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Muon Reconstruction and Identification at CMS

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Abstract

The Compact Muon Solenoid (CMS) is a general purpose detector currently being constructed for operation at the Large Hadron Collider (LHC) at CERN. One of the main goals of the CMS design is to ensure efficient and accurate identification and reconstruction of muons. This contribution describes two software algorithms that have been developed for reconstructing muons in the CMS experiment. In one approach stand-alone muons are reconstructed in the muon system and matched to a track in the central detector. The other technique starts from central tracks and extrapolates them toward the outer detector to look for compatible muon signatures in the calorimeter and muon chambers. Both approaches are complementary. The expected performance has been studied in detail using Monte Carlo simulation. During the recent Magnet Test and Cosmic Challenge (MTCC) the muon reconstruction was employed successfully to reconstruct cosmic muons traversing a full slice of the CMS detector.

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1 Introduction

The efficient and pure identification of muons and the reconstruction of their momentum with high precision over a large range of muon energies is crucial for the LHC physics program. The general-purpose CMS detector [1] provides excellent muon identification and reconstruction capabilities. A large superconducting solenoid [5] with a 4 T magnetic field provides strong bending power, allowing a precise measurement of the momentum. Centrally produced muons are detected in the central tracker, calorimeters and a hermetic muon system. The silicon tracker [2], electromagnetic calorimeter (ECAL) [3] and hadronic calorimeter (HCAL) [4] are located inside the magnet coil. The hadron outer (HO) detector consists of scintillator layers outside the magnet coil, in the barrel region of the detector. The muon system [6] consists of three different types of detectors, sandwiched between layers of the iron return yoke. In the barrel region drift tube (DT) chambers are used, while the end caps are instrumented with cathode strip chambers (CSCs). Good time resolution is provided by Resistive Plate Chambers (RPCs) both in the barrel and end cap.

This contribution describes two approaches that have been developed for reconstructing muons in the CMS experiment. A brief description is given of the two algorithms and their performance expected from Monte Carlo studies. In addition we report the successful application of muon reconstruction in the new CMSSW software framework using data from the recent Magnet Test and Cosmic Challenge (MTCC).

2 Muon Reconstruction

The standard muon reconstruction algorithm starts by searching for muon candidates using the data from the muon detectors only. Local muon reconstruction is used to reconstruct muon segments (or clusters) from hits in individual DT and CSC (or RPC) chambers. Starting from the innermost muon station with a reconstructed segment and combining it with compatible segments (and/or hits) in other muon stations, stand-alone muon tracks are formed using a Kalman filter technique. The muon trajectory is extrapolated from the innermost muon station to the outer tracker surface to search for a compatible track reconstructed in the silicon tracker. A global fit is performed using hits in the silicon tracker together with hits that were included in the original stand-alone muon track. Detailed studies of the performance have been done using full detector simulation, pile-up events and realistic detector misalignment scenario's [7, 8].

3 Muon Identification

Figure 1: Muon compatibility for tracks from simulated $p_T = 10 \text{ GeV}/c$ single muons and pions in the end cap of the detector, based solely on the observed energy deposits in the calorimeters.

The muon identification algorithm is an inside-out algorithm that starts from all reconstructed tracks from the silicon tracking detector and quantifies for each track what the compatibility is with the muon hypothesis. It

Figure 2: Efficiencies for global muon reconstruction and global muon reconstruction plus identification, as a function of pseudorapidity for $p_T = 5$ GeV/ c single muons.

extrapolates the track outward and searches within a narrow cone around the track for energy deposits compatible with a minimum ionizing particle in the calorimeter and muon hits and segments in the muon system. Based on the measured energies a compatibility value between 0 and 1 is calculated. In Figure 1 the muon compatibility value is shown for $p_T = 10$ GeV/ c pions and muons in the end cap, based solely on energy deposits in the calorimeter associated to the candidate tracks. Similarly a muon-compatibility based on hits and segments in the muon system is calculated. Figure 2 shows the gain in muon identification efficiency that can be achieved by using this inside-out approach in addition to the standard muon reconstruction. For this plot a track is considered to be identified as a muon when it has a calorimeter-based muon compatibility larger than 0.8, and a muon-system based compatibility larger than 0.4. These cuts can be optimized depending on the physics application. Studies [7, 9] based on full detector simulation show that especially for low- p_T muons a significant gain in efficiency can be obtained with low rates ($\approx 0.2\%$) of mis-identification of pions as muons, even inside jets.

4 The Magnet Test and Cosmic Challenge

During the months of July and August 2006 CMS performed the first part of the Magnet Test and Cosmic Challenge (MTCC), a crucial commissioning test in which the main goal was to switch on and test the 4 Tesla superconducting solenoid in the surface assembly hall, before lowering the CMS detector to the underground cavern. This provided a unique opportunity to operate all the sub-detectors of CMS in a combined slice test and record cosmic muons with and without magnetic field. Participating detectors included most of a 60 degree sector of two barrel wheels and end cap of the muon system, two ECAL super modules, 15 HCAL wedges, and 133 single and double-sided Silicon Strip Tracker modules, with up to six tracker layers that could be traversed by a straight muon track. During the ‘phase I’ of the MTCC more than 70 million events were recorded by the data-acquisition system and shipped to CERN and other analysis centers around the globe. During the last weekend of data taking more than 25 million cosmic triggered events were recorded with the principle sub-detectors active, of which 15 million events with a stable magnetic field of 3.8-4.0 T.

All of these events were recorded, reconstructed and analyzed using the new CMSSW software framework. This included the muon reconstruction, freshly ported from the old to the new framework. In Figure 3, an example is shown of a cosmic muon traversing all subdetectors of CMS. A stand-alone muon was reconstructed from the muon segments in the DT chambers, and extrapolated backwards through the central detector taking into account the magnetic field and material effects. The large set of good quality MTCC data will be used to study detector performance in detail, and to test and further optimize our reconstruction algorithms. During the ‘phase II’ of the MTCC during the month of October the magnetic field inside the coil will be mapped with great precision and further cosmic data will be taken with HCAL and the muon detectors.

Figure 3: Event display of a cosmic muon traversing the CMS detector. This event was recorded on the 27th of August 2006, with a current of 18159 A in the CMS solenoid, corresponding to a magnetic field of approximately 3.8 T. A stand-alone muon track was reconstructed from muon segments in the DT chambers at the bottom of the detector. The green line shows the extrapolation of the stand-alone muon track back into the detector, taking into account a detailed model of the magnetic field (calculated for a 4.0 T field).

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