High-Voltage studies for new GE1/1 GEM Station in the CMS Experiment

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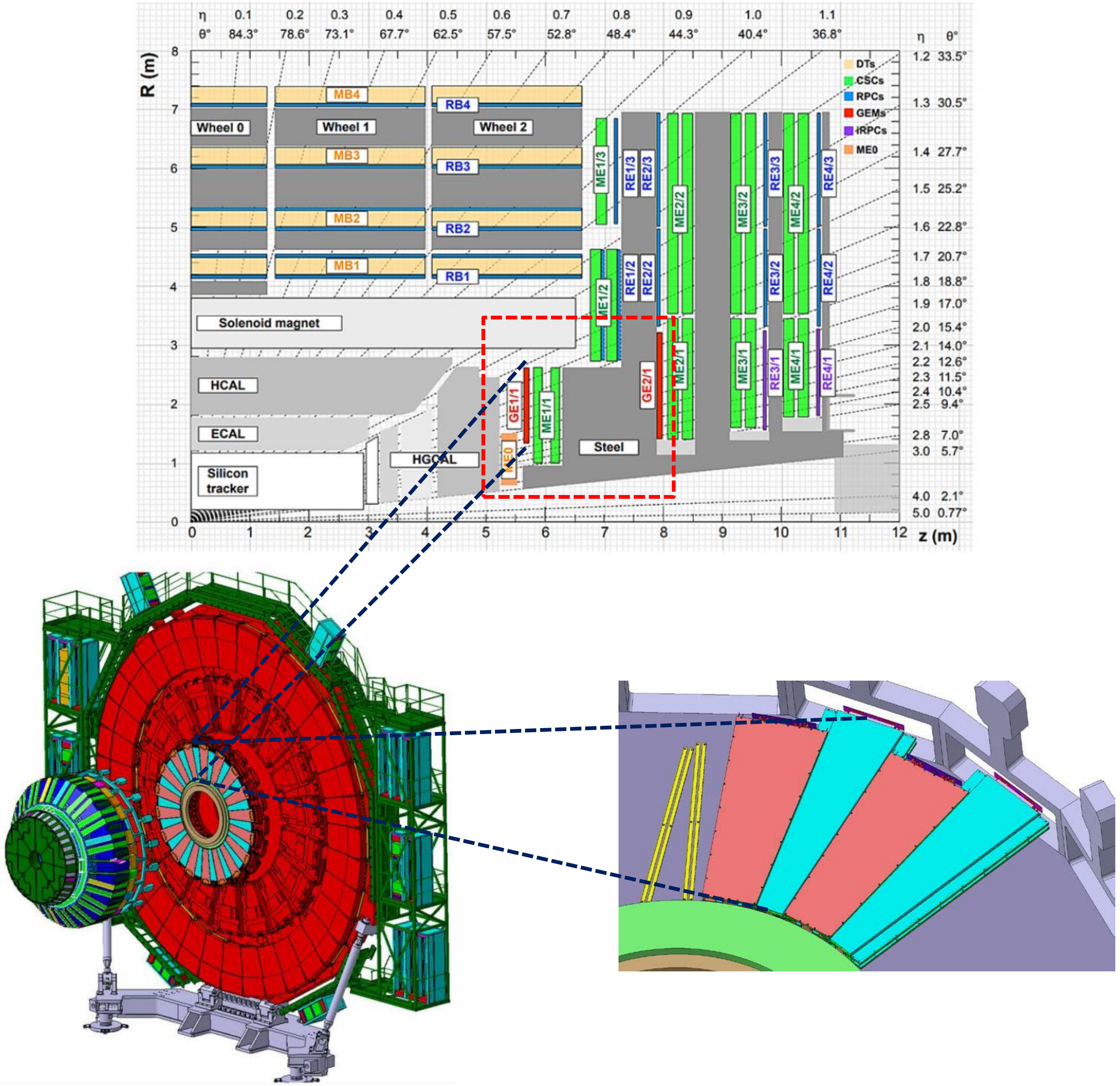
The CMS Phase 2 muon detector



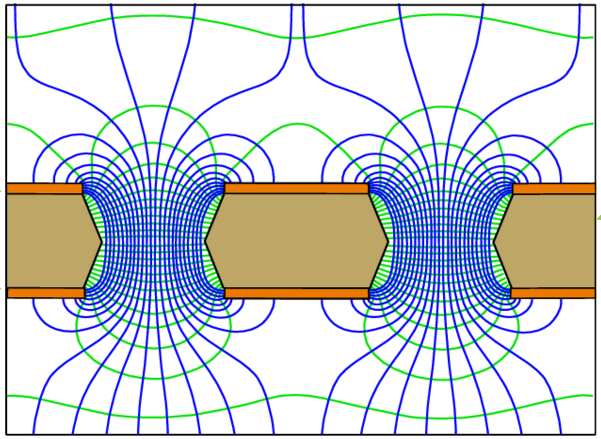
- To extend the sensitivity for new physics searches, a major upgrade of the LHC has been decided and is being prepared, the **H**igh **L**uminosity **LHC** (**HL-LHC**)
- The **forward region** must be completed with additional muon detectors
- One challenge is the **high rate** of the incident particles in the most forward region of the CMS detector.

  → **M**icro-**p**attern **g**aseous **d**etectors (**MPGD**) capable of operating in higher rates

- The upgrade of the CMS Muon Spectrometer foresees the installation of three new muon stations based on the **G**as **E**lectron **M**ultiplier (**GEM**) technology:
  - **GE1/1**, $\mathbf{1.55 < |\eta| < 2.18}$ **Installed**
  - GE2/1, $1.62 < |\eta| < 2.43$
  - ME0, $2.0 < |\eta| < 2.8$

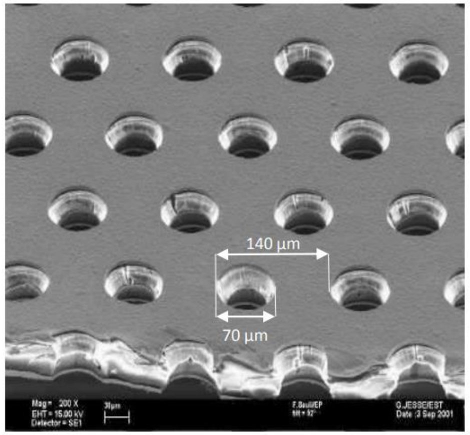
The GEM technology

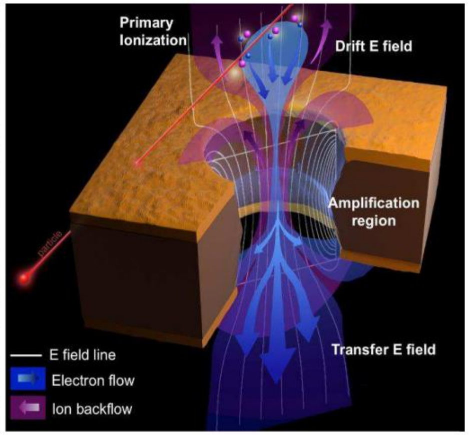
- The **G**EM **E**ndcap Ring **1** Station **1** (**GE1/1**) consists in **Triple** GEM detectors → **3 GEM foils**
- **The GEM foil**:



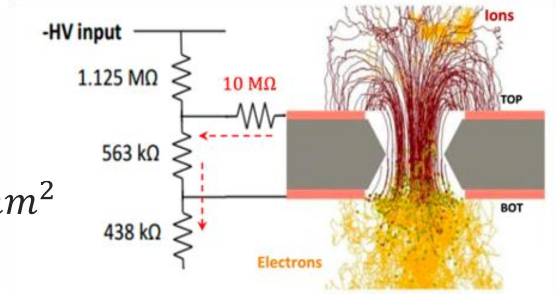
Copper cladding ($5\ \mu m$)

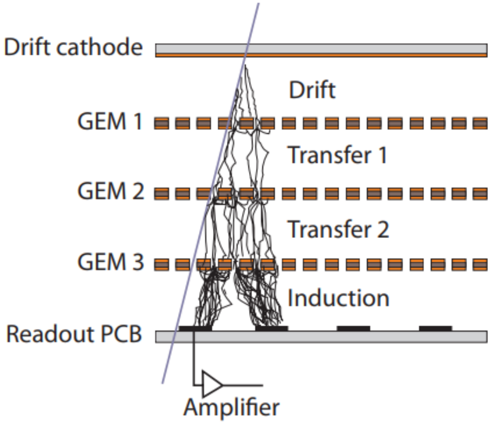
Kapton ($50\ \mu m$)





- Foil chemically perforated
- Biconical holes
- High hole density: $50 - 100/mm^2$
- Gas mixture $\mathbf{Ar/CO_2}$ 70:30





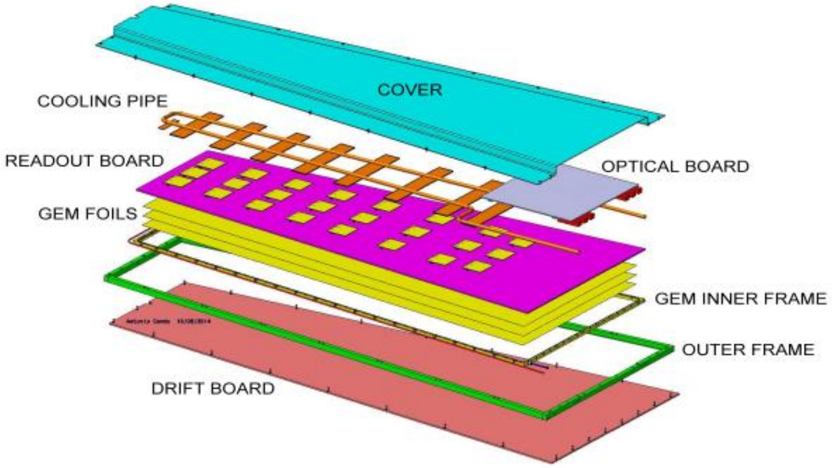
GE1/1 Gap Sizes	Typical Potentials	Typical Voltages	Typical El. Fields [kV/cm]
	3200 V		
3 mm		770 V	2.6
	2430 V 2050 V	380 V	64.0
1 mm		300 V	3.0
	1750 V 1380 V	370 V	62.0
2 mm		600 V	3.0
	780 V 430 V	350 V	60.0
1 mm		430 V	4.3
	0 V		

F. Sauli, *"GEM: A new concept for electron amplification in gas detectors"*, Nucl. Instrum. Meth. A 386 (1997) 531

- GEM foils placed at **few mm** and immersed in a gas mixture
- The voltage is applied between the two copper-clad surfaces → **intense electric field** in the GEM holes
- The electrons produced by primary ionization drift towards the holes → they acquire enough kinetic energy to produce **secondary ionization** in the gas
  - This produces an **electron avalanche process**, which induces an electrical signal on the readout strips
- Combining the three GEM foils the **gain** reaches values of the order of $\sim \mathbf{10^4}$

The GE1/1 station

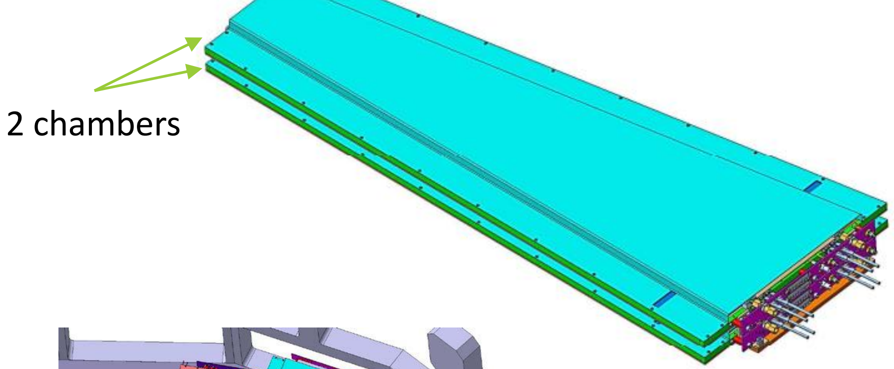
Single chamber



- A GE1/1 chamber has:
  - large trapezoidal area ($\sim m^2$)
  - 24 digital readout sectors: 8 reference partitions in η

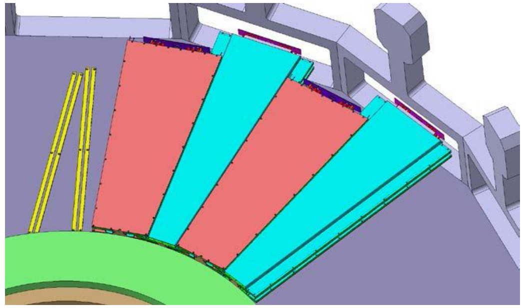
- Chambers are organized in pairs of module: two detectors define a GE1/1 **Super-Chamber**

Super-chamber



- The GE1/1 station consists in **36** super-chambers per endcap, alternating long ($1.55 < |\eta| < 2.18$) and short ($1.61 < |\eta| < 2.18$): difference in area about ~15%

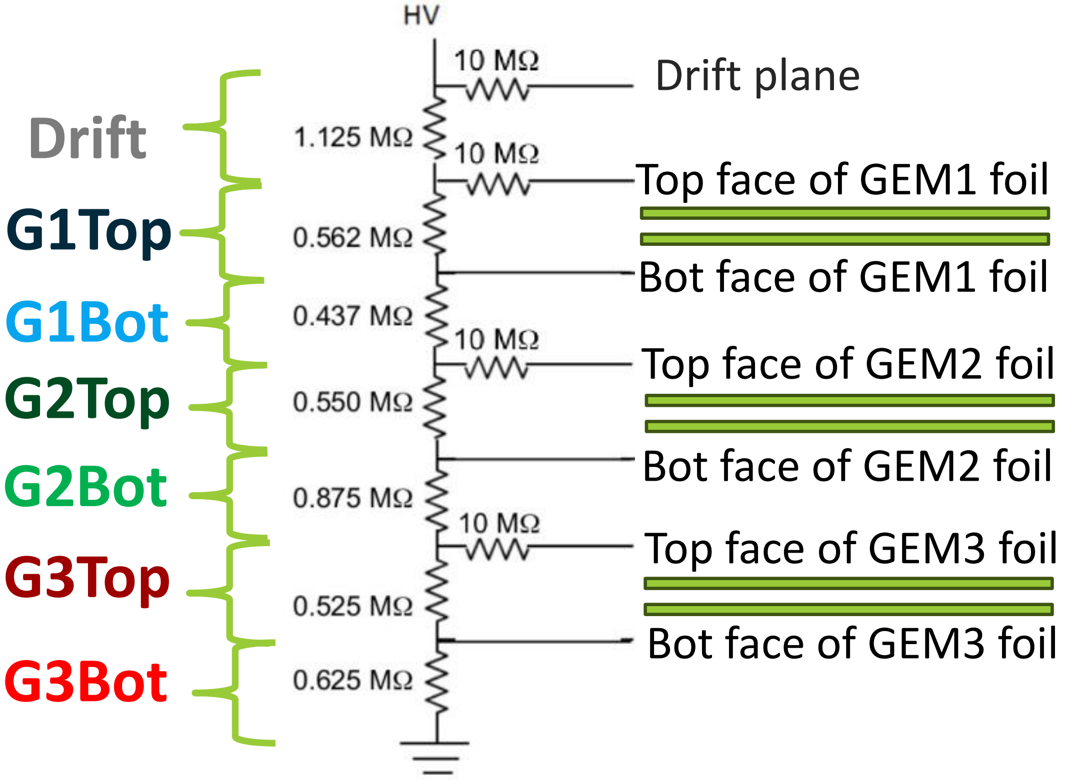
- Each chamber covers 10.15°



CMS Collaboration, "CMS Technical Design Report for Muon Endcap GEM Upgrade", cds.cern.ch/record/2021453/

The GE1/1 operation

- HV provided to a super-chamber with multichannel power supply CAEN **A1515** boards → detector powered **in pairs**
- In one detector, **7 channels** need to be powered
- Voltage global **working point** is defined by the current flowing in the reference resistive divider ($\mathbf{I_{eq}}$), related to the gain of the detector



Voltage configuration I_{eq}= 680 μA	
Drift	765 V
G1Top	382.2 V
G1Bot	297.2 V
G2Top	374 V
G2Bot	595 V
G3Top	357 V
G3Bot	425 V

- Requirements:
  - **Rate capability** of $10\ \mathrm{kHz/cm^2}$
  - No aging effects after $200\ \mathrm{mC/cm^2}$ of integrated charge.

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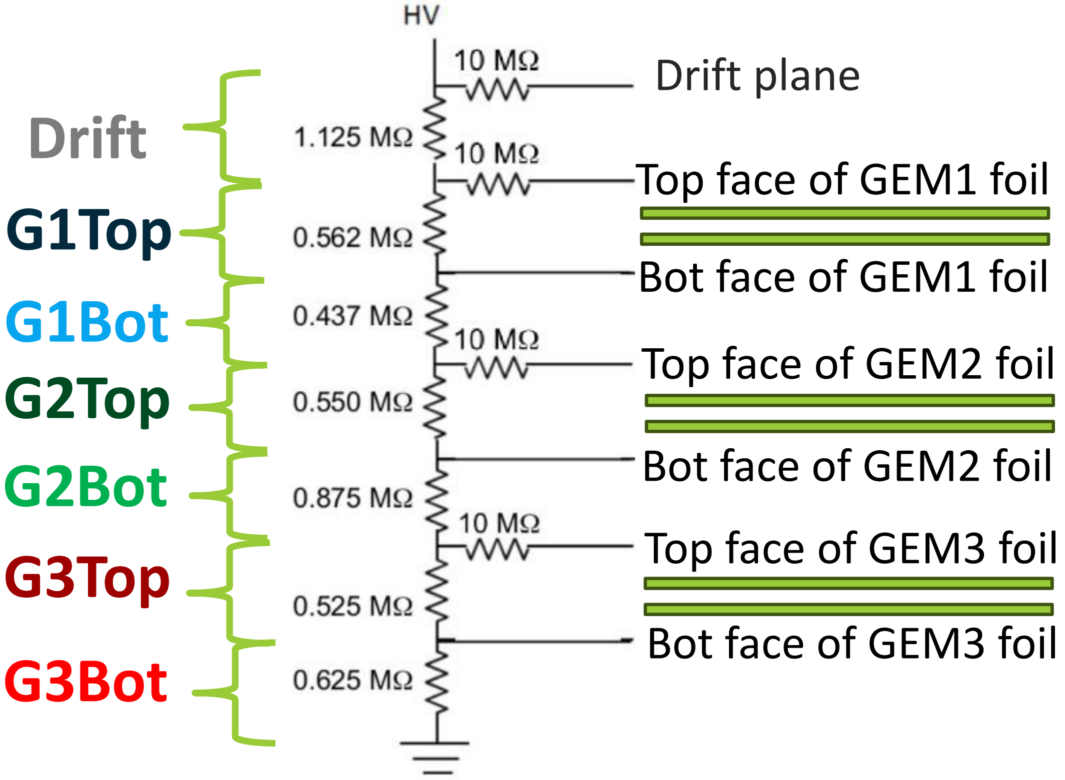

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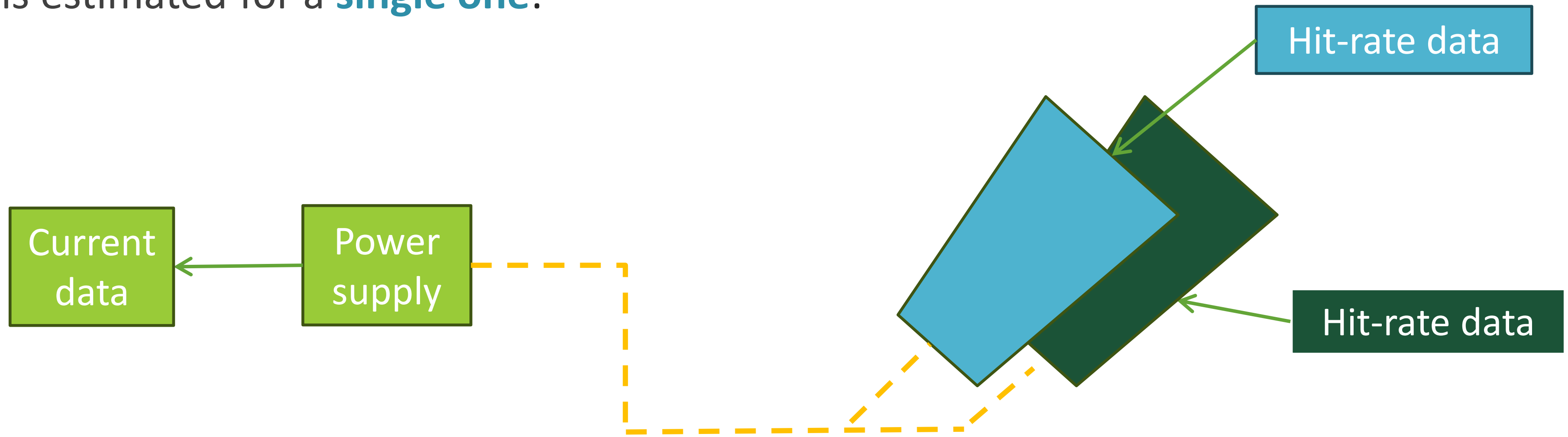
- Requirements:
  - **Rate capability** of $10\ \mathrm{kHz/cm^2}$ → Study the current in relation to background hit rate
  - No aging effects after $200\ \mathrm{mC/cm^2}$ of integrated charge.

Data processing

- *Key concept*: if the rate of **ionizing particles** passing through a chamber **increases**, also the monitored **current** must **increase**

- The A1515 powers a super-chamber: **current measurements** refer to a **pair of chambers**
- The **hit-rate** is estimated for a **single one**:



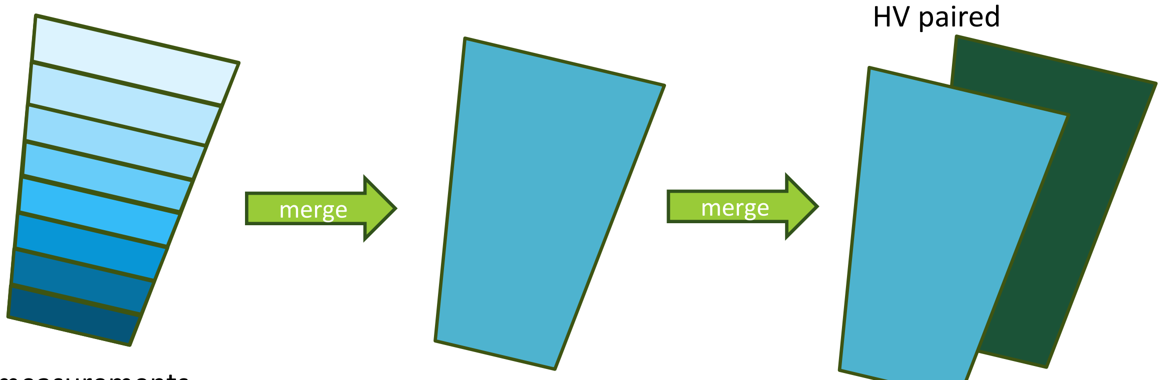
- Study the correlation for the **HV matching chambers**

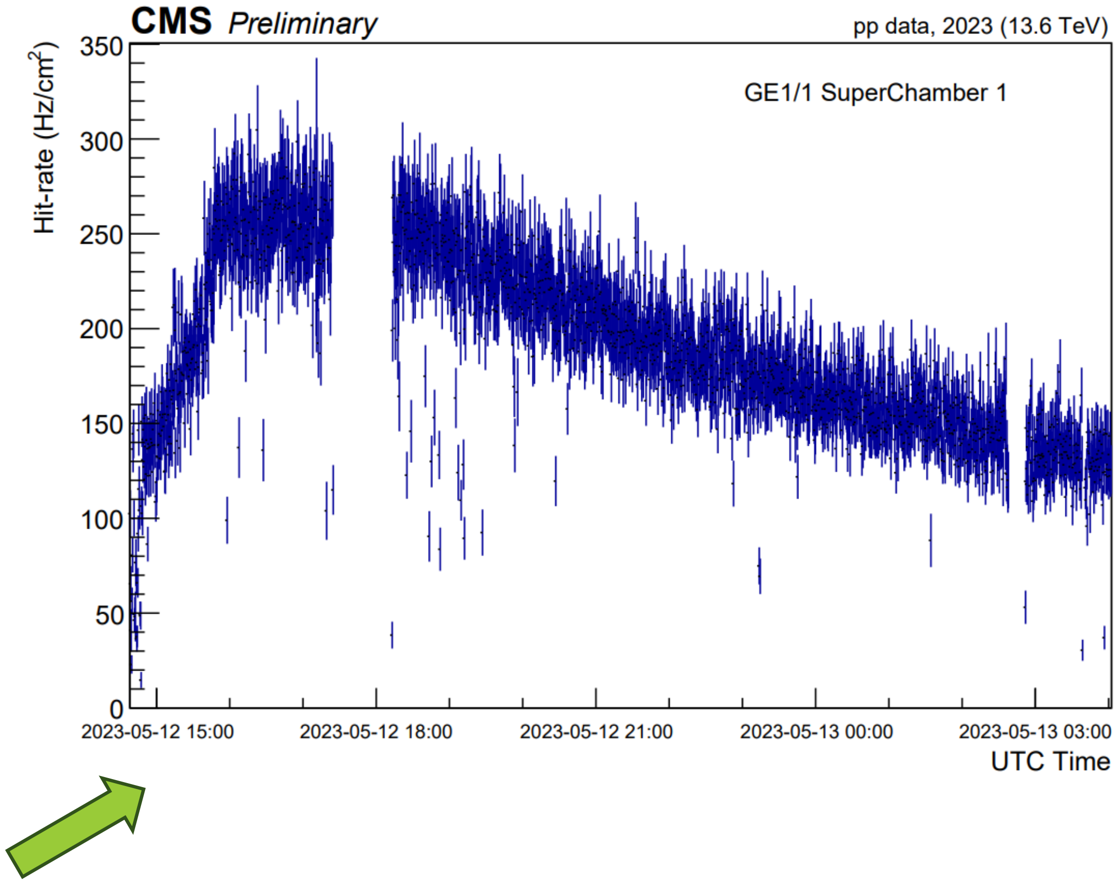
Background hit-rate

- Background rate definition (Hz/cm^2) :

$$Rate = \frac{1}{n \cdot \Delta t \cdot A} \sum_i Hit_i(\Delta t)$$

- n : number of events in a Lumi-Section (LS), the reference data collection period used by CMS corresponding to $\sim$ 23 s
- Δt: $25\ ns \times 8$ bunch crossings
- A: effective area (cm^2)

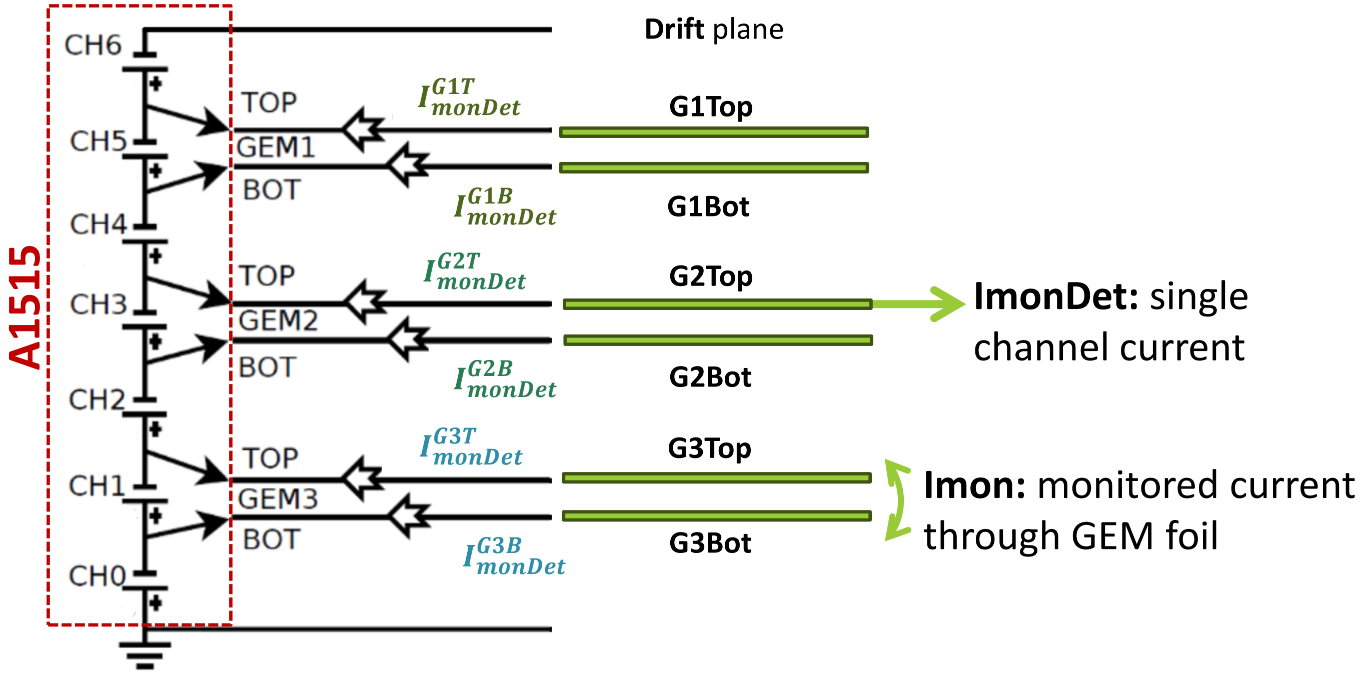




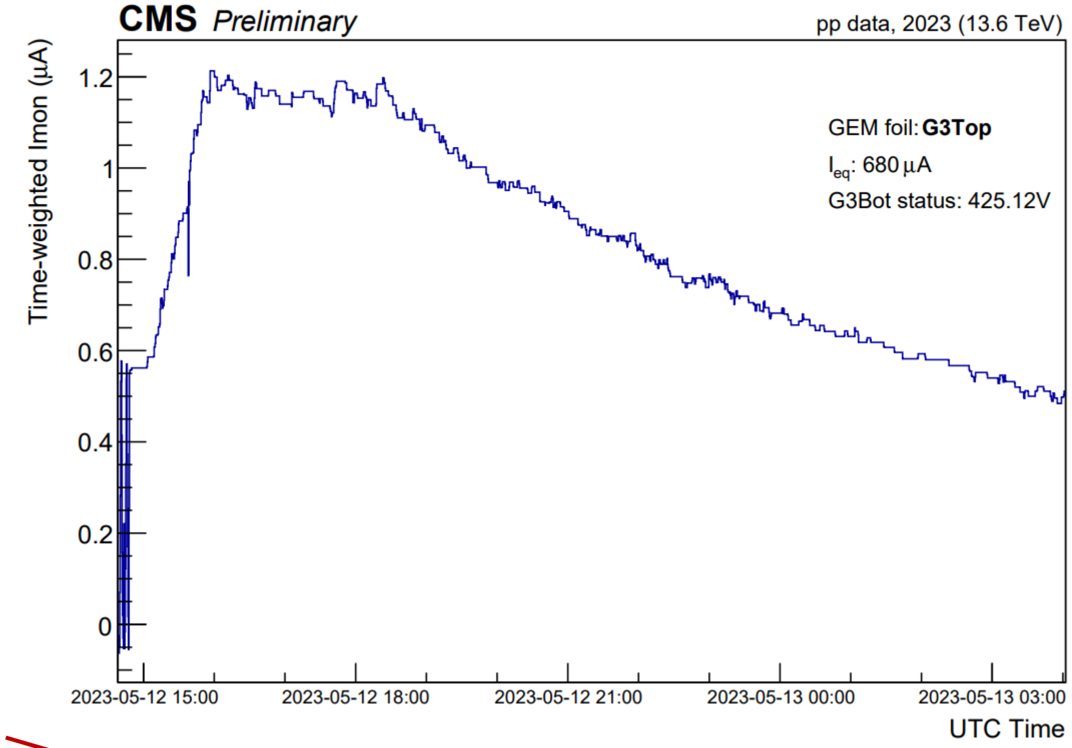
- The hit-rate is normalized by the total area of a super-chamber
- Background rate in time evaluated for each super-chamber in both endcaps

Current measurements

- A1515 board currents logic



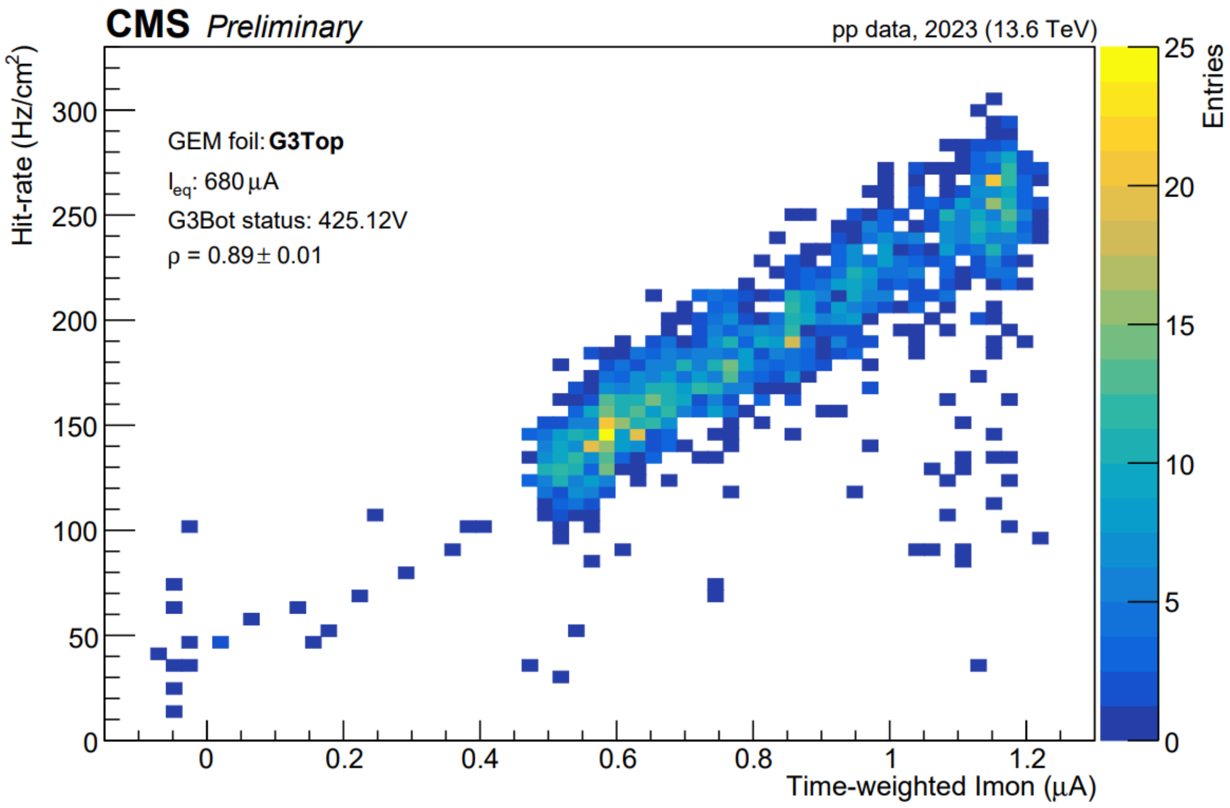
	$I^{Drift}_{monDet} = I^{Drift}_{mon}$	
$I^{G1T}_{monDet} = I^{G1T}_{mon} - I^{Drift}_{mon}$	$I^{G2T}_{monDet} = I^{G2T}_{mon} - I^{G1B}_{mon}$	$I^{G3T}_{monDet} = I^{G3T}_{mon} - I^{G2B}_{mon}$
$I^{G1B}_{monDet} = I^{G1B}_{mon} - I^{G1T}_{mon}$	$I^{G2B}_{monDet} = I^{G2B}_{mon} - I^{G2T}_{mon}$	$I^{G3B}_{monDet} = I^{G3B}_{mon} - I^{G3T}_{mon}$



This current directly related to amplification current

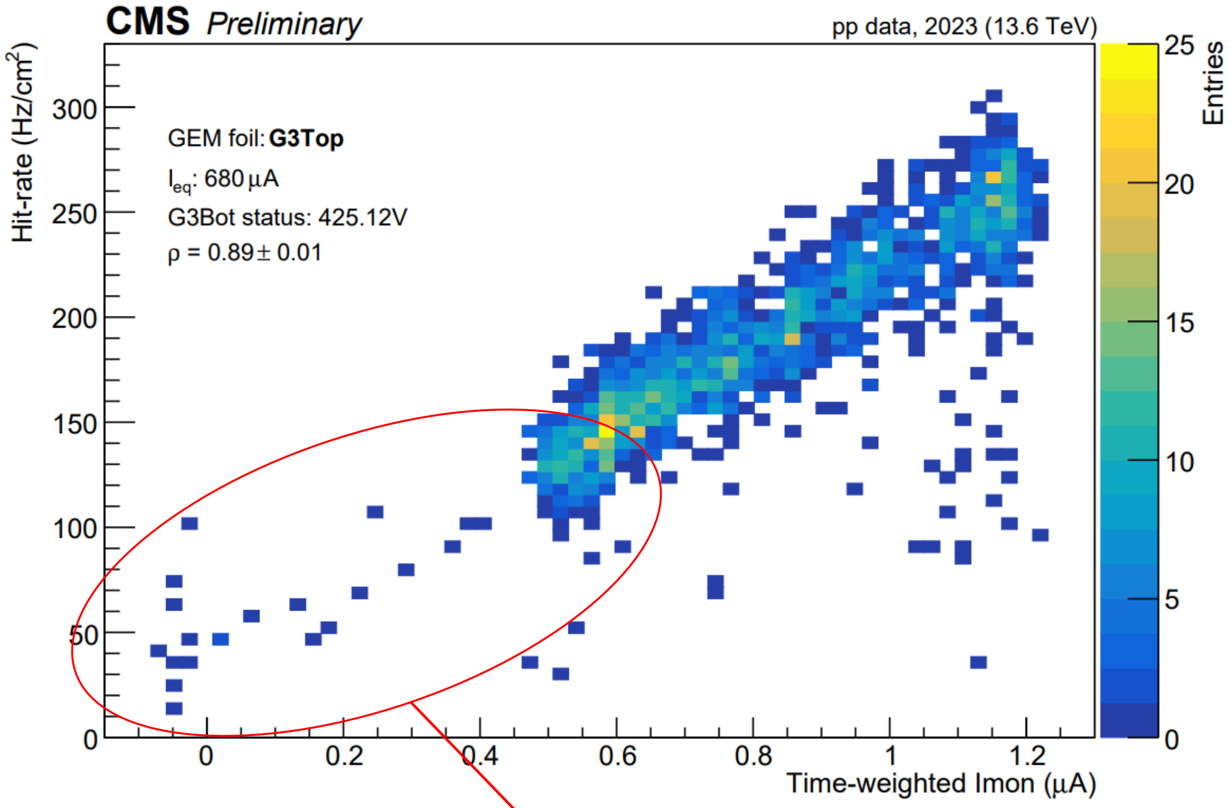
- Current related to a super-chamber
- G3Top is where it is expected more current (more contribution from the electron avalanche)
- To correlate with hit-rate data, currents **averaged** over the time intervals in which the hit-rate measurements are recorded

Correlation: rate vs current



- Study of the correlation between baseline **current** and background **hit-rate** in **GE1/1** chambers
- Quantities clearly correlated

Correlation: rate vs current



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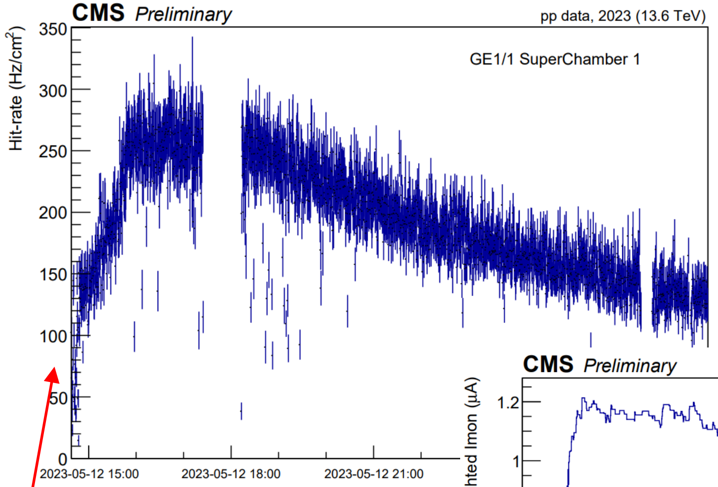
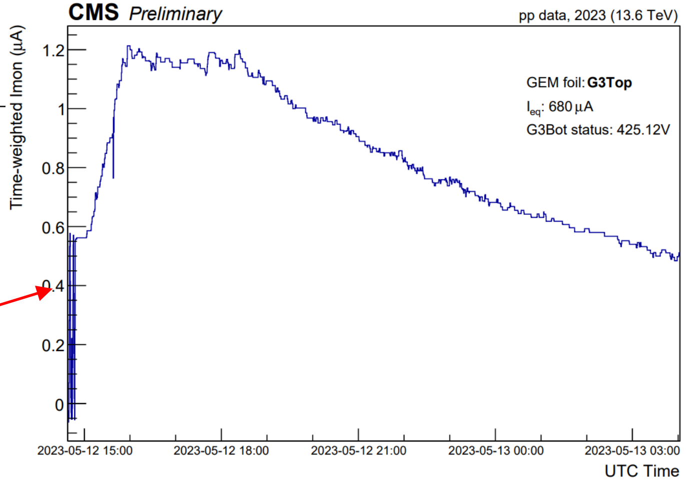
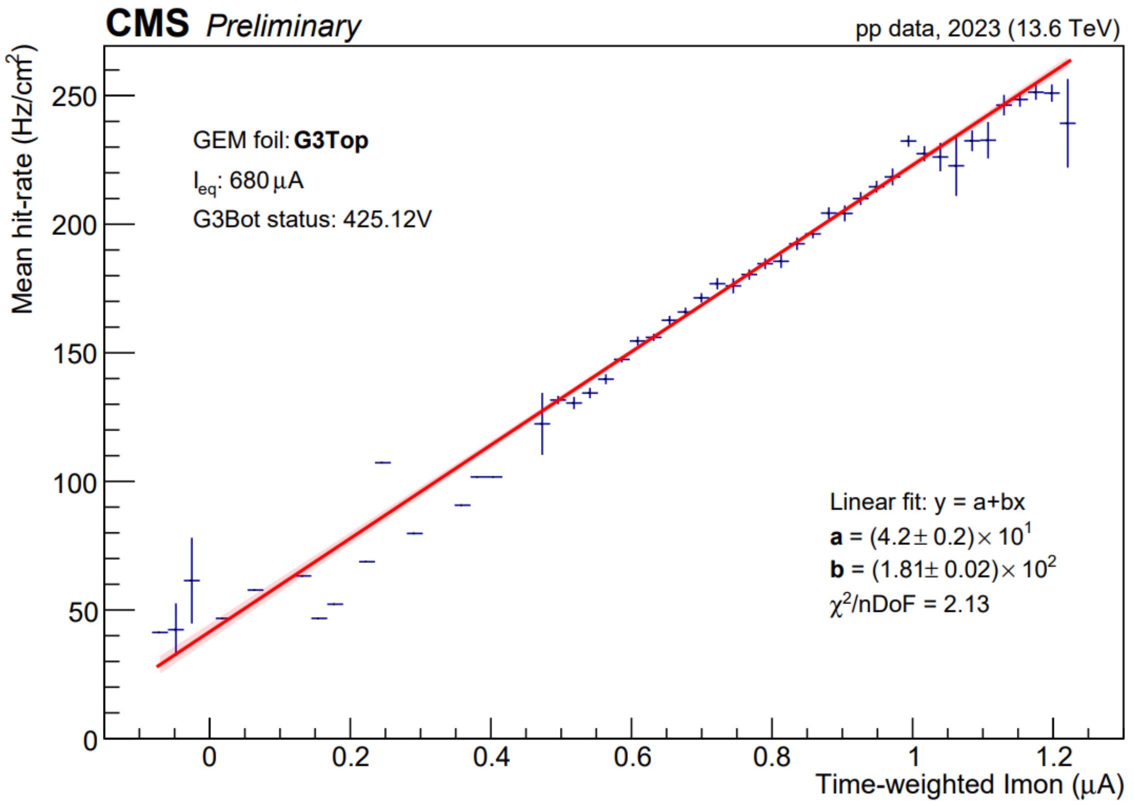




The first points correspond to the start of CMS data taking, in correspondence of beam separation ("emittance") scans:

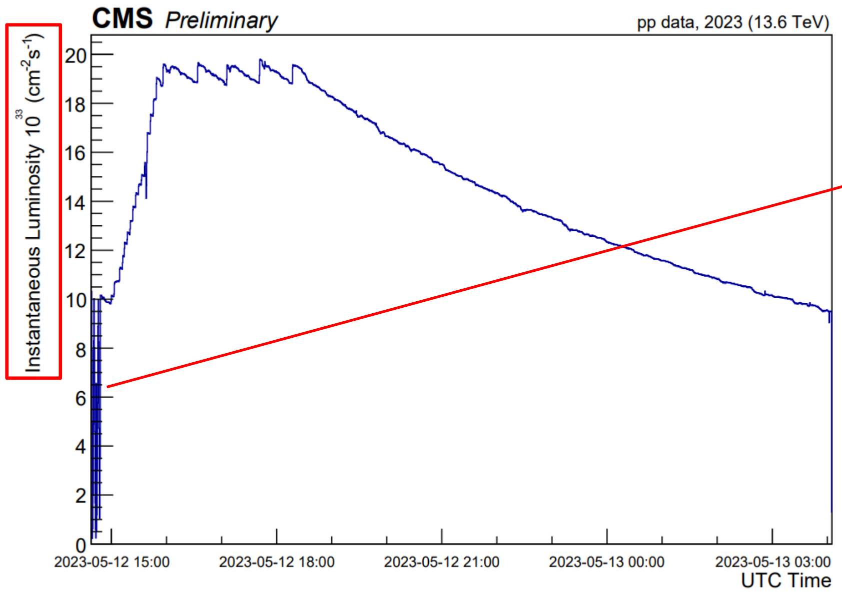
- sudden variations in instantaneous luminosity, observed also in rate and current
- in these conditions, there is no compatibility with what was estimated in the steady-state phase

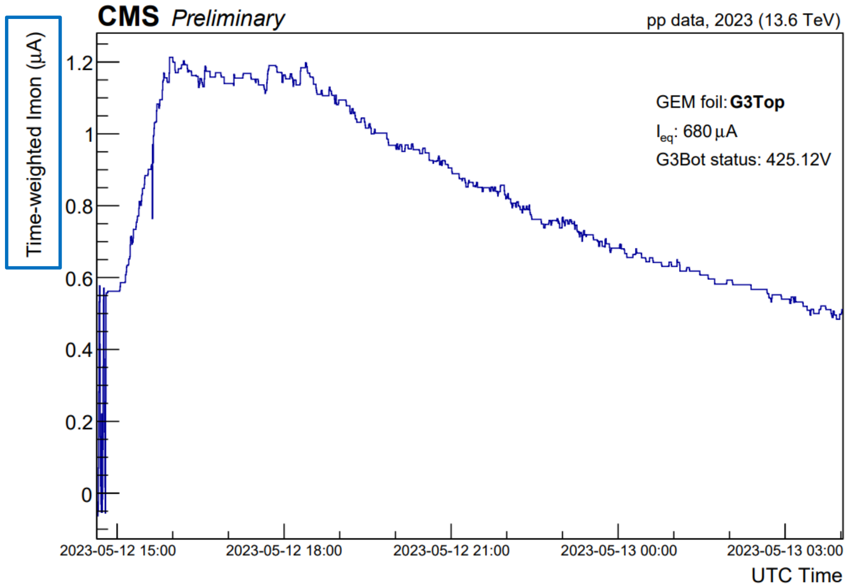
Correlation: rate vs current



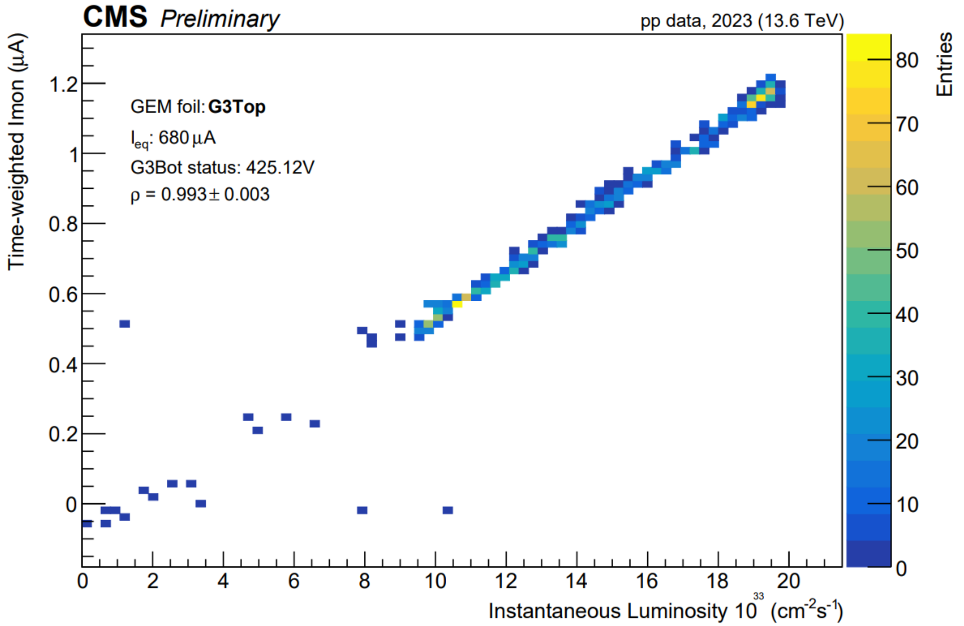
- Study of the correlation between baseline **current** and background **hit-rate** in **GE1/1** chambers
- Quantities clearly correlated
- Analysis strategy: linear fit to **profile distribution**
  - Fix a bin in the x axis
  - Evaluate the mean along the y axis of the corresponding two-dimensional distribution
  - It helps in statistical treatment of high fluctuations
- **Linear trend:** no signs of saturation in rate-capability

Correlation: current vs luminosity



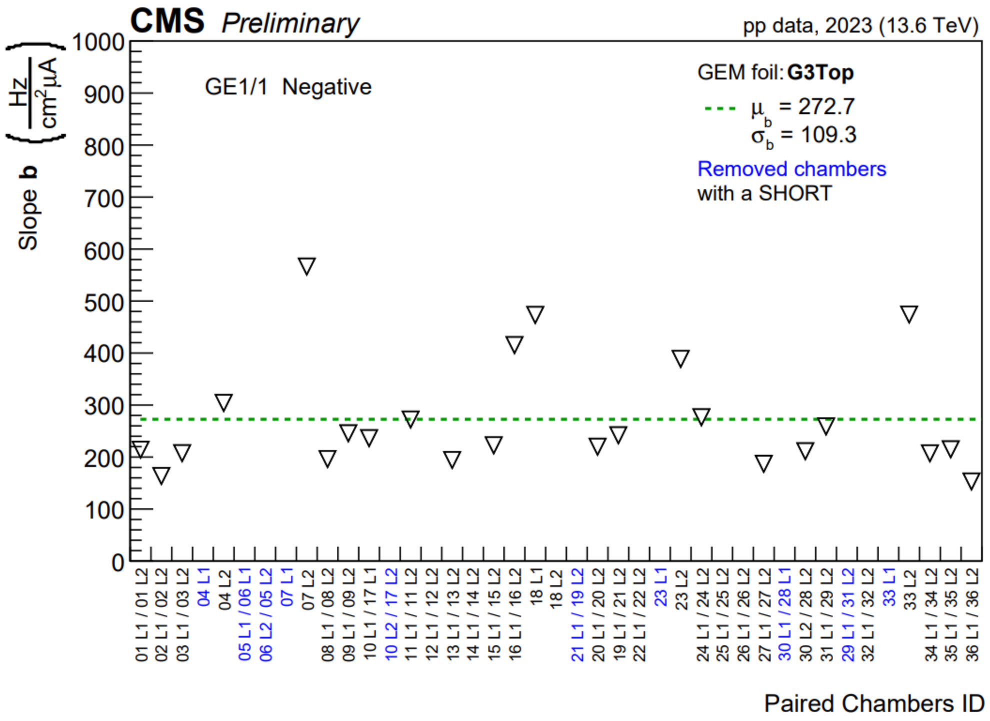


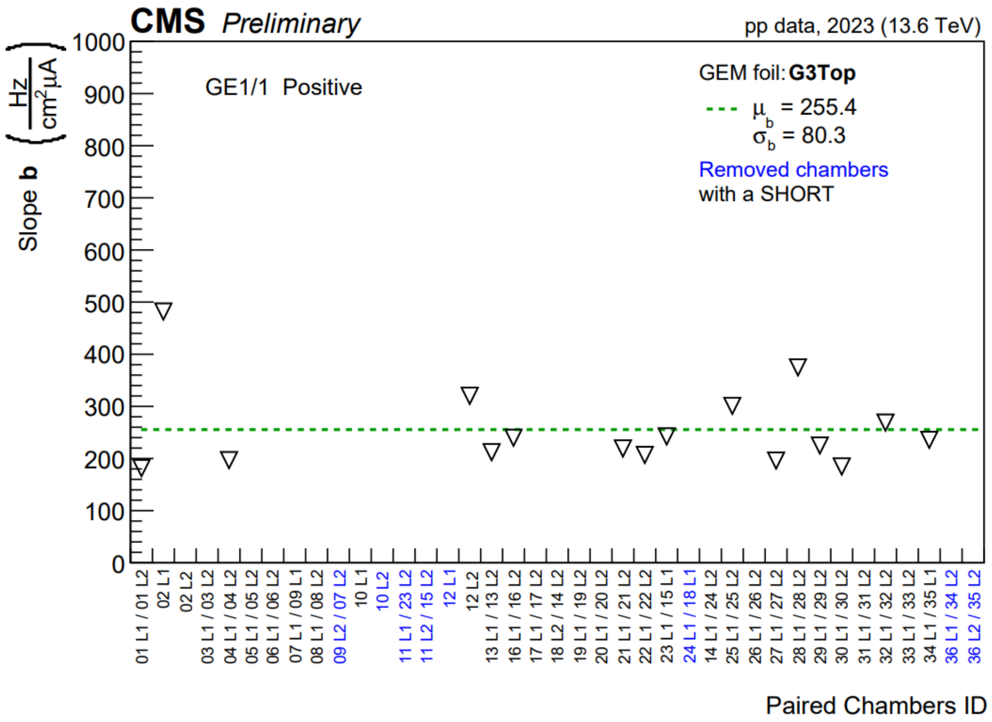
- Typical signature at the beginning of data taking: Emittance scan
- The luminosity data is averaged over a LS
- Study of the correlation between baseline **current** and instantaneous luminosity in **GE1/1** chambers
- Quantities clearly correlated
- **Linear trend:** the monitored **current increases as** the instantaneous **luminosity increases**, which confirms that the detectors can operate even in high-rate scenarios.



Summary

- Analysis carried out for each super-chamber in **both endcaps**
- The **average slopes** of both endcaps are comparable, confirming a coherent operation of the GE1/1 detectors in terms of response in current at the corresponding hit-rate scenario





More about short-circuits: Analysis of discharge events in the CMS GE1/1 GEM detectors in presence of LHC beam

Conclusions

Constant attention to optimize GE1/1 operations

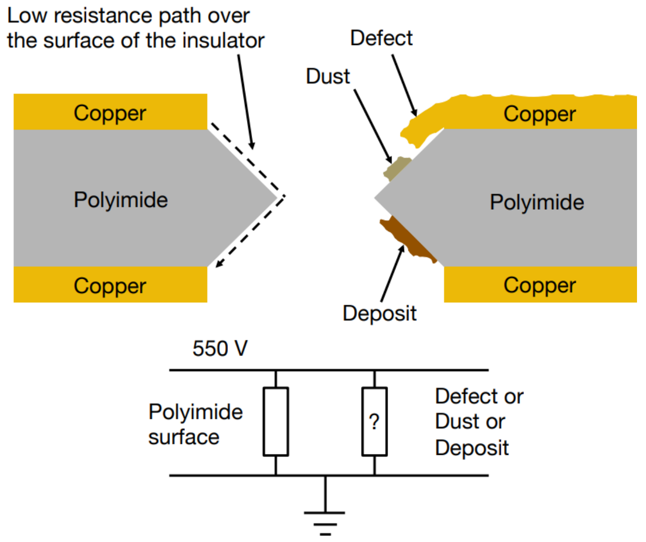
- The analysis confirms the **expected correlation** between hit-rate and monitored current
- No signs of **saturation** in rate-capability in GE1/1 → we are quite below the maximum rate capability

- This is an important result in the perspective of the regime in which **ME0** will operate:
  - It will be the closest muon station to LHC beam line
  - **ME0** has as a requirement a **high-rate capability**, with an expected background particle fluxes up to $\mathbf{150\ kHz/cm^2}$ and longevity over an integrated charge of **9** $\mathbf{C/cm^2}$

- extrapolation of **the expected baseline** currents for **ME0** and integrated electric charge

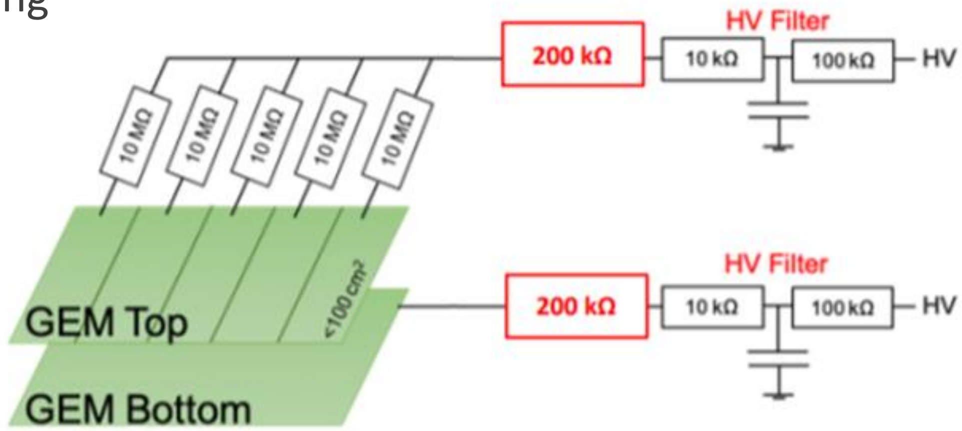
Backup

Short circuit



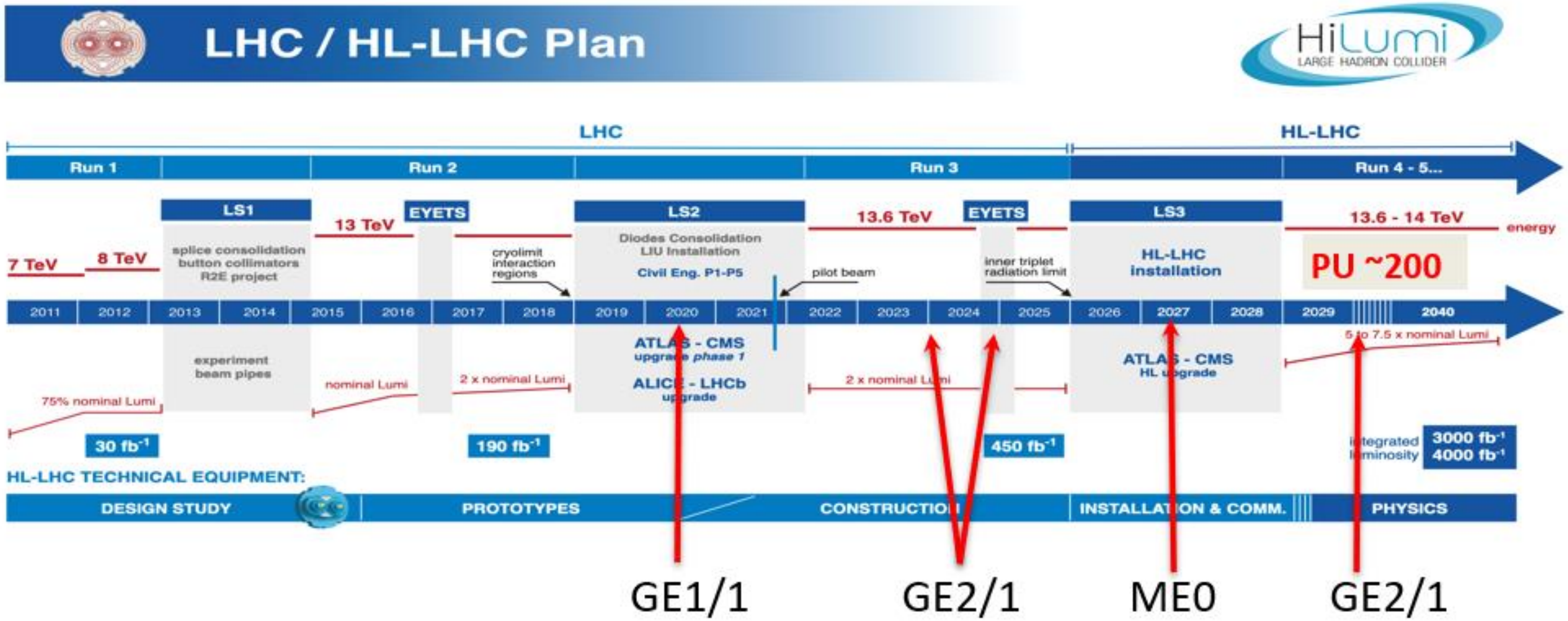
- A short circuit is a connection between top and bottom face of a GEM foil
- **Defects or depositions on GEM foil** can create temporary or permanent short circuit between top and bottom electrode
- It appears as an increase in baseline current

- It causes a drop of the applied voltage → the foil stops amplifying the crossing electrons

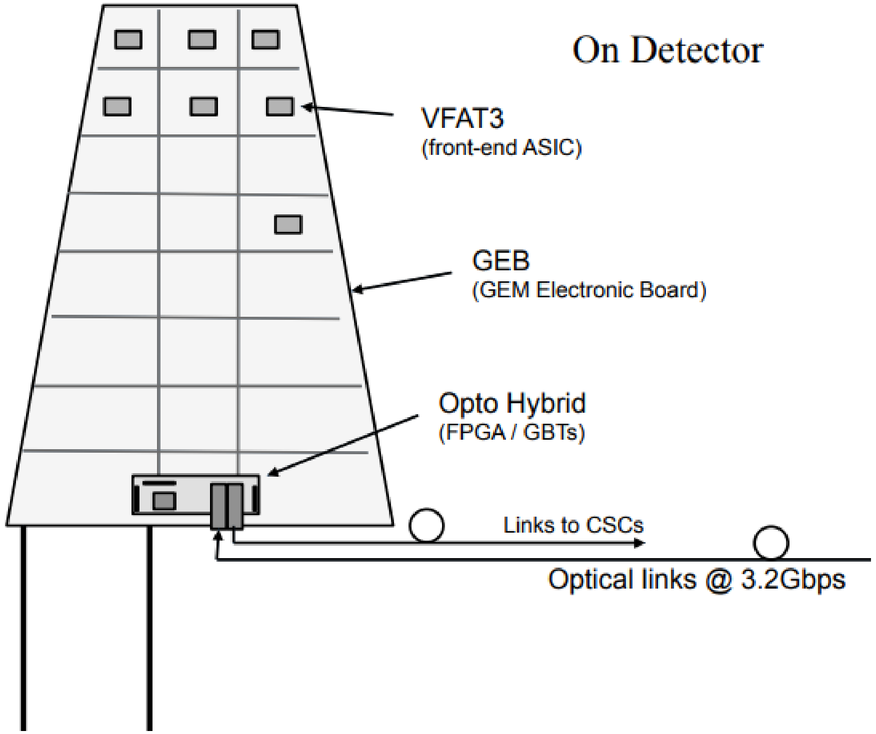


- **Mitigation:** segmentation of the foil in sectors
  - if one sector deactivates the others keep operating

GEM schedule



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)**
- **OptoHybrid board** on the detector hosting GBTs and FPGA
- Data sent by the OH to the backend electronics by **VTRx optical transceivers**