

# Space charge effect in ProtoDUNE-VD

DUNE France Analysis meeting

01/04/2026

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# Study goal and parameters

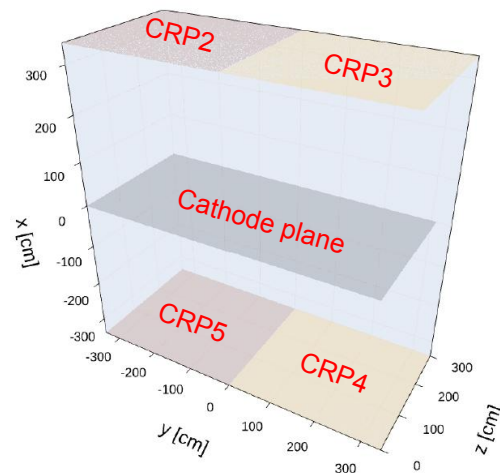
→ Characterize the space charge in ProtoDUNE-VD by using cosmic muon tracks

Parameters :

[Lardon](#) as the data reconstruction software

Run 39350 :

→ Cosmics run before CRP2 incident (2025-09-09 to 2025-09-15)

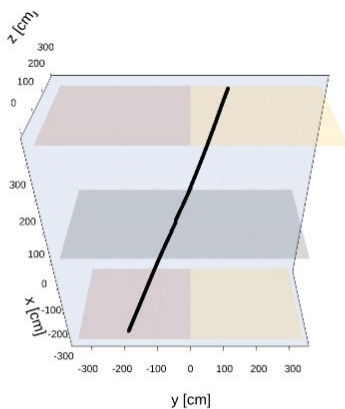


PDVD representation used

# Selected tracks

**Anode-Cathode-Anode tracks** : Go through the **top anode** planes, the **cathode** plane and the **bottom anode** planes

→ The entry point and the exit point are known



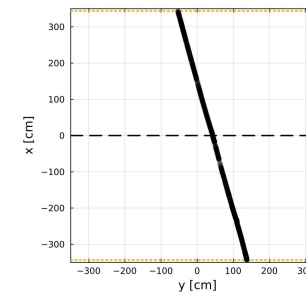
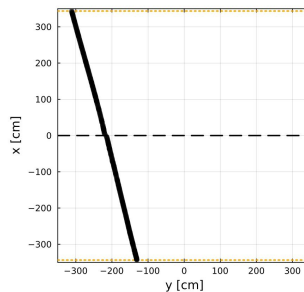
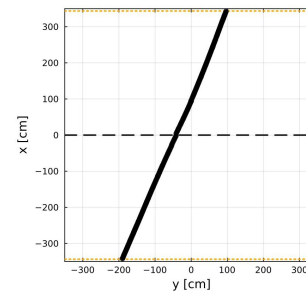
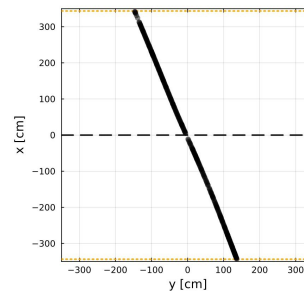
→ Lardon allows us to select them via boolean variables

## Additional selection :

The number of hits in the tracks has to be  $> 30$

A sanity check is done to verify if the tracks go through each anode planes

Example of selected tracks :



**Number of selected tracks : 3396** (out of more than 2 million of tracks)

# Space charge computation

**Space charge is computed by comparing the expected positions with the reconstructed positions**

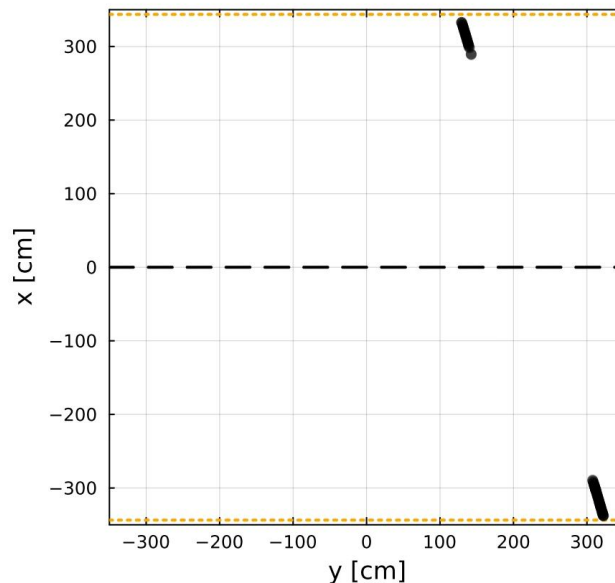
How the expected positions are calculated :

→ **Hits of the track in the first 50cm near the anode planes are selected**

→ A direction is computed with a reference point (barycenter) and the covariance of the hits

→ The reconstructed positions are projected on the fitted straight line

→ The difference between the reconstructed position and the expected position is calculated for each axis at each position



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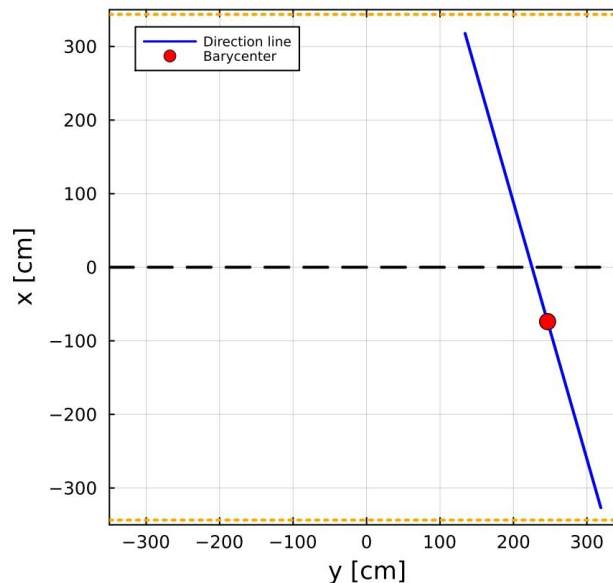
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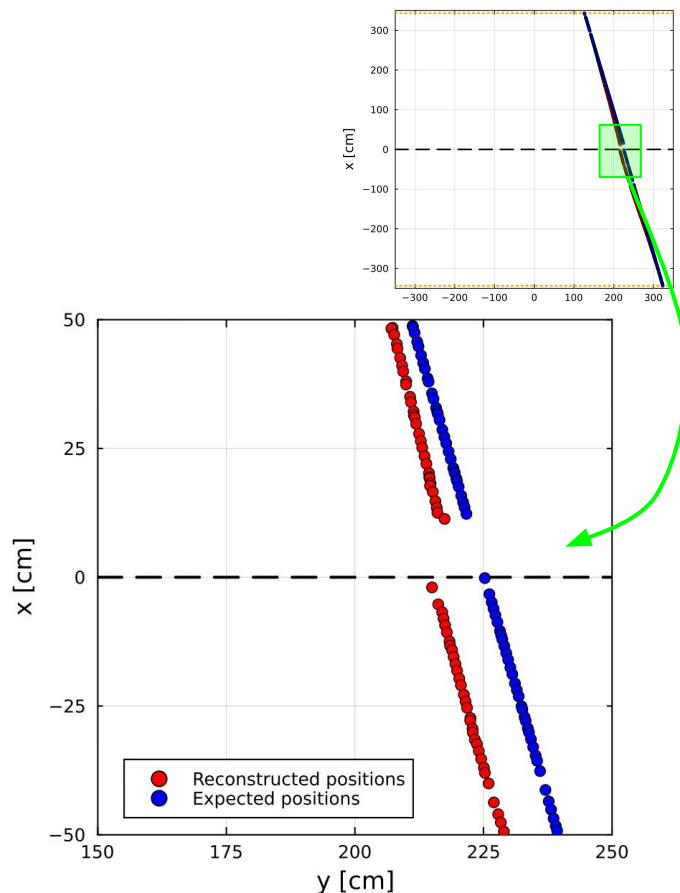
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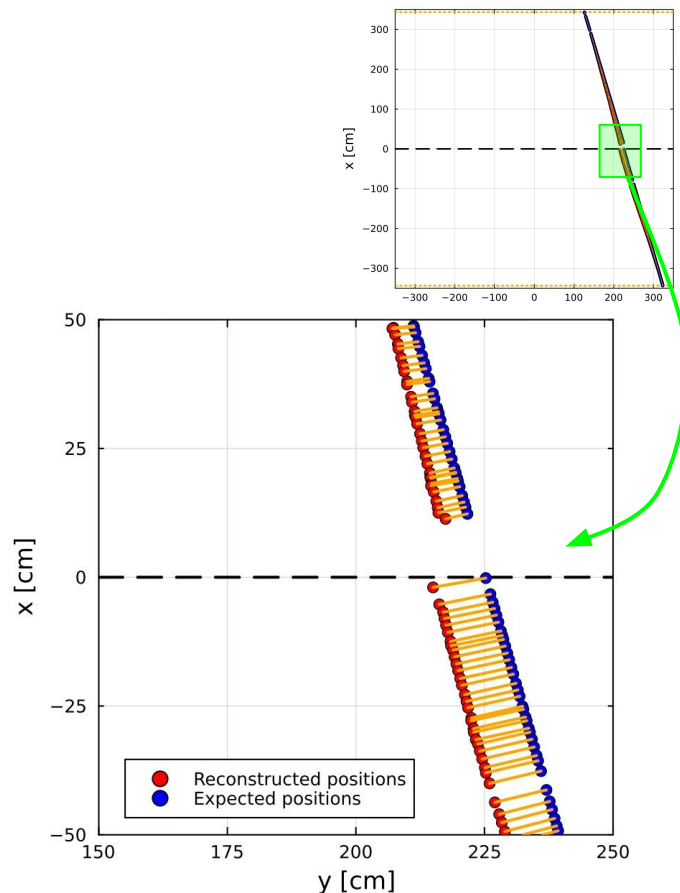
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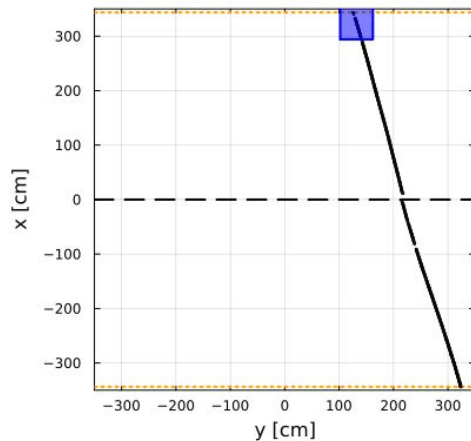
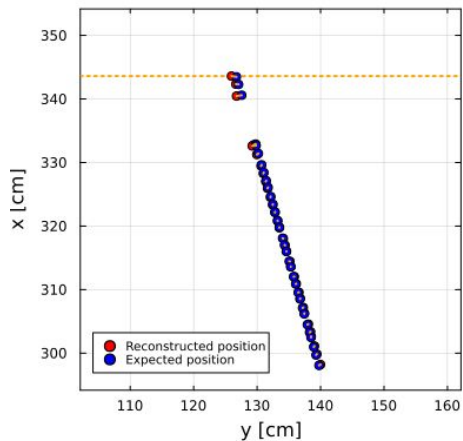
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→ The reconstructed positions are projected on the fitted straight line

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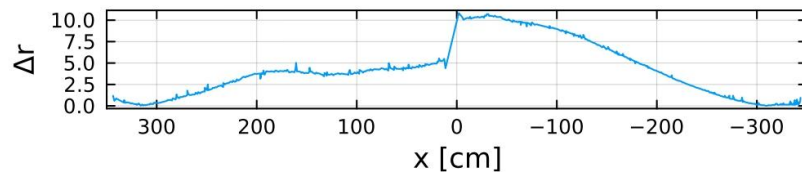
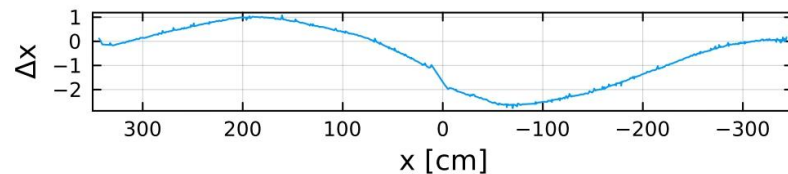
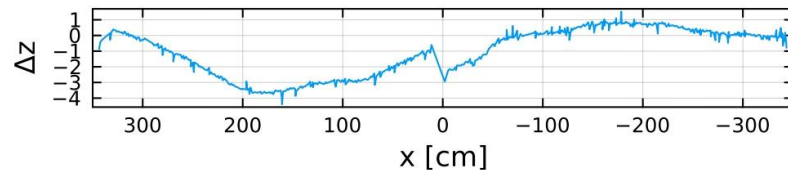
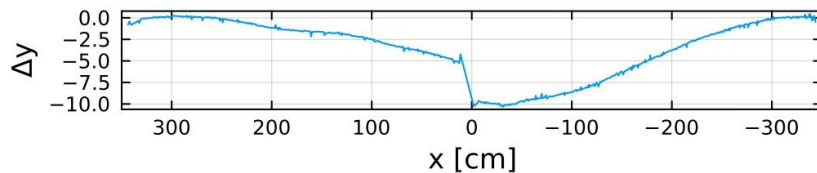
# Space charge computation



→ Along the track, the differences become more and more important when moving toward the cathode

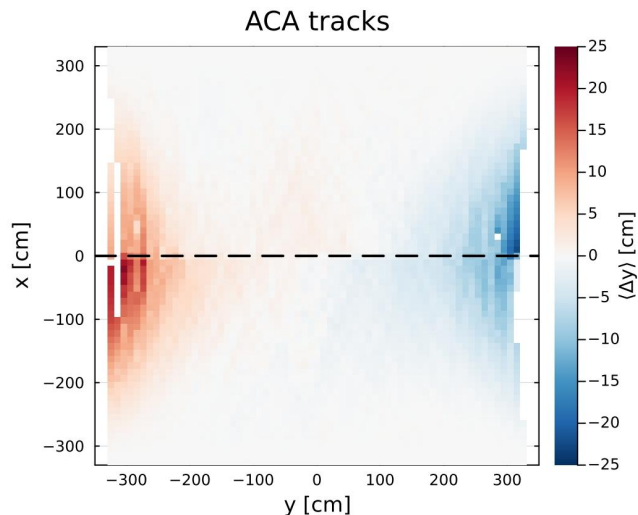
## Top Anodes

## Bottom Anodes

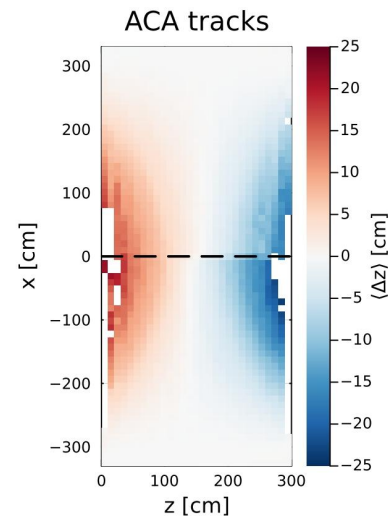


# Results for Anode-Cathode-Anode tracks

Average horizontal differences of all the Anode-Cathode-Anode tracks :  $\Delta y$  and  $\Delta z$



Color description :  
Red : right shift  
Blue : left shift

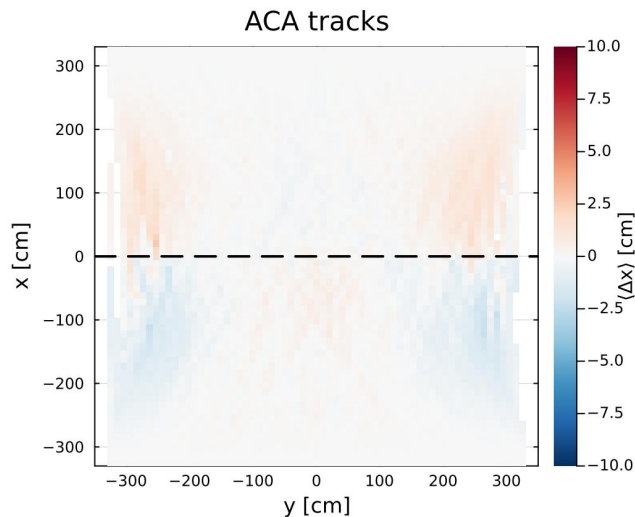


→ The differences along the horizontal axis show that the space charge shifts the positions towards the center of the volume

→ The modification of the electric field lines by the space charge effect is more significant at the edge of the detector, near the field cage and the cathode

# Results for Anode-Cathode-Anode tracks

Average vertical differences of all the Anode-Cathode-Anode tracks :  $\Delta x$



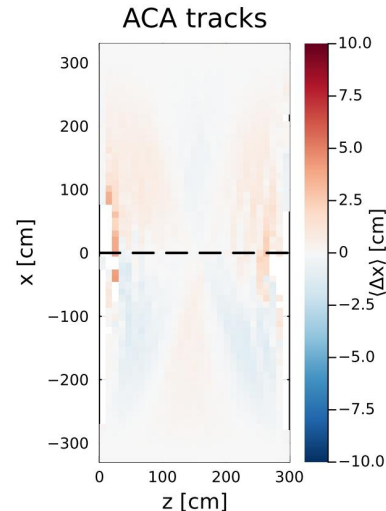
Color description :

Red : up shift

Blue : down shift



Color scale is  
reduced to  
(-10,10)



→ The differences along the vertical axis are less important and show that the space charge shifts the positions differently according to the location in the detector

→ The flow of argon is not uniform at the center of the detector due to different components (ex : ARAPUCAs) and the electric field lines are modified according to the number of accumulated ions

# Space charge computation for both volumes

**Do we obtain the same results if we separate the two volumes ?**

Space charge is computed by comparing the expected positions with the reconstructed positions

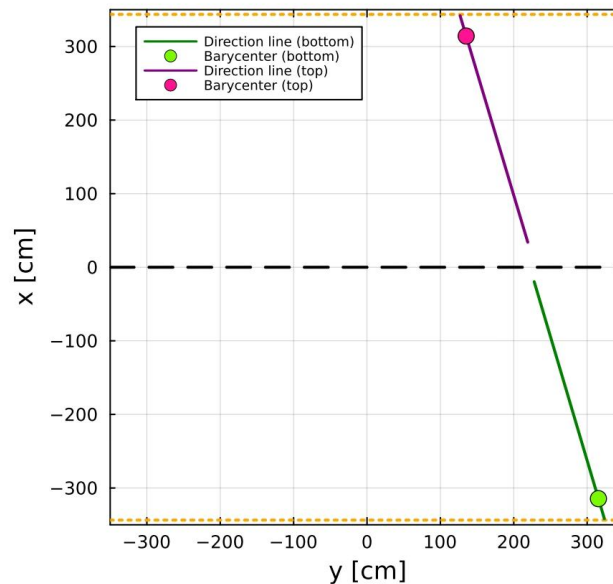
How the expected positions are calculated :

→ Hits of the track in the first 50cm near the anode planes are selected

→ **Two directions are computed (top and bottom) with two reference points and two covariances**

→ The reconstructed positions are projected on the fitted straight line

→ The difference between the reconstructed position and the expected position is calculated for each axis at each position



# Space charge computation for both volumes

**Do we obtain the same results if we separate the two volumes ?**

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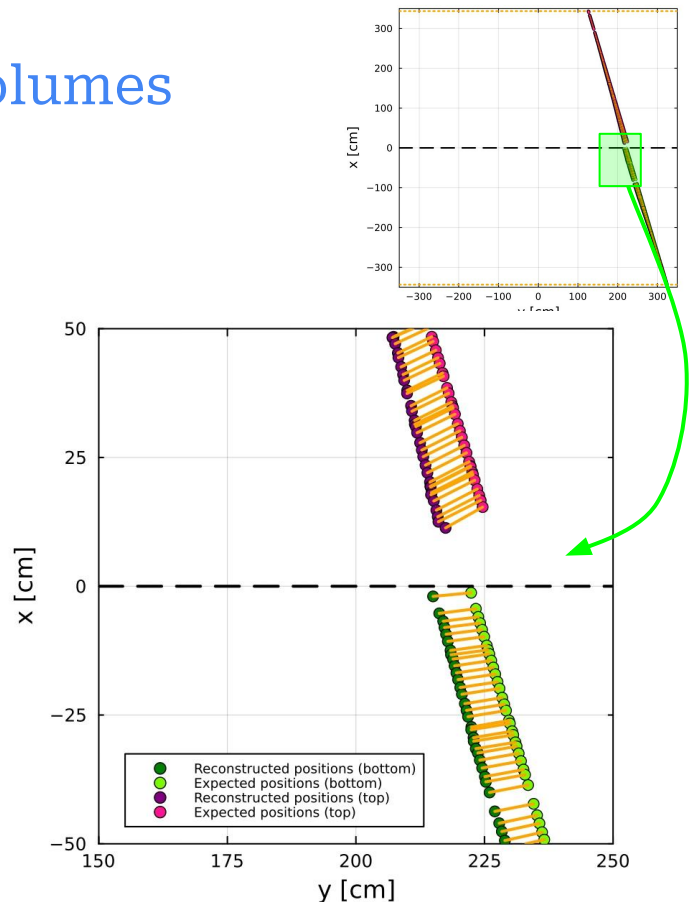
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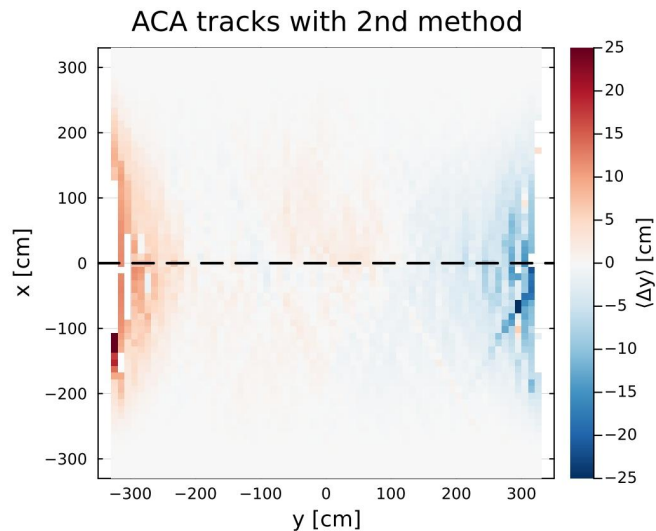
→ **The reconstructed positions are projected on the fitted straight lines**

→ **The difference between the reconstructed position and the expected position is calculated for each axis at each position**

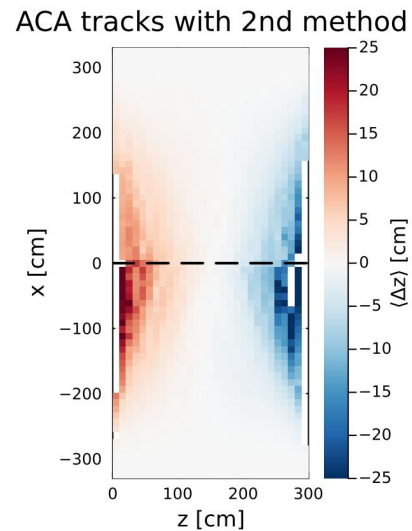


# Results for both volumes

Average horizontal differences of all the Anode-Cathode-Anode tracks :  $\Delta y$  and  $\Delta z$



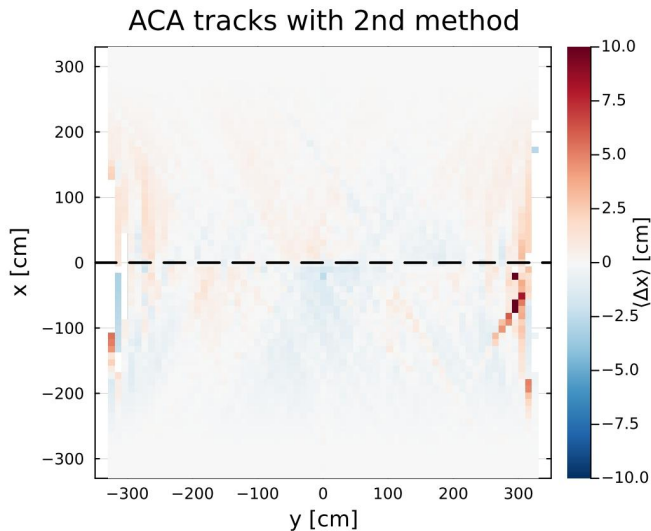
Color description :  
Red : right shift  
Blue : left shift



→ The two different methods show very close results

# Results for both volumes

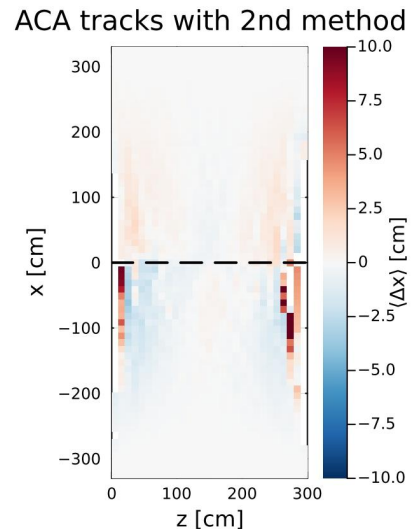
Average vertical differences of all the Anode-Cathode-Anode tracks :  $\Delta x$



Color description :  
Red : up shift  
Blue : down shift



Color scale is  
reduced to  
(-10,10)

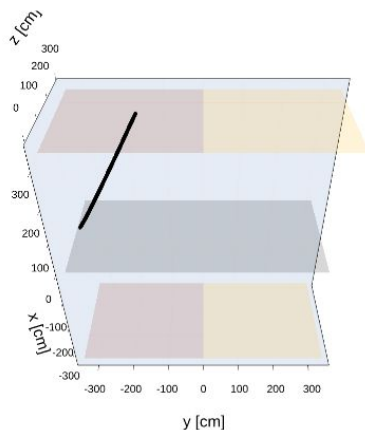


→The precise comparison between the two methods is complex but they both show similar trends

# Second selection

**Selection extended to Anode crosser tracks :** Go through either the **top anode planes**, or the **bottom anode planes**

→ The entry point is known



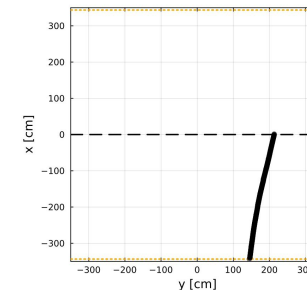
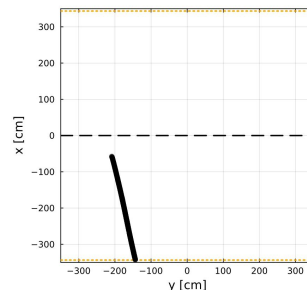
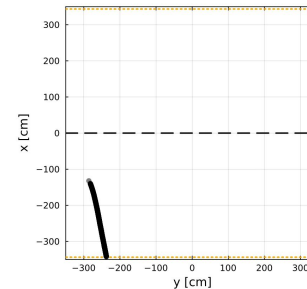
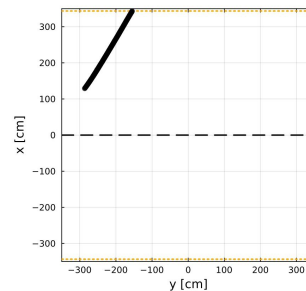
→ Lardon allows us to select them via boolean variables

## Additional selection :

The number of hits in the tracks has to be  $> 30$

A sanity check is done to verify if the tracks go through each anode planes

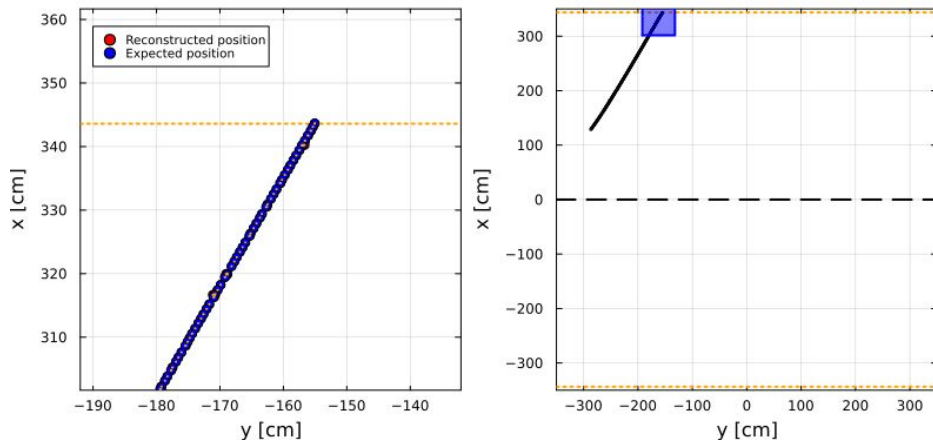
Example of selected tracks :



**Number of selected tracks : 262 555** (out of 500 000 tracks)

# Space charge computation

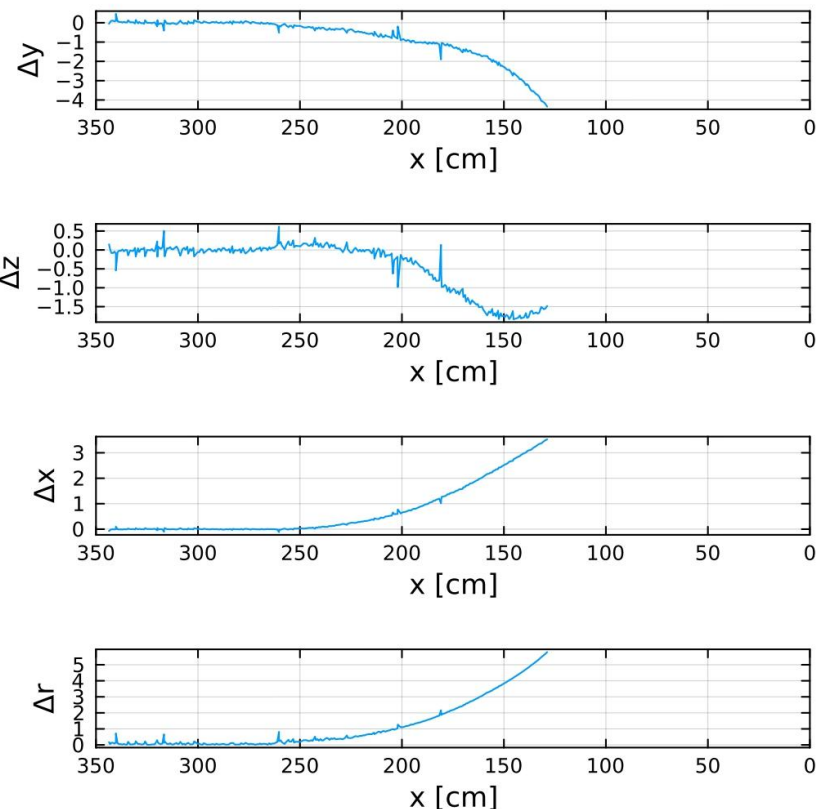
The same method is applied here :  
first 50cm hits selection → Direction fit → Projection → Differences



→ The differences becomes increasingly significant as one moves away from the anode plane

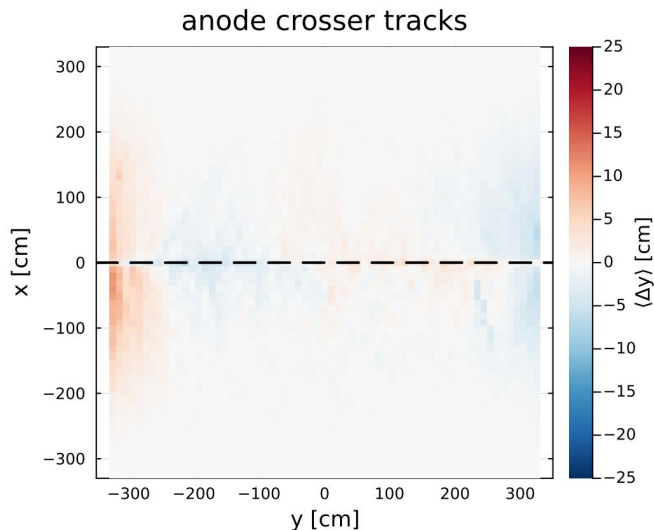
Top Anodes

Cathode

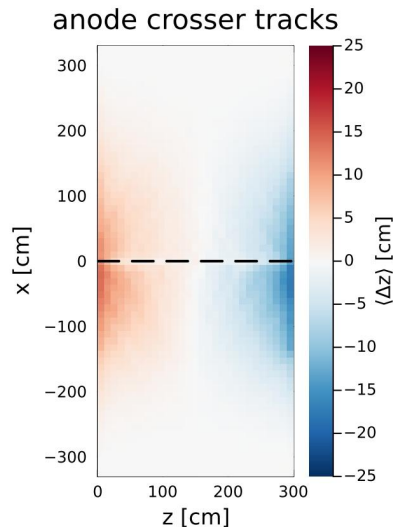


# Results for Anode crosser tracks

Average horizontal differences of all the Anode crosser tracks :  $\Delta y$  and  $\Delta z$



Color description :  
Red : right shift  
Blue : left shift

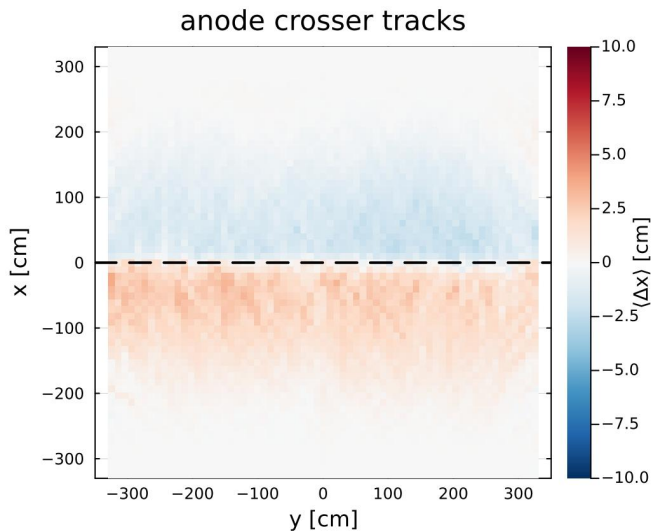


→ The differences along the horizontal axis show that the space charge shifts the positions towards the center of the volume

→ As for the Anode-Cathode-Anode tracks, the modification of the electric field lines is more important near the field cage

# Results for Anode crosser tracks

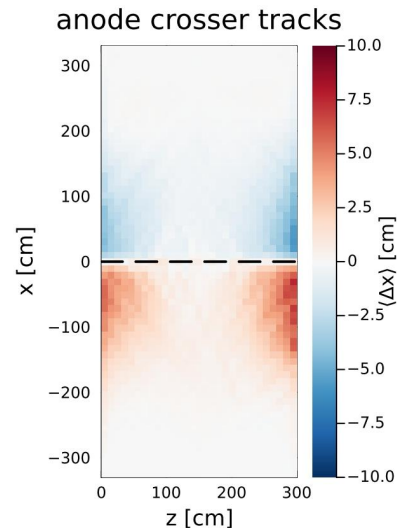
Average vertical differences of all the Anode crosser tracks :  $\Delta x$



Color description :  
Red : up shift  
Blue : down shift



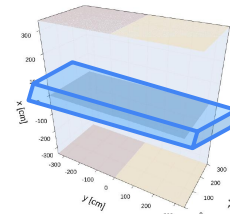
Color scale is  
reduced to  
(-10,10)



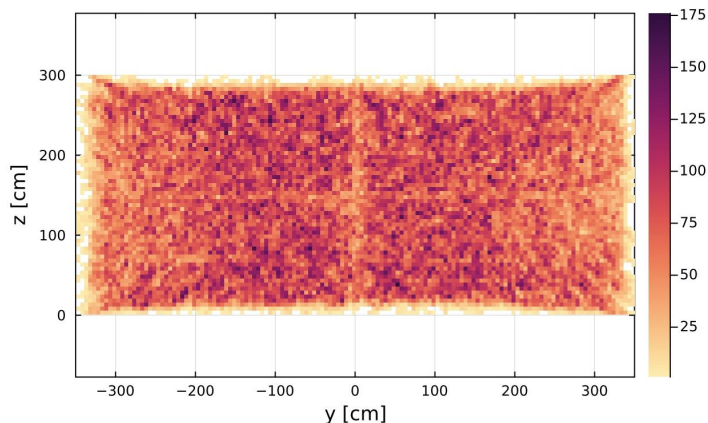
→ The differences along the vertical axis are less important and show that the space charge shifts the positions towards the cathode plane

→ Unlike the Anode-Cathode-Anode tracks, The space charge effect is uniform and reversed

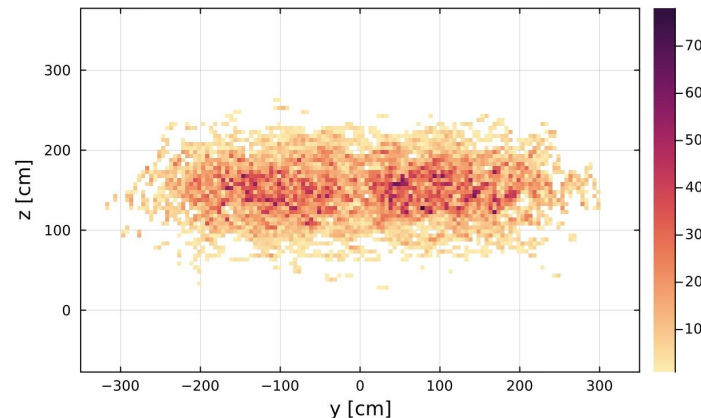
# Topography of the selected tracks



Hits of the selected tracks for  $-25 < x < 25$  → hits located around the cathode plane



Anode crosser tracks



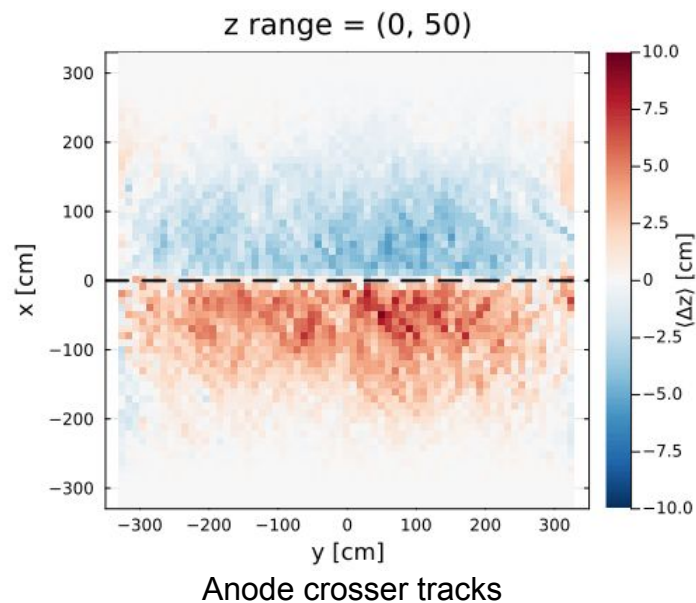
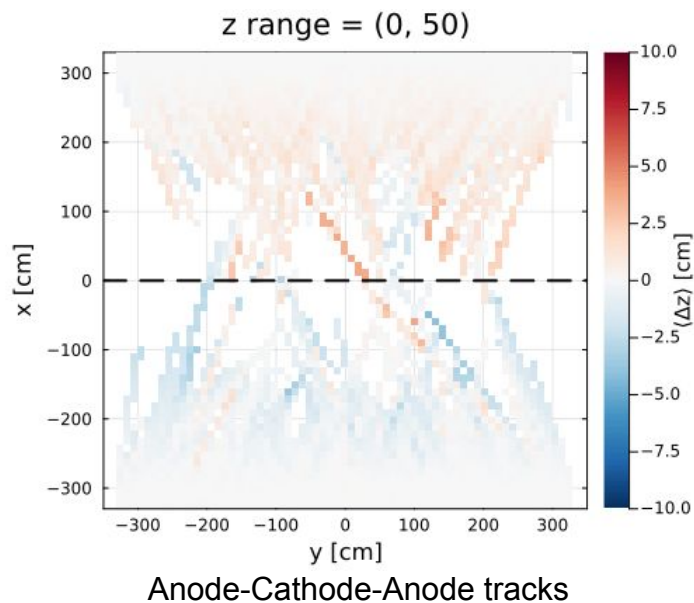
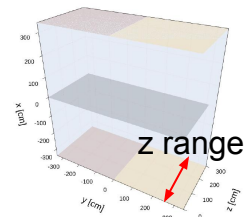
Anode-Cathode-Anode tracks

The selected Anode-Cathode-Anode tracks are mostly in the center of the detector

The selected Anode crosser tracks are all over the ZY plane

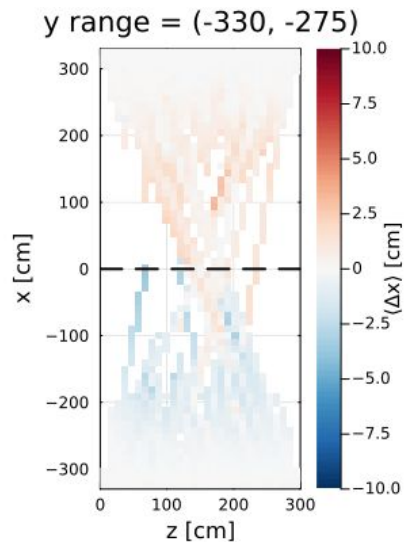
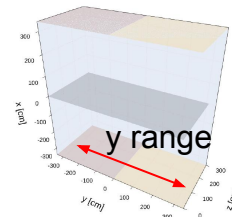
Different components are involved in the space charge effect → Field cage at the edge of the active volume

# Evolution of the space charge

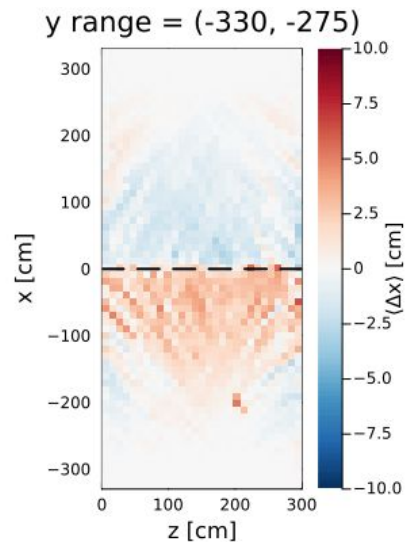


The ranges at the center of the active volume show similar trends between the two selections

# Evolution of the space charge



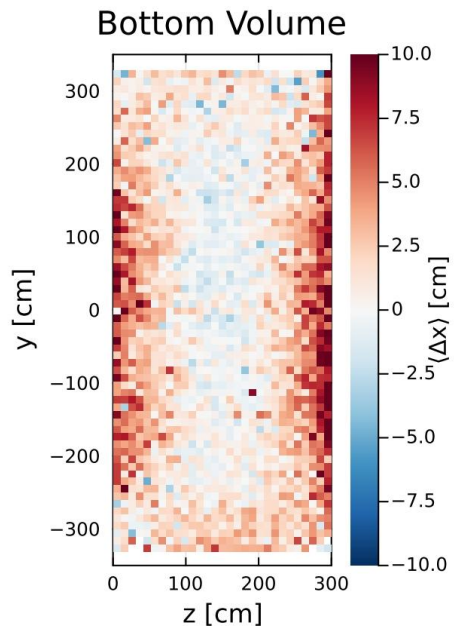
Anode-Cathode-Anode tracks



Anode crosser tracks

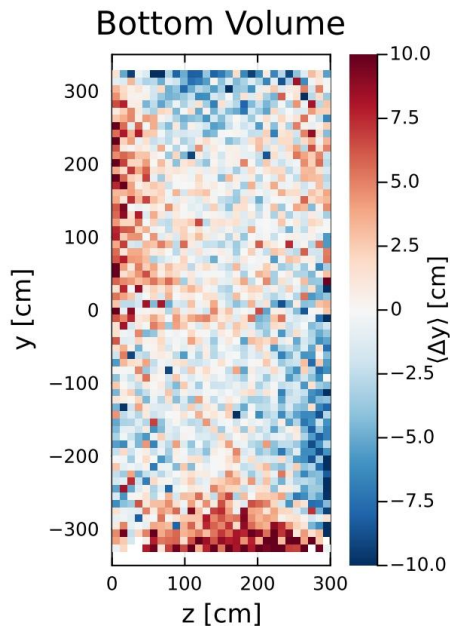
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# Space charge on the cathode plane

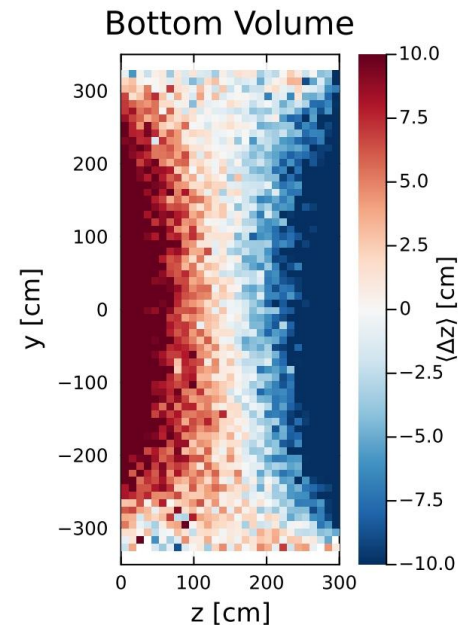


Positive  $\Delta x$  at the edges  $\rightarrow$  up shift  $\rightarrow$   
Anode crosser tracks

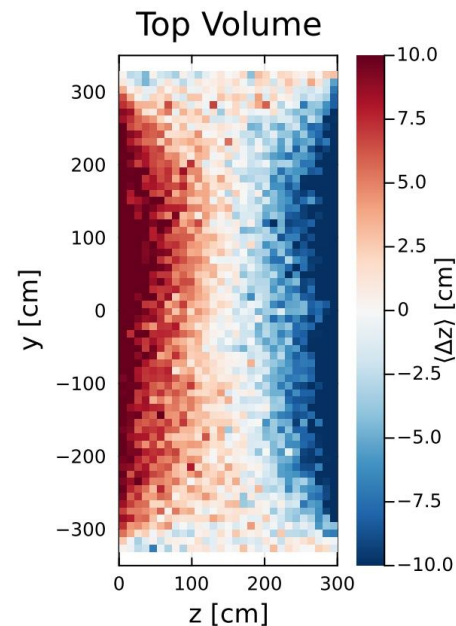
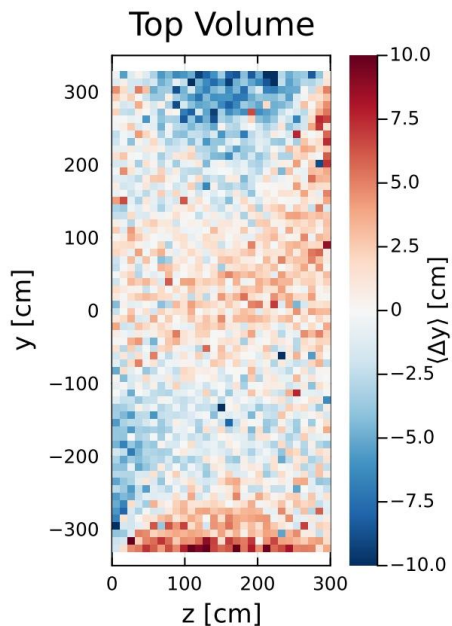
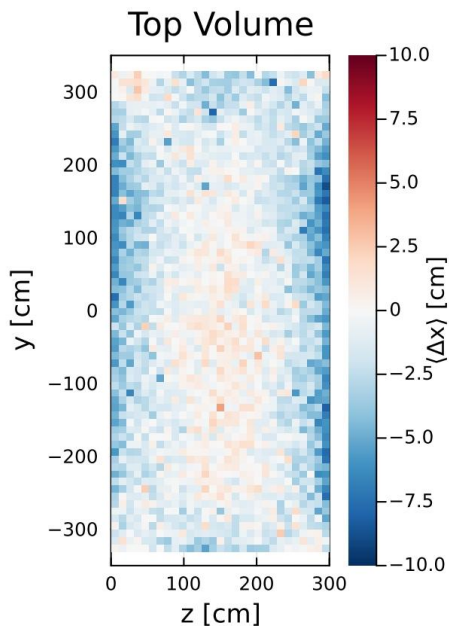
Negative  $\Delta x$  at the center  $\rightarrow$  down  
shift  $\rightarrow$  Anode-Cathode-Anode tracks



Both  $\Delta y$  and  $\Delta z$  show shift toward the center of the volume



# Space charge on the cathode plane



Negative  $\Delta x$  at the edges  $\rightarrow$  down shift  $\rightarrow$  Anode crosser tracks

Positive  $\Delta x$  at the center  $\rightarrow$  up shift  $\rightarrow$  Anode-Cathode-Anode tracks

Both  $\Delta y$  and  $\Delta z$  show shift toward the center of the volume

# Conclusion and perspective

Cosmic muon tracks allowed us to do a first characterization of space charge effect in PDVD

- Anode-Cathode-Anode tracks show space charge effect pushing horizontally the hits towards the center of the active volume
- The vertical differences are less uniform and smaller

→More statistics of Anode-Cathode-Anode tracks might help us to characterize better the space charge effect

The study has been then extended to Anode crosser tracks

- Same trend in the horizontal axis
- Some regions show different trends compared to Anode-Cathode-Cathode tracks (under investigation)

→By scanning different regions along the horizontal axis, the two cases show similar results

To improve our study, we plan to :

- Remove the stopping muons by looking at the  $dQ/dx$  (only affect the top volume)
- Matching light with the charge to have a better spatial resolution