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# The ALICE muon trigger system: cosmic ray commissioning and first beam-induced events

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## Abstract

The ALICE experiment is designed to study strongly interacting nuclear matter which will be produced in heavy ion collisions at the Large Hadron Collider (LHC). The muon spectrometer of the ALICE experiment is equipped with a trigger system based on resistive plate chambers. A commissioning phase was started in 2008 with the detection of cosmic rays and induced particles of the first beam injections into the LHC ring. The performance of the whole muon trigger system achieved during the commissioning phase are presented.

*Key words:* Muon spectrometer, Trigger system, Resistive Plate Chamber (RPC)

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## 1. Introduction

ALICE (A Large Ion Collider Experiment) is the detector designed for the study of nucleus-nucleus collisions at the CERN Large Hadron Collider (LHC). Its physics program will address questions concerning QCD of hot and dense nuclear matter produced in central heavy ion collisions. The main goal of ALICE is to characterize a deconfined state of nuclear matter called the Quark-Gluon Plasma (QGP) [1].

The ALICE detector [2] is composed of three parts:

- a central barrel ( $|\eta| \leq 0.9$ ) with detectors measuring hadrons, electrons and photons,
- a set of forward detectors used to characterize the event and interaction trigger,
- a forward muon spectrometer ( $-4.0 < \eta < -2.5$ ).

All detectors are designed to work in an environment with large particle multiplicities: theoretical models predict between 2000 and 6000 charged particle per rapidity unit at mid-rapidity for the most central Pb-Pb collisions at a nucleon-nucleon center of mass energy  $\sqrt{s_{NN}} = 5.5$  TeV.

The main role of the ALICE muon spectrometer [3] is to study the production of quarkonia and heavy quarks via their muonic decays [4]. Theoretical models predict that the quarkonia production in a QGP can be reduced by a color screening effect or increased by statistical hadronization of uncorrelated heavy quark-antiquark pairs [5]. Furthermore, the magnitude of these effects is sensitive to the properties of the medium, like its energy density.

To reach this physics goal, quarkonia should be reconstructed with the maximum efficiency over their whole  $p_T$  range and

with a mass resolution of the order of  $70 \text{ MeV}/c^2$  for the  $J/\psi$  family ( $m_{J/\psi} \approx 3 \text{ GeV}/c^2$ ) and  $100 \text{ MeV}/c^2$  for the  $\Upsilon$  one ( $m_{\Upsilon} \approx 10 \text{ GeV}/c^2$ ). This implies that the momentum of muons from  $\Upsilon$  decay must be determined at the percent level.

The muon spectrometer, with an angular acceptance of  $2^0 < \theta < 9^0$  (with  $\theta$  the polar angle respect to the LHC beam axis) over the full azimuthal range, consists of a front absorber, a beam shielding, ten high resolution tracking chambers, a dipole magnet, an iron wall and a trigger system.

## 2. The muon trigger system and its pre-commissioning

The trigger system of the muon spectrometer is composed of two stations of two detection planes (for a total area of  $140 \text{ m}^2$ ) located respectively at 16 m and 17 m from the interaction vertex (see Fig. 1). Each detection plane is mechanically divided in two half-planes of nine individual Resistive Plate Chambers (RPCs). These detectors are made of two bakelite planes spaced by a gas gap of 2 mm [6] and can work either in streamer ( $HV \sim 8 \text{ kV}$ ) or in avalanche ( $HV \sim 10 \text{ kV}$ ) mode with appropriate gas mixtures. Their readout planes are segmented in strips of 1 - 2 - 4 cm wide in bending plane and 2 - 4 cm wide in non-bending plane. The associated front-end electronics (FEE) [7], for a total of 21,000 channels, is based on a dedicated dual thresholds ASIC.

The FEE signals are sampled at 40 MHz (25 ns) by an off-detector trigger electronics is organized in three steps : 234 Local, 16 Regional and 1 Global boards [8]. Each Local board corresponds to a projective zone with respect to the interaction point. The trigger system selects tracks ( $\mu^\pm$ ) above two  $p_T$  thresholds in parallel to deliver five trigger signals: single muon (with a  $p_T$  cut), low and high  $p_T$  cuts for both like-sign and unlike-sign dimuon. The trigger signals are delivered to the Central Trigger Processor of ALICE about 800 ns after the collision. A front-end test system (FET) allows to simulate RPC-

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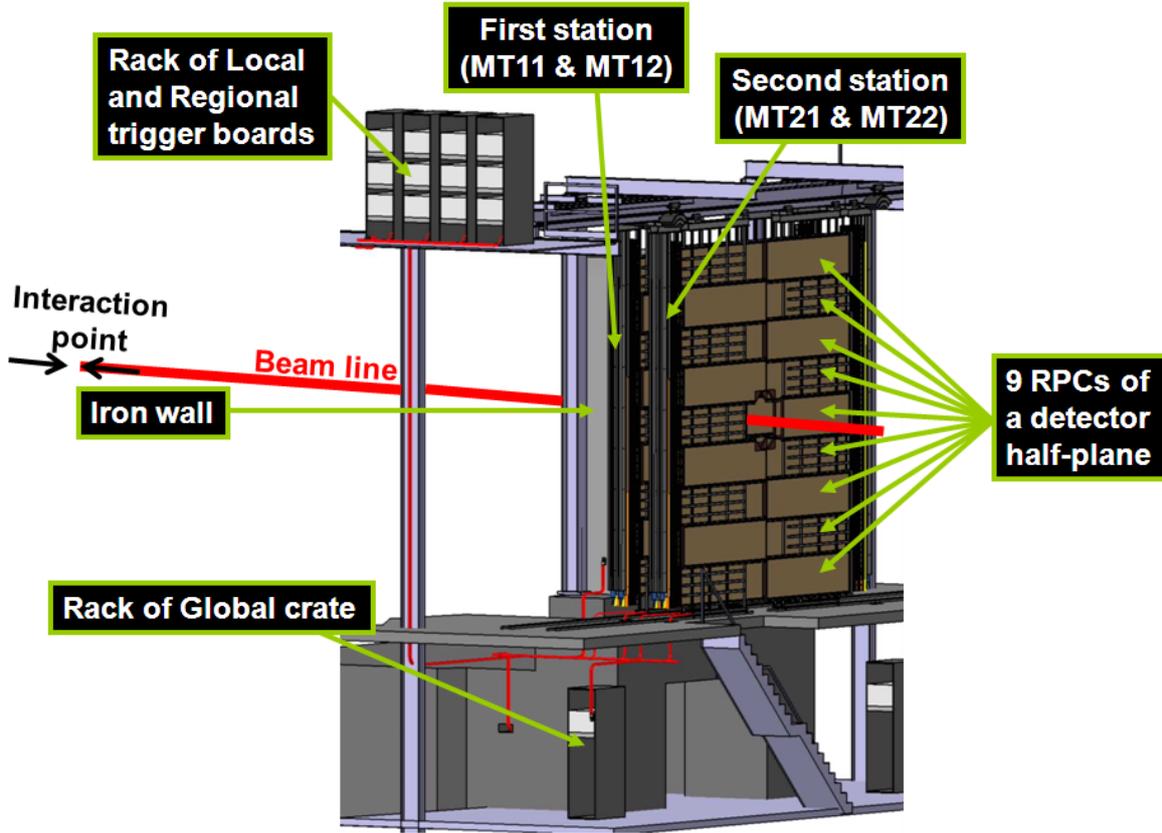


Figure 1: Schematic 3-D view of the ALICE muon trigger system (other ALICE subdetectors are not represented for the clarity of the scheme).

like pulses at the FEE input to check the whole electronics chain from FEE to readout, but also the trigger algorithm and the timing of the system.

An intensive R&D phase for detector development was carried out with the help of test beam at the CERN Proton Synchrotron and Super Proton Synchrotron, and also by using the CERN Gamma Irradiation Facility for ageing purposes. So, the main performances achieved in streamer mode are: a time resolution  $< 2$  ns [9], a spatial resolution  $< 1$  cm [10], a rate capability  $> 100$  Hz/cm<sup>2</sup> and an integrated yield  $> 100$  Mhits/cm<sup>2</sup> [11].

After installation in mid-2007, a pre-commissioning phase of the electronics chain was carried out. The results indicate that the FEE signals (22 ns wide LVDS) have a small timing dispersion: an almost full efficiency plateau of 10 ns wide to pick up all FEE signals by the trigger electronics was measured [12].

### 3. Cosmic rays commissioning

Due to its geometrical acceptance, the ALICE muon spectrometer is not designed to detect cosmic rays (cosmic flux  $\propto \cos^2 \alpha$ , with the zenithal angle  $\alpha = \theta - \frac{\pi}{2}$ ). Nevertheless, two periods of cosmic ray data taking were scheduled to study the performance of the system: in May-June 2008 with  $\sim 50,000$  events and in March-April 2009 with  $\sim 85,000$  events recorded. These data were mainly obtained with the muon dipole magnet off and with the RPCs operating in streamer mode (a short test in avalanche mode was carried out at the end of the 2009 run).

The RPC efficiency was studied by using the detection plane redundancy. Indeed, the trigger algorithm requires only three over four detection planes to be fired, allowing to study the fourth plane. It results in an efficiency greater than 90% for all RPCs. This rather conservative value is due both to the poor statistics for the RPCs closest to the beam and to geometrical systematic effects relevant in cosmic ray detection. Furthermore, as cosmic rays are not synchronized with the LHC clock used by the electronics, the FEE timing dispersion induced a loss of efficiency. All these effects result in a reduction of the measured efficiency.

The counting rate  $R_{RPC}$  (due to noise) was measured for each RPC (see Fig. 2). The average counting rate is relatively weak:  $\langle R_{RPC} \rangle = 0.012$  Hz/cm<sup>2</sup>.

The RPC current  $I_{RPC}$  was also monitored. Its trend is stable in time and the distribution for all RPCs, displayed in Fig. 3, shows that most of the RPCs have a weak current:  $\langle I_{RPC} \rangle = 0.44$   $\mu$ A and  $I_{RPC} < 3$   $\mu$ A.

With the four muon trigger planes at nominal high voltage, the total trigger rate was 0.18 Hz. The data analysis shows that events are divided in two types:  $\sim 60$  % of showers with a large number of hits on each detection planes and  $\sim 40$  % of single tracks ( $\mu^\pm$ ). The polar angle distribution  $\theta_y$  of single tracks in vertical plane ( $z, y$ ) is displayed in Fig. 4. The general shape of the  $\theta_y$  distribution reflects the cosmic ray zenithal distribution, but with an asymmetry between negative and positive angles. Positive angles are associated to forward particles (com-

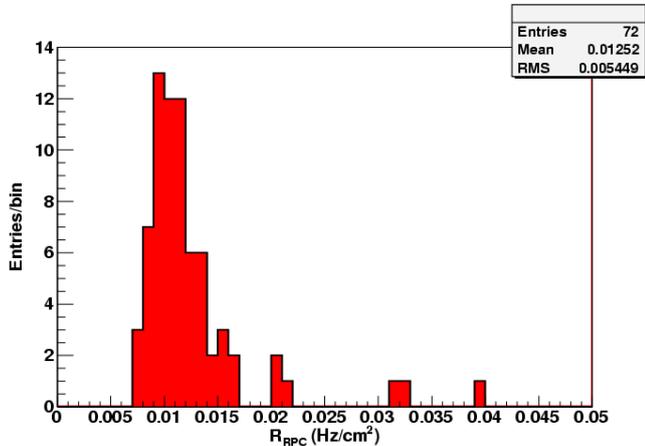


Figure 2: RPCs counting rate  $R_{RPC}$  distribution.

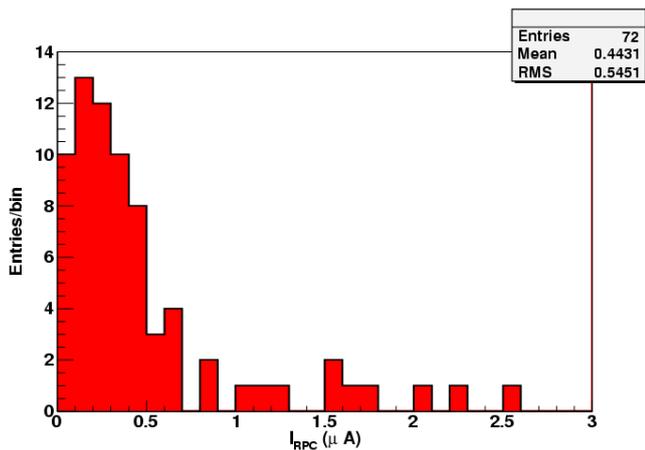


Figure 3: RPCs current  $I_{RPC}$  distribution.

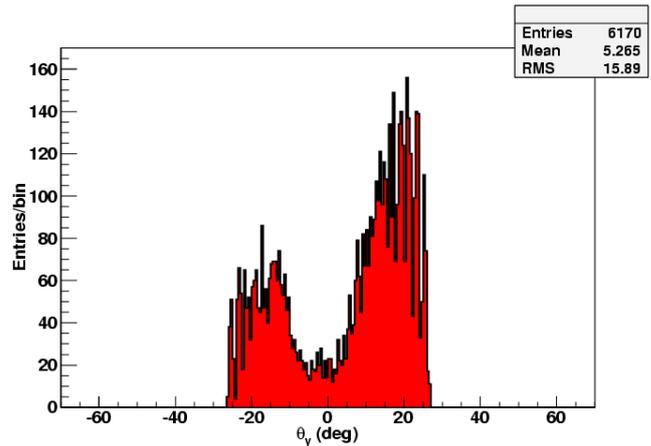


Figure 4: Polar angle distribution in vertical plane ( $\theta_y$ ) of single cosmic ray tracks.

ing from the interaction point), while negative angles are due to backward particles (coming from Jura mountain side, opposite to the interaction point). This asymmetry is due to the timing of the front-end electronics which is tuned to get the best efficiency for forward particles. Moreover, it has been conjectured that the flux of backward cosmic rays might be reduced further by a shadow effect of the Jura mountain.

#### 4. First LHC beam induced events

The first LHC beam injections through the injection line close to ALICE were performed in August 2008. The beam injections have consisted of bunches of about  $10^9$  protons at SPS energy (450 GeV) every 48 s.

At each injection most of the trigger zones were fired. The hit rate as a function of time for one detection plane is shown in Fig. 5. The continuum corresponds to the counting rate of one entire detection plane  $\sim (0.012 \text{ Hz/cm}^2) \times (35 \text{ m}^2) = 4200$  hits/s. The peaks show the effect of the proton bunches. From this plot, we deduce that the number of hits per plane was at least 5000 in the bending plane (over 3744 strips) and 2000 in the non-bending plane (over 1504 strips). Keeping in mind that if several particles cross the same strip only one hit is seen by the FEE, this indicates that presumably all the strips of the muon trigger were fired more than once per bunch. This flow of particles was due to the effect of a beam screen ( $15 \mu\text{m Ti}$ ) placed in the injection line, about 350 m from ALICE.

#### 5. Conclusion

After several years of R&D, installation and electronics pre-commissioning, the ALICE muon trigger system is now fully operational. It has been tested with cosmic rays and with the first LHC beam injections. The cosmic rays were used to check the performances of the system.

The LHC restart is scheduled for autumn 2009. The next step will be to finalize the global timing of the muon trigger system with the first collisions and then to measure the performance of the detector in real LHC conditions.

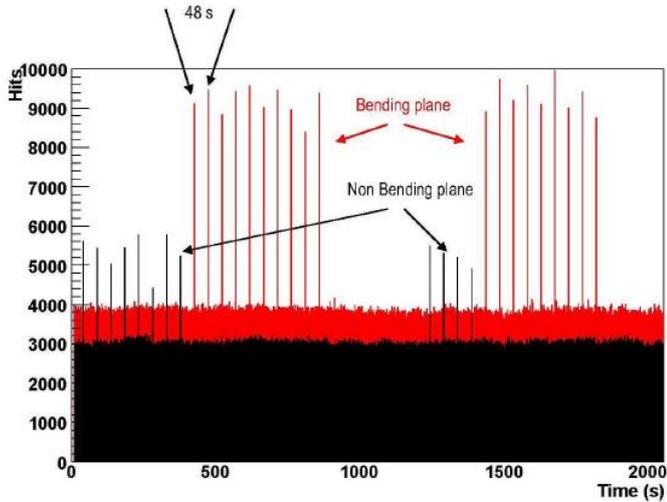


Figure 5: Hit rate as a function of time recorded by one detection plane of the muon trigger system during first LHC beam injections: in red for the bending plane and in black for the non-bending plane.

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