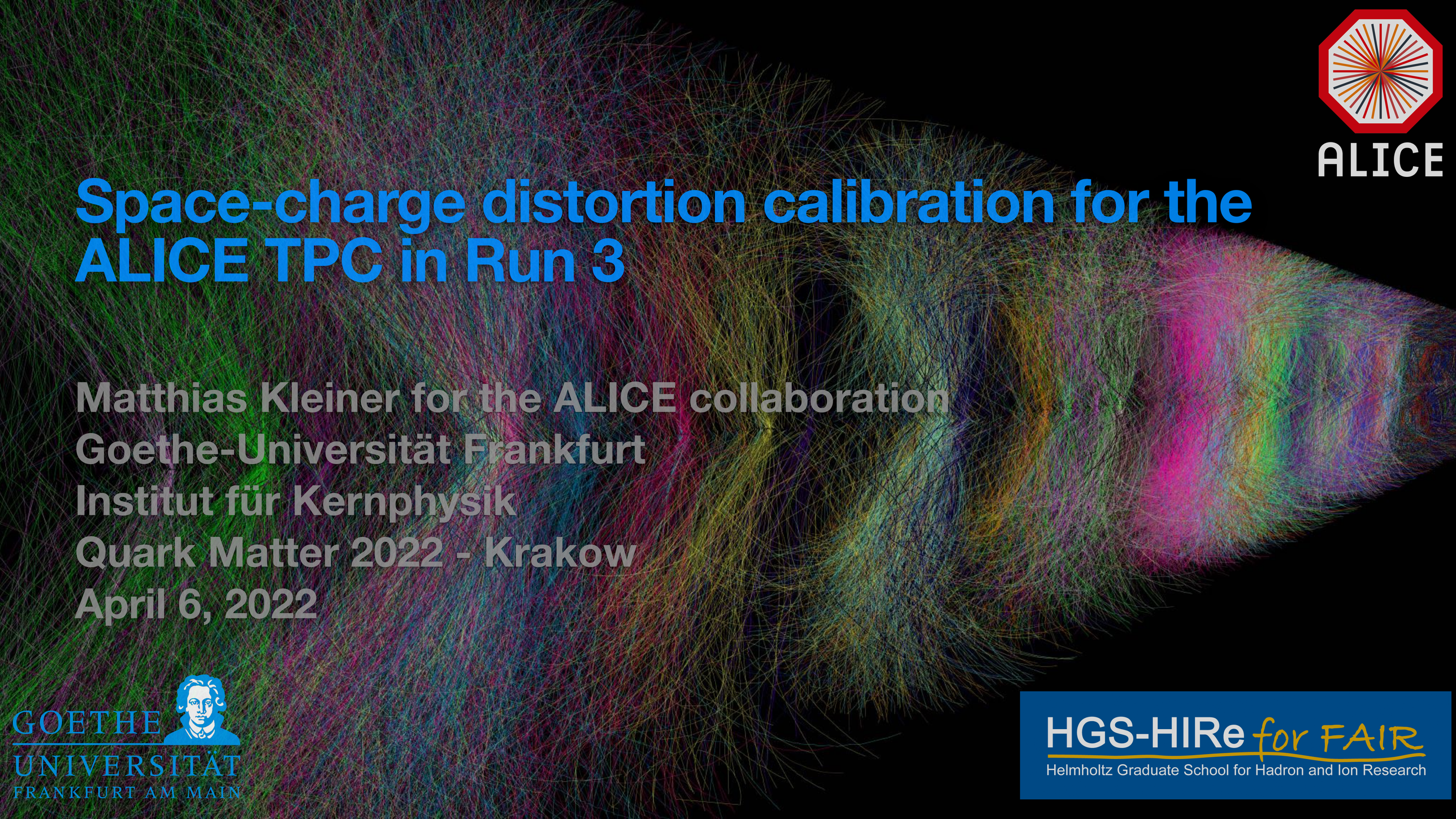


Space-charge distortion calibration for the ALICE TPC in Run 3

Matthias Kleiner for the ALICE collaboration
Goethe-Universität Frankfurt
Institut für Kernphysik
Quark Matter 2022 - Krakow
April 6, 2022

Motivation

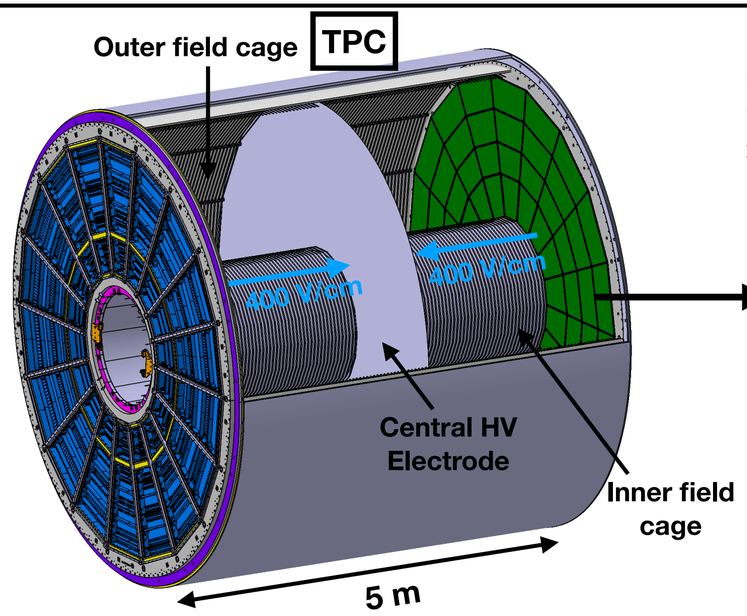
ALICE Time Projection Chamber (TPC)

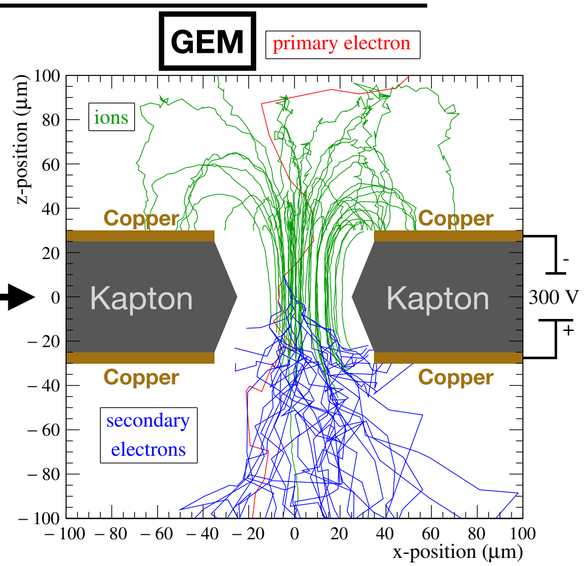
Detection

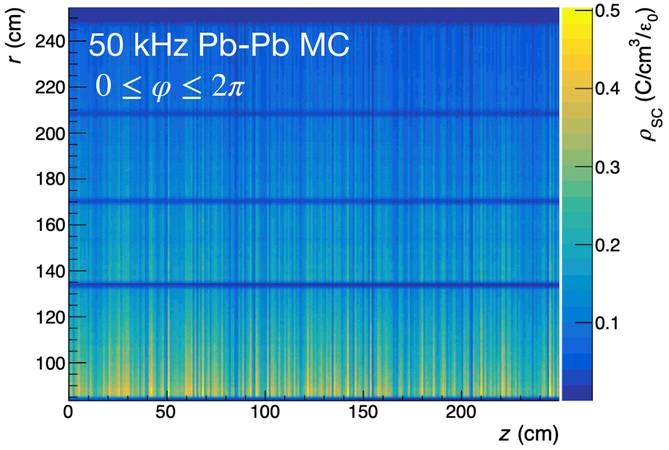
- Multiplication of primary electrons
- TPC Upgrade: Stacks of four Gas Electron Multipliers (GEM)
  - ➡ See: Technical Design Report

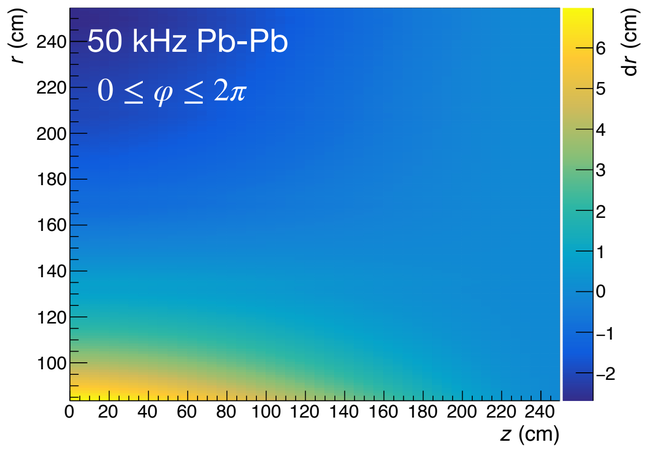
Ion backflow (IBF)

- Ions from amplification enter drift volume
- Slow drift velocity compared to electrons
  - ➡ Ions from *n* events piling up in the volume
  - ➡ Space-charge density ρ_{SC}
  - ➡ Distortion of electron drift path in r, φ, z
  - ➡ Distortion correction: $\mathrm{d}r_{max} \approx 10\,\mathrm{cm} \rightarrow 200\,\mu\mathrm{m}$









Space-charge density fluctuations

Space-charge density dependencies

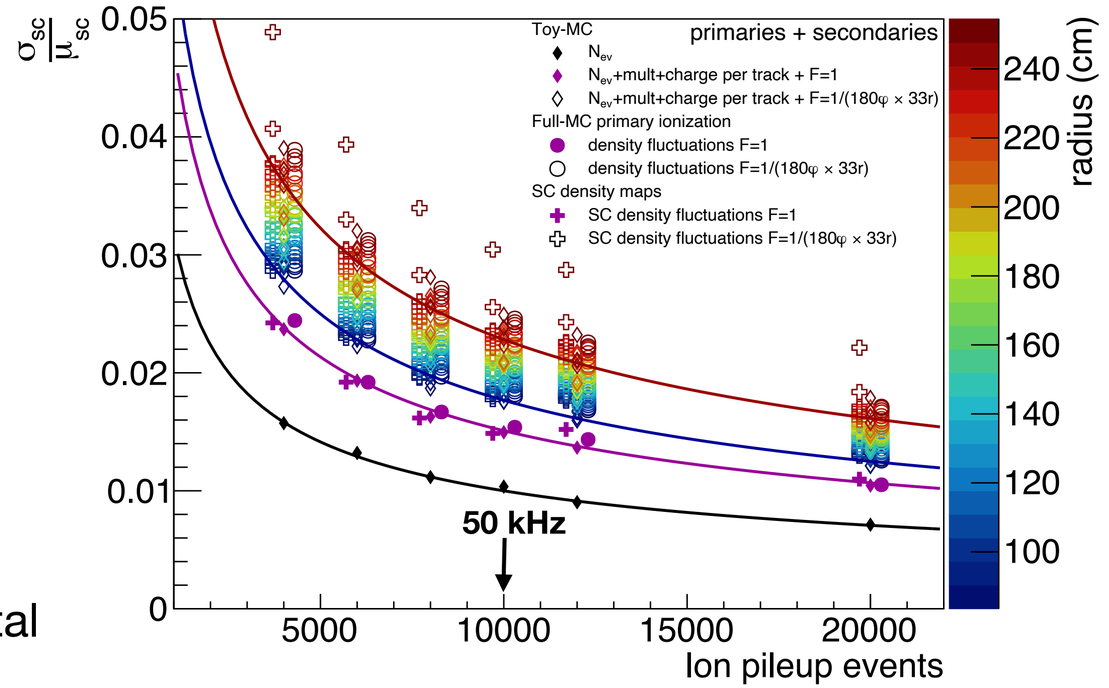
1. Number of ion pile-up events (Poisson distribution)
2. Primary + secondary track multiplicity per event
3. Number of tracks per volume element
4. Energy loss per track

- Analytical formula agrees well with fluctuations from MC
- Fluctuations of ~2% expected at 50 kHz Pb-Pb

➡ Distortion fluctuations $\left(\mathcal{O}(\text{mm} - \text{cm})\right)$

➡ Correction on time scales of $5\text{ms} - 10\text{ms}$

➡ Approximation of density fluctuations with integrated digital currents (IDCs) required for correction procedures



$$\frac{\sigma_{sc}}{\mu_{sc}} = \underbrace{\frac{1}{\sqrt{N^{ion}_{pileup}}}}_{1} \sqrt{1 + \underbrace{\left(\frac{\sigma_{N_{mult,prim}}}{\mu_{N_{mult,prim}}}\right)^2 + \left(\frac{\sigma_{N_{mult,relsec}}}{\mu_{N_{mult,relsec}}}\right)^2}_{2} + \frac{1}{\left(F_{prim}(r) \cdot \mu_{N_{mult,prim}} + F_{sec}(r) \cdot \mu_{N_{mult,sec}}\right)} \underbrace{\left[1 + \left(\frac{\sigma_{Q_{track,prim}}(r)}{\mu_{Q_{track,prim}}(r)}\right)^2 + \left(\frac{\sigma_{Q_{track,sec}}(r)}{\mu_{Q_{track,sec}}(r)}\right)^2\right]}_{3\ \ 4}}$$

Integrated digital currents (IDCs)

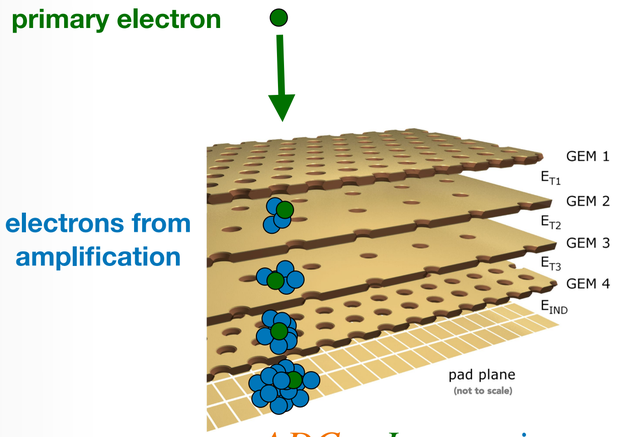
- Integration of *ADC* values over ~1ms
- $ADC \propto I_{prim} \cdot gain$
- $\rho_{SC} \propto I_{prim} \cdot gain \cdot IBF$
- Estimate for space-charge density fluctuations
- IDCs to be used for
    1. Input for corrections of distortions
    2. QA of detector

Storage in the CCDB

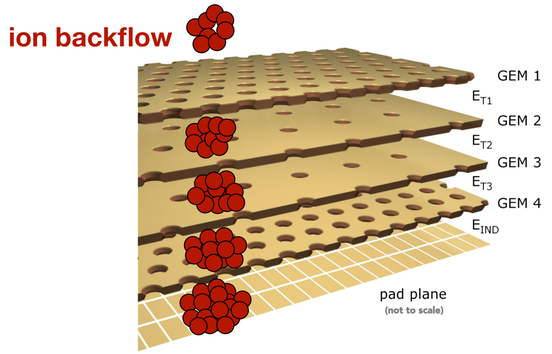
- Data reduction (1 GB/s → 46 MB/s)
    1. Factorisation of IDCs

$$I(r,\varphi,t) = I_0(r,\varphi) \cdot I_1(t) \cdot \Delta I(r,\varphi,t)$$
$$I_0(r,\varphi) = \langle I(r,\varphi,t) \rangle_t$$
$$I_1(t) = \langle I(r,\varphi,t)/I_0(r,\varphi) \rangle_{r,\varphi}$$
$$\Delta I(r,\varphi,t) = I(r,\varphi,t)/\left(I_0(r,\varphi) \cdot I_1(t)\right)$$

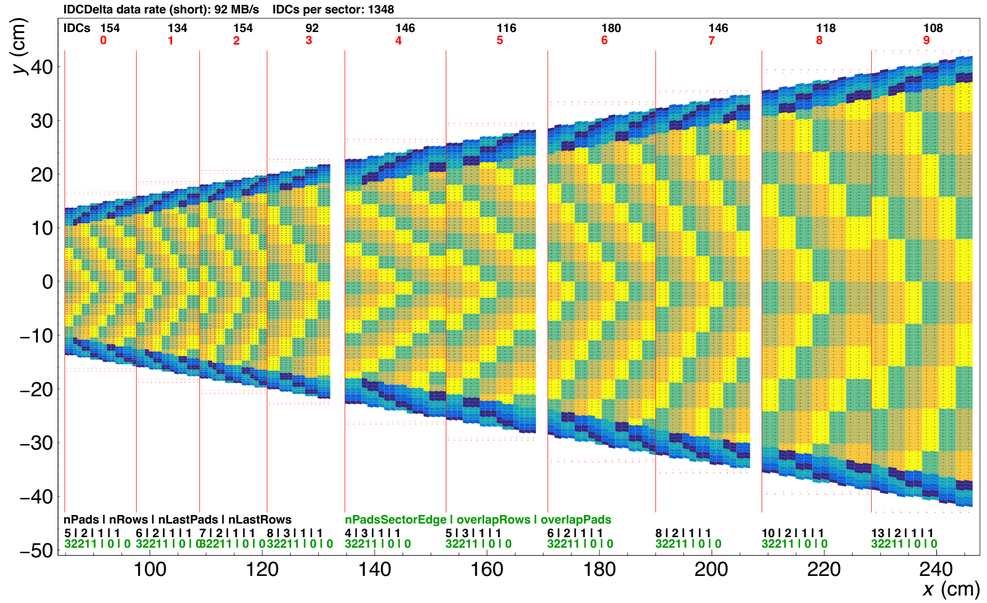
    2. Averaging + compression (char) of $\Delta I(r,\varphi,t)$



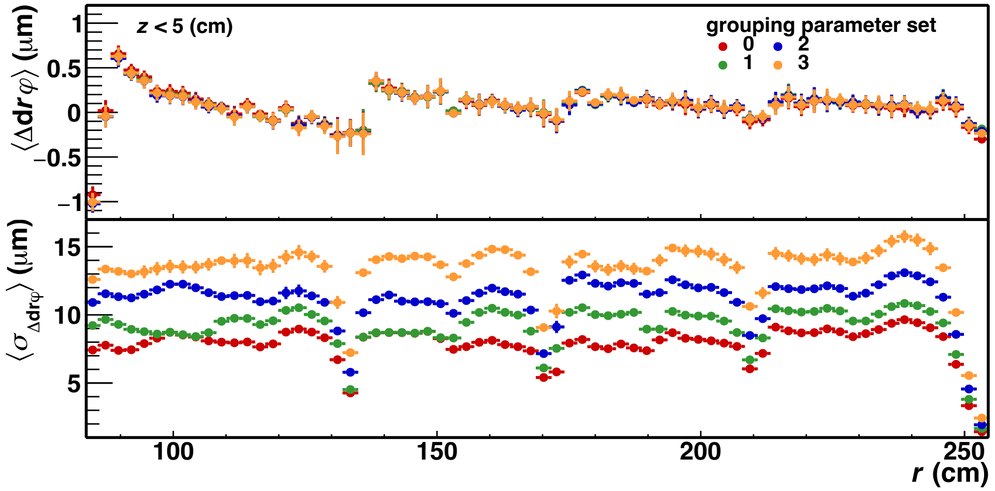
$$\rho_{SC} \propto I_{prim} \cdot gain \cdot IBF$$

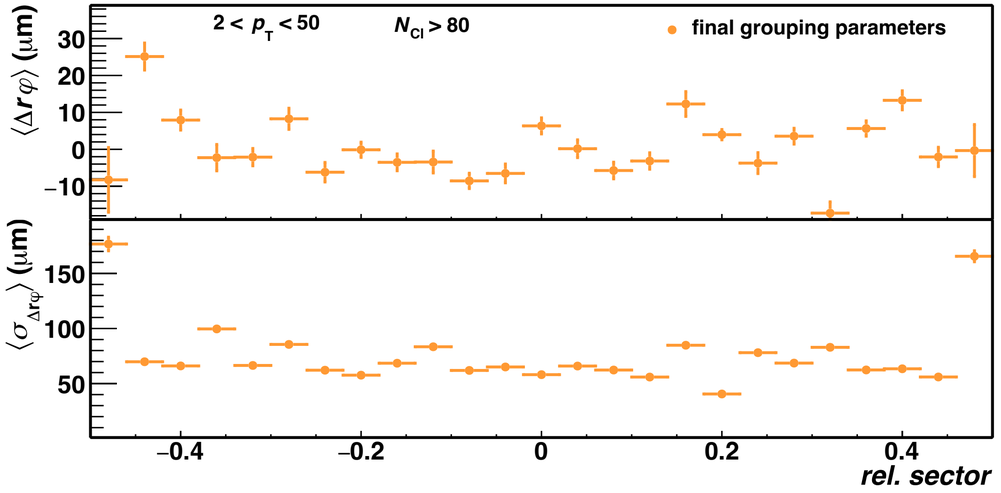


$$ADC \propto I_{prim} \cdot gain$$



IDCs optimisation

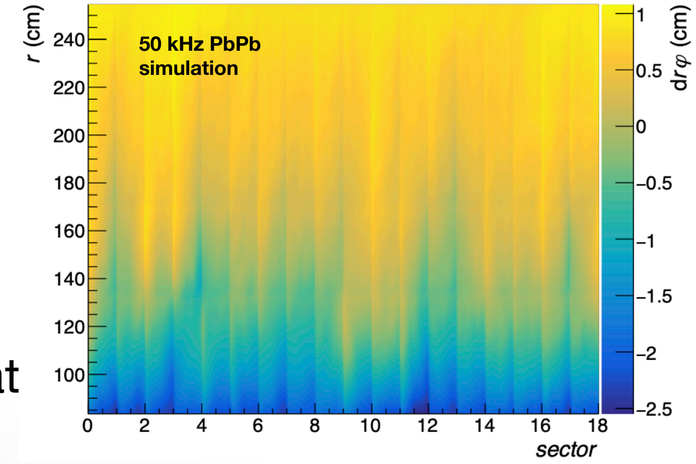




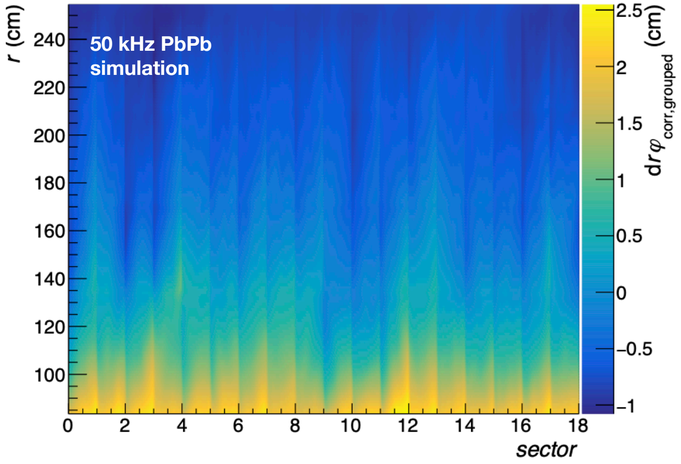
Grouping studies of IDCs

- Comparison of reference distortions with corrections after grouping
- Optimisation of the grouping parameters
  - ➡ Visualisation using RootInteractive
  - ➡ Radial dependency of grouping
  - ➡ Flat $\sigma_{\Delta dr\varphi}$ as a function of radius
  - ➡ Minimisation of track parameter residuals at sector edges

reference space-charge distortions



grouped space-charge corrections



Space-charge distortion calibration

Synchronous reconstruction	Asynchronous reconstruction
Online processing of data	Offline processing of data
Detector calibration and data compression	Generation of final reconstruction output
Correction of average distortions (calibration interval: $\mathcal{O}$(min))	
Maps from previous calibration intervals	Correction map extracted from data
Distortion-fluctuation correction (calibration interval: (5-10 ms))	
1D ➔ 3D	1D ➔ 3D for pp (200 kHz - 1000 kHz) 3D ➔ 3D for Pb-Pb
Precision of calibration	
$\mathcal{O}$(mm): tracking	200 μm: intrinsic TPC resolution

1D→3D distortion-fluctuation correction

- Input
  - ➡ Numerical derivatives of the average correction at r, φ, z
  - ➡ Fourier coefficients c_k of 1D-IDCs
- Output
  - ➡ Correction of 1D distortion-fluctuations