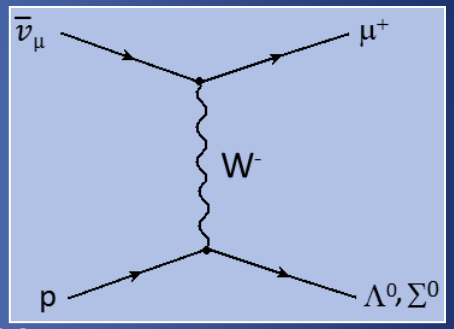
Anti-Neutrino-Induced Neutral Hyperon Production with ArgoNeuT

Saima Farooq
Tim Bolton
Kansas State University
APS Prairie Section Meeting, Lawrence, KS
Nov 9th, 2012

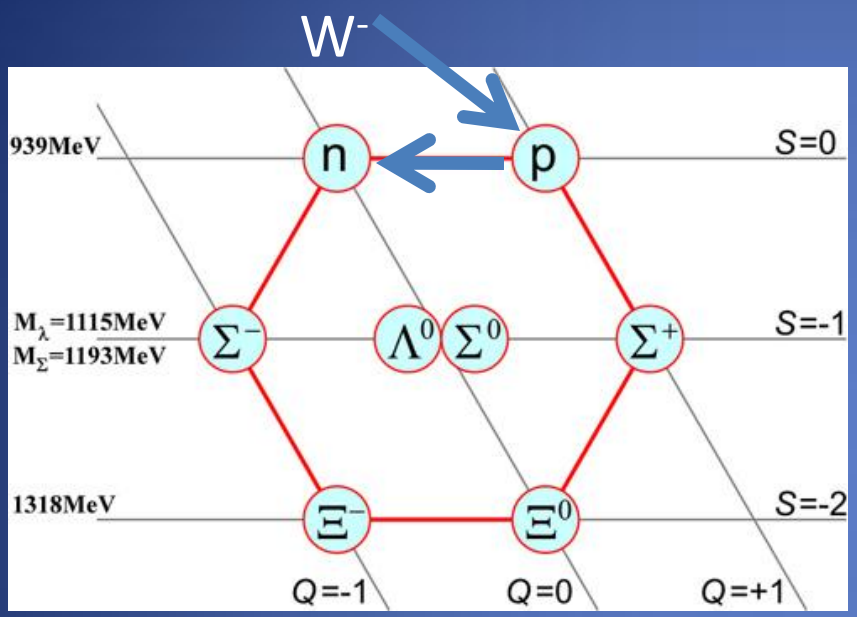
Motivation

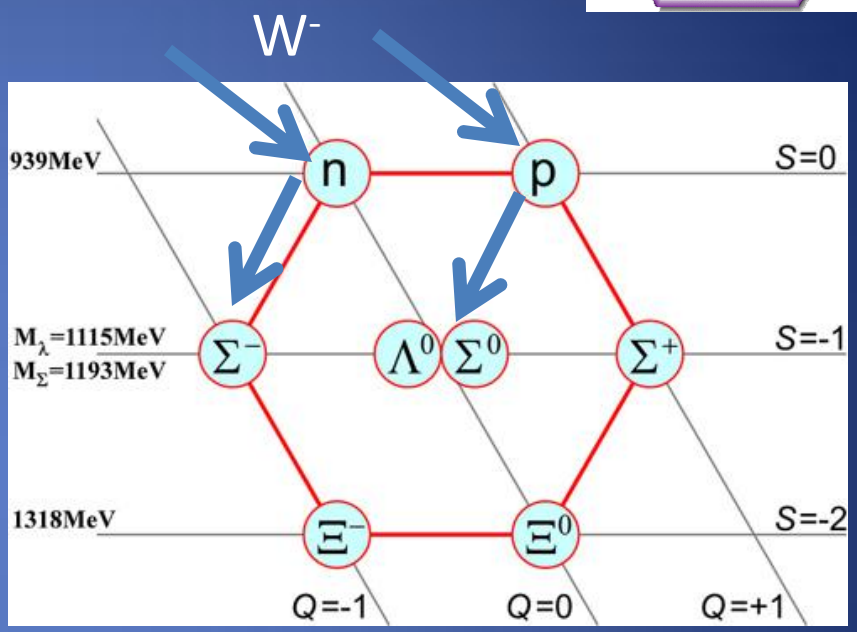
- Charge Current Quasi-Elastic (CCQE) Hyperon Production is the Simplest $\overline{\nu}_\mu$N Process after CCQE process of Neutrino from the Nucleon
- Existing Experimental Data on Hyperon Production via CCQE scattering with anti-neutrinos is Sparse
- CCQE Hyperon Production will have Different Nuclear Response than CCQE Neutron Production due to the absence of Pauli effects for the Hyperons
- LArTPC can SEE a Hyperon. Other Coarser Grained Detectors Probably Cannot
- Much of the ArgoNeuT Data is in $\overline{\nu}_\mu$ Mode



$\Lambda^0 \rightarrow \pi^- + p$

Physics of CCQE Λ^0/Σ^0 /Σ^- Production





- Basics:
  - Antineutrino only. (u→s transition), E_ν>325 MeV threshold. For LBNE, an "antineutrino tagger"
  - In $SU(3)_F$ symmetric quark model, very closely related to QE n-production. Many form factors are the same.
  - $\sigma_{(\Lambda 0+\Sigma 0)} \cong \sigma_{(\Sigma -)} \cong \tan^2\theta_C \sigma_{(n)} < 0.05 \times \sigma_{(n)}$, since $M_{\Lambda,\Sigma} \cong M_n + 200$ MeV

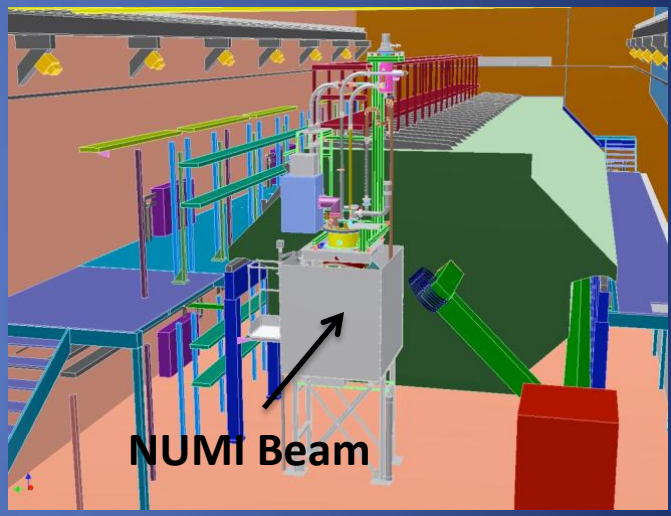
Neutrino Experiment

Needed:

- Intense Beam
- High Resolution Detector
- Dense and Homogeneous Medium
- Low energy Threshold
- Precise Calorimetric Reconstruction
- Particle ID (dE/dx) [photon/electron separation – background rejection]

ArgoNeut Experiment

- ArgoNeuT is a joint NSF/DOE R&D test project at Fermilab to expose a small-scale "liquid argon time projection chamber" (LArTPC) to the NuMI neutrino beam
- ArgoNeuT is located at Fermilab upstream of the MINOS near detector, and is calibrated using muons that traverse the chamber and penetrate several layers into MINOS.
- ArgoNeut can see neutrino interactions (~150 events/day): 1st time in the U.S., 1st time ever in a low-Energy beam
- ArgoNeuT also serves as a stepping stone to larger detectors like MicroBooNE and LBNE, by providing experience in operating underground argon recirculation, trigger, and readout systems.



MINOS Hall : 1Km from Target
ArgoNeut: Upstream of MINOS
(2009-10)

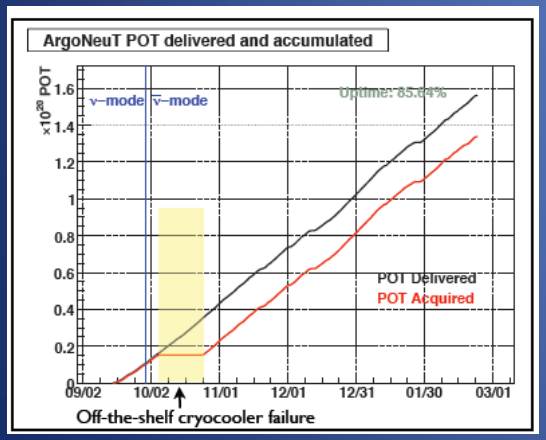
ArgoNeut Run-I

Expect ~ 15.88 ± 0.2(stat) ± 14.3 (syst)* CCQE Neutral Hyperon events

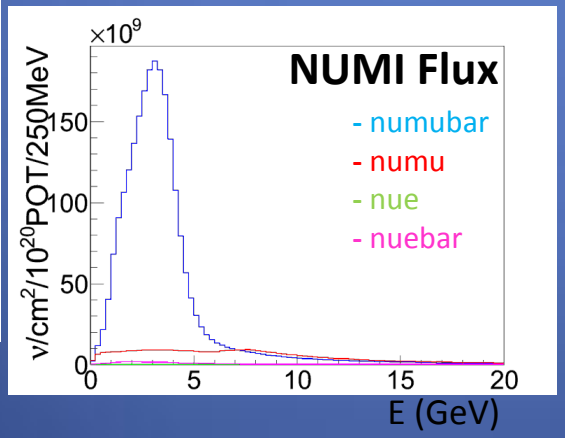
With Primary and Secondary Vertex in FV and neutral hyperon final decay products are charged particles

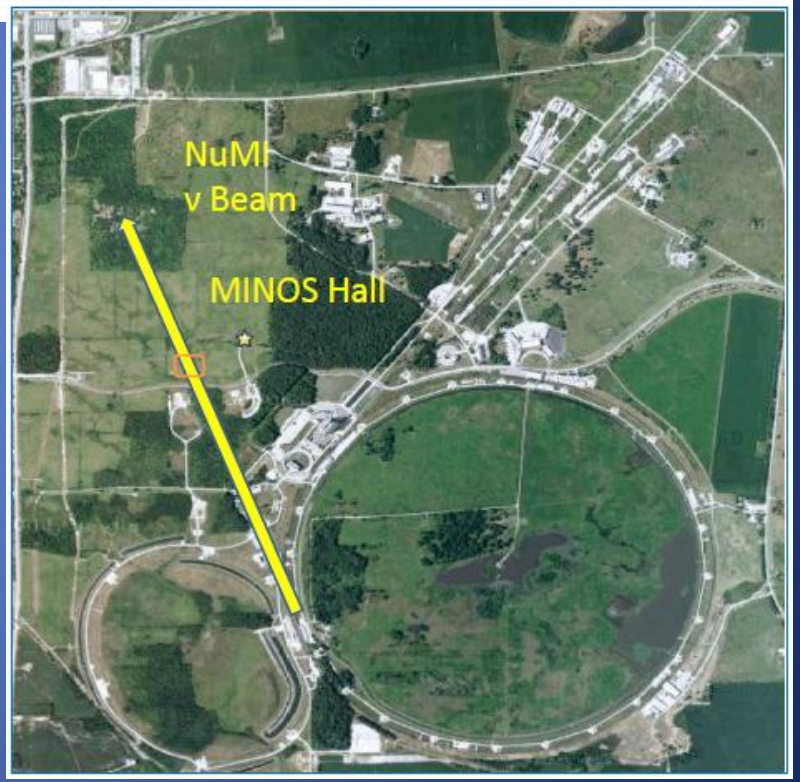
Plan to include Charge Current Deep Inelastic Neutral Hyperon Event Sample as well

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



2 Weeks Neutrino-Mode
4.5 Months Anti-Neutrino-Mode
3 Weeks Downtime





NuMI Beam at Fermilab

120GeV Protons -> Graphite Target -> π-> ν_μ

*C.H.Llewellyn-Smith: Phys. Rep. C 3 (1972) 261, *D. Casper (UC, Irvine): Nucl. Phys. Proc. Suppl. 112 (2002) 161-170

ArgoNeut's Working

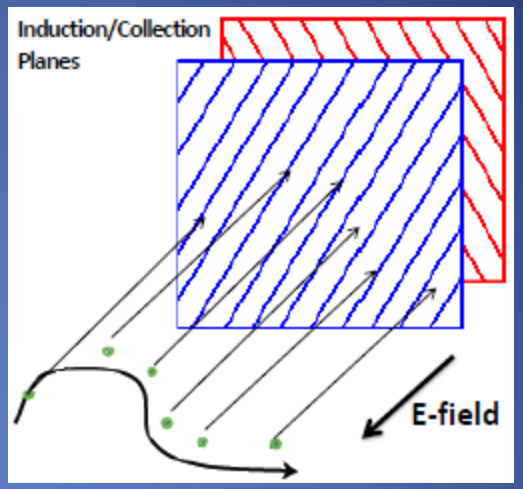
There are three main systems in ArgoNeuT

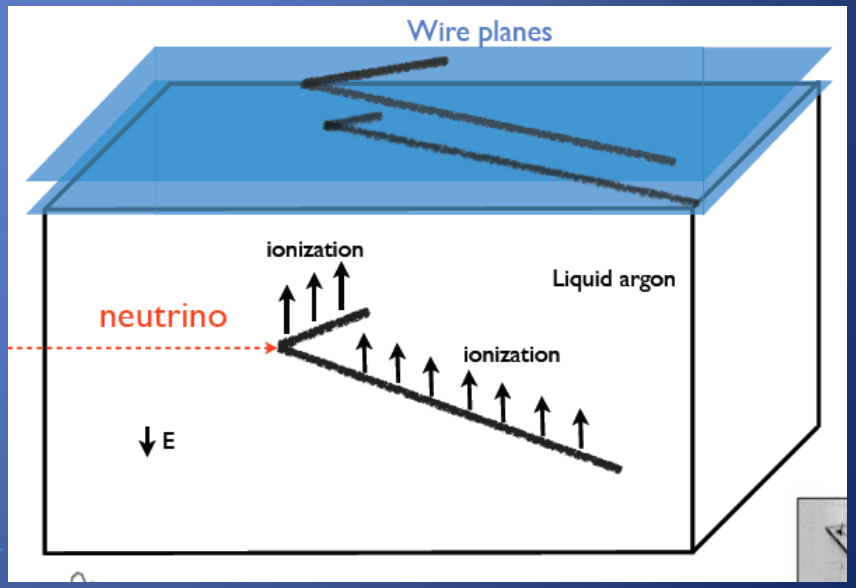
1. **<u>The Time Projection Chamber (TPC)</u>**
2. The Purity System
3. The Recirculation System

ArgoNeut's Working (1)

1. The TPC:

Cryostat Volume	**500 Liters**
TPC Volume	175 Liters
TPC Dimensions	47.5x40x90cm^3
# Wire Planes	2
Wires Orientation	30^0 from Vertical
# Electronic Channels	480 (240 in each wire plane)
Electric Field	500V/m
Plane Pitch	0.4cm
Wire Pitch	0.4cm
Wire Spacing	0.4cm
Time Sample (2048 time samples/spill)	400μs

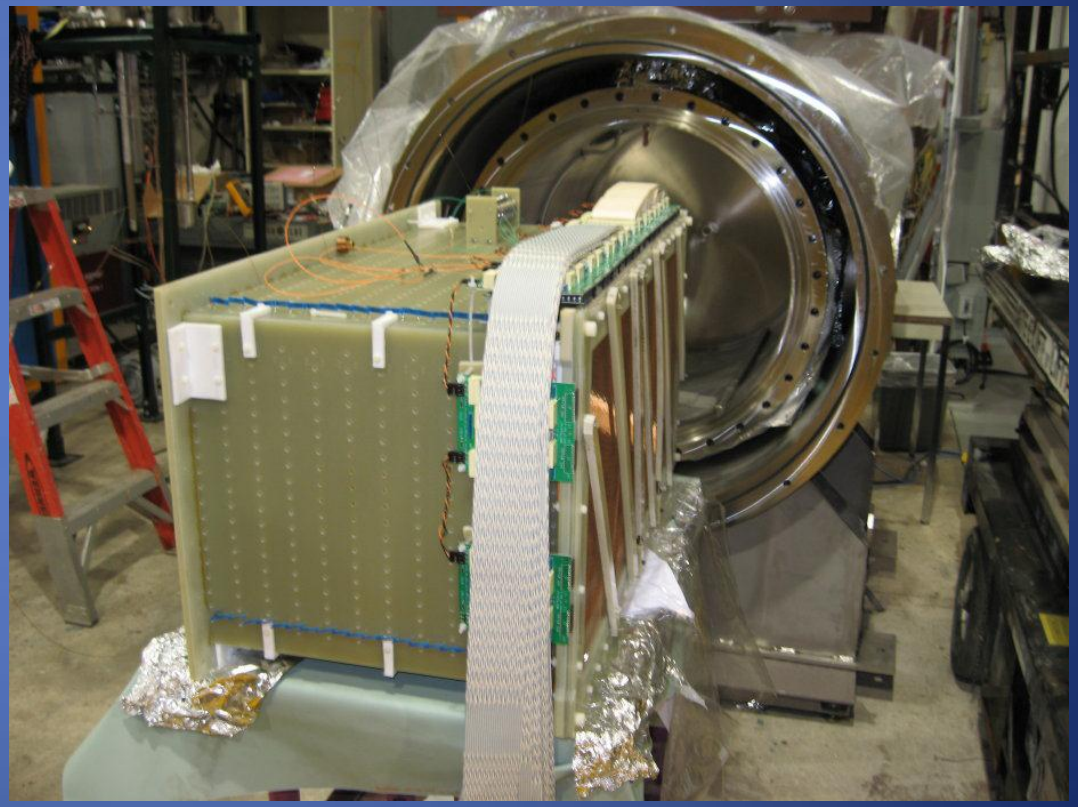




induction plane + collection plane + time = 3D image of event (w/ calorimetric info)

The TPC

ArgoNeuT Sitting at LabF in Fermilab



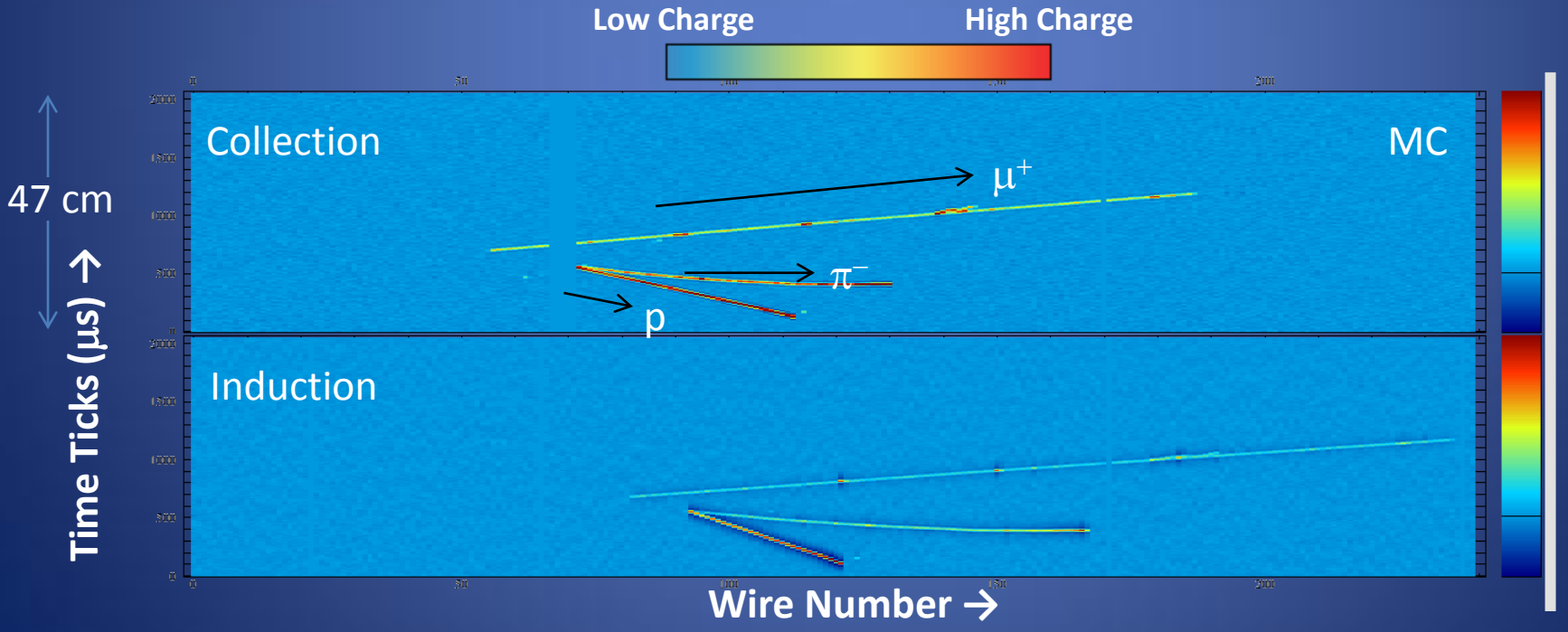
The TPC Ready to Enter Inner Cryostat

Event Generation and Display

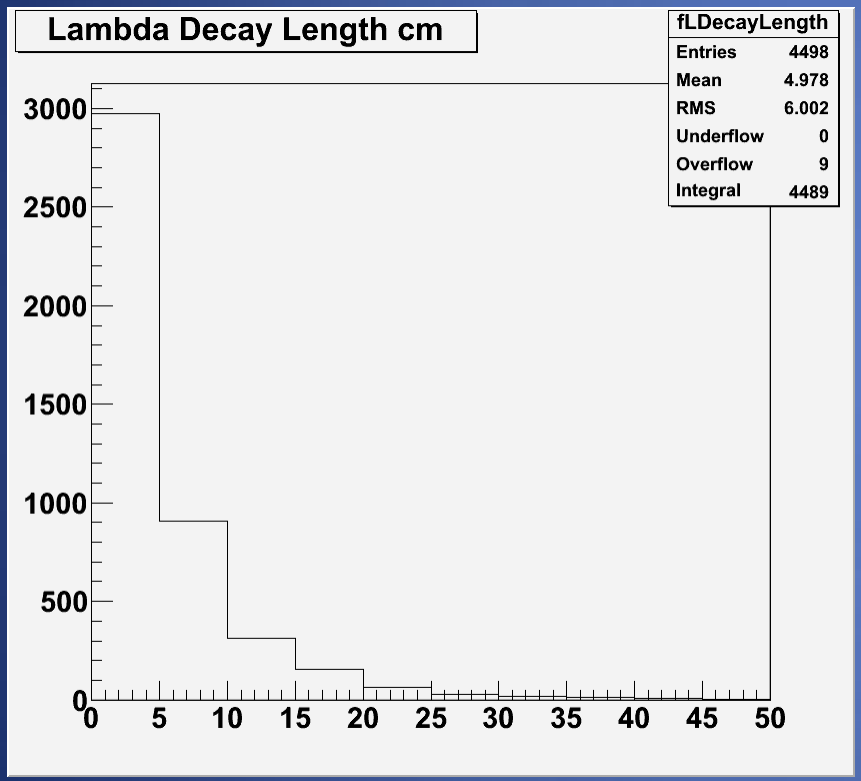
- **NUANCE Event Generator** and GEANT4 are used to Simulate the CCQE Hyperon Events in the Detector
- CCQE Λ^0 Event:

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + \Lambda^0$$

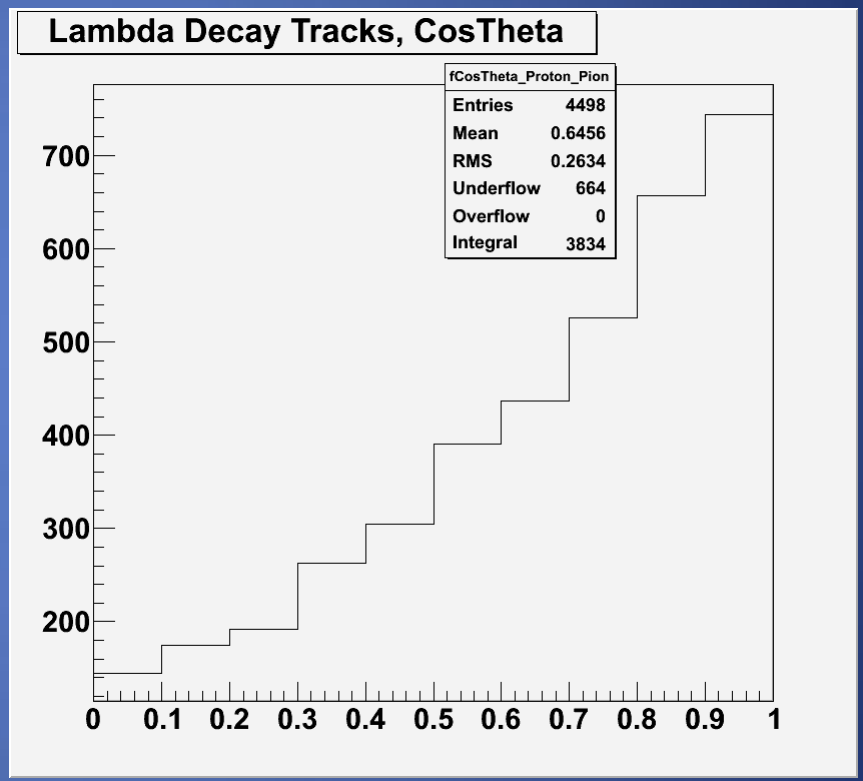
And then $\Lambda^0 \rightarrow \pi^- + p$



Event Generation Using NUANCE and GEANT4



Mean Decay Length of Λ^0 = 5cm



Mean Λ^0 'V Decay' Angle = 50^0

Detached Vertex and V Decay Topology can be Observed

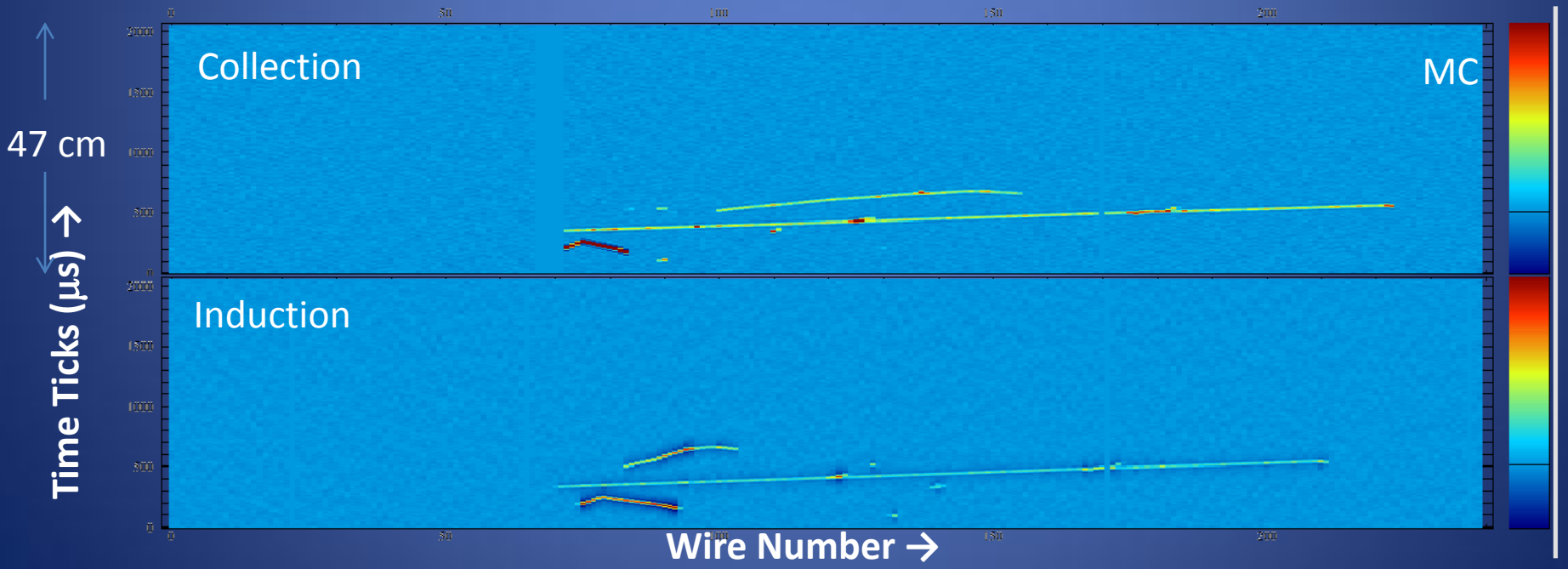
Event Generation and Display

- CCQE Σ^0 Event:

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + \Sigma^0$$

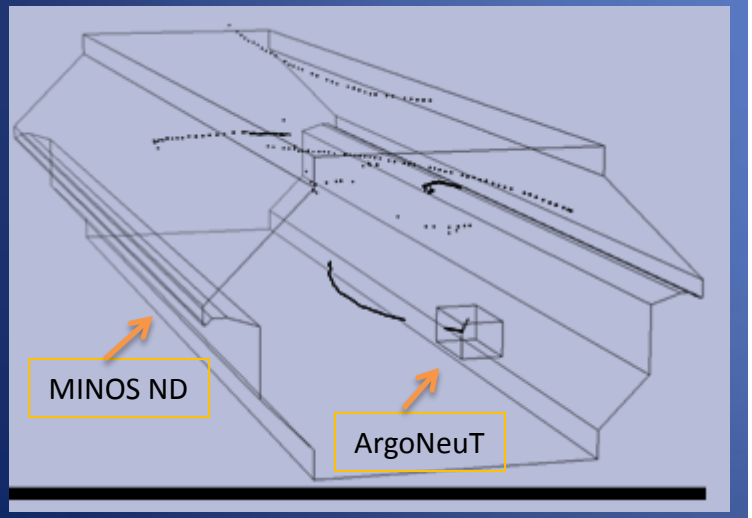
And then $\Sigma^0 \rightarrow \gamma + \Lambda^0$

And then $\Lambda^0 \rightarrow \pi^- + p$

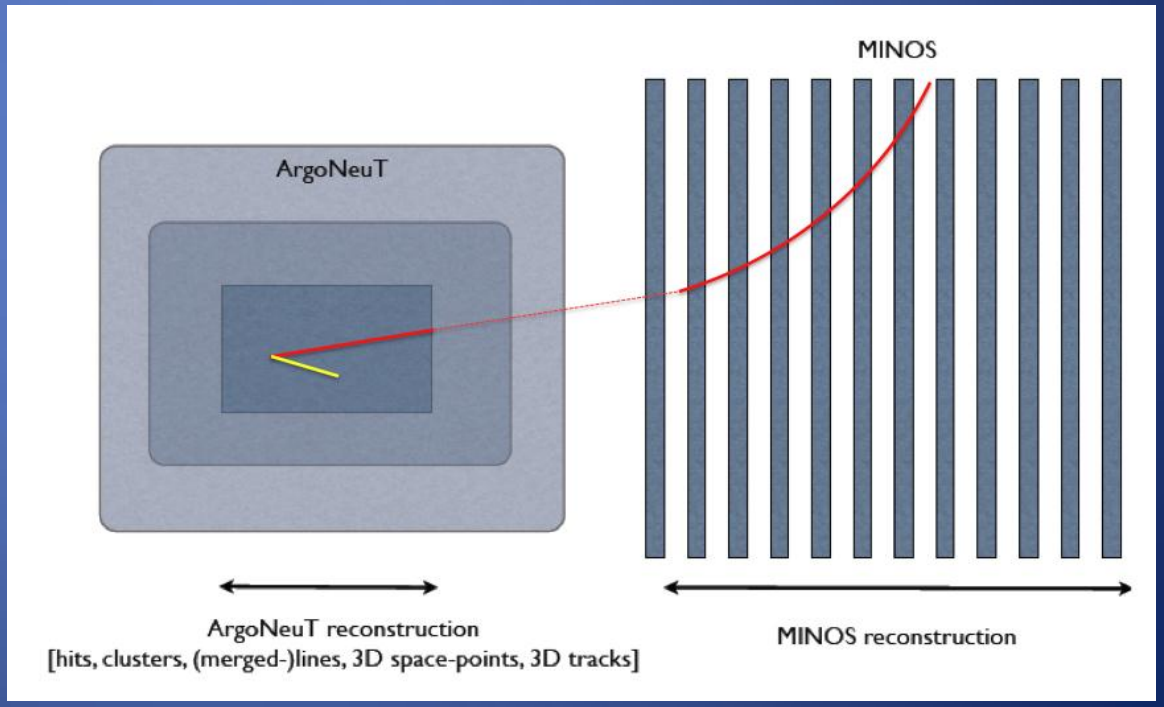


Event Reconstruction and MINOS Matching

- **Software:** LArSoft, which is detector agnostic (for all LArTPCs)
  - Separate modules - highly configurable
- **Reconstruction:** Hits -> Clusters -> Tracks -> Vertex -> Shower. Calorimetry
- MINOS near detector allows energy and charge reconstruction of muons



ArgoNeuT Track Matched with MINOS Track

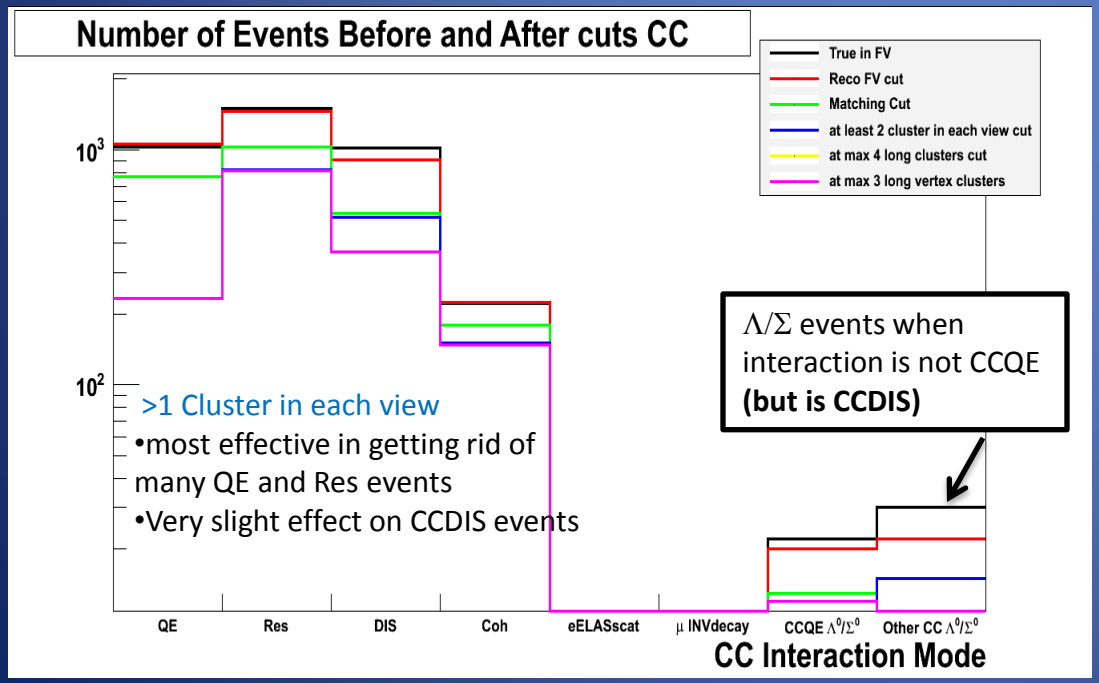


Preliminary Cuts – Work In Progress

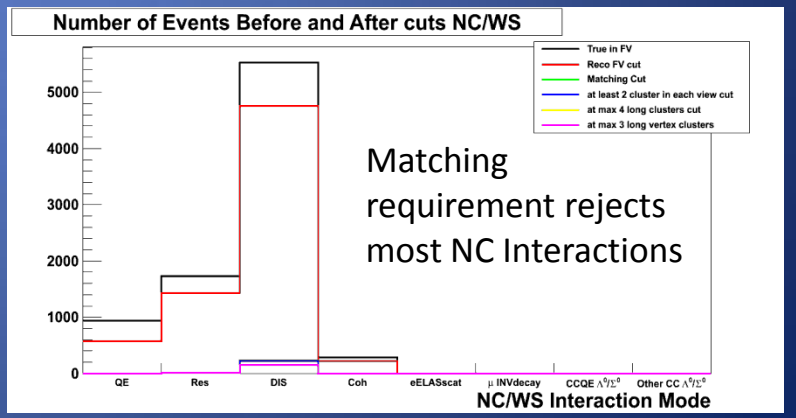
Cuts for data (picking up CCQE lambda/Sigma events)

- Primary Vertex Reco in FV
  (for last 2 bins: also true secondary vertex with ppi- in FV)
- Matched with MINOS with Correct Sign
- >1 Cluster in each View
- < 5 Long Clusters in an event (long cluster has > 25 hits)
- < 4 Long Vertex Cluster (Vertex clusters are when: wire_diff < 7 wires && time_diff < 70 ticks)

Primary cuts for data (picking up CCDIS, CCQE lambda/Sigma events)



Cut	Rejects
Matching with mu+	NC + CCRES + CCDIS
>1 Cluster in each plane view	CCQE + CCRES
At max 4 long clusters	CCDIS
At max 3 long vertex clusters	Some CCDIS

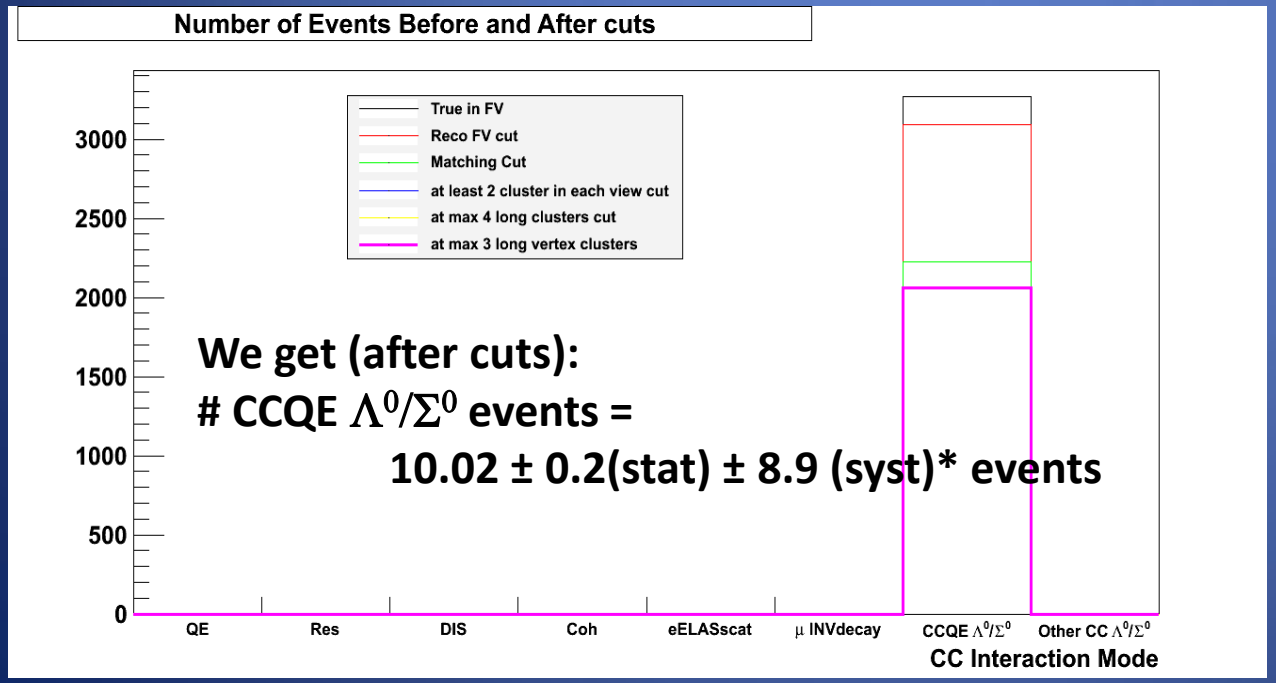


10K Nuance Λ^0/Σ^0 CCQE Events

CUTS (Efficiency)

- Decay to ppi- in FV (truth based), Primary Vertex Reconstructed in FV
- Matched with MINOS with Correct Sign (84%)
- >1 Cluster in each View
- < 5 Long Clusters in an event (long cluster has > 25 hits)
- < 4 Long Vertex Cluster (Vertex clusters are when: wire_diff < 7 wires && time_diff < 70 ticks)

- 61.6% decay to π^-+p
- Out of above 86% decay in FV



- Statistical Error come from error on Total efficiency

- Systematic error comes from the difference in two cross section models, Llewellyn Smith Model and NUANCE Model

- Uncertainty in flux, POT, number of targets etc is not considered; systematics from the two models is probably the highest among all other contributions to systematic uncertainty

*C.H.Llewellyn-Smith: Phys. Rep. C 3 (1972) 261, *D. Casper (UC, Irvine): Nucl. Phys. Proc. Suppl. 112 (2002) 161-170

Future

- ArgoNeuT detector will be re-used in a test beam to calibrate the response of LarTPCs to charged particles (muon, electron, proton and pion) Spring 2013.
- MicroBooNE (in construction at Fermilab, Batavia, IL)
- LBNE (Long Baseline ν Experiment)

MicroBooNE TPC Parts Cleaning at Lab F in Fermilab

MicroBooNE TPC Construction Status at Fermilab as of Last Week

Summary

- LArTPCs with excellent resolution allow us to study rare event types
- ArgoNeuT: LArTPC 1st time in the U.S., 1st time ever in a low-Energy beam
- CCQE hyperon event simulation is produced using NUANCE Event Generator in LArSoft, software and Analysis tools development is on its way
- ArgoNeuT will be re-used in calibrating the LArTPCs response to different particles
- ArgoNeuT's running gives experience with LArTPCs and will pave the way for future experiments, such as MicroBooNE and LBNE

ArgoNeuT Collaboration

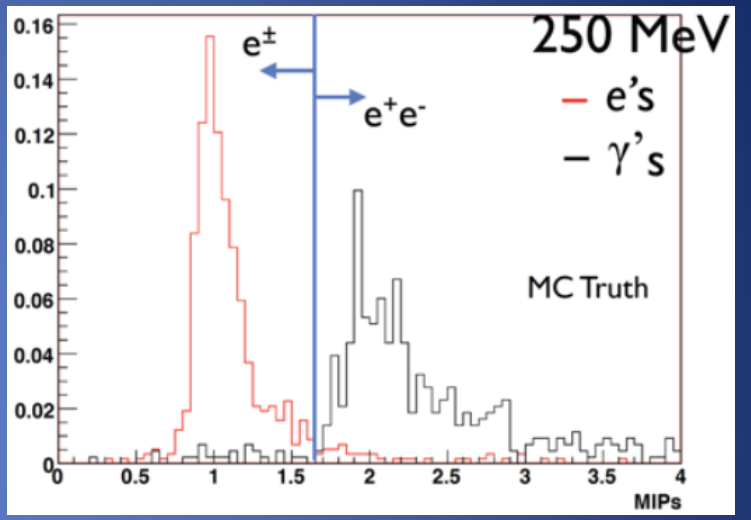
- F. Cavanna
  University of L'Aquila
- A. Ereditato, S. Haug, B. Rossi, M. Weber
  University of Bern
- B. Baller, H. Greenlee, C. James, S. Pordes, G. Rameika, B. Rebel, G. Zeller
  Fermi National Accelerator Laboratory
- M. Antonello, O. Palamara
  Gran Sasso National Laboratory
- T. Bolton, S. Farooq, G. Horton-Smith, D. McKee
  Kansas State University
- C. Bromberg, D. Edmunds, P. Laurens, B. Page
  Michigan State University
- M. Soderberg*
  Syracuse University
- K. Lang. R. Mehdiyev
  The University of Texas at Austin
- C. Anderson, E. Church, B. Fleming, R. Guenette, S. Linden, K. Partyka, A. Patch, J. Spitz, A. Szelc
  Yale University
- *spokesperson

Thank You!

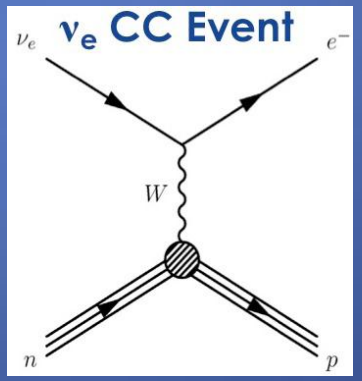
Back Up Slides

ArgoNeut Physics Goals

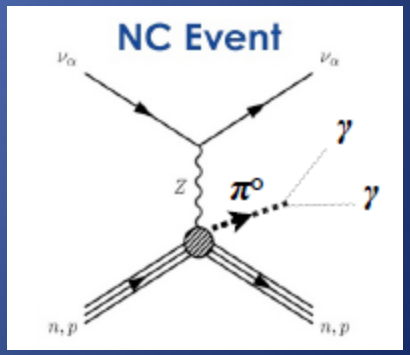
- **Low Energy Cross-Sections** Measurements in Liquid Argon
- **Axial Mass** Measurement
- Liquid argon could also help measure **the Strange Content of Nucleons**
- **Increased Accuracy**: The measurement of a gamma's dE/dx is approximately twice that of an electron (~4.2 MeV/cm: ~2.1 MeV/cm).
- Demonstrating the Effectiveness of the Liquid Argon **Purification Techniques** for bigger and better detectors (MicroBooNE, LBNE)
- **Long Term Goals**: Continued measurements of neutrino oscillation parameters, testing for CP violation in the lepton sector, detecting dark matter directly, and searching for proton decay.



dE/dx for electron and gammas in first 2.4cm of the track



"appearance" signal



"appearance" background

Why Nobel Gas a Target for Neutrinos?

- **Abundant ionization electrons** and scintillation light can both be used for detection.
- **Ionization can be drifted** over long distances, provided with the purity of liquid.
- **Excellent dielectric properties**, accommodates 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).

						
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
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	

ArgoNeut's Working (2)

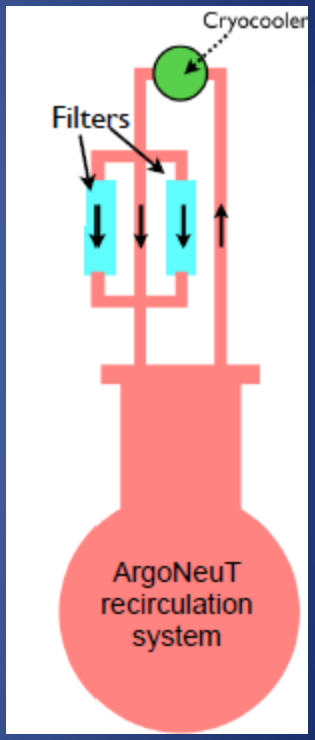
2. Purity System:

- Filter contains copper granules, which are oxidized by the incoming oxygen impurities to form copper (II) oxide. (Oxygen is highly electronegative, could absorb ionized particles produced by an event and impact the energy registered by the system)

- Once the copper is saturated with oxygen, the filter is heated to around 250° C to regenerate and remove the oxygen from the copper granules, allowing the pellets to process more argon.

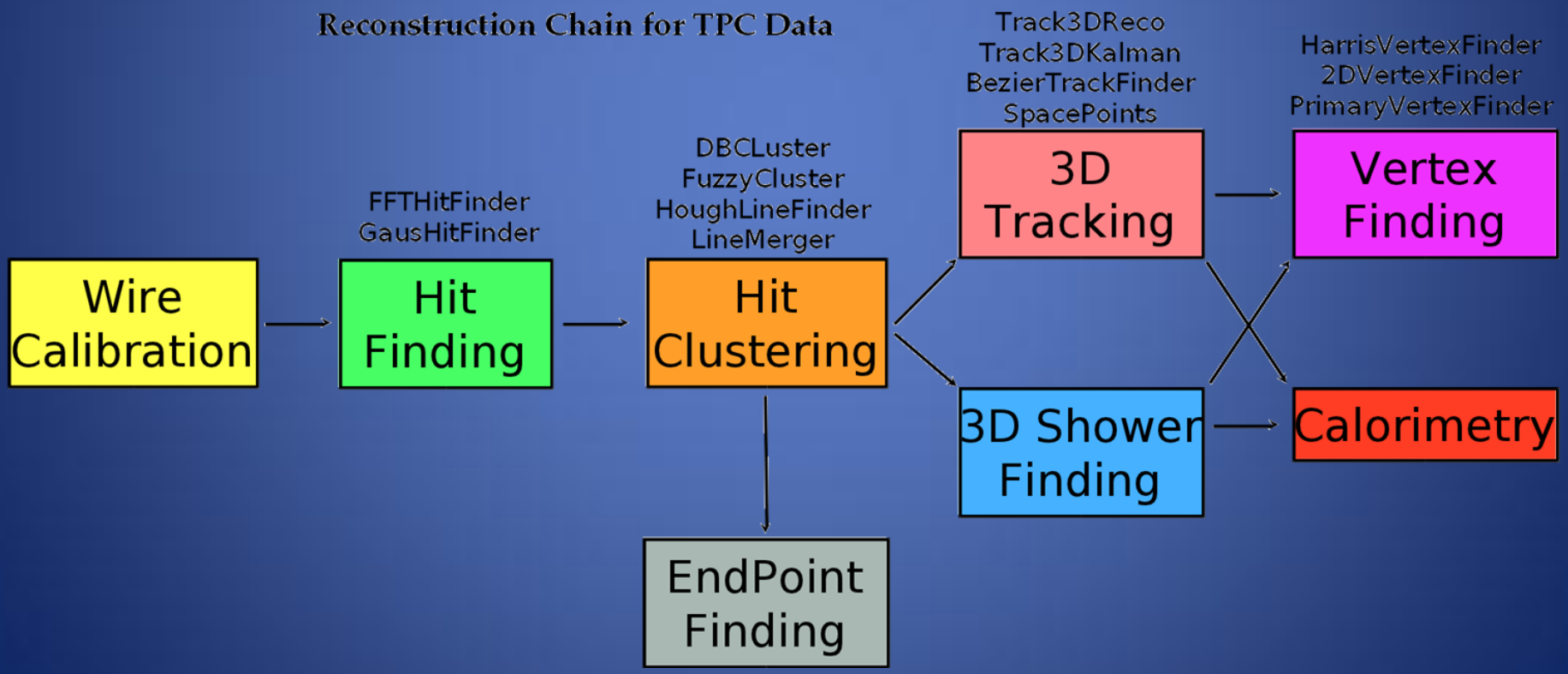
3. Recirculation System:

- Evaporated argon (B.P 87K) in the Cryostat travels up a system of pipes to a Cryocooler; a machine that extracts heat from an object to bring its temperature down to less than 150K. The newly liquefied argon flows back down another system of pipes to the TPC.



Event Reconstruction

- Software: LArSoft, which is detector agnostic (for all LArTPCs)
- Separate modules - highly configurable



Particle ID

- LArTPCs excellent granularity allows for excellent particle ID based on dE/dx vs Residual Range (distance from end of the track)