Data-driven and ML-based approaches for the ALICE TPC space-charge distortion corrections

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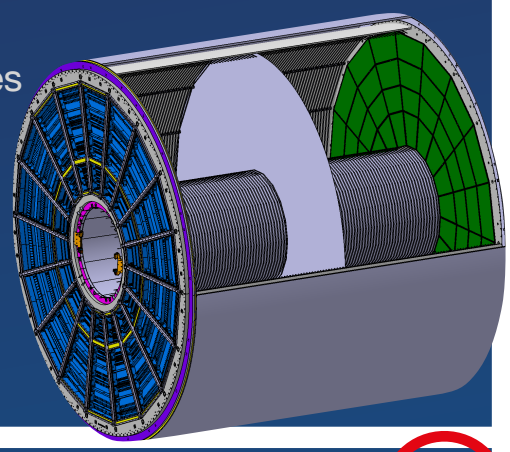
ALICE

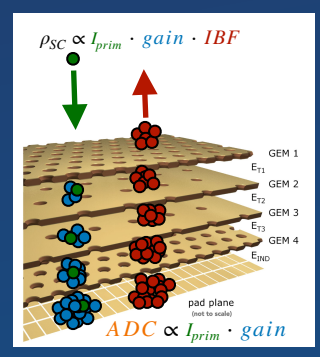
1 ALICE Time Projection Chamber

- Main tracking detector
- Identification of charged particles
- Volume ≈ 90 m^3
- Uniform drift field of 400 V/cm
- Ne-CO_2-N_2 (90-10-5)

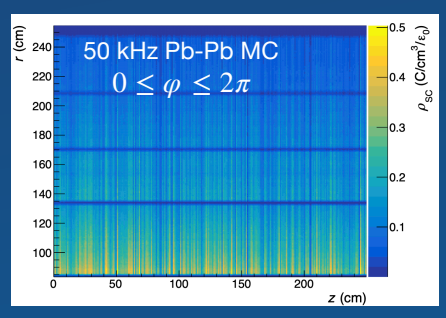


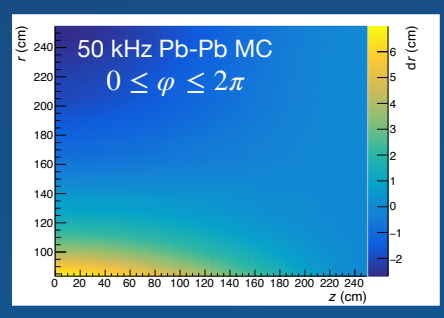
2 TPC readout system TPC Upgrade

TPC upgrade
- Stacks of four Gas Electron Multiplier (GEM) foils
- Continuous read out



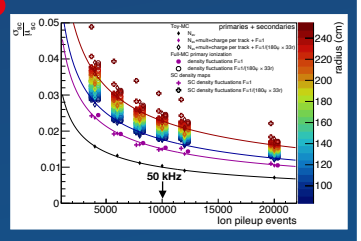
Ion backflow
- Suppression to ~1%
- Ions from $N^{ion}_{pileup} = IR \cdot t_{Ion}$ events piling up in the volume
  - Space-charge density ρ_{SC}
- Distortion of electron drift path in r, φ, z
- Distortion correction: d$r_{max} \approx 10\,\text{cm} \rightarrow 200\,\mu\text{m}$





3 Space-charge density fluctuations

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



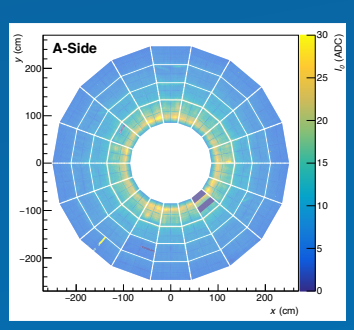
$$\frac{\sigma_{sc}}{\mu_{sc}} = \underbrace{\frac{1}{\sqrt{N^{ion}_{pileup}}}}_{1} \sqrt{1 + \underbrace{\left(\frac{\sigma_{N_{mult,prim}}}{\mu_{N_{mult,prim}}}\right)^2 + \left(\frac{\sigma_{N_{mult,relsec}}}{\mu_{N_{mult,relsec}}}\right)^2}_{2} + \frac{1}{\left(F_{prim}(r) \cdot \mu_{N_{mult,prim}}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

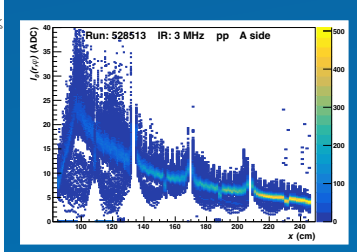
- Time scales of $5\text{ms} - 10\text{ms}$
- Approximation of density fluctuations with integrated digital currents (IDCs) required for correction procedures

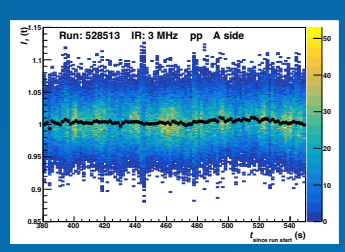
4 Integrated digital currents

IDCs
- Integration of ADC values over ~1ms
- Estimate for space-charge density fluctuations
- IDCs to be used for
  - Input for corrections of distortions
  - QA of detector

Storage in the CCDB
- Data reduction (1 GB/s → 46 MB/s)
- Factorisation of IDCs
  - $I(r, \varphi, t) = I_0(r, \varphi) \cdot I_1(t) \cdot \Delta I(r, \varphi, t)$
  - $I_0(r, \varphi) = \langle I(r, \varphi, t) \rangle_t$
  - $I_1(t) = \langle I(r, \varphi, t) / I_0(r, \varphi) \rangle_{r,\varphi}$
  - $\Delta I(r, \varphi, t) = I(r, \varphi, t) / \left(I_0(r, \varphi) \cdot I_1(t)\right)$
- Averaging + compression of $\Delta I(r, \varphi, t)$

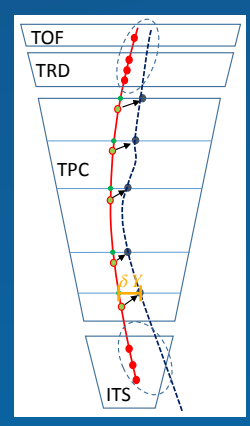




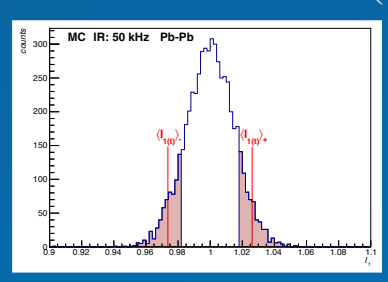


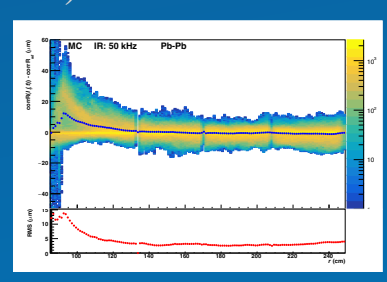
5 Space-charge distortion correction

Correction of average distortions
- TPC tracking using relaxed tolerances
  - Matching with ITS and TRD + TOF
- Reference track: ITS-TRD-TOF refit
- Measurement and storage of $\delta Y, \delta Z$
- Calibration interval $\mathcal{O}$(min)
- Parametrisation of extracted corrections
  - $\delta Y, \delta Z \rightarrow \Delta x, \Delta y, \Delta z$



Scaling of mean correction map
- Derivative of average correction $\frac{\delta\Delta}{\delta I_1} = \left(\frac{corr_{\langle I_{1(t)} \rangle_+} - corr_{\langle I_{1(t)} \rangle_-}}{\langle I_{1(t)} \rangle_+ - \langle I_{1(t)} \rangle_-}\right)$
- $corr\left(I_1(t)\right) = corr_{\textbf{avg}} + I_1(t) \cdot \frac{\delta\Delta}{\delta I_1}$
- Calibration interval $\mathcal{O}$(10 ms)





1D distortions fluctuation correction using ML
- Ongoing studies with random forrest and neural network
  - Input: Fourier coefficients of $I_1(t)$ and $\frac{\delta\Delta}{\delta I_1}$
  - Output: Correction of 1D-distortion fluctuation
- Calibration interval $\mathcal{O}$(10 ms)