ArgoNeuT and MicroBooNE: LAr TPC's at Fermilab:

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Outline

- LAr TPC technology, present challenges
- ArgoNeuT Test Experiment: Design, R&D/ Physics Goals, First Events
- MicroBooNE Experiment: Design, R&D/Physics Goals
- Conclusions

Present Scenario in Neutrino Physics

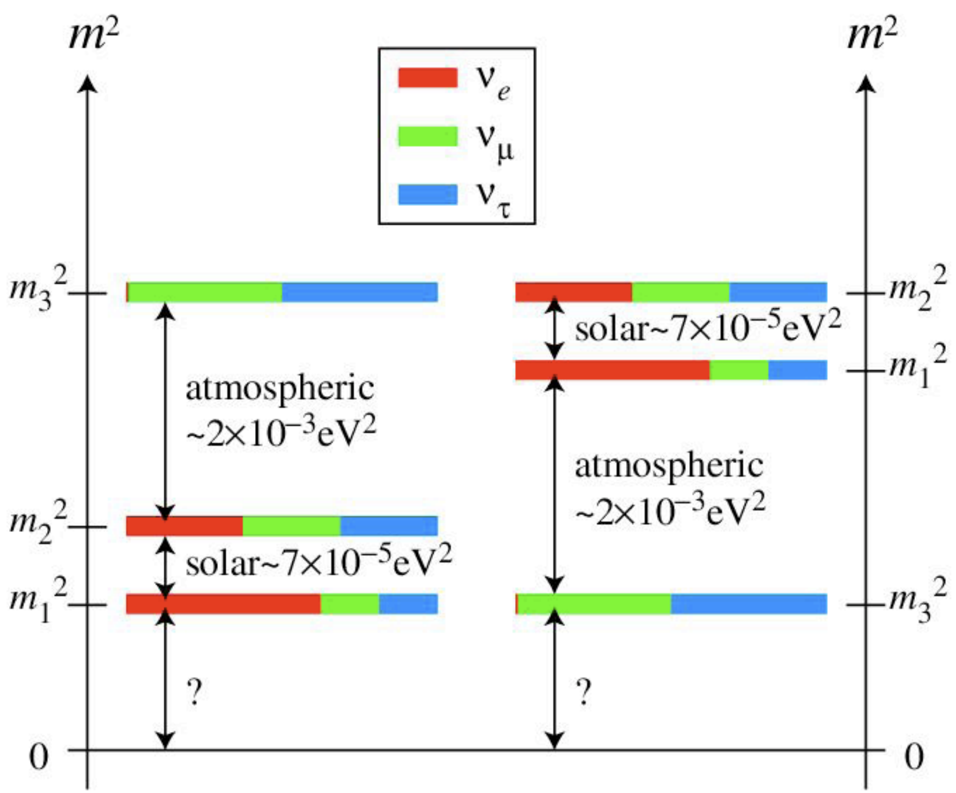
Known

$\Delta m_{21}^2 \sim 7\times10^{-5} eV^2$

$\Delta m_{32}^2 \sim 2\times10^{-3} eV^2$

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

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



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?

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

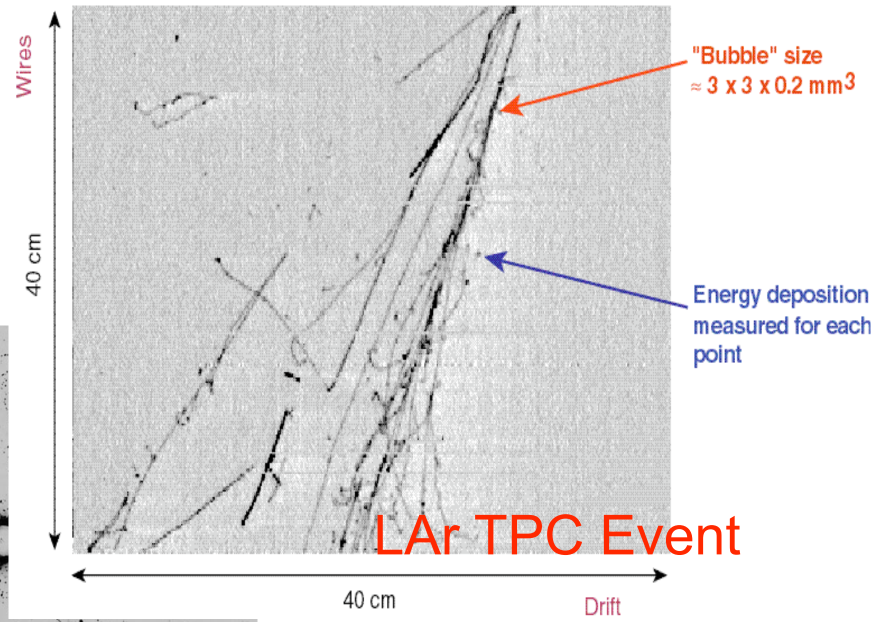
The LAr TPC (Time Projection Chamber) *Technology has been conceived and developed in Italy by the ICARUS Collaboration that has carried out the construction and test of the ICARUS T600 detector (600 tons of LAr).*

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**

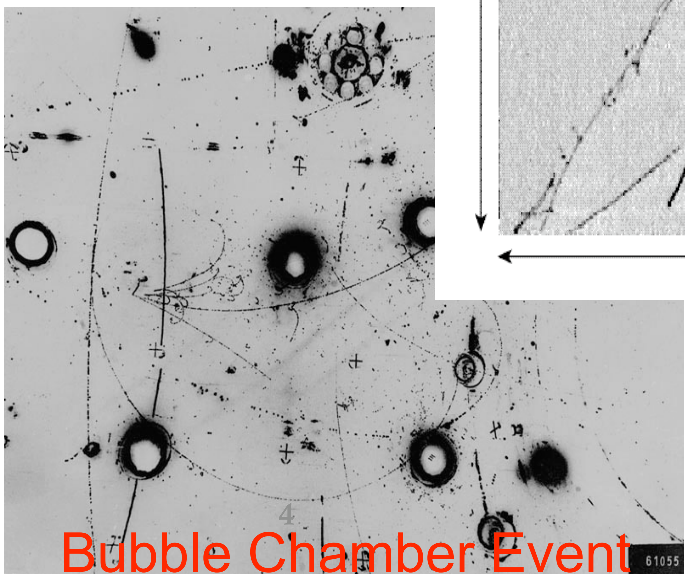
The LAr TPC is considered a novel Electronic Bubble Chamber

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



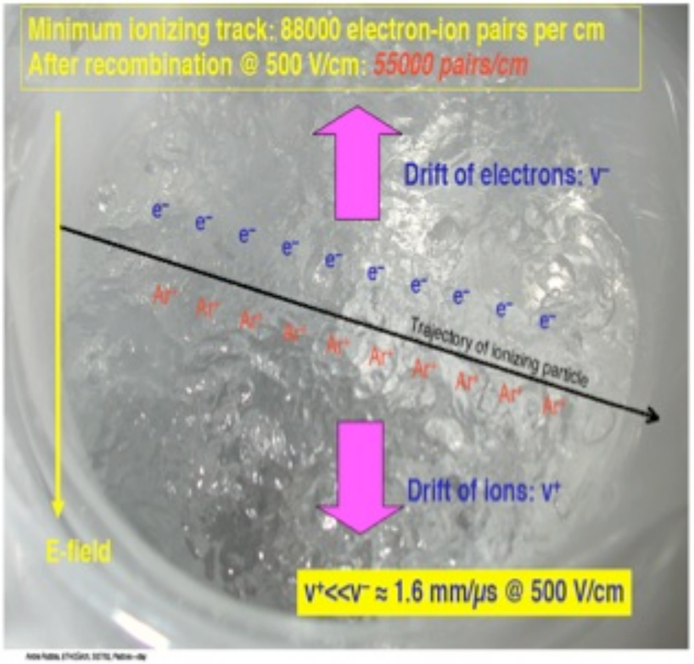
LAr TPC Event

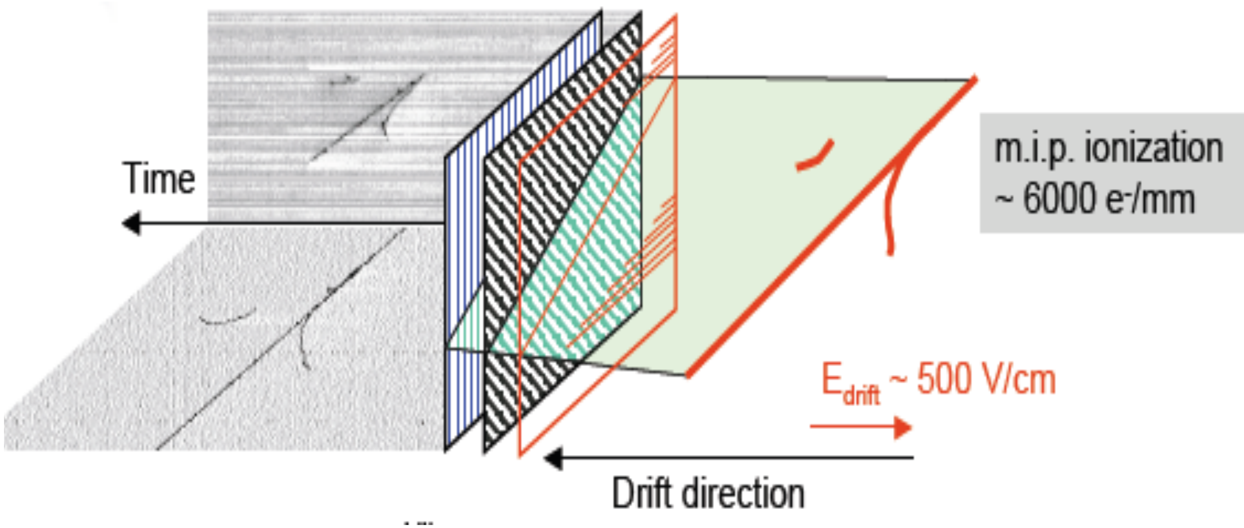


Bubble Chamber Event

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





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)

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm³]	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 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)

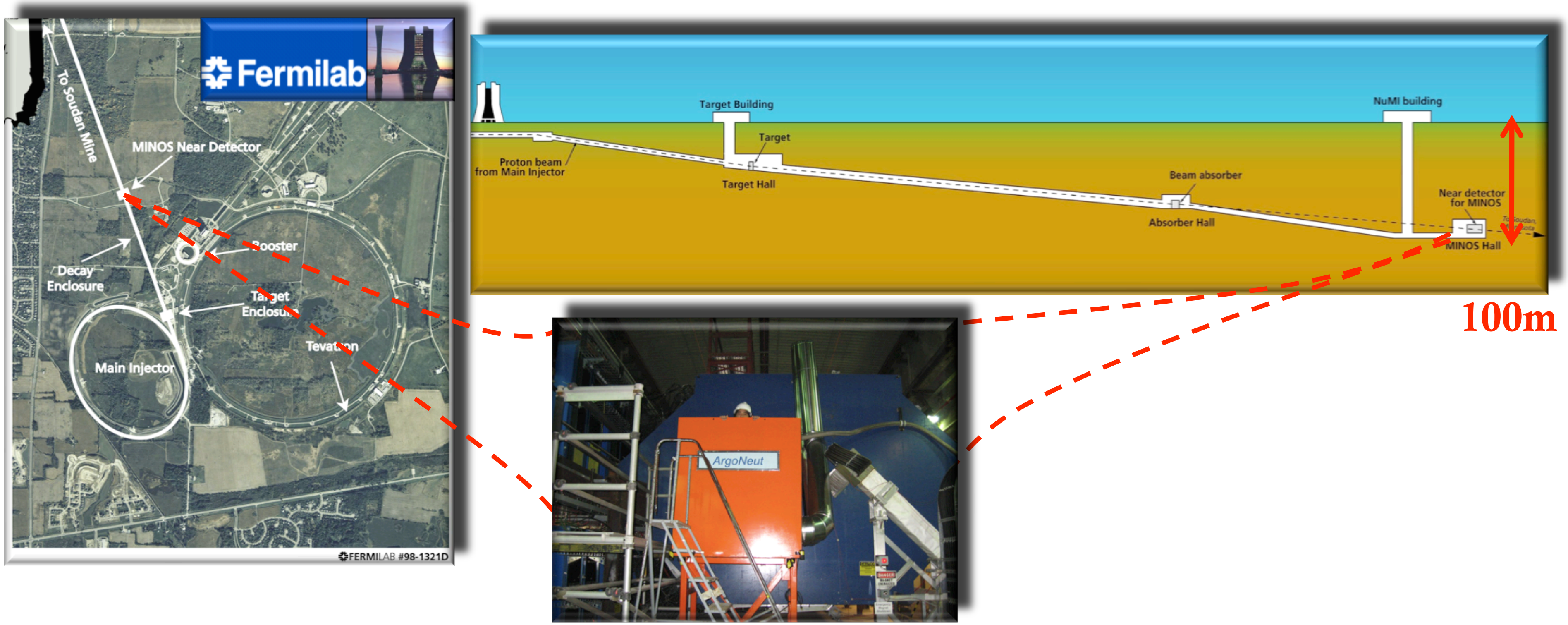
- Purity:
  - LAr high purity necessary for long-drifts (many meters) characteristic of a very large detector (1.5 meter drift requires purity level ≥ 0.03 ppb)
  - Outgassing of detector materials' impact on purity must be under control.

- 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)

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.

The ArgoNeuT Collaboration

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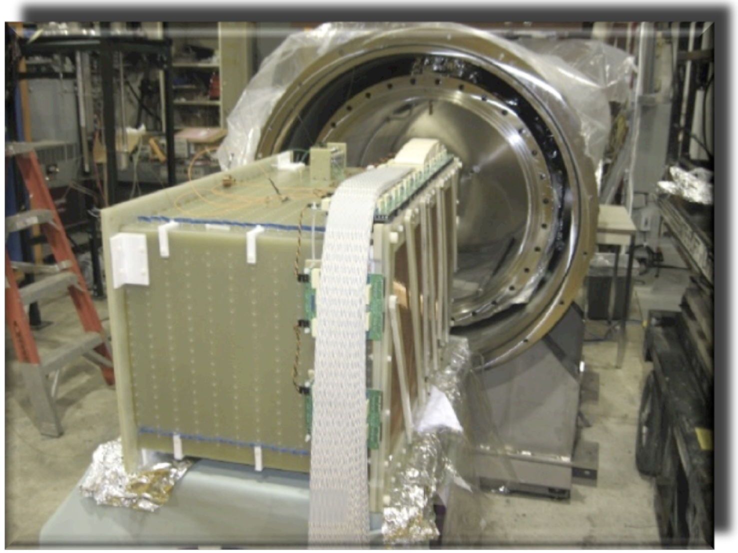
ArgoNeuT Goals

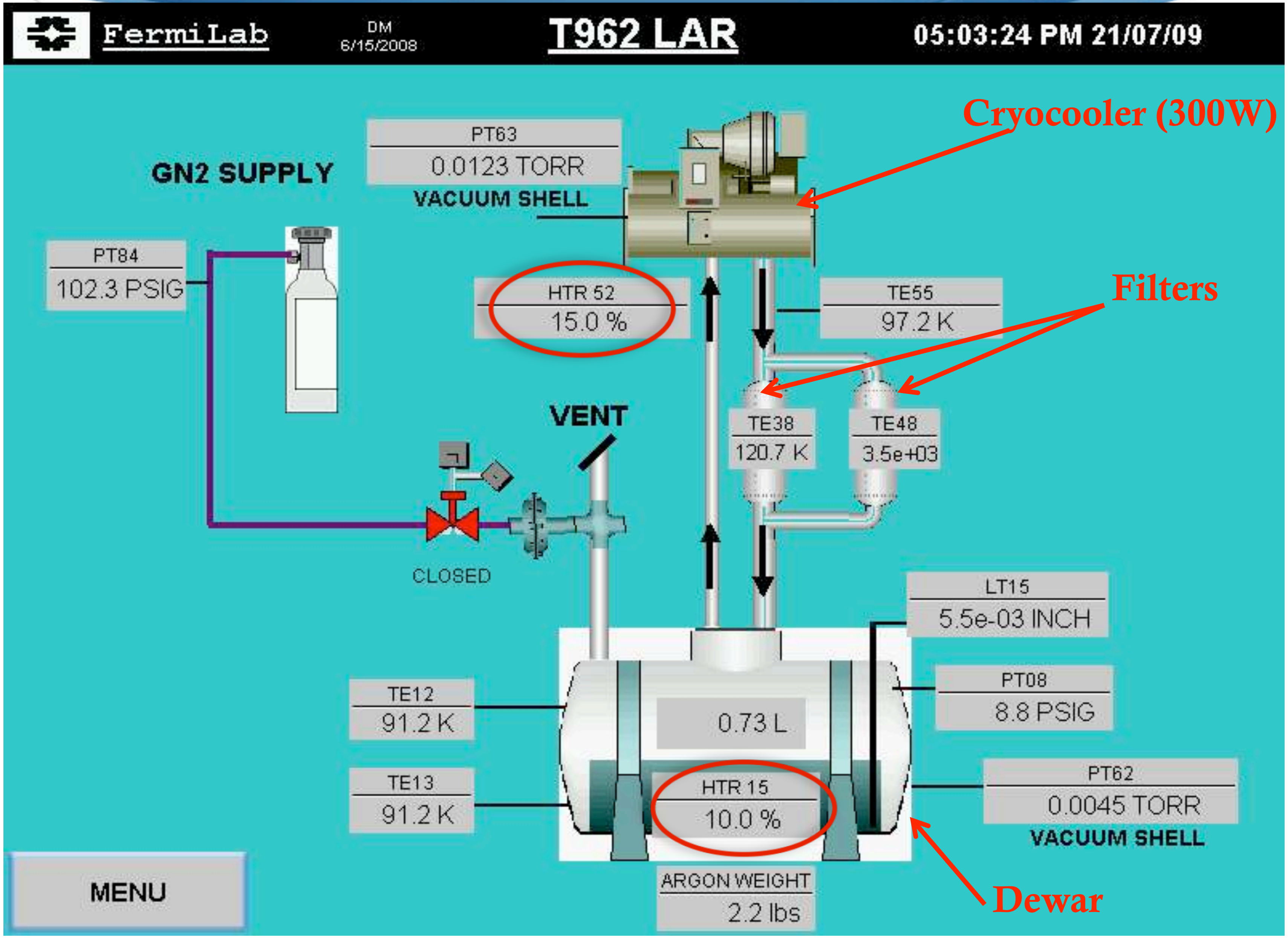
- ArgoNeuT will address some of the hardware and physics R&D issues on the way toward massive LAr TPC detectors (MicroBooNE, LAr20 etc..) in terms of:
  - Argon purity, electronics, detector design and construction, etc.
  - Development of MC Simulation and off line reconstruction
- Demonstrate **particle 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 (~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

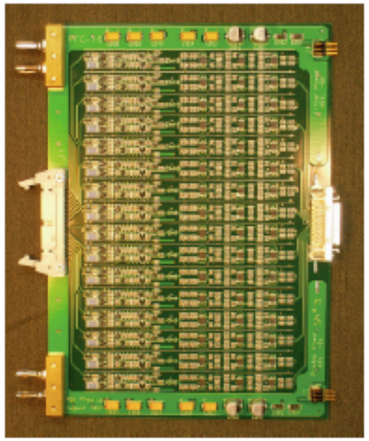


ArgoNeuT Cryogenic System

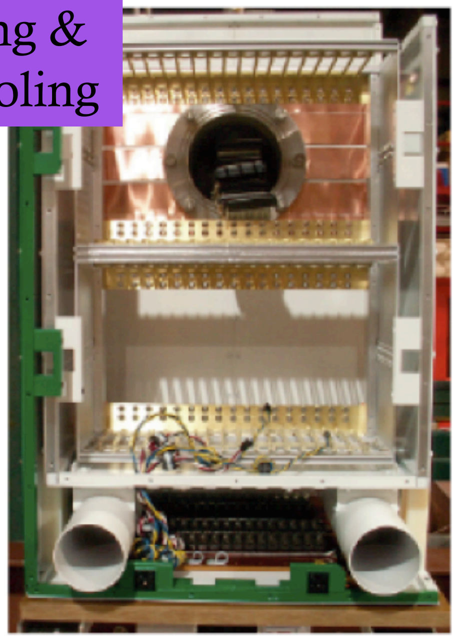


ArgoNeuT Electronics

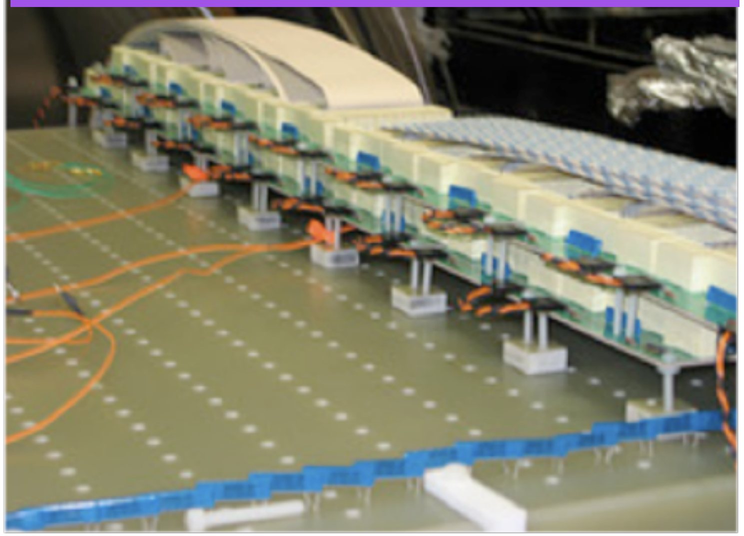
- Readout electronics and DAQ
  - Preamplifier with onboard FET front-end for each wire/channel
  - RF shielding, “remote” cooling → for noise reduction
  - 15 ADC/FPGA cards, 2048 samples/channel
  - Bias voltage distribution card at LAr temperature → Cards plug into matching TPC connectors, signal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



PreAmp Board

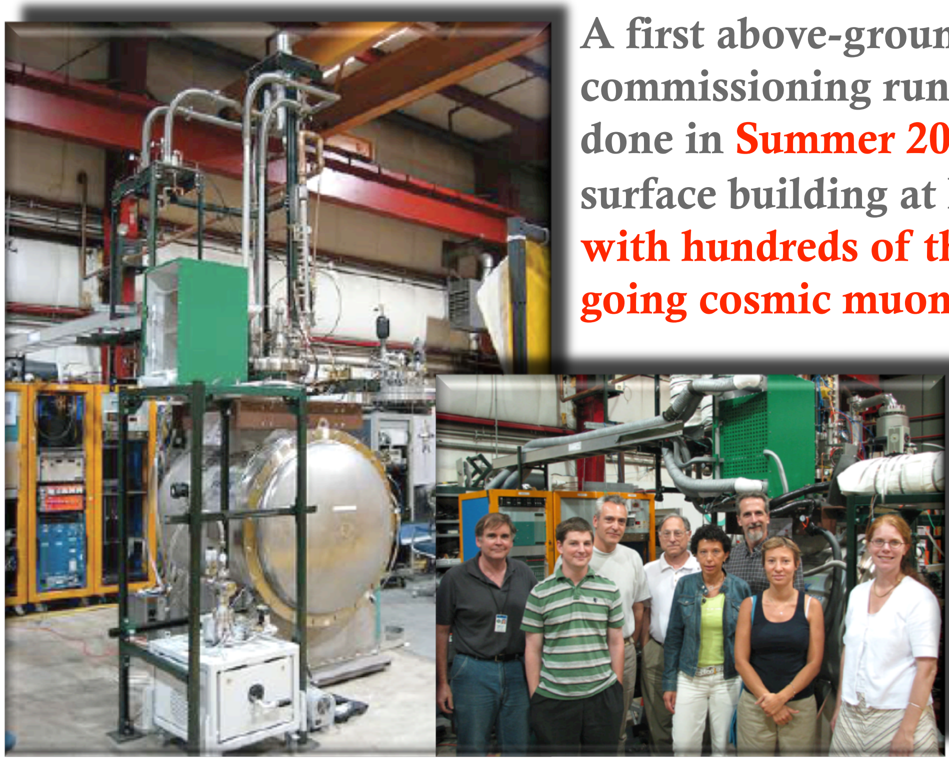


RF shielding & Preamp cooling

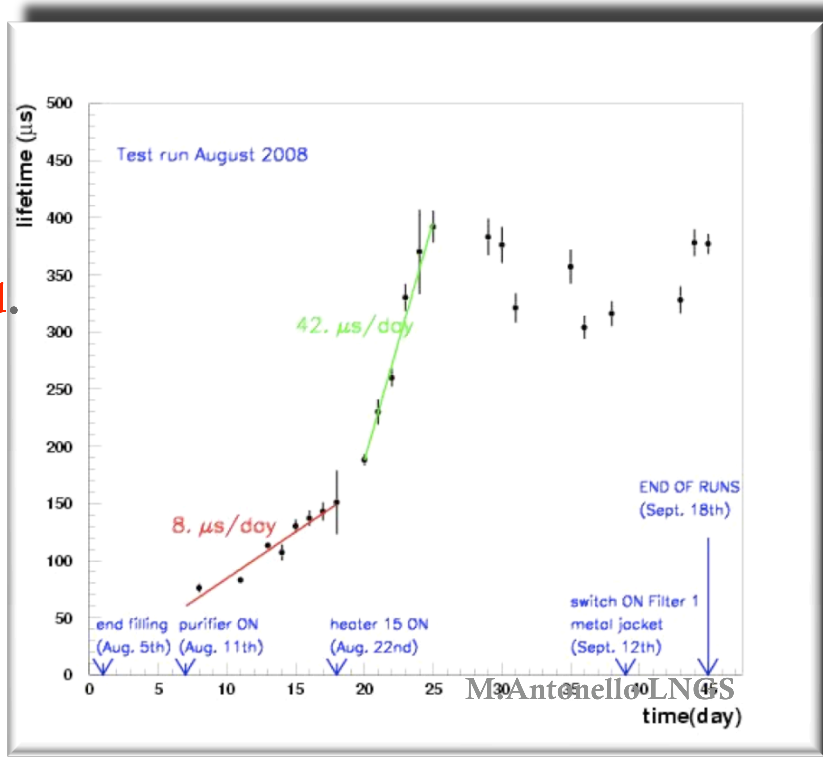


Two layers of bias voltage distribution cards on top of TPC

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**.

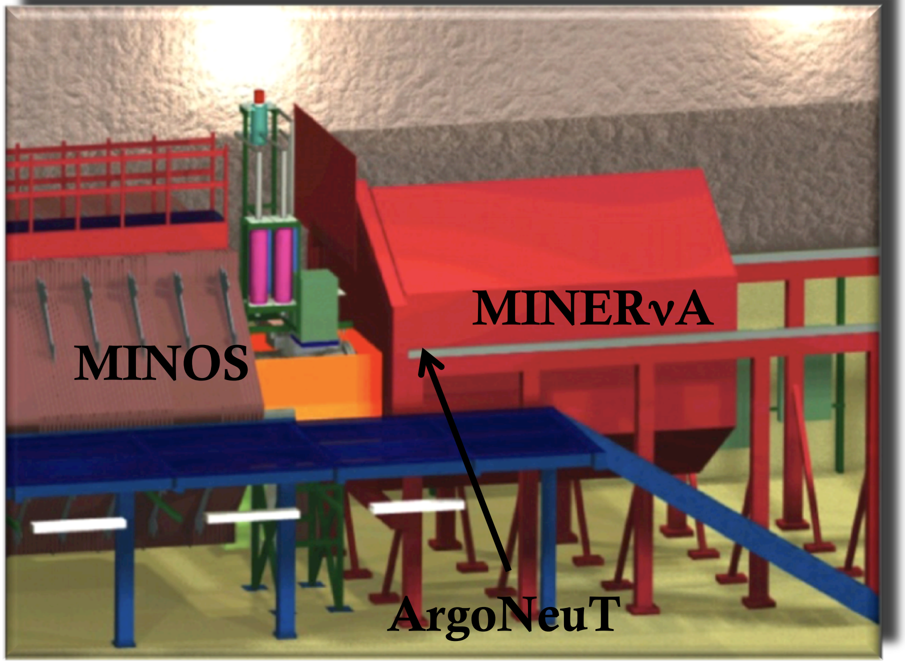


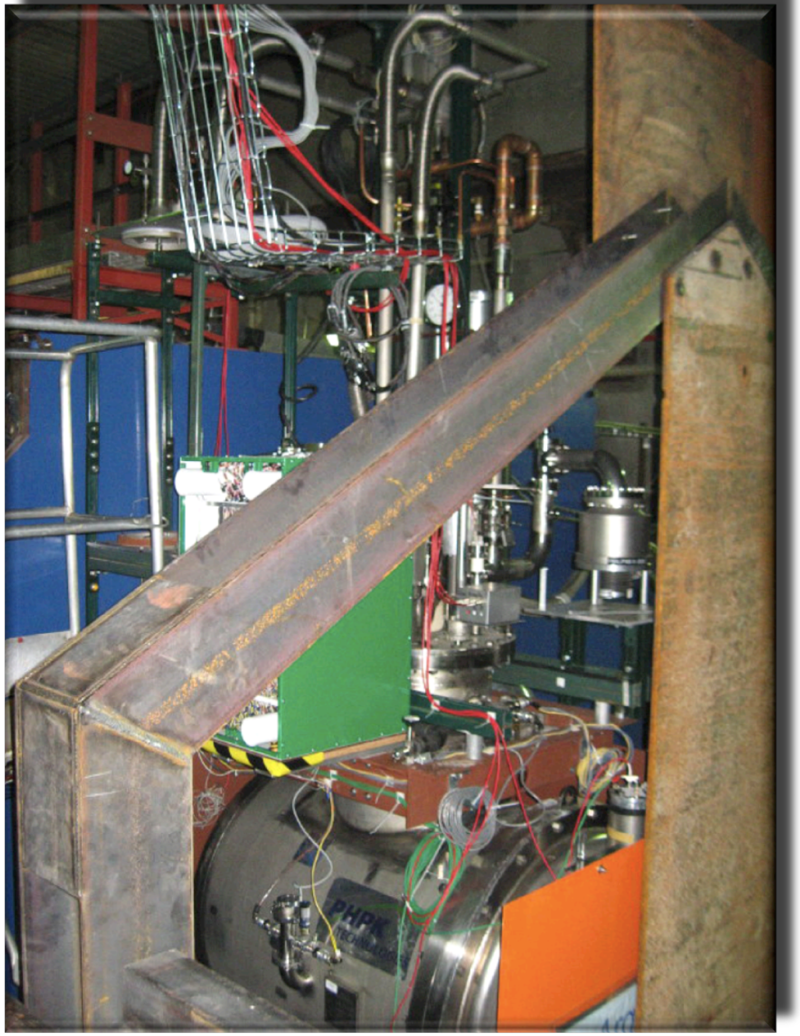
ArgoNeuT Commissioning Underground

- 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 15^{th} → beam shut down
- Now triggering on horizontal and vertical cosmic muons for calibration purposes (~15000 triggers acquired until now)

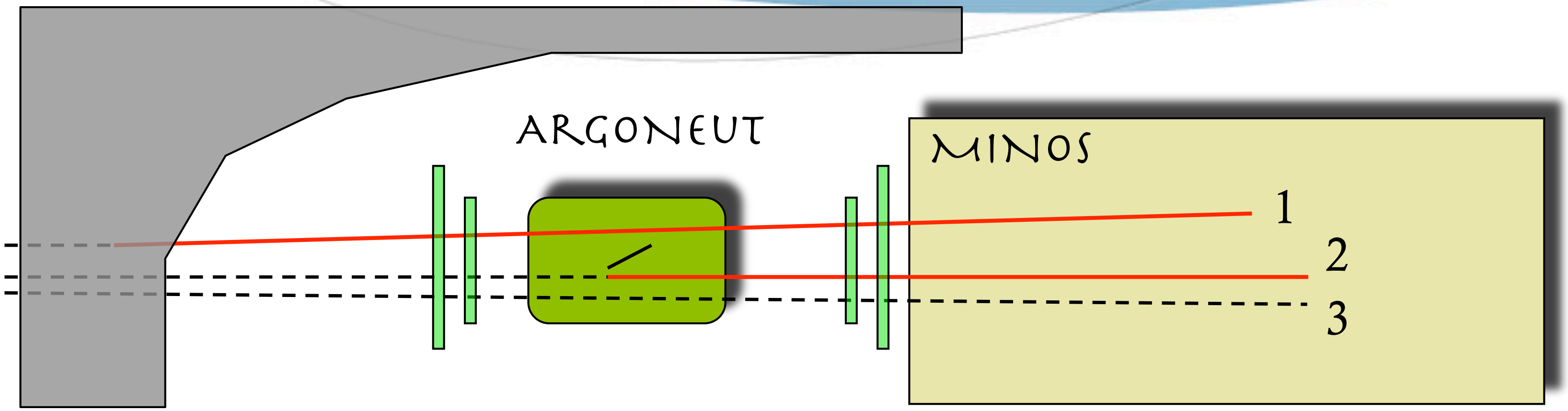
ArgoNeuT Trip to Underground

ArgoNeuT Underground Location





External Trigger for ν -beam operation

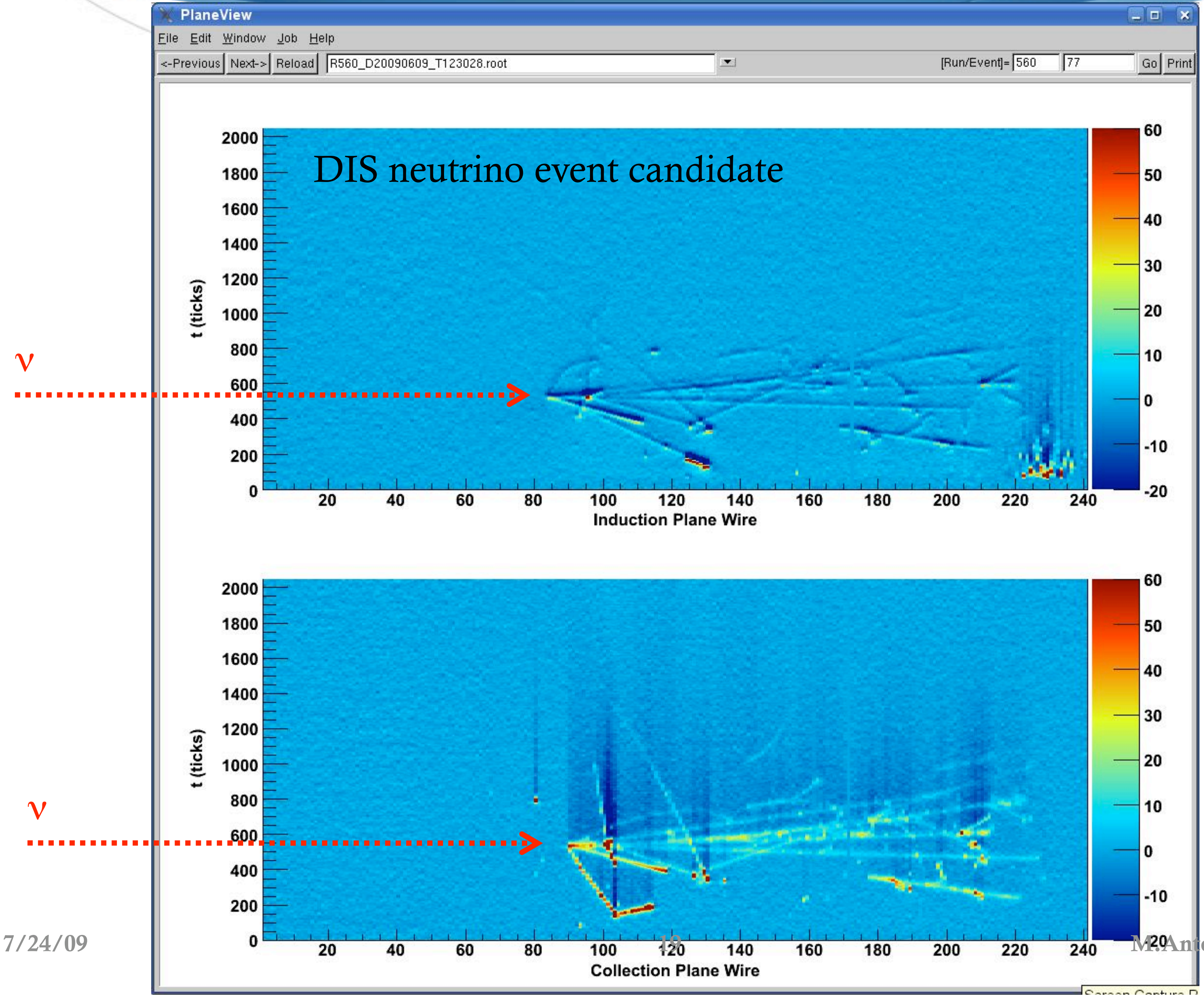


Three main topologies:

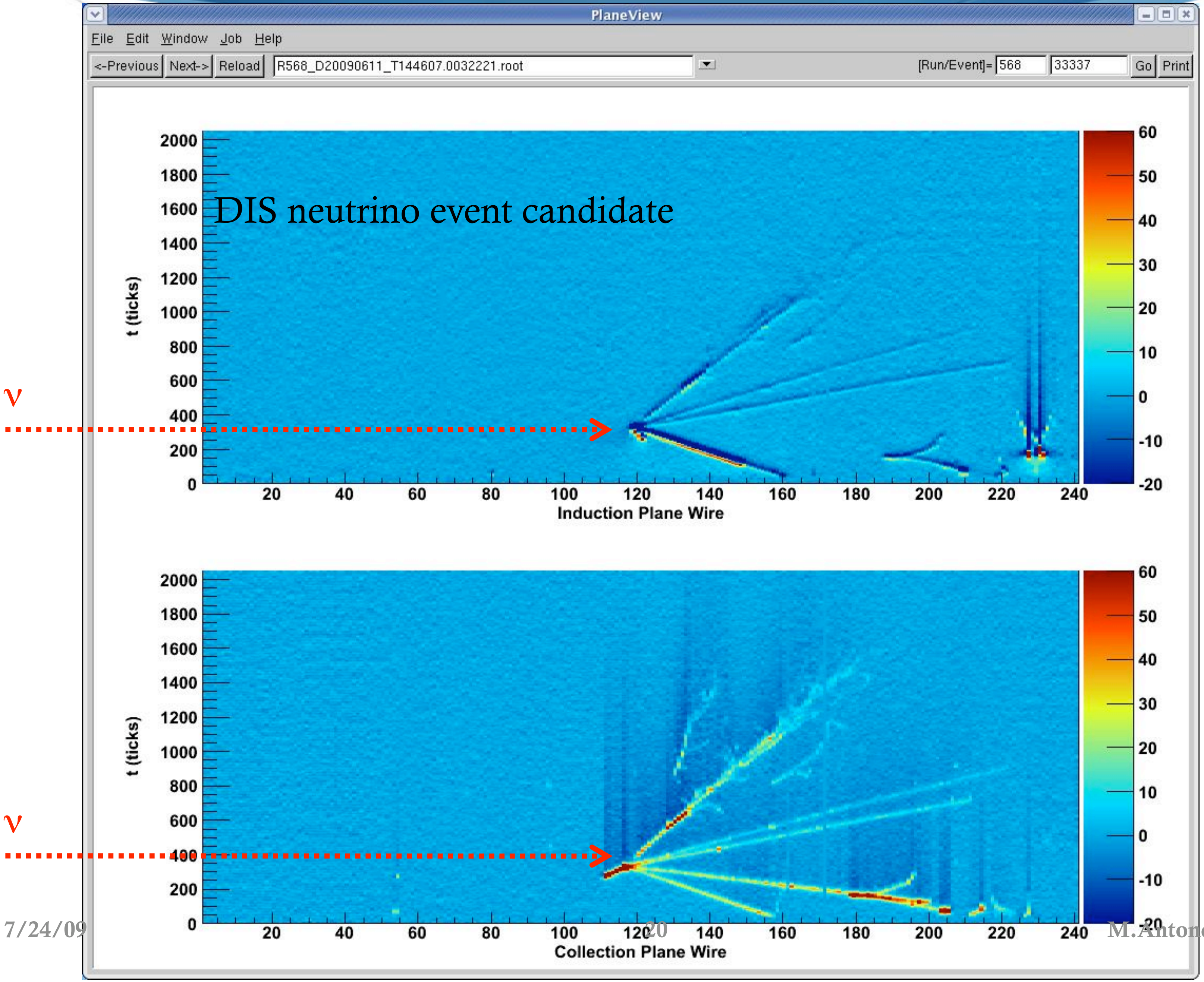
1. through-going μ from ν-int. in the rock upstream
2. ν-int in LAr (good event to be selected)
3. Empty event: No interaction in coincidence with beam spill

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

ArgoNeuT Event Display: Raw Data



ArgoNeuT Event Display: Raw Data



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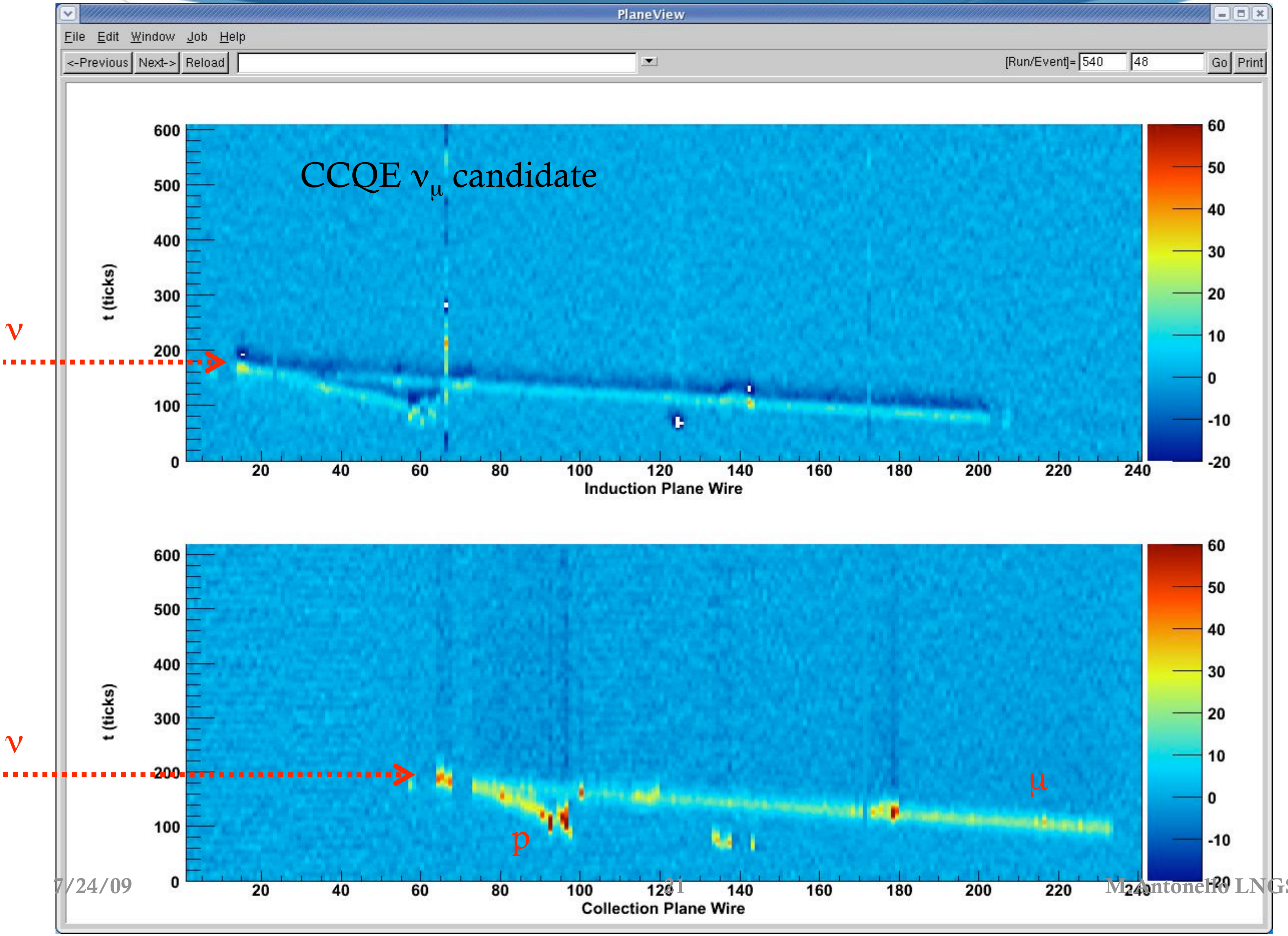
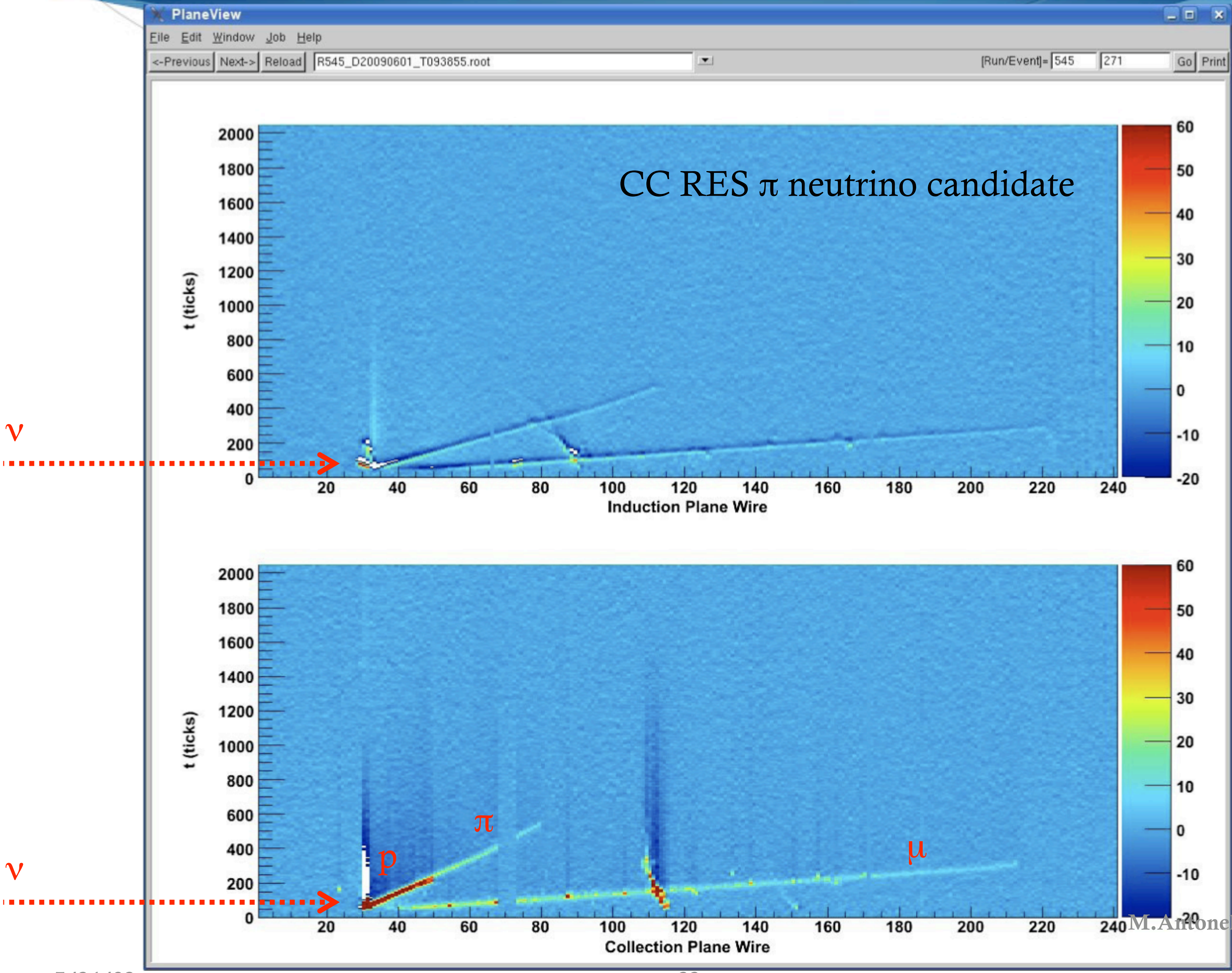


ArgoNeuT Event Display: Raw Data



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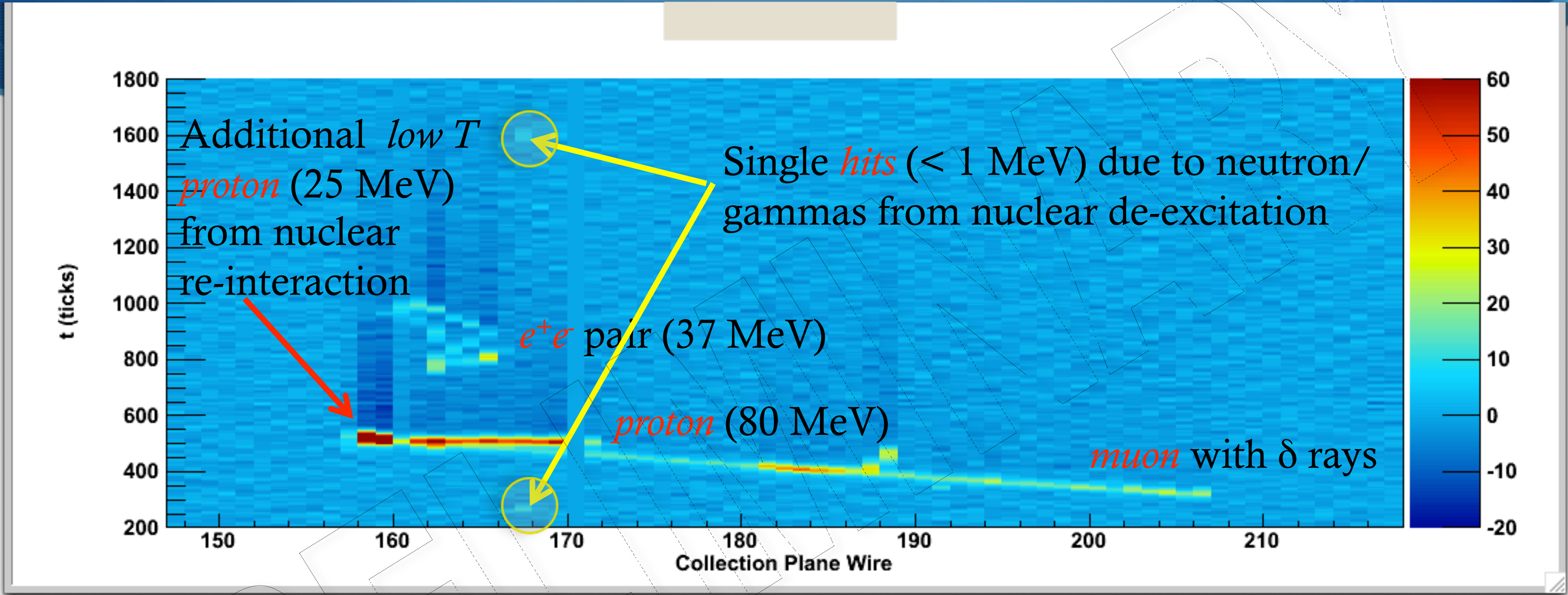
ArgoNeuT: Reconstructed CC ν Event

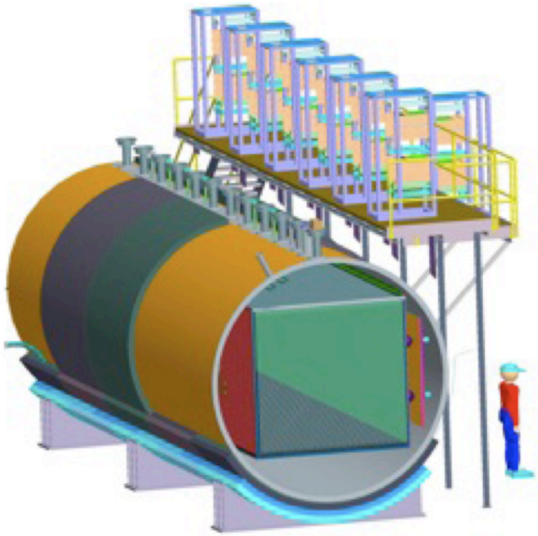


This event reconstruction is still preliminary.

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.

MicroBooNE

- MicroBooNE is a proposed LArTPC detector to run in the on-axis Booster and off-axis NuMI beam on the surface at Fermilab.
- MicroBooNE intend to combine hardware R&D with a relevant physics program in the way toward massive LAr TPC detectors.
- Hardware goals:
  - Cold electronics
  - Long Drift (high level purity required)
  - Purity through detector purging with GAr before filling (without evacuating)
- Physics goals
  - Investigate the MiniBooNE low energy excess
  - Measure low energy Cross-section
- Software goals:
  - Develop automated 3D and calorimetric reconstruction and Particle ID



Jun 2008 → Fermilab Directorate Stage I approval
NSF MRI and DOE funded

MicroBooNE Collaboration

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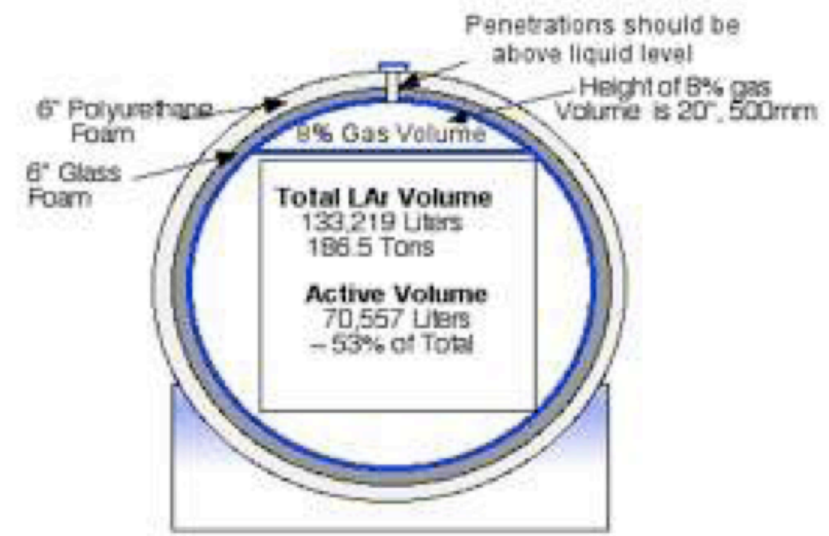
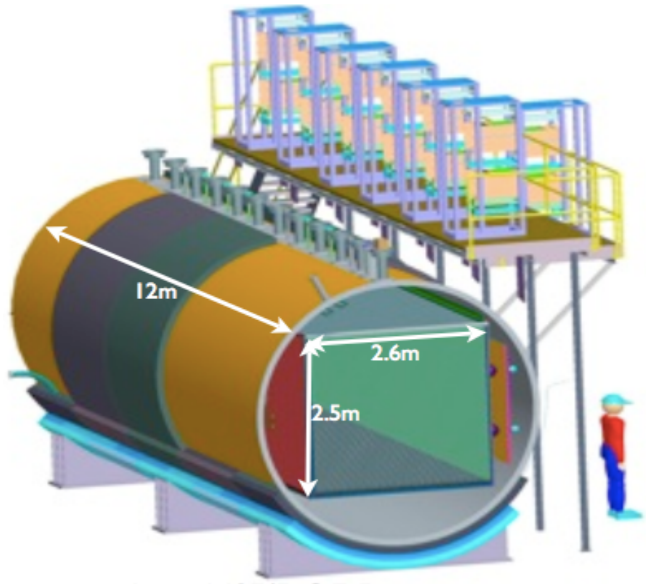
I was asked to include in my ArgoNeuT Talk a part on MicorBooNE, but I am not a Collaboration member…

MicroBooNE Design

- Cryostat (170 Tons LAr) as large as can be built commercially and trucked to site; Single wall, mechanically insulated (glass and polyurethane foam)
- TPC parameters:
  - 100 (70) Tons active (fiducial) volume
  - 2.6 m drift @ 500V/cm → 1.6ms drift time
  - ~10.000 channels (using cold preamplifier)
  - 3 Readout planes (±60° Induction, vertical Collection planes)
- ~30 PMT for triggering;
- Purification/Recirculation system

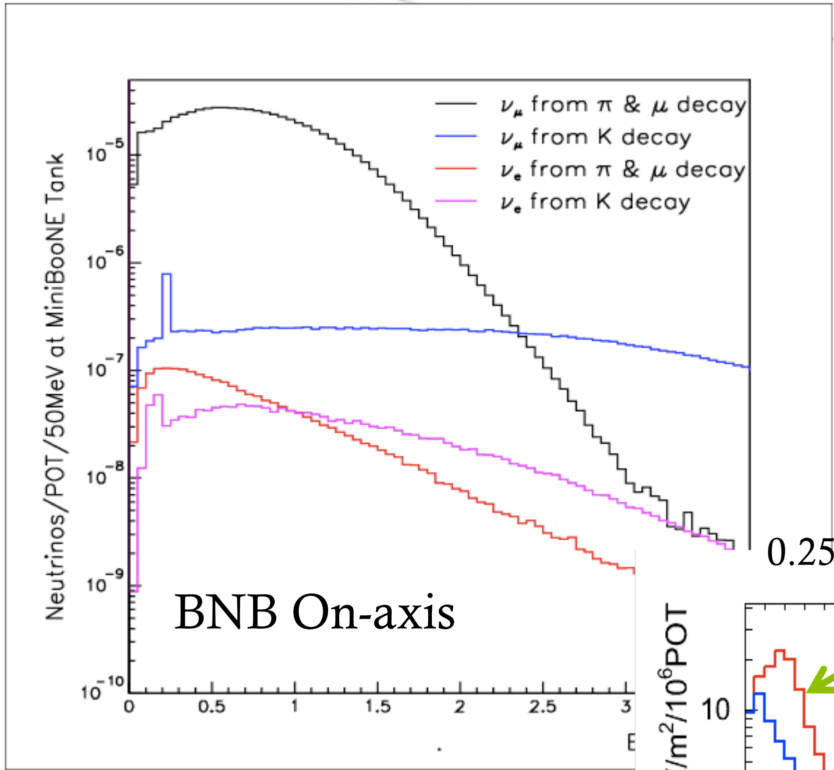


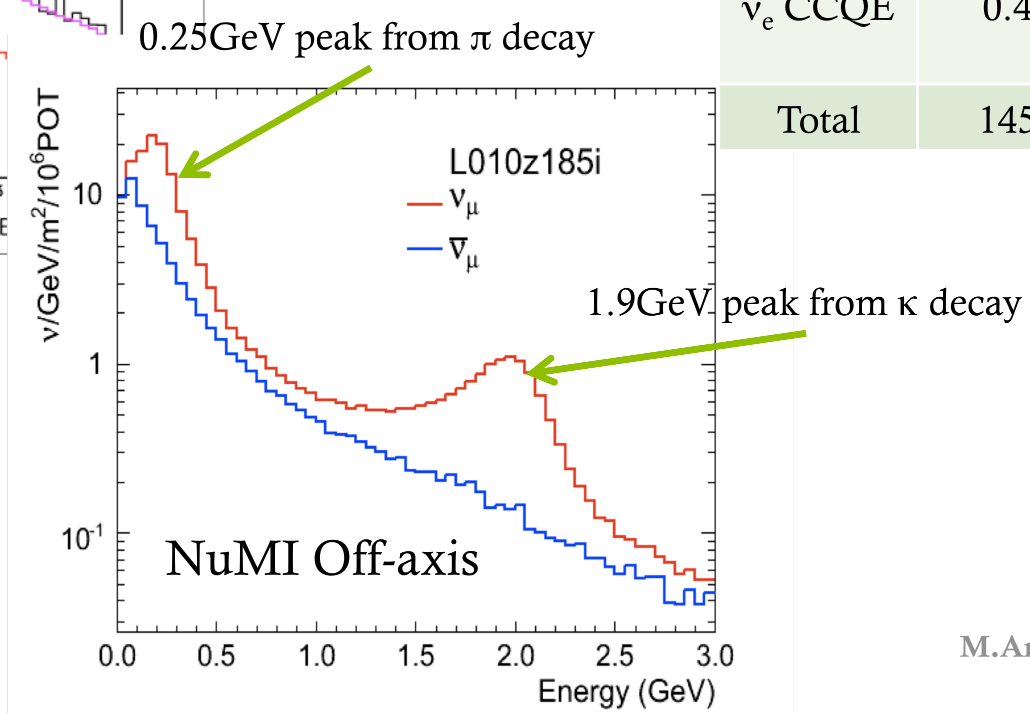


MicroBooNE Location

- μ BooNE will be located on surface, adjacent to the MiniBooNE hall, on-axis to the BNB and slightly off-axis (110 mrad) to the NuMI beam.

MicroBooNE: Fluxes and Expected Event Rate



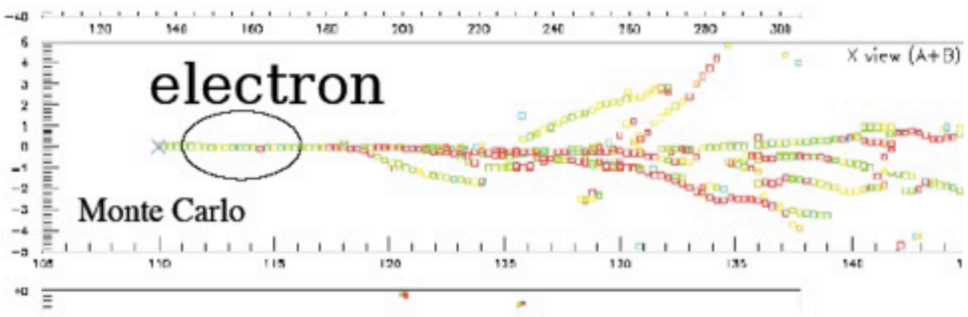


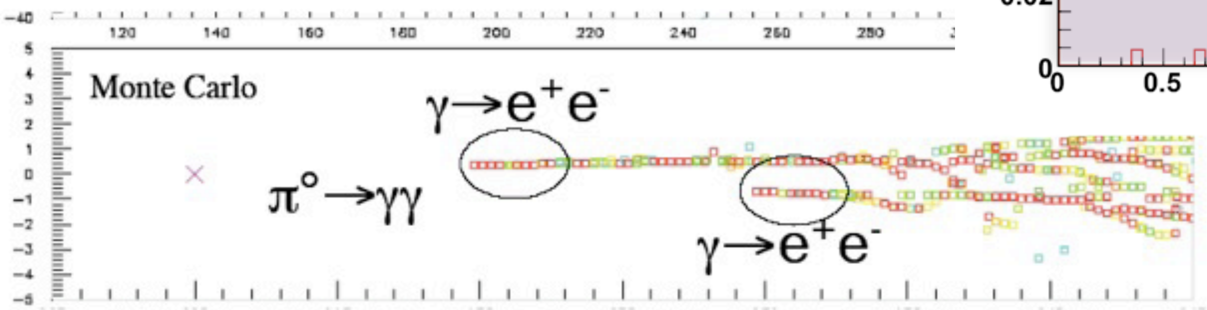
Total request

	BNB	NuMI
POT	6×10^{20}	8×10^{20}
ν_μ CCQE	68k	25k
NC π^0	8k	3k
ν_e CCQE	0.4k	1.2k
Total	145k	60k

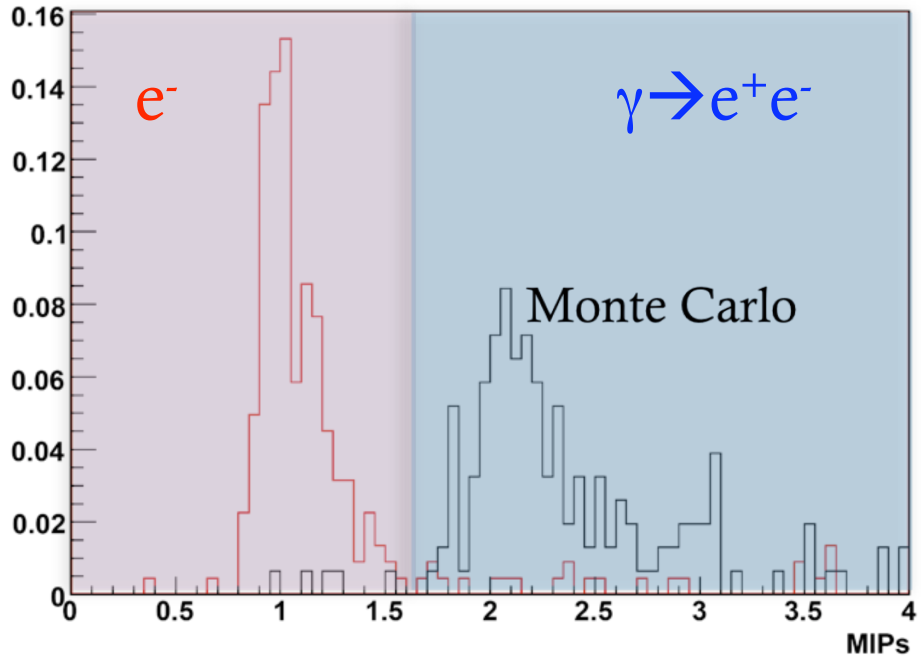
LAr TPC $e/\pi^0(\gamma\gamma)$ separation

- 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 $\nu_\mu NC\pi^0$ from signal (ν_e CC)
- → very important for $\nu_\mu \rightarrow \nu_e$ oscillation experiments





1GeV e^-'s vs 1GeV γ's



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MicroBooNE: Physics Goals

MicroBooNE will address the MiniBooNE low energy excess exploiting the LAr TPC capability of separating e- from π^0 ($\gamma\gamma$) (from dE/dx measurement and/or topological analysis of the first cm of track)

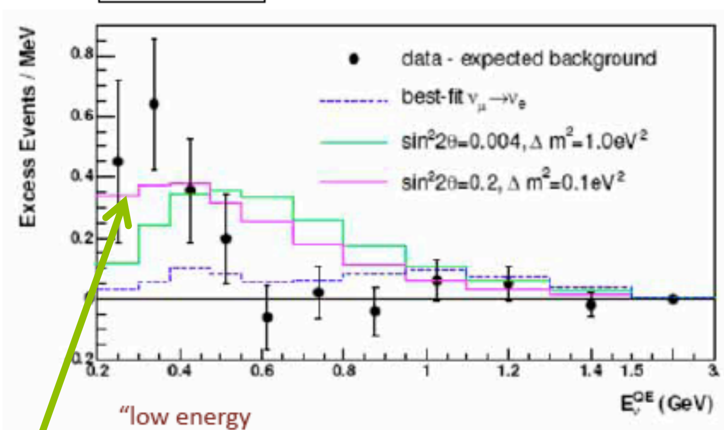
MiniBooNE Result Excess

200-300MeV: 45.2±26.0 events

300-475MeV: 83.7±24.5 events

No Excess observed for antineutrinos

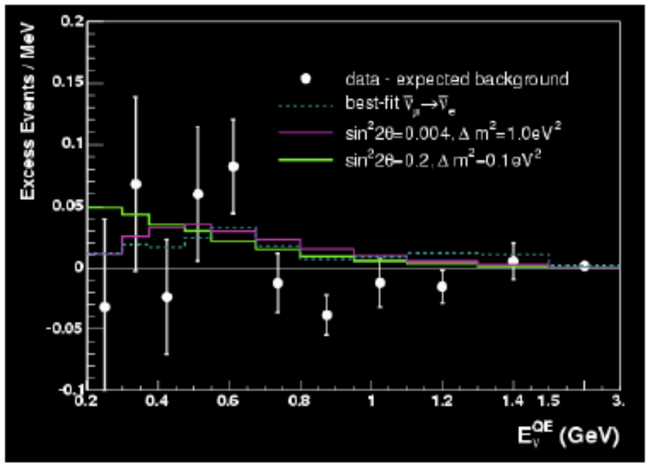
neutrinos



"low energy Mini-BooNE excess"

Karagiorgi FNAL Seminar

anti-neutrinos



From MC studies → good BG rejection (>90%) of $\nu_\mu NC\pi^0$ and $\Delta \to N\gamma$ events

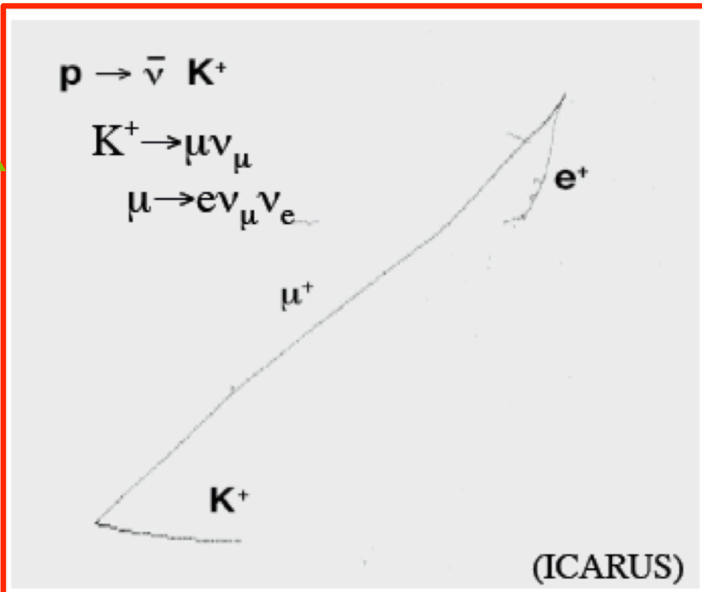
MicroBooNE will be able to reconstruct events below the MiniBooNE energy threshold

BG (mainly $\nu_\mu NC\pi^0$) or new Physics?

MicroBooNE: Other Physics Goals

- Low Energy Cross-Section Measurements (CCQE, NC π^0, $\Delta \rightarrow N\gamma$, Photonuclear, ...) exploiting the LArTPC capability to perform a detailed event reconstruction

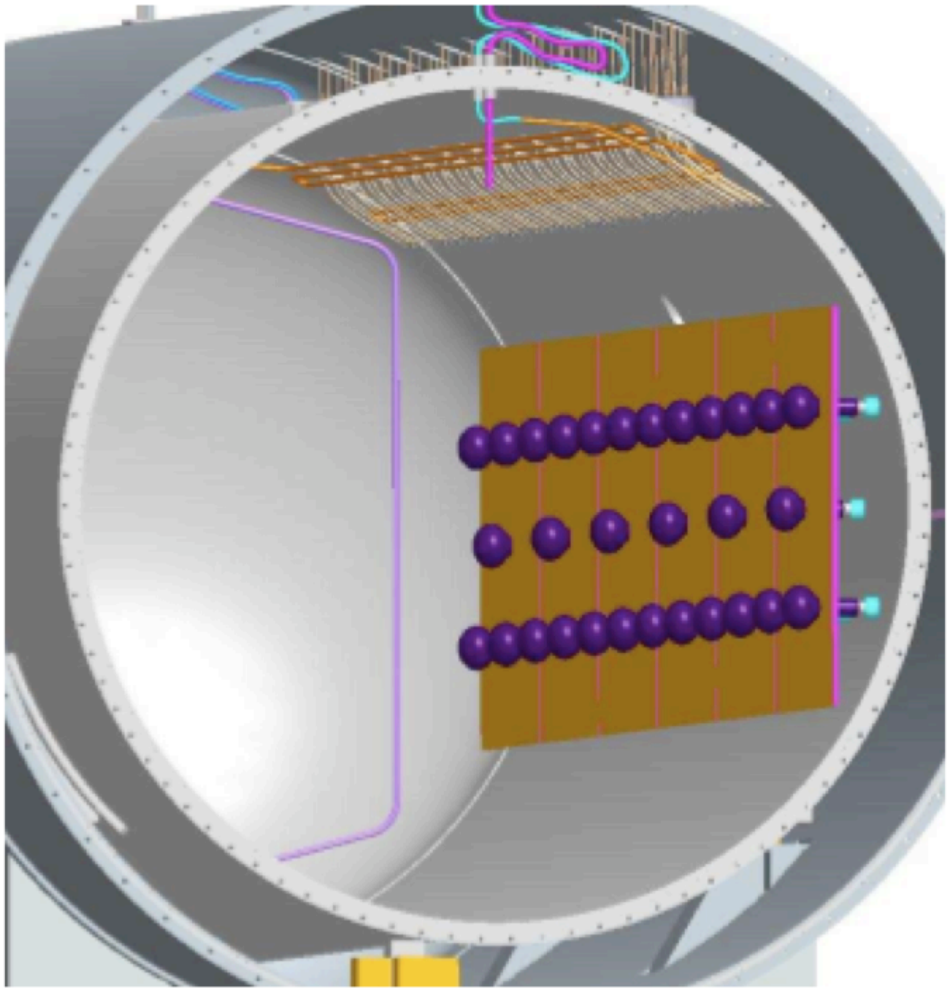
- Use small (~500) sample of Kaons to study proton-decay sensitivity for future massive LAr TPC detectors.



- Detect Supernova neutrinos through several reactions:
  - Elastic Scattering: $\nu + e^- \rightarrow \nu + e^-$
  - NC : $\nu_e + {}^{40}Ar \rightarrow \nu_e + {}^{40}Ar^*$
    $${}^{40}Ar^* \rightarrow {}^{40}Ar + \gamma$$
  - Absorption (CC): $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$
    $${}^{40}K^* \rightarrow {}^{40}K + \gamma$$
    anti- $\nu_e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$
    $${}^{40}Cl^* \rightarrow {}^{40}Cl + \gamma$$

MicroBooNE: Light Detection

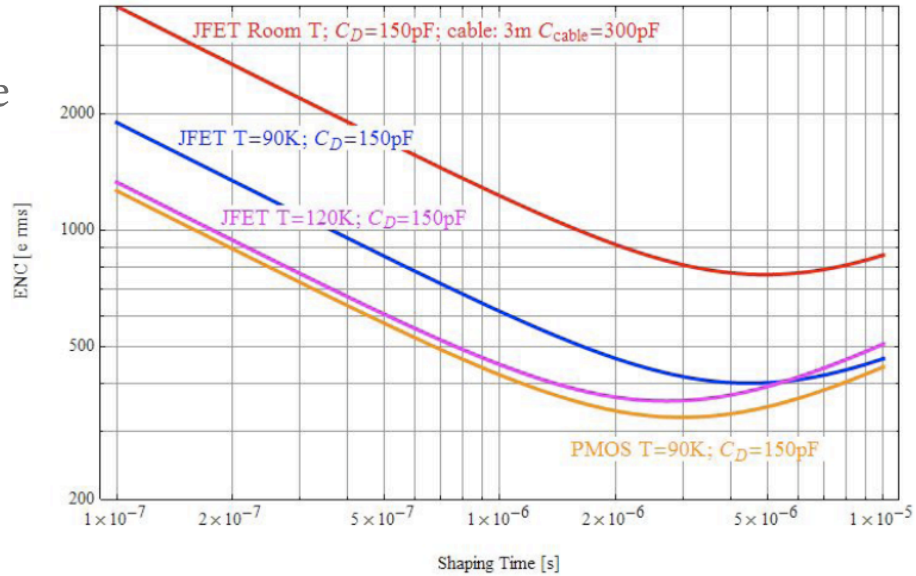
- 30 PMTs immersed in LAr, facing the TPC for:
  - t0 determination
  - data reduction purposes: *i.e. - require coincidence of beam spill and light signal in PMTs* Most likely will use 8” tubes from Hamamatsu
- Coated with wavelength shifter (TPB + polystyrene mixture or TPB) to allow collection of VUV light (λ ~ 128nm)

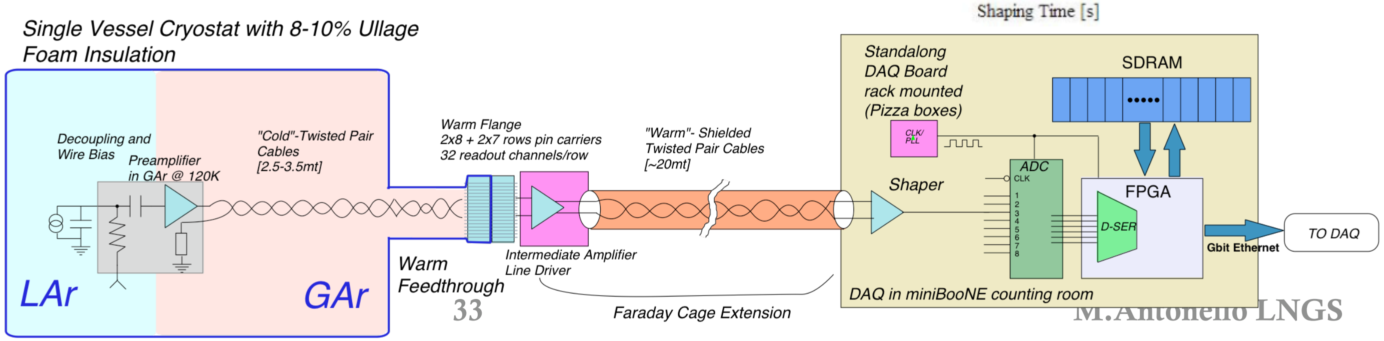


MicroBooNE: Cold Electronics

- Preamps (JFET input) will be placed inside of cryostat in cold GAr
  - as close as possible to the wire to minimize the connection lengths (reducing the capacitive load seen at the preamplifier input improves S/N)
  - x3 better S/N compared with room temperature performance.
  - Necessary step along the path to large detectors where signals must make long transits.
- It has been checked that Cold Electronics does not affect LAr Purity.

2 Phase R&D:
- Discrete JFET @ T=120K for MicroBooNE
- ASICs w. PMOS input device @ T=90K for beyond MicroBooNE





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, is 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 and MicroBooNE Experiment will also perform relevant physics/ software programs:
  - Measure low energy Cross-section (ArgoNeuT, MicroBooNE)
  - Investigate the MiniBooNE low energy excess (MicrobooNE)
  - Develop automated 3D and calorimetric reconstruction and Particle ID (ArgoNeuT, MicroBooNE)
  - Feasibility of running on surface for $\nu_\mu \rightarrow \nu_e$ Oscillation Experiments (MicroBooNE)