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CMS Silicon Strip Tracker Performance Results with Early 2024 Data

CMS Collaboration

Abstract

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CMS Silicon Strip Tracker Performance Results with Early 2024 Data

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Abstract

The CMS silicon strip tracker consists of inner barrel (TIB) layers, inner discs (TID), outer barrel (TOB) layers, and end-caps (TEC), which close off the tracker on either end. It has been successfully recording data during both Run 1 and Run 2 data taking at the Large Hadron Collider (LHC). Run 3 was resumed in 2022, three years after a long shutdown. In 2023, the CMS silicon strip tracker operated at -22°C. During the LHC technical stop No. 1 in 2024, from June 10 to 15, it was cooled down to -25°C. This document provides the silicon strip tracker performance during the early 2024 data taking from proton-proton collisions, produced at the centre of mass energy of 13.6 TeV.

The performance results focus on data taken in 2024 until August. They comprise signal-to-noise ratio as well as trends as a function of both instantaneous and integrated luminosity, hit efficiency as a function of the instantaneous luminosity and the pileup, hit resolution, evolution of bad module components, and the measurement of the energy loss.

Signal-to-noise ratio

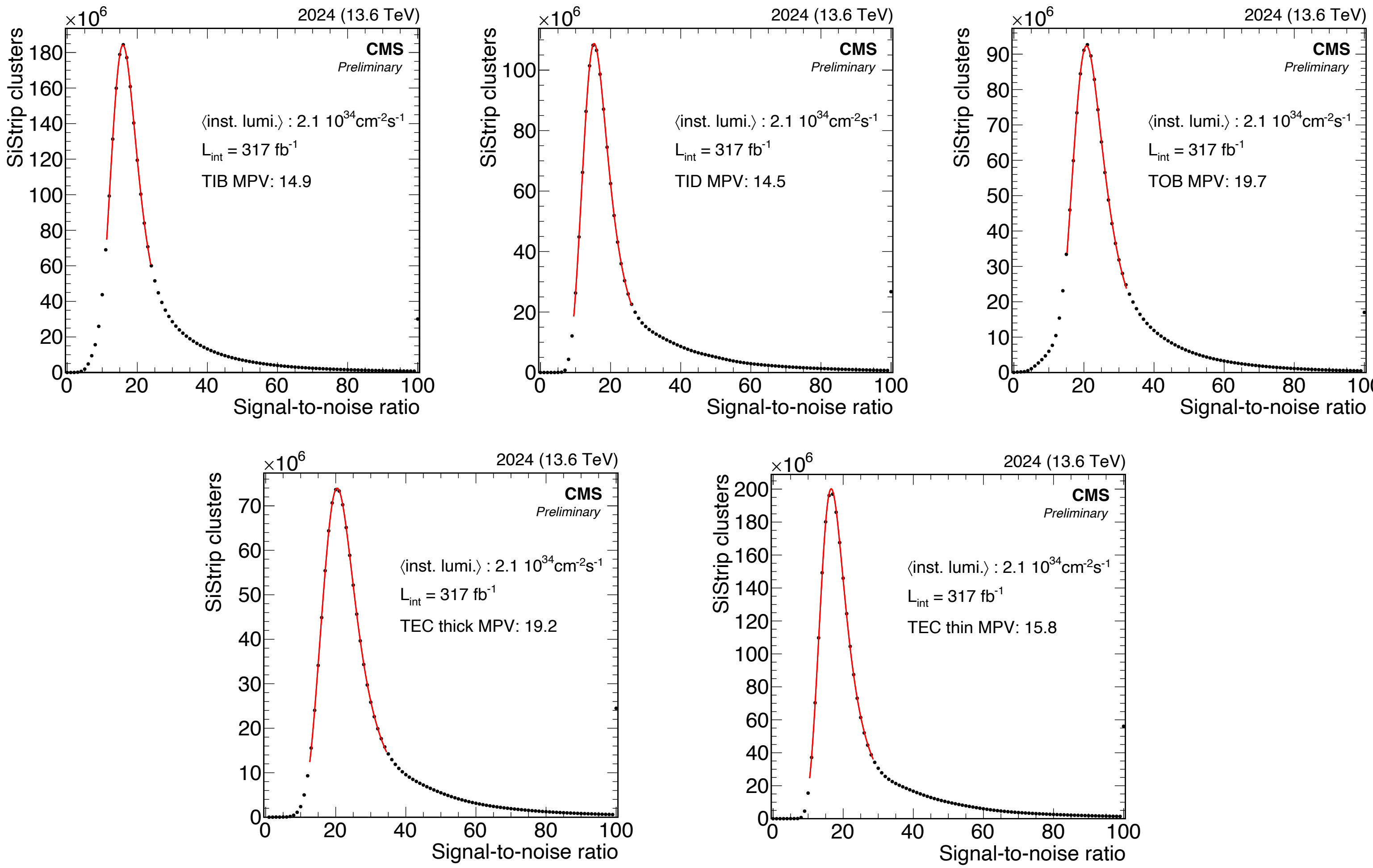


Figure 1: The Signal-to-noise ratio, corrected for pathlength inside the silicon, is shown for an early 2024 13.6 TeV pp collisions run where the silicon strip tracker was operated in deconvolution mode (nominal conditions), and cooled down to -25°C. The position of the MPV of the peak is given, estimated from a fit to a Landau convoluted with a Gaussian distribution. The lifetime integrated luminosity of high-energy pp collisions delivered by the LHC was 317 fb^{-1}.

Signal-to-noise ratio trend

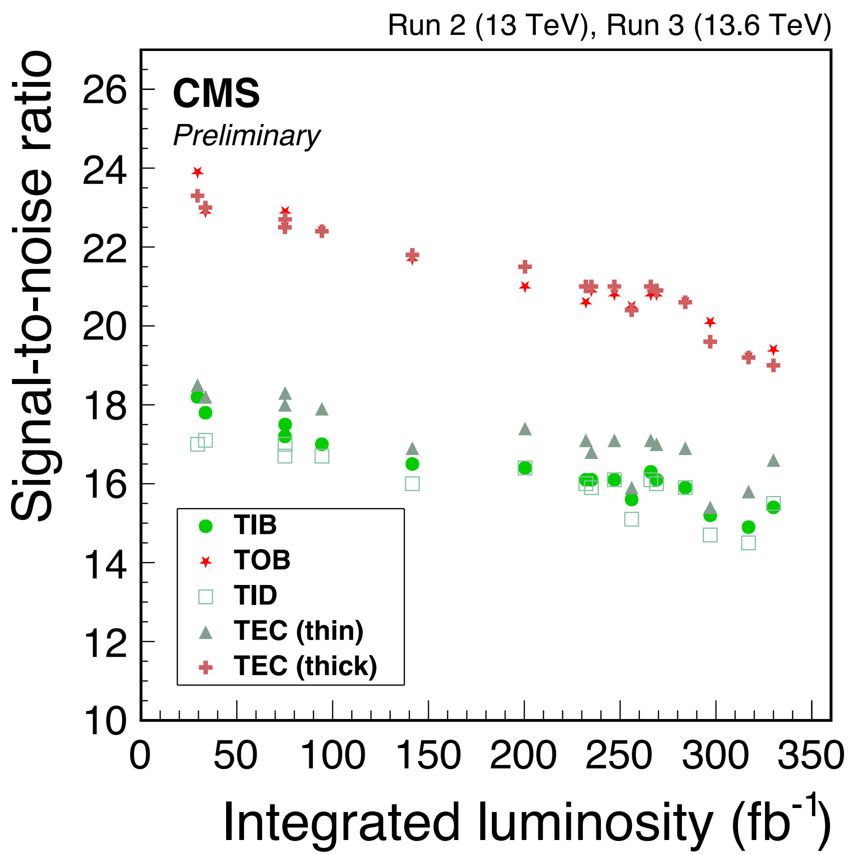


Figure 2: The Signal-to-noise ratio (S/N) measured in pp collisions since Run 2 is reported as a function of the integrated delivered luminosity. Measurements have been performed split per sensor thickness in the Tracker End-caps (320 μm or 500 μm). The S/N scales with integrated luminosity.

Signal-to-noise ratio trend

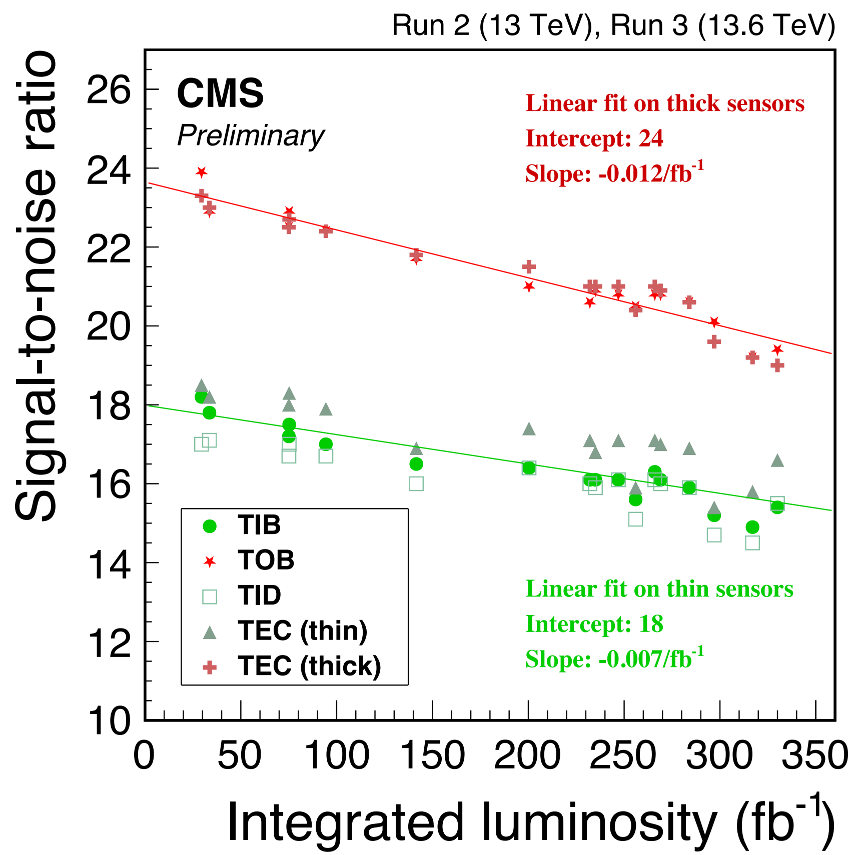


Figure 3: The Signal-to-noise ratio (S/N) measured in pp collisions since Run 2 is reported as a function of the integrated delivered luminosity. Measurements have been performed split per sensor thickness in the Tracker End-caps (320 μm or 500 μm). The S/N scales with integrated luminosity. The data were fitted with a linear function.

Hit efficiency

The **hit efficiency** is defined as the ratio of detected hits to the number of expected hits belonging to a track. Regular measurements of the hit efficiency are made using collision and cosmic data.

Only high-quality tracks are selected for the measurement of the hit efficiency. Tracks are selected with the following cuts:

- A transverse momentum of $p_T > 1$ GeV,
- At least 11 valid hits.

To reduce false track-to-cluster association, only tracks that have no additional trajectories within 5 mm are considered. Hits from the pixel layer under study are not removed when the tracks are reconstructed.

Hit efficiency

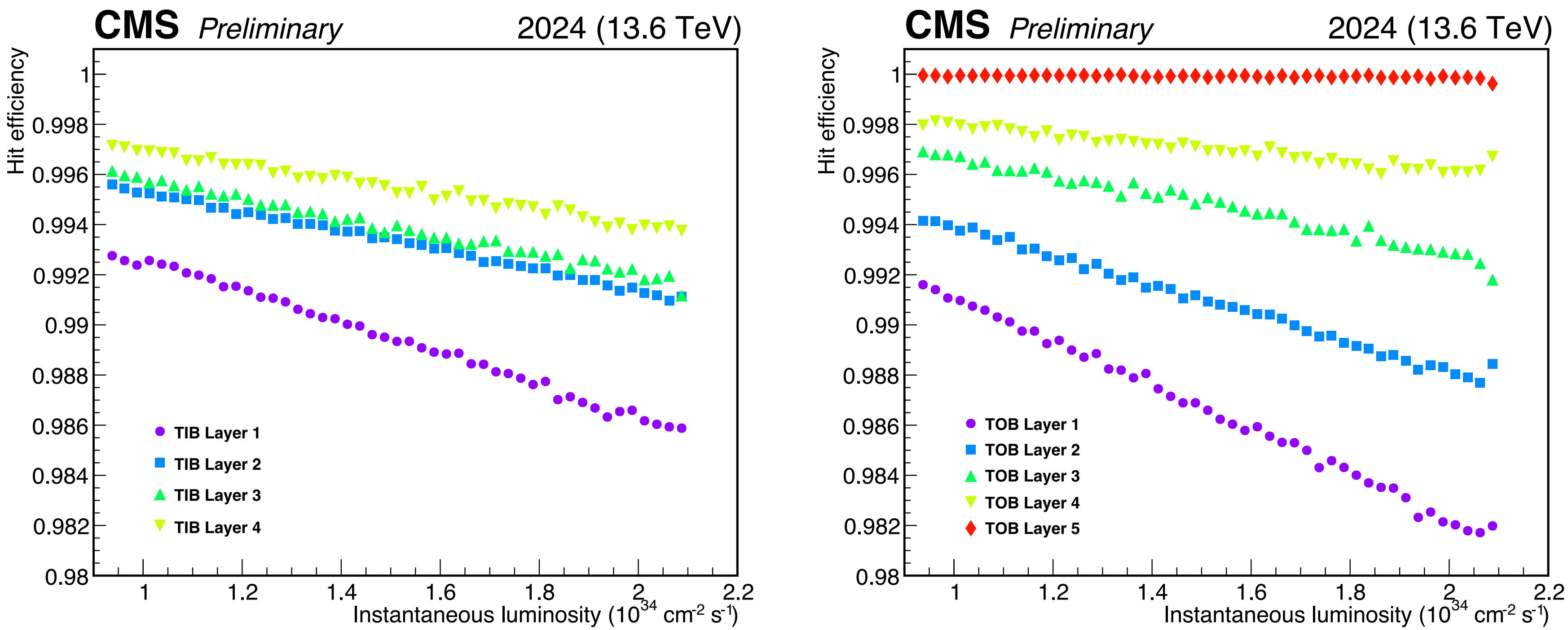
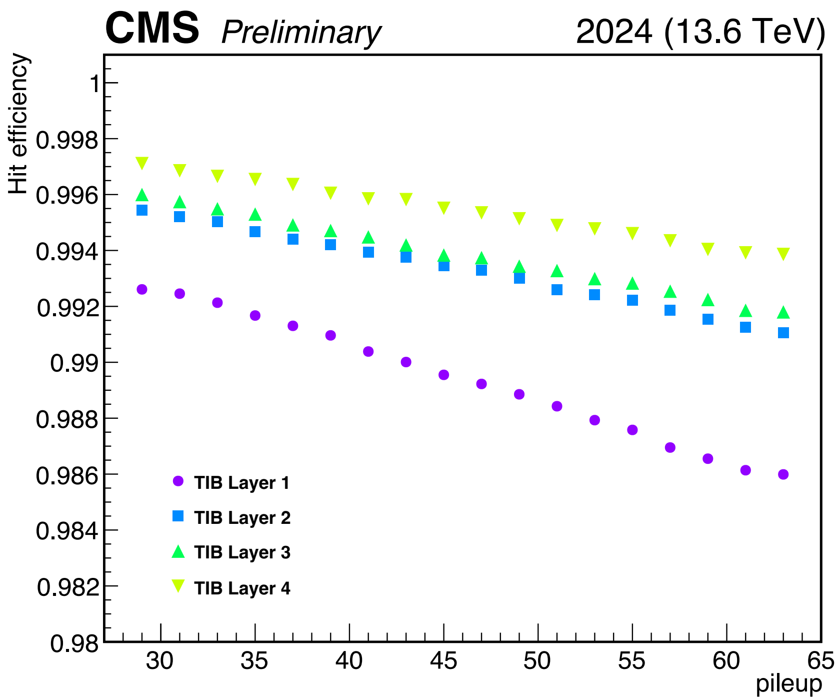


Figure 4: Hit efficiency of Silicon Strip detectors from four tracker inner barrel (TIB) layers (left) and five tracker outer barrel (TOB) layers (right) as a function of the instantaneous luminosity. Data from a 13.6 TeV fill taken in May 2024 were used. For a standard fill, the luminosity is under $2.2 \cdot 10^{34}$ cm^{-2} s^{-1}.

Hit efficiency



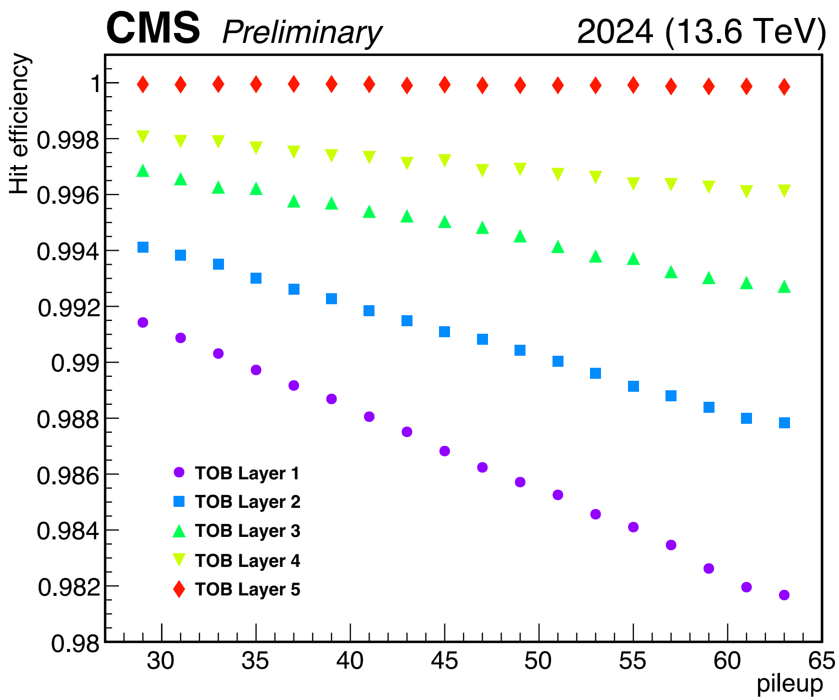


Figure 5: Hit efficiency of Silicon Strip detectors from four tracker inner barrel (TIB) layers (left) and five tracker outer barrel (TOB) layers (right) as a function of the pileup. Data from a 13.6 TeV fill taken in May 2024 were used. For a standard fill, the luminosity is under $2.2 \cdot 10^{34}$ cm^{-2} s^{-1}.

Hit resolution

The **strip hit resolution** is computed by using hits in overlapping modules of the same layer ("pair method").

Tracks are selected with the following cuts:

- A transverse momentum of $p_T > 3$ GeV,
- At least 8 valid hits,
- A track χ^2 probability $\geq 10^{-3}$.

Hits pairs are selected by requiring:

- At most 4 strips cluster width,
- Clusters that are of the same width in both the modules,
- Predicted path (distance of propagation from one surface to the next) < 7 cm,
  i.e. only pairs within the same layer are allowed,
- Error on predicted distance in the bending coordinate between the two hits < 25 μm.

Reference: PoS (Vertex 2017) 013: https://pos.sissa.it/309/013/pdf

Hit resolution

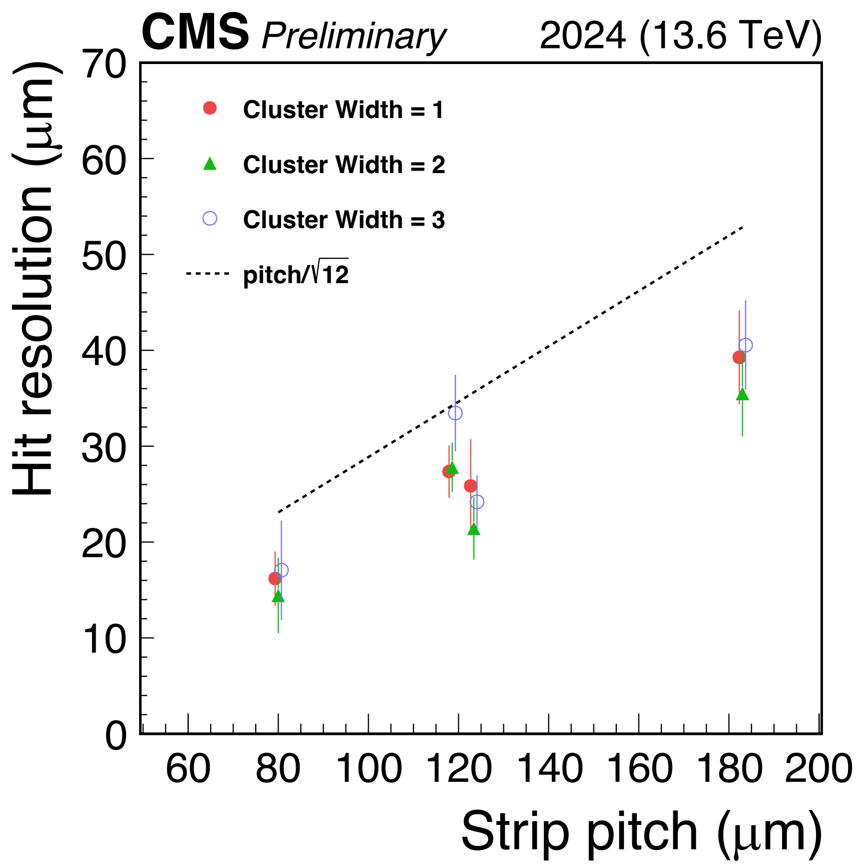


Figure 6: Strip hit resolution is shown for an early 2024 13.6 TeV pp collisions run where the silicon strip tracker was operated in deconvolution mode (nominal conditions) and cooled down to -22°C. Strip hit resolution is derived by selecting pairs of hits in different types of overlapping sensors and for different cluster widths expressed in units of number of strips. The theoretically expected resolution from a binary readout tracking detector (i.e., hit or no hit) is also displayed, showing that the silicon strip tracker hit resolution is consistently better than this limit.

Energy loss measurement

The **energy lost** is estimated by using events with a good reconstructed primary vertex, tracks passing the high purity selection and using the cuts listed below:

- At least 8 valid hits,
- At least 2 pixel hits,
- A fraction of valid hits on the trajectory of at least 80%,
- A transverse momentum of p_T > 0.5 GeV,
- A momentum of p < 50 GeV,
- A track impact parameter in the transverse plane of $|\mathrm{d_{xy}}|$ < 0.5 cm,
- A track impact parameter in the longitudinal direction of $|\mathrm{d_z}|$ < 0.5 cm,
- A relative uncertainty on the transverse momentum of $p_{T,err}/p_T$ < 0.25,
- A track reduced chi square of χ^2/ndf < 5.

For each track, the energy loss estimator is computed from the dE/dx of the associated hits in the silicon strip tracker using the harmonic mean of grade k = -2:

$$\frac{dE}{dx} = \left(\frac{1}{N}\sum_i (\Delta E/\Delta x)^k\right)^{\frac{1}{k}}$$

Energy loss measurement

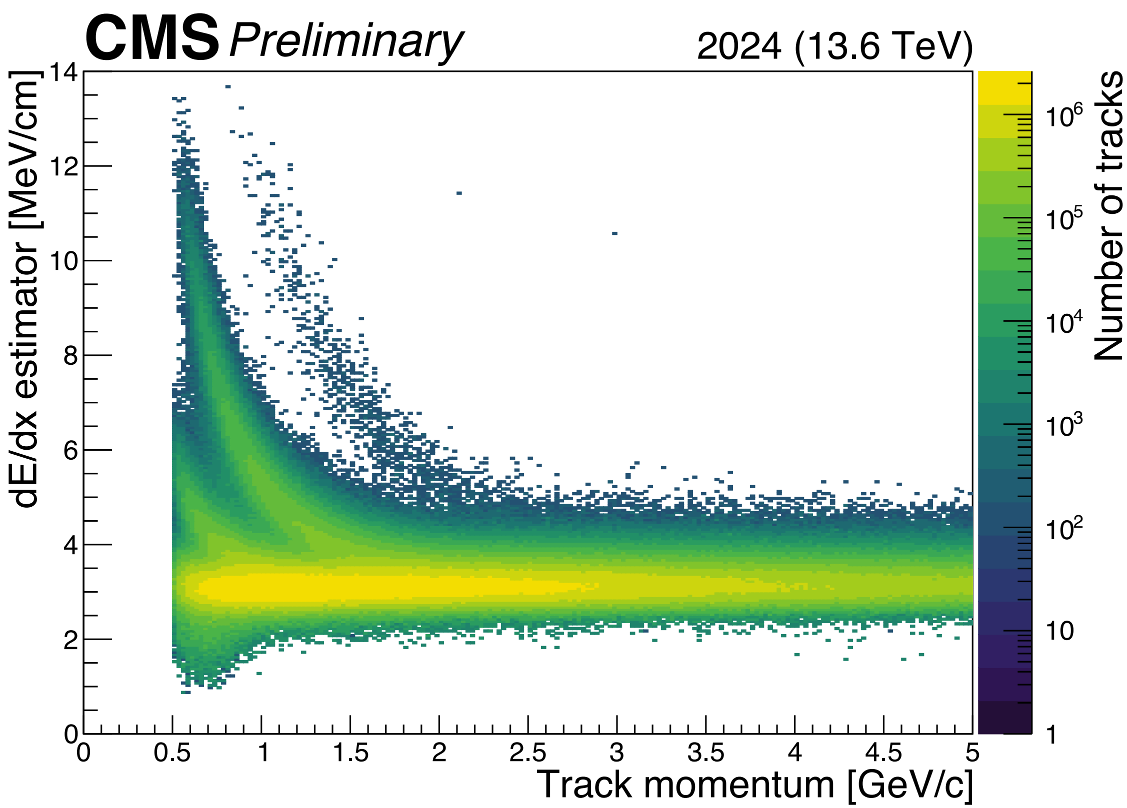


Figure 9: Energy loss measurement as a function of the track momentum using the Pixel-Less Harmonic-2 estimator. From right to left we can clearly see the deuteron, proton, kaon, and pion bands.

Energy loss measurement

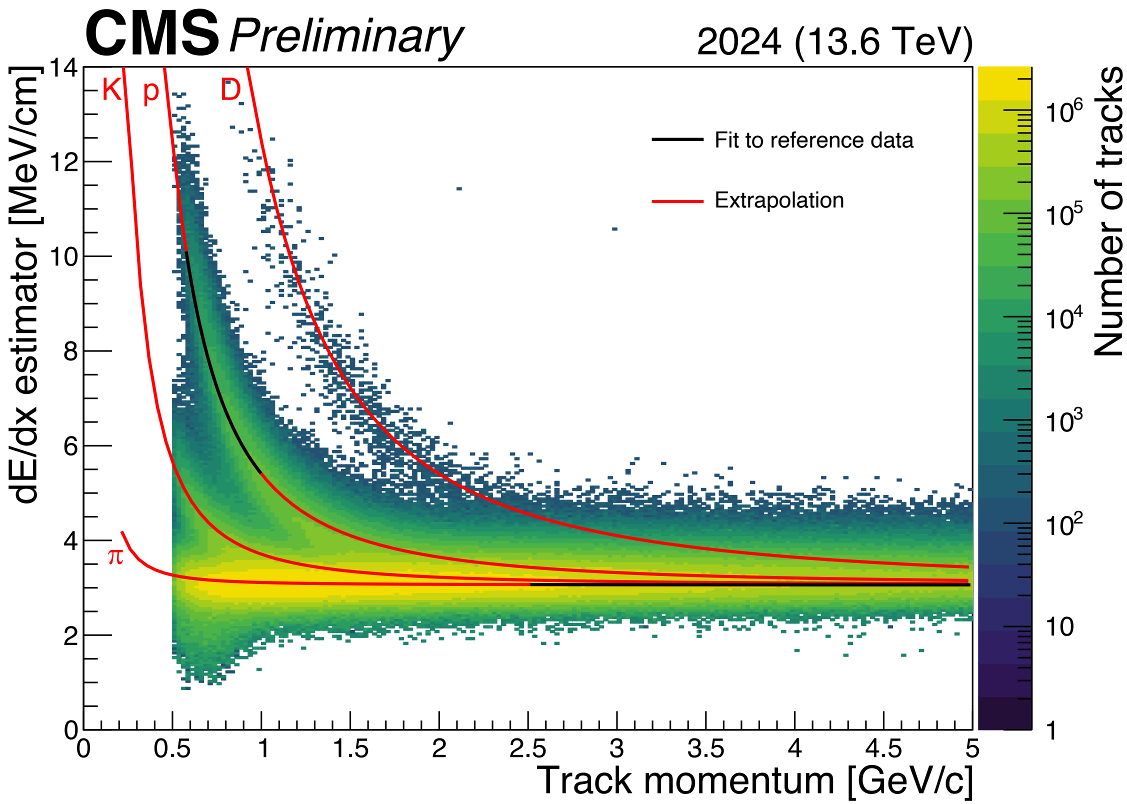


Figure 7: Energy loss measurement as a function of the track momentum using the Pixel-Less Harmonic-2 estimator. The data were fitted on the shown proton and pion band using the function $\frac{dE}{dx} = K\frac{m^2}{p^2} + C$ where K and C are the fit parameters, that was then extrapolated on the deuteron and kaon bands.

Energy loss measurement

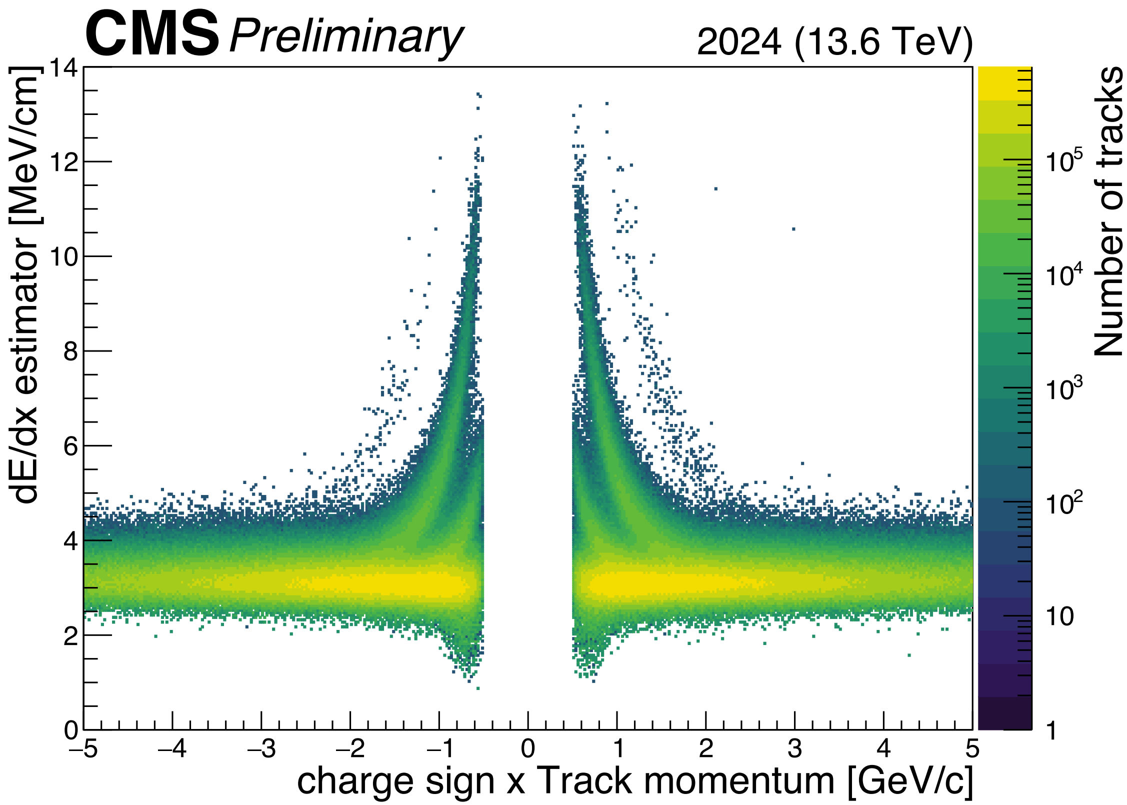


Figure 8: Energy loss measurement as a function of the track momentum times sign of charge using the Pixel-Less Harmonic-2 estimator.

Bad components

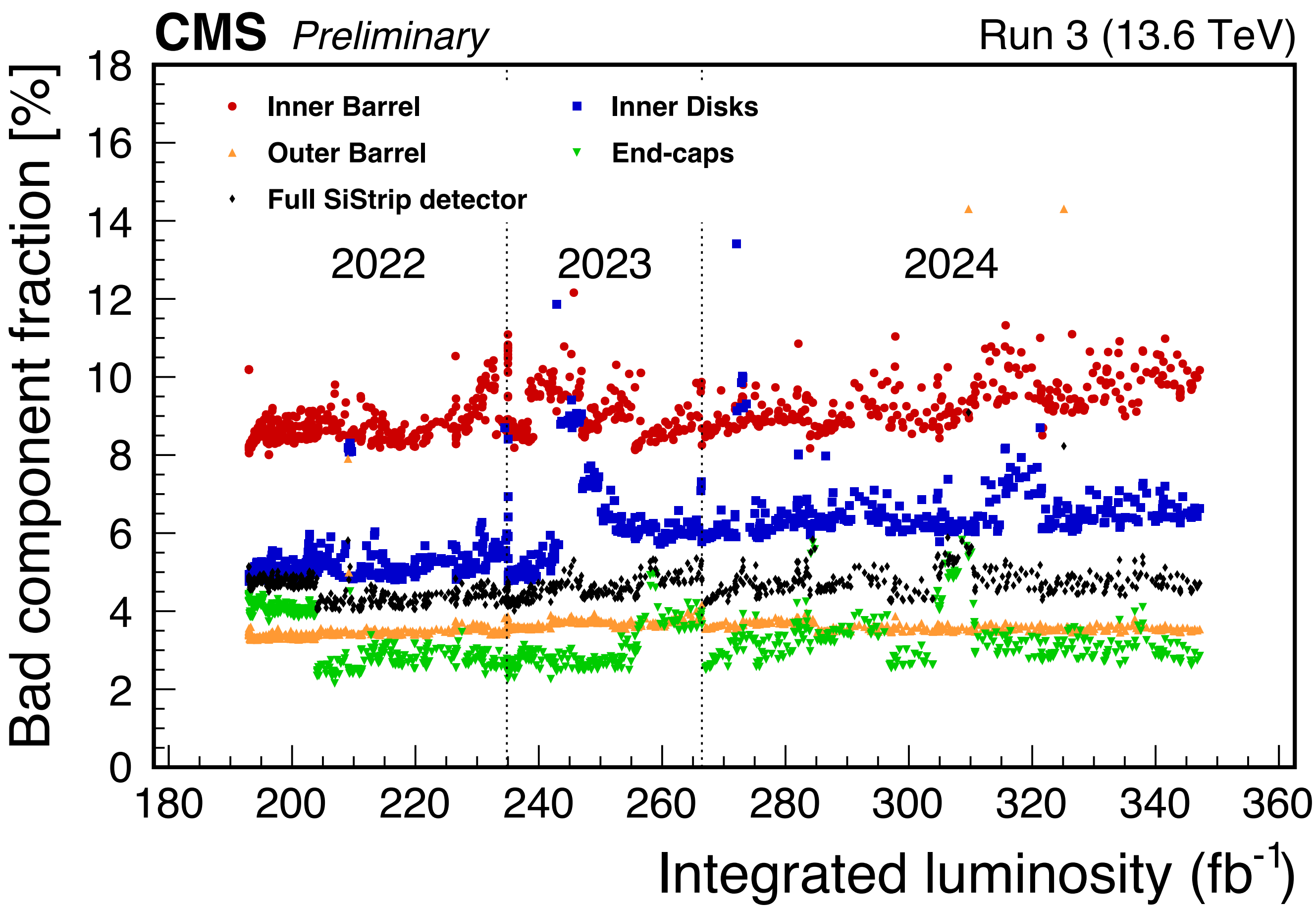


Figure 10: The evolution of the global fraction of module components flagged as bad for offline reconstruction for pp collisions at a centre of mass energy of 13.6 TeV as a function of integrated delivered luminosity. The data include 2022, 2023, and part of 2024 up to 19/08/2024. The initial offset of 193 fb^{-1} corresponds to the integrated luminosity of Run 1 and Run 2. The drop in bad module fraction around 205 fb^{-1} is due to the recovery of a cooling loop in End-caps. The several jumps in bad module fraction are due to many modules whose power supplies were turned off.