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

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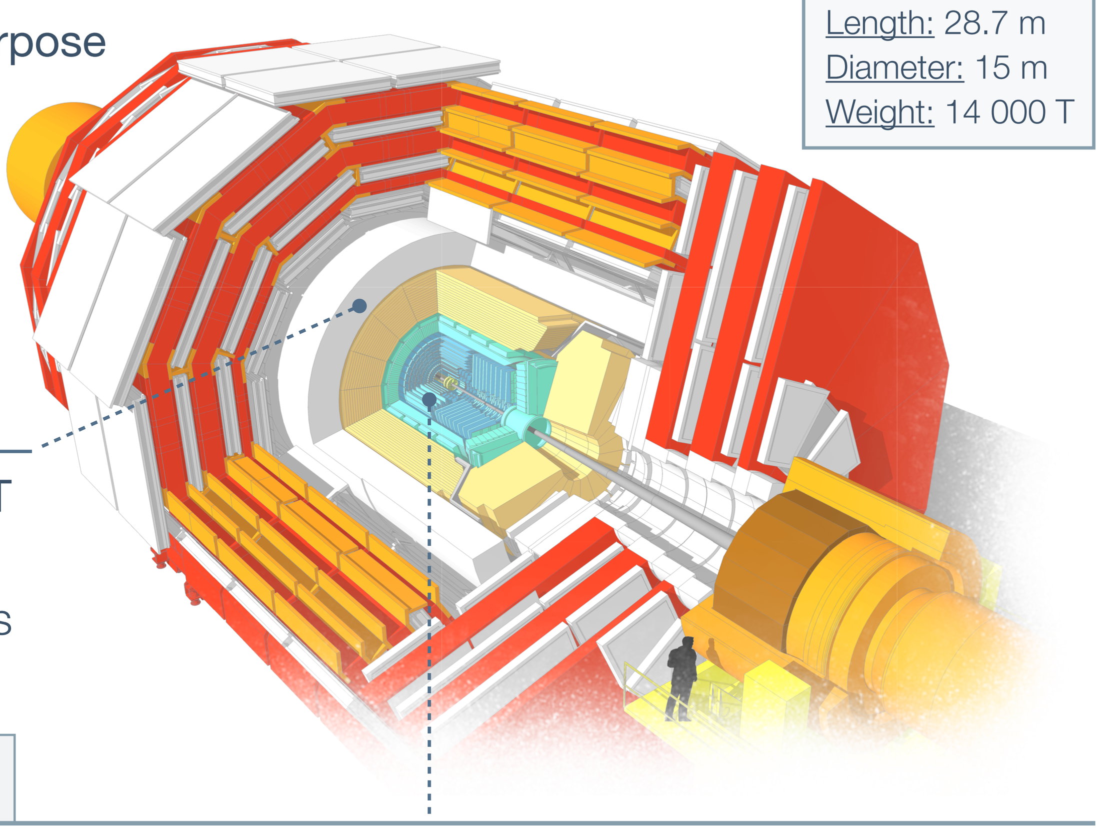
CMS detector

One of the 2 multipurpose detectors at LHC.

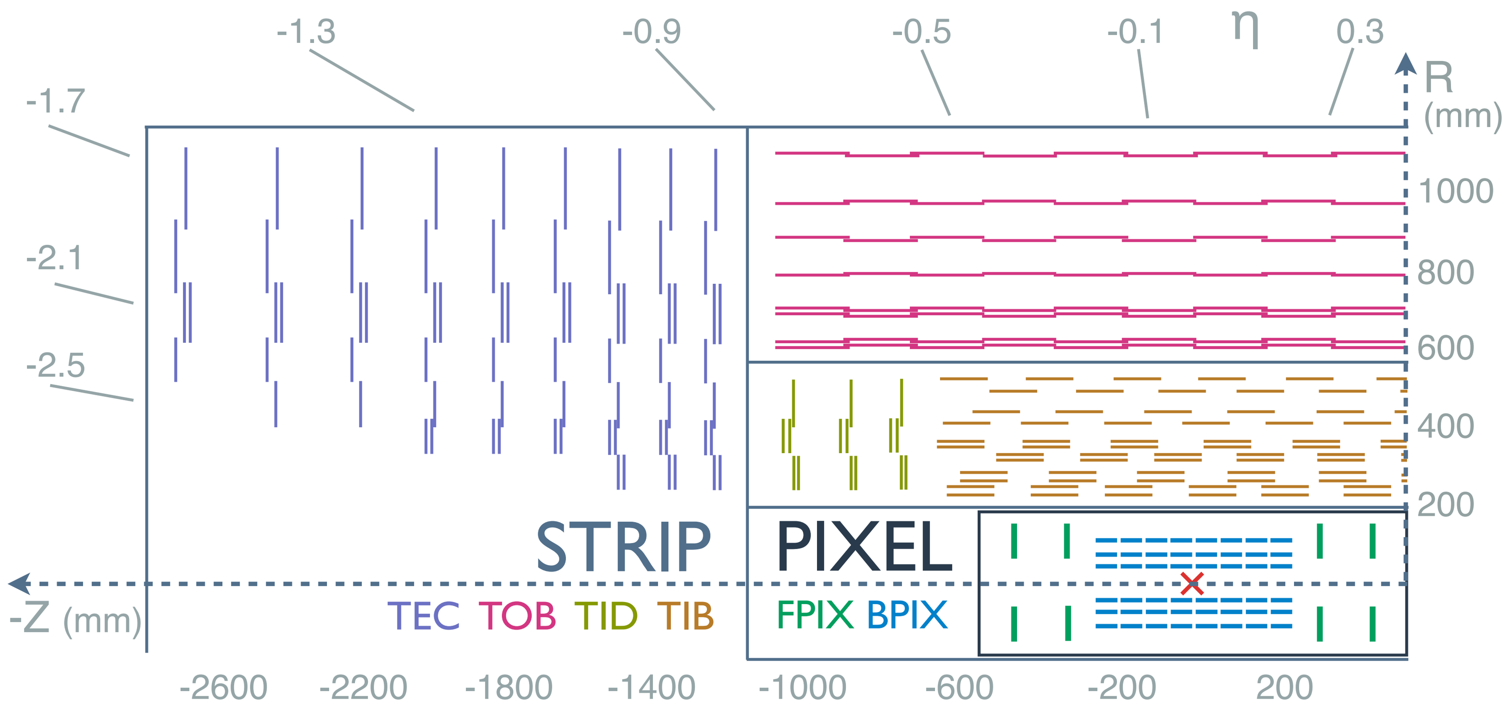
Length: 28.7 m
Diameter: 15 m
Weight: 14 000 T



Superconducting solenoid

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

Silicon tracker

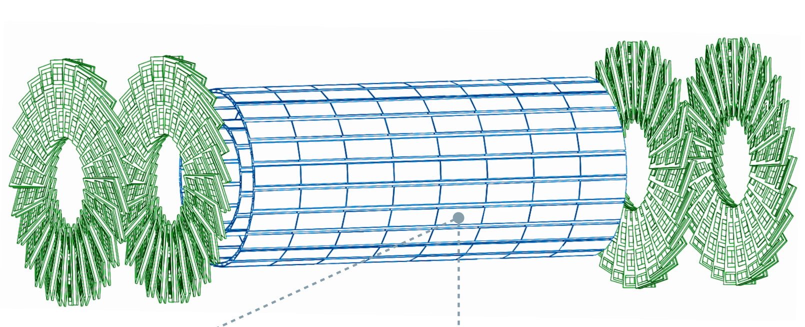


- Innermost detector
- Measures trajectories of charged particles
- Used in practically **all** physics analyses
- Estimation of p_T, impact parameter

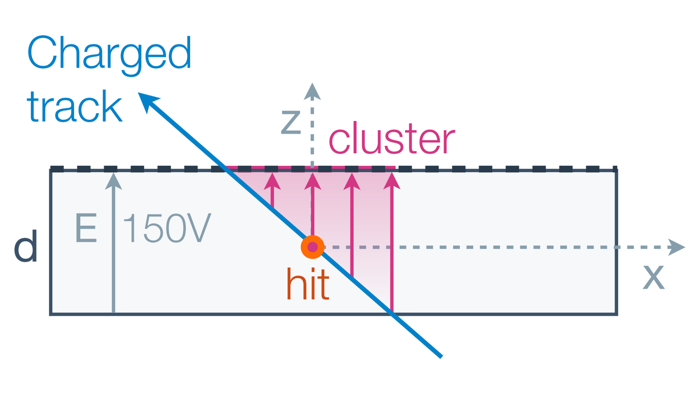
STRIP: 1D				PIXEL: 2D	
TEC	TOB	TID	TIB	FPIX	BPIX
10 288	10 416	816	2 724	672	768
24 244 microstrip sensors				1 440 pixel sensors	
≥ 23 μm resolution				≥ 10 μm resolution	

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.

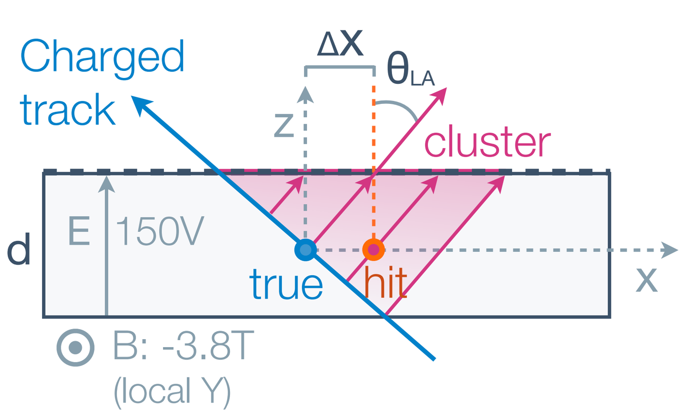


BPIX module: B = 0T



- 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.

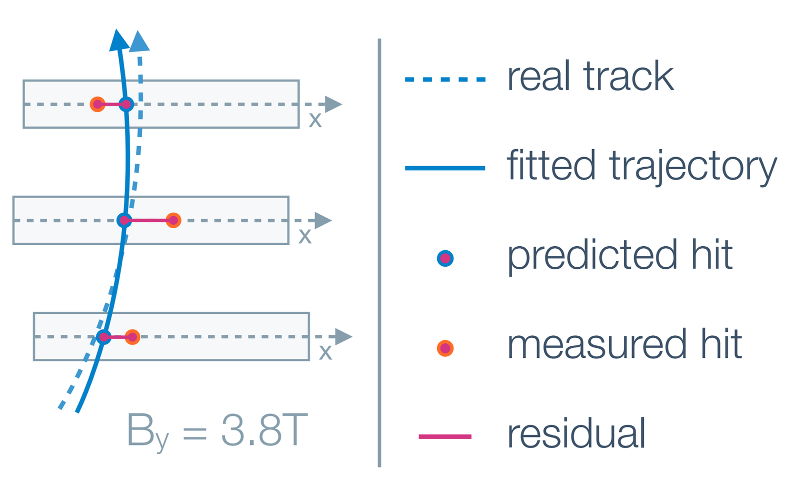
BPIX module: B = 3.8T



$\Delta x = \tan(\theta_{LA}) \cdot d/2$	d = 285 μm
$\tan(\theta_{LA}) = \mu \cdot B_y$	μ – mobility

- If B≠0, **Lorentz force deflects the signal** charge by angle θ_{LA}.
- Increases cluster size, shifts the hit position by Δx.
- Lorentz angle parameterized in terms of 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:

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

$m_{ij} \pm \sigma_{ij}$ – measured position of the hit;
f_{ij} – predicted position of the hit;
$\mathbf{p}$ – "global" (detector) parameters;
$\mathbf{q}_j$ – track parameters;

f_{ij} linearization, matrix size reduction → Matrix equation: $\mathbf{C}\Delta\mathbf{p} = \mathbf{b}$

More than **200 000** parameters (**p**) can be determined simultaneously:

Up to **9 alignment parameters** per sensor		
⟺	x y z	Shift along axis
⟲	α β γ	Tilt around axis
◡	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.

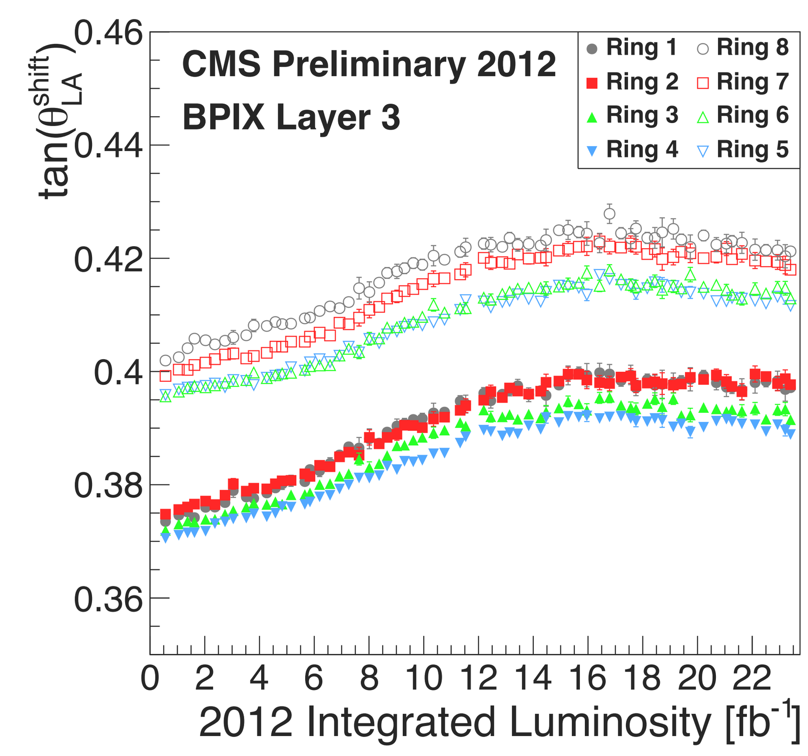
↳ **~92 000 parameters**

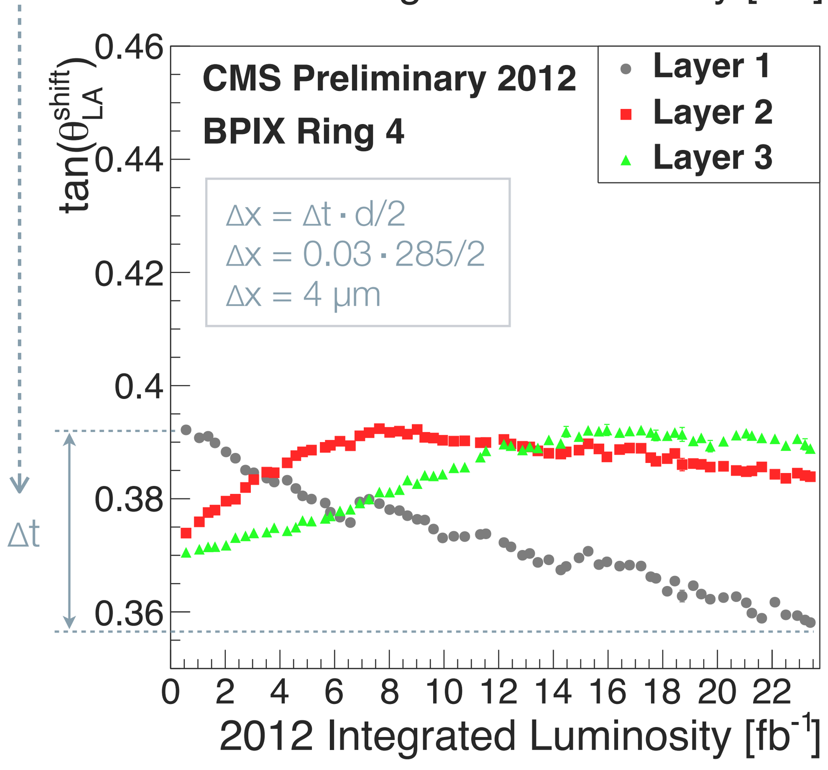
\+ **Lorentz angle in BPIX (1 560 parameters):**

3 layers × 8 rings × 65 time intervals (~330 pb^{-1} each)

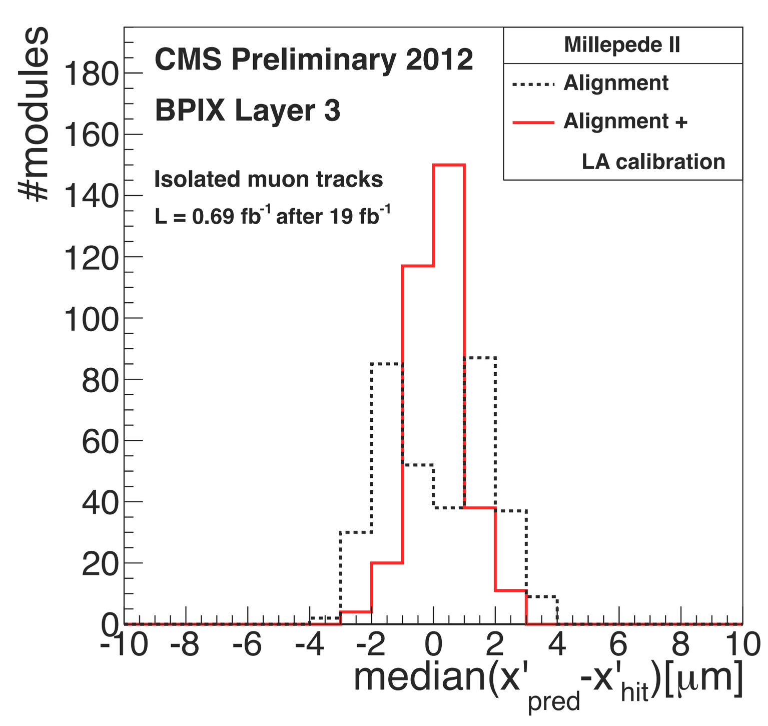
Lorentz angle time dependence

- Consistent development in all rings of the BPIX.
- **Clear offset** between Z<0 and Z>0 parts due to different operating conditions.
- 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.