Performance of Drift Tube Detectors at Very High Counting Rates at High-Luminosity LHC

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The muon detectors of the LHC experiments require high precision tracking detectors covering large areas. Drift tube detectors provide a robust and efficient solution even at the high background rates of neutrons and γ rays experienced in the forward regions of the muon spectrometer of the ATLAS experiment which is equipped with muon drift-tube (MDT) chambers with 30 mm tube diameter. For the high-luminosity upgrades of the LHC, the background flux is expected to increase by almost an order of magnitude compared to the design lumnosity to about 14 kHz/cm^2.

Muon detectors with 15 mm diameter aluminium drift tubes filled with an Ar:CO_2(93:7) gas mixture at 3 bar absolute pressure and operated at 2760 V leading to a maximum drift time of 185 ns have been developed. A complete prototype chamber with 8 layers of 1 m long tubes has been constructed with an anode wire positioning accuracy of 16 μm as measured with cosmic rays using precise reference chambers Several such sMDT chambers are under construction for the upgrade of the ATLAS muon spectrometer in the 2013/14 LHC shutdown period. One chamber is already in operation in the high-background forward region of the muon spectrometer since the start of the 2012 LHC run.

The high-rate performance of the drift tube chambers has been studied with cosmic rays in the Gamma Irradiation Facility (GIF) at CERN in 2011 at background rates up to 1400 kHz/tube and 8.5 kHz/cm^2 and in a high-intensity 20 MeV proton beam at the Munich Van-der-Graaf Tandem accelerator in 2011 and 2012 up to irradiation rates of 2800 kHz/tube and 1330 kHz/cm^2, far beyond the background rates expected in the ATLAS muon spectrometer at high-luminosity LHC upgrades. With the 3.8 times shorter maximum drift time of 185 ns the drift-tube occupancy per unit length is reduced by a factor of 7.6. The degradation rate of the drift-tube spatial resolution due to space charge effects is reduced by more than an order of magnitude (see Fig. 1, left). The effect of space charge fluctuations deteriorating the resolution of the 30 mm diameter drift-tube detectors in the ATLAS experiment

The shorter maximum drift time allows also for a reduction of the adjustable deadtime of the readout electronics from 790 ns to the minimum of 175 ns reducing by a factor of 4 the rate of degradation with the background counting rate of the 3σ efficiency (see Fig. 1, right), the probability for detecting the correct muon hit in a tube within 3 times the drift-tube resolution which is the relevant quantity for evaluation of the tracking efficiency. With signal shaping optimised for 175 ns deadtime with faster baseline restoration than in the present ATLAS MDT chamber readout electronics used for the tests, an improvement by a factor of 6.5 is expected from the simulation (see Fig. 1, right).

With not more than 2 times 6 tube layers, a chamber spatial resolution of better than 40 μm and a tracking efficiency of better than 99% is achieved up to background rates far beyond the rates expected at high-luminosity LHC. At the latter rates, there is negligible degradation compared to the performance without irradiation.

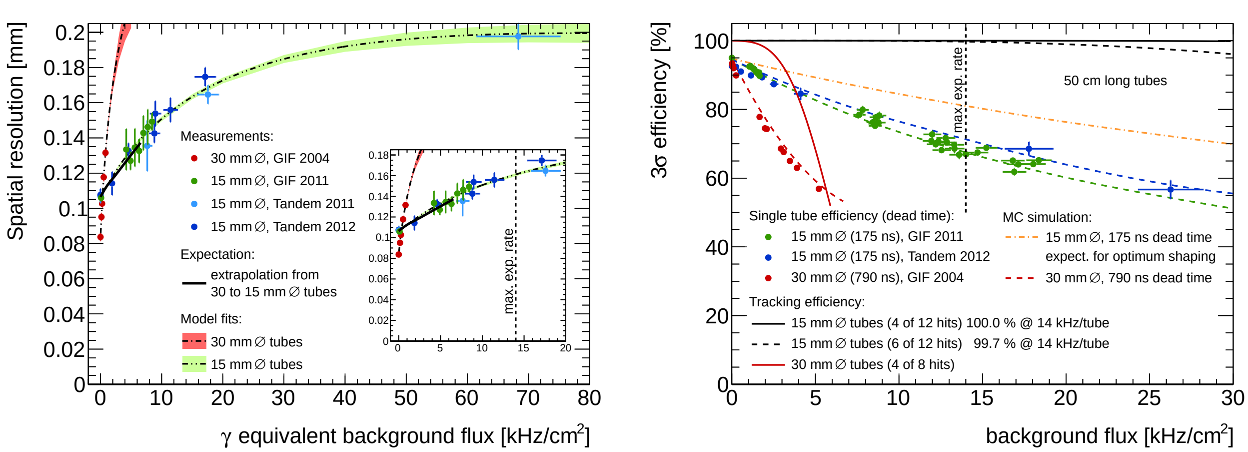

Figure 1: Comparison of the single-tube resolution (left) and of the 3σ efficiency of 0.5 m long drift tubes (right) for 15 mm and 30 mm tube diameter. The expected improvement of the efficiency for signal shaping optimised for 175 ns deadtime is also shown. The maximum background rate expected at LHC luminosity upgrades is indicated.