Comparison of DT Testbeam Results on Local Track Reconstruction with the OSCAR + ORCA Simulation

U. Gasparini, S. Lacaprara, A. Meneguzzo, P. Ronchese, S. Vanini, M. Zanetti

Physics Department of Padua University and INFN Padova, Italy

F.R. Cavallo, S. Marcellini

INFN Bologna, Italy

N. Amapane\textsuperscript{a)}, G. Cerminara

Physics Department of Torino University and INFN Torino, Italy

Abstract

In this note the results from the hit reconstruction and local track reconstruction inside two DT muon barrel chambers exposed to a muon testbeam in October 2004 are compared with the output from the full simulation based on the CMS simulation program, OSCAR, and on the reconstruction package ORCA, currently used for the studies performed for the CMS Physics TDR.

\textsuperscript{a)} Now at CERN, Geneva
1 Introduction

In October 2004 two Muon Barrel DT chambers of the Muon Detector system of CMS [1] were exposed to a bunched muon test beam at CERN, with various muon energies and inclination angles. In the test beam setup the two chambers where displaced about 60 cm from each other, and, in some runs, two iron slabs were inserted among them in order to simulate the situation seen in the CMS iron yokes. The main purpose of the test beam was the study of the performance of the L1 trigger, up to the DT TrackFinder. As a by-product, it was possible to study in detail the performance of the chambers as far as pattern recognition and local track reconstruction are concerned, in presence of electromagnetic showers up to a muon energy of 300 GeV. Test beam data and a full simulation of the testbeam setup using the OSCAR CMS simulation program [2] based on Geant4 package were processed using the same reconstruction program developed within the CMS reconstruction package, ORCA [3].

2 Experimental Testbeam Setup

A Barrel Muon chamber consists of 3 independent units, called SuperLayers (SL), each of them having 4 planes (“layers”) of drift tube cells assembled together, as shown in Fig. 1. The anode wire pitch determining the cell size is 4.2 cm; the cells in a layer are separated by 1.3 mm thick Al I-beams. Two SLs, named $SL_{\phi_1}$ and $SL_{\phi_2}$, measure the muon track position in the CMS $r - \phi$ bending plane, while the third one, $SL_{\theta}$, measures the position in the r-z plane parallel to the beam direction. A honeycomb structure separates an $SL_{\phi}$ SL from the other two SL’s, thus giving a lever arm length of about 28 cm for the measurement of a track direction inside each chamber in the CMS bending plane. The chamber length (along the beam direction in CMS) is about 2.5 m, while the size along the orthogonal direction depends on the chamber location in the return yokes of the CMS magnet, ranging from about 2.0 m for the innermost station (named MB1) to about 4.0 m for the outermost one (MB4). A general description of the Muon Detector system of CMS can be found in [1], while more details on the chamber characteristics and performances can be found in [4].

![Figure 1: Cross-sectional view of an MB3 chamber.](image)

Two Muon Barrel chambers, one of MB1 type (to be inserted in the first station layer of CMS) and one of MB3 type (which will go in the third station layer in CMS) were placed in the test beam setup schematically shown in Fig. 2. A picture of the two chambers in the testbeam area is seen in Fig. 3. The whole system was installed in the H2 zone of the CERN SpS North Area and exposed to a secondary muon beam with momentum varying from 30 to 300 GeV/c. The test was carried out using the SpS radio frequency similar to the one foreseen for the LHC. The proton beam delivered by the SpS hit a primary target in narrow bunches (about 2 ns long, separated by 25 ns) generating muons. From these muons a secondary beam with the same time structure of the proton primary beam was formed, by selecting the proper particle momentum. Trains of 48 bunches occurred every 23 $\mu$s orbit during a SpS spill of 2.7 s length. Since a secondary beam was used, the mean muon occupancy in a bunch was rather low, of the order of $10^{-2} - 10^{-3}$, and therefore muons were separated in time by several microseconds on average. The 40 MHz signal, synchronous with the accelerator RF signal, was distributed in the experimental area via a TTC system through optical links, and it was used as clock signal for the readout and trigger electronics.

An external beam trigger was given by the coincidence of two plastic scintillators defining a 10x10 cm$^2$ area.
Details of the electronics and data read-out system of the experimental set-up can be found in [5]. In order to simulate the effect of the material in the CMS muon detector, two iron slabs, 5 cm thick each, were placed between the two stations. Two additional iron slabs, still 5 cm thick each, were also placed one in front MB1, and one behind MB3, the latter to simulate back-scattering. Concrete blocks were placed just up-stream the two trigger scintillators.

Figure 2: Schematic top view of the 2004 DT test beam setup.

Figure 3: The 2004 DT test beam setup at CERN.

3 Testbeam Simulation

The test beam geometry was described in an xml file given in input to the OSCAR simulation program, using the simulation of the DT testbeam configuration provided in [7]; a snapshot of the geometry as seen by the CMS graphic package, IGUANA [6], can be seen in Fig. 4. The standard datacard configuration file defining the Geant4 cuts, used for the official CMS Monte Carlo productions, was used for the OSCAR simulation. Specifically, secondary particles were followed in the iron down to energy corresponding to 1 mm range for electrons and positrons and 10 mm for bremsstrahlung photons [8].

4 Comparison of Real Data with Monte Carlo Simulation

4.1 Digitization and hit reconstruction

The simulation of the detector response [9], named “digitization”, in ORCA is performed by parametrizing the DT cell behaviour as a function of the hit position in the cell and of the track inclination [10]. This behaviour has been studied using a cell simulation based on the GARFIELD package and extensively checked against the test
beam data collected in 2002 on the first CMS DT muon chamber [11]. The spread in the arrival time of the drifting electrons to the DT anode wire predicted by the GARFIELD simulation was about 3 ns, corresponding to a single hit resolution of about 160 μm, which is slightly smaller than what is observed in the data (cf. Sec.5). For this reason, an additional gaussian smearing with a sigma of 2.5 ns was applied in the digitization method.

Figures 5a,b show the comparison of the drift time distribution observed in testbeam data (dots) with the one obtained from the Monte Carlo simulation (full line histogram), for two different angles of incidence of the muon beam. The data were collected with a beam of 300 GeV muons with normal incidence with respect to the chamber plane (left plot) and with 150 GeV muons at the angle $\theta = 10^\circ$ with respect to the direction normal to the chamber plane. The slight excess observed in real data at normal incidence for small arrival times could be due to soft $\delta$-rays produced in the gas which, although generated in the simulation, are not considered in the following digitization step if they stop in the volume of the cell (only hits from the $\delta$-rays entering and exiting the cell volume are digitized). The $\delta$-ray hits mask the hit from the muon when they are closer to the wire, thus shifting toward smaller values the observed time of signal arrival. In the data, the effect is slightly more pronounced at normal incidence, as shown in Fig. 5c, while in the simulation the effect is predicted to be independent from the muon track angle. The mechanism for which this discrepancy shows up is not clear; the overall difference between data and simulation is anyway small, as can be seen from the relatively good agreement in the scatter plots reported in Fig. 6 for real (left) and simulated data (right). The figures show the distributions of the maximum drift times, $T_{\text{max}}$, computed in layers 1,2,3 vs the same quantity computed in layers 2,3,4 of the same SL in a chamber. The $T_{\text{max}}$ variables, defined as:

$$T_{\text{max}}^{123} = (T_1 + T_3)/2 + T_2,$$
$$T_{\text{max}}^{234} = (T_2 + T_4)/2 + T_3,$$

where the $T_i$ are the drift times observed in the hit cells in the different layers, measure the drift time (approximately 380 ns) corresponding to one half of the cell size (i.e. 2.1 cm, including the I-beam size) independently from the track position and inclination. This is true if each of the cells measures the hit of the crossing muon, i.e. if the muon hits are not masked by a $\delta$-ray signal arriving to the cell wire before the muon one. If instead this happens, the measured $T_{\text{max}}$ is shorter. In the events populating the vertical and horizontal lines seen in the scatter plots, the $\delta$-rays mask the true muon signal in one of the outer layers of the SL quadruplet, while in the populations along the inclined lines the $\delta$-rays mask the true hit in one of the internal layer or in more than one layer. It can be seen that the population along the different lines are slightly more pronounced in the real data. This can also be seen, for instance, in the distribution of the $T_{\text{max}}$ variable built from the arrival times in the first 3 consecutive layers in a SL, shown in Fig. 7.

Figure 8 shows the multiplicity distribution of the reconstructed hits in chamber MB3 for a 300 GeV incident muon beam, in the case in which the iron slabs (10 cm thick in total) were inserted between the two chambers; the real and simulation data distributions are normalized to the number of selected events having only one clean track and no shower activity in MB1 (i.e. selecting events with less than 20 reconstructed hits in MB1). It can be seen that the reconstructed hit multiplicity is underestimated in the Monte Carlo simulation in the region below 25 hits per chamber, predicting a larger fraction of events in which the number of reconstructed hits generated by a muon is
Figure 5: Drift time distribution for muons with a) normal incidence with respect to the chamber plane and b) for the angle $\theta = 10^\circ$ with respect to the normal direction. Circles: test beam data; full line histograms: Monte Carlo simulation. c) The distributions in the data for the two different incident angles are compared: full line: $\theta = 0^\circ$, dashed line: $\theta = 10^\circ$.

Figure 6: Scatter plot of the $T_{\text{max}}$ distribution computed in the layers 1-3 of a chamber SL vs the $T_{\text{max}}$ computed in the layers 2-4 (see Fig.1): test beam data (left), simulation data (right).

exactly 12 (i.e. the number of cells crossed by the muon). On the other hand, the high multiplicity component of the distribution due to muon showering is well reproduced by the simulation. As it will be shown later, these small differences have a negligible impact on the correct simulation of the performance of the chamber, as far as the local reconstruction of track segments is concerned.

5 Local Track Reconstruction in the Chambers

The standard pattern recognition algorithm and the track segment fit developed in ORCA were applied to the test beam and to the simulated data. Despite the small observed differences, the capability to reconstruct a muon track segment is well reproduced by the simulation. This can be seen in Fig. 9, showing the number of track segments with more than 5 hits included in the fit reconstructed in the MB3 chamber, in the plane in which 2 SLs are used (the “$r-\phi$ view” of CMS). As above, the Monte Carlo simulation and data distributions are normalized to the number of selected events having only one clean track and no shower activity in MB1. The left plot refers to data collected without the iron slabs, with chamber MB3 rotated by $10^\circ$ with respect to normal incidence. It can be seen that at least one muon candidate is reconstructed in more than 99.5% of the cases in the data (100% in the simulation). The right plot in Fig. 9 shows the same distribution for data collected at normal incidence angle, with the iron slabs inserted. In this case, in about 2.5% of the events no track candidate is reconstructed both in Monte Carlo simulation and data. The observed inefficiency is mainly due to the I-beams (1.3 mm thick) separating the DT cells in a layer. This is shown in Fig. 10, in which the track segment reconstruction efficiency is plotted vs the impact...
Figure 7: $T_{\mu\nu}^{123}$ distribution in one chamber SL: real data (dots), simulation data (full line).

Figure 8: Multiplicity distribution of reconstructed hits in MB3 chamber: data (dots), simulation (full line histogram).

position of the muon in MB3 predicted by the extrapolation from the track segment measured in MB1. The left plot shows the case with the chamber rotated, which is not affected by the presence of the I-beams separating the cells, while the right plot shows the data at normal incidence, in which the efficiency losses at positions separated by the half cell size (2.1 cm) are clearly visible.
From the right plot of Fig. 9, it can be also seen that when the iron slabs are inserted between the chambers the simulation slightly overestimate the number of reconstructed additional track segments, coming from hard $\delta$-rays passing both $\phi$ SL's of the chamber.

Figure 9: Multiplicity distribution of reconstructed track segments in MB3. Left: beam energy 150 GeV, no absorber inserted, beam direction inclined by $10^\circ$ with respect to the normal incidence; Right: beam energy 300 GeV, iron absorber inserted, muon beam at normal incidence with respect to the chamber plane. Dots correspond to real data, full line histogram to simulated data.

Figure 10: Track segment reconstruction efficiency vs predicted track position in MB3. Left: beam direction inclined by $10^\circ$ with respect to the normal direction; Right: muon beam at normal incidence. Real data (dotted line), simulation (full line).

The distribution of the residuals of the reconstructed hit with respect to the predicted position by the track fit for track segments in the $r-\phi$ view with 8 associated hits is shown in Fig. 11. The fitted resolution is about 190 $\mu$m.

The resolution of the determination of the angle giving the track segment direction (the quantity usually referred to as $\psi_{hrend}$ in the CMS Level-1 and High Level Trigger [9] reconstruction algorithms) can be measured by the angular matching between the track segments measured in the two chambers MB1 and MB3. The scatter plot of
Figure 11: Reconstructed hit residuals with respect to track fit: data (dots), simulation (full line).

the two angles, defined with respect to the direction normal to the chamber plane, is shown in Fig. 12 for real data. The correlation between the two angles, clearly visible in the plot, is due to the beam divergence. The distribution is not centered at $\phi = 0$ because of the imperfect alignment of the chambers with respect to the normal to the beam line (the mean beam angle being about $2 \times 10^{-5}$ rad). The distribution of the difference between the angles measured in MB1 and MB3 is shown in Fig. 13 for tracks at normal incidence (right) and at the angle $\theta = 10^\circ$ with respect to the normal direction (left). In computing the real data distribution, a tilt angle correction between the two chambers, $\Delta \phi = 3.5 \times 10^{-4}$ rad, was applied. The fitted resolution is $\sigma_{\Delta \phi} = 1.2$ mrad and 1.3 mrad in the two cases respectively, resulting in an angular resolution smaller than 1.0 mrad on the determination of the muon direction by a single chamber.

6 Summary

The hit reconstruction and local segment reconstruction inside muon DT chambers was studied in testbeam data collected with a muon beam energy of 150 and 300 GeV, at zero and $10^\circ$ incident angles with respect to the chambers plane. The testbeam setup consisted of two chambers with iron slabs inserted in between, to reproduce the situation seen in the CMS iron yoke by the first two Muon Barrel stations. The results were compared with the simulation based on the official CMS programs OSCAR and ORCA. It was shown that the simulation well reproduces the chamber performances observed in the data, although some small discrepancies are observed in the drift time distributions and in hit multiplicity distributions. The number of reconstructed track segments when the iron slabs are inserted between the chambers is also slightly overestimated in the simulation; this effect will be further investigated as a function of the beam energy.

References


Figure 12: Scatter plot of the muon measured angles in the $r - \phi$ view in MB3 and MB1 for real data.

Figure 13: Distribution of angular difference between reconstructed track segments in MB3 and MB1 chambers. Left: beam direction inclined by $10^\circ$ with respect to the normal direction; right: normal incidence. Real data (dots), simulation (full line histogram).

https://uimon.cern.ch/twiki/bin/view/CMS/DTTestBeamSimulation.
[8] /afs/cern.ch/cms/Releases/OSCAR/OSCAR365/src/Data/ProductionCuts/MuonProdCuts.xml
