ArgoNeuT: a liquid argon TPC for the study of ν *interactions in the intermediate* energy range.

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Outline

- LAr TPC technology
- ArgoNeuT Test Experiment: Design, R&D / Physics Goals, Present Status
- Events gallery and a preliminary Event Reconstruction
- Conclusions

Present Scenario in Neutrino Physics

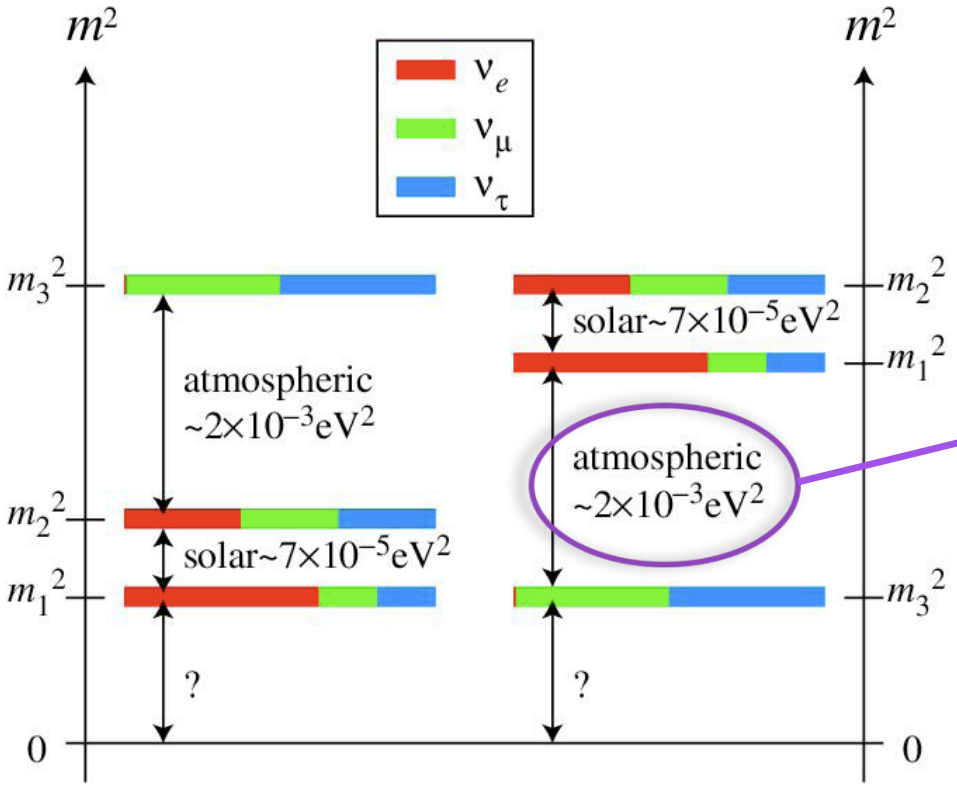
Known

$\Delta m^2_{21} \sim 7 \times 10^{-5} eV^2$

$\Delta m^2_{32} \sim 2 \times 10^{-3} eV^2$

$\theta_{12} \sim 33^\circ$

$\theta_{23} \sim 45^\circ$



Open Questions in ν Oscillation sector:
- Which is the value of ϑ_{13}?
- Is mass hierarchy normal or inverted?
- Is there CPV in neutrino sector?
- Are there more then 3 ν mass eigenstates?

Long BaseLine (**750km**) ν oscillation experiments are focused in the *"few GeV"* energy range where the probability for ν-flavour transition is maximum

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta) \cdot \sin^2\left(1.27\Delta m^2 \frac{L}{E}\right) \approx P_{max}$$

~ 1GeV

Answer Needs:
- High Intensity Neutrino Beams
- Massive Detector with good BG rejection

In this sense the LAr TPC seems to be an ideal detector

LAr TPC Technology

The LAr TPC (Time Projection Chamber) *Technology has been conceived and developed in Italy by the ICARUS Collaboration that has carried out the construction and test of the ICARUS T600 detector (600 tons of LAr).*

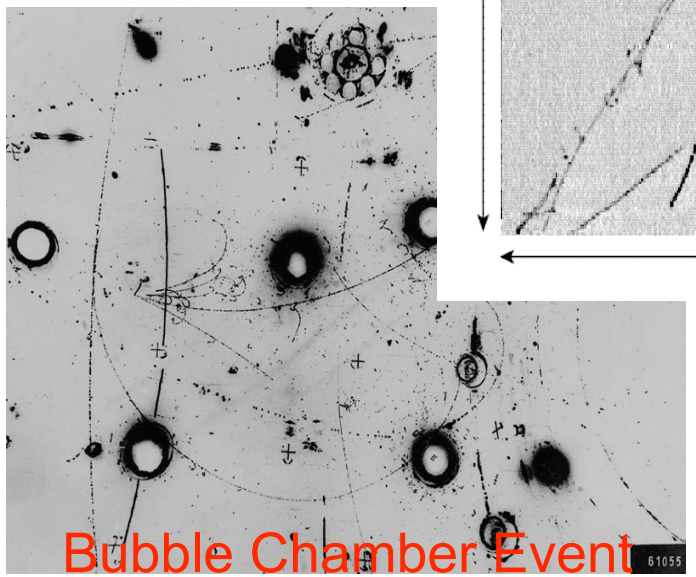
The LAr TPC is a detector particularly suitable to study neutrino interactions due to its high energy resolution and its robust particle identification capability in the **few GeV range**

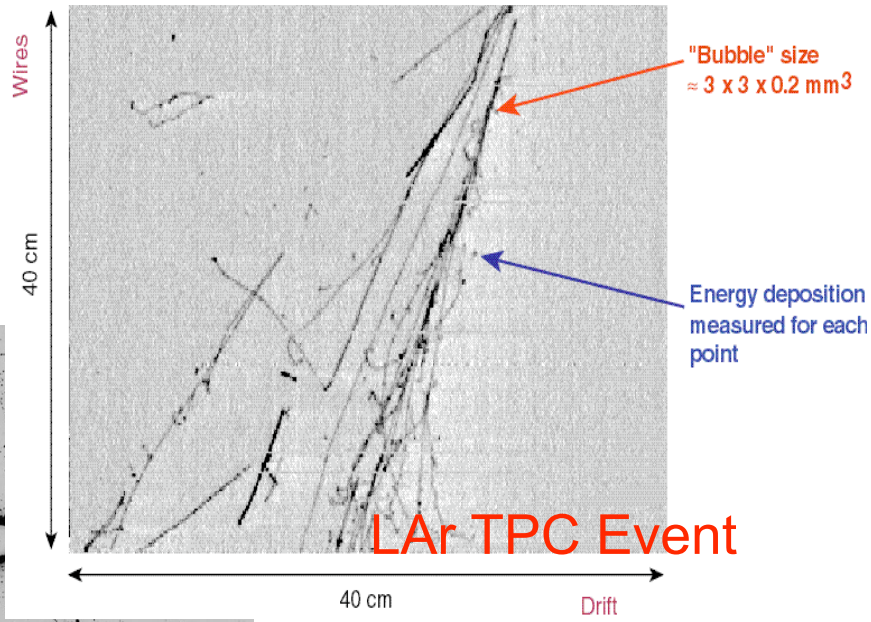
The LAr TPC is considered a novel Electronic Bubble Chamber

Main characteristics:

- Imaging (3D reconstruction)
- High spatial (~mm) and energy resolution
- Low energy threshold (down to few MeV)
- Self-triggering capability
- Continuously sensitive
- Scalable (in principle) to high mass scale ~10-100 kton

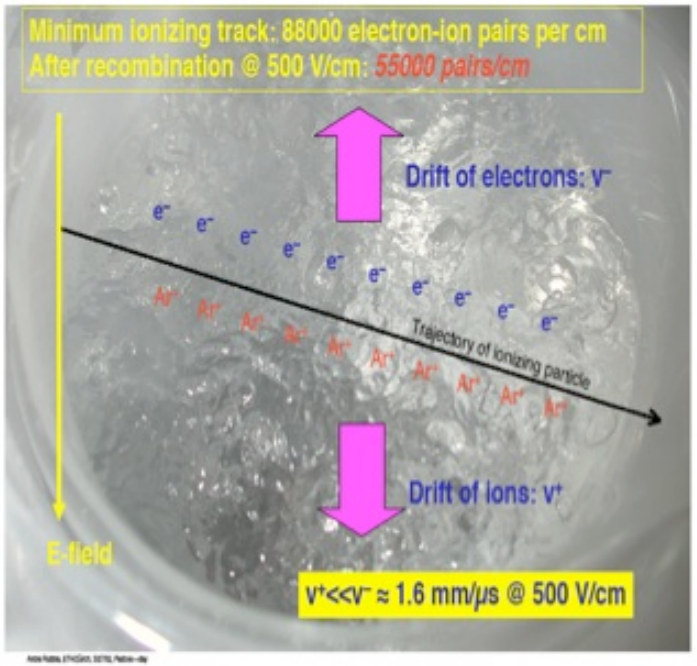
To be proved!!

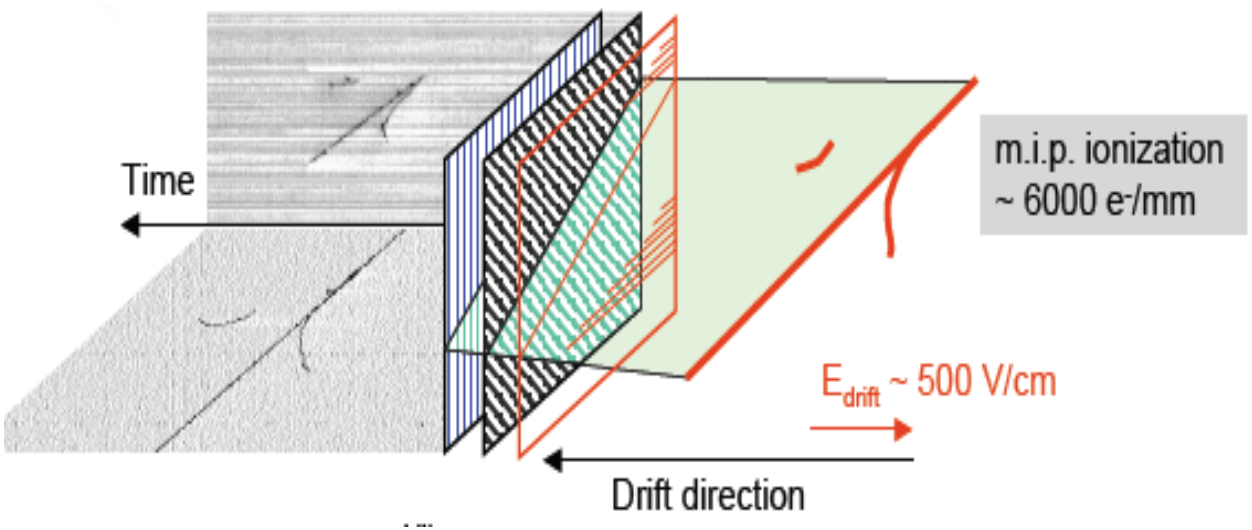




LAr TPC Working Principle

- A charged particle crossing LAr produces e^--Ar^+ pairs along its path.
- An Electric Field applied to the LAr volume makes ionization electrons drifting toward the TPC anode (made of 3 parallel wire planes: 1 grid and 2 read-out planes, wire pitch ~3-4mm)
- Electrons drift over very long distances if Argon is very pure (1 meter drift requires purity level at 0.1 ppb)
- Charges induces an electronic signal on the wires.
- Signals are acquired through low noise charge amplifiers.
- Multiple non-destructing read-out wire signals can be assembled for 3D (and calorimetric) event reconstruction

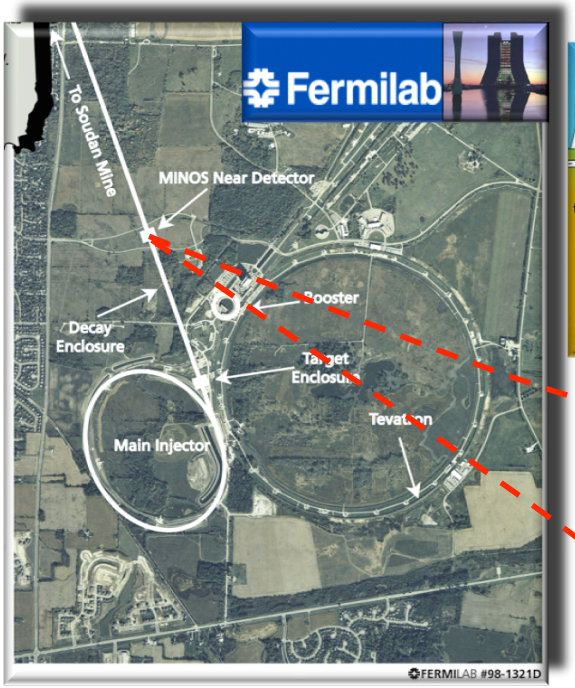


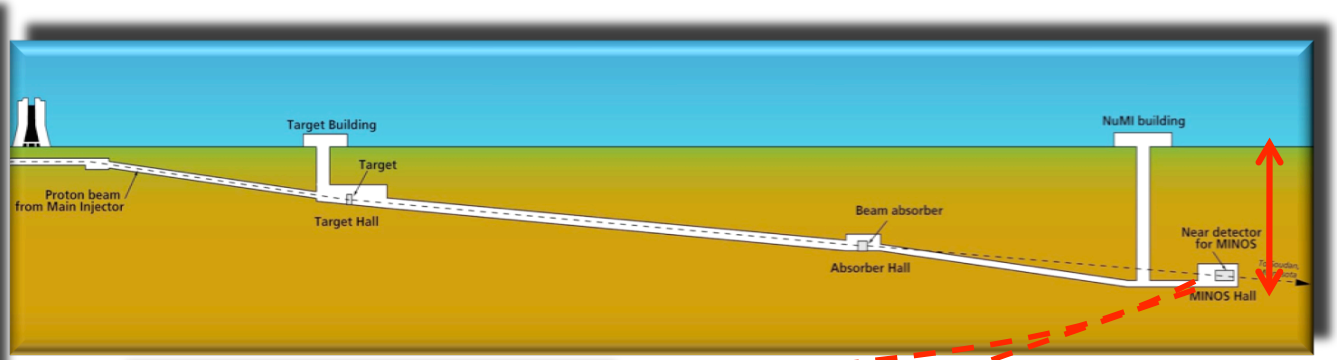


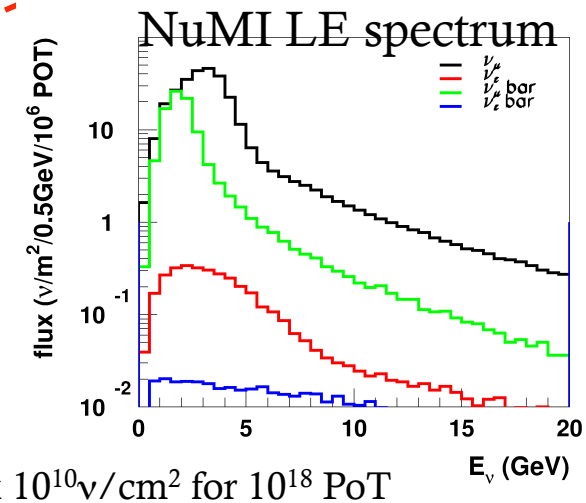
The ArgoNeuT Experiment

- ArgoNeuT is a joint NSF/DOE R&D project at Fermilab (USA) to expose a small Liquid Argon TPC to the NuMI low energy neutrino beam.

- ArgoNeuT detector is presently located between MINERνA and the MINOS near detector at NuMI Tunnel – 100m underground. Muons escaping the TPC are reconstructed in MINOS ND.







Collecting events in the 0.1 to 10 GeV range, ArgoNeuT is producing the first ever data for low energy neutrino interactions within a LArTPC.

$\Phi_\nu = 3 \times 10^{10} \nu/cm^2$ for 10^{18} PoT

The ArgoNeuT Collaboration

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The University of Texas at Austin

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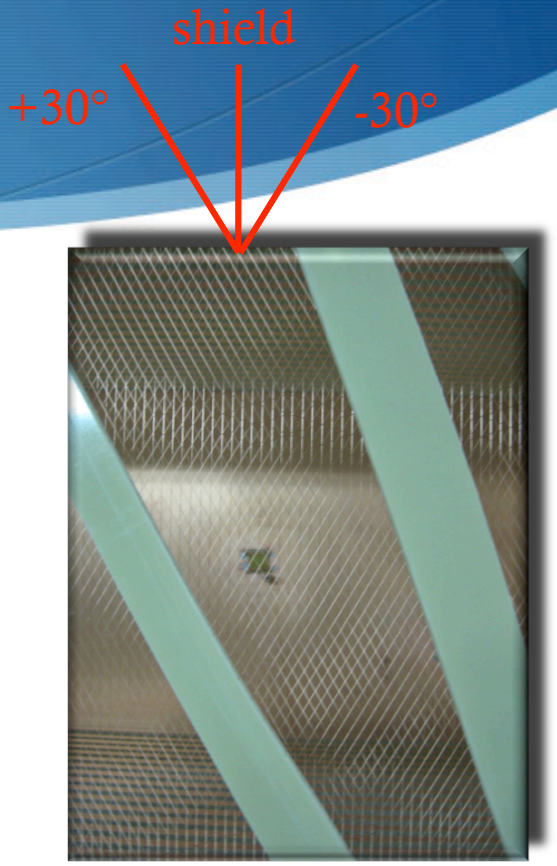
Yale University

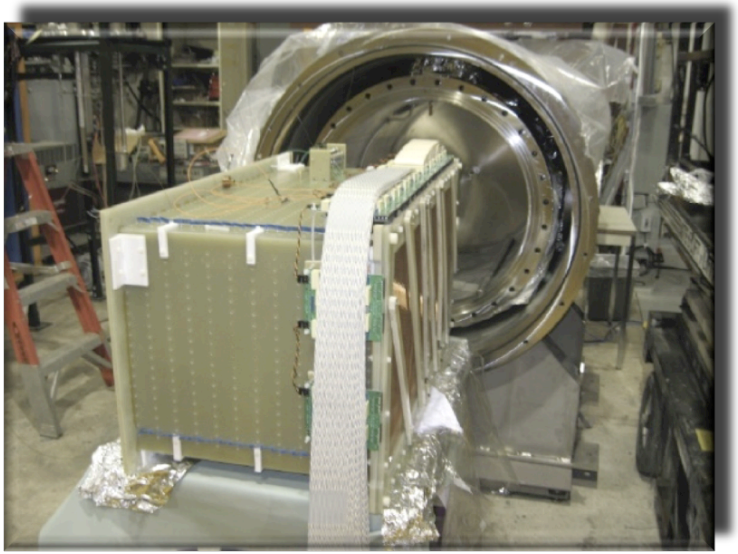
ArgoNeuT Goals

- ArgoNeuT will address some of the hardware and physics R&D issues on the way toward massive LAr TPC detectors (MicroBooNE, LAr20 etc..) in terms of:
  - Argon purity, electronics, detector design and construction, etc.
  - Development of MC Simulation and off line reconstruction
- Demonstrate **particle ID** capabilities of LArTPCs with **dE/dx and Range** measurements
- Physics:
  - Study CC and NC neutrino events in the “few GeV range” in LAr
  - Precise CC QE ν_μ cross section measurement in Argon

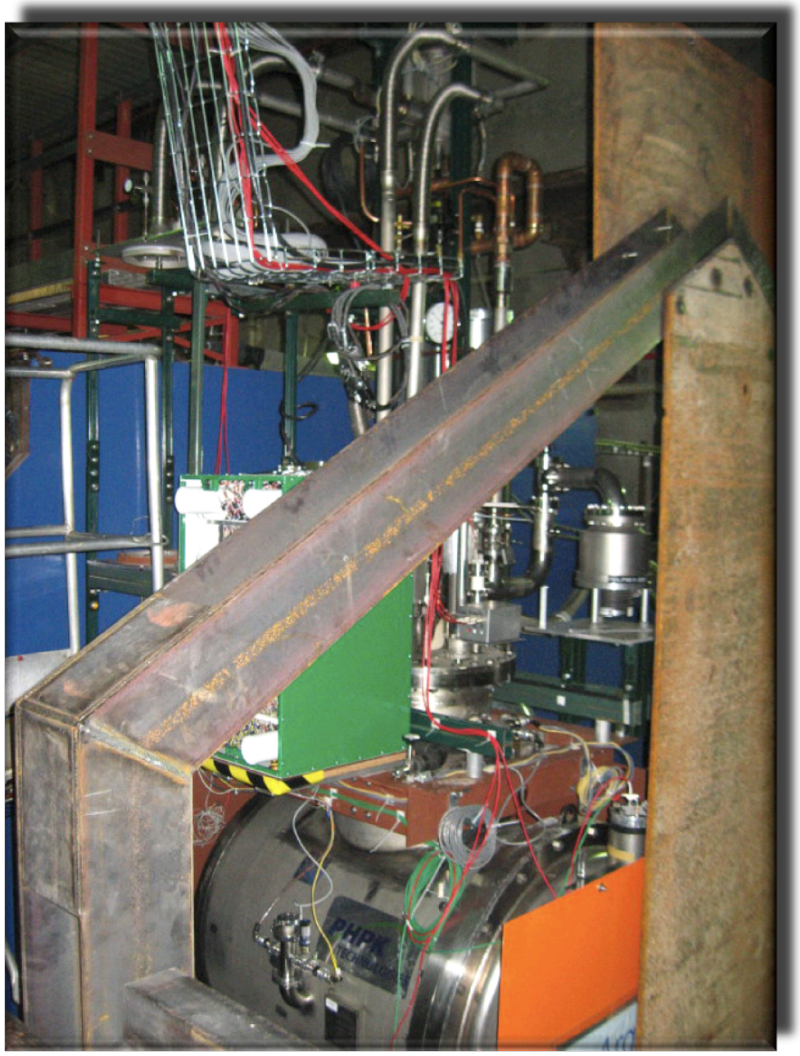
ArgoNeuT Design

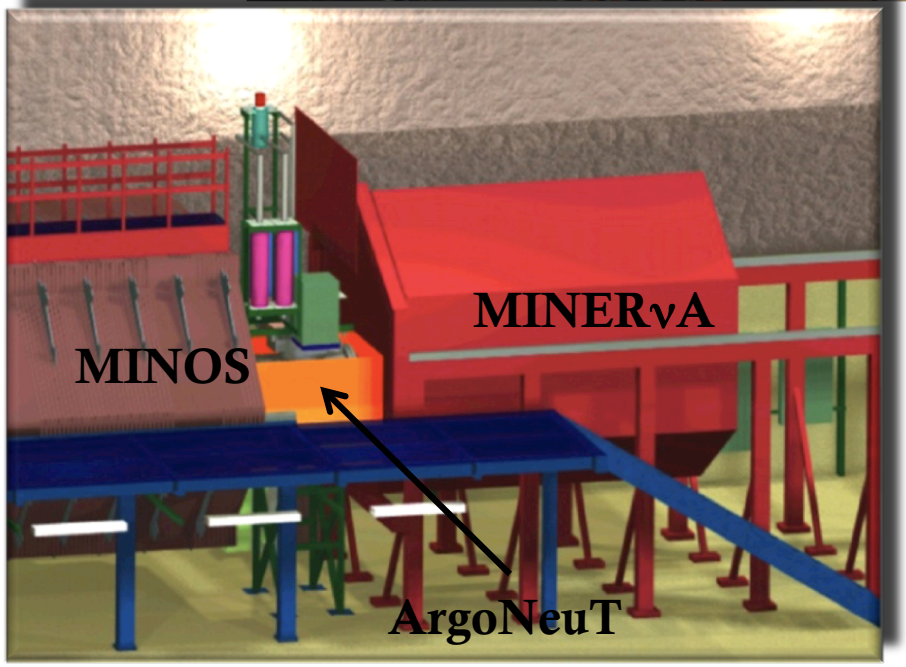


- 170 L LAr active volume (47x40x90 cm^3 ~235kg; total volume 500 L)
- 2 read-out planes: Induction and Collection
- 240 wires per plane.
- Wires orientation: ± 30° with respect to vertical
- 4mm wire pitch, 4mm plane spacing
- 2048 samples over 400 microseconds (per spill)
- 500 V/cm electric field
- 47 cm maximum drift

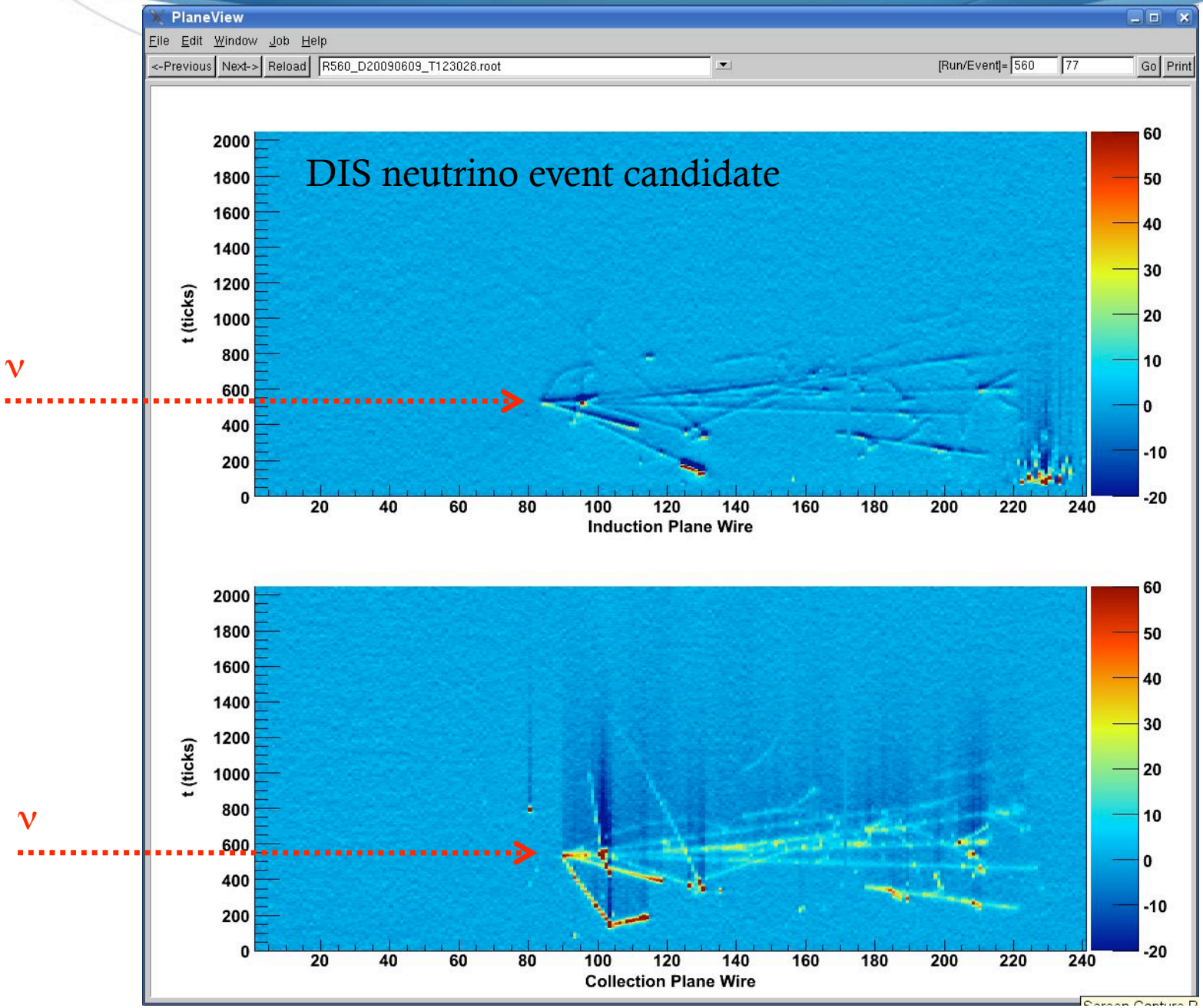


ArgoNeuT Underground Location





ArgoNeuT Event Display: Raw Data



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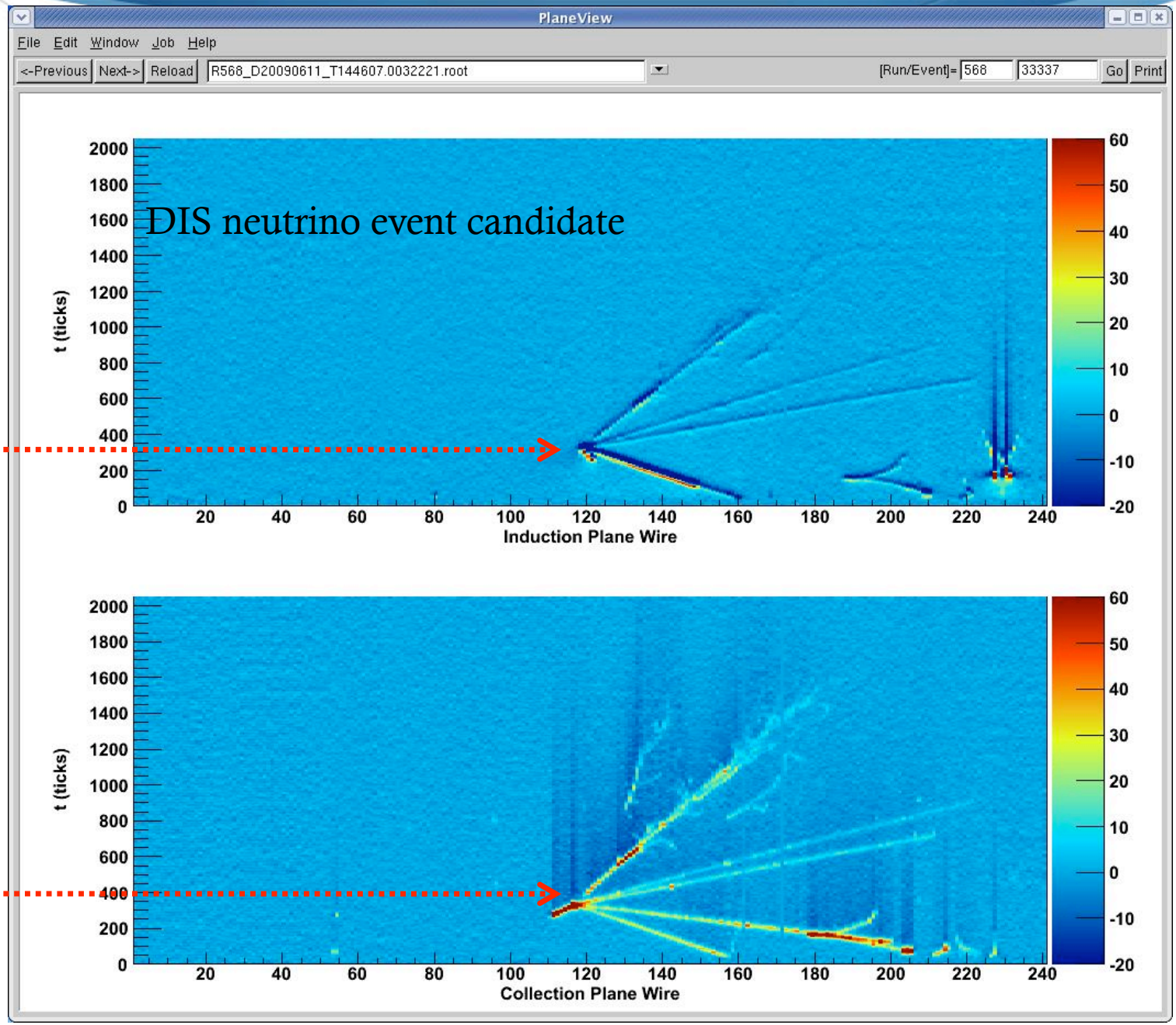

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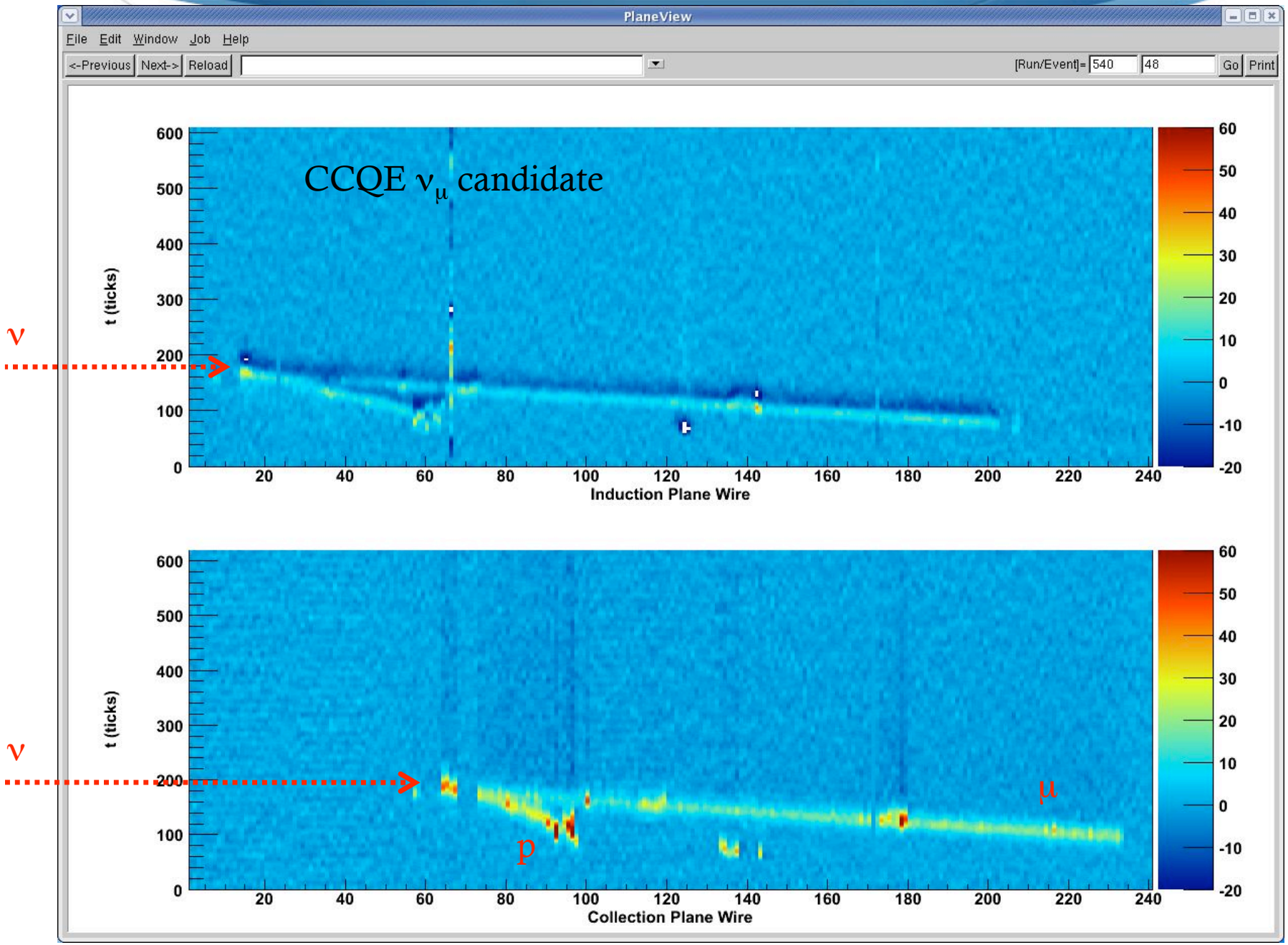

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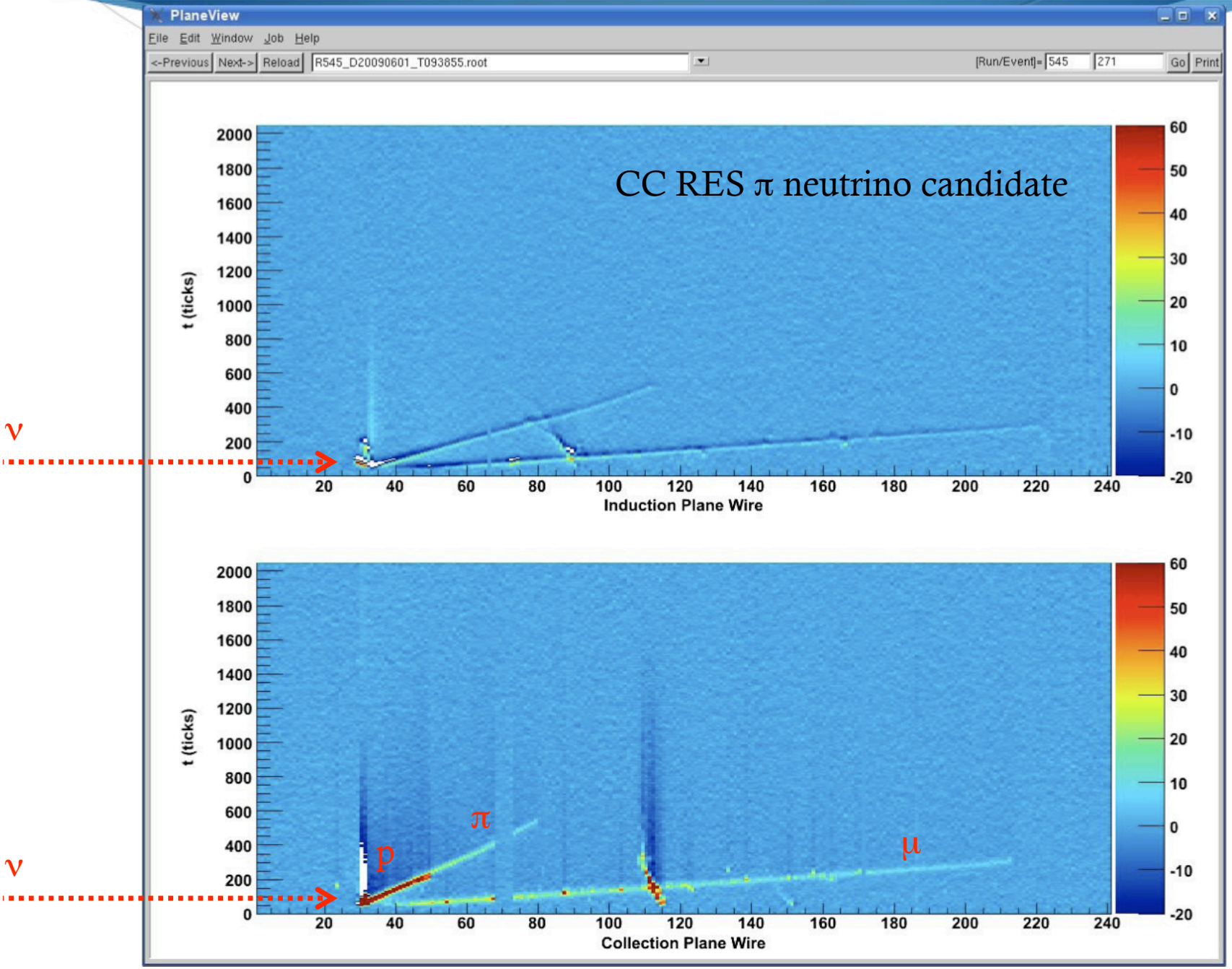
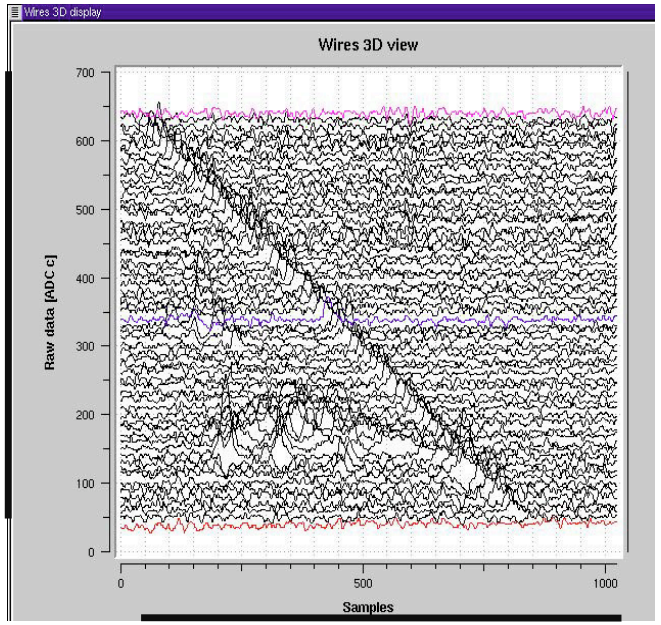


Event reconstruction procedure in LAr TPC (I)

The purpose of the reconstruction procedure is to extract physical information provided by the wire output signals (multiple non-destructing read-out planes), i.e. the energy deposited by the different particles and the space coordinates where such a deposition has occurred (HIT)

➔ to build a complete 3D (imaging) and calorimetric picture of the event

wire



time

The offline reconstruction procedure consists of:

1. *hit identification*: the hits are independently searched for in every wire as signal regions of a certain width above the baseline;

2. *hit reconstruction*: the parameters defining the hit (position, height, area), which contain the physical information, are determined;

Event reconstruction procedure in LAr TPC (II)

3. *cluster reconstruction*: hits are grouped based on their position in the wire/drift coordinate plane (2D reconstruction);

4. *3D hit reconstruction*: the hit spatial coordinates are reconstructed by the association of hits from different views into common track segments;

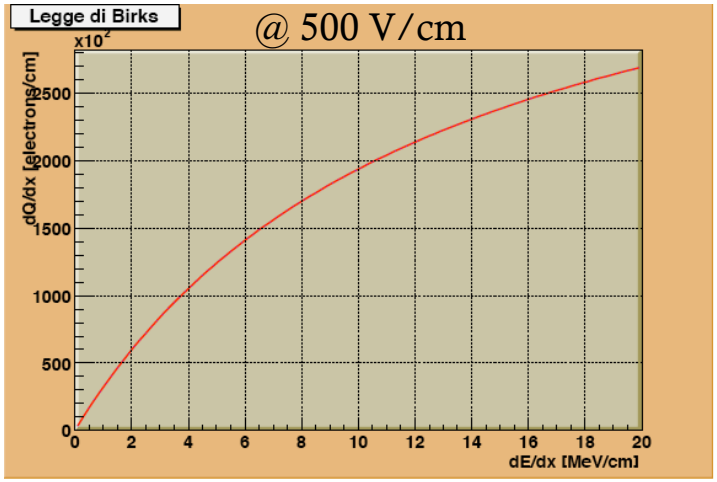
5. *calorimetric reconstruction*: the determination of the energy release in LAr is performed in two steps:

- accounting for the charge loss due to the attachment by electro-negative impurities

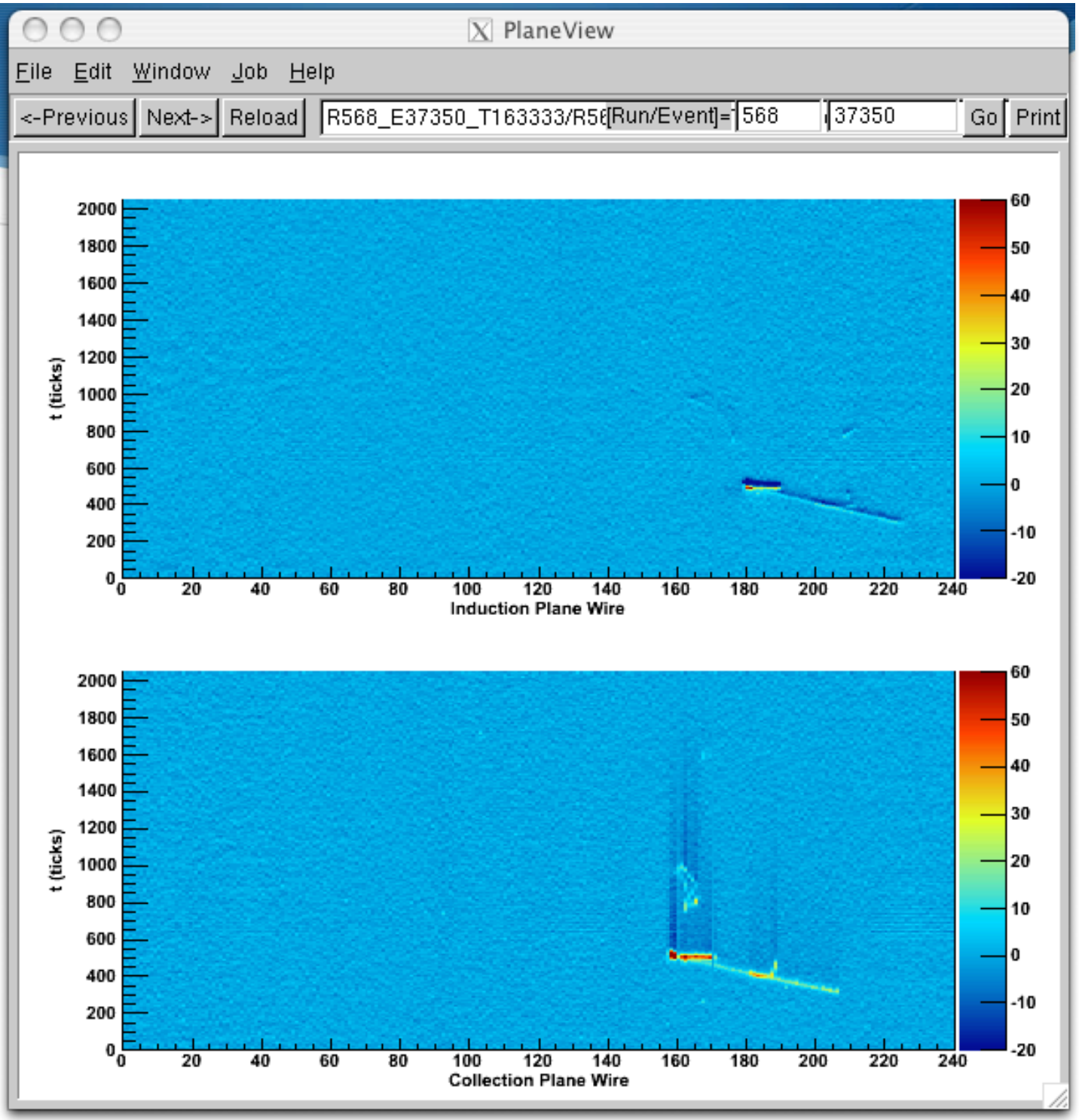
$$Q_{corr} = Q\, e^{td/\tau_e}$$

- charge to energy conversion with correction for the quenching effect on the ionization charge in LAr (Birks law).

6. *Particle ID:* with dE/dx measurement vs. range



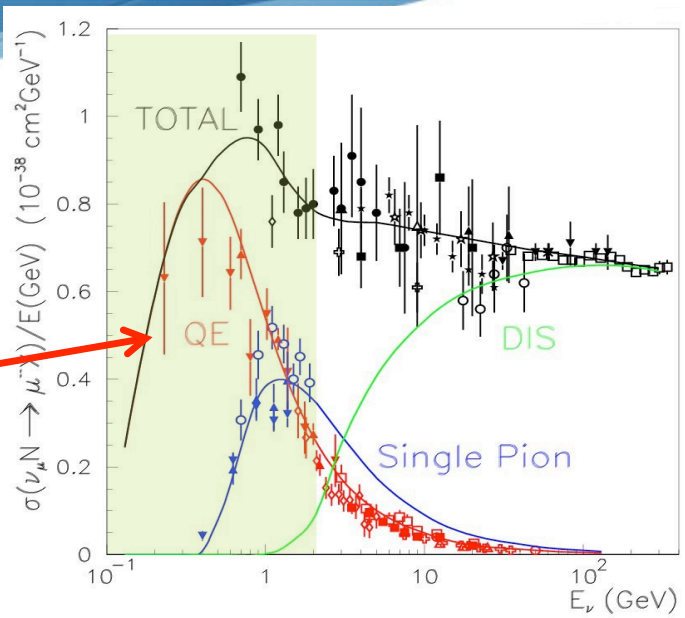
A particularly interesting event: sensitivity to nuclear effects?



Reconstruction of neutrino CC interactions

ArgoNeuT expected rate at NuMI :
(~ 18 QE + ~ 15 RES + ~ 80 DIS) events/day

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



QE process:

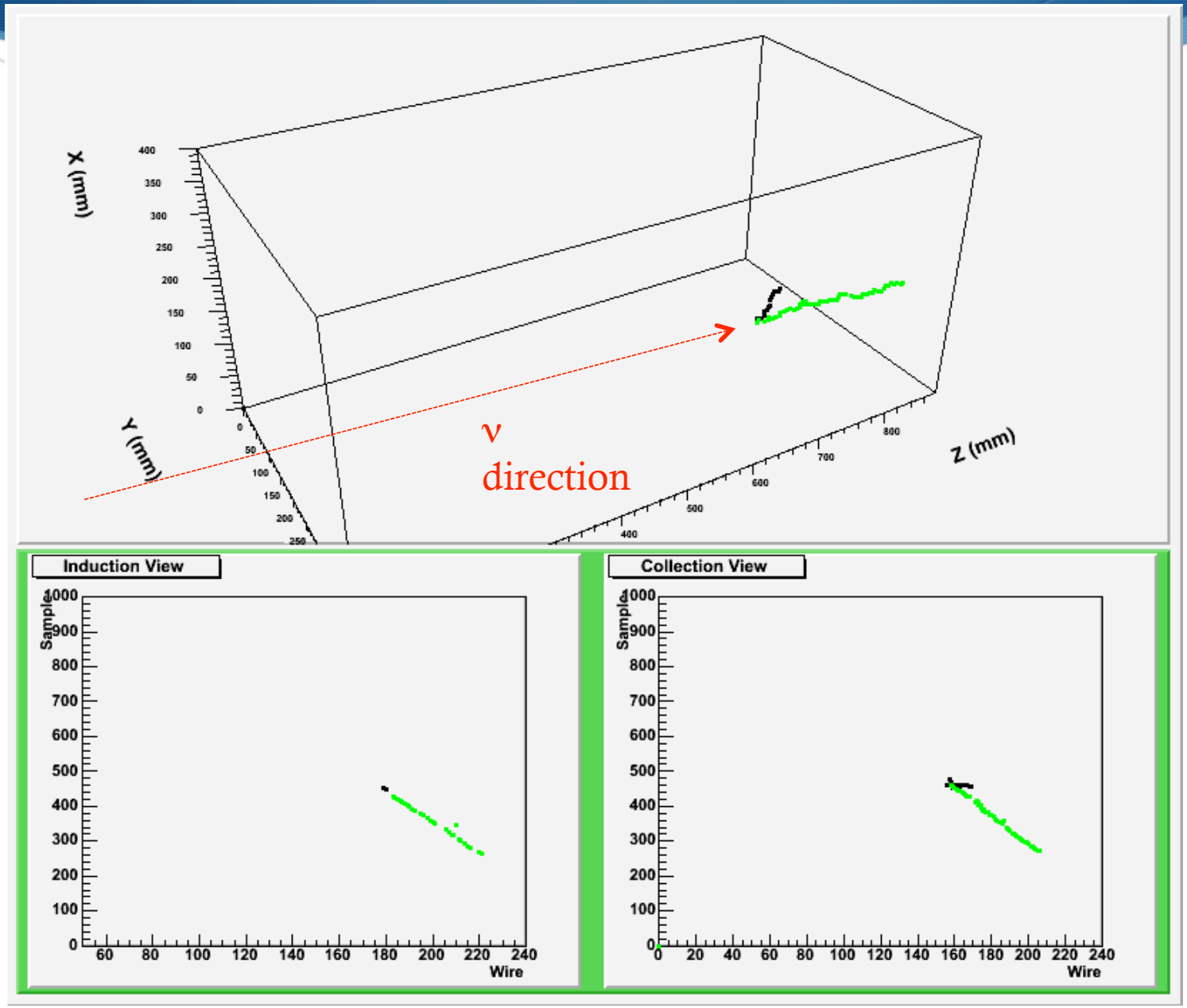
$\nu_\mu + n \rightarrow \mu^- + p$ (reaction on free nucleon)
when nucleon bound in the nuclear target nuclear effects must be taken into account:
$\nu_\mu + A(n) \rightarrow \mu^- + p + (A\text{-}1)^*$

FSI

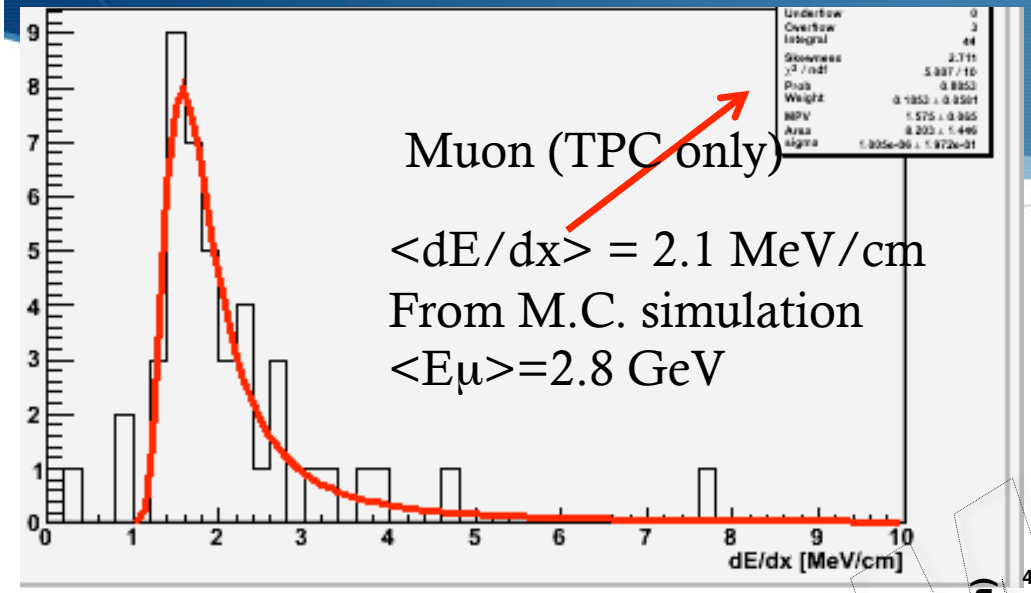
- -Nuclear evaporation (low T p and n)
- -Fission (nuclear fragments)
- - γ emission from nuclear de-excitation

These products are usually neglected because not detectable, unless…
…. a high quality imaging detector is in use !!

2D and 3D reconstruction of the event



Final State Muon and Proton reconstruction

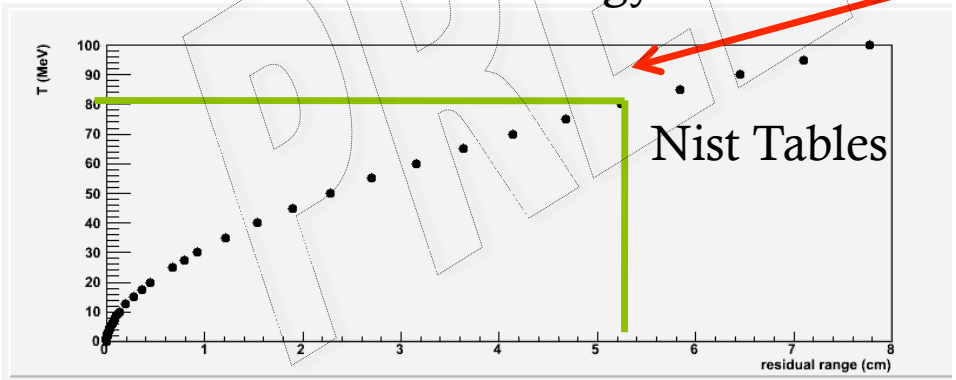


Muon (TPC only)

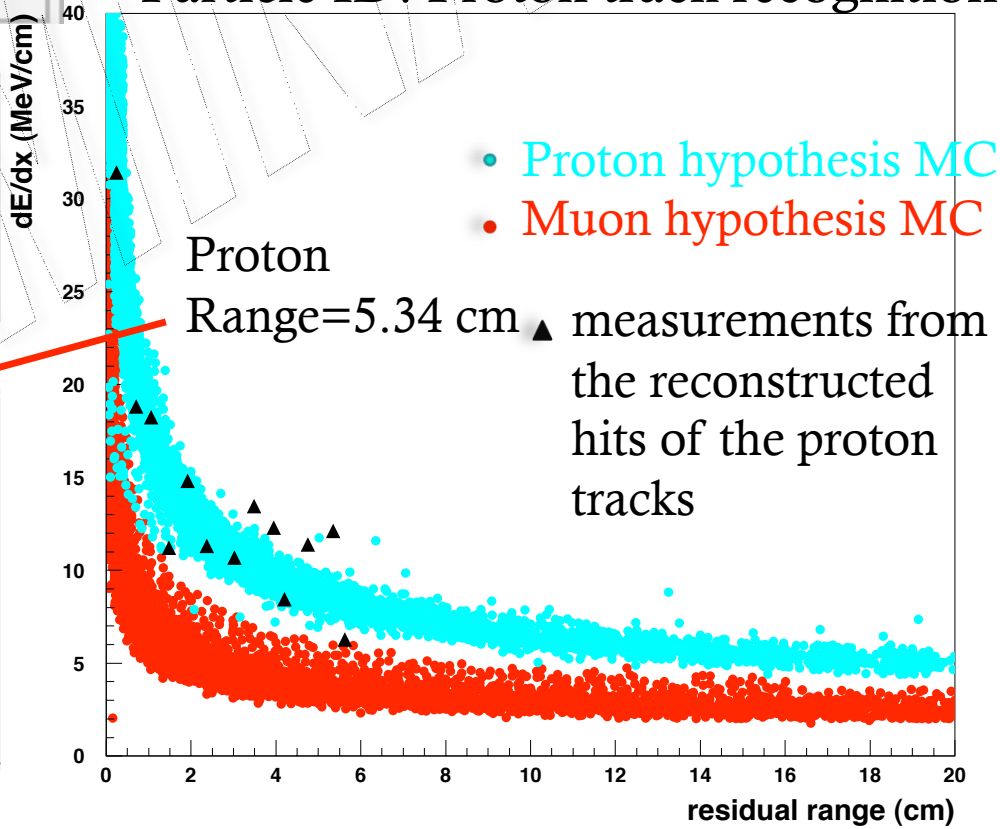
<dE/dx> = 2.1 MeV/cm
From M.C. simulation
<Eμ>=2.8 GeV

Proton reconstruction and momentum meas. performed using only TPC information. Kinetic energy calculated from range.

Proton kinetic energy = 80 MeV

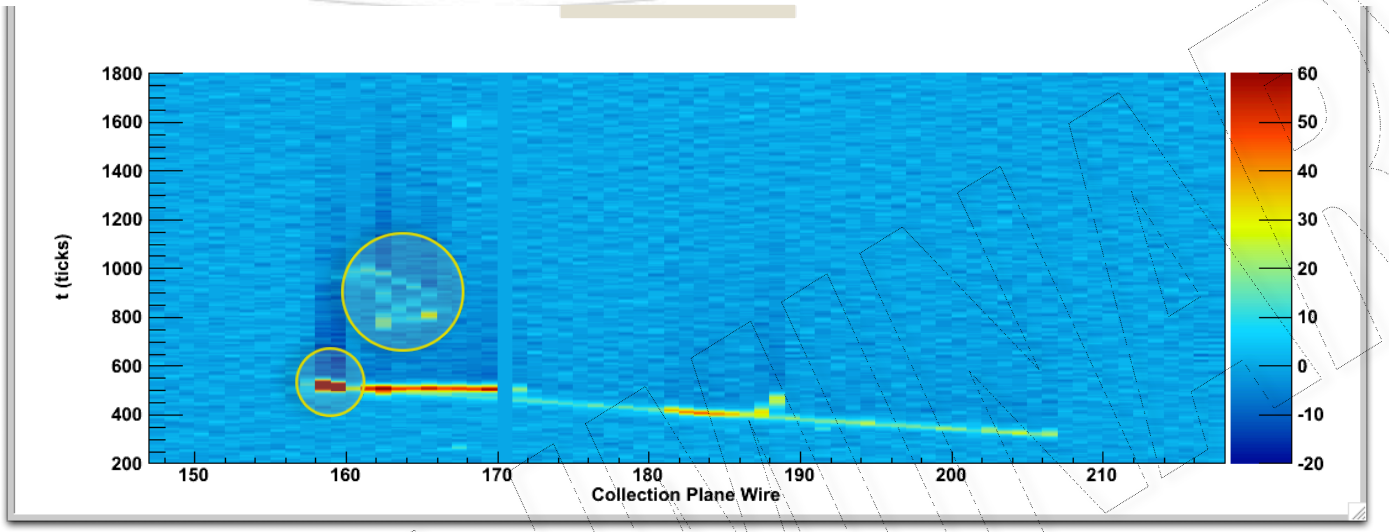


Particle ID: Proton track recognition



PRELIMINARY

A closer inspection of the event topology (thanks to the imaging capabilities of the LAr TPC) shows:



1) **<u>large activity near the vertex</u>**

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

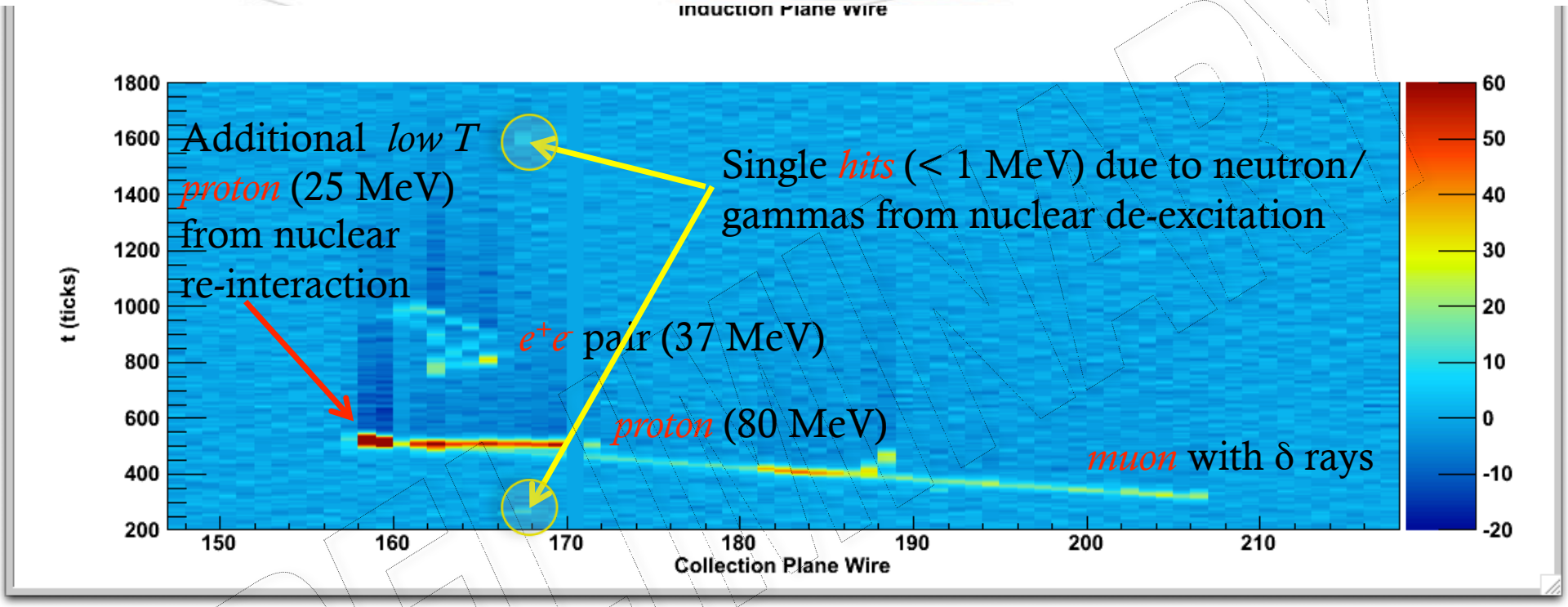
X compatible with a second 25 MeV p track

from nuclear evaporation (FSI in nucleus) or pion re-absorption

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

PRELIMINARY

ArgoNeuT: Reconstructed CC ν Event



This event reconstruction is still 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.

PRELIMINARY

Conclusions and Outlooks

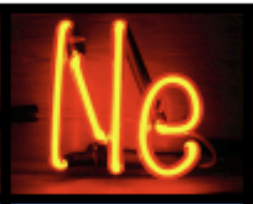
- The LArTPC Detector, due to its very high spatial and energy resolution and due to its good particle ID capability and BG rejection power (down to the "few GeV" range), is recognised as an ideal detector for the future Long Baseline Massive Neutrino experiments
- The feasibility of scaling the LArTPC to ~10-100ktons masses is the key issue of the present R&D activity in this sector.
- The ArgoNeuT Test Experiment now running (and the proposed MicroBooNE Experiment) at Fermilab will address many of the hardware R&D issues
- ArgoNeuT Test Experiment perform relevant physics/software programs:
  - Measure low energy Cross-section
  - Develop automated 3D and calorimetric reconstruction and Particle ID
- A first tentative neutrino event reconstruction has been done (nuclear effects details)
- A big effort is under way to improve the event reconstruction procedures exploiting the full imaging and calorimetric potentialities of the LAr TPC technique.

Backup slides

LAr as Active Medium

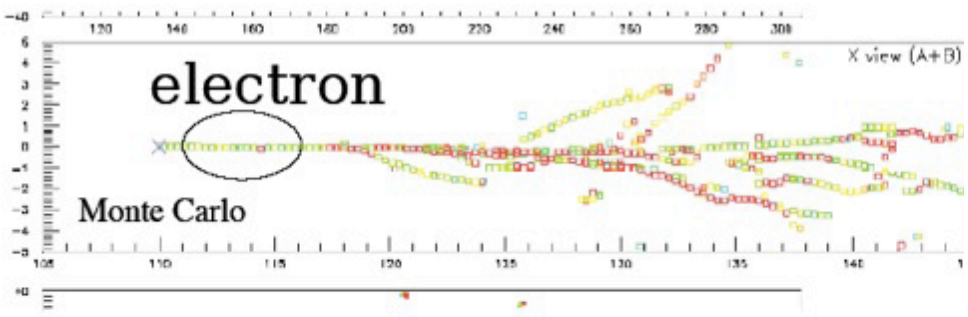
"There are several reasons why pure LAr can be considered as an almost ideal material for a liquid target TPC: it is dense, it does not attach electrons and hence it permits long drift-times, it has a high electron mobility, it is easy to obtain and to purify, it is inert, it is cheap. … From the Physical point of view, LAr has properties which make it very similar to the freon of the celebrated Gargamelle experiment".

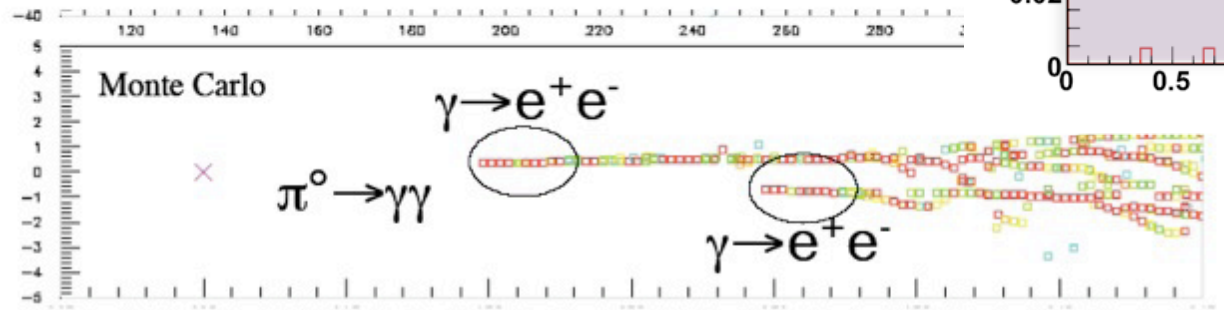
C. Rubbia, The Liquid-Argon Time Projection Chamber: A New Concept For Neutrino Detector, CERN-EP/77-08 (1977)

						
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
Scintillation [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation λ [nm]	80	78	128	150	175	

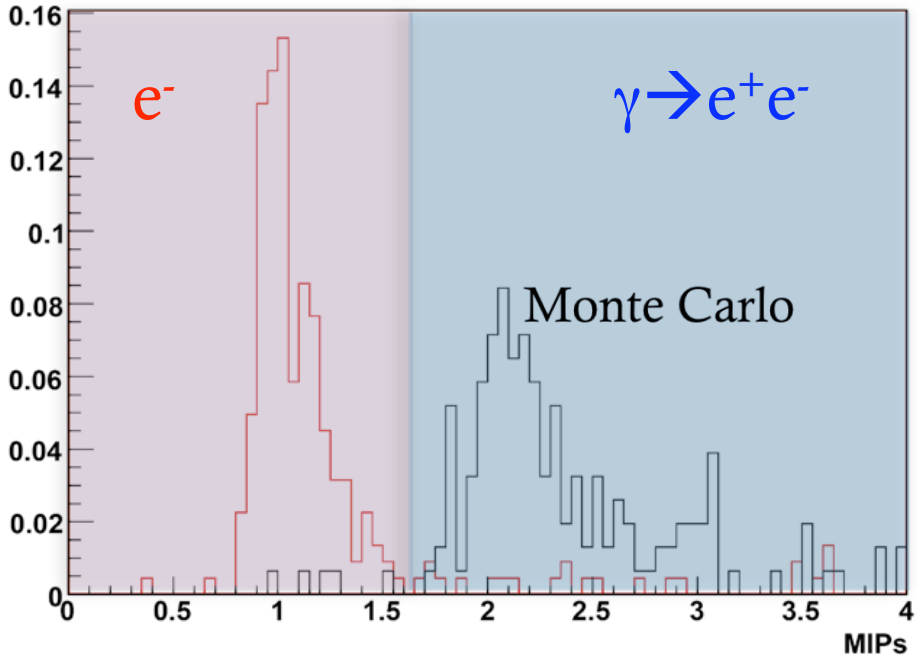
LAr TPC e/$\pi^0(\gamma\gamma)$ separation

- LAr TPC can separate e/gamma through topological analysis and calorimetric measurement of the first cm of track (1mip for e , 2 mip's for gamma) (MC→efficiency>90%)
- This allows to reject BG events like ν_μNCπ^0 from signal (ν_e CC)
- → very important for $\nu_\mu \rightarrow \nu_e$ oscillation experiments





1GeV e⁻'s vs 1GeV γ's



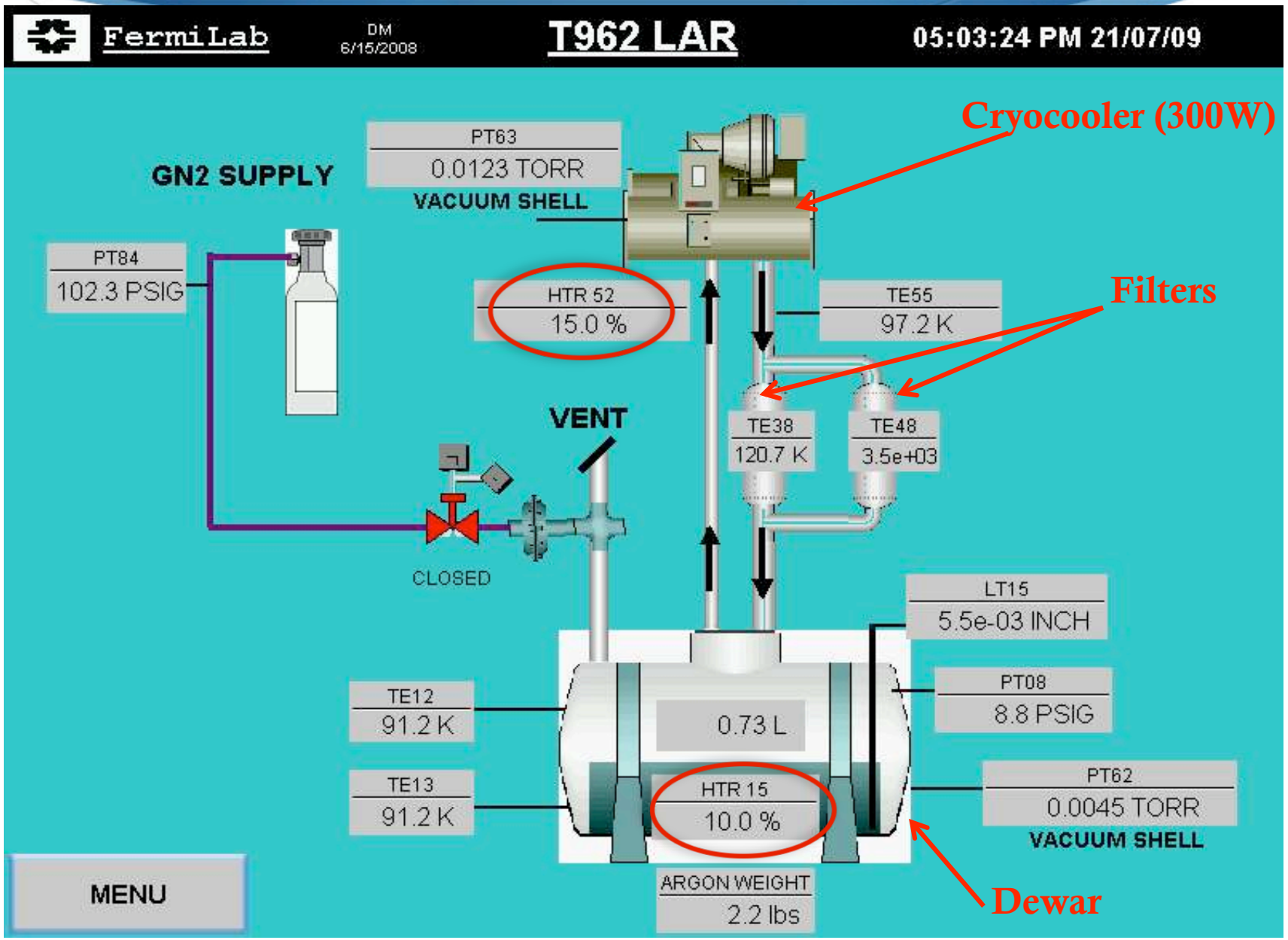
LAr TPC Challenges

- Key issue is ***feasibility of scaling in size*** in terms of purity, cryostat design, electronic noise and number of channels, safety requirements (Oxygen Deficiency Hazard)

- Purity:
  - LAr high purity necessary for long-drifts (many meters) characteristic of a very large detector (1.5 meter drift requires purity level ≥ 0.03 ppb)
  - Outgassing of detector materials' impact on purity must be under control.

- Electronics:
  - Wire signals are small, so sources of electronic noise must be strictly controlled.
  - High sampling rate + many wires = Flood of raw data to be reduced (zero suppression)

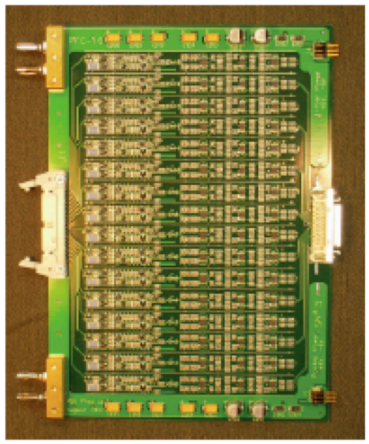
ArgoNeuT Cryogenic System



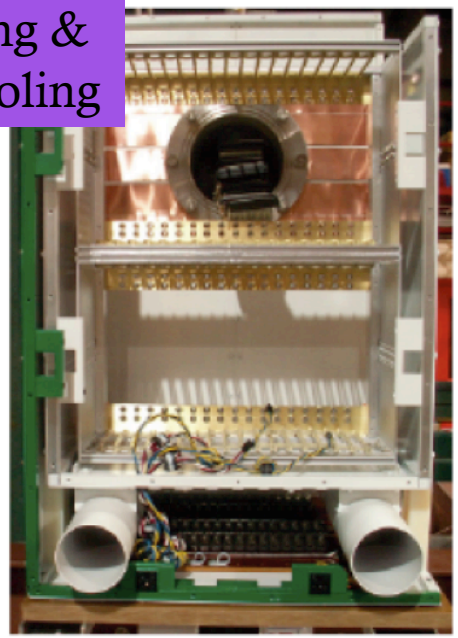
ArgoNeuT Electronics

- Readout electronics and DAQ
  - Preamplifier with onboard FET front-end for each wire/channel
  - RF shielding, "remote" cooling → for noise reduction
  - 15 ADC/FPGA cards, 2048 samples/channel
  - Bias voltage distribution card at LAr temperature → Cards plug into matching TPC connectors, signal cables plug into the card

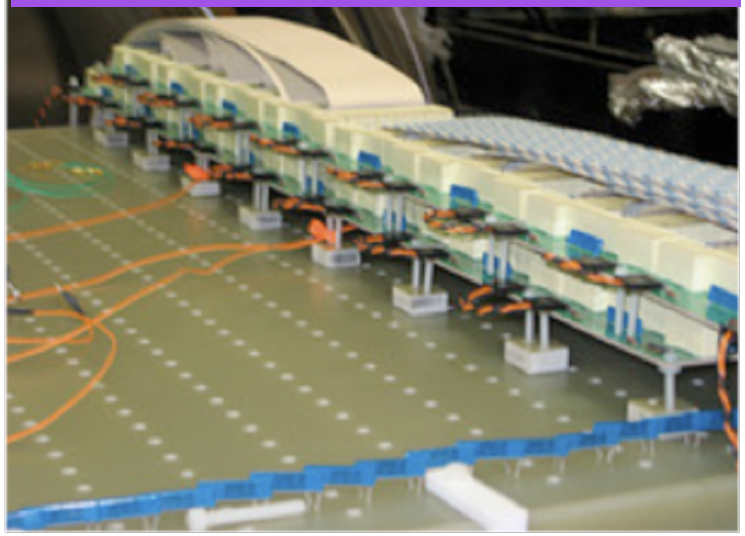
PreAmp Board



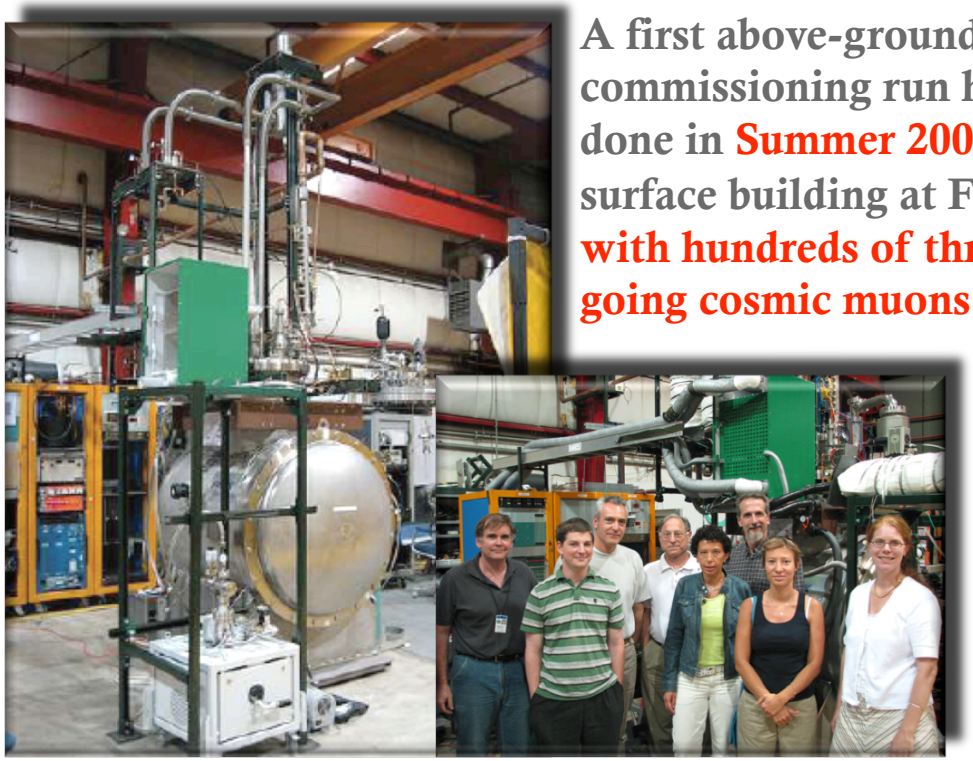
RF shielding & Preamp cooling



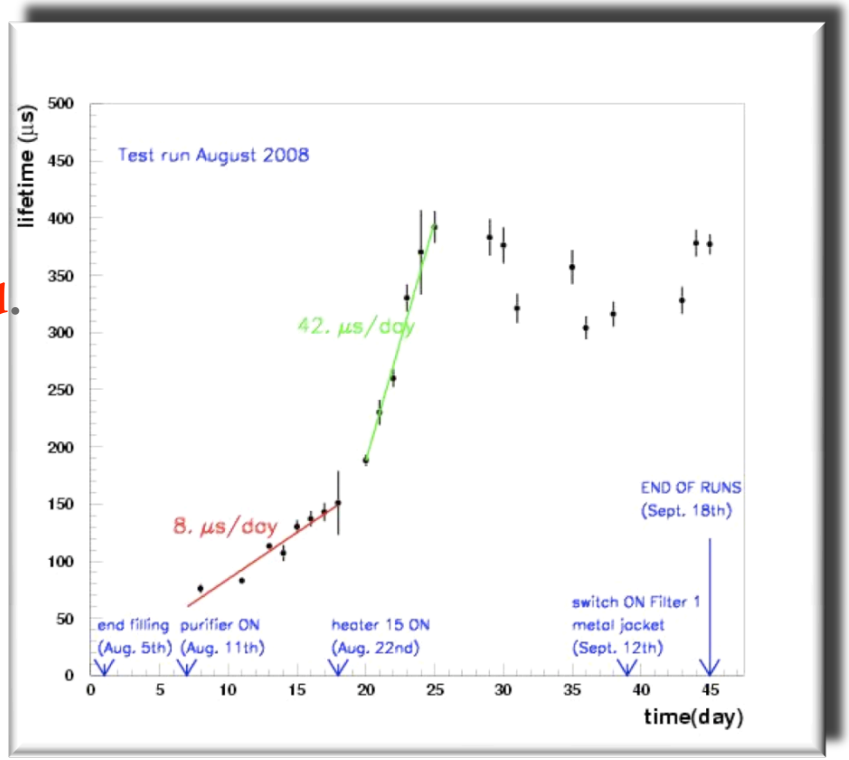
Two layers of bias voltage distribution cards on top of TPC



Commissioning Above Ground



A first above-ground commissioning run has been done in **Summer 2008** in a surface building at Fermilab, **with hundreds of through-going cosmic muons acquired.**

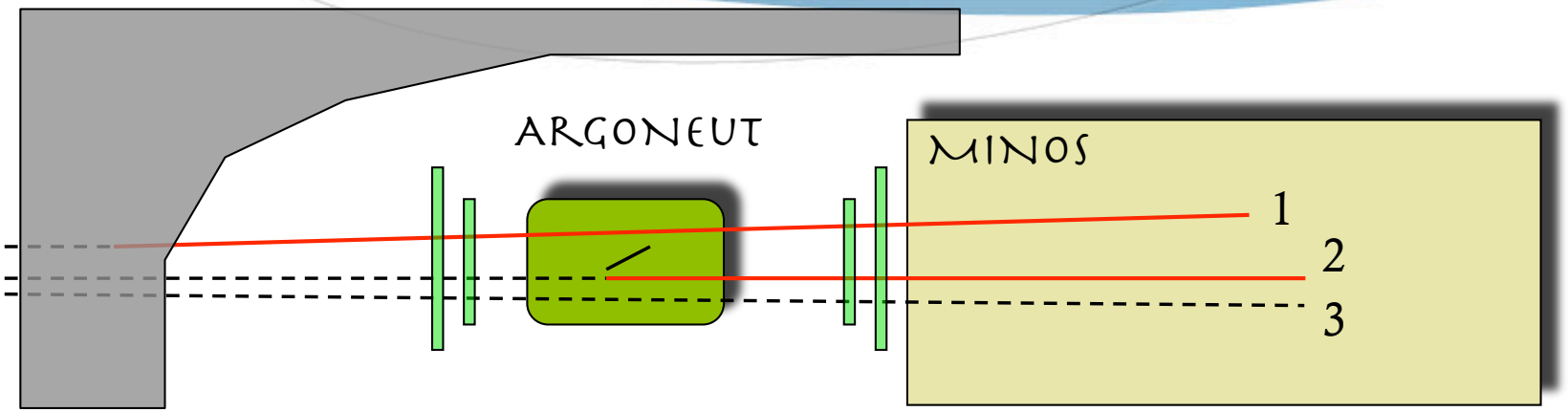


ArgoNeuT Commissioning Underground

- Detector moved into the MINOS hall in January 2009
- Underground Safety approval obtained in May 09 → Start Filling
- Fast Filling (11 hours with 7-8 dewars of 160 L of LAr)
- From May 10 to 15 → Cryogenic system into steady conditions
- Purity improvement by closed loop recirculation/filtering
- On June 15th → beam shut down
- In the summer → triggering on horizontal and vertical cosmic muons for calibration purposes (~15000 triggers acquired)
- From mid of September beam (and ArgoNeuT acquisition) restarted

ArgoNeuT Trip to Underground

External Trigger for ν -beam operation



Three main topologies:

1. through-going μ from ν-int. in the rock upstream
2. ν-int in LAr (good event to be selected)
3. Empty event: No interaction in coincidence with beam spill

Event Type	# of events in 180 days (1.4×10^{20} POT) – ν mode	# of events in 180 days (1.4×10^{20} POT) – anti-ν mode
ν_μCC	19337	6109
anti-ν_μCC	1692	5490
ν_eCC	362	118
NC	6526	4015
Total	27917	15732