Background Rate Measurement of the GE1/1 Detector in the CMS Experiment

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on behalf of the CMS collaboration

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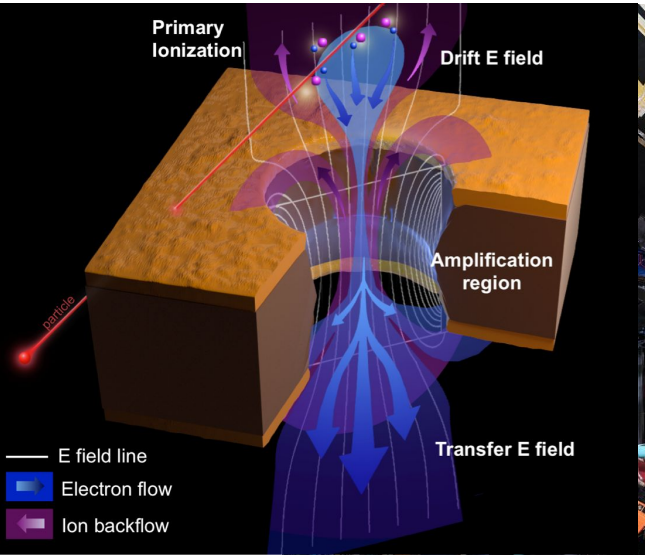
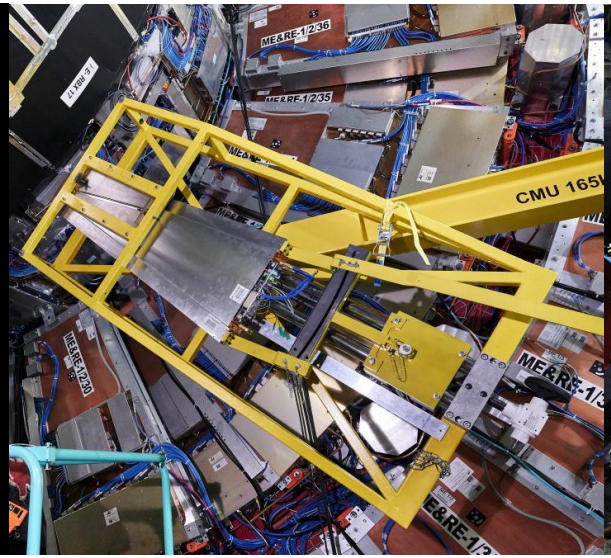
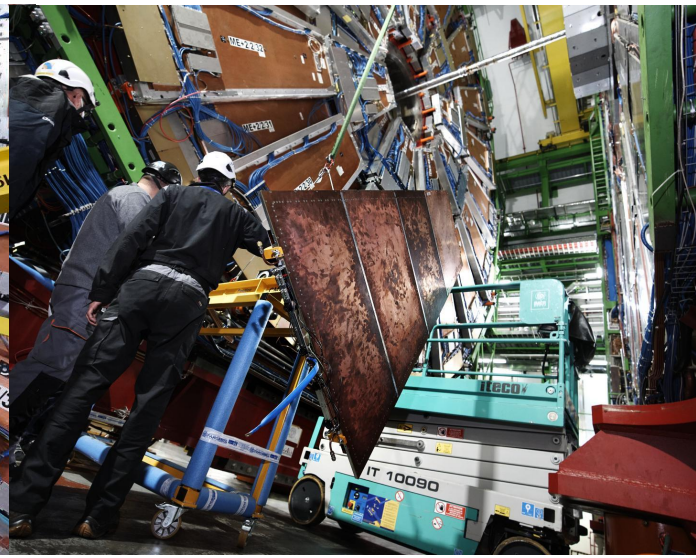
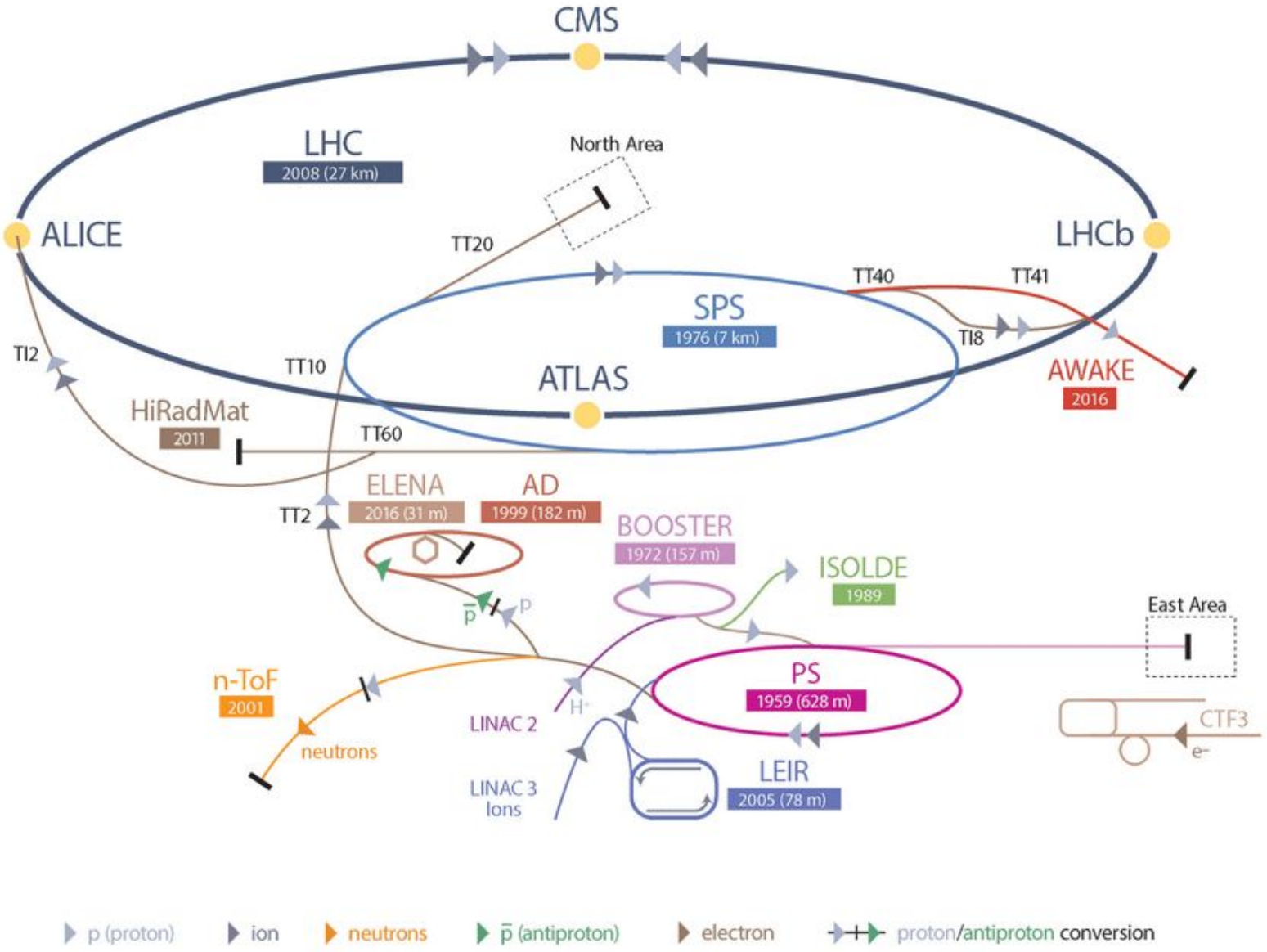


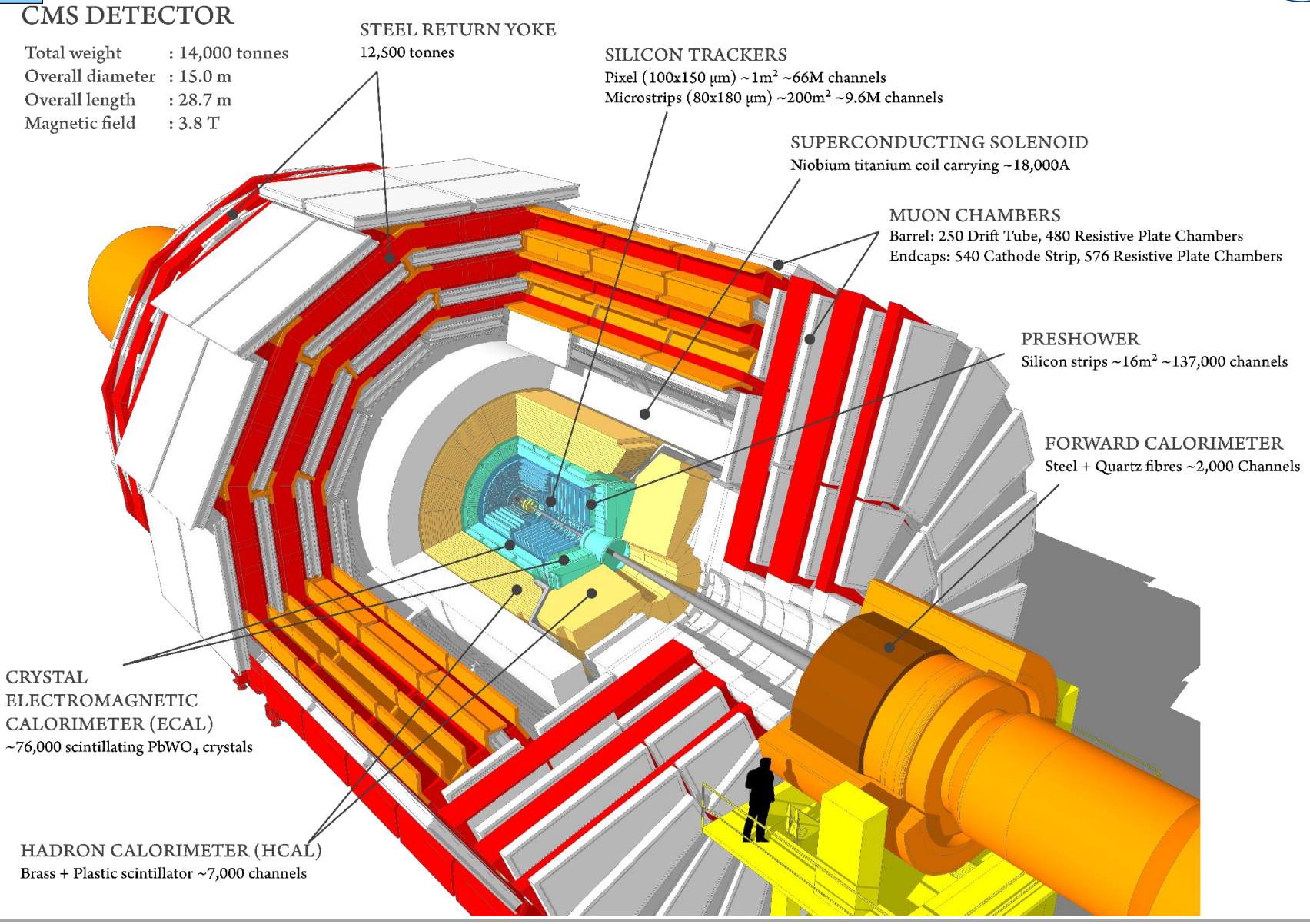




Large Hadron Collider

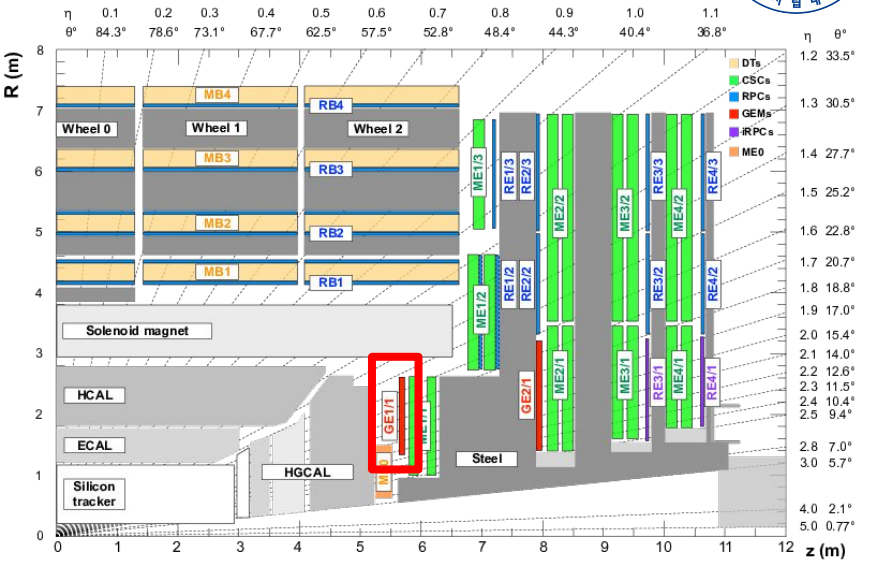


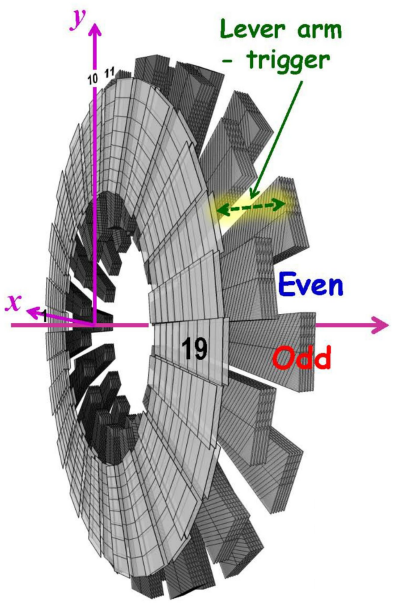
CMS Detector

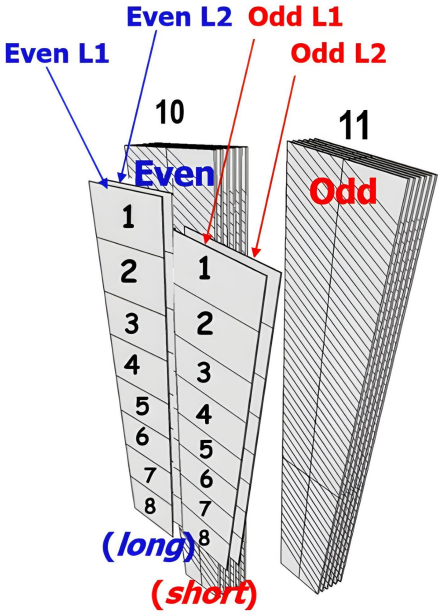


GE1/1 System

- Installed in the **forward region** of the CMS Endcap
  - η Coverage: 1.55 < |η| < 2.18
- Detectors are organized in pairs of modules and two detectors define a Super-Chamber
- Super-Chambers are grouped by **layer**:
  - **Layer 1** (closer to the interaction point)
  - **Layer 2** (farther from the interaction point)
- The GE1/1 station consists of 36 super-chambers
  - **Short** chambers (odd number)
  - **Long** chambers (even number)
- Each chamber is divided in **8 η-partitions**
  - iη = 8 (closer to the beamline)
  - iη = 1 (farther from the beamline)



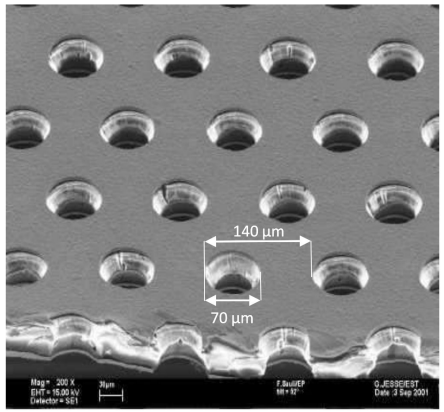


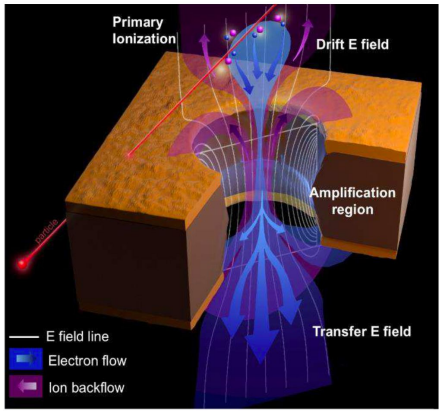


Gas Electron Multiplier (GEM)

GEM Foil

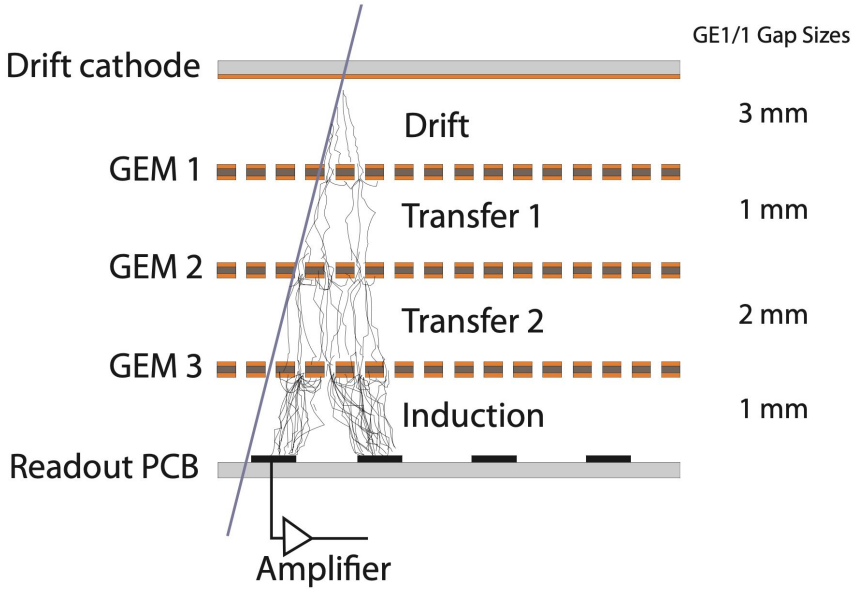
- Micro-Pattern Gaseous Detector
- Thin polyimide sheet with dense microscopic holes
- Coated with copper on both sides





Triple-GEM detector

- Three GEM foils placed between Drift Board and readout PCB
- Gas Mixture: Ar/CO_2 (70/30)
- Ionization electrons are amplified in high electric fields across the GEM foils
- Triple-GEM configuration used in CMS muon system
  - **GE1/1: Fully Installed**
  - GE2/1: Partially installed
  - ME0: Will be installed during the LS3



Background Rate Measurement

Why background rate measurement in muon system?

- Background particles can make the efficient detection of muons more difficult
- As the HL-LHC reaches higher levels of instantaneous luminosity, the background rate is expected to increase

  ⇒ Essential to understand the rate behavior with respect to instantaneous luminosity

Dataset information

- *pp* collision data at $\sqrt{s}$ = *13.6 TeV* (816 pb^{-1} recorded on the 15th October 2024)
- **ZeroBias** dataset (no physics object requirements, zero-bias random trigger)
- We normalize the hits and events to correct for the bunch crossing Id bias of the ZeroBias trigger menu

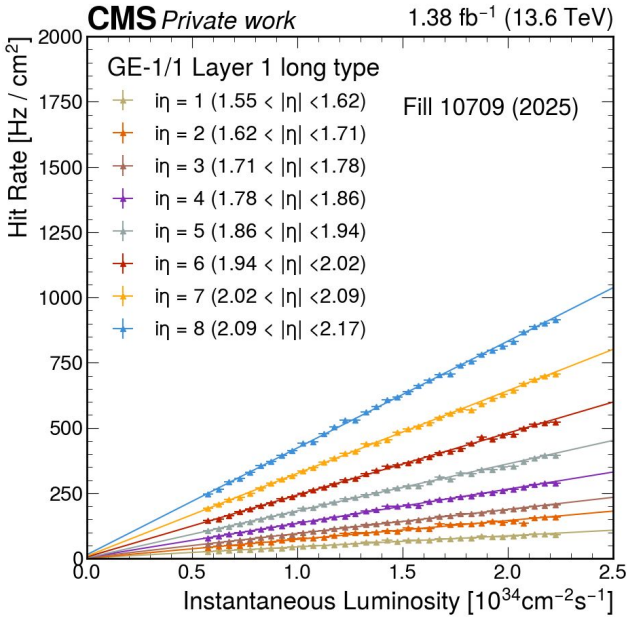
Rate definition

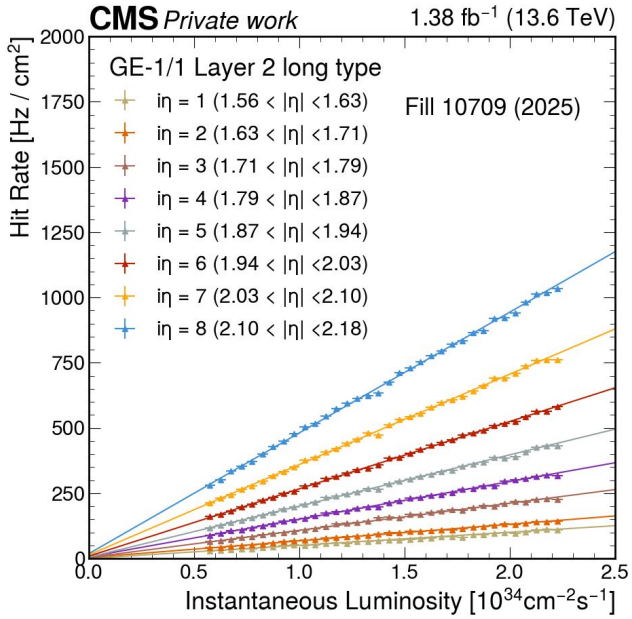
$$\mathrm{Rate} = \frac{\sum_{i}^{n} N_i^{\mathrm{hits}}}{n \cdot \Delta t \cdot A}$$

- N_i^{hits}: Number of hits registered by a GEM chamber or eta partition in event i
- n: Number of events
- Δt: GE1/1 event time widow (25ns x 8 BXs)
  - When an event is saved, GE1/1 readout includes surrounding bunch crossings (total 8 BXs)
  - During commissioning, the delay was tuned by comparing the GEM signal with muon trigger information to maximize the hit detection efficiency (CMS DP-2024/125)
- A: Effective area of detector

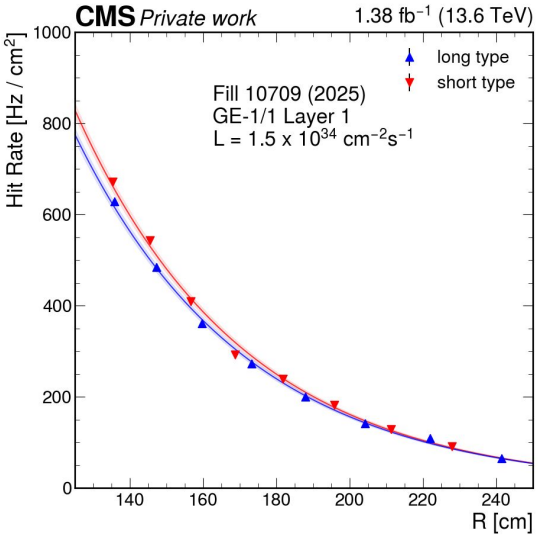
Rate vs Instantaneous Luminosity

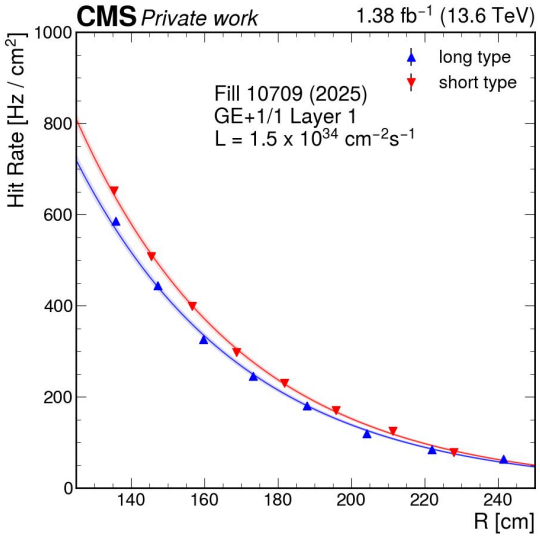
- Hit rate for GE1/1 negative endcap Layer 1 (long-type and short-type)
- η-partitions with efficiency > 95% were used for the rate measurement
- Each data point represents the average hit rate per unit area in a given η-partition, for both long-type (left) and short-type (right) chambers
- Linear fits were performed for each η-partition with the y-intercept constrained to be positive

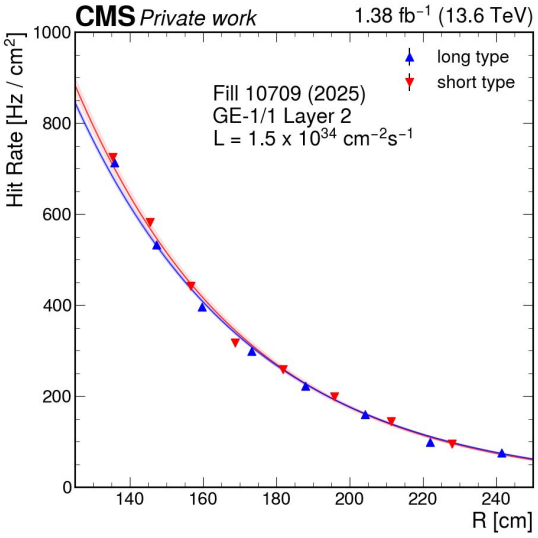


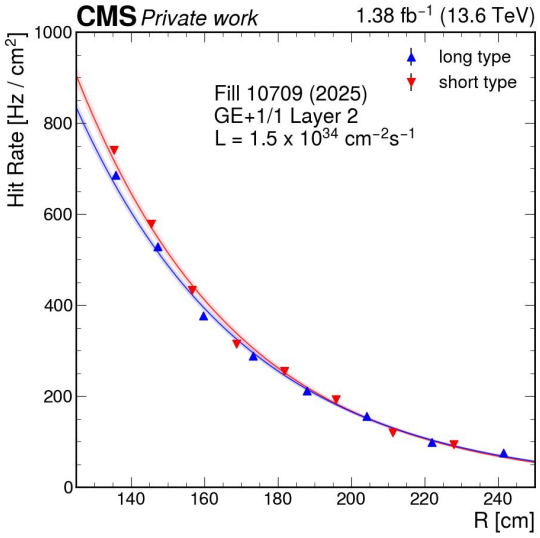


Rate vs Distance from Beamline



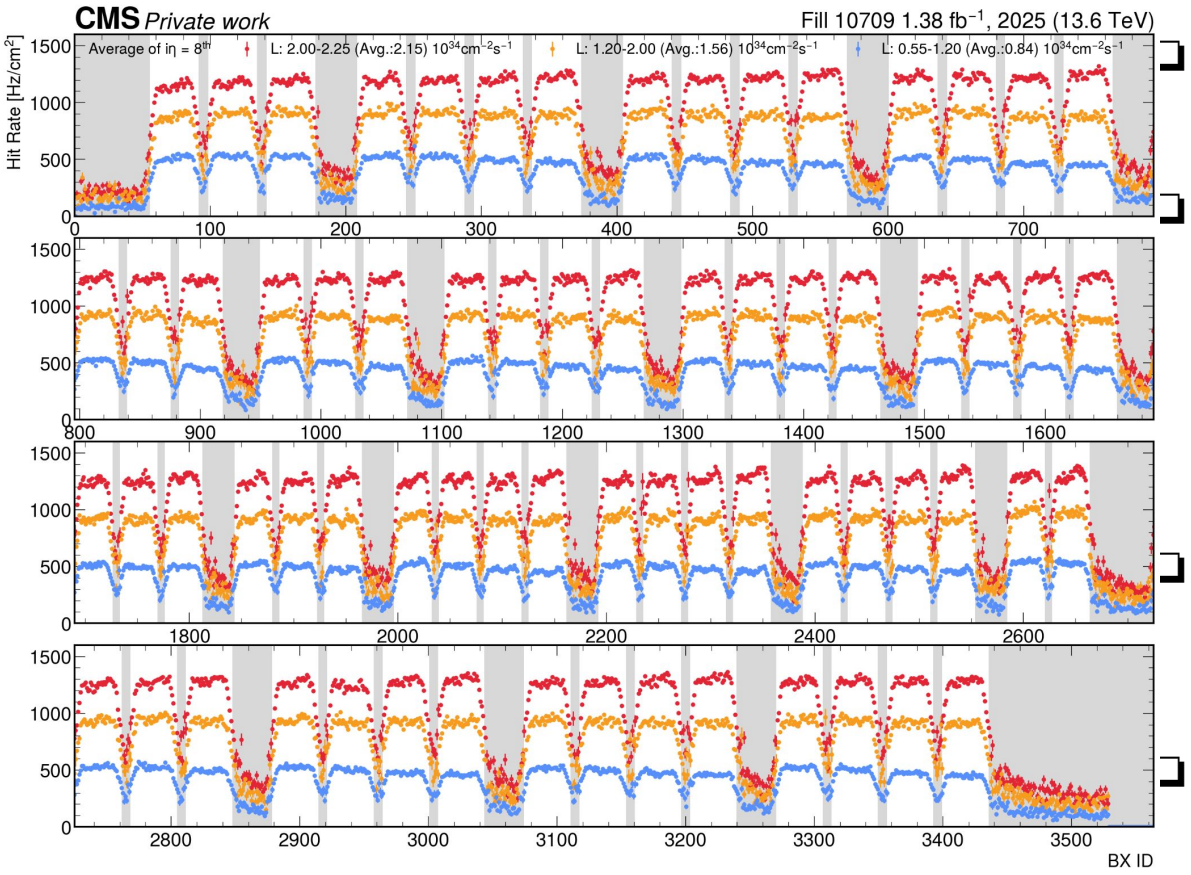






- Hit rate as a function of R (distance from the centre of each η-partition to beamline axis) at an instantaneous luminosity of 1.5×10^{34} $cm^{-2}s^{-1}$
- The hit rates are interpolated from the linear fits in the hit rate as a function of instantaneous luminosity
- An exponential fit is applied to model the radial dependence of the hit rate for each chamber type
- Shaded bands represent the fit uncertainties

Rate vs Bunch Crossing ID



Average hit rate of η = 8 partitions as a function of bunch crossing ID (BX ID)

Rates are shown for two ranges of instantaneous luminosity

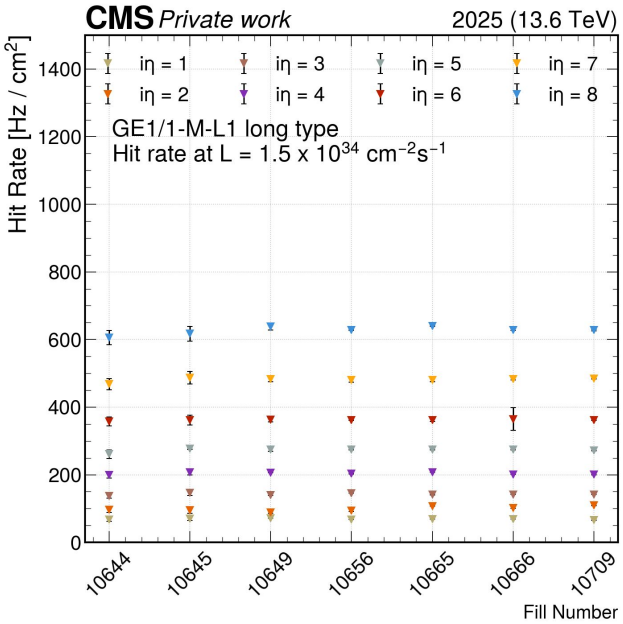
- $1.40 – 1.80 \times 10^{34}$ cm^{-2}s^{-1} (average: 1.57×10^{34} cm^{-2}s^{-1})
- $1.80 – 2.15 \times 10^{34}$ cm^{-2}s^{-1} (average: 2.03×10^{34} cm^{-2}s^{-1})

The hit rate is evaluated per BX ID and shows the expected periodic structure from the LHC bunch filling scheme

Shaded regions with dashed lines indicate non-colliding bunches, where no bunches interacted at the interaction point

* BX ID: ID assigned to each 25 ns time of the LHC Fill (up to 3564 bunch slots)

Rate Stability across Fills



- Rates of GE1/1 negative endcap Layer 1 long type using 2025 Fills that have varying number of colliding bunches
- Despite varying number of colliding bunches, the luminosity-normalized background rate remains stable across different fills

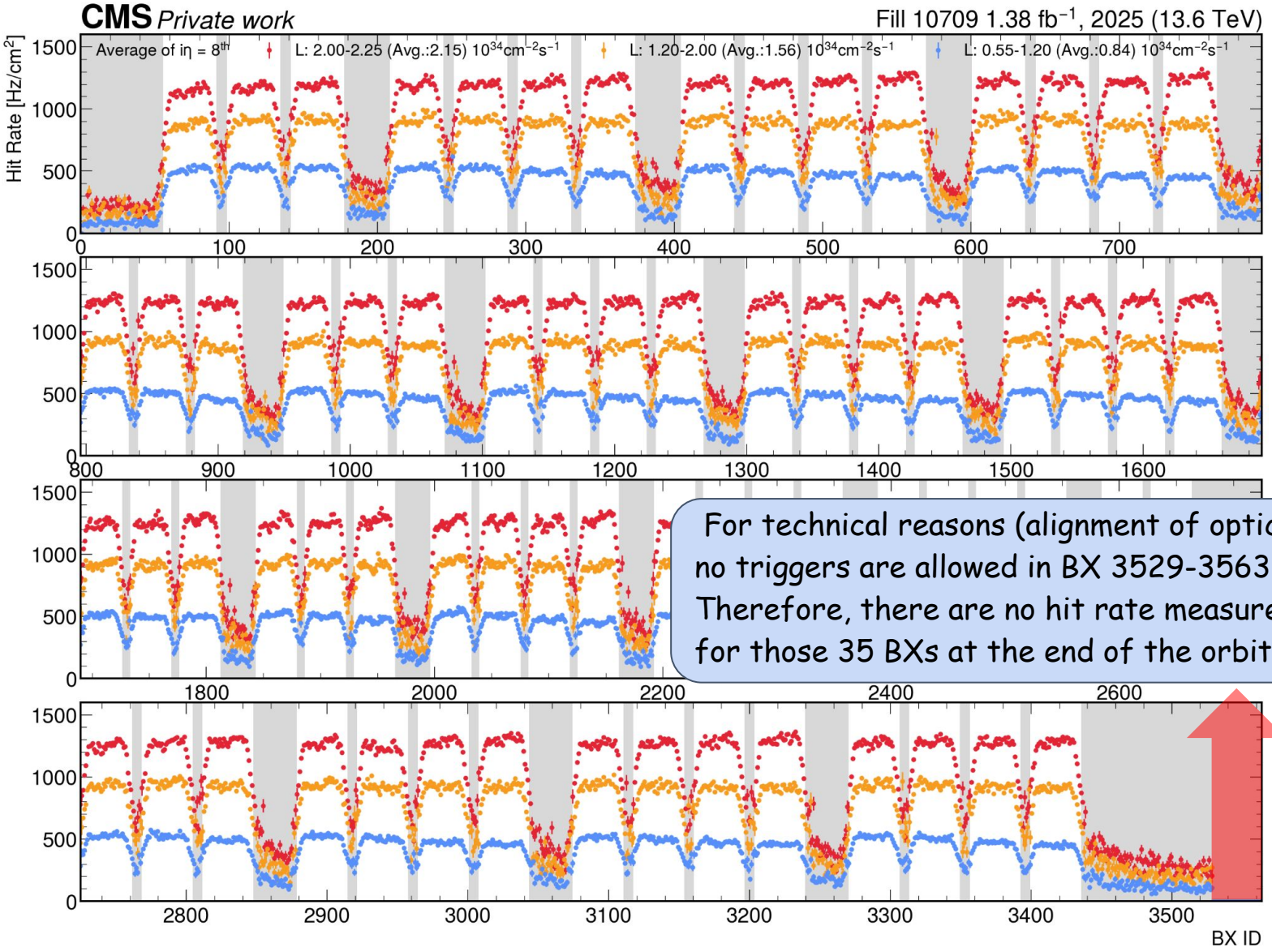
Summary

- GE1/1 background rates at $\sqrt{s}$ = 13.6 TeV (1.38 fb^{-1}, May 2025) were measured to understand performance impact under increased HL-LHC luminosity

- Measurements show consistent trends
  - Rate vs Instantaneous Luminosity: **Linear increase** along instantaneous luminosity
  - Rate vs Radius: **Exponential decrease** as a function of distance from beamline
  - Rate vs BX ID: Periodic pattern **matches with LHC bunch structure**
  - Rate stability over fills: **Stable rate across different fill configurations** in 2025

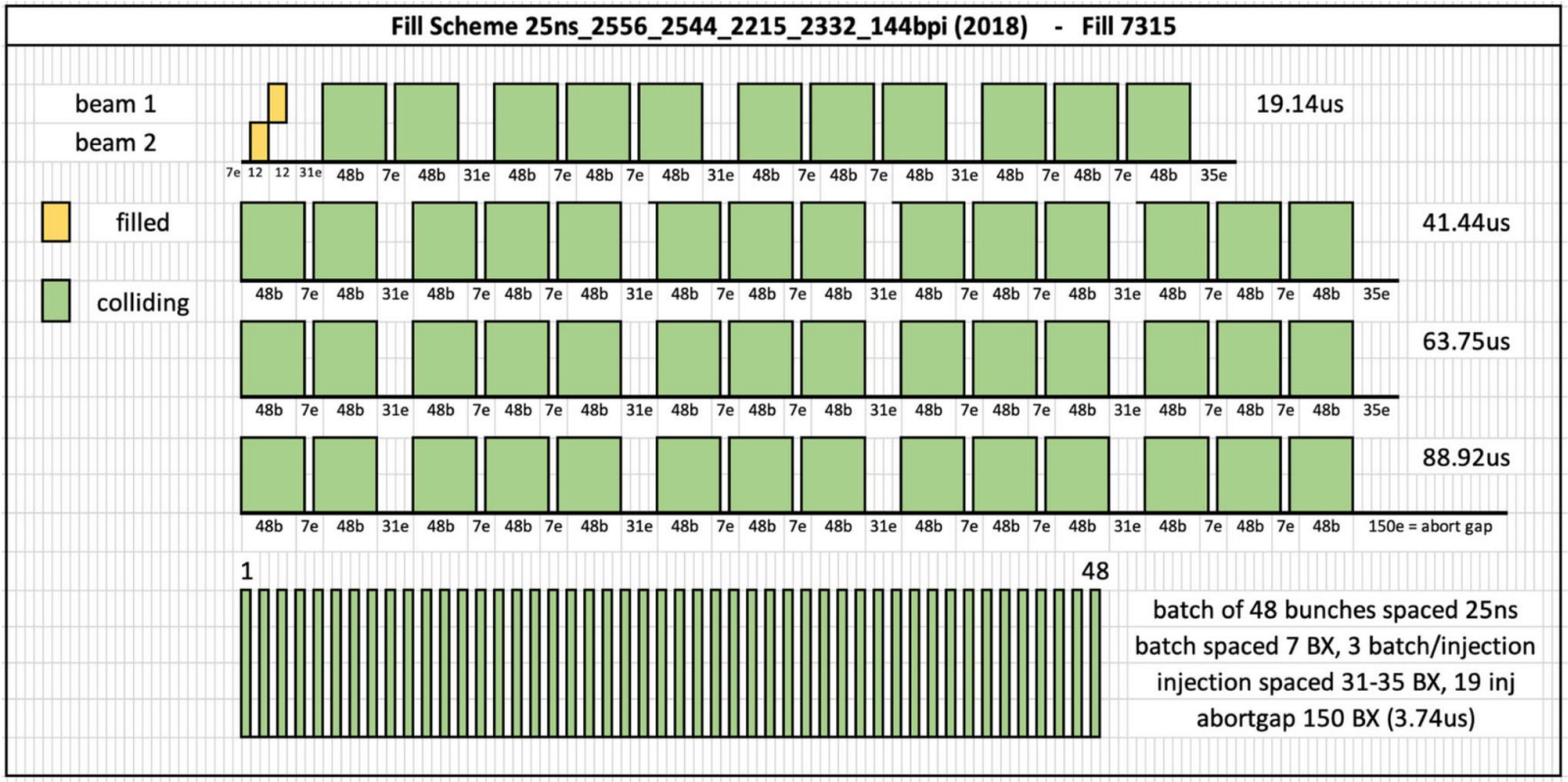
backup

Rate vs Bunch Crossing



For technical reasons (alignment of optical links) no triggers are allowed in BX 3529-3563. Therefore, there are no hit rate measurement for those 35 BXs at the end of the orbit.

Fill Scheme



Ref: [Eur. Phys. J. C (2024) 84:955]

Analysis Procedure

GE1/1 Background Rate Analysis Procedure

- Extract GE1/1 and event information from muon background ntuple (processed from zero-bias random trigger dataset)

- Apply data cleaning
  - Chambers with **> 30% unfired strips** in any run are excluded
  - Flower events are filtered (CMS DP-2024/051)
  - **Inactive VFAT3** readout chips are excluded using the signal from the frontend firmware
  - **Hot strips** (fired in > 0.1% of events in a run) are removed in that run
  - **Muon certification mask** is applied to select good LSs, where muon subdetectors are operating as expected
  - Chambers or η-partitions with > 95% global muon efficiency in the Offline Data Quality Monitoring (DQM) are used in the following results
    - This efficiency is obtained with global muons that pass the tight identification criteria and have $p_T > 20$ GeV

- **Hot strips** and **inactive VFAT3s** are not included in the detector area calculation

Background Rate Measurement

Rate definition

$$\text{Rate} = \frac{\sum_{i}^{n} N_i^{\text{hits}}}{n \cdot \Delta t \cdot A}$$

- n: Number of events in a given context
  - For rate at certain instantaneous luminosity,
    n refers to the number of events within a specific **luminosity bin**
  - For time-based background rate,
    n is the number of events in each **Luminosity Section (LS)**; the reference data collection period used by CMS corresponding to ~ 23 seconds
  - For rate at specific bunch crossing ID,
    n corresponds to events in a specific **bunch crossing ID (BX ID)**
- N_i^{hits}: Number of hits registered by a GEM chamber or eta partition in event i
- Δt: GE1/1 event time widow (25ns x 8 BXs)
  - When an event is saved, GE1/1 readout includes surrounding bunch crossings (total 8 BXs)
- A: Effective area of detector