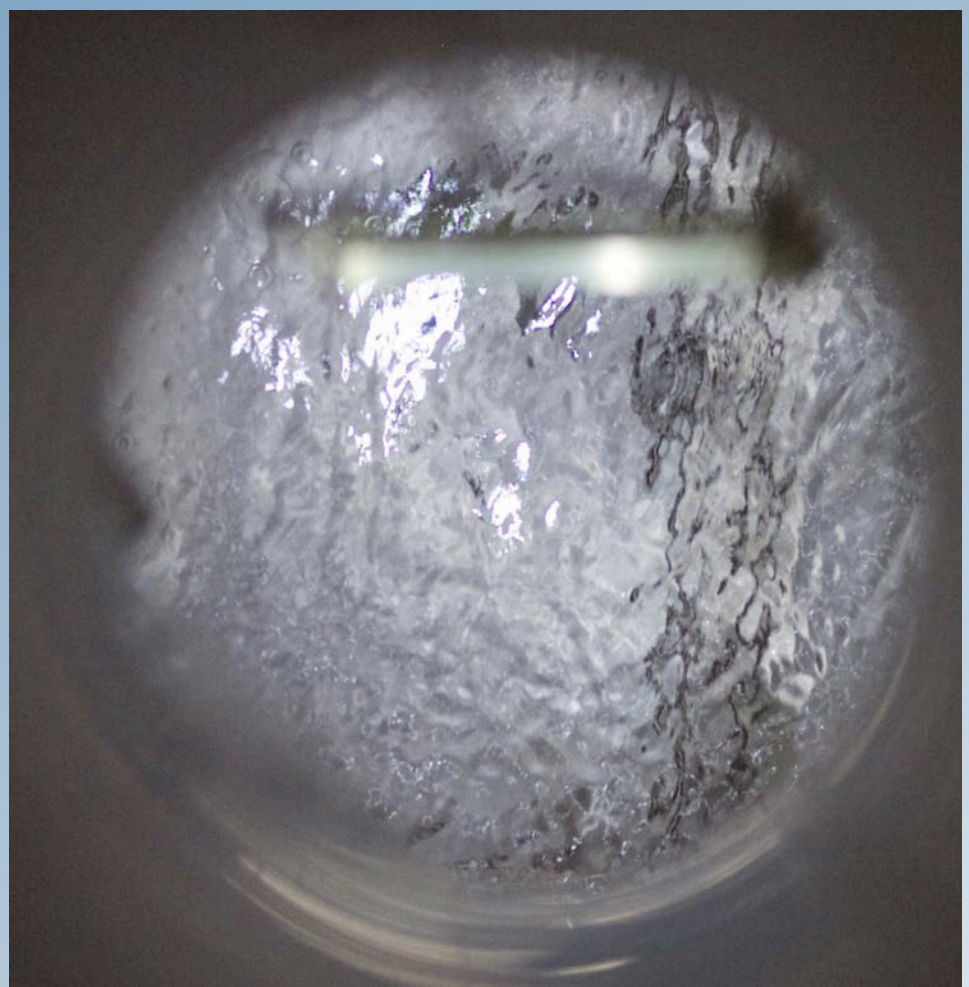
Liquid Argon Detector Simulation and Reconstruction

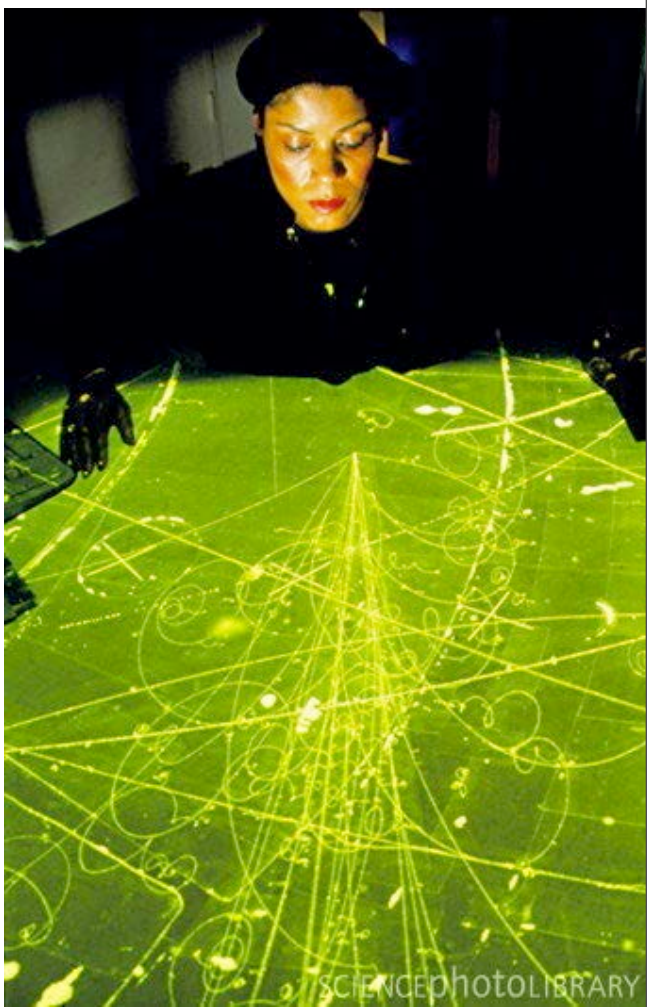


Brian Rebel

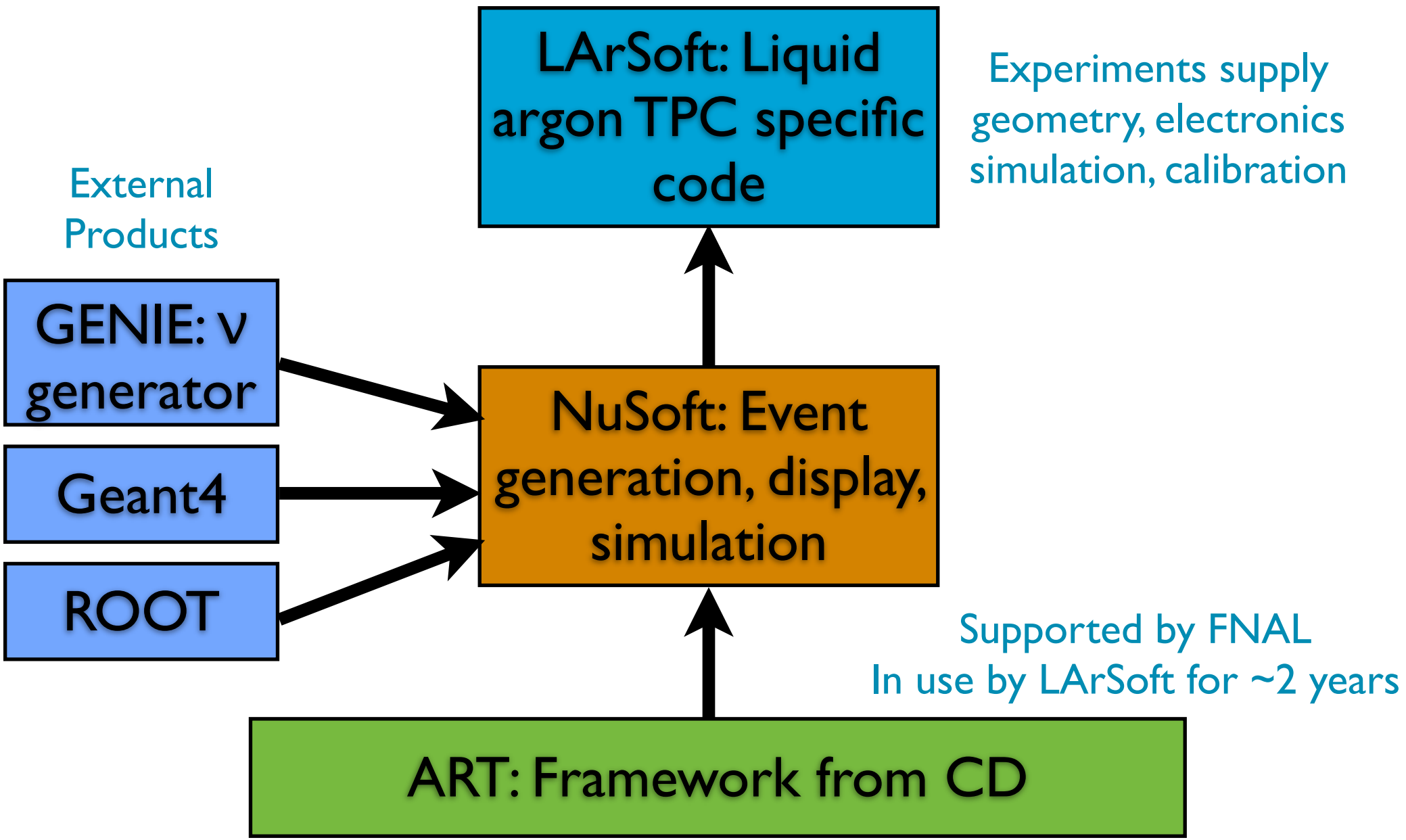
September 2012

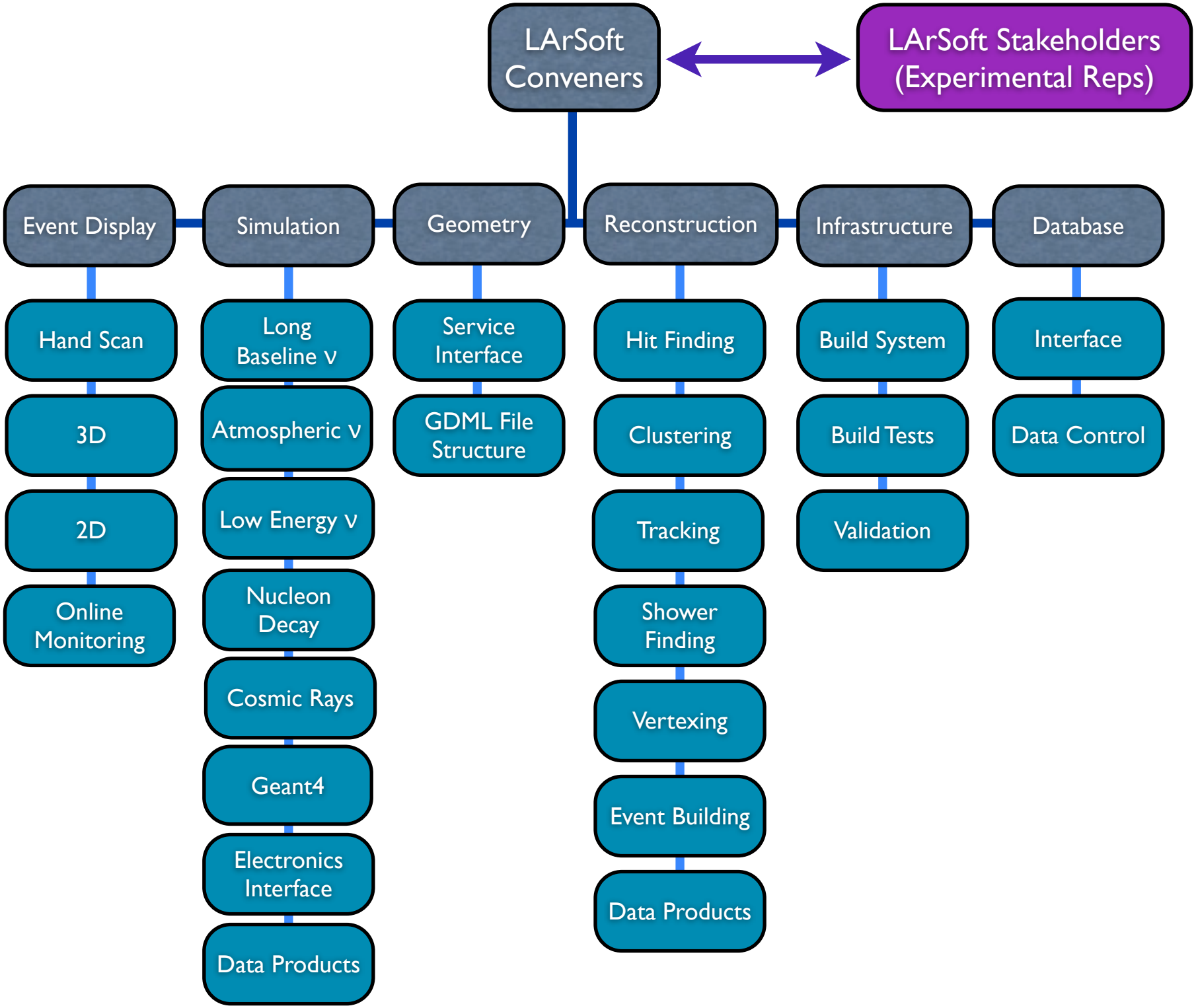
LArSoft Overview

- LArTPCs provide bubble chamber quality images in a digital format
- LArSoft is a simulation, reconstruction and analysis framework for any LArTPC
  - Started in 2008 with goal of fully automated reconstruction for any LArTPC
  - Automated reconstruction has been done by ICARUS and for T2K 2km proposal
  - Previous experiments have developed individual simulation and reconstruction software
- LArSoft takes this effort further by leveraging the efforts of a variety of experiments into a single product
- First time such an endeavor has been attempted



Organization of LArSoft



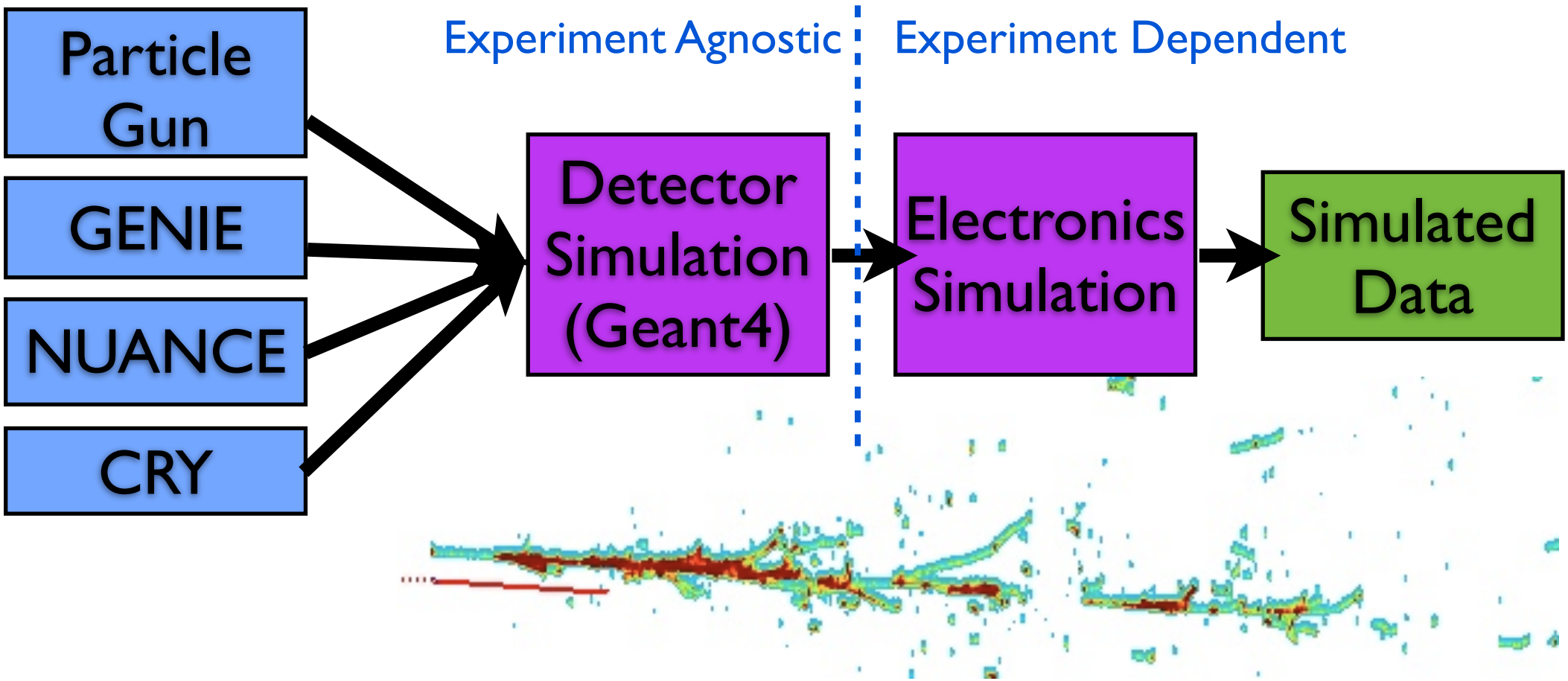

LArSoft Conveners
LArSoft Stakeholders (Experimental Reps)
Event Display
Simulation
Geometry
Reconstruction
Infrastructure
Database
Hand Scan
3D
2D
Online Monitoring
Long Baseline ν
Atmospheric ν
Low Energy ν
Nucleon Decay
Cosmic Rays
Geant4
Electronics Interface
Data Products
Service Interface
GDML File Structure
Hit Finding
Clustering
Tracking
Shower Finding
Vertexing
Event Building
Data Products
Build System
Build Tests
Validation
Interface
Data Control

LArSoft Participation

- LArSoft is designed to service any LArTPC
- 25+ contributors to LArSoft, many joined in past year
- Regular workshops and meetings provide forum to discuss ideas and advance the code
- ArgoNeuT contributors are leading the way as they have actual data
- MicroBooNE and LBNE benefiting from those efforts, also contributing code
- Contributors are enjoying the challenge of reconstructing neutrino interactions in liquid argon

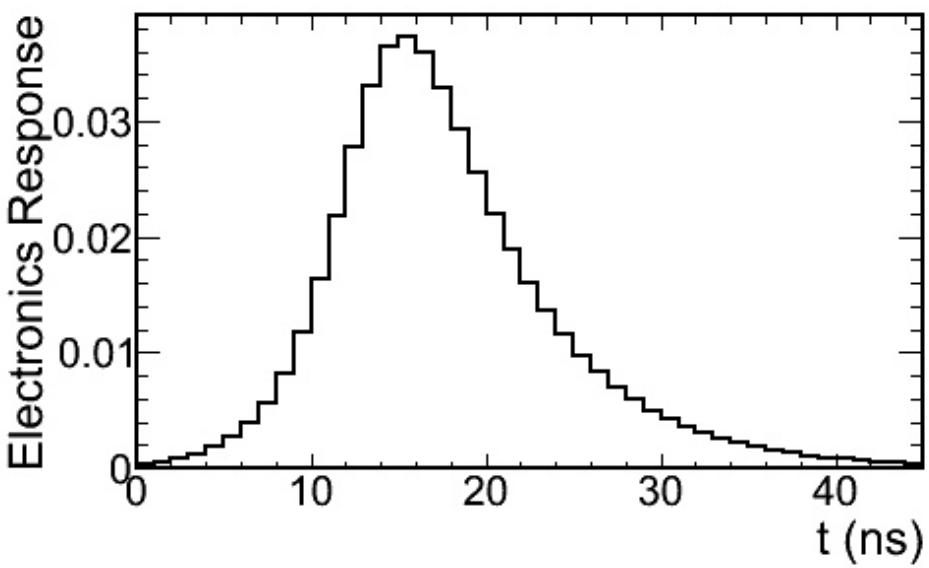
Simulation Chain

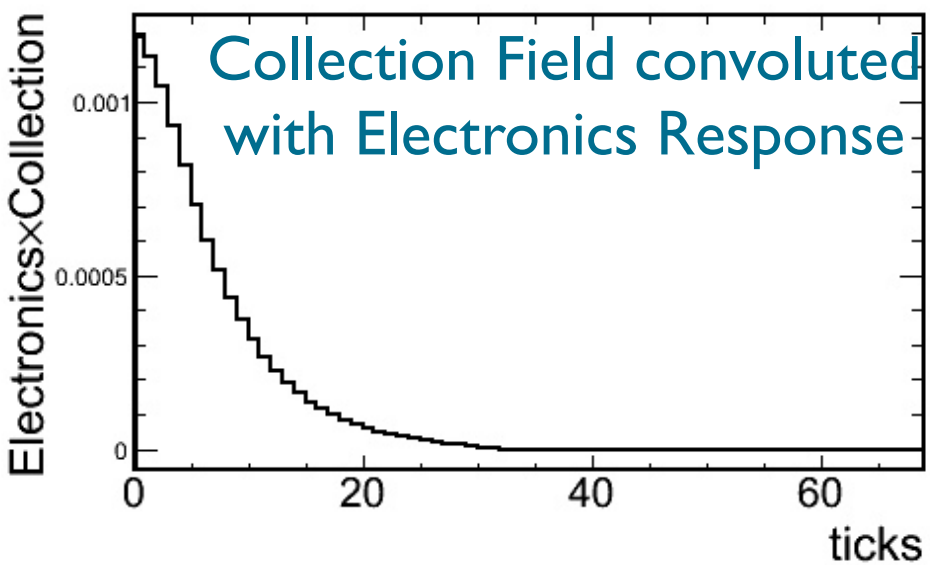
- The simulation has experiment agnostic and experiment dependent aspects
- All experiment agnostic simulation code has been in place and working for over 3 years
- Experiments have to provide a GDML file with the geometry description



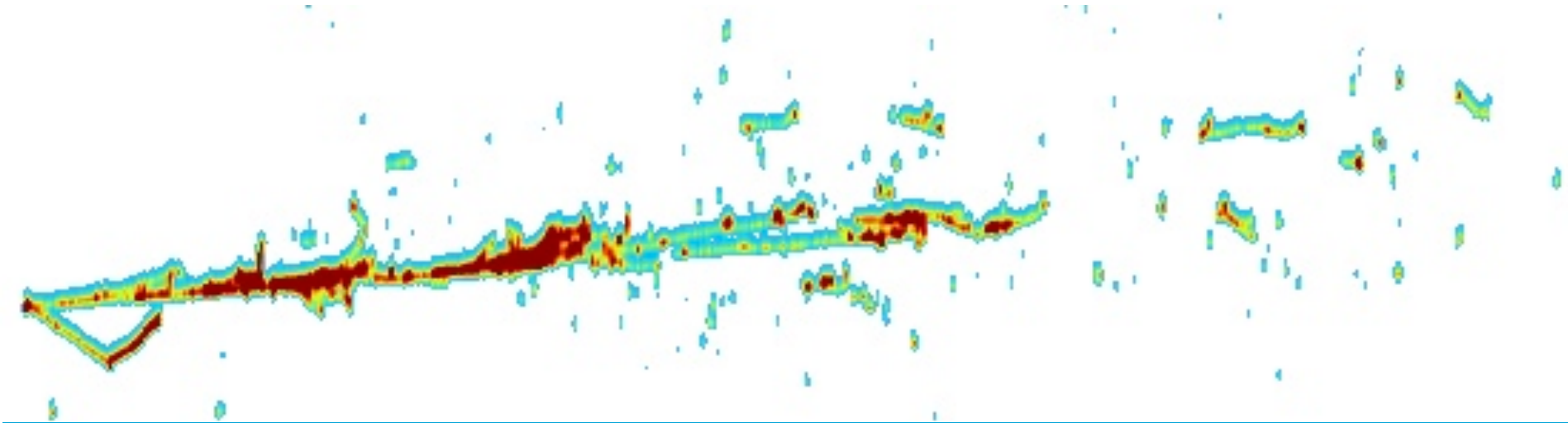
Electronics Simulation

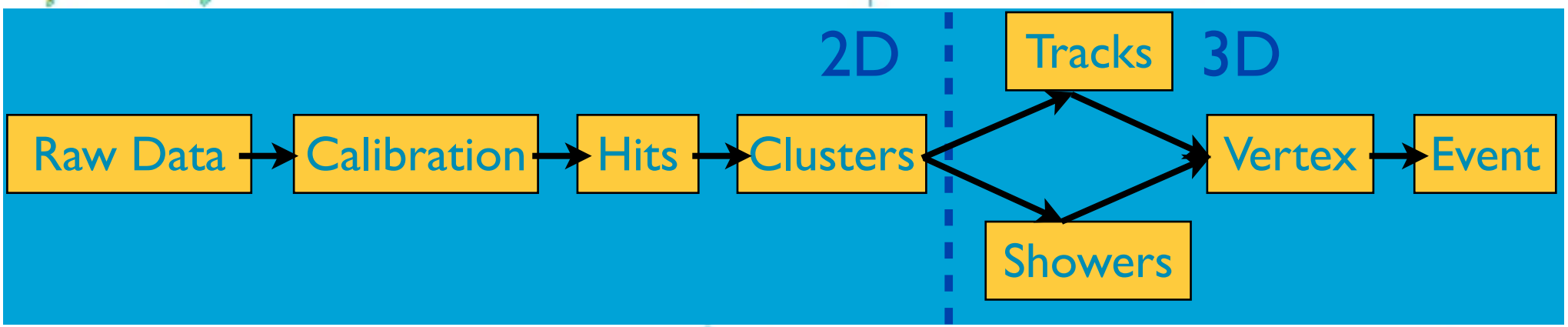
- Each experiment is responsible for its own electronics simulation module
- The simulation would still be written in LArSoft and would run in a job path as it is possible to plug and play with various modules
- Below are examples of electronics simulations for MicroBooNE
- The MicroBooNE code is in the repository and can be used as a placeholder



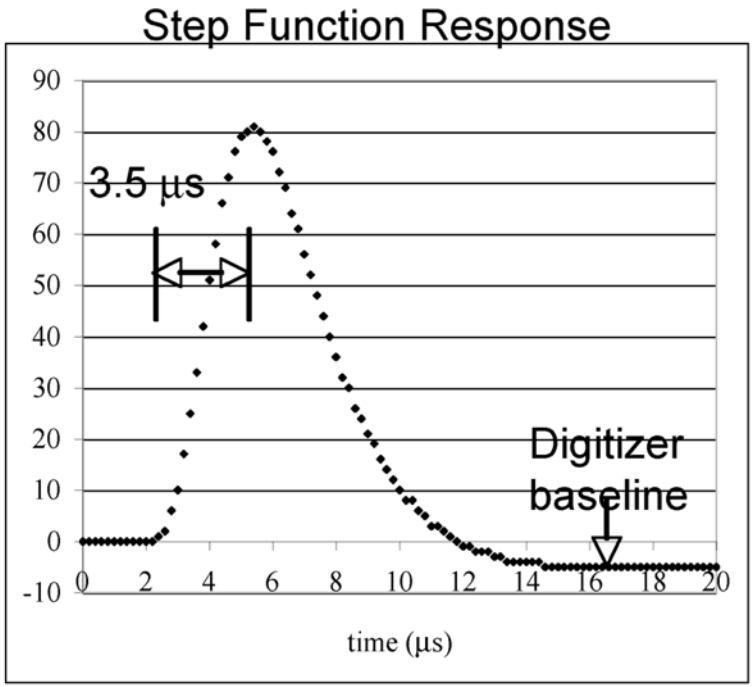


Reconstruction Chain

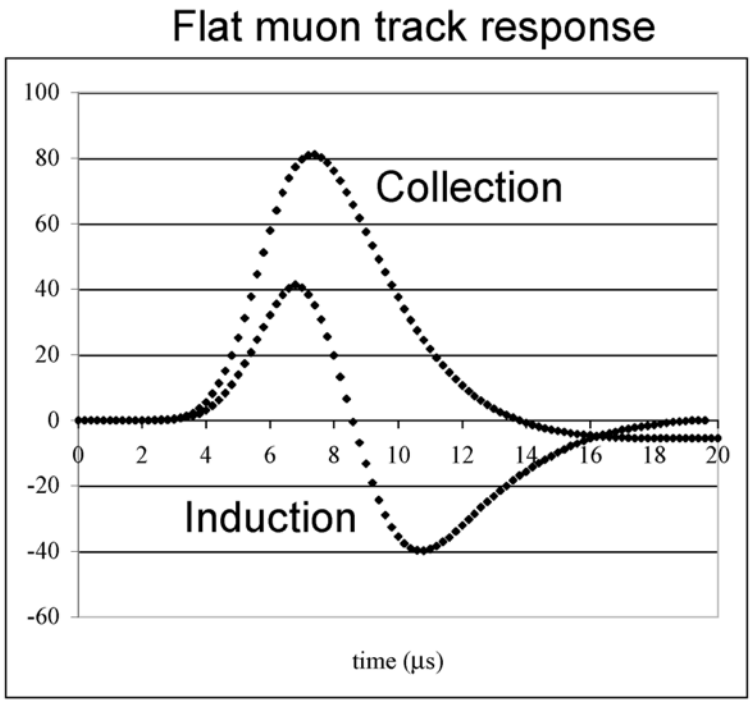




Calibration

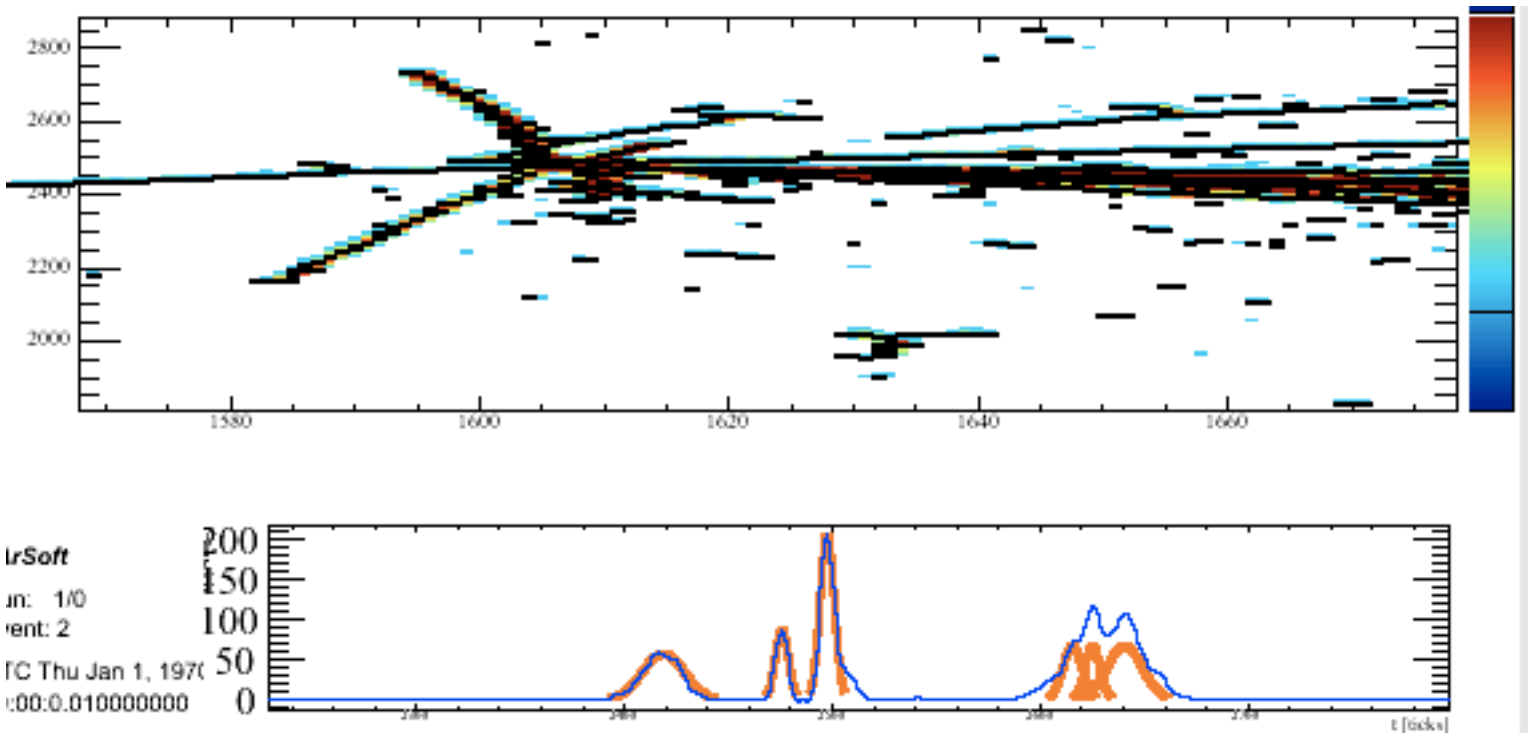


MSU



- First step is to take the raw data and perform any necessary calibrations
- Use a FFT to deconvolve electronics response from the signal
- Converts bipolar pulses to unipolar, also filters noise at both high and low frequencies
- Output has calibrated signal for each tick of the clock

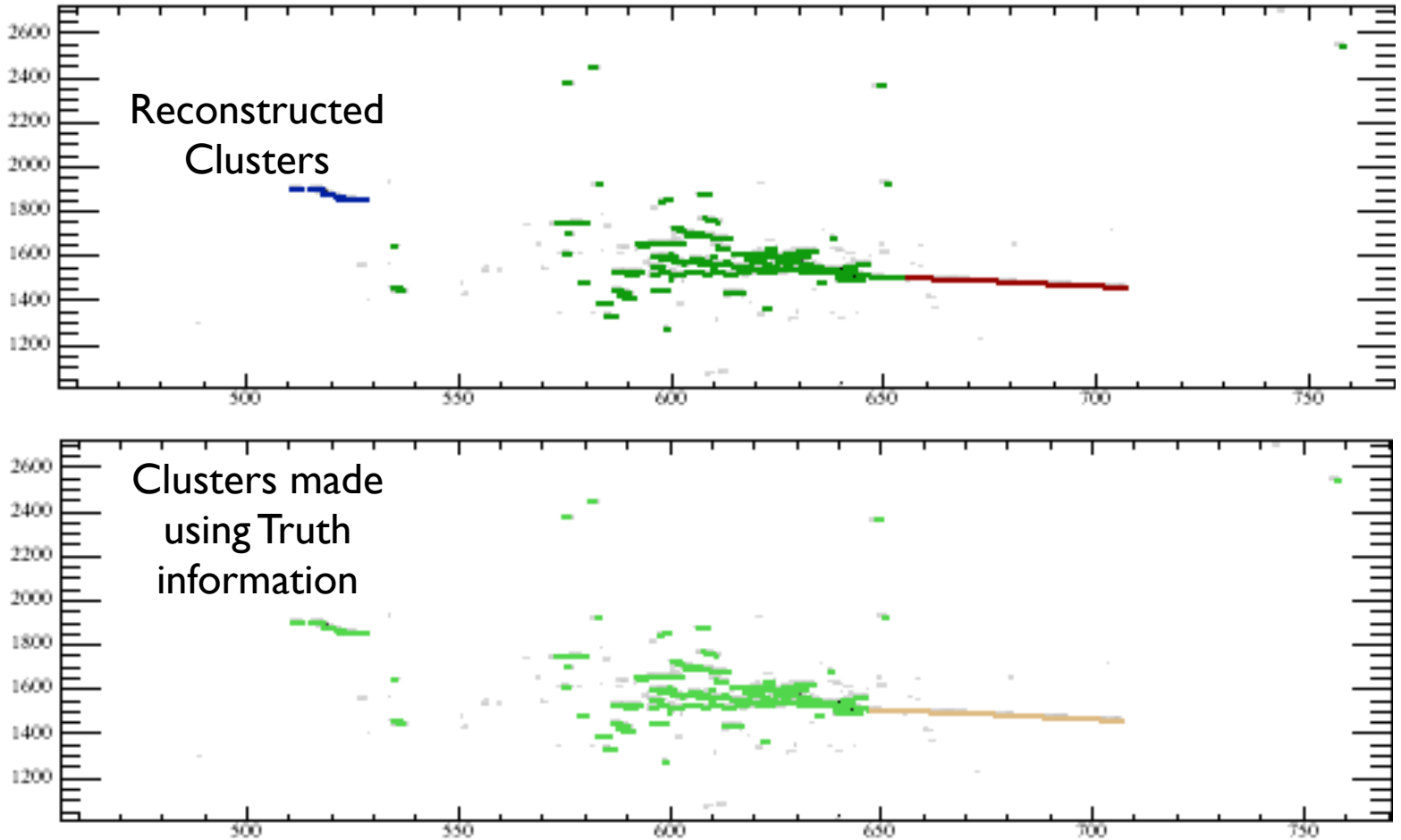
Hits



Syracuse

- Hits are signals on a wire that have gone above a determined ADC threshold
- Hits are found using a Gaussian fit
- Closely spaced hits are identified using multiple-Gaussian fit

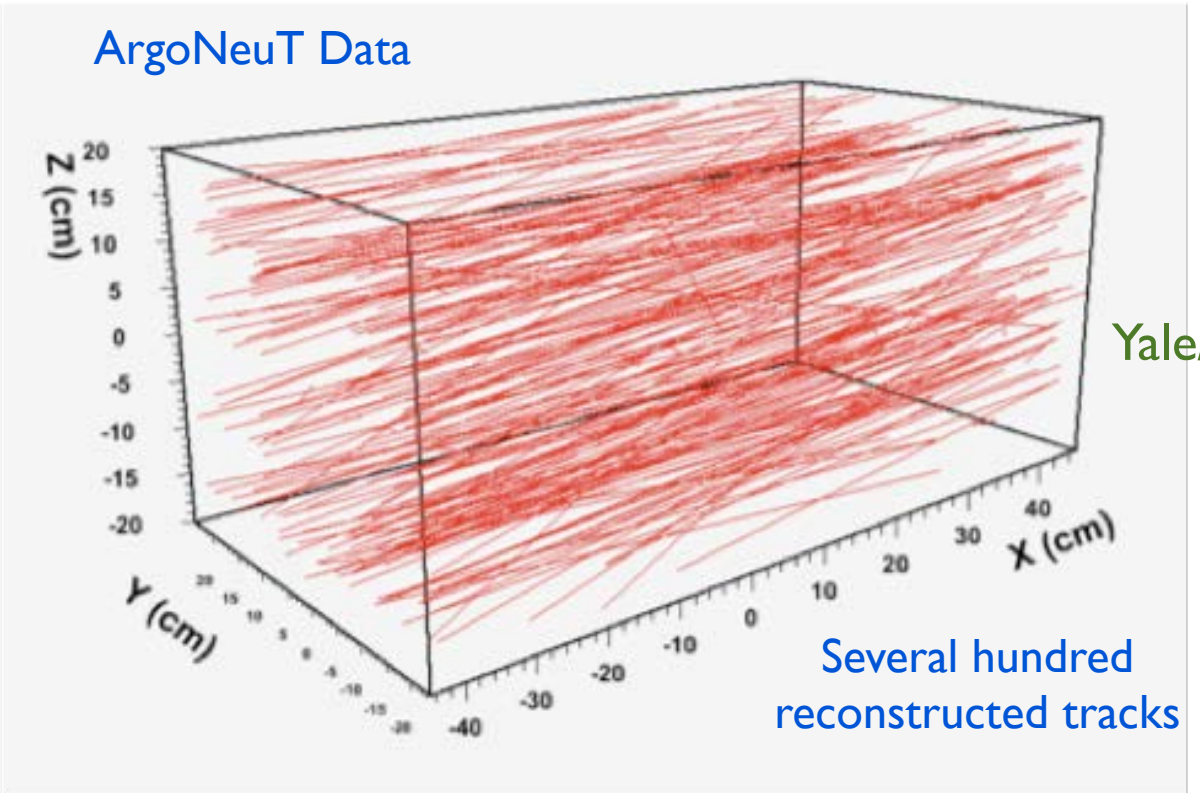
Clusters



Fermilab

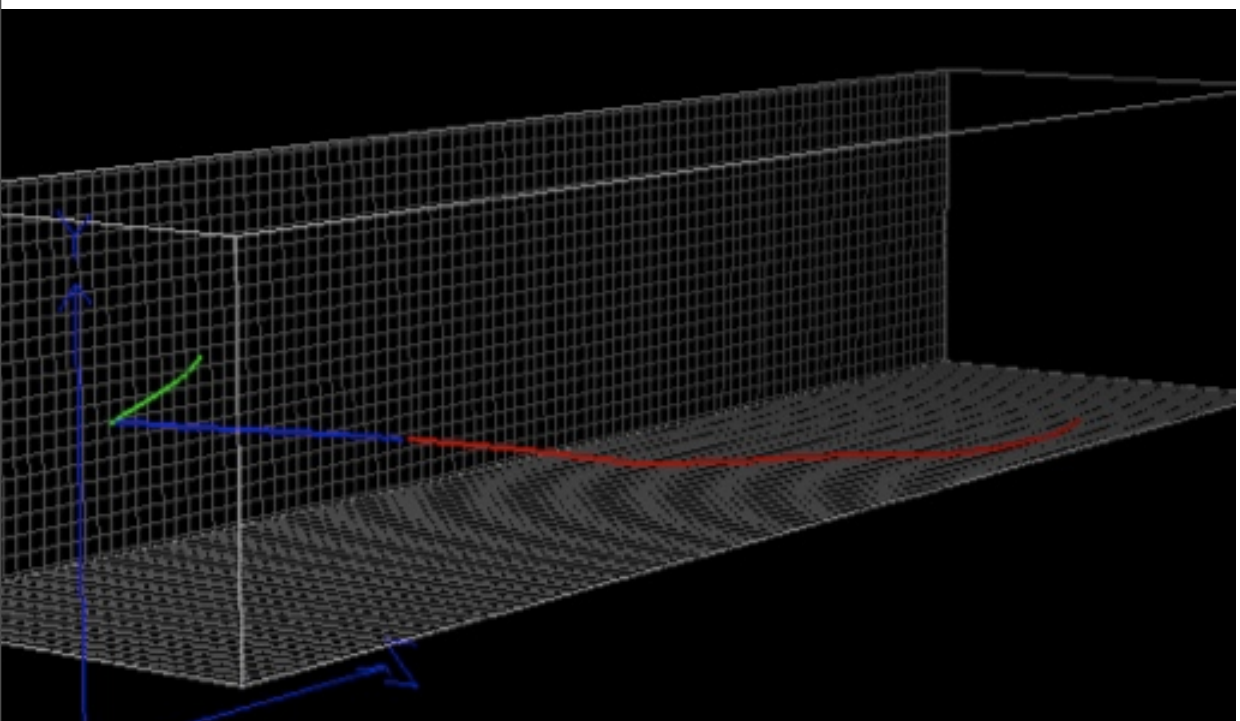
- Clusters are defined as groups of hits that are associated in time and space
- Several techniques available to identify clusters, the above example makes use of a combination of a fuzzy cluster algorithm and Hough transforms
- Some tuning yet to do, but initial results are promising

Tracks

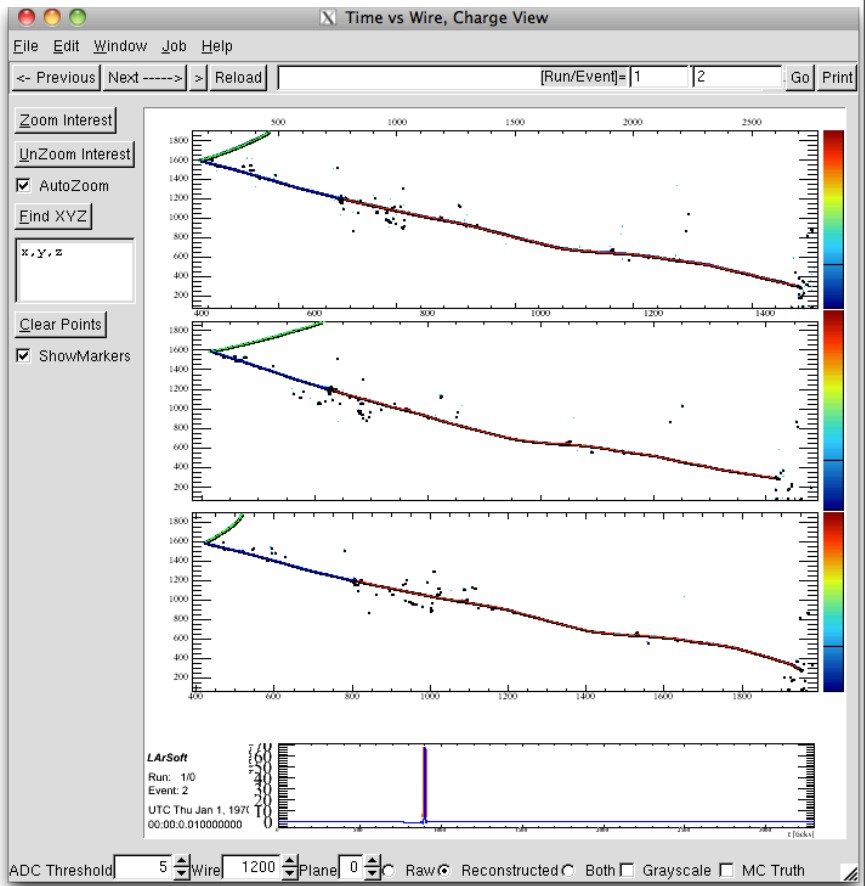


- Clusters from multiple views are merged into either tracks or showers
- Merging requires knowledge of the timing in each view
- Current tracking works well for straight lines, ongoing work to improve algorithms for larger detectors where multiple scattering is a big effect

Tracking from Hits



MIT



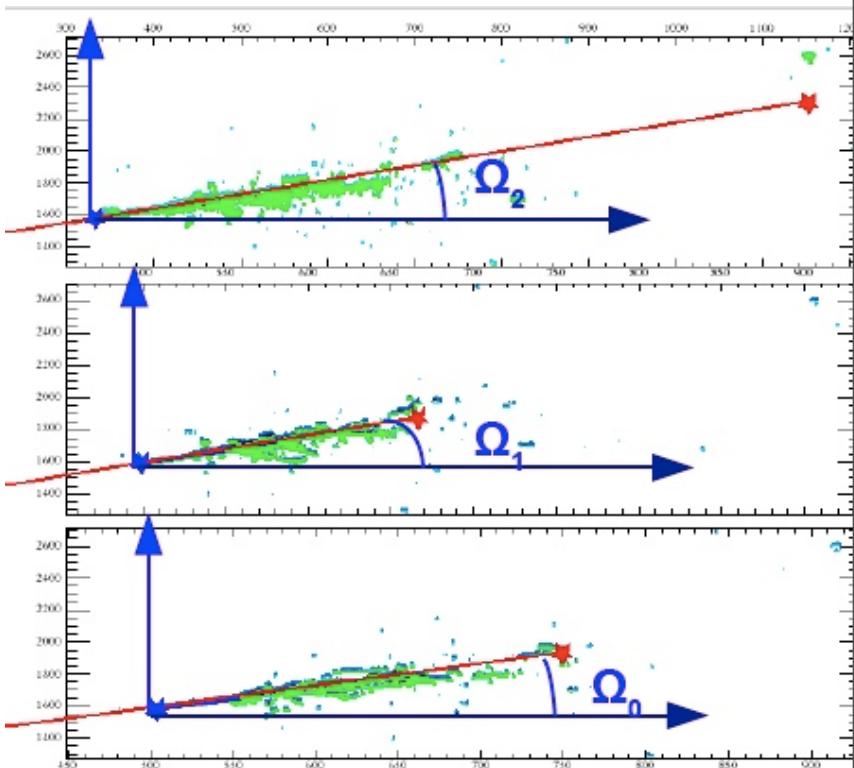
- Bezier method for finding tracks is promising new technique
- Find the possible 3D locations of all hits by using information from all views
- Create seeds based on close by space points that have similar directions
- Connect up the seeds with Bezier curve to create the tracks

Kalman Filtering

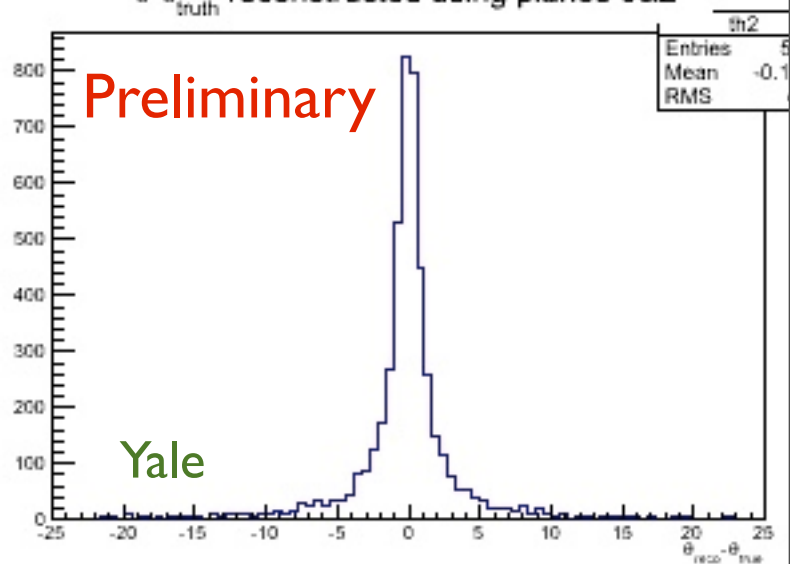
- Two options for Kalman filtering in LArSoft -
  - First is based on Genfit package, however Genfit does not appear to be supported any more
  - LArSoft specific filter under development
- LArSoft specific implementation has benefit of simplicity as it need only worry about one medium rather than having overhead for multiple
- Work is progressing nicely, could either do track finding and filtering/fitting in one step or take pre-produced tracks to do fitting
- Can use the Kalman filter to get an estimate of track momentum from multiple scattering

Shower Reconstruction

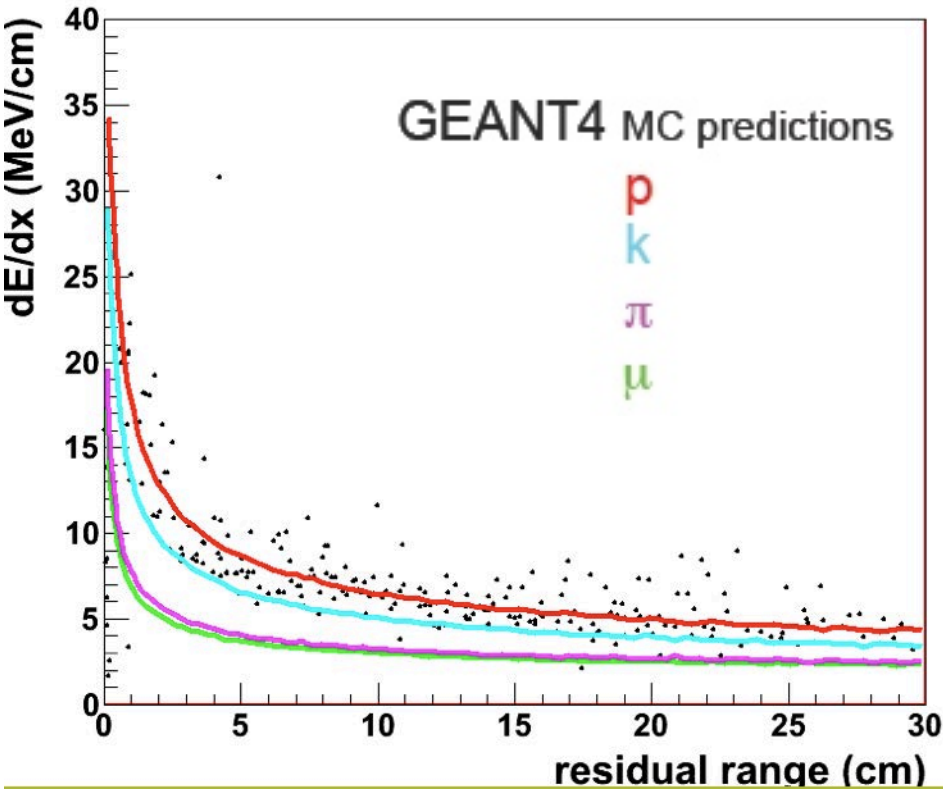
- Strategy is to get the 2D angles of the clusters and use those to reconstruct in 3D
- Then use 3D information to reconstruct the energy deposited, including Birk's law corrections
- First attempts at angle reconstruction are very encouraging, still work to be done
- Can then use the dE/dx information to separate electrons and photons, preliminary studies underway

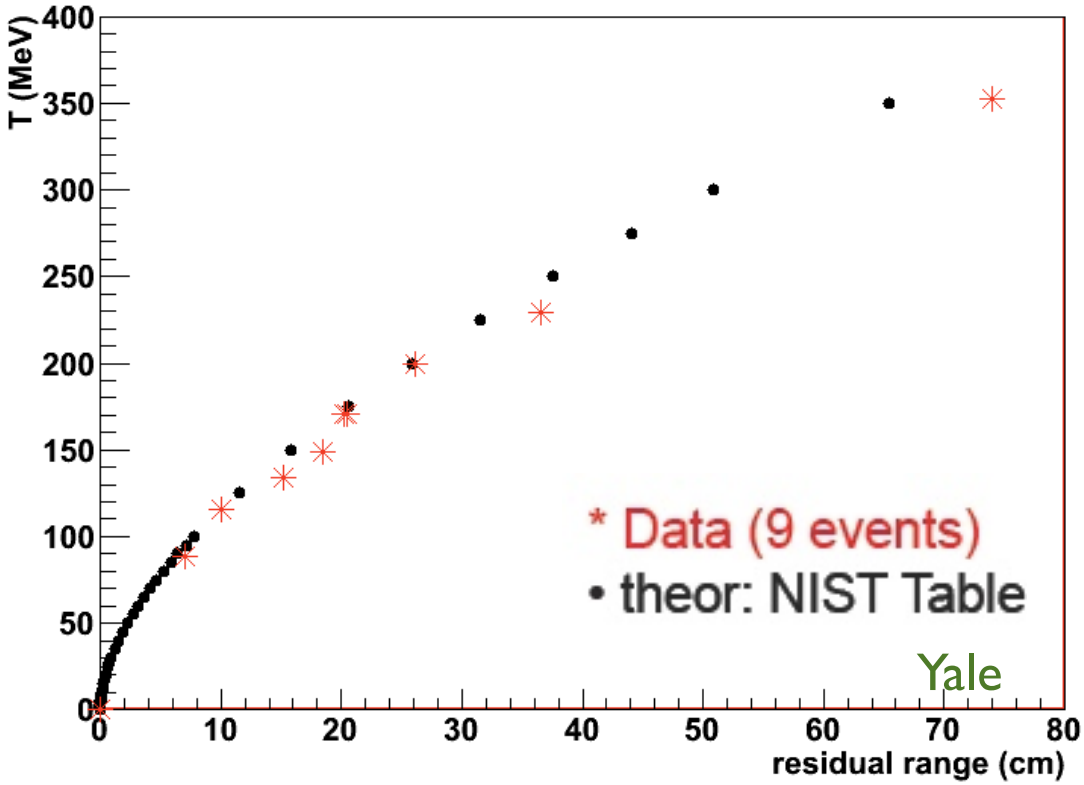


θ-θ_{truth} reconstructed using planes 0&2



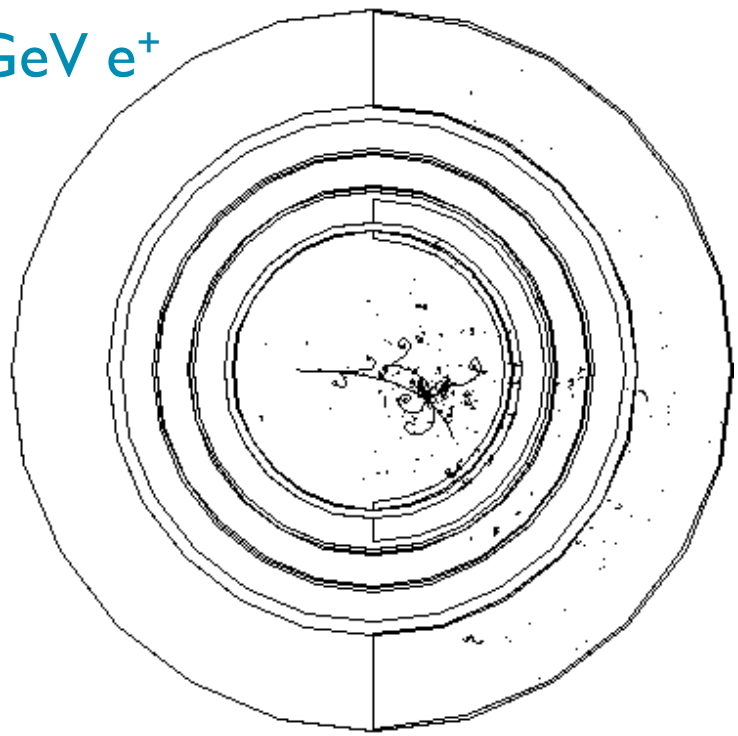
Calorimetric Reconstruction

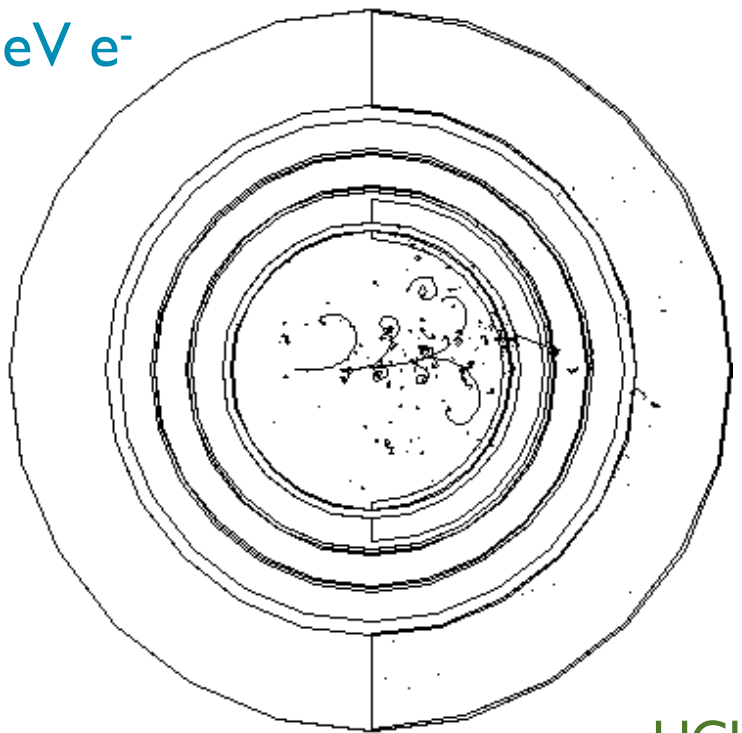




- Use ArgoNeuT data to measure dE/dx along the track and compared to Geant4 predictions
- See nice agreement between data and expectation for protons
- Data matches the prediction from the NIST tables as well

Magnetized Detectors





UCLA

- Some initial studies done by LBNE collaboration on magnetized detectors with an eye towards a magnetized near detector
- Above plots show positrons and electrons in a 6 T field from an MRI magnet
- On going work in LArSoft to provide ability to simulate and reconstruct magnetized detectors

Challenges for High-Intensity Beams

- The relatively long drift times in LArTPCs can cause pile up in high intensity beams
  - Near detectors will have multiple neutrino interactions and cosmic rays
  - Far detectors will mostly have cosmic rays and single neutrino interactions
- Light collection systems may help with separating multiple interactions in the same beam spill
- Shorter drift times could reduce cosmic ray contamination but increase electronics costs

Summary

- LArSoft is a general reconstruction and simulation package for liquid argon TPCs
- The simulation is quite advanced
  - Makes use of interfaces to standard external packages like GENIE, Geant4 and CRY
  - Individual experiments have to write their own electronics simulation code, that is then run as a module in LArSoft
- The reconstruction chain is becoming quite advanced
  - The 2D portion of the chain is becoming well established
  - Lots of recent progress in tracking and shower finding
  - Still need to tie it all together to produce fully reconstructed events
- High intensity beams will provide challenges to the reconstruction, but should be soluble