Construction and Test of a Full Prototype Drift-Tube Chamber for the Upgrade of the ATLAS Muon Spectrometer at High LHC Luminosities

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Abstract

For the planned high-luminosity upgrades of the Large Hadron Collider (LHC) background rates of neutrons and gamma rays of up to 14 kHz/cm^2 are expected which exceed the rate capability of the current ATLAS precision muon tracking detectors, the Monitored Drift Tube (MDT) chambers, with a drift tube diameter of 30 mm. Smaller diameter drift tube (sMDT) chambers with 15 mm tube diameter have been developed for upgrades of the ATLAS muon spectrometer. A full sMDT prototype chamber has been constructed and tested in a muon beam at CERN and with cosmic muons at high background irradiation rates of up to 95 kHz/cm^2 and 1400 kHz/tube. The test results demonstrate the required track reconstruction efficiency and spatial resolution of the sMDT chambers at background rates well beyond the maximum expected values at high-luminosity LHC. The sense wire locations in the prototype chamber have been measured with few microns precision with cosmic rays using precise reference chambers confirming the required wire positioning accuracy of better than the 20 μm.

Keywords: MDT, sMDT, drift tubes, muon chambers, ATLAS, LHC

1. Chamber Design and Fabrication

A full-scale prototype sMDT chamber with 15 mm diameter aluminum drift tubes has been constructed (see Fig. 1a). The prototype has a trapezoidal shape with three different tube lengths of 560, 760 and 960 mm, arranged in 2×8 layers with 72 drift tubes each. The chamber dimension corresponds to the current size of the cathode strip chambers installed in the inner forward regions of the ATLAS muon spectrometer closest to the beam pipe. The challenge for the new chamber design is the four times denser tube package, compared to the Monitored Drift Tube (MDT) chambers of the ATLAS muon spectrometer with 30 mm diameter drift tubes, with corresponding gas and electrical connections to the individual tubes.

Central to the chamber design is the newly developed tube end-plug which insulates the sense wire from the tube wall, centers the wire in the tubes and provides high-voltage-safe connections to the gas distribution manifolds, the readout and high-voltage distribution boards (see Fig. 1b). Ground pins inserted between adjacent tubes electrically interconnect the tube walls and connect them to the ground. The tubes are assembled to a chamber using precise mechanical jigs (see Fig. 1c) positioning the sense wires relative to each other with better than 20 μm accuracy.

2. Drift Tube Performance at High Counting Rates

At high counting rates, the drift tubes of the ATLAS MDT chambers are known to suffer from a degradation of the spatial resolution due to space-charge effects [1, 2] and of the muon detection efficiency due to the increased drift tube occupancy [3]. Both effects can be mitigated by reducing the tube diameter. Other operating parameters of the drift tubes, in particular gas mixture, pressure and gas gain, are kept unchanged.

Decreasing the drift tube diameter from 30 to 15 mm and the operating voltage from 3080 to 2730 V leads to a reduction of the maximum drift time by a factor of 3.8 from about 700 to 185 ns while keeping the gas gain of 2×10^4 [4]. In addition, the background counting rate, dominated by the conversion of the neutron and gamma radiation in the tube walls, decreases proportional to the tube diameter, i.e. by a factor of two per unit tube length. Both effects together lead to a reduction of the occupancy by about a factor of 7.6. At the same time, twice the number of drift tube layers can be accommodated in the same detector volume allowing for additional improvement of the muon tracking efficiency and resolution.

Fluctuations of the space charge and, consequently, of the electric field in the tube lead to variations of the drift velocity in non-linear drift gases like Ar:CO_2 (93:7) causing a deterioration of the spatial resolution which increases rapidly with the drift distance above a value of about 7.5 mm [1, 2]. This effect is eliminated for 15 mm diameter tubes.

At high counting rates, the space-charge generated by the ion cloud drifting towards the tube wall lowers the effective potential near the anode wire leading to a reduction of the gas gain. The resulting loss in signal height grows with the tube inner radius r proportional to r^3 for neutrons and gammas, and r^4 for charged particles. Therefore, the signal height reduction due to space charge for the 15 mm diameter tubes is 8.6 times smaller

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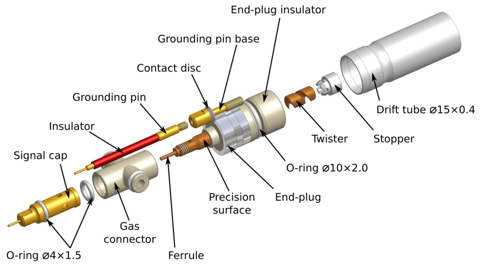
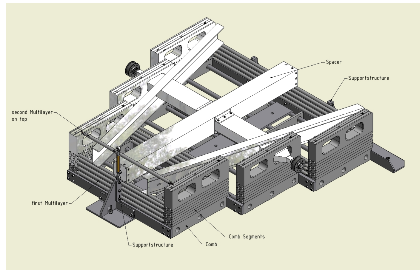
(a) sMDT prototype chamber.



(b) Exploded view of the tube end.



(c) Precision jigging for chamber assembly.

Figure 1: Drift tube and chamber assembly.

for neutrons and gammas, and 17.7 times smaller for charged particles, compared to 30 mm diameter drift tubes.

3. Test Results

The chamber performance has been tested with cosmic ray muons in the Gamma Irradiation Facility (GIF) at CERN at γ counting rates from a 500 GBq ^{137}Cs source of up to 1.4 MHz per tube and at the Munich MLL tandem accelerator with 20 MeV protons at rates up to 100 kHz/cm^2.

Figure 2 shows the measured spatial resolution of 15 and 30 mm diameter drift tubes as a function of the γ background hit rate. The proton hit rates have been rescaled to equivalent γ rates by multiplying them with the average number of primary ionization electrons produced by 20 MeV protons relative to 562 keV γ's.

With increasing background counting rate, the muon hits are increasingly masked by background hits. The $3\,\sigma$ efficiency, defined as the probability that the distance of a muon hit to the reconstructed track is within three times the spatial drift tube resolution, is shown in Fig. 3 as a function of the counting rate in comparison with previous measurements for 30 mm diameter drift tubes [3].

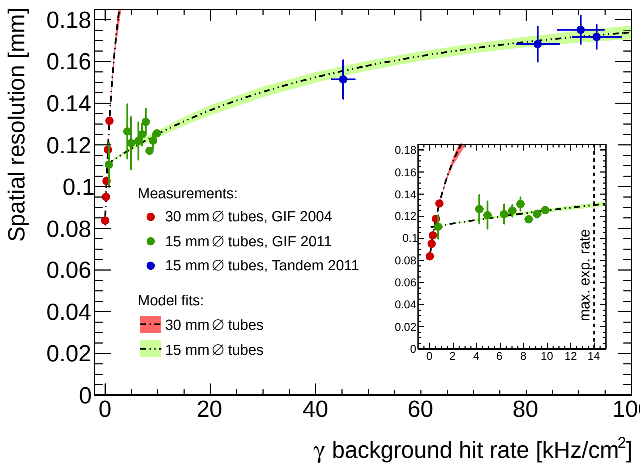


Figure 2: Average single-tube spatial resolution as a function of the γ background hit rate for 15 and 30 mm diameter drift tubes.

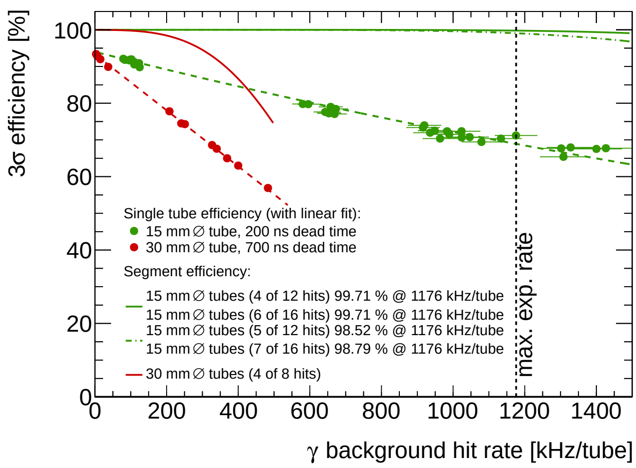


Figure 3: Muon detection efficiency (see text) of 15 and 30 mm diameter drift tubes as a function of the γ ray background hit rate.

4. Conclusions

A full-scale small-diameter drift tube (sMDT) prototype chamber with 1152 drift tubes of 15 mm diameter has been constructed and used for tests of the high-rate performance. Monitored drift tube chambers are a well tested technology for high precision tracking. Reducing the drift tube diameter to 15 mm increases the rate capability considerably, sufficient to cope with the highest background counting rates expected in the ATLAS muon spectrometer of 7 times the LHC design luminosity.

References

[1] M. Aleksa et al., Nucl. Instrum. Methods A446 (2000) 435.
[2] M. Deile et al., Nucl. Instrum. Methods A518 (2004) 65.
[3] S. Horvat et al., IEEE Trans. Nucl. Sci., Vol. 53, No. 2 (2006) 562.
[4] B. Bittner et al., Nucl. Instrum. Methods A617 (2010) 169.