Autocalibration of high precision drift tubes

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We present the results on MDT (monitored drift tubes) autocalibration studies obtained from the analysis of the data collected in Summer 1995 on the H8B Muon Test Beam. In particular we studied the possibility of autocalibration of the MDT using four or three layers of tubes, and we compared the calibration obtained using a precise external tracker with the output of the autocalibration procedure. Results show the feasibility of autocalibration with four and three tubes and the good accuracy of the autocalibration procedure.

1. Introduction

In the framework of the Atlas muon activities we have performed in the H8B test beam at CERN, measurements using an MDT [1] multilayer of four layers, operated with different gas mixtures at three Bar absolute pressure. The main aim of the measurements was to show the feasibility and the accuracy of the autocalibration [2] procedure, and the possibility of autocalibration with only three layers of tubes per multilayer; both problems are of relevance for the design of the Atlas Muon Spectrometer. In the following we present the experimental set up, the autocalibration method, the result of autocalibration obtained using both three and four layers of tubes and the comparison between the MDT Radius-Time (R-T) relation obtained with autocalibration and the one measured with the external tracker.

2. Experimental set-up

In the H8 beam line at CERN, we have set up a muon test facility equipped with a trigger hodoscope made out of four scintillators (2 x 2, 4 x 4, 10 x 10, 10 x 10 cm²), two beam chambers and a reference system (external tracker) made out of two matrices of four by four drift tubes, operated in streamer mode. The muon beam momentum varied between 100 and 180 GeV/c. The data acquisition was based on Spider under the OS9 operating system. We have performed measurements on an MDT made out of four layers containing fifteen drift tubes each. The chamber was made of single aluminum tubes 400 μm thick, 3.010 cm diameter and 80 cm in length. We used 50 μm gold plated W-Re wires. We used the following gas mixtures: Ar 94.6 % C₂H₆ 0.4 % CO₂ 5% at a pressure of 3 Bar absolute. The tubes were operated in proportional mode at 3.1 KV. The front end electronics was based on the VTX chip [3], the amplification was 1 mV/fC and the peaking time 8 ns. After the preamplification board there was a voltage amplifier and discriminator card in which the signal was amplified by a factor of ten and then discriminated. The discrimination threshold was set quite high (300 mV) due to noise and cross talk problems between channels, corresponding, at a typical gas gain of 4x10⁴, to about 100 electrons. Finally the discriminated ECL signals were fed in a LeCroy 2277 TDC with a LSB of 1 ns and a range up to 64 μs. Some signals were split before the discriminator and were sent to a LRS 2249 W ADC to measure the charge spectra and the streamer fraction.
3. Auto calibration method

The aim of auto calibration is to obtain the R-T relation, the position of the wires and the zero time (T0s) from the data of the tubes themselves without the help of external detectors. To obtain this we used an iterative procedure in which we first get the 0-approximation of the R-T relation using the well known technique of the integration of the time spectrum, assuming a uniform illumination of the tubes [4]; then using it we fit the tracks in the detector and we measure the systematic error of the current R-T relation from the value of the residuals vs the drift time in the tubes. The 1-approximation of the R-T relation is then obtained correcting the 0-approximation with the value of the systematic error measured at each drift time. This procedure is iterated until the difference between the n-approximation and the n-1 approximation of the R-T relation is negligible. The T0s of each wires is set at the beginning of the procedure to the value of the rise of the time spectrum, known with an accuracy of few ns. The first approximation position of the wires is given by their nominal geometrical position; a better determination of the T0s and of the wire positions is obtained during the iterative procedure studying the residuals of the tracks fit separately for tracks crossing the first tube at R/2, where R is the geometrical tube radius, will cross all the other tubes almost in the same position. In this condition it is possible to select all the tracks passing at the center of the tubes asking that the drift time of the tubes being nearly equal (± 5 ns).

In this way we obtain a gaussian distribution of drift time corresponding to a drift distance equal to R/2 Fig (1), which sets the absolute scale with high precision. Another common problem of the auto calibration method is due to the least square fitting procedure in presence of systematic errors coming from the R-T relation. It is possible to
demonstrate that the reconstruction of a track, obtained using four measured points all affected by systematic errors of the same magnitude, results in a wrong reconstructed direction of the track while the intercept of the track in the mid plane of the detector is not affected. To correct for this we have used different weights in the fit for the different measured points, namely the two outer layers’ weight is set to 1 while the internal layers’ weight is set to 3. In the case of three tube autocalibration the situation is different, in fact the direction of the reconstructed track is not affected by the systematic errors on the measured point while the intercept at the central plane of the detector is wrong. In this case the weights used are 1 for the external layers and 2 for the internal one. This weighting technique is used only in the autocalibration procedure and not during the track fitting after calibration.

4. Result on external trackers

The external tracker is made of two identical detectors each of which consist in a matrix of 4 x 4, 500 μm thick alluminum drift tubes, 3.030 cm diameter, 30 cm long, wired with a 100 μm alluminum wire. The gas mixture used was 60% 1-Butane and 40% Argon at normal pressure, the high voltage was set to 5200 V, the detector was operated in streamer mode. The readout chain for each channel consisted simply in a discriminator whose threshold was set to 30 mV, and a LRS 2277 TDC. We have autocalibrated the two trackers using the procedure previously explained on groups of four aligned tubes (quadruplet). Using the 0-iteration R-T relation we measure the residuals Fig (2) with respect to the fitted tracks for each tube defined as:

\[ Res = \gamma^{fit} - \gamma^{meas} \]  

(3)

From this figure we see that the systematic error on the 0-iteration R-T relation is as high as 500 μm, and is rapidly varing with the drift time; at the distance of R/2, the error is zero by definition because that point was used to set the space absolute scale. In Fig (3) we present the situation of the residuals of the four tubes after the first iteration. The residual distribution vs the drift time is flat and is centered to zero. Moreover if we study the variable

\[ R = \frac{(\gamma_1^{meas} + \gamma_3^{meas})}{2} + \gamma_2^{meas} \]  

(4)

where \( \gamma_n^{meas} \) indicates the measured distance in tube n, and R, in our geometrical situation should be equal for each event, to the distance between the wires of two staggered planes. We see that the mean value of this distribution 1.514 cm is in very good agreement with what expected from the tracker mechanical construction, proving the good accuracy of the absolute distance scale. We have repeated the procedure for other two iterations and the measured R-T relation shows no relevant difference with the previous ones, indicating the very fast convergence of the autocalibration procedure. We have applied the autocalibration procedure to different quadruplets in the first and the second tracker obtaining always consistent results, so that we can use a single R-T relation for each detector (there is a small systematic difference between the R-T relation of the two trackers). We have also studied the variations with time of the R-T relation finding it very stable. After the calibration procedure we have fit tracks in the two detectors separately, using an average single point resolution of 65 μm, the resulting distribution of the \( \chi^2 \) probability Fig (4) is flat showing the good space accuracy of the

![Figure 2. 0-iteration residuals.](image)
single tubes. After aligning the two detectors we have fit tracks using both trackers. The two detectors were set at a distance of about 9 metres on the beam line to assure a good determination of the direction of the beam tracks. Unfortunately, due to the presence on the beam line of material (radioactive source shielding) introducing a large multiple scattering, the precision of the interpolation of the tracks on the MDT in between the two trackers is not very accurate (≥ 300 μm) because of the big distance between the two trackers.

5. Results on MDT

A typical time spectrum for an MDT tube is shown in Fig (5). We notice that the rise of the spectrum is rather slow because of the high threshold used. It gives problems in the first determination of the T0s and introduces a dead region close to the wire (≥ 1 mm). The residuals vs the drift time using the 0-iteration R-T relation are shown in Fig (6), also in this case we see the big systematic errors due to the wrong 0-iteration R-T relation. After few iterations the autocalibration procedure converges and the residuals vs drift time, shown in Fig (8), are flat and centered to zero. The distribution of the variable \((Y_{1\text{meas}} + Y_{3\text{meas}})/2 + Y_{2\text{meas}}\) is centered to 1.504 cm showing again the precision of the absolute space scale. After the calibration procedure we fit tracks in the MDT, the resulting distribution of the \(\chi^2\) probability is flat using an average single point resolution of 110 μm. The resolution is mainly limited by the high threshold used, in fact our resolution figure is in good agreement with the resolution calculated by a detailed simulation of the drift tube response [5] in which the threshold was set to 100 electrons.

6. Three vs four tubes auto calibration

We have repeated the calibration procedure on both the external tracker and the MDT using only three contiguous tubes instead of four tubes and we have compared the resulting R-T relations bin by bin. The R-T relations obtained with the two procedures give very similar results on the whole drift distance (about 10 μm difference) except close to the wire and to the end wall of the tube where we notice a peak structure of about 40 μm in the R-T relations difference. We still have to investigate the nature of this systematic difference, but from the practical point of view we think that it is not relevant because it influences a very small part of the tube where anyway the space resolution is quite degraded (≥ 100 μm).
7. Comparison between autocalibration and external tracker calibration

The easiest way to measure the R-T relation for a drift tube is to use a precise tracking detector to determine, event by event, the distance of closest approach of a track to the wire of the tube, and to correlate it with the corresponding drift time. We used our external tracker to define tracks impinging on the MDT and we measured the R-T relation for the MDT tubes in an independent way with respect to the autocalibration procedure. The distribution of the difference between the distance of closest approach defined by the external tracker and the one measured using the autocalibration is shown in Fig(8). The width of this distribution (≈300 μm) is due, as previously stated (cf 4), to multiple scattering on the source shielding. We see that there is a good agreement between the two R-T relations in the whole tube apart from a region of ±1.5 mm from the wire and the corresponding region close to the tube wall. This systematic error is due to the high threshold used for the MDT; this is explained in the following. Consider a track crossing the tube right on the wire, then ideally the measured time and distance from the wire would be zero. Now if we set a threshold of N electrons and a crossing muon produces M electrons/cm which drift toward the wire with a constant velocity $V^{\text{drift}}$, the minimum time detectable will be the time needed by N electrons to reach the wire:

$$T_{\text{min}} = \frac{N}{(2 \times M \times V^{\text{drift}})}$$  \hspace{1cm} (5)$$

the factor 2 being due to the fact that the electrons are produced on both sides of the wire. Correspondingly all the tracks passing very close to the wire will be reconstructed at a minimum distance from the wire given by:

$$R_{\text{min}} = \frac{N}{(2 \times M)}$$  \hspace{1cm} (6)$$

In our case, with a threshold of 100 electrons, 300 electrons/cm produced and an average drift velocity $V^{\text{drift}}$ of about 30 μm/ns the minimum distance from the wire is 1.6 mm and the minimum time to collect the 100 electrons is about 50 ns. Those values gives us respectively the size of the zone interested by the systematic error in the R-T relation obtained with the autocalibration procedure and the slowness of the rise of the time spectrum for the MDT.

8. Conclusions

During the summer 1995 we have set up and successfully operated a muon test facility in the HSB zone, where we made measurements on one
MDT prototype. The focus of our studies was centered on the autocalibration procedure used to calibrate both the MDT prototype and a set of drift tubes used as a precision external tracker. The results on the tracker shows the very good spacial resolution of this device, 65 μm each single point, and the fast convergence of the autocalibration procedure. The MDT results shows a resolution of about 110 mm and also in this case the convergence of the calibration procedure is very fast. We demonstrated the possibility of autocalibrating the tubes using three layers of tubes showing that there is a very small difference between the R-T relations obtained using three or four layers. Eventually we checked the autocalibration procedure comparing the R-T relation for the MDT measured using the external tracker with the one obtained by autocalibration. For the whole drift distance, except for a small region close to the wire and the end wall, the two R-T relation are in good agreement, showing the correctness of the autocalibration procedure.

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