Development of Precision Muon Drift Tube Detectors for the High-Luminosity Upgrade of the LHC

B. Bittner, J. Dubbert, S. Horvat, M. Kilgenstein, O. Kortner, H. Kroha, F. Legger, R. Richter, P. Schwegler

Max-Planck-Institut für Physik, Munich

S. Adomeit, O. Biebel, A. Engl, R. Hertenberger, F. Rauscher, A. Zibell

Ludwig-Maximilian-Universität, Munich

For use at the future Super-LHC a new type of muon detector has been developed. It is based on the proven MDT drift tube design, but with tubes of half the diameter, leading to higher rate capabilities by an order of magnitude. We present test results on efficiency and position resolution at high background rates and describe the practical implementation in a real-size prototype.

1. Upgrade of the LHC towards higher Luminosities

The design luminosity of the LHC of $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is expected to be reached after a few years of data taking at lower luminosity. The *integrated* luminosity after 10 years of operation is expected to be about $\sim$ 300 fb^{-1}. With a series of upgrades of the CERN accelerator complex an increase by an order of magnitude could be achieved, leading to an integrated luminosity of up to 3000 fb^{-1} after 10 years of additional running (Super-LHC or SLHC). To help the LHC detectors to cope with this luminosity increase, a new operation mode of the machine is foreseen ("luminosity levelling"), providing a peak luminosity at the beginning of the fill of only $4 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, yet yielding a 10 times higher integrated luminosity over the fill.

While this reduction of the *peak* relative to the *integrated* luminosity by a factor of 2.5 represents a substantial alleviation for the operation of the ATLAS detector, the factor 4 increase relative to the original design value still calls for a major upgrade effort for all subsystems of the ATLAS detector.

At luminosities far beyond the design value the MDT drift tube chambers will face the challenge to maintain excellent tracking efficiency in the presence of high background hit rates, due to gamma conversions. In this article we present a R&D project for the upgrade of the muon tracking system to cope with high background rates, expected at the SLHC.

2. Tracking with in high–background environment

The outer region of the ATLAS detector, where the muon chambers are located, receives high rates of low-energy neutrons, mainly due to shower leakage from calorimeters and shielding structures in the high-η region. At the nominal luminosity, gammas from neutron capture and related conversion electrons are expected to generate hit rates in the range 50–300 kHz in each MDT tube. A conversion electron may create an inefficiency if the signal arrives *before* the muon signal. The muon detection efficiency thus becomes $\exp(-\tau\times\mathrm{f}) \approx 1-\tau\times\mathrm{f}$, where τ is the average drift time in the MDT tubes and f the hit rate due to gamma conversions.

At high rates of n/γ background, the efficiency may be further reduced by a decrease of the gas amplification due to space charge from slowly drifting positive ions in the tubes, while the *fluctuations* of the space charge tend to degrade the spatial resolution by up to about 20 % at the highest rates.

The effects of gamma conversions in the MDT tubes have been studied in detail using a muon beam in the presence of intense γ-irradiation of up to 500 Hz/cm^2 (i.e. $\sim$300 kHz/tube), as delivered by the Gamma Irradiation Facility at CERN (GIF) [1]. While the γ-rates at the GIF correspond to only about 30 % of the background levels expected for the hottest regions at the SLHC, the results of these measurements already allow to define the baseline of a chamber design with much improved tracking capability: MDT drift tubes with only half the tube diameter offer a reduction of the drift time by a factor 3.5, due to the non-linear relation between track distance from the central wire and drift time (r-t relation) and in addition by a factor 2 from the exposed area, thus yielding a factor 7 in the reduction of the hit rate due to n/γ background. Moreover, up to two times more tube layers can be accommodated in the available space, leading to improved track finding efficiency and position resolution (see Fig. 1).

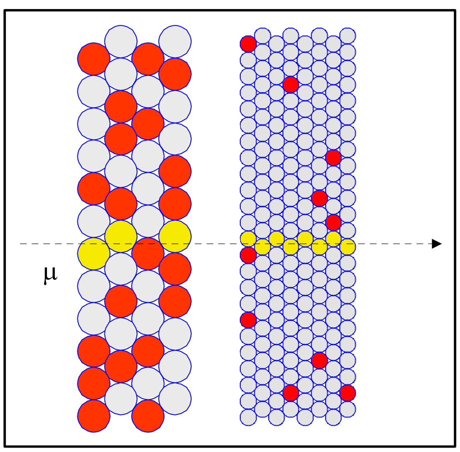

Figure 1. The tracking quality in 30 mm and 15 mm drift tubes in a region of high n/γ background. The occupancies from background hits (red dots) are 50% in the 30 mm tubes but only 7% in the 15 mm tubes due to shorter drift time and smaller area.

The reduction of the tube diameter of the MDT tubes allows to maintain the main advantages of the drift tube concept: (a) independence of the position resolution from the angle of incidence onto the chamber plane (contrary to drift chambers with rectangular drift geometry) (b) operational independance of each tube, where any malfunction of a tube can only generate a negligible inefficiency (c) modularity of chamber construction.

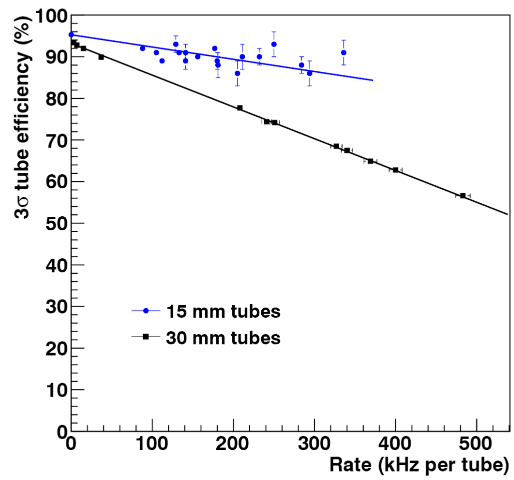

Figure 2. Efficiency vs. hit rate per tube for 30 mm and 15 mm drift tubes.

To verify the performance of 15 mm ("small") tubes a number of tests was executed, using cosmic muon tracks. A pair of 30 mm ("large") drift tube chambers was used as reference, defining the position of the muon track, while a layer of small tubes was the device under test. Tubes along the track are called 'efficient' when the hit is detected inside a 3σ road, as defined by the reference tubes.

This measurement was done in the presence of adjustable levels of gamma background due to the GIF facility at CERN. Fig. 2 shows the efficiency of small and large tubes vs. hit rate from gamma conversions. As expected, small tubes provide a much better performance at high background rates. The efficiency at rate zero deviates from 100 % due to tracks passing across or close to the tube walls and due to δ-electrons shifting the hit position outside the 3σ acceptance road. The average position resolution in the small tubes was about 120 μm. Due to the short drift compared to large tubes, this value showed little dependence on the background rate.

3. Technical Implementation

Going from large to small tubes as construction elements for MDT chambers poses a number of technical challenges, as the higher tube density requires more refined electrical and gas connections on the same available service area. A particular problem is the supply of the tubes with the operating voltage of 2730 V, requiring isolation distances which cannot be realized on the area available for the readout boards. The integration of the HV decoupling capacitors into the end-plugs of the tubes was therefore a central requirement for the tube design. In a similar way, gas supplies had to be simplified to facilitate the integration of the tubes.

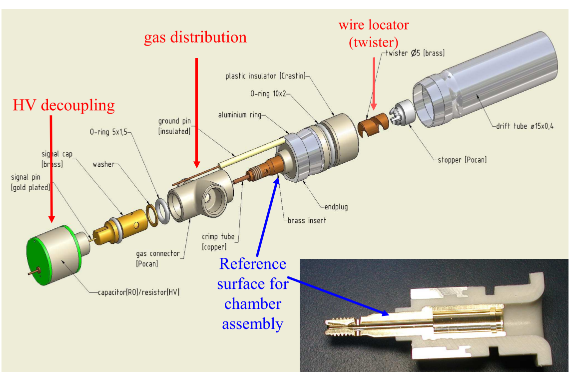

Figure 3. Structure of a small drift tube with gas connection and decoupling capacitor in the longitudinal direction (green zylinder). The plastic parts are injection moulded.

Fig. 3 shows the tube design, HV capacitor and gas distribution being integrated into the structure of the end-plug.

The integration of tubes into chambers is achieved by bonding tubes layer by layer with epoxy glue. In production tests, tubes were fixed in precision supports (”combs”) during curing, and the target accuracy of 20 μm was obtained. A module with 8 tube layers was glued in a time span of a few hours. With curing overnight, the assembly of a module took only one day.

Presently, a full prototype of a MDT chamber in small tube technology is under construction. It consists of 2×8 tube layers and is designed to fit into the inner part of the muon detector in the very forward direction, where rates are highest (Fig. 4). This prototype will be available for tests at the GIF facility by fall 2010. The readout will be achieved with available electronics for the large tube chambers, specially adapted for use with the new chamber geometry.

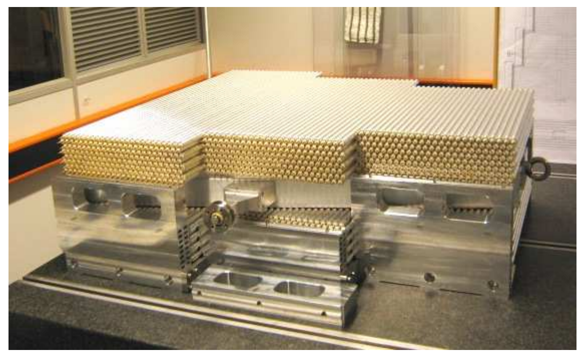

Figure 4. The small tube prototype chamber after assembly, consisting of two modules of 8 tube layers, 72 tubes per layer and 1152 tubes in total.

REFERENCES

1. M. Deile et al., Proceedings of the 9^{th} Pisa Meeting on Advanced Detectors, Isola d'Elba, Italy, 25–31 May 2003, Nucl. Instr. and Methods **A518** (2004) 65;
   proceedings of the 10^{th} Vienna Conference on Instrumentation, Vienna, Austria, 16–21 February 2004, Nucl. Instr. and Methods **A535** (2004) 212;
   S. Horvat et al., IEEE Transactions on Nuclear Science, Vol. 53, No. 2 (2006) 562.
2. J. Dubbert et al., proceedings of the 2007 IEEE Nuclear Science Symposium, Honolulu, Hawaii, USA, 28 October–2 November 2007, MPI report, MPP-2007-172, November 2007, to be published in the IEEE Transactions on Nuclear Science.