High–Rate Performance of New Fast Muon Drift Tube Chambers for LHC Upgrades

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The muon detectors 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 aluminium tubes of 30 mm diameter, each equipped with a single central anode wire, resulting in 350000 readout 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%. Spatial resolution and detection efficiency degenerate at higher rates due to space-charge effects occupancy for the long drift times, respectively. Upgrades of the LHC beyond its design luminosity of 1×10^{34} $cm^{-2}\,s^{-1}$ will require a rate capability of the muon tracking chambers of up to 10 kHz/cm^2. A cost-effective and robust upgrade solution for the ATLAS muon spectrometer consists of substituting the muon chambers in the high–rate endcap regions by drift-tube chambers with smaller tube diameter of 15 mm. Keeping the operating parameters (gas mixture, pressure, and gain) like for the present MDT chambers allows for integration into the muon spectrometer using the existing gas distribution system. The smaller tube diameter significantly improves the rate capability:

- The maximum drift time is reduced by a factor of 3.5 to about 200 ns and the tube cross section by a factor of 2 reducing the occupancy by a factor of 7.
- Gain drop effects due to space charge near the wire are suppressed by a factor of about $(1/2)^3$ while the effects of space charge fluctuations for drift radii larger than 7 mm deteriorating the spacial resolution are eliminated, keeping the resolution almost constant up to high rates.
- The increased number of tube layers fitting within the same geometrical envelope allows for significant improvements of the tracking efficiency.

The performance of prototype chamber with 15 mm diameter drift tubes was studied at high γ background rates at the Gamma Irradiation Facility (GIF) at CERN using cosmic muons. Figure 1 shows the experimental setup. The prototype chamber consists of 1152 tubes arranged in 2×8 layers. An average spatial resolution of individual drift tubes of 112 μm was measured with background irradiation, which is compatible the expectation from the measured spatial resolution of 30 mm diameter tubes as a function of the drift distance (see fig. 3) and leads to a chamber resolution of 40 μm. The efficiency of detecting a muon hit with the correct drift radius within 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. 4). The 3σ single tube efficiency is 94% without background irradiation (below 100% because of δ electrons knocked off the tube wall by impinging muons) and drops to 85% at a counting rate of 300 kHz per tube, corresponding to the maximum counting rate expected at the LHC design luminosity. Rates up to 0.8 MHz per tube are expected for LHC luminosity upgrades to 5 times the design luminosity. At those rates, the 3σ single tube efficiency is measured to be $> 75\%$ at an occupancy of 16%. The drop of tube efficiency is compensated by redundant measurements in the larger number of tube layers allowing for a muon track reconstruction efficiency grater than 99% up to counting rates of 1.75 MHz per tube.

In addition to the tests at high γ background rates, measurements with the full-scale prototype chamber were performed in a high momentum muons beam at CERN. The setup is show in Figure 2. The test allowed for tracking and resolution studies and for the verification of the performance of the auto-calibration algorithm used to determine the space-to-drift time relation in-situ. The measured spatial resolution agrees well with the expectations form measurements with 30 mm diameter drift tubes. (see fig. 3).

The response of the 15 mm diameter drift tubes and their read-out electronics to highly ionizing particles was measured in a high-intensity proton beam and with a neutron source at the Meier-Leibnitz Laboratory at Garching, Germany.

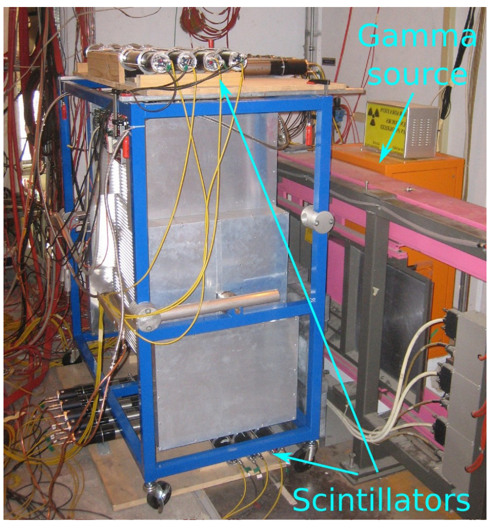

Figure 1: Setup for the spatial resolution and efficiency measurement of 15 mm diameter drift tubes in the prototype chamber at the Gamma Irradiation Facility at CERN.

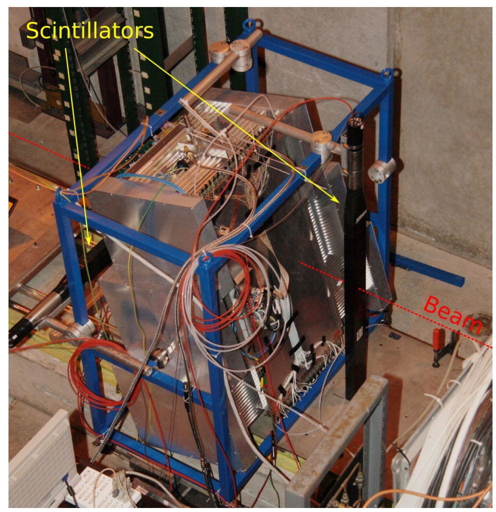

Figure 2: Prototype chamber with 15 mm diameter drift tubes in the 180 GeV muon beam line at CERN.

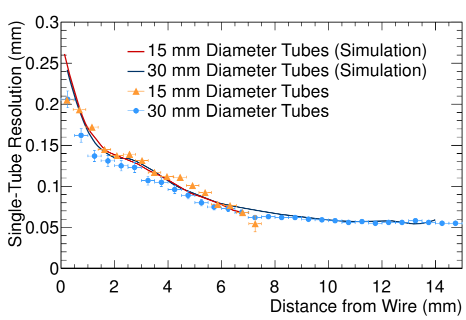

Figure 3: Single-tube spatial resolution measured for high p_T muon tracks for 15 and 30 mm diameter dirft tubes without background irradiation.

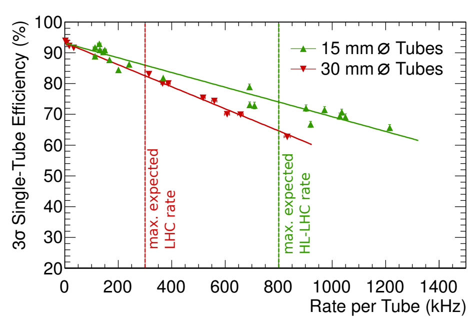

Figure 4: Single-tube efficiency as a function of the background counting rate for 15 and 30 mm diameter drift tubes. The maximum background counting rates expected at the LHC design luminosity and at 5 times the design luminosity for the high-luminosity upgrades of the LHC (HL-LHC) are marked.