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Design and Performance of the ALICE Muon Trigger System

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The Forward Muon Spectrometer is one of the main components of ALICE, the dedicated heavy-ion experiment at the LHC. Its main goal is to measure heavy quarkonia (J/ψ and Υ families) production in their $\mu^+\mu^-$ decay channel. The muon trigger has to match the maximum trigger rate of about 1 kHz which can be handled by the DAQ. Therefore an event selection is performed by applying a suitable p_t cut on each muon of the pair. The trigger system is based on Resistive Plate Chambers. The experimental conditions, the trigger architecture, its principle and its performance predicted by simulation are presented.

1. Introduction

ALICE [1] (A Large Ion Collider Experiment) is the detector designed for the study of nucleus-nucleus interactions at the LHC. It will investigate the physics of strongly interacting matter at extreme energy-densities to characterize the deconfined state of matter called the Quark-Gluon-Plasma (QGP) [2]. Among the most promising probes, heavy-quarkonia states are particularly interesting since they are hard penetrating probes which provide an essential tool to study the earliest and hottest stages of heavy-ion collisions [3].

ALICE will study the heaviest collision system (Pb-Pb) and also intermediate and low-mass A-A systems. In addition, measurements will be performed for pp (and pA) collisions both as a reference and as a mean to explore proton-proton physics in a new energy domain.
ALICE is equipped with a Forward Muon Spectrometer to study resonances production from the low-mass region to the region of the Υ family as well as open heavy flavors. Quarkonia will be detected in their dimuon decay channel in the angular acceptance of [171°, 178°], corresponding to the pseudorapidity interval $-4 \leq \eta \leq -2.5$. The spectrometer consists of a front absorber and a small angle absorber (beam shielding), a set of high resolution tracking chambers, a dipole magnet, an iron wall (muon filter) and a trigger system.

2. Muon Trigger design considerations

The goal of the muon trigger is to select unlike-sign muon pairs from the decay of resonances, like-sign muon pairs for the background combinatorial studies and single muons from open heavy flavors. In central Pb-Pb collisions, about eight muons from π and K decays are expected per event in the spectrometer. As shown in Fig. 1, these background muons are mainly emitted at low transverse momentum. To reduce to an acceptable level the probability of triggering on

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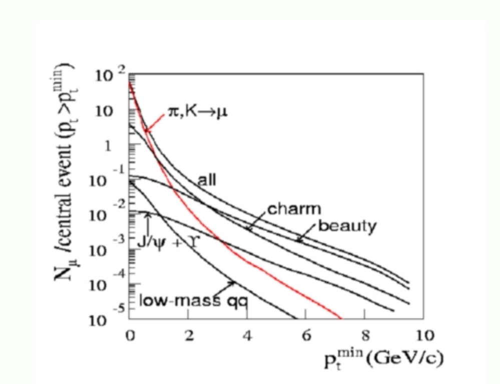

Figure 1. Average number of muons per central Pb-Pb collision with $p_t \geq p_t^{min}$ as a function of p_t^{min} (GeV/c) in the range $-4 < \eta < -2.5$.

events where low-$p_{\rm t}$ muons are not accompanied by the high-$p_{\rm t}$ heavy quarkonia decay partner, a $p_{\rm t}$ cut has to be applied at the trigger level on each muon of the pair.

The requirements for the muon trigger system are the following:

- To work in pipelined mode at a frequency of 40 MHz (ALICE Level 0 trigger constraint);
- To be generated with a total latency of less than 800 ns (given by the ALICE L0 trigger);
- To limit the dimuon rate to a maximum of 1 kHz (given by the DAQ limit and the High Level Trigger);
- To allow the pre-defined $p_{\rm t}$ cuts to be modified depending on the running conditions.

To perform the p_t selection, a position-sensitive trigger detector with space resolution of the order of few mm (for 1 cm read-out strips) is needed. This resolution is achieved by Resistive Plate Chambers (RPC) operated in streamer mode [4].

3. Trigger detector

The trigger system is based on two large area (6×6 m^2) trigger stations (MT1 and MT2) separated by 1 m and placed behind the muon filter (a 1.2 m thick iron wall). Each station consists of two detection planes of 18 single-gap RPCs each. The trigger detector arranged in projective geometry is a relatively small and accessible system. To achieve the required rate capability, RPC electrodes are made of low-resistivity bakelite ($\rho \simeq 10^9$ Ω·cm) [5] coated with two linseed oil layers. The x-y coordinates of the RPC hits are read-out by means of two planes of orthogonal copper-strips oriented along the horizontal (X) and vertical (Y) directions (perpendicular to the beam axis). To keep the occupancy constant, pitch and length of the strips increase with their distance from the beam axis approximatively in the same proportion as the background-hit rate per area unit decreases. The strip pitch is also conditioned by the resolution needed for the p_t cut. The characteristics of the read-out strips are summarized in Tab. 1.

The design of the trigger system is optimized for heavy–ion collisions. Nevertheless, data will also be collected in pp collisions for which the experimental conditions (in particular background from beam-interactions with the residual gas in the beam pipe during the long data taking periods) show substantial differences with respect to heavy–ion operations. Recent studies have shown that the specific pp requirements can be fulfilled with an adequate tuning of the working parameters of the detector and of the Front End Electronics (FEE) [6].

4. Trigger principle

The cut on muon transverse momentum is implemented according to the following method. A muon created at the Interaction Point (IP) is bent by the dipole field and fires MT1 and MT2 in (X_1, Y_1) and (X_2, Y_2) respectively. The magnetic deviation δY_2 is defined as the distance between the muon impact point on MT2 w.r.t. the one ($Y_{2,\infty}$) of an infinite momentum track which fires the MT1 station in (X_1, Y_1) (see Fig.2). A cut on δY_2 increasing proportionally to Y_f (Y position in the dipole middle-plane) is equivalent to a p_t cut, at first order. The calculated values of δY_2 are stored in look-up tables and compared with the measured deviation. The x coordinate informa-

	X strip (hor.)			Y strip (vert.)	
width (mm)					
MT1	10.6	21.2	42.4	21.2	42.4
MT2	11.3	22.6	45.2	22.6	45.2
Nb. of strips	3840	8448	2688	3008	3008
Total		14976		6016	

Table 1
Number of strips in X and Y direction. X strips provide y coordinates while Y strips give x coordinates.

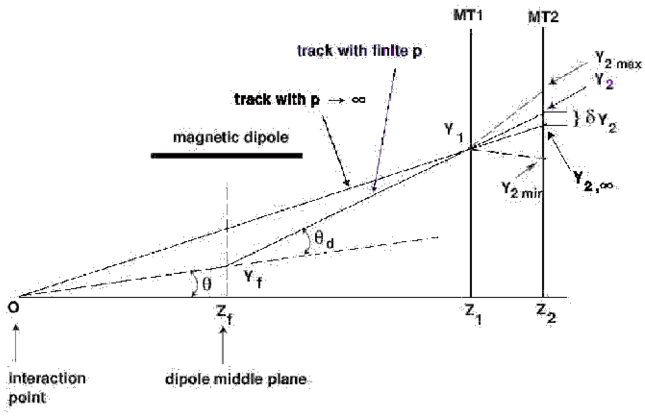

Figure 2. The muon arm trigger principle: projection on the bending plane (Y coordinate).

tion is used to ensure that the tracks point back to the IP. This provides a very effective mean to reduce background.

A dimuon trigger is issued if at least two tracks, above a pre-defined p_t threshold are detected in an event. According to the simulation results, a "low" p_t cut ($\sim$1 GeV/c) can be used for J/ψ, and a " high" p_t cut ($\sim$1.5 GeV/c) for Υ selection.

5. Architecture and trigger electronics

The muon trigger is generated using the information of the four RPC planes. The RPCs are equipped with dual-threshold front-end electronics (ADULT) [7], designed to improve the timing performance of the detector and to match the time resolution (1- 2 ns) needed for the identification of the bunch crossing (each 25 ns in pp collisions).

The local-trigger electronics (234 VME boards hosted in 16 crates) receives digital signals called "bit-pattern" sequences from the FEE ($\sim$2000 cards). Two main functions are implemented in the local electronics:

- The generation of the local L0 muon triggers (on single tracks above low/high p_t thresholds) based on the trigger algorithm located in FPGAs (Field Programmable Gate Arrays);
- The copy of the input bit-patterns which are stored in a pipelined memory read out at the occurence of an ALICE trigger.

Futhermore, the local electronics calculates the track deviation in the bending plane. A minimum of three detector planes fired (out of four possible) is required. The response time is 250 ns. The local-trigger information is then sent to the regional-trigger board (1 per VME crate housing the local boards) and then to the global-trigger electronics which delivers a signal for sin-

	$f_{\rm coll}^{\rm inel}$(Hz)	$F_{\mu\mu}^{\rm Apt}$(Hz)	$F_{\mu\mu}^{\rm Lpt}$(Hz)	$F_{\mu\mu}^{\rm Hpt}$(Hz)
Pb-Pb collisions	4000	910	260	37
Ar-Ar collisions	1.5×10^5	4500	540	50
pp collisions	$2{\times}10^5$	30 ± 7	10 ± 4	5 ± 3

Table 2
Trigger rates for minimum biais Pb-Pb, Ar-Ar and pp ?ollisions.

gle muons as well as for muon pairs for the whole trigger system. The total muon trigger latency is $\sim$ 650 ns, including cable delays. It participates in the L0 of the general ALICE trigger system [8].

6. Performance

Muons from different sources have been simulated by means of PYTHIA 6.2 and HIJING generators. The particle transport up to the trigger detector is done with GEANT3. A J/ψ and Υ trigger efficiency of 69% and 91% is obtained with the low p_t and high p_t cuts respectively. The efficiciency calculations are normalized with muons firing 3/4 detector planes. The trigger rates, presented in Tab. 2, are given for the low and high p_t cuts ($F_{\mu\mu}^{\rm Lpt}$ and $F_{\mu\mu}^{\rm Hpt}$) as well as "without cut"($F_{\mu\mu}^{\rm Apt}$) corresponding to a minimum accessible p_t ($\sim$0.5 GeV/c). The rates are calculated for minimum bias events at the nominal ALICE luminosities for the Pb-Pb and Ar-Ar systems.

Concerning the minimum bias pp collisions at 14 TeV, PYTHIA 6.214 was used with GEANT3 for the transport. The trigger efficiencies for J/Ψ and Υ are 72% and 96%. The difference w.r.t. efficiencies in Pb-Pb is due to the different shape of the quarkonia $p_{\rm t}$ distributions (from the Color Evaporation Model [9]) leading to different $p_{\rm t}$ distributions of the muons. According to Tab. 2, we expect a trigger rate of about 10 Hz with the low $p_{\rm t}$ cut. These rates in pp take into account only particles coming from the IP. Background from beam-interactions with the residual gas in the beam pipe can be efficiently rejected by the VZERO detector.

7. Conclusions

The trigger system of the ALICE Forward Muon Spectrometer is now fully designed and satisfies the DAQ requirements (dimuon trigger rates $<$ 1 kHz independent of the collision system).

The production tests are close to completion. 75% of RPCs are built and tested [10]. The production and tests of the front-end electronics are completed along with the cables from FEE to local electronics (1500 cables). Local/regional/global-trigger electronics production is done, the end of tests is forseen for next spring.

The ageing tests in streamer mode for heavy-ion data taking are completed. The ageing tests for pp data taking are in process and have exceeded a 4 years correspondence of the pp program.
The installation in the ALICE cavern is scheduled in Spring 2006, to be ready for LHC startup.

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