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Allineamento dell'ITS con Millepede

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per la Collaborazione ALICE

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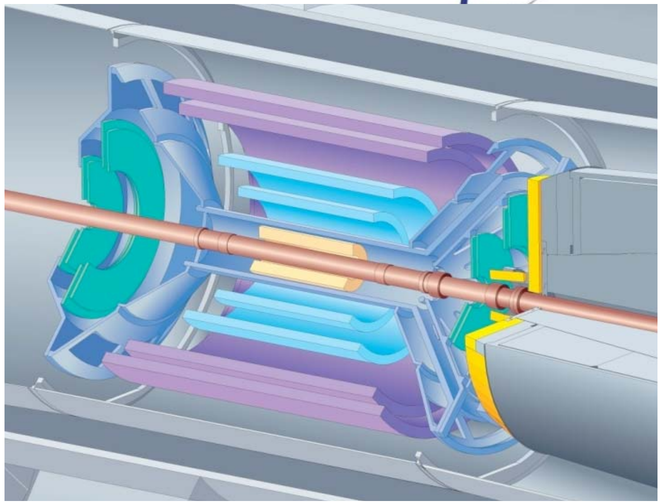
Contents

- ALICE ITS detector description
- ITS commissioning and cosmic data taking
- Alignment strategy
- Alignment results
- Future activity on ITS alignment

The Inner Tracking System



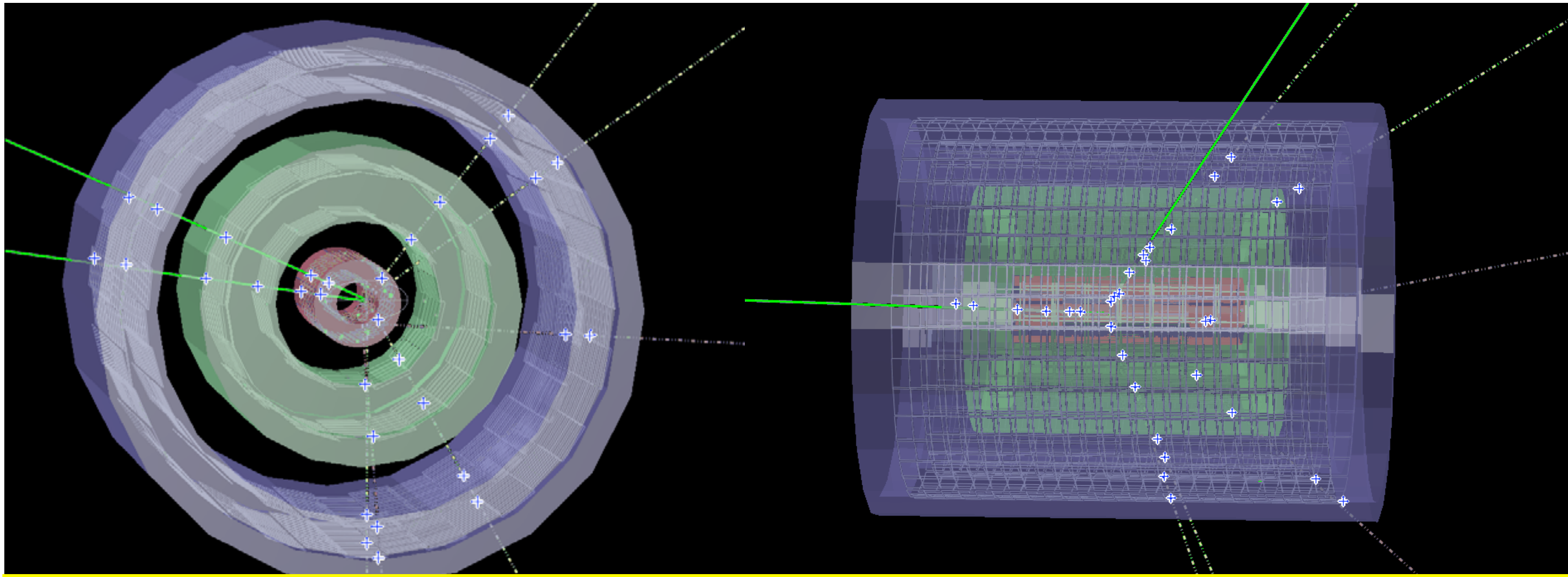
- Design goals
  - Optimal resolution for primary vertex and track impact parameter
  - Minimum distance of innermost layer from beam axis (<r>≈ 3.9 cm) and material budget
  - 2D devices in all the layers

Layer	Det. Type	Radius (cm)	Resolution (μm)		N of modules
			rφ	Z	
1	SPD	3.9	11	110	80
2		7.6	11	110	160
3	SDD	15.0	35	25	84
4		23.9	35	25	176
5	SSD	38.0	20	830	748
6		43.0	20	830	950

TOTAL: MODULES 2198
D.O.F. ~ 13200

ITS Commissioning

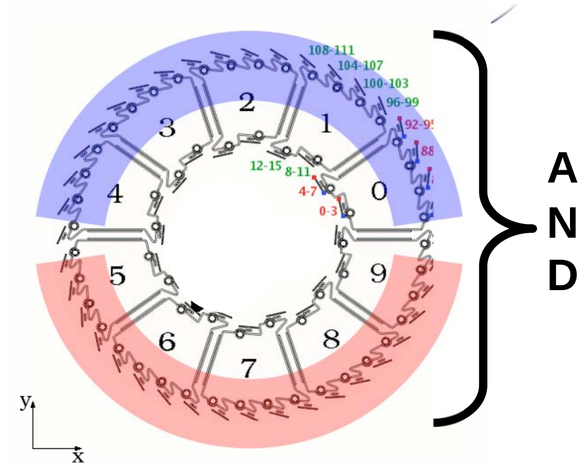
- Successful commissioning run with cosmic rays during summer 2008 for the ALICE Inner Tracking System
- Cosmic runs with SPD FastOR trigger
  - First alignment of the ITS modules + test TPC/ITS track matching
  - Absolute calibration of the charge signal in SDD and SSD



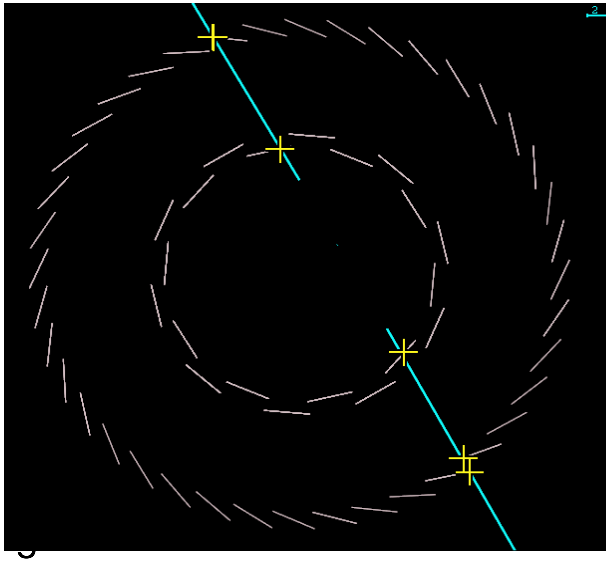
7-track event collected with circulating LHC beam2 on Sept. 11th 2008

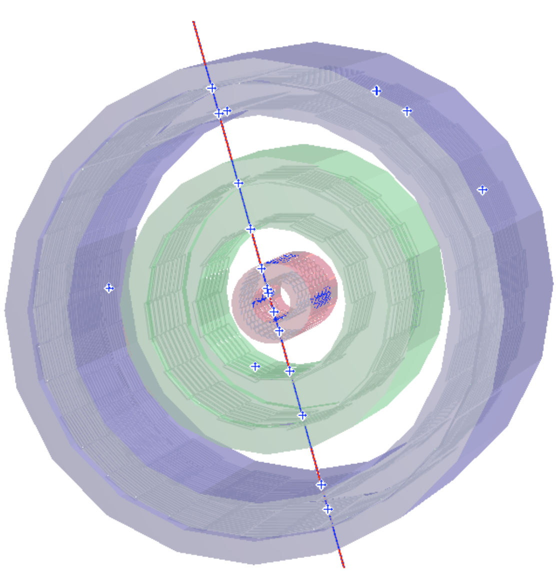
Cosmic rays triggering and tracking

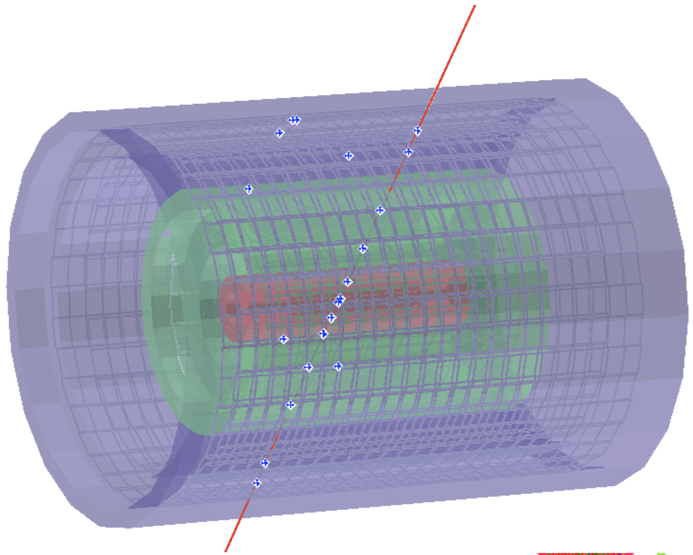
- Trigger: SPD FastOR
  - Coincidence between <u>top outer</u> SPD layer and <u>bottom outer</u> SPD layer
  - rate: 0.18 Hz



- ITS Stand-Alone tracker adapted for cosmic tracks
  - ⇨ "Fake" vertex = point of closest approach between two "tracklets" built in the top and bottom SPD half-barrels
  - ⇨ Search for two back-to-back tracks starting from this vertex

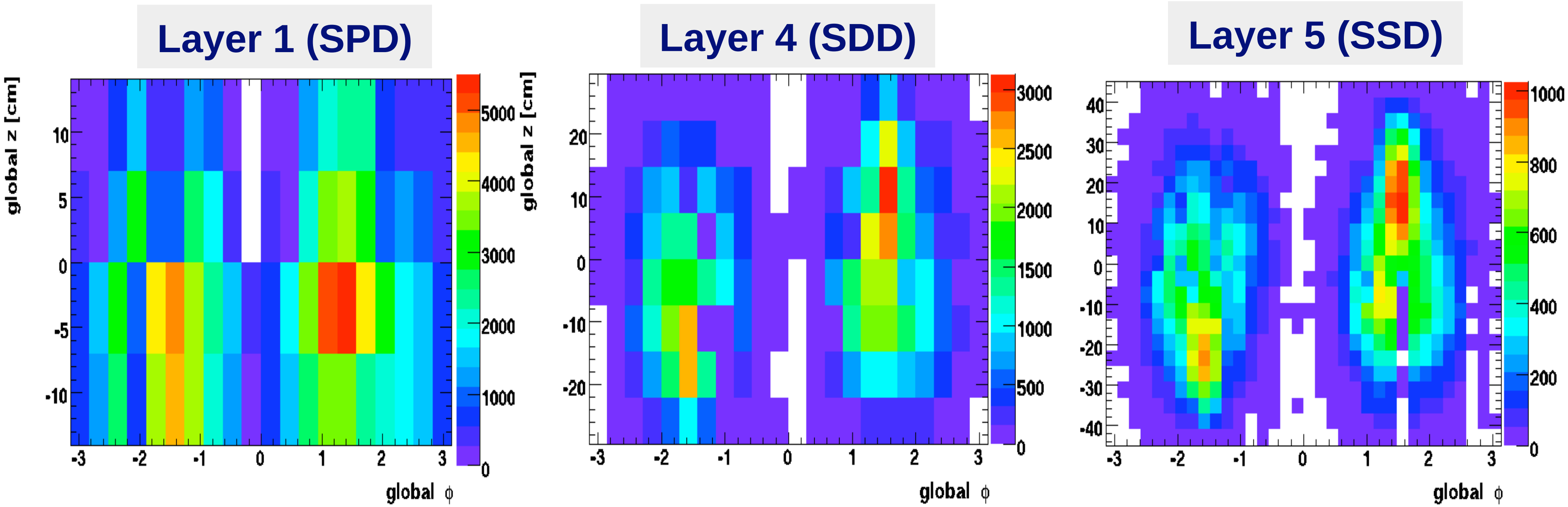






2008 cosmic ray tracks data sample

- Statistics collected ≈ **10^5 good events**
  (i.e. reconstructed with 3 or 4 points in SPD Barrel)



More selections:

- 50k with 4 pts in SPD (used for the alignment of SPD)
- 40k con 3 pts in SPD and 3 pts in SSD
- 20k con 4 pts in SPD and 4 pts in SSD (used for alignment of SSD)

The Alice ITS Alignment challenge

The goals for the alignment procedures are set by asking that the overall effect of residual unknown misalignments should not significantly degrade the resolutions.

The target of the realignment program is that the **resolution worsening** due to misalignment **shouldn't exceed 20%** of the nominal resolution.

As an example: for the SPD, whose position resolution is about 11 μm in the most precise direction, a residual misalignment not larger than 8 μm can be tolerated.

The task of aligning the ALICE ITS is challenging also due to the large number of degrees of freedom, which are more than 13,000.

Alignment strategy

Need to extract the alignment objects (translations and rotations) for the 2198 ITS modules:

– Use **geometrical survey data**: measurements of sensor positions on ladders (SDD and SSD) during the assembly and ladders positions on the support cone (SSD)

– Cocktail of both **cosmic and proton proton collision tracks**, to cover the entire ITS surface and to exploit the modules correlations: two alignment methods used, Millepede and an iterative module-by-module approach *(see talk of A. Rossi)*

As a monitor:

– hardware alignment monitoring system (based on collimated laser beams, mirrors and CCD cameras) to monitor physical movements of ITS with respect to TPC

– point-to-track (residual) distributions for selected configurations

MILLEPEDE: a global solution

Original development by V. Blobel (*http://www.desy.de/~blobel/wwwmille.html*)

Millepede: Linear Least Squares Fits with a Large Number of Parameters

Main requirement: the measured value (the residual) can be expressed as a linear function of G global (alignment) parameters a_l and L local (track) parameters p_j

$$z_i = y_i - f(x_i, \overline{p}, \overline{a}) = \sum_{j=1}^{L} \frac{\partial f}{\partial p_j} \Delta p_j + \sum_{l=1}^{G} \frac{\partial f}{\partial a_l} \Delta a_l$$

In this limit (linear case) the solution of the least squares problem for a set of N tracks leads to an inversion of a (N*L+G)-size matrix

Example: G=100, L=4, N=1,000,000 $\Rightarrow$ **size = 4,000,100** but **only 100** values are of interest

Millepede exploits smartly the special properties of the matrix and solves the linear problem wrt <u>only</u> the global (alignment) parameters

MILLEPEDE: a global solution

Two implemetations:

Millepede I:

- upper limit on the number of alignment parameters is between one and ten thousand
- single code

Millepede II:

- has a **much larger limit on the number of alignment parameters**
- performs a much faster (approx.) minimization
- two step code: Mille (the user part: fill the matrix according to geometry and data information) + Pede (inverting the global matrix)

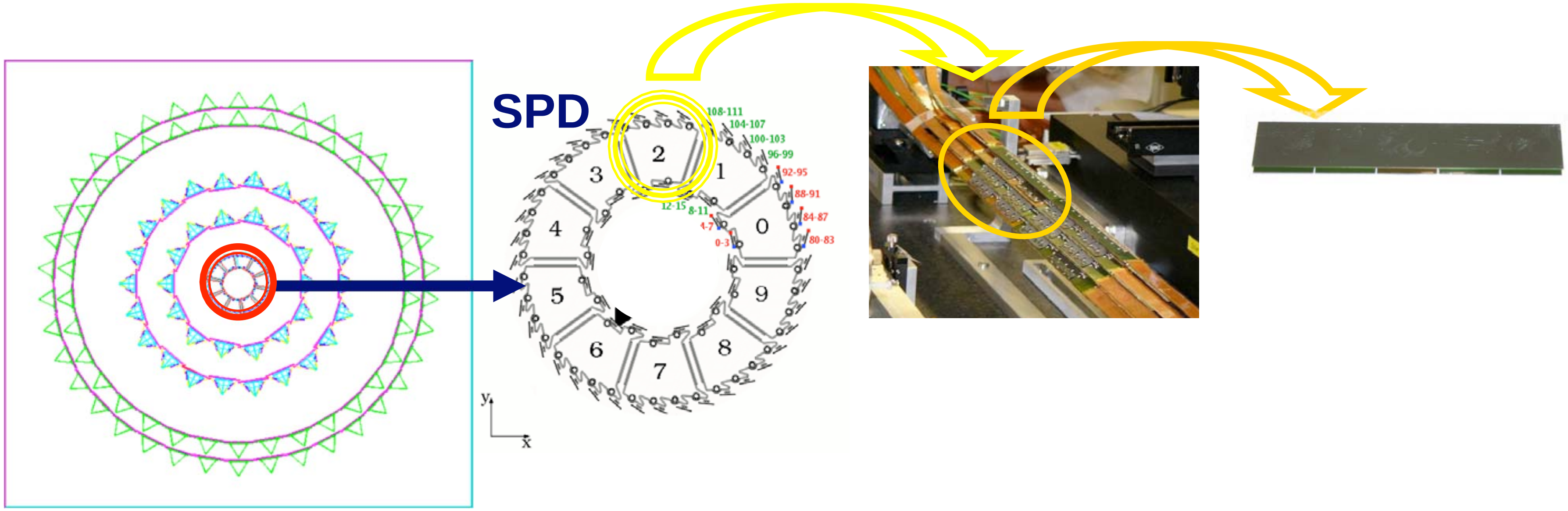
for the full ITS, MP2 takes ~1h CPU time on a reasonable computer

MillePede for ALICE ITS

- **Initialization from a configuration file**
  - Starting geometry (*ideal or "prealigned"*)
  - set list of modules to be aligned (possibility to define "super-modules", custom volume made up of sensitive modules (for example: half ladder)
  - set some track selection criteria
  - Set constraints
    - on the mean or the median of selected parameters are imposed after the fit (smaller matrix size)
    - on the local shifts: to avoid overlaps and to stay close to the survey results
- **Calculation of the local and global derivatives** (fill the matrix)

ITS Alignment procedure

STEP 1: hierarchical alignment of the SPD



1. SPD SECTORS (10)
2. SPD HALF-STAVES (120)
3. SPD LADDERS (sensitive modules 240)

for a total of 370 align objects

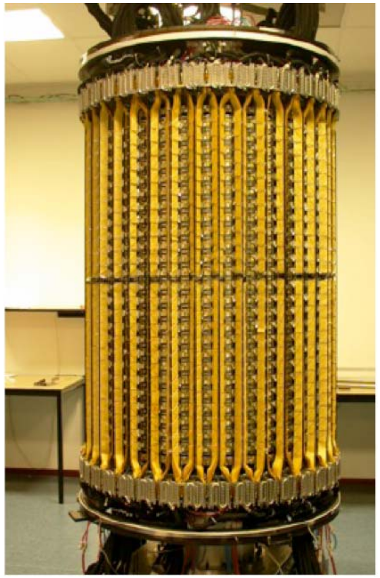
ITS Alignment procedure

STEP 2: alignment of the SSD

1. apply survey for the sensor positions on ladders and for ladders on supporting cone

2. fix upper Half Layer 6 of SSD

3. align with Millepede the whole SPD barrel + remaining SSD Half Layers;
   => with the currently (2008) available statistics, <u>no improvement by aligning smaller SSD group of modules</u> (like ladders, half ladders or single modules…)



STEP 3: alignment of the SDD

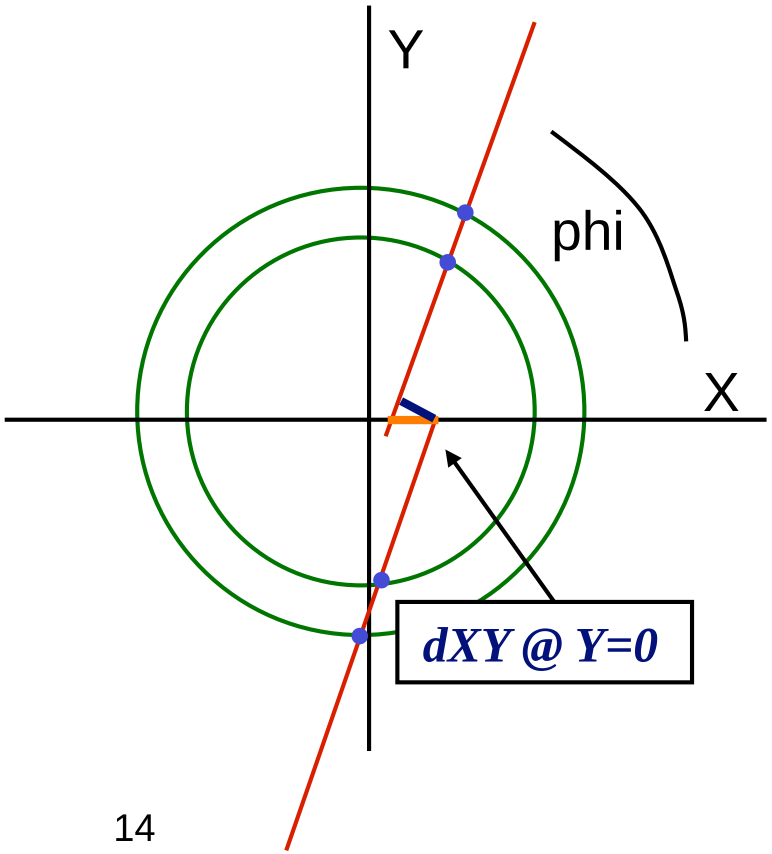
Coming soon...

STEP 4: alignment of the whole ITS with respect to TPC

Observables sensitive to misalignment

1) top-bottom tracks mismatch at Y=0 (*dXYatY=0*)

We split each track in an "upper" and a "lower" part and we compare properties like directions and positions of the two segments. The main variable is the *dXYatY=0*, **the track-to-track distance measured at Y=0**



WHAT FROM *dXYatY=0*

• using **cosmic ray tracks**, upper segment and lower segment belong to same track => ***dXYatY=0*** is a direct measurement of the resolution of the track impact parameter d_0:

$$\sigma^2_{\Delta xy} = 2\sigma^2_{d0}$$

• in the simple case of a 2-layer detector, for tracks passing close the detector center, ***dXYatY=0*** can provide an estimate of the spatial resolution:

$$\sigma^2_{\Delta xy} = 2\frac{(r_1^2\sigma^2_{sp,2} + r_2^2\sigma^2_{sp,1})}{(r_1 - r_2)^2} \sim 2\sigma^2_{sp}\frac{(r_1^2 + r_2^2)}{(r_1 - r_2)^2}$$

Observables sensitive to misalignment

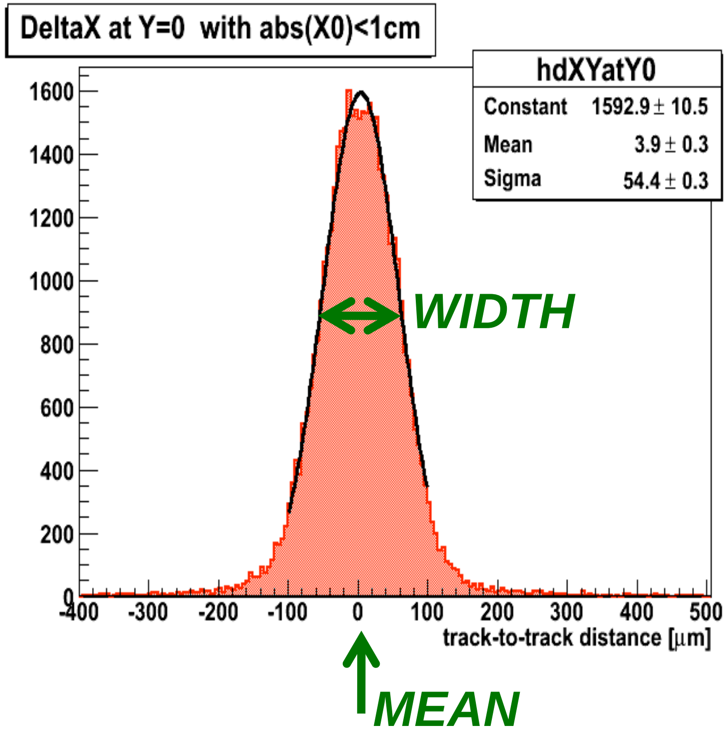
1) top-bottom tracks mismatch at Y=0 (*dXYatY=0*)

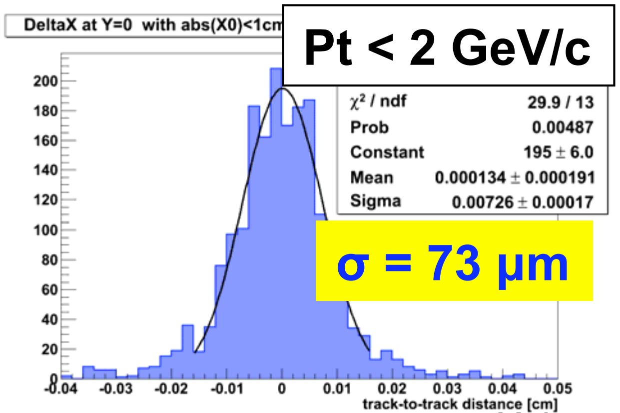
Example of a *dXYatY=0* distribution

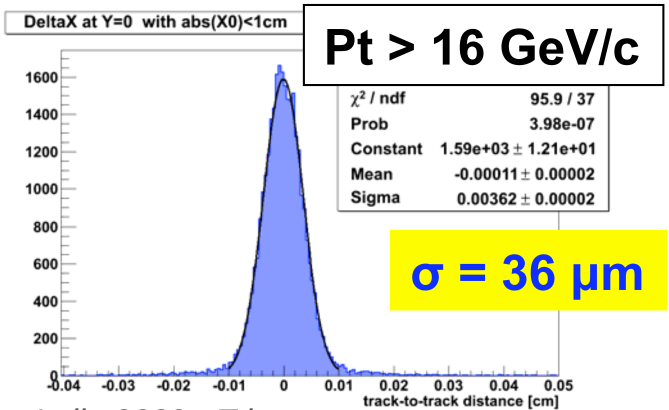
- **Mean value** and **width** are sensitive to misalignmment

- the **mean** value depends only on misalignment

- the **width** depends also on:
  1. multiple scattering (p_T-dependent)







Observables sensitive to misalignment

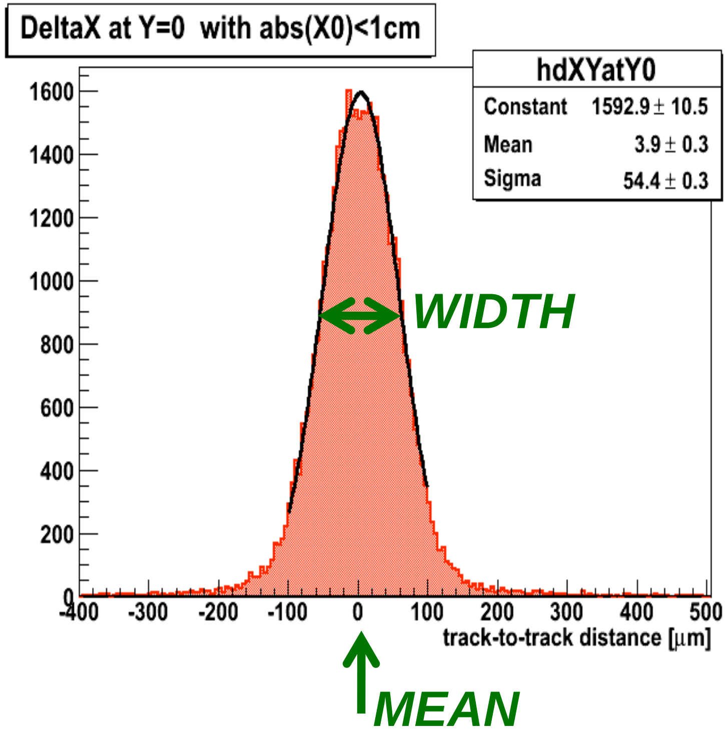
1) top-bottom tracks mismatch at Y=0 (*dXYatY=0*)

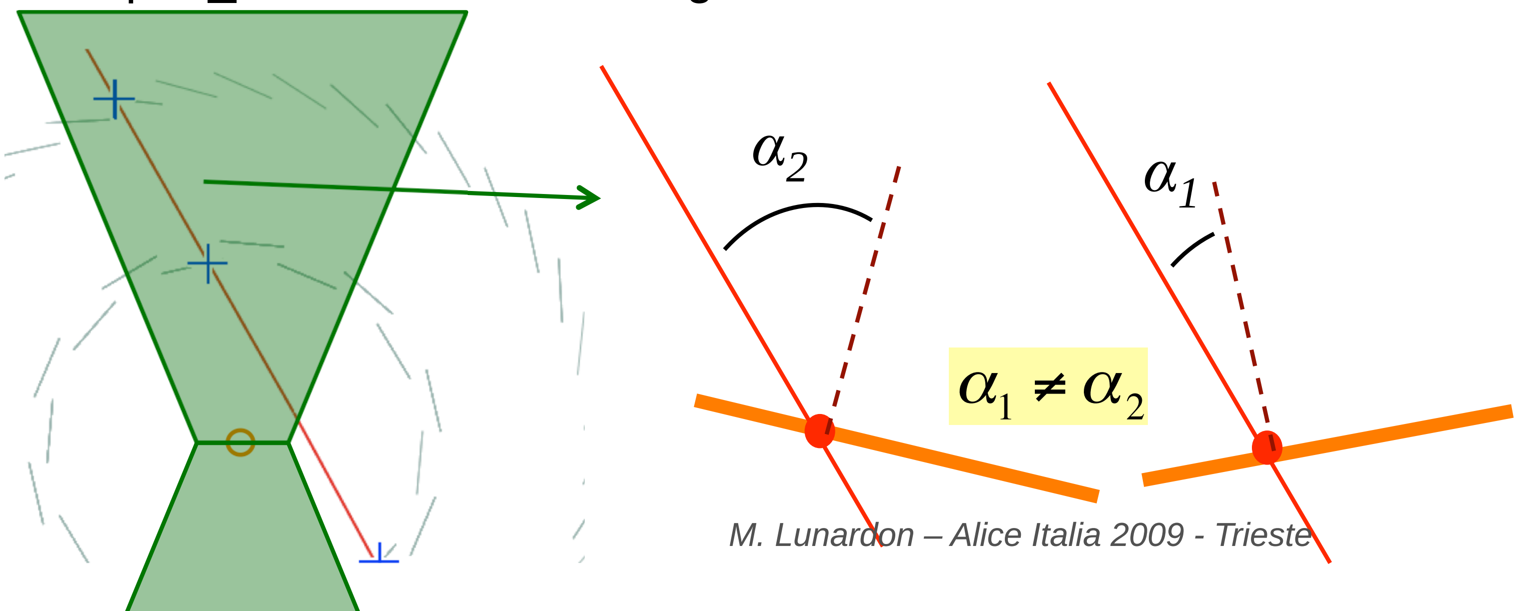
- the **width** depends also on:

  2. incident angle (intrinsic spatial resolution)
  3. non-gaussian tails

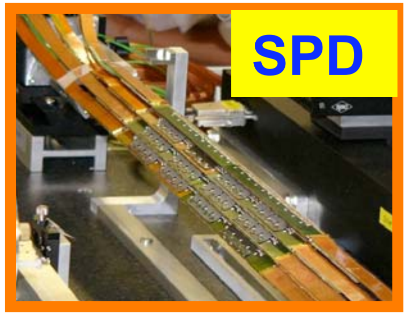
For cosmic ray tracks: large distribution of possible incident angles and distances => we use a ***selection of tracks passing whithin 1 cm*** from the detector center (*abs(XatY=0 < 1 cm*)

<alpha_SPD1> ~ 0 ÷ 15 deg
<alpha_SPD2> ~ 15 ÷ 30 deg



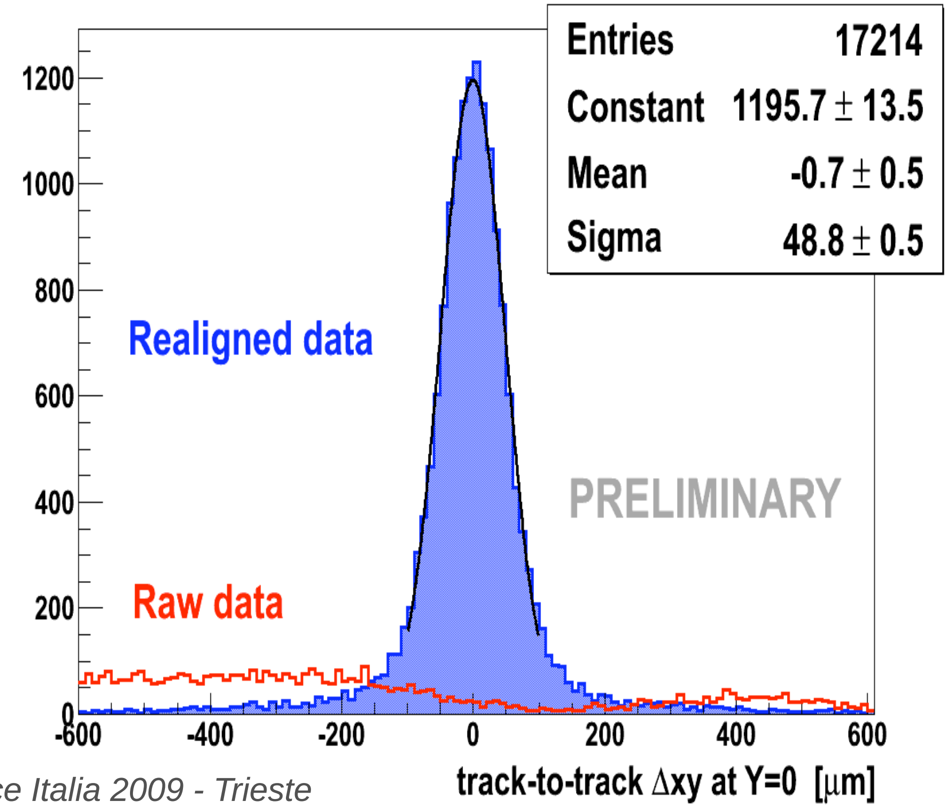


Millepede alignment of SPD



Cosmic Data 2008: realigned data

- alignment with 4 pts tracks (50k)
- 75% of SPD modules with more than 50 counts “well aligned”
- **mean value** less than 1 μm
- **large tails**, not present in simulation, probably due to multiple scattering (real p_T distribution different from the one in simulation?) => **need B-ON data**!
- sigma of fit in [-100,100] μm ~ **50 μm** (for comparison: 38 μm in simulation with no misalignment)

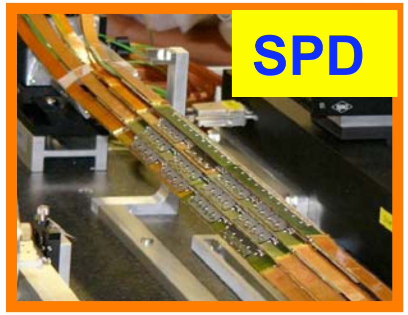


$$\sigma^2_{\Delta xy} \quad \rightarrow \quad \sigma_{sp,eff} \leq 14\ \mu m$$

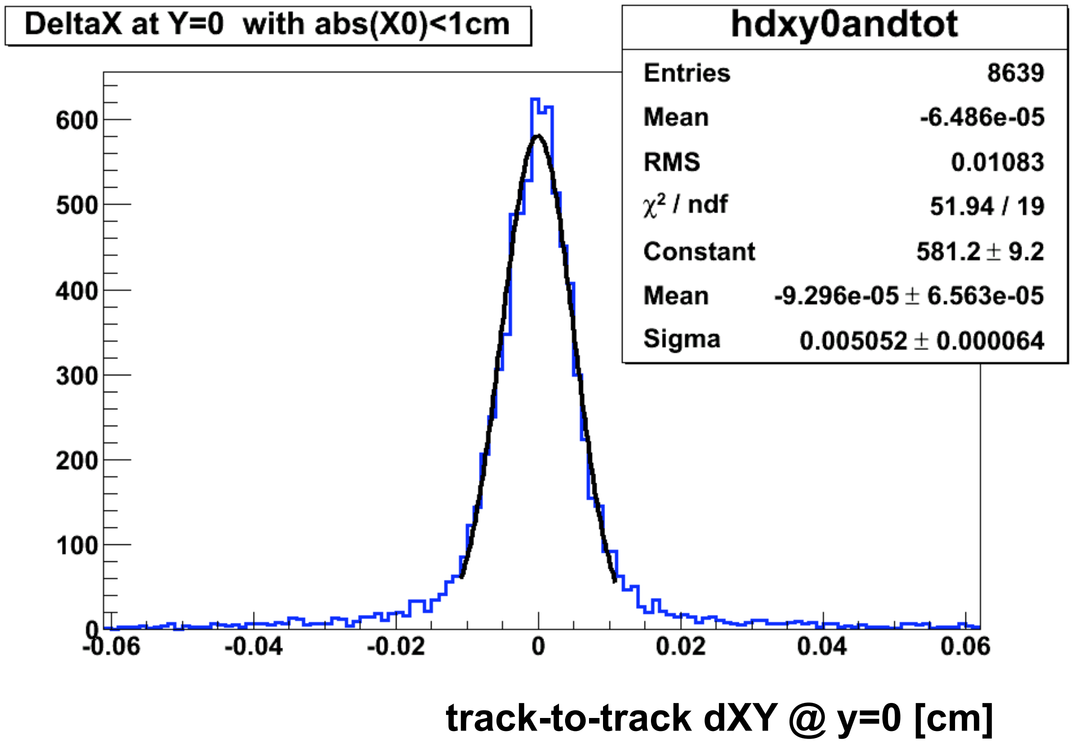
- **average value <SPD1/SPD2>**
- **which p_T?**

Millepede alignment of SPD

Cosmic Data 2008: realigned data



SPD alignment test with independent track samples



Alignment with **even** tracks (25k 4-pts tracks)

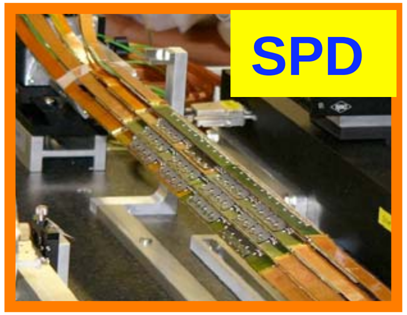
Check with **odd** tracks:

mean ~ 0

σ ~ **50 μm**

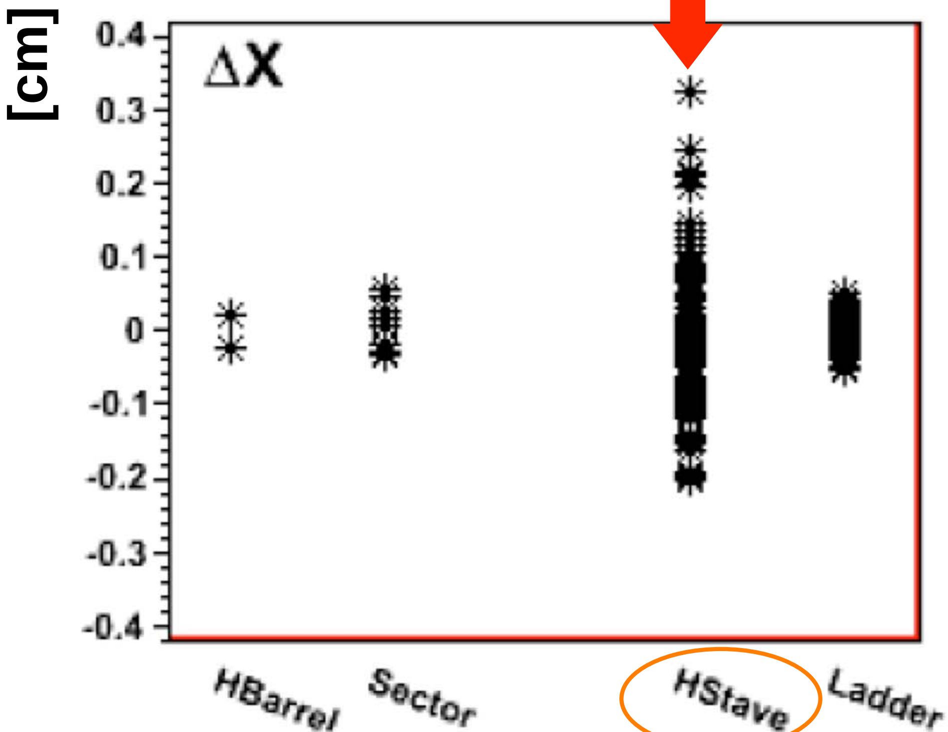
Millepede alignment of SPD

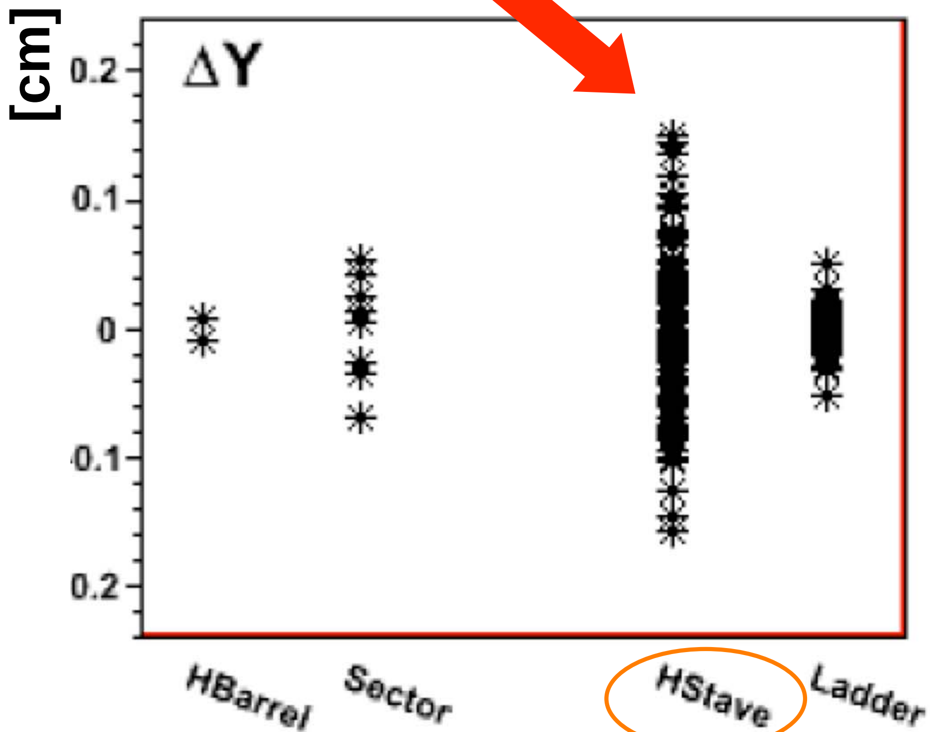
Cosmic Data 2008: realigned data



SPD correction parameters for hierarchy levels

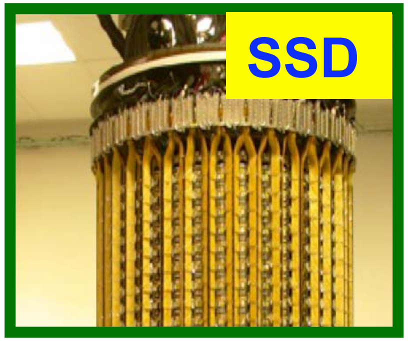
The Half-Staves require strongest corrections





Millepede alignment of SPD + SSD

Cosmic Data 2008: realigned data



- most of the SSD alignment from **survey measurements** (*see talk of A. Rossi*)

- millepede alignment of **SSD Half Layers** (largest "piece of detector" that gives a significant improvement on *dXYatY=0* distribution)

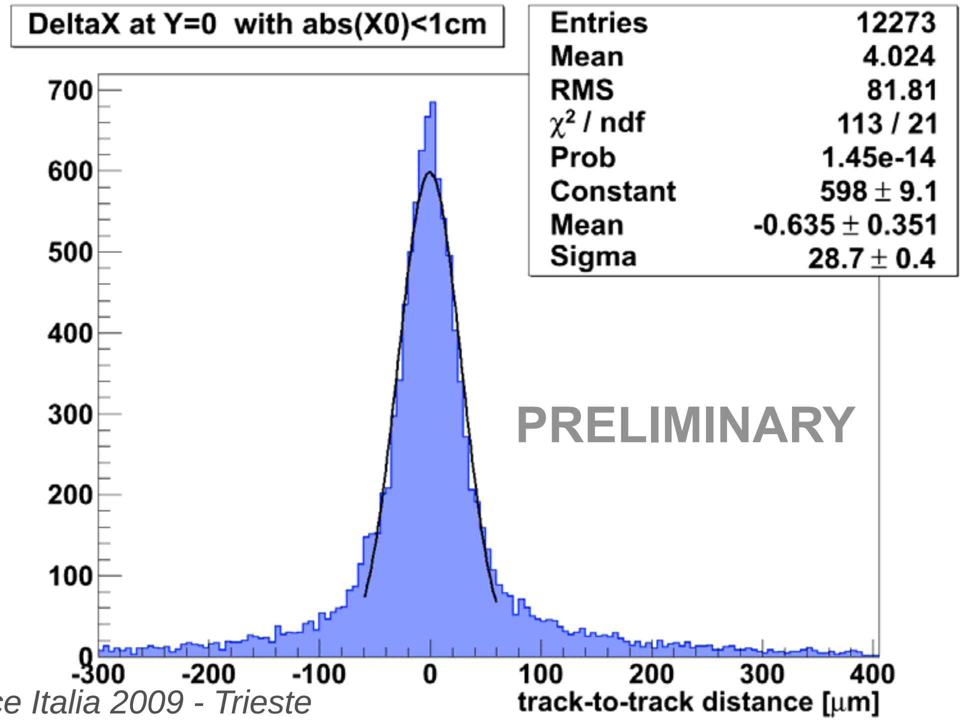
- **mean value** less than 1 µm

- **even larger tails**, probably due to multiple scattering => **need B-ON data**!

- sigma of fit in [-60,60] µm ~ **30 µm** (for comparison: 19 µm in simulation with no misalignment)

$$\sigma^2_{\Delta xy} \quad \rightarrow \quad \sigma_{d0} \approx 20\ \mu m$$

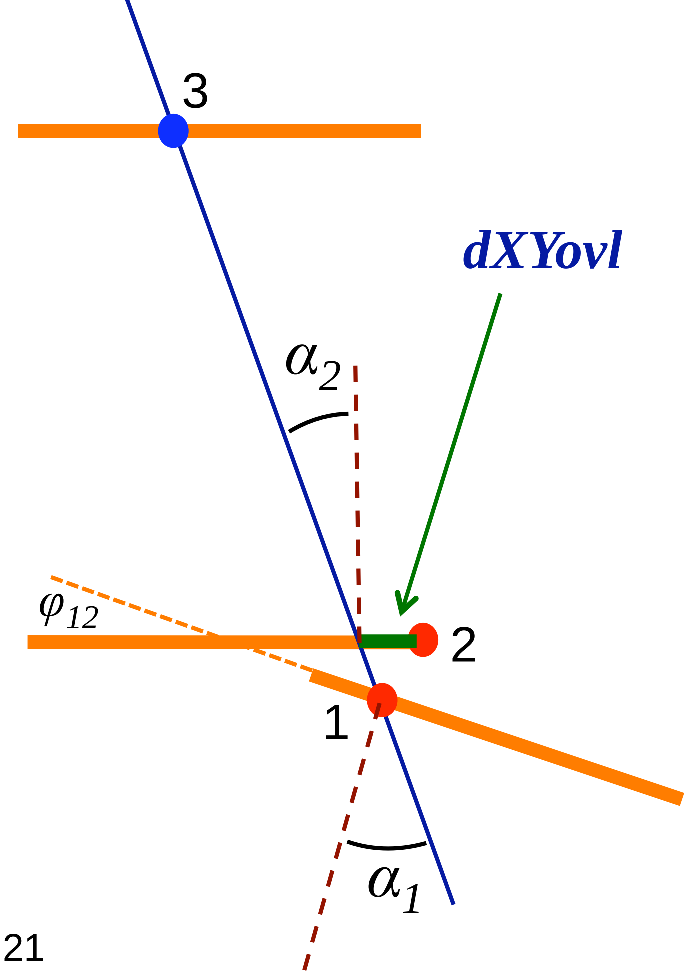
- no SDD inside (4 pts/track)
- **which p_T?**



Observables sensitive to misalignment

2) point-to-track distance for clusters in overlapping modules (*dXYovl*)

We measure the **point-to-track distance** for clusters in the regions of overlap between modules of the same layer. The distance *dXYovl* is projected on the module 2 plane (see drawing)



WHAT FROM *dXYovl*

• the width of the distribution is directly correlated with the effective spatial resolution of the overlapping clusters:

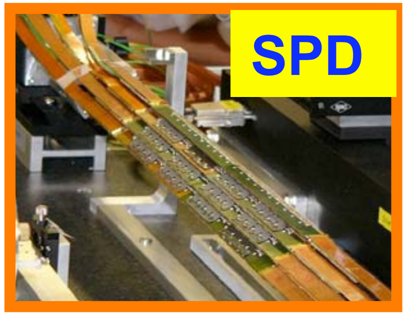
$$\sigma^2_{dXYovl} = \sigma^2_{cl2}(\alpha_2) + \sigma^2_{cl1}(\alpha_1)\cos^2(\varphi_{12})$$

• main advantage: because of the short distance between overlapping clusters, **the dependence on multiple scattering is negligible** (no need for p_T info)

• both mean value and width are sensitive to misalignment

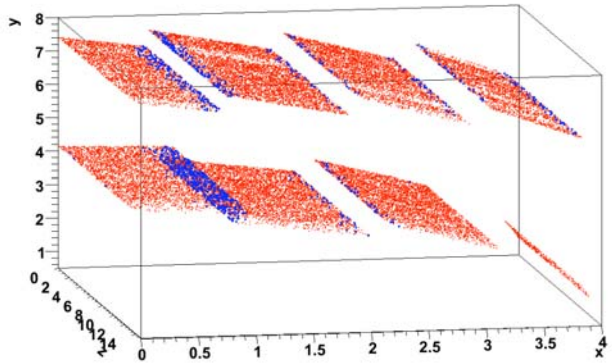
Millepede alignment of SPD

Cosmic Data 2008: realigned data



• selection of tracks passing close to center (abs(XatY0)<1cm) to reduce incident-angle spread => three selected regions around 5,15 and 23 deg

Overlapping regions in SPD (2008 data)

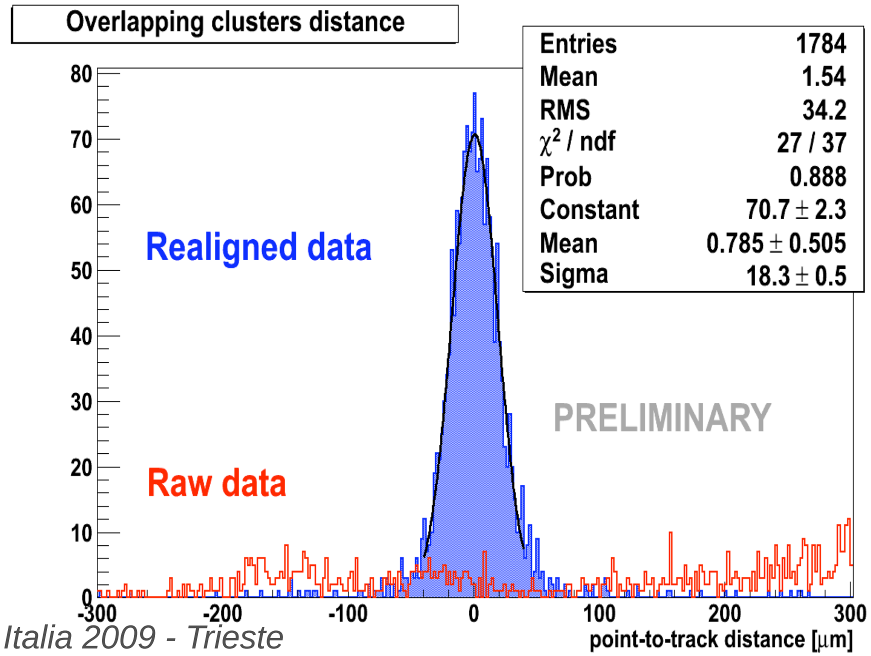


• **mean value** less than 1 μm

• **small tails** mainly due to angle selection

• sigma of fit in ~ **18 ÷ 19 μm**

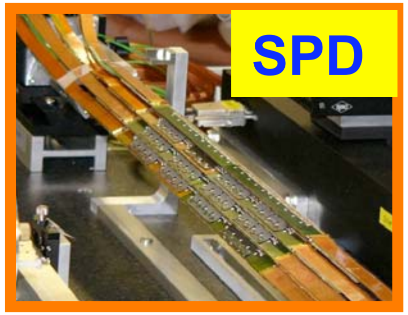
(for comparison: ~ 15 ÷ 16 μm in simulation with no misalignment)



*Available statistics not so large, but enough for more detailed analysis as a function of the **incident angle***

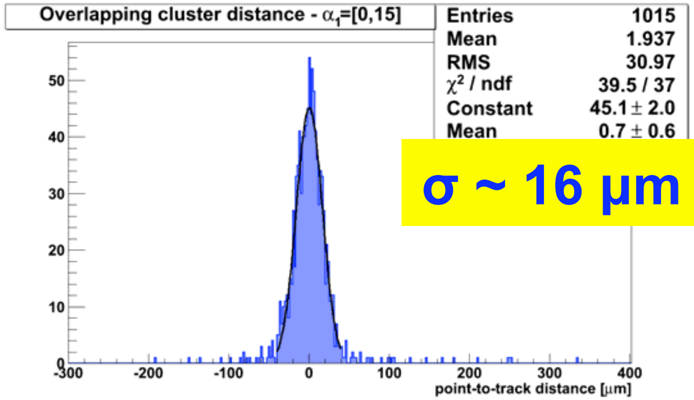
Millepede alignment of SPD

Cosmic Data 2008: realigned data



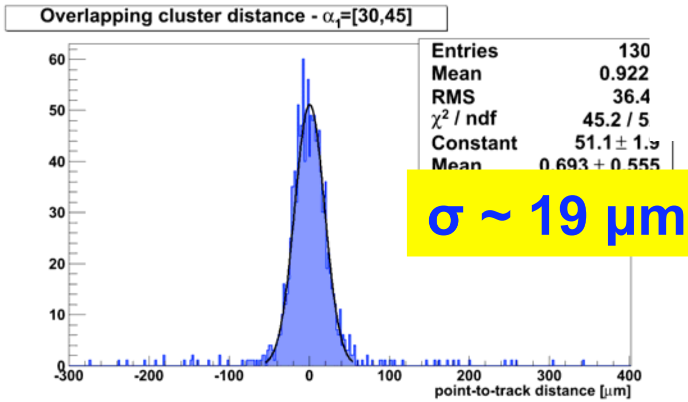
Incident-angle dependent analysis

Selection: tracks with 4 pts in SPD in modules aligned with more than 50 counts
Extra clusters NOT USED in the alignment



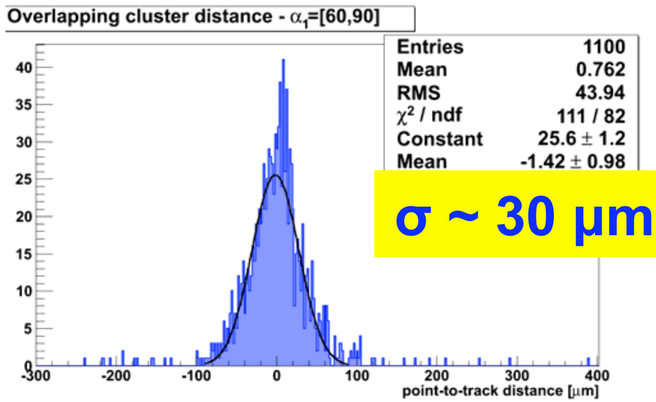
σ ~ 16 μm

$<\alpha_1> / <\alpha_2>$ ~ 9 / 2 deg



σ ~ 19 μm

$<\alpha_1> / <\alpha_2>$ ~ 25 / 12 deg

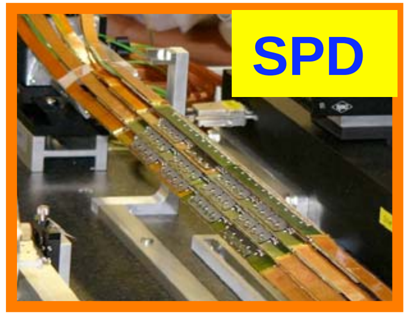


σ ~ 30 μm

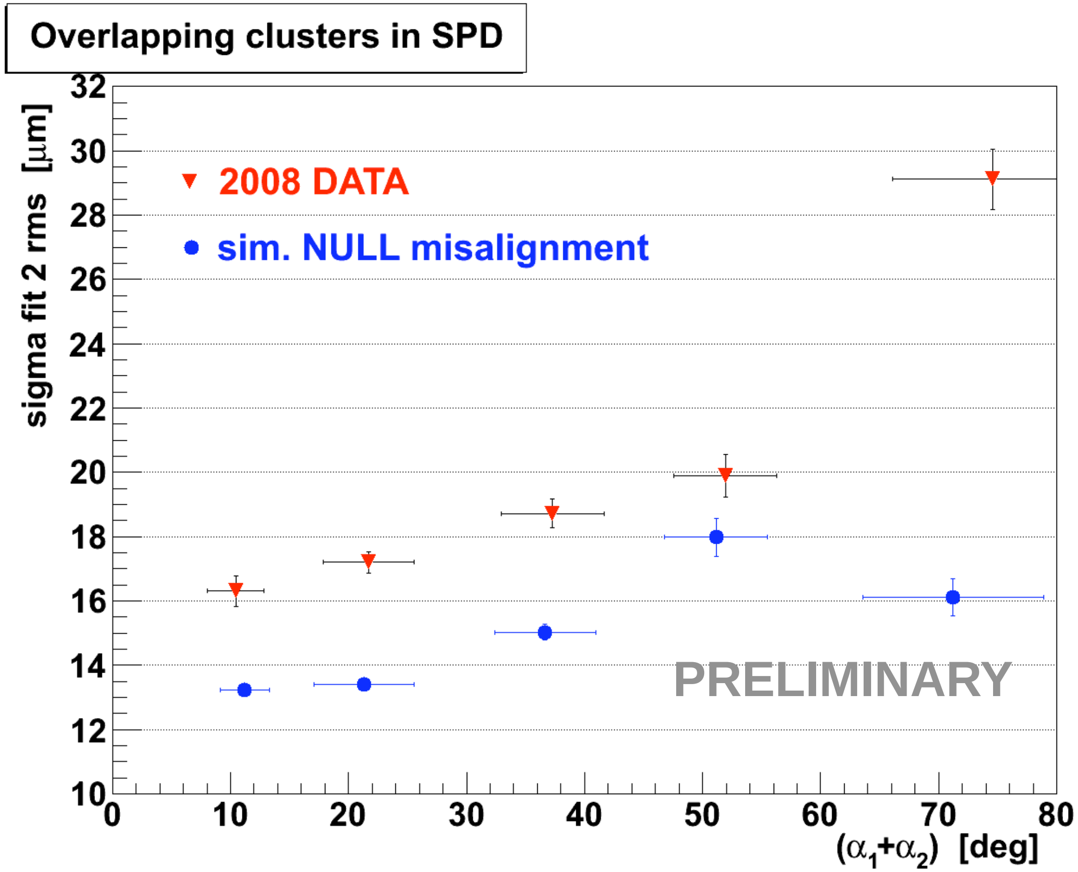
$<\alpha_1> / <\alpha_2>$ ~ 46 / 28 deg

Millepede alignment of SPD

Cosmic Data 2008: realigned data



Incident-angle dependent analysis



- clear dependence of the width of the distribution on the incident angle of the tracks

- similar dependece as in simulation, 2 ÷ 4 µm higher

By selecting proper angles:

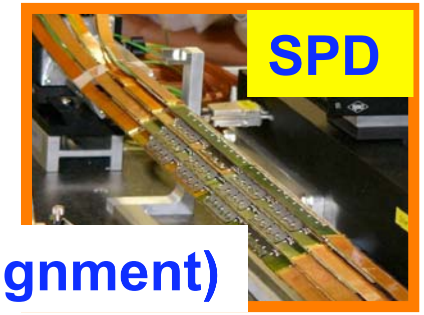
$$\sigma_{sp,eff} \approx 12 \div 14\ \mu m$$

for angles α ~ 0 ÷ 20 deg

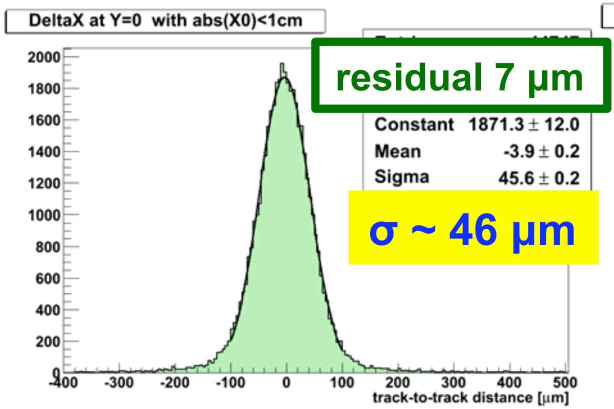
Warning: low statistics; wait for 2009 data to be confirmed

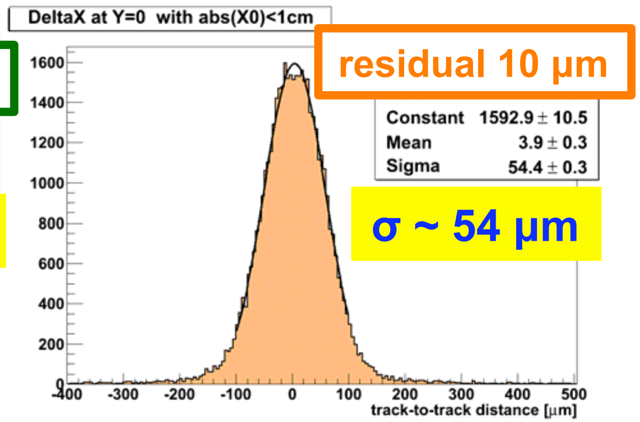
Millepede alignment of SPD

Cosmic Data 2008: realigned data

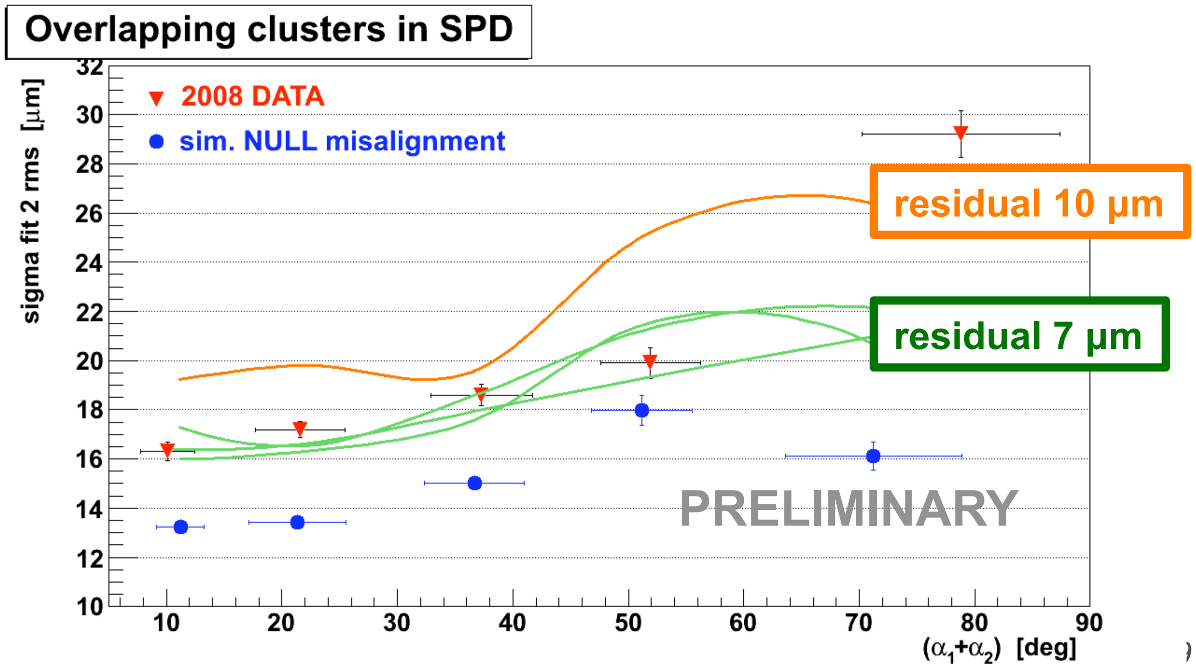


Comparison with simulation+(random residual misalignment)





- *dXYatY=0* and *dXYovl* evaluated in simulation with different residual misalignment. Residual of about **7 micron** and **10 micron** (random) are shown here.



ideal simulation with a residual random misalignment of 6÷8 µm very similar to 2008 data

Good for PDC09 simulation studies *(see talk of A. Dainese)*

Observables sensitive to misalignment

3) point-to-track distance for clusters in overlapping modules (*dXYovl*) with "mean subtraction"

1. the point-to-track distance is computed separately for each pair of overlapping modules;
2. the distribution is shifted to have mean value equal to zero (*mean subtraction*);
3. all the corrected distribution are summed up together.

=> remove the **systematic shift** between the modules of the pair ~ **remove most of translational misalignment** in the bending plane (original idea by A. Rossi – details on his presentation at the *ITS alignment meeting 27/7/09*)

After alignment, we expect: $\sigma^2_{obs} \approx 2\sigma^2_{sp} + 2\sigma^2_{RES}$

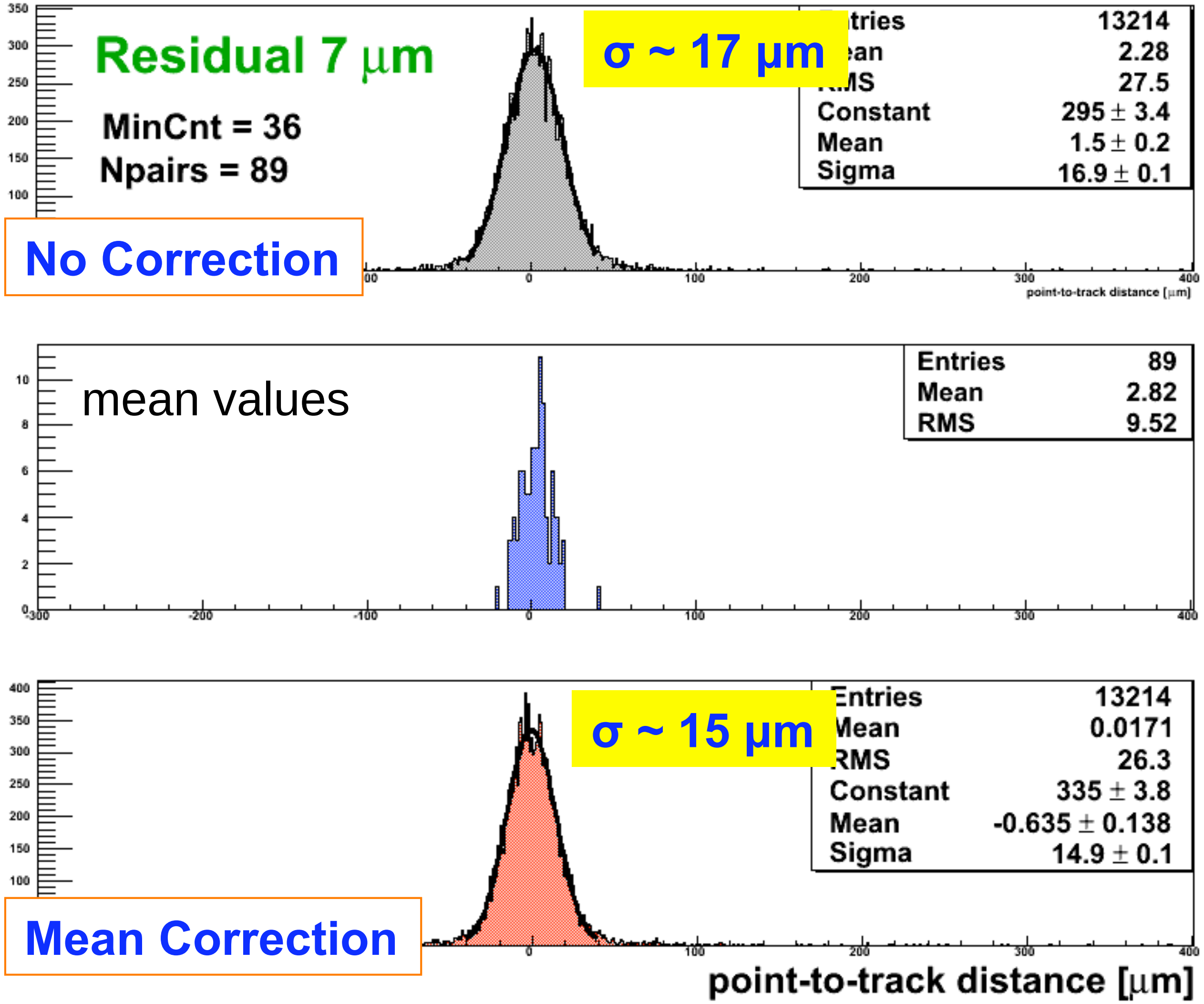
For pairs of modules with enogh statistics: $\sigma^2_{obs} - \sigma^2_{obs,corr} \approx 2(\sigma^2_{RES} - \sigma^2_{NS\_RES})$

can measure a significant part of the residual misalignment!

Observables sensitive to misalignment

3) point-to-track distance for clusters in overlapping modules (*dXYovl*) with "mean subtraction"

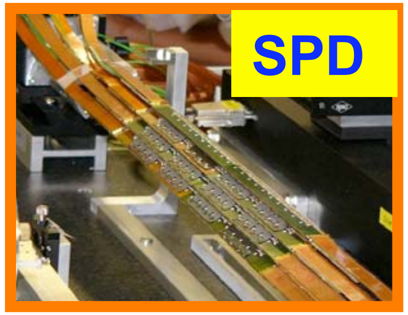
simulation+(random residual misalignment)

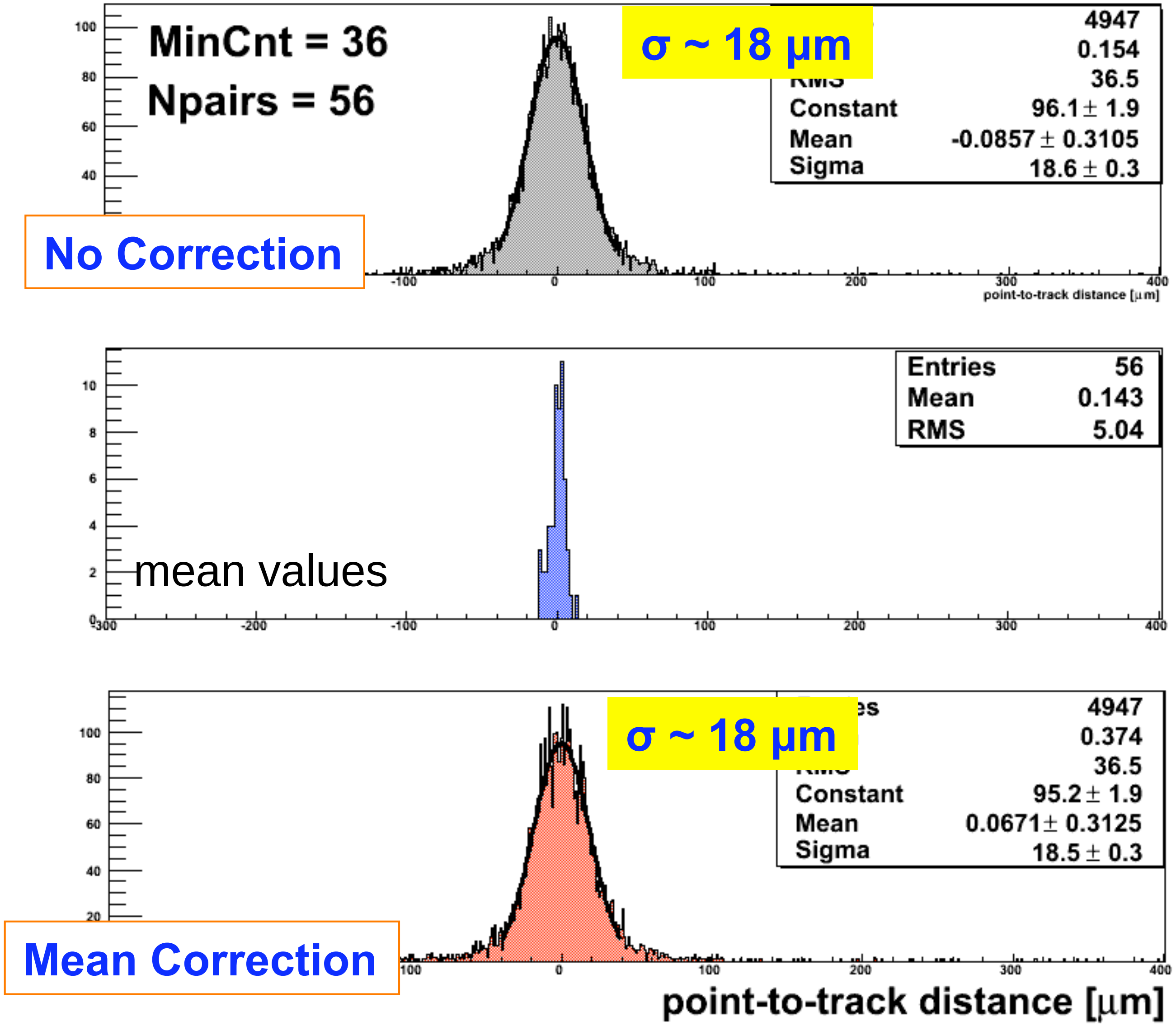


as expected, after correction the width is significantly reduced!

Millepede alignment of SPD

Cosmic Data 2008: realigned data





No width reduction after mean subtraction!

Residual misalignment not yet understood...

Summary

- Successful cosmic rays run during summer 2008 for the ALICE Inner Tracking System: we collected cosmic rays with the full ITS powered (85% of the SPD, 95% of SDD, 85%of SSD).

- **SPD**: about 80% of the modules have been aligned with Millepede. First results with cosmic ray tracks show that we are getting close to our alignment target: ideal simulation with a residual misalignment of about 6÷8 micron

- **SDD**: Millepede recently adapted to include calibration parameters t_0 and v_{drift}) in the global alignment (-> A. Rossi). Wait for 2009 data to complete the alignment…

- **SSD** well aligned with survey measurements. Millepede used only to adjust half layers position. Alignment of ladders or single modules still under study…

- Need cross checks with pp data, especially on the sides

Future plans for ITS alignment

- **Cosmics 2009 w/o B field to:**
  - Check alignment obtained with 2008 data (realign)
  - Study the performance as a function of the momentum: need p_T information to understand the contribution of multiple scattering
  - Study of weak modes
- **pp collisions:**
  - complete the alignment for the whole ITS
  - Study of the performance with B-off data
  - continuous check of alignment quality (monitoring) with B-on (when conditions change: e.g. field)