ArgoNeuT

DPF 2009

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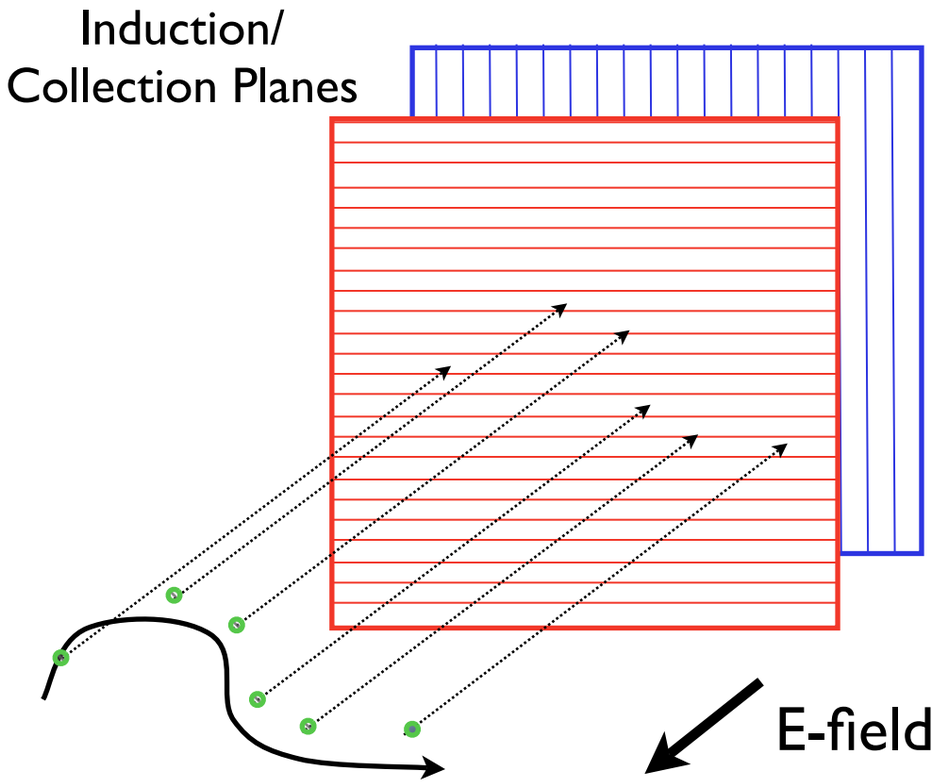
LArTPC Principal

TPC = Time Projection Chamber

- Neutrino interactions inside a TPC* produce ionization particles
- Ionization drifts along electric field lines towards wireplanes, which are connected to low-noise charge amplifiers and fast ADCs.
- Location of wires within a plane provide position measurements...timing of pulse information needed to determine drift coordinate.
- Multiple non-destructive wireplanes can be utilized, providing independent position measurements needed for full 3-D reconstruction.
- Knowledge of drift speed, and T_0 of events, used to project back along drift direction to particle's origin.
- Scintillation light also present, can be collected by Photomultiplier Tubes and used in triggering.



Refs:

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

Wireplanes

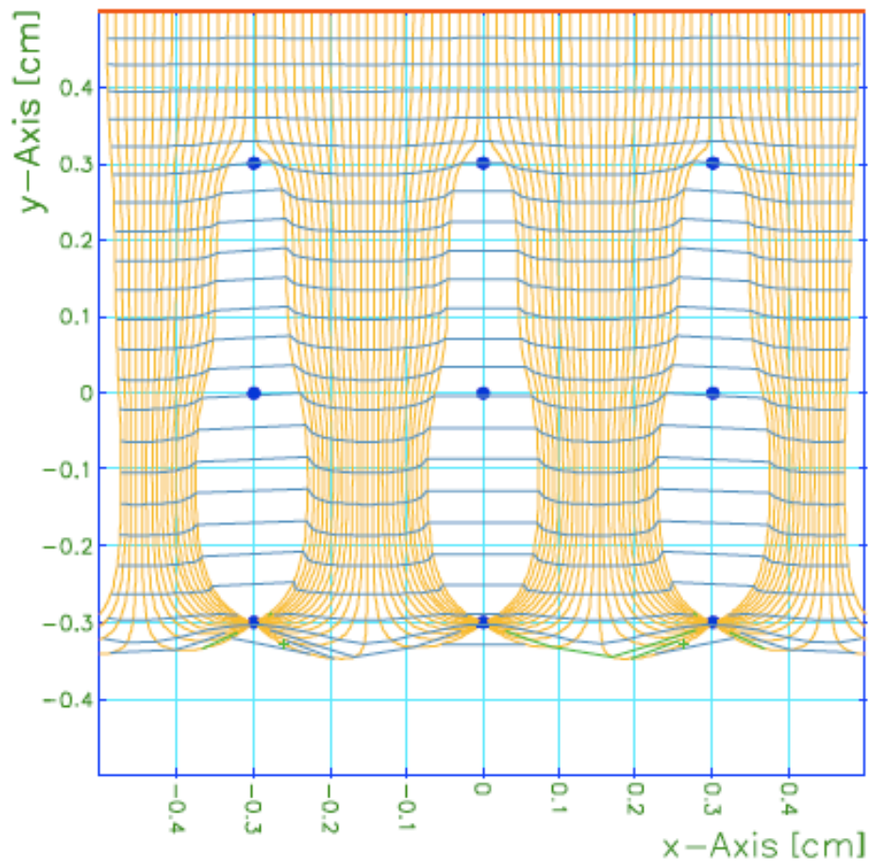
- TPC wireplanes act as an electrostatic grid*.
- Transparency is a function of wire geometry and electric fields before/after each plane.
  - Transparency + Multiple wireplanes = complimentary position measurements of same particle.
- Choose bias voltages to keep constant drift field up to first induction plane, then choose for maximum transparency between planes.
- Shielding effect of grid helps shape pulses.

$$\frac{E_2}{E_1} \geq \frac{1+\rho}{1-\rho}$$

100% Transparency Condition

$$\rho = \frac{2\pi r}{d}$$

r = wire radius
d = wire pitch



Refs:
*.) *Design of Grid Ionization Chambers*, O. Bunemann, T.E. Cranshaw, and J.A. Harvey; *Canadian Journal of Research*, 27, 191-206, (1949)

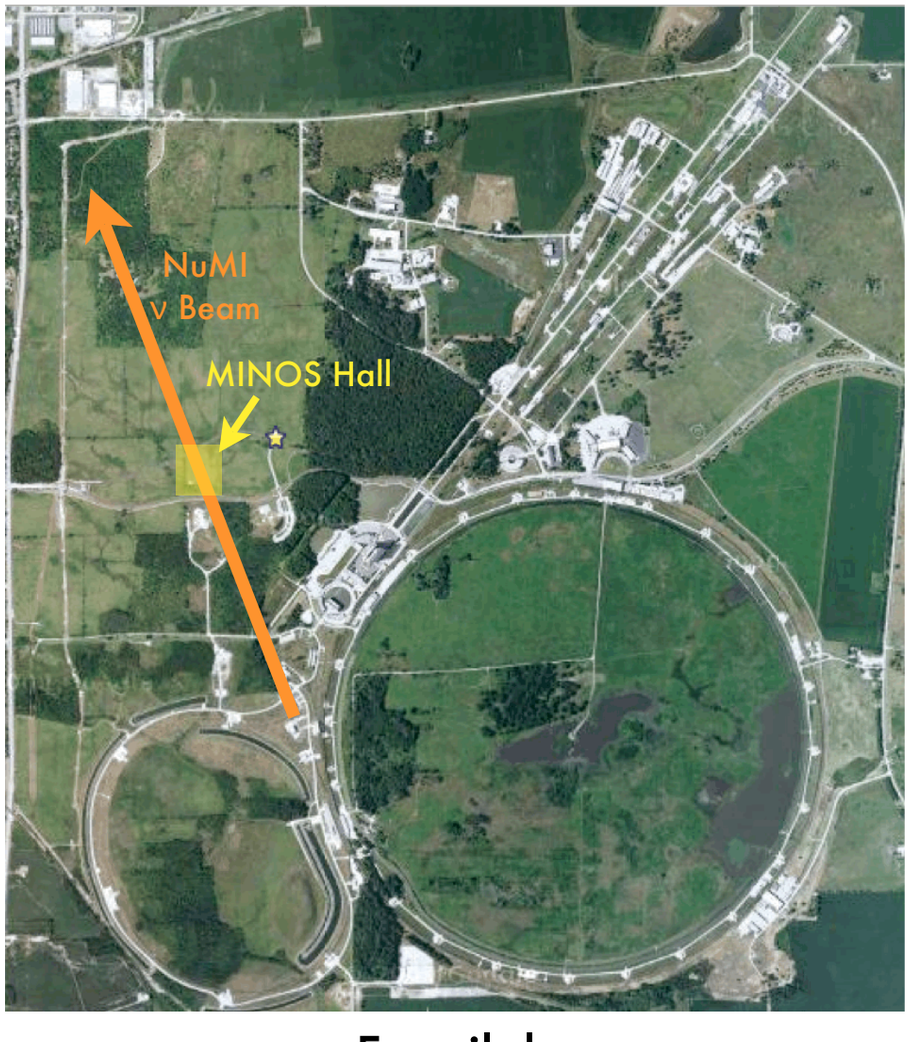
Noble Liquid Properties

- Abundant ionization and scintillation light can be used for detection.
- Ionization electrons can be drifted over long distances in these liquids if they are purified.
- Excellent dielectric properties allow these liquids to accommodate very high-voltages.
- Argon is relatively cheap and easy to obtain (1% of atmosphere).

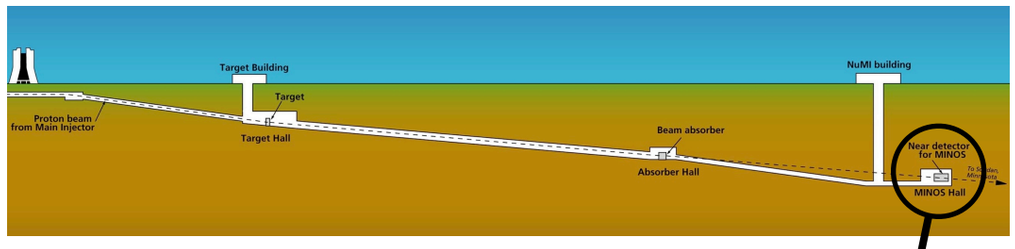
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	

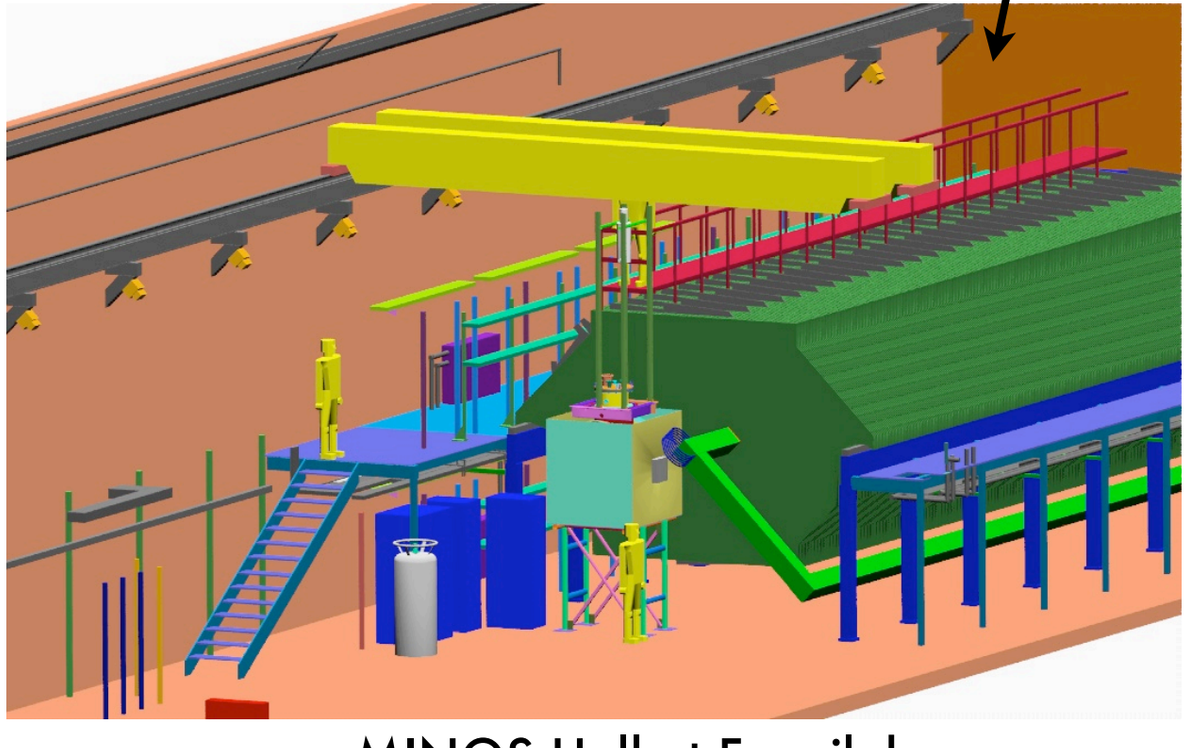
ArgoNeuT Introduction

- ArgoNeuT is a ~175 liter Liquid Argon Time Projection Chamber (LArTPC)
- Jointly funded by DOE/NSF
- Sits in NuMI beam at Fermilab, in front of MINOS near detector (to aid in muon reconstruction).
- Goals:
  - Gain experience building/running LArTPCs.
  - Accumulate a sample of neutrino events (1st time in the U.S., 1st time ever in a low-E beam).
  - Confront some aspects of underground running and safety.
  - Develop simulation of LArTPCs and compare with data.



Fermilab





MINOS Hall at Fermilab

ArgoNeuT Collaboration

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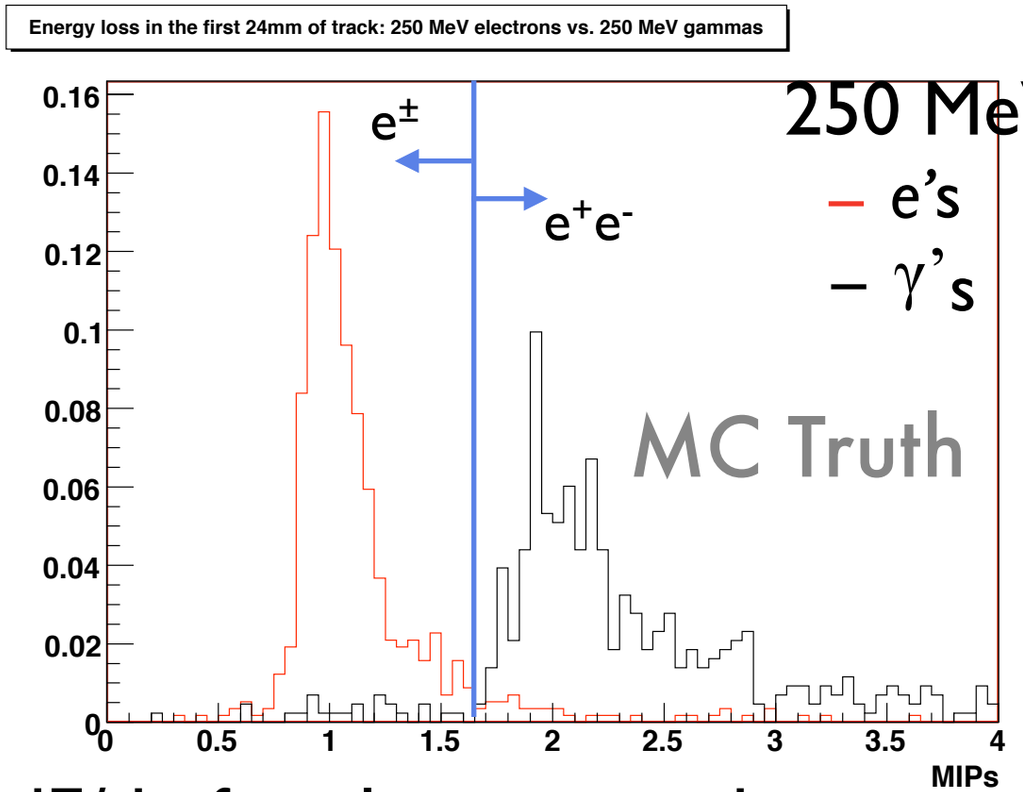
ArgoNeuT Physics Goals

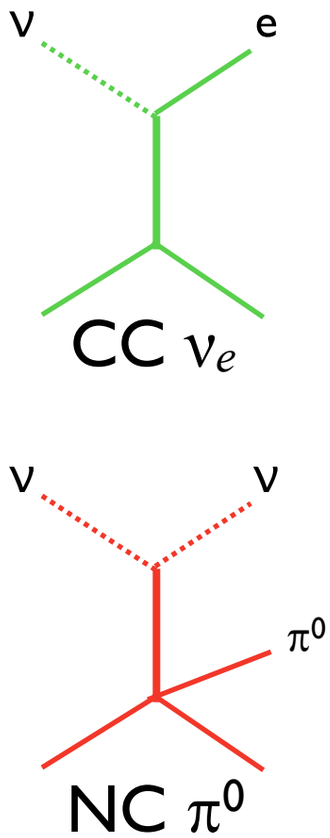
- Demonstrate e/γ separation → superior background rejection
  - Particle identification comes from energy deposition (dE/dx) measured along track.
  - Important for ν_e appearance: Excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
  - Topological cuts will also improve signal/background separation
- Measure charged-current cross-section in the 1-10GeV range.
- Develop reconstruction techniques useful for all future LArTPCs.



dE/dx for electrons and gammas in first 2.4 cm of track

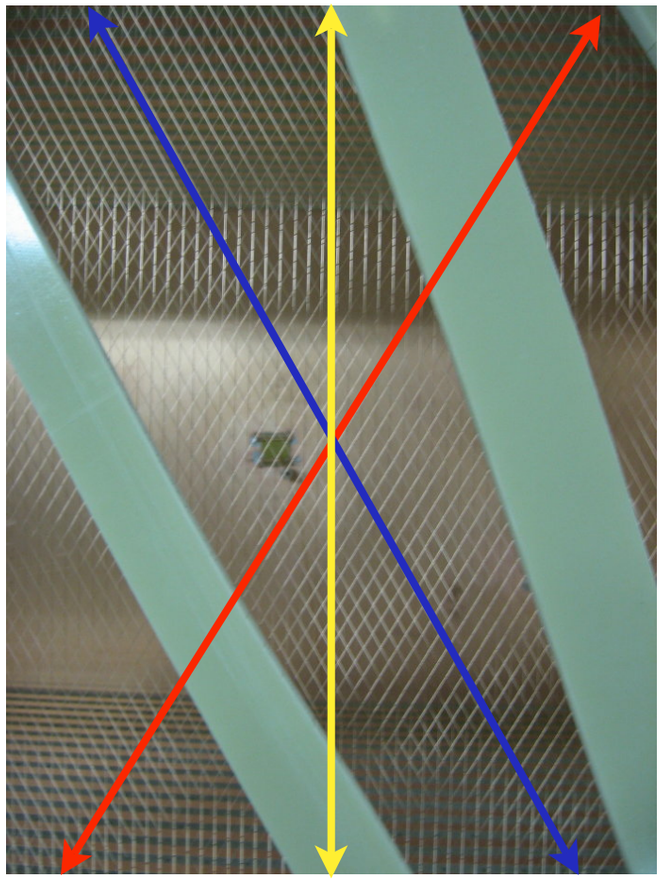
Event Type	# in ArgoNeuT/day (0.8×10^{17})
ν_μ CC	160
$\overline{\nu_\mu}$ CC	14
ν_e CC	3
NC	54
Total	231

Expected event rate in neutrino mode

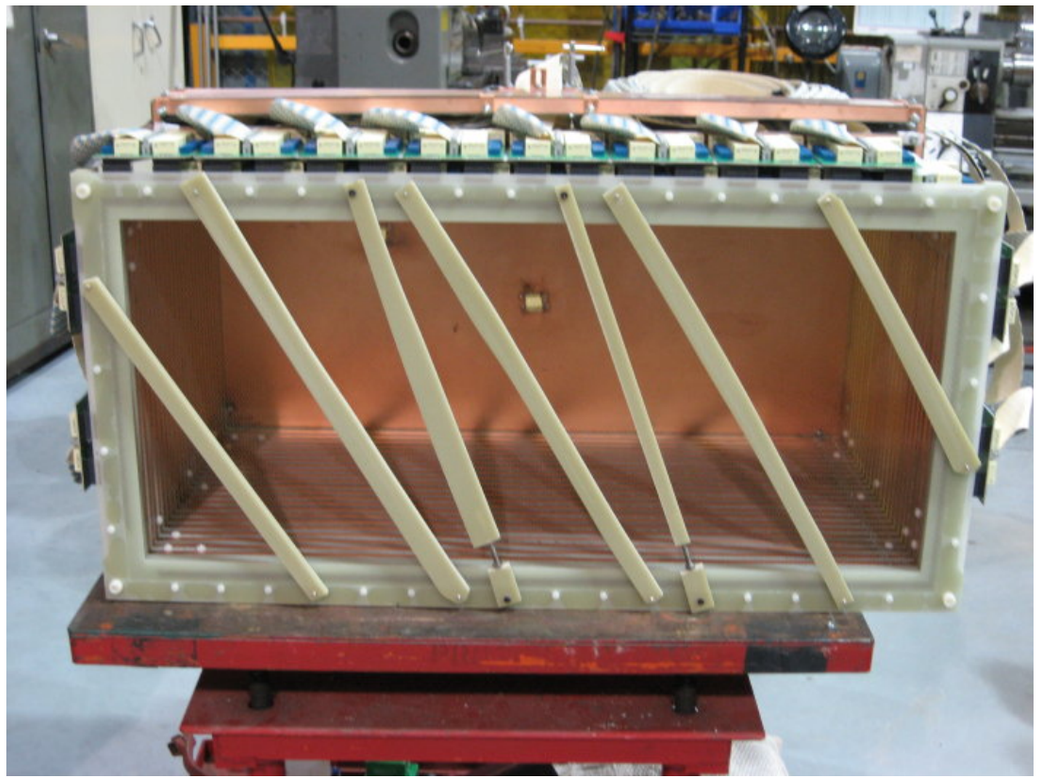


ArgoNeuT TPC

- 175 liter active volume in TPC
- 480 channels of electronic readout built by MSU.
- Collection, Induction2, Induction1 planes. Wires at ±60°
- 4mm wire pitch, 4mm plane spacing.
- 500V/cm electric field, Max. drift of ~50cm.
- Purity monitor for measuring electron lifetime in liquid argon.



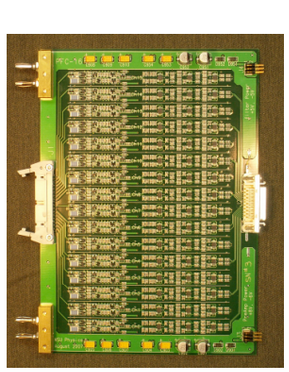
Wire Orientations

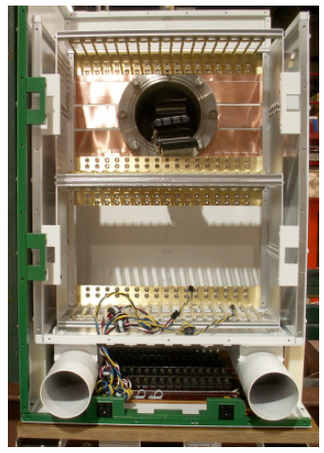


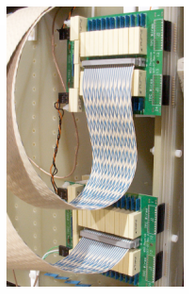
TPC with readout cables

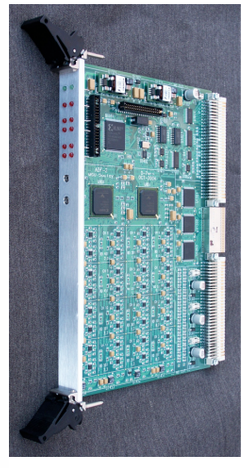
ArgoNeuT Electronics

- Bias voltage distribution & blocking capacitors on the TPC
- FET preamplifier similar to D0/ICARUS front-end
- Wide bandwidth filtering (10 - 159 kHz, now)
  - Full information on most hits/tracks
  - Employ DSP to extract hit/track parameters
- ADF2 card, sample at 5 MHz, 2048 samples/channel
- Minimize noise sources
  - Double shielding of feed-through and preamplifiers
  - Remote ducted cooling
  - Extensive DC power filtering



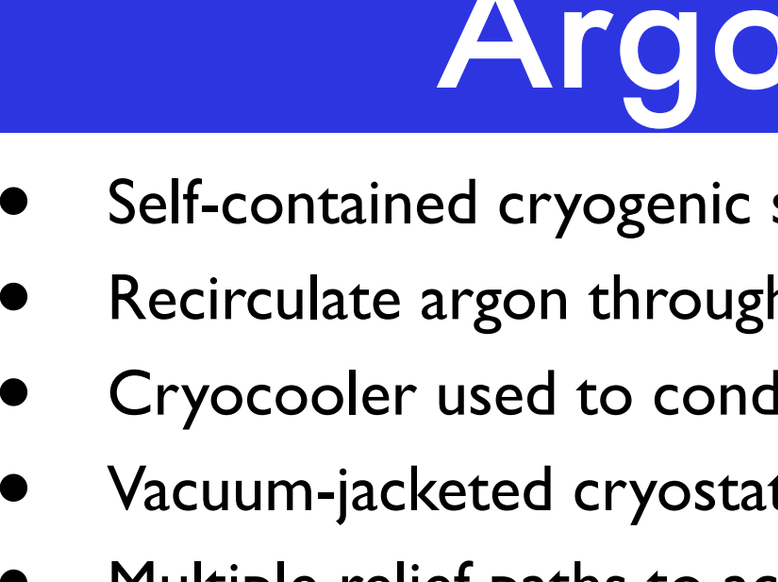






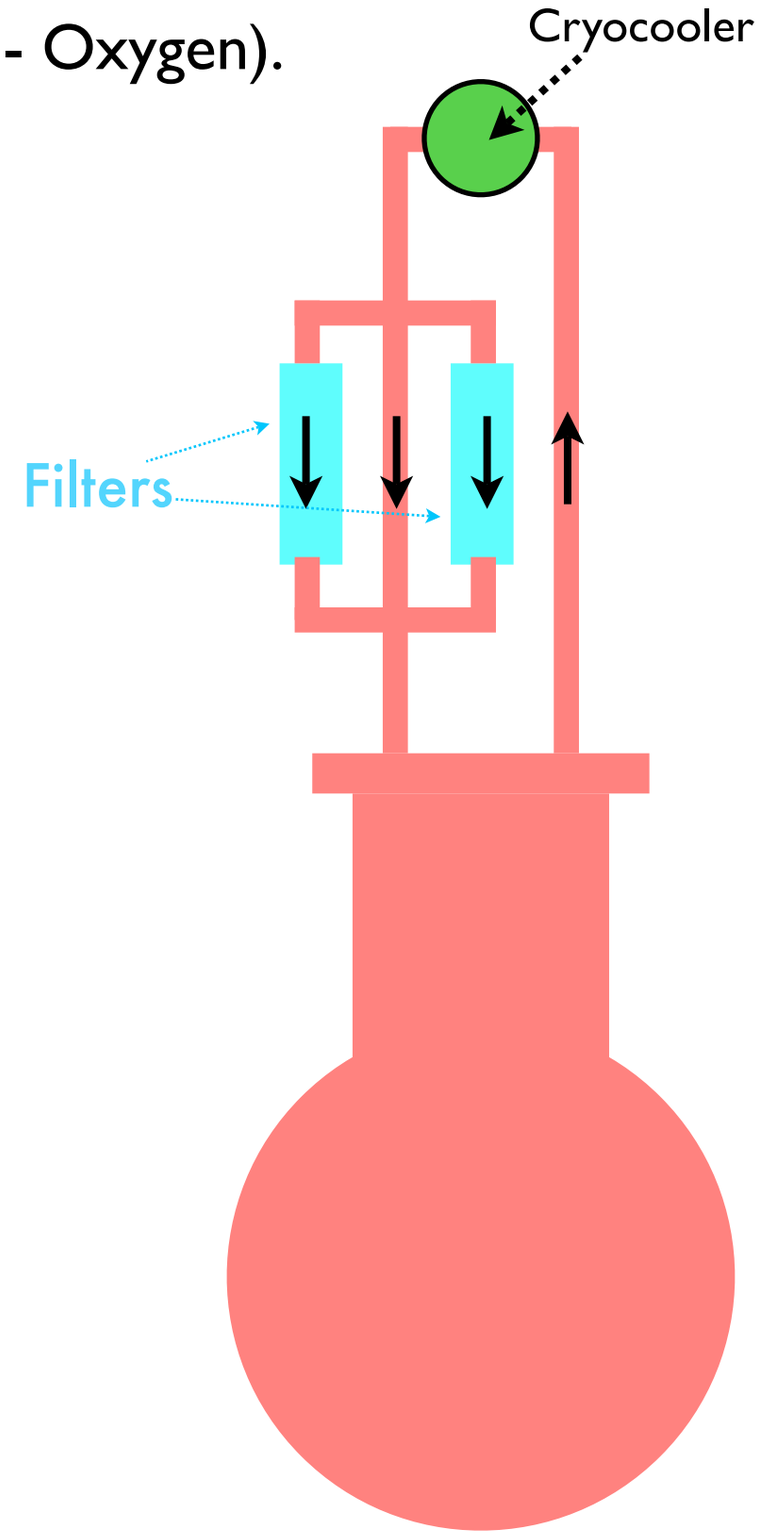
ArgoNeuT Cryogenics

- Self-contained cryogenic system (*i*.e. - maintain constant Argon supply).
- Recirculate argon through filters* to remove impurities (e.g. - Oxygen).
- Cryocooler used to condense boil-off gas.
- Vacuum-jacketed cryostats/pipes for insulation.
- Multiple relief paths to achieve safe running.



Vacuum-insulated vessel.

ArgoNeuT at PAB.



Refs:
*.) *A Regenerable Filter for Liquid Argon Purification*, A. Curioni *et. al*; *NIM A* 605 (2009) 306-311

Underground Operation

Many safety issues addressed to prepare for underground operation that must maintain ODH-0 rating of tunnel:

- ArgoNeuT sits in a mixing bathtub that acts as tertiary containment in case both cryostats leak.
- All possible trapped volumes are instrumented with relief valves routed to vent line.
- Vent line runs up and out shaft, to ensure no argon released in tunnel.
- 2 ODH monitors - Trigger multiple alarms (siren/horns/FIRUS) if oxygen deficiency is detected.
- Slow control system in tunnel, and online, to alert of any ODH hazards.

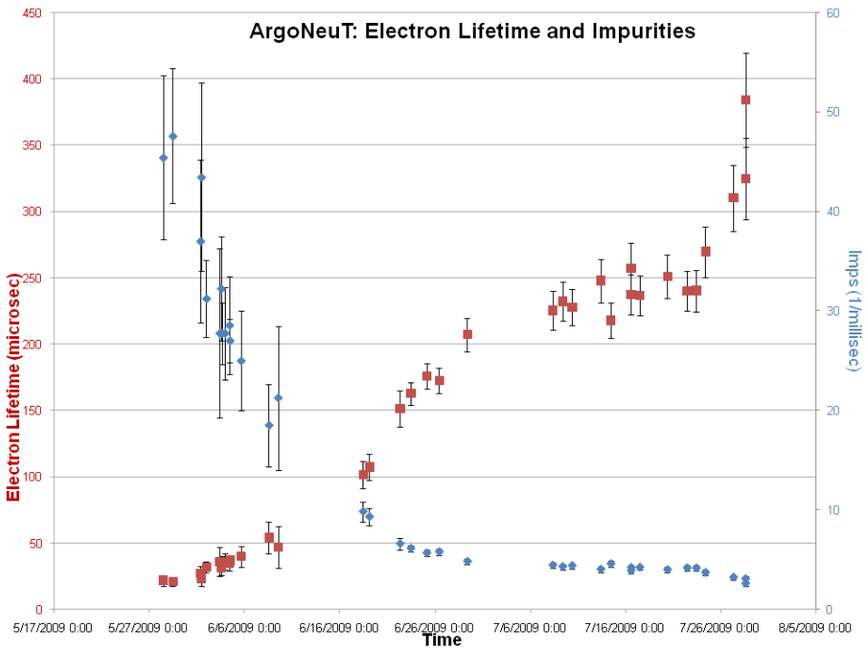
"Bathtub"

Vent Line

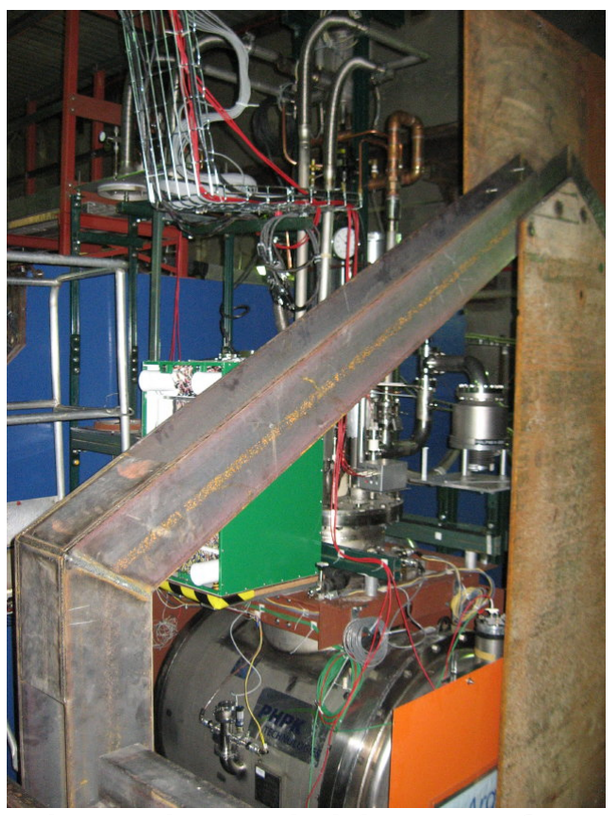
Ducts for mixing fans

Detector Status

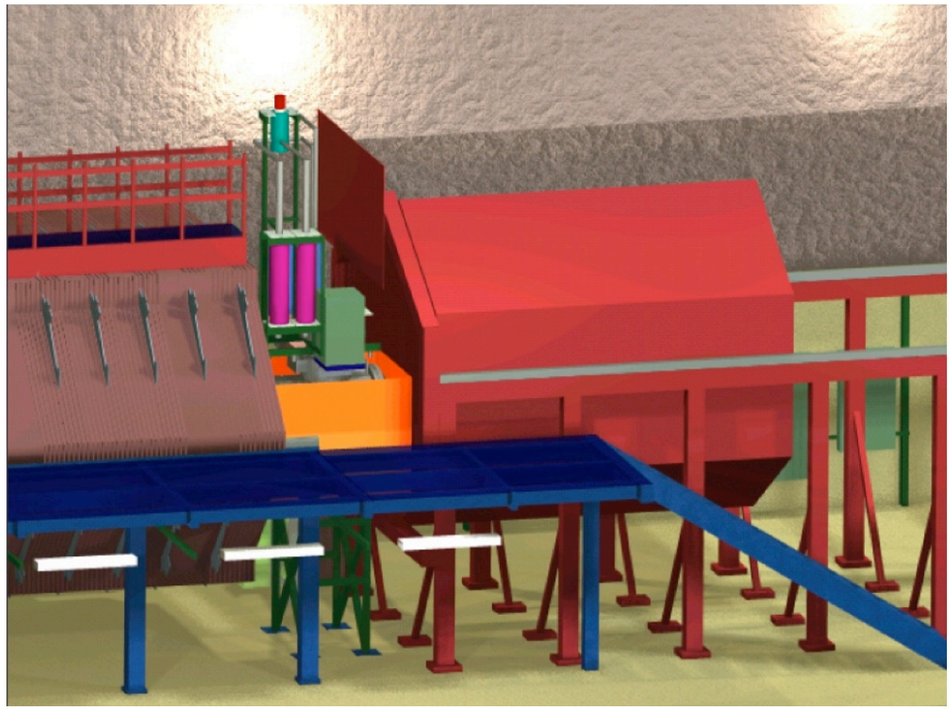
- Filled the cryostat underground Friday, May 8.
- Initial argon purity was low....recirculating has cleaned things up...and should continue to do so.
- Took neutrino data for ~1 month before summer shutdown...hope to continue in the Fall.
- Cryo. system is still operating in a very stable mode today.



Moving underground



Looking through Minerva frame.

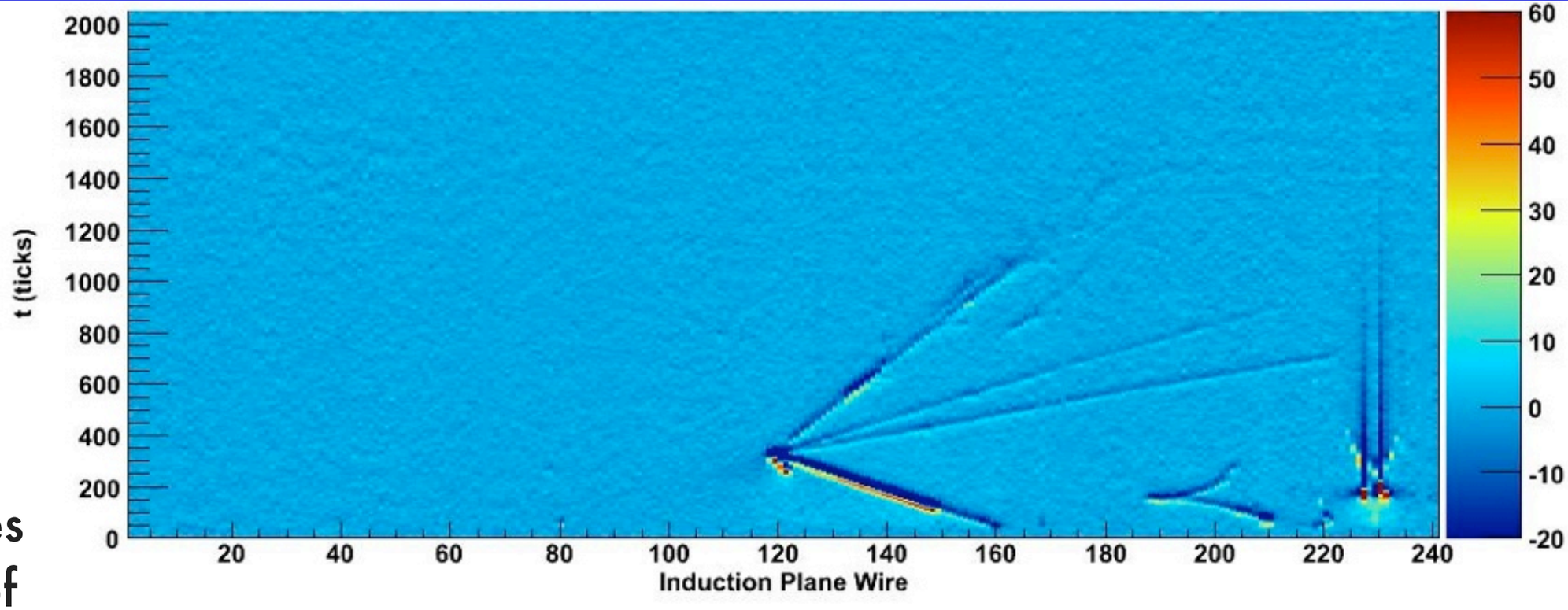


Schematic of NuMI experiments

ArgoNeuT Event Displays (preliminary!)

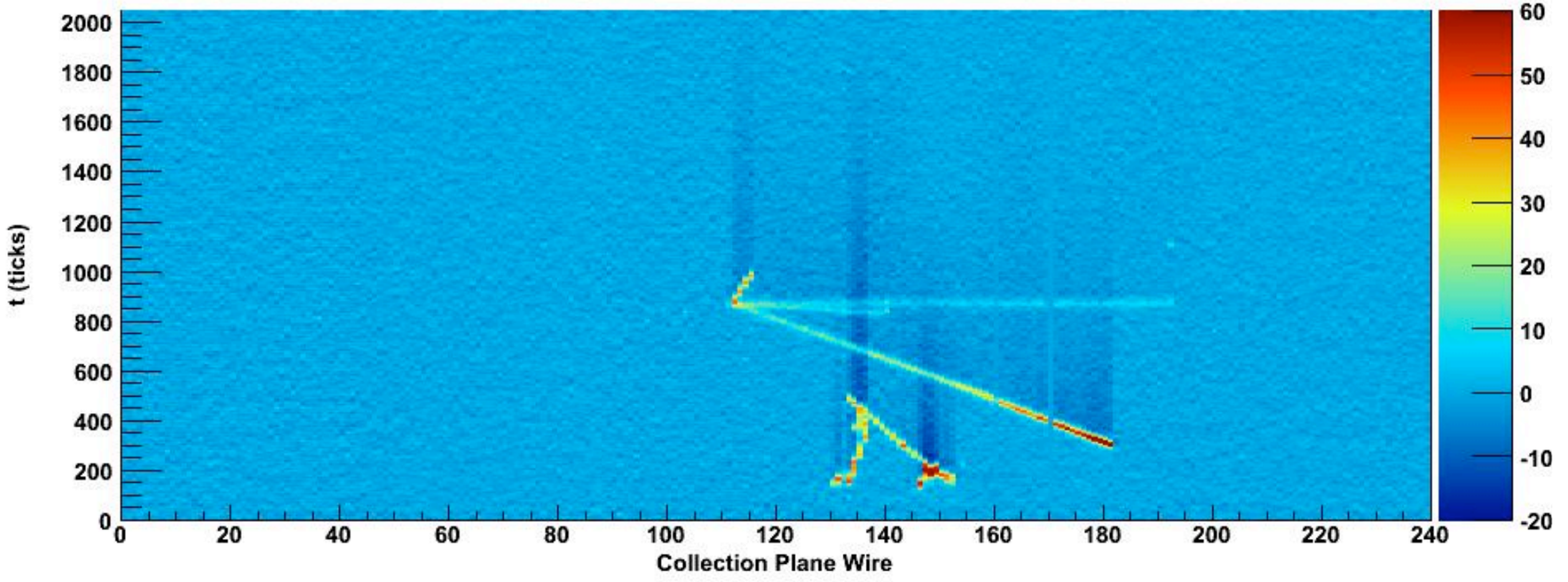
Neutrino Event: DIS Candidate

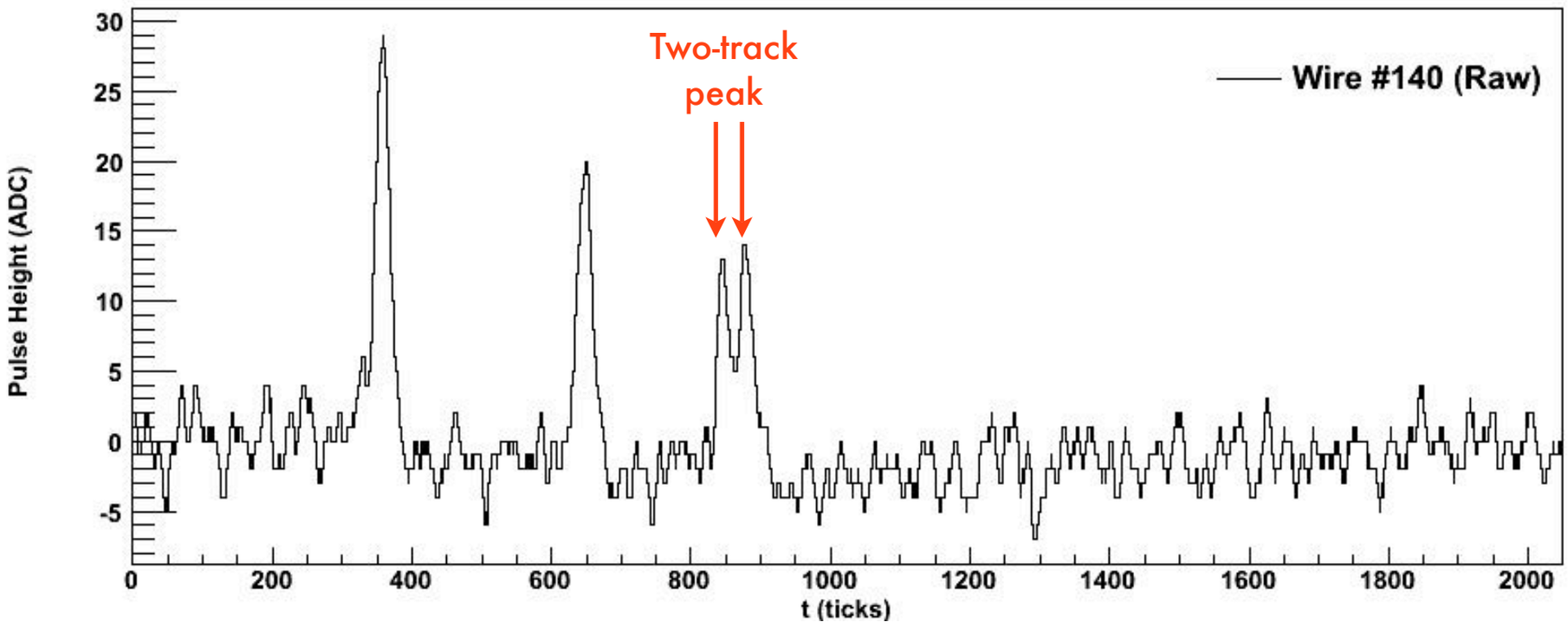
TPC provides two views of each event



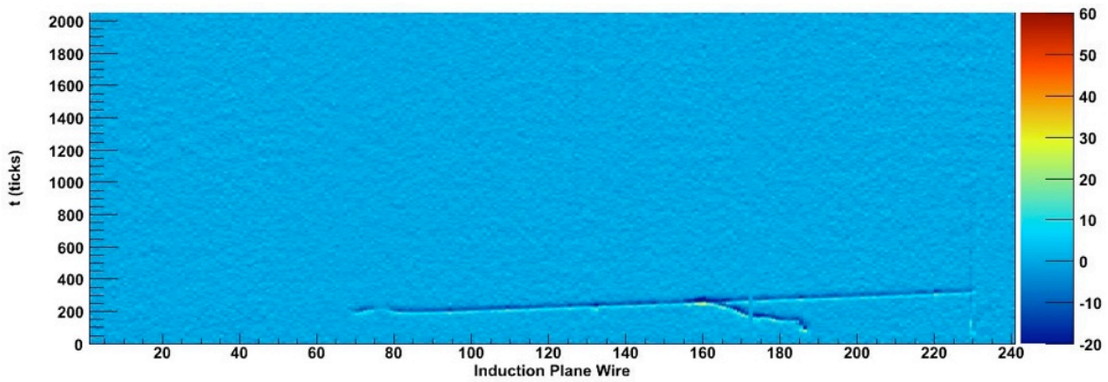
Neutrino Events

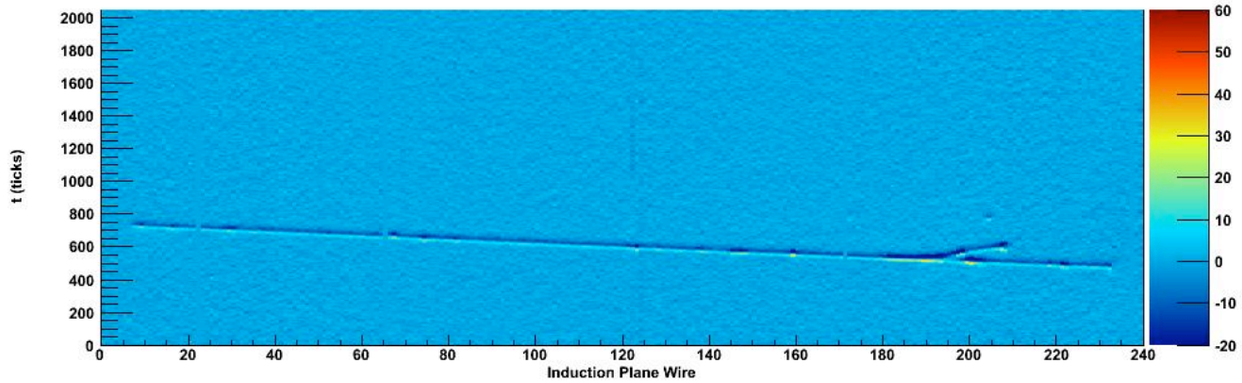
- Very fine pixel size (4mm x 0.3mm)
- ~14ADC counts per 1fC of charge.
- Dark "bands" are due to electronics returning to baseline...
- Fourier decomposition can be used to remove electronics response.
- Developing code to extract "hit" information from wire signals, perform tracking, etc...

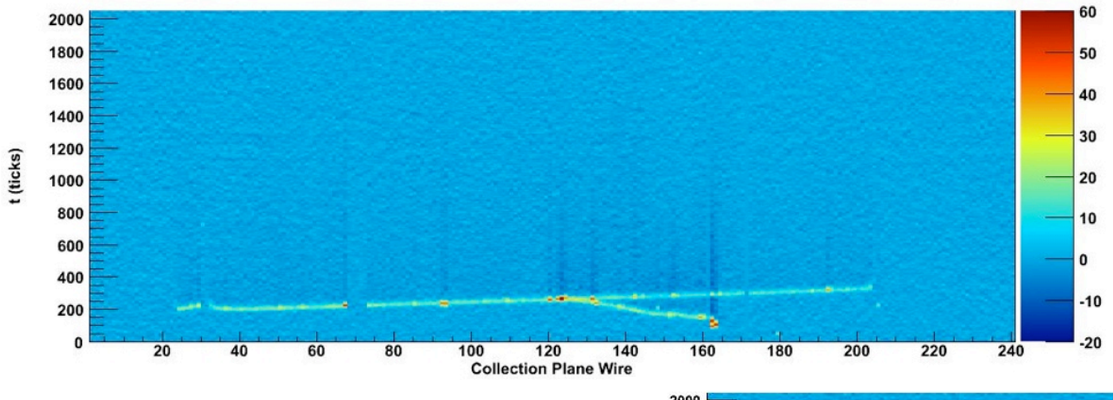


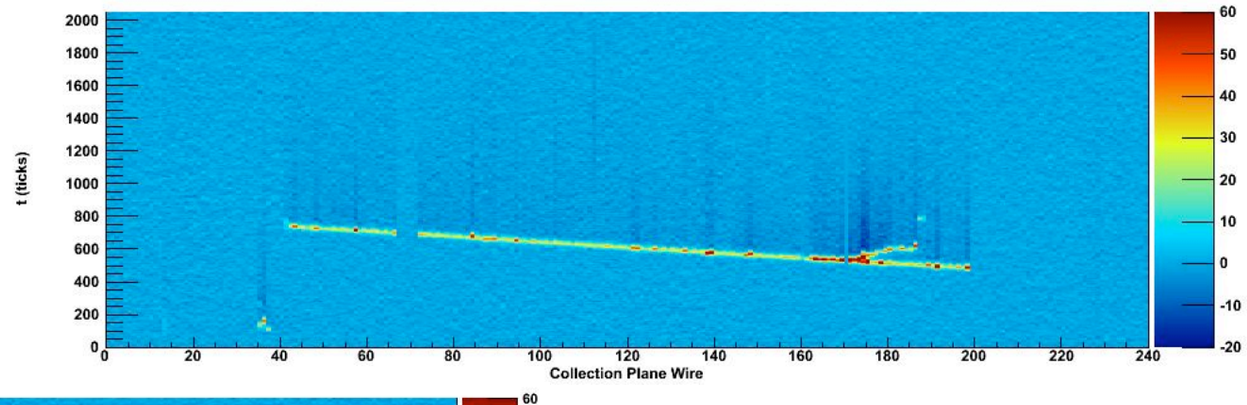


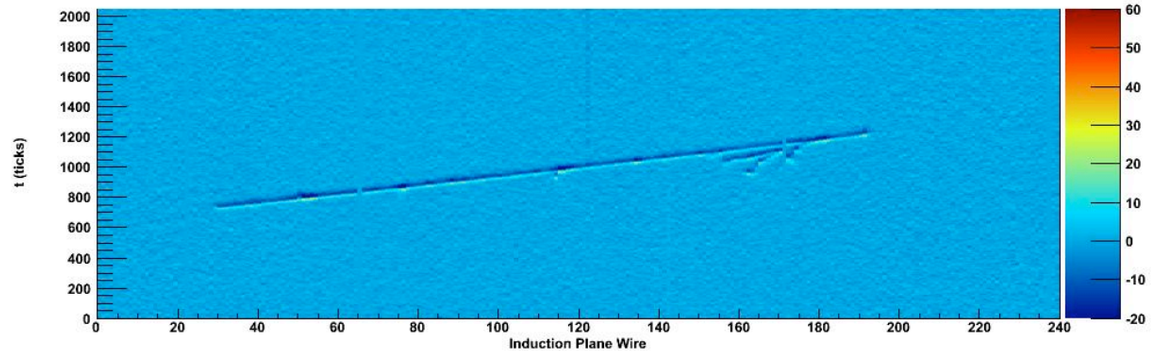
Some Muons with Deltas

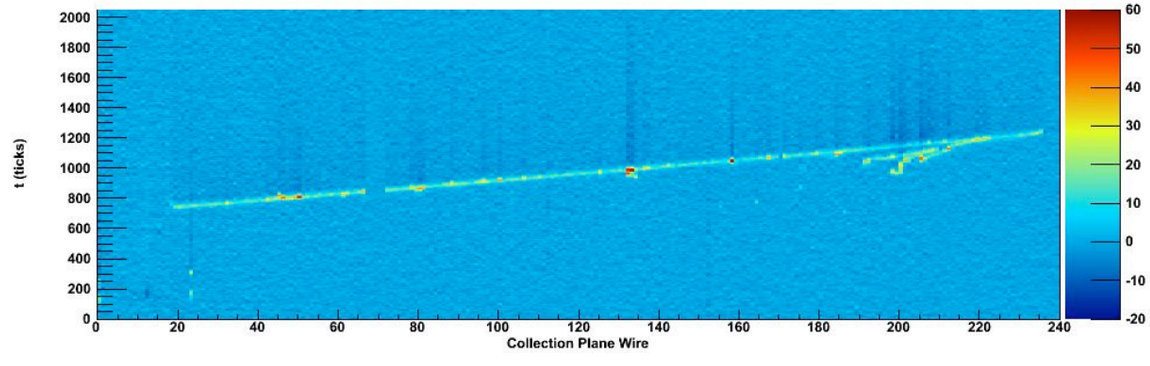






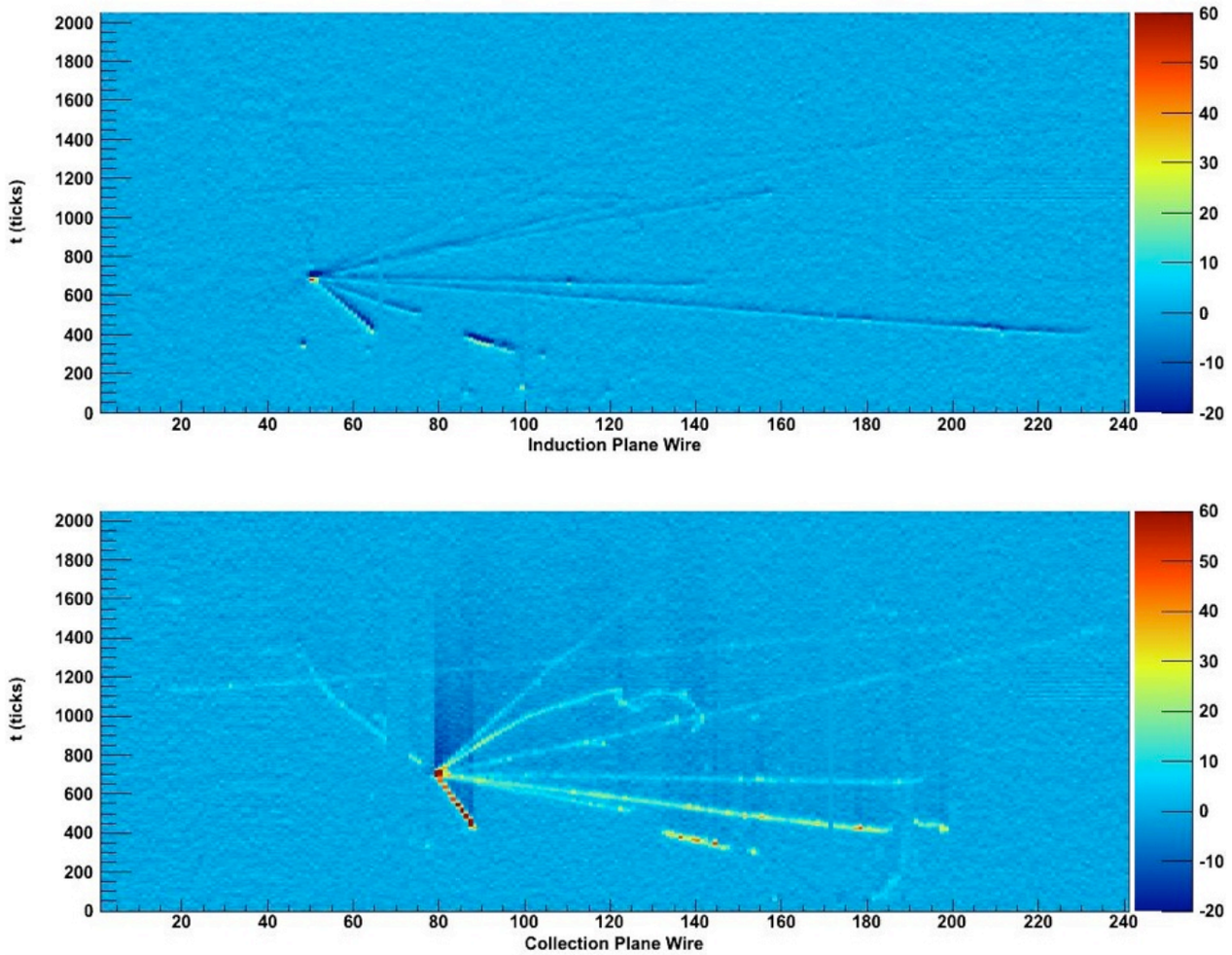


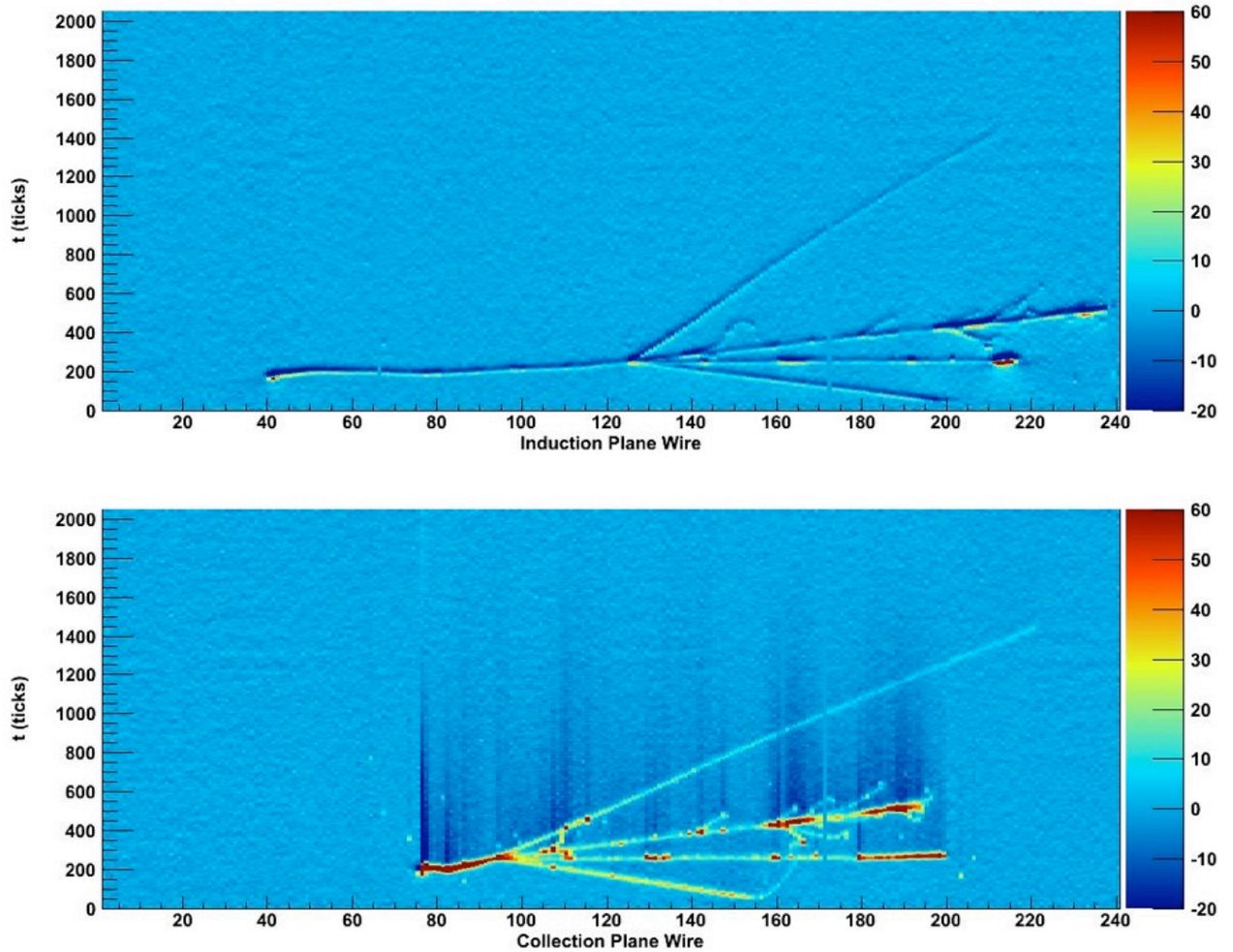




Neutrino Events

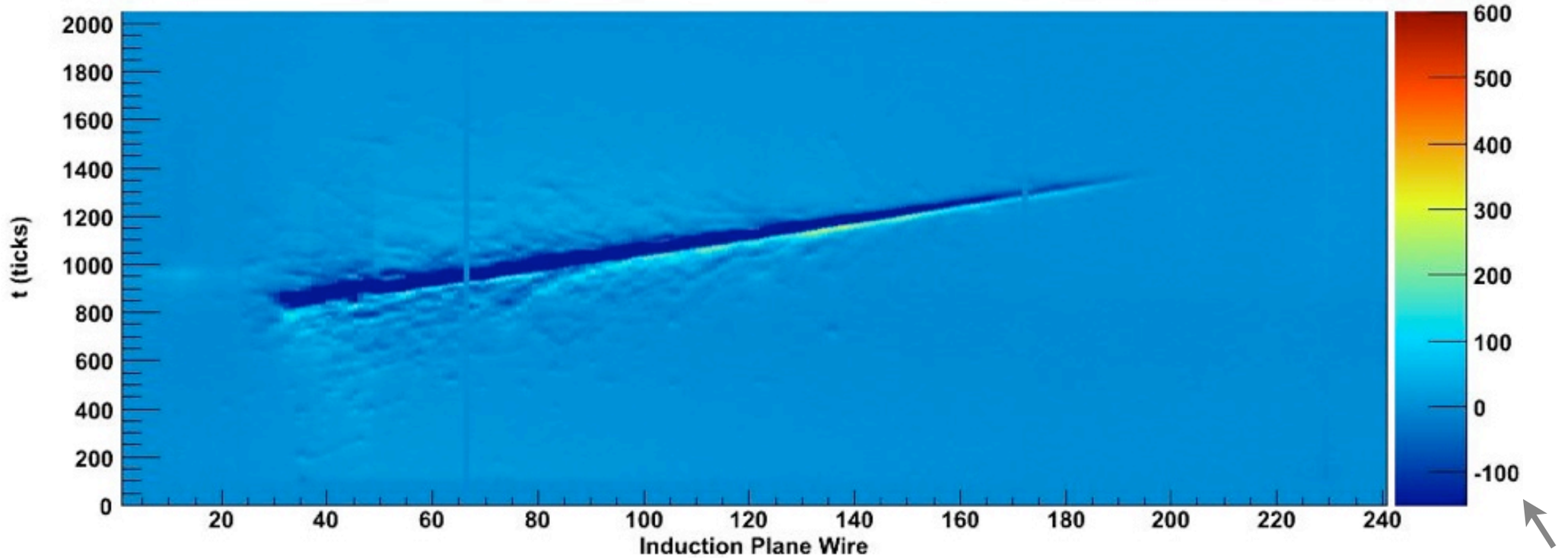
Two more DIS candidates.



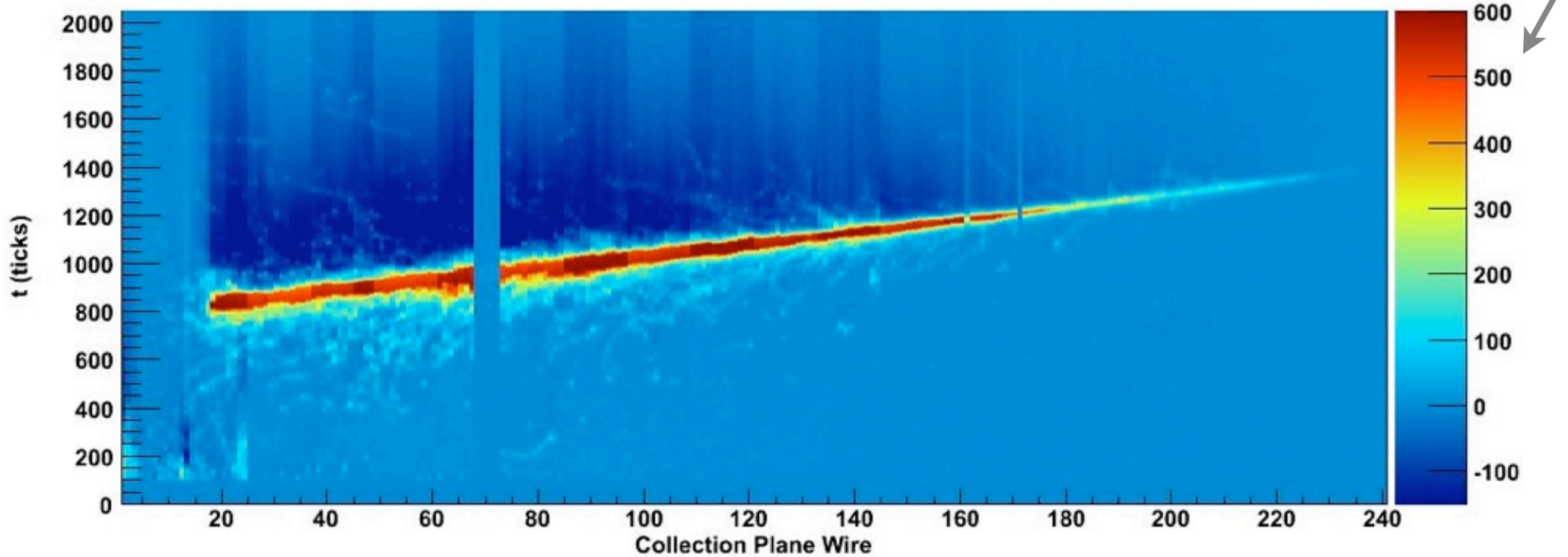


Cosmic Events

Very energetic cosmic-ray event…pushes many ADCs to their upper/lower threshold



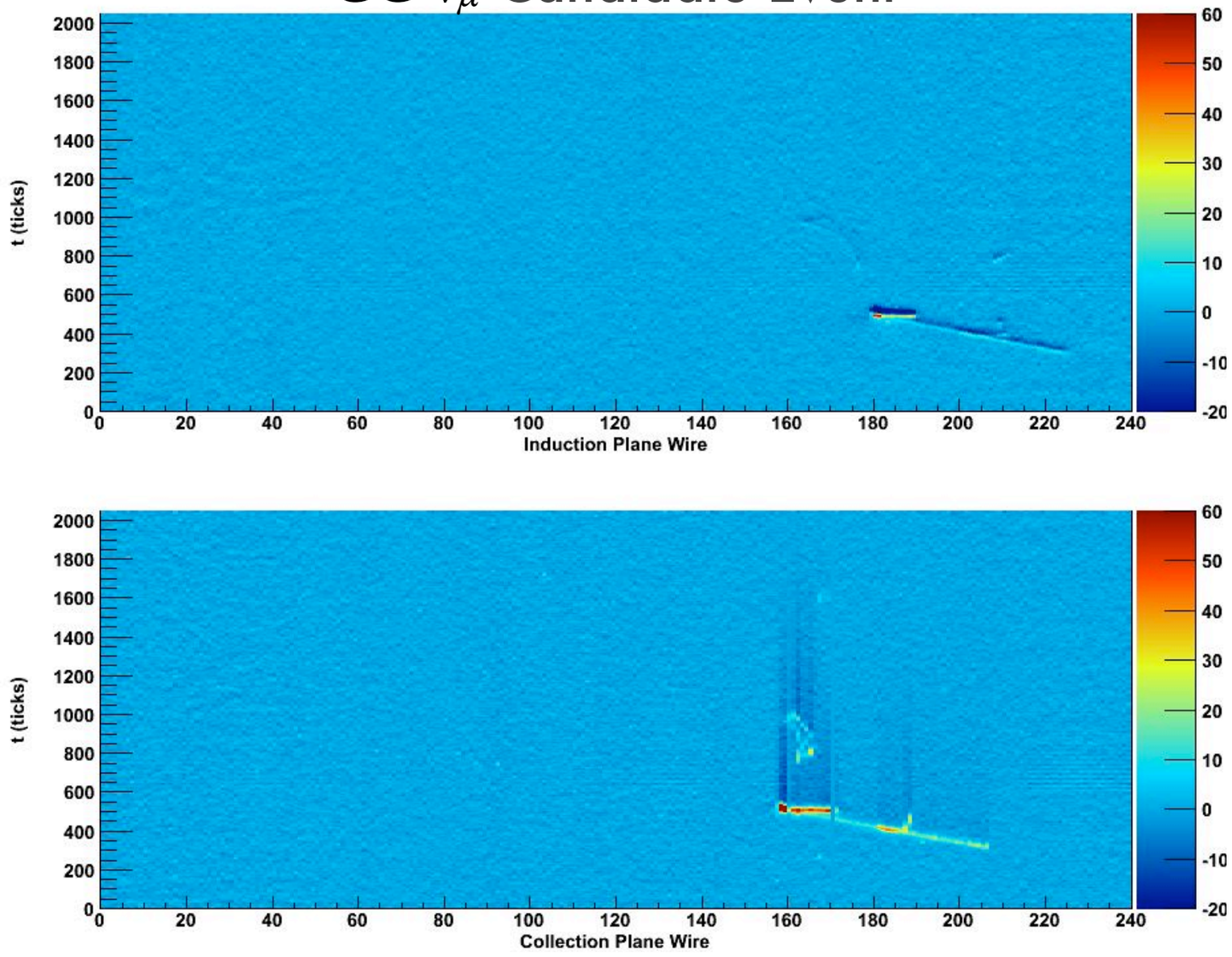
Note Increased Scale



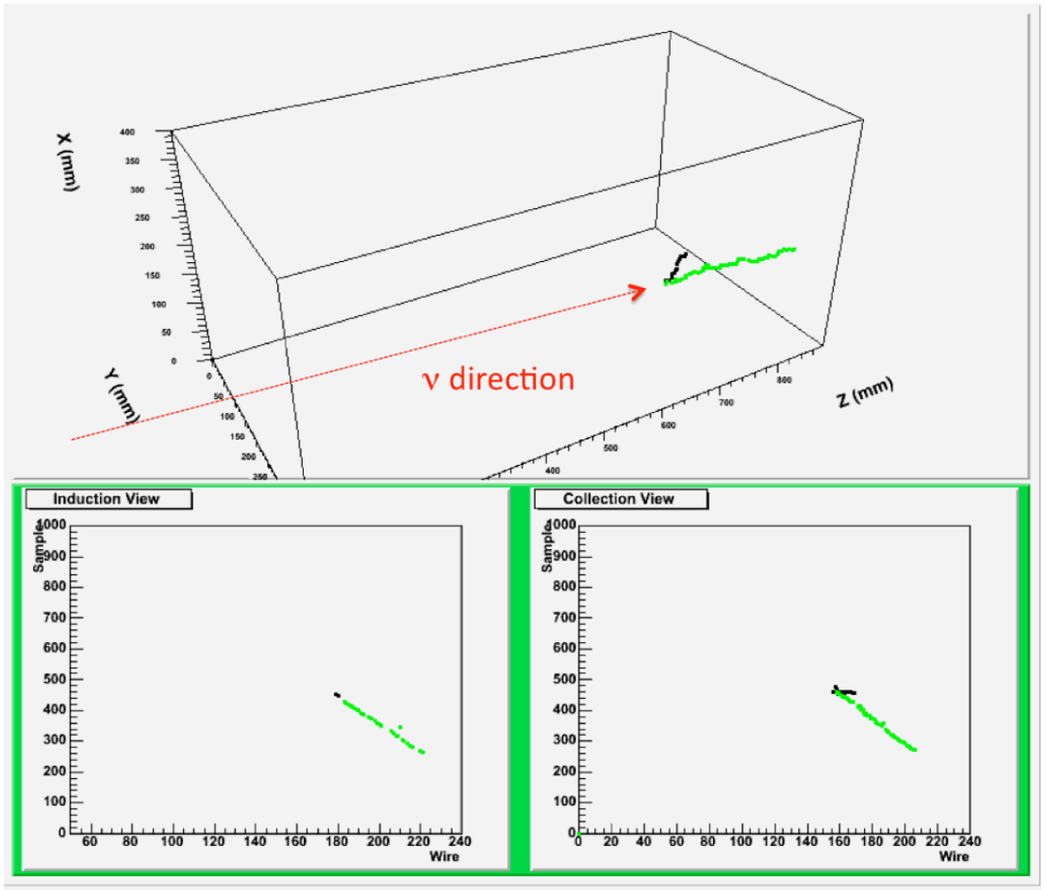
Reconstructing Events

- Much activity in developing full simulation/reconstruction software for ArgoNeuT (and future LArTPCs).
- Initial attempts at 3D event reconstruction have been made by ArgoNeuT collaborators.

CC ν_μ Candidate Event



Reconstructed "hits" and 3D view



O. Palamara

Conclusion

- ArgoNeuT starting to provide a sample of neutrino events in an LArTPC, for the 1st time in the U.S., and the 1st time ever in a low-Energy beam.
- Analysis software being developed is general purpose for future LArTPCs.
- Real data/experience is invaluable in improving LArTPC technique.
- Many thanks to Fermilab for their support of this project!