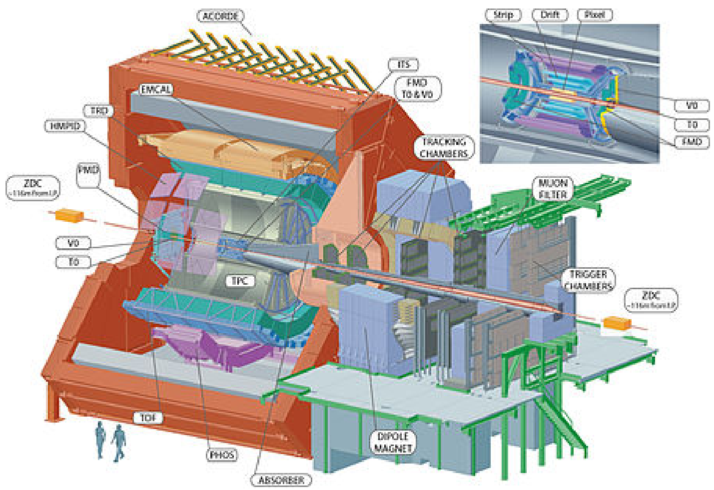
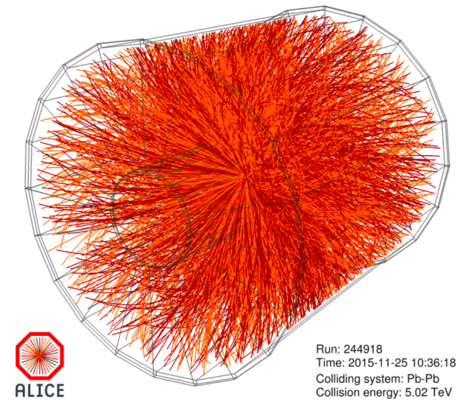
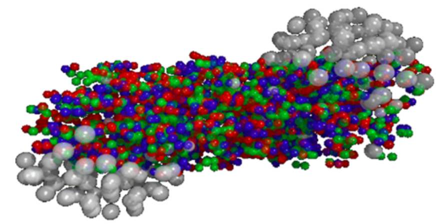
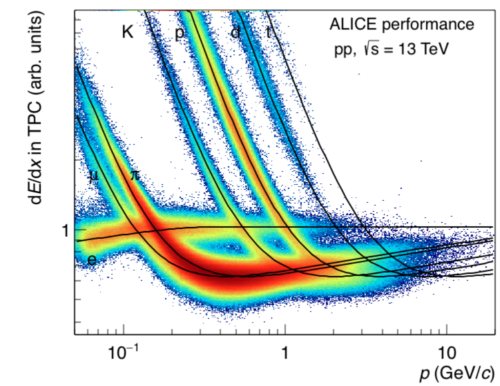








Track reconstruction in high density environment

Marian Ivanov

See talk by Yiota Chatzidaki:
Cross-talk and Ion-tail analysis of the upgraded ALICE TPC with GEM readout

See talk by Ernst Hellbär:
Calibration of space-charge effects and distortions of the electric field in the ALICE TPC

Outlook

ALICE TPC nominal performance in Run 1-2 (MWPC readout) and Run 3-4 (GEM readout)

- TPC standalone
- Global barrel (ITS+TPC+(TRD)) reconstruction - ALICE default

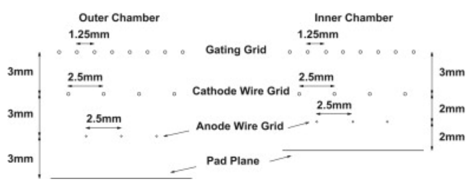
Baseline bias and baseline fluctuation

- Common mode and ion tail. Why should they be corrected online?
- Impact on the performance

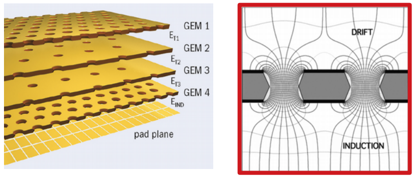
Space point distortion and its fluctuations

Performance parameterization in high density environment

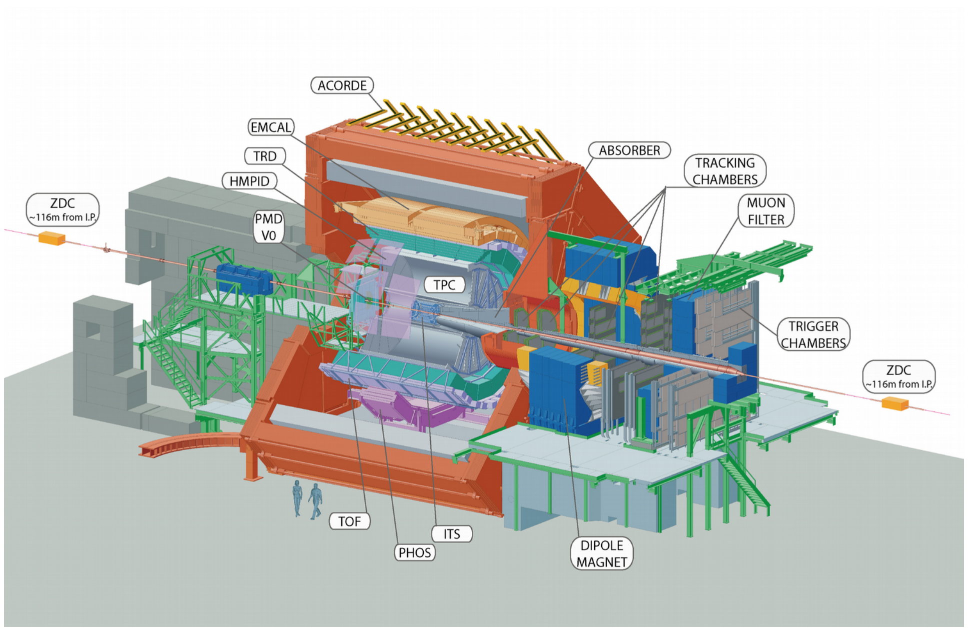
Upgrade of the ALICE TPC: MWPCs → GEM-based readout (Run3)



Run 1-2 (MWPC readout)



Run 3-4 (GEM readout)



ALICE TPC nominal performance in Run 1-2 MWPC readout

Combined tracking vs TPC stand-alone

Up to 159 space points measured

- Typical position resolution in low density varies in range 0.3-2 mm
  - σ ~ 0.6 mm (for high momenta tracks → small bending inclination angle)
- **Track extrapolation precision** at the entrance of the TPC **of about σ_{tr} ~ 0.15 mm**

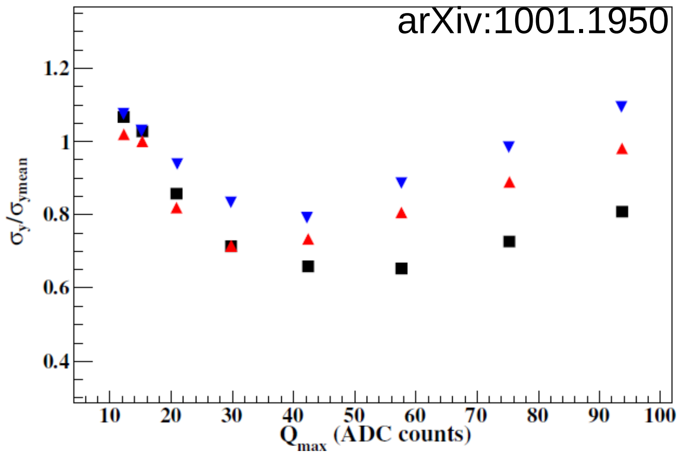
Space point resolution depends on:

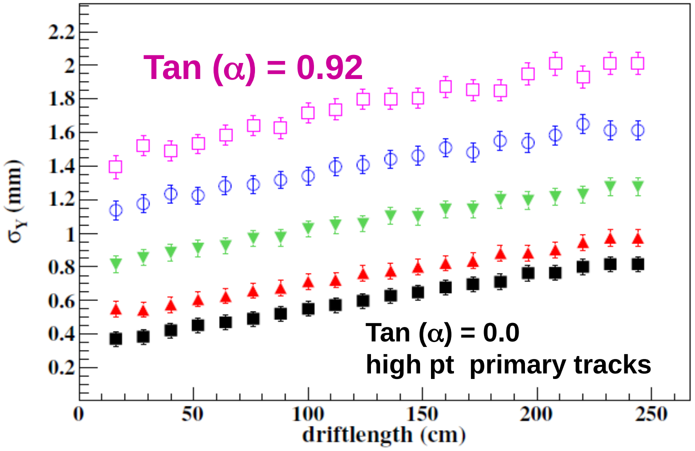
- Drift length, track inclination angle, deposited charge Q, pad geometry (mainly pad length)
- Baseline fluctuation and local occupancy

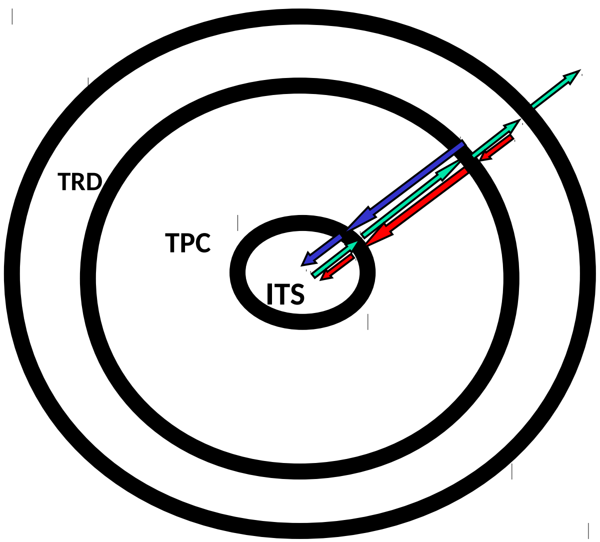
Requirement: TPC space point distortion calibration σ < 0.15 mm

$$\sigma_{cl}^2 \approx \sigma_{cl0}^2 + \frac{2(\sigma_D L_{Drift})^2}{< N_{el} >} + \frac{(L_{Pad}\tan(\alpha))^2}{12 < N_{Prim} >}$$

$$\sigma_{Tr} \approx \frac{\sigma_{cl}}{\sqrt{N_{cl}/3}}$$





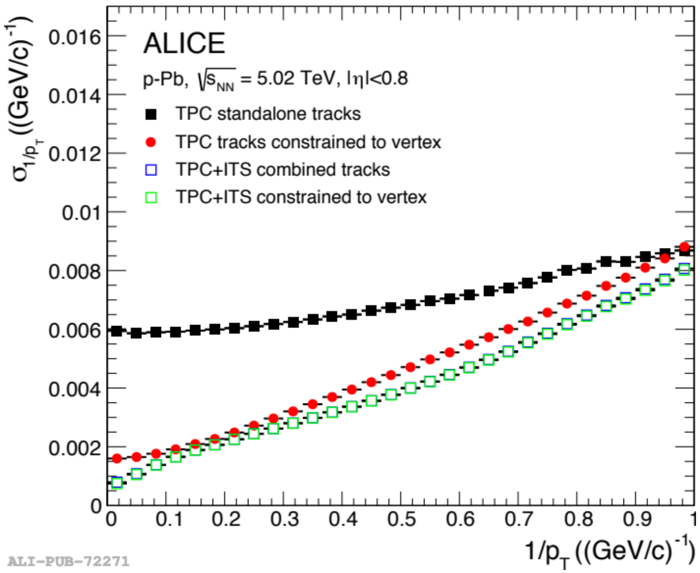


Combined tracking - Kalman filter in 3 iterations:

- **Inward tracking** – TPC-ITS
- **Back propagation** –ITS-TPC-TRD-PID detectors
- **Refit** tracks towards the vertex (TRD-TPC-ITS)

*Algorithm optimized for reconstruction of primary tracks. For decay topology extended versions of algorithm used to track also deep secondary tracks

In standard ALICE analysis combined tracking is used.



$$\frac{\sigma_{p_T}}{p_T} = \sigma_{q/p_T} p_T$$

	TPC	TPC+ITS
1 GeV	0.8%	0.8 %
100 GeV/c	**60 %**	**6-8 %**

Kalman filter:

- Space points reconstructed before tracking
- Simultaneous track recognition and reconstruction
- Taking into account
  - **multiple scattering**
  - magnetic field in-homogeneity
  - **mean energy loss**
- **Efficient way to match tracks between several detectors**

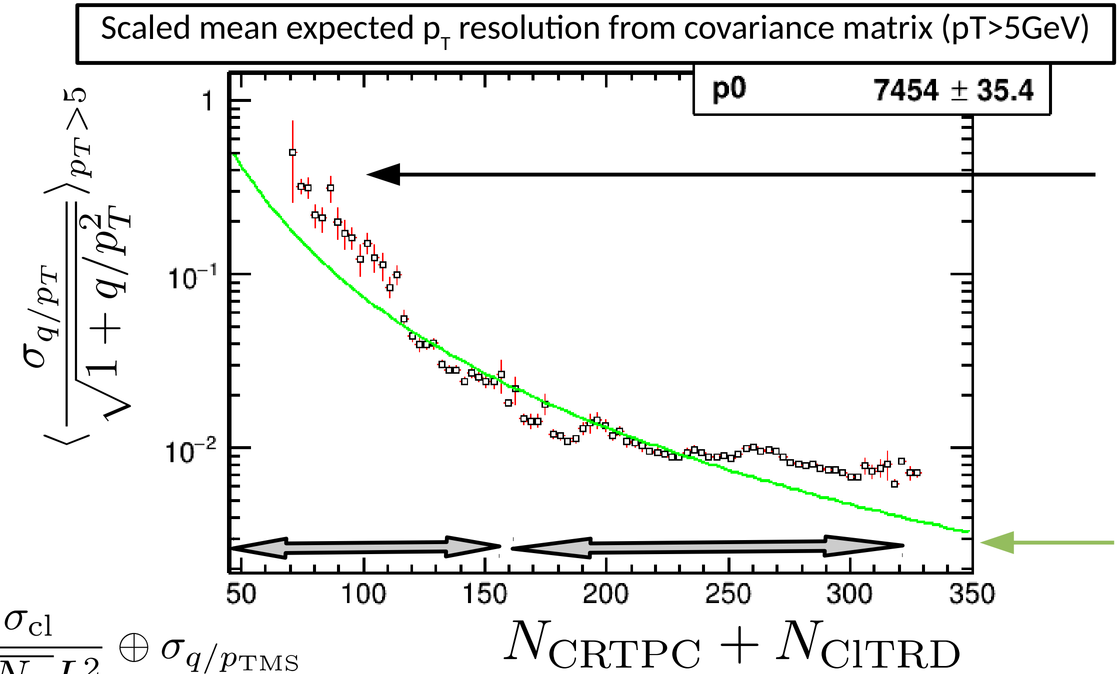
Space points for Kalman filter, assumptions:

- Gaussian errors with **known sigma**
- Space point residuals **not correlated**
- Correlated error added to the track at **detector boundaries**

In standard ALICE analysis combined tracking is used.

For p > 1 GeV (low multiple scattering) combined momentum resolution significantly better than TPC standalone

Run 2 - Barrel tracking - p_T resolution using TRD in refit



- Short track → worse resolution
- Edge cluster → higher error assigned
- Deviation from scaling

raw scaling $N^{-2.5}$

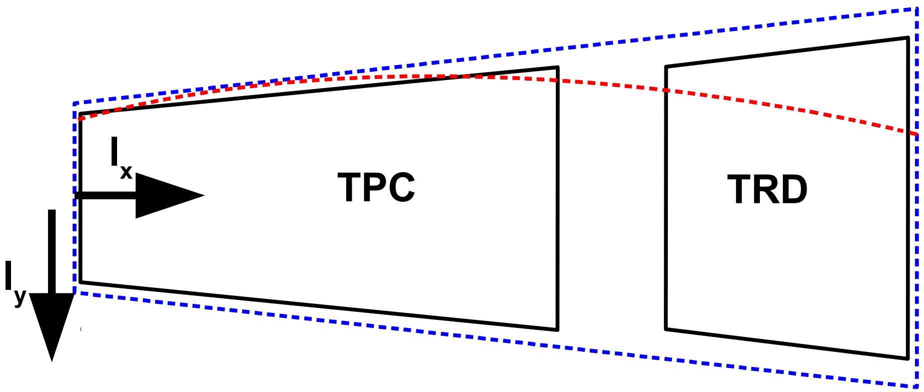
$$\sigma_{q/p_T} \approx \frac{\sigma_{\mathrm{cl}}}{\sqrt{N_{\mathrm{cl}}}L^2} \oplus \sigma_{q/p_{T\mathrm{MS}}}$$

$$\frac{\sigma_{p_\mathrm{T}}}{p_\mathrm{T}} = \sigma_{q/p_\mathrm{T}} p_\mathrm{T}$$

Simplified analytical expectation for homogeneously spaced points with uniform resolution

- Run 2 - TRD detector fully equipped - further improvement of resolution including TRD in refit
- For short tracks <130 *TPC crossed pad-rows(N_{CR}) + TRD N_{cl}* steep worsening of p_T resolution
- At N_{CR} <70, p_T resolution 10 times worse than for long tracks N_{CR}>130

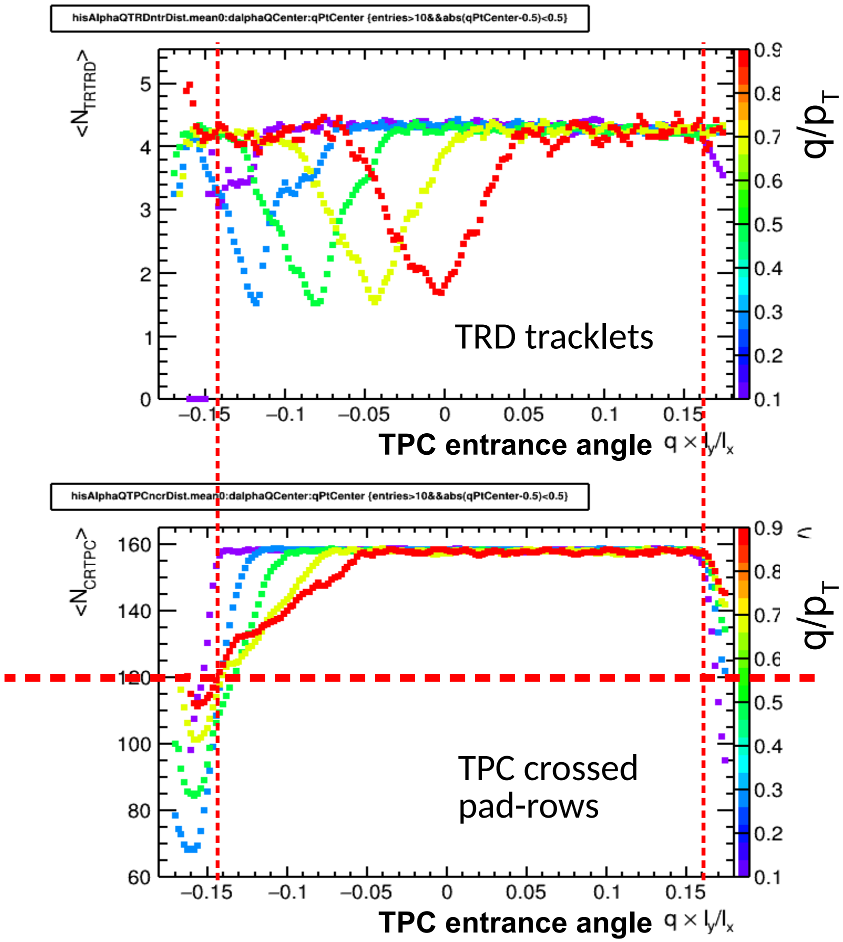
For tracks crossing TPC dead zones significant improvement of resolution by including TRD in track refit



TPC dead zone
$\Delta r\phi \sim 1.5$ cm
10 % at l_x=83.6

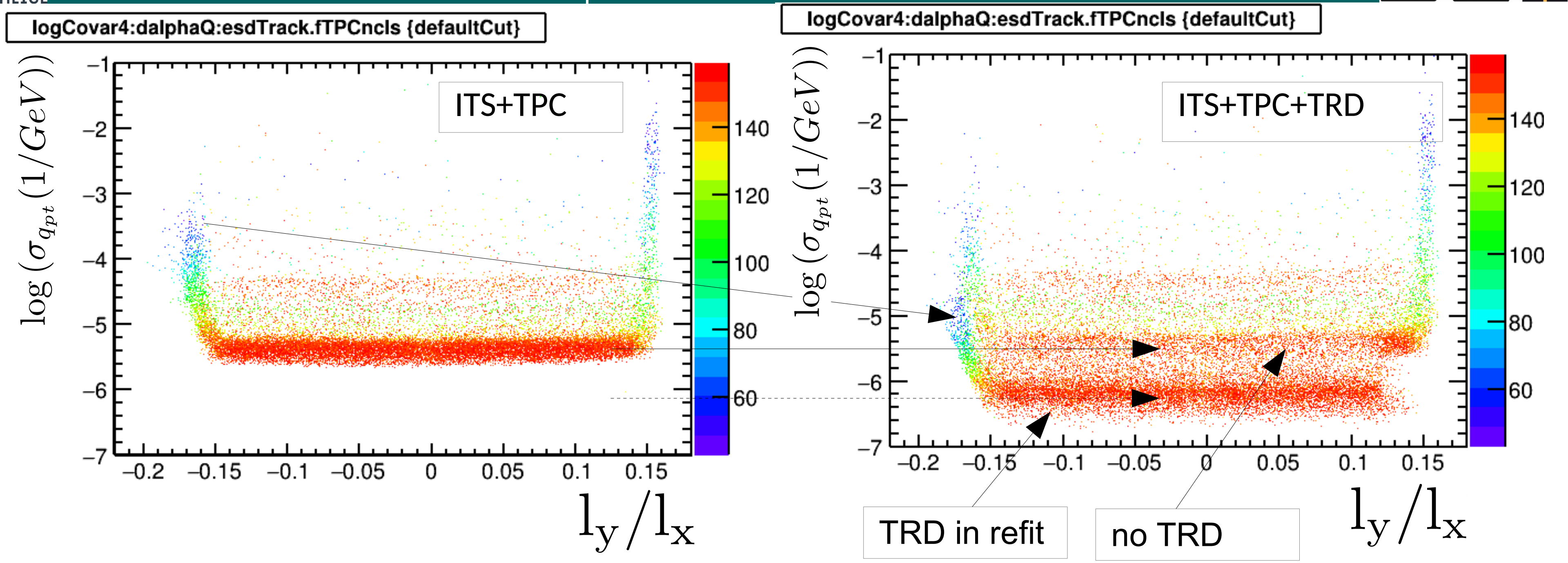
TRD dead zone
$\Delta r\phi \sim 7$ cm
15 % at l_x=300cm

Number of measurement vs local y position at the TPC entrance (l_x=83.6 cm)



Tracks in TPC dead zone - usually bent into active zone of TRD
→ Significant improvement of resolution using TRD in track refit.

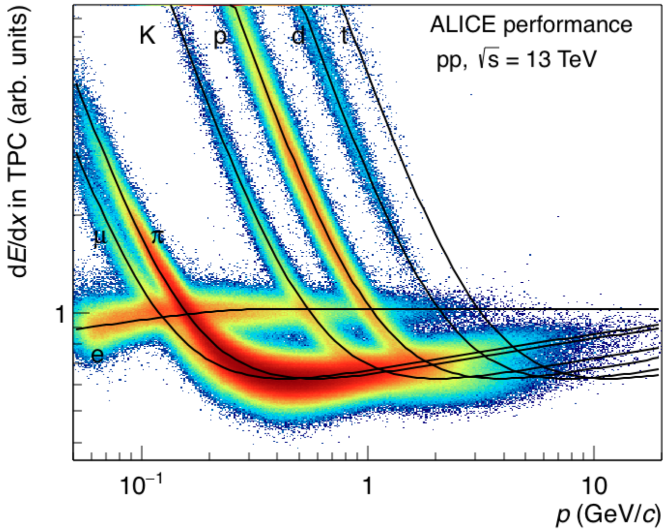
Expected p_T resolution. With/Without TRD

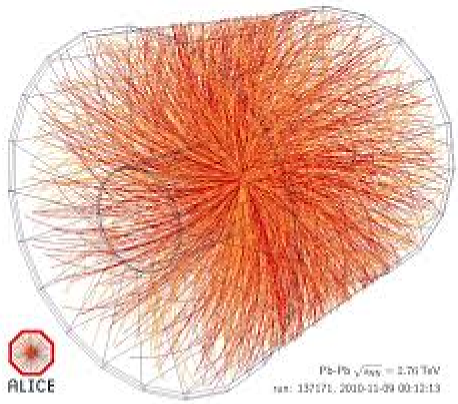


$\sigma_{q/pt}$ as a function of relative sector position at the TPC entrance for p_T>5 GeV (N_{CR} TPC as a color code)

- Long track region - 2 times better resolution with TRD than without TRD
- Short tracks bending into TRD recovered (left edge - q l_y/l_x< -0.15)
- Part of short tracks are in dead TRD area (right edge - q l_y/l_x > 0.15)

Including TRD - significant improvement in the resolution of the bulk and recovery at the edges

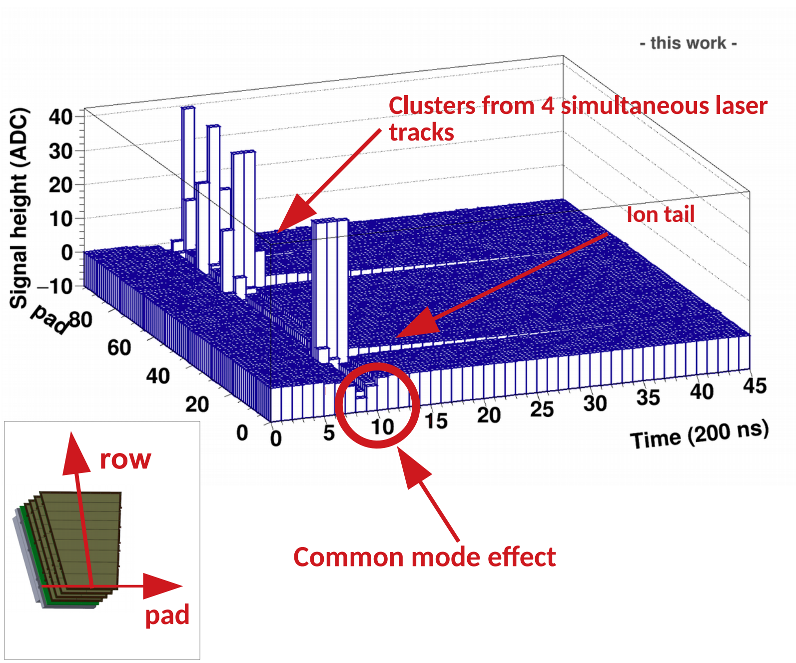




Baseline fluctuation due common mode and ion tail

See talk: Cross-talk and Ion-tail analysis of the upgraded ALICE TPC with GEM readout

Run 3 GEM: Analysis of common mode and ion tail using laser system



$$\sum_{pad} Q_{neg} = k \sum_{pad} Q_{pos}$$

Significant baseline fluctuation- MWPC & GEM

- ALICE nominal design
- common mode induced signal
  - k_{MWPC}~1
  - k_{GEM}~0.5
- ion tail induced signal
  - I_{MWPC}~0.5
  - I_{GEM} ~0.06

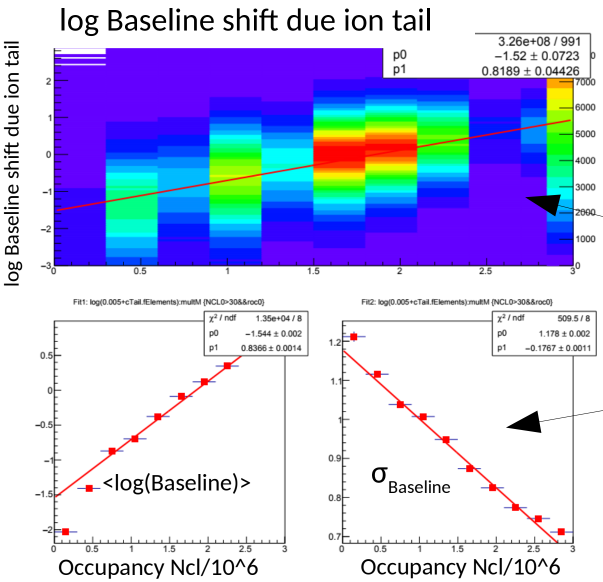
In Run 3 higher luminosity

- PbPb 2-8 kHz → 50 kHz

Significant deterioration of PID and tracking performance due to baseline fluctuation.
In Run 3 it should be corrected online - before data compression.

Baseline fluctuation - Ion tail and CM

$$\sum_{pad} Q_{neg} = k \sum_{pad} Q_{pos}$$



Significant baseline fluctuation- MWPC & GEM

- ALICE nominal design
- common mode **(k_{MWPC}~1, k_{GEM}~0.5)**
- ion tail (**I_{MWPC}~0.5, I_{GEM} ~0.06**)

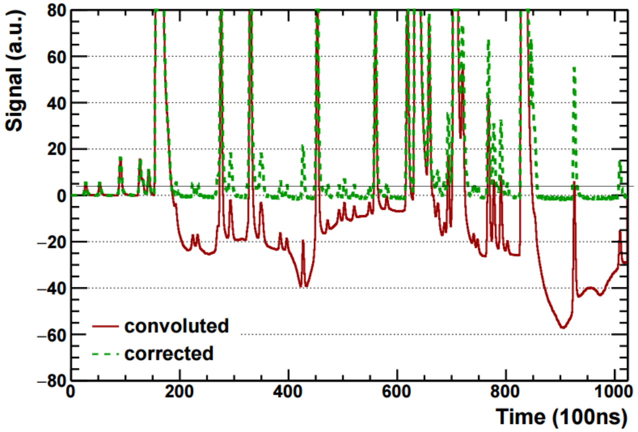
Baseline bias and baseline fluctuation - Run 2

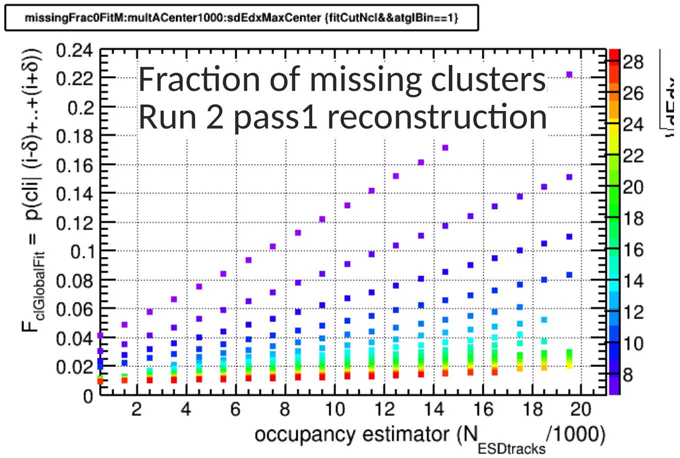
- Fluctuation - log normal distribution
- Mean bias up to 3 ADC (exp(1)) for central events
- Relative fluctuation ~ 220 % (exp(0.9))
- Hardware correction not stable. Switched OFF
- Offline software correction used
  - **effective multiplicity correction not precise**

Run 3

- Optimization of online baseline correction
- Hardware field optimization to reduce ion tail integral
- Effect in Run 3 smaller but luminosity/occupancy significantly higher
- **Run 2 IR ~8 kHz → Run 3 50 k Hz**

Significant deterioration of PID and tracking performance due to baseline fluctuation
In Run 3 it should be corrected online - before data compression





$$Q^* = Q_{orig} + Q_{base}$$

$$\overline{Q_{base}} \approx occ \times \overline{Q} \times \frac{I_{neg}}{I_{pos}}$$

$$1 - P_{clthr} = \int_0^{thr} Q_{\max} + Q_{base} dx$$

$$\sigma_{yB} \approx \frac{\sigma_{Qbaseline}}{Q_{cluster}} w_{pad}$$

$$\sigma_y^2 = \sigma_{yLF}^2 + \sigma_{yB}^2$$

TPC baseline modified at high occupancy

- Depends on occupancy, mean Q (3-4 MIPS) and ion tail integral
- $<\log(Q_{MIP})>\sim 3$ - comparable with $<\log(Q_{Baseline})>\sim 0.5$

Cluster losses:

- **Signal below baseline+threshold**
- **Partial cluster loss (shorter signal) - 1 pad clusters**
- **Increased position fluctuation**
  - ***cluster residuals outside of tracking tolerances***

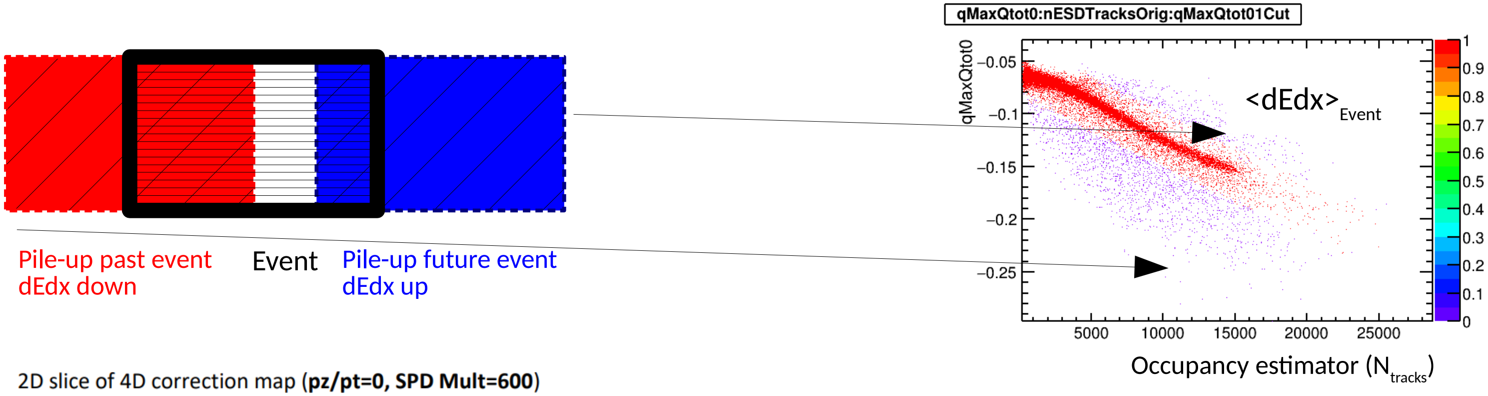
Effect to be corrected/simulated

- hardware correction (e.g. ALTRO) switched off, not numerically stable
- Offline emulation of the event and corrections

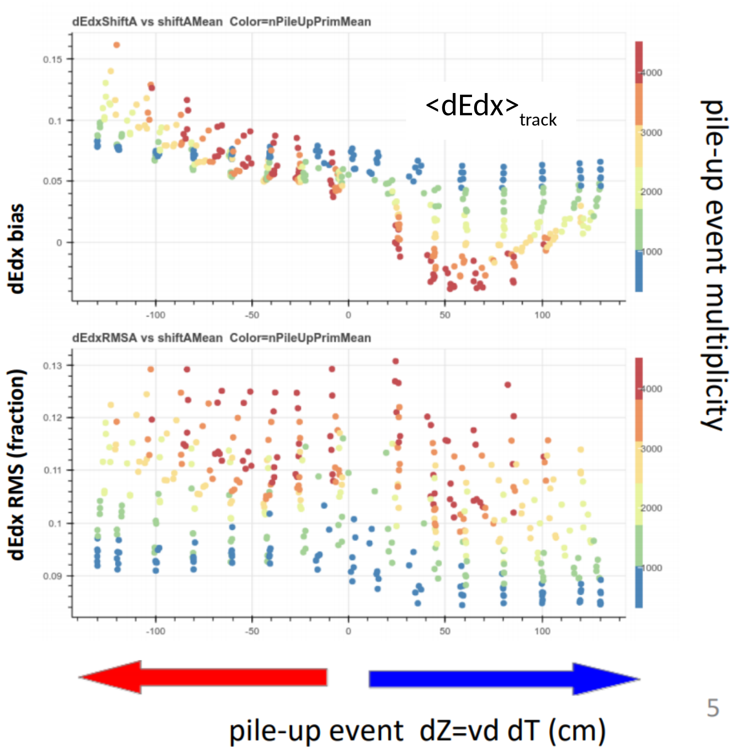
Missing cluster to track association reduced in "pass3" re-reconstruction

- Part of cluster loss recovered using *baseline fluctuation aware error parameterization*

Ion tail +CM effect offline correction - dEdx



2D slice of 4D correction map **(pz/pt=0, SPD Mult=600)**



Correlated dEdx bias and mean event <dEdx> depends on charge distribution

- Modified cluster charge PDF can not be corrected by a simple shift as function of density estimator (e.g. N_{tracks})
- Low Q charge - cut-off bias
- Proper local correction needed
  - Integrals and time profile to be known with high precision
  - Problem in first reconstruction pass - dEdx bias was pile-up position dependent
- Data already compressed - not raw data available

Part of the effect corrected in the reconstruction and part in the physics analysis using residual 5 dimensional correction function

In Run 2 (MWPC) partial recovery of the performance using offline ion tail correction. In Run 3 online correction before zero suppression to be done

RootInteractive for dEdx perfromance parameterization

Interactive N dimensional dEdx pile-up correction maps:

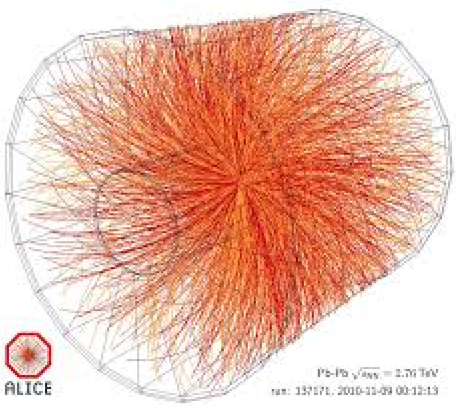
- https://drive.google.com/file/d/1ei0BfMCxCfN4DztzXT-Qo7YsdIY2BHkT/view?usp=sharing

Interactive dEdx performance map:

- https://indico.cern.ch/event/889369/contributions/4011353/attachments/2118297/3564404/go

Interactive cluster distribution map:

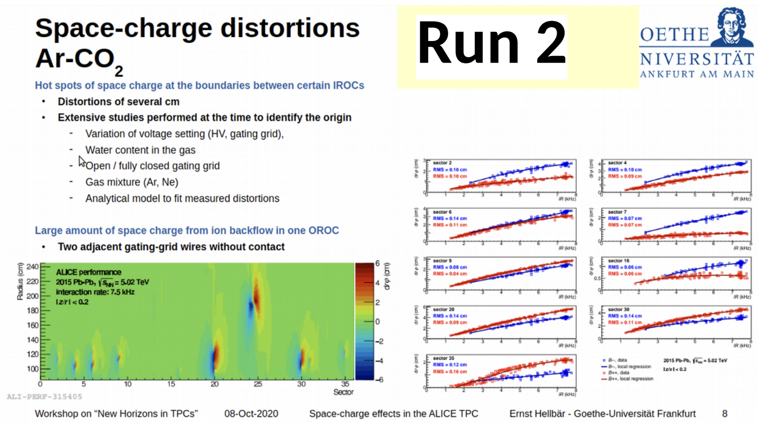
- https://indico.cern.ch/event/889369/contributions/4011353/attachments/2118297/3565833/go

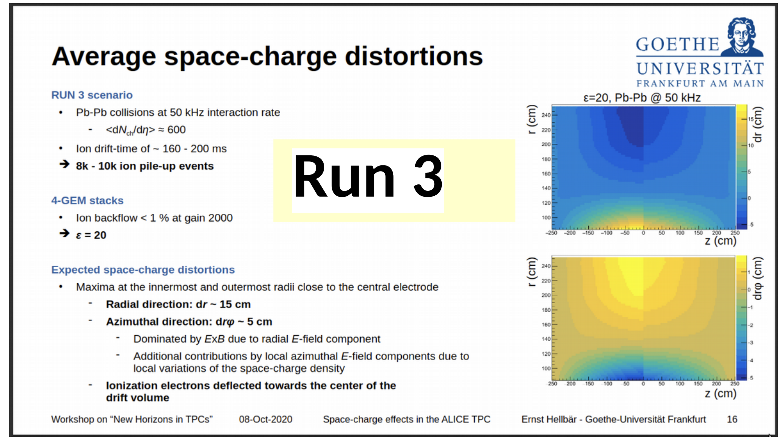


Distortions and distortion fluctuation
and
Impact on detector performance

See talk by Ernst:
Calibration of space-charge effects and distortions of the electric field in the ALICE TPC

Space charge distortion in Run 1-2 and Run 3





See talk:
Calibration of space-charge effects and distortions of the electric field in the ALICE TPC

Run 2 - mostly local distortion localized in few hotspots Δ ~ O(0-2 cm), relative fluctuation ~ 20%

Run 3 - global distortion Δ ~ O(0-20 cm) for max rate, relative fluctuation ~ 2-4 %

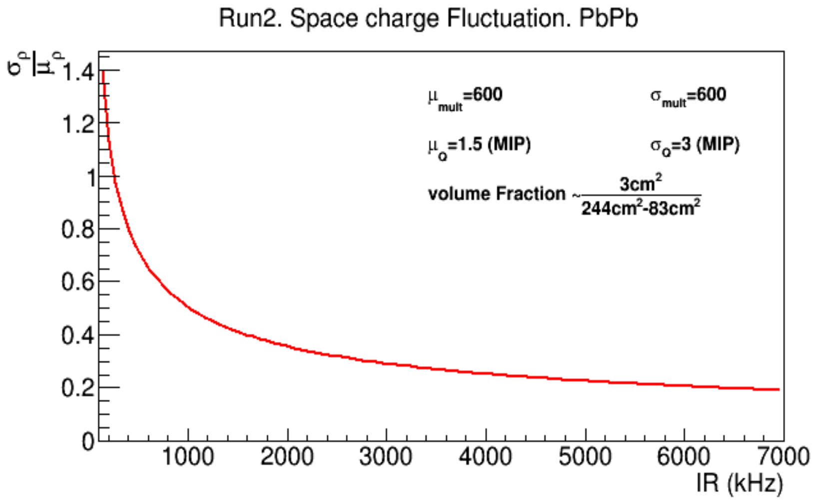
- In RUN3 distortion fluctuation to be calibrated in short fluctuation time intervals << ion drift

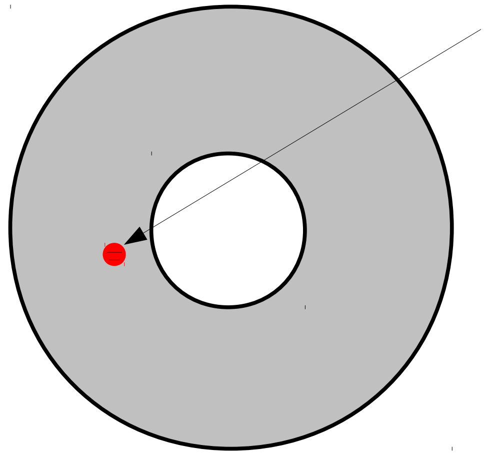
In Run 2 only mean distortion calibrated

- fluctuation correction based on current measurement not possible - not continuous readout
- some aspects were less critical
  - DCA approach not converged - too small statistic
- mean distortion in RUN2 significantly smaller - only in critical regions resolution significantly worse → **locally higher errors assigned to points using correction resolution maps**

Using combined tracking with ITS+TPC+TRD impact of the local distortion significantly mitigated

Space charge (distortion) fluctuation





- **Run2 scenario**
- Small ion hotspot
- Ion integration time ~ 0.1 s
- S ~ 3x3 cm
- R_{in}~83 cm
- R_{out}~245cm
- Volume fraction
- F = 0.00017

$$\frac{\sigma_{\rm sc}}{\mu_{\rm sc}} = \frac{1}{\sqrt{N^{\rm ion}_{\rm pileup}}} \sqrt{1 + \left(\frac{\sigma_{N_{mult}}}{\mu_{N_{mult}}}\right)^2 + \frac{1}{F\mu_{N_{mult}}}\left(1 + \left(\frac{\sigma_{Qtrack}}{\mu_{Qtrack}}\right)^2\right)}$$

Expected relative fluctuation of space charge originating at volume

Significant relative fluctuation of space charge

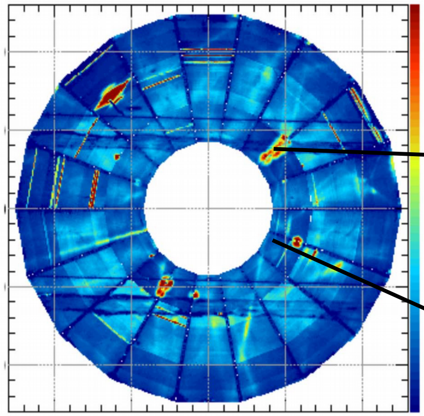
Limit cases:

- big volume limit $1/(F\mu_{track})<<2 \rightarrow \sigma/\mu \sim \mathrm{sqrt}(1/N_{Events})$
- small volume limit $1/(F\mu_{track})>>2 \rightarrow \sigma/\mu \sim 1/F^{*}\mathrm{sqrt}(1/N_{track})$

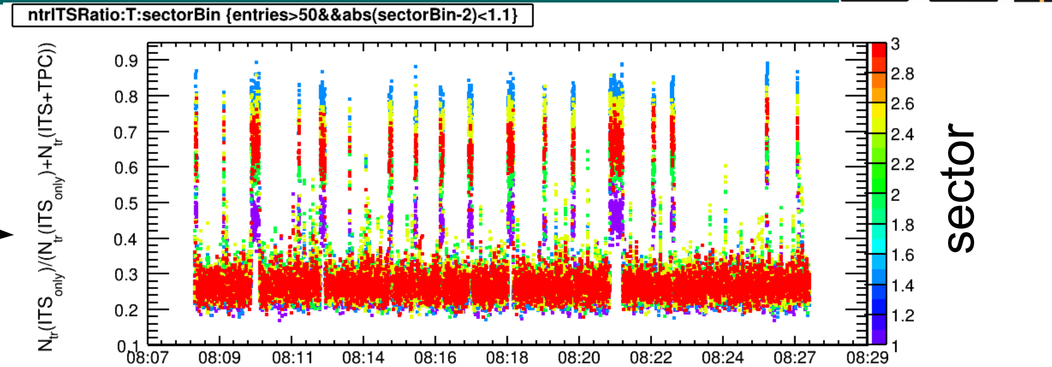
Run 2 O(20-30%) for pp and PbPb small volume limit - consistent with measurement

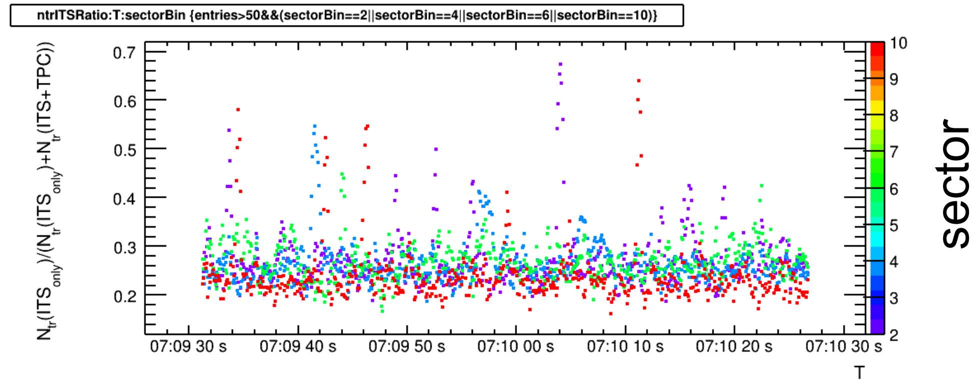
Run3 Pb-Pb O(2-5%)

Run2 - Distortion Fluctuations - outliers



Time series of local TPC → ITS mis-match





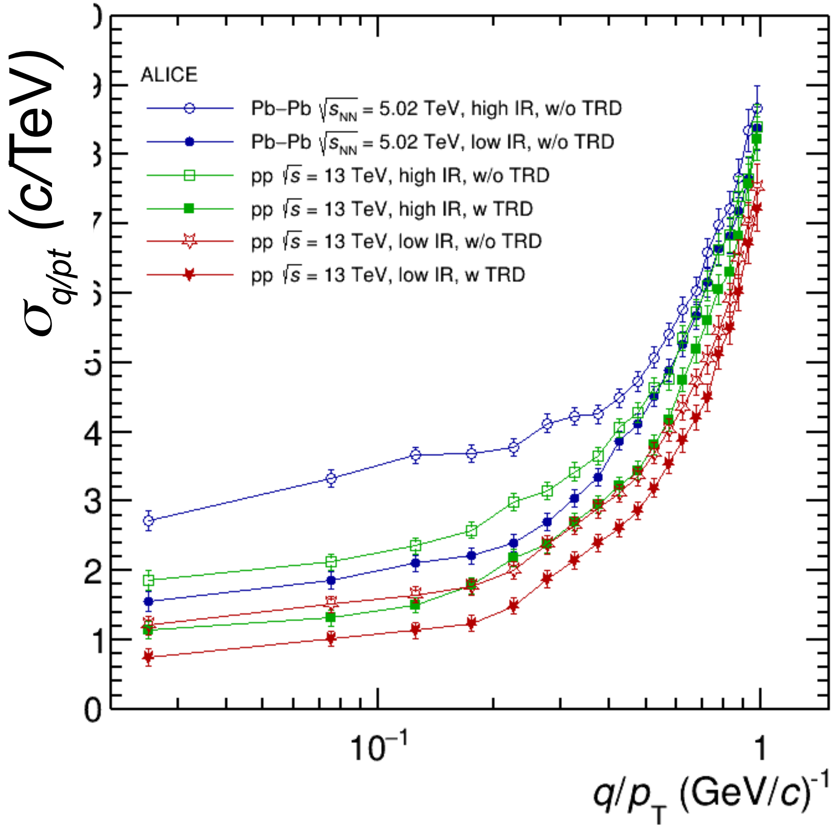
- Time series - Normally hotspots with **O(0.5) seconds corresponding to ion drift time**
- Local distortion fluctuation → locally worse resolution →
  - decrease of mean "***TPC →ITS***" **matching efficiency**
- Distortion independent- see e.g. time position of spikes **sector bins 2, 4, 6, 10**
- Fluctuation in **sector 2** - wider outlier time ranges indicate onset of distortion

In Run 3 time series with ion drift granularity will be available in physics analysis

RootInteractive and Performance parameterization in high density environment

p_T resolution before hardware distortion mitigation

$$\sigma_{p_T}/p_T = \sigma_{q/p_T} \times p_T$$

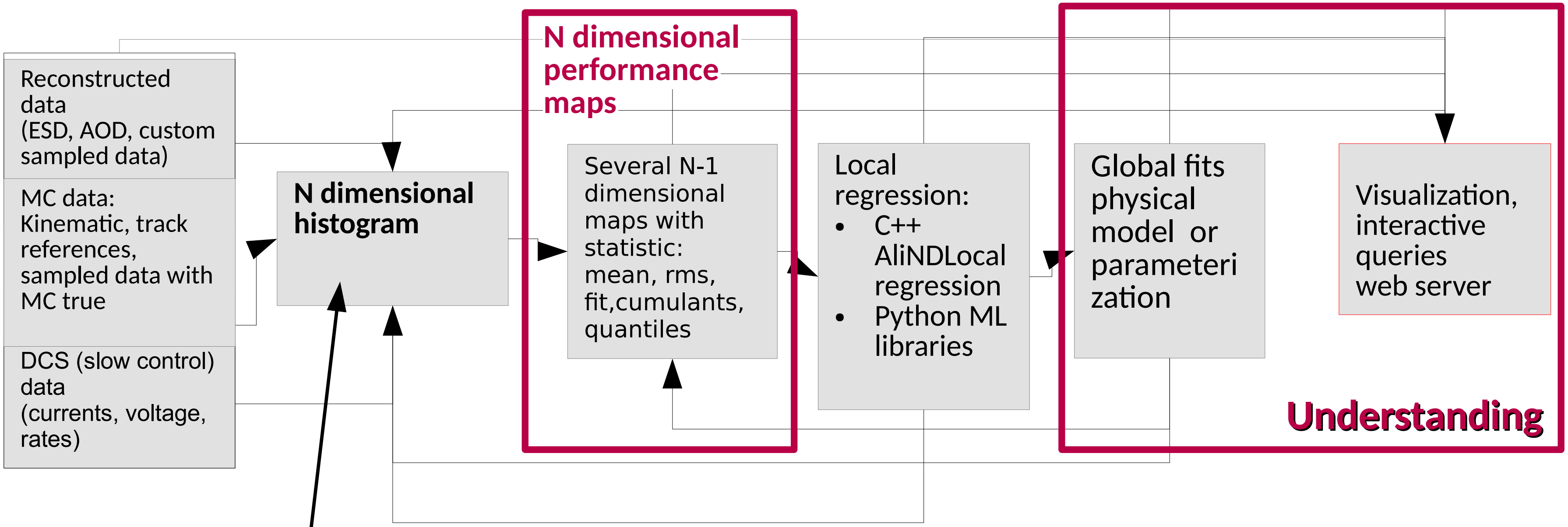


Default - ITS and TPC tracking
- with TRD in reconstruction
- w/o TRD in reconstruction

q/p_T resolution from the **covariance matrix** multiplied by constrained **angular pulls**

	Low IR	High IR
	σ_{1pt}(1/Gev)	σ_{1pt}(1/Gev)
pp w/o TRD	**0.0012**	**0.0018**
pp with TRD	**0.0007**	**0.0012**
PbPb w/o TRD	**0.0016**	**0.0028**

- **Using TRD in the track refit - improvement of p_T resolution**
- **At high IR resolution significantly worse than in low IR due to distortion fluctuation**
- **PbPb (Minimum bias) significantly worse than in pp due to baseline fluctuation**



$$f(p_0, p_1, p_2, \ldots) \neq f_0(p_0) \oplus f_1(p_1) \oplus f_2(p_2) \oplus \ldots$$

Calibration/performance maps in multidimensional space

- dimensionality depends on the problem to study (and on available resources)
- Data →Histogram → set of ND maps → set of Machine learning regression → Global fits
  → **Interactively visualization on web server**

RootInteractive to interactively manipulate function and functional composition

Resolution,pulls and bias maps: Definition

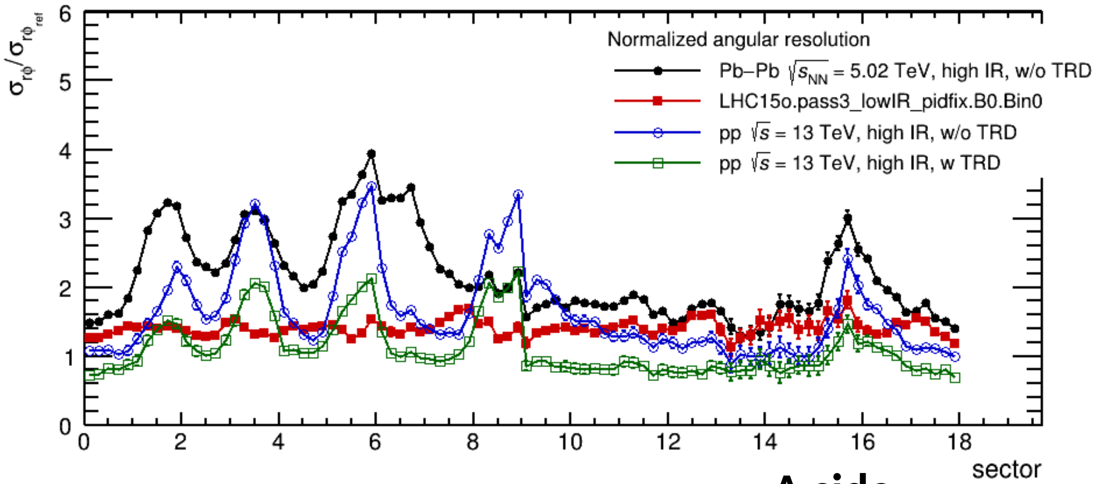
$$\vec{P}_{\mathrm{DET}} = l_y, l_z, sin(\phi), tan(\theta), q/p_T$$
$$\Delta_P = \vec{P}_{\mathrm{DET0}} - \vec{P}_{\mathrm{DET1}} \tag{1}$$
$$pull_{Pi} = \frac{P_{iDet0} - P_{iDet1}}{\sqrt{\sigma^2_{P_{iDet0}} + \sigma^2_{P_{iDet1}}}}$$

Performance maps created from distribution of track matching Δ and pulls in multi-dimensional histograms

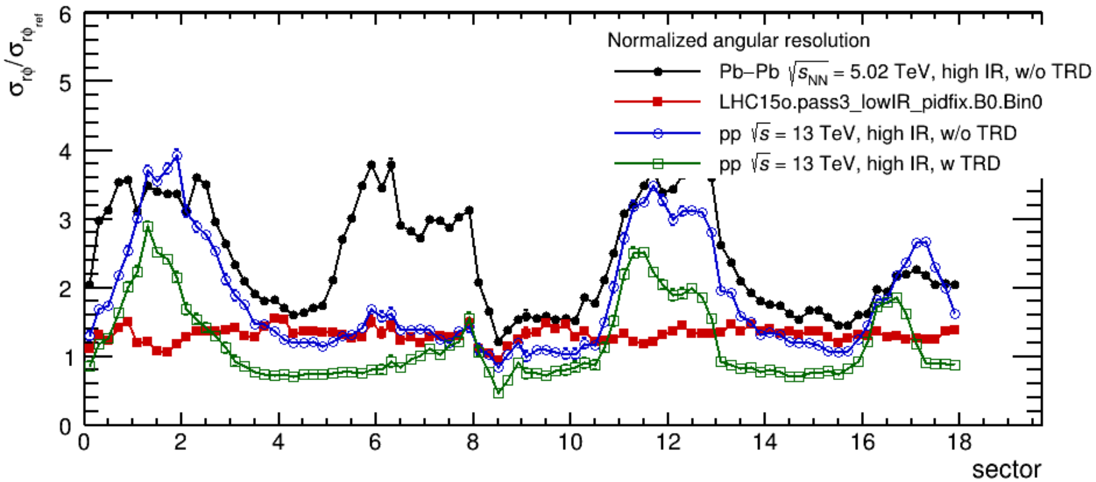
- statistical information of PDF in bins: extracted entries mean, rms, LTM, gauss fit
- **Track matching delta and pulls more sensitive to tracking imperfection** than χ2 (mostly dominated by point error)
- Track matching pulls to estimate imperfection of covariance matrix information

Next slides:

- DET0=TPC+(TRD) track
- DET1=ITS+TPC+(TRD) track
- Shown statistics: rms of gaussian fits
- Explicitly indicating if the track constrained to vertex or not



A side



C side

PbPb high rate w/o TRD
PbPb low rate w/o TRD
pp high rate w/o TRD
pp high rate with TRD in tracking

Performance map normalized to reference performance map -
pp low IR (LHC15n) w/o TRD

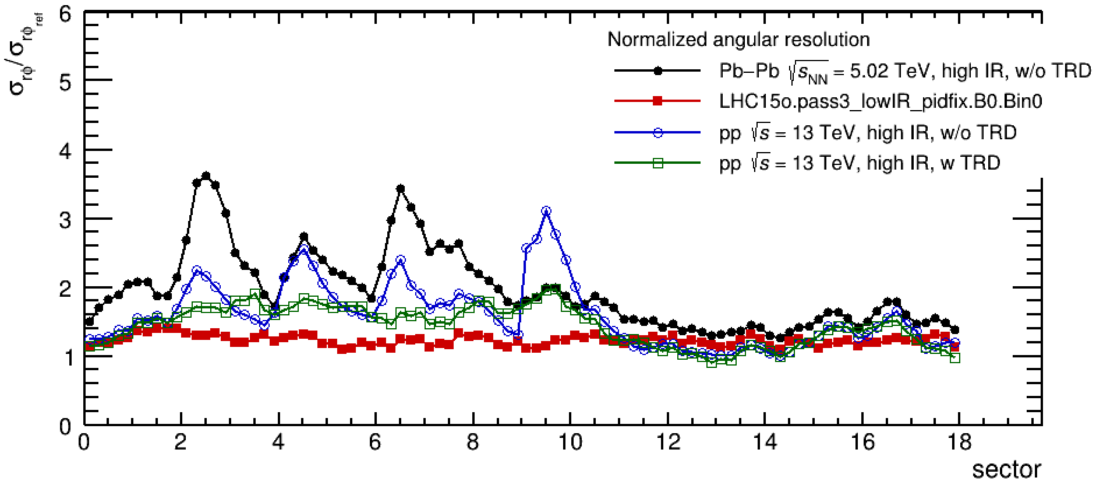
At high IR non flat performance map

Significantly worse performance in region with **local distortion**

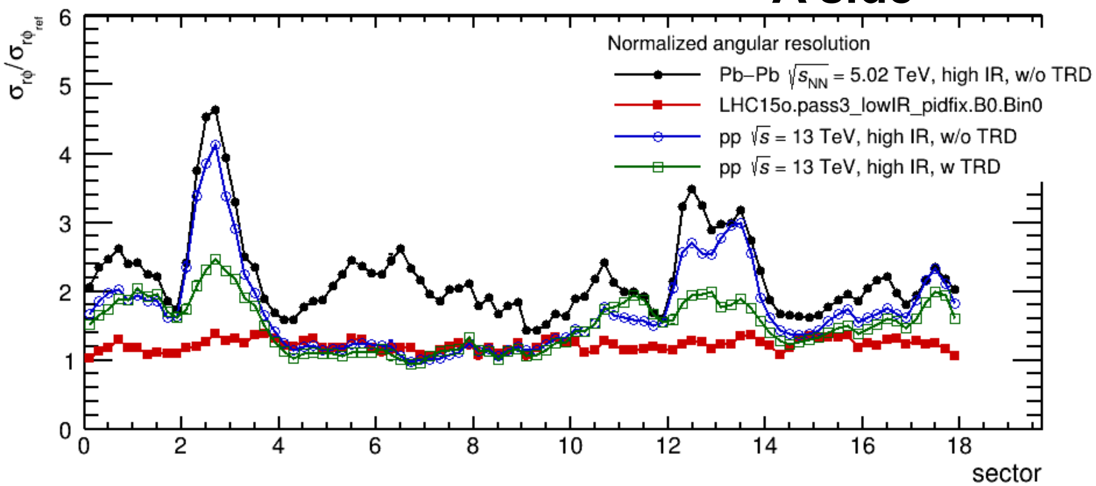
Significant improvement- sector modulation reduced

More homogeneous performance

Overall performance better using TRD in refit.
Impact of distortion partially mitigated



A side



C side

PbPb high rate w/o TRD
PbPb low rate w/o TRD
pp high rate w/o TRD
pp high rate with TRD in tracking

Performance map normalized to reference performance map - pp low IR (LHC15n) w/o TRD

At high IR non flat performance map

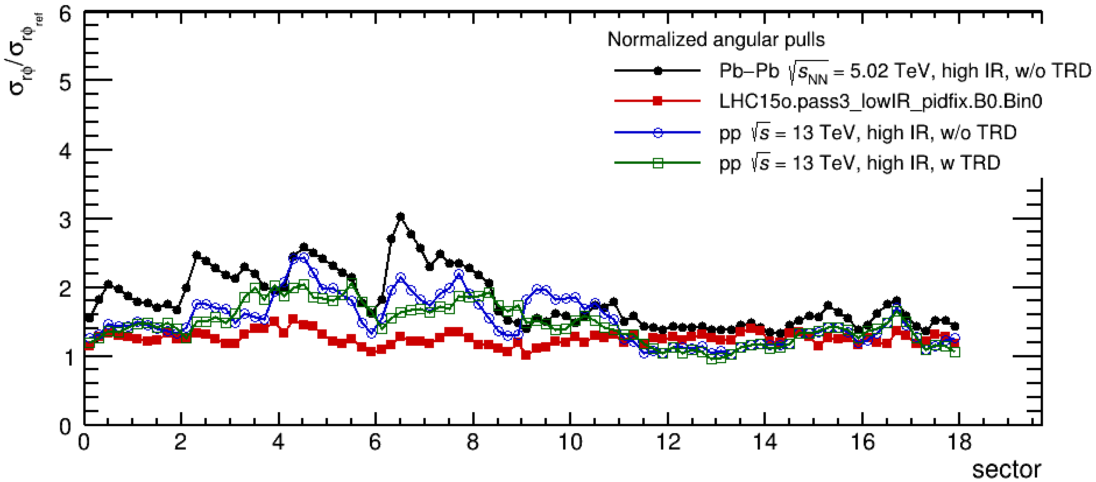
Significantly worse performance in region with local **distortion**

Using TRD significant improvement sector modulation reduced

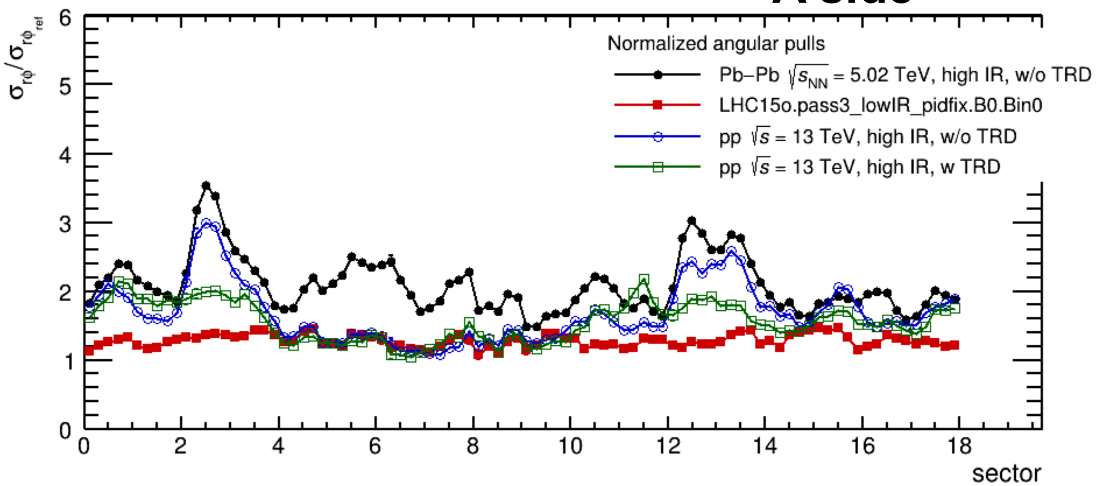
Using TRD more homogeneous performance

Overall performance better using TRD in refit.
Impact of distortion partially mitigated

Const. Angular pulls: Comparison of the reco. productions



A side



C side

PbPb high rate w/o TRD
PbPb low rate w/o TRD
pp high rate w/o TRD
pp high rate with TRD in tracking

Performance map normalized to reference performance map - pp low IR (LHC15n) w/o TRD

At high IR non flat performance map

Significantly worse performance in region with local distortion
Covariance matrix describes local worsening only **partially**

Significant improvement- sector modulation reduced

Overall performance better using TRD in refit.
Impact of distortion partially mitigated

Summary

Performance parameterization in high density environment presented

Multidimensional analysis (RootInteractive) is crucial for understanding of the detector

Alice TPC nominal performance in Run 1-2 (MWPC readout) and Run 3-4 (GEM readout)

- Precission of TPC standalone tracking worse than combined barrel tracking
  - critical for high pT tracks and tracks close to dead zone
- Global barrel (ITS+TPC+(TRD)) reconstruction significantly better including TRD

Baseline bias and baseline fluctuation

- Common mode and ion tail → it should be corrected online
- Impact on the performance is significant as shown in Run 2

Space point distortion and its fluctuations

- For Run 3 to be corrected from 20 cm down to 0.15 mm

New project - fast detector system performance parameterization

- For next workshop ?
- Resolution/efficency/fakes as function of:
  - track parameters (pt, position, particle type)
  - detector parameters
  - position, TOF, occupancy

Use cases presented during workshop:

- Residual distortion maps performance monitoring (Ernst)
  - https://indico.cern.ch/event/889369/contributions/4011360/attachments/2118260/3564346/figPerformance_flucDistRDiff_phi.html
  - https://indico.cern.ch/event/889369/contributions/4011360/attachments/2118260/3564347/figPerformance_flucDistRDiff_r.html
- Ion tail and common mode performance studies (video and set of interactive html from talk of Yiota)
  - https://indico.cern.ch/event/889369/contributions/4044542/
- Interactive N dimensional dEdx pile-up correction maps:
  - https://drive.google.com/file/d/1ei0BfMCxCfN4DztzXT-Qo7YsdIY2BHkT/view?usp=sharing
- Interactive dEdx performance map:
  - https://indico.cern.ch/event/889369/contributions/4011353/attachments/2118297/3564404/go
- Performance maps - number of assigned clusters:
  - https://drive.google.com/file/d/1ei0BfMCxCfN4DztzXT-Qo7YsdIY2BHkT/view?usp=sharing
  - https://drive.google.com/file/d/1gL3J7GvIuSbYBBsqcybxvPKsfgwWCCRo/view?usp=sharing

Backup

Input material

Input material

Alice week - reconstruction modification:

- https://indico.cern.ch/event/899518/contributions/3795603/attachments/2009215/3356479/PWGPP-571-ReconstructionModification2018_AliceWeek2503.pdf

QA tools meeting (mostly dEdx parameterization at high occupancy)

- https://indico.cern.ch/event/717601/
- https://indico.cern.ch/event/717601/contributions/2955883/attachments/1626815/2590914/ATO-436PIDSelectionInvariant.pdf
- https://indico.cern.ch/event/717601/contributions/2955883/att15/2590911/MultiDimensionalVisualization_v2.pdf

QA tools and WP7 - ML

- https://indico.cern.ch/event/717601/contributions/2955883/
- ATO-436PIDSelectionInvariant.pdf

PbPb 2018 Pile-up discussion

- https://indico.cern.ch/event/804601/contributions/3352020/
- ATO-452_IonTail_1303ForElectronDiscussion.fodp

TPC 2010

- https://www.sciencedirect.com/science/article/pii/S0168900210008910