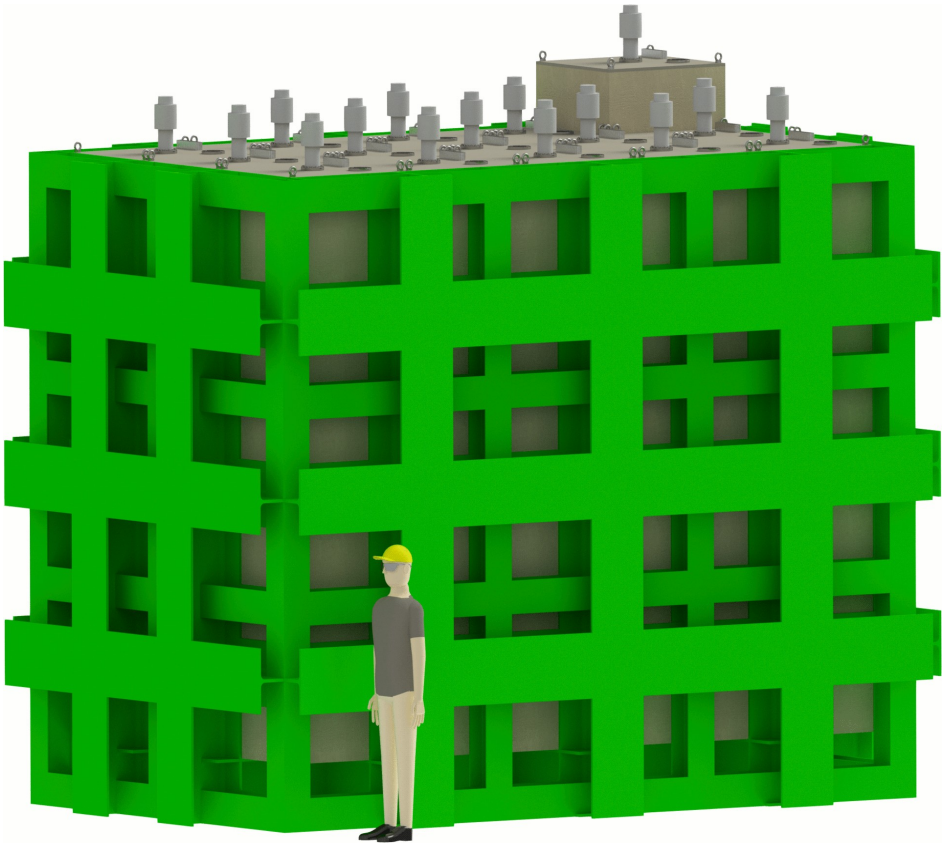
ArgonCube: Simulation Requirements

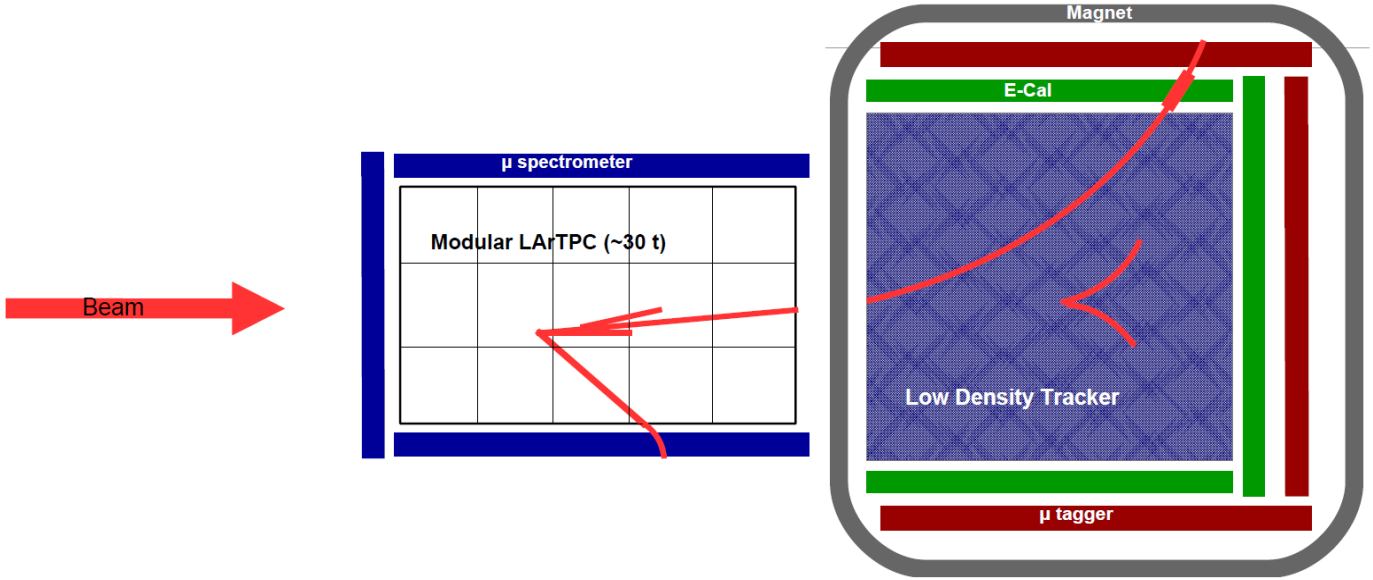


Jonathan Asaadi

ArgonCube Collaboration Meeting Oct. 2017

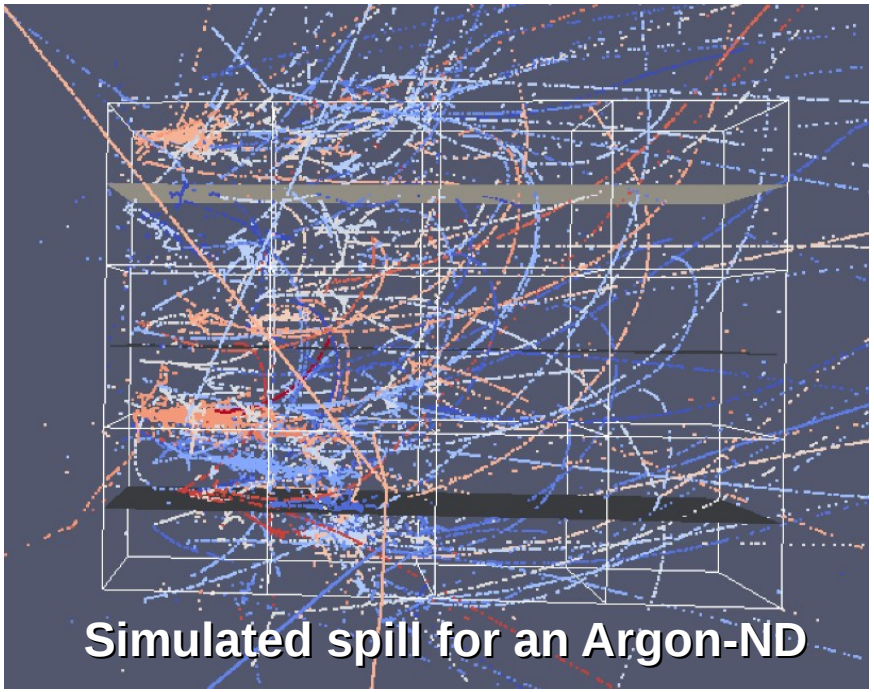
Current Vision

- **The current understanding of the DUNE-ND has ArgonCube detector sitting in front of some low density, magnetized, fine-grain tracker**
  - Provides the same nuclear target as the far detector
  - Works in tandem with the tracker to determine the sign of lepton
  - Both detectors complement each others capabilities and allows for a robust ND measurement of the beam
- **The ArgonCube ND is envisioned to be a pixel based LArTPC made of multiple independent TPC modules**
  - Need to include pixel based readout into simulations
  - Need a treatment of independent TPC modules and the material between them



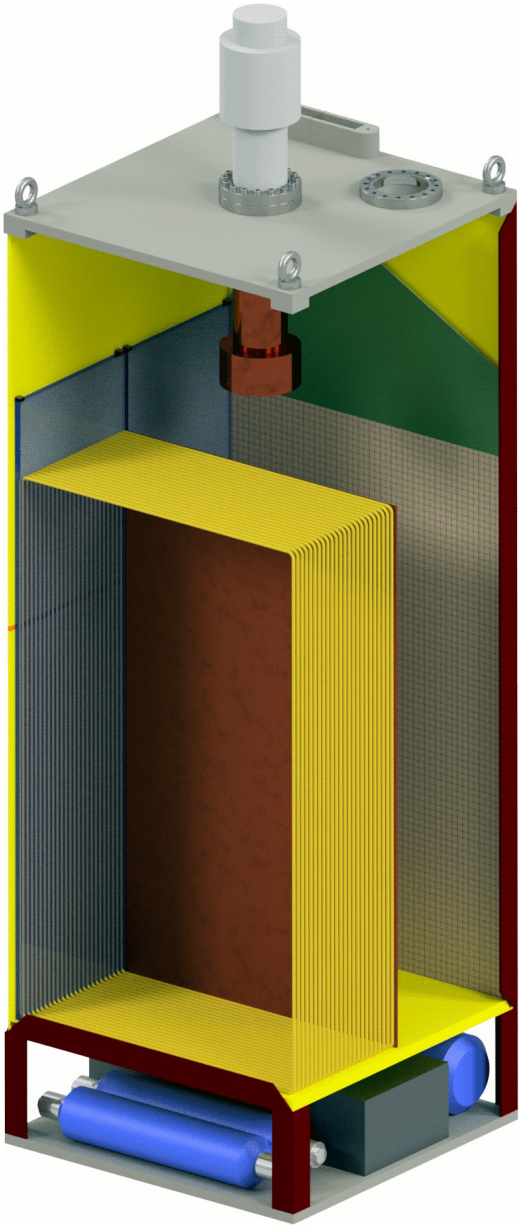
Work underway

- **Some aspects of the necessary simulation work for ArgonCube have already been done during the near detector task force**
  - E.g.: Simulation of the DUNE-ND flux
  - Inclusion of “dirt events” and “pile-up”
  - Visualization of activity inside the module
- **However, other aspects failed to come to fruition during this exercise**
  - Simulation of pixel based readout
  - Integrating information with other detectors
  - Study of detector responses
  - Any realistic reconstruction

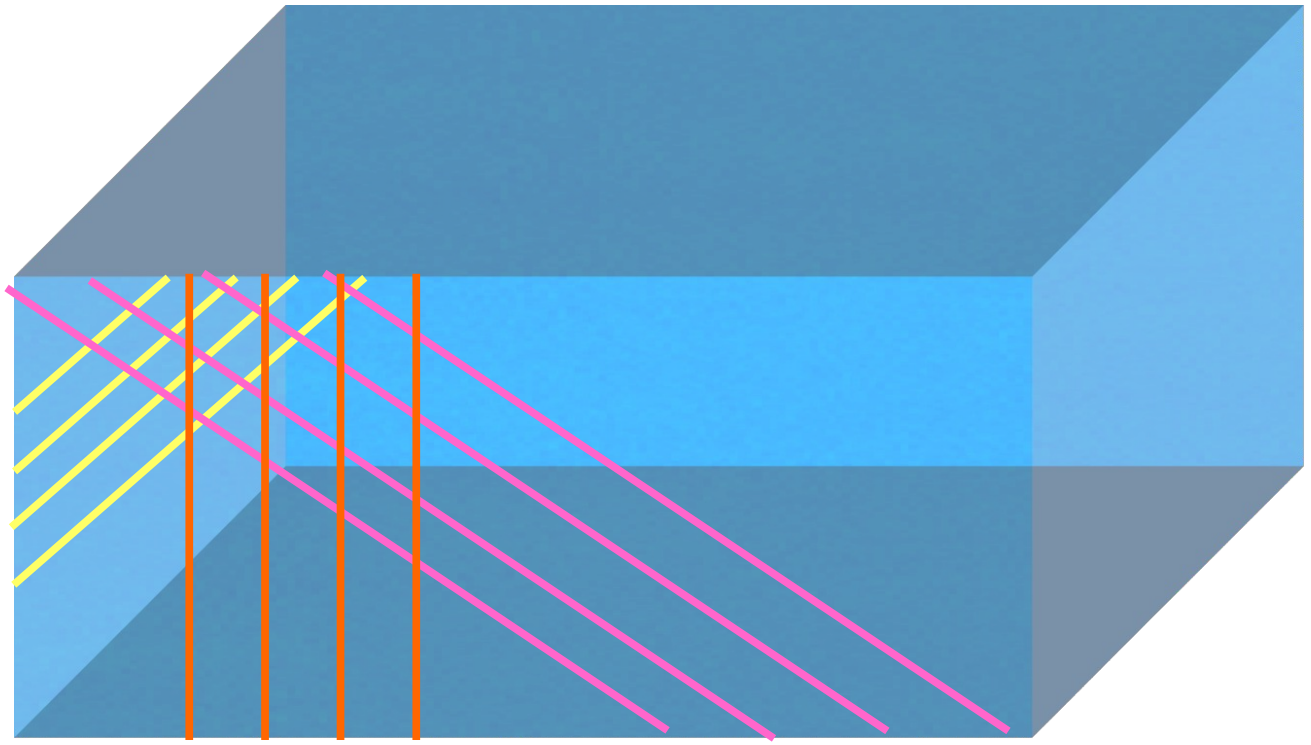

Simulated spill for an Argon-ND

Pixel Based LArTPC

- **The first challenge will be the incorporation is a pixel based TPC into the existing simulation framework (e.g. LArSoft)**
  - Good news: LArSoft people are actually aware and are thinking/working towards a framework
  - Bad news: The challenges are not small
    - Fitting this kind of readout into LArSoft will require rethinking many core parts of the framework
- **Once the readout side of the pixel based TPC simulation is done, then the inclusion of already existing 3d reconstruction tools have to be tackled next**

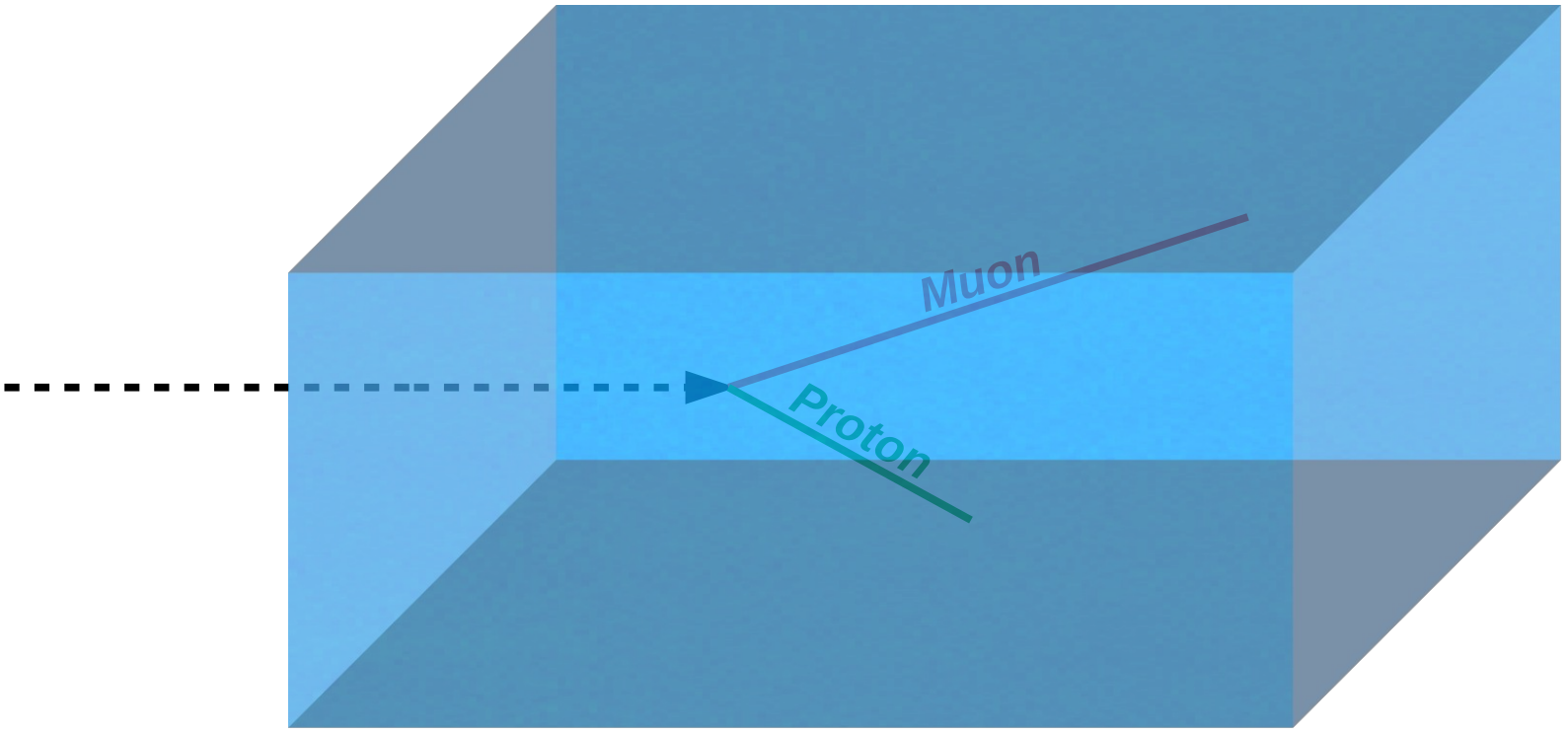


How the simulation works now



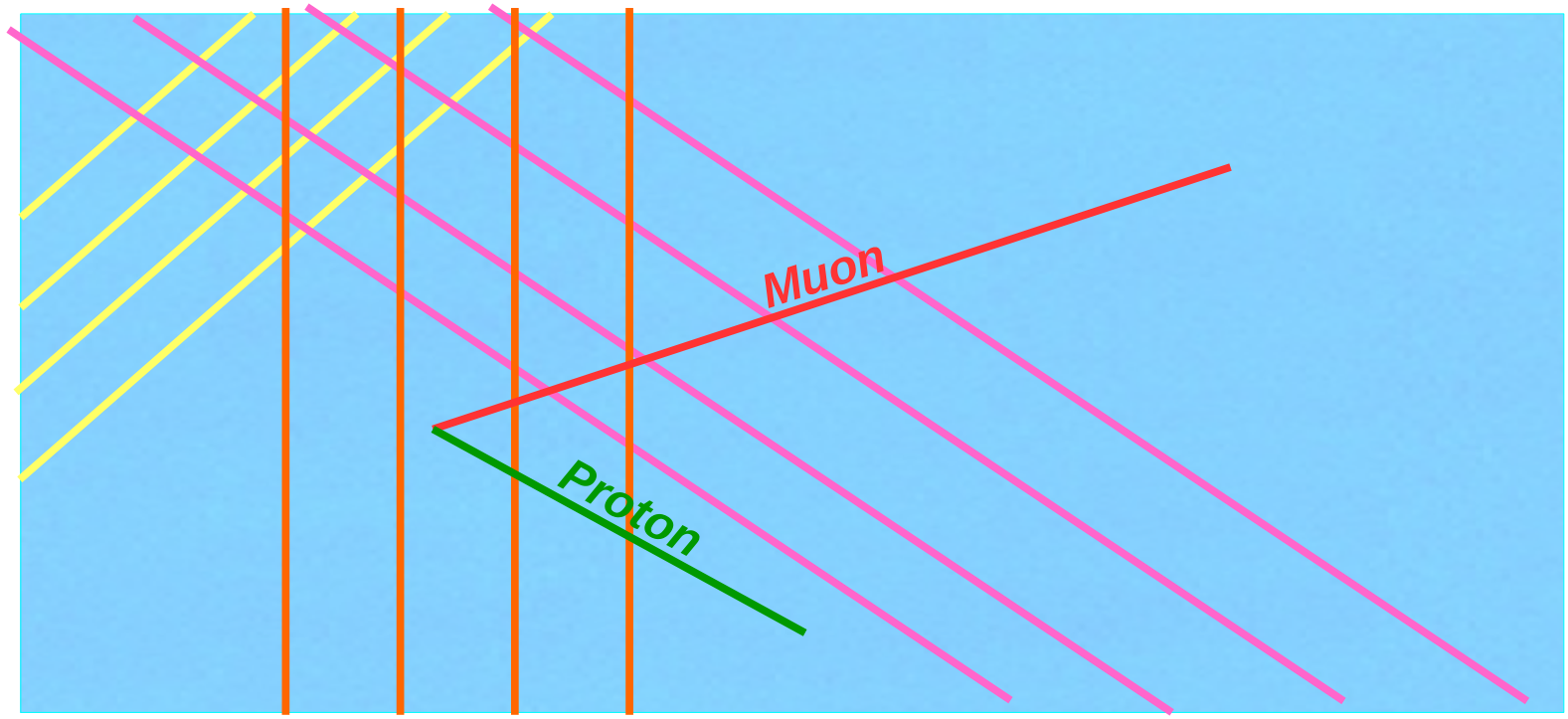
- **In your GDML file (geometry file) you define the start and end points of your wires in each of your planes (induction/collection)**
  - Something slightly more complicated for the wrapped wires found in the far detector
- **Each wire represents an sensitive element in your detector**

How the simulation works now



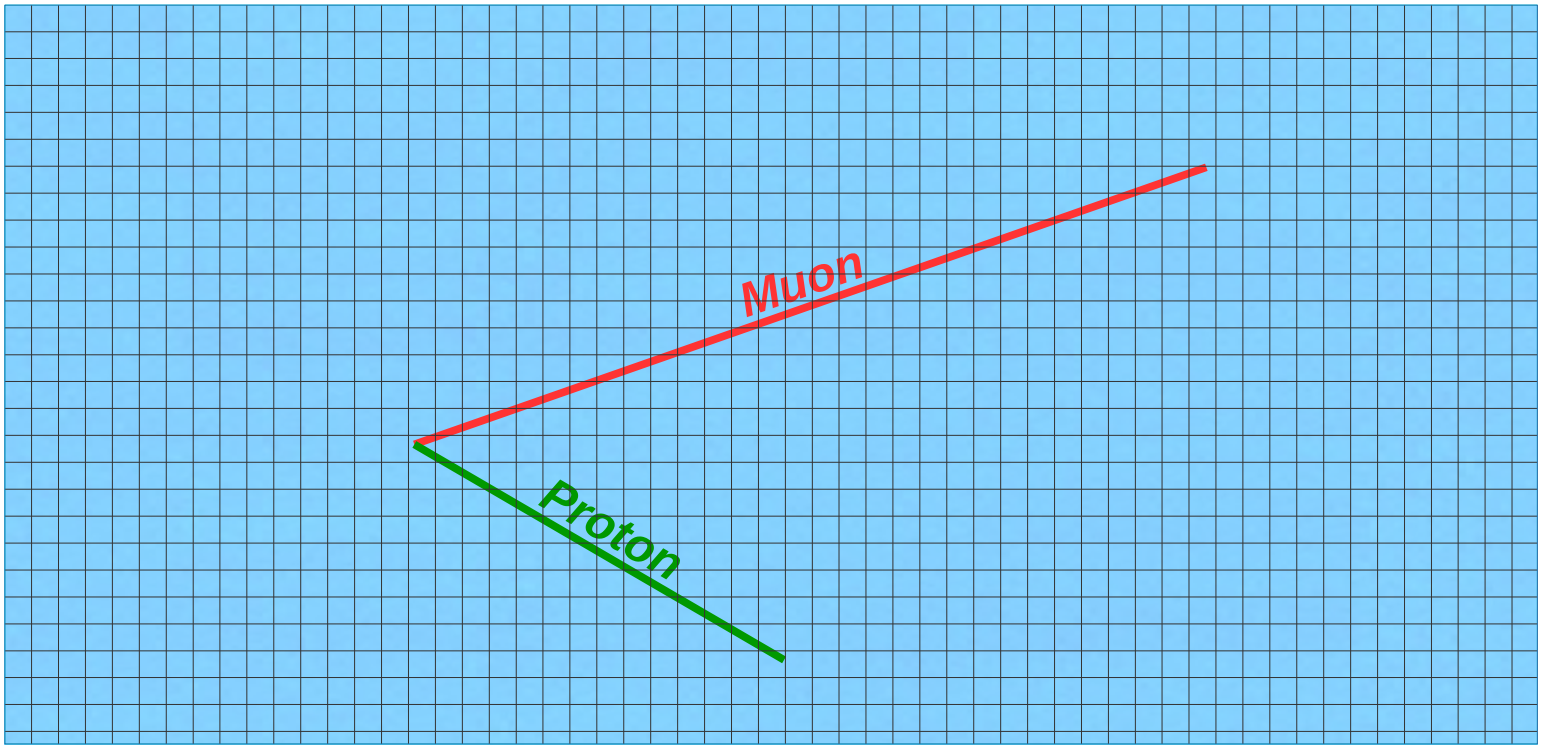
- **When a charged particle traverses the argon you get its x,y,z location of the ionization from Geant4 (simIDE's)**

How the simulation works now



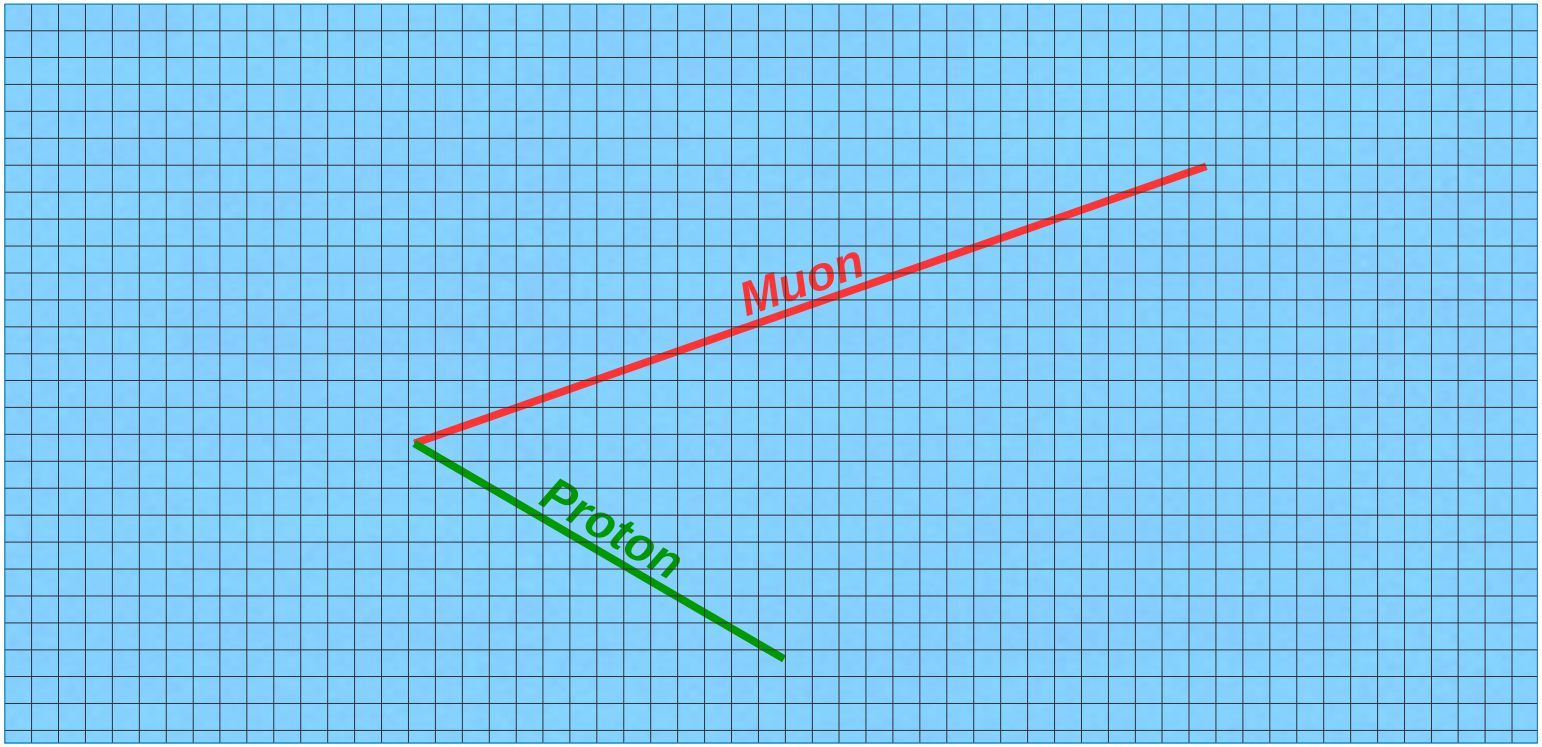
- **This charge is then projected onto the 2-d (taking into account charge drift effects) by asking for the “nearest wire”**
  - Given a bit of charge in the detector, it finds the nearest wire in a given plane
- **In principle the same thing could occur for a pixel based TPC**
  - However, there are some problems that need to be overcome

How the simulation works now



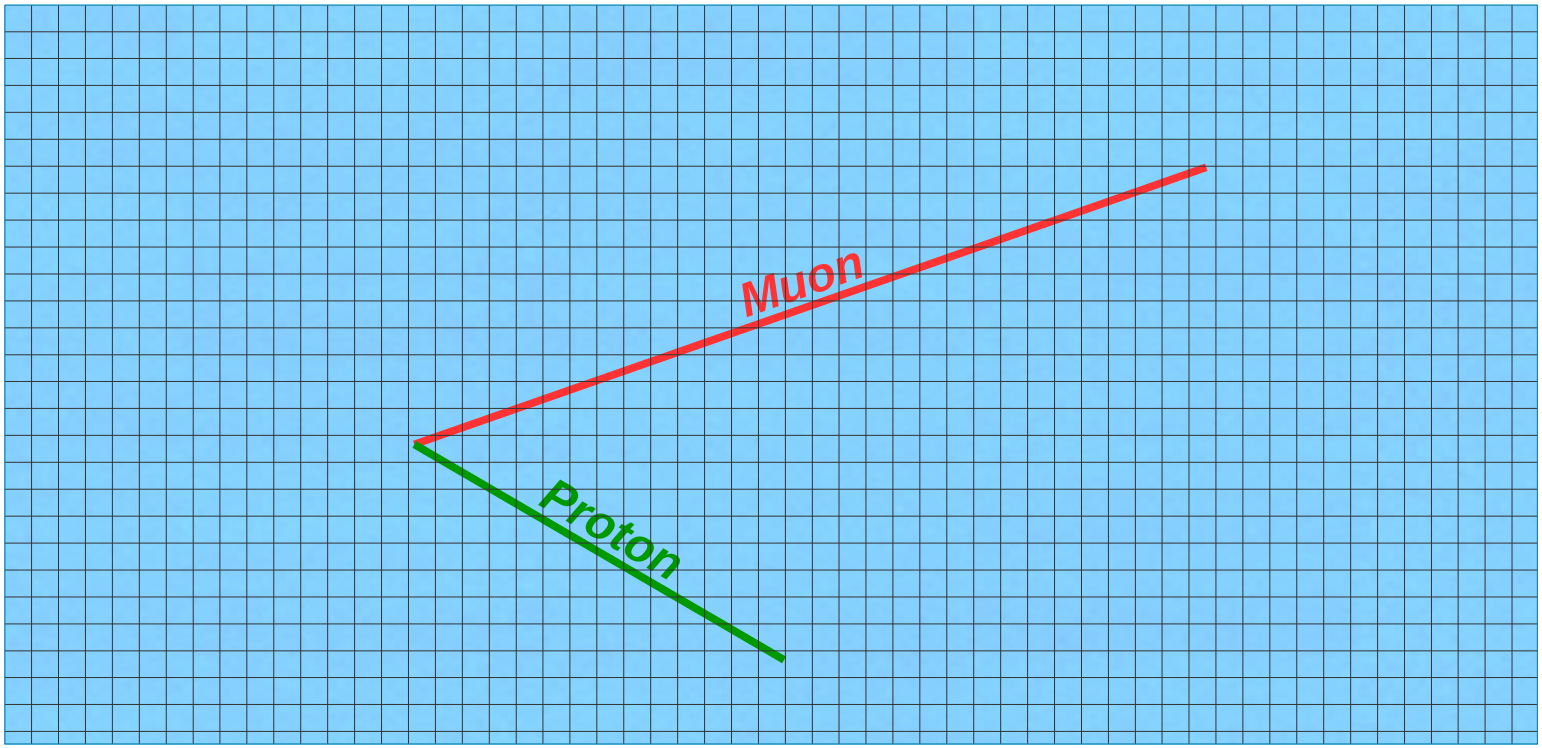
- **Challenge 1:**
  - The number of channels is MUCH larger to simulate here!
    - SimChannel aspect of LArSoft is one of the more memory and computationally intensive parts right now often ballooning the size of files to an unmanageable size
  - Also, you are doing this two drift regions per module times “N” number of modules in the near detector
  - This will require rethinking this aspect of the simulation some

How the simulation works now



- **Challenge 2:**
  - The pixels have a finite width which shouldn't be (can't be?) ignored
    - Right now the wires are treated as line like objects spaced according to the wire pitch
    - We could think of the center of the pixel as the only relevant part, but field simulations need to be done (underway by the LBNL folks) to understand this behavior completely (see backup slides)

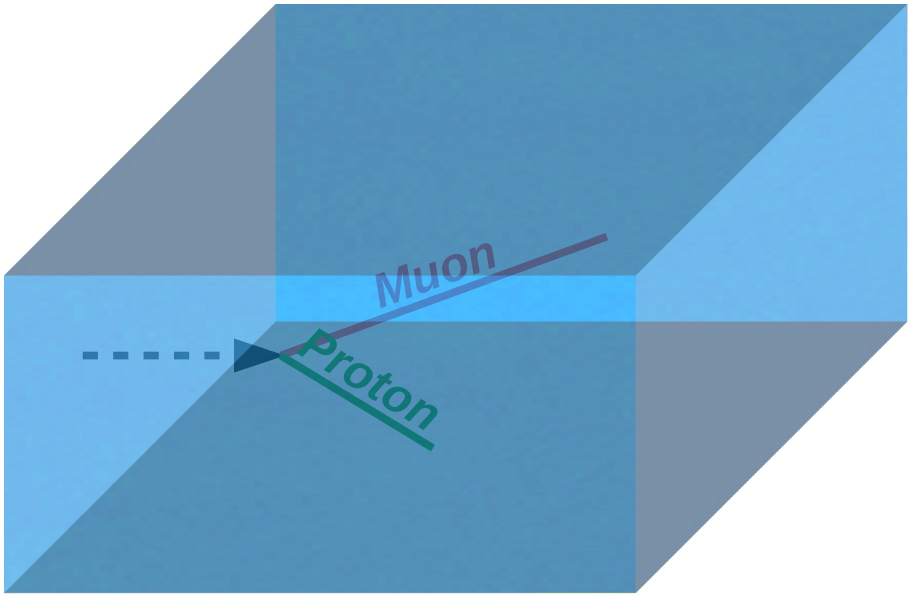
How the simulation works now



- **Challenge 3:**
  - Electronic simulations for pixel detectors aren't mature (yet) for their inclusion into the simulation
    - Again, work which is underway (LBNL group)
    - Since we are re-imagining the readout for these detectors, it may be enough to just use the existing noise/response models...but the actual answer needs to be informed by small scale prototypes/test-stands

3d Reconstruction Tools

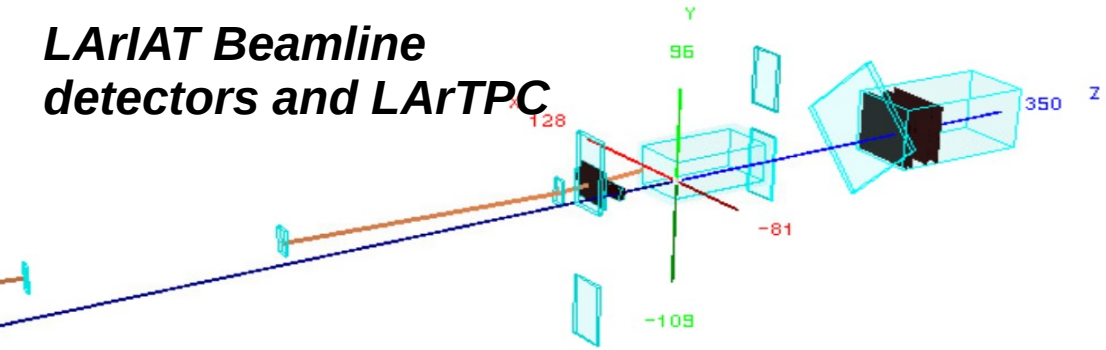
- **Once you have 3d points from the pixel based readout, then some of the exisiting reconstruction tools will need to be adapted**
  - For example: Pandora based pattern recognition uses hits on wires as its fundamental object (creating its own 3d points)
  - Similarly for some track/shower reconstruction objects which treat 2d clusters in wire planes (made of hits) as their fundamental object
    - Much of this adaptation is work that will begin with the LArIAT based pixel readout (PixLAr), that I will tell you more about tomorrow
- **Some of the reconstruction algorithms already work in 3d and using pixels actually removes a level of complication for them**
  - For example: WireCell reconstruction might see significant improvements with the removal of all the ambiguities that arise from wires (might need to be renamed to PixelCell)
  - SLAC group has expressed interest in bringing to bear their deep learning tools on such a readout

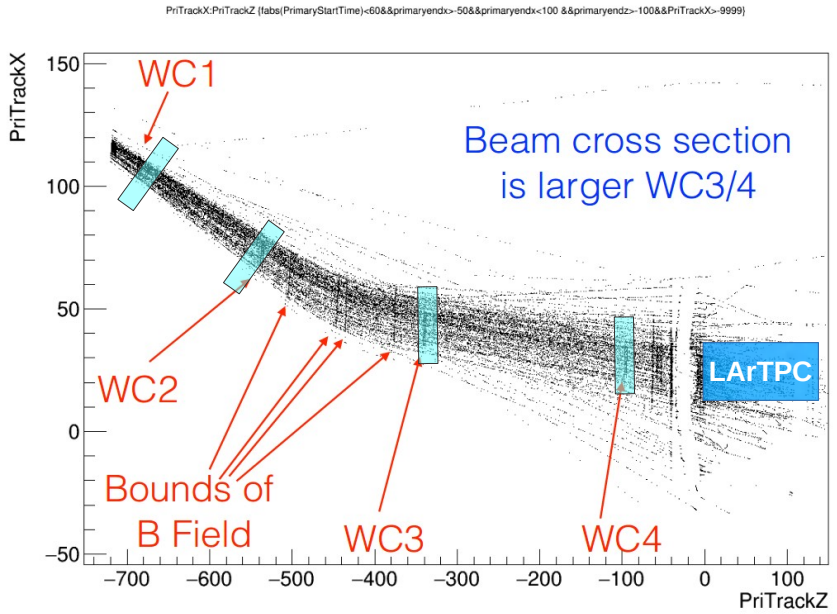


3d Reconstruction Tools

- **Stitching together information between TPC modules should be relatively straightforward**
  - Experience from 35ton, protoDUNE, and SBND should help here
- **Incorporation of auxillary detectors (such as muon spectrometers) can also be "easily" handled within the LArSoft framework**
  - Experience from LArIAT incorporating many other beamline detectors shows this can be done fairly easily

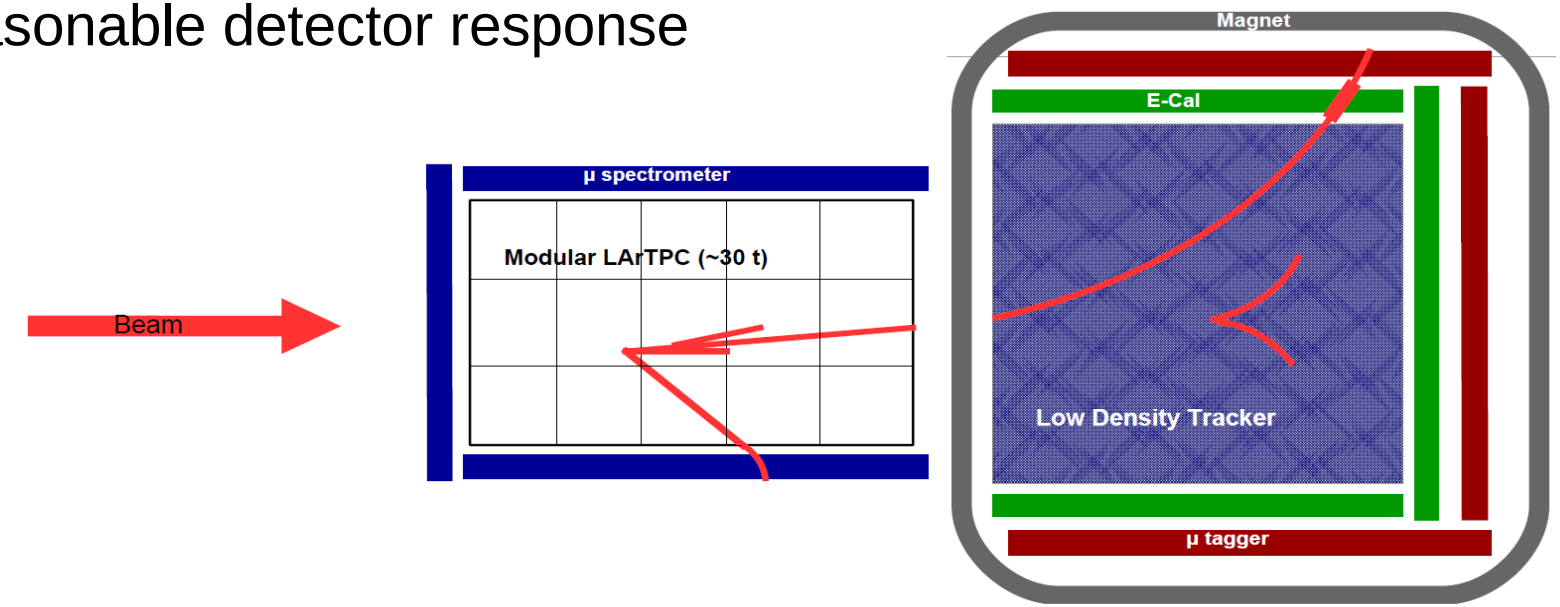
LArIAT Beamline detectors and LArTPC





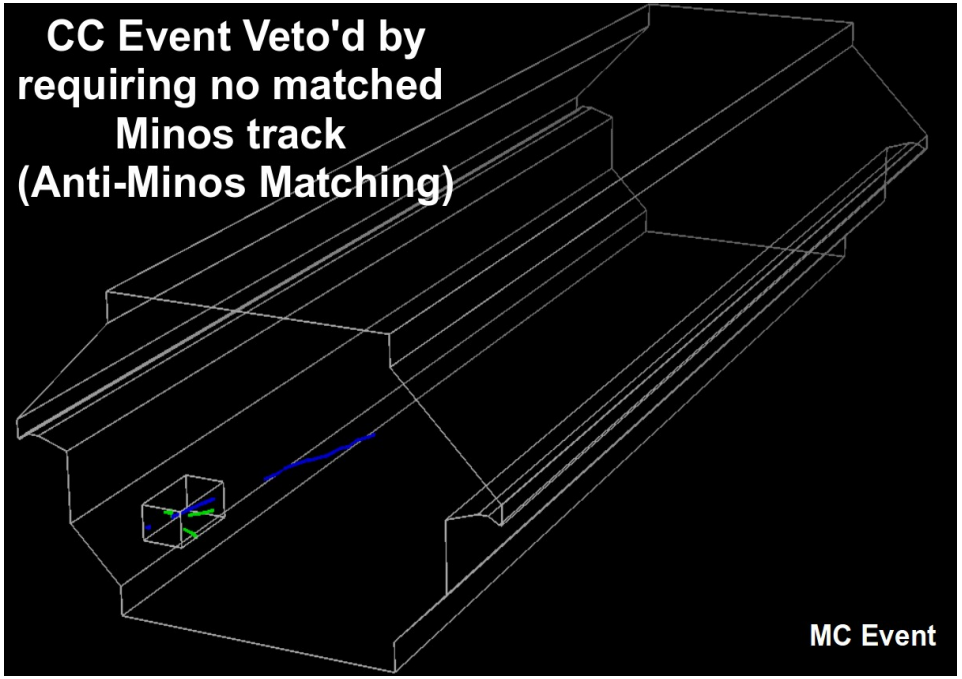
Other Near Detectors

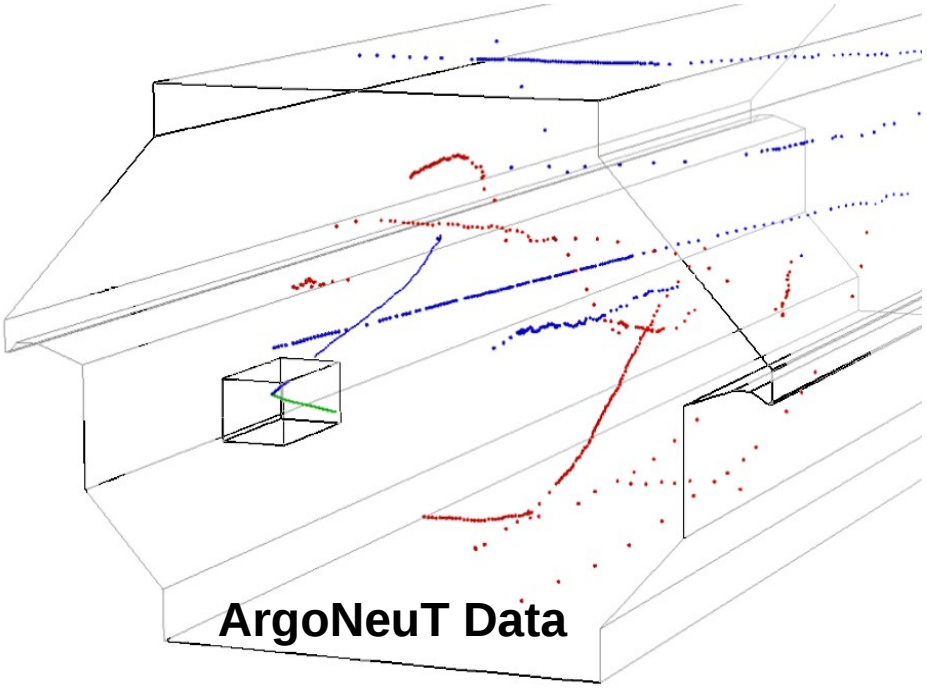
- **Since there will be a fine grain, magnetized, tracking detector downstream of the ArgonCube detector, the incorporation of this detector into the simulation needs to be done**
  - Matching tracks created in ArgonCube to tracks and their curvature in the FG-tracker will effect the overall kinematic performance of the ND
  - Modeling of this acceptance should be taken into account when assessing the effect the LArTPC detector will have on far detector systematics
- It is my opinion that the details of the simulation of the FGT should be left external to the simulation of the ArgonCube module
  - Except to take into account geometrical acceptances along with a reasonable detector response



Other Near Detectors

- **This is something that we've done before!**
  - ArgoNeuT would simulate tracks in the MINOS-ND
  - This was done by passing particle information to the MINOS simulation (which was an external package) and then returning a reconstructed track
- **For data, the syncing of the readout from ArgoNeuT with the MINOS-ND was done offline**
  - Again, returning reconstructed MINOS tracks for matching

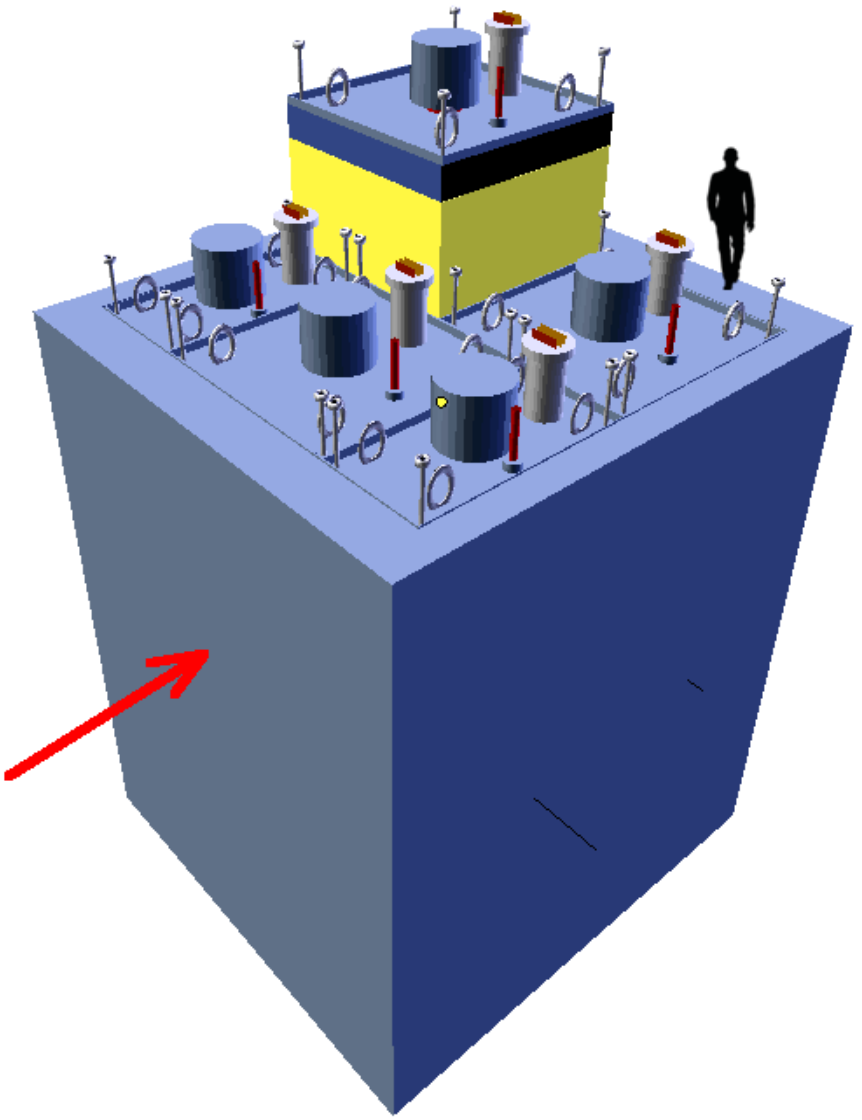




Path forward

- **Work to include a pixel based LArTPC simulation into LArSoft is just starting to be pursued in earnest**
  - The LArIAT based pixel detector (PixLAr) provides an excellent small scale test bed for converting Geant4 information into 2-d pixels (more on this tomorrow)
    - Even better, we'll have some data to verify this procedure against
  - Work with the LArSoft team in the coming days to approach the technical challenges
  - I expect this to be a 6-12 month long endeavor
- **Standalone (outside of LArSoft) simulation work for the DUNE near detector is continuing**
  - Inclusion of both ArgonCube along with an FGT given realistic neutrino flux and pile-up / dirt events based on the experience gained during the DUNE-ND task force exercise
    - Still remains to be seen how the outcome of this work gets folded into the oscillation sensitivity framework
    - Although it is known that this needs to be the aim
    - This is work that should continue for the next many months
  - A short-term strategy (see backup slides) for using existing LArSoft objects to attempt some reasonable reconstruction expectations within the LArSoft framework was attempted during the Near Detector task force
    - Ultimately people power limitations lead to this work not being completed....but the strategy is one that could work
    - This would likely take 4-6 months to complete (1 student working 100% of their time and external LArSoft expertise)
- **Adaptation of existing reconstruction software for ArgonCube is work that very much needs to be done**
  - This should help inform both the reconstruction and the detector design choices
  - Large area where new collaborators can contribute quite a lot!
    - Again, PixLAr's upcoming run will be an excellent place to contribute!

Questions / Comments



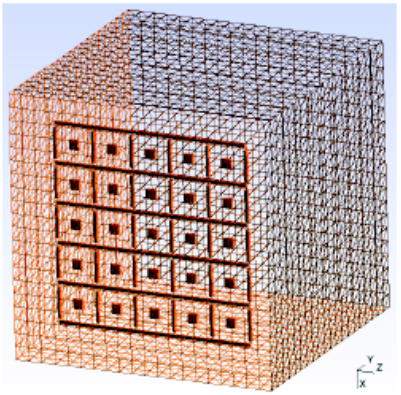
Backup Slides

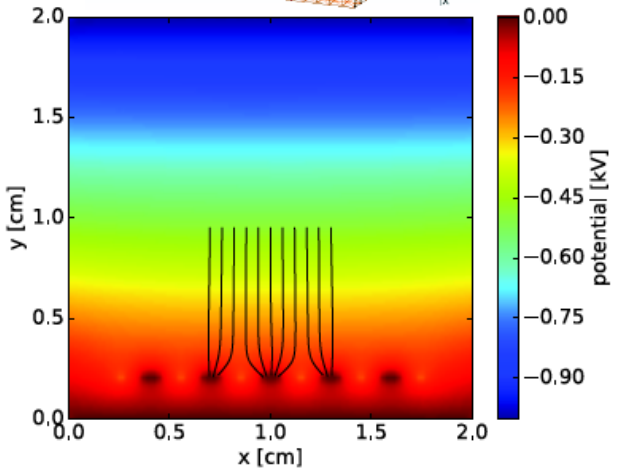
Design Tools

Slide from D.Dwyer talk at ND-workshop

Developed a set of tools to assess TPC readout design

Sensor model in 3D

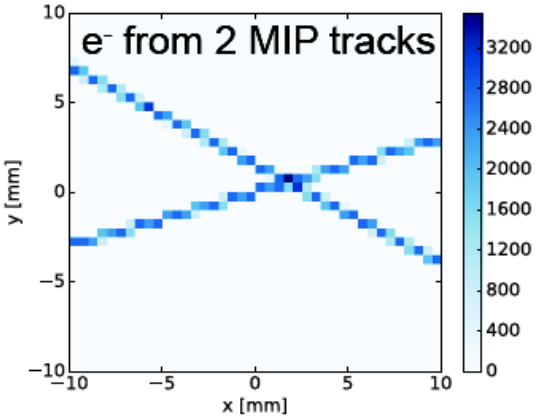


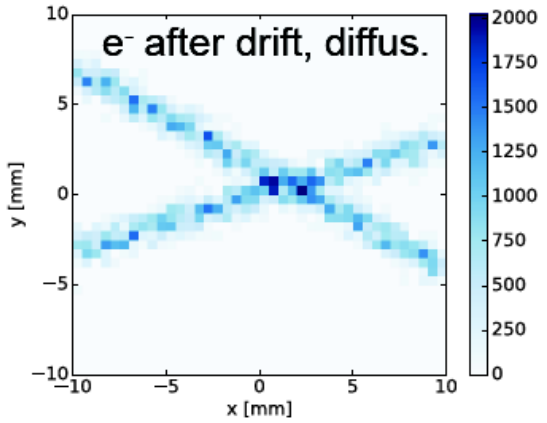


3D drift field, pix response

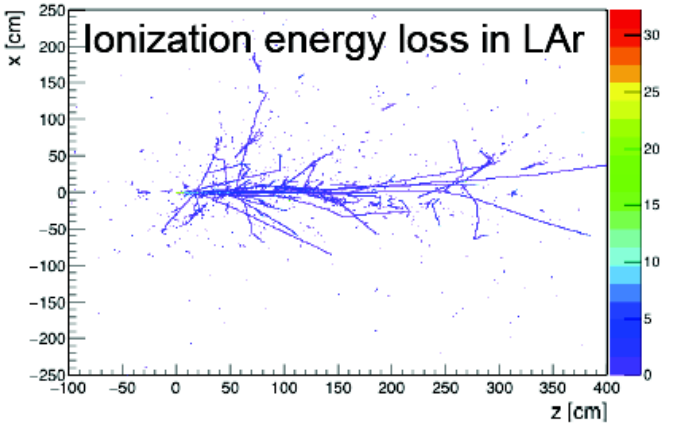
→ *Thanks to B. Viren for intro to BEM tools*

Ionization, recomb., drift loss, diffusion

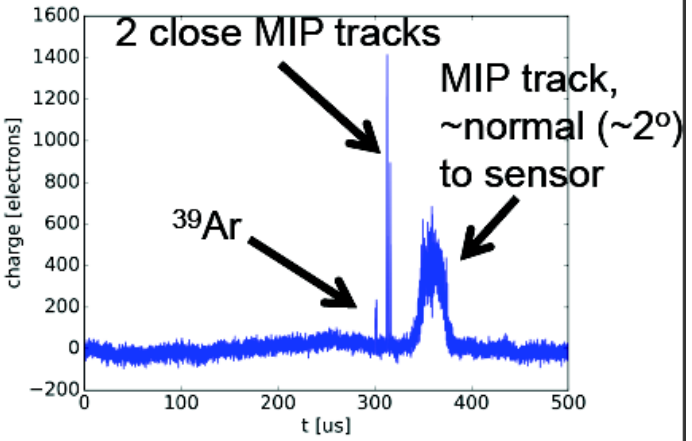




Fast primitive Geant4 sim.



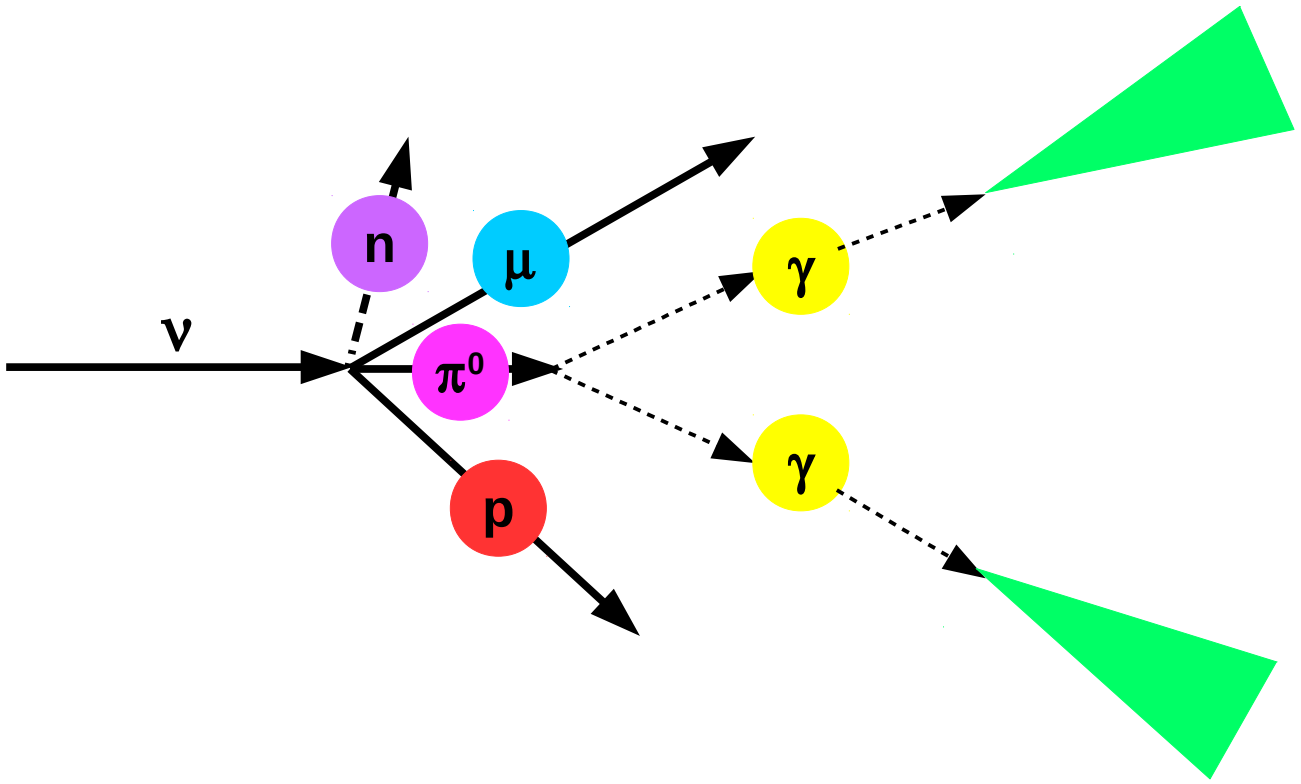
Realistic signals (with noise)



Signals have been input to IC modeling program (Spice, Cadence) to assess IC design, performance.

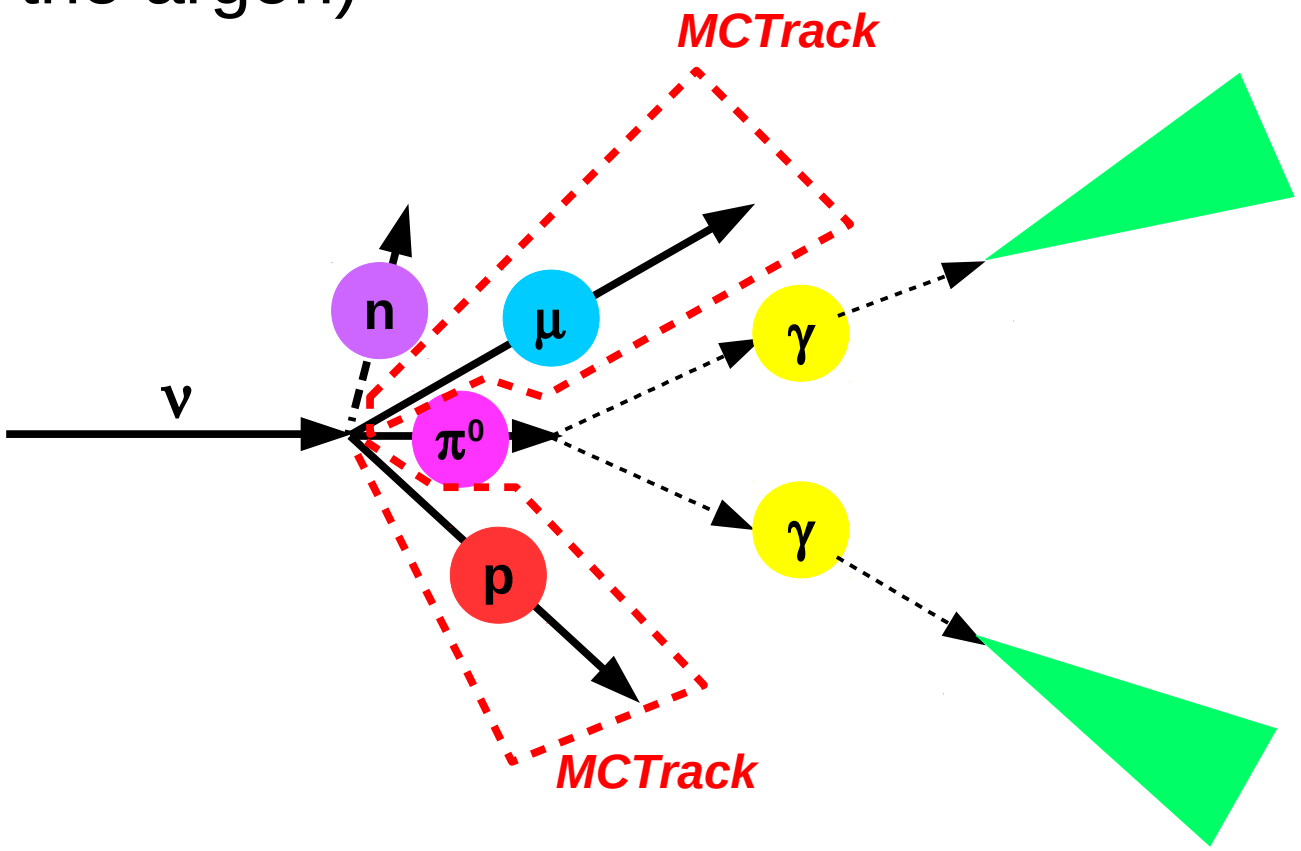
Near Term Strategy

- **Take the Monte Carlo truth level objects so we can classify each event completely**
- **The use the LArSoft truth object MCTrack and MCShower to represent the 3d deposited charge information that would be seen by a pixel readout**



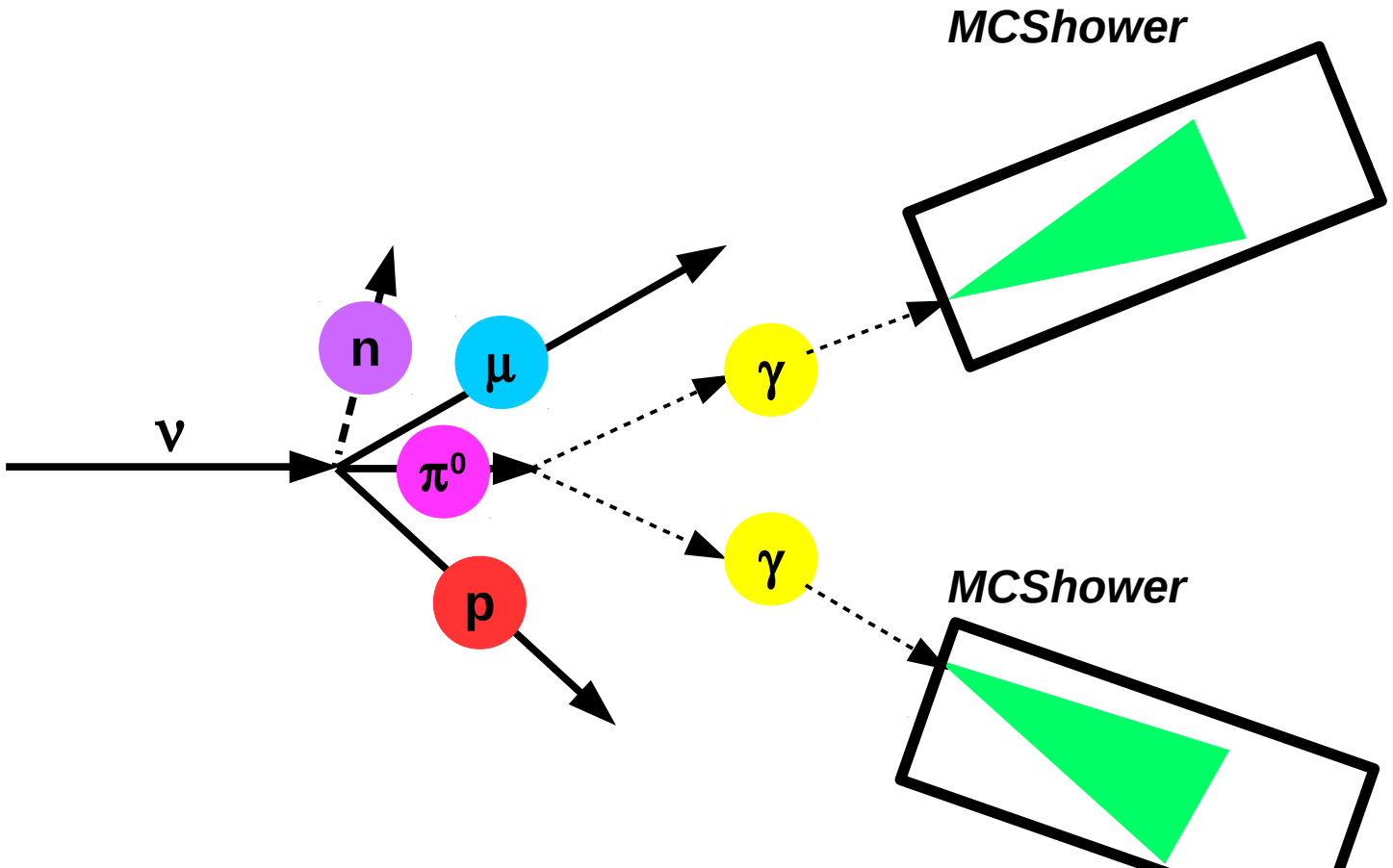
Near Term Strategy

- **MCTrack represents the 3d deposited energy and momentum of an object that would create what you would think of as a "track"**
  - e.g. Protons, muons, charged pions, kaons etc….
  - neutral particles aren't in the MCTrack (since they don't ionize the argon)



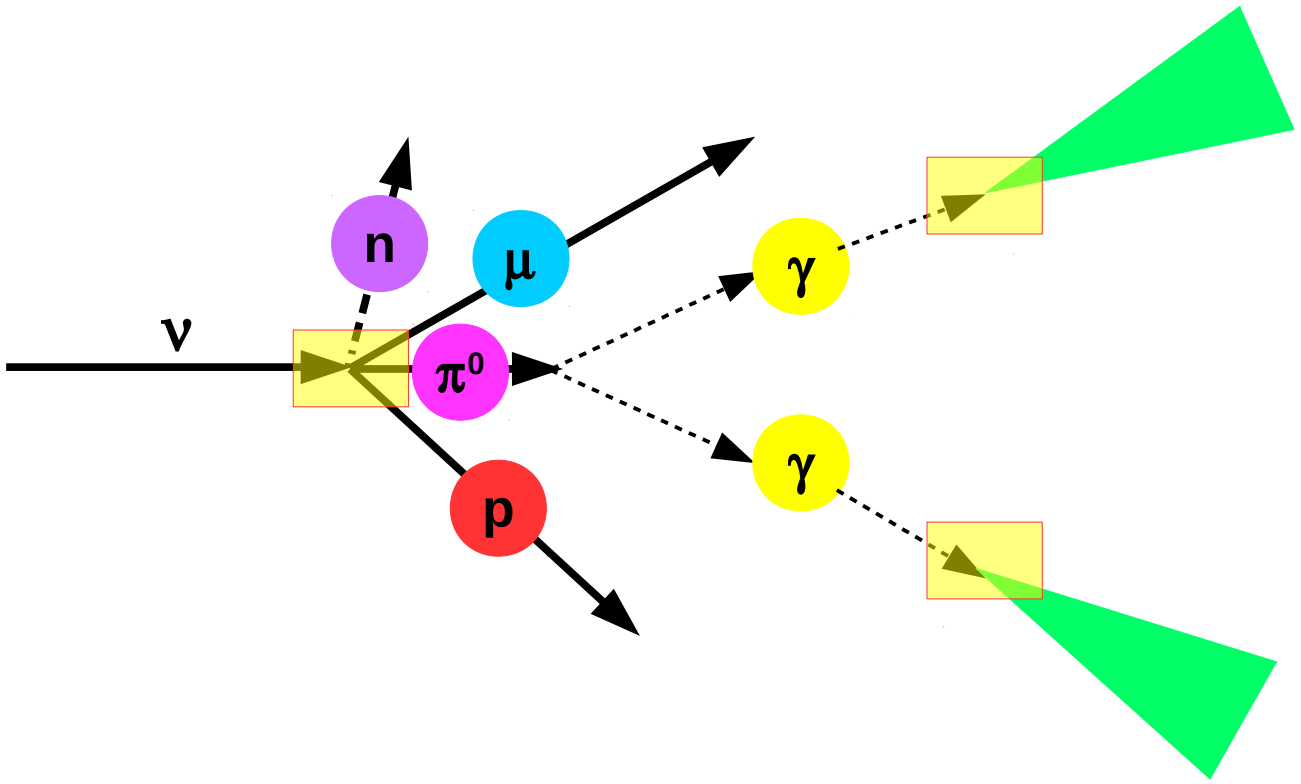
Near Term Strategy

- **MCShower represents the 3d deposited energy and momentum of an object you would think of as a electromagnetic shower**
  - e.g. photons and electrons



Near Term Strategy

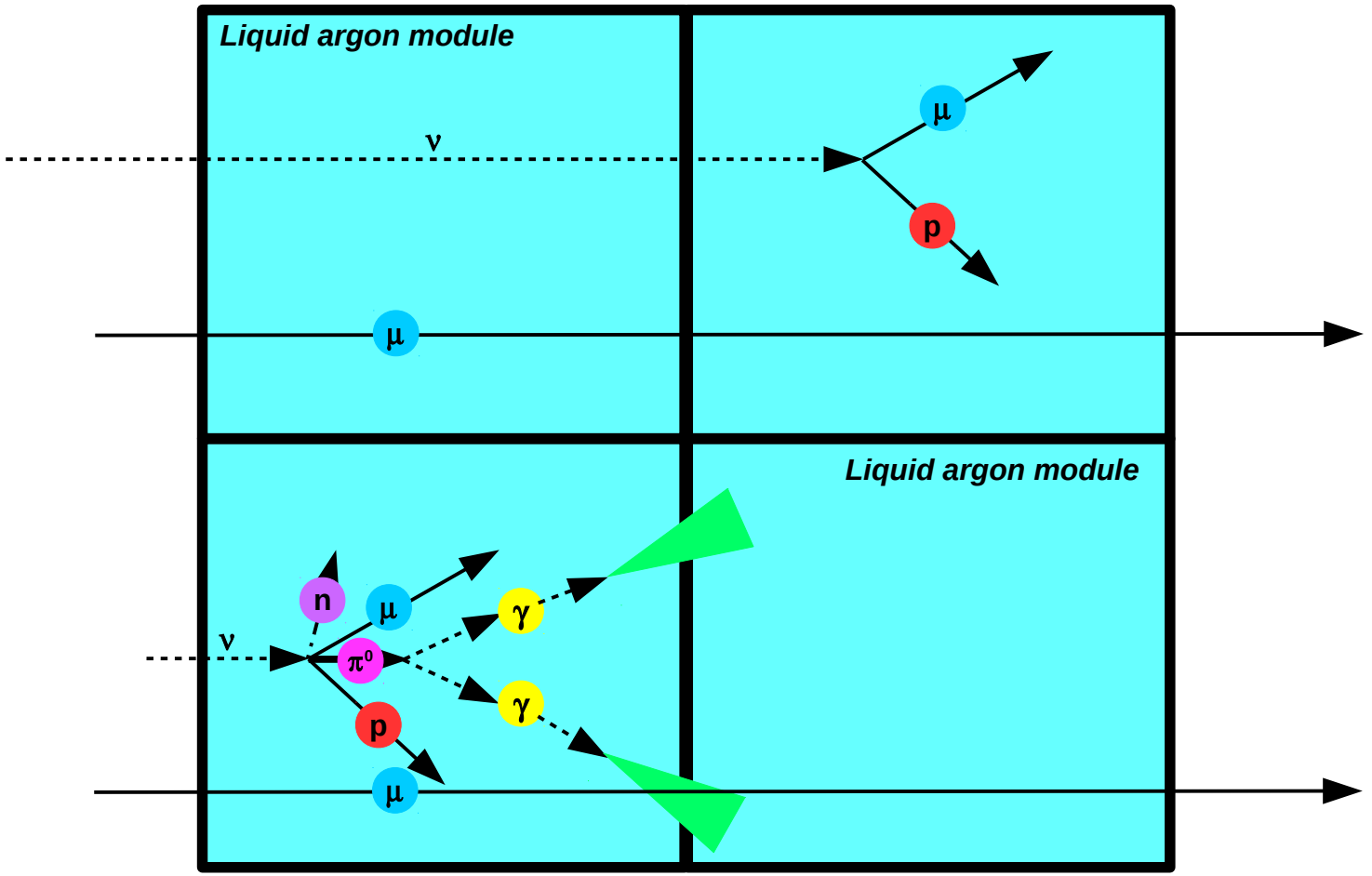
- **Since for all of these objects we have their true deposited energy position, momentum, and vertex position we can apply resolution smearing guided by the latest understanding from operating liquid argon experiments**



Near Term Strategy

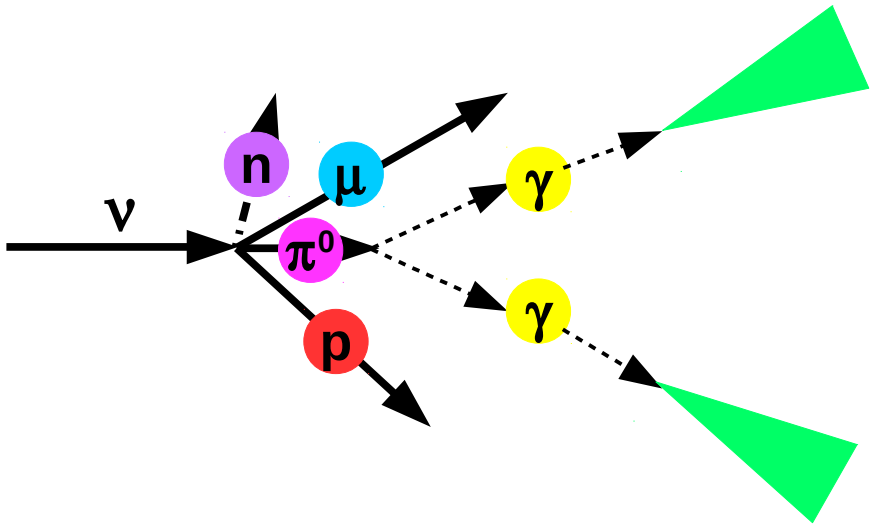
- **Additionally, we can use these tools to understand different effects**
  - Pile-up
  - Containment
  - Rock muons

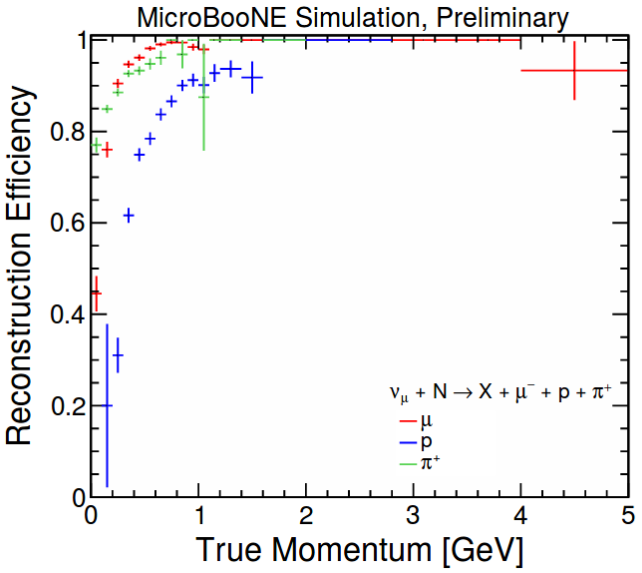
Easy to draw the picture...a bit harder to get all these tools in place….but we are very close to having the first iteration of this type of study complete

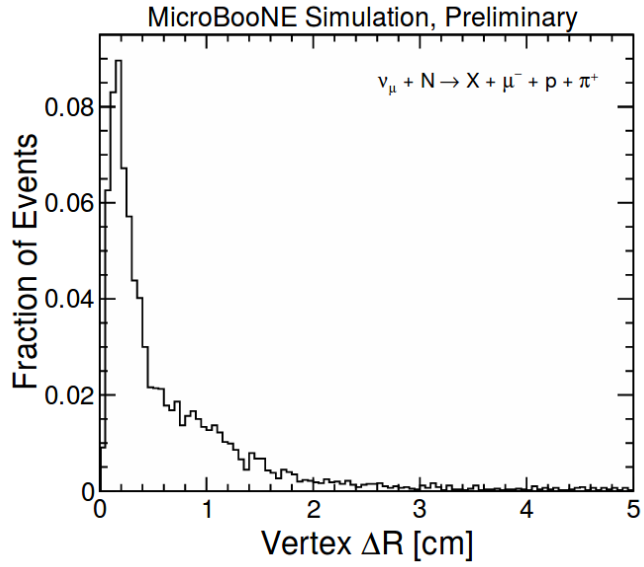


Near Term Strategy

- To begin with, we are applying a "smearing" to each vertex to fake the resolution
- We also smear out the start point of the MCTracks and MCShowers
- We then apply a PID efficiency to each MCTrack and MCShower
- Finally, we associate the "reconstructed" MCTrack and MCShowers to the vertex for neutrino interaction identification







See MicroBooNE public note:
"The Pandora multi-algorithm approach to automated pattern recognition in LAr TPC detectors "
MICROBOONE-NOTE-1015-PUB