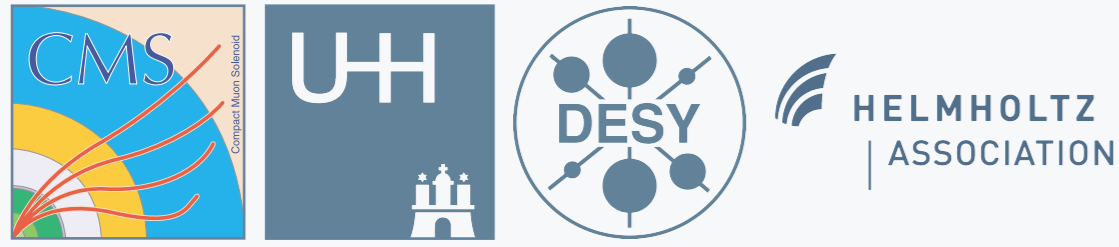


# Simultaneous alignment and Lorentz angle calibration in the CMS silicon tracker using Millepede II

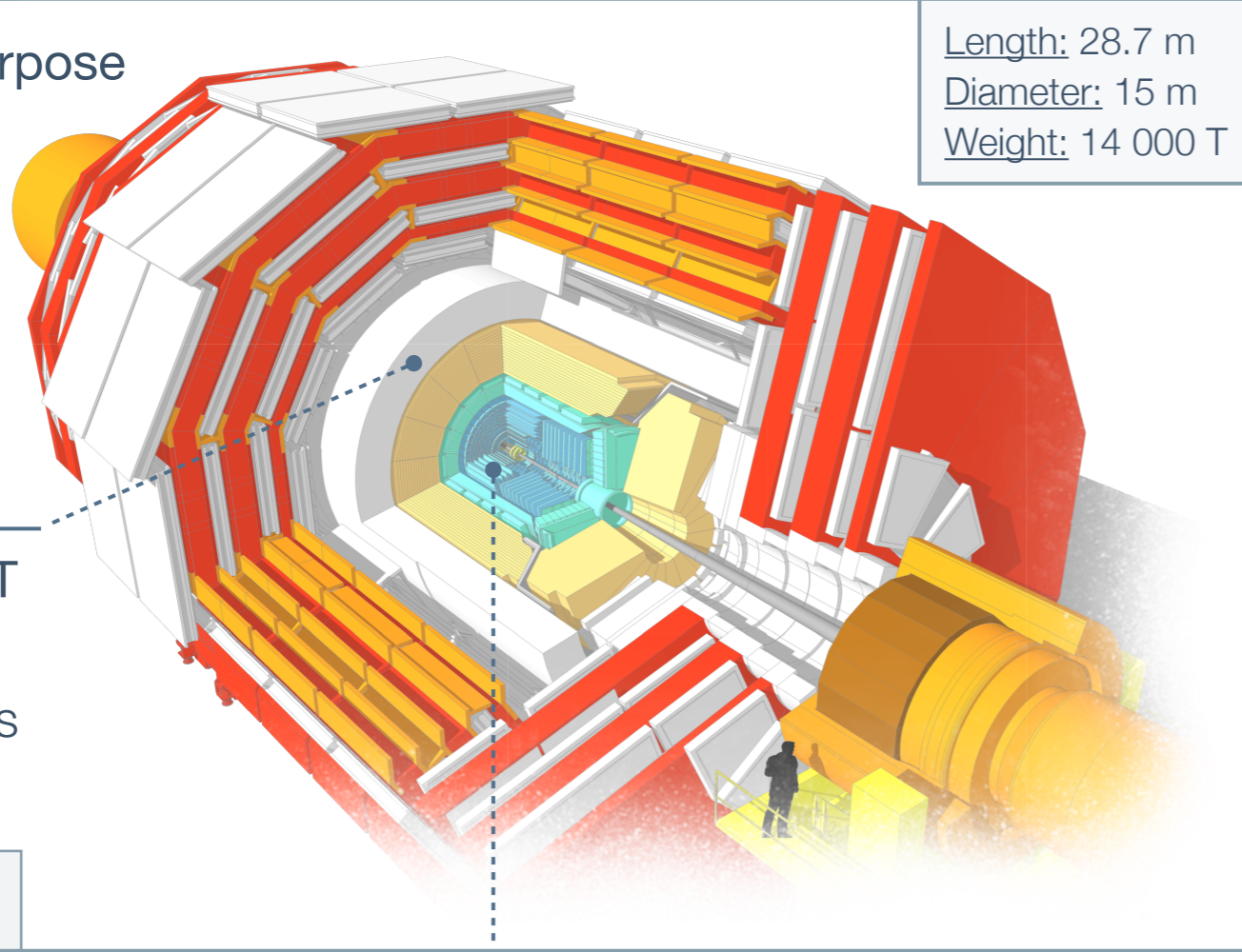


EPS HEP 2013 (18-24 July, Stockholm, Sweden)

Nazar Bartosik (Deutsches Elektronen-Synchrotron, Germany)  
on behalf of the CMS Collaboration

## CMS detector

One of the 2 multipurpose detectors at LHC.

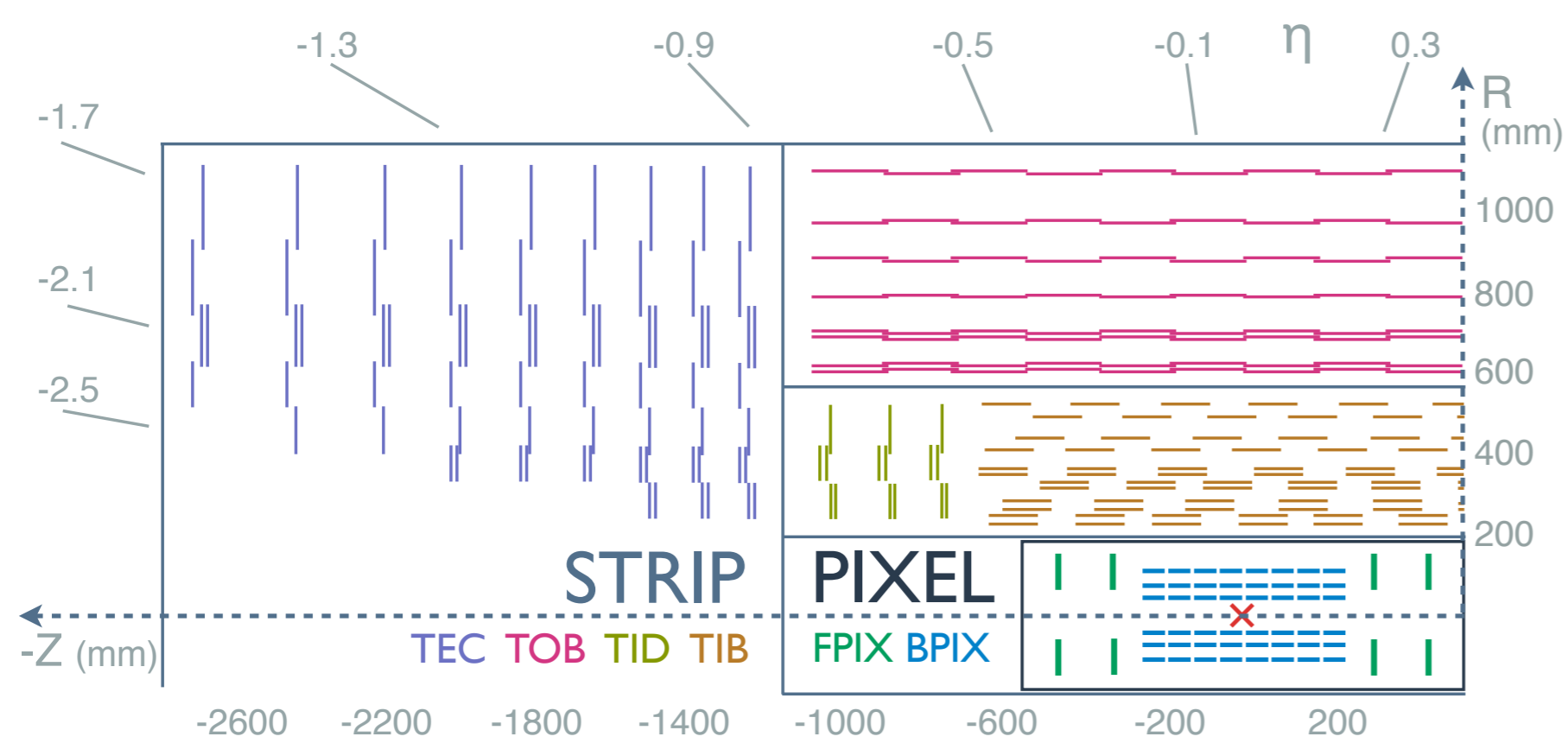


Length: 28.7 m  
Diameter: 15 m  
Weight: 14 000 T

## Superconducting solenoid

- Magnetic field: 3.8T
- Bends trajectories of charged particles

## Silicon tracker

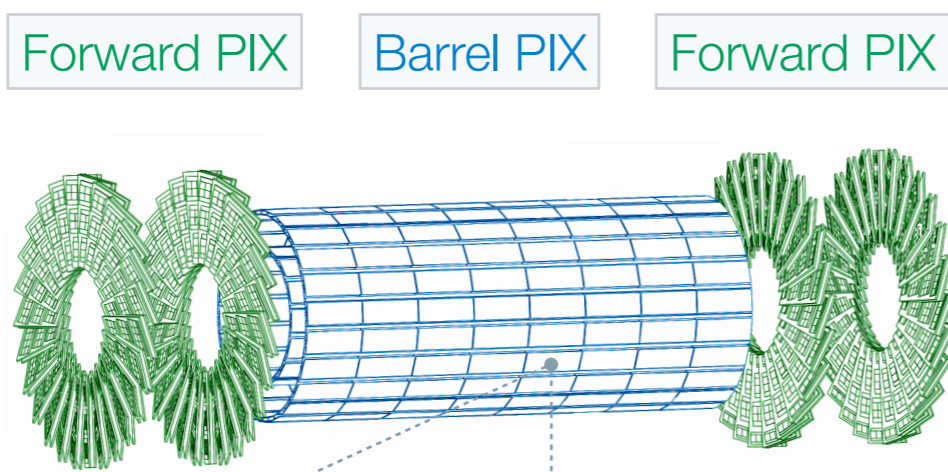


- Innermost detector
- Measures trajectories of charged particles
- Used in practically all physics analyses
- Estimation of  $p_T$ , impact parameter

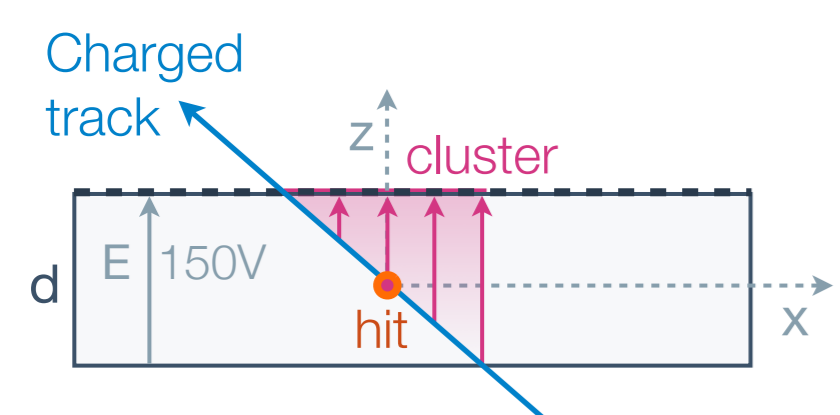
STRIP: ID				PIXEL: 2D	
TEC	TOB	TID	TIB	FPIX	BPIX
10 288	10 416	816	2 724	672	768
24 244 microstrip sensors				1 440 pixel sensors	
≥ 23 μm resolution				≥ 10 μm resolution	

## Pixel detector

- Highest resolution.
- Closest to the interaction point.
- Largest irradiation dose.
- Sensor properties can change during detector operation.
- Resolution most sensitive to misalignment and miscalibration.

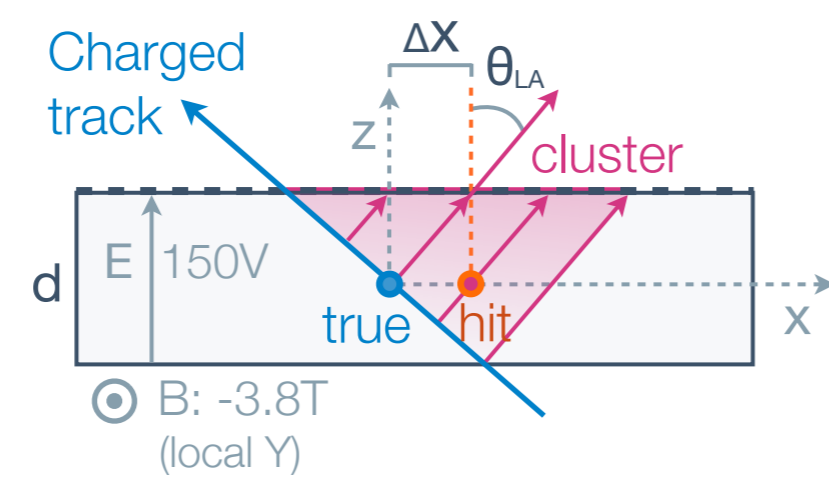


## BPIX module: B = 0T



- Track induces signal charge drifting under E field.
- Global hit position directly depends on global module position, orientation, curvature.
- Center of collected charge cluster treated as measured hit position.

## BPIX module: B = 3.8T



- If  $B \neq 0$ , Lorentz force deflects the signal charge by angle  $\theta_{LA}$ .
- Increases cluster size, shifts the hit position by  $\Delta x$ .
- Lorentz angle parameterized in terms of mobility.

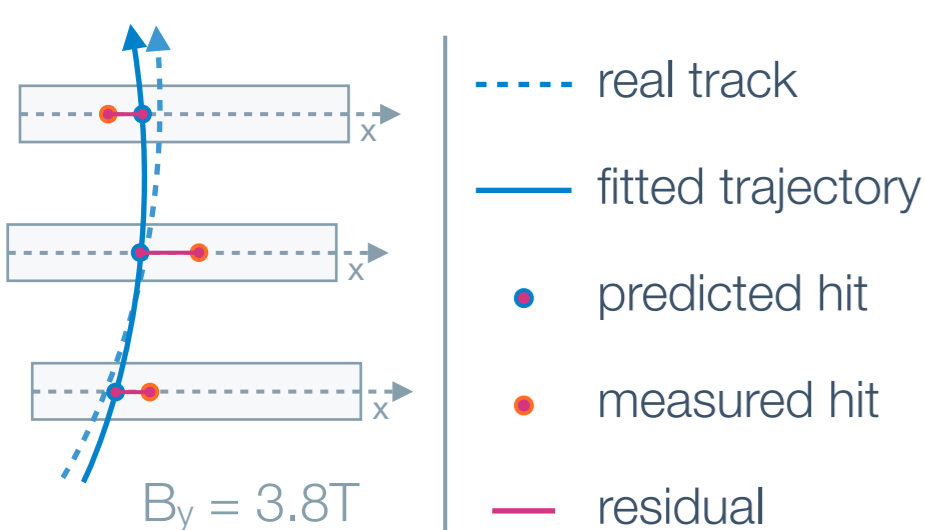
$$\Delta x = \tan(\theta_{LA}) \cdot d/2 \quad d = 285 \mu\text{m}$$

$$\tan(\theta_{LA}) = \mu \cdot B_y \quad \mu - \text{mobility}$$

- **Mobility** depends on:
  - accumulated irradiation dose
  - temperature of the module
  - bias voltage, ...

- Tracks measured in different magnetic fields are used to disentangle alignment and Lorentz angle effect.

## Track-hit residuals



## Track-based alignment with Millepede II

- Misalignment and miscalibration of the detector increase track-hit residuals.
- Based on minimization of **normalized track-hit residuals** using function:

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

$f_{ij}$  linearization, matrix size reduction

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

More than 200 000 parameters ( $\mathbf{p}$ ) can be determined simultaneously:

Up to 9 alignment parameters per sensor				
$\leftrightarrow$	x	y	z	Shift along axis
$\curvearrowright$	$\alpha$	$\beta$	$\gamma$	Tilt around axis
$\cup$	$w_0$	$w_1$	$w_2$	Surface distortion

Calibration parameters [NEW]  
Lorentz angle

If not properly determined, affects the alignment parameters.

## Alignment procedure

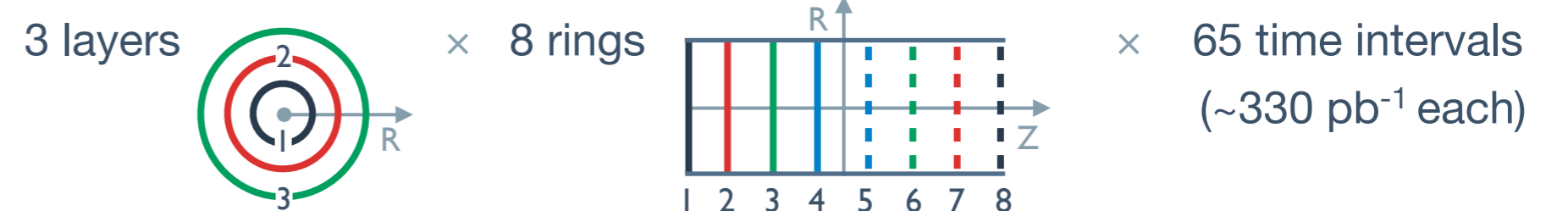
- Similar to the official baseline alignment, extended to full 2012 data (65 million tracks):

Tracks from	Isolated muons	Z→μμ decays	Low $p_T$ tracks	Cosmic rays
# (3.8T)	28 million	10 million	14 million	2.5 million
# (0T)			10 million	0.5 million

- To disentangle module alignment and Lorentz angle calibration.
- Alignment of module positions and orientations, accounting for movements (31 time intervals) of the large structures.

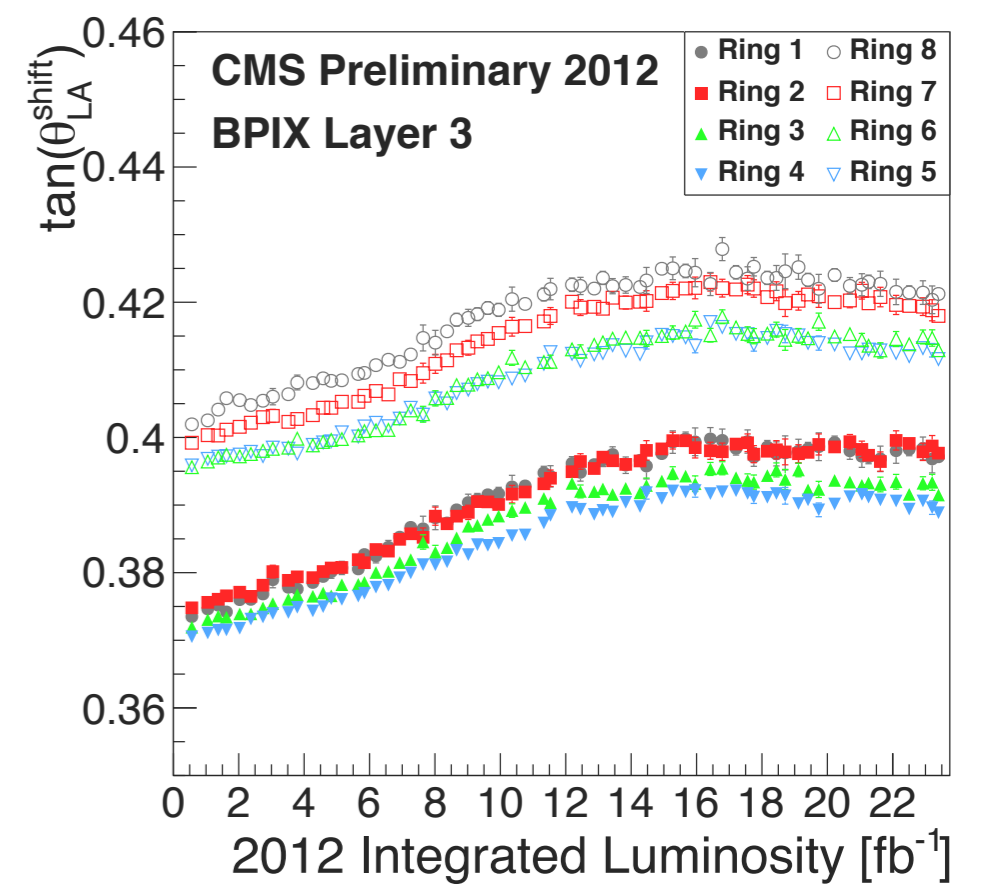
↳ ~92 000 parameters

+ Lorentz angle in BPIX (1 560 parameters):

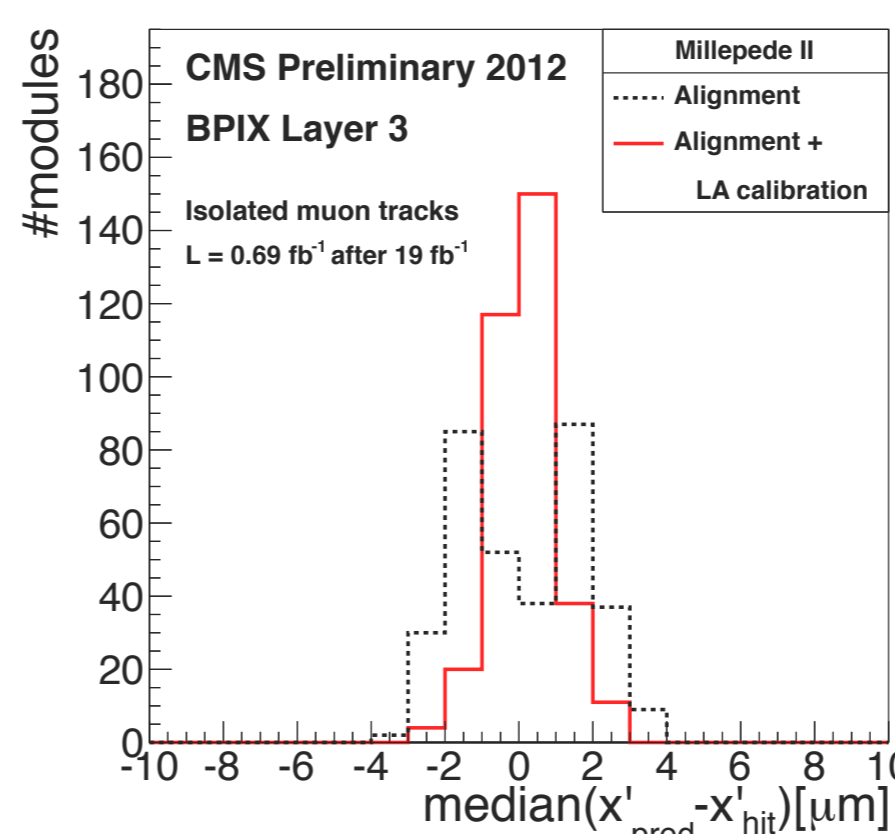


## Lorentz angle time dependence

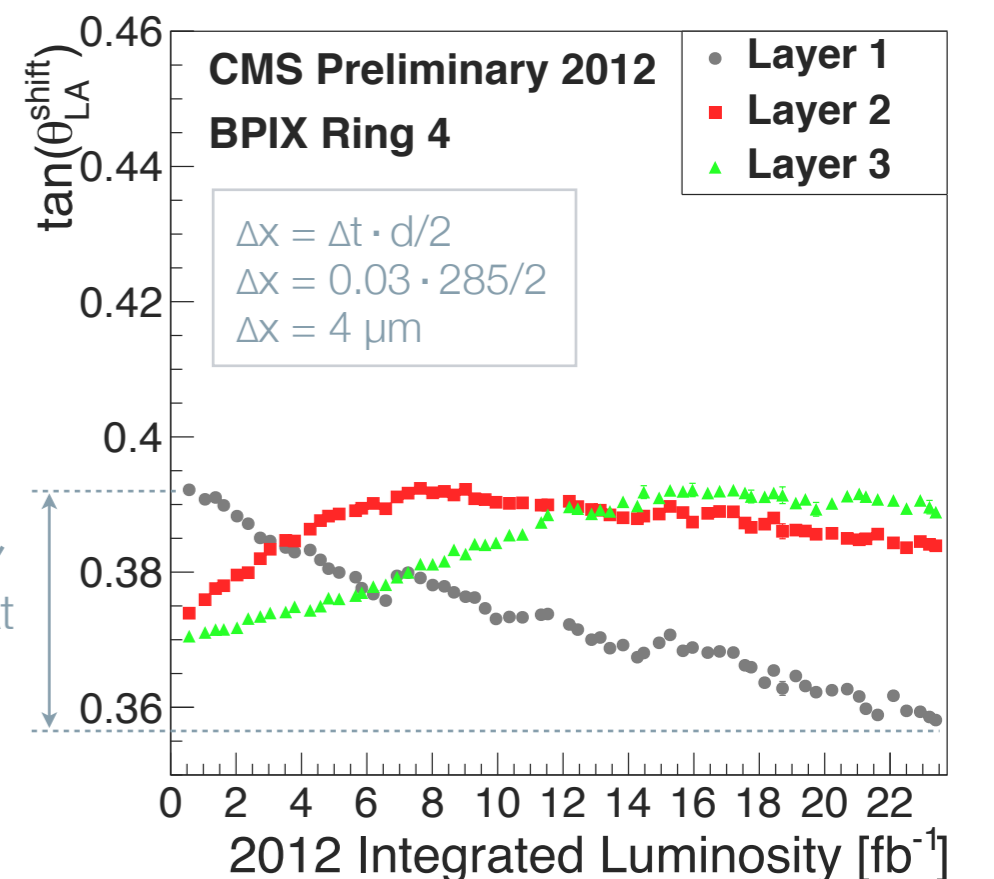
- Consistent development in all rings of the BPIX.
- Clear offset between negative ( $Z < 0$ ) and positive ( $Z > 0$ ) parts (different bias voltage?).
- Variation of Lorentz angle equivalent to shift of the module by up to 4 μm.
- Different shape of evolution among layers.
- Can be the same behaviour delayed in distant layers (lower accumulated irradiation dose).
- Lorentz angle expected to change faster after LS1 due to increased irradiation dose.



## Validation of the result



- Analyzed residuals of 2 million high  $p_T$  tracks.
- Median of the residuals calculated for each module (1 entry per module).
- Narrower peak clearly seen with simultaneous alignment and Lorentz angle calibration.



## Conclusions

- Lorentz angle measured in BPIX for full 2012 data with high precision to see local variations and time dependence (using Millepede II and additional 0T data).
- Combined approach (simultaneous module alignment and Lorentz angle calibration) improves overall precision of hit reconstruction ⇒ tracking, vertexing, b-tagging.
- Allows consistent use of 3.8T and 0T data in alignment.
- Will be in even higher demand after LS1, with more rapid Lorentz angle development.