Reconstruction developments for DUNE and DUNE prototype

R. Sulej, FNAL/NCBJ

- also about timescales for various activities
- and on specific goals and features of DUNE detectors/prototypes

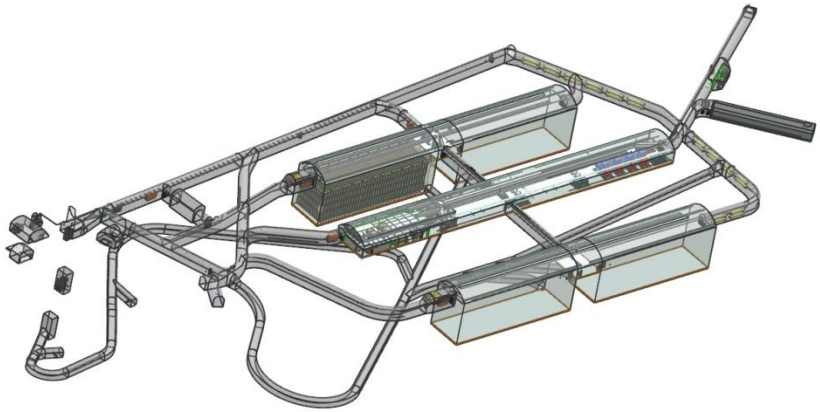
- **Some goals (and obstacles) are common with MicroBooNE**
  - noise mitigation and signal processing
  - cosmic muons tagging for ProtoDUNE and DUNE „no beam” events
  - neutrino event classification and reconstruction – apply in FD, prepare on ProtoDUNE
- **People&efforts are DUNE and MicroBooNE, …: Pandora, Wire-Cell, …**
  - appologies if I call something „DUNE” but is done for many experiments
- **Some goals and conditions are specific to DUNE Far Detector and prototypes**
  - neutrinos energy higher, events much more busy, more complicated vertex
  - underground: no cosmic μ on ν events in FD, no space-charge in FD
  - ~70 cosmic μ in each test-beam event in ProtoDUNE
  - significant space charge in ProtoDUNE
  - modularized detector design, APA readout planes in SP
  - no-beam physics (events differ): nucleon decay, supernova, atmospheric ν's, low energy neutrinos
  - ProtoDUNE measurements on the charged particles beam

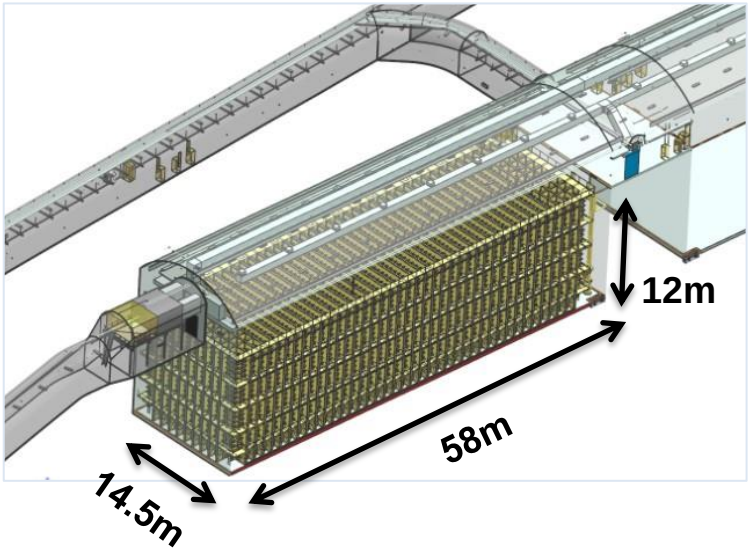
DUNE activities and timescales

- 35t data reconstruction and analysis: NOW
- ProtoDUNE TDR: NOW
- Tools for beam ν, atm. ν, SNB, nucleaon decay (according to TF schedule)
  - Detector design optimization / choice justification
  - Physics sensitivities using full sim+reco chain

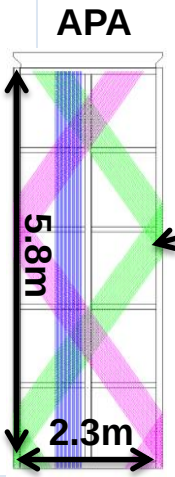
    → final report: by March 2017
- ProtoDUNE data from test beam at CERN: by 2018
- DUNE TDR writing … publishing 2019
- DUNE FD first module: 2024
- Neutrino beam to SURF: 2026

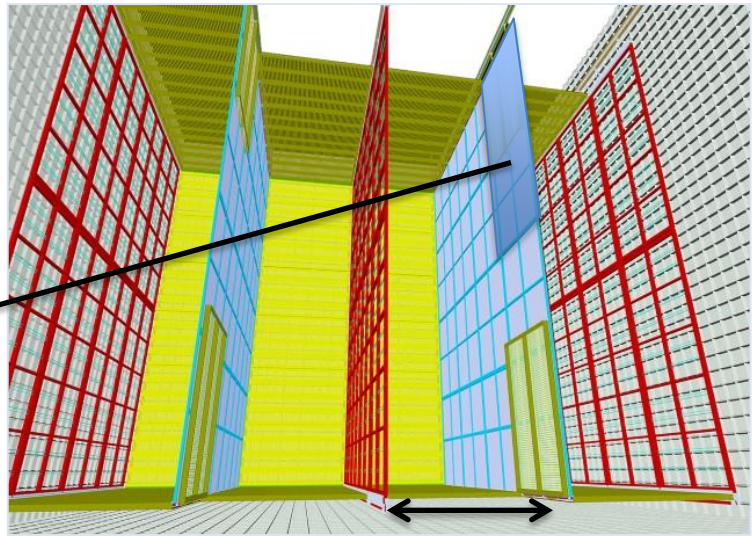
DUNE Far Detectors at SURF





- 4x 10kt modules, multi-TPC
- dual-phase – slides from Dorota
- single-phase APA readout planes:
  - **150 APA's, 300 TPC's**
  - baseline design:
    - **3.6m drift, long wires, 3 ms τ_e**
    - 1 collection, 2 induction, grid
    - „wrapped wires" of inductions
    - 4.67mm wire pitch
    - ±36° deg induction off vertial





DUNE physics

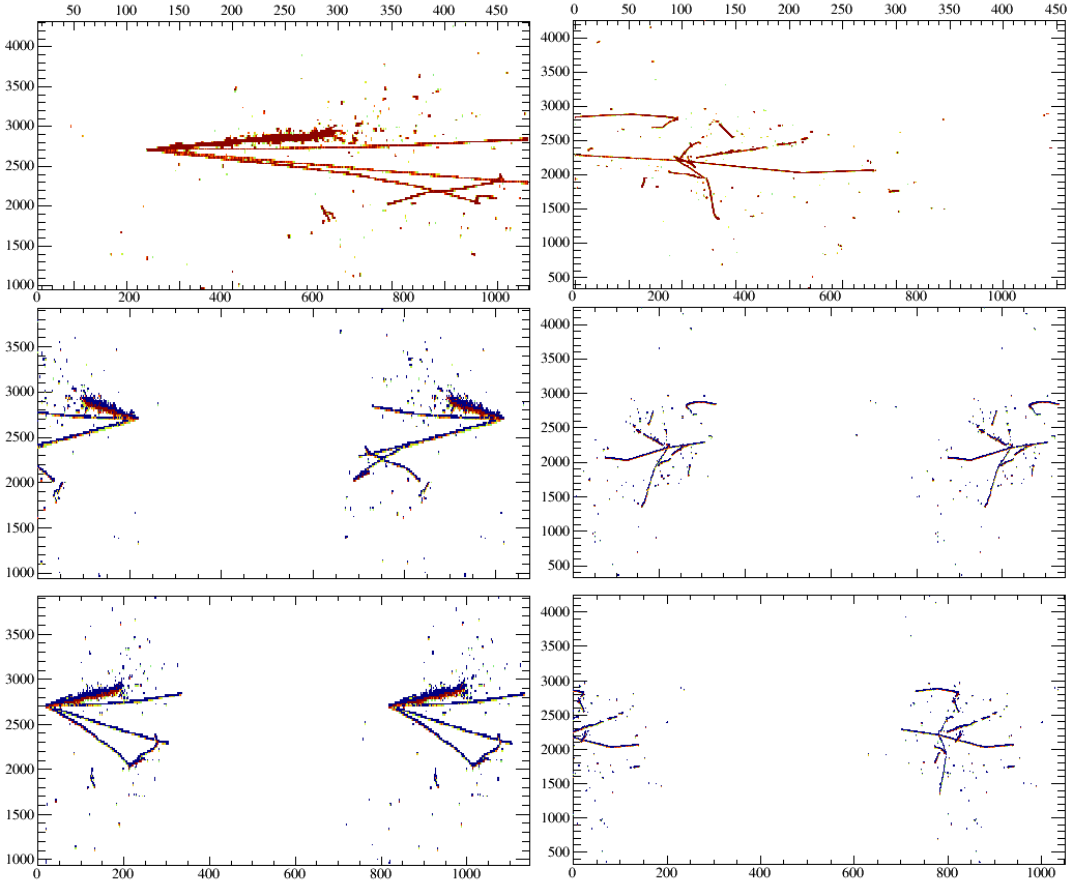
- **Long Baseline Neutrino Oscillations**
- **Sterile neutrinos**
- **Neutrino cross-sections**

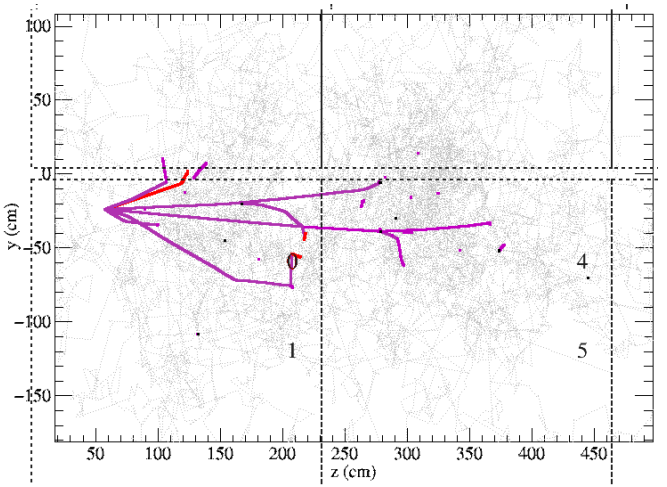
ν beam physics

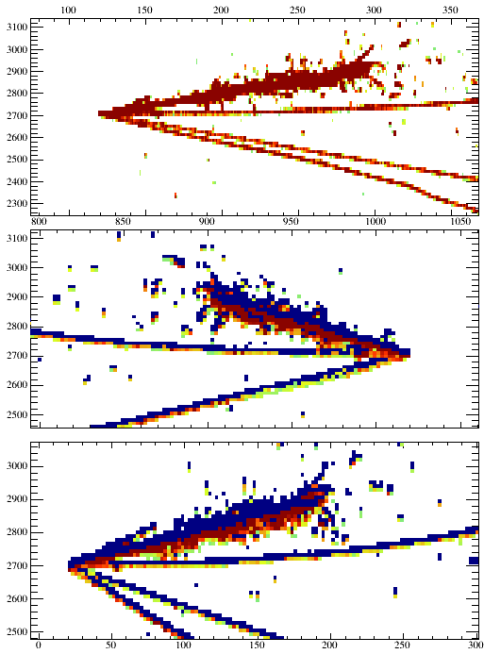
- **Nucleon Decay**
- **Neutrino Astrophysics, including supernovae neutrino bursts**
- **Atmospheric neutrinos**

no beam physics

ν_e event (beam) in multi-TPC, APA-based design of DUNE FD

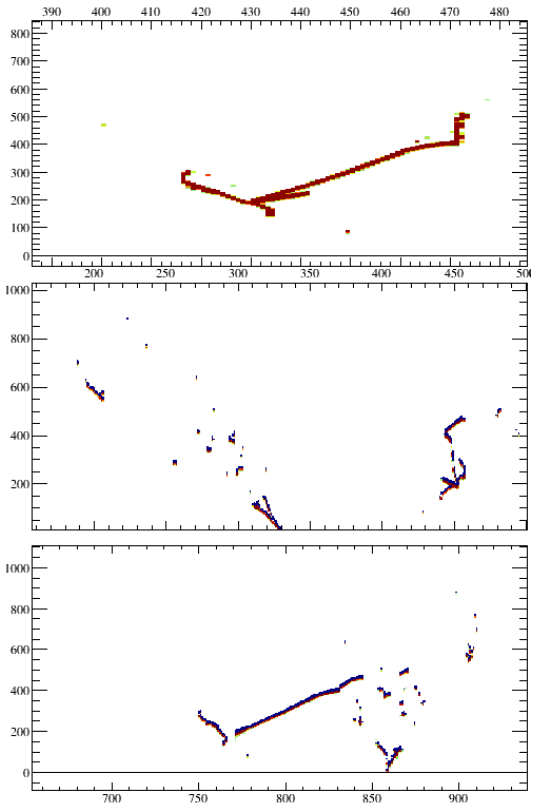




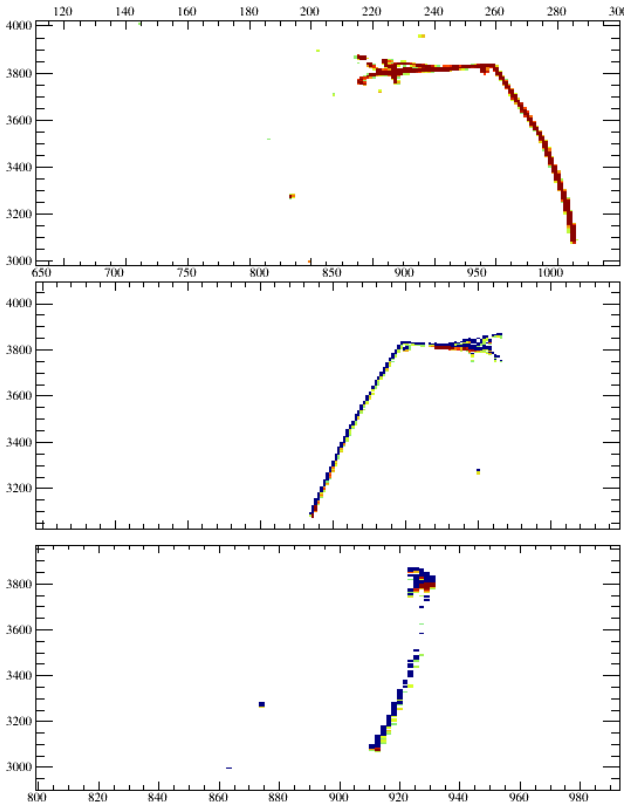


- dead regions, cross-TPC stitching neeted,
- ambiguity (busy events suffering if on both sides of APA)
- and one pro: segmented view of an event
- usual goal: **e/gamma separation is the highest priority**

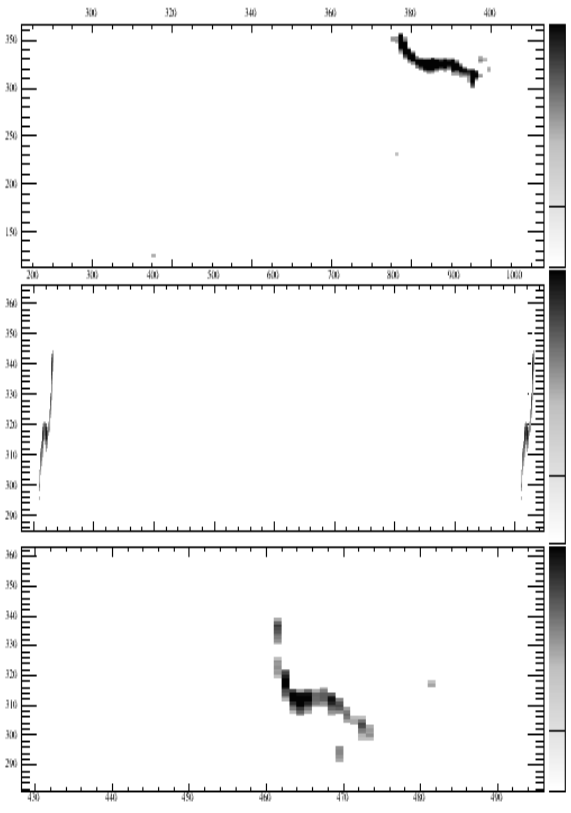
”no beam” events in DUNE FD



proton decay



atm. neutrino



SN neutrino

- mostly small events
- **need T0:** photon detection correlated to TPC event, drift distance measured via diffusion
- low energy, high efficiency PID, … - all need very precise reconstruction

Reconstruction milestones for DUNE FD, DUNE priorities summary

- **e / gamma separation in full event**
- **neutrino energy estimation**

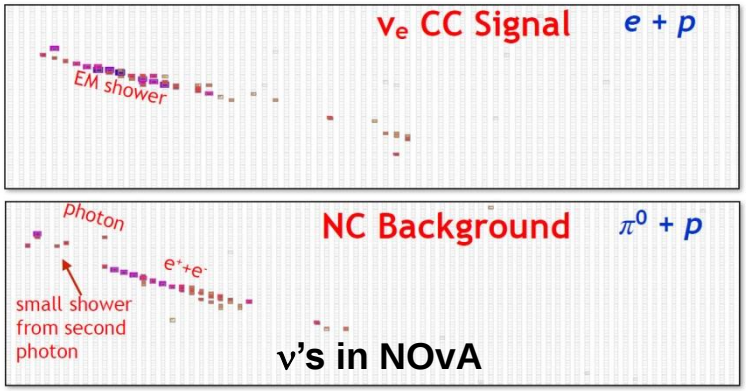
the key is **PATTERN RECOGNITION**

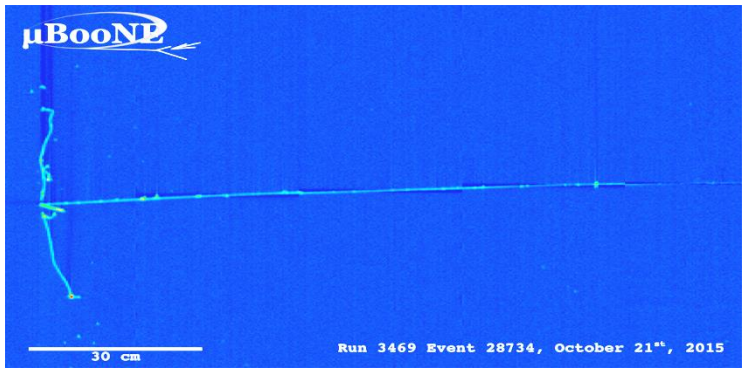
→ higher resolution than NOvA:

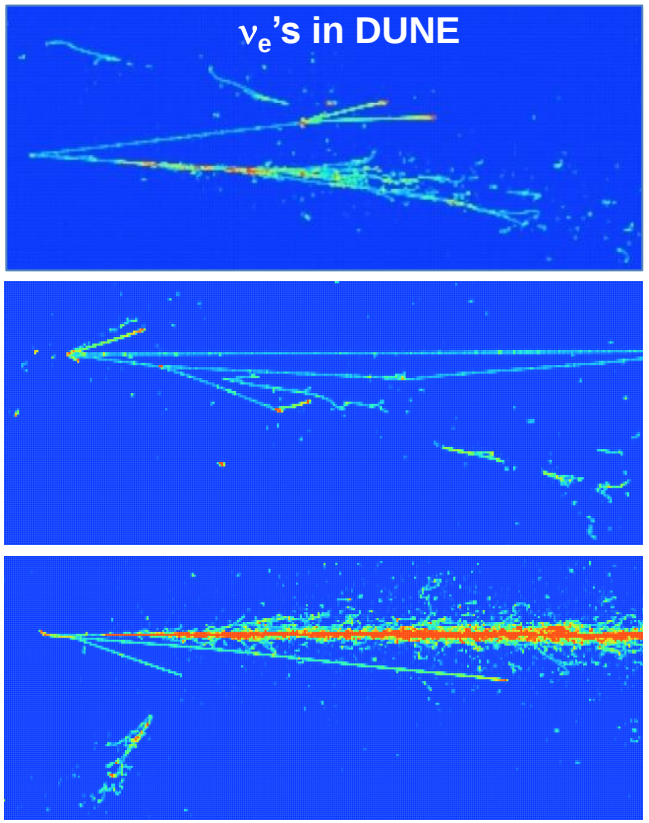
→ higher energy than NOvA & uBoone:

O(100) more data for ν_e selection

more busy & complex topologies





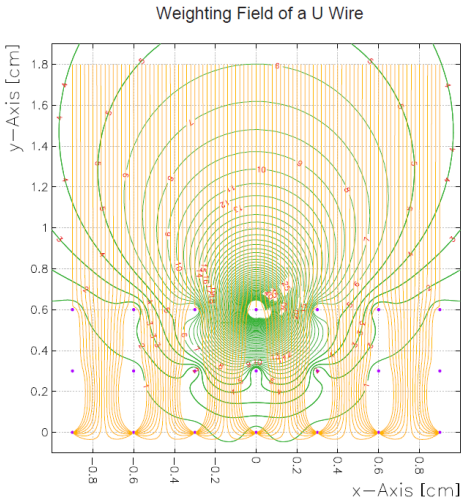


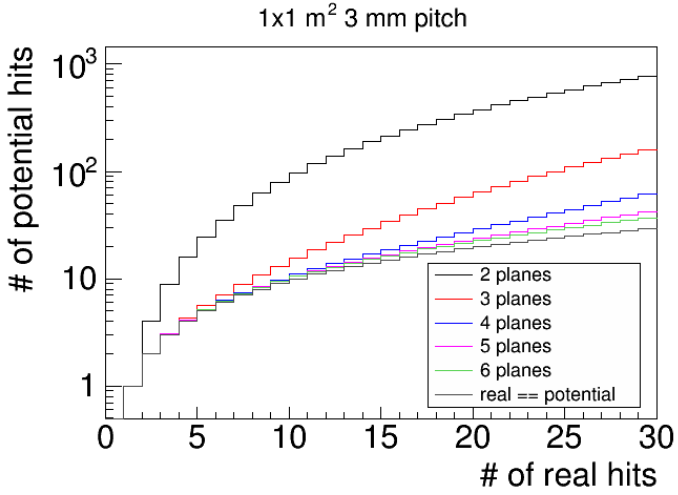
Reconstruction milestones for DUNE FD

- realistic wire signals simulation: implementation of induction effects with 2D approx. done in Wire-Cell, **need them in LArSoft**;
- noise patterns, noise levels: room to make models / sim tools / and filters

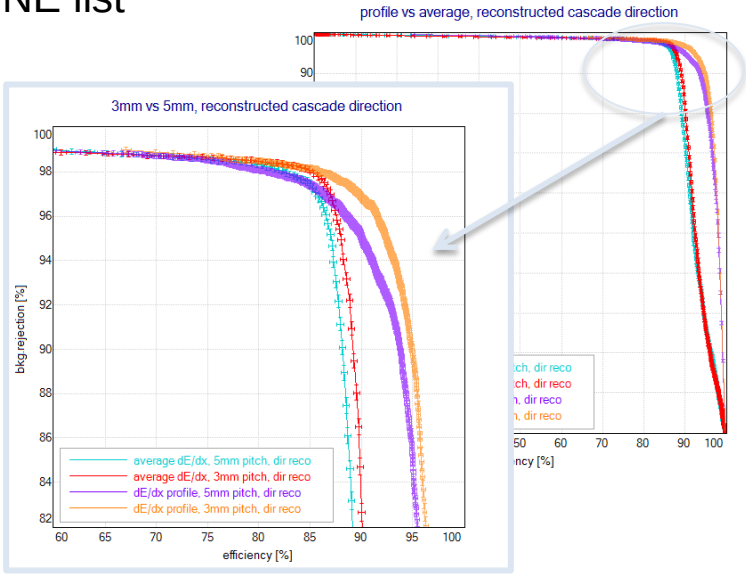
- **e / gamma separation in full event** (recognition of electron candidates, dE/dx and „gap" in ν vertex realm): lack of this forces studies with simplified or toy MC's

- **neutrino energy estimation** → some overlap with ProtoDUNE
- **number of „general purpose" goals** → see ProtoDUNE list





hit association ambiguity in X-plane geometry
„single" hits, no 2D correlations, attempts to quantify impact of having just 2 or 3 (or 4?) planes



e/gamma separation by dE/dx
isolated showers plus attempt to mimic crowded vertex issues

Detector simulation / event reconstruction chain in DUNE FD

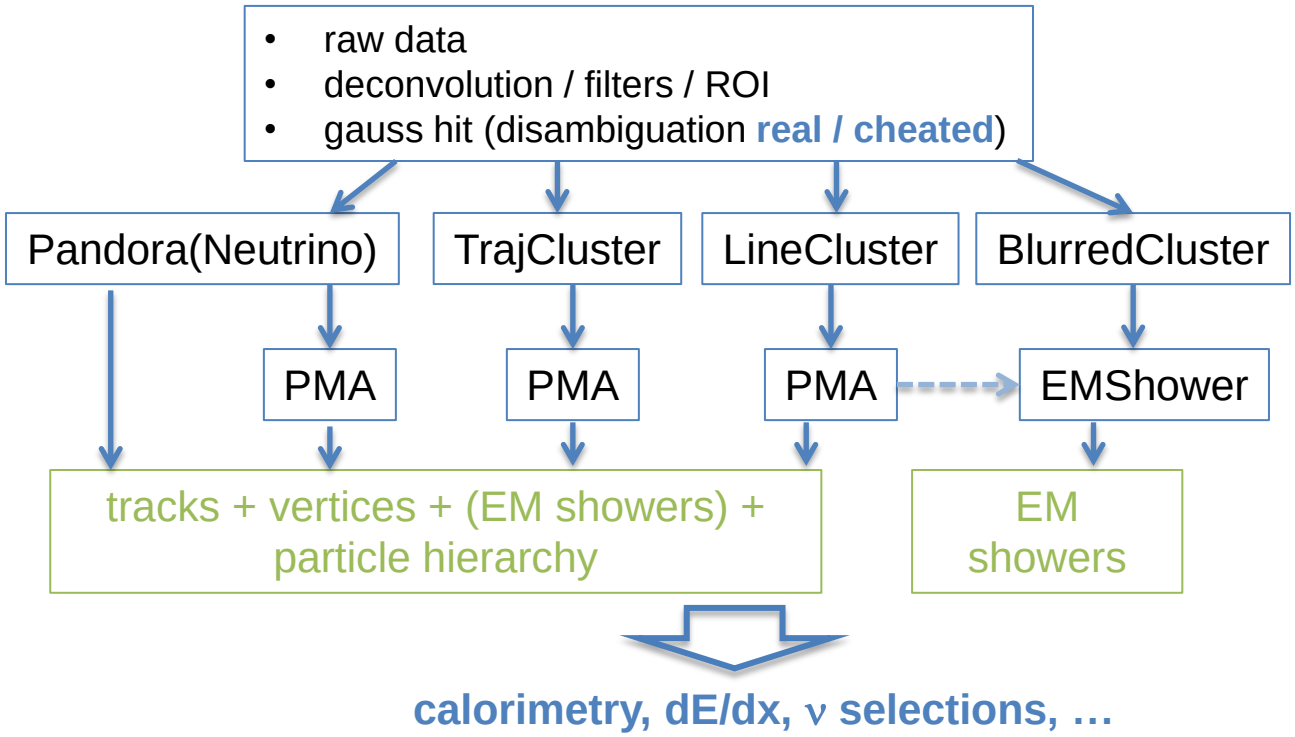
with respect to MicroBooNE (see Wes slides from the previous meeting):

- all done on *simulations* (real data only from 35t)
- *purpose*: tools for physics goals / detector design optimizations
  - many studies on single particles, we also keep more reco paths to test dedicated algorithms
  - series of MCC which progresively cover more DUNE physics goals (as more simulation tools appear), feedback from analysis groups, …
- \- cosmic muon pass (underground FD)
- \+ disambiguation step needed for APA wrapped wires
- \+ TPC stiching

hit finding/fitting

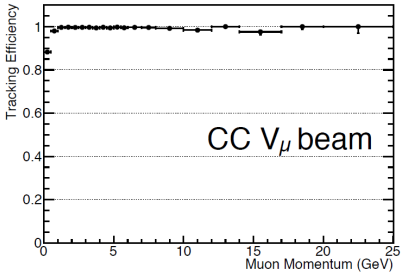
clustering

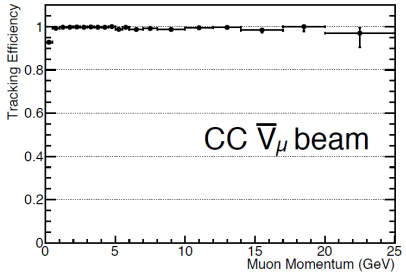
tracking & shower reco

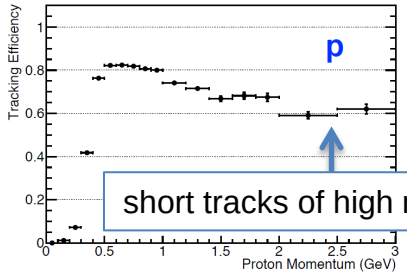


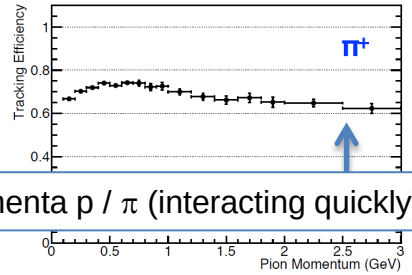
MC challenges

Only preview of tracking eff. in neutrino events from A.Higuera, see [full set of MCC7 results] (includes also first look at DP):



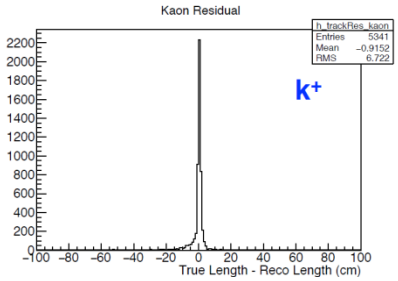


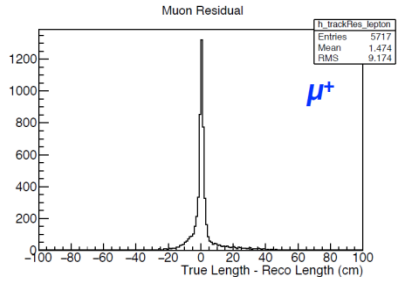


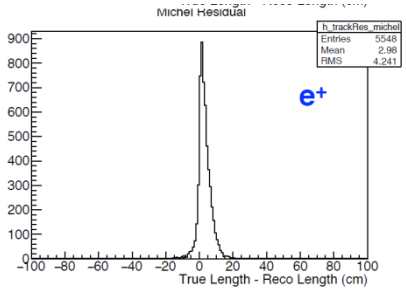


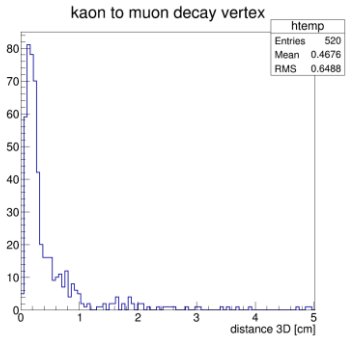
short tracks of high momenta p / π (interacting quickly)

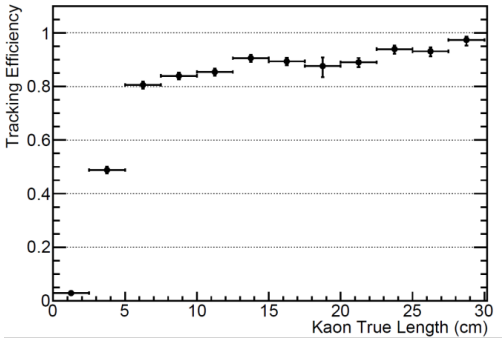
Tracking Residuals Proton Decay, p → K+$\bar{\nu}$

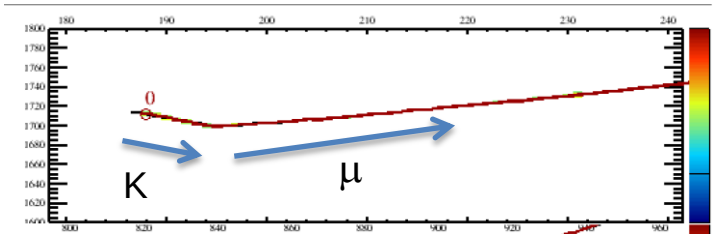


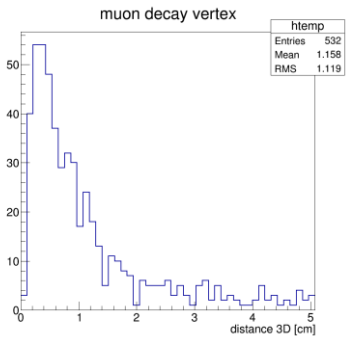






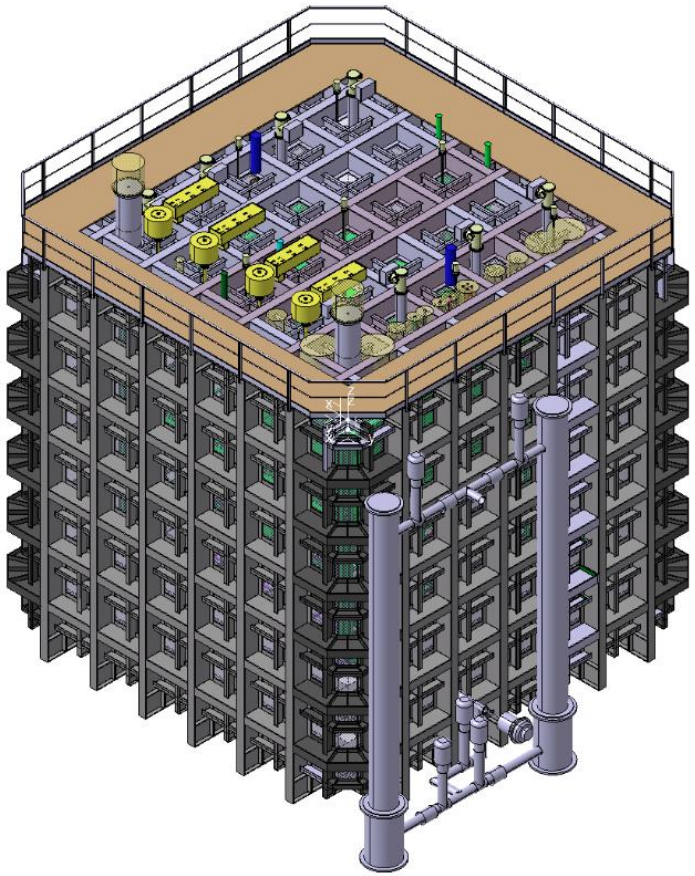


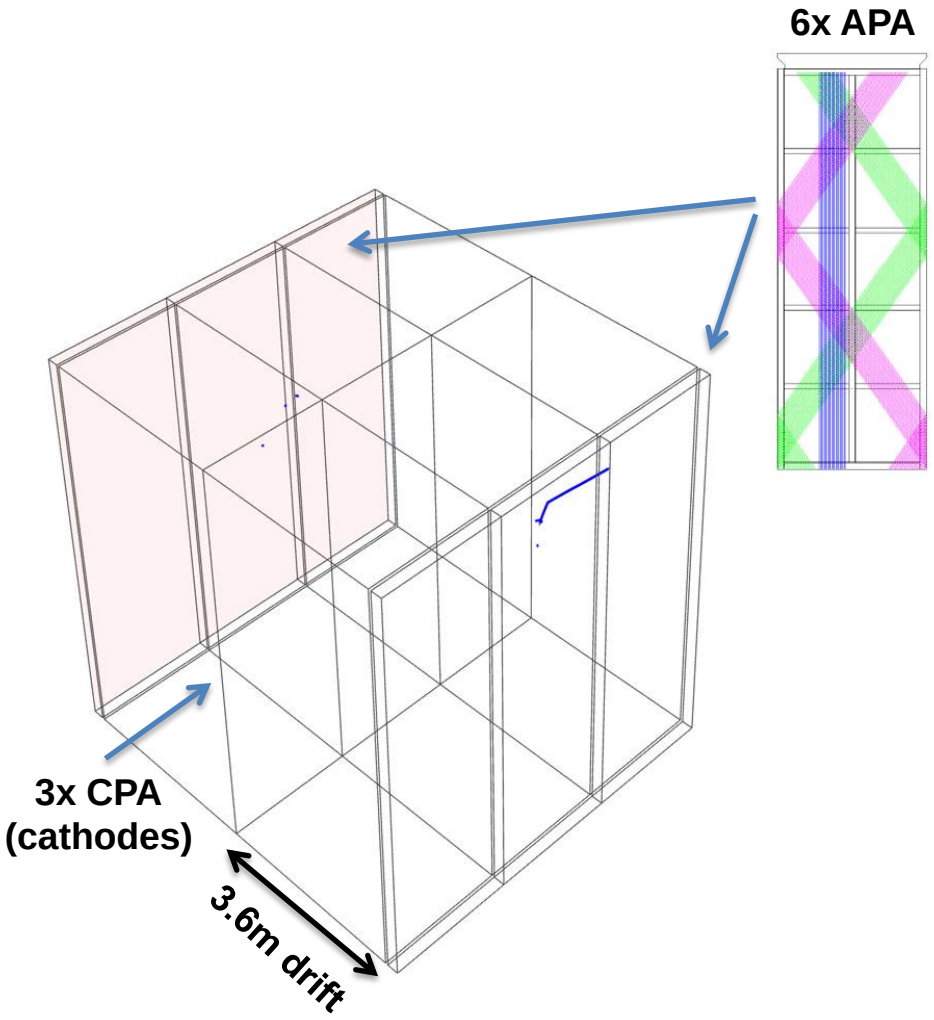




μ track likes to continue and eat part of electron
K dacay likes so be missed and μ track includes K
…but if pattern reco OK, then 3D can go to sub-pitch resolution

ProtoDUNE-SP at CERN



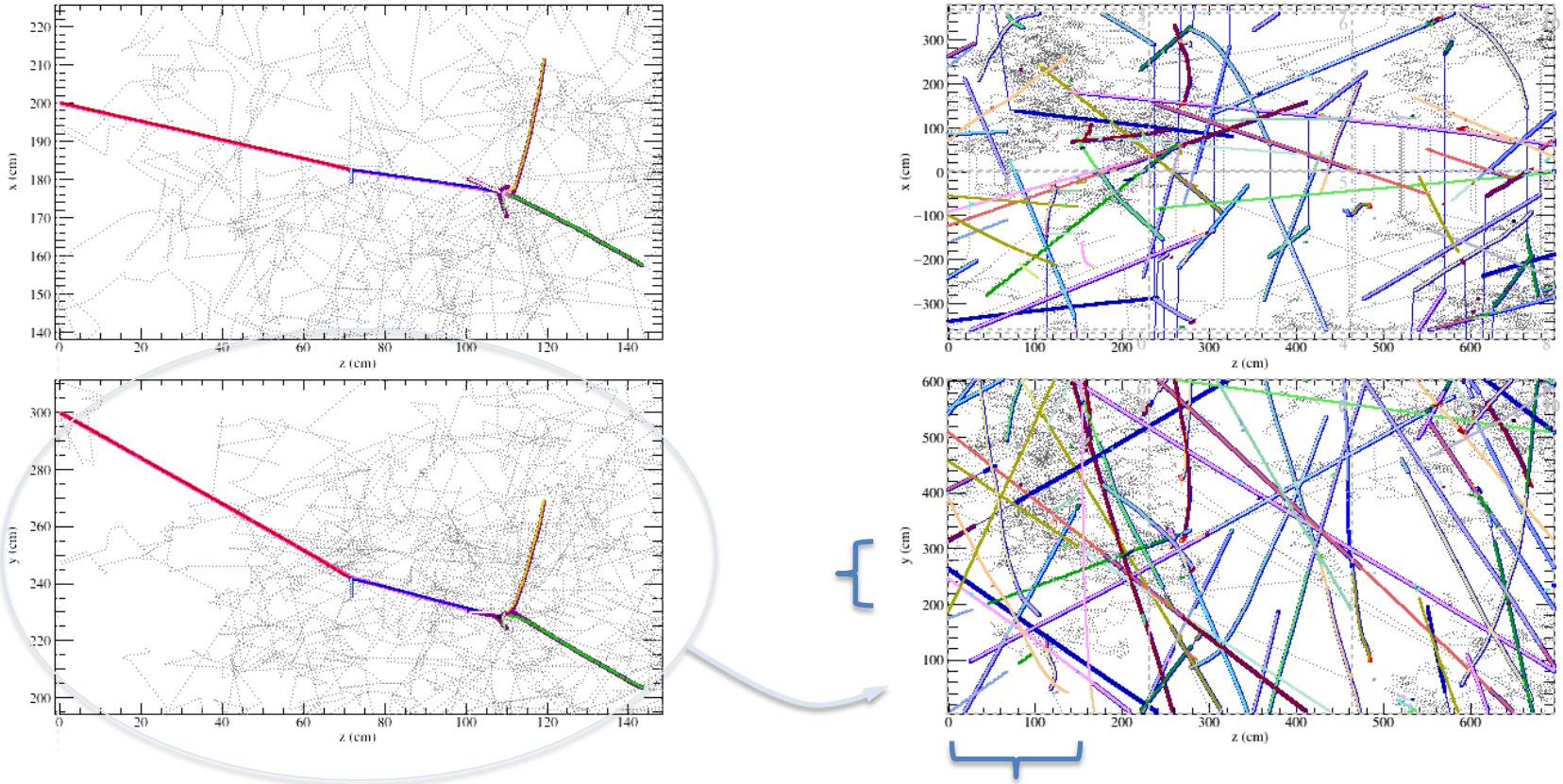


- the same components as FD, ~700t LAr, 6 TPC, wires wrapped (but no ambiguity)
- **on surface**
- **on test beam**

ProtoDUNE beam particle together with cosmic μ's

proton 2 GeV/c (fraction of TPC)

cosmic μ's (all TPC's, no beam halo here)



- small events, big events, beam events, cosmic μ events: **all to be used for measurements and calibrations**
- need photon detection correlated to TPC event: to the max. possible in such conditions

ProtoDUNE: calibrations and data-MC for FD physics

proposed:

- **electron showers**
- **muon energy scale**
- **hadron energy scale**
- **missing energy in hadron events**
- **ADC to energy, uniformity**
- **diffusion, E-field response**
- **e/gamma separation** (π^0 rejection)
- **recombination ang. dependency**
- **PID (stopping/low energy)**
- **calibrations/monitoring with μ**
- **NDK related studies**

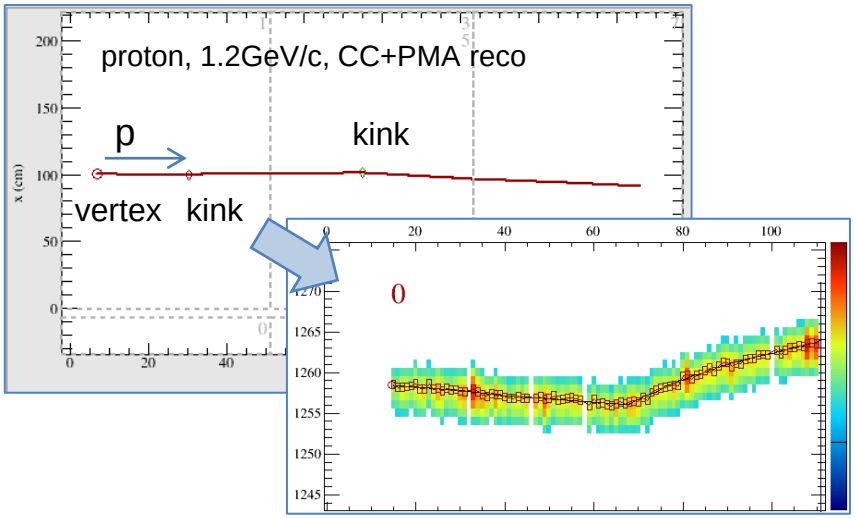
→ not everything will be possible with the beam time constraints
→ no people to cover all tasks

→ select what is the highest priority & doable given ProtoDUNE conditions

ProtoDUNE physics opportunities

- **EM fraction in hadronic shower**
- **exclusive crossections, hadronic interactions multiplicity, pi0 prod. models**
- **pi crossections**
- **hadron showers topology**
- **kaons (if available, not likely…)**

Side note



- attempts to find all interactions with „standard" reco
- and with CNN based raw ADC processing

→ not everything will be possible with the beam time / momentum constraints
→ MC models validation overlaps with „physics for DUNE FD"

→ select what is the highest priority & doable given ProtoDUNE conditions

ProtoDUNE reconstruction tasks

→ for measurement goals
→ with FD overlap

- **signal processing**
  - 1D/2D noise reduction
  - 1D/2D deconvolution

→ e / γ (π^0 rejection)

→ *all other reco…*

- **cosmic muon tracks reconstruction**
  - selection of topologies: wire-plane-crossing, stopping, …
  - subtraction of charge overlayed with beam event
  - association of surrounding EM activity
  - integration with muon tagger data

→ μ -based calibrations
…and all ProtDUNE measurements

- **CNN-based pattern recognition**
  - selection of EM component
  - decay / interaction vertex location
  - identification / location of „clean" event (stopping cosmic mu, maybe similar idea for beam)

→ μ -based calibrations
π^0 -based calibrations
e / γ (π^0 rejection)
NDK (decays, vertex)
MC models

- **particle hierarchy reconstruction**
  - integration with beamline particle reco
  - interaction channels classification
  - shower categhorization

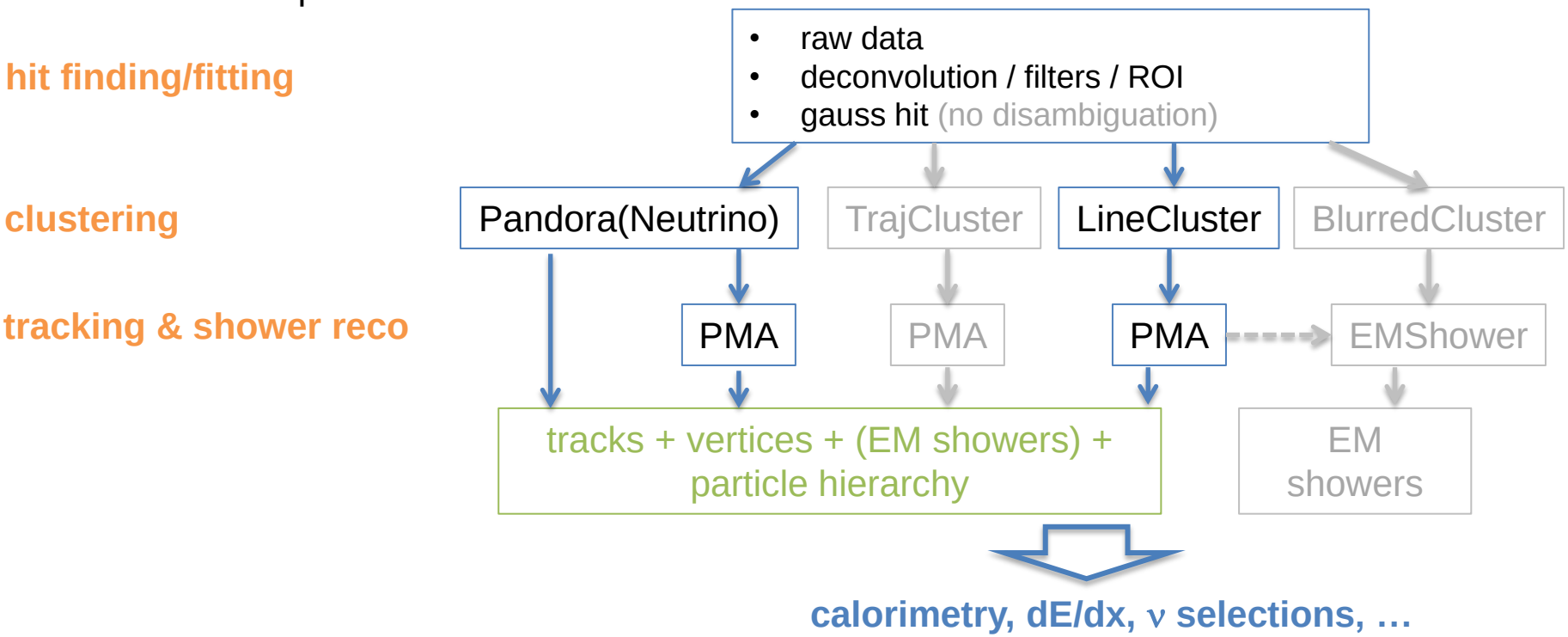
→ crossections
energy scales
MC models
missing energy

→ **See posted PhD project on machine learning for LArTPC at CERN!**

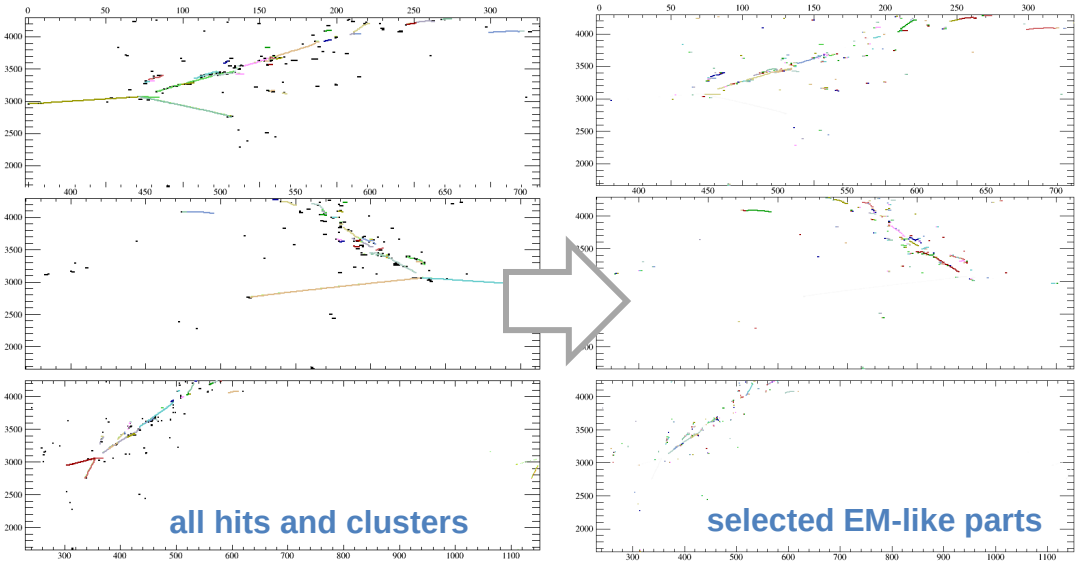
Detector Simulation / event reconstruction chain in ProtoDUNE

with respect to DUNE FD configurations:

- *purpose*: tools for calibrations / detector response characterization / measurement goals
  - the same as FD: many studies on single particles, more reco paths to test dedicated algorithms
  - just starting with MCC(6 & 7) – launched together with FD, beam particle samples, cosmic muons, overlayed samples (note: 100-event file = 20GB!)
- cosmic muon pass: to be defined, testing muon tracking efficiency, μ-related EM activity selection not yet developed
- - disambiguation step (only 1 side of each APA used)
- - not all FD paths used now

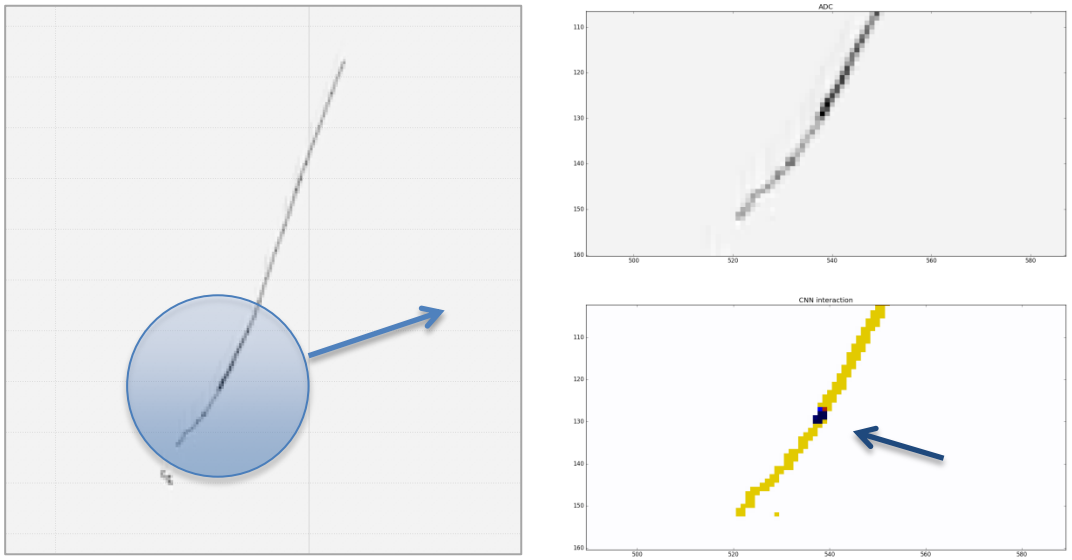


CNN-based pattern recognition in DUNE and ProtoDUNE



EM-like vs track-like ID:

- integrated with LArSoft
  (but not yet in MCC reco chain)
- **96.2%** track / **96.6%** EM correct cluster ID rate (2GeV/c π^+ like events in ProtoDUNE)
- EM selection in ν_e events – need dedicated model, started, usual data issues: O(100GB) training



co-linear particles – typical source of standard tracking confusion

Vertex and decay point finding:

- muon → electron decay works
  important for calibrations
- next:
  <u>kaon decay for NDK</u>
  missed interactions for x-sect
- ν selectrion: big data – need many events, progressing

Summary

Most pressing reconstruction issues:

- Pattern recognition for ν_e selection
  → CNN based approach ongoing, lot of juggle with data
- Neutrino energy reconstruction
  → use ProtoDUNE for several aspects

- Wire signals simulation (LArSoft implementation)

Number of more „specialized" reco goals:

- Low eneregy neutrino reconstruction tools (FD)
- „Narrow" pattern recognition tasks: EM/track, decays, interaction vtx (FD, ProtoDUNE)
- Detailed study of particle hierarchy reco capabilities (ProtoDUNE, then useful also in FD)
- Cosmic muon based calibrations (ProtoDUNE, then useful also in FD)
- Cosmic muon subtraction from test beam (ProtoDUNE)
- Faster CNN inference implementation (just work on code)
- …