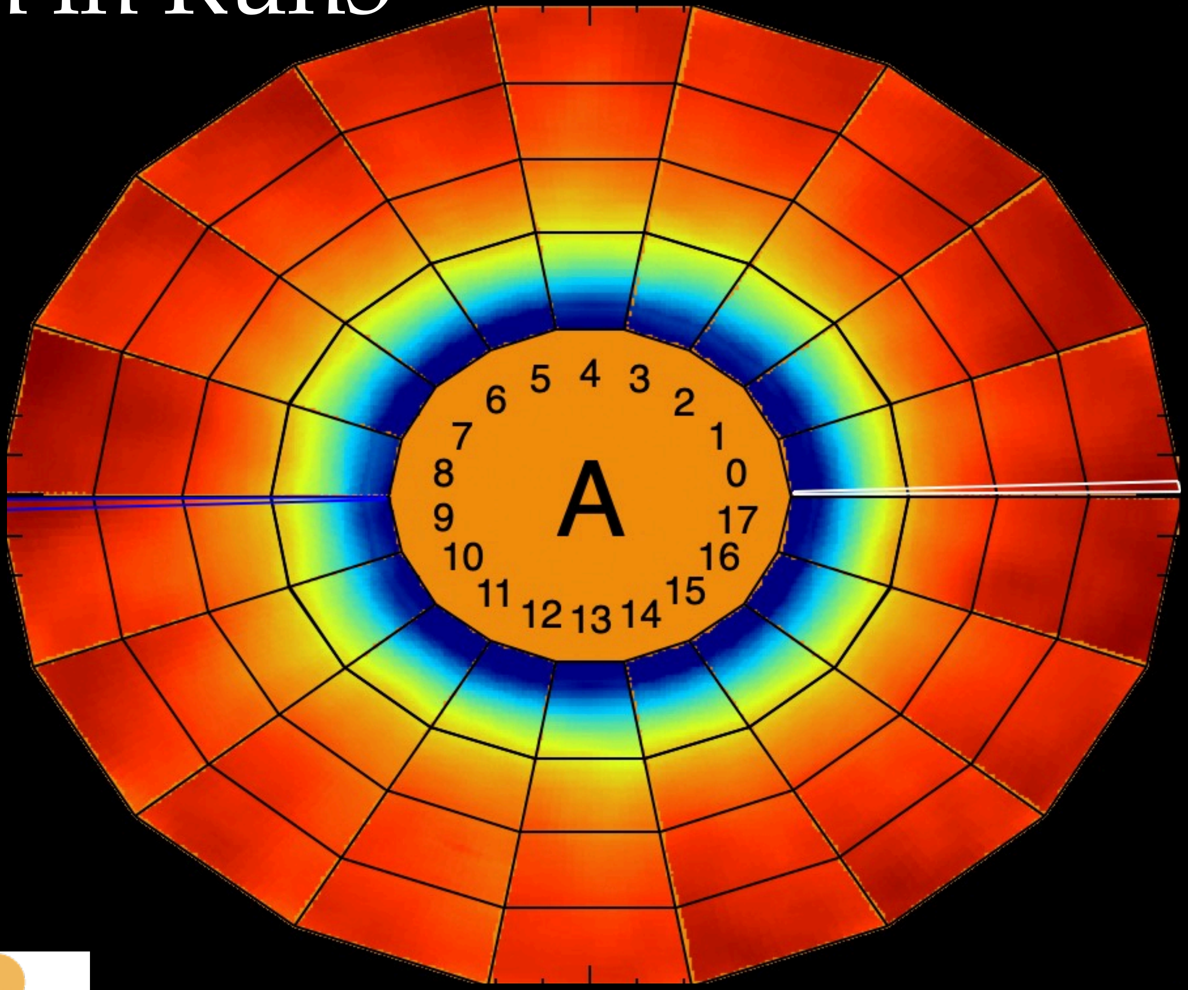
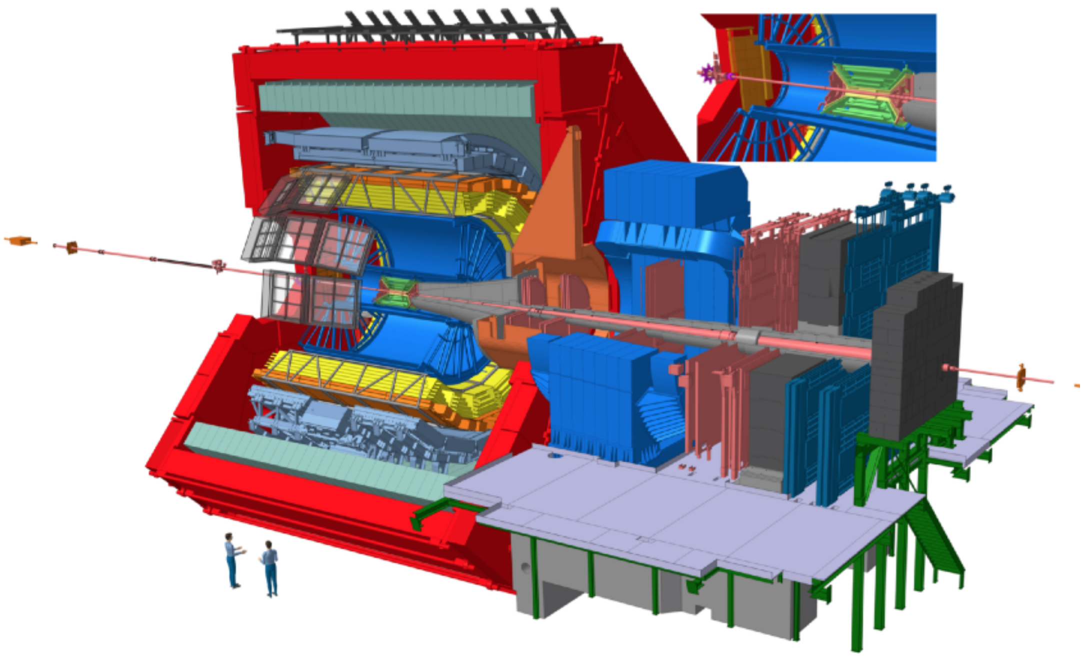
ALICE TPC Space Charge Distortion Calibration in Run3

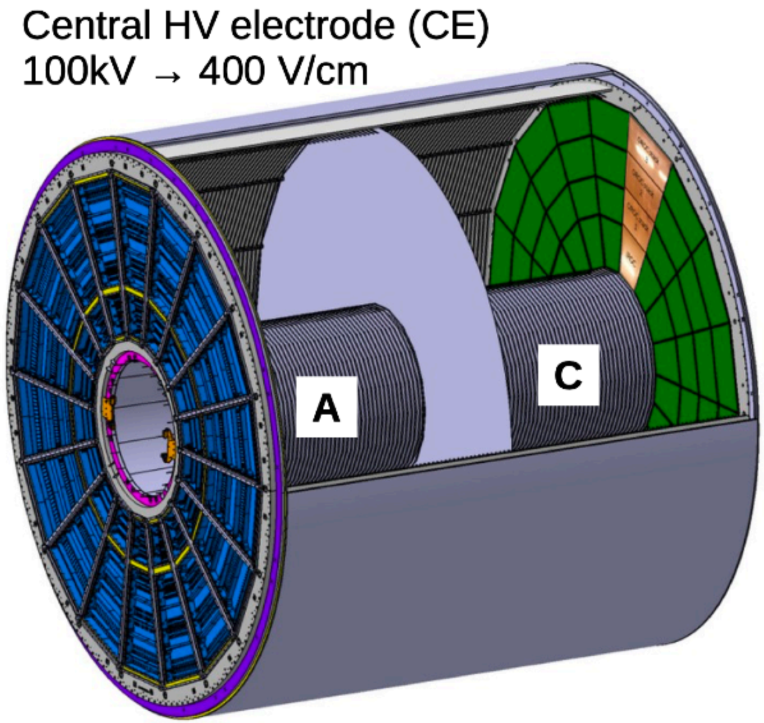


Alexander Schmah for the TPC Group

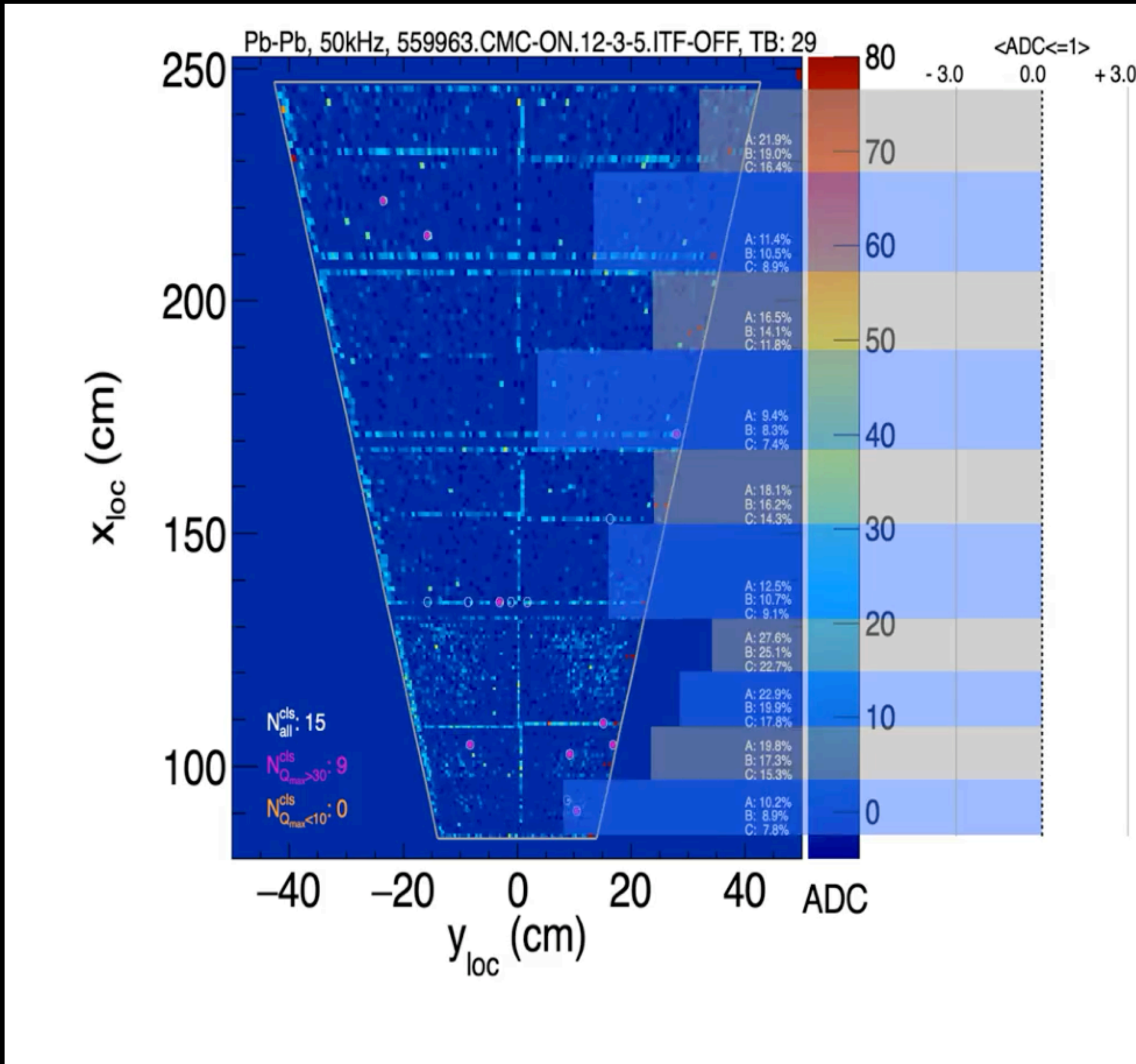
09.12.2024

ALICE - TPC





- Dedicated heavy-ion experiment.
- Upgraded for Run3: continuous readout + GEMs.



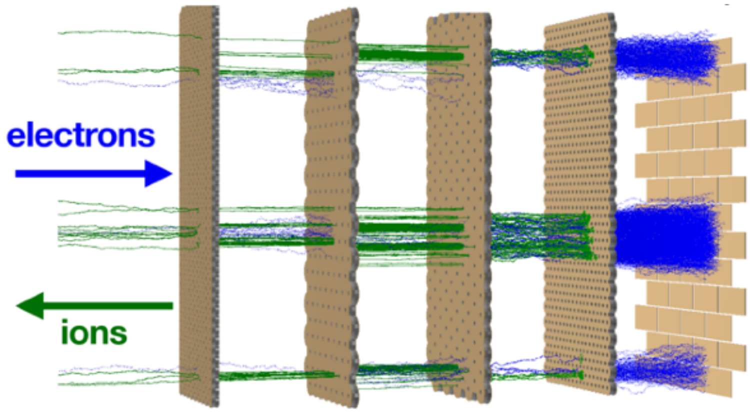
- 50kHz Pb-Pb, Run3, 2024
- Raw data, with common mode correction activated.
- Circles show reconstructed TPC clusters.
- Every image corresponds to 200 ns.

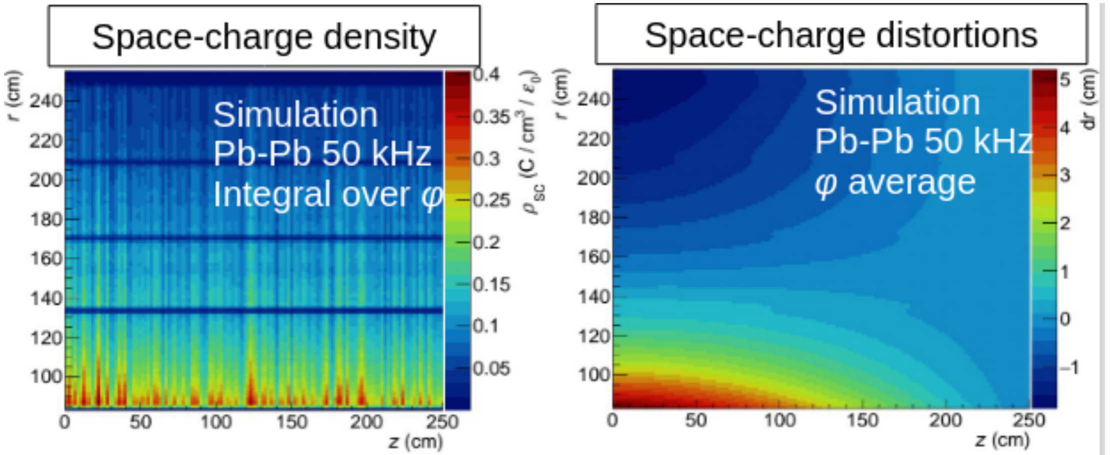
Space Charge Distortion Corrections

Space Charge Distortions

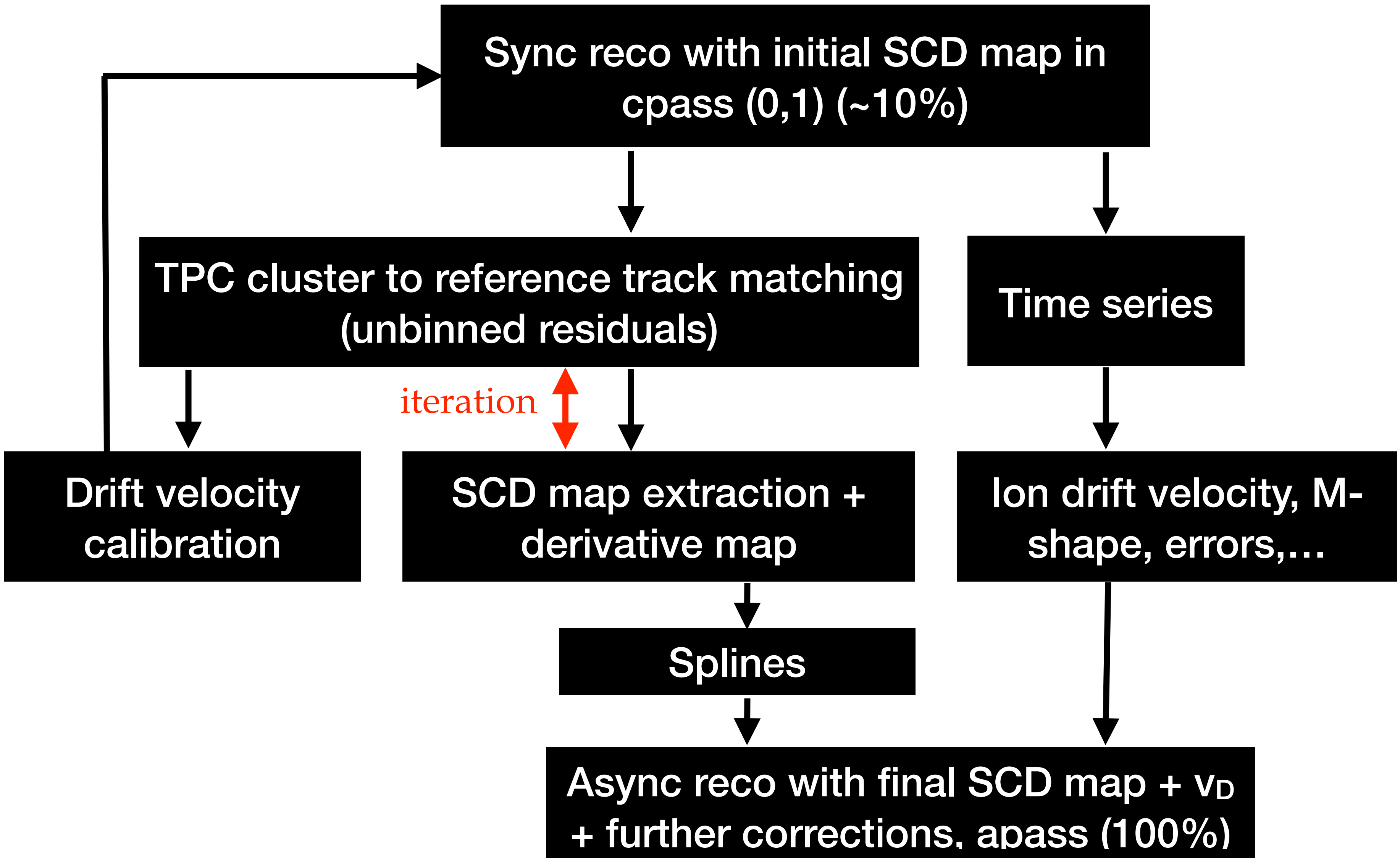
- Ions from the amplification stage move back into the drift volume

- Ions are slow (~200 ms for full drift)
  - Ions from large number of events pile up (~10k events @ 50 kHz IR)
  - Significant space-charge density (SCD) in drift volume
  - Large average distortions (O(5-10 cm))
  - Intrinsic TPC resolution: ~200 μm
  - $\rho_{SC} \sim I_{prim} \bullet gain \bullet IBF$



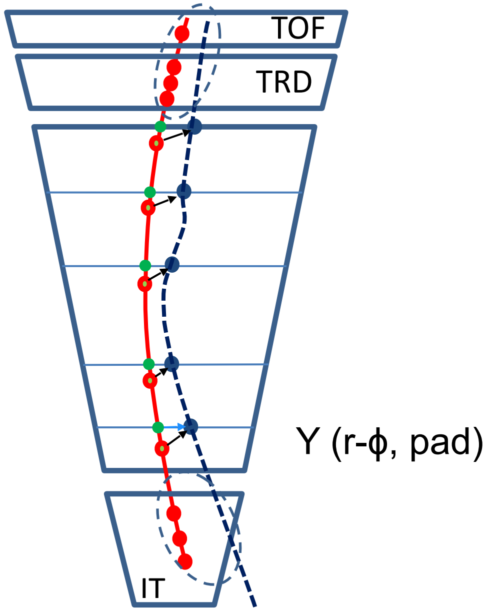


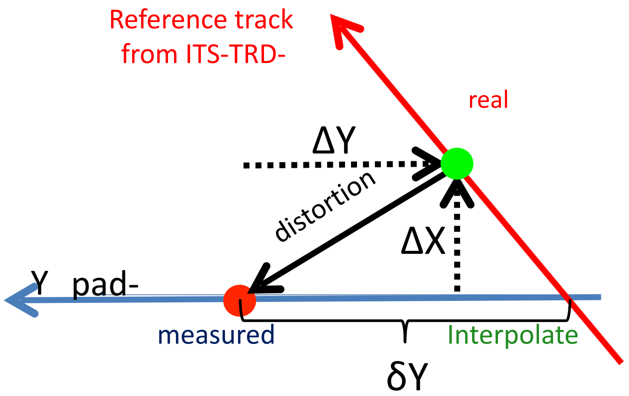
Correction Workflow



Extracting the Residuals

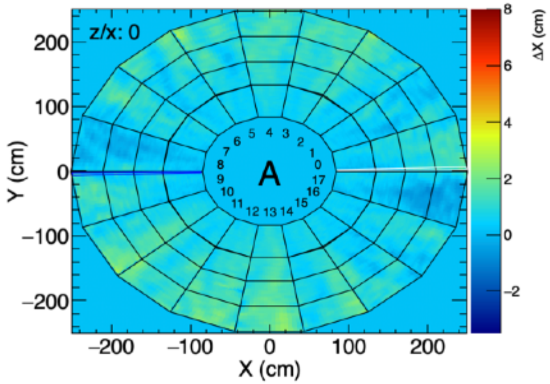
- Define reference track position in TPC from ITS extrapolation (or ITS-TRD-TOF interpolation)
- Collect δy and δz differences between distorted clusters and reference points in TPC sub-volumes (2.7M voxels)
- Output: *unbinned residuals*
- Build voxel maps from unbinned residuals to extract real distortions **Δ**X, **Δ**Y, **Δ**Z



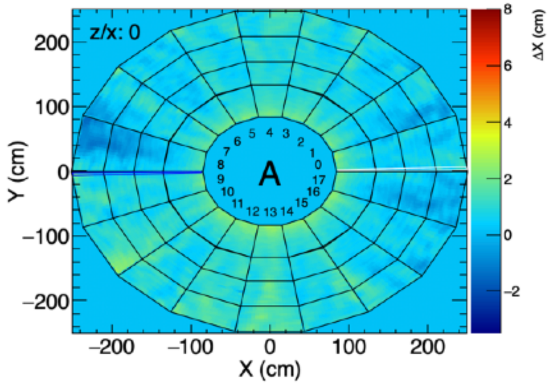


Space Charge Distortion Maps

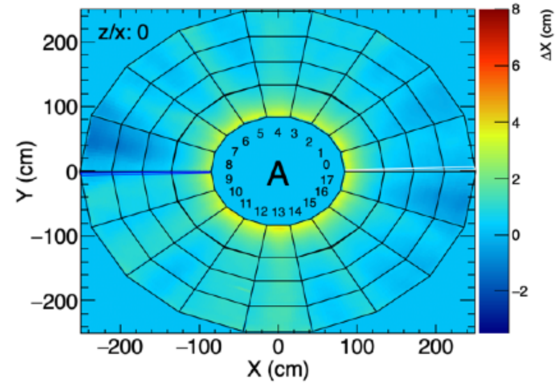
50 Hz



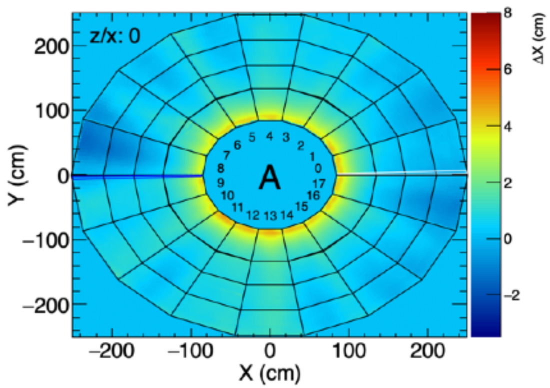
8 kHz



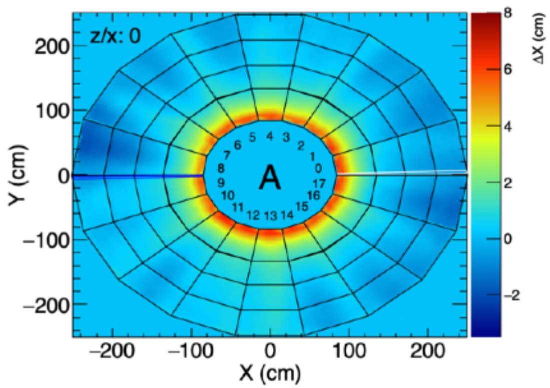
15 kHz



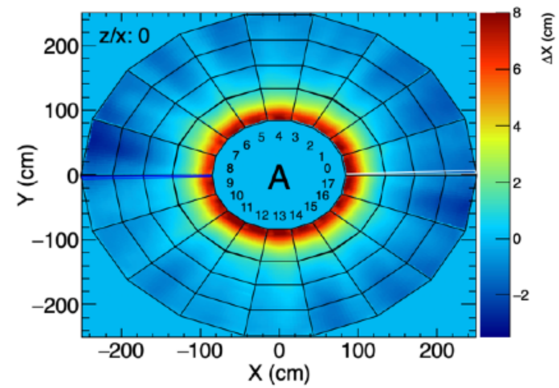
18 kHz



27 kHz

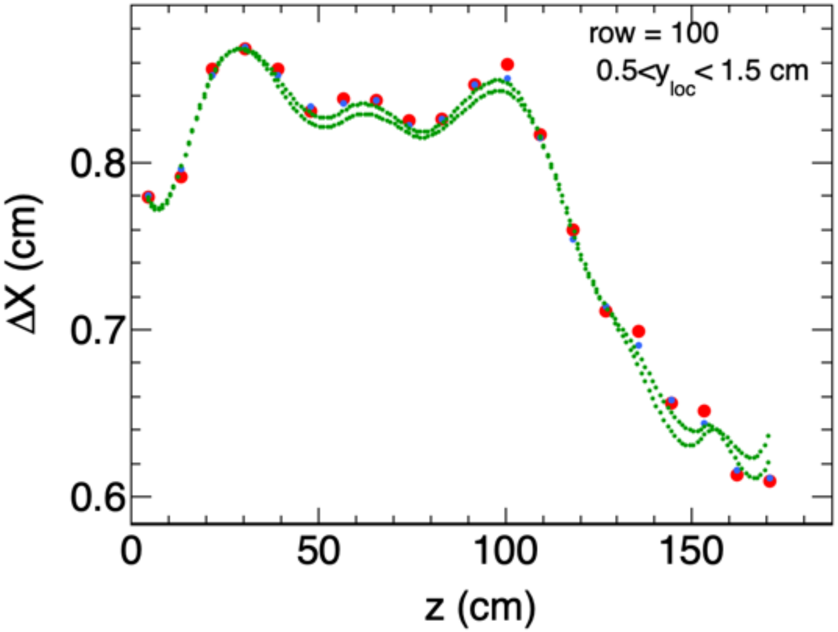


38 kHz



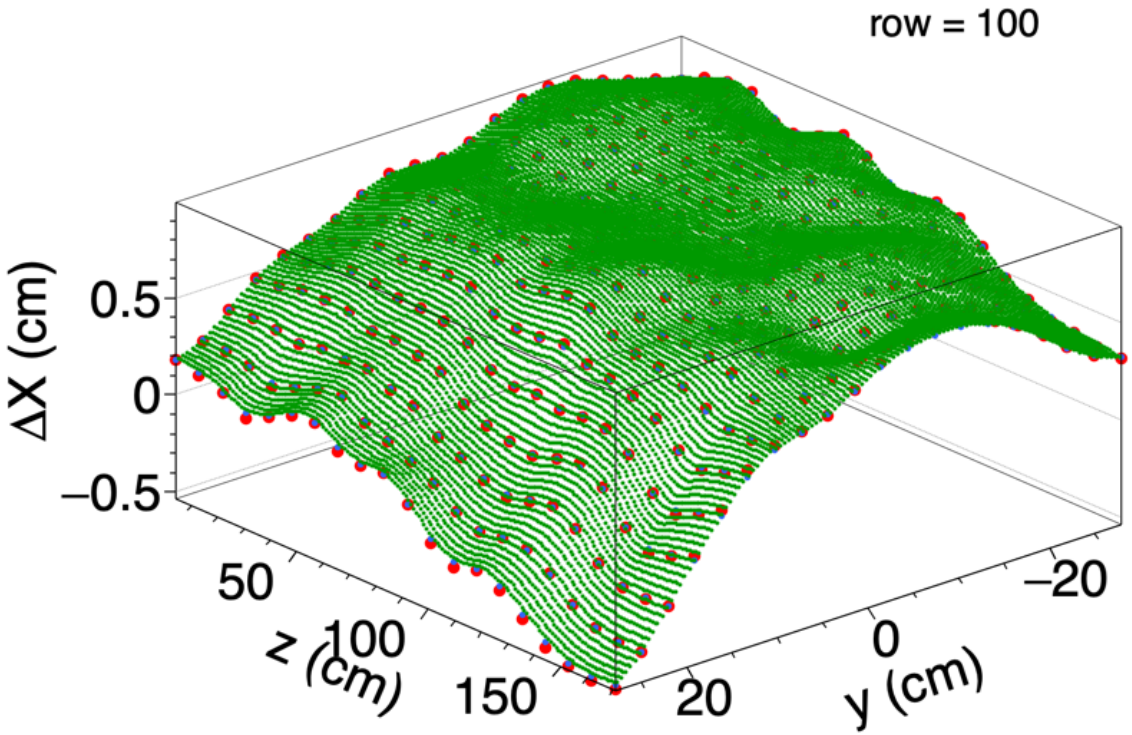
- Average maps. Fluctuations and IR dependence are treated on top.
- Distortions up to ~8 cm in radial direction!

Splines



- Splines: analytical representation of the binned maps.
- Used during GPU reconstruction.

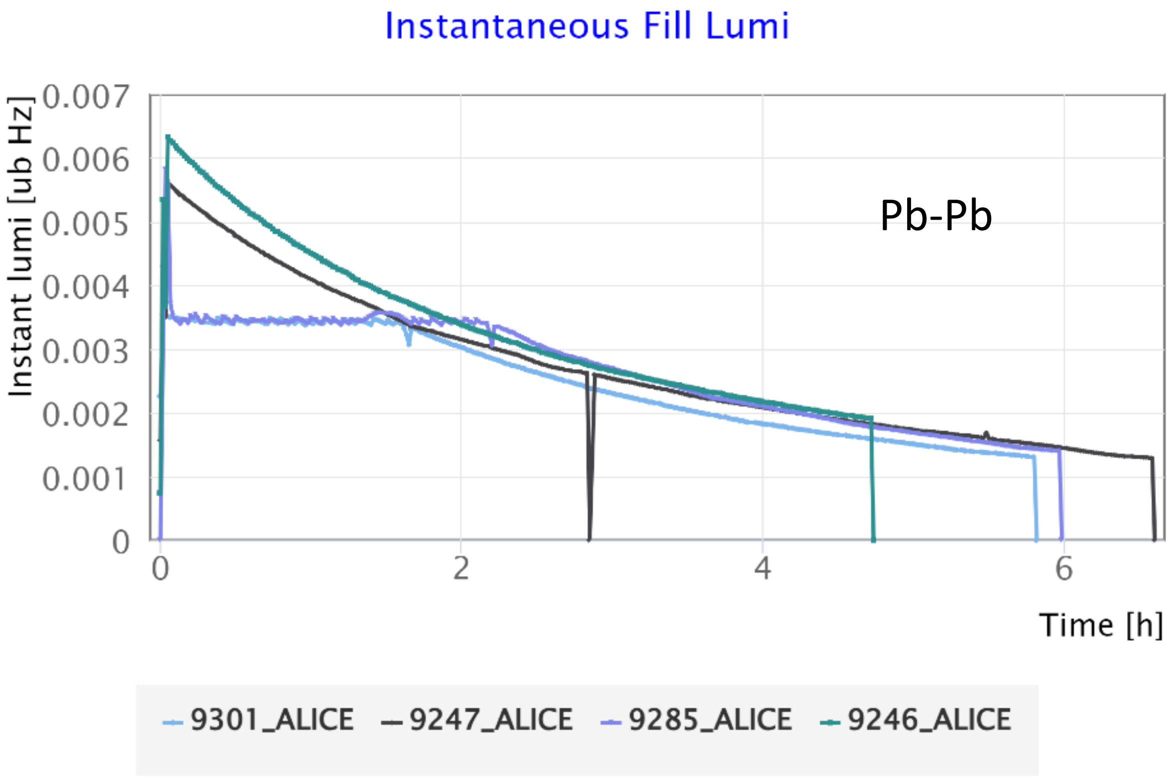
Spline QA



- Example of a 2D spline for pad row 100.

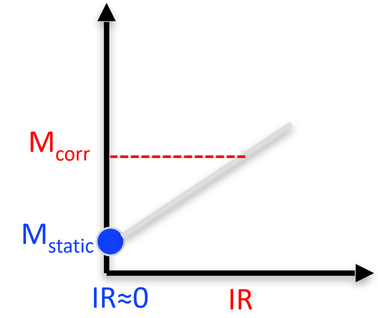
Interaction Rate Dependence

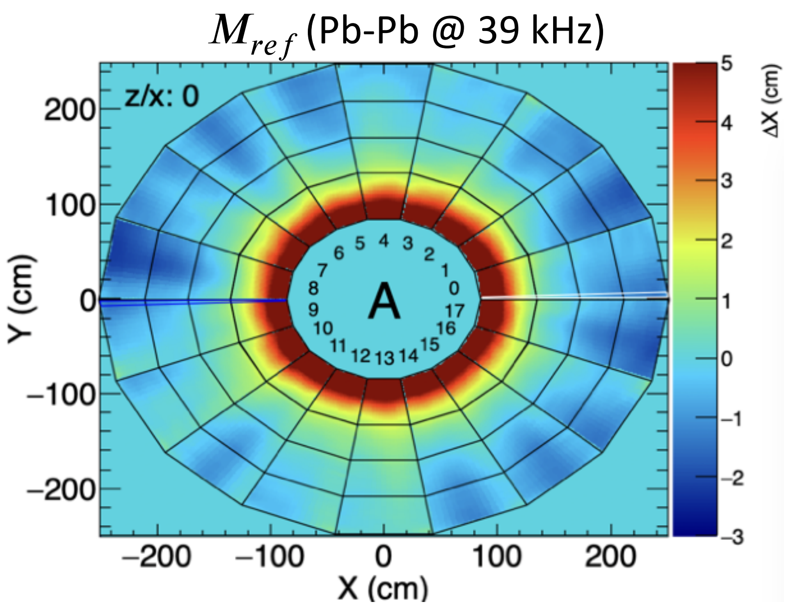
- In Pb-Pb interaction rate drops rapidly within a fill
  - Additional complication for SCD calibration – expected leveling at least for major part of the fill
- SCD correction must account for IR changes

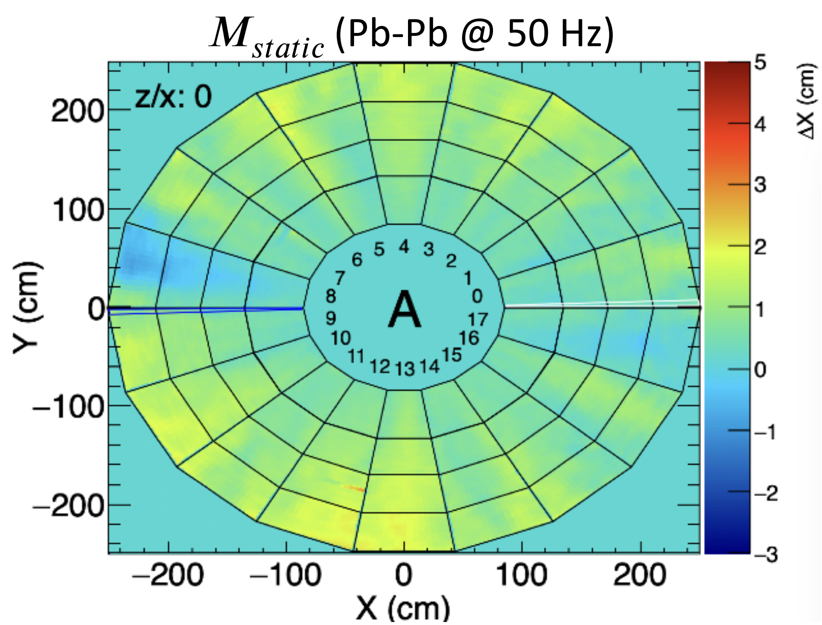


IR Dependence, Linear Scaling

- $M_{corr}(IR) = (M_{ref}(IR_{ref}) - M_{static}) \bullet IR/IR_{ref} + M_{static}$
- M_{static}: long-term-average map at *low IR* $(IR \approx 0)$
- M_{ref}: long-term-average reference map at *high IR* (IR_{ref})
- Caveat*:* distortions do *not* scale exactly linearly with IR

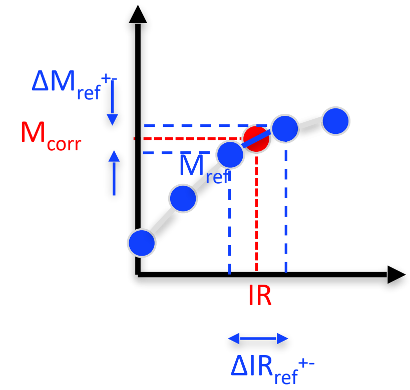




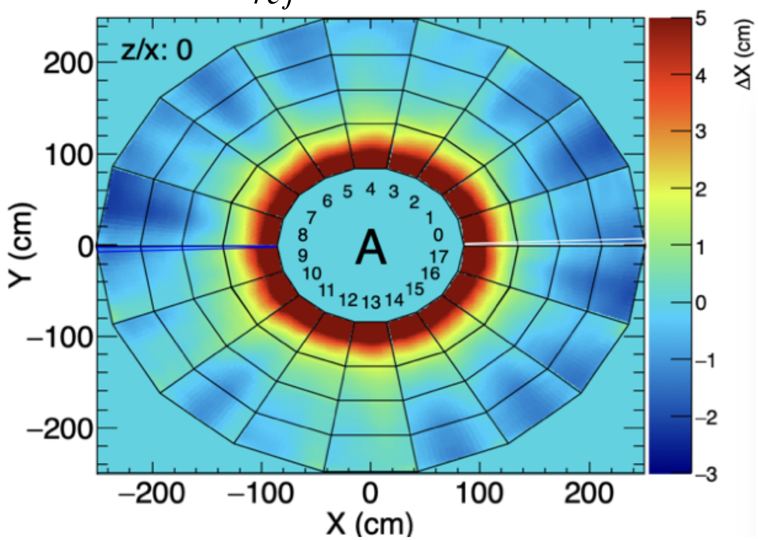


IR Dependence, Differential Scaling

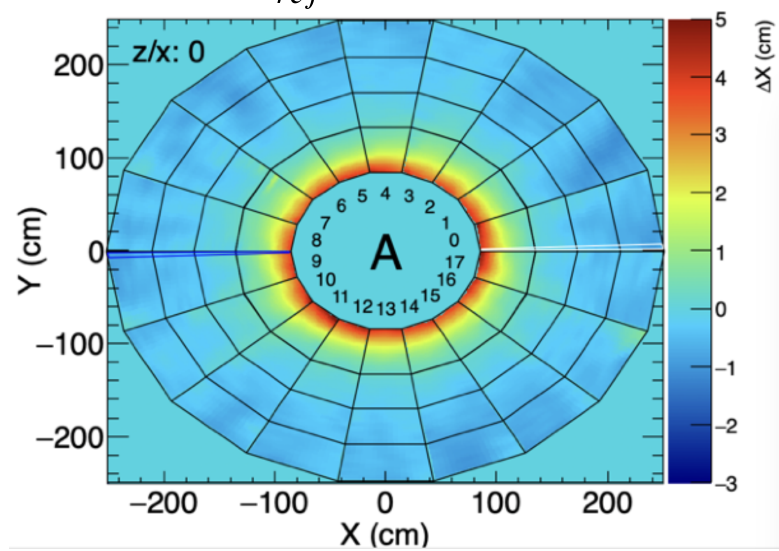
- $M_{corr}(IR) = M_{ref}(IR_{ref}) + \Delta M^{\pm}_{ref}/\Delta IR^{\pm}_{ref} \cdot (IR - IR_{ref})$
- M_{ref}: long-term-average reference map at *high IR* L_{ref}
- $\Delta M^{\pm}_{ref}$: *derivative map,* difference between two maps at slightly different interaction rates around *IR*
- Improved scaling behaviour
- IR variations from ZDC or *Integrated Digital Currents* (IDCs)



M_{ref} (Pb-Pb @ 39 kHz)

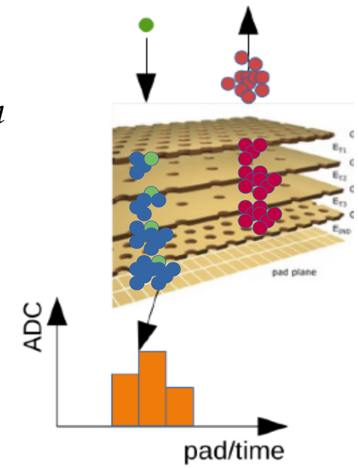


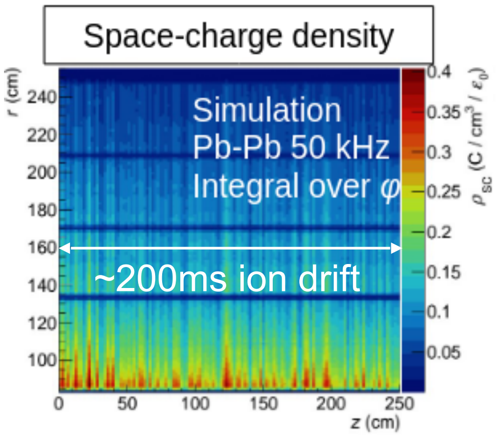
$\Delta M^{\pm}_{ref}$ (39 kHz-29kHz)

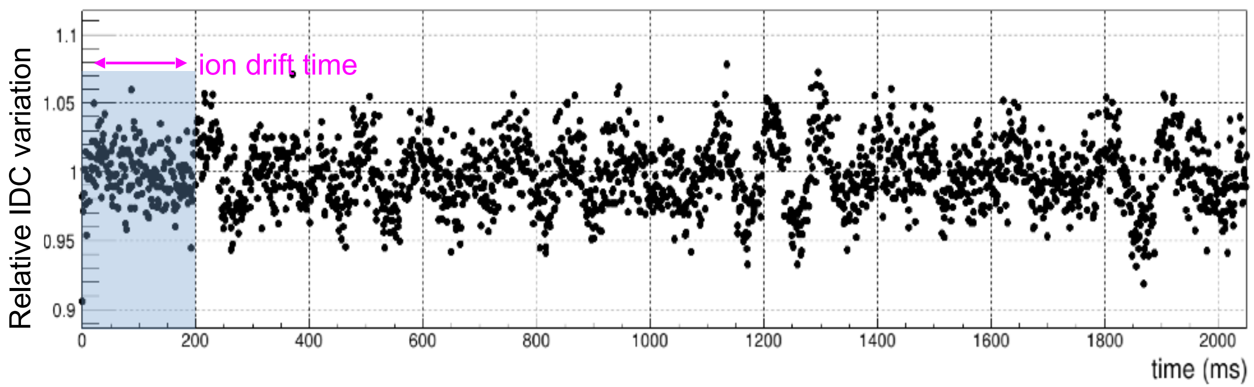


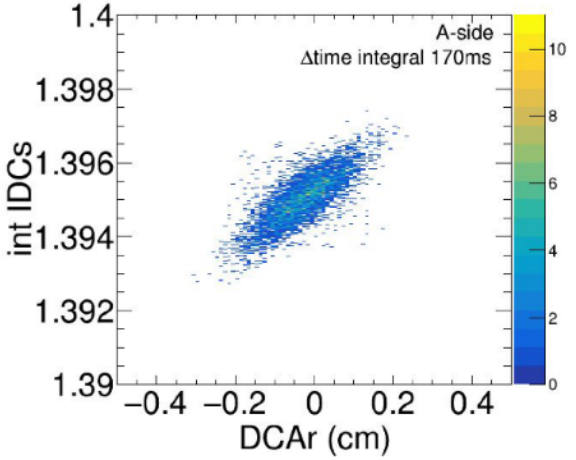
Integrated Digital Currents

- *IDCs* – the ultimate measure for SC variations and fluctuations:
  - *Pad-by-pad ADC values integrated over 1 ms inside the CRU, injected in data stream*
- SC density related to IDC via IBF
  - $\rho_{SC} \sim I_{prim} \bullet gain \bullet IBF$
  - $IDC \sim I_{prim} \bullet gain$
- Relevant for ρ_{SC} fluctuations: *IDC* history over typical *ion drift time* (200ms)

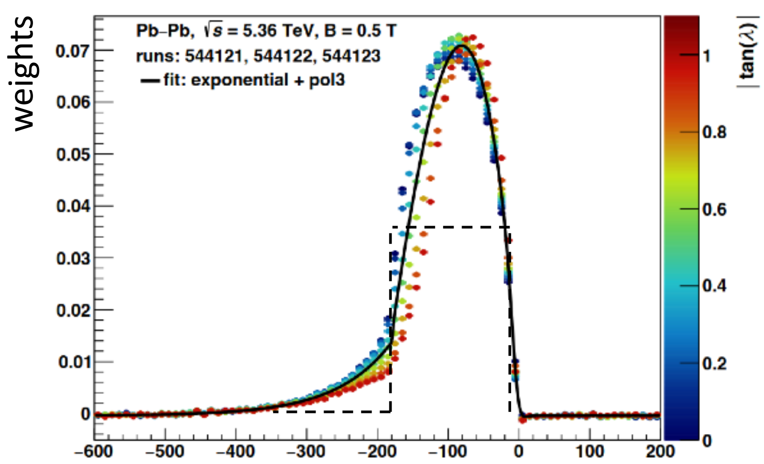


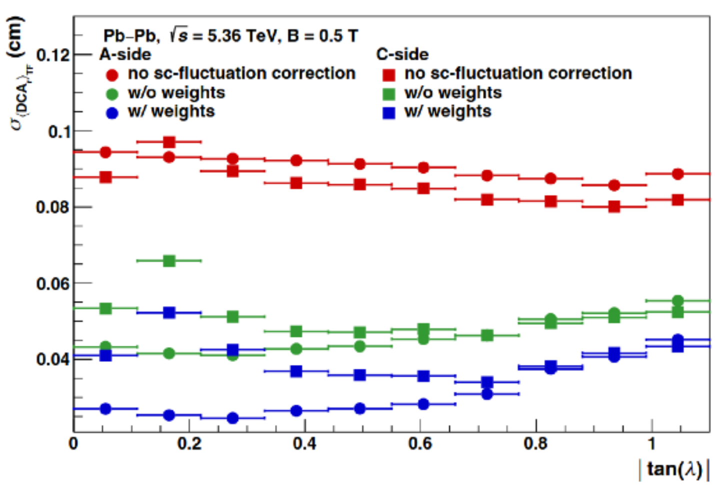




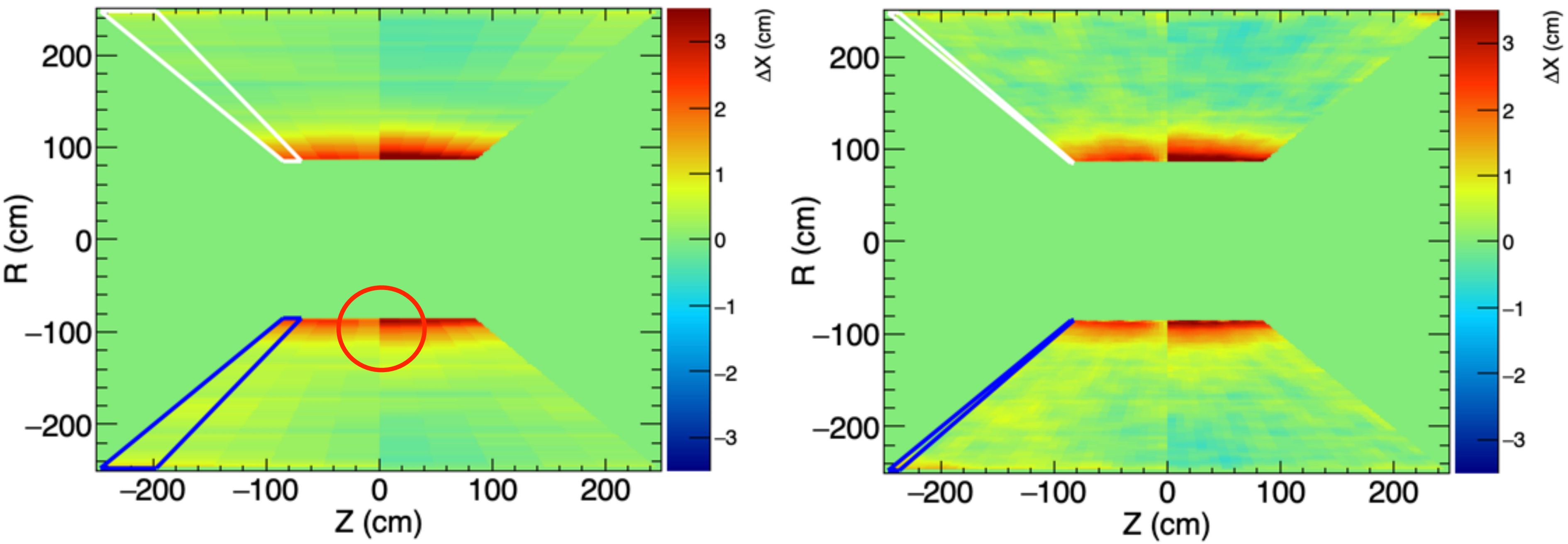


- Not all ions from the past 200 ms contribute equally to the distortions
- Δt – dependent weights developed based on correlation with observed distortions (DCA_r)
- Significant improvement compared to flat weight





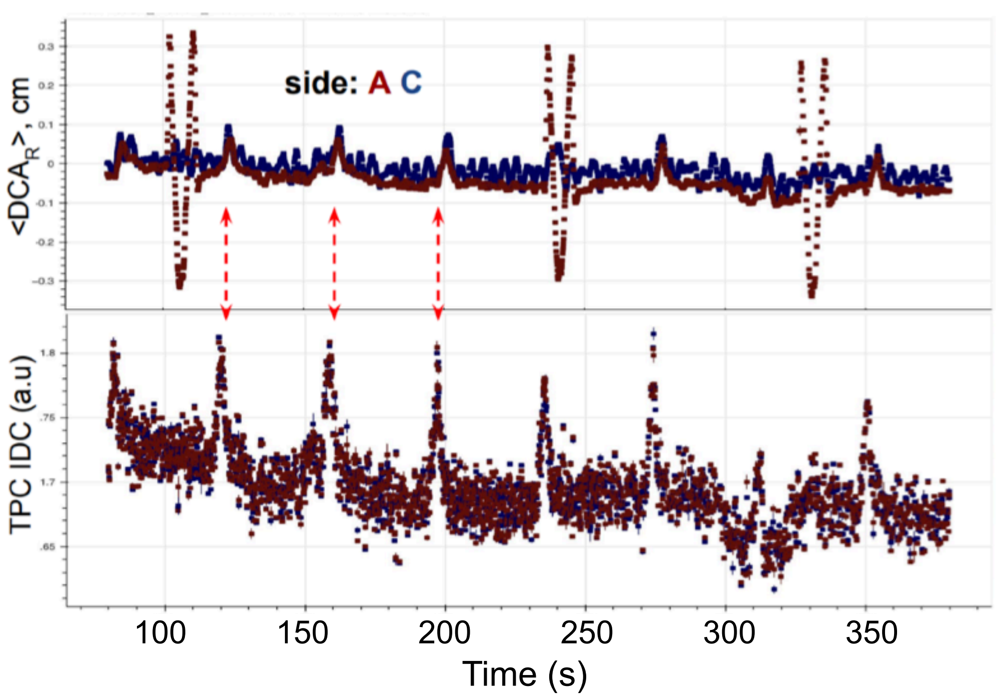
Map Granularity



- Standard setting so far: 36 sectors, 15 bins in Y, 152 in X, 5 in Z: 410400 voxels
- Now: Increase in Z from 5 to 20 (tested up to 25), 20 in Y (tested up to 30)
- Especially at the central electrode we need a higher granularity to follow the gradients.
- Future: Non-equidistant binning!

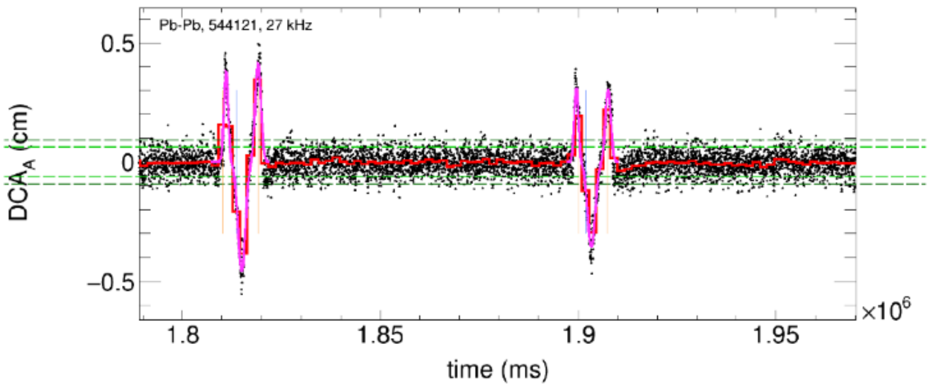
Hardware Related Effects

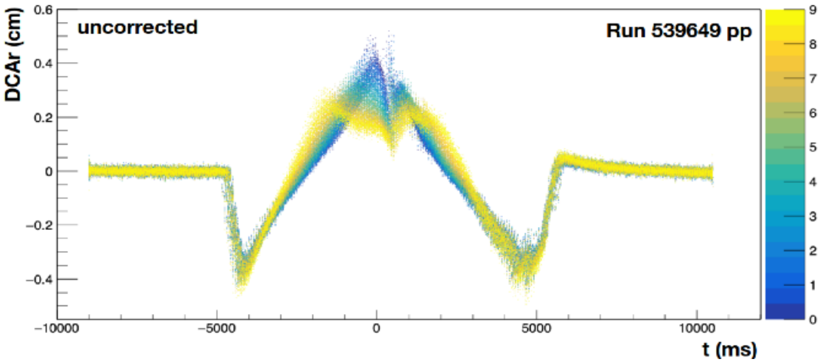
M-Shape Distortions

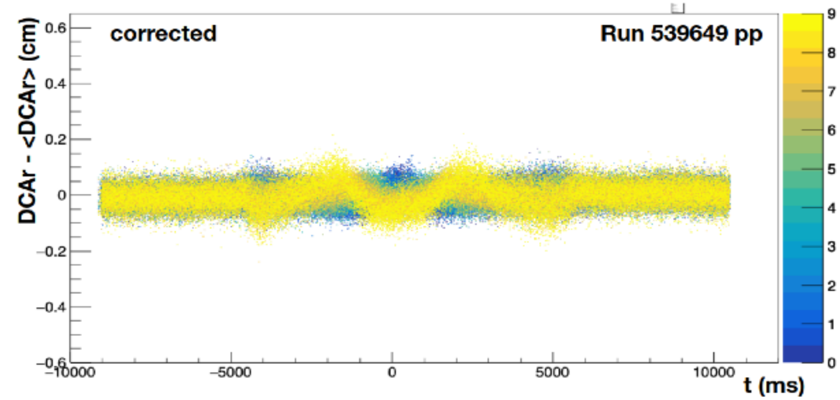


- In general, very good correspondence between observed distortions and IDCs
  - Ideal tool to correct for SC fluctuations
- Additional M-shaped distortion patterns observed with no correspondence to IDCs
  - Origin is not space charge
  - Magnitude larger than typical SCD
  - Duration O(10s)
  - Only on the A-side
  - Frequency changes but not related to IR

M-Shape Correction



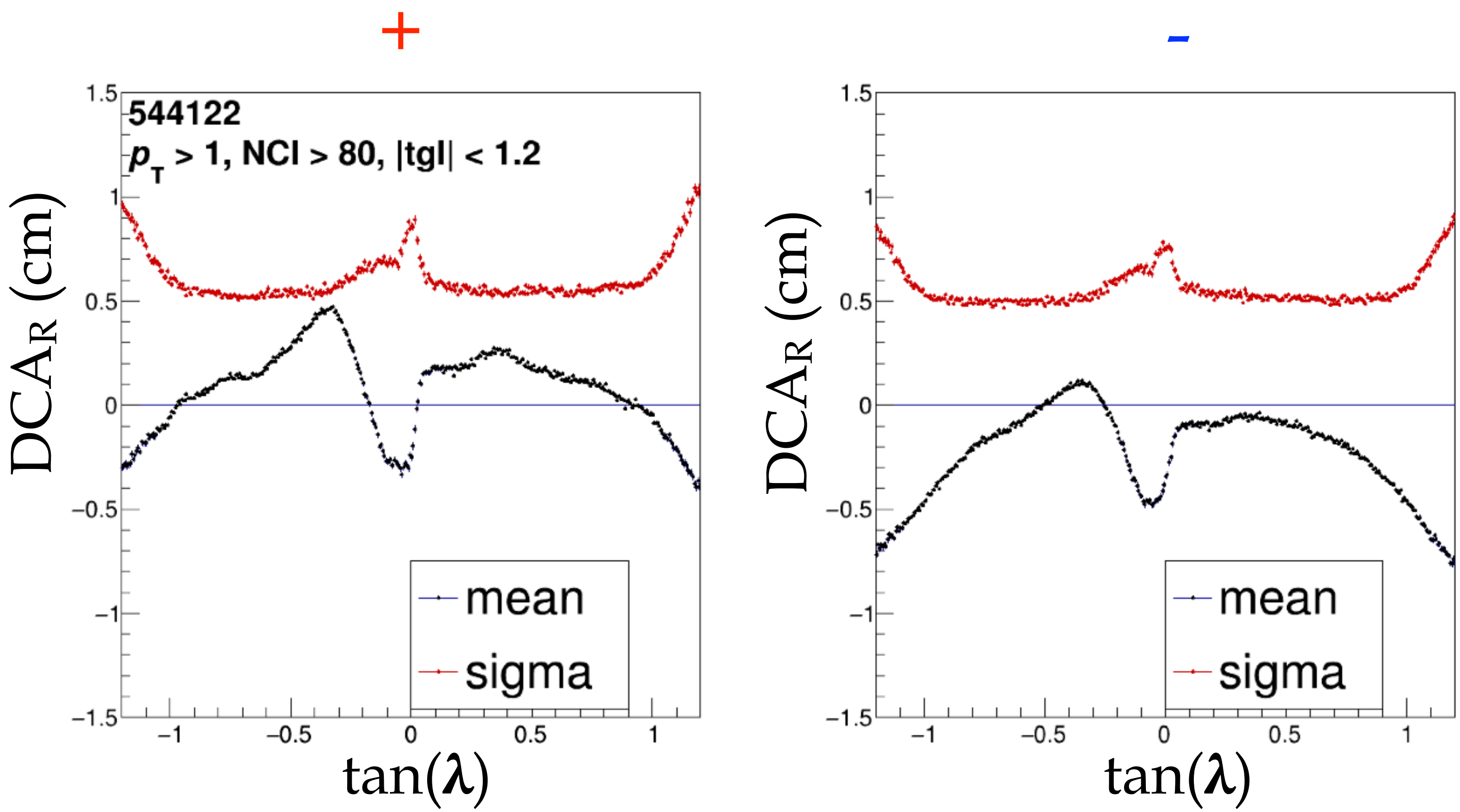




- M-shaped excursions detected in full data set
- Correction implemented based on parametric model of field cage boundary condition variations
- Added to SCD maps.
- Origin is a leak in one of the field cage resistor rod cooling circuits
- Cooling water removed during YETS – solved

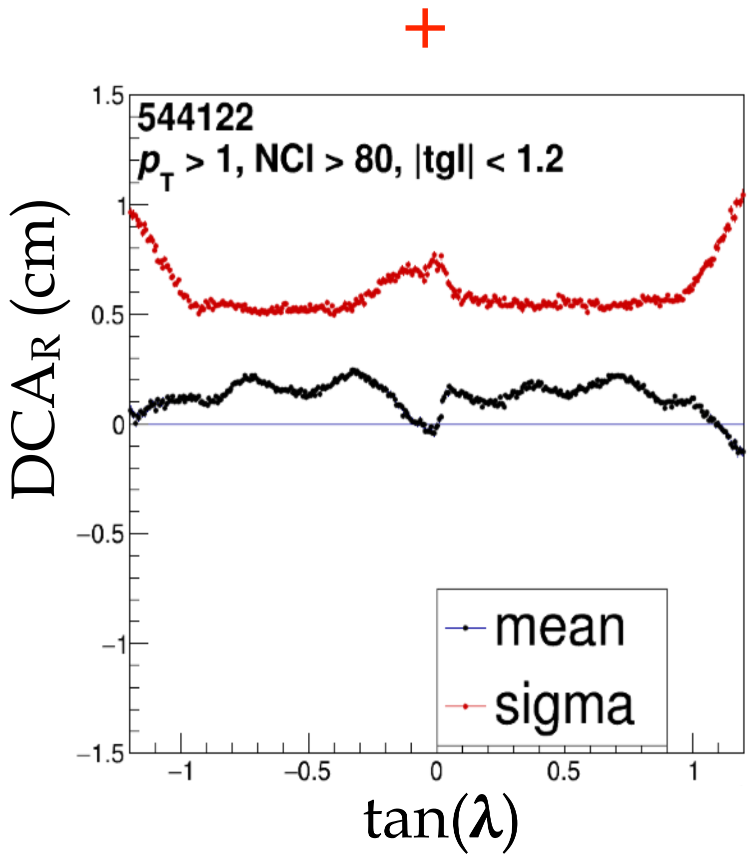
Performance

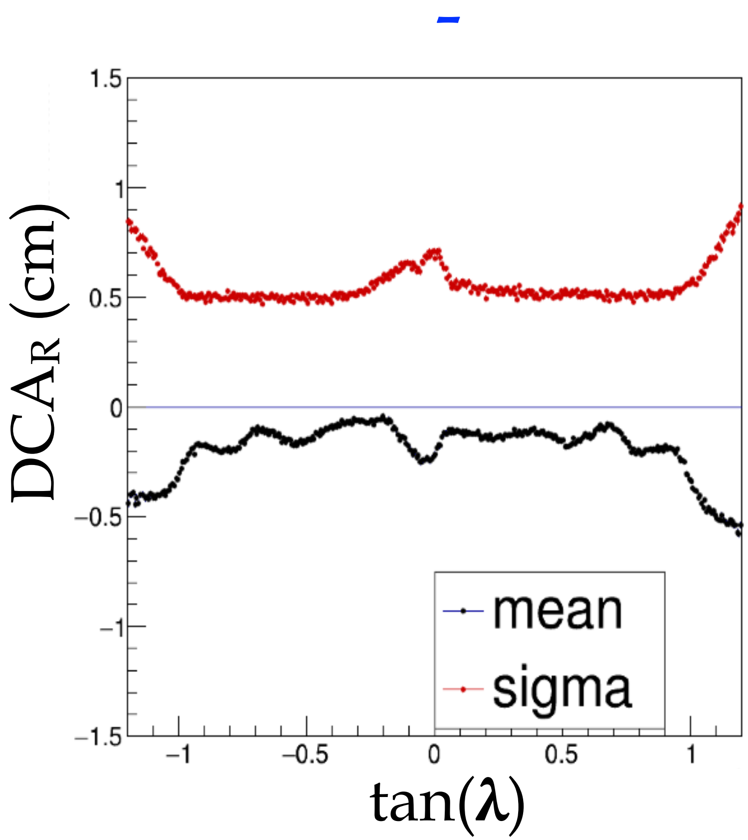
544122, NY=15, NZ=5



- 15kHz Pb-Pb
- Standard binning for voxel map
- TPC only tracks!

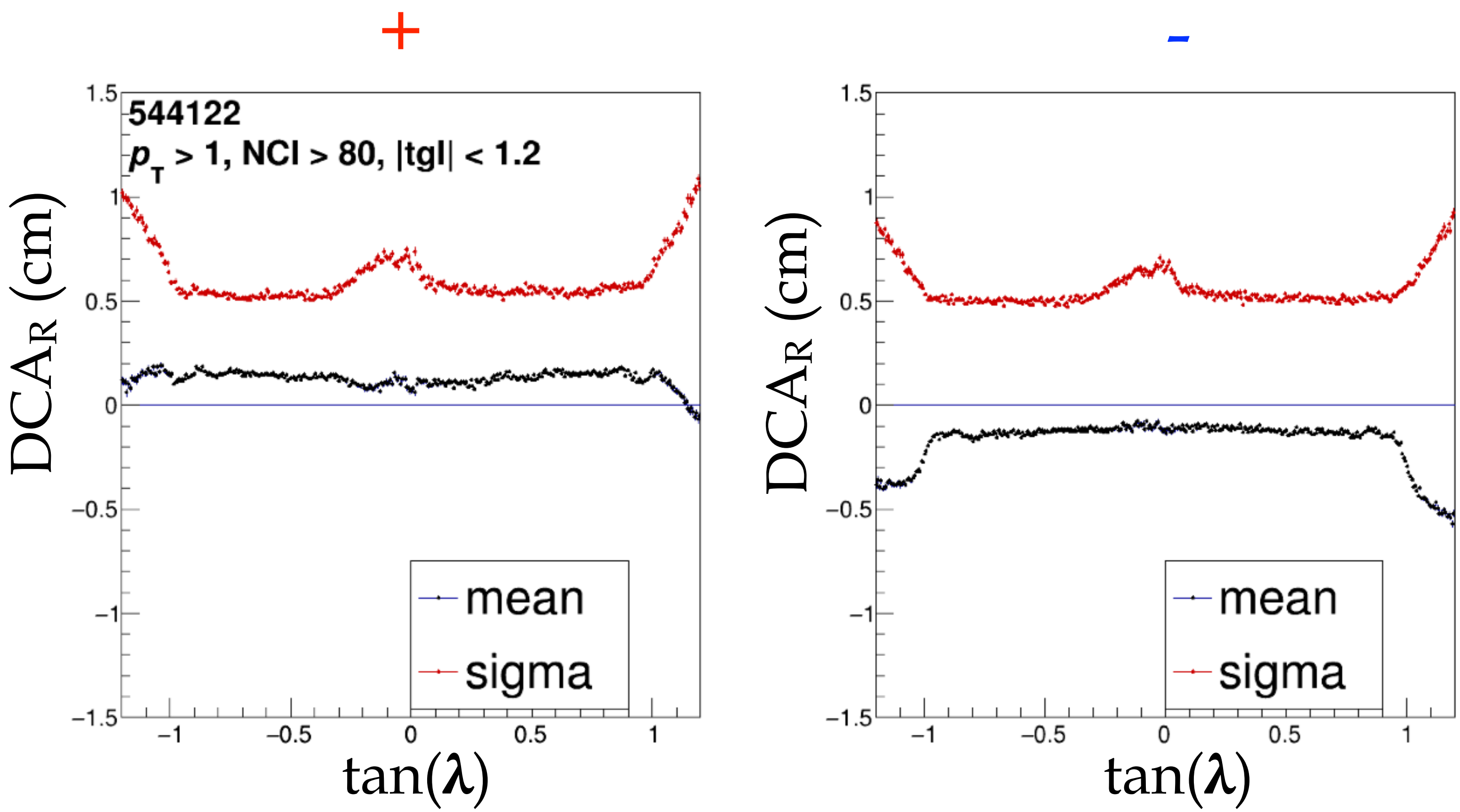
544122, NY=15, NZ=10





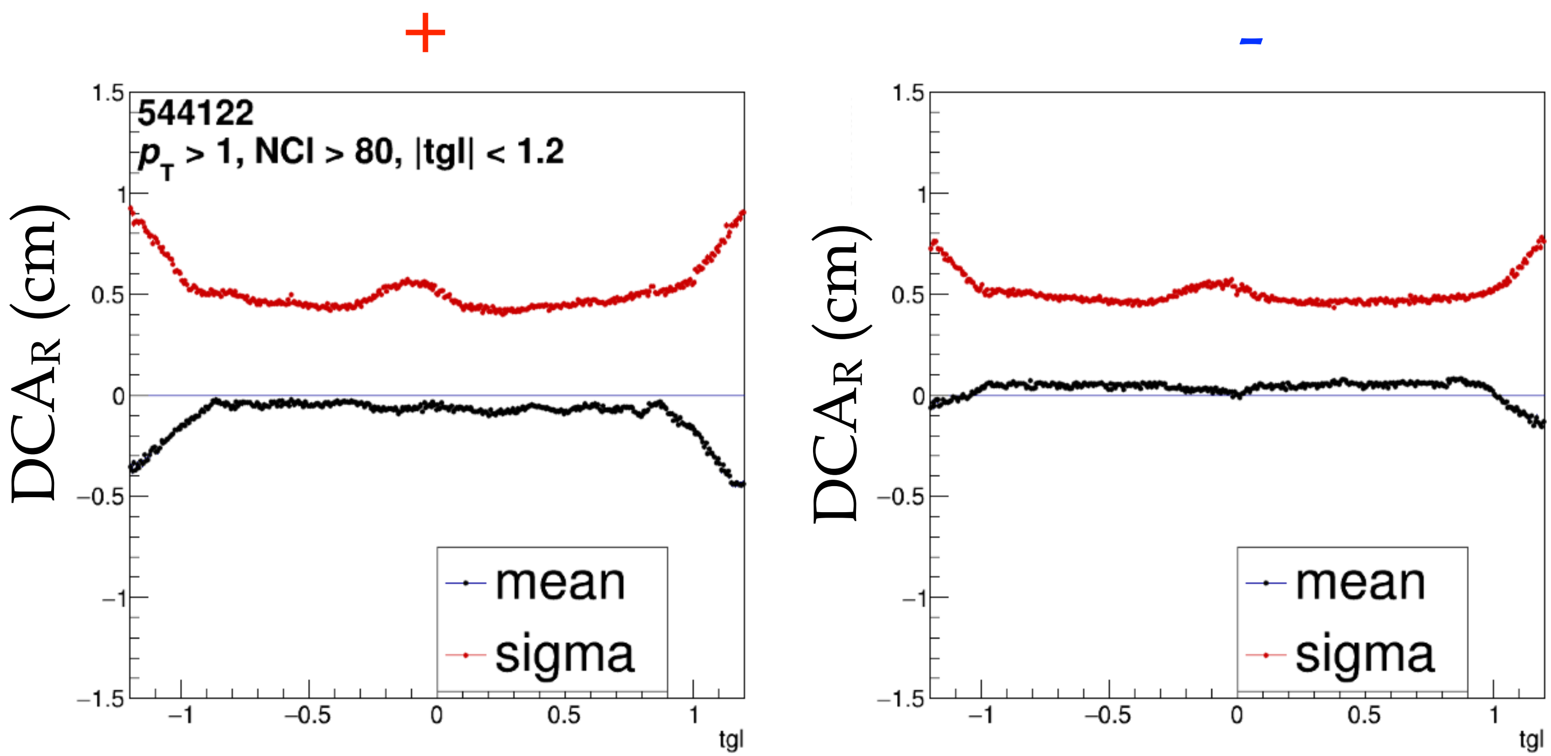
- 15kHz Pb-Pb
- Double number of bins on z-axis

544122, itt, NY=15, NZ=20



- 15kHz Pb-Pb
- Four times number of bins on z-axis
- Iteration method used

15kHz Pb-Pb, Development Approach

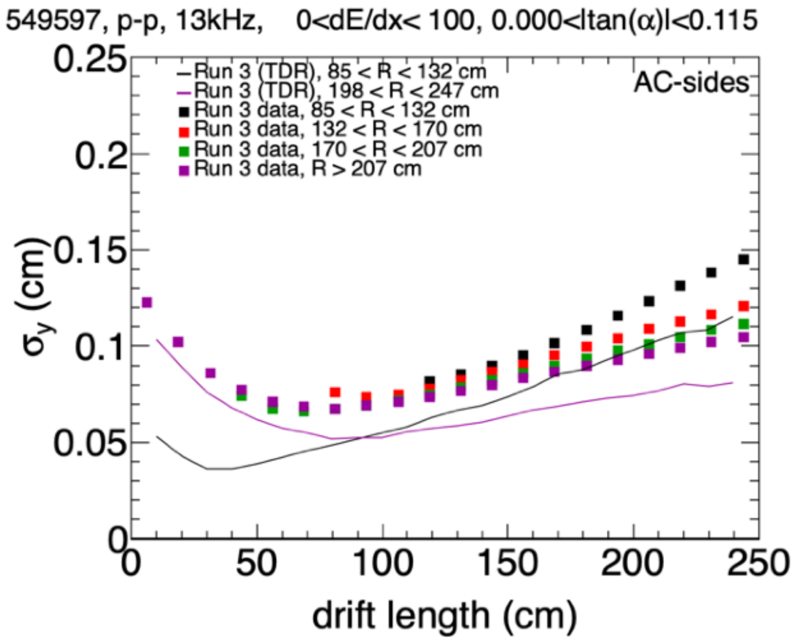


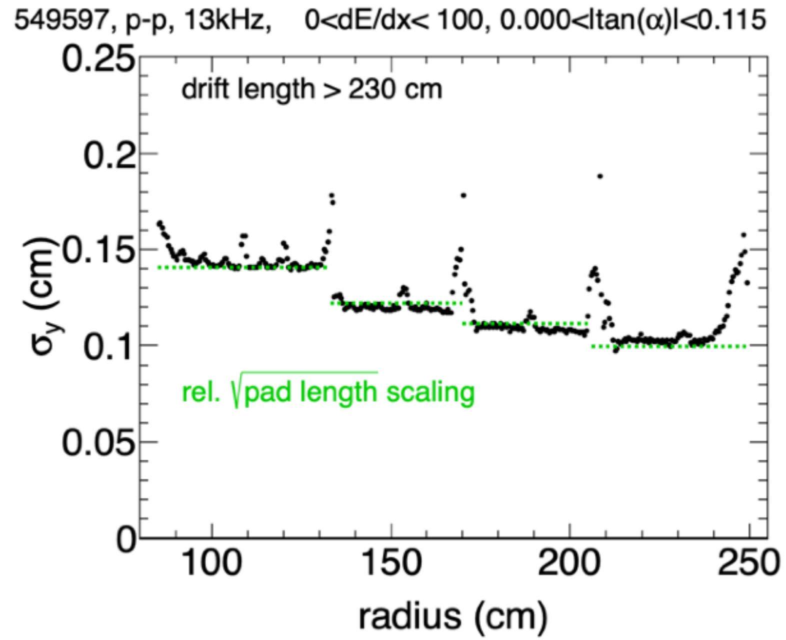
tan(λ)

- 15kHz Pb-Pb.
- 30 bins in y, 20 bins in z.
- Best performance in mean and sigma so far.
- Further tests ongoing.

TPC Intrinsic Resolution

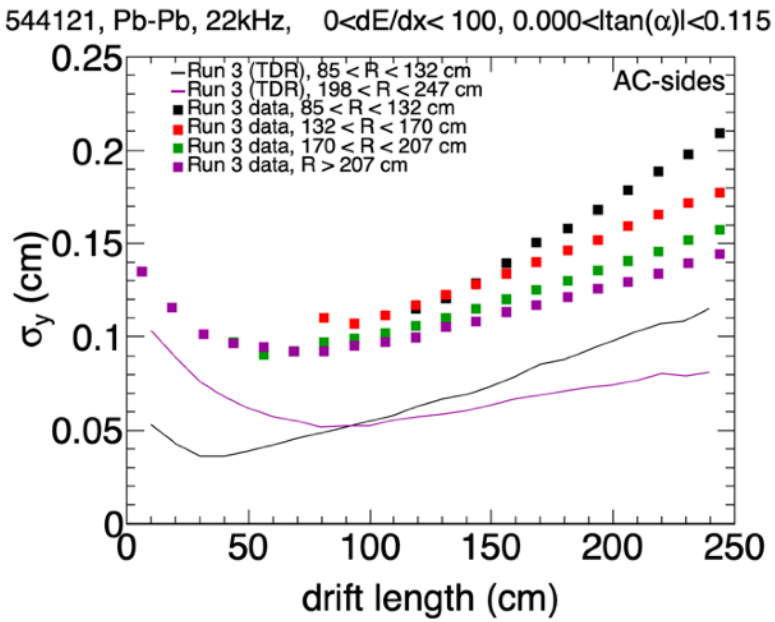
Intrinsic TPC Resolution

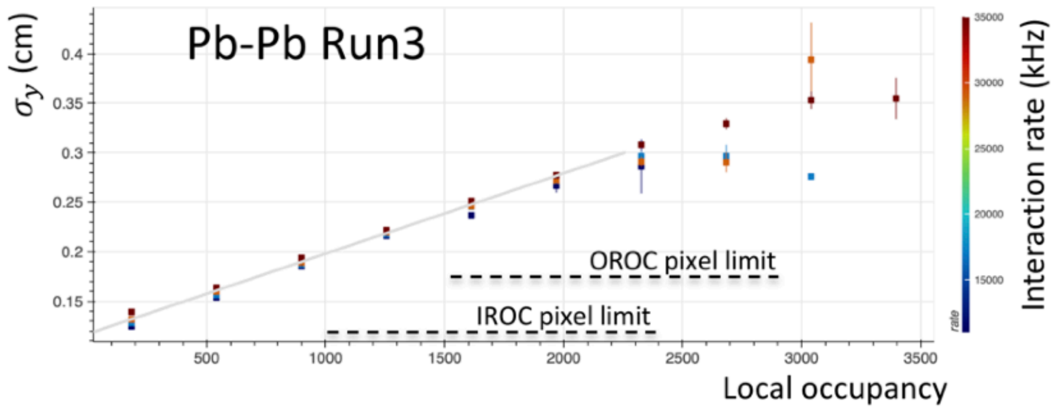




- Very low IR p-p → low occupancy → mainly TPC intrinsic effects.
- At low drift length we have a significant fraction of one pad clusters.
- At larger drift length multi-pad clusters dominate.
- **Data is in agreement with TDR calculations** (modulo known factor √2 due to lower electron transparency).

Pb-Pb Space Point Resolution





- Does not depend on IR → no space charge distortion effect!
- Dominated by local occupancy effects.

Summary

Summary:

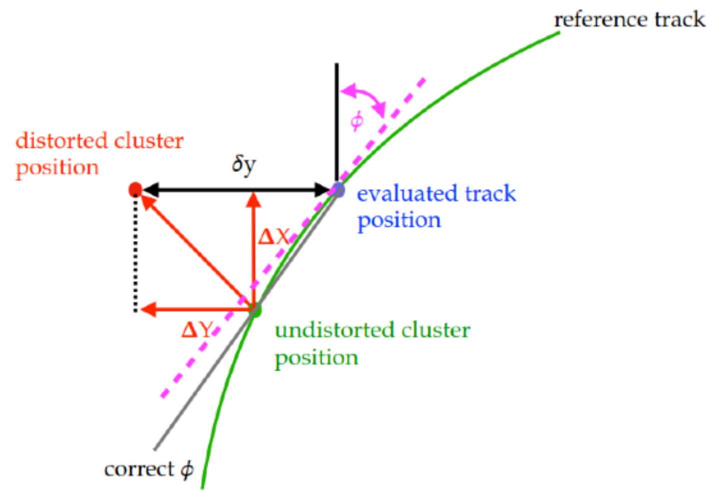
- Space charge distortions are as expected in terms of magnitude and fluctuations.
- Space charge distortion calibration is right now limited by precisions of external detectors.
- TPC intrinsic resolution as expected! Occupancy dependence is dominating the resolution (clusterization + tracking).

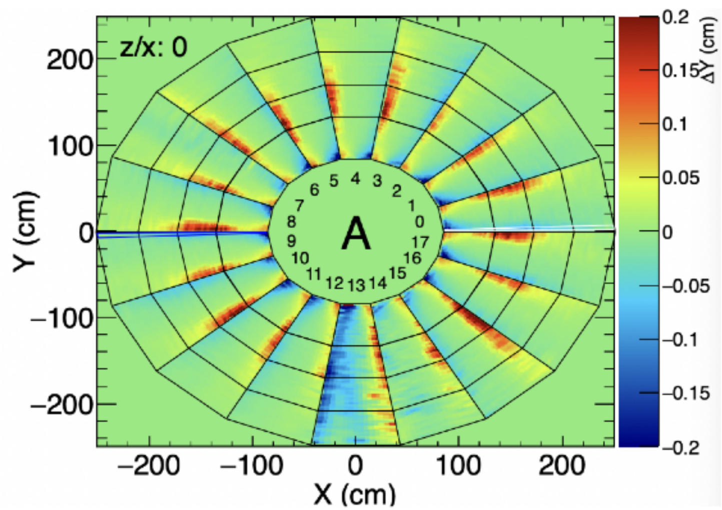
Backup

Iterative Procedure for Residual Extraction

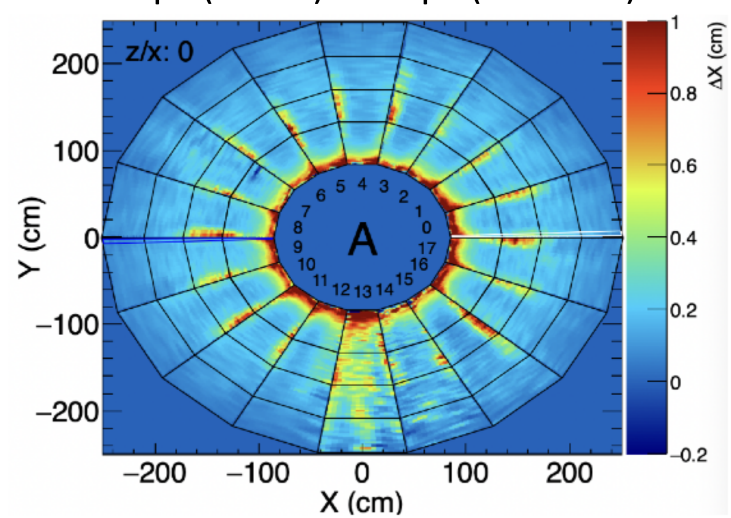
Improvement:

- Take track curvature into account for distortion extraction
- Sizeable differences as compared to map from linear track approximation
- Impact on reconstruction performance under investigation
- Alternative approach is being developed

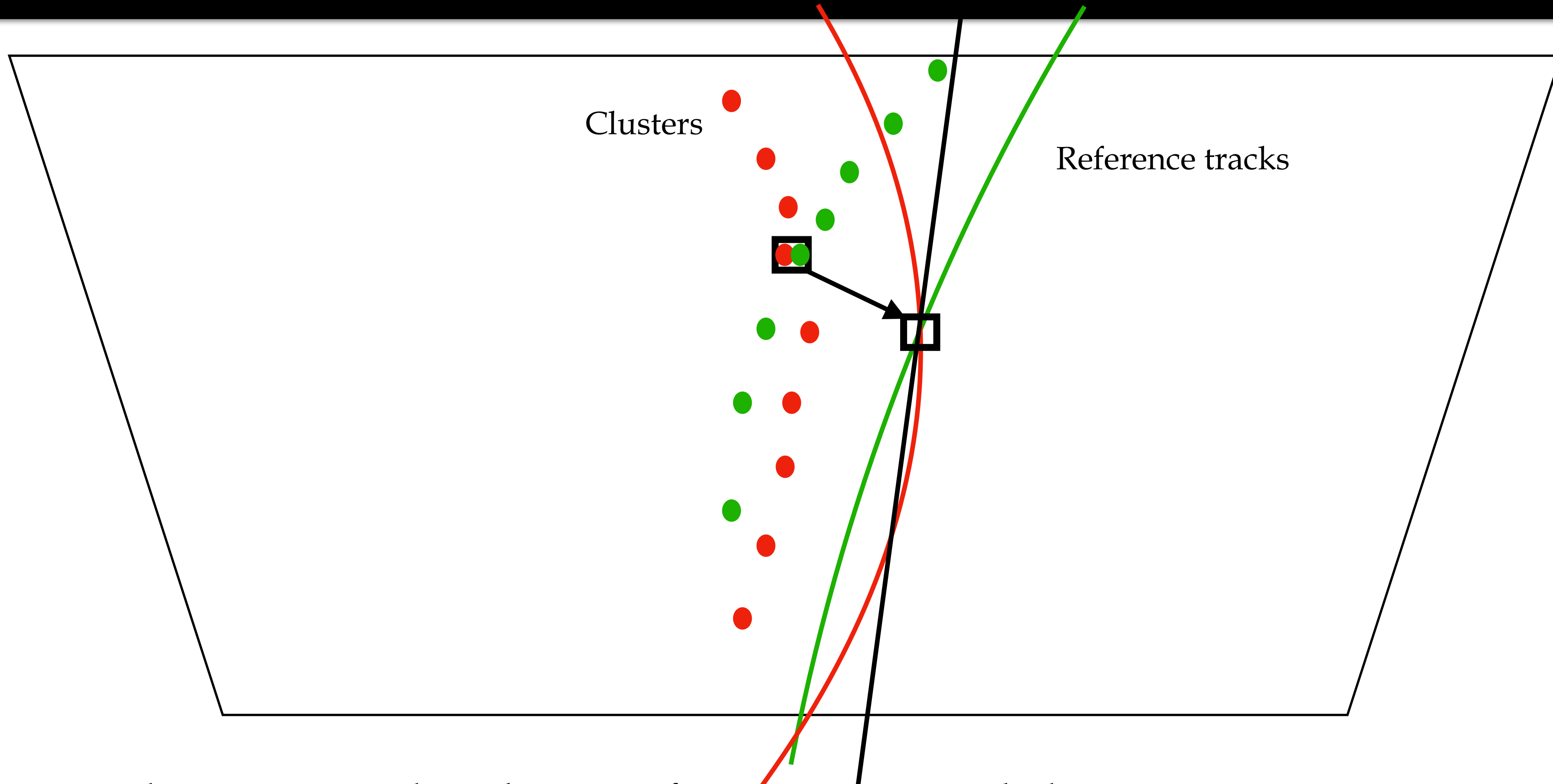




maps (linear) – maps (iterative)



Alternative Approach for Residuals



- Select one voxel in the TPC for reconstructed clusters.
- Calculate circle in x-y plane for matched reference tracks close to selected voxel.
- Shift circle by the difference between cluster position and voxel center.
- Calculate crossing points for + and - tracks (circles).