008
★CD-0 (Mission Need) in October 2009
★CD-1 July 2010
★CD-2/CD-3a (Fall 2010)
★Turn On (2012-2013)



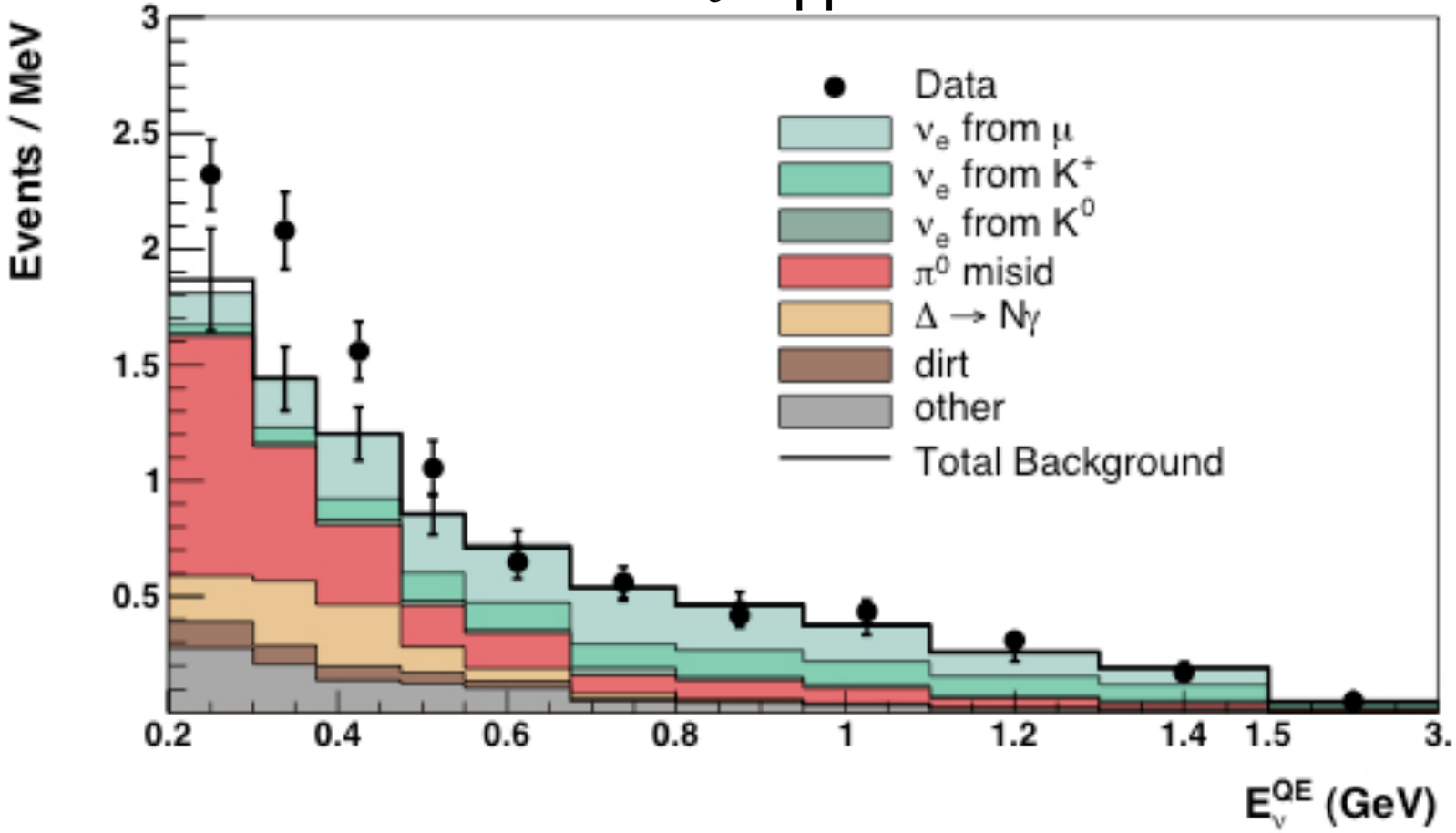


MicroBooNE Experiment

MicroBooNE: Physics Goals

- Address the MiniBooNE low energy excess
  - Does MicroBooNE confirm the excess?
  - Utilize dE/dx + topology to determine if it is an electron-like or gamma-like process
- Low Energy Cross-Section Measurements (CCQE, NC π^o, $\Delta \rightarrow N\gamma$, ...)
- Study processes relevant for proton-decay searches in a large LArTPC (PID, kaon decay)
- Fully implement automated reconstruction (building on ArgoNeuT's effort)

MiniBooNE ν_e Appearance Result



MiniBooNE Neutrino-Mode Excess

200-300MeV: 45.2±26.0 events

300-475MeV: 83.7±24.5 events

MicroBooNE will have >5σ significance for electron-like excess, >3.3σ for photon-like excess.

Refs:

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

The (near) future

- First ArgoNeuT results appearing in Fall/Winter 2010.
  - Muon reconstruction.
  - CCQE-like differential cross section and vertex activity analyses.
- ArgoNeuT Phase II
  - An upgraded ArgoNeuT is being proposed to go in the Booster Neutrino Beam (BNB; SciBooNE hall) at Fermilab in Fall/Winter 2010.
- MicroBooNE
  - A 90 ton active volume LArTPC in the BNB at Fermilab, to explore the MiniBooNE low-energy excess, measure precise ~1 GeV cross sections, and perform R&D for kton-scale LArTPCs, starting in 2012/13.
- All of this work is paving the way for a kton-scale LArTPC!

Thanks Paul!