Operation of CMS GE1/1 GEM detectors in Run-3

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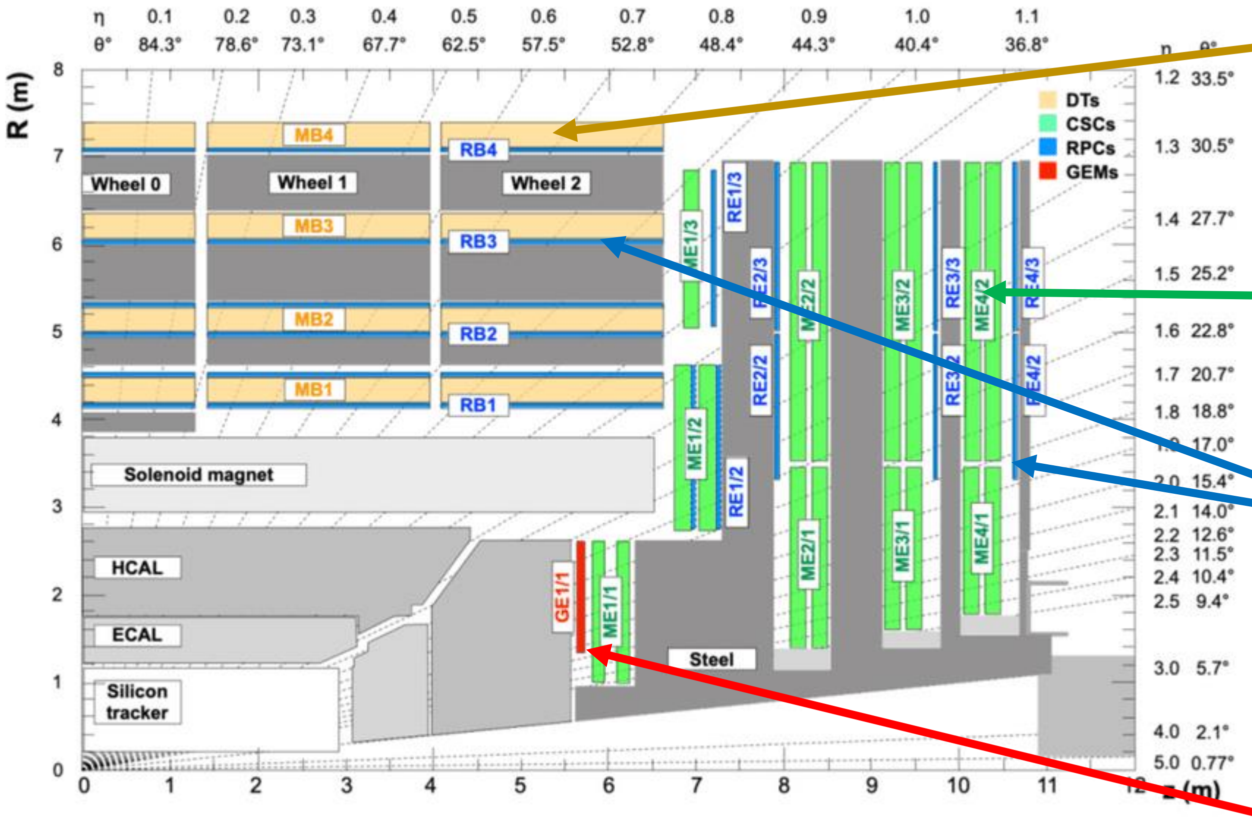
Simone Calzaferri
University of Pavia (Italy)
On behalf of the CMS Muon Group

In this talk

- Detector stability:
  - Discharges
  - Short circuits in GEM foils

- Detector performances:
  - Electronics stability
  - High multiplicity events and hit occupancy
  - Muon bending angle vs muon p_T
  - Muon detection efficiency

The present CMS muon system



DT: Drift Tubes
Coverage: $|\eta|<1.2$

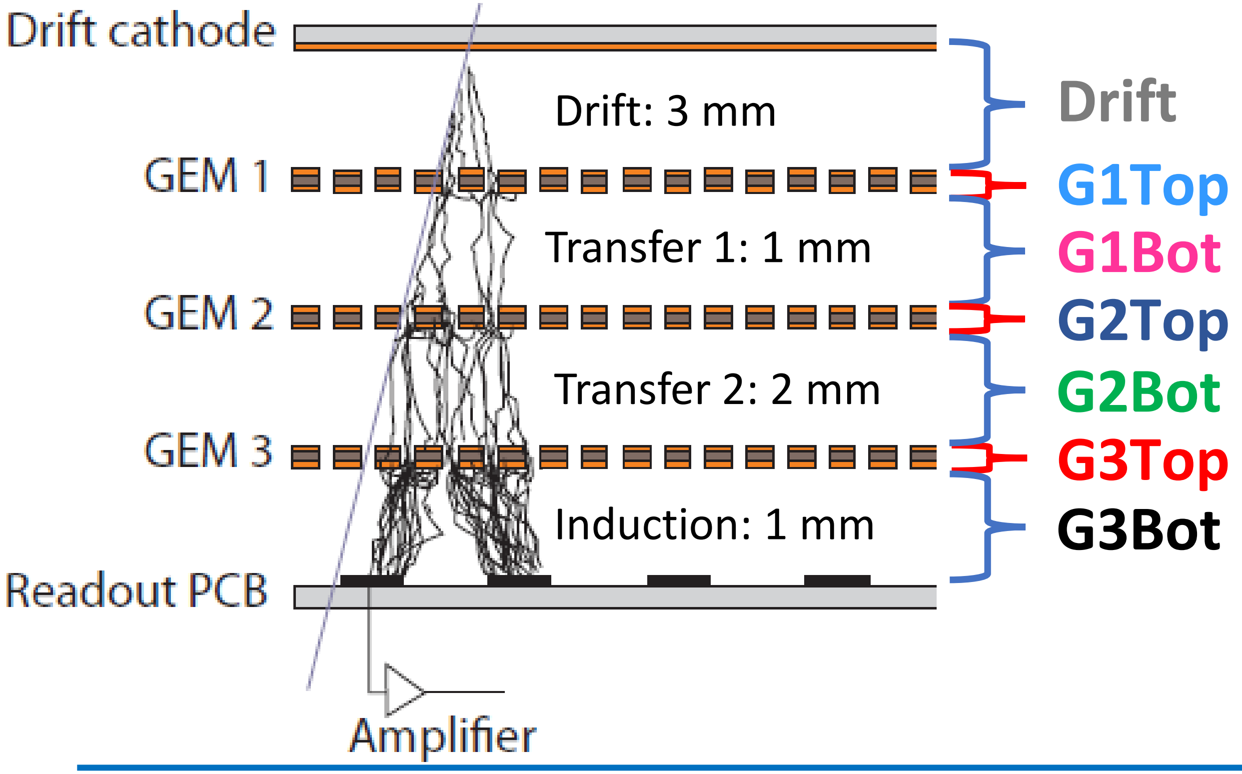
CSC: Cathode Strip Chambers
Coverage: $0.9 < |\eta| < 2.4$

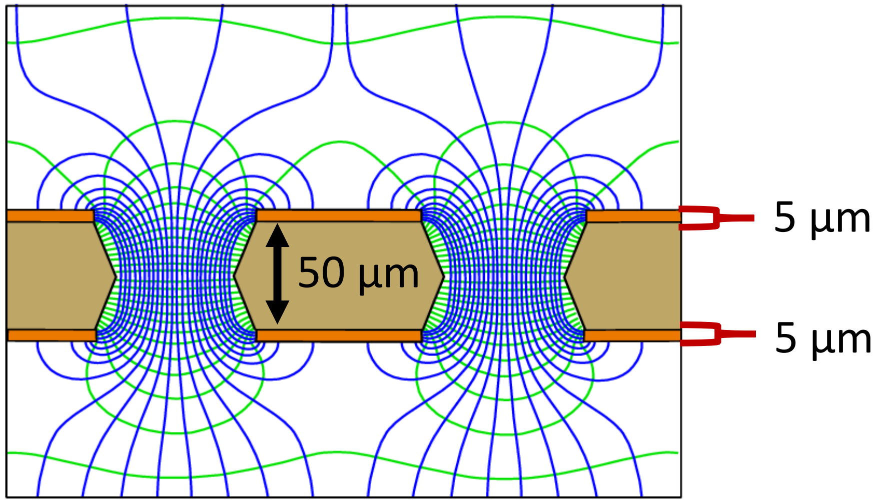
RPC: Resistive Plate Chambers
Coverage: $|\eta|<1.9$

GEM: Gas Electron Multiplier
Coverage GE1/1: $1.55 < |\eta| < 2.18$

The CMS GE1/1 station

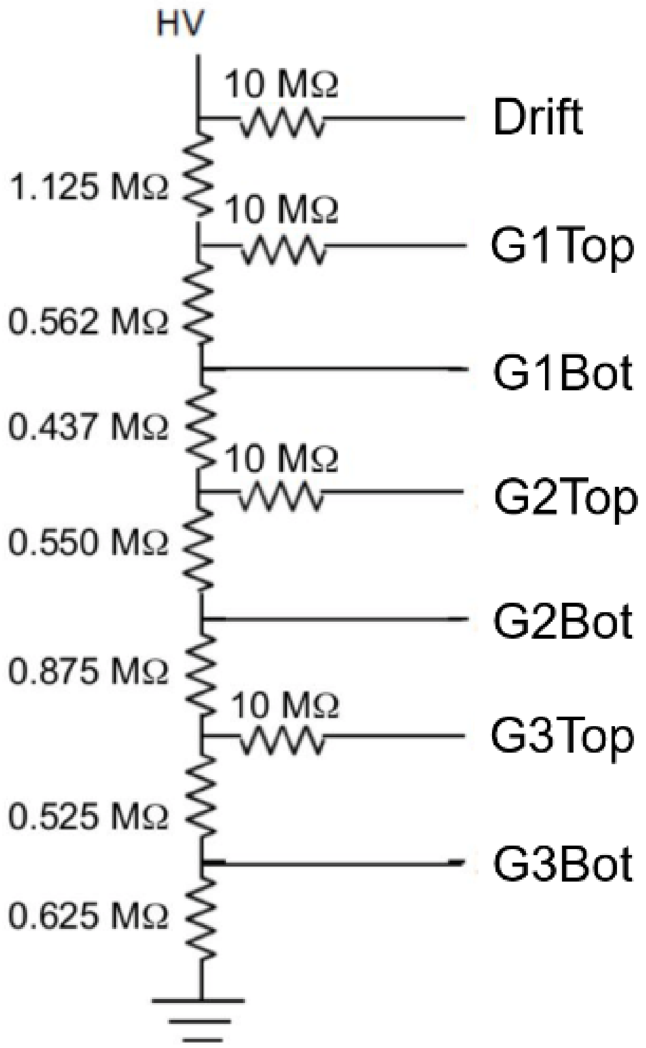
- Triple GEM detectors
- Gas mixture: Ar/CO_2 (70/30)
- HV provided with multichannel power supply CAEN A1515 boards
  - Detectors are powered in pairs (same power supply for two detectors)





The GEM foil:
- Biconical holes
- Diameter: 70 µm
- Pitch: 140 µm
- Kapton thickness 50 µm
- Copper cladded on both sides (5 µm)

HV working point



- The gain of chambers is measured using a **resistive divider**
  - It fixes the ratios between voltages applied on the 7 electrodes
  - Reference for the setting of the chamber when powered with a **multichannel power supply**
    - Voltage global working point is identified by the current flowing in the reference resistive divider (I_{eq})
    - **Needed to** understand behaviour of detectors during operations (Example $I_{eq} = 690\ \mu A$: Gain $\approx 10^4$)

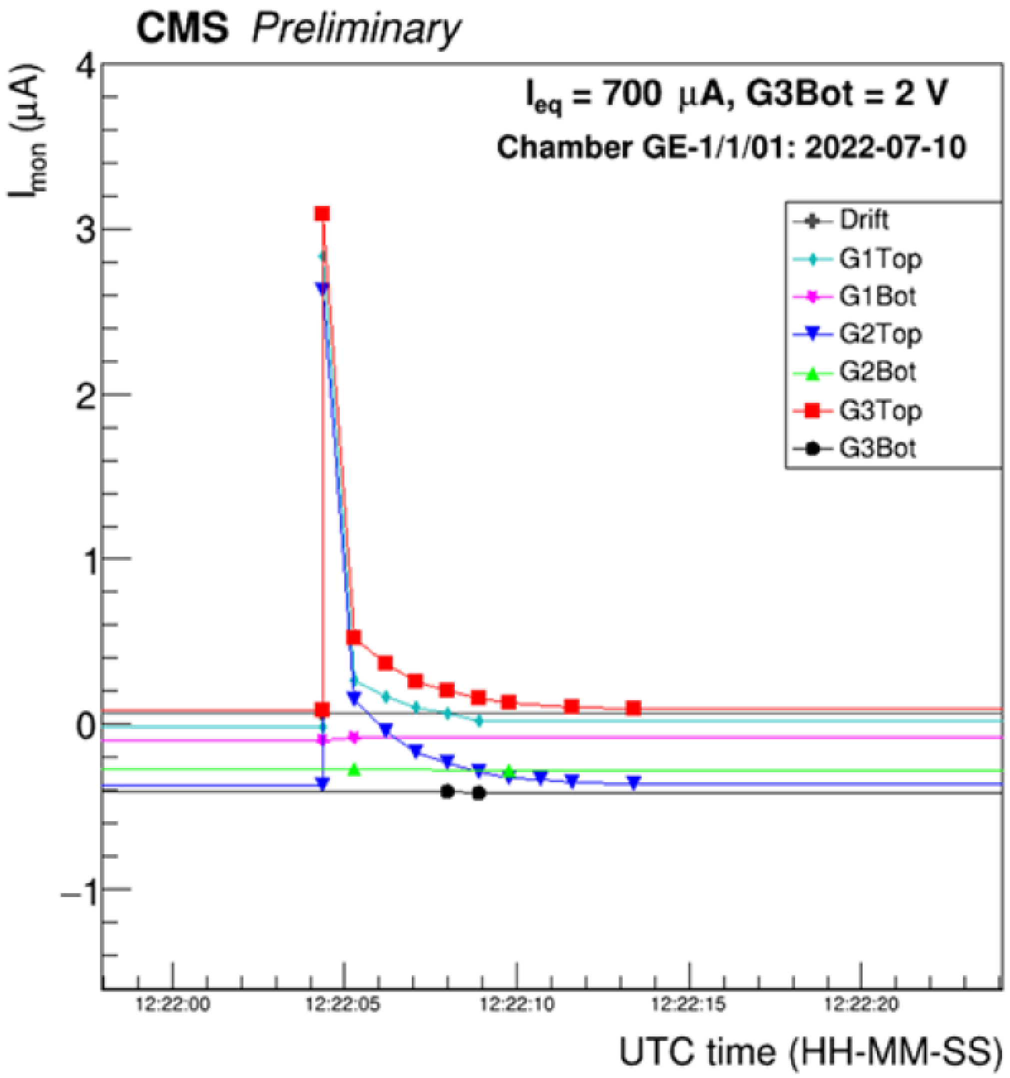
Configuration $I_{eq} = 690\ \mu A$			
Drift	776 V	**G1Top**	387 V
G1Bot	302 V	**G2Top**	379 V
G2Bot	604 V	**G3Top**	362 V
G3Bot	431 V		

Detector stability

- HV system → amplification of the primary ionization charge generated by crossing ionising particle

- Mainly affected by:
  - Discharges
  - Short circuits in GEM foils

Discharges

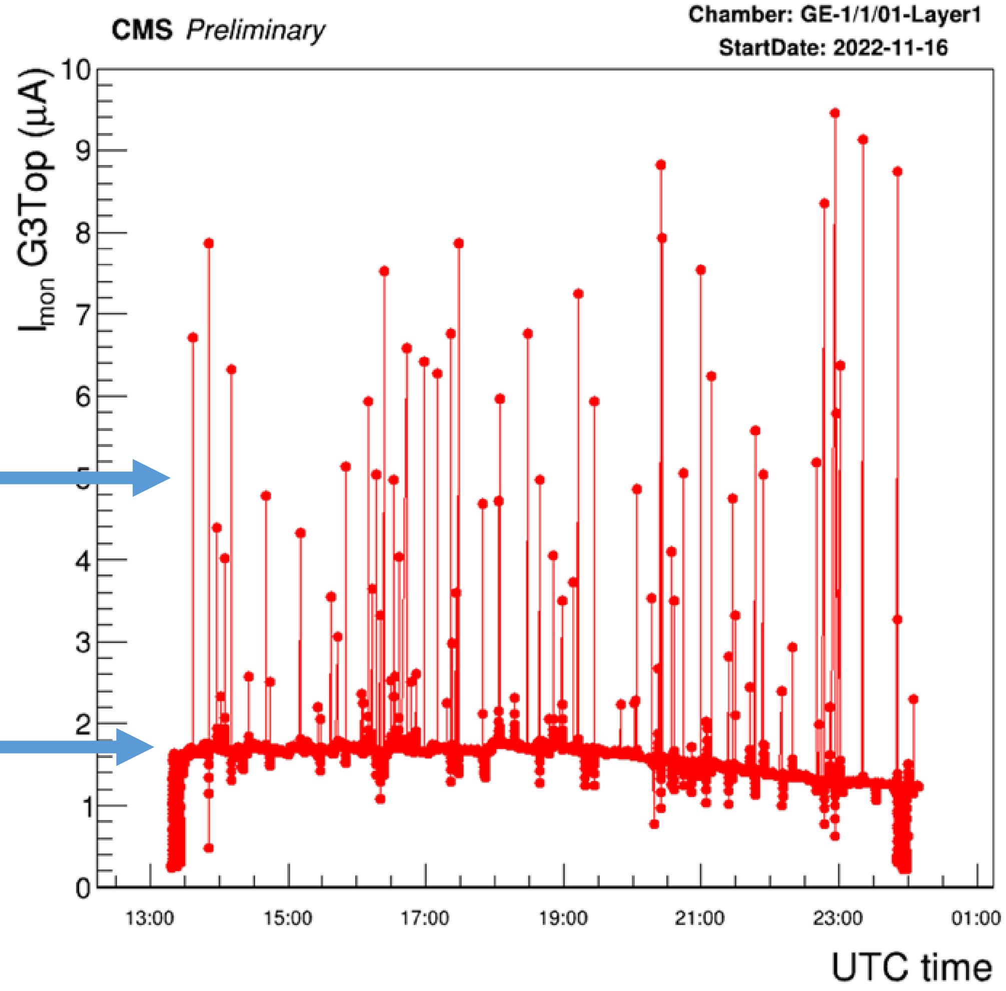


- What is a discharge?
  - Transient transfer of charge between the detector planes
- How it looks like?
  - Spike in current above the baseline current
- Impact?
  - It can trigger HV trips → the current spike can overcome the current limit of the HV channel
  - It can damage channels of the front-end electronics, if the discharge propagates towards the readout plane

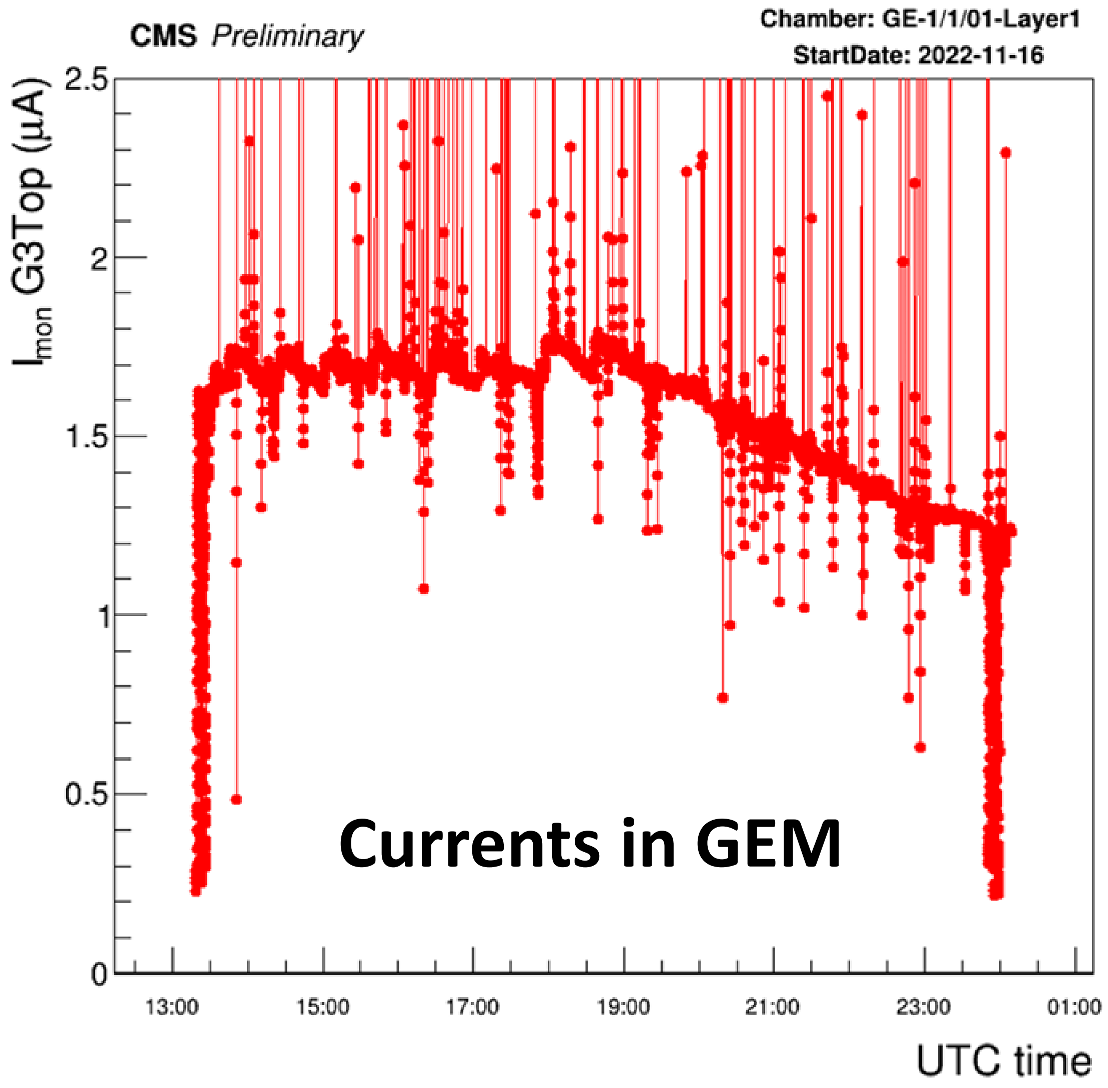
Baseline current in presence of beam

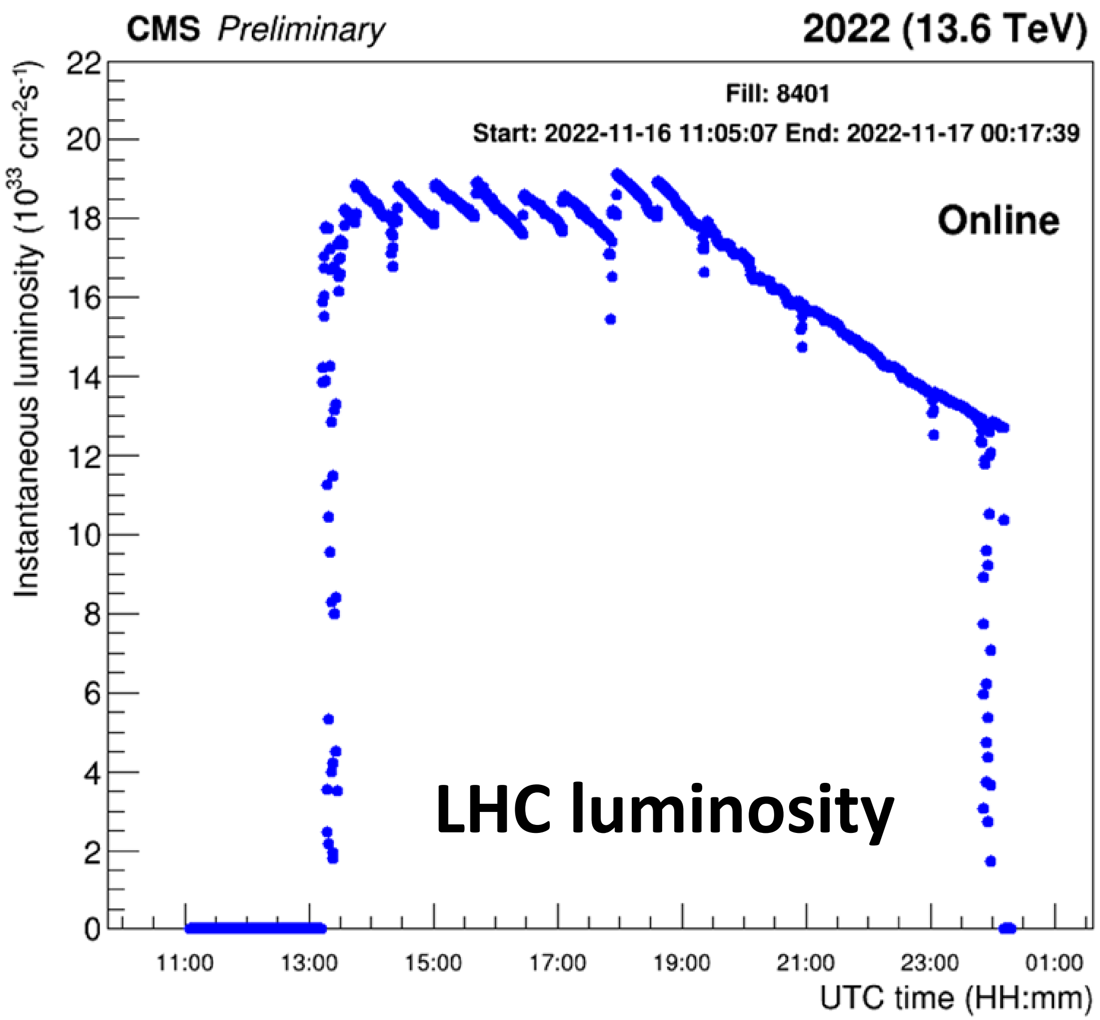
Discharges

Baseline current

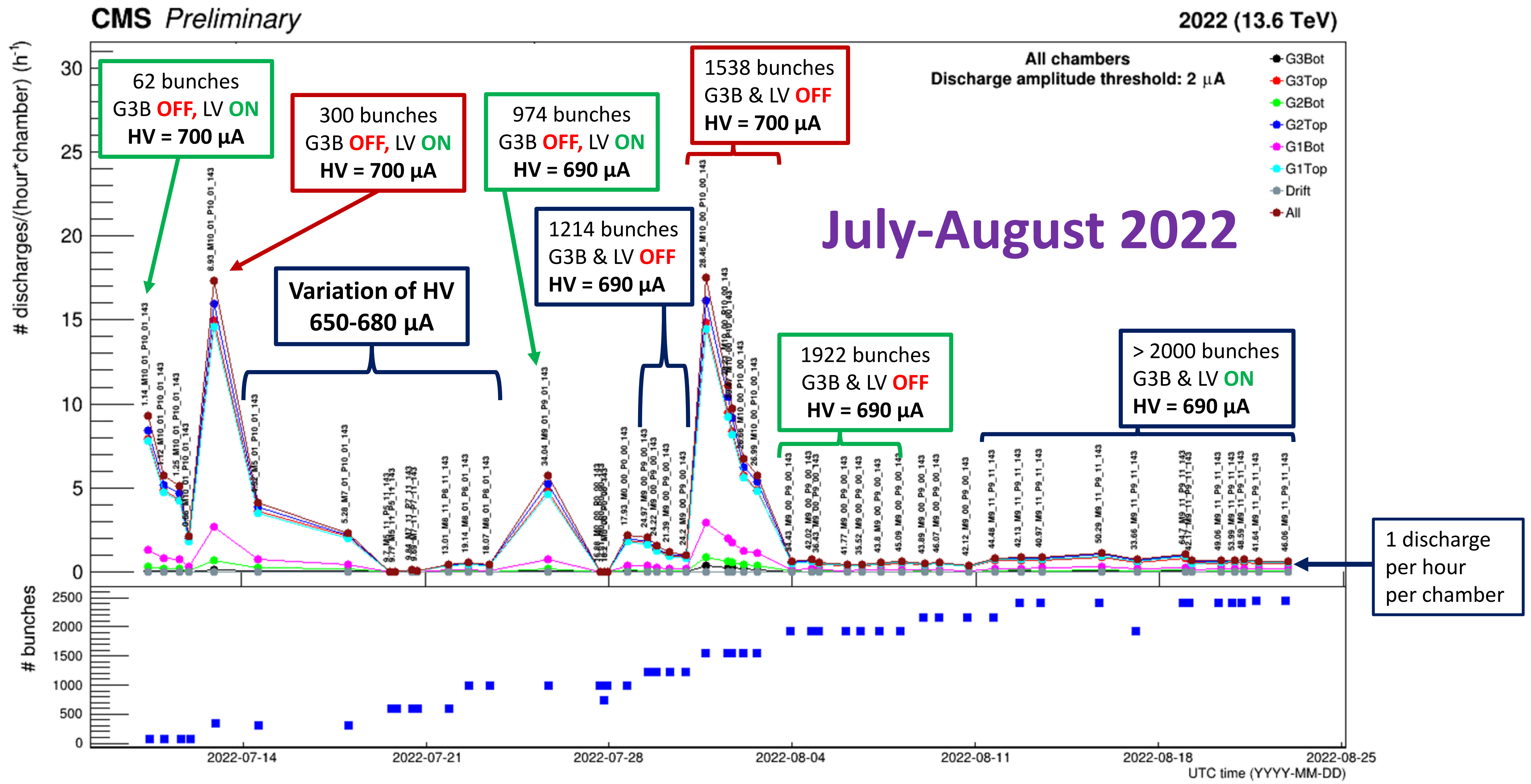


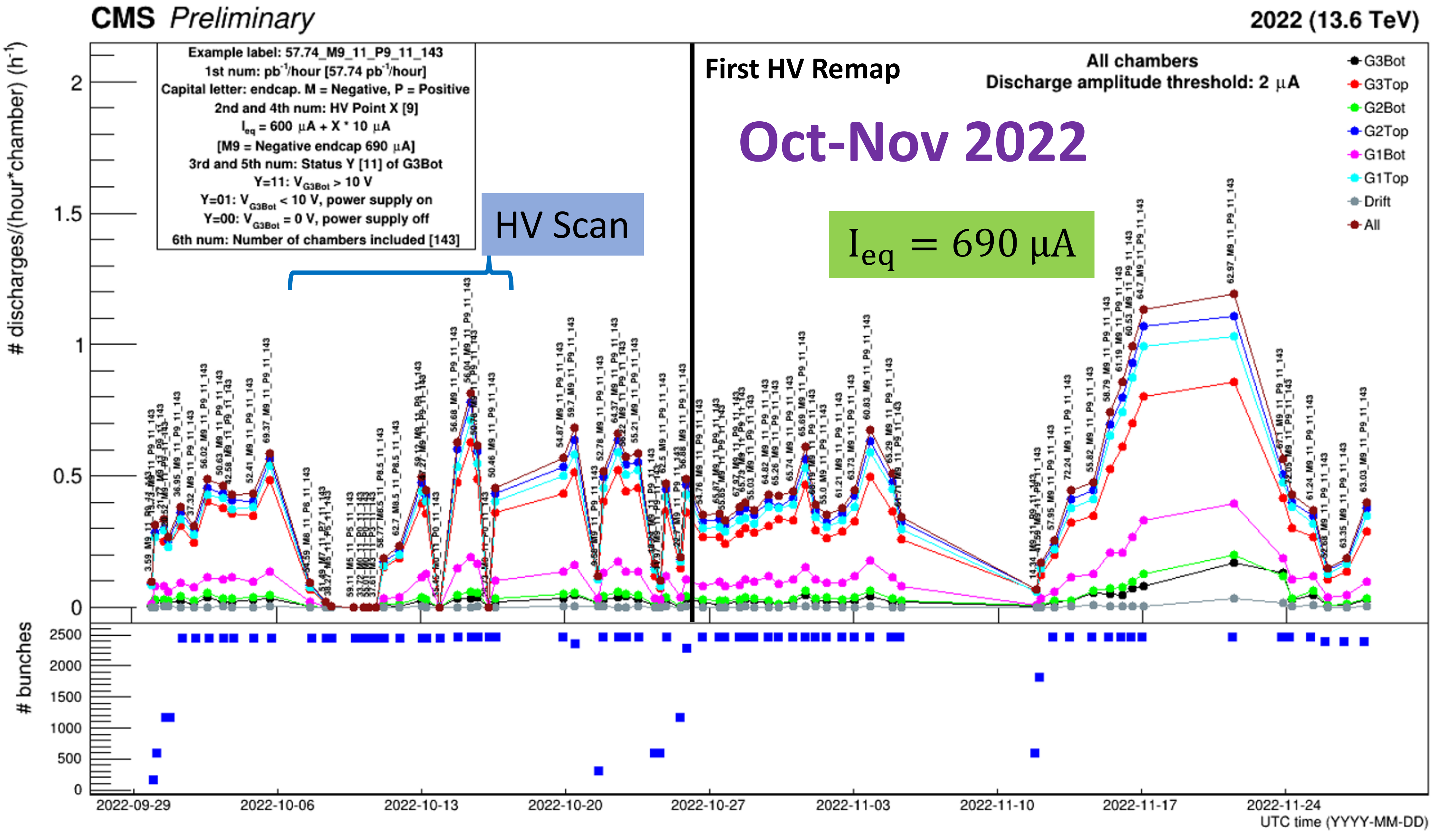
Baseline current vs LHC luminosity

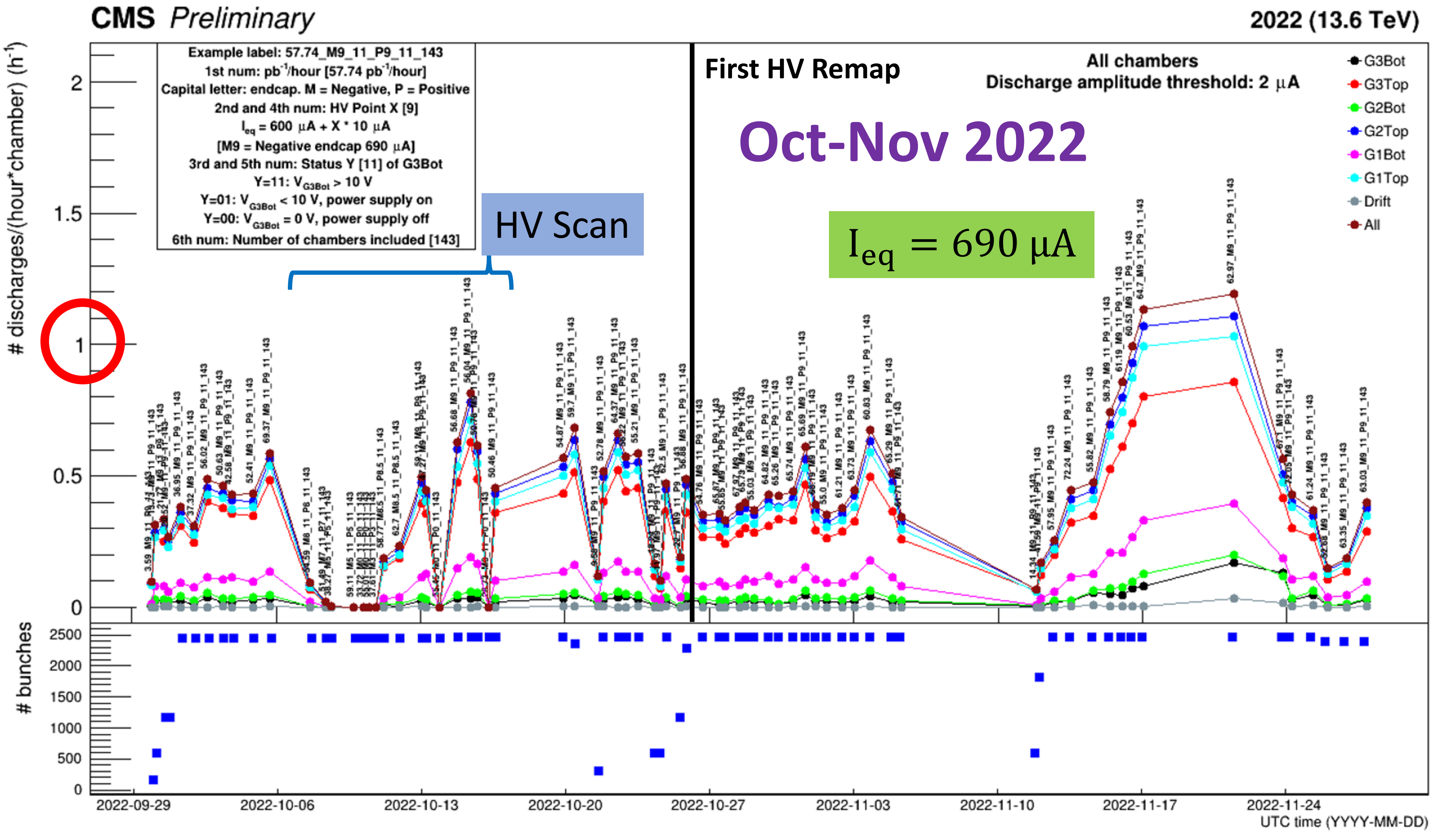




Discharges in Run-3


CMS Preliminary
2022 (13.6 TeV)
All chambers
Discharge amplitude threshold: 2 µA
G3Bot
G3Top
G2Bot
G2Top
G1Bot
G1Top
Drift
All
July-August 2022
62 bunches
G3B OFF, LV ON
HV = 700 µA
300 bunches
G3B OFF, LV ON
HV = 700 µA
974 bunches
G3B OFF, LV ON
HV = 690 µA
1538 bunches
G3B & LV OFF
HV = 700 µA
1214 bunches
G3B & LV OFF
HV = 690 µA
Variation of HV
650-680 µA
1922 bunches
G3B & LV OFF
HV = 690 µA
> 2000 bunches
G3B & LV ON
HV = 690 µA
1 discharge
per hour
per chamber
discharges/(hour*chamber) (h^{-1})
bunches
2022-07-14
2022-07-21
2022-07-28
2022-08-04
2022-08-11
2022-08-18
2022-08-25
UTC time (YYYY-MM-DD)


CMS Preliminary
2022 (13.6 TeV)
Example label: 57.74_M9_11_P9_11_143
1st num: pb^{-1}/hour [57.74 pb^{-1}/hour]
Capital letter: endcap. M = Negative, P = Positive
2nd and 4th num: HV Point X [9]
I_{eq} = 600 µA + X * 10 µA
[M9 = Negative endcap 690 µA]
3rd and 5th num: Status Y [11] of G3Bot
Y=11: V_{G3Bot} > 10 V
Y=01: V_{G3Bot} < 10 V, power supply on
Y=00: V_{G3Bot} = 0 V, power supply off
6th num: Number of chambers included [143]
HV Scan
First HV Remap
Oct-Nov 2022
$I_{eq} = 690\ \mu A$
All chambers
Discharge amplitude threshold: 2 µA
G3Bot
G3Top
G2Bot
G2Top
G1Bot
G1Top
Drift
All
discharges/(hour*chamber) (h^{-1})
bunches
UTC time (YYYY-MM-DD)
2022-09-29
2022-10-06
2022-10-13
2022-10-20
2022-10-27
2022-11-03
2022-11-10
2022-11-17
2022-11-24


CMS Preliminary
2022 (13.6 TeV)
Example label: 57.74_M9_11_P9_11_143
1st num: pb⁻¹/hour [57.74 pb⁻¹/hour]
Capital letter: endcap. M = Negative, P = Positive
2nd and 4th num: HV Point X [9]
I_eq = 600 μA + X * 10 μA
[M9 = Negative endcap 690 μA]
3rd and 5th num: Status Y [11] of G3Bot
Y=11: V_G3Bot > 10 V
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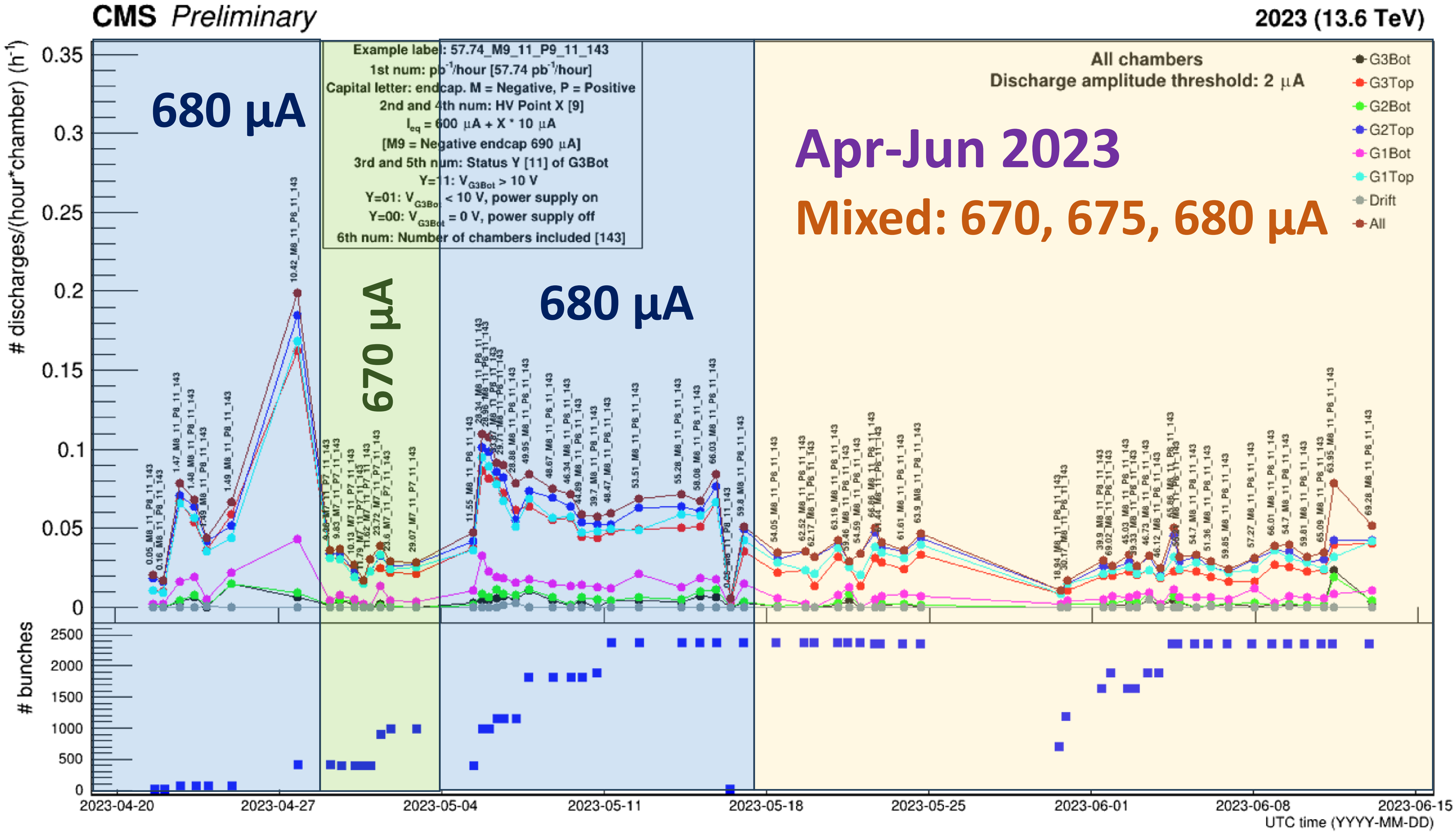
6th num: Number of chambers included [143]
HV Scan
First HV Remap
All chambers
Discharge amplitude threshold: 2 μA
Oct-Nov 2022
$I_{eq} = 690\ \mu A$
G3Bot
G3Top
G2Bot
G2Top
G1Bot
G1Top
Drift
All
discharges/(hour*chamber) (h⁻¹)
bunches
UTC time (YYYY-MM-DD)



CMS Preliminary
2023 (13.6 TeV)
Example label: 57.74_M9_11_P9_11_143
1st num: pb^{-1}/hour [57.74 pb^{-1}/hour]
Capital letter: endcap. M = Negative, P = Positive
2nd and 4th num: HV Point X [9]
I_{eq} = 600 µA + X * 10 µA
[M9 = Negative endcap 690 µA]
3rd and 5th num: Status Y [11] of G3Bot
Y=11: V_{G3Bot} > 10 V
Y=01: V_{G3Bot} < 10 V, power supply on
Y=00: V_{G3Bot} = 0 V, power supply off
6th num: Number of chambers included [143]
All chambers
Discharge amplitude threshold: 2 µA
680 µA
670 µA
680 µA
Apr-Jun 2023
Mixed: 670, 675, 680 µA
G3Bot
G3Top
G2Bot
G2Top
G1Bot
G1Top
Drift
All
discharges/(hour*chamber) (h^{-1})
bunches
UTC time (YYYY-MM-DD)
2023-04-20
2023-04-27
2023-05-04
2023-05-11
2023-05-18
2023-05-25
2023-06-01
2023-06-08
2023-06-15

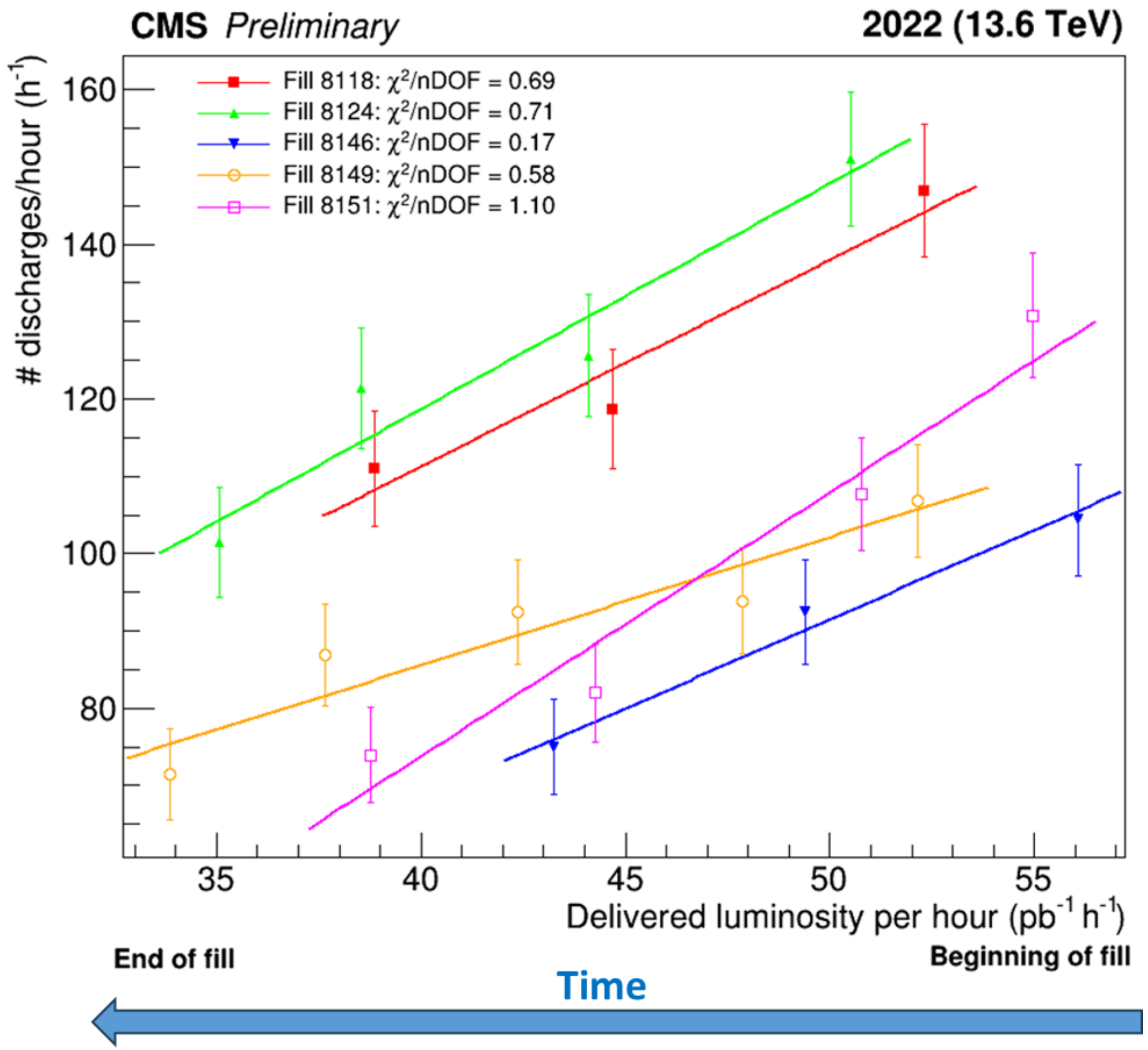
Discharge rate during Pb-Pb collisions

- Low discharge rate during Pb-Pb collisions

- Much lower instantanous luminosity from the LHC
  - p-p collisions: $\sim 10^{34} cm^{-2} s^{-1}$
  - Pb-Pb collisions: $\sim 10^{27} cm^{-2} s^{-1}$

Quantity	Average per fill	Total
Discharges (143 detectors)	5.9 ± 0.7	347
Delivered luminosity	$34.0 \pm 2.7\ \mu b^{-1}$	$2005.7\ \mu b^{-1}$

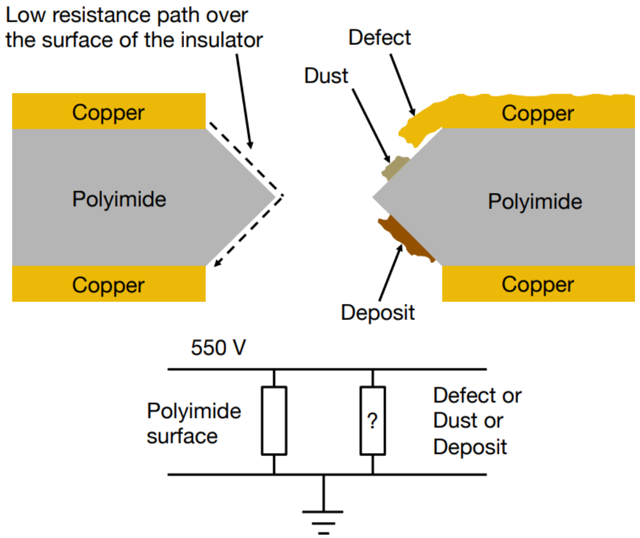
Discharges vs LHC luminosity



- Data of 5 LHC fills analysed
  - Fixed HV working point: $\mathrm{I_{eq}} = 690\ \mu\mathrm{A}$
- **Correlation between discharge rate vs luminosity of the LHC**
- **Complications:**
  - The discharge rate for a given chamber can change in time
    → generation or removal of imperfections in the GEM foil which generate the discharges
- **To study:**
  - Dependence of the discharge rate on the HV working point
    - Feasible with data of HV scan 2024

Short circuits in GEM foils

Short circuit in a GEM foil?



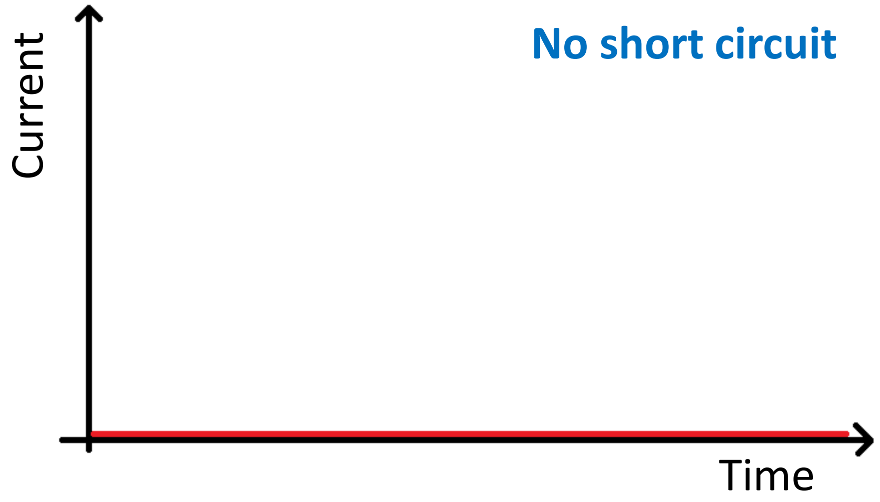
What is:

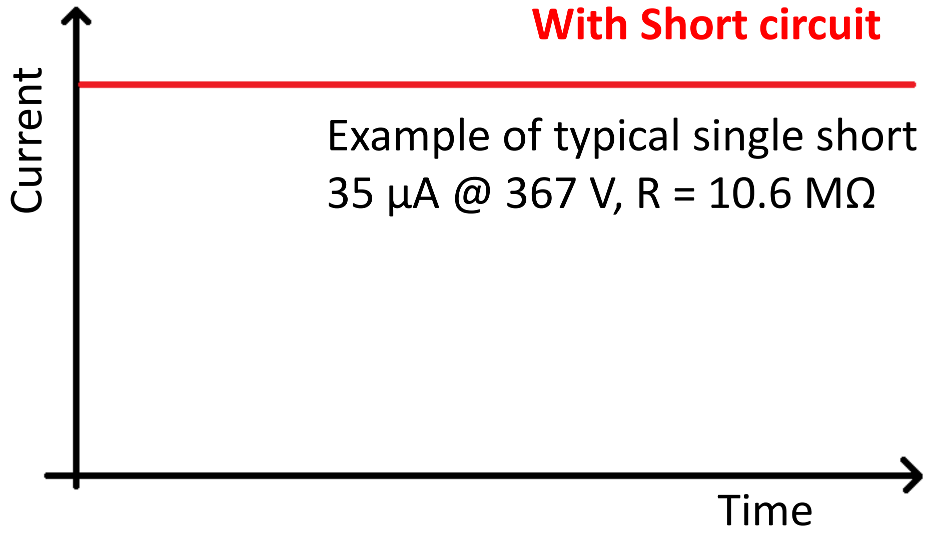
- Connection between top and bottom face of a GEM foil

Why:

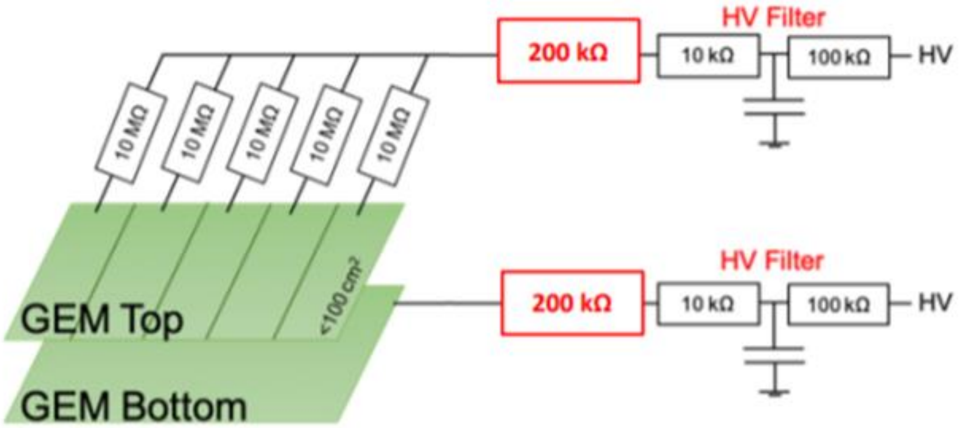
- **Defects or depositions on GEM foil** can create temporary or permanent short circuit between top and bottom electrode

How does it look like?:





Design of HV distribution



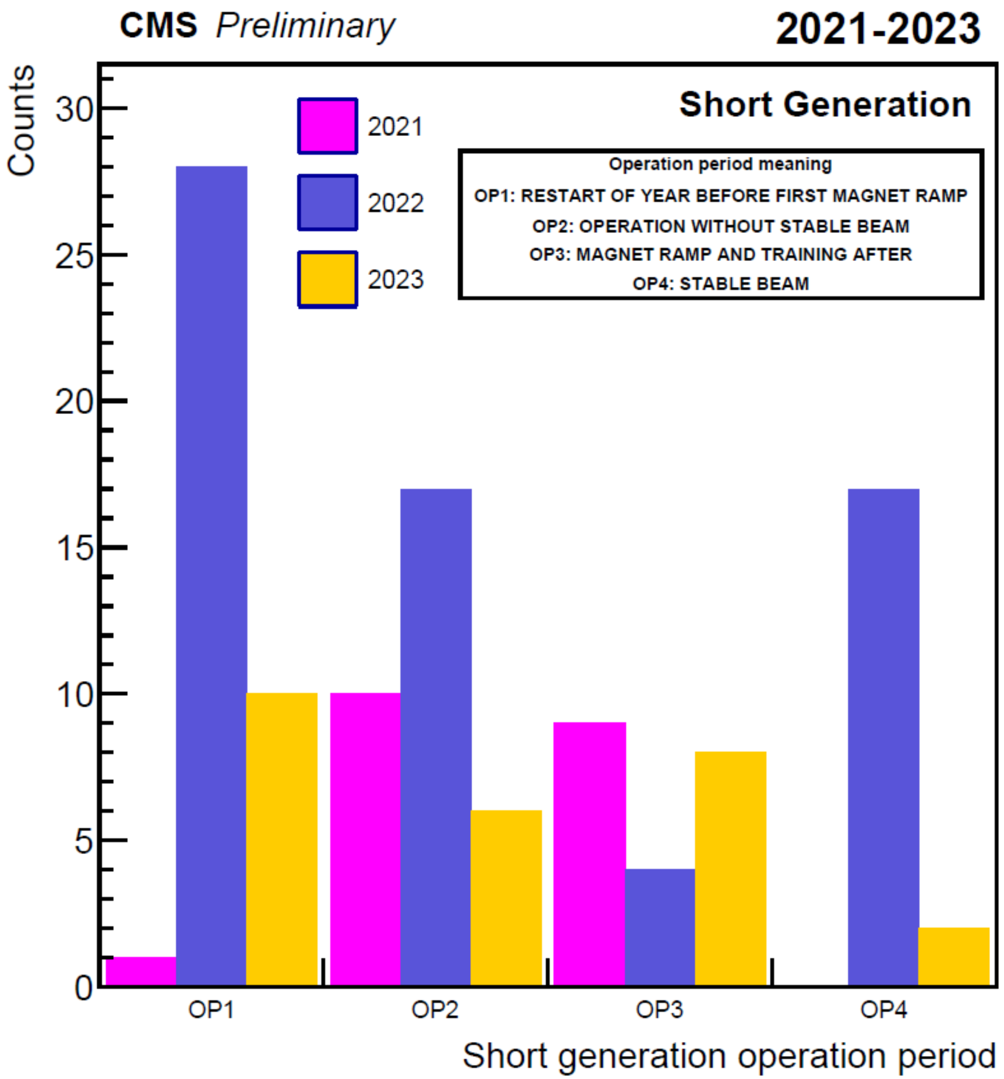
- **Impact:** drop of the voltage applied → the foil stops amplifying the crossing electrons
- **Mitigation:** segmentation of the foil in sectors
  - if one sector deactivates the others keep operating
  - 40 (47) HV sectors in short (long) GE1/1 chambers
  - High current drained by the power supply if a short circuit is created → HV compensation needed due to the drop of voltage on the HV filter resistors

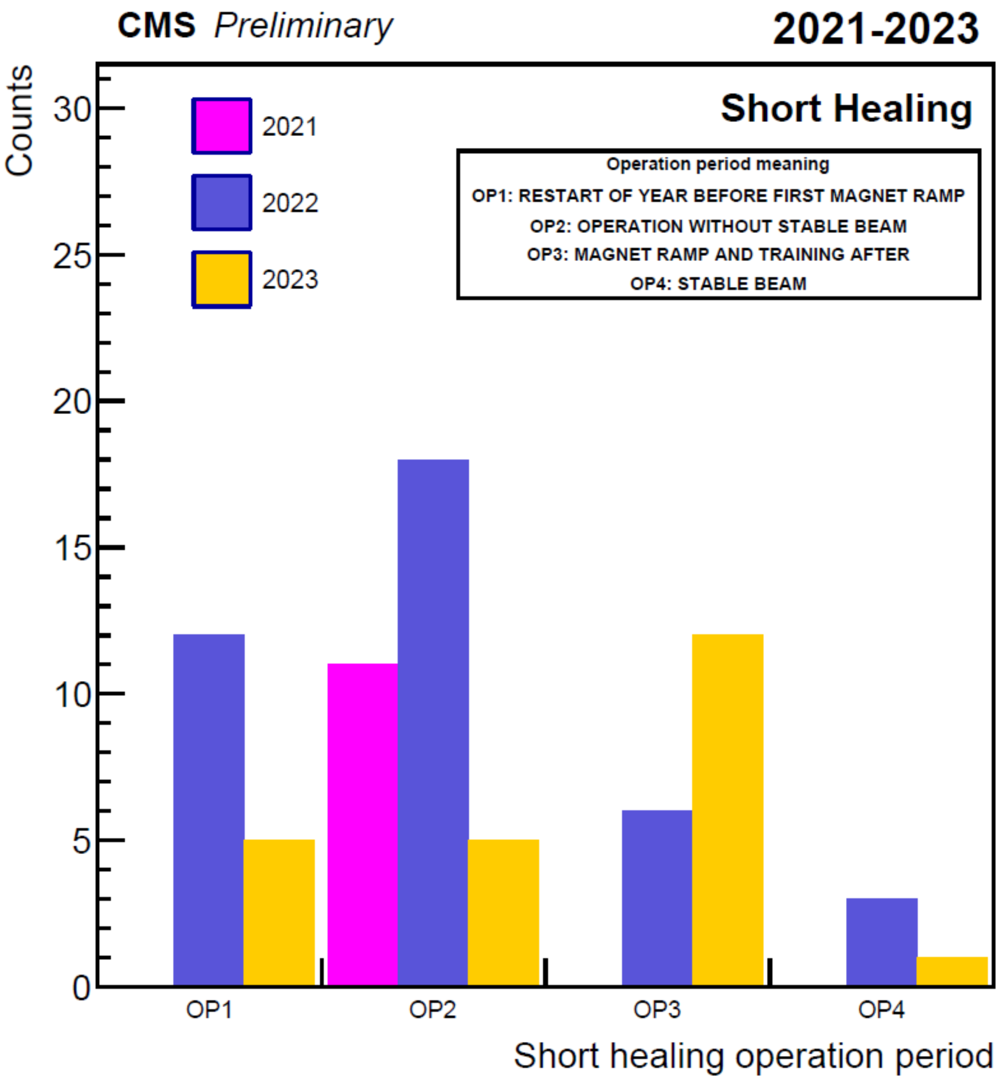
Is a short forever?

Implemented HV protection for magnet operations

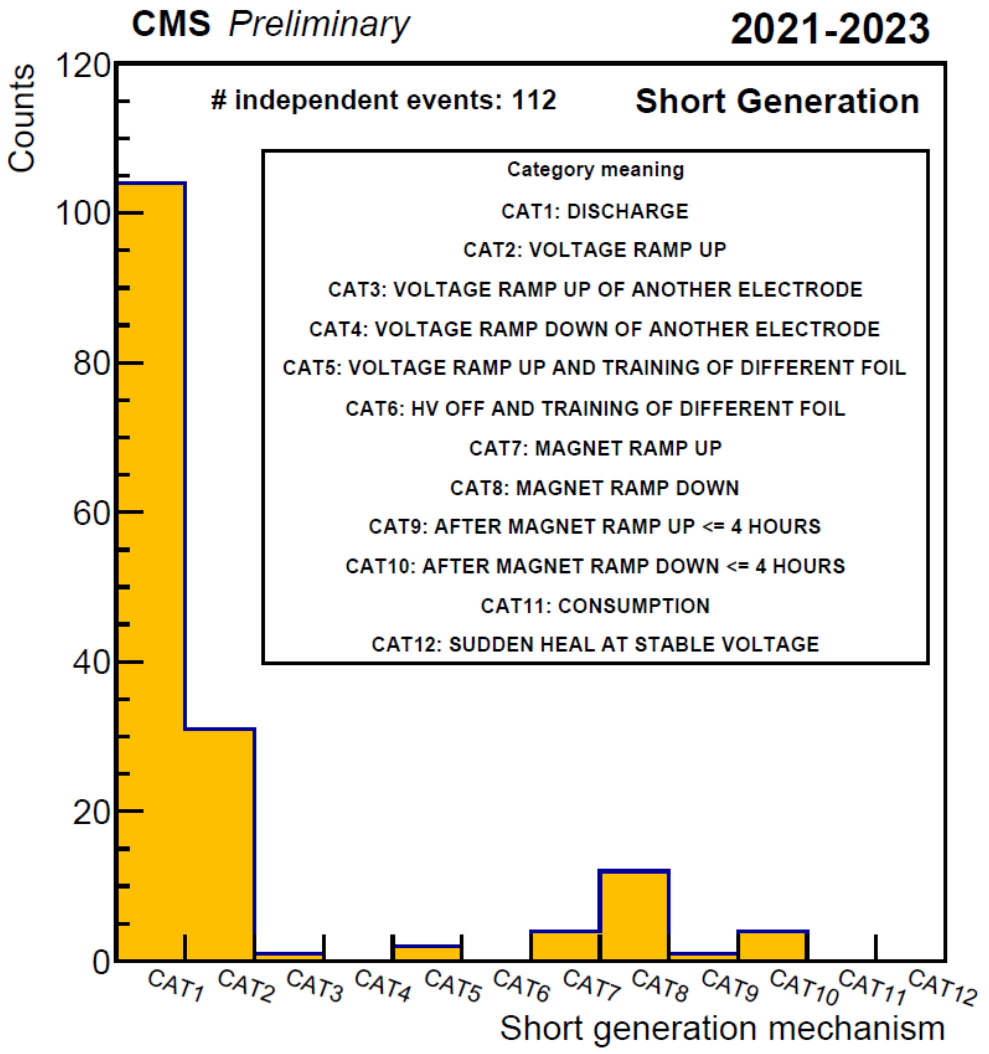
- HV on GEM foils set to 420 V, gas gaps turned OFF

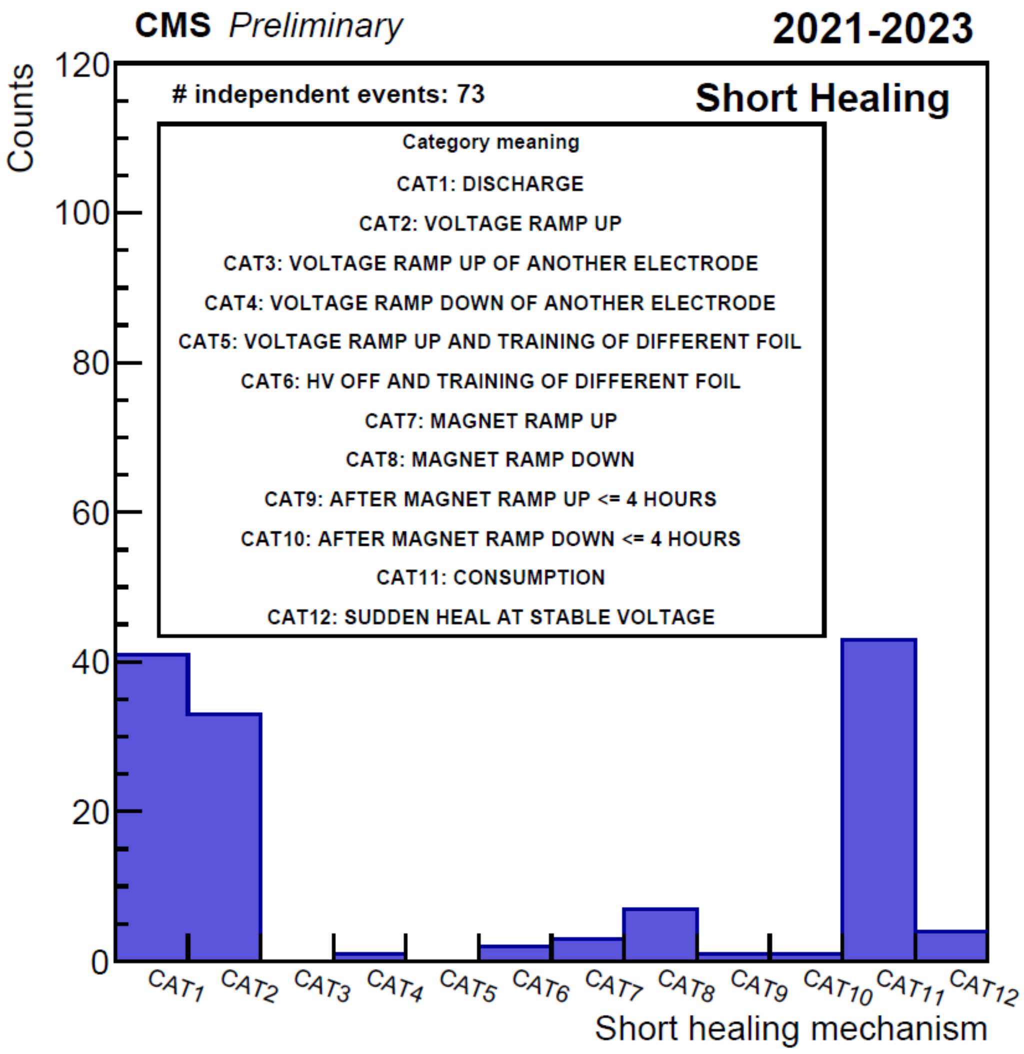
Article on tests done with Goliath Magnet in CERN North Area
10.1088/1748-0221/18/11/P11029



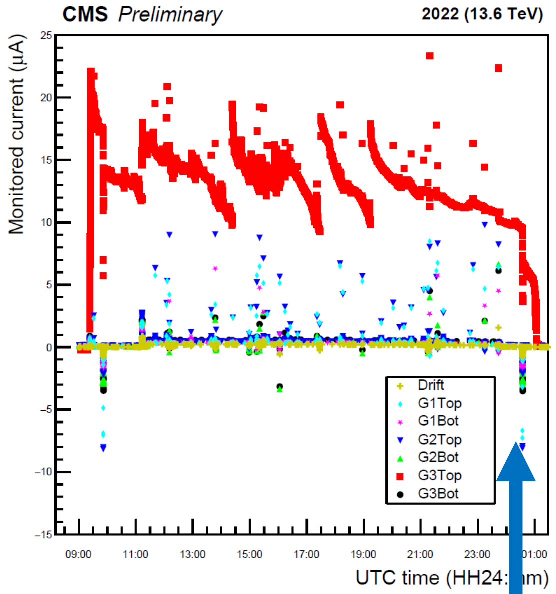


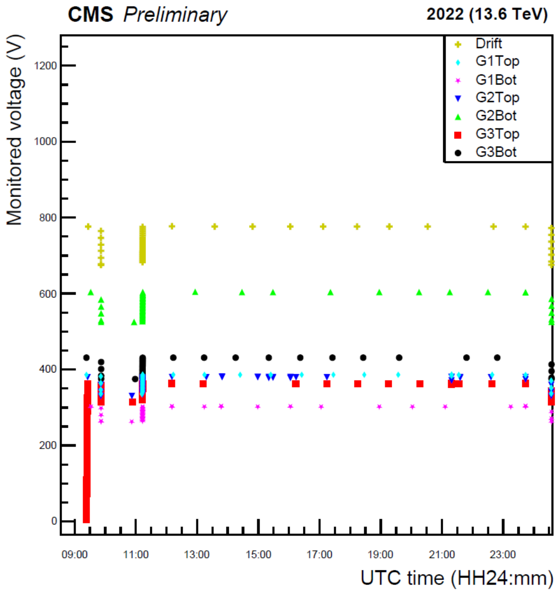
Mechanisms involved in generation/healing of shorts in GE1/1 GEM foils

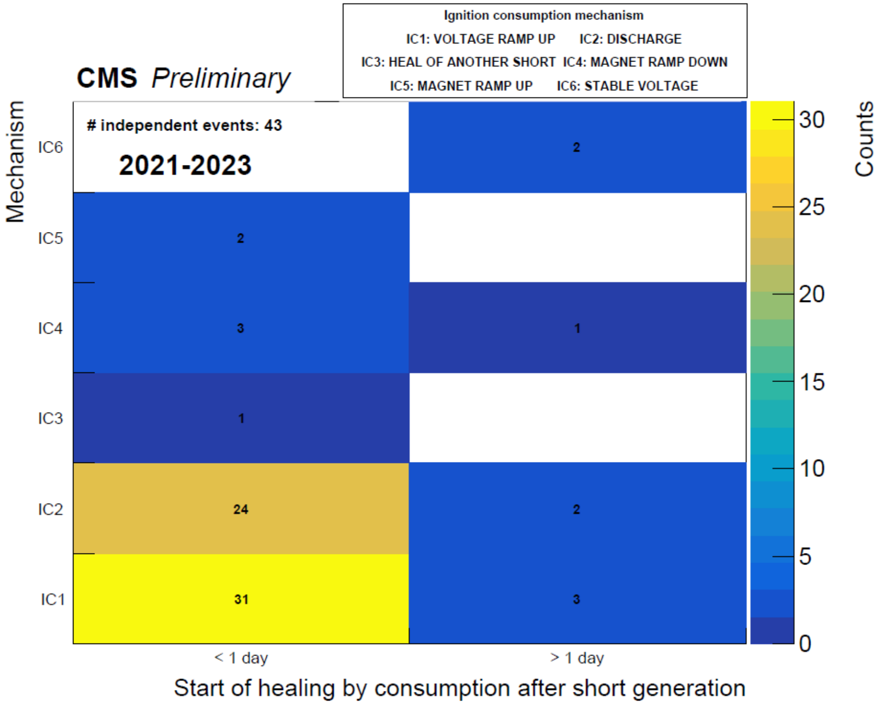


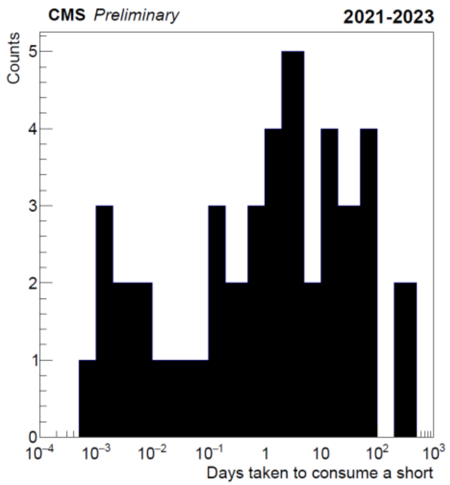


Are some short circuits weaker?





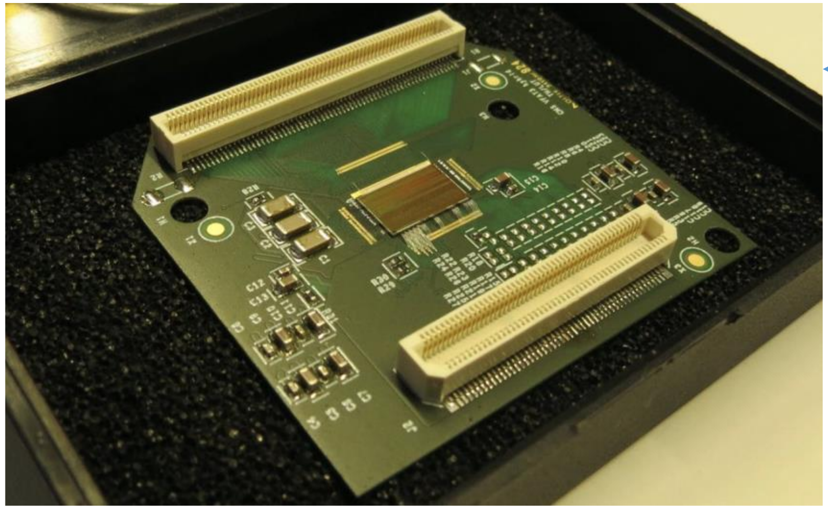


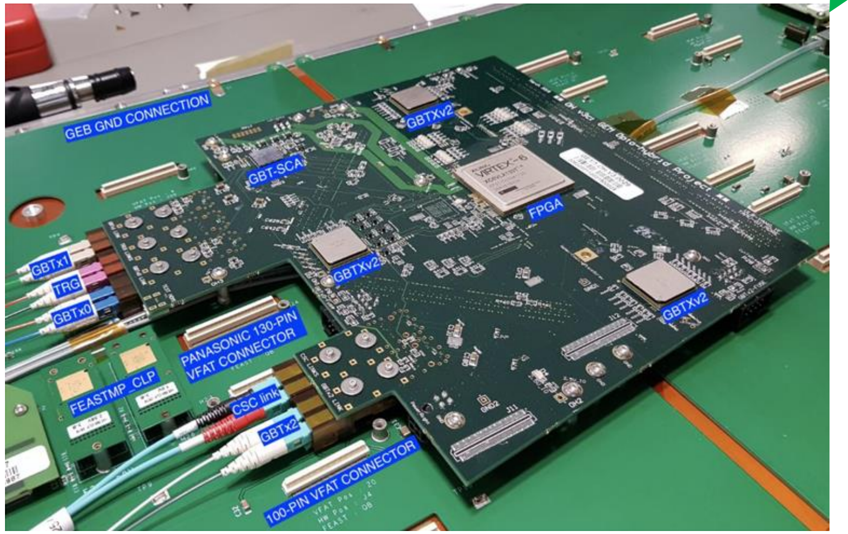


- In some cases a short has not a perfect conductive connection between the top and bottom face of GEM foil: Resistance not compatible with that of HV distribution schema
- In these cases it usually consumes, **gradually decreasing the drained current**
  - **Mechanisms igniting consumption** of a short
  - **Time** needed to totally heal by consumption

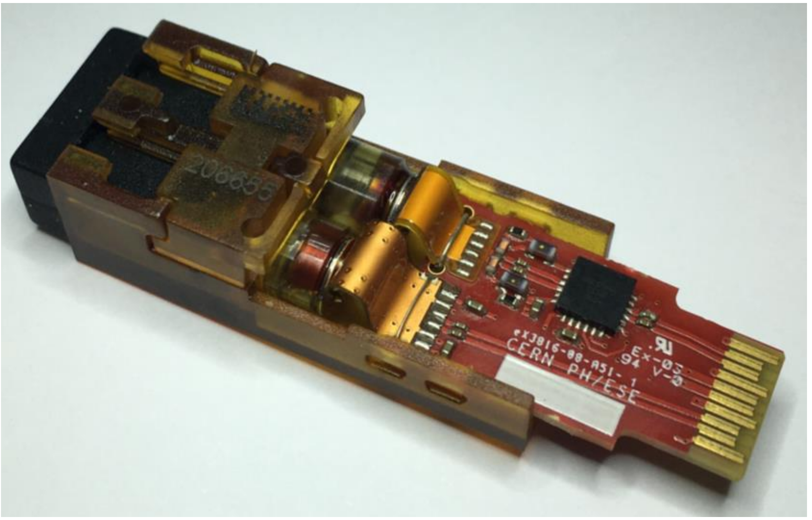
Detector performances

GE1/1 electronics

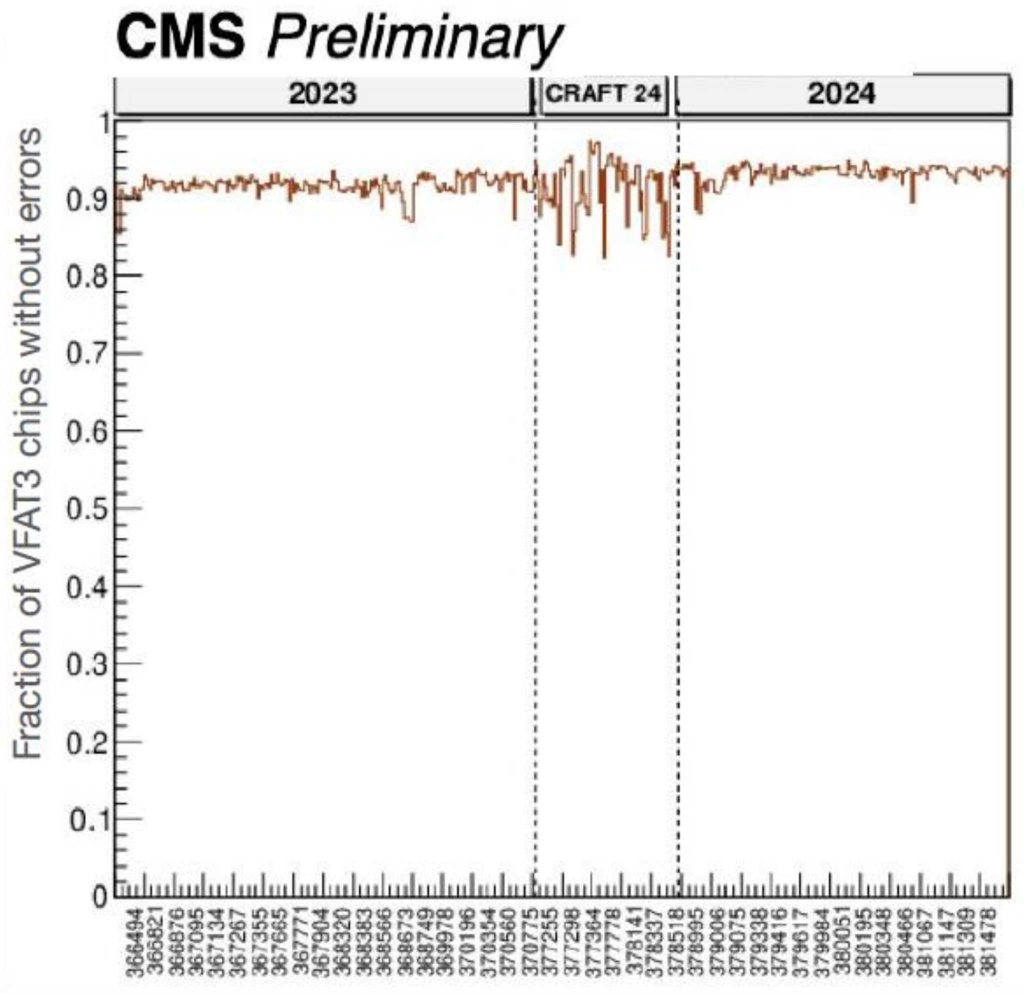




- Front-end electronics of GE1/1 detectors: VFAT3 chips
  - 24 per detector
- Groups of VFAT3 chips read by GBT (Giga Bit Transceivers)
  - 3 per detector
- OptoHybrid board on the detector hosting GBTs and FPGA
  - 1 per detector
- Data sent by the OH to the backend electronics by VTRx optical transceivers
  - 3 per detector



Electronics stability



Electronics stability issues from:

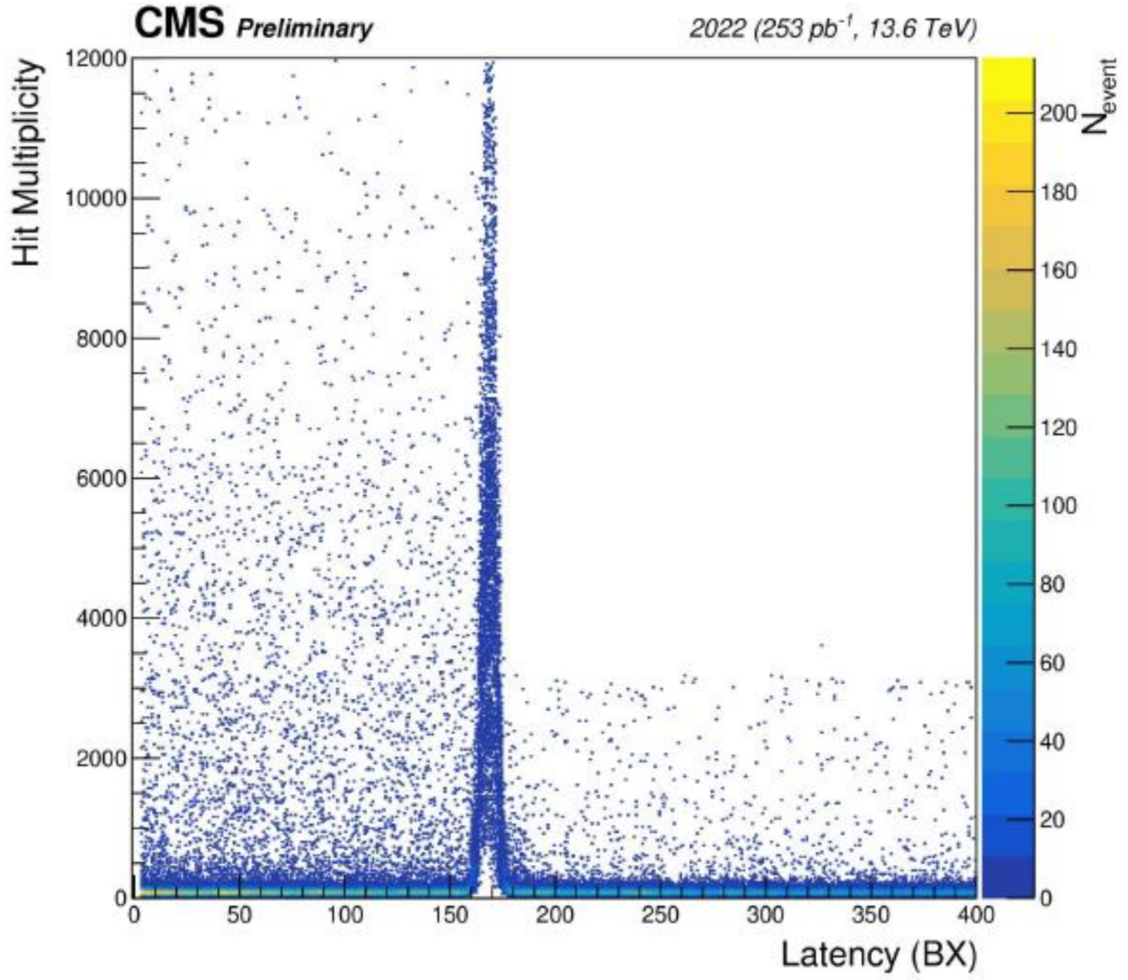
- **GBTx not fetching correct configuration** from fuses after power-on
  - **Fixed by:** Interaction with DCS for automatic power cycle
- **VTRx glue outgassing** [1] → GBT unstable
  - Some VTRx are expected to bake in situ during operations
  - Intervention on chambers (installation of cooled VTRx) foreseen to LS3
- **Front-end chips (VFAT) communication issues**
  - Probable consequence of issues mentioned above

Minimized by:

- **During run:** progressive masking of the affected front-end
- **During interfill:** electronics power cycle and reconfiguration

[1] https://indico.cern.ch/event/1099169

High multiplicity events

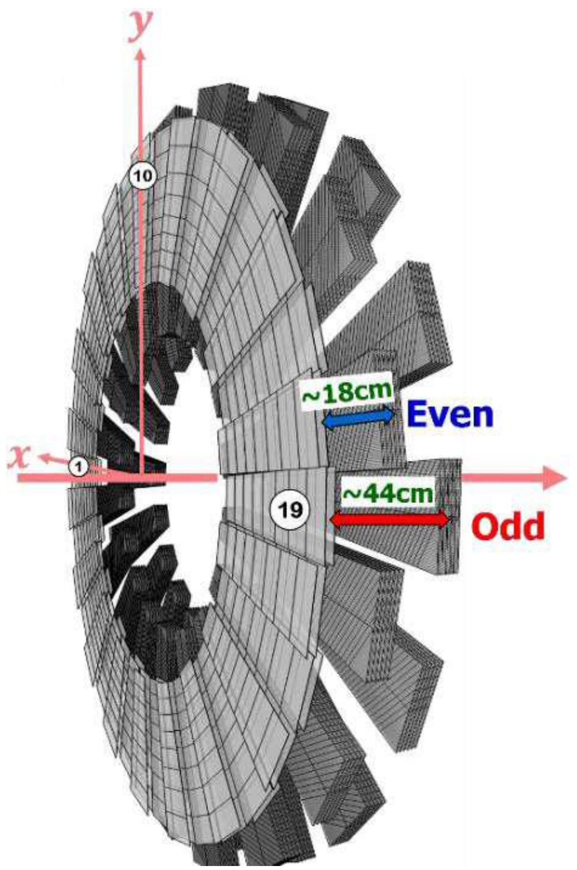


- What: sometimes observed high multiplicity events in the GE1/1 chambers

- Why:
  - The L1 trigger signal for accepting an event (L1A) generates a noise signal that can overcome the threshold set in the VFAT3 for the acquisition of data, ~ 160 BX later

- Minimized by: multi-BX (Bunch-Crossing) window masking applied at trigger level: 95% of events filtered

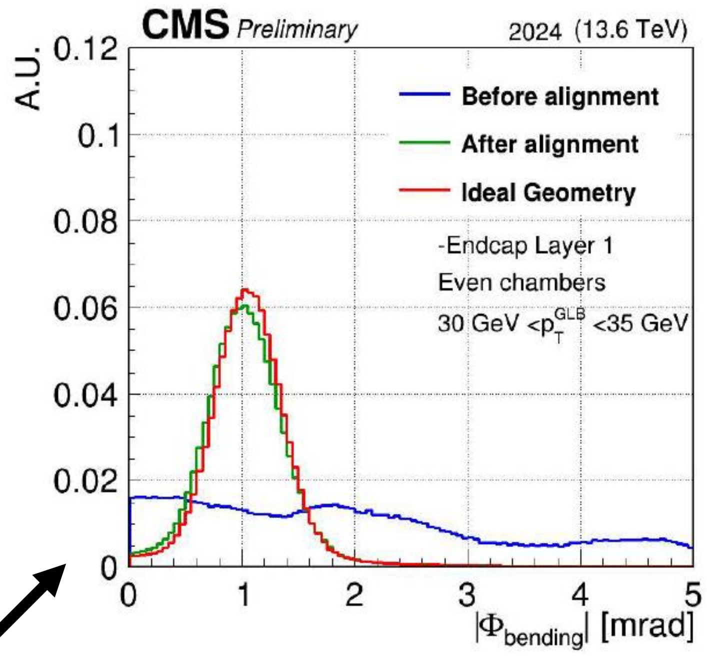
Bending angle

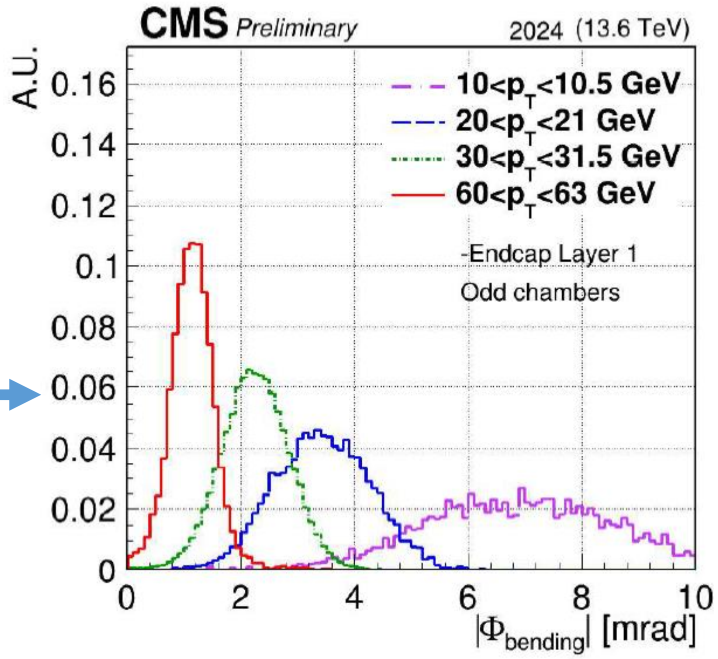


- Implemented alignment between CSC (ME1/1) and GEM (GE1/1) chambers
  - Different distance between ME1/1 and GE1/1
    - Even chamber: 18 cm
    - Odd chamber: 44 cm

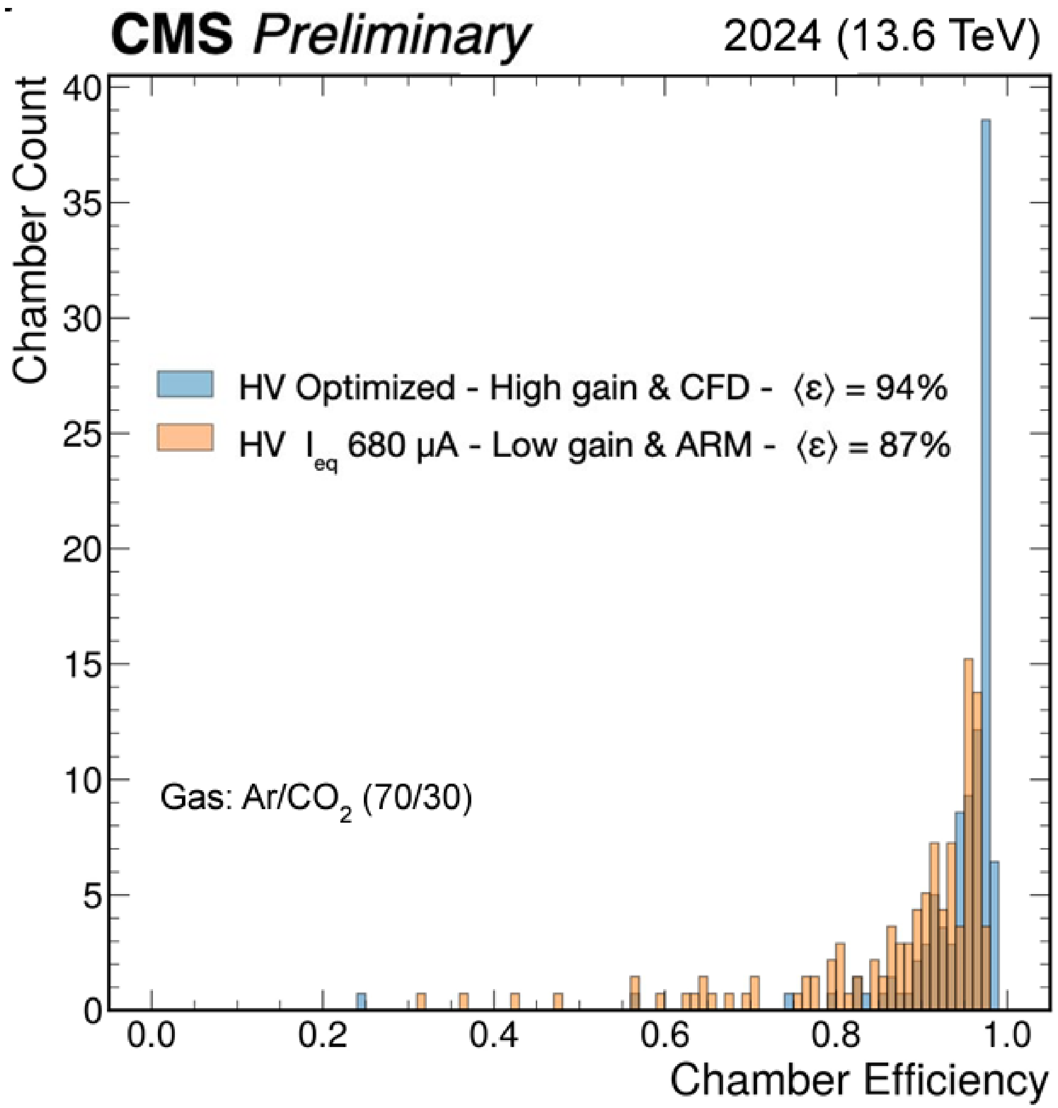
- **Bending angle** distribution with Global muons ($30\ \mathrm{GeV} < p_T^{GLB} < 35\ \mathrm{GeV}$)
  $\phi_{bending} = \phi_{ME1/1\ segment} - \phi_{GE1/1\ rechit}$

- $\boldsymbol{p_T}$ **dependence** of the bendind angle distribution ($\phi_{bending} \propto p_T^{-1}$)





Chamber efficiency



- HV scan 2024
  - Investigated several HV working points
  - Tested several electronics configurations
- New HV working point tuned per chamber
  - Depending on chamber efficiency vs HV curve: look if the chamber is at efficiency plateau at a given I_{eq}
  - Chamber discharge rate
- **Efficiency now:** 94 %
  - Set of working points used:

$$I_{eq} = 685 - 700\ \mu A$$

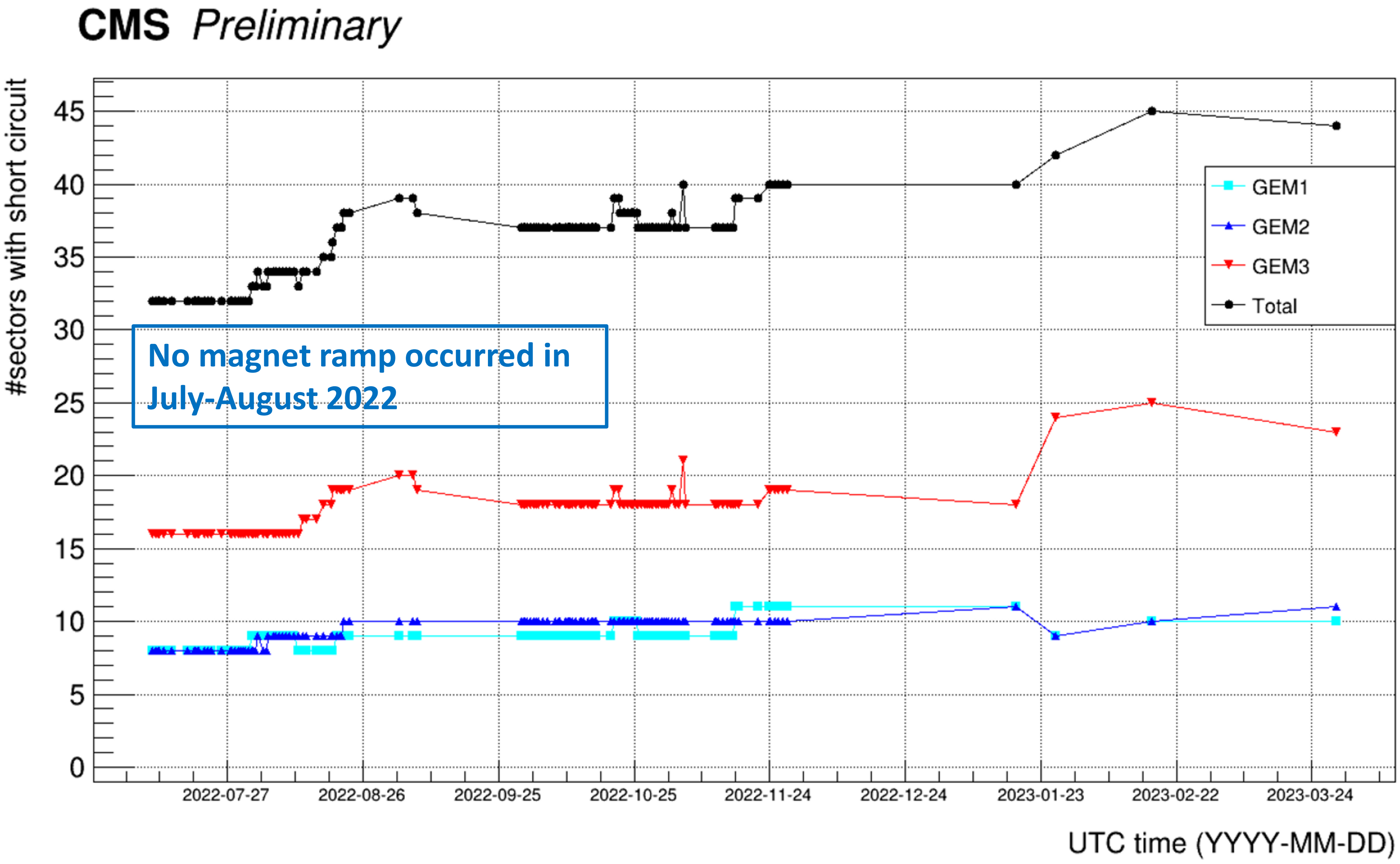
Conclusion

- A lot of knowledge was accumulated on the operation of GE1/1 detectors
  - Stability of the detector, usage of the electronics during data taking in CMS, performances during collisions

- Operations of GE1/1 are proceeding and constant attention is put in optimizing them, together with studies to support the datataking

Backup

Evolution of short circuits: #HV sectors



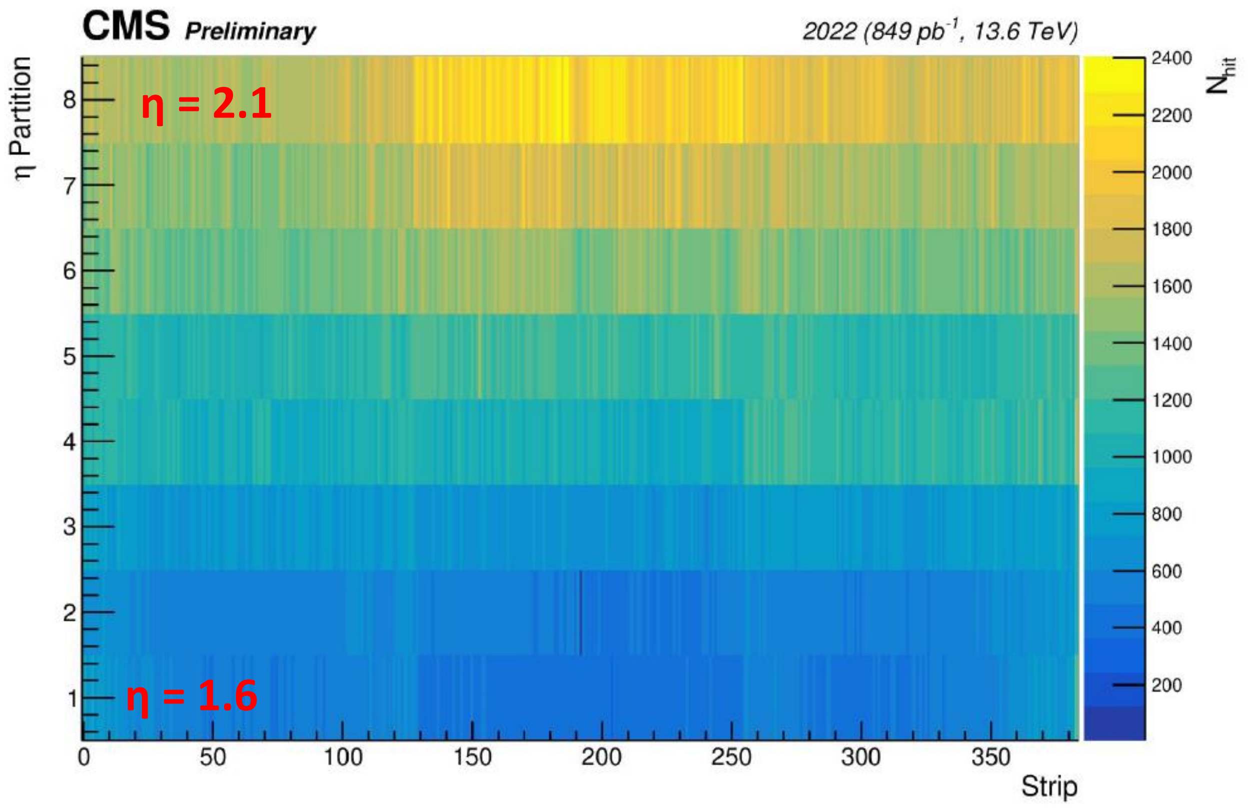
- **July-August 2022:**
  - No magnet ramp
  - No disk movement

→ Just discharges as responsible for short circuit generation

Mainly affected foil: GEM 3

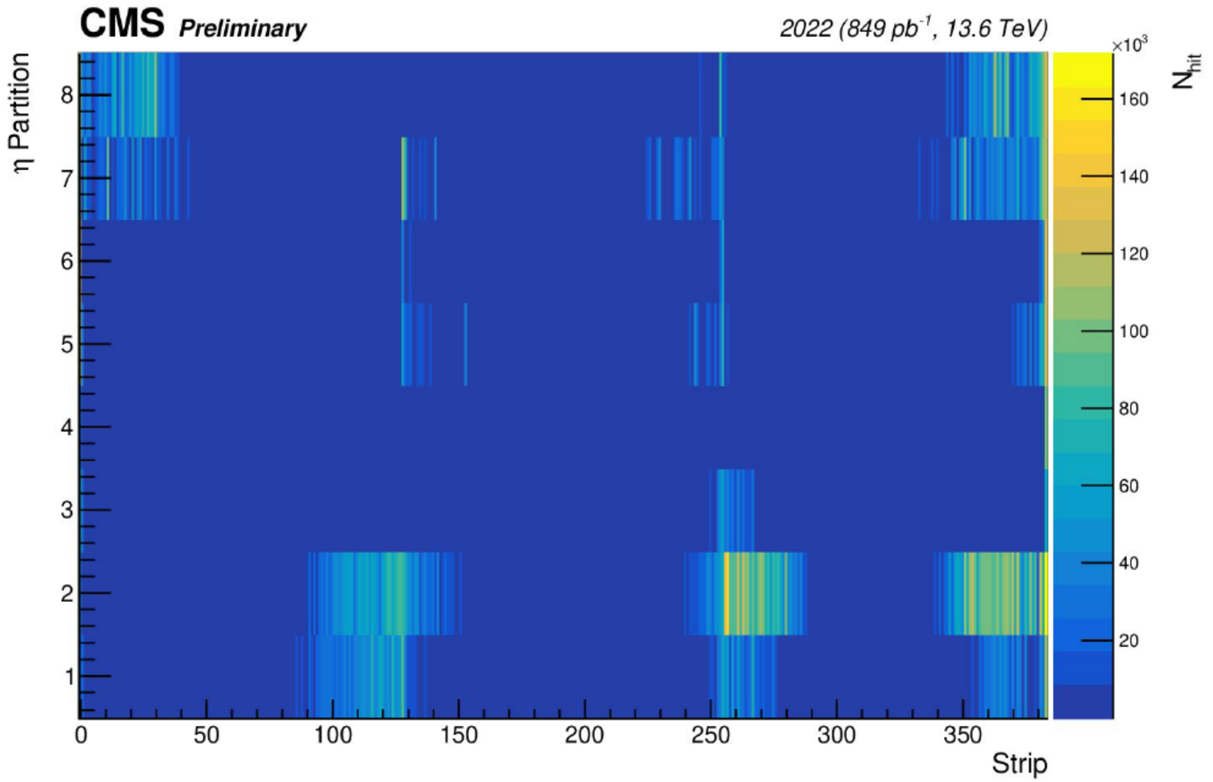
- Closest to the readout and crossed by the highest charge during avalanche multiplication of primary ionisation electrons

Hit occupancy plot



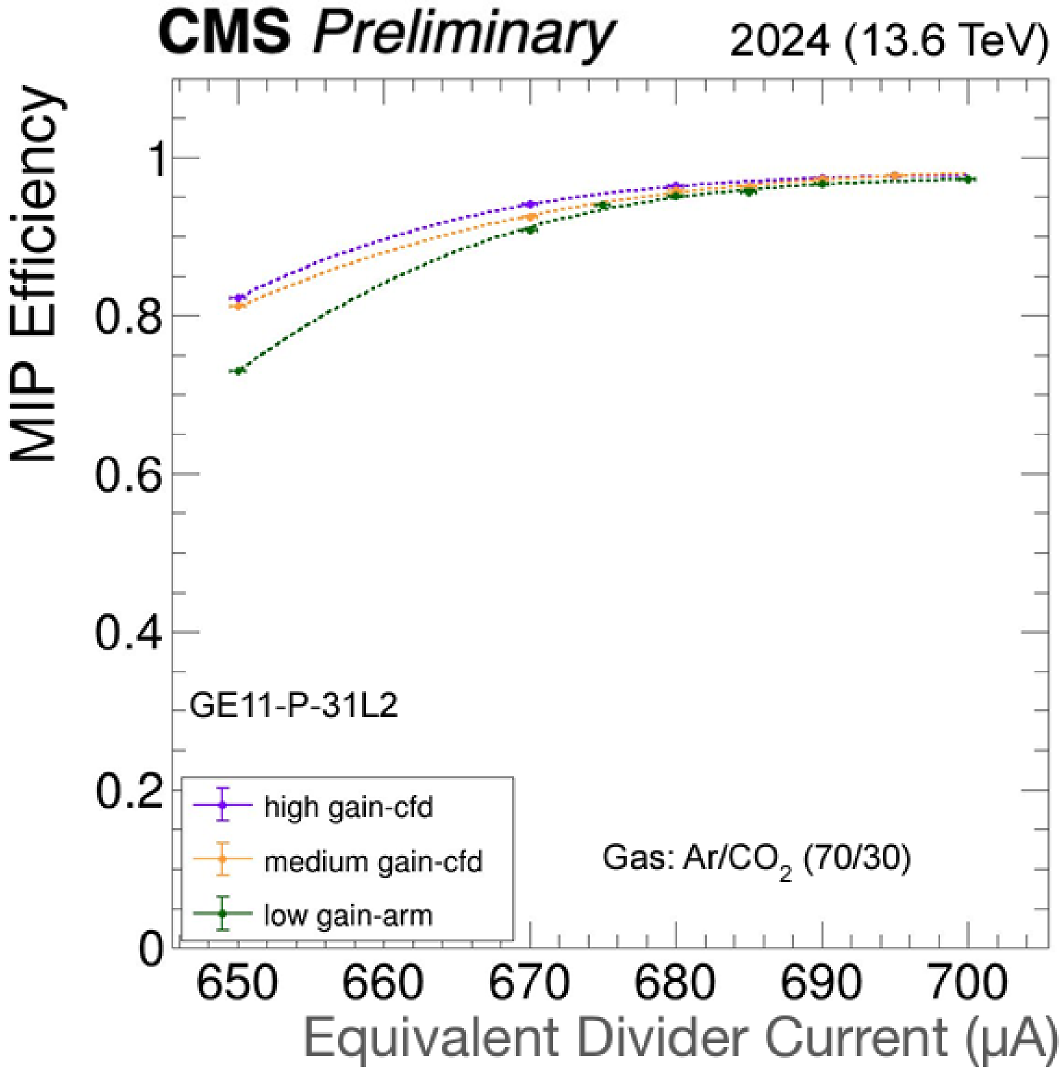
Higher eta → higher number of hits due to background radiation

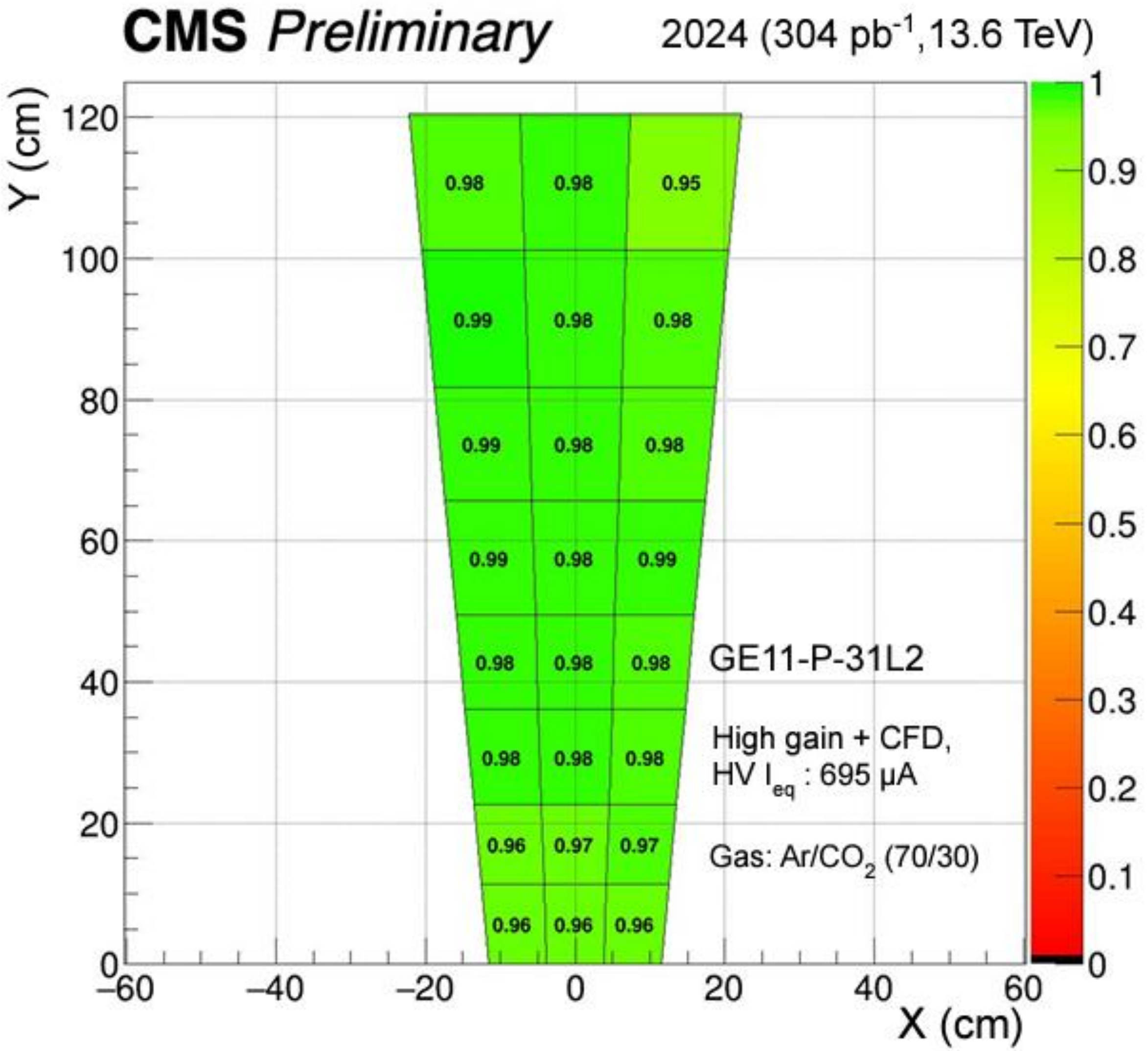
High Multiplicity event



During a high multiplicity event a lot of fake hits are present on top of those due to the background (can be noticed from the scale). In particular the hits concentrate on the edges of VFAT chips, each reading a group of 128 strips

Efficiency vs HV working point





Notes on chamber efficiency

- Removed the inefficiencies due to HV trips and electronics communications issues

- Muons used in the efficiency calculation are:
  - STA muons of pT > 10 GeV
  - quality requirements: at least 15 hits (at least 1 in ME1/1), $\chi^2 < 5$
  - fiducial region of the detector defined with borders of 1.5 cm from the edges of the η partition and 0.0075 rad from the lateral edges of the chamber.