Module X
Electric field uniformity study by investigating spatial offset

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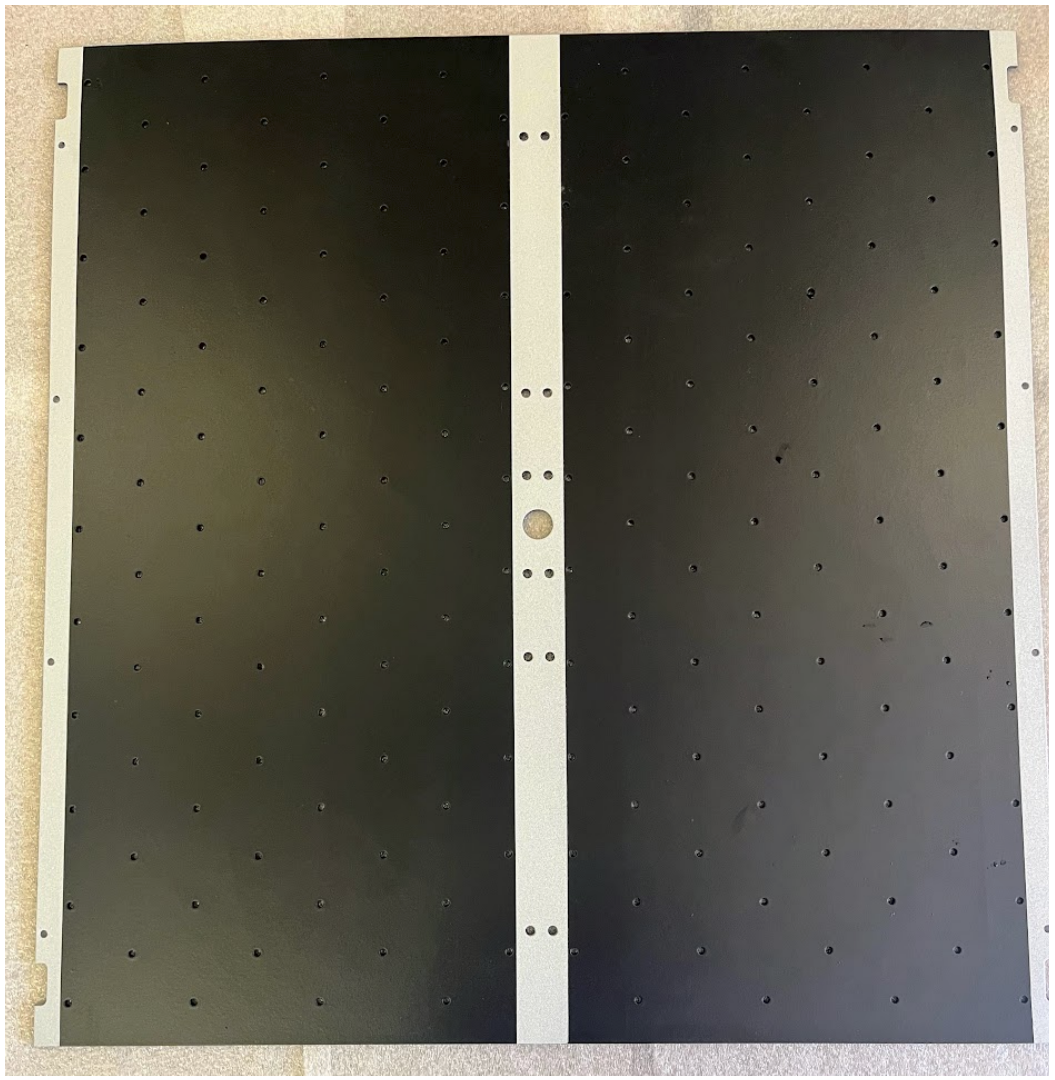
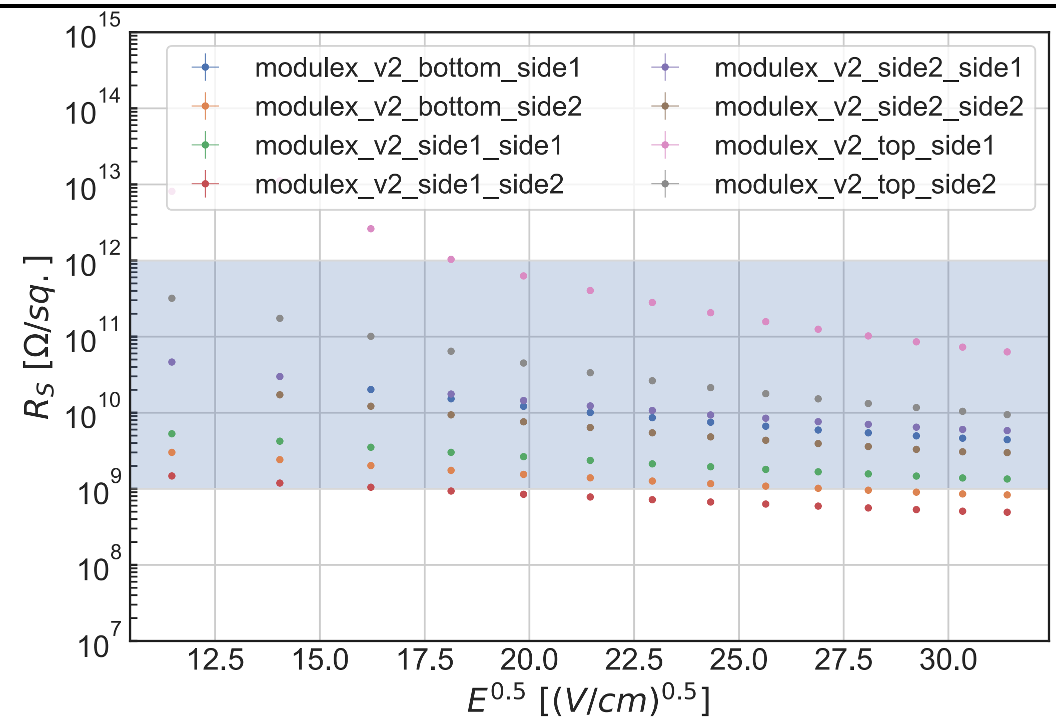
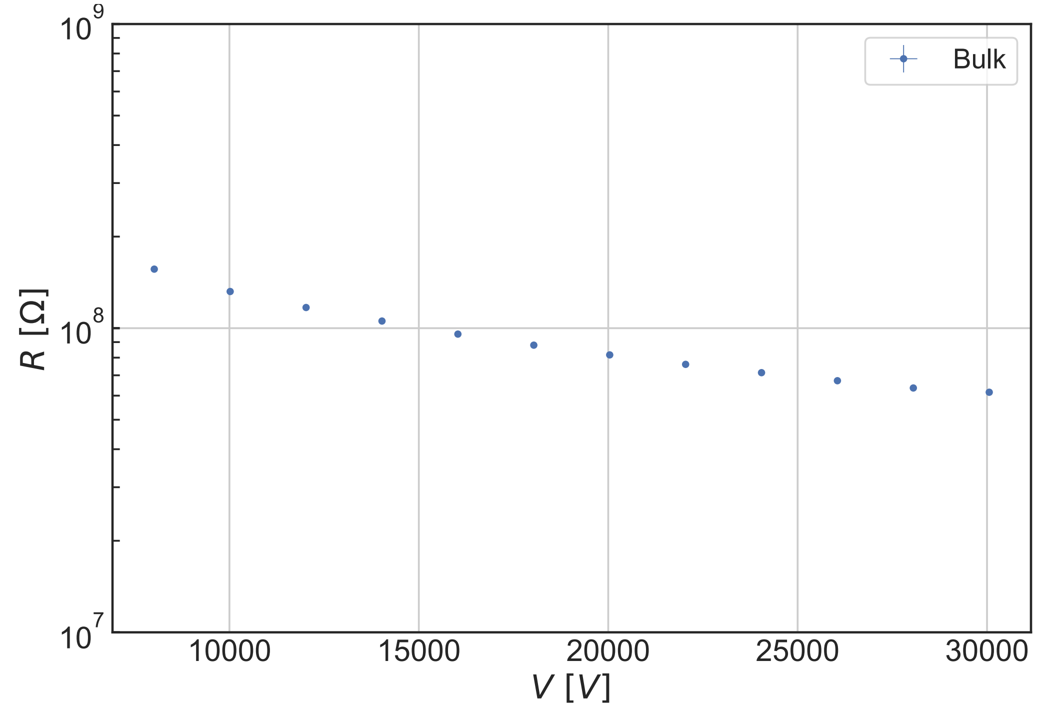
ModX Configuration





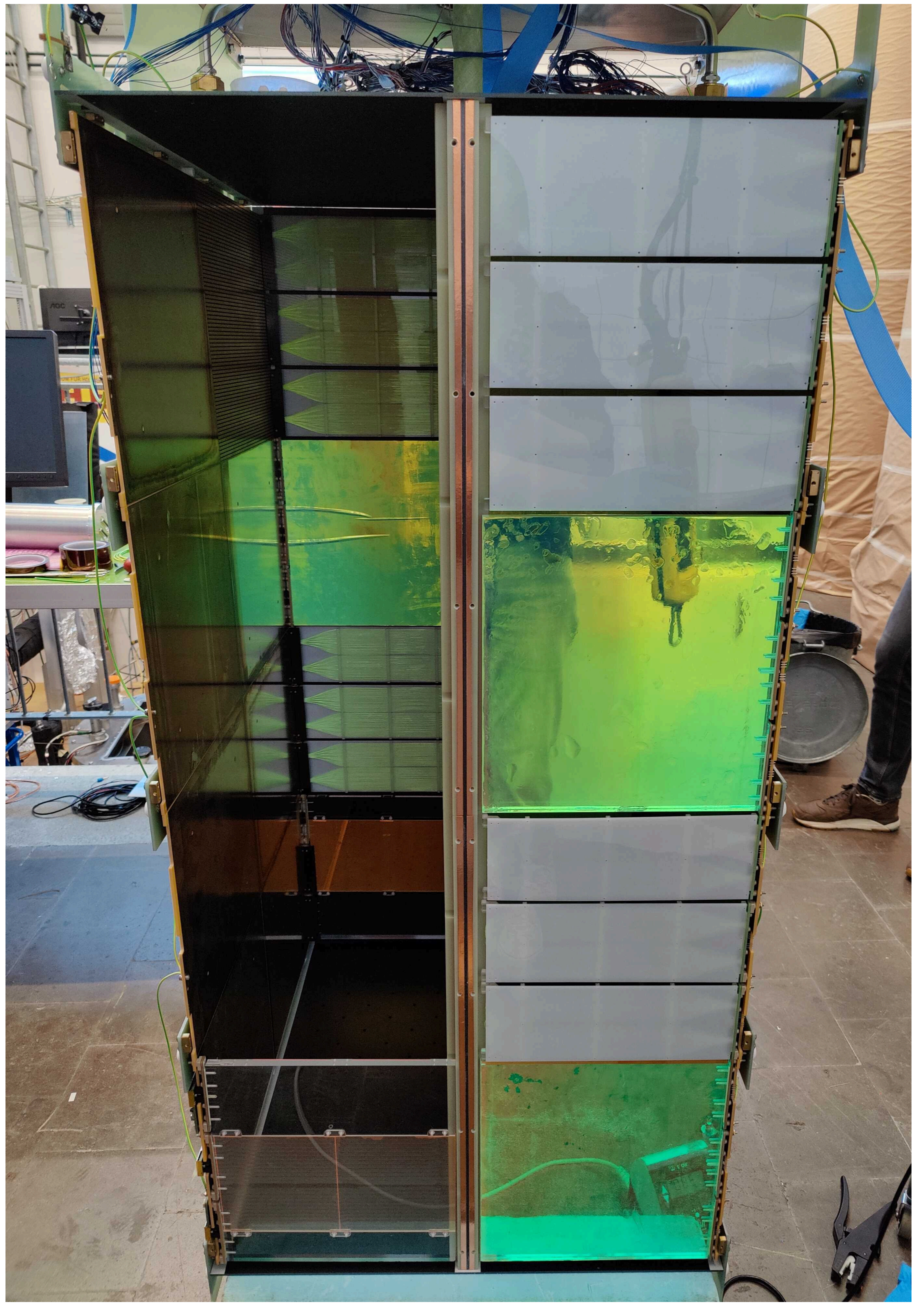
Francois D.



Francois D.

ModX is to test the field shell design of carbon loaded epoxy applied directly on the FR4/G10. The left plot shows the top panel. The metal strip is zinc coated on top of the carbon loaded epoxy layer for the cathode and the anodes. The top and bottom panels have holes for LAr circulation and the side panels do not have these recirculation holes. The sheet resistance of each panel and the calculated bulk resistance are shown above. The sheet resistance are generally higher than DR8 (used in 2x2), and the variance in the sheet resistance is also larger compared to DR8.

ModX Configuration



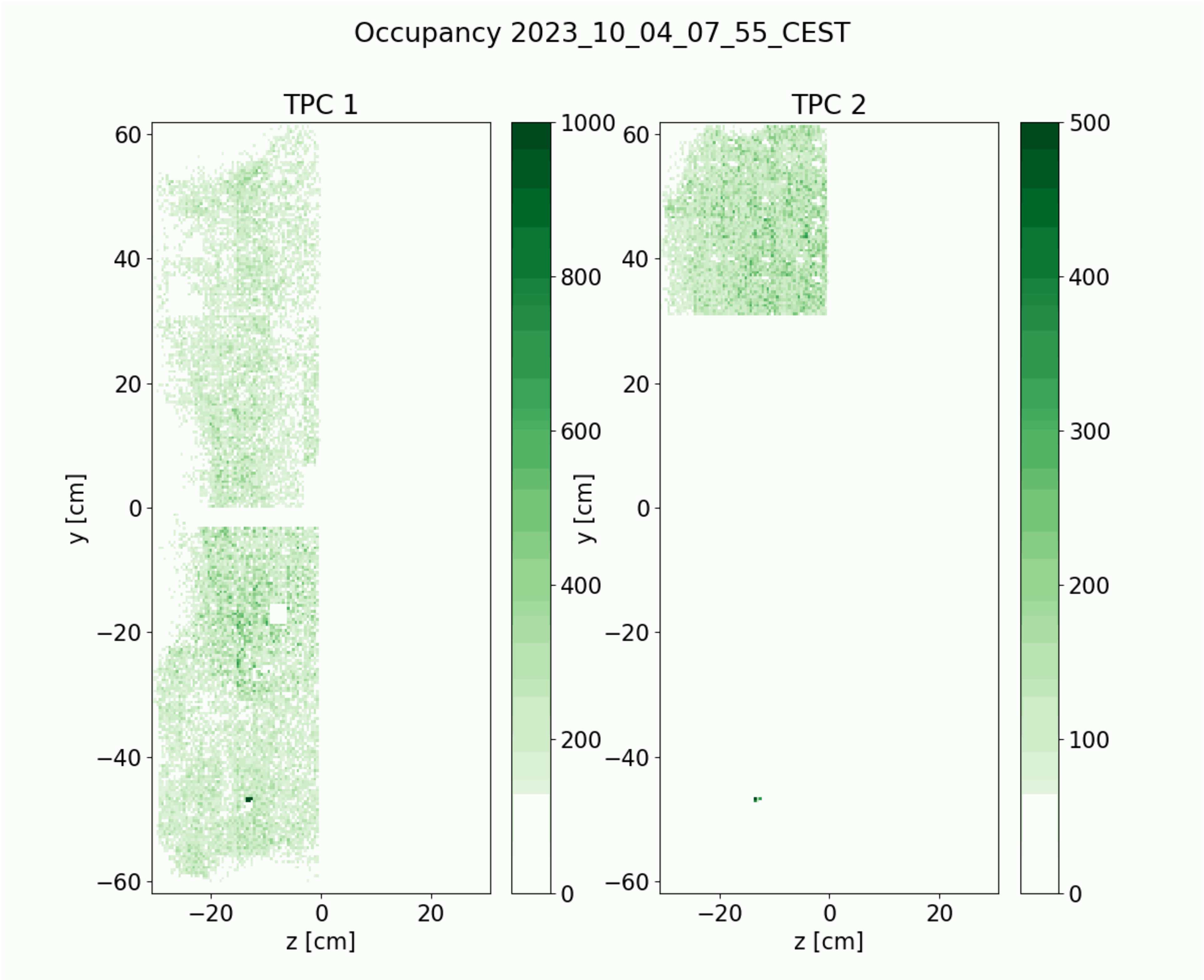
ModX is equipped with 5 LArPix tiles; 4 in a column from top to bottom in one TPC (TPC1); the 5th one is installed in the other TPC (TPC2) facing the top tile of the 4. The light detectors in TPC1 in configured the same as in other 2x2 modules. In TPC2, the side close to the LArPix tile is equipped with two units of LCMs and a unit of ArcLight in alternating order, The bottom on both sides are equipped with ArCLight R&D panels.

Data set

- ***ndlar_flow* for ModX processing:** https://github.com/DUNE/ndlar_flow/tree/feature_ModX
- **Analysis code:** https://github.com/YifanC/ModX_ana
- **Raw to processed data on NERSC:** /global/cfs/cdirs/dune/www/data/ModuleX
- **Run log:** https://docs.google.com/spreadsheets/d/1fZJGKieJlxj6GnzuT_aP2t47XGkPIVygcDSQx99itAc/edit?usp=sharing
- Focus on the two run periods at the nominal electric field (0.5 kV/cm)
  - The division of the two run nominal E-field run periods is the ramp up in HV to 1 kV/cm
  - Each file is about 10 min cosmic data.
  - The nominal E-field **run period 1** is roughly **12 hours**.
  - The nominal E-field **run period 2** is roughly **24 hours**.

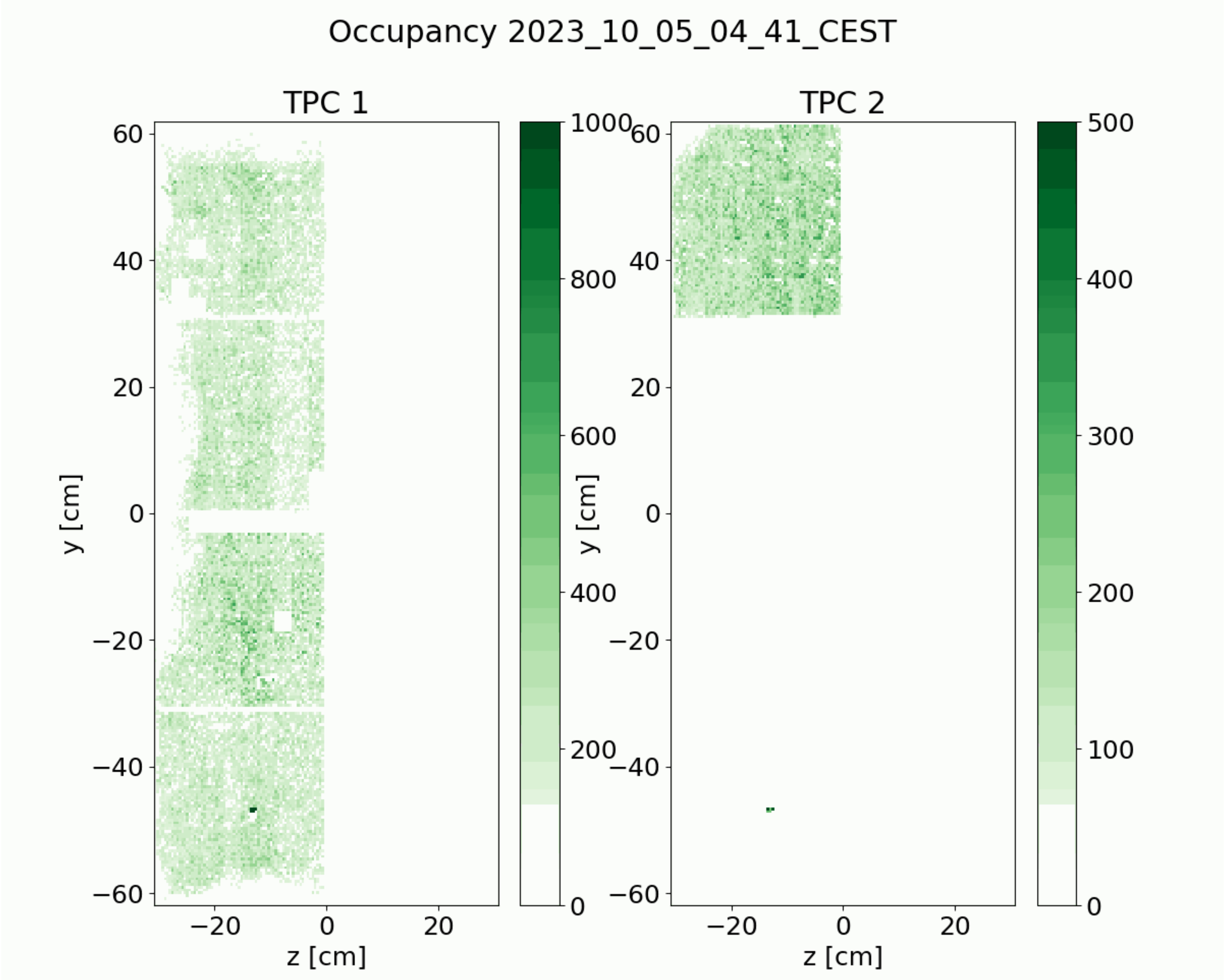
Pixel Occupancy @ Nominal E-field Period 1

Each file is “normalized” to 10min.
The bin content shows the number of pixel readout in the file.
A few corner areas are missing. No particular dense region are found.
The pattern shows up at the very beginning since the HV ramp up, and the pattern is stable over time.



Pixel Occupancy @ Nominal E-field Period 2

Each file is "normalized" to 10min.
The bin content shows the number of pixel readout in the file.
A few corner areas are missing. No particular dense region are found. The pattern is stable over time.
The files with high occupancy are mostly short runs, which hints that there was discharge and shifter intervention.



Detector Edges

Using the edge most hits of the "crossing" track clusters to determine the edge of the TPCs.

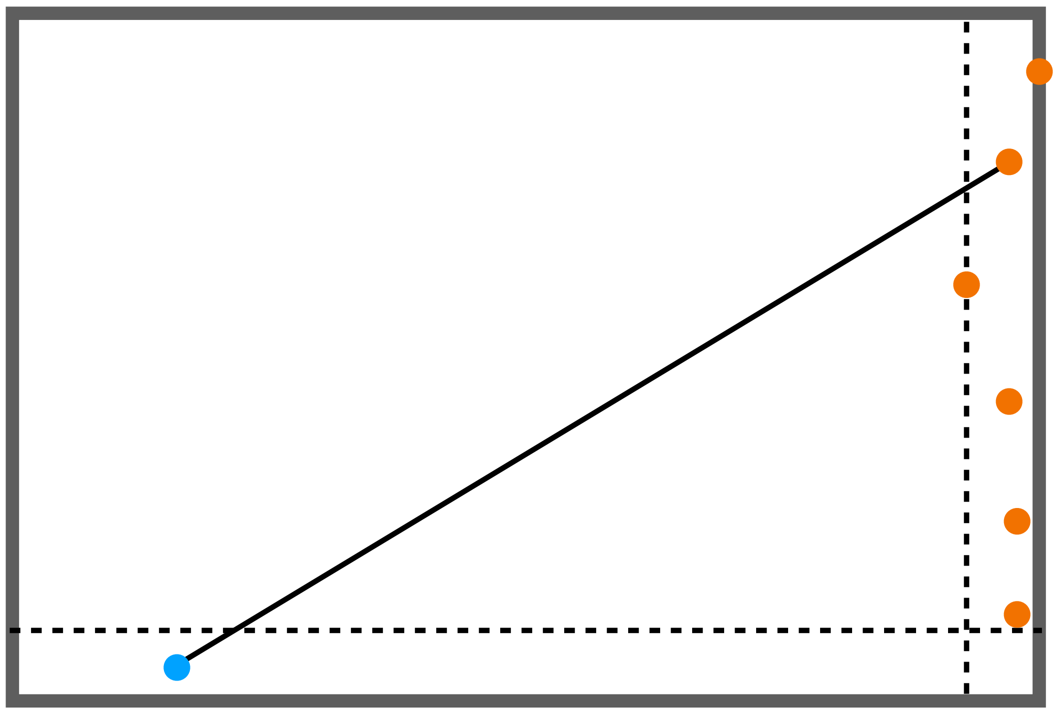
"Crossing" is defined by if the edge most hit is within 4 cm of the edge of the TPCs.

For the event building, larpix data packets is grouped in time.

The T0 is given by the external trigger from the LRS.

Caveat 1: the time and therefore the drift position for the hits can be funky if there are multiple interactions in the same event, but it rarely happens.

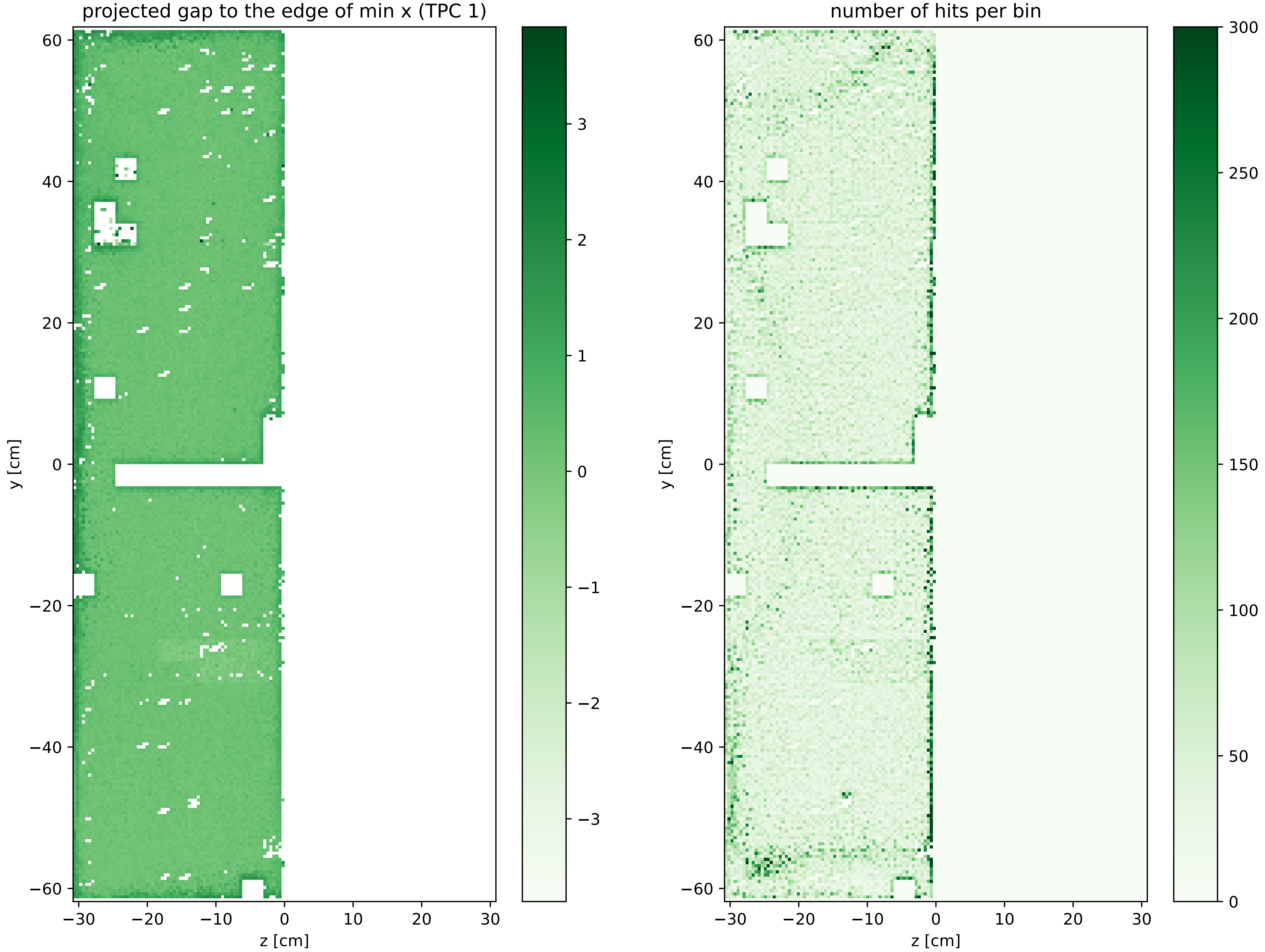
Caveat 2: The edge of disabled readout channels tend to show the maximumly allowed edge threshold (4 cm)



Detector Edges: x_min (Anode TPC1)

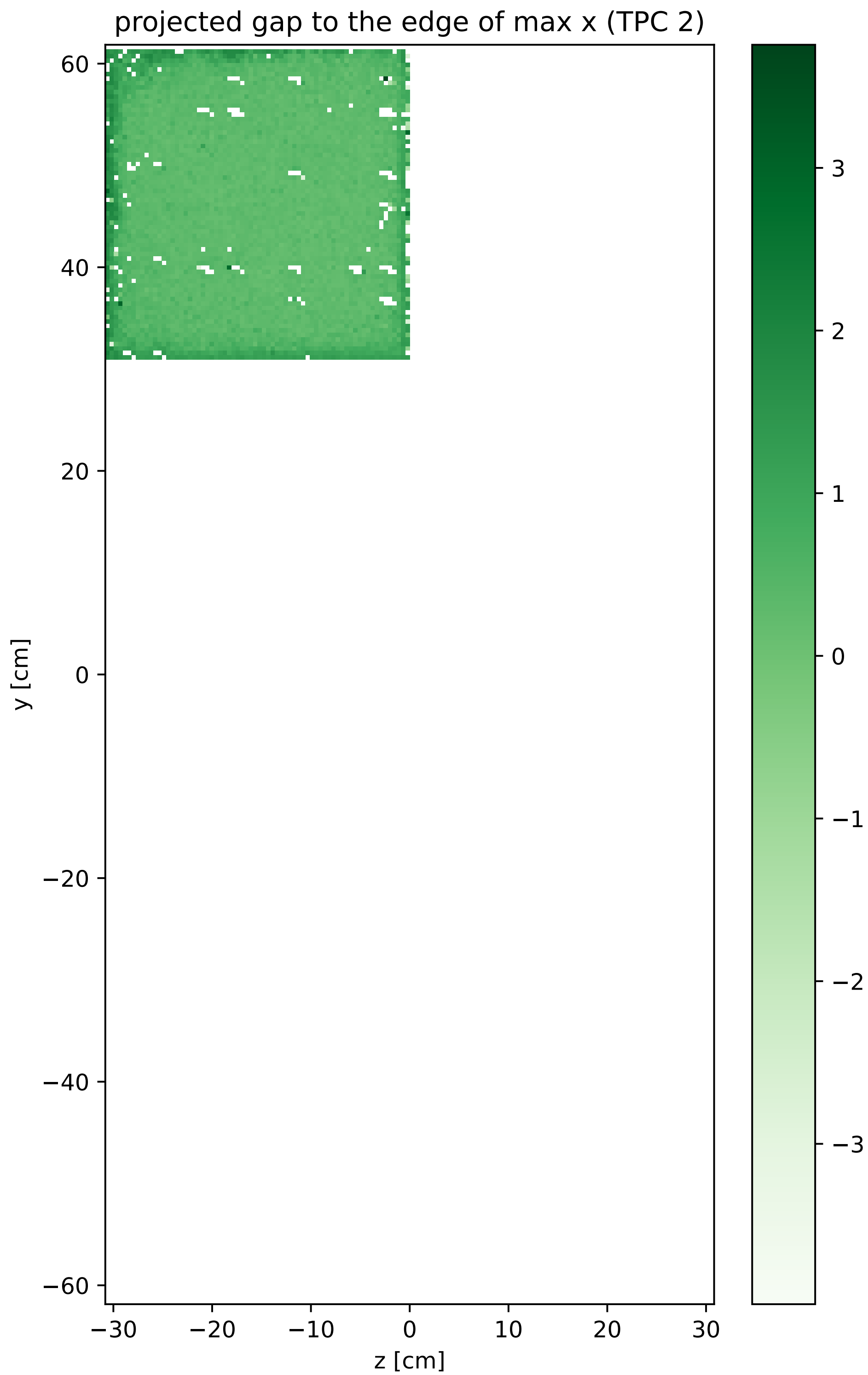
From all the runs at the nominal field including period 1 and 2.

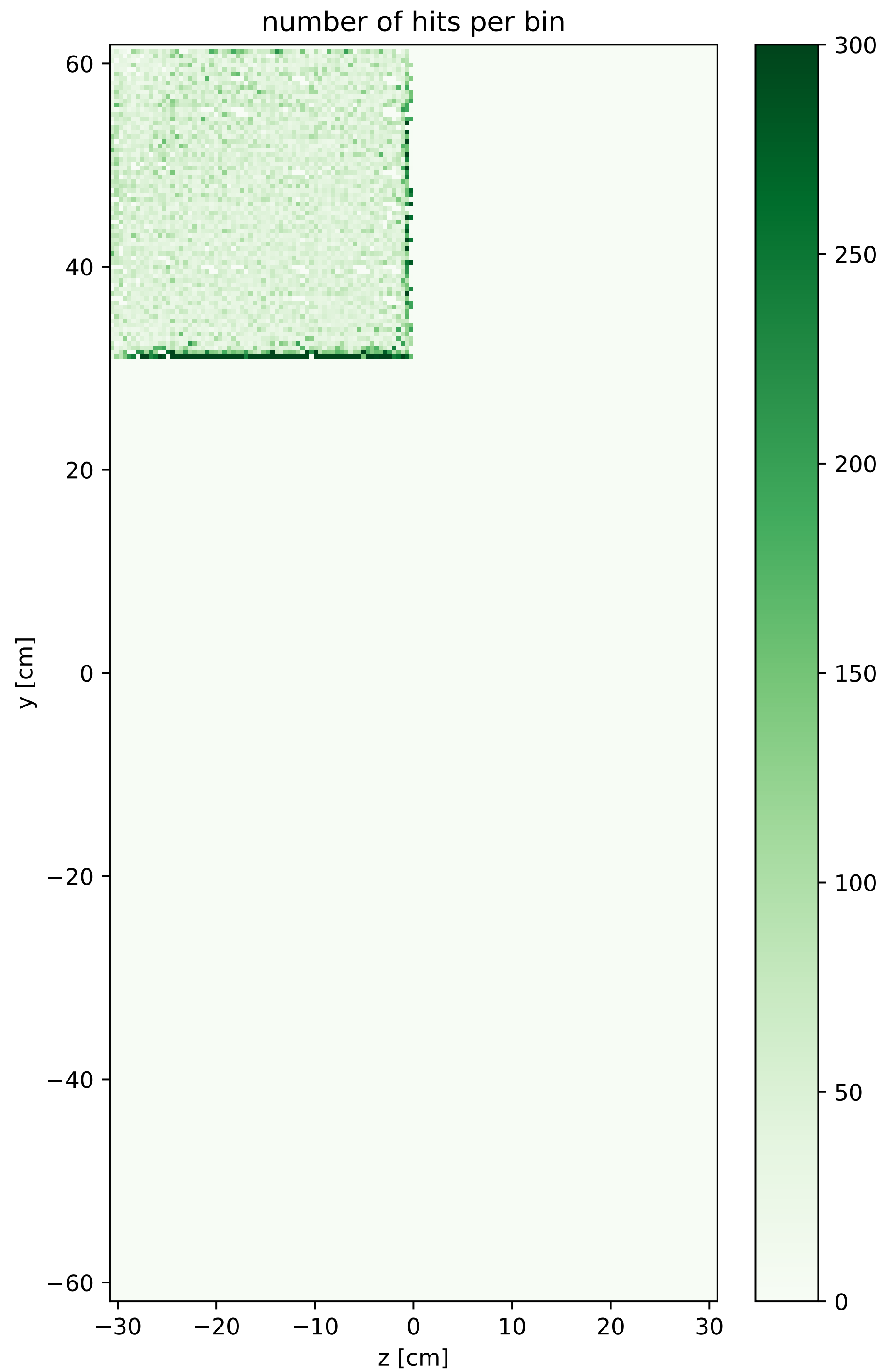
Sanity check: The anode is flat at x_min with dx = edge_x - x_min ~ 0.



Detector Edges: x_max (Anode TPC2)

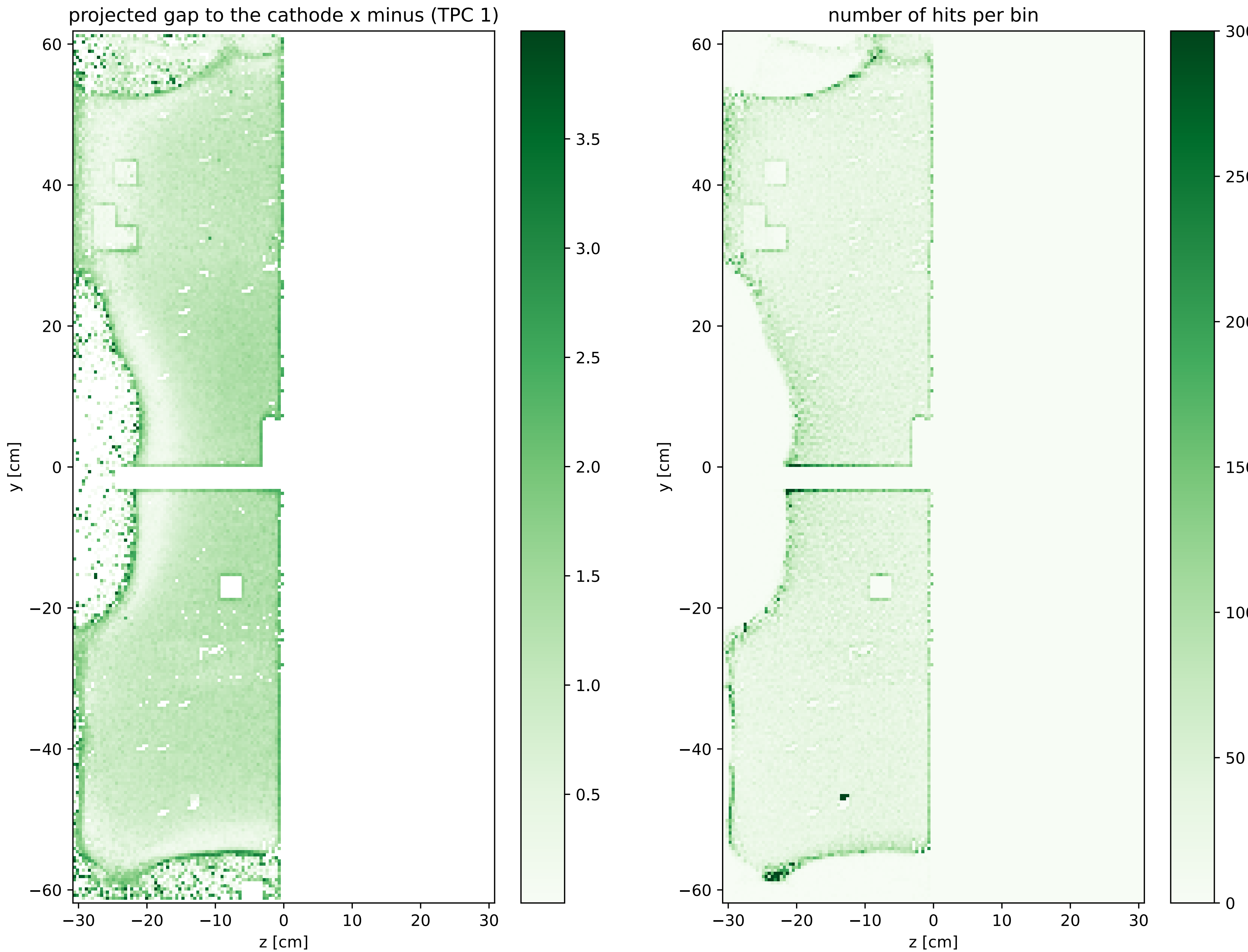
From all the runs at the nominal field including period 1 and 2.
Sanity check: The anode is flat at x_max with dx = x_max - edge_x ~ 0.





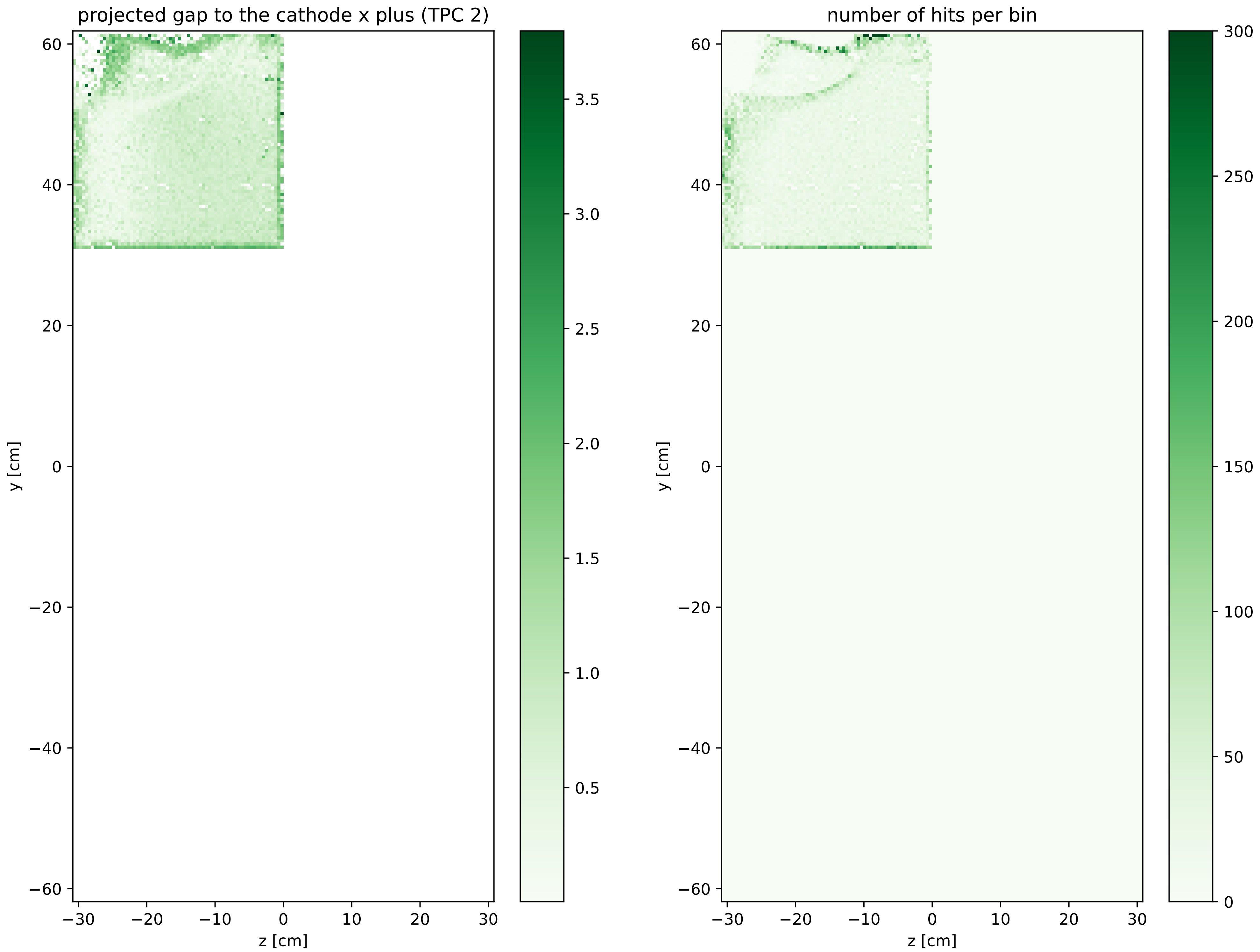
Detector Edges: x ~ 0- (Cathode TPC1)

From all the runs at the nominal field including period 1 and 2.
The projected gap to the cathode is -edge_x.
Other than the missing corners, there is a 1-2 cm slope in the cathode plane



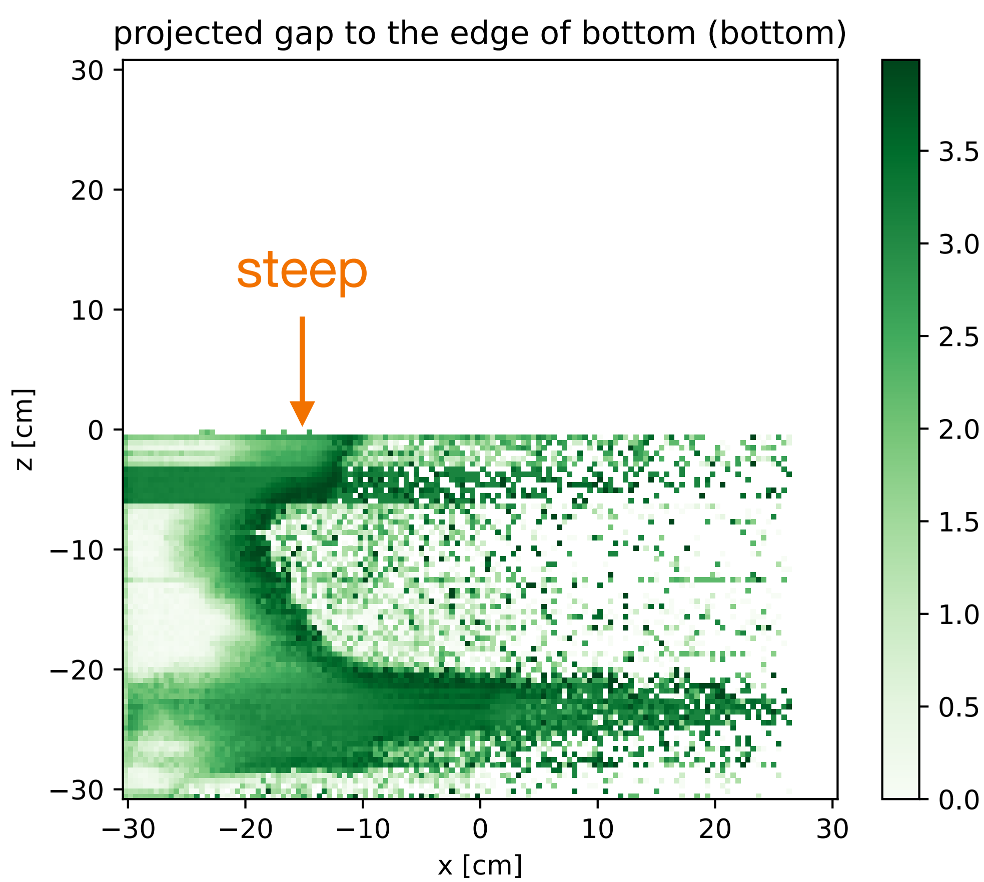
Detector Edges: x ~ 0+ (Cathode TPC2)

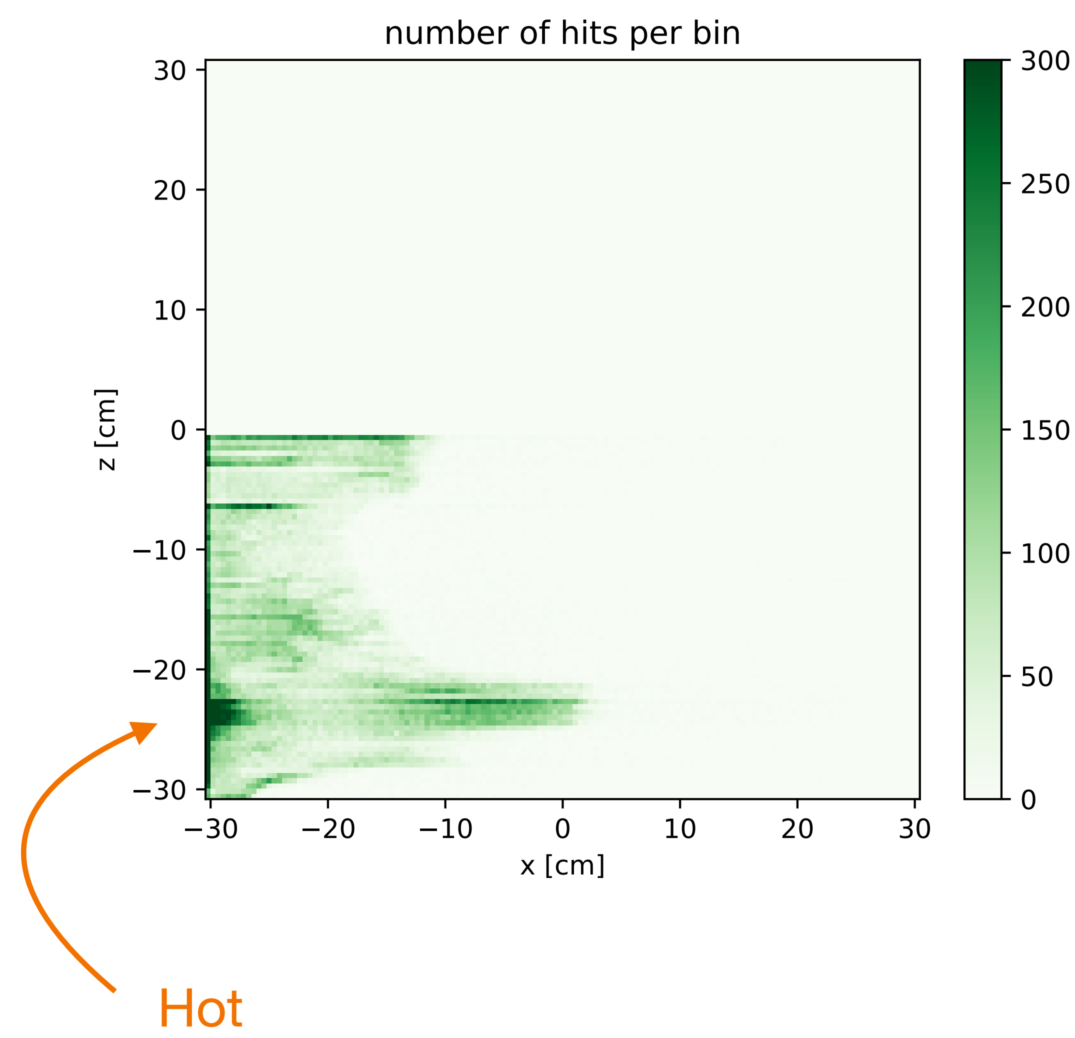
From all the runs at the nominal field including period 1 and 2.
The projected gap to the cathode is edge_x.
Other than the missing corners, there is a 1-2 cm slope in the cathode plane



Detector Edges: y_min (Bottom)

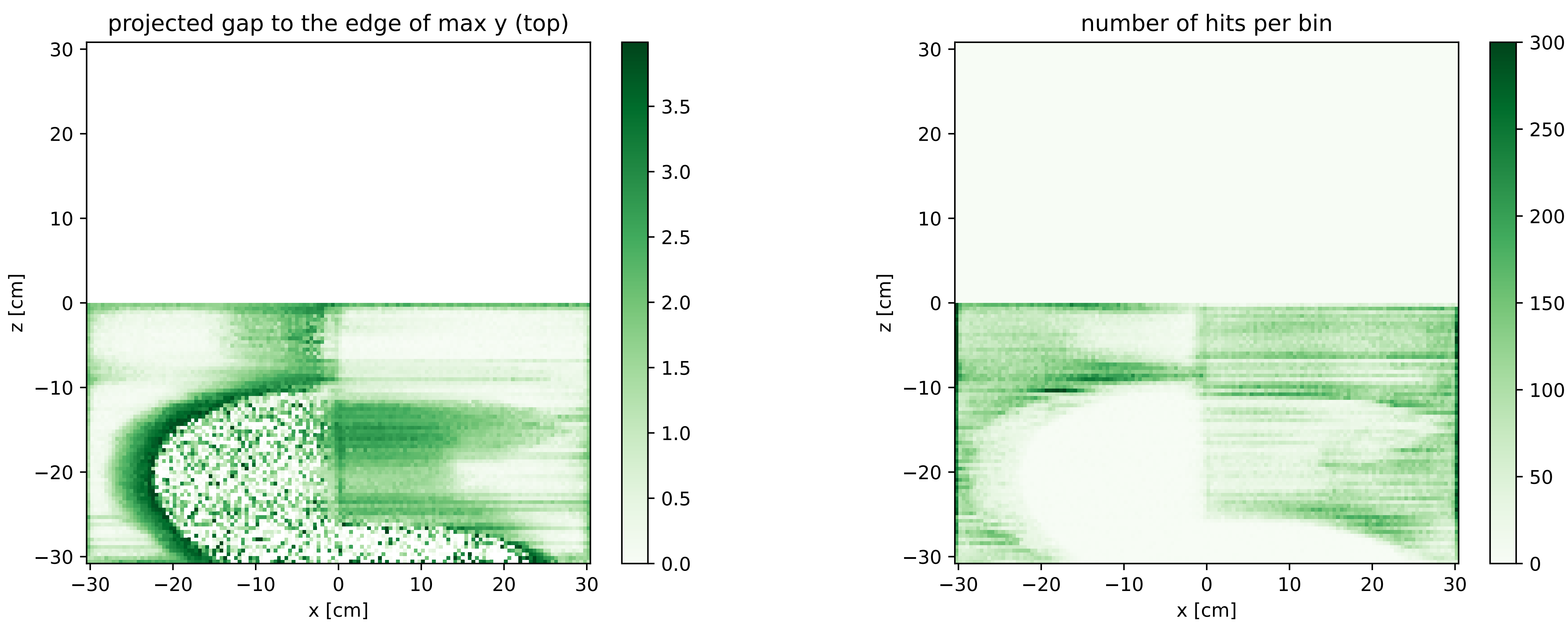
From all the runs at the nominal field including period 1 and 2.
The detector edge ramp is very steep.
The projected y distortion (edge_y - y_min) is close to 0 near the anode.
“Hot” bins near (x, z) ~ (-30, -22).





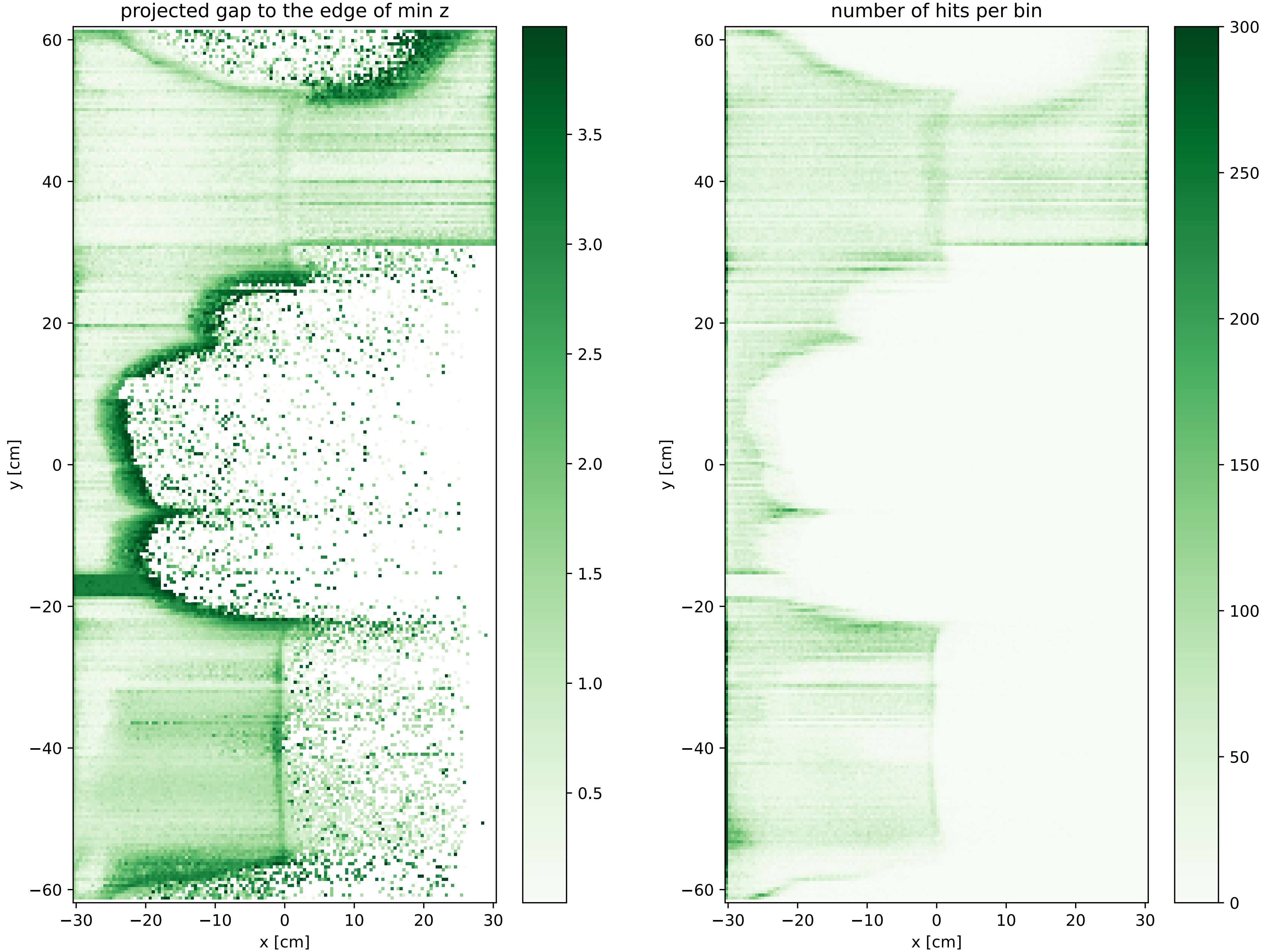
Detector Edges: y_max (Top)

From all the runs at the nominal field including period 1 and 2.
The detector edge ramp is very steep.
The projected y distortion (y_max - edge_y) is close to 0 near the anode.
The two sides are not symmetric.



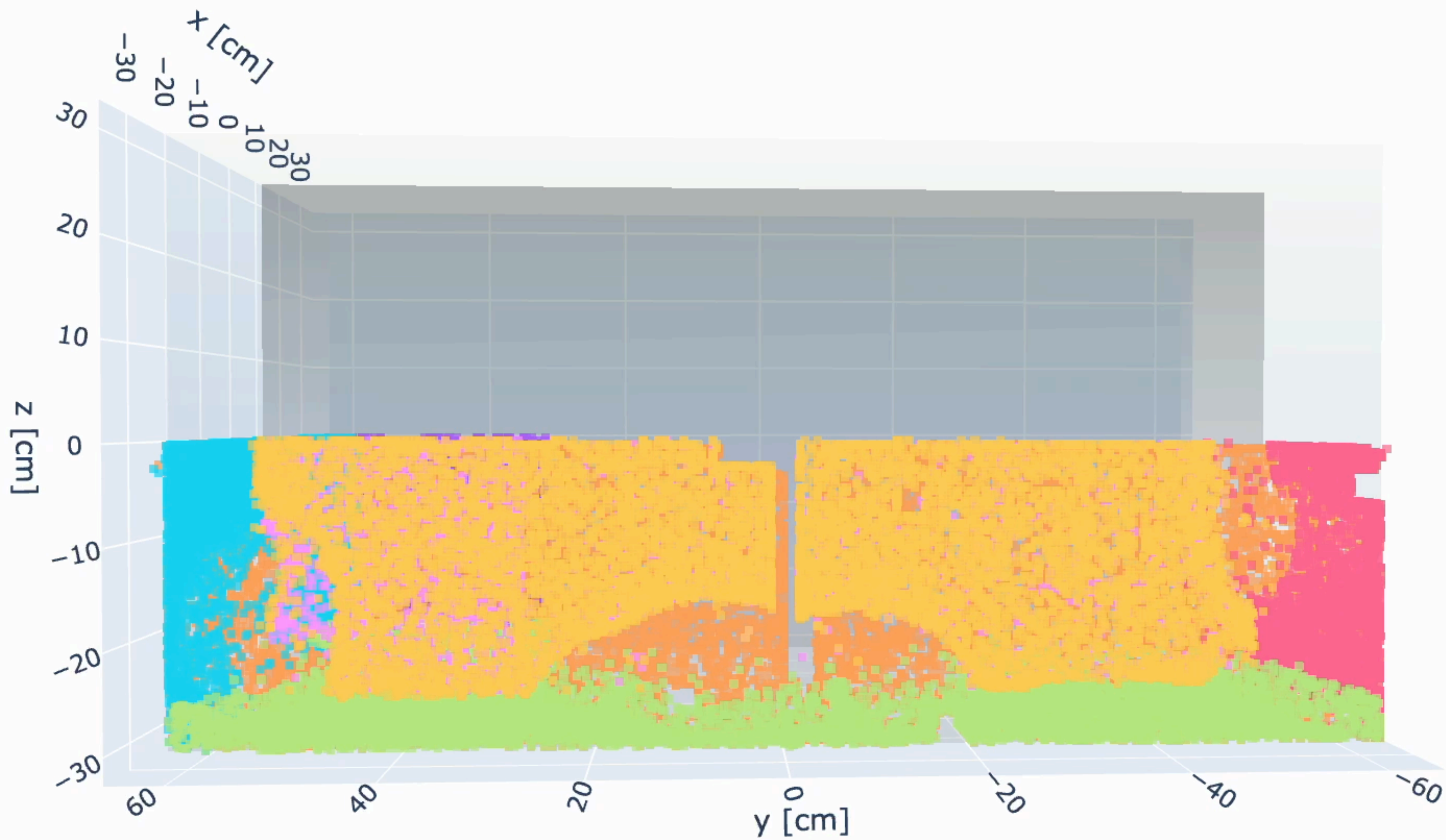
Detector Edges: z_min (Side)

From all the runs at the nominal field including period 1 and 2.
The detector edge ramp is very steep (edge_z - z_min). Large area is missing.
The two sides (TPCs) are not symmetric. The top-bottom are also not symmetric.
The shape in the middle does not perfectly align with the light detectors.
The observed cathodes overlap and are uneven (~1-2 cm scale).



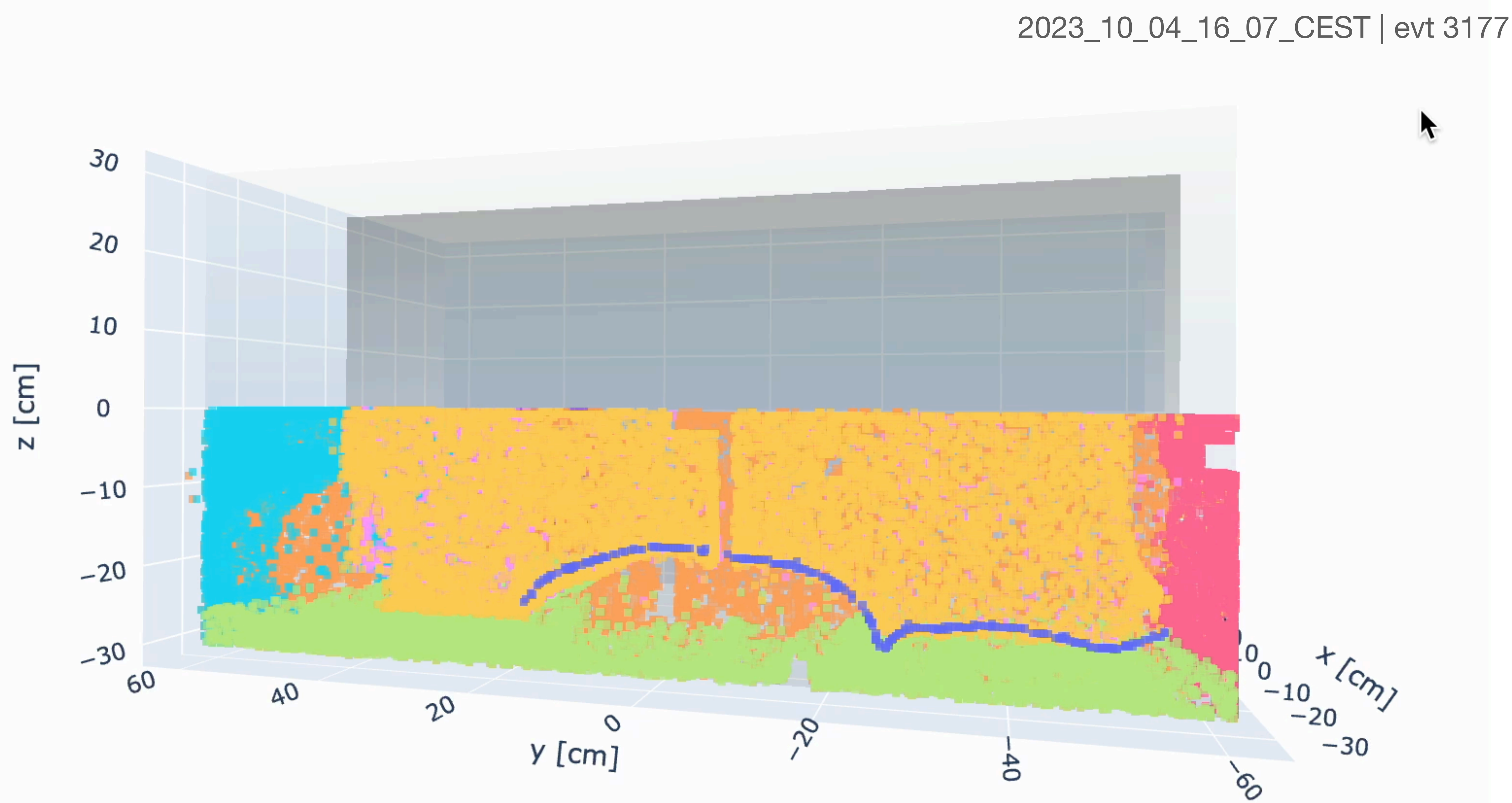
Detector Edges in 3D

A large area close to the y-center, on the edge of z and close to the cathode is “missing”.
A large area at the top (y_max), on the edge of z and close to the cathode is “missing”.
A large area at the bottom (y_min), towards the center of the z and close to the cathode is “missing”.
“Missing” means the actual TPC boundary in the readout is significantly inwards, about 15 cm in depth.
Note the position of the top and bottom area is at different z position (edge vs center).
At the top, the shape of the missing areas are also different in the two TPCs.



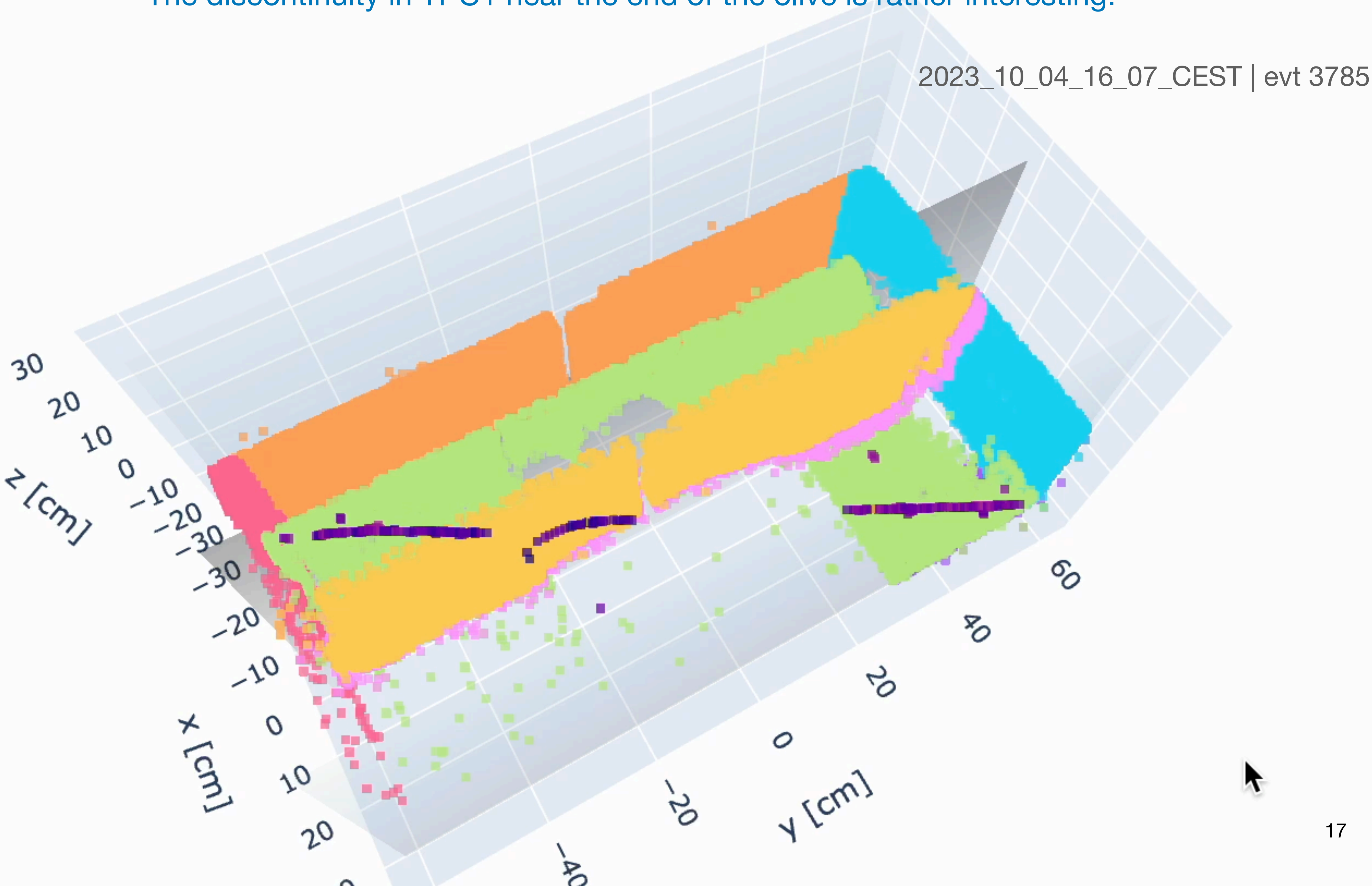
Deformed Track in the TPCs: Example 1

The missing areas roughly follow the shape of an olive.
Here you can see some examples of tracks going along the edge of the olive shape.
This means the missing areas are observed TPC edge being pushed in, not cut off!
The kink and minor dome on the track next to the olive shape is interesting.



Deformed Track in the TPCs: Example 2

The missing areas roughly follow the shape of an olive.
Here you can see some examples of tracks going along the edge of the olive shape.
This means the missing areas are observed TPC edge being pushed in, not cut off!
The discontinuity in TPC1 near the end of the olive is rather interesting.



Deformed Track in the TPCs: Example 3

The missing areas roughly follow the shape of an olive.
Here you can see some examples of tracks going along the edge of the olive shape.
It has some distance away from the visible edge of the TPC.
The track still follows the shape of the olive, which indicates that the squeezing effect is concerning a large area of the TPCs.
Also see the track close to the top of the TPC.

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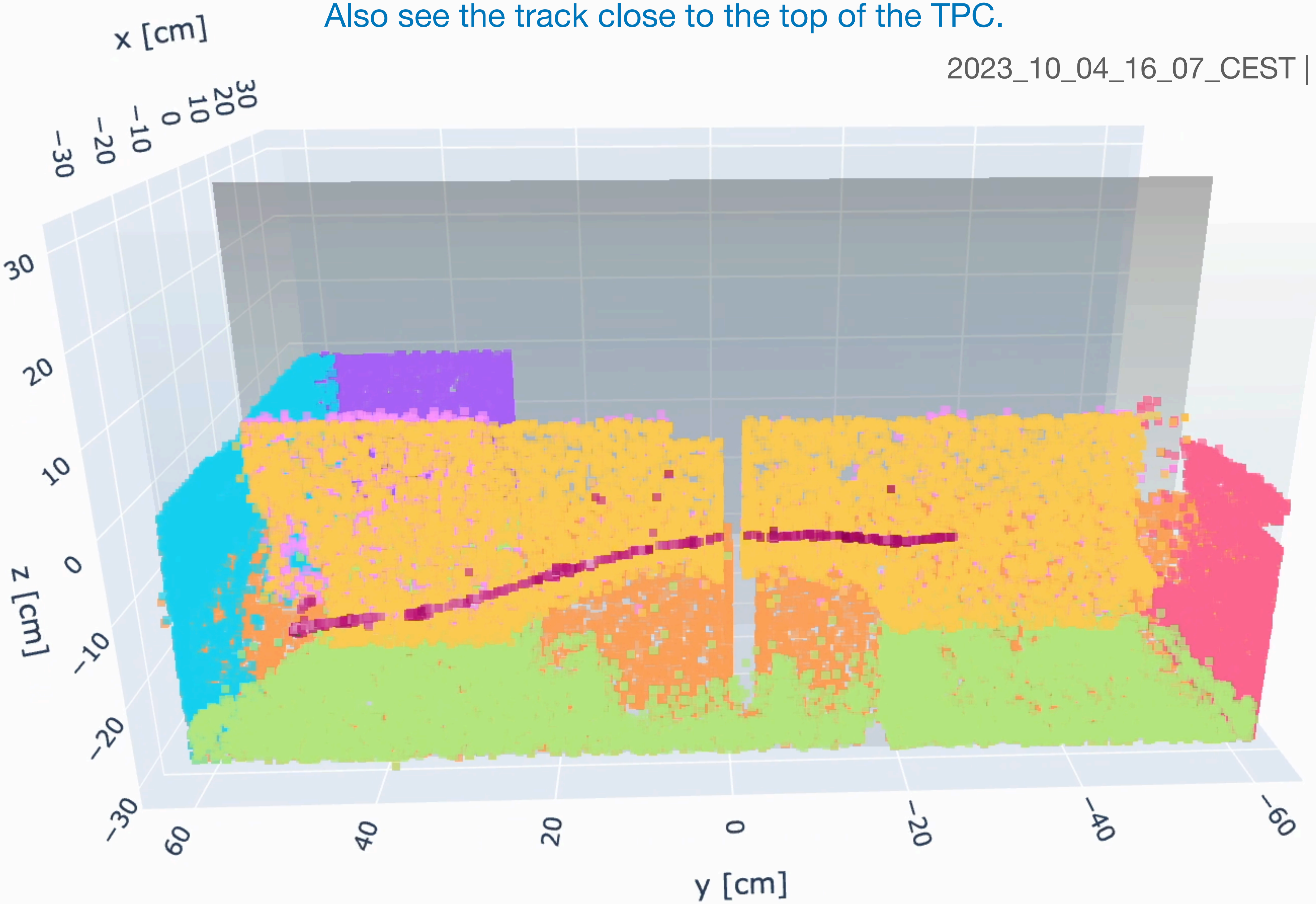
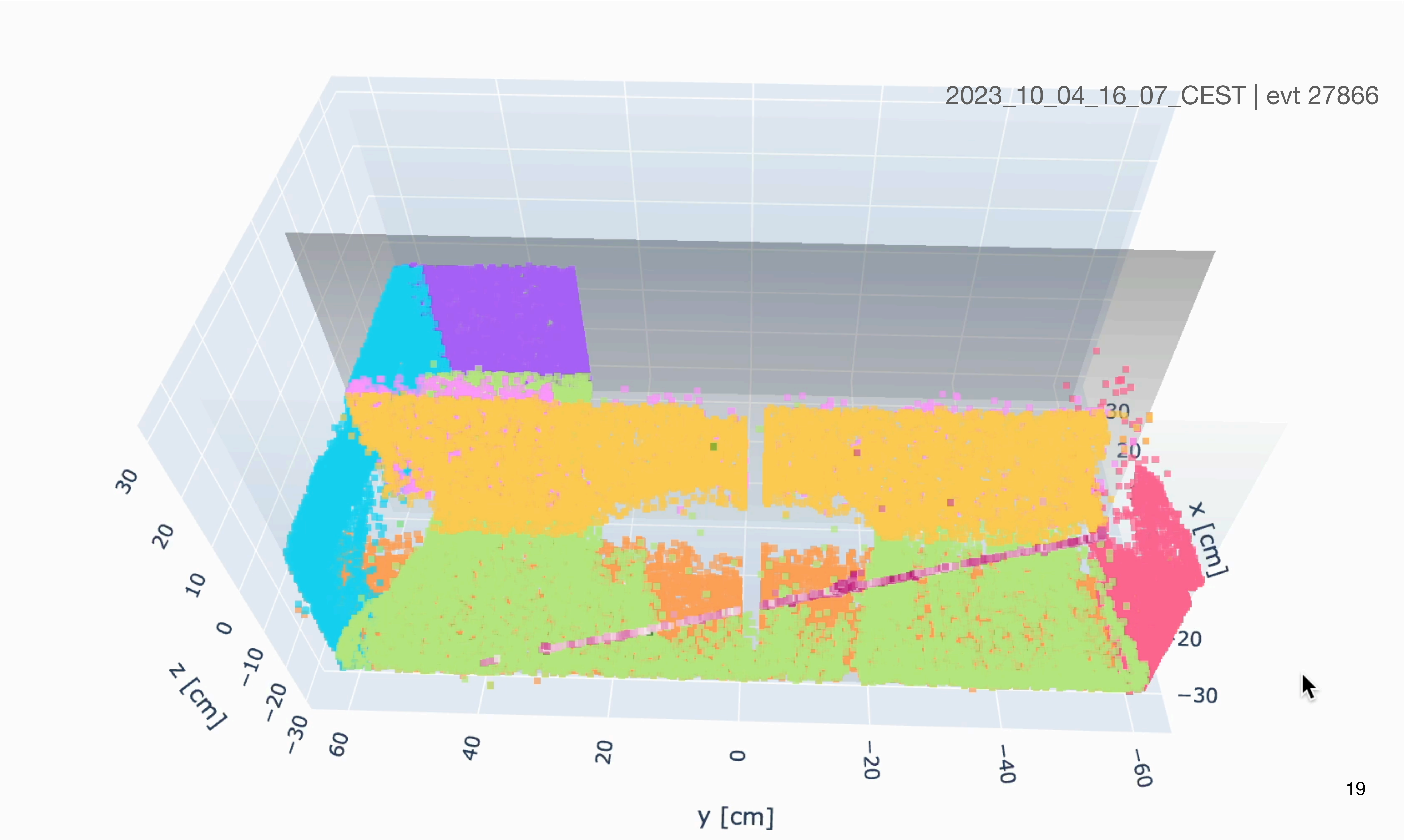
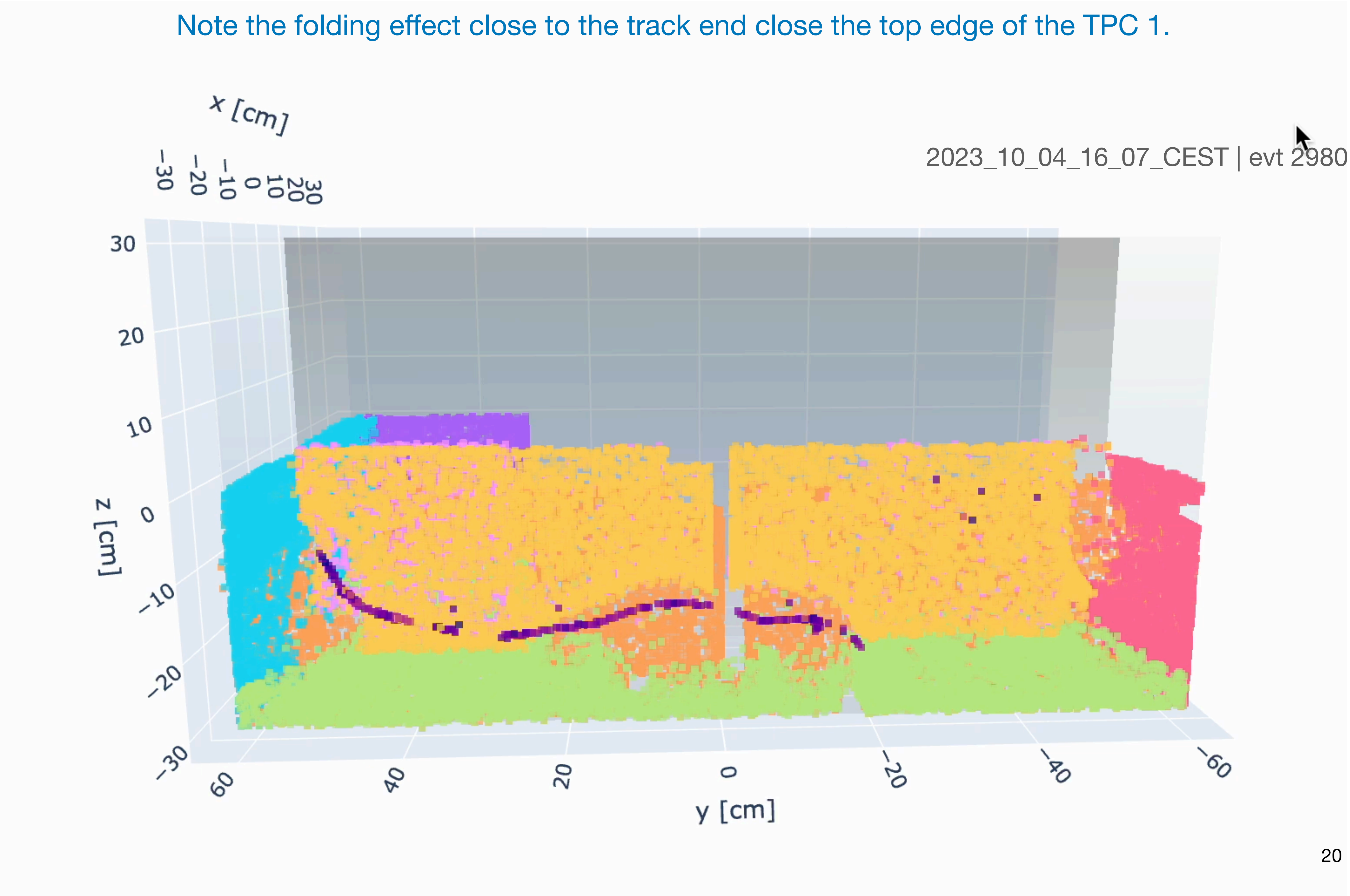


Deformed Track in the TPCs: Example 4

Note the folding effect close to the track end on the bottom edge of the TPC 1.

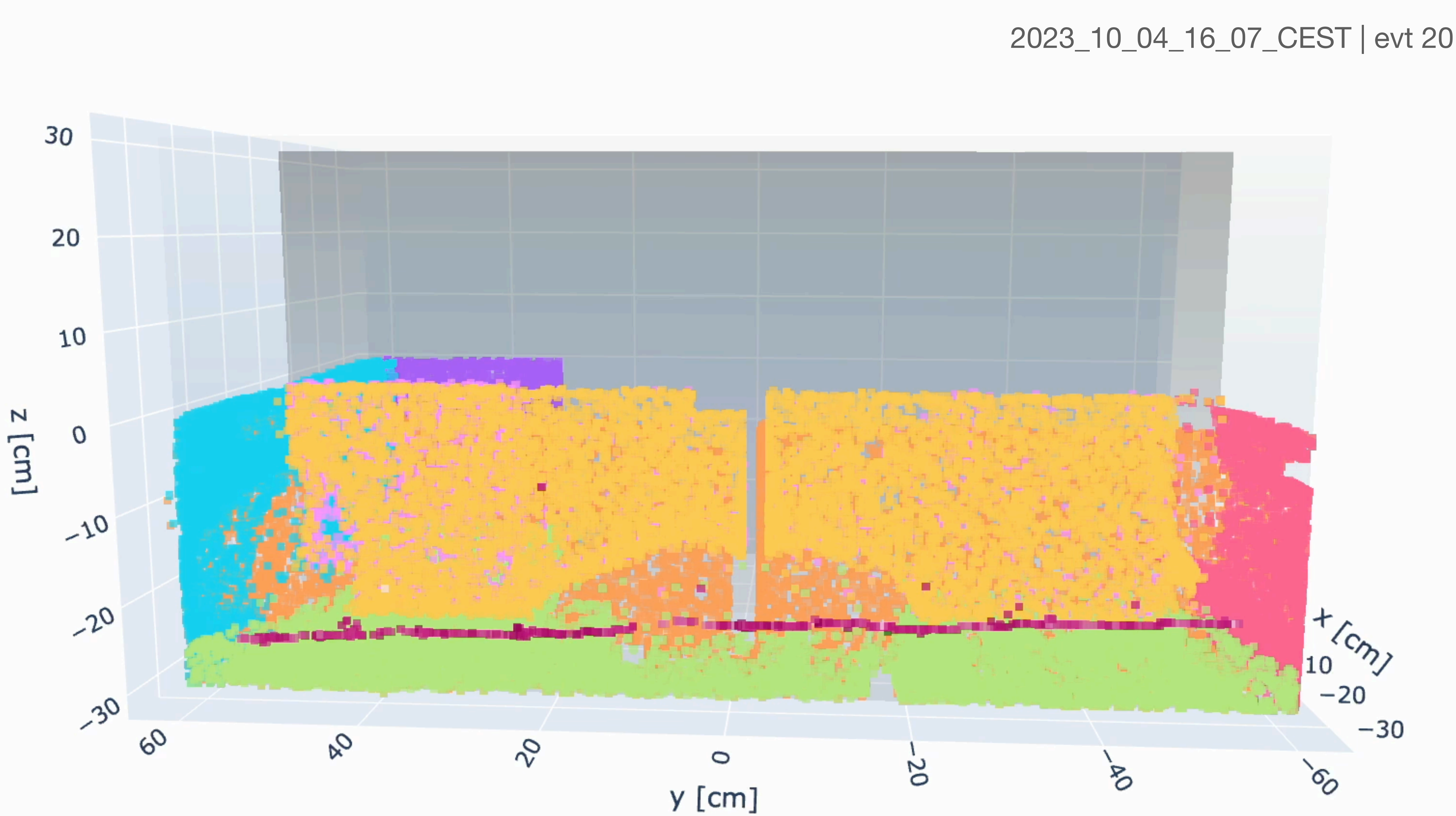


Deformed Track in the TPCs: Example 5



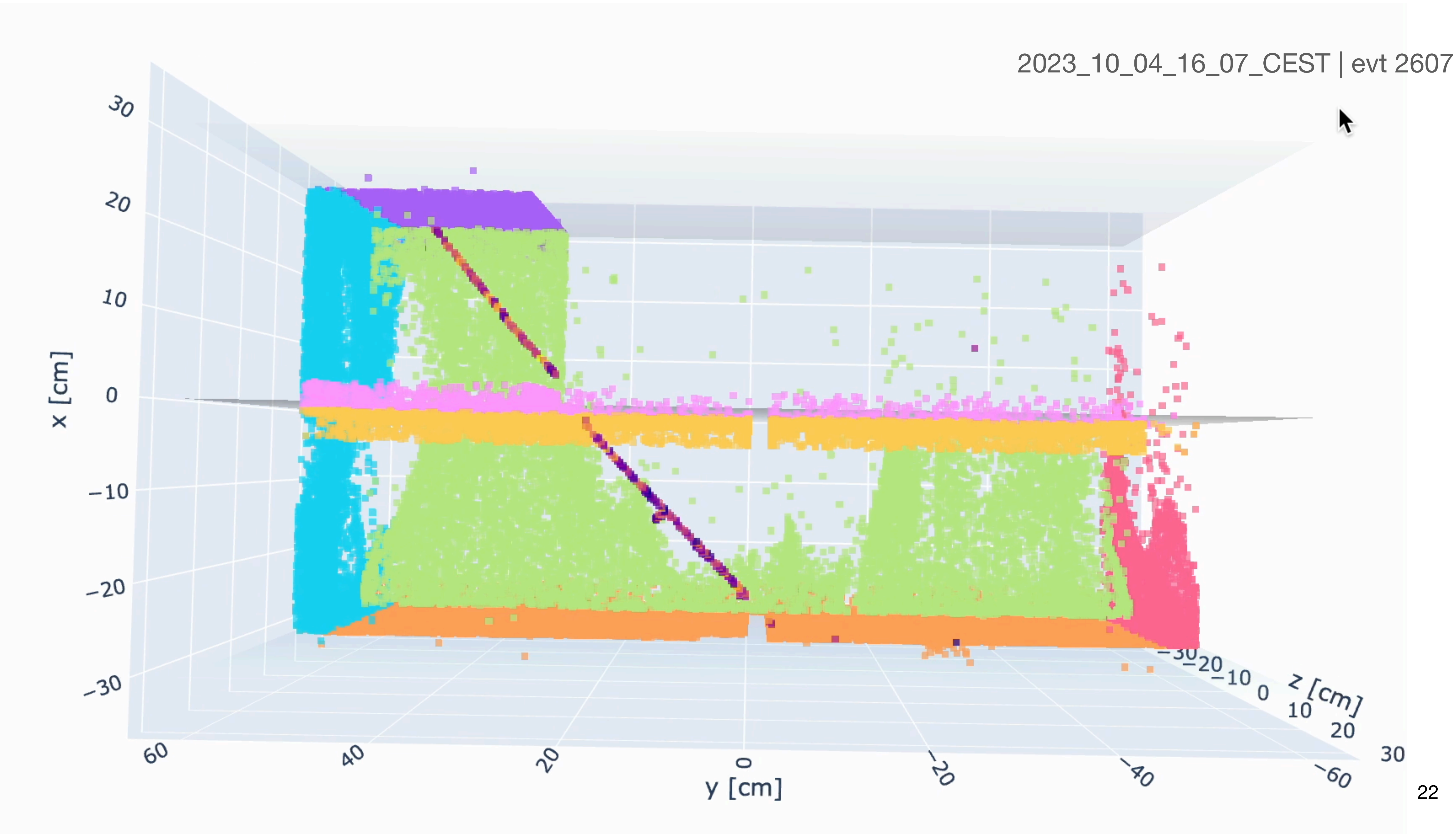
Deformed Track in the TPCs: Example 6

The missing areas roughly follow the shape of an olive.
Here you can see some examples of tracks going along the edge of the olive shape.
It is a track very close to the low edge of the olive. Otherwise, it is fairly straight.

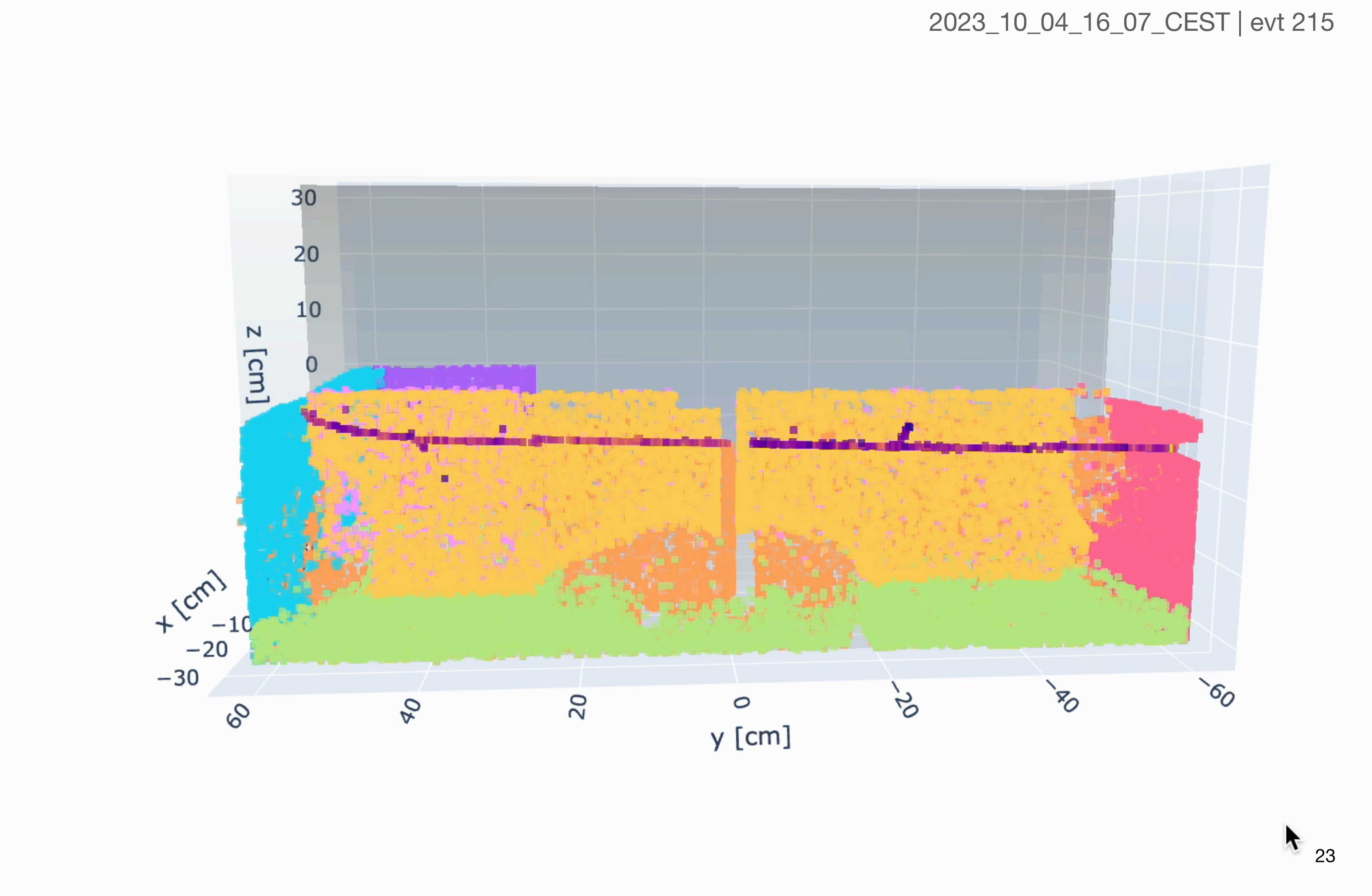


Deformed Track in the TPCs: Example 7

The discontinuity and the very different directions in the two TPCs suggest the behaviors in the two TPCs are very different.



Straight tracks are also common



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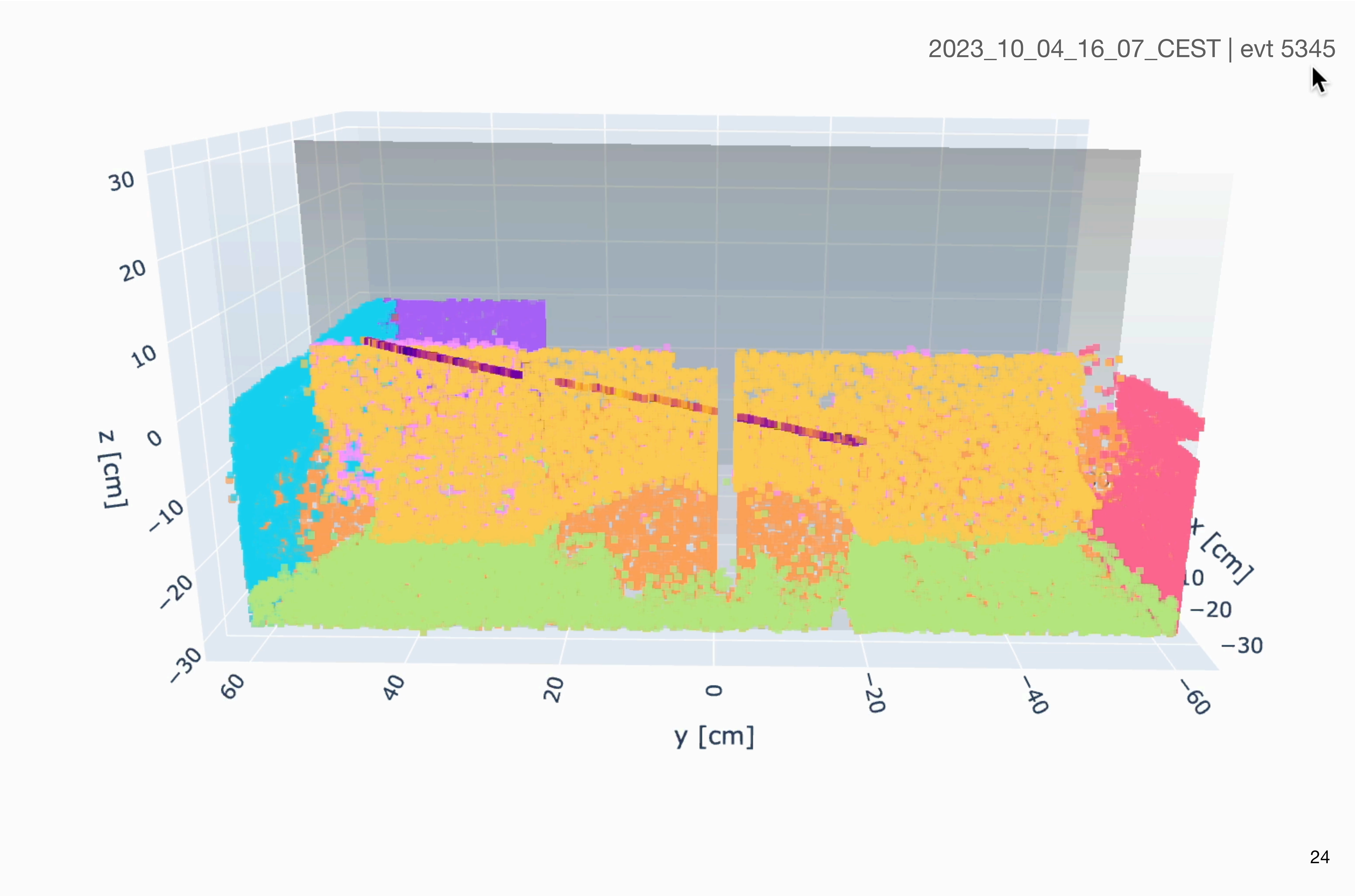

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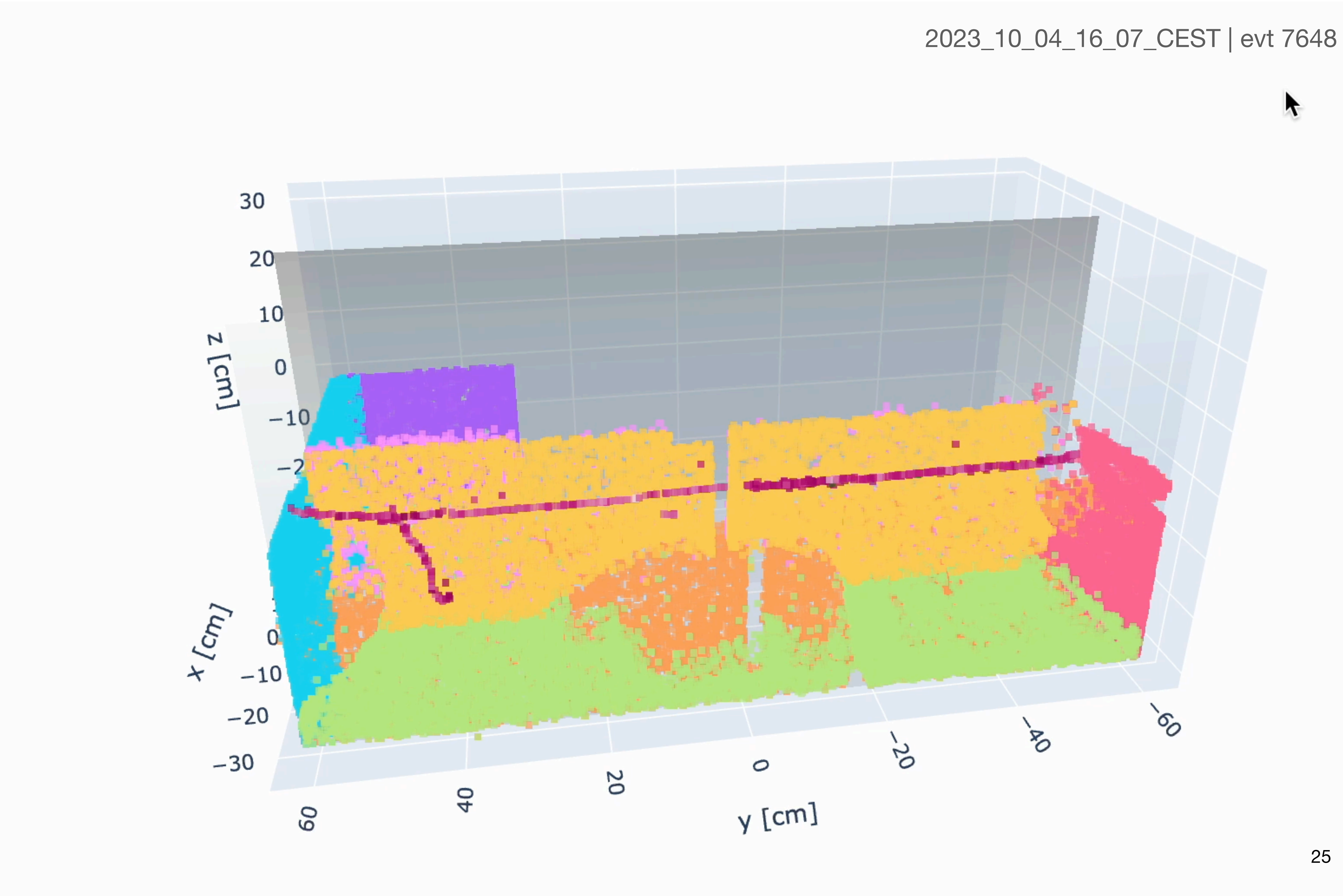

Other Ideas Used for Diagnosing

- Observation: cosmic tracks are not as straight as we expected.
- Checked the variance on the second principal axis of the fitted track.
- Reconstructed track segments
  - Hit density within track segments
    - Expecting high hit density close to the edge of the olives
    - However, given the common cosmic directions, the observed segment hit density is not significantly higher.
  - The angular differences between neighboring segments
    - If the “refraction” is strong within a segment, the line fit for a segment would not work well
    - It’s helpful to have short segments to follow the trend of the track, but then line fit is again difficult with few hits.
- The previous track examples cover what we want to probe with the track segments.

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- Reconstructed track segments
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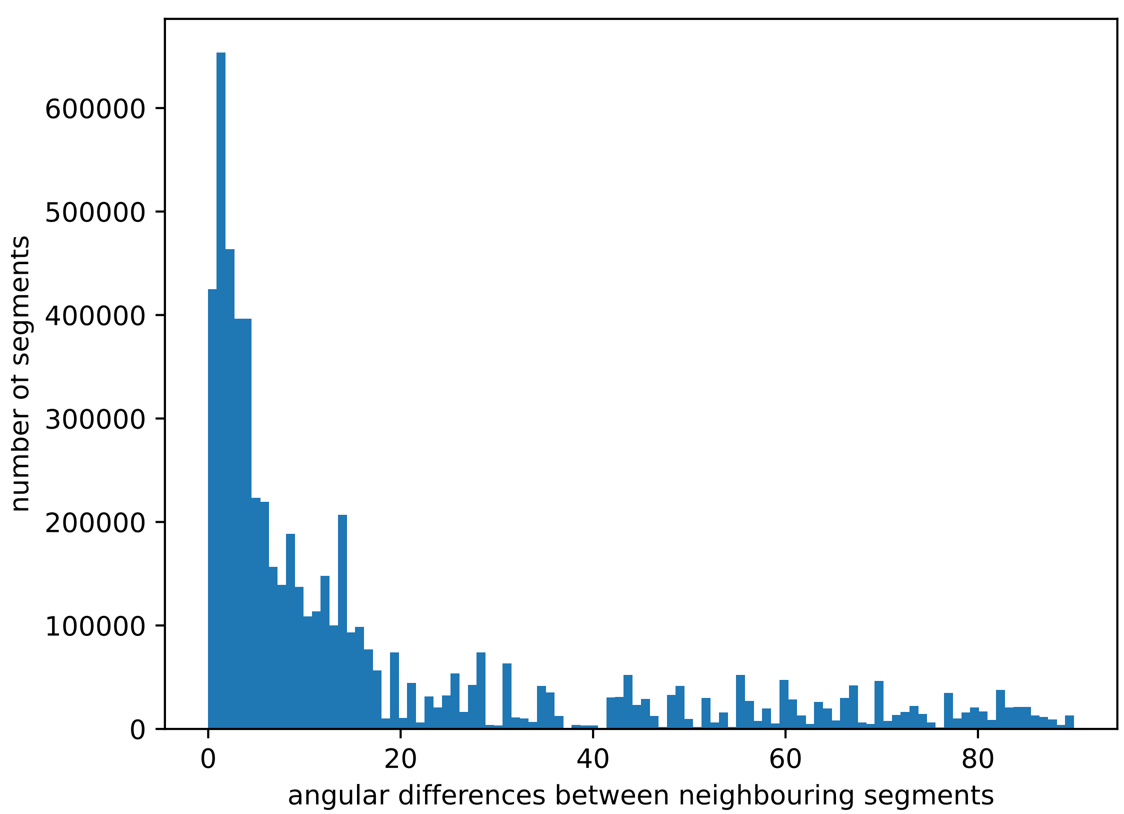

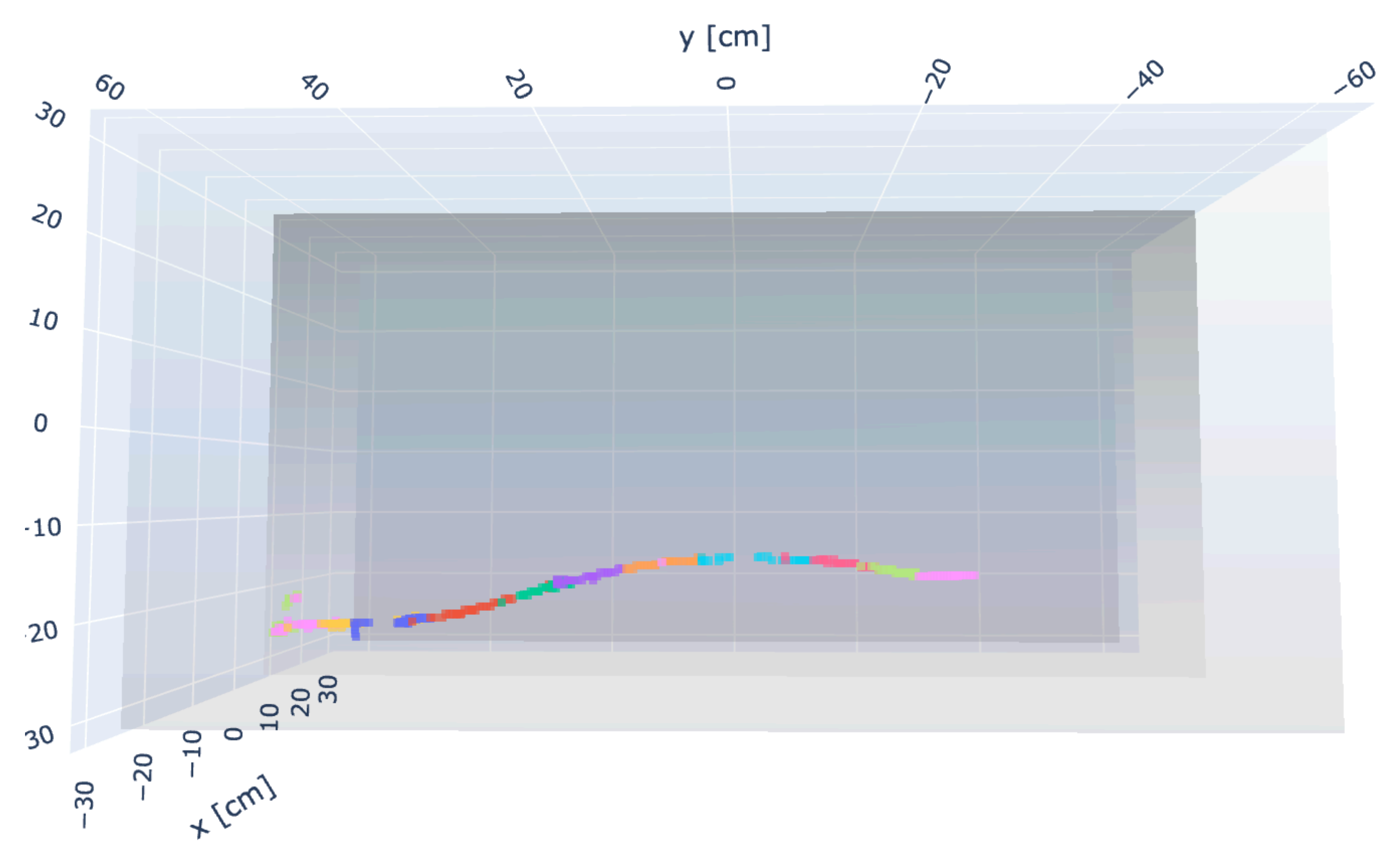

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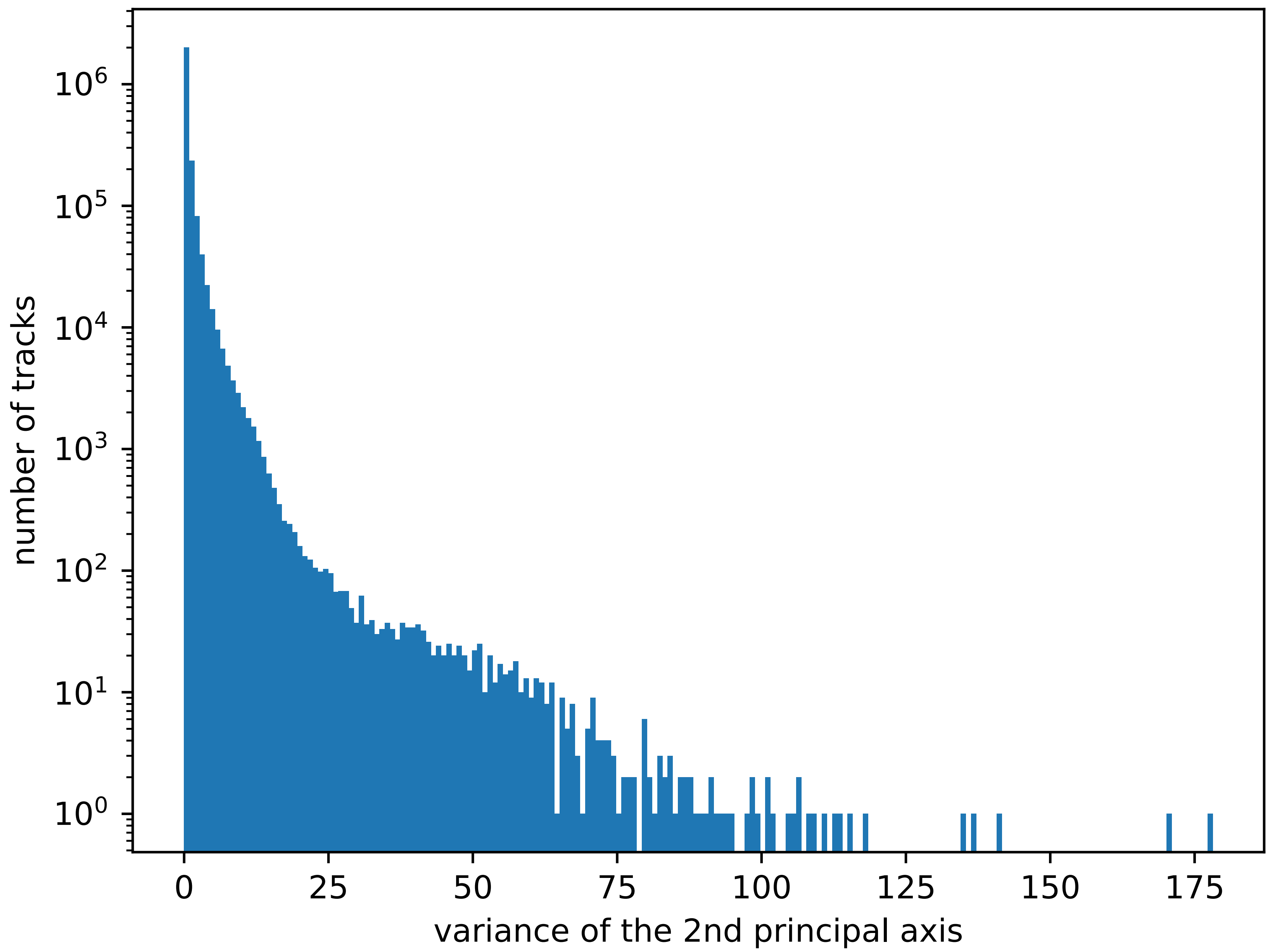

Thoughts 1

- ModX shows that the field shell made of carbon loaded epoxy is not ideal for the TPC operation as we had hoped for, at least not in the current configuration.
- After the data run, the side panels were taken off for visual inspection. There was no visible deformation of any kinds. We noticed that a washer was left in the bottom of TPC2 and some cracks appeared in one ArcLight module.
- Tracks deform significantly in the neighborhood of the olive-shaped edge boundary. Tracks away from the olive-shaped edge are straight. The olive-shaped area takes significant portion in the expected TPC volume. It is not symmetric in the two TPCs, not even in the top and bottom of TPC1.
- The distortion appear at the beginning of the data taking (a few minutes after HV ramp up), and it seems to be stable over time.
- The cause of the olives (my guess) is likely electron accumulation close to the TPC surfaces (due to electro-negative attachment of the material maybe?). The attachment will affect the cathode and the field shells similarly, because they were produced in similar ways. The electrons could not populate in the center of the cathode, because the ions would neutralize them on the way to the cathode. Maybe the resistance in the cathode is high, so the ion mobility in the cathode panel is low, and therefore it might take a while for the ions to drift towards the metal ring of the cathode. The electrons could be more likely to be attracted to the edge with the slow ions in the cathode plane. The separated islands of olives could be due to the electron repulsion in the TPC volume. In that sense, not only the surface property of the electron attachment matters, but also the sheet resistance plays a role. Perhaps that leads to the asymmetry of the patterns. On DR8, we observed a few times of differences in sheet resistance, but the carbon loaded epoxy results in 1 to 3 orders differences in sheet resistance.

Thoughts 2

- To investigate this further, probably one can (1) install a different cathode in a single cube and (2) use a mix of carbon loaded epoxy field shell and DR8 to compare with a ModX-like set up.
- It is not clear for the side panel, how much effect is due to the light detector property and how much effect is caused by the field shell itself, but patterns in the top and the bottom show that the light detectors are not the only culprit if at all.
- Typically the 2x2 modules with DR8 yield ~cm distortion at the edge a few cm to the cathode.
- If my reasoning were not completely wrong, I think it might be worth to revisit or verify the cathode design and to be cautious when introducing the carbon loaded epoxy as part of the field shell.
- It is challenging to use carbon loaded epoxy strip as resistors, as the uniformity within the sheet is not well controlled at the moment.
- The proposal to have carbon loaded epoxy strip with metal at the edge connected with resistors is cool! The short and direct path to the metal connection may ease the problem of what we see in ModX. Electrons may still be stuck between the resistive strips (bare FR4), as it's difficult for them to move elsewhere. Electrons may still be attached around the resistive strips for similar reasons, but I would assume lower resistance could help. The strip width and the gap size may have visible effect on the edge electric field uniformity(?). The scale of the effect needs to be quantified with tests.