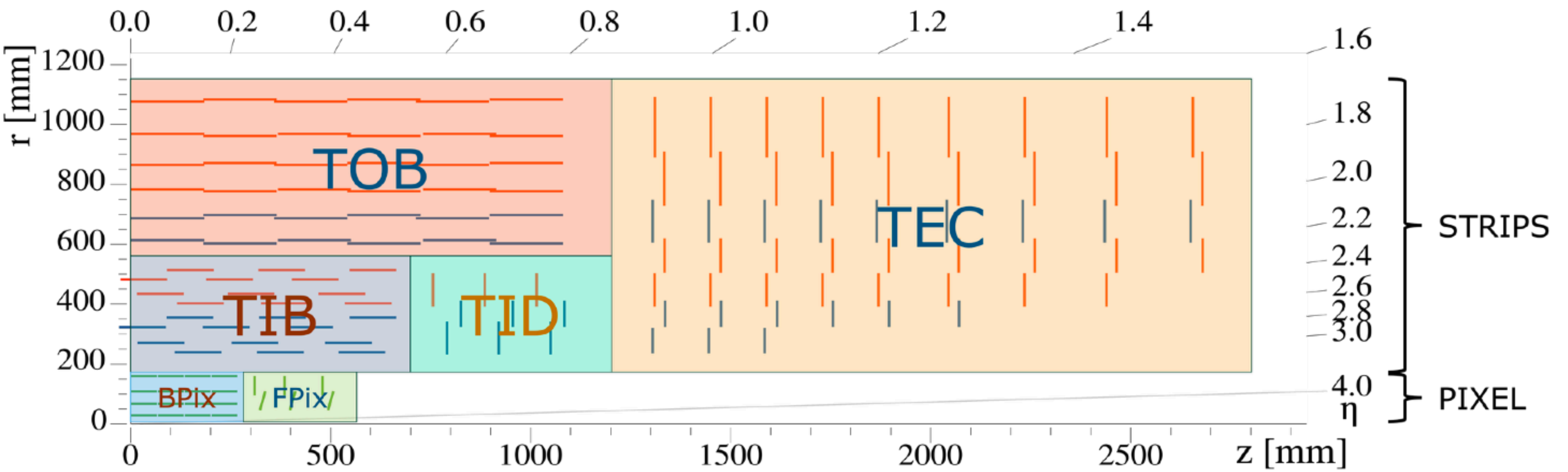
Operation and performance of the current CMS Pixel Detector

Grace Haza on behalf of the CMS collaboration

VERTEX 2023

16 October 2023

Tracking detectors of CMS



Pixel tracker

➡ Barrel Pixels and Forward Pixels

Strip tracker

➡ Tracker Inner Barrel, Tracker Inner Disk, Tracker Outer Barrel, Tracker Endcap

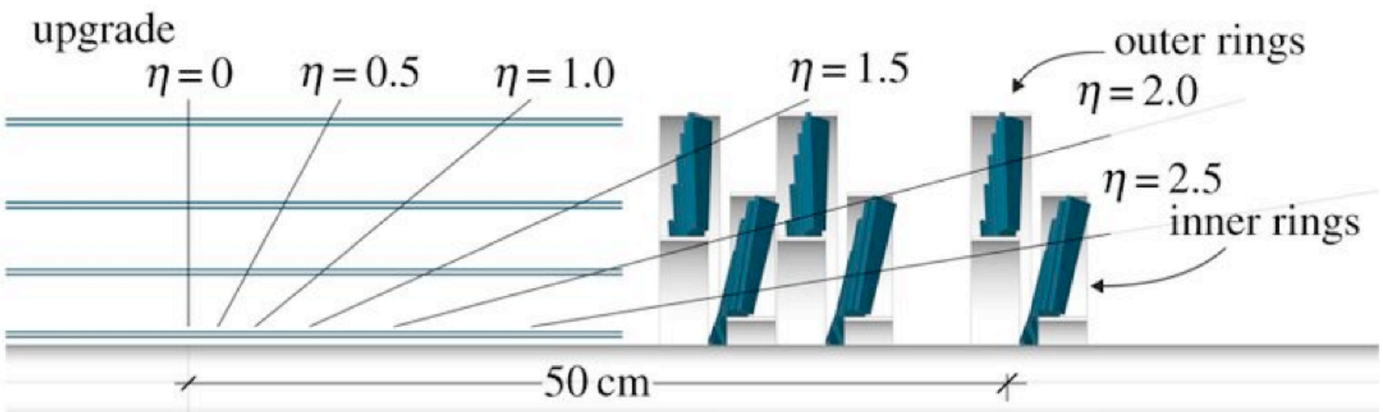
Pixel detector

Barrel pixels (BPix)
- 4 layers
- 1184 total modules

Forward pixels (FPix)
- 3 disks * 2 rings on each end
- 672 total modules

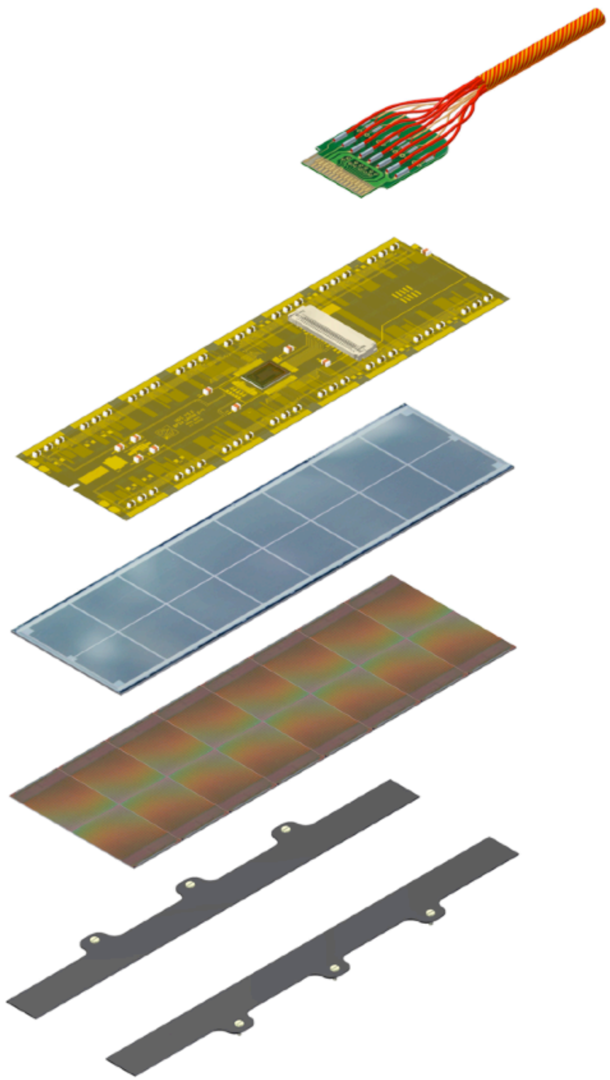
Layer 4
r = 160mm

Layer1
r = 29mm



- Pixel Phase 1 installed winter 2016/2017
- 4 hit coverage up to |η| < 3

Module design



Signal and power cables

Token bit manager (TBM) chip
- Receives clock, level 1 trigger accept, configuration data
- Orchestrates readout
- 2 TBM/module in layer 1

Silicon sensor
- (150x100) μm^2
- 280 μm n-in-n

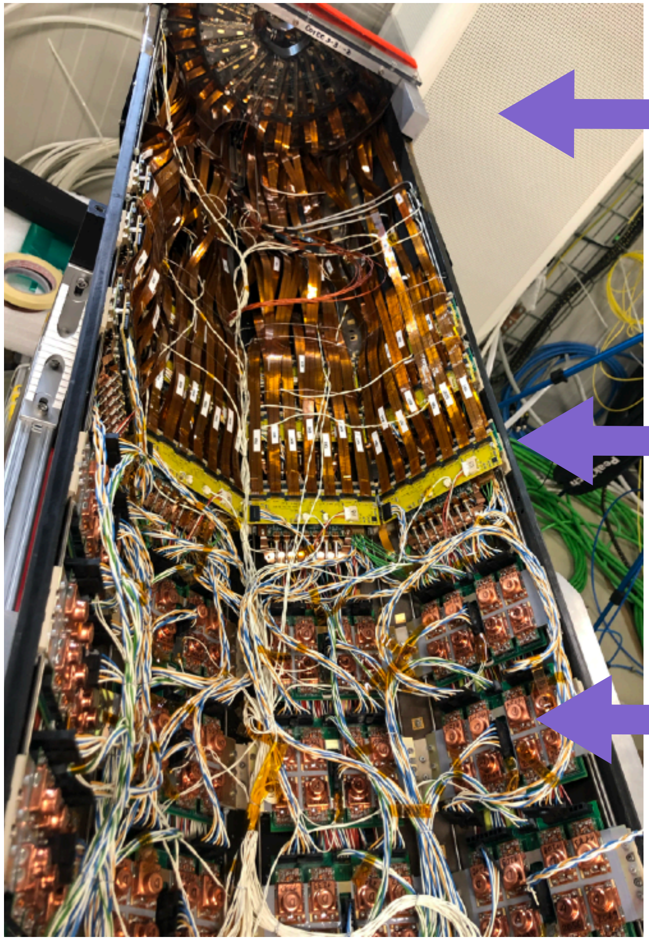
Read out chips

PSI46dig
- Digital readout
- Double column drain
- > 90% efficiency up to 200MHz/cm^2 hit rate

PROC600
- Specialized for layer 1
- Dynamic cluster drain
- > 90% efficiency up to 600MHz/cm^2 hit rate

Base strip

Detector with service cylinder



Modules

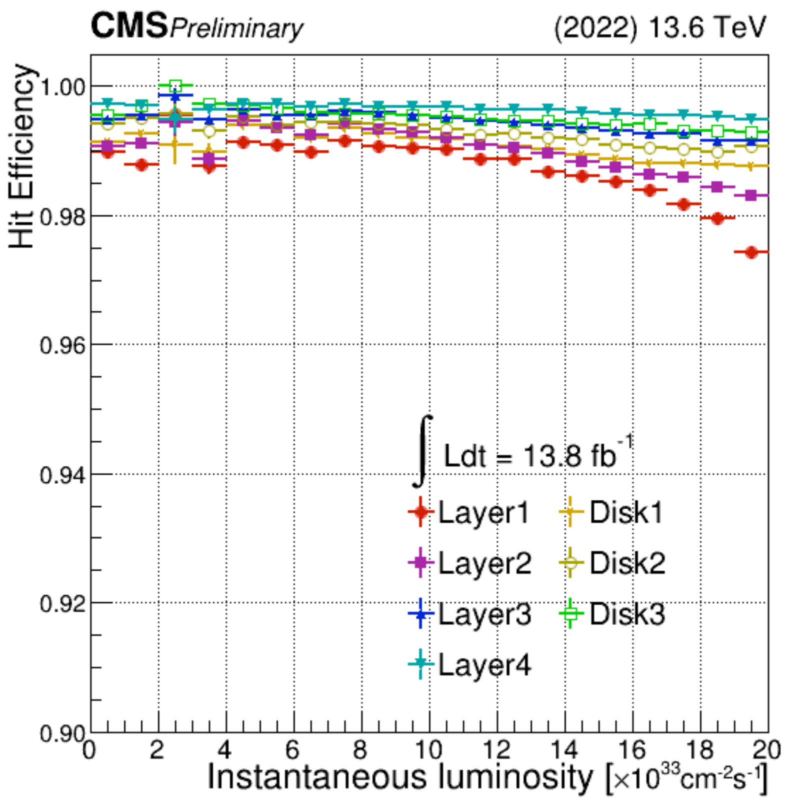
Portcards with delay chips

DCDC converters

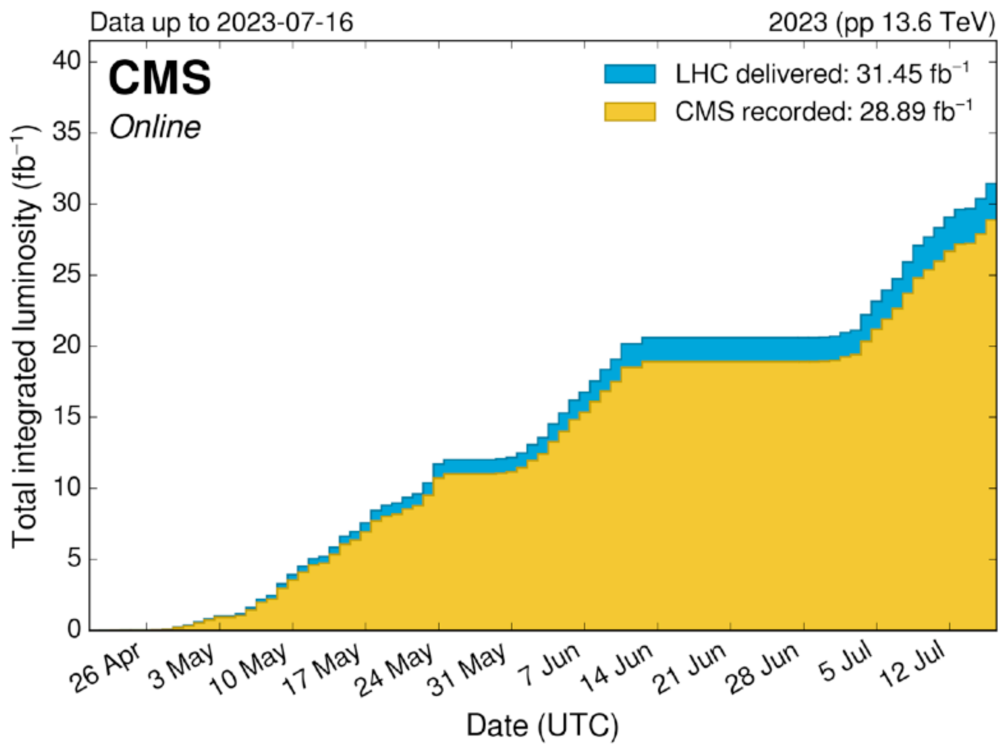
Beginning of Run 3

- Pixels refurbished and reinstalled in June 2021
- **Completely new layer 1** has significant improvements
  - ➡Readout chip decreased dynamic inefficiency and reduced crosstalk
  - ➡New TBM with additional delay option
  - ➡New high density interconnect for more robust HV operation
- Some layer 2 modules replaced
- New DCDC converters
- Improved FPix cooling connections

➡**Excellent performance in start of Run 3 in 2022**

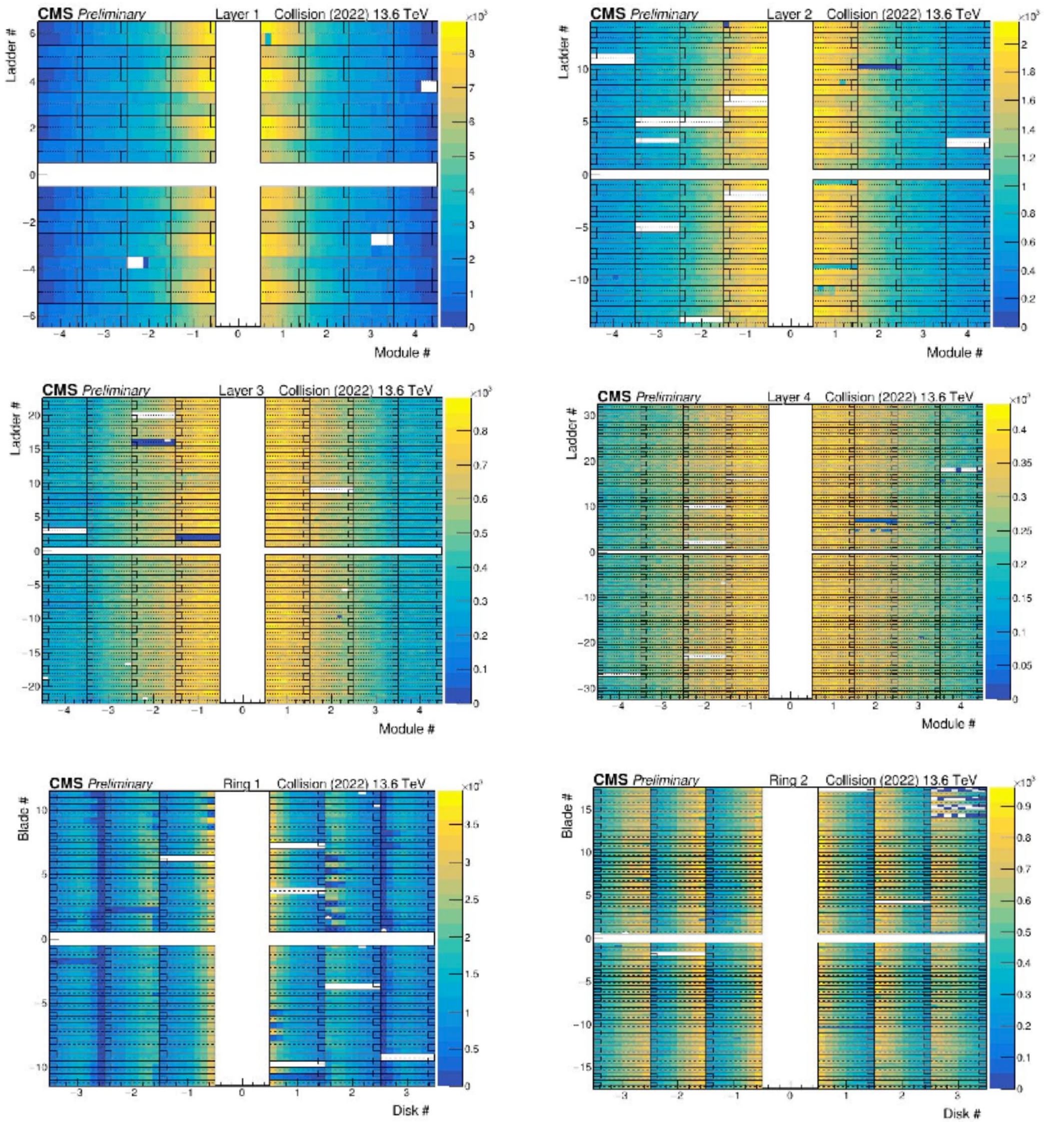


LHC operation in 2023



- **April 2023:** Stable beams @ 900 GeV, then 13.6 TeV
- **July 2023:** LHC incident
- **September 2023:** LHC recovered and began heavy ion data-taking

Active detector fraction

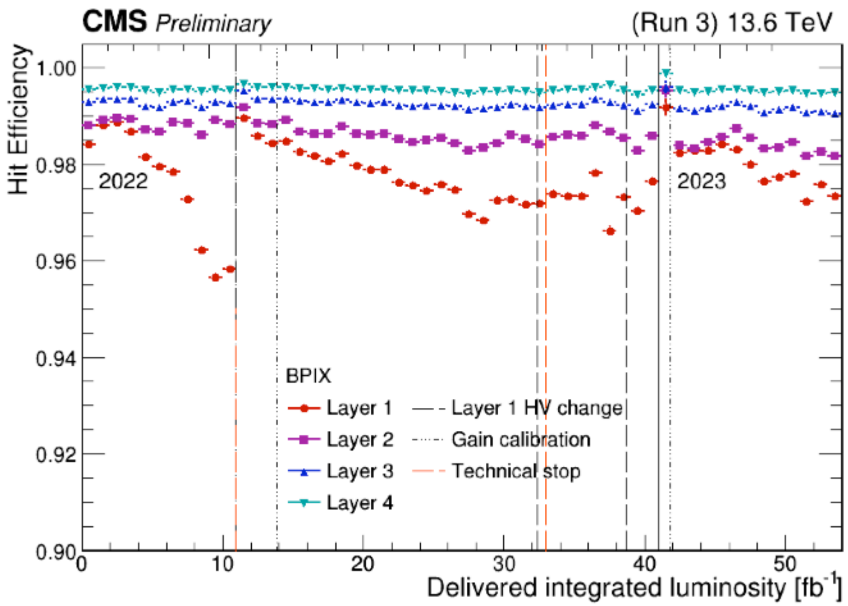


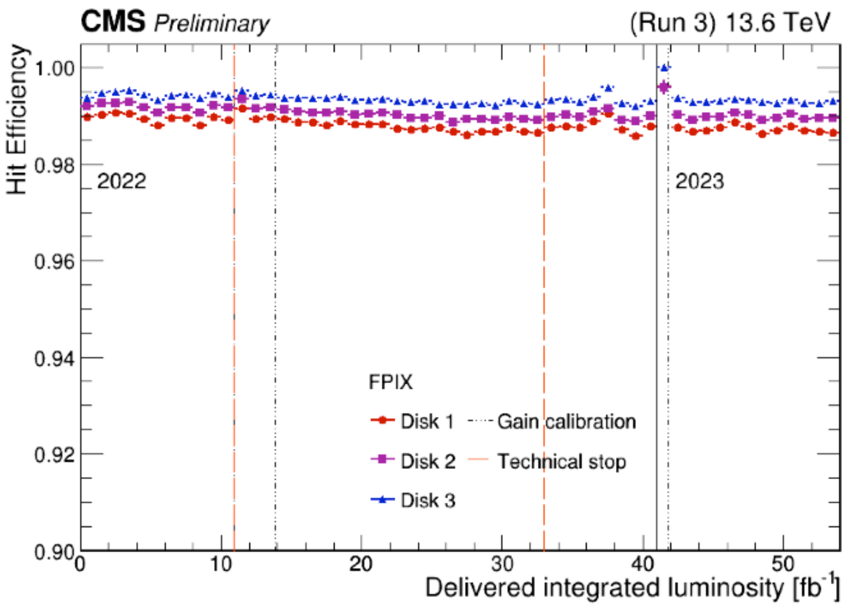
Active fraction at beginning of June 2023

➡ 98.4 % of Barrel Pixels

➡ 97.9 % of Forward Pixels

Hit efficiency

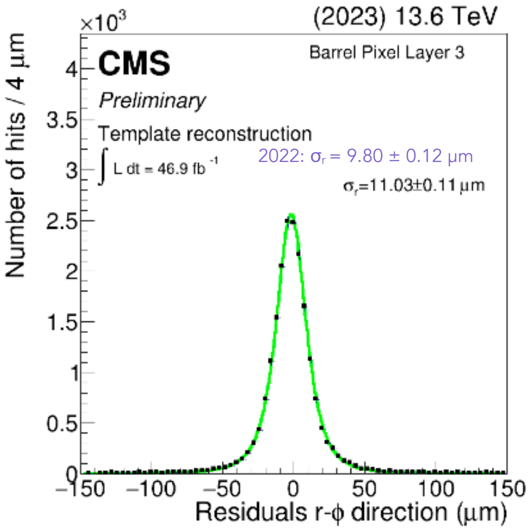


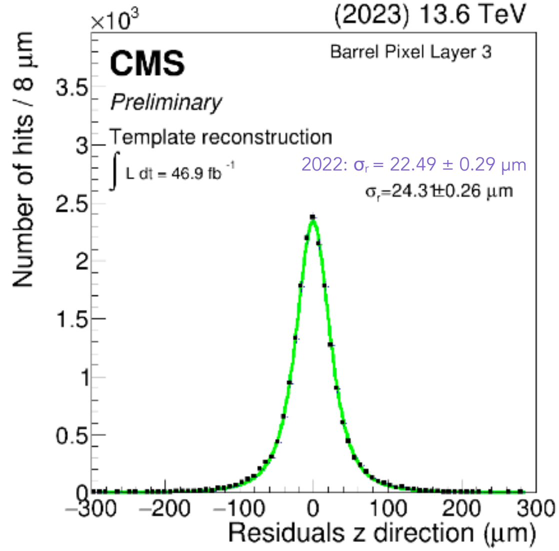


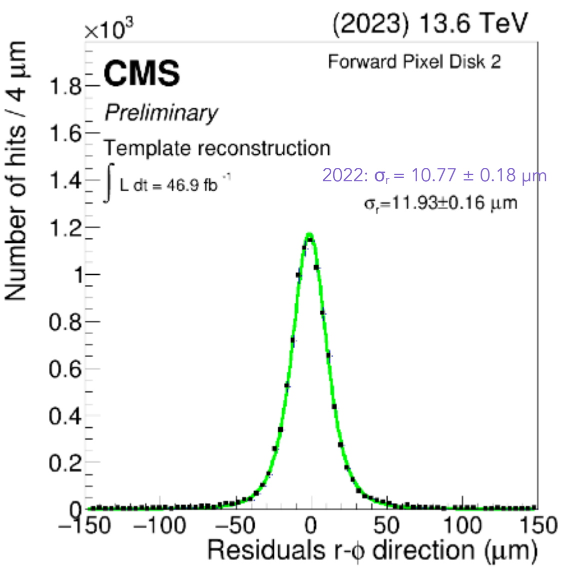
- Hit efficiency affected by gain calibration, HV setting, and annealing during technical stops

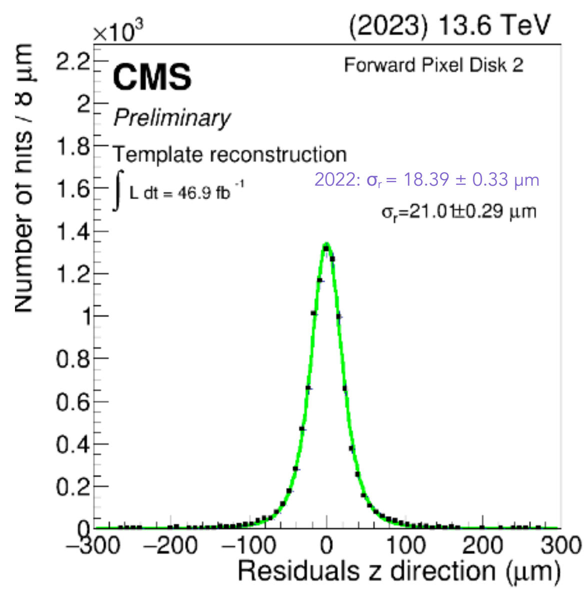
➡ High hit efficiencies for all layers and disks

Resolution







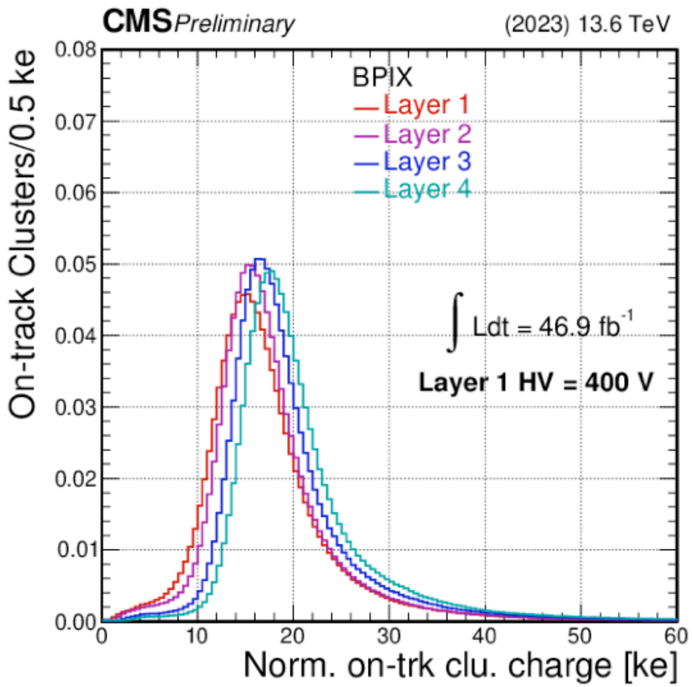


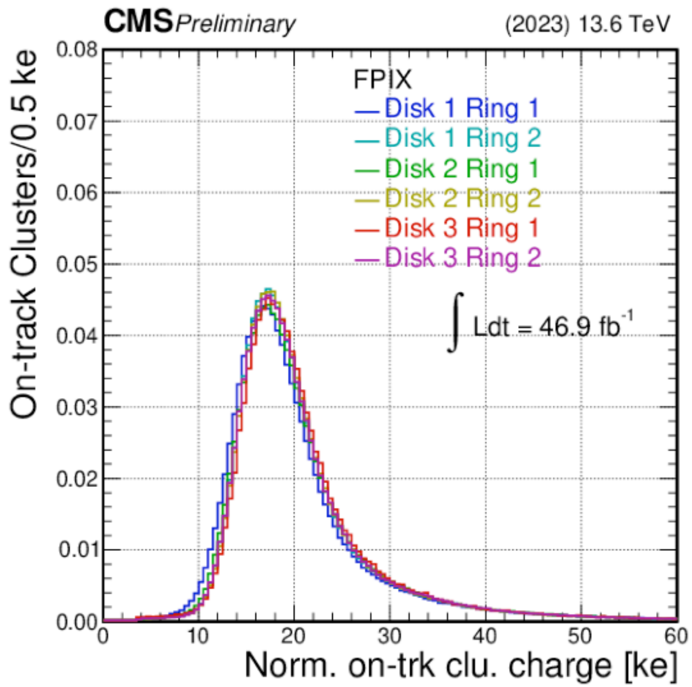
Great position resolution

➡ Performance consistent with expected evolution

➡ Comparable to performance seen in 2022 and Run 2

Cluster charge distributions





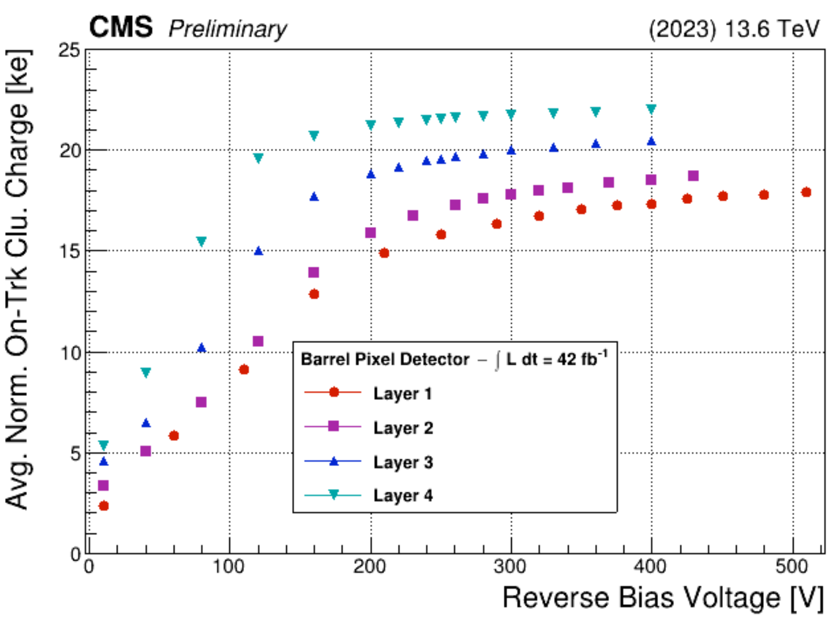
On-track cluster charge consistent across detector

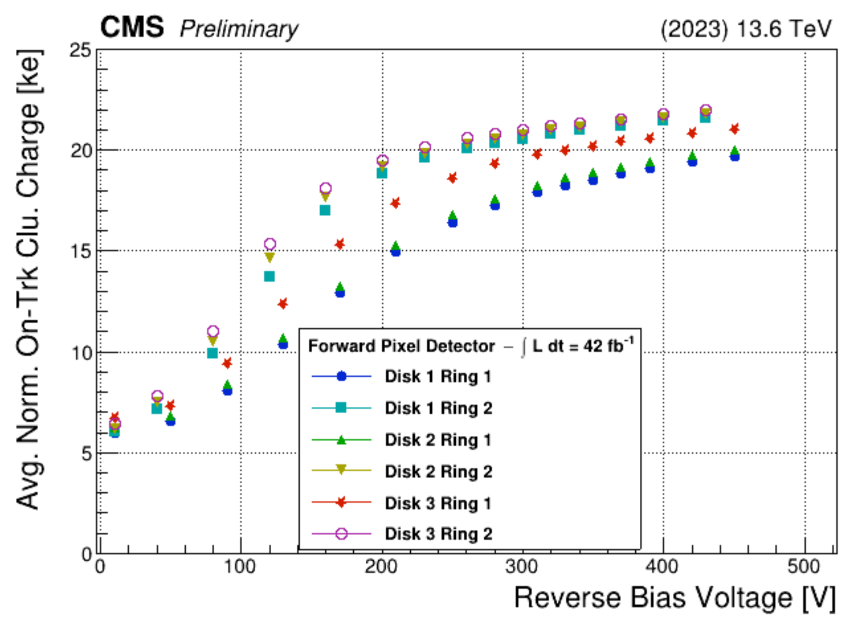
Cluster charge measurement

Cluster charge measured as function of bias voltage to determine when settings should be adjusted

Current settings

- Layer 1: 450V
- Layer 2: 350V
- Layer 3 & 4: 250V
- Ring 1: 350V
- Ring 2: 300V



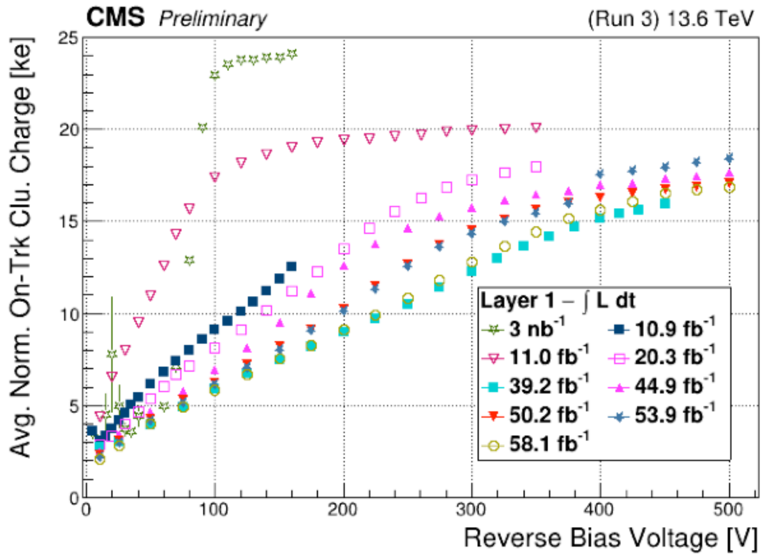


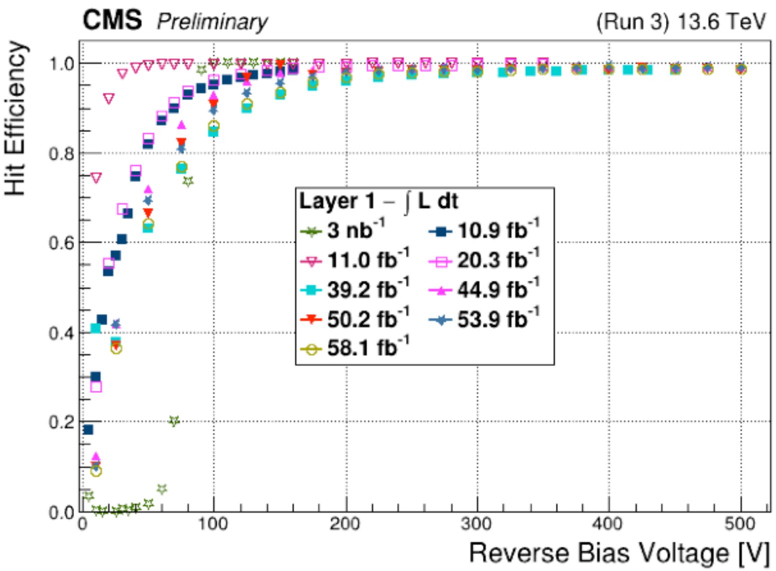
Layer 1 radiation damage

Layer 1 evolving rapidly

➡ HV bias scans performed regularly to monitor performance

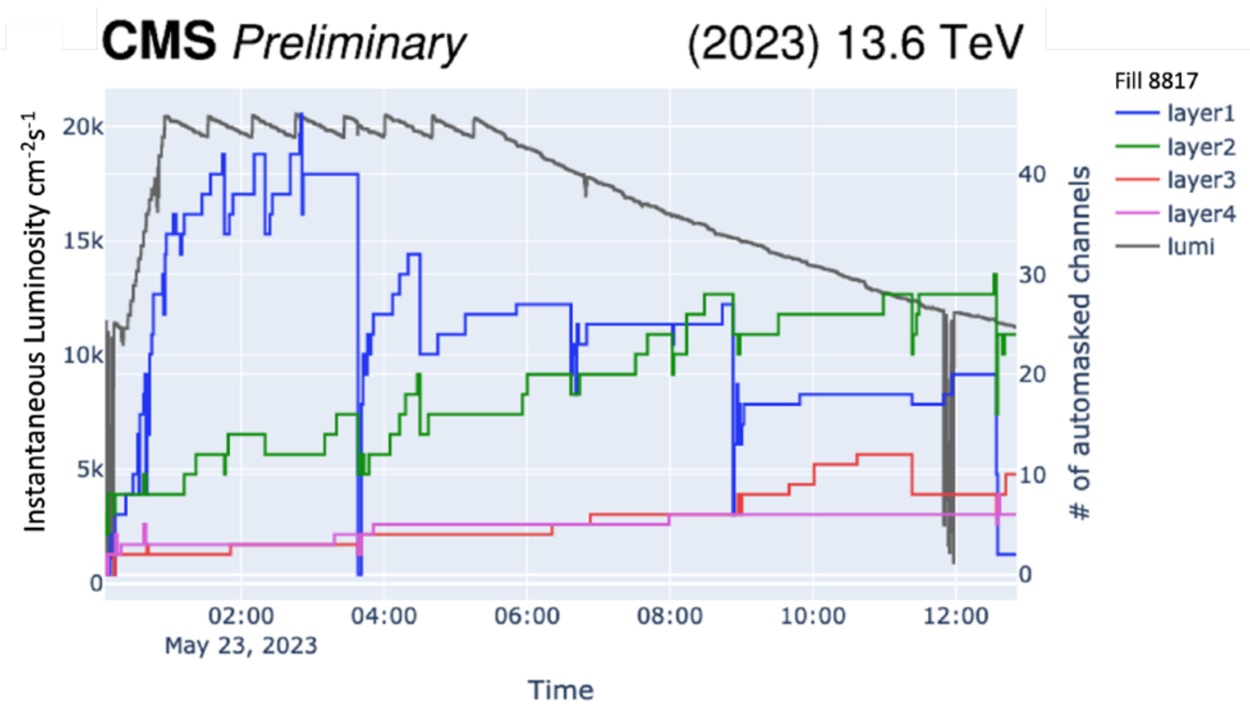
➡ Layer 1 began Run 3 with HV bias of 150V, now at 450V





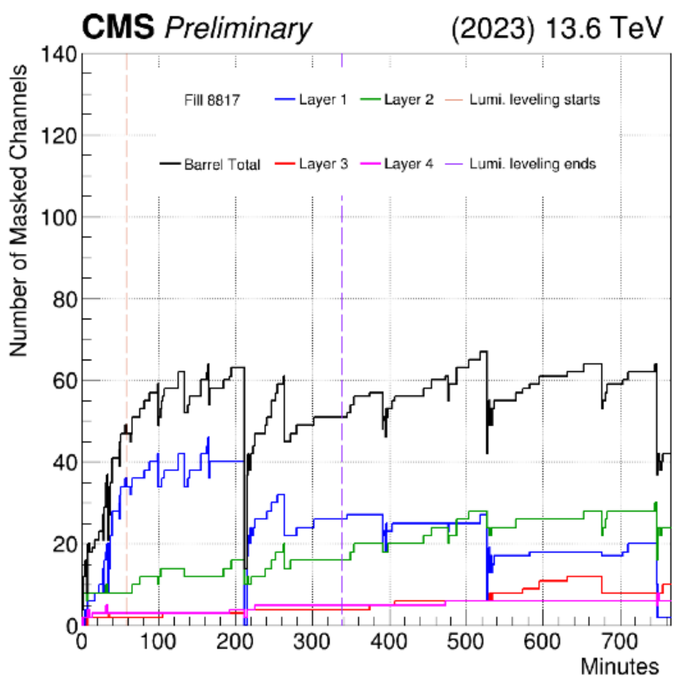
Automasked channels

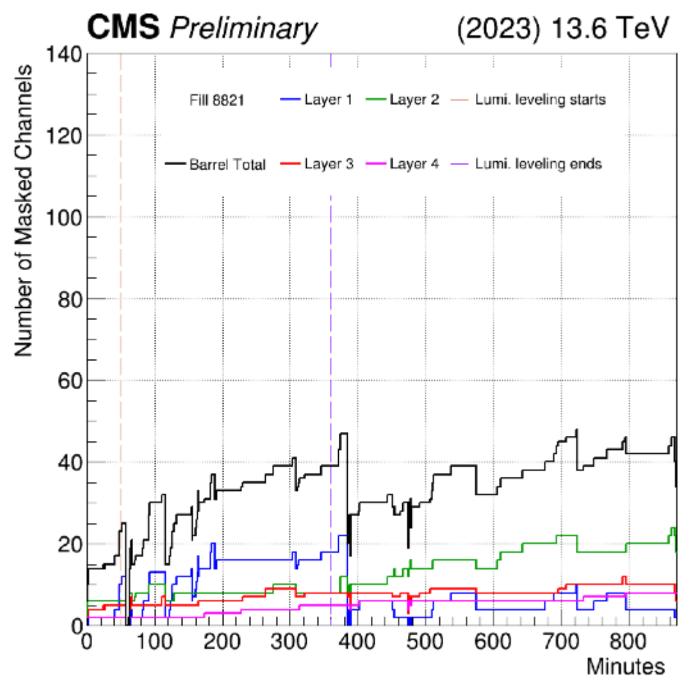
- Channels masked during data-taking due to readout errors
  - ➡ **Layer 1:** operational problem first mitigated by increasing number of allowed readout errors before channel masking
  - ➡ **Layer 2-4:** unrecoverable SEUs accumulate over a fill
- Recovery action at certain pile up
- Data quality remained good for CMS



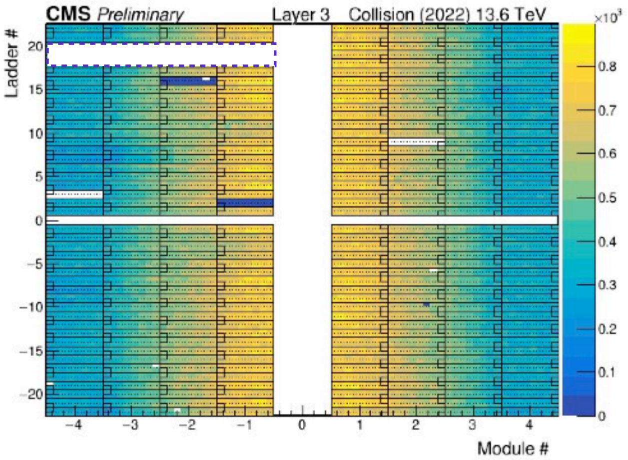
Automasked channels

- Problem greatly mitigated by adjusting phases of the 400MHz data transmission (relative phase of readout chip and TBM)
  - ➡ Calibrations do not not always predict a good setting for high rate data transfer
- Automasking of Layer 1 modules now very low, usually 1% of channels

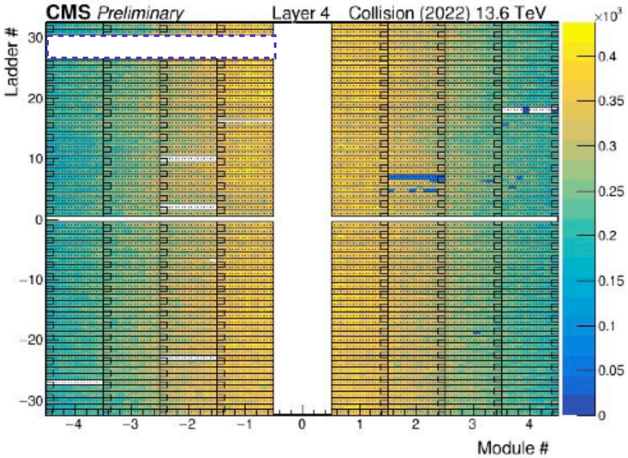


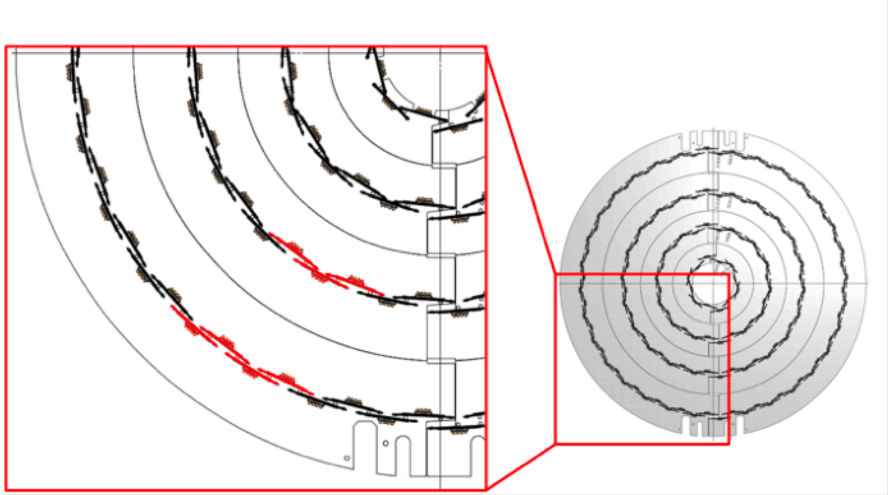


QPLL issue

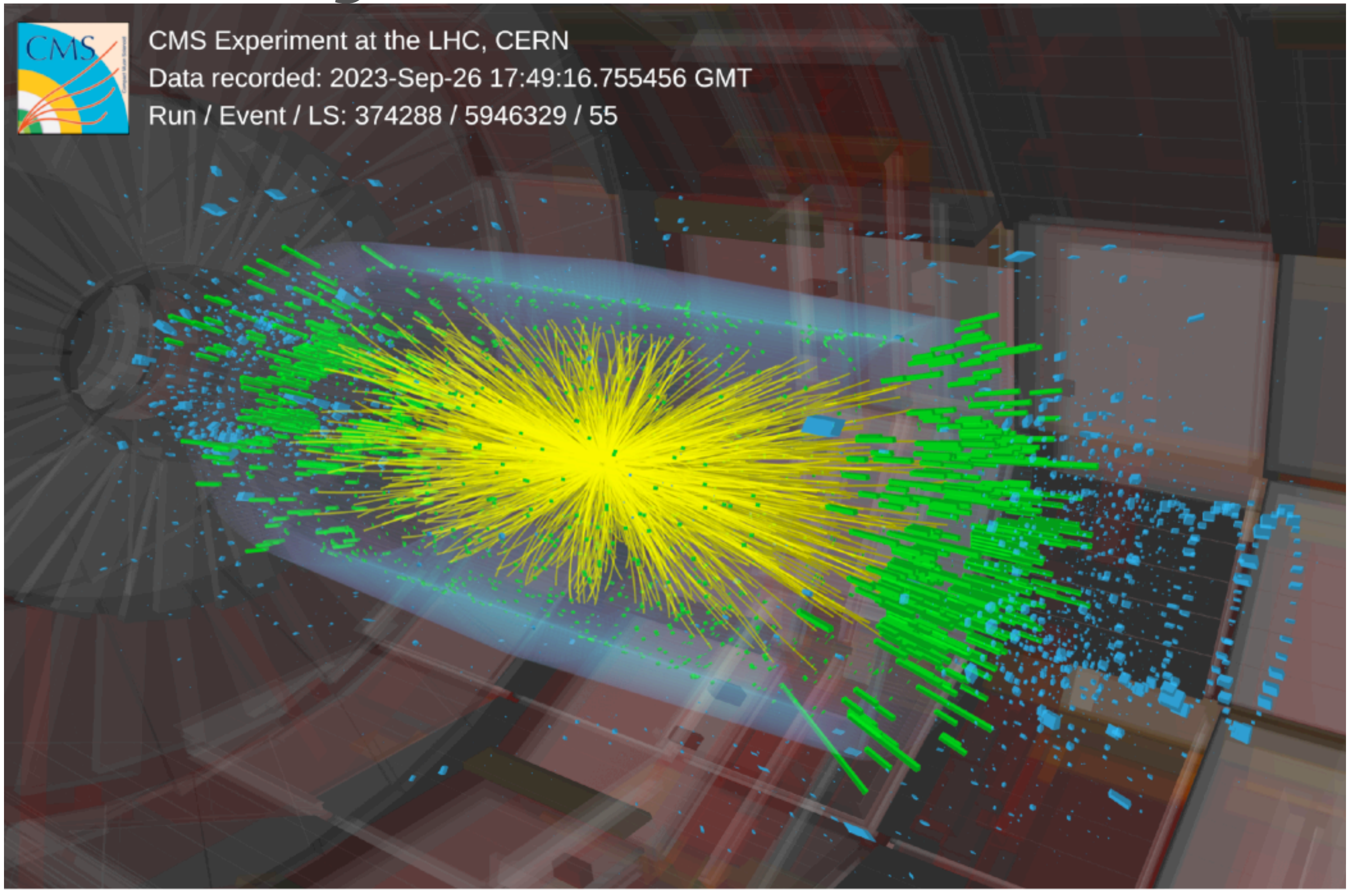


- Quartz controlled PLL circuit does not lock to LHC clock
- Layers 3 and 4 of one sector of barrel pixels affected
- Modules are not currently read out
    - ➡ Fixing the issue would require extracting and reinstalling pixel detector





Heavy ion collisions

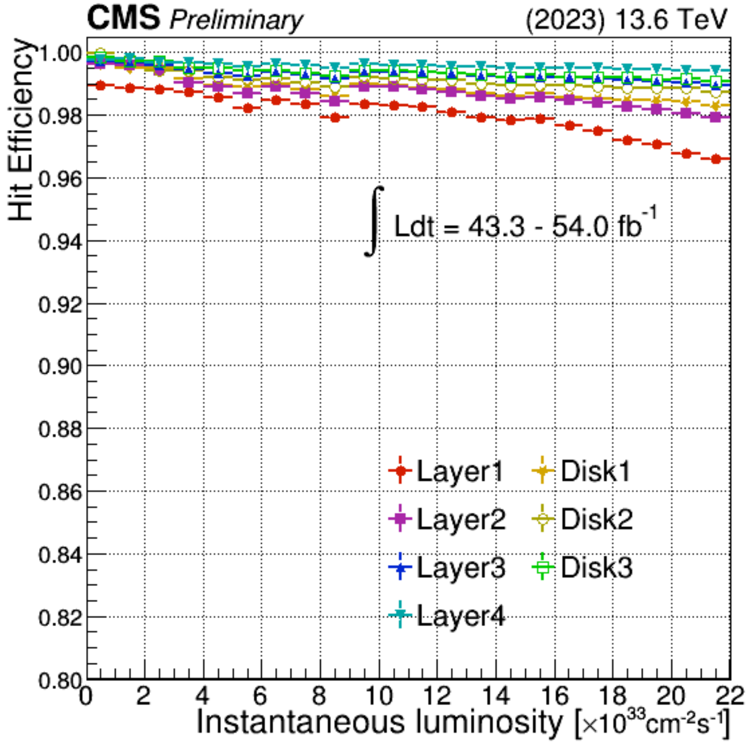


Pixels performing well during heavy ion collisions

- Buffers increased to allow for larger event sizes in readout
- Low luminosity leads to virtually no SEUs

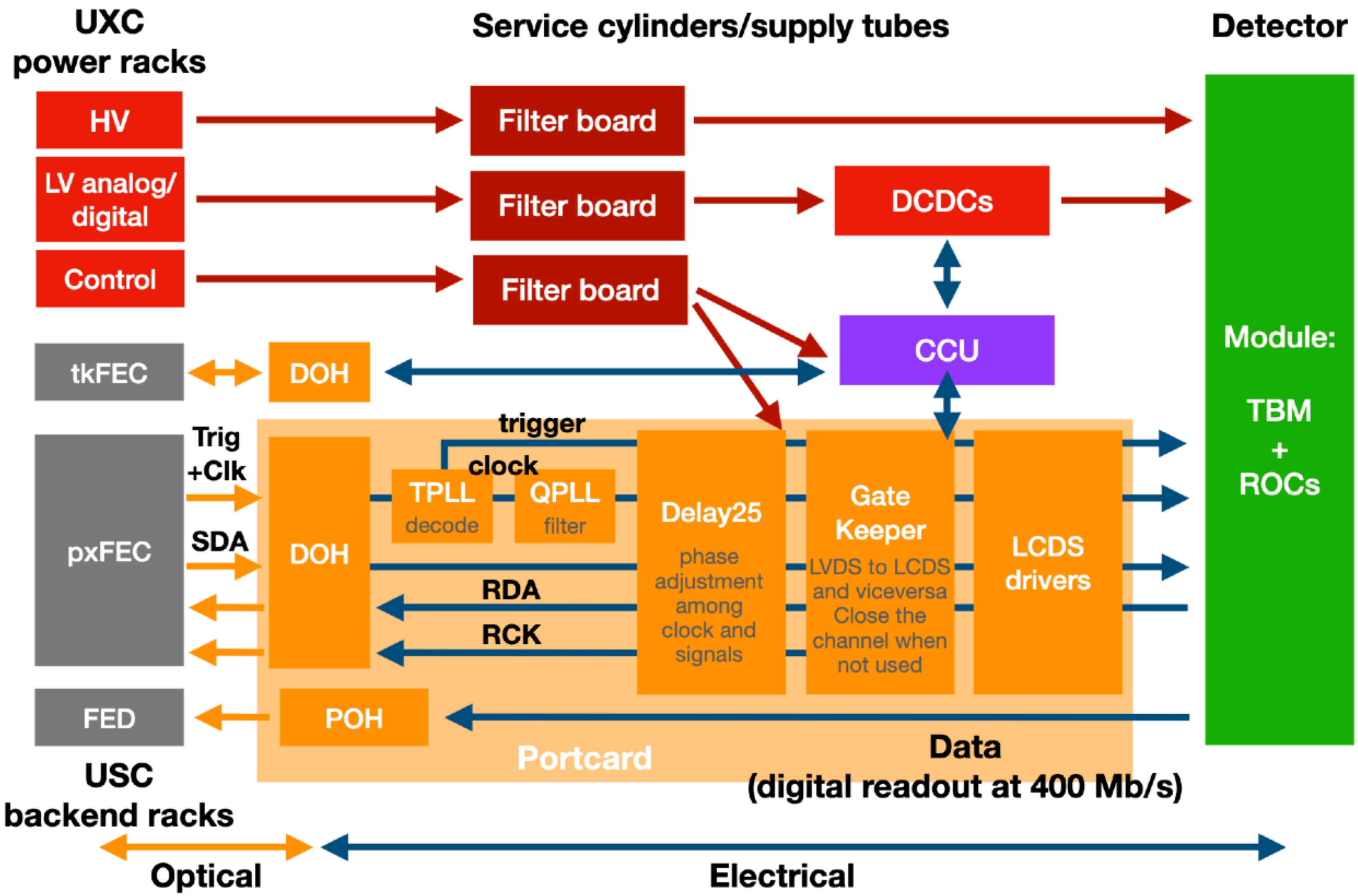
Summary

- Detector in good health with continuous monitoring and calibrations
- **Overall successful performance** in data collection with proton-proton collisions with inst. lumi up to $2*10^{34}$ $cm^{-2}s^{-1}$
  - readout errors resolved by adjusting timing setting
  - QPLL issue persists
- Heavy ion collision data collection ongoing
- Looking forward to the rest of Run 3!



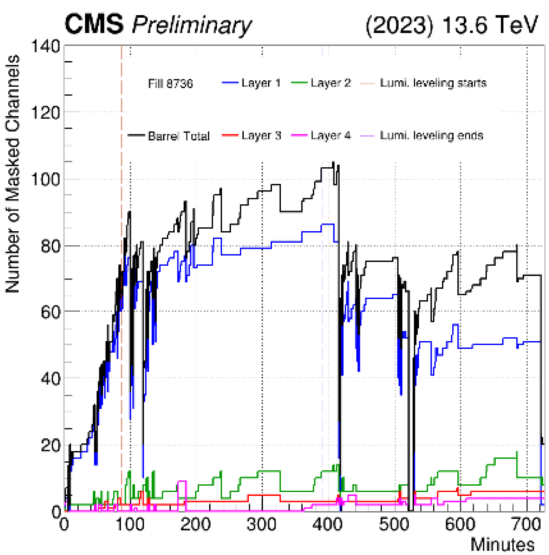
Backup

Hardware connections

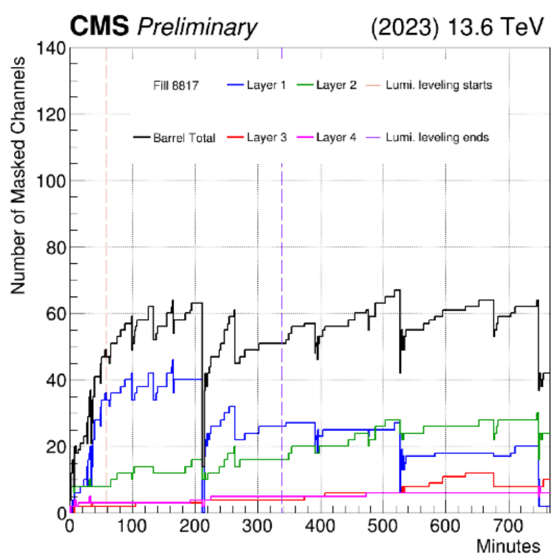


Automasked channels

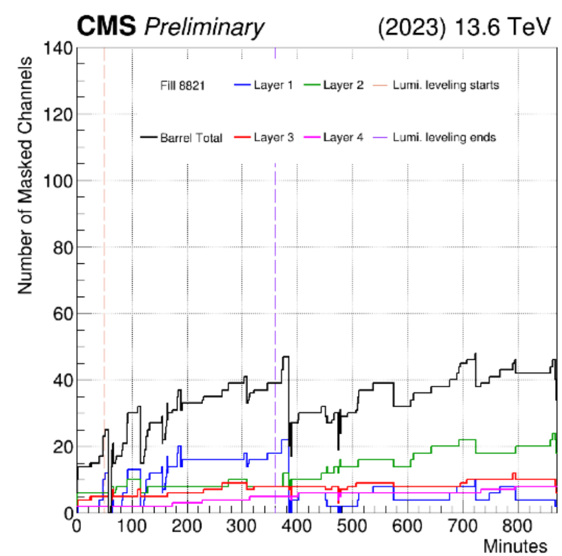
- **Fill 8736:** Channel auto-masked if there are 30 Out-of-Sync (OOS) errors seen in one minute in the channel
- **Fill 8817:** OOS setting was changed from 30 OOS/minute to 63 OOS/minute
- **Fill 8821:** The Token Bit Manager phase settings of several modules in BPix Layer 1 were changed



Fill 8736



Fill 8817



Fill 8821

Automasked channels: fill details

Fill 8736 (8 May 2023):

- Number of bunches: 1805
- Peak instantaneous luminosity: 1.56×10^{34} cm^{-2} s^{-1}
- Peak PU: 61.401

Fill 8817 (24 May 2023):

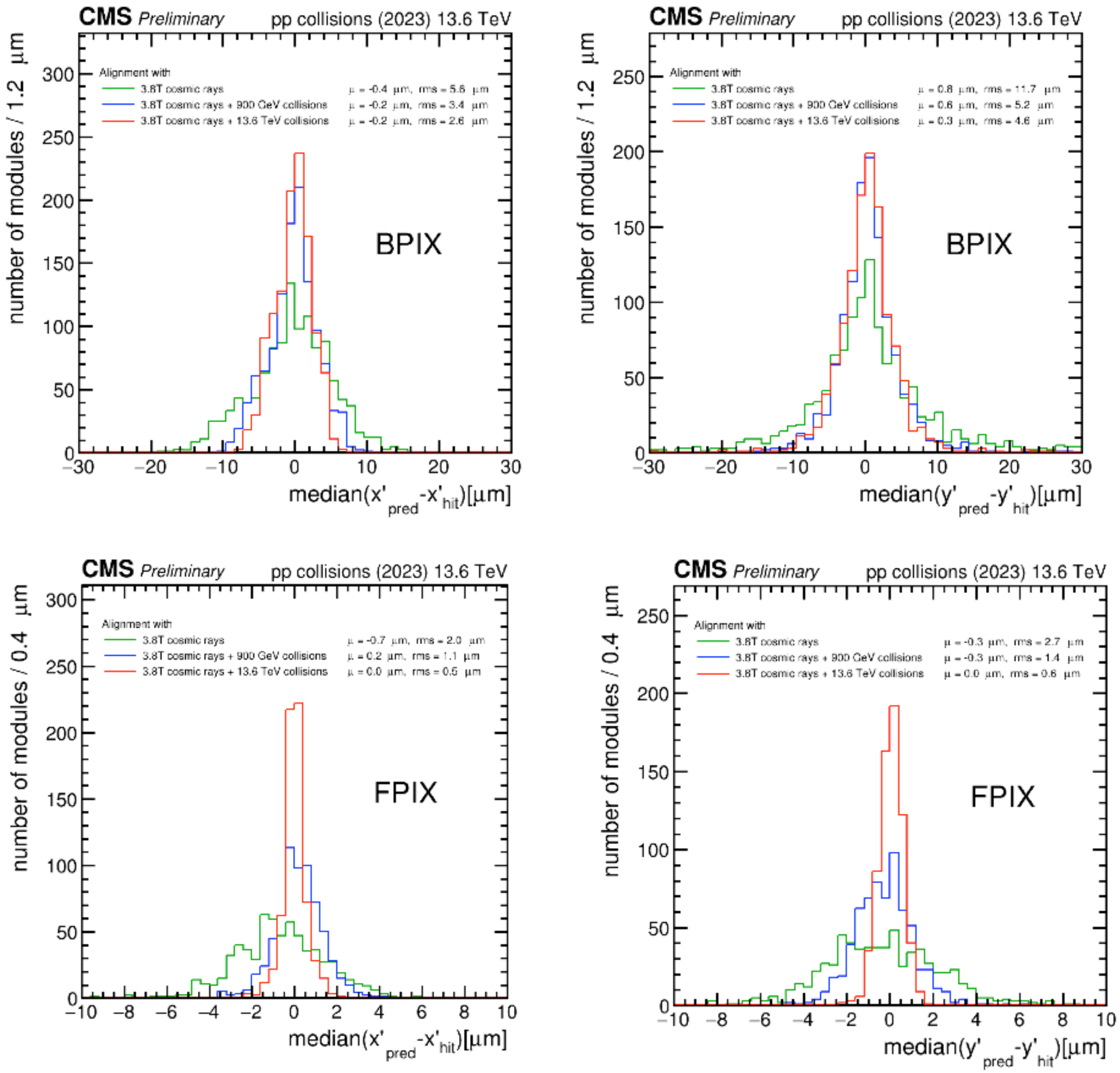
- Number of bunches: 2345
- Peak instantaneous luminosity: 2.05×10^{34} cm^{-2} s^{-1}
- Peak PU: 62.299

Fill 8821 (25 May 2023):

- Number of bunches: 2345
- Peak instantaneous luminosity: 2.12×10^{34} cm^{-2} s^{-1}
- Peak PU: 64.316

- All fills have the same trigger rate

Alignment



- Alignment performed with cosmic rays, 900GeV collisions, 13.6TeV collisions
- Distributions are medians of track-hit residuals
- Hit prediction obtained from all other track hits
- Median of distribution taken for each module
- Width of this distribution constitutes a measure of the local precision of the alignment results
- Deviations from zero indicate possible biases

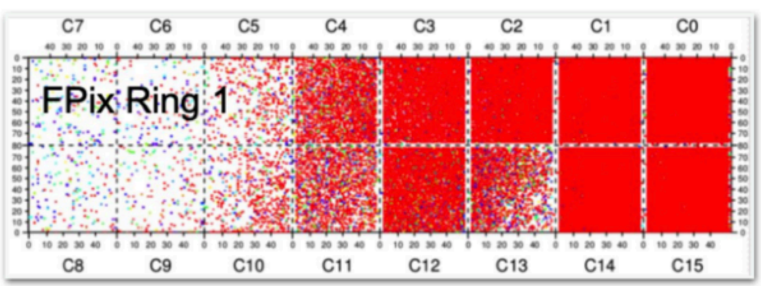
DCDC issue in Run 2

- Flaw in FEAST chip design
- When DCDC disabled, charge build up on circuit due to irradiation, causing DCDC to break
- Impact:
  - converters not used to power cycle modules
  - powercycling needed for stuck TBMs
  - reduced power supply voltage to 9V
  - high current trips in power groups with higher number of modules
  - disabled a few DCDC converters to prevent trips
  - no broken DCDC converters in 2018

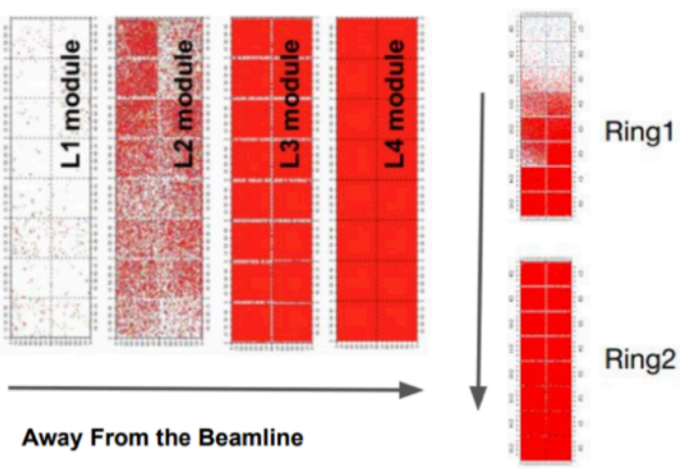
DCDC damaged modules

DCDC damaged modules not correctly powered

- Sensor leakage current cannot be drained efficiently if the ROC is not powered
- Bias voltage (HV) ON and module power (LV) OFF leads to bad grounding
- Leakage current is drained through the pre-amplifier, damaging the pre-amplifier and the module
- Damage seems to accumulate with radiation and distance from beamline
- 6 (accessible) Layer 1 modules replaced during 2017-18 YETS out of total 8 damaged modules in Layer 1
- Accessible DCDC-damaged modules in Layer 2 were replaced during LS2



Damages due to HV on and LV off



Hit efficiency and hit residuals measurement

Hit efficiency is the probability to find any cluster within 1mm around an expected hit independent of the cluster quality

- Measured using muon tracks with pT > 2 GeV
- Bad components of the pixel detector are excluded from the measurement

Hit residuals measurement:

- Triplet method
  - p_T > 12 (4) GeV tracks with hits in 3 layers (disks) are selected and refitted using hits in two of three layers (disks) for the BPIX (FPIX).
  - Trajectory is extrapolated to remaining layer (disk) and residuals with the actual hit are calculated for the BPIX (FPIX)
  - Residual distribution fitted with the Student-t function to obtain the mean offset (μ) and resolution (σ)
    - Residual offset (mean) and resolution are obtained from the fit
  - Triplets considered:
    - Layer 3: propagate from hits on Layer 2 and 4
    - Disk 2: propagate from hits on Disks 1 and 3
- Reconstruction:
  - Generic:
    - Simple algorithm based on track position and angle
    - Used in our High Level Triggers (HLT) and early track iterations offline
  - Template:
    - Algorithm based on detailed cluster shape simulations
    - Used in the final fit of each track in the offline reconstruction