CMS Torino weekly meeting, 6th April 2009

The CMS silicon Tracker alignment and its influence on physics performance

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Outline

Alignment

Main concepts

Track-based alignment

Tracker alignment with real data (Global Run)

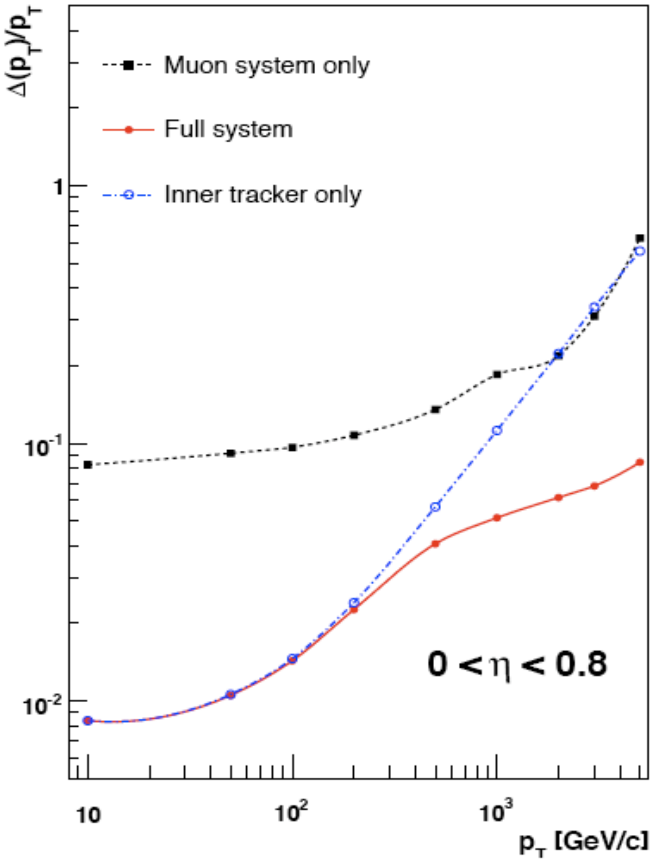
Results, improvements, challenges…

Tracker Systematic misalignment studies (weak modes)

Impact on physics performance

Impact of the Tracker alignment on the muon momentum scale

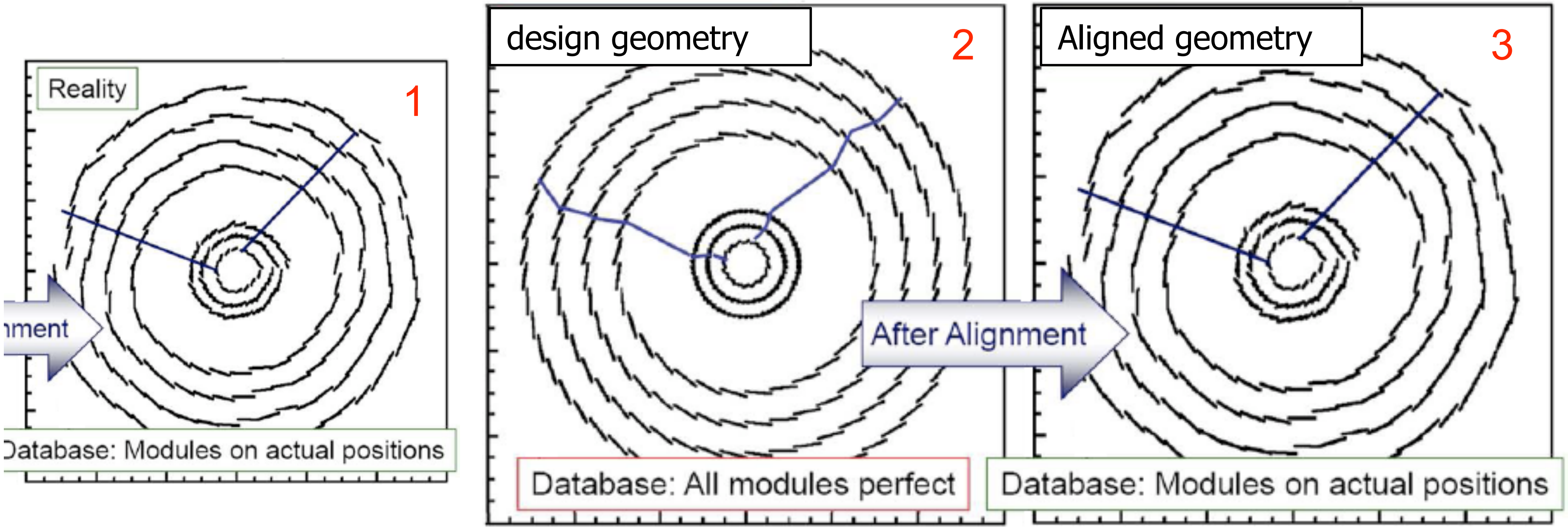
Why alignment is needed?



$\Delta p_T/p_T$ in the central region

- Tracker is essential to measure the particles' momentum
- For p < 20 GeV the $\Delta p_T/p_T$ is dominated by the Multiple Coulomb Scattering, while for the high momentum muons, systematic effects of misaligned detectors become relevant.
- This effect is minimised by alignment procedures

Tracker alignment: the basic idea

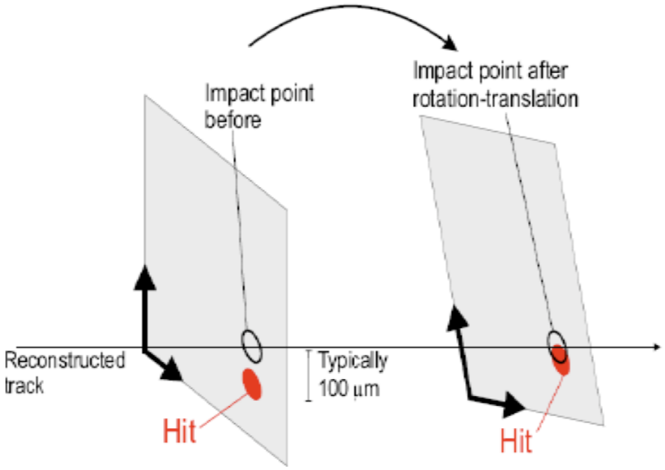


- In the reality the detector is misaligned: a particle of high momentum (e.g. p=40 GeV) is a 'straigth line' assuming real geometry (fig.1)
- Using the design geometry the track reconstruction could assign a curvature and consequently give a wrong momentum estimate (fig.2)
- After alignment the track is re-fitted with the new geometry (near to the real one) and a correct measurement of the momentum is performed (fig.3)

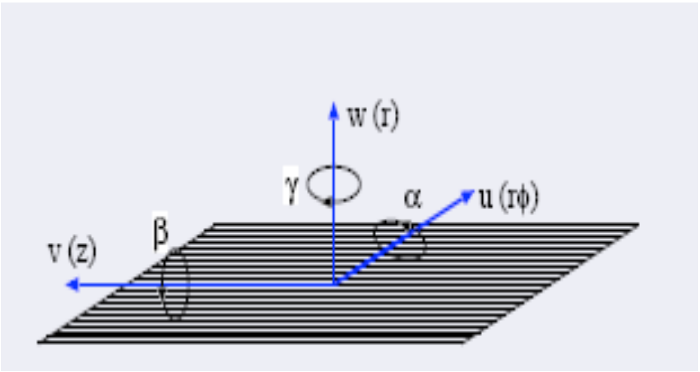
Track-based alignment

- Different kind of tracks (cosmic ray μ, μ from Z and W decay, etc..)
- Positions measured by hit strips (u_k^{hit}) and positions extrapolated from the reconstructed trajectory (u_k^{fit}) are sistematically shifted
- Residual *r* : $\vec{r}_k = \vec{u}_k^{\,hit} - \vec{u}_k^{\,fit} = \vec{u}_k^{\,hit} - \mathrm{P} \cdot \vec{x}_k$, where *x* are local modules coordinates

after alignment



local modules coordinates



P (Δu, Δv, Δw, α, β, γ)

- Final aim of track-based alignment is to minimize the track-residuals
- 6 d.o.f. x 15k modules = O(100k) unknowns

Track-based alignment algorithms

- A track-based alignment algorithm is aimed at minimizing a global χ^2 function, determining the *alignment parameters* :

$$\boxed{\chi^2 = \sum_k^{hits} r_k^T(p,q) V_k^{-1} r_k(p,q)}$$

$$\boxed{r_k = u_k^{hit} - u_k^{fit}(p,q)}$$

V = covariance matrix from fit

p = alignment parameters

q = track parameters

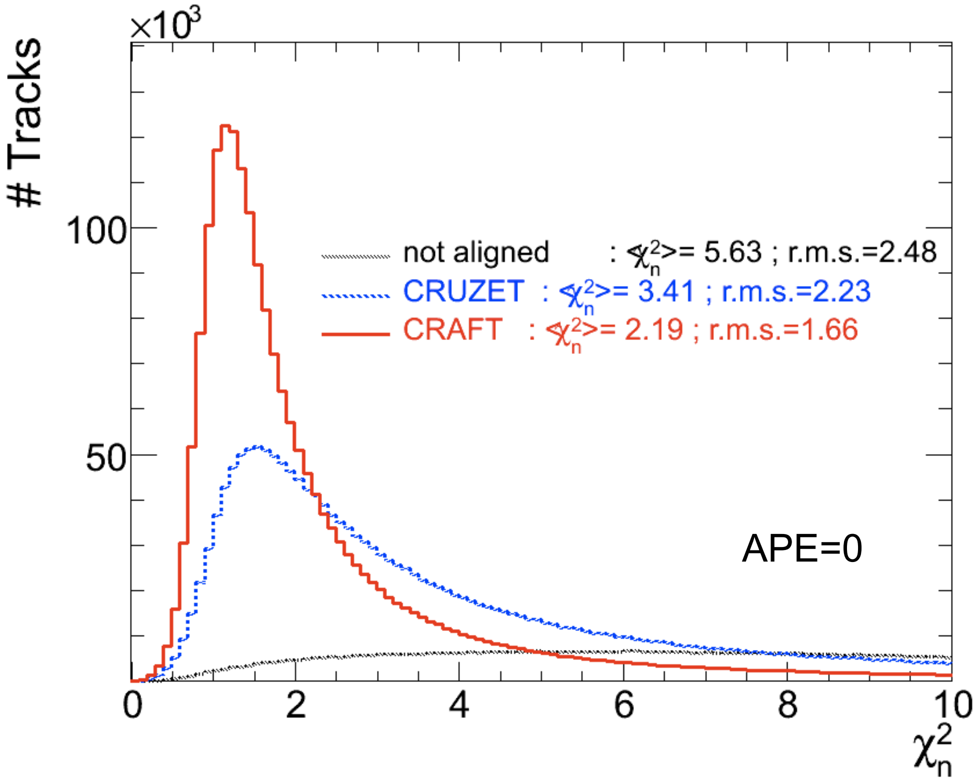
r_k = residual depending from *p* and *q*

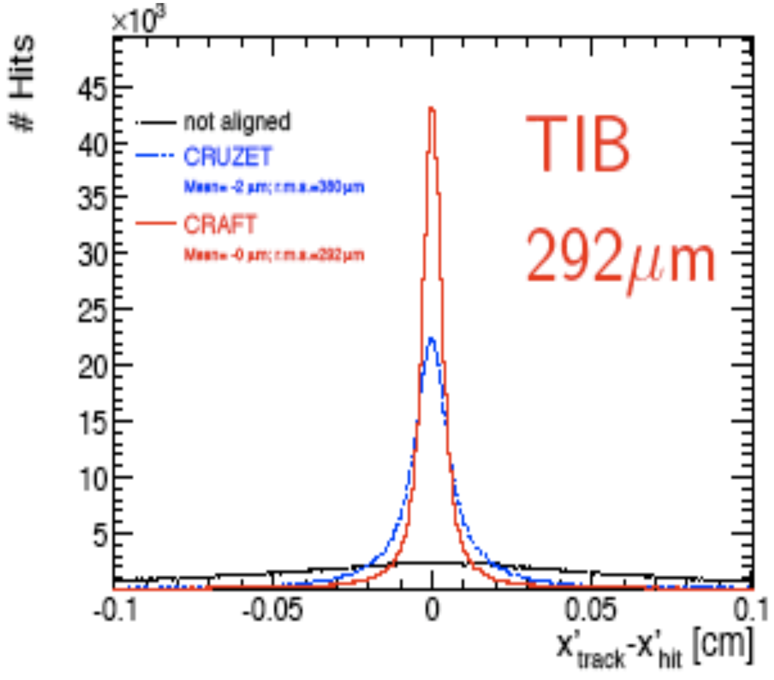
- A complex system of equations to solve
- Three alignment algorithms available in CMS software:
  - ✓ HIP (Hits and Impact Points) (Helsinki) - Iterative procedure: local analytical χ^2 equation for *p* only.
  - ✓ MillePede II (Hamburg) - Global solution of the χ^2 equation for *p* and *q* : all correlations considered.
  - ✓ Kalman Filter (Wien) - Sequential method updating alignment parameters after every track.
- I was focused on the track-based alignment with MillePede algorithm

Status of alignment

Results from CRAFT

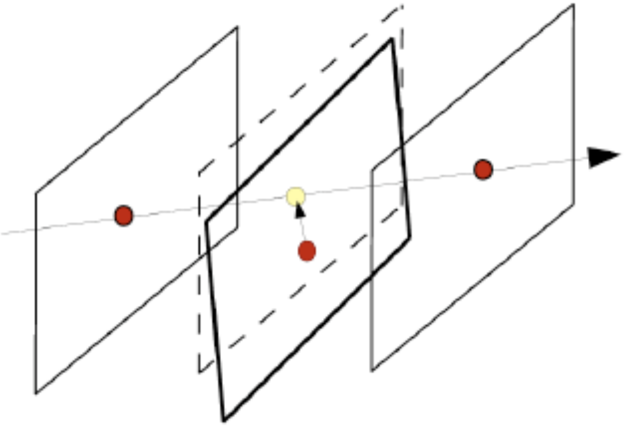
- Dataset for alignment : 3.9 M evts for CRAFT (400k evts for CRuZeT)
- Goodness of a track given by χ^2 distribution: overall improvement
- Improvement between CRUZET and CRAFT: the B field allows to measure the particle momentum and better estimation of MS
- First pixel module alignment performed (3% tracks in PXB, 1.5 % in PXF)

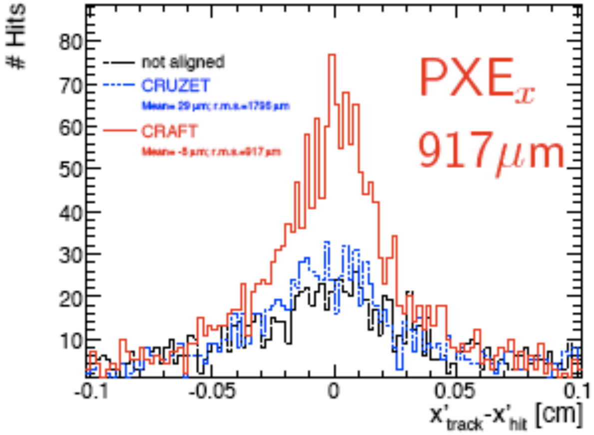


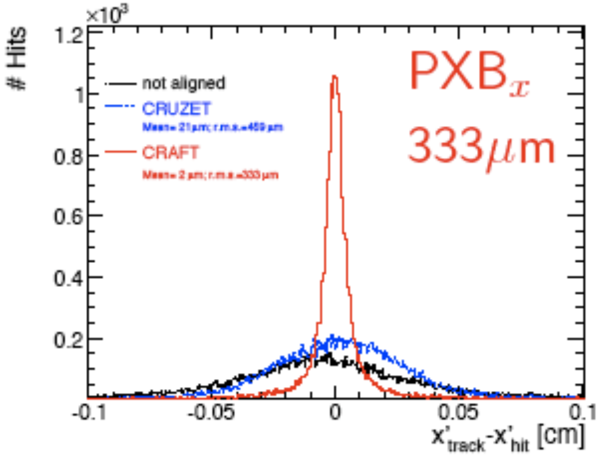


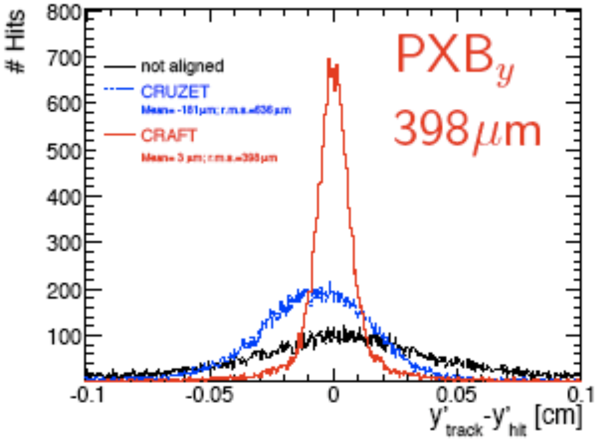
Residuals in Pixels

- Residuals ⇐ multiple scattering + hit errors + alignment errors
  (random) (random) (systematic)





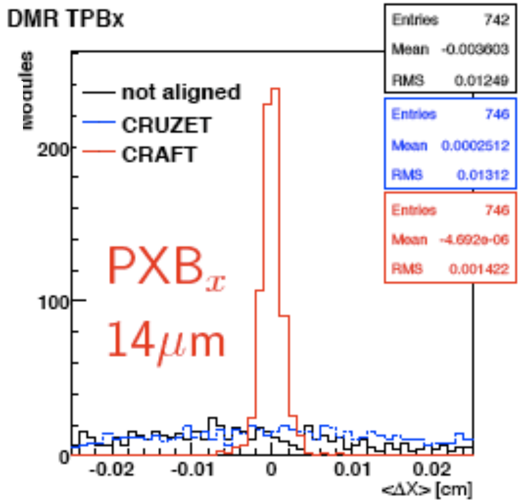


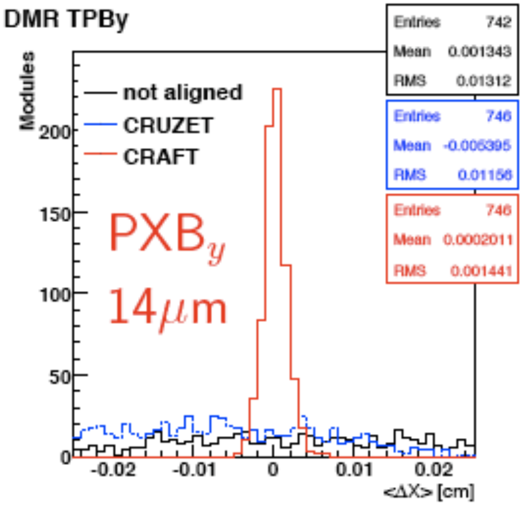


Estimation of remaining misalignment

- "DMR' (Distribution of the Median of the Residuals)
  multiple scattering + hit errors decoupling
  - illustrate alignment errors, no systematics
  - reproduces MC misalignment
  - but only sensitive coordinate
  - averaged over illuminated modules

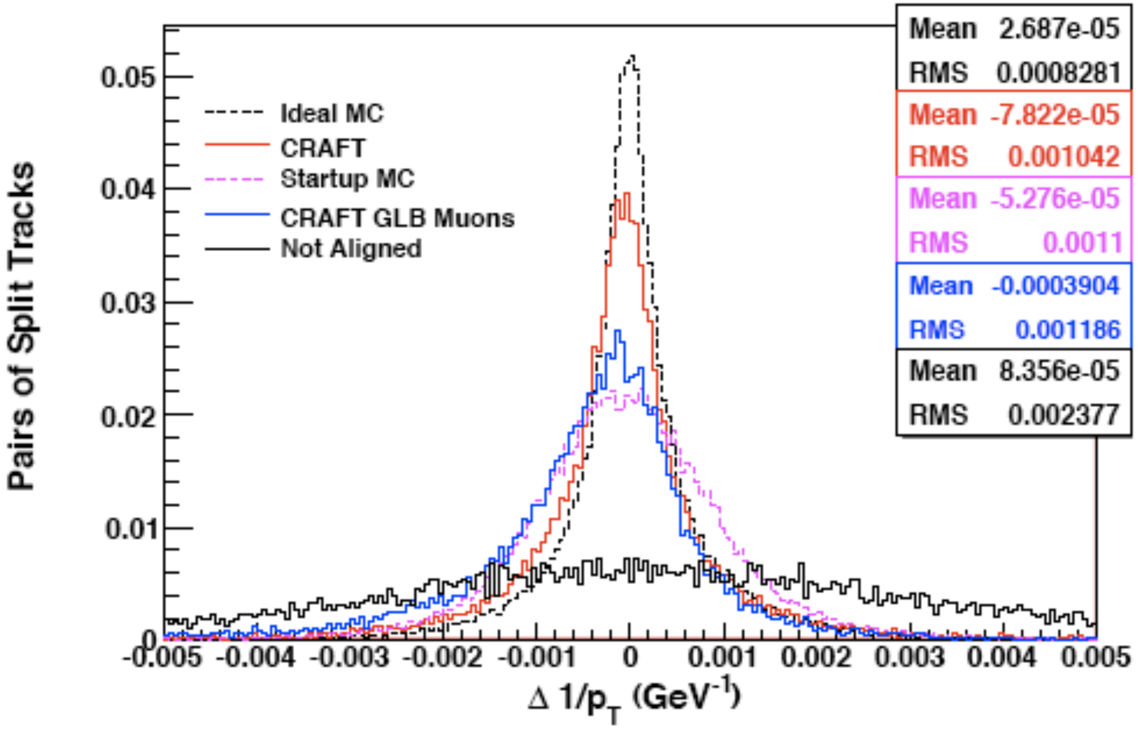
DMR (rms/μm)	not aligned	CRUZET μm	CRAFT μm	APE μm	modules >30 hits
PXB (x)	125	131	14	200	746/768
PXB (y)	134	115	14	200	–
PXE (x)	133	134	$(41)_{\text{not db}}$	1000	416/672
PXE (y)	104	99	$(39)_{\text{not db}}$	1000	–
TIB	144	44	10	100	2619/2724
TOB	111	44	10	100	5129/5208
TID	113	84	22	300	806/816
TEC	119	70	30	300	6198/6400

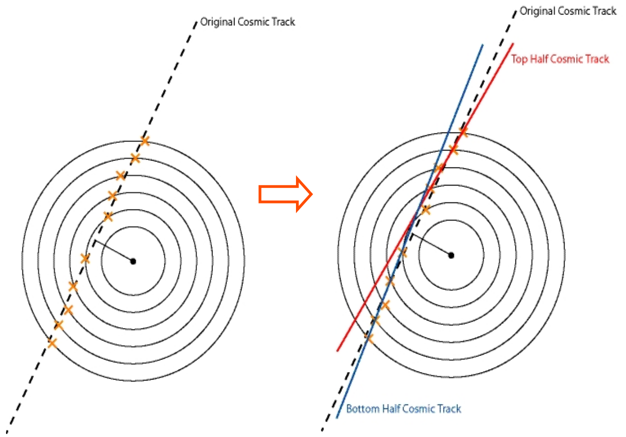




Impact of the alignment on the 'physics'

- tracks spitted in two halves (top and bottom leg)
- Differences $\Delta 1/p_T$ between two legs plotted (rms taken as $\sigma 1/p_T$)



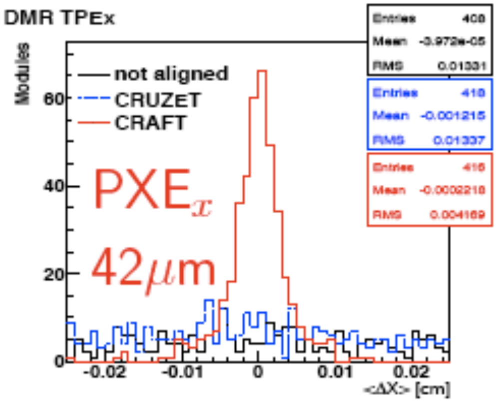


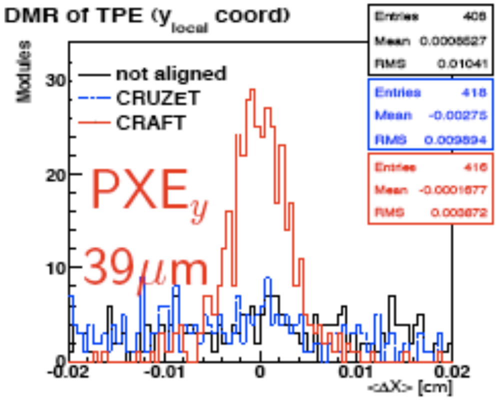
- p> 5 GeV
- # hits >9 (2 hits in PXB)
- PCA of original track inside pixel volume

- CRAFT alignment close to 100 pb^{-1} scenario in the Strips and 10 pb^{-1} scenario in the Pixel!!

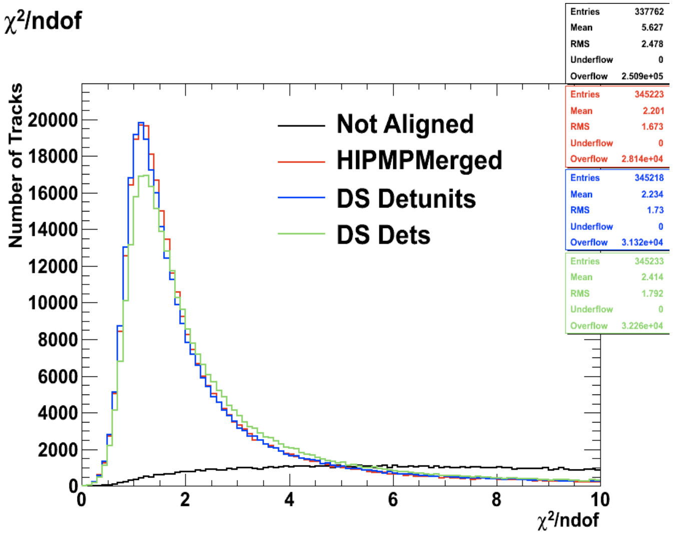
Most recent activities/improvements

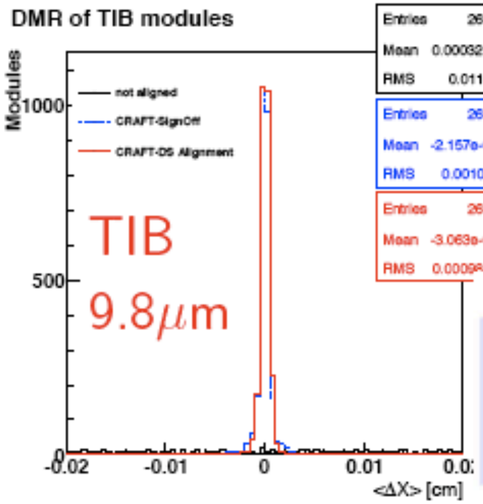
- Module alignment of Pixel Endcap: ~40μm precision



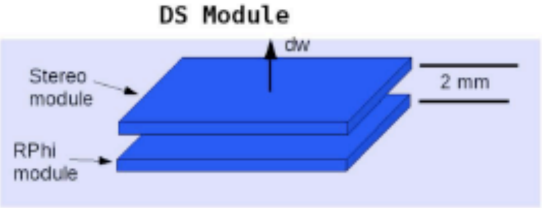


- Alignment of two sides of Double-Sided strip modules (u, w, γ)



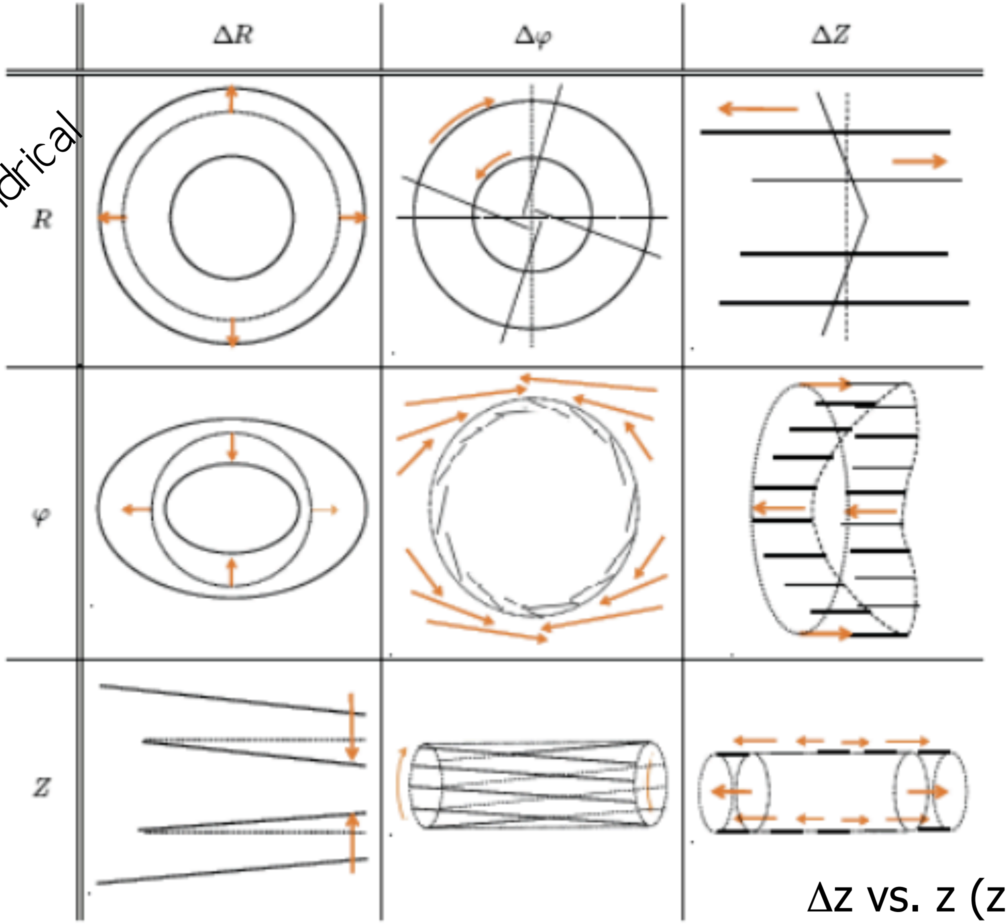


No more un-physical shifts: local 'u' aligned separately for Stereo and R-Phi component



Study of the systematic misaligment

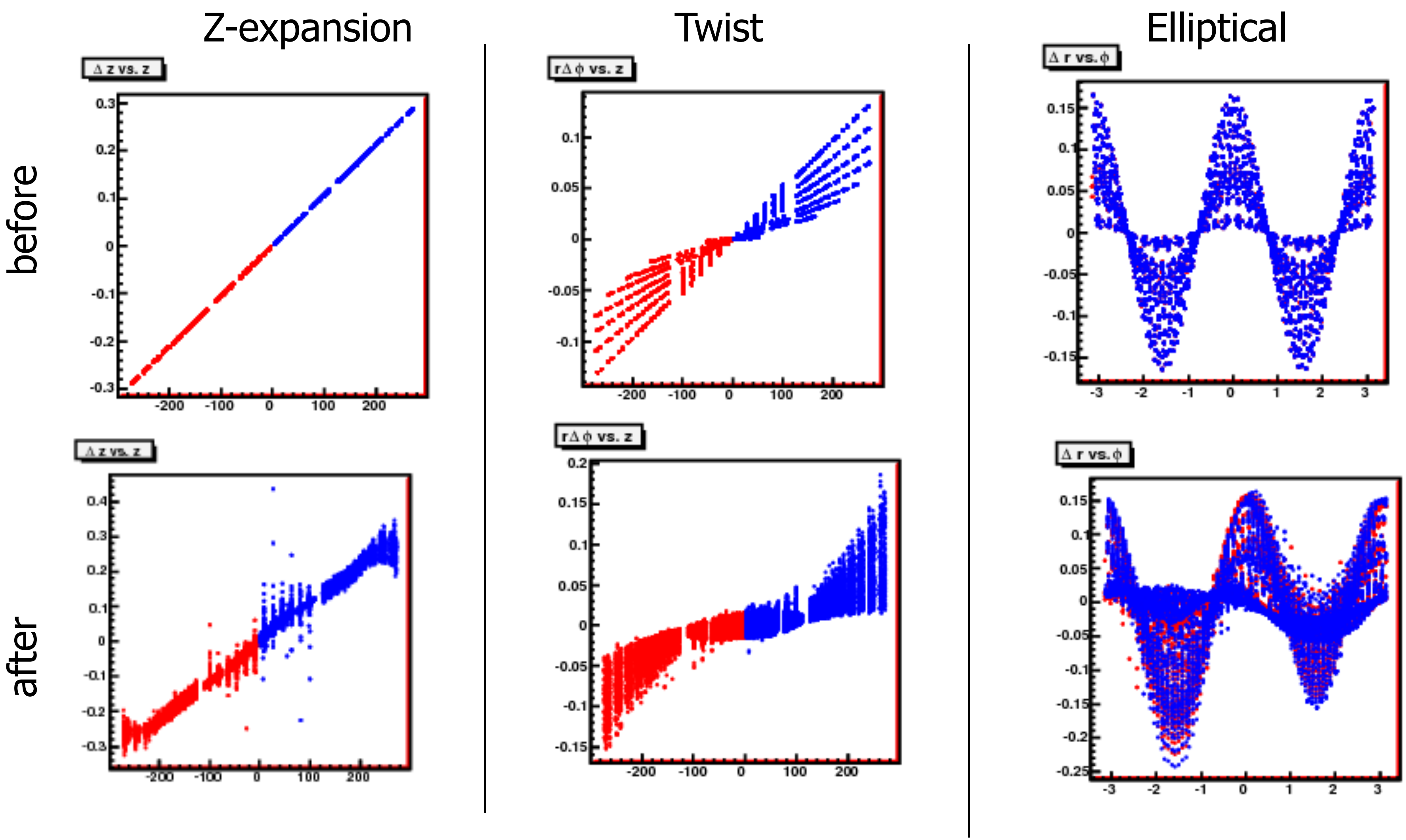
- Investigation of possible ‘weak modes’
- Weak mode = composite geometrical distorsion: track Chi2 not sensible!



9 distorsions for a cylindrical geometry

Δz vs. z (z-expansion)

Geometrical effects



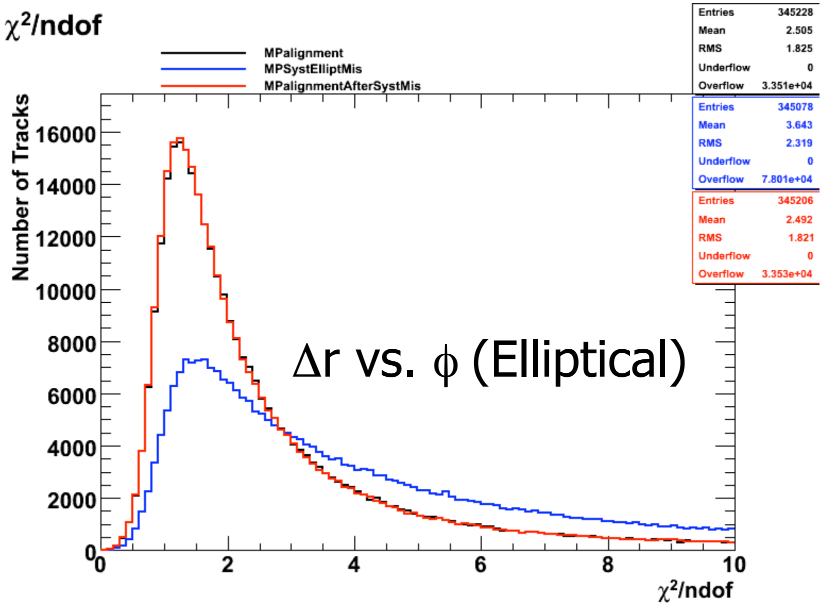
Effects on Track Chi2

- ❑ Validation over 350k tracks

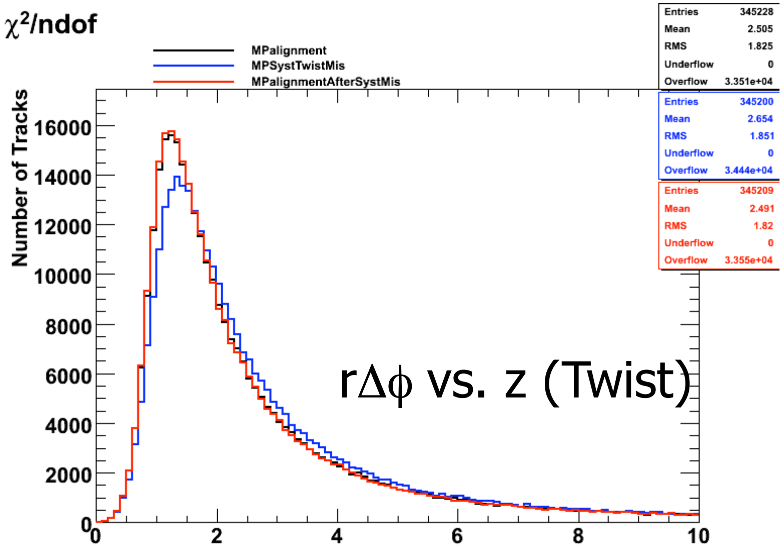
Black= MP starting object

Blue= misaligned

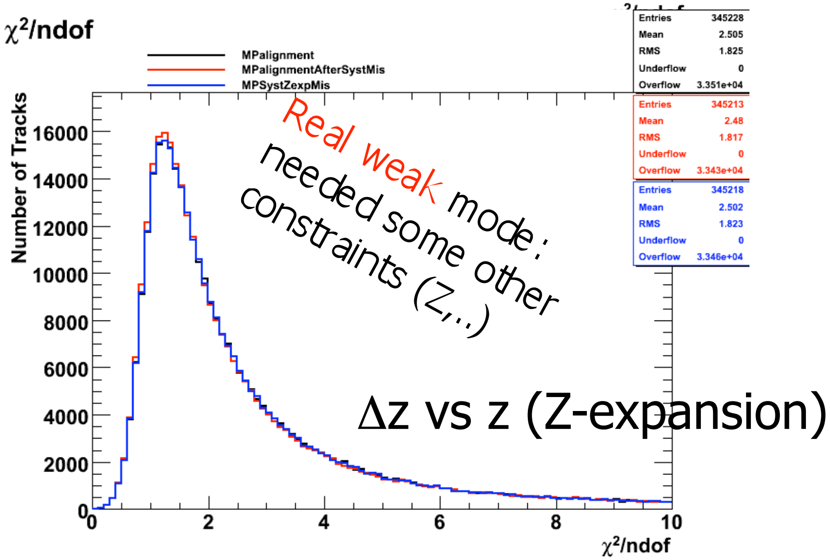
red= aligned on top of misalignment



Δr vs. ϕ (Elliptical)



$r\Delta\phi$ vs. z (Twist)



Real weak mode: needed some other constraints (Z,..)

Δz vs z (Z-expansion)

Impact of the Tracker alignment on physics performances

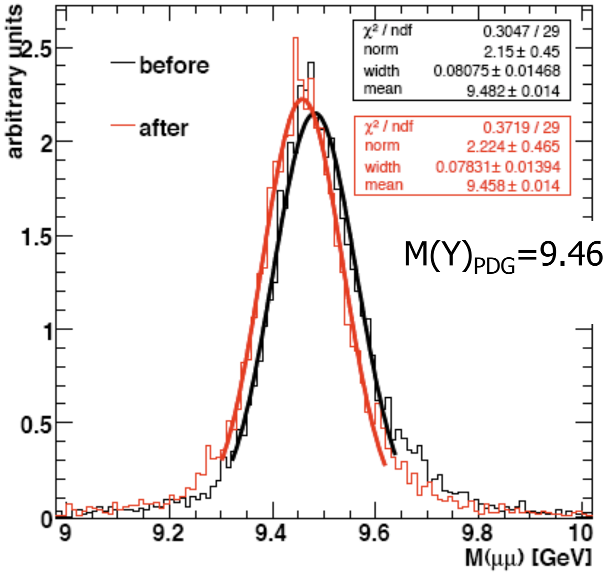
Calibration of muon momentum scale

- The measurement of muon momentum is affected by:
  - ✓ Tracker misalignment
  - ✓ Muon system misalignment
  - ✓ B field distortions
  - ✓ interaction with material
- Well known resonances (J/ψ, Y, Z) used to correct the muon momentum scale

- $p_T \approx 1.5 \div 30$ GeV (J/ψ and Y)
- $p_T \approx 30 \div 60$ GeV (Z)

Peak position: scale

Resonance shape: resolution



$M(Y)_{PDG}$=9.460 GeV

- Goals:
  - ✓ release a function of the muon kinematics to calibrate the muon momentum scale in order to center the peak

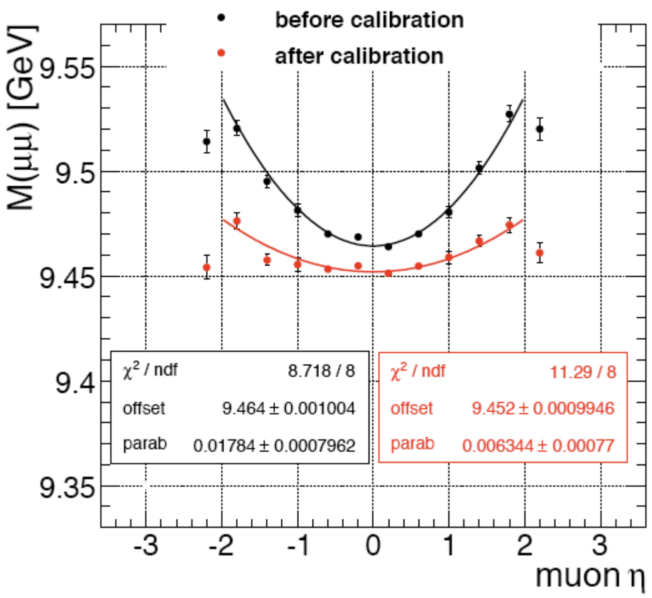
Existing tool

- ❑ Resonances mass (Z, J/ψ,Υ) as a function of all the possible muon kinematic variables (η, ϕ, p_t, charge)

$$F(c_i, M') = Lorentz(M_{ref}, \Gamma, M) \times Gaussian(\mu, \sigma, M - M') + background(c_i; M')$$

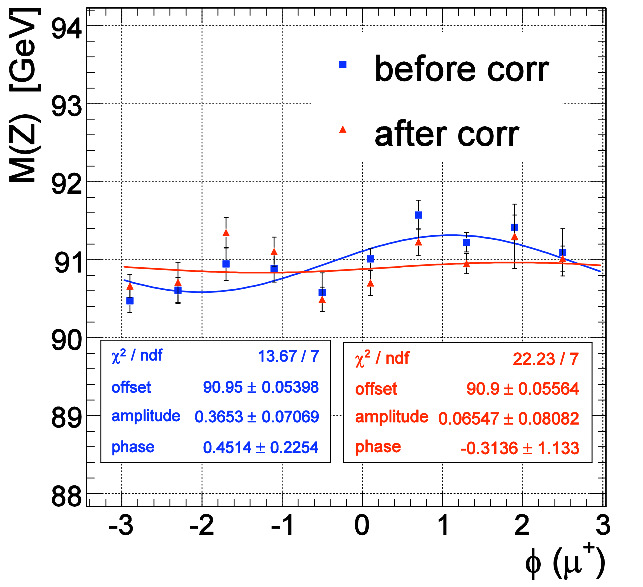
- ❑ Ansatz functions: scale $p_t' = F(a_j; p_t, \eta, \phi, q) \times p_t \rightarrow M'(p'_{t1}, p'_{t2})$
  resolution $\sigma_\eta, \sigma_\phi, \sigma_{pt} = G_i(b_j; p_t, \eta, \phi)$

- ❑ Multivariate likelihood approach
- ❑ Use resonance data to compute likelihood, mimize, and determine parameters a_j, b_j, c_j



Impact of the Tracker misalignment

- Effects produced by Tracker misalignment (with the precision expected after 10 pb^{-1}) on the Z boson invariant mass



TO DO:

*Refit tracks instead of re-reco

*Apply standard misalignment

*Apply alignment constants from CRAFT

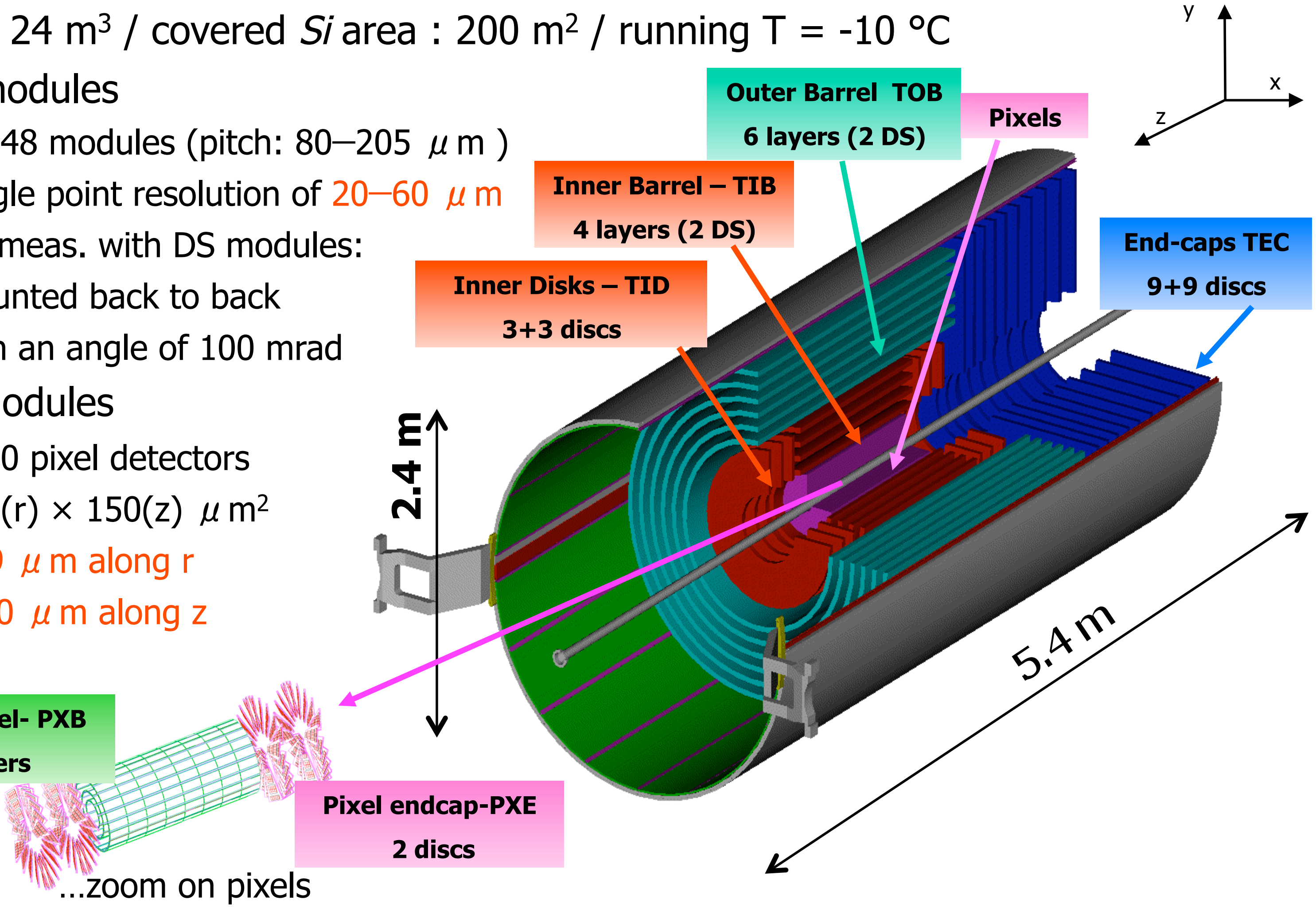
*Evaluate the impact of systematic misalignments

- Calculated systematics on Z cross section:
  - ✓ **3.5 %** before corrections
  - ✓ **0.9 %** after corrections

BACKUP slides

The CMS silicon Tracker

- World's largest silicon tracking detector
- Volume: 24 m^3 / covered *Si* area : 200 m^2 / running T = -10 °C
- STRIP modules
  - ✓ 15148 modules (pitch: 80–205 μm)
  - ✓ Single point resolution of 20–60 μm
  - ✓ 2D meas. with DS modules: mounted back to back with an angle of 100 mrad
- PIXEL modules
  - ✓ 1440 pixel detectors
  - ✓ 100(r) × 150(z) μm^2
  - ✓ σ = 9 μm along r
  - ✓ σ = 20 μm along z



…zoom on pixels

MillePede alignment algorithm

- V. Blobel (University of Hamburg)
- χ^2 function mimisation taking into acount *track* and *alignment* parameters
- The global χ^2 function can be expressed as the sum of local contribution

$$\boxed{\chi^2(p,q) = \sum_{j}^{tracks} \chi_j^2(p,q_j)}$$

- The local χ^2_j can be written in terms of residuals between measured hit position (y_i) and the corrisponding prediction of the track model, $f_i(p,q_j)$

$$\boxed{\chi_j^2(p,q_j) = \sum_{i}^{hits} \frac{(y_i - f_i(p,q_j))}{\sigma_i^2}}$$

- Given reasonable start values p_0 and q_{j0} as expected in alignment, the track model $f_i(p,q_j)$ can be linearised

$$\boxed{\chi_j^2(p,q_j) \approx \sum_{i}^{hits} \frac{\left(y_i - f_i(p_0,q_{j0}) + \frac{\partial f_i}{\partial p} a + \frac{\partial f_i}{\partial q_j} \Delta q_j \right)^2}{\sigma_i^2}}$$

- Minimization leads to the matrix equation $Ca = b$ where *C* is built from the derivatives and the vector *b* from derivatives and residuals
- Alignment parameters *a* are determined