TPC calibration: theoretical considerations and data driven approach

Boundary error - semistatic and static distortion

Why is the RUN2 calibration not sufficient in RUN3? And what we can do about it?

Proposal:

ATO-490: **Data driven current → distortion correction** 1D → 3D, 3x1D → 3D using ITS, TRD, TOF interpolation

Outlook (0)

Distortion correction:

- **Run 1/Run 2/Run3 distortion calibration**
- Mean space charge distortion correction
- Space charge distortion fluctuation and interplay with static and semistatic distortion

Numerical/Analytical model + neural network (CNN) validation

- Is it possible to obtain data driven distortion fluctuation calibration ?
- Can we use such procedure for analytical model validation ?
- What is the precision of data driven method ?
- Why is the RUN2 calibration schema not sufficient in RUN3?

Space charge and distortion fluctuation model

Distortion fluctuation - data driven calibration

Boundary error and Machine learning consideration

Outlook (1)

Proposal Distortion fluctuation data driven calibration - Fluctuation of current as **a white noise**

- Data driven calibration using discrete (generalized) Fourier transform
  - obtaining numerical derivative of distortion maps
- $\Delta I = \sum c_j \Phi_j$
- $\Delta_n(r, r\varphi, z) = f_n(c_n \Phi_j)$
- $\Delta(r, r\varphi, z) = \sum \Delta_n(r, r\varphi, z) = \sum f_n(c_j \Phi_j)$

Boundary effect consideration:

- Distortion do not commute ....
- Calibrated distortion maps obtained as averaged map for given mean current
- **Distortion fluctuation typical higher than distortion due boundary effect e.g. O(1 cm) for CE charging up**
- Could we obtain "real" map by de-convolution e.g. using Δ_0 Kernel
- 3D calibration models - not enough granularity, resp. statistics for "boundary effects"

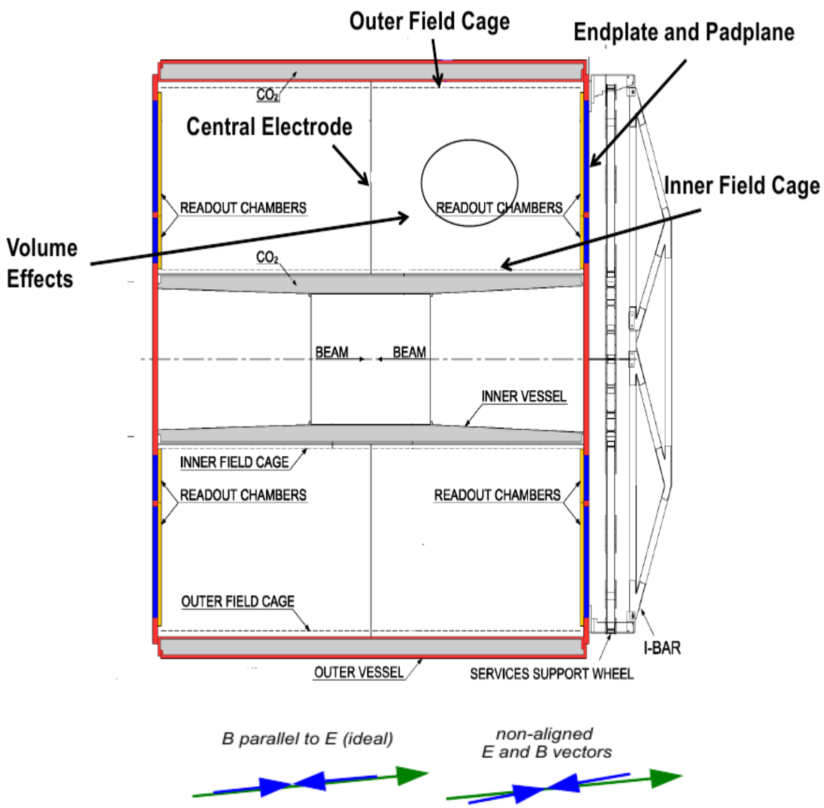
Run 1/Run 2/ Run 3 : Boundary error calibration.

Static and semistatic (charge up, and $\omega\tau$ - v_{drift}) distortion

more details in

- Run 1 distortion calibration: https://indico.cern.ch/event/128634/contributions/112892/attachments/86275/123631/TPCSpacePointcorection.pdf

Run 1: Composed correction framework



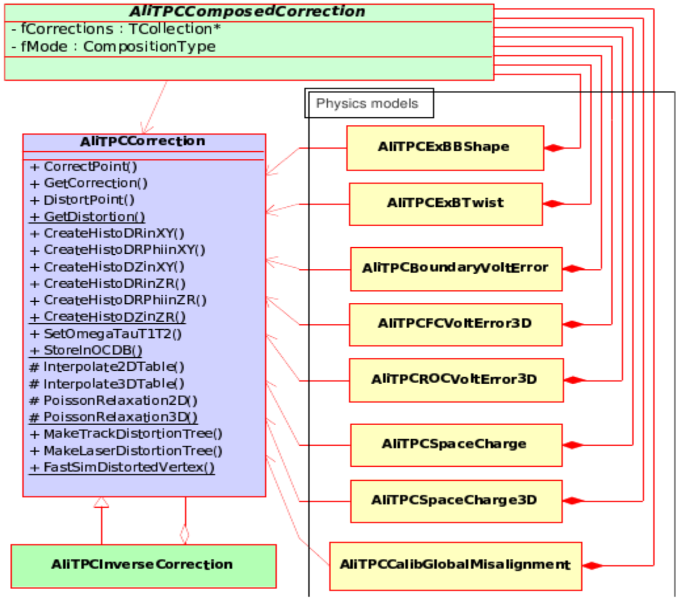
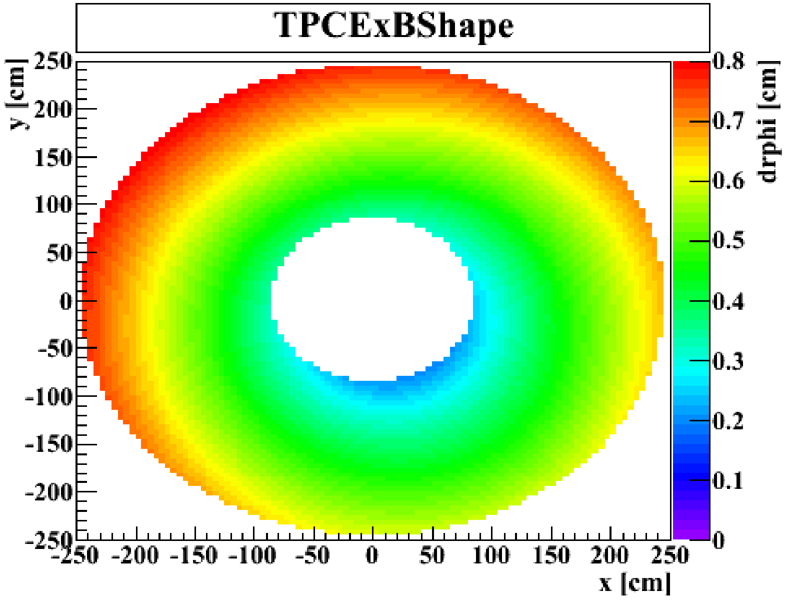


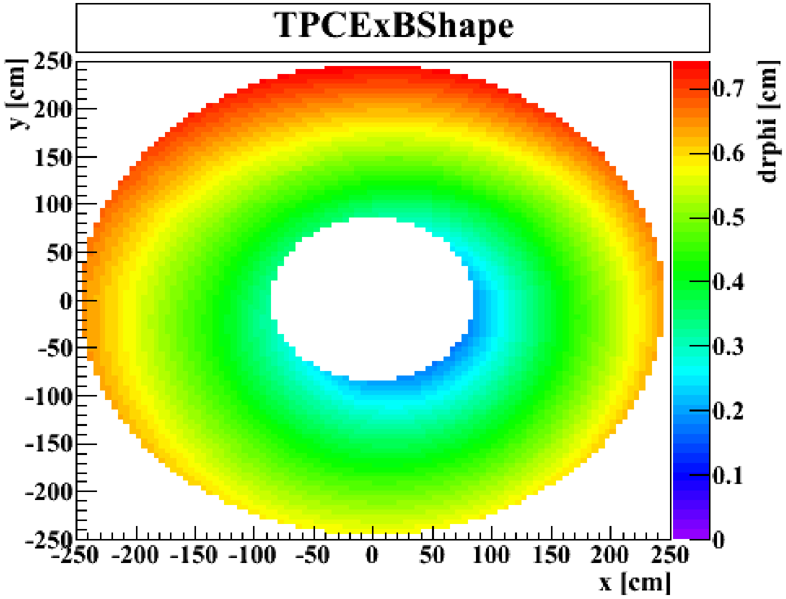
Figure 3: Simplified class diagram showing the inheritance structure and the most general functions

Misalignment, E field misalignment or charging up of the TPC boundaries (ROC,FC, CE) leads to static and semistatic distortion

Run 1 data corrected using set of analytical model (No outer detectors available in that time)
Composed distortion - linear combination of partial distortion

Space point distortion due B field.





Input data – integral of B field map

Parameters to validate/fit:

- T1, T2, omega-tau
- Gas dependent

Special runs to validate models and to extract parameters:

- B-field scan
- E-field scan

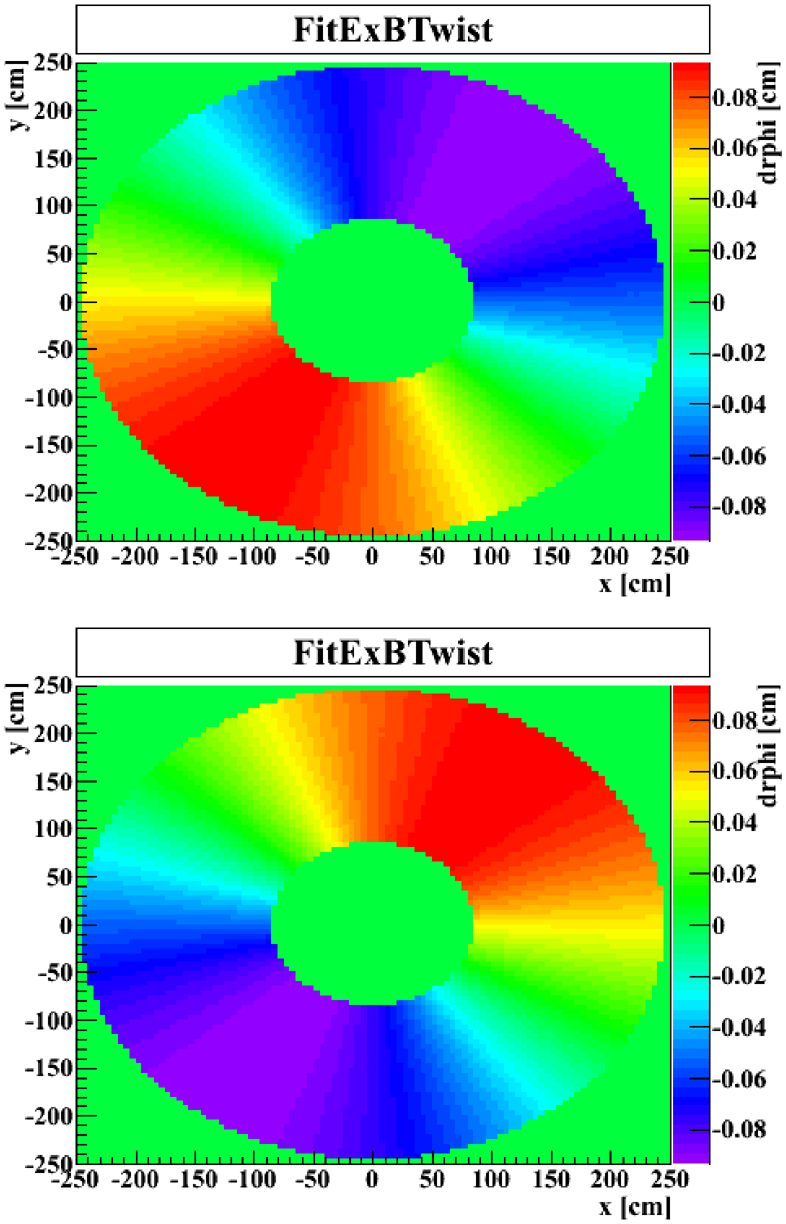
Time dependence:

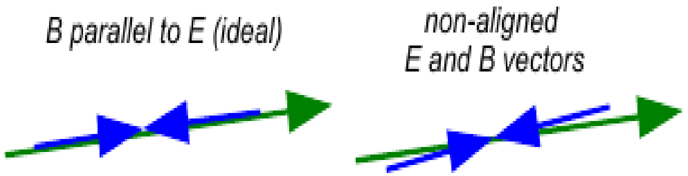
- Omega-tau – depends on the time in similar way as the drift velocity
-

Following the alignment and ωτ - v_{drift}

No sharp gradient

ExB twist





Space point distortion due global misalignment of the magnetic field and E-field in the TPC drift volume

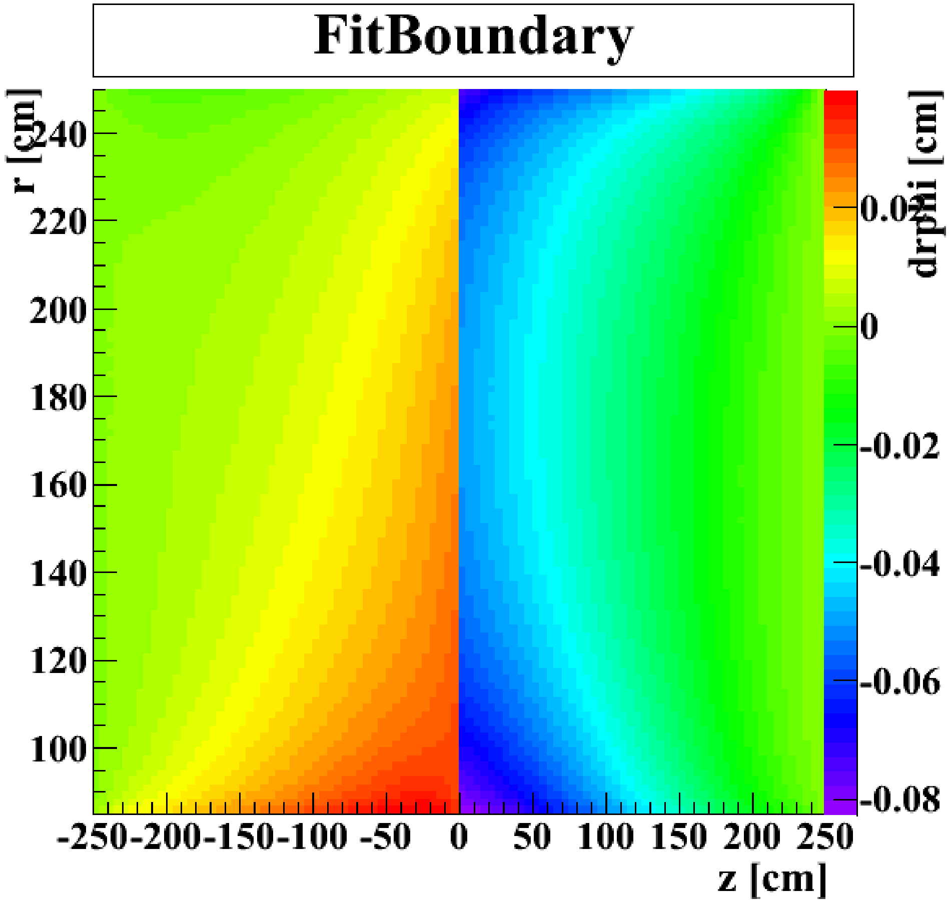
2 parameters to fit

Time dependence:

Following the alignment and $\omega\tau$ - v_{drift}

No sharp gradient

Boundary voltage



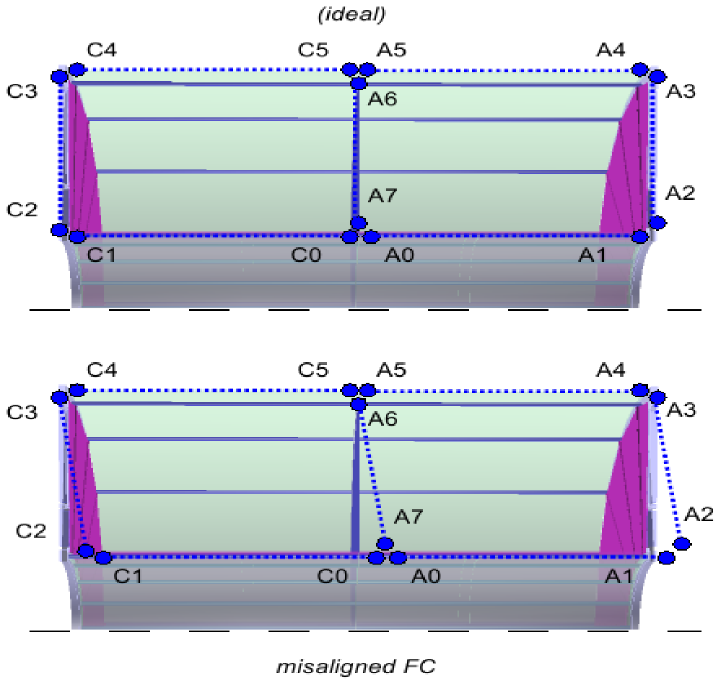
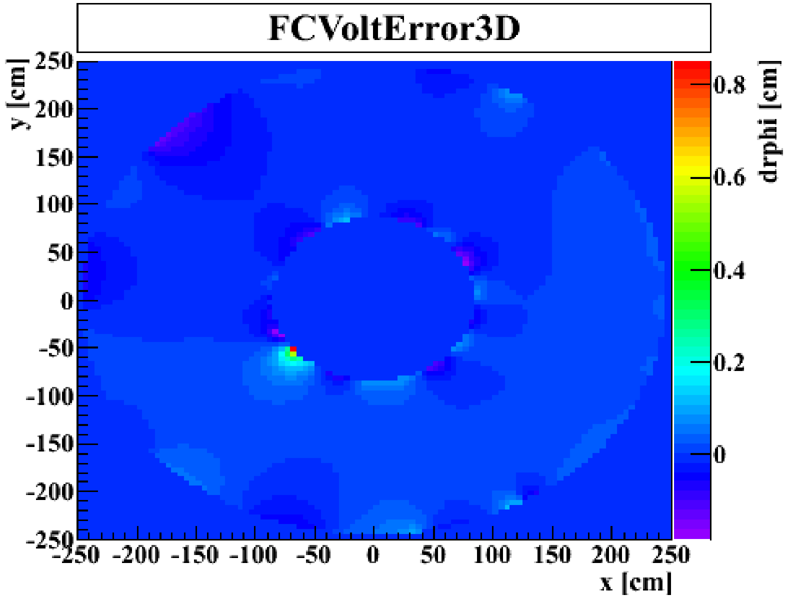
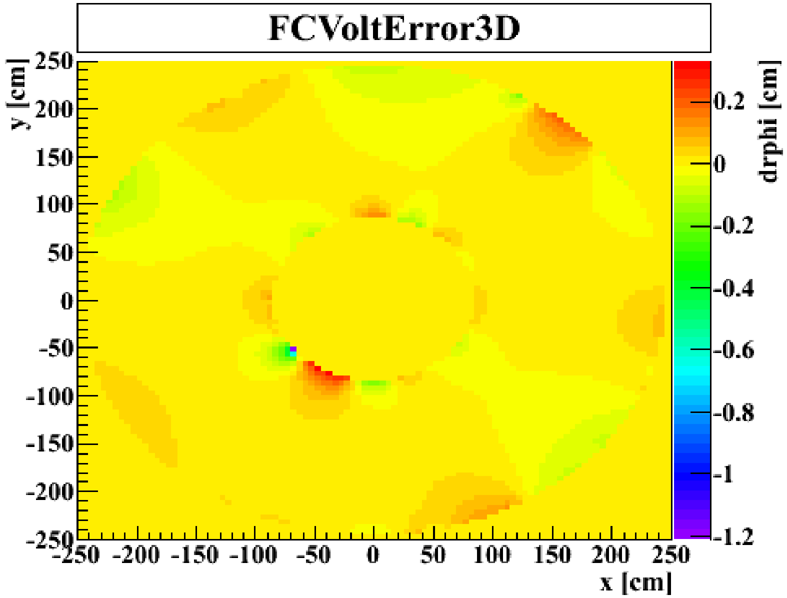


Figure 5: Numbering scheme of the vectors to set the Boundary conditions in AliTPCBoundaryVoltError. Top: ideal case, bottom: conical deformation of 1 mm at the IFC (e.g. $A0 = A1 = A2 = A7 = 40V$ and $C0, C1, C2 = -40V$)

Static
No sharp gradient

Field cage and Rod alignment





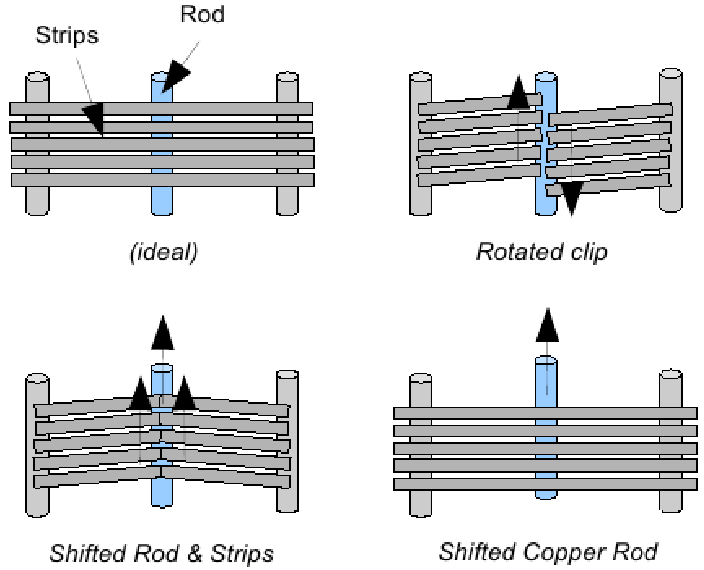
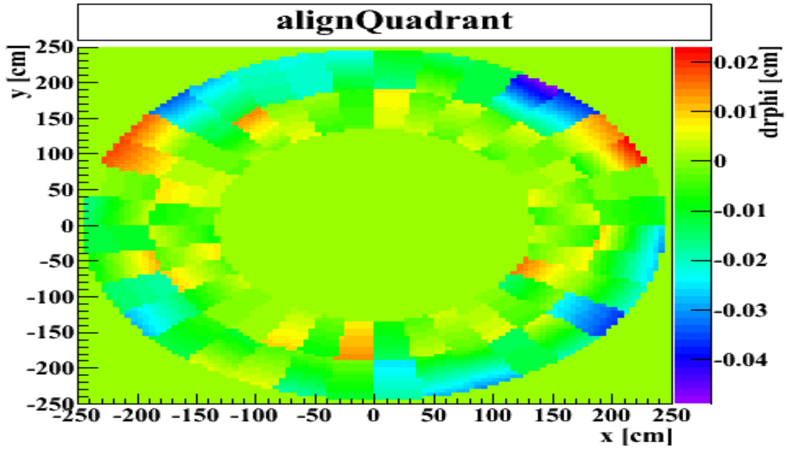
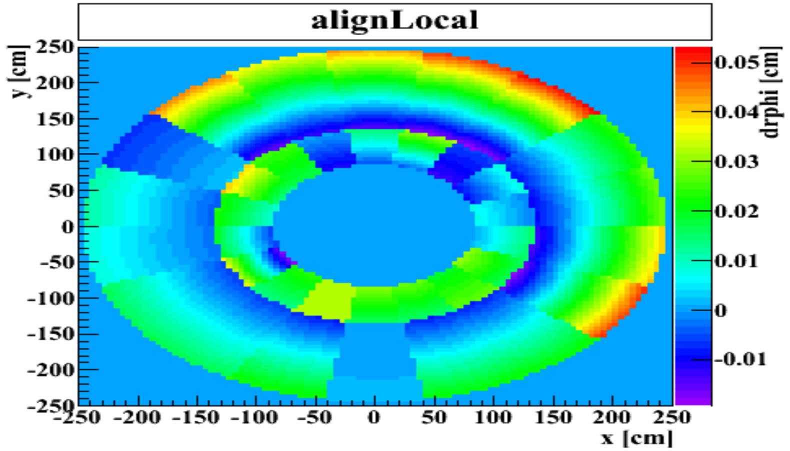


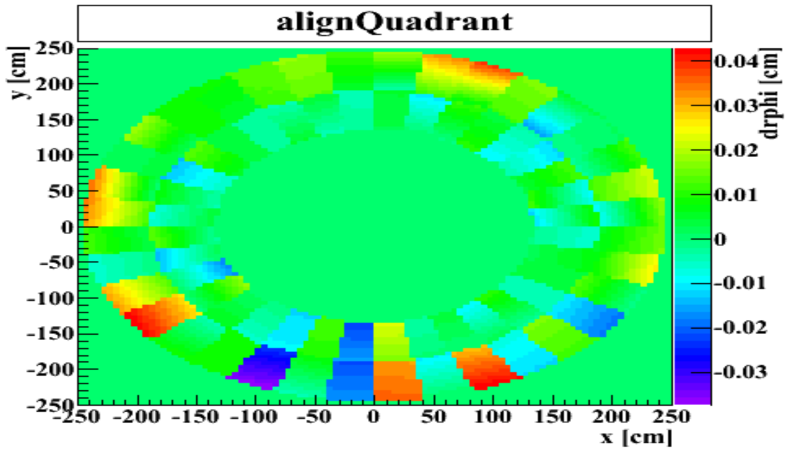
Figure 7: Misalignment scenarios of the FC components at each rod

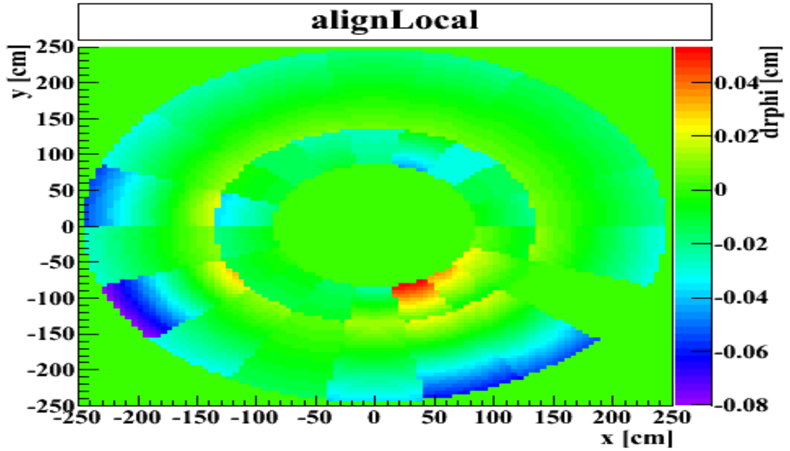
- 18 (rods) x 2 (IFC,OFC) x 2 (A side, C-side)
- 2 rotated clips x 2 (A side, C-side)
- B field 0 data used for the alignment/calibration
  - Fitting of the distortion maps

Sharp gradient
Rod - semi-static.



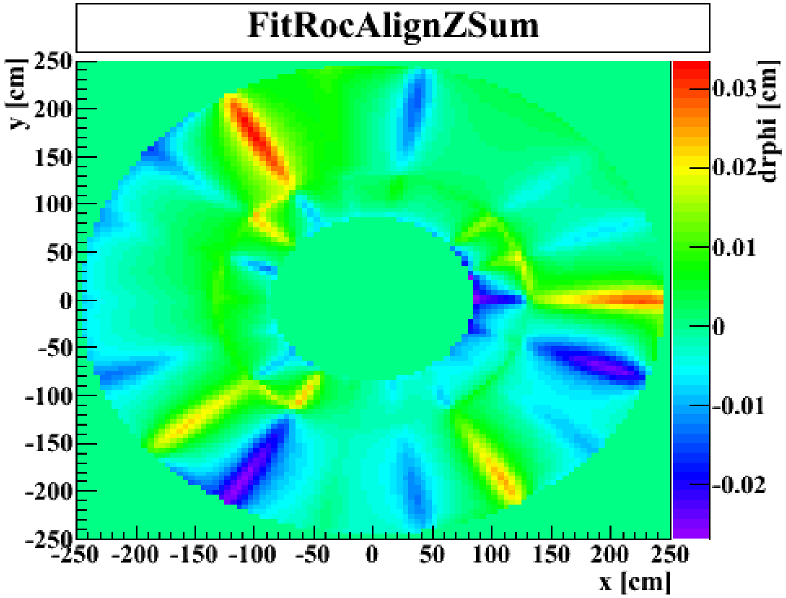






Sharp gradient. Semi-static.
In Run 3 misalignment bigger than in Run1

ROC z alignment



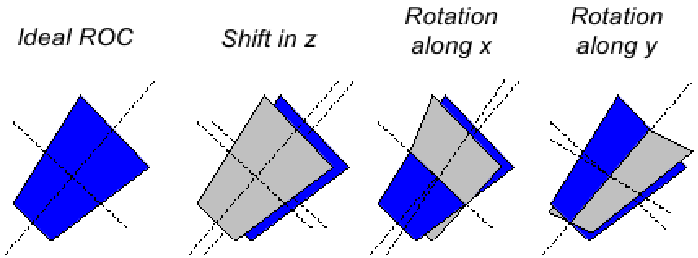
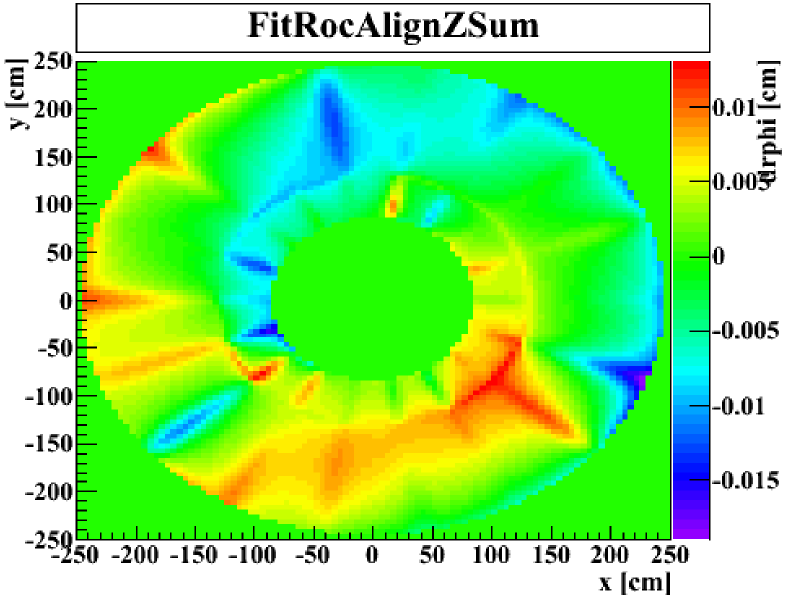


Figure 8: Misalignment scenarios of the ROCs in z

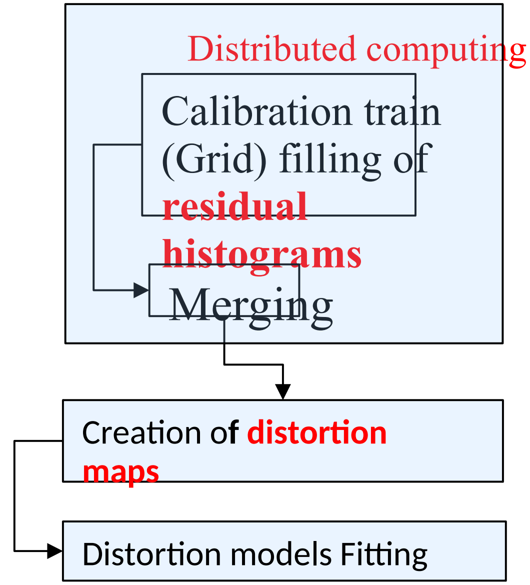


Modification of the E field due misalignment →
Sharp gradient in distortion close to ROC boundaries
Semi-static.
In Run 3 misalignment bigger than in Run1

RUN1: TPC Distortion/Alignment Fitting

Assumptions:

- Space point distortion transformation commute (the order of applying of corrections is not important)
- Space point distortion can be approximated as a linear combination of the "partial distortion" functions with given parameter:
  - $\Delta = \Sigma \; ki \; Ei$
- Space point distortion not directly observed. We define the set of observables O.
  - $\Delta O = \Sigma \; ki \; Oei$
- Under given assumption the analytical (non iterative) global minimization of distortion maps can be performed solving the set of linear equations.
- Assumptions were tested for the typical distortion in the TPC, moreover the assumption were tested also for the fitted parameters.



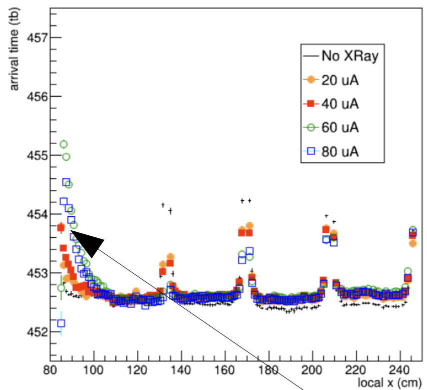
Distortion calibration (Linear fits using libStat)

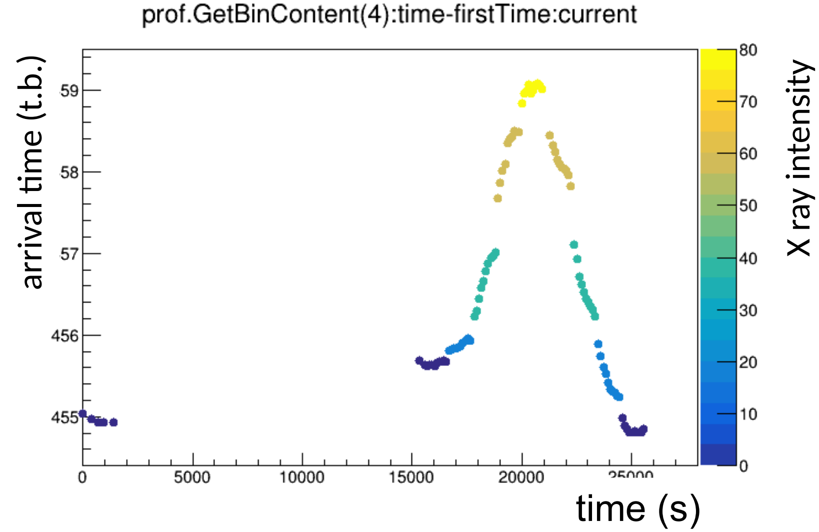
- Input data observables and fit models from the tree
- Possibility to add constrains
- Possibility to check differntialy the the fit values (return value of the FitPlaneConstrain)
- Extraction of the partial fits

Run 1 calibration based mostly on the track matching (vertex, external tracks)
In Run 2, Run 3 -calibration simpler - using point - track interpolation residuals
For some type of calibration and calibration QA track/vertex matching will be used

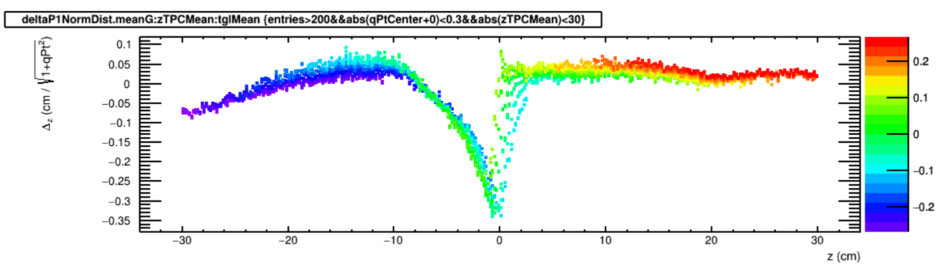
Central electrode charge up

- X-Ray load changes arrival time
- 60uA was run after 80uA in time
- Strong indication of charge-up
- Would be good to have X-Ray + laser from A-Side
- Cross-check with laser tracks
  - Expectation: time distortions should only be seen in last laser layer, closest to CE





TPC DCAz (Run2 - cpass1_pass3)



Distortion in the TPC on the C side close to the Central electrode (R~<100 cm, z~5 cm)

Observed already in Run 1 and Run2 → bigger in Run3

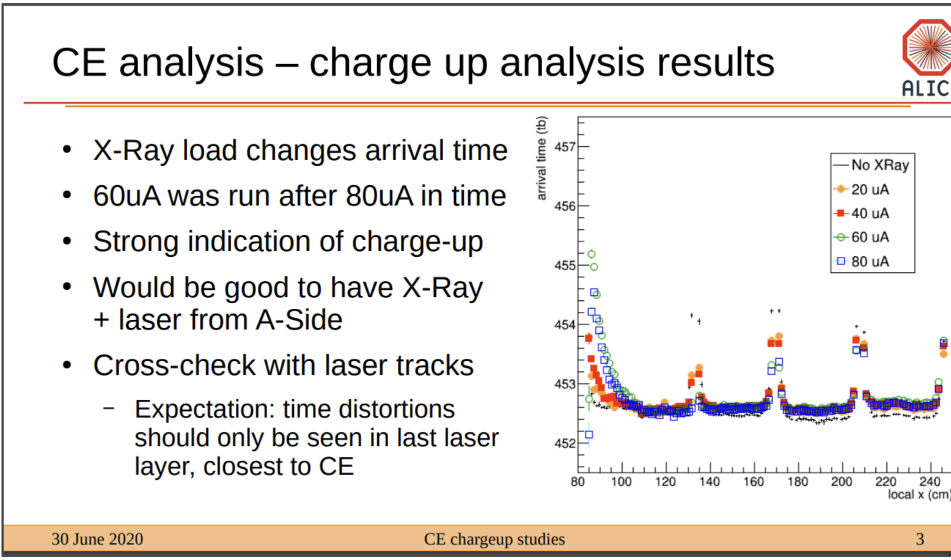
Not perfectly corrected using Run2 type calibration

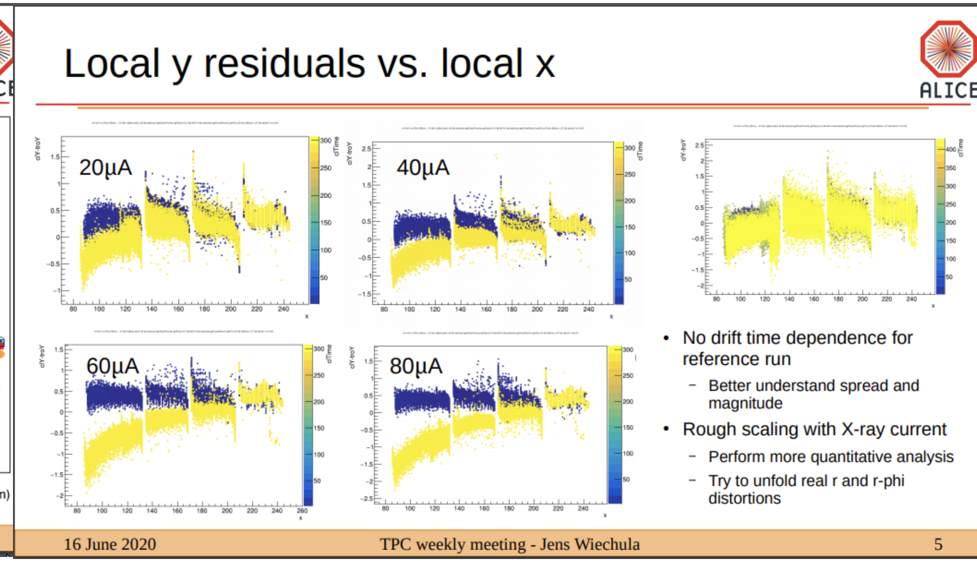
- too strong gradient for standard procedures

Changing in time - flux convoluted in time - (2 time constants?)

Strong gradient -not catched by default procedure
Time constants ~ O(minute)
In Run 3 impact bigger than in Run1
Template fit (similar to RUN1 type) to be tested - fitting charge

GEM charging up





Distrotion between stack - modification of the arival time and seen also in R and Rφ distortion

- non perfect E field alignment

Charging up observed ?

- I assume similar as for CE C side

Strong gradient
Time constants ~ O(minute) ?
New in Run3
Template fit (similar to RUN1 type) to be tested - fitting charge

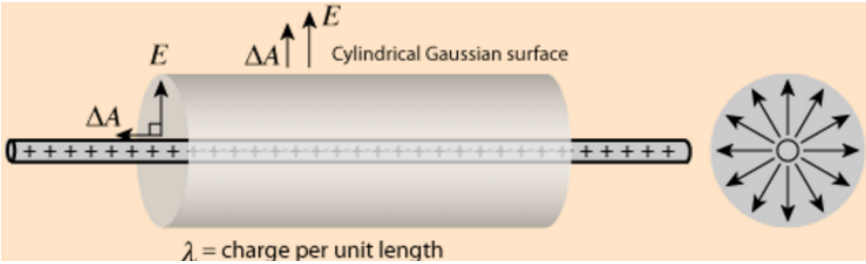
For sicsussion - RUN2 - Distortion fit model Validation of numerical calculation using real data

example test case - line charge

simulation and validation of the boundary effect critical

Electric Field of Line Charge

The electric field of an **infinite line charge** with a uniform linear charge density can be obtained by a using **Gauss' law.**



$$|E(\Delta_R)| = \frac{\lambda}{2\pi\epsilon\Delta_R}$$

$$E(r, r\phi) = \sum \frac{Q_i}{\Delta R_i}$$

Fit model

Set of individual small hotshots, producing line charge.

- occupancy analysis (ref.)
- $\delta(\Delta R)/\delta R$ analysis

Infinite line approximation used in following slides, to obtain initial parameters for full E field calculation

$$E(r, r\phi) = \sum_{i=0}^{N_s} \frac{\lambda_i}{\sqrt{(r - r_i)^2 + (r\phi - r\phi_i)^2}}$$

Fit model

Infinite line approximation used in following slides, to obtain initial parameters for full E field calculation.

2- dimensional fit in **z bins:**

- Finite size (radius) of the ion line - introducing additional scaling parameter **Δ0**$_i$.
- ωτ used as a free fit parameter.

Automatic localization of the peaks - work in progress.

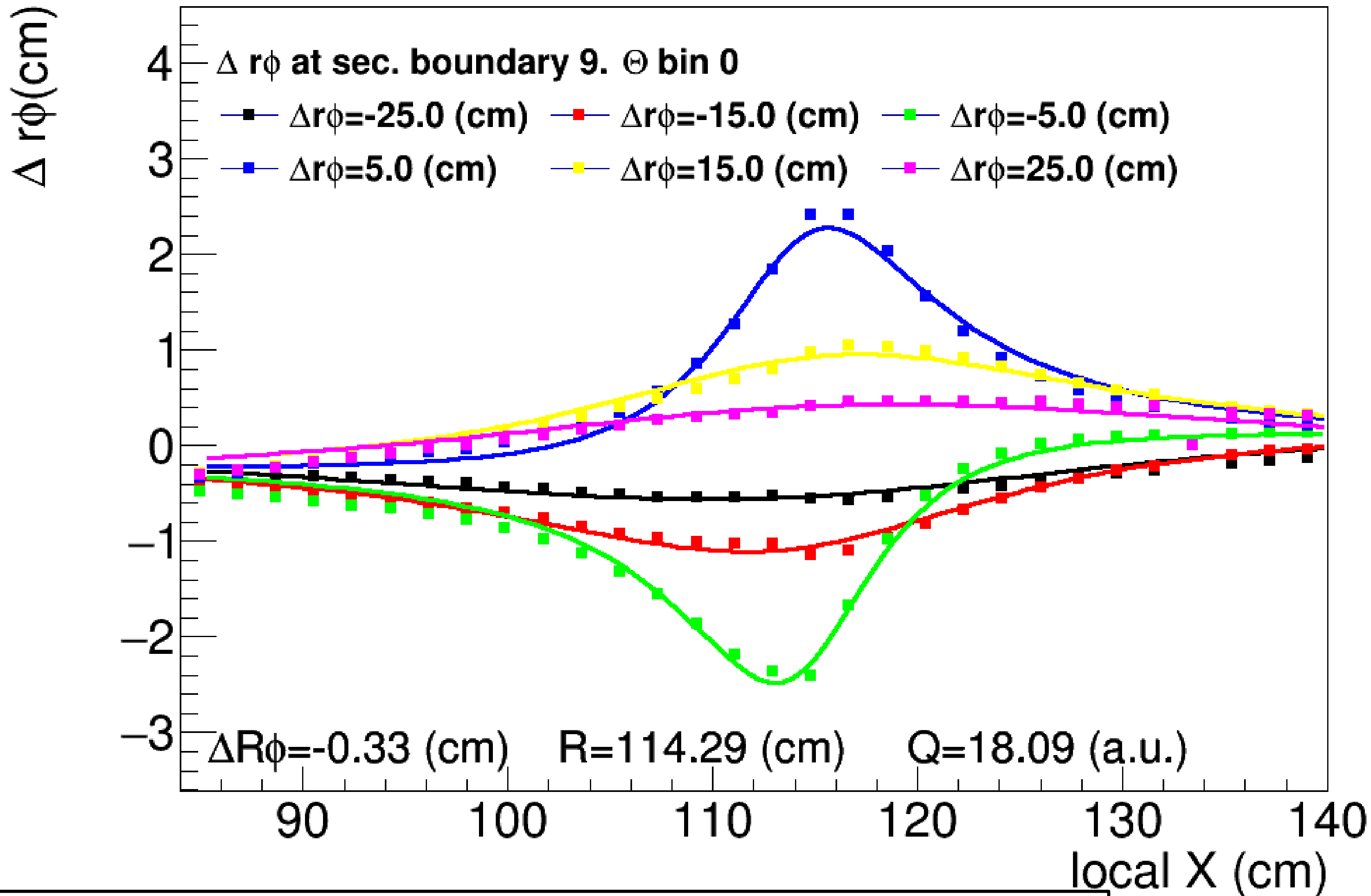
- Only one peak fits shown in next slides

$$\boxed{\begin{aligned} E_r(r, r\phi) &= \sum_{i=0}^{N_s} \frac{(r - r_i)\lambda_i}{(r - r_i)^2 + (r\phi - r\phi_i)^2 + \Delta 0_i^2} \\ E_{r\phi}(r, r\phi) &= \sum_{i=0}^{N_s} \frac{(r\phi - r\phi_i)\lambda_i}{(r - r_i)^2 + (r\phi - r\phi_i)^2 + \Delta 0_i^2} \end{aligned}}$$

$$\Delta_{r\phi} \approx E_{r\phi} + \omega\tau E_r$$

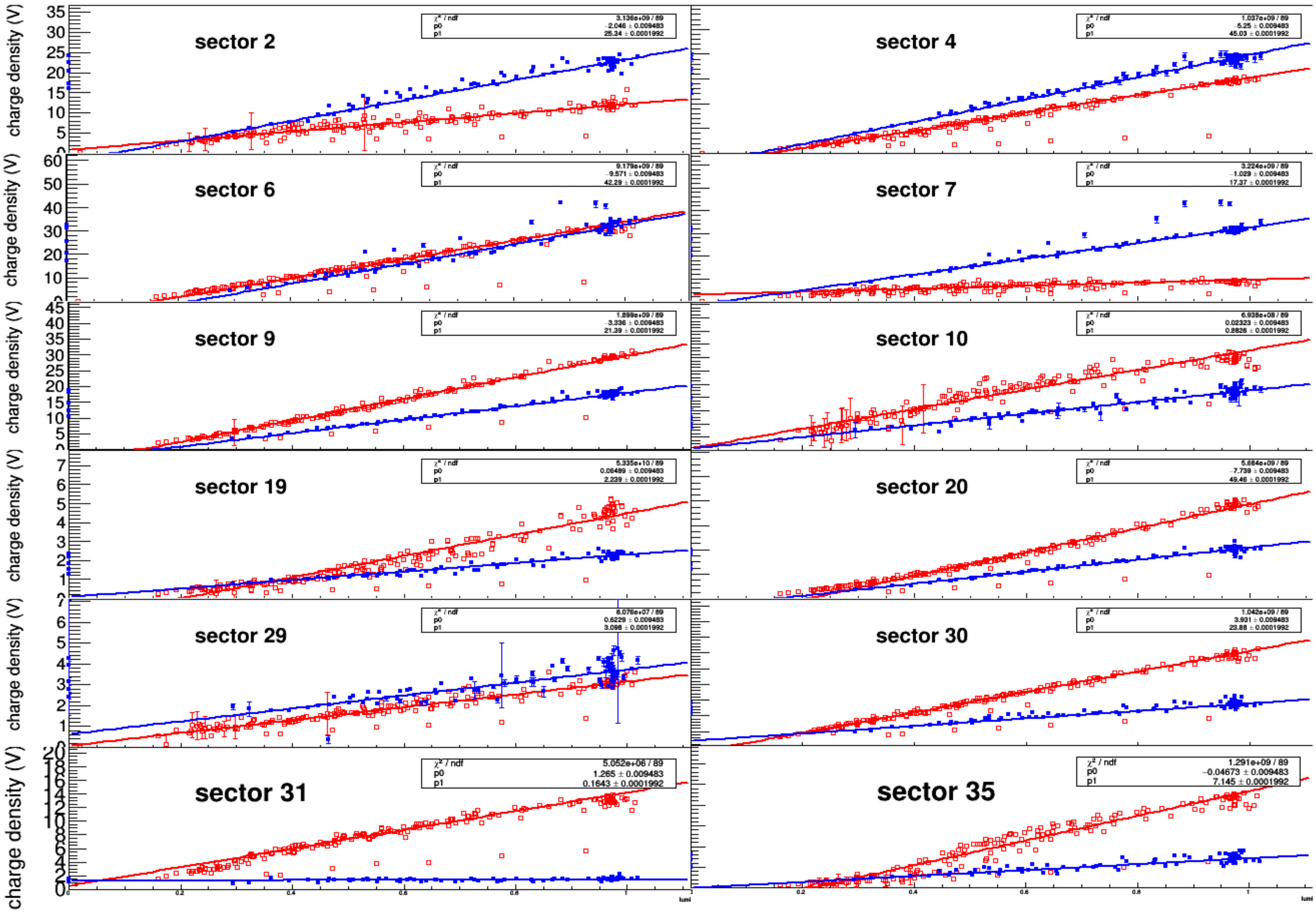
$$\Delta_r \approx E_r + \omega\tau E_{r\phi}$$

$\Delta r\phi$ fit example . Sector 9, θ bin 0.



Sector 9 - One peak

Line charge density (LHC15o)



Why is the RUN2 calibration not sufficient in RUN3?
Why do we have to understand origin of distortion?

RUN 2 distortion calibration. Assumptions summary

RUN2 distortion calibration was developed as a clone of original RUN3 Proof of concept calibration (TPC/TDR, 2013, MI, Jens, Enst)

- In our original RUN3 proposal we were considering to follow fluctuation time intervals

In RUN2, RUN3 schema could not be applied

- no continuous readout - not possible to follow fluctuations
- no current measurement
- moreover, some aspects were less critical (see next slides)
  - e.g. mean distortion in RUN2 was significantly smaller
  - in critical regions resolution significantly worse

We learned a lot in RUN2, but we should be aware of shortcomings

RUN 2 distortion calibration. Assumptions summary

Distortion commute

- Combined distortions due set of boundary error defects are liner combination of partial distrtions
- More less fine **space charge (SC)** distortion region far away from **boundaries error (BE)** region
- **Δ(SC+BE)!=Δ(SC)+ ΣΔ(BE), but**
- **Δ_L(SC+BE)!=Δ_L(SC)+ ΣΔ_L(BE)**

Distortion maps are linearly scaling with rate

- not valid even in RUN2

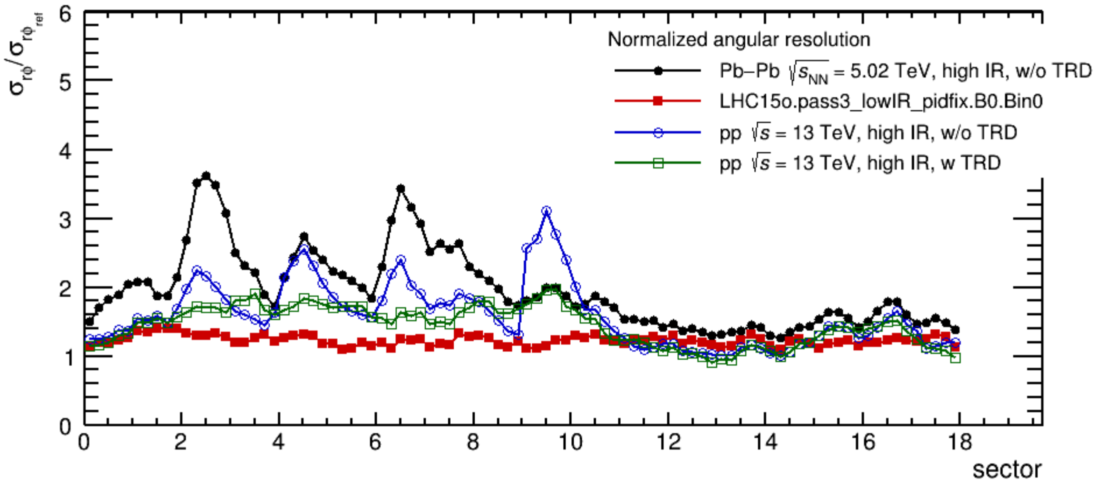
It is enough to correct mean distortion and assign big error to fluctuating regions

- enough in case small spots distortion as in the RUN2
- far not enough for RUN3 distortion - full TPC fluctuates

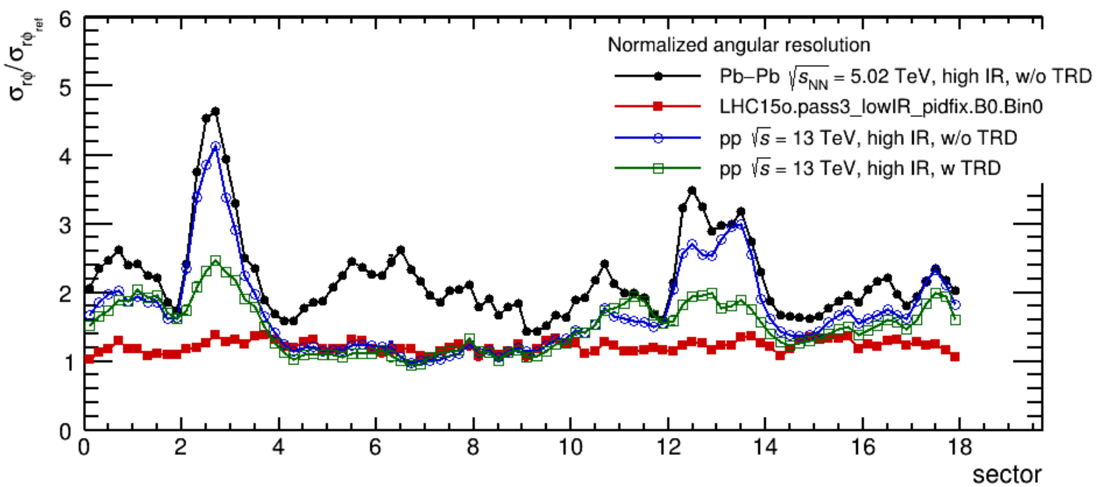
Distortion maps obtained in long calibration time intervals are not maps corresponding to mean currents but averaged distortion maps integrated over fluctuations

- **boundary errors are smear out in average - but not in reality**

RUN2: Impact of the residual fluctuation (TRD mitigation example)



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 O(3-5)**

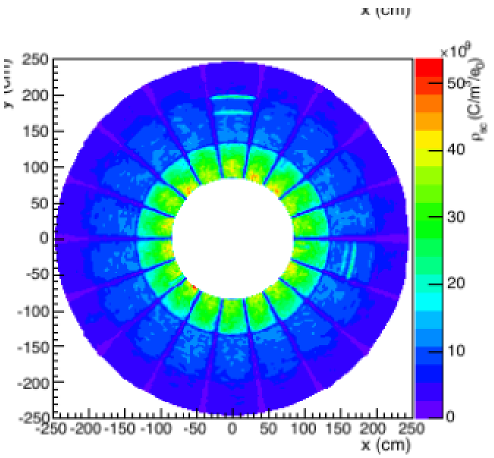
Using TRD significant improvement sector modulation reduced

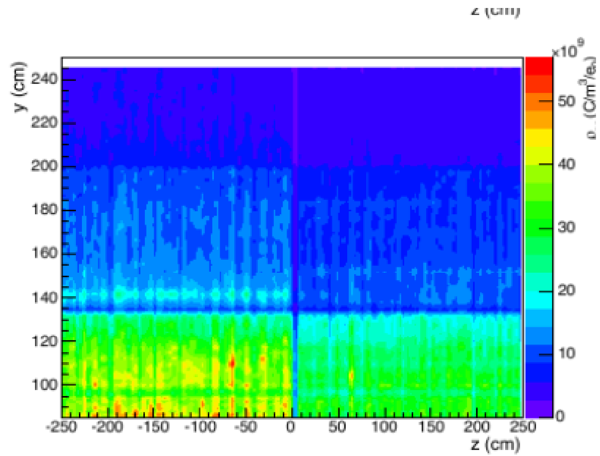
Using TRD more homogeneous performance

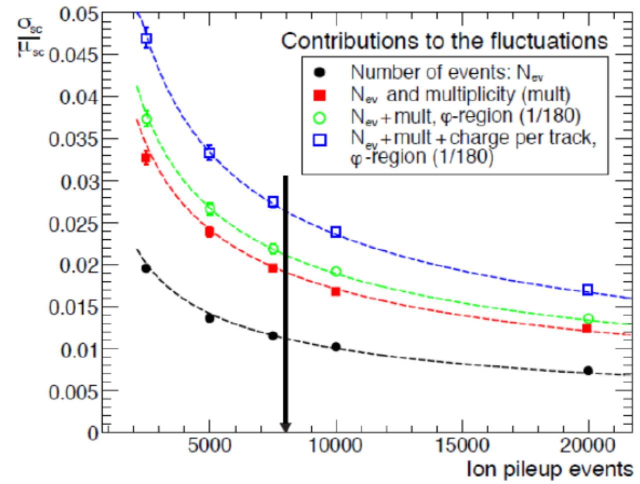
Overall performance better using TRD in refit

Reminder: Space charge density and distortion fluctuation origin and analytical models

Distortion fluctuation calibration (Old slide - 2019)







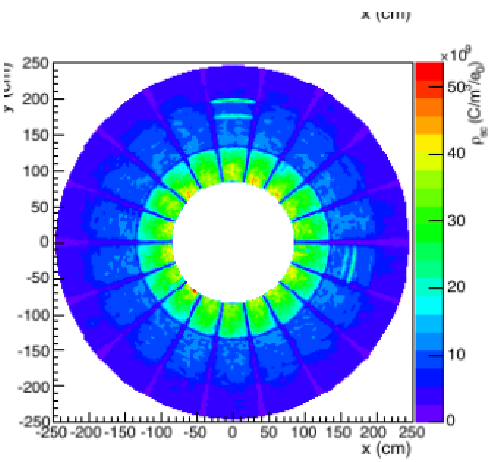
Space charge distortion distortion global and local fluctuation ~ 2-5 % (0.6-1.0 cm)

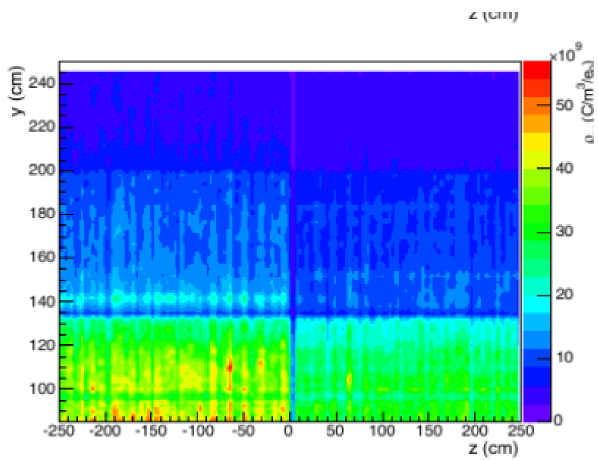
- Mean distortion to be calibrated using cluster - ITS-TRD+TOF residual maps O(s)-O(min)
- Calibration algorithm can (not?) follow fluctuation insufficient statistic

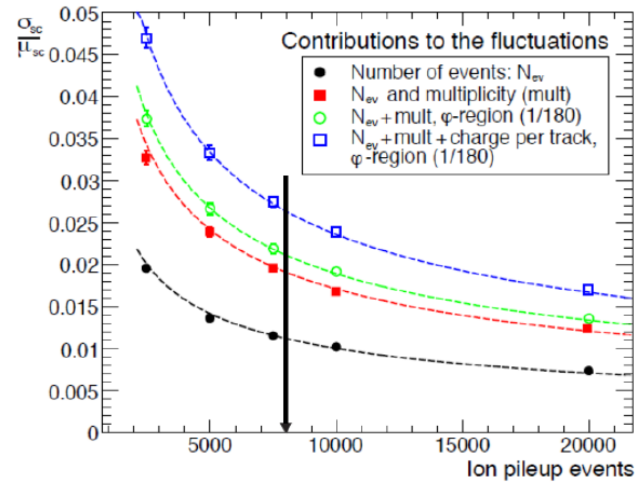
Fluctuation to be calibrated with time granularity ~ 5 ms

- Precise digital current to be used
  - Epsilon maps to be regularly updated
- **Convolutional Neural Network** (U-Net implementation) used in test
- TPC tracklet - track (combined and TPC only) residuals as an QA of the method and as a alternative calibration

Distortion fluctuation calibration: Data driven ?







Space charge distortion distortion global and local fluctuation ~ 3-5 % (0.6-1.0 cm)

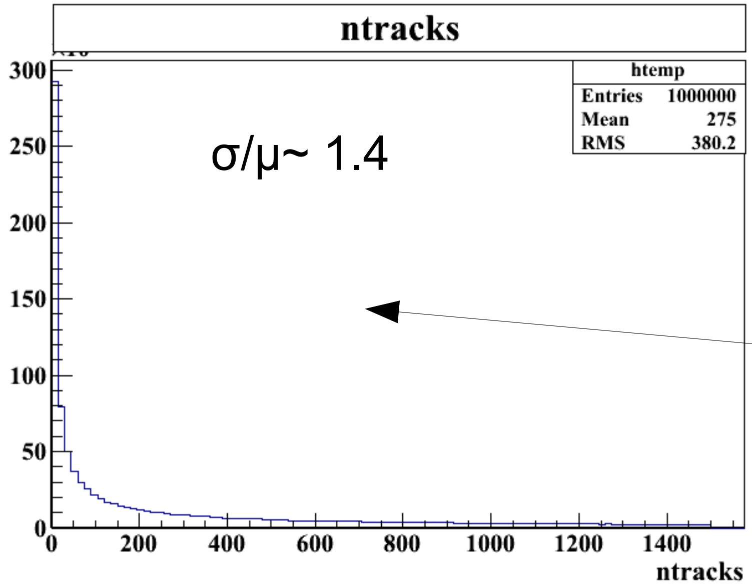
- Mean distortion to be calibrated using cluster - ITS-TRD+TOF residual maps O(s)-O(min)

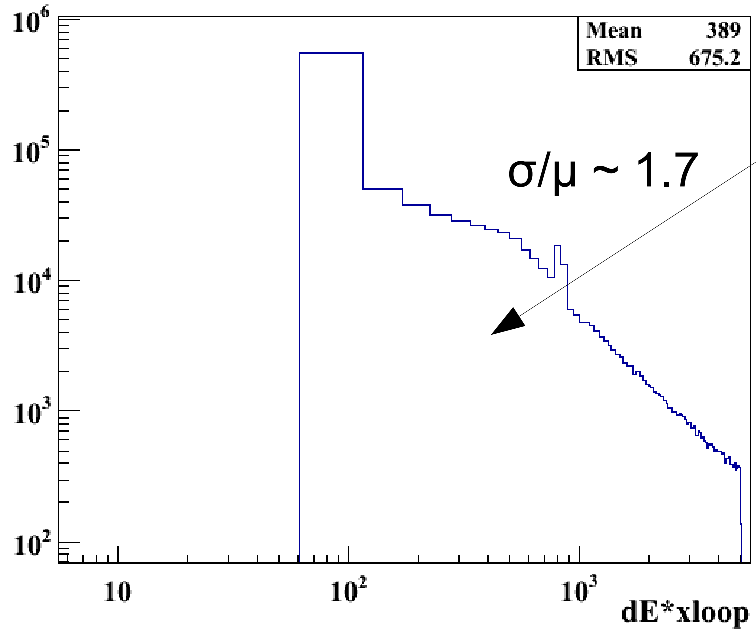
Algorithm can (not?) follow fluctuation insufficient statistic

New data driven (ITS-> TPC <-- TRD+TOF) method proposed

- new idea working on data augment for U-net

Charge density fluctuation: Processes (ToyMC)





What is fluctuating?

IRx t → N_e events within ion drift window (~0.2 s)

- Poisson distribution σ/μ =1/sqrt(Nev))

Event → N_t tracks - number of tracks per event

- MB multiplicity distribution σ/μ~ 1.4

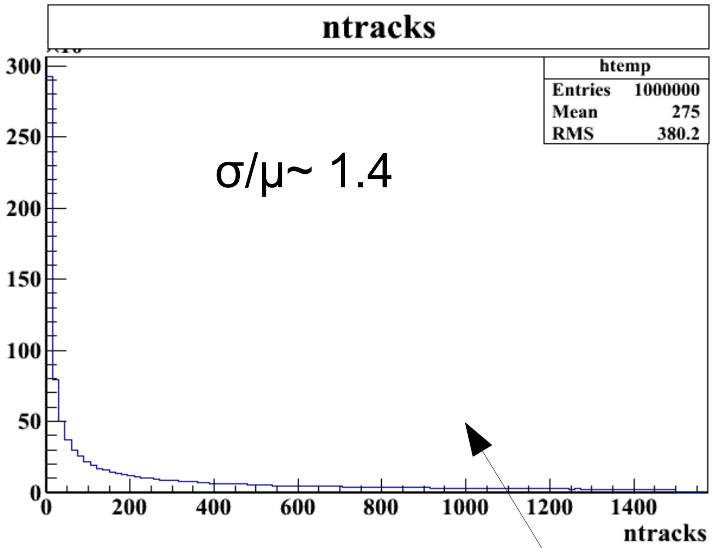
Nt tracks → tracks in region

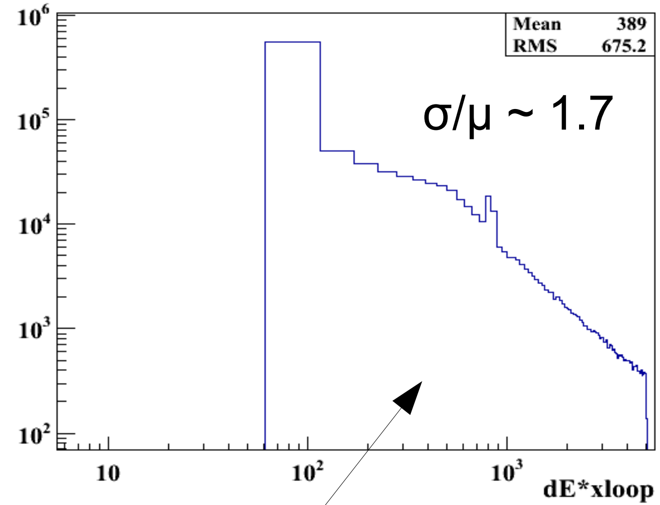
- Fraction 1/36 resp. 1/180. used

Track → dE - track energy deposit

- => σ/μ ~ 1.7

Density fluctuation: Analytical formula



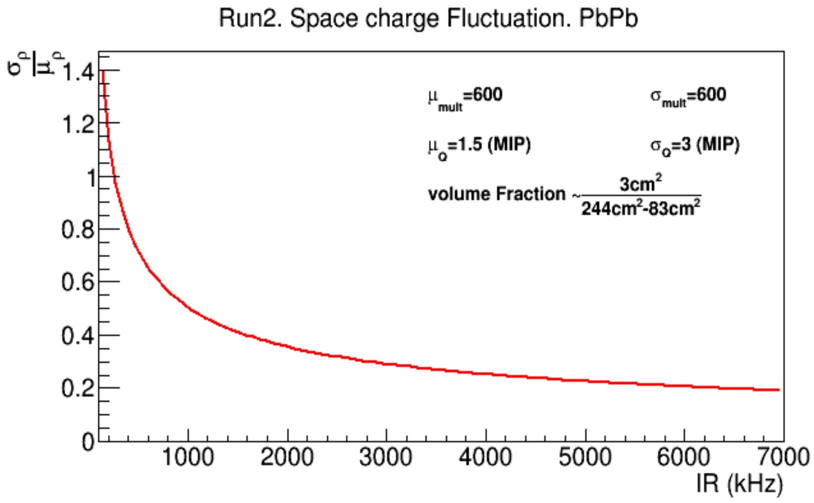


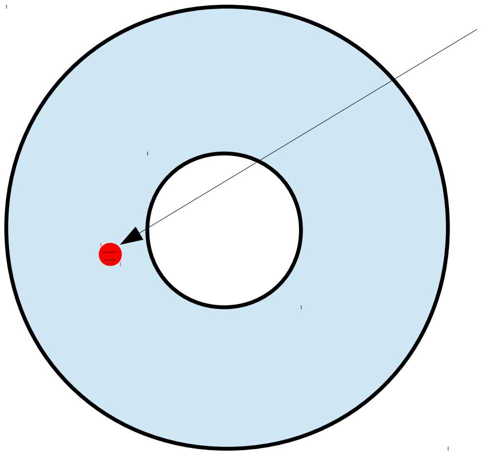
writen as

$$\frac{\sigma}{\mu} = \sqrt{\left(1+\frac{\sigma^2_{N_{MB}}}{\mu^2_{N_{MB}}}\right) + \left(1+\frac{\sigma^2_{N_Q}}{\mu^2_{N_Q}}\right)\frac{1}{F\mu_{N_{MB}}}}/\sqrt{\mathrm{IR}\Delta t}, \qquad (7.1)$$

where $\frac{\sigma_{N_{MB}}}{\mu_{N_{MB}}}$ is the relative spread of the number of tracks for MB events and $\frac{\sigma_{N_Q}}{\mu_{N_Q}}$ is the relative spread of the charge per one track. In toy MC the $\frac{\sigma_{N_{MB}}}{\mu_{N_{MB}}} \approx 1.4$ and the relative spread of the charge per track is $\frac{\sigma_{N_Q}}{\mu_{N_Q}} \approx 1.7$ mainly due looping low momenta tracks.

Space charge 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 the space charge

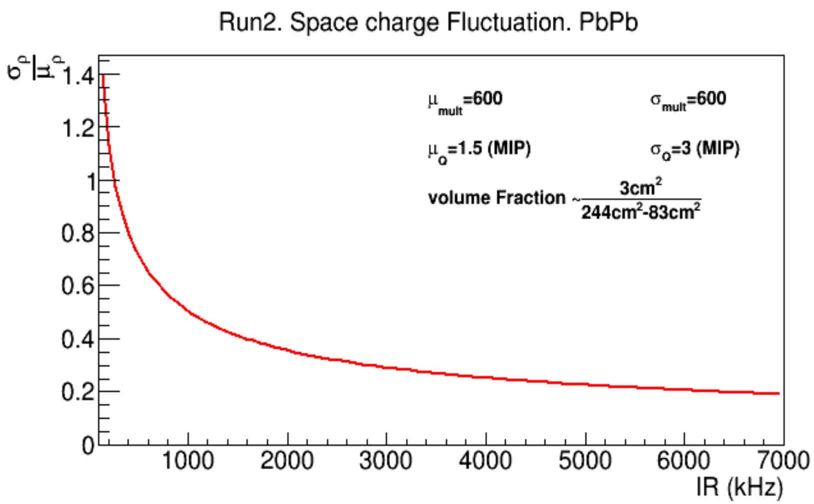
Limit cases:

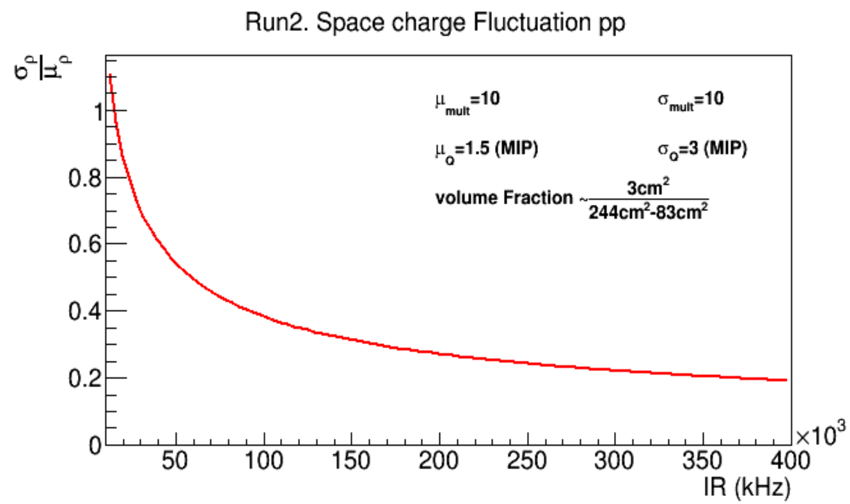
- big volume limit $1/(F\mu_{track})<<2 \rightarrow \sigma/\mu\text{~}\mathrm{sqrt}(1/N_{Events})$
- small volume limit $1/(F\mu_{track})>>2 \rightarrow \sigma/\mu\text{~}1/F^*\mathrm{sqrt}(1/N_{track})$

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

Run3 Pb-Pb O(2-5%)

Space charge fluctuation





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

Expected relative fluctuation of space charge

Significant relative fluctuation of the space charge

Limit cases:

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

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

Run3 Pb-Pb O(2-5%)

Current fluctuation as a white noise

Current fluctuation → Density fluctuation → Distortion fluctuation

$$i(r, r\phi, t) = \langle i(r, r\phi, t)\rangle + \Delta i(r, r\phi, t)$$

$$i(r, r\phi, t) = \langle i(r, r\phi, t)\rangle + \Delta i(r, r\phi, t) \quad (1)$$

$$\rho(r, r\phi, z) = \int_{t0}^{t0+\Delta_t} \epsilon(r, r\phi, t) i_{\mathrm{ROC}}(r, r\phi, t) + i_{\mathrm{DRIFT}}(r, r\phi, z, t) \mathrm{d}t \quad (2)$$

$$\vec{\Delta}(r, r\phi, z) = \vec{f}_\rho(\rho(r, r\phi, z) \quad (3)$$

$$\vec{\Delta}(r, r\phi, z) = \vec{f}_i(i(r, r\phi, t)) \quad (4)$$

1) Ion deposits around mean value **(white noise in time)**
2) Density can be obtained integrating currents along ion drift lines
3) Distortion Δ as function of density ρ (not measured experimentally)
4) **Goal: Distortion Δ as function of current i_{ROC}(r,rφ,t)**
    1) i_{ROC} measured experimentally, i_{ROC} ~ ε i_{DRIFT} → i_{ROC} >> i_{DRIFT}
    2) Ion feedback ε(r,rφ,t) is not well known. To be calibrated

Current fluctuation approximated as (Gausian) white noise

$$i(r, r\phi, t) = \langle i(r, r\phi, t)\rangle + \Delta i(r, r\phi, t) \qquad (1)$$

$$i(r, r\phi, t) = \langle i(r, r\phi, t)\rangle + \sum_{N=0} c_n \Phi_n(r, r\phi, t) \qquad (2)$$

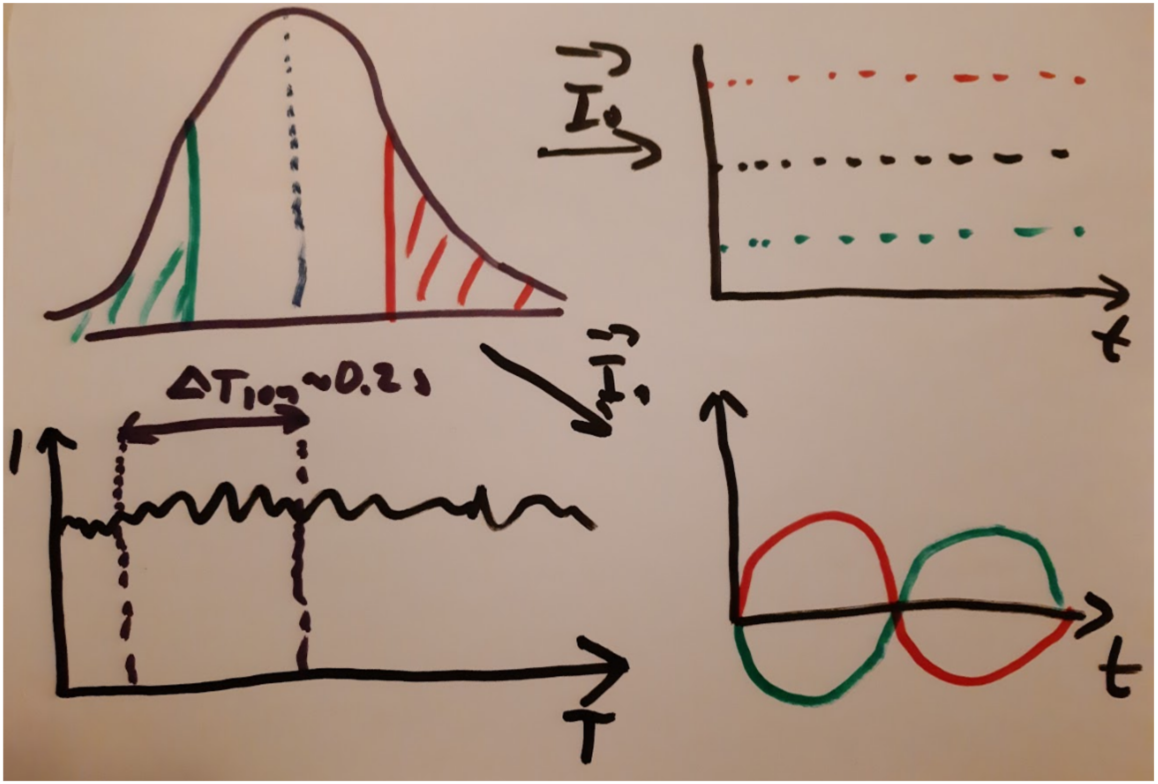
ΔI is a (~Gausian) white noise vector

A random vector is said to be a white noise vector or white random vector if its components each have a probability distribution with zero mean and finite variance, and are statistically independent

- *the covariance matrix R of the components of a white noise vector w with n elements must be an n by n diagonal matrix*
- *if in addition every variable in w also has a normal distribution with the same variance σ^2, w is said to be a* **Gaussian white noise vector**
- *under most types of discrete Fourier transform, such as FFT and Hartley, the transform W of w will be a Gaussian white noise vector*
- *Under that definition, a Gaussian white noise vector will have a perfectly* **flat power spectrum,** *with* $P_i = \sigma^2$ *for all i.*

https://en.wikipedia.org/wiki/White_noise

Current fluctuation as white noise



Example timings:

$T_{calibration}$ ~ O(1 min)

$T_{ion\ drift}$ ~ O(0.2s)

$T_{sampling}$ ~O(0.01s)

→

Within example calibration time interval:

- O(300) full ion drift
- O(6000) calibration Δ windows

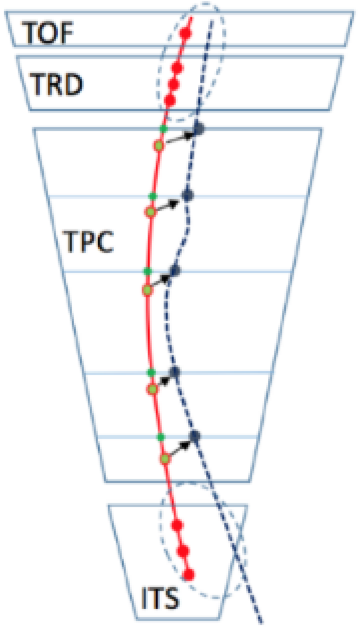
Fourier coefficient c_n extracted for each Δ window

- PDF μ=0, σ
- Fourier coefficient c_n independent

Selecting Δ windows based on c_n percentile - **Upper**/**Middle**/**Lower** (e.g. 20 % percentile)

- averaging over Δ windows - mean currents for given frequency can be selected

Data driven distortion calibration Δ as function of current i(r,rφ,t)



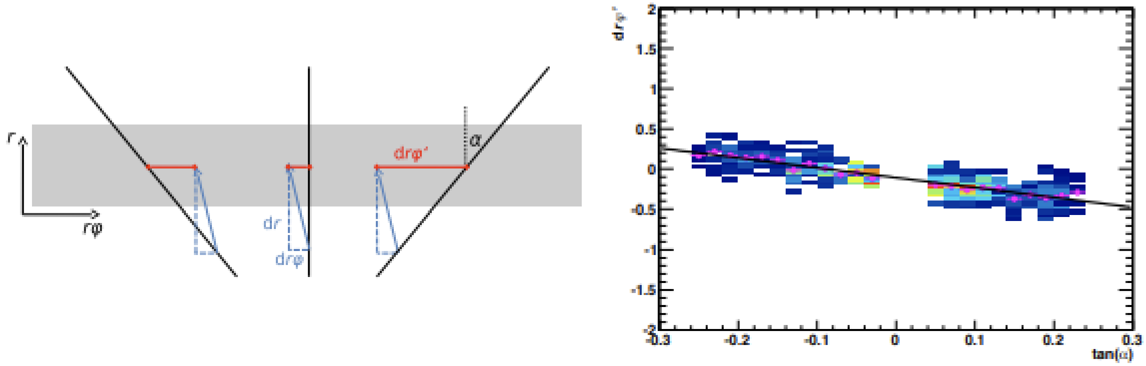
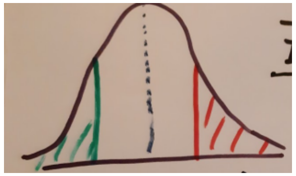


Figure 8.8: (Left) Illustration of the measured $r\varphi$ distortions being composed of the real $r\varphi$ distorions and the radial distortions, shown for three example tracks crossing a pad row (grey area) under different local track inclination angles α. (Right) Measured correlation between $dr\varphi'$ and $\tan(\alpha)$ (see text).



Standard distortion calibration extracted for specially triggered Δ time windows

- percentile of overall statistics used - should be precise enough
- c_n statistic reused

$\Delta_n(r,r\varphi,z) = f_n(c_n\Phi_j)$

$\Delta_n(r,r\varphi,z) = f_n(c_n\Phi_j)$

$$i(r, r\phi, t) = \langle i(r, r\phi, t)\rangle + \Delta i(r, r\phi, t) \quad (1)$$

$$i(r, r\phi, t) = \langle i(r, r\phi, t)\rangle + \sum_{N=0} c_n \Phi_n(r, r\phi, t) \quad (2)$$

Digital Currents generalized Fourier decomposition

$$\vec{\Delta}(r, r\phi, z) = \vec{f}_i(i(r, r\phi, t)) \quad (1)$$

$$\vec{\Delta}(r, r\phi, z) = \overrightarrow{f_{<i>}}(\langle i(r, r\phi, t)\rangle) + \overrightarrow{f_{\Delta_i}}((r, r\phi, t)) \quad (2)$$

$$\vec{\Delta}(r, r\phi, z) = \overrightarrow{f_{<i>}}(\langle i(r, r\phi, t)\rangle) + \sum_{n=0}^{N} c_n \vec{f}_n(\Phi_n(r, r\phi, t)) \quad (3)$$

Distortion decomposition - to be proven
Special treatment of the boundary condition

To do and open questions

Test to be done using Toy MC event input or O2 events

1) Test: c_n orthogonality assumptions for digital current
2) Test: Non triggered frequencies should vanish in average current
3) How many fourier transform needed - In previous studies (5-10 ms ?)
4) Test "linearity"assumptions for composed distortion
5) Could be $\Delta_n = f_n(\Phi_n)$ approximated by "trivial function" and Δ_0
    1) do we need N maps or is one Δ_0 sufficient

Calibrated distortion maps are obtained as averaged map for given mean current

- Distortion fluctuation typical higher than distortion due boudary effect
    - e.g. O(1 cm) for CE charging up
- Could we obtained "real" map by deconvolution e.g. using Δ_0 Kernel

Distortion fluctuation calibration using ND pipeline

Histogram based similar to original implementation

- Using RUN2 type of calibration - procedure to be repeated several times

Algorithm:

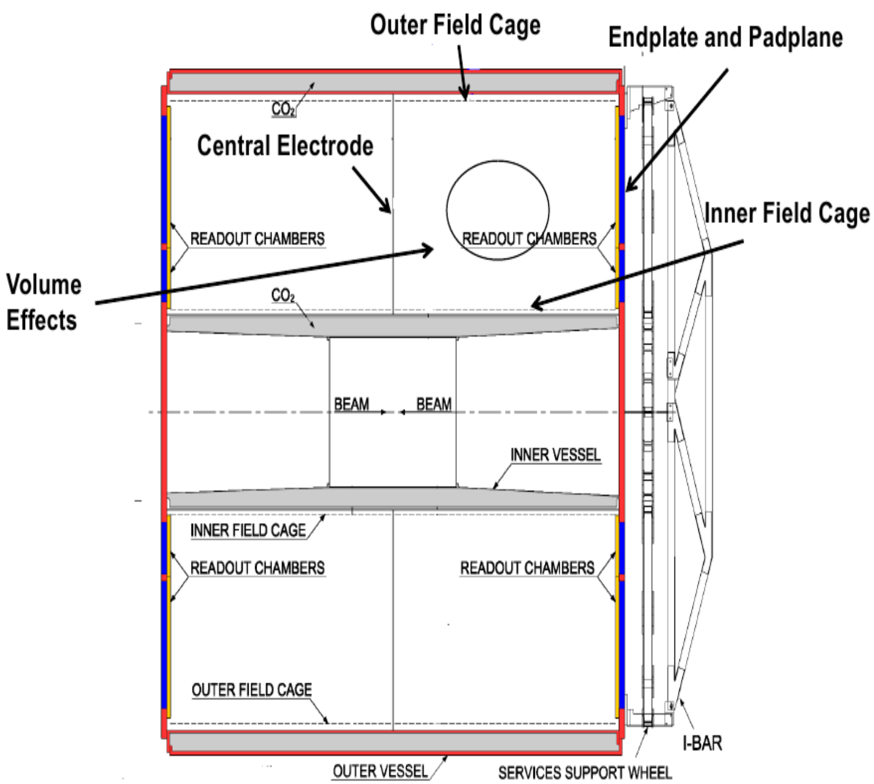
1) Residual extraction (similar as in RUN2)
   1) maybe try to use also TOF only (tagged by time match)
   2) Radial distortion at low R will profit from special trigger - flat z vertex
2) residual histogramming per $T_{sampling}$ (0.005-0.01 s)
   1) done once
3) histogram merging per Fourier coefficient group (n times)
4) distortion map (and mean current) extraction per Fourier coefficient (n times)

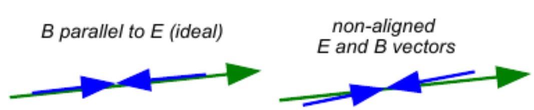
N dimensional pipeline (new version):

- PyTorch (CPU,GPU) based histogramming in progress
- TensorFlow/PyTorch (CPU, GPU) fitting in progress

In case f_n can be approximated by **$f_0 \int \Phi_n$ - (to be checked)** - procedure can faster as current implementation

Boundary error calibration.
Static and semistatic distortion





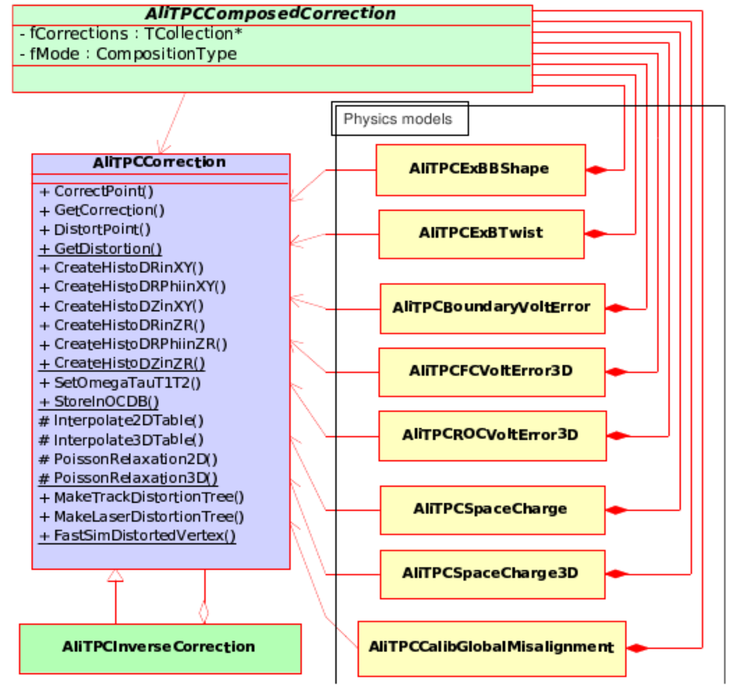
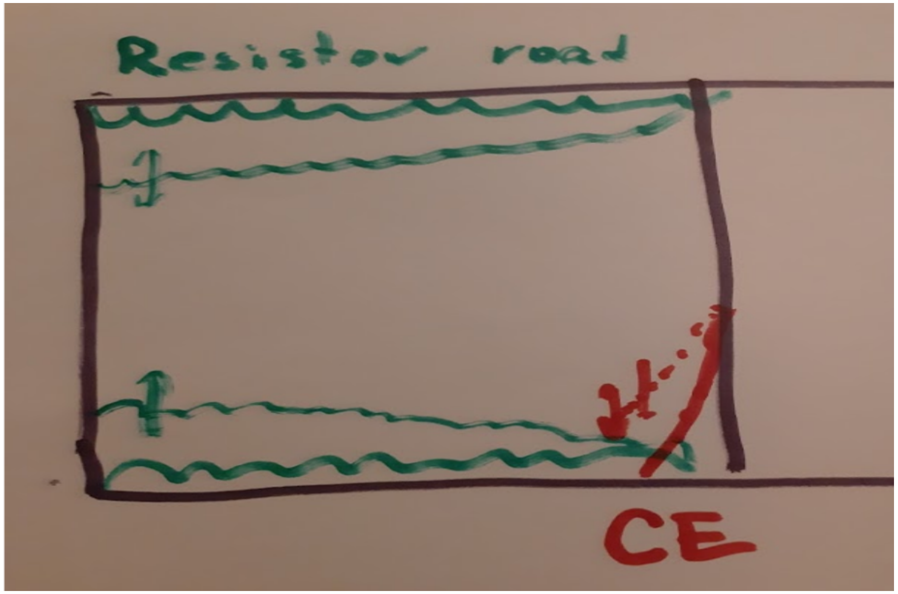


Figure 3: Simplified class diagram showing the inheritance structure and the most general functions

Run 1 data corrected using set of analytical model (No outer detectors available in that time)

Composed distortion - linear combination of partial distortion

Boundary effects and commutative of transformation



Distortion sources:
SC - Space charge
Boundary effects:

- **CE charging**
- **Resistor road granularity**
- Cover voltage misalignment
- ROC misalignment
- Resistor road misalignemnt

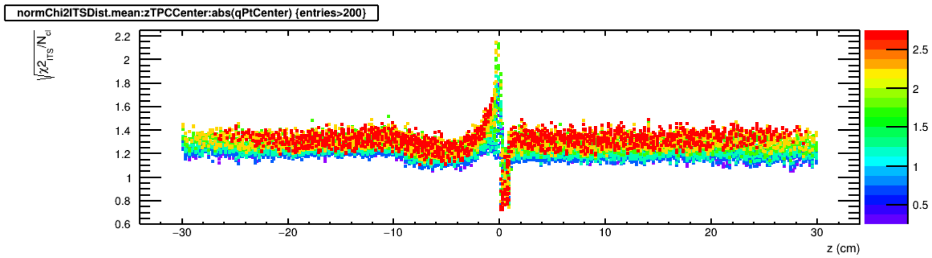
Commutative (distortion composition) in distortion calibration. Why is it important?

- integrated distortions does not commute
  - **$\Delta(SC+BE) != \Delta(SC) + \Sigma\Delta(BE)$**
- but local distortions commute
  - **$\Delta_L(SC+BE) = \Delta_L(SC) + \Sigma\Delta_L(BE)$**

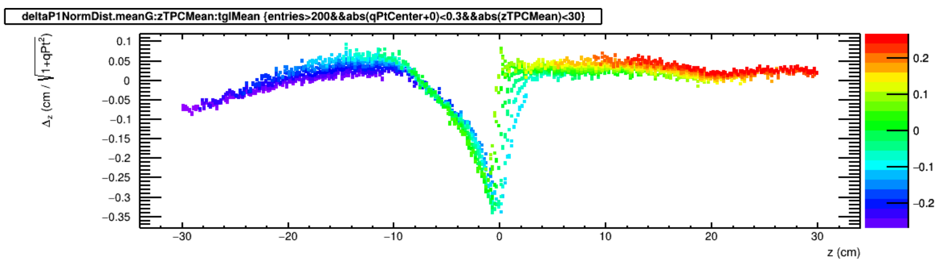
In mean distortion map, sharp boundary error distortion are "washed out"

Is it important ? Run 2 example Central electrode

ITS chi2 (cpass1_pass3)



TPC DCAz (cpass1_pass3)



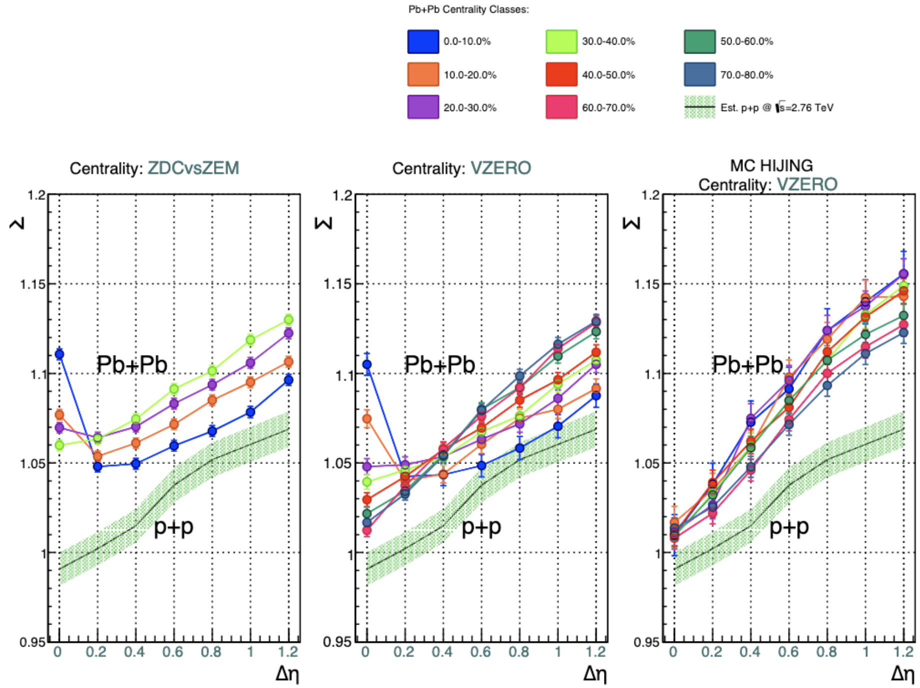


Figure 27: The value of the strongly intensive quantity sigma Σ obtained for Pb+Pb collisions at $\sqrt{s_{NN}} =$ 2.76 TeV in the ALICE experiment (circles) for 10% width of centrality class, plotted as a function of $\Delta\eta$. In the figure, the results for various centrality classes of Pb+Pb collisions, from central to peripheral reactions, are marked by different colors. The first two panels show values for experimental data for two

Residual mis-calibration due boundary error is affecting kinematical and QA variables an matching efficiency (see e.g. mean ITS chi2 and TPC DCAz bias)

- at RUN3 charging up (not proportional to IR) will be bigger

Depending on the track selection effect can be quite significant. Mostly in differential studies (see e.g correlation studies https://alice-notes.web.cern.ch/node/676)

- for central events ~ 10 % increase at central eta

Boundary error calibration

Most of the boundary error distortion are phi symmetric

- Central electrode φ symmetry
- ROC - cover φ%20 symmetry

Sharp edges - gradient comparable with RMS of distortion fluctuation

- in mean distortion map will be "smeared out"

For RUN3 calibration proposal is to calibrate BE separately:

- create "analytical model" or data driven template model
- in case distortion change in time (e.g charging up), partial maps to be re-scaled

Procedure should be tested with RUN2 data:

- Test scaling assumptions
- Provide higher quality RUN2 data

Machine learning consideration

U -Net - Symmetry breaking

Convolutional neural network- U net used ΔR(Δρ)

- translation symmetry assumption used
- **asymmetry in solution should only due asymmetries in ρ**

Distortion are not linearly scaling with density, **Local derivative of distortion are position dependent**

- distortions are saturating (e.g. can not be bigger than TPC size)
- additional information to be added to training
- **we propose experimentally measured local derivative**

Ion feedback (position dependent) need to be calibrated - not straightforward

- **using experimentally observed value of derivative preferable**

ExB is breaking symmetry:

- **Using rotated vector ΔR*,ΔRφ* instead of the ΔR, ΔRφ impact of symmetry breaking**

Neural network and boundary effect

Current version of neural network is ignoring distortion due boundary effect

- measured distortion maps edge distortion smeared by distortion fluctuation

Several ways to treat them in the future:

- **add boundary error to input simulation**
  - distortion due boundary error change in time (e.g CE charging up)
  - few (1 for the CE) parameter model preferable
- **add effective correction as a patch for the "standard" NN**
- **Disentangle between the space charge and BE using local distortion instead of the global distortion**

In all cases we should be ready with analytical models/templates for the boundary distortion in advance

- **obtain model/templates**
- **prepare time dependent calibration of model (local scaling)**

Granularity consideration

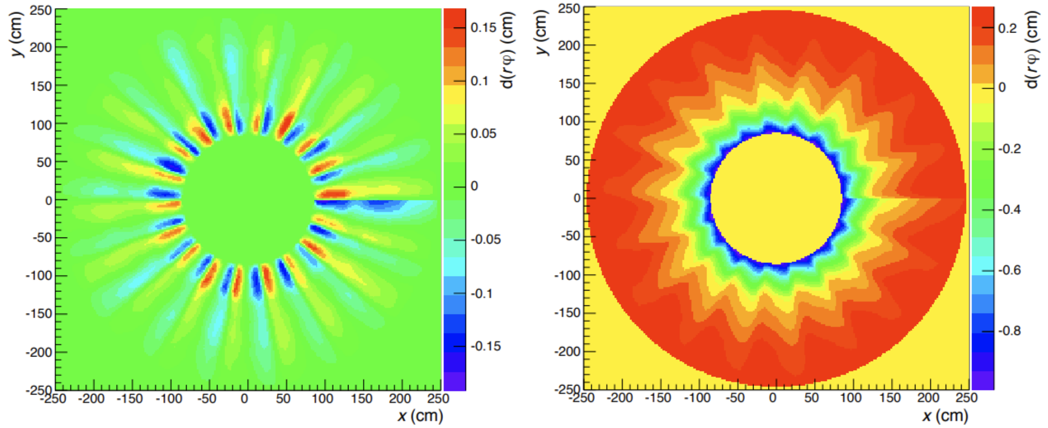
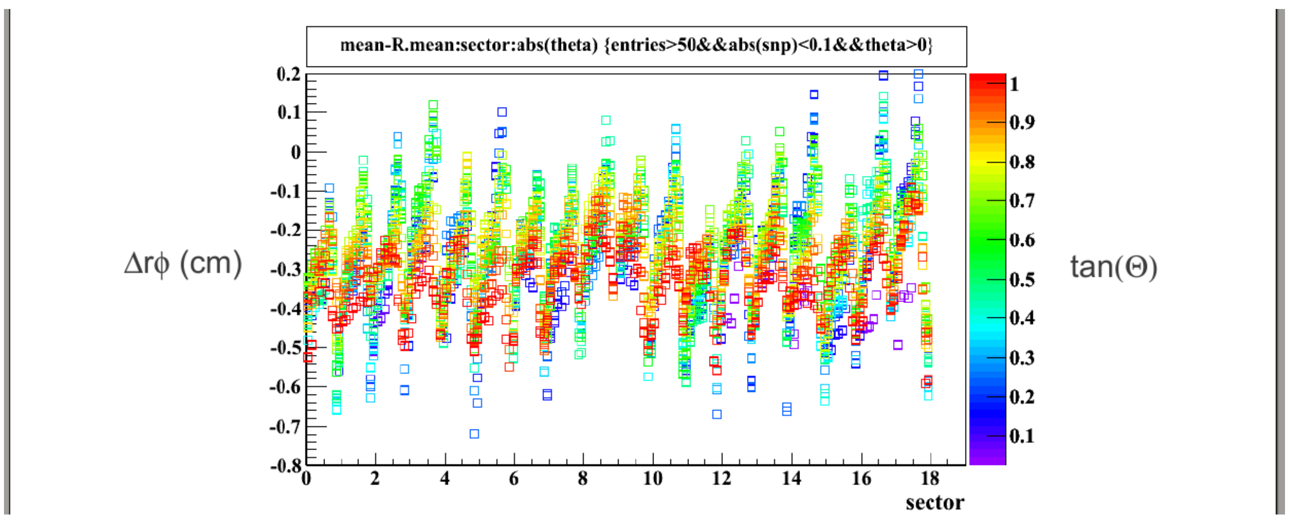
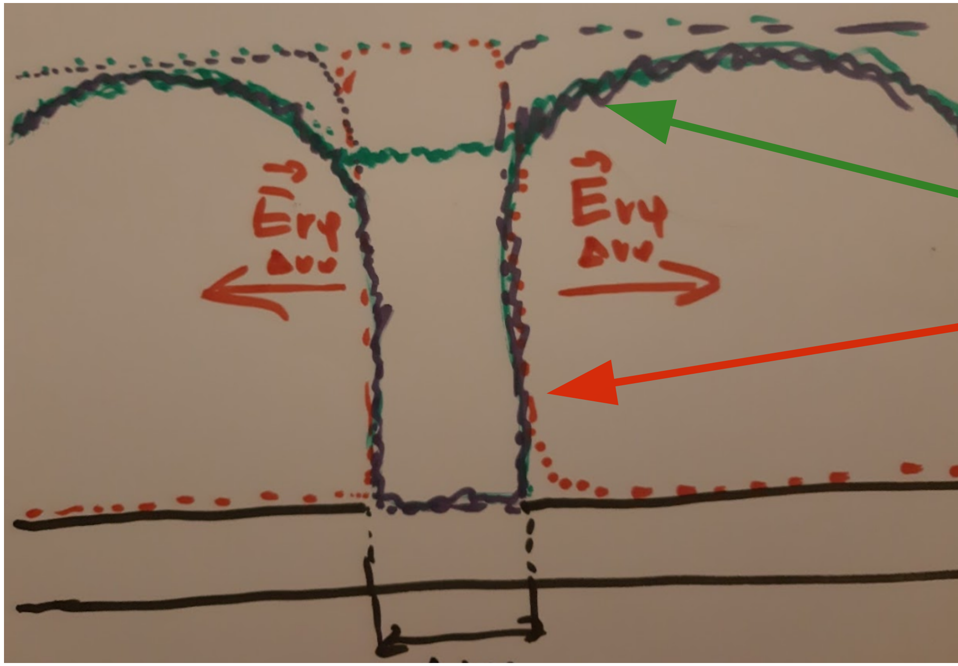


Figure 7.12: *xy* projection of the $r\varphi$ distortion map close to the TPC central electrode (at $z = 10\,\mathrm{cm}$). The data are based on a detailed 3-dimensional space charge map normalized to $\varepsilon = 5$ (in order to avoid complications due to non-linearities). The figures illustrate the effect of a sector modulation that is modified by the magnetic field, which is set to $B = 0\,\mathrm{T}$ (left) and $B = 0.5\,\mathrm{T}$ (right).

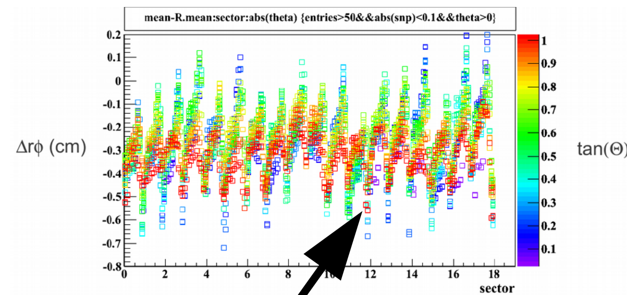


Dead zones and missing charge approximation



Density profile ρ
- dot line - idealistic
- full line - including ε(r,rφ)

Density decomposition:
- **flat density**
- **Δ missing charge at dead zone**



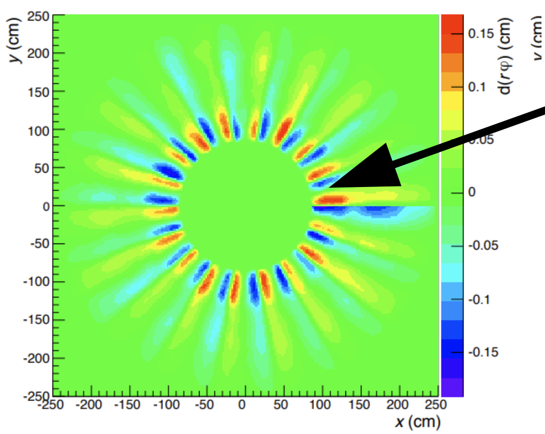


Figure 7.12: *xy* projection of the $r\varphi$ distortion map close to the
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linearities). The figures illustrate the effect of a sectc
set to $B = 0\,\mathrm{T}$ (left) and $B = 0.5\,\mathrm{T}$ (right).

Large gradient of the Δrφ* distortion at the sector boundaries

Density ρ(r,rφ,z) can be decomposed to **"flat" density component** and **Δ density component (~plane charge)**

Using Δρ(r,rφ,z) → Δ(Δ(r,rφ,z)) - <Δ Δ density> component (~plane charge) distribution is gaussian with σ~c_0

ExB symmetry breaking and distortion Δ decomposition

$$\Delta^*_R = k_{RR}\Delta_R + k_{RR\phi}\Delta_{R\phi} \qquad (1)$$

$$\Delta^*_{R\phi} = k_{R\phi R}\Delta_R + k_{R\phi R}\Delta_{R\phi} \qquad (2)$$

Local distortion ΔL can be approximated by Langewin equation. trajectory depends on the E, field, B field and ωτ

E field:

- E_r field ~ φ symmetric
- $E_{r\varphi}$ field << E_r + plane charge component

B field:

- $B_z(r,r\varphi,z)$ ~ 0.5 T +-1-2%
- $B_{r\varphi}(r,r\varphi,z)$ - φ modulated - B field center is shfifted

Approximated transformation * - Δ* defined by E field and ρ

Effect to be quantified

Backup

Offline week 2020

- https://indico.cern.ch/event/896796/contributions/3784060/attachments/2007406/3353024/ATO-490-NeuralNettwork_AndNDPipeline.pdf
- ATO-490-NeuralNettwork_AndNDPipeline.pdf
- ATO-490-DataDrivenCorrection_1903.pdf
-

Offline week 2011:

https://indico.cern.ch/event/128634/contributions/112892/attachments/86275/123631/TPCSpacePointcorection.pdf

- TPCSpacePointcorection.pdf

Tracking workshop:

- https://indico.gsi.de/event/1469/contributions/4047/attachments/3283/4132/AliceTracking.pdf
- AliceTracking.pdf

TPC planning meeting -tracking perfromance and distrotion calibration

- https://indico.cern.ch/event/174670/
- MITPCPlanningMeeting0202.odp

Info

Links to some my old TPC/TDR presentations:

- /eos/user/t/tpcdrop/www/TPCTDR.backupMI/
- /data2/miranov/TPCTDR
-

Links to all distortion calibration should be in /eos and Wiki