Position resolution and efficiency measurements with large scale Thin Gap Chambers for the super LHC

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Abstract

New developments in Thin Gap Chambers (TGC) detectors to provide fast trigger and high precision muon tracking under sLHC conditions are presented. The modified detectors are shown to stand a high total irradiation dose equivalent to 6 Coulomb/cm\textsuperscript{2} of wire, without showing any deterioration in their performance. Two large (1.2 × 0.8 m\textsuperscript{2}) prototypes containing four gaps, each gap providing pad, strips and wires readout, with a total thickness of 50 mm, have been constructed. Their local spatial resolution has been measured in a 100 GeV/c muon test beam at CERN. At perpendicular incidence angle, single gap position resolution better than 60 µm has been obtained. For incidence angle of 20° resolution of less than 100 µm was achieved. TGC prototypes were also tested under a flux of 10\textsuperscript{5} Hz/cm\textsuperscript{2} of 5.5-6.5 MeV neutrons, showing a high efficiency for cosmic muons detection.

Key words: super LHC, Thin Gap Chamber, Aging effect, Position resolution

1. Introduction

The expected background rates in the forward region of the ATLAS Muon Spectrometer at the sLHC are expected to be higher by one order of magnitude compared to those at the LHC. Some of the present Muon Spectrometer components will fail to cope with these high rates and will have to be replaced. In particular, the expected rate of neutrons with energies above 100 keV may exceed 10\textsuperscript{5} Hz/cm\textsuperscript{2}.

The higher rate of photons and minimum ionizing particles (MIPs) should be matched by a comparable increase in the rate capability of the various detector components. In addition, few MeV neutrons may give rise to very high signals due to the struggling of recoil carbon nuclei from the gas and detector walls. The Thin Gap Chamber (TGC) detectors have been used successfully in the OPAL experiment at LEP and are now a part of the ATLAS end-cap muon trigger system.

The TGC is a multiwire chamber with 50 µm diameter gold-plated tungsten wires, comprising the anode plane, located between FR4 walls coated with resistive carbon that serves as the cathode. The spacing between the wires is 1.8 mm and the anode-cathode spacing is 1.4 mm. The operational gas is a mixture of 55% CO\textsubscript{2} and 45% n-pentane. The carbon coating is transparent so that signals can be read out from strips or pads outside the gas volume. A schematic view of the TGC with wire, strip and pad readout is shown in Fig. 1.

The present publication aims to show that a single layer TGC can provide spatial resolution better than 100 µm and hence to fulfill the ATLAS-sLHC requirement. This ability, coupled with the high rate capabilities and time resolution, makes the TGC technology a good candidate for triggering and tracking of high momentum muons at the sLHC. The combination of a local trigger and good position resolution in the same gas gap would save precious space and simplify the structure of the future sLHC Muon Spectrometer. TGC trigger should provide fast signals, with an angular resolution of 1 mrad, within the present ATLAS timing restrictions of latency for the first level trigger.

2. Aging and space charge effects

The ability to withstand long term high radiation without showing aging effects is a prerequisite for any proposed device
at the sLHC. Another concern is the deterioration of performance due to space charge effects. The detectors must, therefore, be radiation tolerant and should have inherent weak rate dependence. Aging effects were studied by irradiating a small (10×10 cm²) TGC detector with a ⁹⁰Sr beta source (with electron energies of 0.546 and 2.283 MeV) during a five months period. The irradiation was followed by a microscopic and chemical analysis of the wire deposits. The microscope picture in Fig. 2 shows that the deposits are widely spaced, which leads to negligible changes in the electric field between anodes and cathodes. The chemical spectrum in Fig. 3 shows that the deposits consist mainly of carbon and oxygen, which are clearly related to the gas components and not to impurities in the gas system. The TGC anode count rate as a function of the accumulated charge is shown in Fig. 4. No rate decrease has been observed. The detector showed no deterioration in its response to electrons after being irradiated by the equivalent of 6 Coulomb/cm (approximately 100 years of sLHC). Space charge effect measurements are described in detail in [4]. No space charge accumulation was observed up to 100 kHz/cm² signal hit rate.

Figure 2: A microscopical picture of the wires from the same detector, one of which was irradiated by the equivalent of 6 Coulomb/cm, while the other not.

Figure 3: Chemical spectrum of the irradiated wire deposits.

3. Design and construction of the TGC Large Prototype

Two large prototypes, that can be assembled into a full size detector, 1.2 × 0.8 m² each, were constructed. Each prototype includes four layers of TGCs (their layout is shown schematically in Fig. 1) and fit in a total thickness of 50 mm. Each layer contains a series of pads for local trigger coincidence and strips, perpendicular to the wires, for high precision position measurement as well as local precision trigger elements. The wires are used for a second coordinate measurement. The large prototype parameters are shown in Table 1.

4. Position resolution test beam at CERN

The position resolution of one of the large TGC prototypes was measured using 100 GeV/c muons from the SPS-H8 test beam at CERN in June 2009. Previous CERN pion test beam results with smaller prototypes are described in [5]. The main goal of the test was to determine the position resolution in each of the layers using analog and fast digital readout, as well as its dependence on the muon incidence angle. Each detector was equipped with 16 strip analog and digital readout channels of similar type as those used in the ATLAS TGC [6].

The external trigger was provided by a coincidence of two plastic scintillators. The position resolution is directly related to the profile of induced charge on the strips and on the accuracy of charge measurement. The actual charge on each of the strips was measured using two 32-channel, 12-bit resolution charge integrating ADC modules CAEN V792. The four

Figure 4: TGC count rate vs. accumulated charge.

| Large prototype parameters          |    |
|-------------------------------------|----|
| Strip-carbon gap                    | 0.1 mm |
| Strip pitch                         | 3.2 mm |
| Inter-strip gap                     | 0.3 mm |
| Wire length in 4 layers             | 0.4, 0.5, 0.6, 0.7 m |
| Number of wires ganged together     | 5 (9 mm granularity) |
| Strip length                        | 1.2 m |
| Pad size                            | 40×10 cm² |
| Carbon surface resistivity          | 50 kΩ/square |
| HV blocking capacitance             | 470 pF |

| Readout electronics parameters      |    |
|-------------------------------------|----|
| Preamplifier gain                   | 0.8V/pC |
| Integration time                    | 16 ns |
| Main amplifier gain                 | 7    |
| Equivalent noise charge             | 7500 electrons at CD=150 pF |

Table 1: Large prototype parameters.
ADC count distributions for a typical event in the 4-layer prototype are shown in Fig. 5. The four track hit positions were determined by a Gaussian fit. For each layer, the expected position was determined by the extrapolation of the positions in the other three layers. The difference between the measured position and the expected position was defined as the residual.

Due to the periodic strip structure, the deviation of the expected hit position from the measured one depends on the hit position. This dependence is clearly seen in Fig. 6. A sinusoidal fit was applied to correct for this differential non-linearity effect. The final deviation was calculated from the fit curve. The residual distributions for each of the four detectors vs. hit position after this correction is shown in Fig. 7. The width of this distribution, $\sigma_{\text{residual}}$, is defined as the local resolution for each detector.

The resolution is also affected by the incidence angle $\phi$, since this angle determines the track projection on the anode wire, as explained in [5].

The angular dependence of the resolution was studied by rotating the chambers with respect to the beam axis. A set of measurements with different anode high voltage (HV) values were performed for incidence angles of: 0, 5, 10, 15, and 20 degrees. three HV values were used: 2.9, 3.0, and 3.1 kV. The local spatial resolution vs. incidence angle for different HV values is shown in Fig. 8. One can see that the resolution deteriorates as the angle increases and improves with higher HV. Single gap resolution of better than 100 $\mu$m is achieved for incidence angles of up to 20° and HV value of 3.0 kV. These values of resolution meet the SLHC requirements.

In order to confirm the suitability of the TGC as a trigger device, we also measured the spatial resolution of the TGC with digital signals from the strips using the time over threshold information for each channel. The time was measured with a VME 32CH TMC TEG3 KEK module. Determination of the hit position and the resolution measuring were done the same way as for the analog readout. The obtained digital resolution values vs. HV for four different geometrical TGC positions (in order to avoid the geometrical systematic) at perpendicular incidence are shown in Fig. 9. At 3.0 kV the average digital resolution is 160 $\mu$m which easily meets the level one trigger angular resolution requirement of 1 mrad for a 200 mm thick detector.

5. Neutron beam test at Demokritos

Muon detecting capabilities of the TGC were also studied when the detector was exposed to a high flux of neutrons. The test was carried out at Demokritos, Greece in October 2009. The facility at Demokritos consists of a 5.5 MV TANDEM T11/25 accelerator, which uses Van de Graaff electrostatic technique with high voltages between 0.4 and 5.5 MV. For the TGC test, neutrons with an energy 5.5-6.5 MeV were produced via the $^2$H($^2$H,n)$^3$He reaction. The detailed description of the Demokritos facility can be found in [7]. Neutron flux measurement was performed via the $^{191}\text{Ir}$(n,2n)$^{190}\text{Ir}$ activation reac-
tion [8]. A schematic view of the experimental setup is shown in Fig. 10. The trigger for cosmic ray muons was provided by the triple coincidence of two pairs of ”monitors” – small TGC prototypes (16×12 cm$^2$) with 3 and 4 mm strips on both sides. The hit position was obtained by four other identical small prototypes (the ”quadruplet”) placed between the monitor pairs, as shown in the schematic. The same type of front-end and readout electronics as in the CERN test was used. The procedure of determining the efficiency and resolution was identical to the one described in the previous section, i.e. by fitting a track using three TGC layers and comparing the predicted and measured positions on the fourth. A hit was considered good if the measured position was less than 10 mm away from the predicted one. Muon detection efficiencies vs. neutron rates are shown in Fig. 11. The efficiency deterioration at high rate is not significant. Although there was a concern that neutrons may give rise to large signals, producing HV breakdown (sparks), no such sparks were observed during the five-day period of the test.

6. $^{60}$Co test at Soreq

The TGC cosmic muon efficiency was also tested under a high flux of gamma photons from a 47 Ci $^{60}$Co source at the Soreq Nuclear Research Center, Israel. While the experimental setup was very similar to the setup at Demokritos (using a large prototype instead of the small quadruplet), no efficiency deterioration was observed under a gamma flux of 2·10$^6$ Hz/cm$^2$, which is 100 times the LHC gamma flux. Efficiency measurements under higher fluxes up to 10$^7$ Hz/cm$^2$ will also be performed.

7. Conclusions

Two large prototypes were constructed and tested in the SPS-H8 test beam at CERN and in a neutron test beam at Demokritos. They show good rate capabilities over large areas, good single gap position resolution (better than 60 μm for minimum ionizing particles at perpendicular incidence angle), fast response, and the option to combine trigger and tracking in the same gas gap, all at a reasonable cost. The TGC detectors showed almost no decrease in muon detection efficiency while operating under 10$^3$ Hz/cm$^2$ flux of 5.5-6.5 MeV neutrons as well as under 2·10$^6$ Hz/cm$^2$ flux of gammas, also no HV sparks were observed. Detector irradiation to a total accumulated charge of 6 Coulomb/cm of wire shows no deterioration in its performance.

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References

[1] ATLAS Collaboration, JINST 3 S08003 (2008).
[2] The LEP Collaboration, Physics Reports 427, 257-454 (2006).
[3] ATLAS Collaboration, ATLAS Muon Spectrometer Technical Design Report, CERN/LHCC 97-22 (1997).
[4] H. Fukui et al., Nucl. Instrum. Meth. A 419, 497 (1998).
[5] V. Smakhtin et al., Nucl. Instrum. Meth. A 598 (2009) 196.
[6] O. Sasaki and M. Yoshida, IEEE Trans. Nucl. Sci. 46, 1871 (1999).
[7] T. Alexopoulos et al., Nucl. Instrum. Meth. A 575, 402 (2007).
[8] N. Patronis et al., Phys. Rev. C 75, 034607 (2007).