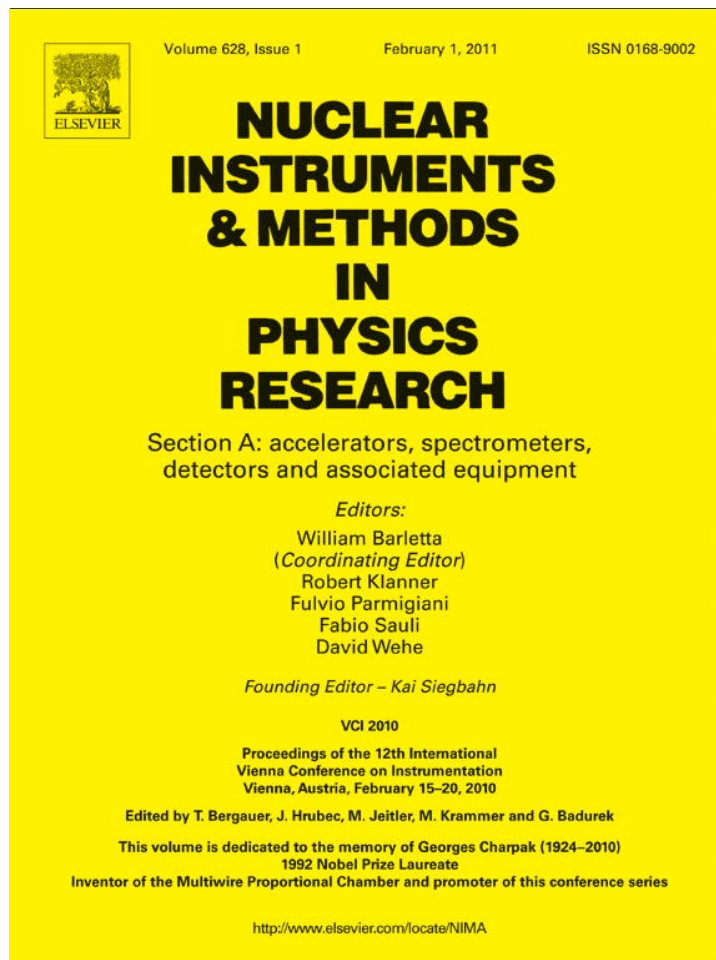


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Development of fast high-resolution muon drift-tube detectors for high counting rates

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ABSTRACT

Pressurized drift-tube chambers are efficient detectors for high-precision tracking over large areas. The Monitored Drift-Tube (MDT) chambers of the muon spectrometer of the ATLAS detector at the Large Hadron Collider (LHC) reach a spatial resolution of 35 μm and almost 100% tracking efficiency with 6 layers of 30 mm diameter drift tubes operated with an Ar:CO₂ (93:7) gas mixture at 3 bar and a gas gain of 20 000. The ATLAS MDT chambers are designed to cope with background counting rates due to neutrons and γ rays of up to about 300 kHz per tube which will be exceeded for LHC luminosities larger than the design value of 10³⁴ cm⁻² s⁻¹. Decreasing the drift-tube diameter to 15 mm while keeping the other parameters, including the gas gain, unchanged reduces the maximum drift time from about 700 to 200 ns and the drift-tube occupancy by a factor of 7. New drift-tube chambers for the endcap regions of the ATLAS muon spectrometer have been designed. A prototype chamber consisting of 12 times 8 layers of 15 mm diameter drift tubes of 1 m length has been constructed with a sense wire positioning accuracy of 20 μm. The 15 mm diameter drift-tubes have been tested with cosmic rays in the Gamma Irradiation Facility at CERN at γ counting rates of up to 1.85 MHz.

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1. Introduction

The muon detectors of the experiments at the Large Hadron Collider (LHC) will encounter unprecedentedly high background counting rates due to neutrons and γ rays in the energy range of up to about 10 MeV which originate mainly from secondary interactions of the hadronic collision products with accelerator elements, shielding material and the detector components. The LHC schedule foresees a continuous increase of the luminosity eventually exceeding the original design value of 10³⁴ cm⁻² s⁻¹. Assuming that the background rates approximately scale with the luminosity, the rate capability of the muon detectors will be exceeded. The Monitored Drift-Tube (MDT) chambers in the muon spectrometer of the ATLAS detector at the LHC [1,2], for example, are designed to cope with counting rates of up to about 300 kHz in the endcap regions of the spectrometer corresponding to an occupancy of 21%.

The MDT chambers consist of two triple or quadruple layers (multilayers) of aluminum drift tubes of 30 mm outer diameter and 0.4 mm wall thickness filled with an Ar:CO₂ (93:7) gas mixture at a pressure of 3 bar. A voltage of 3080 V is applied

between the tube wall and the 50 μm diameter anode wire corresponding to a gas gain of 2 × 10⁴ at low counting rates and resulting in a maximum drift time of about 700 ns. At low counting rates, the average spatial resolution of individual drift tubes is 80 μm applying time-slewing corrections based on pulse height measurements [3]. With a sense-wire positioning accuracy of better than 20 μm, this corresponds to a chamber spatial resolution of 35 μm.

We investigate the possibility of using pressurized drift-tube detectors with a smaller tube diameter and therefore a shorter maximum drift-time in the highest background regions of the muon detectors of the LHC experiments. Building on the experience with the ATLAS MDT chambers, new muon drift-tube detectors with 15 mm diameter tubes have been developed which can cope with 10 times higher background fluxes.

2. Drift-tube performance at high 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 [4,5], and of the muon detection efficiency due to the increased drift-tube occupancy [3]. Both effects can be suppressed by reducing the tube diameter

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while leaving the other operating parameters of the drift tubes, in particular gas mixture, pressure and gas gain, 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 3.5 from about 700 to 200 ns [6]. In addition, the background counting rate, dominated by the conversion of the neutron and gamma radiation in the tube walls, decreases proportionally 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. At the same time, at least twice the number of drift-tube layers can be accommodated in the same detector volume allowing for additional improvement of the muon detection efficiency and spatial resolution.

At high counting rates, the space-charge generated by the ion clouds 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 and, therefore, spatial resolution grows with the inner tube radius R_2 proportionally to $R_2^3 \cdot \ln(R_2/R_1)$ [7] where $R_1 = 25 \mu\text{m}$ is the wire radius. Therefore, the signal height reduction due to space charge is 10 times smaller in 15 mm compared to 30 mm diameter tubes. 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:CO₂ (93:7) causing a deterioration of the spatial resolution which increases rapidly with the drift distance above a value of about 7.5 mm [4,5]. In addition, the space-to-drift time relation for the Ar:CO₂ (93:7) drift gas is more linear at drift

distances below 7.5 mm reducing the sensitivity of the position measurement to environmental parameters such as gas composition and density, magnetic field and, in particular, irradiation rate.

Since the drift-tubes' spatial resolution at low background rates improves with the drift distance, the average single-tube resolution deteriorates from 80 μm for 30 mm diameter tubes [3,5] to about 110 μm for 15 mm diameter tubes. For 30 mm diameter drift-tubes, the resolution has been measured to deteriorate approximately linearly with the counting rate to about 120 μm at 500 Hz/cm² [3,5]. For 15 mm diameter tubes, the rate dependence of the resolution, dominated by the gain drop effect, is expected to be about 10 times smaller (see Fig. 2).

3. Chamber design and fabrication

Central to the chamber design is the development of endplugs for the 15 mm diameter tubes (see Fig. 1) which builds on the endplug design for the ATLAS MDT chambers [8]. The injection moulded plastic endplugs electrically insulate the sense wire from the tube wall and center the wire in the tube with few micron accuracy with respect to the external reference surfaces on the central brass inserts of the endplugs. The wire is tensioned and fixed in copper crimp tubelets at the ends of the brass inserts. The endplugs also provide the interfaces to the gas distribution system (see Fig. 3) and to the readout and high-voltage distribution boards (see Fig. 4). Ground pins inserted between adjacent

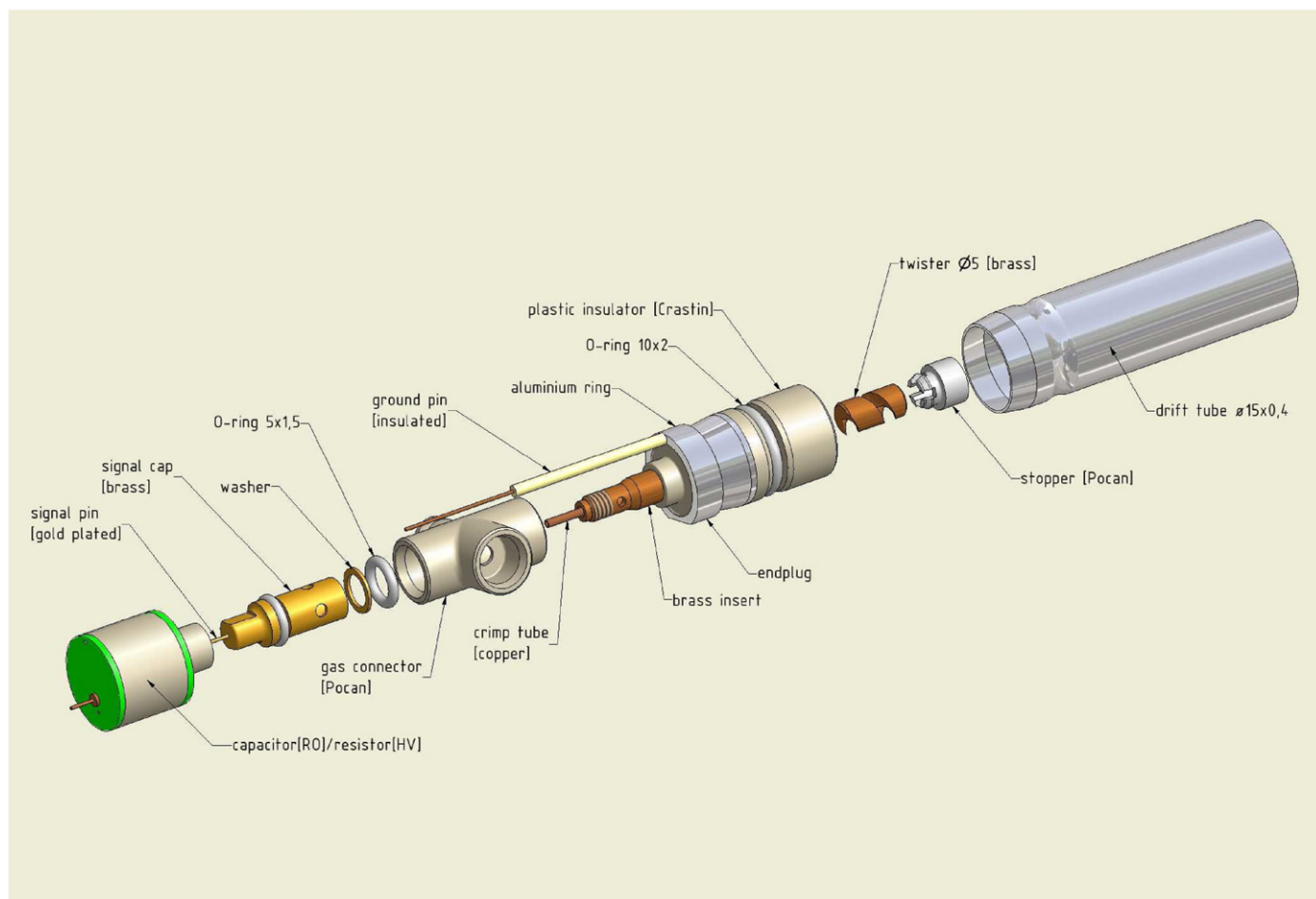


Fig. 1. Exploded view of the endplug for 15 mm diameter drift tubes with interfaces to the gas distribution and to the electronics boards. The spiral-shaped wire locator (twister) with 50 μm inner diameter fits into the central bore of the brass insert (the arrow points to the external reference surface for precise wire positioning in the chamber).

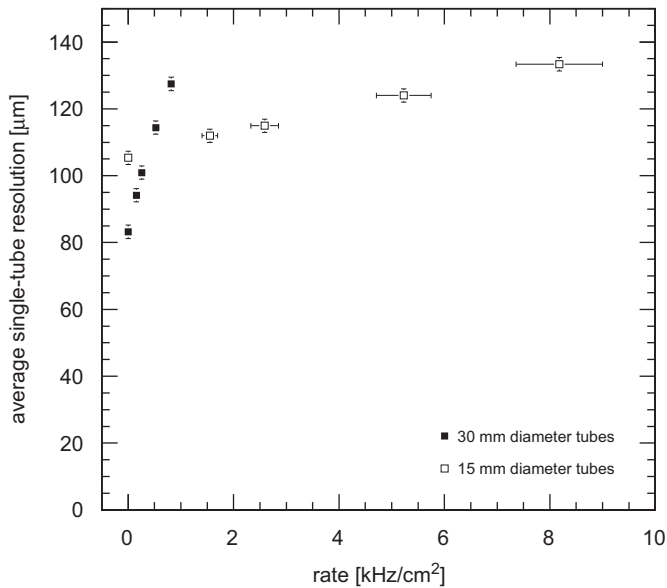


Fig. 2. Average spatial drift-tube resolution as a function of the background counting rate in 15 and 30 mm diameter tubes.

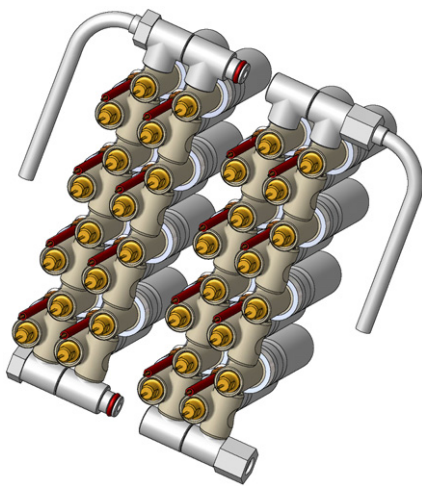


Fig. 3. Modular gas distribution system consisting of injection moulded plastic connections between the tubes and to the gas supply pipes.

tubes electrically interconnect the tube walls and connect them to ground. The decoupling capacitors on the readout end of the tubes and the protection resistors on the high-voltage connection side are housed in insulating plastic cans.

The tubes are assembled to a chamber using precise mechanical jigs (see Fig. 5) positioning the sense wires relative to each other with better than $20\mu\text{m}$ accuracy using the external reference surfaces of the endplugs. All tubes of a multilayer can be assembled and glued together in a single step requiring only one working day. A prototype chamber consisting of 12 layers with eight 1 m long drift tubes has been constructed (see Fig. 5). Standard aluminum tubes with 0.4 mm wall thickness and tolerances of $\pm 0.1\text{ mm}$ on diameter, roundness and concentricity, and of $\pm 0.5\text{ mm}$ on the straightness have been used successfully. Measurements of the prototype chamber in a cosmic ray test stand with two ATLAS MDT chambers as tracking references [9] confirmed the desired wire positioning accuracy of $20\mu\text{m}$.

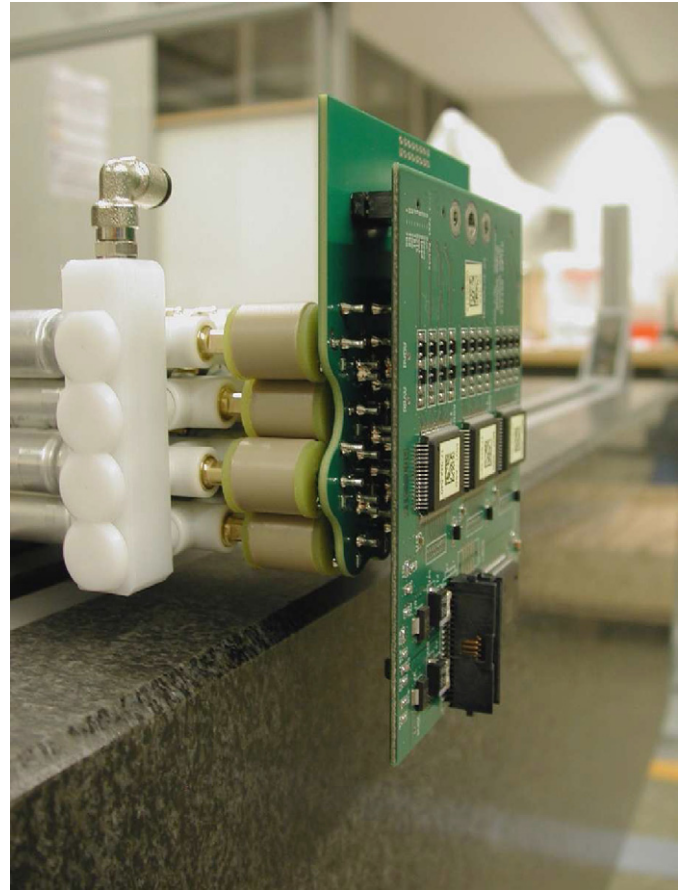


Fig. 4. Photograph of the interface between the drift tubes and the readout electronics. The white plastic gas connectors (on the left) and the insulating cans for the high-voltage decoupling capacitors between the signal caps on the endplugs and the readout boards are visible.



Fig. 5. Assembly of a prototype chamber with 15 mm diameter drift tubes. The external endplug reference surfaces at both tube ends are inserted in precise mechanical jigs (before the installation of gas connections and signal caps) in order to position the sense wires with better than $20\mu\text{m}$ accuracy.

4. Test results

Drift tubes of 15 mm diameter and 1 m length equipped with the ATLAS MDT readout electronics [2] have been tested with cosmic ray muons in the Gamma Irradiation Facility (GIF) at CERN at γ counting rates of up to 1.85 kHz. The test setup with two MDT reference chambers above and below the tested detectors is described in Ref. [10]. The adjustable dead time of the readout electronics was set to its minimum value of 200 ns.

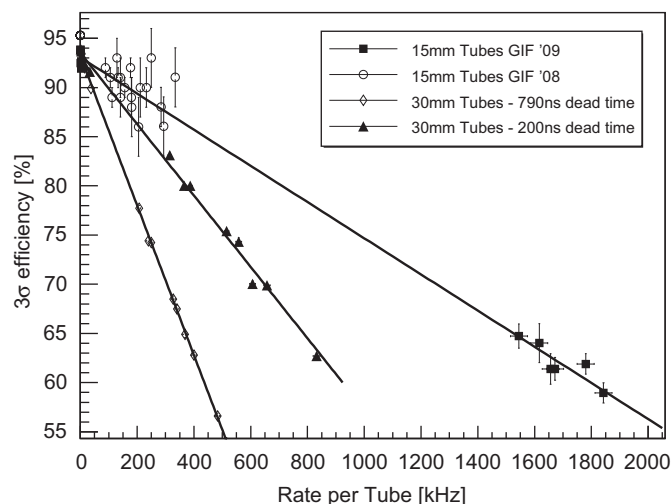


Fig. 6. Muon detection efficiency (see text) of 15 and 30 mm diameter drift tubes as a function of the γ ray background counting rate.

With increasing background counting rate, the muon hits are increasingly masked by background hits. The measured probability to detect a muon hit at the drift radius, expected within three times the spatial drift-tube resolution of the extrapolation

from the reference chambers, is shown in Fig. 6 as a function of the counting rate, in comparison with previous measurements for 30 mm diameter drift tubes with the same readout electronics with 200 and 790 ns dead-time settings [3]. The drift-tube efficiency is considerably increased as expected, approximately by the ratio of the sums of the maximum drift time and the electronics dead time.

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