System Tests with the TEPX Detector for the CMS Inner Tracker Upgrade

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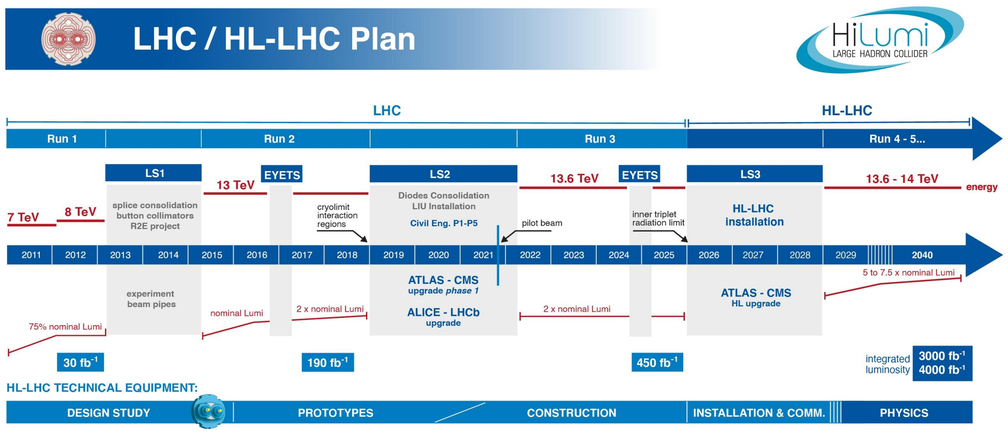
The High-Luminosity LHC and Phase-2 Upgrade

The upcoming HL-LHC upgrade during Long Shutdown 3 (LS3), followed by Phase-2 operation, is an ambitious upgrade of the LHC, allowing it to increase statistics, enabling more precise measurements and the potential to observe rare processes not currently detectable.

5 – 7.5x
instantaneous luminosity compared to the designed one at Run II ($1\times10^{34}\,cm^{-2}s^{-1}$)

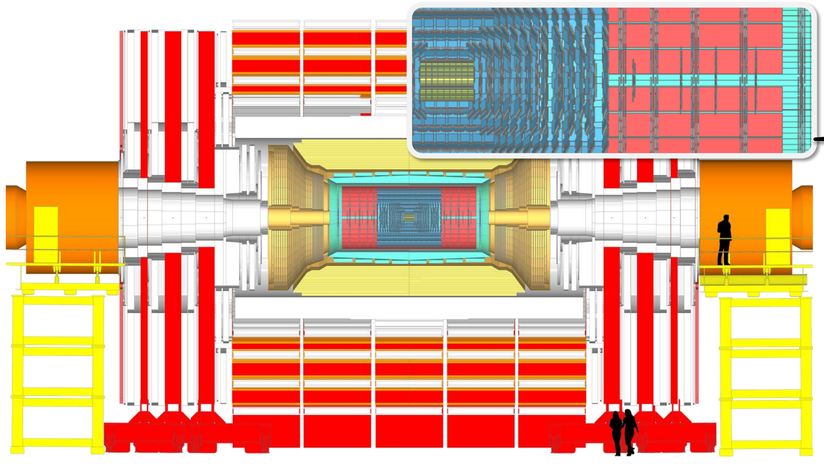
10x
integrated luminosity over the 10 years compared to the LHC baseline program

Up to 200
additional pp collisions within the same or adjacent bunch crossing (pileup)

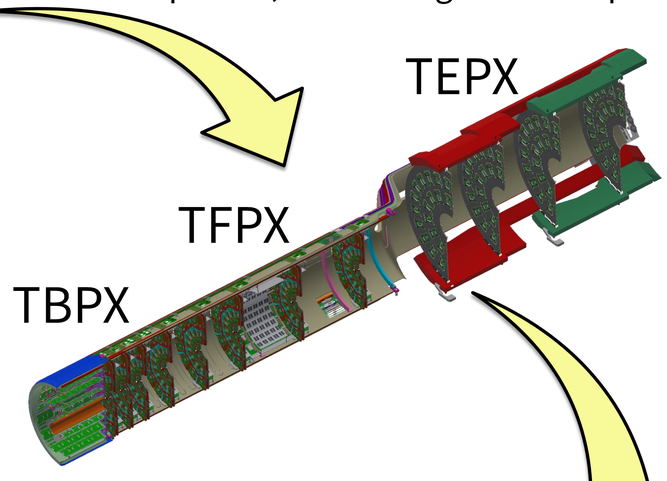


CMS Phase-2 Tracker System and the Tracker Endcap PiXel Detector (TEPX)

The CMS will undergo significant upgrades to handle the increased data rates and harsher operational conditions expected in the HL-LHC era with its inner tracker system completely replaced, continuing its role in pushing the frontiers of particle physics.



- Reconstruct charged-particle tracks with > 99% efficiency and momentum determination.
- Primary- and secondary-vertex reconstruction

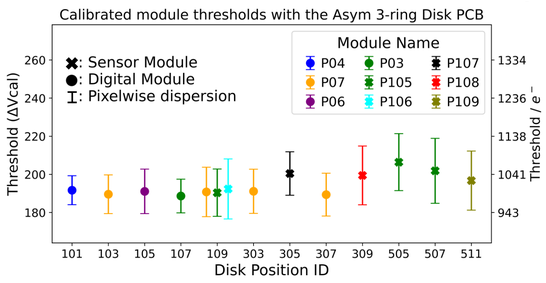


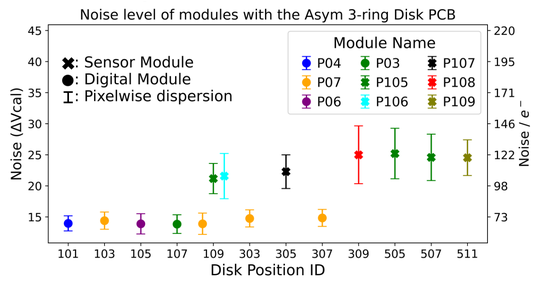
CMS Phase-2 Inner Tracker Upgrade

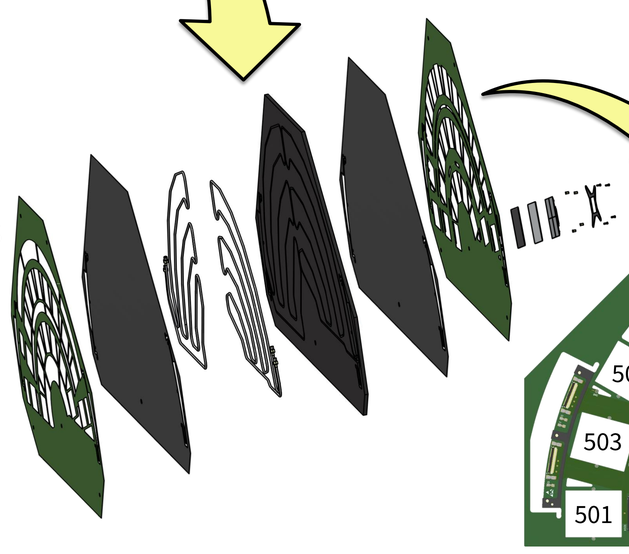
	Phase 1		Phase 2
Mechanics	4 layers + 6 disks	→	4 layers + 24 disks
Active Si area	2 m^2	→	5 m^2
Channels	124M	→	2000M
Pixel size	$100\times150\mu m^2$	→	$25\times100\mu m^2$
Radiation tolerance	300 Mrad	→	1000 Mrad

TEPX Disk Validation

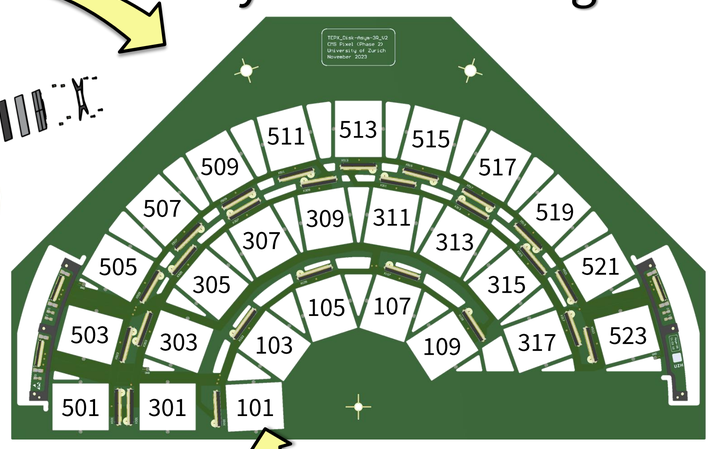
- 4 different layouts: asymmetric/symmetric 2-ring/3-ring disk PCB
- 4-layer Polyimide PCB with Epoxy adhesive, 446µm thickness
- Serial power distribution, module test results consistent with standalone tests
- Consistent, low noise level across positions compared to calibrated threshold



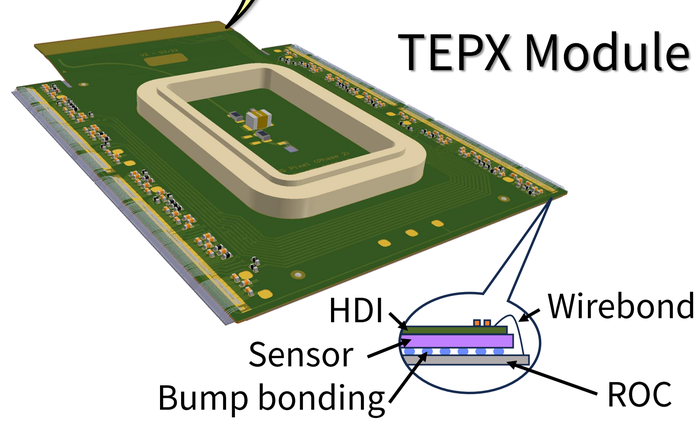




Asymmetric 3-ring PCB



TEPX Module

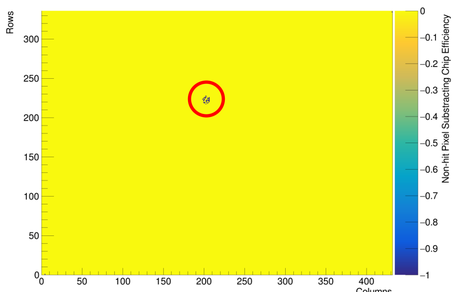


Disconnected Channel Identification in Modules

Establishing an accurate and efficient method for identifying disconnected channels is crucial. Here we compared three methods to identify disconnected channels in TEPX modules, where silicon sensor cells are individually bump bonded onto the readout chip (ROC) pixels.

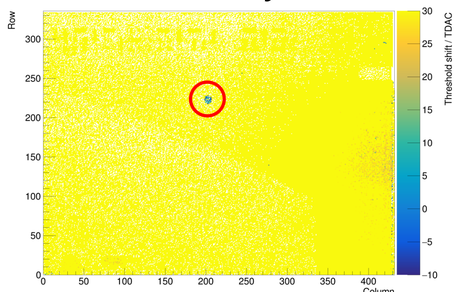
Source Radiation

- Hit count with Sr-90 source placed on the module.
- Time-consuming. Affected by the HDI structure.



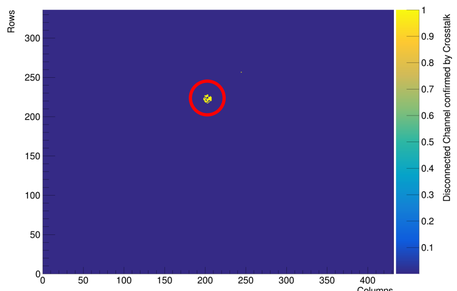
Threshold/Noise Shift

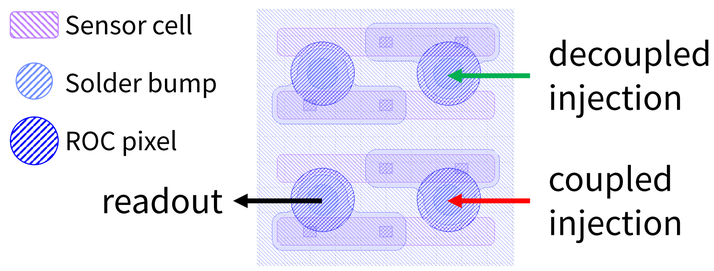
- Measure the thres./noise shift with neg./pos. bias voltage on the sensor.
- Currently shows dependency on sensor. Affected by the HDI structure.



Pixel Crosstalk

- Measure the crosstalk between nearby coupled/decoupled pixels.
- Simple and fast. Limited by the noise and crosstalk level.

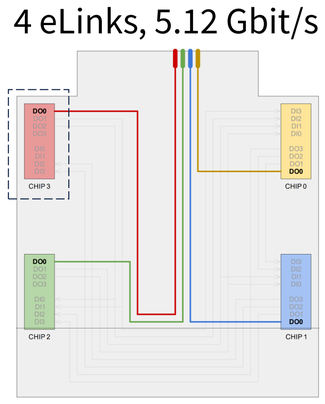




TEPX Module Data Merging Test with the Final Version CROC

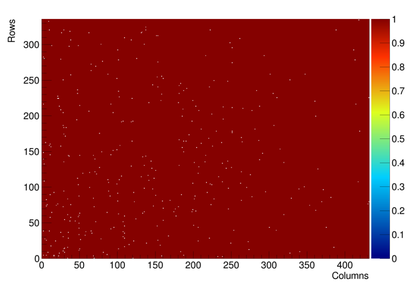
To reduce materials and cabling, the disk PCB has fewer readout data lanes in its outer rings, compatible with the lower hit rate in the outer region. In the outer rings, data from different ROCs in the same module is merged with the High-Density Interconnect (HDI). The commands are also sent to the primary chip first and then delivered to others. The merged readout scheme is compared and validated with the standard readout on the same module.

4 eLinks, 5.12 Gbit/s

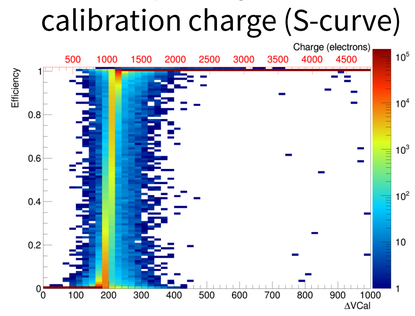


Scan results on CHIP 3

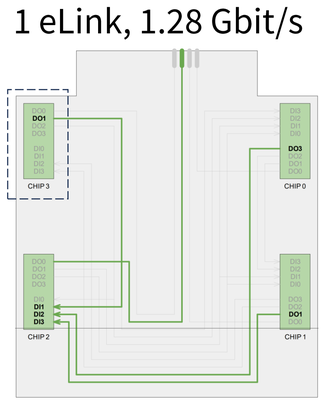
Active pixels scan



Efficiency vs. injected calibration charge (S-curve)



1 eLink, 1.28 Gbit/s



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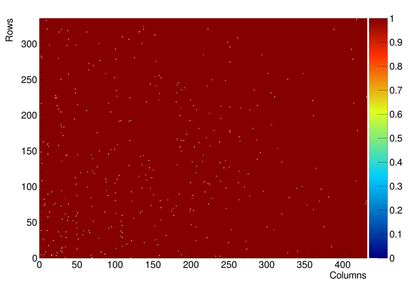
Active pixels scan



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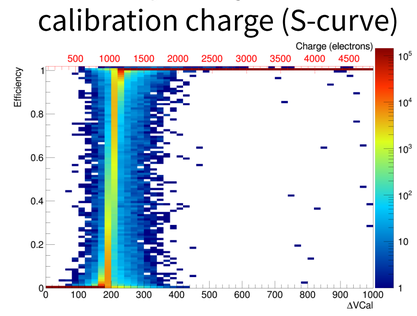

References

CMS Collaboration, *The Phase-2 Upgrade of the CMS Tracker*, CERN-LHCC-2017-009, CMS-TDR-014 (2017)
RD53 Collaboration, *RD53C Chip Manual*, CERN-RD53-PUB-24-001 (2024)