Overview of practical aspects of protoDUNE data

Dorota Stefan CERN

Robert Sulej FNAL

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Outline

- Characteristic of events in protoDUNE:
  - various topologies,
  - energy range.

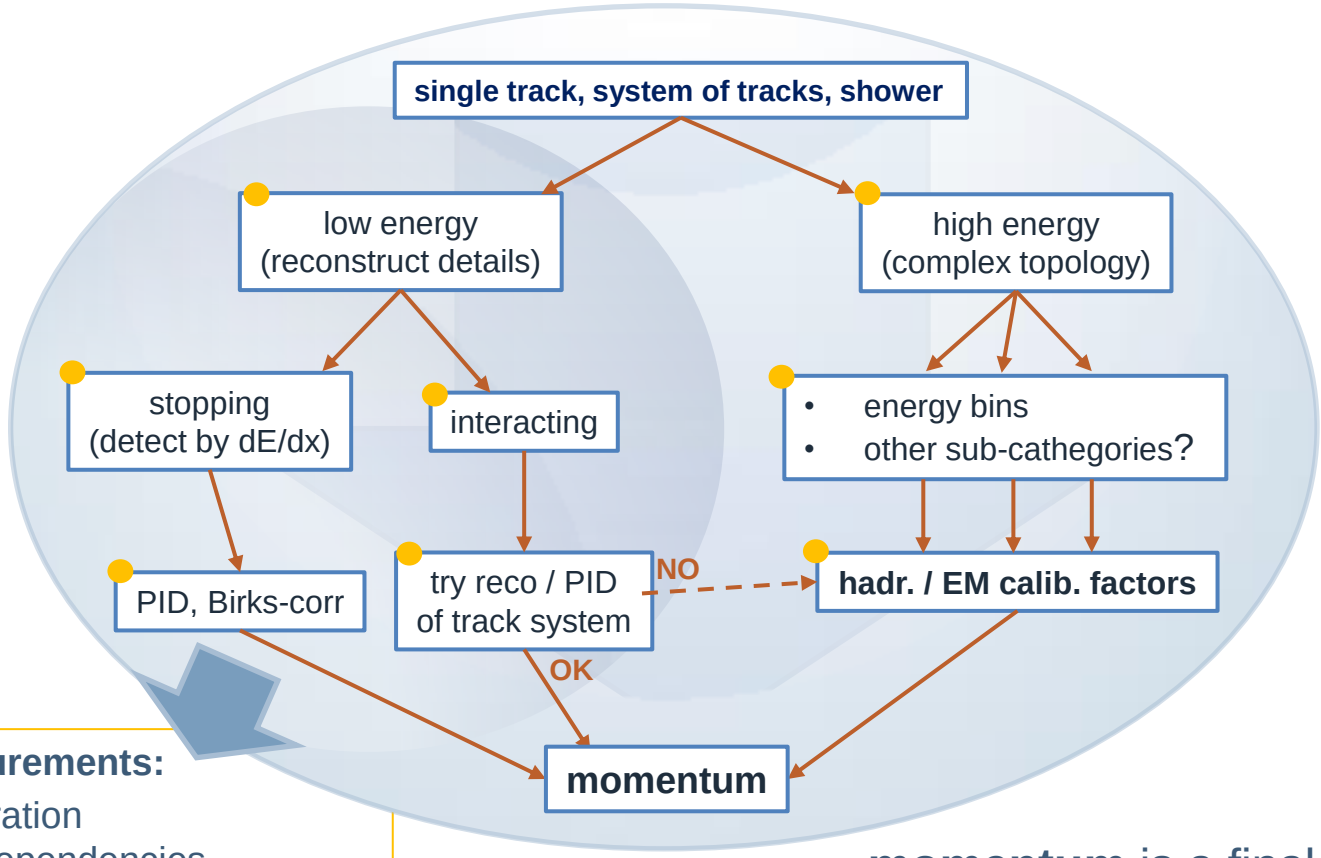
- Current reconstruction approach.

- Calibration possibilities: cosmic muons and π^0's.

- Detector effects which can have impact on measurements.

- Physics in protoDUNE: *goes together with the above topics*.

Potential use of events with various topologies



Other measurements:

- PID calibration
- angular dependencies
- reconstruction tests

momentum is a final goal → many calibrations and models testing on the way to it

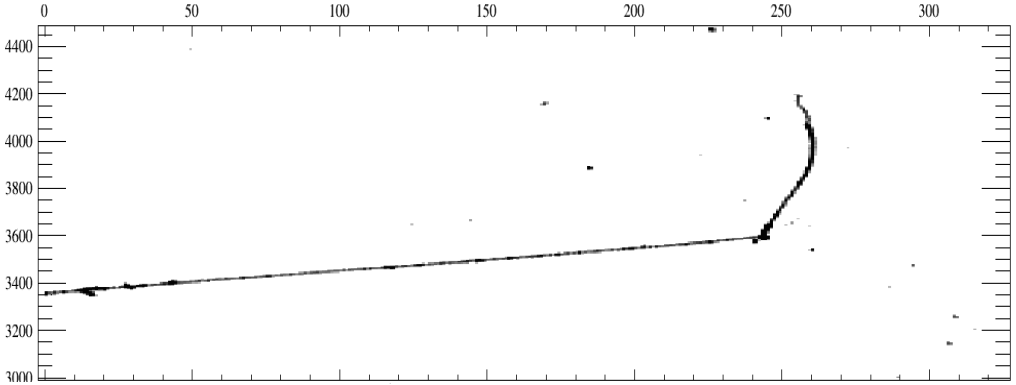
Different approach in energy ranges

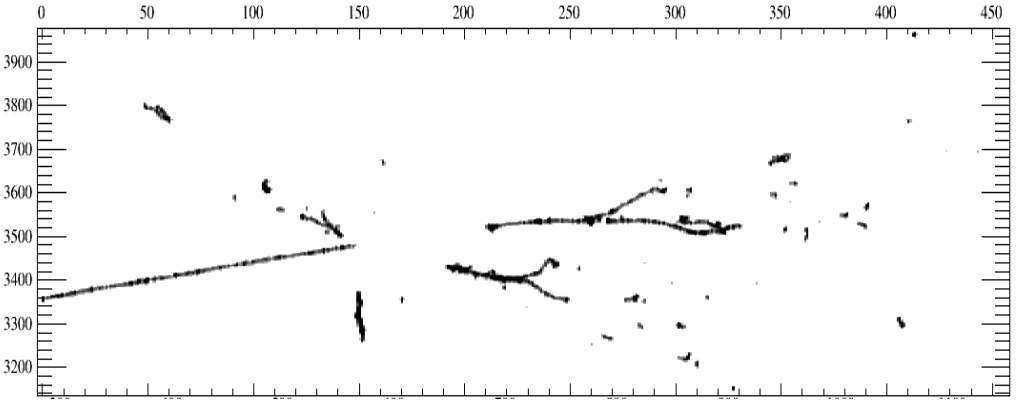
- Energy resolution for hadronic showers in LArTPC, as usually stated:

  $\Delta E/E \sim 30\% / \sqrt{E[GeV]}$

- But at low energy:
  - stopping particles: $\Delta E/E$ <~4-5%
  - low multiplicity: $\Delta E/E$ = ?
  - high diversity of topologies.
- Methods for the momentum reconstruction can be designed on MC.
- Reconstruction validation to be done on data and real-life detector conditions.
- Low level Energy/Momentum reconstruction to be calibrated on real data (ADC to GeV, including all detector effects).
- MC models to be calibrated on real data (hopefully problem decoupled from ADC to GeV).

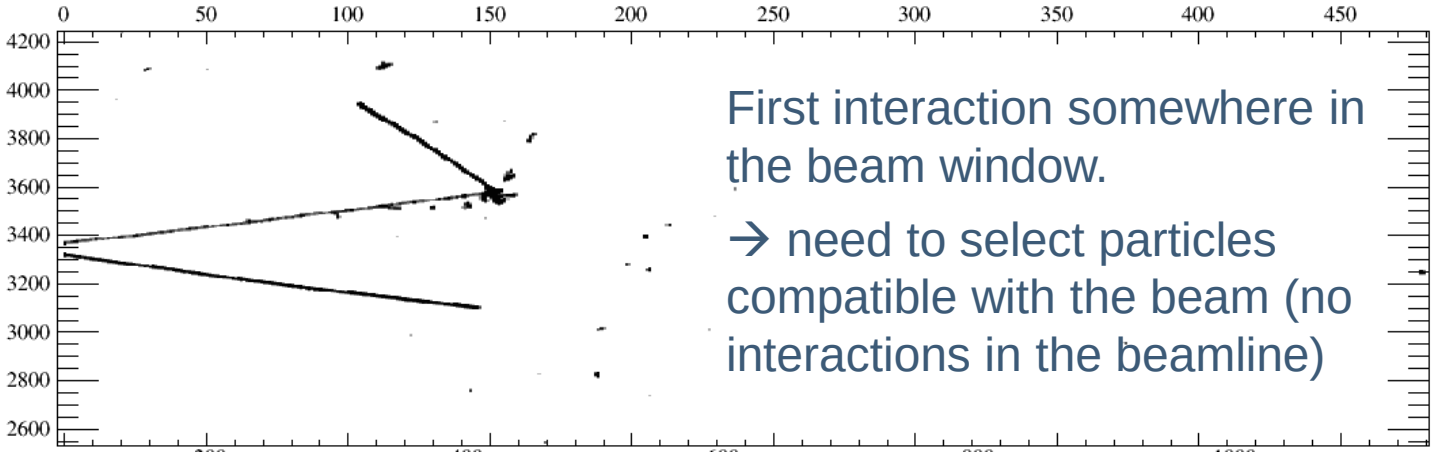
Example of 1GeV pion





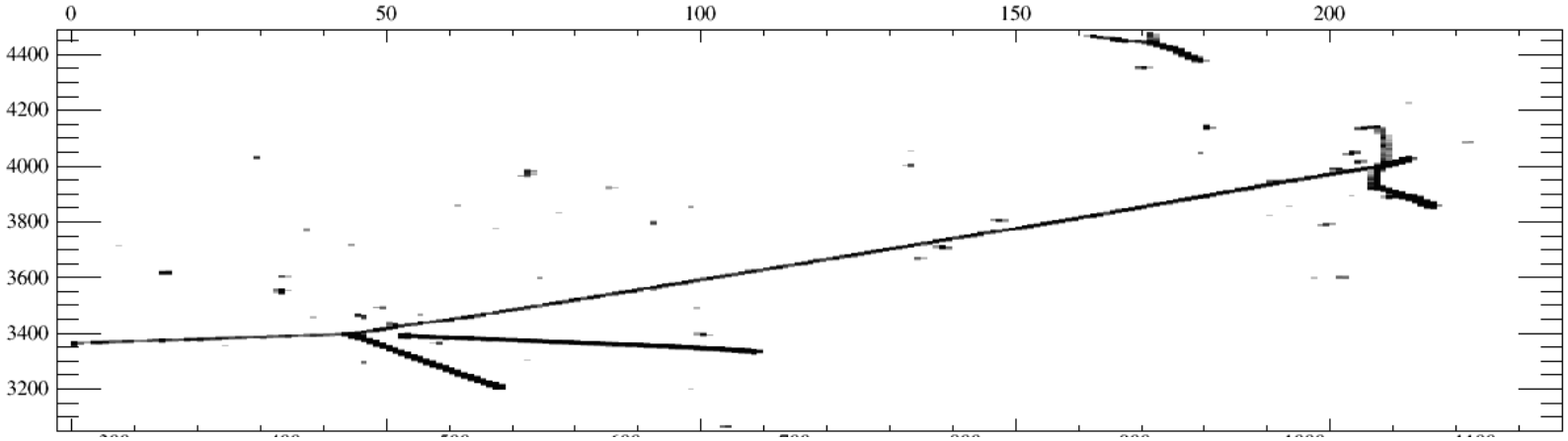
- Relatively clean events to be reconstructed but a lot of neutrons is produced.
- π^0 , stopping, decaying particles at secondary vertexes.
- Physics: EM fraction in hadronic shower (can validate π^0 production models).
- Physics: pion interaction crossections; „missing energy”.

Example of 2 GeV pions

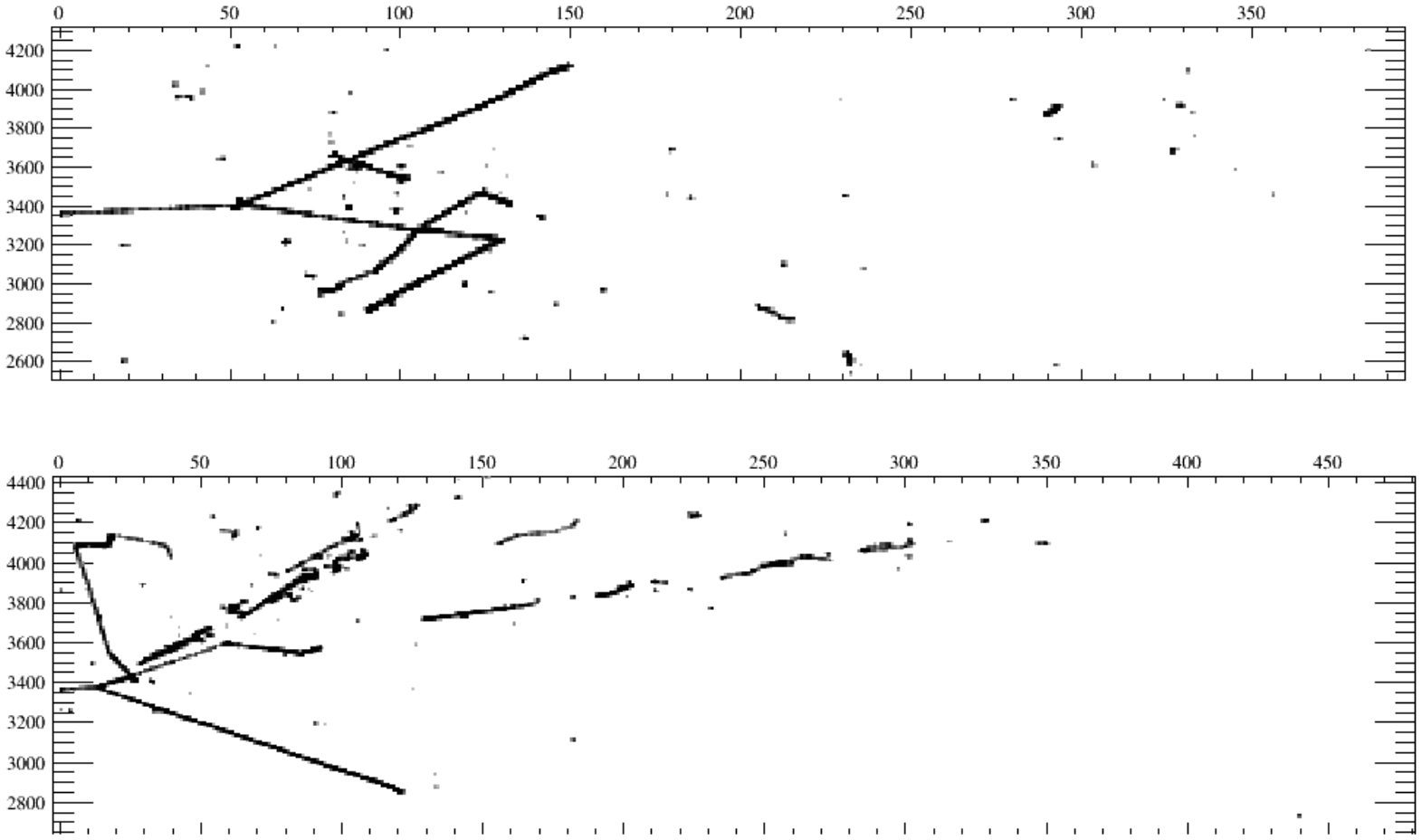


First interaction somewhere in the beam window.

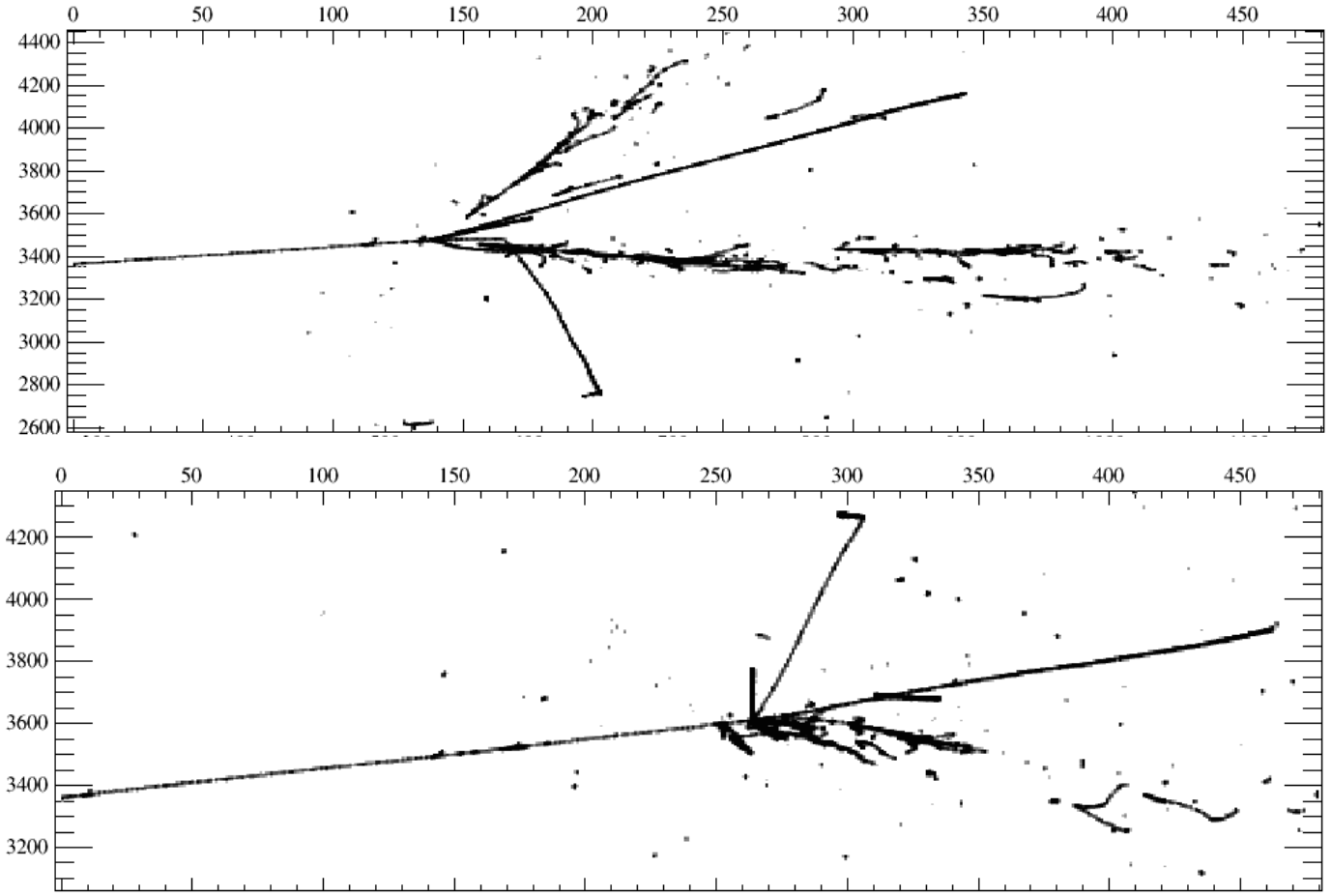
→ need to select particles compatible with the beam (no interactions in the beamline)



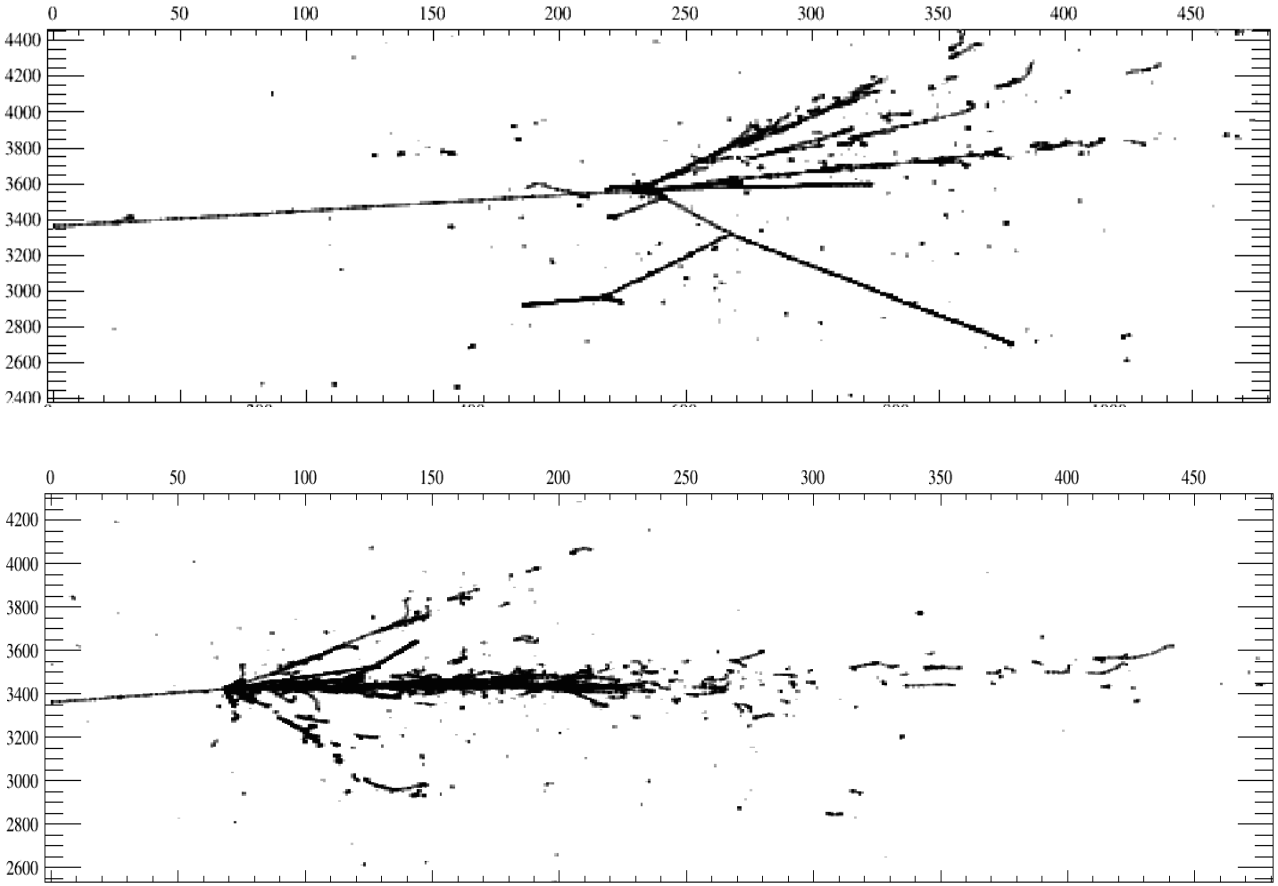
Examples of 3 GeV pions



Example of 5 GeV pions

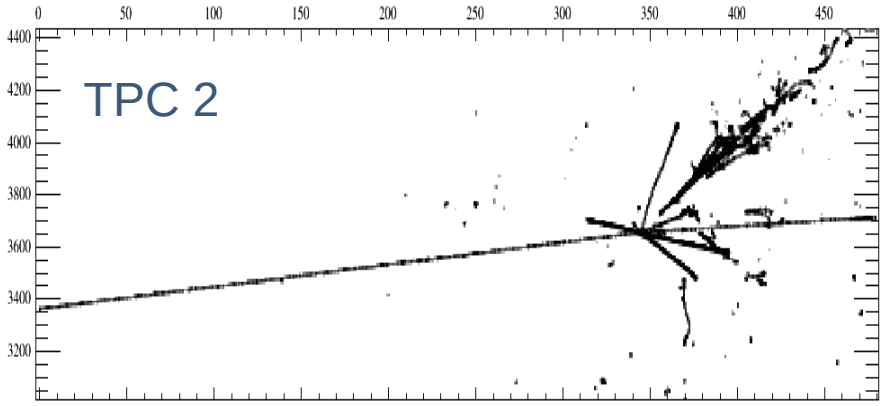


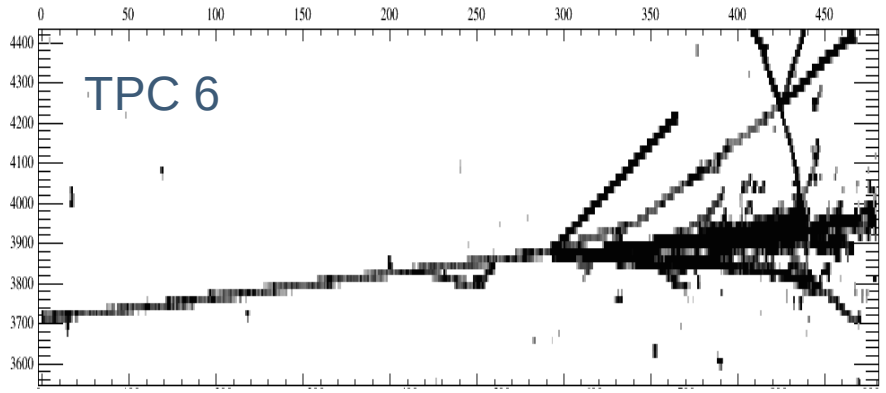
Examples of 7 GeV pions

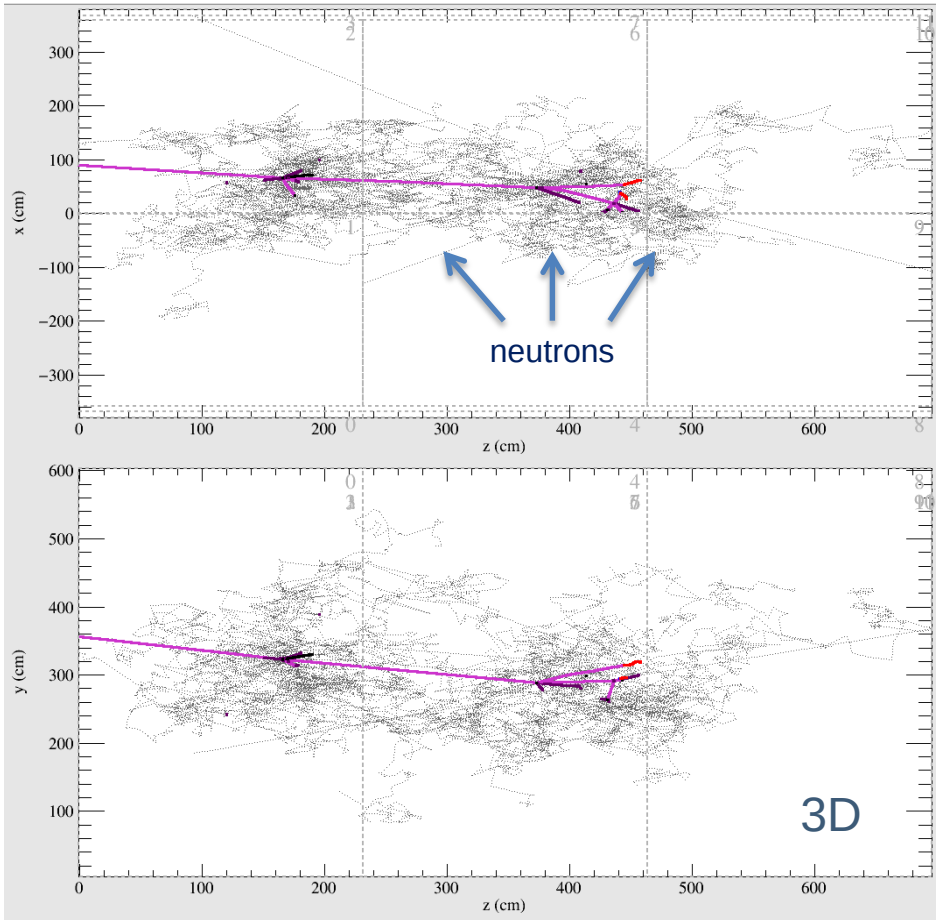


- Overlap of many particles; recognition of features in the interaction region becomes difficult
- This energy can happen in neutrino events.

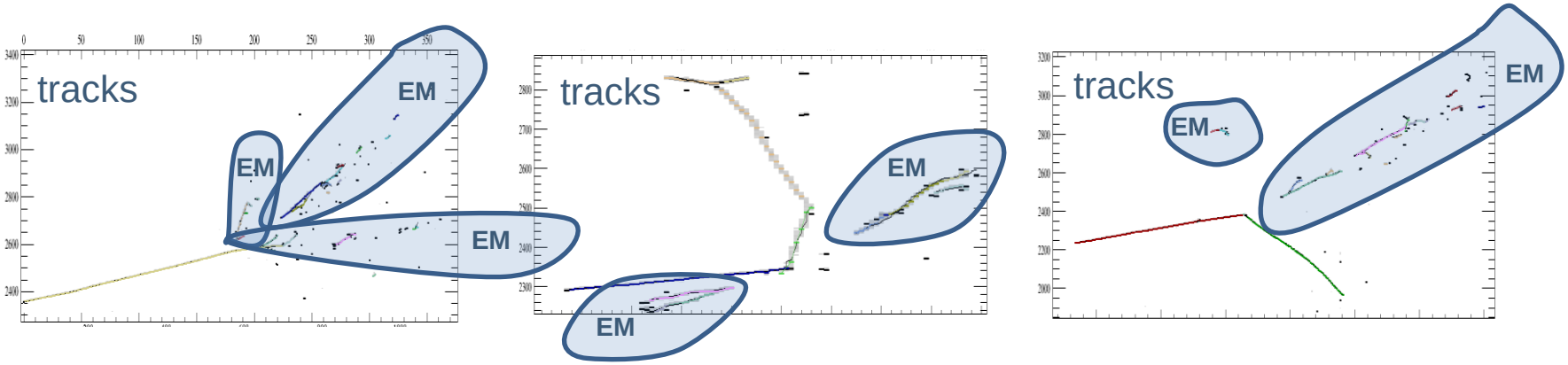
Examples of 12 GeV pions







Basic idea of present event reconstruction



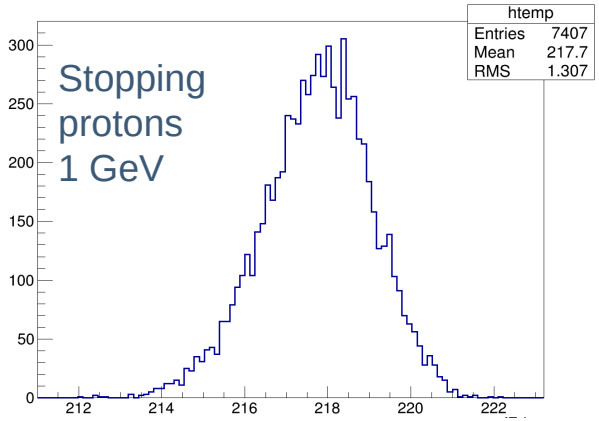
→ Signal finding

→ Seperation of EM showers from tracks & cluster finding

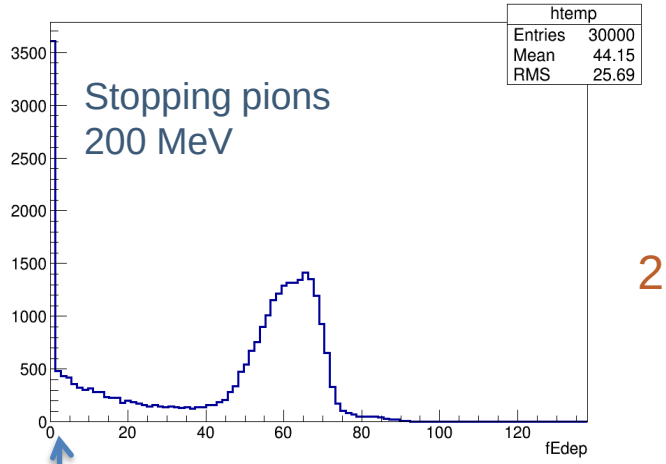
→ 3D trajectory fitting

→ Particle hierarchy reconstruction

MCC 6: output from reconstruction

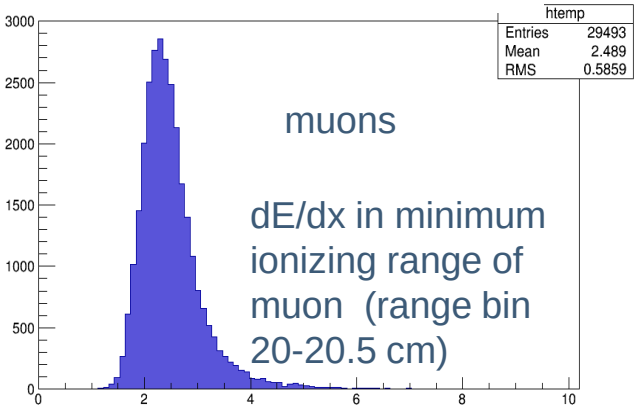


deposited energy [MeV]

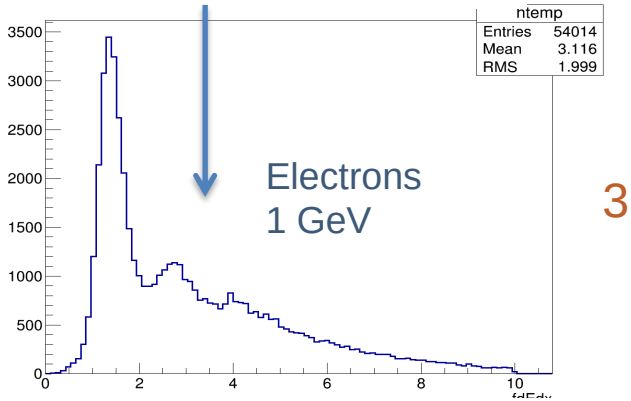


2D reco

effect of the beam window



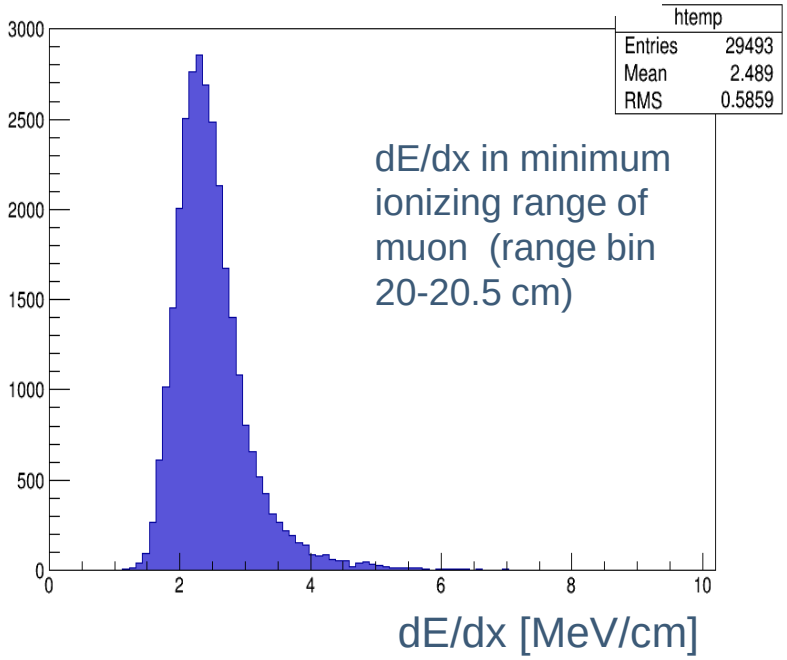
dE/dx [MeV/cm]



3D reco

dE/dx [MeV/cm]

Detector calibration: cosmic muons

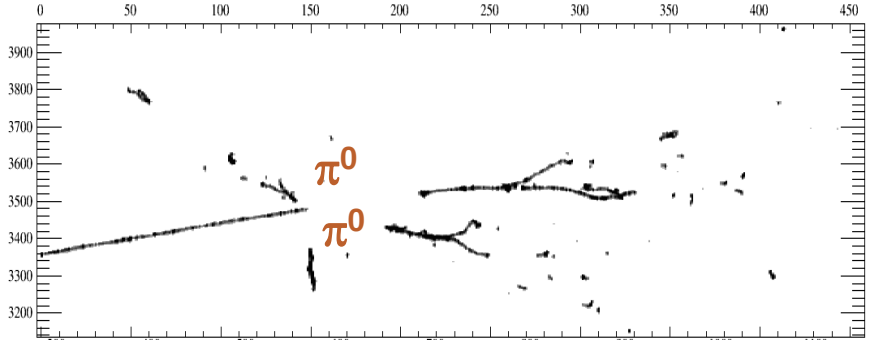


Cosmic muons in protoDUNE

- Decaying muons: known momentum; need develop detection of stoppers.
- Crossing muons: purity, space charge, alignment, …
- Beam muons can be similar to ν_μ muons in FD – prepare to use them.

Detector calibration: π^0

1 GeV pion

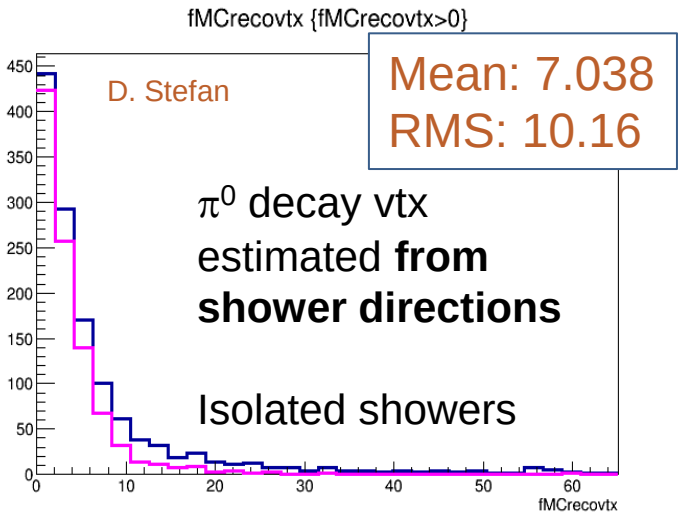


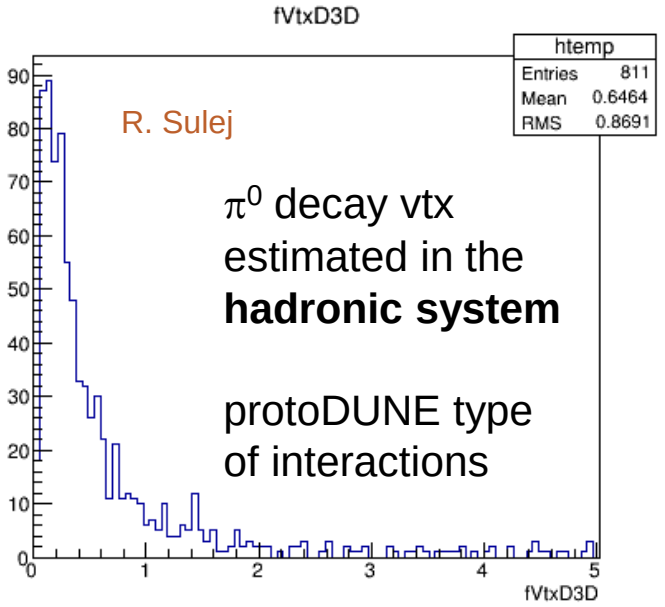
- Need to have full event reconstruction (showers, tracks, vertices).
- Neutral pions are identified by two cascades pointing to the common vtx.

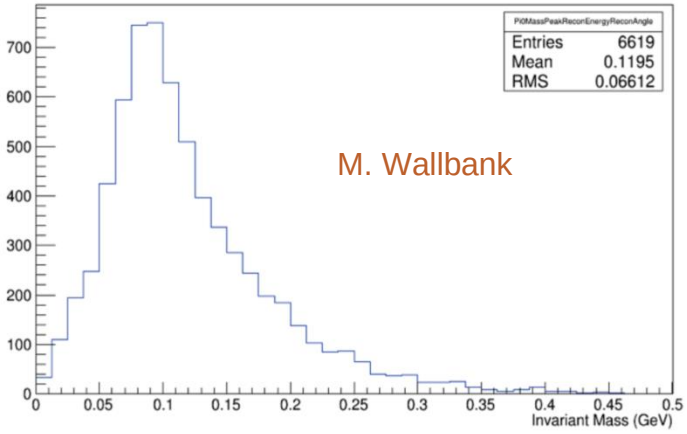
Challenges:

- Separation of showers from tracks (in protoDUNE also separation from cosmic rays and correction of SCE related charge distortions).
- Collect fragments of a single shower / separate different showers.

Detector calibration: π^0



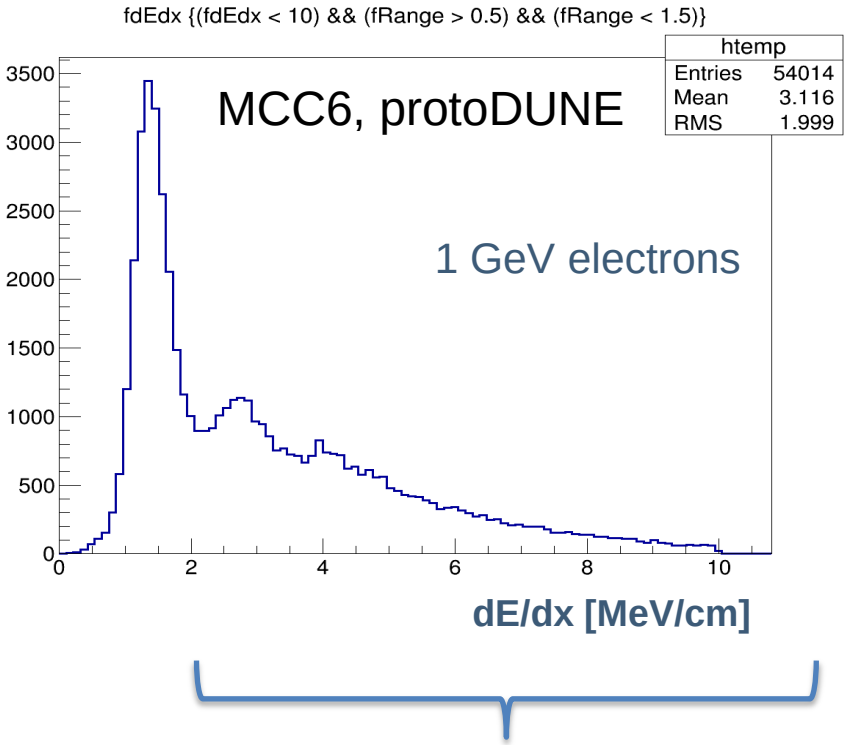




DUNE CM May 2016
Invariant mass of π^0

Isolated π^0 reconstructed

Electron/gamma separation for FD physics studies



distribution includes showers developed before TPC due to material of the beam window

- Electrons in beam direction only, fraction starts showering upstream of TPC.
  - → may be tricky to make use in e/γ separetion study
- Photons from π^0s decay (broad distribution of directions) using 1,2 GeV pions.
  - → very useful for tests of pattern recognition in the interaction vertex region;
  - → sensitive to many detector effects: diffusion, E-field response, noise; important for FD to understand these effects

MCC 6: pions/muons separation

$\mu \rightarrow e$

$\pi \rightarrow \mu \rightarrow e$

Sample generated to look at stoppers with reconstruction.

70% π^+ are stopping or decaying at rest in this sample

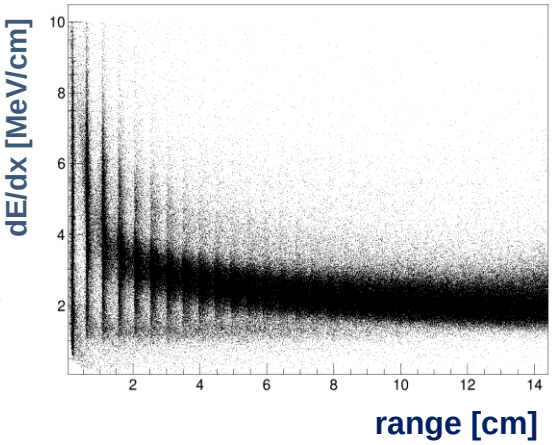
3% π^+ decaying in flight

Higher momenta expected in test-beam.

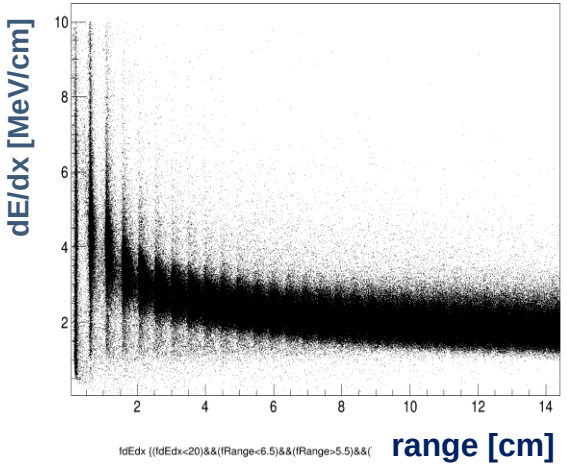
π/μ PID in low energy

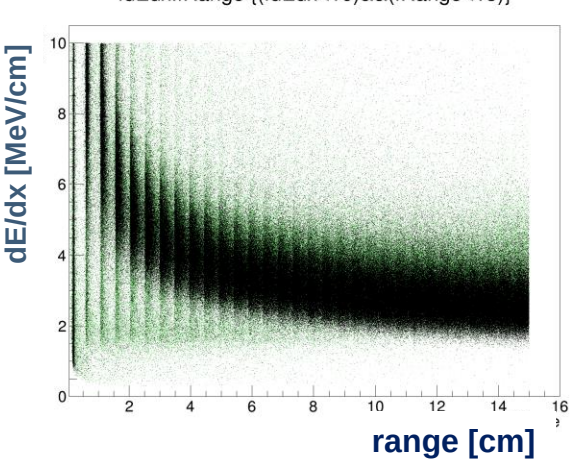
- stop/decay point detection, dE/dx-based PID
- interaction detection for π identification

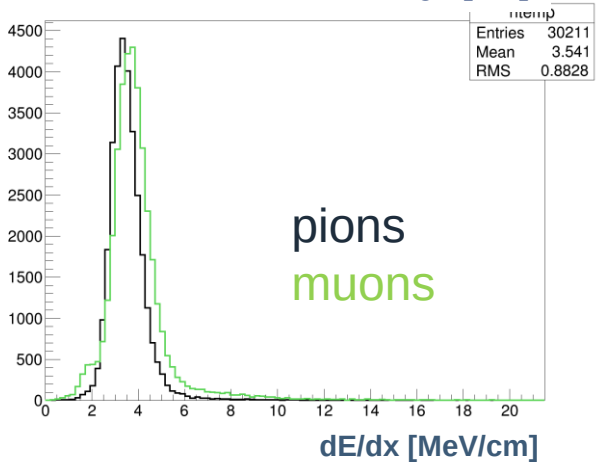
pions 0.2 GeV/c



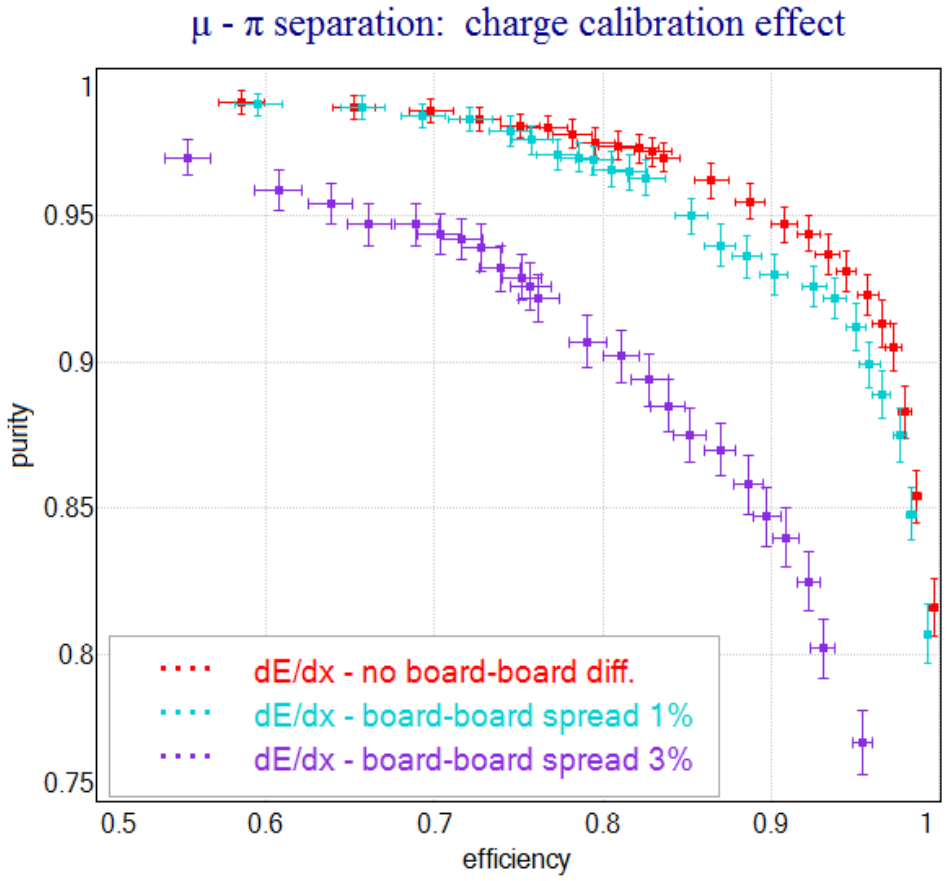
muons 0.2 GeV/c





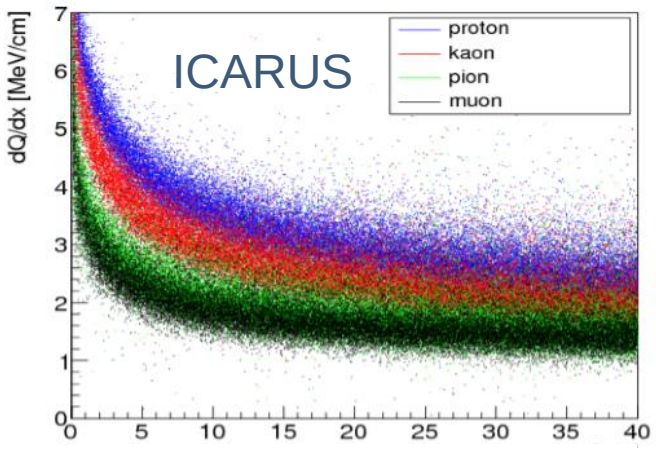


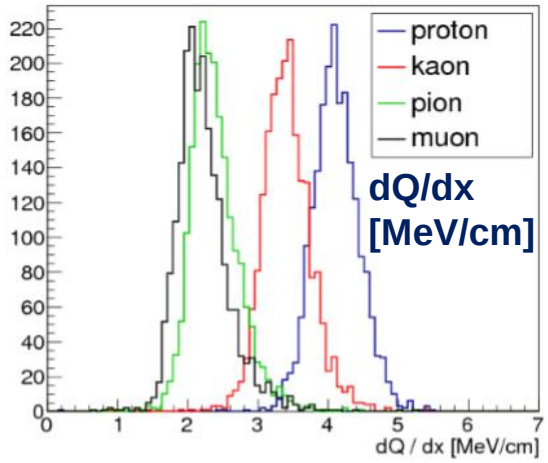
Pions/muons separation studies in ICARUS



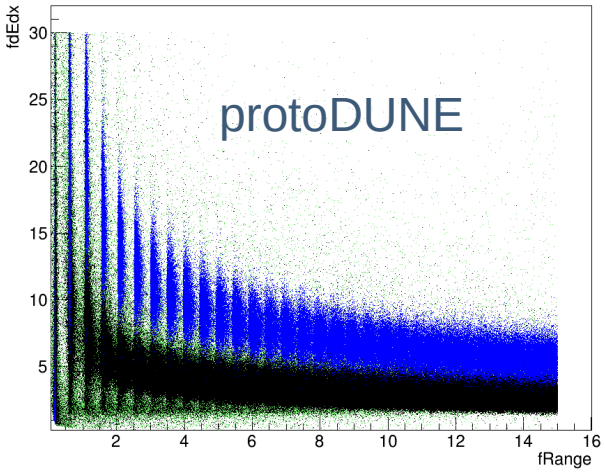
- Study of stopping π/μ separation via dE/dx was done for ICARUS (3mm wire pitch).
- Test: simulate local fluctuations of hit amplitudes at scale comparable to the length used in identification (~10cm).
- Various hardware/physical effects can lead to such fluctuations.
- *Wire-wire random fluctuations* are much less dangerous to PID than systematic scale changes over longer track sections.

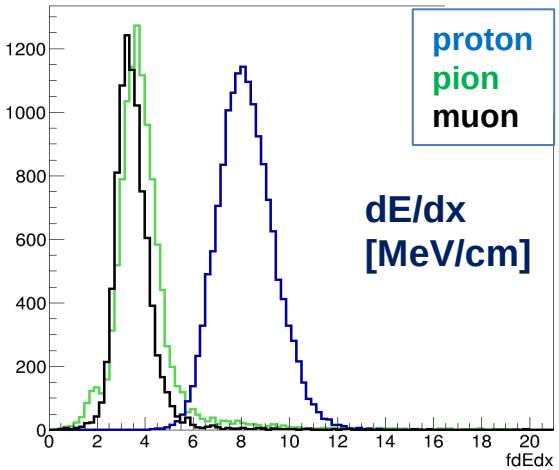
Protons/pions/muons





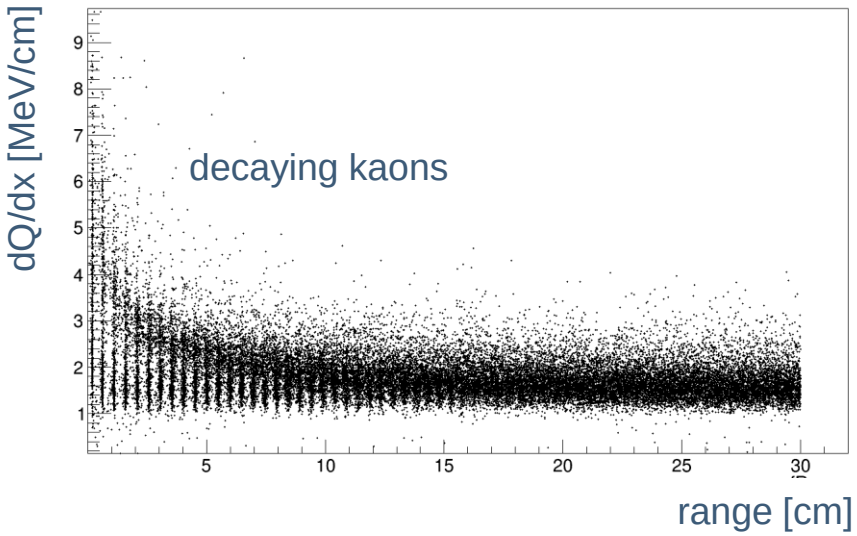
- plots from proposal; ICARUS reco/geo
- no recombination correction here
- isotropic distribution
- **idealistic simulation (no secondary particles propagated)**
- **reconstruction**

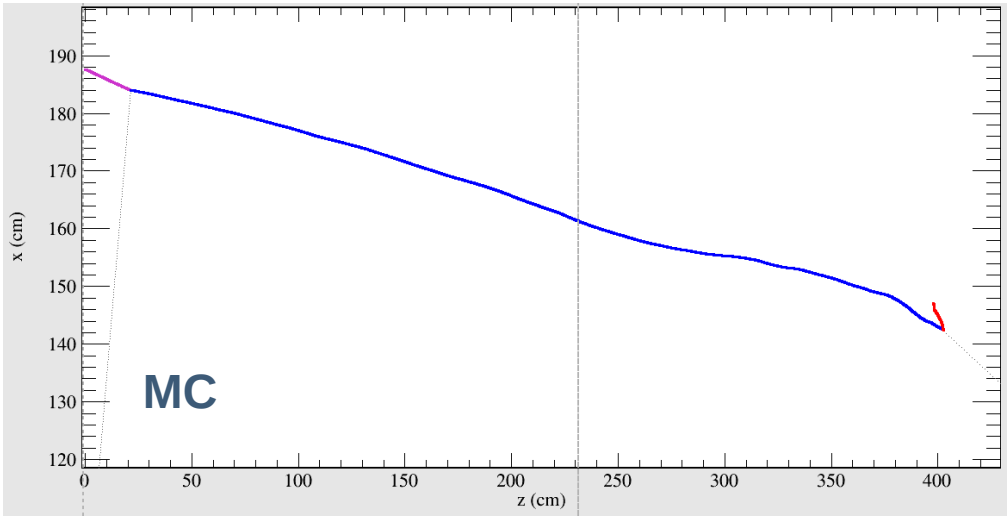


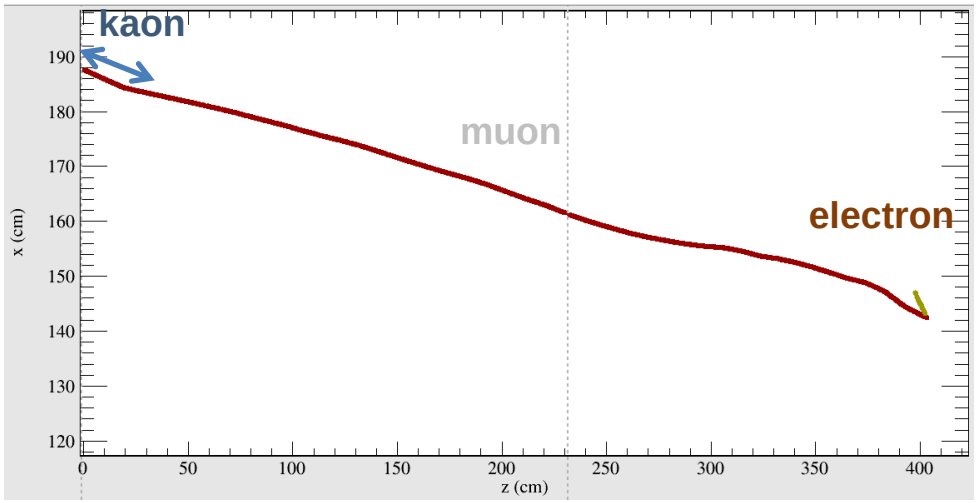


- protoDUNE geo with beam window.
- recombination correction included
- beam direction
- **realistic simulation**
- **full event structure reconstruction**

Decaying kaon reconstruction

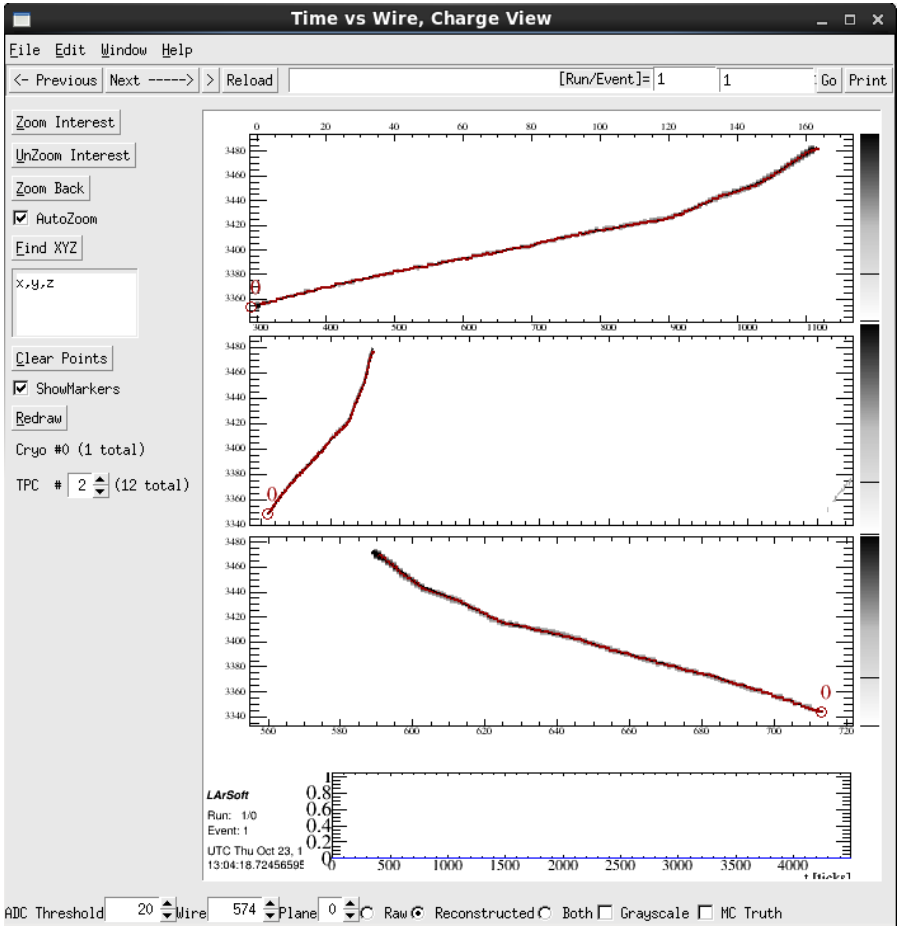


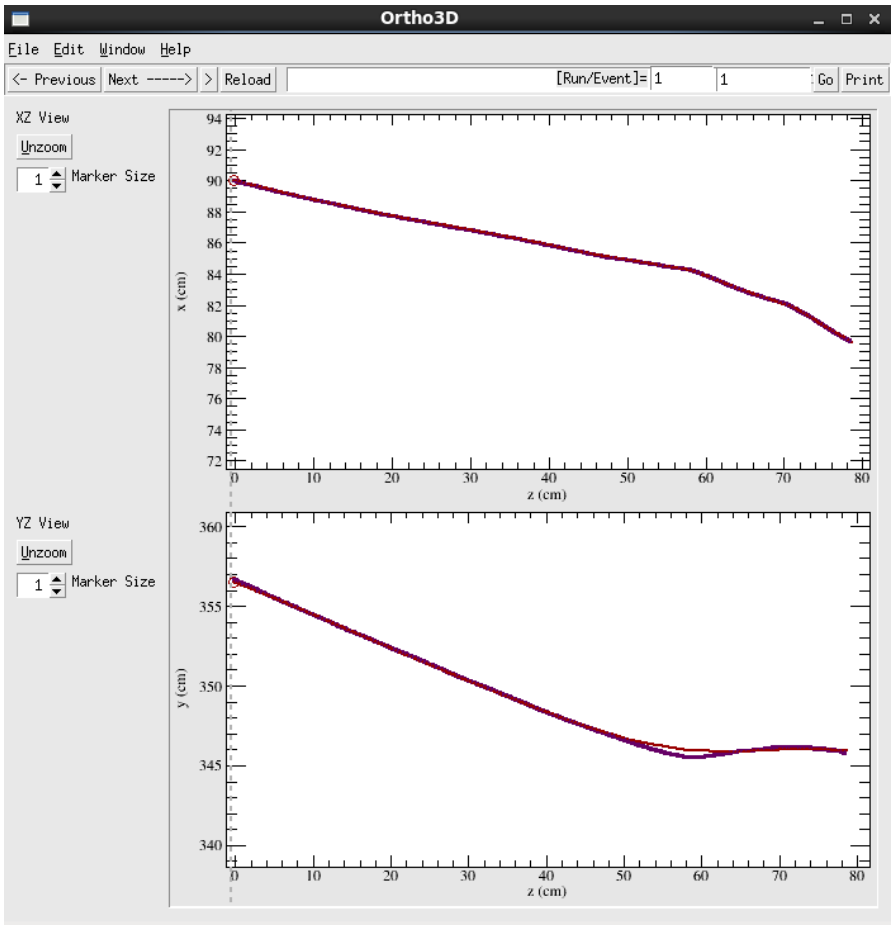




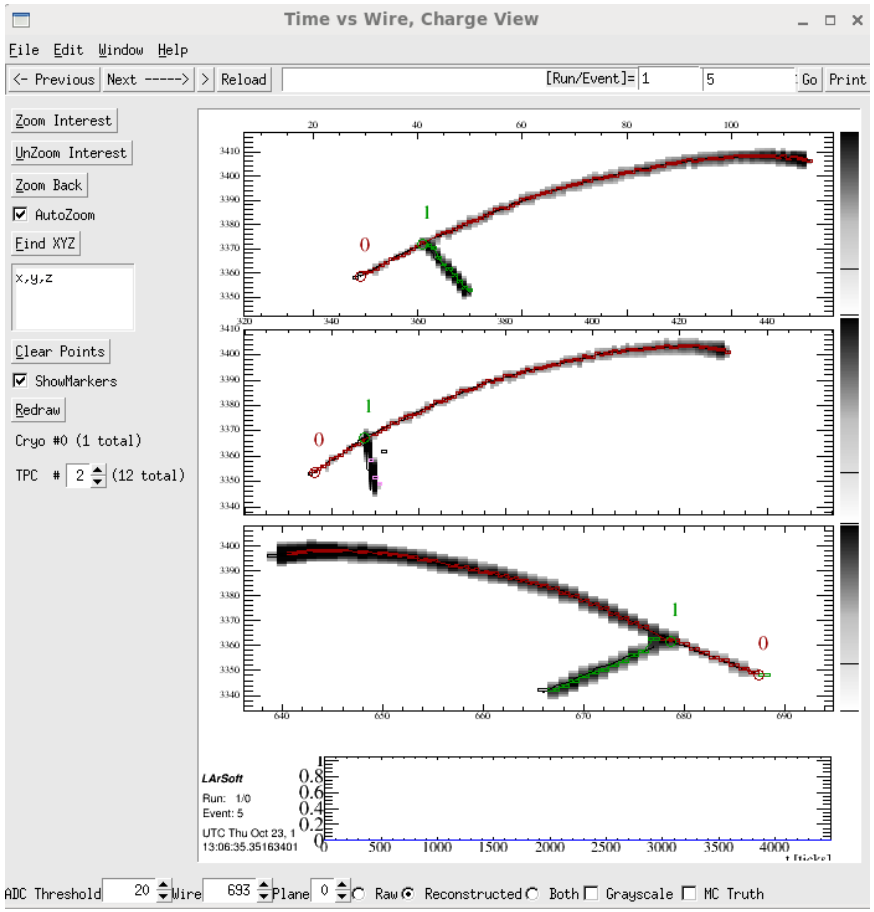
- Decay point identification needed: kaon and muon should be reconstructed separately.
- Physics: kaons crossection, test of nuclear cascades; important for proton decay (but few in test-beam).

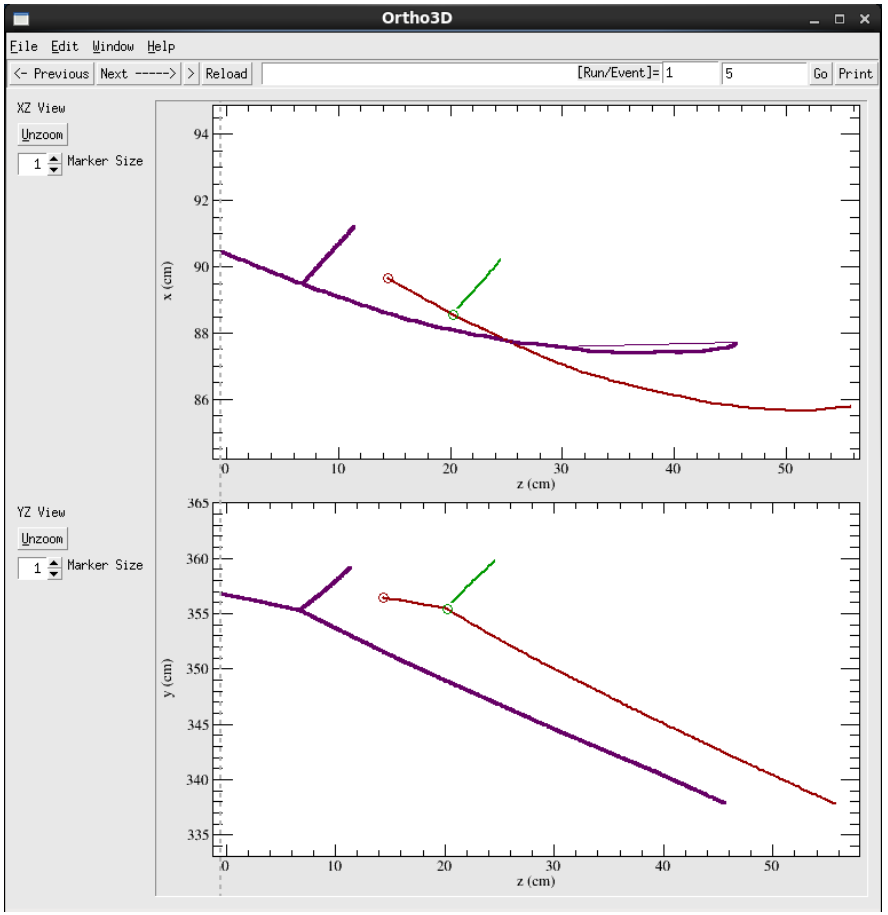
Example of proton spatial reconstruction without space charge effect





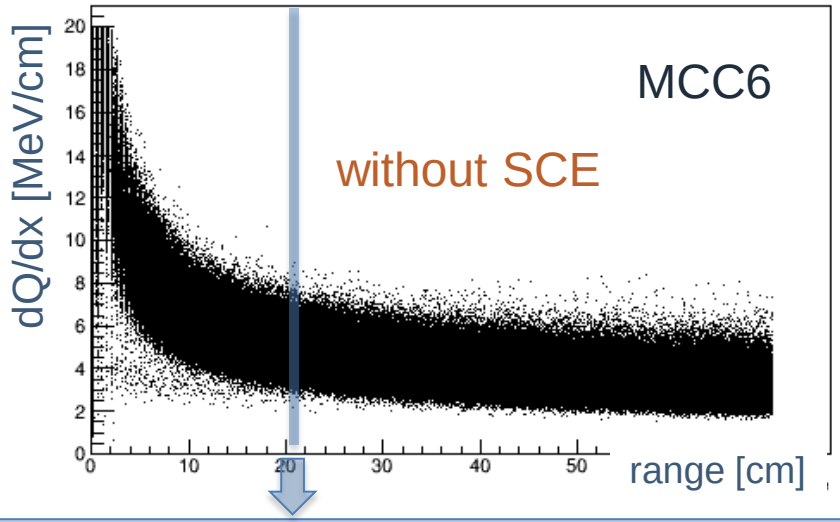
Example of proton spatial reconstruction with space charge effect (only spatial distortions)

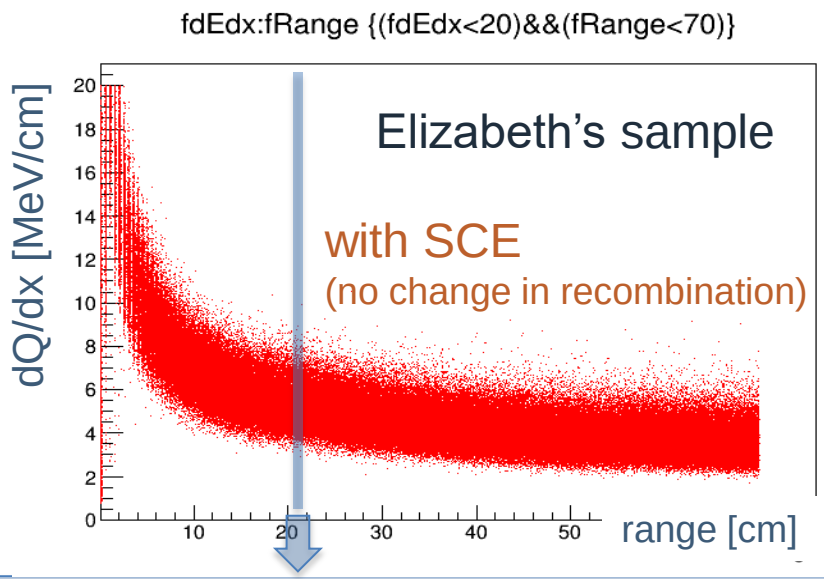


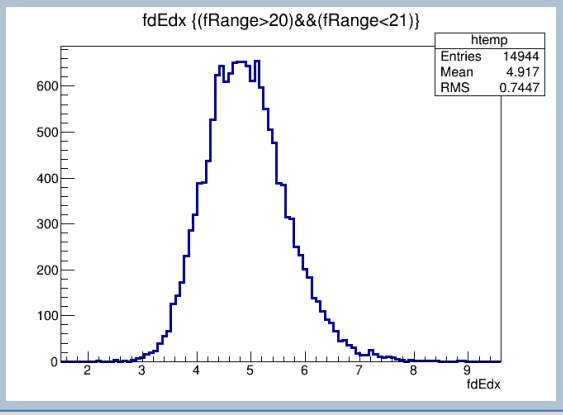


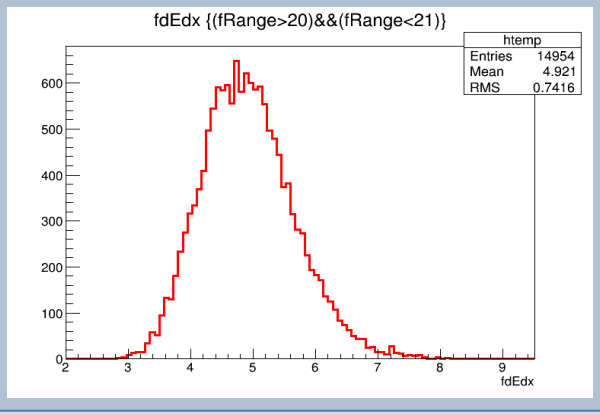
dE/dx vs range for protons (dx shrinking/stretching?)

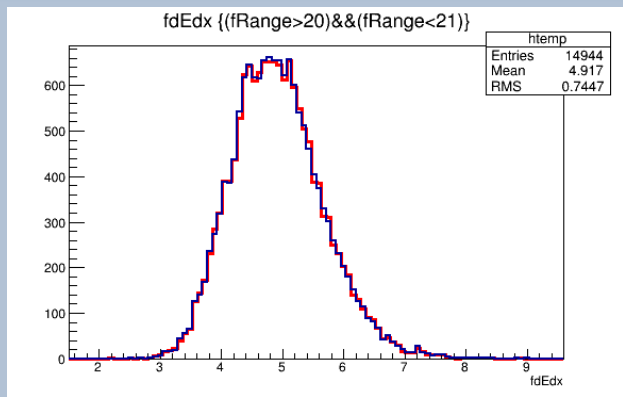
protons 1 GeV/c







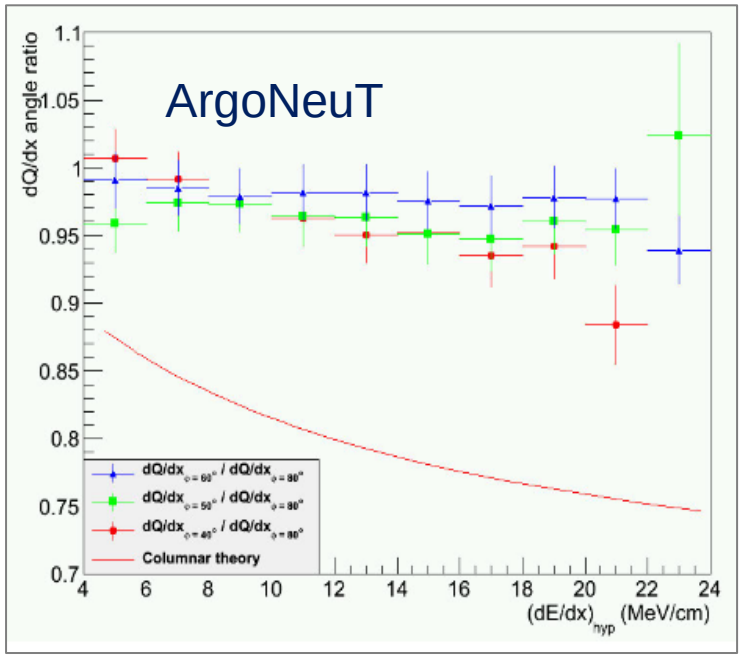




Next: include impact of SCE on recombination

Angular recombination effect

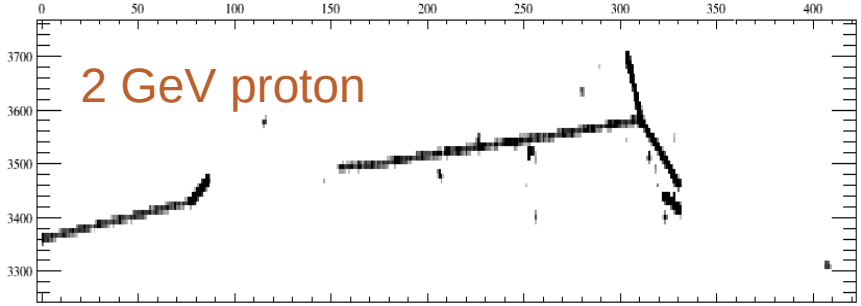
dQ/dx (55º-70º) / dQ/dx (70º-90º)
dQ/dx (47º-55º) / dQ/dx (70º-90º)
dQ/dx (20º-47º) / dQ/dx (70º-90º)



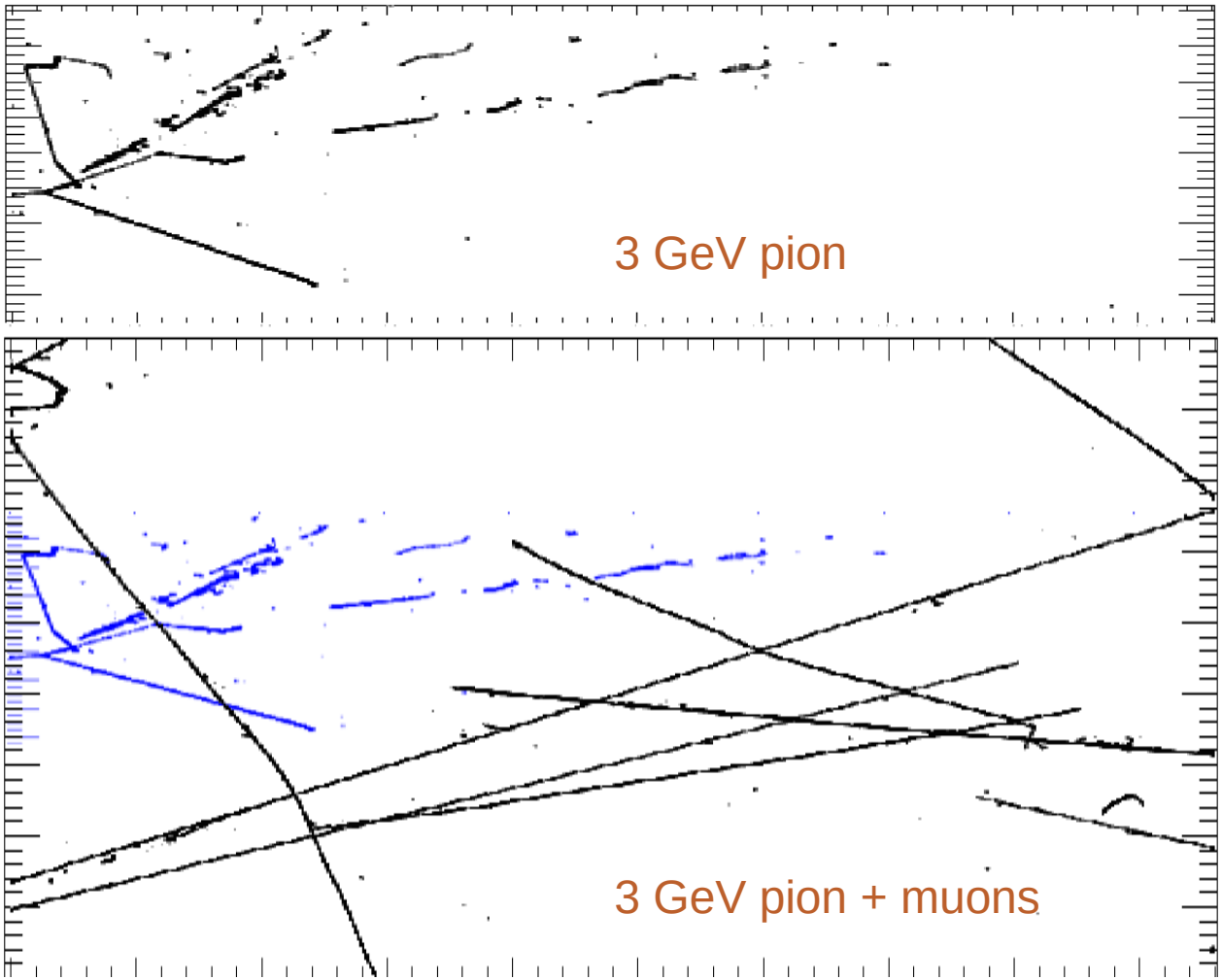
ArgoNeuT data (~3k p candidates)
from: arXiv:1306.1712

Can be studied from secondary stopping particles:

- p and π at 1-2 GeV/c produce clean secondary stopping proton tracks
- feasible to separate from secondary π
- no K produced
- but need to understand SCE

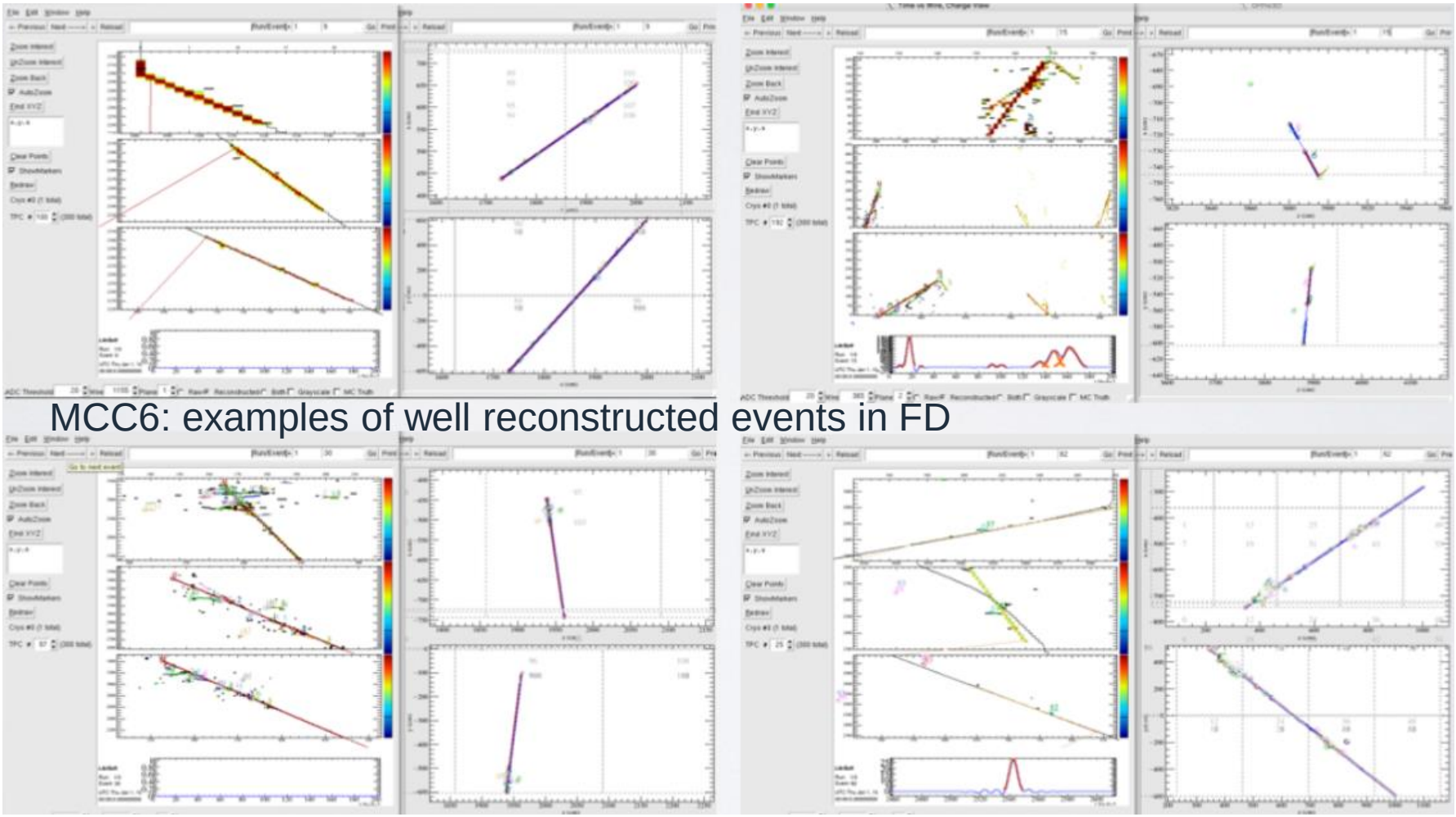


Example of particle beam interaction with cosmics



- Need to work on separation of charge deposition related to cosmic muons from beam events (never tried).
- Actual simulation of overlayed events soon.

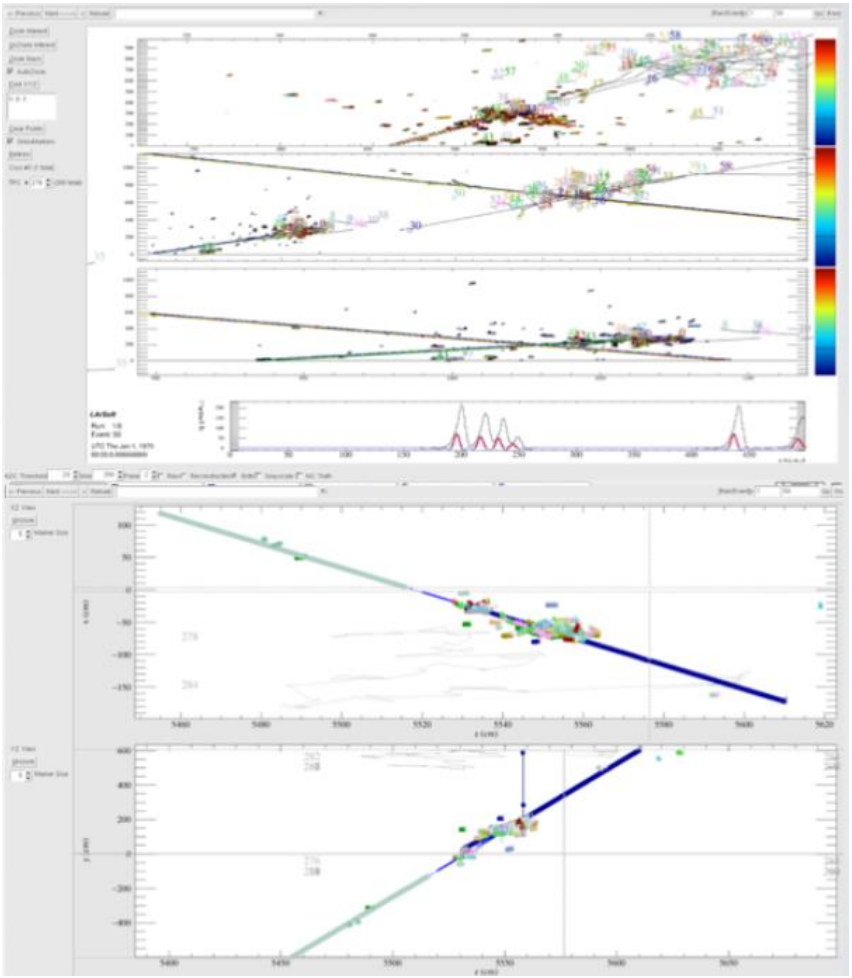
Cosmic rejection for rare physics studies



MCC6: examples of well reconstructed events in FD

pics: Matt Robinson, Vitaly Kudryavtsev, Karl Warburton from CM May 2016

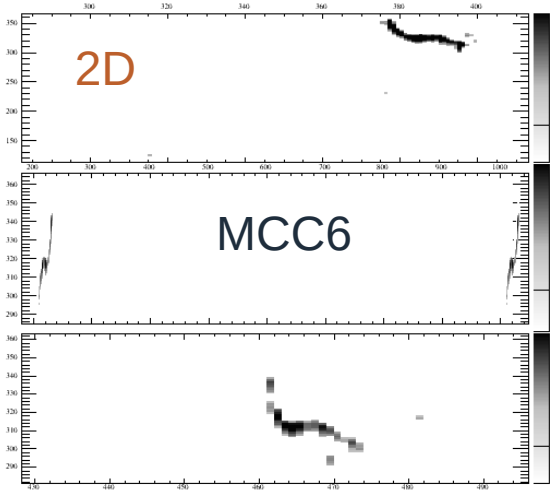
Cosmic rejection for rare physics studies

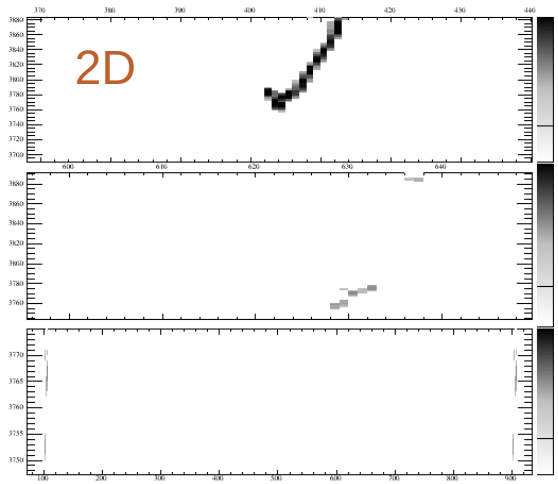


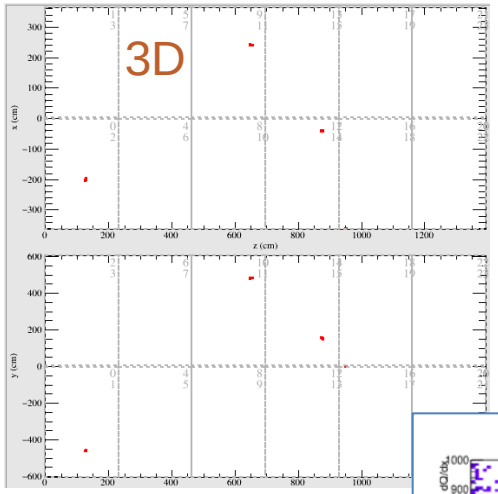
Matt Robinson, Vitaly Kudryavtsev, Karl Warburton from CM May 2016

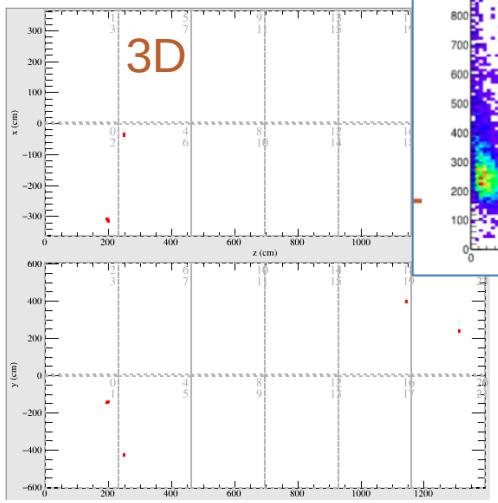
- Main difficulties come from bremsstrahlungs: pieces of a track reconstructed separately → reco development was not focused on this goal until now.
- Recent developments on shower-track splitting should help in reconstruction.
- ProtoDUNEs are very well suited for preparing tools applicable to cosmic mu rejection in FD.

Physics: supernova bursts studies

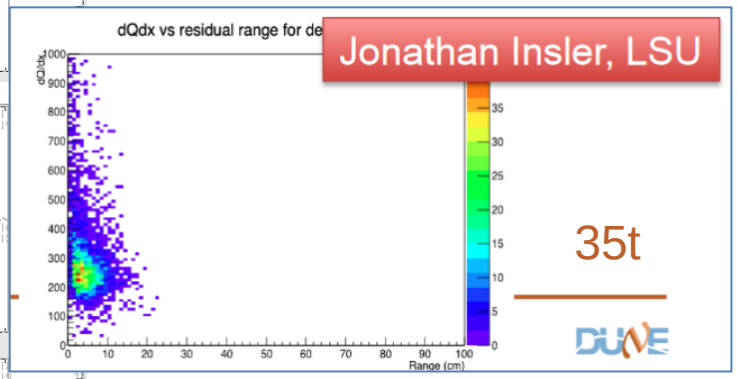








Michel electrons in protoDUNE for supernova studies



Summary

- Even starting from 1GeV/c there is a large variety of topologies: from stopping particles to complex showers.
- 1-2GeV/c is well suited to perform many tasks: from basic calibrations with π^0 to models testing (crossections, EM/hadronic) or more advanced detector studies (recombination ang. dependency); some tasks are, some are not very sensitive to SCE.
- Basic calibrations with cosmic muons seems feasible and much easier than with π^0's.
- Many reco tools exist but still a lot need to be tested and developed.
- Amount of cosmic muons seems to be possible to handle, but just first attempts were done with the reco;
- Several tools developed for protoDUNE well support FD physics goals.
- Tried to provide overview of events that we expect as input to the discussion.

Measurements tasks list:
https://docs.google.com/spreadsheets/d/1qPS5ZwaDtyrMM8GfMvcwoQjyKksz_urL4OMCYYh6yMA/edit?usp=sharing
You are very much welcome to contribute!