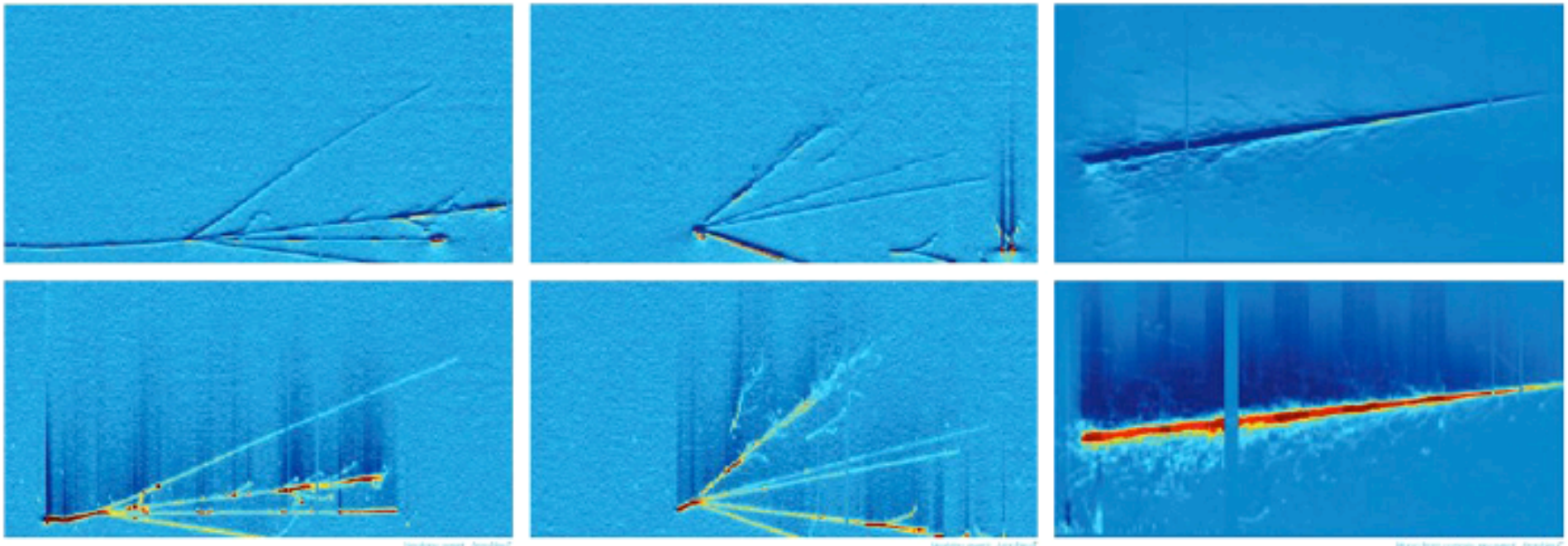
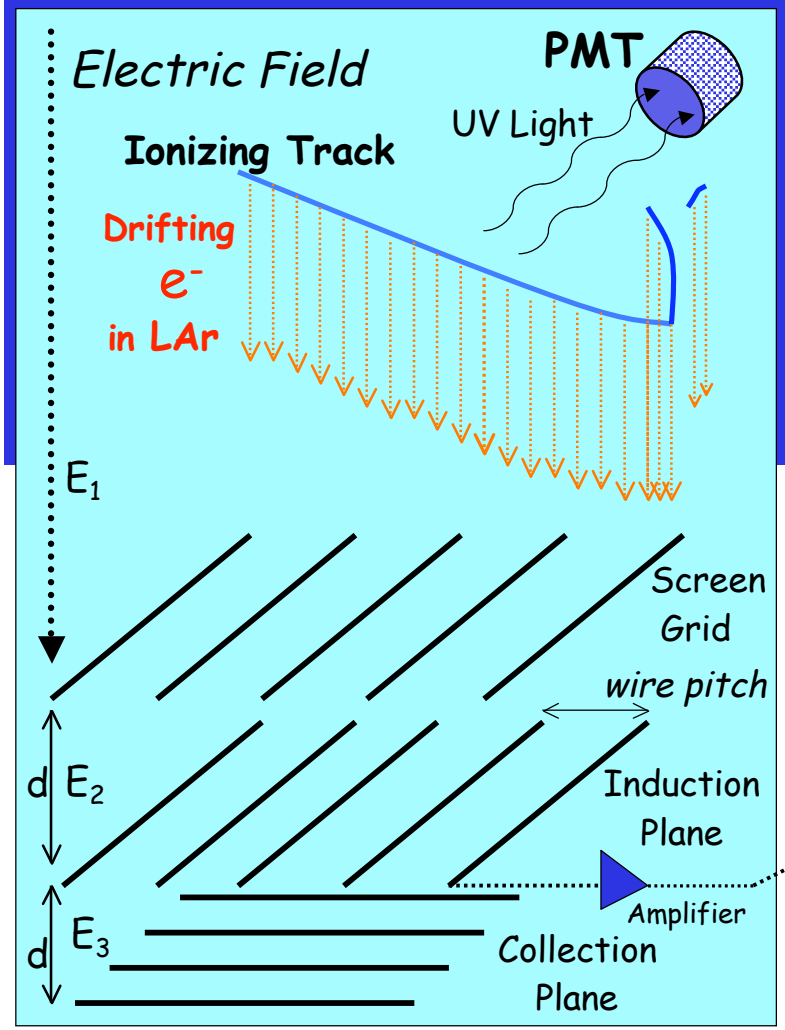
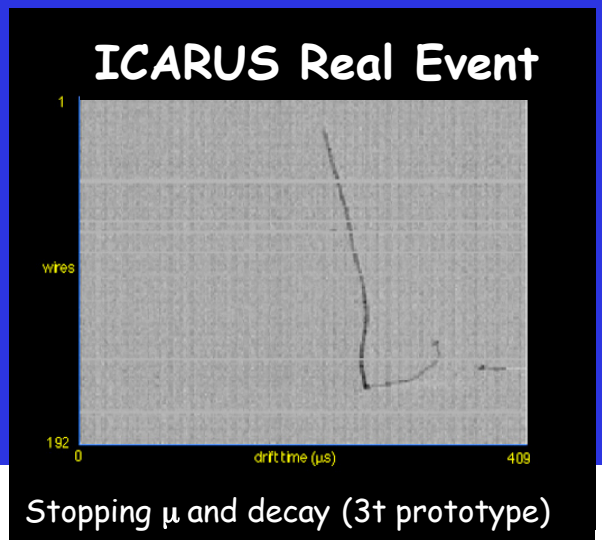


The ArgoNeuT Experiment at FNAL

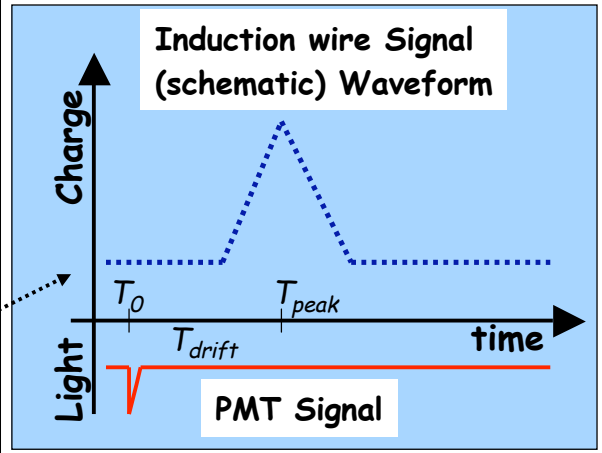
GDR Neutrino - Strasbourg (Oct. 28th, 2009)

Flavio Cavanna
L'Aquila University (Italy)





Stopping μ and decay (3t prototype)



LArTPC* Liquid Argon Time Projection Chamber

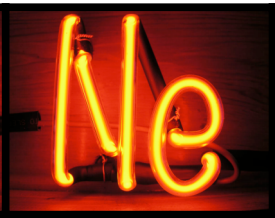
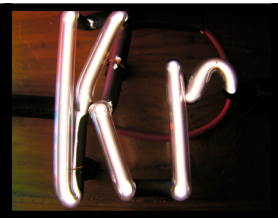
(developed by the Icarus Collab. since the '80)

- (Neutrino) interactions inside the LAr-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)

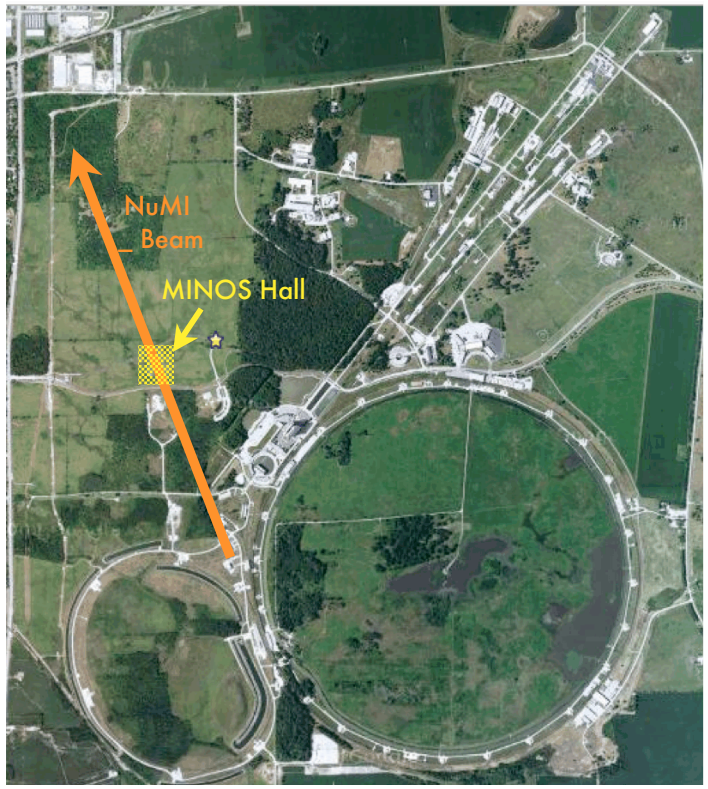
Noble Liquid Properties

- 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).

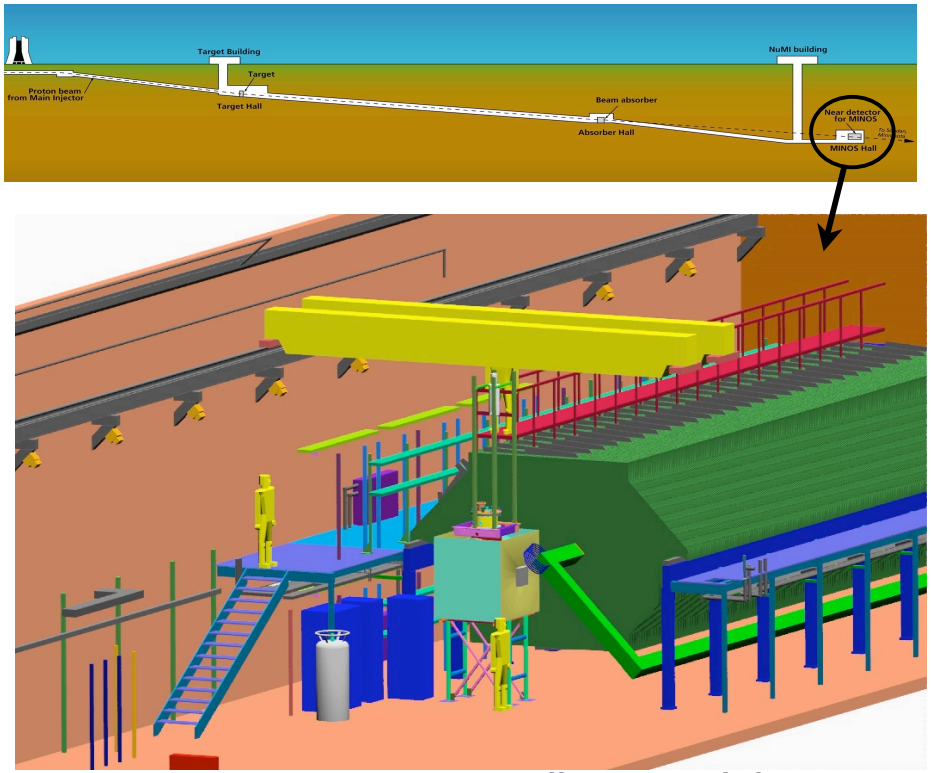
						
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [γ/MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation [nm]	80	78	128	150	175	

ArgoNeuT Introduction

- ArgoNeuT is a ~175 liter (active) Liquid Argon Time Projection Chamber (LArTPC)
- Jointly funded by DOE/NSF -
- Designed and assembled in 2007-08,
- First commissioned (on surface) at FNAL in Summer 2008.
- … and then (early 2009) moved underground in the *NuMI* beam at Fermilab, in front of *MINOS Near Detector* to collect neutrino/antineutrino event in the "few GeV" range (*LE beam option*)



Fermilab



MINOS Hall at Fermilab

ArgoNeuT Collaboration

F. Cavanna, V. Caracciolo
L'Aquila University

B. Baller, C. James, G. Rameika, B. Rebel, K. Partyka
Fermi National Accelerator Laboratory

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S. Kopp, K. Lang
The University of Texas at Austin

C. Anderson, B. Fleming*, S. Linden, M. Soderberg, J. Spitz, T. Wongjirad
Yale University

ArgoNeuT Physics Goals

- Measure charged-current cross-section in the "few GeV" (1-10 GeV) range:
  - CC Quasi-Elastic (QE) channel
  - CC Resonant (RES: $\Delta \rightarrow \pi$ N) channel

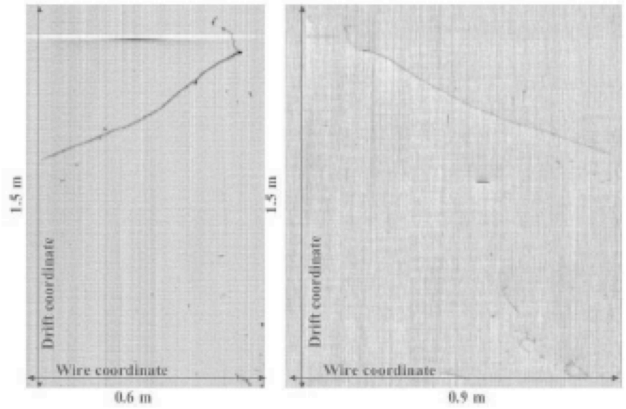
- *e*/γ separation study and optimization $\Rightarrow$ superior background rejection
  - Particle identification comes from energy deposition (dE/dx) measured along track.
  - Important for ν_e appearance: Excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
  - Topological cuts will also improve signal/background separation

- Develop reconstruction techniques useful for all future LArTPCs:
  - full 3D reconstruction of the event topology
  - precise calorimetric reconstruction of deposited energy

Where we start from…

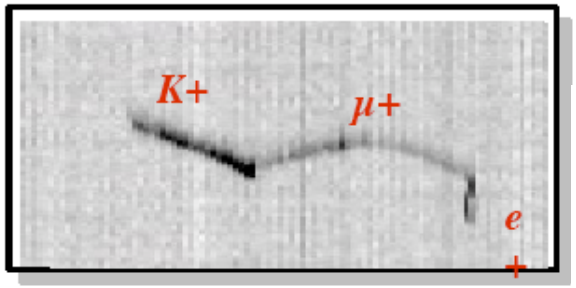
… the ICARUS experience

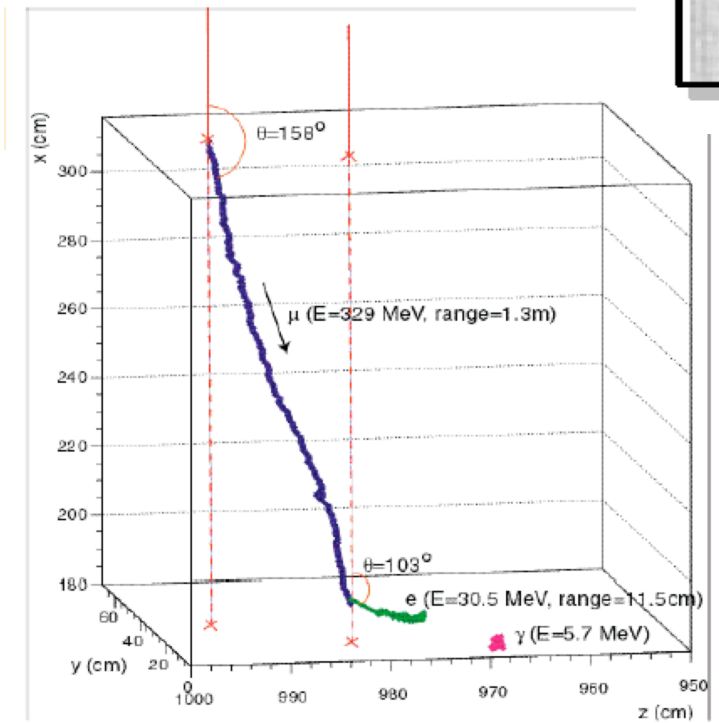
Development/optimization of reconstruction techniques with LArTPC



ICARUS T600 events

Particle IDentification

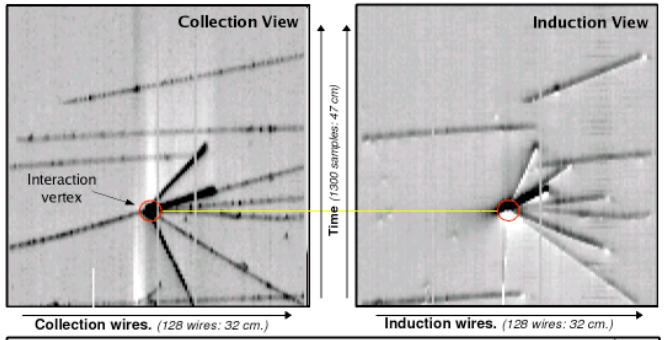


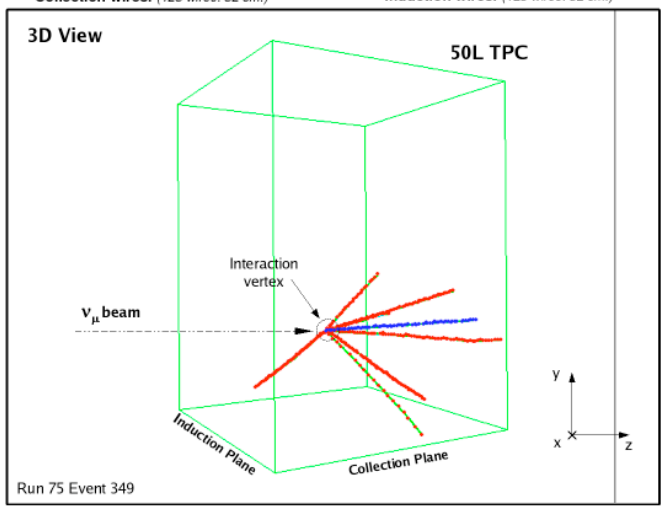


Fully reconstructed stopping muon event: 3D image and Calorimetric information

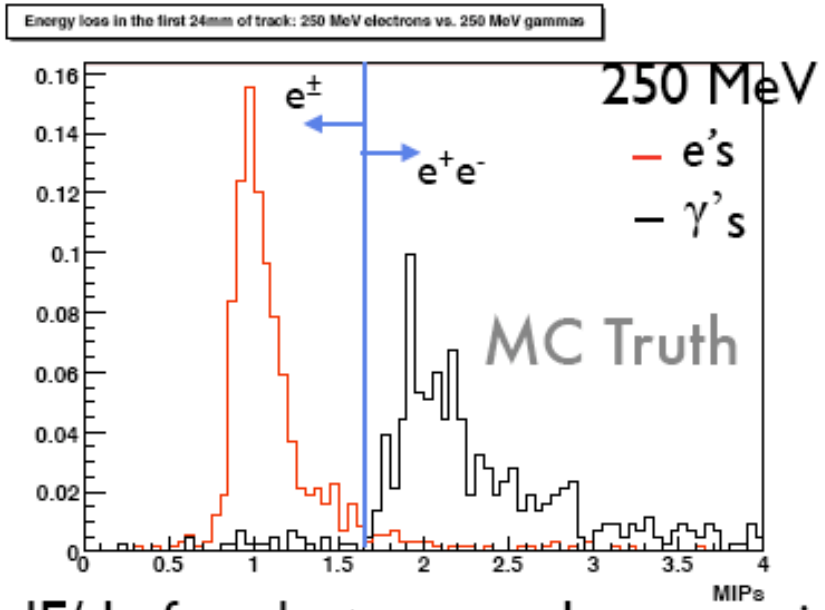
ICARUS 50 lt Detector

DIS nu-event: 3D image, Calorimetric information and PID of

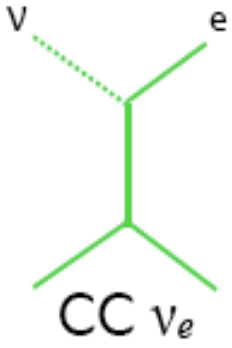




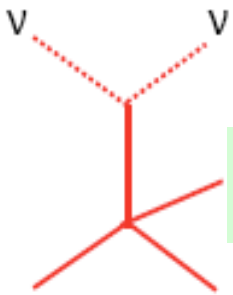
e/γ separation study and optimization



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

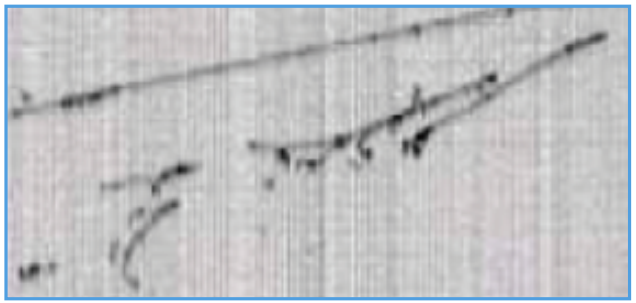


CC ν_e



NC π^0

ICARUS T600 event



$\pi^0 \rightarrow \gamma\,\gamma \rightarrow (e^+e^-)\,(e^+e^-)$

CC-QE cross section in the "few GeV" range

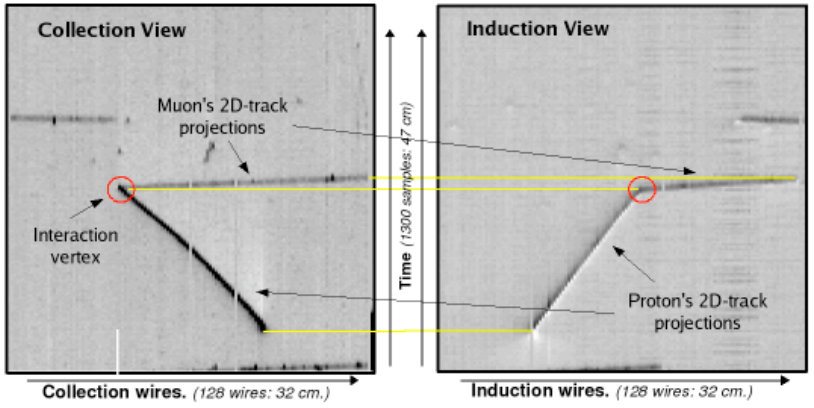
ICARUS 50 lt Detector

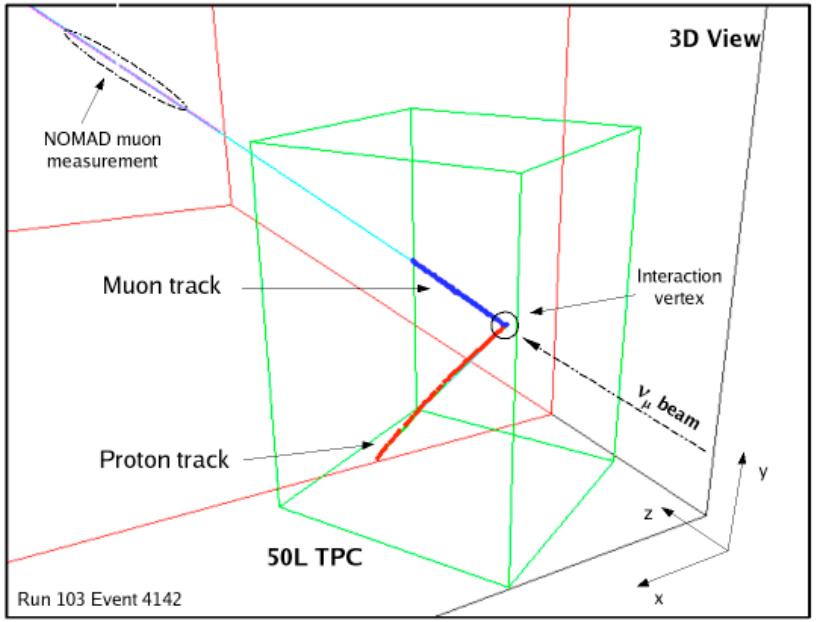
2D views

and

3D reconstruction of QE event

(T_p>40MeV)





QE Xsection:

$$\sigma_{QE} = \frac{N^{QE}}{\Phi \times E_{xp} \times N_{fid} \times T_{live} \times Acc^{QE} \times \mathcal{G}^{QE}}$$

= [0.90 ± 0.10 (stat) ± 0.18 (sys)] × 10^{-38} cm^2

measured ('98) at the CERN WANF High energy Neutrino beam (E_ν = 28 GeV)

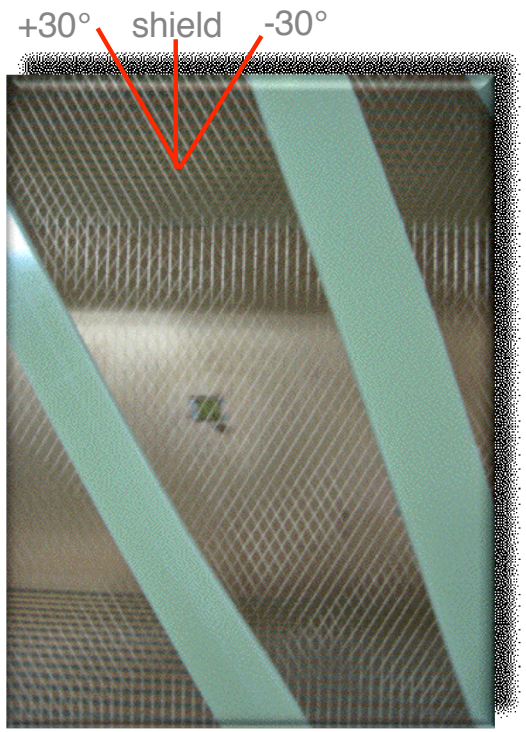
No QE (& RES) data on Ar target (yet) available in the "few GeV range, needed for next generation ν-osc. Experiments with LArTPC's

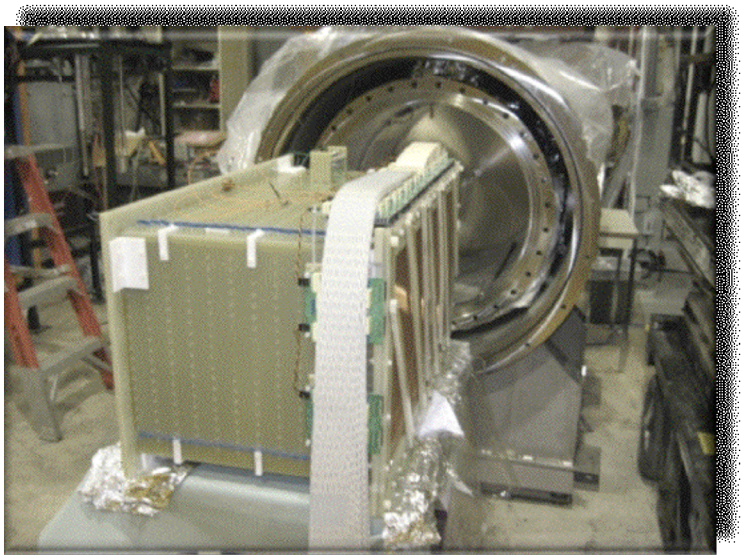
Where we are right now…

The ArgoNeuT detector: status and run

ArgoNeuT Design

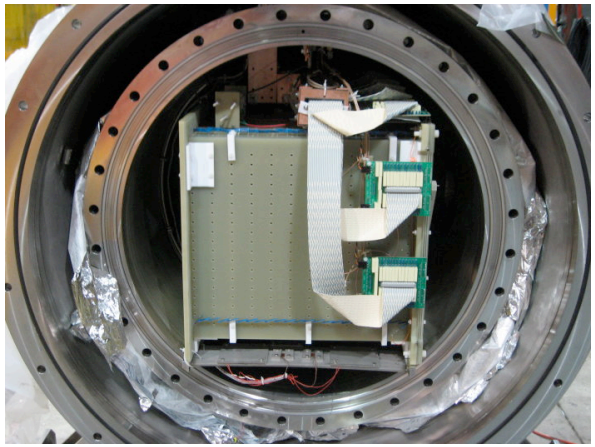
- 170 L LAr active volume (47x40x90cm3 ~235kg total 500 L)
- 2 read-out planes: Induction and Collection
- 240 wires per plane.
- Wires orientation: ± 30° with respect to vertical
- 4mm wire pitch, 4mm plane spacing
- 2048 samples over 400 microseconds (per spill)
- 500 V/cm electric field
- 47 cm maximum drift





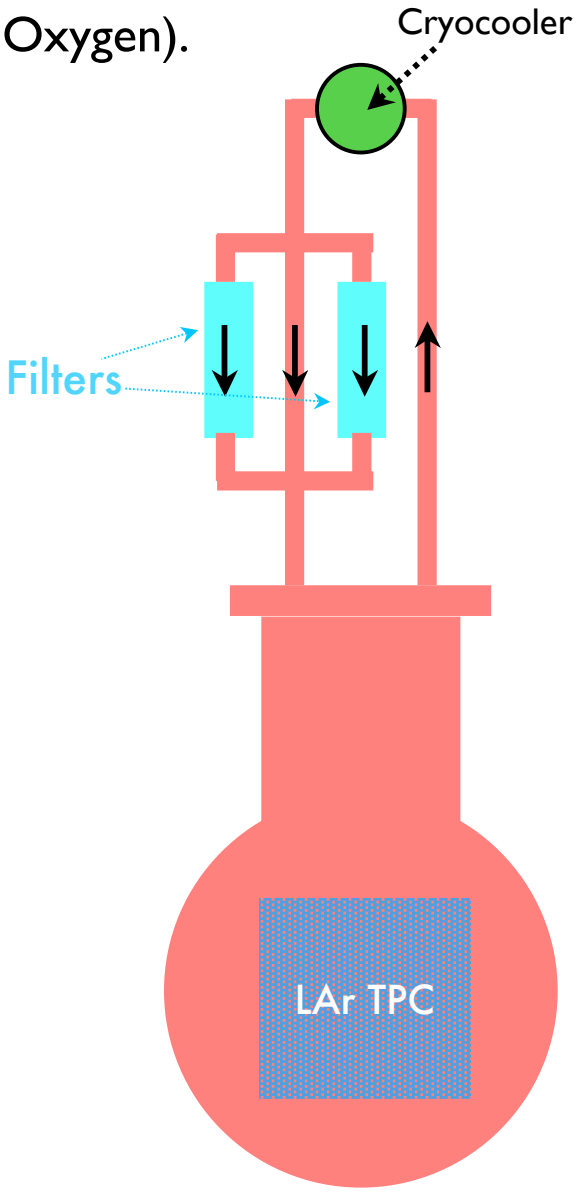
ArgoNeuT Cryogenics

- 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.



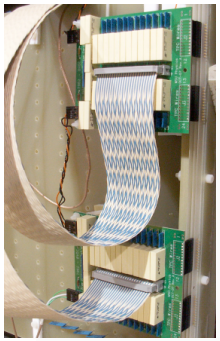
Vacuum-insulated vessel.

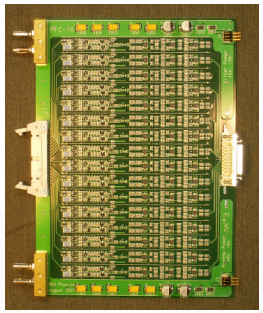
ArgoNeuT at PAB.

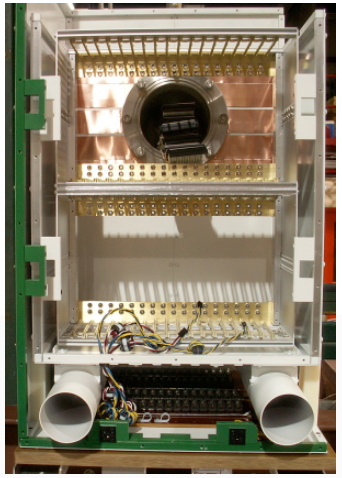


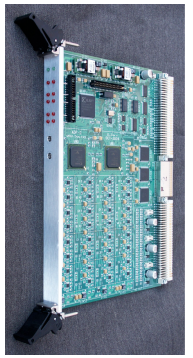
ArgoNeuT Electronics

- 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



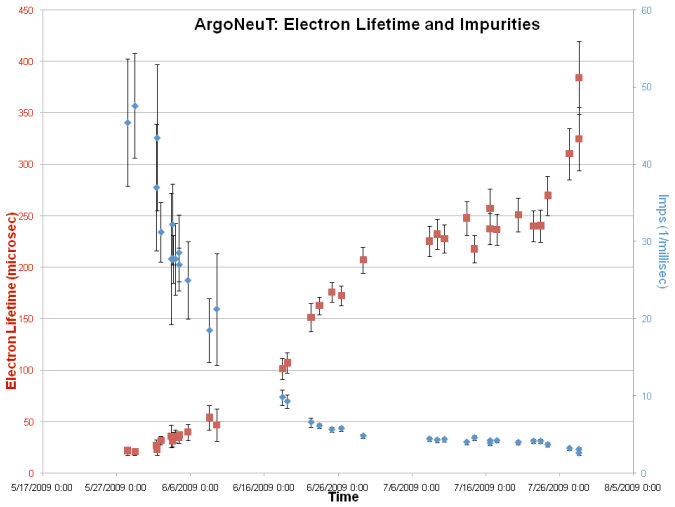






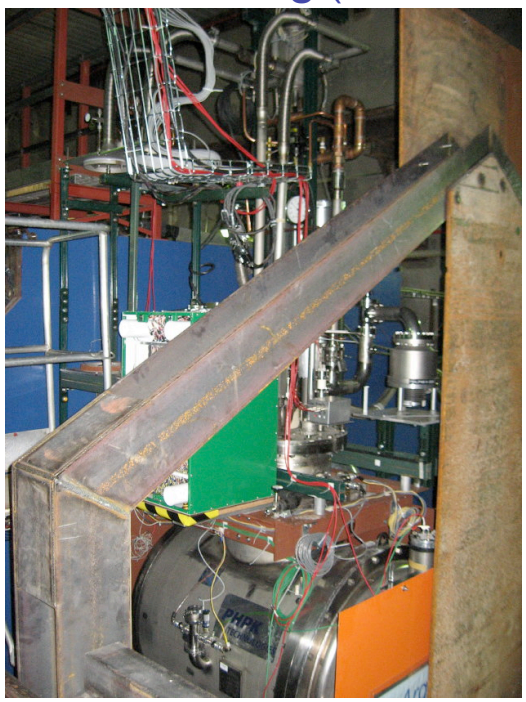
ArgoNeuT Detector: Status

- Filled the cryostat underground (MINOS ND Hall) - May 8th, 2009
- Initial argon purity was low....recirculating has cleaned things up....
- Took neutrino data for ~1 month before summer shutdown (preliminary analysis under way).
- Took cosmic muons (dedicated ext. trigger) over summer (preliminary analysis under way).
- Neutrino/Antineutrino Beam operation restarted on Sept.09 ⇒ new ν-event collected

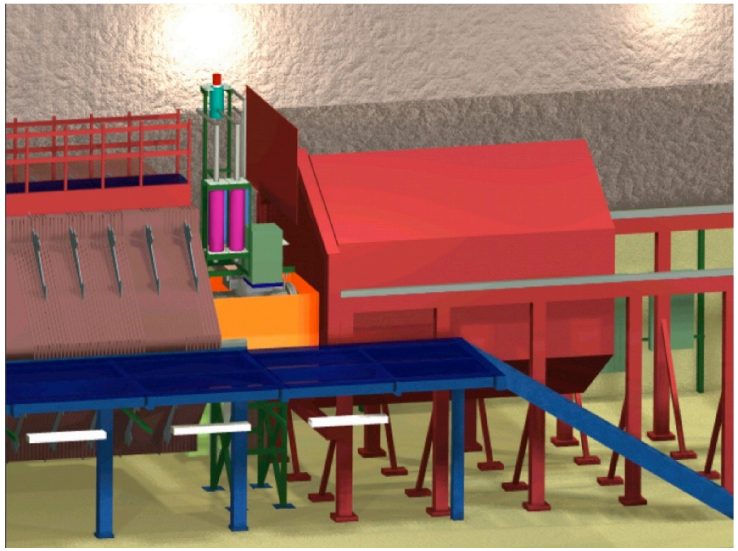


Moving underground

- (Unexpected) Cryocooler failure on Oct. 8th.
- After replacement, operation just re-started !!! (Oct. 25th)
- Data taking (anti-neutrino mode) under way.



Looking through Minerva frame.

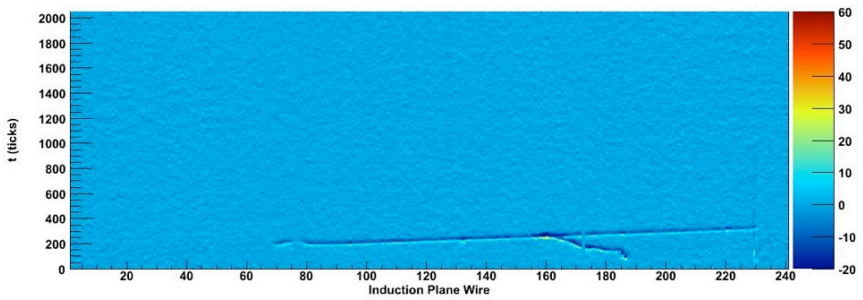


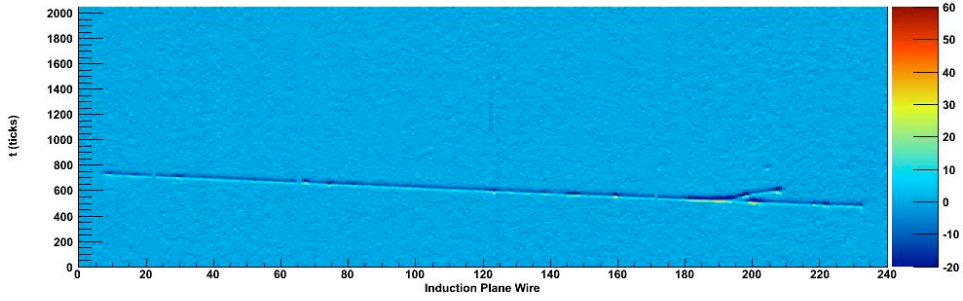
Schematic of NuMI experiments

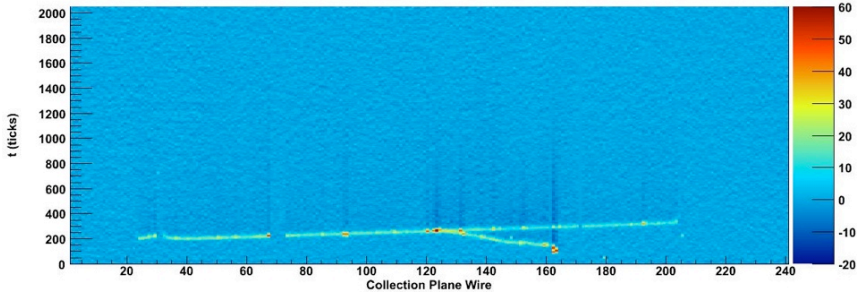
ArgoNeuT Events

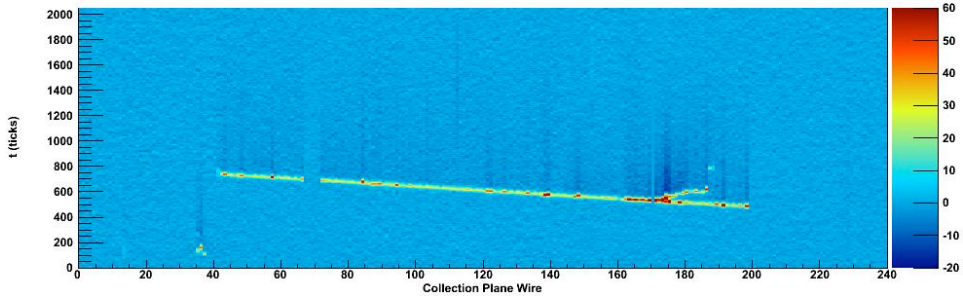
Event Displays,
Filtering and
Reconstruction
(all preliminary!)

Cosmic Muons with Deltas

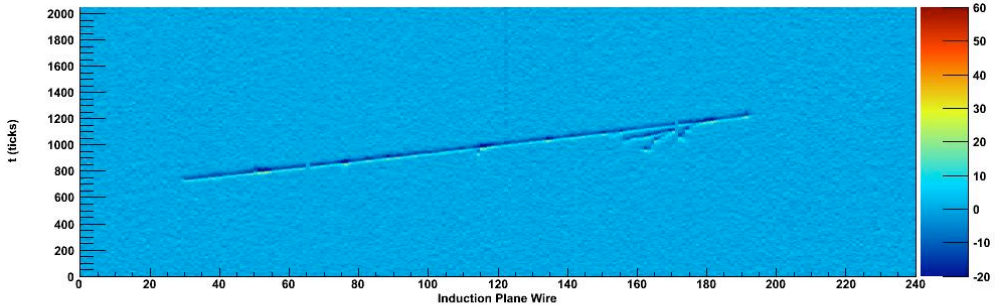


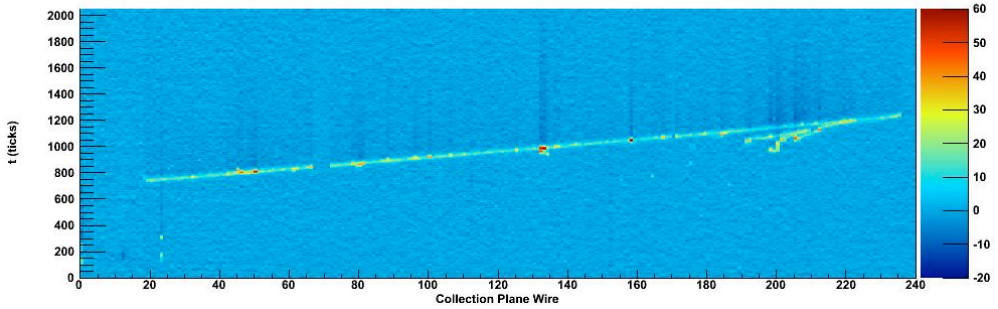






TPC provides two 2D-views of each event

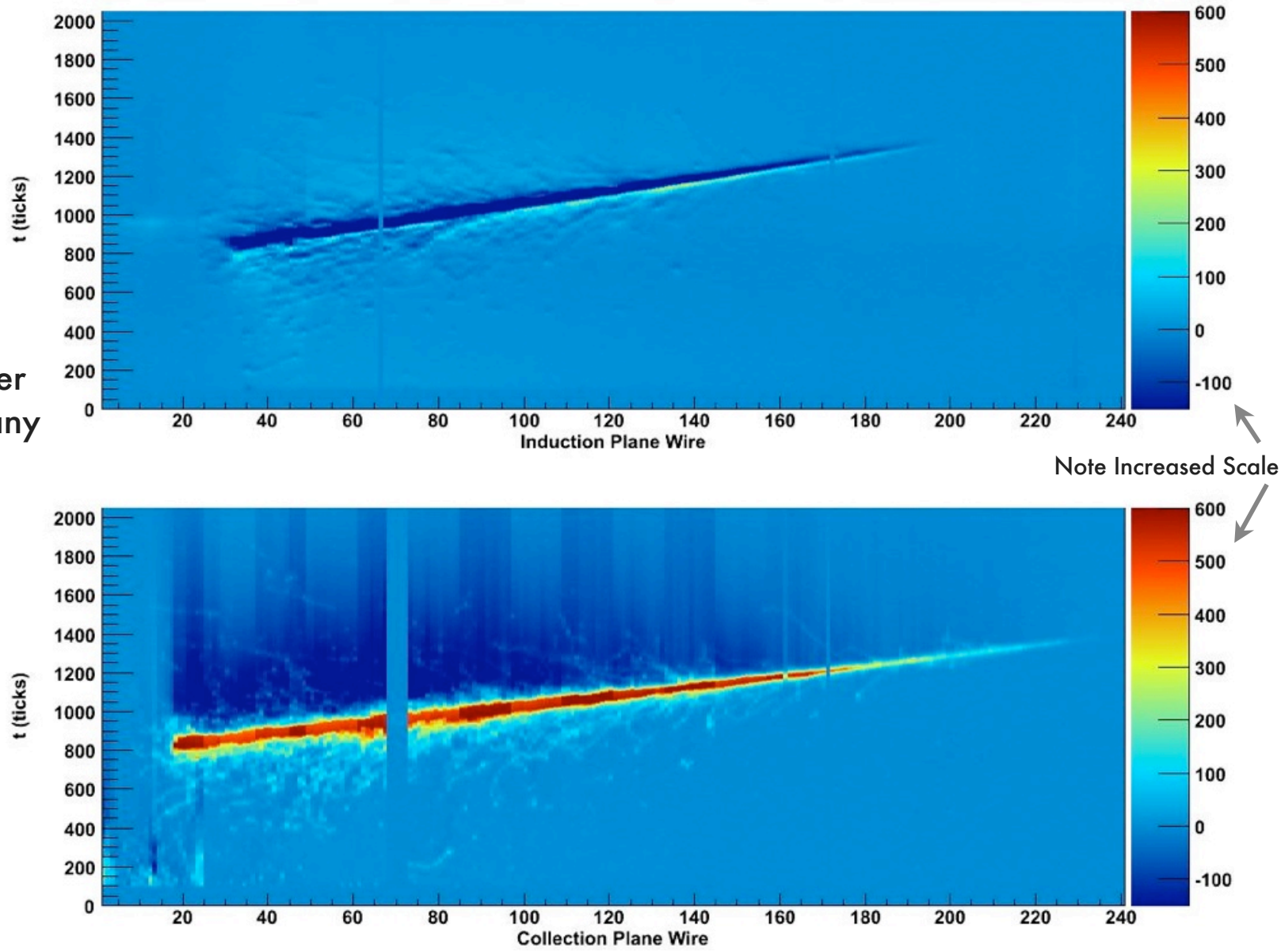




Color Index *(Collection plane)* proportional to amount of energy deposited

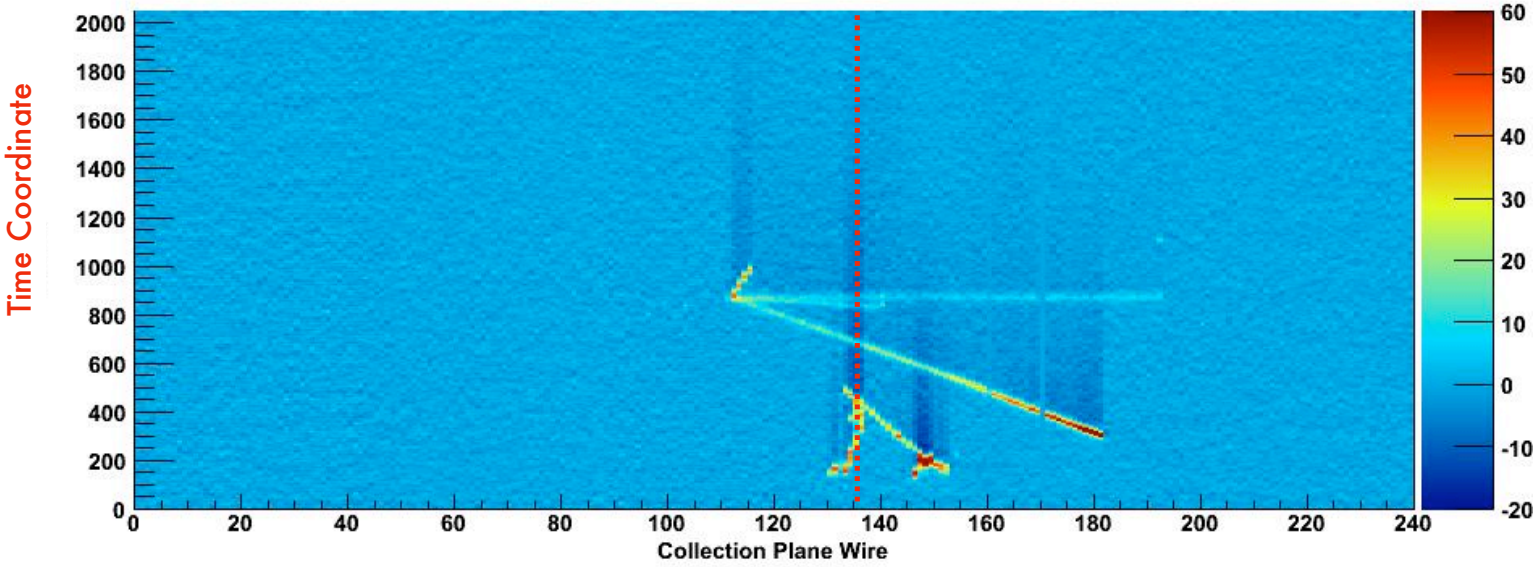
Cosmic Events

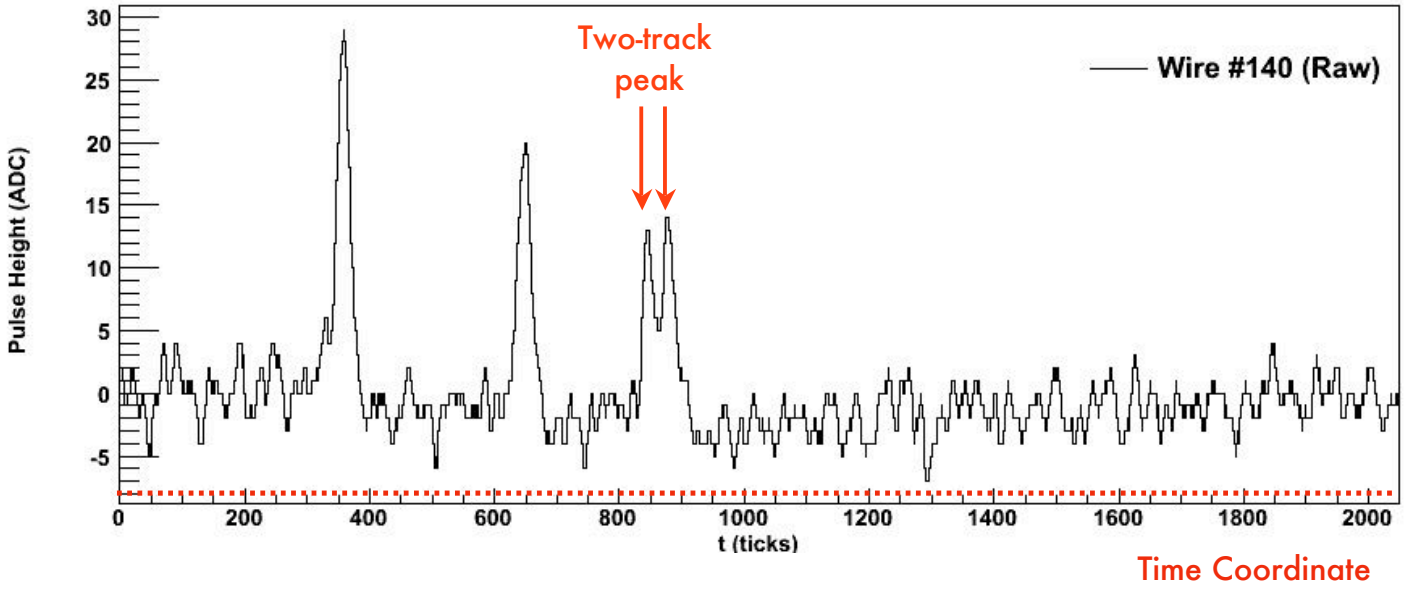
Very energetic cosmic-ray shower event…pushes many ADCs to their upper/lower threshold



Neutrino Events

- Very fine pixel size (4mm x 0.3mm)
- ~14ADC counts per 1fC of charge.
- Dark "shadow 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...

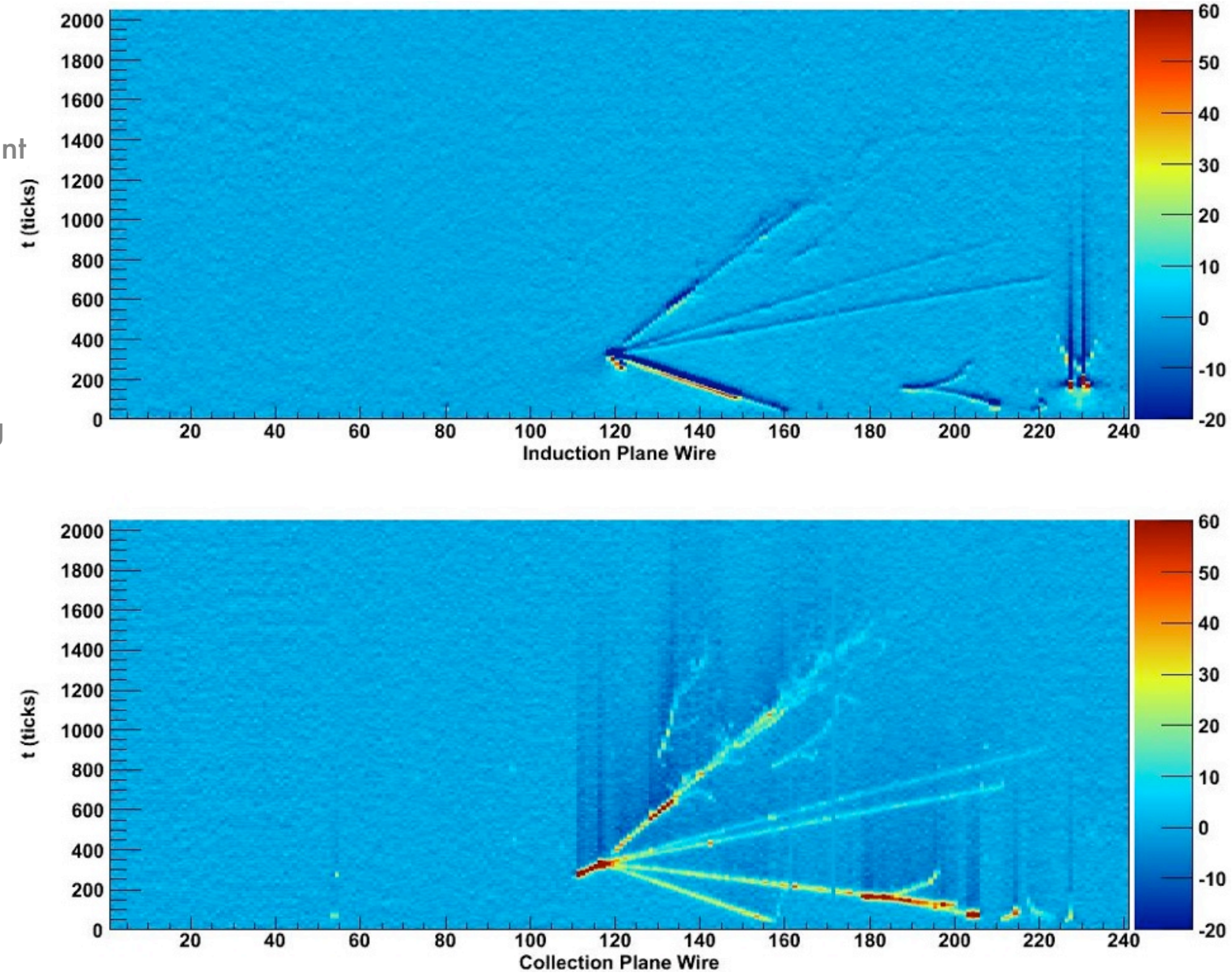




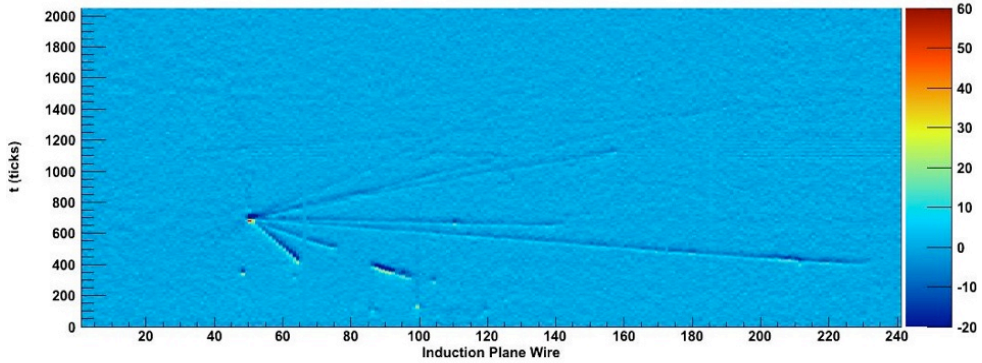
Neutrino Event: DIS Candidate

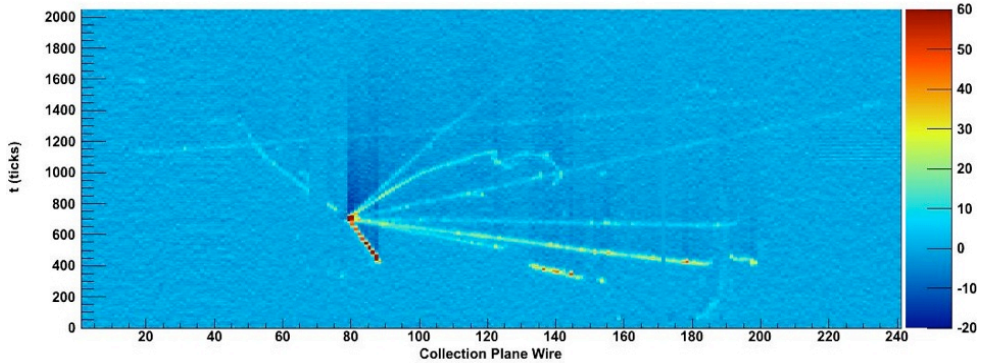
Multi-prong (DIS) event with
- μ (with δ-ray)
- π^0 ($\gamma\gamma$ into elm showers)
- Charged pions (uncontained)
- p (heavily ionizing short track)

NB: Ptcl. ID not really performed (…just by visual attempt)



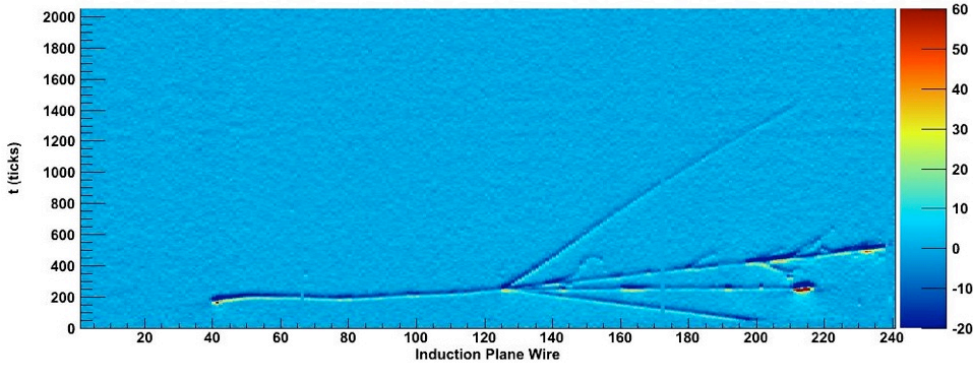
Neutrino Events

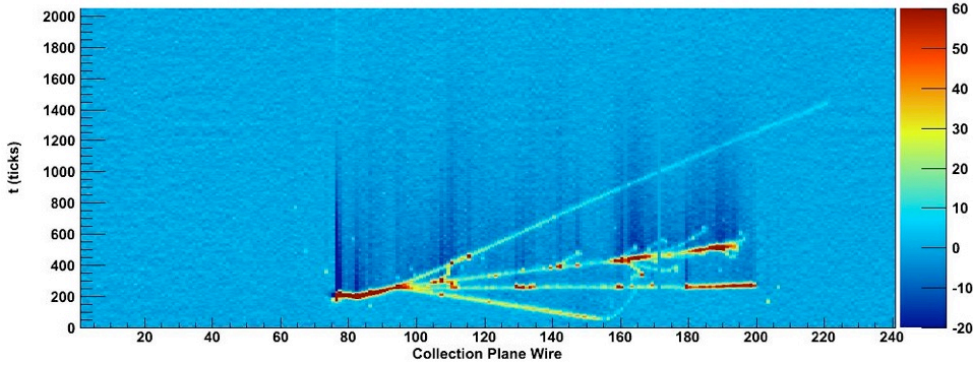




Recoil proton detectable
Down to 30 MeV kin.en

Two more DIS candidates.

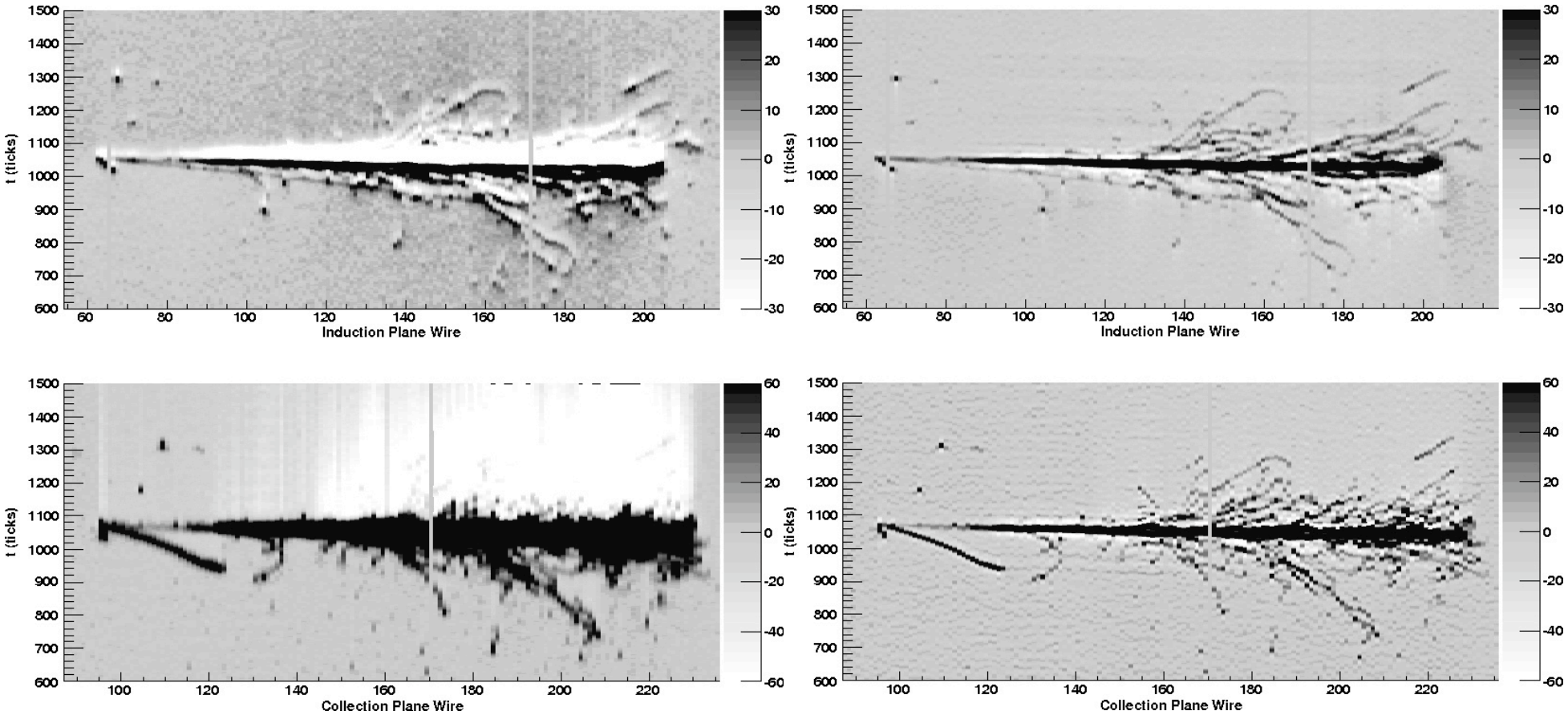




Event Filtering

LArSoft package: Much activity in developing reconstruction/full simulation software for ArgoNeuT (and future LArTPCs)

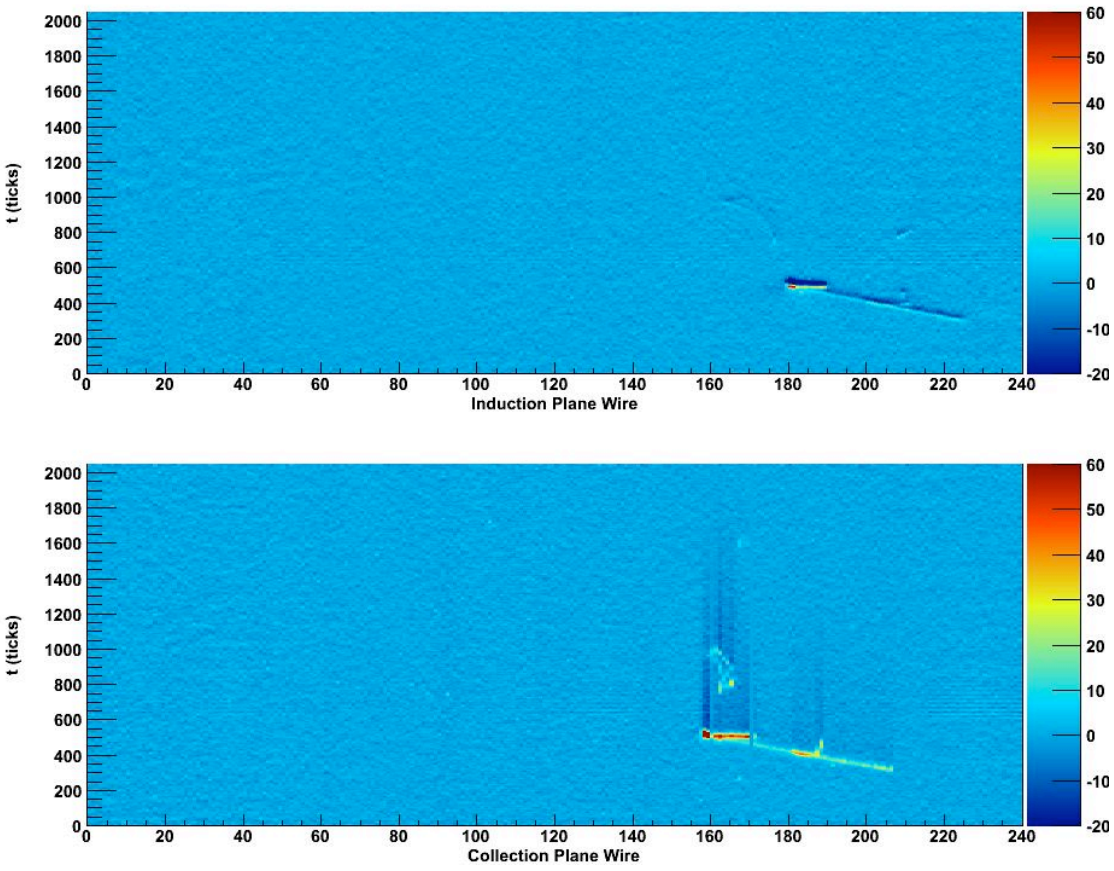
Event filtering: FFT tuning package running on LArSoft



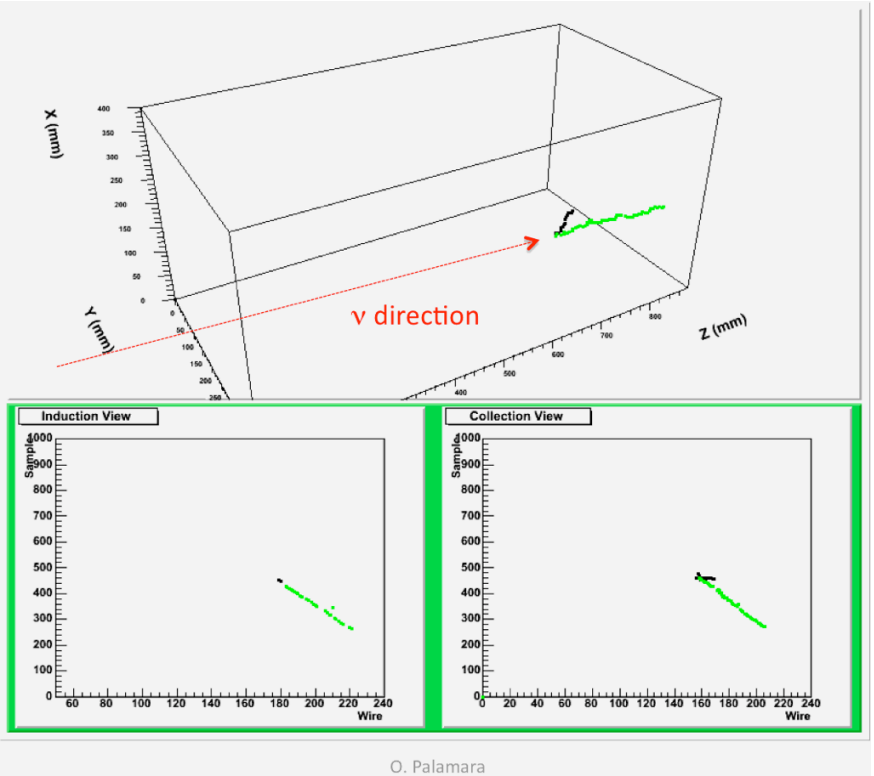
ν_e CC Candidate Event

Reconstructing Events

- Initial attempts at 3D event reconstruction *(and analysis - next two slides)*



Reconstructed "hits" and 3D view



ν_μ CC-QE Candidate Event

O. Palamara

Reconstructing Events

ArgoNeuT expected rate at NuMi :

~ 19 QE events/day + ~ 15 RES events/day + ~ 83 DIS events/day

Main aim of the experiment: QE cross section measurement with Ar target in the few GeV energy range.

Reconstruction of neutrino CC interactions

QE process:

$\nu_\mu + n \rightarrow \mu^- + p$ (reaction on free nucleon)

when nucleon bound in the nuclear target nuclear effects must be taken into account:

$\nu_\mu + A(n) \rightarrow \mu^- + p + (A\text{-}1)^*$

FSI

- -Nuclear evaporation (low kin.en. p and n)
- -Fission (nuclear fragments)
- - γ emission from nuclear de-excitation

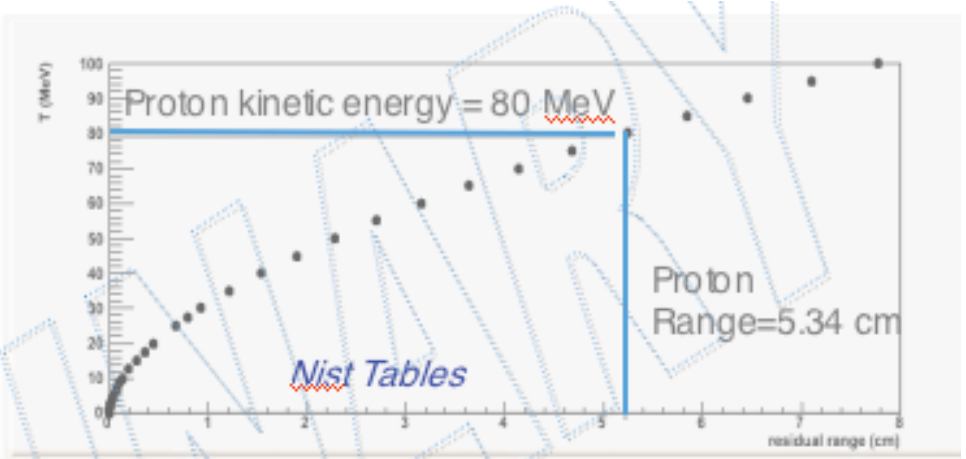
These products are usually neglected because not detectable, unless…

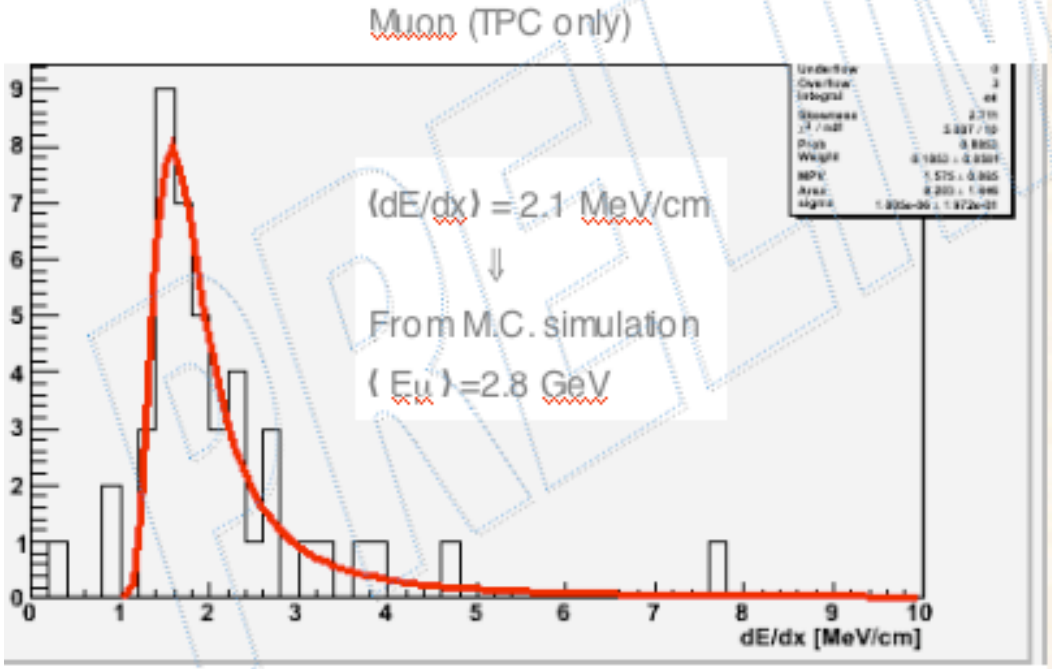
…. a high quality imaging detector is in use !!

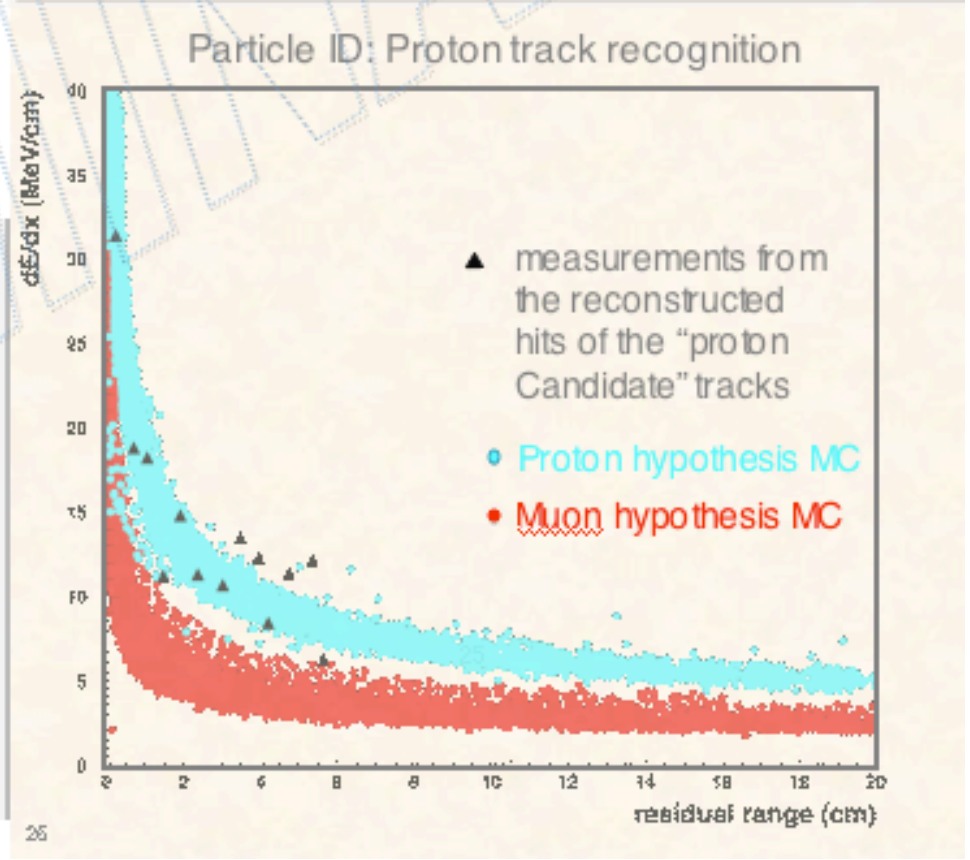
Reconstruction procedure (proton and muon) as for the ICARUS 50 lt

Reconstructing Events

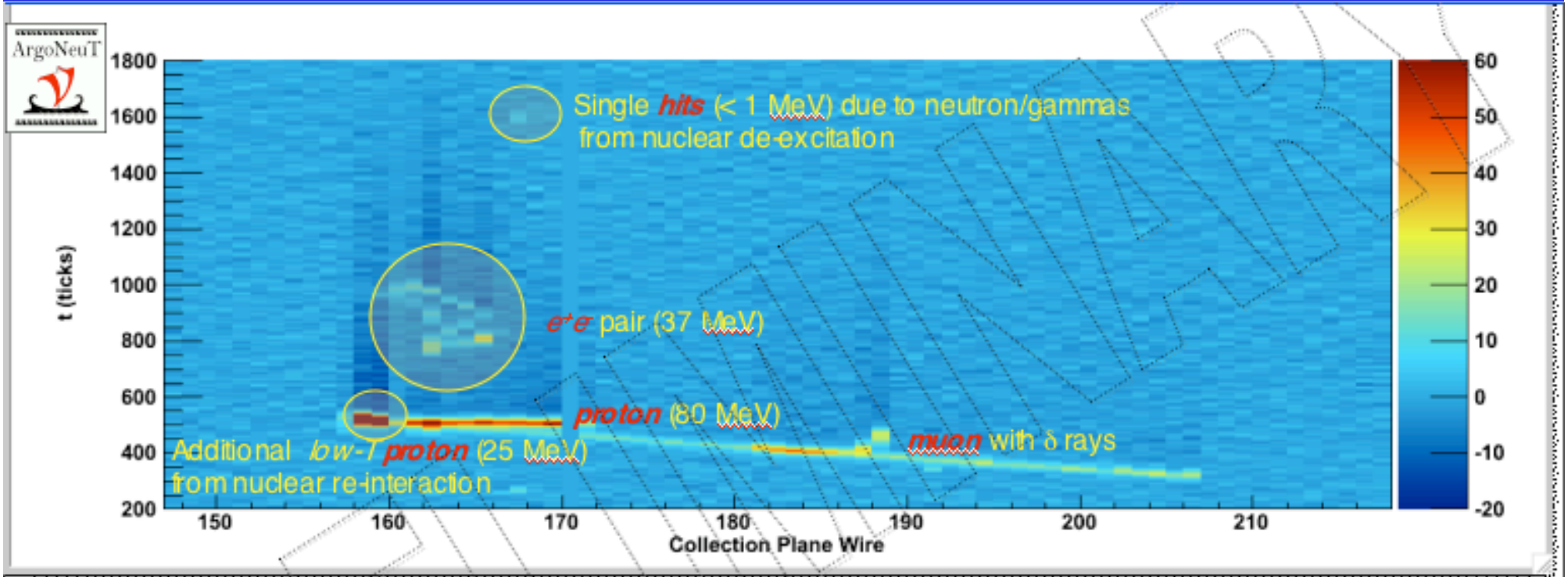
Final State
Muon and ***Proton***
reconstruction







Reconstructing Events



1) large activity near the vertex

$\mu^- + p + X$ (X = additional "short track" [2 wires] associated with high energy density deposition)

X compatible with a second 25 MeV p track from nuclear evaporation (FSI in nucleus) or pion re-absorption

2) an extra energy deposition (37 MeV) possibly associated with the event (e^+e^- pair), induced by a neutral particle.

NB: This event reconstruction is preliminary.

A full and detailed MC simulation including nuclear effects is required for validation.

A preliminary FLUKA MC simulation support the possibility to detect such nuclear effects in LAr TPC.

Goal of Data Analysis

One of the main uncertainties in long baseline oscillation experiments is given by the neutrino-nucleus interaction cross section in the “Few-GeV region”.
In this range the dominant reaction is the Charged Current Quasi Elastic Scattering.

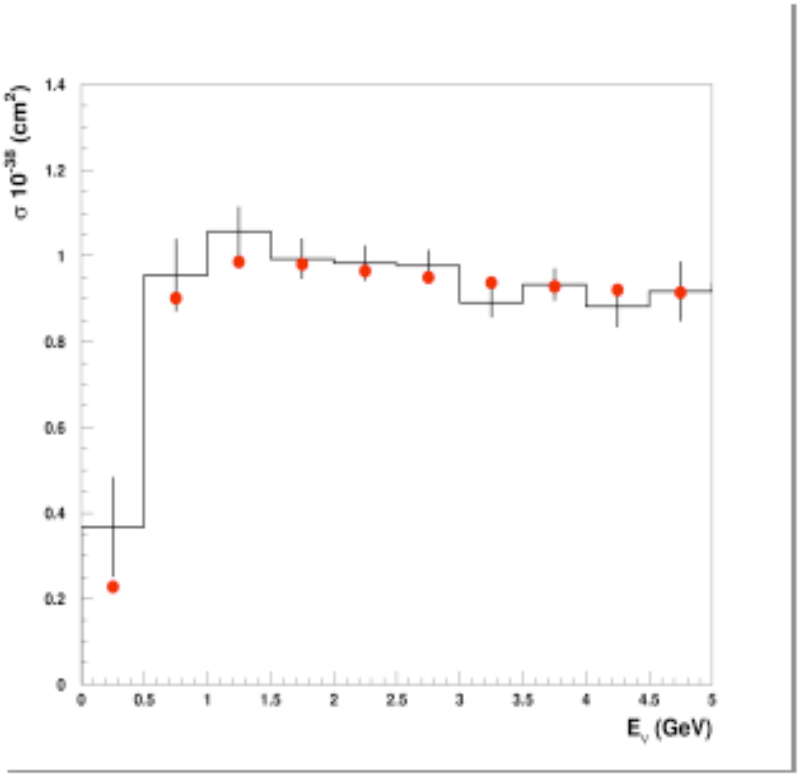
The total number of QE ν_μ events and the relative energy distributions have been MC calculated (LE-NuMI: 8 x 10^{17} PoT/day) as a function of the incoming neutrino energy (bin size 0.5GeV). The value of M_A adopted here is 1.03GeV/c^2 .

The experimental QE X-sect distribution for ArgoNeuT has been MC reproduced as expected from a 180 days run of on-axis exposure on the NuMI Beam.

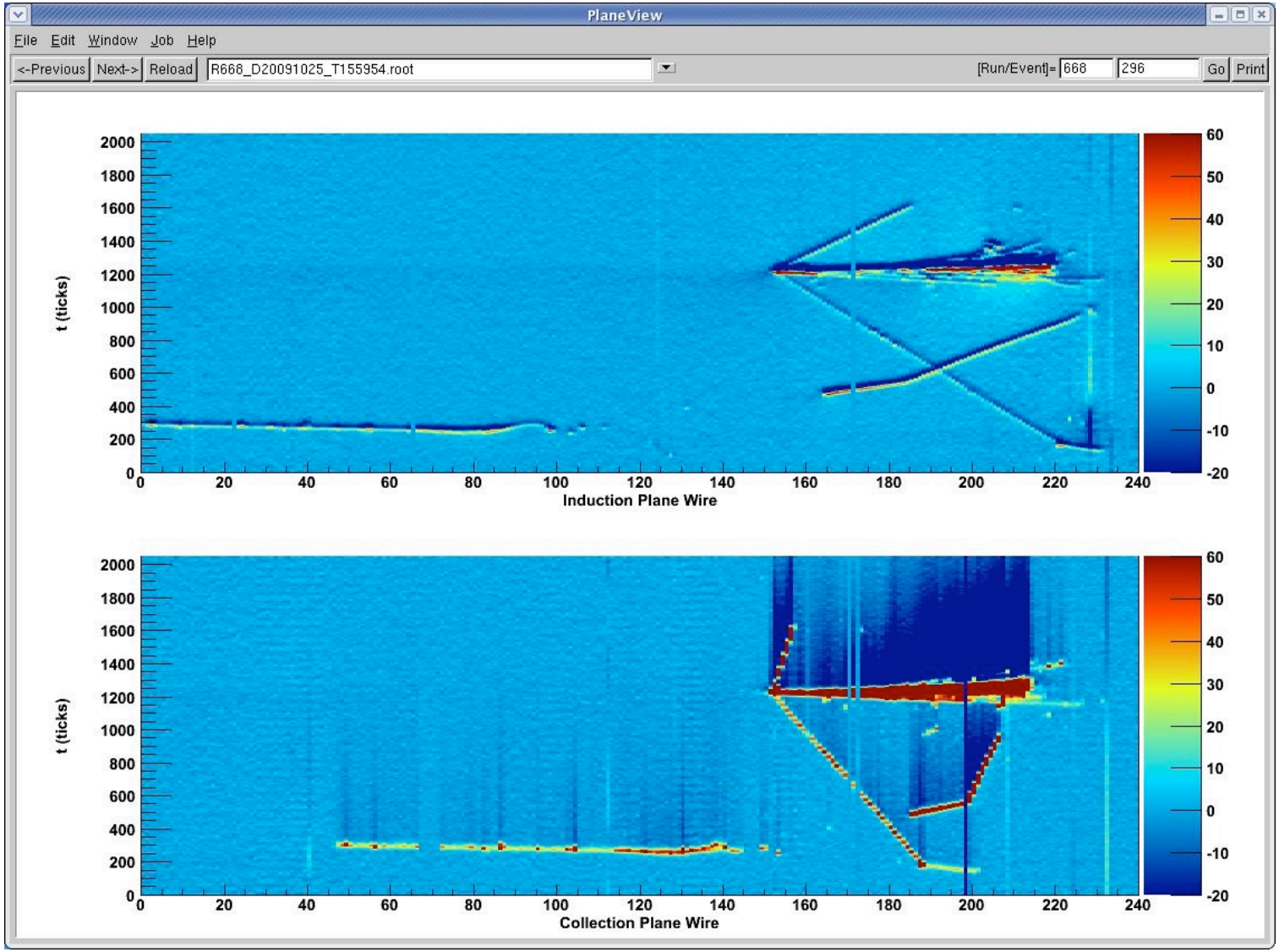
It was assumed that all the collected events are somehow fully reconstructed.

Statistical errors are reported. The red dots indicate the theoretical X-sect (M_A= 1.03).

QE ν_μ Abs. X-sect Reconstruction



ArgoNeuT today…



This is the first anti-nu event collected after operation restart (Oct 25th) !

Conclusion

Next-generation neutrino physics experiments require precision Particle IDentification and fine grained 3D imaging on very large scale. Liquid Argon TPC combines an ideal detection medium with a modern imaging and calorimetric readout technique, scalable to very large volume/mass.

ArgoNeuT is fully operational, providing (large) samples of neutrino/antineutrino events in a (small) LArTPC - for the 1st time in the U.S. and the 1st time ever in a low-Energy beam.

The present run will last untill March,'10.
After this, the extension to further run period is under evaluation

Extensive Real data/experience is invaluable in improving LArTPC technique. Analysis software being developed is general purpose for future LArTPCs

Liquid-Argon Time Projection Chambers

Outlook of R&D Program in the US

Active Volume

Yale TPC & Bo
Yale TPC: Dismantled
Bo: Operational

0.00002 kton

15 x

ArgoNeuT
Operational
Physics: Measure neutrino-argon cross sections

0.0003 kton

330 x

MicroBooNE
Construction begins 2010
Physics: Investigate low-energy neutrino interactions

Measure low energy neutrino Interactions:
- MiniBooNE low energy excess
- Suite of low energy cross section mmnts.

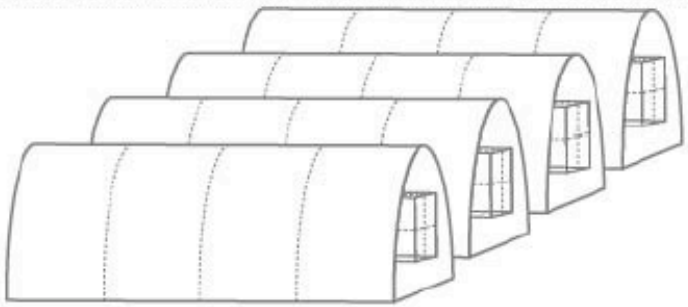
0.1 kton

4 x 50 x

LAr TPC for LBNE
R&D in progress
Physics: Measure neutrino oscillations at 1,000+ km

20 kton

Final goal
Replicate proven technology
Physics: Search for CP violation in neutrino sector



N x 20 kton