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RPC Based Muon Trigger for the CMS Detector at LHC

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1 Introduction

The CMS detector [1] is one of the most challenging applications of RPC's nowadays. The total area covered by RPC's reaches 4000 m^2. The particle rate varies from 1 up to about 1000 Hz/cm^2 depending on the angle. In total of the order of 10^{16} pp collisions per year will be seen. On the average 25 pp collisions take place every 25 ns. The first level single muon trigger has to reduce this rate down to about 1 kHz, i.e. six orders of magnitude.

"CMS" stands for Compact Muon Selenoid, however the detector is capable to measure precisely electrons and photons as well as muons. The name reflects the way the detector has been designed. First a superconducting solenoid generating a magnetic field of 4T has been chosen to facilitate muon trigger and momentum measurement. The strong field leads to a compact design. Both calorimetry and high granularity inner tracker are accomodated inside a large diameter ($\approx$6 m) coil. Overall outlook of the detector is shown in Fig. 1.

2 Physics potential

The CMS detector has been designed to study a wide range of physics phenomena accessible in pp collisions at LHC. Here let me mention only a few highlights:

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- Standard Model Higgs search:
  $H \to \gamma\gamma$, $H \to ZZ^*$, Heavy Higgs ($m_H \approx 1$ TeV)
- Minimal Supersymmetric Standard Model Higgs search:
  h^0, $H^0 \to \gamma\gamma$, A^0, $H^0 \to \tau\tau$, $H^\pm \to \tau\nu$ cs
- Top physics
- CP violation (e.g. $B_d^0 \to J/\psi\ K_S^0$)
- Heavy ion physics (e.g. Υ', Υ'' suppression)

An example of a possible discovery for which the performance of the muon system is crucial is the $H \to ZZ^*$ channel. Simulated mass spectra are presented in Fig. 2. The signal is clearly visible over the background.

3 Detector components

3.1 Inner tracker

A cylindrical volume of r<1.3m and —z—<3.5m around the interaction point is occupied by the inner tracker (Fig. 3). Barrel part is arranged in three superlayers, each having four detector planes. The innermost superlayer is a Silicon Microstrip Detector, others are MicroStrip Gaseous Counters (MSGC). Forward part consist of 5 discs with Silicon Detectors and 18 MSGC discs on each side. High granularity of the detectors has been chosen to allow an efficient pattern recognition in the high track density environment. In total there are $7 \cdot 10^6$ Si channels providing resolution σ=15μm and $12 \cdot 10^6$ MSGC channel giving σ=50μm.

3.2 Calorimetry

General layout of CMS calorimeters is shown in Fig. 4. Two possible solutions of Electromagnetic Calorimeter (ECAL) are investigated. One is made of 26 m^3 of CeF_3 crystals. Crystals are arranged in 110 000 towers, two crystals each. Front area of the tower is 1.6 x 2.4 cm^2. Length of the front and the back crystal is 15 and 27 cm respectively. This solution is expected to provide an energy resolution better than 1% at 50 GeV.

An alternative option is the so called Shashlik Calorimeter. It is a 2 mm lead / 4 mm scintillator sampling calorimeter. Light is collected by 1.2 mm diameter fibers arranged in a 1 cm grid (see Fig. 5). Energy resolution is about 1.5% at 50 GeV.

Hadron Calorimeter (HCAL) is a typical copper/scintillator sampling calorimeter with 4 scintillator plates per interaction length. It gives energy resolution of 10% at 100 GeV and 4% at 1 TeV. First 25 X_0 has finer granularity to be a tail catcher and trigger veto for the ECAL, and eventually to substitute the ECAL in the first phase of the experiment.

Very Forward Calorimeter (VFCAL) is an iron/gas sampling calorimeter. It ensures rapidity coverage up to $|\eta| < 5$.

3.3 Muon detector

The CMS muon system consist of 4 muon stations (see Fig. 1 and 6). Dead spaces are distributed in such a way that every track crosses the sensitive area of at least three stations. Each station is used for triggering as well as for momentum measurement. Momentum measurement requires precise position determination ($\approx 200\mu m$ per measuring plane). Since the expected occupancy is low, drift tubes are natural candidates for muon chambers. The only exception is a very forward region where Cathode Strip Chambers (CSC) are foreseen. Actually two types of chambers are considered: Drift Tubes with Bunch Crossing Capability (DTBX) and Wall-Less Drift Chambers (WLDC). Both will be presented in dedicated talks [2, 3]. Thus, here I describe only general features of the whole system. Total area of the muon stations exceeds 3000 m^2. Every station consists of several layers of chambers. In case of DTBX 8 layers measure $r\varphi$ coordinate, 4 layers measure the orthogonal coordinate. In case of WLDC the corresponding numbers of layers are 6 and 4 respectively. Wires are spaced by 40 mm (DTBX) or 14 mm (WLDC). The total number of channels is of the order of half to one million. Momentum resolution of the muon system alone and combined with the inner tracker are presented in Fig. 8.

4 Muon trigger

4.1 Physics goals

In order to study the phenomena mentioned in Sec. 2 three types of the first level muon trigger are considered:

1. **Inclusive single muon trigger**, $|\eta| < 2$, $p_t^{cut} \approx 25 - 100$ GeV
   to study large p_t W physics and search for massive W'.

2. **Inclusive double muon trigger**, $|\eta| < 2$, $p_t^{cut} \approx 10$ GeV
   this is in fact a Z^0 trigger

3. **Triple muon trigger**, $|\eta| < 2$, $p_t^{cut} \approx 4$ GeV
   e.g. to study CP violation in b decays

4.2 Technical requirements

Rate

An original idea of CMS is to abandon classical three levels structure of the trigger system. Usually the second level trigger is made of fast, dedicated (and therefore expensive) processors providing simple arithmetic operations with high performance. Trends in the computer development suggests that in a few years this task can be taken over by cheap, commercial workstations. Thus after the first level trigger data goes to such an "event filter" which is a computer farm performing tasks usually done by the second and the third level triggers. In case of CMS this event filter is designed to operate with up to 50 kHz total first level trigger rate. In fact we estimate that this rate should not exceed 10 kHz, thus rather large safety margin is assumed. Such a scheme imposes quite high requirements for the first level trigger. For example the single muon trigger rate should be of the order of 1 kHz.

Flexibility

In order to access all the interesting physics channels and to tune the rate to the level acceptable for the event filter the p_t threshold must be adjustable. In the present design the full range 4–100 GeV is covered.

Time resolution

The trigger should be able to assign an event to the proper bunch crossing. Thus the time resolution should be much better than the bunch crossing interval, i.e. 25 ns.

Speed

An answer of the trigger must be available 1 μs after collision.

High acceptance

Searches for rare events require acceptance to be close to 100%. Therefore the muon stations are arranged in such a way that every track (with $p_t > 6$ GeV) crosses at least 3 stations.

Redundancy

Trigger system has to deal properly with all possible inefficiencies, noises, accidental pileup and products of muon radiation. Thus, it has to have substantial redundancy. In CMS this is ensured by the fact that the measurement is done in at least three stations.

4.3 Trigger detectors

In both cases of muon chambers, DTBX and WLDC, possibility of autotriggering is investigated. However, since it will be described in dedicated talks [2, 3] here I will concentrate on a third solution, i.e. muon trigger based on dedicated Resistive Plate Chambers.

The main properties of the RPC, which make them very good candidates for large surface muon trigger chambers, are

- Good time resolution (≤ 5 ns), limited by the signal propagation time along the strips.
- Large signals from m.i.p, allowing simple and cheap analog R/O electronics.
- Construction adapted to the mass production.

In the region above $|\eta| = 2$ particle rate can exceed 100 Hz/cm^2 which is a limit for standard RPC's. Therefore Parallel Plate Chambers (PPC) have been foreseen to cover this region. However recent encouraging results with pure Freon RPC's [4] give a hope that also that region can be accessible for this technique.

4.4 Principle of operation

The solenoidal magnetic field of the CMS detector causes track bending in a plane perpendicular to the beam direction (Fig. 6). In the central part of the detector the magnetic field is almost independent on z coordinate (along the beam direction). In the forward region, bending power of solenoidal magnetic field decreases with pseudorapidity η. However the bending is still big enough to distinguish transverse momenta in wide range of values.

In principle, knowing the vertex, two measuring planes after the coil giving a local track vector are enough to measure momentum and apply a p_t cut. However in order to deal with fluctuations due to multiple scattering and energy losses we make use of 4 measuring planes (one per station). A four point pattern (Fig. 7) is more redundant than the simple vector and gives a sharper cut.

Above idea has to be modified for muons with $p_t < 6$ GeV in the barrel because they are not able to reach outer muon stations. Therefore we place two RPC planes in the first and the second muon station and again use four point pattern to make the p_t cut.

4.5 Practical realization

Since the track is bent in the plane perpendicular to the beam it is enough to know precisely only the φ coordinate. Thus measurement can be done with long strips positioned along the beam in the barrel and radially in the forward region. In the barrel the length of the strips is limited by the signal propagation time. To keep the time resolution below 10 ns the strip length should be of the order of 1 m. In the forward more fine segmentation is required because bending depends on η and different cuts have to be applied for different η regions.

Width of the strips is determined by the required momentum resolution. In order to have efficient p_t cut up to 100 GeV the strip width should be of the order of 5 mrad (3 cm at station 3). Cylindrical symmetry of the problem naturally leads to projective geometry.

4.6 Trigger processor algorithm

A particle passing the detector crosses muon stations, hitting the RPC strips on its way. In the absence of the energy loss and multiple scattering there will be one to one correspondence between the pattern of hits and the muon transverse momentum. In the real world with energy loss and multiple scattering there is a set of hit patterns (masks) for each value of the p_t. The sets of valid mask change with pseudorapidity η. They are practically η independent in the barrel region, but vary in the forward region. The mask sets for two different transverse momenta are ordered i.e. the set for the higher p_t is a subset for the lower p_t. This property allowed us to establish the mask set for a given value of the threshold p_t^{cut}. Such a set can be loaded into a trigger processor. Then every observed track pattern is compared with the predefined masks. A track gives a trigger if its pattern belongs to the set of valid masks.

4.7 Simulation results – efficiencies and rates.

Presented algorithm has been simulated in order to calculate efficiency curves and final trigger rates [5]. The GEANT package has been used to track muons with p_t between 3 and 100 GeV through the CMS detector. Multiple scattering, energy loss and production of secondaries has been taken into account.

The efficiency curves as a function of the muon p_t for different values of p_t^{cut} and η are shown in Fig. 9. The p_t spectra of muons from various processes were then convoluted with the efficiency curves. Starting from the inclusive hadron spectrum we have estimated the rate due to punchthrough using GEISHA shower simulation. This has been checked against measurements made in RD5 experiment. The complete hit pattern in the muon stations was simulated on which the trigger algorithm was then applied.

The resulting integrated trigger rates for various p_t^{cut} values are shown in Fig. 10.

5 R&D

In order to turn ideas into reality an intensive R&D program has already taken off. Most of the work concentrates around the RD5 experiment [6] which will be described in a dedicated talk [7]. R&D on chamber construction is provided by Warsaw group. First prototype, 10x10 cm^2 (Fig. 11), has been built last year and tested with cosmic rays and radioactive sources. As an example, accuracy of the hit position reconstruction is shown in Fig. 12. Next prototype, 50x50 cm^2 is under assembling and it will be tested in April's RD5 run.

6 Conclusions

Resistive Plate Chambers offers a possibility to build powerful muon trigger systems. In the CMS detector the first level muon trigger based on 4000 m^2 of RPC's is able to select efficiently interesting events reducing primary rate by a few orders of magnitude. Adjustable p_t threshold covers the range 4–100 GeV. Robustness of the system is ensured making use of four triggering stations.

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