New global alignment framework for Alice Barrel

(PWGPP-73)

R.Shahoyan, 02/07/2015

ALICE Barrel detectors alignment

- Until now barrel detectors were aligned internally (sometimes using some information from other detectors):
  - ITS: internal alignment, constraining track curvature to TPC measurement. Based on Millipede implementation in aliroot and global fit track model with average MS accounting (no energy loss)
  - TPC, TRD: internal alignment between chambers

- Then detectors were aligned one wrt another with tracks linking them:
  - TRD sectors globally aligned wrt TPC, ITS globally wrt TPC
  - TOF sectors (no individual strips) aligned wrt extrapolation from TPC/TRD

ALICE Barrel detectors alignment

Consequence of standalone internal then mutual alignment

- Not profiting from best pointing resolution (reduced lever arms, number of points)
- Alignment of one detector is affected by calibration (problems) of this and other detectors
- Reduced link between different regions of the same detector: each well connected region aligned internally, but different “branches” are misaligned wrt each other

⇒ Use global alignment with as many as possible detectors, accounting for their calibrations DOFs if needed

Alice barrel has ~ 27k DOF (alignment only, 6 x number of alignable volumes)
→ task well suited for Millepede

- Specifically, for 2015 data it was decided to align ITS/TRD/TOF, <u>skipping</u> the TPC to avoid distortions effect.
- Then calibrate TPC distortions used external reference tracks (see Marian’s presentation)

Millepede II (MP)

https://www.wiki.terascale.de/index.php/Millepede_II

- Assumes that for every track the residuals z_i wrt every measurement y_i with error σ_i at point x_i can be represented in linearized form as :

$$z_i = y_i - f(x_i, \boldsymbol{q}, \boldsymbol{p}) = \sum_{j=1}^{\nu} \left(\frac{\partial f}{\partial q_j} \right) \Delta q_j + \sum_{\ell \in \Omega} \left(\frac{\partial f}{\partial p_\ell} \right) \Delta p_\ell \, .$$

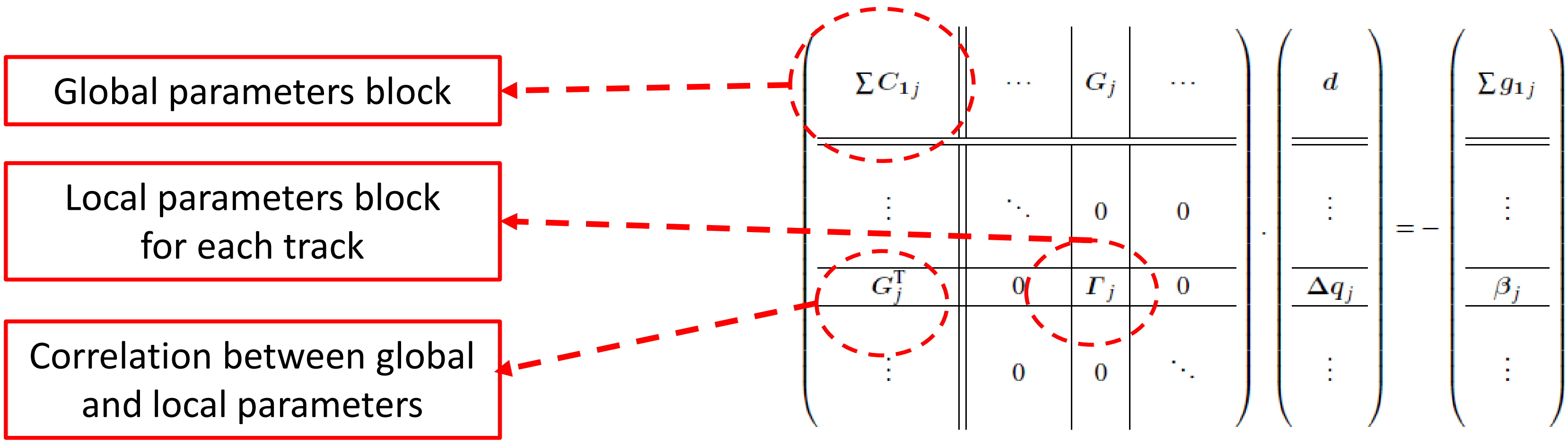
where $f(x_i, q, p)$ is track model depending on set of **local parameters** q (unique for each track) and set of **global parameters** p (describing detector's DOFs)

- Idea of Millepede is to minimize residuals not only wrt global parameters (alignment+calibration)
  but also wrt parameters of each track (reconstructed with misaligned setup)

Millepede II (MP)

https://www.wiki.terascale.de/index.php/Millepede_II

- The alignment/calibration consists of minimization of global $\chi^2 = \sum z^2/\sigma^2$ by simultaneous optimization of p and q_i, $(i = 1, Ntracks)$ via solution of large matrix equation (set of different methods):



- Millepede is basically an interface to store user-calculated residuals + derivatives + sophisticated solver (PEDE) for very large systems of linear equations.
- Allows to impose set of exact linear constraints on global parameters (via Lagrange multipliers)
- Provides different options for outliers rejection / downweighting

Track model for Alice Millepede

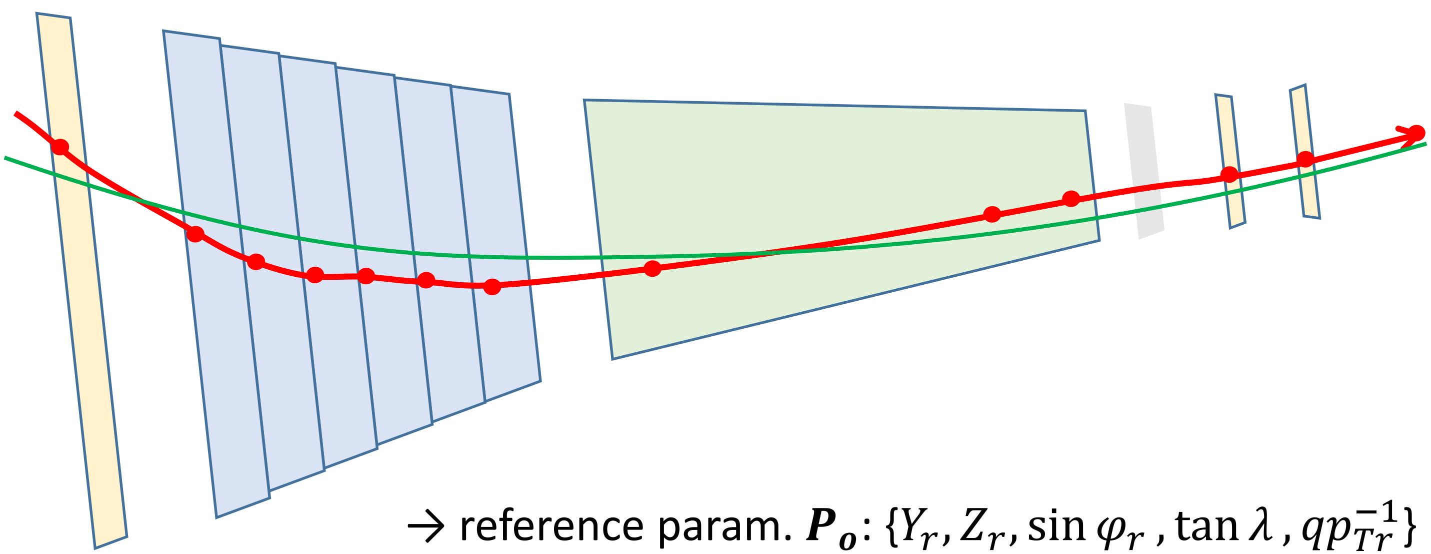
- Millepede needs derivatives of track position wrt its parameters (e.g. defined at some reference point).
- Kalman track model used in ALICE is not directly applicable to MP since it has no "reference" track parameters and their global covariance matrix per se: instead it provides set of best estimates for track state and its errors at each measured point, related via transport matrix.
- LHCb managed to adopt Kalman tracks to MP via very convoluted math, based on analytical smoother, but it is also not appropriate for ALICE, since we use rotations when going from one sensor to another, which prevents from describing transport as really linear transformation
- Preferable to use track model as much as possible close to what is used in reconstruction, to minimize systematic effects of model approximations

- → Use synthetic track model consisting of usual AliExternalTrackParam defined in the reference point + corrections (again AliExternalTrackParam) for kinks due to the mult.scattering between measurements separated by material

Track model for Alice Millepede

Creating alignment track: initial fit

- Extract measurement for participating detectors from ESDfriends AliTrackPoints (misaligned coordinates in global frame)
  - Transform from global frame to volume ideal local frame using alignment matrices used at reconstruction time
  - If needed, correct for known problems (e.g. TOF Z…)
  - Transform to volume tracking frame using matrices of reference alignment (wrt which we define updated alignment)
- If track has small DCA to vertex and vertex has enough number of tracks, add it as a measured point
- Perform standard Kalman fit from outmost point towards reference point (X=0 or Vertex if used as a constraint), accounting for materials



→ reference param. $\boldsymbol{P_o}$: $\{Y_r, Z_r, \sin\varphi_r, \tan\lambda, qp_{Tr}^{-1}\}$

Track model for Alice Millepede

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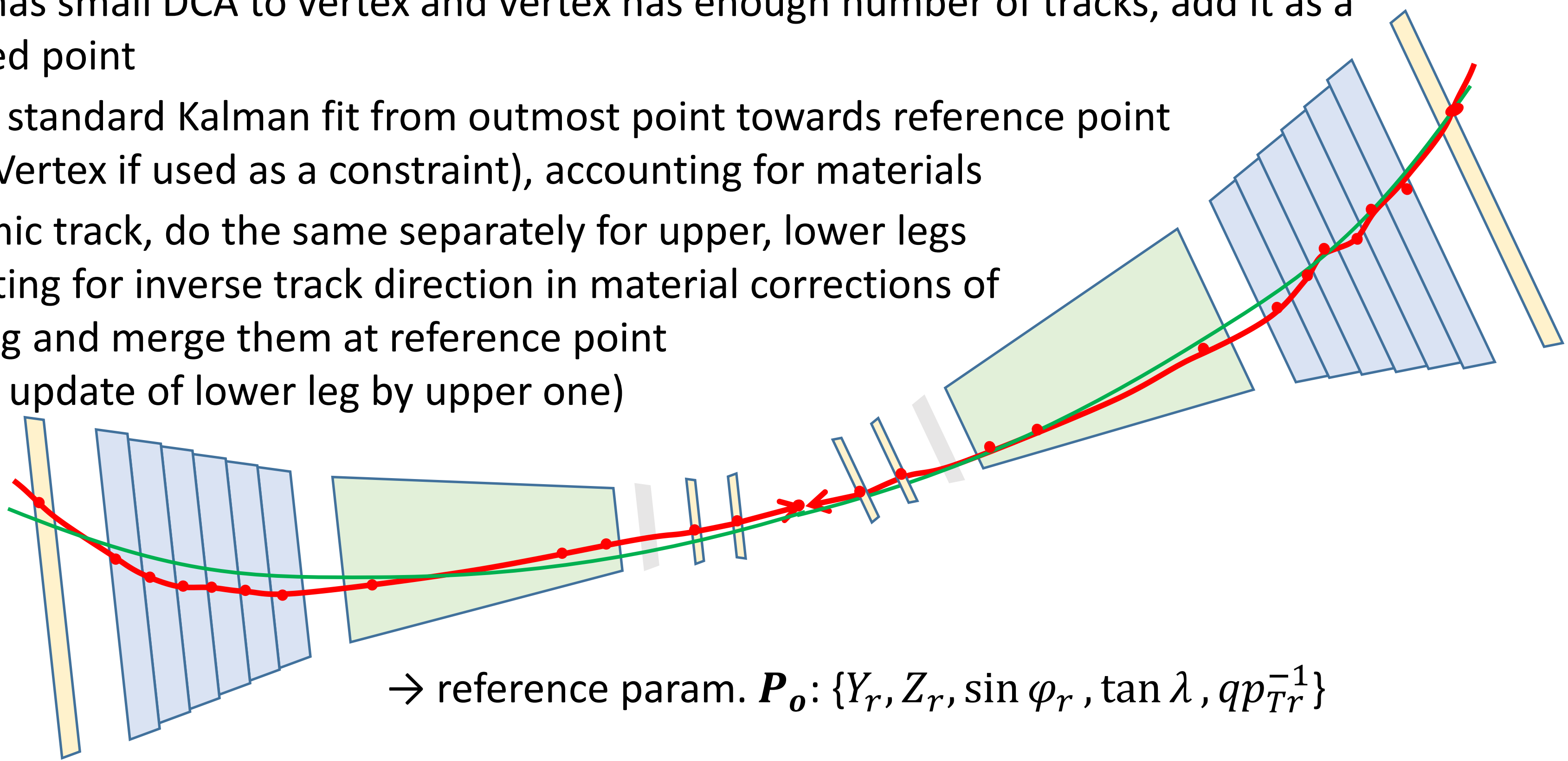
- If track has small DCA to vertex and vertex has enough number of tracks, add it as a measured point
- Perform standard Kalman fit from outmost point towards reference point (X=0 or Vertex if used as a constraint), accounting for materials
- For cosmic track, do the same separately for upper, lower legs (accounting for inverse track direction in material corrections of upper leg and merge them at reference point (Kalman update of lower leg by upper one)

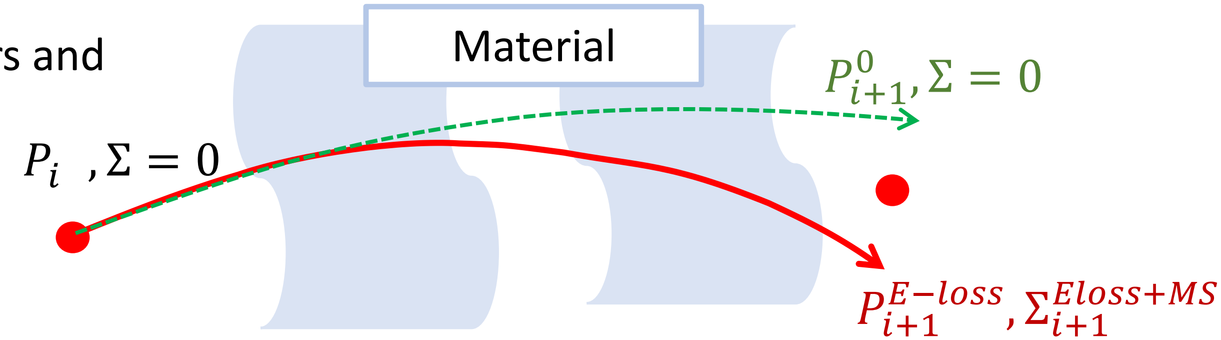


→ reference param. $\boldsymbol{P_o}$: $\{Y_r, Z_r, \sin\varphi_r, \tan\lambda, qp_{Tr}^{-1}\}$

Track model for Alice Millepede

Creating alignment track: accounting for material corrections

- Go outward from one point to another 2 times, starting at each point with cov.matrix ~0 :
  - applying E-loss and MS contribution to cov.matrix
  - w/o correction for materials
  - transform obtained parameters and cov.matrices to target point tracking frame



IF accumulated material budget between points $x/X_o\, p_T > 0.005$ then account

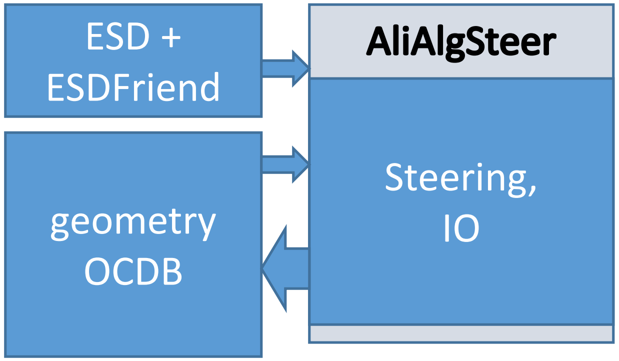
- Difference $\Delta P^E_{i+1} = P^{E-loss}_{i+1} - P^0_{i+1}$ is 5-parameter effective fixed correction for (deterministic) energy loss between to points
- Difference $\Delta\Sigma_{i+1} = \Sigma^{MS}_{i+1} - \Sigma^0_{i+1}$ is 4x4 matrix MS for description of effective kink ΔP^{MS}_{i+1} (5-th row/col discarded)

→ Track equation

- reference kinematic parameter (5 independent variables) $\boldsymbol{P_o}$
- at each point $\boldsymbol{i}$ with material information
  - updated for deterministic e-loss $\boldsymbol{\Delta P_i}$
  - corrected by random 4-parameter kink $\boldsymbol{\Delta P^{MS}_i}$, constrained by its cov. matrix $\boldsymbol{\Delta\Sigma_i}$ (in general, kink parameters are correlated)

Alice Millepede global alignment framework

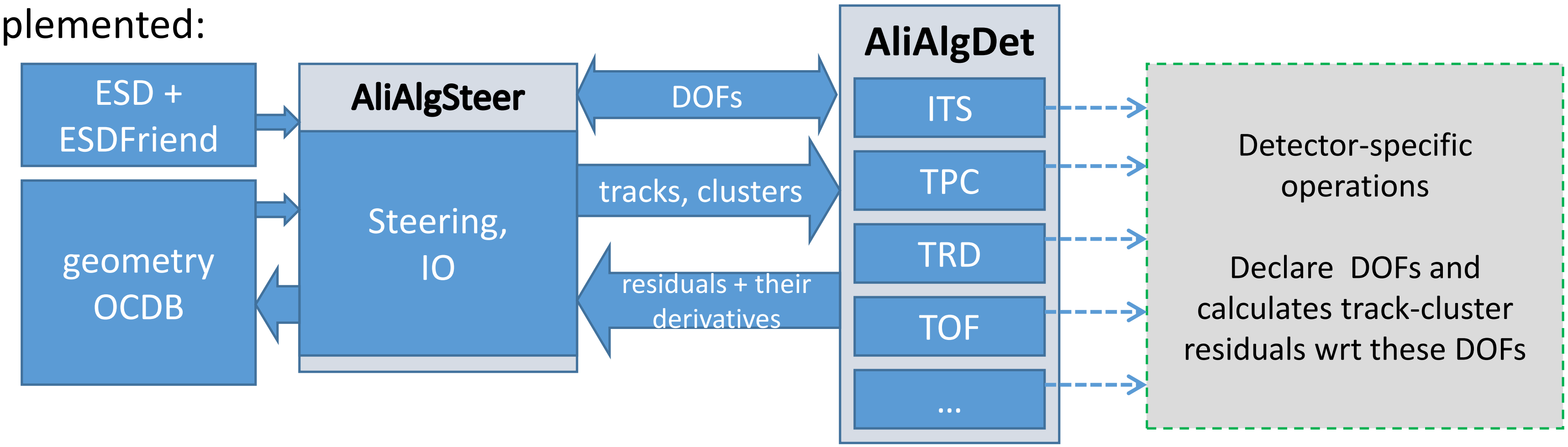
Implemented:



- Steering class AliAlgSteer:
  - General I/O, manipulations with different geometries
  - Assignment of DOFs to detectors

Alice Millepede global alignment framework

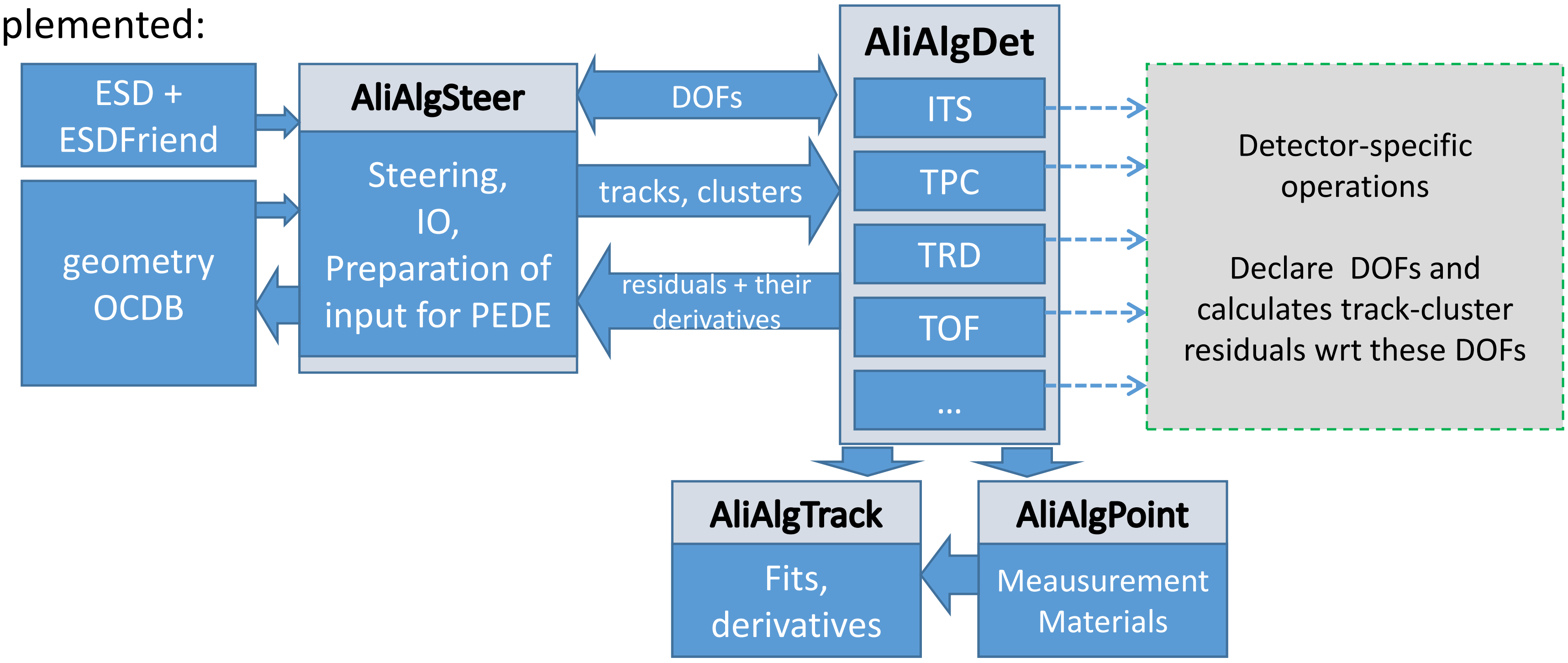
Implemented:



- Steering class AliAlgSteer:
  - General I/O, manipulations with different geometries
  - Assignment of DOFs to detectors
- Detectors (ITS,TPC,TRD,TOF, partially HMPID)
  - Detector I/O, geometry description: AliAlgDet $\Longrightarrow$ AliAlgDetITS …
  - Specific “sensor” volumes AliAlgSens $\Longrightarrow$ AliAlgSensITS …
  - Specific calibration DOFs can be added by detector experts
- Special “sensor” AliAlgVertex to implement/vary event vertex as a measured point

Alice Millepede global alignment framework

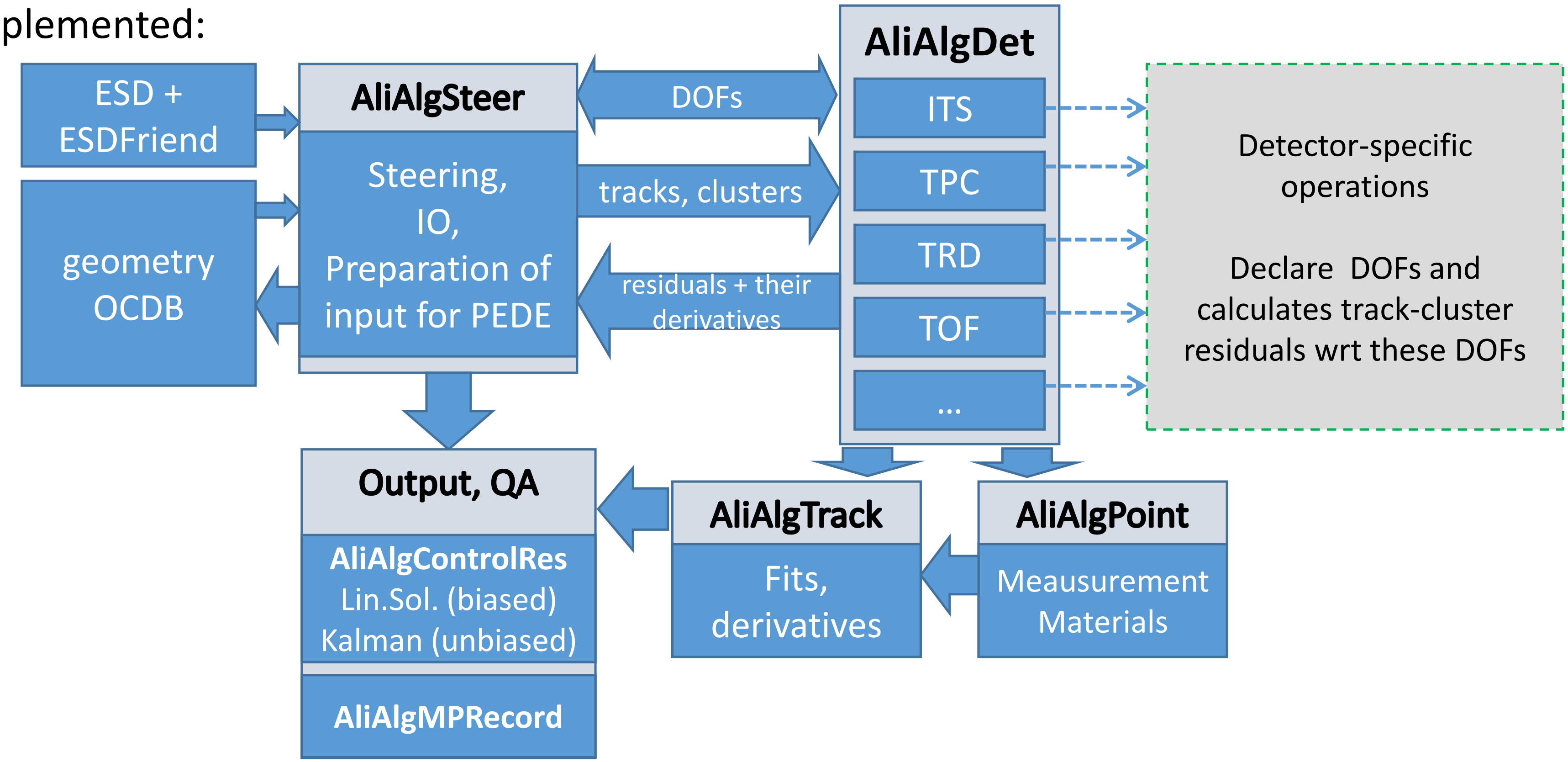
Implemented:



- Conversion of AliTrackPoints from ESDfriends to AliAlgPoint: measurement in the relevant tracking frame + material budget information
- Automatics undoing of alignment/calibration used during reconstruction and application of reference alignment/calibration.
- Alignment track (AliAlgTrack) fit + linearization of derivatives over track parameters (including MS). Two modes: (i)collision tracks, (ii) cosmic tracks made of 2 legs
- Automatic/manual constraints according to detector hierarchy (total movement of child nodes in the parent node frame = 0)

Alice Millepede global alignment framework

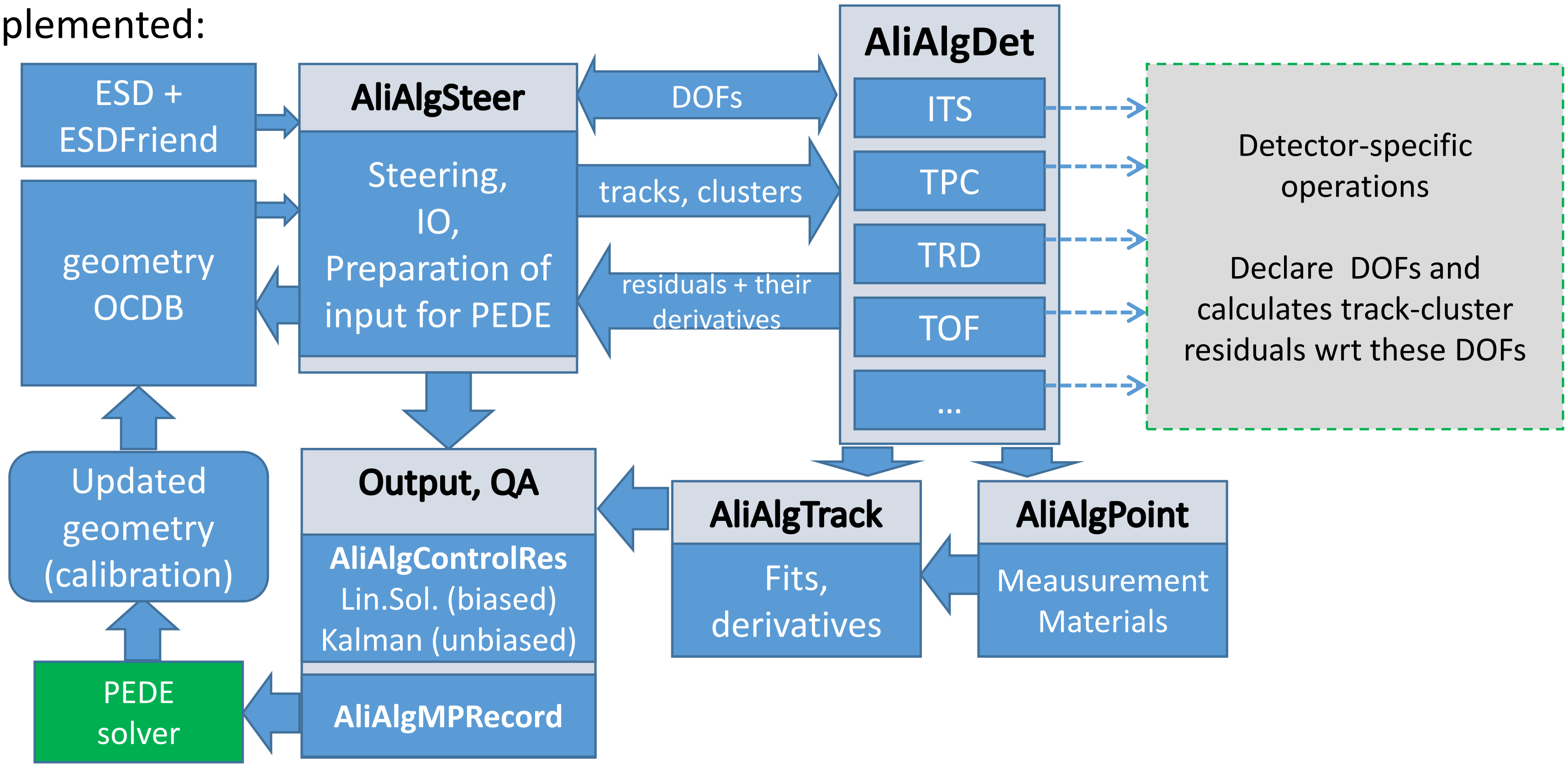
Implemented:



- Automatic/manual constraints according to detector hierarchy (total movement of child nodes in the parent node frame = 0)
- Control residuals
  - Biased (all points contributing, linear eq. solutions, like in PEDE)
  - Unbiased (smoothed Kalman residuals, probed point does not contribute to track)

Alice Millepede global alignment framework

Implemented:



Blue: preparation of input data for PEDE II, processing of its output, various utilities for OCDB manipulation

Green: external PEDE II solver (Fortran 90 + OpenMP) supported by DESY

Input data for PEDE solver

For every track calculate at each measured point:

- Residuals $\Delta Y, \Delta Z$ at reference X (tracking frame) wrt track extrapolation (MS kink parameters set to 0)
- Numerical derivatives $\frac{\partial \Delta Y}{\partial q_l}, \frac{\partial \Delta Z}{\partial q_l}$ of residuals over all track parameters (reference kinematics + kinks parameters)
- Numerical derivatives $\frac{\partial \Delta Y}{\partial p_l}, \frac{\partial \Delta Z}{\partial p_l}$ of residuals over detector's volumes alignment corrections + eventual calibration parameters

Millepede works with 1D uncorrelated measurements:

- transform residuals and derivatives pairs by matrix diagonalizing the covariance matrix $\{\sigma_y^2, \sigma_{yz}, \sigma_z^2\}$ of the measurement (rotation by σ_{yz}/σ_z^2)
- parameters of the MS kink have 0 expectation but are correlated via their cov.matrix $\Delta\Sigma_i$ → find its eigenvalues and use them as errors of 4 independent pseudo-kink parameters
- Build track record as a set of
  - 2 independent residuals, errors + derivatives per measured point
  - 4 independent residuals (0), errors and derivatives (local only, $\equiv 1$) per point with material

Problems affecting alignment

TGeometry precision

- ROOT TGeometry volume positioning/alignment managed by TGeoHMatrix objects
  - Each volume $\boldsymbol{i}$ has its Local-to-MARS transition **ideal** matrix G_i which after alignment becomes **aligned** matrix $\bar{G}_i = \Delta_0 \dots \Delta_i G_i$ where Δ_j is alignment correction matrix for volume $\boldsymbol{j}$ in **global** representation, connected with **local** one δ_j as $\Delta_j G_j = G_j \delta_j$ The hierarchy of volumes in geometry branch goes from $\boldsymbol{j = 0}$ (top node in MARS)
  - The alignment framework stores by convention these **global** correction matrices

- Alignment procedure produces an **incremental** corrections Υ_j for each volume, which must be convoluted with initial alignment as:

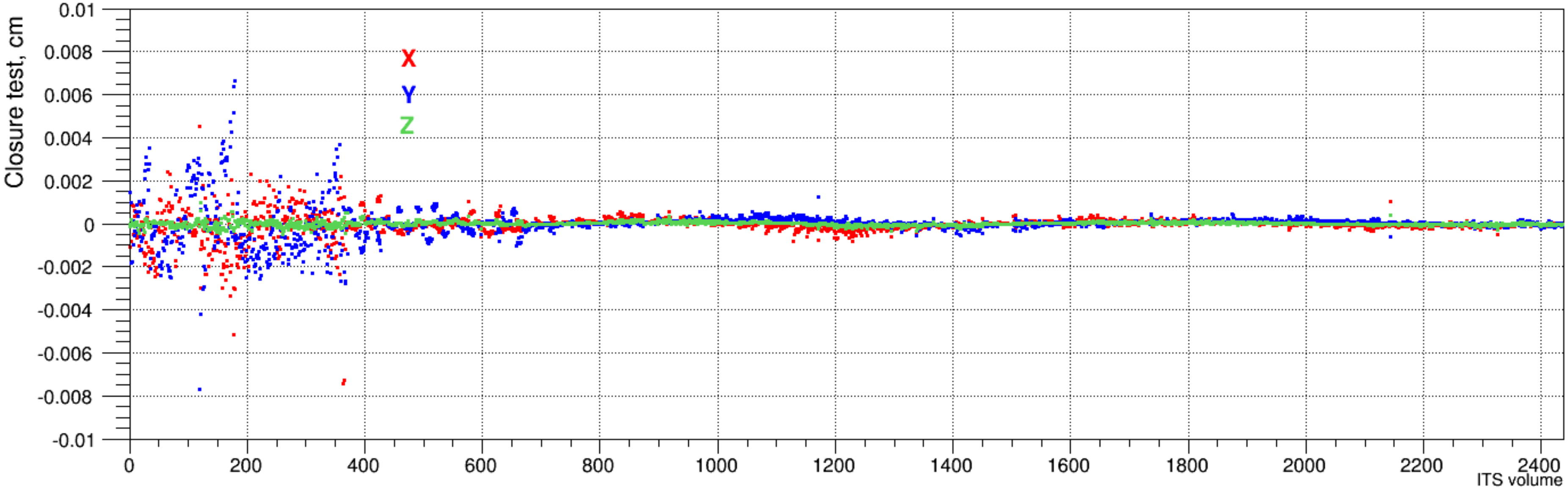
$$\widetilde{\Delta}_i = [\Delta_0 \dots \Delta_{i-1}]^{-1} \Upsilon_i \Delta_0 \dots \Delta_i = G_{i-1} \bar{G}_{i-1}^{-1} \Upsilon_i G_i^{-1} \bar{G}_i$$

  - Therefore, in case of 0 incremental correction:

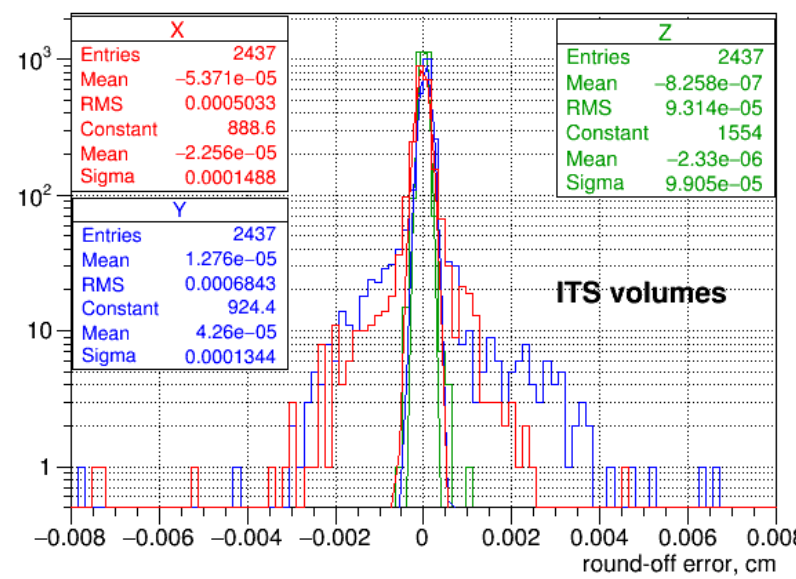
$$\widetilde{\Delta}_i \equiv \Delta_i \quad \Longrightarrow \quad \widetilde{\Delta}_i \Delta_i^{-1} - I = 0$$

TGeometry precision

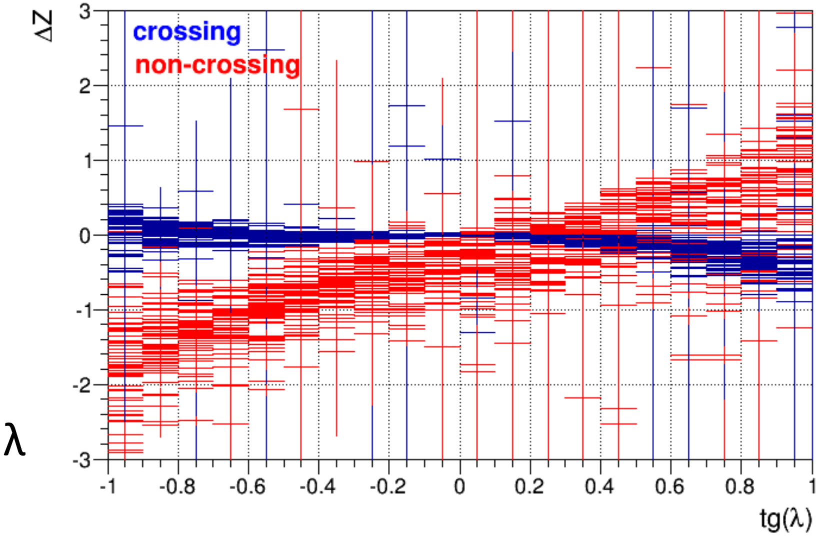
- Instead, the closure test for $\Sigma = \widetilde{\Delta}_i \Delta_i^{-1} - I = (G_{i-1} \bar{G}_{i-1}^{-1}\ G_i^{-1}\ \bar{G}_i)\ \Delta_i^{-1} - I$ shows (case of ITS, particularly bad for SPD due to many rotations by angles far from $k\pi/2$):



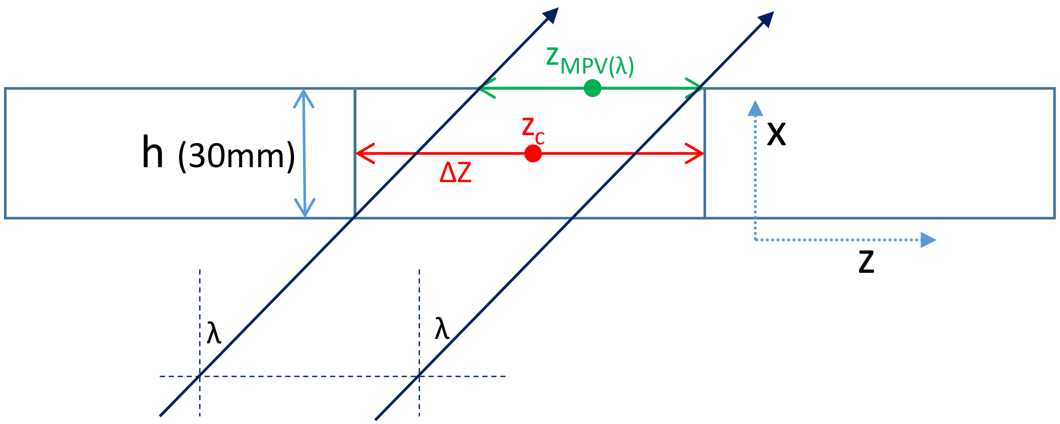
- Reported values X,Y, Z are shifts of residual matrix Σ
- $\Longrightarrow$ Matrix inversion/products introduces significant round-off error which limits the precision of TGeometry
- Might be critical for ITS-upgrade if not corrected



TRD measurement assignment



- We always observe systematic bias of residuals vs track η for **row non-crossing** tracklets
- Their Z coordinate in principle does not depend on any calibration.
- Z of tracklet assigned as the center of fired pad Z_c, neglecting information that if track with inclination λ produced non-crossing tracklets, then the most probable value of Z is shifted: $Z_{MPV} \longrightarrow Z_c + {}^{1}/_{2}\, h \tan(\lambda)$ (in ideal case of no edge effects)



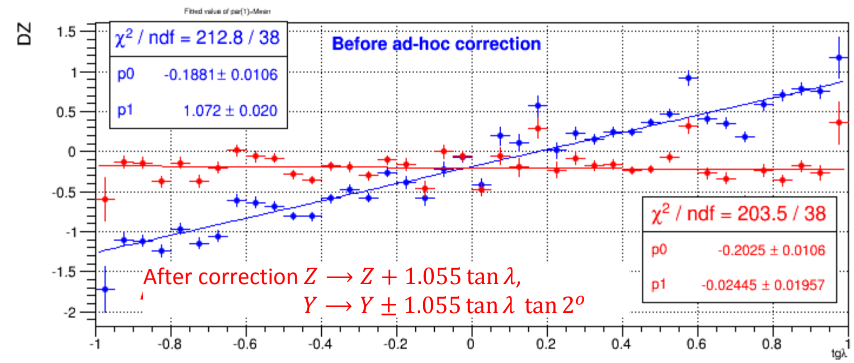
- This bias is equivalent to (fake) shift in X, which would introduce a bias for row-crossing tracklets (potentially more precise but depending on calibrations)
- Due to the tilt of pads in by 2° YZ, the bias is translated also to Y assignment
- Due to the attempts to align biased data, the chambers get fake shifts and rotations.

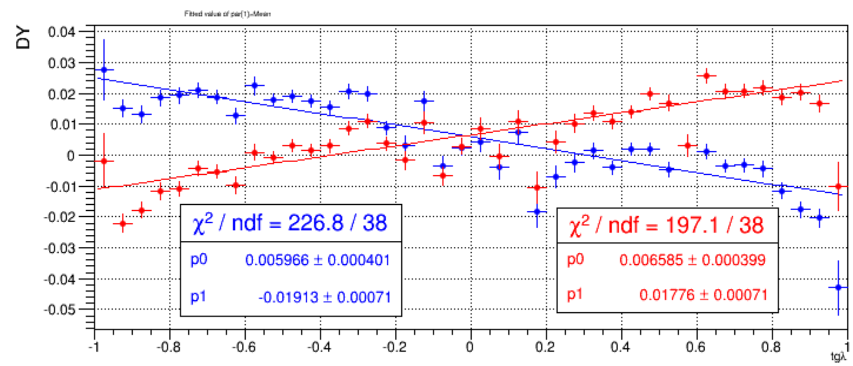
TRD measurement assignment

- To account for edge effects and disentangle from R shifts (affect differently Y and Z residuals) , correct **row non-crossing** tracklets as:

$$Z \longrightarrow Z + p\tan(\lambda) \qquad Y \longrightarrow Y \pm p\tan(\lambda)\ \tan(2^o)$$

- In principle, p can be fitted directly on data, but they might be distorted by previous alignment attempts
  → instead, p is added as a global parameter of Millepede optimization
  (leading to p ~1.6 instead of 1.5 in ideal case)





- Measurements by row-crossing tracklets are masked by adding extra error

- Since Y measurement is affected by calibration (particularly $V_{drift} \times t_0$), extra global parameter ΔVt optionally introduced (equivalent to X shift, but acting on Y measurement only)

- <u>For consistency, corrections used in alignment must be implemented also in future reconstruction.</u>

Bug in applying TOF alignment

- TOF clusters use r, φ and Z in lab, frame
- Because the alignment matrix is applied on-the-fly only in calculation of r and φ the Z measurement is never corrected for the misalignment (~2 cm)
- This should not be critical for TOF matching, since the clusters user only for matching candidate preselection, with large tolerances (to be verified)

→ TOF trackpoints stored in ESDfriends contain correctly misaligned lab. X, Y but ideal Z!

- To account for this TrackPoints → AliAlgPoint converter in the AliAlgSensTOF tries to recover ideal {X,Y,Z} in local frame by accounting for wrong transformations

→ Some distortions are inevitable due to the rotations in existing TOF alignment (should be limited to ~100μm, will below TOF σ ~ 0.7 cm)

- <u>To be fixed in TOF code</u>, with special bit flag set on TrackPoints in ESD friends to signal modified content

Results from LHC15a,c (cosmic) + LHC15f alignment

	B	N .Ev, 10^6	N.Tracks Inp, 10^6	N.Tracks Acc., 10^6
Cosmic	0	126	33	4.1 (1)
Cosmic	+	53	12	0.9 (2)
Cosmic	-	28	11	0.7 (2)
Beam	0	1.6	54	2.5 (3)
Beam	+	5.0	94	2.3 (3)
Beam	-	20.	247	6.2 (3)

(1) No obligatory ITS hit requested, TOF and TRD must contribute to each cosmic leg
(2) At least 2 ITS hits + either TRD or TOF must contribute to each cosmic leg
(3) At least 3 ITS hits (min 1 SPD) + either TRD or TOF must contribute to a track

Detailed plots at https://alice.its.cern.ch/jira/browse/PWGPP-73

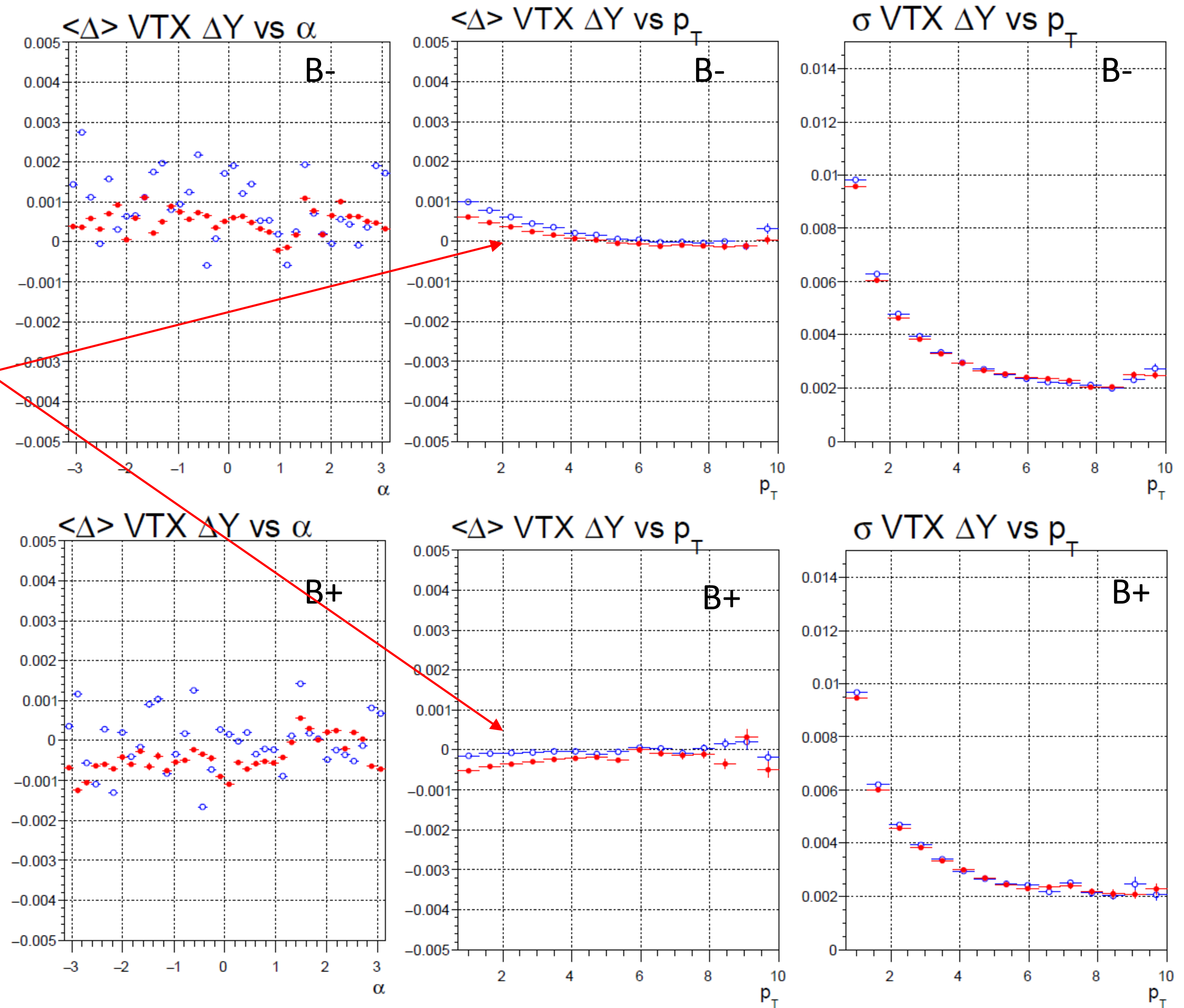
DCA-Y to Vertex

Vertex from reconstruction with old alignment!

- Was used as fixed measured point for new alignment

(assuming that errors were cancelled out)

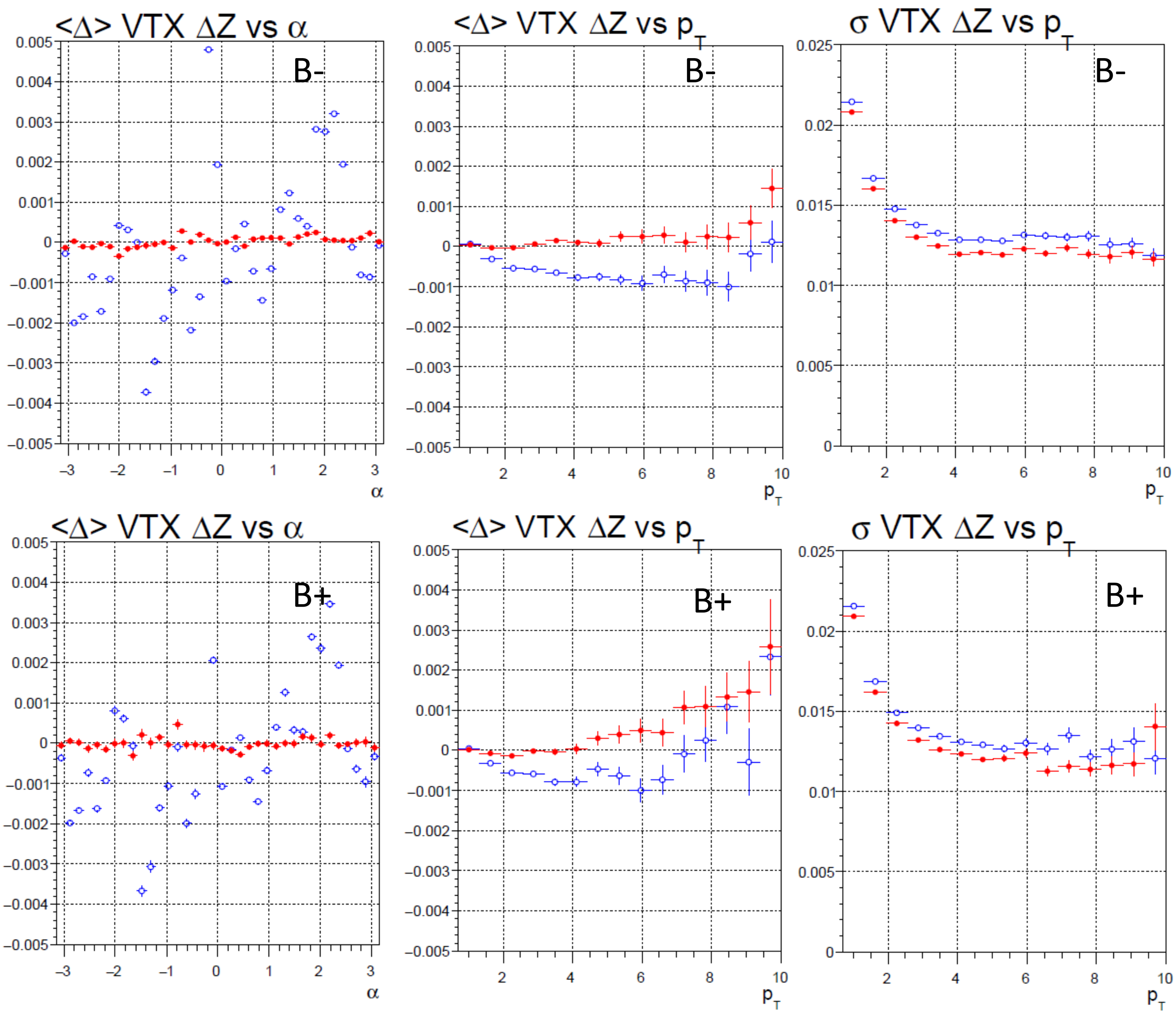
- Attempt to "align" vertex by X,Y,Z shift (field independent) was not successful.
- Systematic DCA dependence on φ, p_T is not yet eliminated
- Currently running test with vertex point downweighed by additional 50 µm error
- Vertex bias also affects alignment at innermost ITS layer



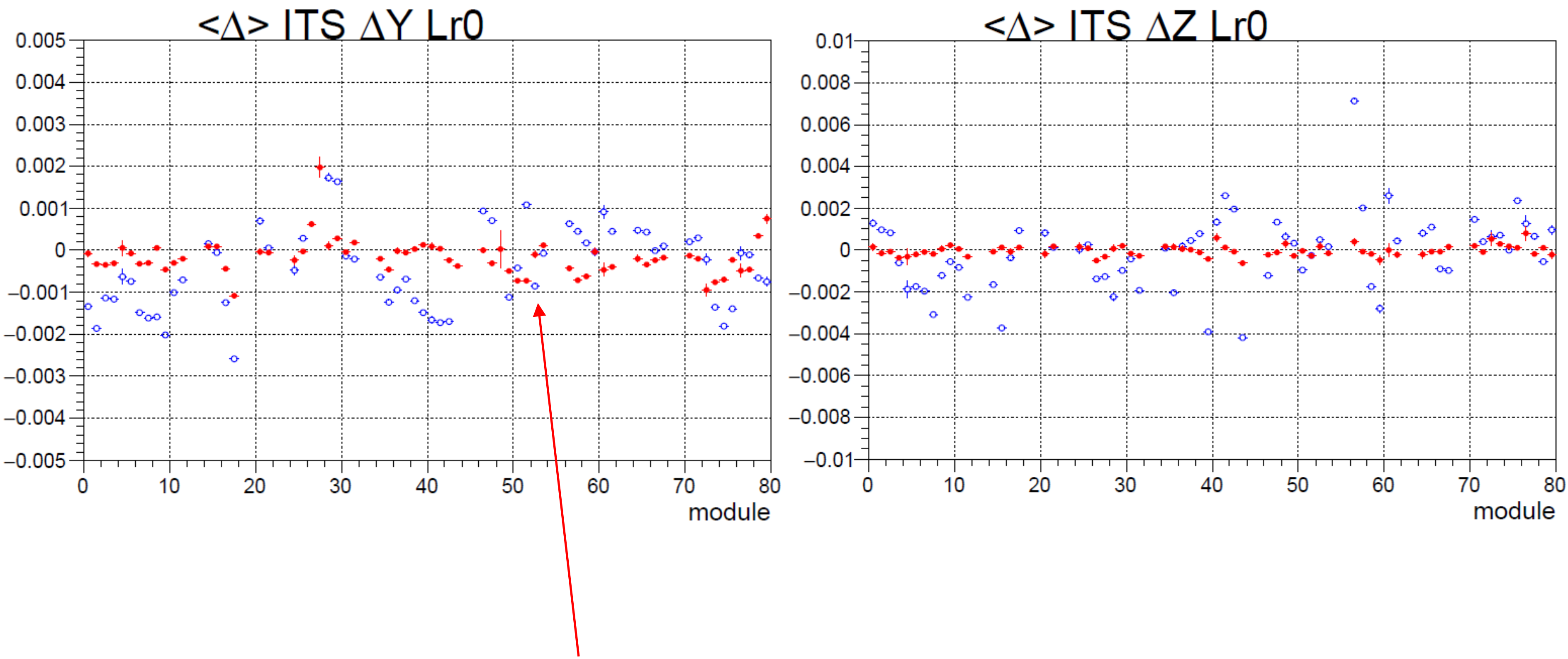
DCA-Z to Vertex

Same observation as for Y, although larger gain in DCA uniformity and resolution

Z in old alignment had larger residual misalignments



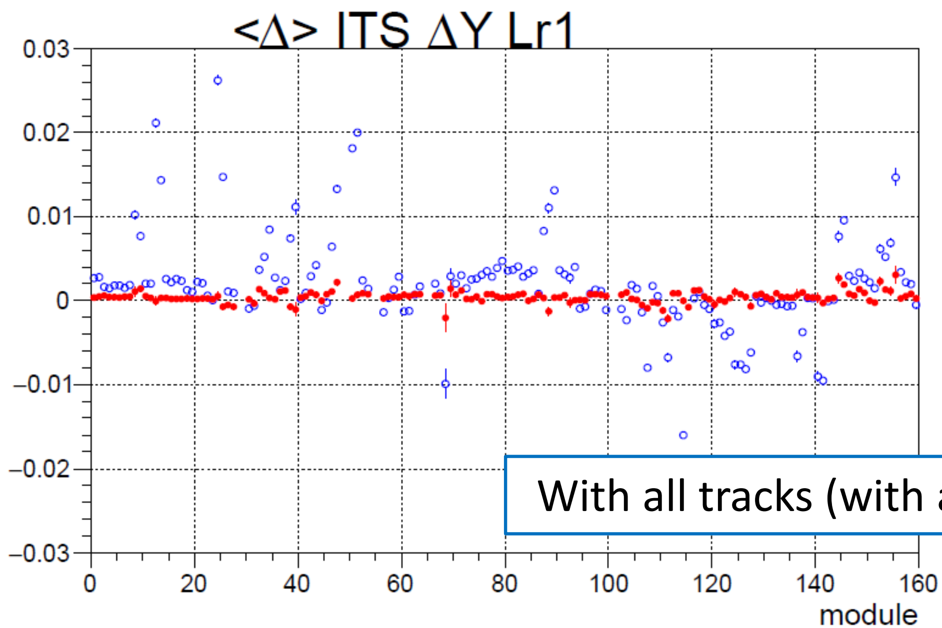
SPD0

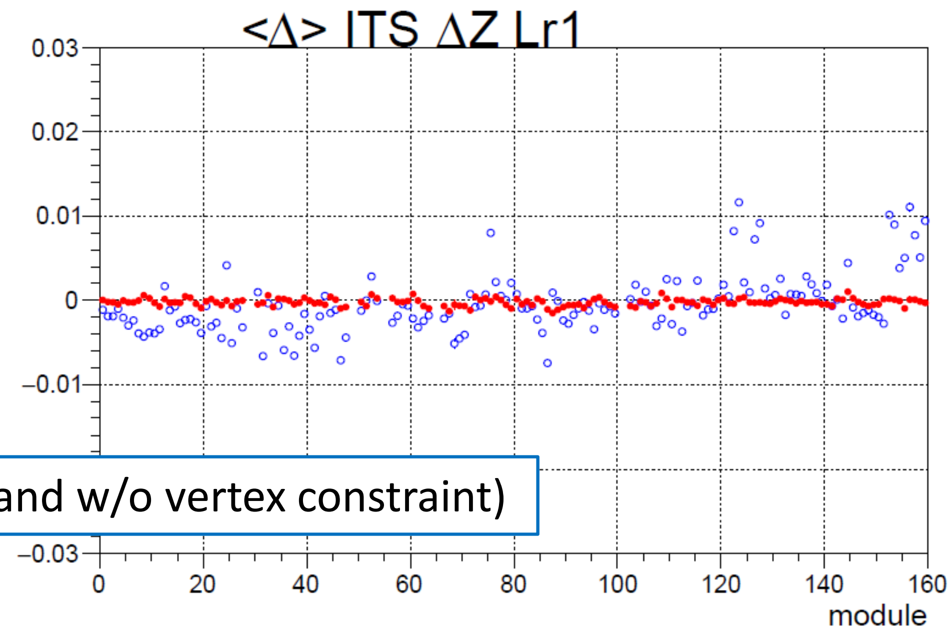


Effect of biased constraint by the vertex

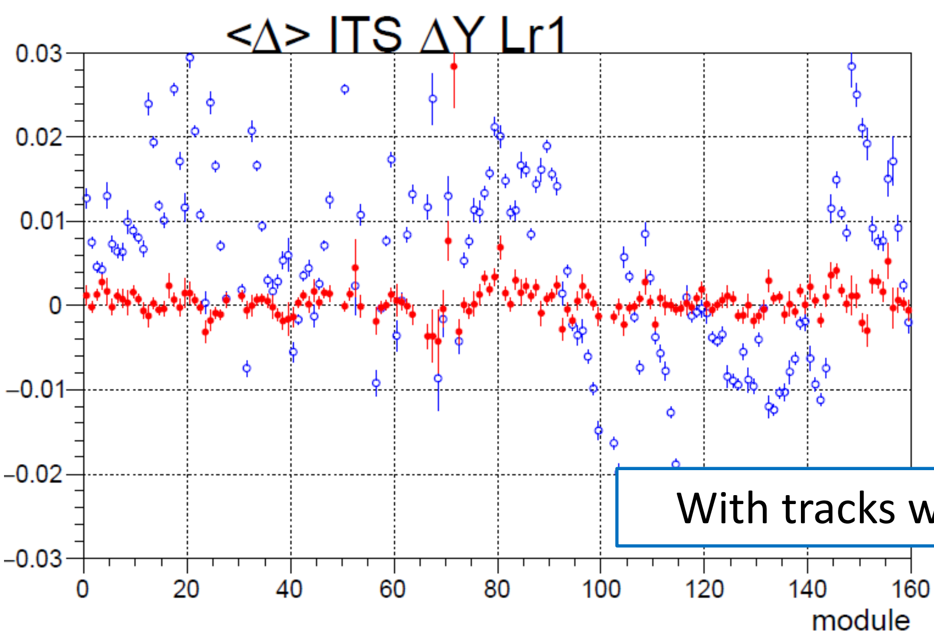
B- field results only shown on following slides

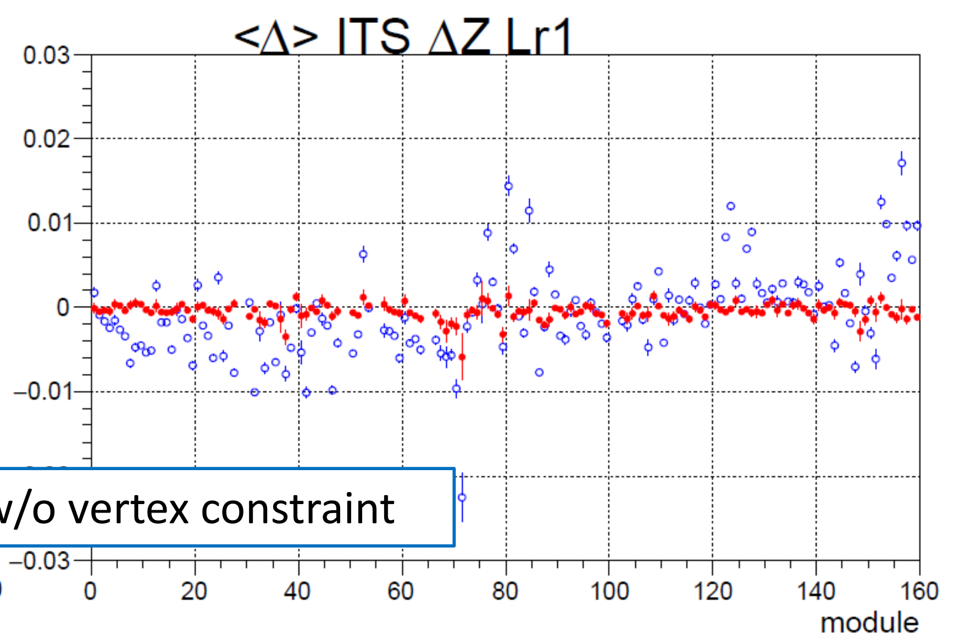
SPD1





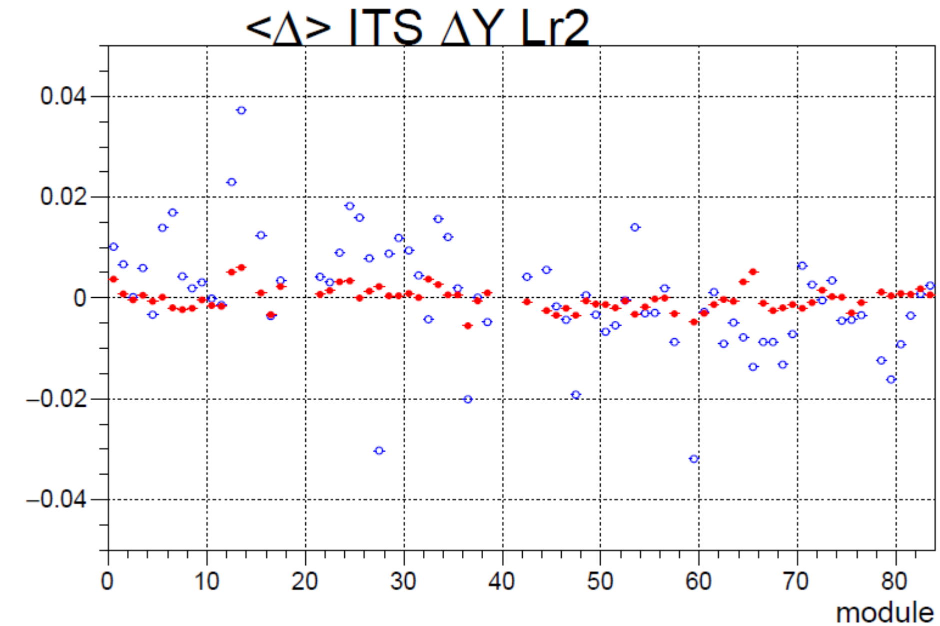
With all tracks (with and w/o vertex constraint)

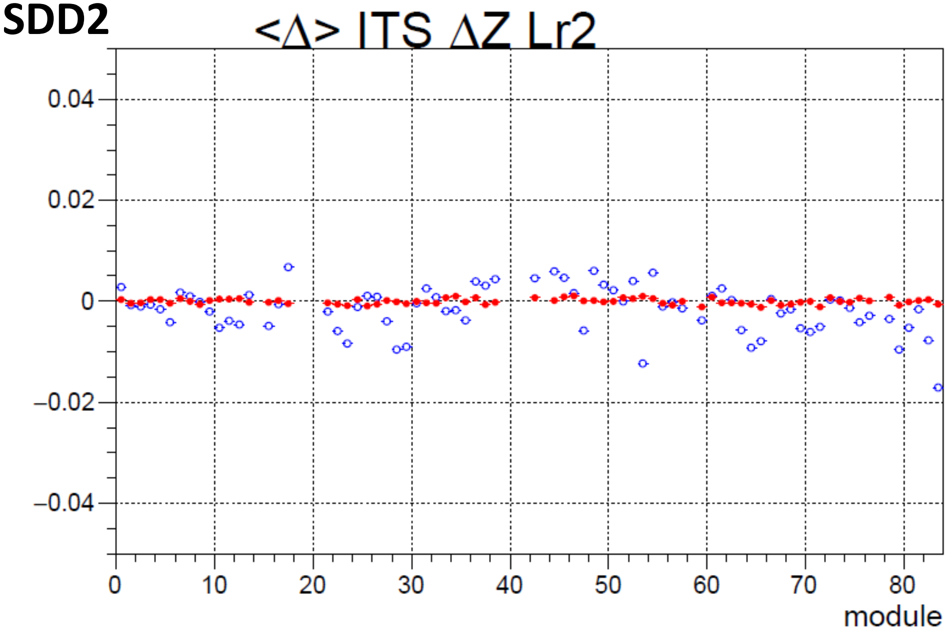




With tracks w/o vertex constraint

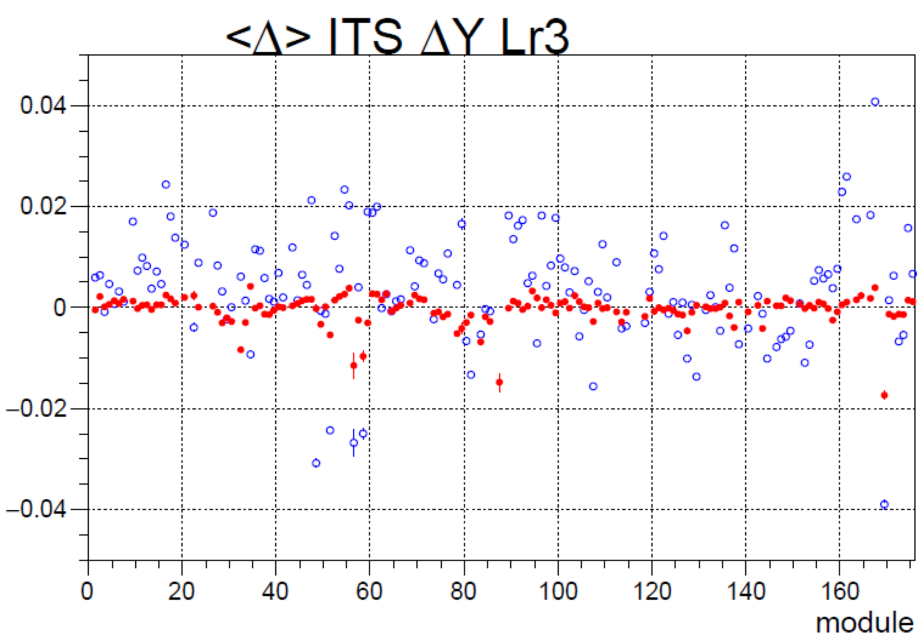
SDD2

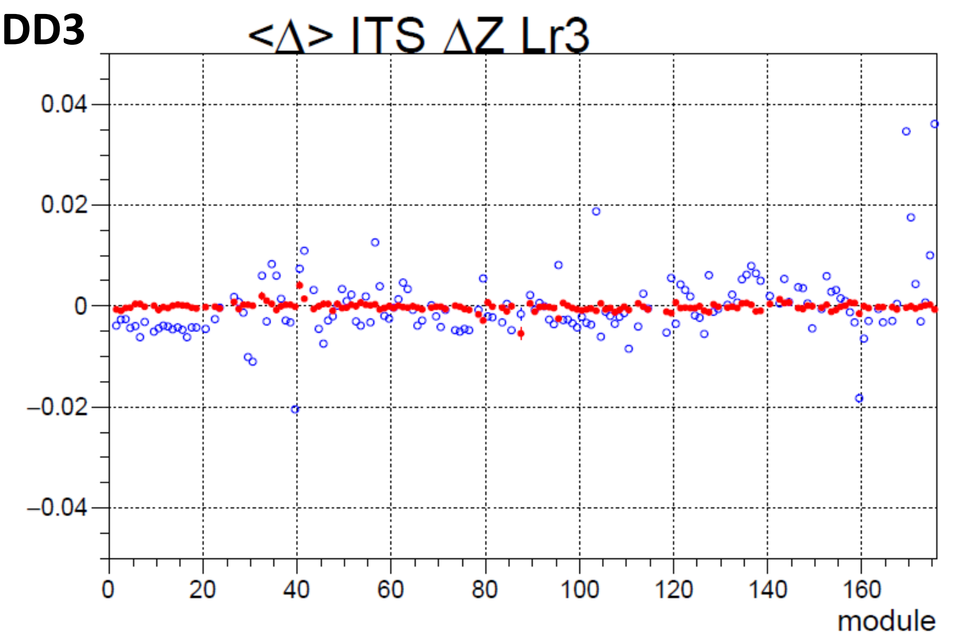




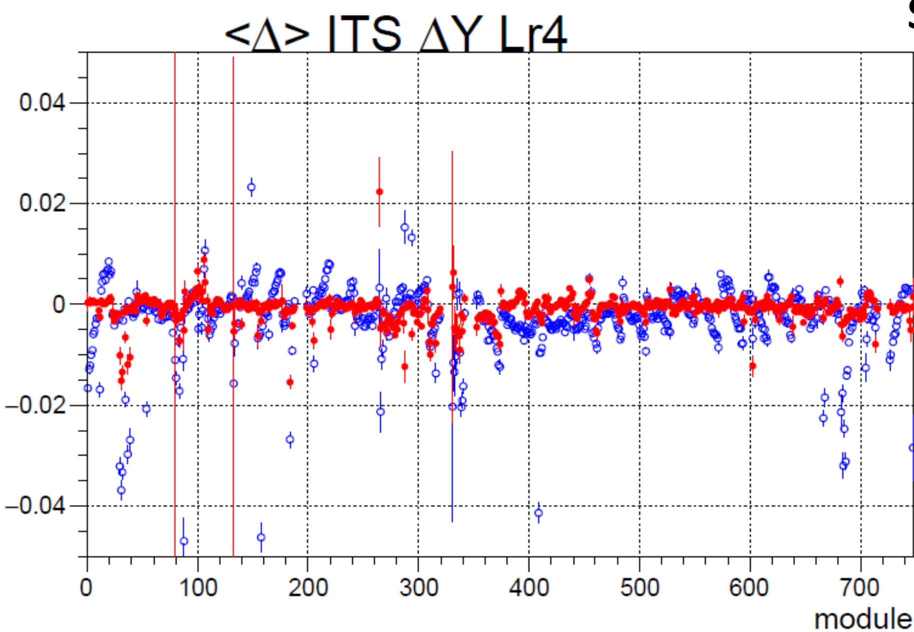
Y measurements is affected by non-calibrated SDD (masked in fits by additional 5 mm error)

SDD3

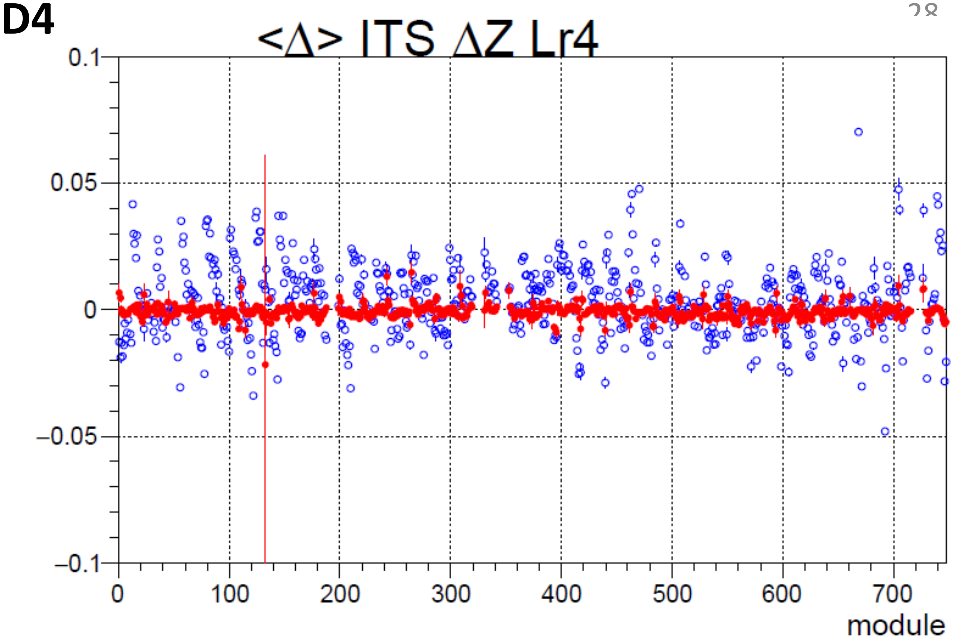




SSD4

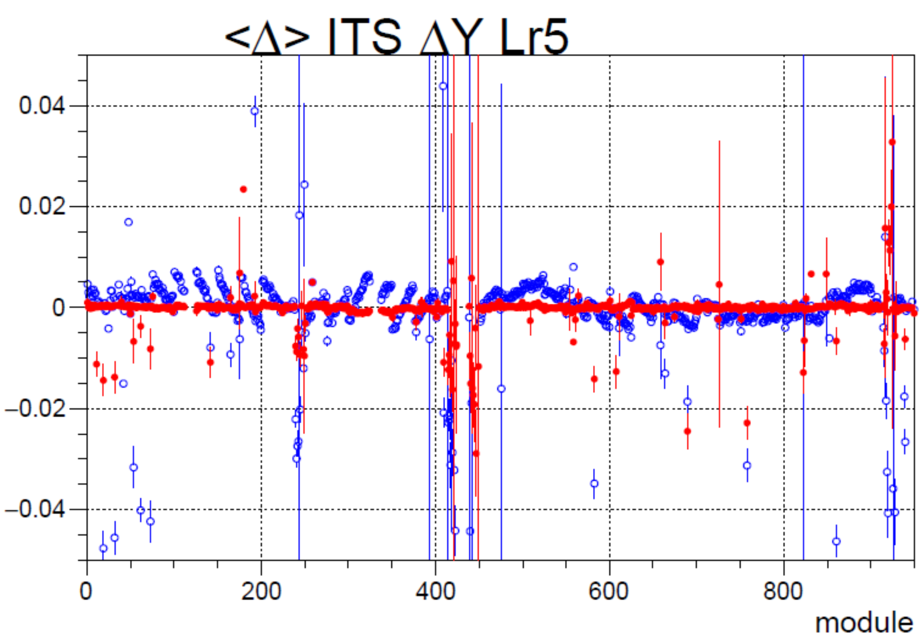


<Δ> ITS ΔY Lr4
0.04
0.02
0
−0.02
−0.04
0
100
200
300
400
500
600
700
module

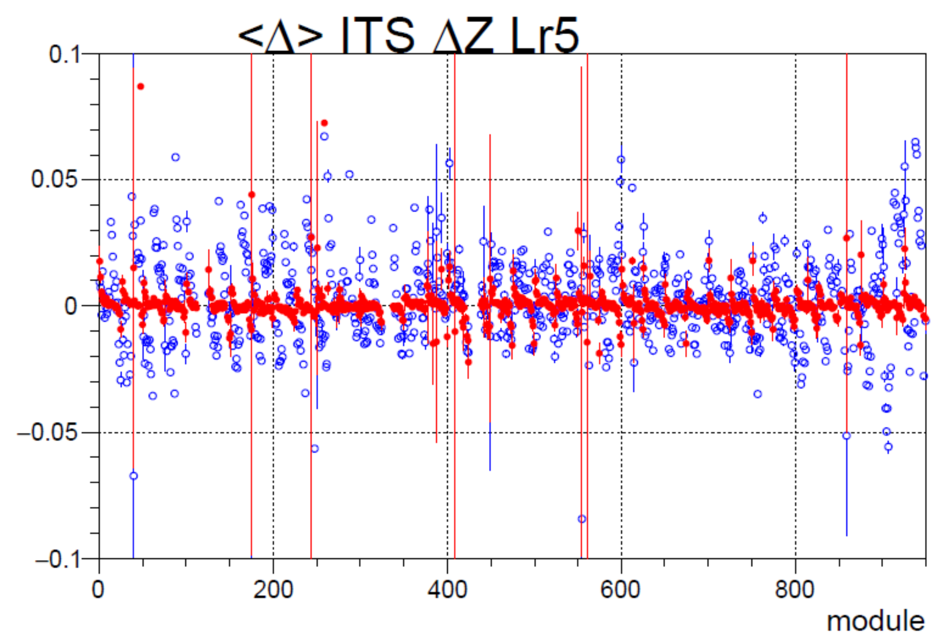


<Δ> ITS ΔZ Lr4
0.1
0.05
0
−0.05
−0.1
0
100
200
300
400
500
600
700
module

SSD5

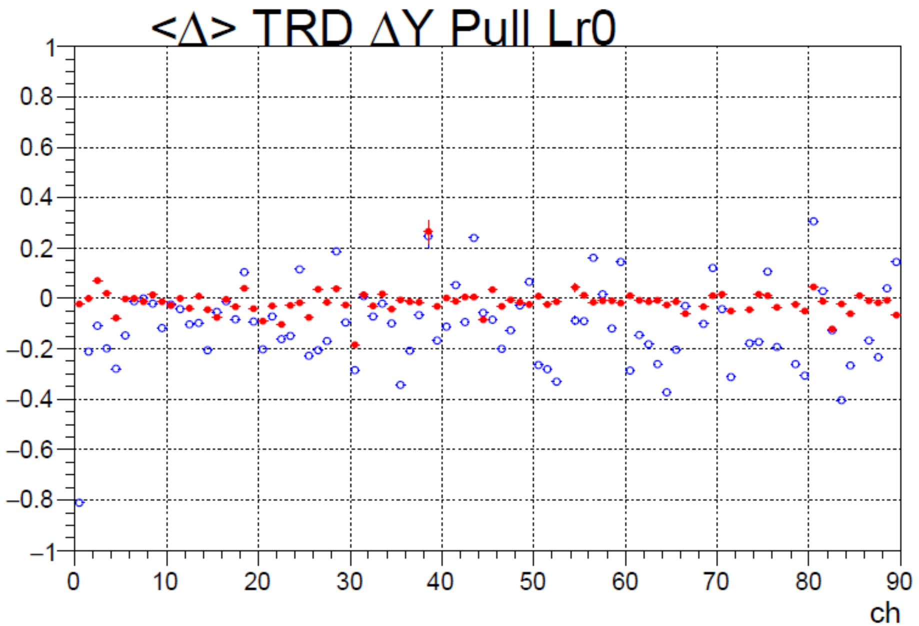


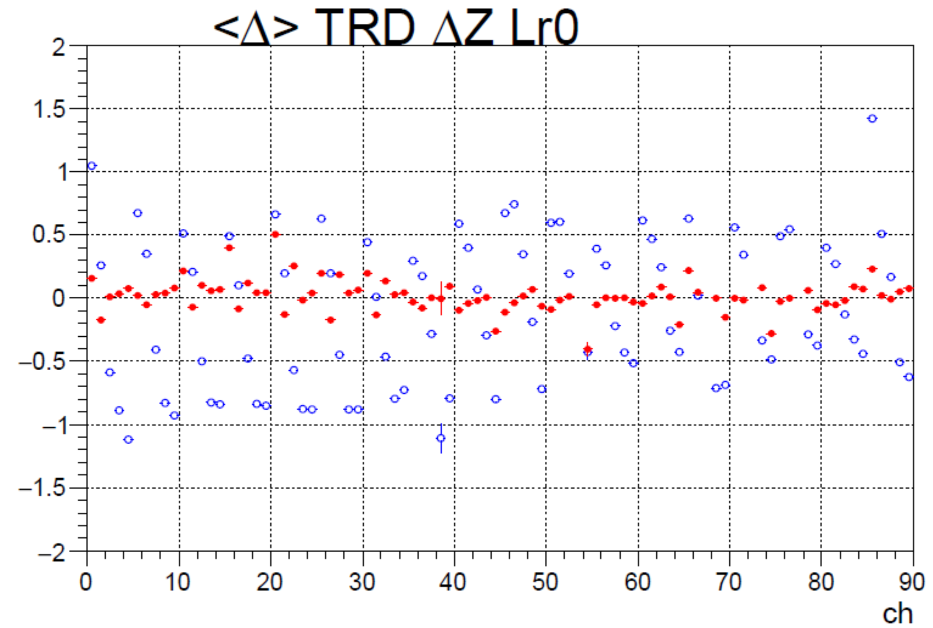
<Δ> ITS ΔY Lr5
0.04
0.02
0
−0.02
−0.04
0
200
400
600
800
module



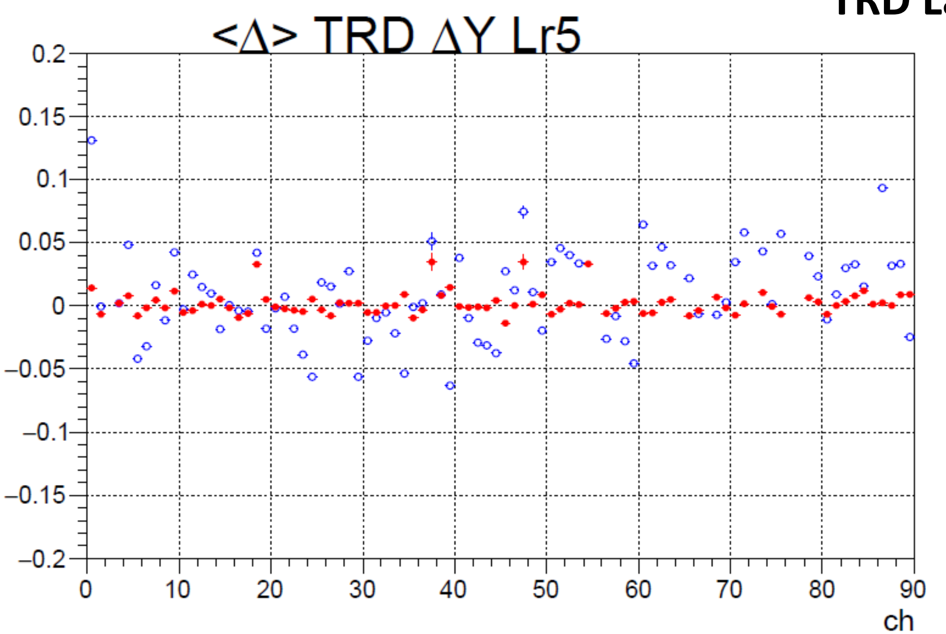
<Δ> ITS ΔZ Lr5
0.1
0.05
0
−0.05
−0.1
0
200
400
600
800
module

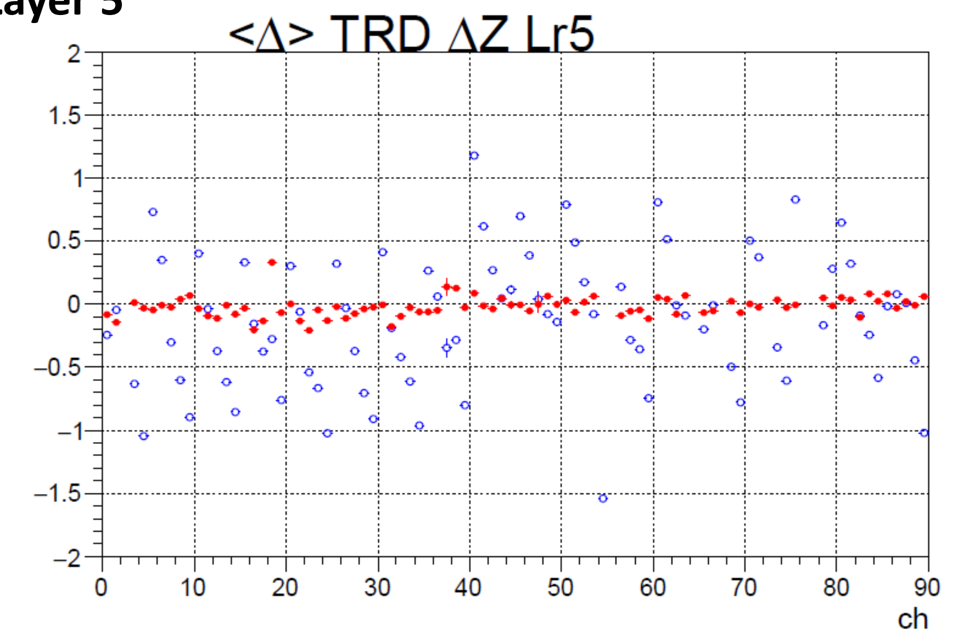
TRD Layer 0



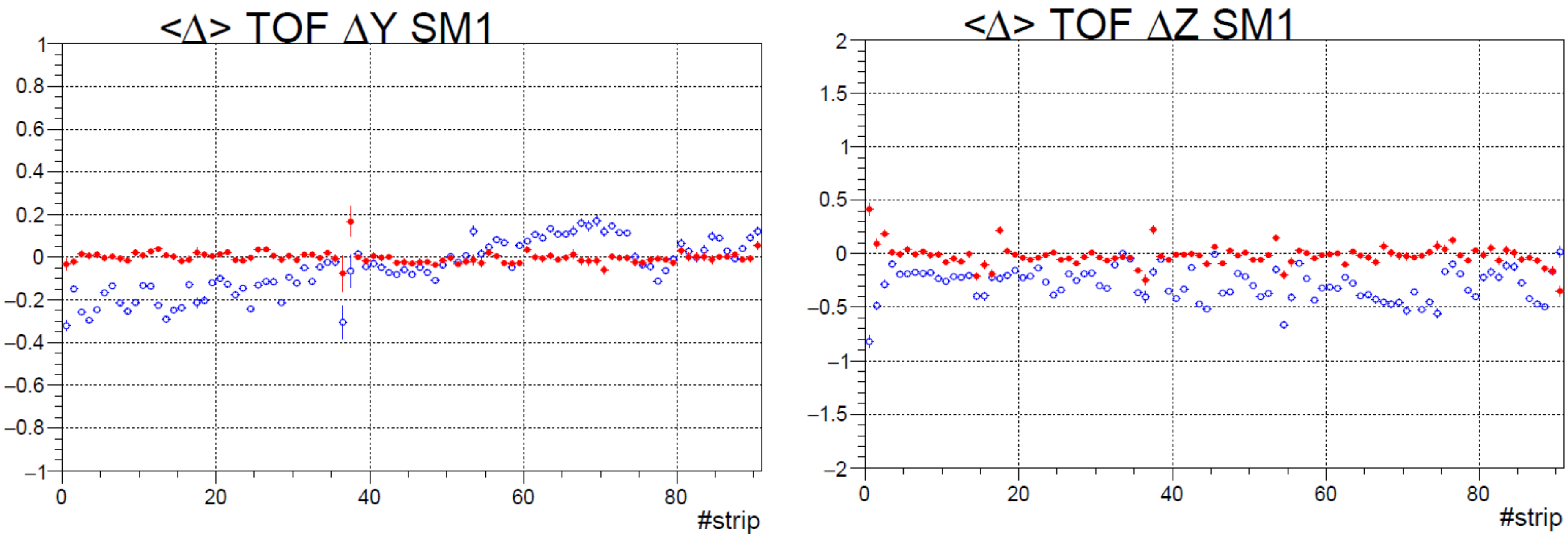


TRD Layer 5

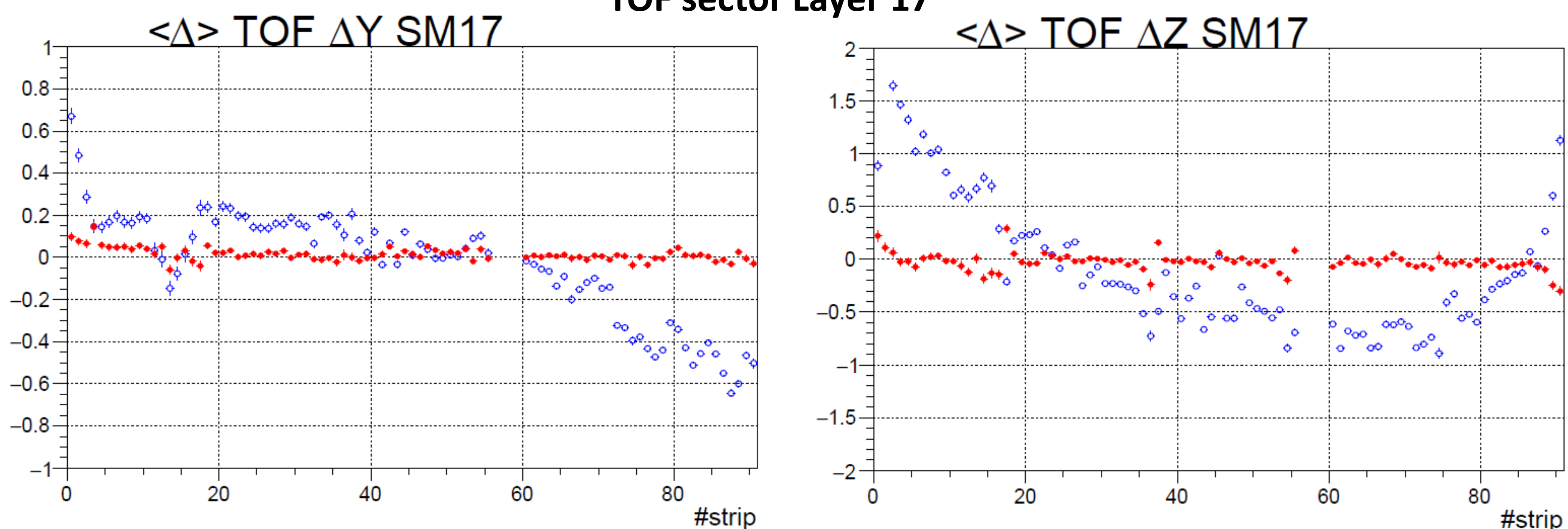




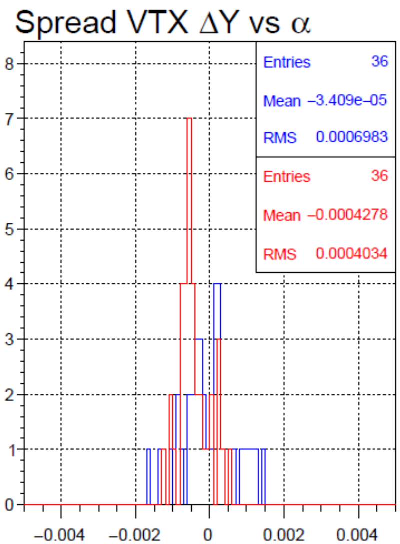
TOF sector Layer 1

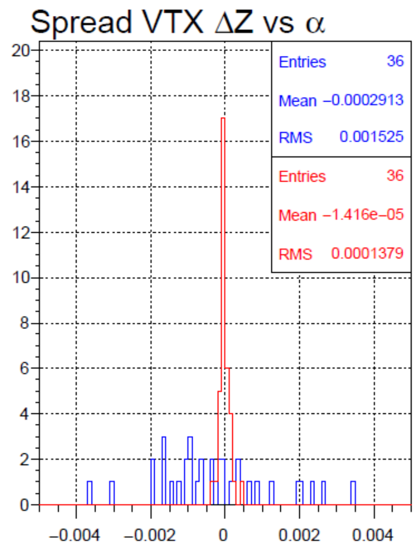


TOF sector Layer 17

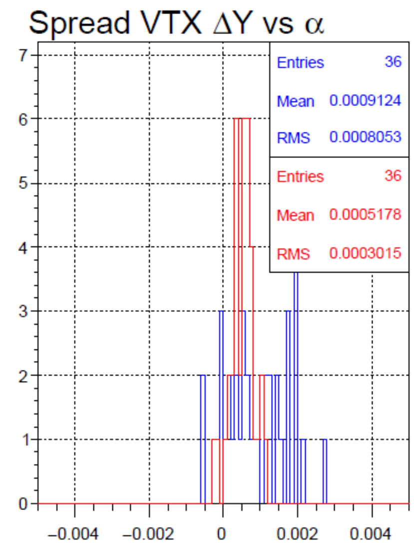


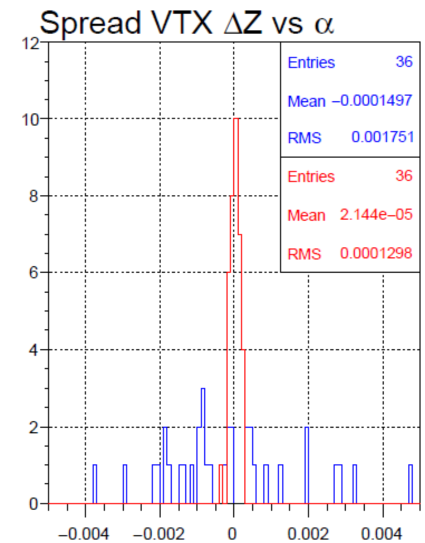
Bin-by-bin (sensor-by-sensor) residuals spread



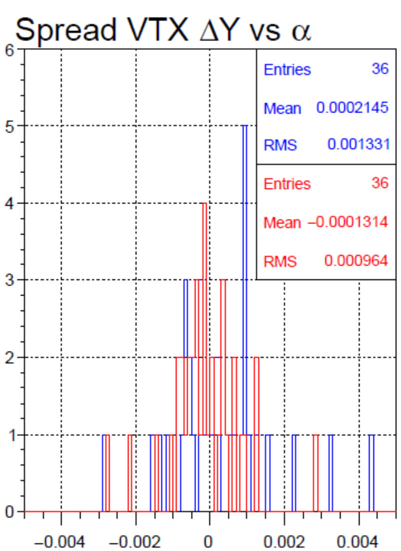


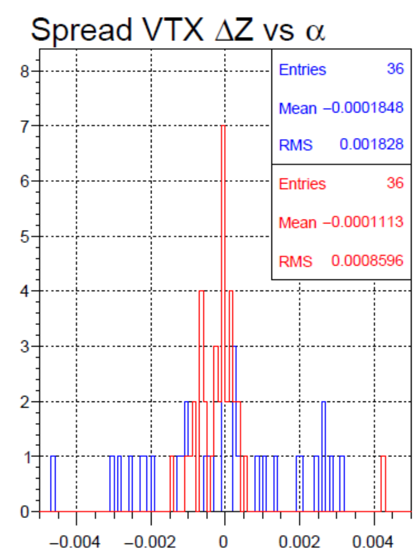
B+



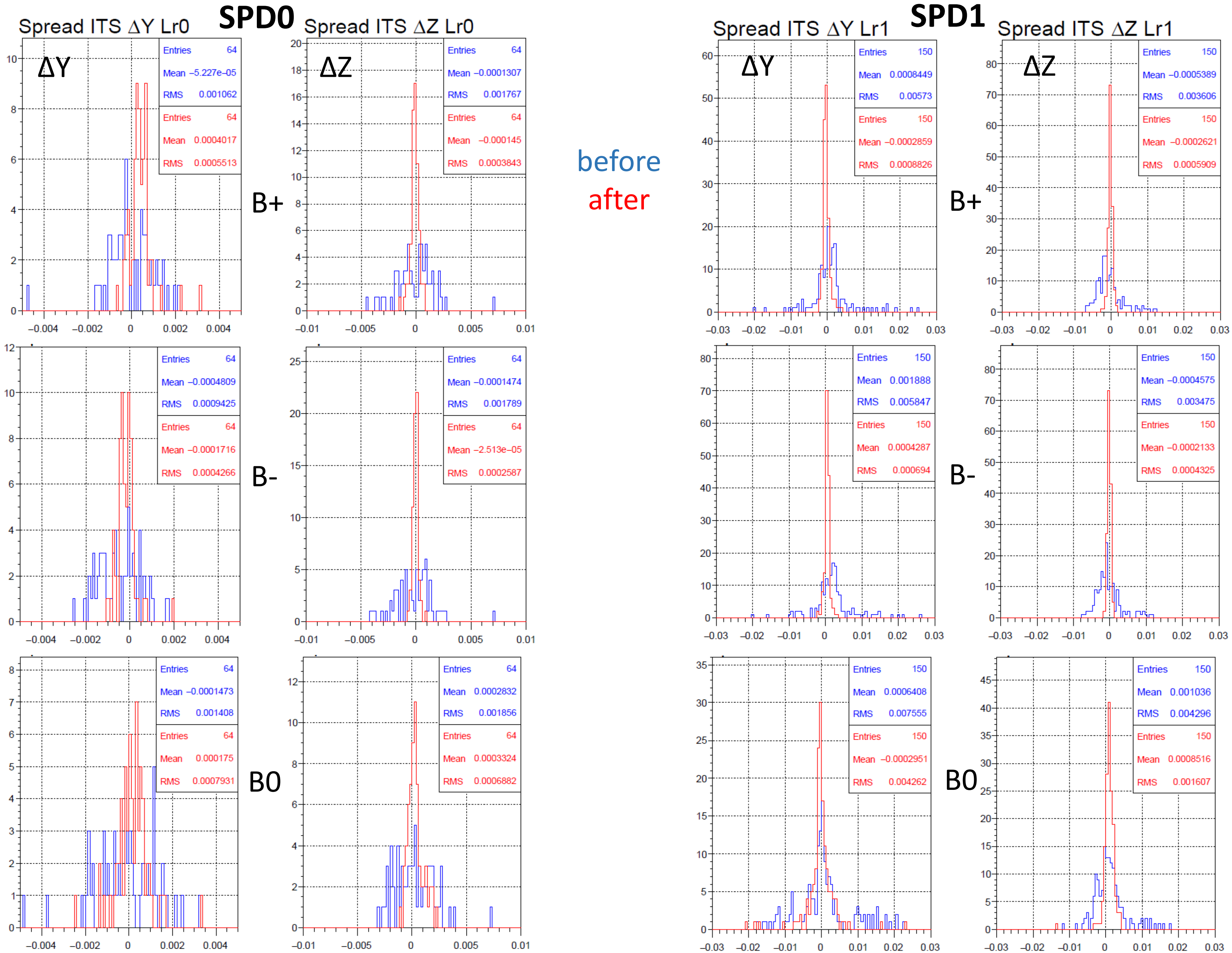


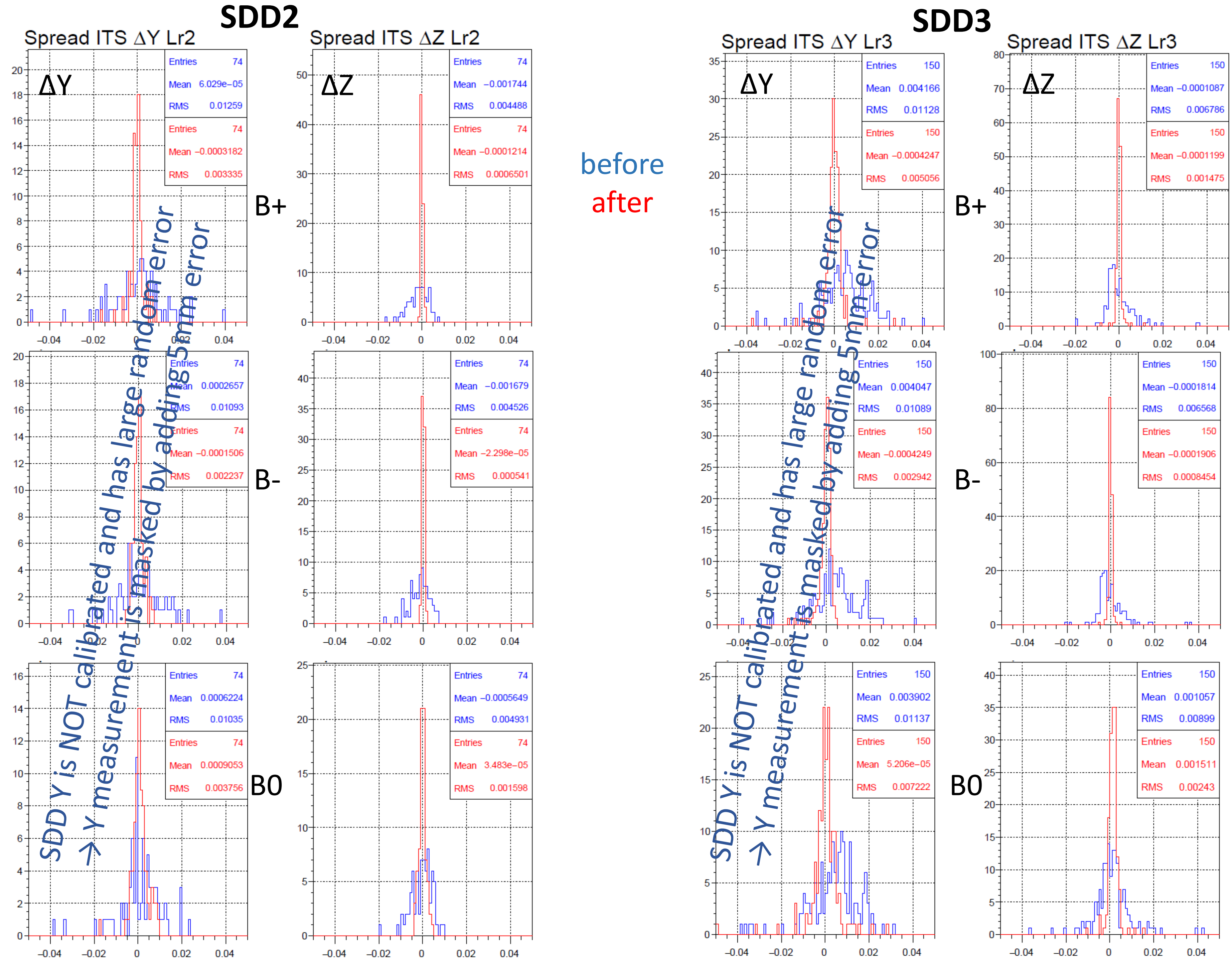
B-

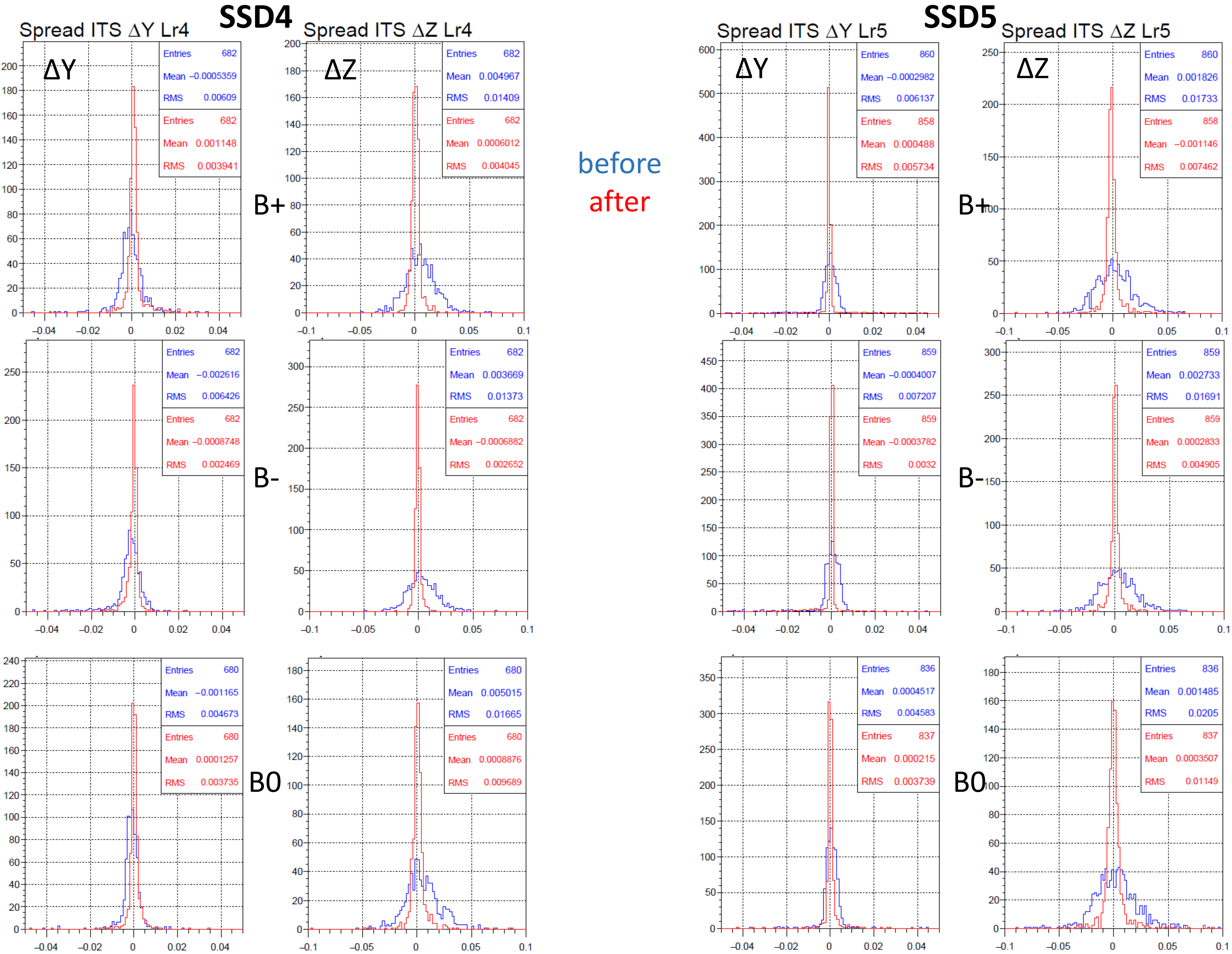


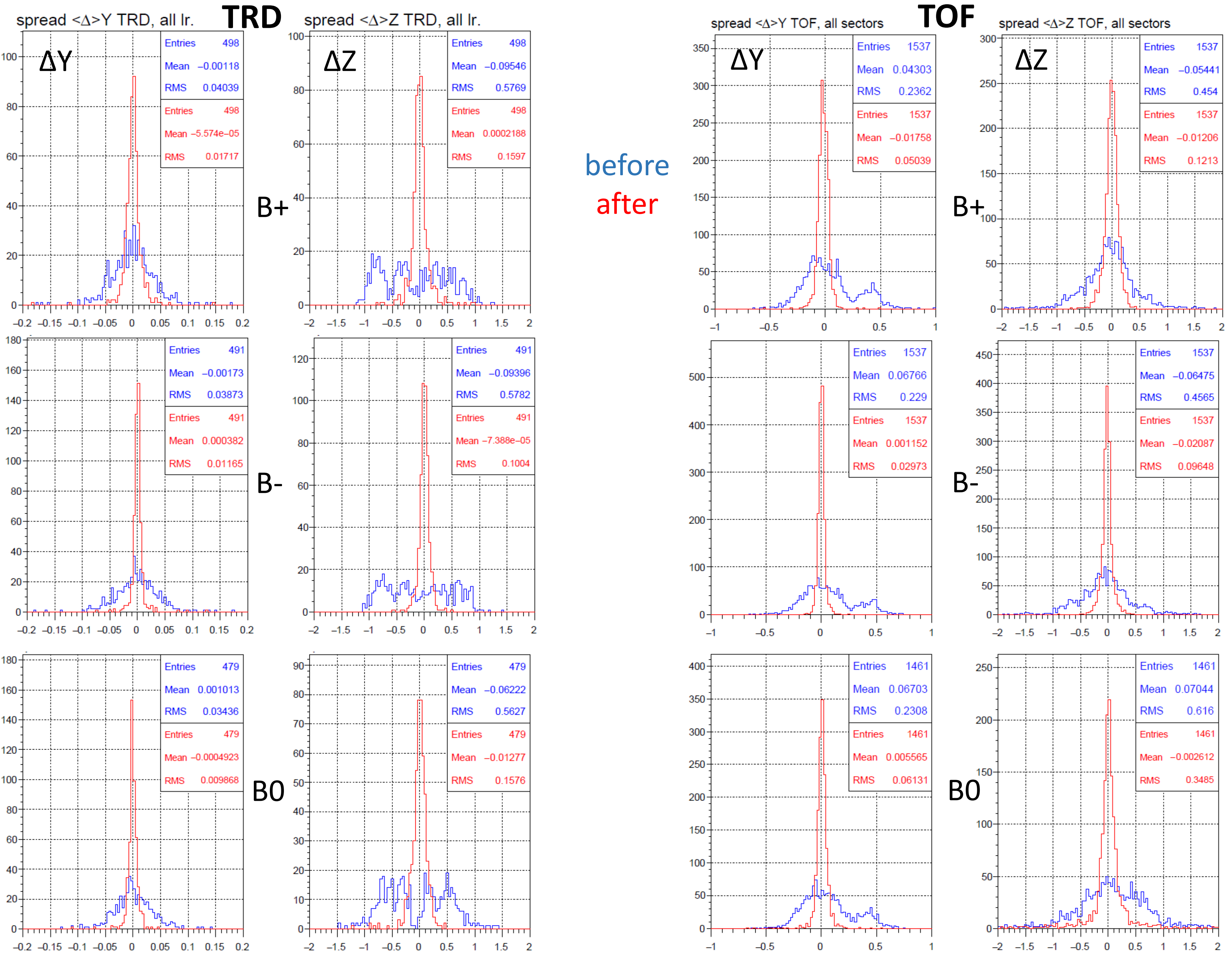


B0


SPD0
SPD1
before
after
Spread ITS ΔY Lr0
Spread ITS ΔZ Lr0
Spread ITS ΔY Lr1
Spread ITS ΔZ Lr1
ΔY
ΔZ
B+
B-
B0
Entries 64
Mean −5.227e−05
RMS 0.001062
Entries 64
Mean 0.0004017
RMS 0.0005513
Entries 64
Mean −0.0001307
RMS 0.001767
Entries 64
Mean −0.000145
RMS 0.0003843
Entries 150
Mean 0.0008449
RMS 0.00573
Entries 150
Mean −0.0002859
RMS 0.0008826
Entries 150
Mean −0.0005389
RMS 0.003606
Entries 150
Mean −0.0002621
RMS 0.0005909
Entries 64
Mean −0.0004809
RMS 0.0009425
Entries 64
Mean −0.0001716
RMS 0.0004266
Entries 64
Mean −0.0001474
RMS 0.001789
Entries 64
Mean −2.513e−05
RMS 0.0002587
Entries 150
Mean 0.001888
RMS 0.005847
Entries 150
Mean 0.0004287
RMS 0.000694
Entries 150
Mean −0.0004575
RMS 0.003475
Entries 150
Mean −0.0002133
RMS 0.0004325
Entries 64
Mean −0.0001473
RMS 0.001408
Entries 64
Mean 0.000175
RMS 0.0007931
Entries 64
Mean 0.0002832
RMS 0.001856
Entries 64
Mean 0.0003324
RMS 0.0006882
Entries 150
Mean 0.0006408
RMS 0.007555
Entries 150
Mean −0.0002951
RMS 0.004262
Entries 150
Mean 0.001036
RMS 0.004296
Entries 150
Mean 0.0008516
RMS 0.001607


SDD2
Spread ITS ΔY Lr2
ΔY
Entries 74
Mean 6.029e−05
RMS 0.01259
Entries 74
Mean −0.0003182
RMS 0.003335
Spread ITS ΔZ Lr2
ΔZ
Entries 74
Mean −0.001744
RMS 0.004488
Entries 74
Mean −0.0001214
RMS 0.0006501
B+
Entries 74
Mean 0.0002657
RMS 0.01093
Entries 74
Mean −0.0001506
RMS 0.002237
Entries 74
Mean −0.001679
RMS 0.004526
Entries 74
Mean −2.298e−05
RMS 0.000541
B-
Entries 74
Mean 0.0006224
RMS 0.01035
Entries 74
Mean 0.0009053
RMS 0.003756
Entries 74
Mean −0.0005649
RMS 0.004931
Entries 74
Mean 3.483e−05
RMS 0.001598
B0
before
after
SDD3
Spread ITS ΔY Lr3
ΔY
Entries 150
Mean 0.004166
RMS 0.01128
Entries 150
Mean −0.0004247
RMS 0.005056
Spread ITS ΔZ Lr3
ΔZ
Entries 150
Mean −0.0001087
RMS 0.006786
Entries 150
Mean −0.0001199
RMS 0.001475
B+
Entries 150
Mean 0.004047
RMS 0.01089
Entries 150
Mean −0.0004249
RMS 0.002942
Entries 150
Mean −0.0001814
RMS 0.006568
Entries 150
Mean −0.0001906
RMS 0.0008454
B-
Entries 150
Mean 0.003902
RMS 0.01137
Entries 150
Mean 5.206e−05
RMS 0.007222
Entries 150
Mean 0.001057
RMS 0.00899
Entries 150
Mean 0.001511
RMS 0.00243
B0
SDD Y is NOT calibrated and has large random error
→ Y measurement is masked by adding 5mm error


SSD4
Spread ITS ΔY Lr4
ΔY
Entries 682
Mean −0.0005359
RMS 0.00609
Entries 682
Mean 0.001148
RMS 0.003941
Spread ITS ΔZ Lr4
ΔZ
Entries 682
Mean 0.004967
RMS 0.01409
Entries 682
Mean 0.0006012
RMS 0.004045
B+
Entries 682
Mean −0.002616
RMS 0.006426
Entries 682
Mean −0.0008748
RMS 0.002469
Entries 682
Mean 0.003669
RMS 0.01373
Entries 682
Mean −0.0006882
RMS 0.002652
B-
Entries 680
Mean −0.001165
RMS 0.004673
Entries 680
Mean 0.0001257
RMS 0.003735
Entries 680
Mean 0.005015
RMS 0.01665
Entries 680
Mean 0.0008876
RMS 0.009689
B0
before
after
SSD5
Spread ITS ΔY Lr5
ΔY
Entries 860
Mean −0.0002982
RMS 0.006137
Entries 858
Mean 0.000488
RMS 0.005734
Spread ITS ΔZ Lr5
ΔZ
Entries 860
Mean 0.001826
RMS 0.01733
Entries 858
Mean −0.001146
RMS 0.007462
B+
Entries 859
Mean −0.0004007
RMS 0.007207
Entries 859
Mean −0.0003782
RMS 0.0032
Entries 859
Mean 0.002733
RMS 0.01691
Entries 859
Mean 0.0002833
RMS 0.004905
B-
Entries 836
Mean 0.0004517
RMS 0.004583
Entries 837
Mean 0.000215
RMS 0.003739
Entries 836
Mean 0.001485
RMS 0.0205
Entries 837
Mean 0.0003507
RMS 0.01149
B0



TRD
TOF
spread <Δ>Y TRD, all lr.
spread <Δ>Z TRD, all lr.
spread <Δ>Y TOF, all sectors
spread <Δ>Z TOF, all sectors
ΔY
ΔZ
before
after
B+
B-
B0
Entries 498 Mean −0.00118 RMS 0.04039
Entries 498 Mean −5.574e−05 RMS 0.01717
Entries 498 Mean −0.09546 RMS 0.5769
Entries 498 Mean 0.0002188 RMS 0.1597
Entries 1537 Mean 0.04303 RMS 0.2362
Entries 1537 Mean −0.01758 RMS 0.05039
Entries 1537 Mean −0.05441 RMS 0.454
Entries 1537 Mean −0.01206 RMS 0.1213
Entries 491 Mean −0.00173 RMS 0.03873
Entries 491 Mean 0.000382 RMS 0.01165
Entries 491 Mean −0.09396 RMS 0.5782
Entries 491 Mean −7.388e−05 RMS 0.1004
Entries 1537 Mean 0.06766 RMS 0.229
Entries 1537 Mean 0.001152 RMS 0.02973
Entries 1537 Mean −0.06475 RMS 0.4565
Entries 1537 Mean −0.02087 RMS 0.09648
Entries 479 Mean 0.001013 RMS 0.03436
Entries 479 Mean −0.0004923 RMS 0.009868
Entries 479 Mean −0.06222 RMS 0.5627
Entries 479 Mean −0.01277 RMS 0.1576
Entries 1461 Mean 0.06703 RMS 0.2308
Entries 1461 Mean 0.005565 RMS 0.06131
Entries 1461 Mean 0.07044 RMS 0.616
Entries 1461 Mean −0.002612 RMS 0.3485

Outlook

- Millepede alignment
  - Try to improve vertex DCA (bias in φ, p_T)
  - Systematic difference between B+, B- and B0 is still observed:
    - In the current ITS/TRD/TOF alignment schema only TRD may introduce such dependence via run/field dependent calibrations
    - Introduce calibration DOF sets for field and run dependent calibration parameters to improve alignment quality (and TRD calibration also)
  - Finalize HMPID module
  - Many ITS sensors are not in the data (list in the backup)

    SPD0: 6/80, SPD1: 10/160,

    SDD2: 9/84, SDD3: 21/176,

    SSD4: 66/748 SSD5: 80/950

    Need additional alignment if reappear in the future data

- For the Run3 upgrade: problems with ROOT TGeoHMatrix precision might be critical for ITS upgrade, fix is needed

Outlook

- Aliroot reconstruction
  - TRD Z assignment for pad-row non-crossing tracklets must be fixed
  - Ion-tail cancelation in TRD: correction for B=0 is applied as for B<0 field
    → to be fixed
    The corrections themselves
    (up to ~200 and ~400 μm depending in B sign) to be checked
  - TOF clusters should receive proper misalignment

  - Once TPC distortion maps are ready, reconstruct high pT filtered data with TRD (TOF?) in the reconstruction, to check the effect on pT resolution, efficiency.

BACKUP

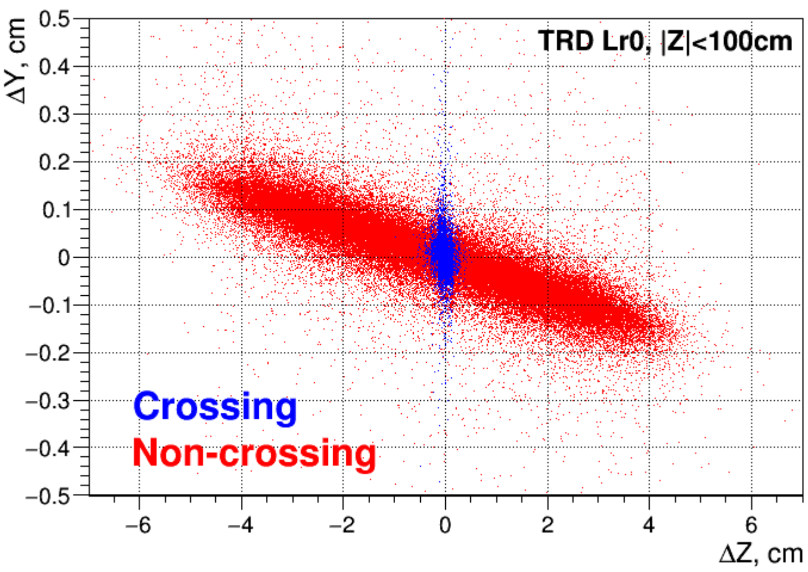
Missing ITS detectors

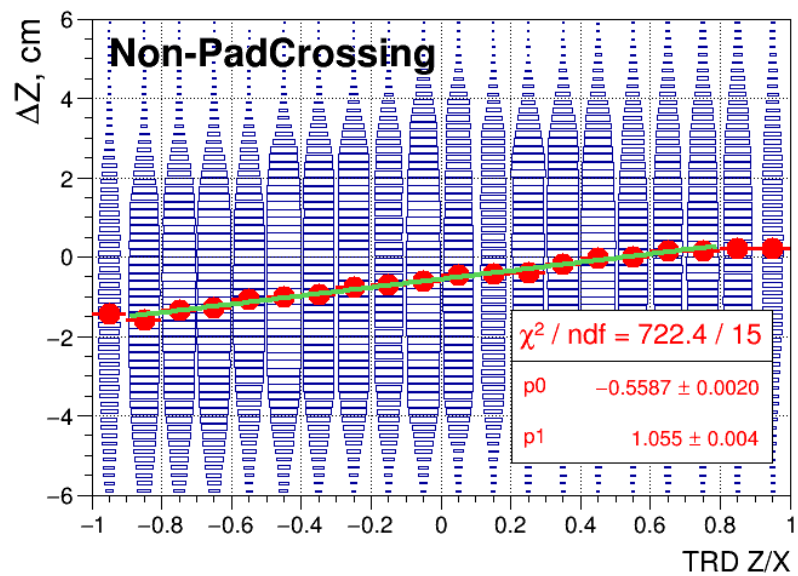

```
SPD0:
Sector1/Stave1/HalfStave0 Sector2/Stave0/HalfStave1 Sector2/Stave1/HalfStave1

SPD1:
Sector3/Stave1/HalfStave1 Sector4/Stave0/HalfStave0 Sector5/Stave1/HalfStave0
Sector6/Stave1/Halfstave1 Sector8/Stave1/Halfstave0

SDD2:
Ladder2/Sensor2 Ladder3/Sensor0 Ladder3/Sensor1 Ladder3/Sensor2  Ladder6/Sensor3
Ladder6/Sensor4 Ladder6/Sensor5 Ladder9/Sensor4 Ladder12/Sensor5

SDD3:
Ladder0/Sensor0  Ladder2/Sensor3  Ladder2/Sensor5  Ladder3/Sensor0  Ladder3/Sensor1
Ladder3/Sensor7  Ladder8/Sensor3  Ladder9/Sensor0  Ladder9/Sensor5  Ladder10/Sensor2
Ladder10/Sensor6 Ladder11/Sensor0 Ladder13/Sensor7 Ladder14/Sensor3 Ladder14/Sensor4
Ladder14/Sensor5 Ladder16/Sensor2 Ladder17/Sensor3 Ladder17/Sensor5 Ladder18/Sensor1
Ladder18/Sensor6 Ladder20/Sensor2 Ladder20/Sensor5 Ladder21/Sensor0

SDD4:
Ladder0/Sensor9   Ladder1/Sensor5   Ladder2/Sensor3   Ladder2/Sensor10  Ladder2/Sensor19
Ladder4/Sensor14  Ladder4/Sensor19  Ladder5/Sensor12  Ladder6/Sensor2   Ladder6/Sensor15
Ladder8/Sensor12  Ladder8/Sensor13  Ladder8/Sensor14  Ladder8/Sensor15  Ladder8/Sensor16
Ladder8/Sensor17  Ladder8/Sensor18  Ladder8/Sensor19  Ladder8/Sensor20  Ladder8/Sensor21
Ladder14/Sensor8  Ladder14/Sensor12 Ladder14/Sensor13 Ladder14/Sensor14 Ladder14/Sensor15
Ladder14/Sensor16 Ladder14/Sensor17 Ladder14/Sensor18 Ladder14/Sensor19 Ladder14/Sensor20
Ladder14/Sensor21 Ladder15/Sensor5  Ladder15/Sensor12 Ladder15/Sensor13 Ladder15/Sensor14
Ladder15/Sensor15 Ladder15/Sensor16 Ladder15/Sensor17 Ladder15/Sensor18 Ladder15/Sensor19
Ladder15/Sensor20 Ladder15/Sensor21 Ladder18/Sensor7  Ladder21/Sensor6  Ladder21/Sensor10
Ladder23/Sensor7  Ladder23/Sensor11 Ladder26/Sensor0  Ladder27/Sensor6  Ladder29/Sensor1
Ladder29/Sensor11 Ladder29/Sensor20 Ladder29/Sensor21 Ladder30/Sensor9  Ladder32/Sensor12
Ladder32/Sensor13 Ladder32/Sensor14 Ladder32/Sensor15 Ladder32/Sensor16 Ladder32/Sensor17
Ladder32/Sensor18 Ladder32/Sensor19 Ladder32/Sensor20 Ladder32/Sensor21 Ladder33/Sensor2
Ladder33/Sensor12
```

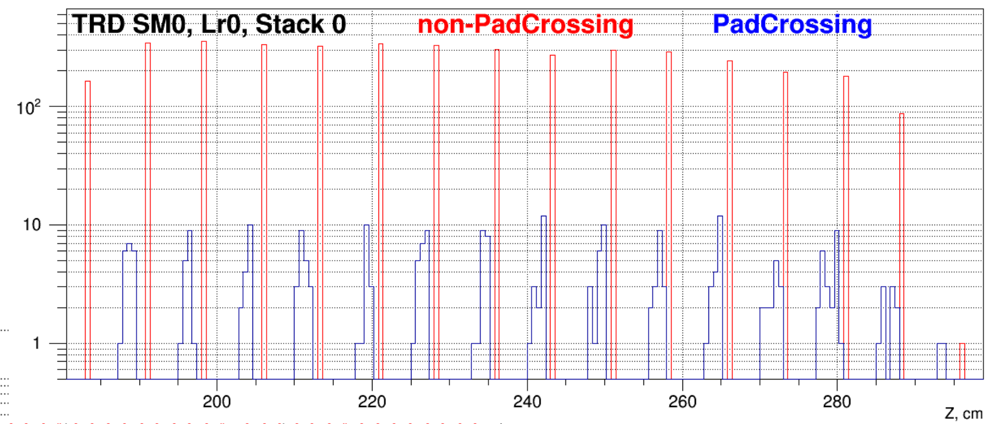
Missing ITS detectors

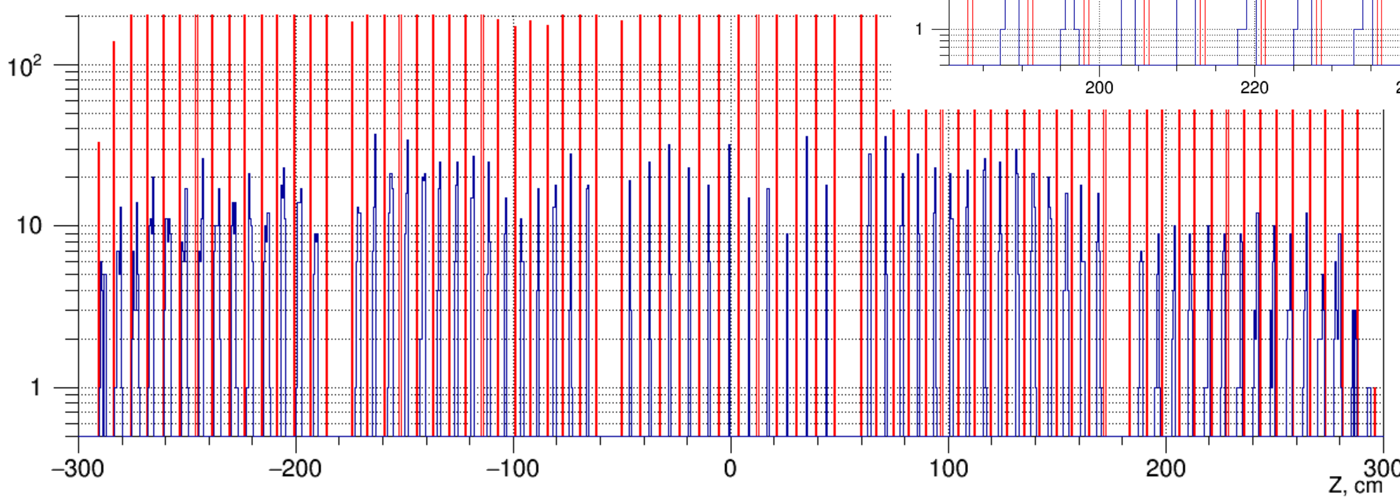
SSD5:

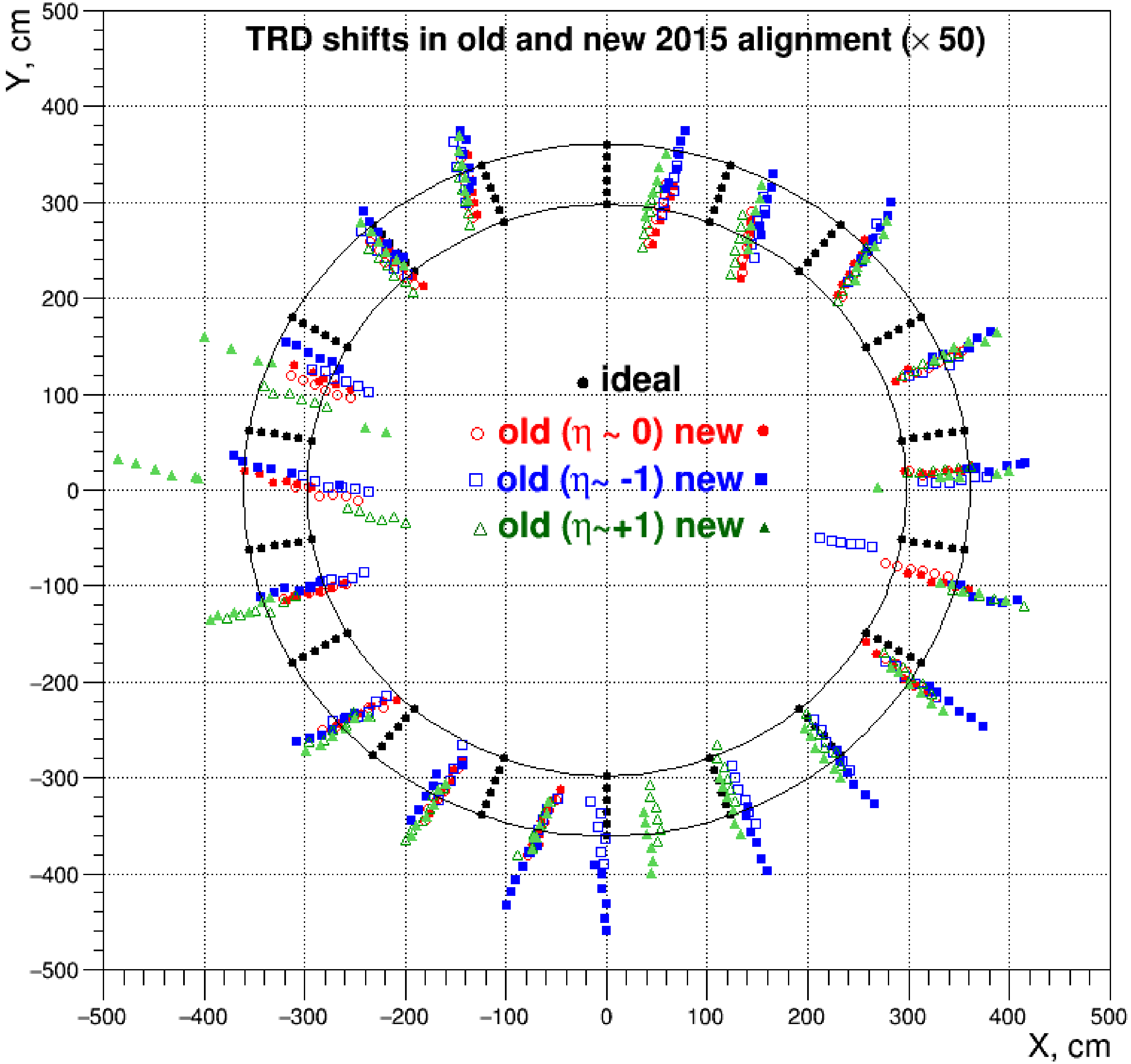
Ladder0/Sensor12	Ladder1/Sensor0	Ladder1/Sensor9	Ladder1/Sensor22	Ladder2/Sensor10
Ladder4/Sensor1	Ladder4/Sensor6	Ladder4/Sensor9	Ladder4/Sensor12	Ladder4/Sensor13
Ladder4/Sensor14	Ladder4/Sensor15	Ladder4/Sensor16	Ladder4/Sensor17	Ladder4/Sensor18
Ladder4/Sensor19	Ladder4/Sensor20	Ladder4/Sensor21	Ladder4/Sensor22	Ladder4/Sensor23
Ladder4/Sensor24	Ladder5/Sensor20	Ladder5/Sensor21	Ladder8/Sensor0	Ladder8/Sensor4
Ladder8/Sensor11	Ladder9/Sensor10	Ladder9/Sensor22	Ladder11/Sensor13	Ladder11/Sensor22
Ladder13/Sensor0	Ladder13/Sensor1	Ladder13/Sensor2	Ladder13/Sensor3	Ladder13/Sensor4
Ladder13/Sensor5	Ladder13/Sensor6	Ladder13/Sensor7	Ladder13/Sensor8	Ladder13/Sensor9
Ladder13/Sensor10	Ladder13/Sensor11	Ladder14/Sensor1	Ladder14/Sensor7	Ladder15/Sensor0
Ladder16/Sensor0	Ladder17/Sensor0	Ladder17/Sensor1	Ladder17/Sensor2	Ladder17/Sensor3
Ladder17/Sensor4	Ladder17/Sensor5	Ladder17/Sensor6	Ladder17/Sensor7	Ladder17/Sensor8
Ladder17/Sensor9	Ladder17/Sensor10	Ladder17/Sensor11	Ladder17/Sensor12	Ladder17/Sensor22
Ladder20/Sensor14	Ladder22/Sensor8	Ladder22/Sensor16	Ladder22/Sensor18	Ladder22/Sensor22
Ladder24/Sensor4	Ladder32/Sensor0	Ladder33/Sensor6	Ladder33/Sensor7	Ladder33/Sensor18
Ladder33/Sensor20	Ladder33/Sensor24	Ladder34/Sensor0	Ladder34/Sensor5	Ladder34/Sensor7
Ladder36/Sensor10	Ladder36/Sensor11	Ladder37/Sensor20	Ladder37/Sensor21	Ladder37/Sensor23


TRD Lr0, |Z|<100cm
ΔY, cm
ΔZ, cm
Crossing
Non-crossing

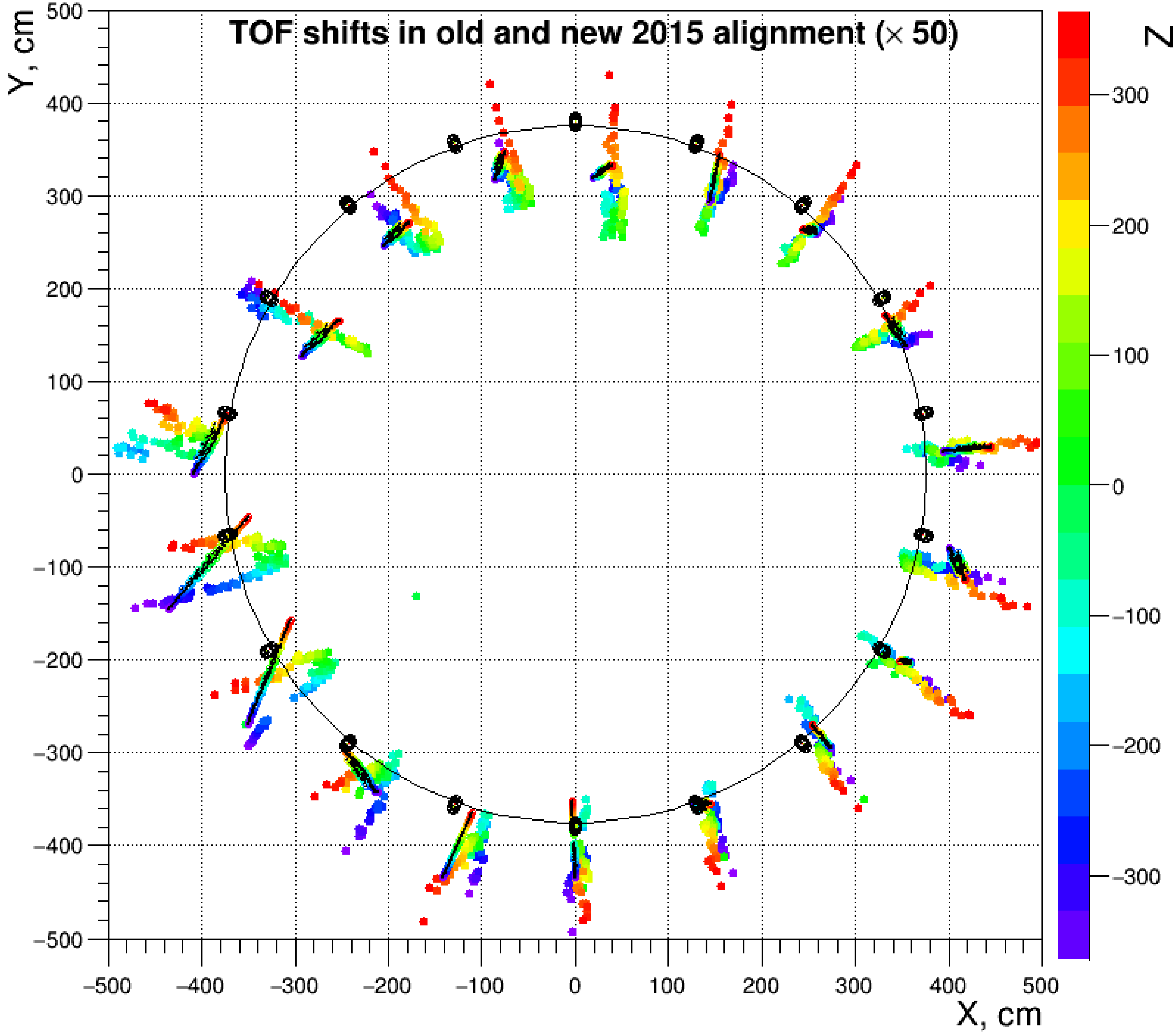

Non-PadCrossing
ΔZ, cm
TRD Z/X
χ² / ndf = 722.4 / 15
p0 −0.5587 ± 0.0020
p1 1.055 ± 0.004


TRD SM0, Lr0, Stack 0
non-PadCrossing
PadCrossing
Z, cm


Z, cm



TRD shifts in old and new 2015 alignment (× 50)
ideal
old (η ~ 0) new
old (η~ -1) new
old (η~+1) new
Y, cm
X, cm
500
400
300
200
100
0
−100
−200
−300
−400
−500
−500
−400
−300
−200
−100
0
100
200
300
400
500



TOF shifts in old and new 2015 alignment (× 50)
Y, cm
X, cm
Z
500
400
300
200
100
0
−100
−200
−300
−400
−500
−500
−400
−300
−200
−100
0
100
200
300
400
500
300
200
100
0
−100
−200
−300