Detector model and reconstruction systematics constrains with ProtoDUNE

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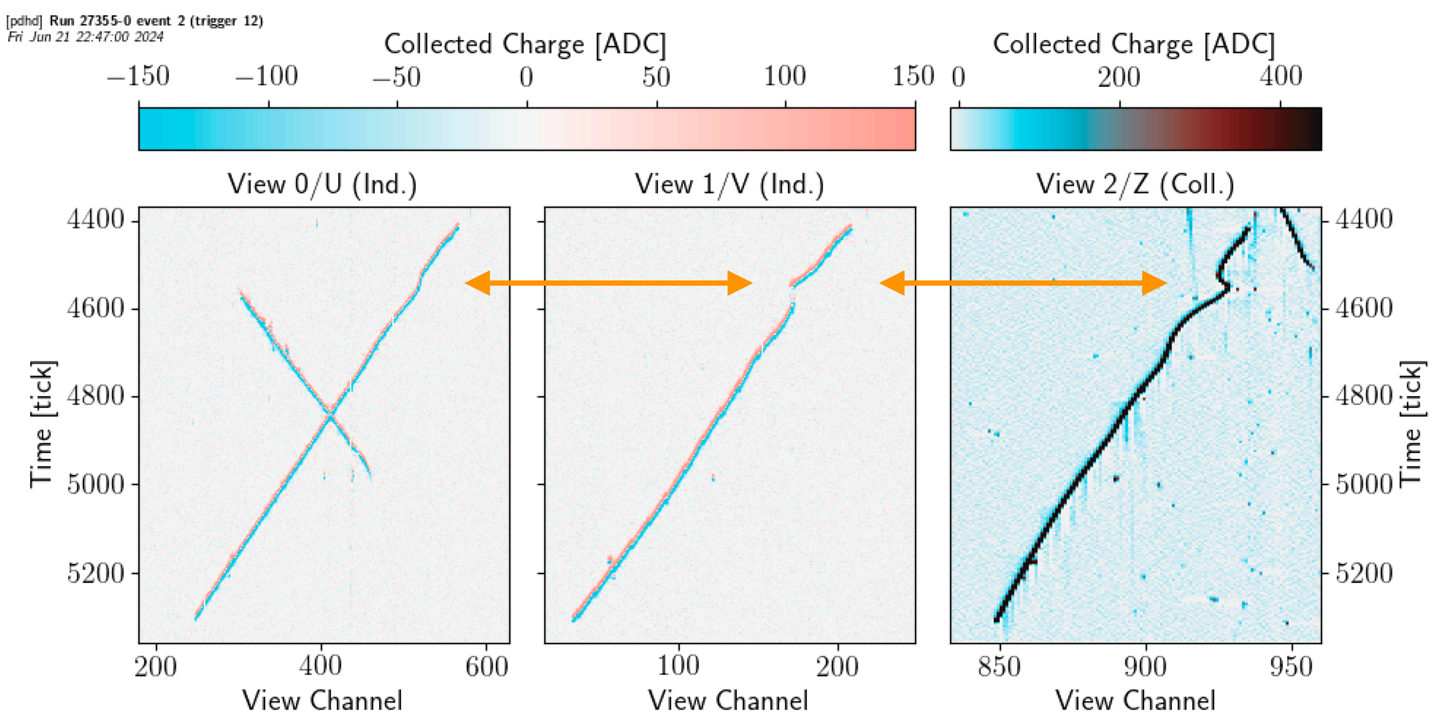
Electric Field Distortions

Main sources of systematics in a LArTPC comes from the non-uniformity of the drift field.

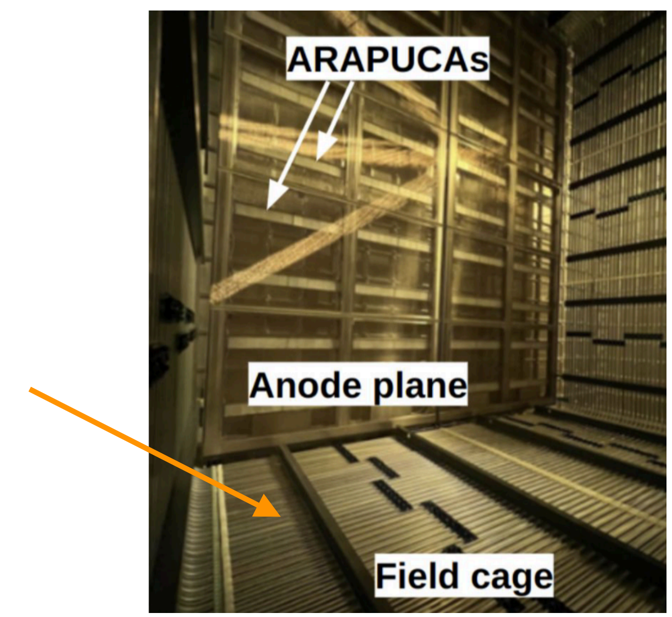
Two main causes of drift field non-uniformity:

- Geometry of the detector due to its cubic shape, and other elements in the active volume



(NB: I don't remember which APA this event is, but you can find examples like that easily in any APA)

Example in PDHD, where we believe the FC supporting beams distorts the field locally



- Slow drift of positive ions (mostly Ar^+) clouds that screens the drift field

-> Very intense for surface detectors like ProtoDUNEs, probably less of a problem in DUNE-FD

Has a significant impact on the uniformity of the drift field, in terms of field direction and field strength

Cosmic Samples

Useful cosmic track topologies to study the detector boundaries and field distortions
-> With just the charge system, the correct timing of the tracks can be retrieve if the tracks crosses at least one instrumented plane

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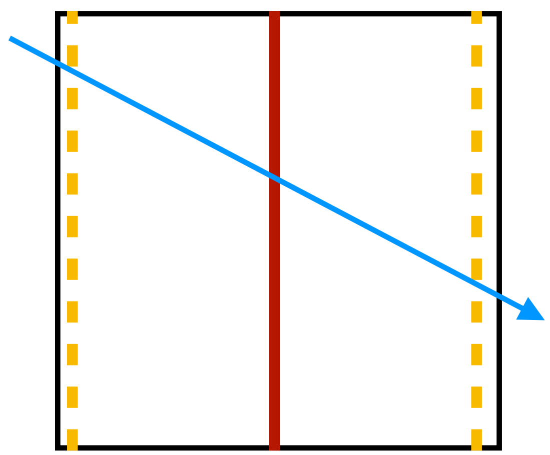
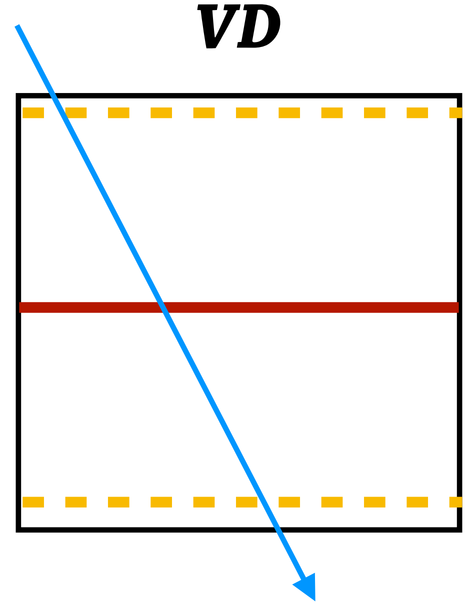


Anode-cathode-anode

-> Golden topology, as it provides 3 crossing planes
-> Easier to have in protoDUNE-VD

VD



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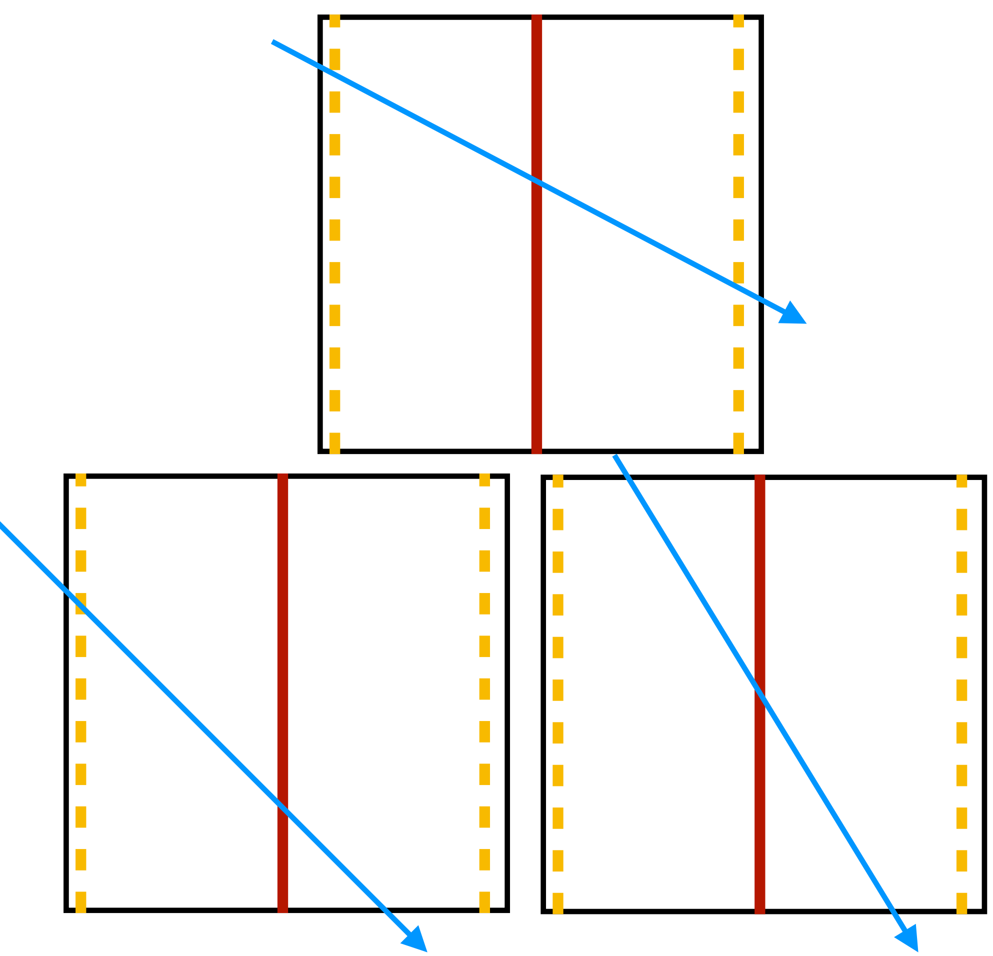

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<u>Cathode-crossers</u>

-> Allow to study the field distortion around the cathode, where the effect is potentially stronger

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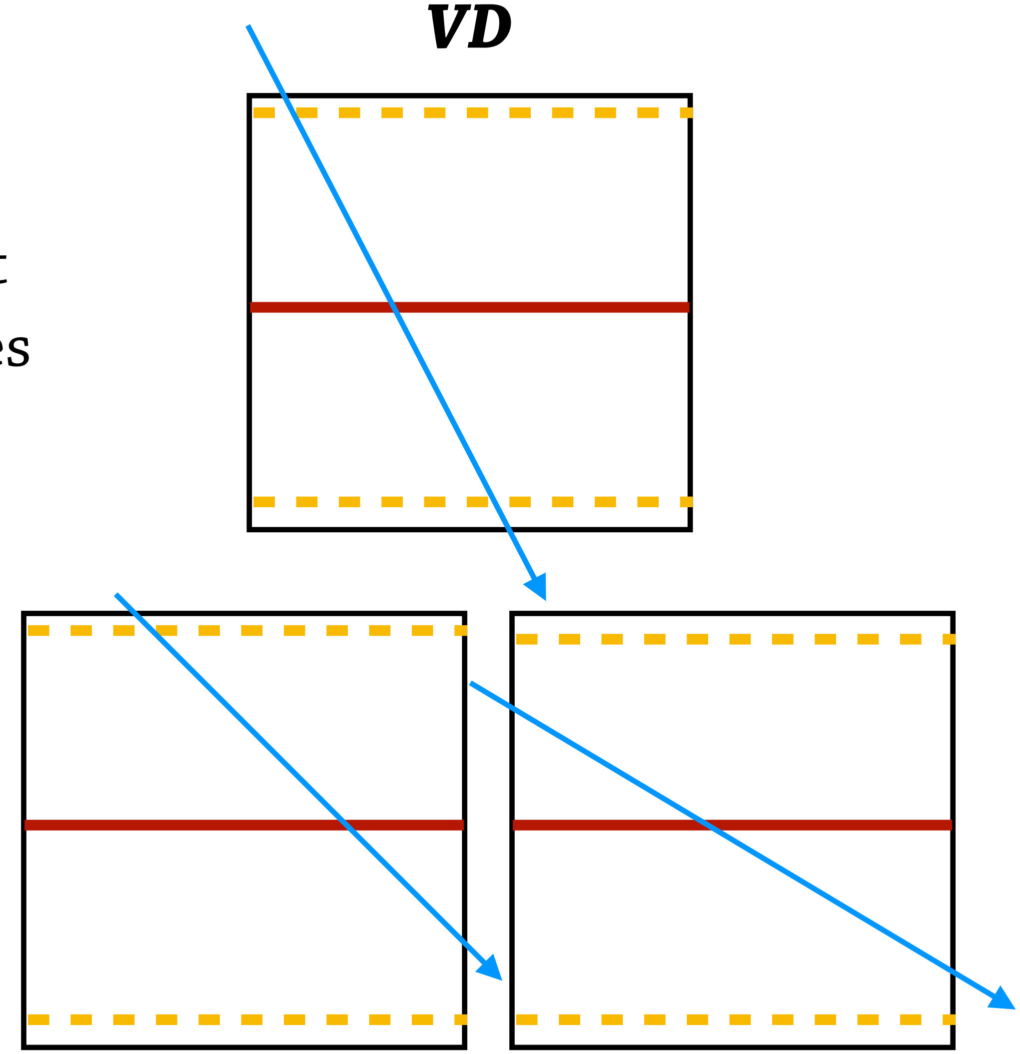

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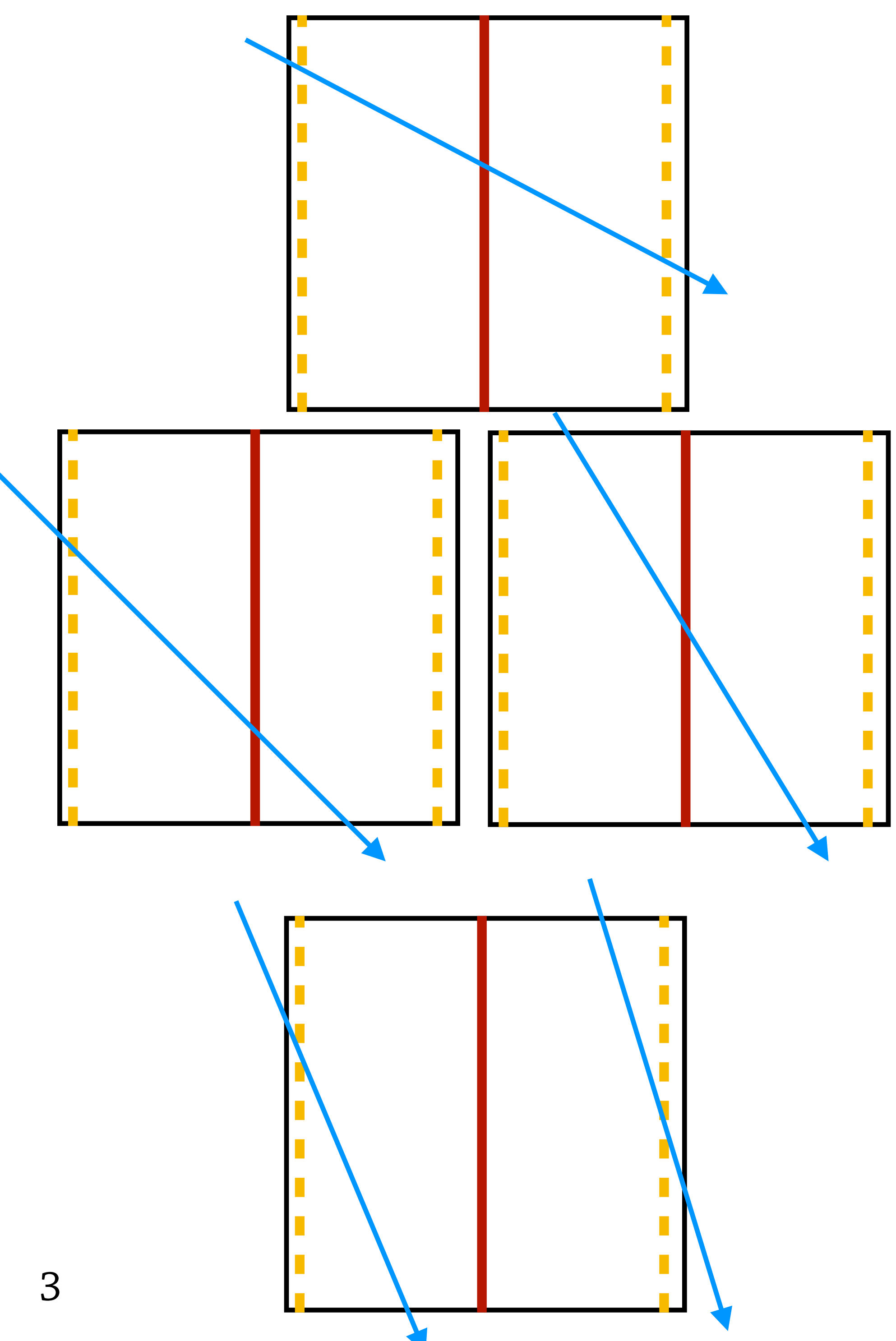

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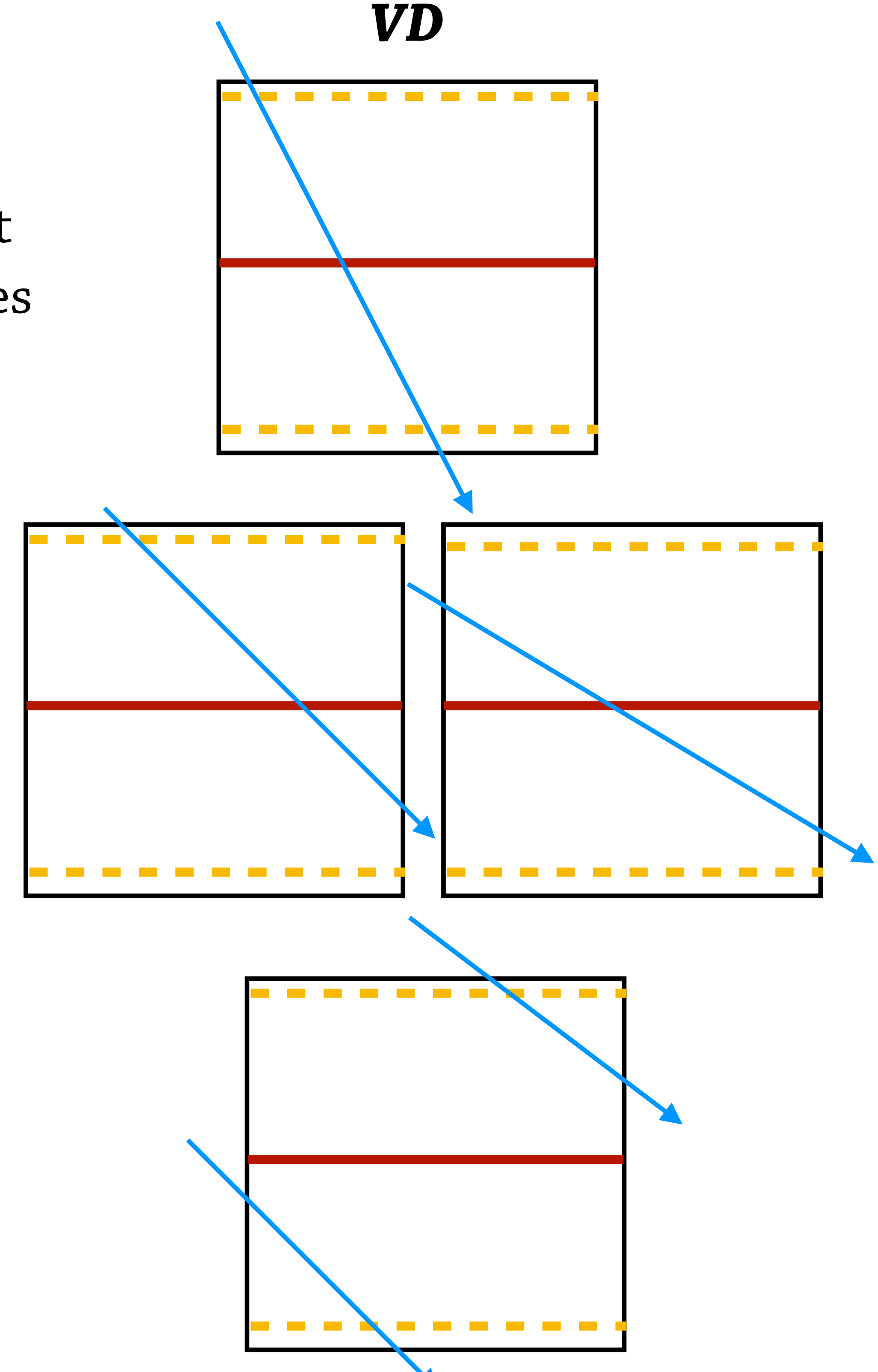
<u>Anode-crossers</u>

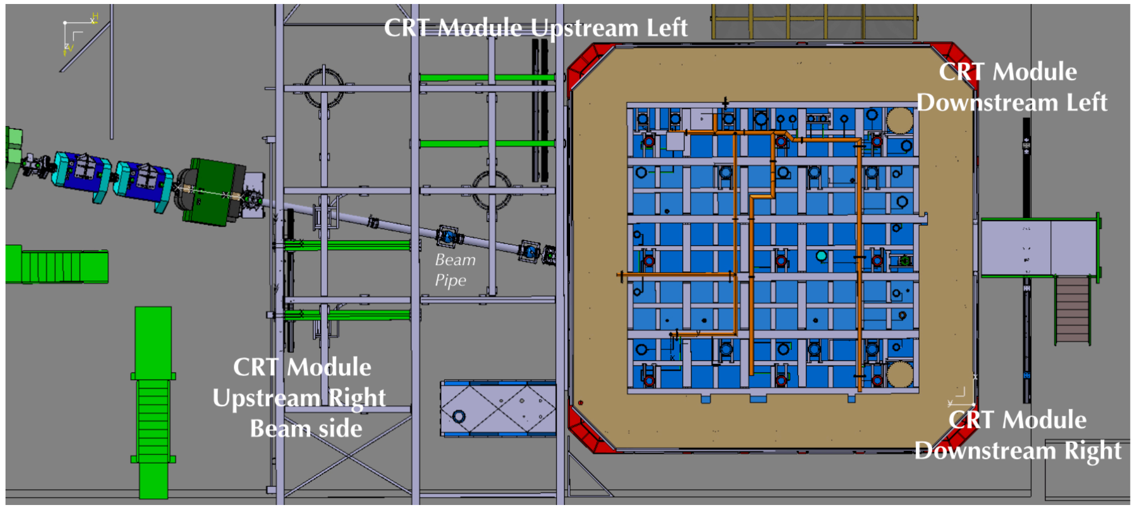
-> Study the field distortion around the anode, calibrate the charge-light delays

VD

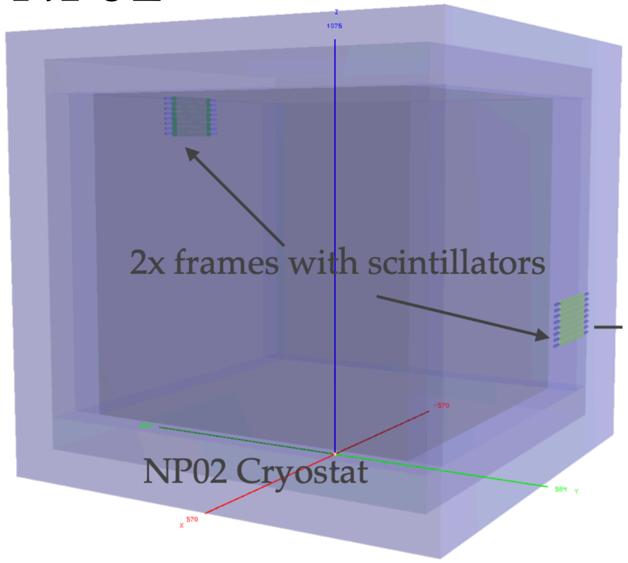


Other samples

NP04



NP02



CRT-trigger tracks

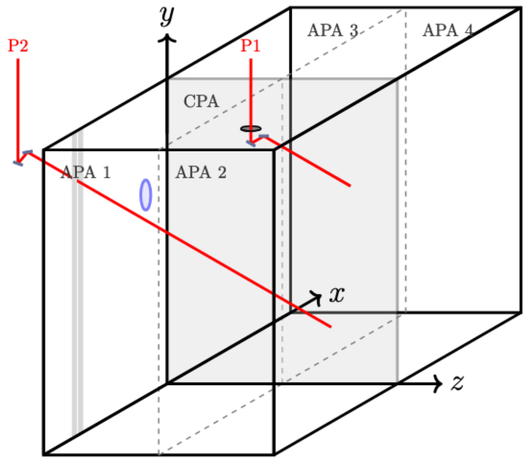
-> The external CRT system provides a track entry and exit point into the active volume

-> Comparison of CRT-tracks reconstruction vs expected trajectories is also useful to probe the space-charge effect

Laser System

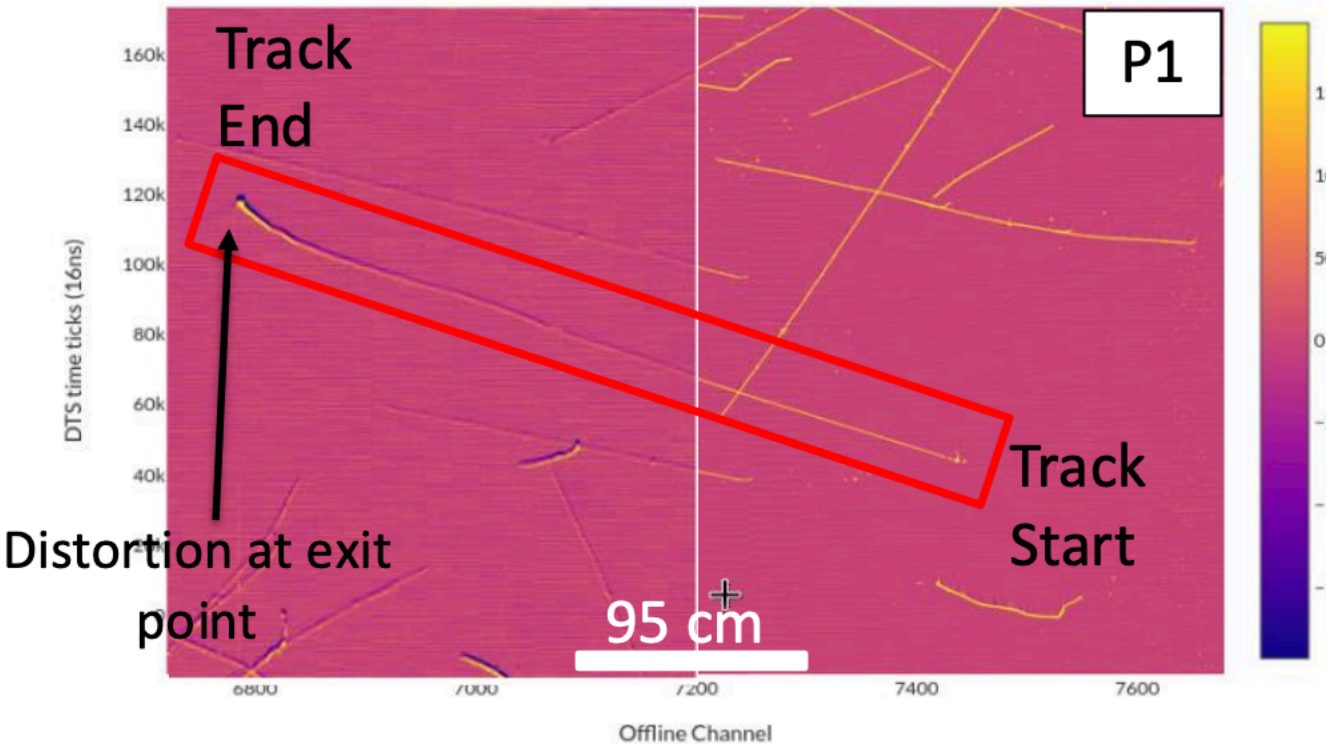
-> A laser is shoot inside the active volume at an energy such that the argon in ionized

-> Many directions can be explored, providing a clean probe to the field distortions



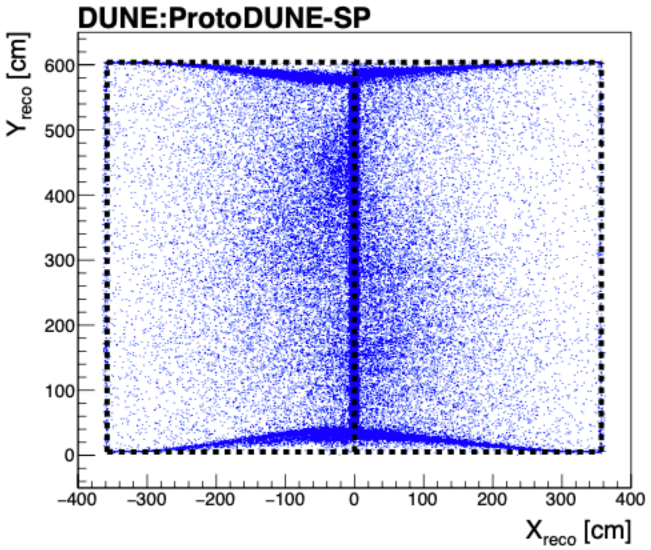
In PDHD, 2 lasers was installed, (P1 & P2), one in PDVD

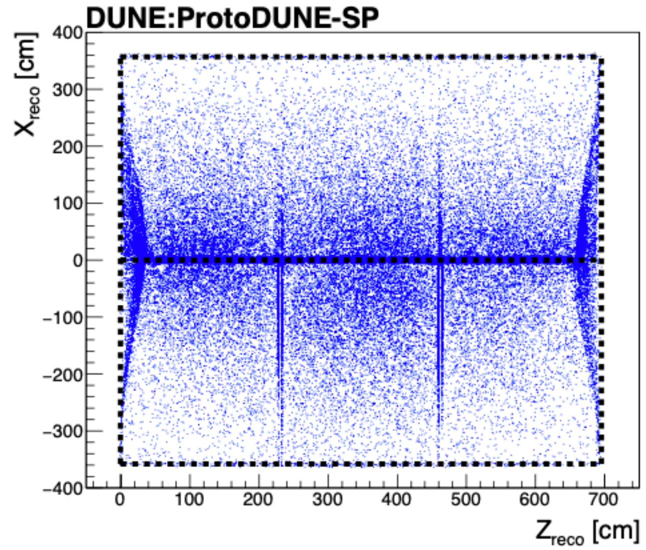
P1 laser track in PDHD, from David Rivera



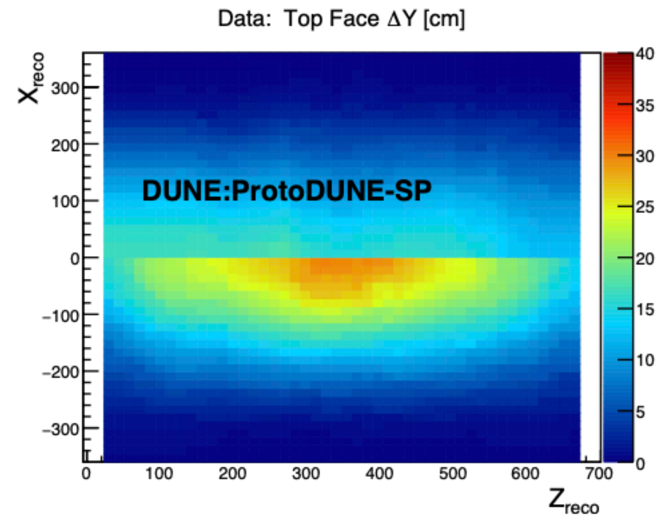
Space-Charge Effects

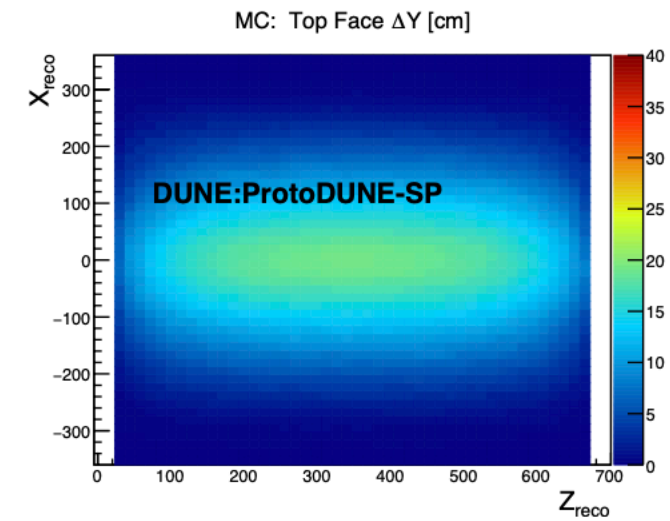
-> These samples allows to probe the drift field distortions, mostly due to the space-charge effects





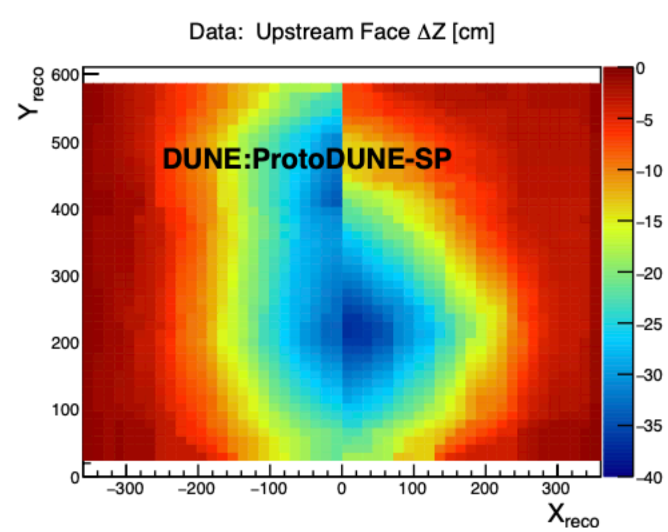
Tracks endpoints is a 1st candle to make sure the detector is symmetric, and the different element position

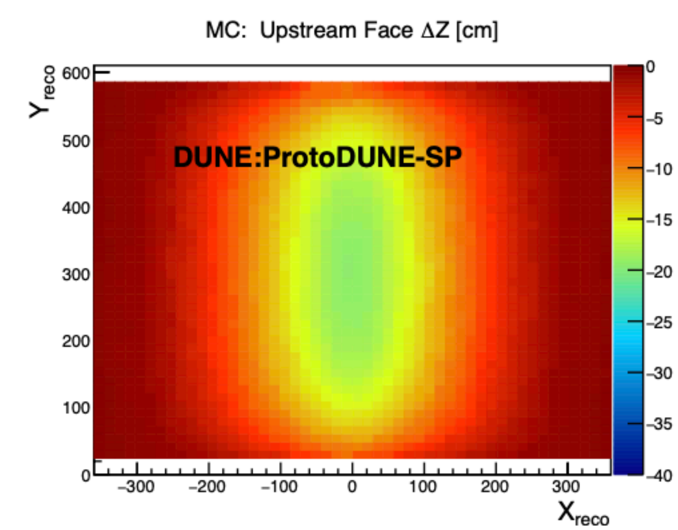




Experience from ProtoDUNE-SP showed that simulations did not reproduce the data correcly

-> Flow of LAr to be taken into account ?





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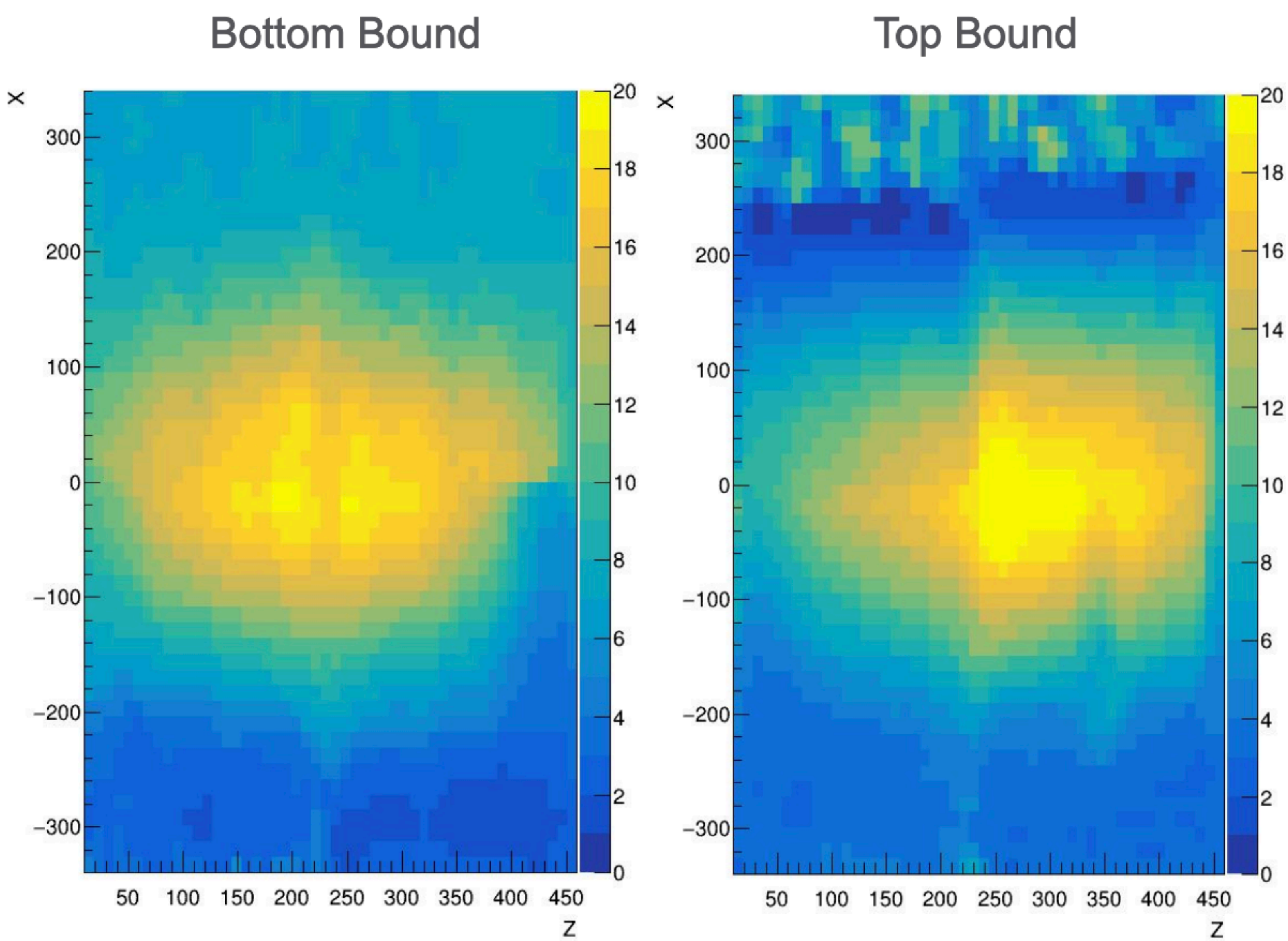
And first analysis of ProtoDUNE-HD shows that (again), the field distortions are not symmetric in the detector (see: Mathew Siden's work on MC and data)

ProtoDUNE-HD, preliminary
Field transverse displacements at y=0 and y=6.1m



Reconstruction

The reconstruction performances and efficiency can be studied with Monte Carlo simulations
-> but data can be different from the simulation (see the space-charge, or APA1 problem of PDHD)

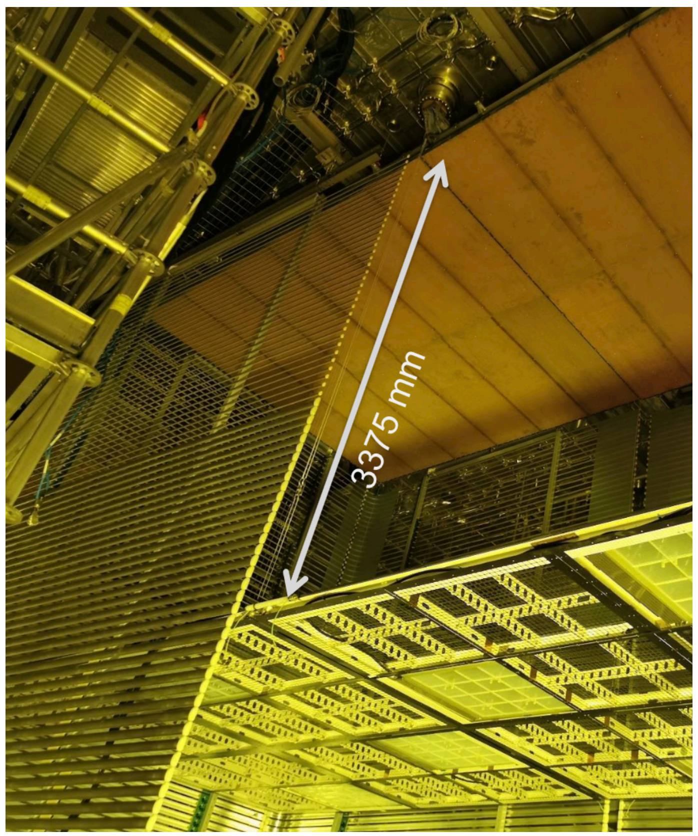
There are ways to study with data the reconstruction efficiency: we 'just' need track samples that can act as the '*truth*'.
Sample that can be used: Laser tracks, CRT-triggered tracks, beam tracks.
For the beam, we can also test how well we can ID the tracks

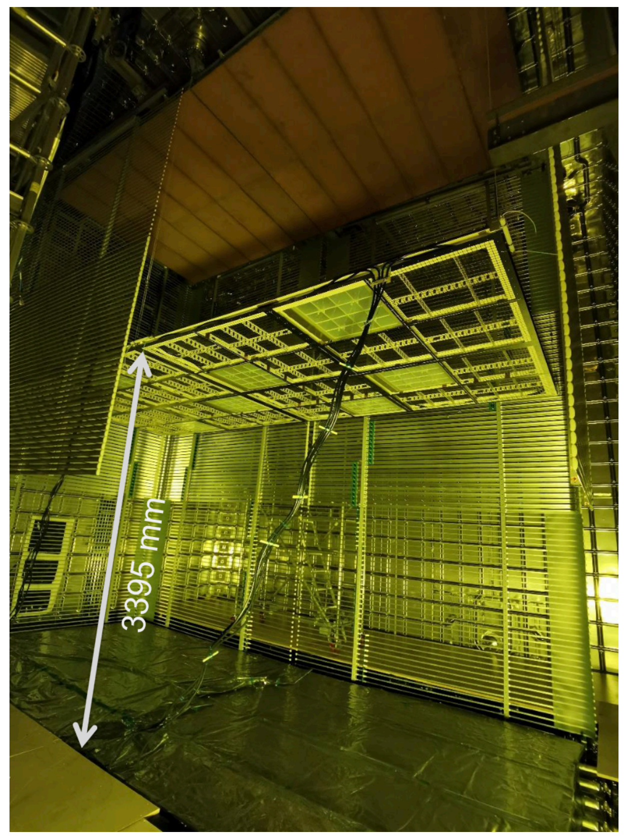
An other method can be through the light detection system:
-> PDS system can say if a track crossed the active volume (flash seen by multiple ×-ARAPUCA) and even build a rough topology of the track, to be compared with what the charge system can say

NB: Matching charge and light events is mandatory if we want to better understand our detector, improve our calorimetry, understand the physics of LAr, properly t_0-tag all tracks.
But matching charge and light tracks are easy to say, not so easy to do!

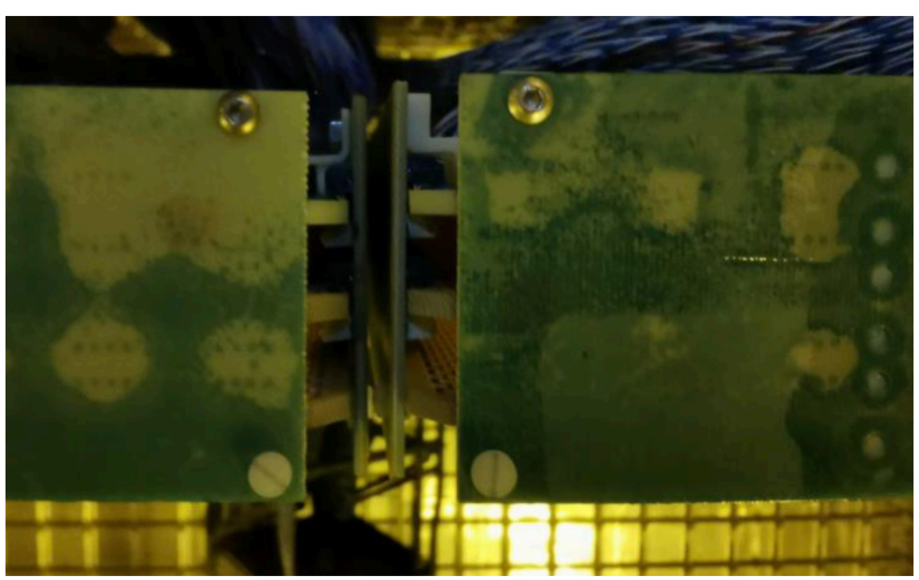
Detector geometry

An other source of systematics can come from our precise knowledge of where are our detector elements -> could be well know at warm but things can change once at cold!





E.g In ProtoDUNE-VD, where the drift distance should be the same for top & bottom volumes, since cable elongation & cathode buoyancy at cold have been taken into account
-> To be check
-> Top CRP+Cathode can be vertically moved



Un-instrumented area between anode (e.g. CRPs gaps for PDVD)
-> what is the behavior of the electric in this region ? Are the electrons lost, diverted to the anode ?
This needs COMSOL simulations and checks with data

Energy scale and resolution

The expected charge deposition of muons is very well known

From the data, the measured dQ/dx can be degraded from many sources:
- Electronic gain: can be monitored frequently with charge injection system of the electronics
- SCE: established with cosmics samples + CRT + laser systems, and dQ/dx corrected
- Impurities: Can be corrected if the track is properly t_0-ed
- Diffusion, transparency, topology, ... : can be studied with data sufficient statistics ; and with dedicated simulation (e.g. work by WireCell team and J. Pinchaut)

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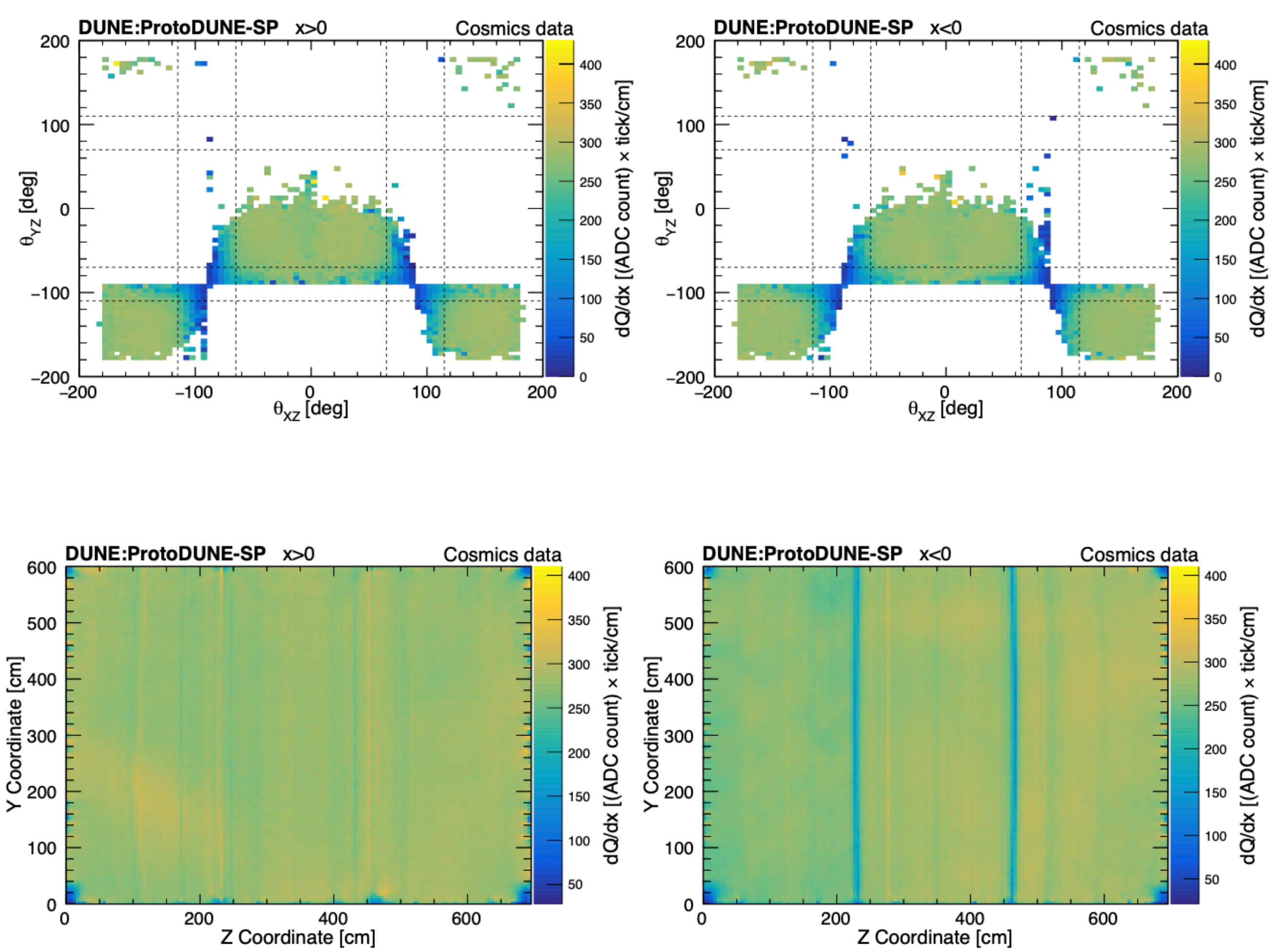
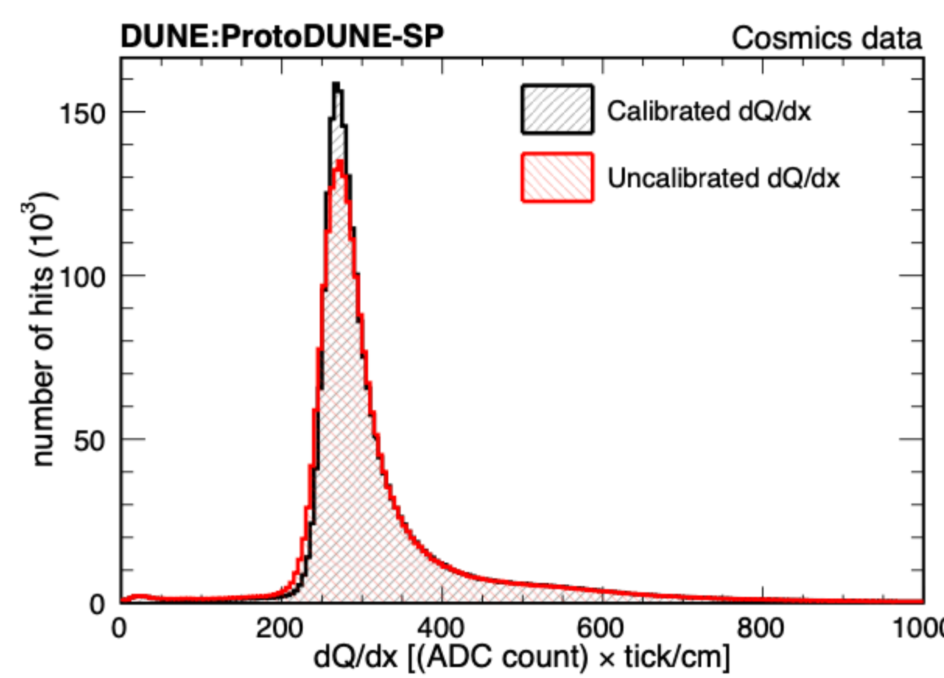
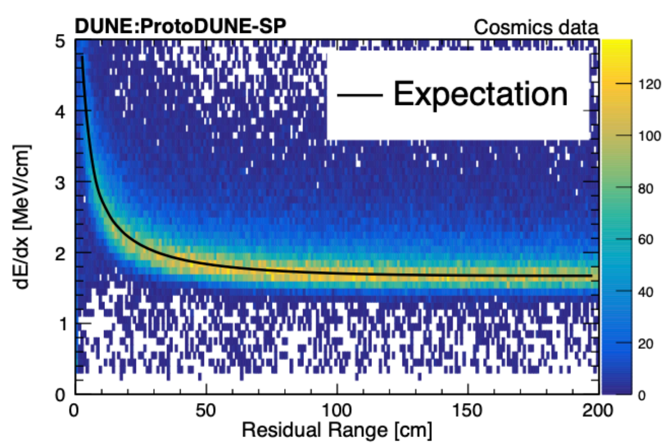


-> In protoDUNE-SP, dQ/dx correction factors was computed along x and (YZ) planes.
-> The overall calibrated dQ/dx distribution of MIP muons is sharper

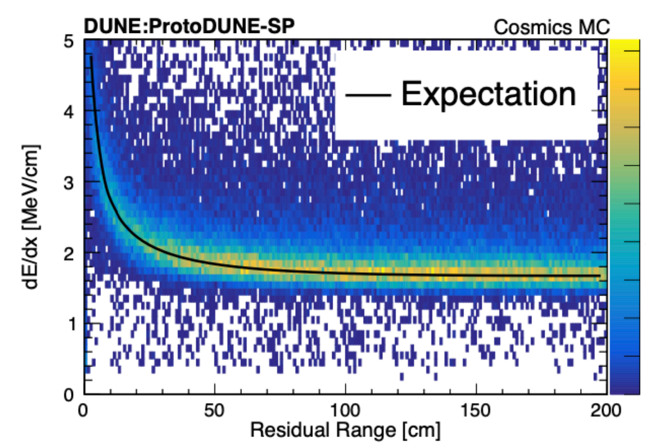


Energy scale and resolution

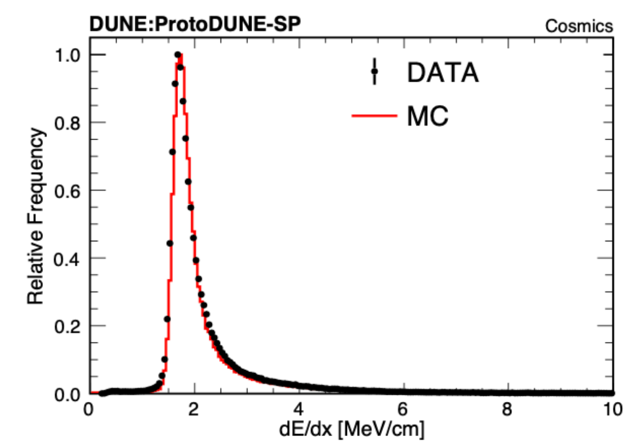
The expected charge deposition of stopping muons is also very well known!
Once the calibration factors are known from data (and better, understood), stopping muons samples can used to provide an energy scale and resolution measurement



(a) Data



(b) MC

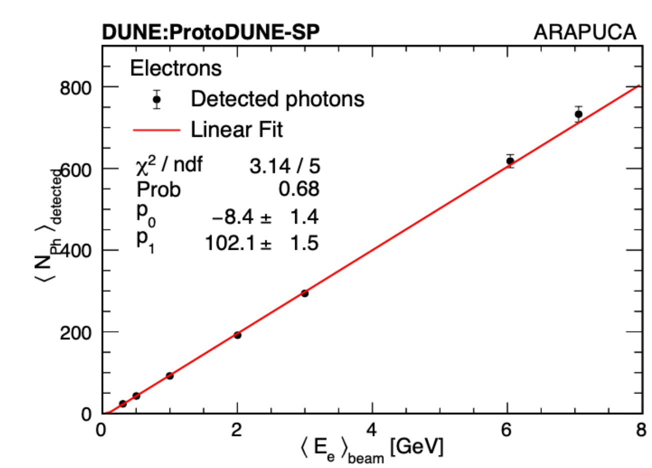


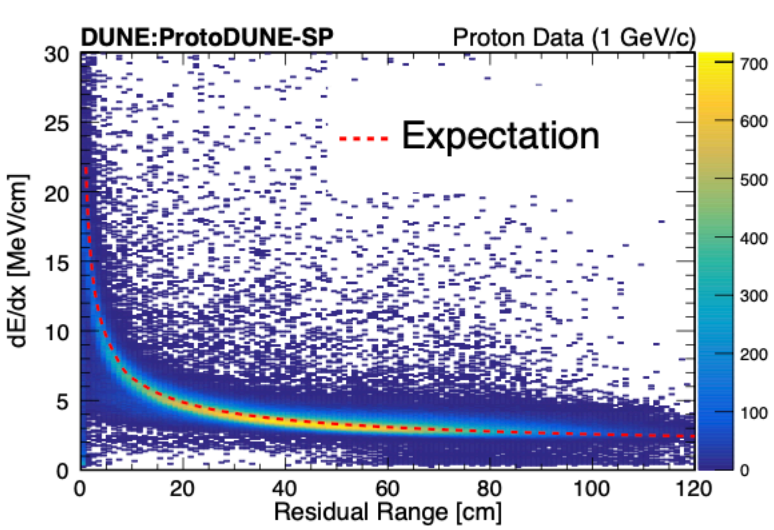
(c) dE/dx comparison

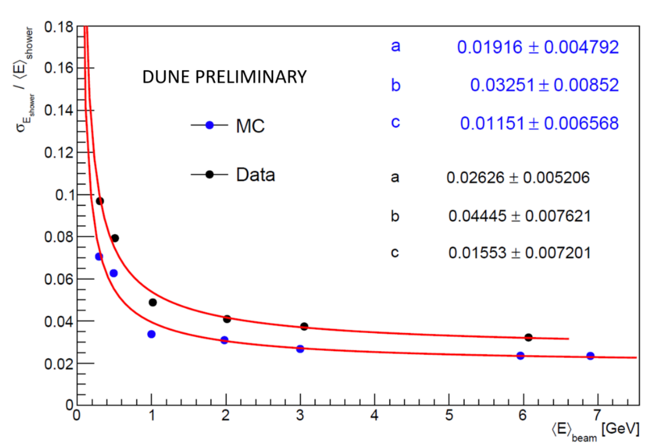
The other method, is to use the beam data :

-> For protoDUNE-HD we had energy scans at both polarities

-> Hope to have the same for protoDUNE-VD next year



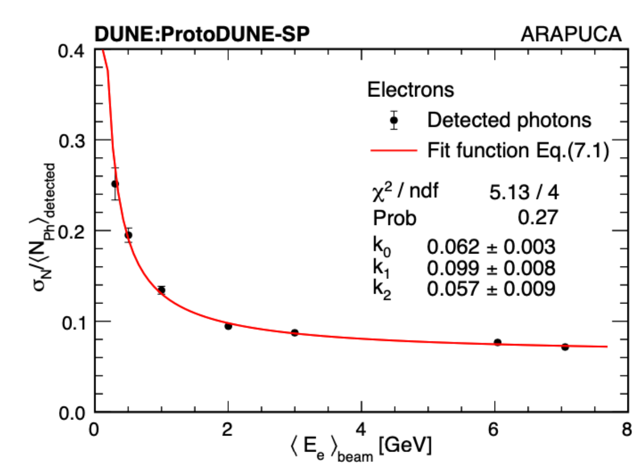




: Measured positron energy resolution across the beam momentum settings of the test beam. The ons are fitted to the equation: $\frac{\sigma_E}{E} = \sqrt{a^2 + (b/\sqrt{<E>})^2 + (c/<E>)^2}$.

Same analysis done for the light system ->

To be done : combined charge and light!



R. Diurba proceeding

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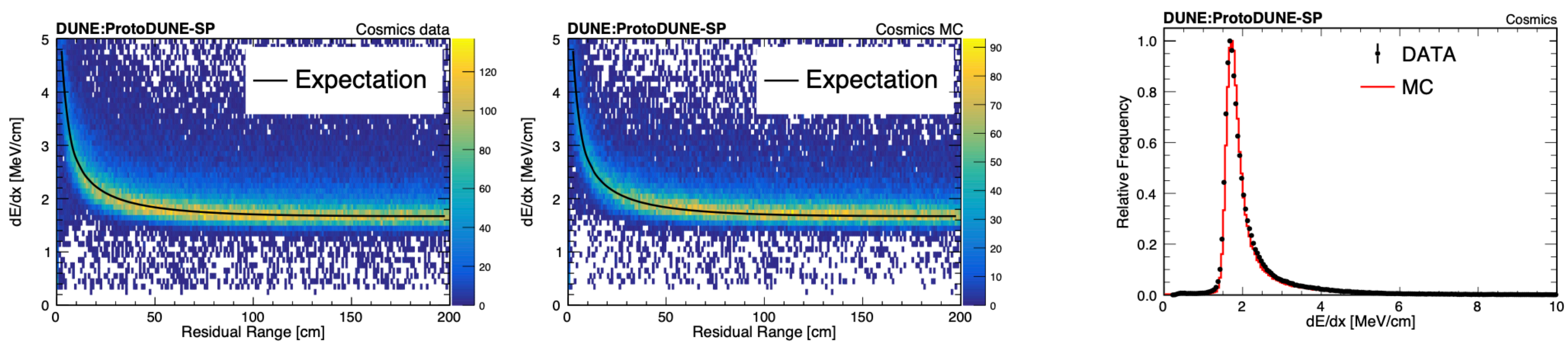

(a) Data (b) MC (c) dE/dx comparison

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With the beam data, we can also try to reconstruct the invariant mass of ‘standard candle’ particles. In particular, those V_0 particles could be interesting:

- $\pi^0 \rightarrow \gamma\gamma$, m = 134 MeV
- $K^0_s \rightarrow \pi^+ \pi^-$, m = 497 MeV
- $\Lambda \rightarrow p\pi^-$, m = 1.115 GeV

Not sure there is a lot of statistics though!

Energy scale and resolution

Low energy :

- Reconstruction of Ar^{39} spectrum, which have a Q_β of 565 keV

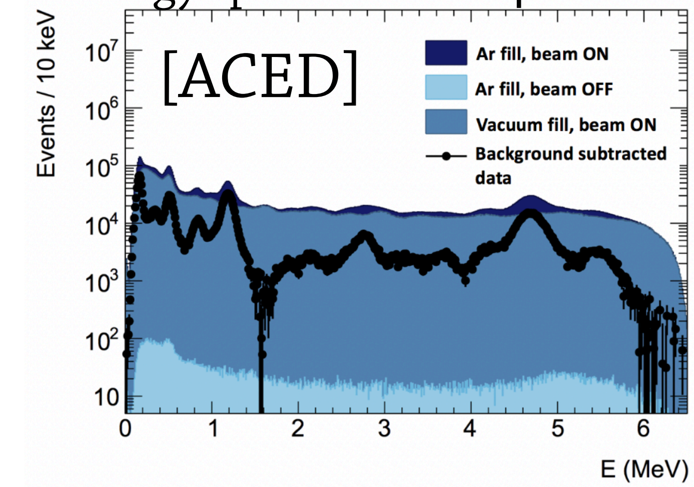
- In protoDUNE-VD, Pulsed Neutron source system is installed
  ->Inject neutrons in the detector from the outside which are captured by Ar^{40}. Ar^{41} de-excitation emits a 6.1 MeV γ cascade, with mostly 167 keV, 1.2 MeV and 4.7 MeV gammas

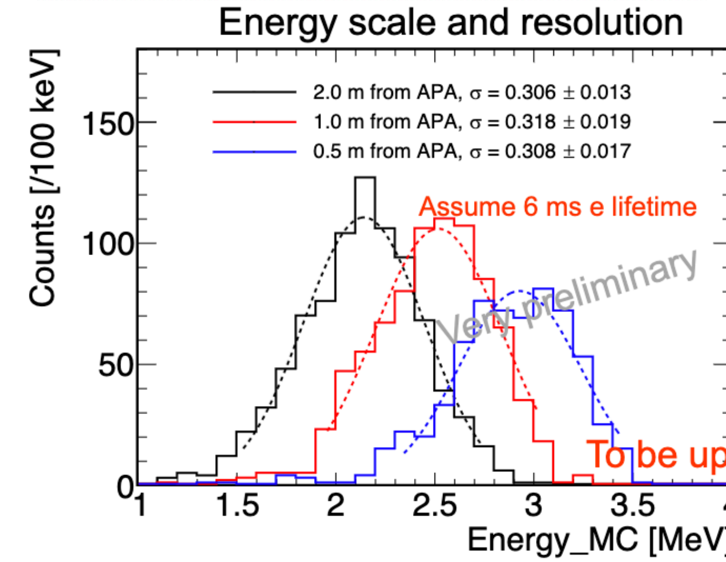
- Bi^{207} source(s) in ProtoDUNE-HD which have a ~1 MeV peak from electronic capture

- Possible Thorium contamination of some detector's element seen with γ up to 2.6 MeV

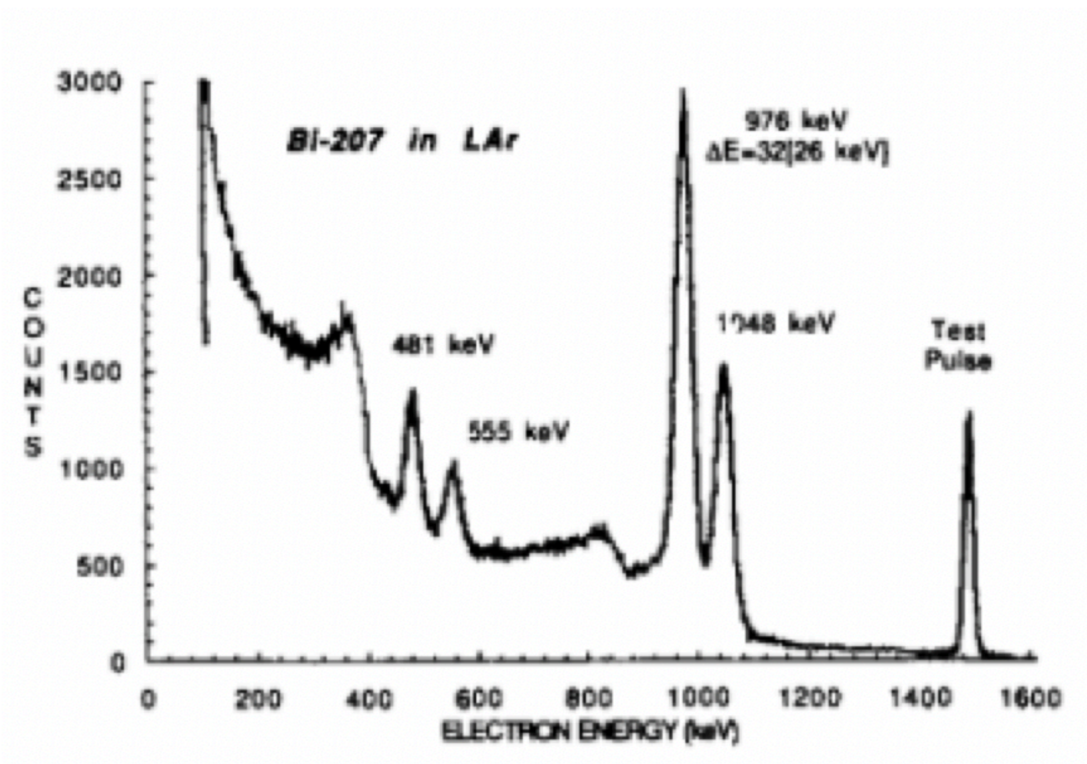
Analysis started on PDHD by E. Lavaut

Energy spectra of Ar^{41} γ cascade





MC Studies



Conclusion

There is a lot of things to do !