Status of the CMS Silicon Strip Tracker

Suvankar Roy Chowdhury
on behalf of the CMS Collaboration

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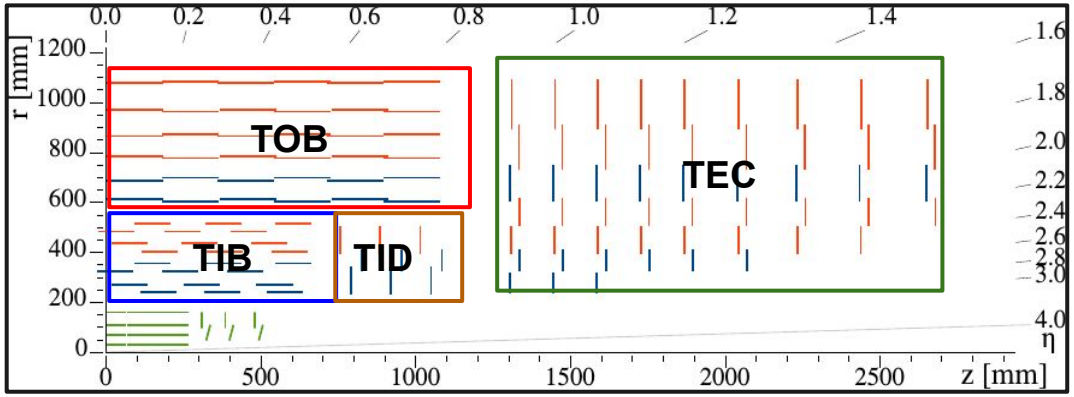
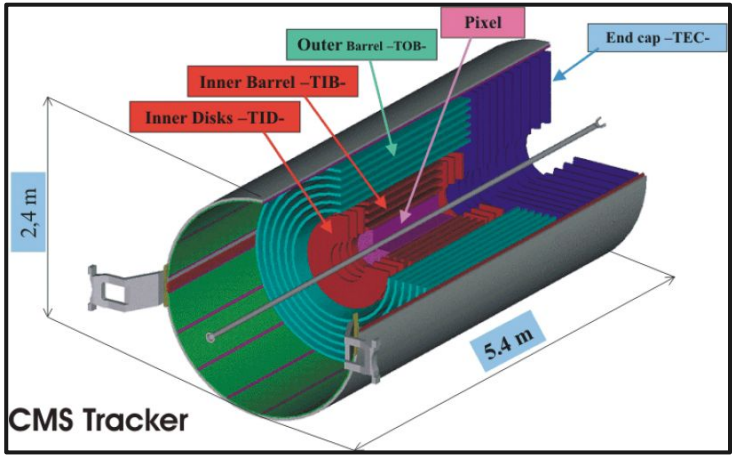
Introduction

- The CMS Silicon Strip tracker
- Data taking conditions
- Performance
  - Bad components
  - S/N
  - Hit Efficiency
  - Hit resolution
- Radiation effects
- Tracking performance
- Outlook

CMS Silicon Strip Tracker



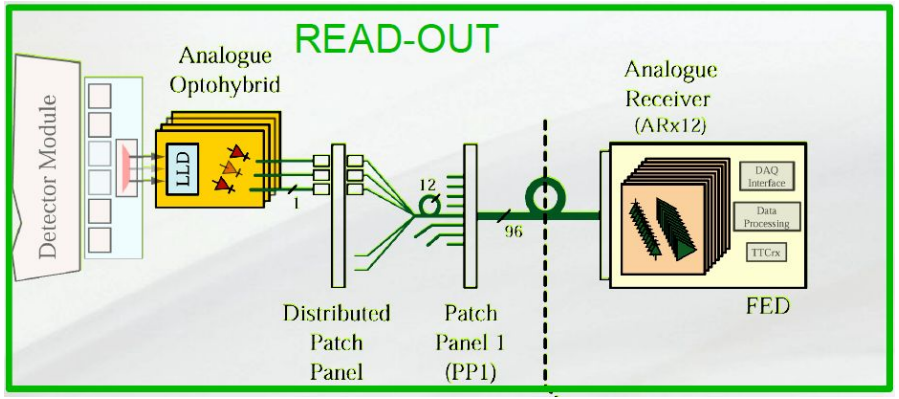


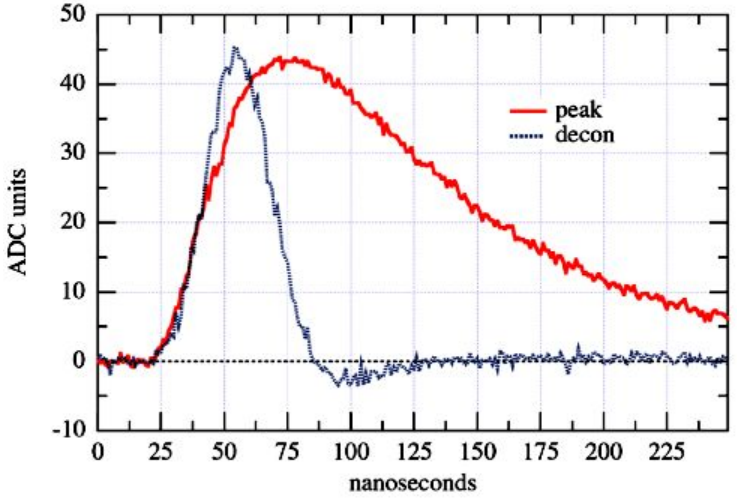
- Active area 200 m^2, 5.6 m long, 2.5 m diameter with 15148 silicon modules, 9.6 million electronic channels.
- 10 layers in barrel region, 4 Inner Barrel (TIB), 6 Outer Barrel (TOB).
- 3+9 discs in the inner disks (TID) and endcaps (TEC)
- Stereo modules (two modules with 100 mrad stereo angle) in 4 layers in barrel & 3 rings in endcap.
- 320 μm Si in inner layers (TIB, TID, TEC ring 1-4), 500 μm Si in outer layers (TOB, TEC ring 5-7)
- Analog readout.

For Pixels, see the talk by Giulia

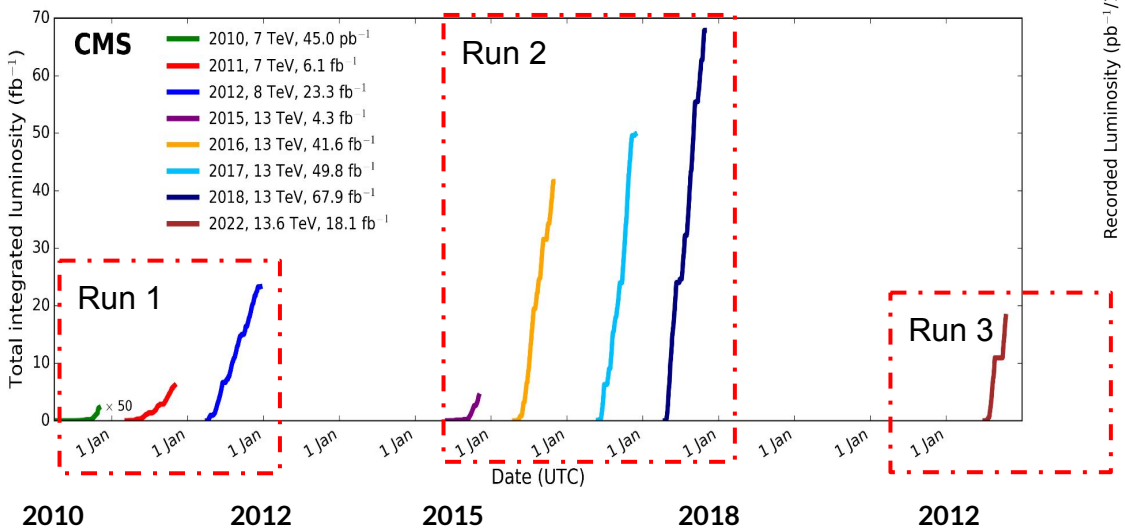
Readout

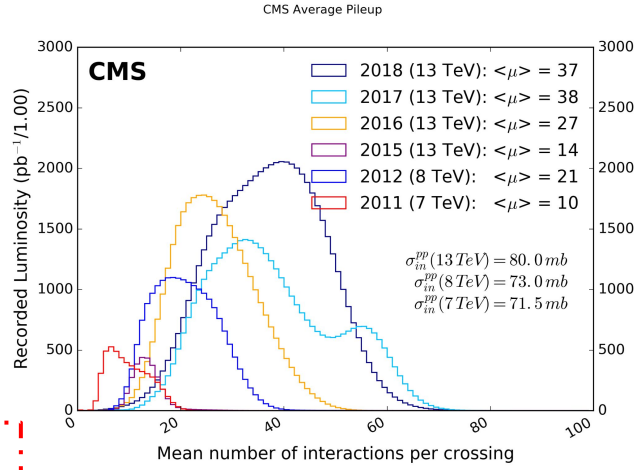
- Analogue readout with APV25 chip.
- Each chip has 128 channels.
- Tracker module have 4 or 6 APV chips.
- Two modes of operation:-
  - Peak mode - single sample - corresponds to the peak voltage of the CR-RC shaped signal.
  - Deconvolution mode - three-sample weighted sum.
- Signal from 2 chips multiplexed to a Laser Driver.
- Signal from APV25 chips converted to optical signal on Analog-opto-hybrid (AOH).

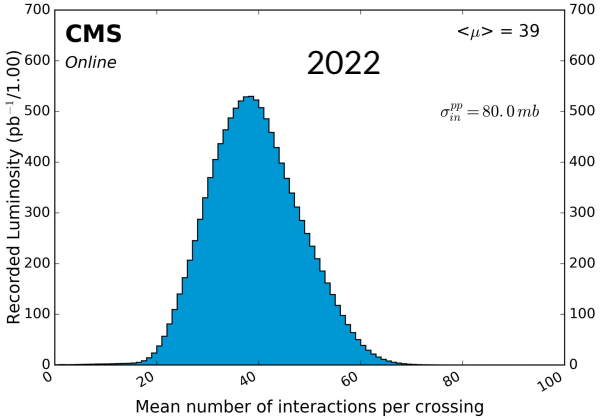




Data taking

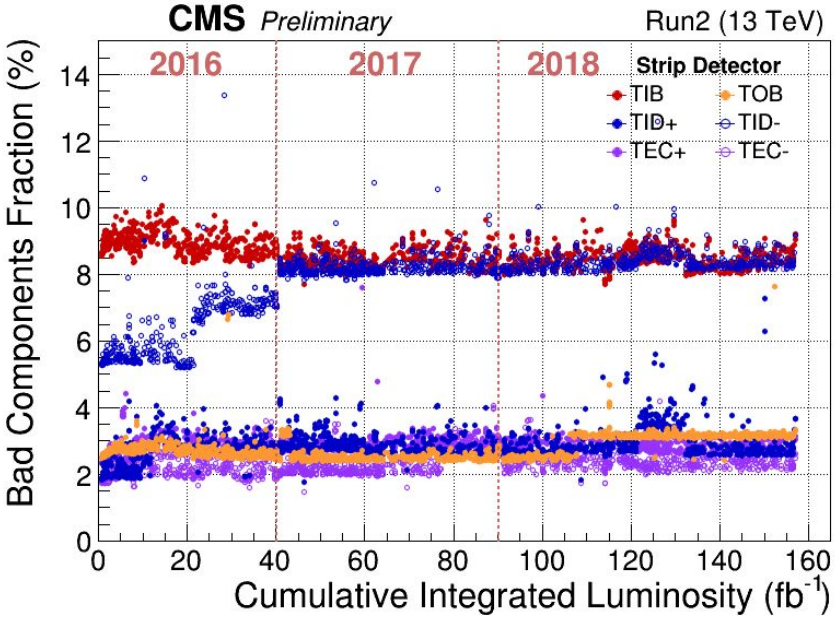


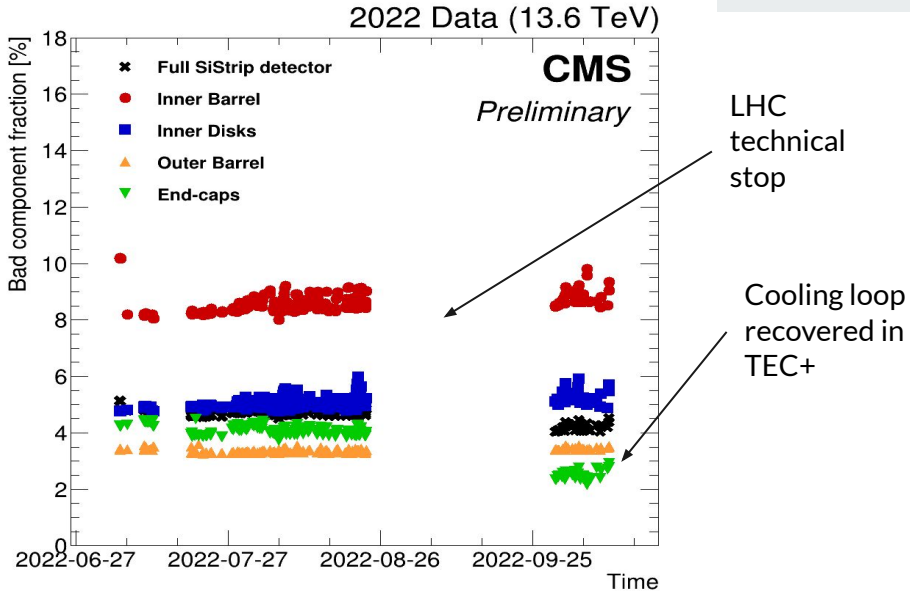




- Luminosity delivered to CMS by the end of Run 2 is ~192 fb^{-1} .

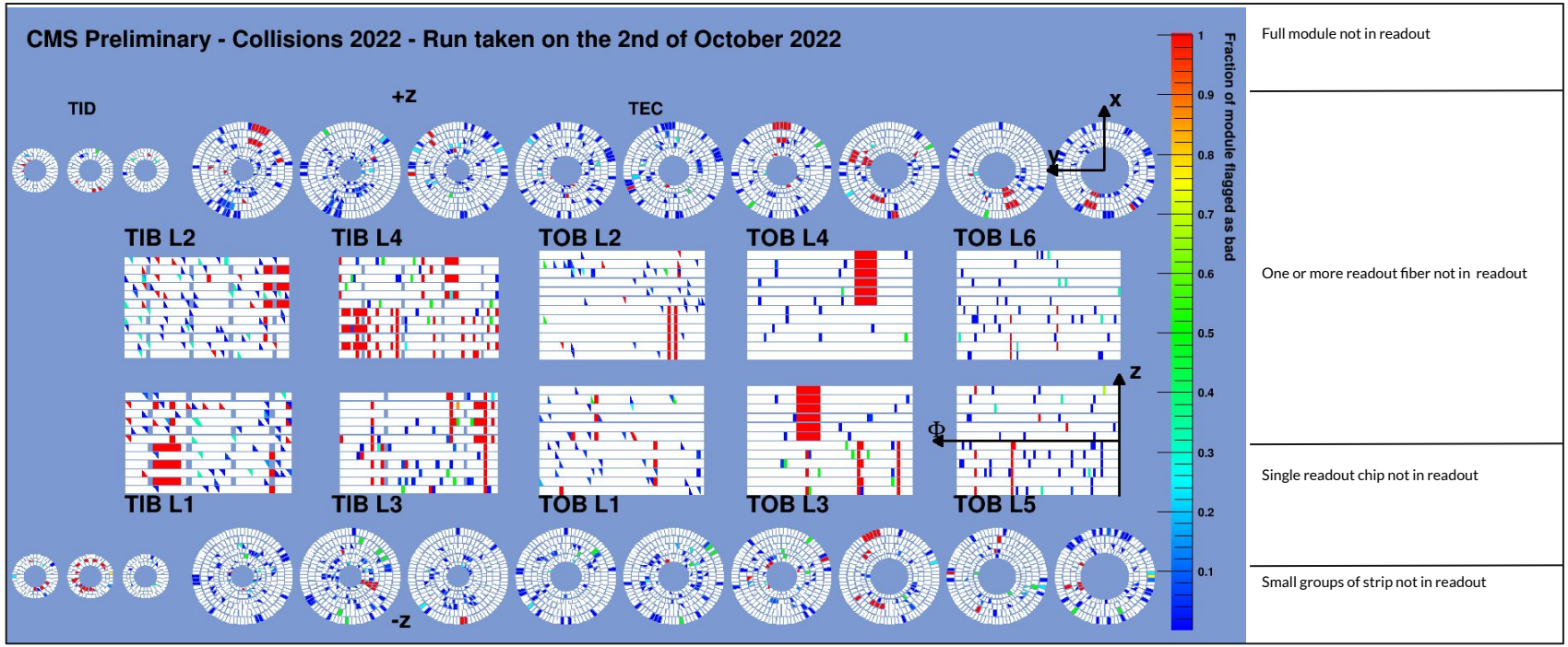
Detector status - Bad components





- Trend of fraction of bad components of the CMS Silicon Strip detector broken down by sub-detector. Each point represents a single run.
- Sources of bad components include:
  - read-out channels excluded from the cabling (typically FEDs).
  - unpowered group of modules and single APV25 chips.
  - group of strips masked from the offline reconstruction by a Prompt Calibration loop algorithm(noisy channels based on the median channel occupancy).
- **Fraction of active channels ~ 96** %.
  - Quite stable in Run 2. Similar trends in Run 3 startup.

Bad components Run 3

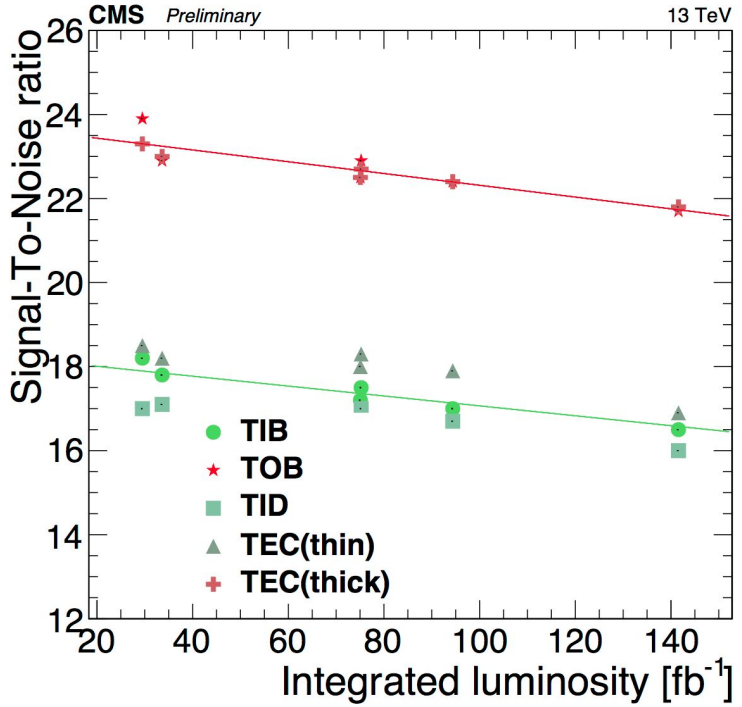


Geometrical representation of the fraction of module components of the CMS strip tracker that is flagged as bad for offline reconstruction during a **13.6 TeV pp collision run** at run taken on **02/10/2022**.

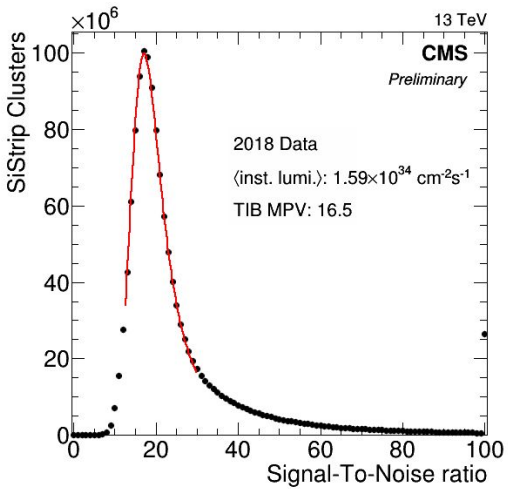
Signal over noise

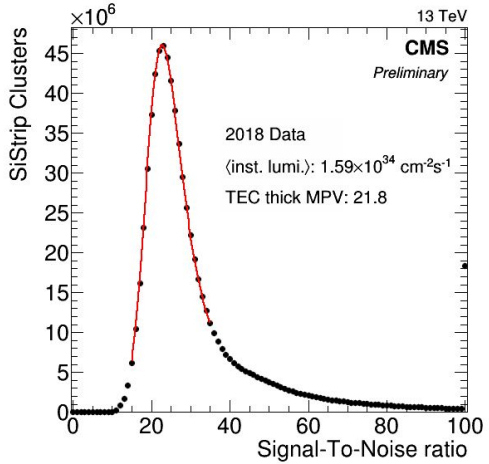
	TIB	TOB	TID	TEC (thin)	TEC (thick)
2016	17.2	22.5	16.7	18.0	22.5
2017	17.5	22.9	17.0	18.3	22.7
2018	16.5	22.1	16.0	16.9	21.8
2022 (13.6 TeV)	16.4	21.0	16.4	17.4	21.5

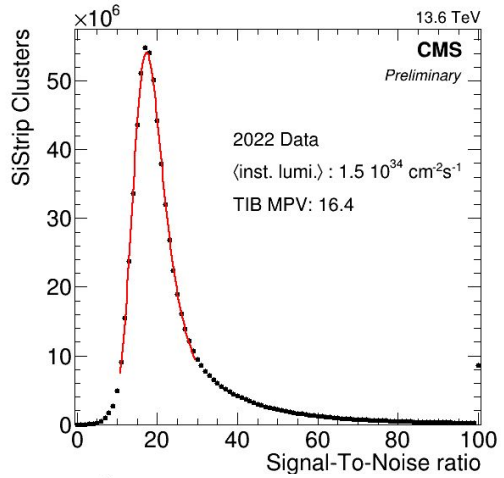
- Important quantity to monitor - affects Zero suppression and Cluster building.
- High signal-to-noise ratio - also at Run 3 startup.
- As expected, a decrease is observed with time.
- Expected S/N ratio at the end of Run 3.
  - Thin sensor - 12.
  - Thick sensor - 18.

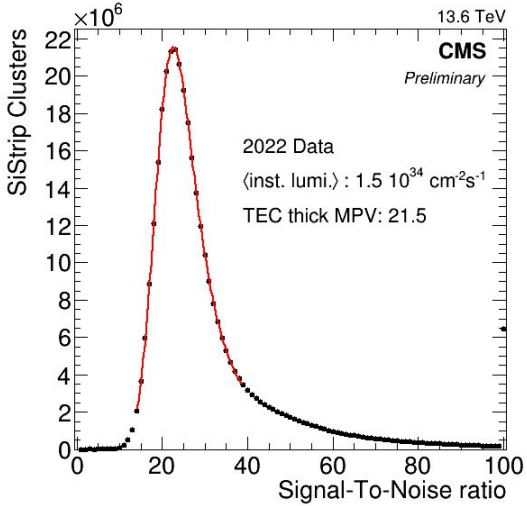


Signal over noise

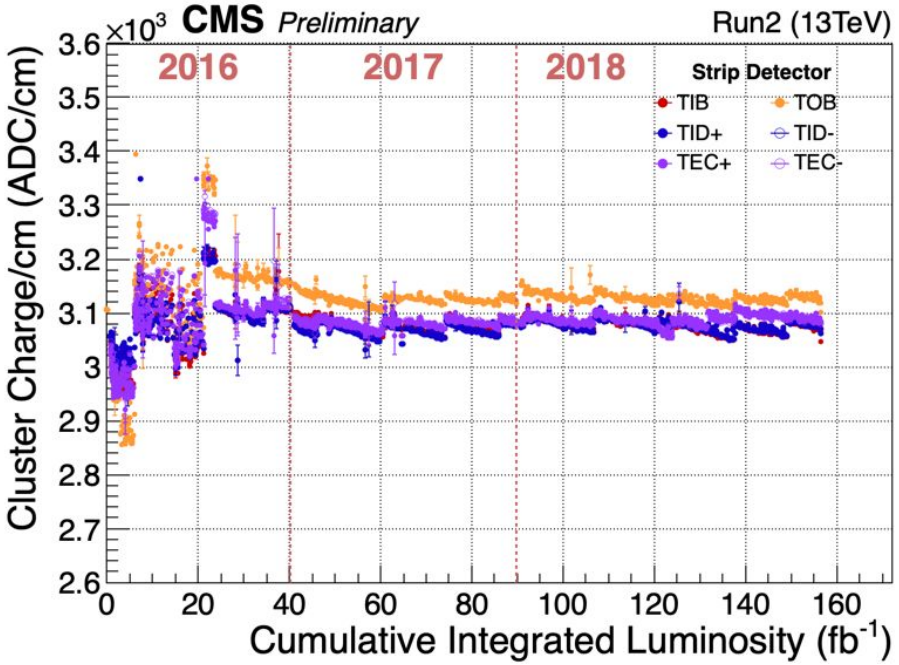








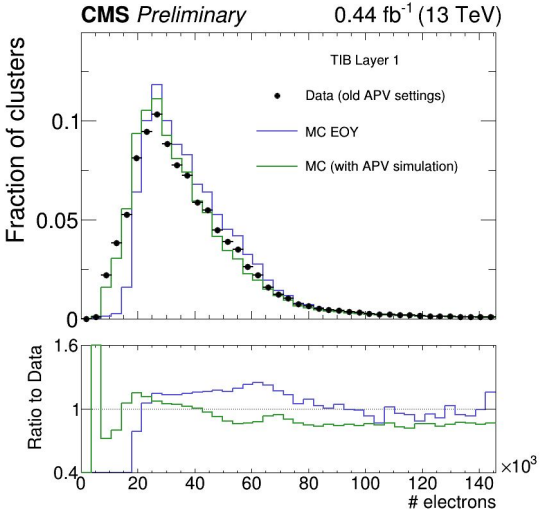
Cluster charge

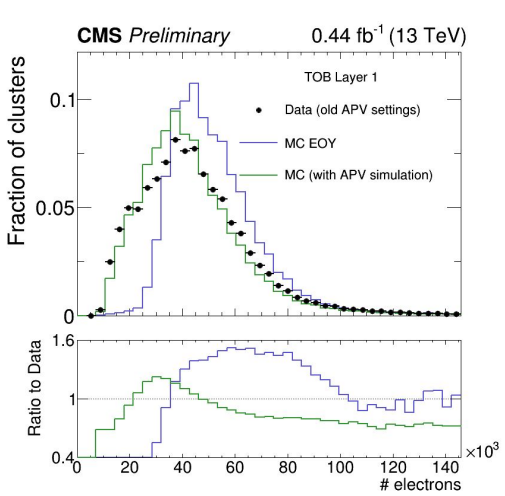


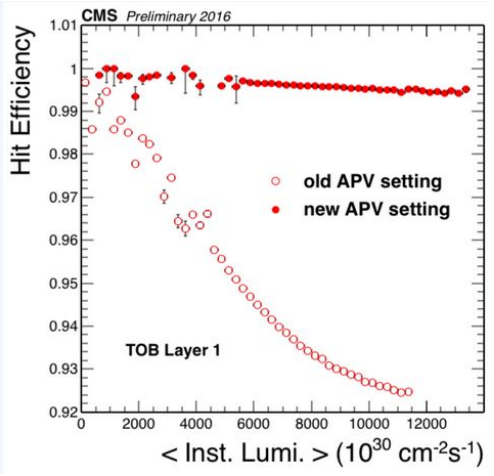
- Cluster charge normalized to the transversed silicon length after offline calibration for each partition as a function of the delivered LHC integrated luminosity.
- Cluster charge is used for energy loss measurement for particle identification.
- Only clusters used to build a track are considered.
- The MPV from a Landau fit is shown. During local reconstruction a correction is applied to the strip charge signal in order to guarantee stability over time of the cluster charge MPV.
- Large fluctuations in the cluster charge in the first 20/fb of 2016 data are caused by the saturation of the pre-amplifier of the APV chip.
  - The effect had a strong instantaneous luminosity dependence and resulted in the deviation from a Landau distribution. The effect has been partially mitigated with the updated calibration derived for the Legacy reprocessing of the Run 2 data.
- The later discontinuities in the trend are due to the updates of the gain and noise/pedestal values.

Pre-amplifier issue

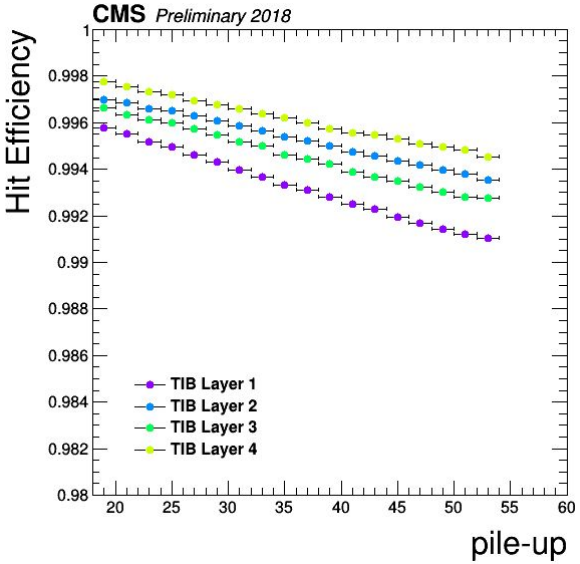
- In late 2015 and early 2016, Strip tracker observed lowering of S/N and loss of hits on track.
- This was due to the saturation of the pre-amplifier of the APV25 chip.
  - The drain speed of the pre-amplifier was affected by the change in operating temperature and high occupancy.
  - Lead to a very slow discharge of the amplifier with a decay constant O(15μs).
  - About 20 fb^{-1} of 2016 data were affected.
  - The drain speed was changed on the 13th August 2016 to allow for faster recovery of the pre-amplifier, and recovery of the hit efficiency to the same level as in Run 1.

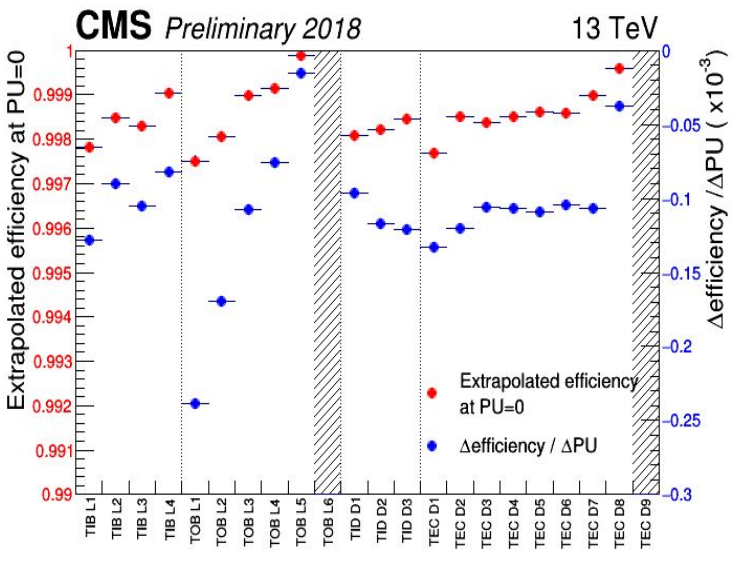


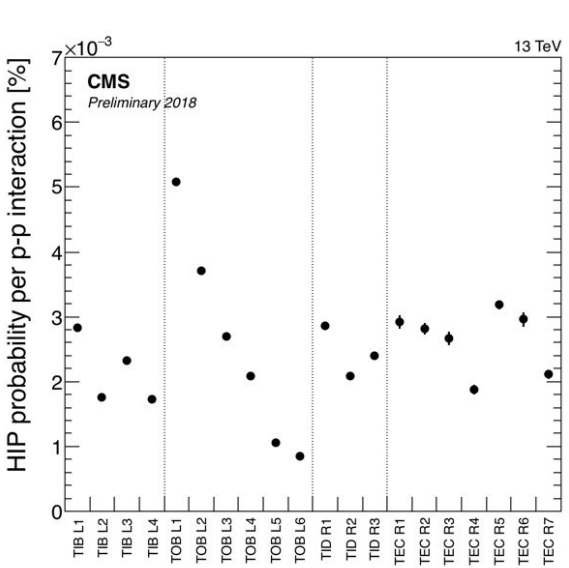




Hit Efficiency



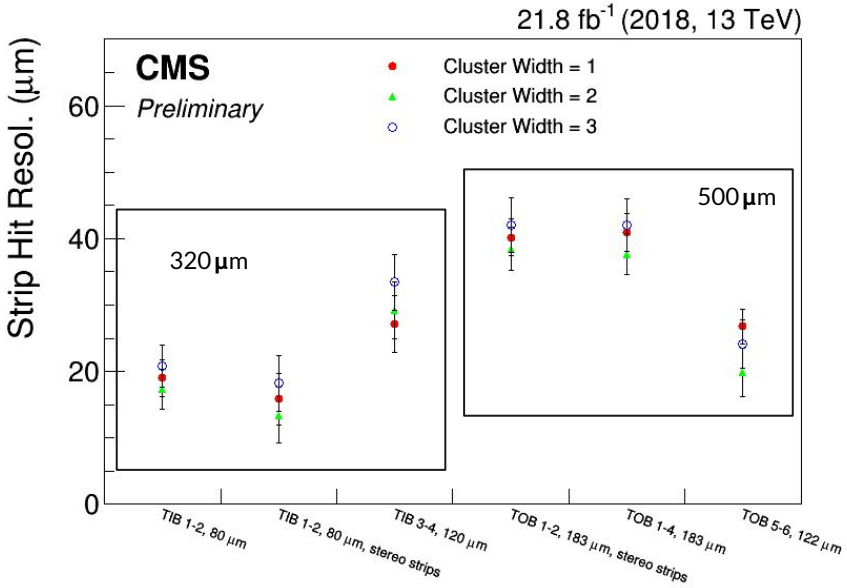


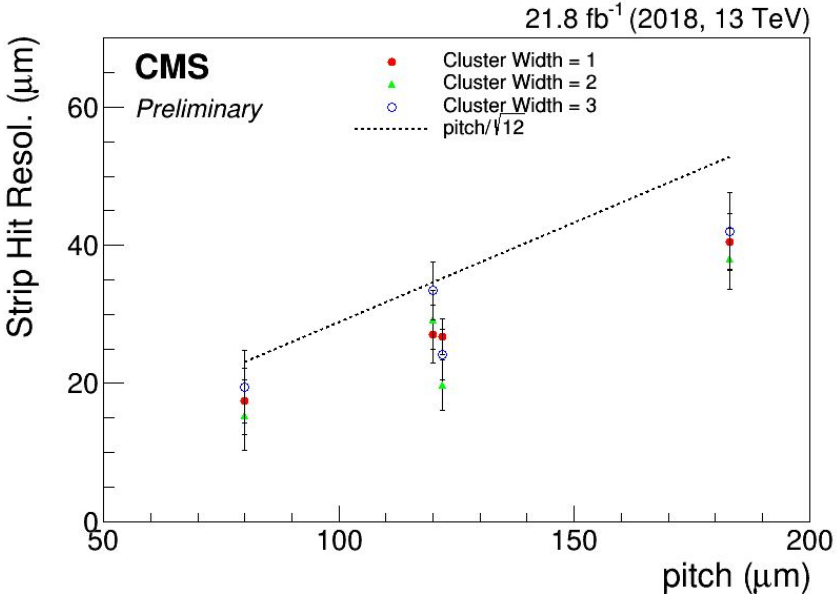


- Efficiency is measured using high purity tracks.
- Efficiency is the fraction of traversing tracks with a hit anywhere within a range of 15 strips.
- The modules flagged as bad are not included in the measurement.
- Eff. scales linearly with inst. lumi and pileup and is 98% even at high PU.
- Run 3 startup hit efficiency is quite good comparing to Run 2.

- Highly Ionising Particles (HIP) affect the hit efficiency.
- Amount of energy released by a HIP ~100 times higher compared to a MIP.
- Leads to high dead-time ~ 5bx.

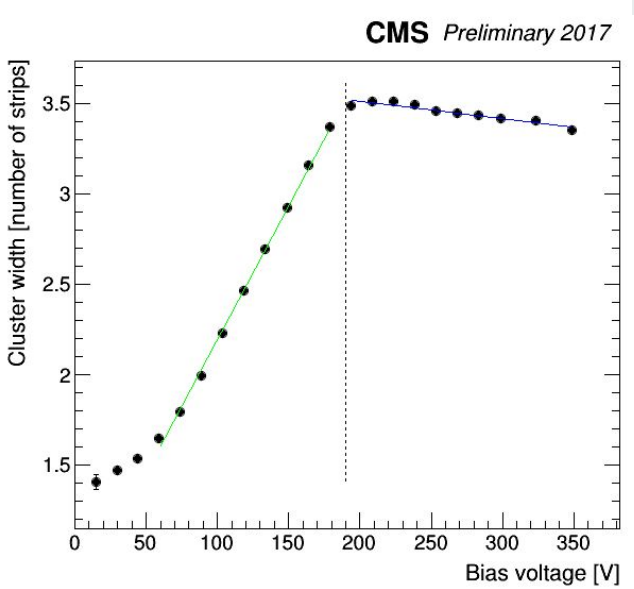
Hit Resolution



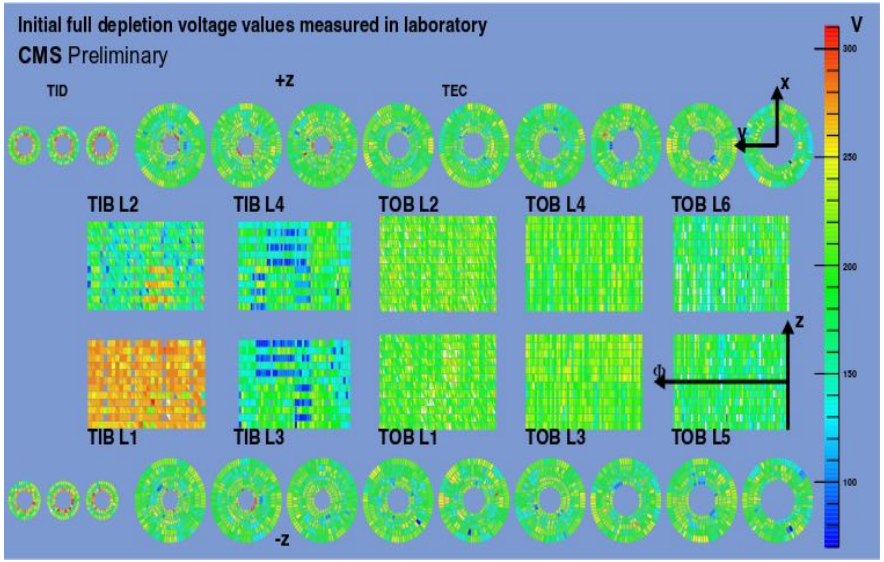


- Estimated from “pair” method - hits from overlapping modules of the same layer.
- Improved resolution for large cluster width due to charge sharing.

Radiation Effects - I



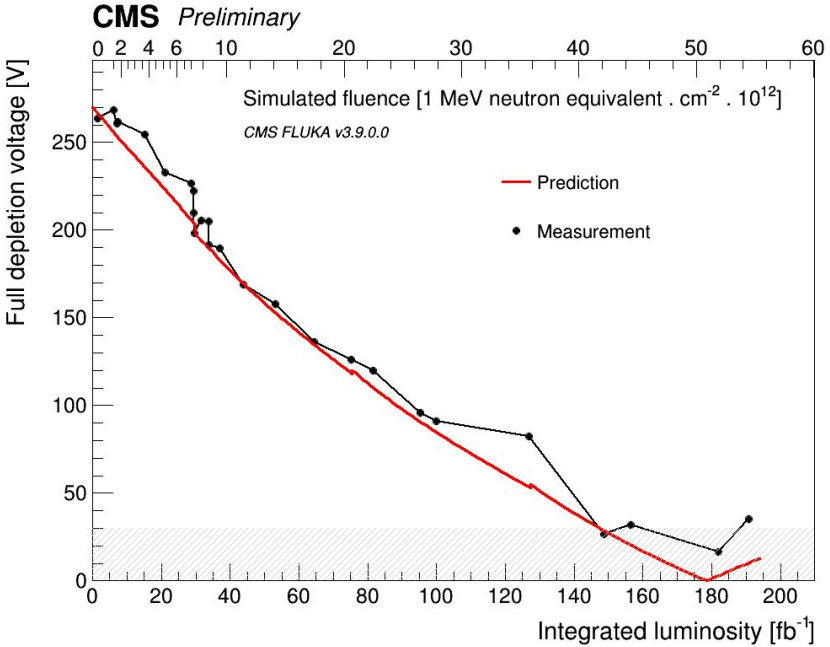
- Determined from the cluster width.
- Linear fit performed on both slopes.
- Crossing point gives the V_{depl} .



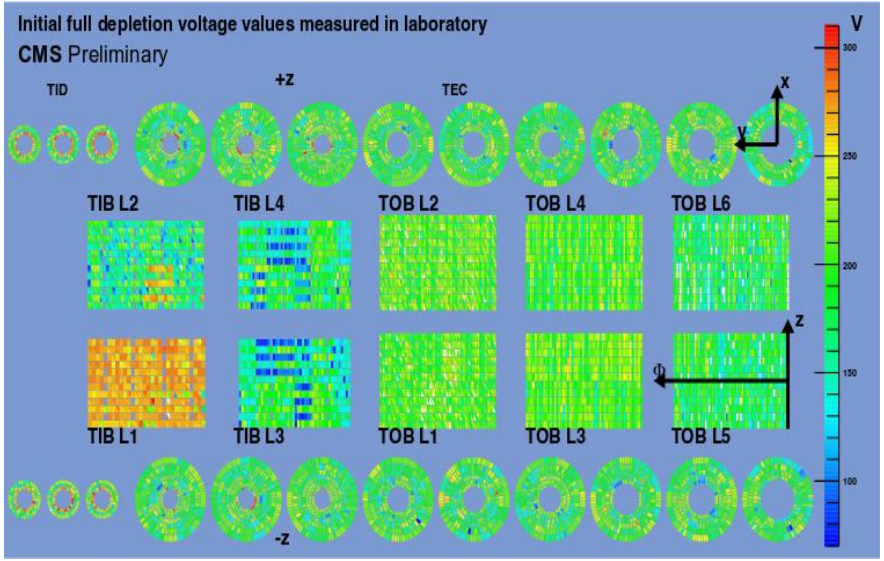
- Initial full depletion voltage values measured at the time of tracker construction.
- Inner layer have a larger value of the initial full depletion voltage to allow a larger evolution range as they will receive a larger fluence.

- Radiation effects are monitored by checking -
  - Depletion voltage (V_{depl}) - full bias scans are performed at least twice a year. Smaller scans on specific power groups done ~1/month.

Radiation Effects - II



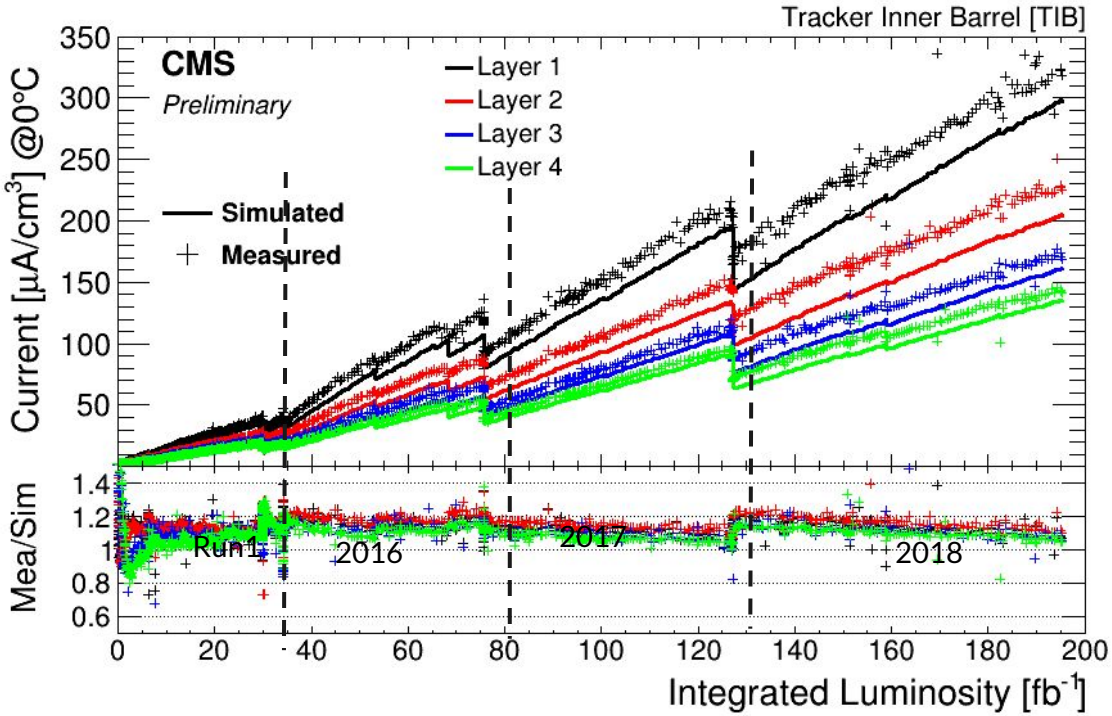
- Evolution of Vdepl in one TIB Layer 1 sensor.
- TIB L1 reached inversion point at the end of Run 2 : 192 fb^{-1} delivered.
- The break occurring at an integrated luminosity close to 30 fb^{-1} in the curves is due to the long shut down period between Run 1 and 2. The opening of the CMS detector and cooling plant maintenance resulted in extended periods during which the silicon detector was not cooled.



- Initial full depletion voltage values measured at the time of tracker construction.
- Inner layer have a larger value of the initial full depletion voltage to allow a larger evolution range as they will receive a larger fluence.

Radiation Effects - IV

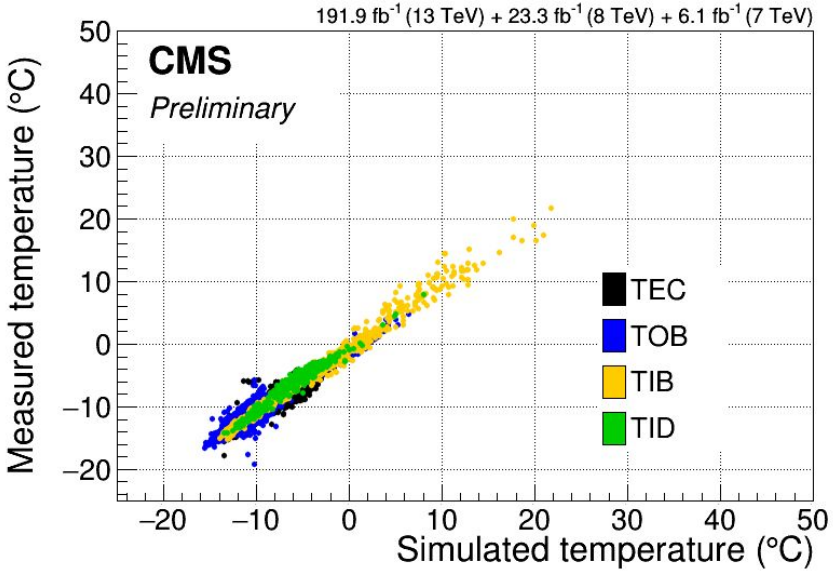
- Leakage current simulations are done based on sensor temperature measurement.
- Fluence for each sensor is estimated according to CMS FLUKA studies scaled to 1 MeV neutron equivalent.

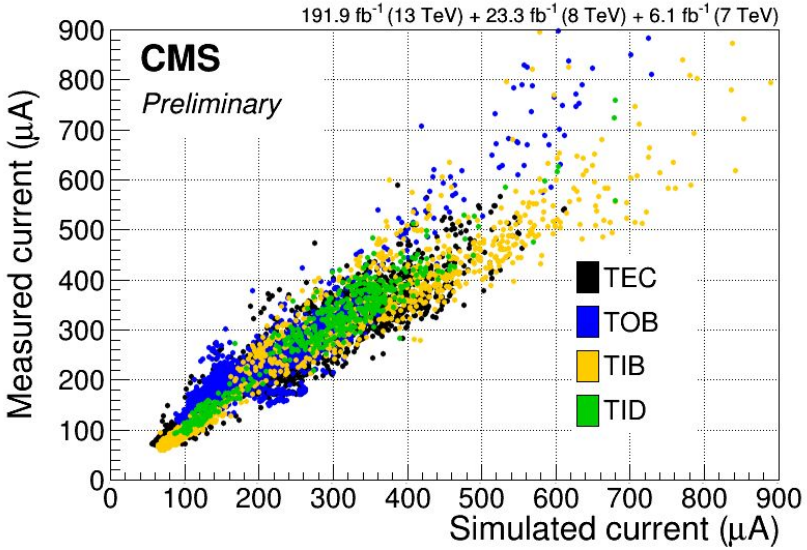


- Leakage current as a function of integrated luminosity.
- The current is averaged over all sensors in a given layer.
- Changes due to annealing during stops and change of temperature.
- Differences in simulation and observed is well within uncertainties from FLUKA simulations and modelling parameters.

Radiation Effects - III

- Leakage current simulations are done based on sensor temperature measurement.
- Fluence for each sensor is estimated according to CMS FLUKA studies scaled to 1 MeV neutron equivalent.

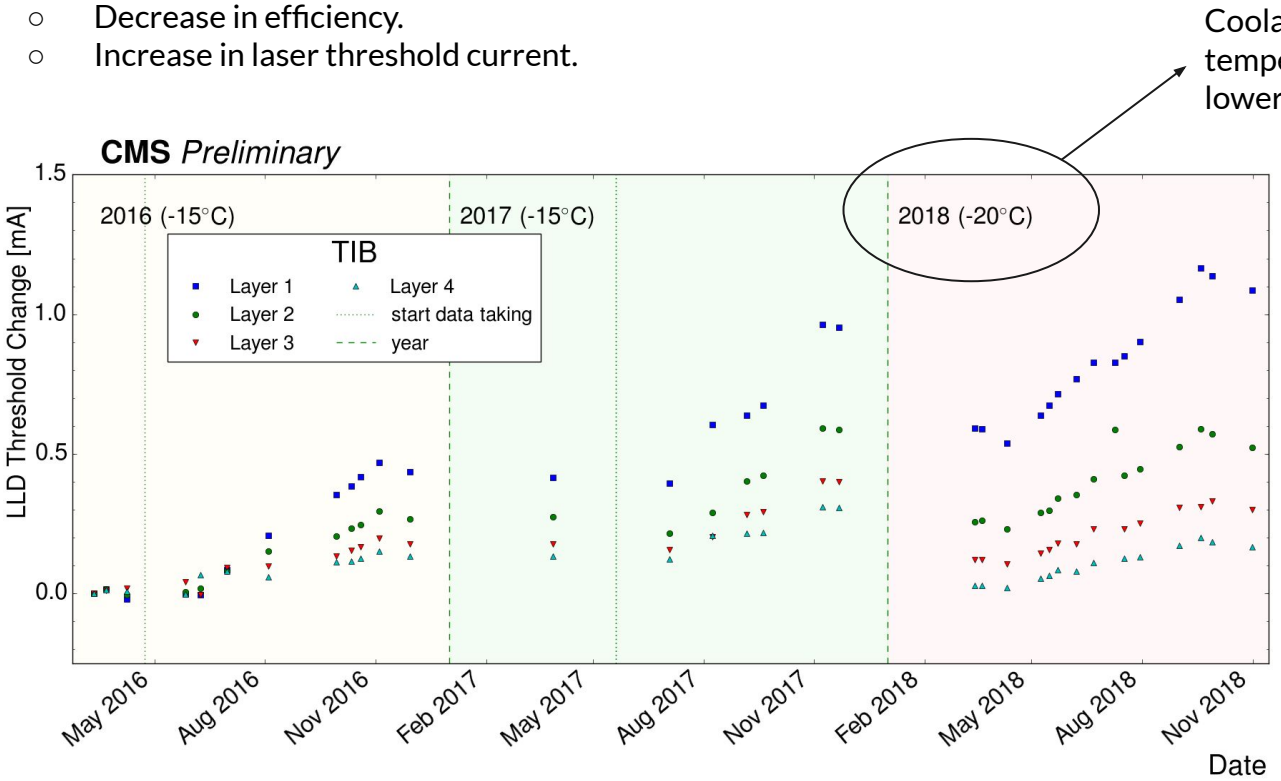




Good overall agreement between measurement and simulation.

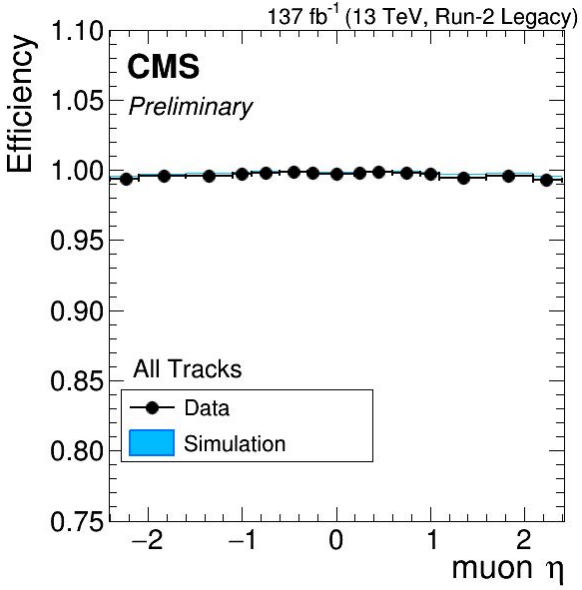
Radiation Effects -V

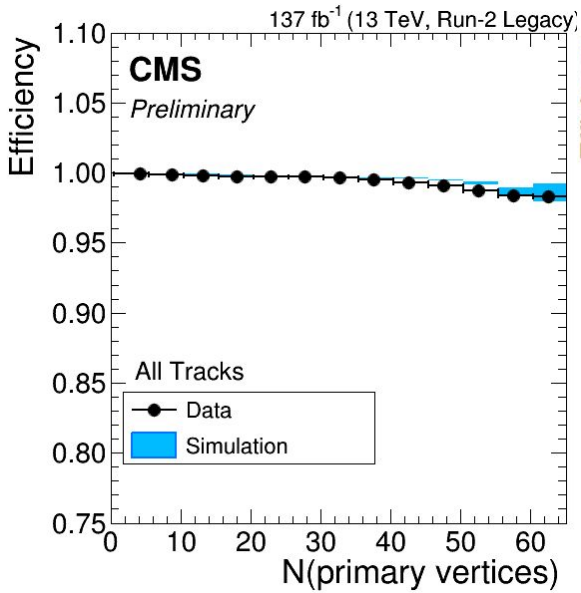
- The optical readout is affected by radiation.
  - Decrease in efficiency.
  - Increase in laser threshold current.

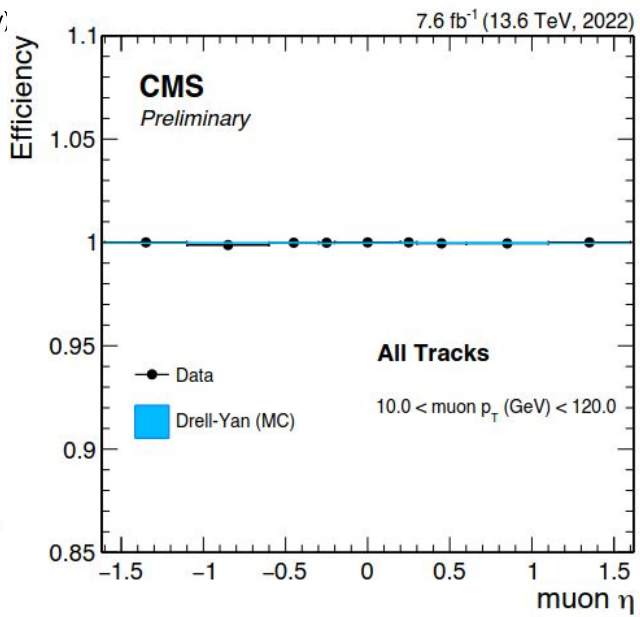


- Increase in high lumi periods.
- Dependance of radius.

Tracking







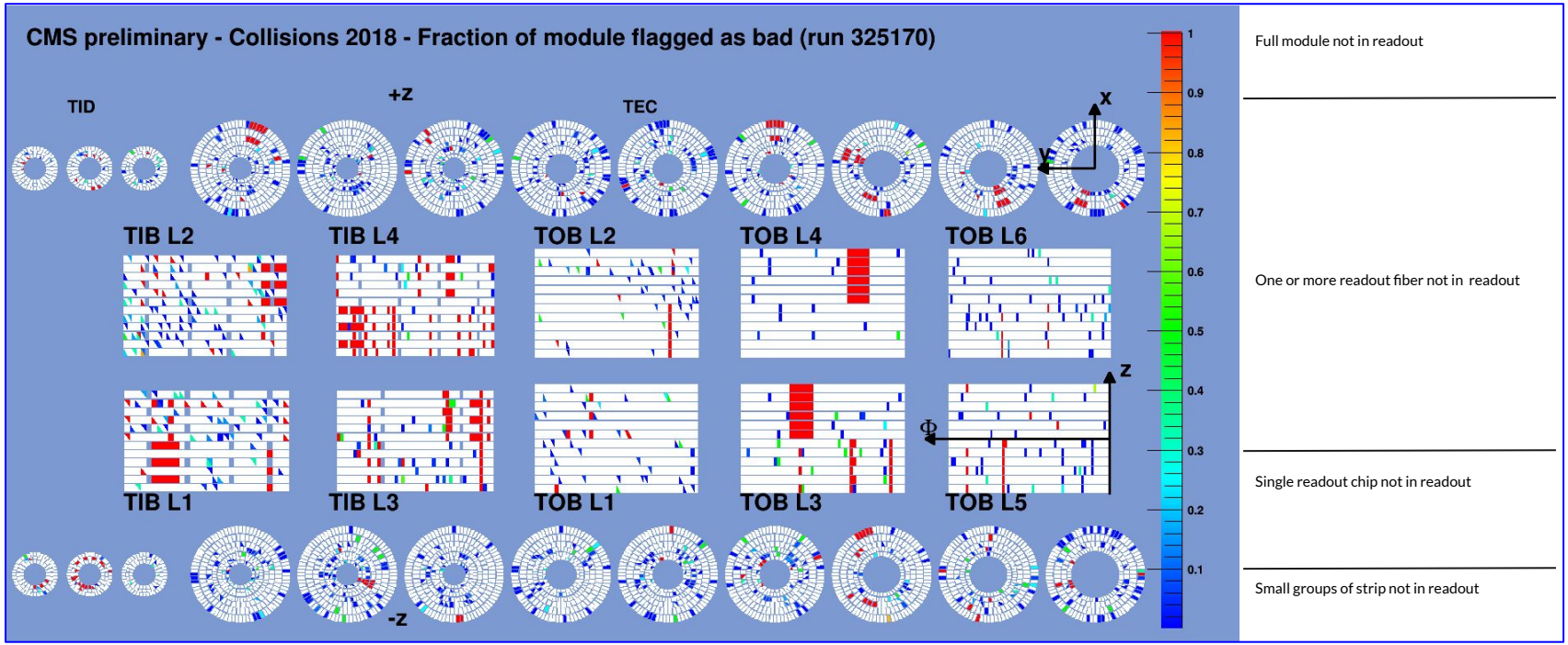
- Efficiency measured with the Tag and Probe method using Z to mu mu events.
- Tracking efficiency vs eta and #of primary vertices quite stable.
- Early Run3 tracking performance is also excellent.

Conclusion

- The CMS Silicon Strip Tracker operational and performing well after ~ 12 years of operation.
- Active detector fraction was quite stable during Run 2.
- Signal to Noise is quite stable and close to expectation.
  - APV25 pre-amplifier saturation seen at high luminosity in 2015/16 has been fixed.
- Hit Efficiency and resolution also match expectation.
- Effect of radiation visible.
  - Leakage current, Depletion voltages are monitored.
  - Simulation in place to model the behaviour of the detector with increased radiation.
- Excellent tracking performance in Run 2 and early Run 3 data taking.
- Studies are ongoing with data collected at 13.6 TeV this year and more results are expected by the end of this year.

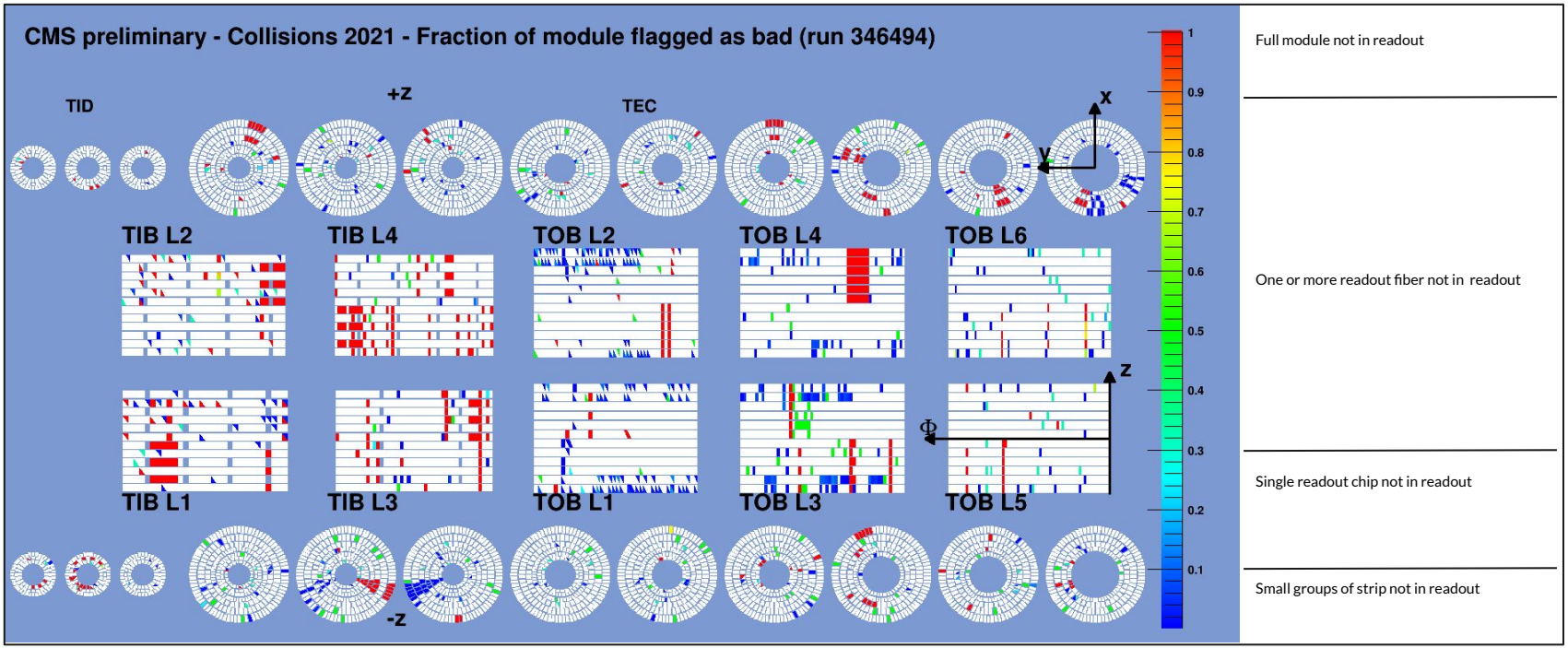
Backup

Bad components end of Run 2



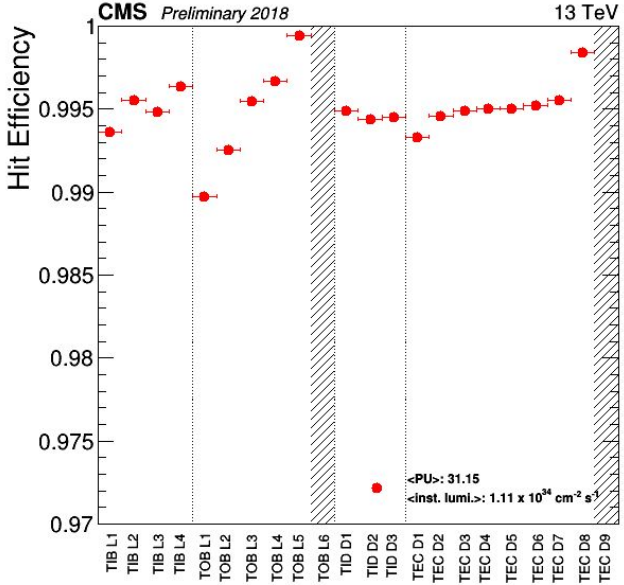
Geometrical representation of the fraction of module components of the CMS strip tracker that is flagged as bad for offline reconstruction during a run at the end of Run 2. Modules in white have no components flagged as bad. The map is from a **13 TeV collision run taken on 24/10/2018**.

Bad Components 2021

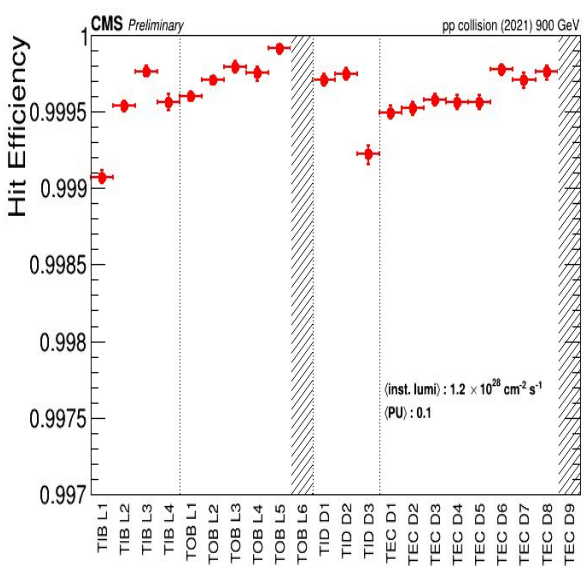


Geometrical representation of the fraction of module components of the CMS strip tracker that is flagged as bad for offline reconstruction during a 900 GeV collision run taken on 31/10/2021. The recovered area that was fully disabled in the third layer of the TOB corresponds to a recovered FED.

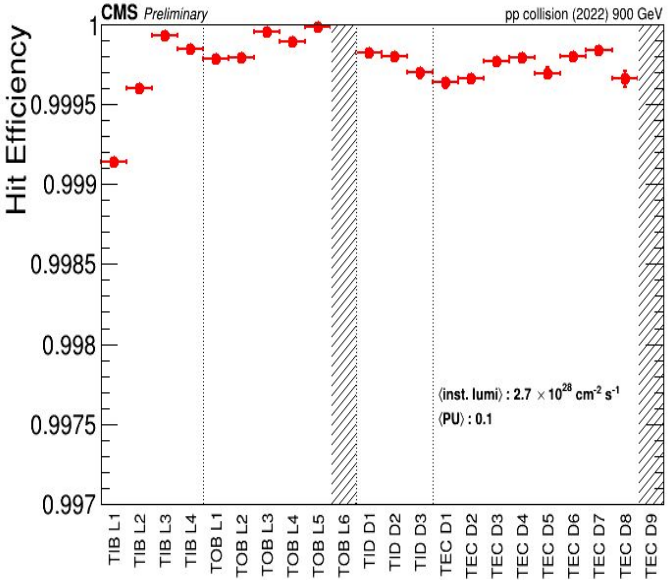
Hit Efficiency 2018/ 2021 / 2022



2018



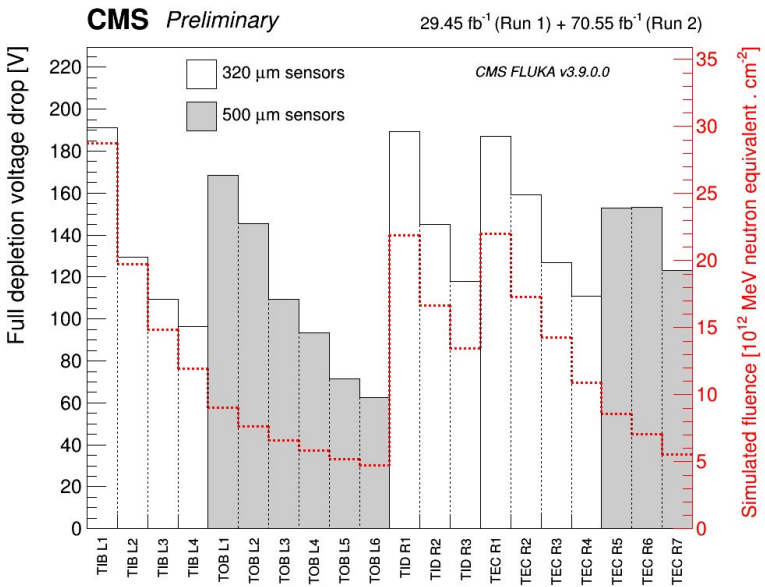
2021

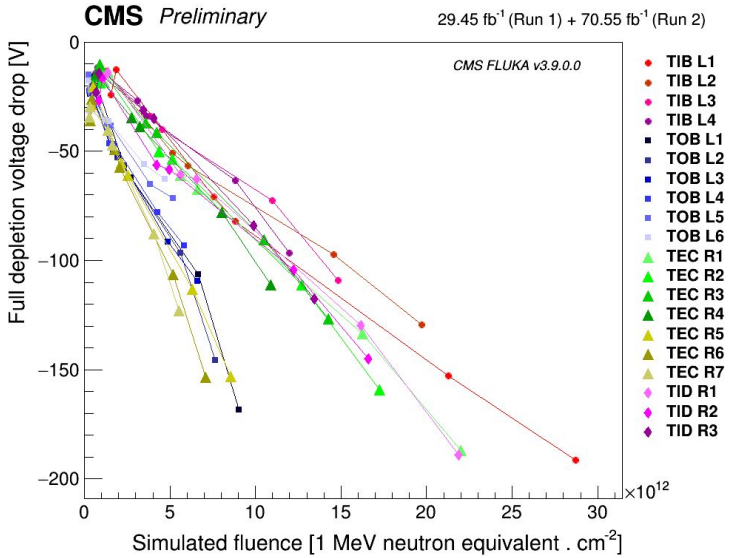


2022

- Startup hit efficiency is quite good comparing to Run 2
- Measurements with 13.6 TeV 2022 data in progress

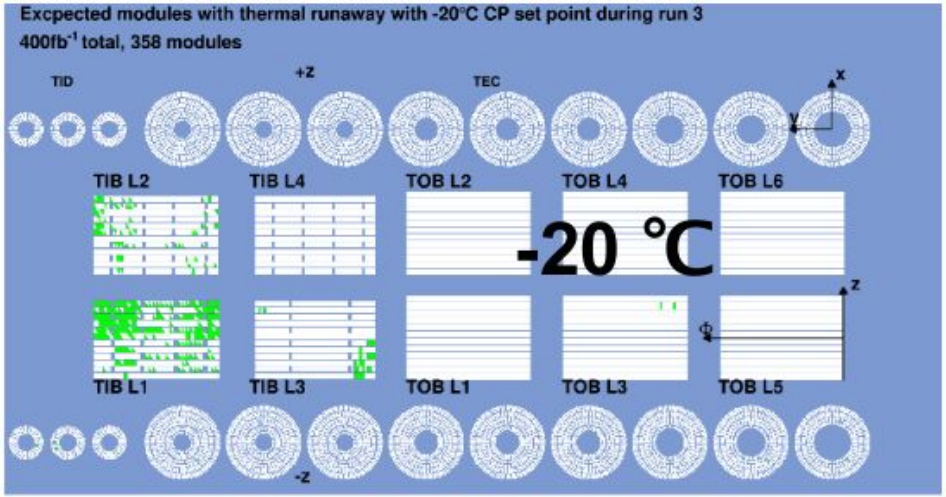
Full depletion voltage

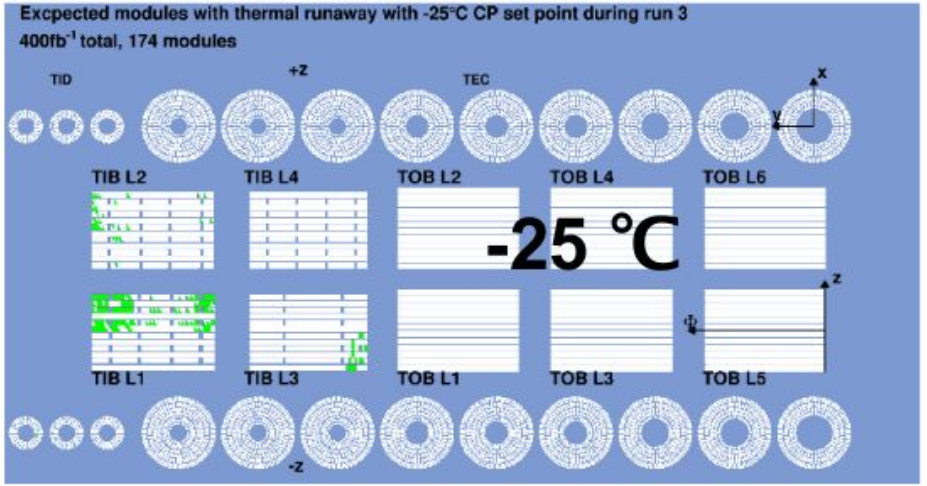




- Averaged relative evolution with fluence of the full depletion voltages of the Strip Tracker sensors for all layers until september 2017.
- The full depletion voltage is proportional to the thickness of the sensor.
    - the evolution is steeper for TOB layers and TEC outermost rings (500 um-thick sensors) than for other layers (320 um-thick sensors).

Leakage current





- Expected modules with the thermal runaway at the end Run 3 (400 fb^{-1})
- Number of thermal runaways reduced by decreasing the cooling set points