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Study of the GEM chamber for the upgrade of the LHCb muon system

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Summary. — Triple-GEM chambers, so far used in the inner region of the first muon station at LHCb, are the ideal candidates to replace the MWPCs in the regions where, after the upgrade in 2018, the particle rate will be as high as $2\,\mathrm{MHz/cm^2}$. In this work, the results of a study on the GEM efficiency and time performances are shown.

1. – Introduction

The LHCb Muon System is comprised of 5 rectangular stations (M1-M5) placed along the beam axis. Each station is divided into 4 regions (R1-R4) equipped with MWPCs. In the R1 region of the M1 station, where the particle flux is higher, 12 Triple-GEM detectors are used in place of the multiwire chambers [1]. During the last years of LHCb operations, GEM chambers have shown remarkable rate capability and high aging resistance, and are the natural candidates to constitute the future inner region of the muon system, after the upgrade scheduled in 2018.

To provide uniformity, using the same gas mixture across the entire muon detector will be desirable: a key purpose of this work is to test the GEM chambers using the gas mixture so far used in the MWPCs, in order to find out if it will be possible to operate with a single gas mixture after the upgrade. Performance analyses of the triple-GEM detector were conducted in a cosmic ray station, in the Sapienza University of Rome, by triggering muons with plastic scintillators [2]. Several measurements are taken using two gas mixture with the following volume percentages: $Ar/CO_2/CF_4$ 40:55:5 (named **A** gas mixture) and 45:15:40 (named **B** gas mixture), so far used in the LHCb MWPCs and GEMs, respectively.

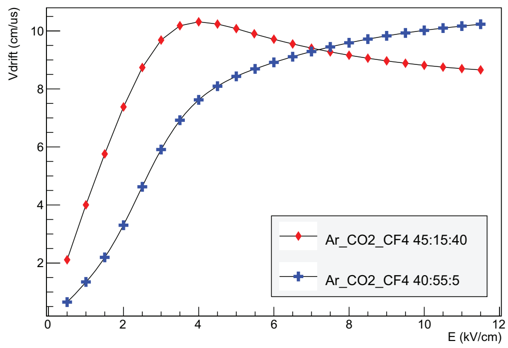

Fig. 1. – Simulated drift velocity for the two $Ar/CO_2/CF_4$ mixtures.

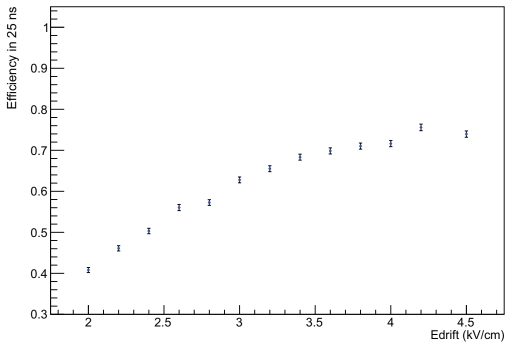

Fig. 2. – Measured 25 ns efficiency in the **A** mixture as a function of E_d, fixing $V_{gem} = 1255\,\mathrm{V}$.

2. – Gas simulation with GARFIELD

The primary performance criterion for the muon chambers in LHCb is a high efficiency in the bunch crossing time window: 25 ns. Thus, beside to a high efficiency, the detectors must ensure a good time performance, which is related to the statistics of clusterization in the drift gap. For a high energy muon traversing the GEM, the distance x of the ionization cluster closer to the first GEM has the probability distribution $P(x) = ne^{-nx}$, with $\sigma(x) = 1/n$, where n is the number of ionization clusters per unit length [3]. Therefore, if the first cluster is always detected, the detector time resolution would be $\sigma(t) = 1/nv_{drift}$. Thus, to improve time resolution, a gas mixture with large clusterization and high drift velocity should be used.

A simulation with GARFIELD [4] of the the specific clusterization caused by a minimum ionizing muon traversing the gas is carried out. The mean number of clusters produced per cm by a track is $n_A = 46,4$ clusters/cm for the **A** mixture, while the **B** mixture has large clusterization: $n_B = 57,4$ clusters/cm. Figure 1 shows the simulated electron drift velocity under increasing electric field. The large CF_4 component leads to a higher drift velocity, resulting in a faster detector response.

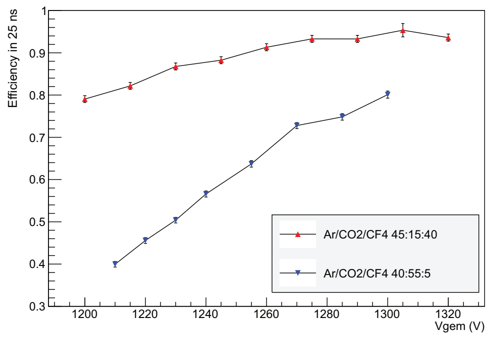

Fig. 3. – Measured 25 ns efficiency in the gas mixtures, with $E_d = 3.0\,\mathrm{kV/cm}$.

3. – Cosmic ray measurements

First a detailed analysis of the GEM performances is carried out in order to find the optimal values of the chamber electric fields. In fig. 2, a systematic study with the **A** gas mixture is performed in order to find the optimal drift field value. As one can expect from the simulation, increasing the drift field from 3.0 to 4.0 kV/cm leads to a faster electron drifting, which in turns leads to better detector time performance: the 25 ns efficiency increases, reflecting the trend seen in fig. 1. Note that setting an electric field value which is too high prevents the field lines in the gap from matching up with the GEM field lines, leading to electron defocusing effect and therefore inefficiency.

At these field values, transfer fields do not alter the GEM performance in a significant way. We therefore choose to fix them at an intermediate value of $E_{t1} = E_{t2} = 3.0\,\mathrm{kV/cm}$. Increasing the field in the transfer gaps to 4.0 kV/cm causes electron clouds to drift faster, as shown in fig. 1. The total observed time anticipation (12.8 ns) is compatible with the simulated drift velocities and a 3 mm total path for the two transfer gaps.

4. – Results

Figure 3 directly compares the measured triple-GEM efficiency in 25 ns in the two gas mixtures. The advantage of a large CF_4 component in the **B** mixture is clear: the time performances are considerably better when the drift velocity is higher, as anticipated in sect. **2**. Moreover, higher cluster size values observed in the **B** mixture suggest a higher gain (fig. 4); in fact, the **B** mixture has a larger Ar/CO_2 ratio than the **A** mixture [3].

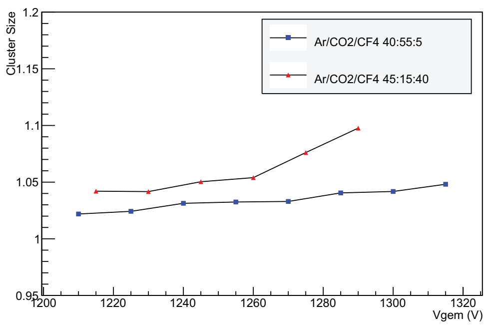

Fig. 4. – Mean value of the cluster size as a function of the GEM voltage.

5. – Conclusion

With the upcoming LHCb upgrade in 2018, the triple-GEM chamber performances have been investigated by using two different gas mixtures, so far used in the LHCb MWPCs and GEMs, as a function of the electric field configuration. As predicted by the GARFIELD simulation, the results confirmed a drop of the GEM time performances, if the CF_4 component in the mixture decreases from 40% to 5%. At the same time, low cluster size results are probably due to low gain for the 5% CF_4 mixture. The results from the present work provide useful functional GEM parameters for an evaluation, through an extended Monte Carlo simulation, of the global performances of the 2018 LHCb muon system.

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