Simulation of the Dynamic Inefficiency of the CMS Pixel Detector

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Introduction

The Compact Muon Solenoid (CMS) is one of the two general-purpose detectors that measure the products of high energy particle interactions at the LHC. The Silicon Pixel Detector is the innermost part of the CMS Tracker, it has to prevail in the hardest environment in terms of particle fluence and radiation.

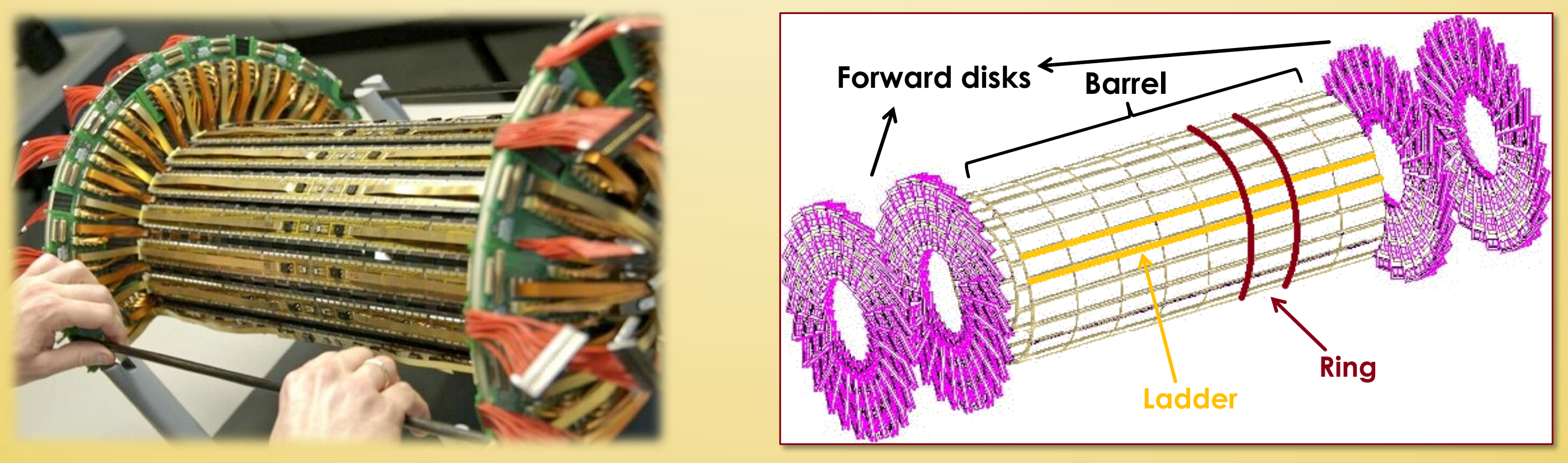

Figure 1: Picture and structure of the Pixel Detector

Several effects may change the efficiency of the detector. There are permanently damaged detector parts (most of them are repaired for the next run period), modules with read-out errors (buffer overflows, time-outs) and Single Event Upsets (SEU). The last one is caused by ionization radiation by flipping the memory state of a chip. This may affect individual pixels, Read-Out Chips (ROC) or the readout electronics of entire modules. The SEUs are solved by reprogramming. Excluding all these effects, there is still a significant efficiency loss that we call dynamic inefficiency.

Dynamic Inefficiency

In a series of high multiplicity events, the buffers (mainly data and time-stamp buffers) of the ROC may overflow which results in data losses that decrease the efficiency. The inefficiency is dynamic in a sense that the size of the effect depends on previous and current events.

The ROC reads out the data of the pixels in double columns. In case of a buffer overflow, all the hits of the double column are lost. Individual pixels and entire ROCs can be inefficient, but data suggests that double column loss is the dominant effect.

In order to properly simulate dynamic inefficiency one would need to use the full simulation of the ROCs, in addition to store the history of several events, which is not achievable in the current CMS simulation software.

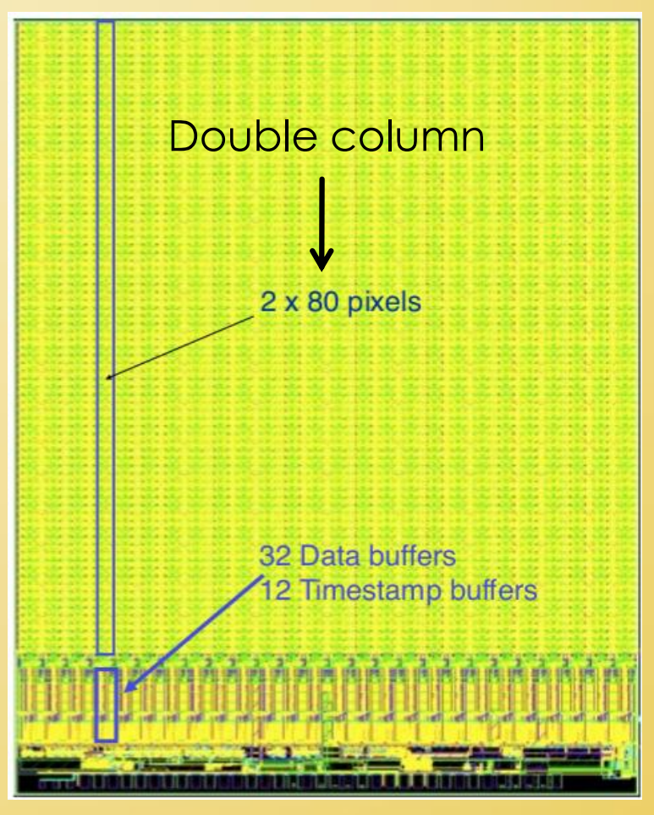

Figure 2: Read-Out Chip

Therefore, a data-driven method has been developed, in which the efficiency is parameterized for each module as a function of instantaneous luminosity and module position (layer, ladder and ring coordinates). This way, the dynamic inefficiency is independent of the quality of the physics simulation, but has to be calibrated for different run conditions. In all three layers of the barrel pixel, the dynamic inefficiency is simulated by double column loss. Results are shown for layer 1 where the effect is visible.

Simulation

The method has been validated by comparing the old and the new simulations to data. The hit efficiency of each module in the simulation is matched to the 8 TeV proton-proton collision data as a function of the instantaneous luminosity and the module positions.

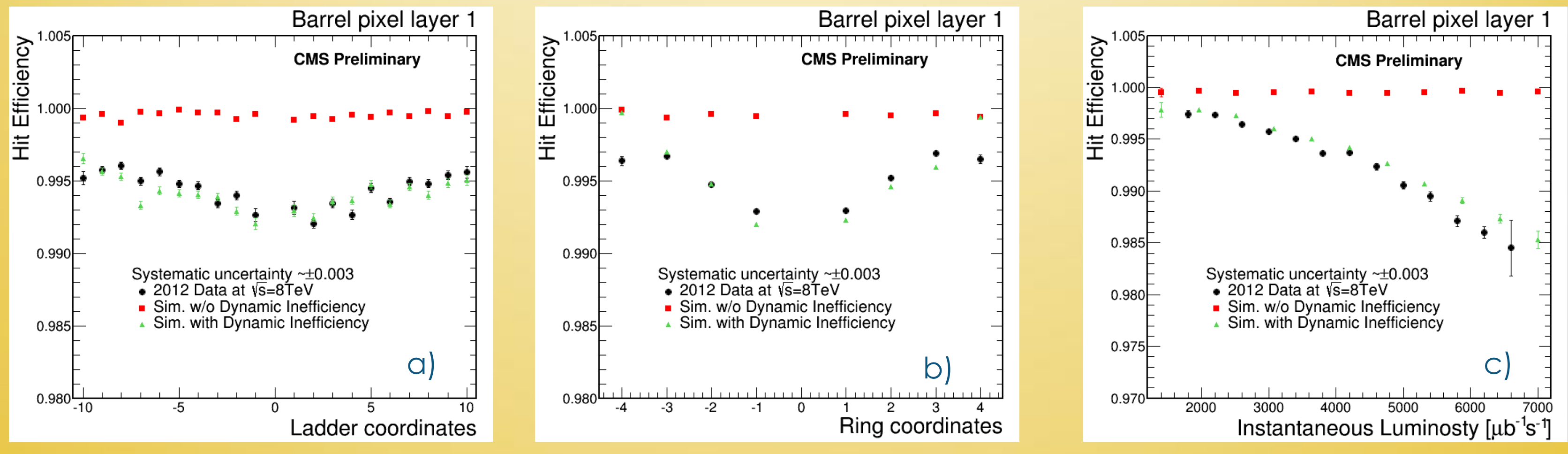

Figure 3: Three variables that the dyn. ineff. simulation is parameterized by: ladder coordinates (correspond to azimuthal angle φ), ring coordinates (correspond to beam axis with collision point in the middle), and instantaneous luminosity

Results

Double column loss method is verified through comparison of track incidence angles parallel (incidence angle α) and perpendicular (incidence angle β) to double columns. In case of double column loss causing the inefficiency, hit efficiency should be independent of incidence angle α, and depend on incidence angle β.

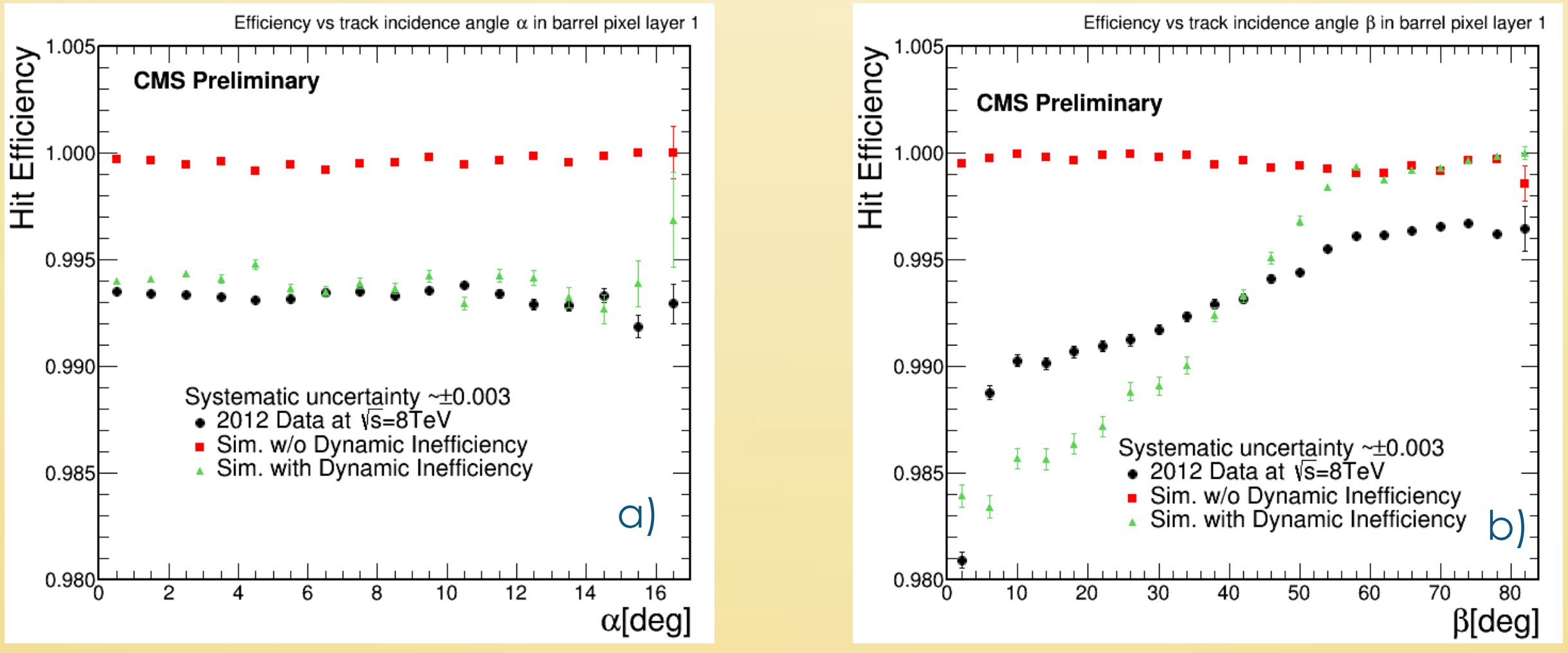

Figure 4: Efficiency dependence on track incidence angles

The incidence angle dependence plots support the assumption that double column loss is the dominant effect. But the shape of Fig.4/b shows that there are other effects behind the inefficiency which can be individual pixel or ROC loss.

The observables that clearly depend on dynamic inefficiency are hard to find. Many parameters were studied in order to cross-check the method, the distribution of number of tracks and clusters showed the most improvement.

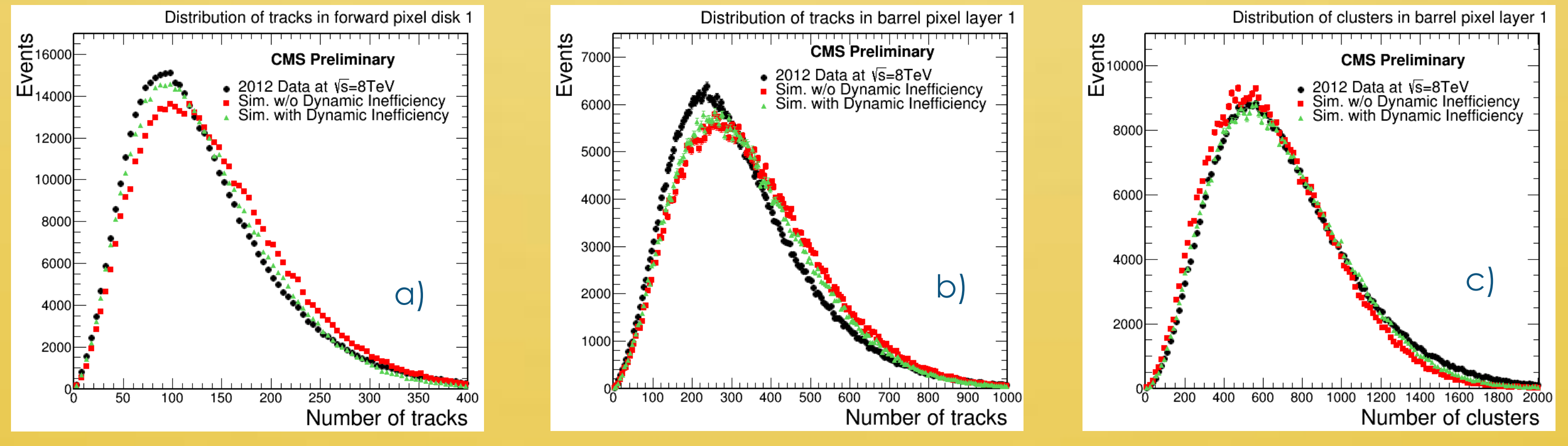

Figure 5: Distribution of number of tracks and clusters in forward and in layer 1

The simulated distribution of the number of tracks crossing the forward disks compares to data better than that of those crossing the first layer because track reconstruction in forward region is more sensitive to barrel hits. Distribution of number of clusters has improved due to cluster splitting by double column loss.

Conclusion

The CMS simulation software has been improved by taking into account the dynamic inefficiency of the pixel detector. A data-driven method was developed which has to be calibrated under different run conditions. The technique has been validated by comparing several variables in data and Monte-Carlo. The new simulation shows better agreement with data. Further improvement of the simulation is feasible such as including entire ROC and individual pixel loss.

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References

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