Performance of Fast High-Resolution Muon Drift Tube Chambers for LHC Upgrades

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The muon spectrometers of the LHC experiments require high precision tracking detectors covering large areas. The only viable and affordable solution are gaseous detectors. The muon spectrometer of the ATLAS experiment uses 1150 Monitored Drift Tube (MDT) chambers built of 2×3 (or 4) layers of densely packed aluminum tubes of 30 mm diameter, each equipped with a single central anode wire, resulting in 350 k read-out channels. Operated with an Ar/CO_2 gas mixture at 3 bar absolute, the maximum drift time of primary ionization electrons to the anode wires is about 700 ns. Up to background counting rates of about 0.5 kHz/cm^2, the MDT chambers reach a spatial resolution of 40 μm and a tracking efficiency of almost 100%. Limiting factors at higher rates are space-charge effects and the long drift times, respectively. Future upgrades of the muon spectrometer in the very forward region at pseudo-rapidities of η = 2.0–2.7 and luminosity upgrades of the LHC beyond its design luminosity of 1×10^{34} cm^{-2} s^{-1} will require a rate capability of up to 10 kHz/cm^2. A cost-effective upgrade option consists of substituting MDT chambers in the high rate regions by drift tube chambers with a smaller tube diameter of 15 mm. Keeping the operating parameters (gas mixture, pressure, and gain) the same as for the MDT chambers allows for integration into the muon spectrometer while re-using existing services. The smaller tube diameter significantly improves the rate capability:

- The maximum drift time is reduced to 200 ns.
- Space charge effects are suppressed by a factor of about $(1/2)^3$, keeping the resolution almost constant up to high rates.
- The increased number of tube layers with the same geometrical envelope improves the pattern recognition.

The performance of prototype drift tubes with 15 mm diameter was studied at high γ background rates at the Gamma Irradiation Facility (GIF) at CERN using cosmic muons tracked in two reference chambers. Figure 1 shows the setup. An average spatial resolution of 112 μm was measured for the 15 mm diameter tubes, compatible with expectations from the measured spatial resolution of 30 mm diameter tubes as a function of the drift distance (see fig. 2). This leads to a chamber resolution of 40 μm without background radiation and of 45 μm at a background counting rate of 1 kHz/cm^2, the maximum rate achieved in the GIF. The efficiency of detecting a muon hit with the correct drift radius with 3 times the tube resolution (3σ tube efficiency) was measured up to a maximum background counting rate of 1.2 MHz per tube (see fig. 3 for the first results). The 3σ single tube efficiency is 95% without background irradiation ($<$ 100% because of δ electrons knocked off the tube wall by impinging muons) and drops to 85% at a counting rate of 340 kHz per tube, corresponding to more than twice the maximum counting rate expected at the LHC design luminosity. Rates of up 0.7 MHz per tube are expected for LHC luminosity upgrades. At those rates the 3σ single tube efficiency is expected to be $>$ 75% at an occupancy of 13%. The drop of tube efficiency can be compensated by redundant measurements in the up to twice as large number of layers, allowing for a muon track reconstruction efficiency $> 99\%$ up to the a counting rate of 1.75 MHz per tube.

In addition to the tests at high γ background, measurements with a full-scale prototype chamber with high momentum muons are scheduled for July/August 2010 at the H8 beam line at CERN. This chamber will consists of 1152 tubes arranged in 2×8 layers. It will allow for tracking and resolution studies and the verification of the performance of the auto-calibration algorithm used to determine the space-to-drift time relation in-situ.

A further important test, the response of the 15 mm diameter drift tubes and their read-out electronics to highly ionizing particles will be performed in summer 2010 at the Tandem accelerator of the Meier-Leibnitz-Laboratory at Munich, Germany. Results of all measurements will be reported.

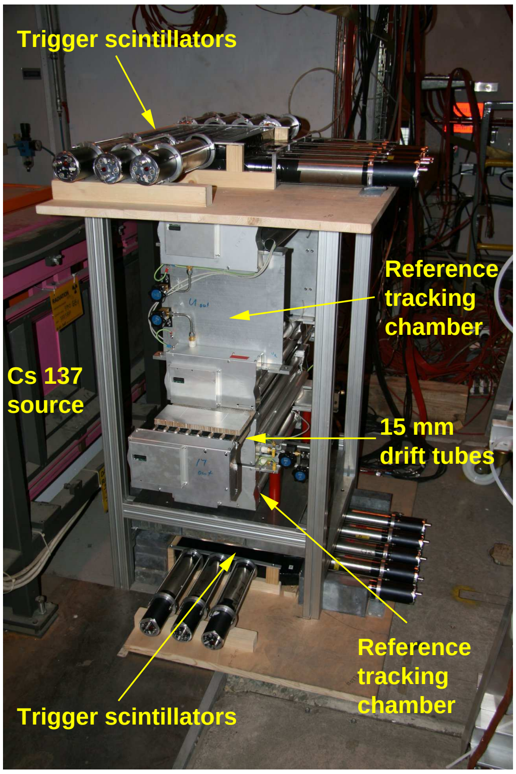

Fig. 1: Setup used for resolution and efficiency studies of 15 mm drift tubes at the Gamma Irradiation Facility at CERN.

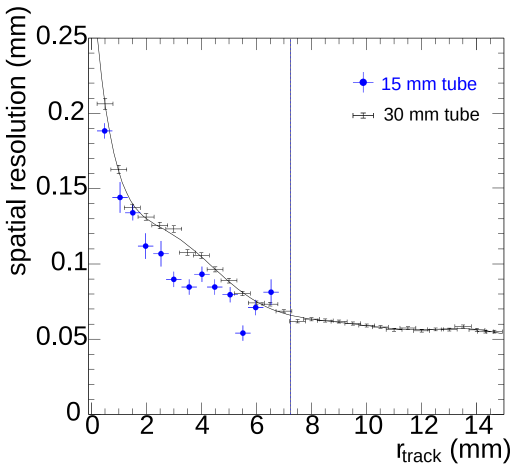

Fig. 2: Comparison of the spatial resolution of a 15 mm and a 30 mm diameter drift tube as a function of the distance of the track from the anode wire.

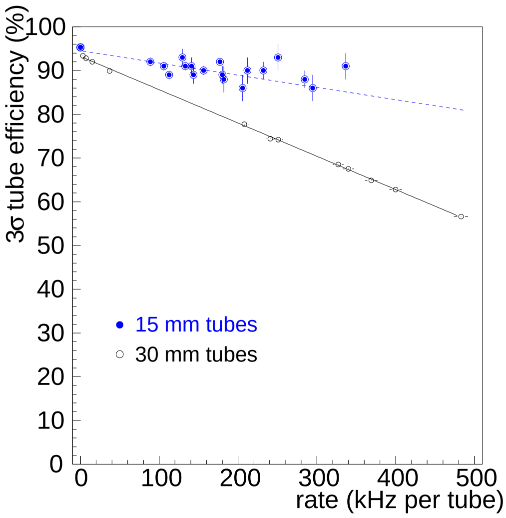

Fig. 3: Measured 3σ single tube efficiencies. The dashed line indicate the expected efficiency from 30 mm tube tests, taking into account multiple hits.