Status Report on MDT aging and operating point

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1 The MDT for μ precision tracking in ATLAS

The ATLAS detector for LHC is designed to have a powerful stand-alone muon detector, based on an air toroid superconducting magnet with high precision tracking chambers and fast trigger detectors. The aim is to achieve a Δp/p smaller then 10% at 1 TeV and 2% at 100 GeV.

The general layout is shown in fig.1.

For the precision tracking the MDT(Monitored Drift Tubes) have been chosen, as an evolution of the concepts developed in the three technologies previously proposed(High Pressure Drift Tubes, Tilted Jet Cell Chambers, Honeycomb Strip Chambers).

The MDT are drift tubes operated at high pressure. The advantage of this technology is the high intrinsic resolution and the simplicity and independence of the individual channels. The required precision on each channel is well below 100 μm.

In the following the operation of the MDT in the LHC environment, to achieve the desired characteristics, will be discussed, after a brief mention about the mechanical precision.

2 Mechanical precision

The global precision of the MDT detector requires a high mechanical precision at the level of 20 μm RMS on the position of the individual wires.

Suitable assembly methods have been proposed and are being studied with the construction of various prototypes. Full scale prototypes of different size chambers are scheduled to be ready by september this year. The test beam data and X-ray tomography will be used to establish the precision achieved.

A complex alignement system is also needed to achieve a positioning error of less than 30 μm; it will also be tested this year (DATCHA0 and DATCHA1 tests)

3 Working environment

The main aspects of the working environment in which the MDTs must operate, which influence the performances, are the magnetic field uniformity and the radiation environment.

3.1 Magnetic field

The chambers have to be operated in a very high magnetic field, which presents regions of high disuniformity close to the coils of the toroids. A field map and the integral field as a function of the pseudorapidity are shown in fig.2.

3.2 Radiation environment

The high luminosity of LHC produces a high particle flux from the beam-beam interactions and in addition a high level of neutron and gamma background from the beam interaction on the forward elements (magnets, beam pipe....)

The particle flux in the muon spectrometer is shown in fig.3.

Taking into account the detection efficiency, the rate in the MDT is shown in fig.4.

From fig.4, one can see that in the inner muon station the rate is something less of 100 hz/cm^2 for $\eta \leq 1.6$. In the region of large η the MDT technique is replaced by the CSC(Cathode Strip Chambers) one, which can stand higher rates. Further studies to reduce the background by optimizing the shielding and crack geometry are under way.

Background calculations are done with a realistic simulation of the detector. There is however involved a large uncertainty.

In order to have a safety margin, the MDT parameters are designed to operate for 10 years in a level of background a factor 5 higher than the currently anticipated one.

3.3 Autocalibration

To achieve the position measurement precision at the level given by the intrinsic wire resolution, a proper calibration of the r-t relation must be obtained.

The procedure used is autocalibration, using the tracks in the muon spectrometer during normal operation.

The r-t relation is determined with an iterative process, improving at each step the r-t relation using the points from the fit of the tracks.

The detector is subdivided in many smaller regions, so that all the parameters influencing the r-t relation are uniform enough in the region, and local variations are calibrated out. The autocalibration has been studied with simulation and with real data.

Another approach which provides directly the drift velocity as function of the time from a convenient staggering of the wires, is under consideration: it could provide an easy way to improve on the systematics.

4 Optimization criteria

The main parameters of the MDT to be fixed are

a) the gas mixture composition,

b) the gas pressure,

c) the gas gain,

d) the tube diameter,

e) the wire diameter,

f) the threshold and the shaping time of the electronics.

Those parameters are strongly correlated and the optimal value cannot be determined independently of each other.

In the following the relevant aspects of each item will be discussed, in order to establish the guidelines for the overall optimization.

4.1 Gas mixture composition

A first requirement on the gas mixture is, for safety reasons, the non flammability. This puts a limit on the amount of hydrocarbon component in the MDT, at a few percent.

Another requirement is a short total collection time ($\leq$1 μs), in order to limit the occupancy. Due to the variable electric field in the tube, some "saturation" property of the drift velocity is required, in order to limit the systematics due to dependence on the various parameters (pressure, temperature,etc..).

A very low level of streamer ($\leq$ 1%) is required, in order to limit the total integrated charge on the wire.

A low Lorentz angle is necessary to limit the systematic associated with the magnetic field disuniformity.

4.2 Gas pressure

The main motivation for the use of high pressure is that it reduces the diffusion and the cluster position fluctuation, allowing to reach a better intrinsic wire resolution. It also reduces the Lorentz angle.

The drawback of the high pressure is the increase in the collected charge, which will worsen the aging, a crucial issue at LHC.

4.3 Gas gain

The tubes are operated in a proportional regime. The choice of the gas gain must balance the advantage of a high gas gain (improved resolution in the drift time measurement), with the disadvantage of a larger collected charge on the wire.

Also higher gains bring increased streamer rate.

On the other hand a lower limit for the gas gain is given by the requirement that the signal/noise ratio be at least 5.

4.4 Tube diameter

Large tube diameters lead to increased occupancy(as d^2) and lower electric field on the walls.

Small tube diameters improve on the previous point but lead to an increase of the number of channels, and therefore cost, and to a worse average resolution, since the resolution deteriorates in the region close to the wire.

4.5 Wire diameter

Higher wire diameters improve the electric field uniformity but require higher HV and also can increase the streamer rate.

Smaller wire diameters are more difficult to deal with in the wiring of the tubes (less mechanical strenght).

4.6 Threshold and shaping time

The threshold in terms of number of electrons influences the resolution as a function of the radius.

The peaking time of the shaper determines the fraction of collected charge, which is detected by the discriminator.

5 Simulation and experimental studies

An intensive R&D work has been carried on by the muon collaboration to find suitable operation points.

A series of gas mixtures have been studied using the Magboltz and Garfield simulation programs in order to determine the drift properties of the gas. In fig.5 some of the results obtained are shown.

In this study the dependence of the drift on the changes of the parameters of the detectors has been investigated.

This includes temperature,pressure,high voltage,magnetic field, tube wall displacement,gas mixture composition. The results are summarized in the table 1 in terms of the RMS of the bias produced by a reasonable amount of change in the parameters.

For the potentially appropriate gas mixtures individuated by the simulation study, an experimental study has been carried on to measure the gas gain and the streamer rate.

Different wire diameters and different high pressure values have been also used. Some results are summarized in table 2 which shows the gas gain value that can be achieved while keeping the streamer rate at the 1% level.

The electronic noise and the fraction of charge collected for various peaking times has also been evaluated (table 3).

The minimum gas gain must be

$$\mathrm{G}_{min} = 5^*\mathrm{ENC}/\mathrm{Q}_{thr}$$

The resolution has been studied as a function of the effective discriminator threshold (fig.6).

In order to establish a base for the choice of the pressure, the performances at different pressure have been investigated by simulation, determining the resolution as a function of the drift distance, in conditions of equal collected charge on the wire.

The result is shown in fig.7.

The autocalibration method has been studied by a realistic simulation of the detector, including the magnetic field map and the background.

The table 4 reports the results in terms of the resolution achieved.

The autocalibration in a magnetic field has also been studied experimentally on a test beam. Combining data taken at different field intensities and angles with the detector, the autocalibration in the ATLAS muon spectrometer could be imitated.

The error due to magnetic field variations has been determined and is shown in fig.8.

6 Aging

The MDT must operate for 10 years at LHC, without appreciable deterioration of the performances.

It is necessary, therefore, to operate the MDT in conditions which will guarantee that the collected charge on the wires is below the safety limit.

The aging process due to a given collected charge depends on many other parameters: gas composition, materials used in the construction of the chamber in contact with the gas, rate of irradiation.

In particular the dependence on the rate of irradiation makes it difficult to establish experimentally in laboratory tests the aging due to the radiation caused by a 10 years exposition at LHC.

The existing experience with the aging of various chambers indicates that below the level of 1 C/cm the aging effect is limited.

We have investigated in laboratory irradiation tests the behaviour of the MDT. Preliminary results indicate that there is essentially no pulse-height degradation up to 1 C/cm, even without any particular selection of the construction materials.

Recent results with ultra-clean tests revealed no significant aging effects up to 3 C/cm (fig. 9).

More studies are going on aimed at a better understanding of the influence of the construction materials, the treatment of the surface of the tube, the operating conditions. Our present understanding is that the deposited charge over 10 years of LHC operation has to be kept below the limit of 0.7 C/cm.

The results of the on going studies will further clarify this aging issue.

7 The operating point

From the various studies illustrated above, a working point for the ATLAS MDT detector, which allows for operation over 10 years at the LHC design luminosity,has been individuated.

It is specified by:

Tube diameter = 3 cm

Wire diameter = 50 μm

Gas gain = $2*10^4$

Gas pressure = 3 bars

Peaking time = 15 ns

Threshold = 25 electrons

Gas mixture = $Ar/CO_2/CH_4$: 92/5/3

or $Ar/N_2/CH_4$: 91/4/5

or $Ar/CO_2/CF_4$

or $Ar/N_2/C_2H_6$

or 4 component mixtures.

With a rate of 100 hz/cm^2, the integrated charge, for minimum ionizing particles, is Q = 0.067 C/cm. The primary ionization of the gammas and neutrons which dominate the counting rate, has been estimated to be a factor 2 higher, averaged over the energy spectrum. This gives an integrated charge Q = 0.13 C/cm.

If we take into account a safety factor of 5 on the background rate, the charge is Q = 0.67 C/cm, within the limit of the radiation hardness achievable with the MDT detector.

In addition, it has also to be considered that the main part of the muon spectrometer is irradiated by particle fluxes considerably smaller than the ones corresponding to the worst scenario considered above, by at least a factor 20.

The r-t relation of the $Ar/N_2/CH_4$ mixture shows, as can be seen in fig.10, a rather linear behaviour.

The average resolution, which can be obtained, is reported in fig.11.