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CMS
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Universität Hamburg

A Global CMS-Tracker Alignment Strategy

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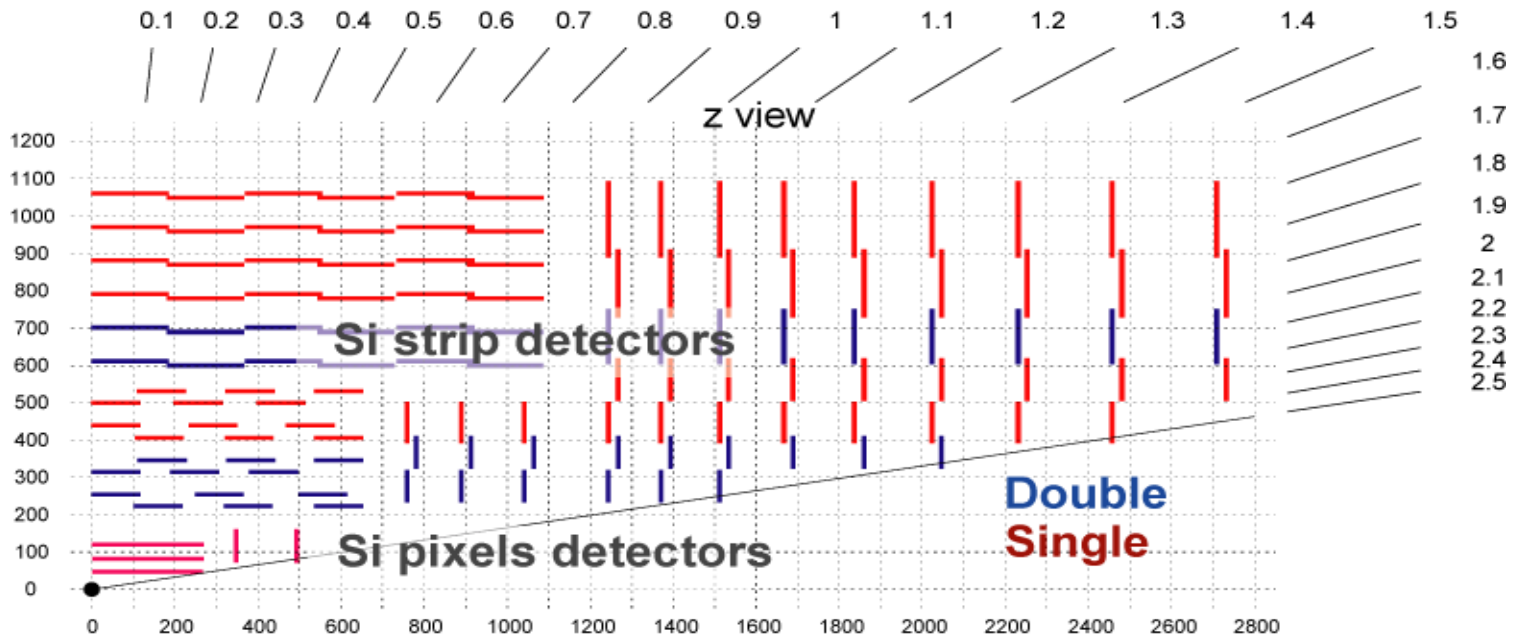
The Alignment Challenge



The layout of the CMS inner tracker

The unique size of the CMS Tracker leads to a unique alignment challenge.

- ~ 50k alignment parameters (3 for 1D, 4 for 2D modules).
- Total size ~18 m^3.
- High resolution $\rightarrow$ high alignment precision demands.
- Golden channel ee$\rightarrow\mu\mu$ missing.

Previous strategies and algorithms cannot be easily adopted.

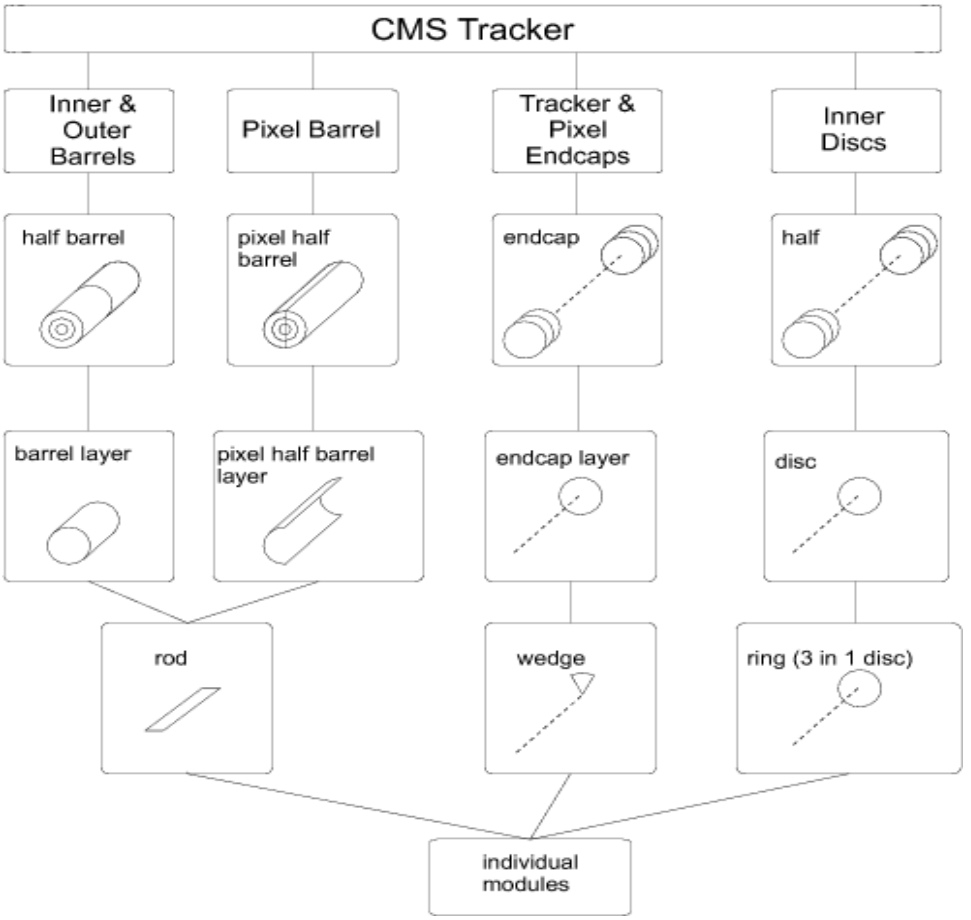
Misalignment Simulation

Two default scenarios for the Tracker have been defined (CMSAN 2005/036).

First data scenario:
- Survey and mechanical precision.
- Laser alignment
- Misalignment of tracker modules 100µm – 500µm.
- First pixel barrel pre-alignment ~ 15µm.

Long term scenario:
- Luminosity > 1 fb^{-1}
- PTDR educated guess of alignment knowledge.

An alignment milestone:
- Establish alignment procedure and precisions for < 1 fb^{-1}.



The correlated nature of misalignment is taken into account in the misalignment simulation!

Generic Problem of Alignment

Track based alignment:

Concept: Track based alignment minimizes the average χ^2 of the track fits.

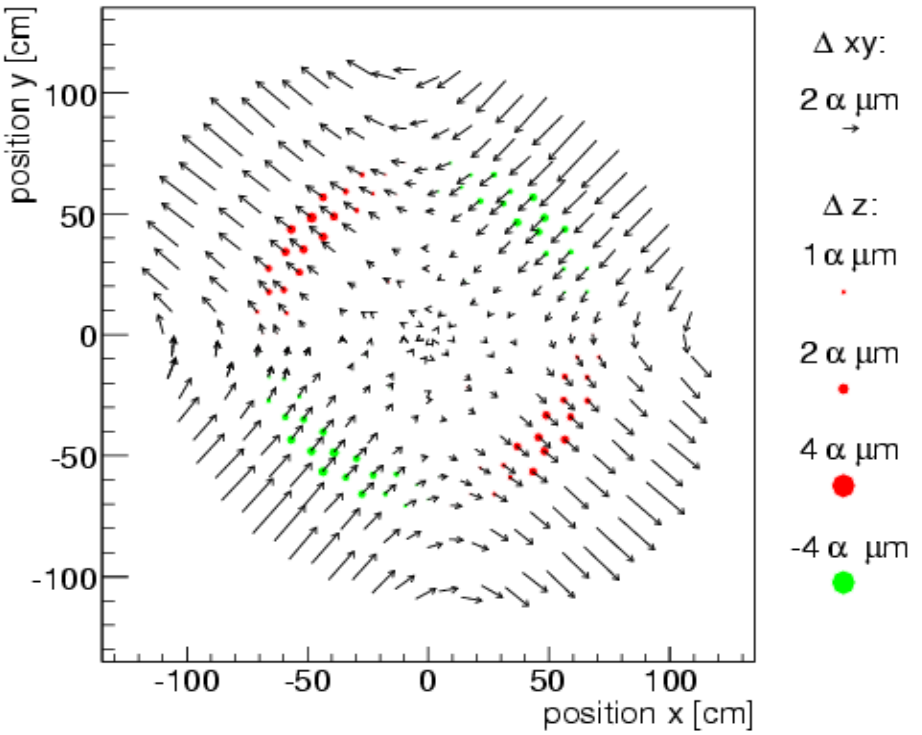
Problem: Some deformations of the tracker leave this χ^2 invariant.

- This is a generic problem independent of the used algorithm.
- These deformations dominate the remaining misalignment.

More sources of information required than only χ^2 of track fits!

Detailed studies have been performed to understand and classify χ^2 invariant deformations. (Alignment-meeting 23.1)
http://indico.cern.ch/conferenceDisplay.py?confId=10925

Illustration of χ^2 invariant deformations:



Sources of Information

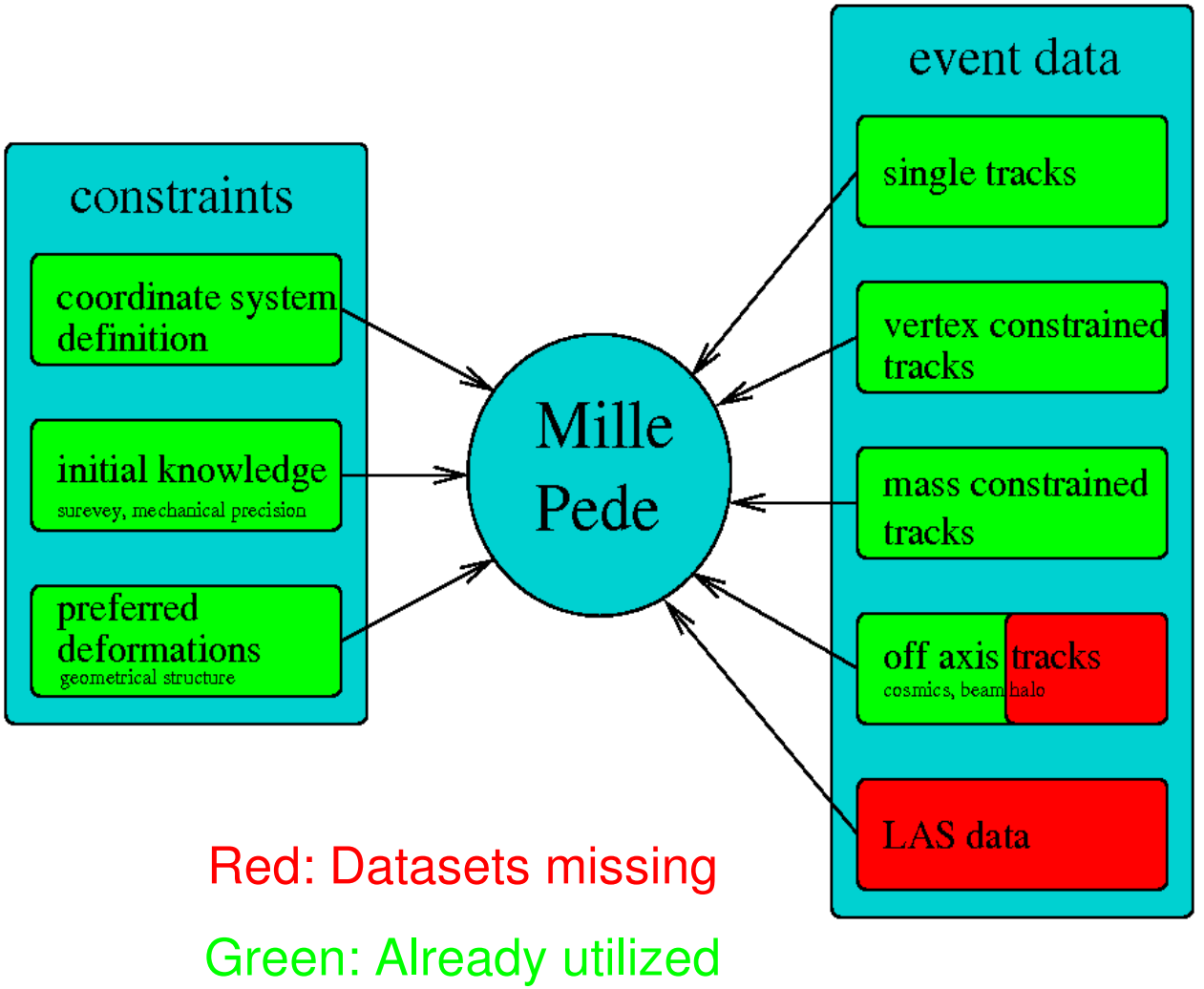
Prior Knowledge:

- Uncertainties of alignment parameters can be estimated from survey measurements and mechanical mounting precision.
- The geometry of supporting structures is known.

Complementary data sets:

- Data sets like cosmics and beam halo muons constrain deformations.
- Constraints on the trajectory fit like mass and vertex constraint.

Schematic illustration of input to Millepede



Red: Datasets missing

Green: Already utilized

Millepede Algorithm

The **average χ^2 of track fits** is dependent on **all alignment parameters and all track parameters**.

All track and alignment parameters are free parameters in the Millepede algorithm, only alignment parameters are determined:

No track parameters fixed -> no bias introduced!

All parameters free -> **All correlations between alignment parameters taken into account!**

Constraints and uncertainties on alignment parameters are implemented by standard methods (Lagrangian Multipliers, pre-sigma, measurements):

Prior knowledge is implemented!

Single pass though data sufficient (non-linearities are small):

Short turn around time!

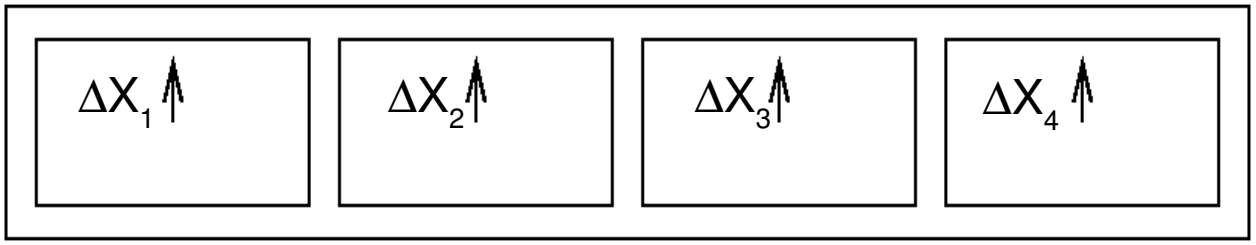
Simultaneous Alignment Strategy

Relative Alignment Parametrization:

Alignment parameters are defined with respect to the next supporting structure:

Example:
New parameter ΔX_C
Constraint $\Sigma \Delta x_i = 0$

$\sigma(\Delta X_c) > \sigma(\Delta x_i)$



- Allows to apply initial knowledge as it is typically known.
- Allows to **simultaneously** align hierarchies (modules, rod,layer)

Tracker and Pixel Alignment done simultaneously!

Single pass through data sufficient!

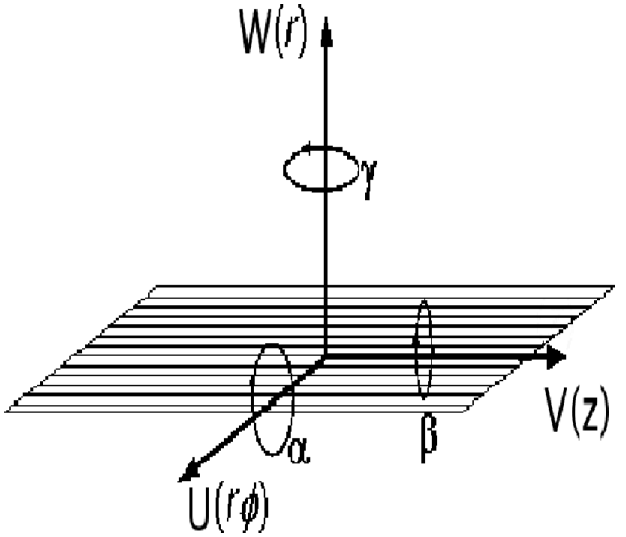
The Case Study

Misalignment:

Default first data scenario.

Data sets:

- 0.5 mio. Z (0.5 fb^{-1}) mass and vertex constraint
- 25 k cosmics with momentum > 50 GeV
- Single muons of 1.5 mio. Z ~ 3 mio W (0.5 fb^{-1}) events



Alignment:

- All silicon modules (PB,PE,TIB,TID,TOB,TEC)
- 3 (2 for 1D) translation and the rotation around normal of sensor.

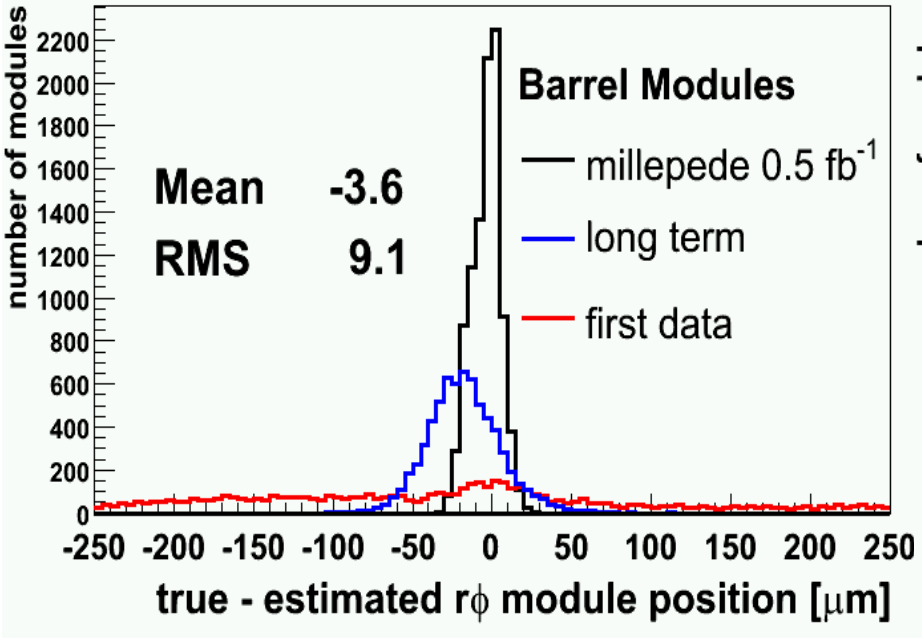
Coordinate Definition:

- Center of the pixel barrel sensors.

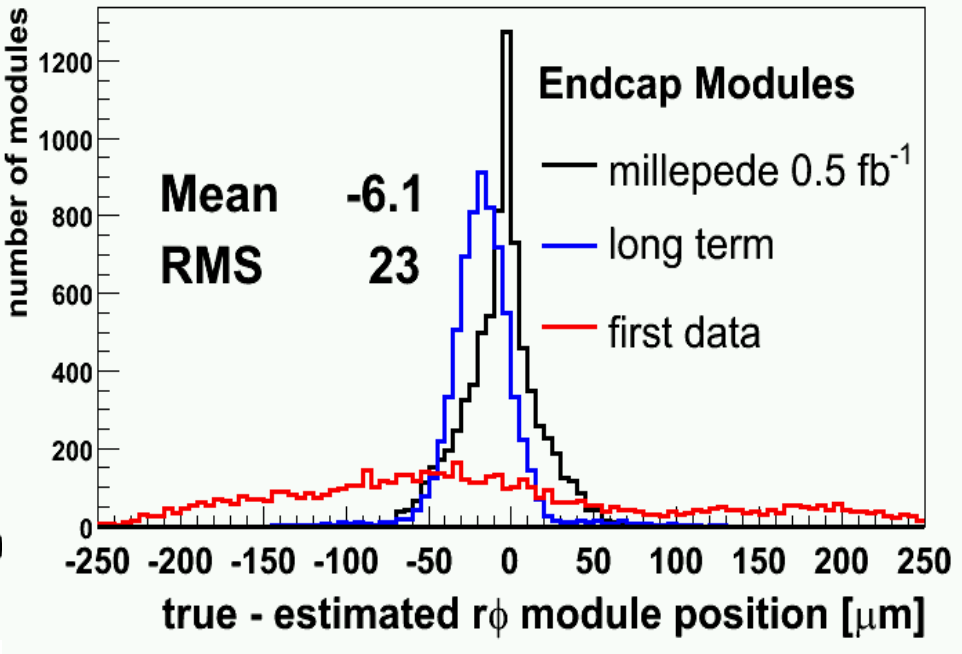
Results: Misalignment in rϕ

Cosmics and single muons of 2 mio. Z^0 events used.

PB,TIB,TOB



PE,TID,TEC



Barrel Modules RMS = 9 μm

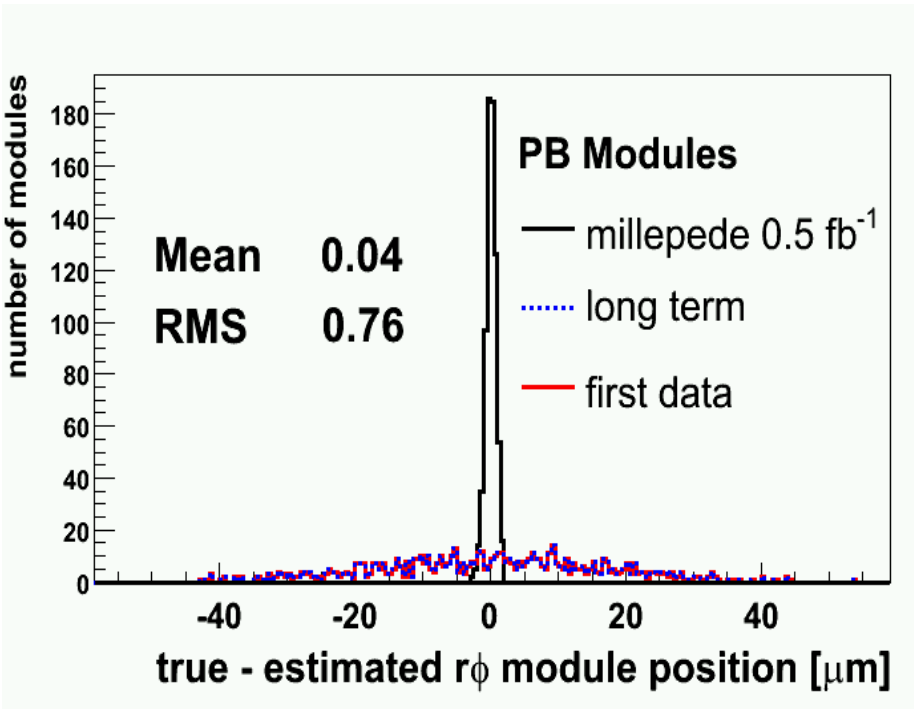
Pixel barrel alignment significantly better than in the long term scenario.

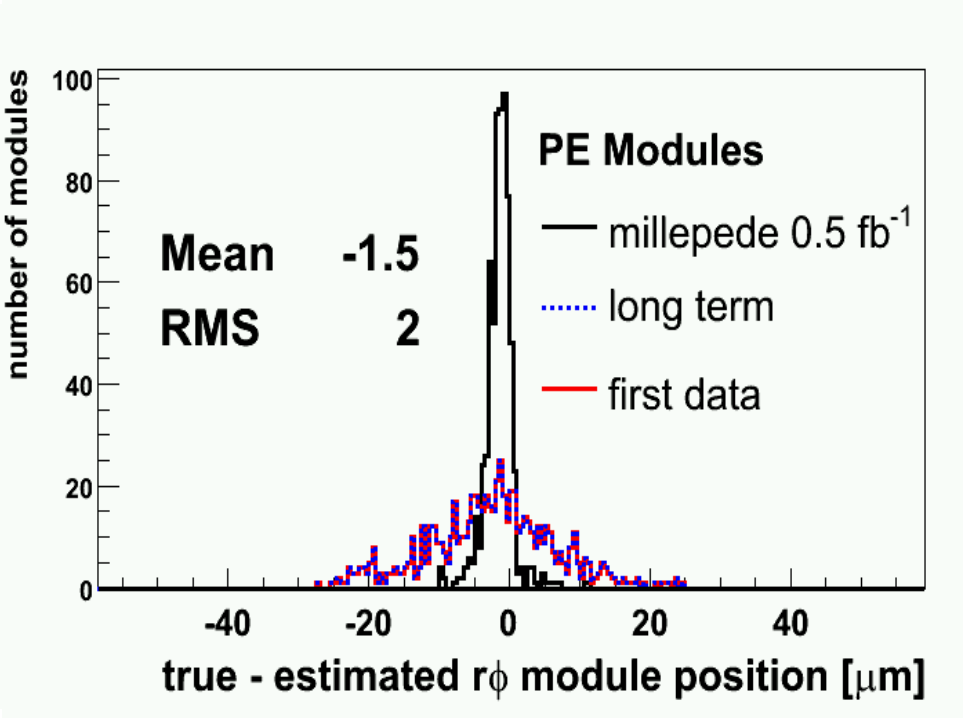
Endcap Modules RMS = 22 μm

The mean is better than the longterm scenario! The RMS is similar.

Milestone reached!

Results: Pixel Misalignment in rϕ





Pixel barrel RMS < 1 μm

Pixel barrel alignment an **order of magnitude** better than in the long term scenario.

Pixel endcap RMS = 2 μm

Better than long term scenario.
Further studies needed.

Pixel aligned to μm precision!

Computing Requirements

Millepede II developed by V. Blobel

Memory requirements:

More complementary datasets lead to denser matrices:

- Sparse Matrix Memory ≈ 12.5 GB x density.
- Full Matrix ≈ 8.3 GB memory

CPU Requirements:

Denser matrices increase CPU time if sparse matrix algorithms are used (GMRES).

Computing needs of the study:

- Data: cosmics, 500k mass constrained tracks, and single tracks
- Density 15%.
- CPU solving matrix equation: 10 minutes

Note: For outlier rejection 5 internal iteration in Millepede have been done!

Parameters: 50k
Memory: 2GB
CPU time total: 1:40

Hamburg resources: 64 Bit, 8GB

CPU and Memory needs modest!

Conclusion

A global alignment strategy shown has been and **tested:**

- Align the full strip and pixel tracker!
- Complementary data sets.
- Utilizing initial knowledge.
- Powerful Algorithm (Millepede II).

First time full alignment procedure tested in CMS!

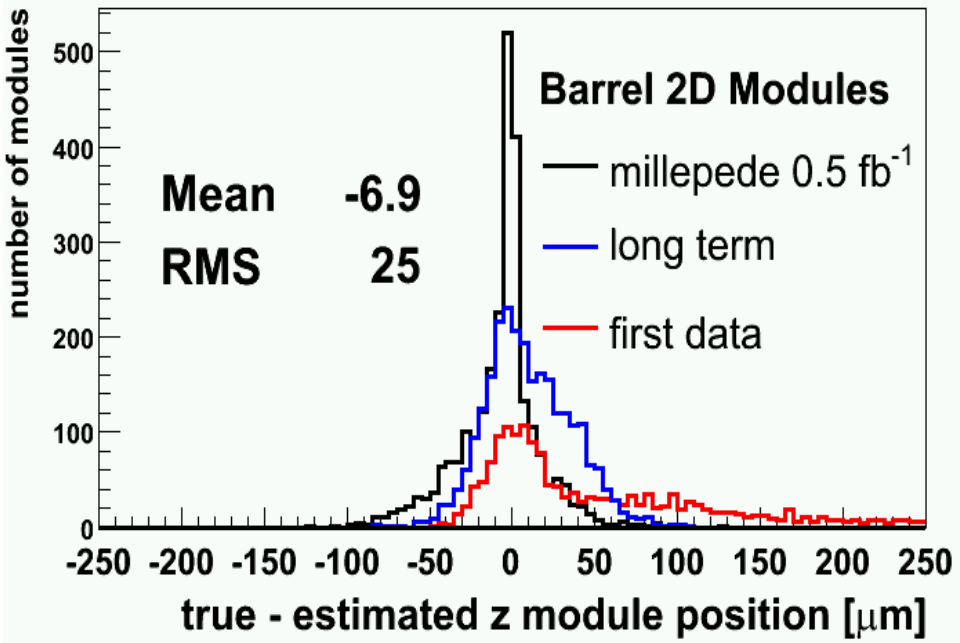
The alignment precision reached is better than the physics technical design report estimate!

Corresponds to milestone!

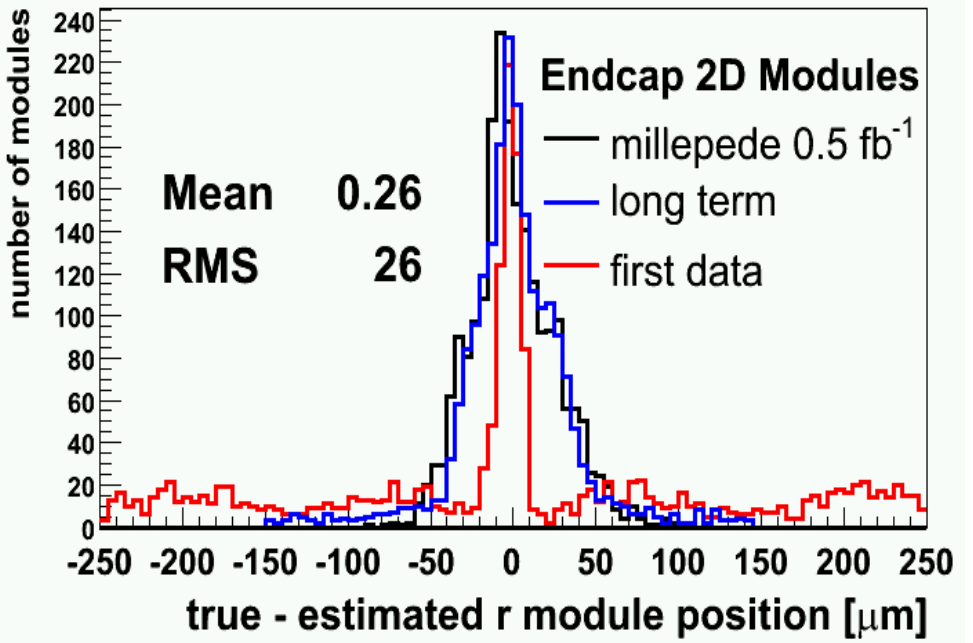
Framework for further studies build!

Backup: Misalignment in z and r

PB,TIB,TOB Δz:



PE,TID,TEC Δr:

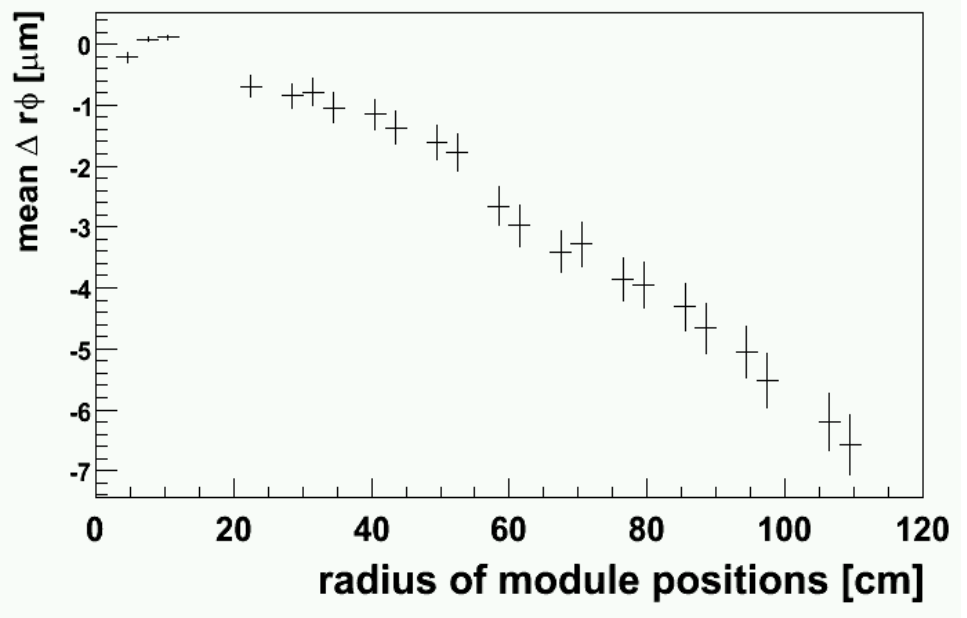


- **Remaining misalignment << resolution.**
- Also the second sensitive coordinates (barrel z, endcap r) similar or better aligned than in the long term scenario.

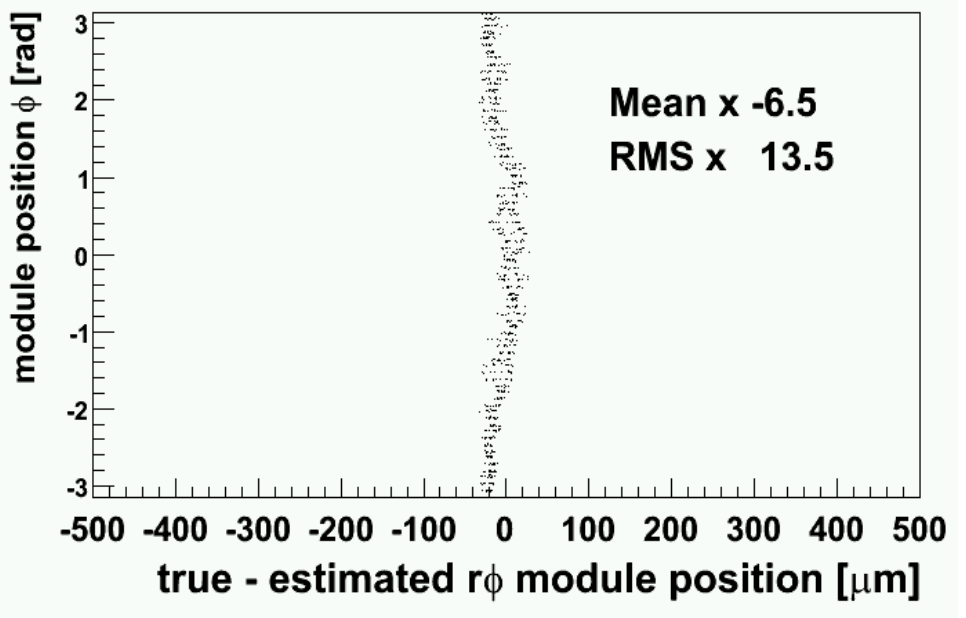
Promising results for all alignment parameters.

Results: Remaining Misalignment in rϕ

Mean Δrϕ of barrel modules vs. radius:



ϕ of last barrel layer modules vs. Δrϕ

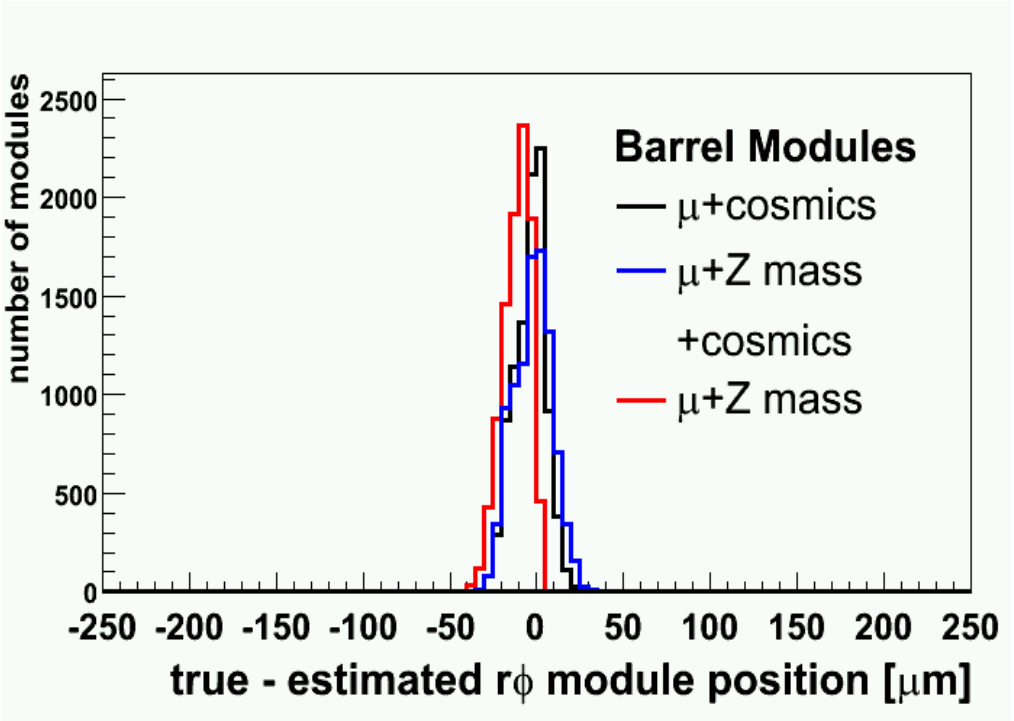


Remaining misalignment is dominated by global deformations:

- Bias in ϕ the order of μrad.
- Bias in Pt in the order of MeV at ~50 GeV

More cosmics, mass constrained track, beam halo ... will help!

Different Datasets



Data	Mean [μm]	RMS [μm]
μ + Z mass	-11.2	7.9
μ + cosmics	-3.6	9.1*
μ + Z mass + cosmics	-2	10.8*

* to be studied

The complementary datasets reduce global correlations:

- Mean displacements are reduced!

Exotic data sets like cosmics need special care:

- Hit reconstruction and hit error estimation for tracks with large inclination angles.
- Linearization effects for Z mass constraint.
- LAS and beam halo missing!

Further efforts needed (see new alignment milestones)

Cosmics are of vital importance to alignment!

Outlook

Alignment studies:

- Alignment with different statistics.

Alignment with real data:

- TIF alignment

Alignment Monitoring:

- Data based monitoring procedure

Production of new datasets:

- Beam halo, laser trajectories ...

Backup: Outlier Rejection

All tracks are refitted with the alignment parameters of the previous iteration for each internal iteration of Millepede.

Track rejection:

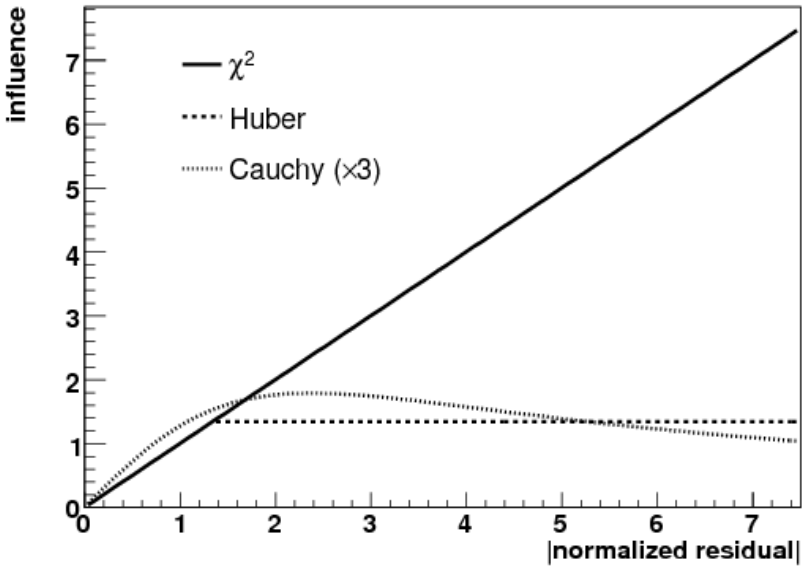
- Cut on the standard deviation of track fit.
- Cut tightened for each iteration.

Hit weighting:

- Single outlier hits down weighed.
- If average weight < 80%, the track is rejected.

Mixture of both used in presented study.

Influence vs. normalized residual:



Weight factor vs normalized residual: