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The Compact Muon Solenoid Experiment

CMS Performance Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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40MHz Scouting Muon Studies

CMS Collaboration

Abstract

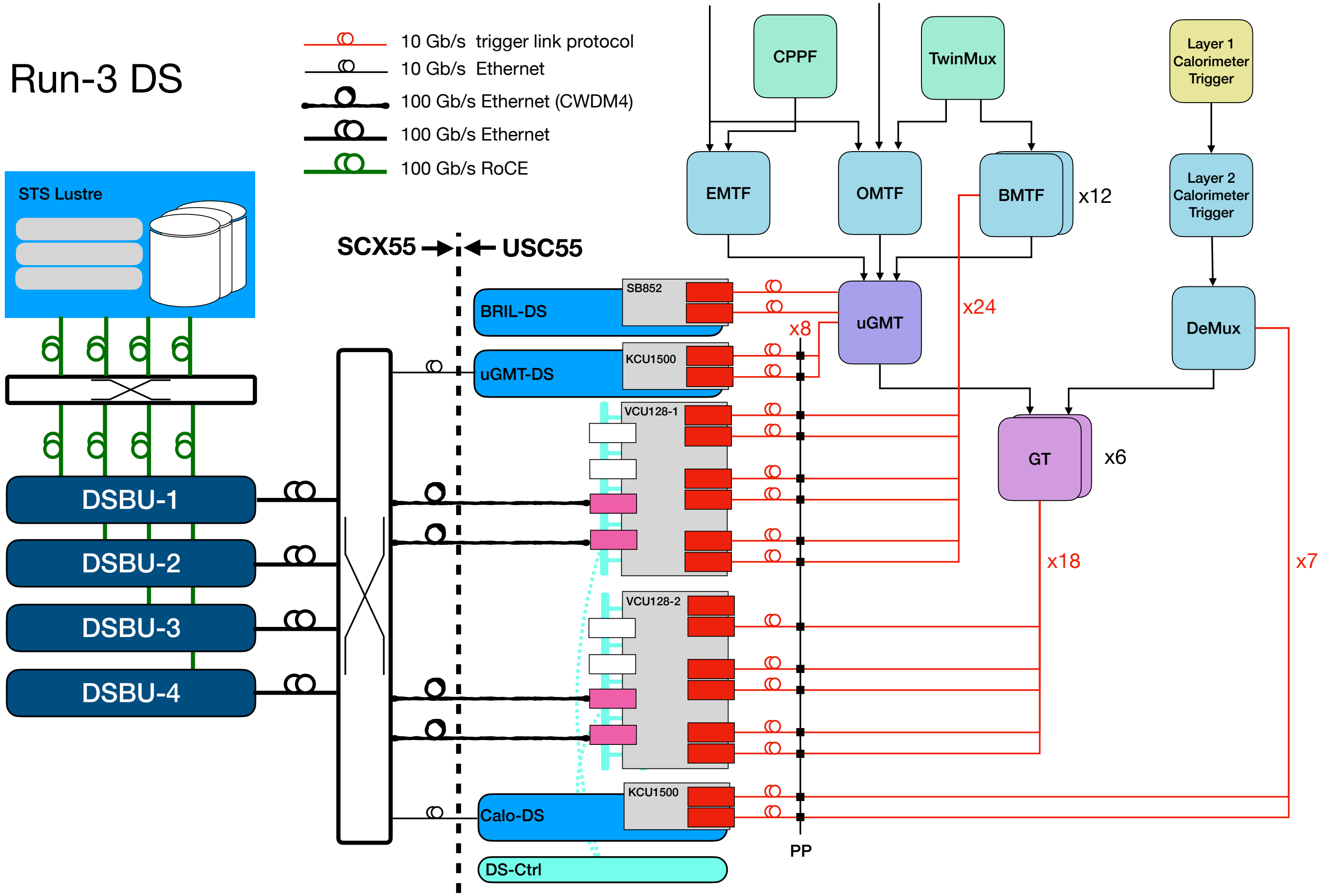
The 40MHz Scouting system is a novel data acquisition system, parallel to the Level-1 trigger, that collects the Level-1 trigger primitives at the full bunch crossing rate.

It was first demonstrated in 2018 at the end of Run 2 and the system has been updated for Run 3. The Run 3 demonstrator captures data from multiple sources: the outputs of the Global Muon Trigger (GMT), data from Calorimeter Layer 2 and the Global Trigger (GT) and the inputs of the Barrel Muon Track Finder (BMTF).

40MHz Scouting muon studies

cms-dpg-conveners-l1t@cern.ch

The Level-1 Scouting system



Run 3 demonstrator system of the Level-1 Scouting

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40MHz GMT Scouting muons study

The study characterizes the muons of Global Muon Trigger (GMT) read by the 40MHz Scouting system. The ability of the 40MHz Scouting systems to record the trigger objects for all bunch crossings makes it possible to perform a study of the GMT muons over multiple bunch crossings.

From the GMT, the Level-1 Scouting system captures up to 8 muons per bunch crossing; only a zero suppression of the empty bunch crossings (bunch crossings with no muons recorded) is applied, with no further filters or selection. For each muon, the following parameters are available: orbit number, bunch crossing number, azimuthal angle ϕ, pseudorapidity η, transverse momentum p_T, charge q, quality, impact parameter d_{xy}.

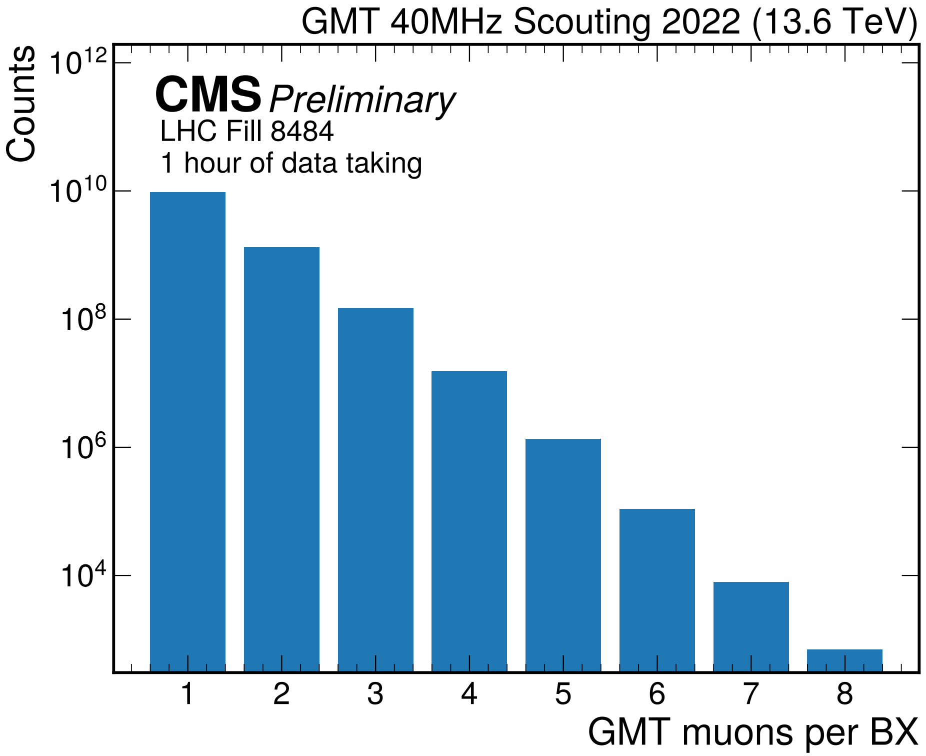
The data taken into account were acquired with the Run 3 40MHz Scouting demonstrator in 2022. The data shown correspond to 1 hour of data taking of the LHC fill 8484, on 25th November 2022. Its filling scheme[1,2] is :

"25ns_2462b_2450_1737_1735_180bpi_17inj_2INDIV"
{spacing}_{bunches}_{IP1/5}_{IP2}_{IP8}_{trainlength}_{injections}_{special info}

For the analyzed data, the pileup (PU) is 52, while the instantaneous luminosity is $1.8 \cdot 10^{34}$ cm^2 s^{-1} .

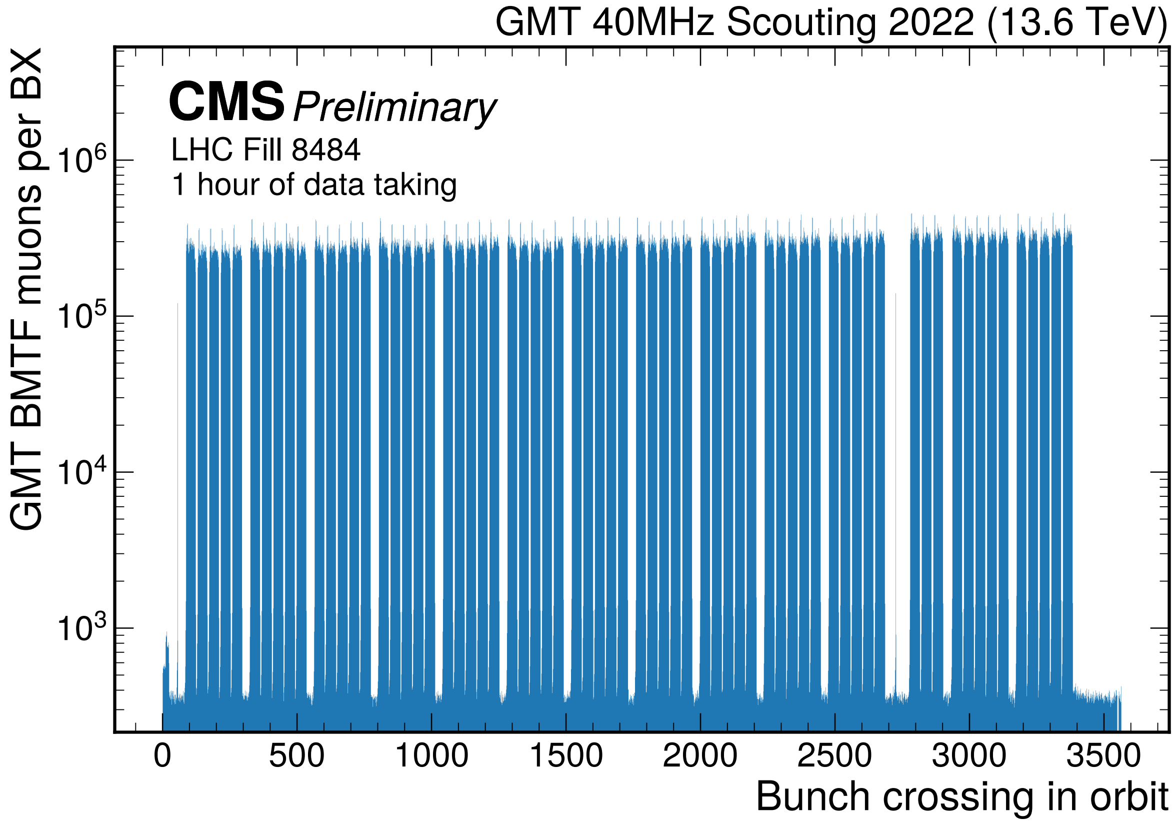
[1] https://lpc.web.cern.ch/cgi-bin/fillingSchemeTab.py
[2] https://lpc.web.cern.ch/cgi-bin/filling_schemes.py?schemeName=25ns_2462b_2450_1737_1735_180bpi_17inj_2INDIV

Multiplicity of GMT muons



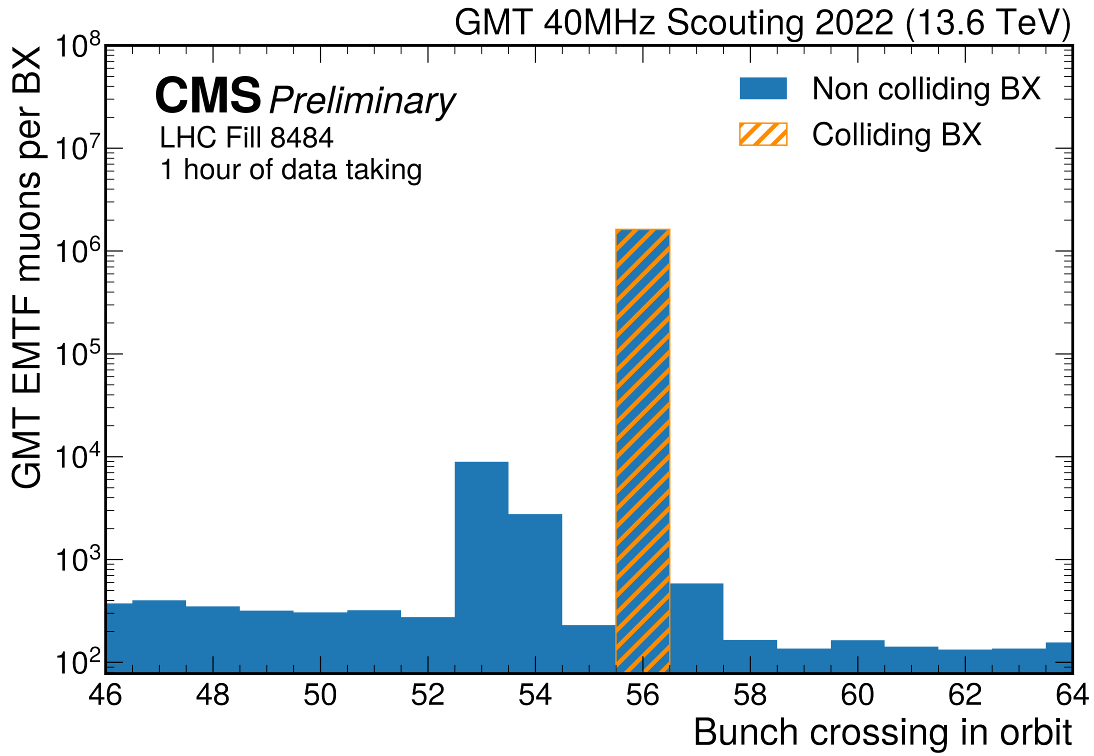
Global Muon Trigger (GMT) muons multiplicity in the same bunch crossing (BX) as recorded by the 40MHz Scouting system in 2022. The system captures up to 8 muons per BX from the GMT; the zero suppression removes the empty bunch crossings (bunch crossings with no muons recorded). The data shown correspond to 1 hour of data taking of the LHC fill 8484, on 25th November 2022.

GMT BMTF muon occupancy per bunch crossing



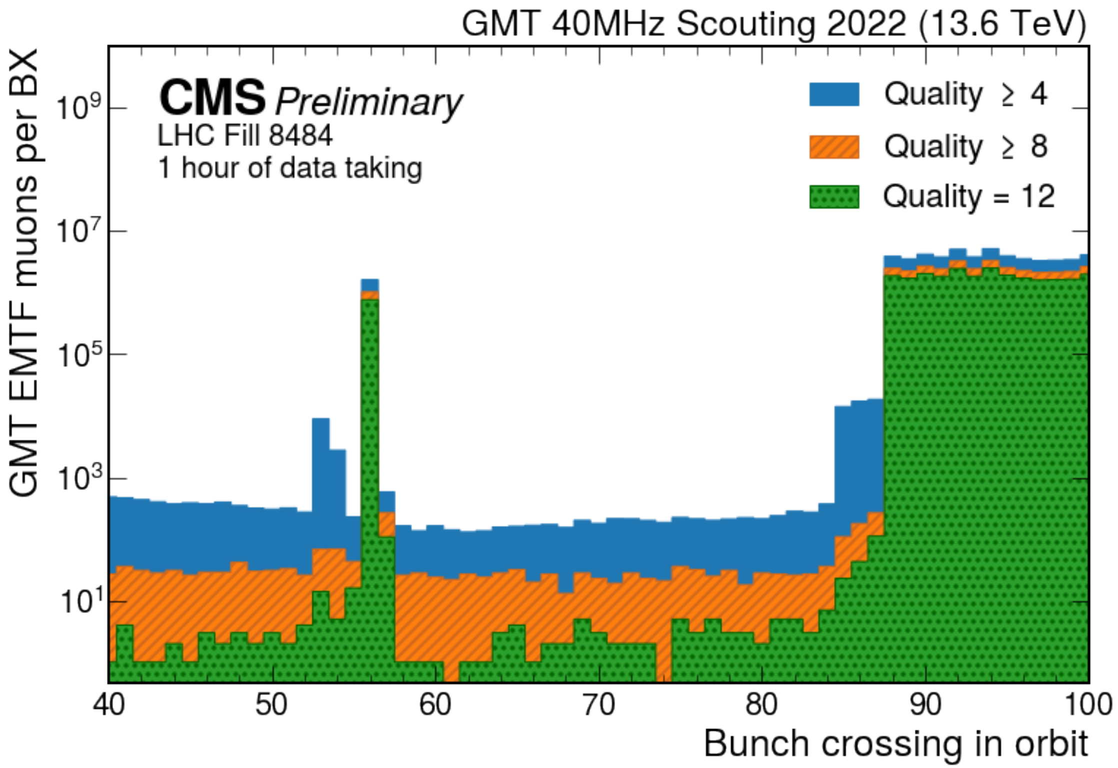
Global Muon Trigger (GMT) muons occupancy per bunch crossing (BX) within an LHC orbit for muons reconstructed by the Barrel Muon Track Finder (BMTF). An orbit contains 3564 bunch crossings. Each bin in the figure corresponds to a bunch crossing. The figure highlights the filling scheme of the LHC fill 8484 with 2450 colliding bunches in CMS. A higher number of counts can be observed for the colliding bunches in CMS. The counts in non-colliding bunches result from cosmic muon contributions as well as beam halo. The higher occupancy visible in the first bunches of trains is due to the higher instantaneous luminosity at the beginning of an injection; bunches towards the end of the orbit exhibit a higher bunch luminosity, which was separately observed by the CMS luminometers in this particular fill. The data shown correspond to 1 hour of data taking.

Single isolated colliding bunch in CMS



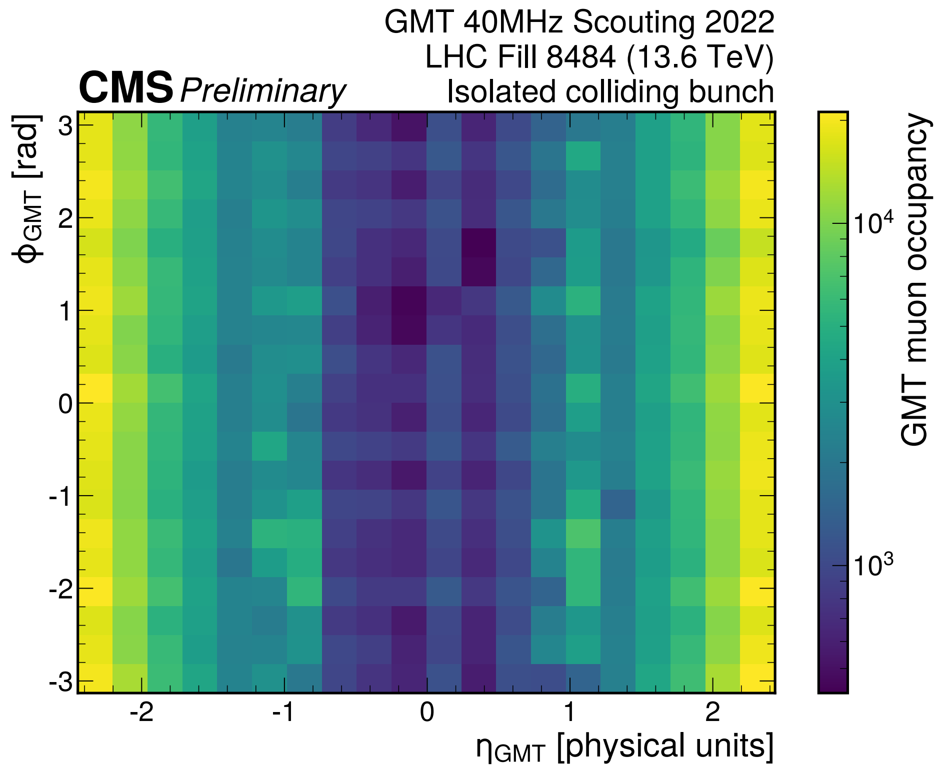
Global Muon Trigger (GMT) muons occupancy per bunch crossing (BX) within an LHC orbit for muons reconstructed by the Endcap Muon Track Finder (EMTF) in the BX range [46,64]. The single isolated colliding bunch (BX 56) is highlighted by the orange transversal lines. The Scouting System, recording all bunch crossing, enables the observation of effects like the beam halo. Due to the beam halo effect, it is visible an increased number of counts in non-colliding bunch crossings. Given that the bunches are spaced at 25ns and that the muon's reconstruction time is shifted by $t = 2\frac{|z(CSC)|}{c} \sim 50$ ns, where z(CSC) stands for the z coordinate of a muon in the Cathode Strip Chambers, the bunches that exhibit more counts are those at -3 and -2 BXs before the colliding bunch.

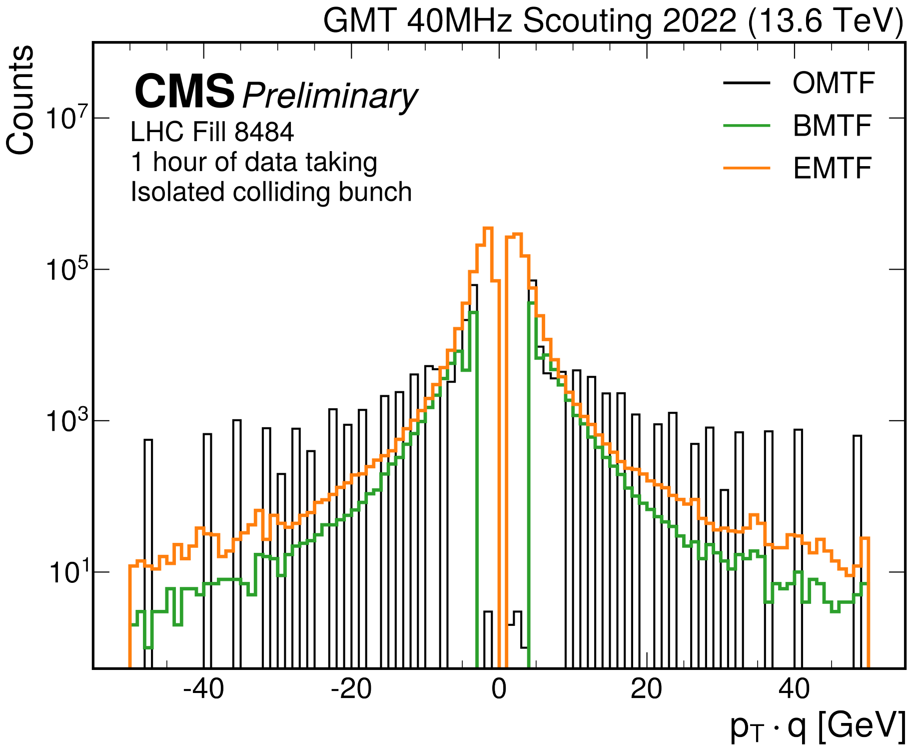
GMT EMTF muon occupancy per bunch crossing with quality cuts



Global Muon Trigger (GMT) muons occupancy per bunch crossing (BX) for muons reconstructed by the Endcap Muon Track Finder (EMTF) in the BX range [40,100]. The figure displays the occupancy for different quality cuts; the quality can assume values {0,4,8,12} where a greater value denotes a muon of higher quality. The three histograms are superimposed: muons with a quality equal to or greater than 4 (blue), muons with a quality equal to or greater than 8 (orange), and muons with a quality equal to 12 (green). In comparison to the isolated colliding bunch (BX 56), the beam halo becomes less noticeable as the muon quality improves, with a decrease in counts at -3 and -2 BXs (BXs 53, 54). Moreover, the same effect of beam halo can be seen prior to a train of colliding bunches at BXs of -3, -2, and -1 (BXs 85, 86, 87).

Muons’ parameters for a single isolated colliding bunch in CMS

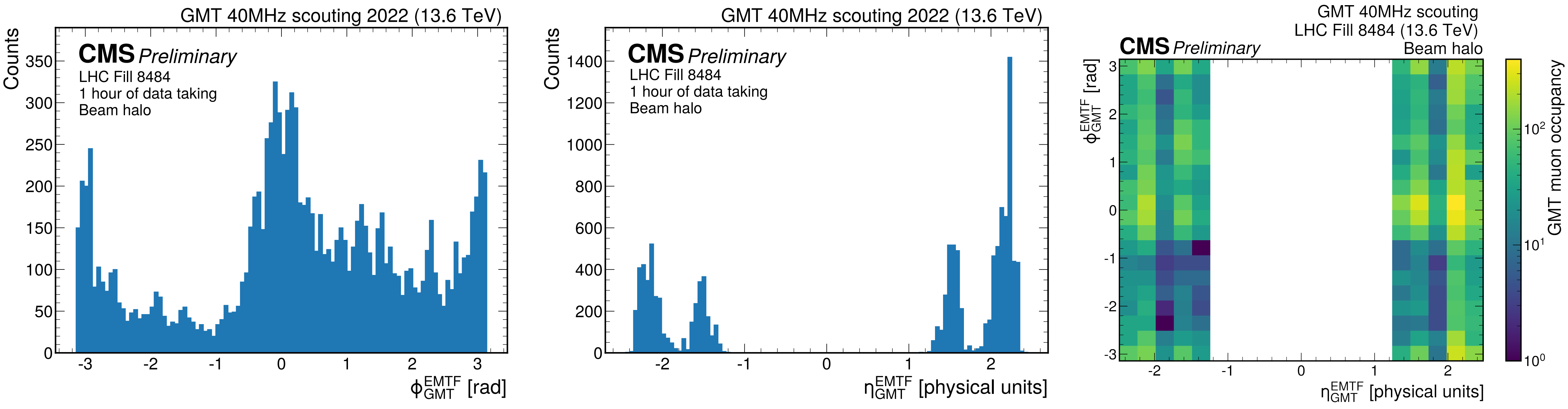




(left) The correlation between η and ϕ, which shows the occupancy of the Global Muon Trigger (GMT) muons for a single isolated colliding bunch (BX 56). The data shown correspond to 1 hour of data taking of the LHC fill 8484.

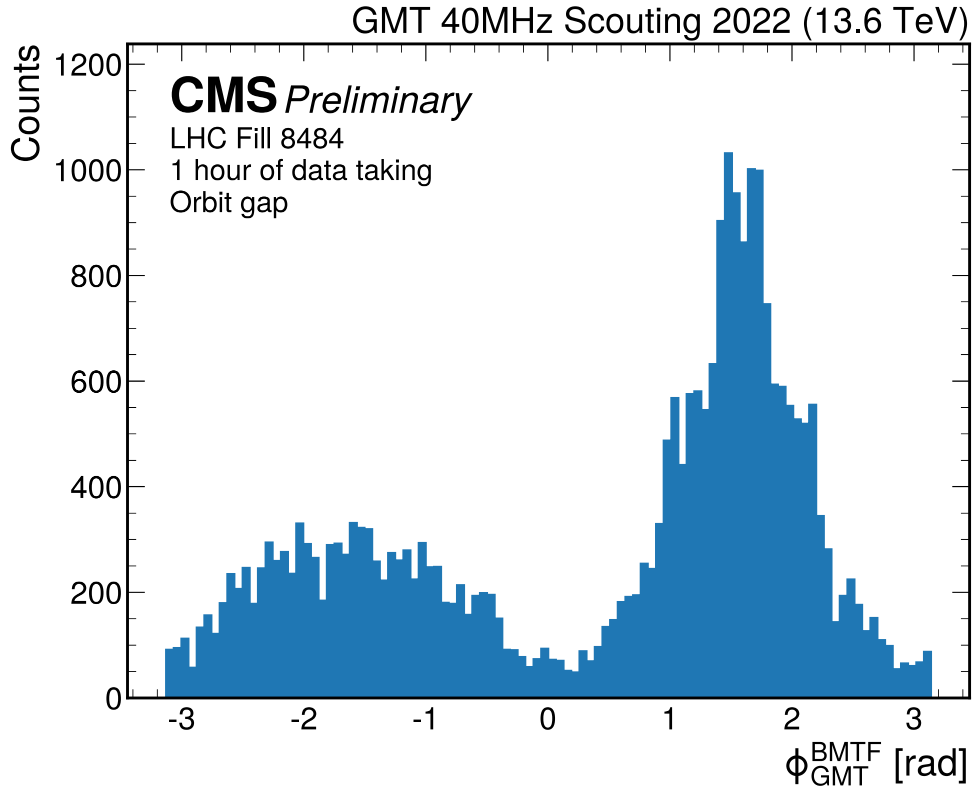
(right) The transverse momentum p_T distribution of the GMT muons multiplied by the charge q from the BMTF (green), EMTF (orange) and OMTF (black) for a single isolated colliding bunch (BX 56). The coarse binning for the OMTF values is a result of the quantisation in the FPGA logic for estimating the p_T.

Beam halo effects



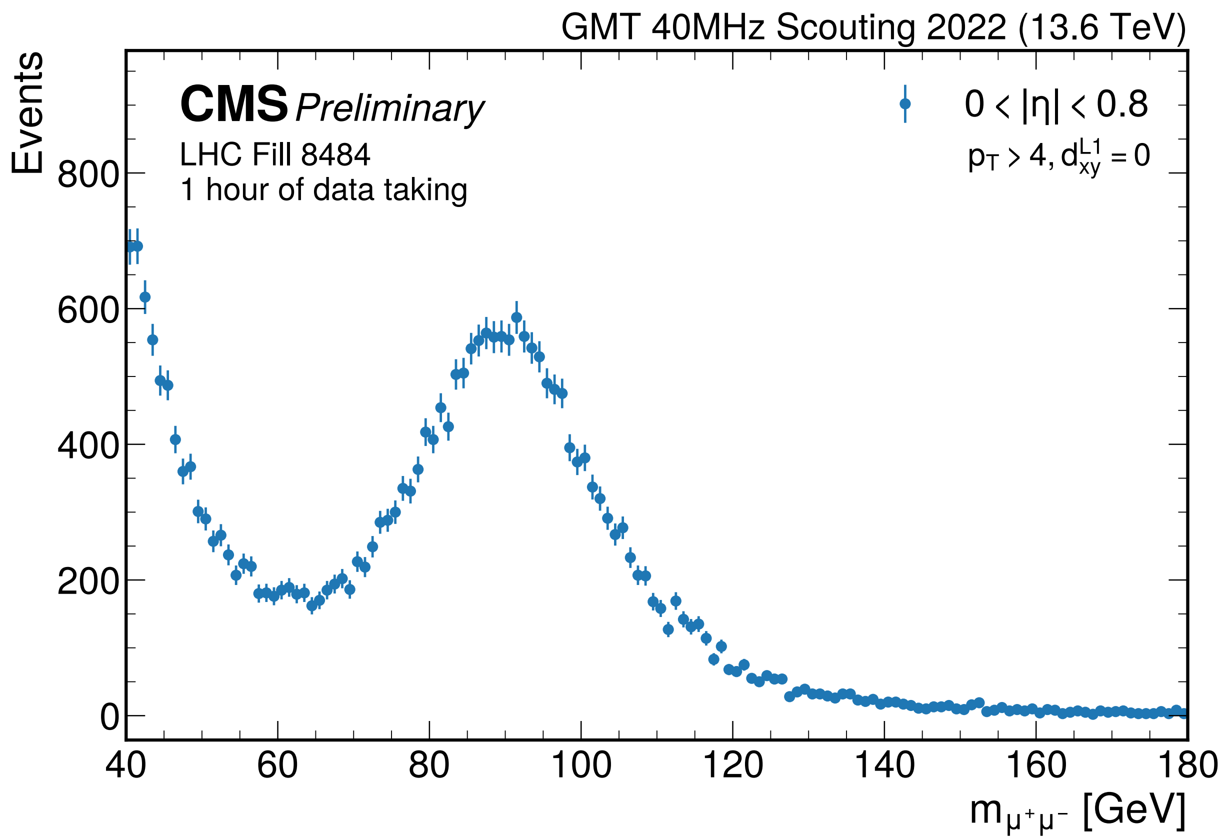
The distribution of the azimuthal angle ϕ **(left)**, the pseudorapidity η **(centre)** and the correlation between η and ϕ **(right)** for the GMT muons reconstructed by the Endcap Muon Track Finder (EMTF) for -3 and -2 bunch crossings (BXs 53, 54) before a single isolated colliding bunch (BX 56). The η $vs.$ ϕ figure shows the occupancy of the muons: a higher occupancy is observed in a detector region corresponding to the accelerator plane ($\phi \sim 0$ and $|\phi| \sim \pi$) . A greater beam halo contribution can explain the asymmetry for positive η: in this fill beam 1 (travelling clockwise from the positive η side in CMS coordinate) exhibits a larger halo. The corresponding muons are thus predominantly produced on the beam pipe plane (x-z), which is consistent with the beam halo effect.

Distribution of the azimuthal angle for muons in the *Orbit gap*



The figure shows the distribution of the azimuthal angle ϕ for the GMT muons reconstructed by the Barrel Muon Track Finder (BMTF) in a range of consecutive non colliding bunch crossing at the end of every LHC orbit. This region, referred to as *Orbit gap*, includes the interval between bunch crossings 3390 and 3540. It is expected to have more muons in the positive ϕ region since the majority of cosmic muons enter the detector from the top ($0 < \phi < \pi$). Then, due to the interaction with the detector and the magnetic field, the angular distribution spreads out, and some cosmic muons may even be scattered out before being reconstructed in the bottom part ($-\pi < \phi < 0$).

Di-muon invariant mass distribution



The invariant mass distribution produced from opposite sign pairs of GMT muons reconstructed by the Barrel Muon Track Finder (BMTF) and recorded by the 40MHz Scouting system in 2022. Only bunch crossings with exactly two muons in the barrel region of the detector are considered. A calibration procedure is applied to the muons to correct the Level-1 p_T estimate. The two muons are required to have a transverse momentum $p_T > 4$ GeV and a Level-1 impact parameter d_{xy}^{L1} equal to zero, signifying an impact parameter $d_{xy}^{L1} \leq 40$ cm.