Performance of an MDT cosmic test stand: a Monte Carlo evaluation.

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1-Introduction.

The high level of mechanical accuracy in the wire location represents one of the main characteristics of the MDT chambers. The X-ray measurements performed at CERN have certified this accuracy; almost all the measured chambers have an r.m.s. respect to the nominal position below 20 µm. It has been also observed that, leaving free, in the fit to the measured wire grid, few global parameters, like the relative distance, the rotation and the angle between multilayers (chamber mechanical parameters), we can obtain a substantial improvement (up to 5-7 µm) in the wire r.m.s. that can boost the ultimate precision of the Atlas muon spectrometer. This is due to the better accuracy that can be obtained, at the construction level, in the wire location inside a multilayer respect to the relative positioning of one multilayer respect to the other.

More sophisticated approaches [1] trying to obtain single wire positions from mechanical measurements, offer only a marginal improvement respect to the few parameters fit and are much more difficult to perform.

Only a small (10-15%) fraction of all MDTs can be X-ray inspected at the CERN Tomograph [2], but all the chambers are expected to be certified in a cosmic rays stand. We can therefore try to optimize the chamber geometrical parameters from the analysis of the cosmic rays data. It will also be possible to perform the same analysis during the Atlas commissioning period with cosmic rays or during low luminosity runs. In this way we will be able to improve the performance of the spectrometer checking the quality of all detectors.

The aim of this note is the Monte Carlo evaluation of the performance of a simple cosmic rays test facility, looking in particular to the resolution that can be obtained in the measurements of the chamber geometrical parameters. In section 2 we will describe the set up and the chamber simulation. In section 3 we will validate the simulation and the track reconstruction procedure using high-energy muons, comparing the results with H8 experimental data taken in the 2002. In section 4 the same analysis will be performed with the cosmic rays simulation. Finally section 5 will deal with the
reconstruction of the chamber geometrical parameters and the corresponding resolutions that can be achieved.

2-The simulated set up and the MDT chamber description.

The simulated cosmic test set up (almost identical to the Rome3 cosmic test facility [3]) is shown in figure1; 3 planes of RPC counters are placed in a tower 2.5 m high, one plane on top and two planes at the bottom at 12 cm distance with 5.5 cm of lead in the middle, providing a fast cosmic trigger with 1 ns time resolution. This trigger hodoscope covers an area of 2.8 x 1.2 m² and houses up to three MDT chambers of the BIL type. Along the tubes the trigger counters are segmented in 6 sub towers and only the two extreme sub towers will be used for the study of wire positions near the end plugs.

We have used a GEANT 4 (version 5.2) [4] based Monte Carlo simulation program to trace the simulated particles through the trigger detectors and the MDT chambers. The wire positions have been smeared around their nominal locations with a $\sigma$ of 10 $\mu$m both in z and in y (we will use in the following the standard MDT reference system with x the along the wire, y orthogonal to the layers and z orthogonal to the wire along the tube layer). All the materials (including the glue) and the signal delays have been described in detail.

For the hit digitization we have used the results of a Garfield Monte Carlo study [5], where the drift behavior of a tube, in the standard MDT operating conditions [6], has been simulated. Fig.2 shows the correlation between the measured drift time and the perpendicular distance of the track from the wire obtained from the Garfield simulation. The events below the correlation band are due to $\delta$ rays produced in the gas and reaching the wire before the ionization of the primary charged particle. After removal of these events, the distribution function of the drift time, for a given the radial distance, is well described by a gaussian, even at small distances from the wire. For each radial distance the average drift time and the corresponding r.m.s. can be computed providing the “$r$ to $t$” relation and smearing for the digit generation in each hit tube.

3-Test with high-energy muons.

In order to validate the GEANT Monte Carlo generation and the reconstruction software without the additional complications coming from the low momentum tracks of the cosmic muon spectrum, high energy muons were used; we have generated a sample of $\approx$103 K high energy muons (180 GeV/c), with a geometrical configuration very similar to the one in H8 test beam (10 x 10 cm² trigger counter, angular spread $\approx$0.1 mrad both in y-z and y-x planes, chamber at 14° respect to the y axis).

We have analyzed only one of the two multilayers and requested, at the pattern recognition level, one and only one “string” without additional hits, where a “string” is defined as 4 tubes fired, one in each layer. This request reduces the initial sample hitting the chamber to 96 K events. The loss, about 7% of the events, is due both to
geometrical inefficiencies (<1% at this impact angle, as expected from the dead regions of the chamber) and to the presence of extra hits associated to the production of high-energy $\delta$ rays within the multilayer itself.

As a comparison we have applied the same selection to the H8 data at the same energy. Masking noisy channels and avoiding regions with dead channels, the “string” request rejects about 14% of events; inefficiencies are in agreement with MC expectation while the fraction of events with extra hits shows a sizeable discrepancy (13% compared to 6%) which is due to some GEANT4 underestimation of the $\delta$ production with the default cuts. Discrepancies of the same size appear also in the comparison between measured drift times. In fact, the effect of high energy $\delta$ rays is twofold: the extra particles affect both the number of hits, when entering a tube not crossed by the primary particle, and the measured drift time, when entering a tube already crossed by the primary particle and spoiling its drift time measurement.

The number of hits spoiled by the presence of a $\delta$ ray can be estimated from the plot of $t_1$ versus $t_3$, where $t_{1,3}$ are the drift times observed in layer 1 and in layer 3. Thanks to the very small angular spread of the beam, the good hits lie on a clear correlation band while the points below the band are events in which at least one of the two drift times is due to a $\delta$ ray. From figure 3a the fraction of spoiled hits per tube in the simulation is $\approx 2.5\%$ (i.e.10% for a track). The same plot for the test beam data (figure 3b) gives an higher probability $\approx 4.5\%$(i.e.18% for a track), pointing again to an underestimation of the $\delta$ ray production in the simulation.

For the track reconstruction of simulated events we have used the “t to r” relation and the corresponding resolution coming from [5]; the $t_0$ has been obtained from the fit of the leading edge of the drift spectrum, shifting the origin in order to reproduce the $t_0$ obtained from the Garfield simulation ($t_0 = 23$ ns).

The track fit ($z= ay+b$) to the radial circles uses the same algorithm described in [7], with y,z origin in the center between the two multilayers. The resulting $\chi^2$ probability distribution is shown in figure 4; apart for a large peak at very low probabilities the distribution is flat, showing that the resolution obtained in [5] from the r.m.s. of the r distributions is an acceptable approximation for the correct track reconstruction. The peak at low probabilities corresponds to the $\delta$ ray production in the gas or in the tube walls; a cut at $\chi^2 < 9$ (P($\chi^2$)<0.01 for 2 degrees of freedom) removes ~9 K out of 96 K tracks, corresponding to a probability of a $\delta$ ray spoiling the track hit of 9% in agreement with the fraction estimated from the plot of $t_1$ versus $t_3$. Figures 5a and 5b show the straight line fit parameters a and b compared to the generated values ($a_{fit}-a_{gen}$, $b_{fit}-b_{gen}$). After the P($\chi^2$) cut the single multilayer resolutions are $\sigma_a = 1.64$ mrad and $\sigma_b = 234 \mu m$ for a and b respectively.

The pulls, defined as (generated value– reconstructed value)/$\sigma$, are shown in figures 6a and 6b; their fit with a gaussian shape gives an average value compatible with 0 and $\sigma=1$ in both cases, showing the good quality of the reconstruction and the correct estimation of the errors on a and b.

H8 data were reconstructed using the “t to r” relation and resolution produced by CALIB[8]. The $\chi^2$ probability distribution is shown in figure 7 and agrees well with the
one obtained on simulated data but for the size of the peak at small probabilities, which gives a probability of a δ ray spoiling a track hit of 17%, in agreement with the fraction estimated on H8 data from the plot of $t_1$ versus $t_3$.

Finally the autocalibration procedure used by CALIB to compute the “t to r” relation and the spatial resolution was checked on a simulated sample of 180 GeV/c muons with a wider angular distribution ($\sigma = 0.1$ rad). The angular spread of the tracks of the used sample is in fact essential for the convergence of the autocalibration algorithm. The resulting “t to r” has been compared with the one used in the generation; in figures 8a and 8b the difference of the two is shown as function of the drift time and of the distance from the wire. The discrepancies are typically at the level of 1 ns or 20 µm, showing the very good performance of the autocalibration procedure.

4-The MC simulation of the cosmic test stand.

The cosmic spectrum from experimental measurements at sea level for vertical muons [9] with the proper $\cos^2(\theta)$ ($\theta$ is defined as the angle of the track respect to the vertical direction) angular distribution has been used to simulate the behavior of the cosmic test stand (the angular dependence of the momentum spectrum has been neglected; as a result the average momentum of the simulated muons is slightly underestimated). Three MDTs have been inserted in the tower but only the data from the middle chamber and from the first trigger sub tower have been used in the analysis. A total of ~120K triggers have been generated in the same conditions as in the previous paragraph; no electronic noise has been introduced. The trigger acceptance, defined as $[\text{n.of events with at least 1 hit}/ \text{N.of triggers}]$ is 94%, in good agreement with the real data (93%). The momentum spectrum of the triggered tracks can be seen in fig.9; the cut introduced by the 5.5 cm lead absorber is clearly visible.

The fraction of (events with at least 4 hits)/(events with at least 1 hit) is 91%, to be compared with 93% for the cosmic data, corresponding to the expected geometrical inefficiency of the detector for tracks with a wide angular distribution.

For the “t to r” relation and resolution we have used the CALIB results on the same sample; with a final cut on the $P(\chi^2) > 0.08$ and at least 20 iterations we obtain a “t to r” relation in agreement, at the 20 µm level, with the generated one.

The $P(\chi^2)$ for tracks reconstructed in multilayer 1 is shown in figure 10; as expected the multiple scattering contribution to the hit resolution of the low energy muons results in an underestimation of the uncertainty in the track position, as it is clear from the increase of the distribution towards low probabilities. The very low momentum muons, together with the δ ray production in the tube, are responsible for the large peak below 10% probability. If we accept tracks with $P(\chi^2) > 8 %$, the track reconstruction efficiency (defined respect to the “at least 4 hits” sample) is 65% and the pulls in a and b, Fig11a,b have $\sigma \sim 1.4/1.3$ due to the neglected multiple scattering contribution.

The effective resolution on a and b (generated – reconstructed) is shown in fig. 12 a,b; from a gaussian fit we get 2.3 mrad resolution on a and 296 µm on b.
Reconstructing now the tracks independently in both multilayers we can compare the a and b obtained in the two multilayers; the difference between the two is shown in fig. 13 a,b; the sigmas are, as expected, $\sqrt{2}$ times the results of fig. 12.

5-Reconstruction of chamber geometry.

As we have stated in the introduction, the optimization of few geometrical parameters can improve in a significant way the description of the MDT geometry and therefore the final spectrometer performance. As we have seen from the Tomograph results and assuming a good internal geometry of individual multilayers the main parameters needed for optimizing the overall chamber geometry are (see fig. 14):

$\Delta \alpha$: the relative angle between the two multilayers internal reference systems

$\Delta z_0$: the horizontal shift (in z direction) of one multilayer reference system respect to the other

$\Delta y_0$: the difference between the nominal and effective separation between the two multilayers in the y direction

The knowledge of these 3 parameters at the two chamber ends (RO and HV side) will allow to measure the two additional angles $\Delta \beta$ and $\Delta \gamma$, corresponding to the rotation of the first multilayer respect to the second in the x-z plane and in the x-y plane.

These parameters must be measured with an accuracy of few microns for $\Delta y_0$ and $\Delta z_0$ and of few microradians for $\Delta \alpha$, $\Delta \beta$ and $\Delta \gamma$ in order to bring the knowledge of the overall chamber geometry at the 10 $\mu$m level (r.m.s.). As we have seen from the previous section, the intrinsic accuracy on a and b (having placed the track reference system in the medium plane of the chamber) are ~2 mrad and ~ 300 $\mu$m respectively. With a statistics of 100 K good tracks in the two extreme sub towers of the cosmic trigger we can therefore measure $\Delta \alpha$ with ~ 10 $\mu$rad accuracy, $\Delta z_0$ with ~1.0 $\mu$m and $\Delta y_0$ a factor 10-20 worse, depending on the stereo angle. From simple geometrical considerations $\Delta b$, the difference of the track intercept in the middle plane between the two multilayers as reconstructed in multilayer 1 and multilayer 2, can be written as:

$$\Delta b \approx \Delta y_0 \cdot a + (L \cdot \Delta \alpha + \Delta z_0) = m \cdot a + q$$

$L = distance\ center\ multilayer \rightarrow central\ plane$

$a = track\ angular\ coefficient$

$\Delta \alpha \approx a_{\text{MLayer1}} - a_{\text{MLayer2}}$

$\Delta y_0 = error\ in\ the\ distance\ between\ the\ two\ Mlayers$

$\Delta z_0 = orizontal\ shift\ between\ Mlayers$
i.e. a straight line in the $\Delta b$ versus $a$ plane. Having measured $\Delta \alpha$ from the comparison of the track angular coefficient in the two multilayers, a linear fit to $\Delta b$ versus $a$ should allow a measurement of $\Delta y_0$ and $\Delta z_0$ with the required accuracy. From the data of Rome3 cosmic rays stand, the required statistics of $\sim 200K$ triggers (taking into account the overall efficiency for having a good track in both multilayers) within a sub tower can be easily collected in a $36 h$ run.

In order to verify the accuracy that can be reached we have generated a sample of $\sim 200K$ triggers in the same conditions of section 4 but introducing a distorted geometry in the chamber description ($\Delta \alpha = 500 \mu$rad, $\Delta y_0 = 700 \mu$m, $\Delta z_0 = 100 \mu$m). Following the same procedure as in section 4 and using the autocalibration to get the “t to r” relation, we have reconstructed in the first sub tower $\sim 100 K$ tracks in both multilayers independently.

The $\Delta \alpha$ distribution is shown in fig. 15; the gaussian fit gives $\Delta \alpha = 476 \mu$rad with an error on the mean of $10 \mu$rad.

The $\Delta b$ versus $a$ plot is presented in fig. 16; the linear behavior is clearly visible. The fit to $\Delta b$ versus $a$ data gives: $\Delta y_0 = 704 \pm 19 \mu$m and $\Delta z_0 = 102 \pm 3 \mu$m, in very good agreement with the distortions introduced in the simulation.

As a cross check, the same plot on the high-energy muons and with undistorted chamber geometry is shown in Fig.17. As expected $\Delta y_0 = 26 \pm 19 \mu$m and $\Delta z_0 = 2 \pm 2 \mu$m, well compatible with 0.

6-Conclusions.

In this note we have presented the expected performance of an MDT chamber in a simple cosmic rays stand; in particular we have shown that, with a relatively modest amount of data taking we can measure, with an accuracy comparable to the one of the Tomograph device, the main geometrical deviations of a chamber, respect to the nominal site parameters. This result can be validated analyzing the cosmic data collected with chambers that has been measured at the Tomograph facility and this type of analysis should be extended to all the MDT chambers in order to improve the overall Atlas muon spectrometer performance.

References.


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   R.Veenhof. GARFIELD: a drift chamber simulation program. CERN program library W5050.


**Figure 1.** Lay out of the simulated cosmic ray stand.

**Figure 2.** Drift time versus perpendicular distance of the track from the wire obtained from the Garfield simulation.
Figure 3a. $t_1$ versus $t_3$ from 180 Gev/c MC data.

Figure 3b. $t_1$ versus $t_3$ from 180 Gev/c H8 data.
Figure 4. $P(\chi^2)$ distribution for the fitted tracks from MC simulation at 180GeV/c.

Figure 5a,5b. The straight line fit parameters $a$ and $b$ compared to the generated values ($a_{\text{fit}}-a_{\text{gen}}$, $b_{\text{fit}}-b_{\text{gen}}$).
**Figure 6a,6b.** Pulls on track parameters a,b (chisq cut <9).

**Figure 7.** $P(\chi^2)$ distribution for the fitted tracks from H8 data at 180GeV/c.
Figure 8a,8b. Difference between the “t to r” from Garfield and the one obtained from CALIB.
**Figure 9.** The momentum spectrum of the triggered tracks in the cosmic ray test stand.

**Figure 10.** $P(\chi^2)$ distribution for the fitted tracks from the MC simulation of the cosmic ray test stand.
Figure 11a,11b. Pulls on track parameters a,b \((P(\chi^2) > 0.08)\).

Figure 12a,12b. The effective resolution on a and b (generated – reconstructed).
**Figure 13a,13b.** The difference between a and b as reconstructed in mlayer1 and in mlayer2.
**Figure 14.** The main parameters needed for optimizing the overall MDT chamber geometry

\[ \Delta \beta : \text{rotation angle in } x,z \text{ plane} \]

\[ \Delta \gamma : \text{rotation angle in } x,y \text{ plane} \]

**Figure 15.** Da between the angular coefficient of the track as reconstructed in mlayer1 and mlayer2.
Figure 16. $\Delta b$ between the impact point on the chamber middle plane of the same track reconstructed in mlayer1 and mlayer2 versus the track angular coefficient (distorted geometry).

Figure 17. $\Delta b$ between the impact point on the chamber middle plane of the same track reconstructed in mlayer1 and mlayer2 versus the track angular coefficient. (undistorted chamber geometry).