



Laboratoire d'Annecy de Physique des Particules

# Performances of the ProtoDUNE Dual Phase experiment

Pablo Kunzé

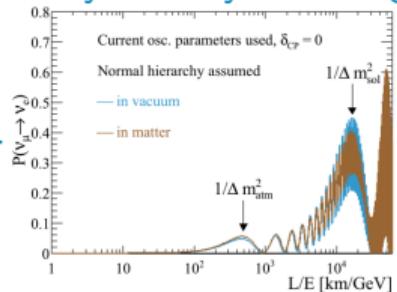
Supervised by Laura Zambelli & Dominique Duchesneau

20 octobre 2021



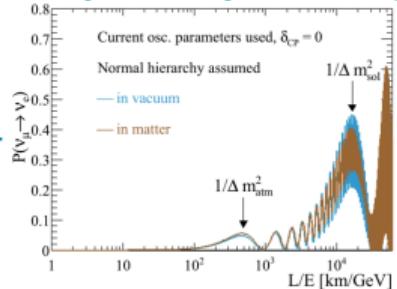
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MONT BLANC

## Neutrinos oscillation CP symmetry breaking ?

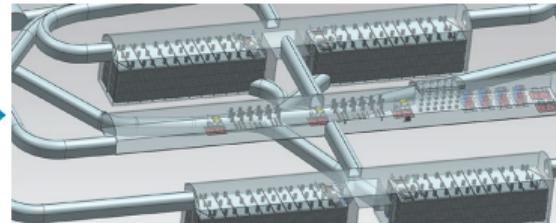


# Introduction

Neutrinos oscillation  
CP symmetry breaking ?

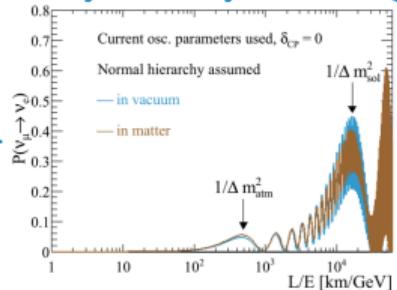


DUNE

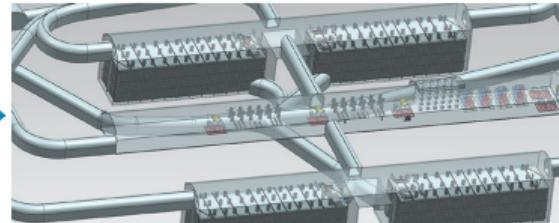


# Introduction

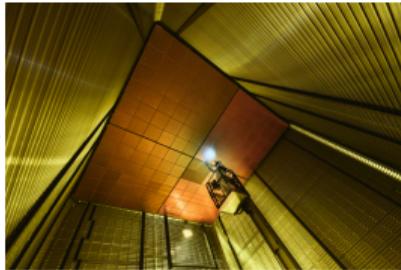
Neutrinos oscillation  
CP symmetry breaking ?



DUNE

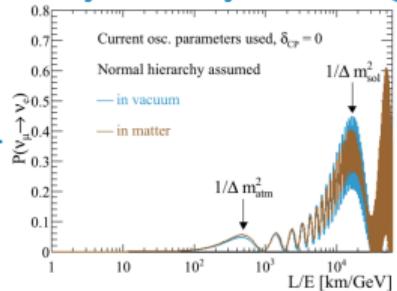


ProtoDUNE

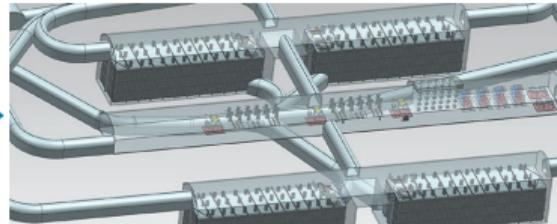


# Introduction

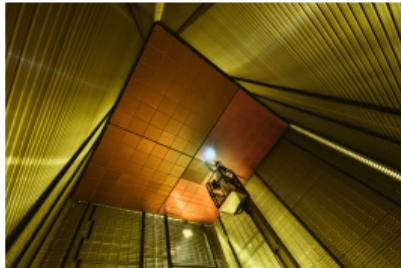
Neutrinos oscillation  
CP symmetry breaking ?



DUNE



ProtoDUNE



Data Analysis and performances

# Neutrinos oscillation



Standard model : 3 neutrinos



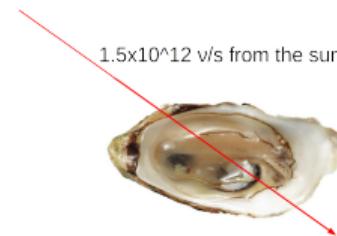
electron  
neutrino



muon  
neutrino



tau  
neutrino

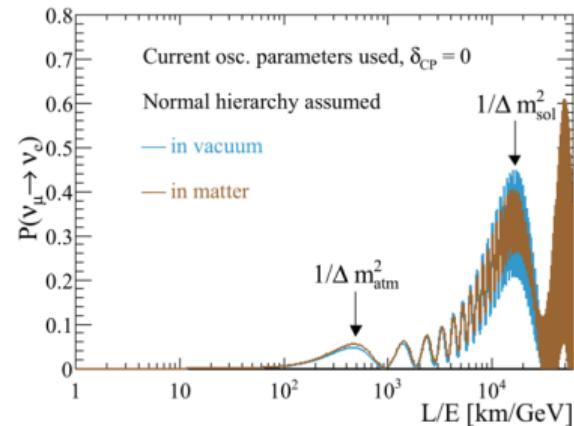


Neutrinos oscillations :  
A neutrino flavor has a probability  
to change along its path  
→ Neutrinos have a mass !

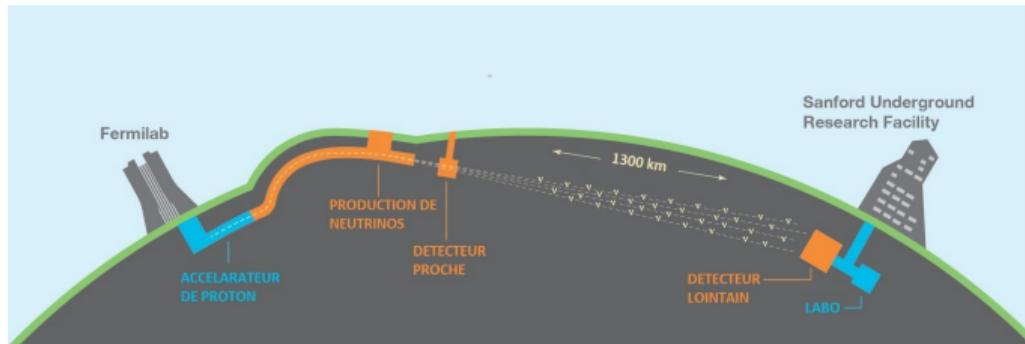
We know  $\theta$  and  $\Delta m^2$  at a few %

DUNE wants to precisely determine :

- **mass hierarchy** ( $5\sigma$  in 3 years)
- **Breaking of CP symmetry in  $\nu$**  ( $\delta_{CP} = 0$  excluded at  $5\sigma$  with 50% of values after 10 years)



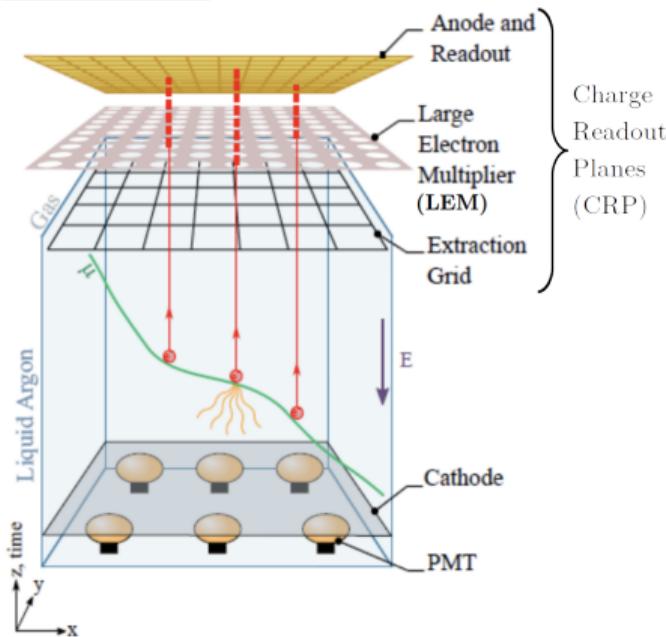
Principle : After a large distance, mesurement of  $P(\nu_\mu \rightarrow \nu_\mu)$ ,  $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu)$ ,  
 $P(\nu_\mu \rightarrow \nu_e)$  and  $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$



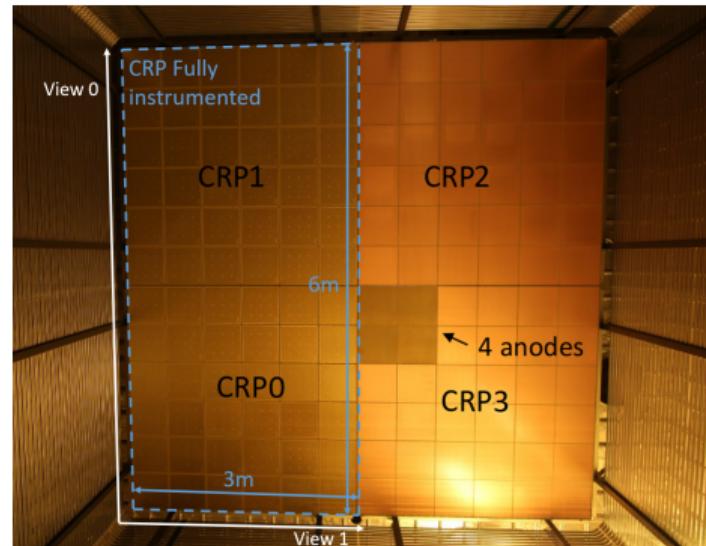
Source : Pure beam of  $\nu_\mu$  or  $\bar{\nu}_\mu$  created at an accelerator  
 $E_\nu \sim \text{GeV}$

Detector : 1300 km from the source and at 1480 m deep  
4 Liquid Argon module of  $60 \times 12 \times 12 \text{ m}^3$  or 10 kt each  
Time Projection Chamber (TPC)

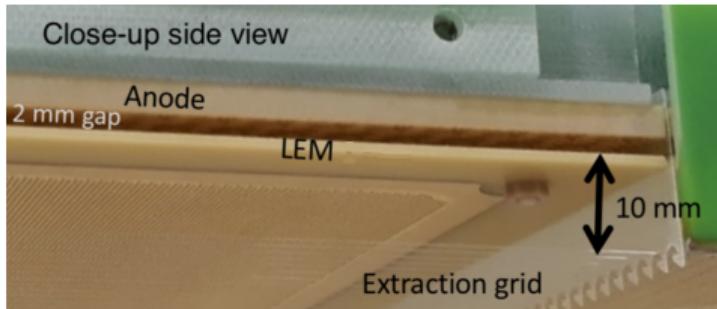
## Dual Phase



CRP from bottom of the detector



# Goal performances of ProtoDUNE DP



Optimal field conditions :

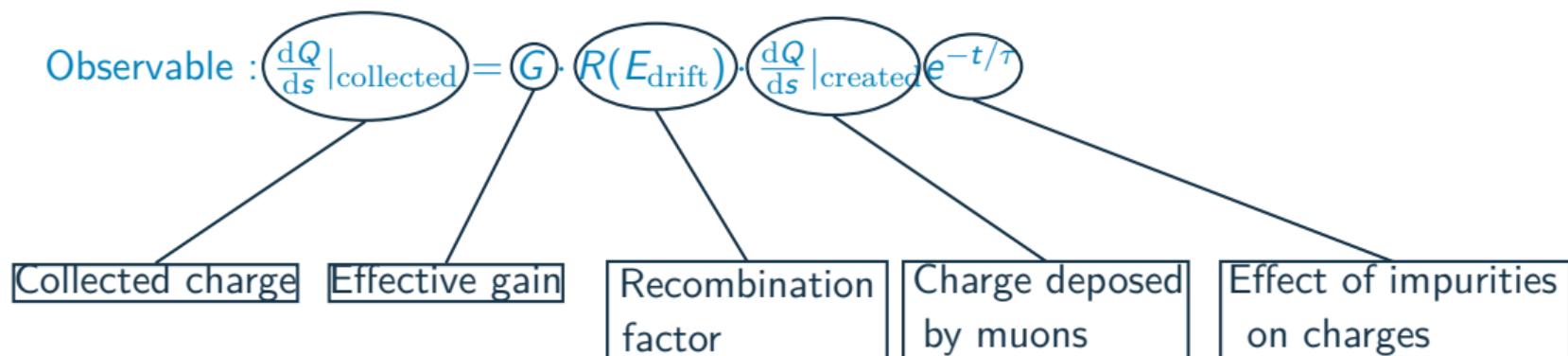
- Extraction : 2 kV/cm
  - Amplification : 30 kV/cm
  - Induction : 2.5 kV/cm
- } Effective gain 20

ProtoDUNE DP has to show :

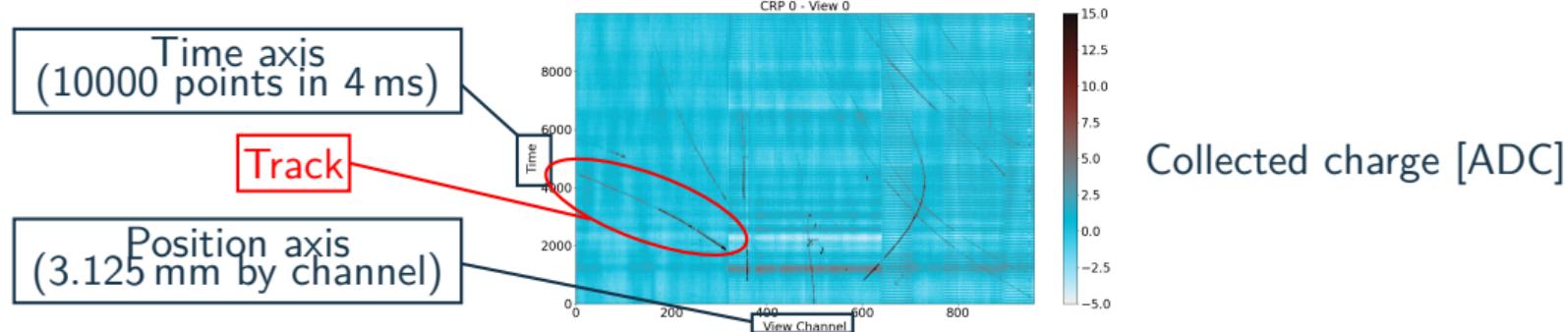
- ▶ Drift field of 500 V/cm over 6 m
- ▶ Optimal gain :  $\sim 20$
- ▶ Time stability
- ▶ Purity of 100 ppt of  $O_2$  eq ( $\tau = 3 \text{ ms}$   $e^-$  lifetime)

ProtoDUNE DP  $6 \times 6 \times 6 \text{ m}^3$  300 t detecting cosmic rays.

Data taken on several days in September, October, November 2019 et January 2020.  
New data taking planned Autumn 2021.



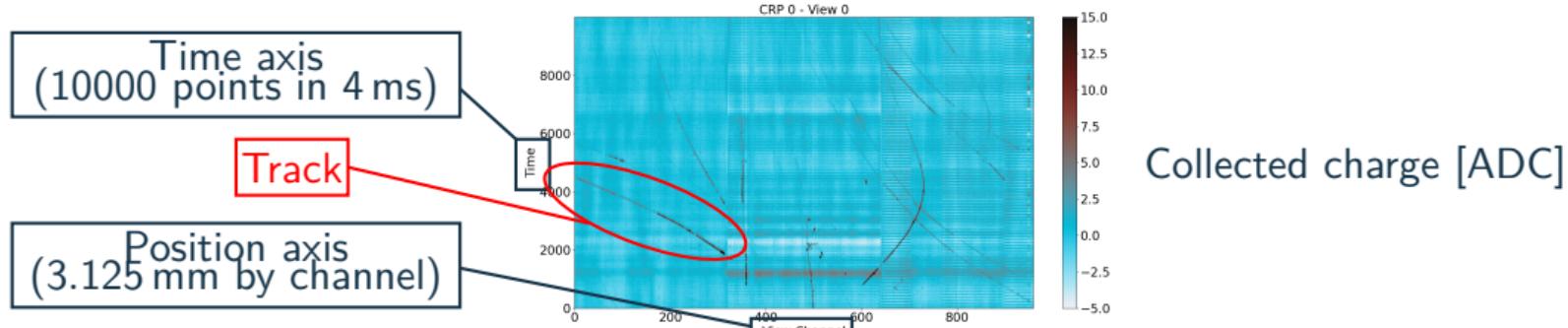
## Event display example



## Tracks reconstruction :

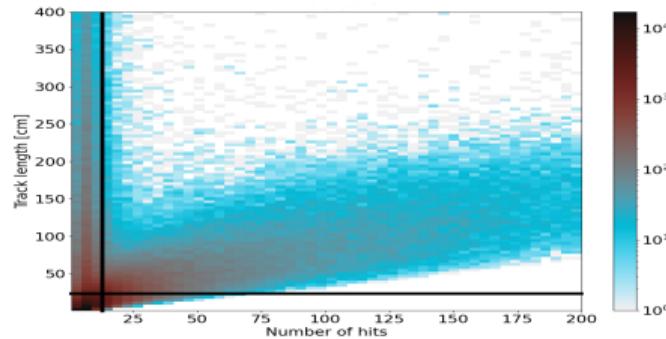
- ▶ Noise filtering
- ▶ Hit finding
- ▶ Associate 2D tracks to 3D tracks

# Track reconstruction and selection



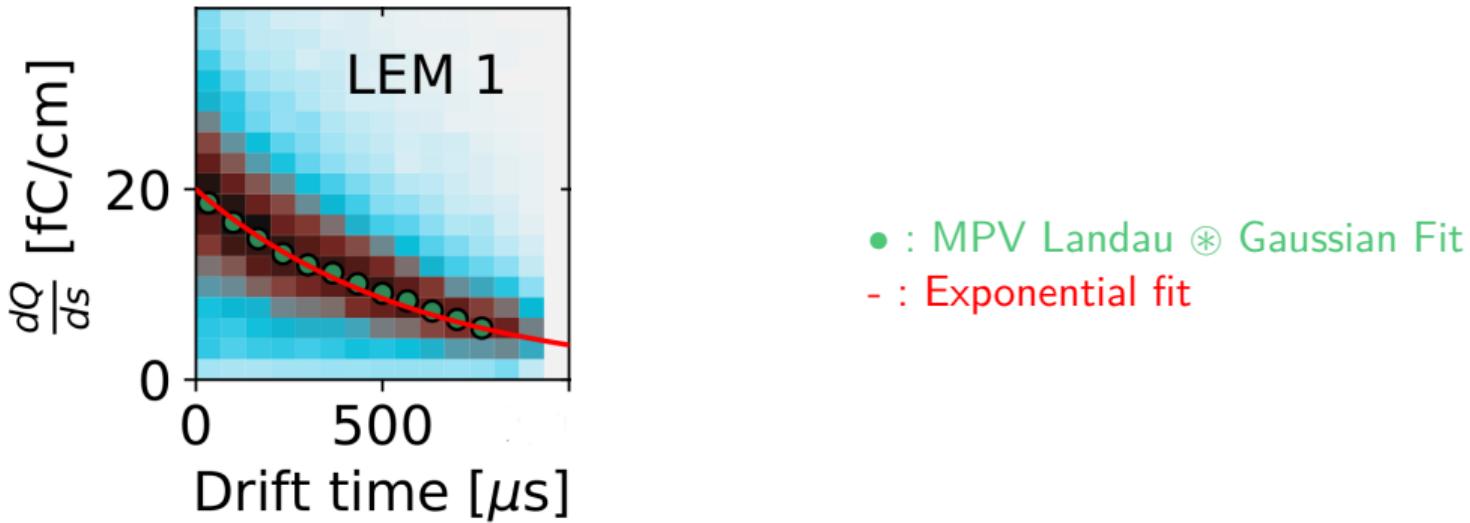
We want cosmic  $\mu$  ( $\frac{dQ}{ds} = 6.12 \text{ fC/cm}$  by view) and good quality tracks :

- ▶ Late tracks and entering by the anode (upper part of the detector)
- ▶ Selection on number of hits in the track, track's length, track's zenithal angle



In a first time, we want to find the purity or the electron lifetime in the liquid Argon with  $\frac{dQ}{ds}|_{\text{collected}} = G \cdot R(E_{\text{drift}}) \cdot \frac{dQ}{ds}|_{\text{created}} e^{-t/\tau}$  :

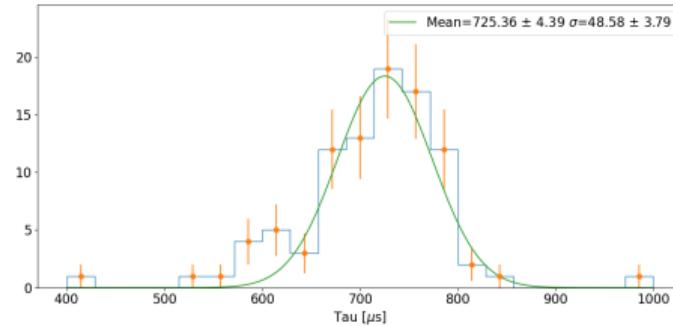
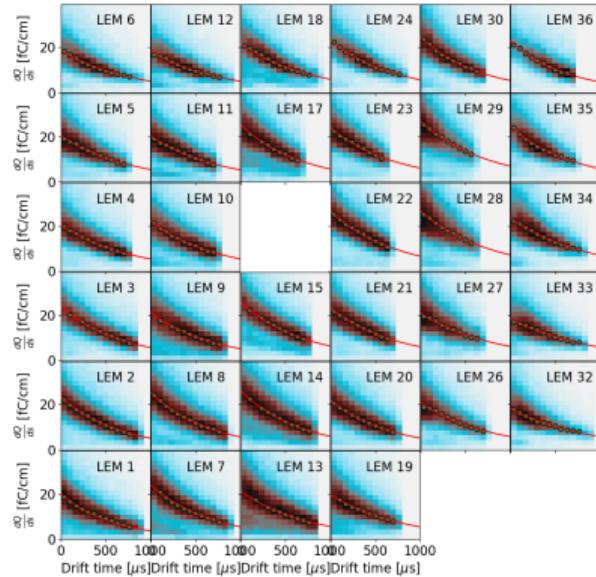
- ▶ Electrons are captured by impurities drifting in the liquid Argon according to  $e^{-t/\tau}$  with  $t$  the drift time and  $\tau$  electron lifetime ( $\rho[\text{ppt}] \sim \frac{300}{\tau[\text{ms}]}$ )
- ▶ By fitting the distribution of  $\frac{dQ}{ds}|_{\text{collected}}$  versus the drift time, we find the electron lifetime.



# Liquid Argon purity for a run in October 2019

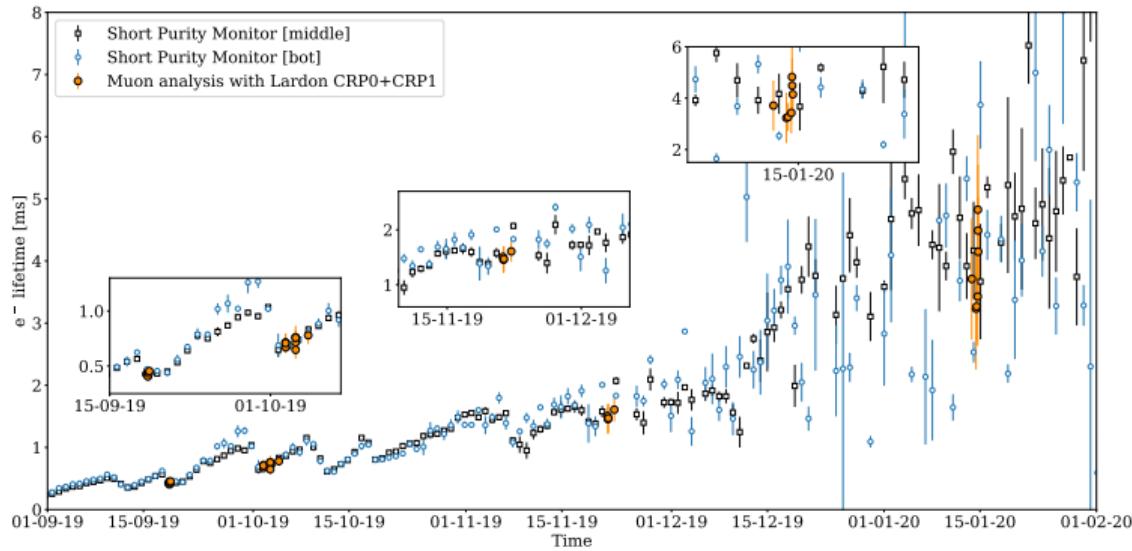


CRP 0 View 0



On average  $\tau = 725.36 \pm 48.58 \mu\text{s}$

# Comparison with purity monitors



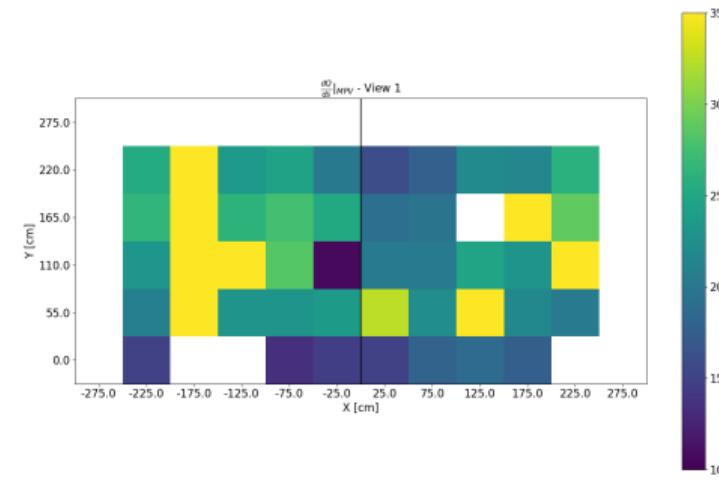
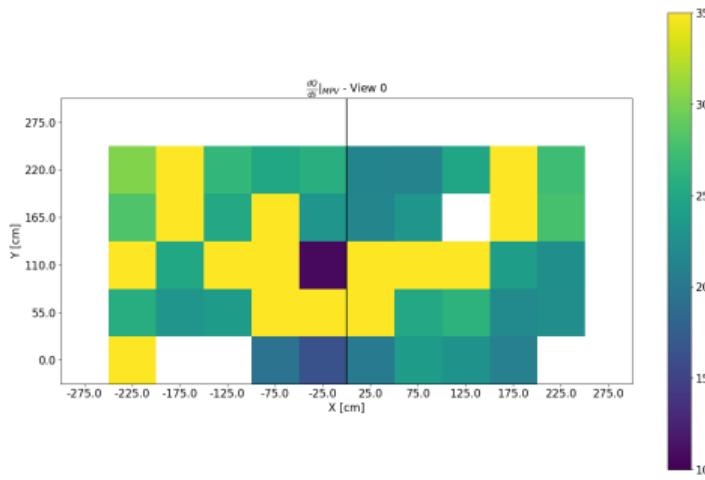
Lifetime found with the analysis in good agreement with values from purity monitor.  
Electron lifetime reach value better than expected.

Now that we know the electron lifetime, we have access to the effective gain :

$$\frac{dQ}{ds}|_{\text{collected}} = G \cdot R(E_{\text{drift}}) \cdot \frac{dQ}{ds}|_{\text{created}} e^{-t/\tau}$$

- ▶ Correct the  $\frac{dQ}{ds}|_{\text{collected}}$  with the  $e^-$  lifetime.
- ▶ By fitting the distribution of  $\frac{dQ}{ds}|_{\text{collected}} e^{t/\tau}$  with a Laundau  $\circledast$  Gaussian Fit, we find the  $\frac{dQ}{ds}|_{\text{MPV}}$ .
- ▶ The effective gain is given by  $\frac{dQ}{ds}|_{\text{MPV}} / R \frac{dQ}{ds}|_{\text{created}}$

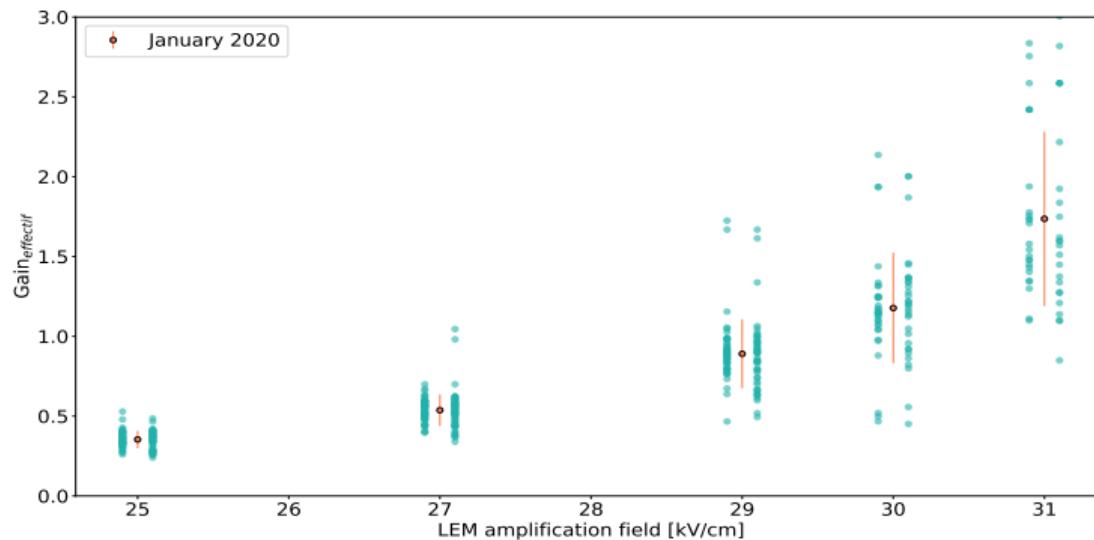
# $\frac{dQ}{ds}|_{MPV}$ for a run in October



On average  $\frac{dQ}{ds}|_{MPV} = 21.97 \pm 3.15 \text{ fC/cm}$ , effective gain of  $\sim 3.6$ .

# Gain vs amplification field

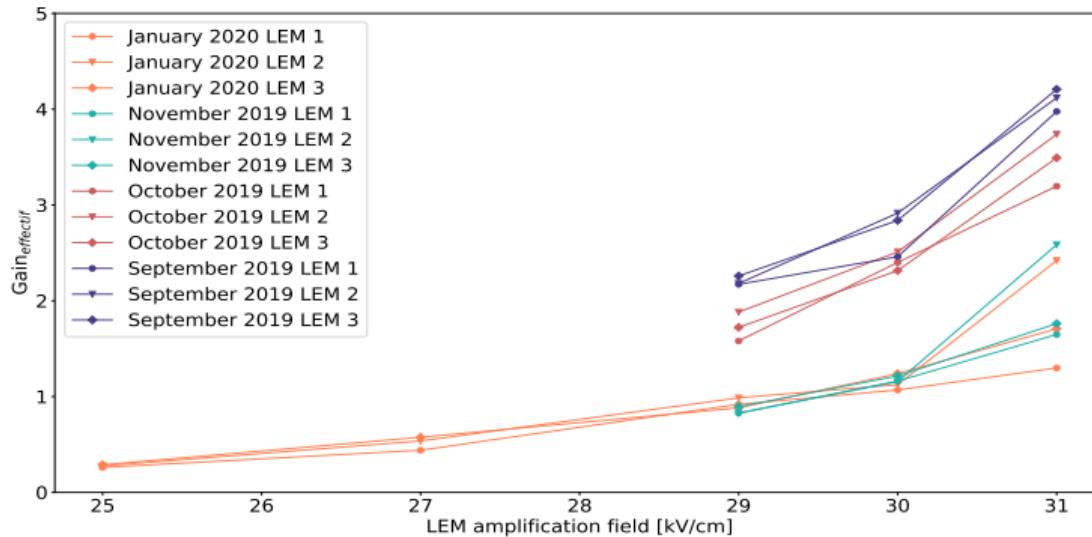
Runs taken in January 2020



Clear increase of gain with the amplification field.

# Gain decreasing over time

Runs taken in September, October, November 2019 and January 2020  
Effective gain vs LEM amplification field for 3 LEMs

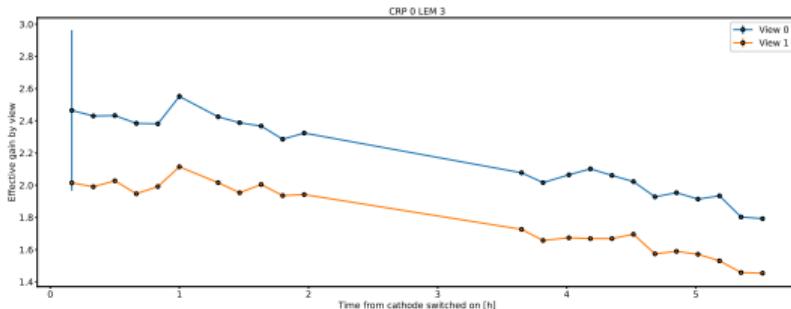
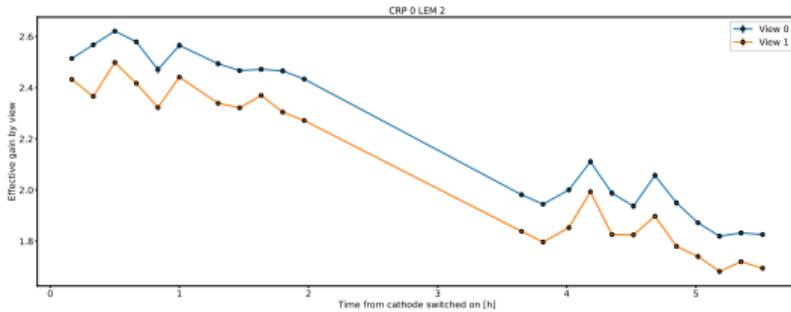


Decrease of gain at same condition with time → Charging-up effect

# Gain decreasing over time

Decrease of the effective gain over a few hours

Run taken 18th of September with same conditions (Extraction : 2 kV/cm,  
Amplification : 29 kV/cm, Collection : 2.5 kV/cm)



- Decrease of gain over time
- Might be due to charging up and space charge effect
- Have to be studied further

- ▶ Really high level of purity reach ( $\sim 3.5$  ms) and seen by the analysis with cosmics muons
  - ▶ Nice exponential increase of gain with the amplification field
  - ▶ Expected decrease of the gain with time
- 
- ▶ New data acquisition this autumn to test the new power supply of the cathode
    - Analysis of the noise, the purity, the gain
  - ▶ Detailed study of the gain and :
    - Charging-up effect
    - Space Charge Effect

# Thanks

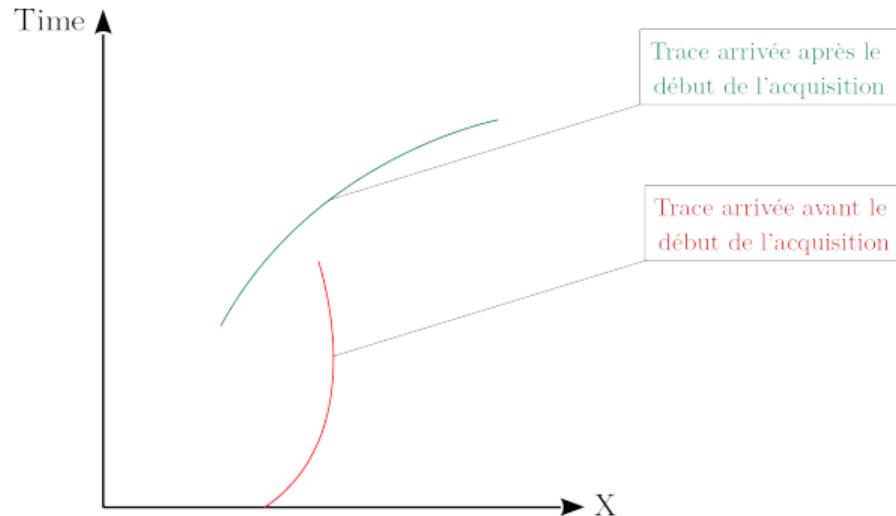
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Thank you for your attention.

## Back-up

# Sélection des traces : traces en retard

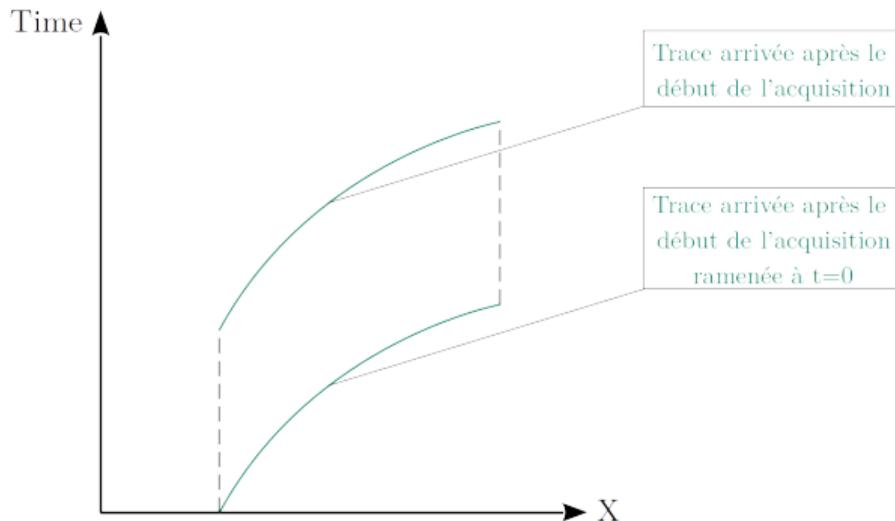


La prise de données se faisant en déclenchement aléatoire, pour être sûr du temps de dérive des électrons :

- ▶ Traces en retard
- ▶ Traces rentrant du dessus du détecteur



# Sélection des traces : traces en retard

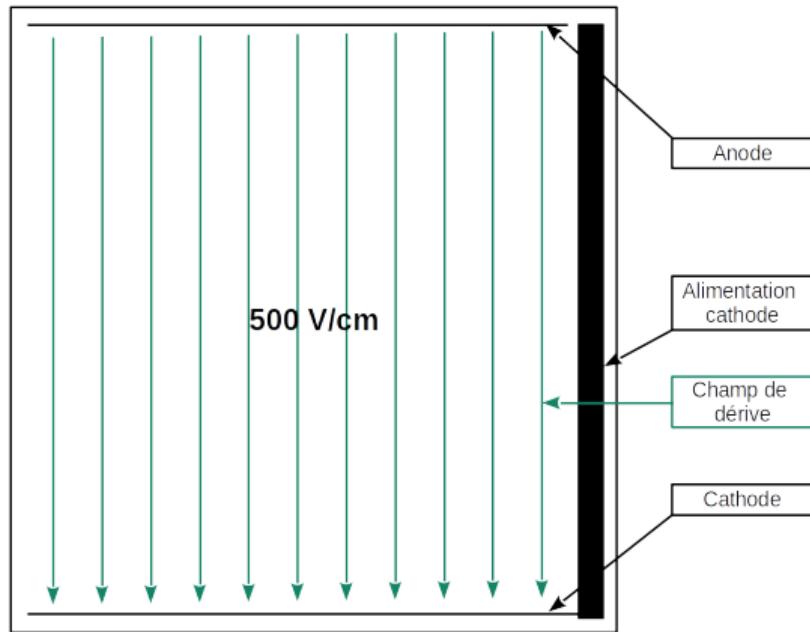


Pour être sur du temps de dérive des électrons :

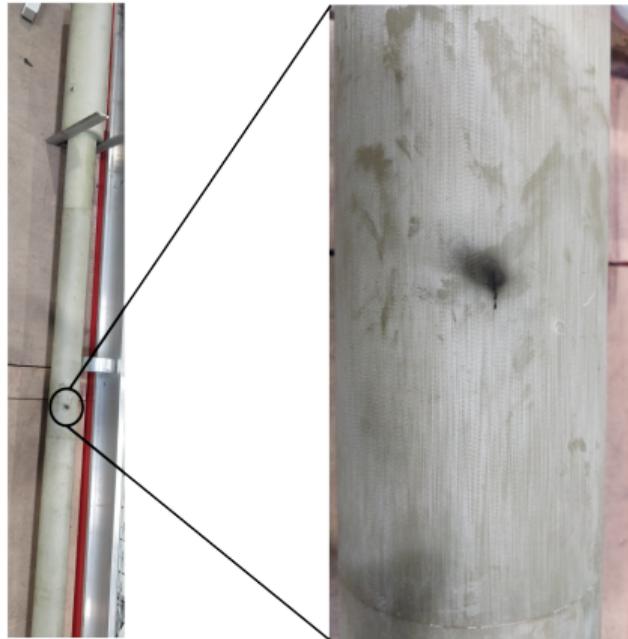
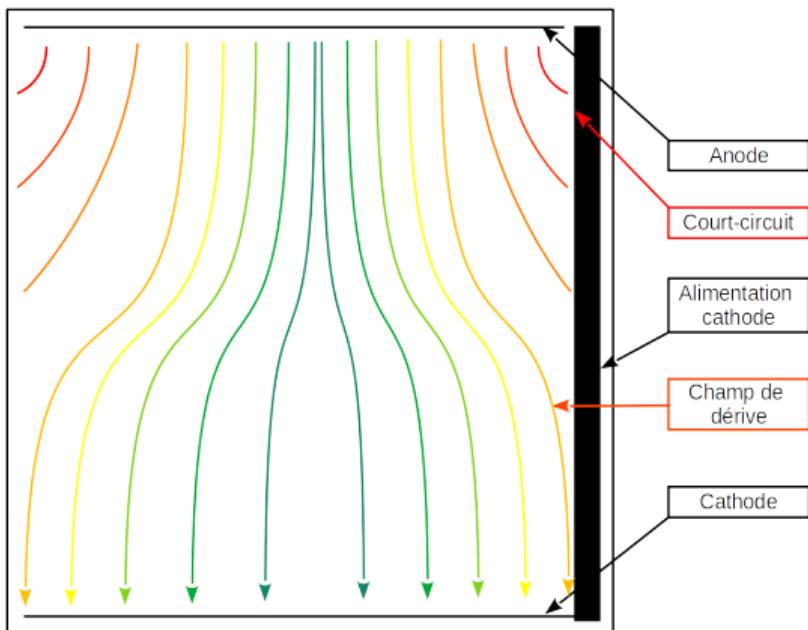
- ▶ Traces en retard
- ▶ Traces rentrant du dessus du détecteur
- ▶ On décale ces traces de sorte qu'elles démarrent à  $t=0$

- ▶ Number of hits in each view  $> 15$
- ▶ Only late tracks, entering at the anode  
(to be sure of the track's depth for purity analysis), and with distance between starting point and side of the active volume  $> 30\text{cm}$
- ▶ Track starting point at more than  $3\text{cm}$  from LEMs borders
- ▶ All length  $> 20\text{cm}$
- ▶  $95^\circ < \theta < 178^\circ$
- ▶ 10% of total tracks passing selections

In order to work properly, the drift field of a TPC has to be uniform and for ProtoDUNE DP at 500 V/cm :



But, short in the cathode's power supply :

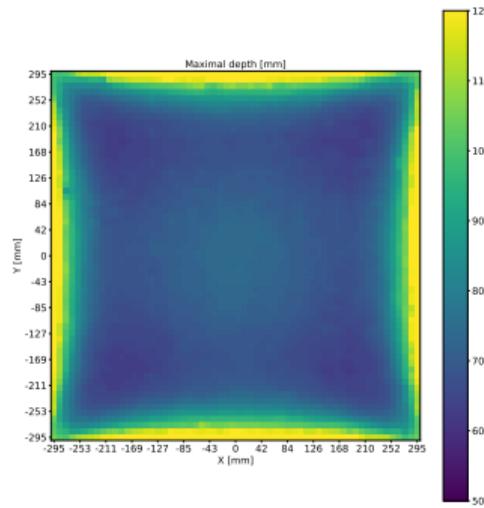
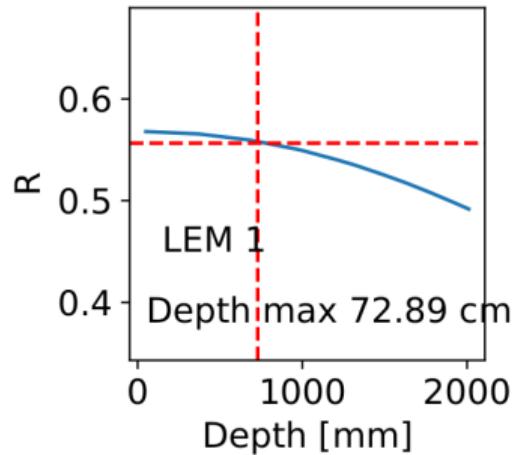


Making the analysis more complex and does not allow to fully characterize the technology.

# Definition of maximal depth

With a COMSOL simulation with the short, we obtained the drift field.

For the analysis, we choose to only consider an area where the field varies by little. To do so, the recombination factor (depending on the drift field) does not vary of more than 2% :



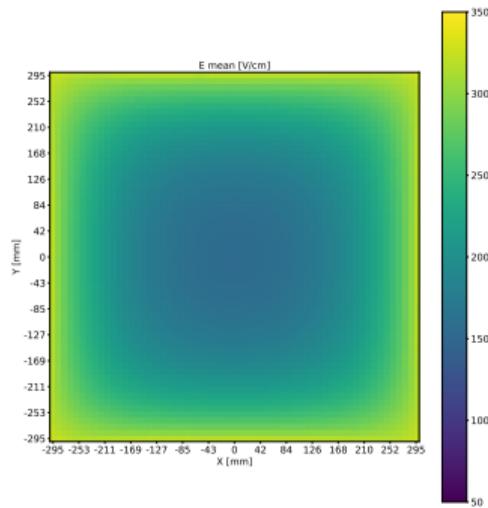
We obtain a maximal depth in each point of the detector.

# Drift field parametrization



Mean drift field from COMSOL simulation → Parametrization of the field depending on the (X,Y) position with a 2D fit and only to the maximal depth

Drift field averaged to the maximal depth defined.

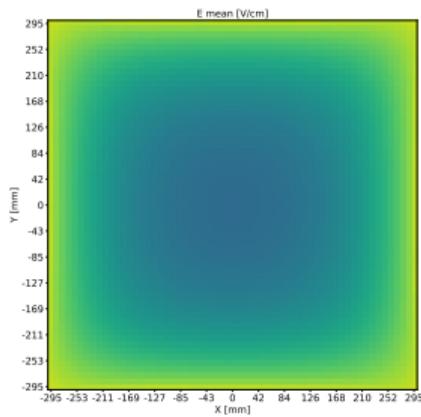


# Drift field parametrization



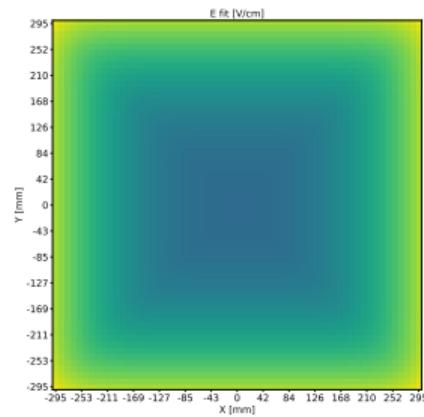
Mean drift field from COMSOL simulation → Parametrization of the field depending on the (X,Y) position with a 2D fit and only to the maximal depth

Mean field



Fit result with Squircle

$$E(x, y) = ((ax)^{10} + (ay)^{10})^{1/4} + b$$

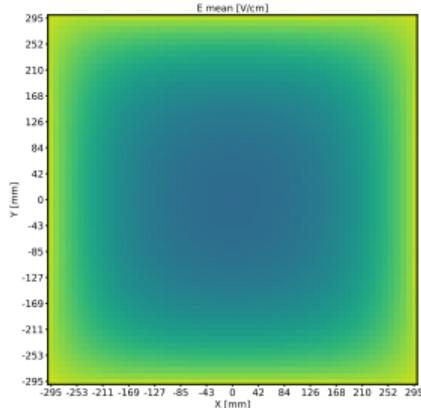


# Drift field parametrization

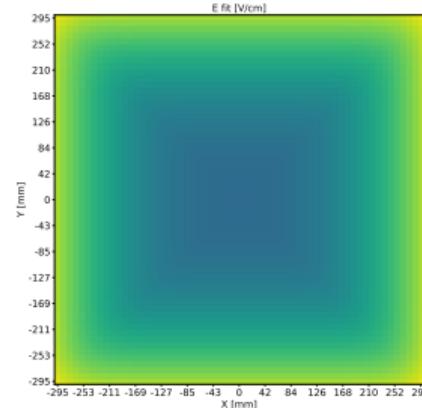


Mean drift field from COMSOL simulation → Parametrization of the field depending on the (X,Y) position with a 2D fit and only to the maximal depth

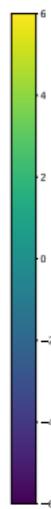
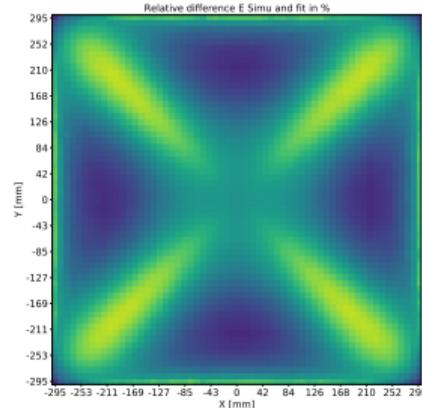
Mean field



Fit result

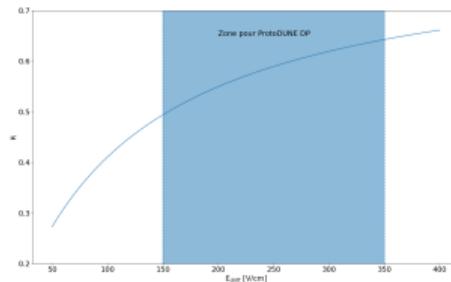


Relative error (-5% to 5%)



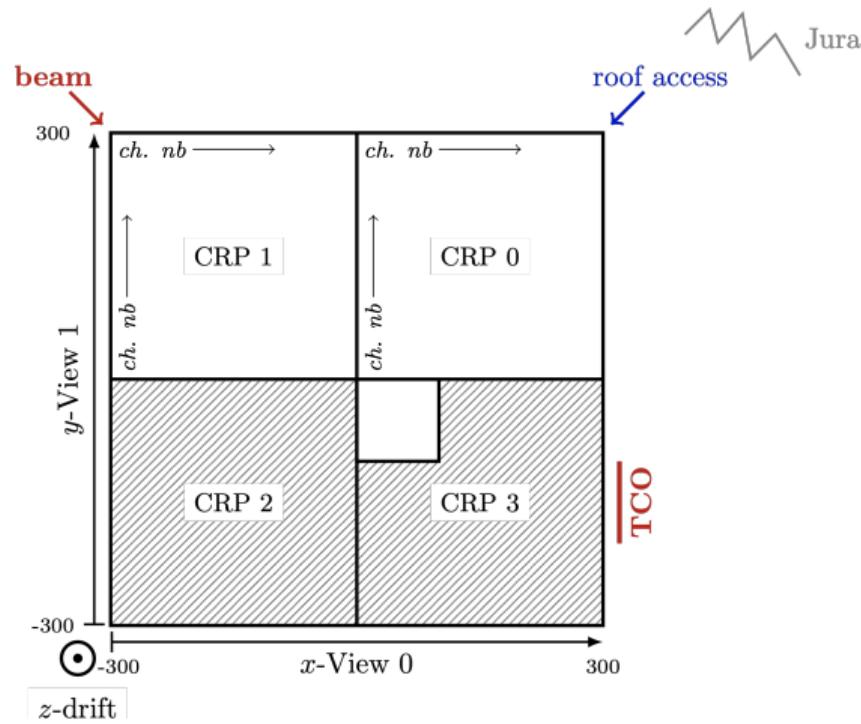
We are interested by  $\frac{dQ}{ds}$  During the tracks reconstruction, for each hits found :

- ▶ Correction of the charge  $dQ$  affected by the recombination factor depending on the drift field



- ▶ Compute the  $ds$  ( $ds = \sqrt{dx^2 + dy^2 + dz^2}$ ) by correcting the  $dz$  with the  $e^-$  velocity according to the drift field.

# Lardon conventions



# $dQ/ds$ vs extraction

CAPP

