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Estimation of tracker material budget with triplet method

CMS Collaboration

Abstract

A novel method for measuring in situ the material budget of a silicon tracker is presented. The method relies on using three consecutive hits, or a triplet, along a reconstructed track, measuring the sagitta in this system and extracting the radiation length locally from the scattering angle. This procedure allows an accurate and granular measurement of the material budget of the tracker. In this note, the material budget estimated with this method of triplets for the CMS Phase 0 Pixel detector is shown.

Estimation of tracker material budget with triplet method.

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Abstract

A novel method for measuring in situ the material budget of a silicon tracker is presented. The method relies on using three consecutive hits along a reconstructed track, measuring the sagitta in this system and extracting the radiation length locally from the scattering angle. This procedure allows an accurate and granular measurement of the material budget of the tracker. In this presentation, the material budget estimated with this method of triplets for the CMS Phase 0 Pixel detector is shown.

Input

- ZeroBias data recorded by the CMS experiment in October 2016 corresponding to an integrated luminosity of 0.45 fb^{-1}.
- Minimum Bias MC sample produced with 2016 geometry.
- Number of tracks used - $10^{\wedge 6}$.

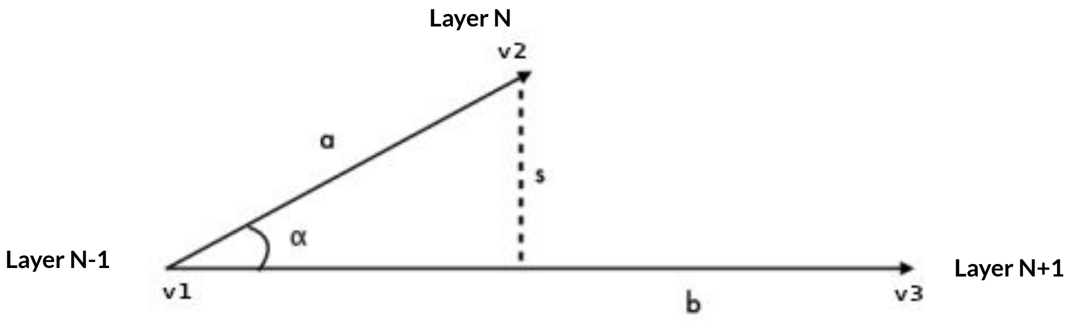
Method of triplets

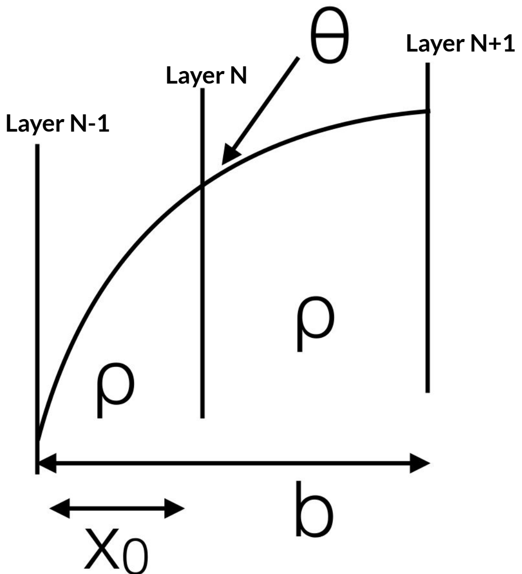
- Take three hits in consecutive layers and form a triplet. Project them on the transverse plane.
  - For each triplet, we plot the quantity $t = \text{sagitta} * p_T^{\text{of the track}}$
  - For tracks with $p_T \sim 1\text{GeV}$, assuming an uniform magnetic field of 3.8 T, we expect $\langle t \rangle = \pm 5.7\times10^{-3}$ GeV/cm
  - Width of the peaks depend on the multiple scattering in the middle layer.
  - Assumption: the material along the trajectory is all concentrated on the central layer of the triplet.
- Track selection
  - Transverse momentum between 0.750 GeV and 1.5 GeV. The lower threshold is to reject tracks which do not traverse the entire radial length of the tracker.
  - The track should have at least 14 hits.
  - The relative uncertainty on the transverse momentum measurement should be less than 1%.
  - The measurement is done in bins of η, z for each layer in barrel.

Method of triplets

Define: $\vec{a} = \vec{v_2} - \vec{v_1}$ $\vec{b} = \vec{v_3} - \vec{v_1}$

$$s = \frac{a_x\, b_y - a_y\, b_x}{|\vec{b}|} \qquad x_0 = \frac{\vec{a} \cdot \vec{b}}{|\vec{b}|}$$





Assume: Scattering happens in the central layer.
Taking ρ as the radius of curvature of the track and θ to be the scattering angle in the middle layer, it can be shown [1] that the sagitta, s, multiplied by the transverse momentum of the track for this system of triplets is,

$$t \equiv \frac{p_T\, s}{x_0(b - x_0)} = -\frac{p_T}{2\rho} - \frac{p_T\,\theta}{b}$$

- The first term on the right is constant for a given system of triplets while the second term depends on multiple scattering.
- Since <θ> is 0, the <**t**> will depend on the expectation value of the first term.

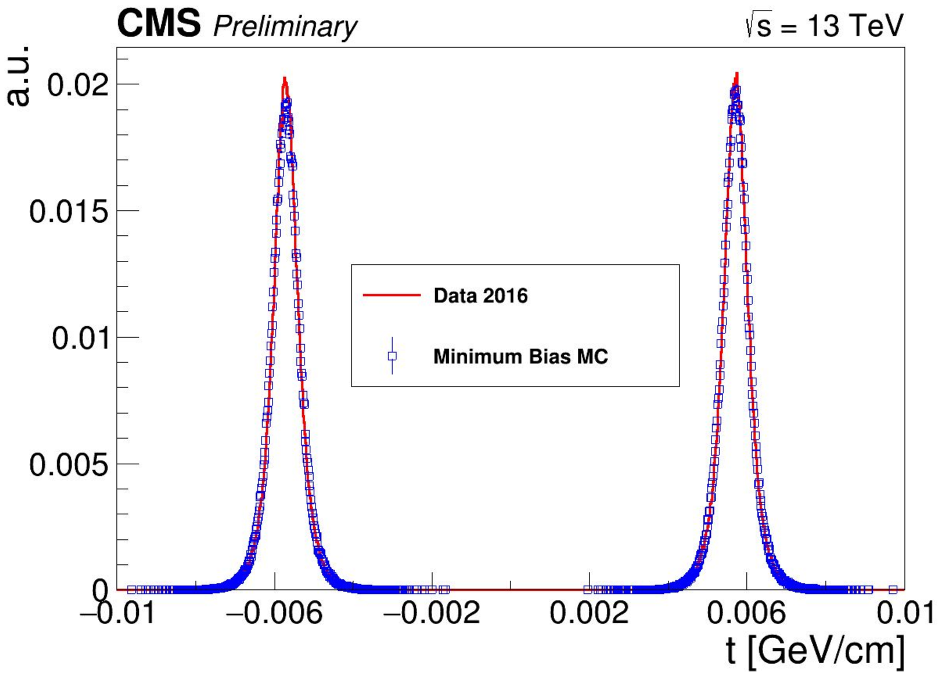
Expectation value of t

$$t \equiv \frac{p_T s}{x_0(b - x_0)} = -\frac{p_T}{2\rho} - \frac{p_T \theta}{b}$$

Since: $$p_T = \pm \frac{0.3 B\rho}{100}$$

Here pT is measured in GeV, B in Tesla and ρ is in cm.

Assuming an uniform magnetic field of 3.8 T, the mean value of the first term in the above equation is,
<**t**> = +/- 0.0057 GeV/cm.



- Plot of quantity t for a triplet with hits in BPIX layer 1, BPIX layer 2, BPIX layer 3 for Data(MC) in red(blue).

Variance of t

The spread of the distribution of t is governed by the spread in θ which in general is given by [1, 2],

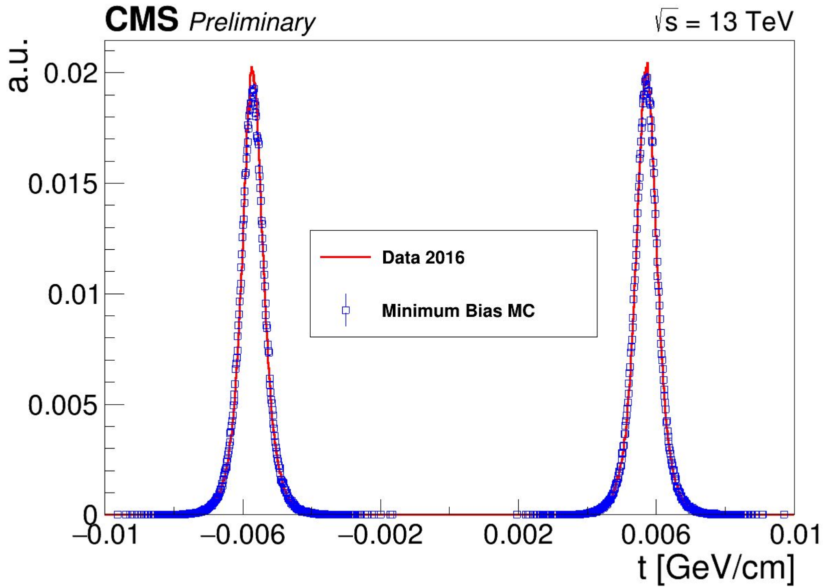
$$\theta_0 = \frac{13.6\ \text{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}\left[1 + 0.038\ln\left(\frac{x}{X_0}\right)\right]$$

Here βc is the velocity, p is the momentum and x/X_0 is the thickness of the scattering layer in radiation lengths. The variance of t can be written as,

$$\Delta t = t_0\frac{\Delta p_T}{p_T} \oplus t_0\frac{\Delta x_0(b-x_0)}{x_0(b-x_0)} \oplus \boxed{\frac{p_T\Delta s}{x_0(b-x_0)} \oplus \Delta\left(\frac{p_T}{b}\theta\right)}$$

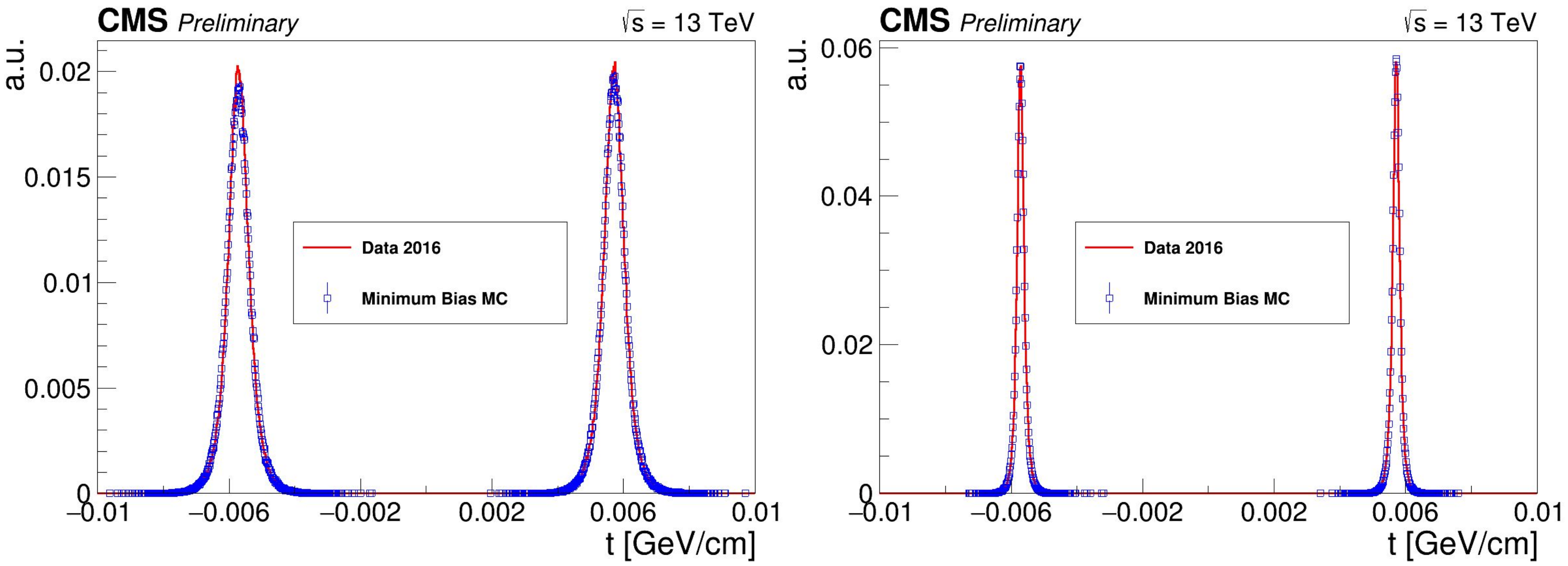
The terms marked in **red** are the dominating terms. In order to separate the contribution of the sagitta uncertainty (third term) and the one of the multiple scattering (fourth term), the variance of **t** is plotted as a function of p_T^2. At $p_T = 0$, the only contribution to the variance comes from the variance of θ,

$$\mathrm{Var}\left(\frac{p_T\theta}{b}\right) \simeq 13.6\frac{x}{X_0}\frac{1}{b^2}$$



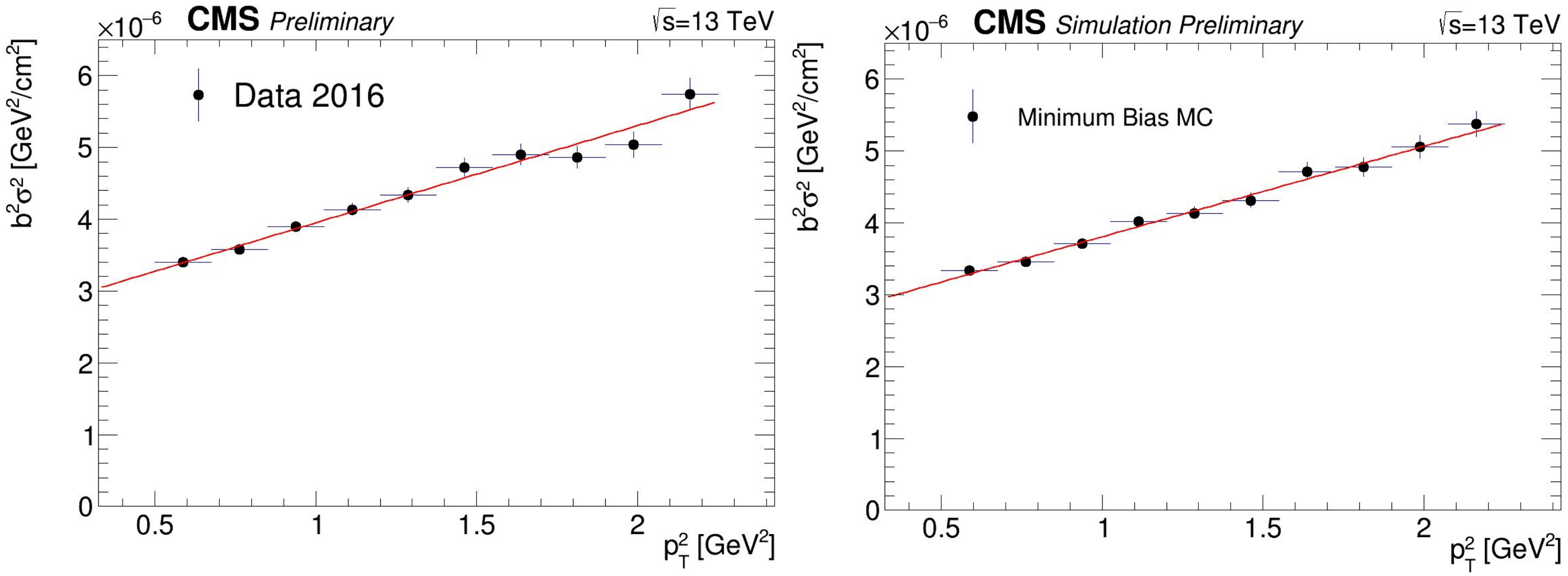
- Plot of quantity t for a triplet with hits in BPIX layer 1, BPIX layer 2, BPIX layer 3 for data(MC) in red(blue).

Expectation value of t



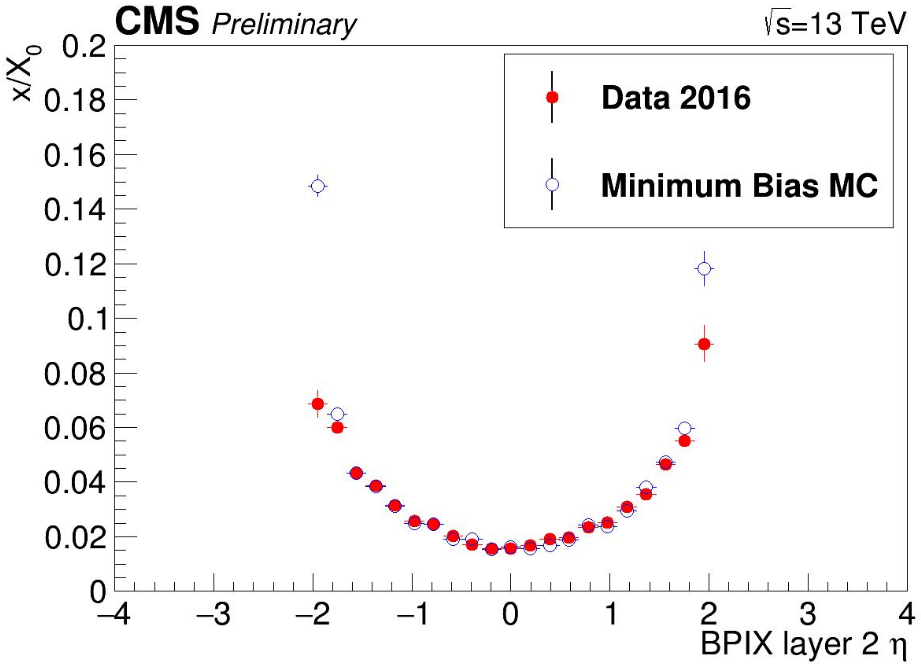
Caption: Plot of quantity **t** for a triplet with hits in BPIX layer 1, BPIX layer 2, BPIX layer 3 (left) and for a triplet with hits in BPIX layer 2, BPIX layer 3, TIB layer 1. The data is marked in red while MC is in blue. The plots are normalized to the area. The mean value of t for both the system of triplets are seen to be +/- 0.0057 GeV/cm.

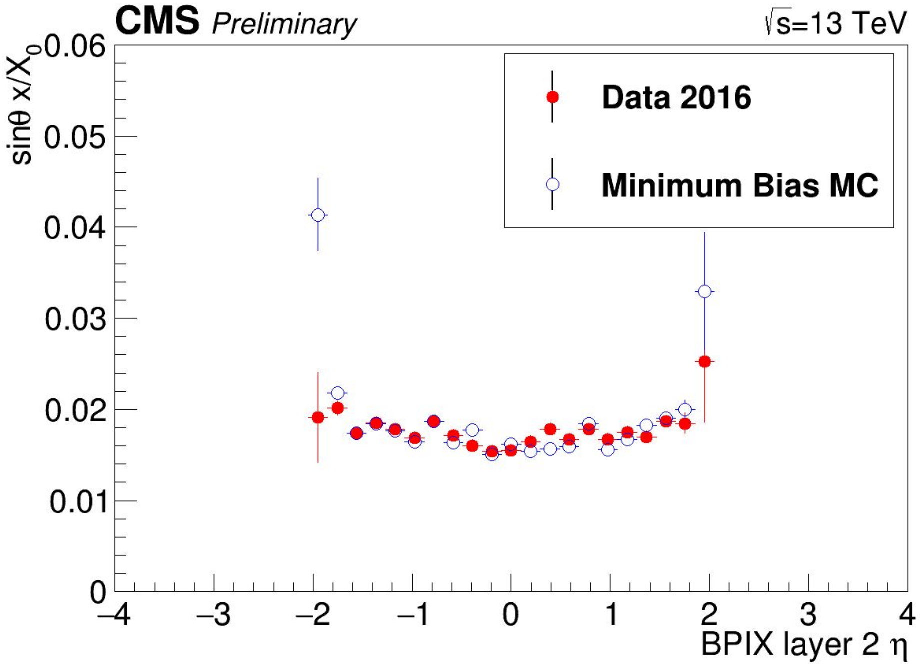
Radiation length – Variance as a function of p^2_T



Caption: Fit of the mean of the variance of the positive and negative **t** distributions multiplied by $\mathbf{b^2}$ as function of $p_T{}^2$ in the bin of η (0, 0.2) for the data(left) and MC(right). The intercept of the fit function gives a measure of the radiation length in the central layer of the triplet. This fit is performed for every η or z bin and the radiation length is extracted.

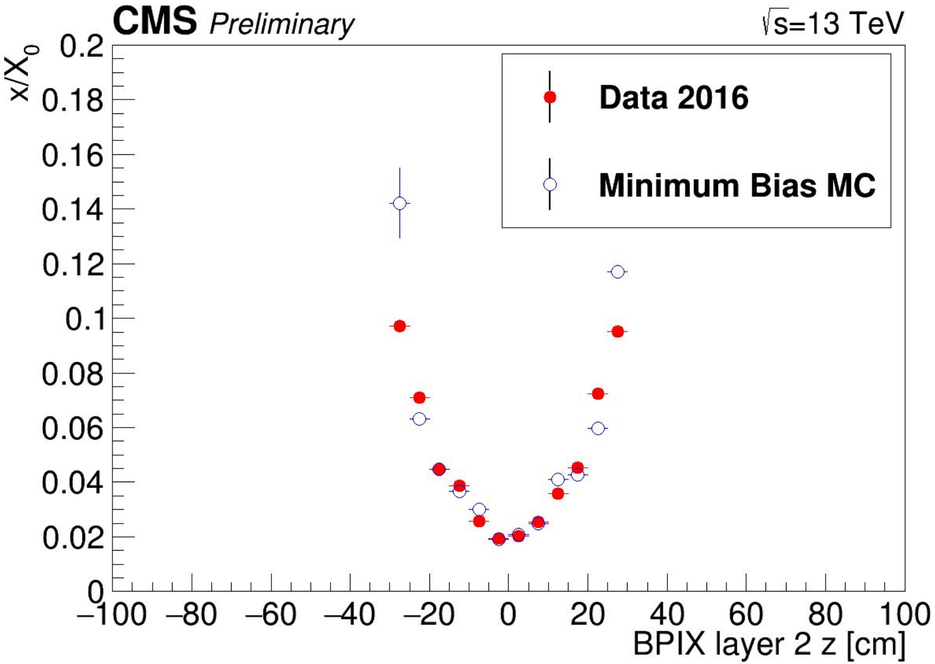
Radiation length for BPix Layer 2.

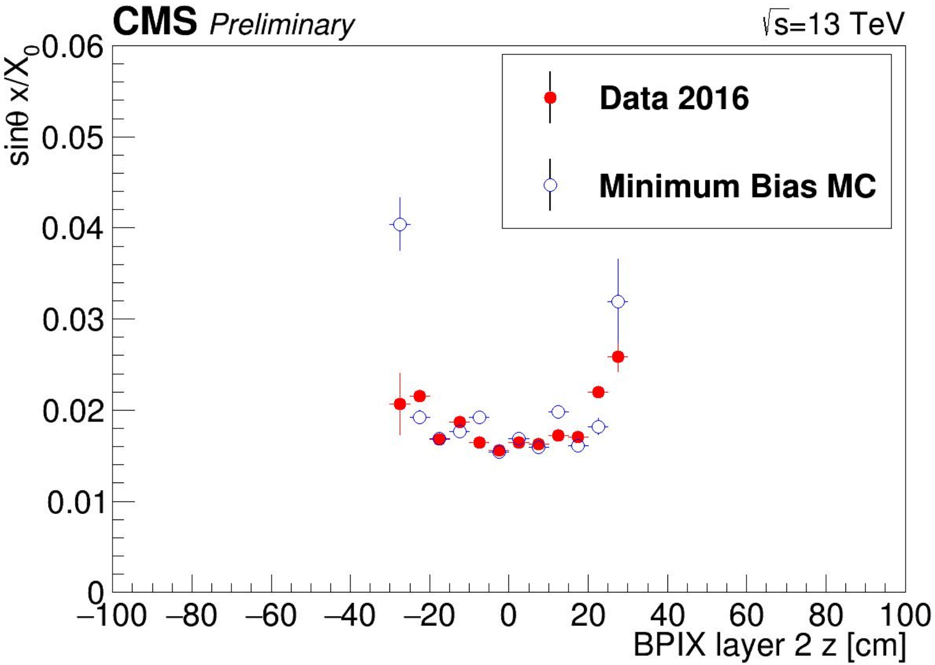




Caption:- Left: Distribution of the traversed radiation length, for DATA (MC) in red (blue) as function of the local η, for the events containing one hit in each of the three consecutive layers: BPIX layer 1, BPIX layer 2, BPIX layer 3. Right: Distribution of the traversed radiation length weighted by sine of the polar angle of the track, for DATA (MC) in red (blue) as function of the local η, for the events containing one hit in each of the three consecutive layers: BPIX layer 1, BPIX layer 2, BPIX layer 3.

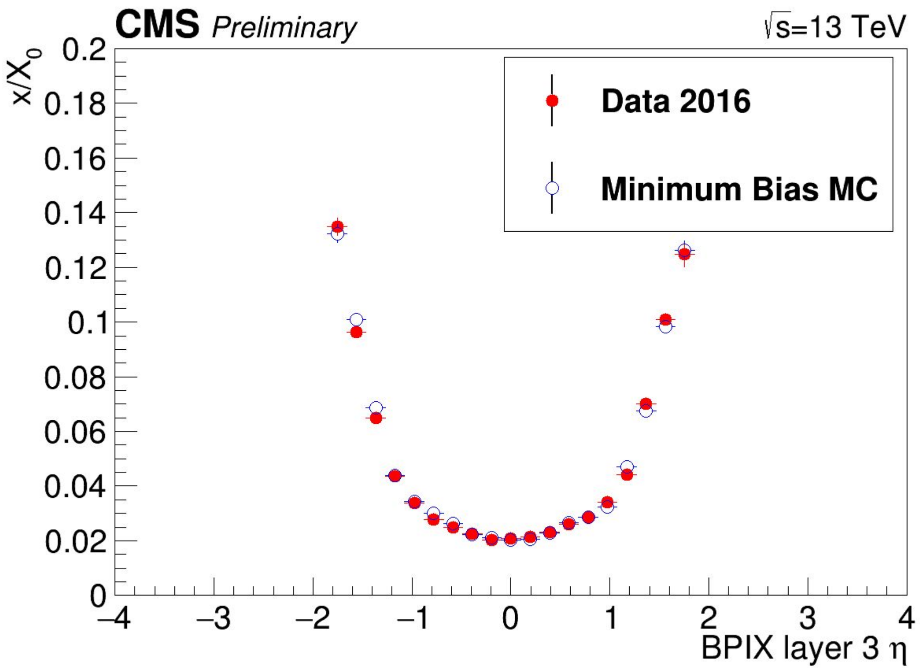
Radiation length for BPix Layer 2.

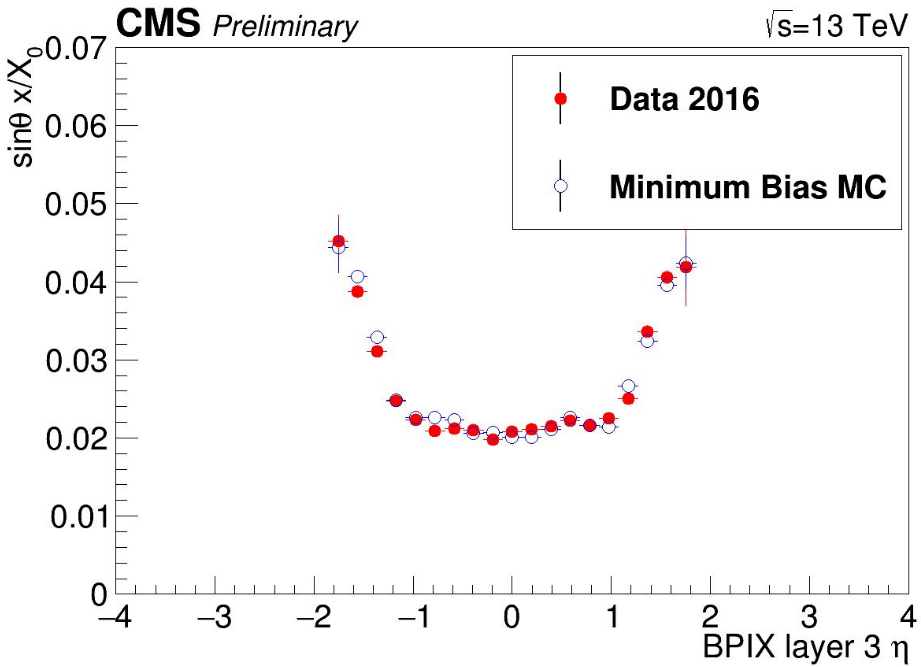




Caption:- Left: Distribution of the traversed radiation length, for DATA (MC) in red (blue) as function of the local z, for the events containing one hit in each of the three consecutive layers: BPIX layer 1, BPIX layer 2, BPIX layer 3. Right: Distribution of the traversed radiation length weighted by sine of the polar angle of the track, for DATA (MC) in red (blue) as function of the local z, for the events containing one hit in each of the three consecutive layers: BPIX layer 1, BPIX layer 2, BPIX layer 3.

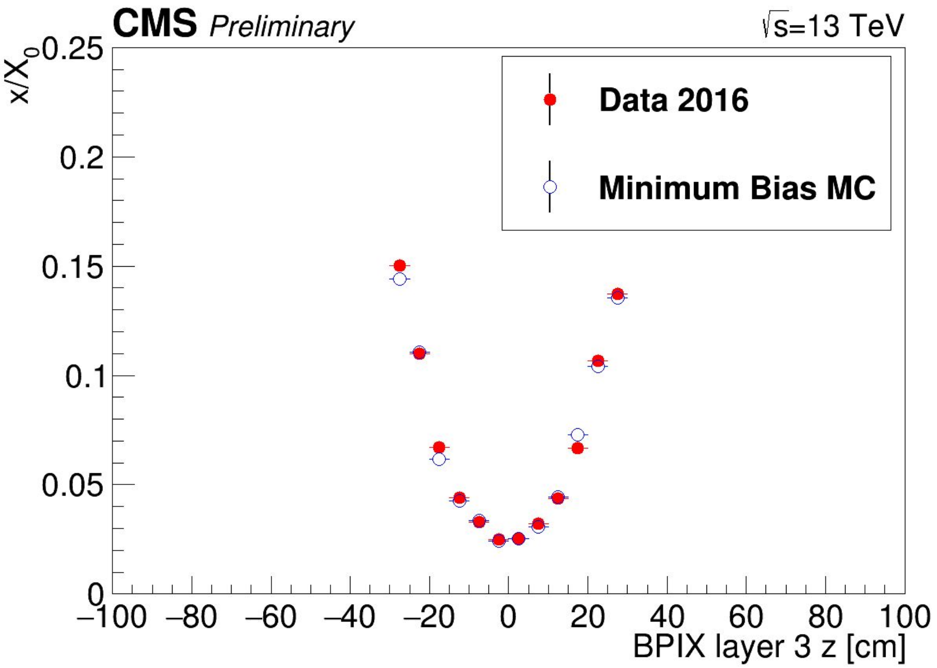
Radiation length for BPixel layer 3.

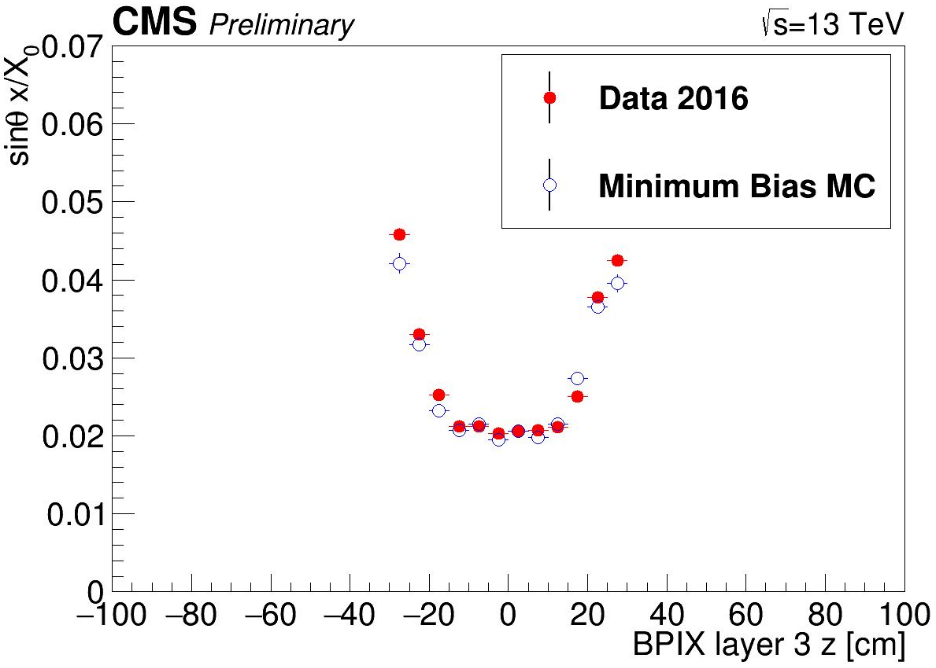




Caption: Left: Distribution of the traversed radiation length, for DATA (MC) in red (blue) as function of the local η, for the events containing one hit in each of the three consecutive layers: BPIX layer 2, BPIX layer 3, TIB layer 1.Right: Distribution of the traversed radiation length weighted by sine of the polar angle of the track, for DATA (MC) in red (blue) as function of the local η, for the events containing one hit in each of the three consecutive layers: BPIX layer 2, BPIX layer 3, TIB layer 1.

Radiation length for BPixel layer 3.





Caption: Left: Distribution of the traversed radiation length, for DATA (MC) in red (blue) as function of the local z, for the events containing one hit in each of the three consecutive layers: BPIX layer 2, BPIX layer 3, TIB layer 1.Right: Distribution of the traversed radiation length weighted by sine of the polar angle of the track, for DATA (MC) in red (blue) as function of the local z, for the events containing one hit in each of the three consecutive layers: BPIX layer 2, BPIX layer 3, TIB layer 1.

Conclusion

- A new method of estimating the material budget of the CMS tracker in situ, with ~ 1GeV tracks, has been presented.

- The radiation length has been measured in data and simulation for the Pixel detector with Phase 0 geometry.

- We notice that, while the distribution of the material in BPIX layer 2 is almost flat(when weighted by sin θ), the one showing the material in BPix layer 3 starts increasing from a value of $|\eta| > 1$. This effect is due to the fact that in the region of η concerned, between the last layer of the pixel detector and the first layer of the TIB, the approximation of constant material fails since the material of the cables and cooling adds to the measurement.

- With CMS aiming for several precision measurements, the precise estimation of material budget can be used as an input for momentum calibration since momentum measurement is affected by the material budget of the tracking system.

- Studies are ongoing to validate the model with the strip detectors of the CMS tracker.

References

[1] E. Manca, “Validation of the muon momentum resolution in view of the W mass measurement with the CMS experiment”, CERN TS-2016-024. http://cds.cern.ch/record/2233647

[2] J.B. Marion and B.A. Zimmerman. Multiple scattering of charged particles. Nuclear Instruments and Methods, 51(1):93 – 101, 1967.