Characterization of a LArTPC
Part 2

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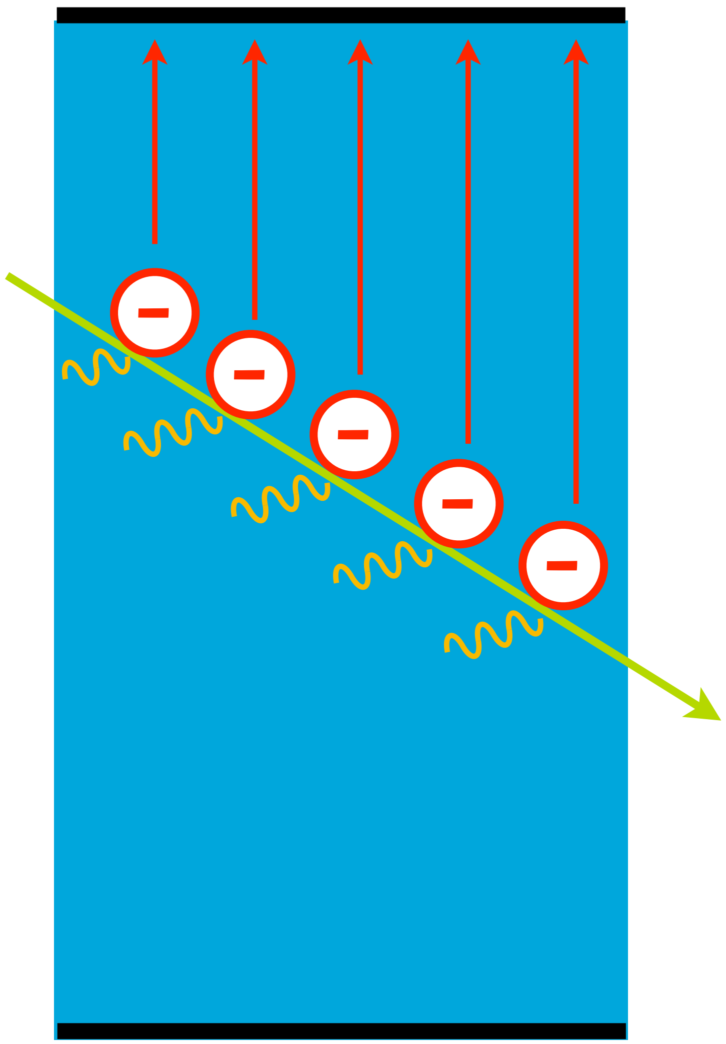
DUNE-FR Analysis Workshop — April 2023

Reminder from Part 1 - ideal LArTPC



When a charged particle crosses LAr, it excites and ionizes Argon:
-> ionization leads to the charged (e^-) signal
-> excitation to the light (γ) signal (c.f. Henrique talk tomorrow)

The fraction of each signal (e^-/γ) depends on the field strength and the type of particle through the recombination.

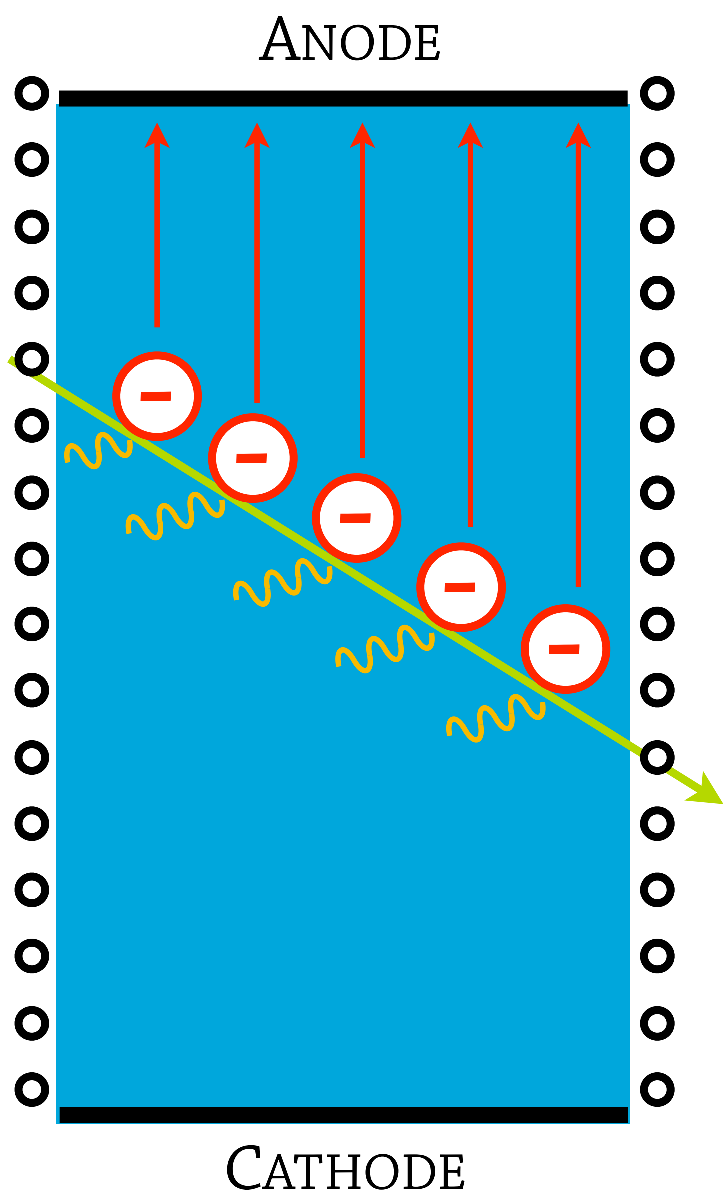
Electrons drift towards the anode along the drift lines at a speed depending on the field strength.

Part of the signal is captured along by the impurities, lost amount depends on drift time, impurity type and field strength.

The electron cloud is smeared in time and space, both diffusions (transverse/longitudinal) depend on drift time and field strength.

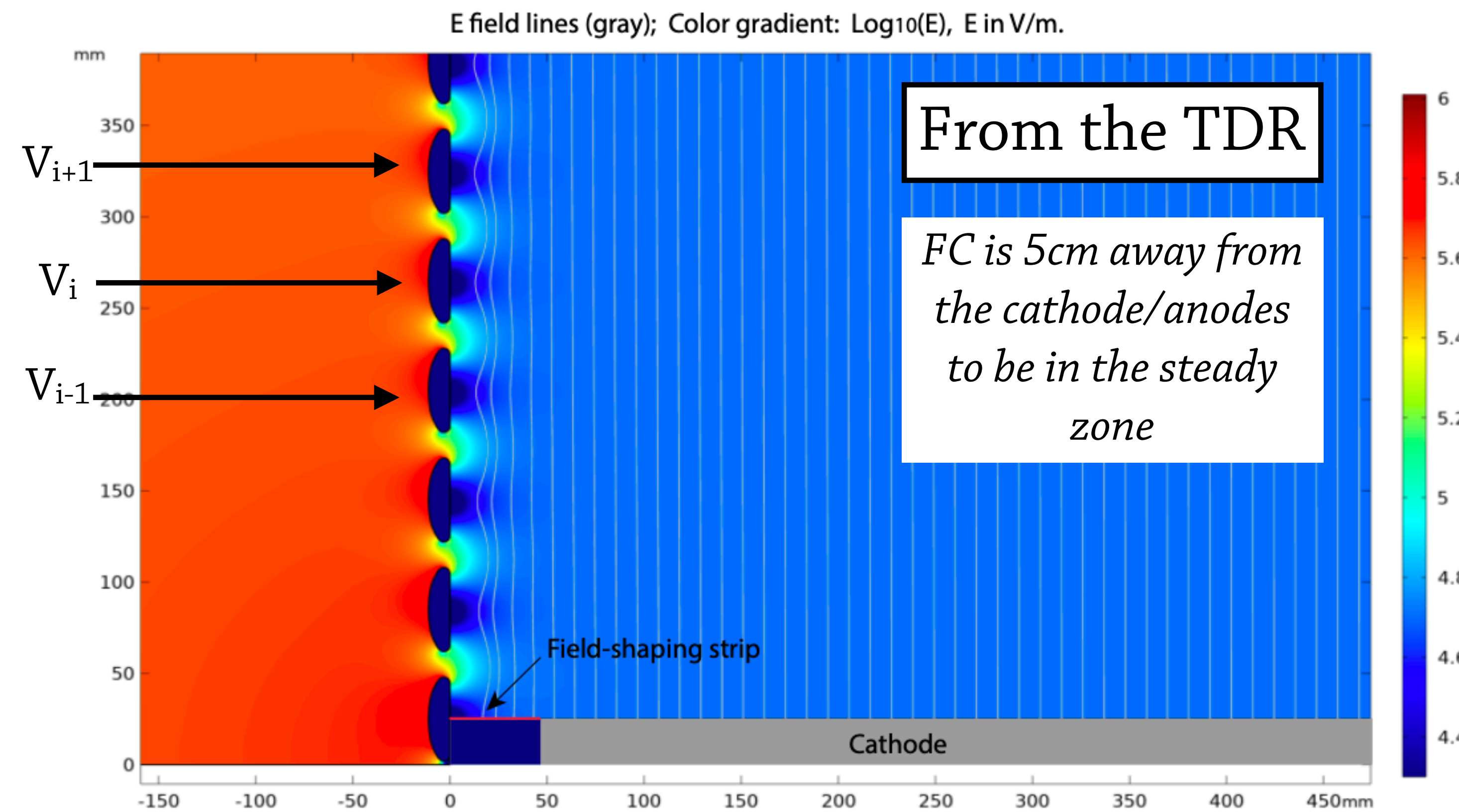
Most of the parameters depends on the field strength and direction

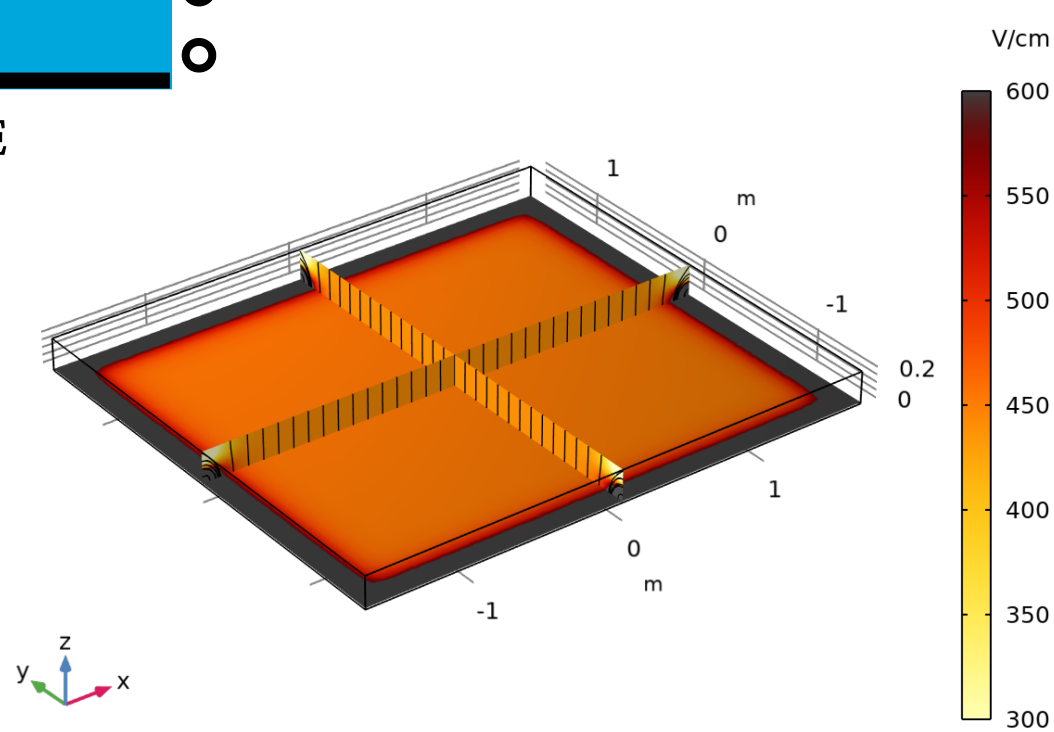
Static Drift Field : The Field Cage



The drift field is generated by a differential potential applied to the cathode and the anode, the field cage regulates the field near the border

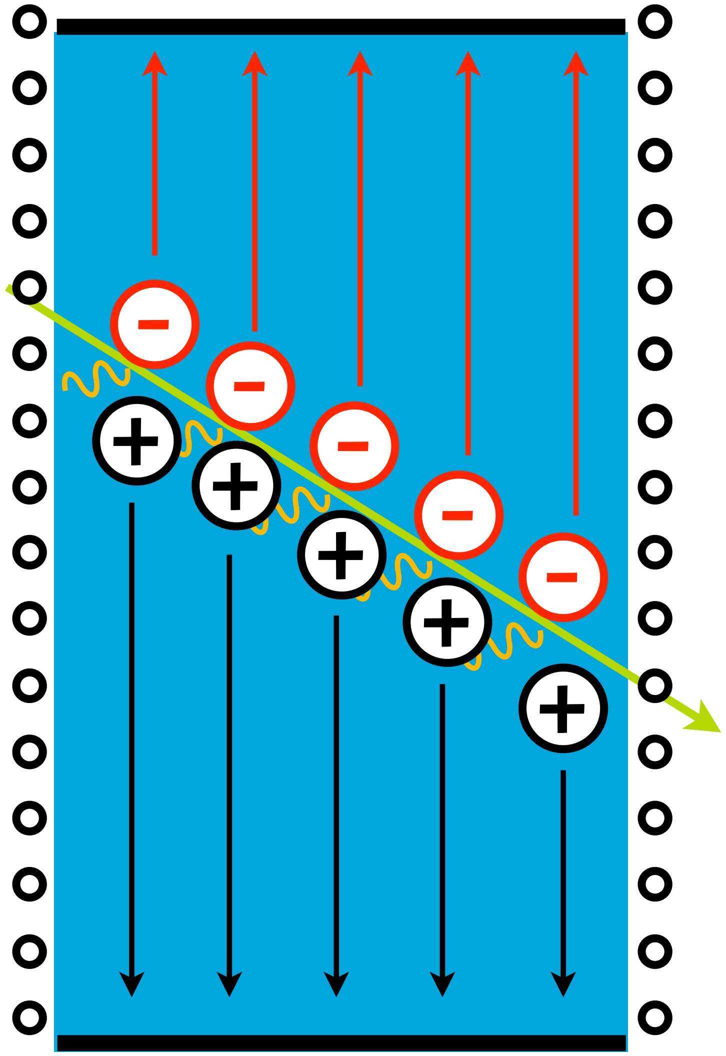
A voltage gradient is provided to the field cage rings





The ColdBox has no Field Cage : the field is distorted near the edges

Dynamic Drift Field non-uniformity



Together with the electrons, argon ions are produced

-> They are attracted to the cathode

-> Ion drift velocity is slow: about <u>1min/meter</u> (*not very well known!*)

↳ much much slower than the electron

In a LArTPC exposed to a large flux of charged particles, an ion cloud builds up to the point where its presence screens the drift field : this is the **space charge effect (SCE).**

The drift field is distorted in **strength and direction**.
The distortions vary in **time and space.**

↳ After some time, one can consider the space charge being stabilized though

Higher flux -> stronger effect
Bigger detector -> stronger effect

| Very important in Module-0 (cosmic ray ; 3.2 m drift)
| Negligible in DUNE-FD (Ar^{39} ; 6.4 m drift)

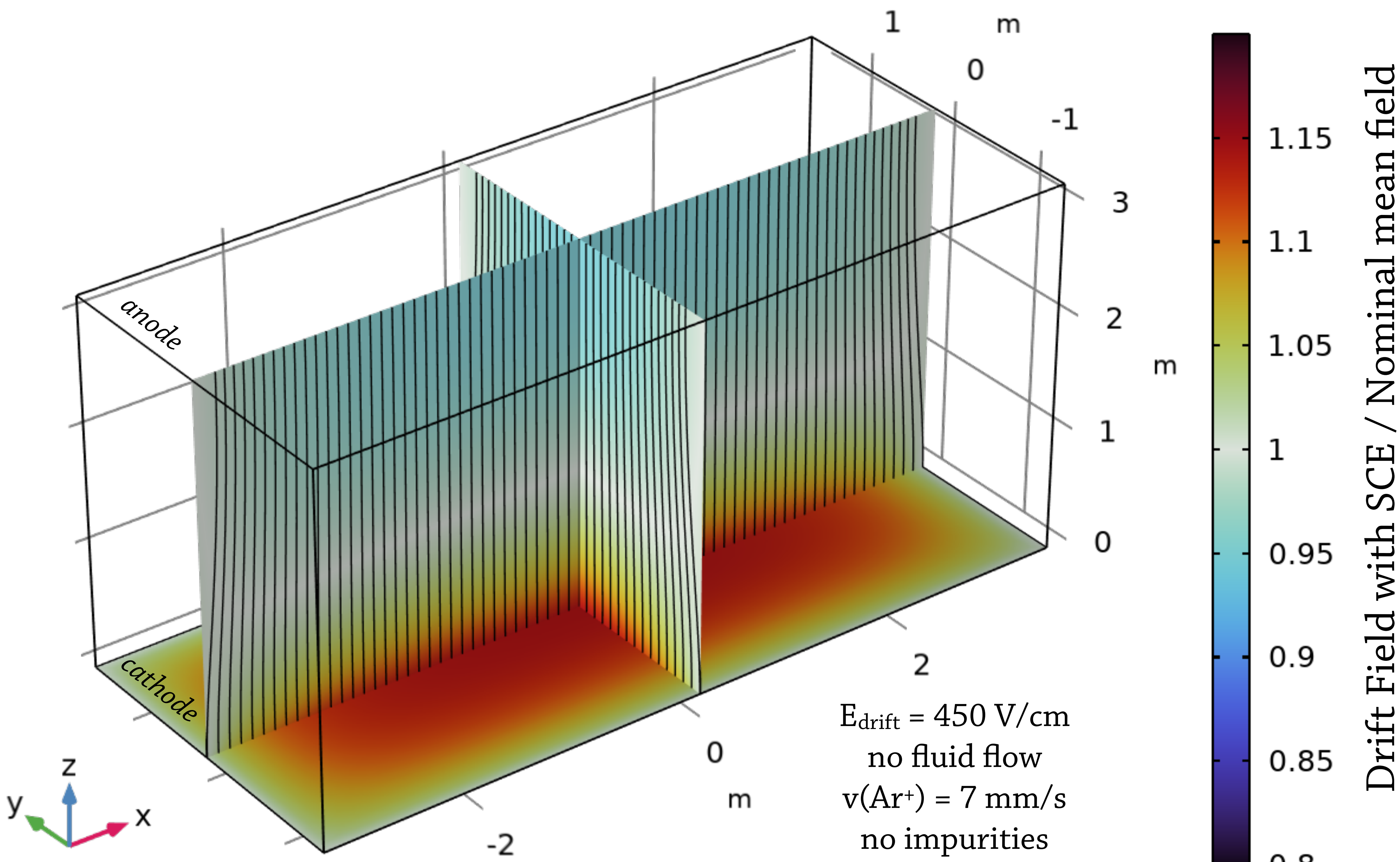
The flow of LAr inside the cryostat is at a speed similar to the argon ion velocity

-> It can plays a significant impact on the SCE

Space Charge Effect

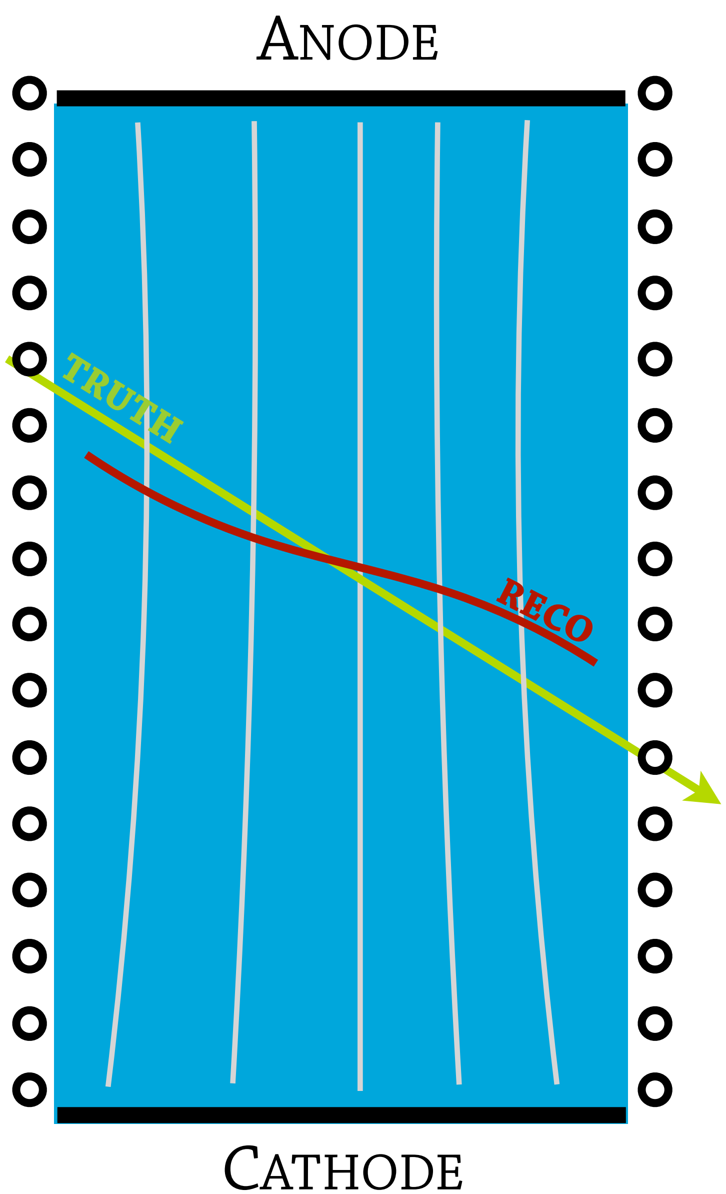
SCE COMSOL simulation for a 3 × 6.8 × 3.2[drift] m^3 LArTPC detector (≡one Module-0 volume)

-> Field is stronger near the cathode (~+10%); weaker near the anode (~-4%)
-> Field lines are curved



E_{drift} = 450 V/cm
no fluid flow
$v(Ar^+)$ = 7 mm/s
no impurities
charge density rate = 2×10^{-10} $C/m^3/s$

Space Charge Effect - impact on tracks



The field strength is not constant : the recombination is position-dependent

Field lines are not straight : tracks are shorter, bended, displaced, delayed

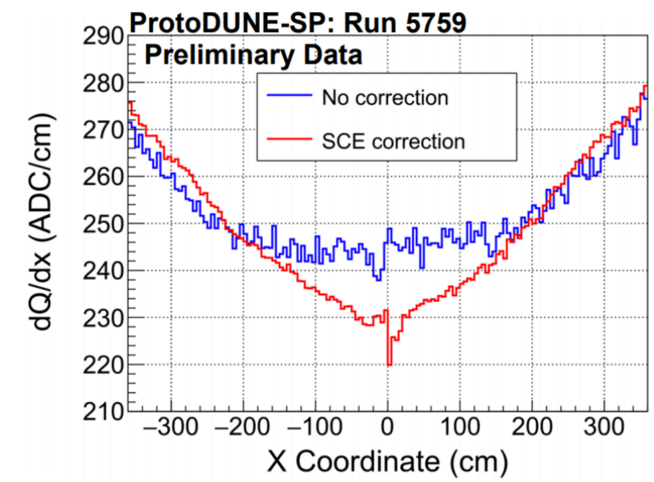
We measure :

$$\frac{dQ}{ds}$$

Both quantities are affected

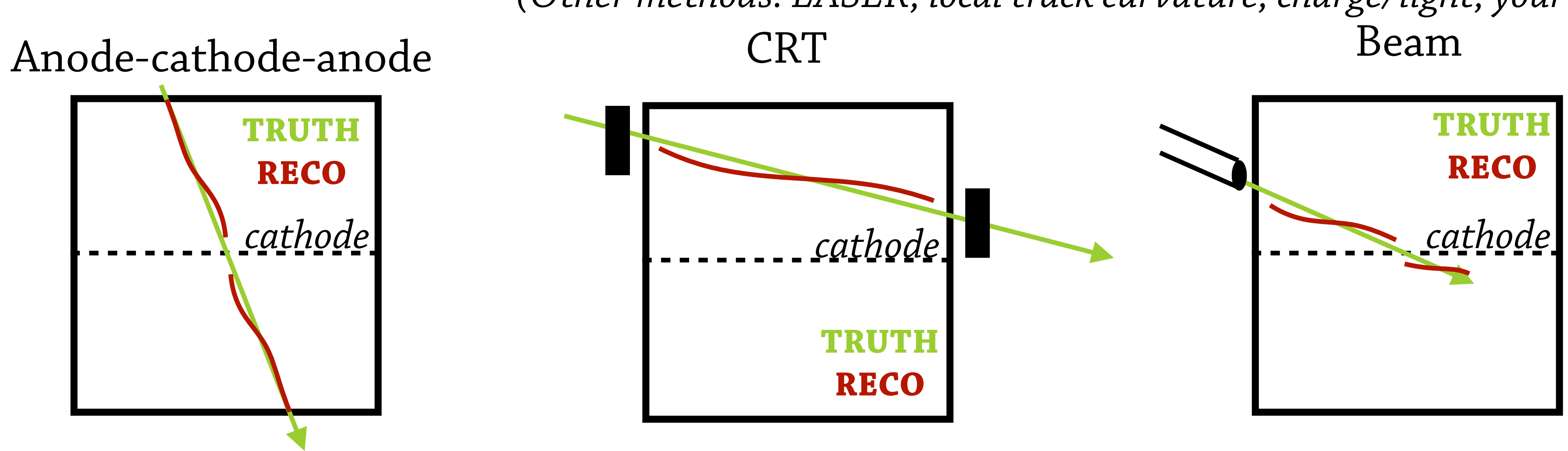
-> Ultimately, SCE affects all analyses foreseen in Module-0

Example : dQ/dx vs drift position in protoDUNE-SP



Map SCE with data: compare known trajectories to reconstructed

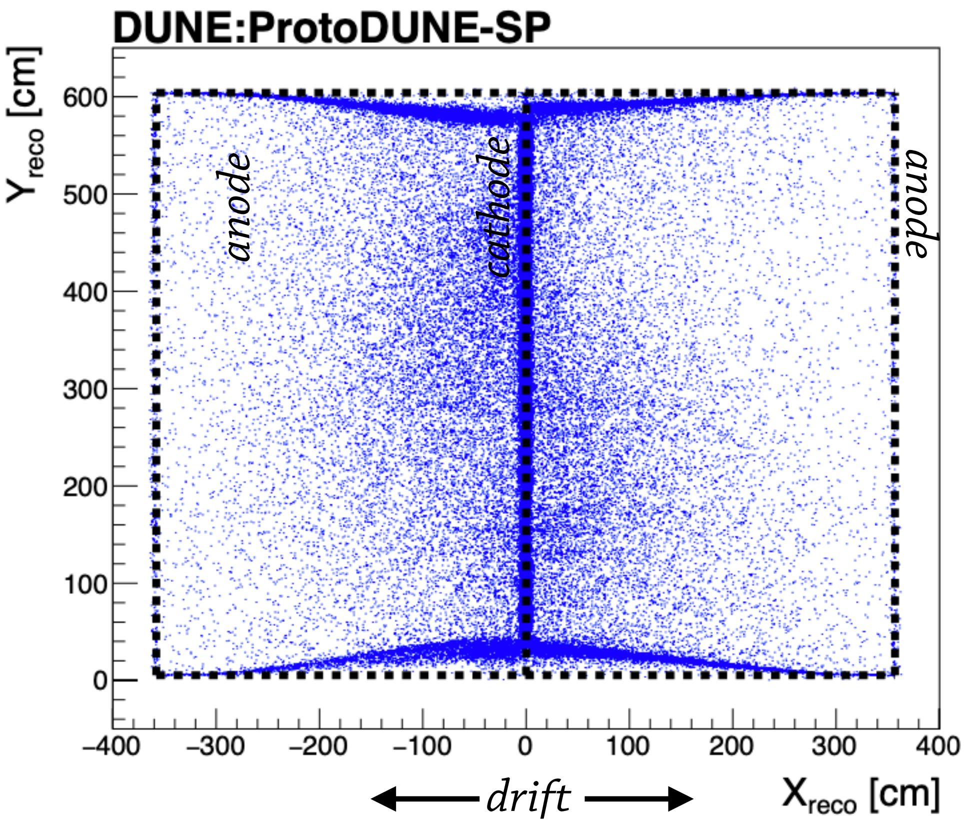
(Other methods: LASER, local track curvature, charge/light, your idea)



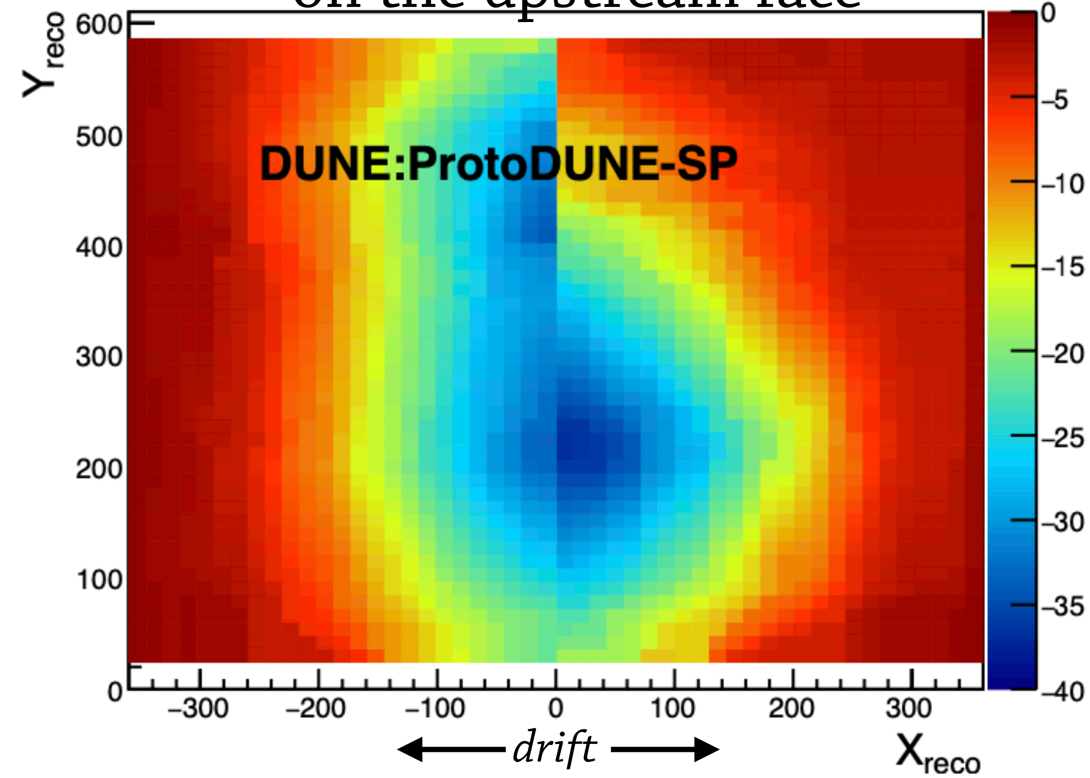
Space charge effect - ProtoDUNE-SP

ProtoDUNE-SP paper

Cosmic-track end points on *xy* plane

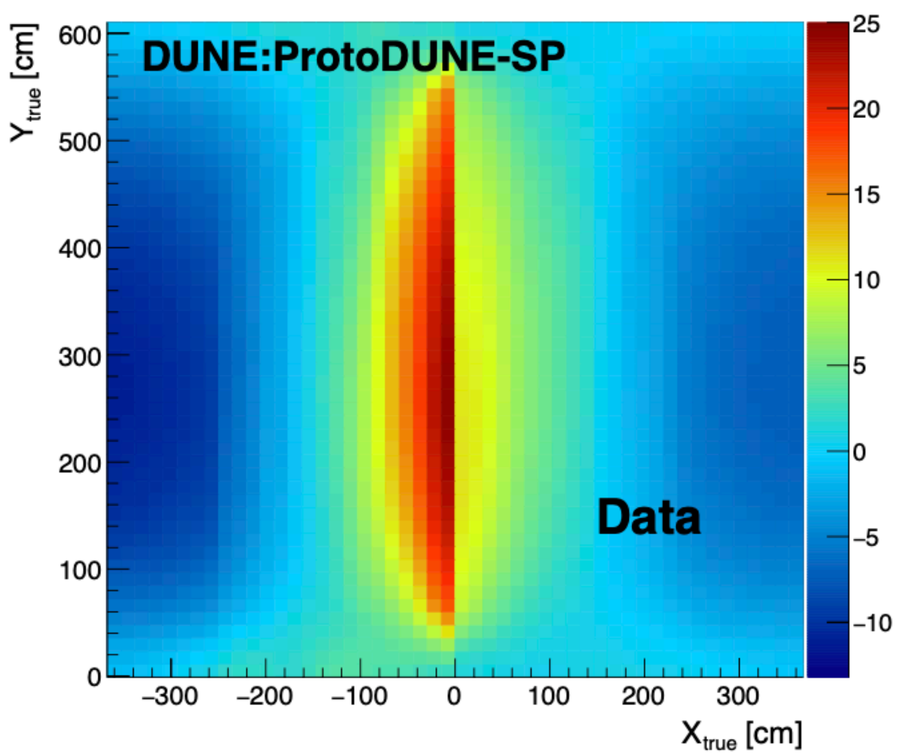


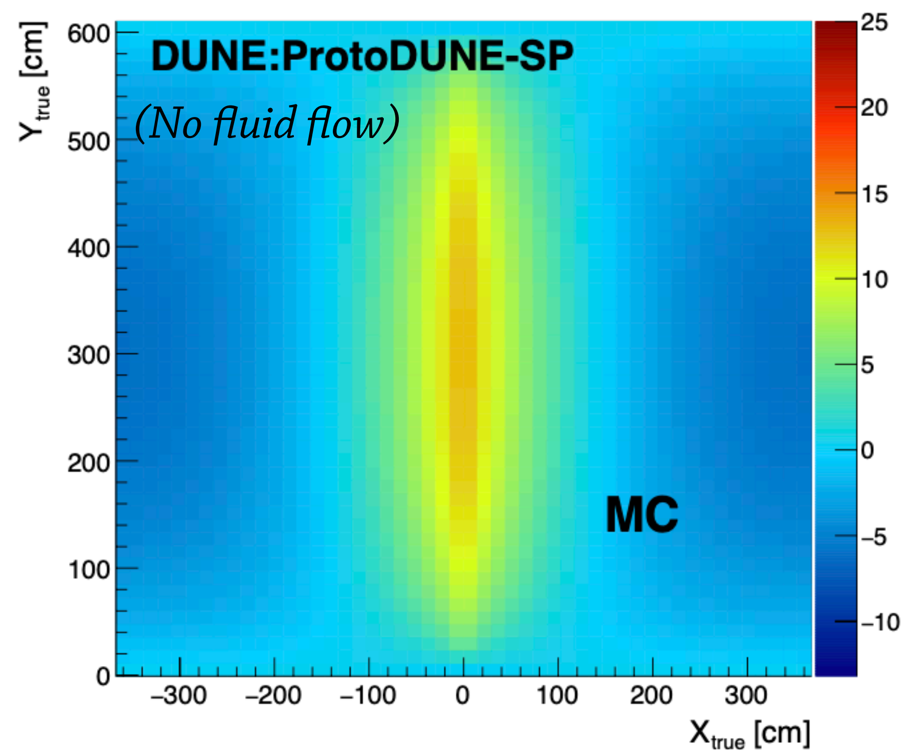
Spatial distortions along Δz on the upstream face



Up to ~40 cm displacement measured!

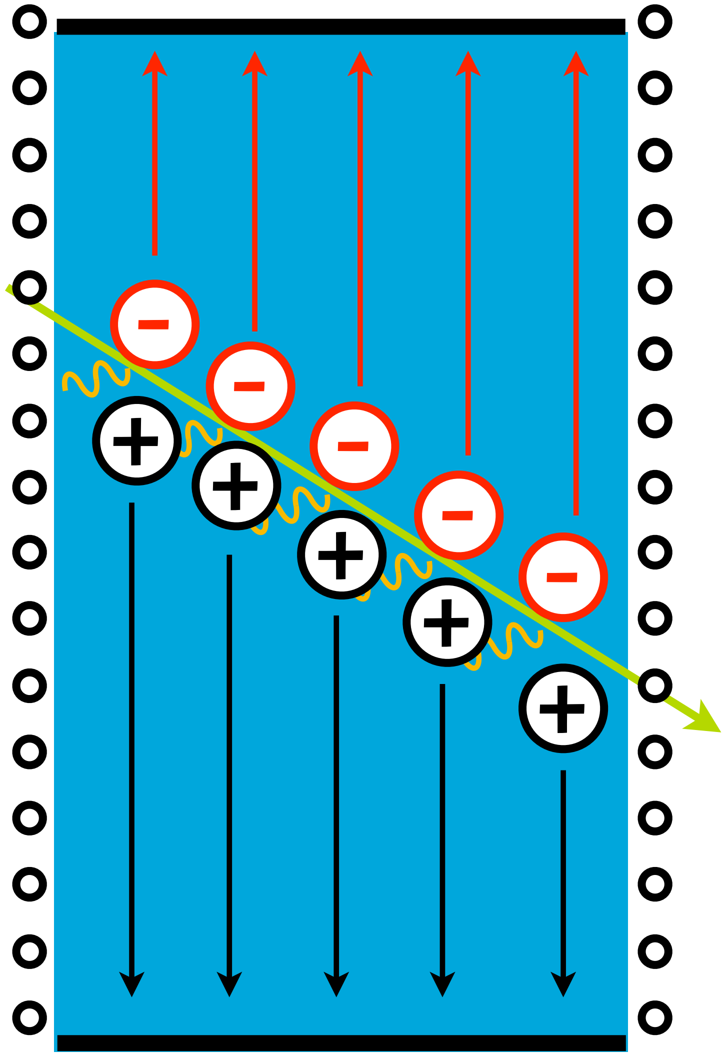
$\Delta E/E_0$ [%] at z = 347 cm





Data/MC differences might comes from LAr flow, and detector effects (CPA tilt)

Space Charge Effect - Simulations



Simulations of SCE :

- analytically or with finite elements software
  -> IN2P3 has COMSOL licence tokens [except for APC]

- Many unknowns / topics to study
  - Ar^+ drift velocity
  - Impurities drift (e.g. O_2^-, H_2O^-)
  - LAr flow: detector elements, sources of heat
  - Detector effects (e.g. anode/cathode planarity)

There is work to do !

From simulation/data build 3D maps **truth** ⟷ **reco** (one-to-one correspondance)

↳ spatial offsets in y & z, drift time offset, local drift field, …

Then one can correct hits position and charge according to the maps

-> Done here in LArSoft

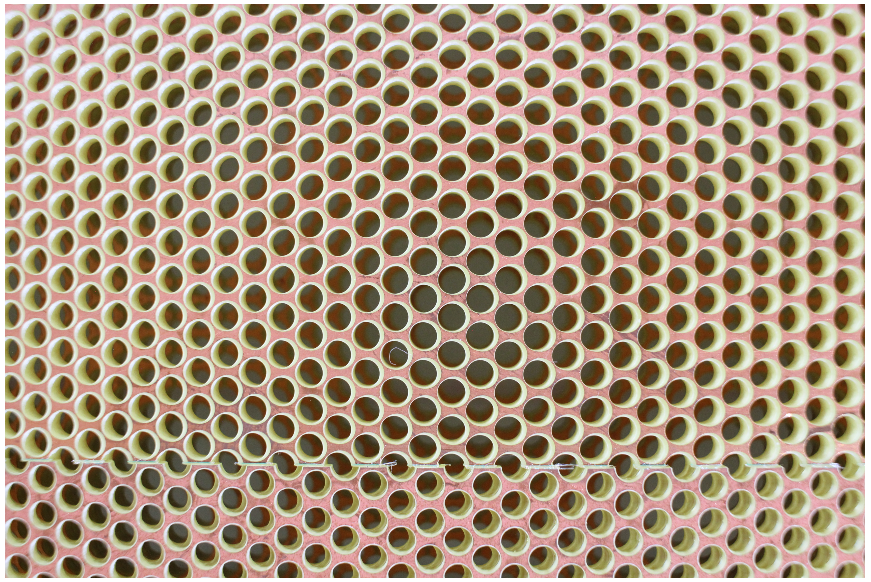
Selection of Papers/Talks on SCE topic :

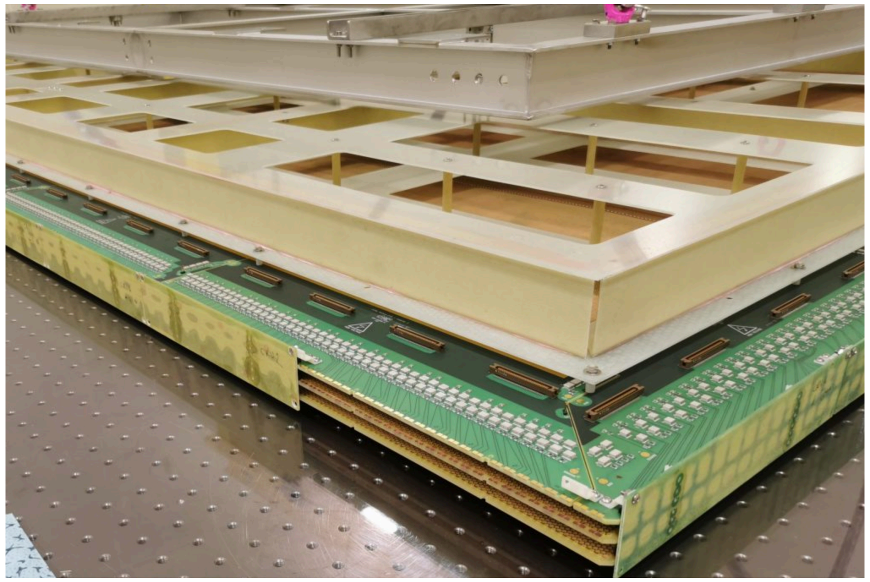
SCE corrections in MicroBoone
SCE in protoDUNE-SP
SCE models review
SCE Numerical solver (under dune review)

Read the charge signal in VD design

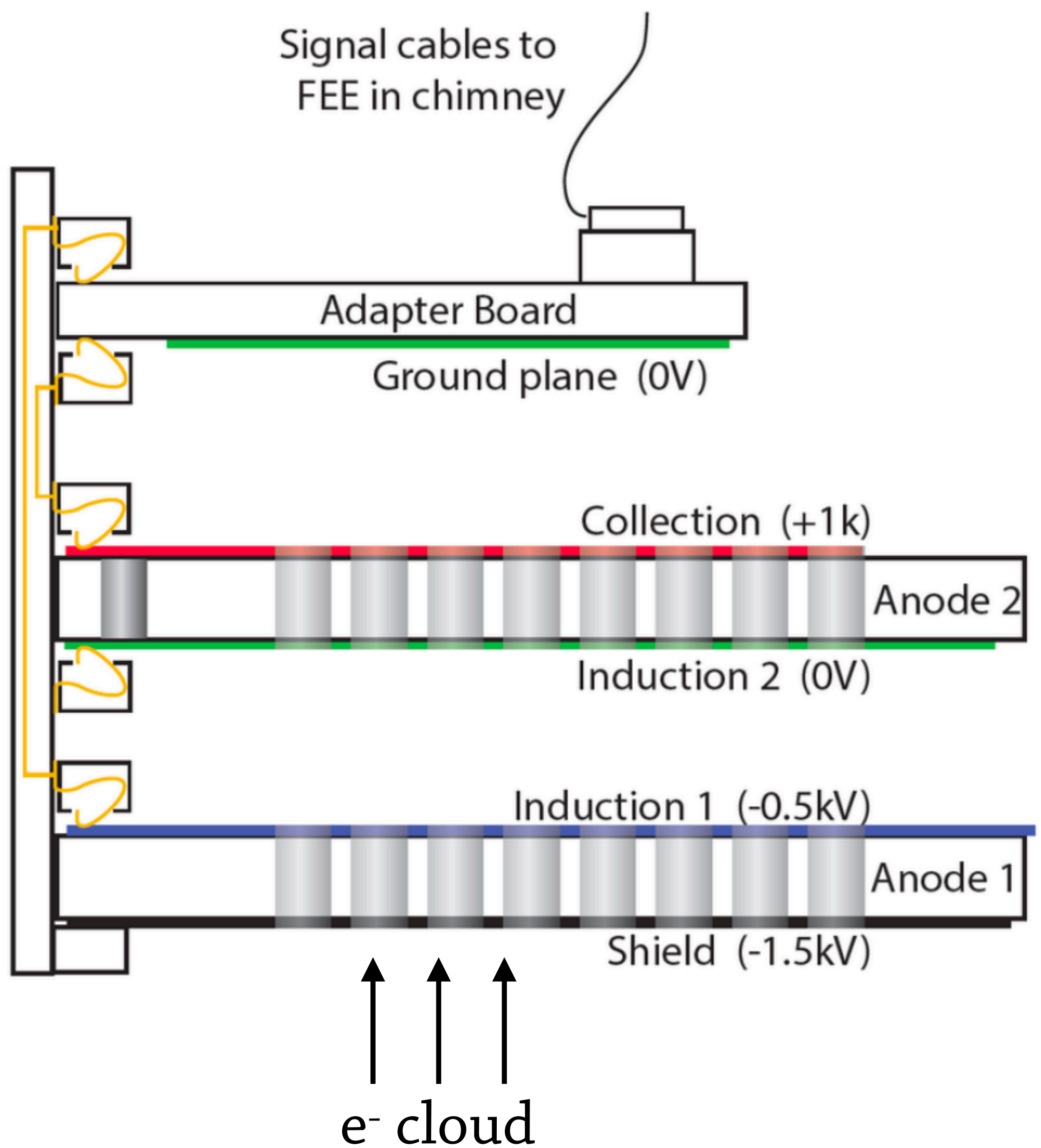
Once the charged signal has been created, propagated, distorted : let's record it

The readout system in the VD design is made of 2 PCB plates (3.2 mm thick, 1cm gap), covered by copper layer, drilled with holes (⌀=2.4mm) arranged in a hexagonal layout (h=2.94mm).





VD Charge Readout

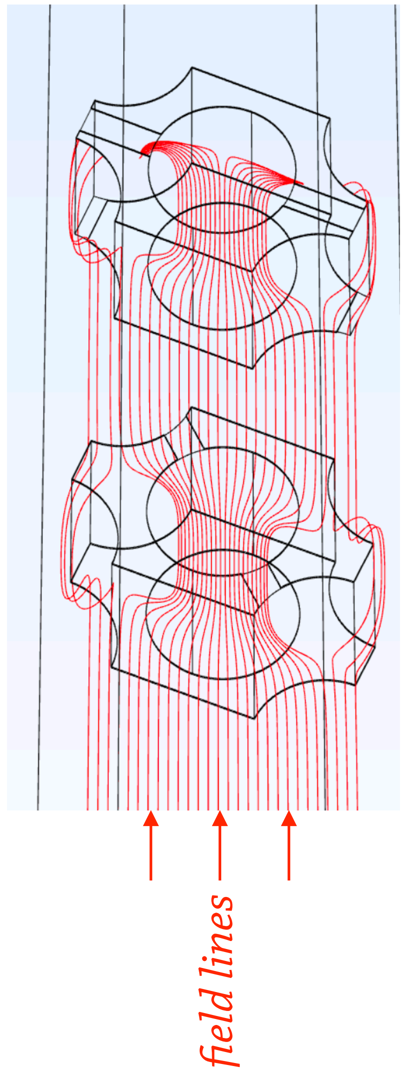


A biais of ≳1 kV across the PCB is needed to lift and focus the electrons in the holes

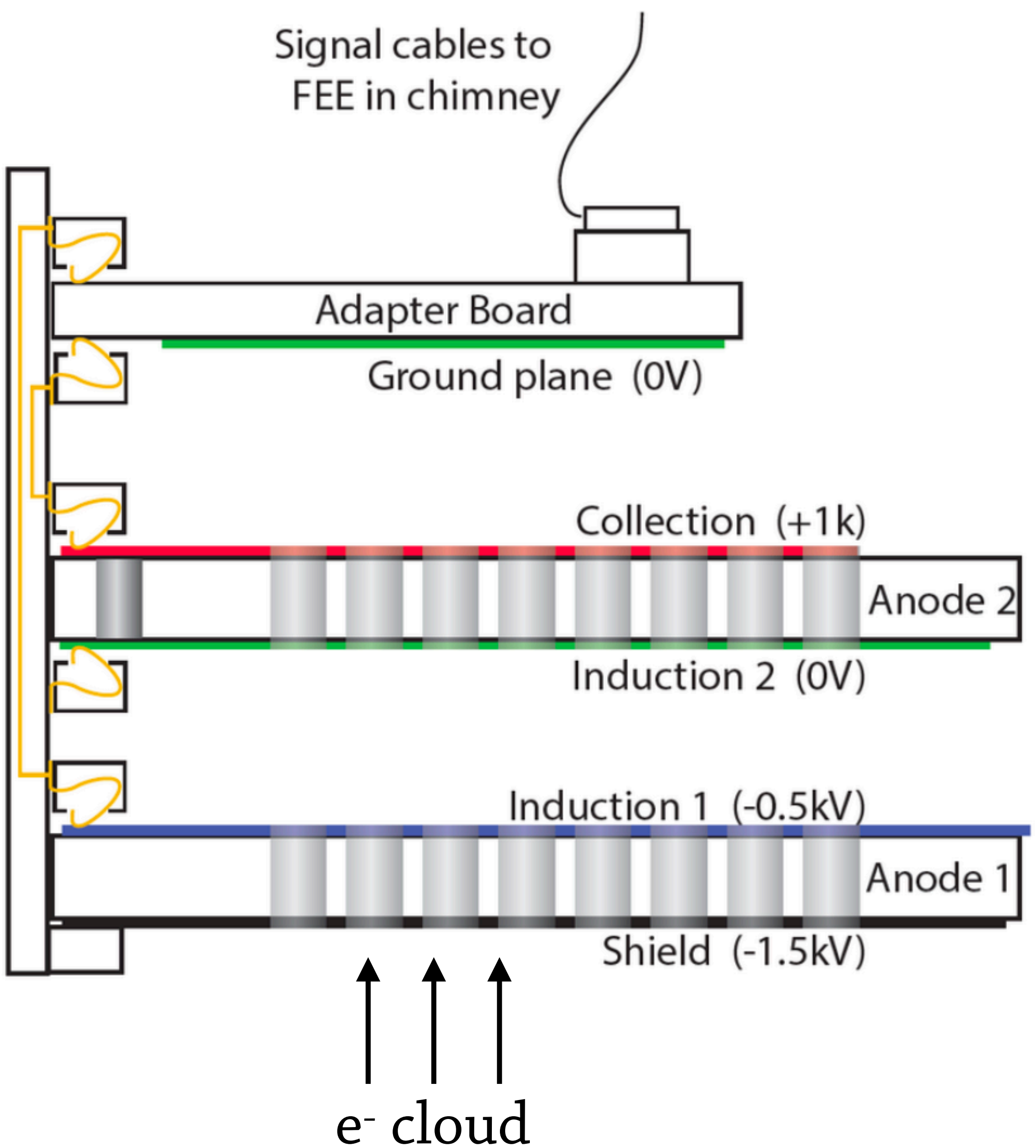
↳ From 50L data and simulations

The 1st face is the shield, it's ***un-instrumented*** and its main purpose is to protect the other faces from discharges

The 2nd and 3rd face reads the signal through ***induction*** ; the 4th face ***collects*** the charges.



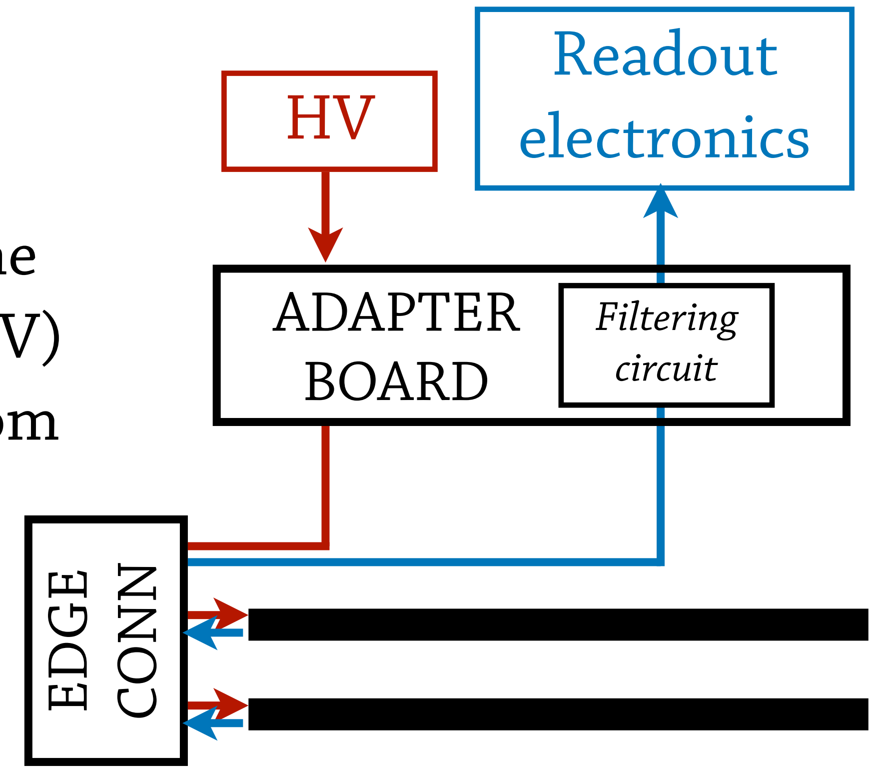
VD Charge Readout



In the gap between PCB the field is similar to the drift field (~500 V/cm).

The Adapter Board :

- provides the HV to the channels (+1kV, -0.5kV)
- filters the HV bias from the output signal



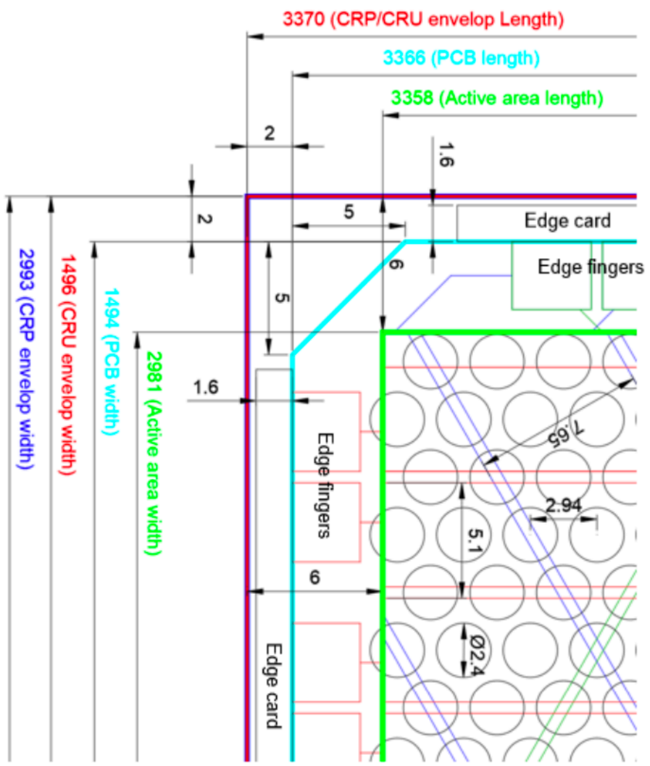
The Adapter Board, the roof (floor), the composite frame are at ground and above (below) the collection view

→ there is a 'dummy' drift field volume with variable strength above (below) the collection

→ Leads to the observation of 'ghost tracks'

VD Charge Readout

The induction and collection views are etched to forms ‘strips’ or ‘channels’ *(also ‘wires’ in LArSoft)*



First Induction - View 0

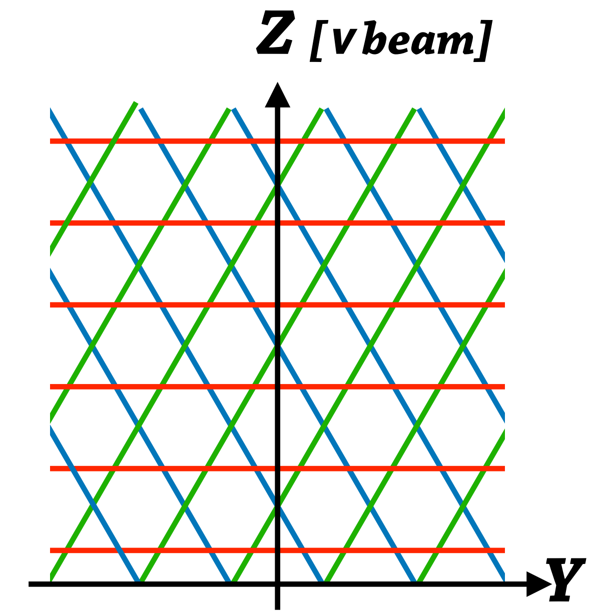
7.65 mm wide, at +30° wrt ν-beam/Z

Second Induction - View 1

7.65 mm wide, at -30° wrt ν-beam/Z

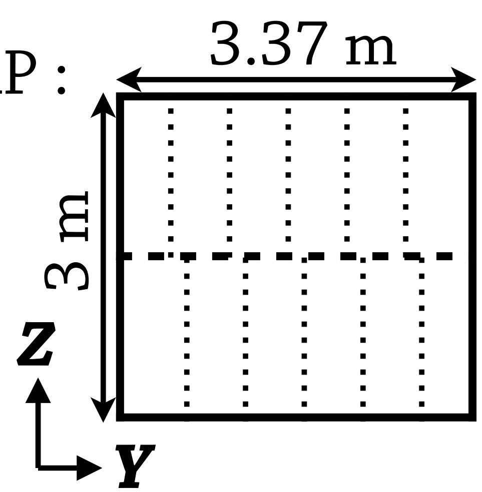
Collection - View 2

5.1 mm wide, at 90° wrt ν-beam/Z



*(In standard LArSoft coordinates where **X** is the drift)*

One CRP :



The manufactured PCB comes in panels of 1.5m×~50cm (3 sizes)

-> 6 panels makes a **CRU** *(charge readout unit, 1.5×3.37m²)*

-> 2 CRU makes a **CRP** *(charge readout plane, 3×3.37 m²)*

-> 6 CRP makes a **Super-Structure** *(6.7×9 m²)*

-> FD-VD total readout plane made of 80 CRP×2 *(20×4, 13.5×60 m²)*

There is no strip continuity at CRU junction :

- View 0 and View 1 has 952 channels each/CRP
- View 2 has 1168 channels/CRP [also split along Y]

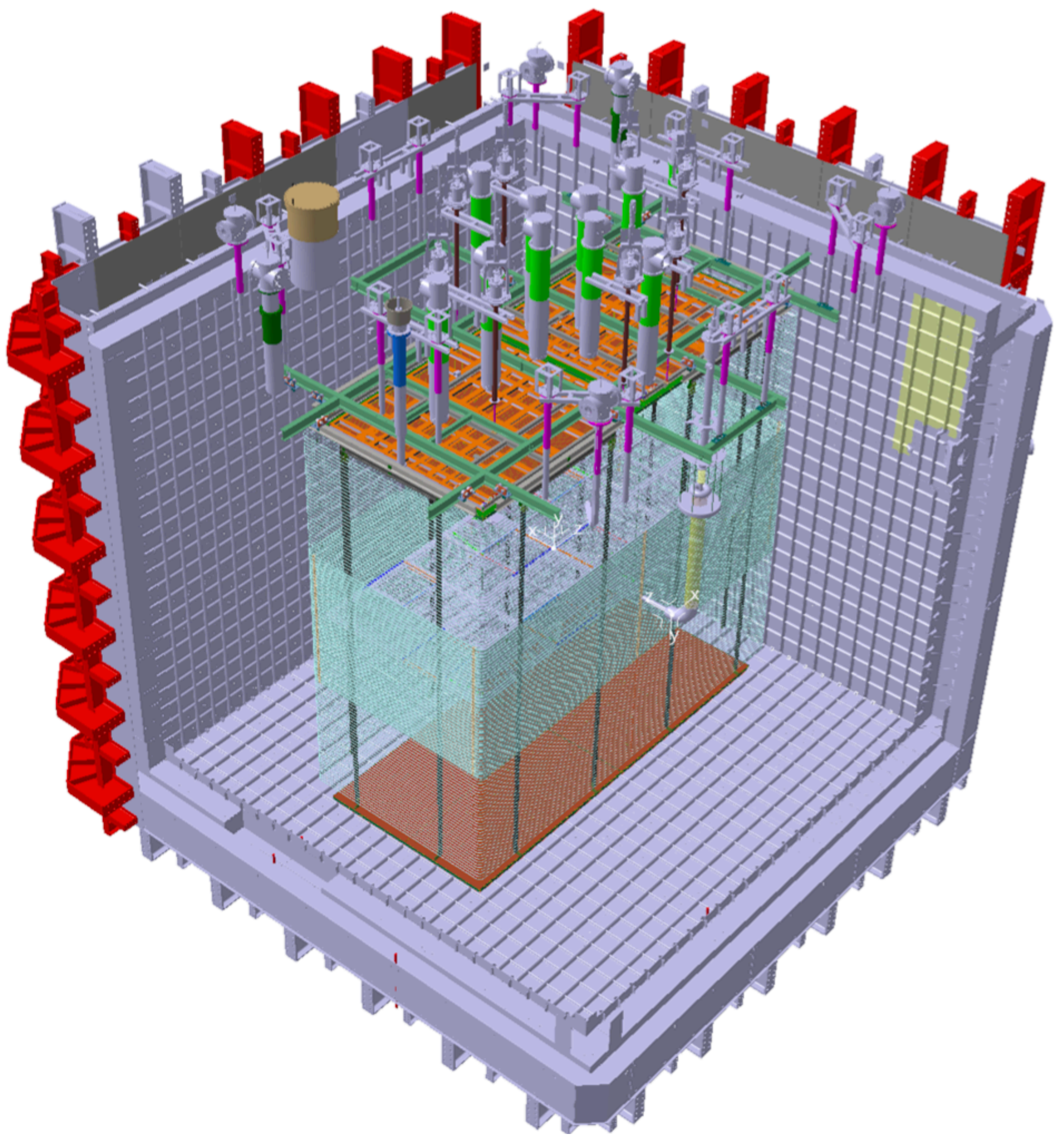
-> For technical reason, in LArSoft a CRP is divided in **4 TPC volumes**

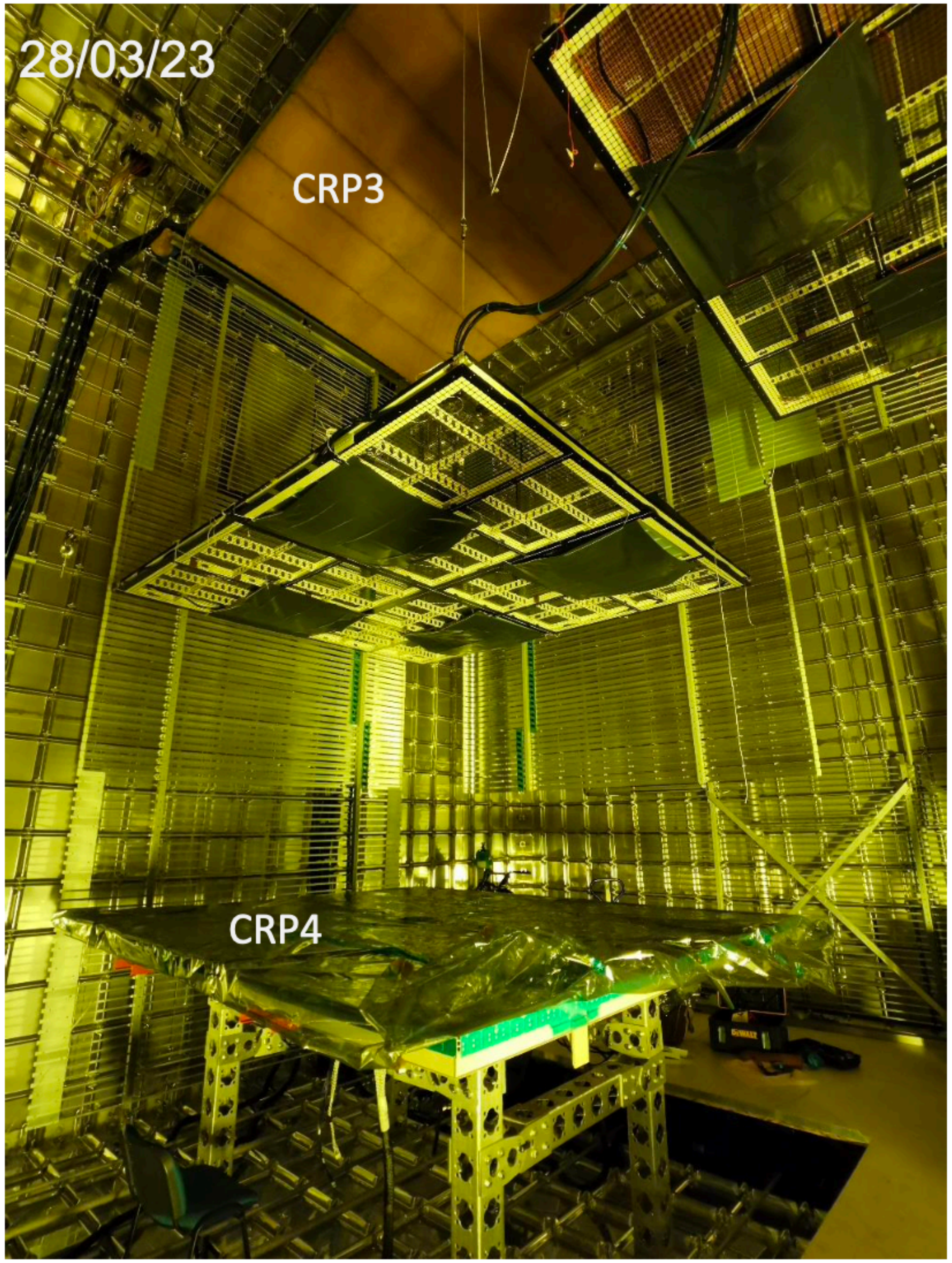
Module-0

In Module-0 : 2 CRP at the top (CRP2&3) and 2 CRP at the bottom (CRP4&5)

-> 3.2 m of drift

-> Beam data foreseen





Signal Formation on strips

We collect two types of signal on the strips : induction and collection.
-> Induction signal is bipolar while the collection is unipolar
-> Both are directly proportional to the amount of electrons

The signal is generated according to Shockley-Ramo theorem
-> Describes the current induced by a charged particule near an electrode :

$$i = qE_W v$$

q : charge of the particle
v : speed of the particle
E_w : Electrode weighting Field

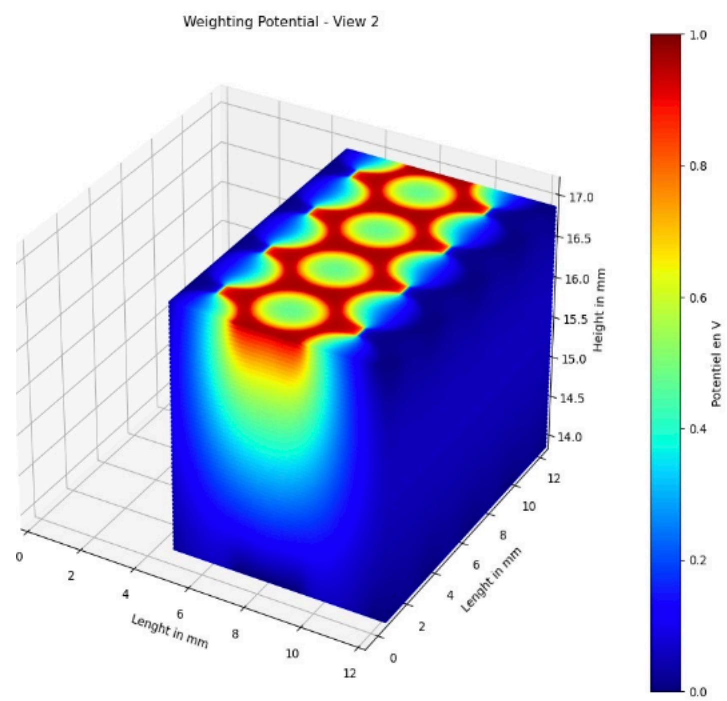
Where the ***Weighting Field*** is the component of the electric field in the direction of at the charge's instantaneous position, under the following conditions: charge removed, given electrode raised to unit potential, and all other conductors grounded.

Signal Formation on strips

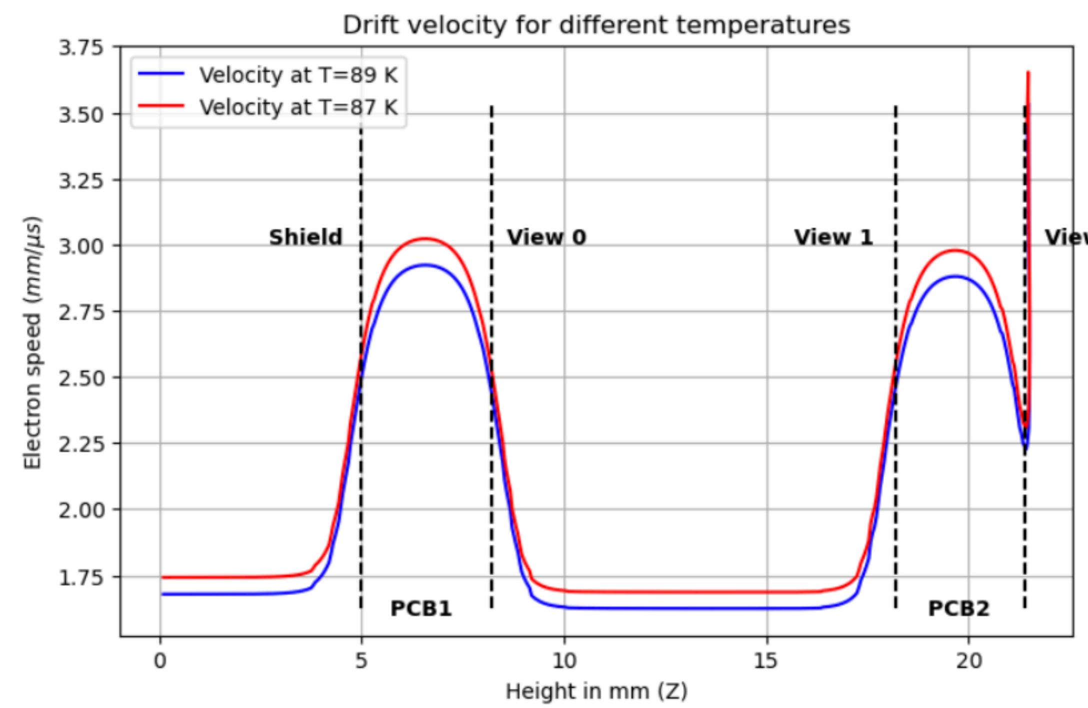
Simulations (numerical, COMSOL, …) generate the electric field strength and lines in the CRP (to get the drift velocity) and the weighting potential

Examples from Joshua's work

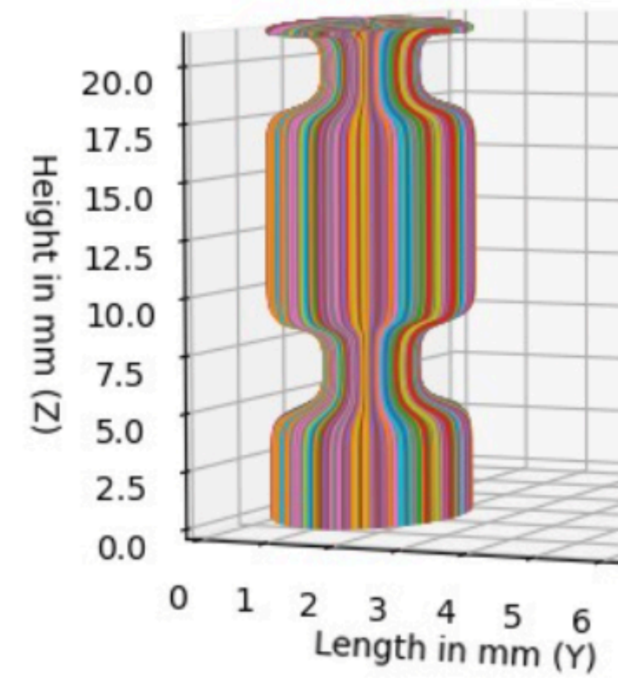
Weighting potential of View 2



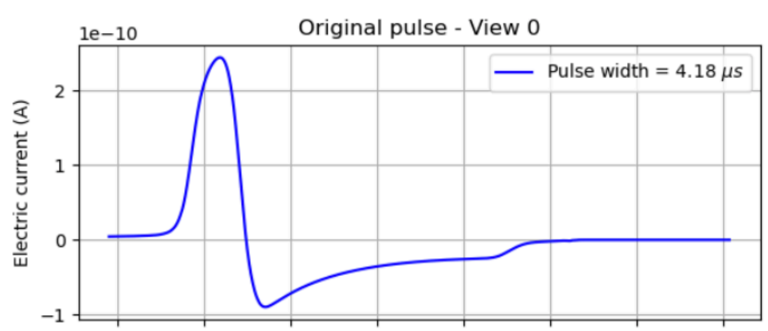
Drift velocity

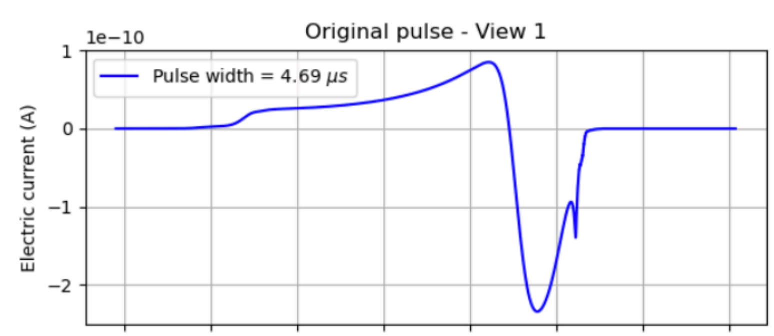


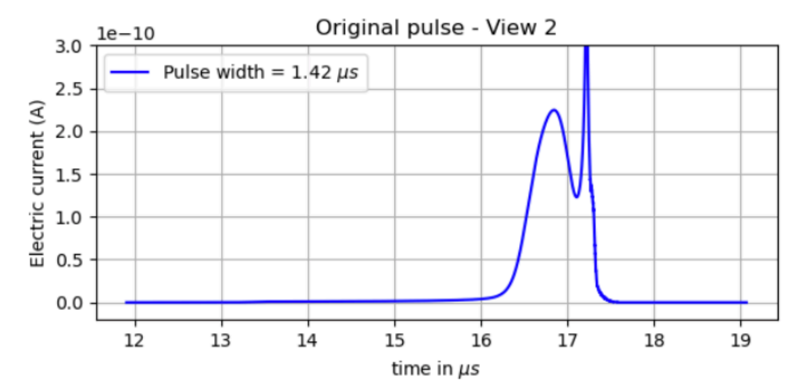
Electrons path



Current generated on the three views:







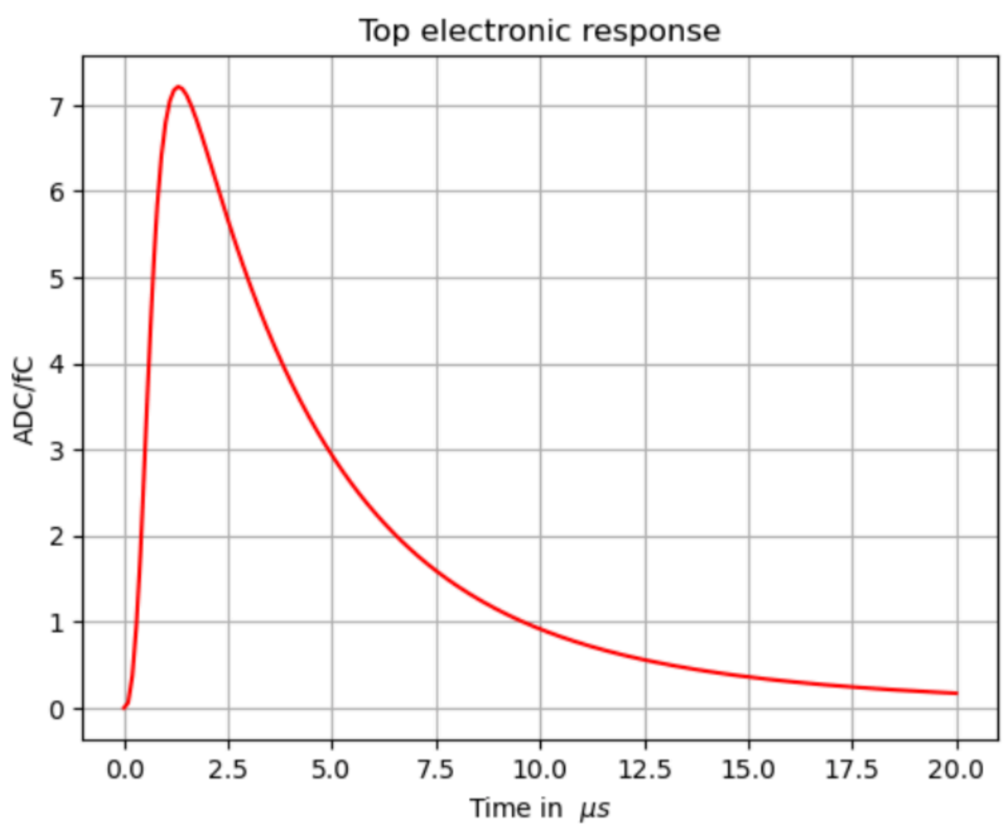
Signal Formation on strips

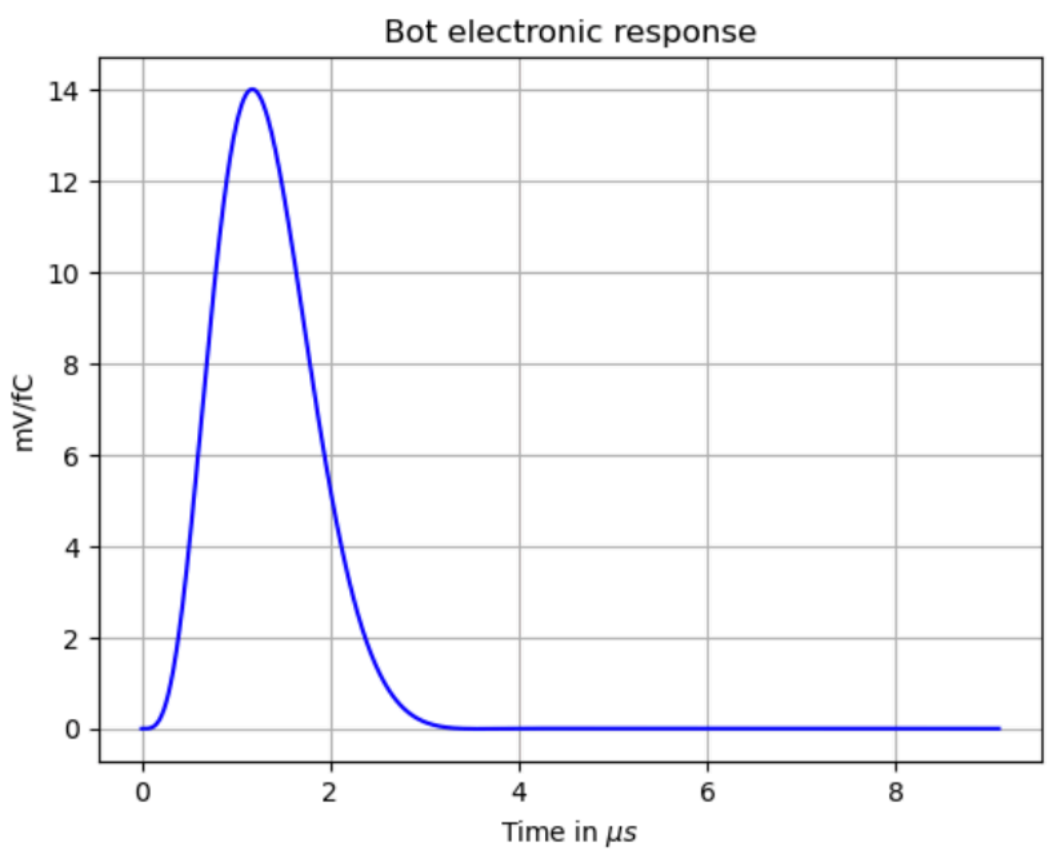
The signal is then shaped / sampled / digitized by the electronics

-> In the VD design we have two electronics :

- « Top » : in 'warm' (accessible in the chimneys)
- « Bottom » : at cold embedded on the CRP

-> The two electronics have different response functions





In conclusions

We have seen the theory, now let's simulate events in a LArTPC !