The development of high performance online tracker for
High Level Trigger of Muon Spectrometer of ALICE

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Abstract

The Muon Spectrometer (MS) of the ALICE experiment at LHC is equipped with a HLT
(High Level Trigger), whose aim is to improve the accuracy of the trigger cuts delivered at the
L0 stage. A computational challenge of real-time event reconstruction is satisfied to achieve this
software trigger cut of the HLT. After the description of the online algorithms, the performance
of the online tracker is compared with that of the offline tracker using the measured pp collisions
at \( \sqrt{s} = 7 \text{ TeV} \).

Key words: ALICE, HLT, Muon Spectrometer, online reconstruction, software trigger

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1. Introduction

Lattice calculations of Quantum ChromoDynamics (QCD), predict that at a critical
temperature (\( \sim 170 \text{ MeV} \)) and energy density (\( \sim 1 \text{ GeV/fm}^3 \)), the nuclear matter un-
dergoes a phase transition to a deconfined state of quarks and gluons [1], also known as
Quark Gluon Plasma (QGP). In the laboratory, the QCD phase diagram and the ex-
pected formation of the QGP can be studied using ultra-relativistic heavy-ion collisions.
The suppression [2] or enhancement [3] of heavy quark resonances in heavy-ion collisions
at LHC is predicted to be a strong signature of QGP as the temperature of the fireball
produced in Pb-Pb collisions is expected to be about three times higher than the critical
temperature.

ALICE (A Large Ion Collider Experiment [4–6]) is a general purpose experiment whose
detectors identify and measure hadrons, electrons, photons and muons produced in p-p
and Pb-Pb collisions at the CERN LHC. ALICE is optimized for heavy-ion reactions and thus is capable to track and identify particles from very low (∼100 MeV/c) to fairly high (∼100 GeV/c) transverse momentum, to reconstruct short lived particles like hyperons, D and B mesons and the heavy quark resonances [J/ψ (c̅c), Υ (b̅b)] in an environment of extreme particle densities. The J/ψ and Υ are reconstructed by ALICE in the central rapidity region (−0.9 < y < 0.9) from their dielectron decay channel and at large rapidity (2.5 < y < 4.0) from their dimuon decay channel using a spectrometer.

This Muon Spectrometer [Fig. 1 (top)] is designed to run at the highest dimuon rate in heavy-ion collisions at LHC (L ∼ 10^{27} cm⁻² s⁻¹ for Pb-Pb beam). It consists of the following components: a passive front absorber to absorb hadrons and photons from the interaction vertex; high granularity tracking system of 5 stations each with two detection planes; a large warm dipole magnet; a passive muon filter wall, followed by four planes of trigger chambers and a inner beam shield surrounding the beam pipe to protect the chambers from high particle flux at large rapidities.

Each tracking chamber provides two dimensional hit information by measuring the charge distributions on two segmented cathode planes. The cathode which has higher resolution in the direction (y-direction) perpendicular to the plane containing the magnetic field (x-direction) and beam axis (z-direction) is referred to as the bending cathode, while the other along the magnetic field is referred to as non-bending cathode. Two tracking stations are placed before, one inside and two after the dipole magnet. The total number of readout pads is about 1.1 million and covers an area of about 100 m². The trigger system consists of four Resistive Plate Chamber (RPC) planes arranged in two stations which are placed behind the muon filter. The trigger system has to select events containing a muon pair coming from the decay of J/ψ or Υ resonances from all possible background contaminations. The main background comes from low-\( p_t \) muons of pion and kaon decays. Thus, the L0 trigger is generated if at least two tracks with opposite charge (or the same charge used in this case for background subtraction), both above a predefined \( p_t \) cut are detected in an event. Two different \( p_t \) thresholds of 1 GeV/c and 2 GeV/c have been chosen for J/ψ and Υ measurement, respectively, according to simulation studies.

However, the coarse grained segmentation of the RPCs and the presence of the iron wall before the trigger stations, do not allow a sharp \( p_t \) cut. This is demonstrated in Fig. 1 (bottom), through a simulation study carried out using the AliRoot framework [7]. It is evident that the L0 trigger passes a substantial number of events which are below the \( p_t \)-threshold. In addition, the trigger efficiency is around 60% near the threshold value of 1 GeV/c and 2 GeV/c. Thus, the primary task of the dimuon High Level Trigger (dHLT) is to refine the \( p_t \) cut in order to increase its selectivity. For this purpose, in the addition to the trigger chambers, the slower but more accurate tracking chambers have been used and a real-time event reconstruction scheme for the entire Muon Spectrometer has been developed.

This scheme should satisfy the following criteria:
(a) The event processing should be done at a rate of 1 kHz for Pb-Pb collisions; (b) The real-time reconstruction should produce results of appreciable quality without losing
any signal event; (c) It should be robust and should not stop processing due to any data corruption in the input buffer.

The event reconstruction in tracking chambers is a two step process, which involves the reconstruction of charge clusters and the track formation using the reconstructed hit points. In offline reconstruction, these two steps are implemented by Mathieson fitting of the charge clusters which are defined by the nearest neighbour algorithm and Kalman filtering, respectively. However, none of them can be applied for real-time reconstruction due to the time constrain set by the expected event rate of 1 kHz. Thus, new algorithms for fast reconstruction have been developed for dHLT [8]. These are described below.
2. Algorithms

**Hit-Reconstruction:** This new algorithm does not identify the charge clusters by nearest neighbour search. Instead, it searches for pads with maximum charge whose immediate neighbours have nonzero charge. The two schemes are equivalent since every cluster has an unique central pad whose charge is greater than other members. Once the central pads are identified, the hit positions along the bending and non-bending directions are given by the centre of gravity of the charges measured on the central pad and the two pads around it in y and x directions, respectively. Finally the information on bending (y-direction) and non-bending (x-direction) cathodes are merged to generate hit position.

**Partial Tracking:** In the first attempt to improve the accuracy of the L0 trigger, the trigger track segments are extended upto the fourth tracking station [8,9]. The straight line tracks in the two tracking stations after the magnetic field give a better p_t estimation than the value obtained from the trigger tracks. The result of this improvement is shown in Fig. 1 (bottom), by the solid lines which are marked by ‘HLT Partial Tracker’. It is evident that there is a marked improvement in accuracy over the L0 trigger, but the trigger efficiencies at p_t = 1 GeV/c and 2 GeV/c are about 20% and the desired efficiency (>90%) is achieved only around 1.5 GeV and 2.5 GeV, respectively. Thus, this method is not suitable for dHLT and the full tracking through the magnetic field is essential.

**Full Tracking:** The Full Tracking formalism creates tracks from the last trigger station to the first tracking station. Various tracking stages has been shown in Fig. 1(top). These are described below.

- **Tracking in Station 4,5:** This part is identical to the Partial Tracking method where the straight line tracks are extrapolated upto the fourth tracking station.
- **Tracking in Station 1,2:** In this part, the small track segments are formed in station 1 and 2 using Cellular Automata [10] (CA) method. The CA formalism has been followed since it does not require any a priori knowledge of the seed for the tracking.
- **Kalman χ^2-test:** Once the track segments are formed before and after the dipole magnet, they are matched through the magnetic field using χ^2 test of Kalman filtering [11]. If the track segments are not matched, the p_t of the track is estimated as in the case of Partial Tracking. This ensures that no physics event is lost in the Full Tracking scheme.
- **Track Extrapolation:** In case of complete tracks, the p_t estimation is further improved by incorporating the corrections due to energy loss and multiple Coulomb scattering in the front absorber.

3. Results

The accuracy and efficiency of the p_t-cut for the Full Tracker is shown in Fig. 1 (bottom), by the solid line marked as ‘HLT Full Tracker’ and have been compared with the offline reconstruction. It can be observed from this simulation study that the estimated p_t’s of the muon tracks match closely with the offline analysis and the desired improvement of the L0 can be achieved.
The framework of the Full Tracker was successfully implemented on the HLT computing farm and all the validation tests were completed before the pp collisions at $\sqrt{s} = 7$ TeV data taking in March, 2010.

In Fig. 2, the effect of the $p_t$-cut from the offline analysis and from the real-time Full Tracker has been compared for pp (“real data”) collisions. The top and bottom panels of the figure show the invariant mass plot around the $J/\psi$ peak when the $p_t$ of one muon was found to be greater than 1 GeV/c by the offline and online reconstruction, respectively. The invariant spectra are fitted with a Gaussian signal and a double exponential functions. The width of the $J/\psi$ peak was found to be 93.8 and 95.5 MeV/c$^2$ for offline
and HLT triggers, respectively. This shows that a sufficient accuracy of the \( p_T \)-cut for the Full Tracker is achieved. However, the counts in the \( J/\psi \) peak for the offline reconstruction is higher by 7% with respect to the online reconstruction. This indicates a small inefficiency of the online trigger. Studies are ongoing to correct this effect.

4. Summary

It has been demonstrated both from simulation and data, that the HLT for the Muon Spectrometer is capable to improve the trigger momentum resolution of the tracks and validate the L0 muon candidates by a sharp \( p_T \) cut. In the coming years of LHC operation, when the luminosity of the beams will reach its nominal values, the dHLT will play a crucial role in background rejection and allow the Muon Spectrometer to run at higher L0 trigger rates. In addition, it is estimated that the use of dHLT, with a loosening of the L0 \( p_t \) cut, will allow recovering about 20% of the low-\( p_t \) muon events.

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