The ArgoNeuT Experiment

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New Perspectives

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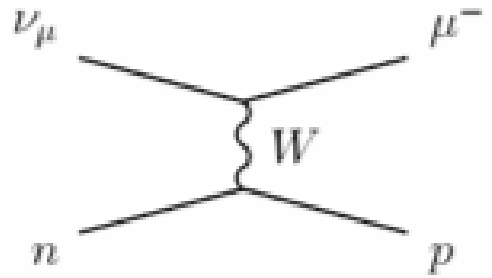
A Brief Overview of Neutrinos

- Neutrinos were first postulated by Wolfgang Pauli in 1930 to preserve the laws of conservation of energy, momentum, and angular momentum in beta decay.
  - $n \rightarrow p + e^- + \overline{\nu}_e$
- Neutrinos were first detected by Clyde Cowan and Frederick Reines in 1956.
  - $\overline{\nu}_e + p \rightarrow n + e^+$
- A second flavor of neutrinos was discovered by Leon Lederman, Melvin Schwartz, and Jack Steinberger in 1962.

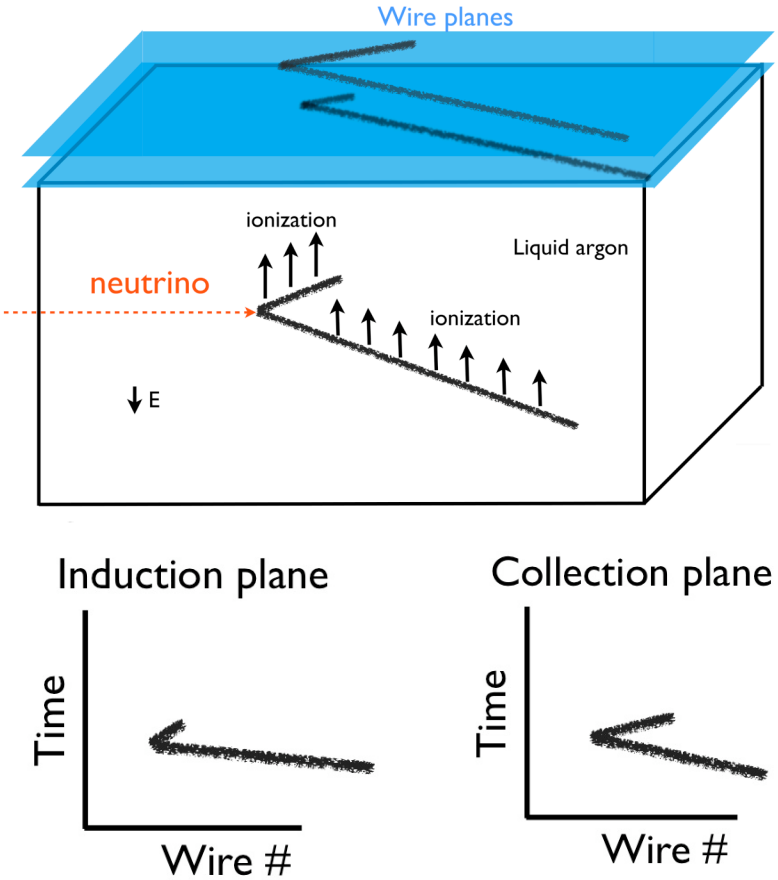
A Brief Overview of Neutrinos

- There are three flavors of neutrinos: ν_e, ν_μ, ν_τ .
  - There are also three flavors of anti-neutrinos.
- Neutrinos interact with matter primarily through the weak force.
  - Cross sections are not well known.



- Neutrinos oscillate from one flavor to another.
  - Neutrinos have mass.
  - Neutrino masses, mixing angles, etc. are only partially known.

The LArTPC Concept

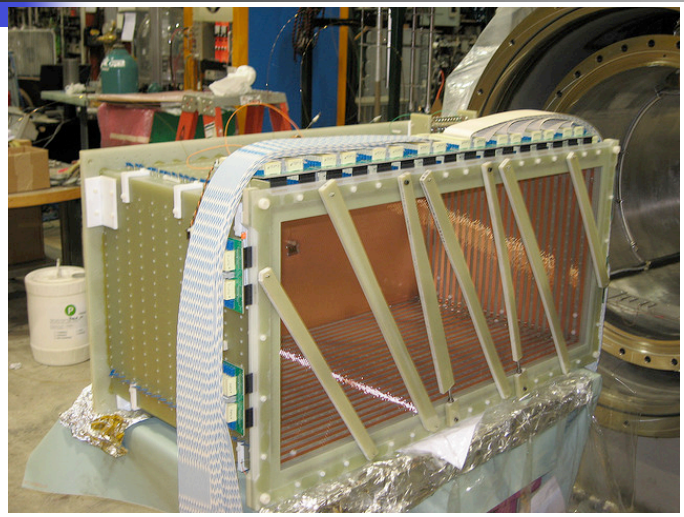


- Combine two wire plane views and time information to get 3D image of event with calorimetric information.

LArTPCs for Neutrinos

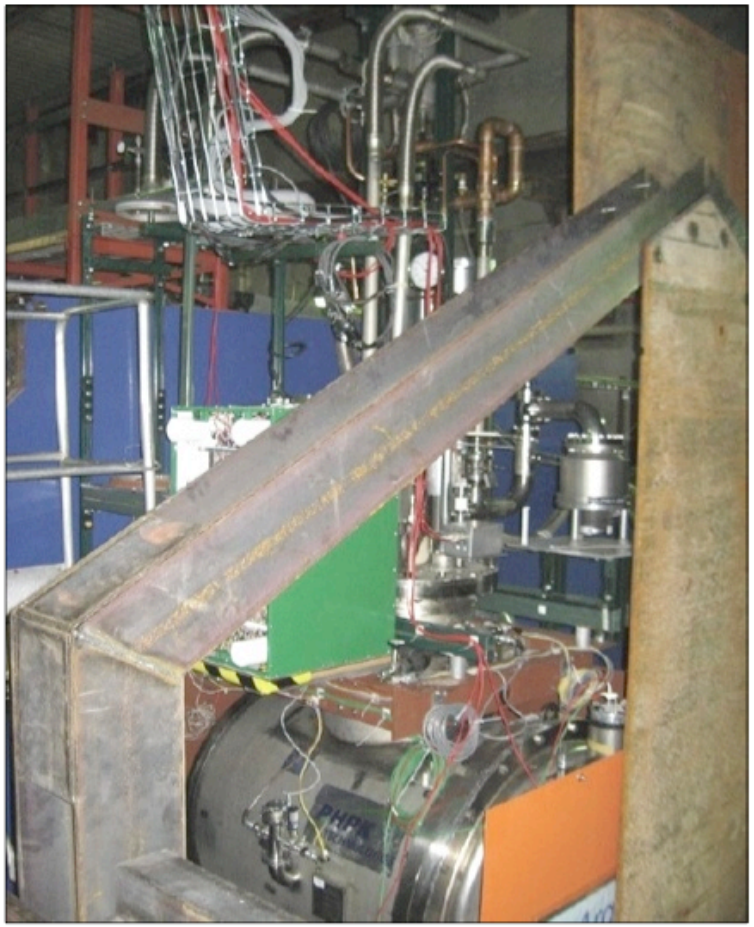
- Liquid argon is a dense target for interactions and is (relatively) cheap. If purified, electrons can be drifted over large distances.
- LArTPCs are sensitive at low energies (~10 MeV).
- Wire spacing and short sampling time yields high resolution.
- Energy deposition (dE/dx) can be used along a track to identify particles.
  - e^- and γ events are easily separable.
  - Protons are identifiable and distinguishable from muons.

ArgoNeuT Detector



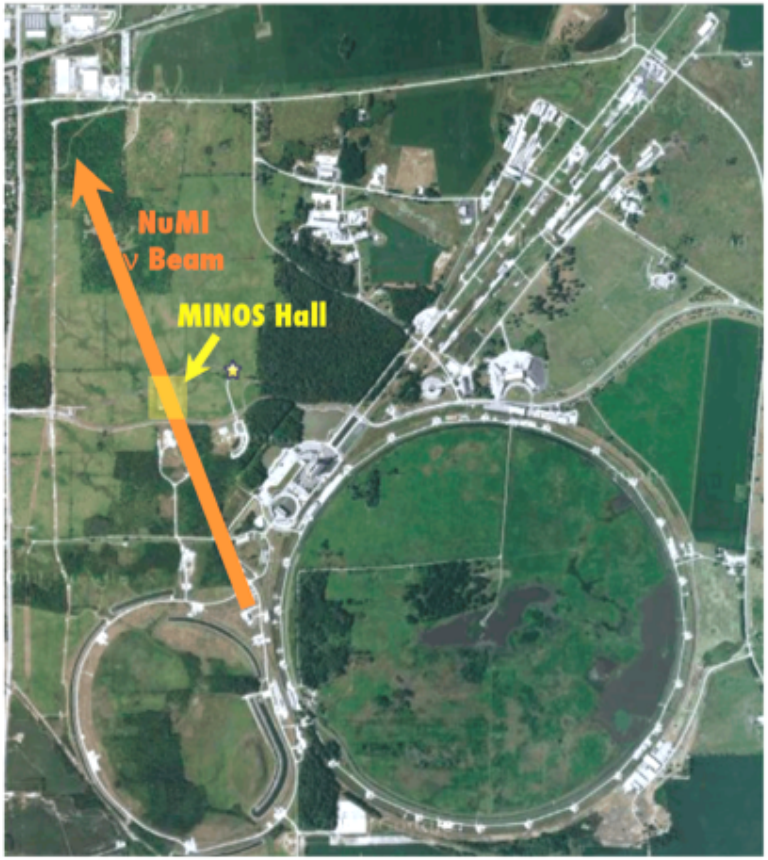
TPC about to enter the cryostat

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Electronics Style (Temp.)	JFET (293 K)
Wire Pitch (Plane Separation)	4 mm (4 mm)
Electric Field	500 V/cm
Max. Drift Length (Time)	0.5 m (330 μs)
Wire Properties	0.15mm diameter BeCu



ArgoNeuT in the beam line

ArgoNeuT in the NuMI Beam

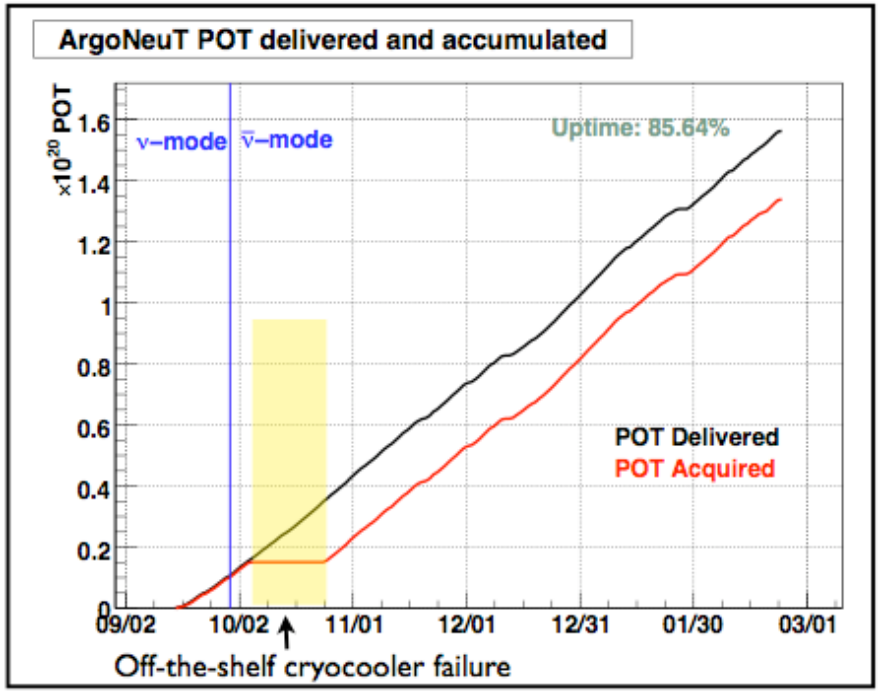


NuMI Beam Line at Fermilab

Schematic of ArgoNeuT
in the MINOS Hall

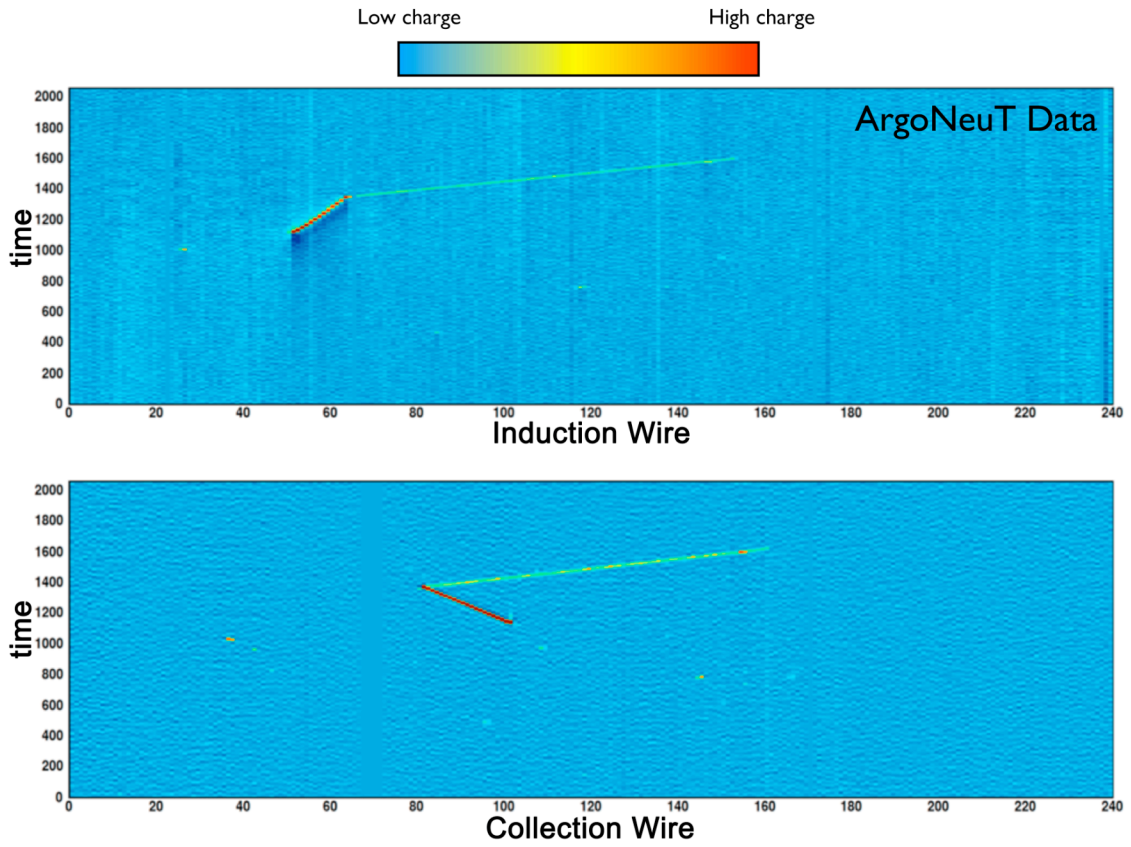
ArgoNeuT Physics Run

- Physics run lasted from 9/14/2009 to 2/22/2010.
- Stable, shift free operation for over five months.
- Collected ~1.35E20 protons on target (P.O.T.).
- First (anti-)neutrino events in a LArTPC in the U.S.!



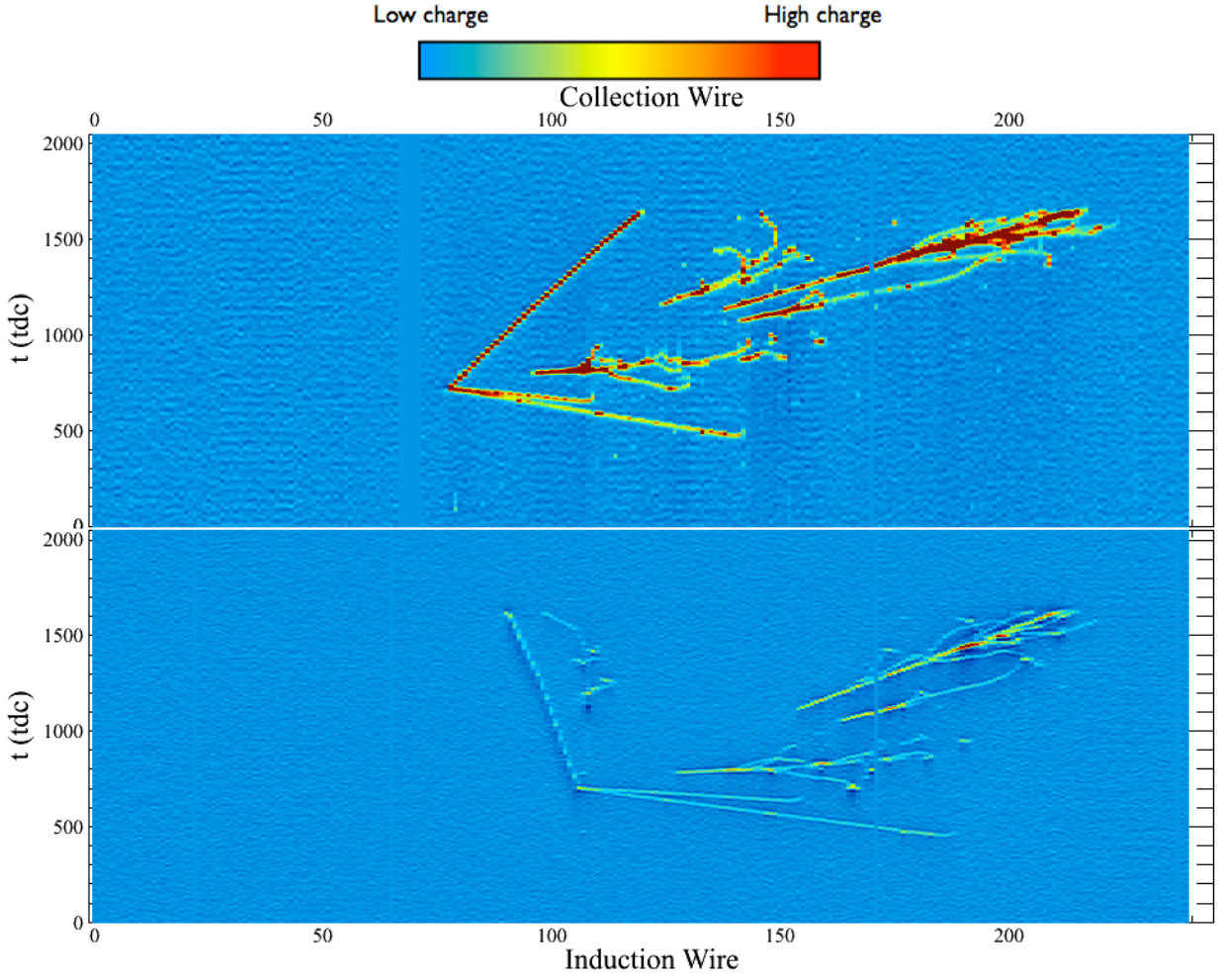
Reaction	#events in AV (~1.35E20 POT)
ν_μ CC	~6600
$\overline{\nu}_\mu$ CC	~4900
ν_μ CCQE	~600
ν_e CC	~130

Candidate ν Events in ArgoNeuT

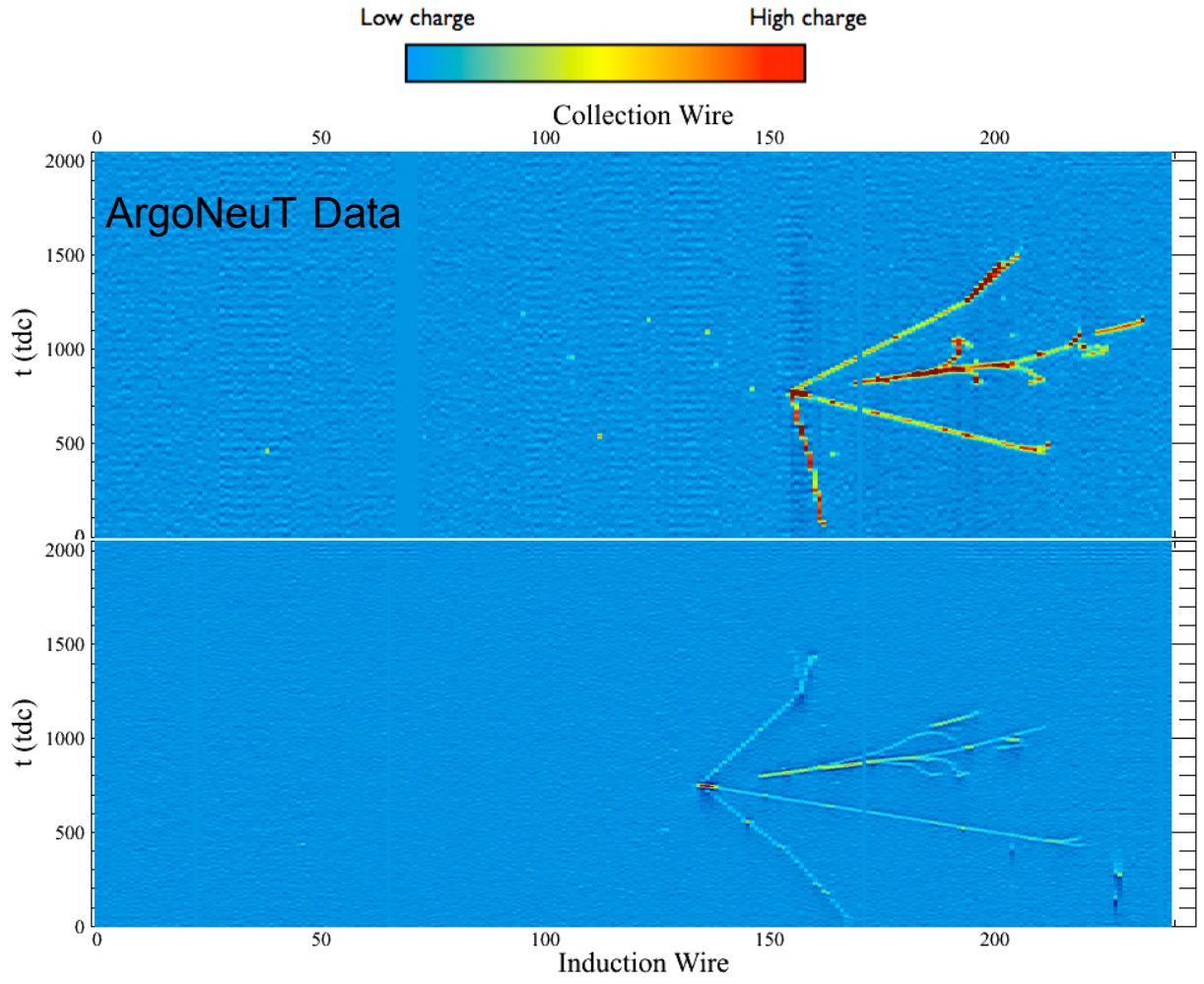


Pixel Size: 4.0 X 0.3 mm^2

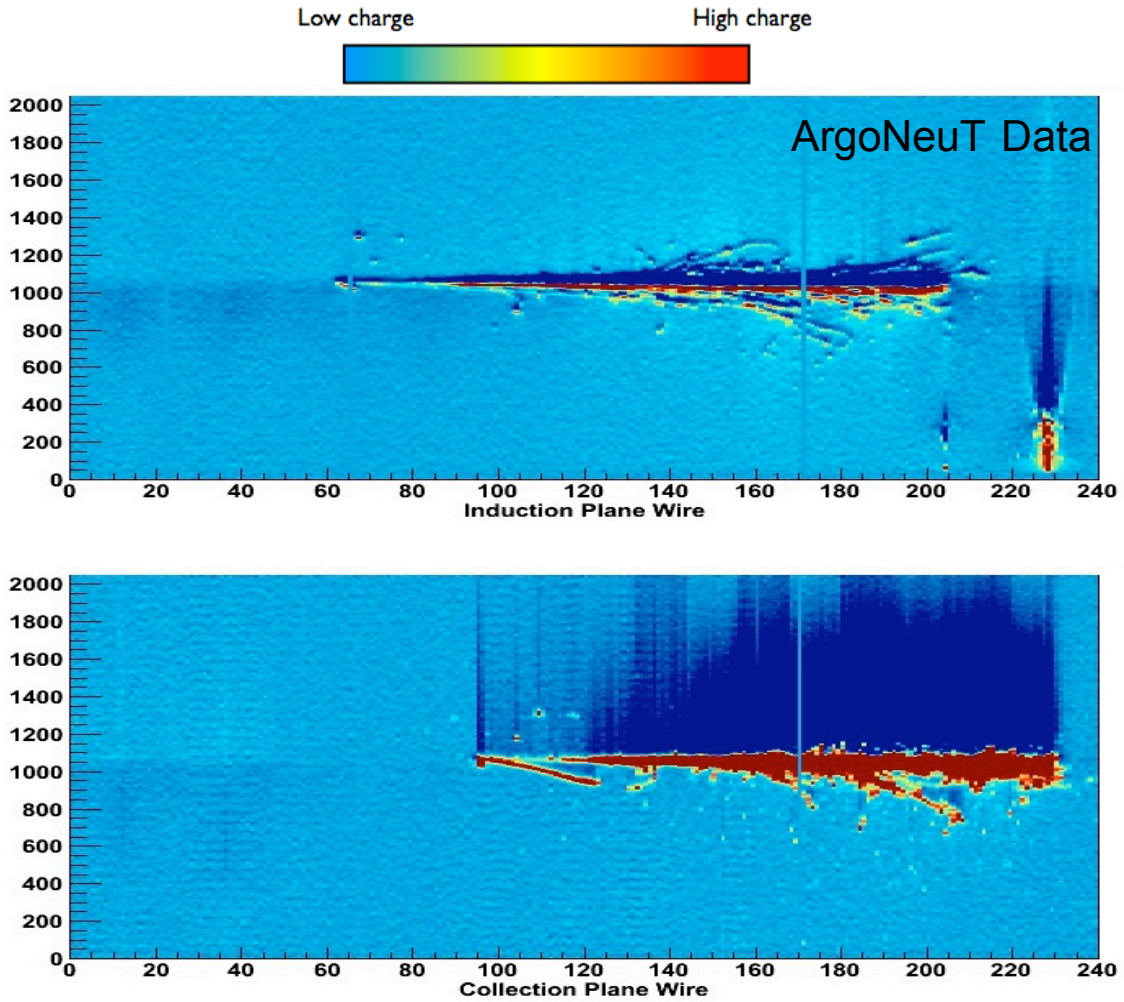
Candidate ν Events in ArgoNeuT



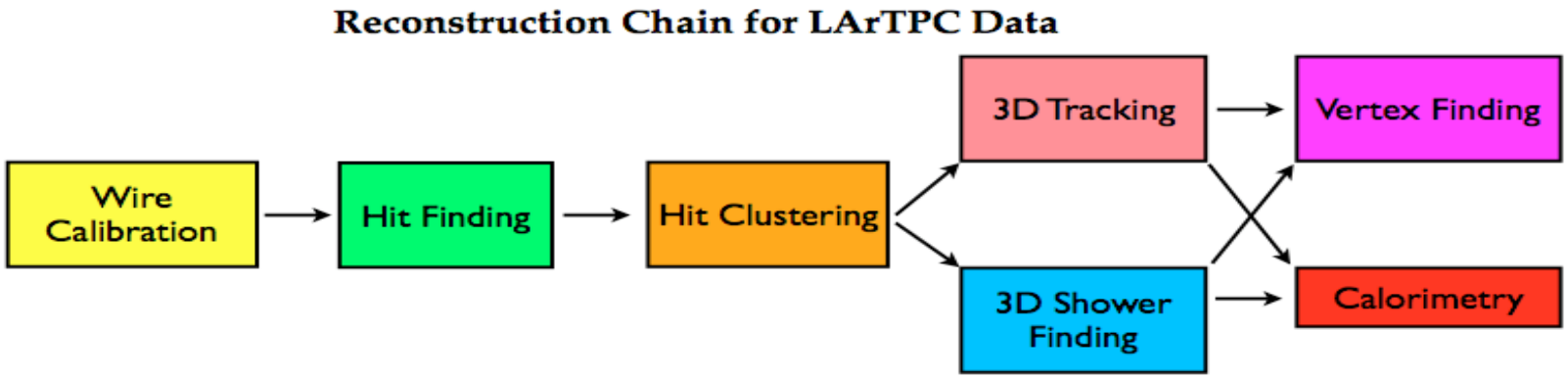
Candidate ν Events in ArgoNeuT



Candidate ν Events in ArgoNeuT

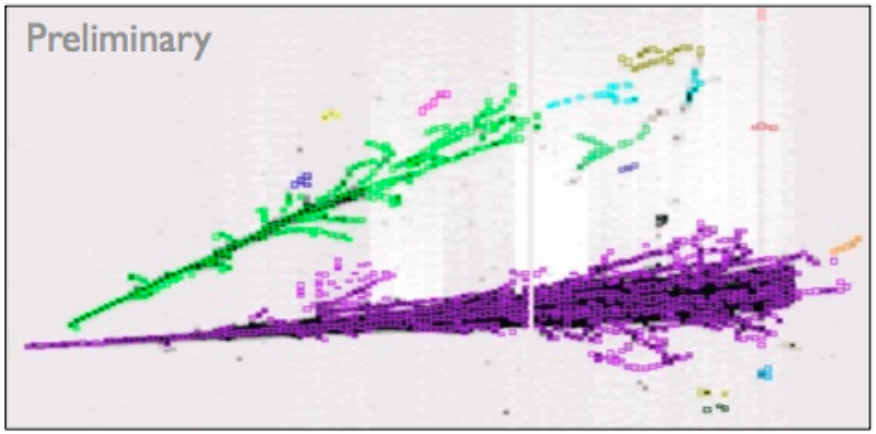


Reconstructing ν Events in ArgoNeuT



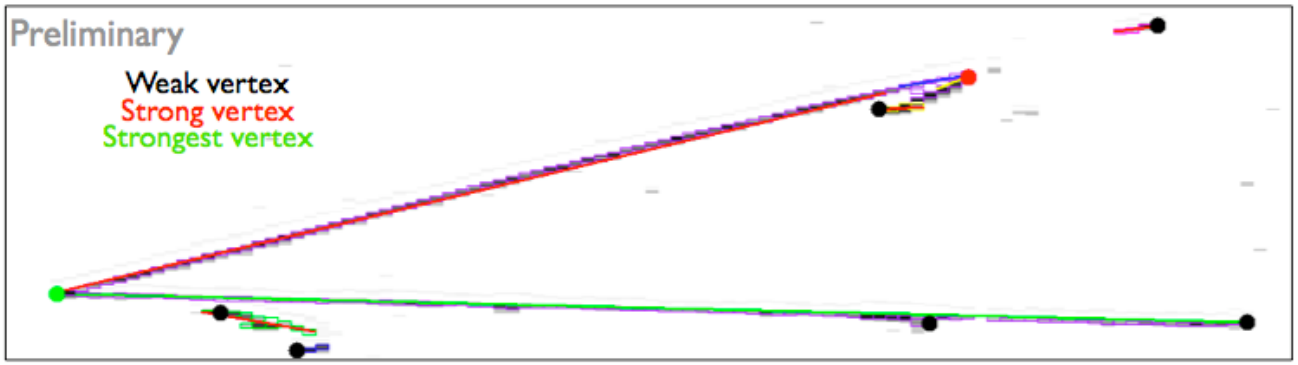
- We must create reconstruction and simulation software from scratch as this is the first time collecting data in LArTPC.
- We have made significant progress towards a full reconstruction and simulation chain. Preliminary reconstruction chain has been developed for ArgoNeuT data.
- Reconstruction software will be used for future LArTPC experiments.

Reconstructing ν Events in ArgoNeuT



Hit finding & density-based clustering

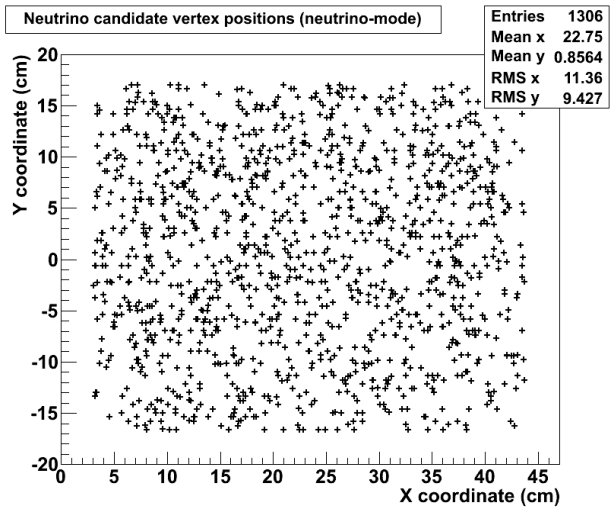
3D reconstruction

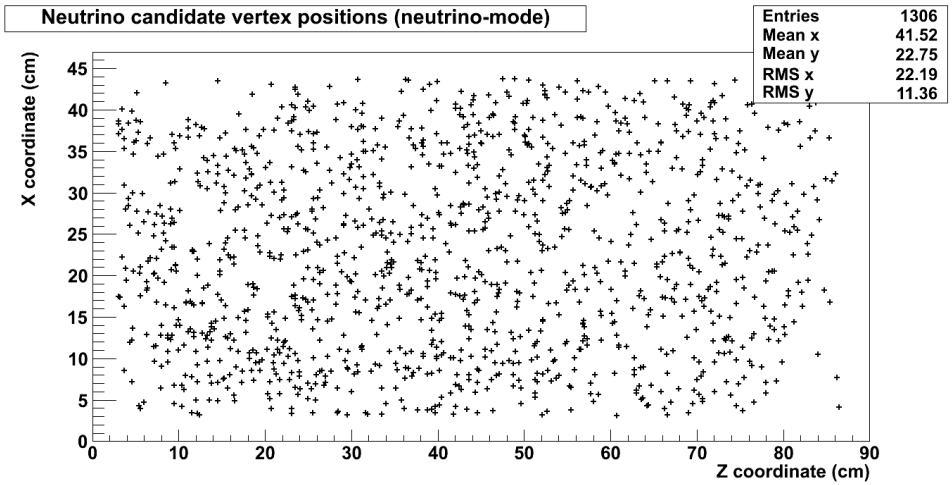


Line finding/fitting & vertex/endpoint finding

Reconstructing ν Events in ArgoNeuT

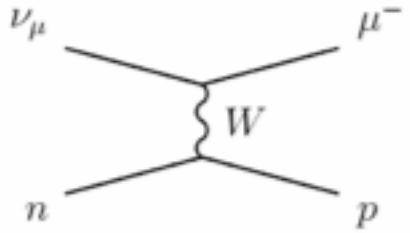
- Collaborators have hand scanned all events in ν mode.
  - Every event was categorized as either: a neutrino, maybe a neutrino, or no neutrino.
  - Number of primary tracks and location of primary vertex were recorded.
- These events are being used to fine tune reconstruction parameters and will be used to cross check final sample of ν events.





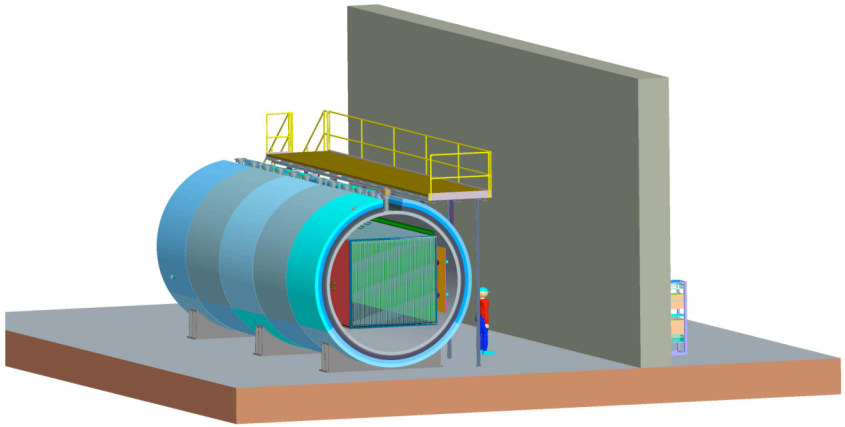
ArgoNeuT Physics Goals

- Measure many (anti-)neutrino cross sections and vertex activity characterization in the 1-5 GeV range.
  - Small statistics
  - CC-inclusive cross section



- Measure ν_e event rate.
- Compare resonant and coherent pion production.
- Initial focus on two weeks of neutrino mode data.
  - Compare MC/Data for inclusive CC events.
- Develop automatic reconstruction techniques for use on future LArTPC experiments.

MicroBooNE



- 170 tons LArTPC with 60 tons fiducial volume.
- Will be exposed to on-axis Booster Neutrino Beam and off-axis NuMI beam.
- Physics goals are to make low energy cross section measurements and address MiniBooNE low energy excess.
- Start taking data in 2013.

Future of LArTPCs in the U.S.

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

15x

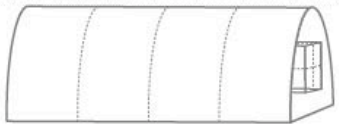
ArgoNeuT
Operational
Physics: Measure neutrino-argon cross sections
0.0003 kton

330x

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

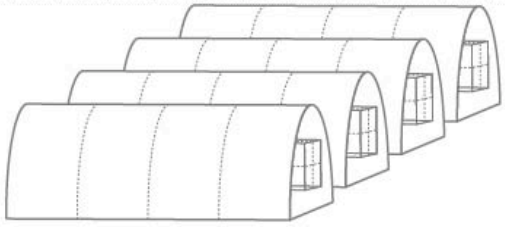
4x50x

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



Long Baseline
Neutrino Experiment

Final goal
Replicate proven technology
Physics: Search for CP violation in neutrino sector
N x 20 kton



Conclusion

- LArTPCs are a promising new technology for neutrino detection.
- ArgoNeuT completed a very successful five month run in 2010. It collected the first neutrino events in a LArTPC in a low energy beam.
- Reconstruction and analysis of ArgoNeuT events is under way.
- First ArgoNeuT results are expected in summer 2011.
  - Muon reconstruction.
  - CCQE-like differential cross section and vertex activity analyses.

ArgoNeuT Collaboration

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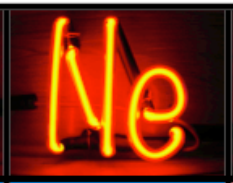
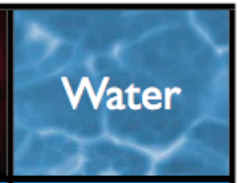
Backup Slides

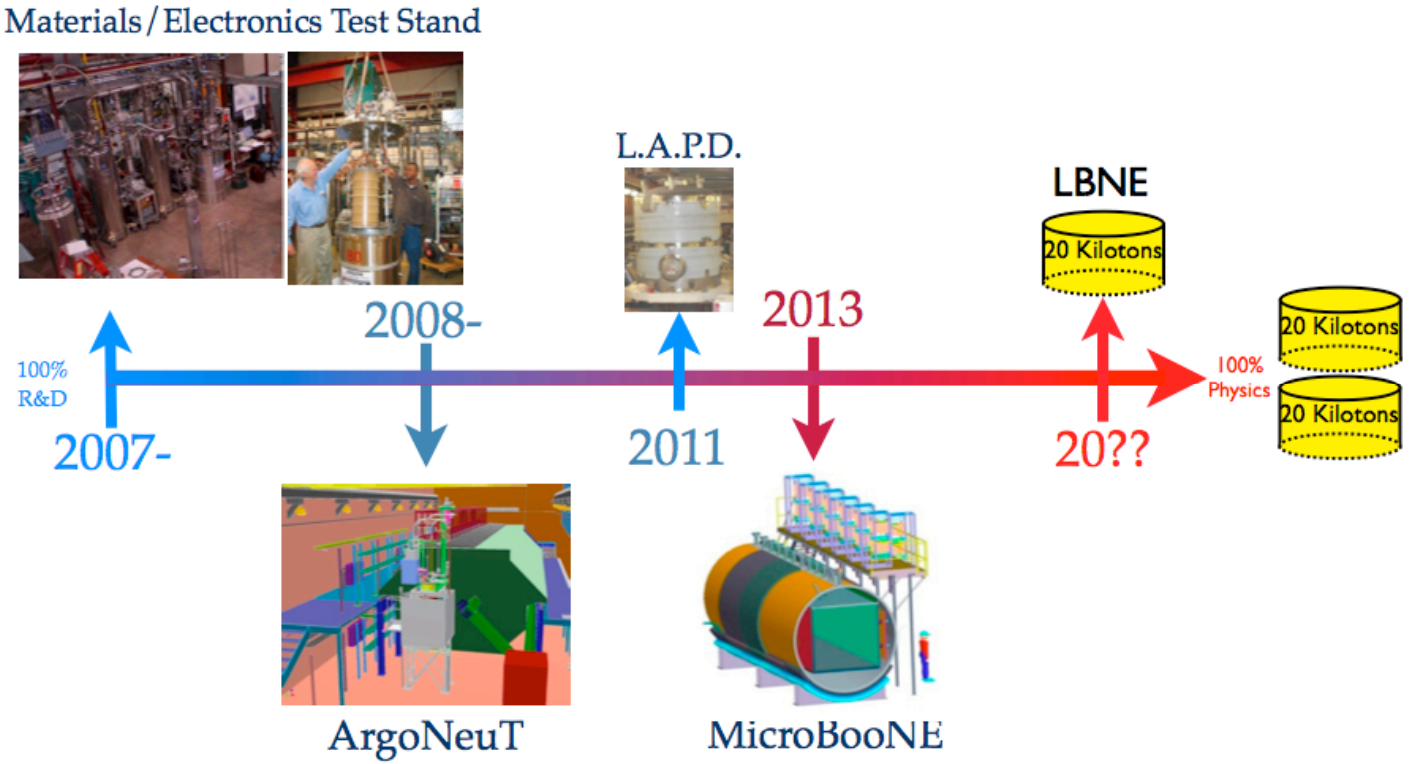
Why Noble Liquids?

- Abundant ionization electrons and scintillation light can both be used for detection.
- If liquids are highly purified (<0.1ppb), ionization can be drifted over long distances.
- Excellent dielectric properties accommodate very large voltages.
- Noble liquids are dense, so they make a good target for neutrinos.
- Argon is relatively cheap and easy to obtain (1% of atmosphere).
- Drawbacks?...no free protons...nuclear effects unavoidable.

						
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
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	

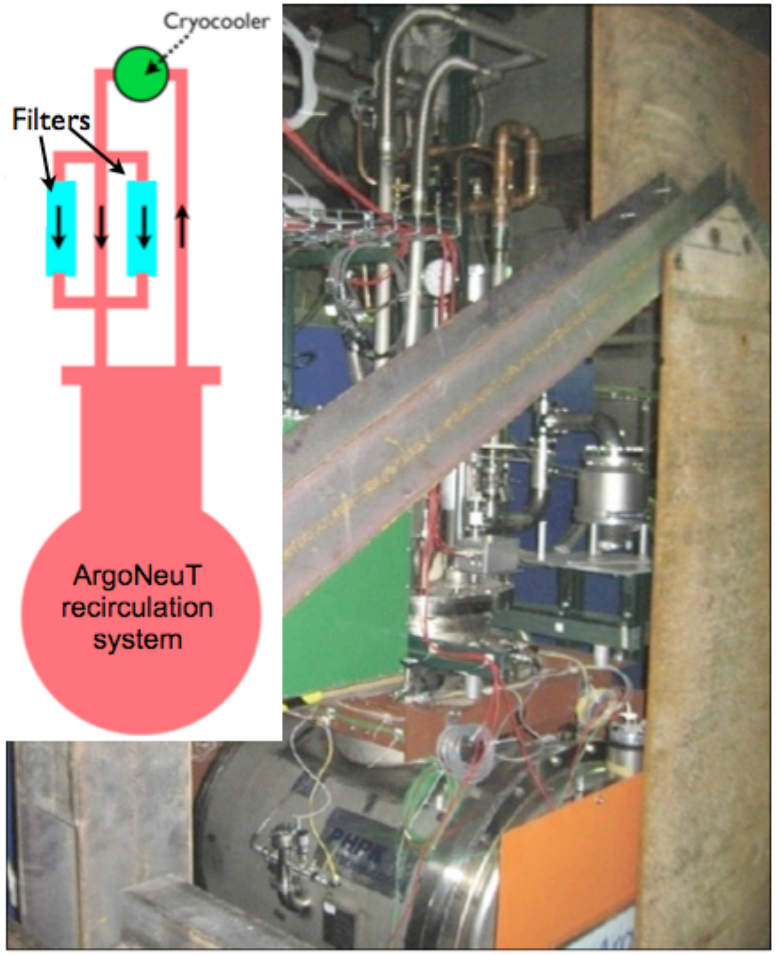
Liquid Argon R&D at Fermilab

Development focused on scaling LArTPCs to sizes necessary for long-baseline experiment.

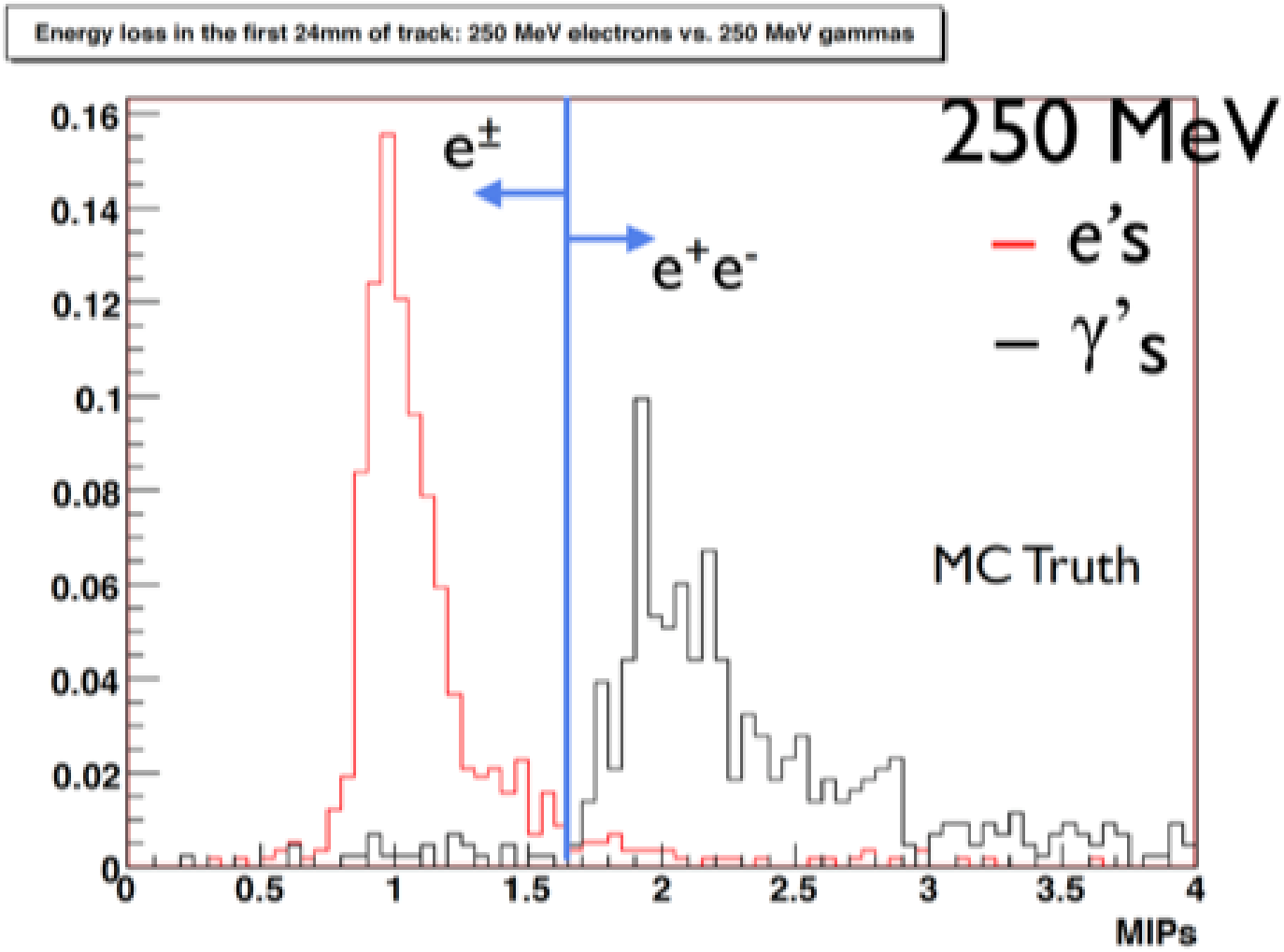


Refs:
1.) *A Regnerable Filter for Liquid Argon Purification* Curioni et al, NIM A605:306-311 (2009)
2.) *A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water* Andrews et al, NIM A608:251-258 (2009)

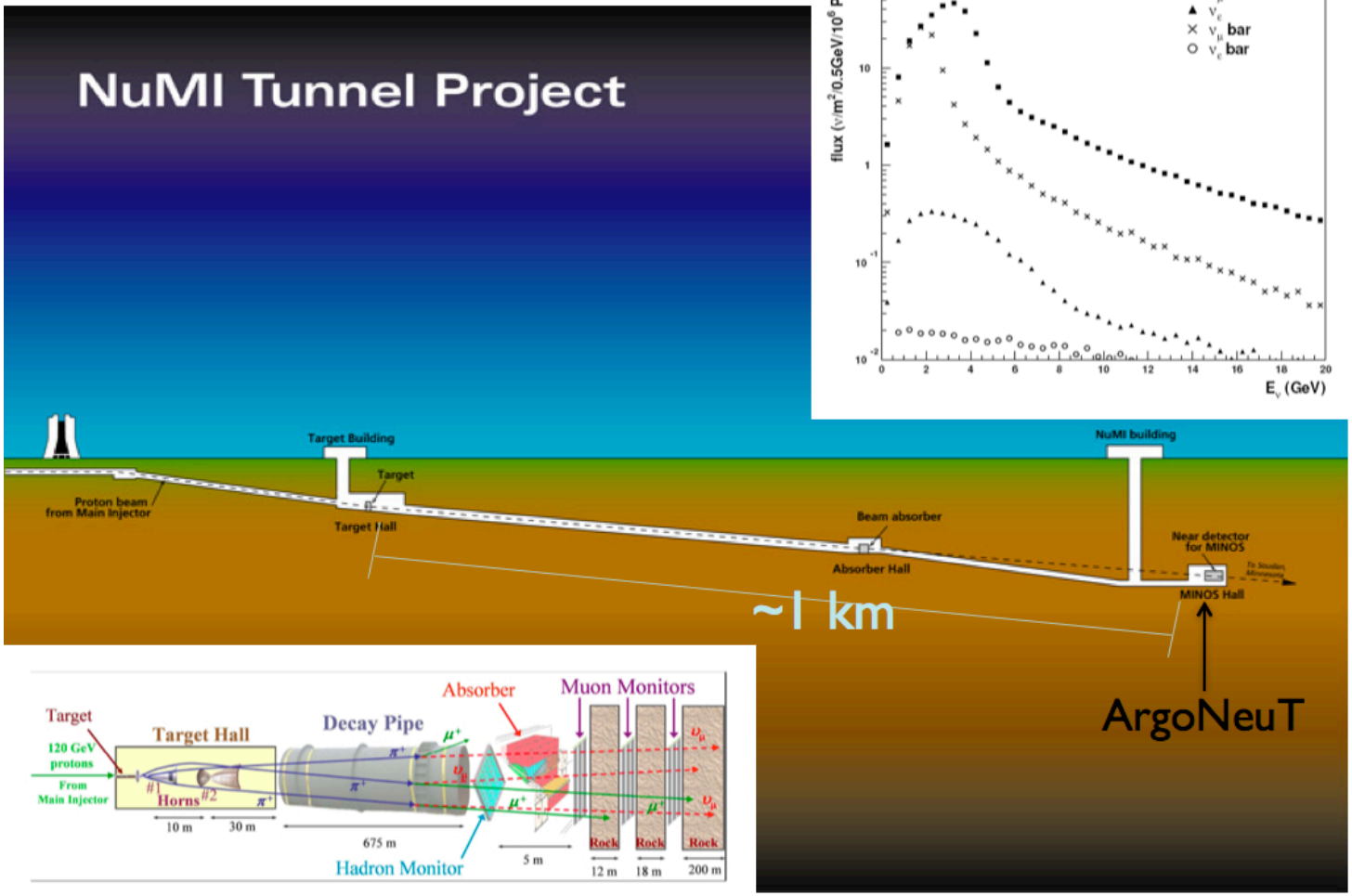
Cryocooler and Filters



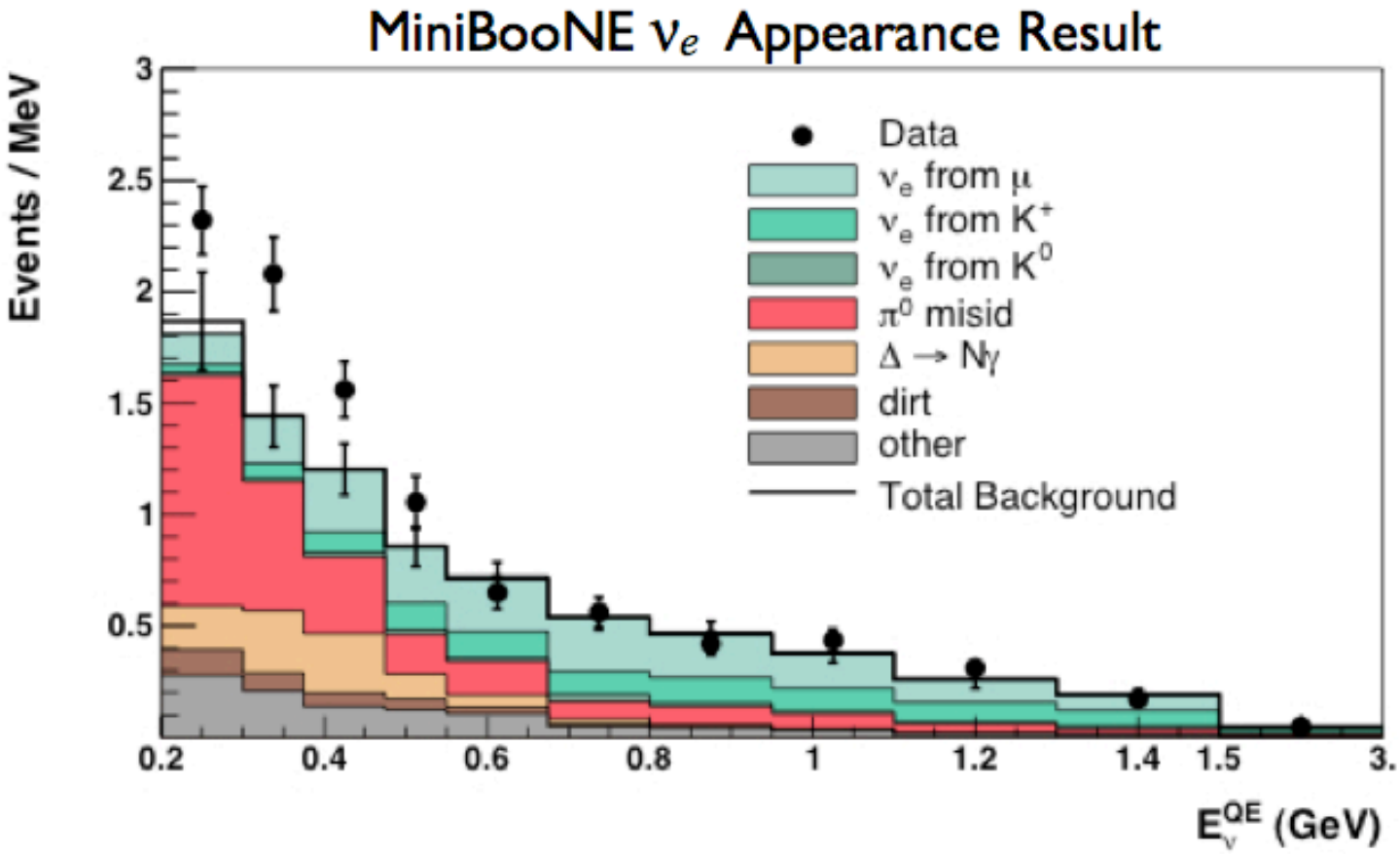
e^- and γ separation



NuMI Beam Line at Fermilab



MiniBooNE Low Energy Excess



Refs:

1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)