Simultaneous alignment and Lorentz angle calibration in the CMS silicon tracker using Millepede II

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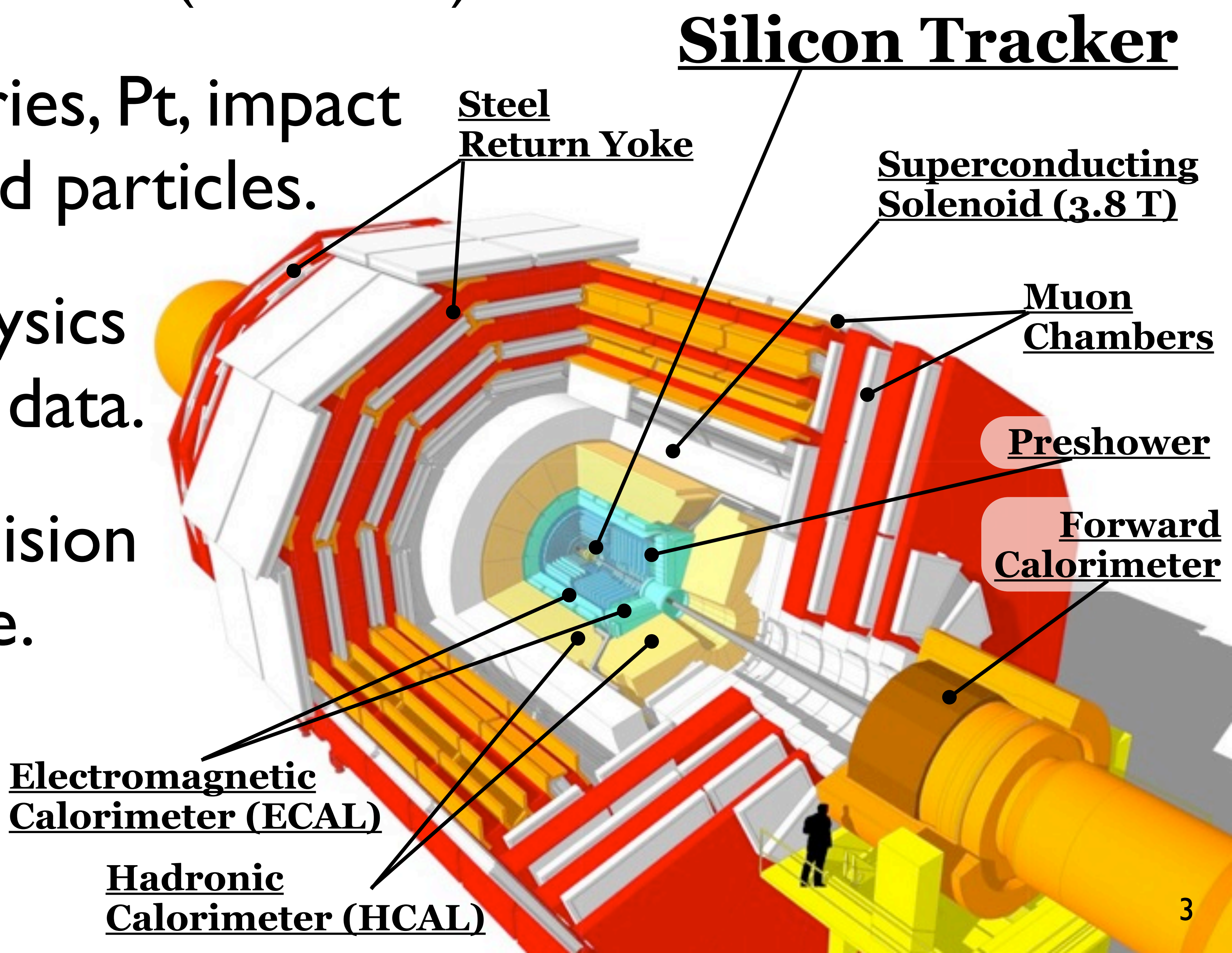
Outline

- Introduction of the CMS detector.
- Track-based alignment with Millepede II.
- Lorentz angle effect.
- Alignment and calibration procedure.
- Results of Lorentz angle calibration.

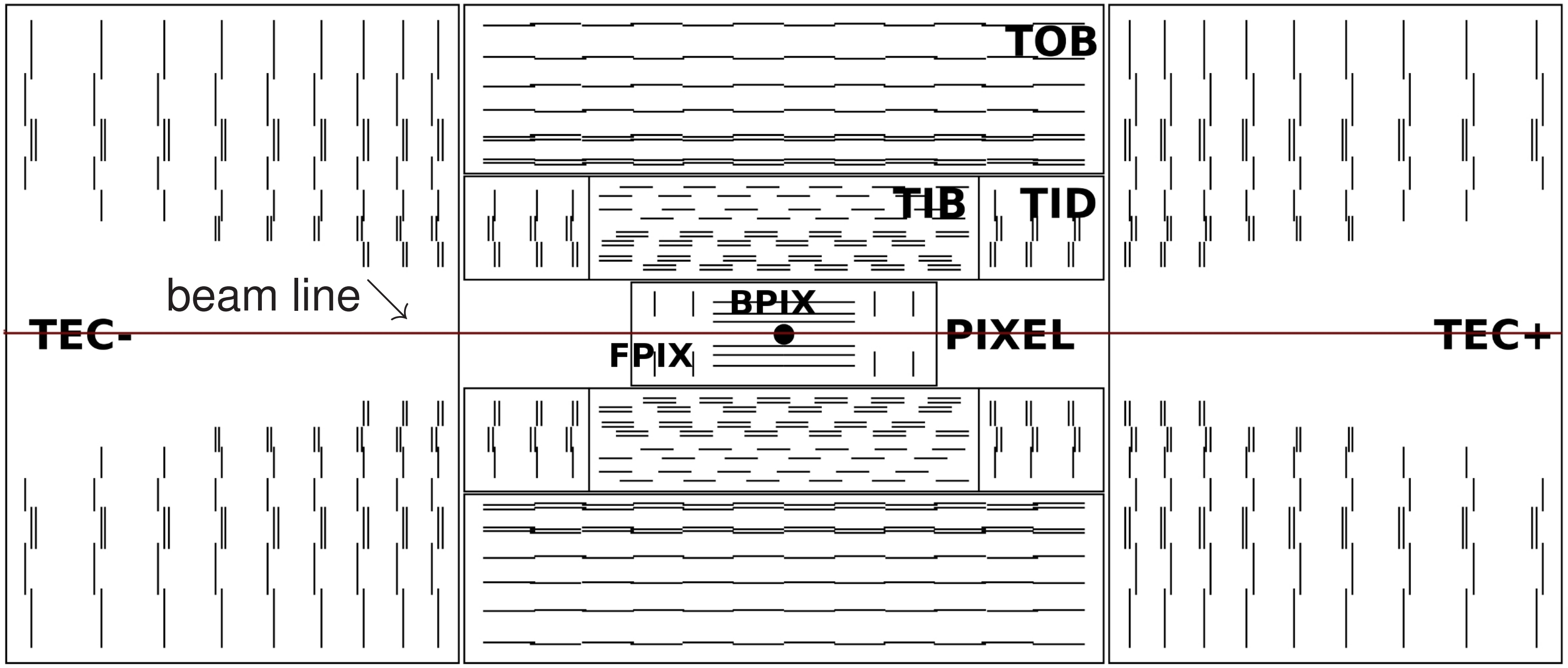
CMS detector

- CMS detector – one of 2 multipurpose detectors at LHC.
- Silicon tracker – innermost detector, enclosed in superconducting solenoid (B = 3.8T).
- Measures trajectories, Pt, impact parameter of charged particles.
- Almost all CMS physics analyses use tracker data.
- Measurement precision is of high importance.



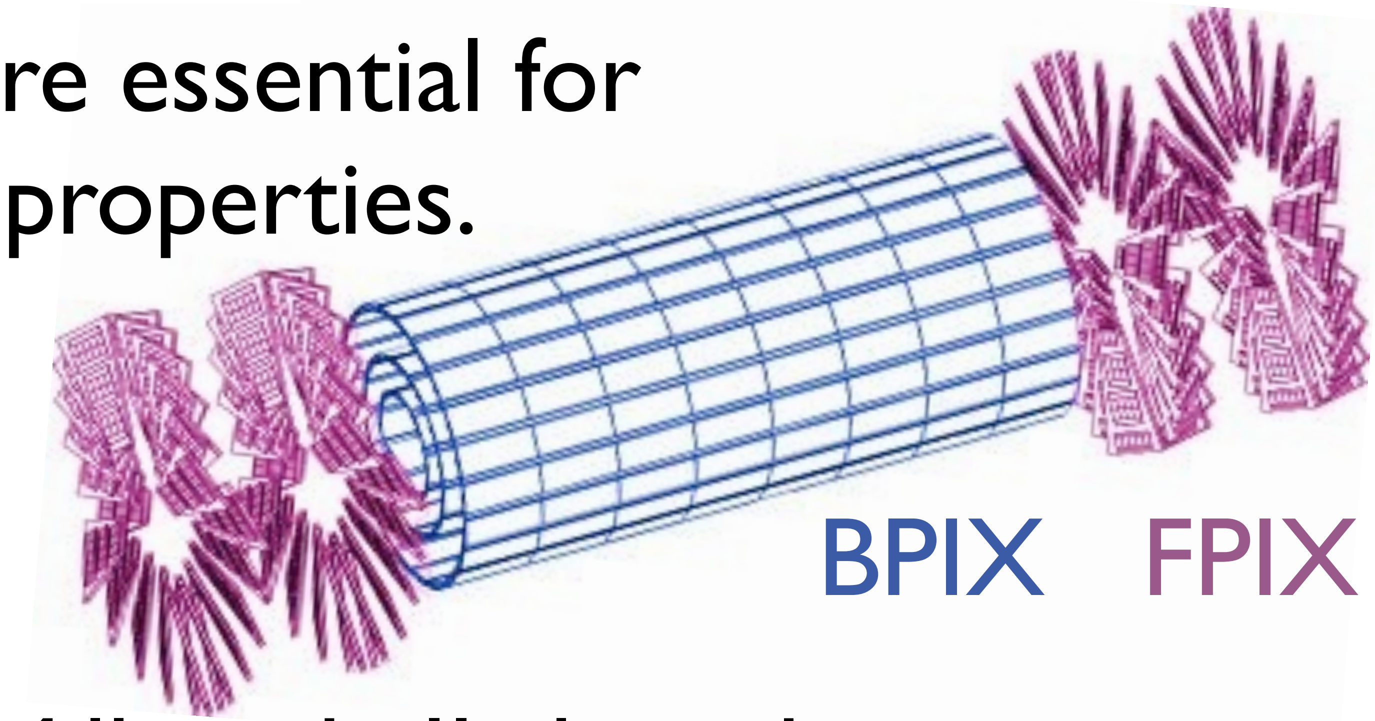
Total weight: 14 K T
Overall diameter: 15 m
Overall length: 28.7 m

Silicon tracker



	Strip (1D)	Pixel (2D)
modules	15118	1440
length	5.4 m	1.1 m
diameter	2.4 m	0.4 m
resolution	≥23 μm	≥9 μm

- Exact positions of modules are essential for precise measurement of track properties.



- Position and orientation of each individual sensor is derived from simultaneous alignment of all modules with Millepede II algorithm.

- Larger structures consisting of groups of modules are also aligned independently as single entities.

Track-based alignment with Millepede II

- Misalignment and miscalibration increase track residuals – distance between measured and predicted hit positions.

- Modules are aligned by minimizing residuals of the tracks.

Minimization function: $$\chi^2(\mathbf{p},\mathbf{q}) = \sum_j^{\text{tracks}} \sum_i^{\text{measurements}} \left(\frac{m_{ij} - f_{ij}(\mathbf{p},\mathbf{q}_j)}{\sigma_{ij}} \right)^2$$

m_{ij} – measured position of the hit;
f_{ij} – predicted position of the hit;
p – global parameters;
q_j – track parameters;

Matrix equation: $$\mathbf{C}'\Delta\mathbf{p} = \mathbf{b}'$$

p can be any parameter, sensitive to the hit position:

alignment parameters:
- module position;
- module orientation;
- sensor surface curvature;

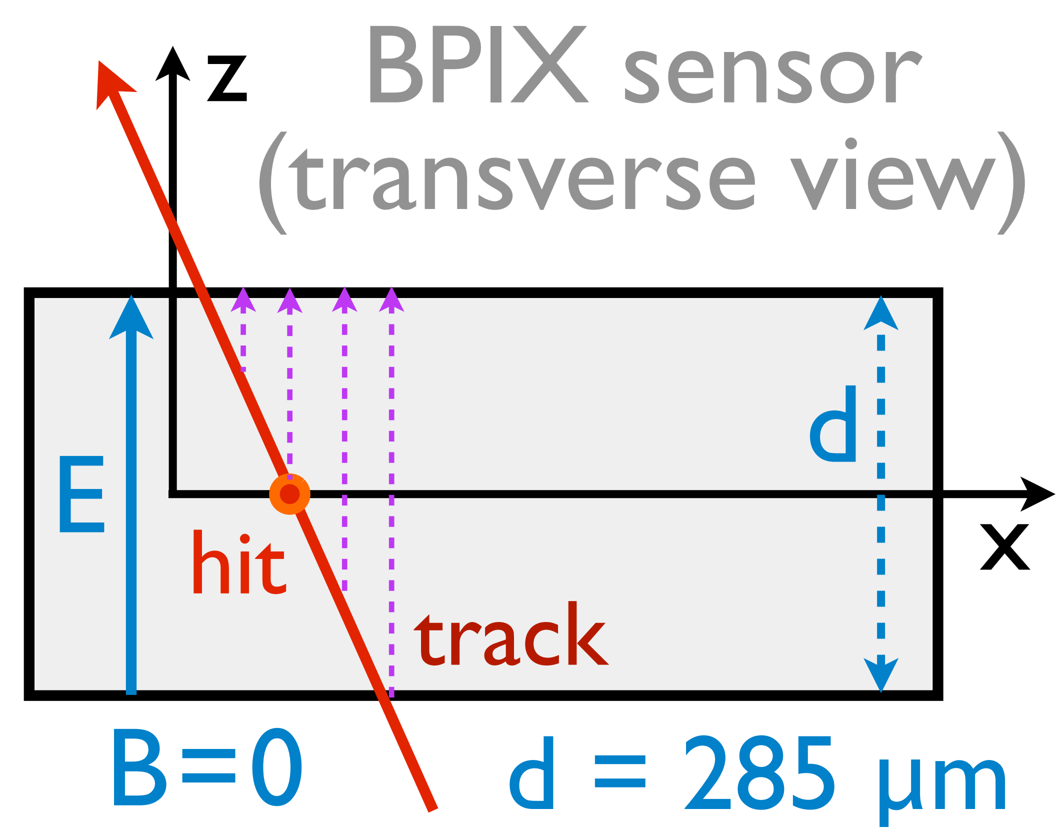
calibration parameters:
- Lorentz angle

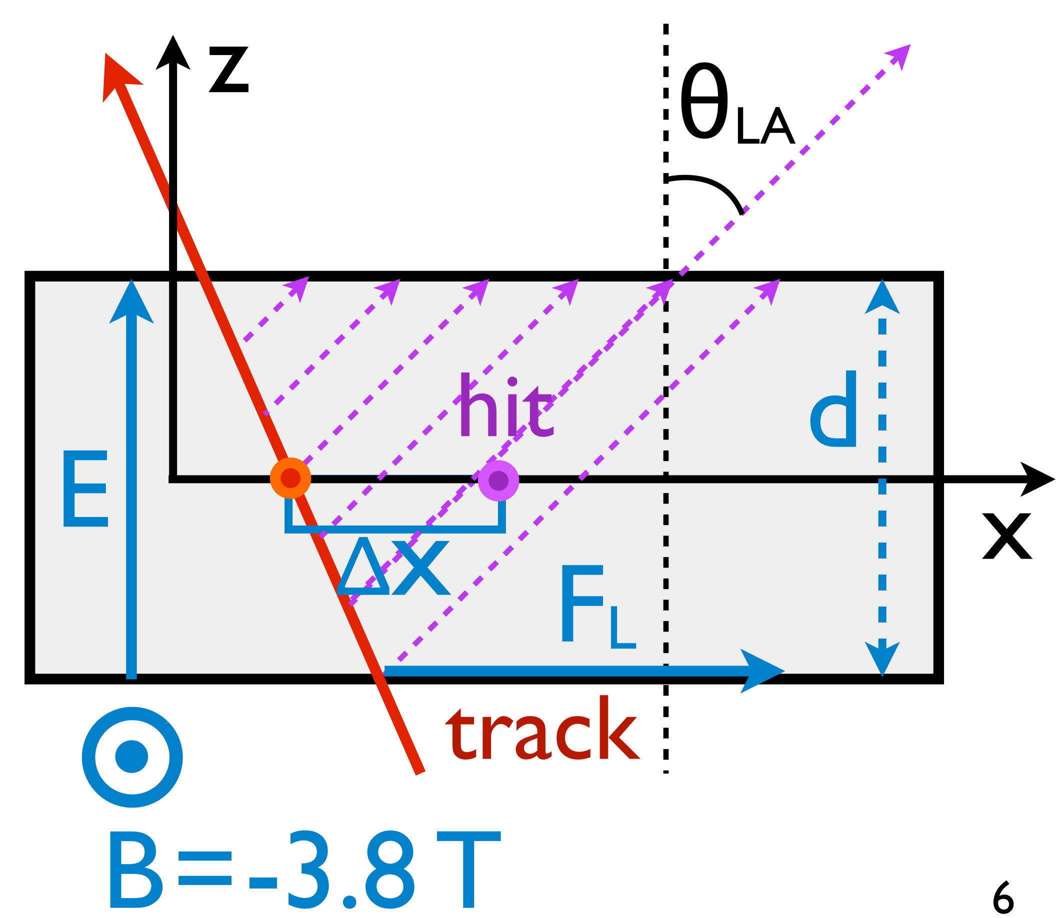
Lorentz angle effect

- Track induces electric charge accelerated by E field.
- If $B \neq 0$, Lorentz force deflects the charge by some (Lorentz) angle.
- Alignment compensates Lorentz drift by shifting the modules.

$$\Delta x = \tan(\theta_{LA}) \cdot d/2$$
$$\tan(\theta_{LA}) = \mu \cdot B_y \quad [\mu \text{ – mobility}]$$

- μ depends on: irradiation dose, temperature, bias voltage.
- Mobility can be included as calibration parameter in the alignment procedure.



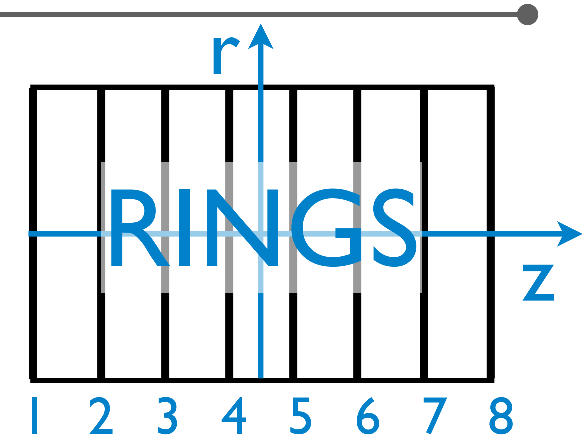


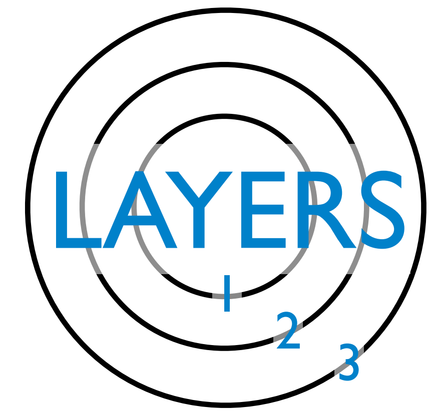
Alignment procedure

- As official full scale tracker alignment approach.
- Data from full period of year 2012: isolated muons, Z–>μμ, low Pt tracks, cosmic rays: overall 50 M tracks.
- Pixel + microstrip modules: constant alignment parameters within large structures (layer, half-disk, half-barrel).
- Large structures: parameters can change with time: 31 intervals of validity (IOV) ⇒ ~200 K alignment parameters.

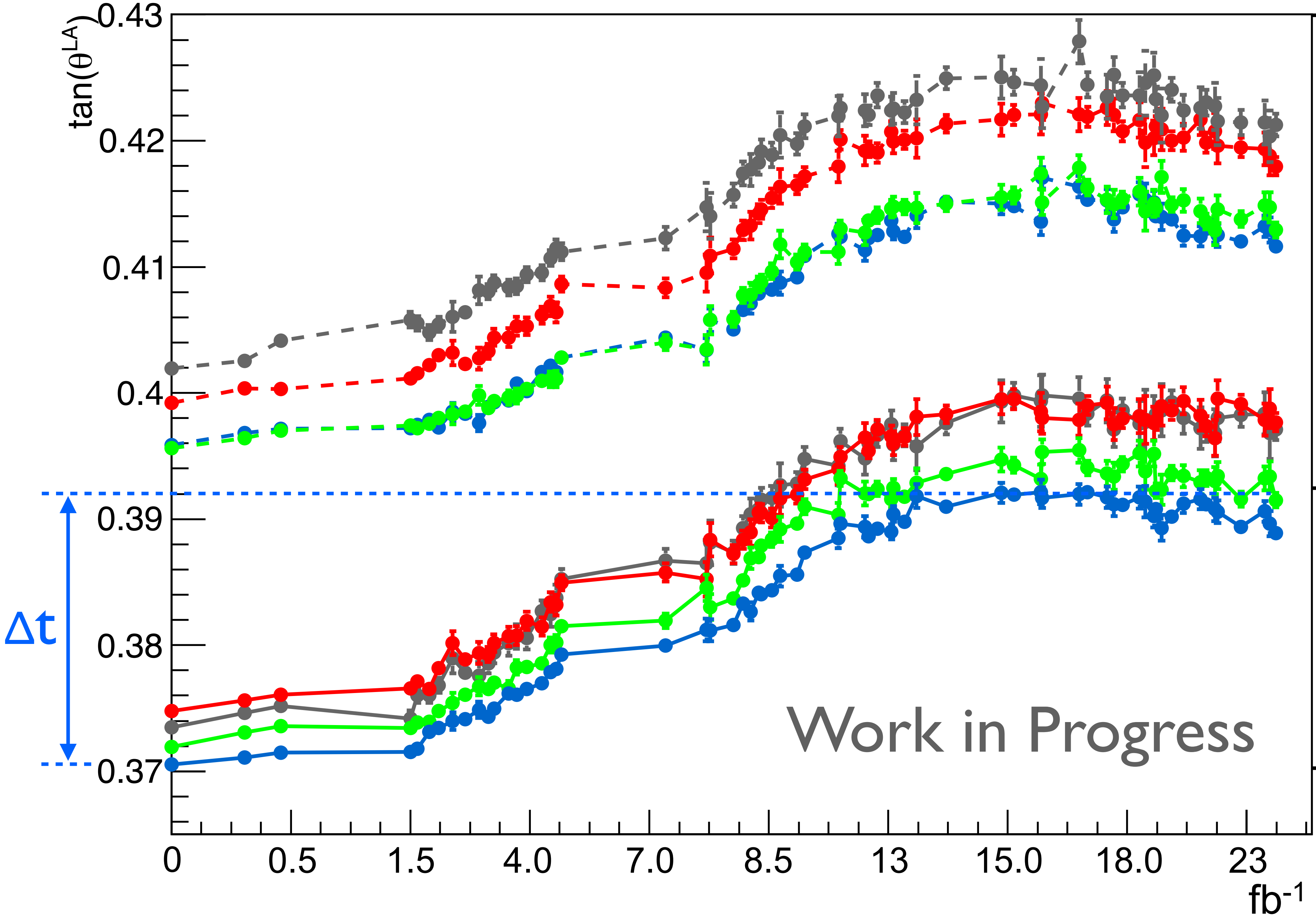
Lorentz angle calibration

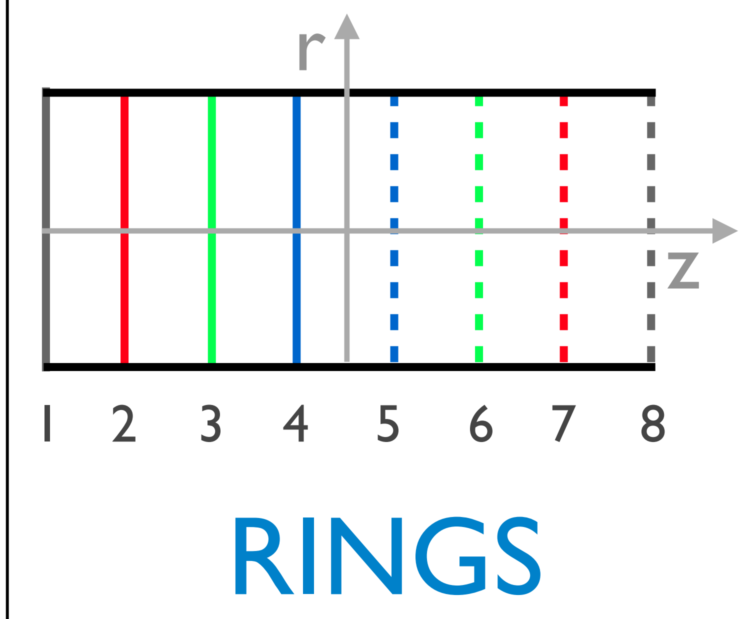
- Corrected μ value is derived.
- 24 parameters in BPIX: 3 layers x 8 rings
- 66 IOVs for Lorentz angle: ~300 pb^{-1}/IOV
- + 0T data (cosmic, collision) – constrain module positions (10 M tracks) – No Lorentz angle effect.





Lorentz angle time dependence





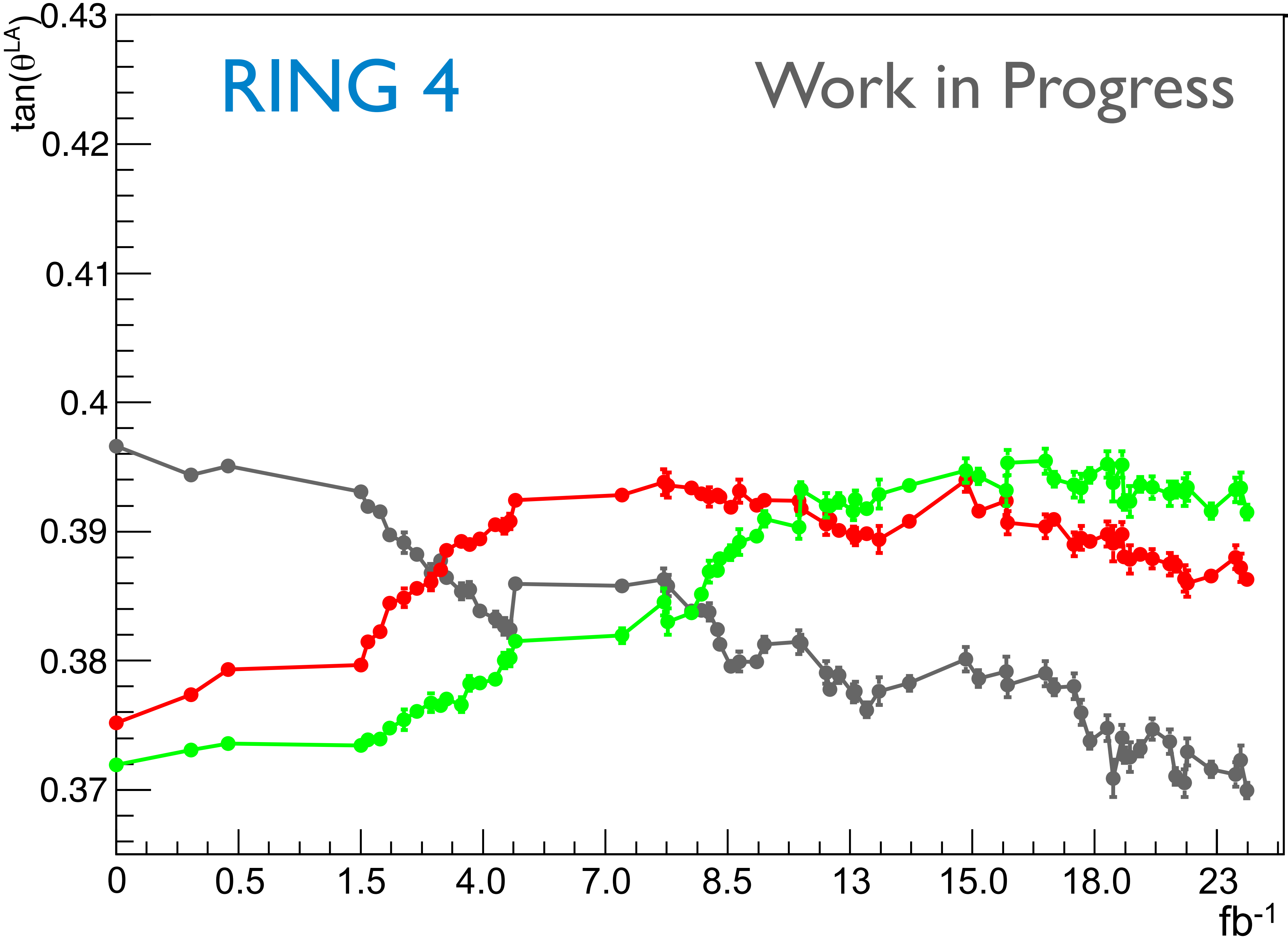
$\Delta x = \Delta t \cdot d/2$

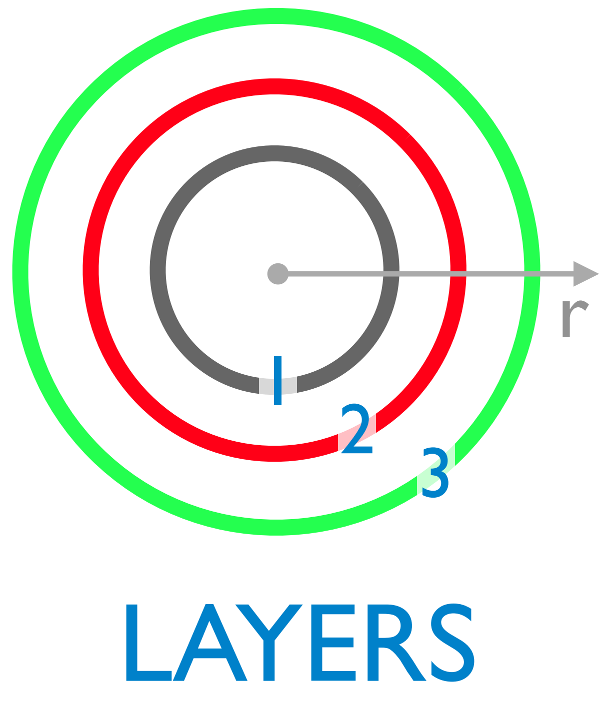
$\Delta x = 0.022 \cdot 285/2$

$\Delta x = 3.14\ \mu m$

- Very precise measurement of Lorentz angle and its evolution.
- Different per ring. Offset of +Z and -Z half of BPIX.
- Lorentz angle change equivalent to sensor shift by 3.14 μm.

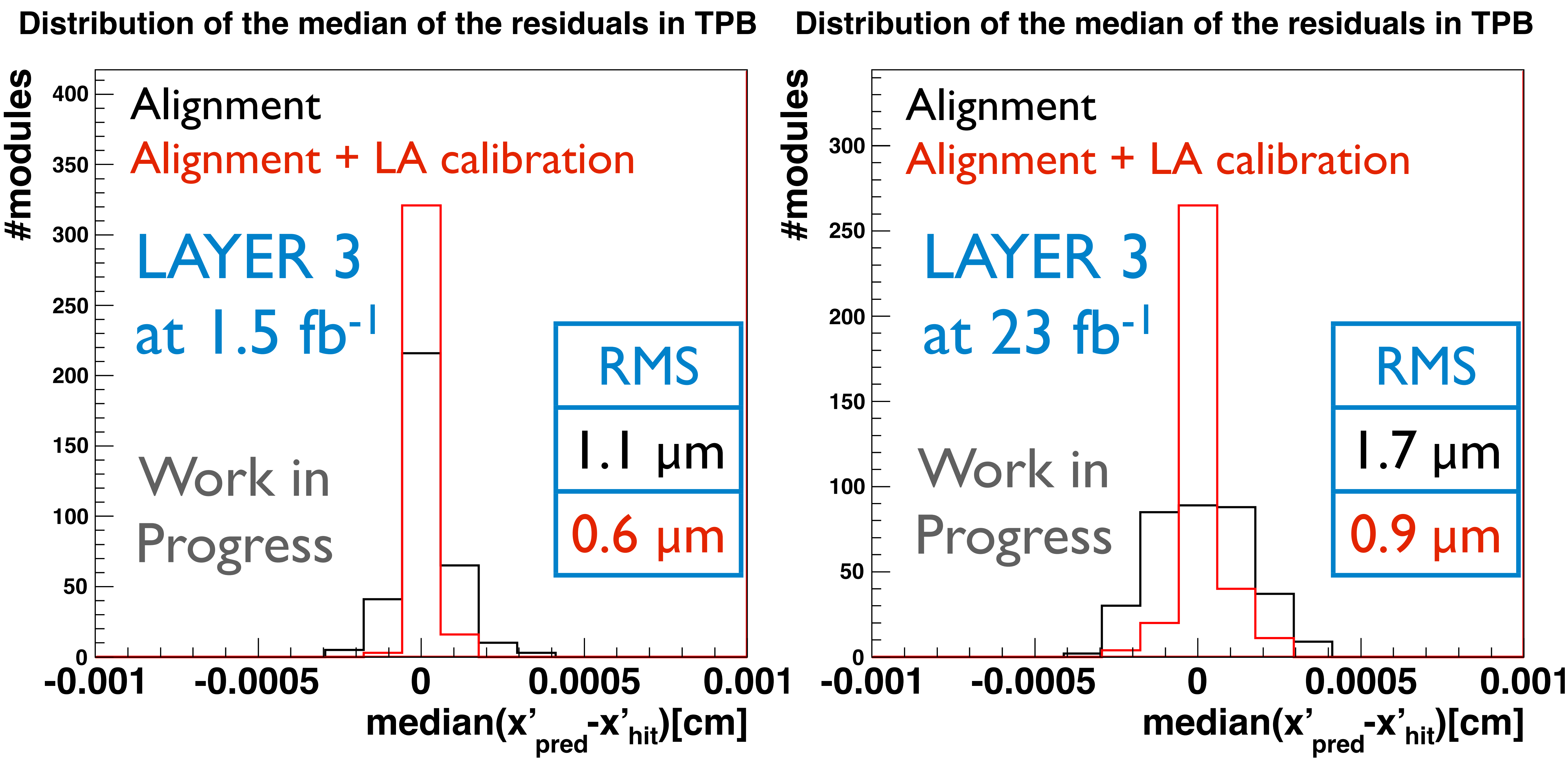
Lorentz angle time dependence





- Different evolution of Lorentz angle in separate layers.
- Can be the same effect repeating in each layer with delay (due to accumulated irradiation dose).

Effect of Lorentz angle calibration

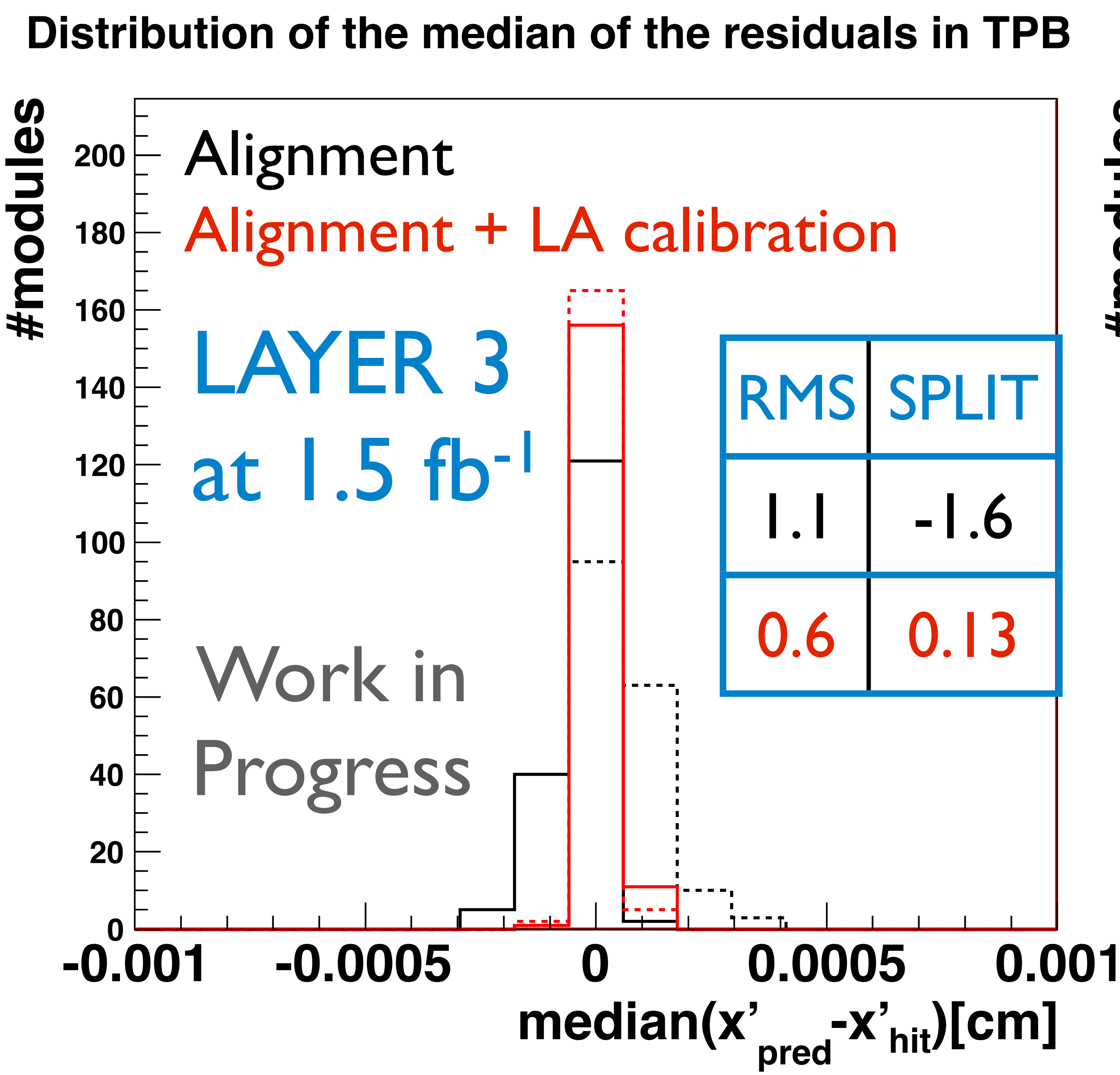


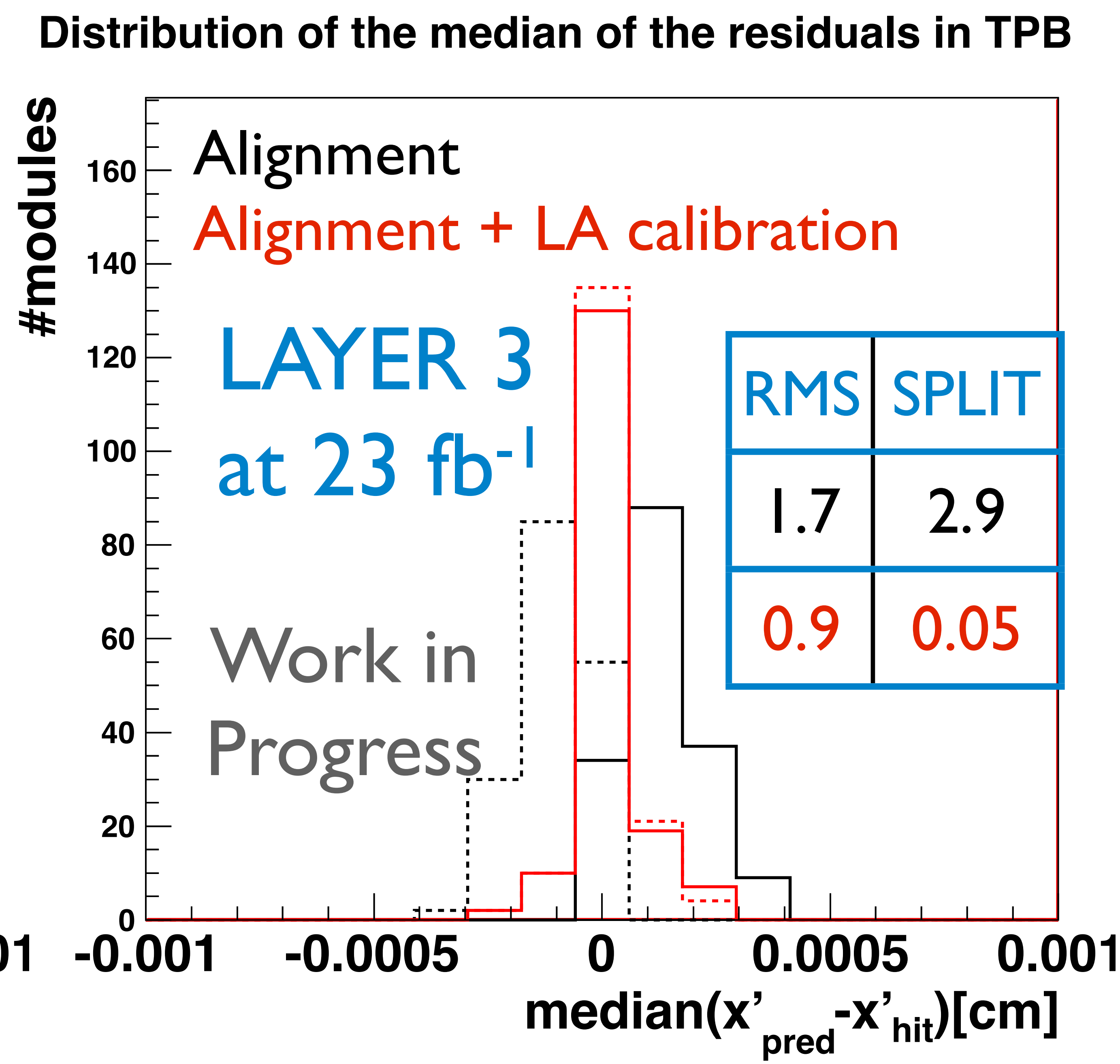
- Alignment precision degrades in later period of time.
- Lorentz angle calibration corrects time dependence, improves alignment precision.

Summary

- Precise determination of Lorentz angle using combined alignment and calibration with Millepede II and 0T data.
- Lorentz angle measured in BPIX for data of full 2012 data-taking period: 66 time ranges, granularity of 24 parameters (3 layers x 8 rings).
- Time dependence largely differs between layers.
- Absolute values differ between halves (+/-) of the BPIX.
- Combined alignment and LA calibration improves alignment precision of the modules.
- Consistency of 3.8T and 0T data allows to use power of 0T data against χ^2 invariant geometry distortions.

Backup





- With time relative shift of modules would be 4.5 μm.
- Lorentz angle calibration corrects time dependence, modules don’t move, preserving correct alignment.