Validation and tests for the alignment of the ALICE Inner Tracking System

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for the ALICE collaboration

in collaboration with
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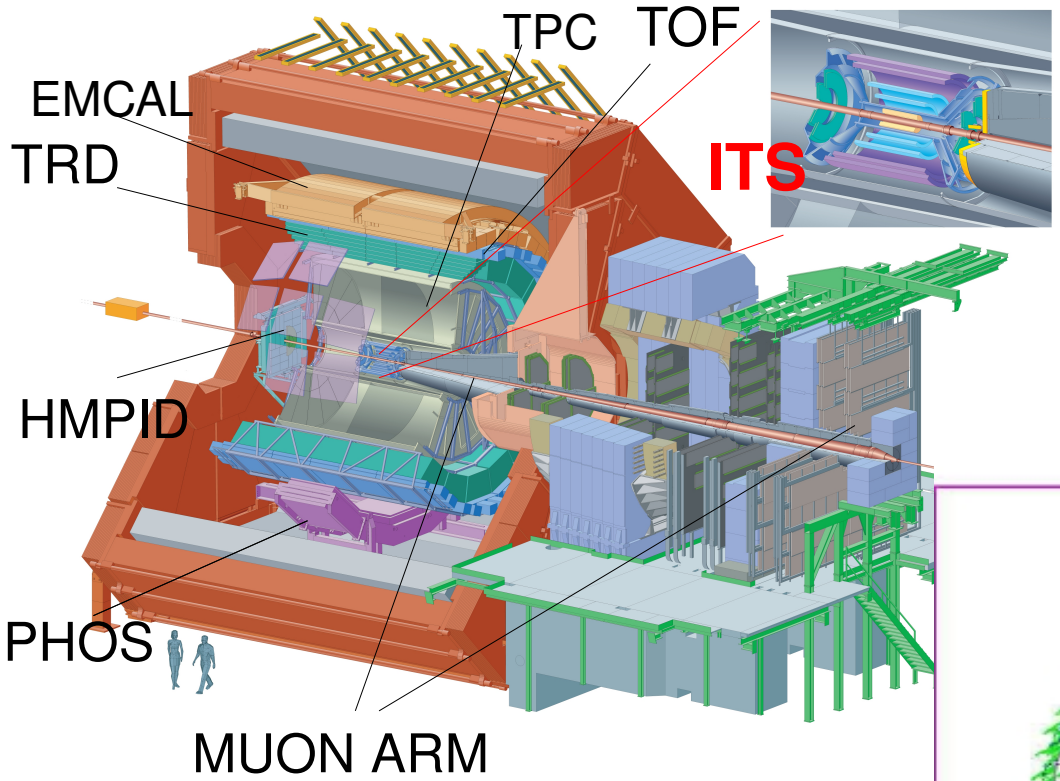
Outline

- Tests with cosmic tracks to check the alignment status with and without magnetic field
- Validation of the SSD survey
- Iterative module-by-module alignment: results for SPD
- SDD alignment and calibration
  - Millepede implementation

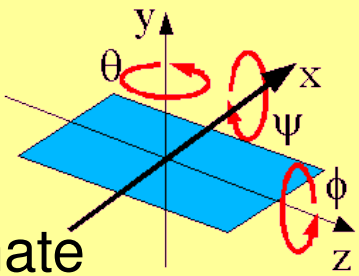
If not specified 2008 cosmic data

ALICE ITS and reference frame

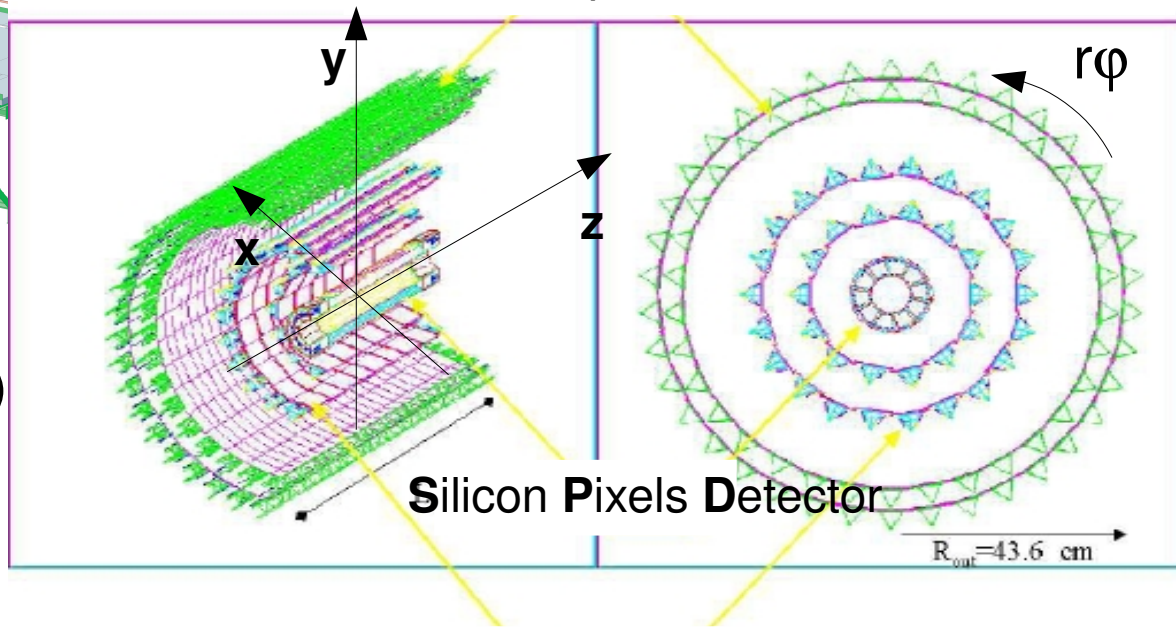


Detector Coordinates:

local x ~ rφ coordinate



Silicon Strip Detector



Silicon Pixels Detector

Silicon Drift Detector

Detector resolution (μm)

	X	Z
SPD	11	100
SDD	35	25
SSD	20	830

Track-to-points residuals

Procedure:

0) Select a set of volumes to refit the tracks ("volFIT") and a set of volumes to inspect ("volINS");

1) Refit the tracks using only the points in the volFIT;

2) Calculate the residuals in global coordinates between the newly fitted track and its points on the volINS. The residuals are defined as follows:

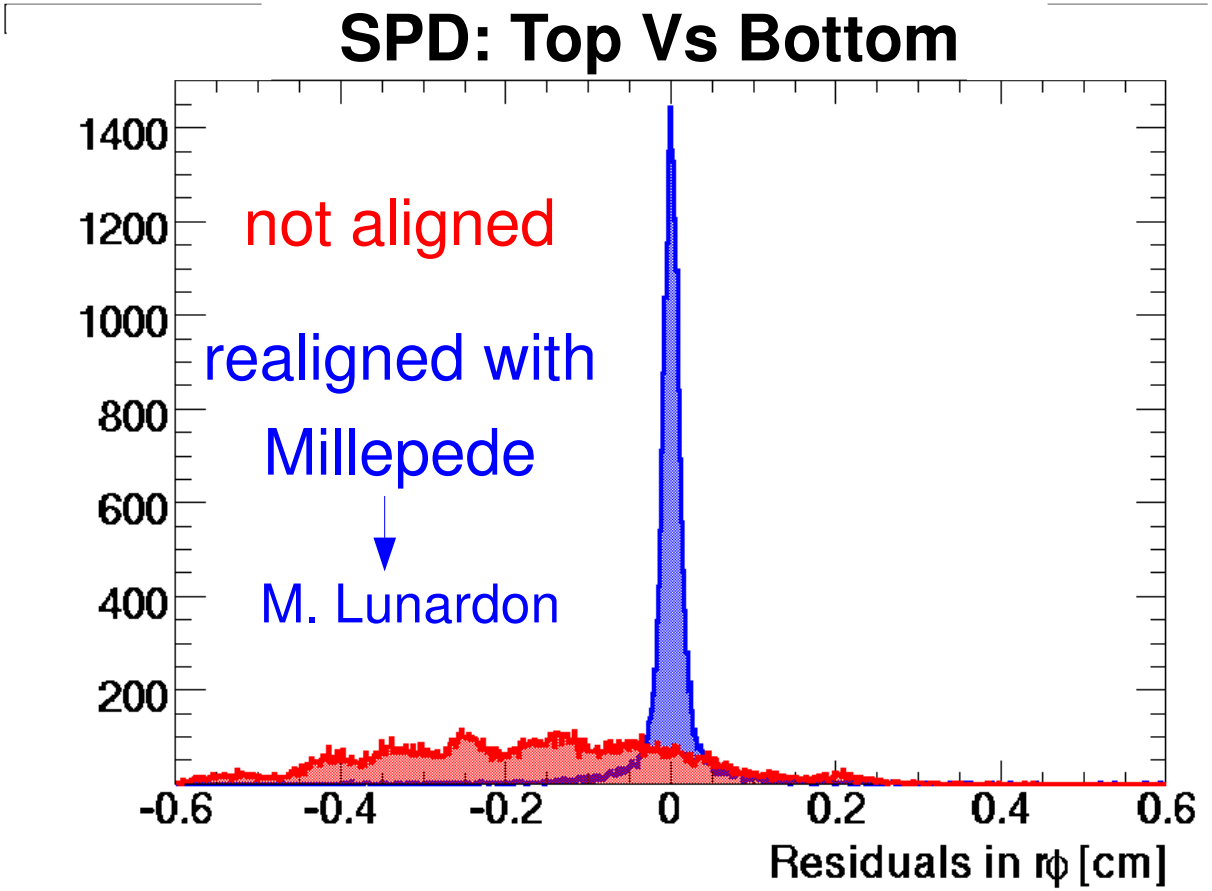
"rφ" $$Res(r\varphi)=\frac{\varphi_{trk}-\varphi_{pt}}{|\varphi_{trk}-\varphi_{pt}|}\sqrt{(X_{trk}-X_{pt})^2+(Y_{trk}-Y_{pt})^2}$$ (≈ local x)

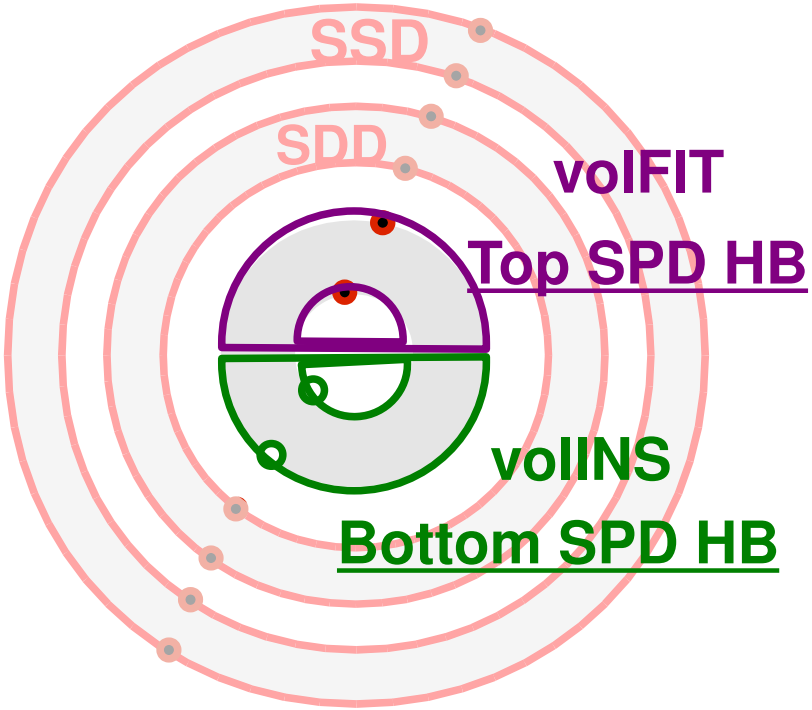
"Z" $$Res(Z)=Z_{trk}-Z_{pt}$$

Tests with track-to-point residuals, **B=0**

Fit the tracks on the Top SPD Half Barrel

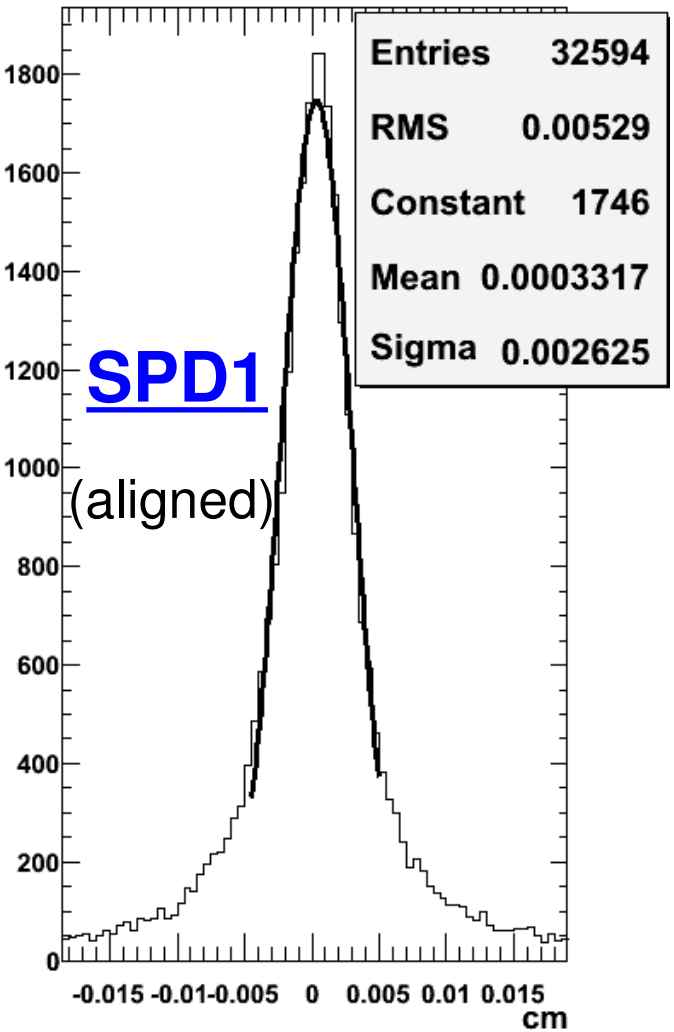
Extract the residuals on the Bottom SPD Half Barrel

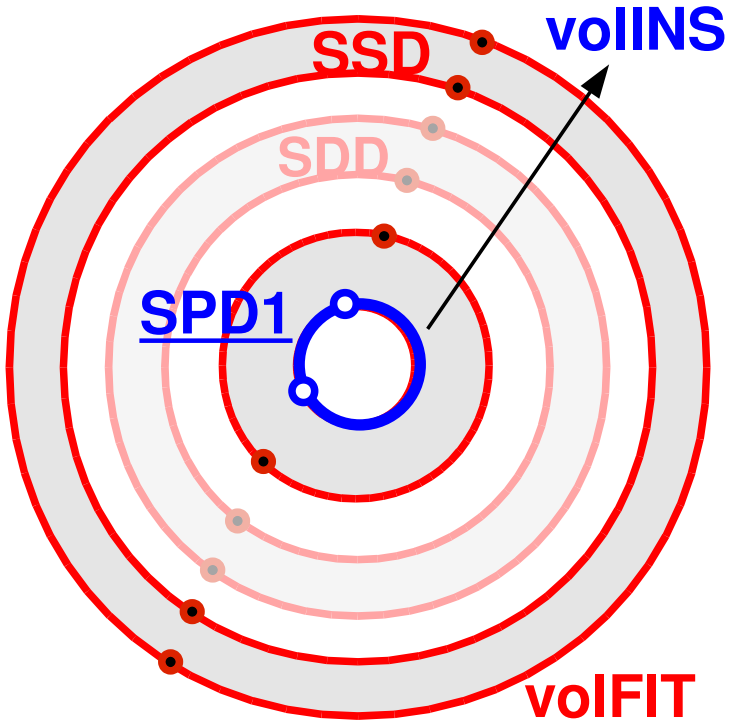




Tests with track-to-point residuals, **B=0**

REQUIREMENT: at least 4 points in the VolFIT





Sigma(rφ) = 26 μm

Tests with track-to-point residuals, **B=0**

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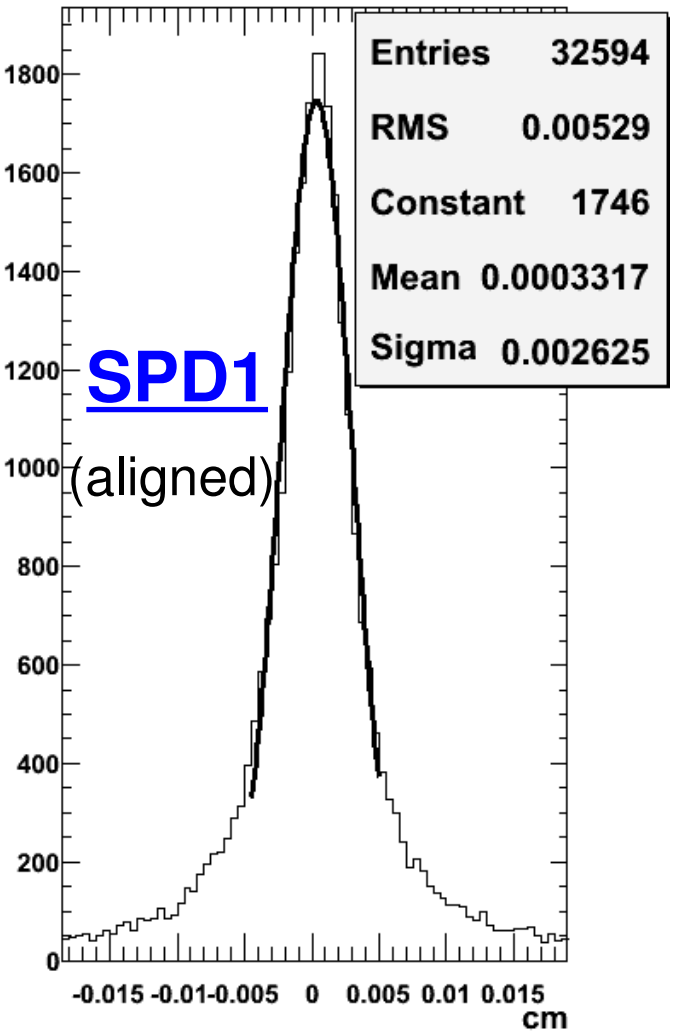

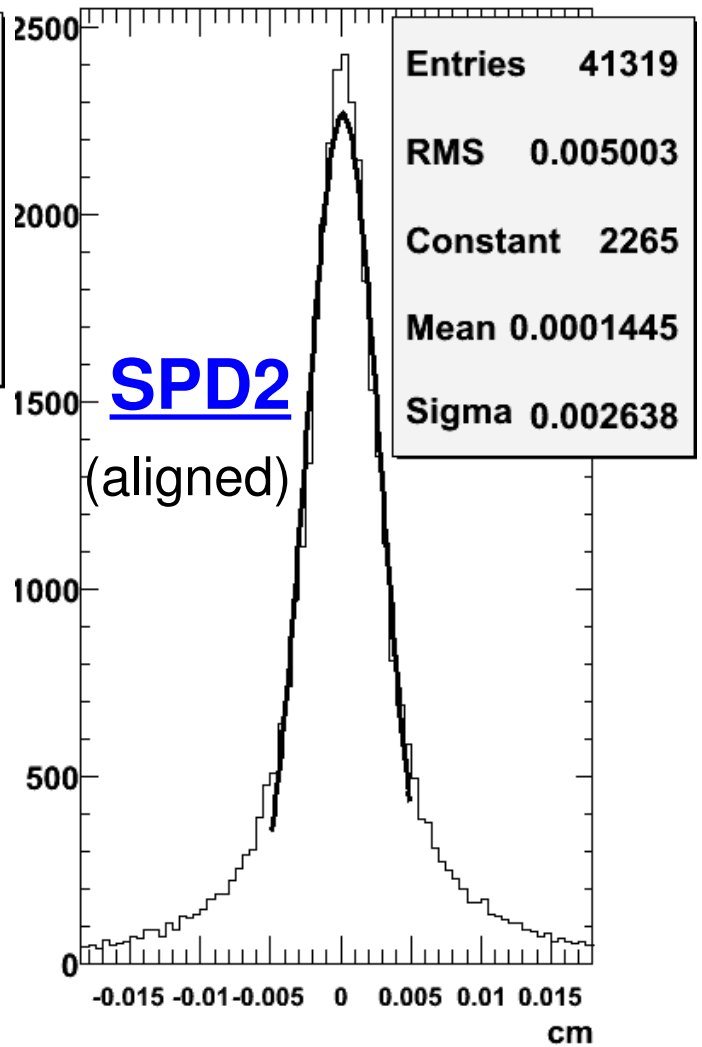

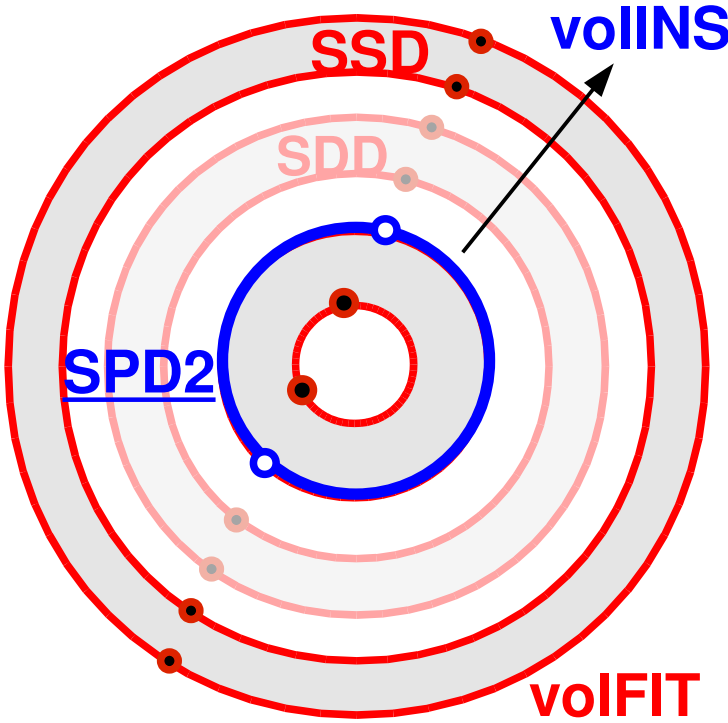

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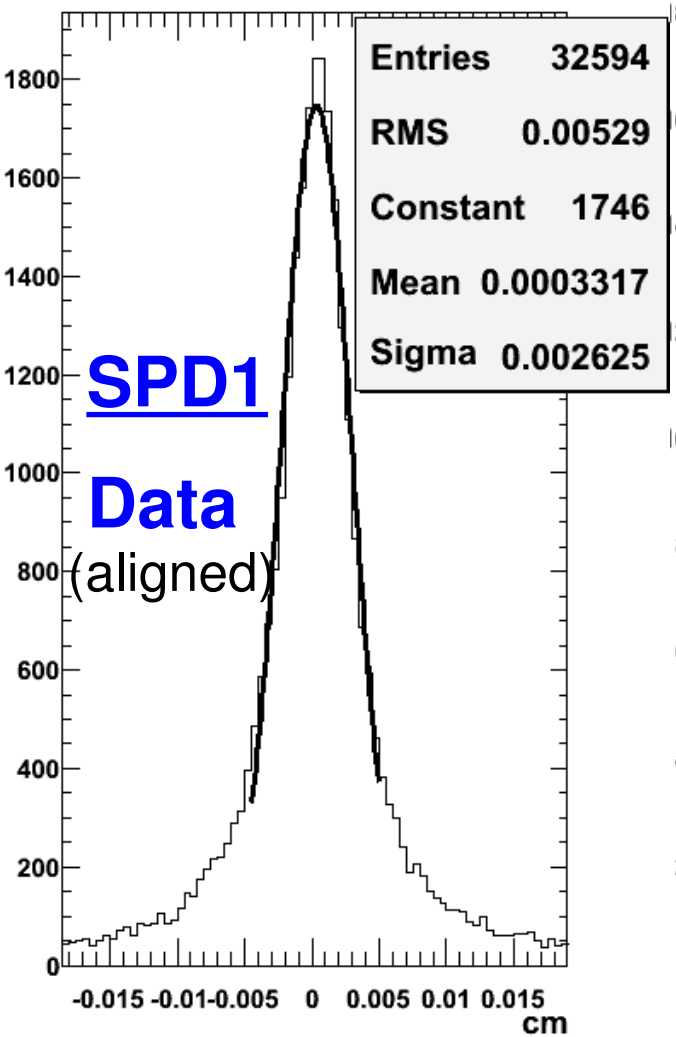
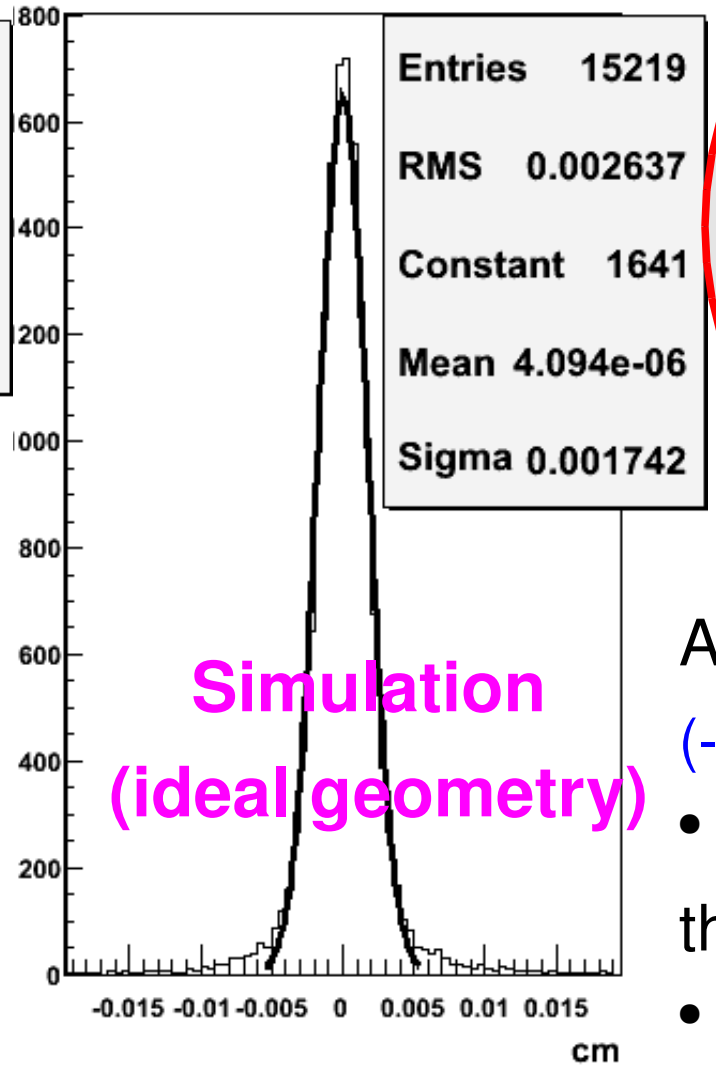
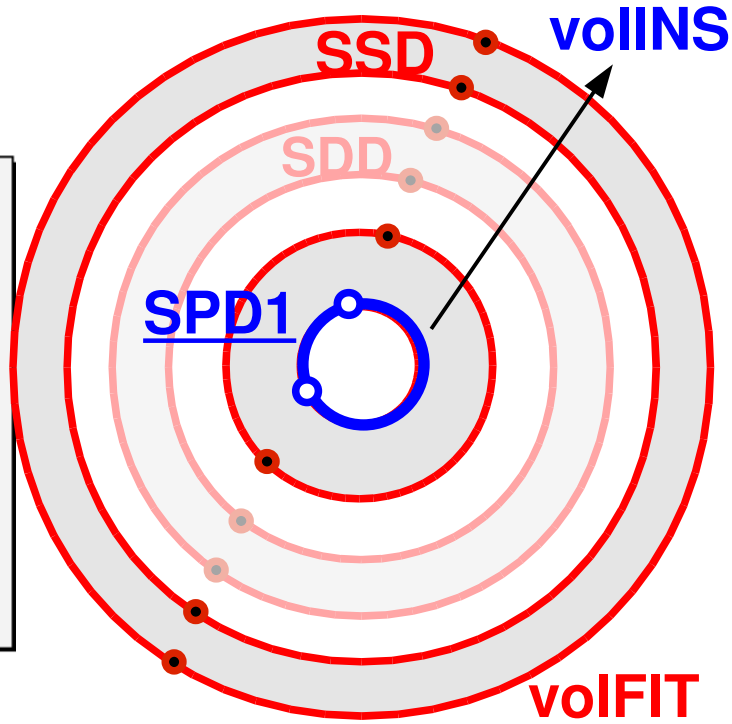






Sigma(rφ) = 26 μm

Sigma(rφ) = 17 μm

Alignment with Millepede (->M. Lunardon):

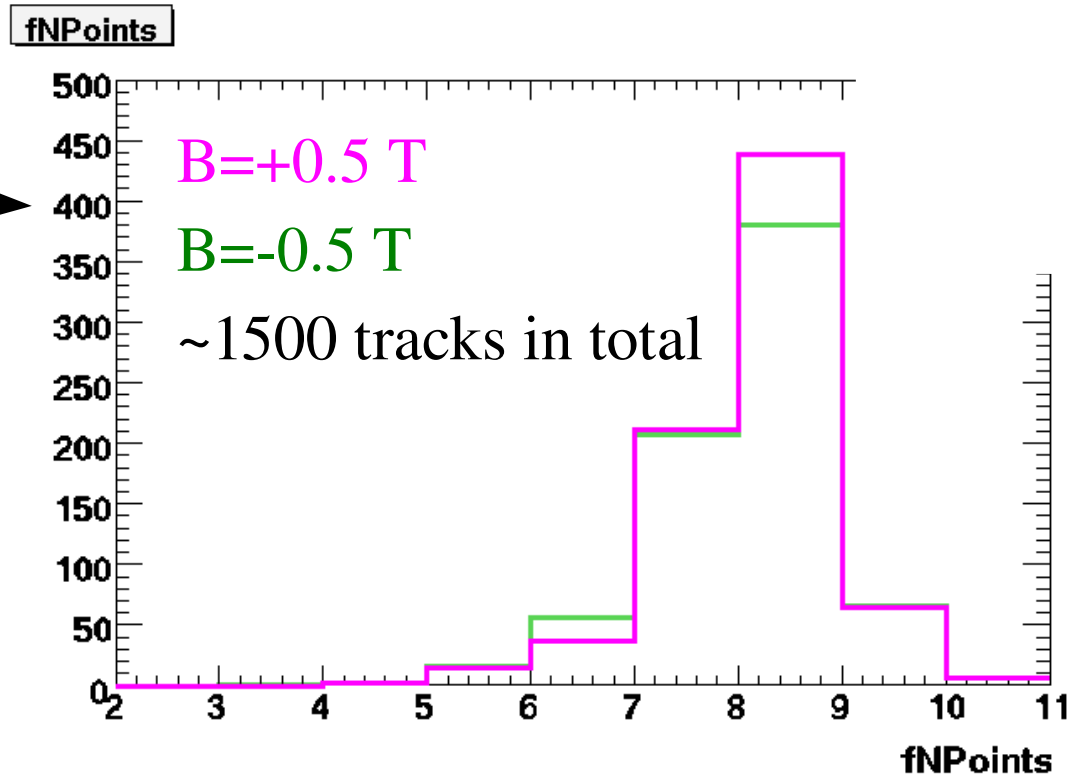
- similar performances for the two layers
- not far from the ideal result

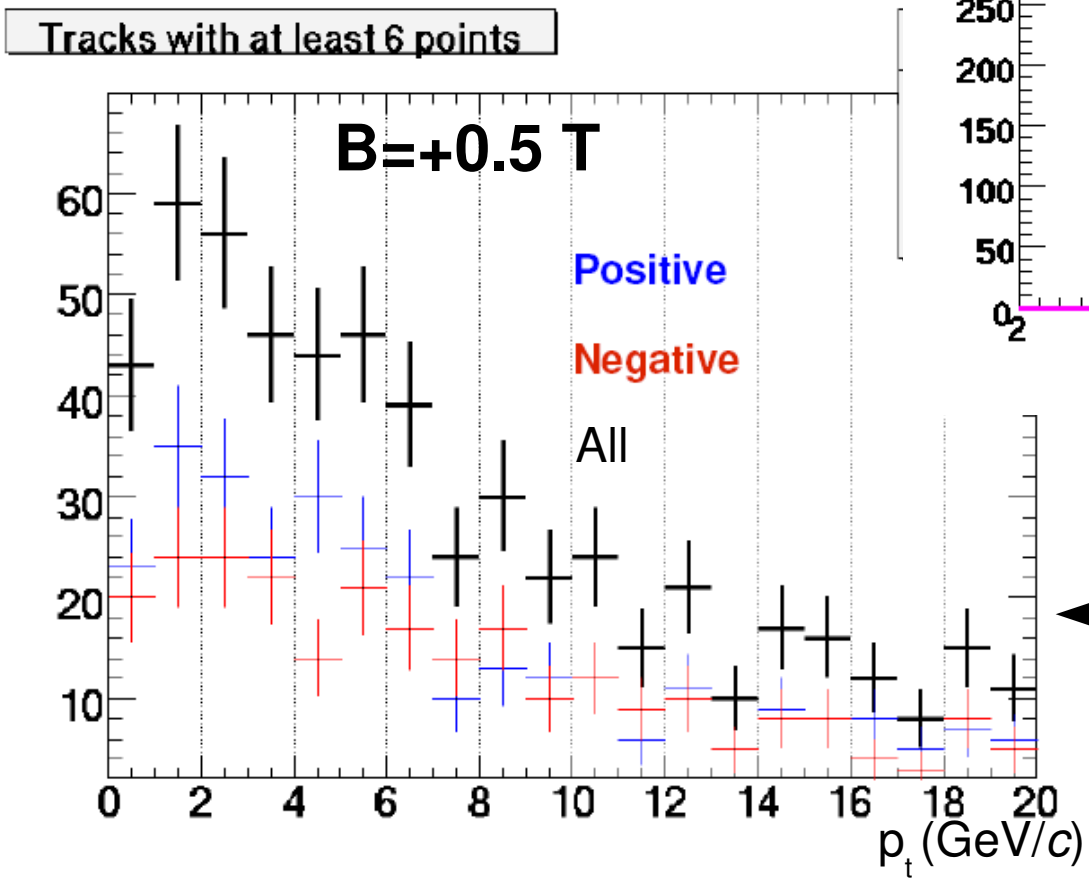
Statistics and pt distribution with B≠0

2008 cosmic data

Number of points per track

for both B=± 0.5 T cases





p_t distribution for B=+0.5

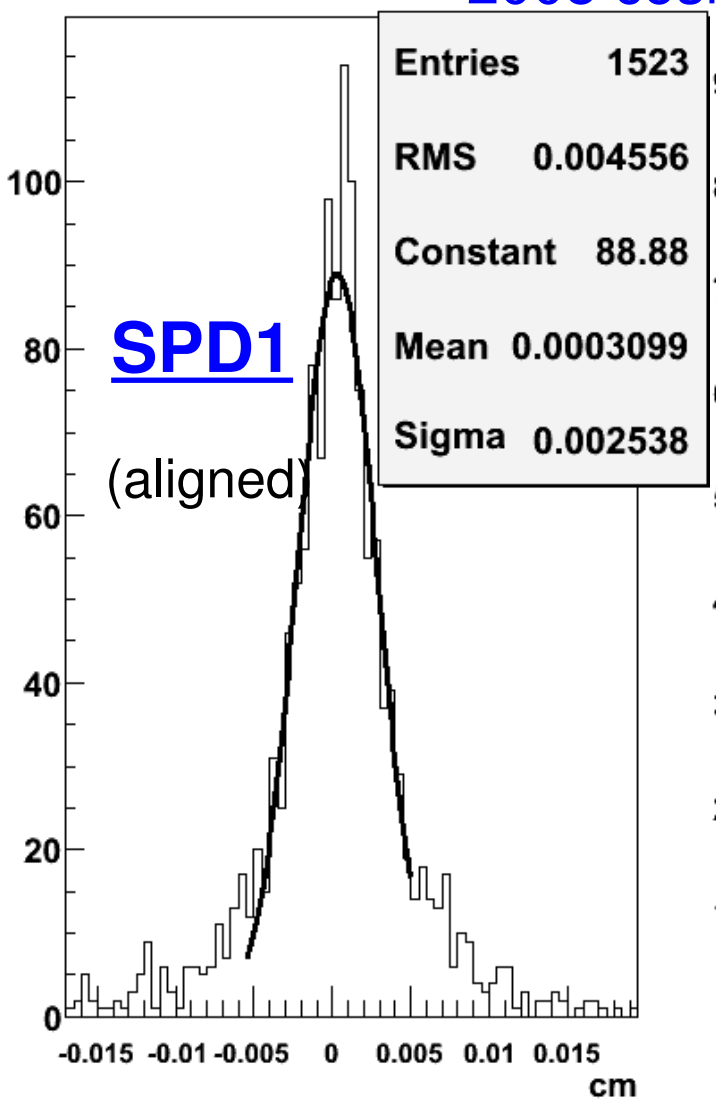
(positive and negative particles)

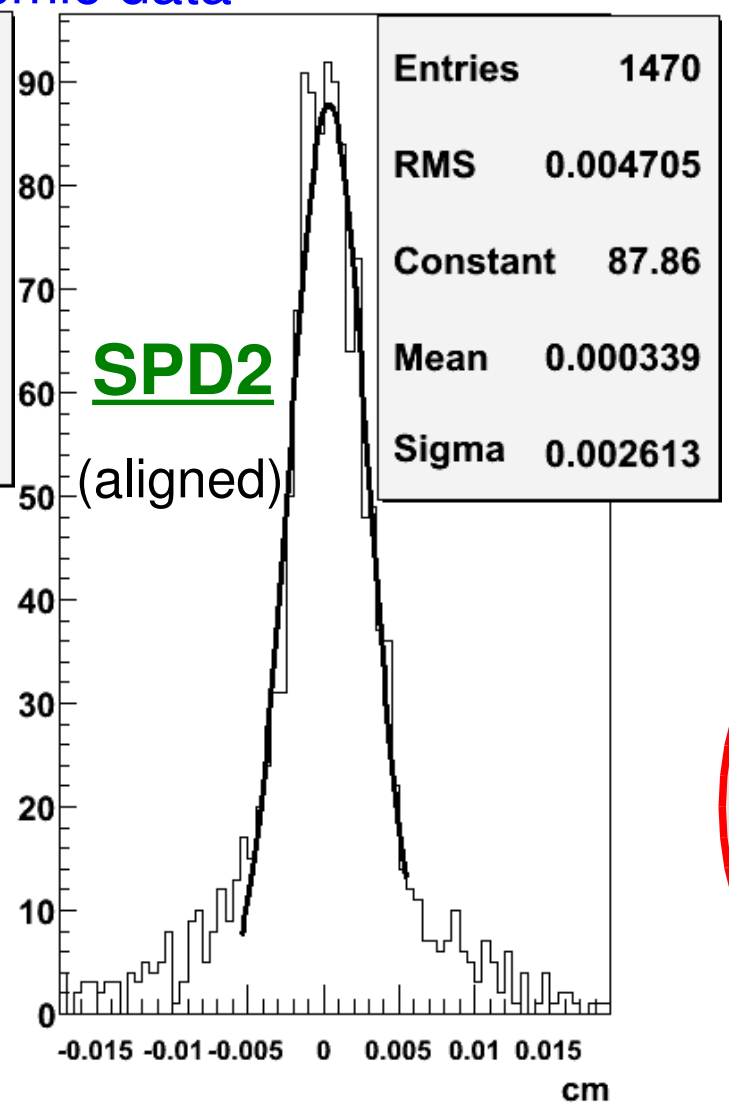
!pt measured with ITS only!

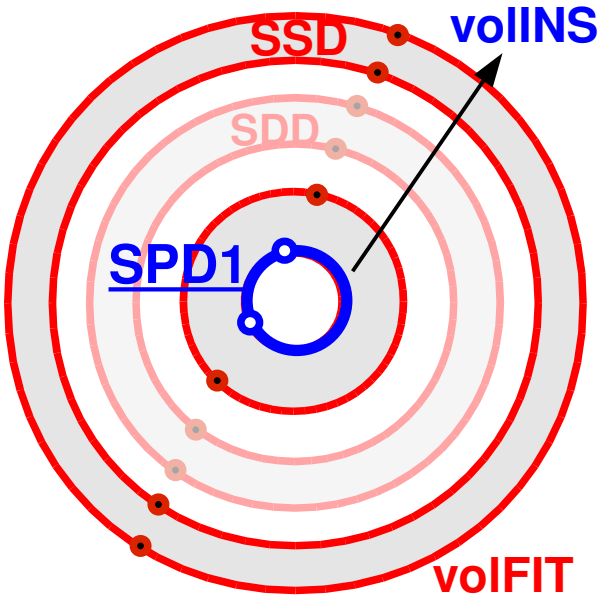
Tests with track-to-point residuals, **B=+0.5 T**

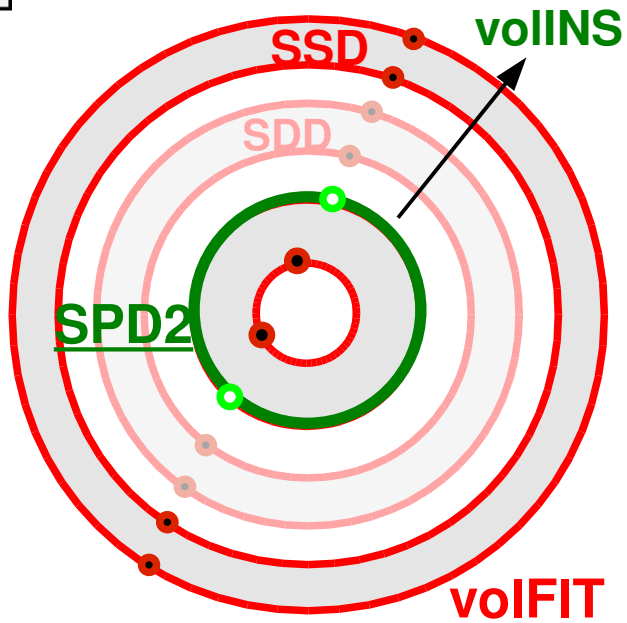
REQUIREMENT: at least 4 points in the VolFIT

2008 cosmic data









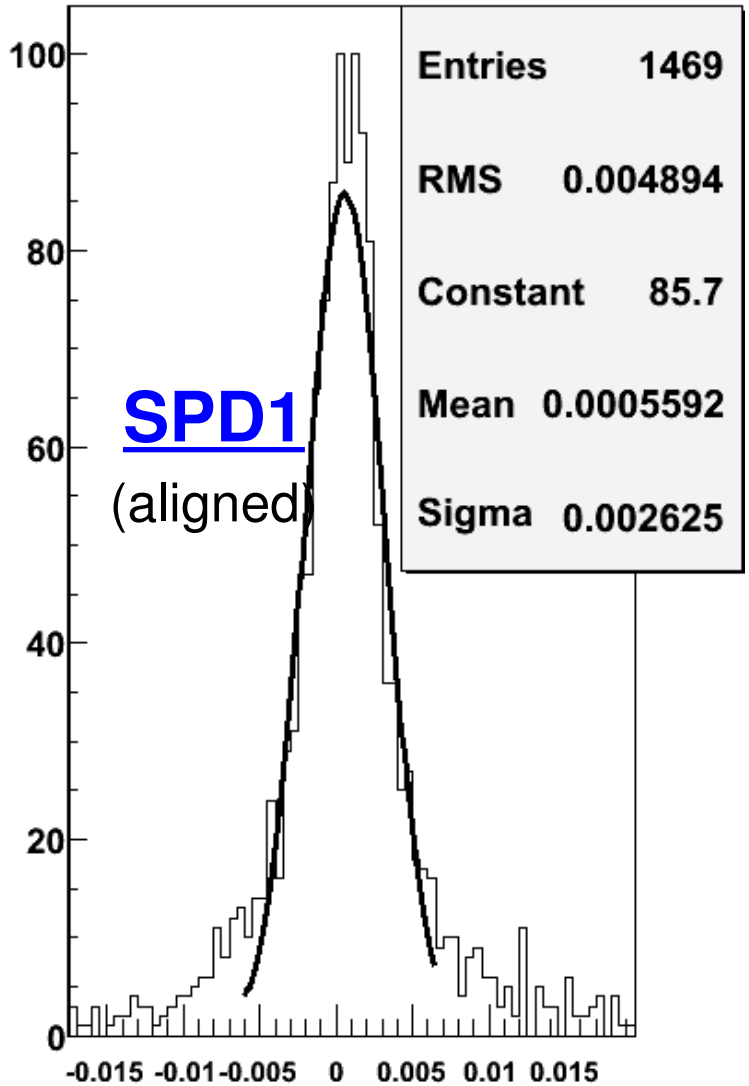
Sigma(rφ) = 25 μm

Sigma(rφ) = 26 μm

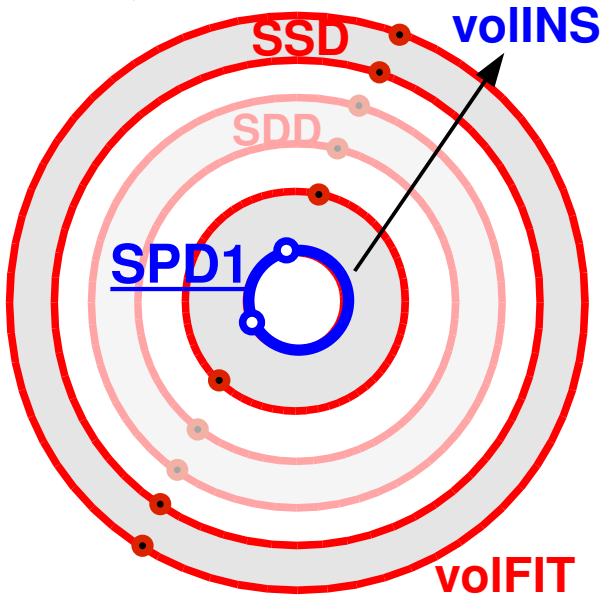
Tests with track-to-point residuals, **B=-0.5 T**

REQUIREMENT: at least 4 points in the VolFIT

2008 cosmic data



Sigma(rφ) = 26 μm



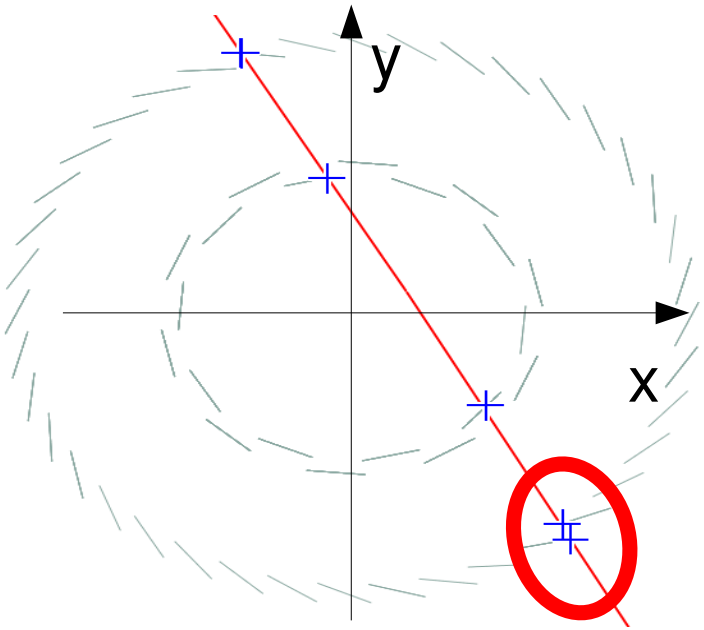
After the alignment with Millepede (->M. Lunardon) the residuals distributions for the SPD are:

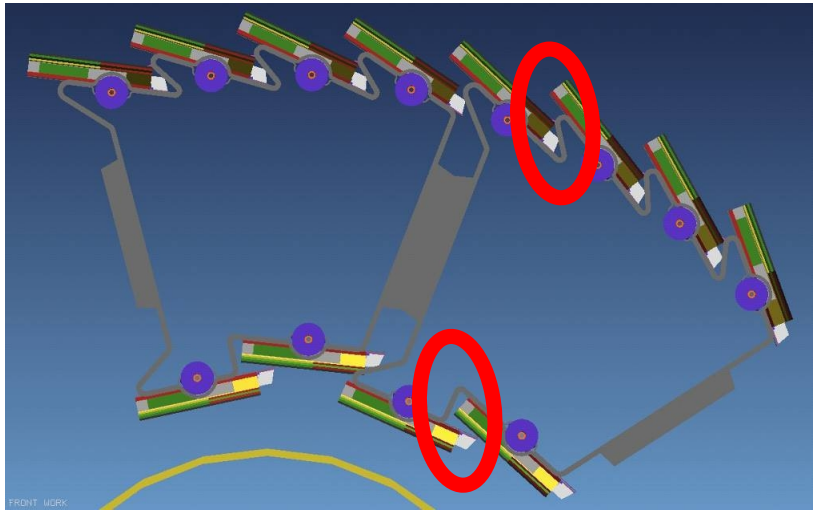
- close to the ideal result
- independent from the
  - presence of the magnetic field
  - polarity of the magnetic field
- similar results for inner and outer SPD layers

“Extra Clusters” in overlapping regions

By design, there is an overlap between adjacent modules both in the transverse plane and along the Z direction (not for SPD). The overlap region is ~1-2% per layer.

➔ a fraction of tracks with two points on the same layer very close in space and whose positions are sensitive to the relative misalignment of the adjacent modules





examples of overlaps in the SPD

"Extra Clusters" in overlapping regions

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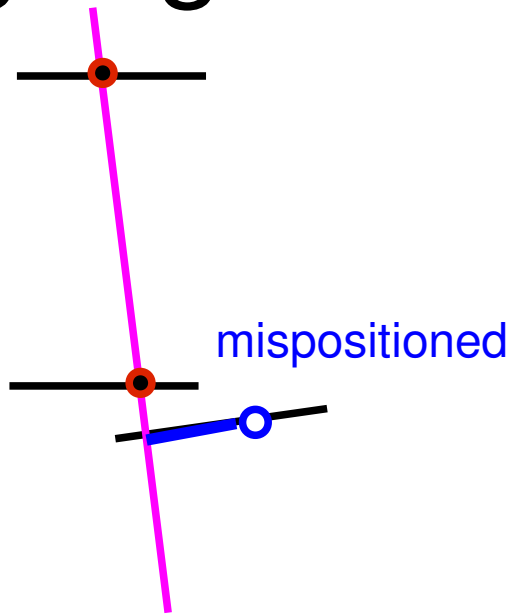
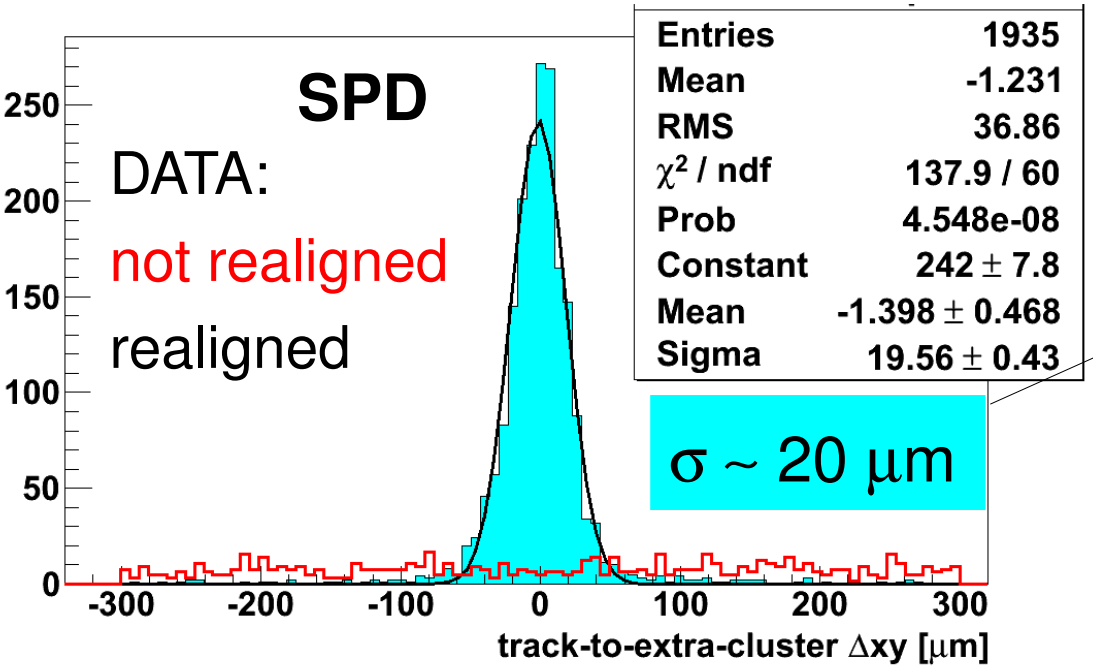


Results with Millepede (->M. Lunardon)



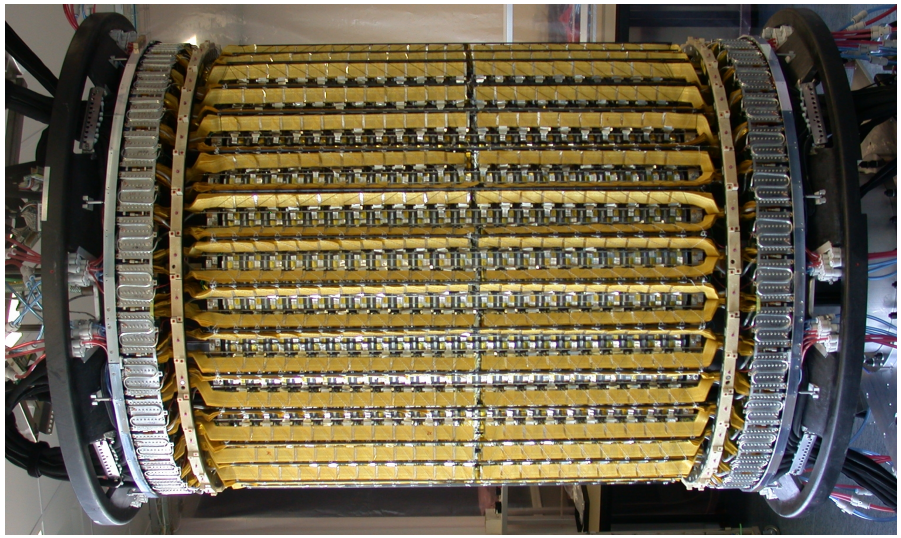
Possible to get an estimate of the average residual misalignment:

$$\sigma(x_{loc}) \approx \frac{\sigma_{ExtrClust}}{\sqrt{2}} \approx 14\,\mu m$$

-> talk by Marcello for a more detailed analysis

SSD survey validation

SSD survey validation



<u>Inner Layer</u>

34 ladders

22 modules each

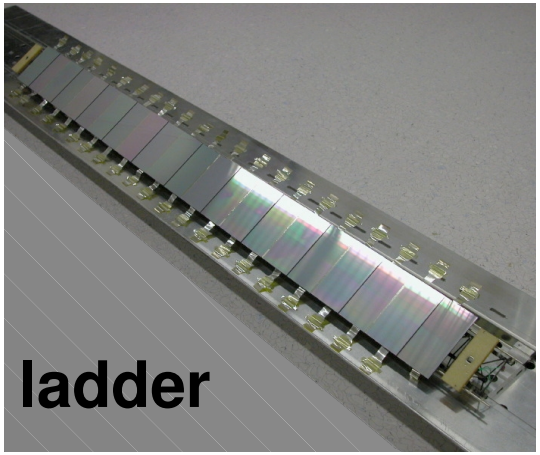
radius ~ 38 cm

<u>Outer layer</u>

38 ladders

25 modules each

radius ~ 43 cm

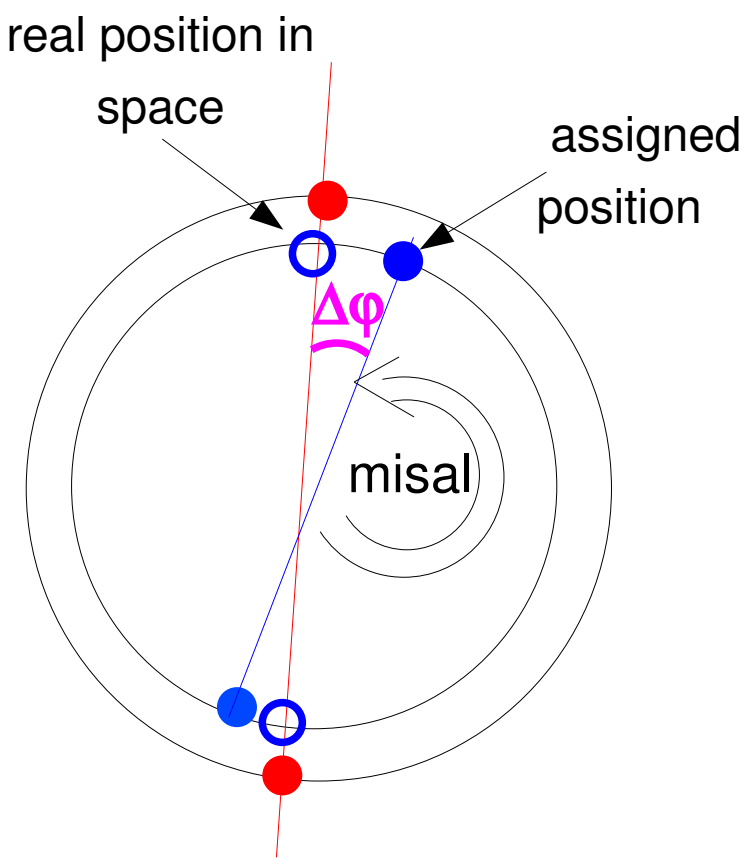


The initial position of the SSD modules are determined by two distinct sets of survey measurements:

- optical measurements -> modules positions on the ladders
- mechanical measurements -> ladders positions with respect to the cone

The values found were tested and validated using cosmic tracks

Track-to-track "residuals"



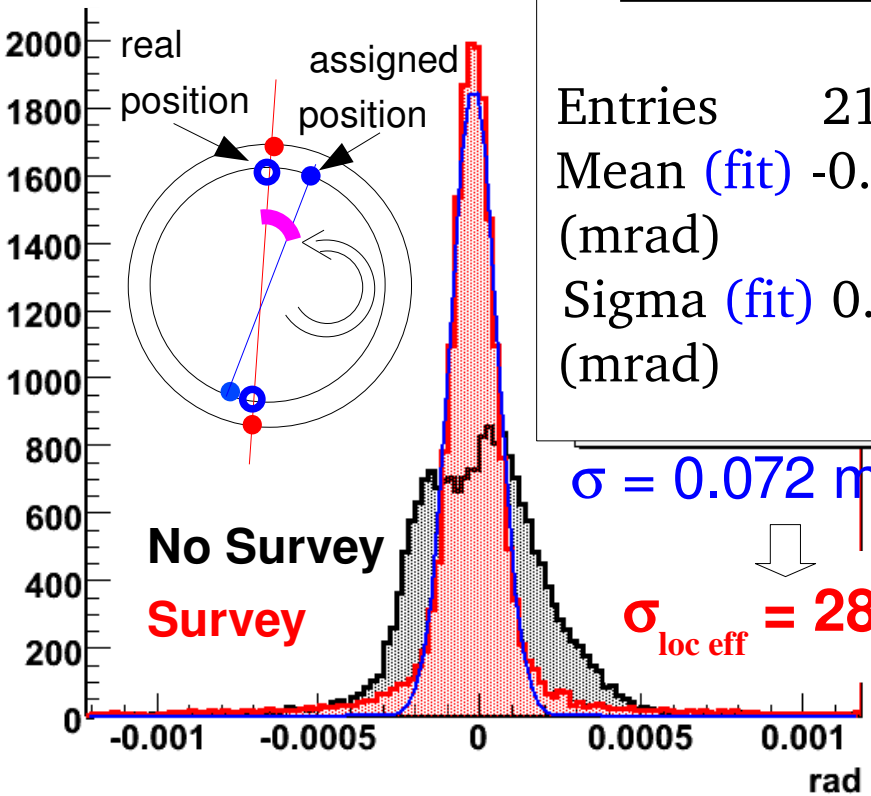
- Consider a single sub-detector
- Split each track in two parts
  - Upper VS Lower
  - Outer Layer VS Inner Layer
- Compare:
  - tracks directions in the XY and YZ planes
  - ΔXYatY=0 (->M. Lunardon)
  - ΔZatY=0

→ easy to relate the observed distributions to effective "local" spatial resolutions, e.g.

$$\sigma^2_{xloc\ eff} \approx 2\,\sigma^2(\Delta\varphi)_{obs} \Big/ \left(\frac{1}{r^2_{INNER}} + \frac{1}{r^2_{OUTER}} \right)$$

SSD survey validation: track-to-track and track-to-point residuals

track-to-track Δφ



With Survey

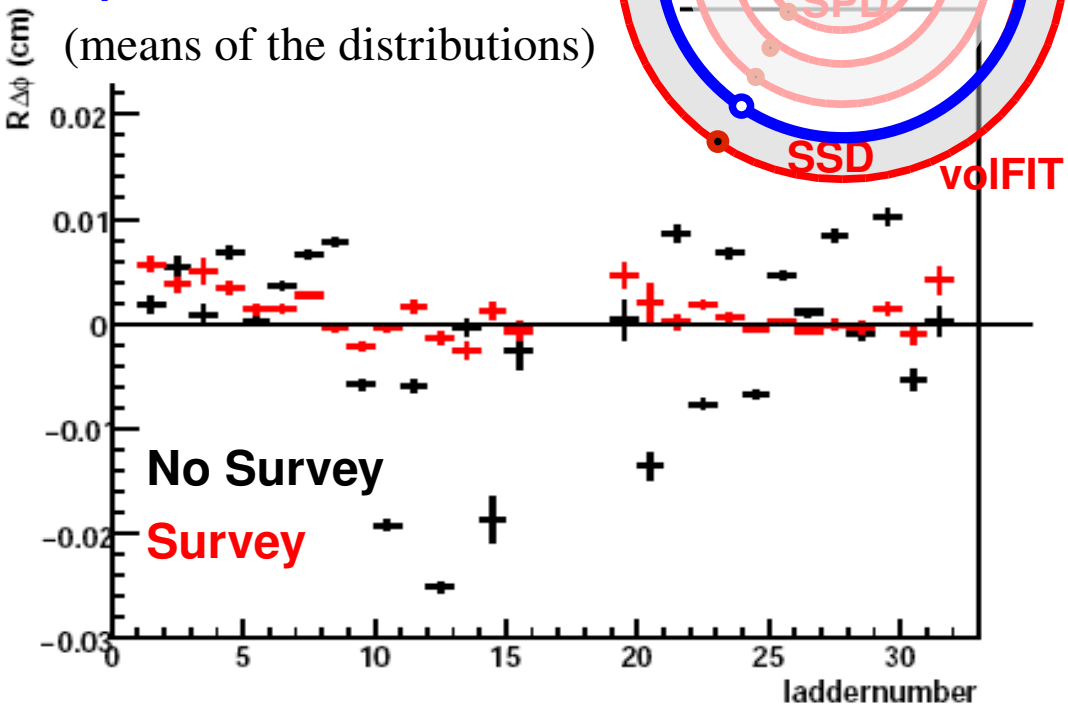
Entries	21143
Mean (fit) (mrad)	-0.019
Sigma (fit) (mrad)	0.072

σ = 0.072 mrad

$\sigma_{loc\ eff}$ = 28 μm

ladders track-to-point rφ residuals

(means of the distributions)

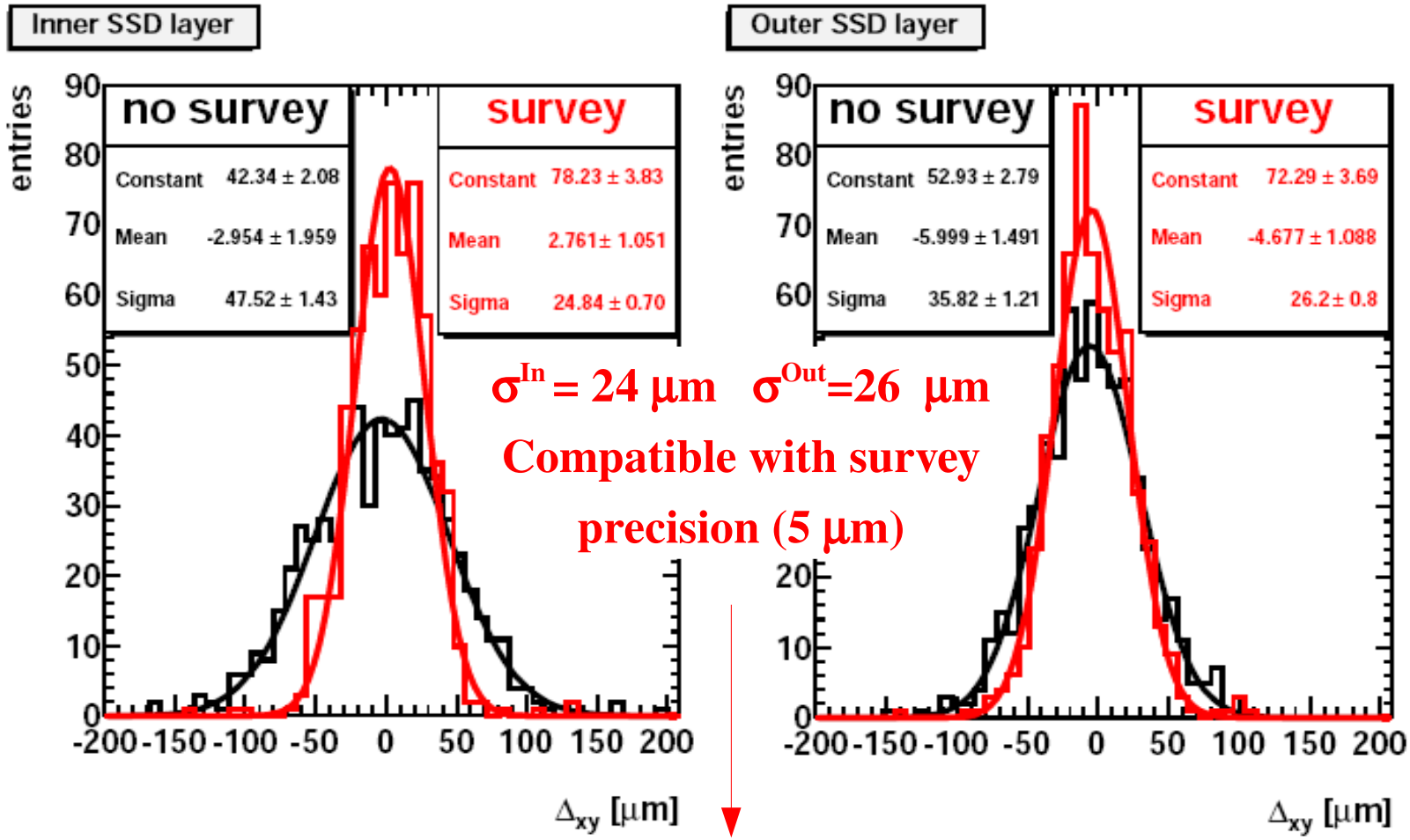


Large improvement using the Survey

Compatible results with the two approaches

SSD survey validation: extra clusters

- "Extra clusters" in **adjacent modules on the same ladder**
- Not sensitive to misalignment between ladders



$\sigma^{In} = 24\ \mu m$ $\sigma^{Out} = 26\ \mu m$

Compatible with survey precision (5 μm)

<u>SSD residual misalignment after Survey</u>:

- modules with respect to the ladder ≤ 5 μm
- position of the ladders ≤ 20 μm

Iterative-module-by-module alignment

Iterative module-by-module alignment

Minimize **module by module** a χ^2 function of the alignment parameters

Assumptions

- The misalignments parameters of the modules are not strongly correlated
- The number of modules crossed by the tracks passing through the module under study must be large

⇩

➔ The influence of the misalignments of the modules on the fits of the tracks is not systematic and statistically sums up to zero

➔ To take account of the residual correlations between the results:

- the **procedure is iterated** until convergence is reached
- the modules are realigned according to a sequence based on the number of tracks passing through them

Further improvements from track selection (χ^2 of the fits, rejection of outliers)

Iterative module-by-module alignment

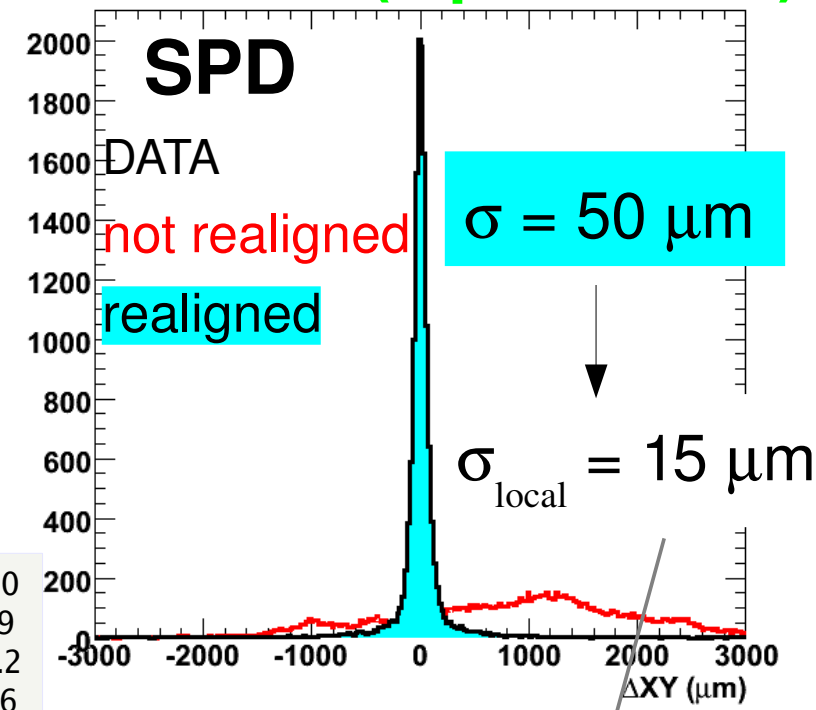
Take advantage of the survey and fix SSD

-> act as a reference

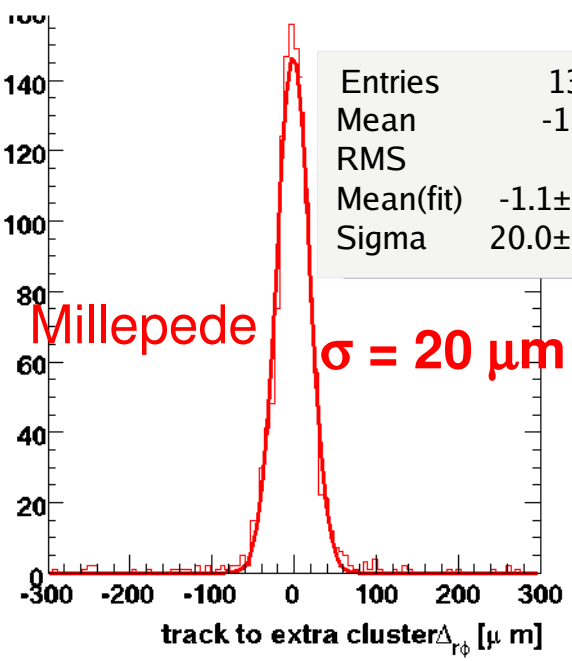
Align SPD with a hierarchical approach:

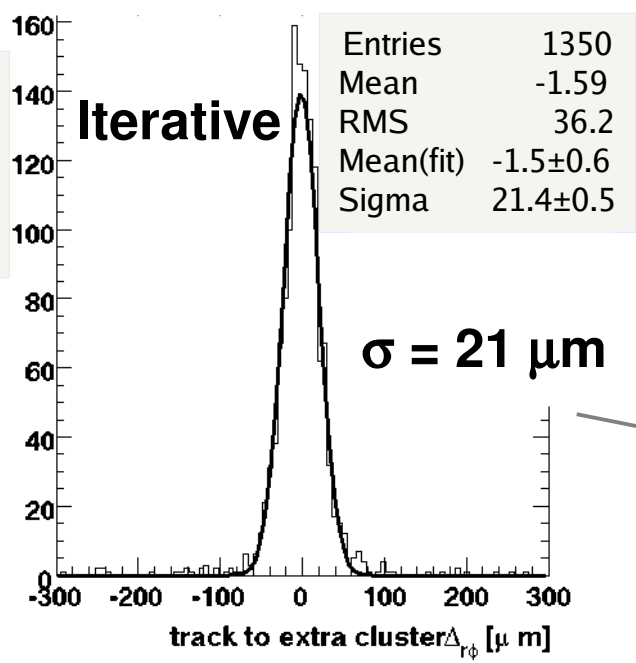
- SPD barrel, half-barrels and sectors w.r.t. SSD
- SPD modules including SPD in the fits

ΔXYatY=0 (4 pts tracks)



Extra Clusters: SPD data





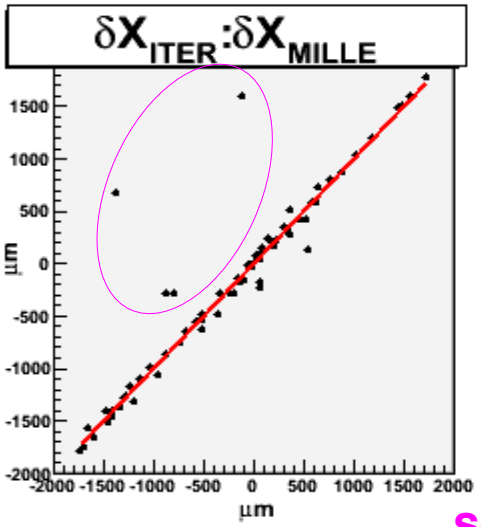
The performance is very close to that of Millepede

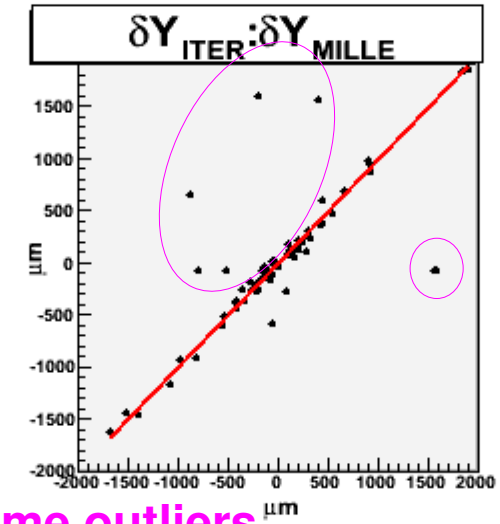
$\sigma_{\text{local x eff.}} \sim 15\ \mu m$

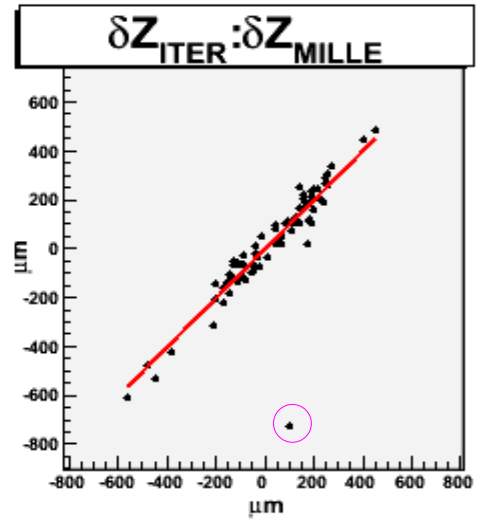
-> residual misal. ≤ 10 μm

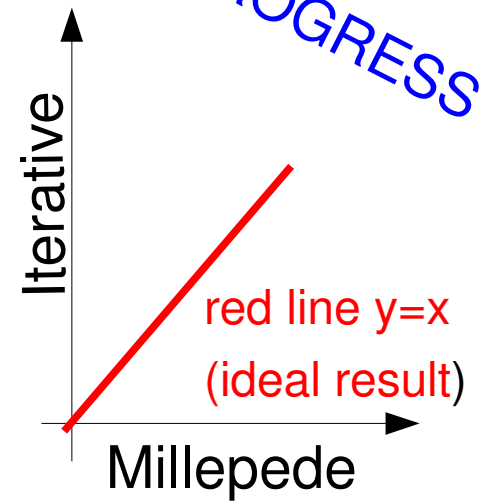
Comparison with Millepede

IN PROGRESS

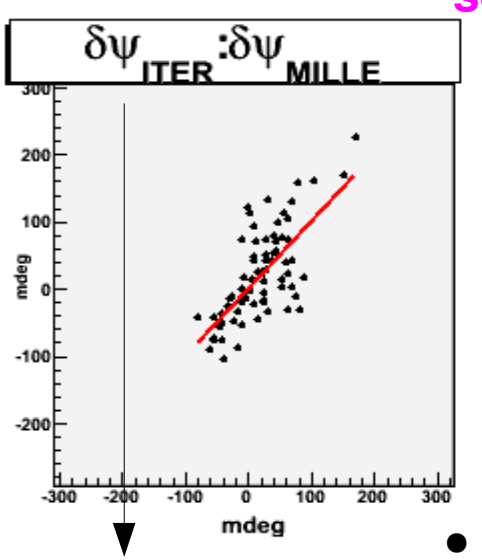


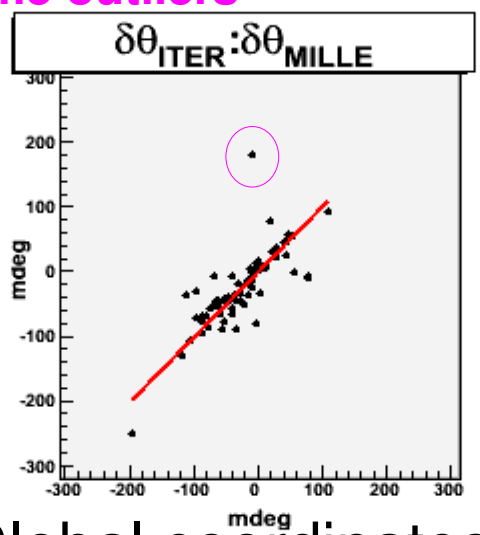


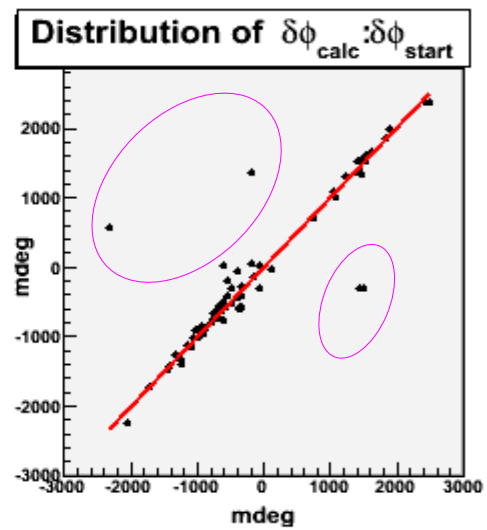


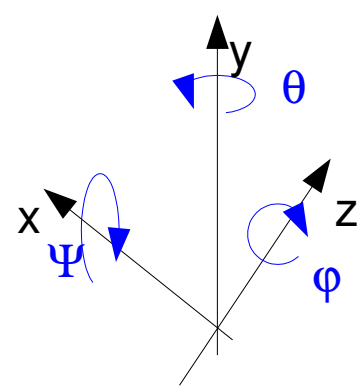


some outliers







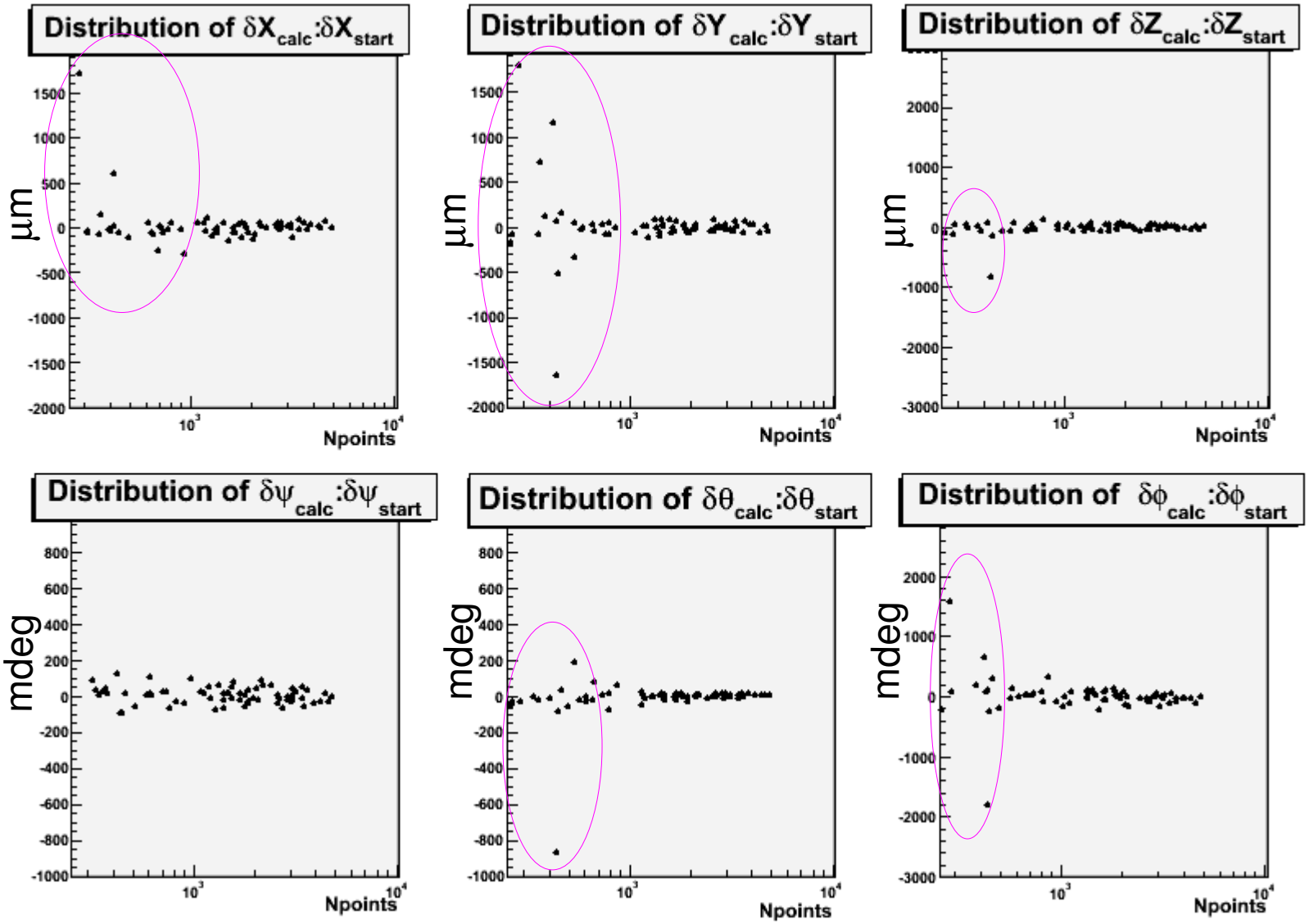


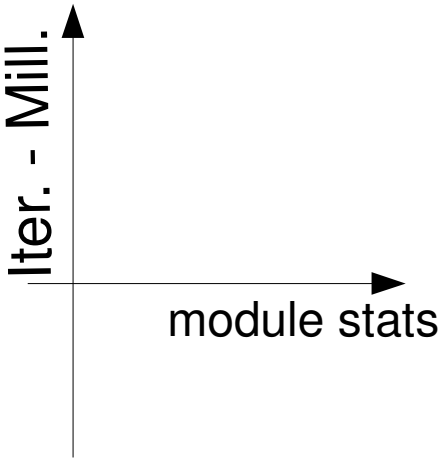
low sensitivity with cosmic tracks

- Global coordinates
- Inner SPD layer
- Correction for a global rototranslation of the ITS

Comparison with Millepede

Inner SPD layer



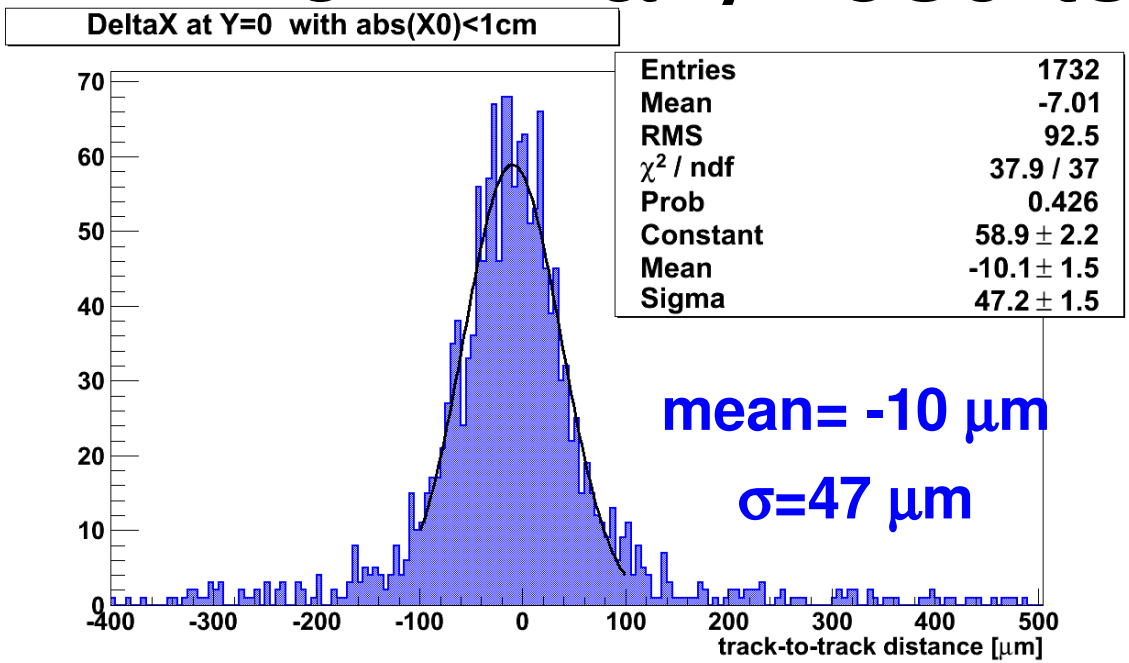


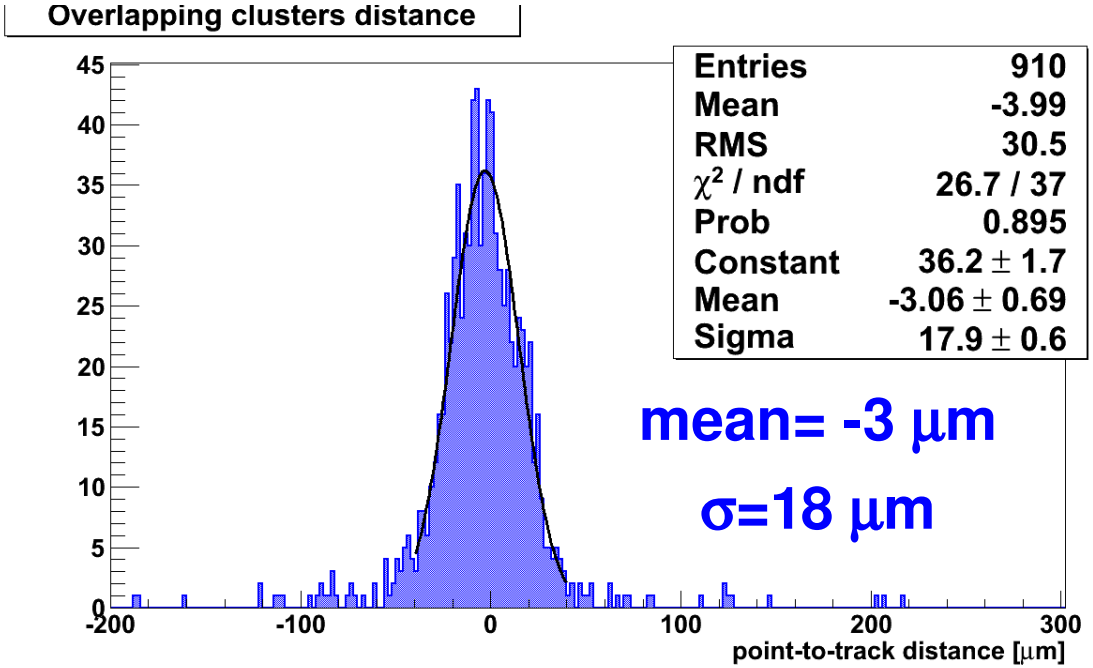
Two (almost) independent methods with similar performances

- cross check
- systematic errors
- "weak modes"

The larger outliers <- low statistics

Preliminary results with 2009 data





SPD standalone before global run

- 20k tracks with 3 pts SPD collected

~1700 tracks selected:

- at least 4 pts in the SPD
- 2 in the top HB, 2 in the bottom HB
  - required to be in modules considered "well aligned" (>50 counts) last year
- $d_0 < 1$ cm

With 2008 Millepede alignment:

- Resolutions very close to last year values!
- The means slightly ≠ 0 (was 0): further analysis in progress

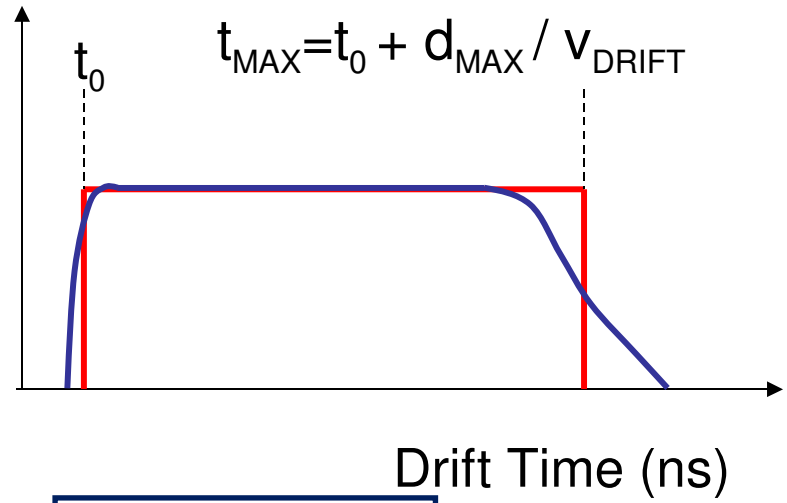
Silicon Drift Detector:

alignment ⟷ calibration

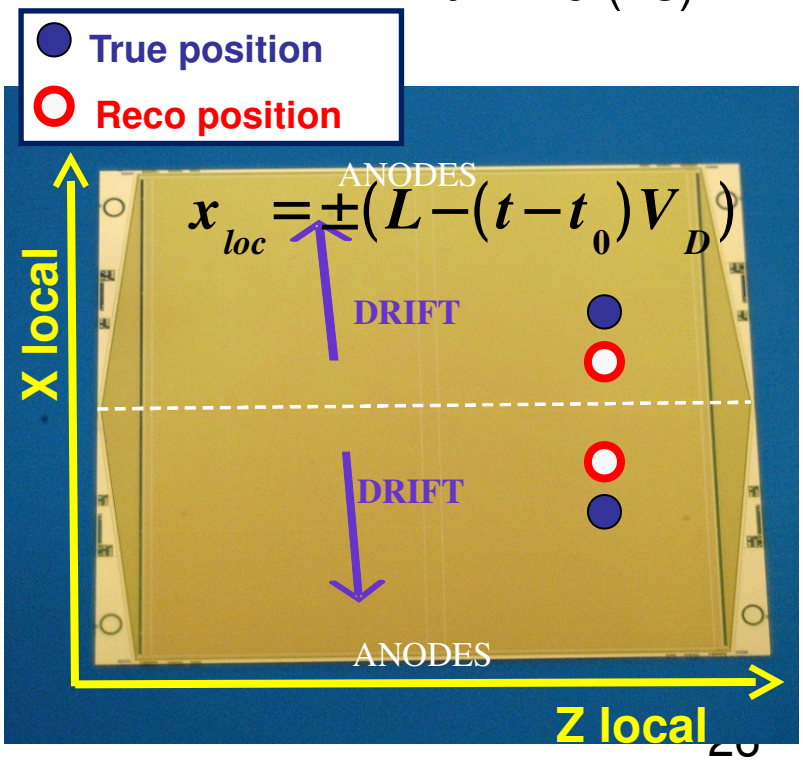
Silicon **Drift** Detector Time Zero calibration

Two strategies developed on simulated data

- Time Zero from minimum drift time
  - Time offset extracted from time distribution of measured clusters
  - Particles crossing the detector on the anodes have drift distance = 0 and should be measured at time = 0.
  - The minimum drift time observed ($t_0 > 0$) is the time zero

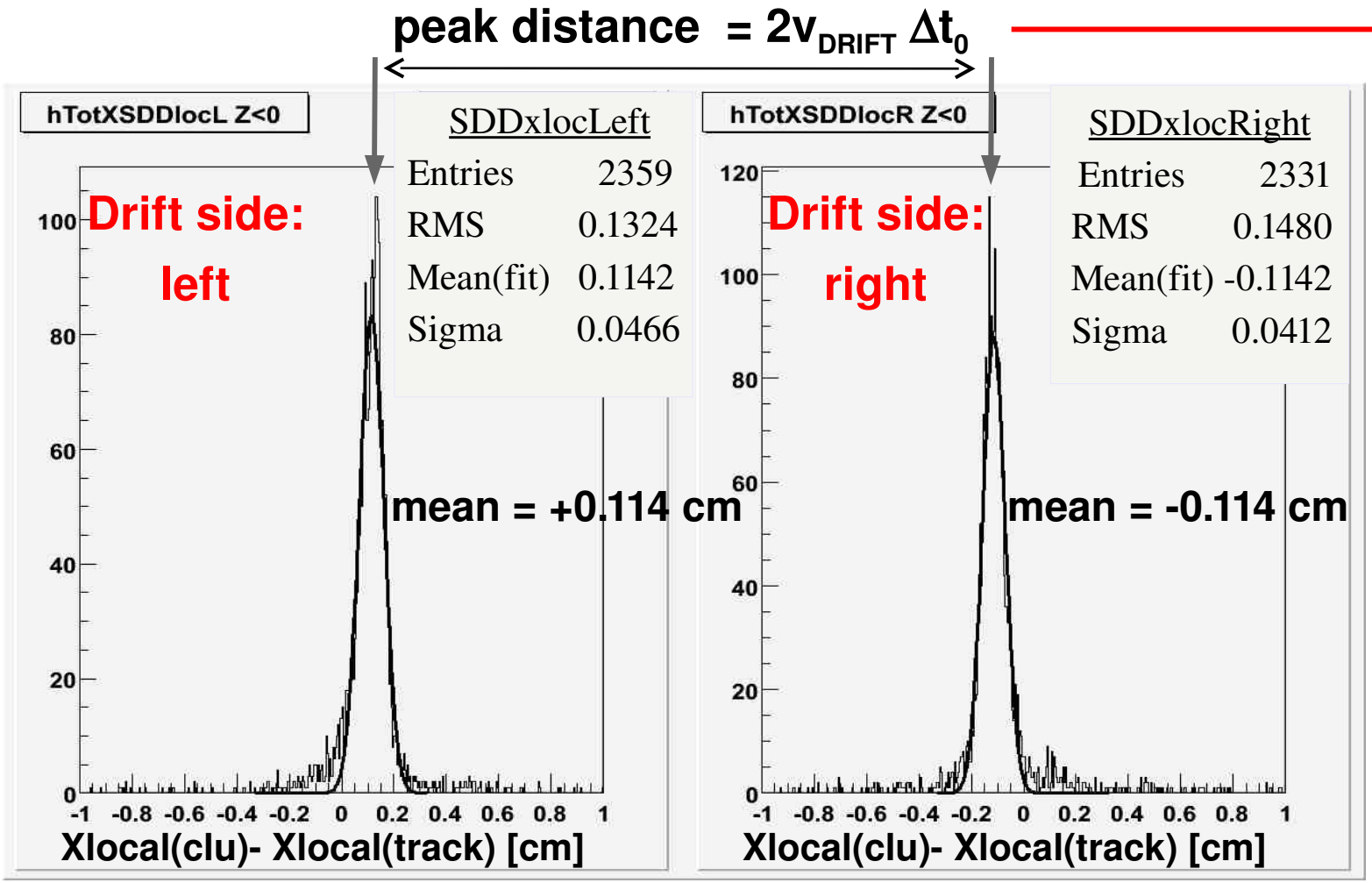


- Time Zero from track-to-cluster residuals
  - Time Zero extracted by exploiting the opposite sign of residuals in the two detector sides
  - A bad calibrated time zero leads to overestimate / underestimate the drift path on both drift sides and therefore to residuals XMEAS – XTRUE of opposite sign in the two sides



Time Zero from residuals (I)

- Calculate the residuals between cosmic track (reconstructed in SPD and SSD) and cluster coordinates separately for the two drift sides

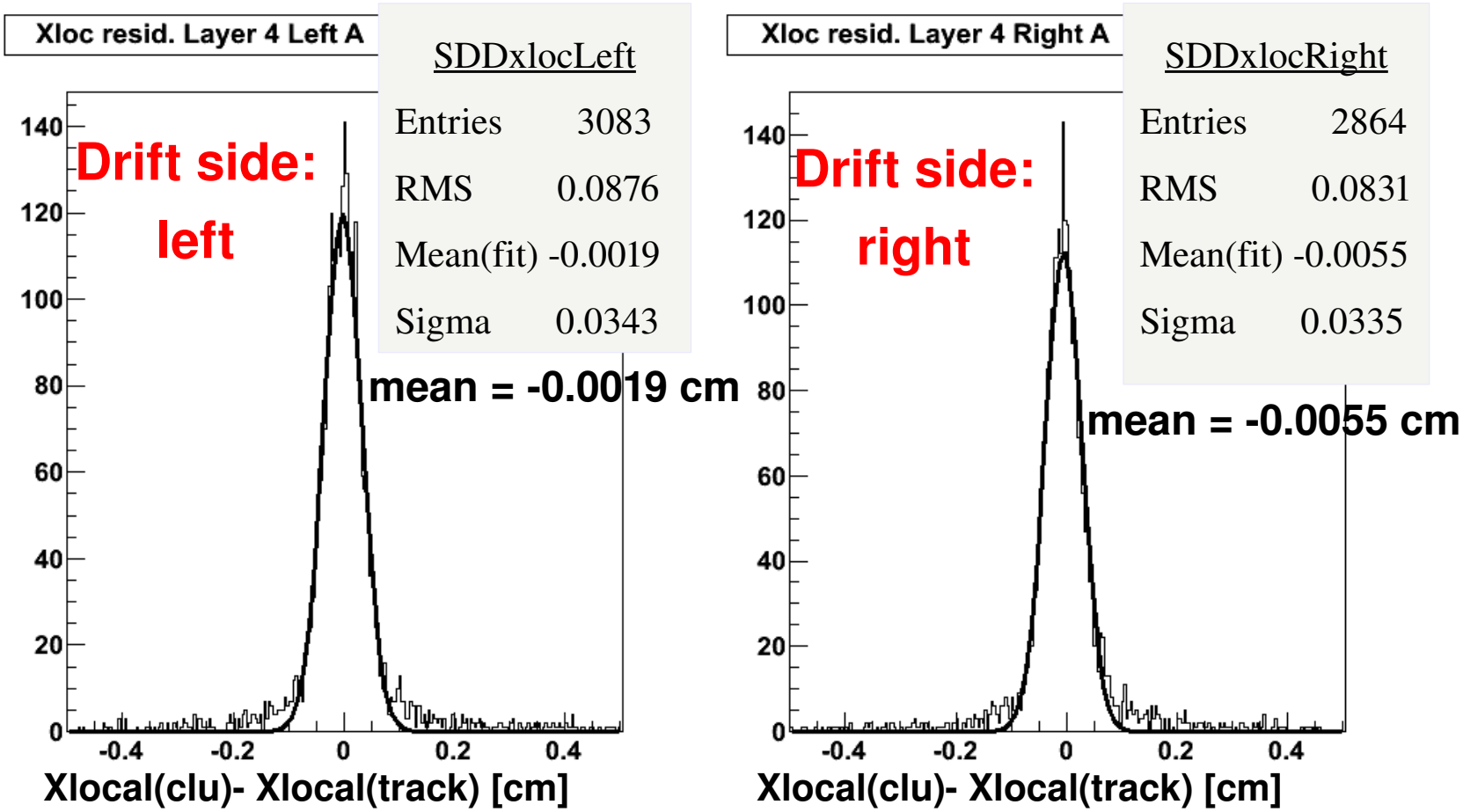


$$\Delta t_0 = \frac{d}{2v_{DRIFT}} \approx \frac{2284}{2 \cdot 6.5} \approx 176\,ns$$

Iterative adjustment of t_0

Time Zero from residuals (II)

- Result after iterative calibration of time zero + geometrical re-alignment of SPD and SSD + exclusion of SDD modules with problems in on-line determination of drift speed
  - Next step: more refined analysis including module-by-module time zero (and drift speed for problematic modules) as free parameters in Millepede minimization



SDD calibration with Millepede

Local x coordinate in the drift direction: $x_l = \pm\left(L-(t-t_0)V_D\right)$

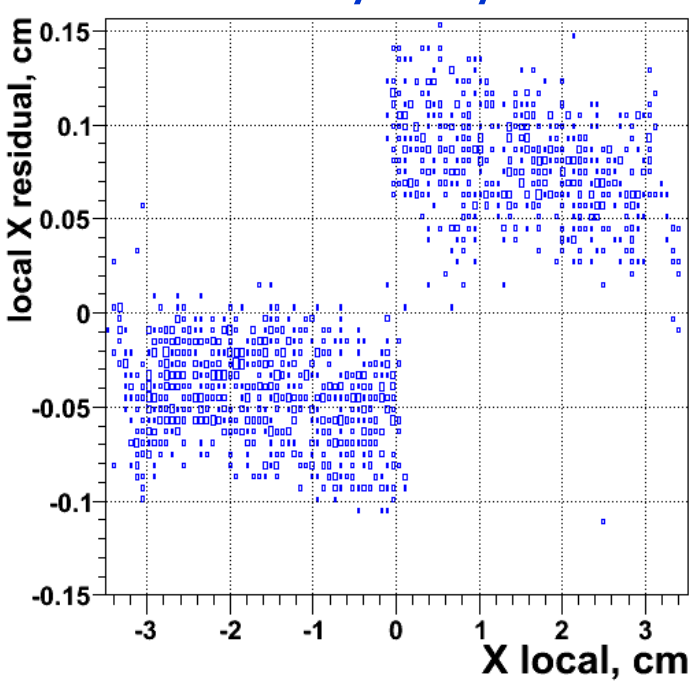
L is the maximum drift length, ***t*** the measured drift time

t_0 and V_D are the time offset and drift speed known initially with limited precision.

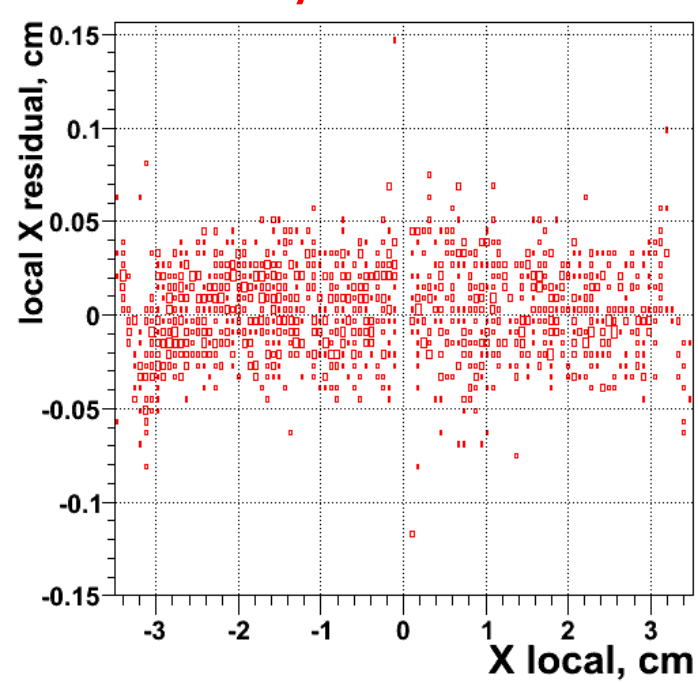
Assume an error for each sensor: a time offset δt_0 and a drift speed δV_D

Local shift in drift direction (linearized): $\delta x_l = \pm\left(\delta t_0 V_D - \delta V_D (t-t_0)\right)$

Geometry only



Geometry + Calibration



Conclusions

- Tools to check and to monitor the status of the ITS alignment are ready and have been tested both with and without magnetic field
- Confirmed the good quality of Millepede alignment for SPD and SSD
- The SSD survey has been validated using cosmic tracks and can be used as the starting point for the alignment
- The SDD calibration is ongoing
- Iterative module-by-module alignment: SPD alignment
  - alignment quality
  - transformations parameters

  } compatible with Millepede

  ➔ promising method for cross-checks and systematic errors evaluation
- Preliminary test on 2009 data: last year alignment results still valid

Extra

Iterative module-by-module alignment

Minimize module by module the χ^2 function

$$\chi^2 = \sum_k (\vec{x}_k^{PCA} - (\delta R \vec{x}_k^{cl} + \delta \vec{t}))^T (C_k^{PCA} + C_k^{cl})^{-1} (\vec{x}_k^{PCA} - (\delta R \vec{x}_k^{cl} + \delta \vec{t})) ,$$

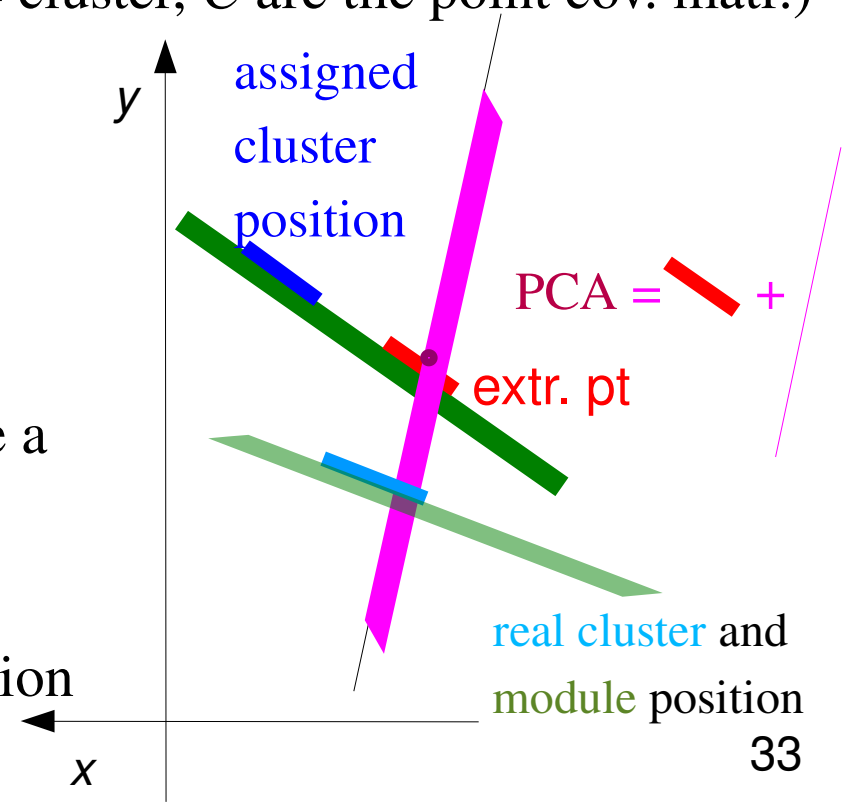
a linear function of the alignment parameters ($\delta \vec{t}$ is the translation vector and δR is the (δ)rotation matrix for small angles)

The sum runs over tracks (PCA -> extrapolated, cl = cluster, C are the point cov. matr.)

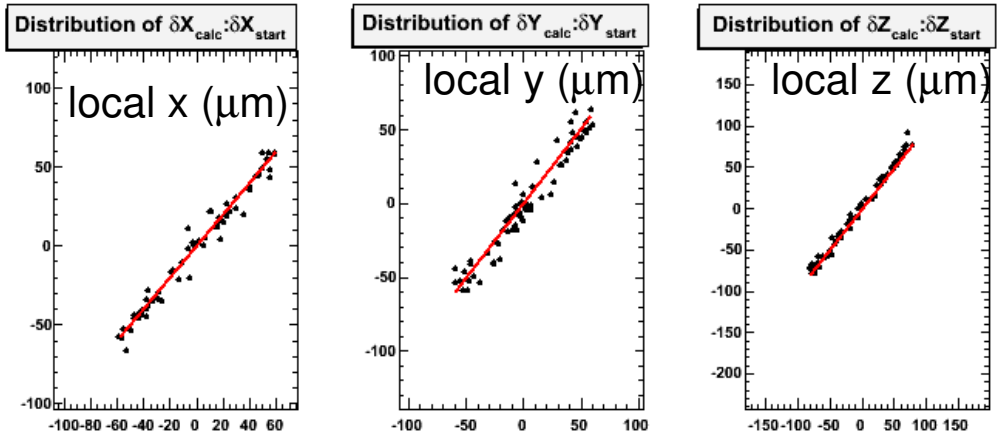
"**Point of Closest Approach**"

To take into account the uncertainty on the module position we construct the PCA:

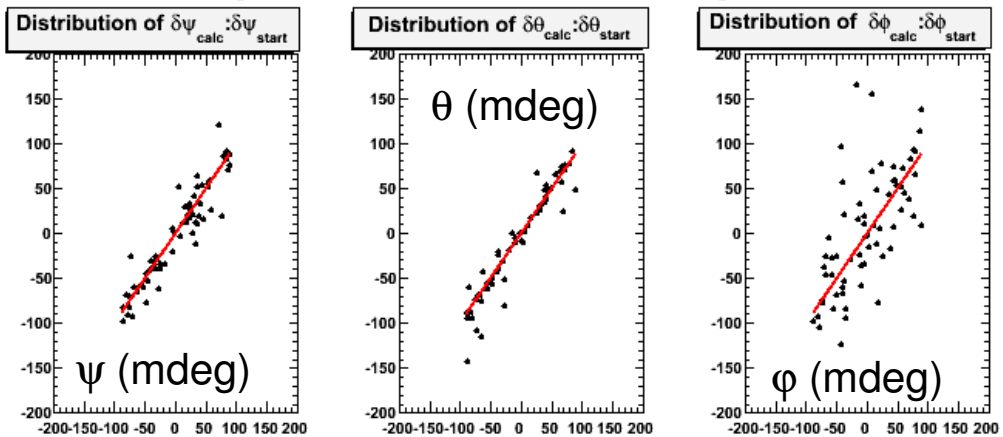
- propagate the track to the plane of a module where a cluster not used in the fit of the track lies
- take the extrapolation point
- enlarge (> 1 cm) its variance along the track direction



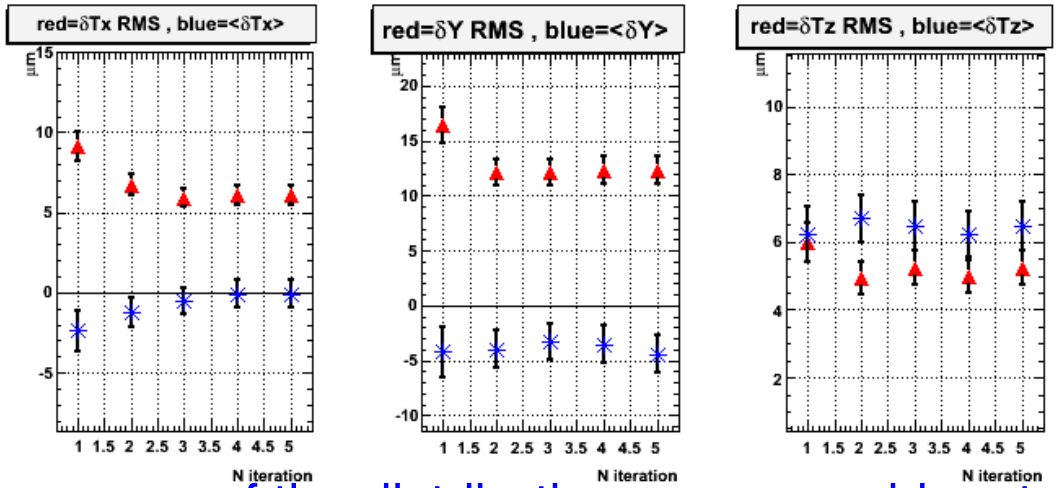
Iterative alignment: test on simulation



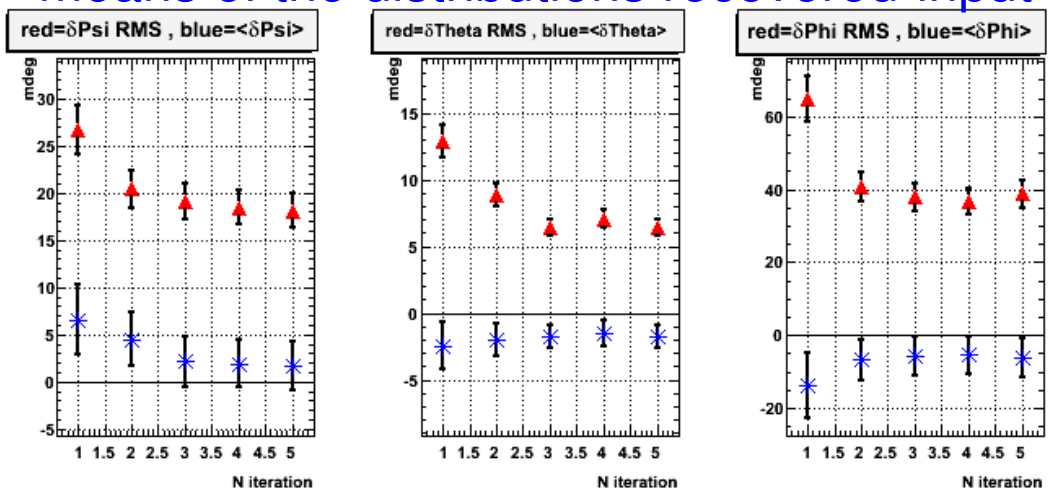
Scatter plot: Recover Vs Input values



Red line = perfect alignment



means of the distributions recovered-input



RMS of the distributions recovered-input

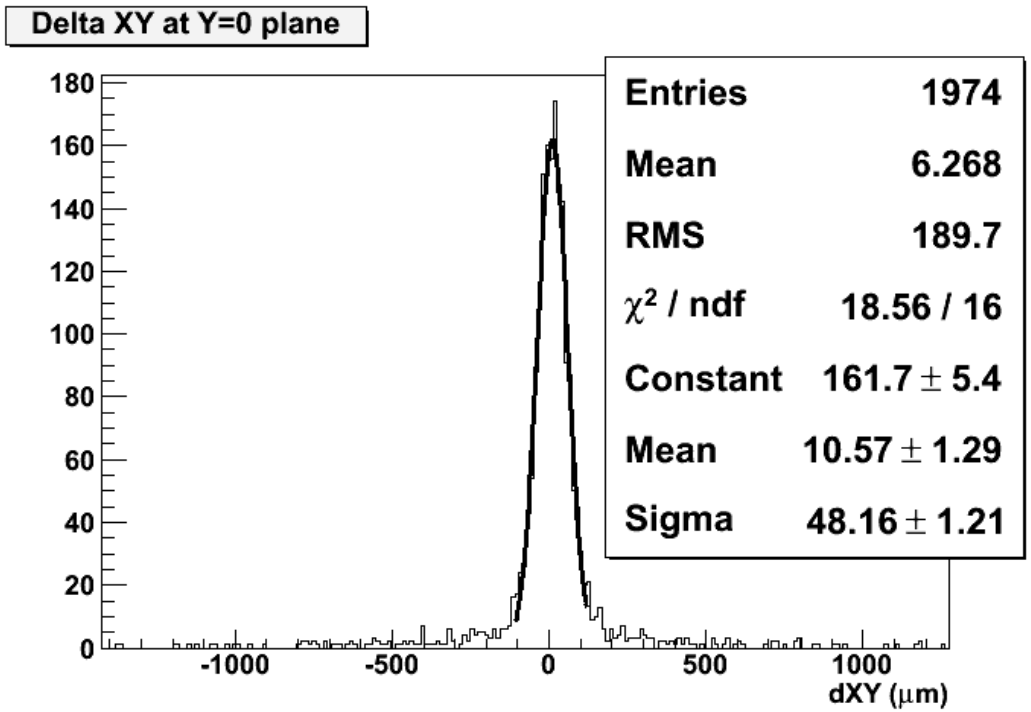
- statistics: 200k tracks
- input misalignments: "uniform" distribution, between ±3 times the resolutions
- 6 pts per tracks required

Results with this summer cosmic data

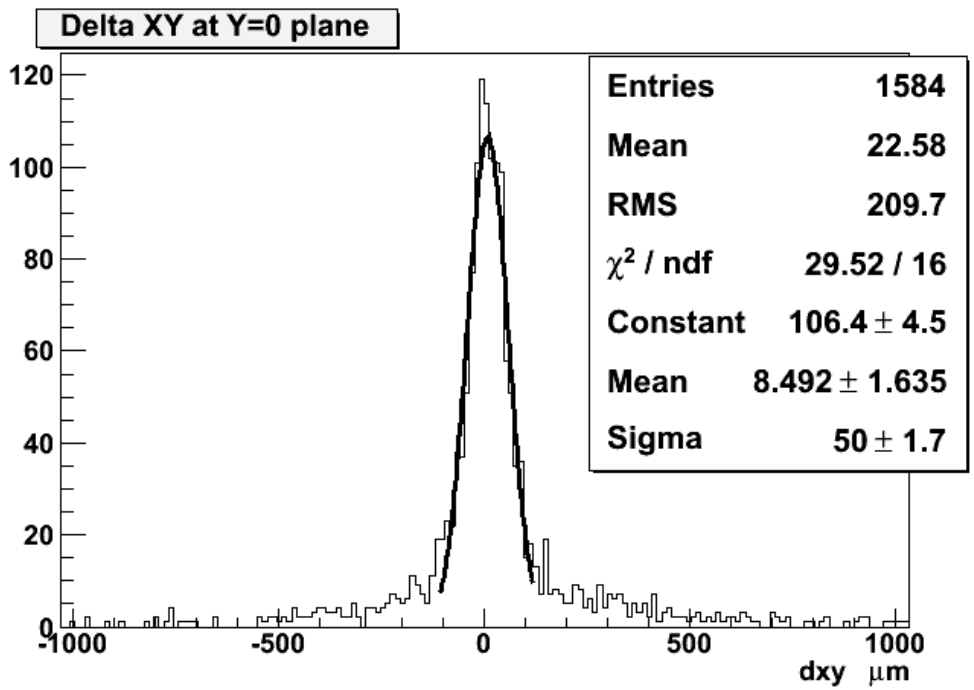
2009 cosmic data (SPD standalone before global run)

Use 2008 alignment results and test them on the new data

Millepede



Iterative



- Resolutions <u>very close to last year</u> values!
- The mean ~10 micron (was 0): further analysis in progress

SDD calibration with Millepede

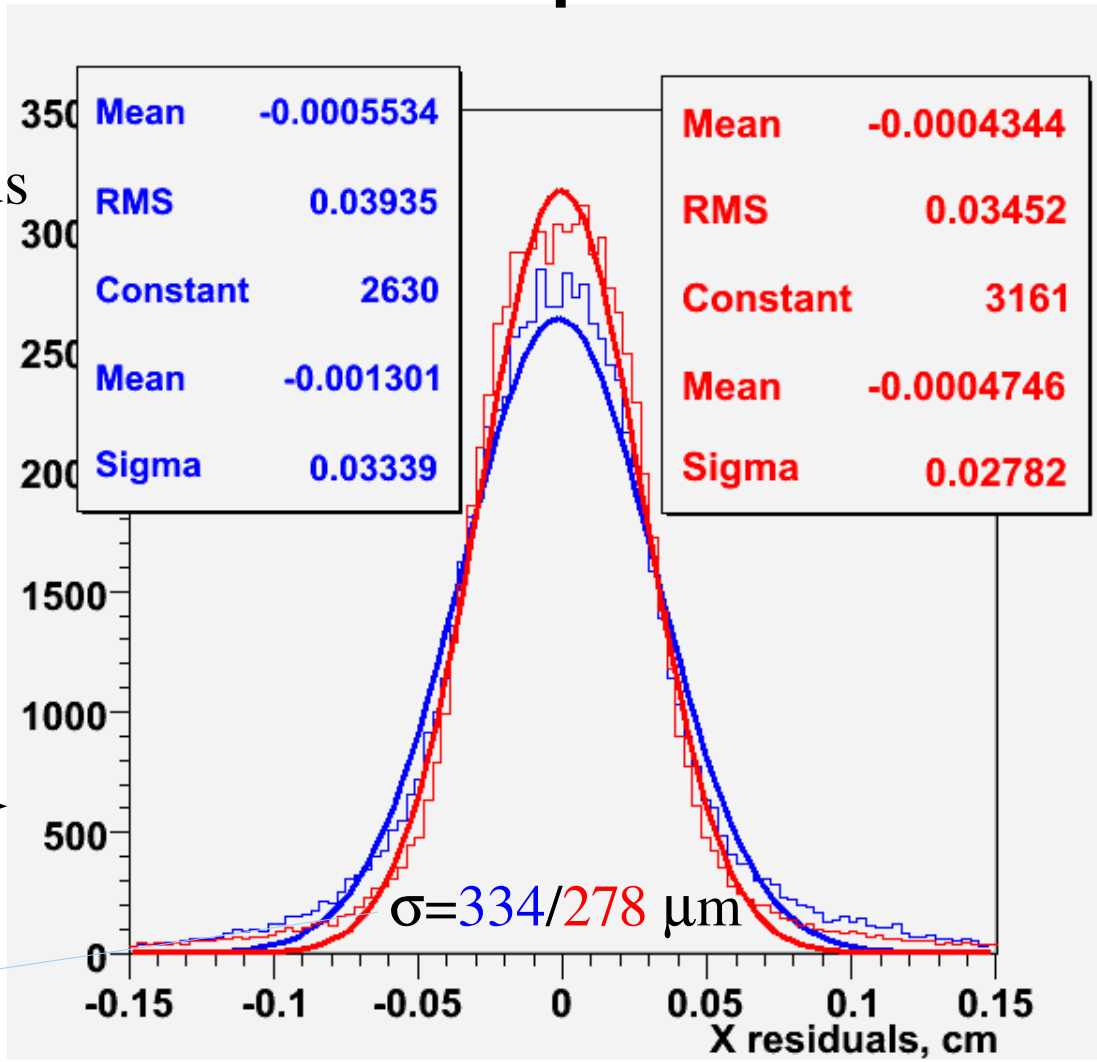
SPD and SSD are fixed from previous alignment step.

SDD varied with:

1) geometry free

2) geometry + calibration free

ALL MODULES



~185 μm improvement in the SDD resolution after the calibration

(still far from the nominal value due to the trigger jitter)

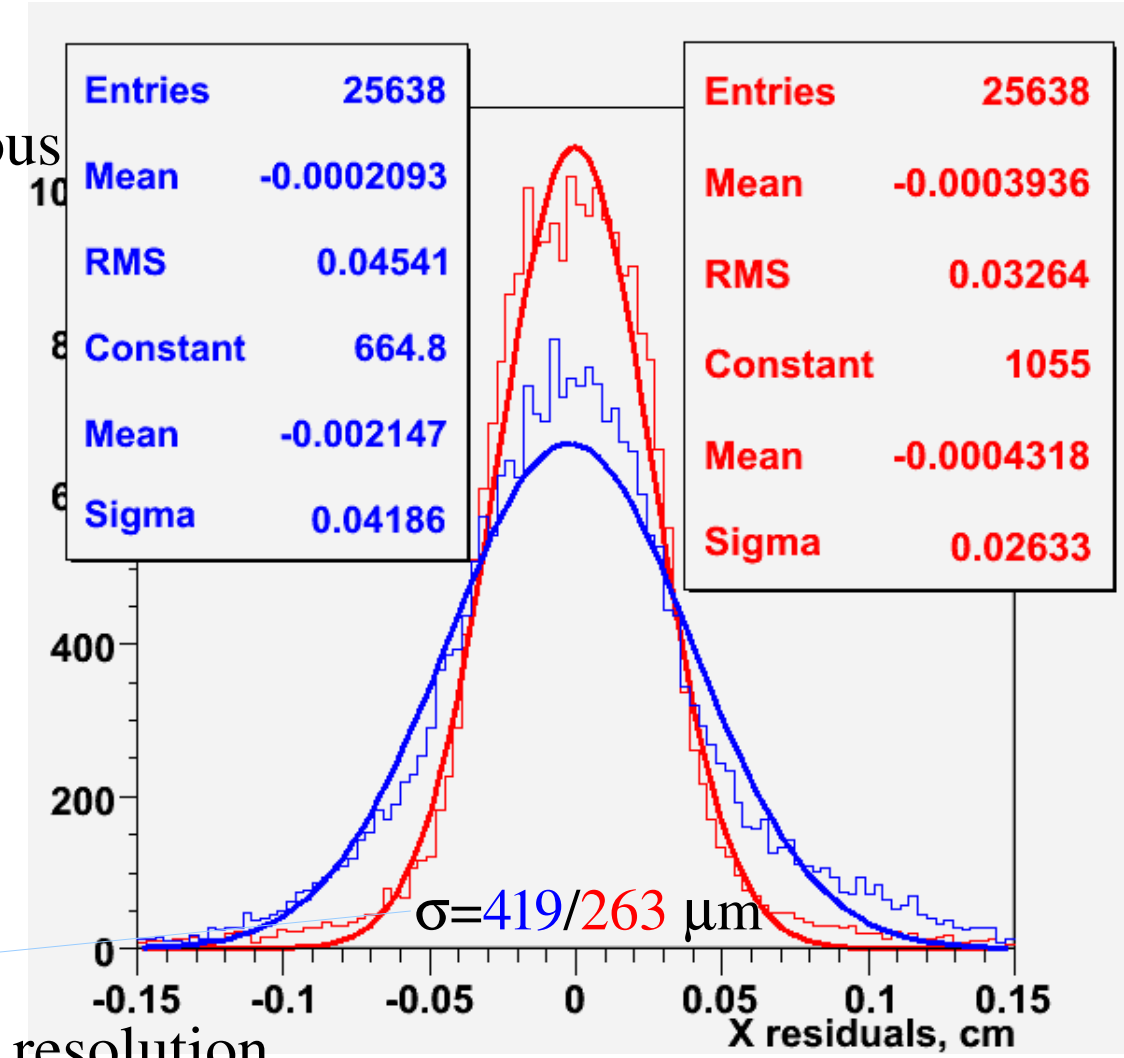
SDD calibration with Millepede (II)

SPD and SSD are fixed from previous alignment step.

SDD varied with:

1) geometry free

2) geometry + calibration free

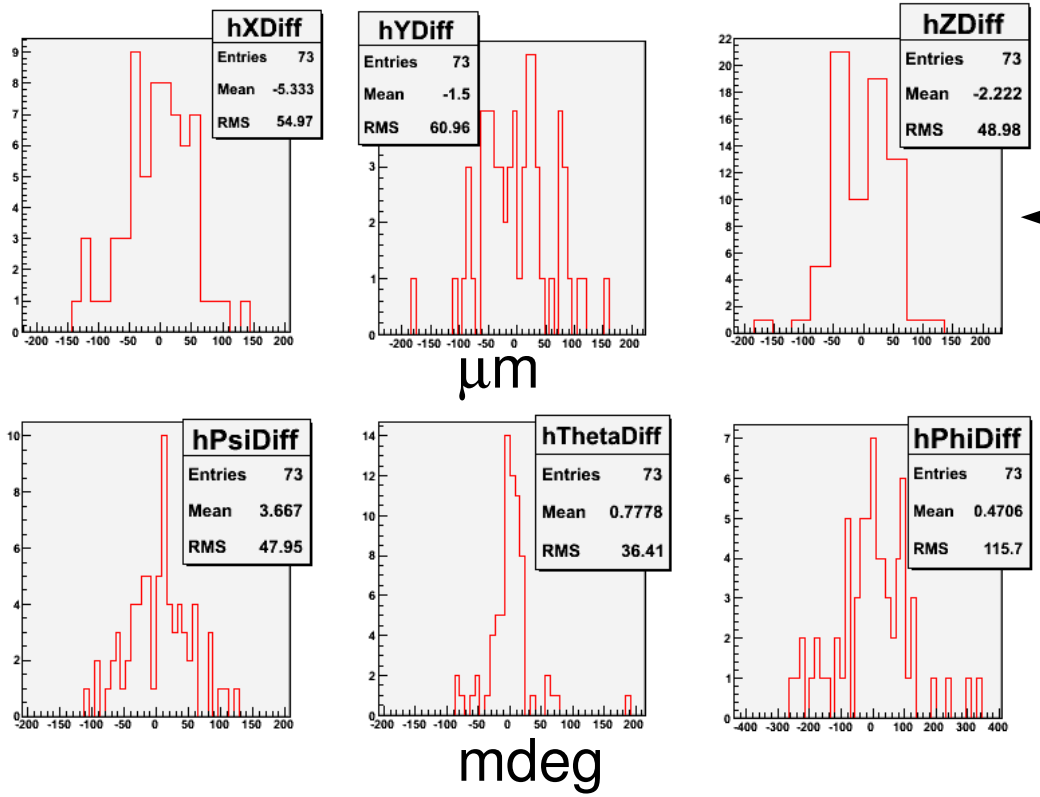


only those modules for which the V_{Drift} calibration is essential

~320 μm improvement in the SDD resolution after the calibration

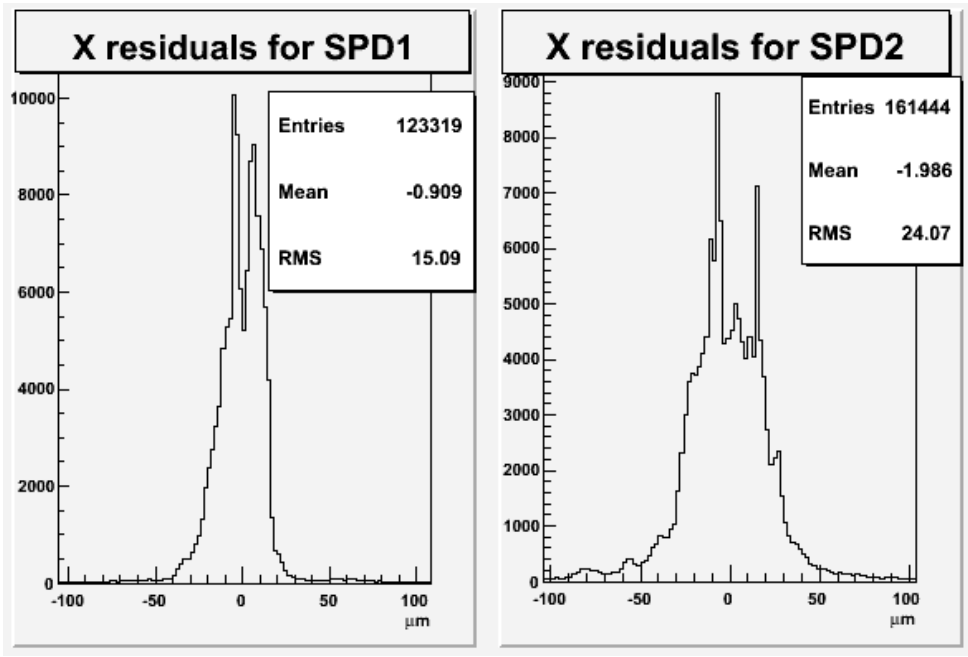
(still far from the nominal value due to the trigger jitter)

Comparison with Millepede

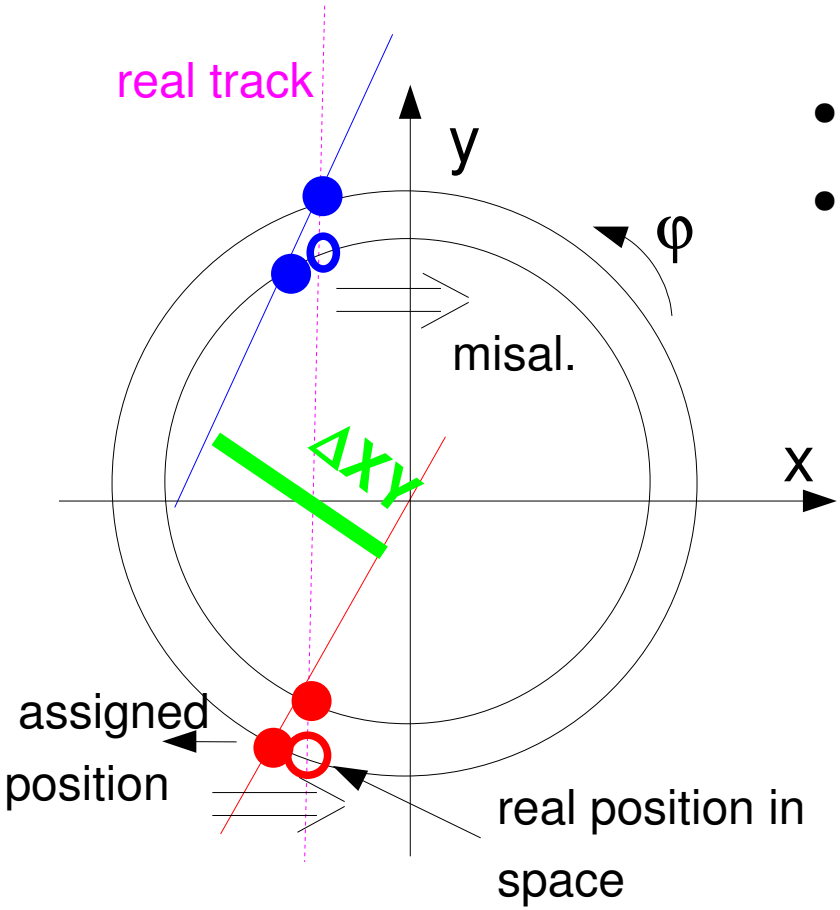


Differences between the recovered parameters for the inner SPD layer

Differences between points positions with the two recovered geometries



Track-to-track residuals, ΔXYatY=0



- Split each track in two (e.g. upper VS lower)
- Compare:
  - tracks directions in the XY and YZ planes
  - ΔXYatY=0
  - ΔZatY=0

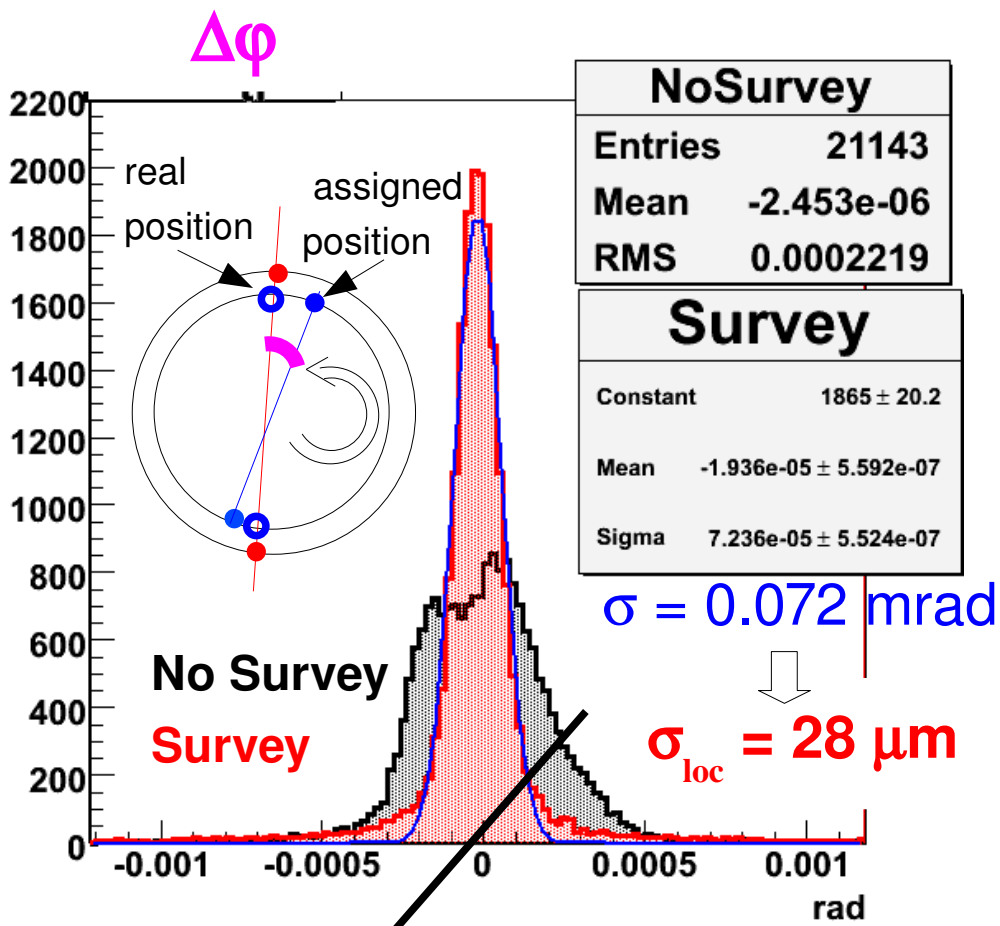
When only the four points on a single detector (-> same σ_{loc}^{ideal}) are used to fit the tracks

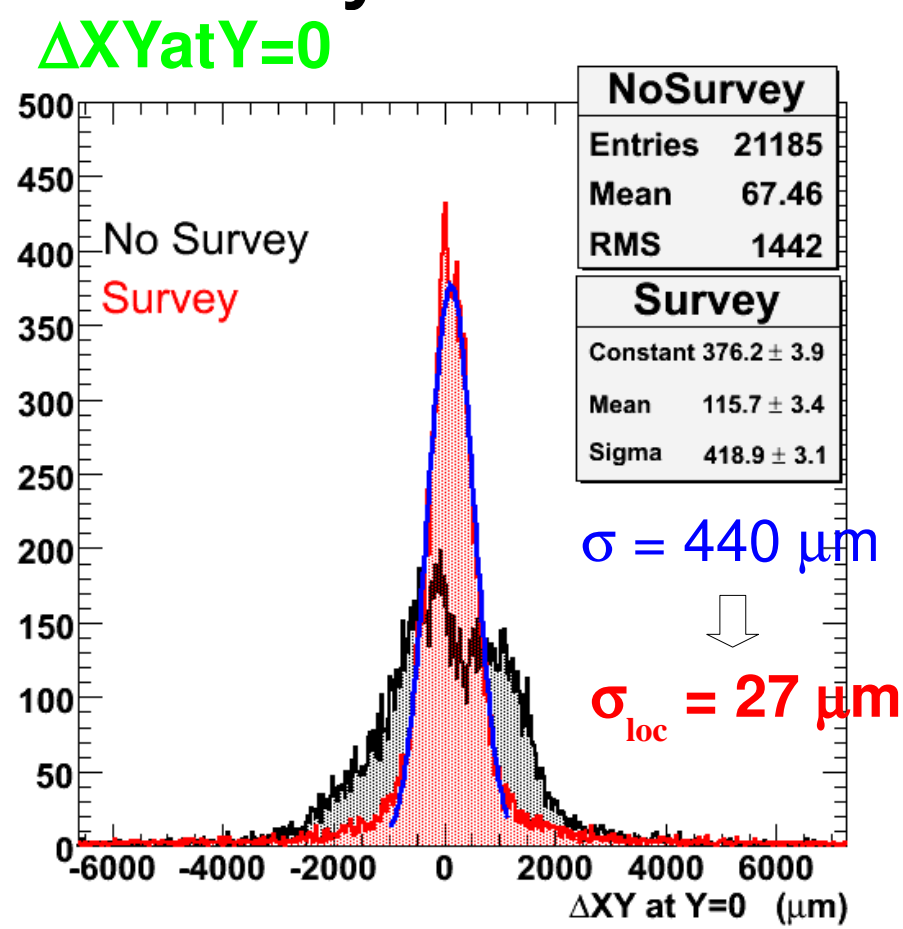
↓

easy to relate the observed distribution to the spatial effective "local" resolution

e.g. $$\sigma^2(x_{loc}) \approx \sigma^2(\Delta XY_{y=0}) \cdot \frac{1}{2} \frac{(r_{OUTER} - r_{INNER})^2}{r_{INNER}^2 + r_{OUTER}^2}$$

SSD survey validation:Track-to-track and residuals analysis





spatial effective resolution

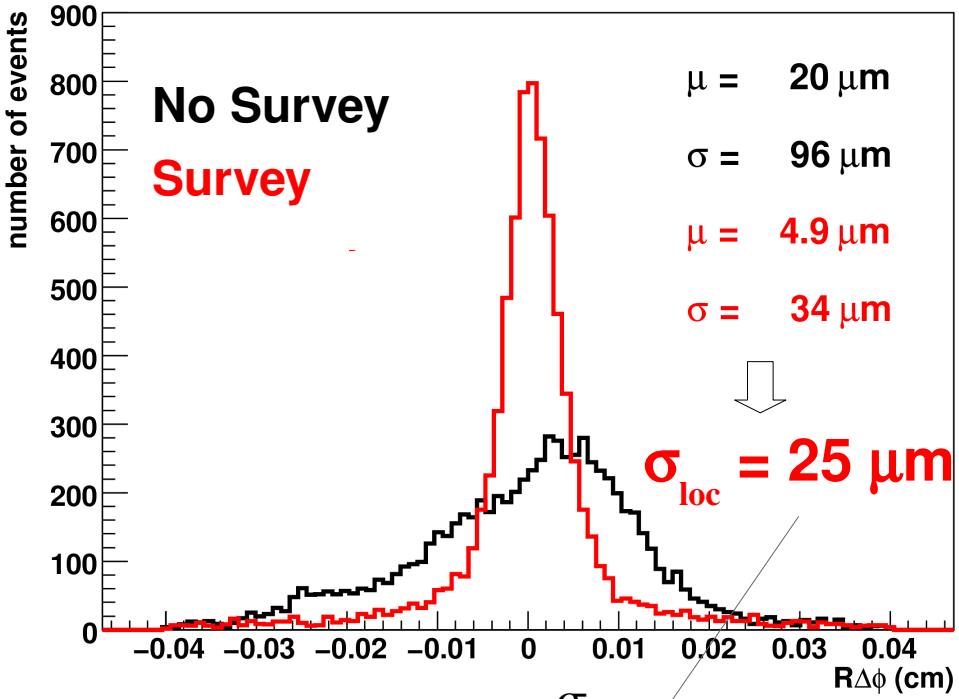
$$\sigma^2_{xloc} \approx 2\,\sigma^2(\Delta\varphi)_{mes} \Big/ \left(\frac{1}{r^2_{INNER}} + \frac{1}{r^2_{OUTER}}\right)$$

Large improvement using the Survey

Same results with the two variables

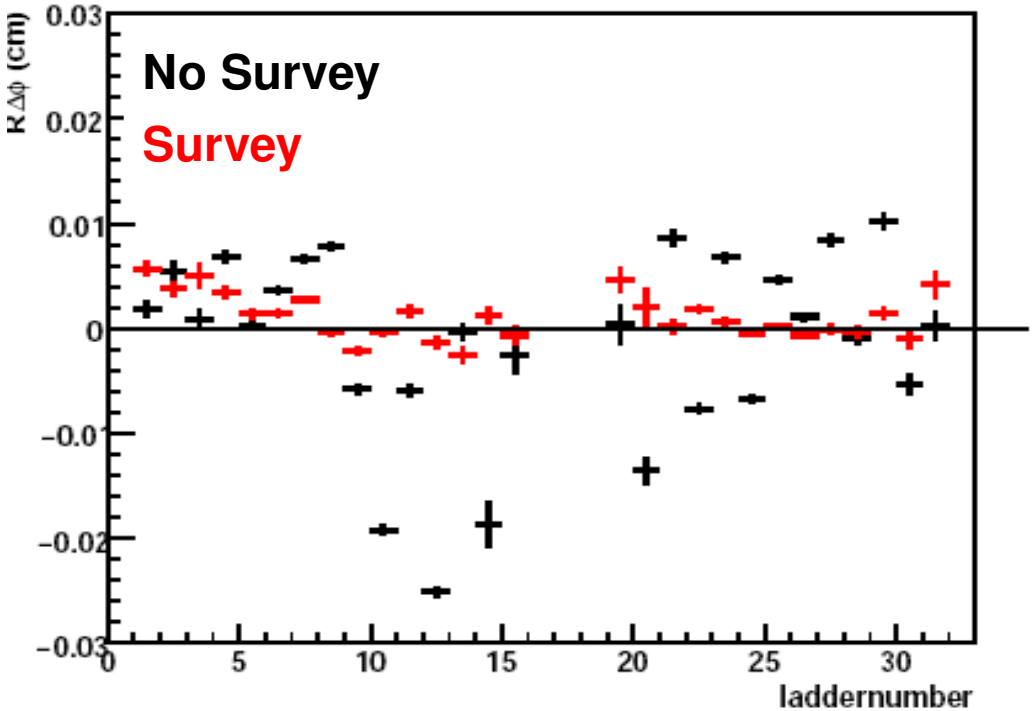
SSD survey validation: residuals

rφ residuals on the inner SSD layer with the tracks fitted on the outer one



$$\sigma(x_{loc}) \approx \frac{\sigma_{res}}{\sqrt{1.9}}$$

spatial resol



Large improvement with the use of the survey

The results are compatible with those obtained looking at the tracks properties