PROCEEDINGS OF SCIENCE

Performance of the LHCb Muon System in high luminosity runs

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The LHCb detector was conceived to operate at an average luminosity of 2×10^{32} cm^{-2} s^{-1}. During the 2012 LHC run, the whole apparatus has shown to be able to perfectly acquire and manage data produced at a luminosity as high as 4×10^{32} cm^{-2} s^{-1}. In this condition, all subdetectors operated at average particle rates higher than the design ones and in particular the detectors equipping the Muon System had to sustain particle rates as high as 100 kHz/cm^2.

In order to study the possibility of further increasing the operation luminosity several tests were perfomed.

This paper reports detailed studies of the performance of the LHCb Muon System in runs with a luminosities between 4×10^{32} cm^{-2} s^{-1} and 10^{33} cm^{-2} s^{-1}.

14th International Conference on B-Physics at Hadron Machines,
April 8-12, 2013
Bologna, Italy

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PoS(Beauty 2013)064

1. Introduction

The LHCb Muon System ([1] and [2]) is composed of five detection stations (M1-M5), equipped with 1380 MWPC ([3], [4]) and 12 triple-GEM detectors [5]. The chambers in stations M2-M5 have four sensitive layers while the chambers in station M1 are composed by only two layers. Each station is subdivided in four regions (R1-R4) equipped with chambers having different readout granularities.

In the four-layer chambers, the corresponding pads in the first and second (third and fourth) layers are ganged in pairs to create the “Physical Channel” (PC). In M1 each single pads represents a PC. Each PC is equipped with an ASD circuit and an integrated circuit for the threshold settings (CARIOCA, [6]) and it is also provided with an individual scaler that allows the counting of the discriminated signals within a certain time gate.

2. The method

All measurements reported in this paper were taken by using the scalers to count the number of hits of each single PC in a 1 s gate. No information is available on the time of the hits and no tracking is performed, so that there is no possibility to distinguish between hits due to electronic noise, hits due to low energy particles and due to penetrating particles. The two (bi-)layers of each chamber are treated as independent detectors

3. The absolute rates

The average rates measured by the Muon System detectors for a luminosity of 10^{33} cm^{-2} s^{-1} are shown in Fig. 1.

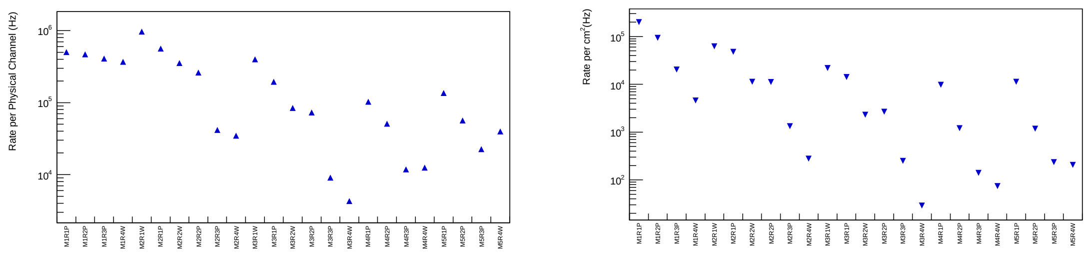

Figure 1: Average rate per Physical Channel (left) and per cm^2 (right) measured for $\mathscr{L} = 10^{33}$ cm^{-2} s^{-1} in the different regions of the Muon Detector.

The maximum average rates per PC are found on the wire pads of the MWPC in M2R1 (970 kHz) and on the cathode pads of the GEM in M1R1 (about 500 kHz) and of the MWPC in M1R2 (about 470 kHz). The maximum average rates per cm^2 are found on the cathode pads of the GEM in M1R1 (about 200 kHz/cm^2) and of the MWPC in M1R2 (about 94 kHz/cm^2). In M2R1 the wire pads count a rate of about 62 kHz/cm^2.

The noise level was evaluated without beam and found to be completely neglibile. The rates measured in each run are thus mainly due to particles and they are expected to be linearly related to the beam luminosity. Their relative behaviors represent useful information to study the detection efficiency of the MWPC as a function of the particle flux.

4. Electronics dead time

Because of the dead-time of the electronics the probability of being inefficient increases with the rate. Let's R be the real rate of particles on a PC and R^* the measured one. If δ is the electronics dead time and if the particles arrive uniformly in time, the inefficiency of each channel is $R^*\delta$ and thus, the measured rate is $R^* = R(1-\delta R^*)$.

Therefore, it is possible to evaluate the real rate from the measured one as:

$$R = \frac{R^*}{1-\delta R^*}. \tag{4.1}$$

4.1 Electronics dead time evaluation

The average electronics dead time δ can be determined from the performed measurements. Given two runs, with luminosities $\mathscr{L}_i = i \times 10^{32}$ cm^{-2} s^{-1} and $\mathscr{L}_j = j \times 10^{32}$ cm^{-2} s^{-1}, it is possible to evaluate, for each one of the 120k PC, the ratio $\rho(R_i^*, R_j^*)$ between the measured rates R_i^* and R_j^* normalized for the luminosities:

$$\rho(R_i^*, R_j^*) = \frac{(R_i^*/\mathscr{L}_i)}{(R_j^*/\mathscr{L}_j)}. \tag{4.2}$$

By introducing $\beta = \mathscr{L}_j/\mathscr{L}_i$, being R_i and R_j the "ideal" rates, measured in case of no-dead-time, it should be: $R_j = \beta R_i$. Thus

$$\rho(R_i^*, R_j^*) = \frac{1+\delta\beta R_i}{1+\delta R_i}. \tag{4.3}$$

From eq. 4.1, it follows that

$$\rho(R_i^*, R_j^*) = 1-\delta R_i^* + \delta\beta R_i^* = 1-\delta\left(\frac{1}{\beta}-1\right)\beta R_i^*. \tag{4.4}$$

For each pair of taken dataset, we can plot the ratio ρ as a function of βR_i^* and fit it with a line as shown on the left in Figure 2 for $i=6$ and $j=4$. From eq.4.4 it follows that if $\mathscr{L}_j > \mathscr{L}_i$, thus β will be smaller than 1 and the slope m of the line is expected to be negative.

We can extract the value of m and β from each pair (i, j) of runs and calculate δ as:

$$\delta = \frac{m}{1/\beta - 1} \tag{4.5}$$

On the right, Figure 2 shows the values obtained for δ in different run pairs. The points have an almost flat distribution and, as expected, do not show any dependence on β. A value of 95$\pm$6 ns was found and it will be used for further calculations in this paper.

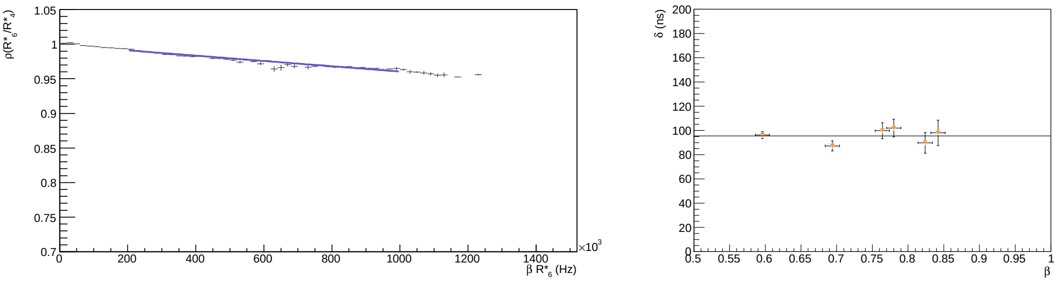

Figure 2: Left: ratio ρ between the measured rate in two runs; Right: behavior of the evaluated electronics dead-time δ as a function of β (see text for details).

5. Measured detection efficiency

The general behavior of the detection efficiency ε can be evaluated by studying $\rho(R_i^*, R_j)$ as a function of the expected particle rate per physical channel (R_i).

$$\varepsilon_i = \rho(R_i^*, R_j) = \frac{(R_i^*/L_i)}{(R_j/L_j)}. \tag{5.1}$$

As it is shown in Figure 3 (left) the electronics dead time gives rise to an inefficiency that increases linearly with the rate, with a slope of about 9%/MHz. The average value of the detection efficiency for each type of PC is shown in Figure 3. Circles represent the efficiencies for a luminosity of 5×10^{32} cm^{-2} s^{-1} while triangles are measured for a luminosity of 10^{33} cm^{-2} s^{-1}.

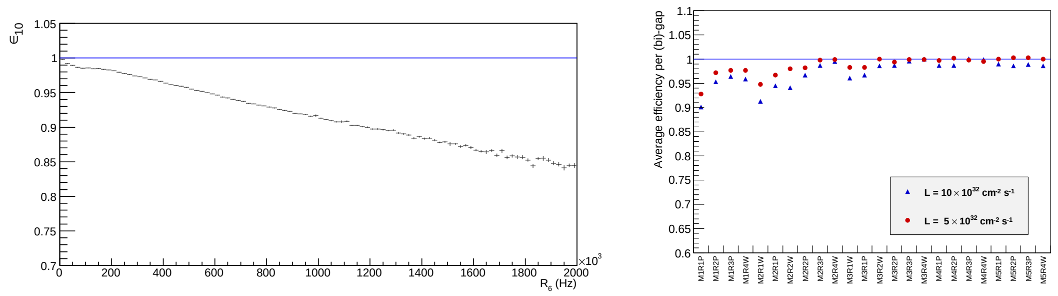

Figure 3: Left: detection efficiency as a function of the particle rate. Right: average detection efficiency evaluated for the different regions of the Muon System.

In the most irradiated regions, for $\mathscr{L} = 10^{33}$ cm^{-2} s^{-1}, the single (bi-)layers efficiency reaches values as low as 90%. Since a large fraction of the rate is due to low energy particles, the inefficiency due to the electronics dead time can be almost totally recovered by means of the logical OR performed by the DIALOG between the two (bi-)gaps. Therefore it is important to check that no other effects, as, for example due to space charge, are spoiling the detection efficiency.

6. Space charge effect evaluation

Figure 4 shows the behavior of $\rho(R_{10}, R_6)$ (see eq. 5.1) as a function of R_{10} once the rates have been corrected for the effect of the electronics dead time.

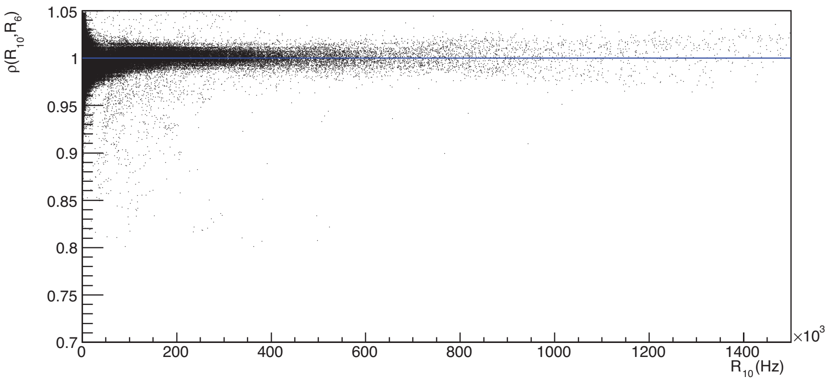

Figure 4: Behavior ρ as a function of the rate per physical channel.

The behavior $\rho(R_{10}, R_6)$ as a function of the rate per PC is almost flat. This is indicating that, once corrected for the effect of the electronics dead time, the detection efficiency of the chamber do not decrease even in the most counting channels.

7. Conclusion

A lot of information was provided by the high luminosity runs. A method has been developed to evaluate the detection efficiency by means of the scalers mounted on board of the Front-End Boards of the LHCb Muon System. The main effect found is the expected inefficiency due to the dead-time of the electronics. No other important effects deteriorating the system efficiency has been found.

References

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