The ArgoNeuT Experiment

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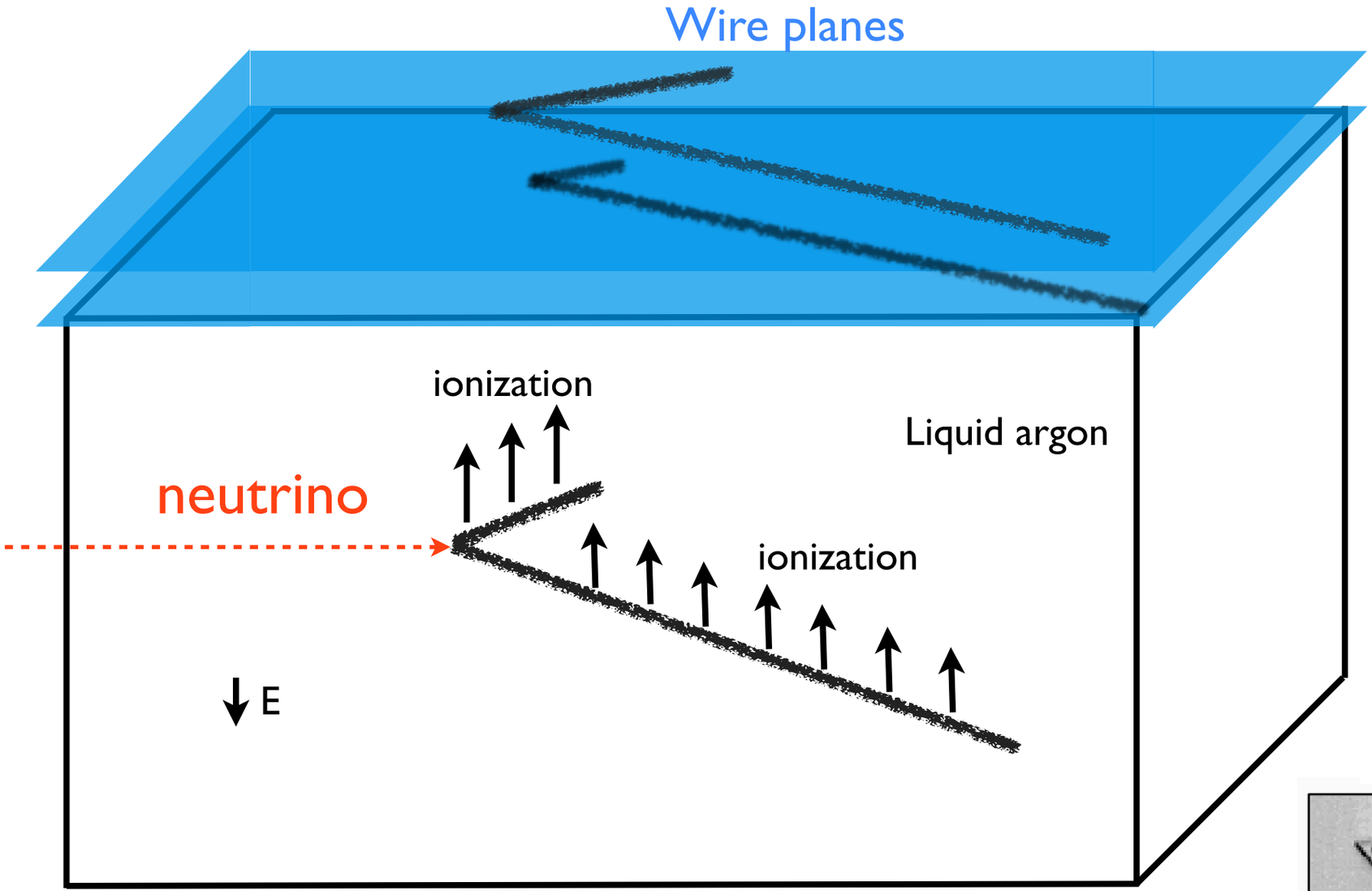
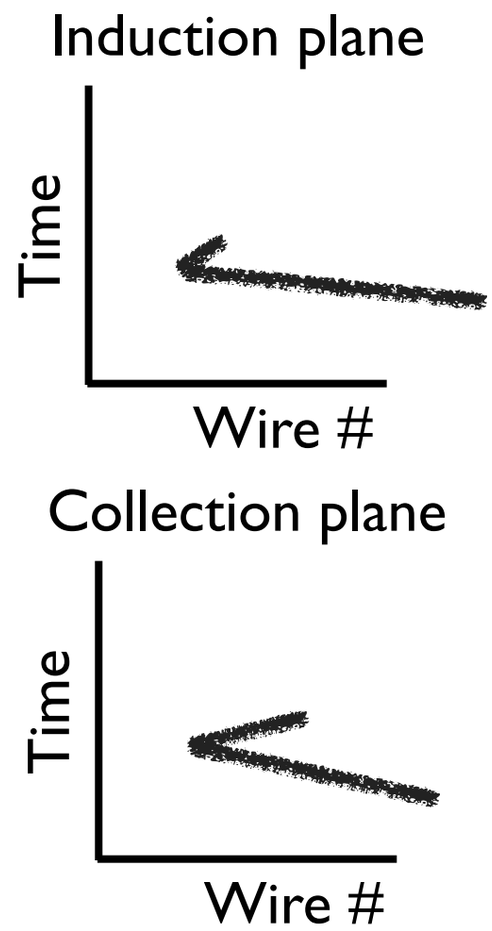
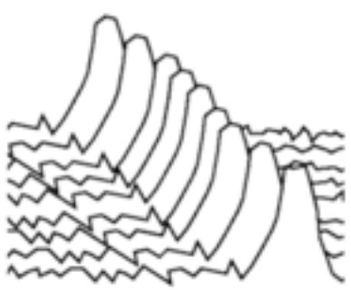
ICHEP 2010, 7/24/2010

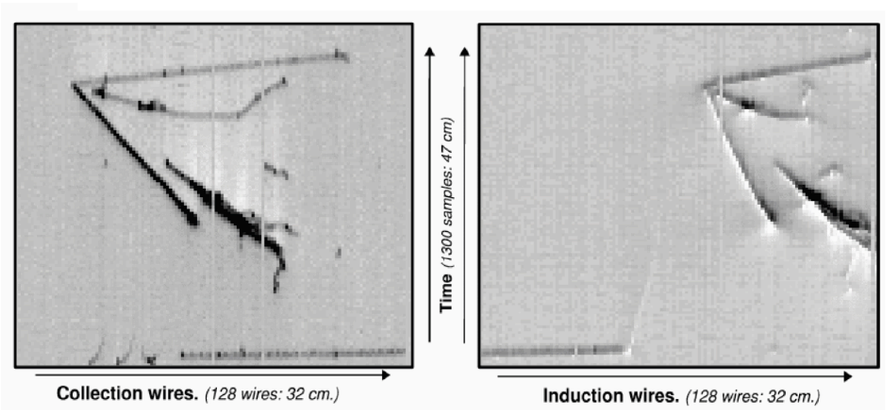
The LArTPC concept







Wire pulses in time give the drift coordinate of the track



ICARUS 50 L in WANF neutrino beam

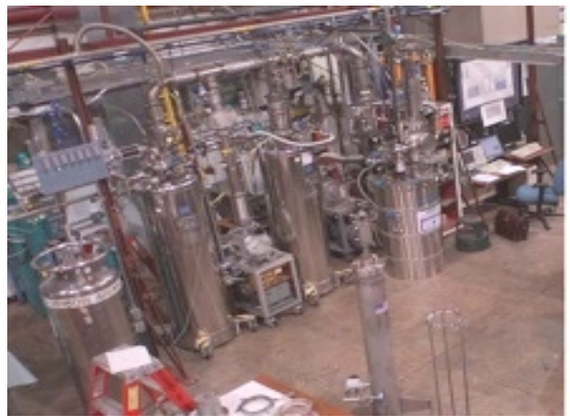
induction plane + collection plane + time = 3D image of event (w/ calorimetric info)

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**

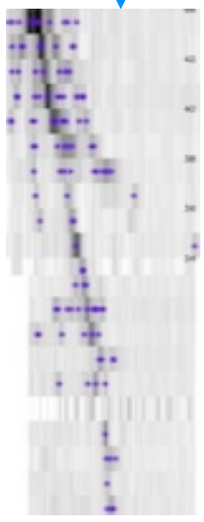
Materials Test Stand



Electronics Test Stand

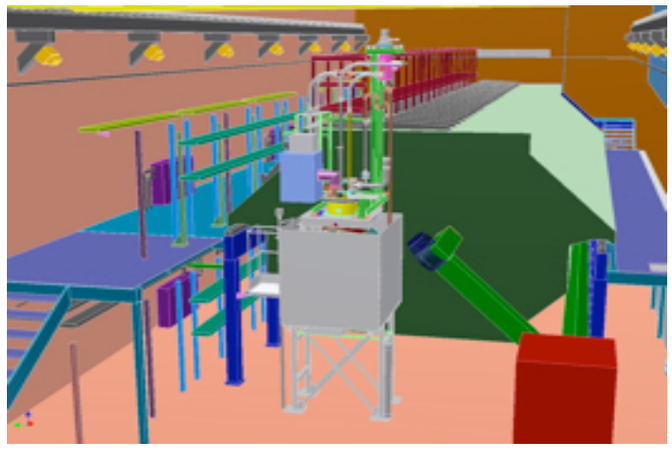
2007 100% R&D

2007-



Yale Tracks
Joshua Spitz, Yale University

2008-

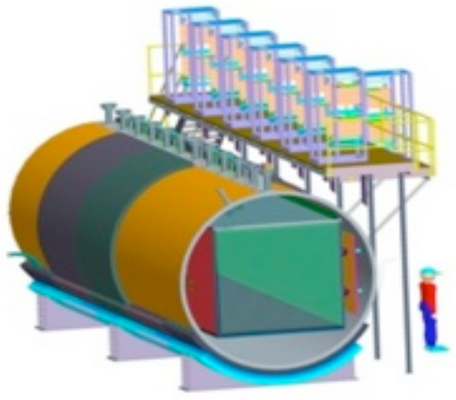


ArgoNeuT
Cross sections

2010-

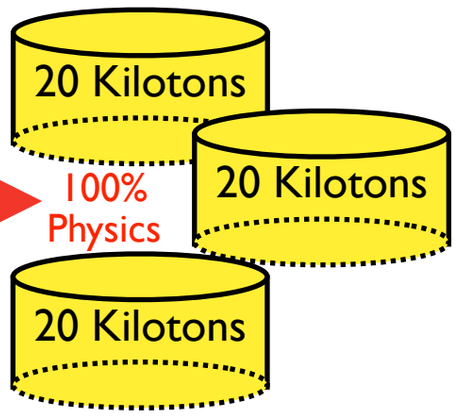
LAr Purity Demonstrator

2013-



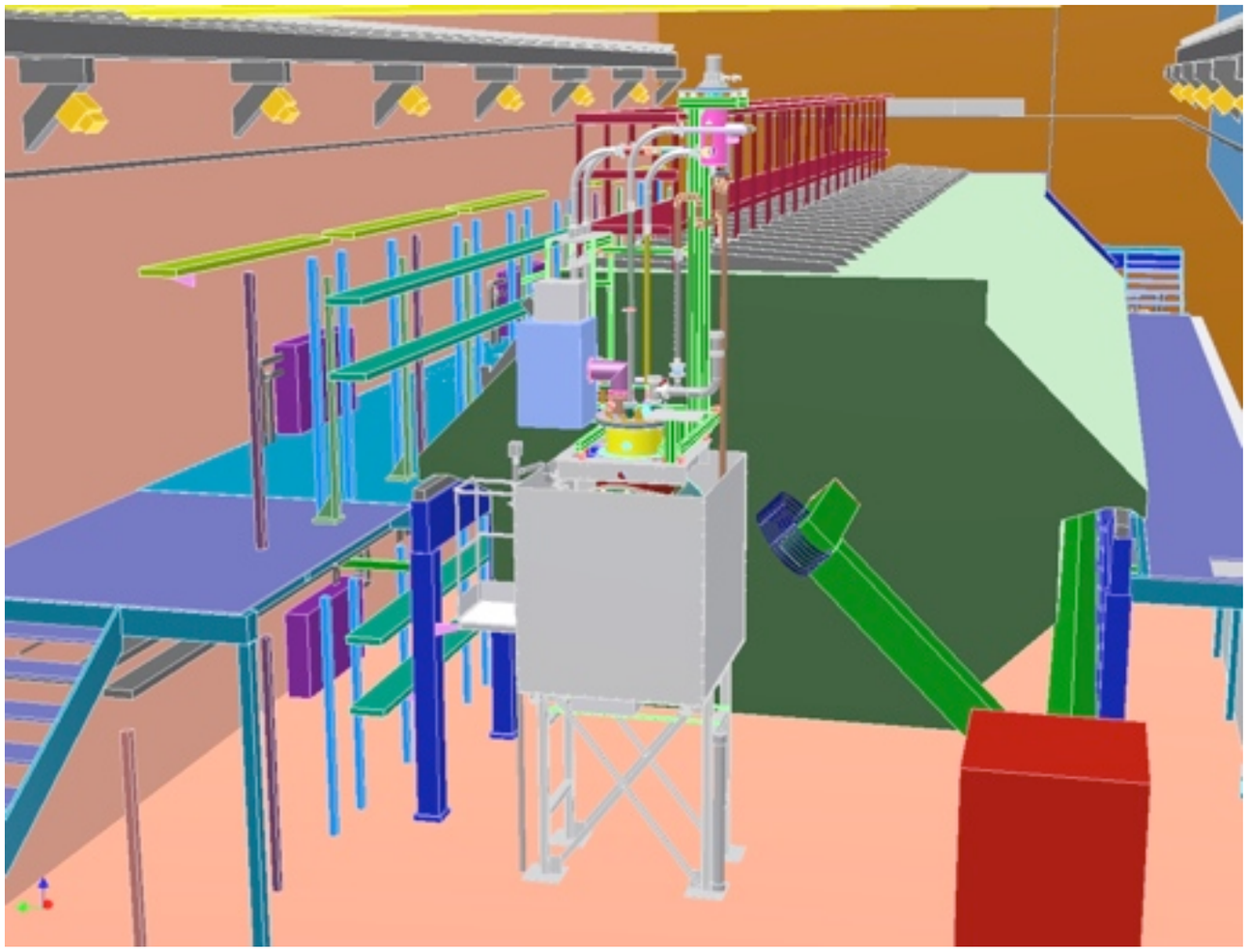
MicroBooNE
Cross sections
MiniBooNE anomalies

20??

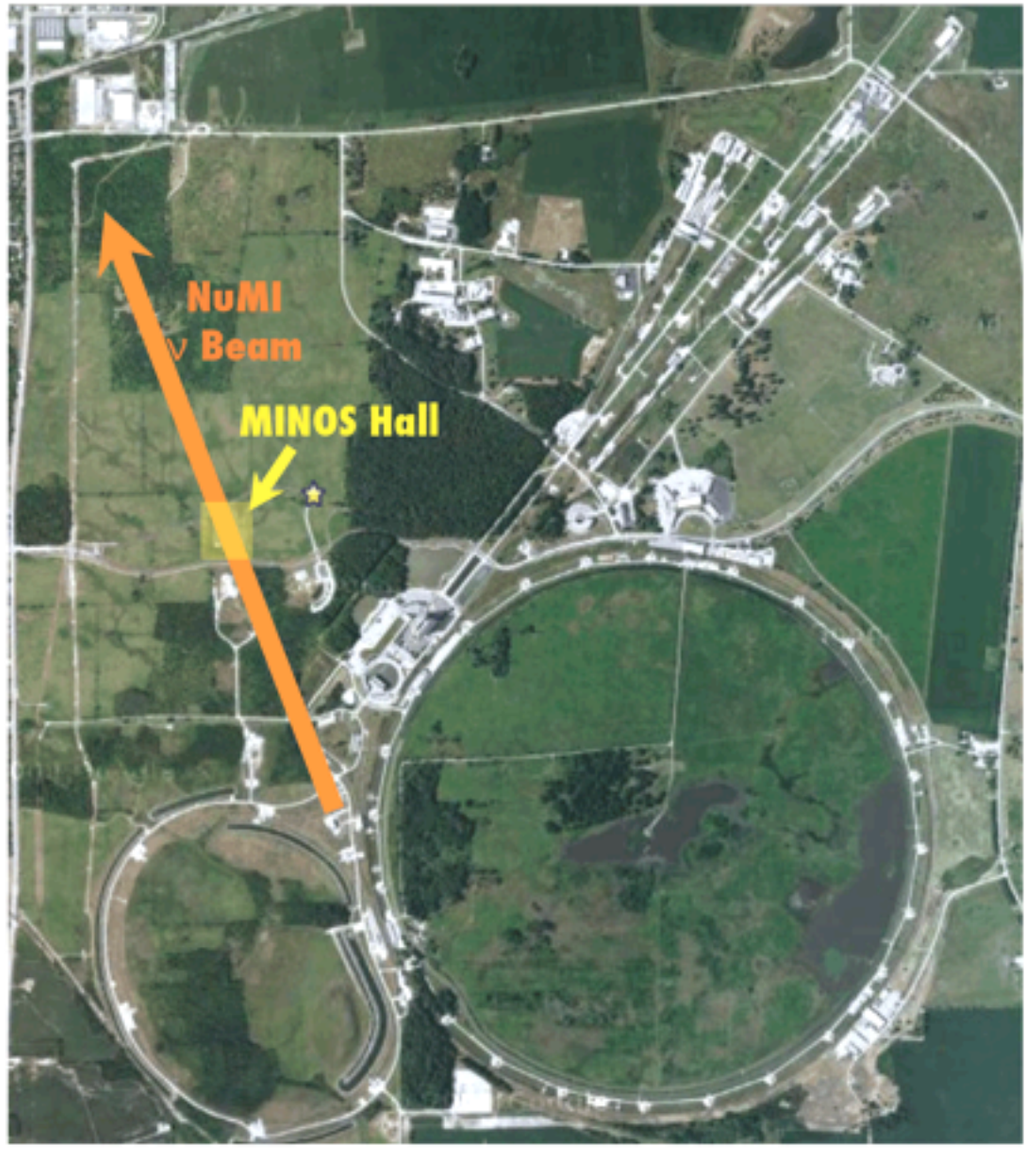


LBNE
Proton decay
θ_{13} and δ_{CP}
Supernova burst
Supernova relic
Geo-neutrinos
Atmospheric ν_τ app.
Atmospheric ν_μ disapp.
...

ArgoNeuT in the NuMI beam

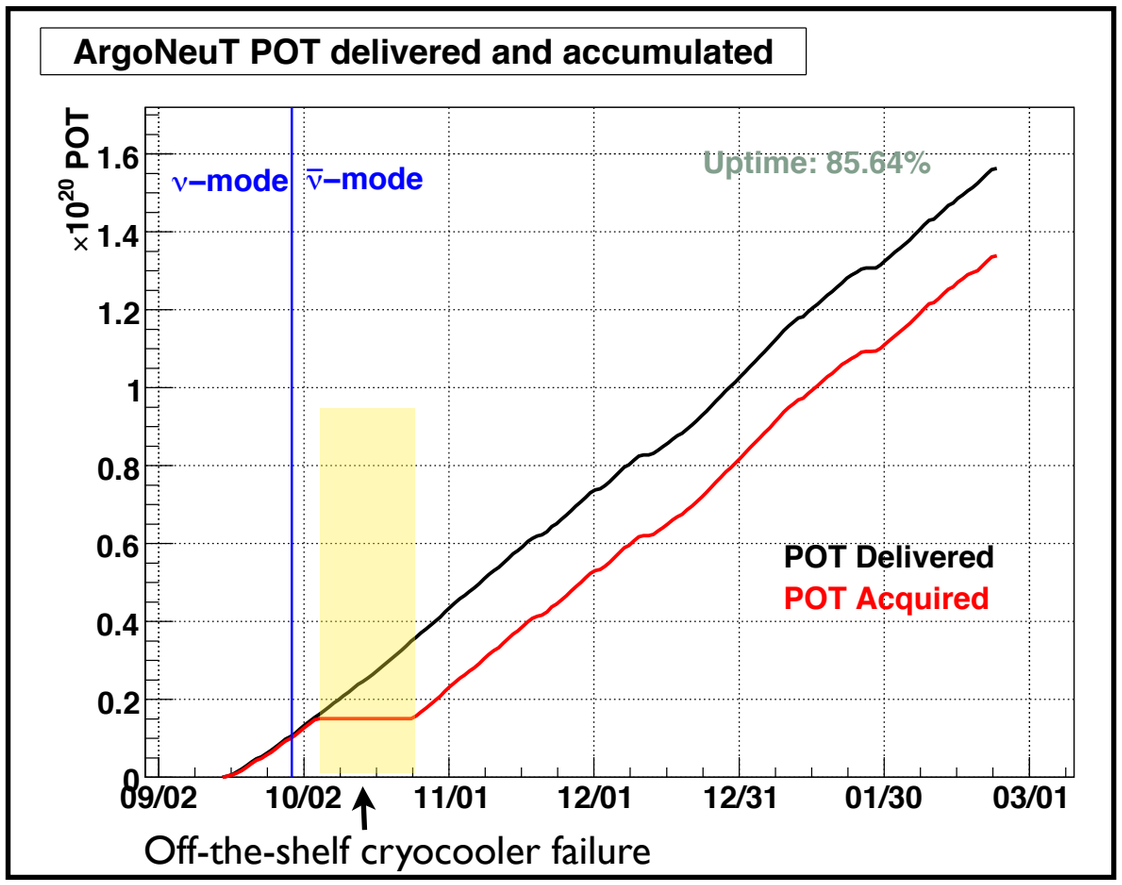


ArgoNeuT, just upstream of the MINOS near detector



NuMI beamline at Fermilab

ArgoNeuT's physics run

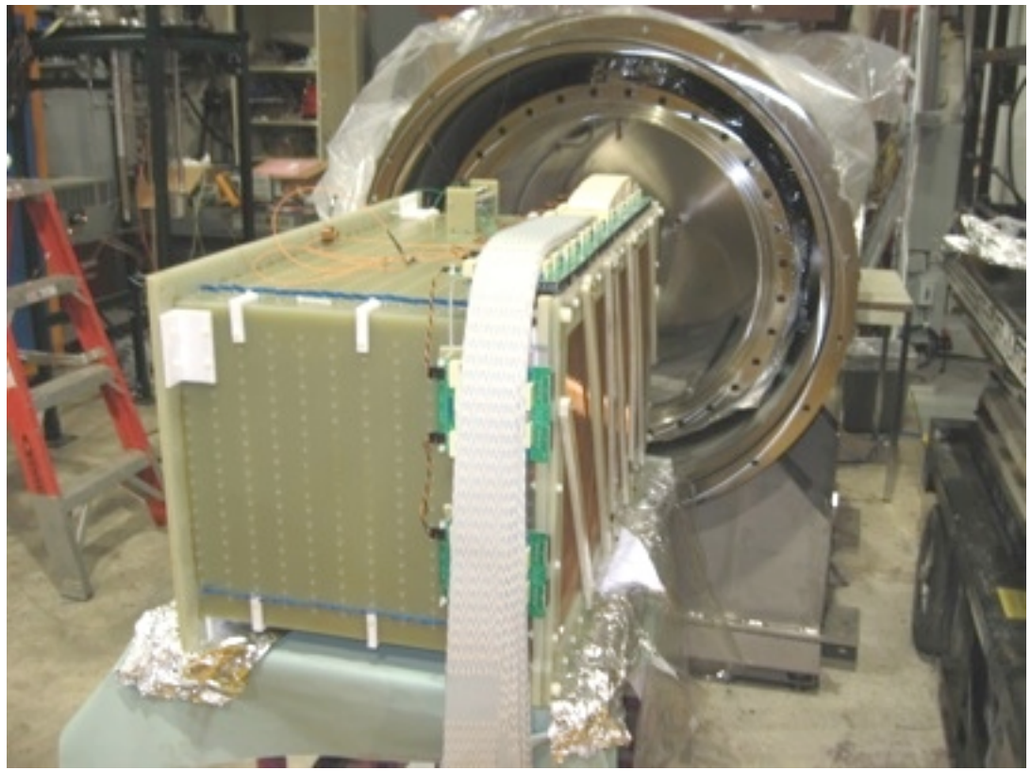


- ArgoNeuT (NSF/DOE) recently completed its phase I physics run, lasting from 9/14/2009-2/22/2010.
- Goals:
  - Multiple neutrino cross section and vertex activity characterization measurements.
    - I will focus on the "CCQE-like" cross section and vertex activity analyses in this talk.
  - dE/dx particle 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

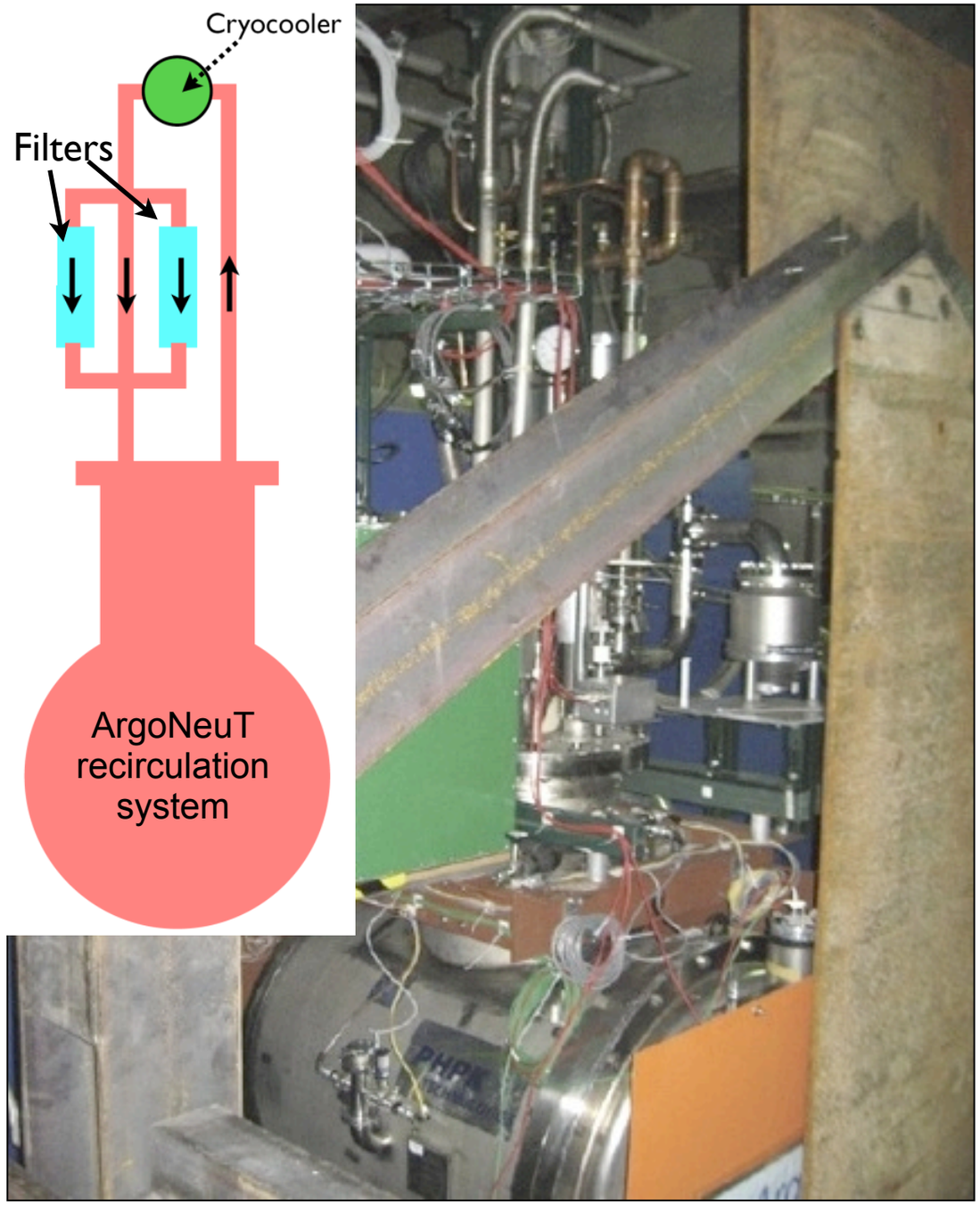
- Stable, shift-free operation for >5 months!
- The first 1000s of (anti-)neutrino LArTPC events collected in a low-energy (~3 GeV) neutrino beam ever!

The TPC and cryostat



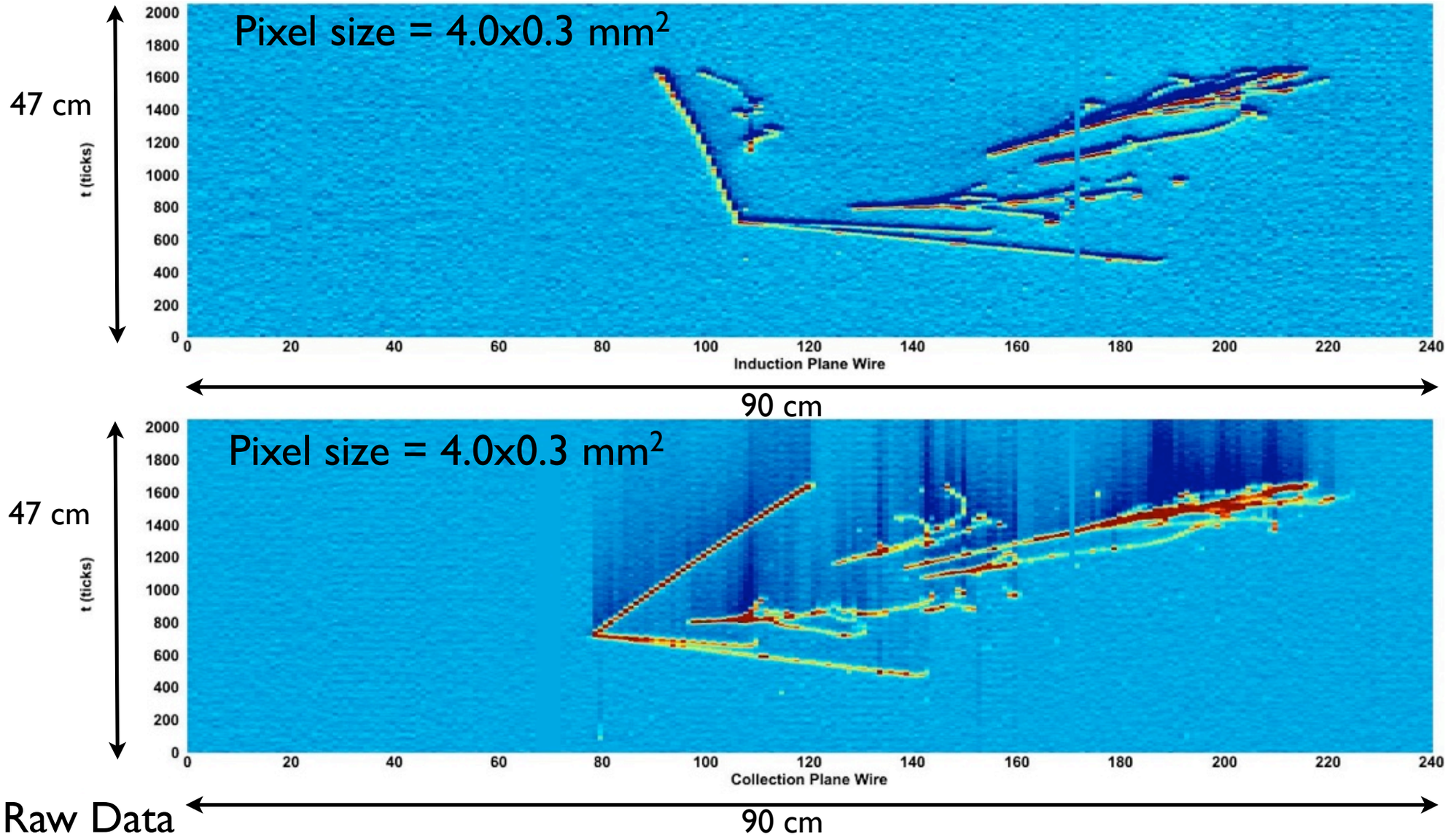
The TPC, about to enter the inner cryostat

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

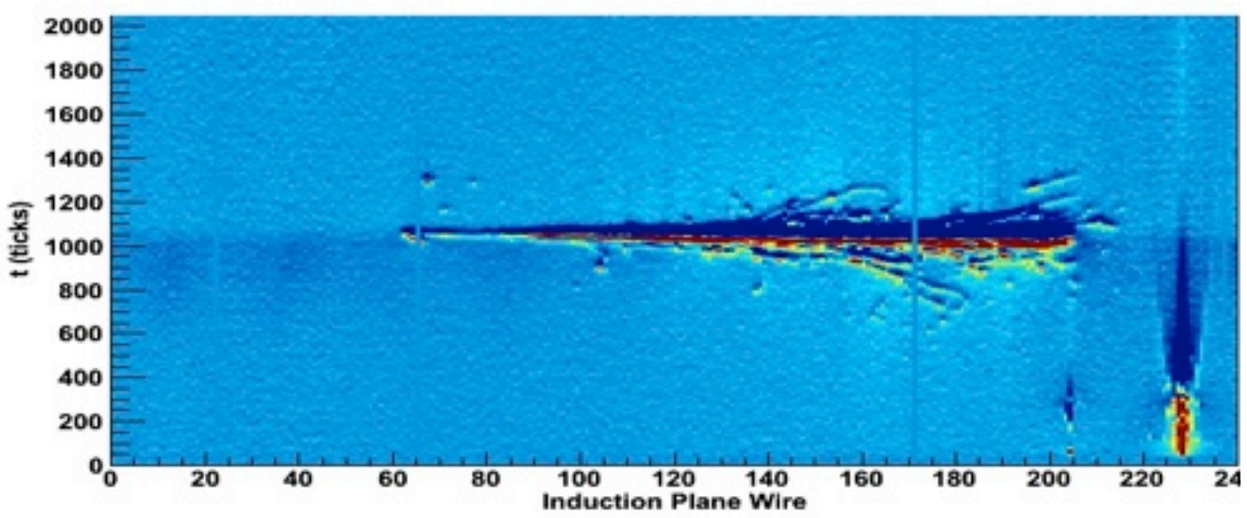
Neutrino event

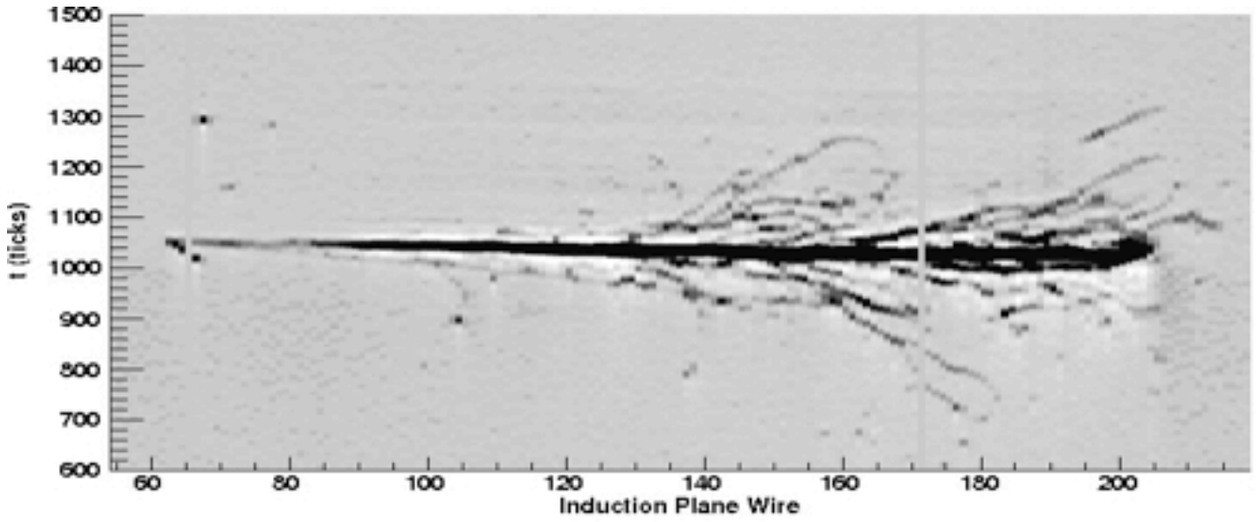


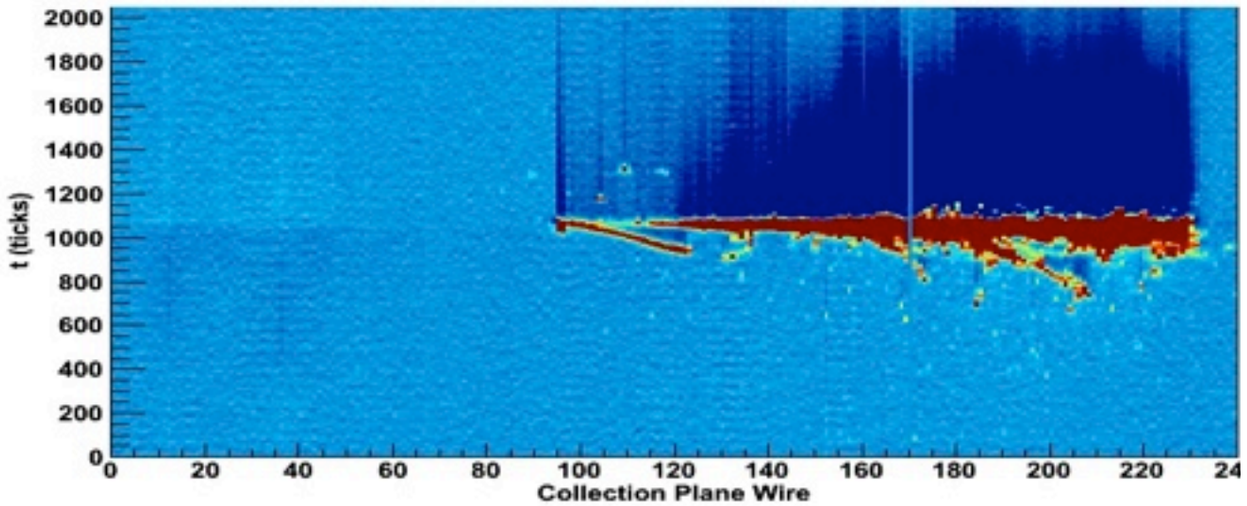
A charged current neutrino DIS event with two pi0 decays.

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

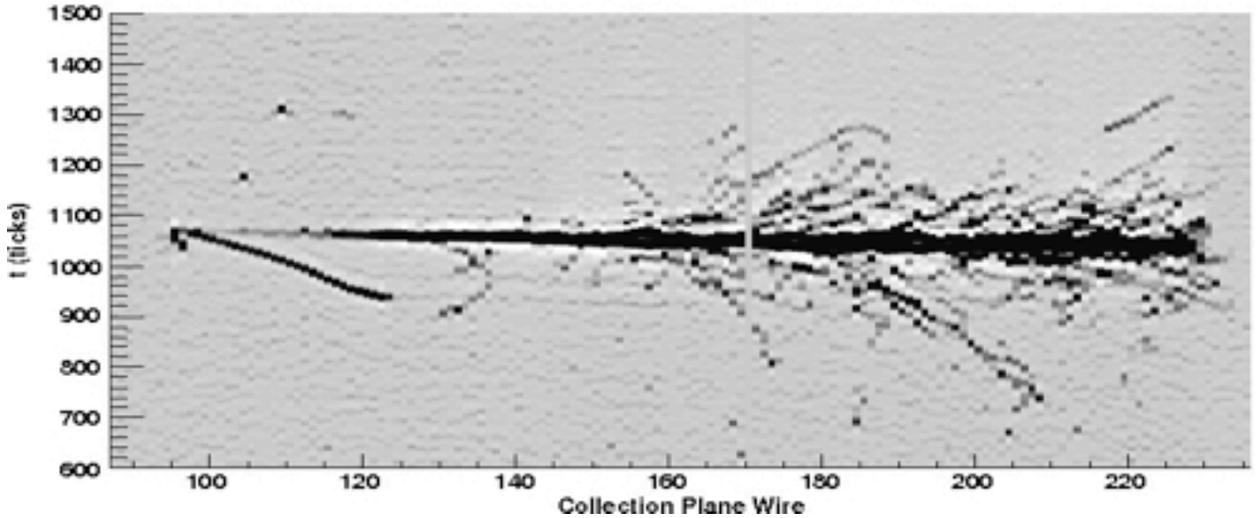
An electron-neutrino







Raw Data

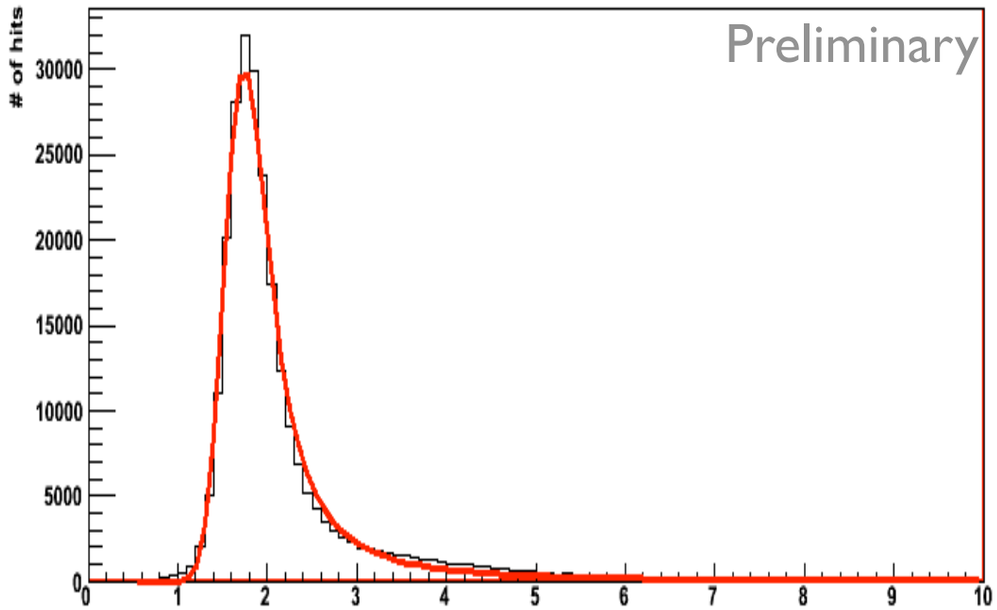


Deconvoluted Data

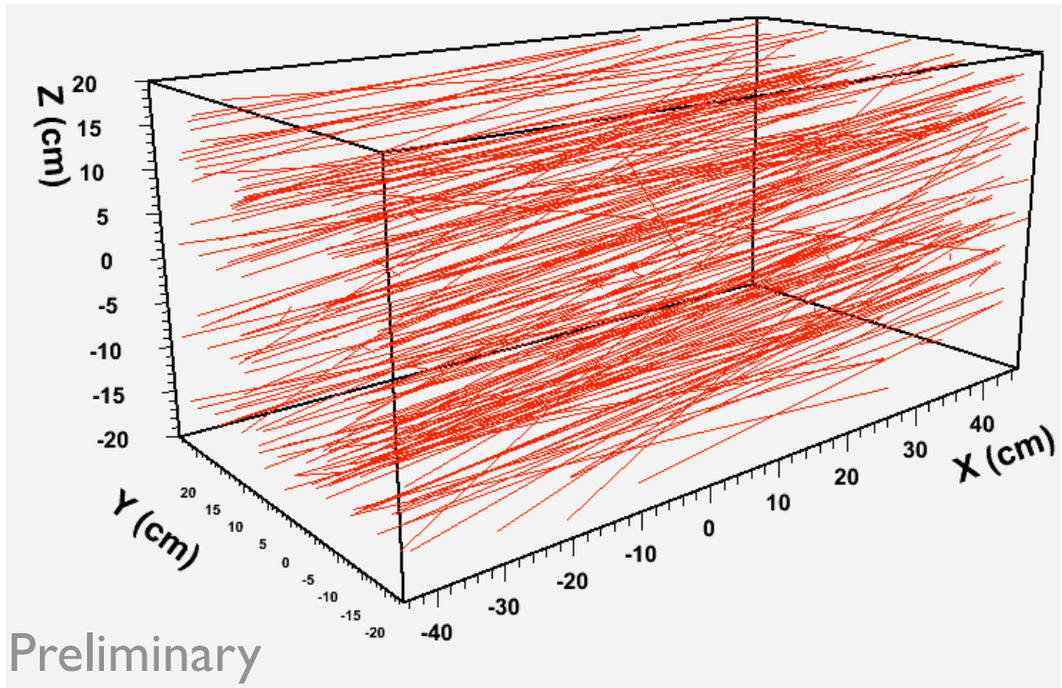
- This (beam-intrinsic) event demonstrates what a signal-like electron-neutrino event looks like to an LArTPC.
- Current and future long baseline neutrino oscillation experiments (MINOS, T2K, NoVA, LBNE, ...) search for electron-neutrino appearance in order to measure θ_{13} and δ_{CP}.

Automated reconstruction of muons

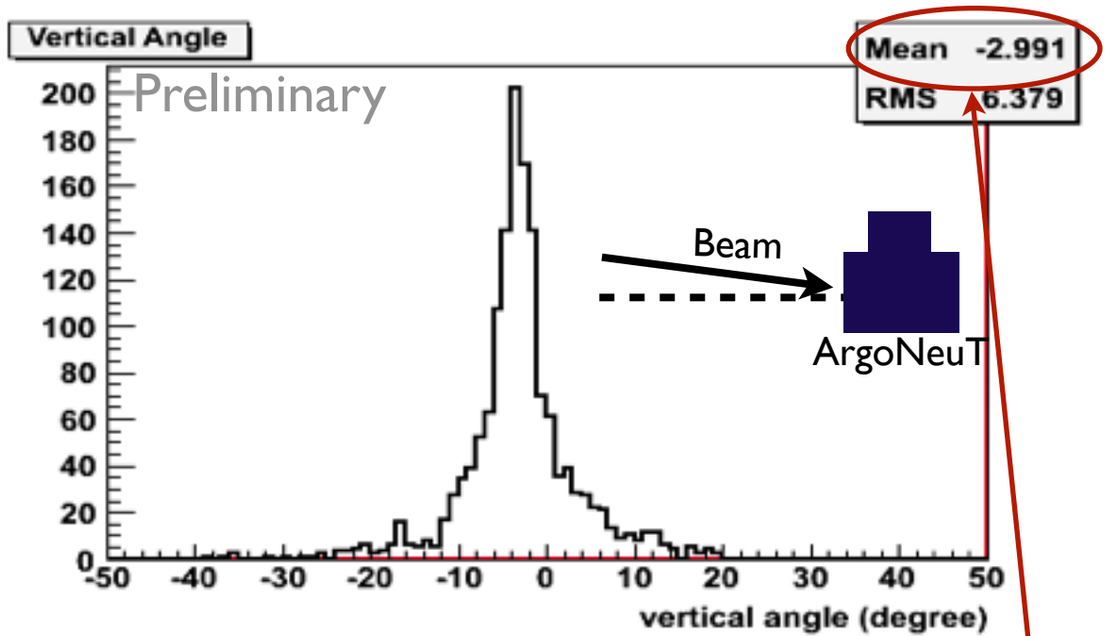
- The first step in ArgoNeuT's neutrino reconstruction algorithm is to reconstruct the muon.
- Along with calorimetry and tracking within the ArgoNeuT TPC, we are also working on matching tracks with the downstream MINOS near detector.



Muon calorimetry (dE/dx)



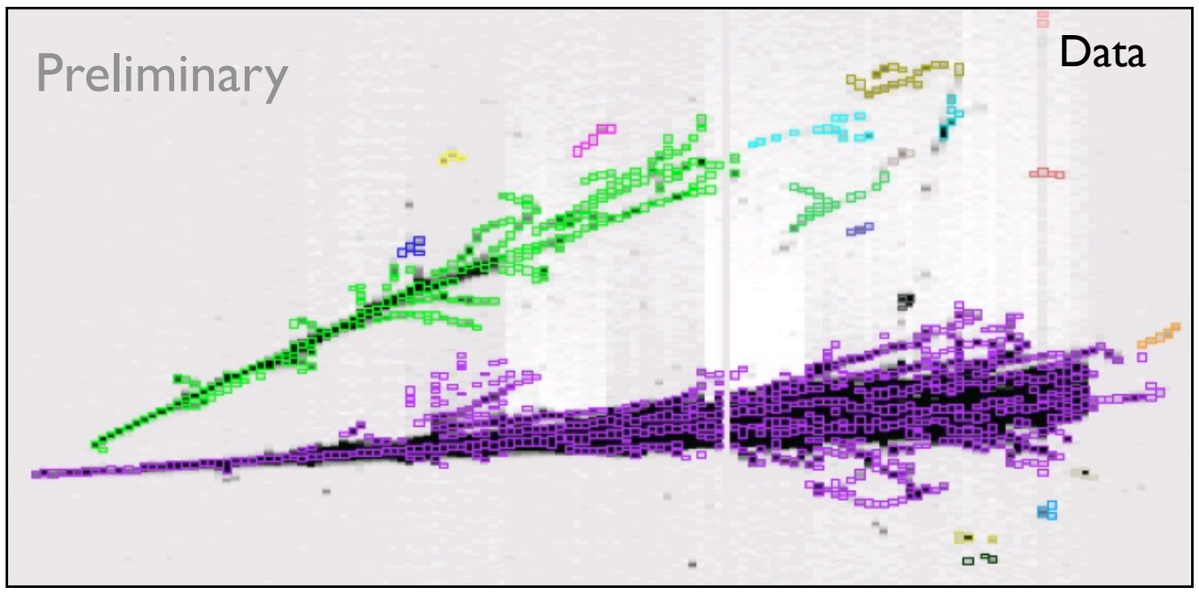
3D-reconstruction of muons



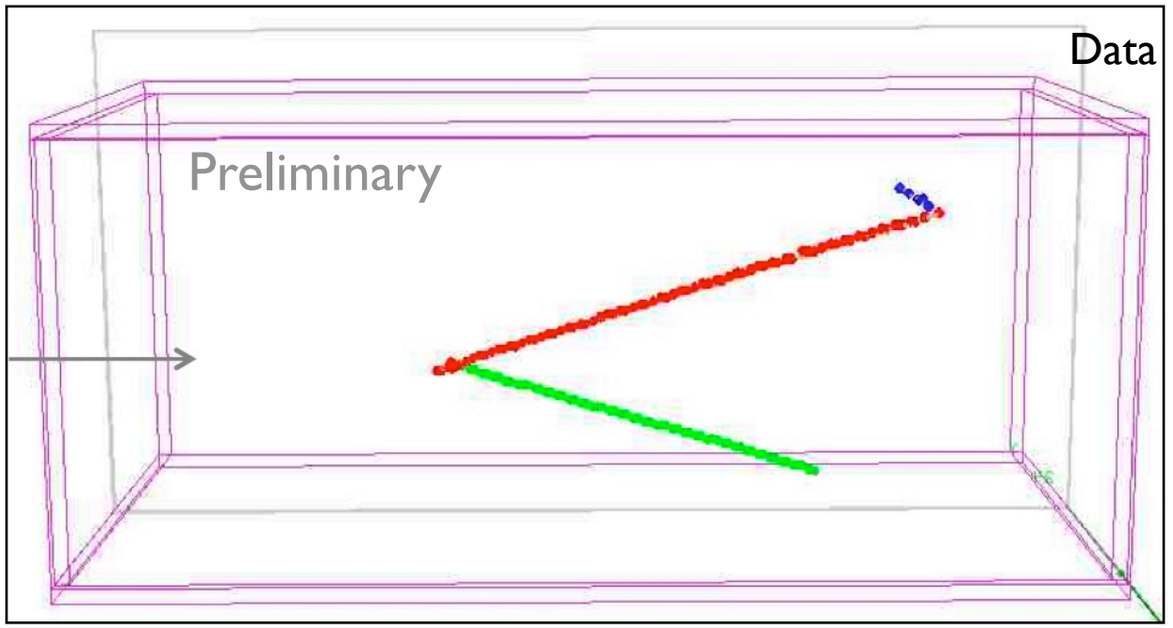
Angular distribution of muons (NuMI beam is at 3°)

Reconstructing neutrino events

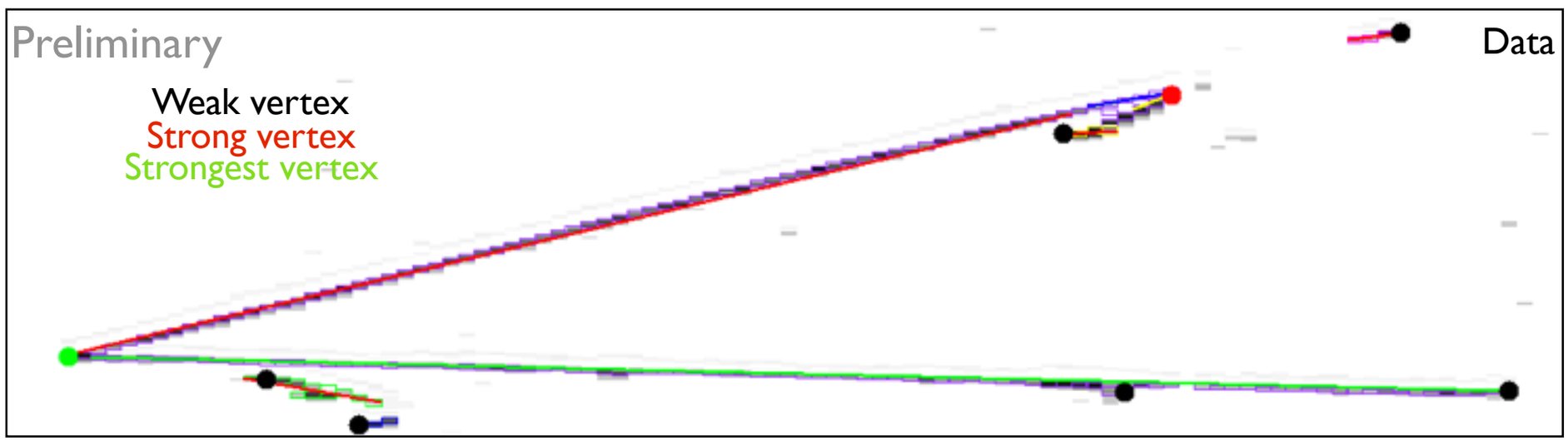
- ArgoNeuT has created an automated reconstruction framework currently capable of hit finding, calorimetry, cluster/line/vertex-finding, track fitting and 3D track matching.



Hit finding + density-based clustering.



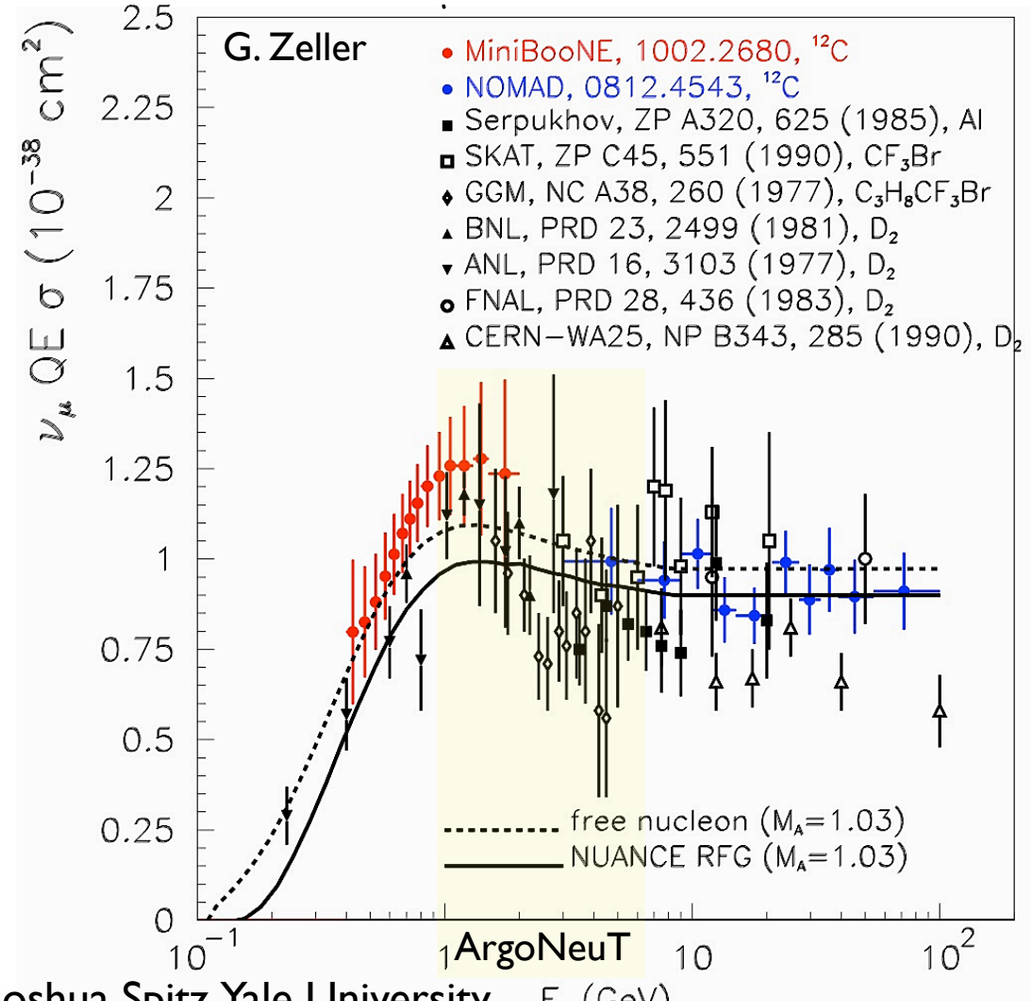
3D reconstruction



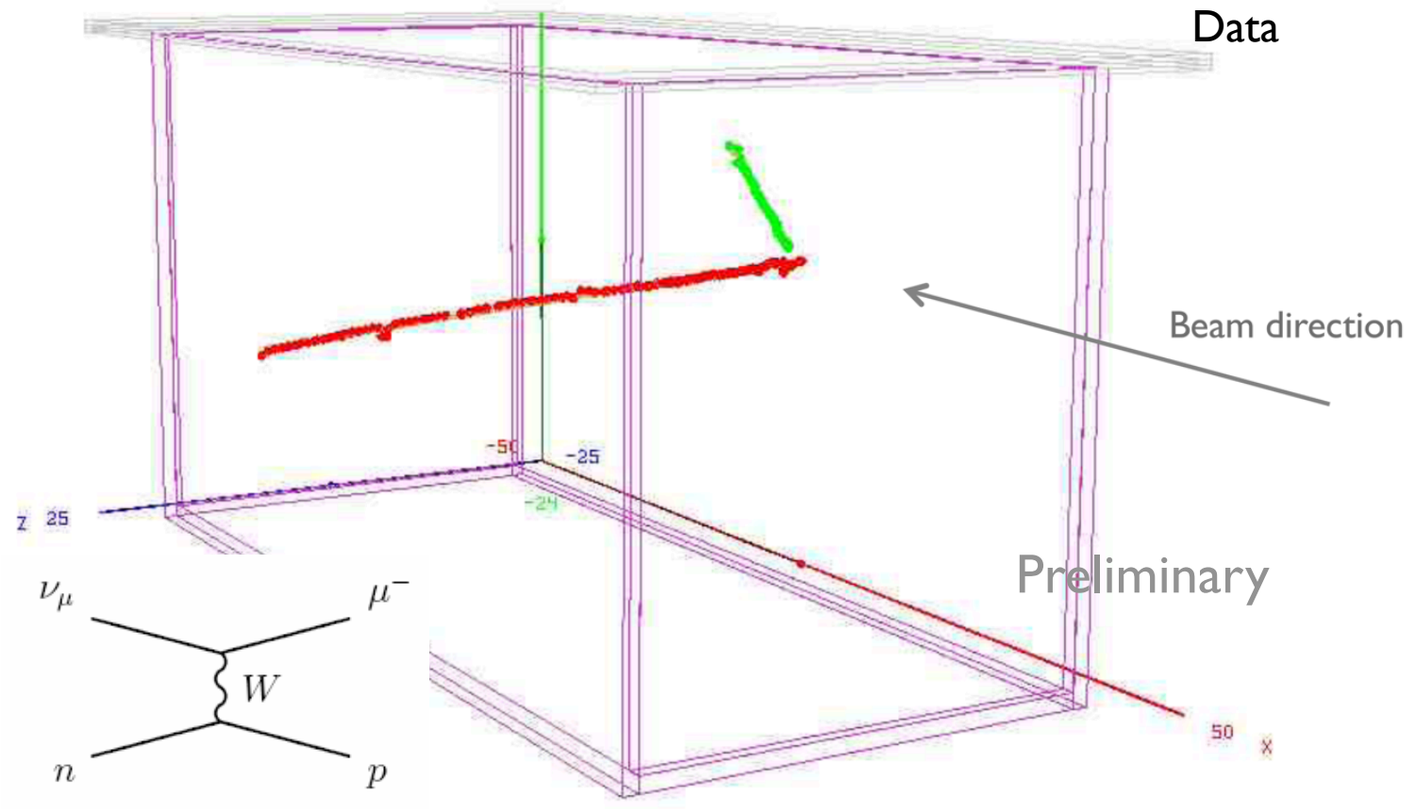
Line finding/fitting + vertex/endpoint finding

Addressing the CCQE puzzle

- The CCQE interaction is 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.
  - Both detectors are unable to fully resolve the "vertex activity" (protons) associated with CCQE events.
- The discrepancy may be due to a CCQE multinucleon channel in which two correlated same-flavor nucleons are ejected (e.g. $\nu_\mu n \rightarrow \mu^- pp$).
- 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.

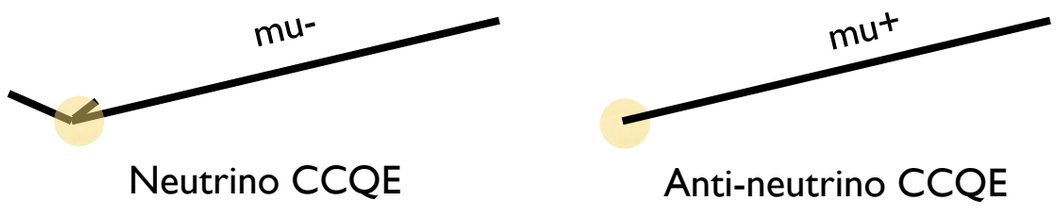


A CCQE-candidate event reconstructed in 3D

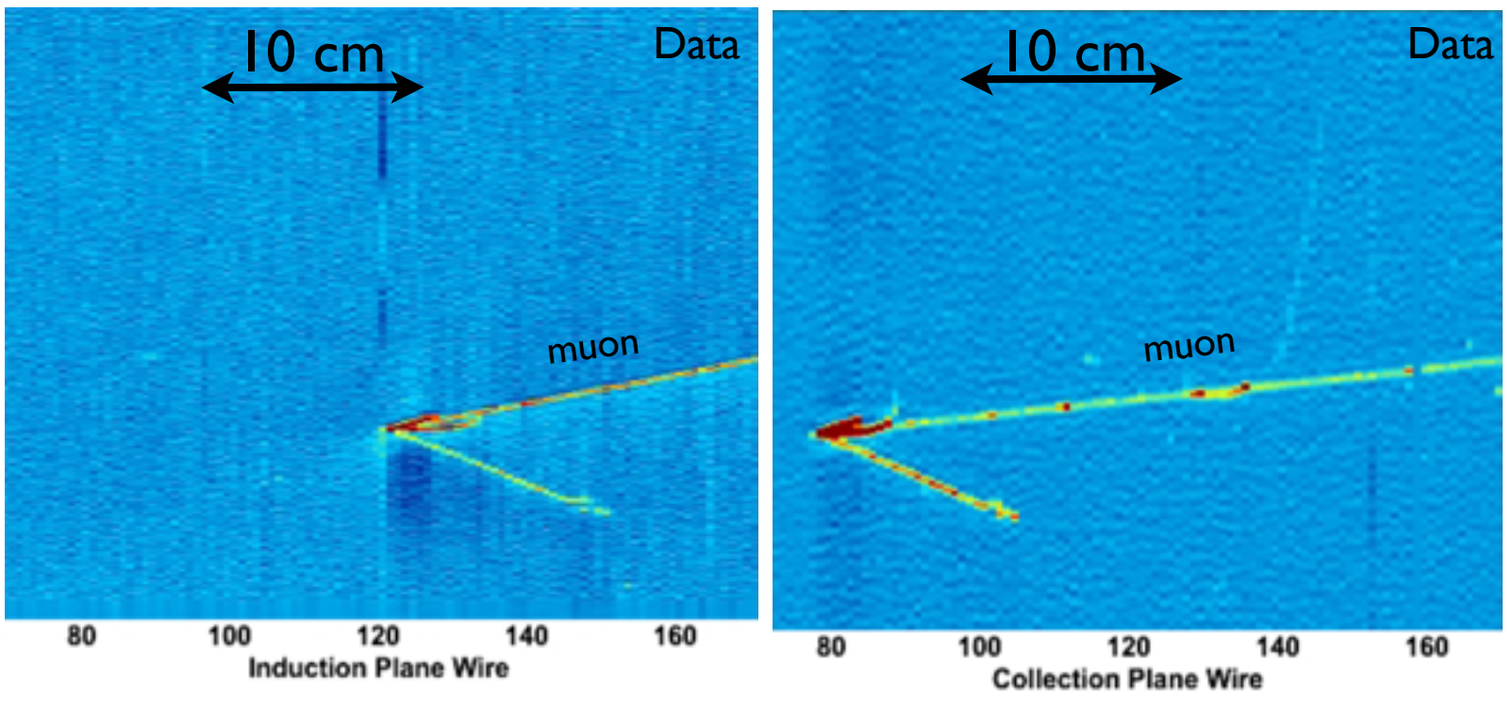


Understanding vertex activity

- Not only is ArgoNeuT able to characterize vertex activity in CCQE-like events, it can also differentiate neutrinos from anti-neutrinos with the help of the MINOS near detector.
- Comparing neutrino and anti-neutrino CCQE-like events may provide some sensitivity to the multinucleon channel, involving 2p (2n) pre-FSI final states for neutrino (anti-neutrino) events.
  - Variables to consider:
    - Backward going and/or high momentum protons.
    - Number of protons exiting vertex.
    - Vertex energy deposition.



Neutrino CCQE Anti-neutrino CCQE



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

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.

The international collaboration

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Phase II

Backup slides

NOMAD and MiniBooNE vertex activity

NOMAD does consider nucleons in their CCQE cross section analysis. However, their energy threshold for proton reconstruction is ~300 MeV.

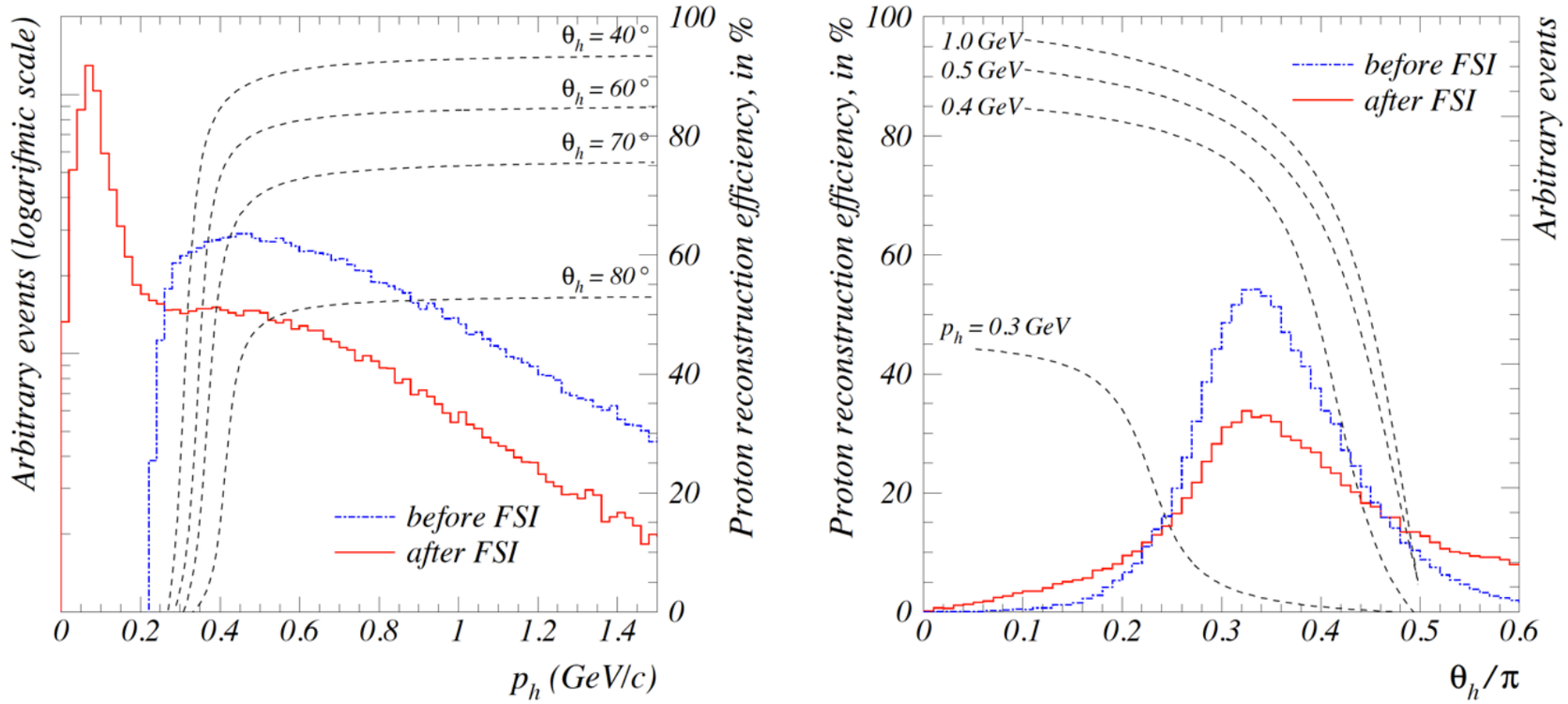
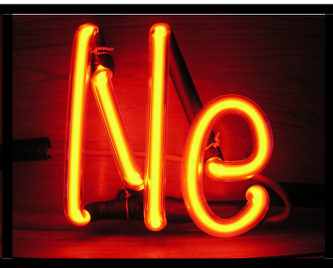
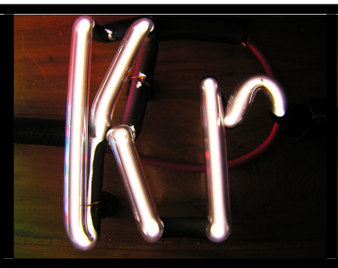


Fig. 6. Distribution of the leading proton momentum (left) and emission angle (right) before (dash-dotted line) and after (solid line) FSI simulation. Dashed lines show the proton reconstruction efficiency as function of the proton momentum and emission angle (for $\pi < \varphi_h < 2\pi$).

- MiniBooNE does not consider nucleons in their CCQE cross section analysis.

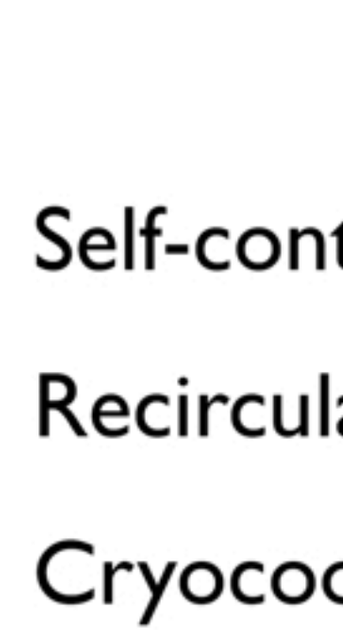
Why argon?

						
	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	

Expensive

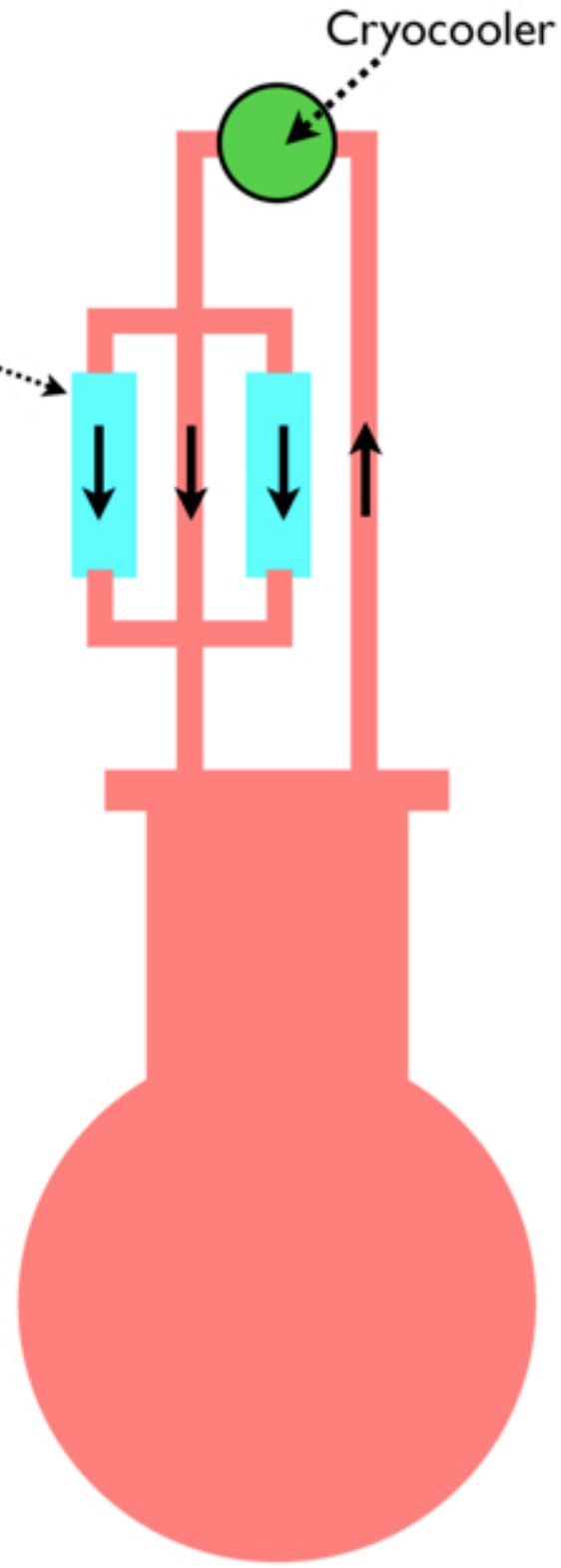
Cryo-system

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



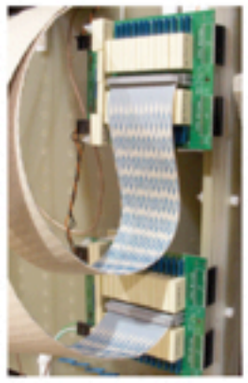
300W Cryocooler

Vacuum-Jacketed Cryostat

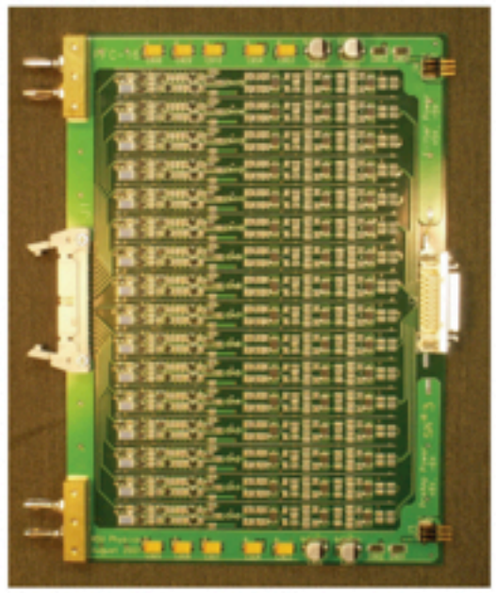


Electronics

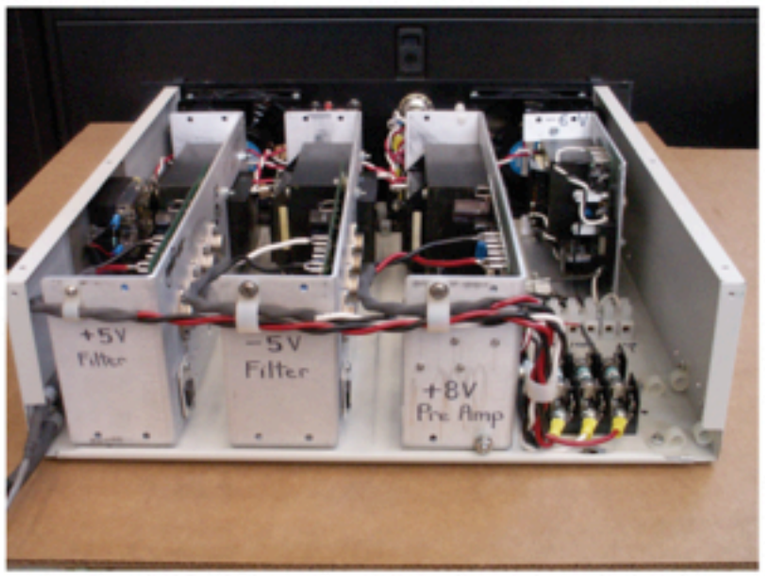
- Electronics for ArgoNeuT (480 channels)
  - Bias voltage distribution & blocking on the TPC
  - FET preamplifier similar to D0/ICARUS front-end
  - Wide bandwidth filtering (10 - 200 kHz, now)
    - Full information on most hits/tracks
    - Employ DSP to extract hit/track parameters
  - ADF2 card, sample at 5 MHz (*i.e.*- 198 ns/sample), 2048 samples/channel
  - Minimize noise sources
    - Double shielding of feed-through and preamplifiers
    - Remote ducted cooling
    - Extensive DC power filtering



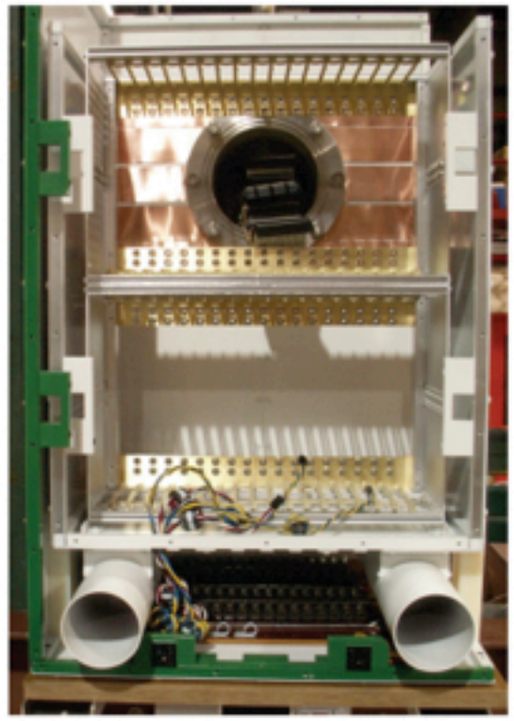
Bias Voltage R & C



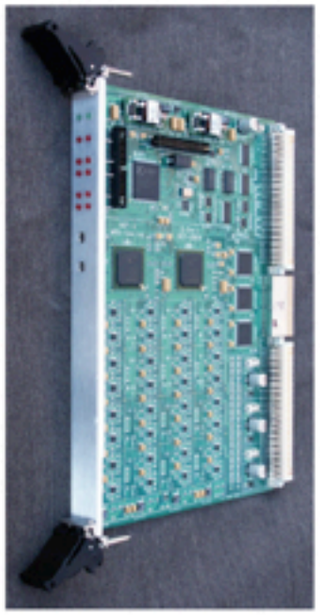
Preamp & filters



Custom power supply

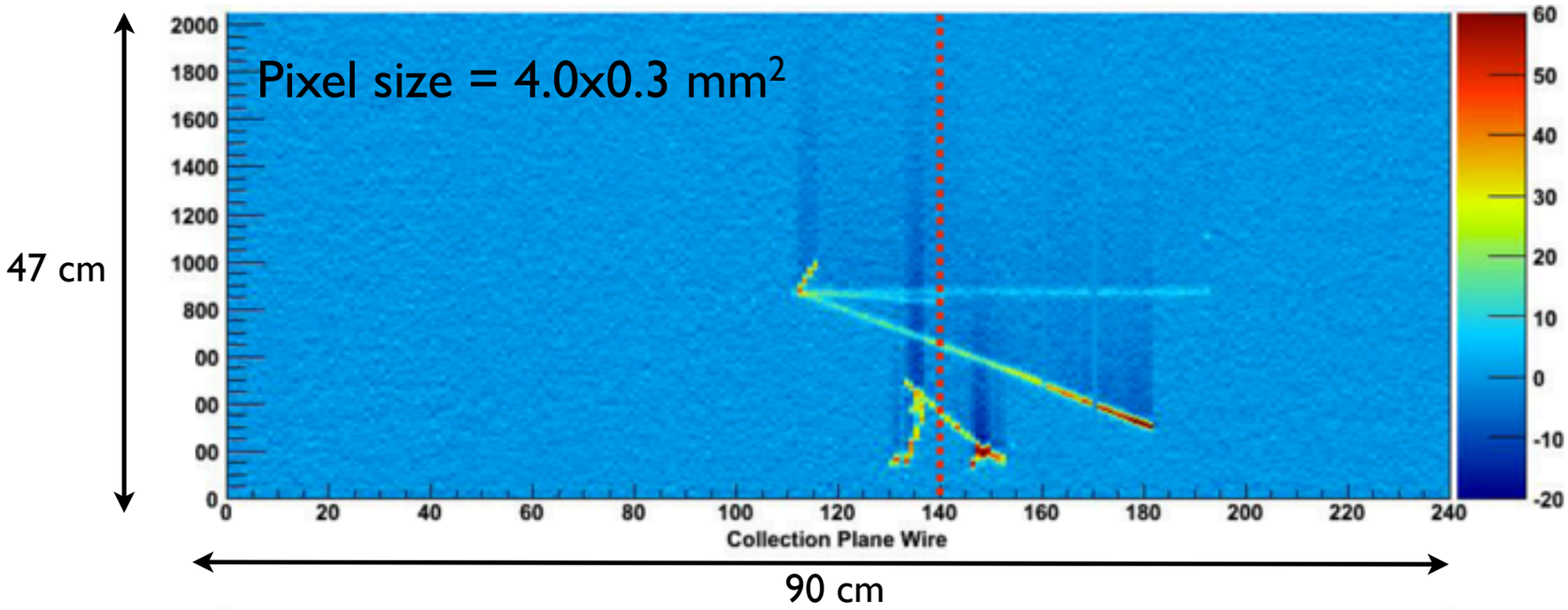


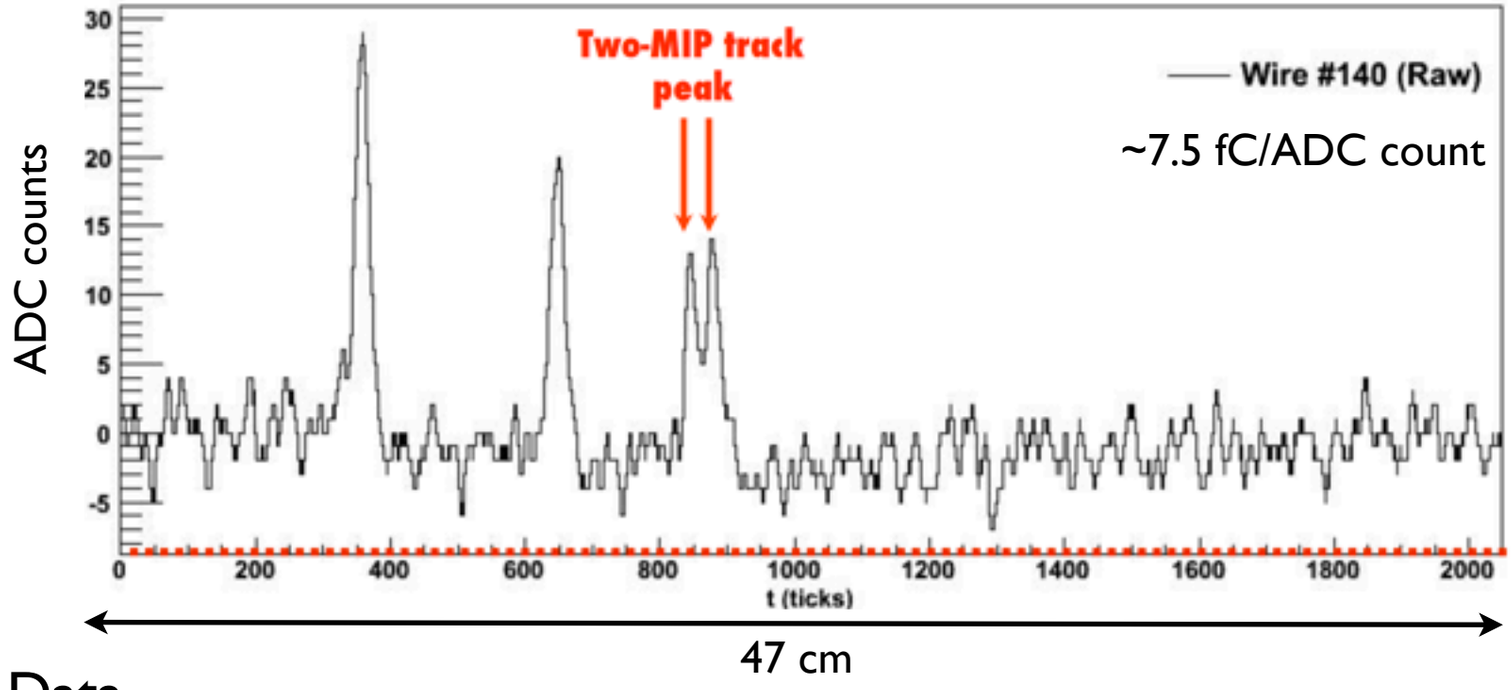
RF shielding & preamp cooling



ADF2

Wire pulses





Raw Data

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