CMS Pixel Upgrade: Robustness Studies of the CMS Tracker

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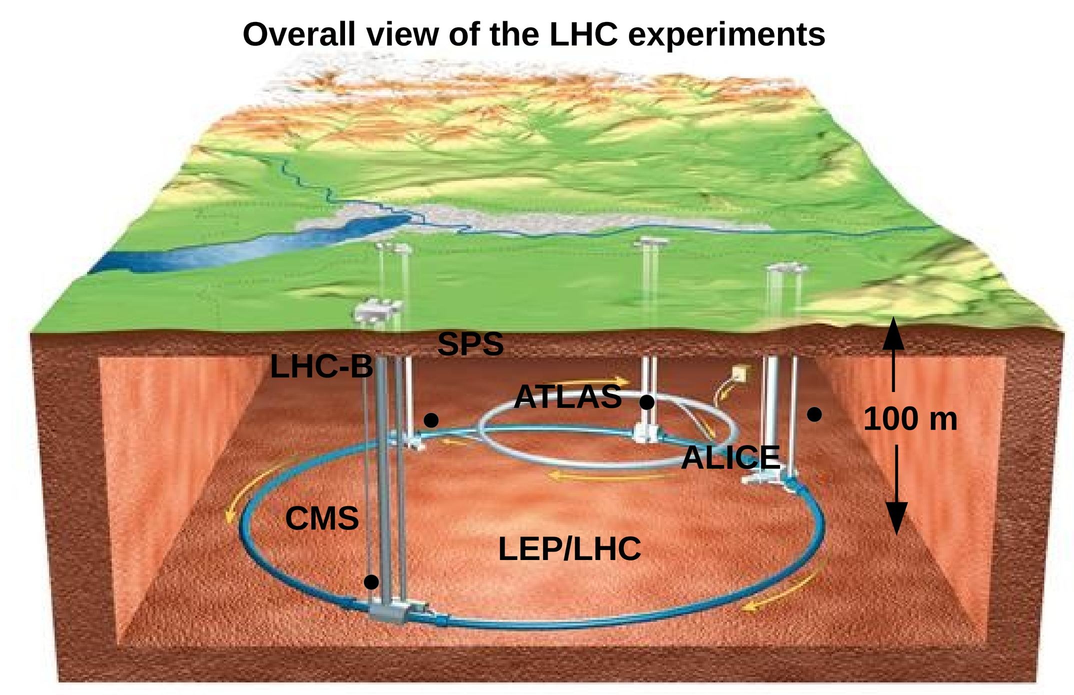
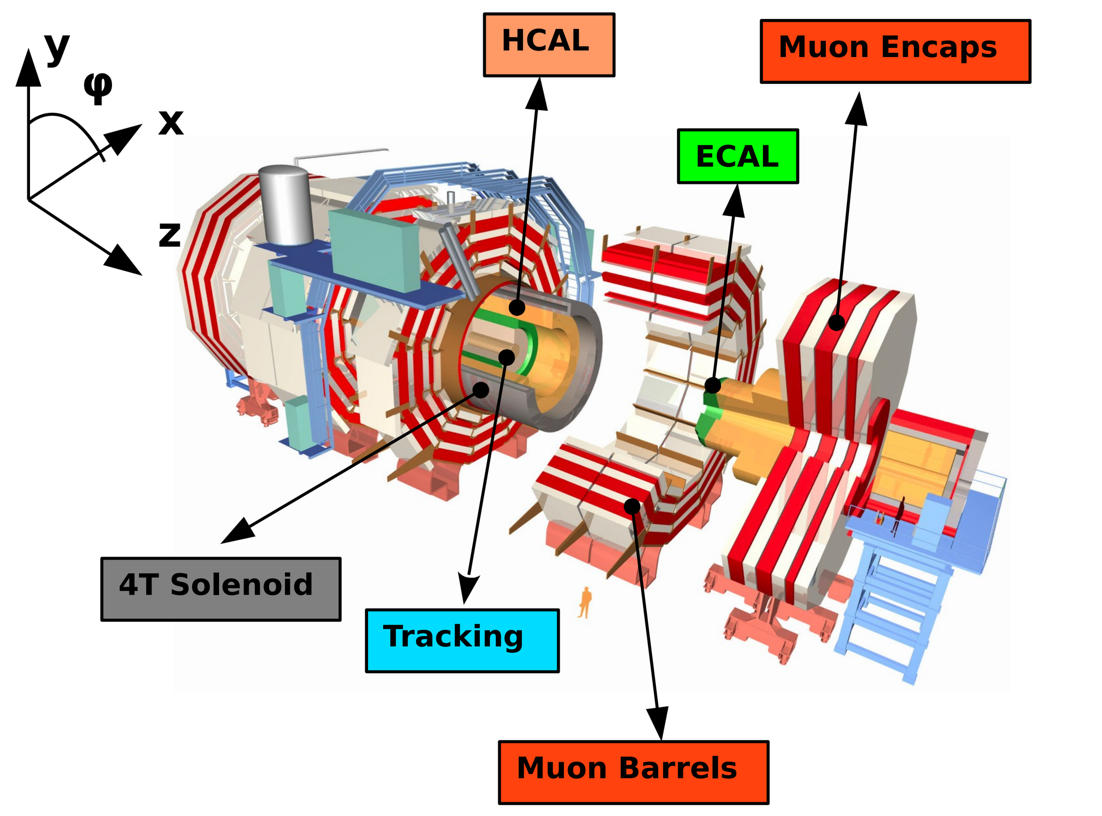
The LHC

The European Organization for Nuclear Research (CERN) is a complex of many accelerators, of which the highlight is a 27km long ring of superconducting magnets with circular structures to boost the energy of the particles along the beam pipe. The beams inside the LHC will be made to collide at four points around the accelerator ring, corresponding to the positions of the four particle detectors; CMS, ATLAS, LHCb & ALICE. Currently the LHC just successfully completed a set of runs at $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with several increases in luminosity and √s= 13 TeV COM energy planned.



The Compact Muon Solenoid (CMS)

The CMS detector is 21.6 m long and has a diameter of 14.6 m, its total weigh is 12500 tons. Its principal characteristic is a huge, high magnetic field (4 Tesla) solenoid, 13 meters in length, and 6 meter in diameter. It was designed to envelop the electromagnetic and hadron calorimetry, all of which surrounds tracking system and allows for the accurate detection of muons..

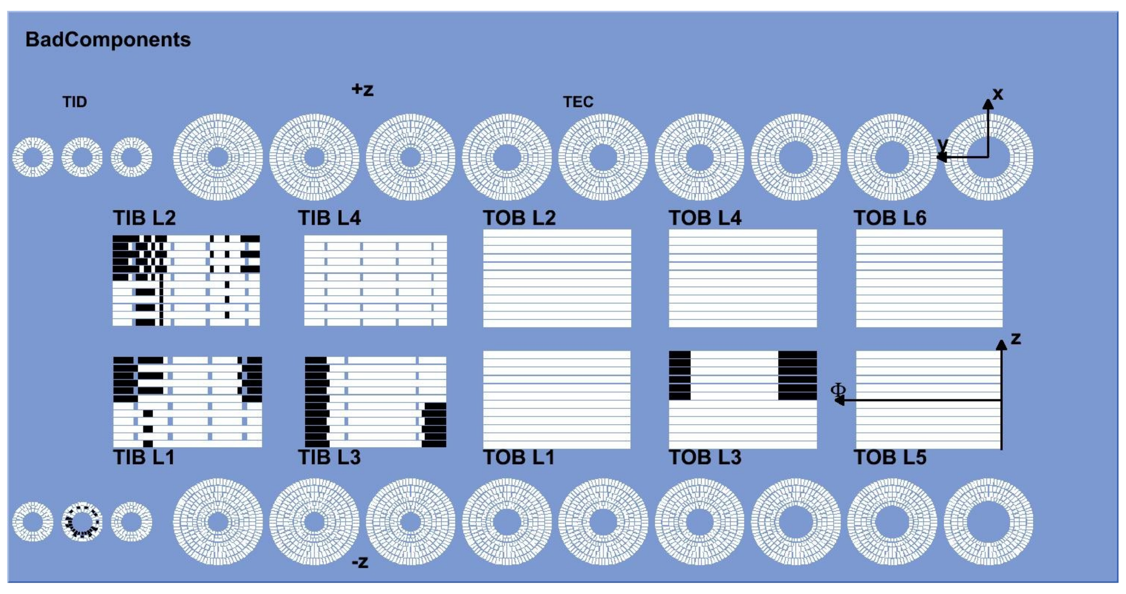


Simulation

The ability of the pixel upgrade to ameliorate inefficiencies in the CMS Tracker Inner Barrel (TIB) detector is presented in this study. In the first scenario we present a degradation study of the TIB by simulating a homogeneous inefficiency of the strip detector due to data loss in the first two layers of the TIB. In the second scenario we simulate specific dead modules which could be degraded or expected to fail at high radiation conditions. Both scenarios are done in two different luminosities. The first (Zero Pileup) with only the signal sample simulated. The second (2E34 cm-2s-1) which at 25ns bunch spacing corresponds to an additional 50 Pileup events in addition to the signal sample.

CMS Tracker Map

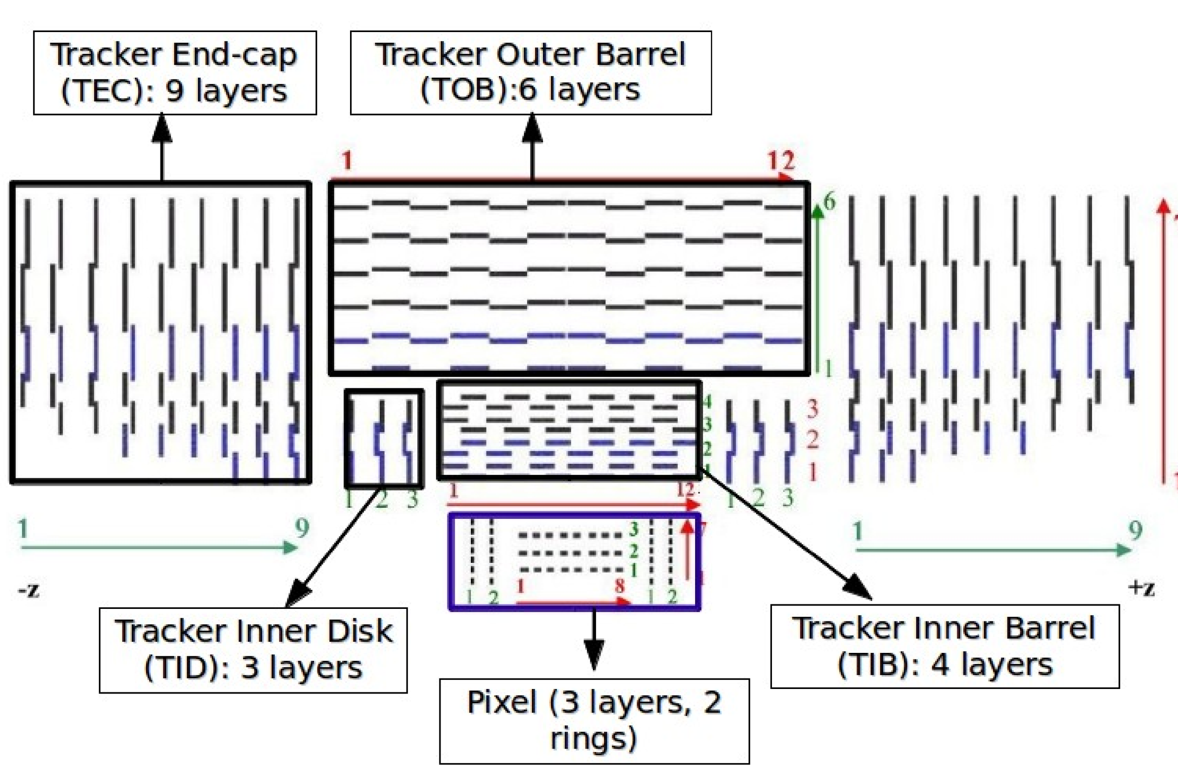
The CMS tracker has 75 million readout channels organized in 16924 modules each one being a complete detector.

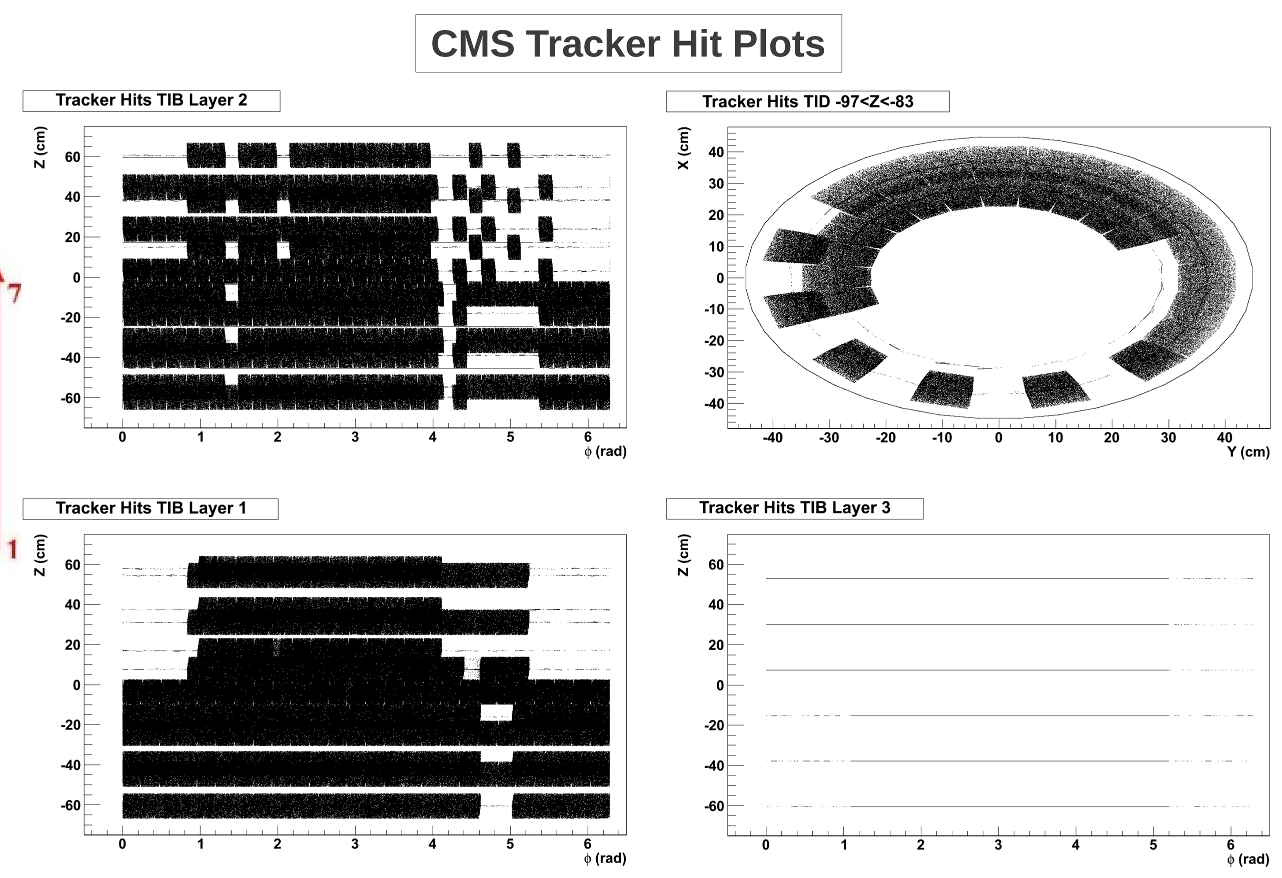


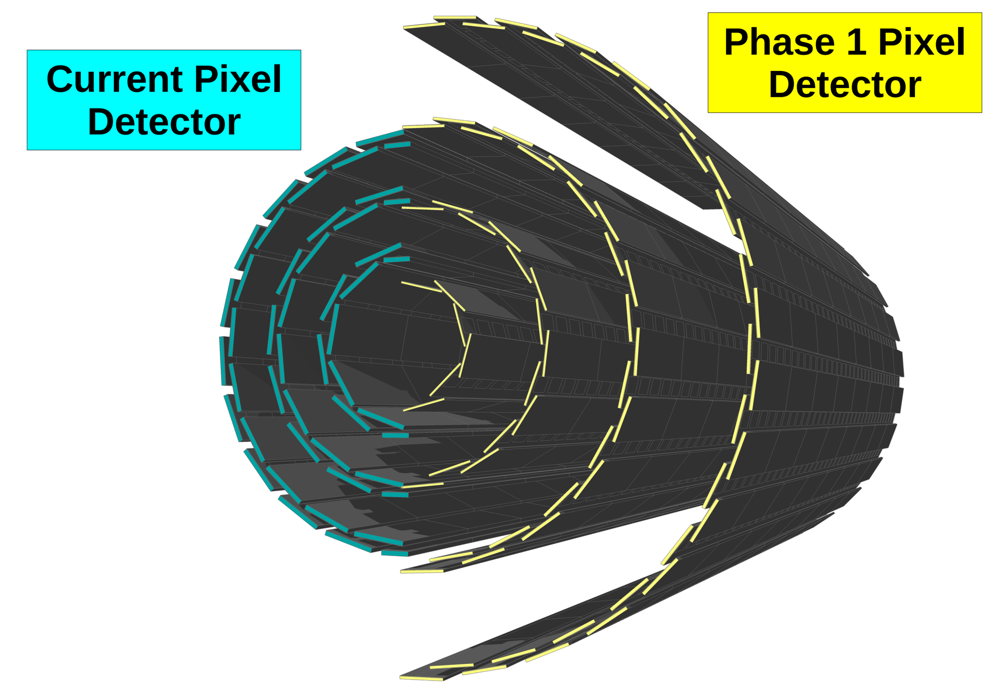
A single module is identified by a unique id with the numbers giving its layer, ring and module position in the ring (dependent on phi). The black modules in the outer tracker are currently operating at higher than design temperatures due to insufficient cooling and has the potential for problems in the future.

CMS Tracking Chamber

The Tracking Chamber occupies the most inner region of CMS. It is composed by several cylindrical concentric layers that are extending from 0.2 m to a radius of 1.1 m and has a length of 5.6 m along the beam pipe direction. These cylindrical structures are what make up up the Tracker Inner Barrel (TIB) and the Tracker Outer Barrel (TOB). The TIB has four barrel layers assembled in shells; the two innermost layers host double-sided detectors glued back to back for provide an accurate measurement of the r − φ and z coordinates of charged particles. Three small disks (TIB) at each end of the TIB provides additional coverage. The TOB consists of six concentric layers, also with double-sided modules in the two innermost layers and 9 disks (TEC) on both side of the barrel.

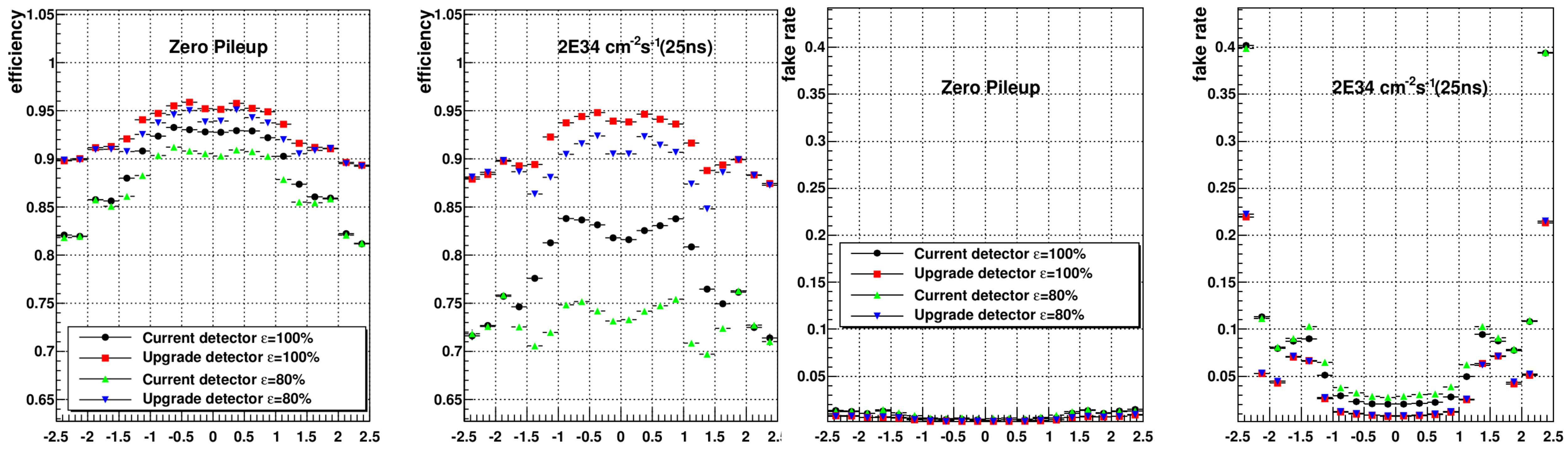






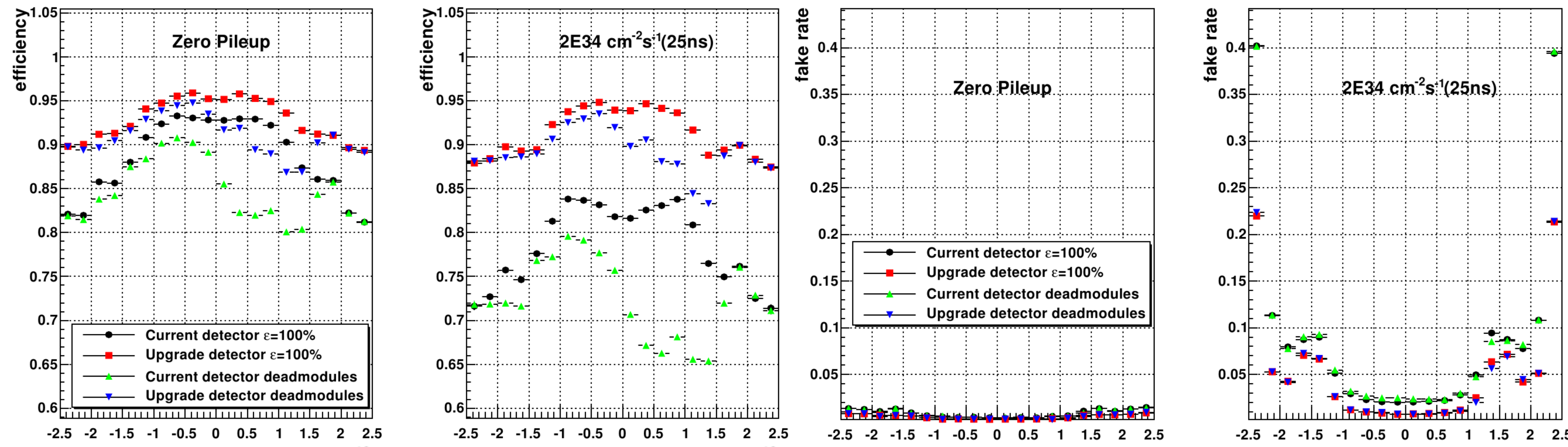
TIB Degradation produced by uniform Inefficiency

A luminosity of $2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ was simulated to study the possible degradation in the first two layers of the TIB in addition to data loss in the pixel ROC (Readout Chip) that could occur at high luminosities. A homogeneous 20% loss of the tracking hit efficiency in the first two layers of TIB was chosen for a case study to be simulated along with up to 16% pixel ROC data loss.



Tracker degradation produced by dead modules failure

In a scenario with high radiation levels some tracker modules may be operating at the limit of their features, hence some tracker modules were selected that could be dead or degrade faster than expected (See top right of poster for a map of dead tracker modules). In the simulation 675 modules were switched off in the tracker outer system as well as 495 modules in the tracker inner barrel (TIB), 132 modules in the tracker outer barrel (TOB), and 48 modules for tracker inner disk (TID). Our reconstruction software will not reconstruct hits for these modules (See CMS Tracker Hit plots).



Upgrade Detector

- The addition of a fourth barrel layer at a radius of 16 cm and a third set of forward disks will maintain the current level of tracking performance even in the high occupancy environment of the upgraded LHC.
- An additional pixel barrel layer will reduce the sensor dead region between adjacent modules and consequently the geometrical inefficiency.
- The third forward disks are arranged such that it maximizes the 4-hit η coverage. The increase in the number of measurement points improves the resolution of longitudinal and transverse impact parameters.

Uniform Inefficiency

- In the pseudorapidity region -1.0<|η|<1.0, the tracking efficiency loss increases more when moving from <PU> = 0 to <PU> = 50 for the current detector (10%) compared to the upgrade detector (5%).
- The fake rate is increased by around 25% in the central region for the current detector with respect to a TIB degradation.
- The simulation shows that the upgrade pixel detector can decrease the track fake rates when degradation in the TIB is considered.

Dead Tracker Modules

- The loss in tracking efficiency at high pile up (PU) is around 19% for the current detector and only 10% for the upgrade detector.
- The efficiency loss in the central region (-0.5<|η|<1.7) is caused mainly by dead modules in the first layer of the TIB. The drop in the efficiency for <PU>=0 compared to <PU>=50 was 15% for current detector and 5% for the upgrade detector.
- The track fake rate always was worse for the current detector (40%) than the upgrade detector (5%) at higher luminosity.
- The track fake rate with the upgrade detector is hardly affected by outer tracker inefficiencies while it will increase substantially for the current detector.