Performance tests of the Drift Tube Muon Chambers for the CMS experiment at the LHC

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The muon system is of crucial importance in the Compact Muon Solenoid (CMS) detector at the LHC as energetic muons are expected to be the signature of many types of events that will be searched for at the new CERN collider. For the barrel part of CMS, a detector based on the Drift Tube (DT) technique was designed to serve both for the offline muon track reconstruction and for the first level trigger. Given the huge background that is expected at the highest collider luminosity, the DT chambers have to match very tight requirements in terms of time resolution and construction accuracy. Prototypes of DT chambers and of the first level trigger electronics were built and tested at CERN with muon beams. The full production is going on in three different european labs, one of them being the INFN Laboratori Nazionali di Legnaro (LNL). The results of the beam tests and of the cosmic tests performed at LNL are compatible with each other and with the general requirements.

1. INTRODUCTION

The first aim of the Large Hadron Collider (LHC) is the final test of the Standard Model with the discovery of the Higgs boson. For a Higgs mass greater than $\sim 130\,GeV$, a relatively clean signature is the decay $H^o \rightarrow Z^{o*}Z^o \rightarrow l\bar{l}l\bar{l}$, with four leptons in the final state. Leptons could also be produced in the decay of supersymetric particles, such as H, h, A, and of new particles expected in more exotic theories. The detection of muons takes place in the outermost part of the detector, where both background and track multiplicity are lower. Nevertheless, searching for events having rates of the order of $\sim 10^{-2}Hz$, with an overall event rate of $\sim 10^9 Hz$ (at the highest machine luminosity), puts very tight conditions on the detector performance. Since the muon detector will contribute to the first level trigger selection of high p_t muons, it must provide a fast muon identification and accurate online momentum measurement. Moreover, the time between two beam collisions (BCO) being $25\,ns$, i.e. much shorter than the time needed to form and process the electronic signals in the detector, also the parent BCO of each muon must be identified. For the offline reconstruction, correct charge assignment must also be provided up to the TeV region. These tasks require a time resolution much smaller than $25\,ns$, a track resolution of $\sim 100\,\mu m$ ($\sim 250\,\mu m$ for single points) and an angular resolution $\sim 1\,mrad$. Finally an online track segment reconstruction must be performed in $< 1\,\mu s$ for the first level trigger.

2. THE DRIFT TUBE CHAMBERS

The CMS muon detector system is described in [1]. In the barrel part it relies on the Drift Tube (DT) Chambers. In this region the expected particle rate is $\sim 10\,Hz/cm^2$ and the longitudinal and radial components of the stray magnetic field in the gas do not exceed 0.4 and $0.8\,T$ respectively. A section of a tube is shown in Fig.1. The electric field is generated by a central anode wire, two aluminium cathode strips at the far ends and two more strips on the near walls: the last are set at an intermediate voltage in order to make the field as uniform as possible. The tube is filled with a mixture of Ar(85%)CO_2(15%). The wire signal is read out by a TDC with a time granularity of $\sim 1\,ns$.

The tubes are arranged in four layers forming a superlayer, as shown in Fig.2; three superlayers make a full chamber: two of them have the wires parallel to the beam and to the magnetic field thus measuring position and curvature in the $R\Phi$ plane, the other one has the wires in

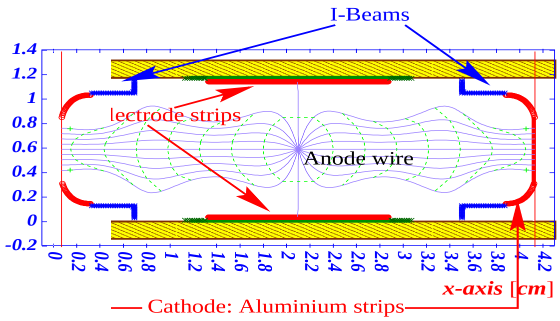

Figure 1. Layout of a Drift tube

the normal direction and measures the position in the RZ plane. Each superlayer is equipped with a set of Bunch and Track Identifiers (BTI): these are electronic devices which clock the wire signals in time slots of 25 ns. At each clock, using a programmable drift velocity, they compute a set of equations and determine when the space points obtained from the elapsed times are aligned. When a BTI finds a set of aligned points, it outputs at the same time: the track segment (intercept and slope), the parent BCO and a flag tagging High (HTrg) or Low (LTrg) quality trigger, given by four or three hits respectively.

3. TEST BEAM RESULTS

The DT's performance was studied exposing a prototype superlayer, made of 16 tubes per layer, to muon test beams at CERN in 1999 [2] and 2000 [3]. During the latter run the prototype was also equipped with a set of BTI's [4]. In 2001 a full final chamber was tested and the results obtained from the prototype were confirmed [5]. To check the effect of magnetic field, the chamber was set inside a magnet. Moreover, the chamber support allowed it to be rotated around both axes: parallel to the wires, and parallel to the drift direction, in order to test the performance of the chamber with inclined tracks and with different components of magnetic field.

The aims of the tests were essentially to check the uniformity of the drift velocity and to measure the drift velocity itself, the time (space) resolution, the chamber efficiency and the BTI efficiency. Moreover, analyses were made of the dependence of each of these measurements on the voltages, on the muon angle of incidence and on the magnetic field. Here follows a summary of these studies.

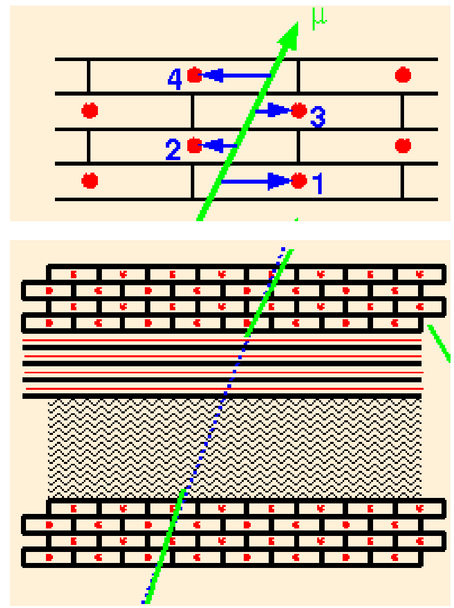

Figure 2. Sketch of a superlayer and of a full DT chamber

3.1. Drift velocity

The drift velocity can be evaluated and its uniformity inspected at a glance looking at the time distribution of the wire signals (Fig.3): in fact its width corresponds to the maximum drift time, T_{MAX}, and its flatness is an indication of the linearity of the space-time relationship. (The peak near $t = 0$ is related to the electron avalanche development).

A more accurate way to evaluate T_{MAX} is to find the position of the peak in the distribution of the Mean Time: $MT = \frac{1}{2}(t_1 + 2t_2 + t_3)$, where t_j is the drift time in layer j (Fig.4). In fact, by geometrical construction, $MT = T_{MAX}$ for

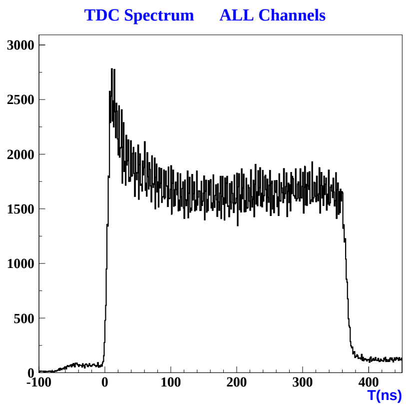

Figure 3. Time distribution of the wire signals.

most of the tracks (see Fig. 2). From Fig.4 one finds for instance: $T_{MAX} = 378\,ns$, i.e. $v_{drift} = 55.6\,\mu m/ns$.

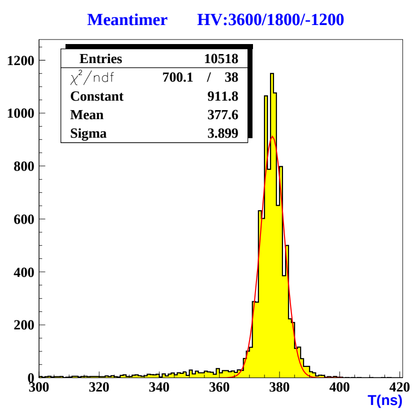

Figure 4. Distribution of $\frac{1}{2}(t_1 + 2t_2 + t_3) \equiv T_{MAX}$

Given a gas composition, the drift velocity is determined by the voltage $V_{drift} \equiv (V_{strip} - V_{cathode})$. In Ar(85%)$CO_2$(15%) it saturates at $V_{drift} \simeq 3000\,V$ reaching a value of $v_{drift} \simeq 55\,\mu m/ns$.

The *apparent* drift velocity also shows a dependence on the track angle, φ, in the plane normal to the wires. In fact the spread of the ionized charge in the drift direction causes an earlier arrival of the signals and hence an apparent increase of v_{drift}. This effect becomes visible for $\varphi > 25^o$.

Finally, any component of the magnetic field not parallel to the drift direction, causing a bending of the drift paths, increases the T_{MAX}, hence decreases the apparent v_{drift}. The effect on v_{drift} of a B field parallel to the wire, B_w, depends on the track inclination. Moreover, for $B_w \geq 0.5\,T$, the distortion of the drift paths spoils the linearity for drift distances $> 16\,mm$.

3.2. Efficiency

The single wire efficiency was measured using a sample of tracks having at least 3 hits in a superlayer and considering the fraction of 4-hit tracks. The overall efficiency is on average $\sim$ 99%. If one uses the fitted track to determine the position, one can verify that the inefficiency is mainly due to the geometrical acceptance: in fact it is $>$ 99.5% everywhere but in the vicinity of the cathode walls.

The efficiency depends on the gas gain, therefore on the voltage $V_{amp} \equiv (V_{wire} - V_{strip})$. The efficiency saturates at $V_{amp} =\sim 1800\,V$.

The single wire efficiency is not affected either by the track angle of incidence nor by the magnetic field, though very large non-linearity effects might prevent the track reconstruction.

3.3. Resolution

The time resolution σ_t can be derived through the RMS of the MT distribution. From Fig.4 one finds for instance: $\sigma_t = 3.18\,ns$ and therefore a space resolution: $\sigma_x \equiv v_{drift}\,\sigma_t = 177\,\mu m$.

Like the efficiency, the resolution depends on V_{amp} through the gas gain. This dependence becomes almost flat at $V_{amp} = 1800\,V$ i.e. at the same voltage that also optimizes the efficiency. This value, together with $V_{drift} = 3000\,V$ led to the choice of the following set of nominal voltages: $V_{wire} = 3600\,V$; $V_{strip} = 1800\,V$; $V_{cathode} = -1200\,V$.

The spread of the ionized charge along the drift direction, produced by tracks having an inclination φ on the plane normal to the wires, naturally worsens the resolution, as shown in Fig.5.A.

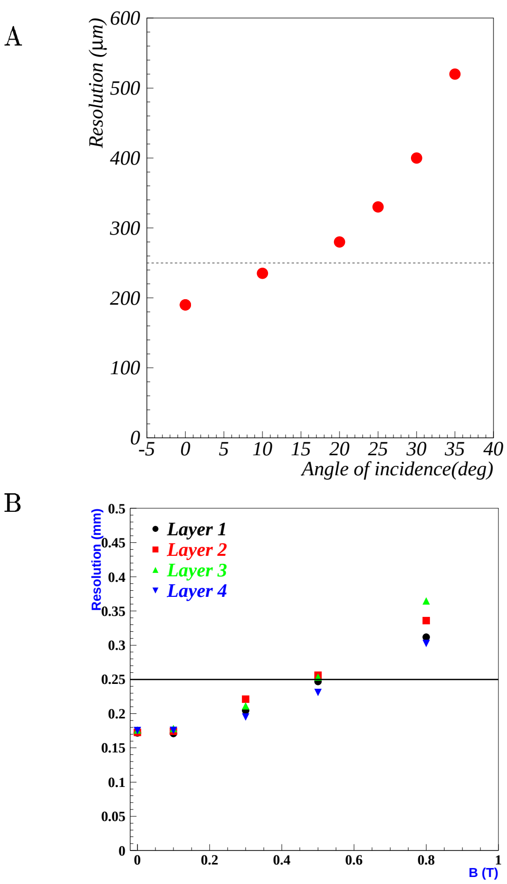

Figure 5. Dependence of the resolution on the angle of incidence (A) and on the magnetic field component parallel to the wire (B).

Similarly, the resolution increases with increasing magnetic fields: it is especially affected by the component parallel to the wire (Fig.5.B), since, as seen above, it induces non-linearity effects.

3.4. BTI efficiency

Any loss of resolution induces a loss of efficiency of the BTI's, as they fail more frequently to find the points aligned at any time. The BTI efficiency was measured varying the magnetic field B_n (normal to the chamber) and the muon angle of incidence. The total (LTrig + HTrig) efficiency is about 95% for normal tracks with no magnetic field. It remains almost stable up to $\sim 35^o$ or up to $0.8\,T$. The HTrig efficiency alone is $\sim 80\%$ at 0^o and $0\,T$; it drops to $\sim 65\%$ for $\varphi = 30^o$ and to $\sim 75\%$ for $B_n = 0.8\,T$. The efficiency drops more dramatically in the presence of a non zero component B_w, along the wire. This problem can be dealt with performing an individual tuning of the programmable drift velocity, for the BTI's sitting in the regions where the magnetic field is most intense.

4. COSMIC TESTS

The production of DT chambers started in 2001 and it is going on in three different european laboratories.

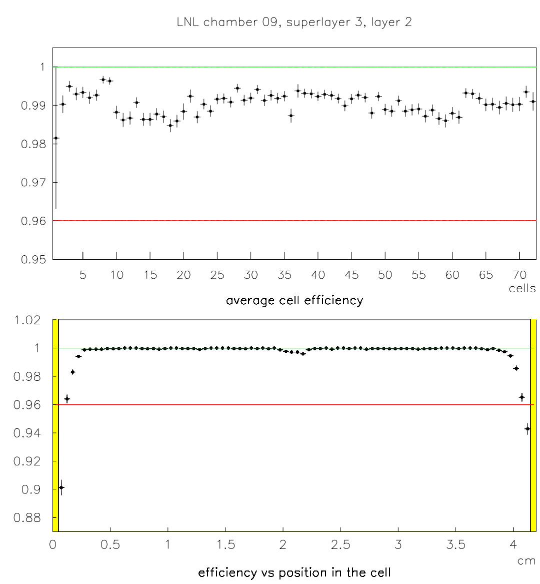

Figure 6. DT efficiency measured with cosmic rays. Top: avarage efficiency cell by cell. Bottom: efficiency as a funcion of the track position in the cell.

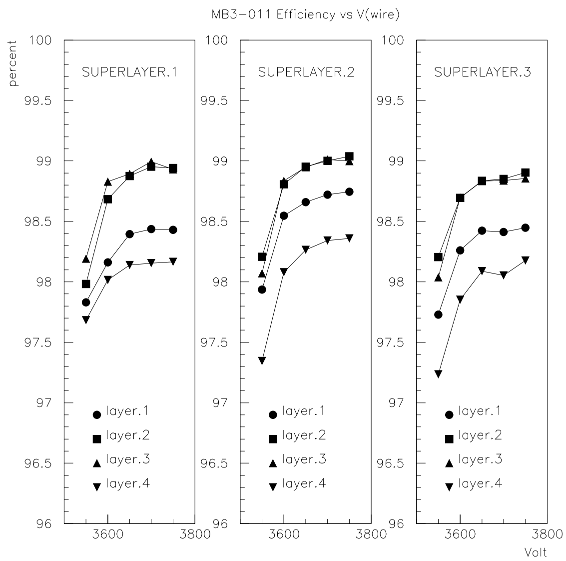

Figure 7. DT efficiency measured with cosmic rays at LNL as a function of anodic voltage ($V_{strip} = 1800\,V$)

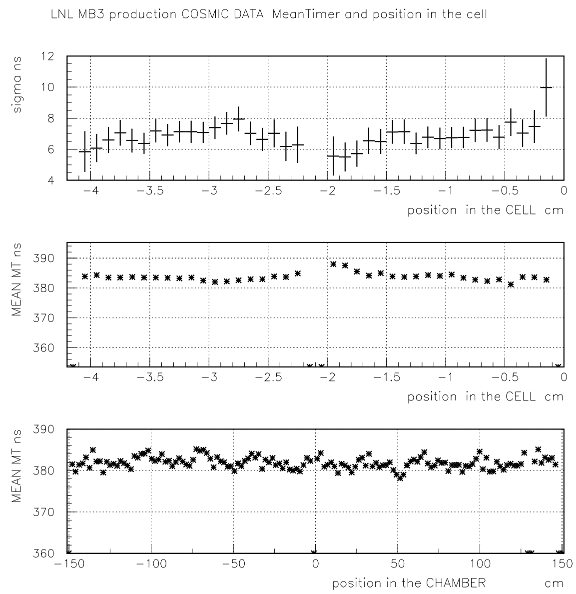

Figure 8. Time resolution vs position in the cell (top); maximum drift time vs position in the cell (middle) and vs position in the chamber (bottom).

At the Laboratori Nazionali di Legnaro (LNL), 10 out of the total scheduled production of 70 chambers were already finished and tested with cosmic rays by the end of October 2002 [6]. In order to get the necessary statistics, a trigger system based on a set of scintillators and photomultipliers was set up, with the largest possible acceptance. The intrinsic time jitter of the scintillators spoils the observed resolution that turns out larger compared to the test beam measurements However, a resolution similar to the one found in the test beam was obtained using for the trigger a narrow coincidence of two small scintillators having negligible jitter. Routine tests, with standard high rates, are used to check, chamber by chamber, the efficiency and the uniformity of both drift velocity and resolution.

The procedures are the same as described for the test beam. The efficiency can be inspected in plots of the kind shown in Fig.6: they are used to spot single inefficient tubes or to cross check possible construction anomalies.

The dependence of the efficiency on the wire voltage was studied on a few chambers and found to be compatible with the expectations and with the previous measurements. The curves are shown in Fig.7.

The uniformity of the drift velocity and of the resolution can be checked by plots like the ones in Fig.8 where the maximum drift time and the resolution show no clear dependence on the position either within the cell or within the chamber.

CONCLUSIONS

Several beam tests on prototypes and the ongoing cosmic tests on the produced chambers have been giving consistent and positive results: the performance of the DT chambers and of the BTI's for the first level trigger match the specifications for CMS in terms of efficiency and resolution, even for inclined tracks and in presence of magnetic fields as intense as expected in CMS. The production is going on and the first trial chamber was already installed in the barrel yoke on August 20th, 2002. The barrel muon detector will be ready to observe the first high p_t leptons from pp collisions in 2007.

ACKNOWLEDGEMENTS

Thanks to the CMS group of LNL and in particular to Anna Meneguzzo who shared with me the analysis of the cosmic data.

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