Liquid Argon Technology for Neutrinos

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7th IDS-NF Plenary Meeting

Talk Outline

- Introduction to Liquid Argon detectors for neutrinos.
- The MicroBooNE Experiment
- Future directions.

Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) combine fine-grained tracking and calorimetry, and appear scalable to very large size.
- U.S. efforts to develop LArTPCs have expanded significantly in recent years.
- These efforts are aimed at developing the technology for a multi-kiloton detector that could be used to do a variety of physics (accelerator neutrinos, proton decay, astrophysics, ...)
- "Smaller" scale detectors, O(100 tons), offer opportunity for interesting physics measurements and important hardware development.

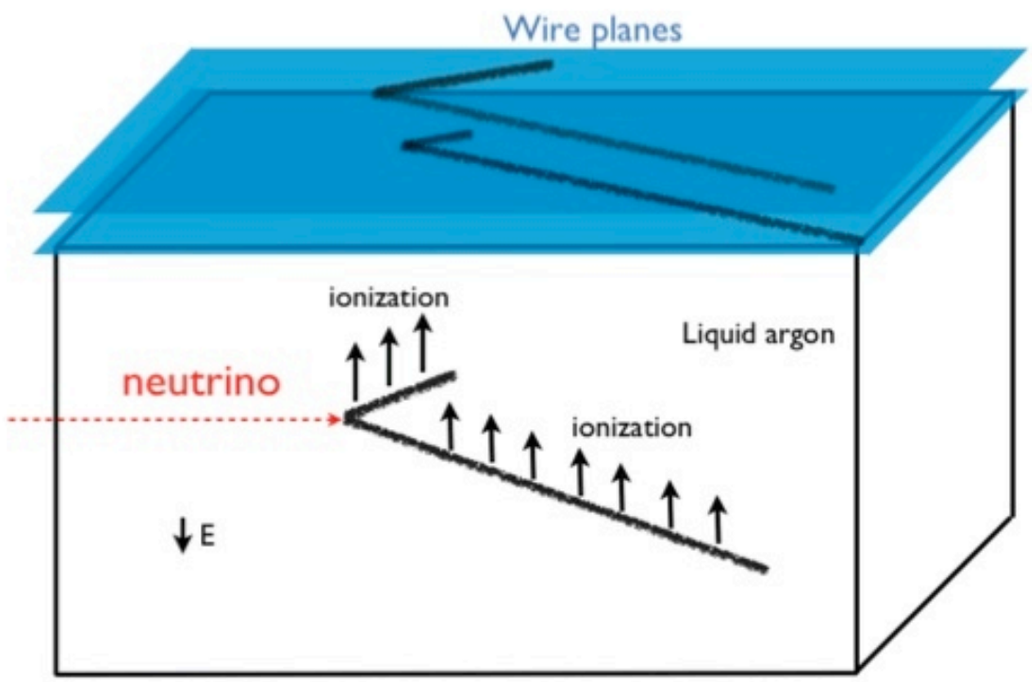
Why Noble Liquids for Neutrinos?

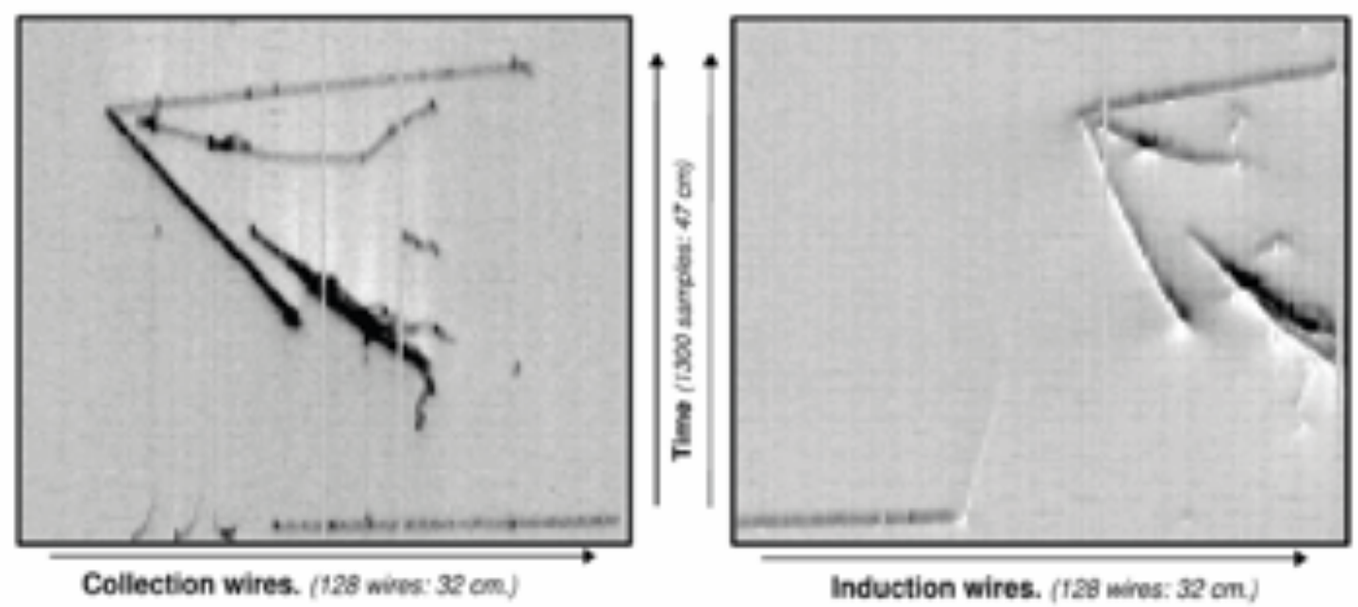
- Abundant ionization electrons and scintillation light can both be used for detection.
- If liquids are highly purified (<0.1ppb), ionization can be drifted over long distances.
- Excellent dielectric properties accommodate very large voltages.
- Noble liquids are dense, so they make a good target for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

	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
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 Neutrino Detectors

- Neutrino interactions in the TPC produce charged particles that ionize the argon as they travel.
- Ionization is drifted along E-field to wireplanes, consisting of wires spaced ~millimeters apart.
- Location of wires within a plane provides position measurements...multiple planes give independent views.
- Timing of wire pulse information is combined with known drift speed to determine drift-direction coordinate.





Images from ICARUS 50-liter TPC.

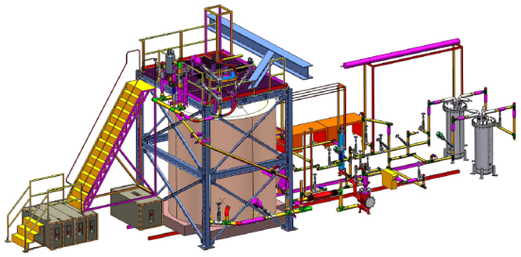
Refs:
1.) *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

Liquid Argon Efforts at Fermilab

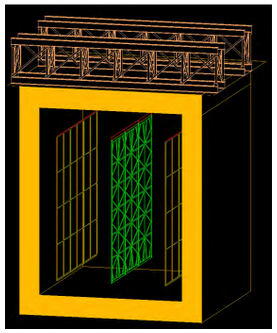
Development focused on scaling LArTPCs to sizes necessary for long-baseline experiment.

Materials / Electronics Test Stand

L.A.P.D.



1-kTon Prototype



100% R&D

2007-

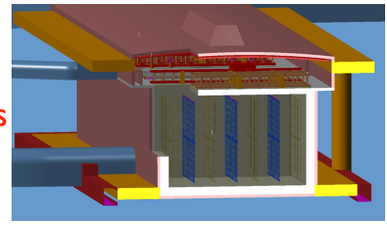
2008-

2011

2013

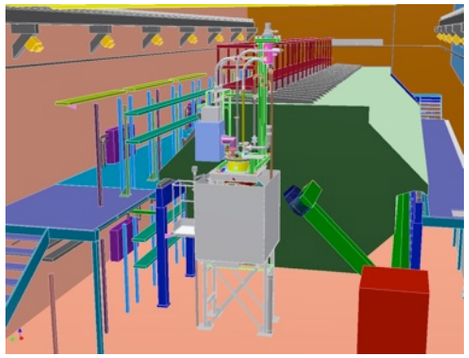
2014

100% Physics

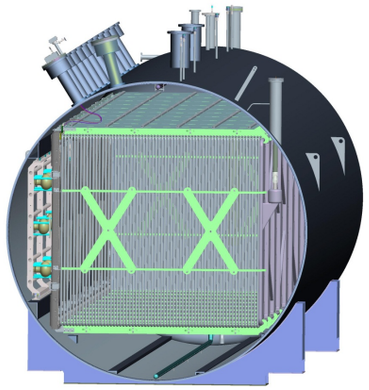


LBNE

20??



ArgoNeuT



MicroBooNE

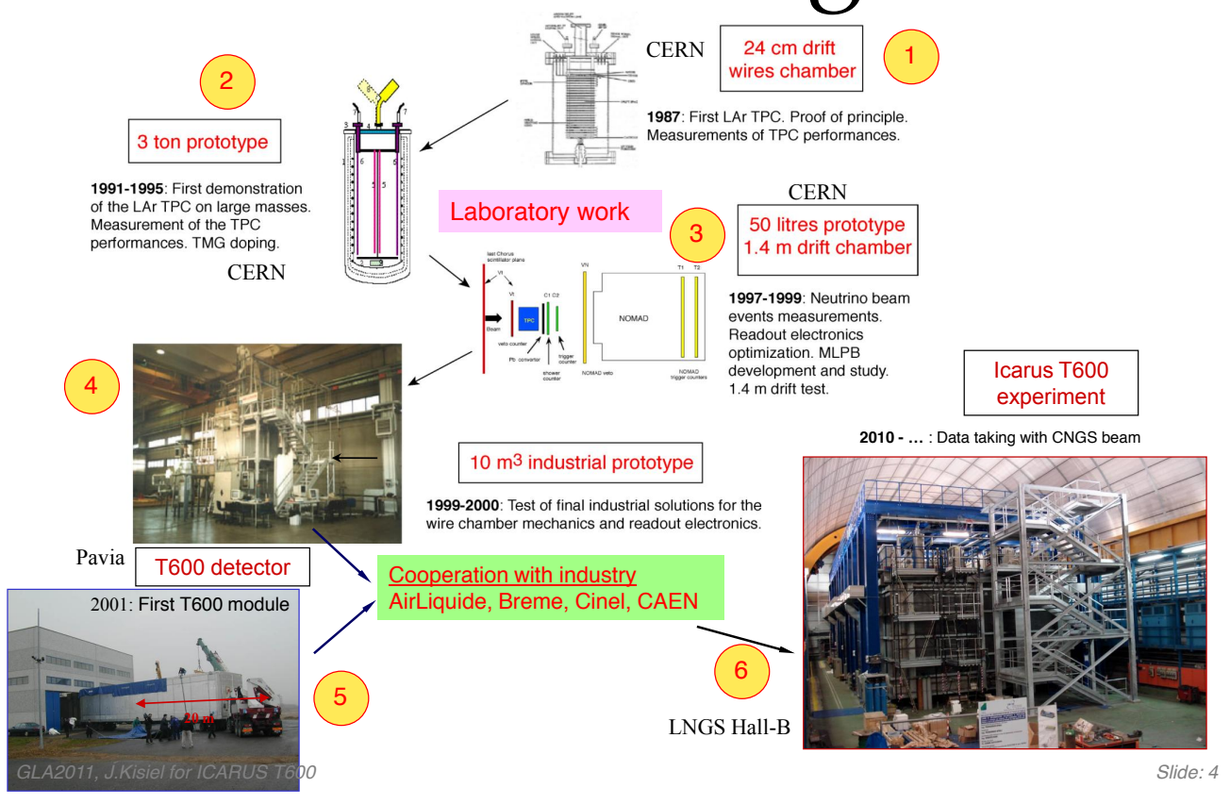
Refs:

1.) *A Regnerable Filter for Liquid Argon Purification* Curioni et al, NIM A605:306-311 (2009)

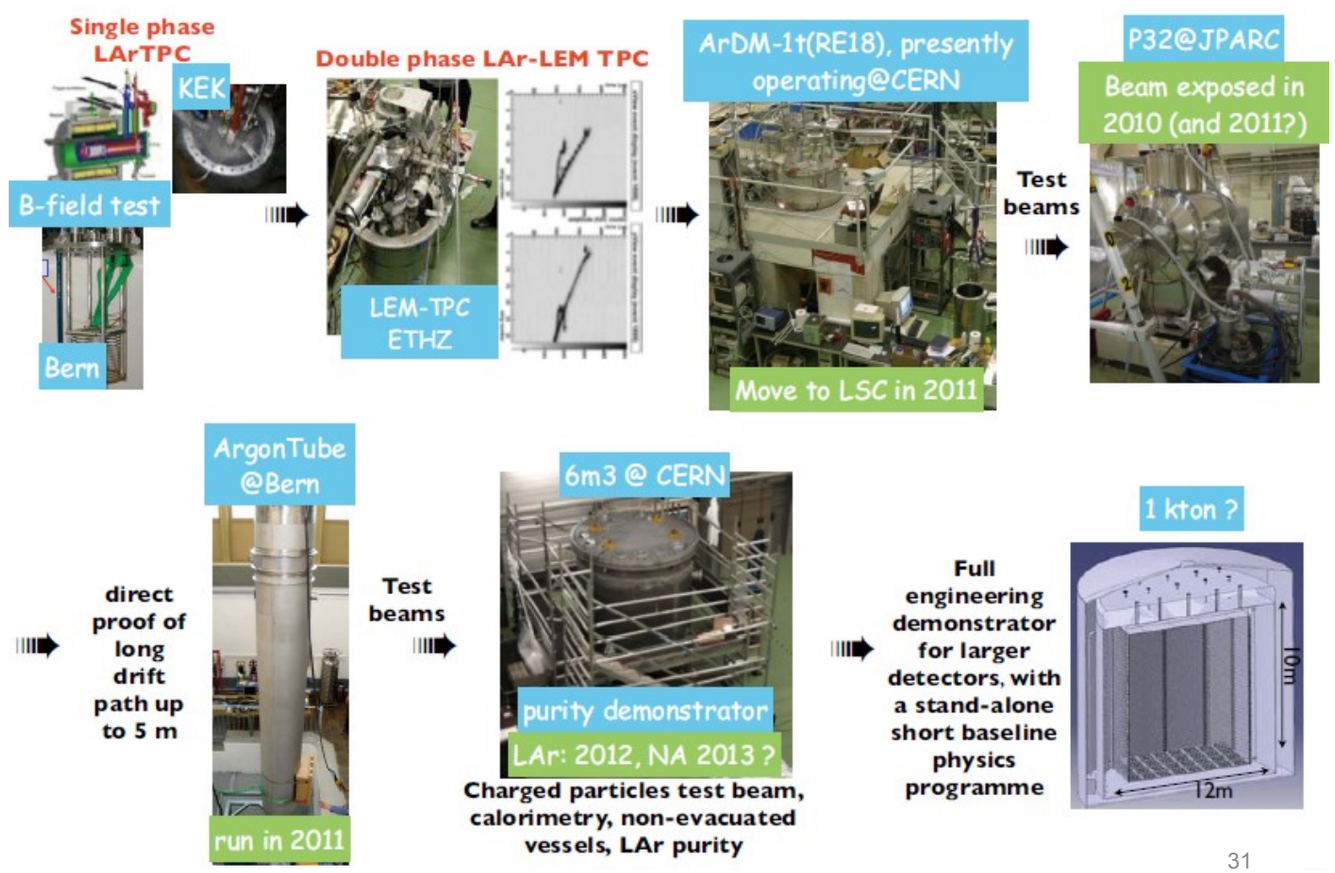
2.) *A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water* Andrews et al, NIM A608:251-258 (2009)

Liquid Argon Worldwide

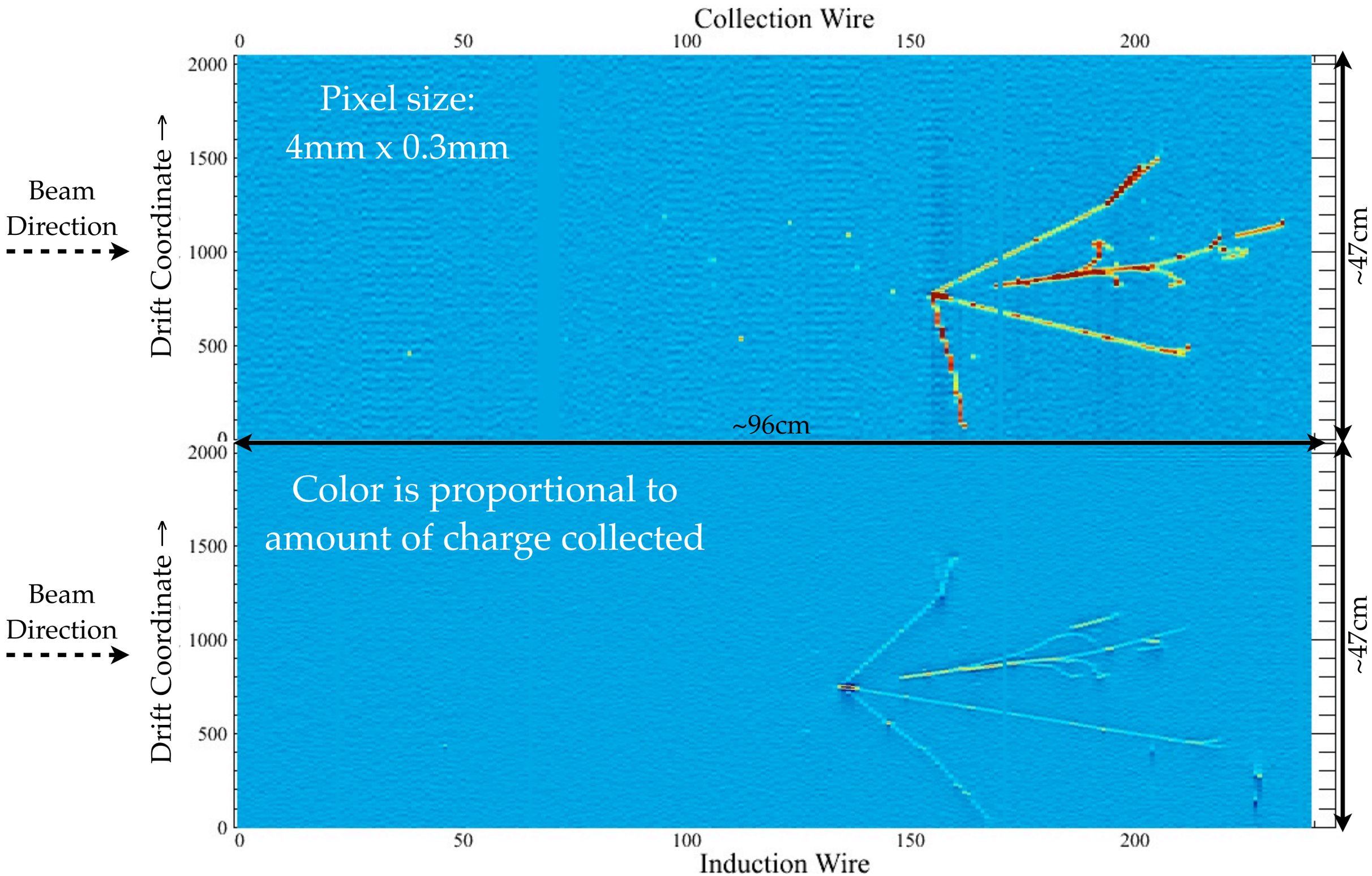
ICARUS Program



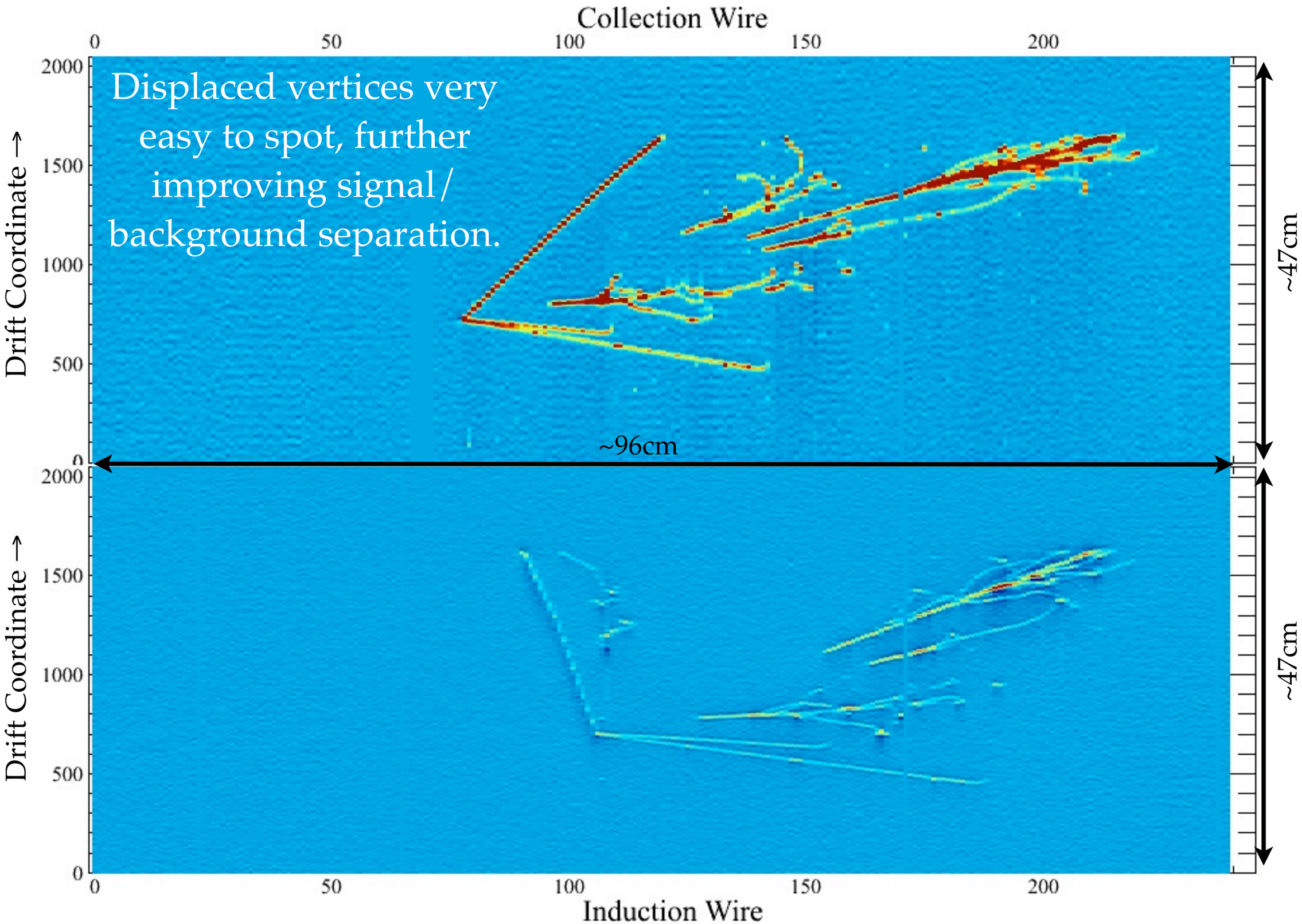
Europe / Japan Program



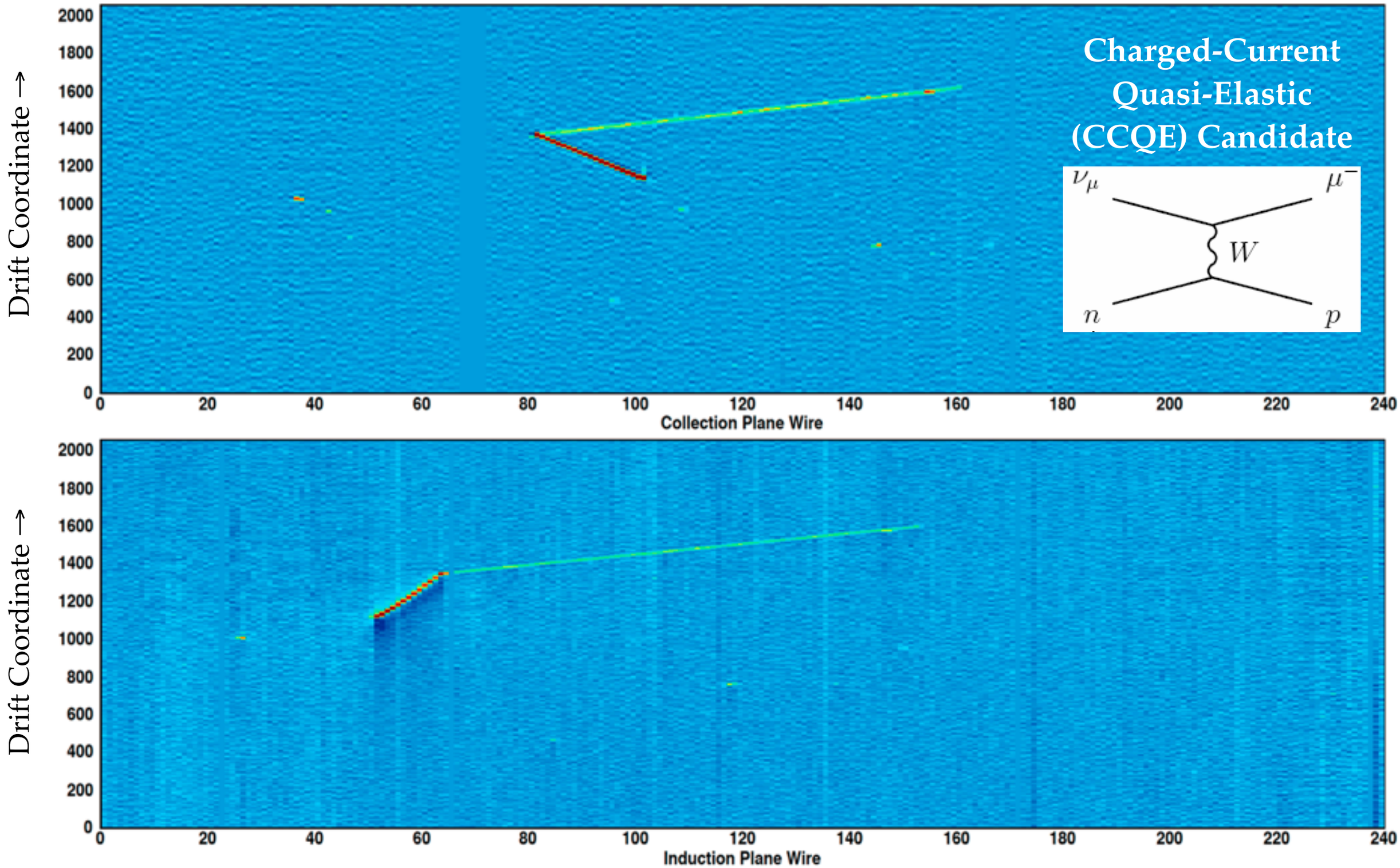
ArgoNeuT Data Event



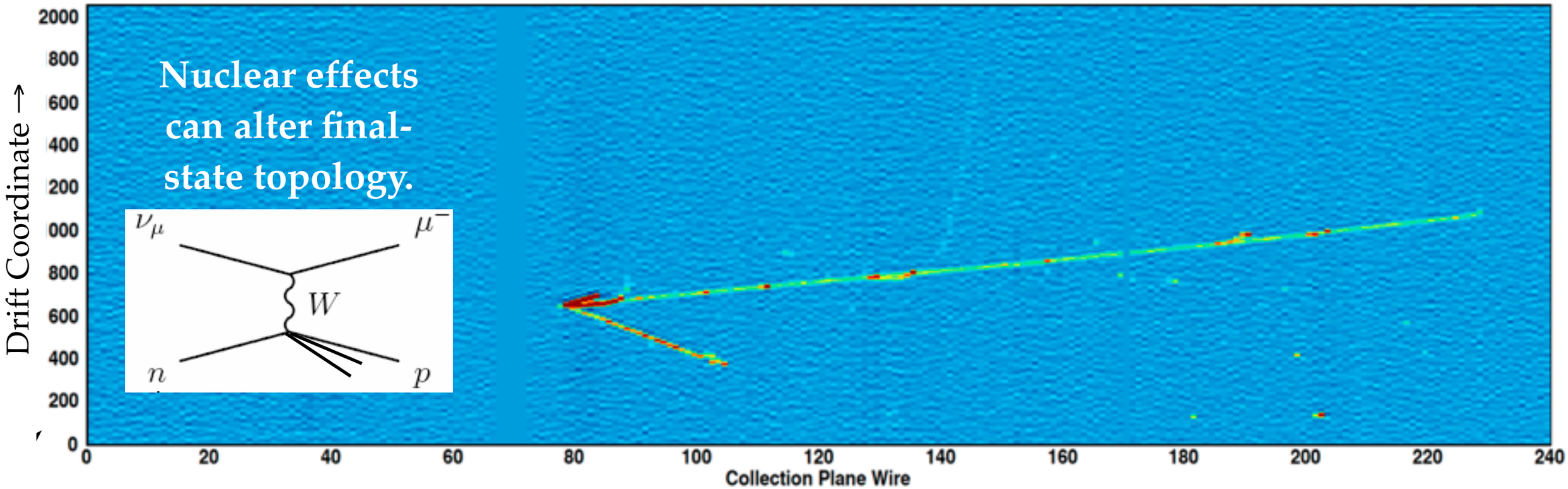
ArgoNeuT Data Event

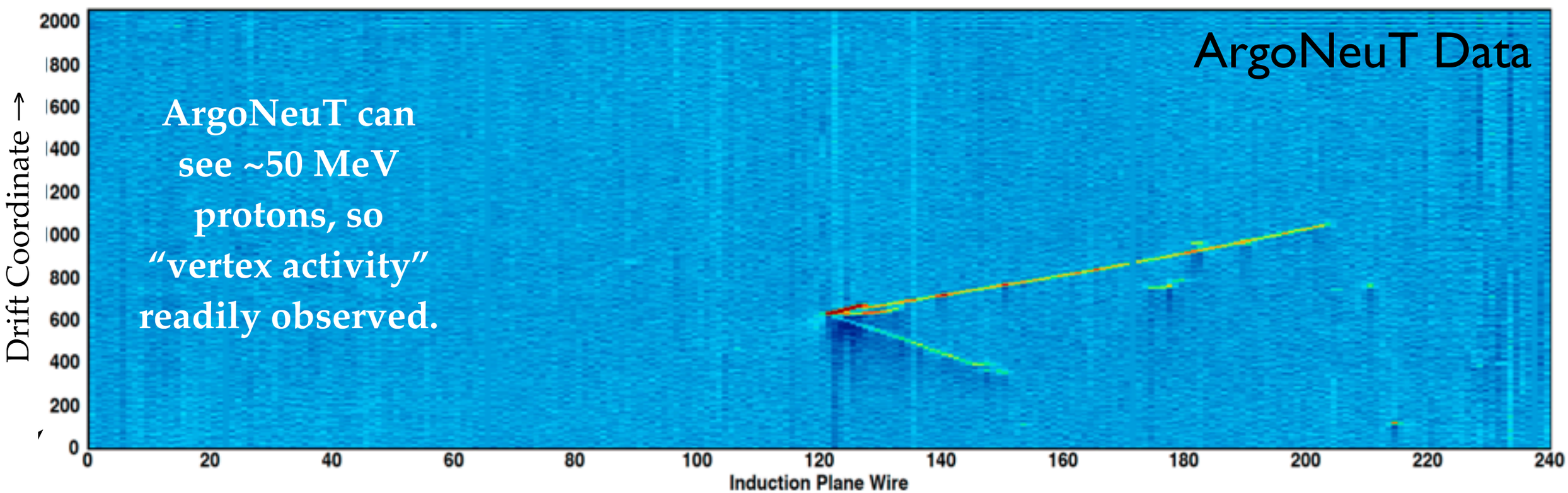


ArgoNeuT Data Event



ArgoNeuT Data Event

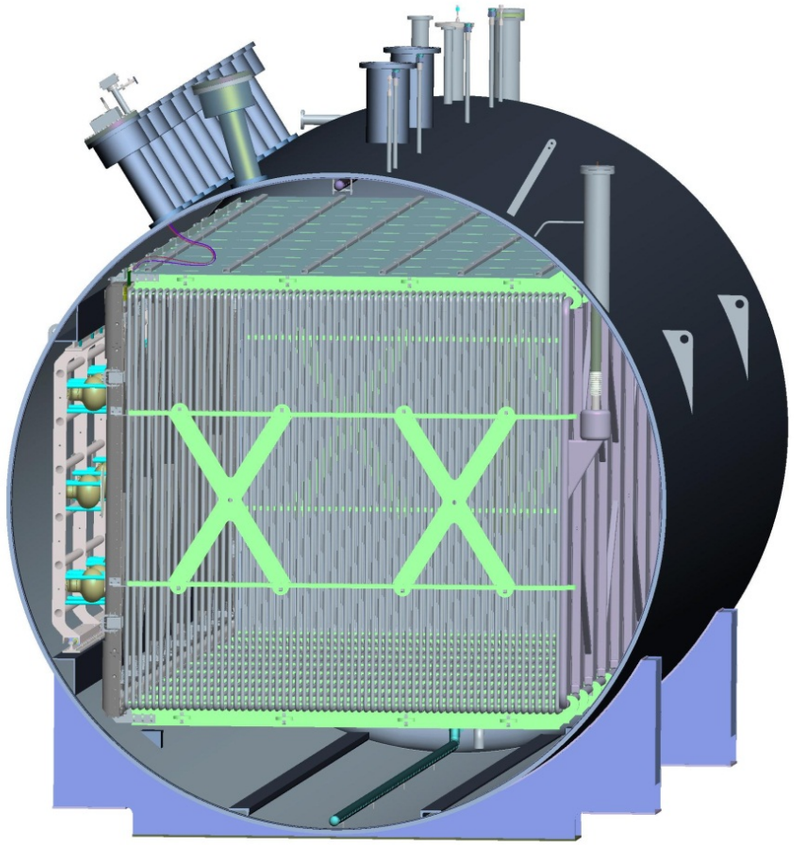




MicroBooNE

- MicroBooNE will operate in the Booster neutrino beam at Fermilab starting in late 2013.
- Combines timely physics with hardware R&D necessary for the evolution of LArTPCs.
  - MiniBooNE low-energy excess
  - Low-Energy Cross-Sections
  - Cold Electronics (preamps in liquid)
  - Long drift (2.5m)

Cryostat Volume	150 Tons
TPC Volume (l x w x h)	89 Tons (10.4m x 2.5m x 2.3m)
# Electronic Channels	8256
Electronics Style (Temp.)	CMOS (87 K)
Wire Pitch (Plane Separation)	3 mm (3mm)
Max. Drift Length (Time)	2.5m (1.5ms)
Wire Properties	0.15mm diameter SS, Cu/Au plated
Light Collection	~30 8″ Hamamatsu PMTs



- ★Stage 1 approval from Fermilab directorate in June 2008
- ★DOE CD-0 (Mission Need) in October 2009
- ★DOE CD-1 June 2010
- ★DOE CD-2/3a (September 2011)

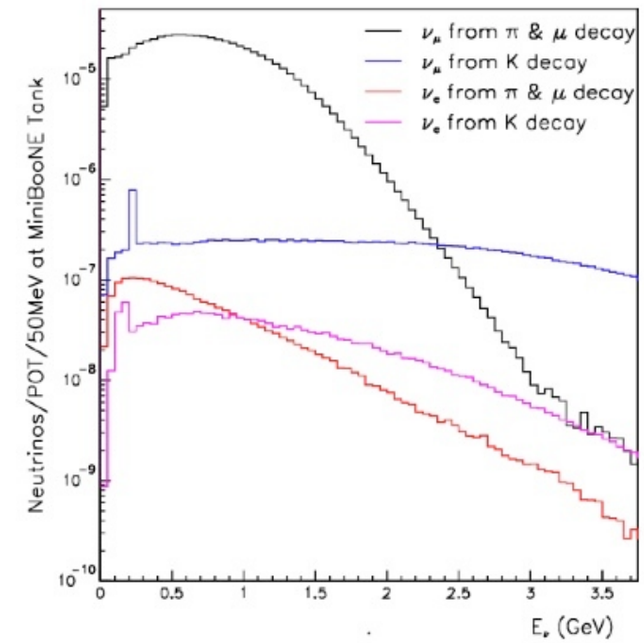
- ➡Joint NSF/DOE Project
- ➡$1.1M NSF MRI for TPC, PMTs

MicroBooNE: Location

- MicroBooNE will sit on surface in on-axis Booster beam (BNB), and off-axis NuMI beam.
- Liquid Argon Test Facility will be located directly upstream of MiniBooNE enclosure. L=470m.
- Large event samples will allow a variety of cross-section measurements.

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

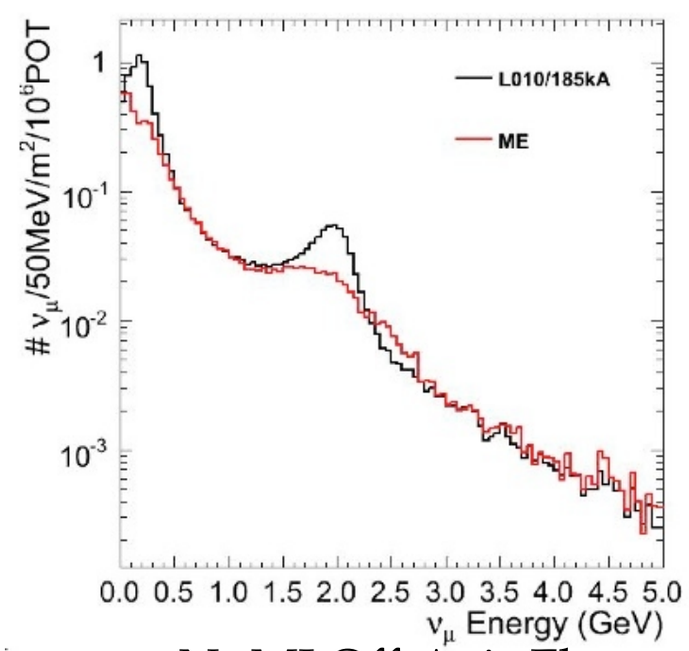
Projected Event Rates for MicroBooNE in 2-3 years.



Booster Flux

Neutrino Beams at Fermilab

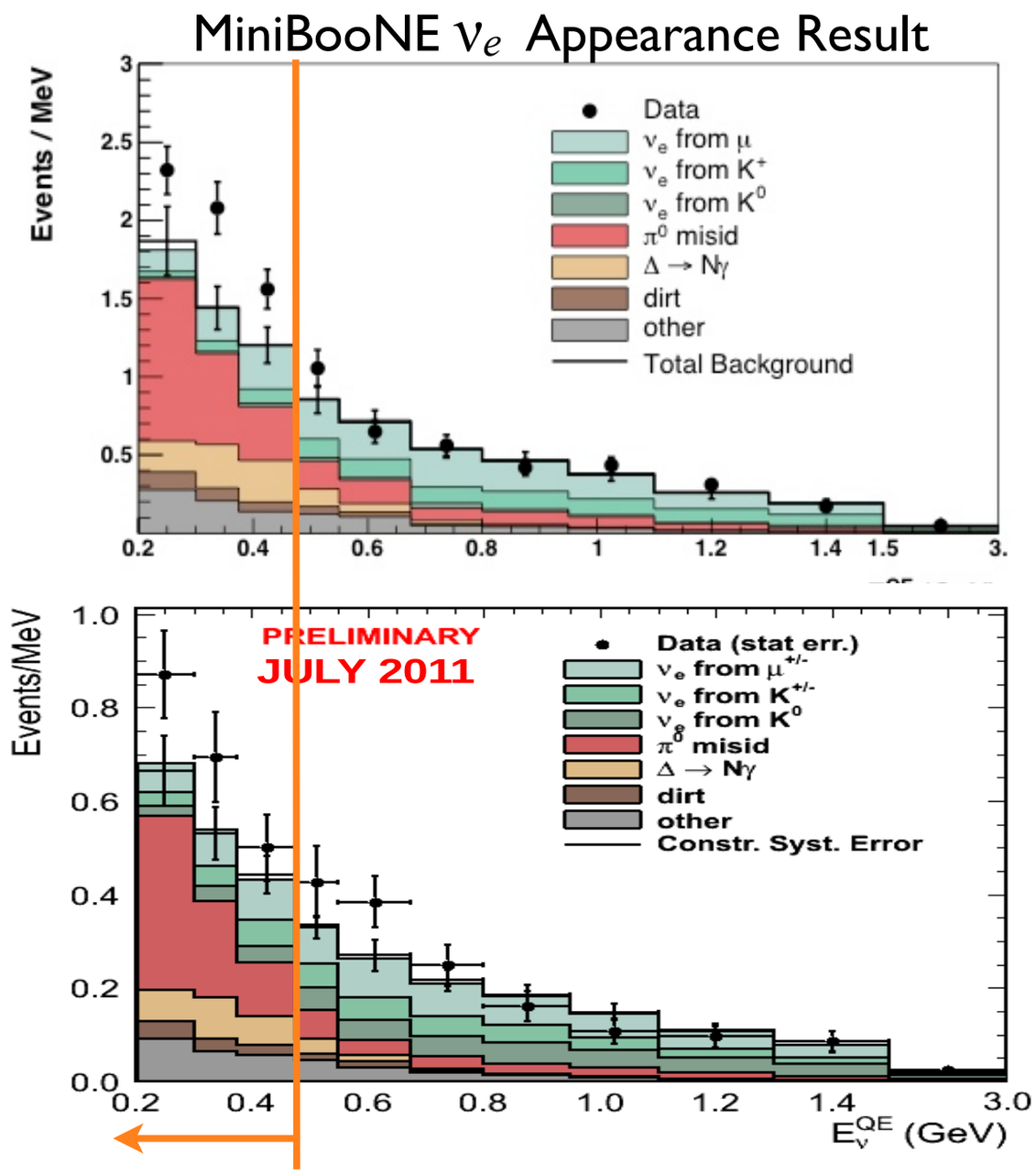
MicroBooNE will be located in Liquid Argon Test Facility



NuMI Off-Axis Flux

MicroBooNE: Physics

- Address the MiniBooNE low energy excess
  - MiniBooNE is a Cerenkov detector that looked for ν_e appearance from a beam of ν_μ
  - Does MicroBooNE confirm the excess?
  - If confirmed, is the excess due to a electron-like or gamma-like process?



MiniBooNE Result Excess
(200-475 MeV)

Neutrino: 128.8±43.4 events

AntiNeutrino: 38.6±18.5 events

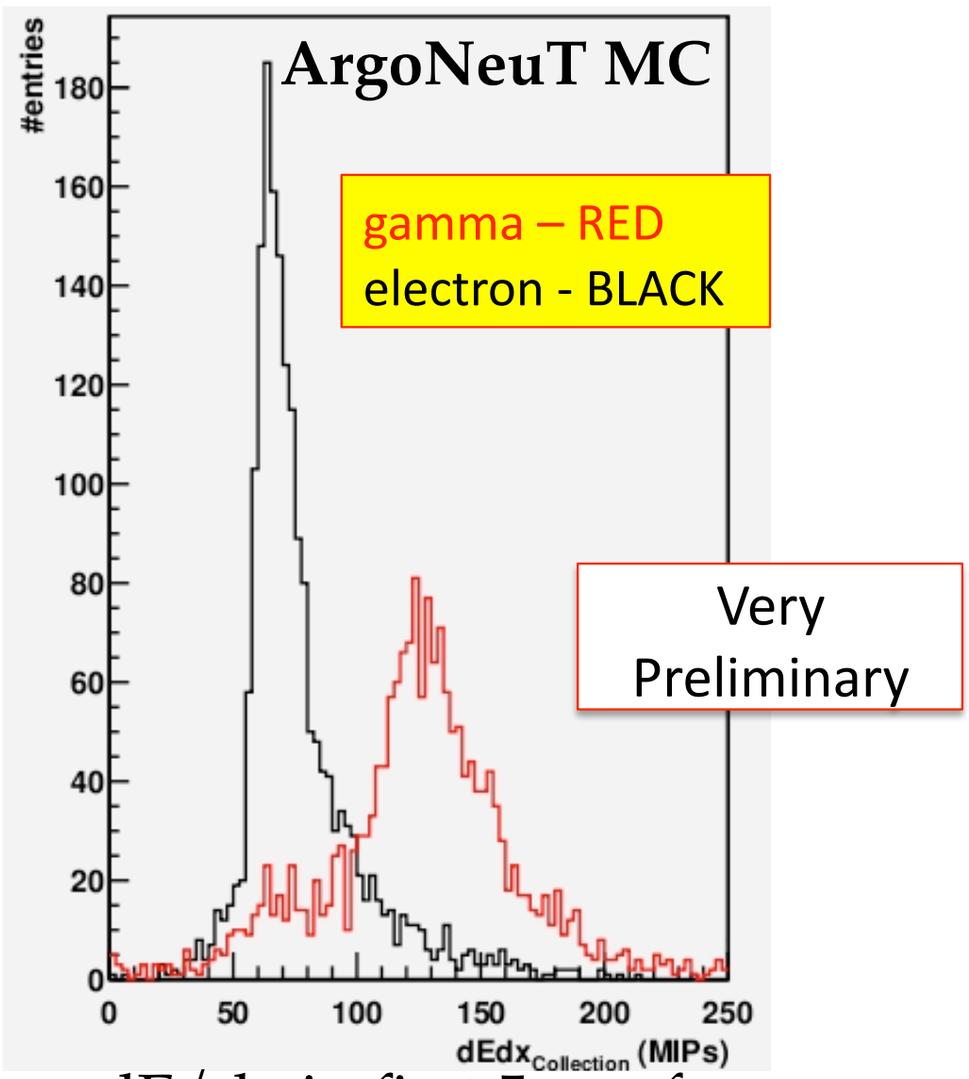
In neutrino mode, MicroBooNE will have ~5.5σ significance for electron-like excess, ~4σ for photon-like excess.

Refs:

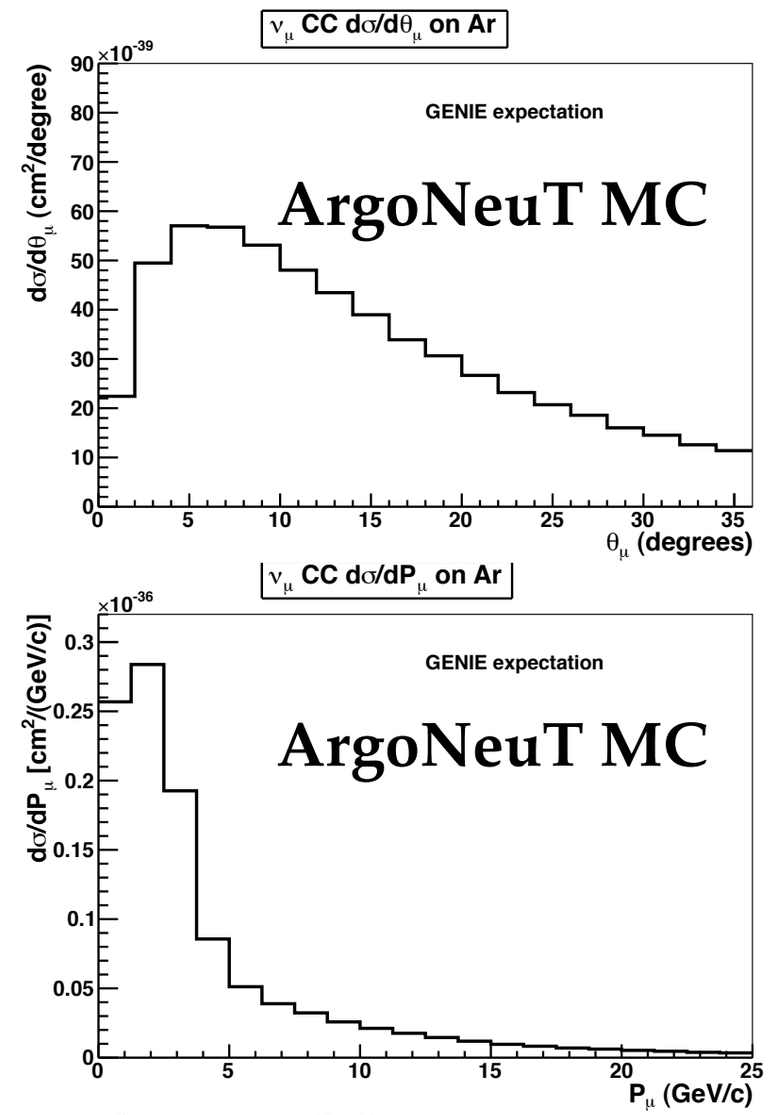
1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)

MicroBooNE: Physics

- Prove effectiveness of electron/gamma separation technique (using dE/dX information).
- Low Energy Cross-Section Measurements (CCQE, NC π^o, $\Delta \rightarrow N\gamma$, Photonuclear, ...)
- Continue development of automated reconstruction (building on ArgoNeuT's effort).



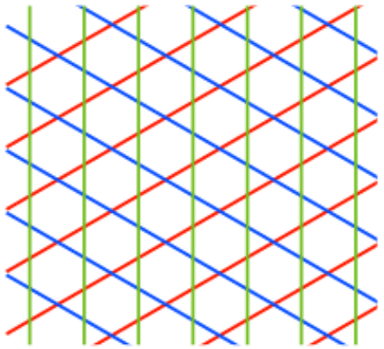
dE/dx in first 5cm of Simulated/Reconstructed Gamma/Electron showers.

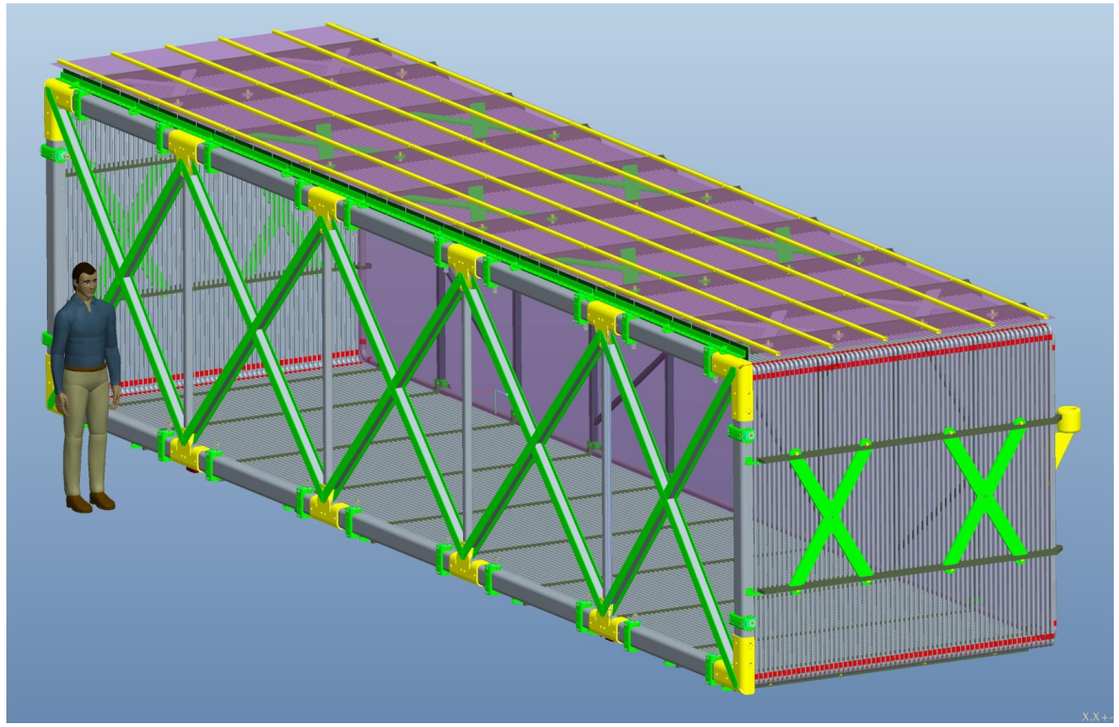


Inclusive CC cross-section in neutrino-mode (simulated/reconstructed/analyzed MC)

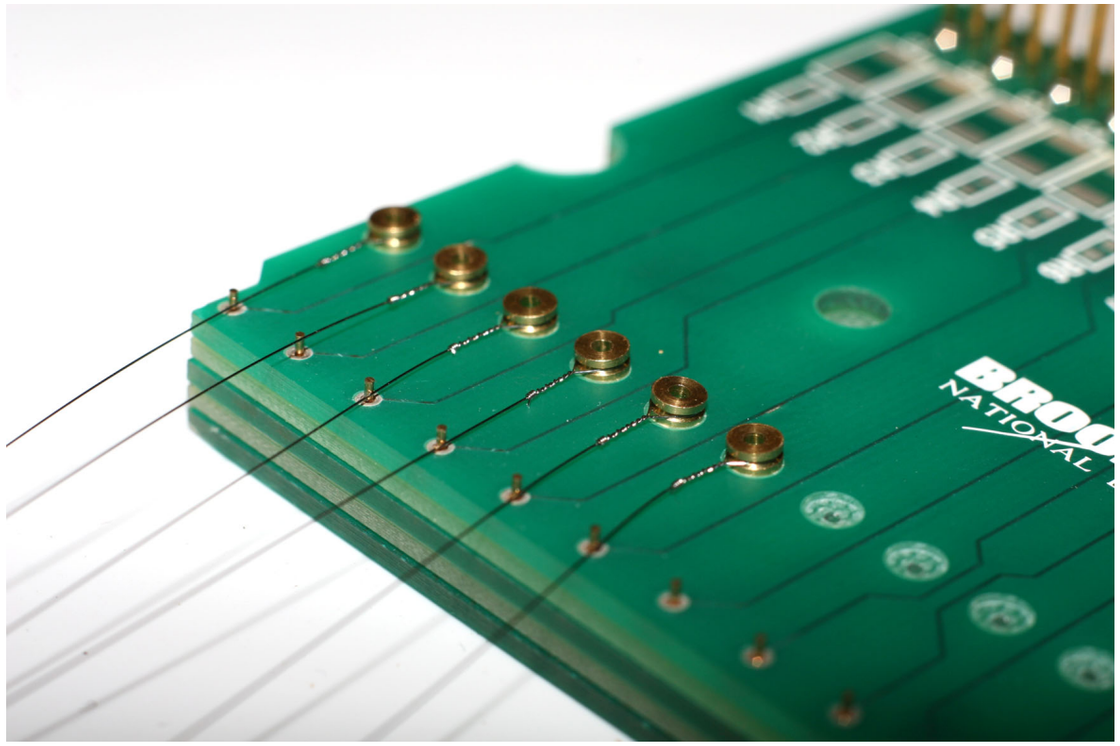
MicroBooNE: TPC

- TPC has 3 instrumented wireplanes (Two Induction at +/-60 from vertical, One Collection with vertical wires).
- Cathode is held at -125kV, setting up 500V/cm drift field.
- Wires are individually terminated around brass ferrules, then positioned on wire carriers.





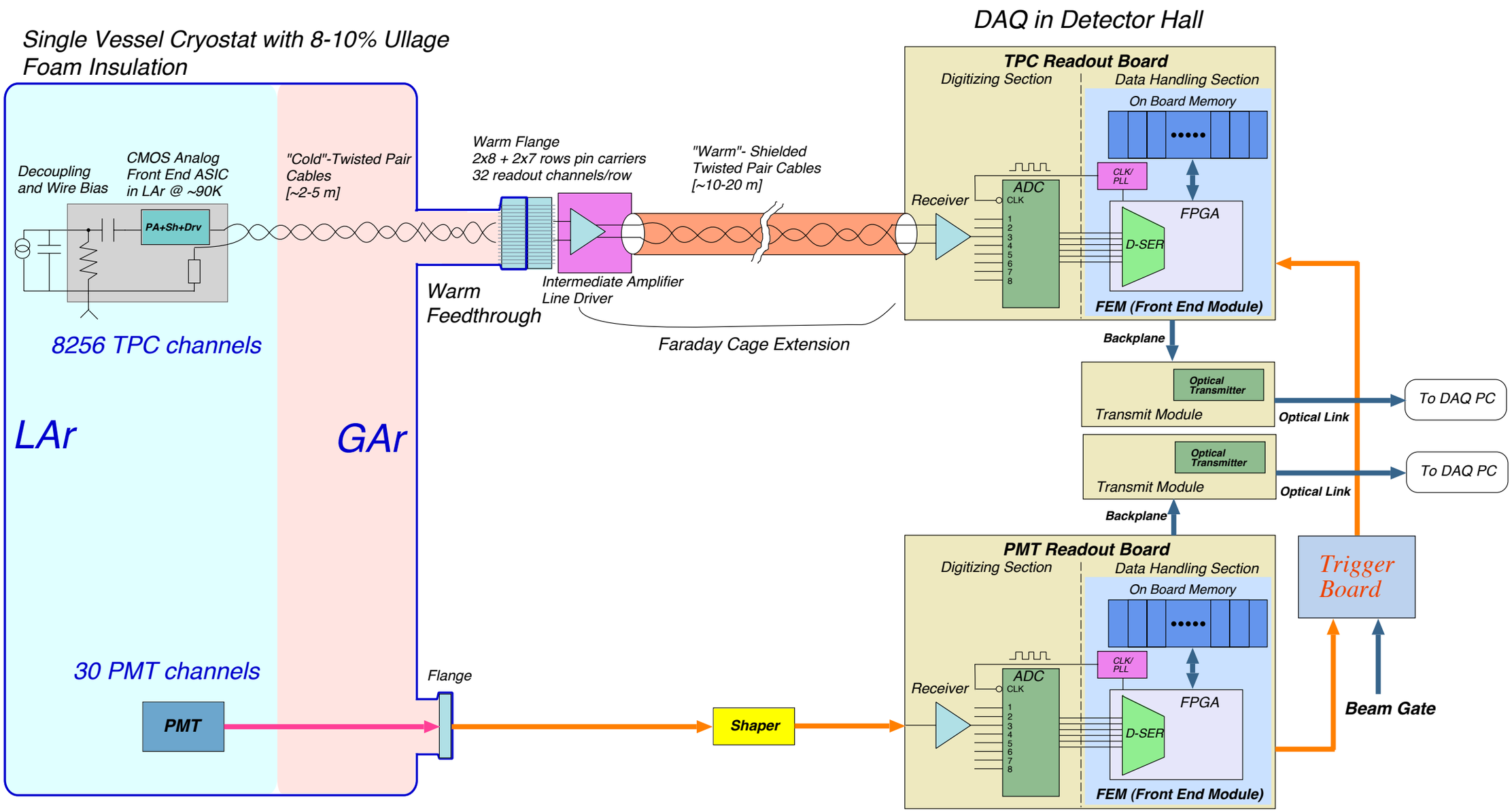
Schematic of MicroBooNE TPC



Prototype wires and wire carrier boards.

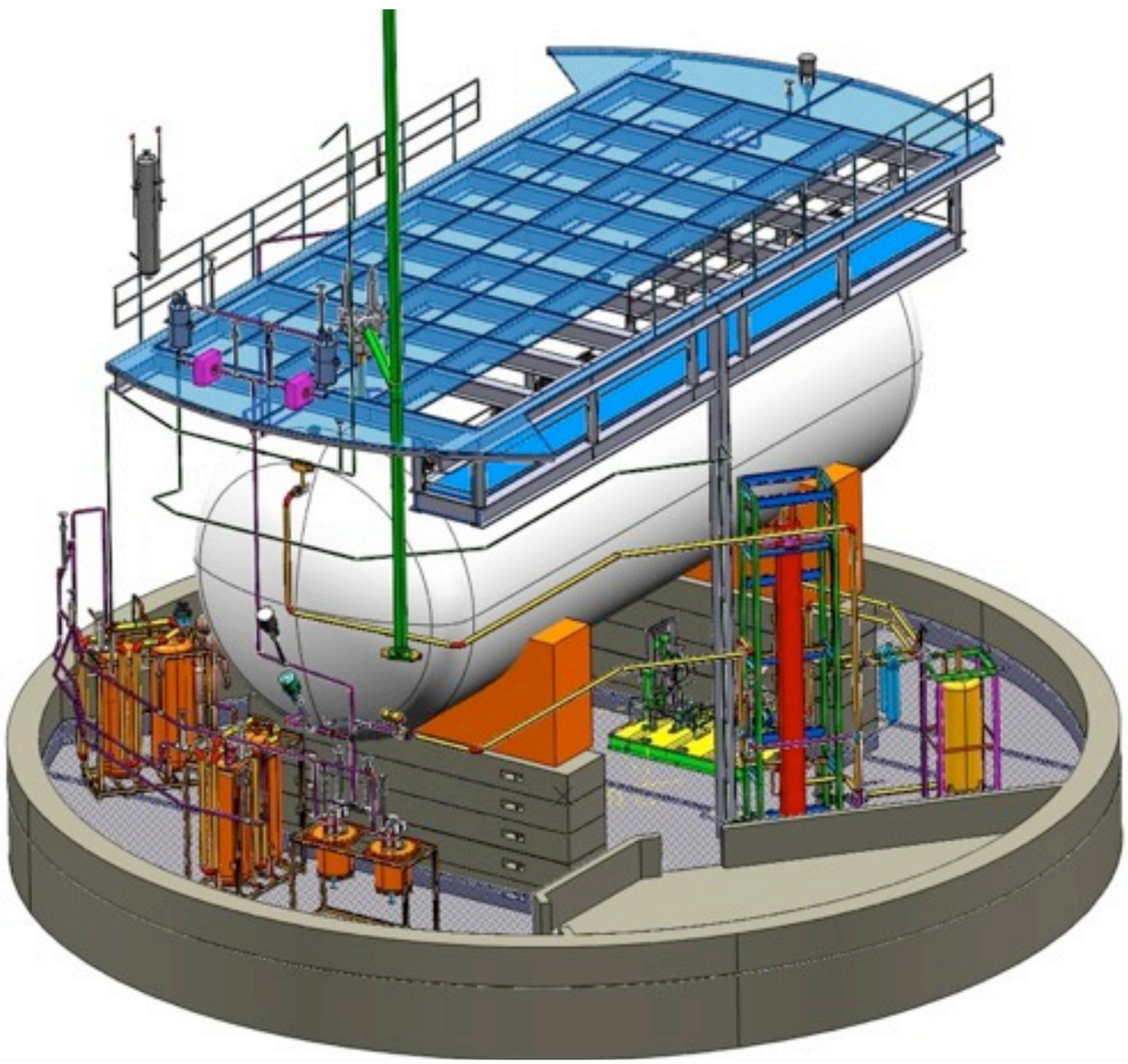
MicroBooNE: Electronics

- CMOS preamplifiers located in liquid, attached to TPC.
- 12-bit ADCs sampled at 2MHz (i.e. - 500ns per sample) for 4.8ms (x3 drift window).
- 1-hour data buffering for Supernova detection signal from SNEWS.



MicroBooNE: Cryogenics

- Cryogenic system consists of filters/pumps/etc... for circulating and purifying LAr.
- Cryostat is evacuable (though the plan is not to evacuate) and foam insulated.

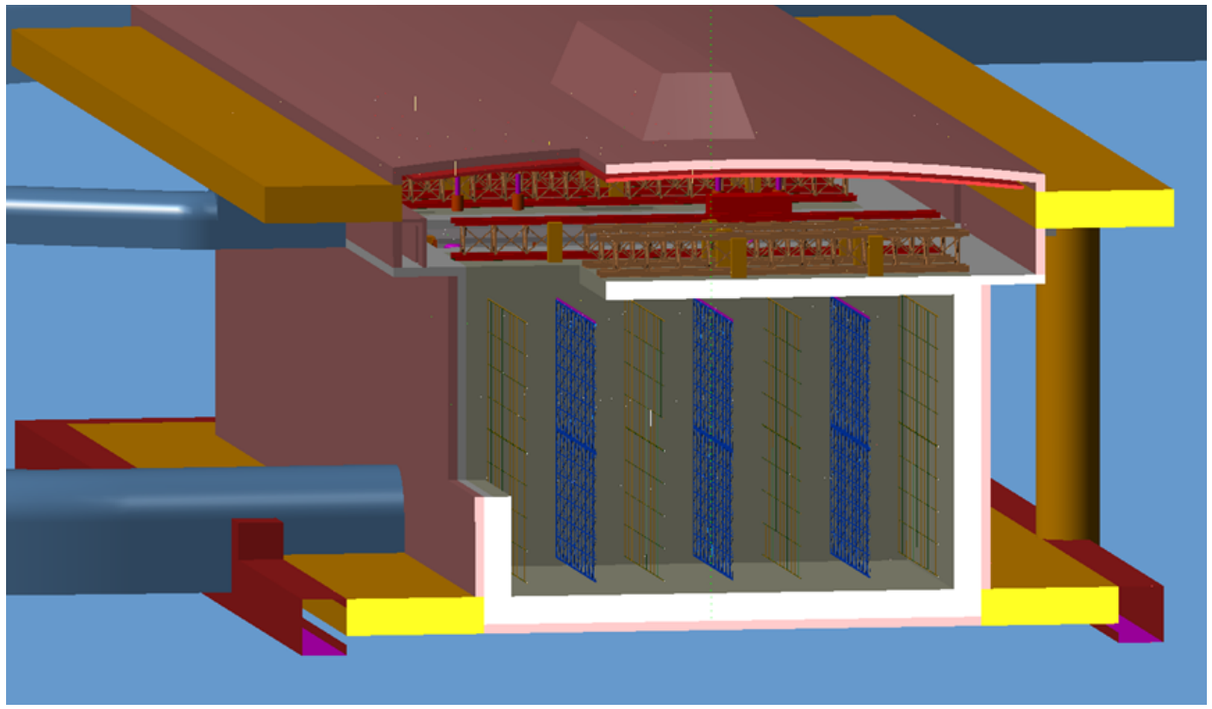


Schematic of MicroBooNE Layout

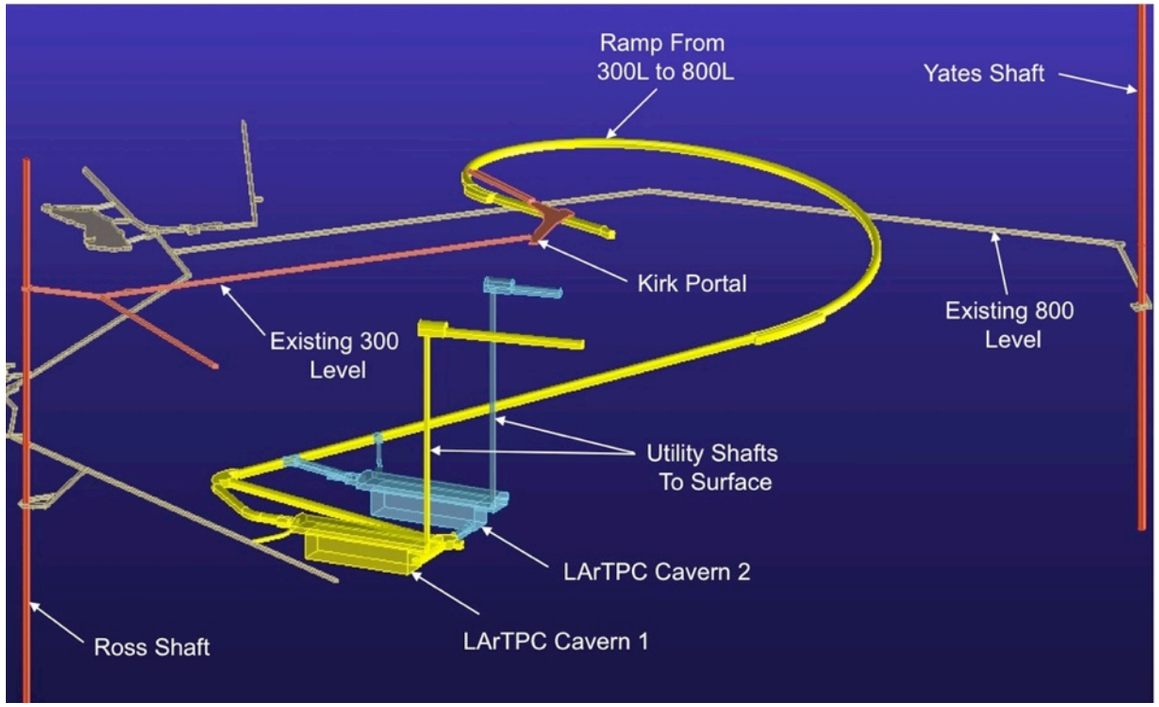
LAPD @ Fermilab

Massive LArTPC Detectors

- Description here is the Reference design for the LBNE project.
- LArTPC would be two ~20 kTon modules.
- Detector located at the 800ft level at Homestake mine.



~20 kTon LArTPC module

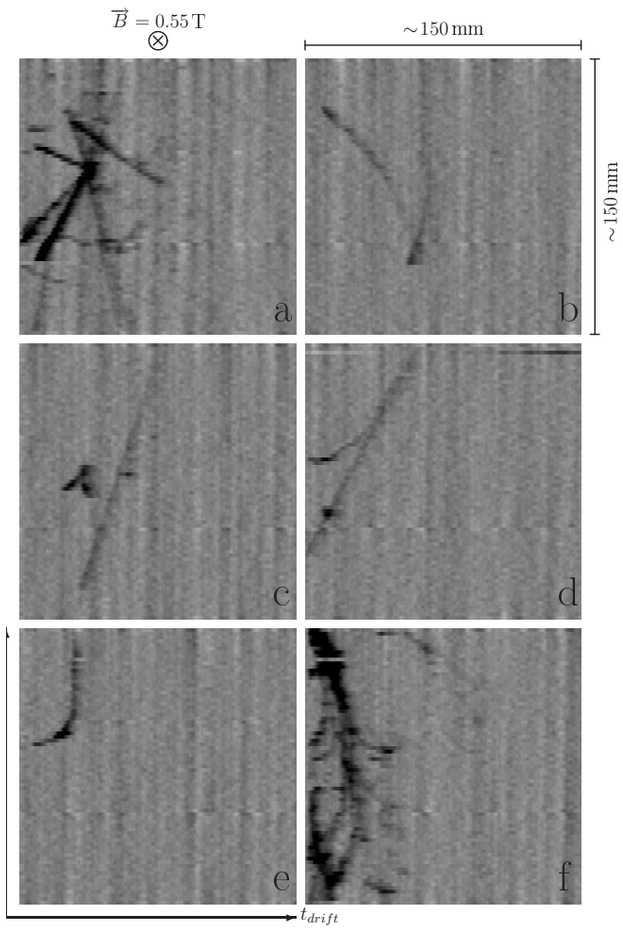


800-ft. level layout.

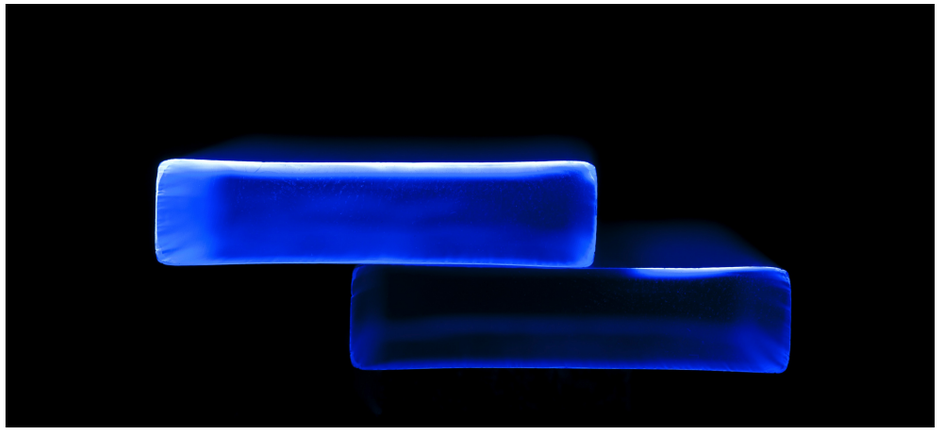
Cryostat Volume	~25 kTons
TPC Volume	~16.7 kTons
# Readout Wires	~275000 (128:1 MUX)
Wire Pitch	5 mm
Electronics Style (Temp.)	CMOS (87 K)
Max. Drift Length	3.7m
Light Collection	TBD

Liquid Argon for Neutrino Factory

- Liquid Argon detectors could be magnetized to allow lepton sign discrimination:
  - One previous LArTPC operated in magnetic field[1].
  - Magnetic field would impact PMTs used for triggering in "typical" LArTPC, requiring new light-collection methods[2] (e.g. - cryogenic lightguides coated with wavelength shifting substance).
  - Reconstruction methods to allow tracking in a magnetized LArTPC.



Tracks in magnetized LArTPC



LightGuide coated with TPB

Refs:

1.) *First results from a Liquid Argon Time Projection Chamber in a Magnetic Field*, A. Badertscher *et. al.*, arXiv:0505151

2.) *Demonstration of a Lightguide Detector for Liquid Argon TPCs*, L. Bugel *et. al.*, arXiv:1101.3013

Conclusion

- Liquid Argon detectors provide exceptional capabilities for neutrino physics, and there is significant R&D ongoing at Fermilab, and worldwide, to develop this technique for very large scales.
- MicroBooNE is the next major step in the U.S. plan for LArTPCs, and it will provide interesting physics and hardware development.
- LBNE experiment considering 40kTon LArTPC as far-detector option, as well as magnetized LArTPC near-detector option.