RPC based tracking system at CERN GIF++ facility

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Introduction

The Resistive Plate Chambers (RPCs) act as muon trigger detector in the Muon System of the Compact Muon Solenoid (CMS) experiment [2]. With the coming upgrade of the Large Hadron Collider (LHC) machine, the High Luminosity LHC (HL-LHC) [1], many detector systems are preparing for upgrades. In particular, the RPC project have two important upgrades: the replacement of the off-detector electronics (called link system) and the extension of the RPC coverage from $|\eta| =$ 1.9 to 2.4 with the new improved RPC (iRPC) detector [3].

To study the performance and stability of RPCs in the HL-LHC conditions, tests are taking place in the CERN Gamma Irradiation Facility (GIF++), where a high energy particle beam (normally muons) and gammas from a gamma source (13 TBq, ^{137}Cs) are combined [4]. The maximum expected background rate is 600 Hz/cm^2 for the RPCs in the current CMS Muon system and 2 kHz/cm^2 for the new iRPCs (including the safety factor of three) [3]. Such high rates can pose a challenge to the measurement as the fake hits can bias the measurements. All data shown in this work was recorded during GIF++ test beam in October 2021.

Experimental Setup

Figure 1 shows a representation of the setup in GIF++. There are two trolleys where the RPCs are placed for irradiation. In addition to the RPCs, two scintillators are placed on each trolley to trigger on the muon beam. The data acquisition is performed using a CAEN Time-to-Digital Converter (TDC) module of type V1190A in which the chambers are connected. A V1718 VME master module is responsible for the communication between the TDC and the computer where the data is stored. To host the VME master controller and the TDC a 6U VME 6021 crate is used.

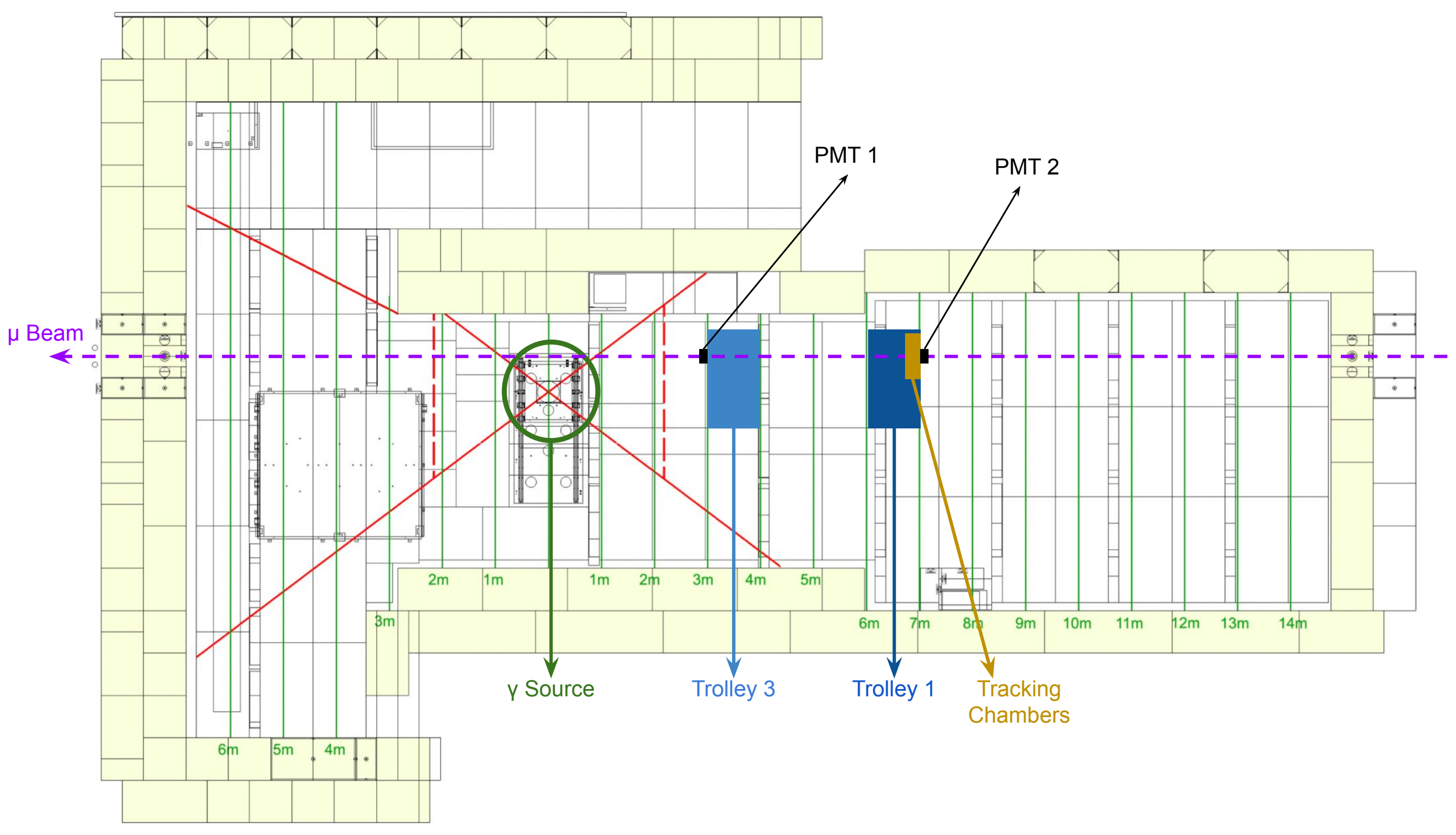


Figure 1: *Experimental setup at GIF++.*

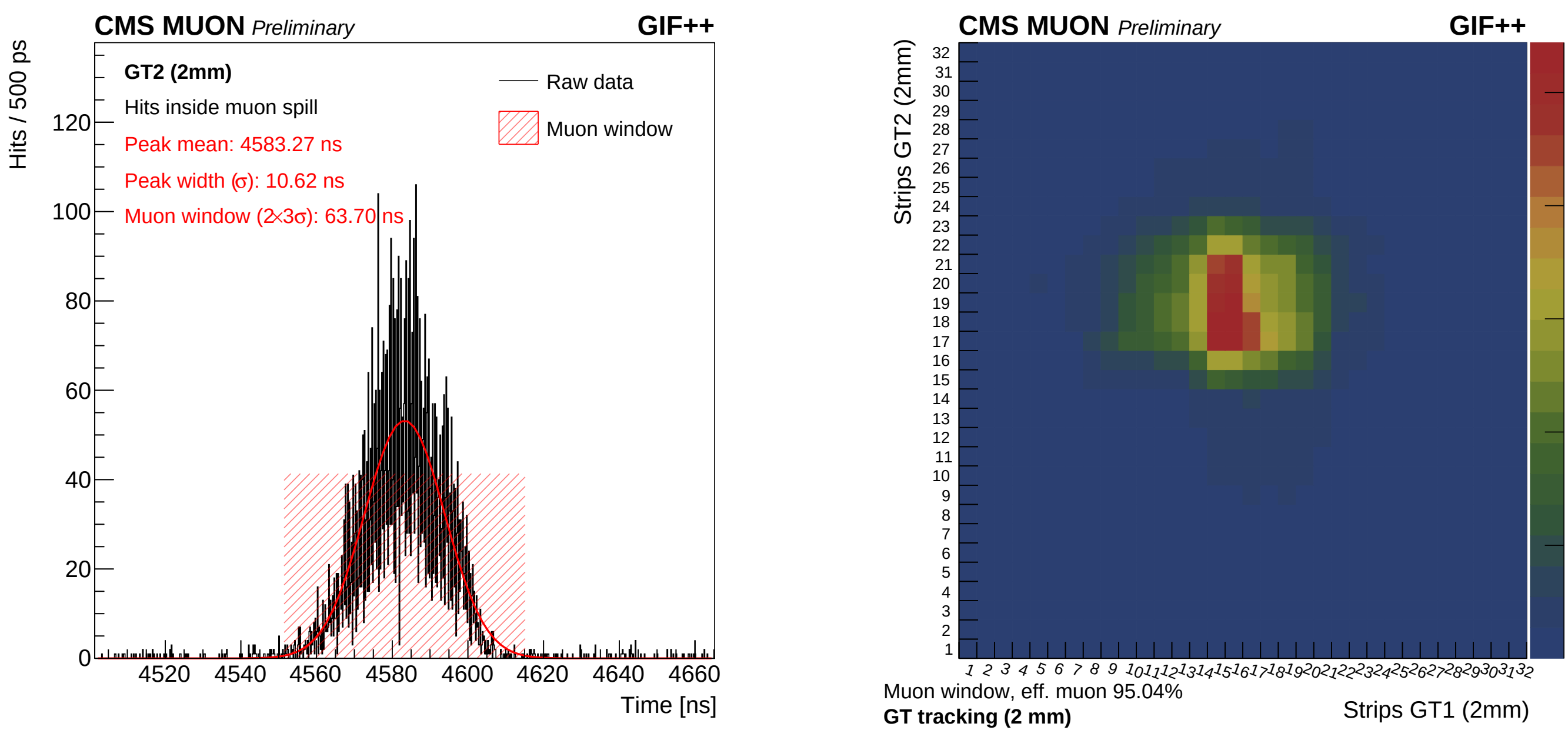
In the trolley farther from the gamma source, there are two tracking RPC chambers, their strip plane oriented perpendicular to each other to allow measurement in two directions. Table 1 summarises the parameters of the tracking and test chambers used in this work. All the chambers are fluxed with the CMS RPC standard gas mixture (95.2% freon ($C_2H_2F_4$), 4.5% isobutane (iC_4H_{10}), and 0.3% sulphur hexafluoride (SF_6)) with a relative humidity of ≈40%. The tracking chambers are always powered on with the high voltage (HV) working point (WP) applied to their electrodes.

Name	Gap type	Strip Plane	Front-End Electronics
GT1 (tracking)	Double Gap HPL 2mm thickness	32 strips 1.45 mm pitch	CMS Electronics 150 fC, 100 ns port width
GT2 (tracking)	Double Gap HPL 2mm thickness	32 strips 1.45 mm pitch	CMS Electronics 150 fC, 100 ns port width
KODEL-C (test)	Double Gap HPL 1.4mm thickness	32 strips 1.94 mm pitch	Custom Electronics 75 fC, 60 ns port width

Table 1: *Characteristics of the chambers used in this work.*

Tracking algorithm

To enable the tracking analysis, it is required at least one hit in both tracking chambers inside the muon time window defined by a Gaussian fit as indicated in the Figure 2(a). A 2D hit profile is made to check their alignment with the muon beam, as it is shown in Figure 2(b). The hit profile is also determined for the test chamber and it is used for alignment between the chambers.



(a) (b)

Figure 2: *Hits from the tracking chambers during the October 2021 test beam data taking.*

The tracking algorithm relies on the assumption that the beam is perpendicular of to the strip plane, therefore it is only needed to extrapolate the position of the hit from the tracking to the test chamber and check for a matching hit. For every event, the following steps are taken:

1. Perform the clusterization of the hits in the tracking chambers, where events with more than one cluster in the tracking chamber are rejected. The cluster barycenters are defined as the mean position in the cluster;
2. Perform the clusterization for the test chambers and calculate the clusters' barycenters;
3. Form a perpendicular track starting from the tracking cluster barycenter;
4. Check for a match in any cluster on the test chamber.

Figure 3 pictures an example of event, where the analysis was performed and a matching hit was found.

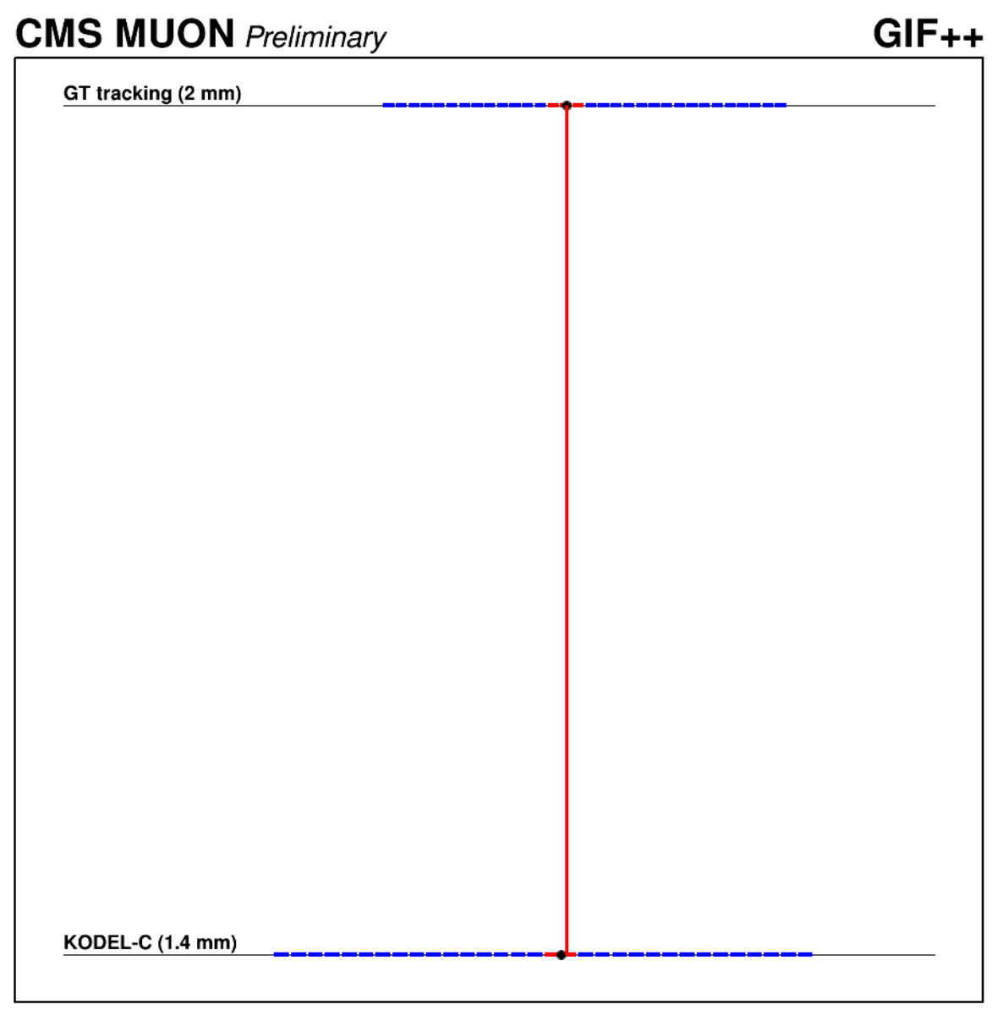
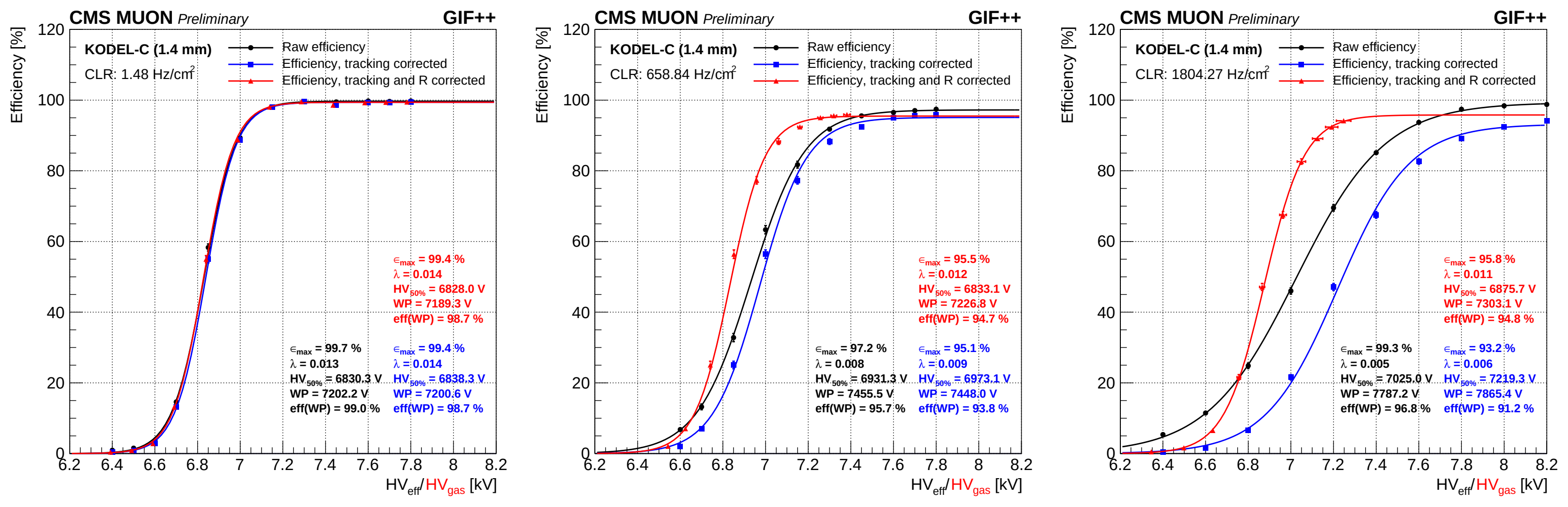


Figure 3: *Example of one event in which the hit on tracking chamber was matched on the test chamber. The strips in red represent the hits and the point in black is the cluster barycenter.*

Performance of the Tracking Algorithm

Efficiency curves of the test chambers were used to assert the validity of the tracking in rejecting the fake hits caused by the gammas. On Figure 4 the efficiency curves are compared on three gamma background conditions. There are three curves on each plot, the one in black is calculated without the tracking, considering all the hits on the muon time window, on the one in blue, only the hits that passed the tracking criteria were considered. Finally, for the red curve, the HV was recalculated to remove the voltage drop caused by the resistance of the electrodes - this correction decouples the shift to the right of the curve on higher cluster rates caused by the increase of the current. Therefore, HV_{gas} is the effective HV applied to the gas volume.

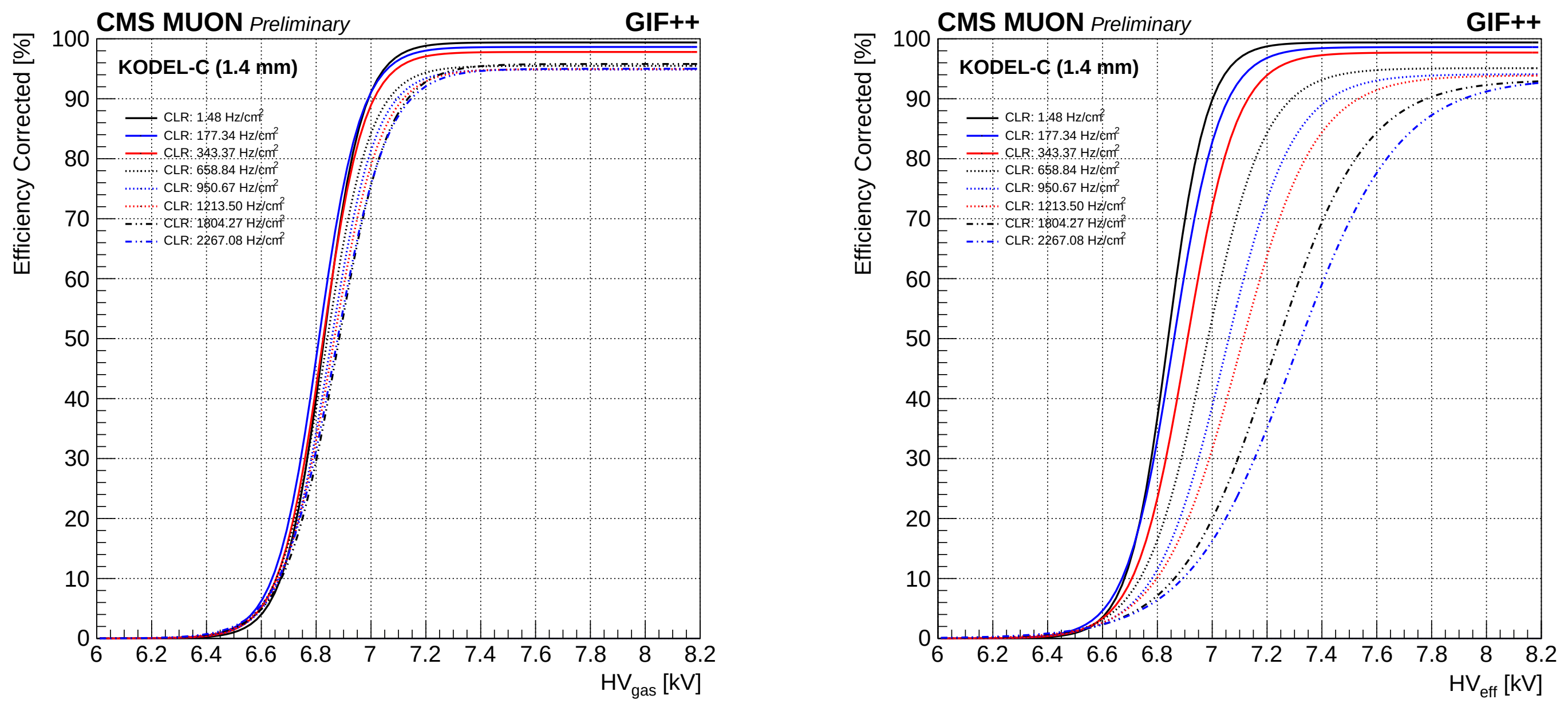
As expected, on Figure 4(a), which was taken in a run with source OFF, the three curves are equivalent since the cluster rate (CLR) and the currents are low. On Figure 4(b) with CLR $\approx$ 648 Hz/cm^2, a shift to the right on the tracking corrected curve is observed, and it is much more noticeable in Figure 4(c) with CLR $\approx$ 1.8 kHz/cm^2. The increase of the maximum efficiency on the raw efficiency curve from the Figure 4(b) to 4(c) indicate a high gamma contamination.



(a) (b) (c)

Figure 4: *Efficiencies and their Sigmoid fits measured at three photon fluxes whose measured gamma cluster rates at the working-point high voltages are 1.804 kHz (a), 0.645 kHz (b), and 1.48 Hz (c), respectively. The curve in black is the efficiency calculated with all hits inside the muon window, the one in blue with tracking correction and the one in red with tracking and resistance correction.*

On Figure 5(a) it is possible to see the curves with tracking and resistance correction. The shift to the right is caused by the reduction of the gas gain at higher rates, while the drop in the maximum efficiency is caused by the dead-time of the electronics. On Figure 5(b) there is no resistance correction, so the main reason for the shift is the voltage drop over the electrode's resistance, coupled with the reasons mentioned before.



(a) (b)

Figure 5: *Efficiency curves for various gamma background rates. On (a) the HV applied is corrected only by pressure and temperature (HV_{eff}), while on (b) the HV is also corrected by the resistance of the gaps (HV_{gas})*

Conclusion

The implementation of the tracking system was moved by the necessity to test the CMS RPC chambers at the conditions of the HL-LHC. The results shows that the tracking system perform very well to remove fake hits from the gamma background, even at rates as high as 2 kHz/cm^2. The test chamber performed very well and showed a increase on the working point of $\approx$650 V with a efficiency loss of $\approx$ 7.5% using the custom electronics with threshold of 75 fC. This system is currently being used for the ageing studies of the CMS RPC system.

Acknowledgements

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