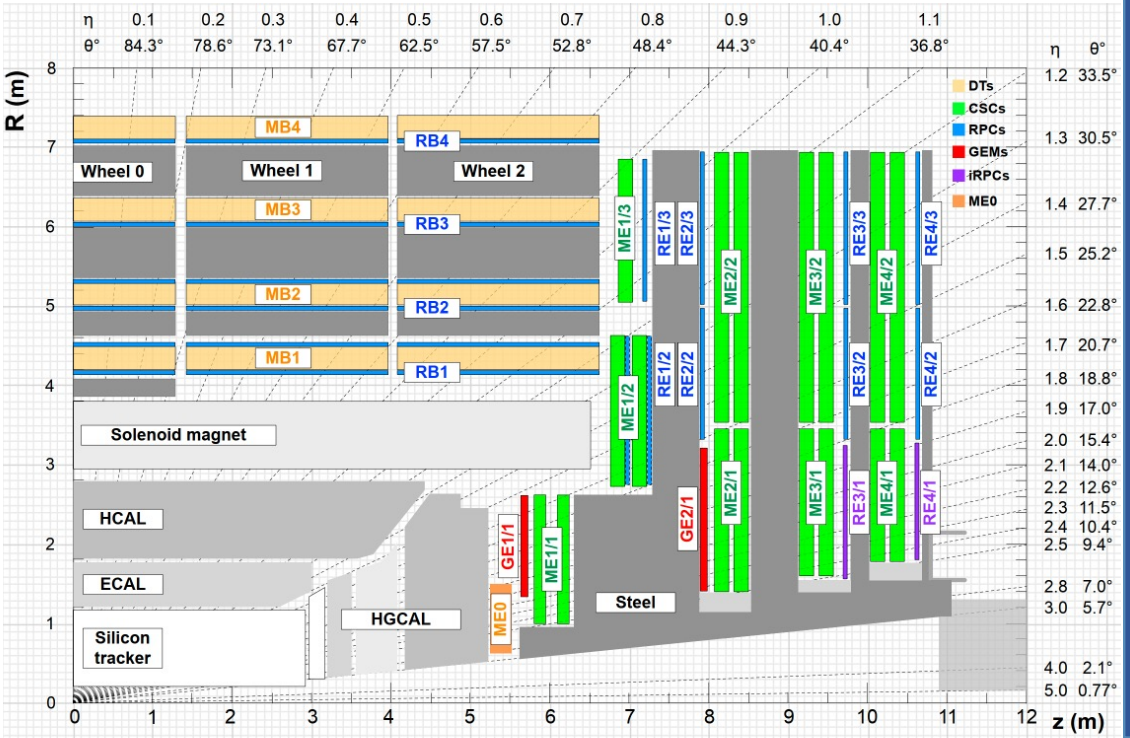
Triple-GEMs@CMS experiment

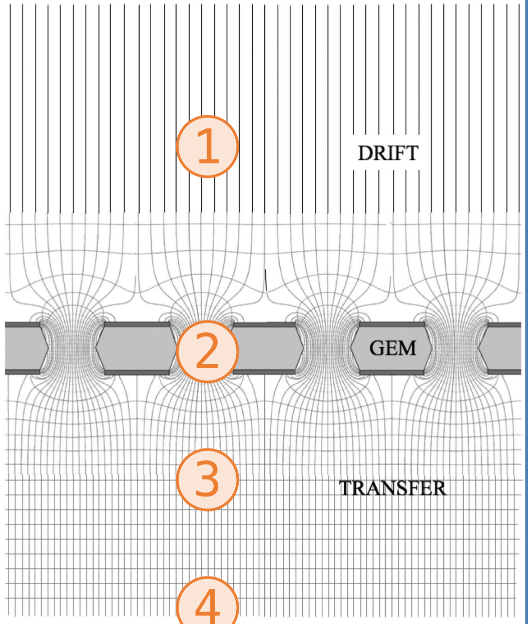
A. Cagnotta – F. Confortini – C. Di Fraia – **L. Favilla** – A.O.M. Iorio – B. Rossi

The Phase-2 Upgrade of the CMS Muon Detectors

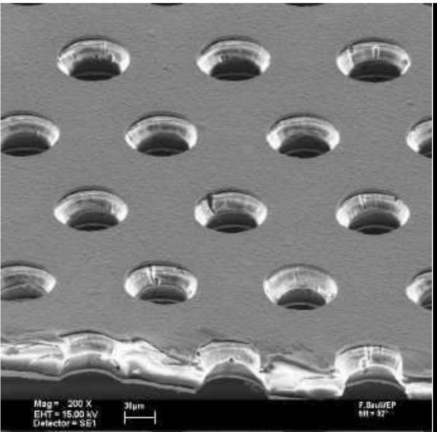
- The muon system is challenged by high particle rates in the forward region of the CMS detector
  - Inst. Lumi: $2\times10^{34}cm^{-2}s^{-1}$ (LHC) → $5 \div 7.5 \times10^{34}cm^{-2}s^{-1}$ (HL-LHC)
  - Pileup: 60 (LHC) → $140 \div 200$ (HL-LHC)
  - Several upgrades taking place to handle such a harsh environment → link to CMS-TDR-016
- Main purpose:
  - $|\eta| < 2.4$ → Enhance identification and triggering capabilities
  - $|\eta| > 2.4$ → Extend muon identification and triggering
- Three new GEM detectors:
  - LS2: **GE1/1** $(1.5 < |\eta| < 2.2)$
  - LS3: **GE2/1** $(1.6 < |\eta| < 2.4)$ & **ME0** $(2.0 < |\eta| < 2.8)$
- CMS Napoli group involved in:
  - GE1/1 operation
  - GE2/1 and ME0 construction & commissioning
  - High-Voltage Power System design & mantainance

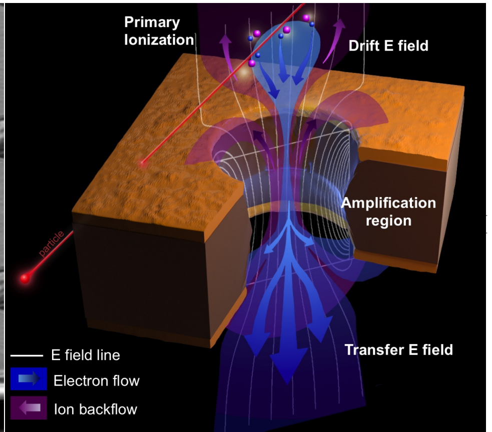


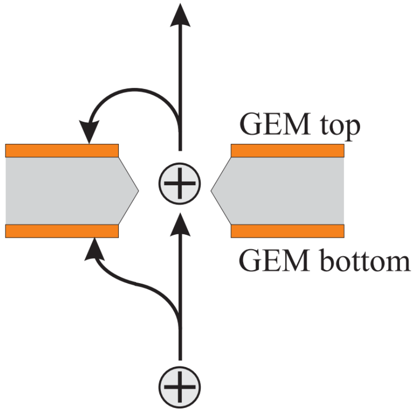
Triple-GEM technology

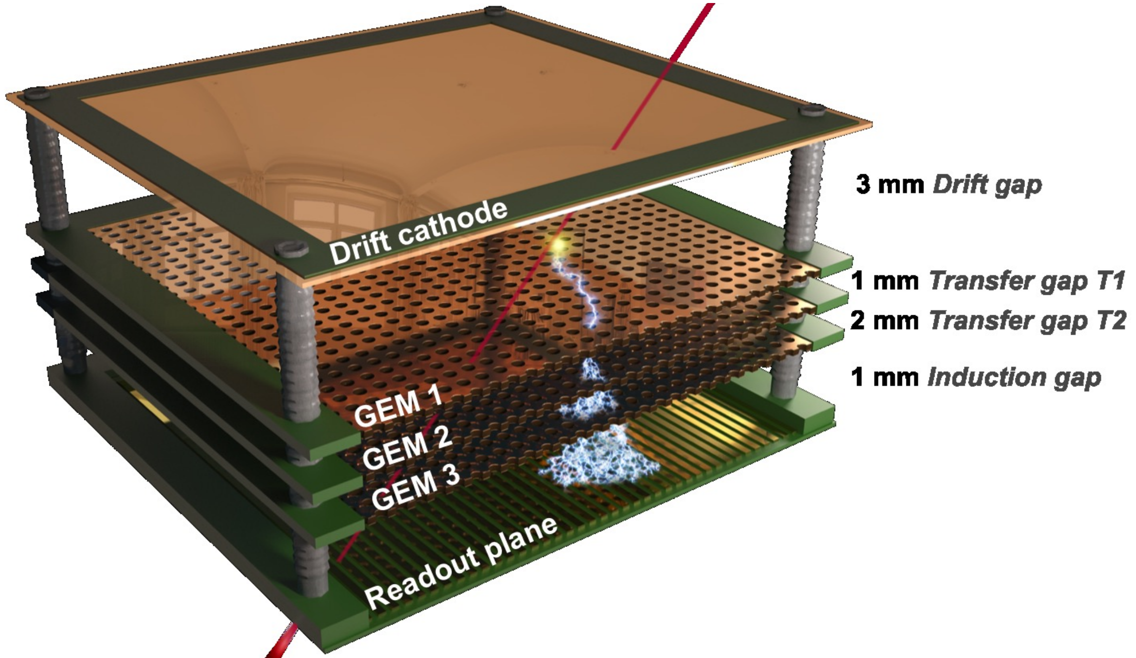


- The ***Gaseous Electron Multipliers (GEMs)***:
  - high-rate capability in harsh environments
  - thin polymer foil metal coated on both sides
  - holed pattern ($50 - 100mm^{-2}$)
- How it works:
  1) electron/ion pairs production
  2) electrons driven towards the holes → secondary ionizations
  3) leave multiplication region and transfers into the lower gap
  4) collection by an electrode or injected into a second multiplying stage
- Characteristics:
  - Gain: $\mathbf{10^4 \div 10^5}$ in triple-stage
  - Spatial resolution: $\sim \mathbf{100\mu m}$
  - Time resolution: $\sim \mathbf{10ns}$



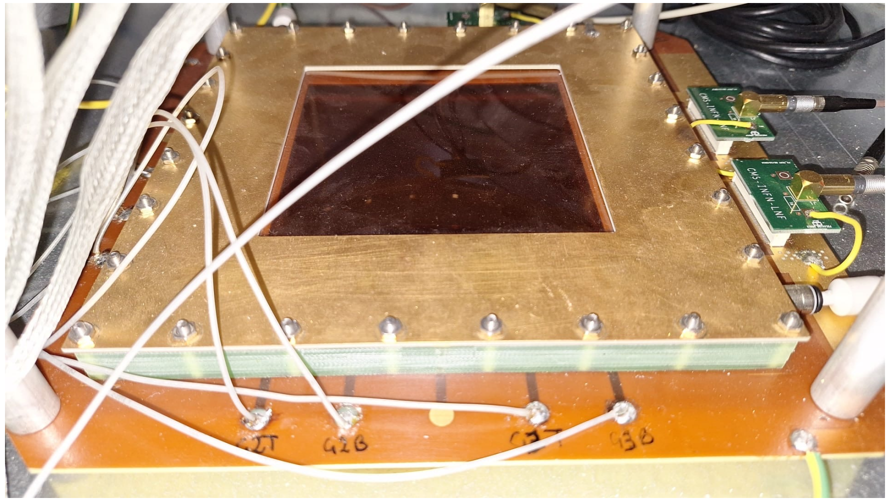


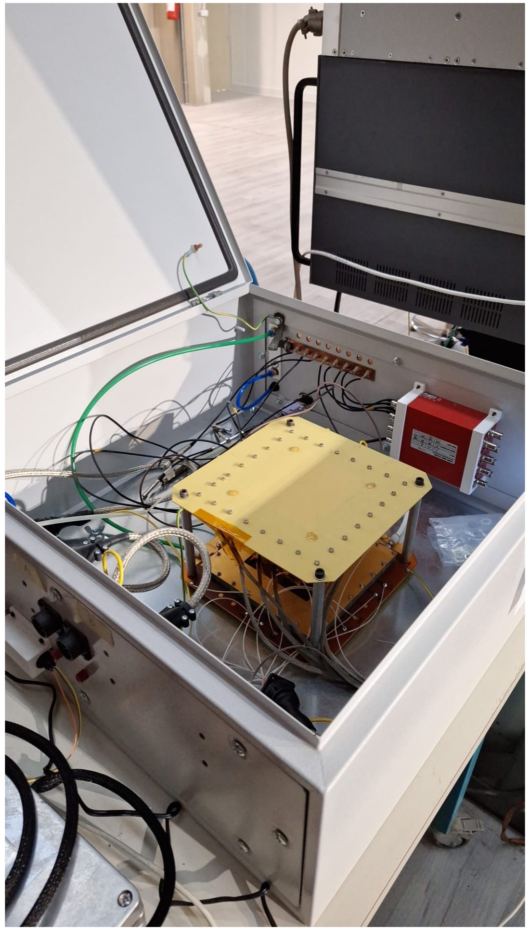




Triple-GEM@INFN – Sezione di Napoli

- $10{\times}10cm^2$ triple-GEM detector ($ArCO_2$ 70:30)
- High-Voltage board:
  - CAEN A1515TG power supply
  - voltage difference between one electrode and the previous one starting from the ground
  - currents sustained by the board itself to compensate any voltage drop/change occurring
  - voltage resolution: $\sim 20mV$
  - current resolution: $\sim 1nA$
- We are able to:
  - Fully characterize a triple GEM and its performances
  - Perform physics studies (electric field optimization)
  - Use it as test bench for custom made pico-ammeter
  - Testing power system components to bring to CERN

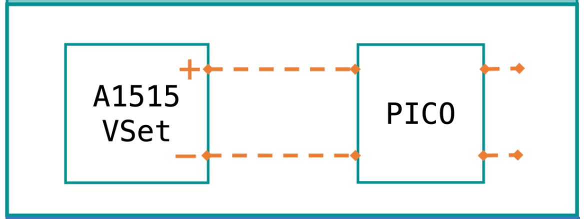




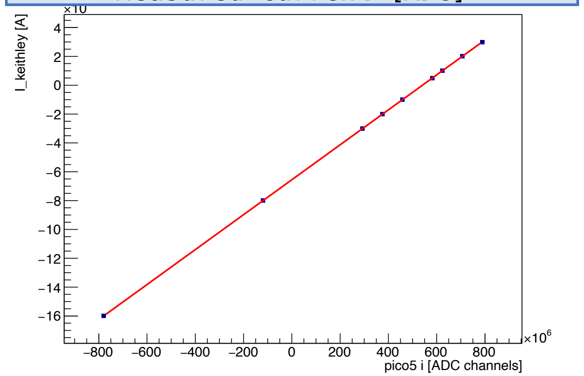
PICO@INFN – Sezione di Napoli

- Pico:
  - High-Voltage monitoring instrument for triple-GEMs
  - capable of measuring currents and voltages
  - current resolution: $\sim 10pA$
  - voltage resolution: $\sim 10mV$
  - sampling rate: up to **400Hz** (1Hz for HV board)
- Performed:
  - current and voltage calibrations
  - resolution estimation

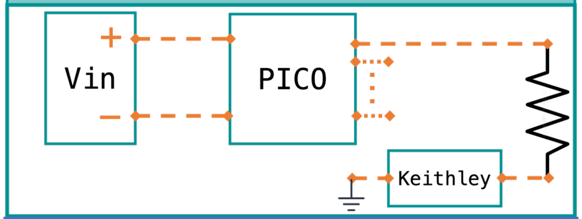
Voltage Calibration



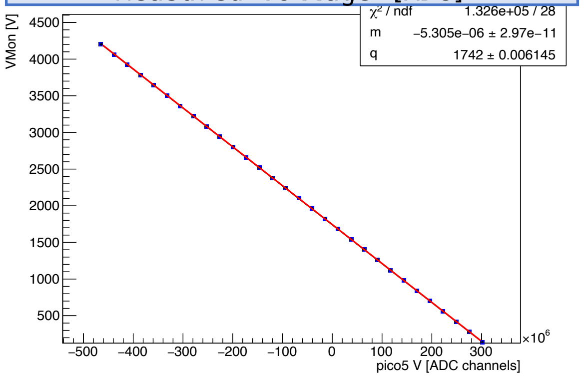
Reference Current [A] vs. Measured Current [ADC]



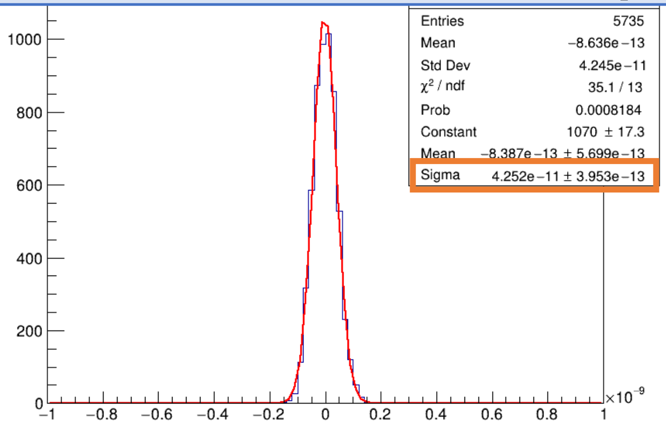
Current Calibration



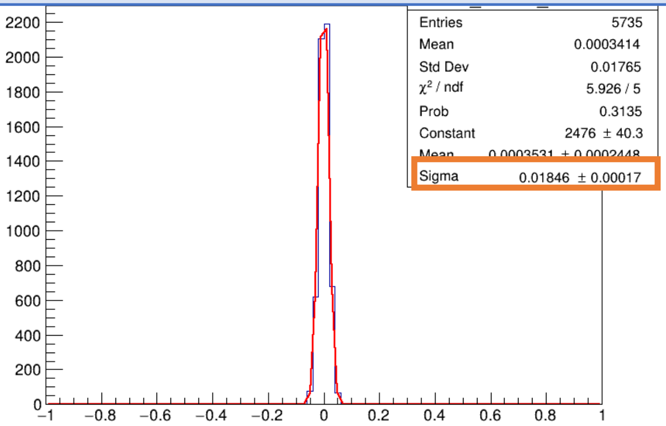
Reference Voltage [V] vs. Measured Voltage [ADC]



I_DRIFT resolution $\sim 40pA$



V_DRIFT resolution $\sim 20mV$



L. Favilla - INFN Group 1

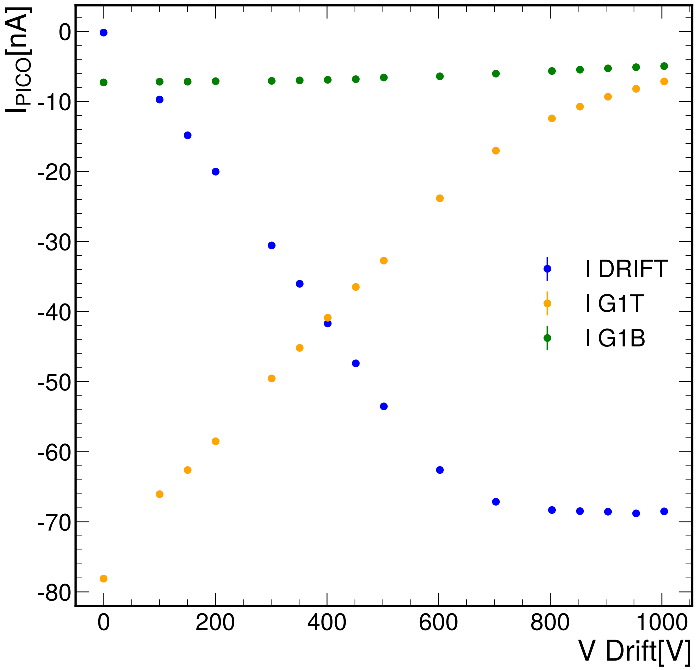
Currents vs. Electric Fields

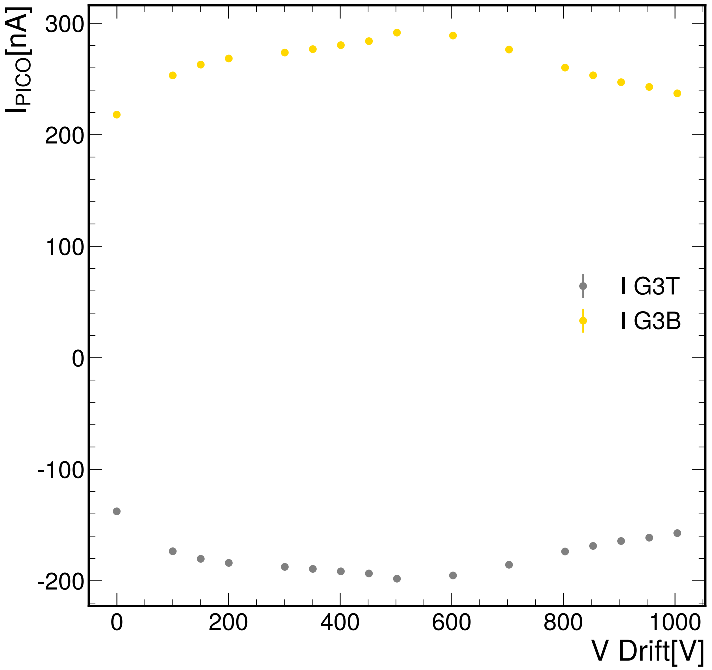
- For the studies, we have used:
  - a $10\times10cm^2$ triple-GEM detector ($ArCO_2$ 70:30)
  - A1515 board as power supplier
  - Fe55 X-rays (5.9keV) source (370MBq)
  - PICO

Channel	Voltage (V)		Electric Field (kV/cm)	
DRIFT	Vary	850	Vary	2.8
G1T	400	Vary	80.0	Vary
G1B	350		3.5	
G2T	400		80.0	
G2B	700		3.5	
G3T	400		80.0	
G3B	450		4.5	

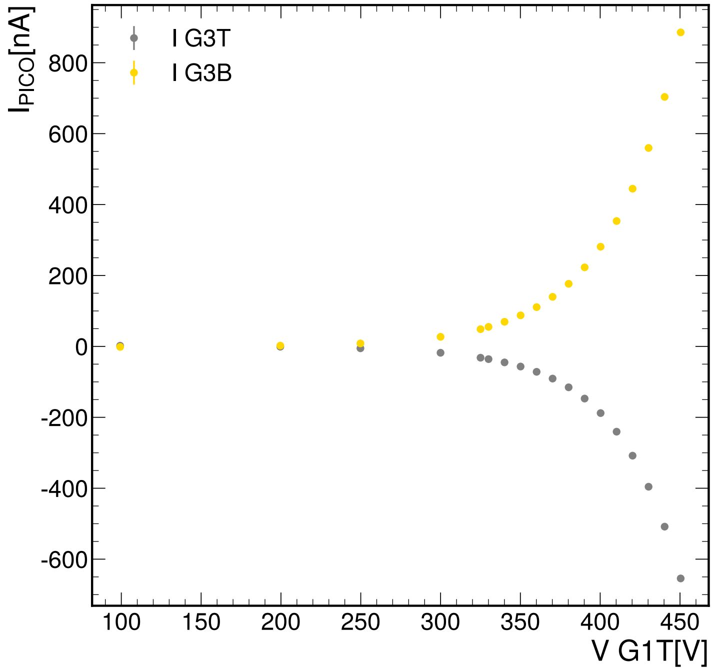
- Procedure:
  - Fixed all electric fields except one
  - Measuring currents when changing the selected field

Varying E_DRIFT





Varying E_GEM1



Pico installation into CMS experiment

- Older version already used in CMS & magnet test@North Area:
  - understanding of the experimental conditions inducing discharges and short circuits in a GEM foil
  - established safety procedure during mangnetic field ramps
  - link to article

PAPER • OPEN ACCESS

Impact of magnetic field on the stability of the CMS GE1/1 GEM detector operation

M. Abbas, S. Abbott, M. Abbrescia, H. Abdalla, A. Abdelalim, S. AbuZeid, D. Aebi, A. Agapitos, A. Ahmad, A. Ahmed ▾ Show full author list

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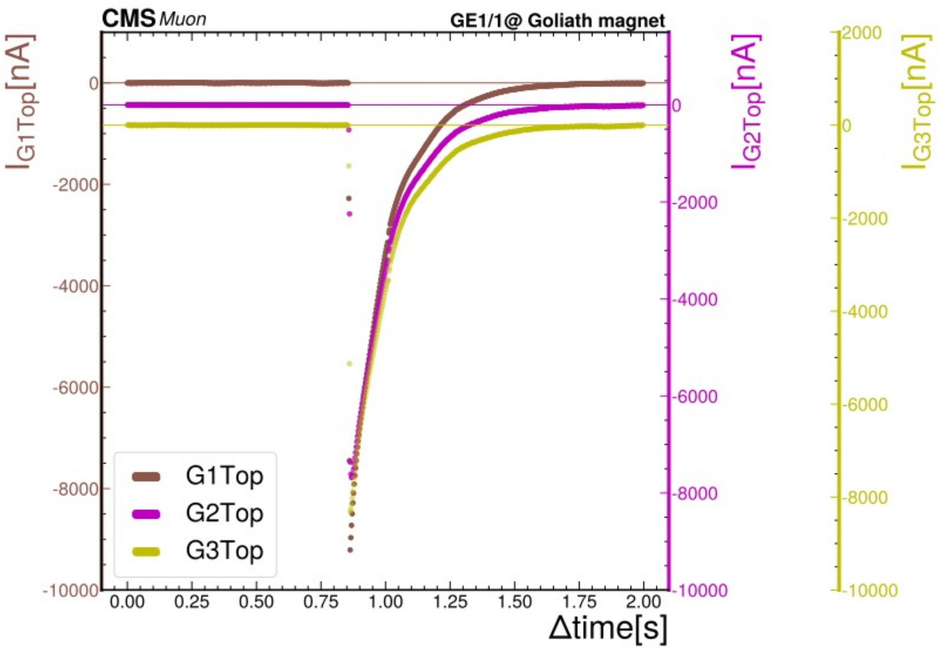
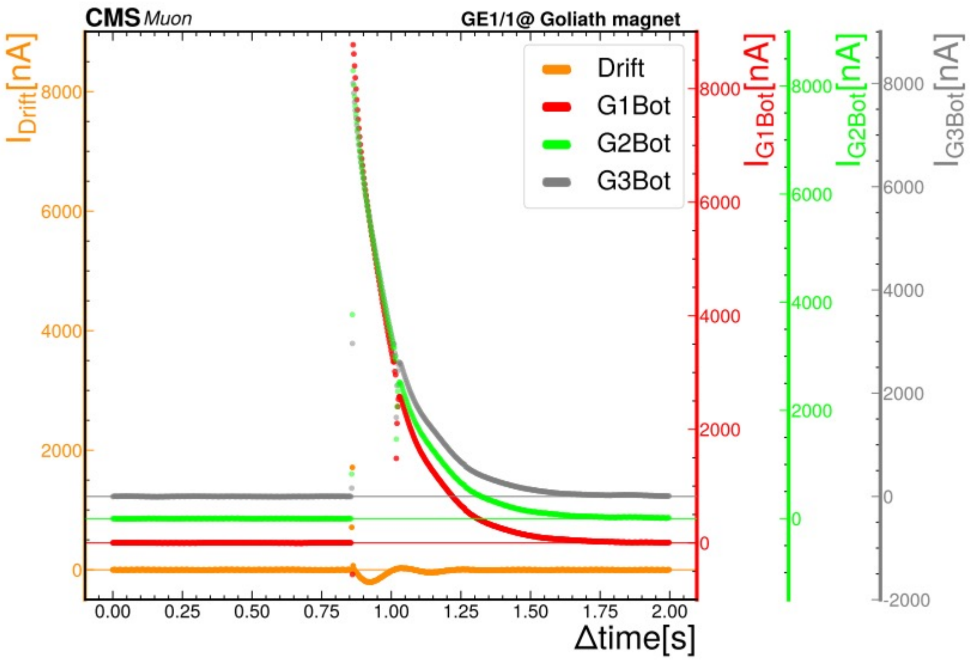
- Goal:
  - install new version this year
  - in depth study of discharges
  - hit-rate/discharge correlation



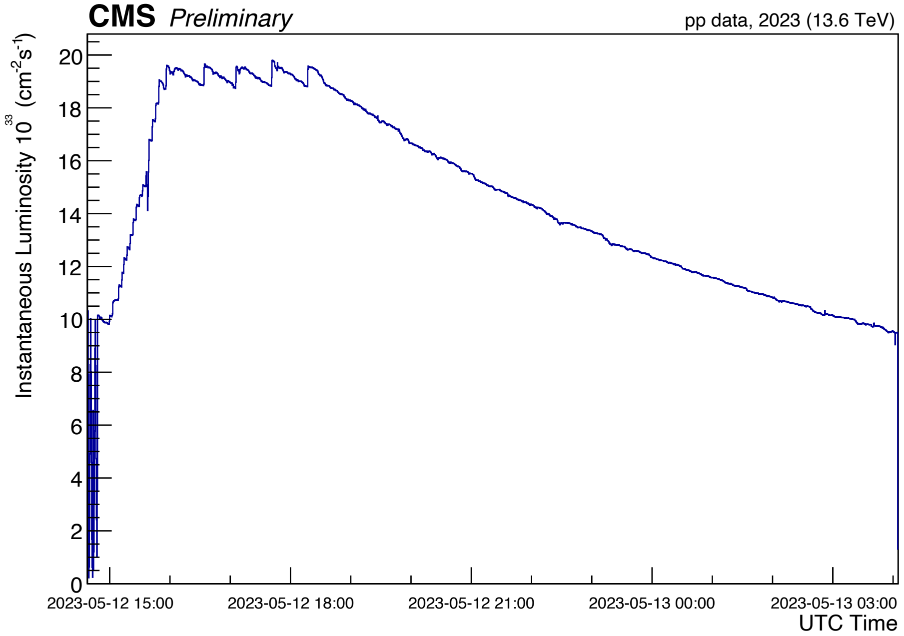


Background study@CMS with Run3 data

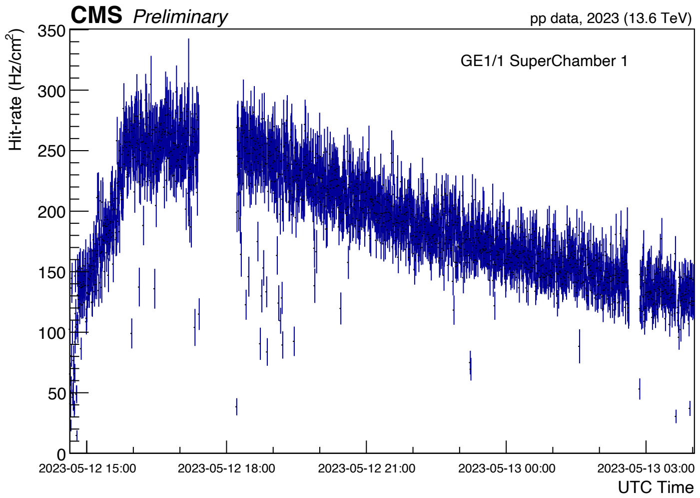
- Optimal muon reconstruction is fundamental → high trigger quality
  - ensured by redundancy
  - threat: **background rate**

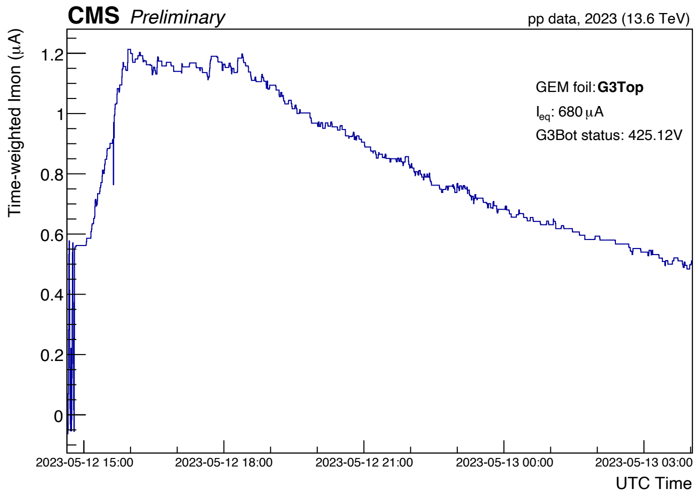
$$Hit\ Rate = \frac{1}{n \cdot \Delta t \cdot A} \sum_{bx=bx_1}^{bx_n} N_{hits}(bx, \Delta t)$$

- Correlation between instantaneous luminosity, hit-rate and monitored currents



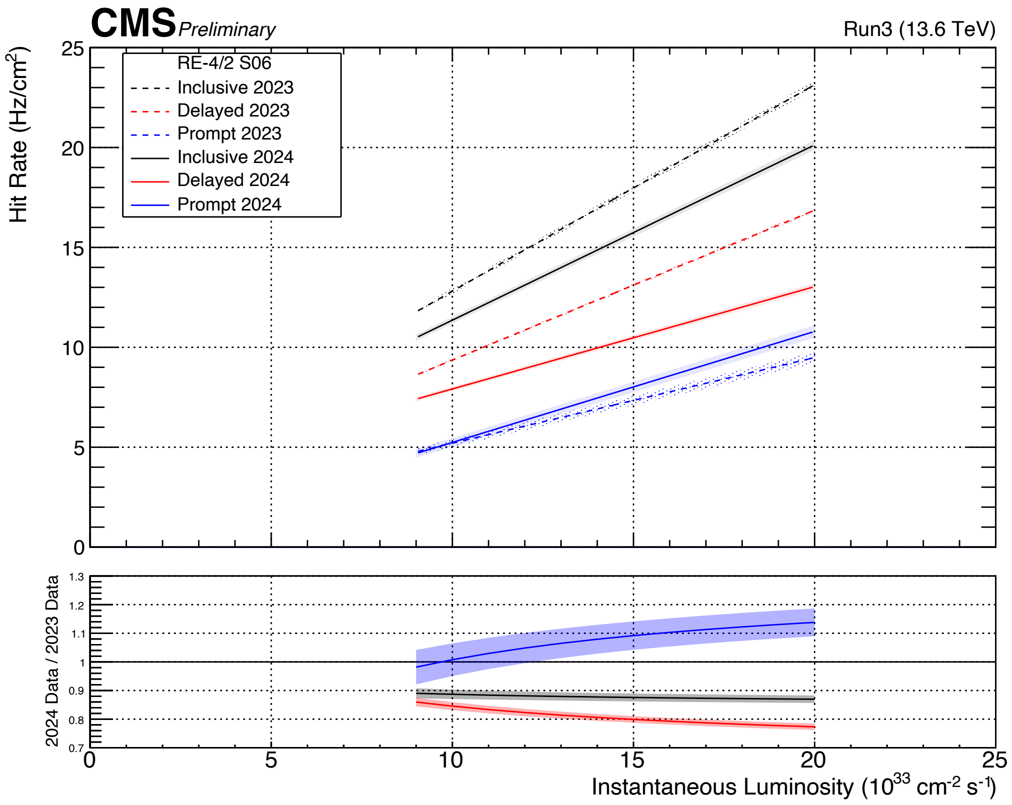
Presented by C. Di Fraia@TWEPP24

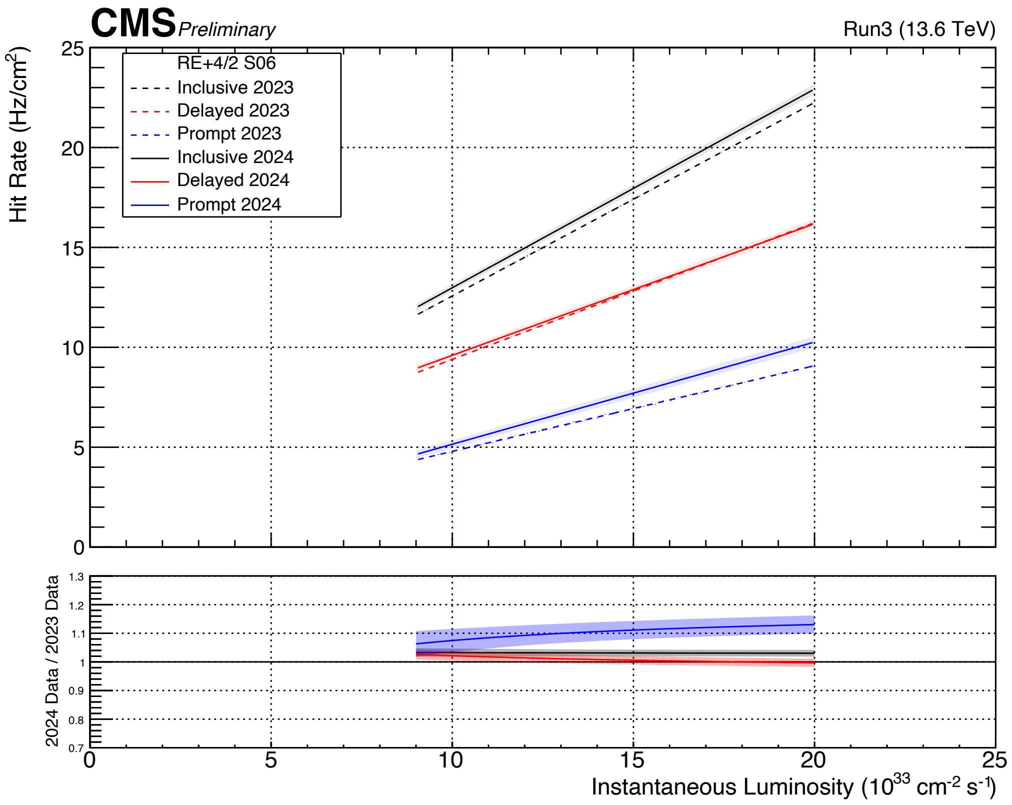




Background in RPC sector@CMS with Run3 data

- The background study is a well established procedure in the RPC sector
  - Possibility to study detector upgrade effects: visible decrease in the **DELAYED** and **INCLUSIVE** backgrounds in the negative endcap due to the New Forward Shielding (NFS)
  - Projection to HL-LHC target luminosity to have a glance of the expected hit-rate → Are our detectors ready?





Presented by L. Favilla@RPC2024

Brief Summary

- Napoli group deeply involved into CMS Muon activities
  - Focus on GEM & RPC @ CMS Muon System since long time
- Gas Electron Multipliers
  - GE1/1 operation
  - GE2/1 and ME0 construction & commissioning
  - High-Voltage Power System design & mantainance
  - Development of custom-made pico-ammeter for discharge study
- Resistive Plate Chambers (RPCs)
  - Background study

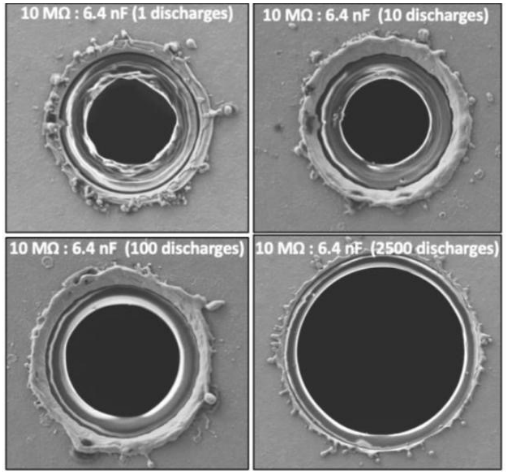


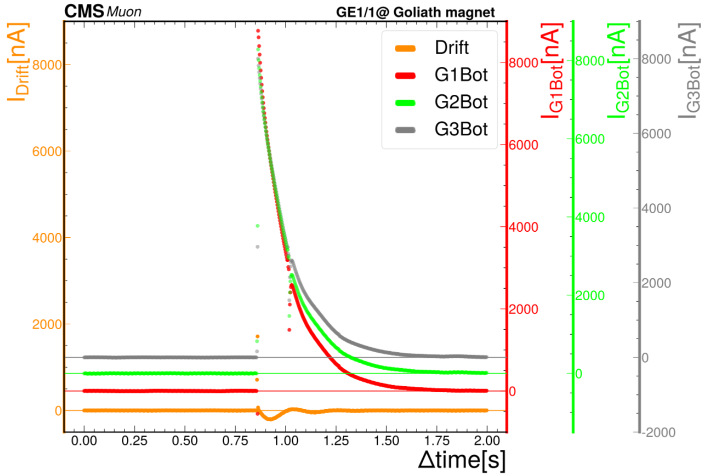



BACKUP

Discharges and Short Circuits

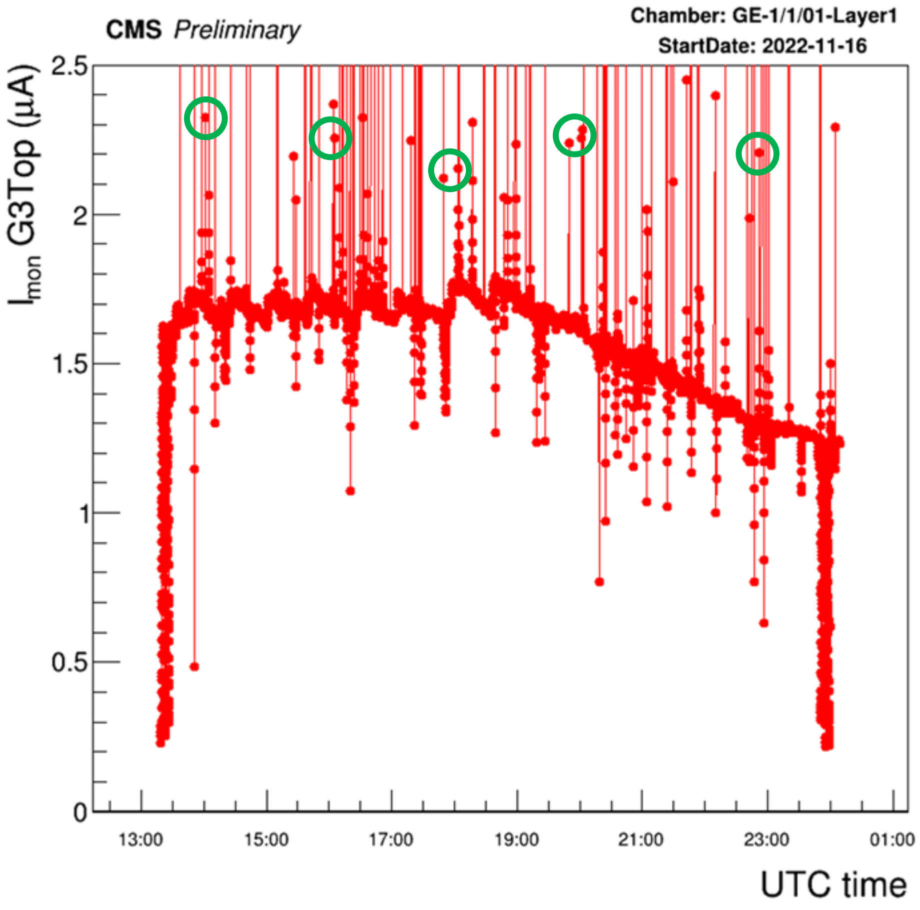
- Why Triple-GEMs?
  - High gain thanks to multiple amplification layers, without approaching the electrical breakdown of a single GEM foil → **Reduced discharge probability**
- A **DISCHARGE**:
  - uncontrolled or excessive release of electric charge within the detector;
  - caused by strong localized electric field (exceeding the ability of the gas to remain stable);
  - *breakdown* occurring at the *Raether limit:* $Q \sim 10^7 \div 10^8 e$.
- They can be triggered by:
  - sharp edges;
  - micro-particles remaining after the production;
  - dirty spots.
- Can lead to:
  - the formation of a **SHORT CIRCUIT**;
  - damage to channels of the front-end electronics.
- How to recognize a discharge:
  - Spike in current above the baseline current.

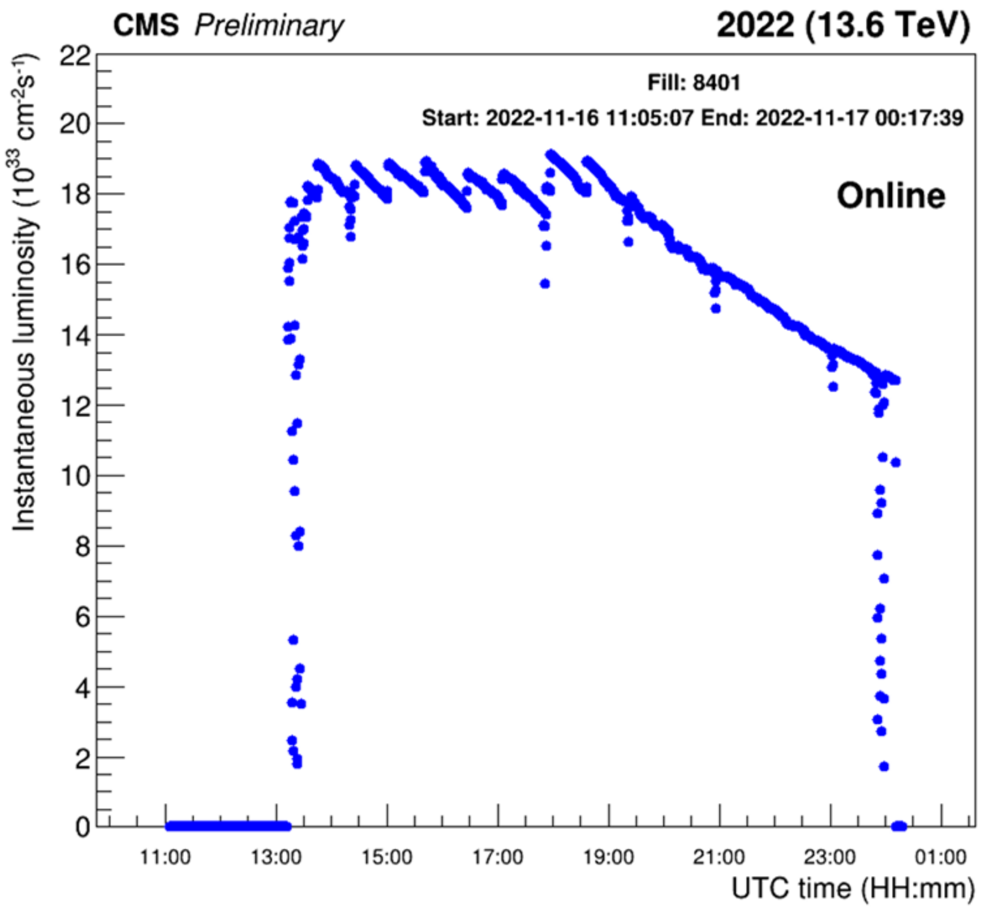




Background and discharges

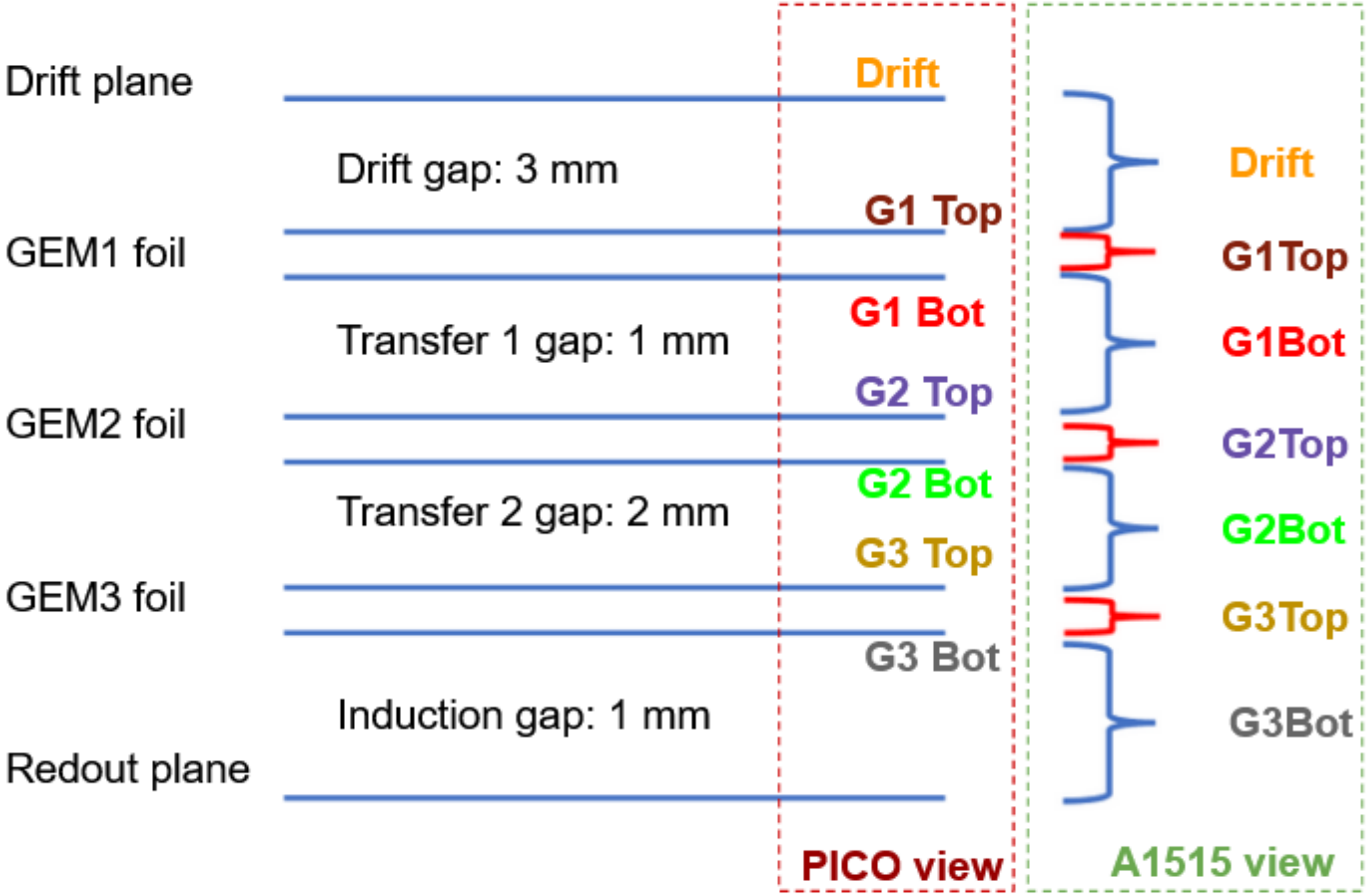
- ❑ Would be interesting to study discharge rate with respect to background hit-rate
  - PICO would be fundamental to have a proper discharge rate calculation





Presented by S. Calzaferri@ICHEP 2024

System Schematic



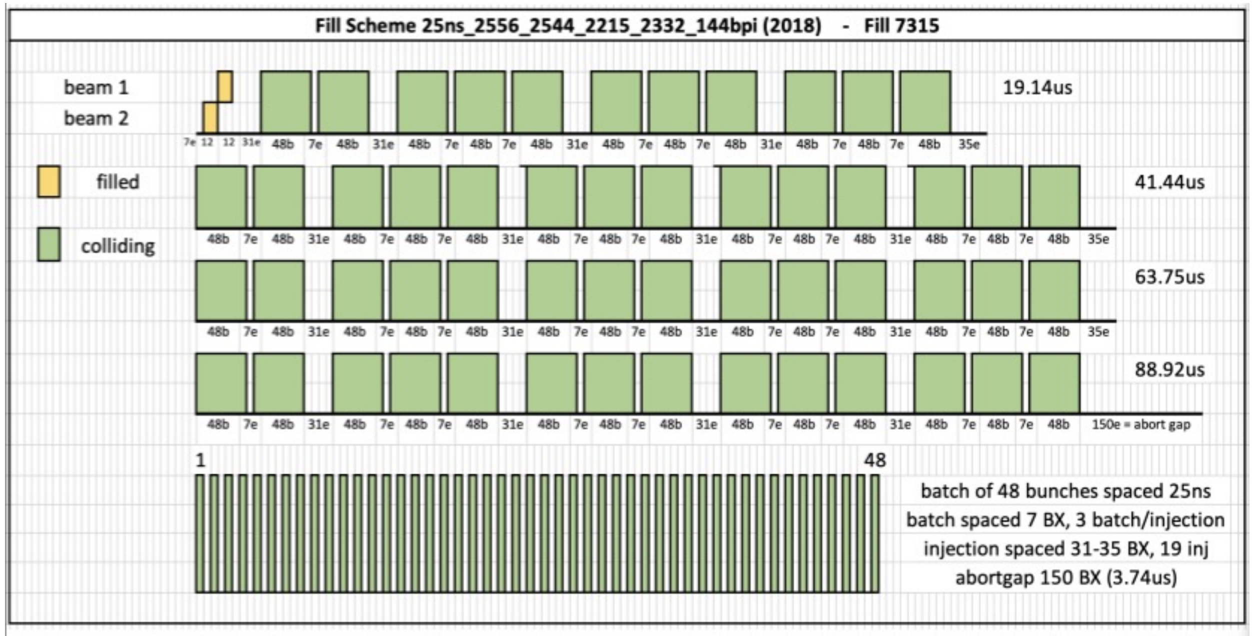
Measuring offline background in RPC

$$Hit\ Rate = \frac{1}{n \cdot \Delta t \cdot A} \sum_{bx=bx_1}^{bx_n} N_{Clusters}(bx, \Delta t)$$

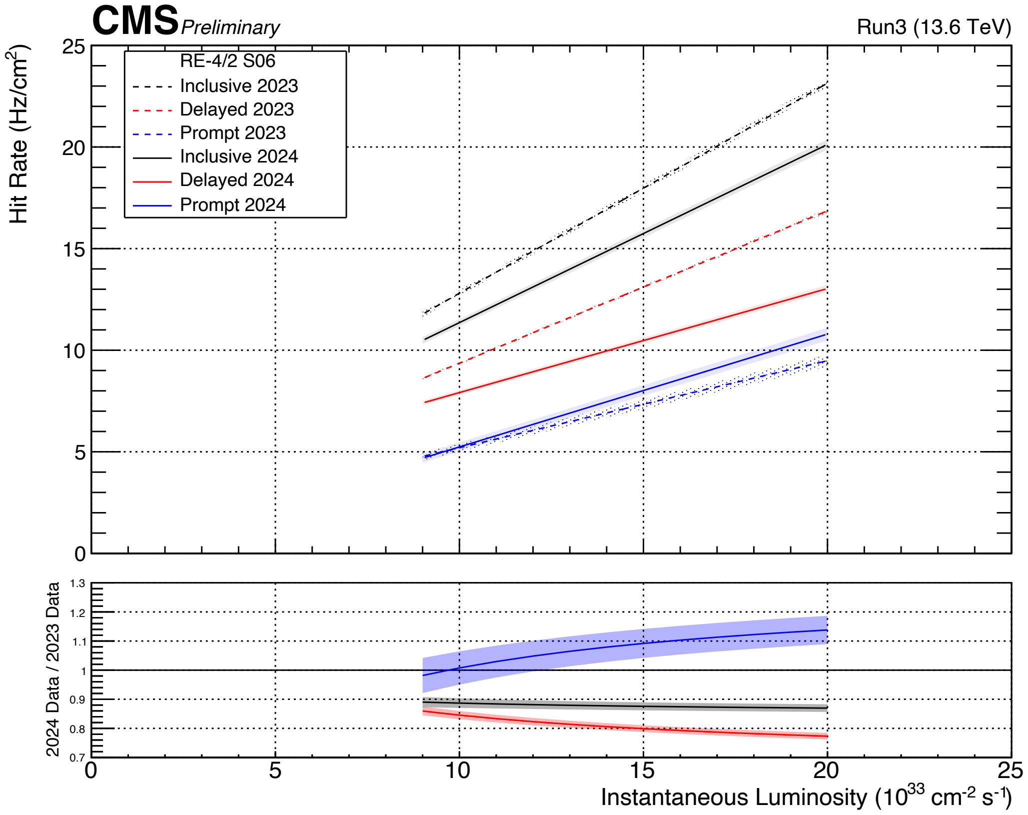
where:

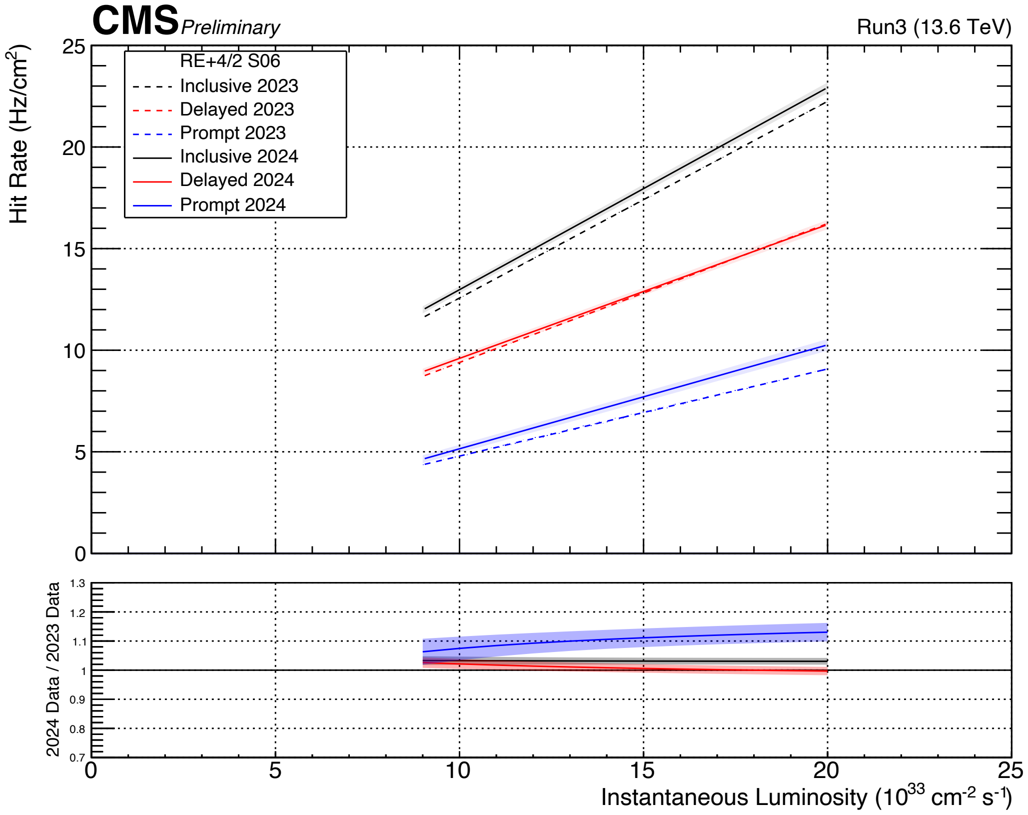
- bx = RPC bunch crossing
- n = total number of RPC bunch crossings in a readout window ($n = 5$, $bx \in [-2,2]$)
- Δt = time window of a single bunch crossing ($\Delta t = 25ns$)
- A = effective area of the RPC subdetector, removing the surface associated to noisy or silent strips
- $N_{Clusters}(bx, \Delta t)$ = number of clusters occurring in the bunch crossings bx in the time window Δt, not involving noisy or silent strips

- 4 fill regions:
  - → Colliding bunches (C)
  - → Non-Colliding bunches (NC)
  - → Pre-Beam bunches (PB)
  - → Beam-Abort bunches (BA)
- 3 kinds of background:
  - → $B_{INCLUSIVE} = \frac{N_{PB}B_{PB}+N_{C}B_{C}+N_{NC}B_{NC}+N_{BA}B_{BA}}{N_{PB}+N_{C}+N_{NC}+N_{BA}}$
  - → $B_{DELAYED} = \frac{N_{PB}B_{PB}+N_{NC}B_{NC}+N_{BA}B_{BA}}{N_{PB}+N_{NC}+N_{BA}}$
  - → $B_{PROMPT} = B_{COLLIDING} - B_{DELAYED}$



Hit Rate vs. Inst. Luminosity per background

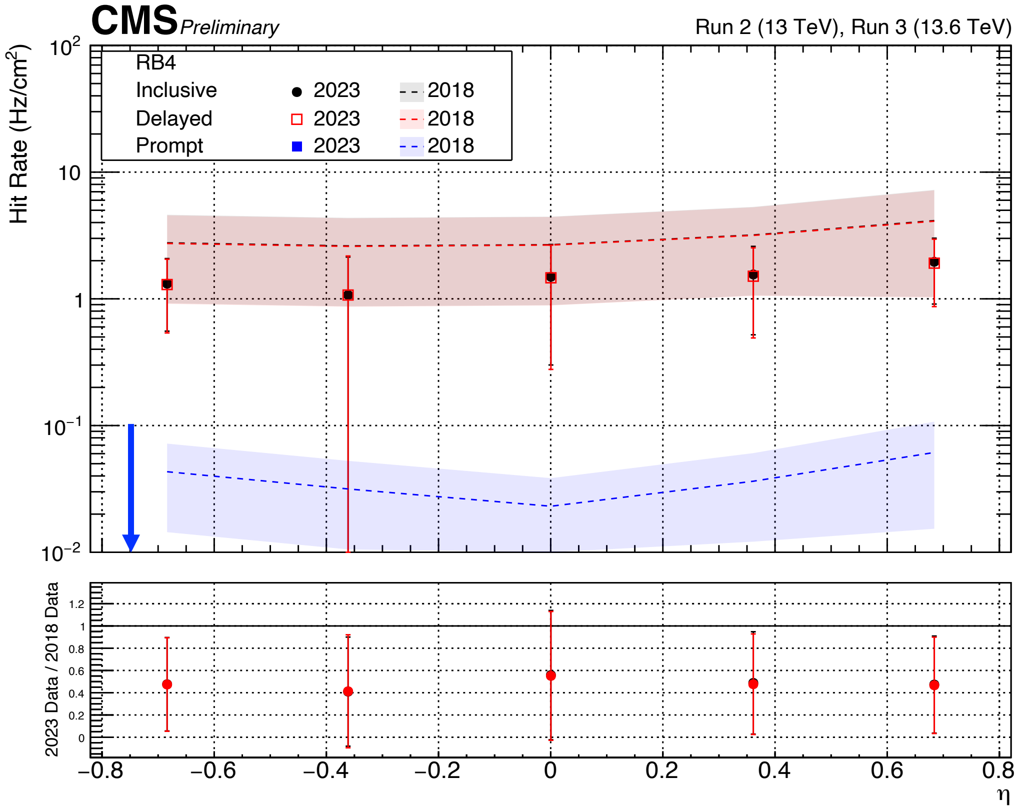


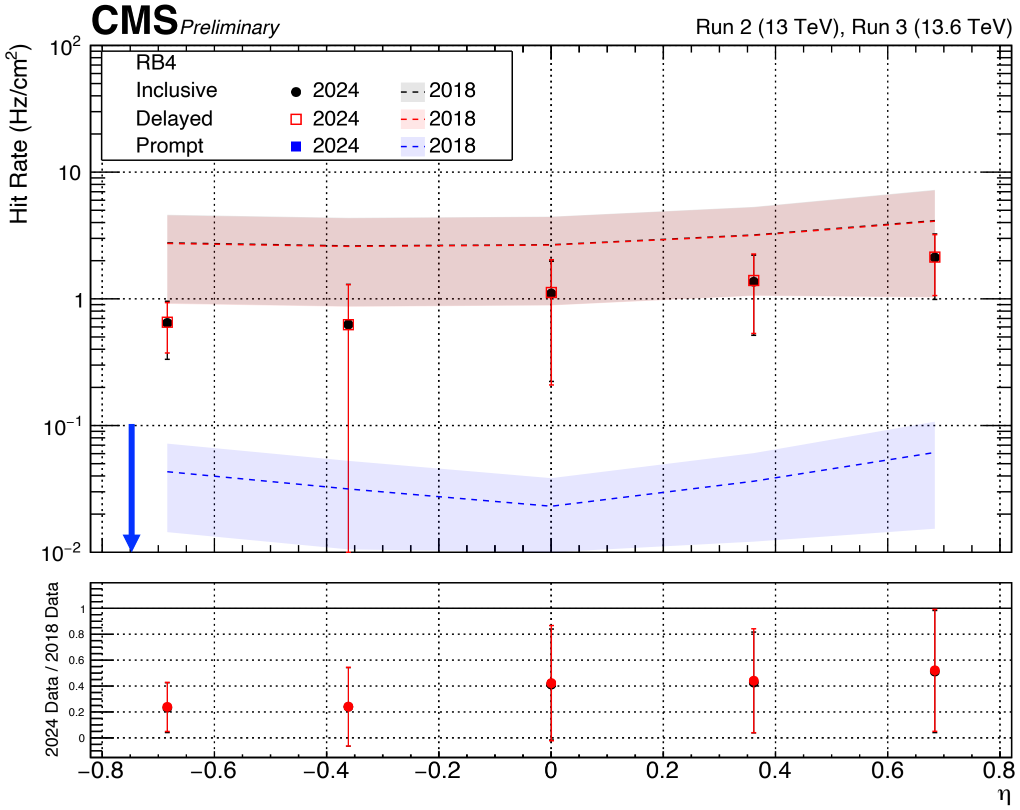


RPC offline hit rate vs. Instantaneous Luminosity per background (RE-4/2 S06,RE+4/2 S06):

- Visible decrease in the **DELAYED** and **INCLUSIVE** backgrounds in the negative endcap due to the NFS
- Increase in the **PROMPT** background: does not depend on the NFS since both endcaps show the same trend
  - → possible arising systematic effect, due to the different filling schemas.

Barrel shielding and New Forward Shielding

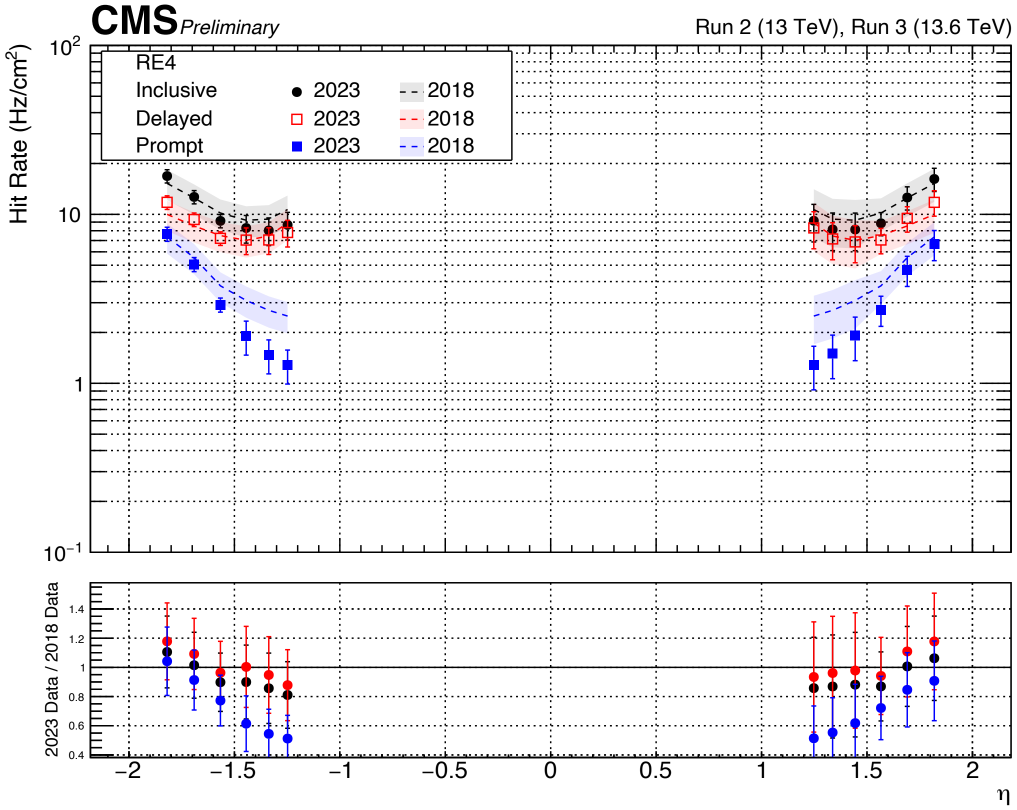


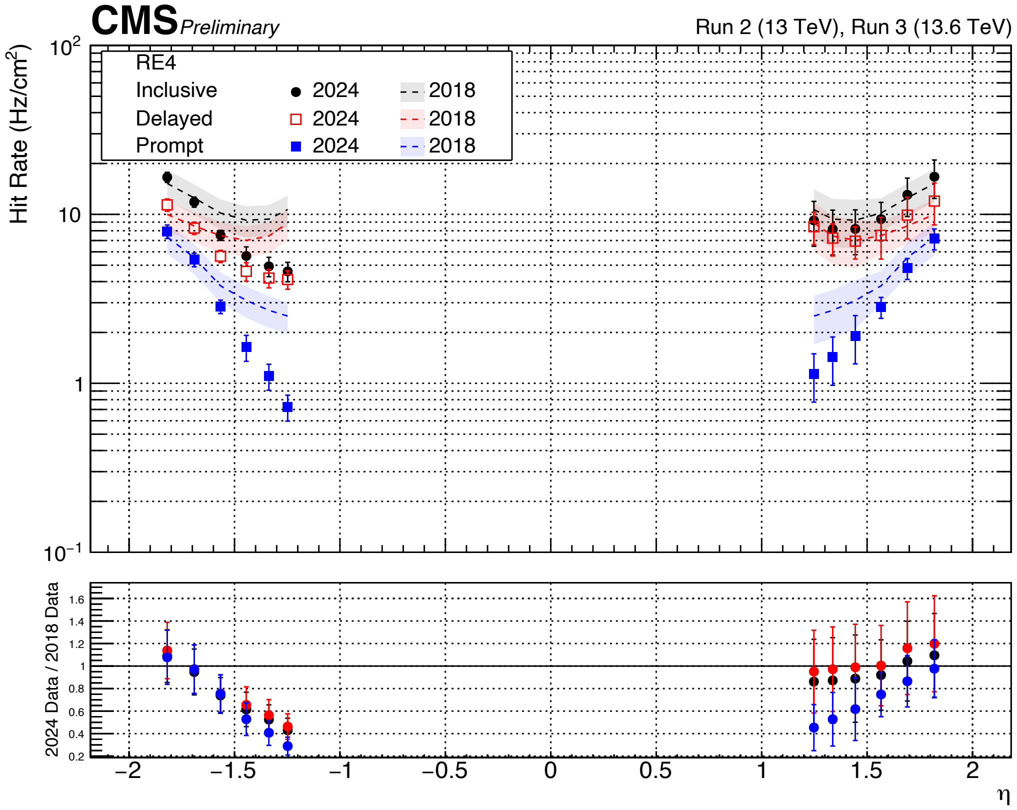


RPC offline hit rate vs. eta (RB4 for 2023 and 2024):

- ❑ On the left plot, barrel shielding combined with the new beam-pipe result in a decrease in the **DELAYED** and **INCLUSIVE** background up to **~ 50%** across all 5 wheels with respect to 2018.
- ❑ On the right plot, also the NFS is affecting the measured hit rate: wheels -2 and -1 experience a reduction in the hit rate up to **~ 80%**, while wheels 0, +1 and +2 have a reduced background of the same percentage as 2023, with respect to 2018 data.

Barrel shielding and New Forward Shielding



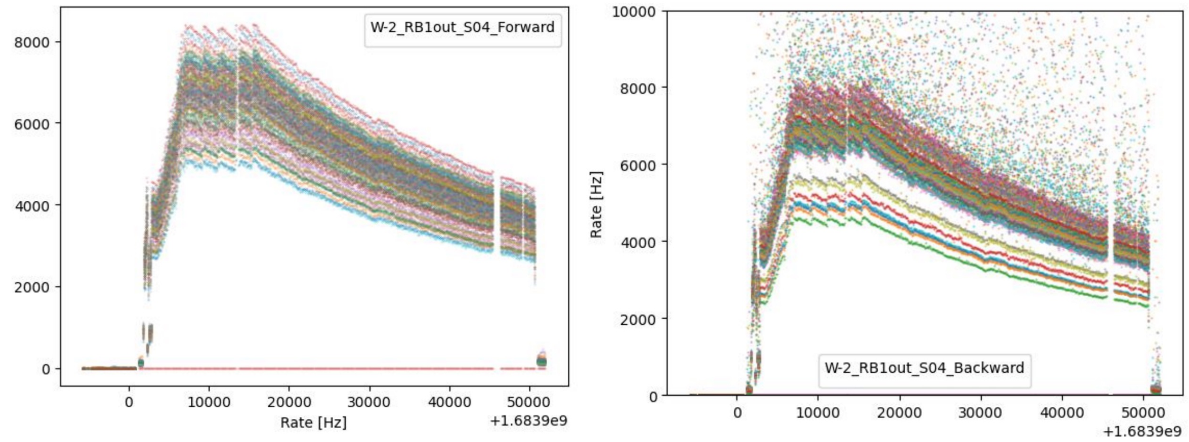


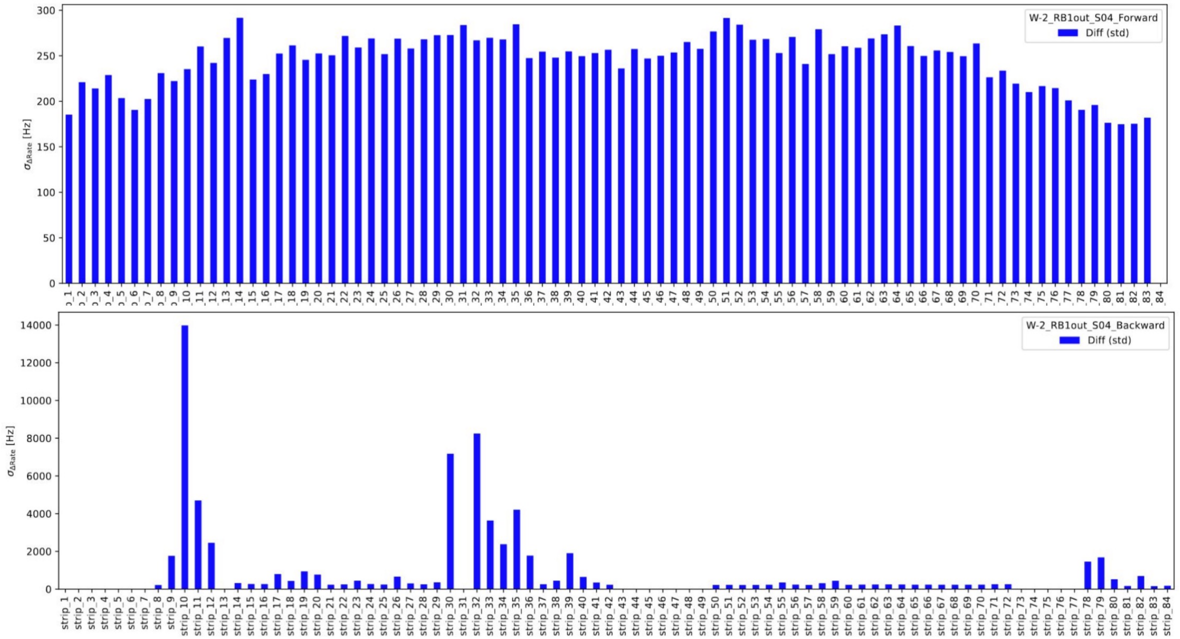
RPC offline hit rate vs. eta (RE4 for 2023 and 2024):

- On the left plot, the barrel shielding combined with the new beam-pipe result in a progressive reduction in the hit rate for all three backgrounds considered when moving outwards from the beam-pipe (i.e. when decreasing $|\eta|$).
  - → Such effect is symmetric between negative and positive endcaps.
- On the right plot, this reduction is not symmetric anymore, because of the presence of the NFS: reduction of the background level up to values **~ 40%** with respect to 2018 data.

What's a noisy strip nowadays?

1. Fix a fill and a chamber
2. We have the rate for all strips in that chamber
3. Calculate the change of rate per time interval for each strip ($\Delta R(t)$)
$$\Delta R(strips_j, t_i) = R(strips_j, t_i) - R(strips_j, t_{i-1})$$
4. Strips with standard deviation of this change of rate ($\sigma_{\Delta R\ (t)}$) greater than 1 kHz is considered to be **NOISY**
5. Will be removed from the hit rate counting





Plots taken from [Horacio's presentation]