Liquid Argon Detector R&D

Mitch Soderberg
NuFACT 2012

Introduction

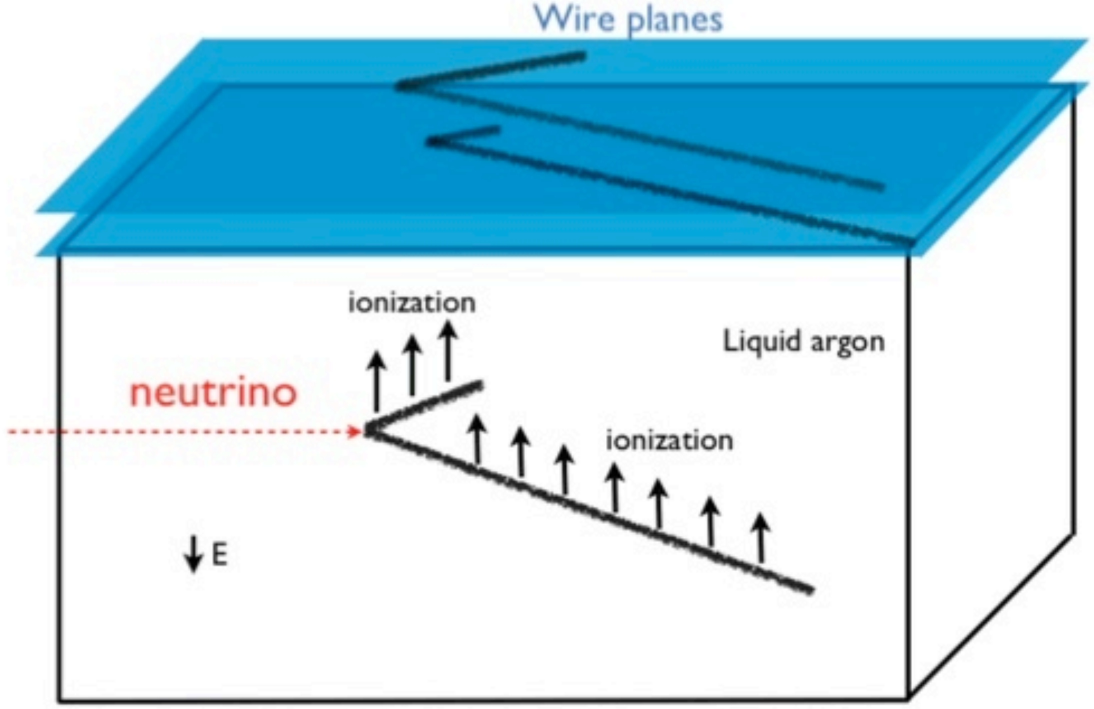
- Liquid Argon Time Projection Chambers (LArTPCs) are imaging detectors that offer exceptional capabilities for studying neutrinos.

- There are numerous efforts worldwide to develop this technology to study neutrino interactions in a long-baseline oscillation experiment.

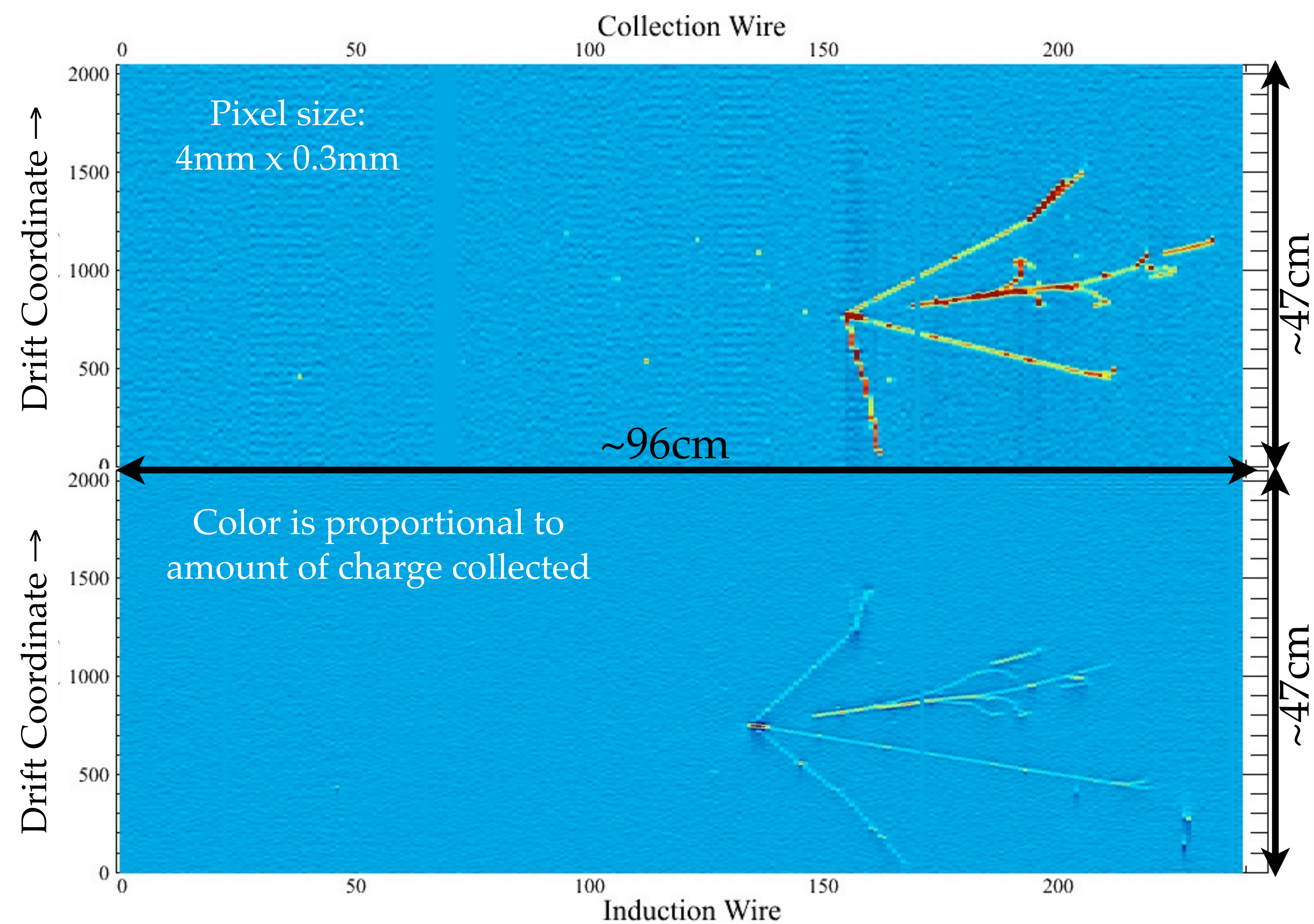
- I will highlight several experiments that are “R&D” in the sense that they inform design of larger detectors. Many offer compelling physics on their own.

Liquid Argon Neutrino Detectors

- Ionization produced in neutrino interactions is drifted along E-field to highly segmented wireplanes.
- Timing of wire pulse information is combined with known drift speed to determine drift-direction coordinate.
- Calorimetry information is extracted from wire pulse characteristics.
- Abundant scintillation light also available for collection and triggering.



LArTPC Principle



ArgoNeuT Data Event

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

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	

Technical Considerations for LArTPCs

- There are numerous technical issues to consider when designing LArTPCs:
  - Purity
  - Wires vs. GEMs
  - Electronics and S/N (warm or cold?)
  - High Voltage (kV? 100's of kV? MV?)
  - Cryogenic recirculation scheme
  - Calibration
  - Reconstruction
- R&D required to develop LArTPCs to the largest scales imagined.

LAr Worldwide

(**Incomplete**) List of Completed/Ongoing/Potential LAr Projects, separated by location of the detectors.

US

Materials Test Stand
ArgoNeuT
Liquid Argon Purity Demonstrator
MicroBooNE
LBNE
1 kTon LArTPC
Test-Beam @ FNAL
Los Alamos LDRD LArTPC
GLADE

Europe

50-liter @ CERN
$10m^3$
ICARUS
LArTPC in B-Field
LANDD @ CERN
ArgonTube @ Bern
UV Laser
GLACIER/LAGUNA
Double-LAr @ CERN-PS

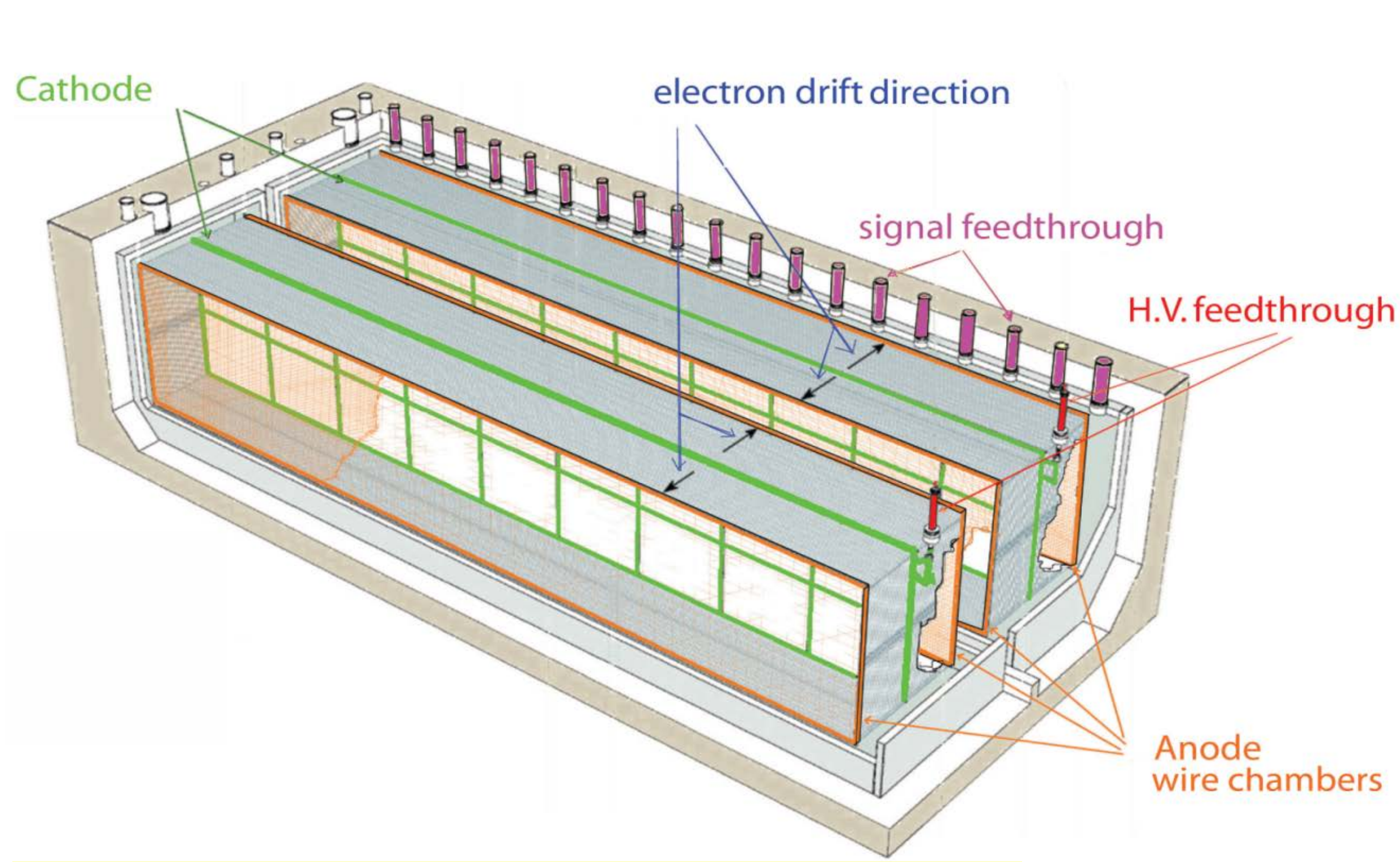
Japan

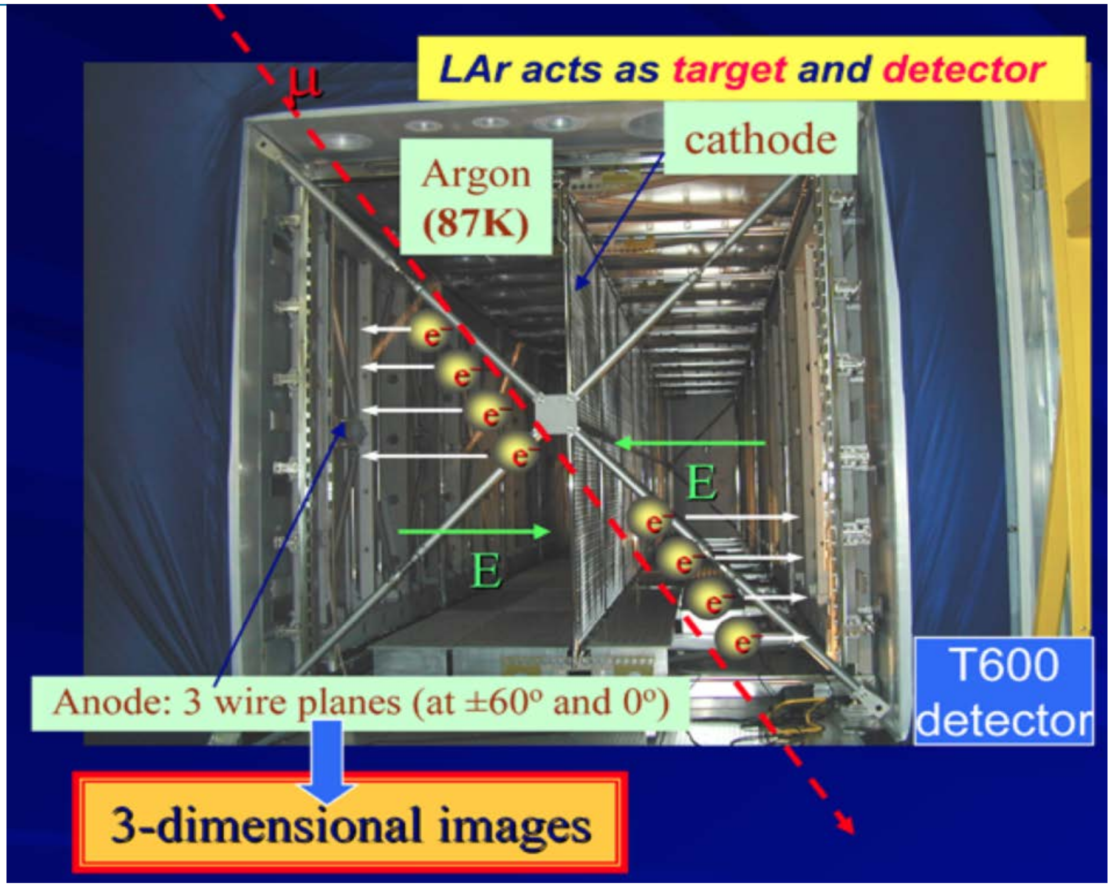
Test-Beam (T32) at J-PARC
100 kTon @ Okinoshima island

LAr also pursued for Dark Matter:
DarkSide, ArDM, DEAP/CLEAN, WARP, Depleted Argon, ...

ICARUS @ Gran Sasso

Slide from P. Sala, NuTown2012 Meeting





- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m (1 ms)
  - HV = -75 kV E = 0.5 kV/cm
  - v-drift = 1.55 mm/μs

Taking data in LNGS hall B

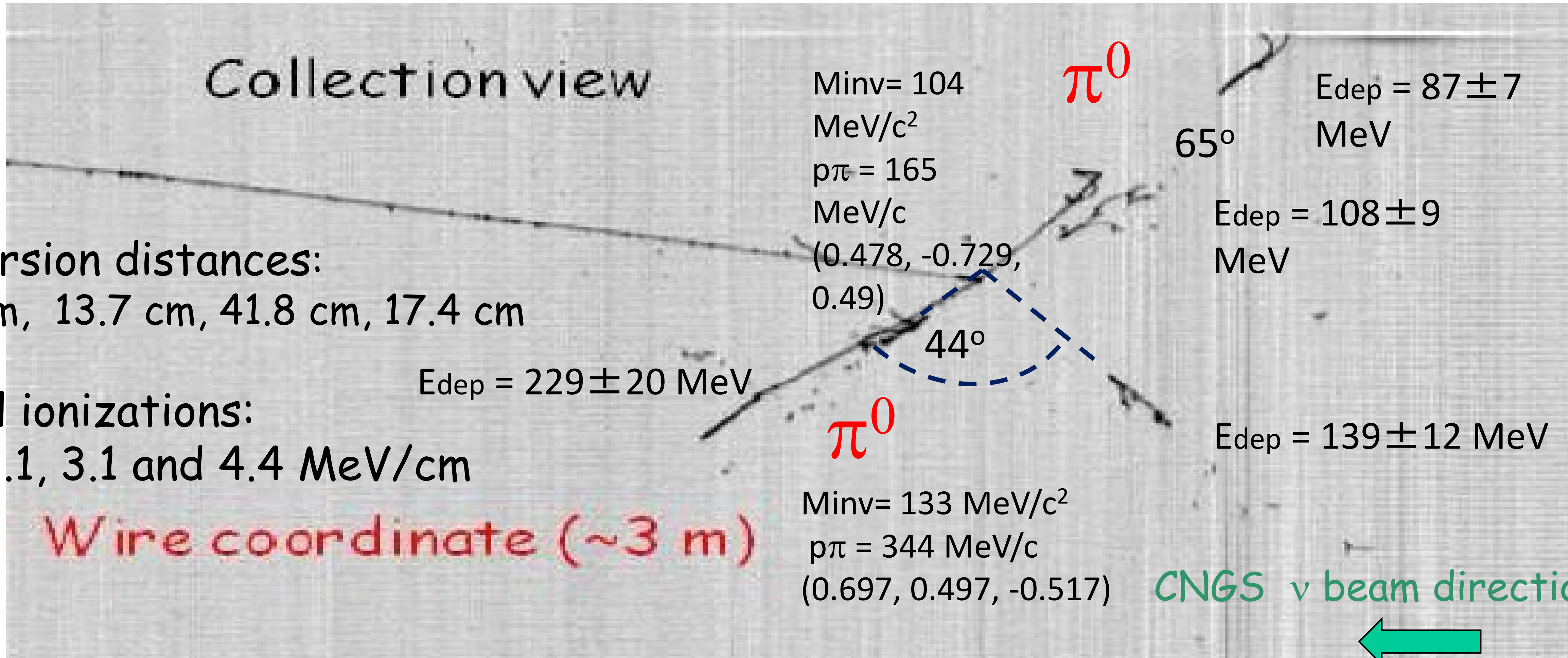
- 4 wire chambers:
  - 2 chambers per module
  - 3 readout wire planes per chamber, wires at 0,±60°
  - ≈ 54000 wires, 3 mm pitch, 3 mm plane spacing
- 20+54 PMTs , 8" Ø, for scintillation light:
  - VUV sensitive (128nm) with wave shifter (TPB)

ICARUS

Slide from P. Sala, NuTown2012 Meeting

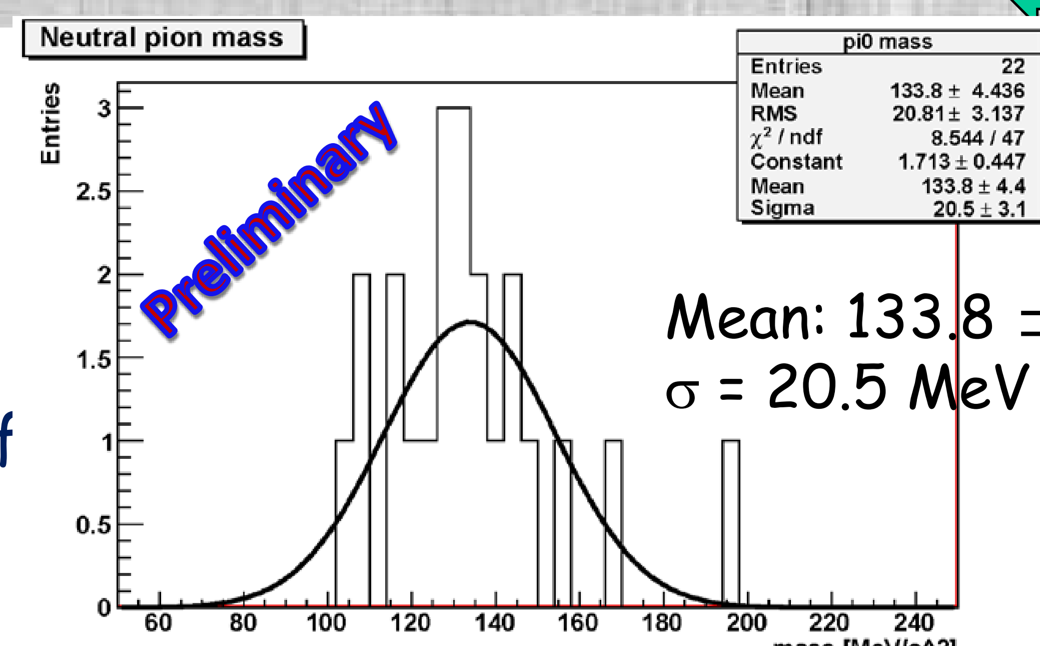
Conversion distances:
71.2 cm, 13.7 cm, 41.8 cm, 17.4 cm

Initial ionizations:
5.1, 6.1, 3.1 and 4.4 MeV/cm



π^0-showers identified by

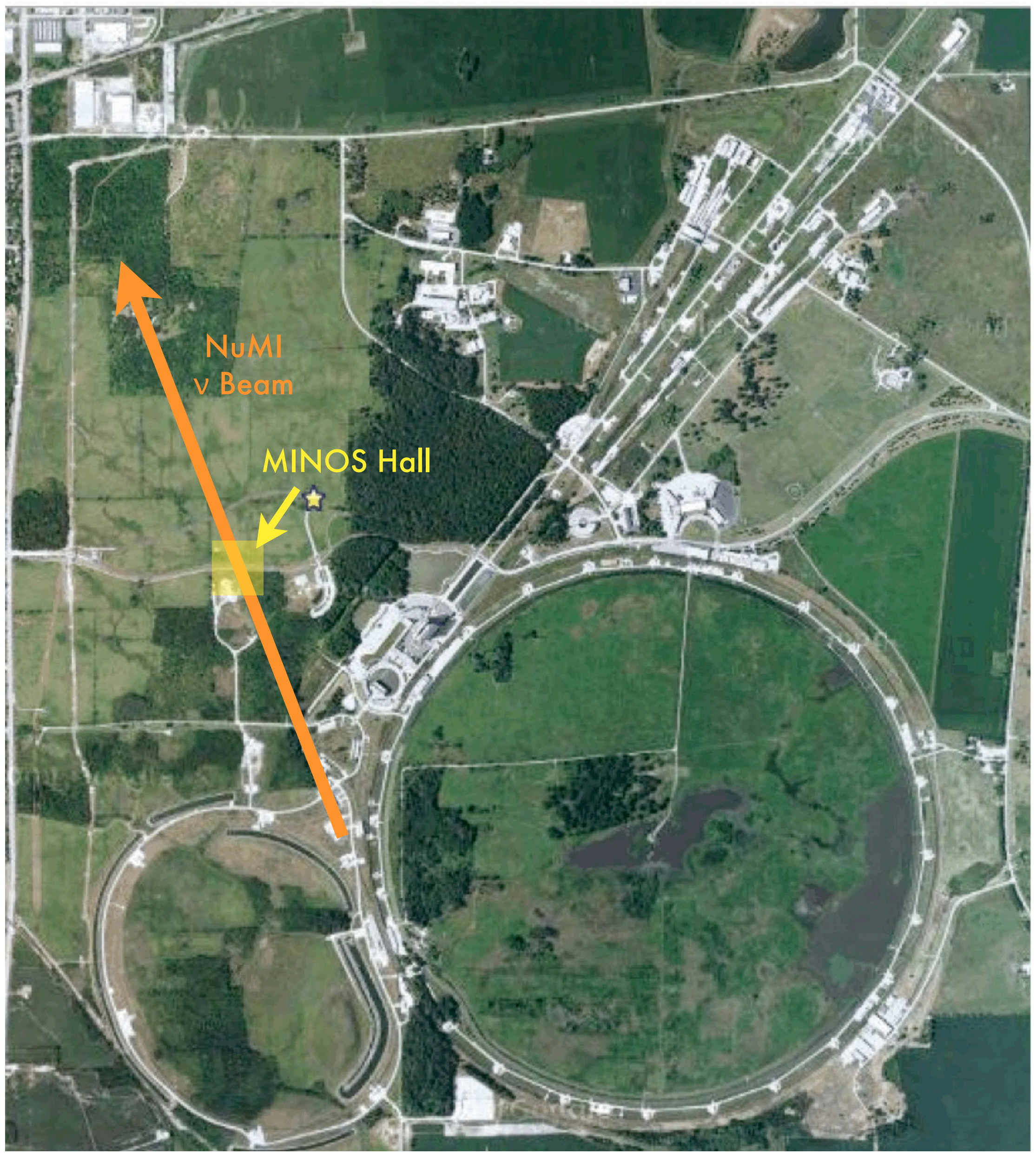
- Photon conversion separated from primary vertex
- Reconstruction of invariant mass
- Ionization in the first segment of showers (1 mip or 2 mips)



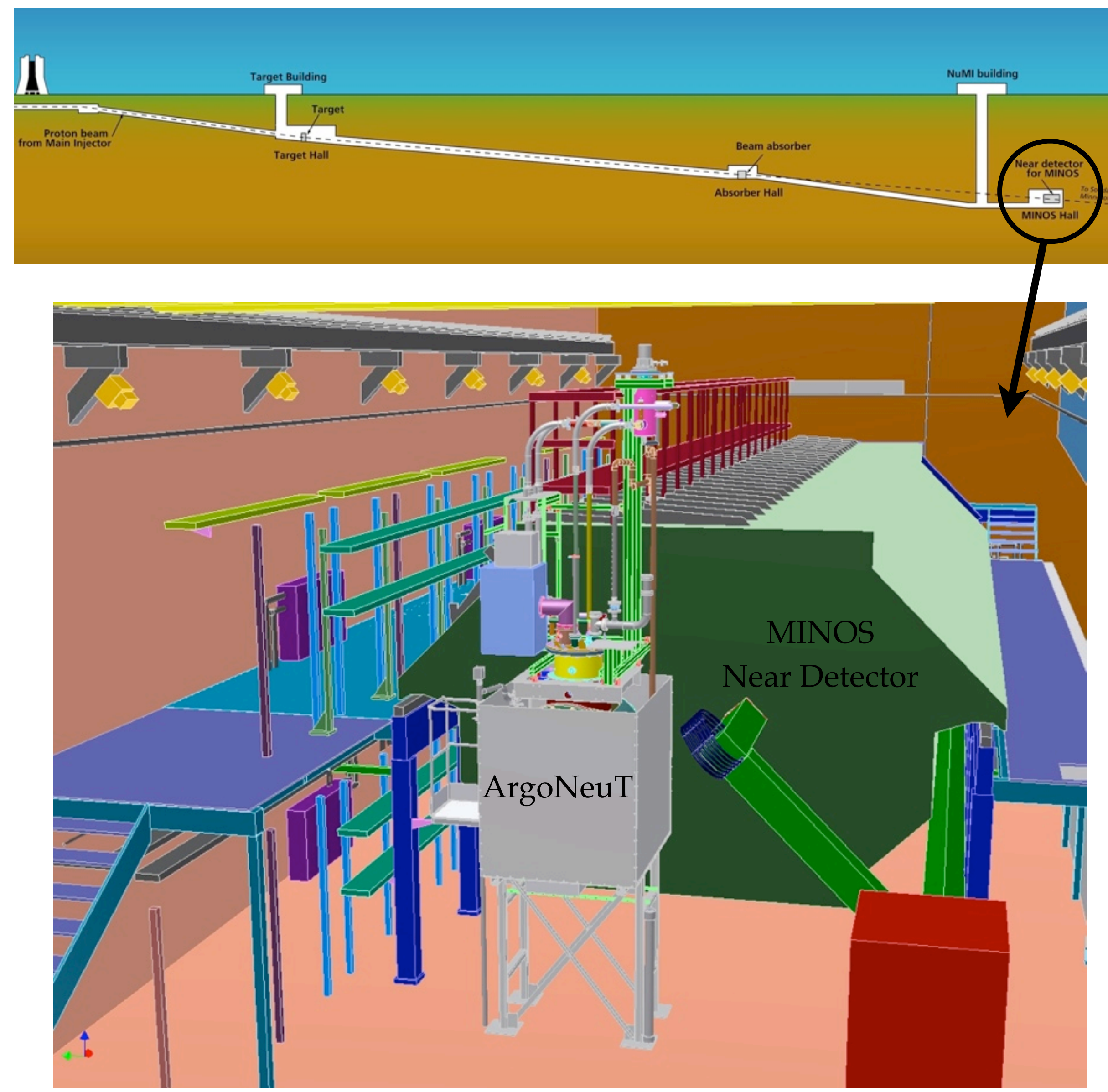
Slide: 15

The ArgoNeuT Project @ Fermilab

- ArgoNeuT (a.k.a. - Fermilab T962) deployed a ~175 liter LArTPC in Fermilab NuMI neutrino beam.
- Located directly upstream of MINOS near detector, which provides full muon reconstruction and sign selection.
- Collected 1.35×10^{20} Protons on Target (POT), predominantly in antineutrino mode.

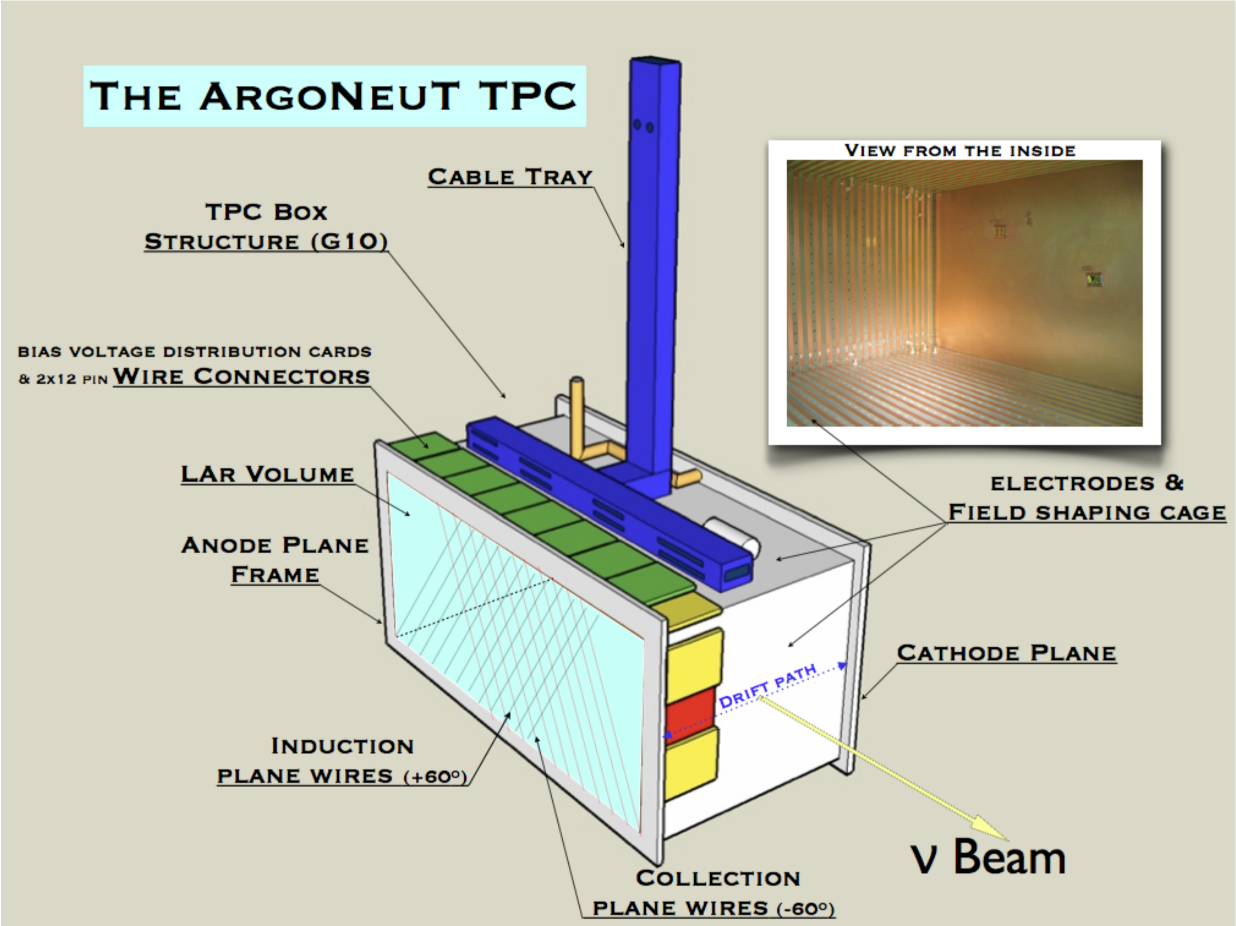


NuMI Beam at Fermilab



MINOS Hall at Fermilab

ArgoNeuT: Detector Details



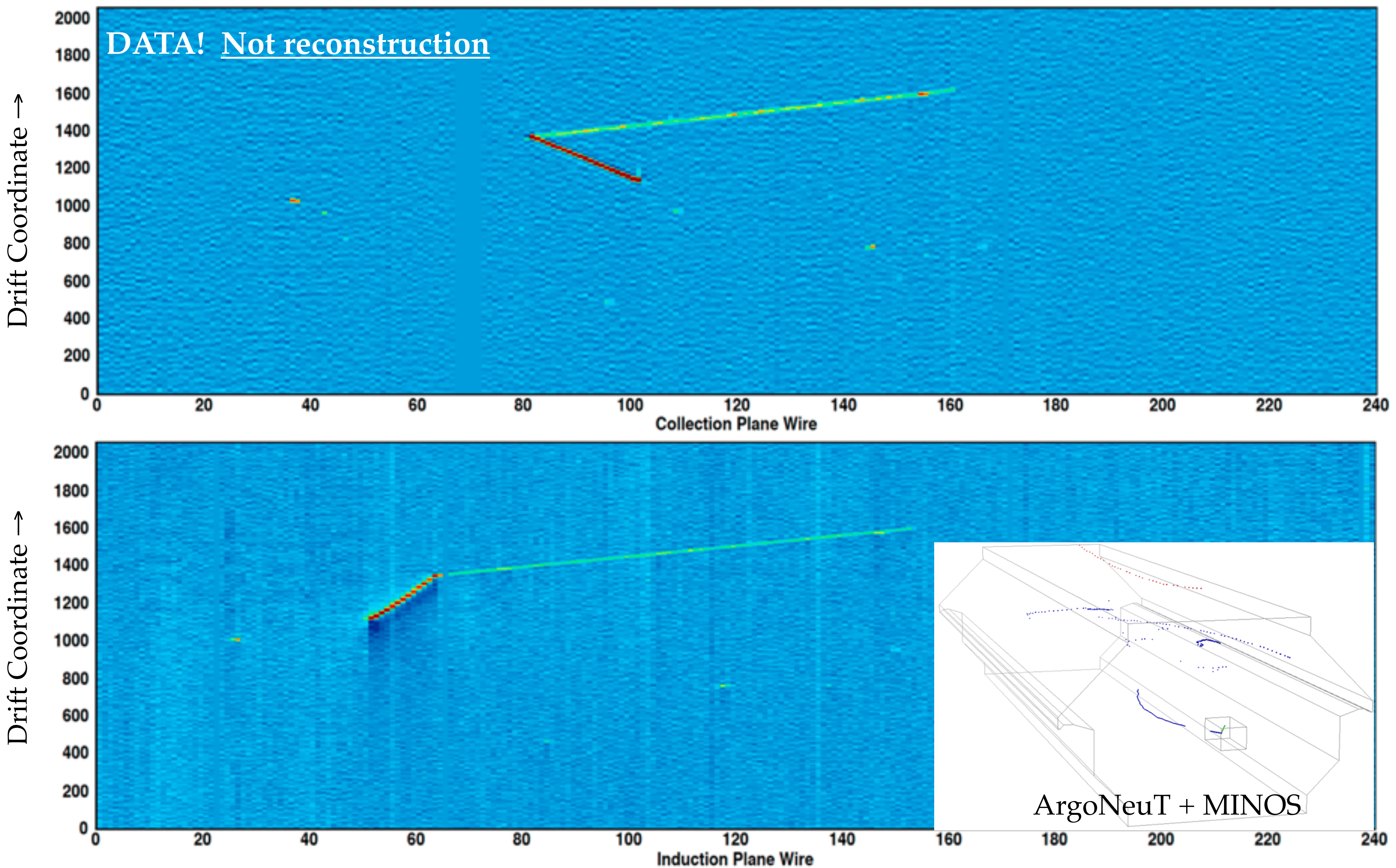
Cryostat Volume	500 Liters
TPC Volume	175 Liters (90cm x 40cm x 47.5cm)
# Electronic Channels	480
Electronics Style (Temp.)	JFET (293 K)
Wire Pitch (Plane Separation)	4 mm (4 mm)
Electric Field	500 V/cm
Max. Drift Length (Time)	0.5 m (330 μs)
Wire Properties	0.15mm diameter BeCu

ArgoNeuT in the NuMI Tunnel

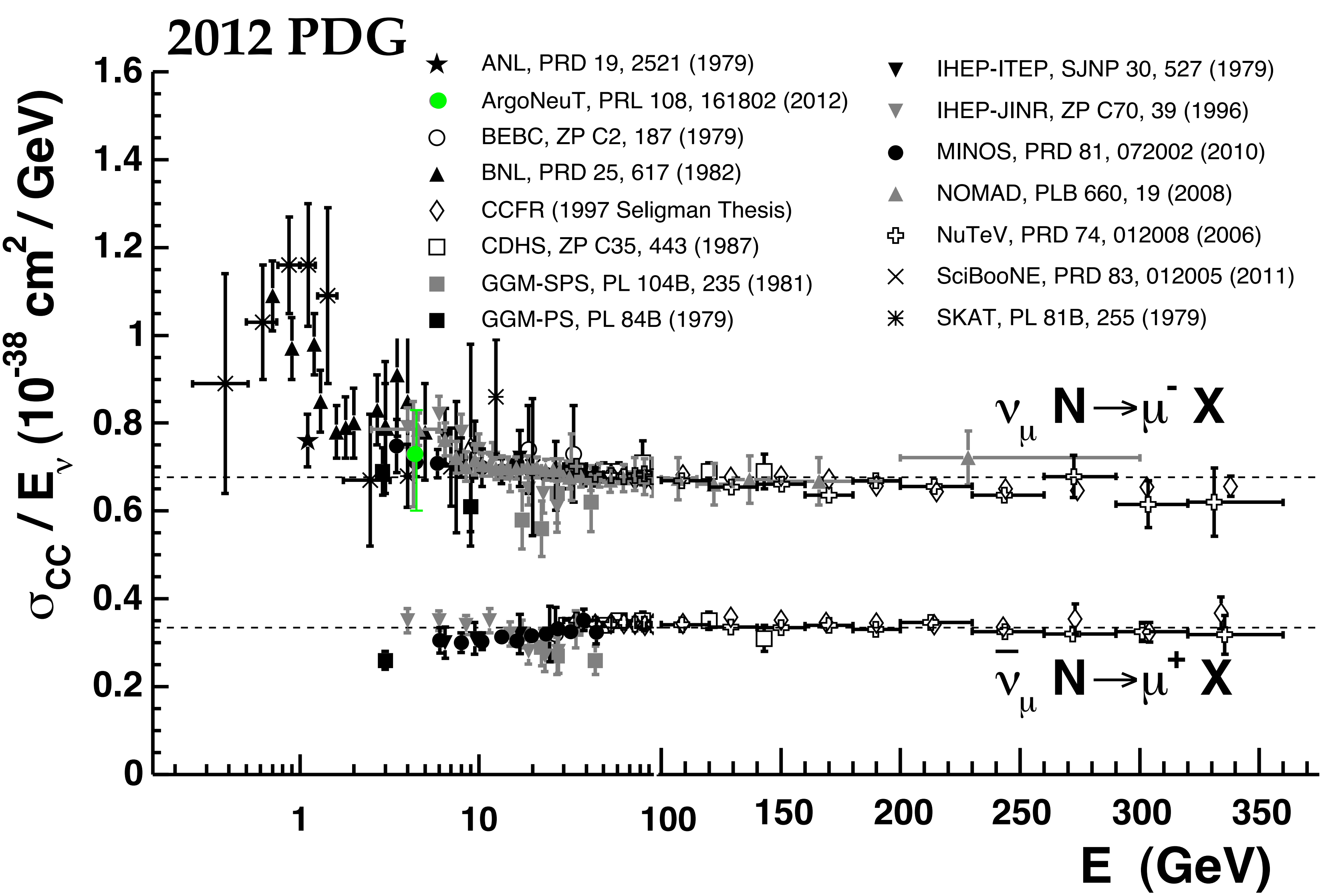
Refs:

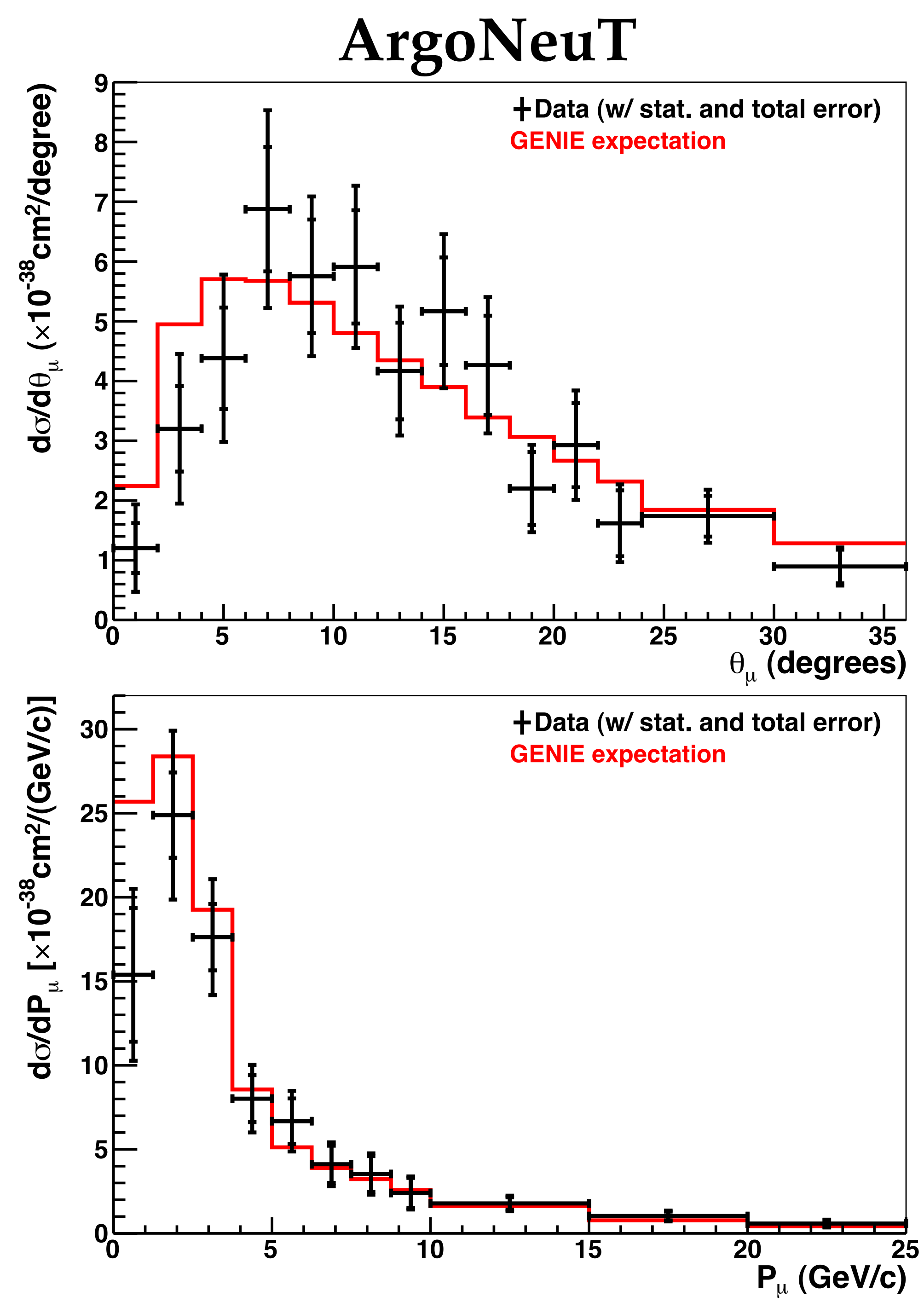
1.) ***The ArgoNeuT detector in the NuMI low-energy beam line at Fermilab*****, C. Anderson et al., arXiv:1205.6747**

ArgoNeuT: Data Event



ArgoNeuT: Physics





Inclusive CC cross-section

Refs:

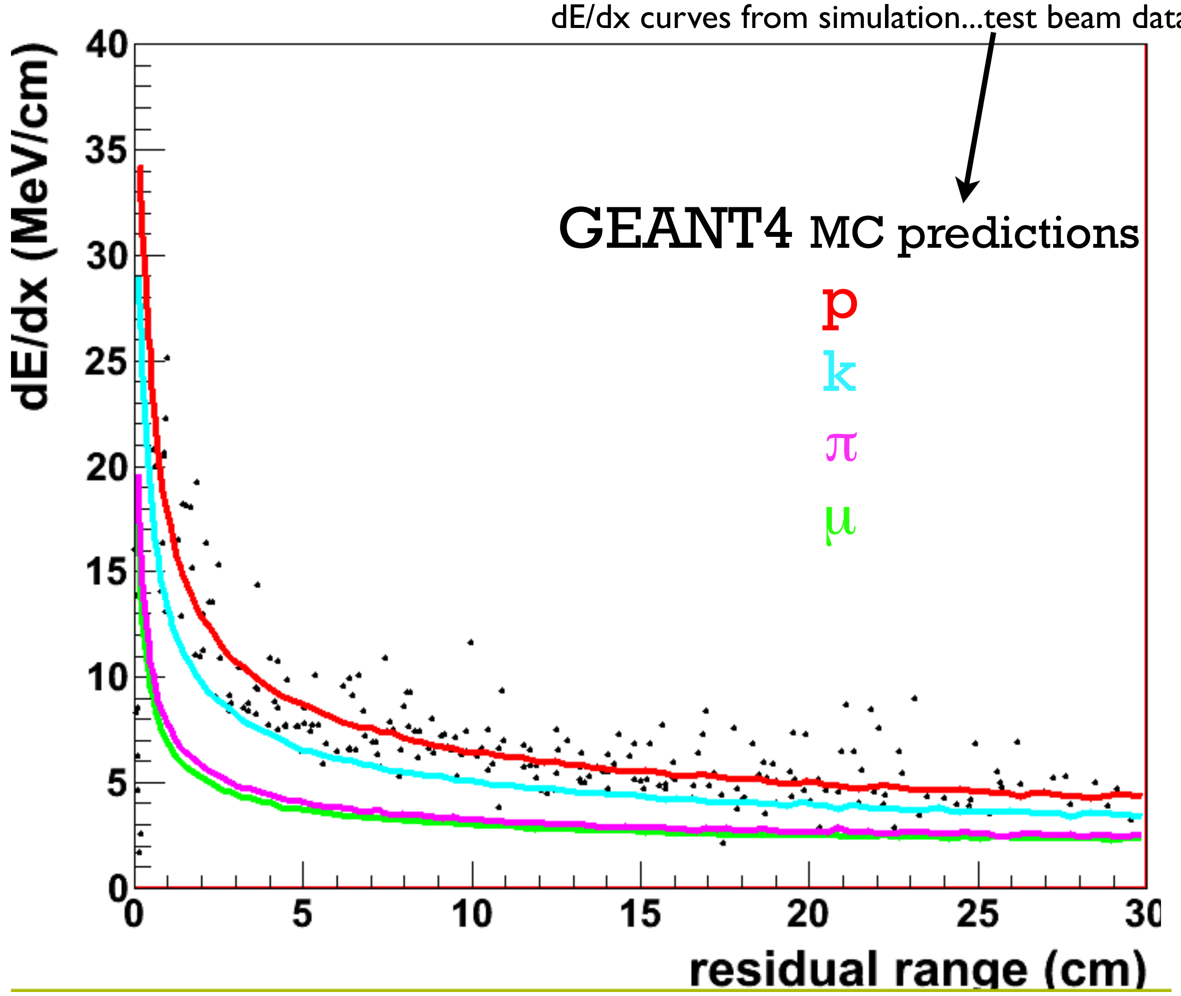
1.) *First Measurements of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon*, C. Anderson et al., PRL 108 (2012) 161802, arXiv:1111.0103

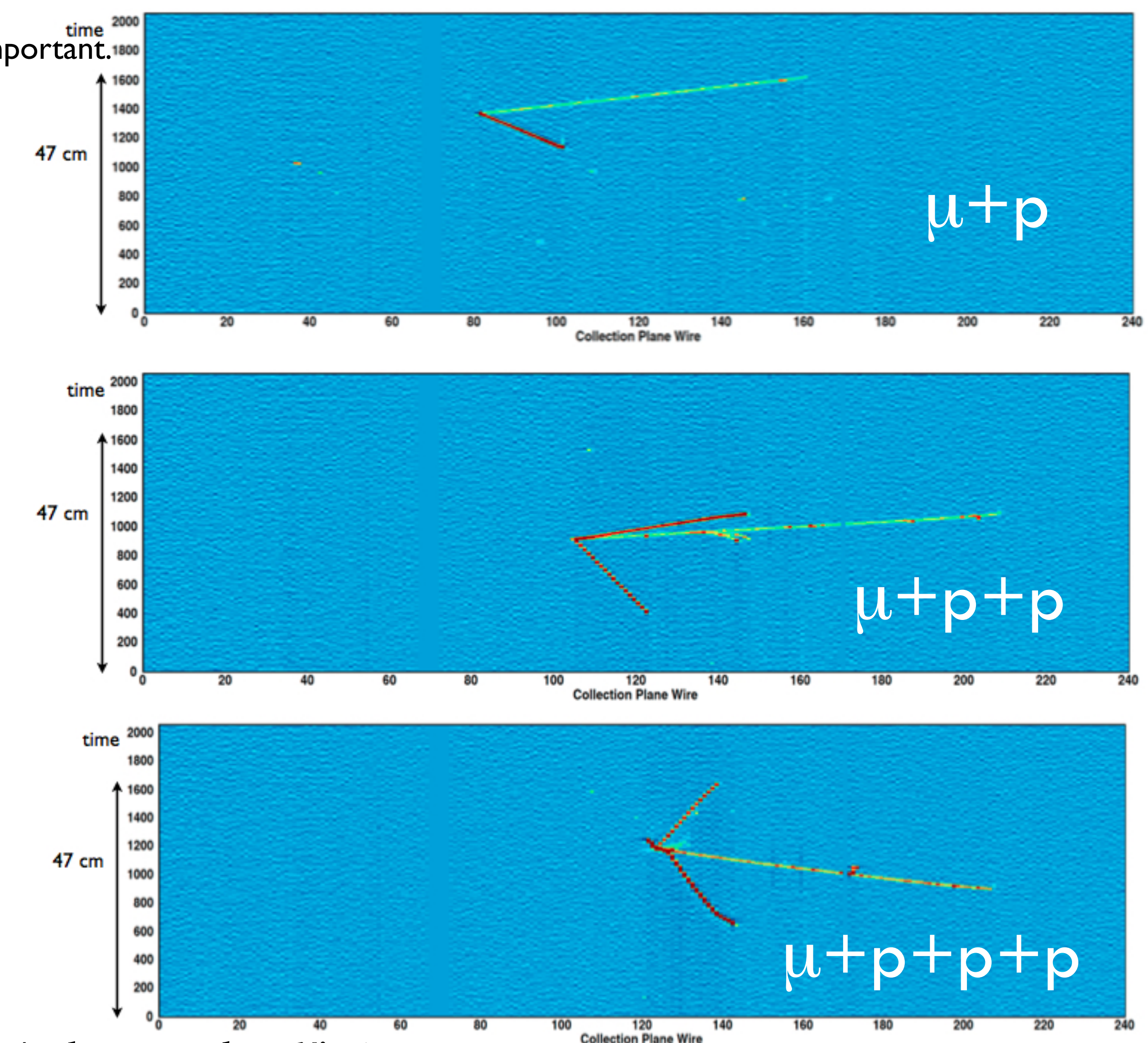
2.) *Neutrino cross section measurements*, J. Beringer et al. (Particle Data Group), Phys. Rev. D**86**, 010001 (2012)

ArgoNeuT: Physics

- Analyses in Progress:
  - Charged-Current Inclusive cross-section in antineutrino mode.
  - Charged-Current Quasi-Elastic exclusive analysis.
  - Stopping Protons to measure recombination behavior.
  - Hyperon Production
  - Initial measurements of dE/dx Particle ID effectiveness.
- Multinucleon Correlations, final-state activity, should be observable/measurable in ArgoNeuT.

dE/dx curves from simulation...test beam data will be important.



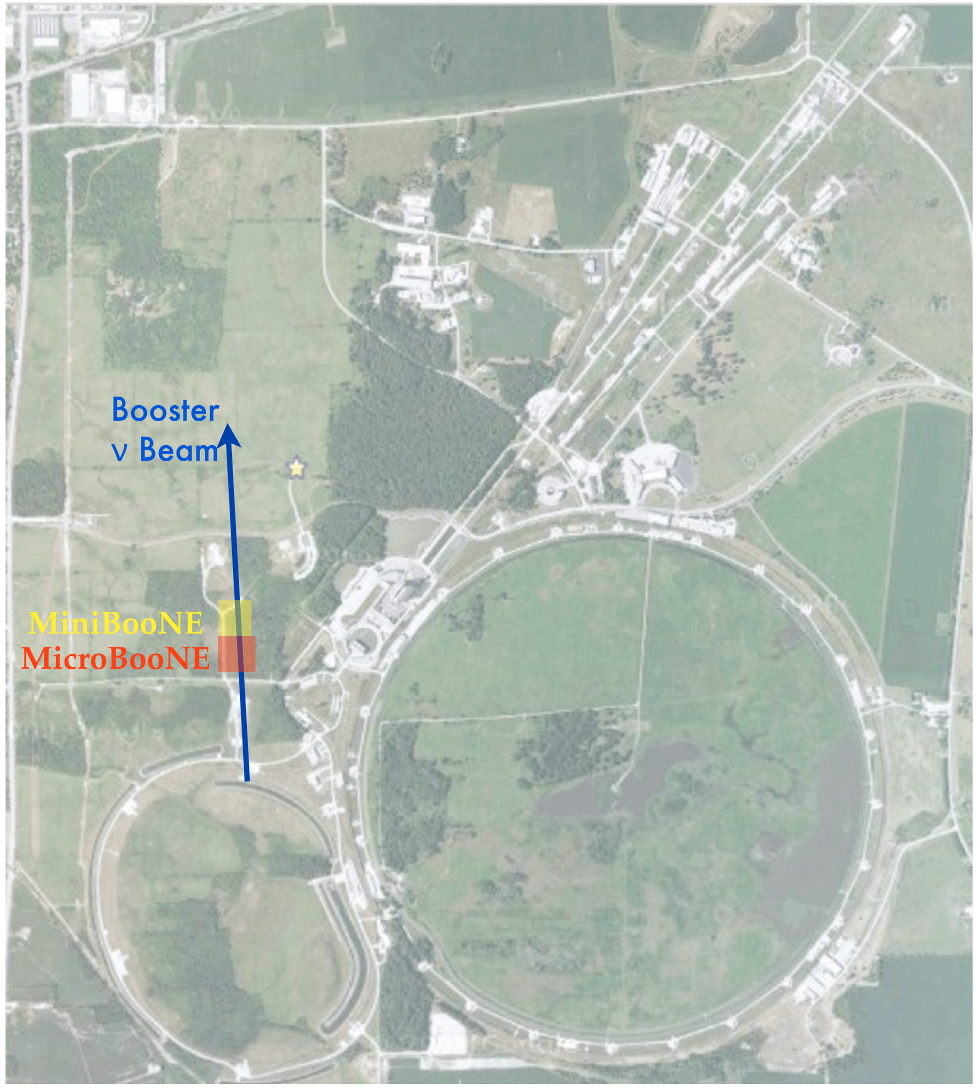


Refs:

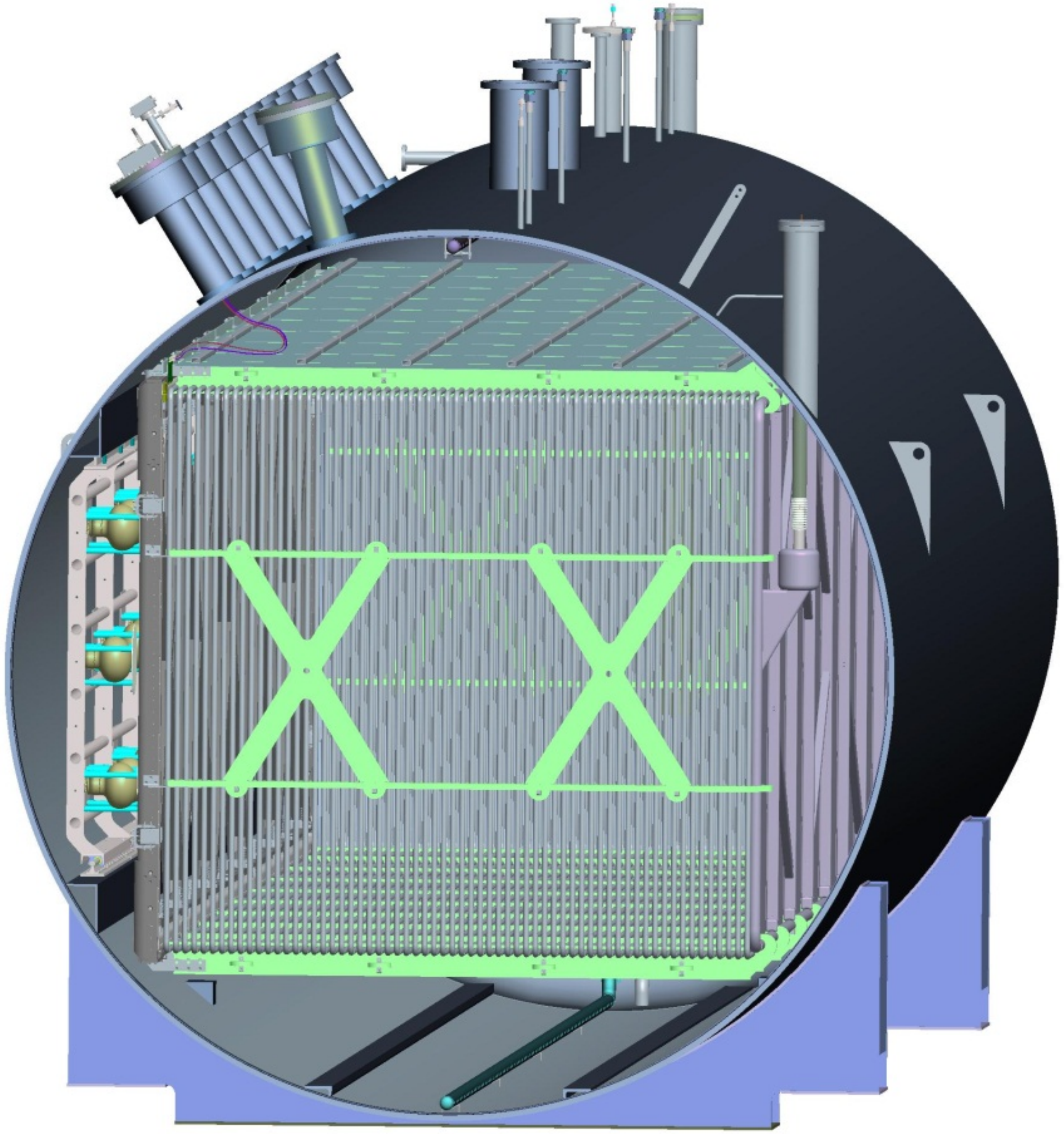
1.) Analysis of a Large Sample of Neutrino-Induced Muons with the ArgoNeuT Detector, C. Anderson et al., arXiv:1205.6702

The MicroBooNE Experiment @ Fermilab

- MicroBooNE will operate in the Booster neutrino beam at Fermilab starting in early 2014.
- Combines physics with hardware R&D necessary for the evolution of LArTPCs.
  - MiniBooNE low-energy excess
  - Low-Energy neutrino cross-sections
  - Cold Electronics (preamplifiers in liquid)
  - Long drift (2.5m)
  - Purity without evacuation.



Booster Neutrino Beam at Fermilab



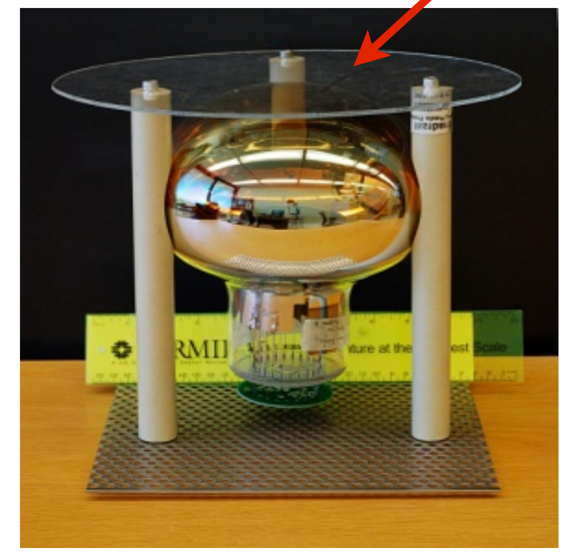
MicroBooNE Detector

Refs:
1.) Proposal for a New Experiment Using the Booster and NuMI Neutrino Beamlines, H. Chen et al., FERMILAB-PROPOSAL-0974

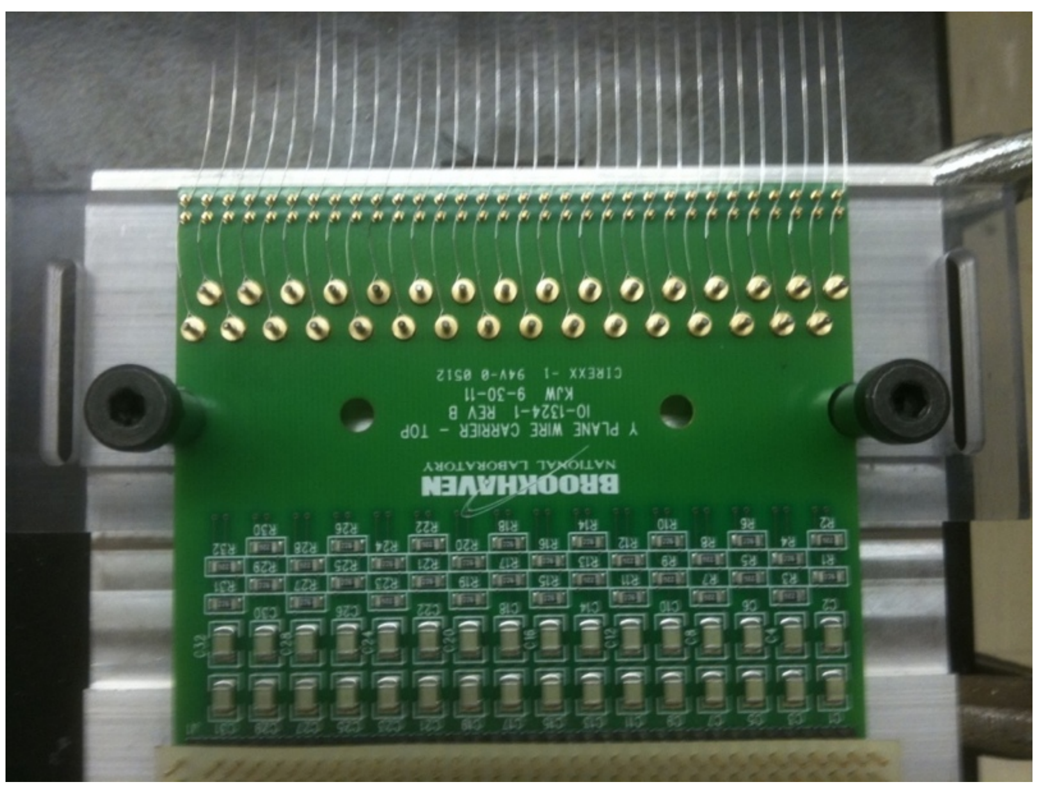
MicroBooNE: Detector Details

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

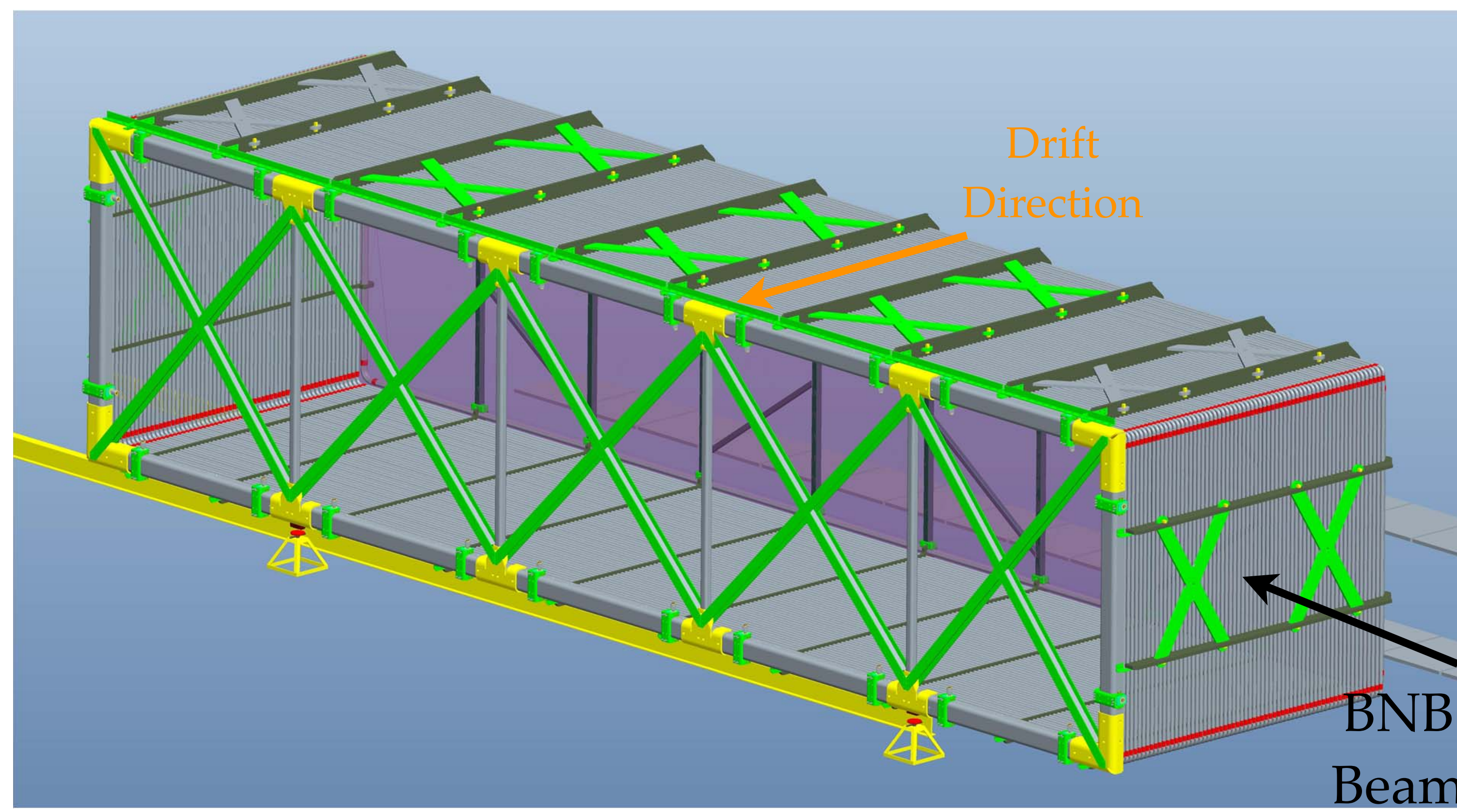
Plate coated with wavelength shifter



PMT Assembly



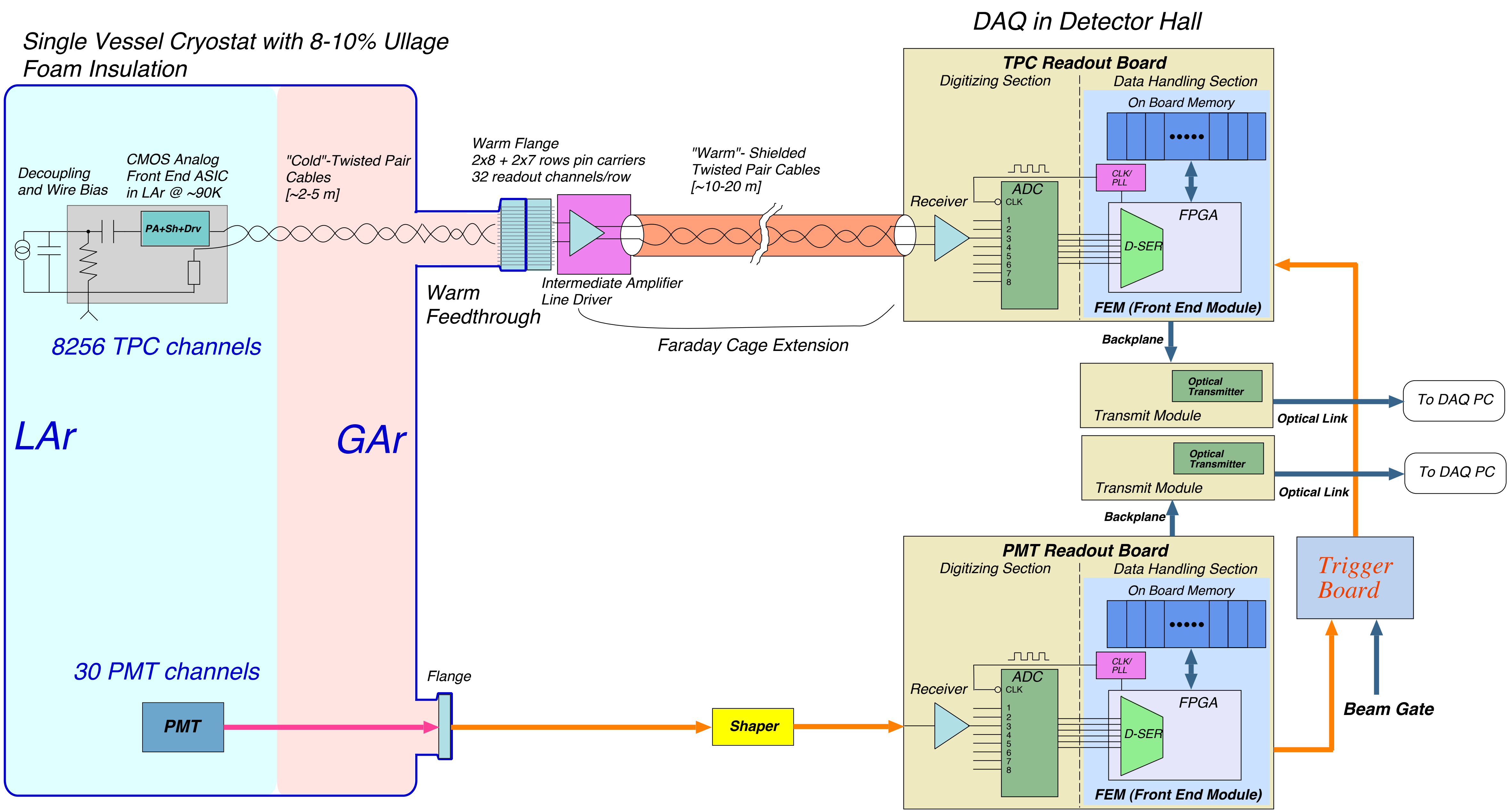
Collection Plane Wire-Carrier Board



TPC

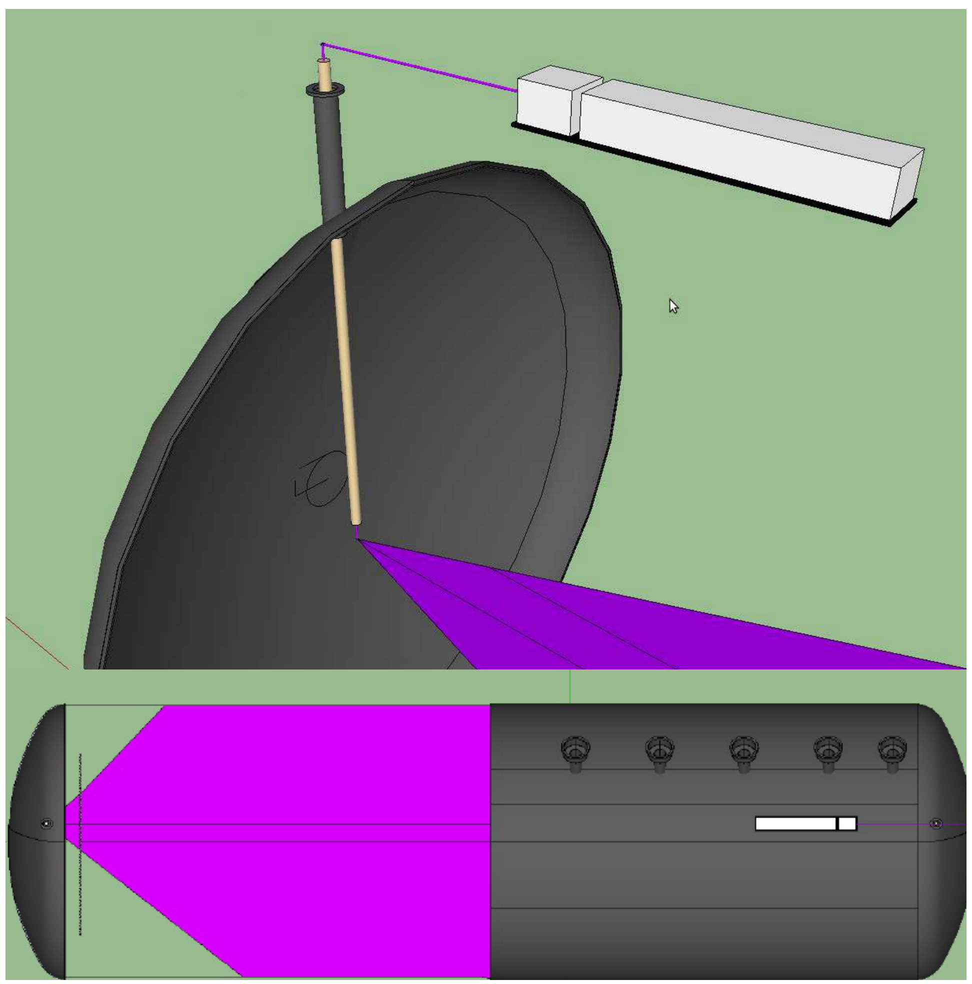
MicroBooNE: Electronics

- CMOS preamplifiers located in liquid, attached to TPC, to minimize noise.
- 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.



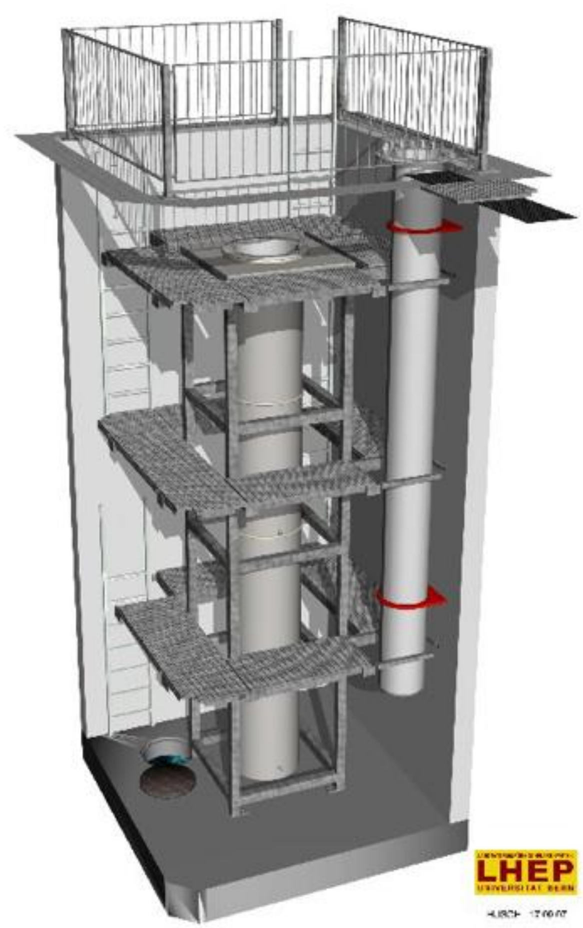
MicroBooNE: UV Laser

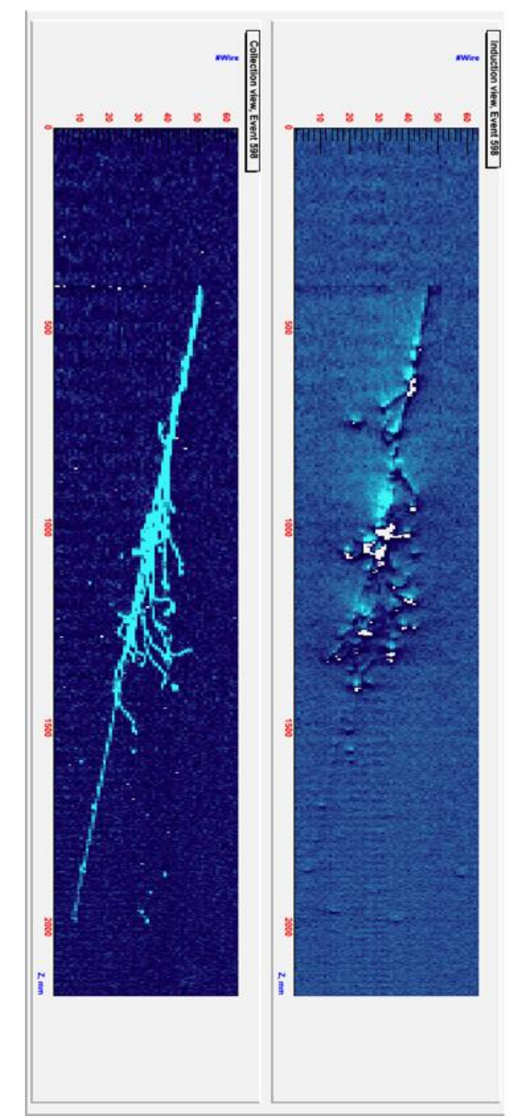
- MicroBooNE is considering adopting UV laser calibration system developed at Bern University.
- Can be used to map electric-field distortions in TPC, as well as allowing precision purity measurements.



UV Laser in MicroBooNE sweeps through TPC volume.

Bern 5m TPC





Refs:

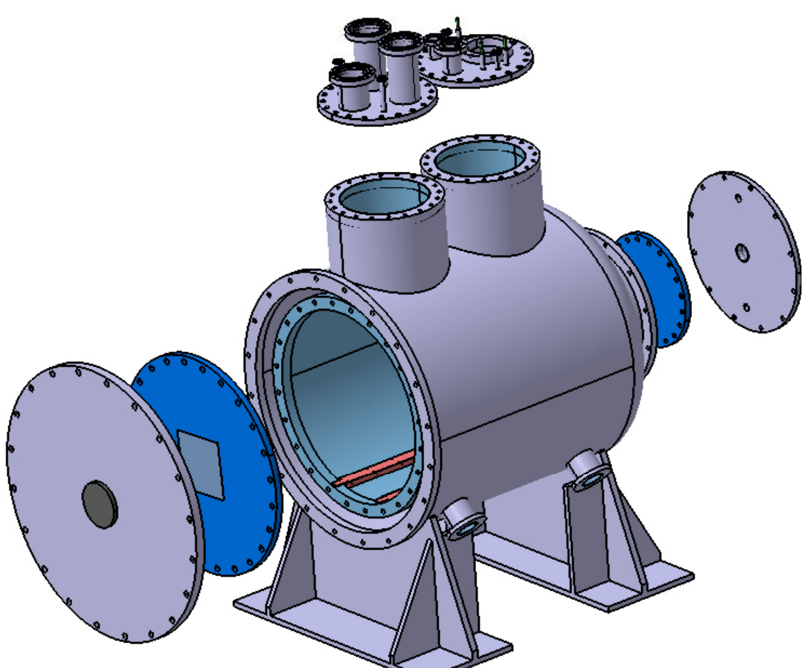
1.) *A prototype liquid Argon Time Projection Chamber for the study of UV laser multi-photonic ionization*, B. Rossi et al., arXiv:0906.3437

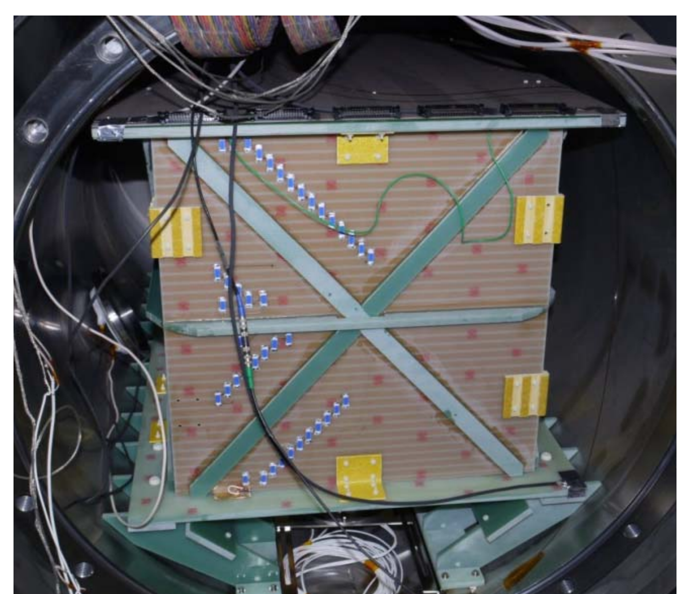
T32 @ J-PARC

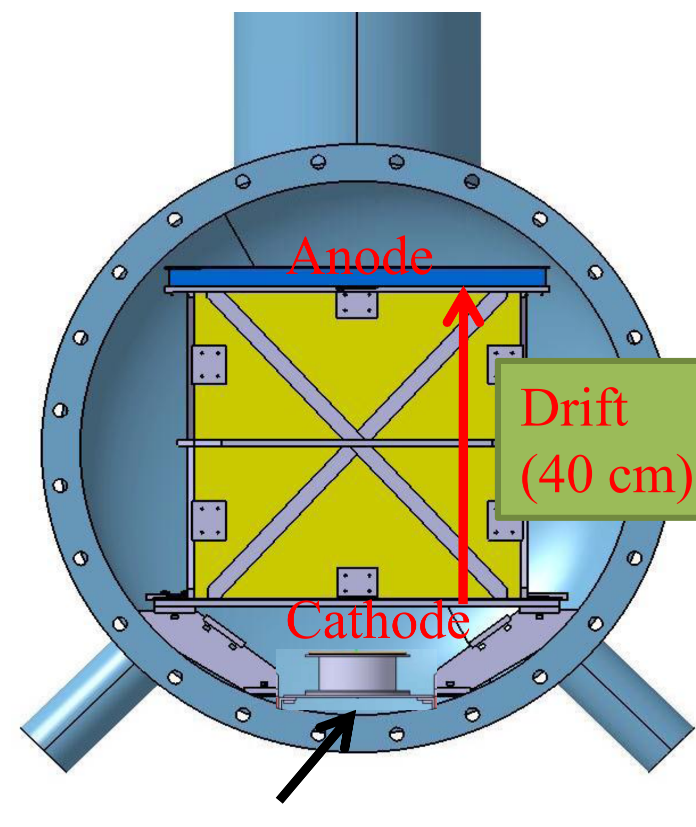
Slide from T. Hasegawa, LBNO-Paris Meeting

250L LAr TPC

- 250L Vessel:
  - Dimension: 70cm Φ × 100cm evacuable, vacuum insulated
  - Small thermal inflow ~30W
  - With beam window ~0.13 X_0
- 40 × 40 × 80 cm^3 TPC inside
  - Drift distance：40 cm







T32 @ J-PARC

Slide from T. Hasegawa, LBNO-Paris Meeting

T32: Event samples from Autumn 2010 run

Event Category	No. of events
K^+ 540 MeV/C (800 MeV/c incident with degrader)	7,000
K^+ 630 MeV/C (800 MeV/c incident with degrader)	40,000
K^+ 680 MeV/c (800 MeV/c incident with degrader)	35,000
π^+ 200 MeV/c	70,000
e^+ 800 MeV/c	2,500
p 800 MeV/c	1,500
e^+ 200 MeV/c	10,000
π^+ dominant 800 MeV/c	3,000
total	170,000

Largest K and π samples ever accumulated for Liquid Argon TPC

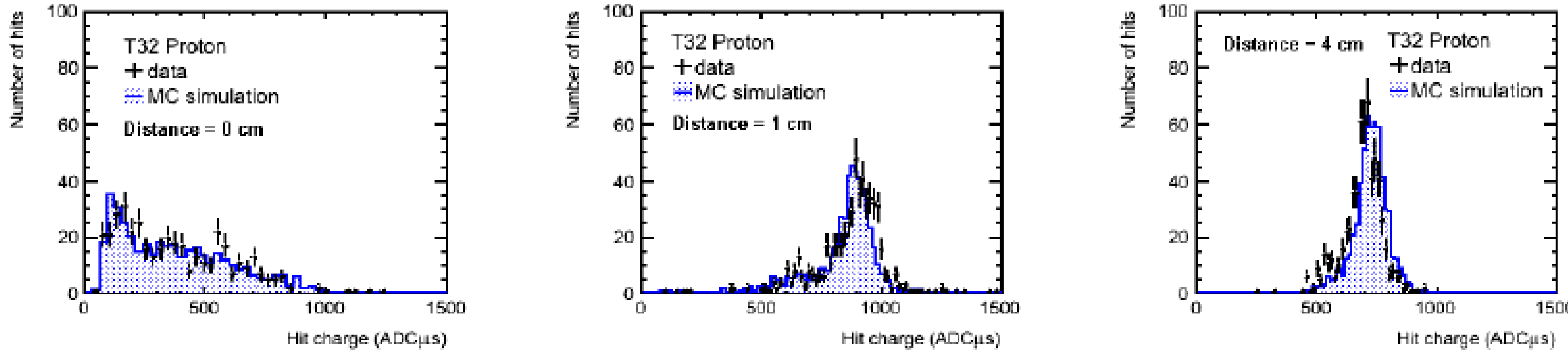
Slide from T. Hasegawa, LBNO-Paris Meeting

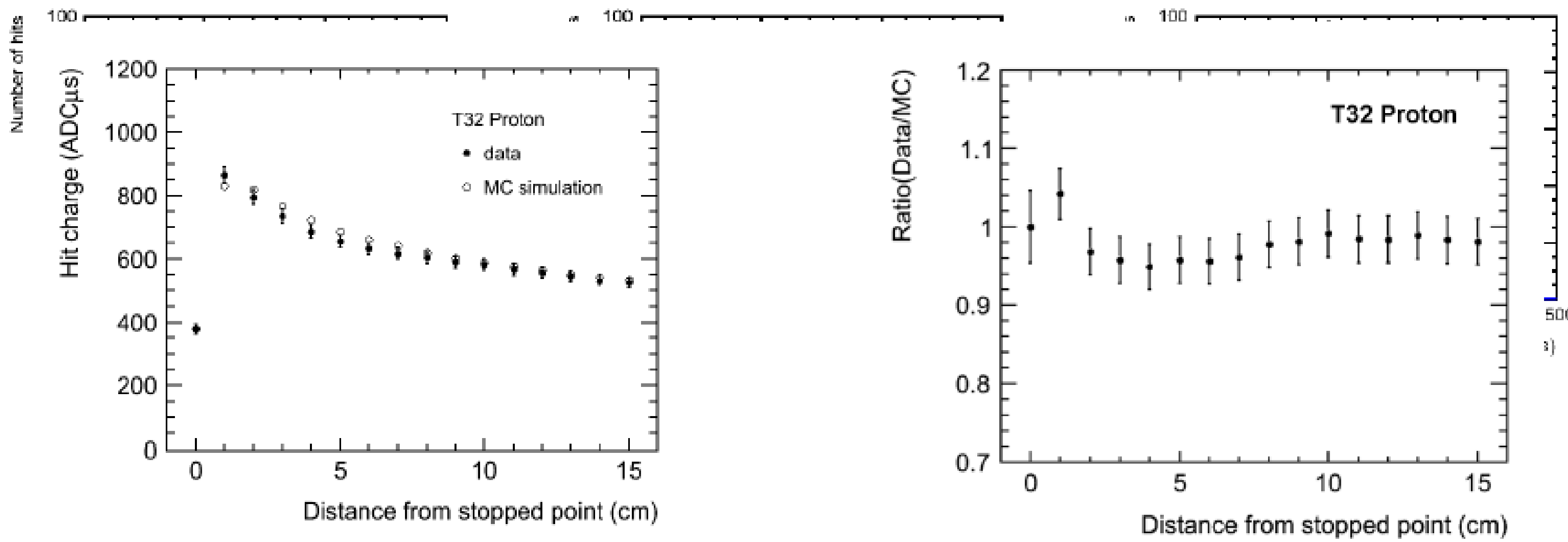
800 MeV/c P: Data-MC comparison

Black : DATA

Blue : MC

➢ **charge (dQ/dx) as a function of distance from stopped point**



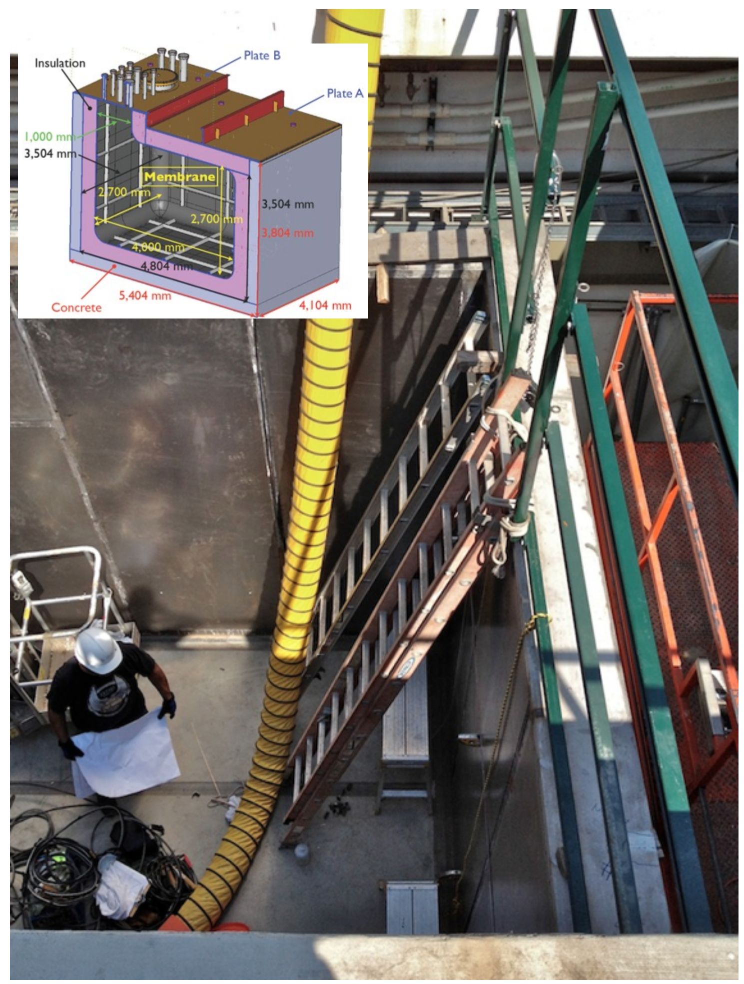


P: Data and MC are in good agreement at high dE/dx region

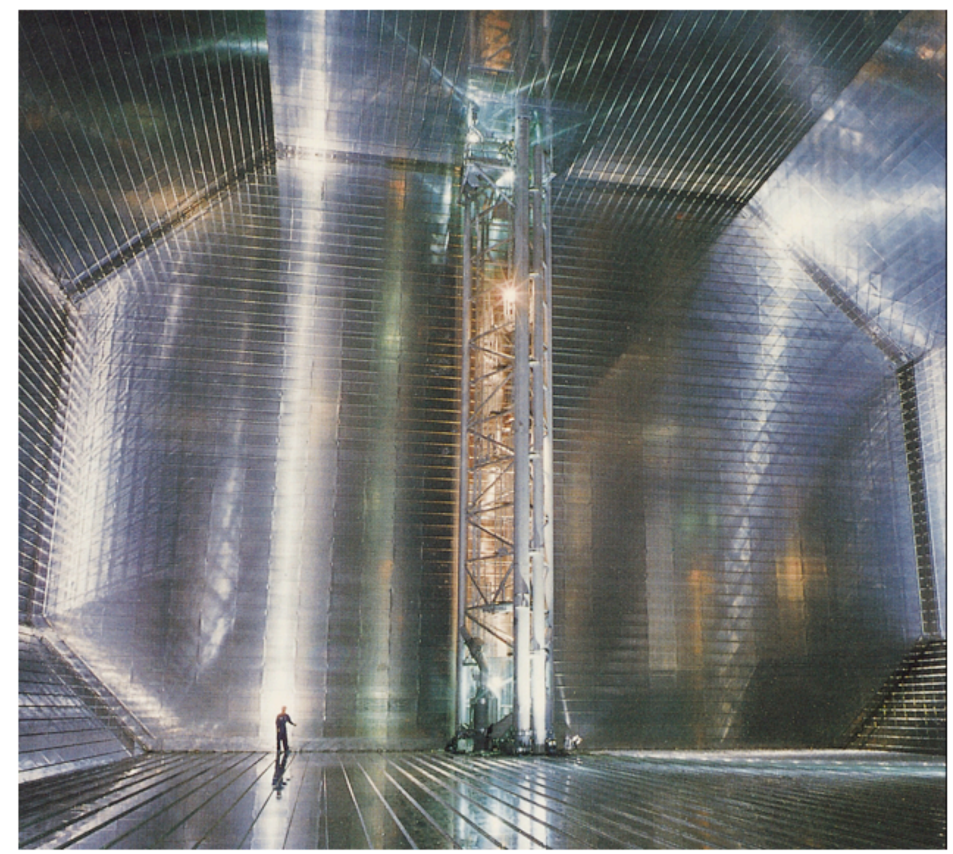
Purity R&D

- LBNE pursuing membrane cryostats, using experience from industry.
- Currently building 35-ton membrane cryostat to demonstrate liquid purity without initial evacuation (as has previously been demonstrated by Liquid Argon Purity Demonstrator in “traditional” cryostat).

LAPD
(30-ton cryostat)



35-ton
Membrane Cryostat

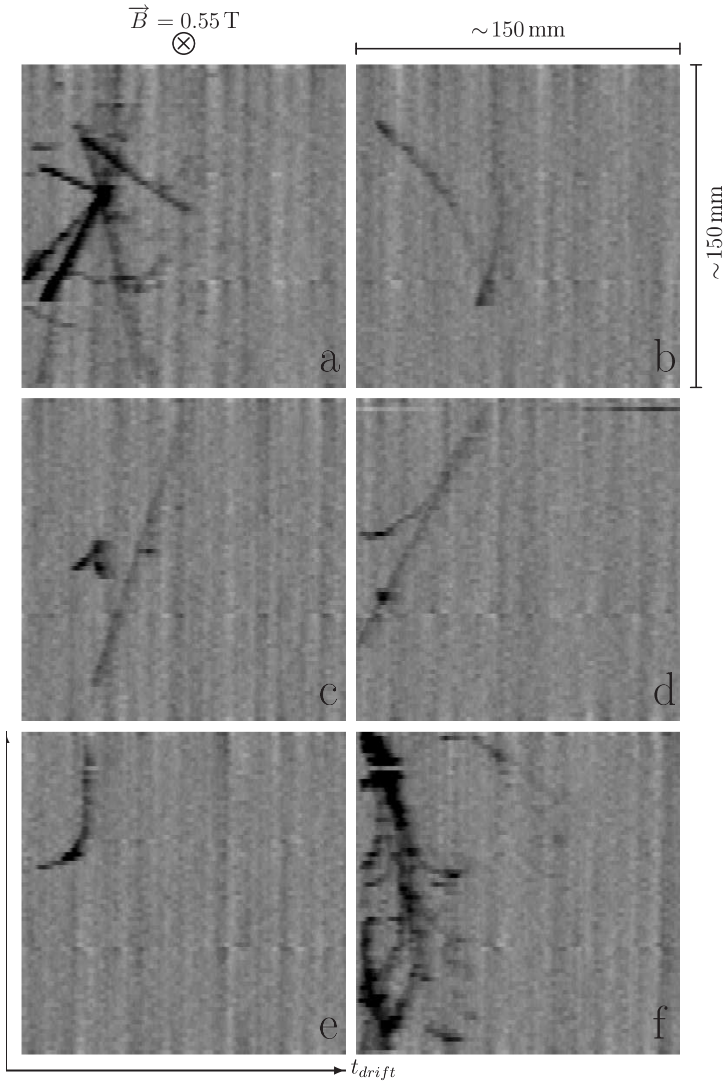


Membrane Cryostat for
industrial LNG shipping

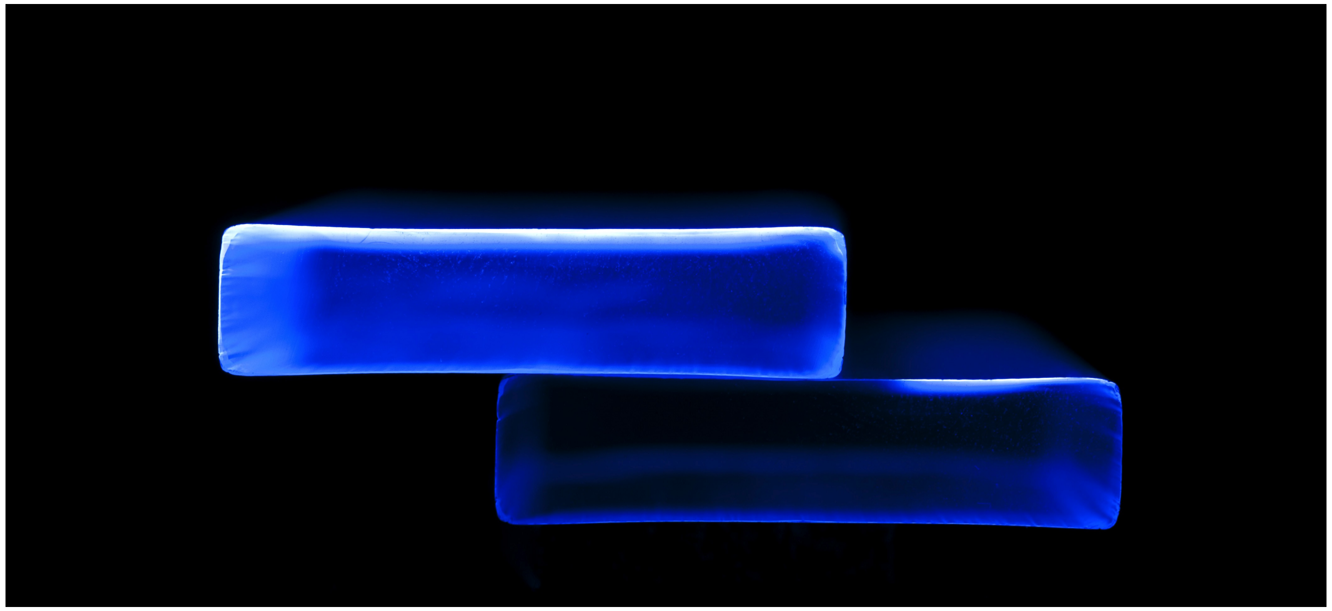
Refs:
1.)*Towards a liquid Argon TPC without evacuation: filling of a 6 m^3 vessel with argon gas from air to ppm impurities concentration through flushing*, A. Curioni et al., arXiv:1009.4073

Further R&D

- Liquid Argon detectors can be magnetized to allow lepton sign discrimination:
  - One previous LArTPC operated in magnetic field[1].
  - Magnetic field could impact PMTs used for triggering in "typical" LArTPC, requiring new light-collection methods[2] (e.g. - cryogenic lightguides coated with wavelength shifting substance)
- Cryogenic light guides to enhance triggering and minimize volume of light collection system.



Tracks in magnetized LArTPC



Light Guide 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

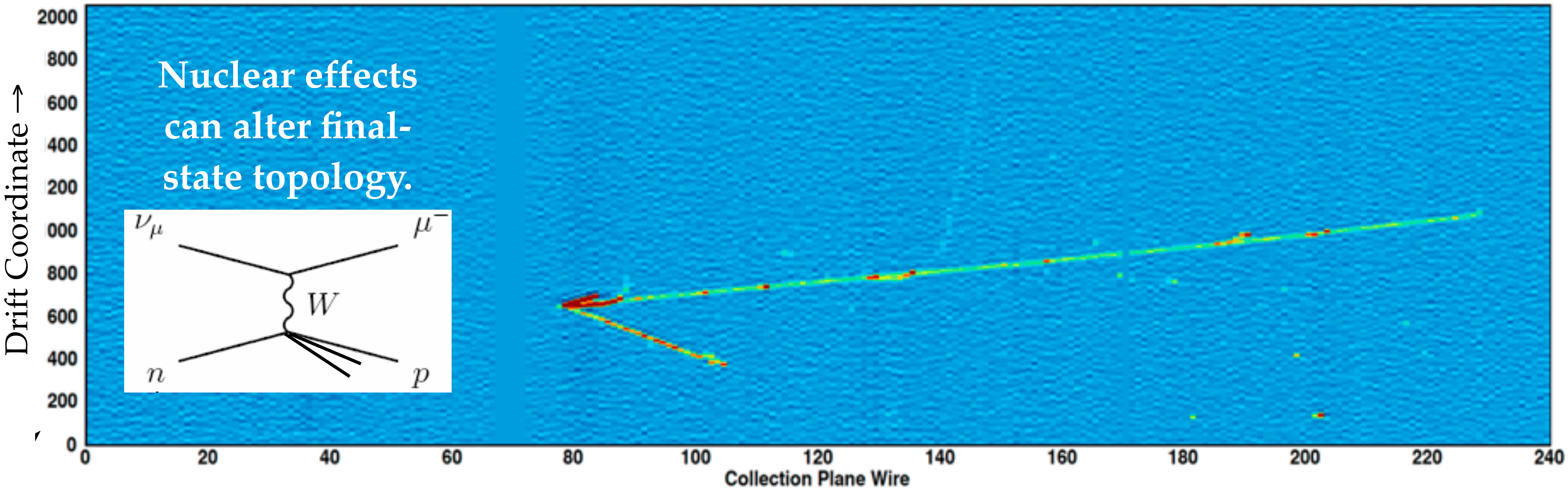
Conclusions

- LArTPCs are powerful detectors for studying neutrinos.
- Efforts are underway worldwide to develop technology to large scale required for long-baseline oscillation studies.
- Interesting physics results from ICARUS, ArgoNeuT, MicroBooNE, etc... will continue to appear along the way to large detectors.

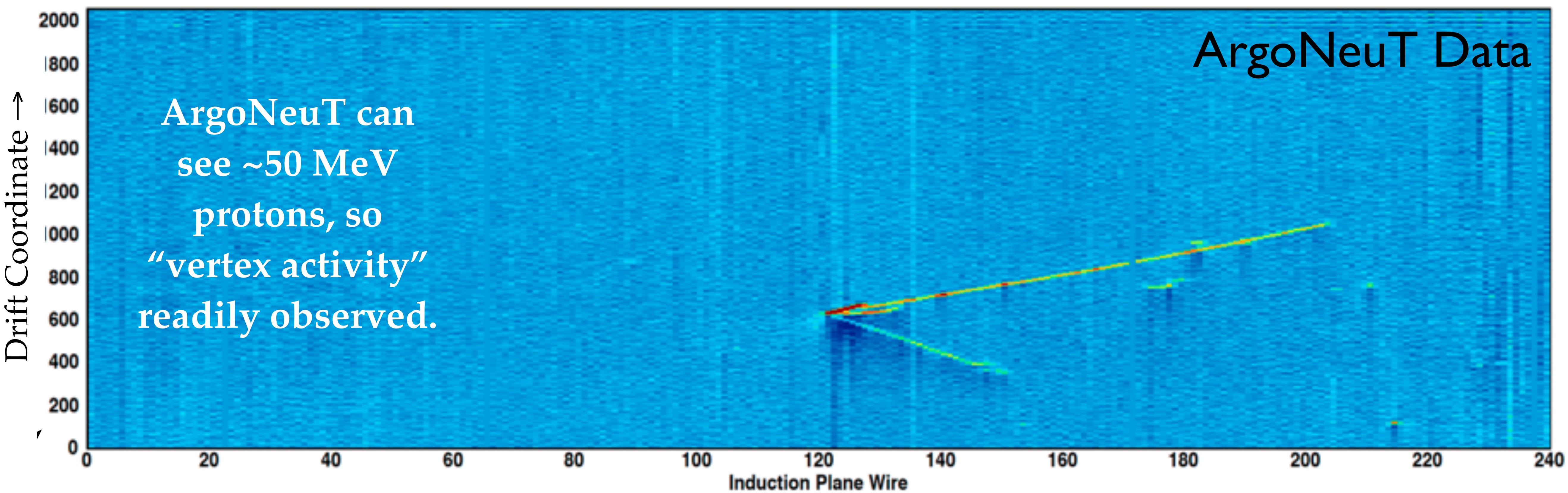
Back-Up Slides

ArgoNeuT Data Event

ArgoNeuT



Nuclear effects can alter final-state topology.

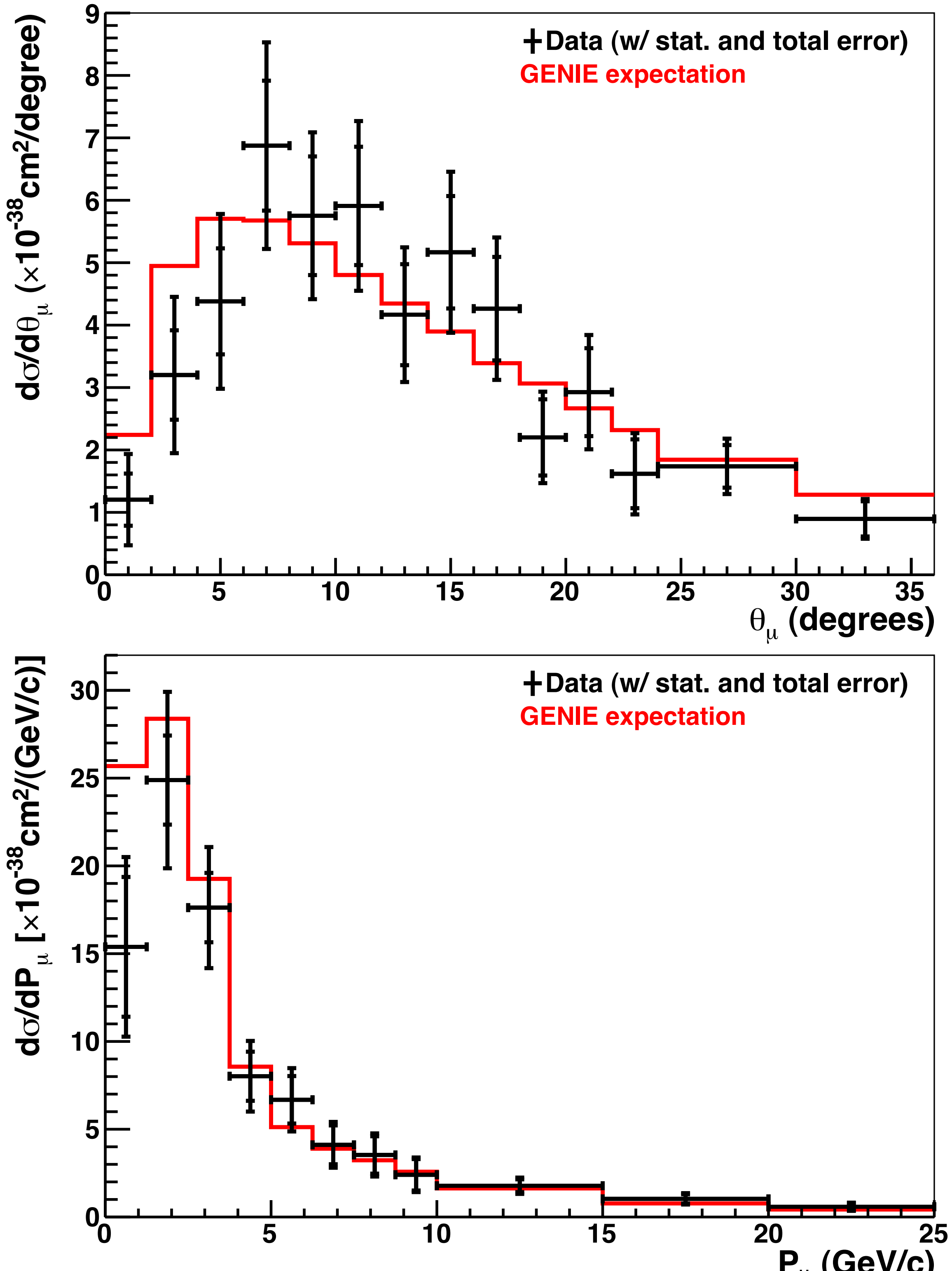


ArgoNeuT can see ~50 MeV protons, so “vertex activity” readily observed.

ArgoNeuT: Physics

- First Results: Using **2 weeks** of neutrino-mode data (8.5×10^{18} POT), the differential cross-section for inclusive charged-current muon neutrino production was measured.
- Analysis Selection:
  - Track originating within ArgoNeuT fiducial region.
  - Match to corresponding track in MINOS near detector.
  - MINOS track is negatively charged.
- First such measurement on Argon!

$$\frac{\partial\sigma(u_i)}{\partial u} = \frac{N_{\mathrm{measured},i} - N_{\mathrm{background},i}}{\Delta u_i \ \epsilon_i \ N_{\mathrm{targ}} \ \Phi}$$

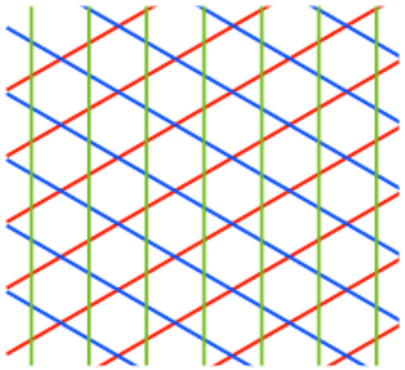


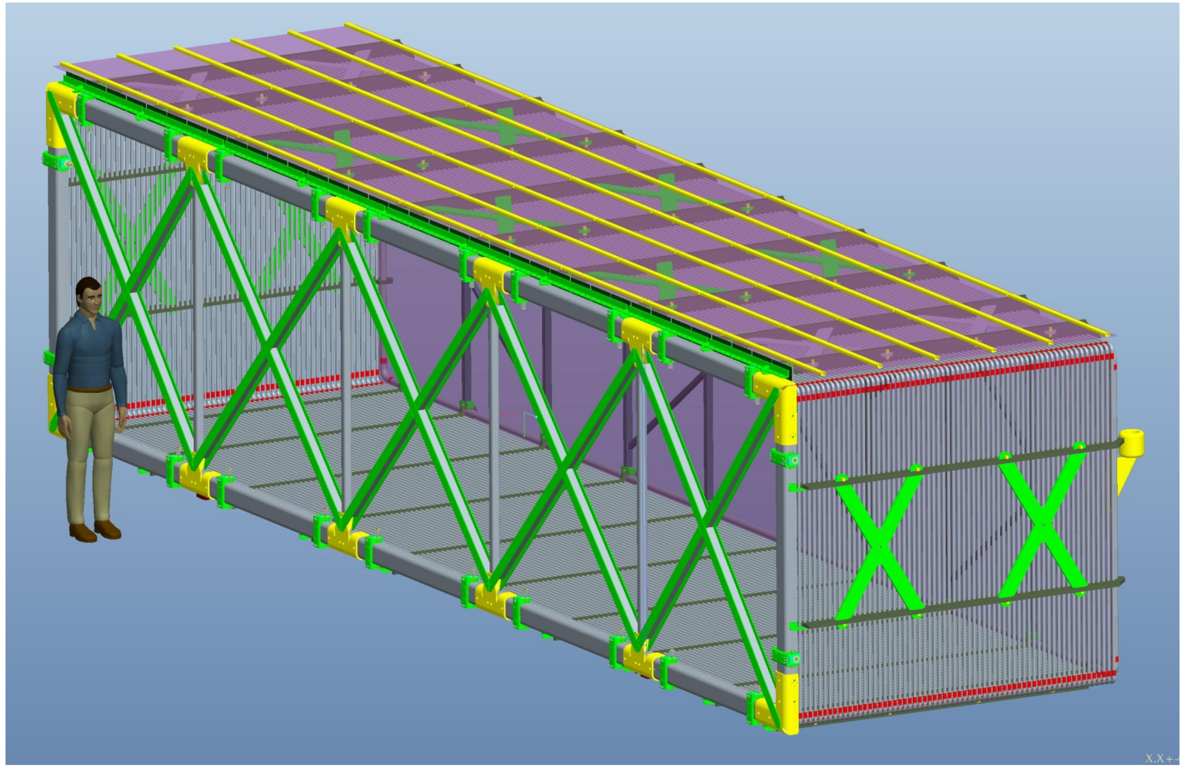
Inclusive CC cross-section

s:
First Measurements of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon, C. Anderson et al., PRL 108 (2012) 161802, arXiv:1111.0103

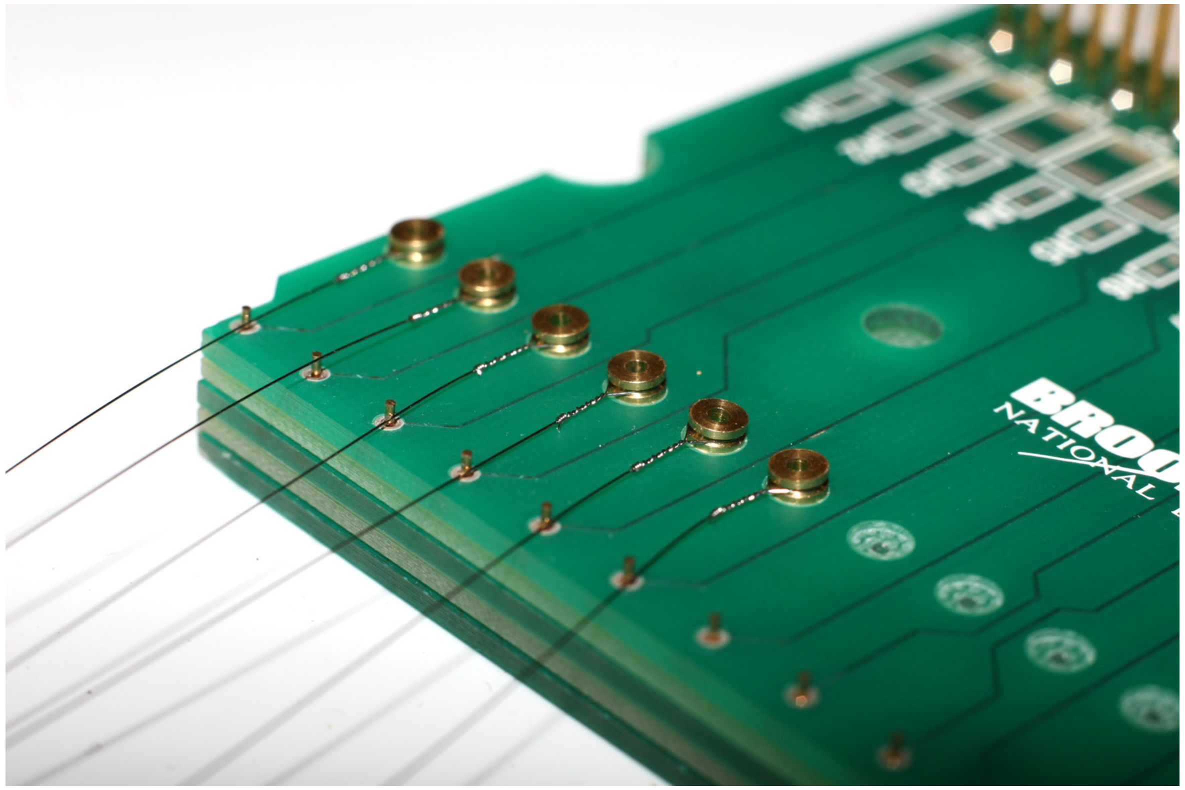
MicroBooNE: TPC

- 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

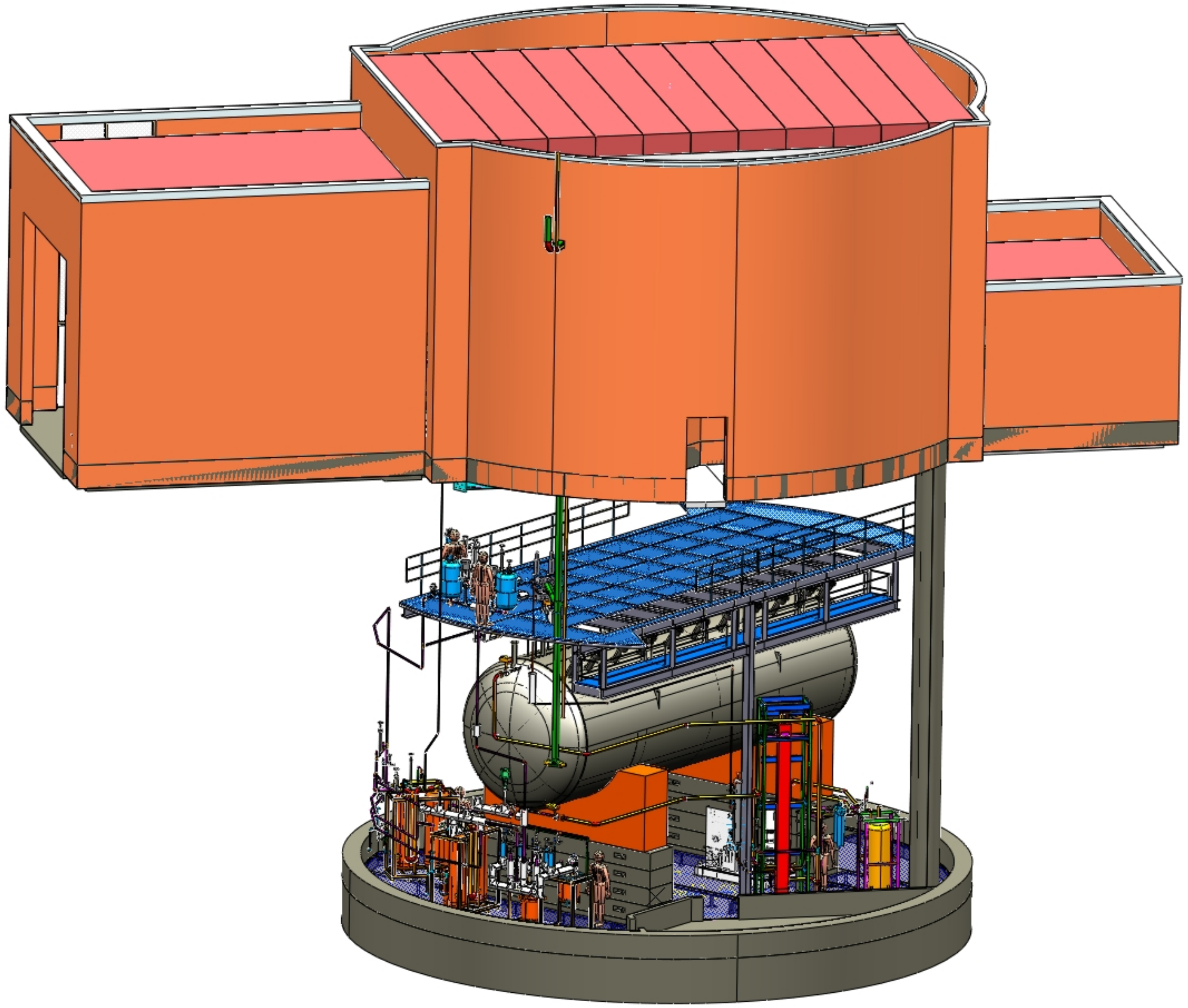


Prototype wires and wire carrier boards.

MicroBooNE: Detector Details

- MicroBooNE will be located in new Liquid Argon Test Facility (LArTF), just upstream of MiniBooNE location.
- Building construction is well underway.

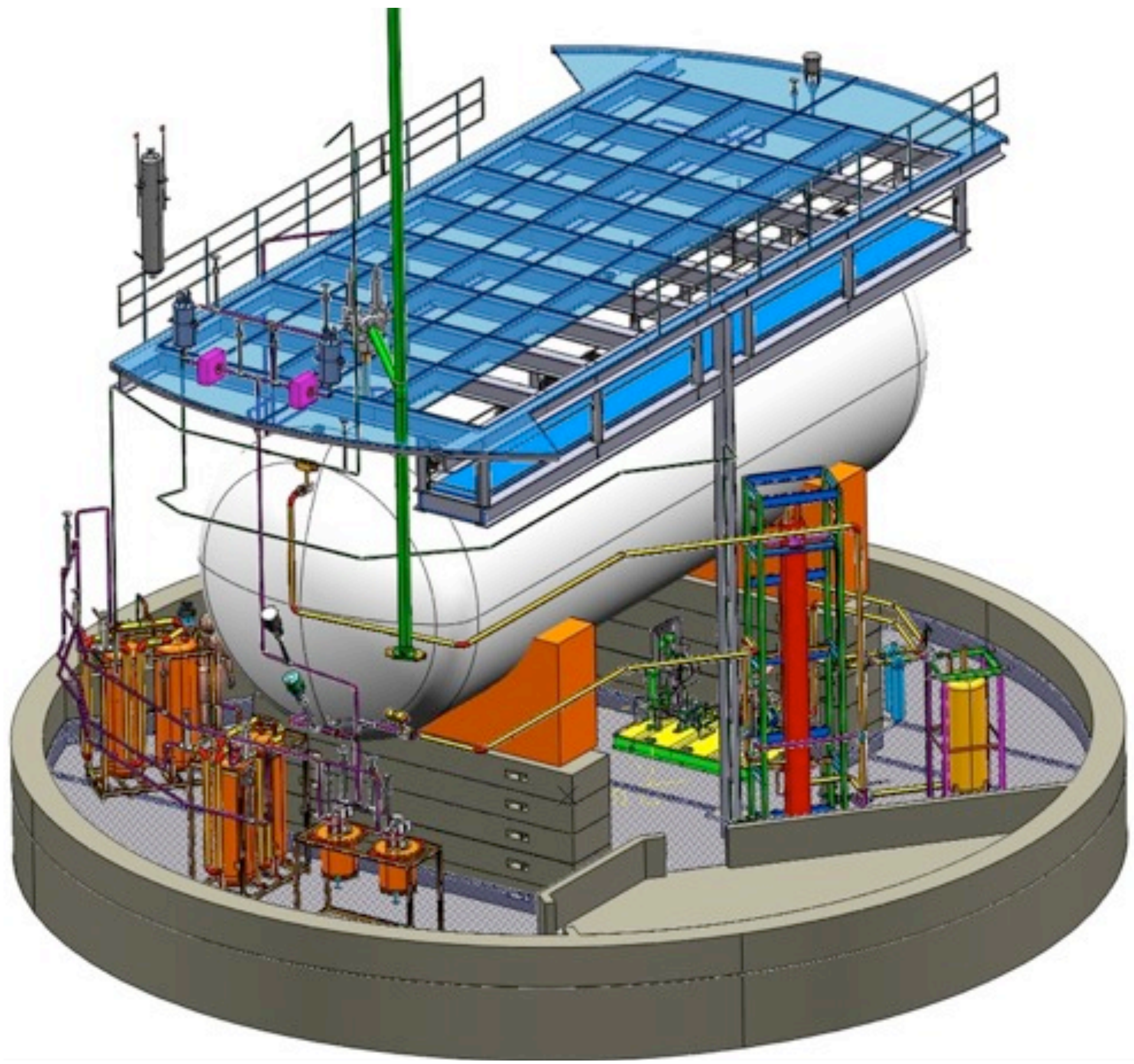
Liquid Argon Test Facility: June 2012



MicroBooNE Layout

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.



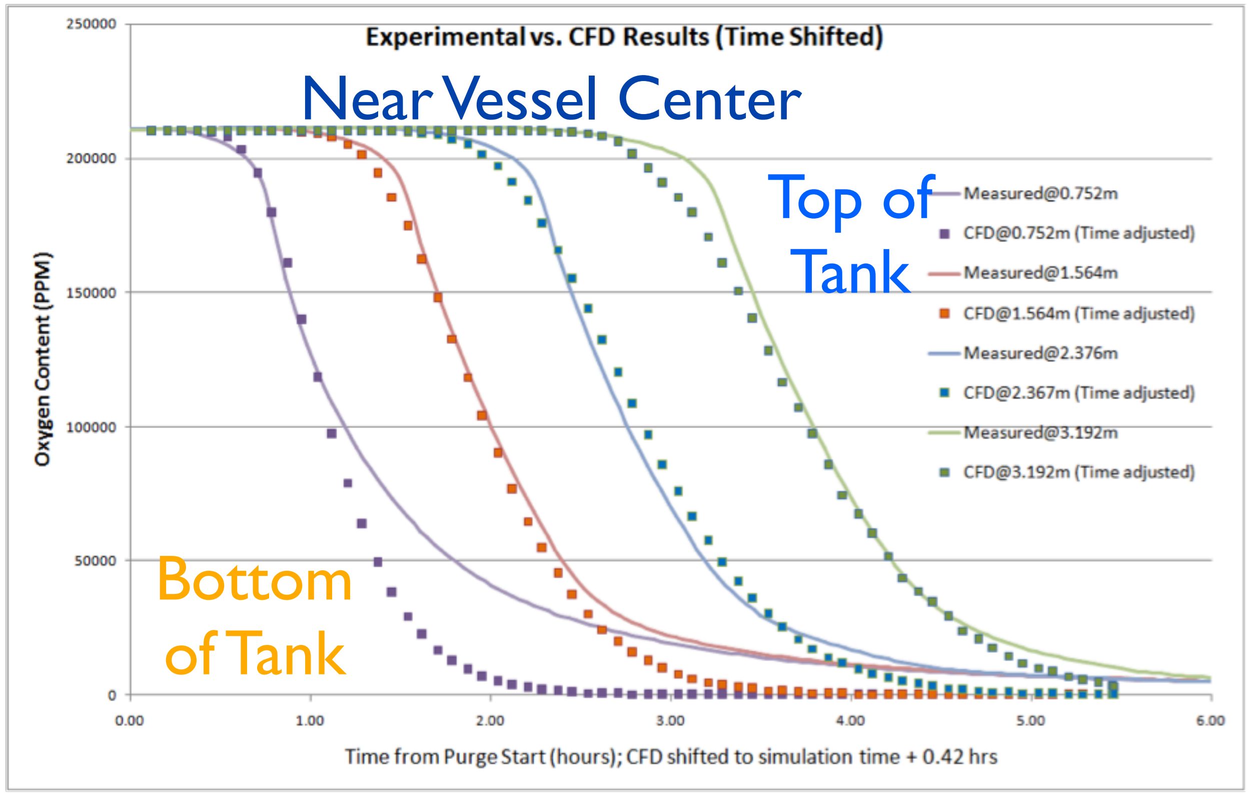
Schematic of MicroBooNE Layout

LAPD @ Fermilab

Large Detectors: Purity

Slide from B. Rebel, 2012 Fermilab PAC Meeting

Gaseous Argon Purge



- Set of sniffer tubes monitored the oxygen content of the gas inside the vessel at various depths throughout the purge
- Plot shows the content relative to the pre-purge state of the tank in solid lines
- Clear front of argon gas moving through the vessel
- Comparison to calculations (points) shows good agreement, aside from some discrepancy in time that is likely due to 3D flow and mixing as argon gas is forced into the bottom of the tank

5