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CMS muon detector and trigger performances

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Abstract

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CMS muon detector and trigger performance

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The CMS muon system has been in full operation since its commissioning with several million events of cosmic ray data. The muon system of the CMS experiment consists of three independent detectors: Resistive Plate Chambers (RPCs) both in the barrel and the endcap, Drift Tubes (DTs) in the barrel, and Cathode Strip Chambers (CSCs) in the endcap region. In this report, the performance of each of these muon detectors and their trigger response are presented.

1. The CMS muon system

Muon identification becomes more crucial for physics analysis as the center-of-mass energy and the luminosity increase. The usefulness of high P_t muons in measurements and searches in the standard model (SM), as well as in beyond the SM, becomes more evident. In LHC era, much of the new physics at LHC is expected to be gleaned within the muon channels.

The bunch crossing rate at the LHC is 40 MHz. It means that the CMS trigger must achieve an enormous reduction and scant but efficient selection of events at a rate of 100 Hz.

To achieve this challenging goal the CMS experiment has designed and built a robust muon system with three muon detectors: drift tubes (DTs), cathode strip chambers (CSCs), and resistive plate chambers (RPCs) [1].

The combined power of these three muon detectors is to trigger and reconstruct muons, and measure the momenta of these muons with high precision [2].

As a dedicated fast muon trigger, the RPCs are installed both in the barrel region and in the endcap region. For the trigger and momentum measurement of the muons, the DTs are installed in the barrel region and CSCs in the endcap region.

Each of three muon detectors is described in the following sections.

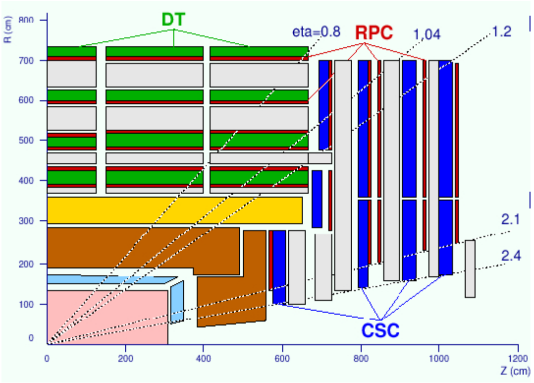

Figure 1. Longitudinal view of one quadrant of the CMS detector. The encompassing return yoke is in gray.

1.1. Resistive Plate Chambers (RPC)

The development of the resistive plate chamber exhibits the accumulated efforts to achieve a good time resolution from a general detector.

A model of a detector with excellent time resolution is the detector developed by Pstove and Fedotovich that showed a time resolution as good as 24 ps in spark mode operation. But the time resolution was obtained from a complicated detector that operates at a high pressure of 12 bar in a pressure vessel and used semiconducting glass as the anode whose resistivity is about $10^9 \sim 10^{10}\Omega \cdot cm$.

Further simplification by Santonico and Cardarelli was needed to avoid the use of special things and maintain the trait of good time resolution. These efforts finally led them to the development of resistive plate chambers. The semiconducting glass was replaced with a highly pressed lamination called bakelite whose resistivity is in the range of $\sim 10^{11}\Omega \cdot cm$, and the high pressure chamber is replaced with a chamber with two parallel resistive electrodes operating at normal pressure. Also, the operation mode is changed from the spark mode to the avalanche mode to increase the rate capability due to lower dead time.

In the CMS RPCs, one side of the bakelite plate is coated with graphite to make the resistive electrode. Two resistive electrodes are separated by 2 mm spacers to form the parallel plate gas gaps, where the opposite side of the electrode embraces the gas volume. For higher trigger efficiency, CMS places the RPC gaps in double layers. And the readout strips are placed between the two layers of the gaps.

The CMS RPC system is employed in both the barrel and the end cap regions. In the barrel region the RPCs are coupled with the DTs, and in the end cap region, RPCs together with CSCs are mounted on the faces of the iron yoke disks. The total number of installed RPCs is 912 chambers of which 480 chambers are installed in the barrel region and 432 chambers in the endcap region.

The RPC shows a time resolution of about $1 \sim 2$ns and is therefore capable of tagging the event in a much shorter time than the 25 ns time interval between the two consecutive LHC proton bunch crossings (BX). Therefore, the RPC can provide a fast trigger for muons and assign the muon track to the correct BX without ambiguity even in the harsh environments of very high rates of background at the LHC.

The RPC trigger algorithm looks for both spatial and temporal coincidences of hits in adjacent layers of the RPCs. This algorithm is implemented in the PACT which looks for patterns of hits in the geometry of the RPCs arranged in pseudo-rapidity. Each pattern corresponds to a certain transverse momentum. Once the PACT finds a pattern, then the pre-assigned transverse momentum is assigned to the pattern of hits. The PACT sends the best 4 muon candidates to the Global Muon Trigger.

1.2. Drift Tube Chambers (DT)

The CMS magnet return yoke consists of 6 endcap disks and 5 barrel wheels. On each wheel, 4 layers of the pockets that form concentric cylinders surrounding the superconducting solenoid coil house the DTs. These 4 concentric layers are called stations as shown in Figure 1. The stations are named MB1, MB2, MB3 and MB4 from the innermost layer to the outermost layer, respectively. The 4 stations of DTs are segmented into 12 sectors.

DTs are made of rectangular drift cells. Four layers of rectangular drift cells are staggered by one-half a cell to form a superlayer (SL). Three SLs form a drift tube chamber where two SLs whose sense wires are placed parallel to the beam line are called the “phi-SL” and the remaining one SL whose sense wire is placed in the transverse direction is called “theta-SL”, to measure the ϕ and θ track coordinates. The track projected in the r-ϕ plane can be measured by the phi-SL and the track projected on the r-θ plane can be measured by the theta-SL. A local muon track will be formed from the hits in the rectangular drift cells. Therefore, enough redundancy is achieved for a muon track that can have up to 12 hits in each station.

For the purpose of the local muon trigger, the trigger electronics as well as the readout electronics are mounted on the chamber. The four components in the trigger electronics are Bunch and Track Identification (BTI), Track Correlators (TRACO), Trigger Servers (TS), and Sector Collectors (SC). The BTIs are interfaced to the front-end electronics.

All the staggered drift cells in the four equidistant planes in each SL are examined for hits that are aligned and coincident by the BTI. Then the BTI produces the track segments from the associated hits, and the track segments information is sent to the TRACO, which correlates the track segments and defines a new track segment. This result is fed into the TS, which selects a track in a multi-track environment.

The best 4 muon candidates per BX are transmitted to the global muon trigger.

1.3. Cathode Strip Chambers (CSC)

In the endcap region there are 6 disk yokes: 3 each in both forward areas. The CSCs are mounted on these disk yokes . The installation on the disk dictates the shape of the CSCs to be trapezoidal. ME1 chambers of the CSCs are mounted in three concentric rings on the first disk (YE1). From the innermost ring to outermost ring ME1/1, ME1/2 and ME1/3 of the CSCs are installed. ME2 chambers are on the second disk (YE2): ME2/1 and ME2/2. ME3 chambers are on the third disk (YE3): ME3/1, ME3/2. And, ME4/1 is mounted on the back side of the YE3. A total of 468 CSCs are installed and commissioned.

The cathode strip chamber consists of 6 anode wire planes interleaved within 7 cathode strip planes. The anode wires are placed azimuthally and the cathode strips are placed radially. Due to its trapezoidal shape, the width of the strip varies from 3.2 mm at the innermost location to 16 mm at the outermost location. The space between two adjacent anode wires varies from 2.5 to 3.175 mm according to its type.

The mode of operation is proportional and an avalanche on a anode wire induces charge on a cathode strip plane. The shape of the induced charge is parameterized by the Gatti function. The number of strips fired by the induced charge is about $3 \sim 4$.

As far as spatial resolution is concerned, the ME1/1 chamber gives a better spatial resolution due to its narrower strips in the given geometry. Since the single plane resolution of ME1/1 is about 80 μm, the 6-plane chamber resolution is 33 μm as expected.

The CSCs can simultaneously trigger and measure the momenta of muons with precision in the endcap region as the DTs do in the barrel region. A muon track segment is formed by combining all measurements from 6 planes. Muon track segments are also called Local Charged Tracks (LCT). Anode LCT can be found by the ALCT board where wire hit patterns in the six planes are examined for originating from the vertex point, and it also determines the BX. Cathode LCT can be found by the CLCT board where strip hit patterns consistent with high Pt tracks are sought. The trigger mother board (TMB) checks for the coincidence of ALCT and CLCT data. If a coincidence is found, then this information is fed into subsequent levels. The best 4 muon candidates from the CSC muon sorter are transmitted to the Global Muon Trigger.

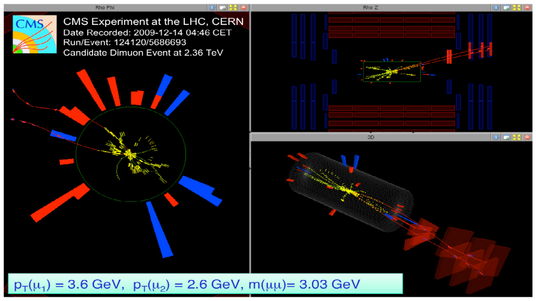

Figure 2. Muon detectors triggered and measured the muon momenta in a dimuon event.

2. Conclusions

All three muon detectors are commissioned and proven to be effective for all the necessary trigger functions, and also in the subsequent muon reconstruction and momentum measurement. The performance of the three CMS muon detectors has met the physics design goals, and these detecors are ready for the physics run as illustrated by the di-muon event in Figure 2.

REFERENCES

1. *CMS Muon Technical Design Report* (CERN/LHCC 97-32)
2. *CMS Trigger Technical Design Report* (CERN/LHCC 2000-38)