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## Precision survey of the readout strips of small-strip Thin Gap Chambers using X-rays for the muon spectrometer upgrade of the ATLAS experiment

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**ABSTRACT:** The instantaneous luminosity of the Large Hadron Collider (LHC) will be increased by a factor of 5 to 7 after a series of upgrades of the CERN accelerator complex. In anticipation to the increased collision rate at the interaction point, the muon end-cap inner station of the ATLAS detector will be replaced with the so-called New Small Wheels (NSWs) during the LHC shutdown of 2019/2020. The NSWs combine the Micromegas and small-strip Thin Gap Chambers (sTGC) technologies. The sTGC detector modules are arranged in trapezoid wedges of 4 detector planes with total active areas varying between 3 and 5 m<sup>2</sup> per plane. Over 1000 azimuthal cathode strips are read out on each plane for precision muon trajectory measurements. The positioning of individual strips must be known to within 100 microns to satisfy the performance targets of this ATLAS upgrade. Non-conformities of the sTGC strip-pattern are therefore measured on finished wedges using an X-ray gun precisely positioned at reference points. The working principles and the spatial resolution measurement of this technique are presented.

**KEYWORDS:** Detector alignment and calibration methods (lasers, sources, particle-beams); Inspection with x-rays; Wire chambers (MWPC, Thin-gap chambers, drift chambers, drift tubes, proportional chambers etc); Muon spectrometers

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## 1 Introduction

The instantaneous luminosity of the Large Hadron Collider (LHC) will be increased by a factor of 5 to 7 relative to the design value<sup>1</sup> after a series of upgrades of the CERN accelerator complex planned over the next decade. In order to benefit from the additional collision data delivered by the LHC while keeping a good sensitivity to key physics processes involving muons, the ATLAS experiment [1] will be upgraded to improve its online muon identification. The upgrade consists in replacing the inner end-cap station of the ATLAS muon spectrometer by the New Small Wheels [2] (NSWs) during the LHC Long Shutdown of 2019/2020. The NSWs will operate by delivering precise candidate muon track segments to the ATLAS trigger processor that will contribute in rejecting spurious muon-triggers that are not associated with real muons from the interaction point.

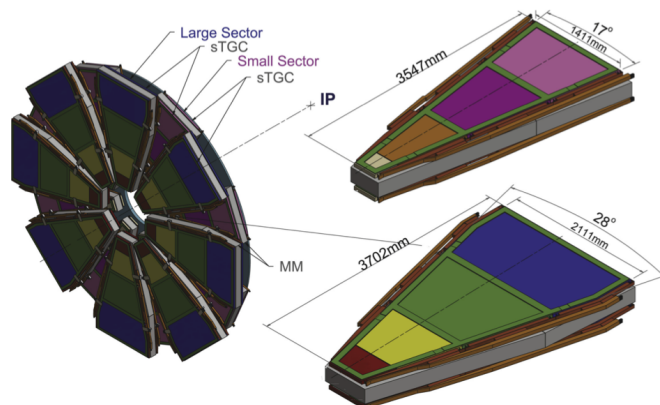
The NSWs are disk-shaped arrangements of planar gaseous ionization chambers divided into 16 trapezoid detector sectors. Each sector combines the Micromegas and small-strip Thin Gap Chamber (sTGC) technologies. Sectors are stacks of two inner Micromegas wedges between two outer sTGC wedges. The sTGC wedges are made up of 3 multiplet modules each having 4 detection layers. The layouts of the NSW and the sTGC wedges are shown in figure 1.

An sTGC is a thin multiwire chamber that operates with a mixture of n-pentane vapour and CO<sub>2</sub>. Each side of the gas volume has a resistive cathode segmented in pads, used for triggering, or azimuthal strips, used for precision muon trajectory measurements in the radial direction. The inner structure of an sTGC gas volume is shown in figure 2.

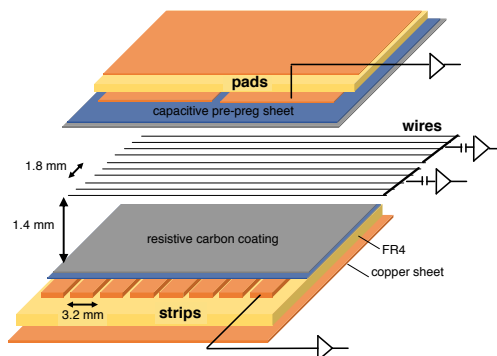
The position of cathode strips in the sTGC wedges must be known to within 100 μm to meet the targeted NSW track reconstruction performances. This requirement is first achieved with stringent construction tolerances on detector components, in particular the cathode planes, and by carrying out thorough QA/QC procedures during manufacturing. In addition, the geometry of cathode strips is surveyed before module assembly using Coordinate Measuring Machines (CMM), and after wedge assembly with the X-ray survey, the focus of these proceedings. The corrected position of the strips in the ATLAS coordinate system ultimately relies on the NSW alignment system which tracks the displacements of sTGC wedges.

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<sup>1</sup> $\mathcal{L}_{\text{nom}} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ .



**Figure 1.** Layout of the NSW and the two types (small and large) of sTGC wedges making up the NSW. The NSW has a diameter of 10 m and wedges have a longitudinal length of at least 3.5 m with active areas of 3 (small wedge) or 5 (large wedge) m<sup>2</sup> per detector plane. © 2020 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.



**Figure 2.** Internal structure of an sTGC gas volume. Anode wires are stretched with a pitch of 1.8 mm, the anode-to-cathode spacing is 1.4 mm, and cathode strips are engraved with a pitch of 3.2 mm. © 2020 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.

## 2 Metrology and alignment of sTGC cathode strips

The sTGC gas volumes are enclosed in trapezoid cathode boards made up of FR-4 covered with an 18  $\mu\text{m}$  copper layer engraved with either pickup strips or pads. The strips and pads are insulated by a 100/200  $\mu\text{m}$  thick capacitive pre-preg sheet covered with a 100/200  $\text{k}\Omega/\square$  resistive graphite-mixture coating.

The strip boards are fitted with precision brass inserts on one of the angled edge. During the glueing of gas volumes into a multipler, the brass inserts are pushed against alignment pins to precisely align the strip boards of the stack. The brass inserts are also used during wedge assembly for the relative positioning of the modules.

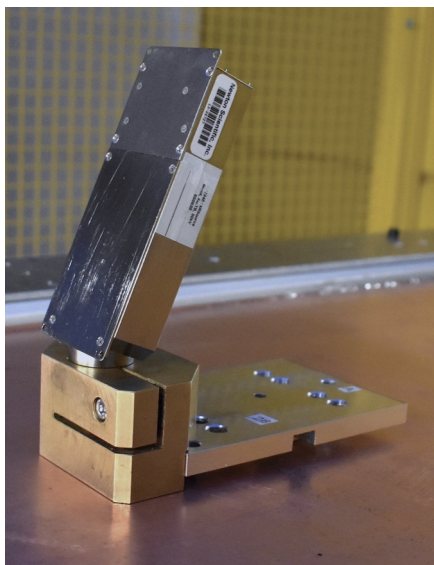
Non-conformities of the boards strip-pattern are measured before gas volume assembly using a CMM. The brass inserts of the tested board are pushed against alignment pins during the CMM survey and define the coordinate system used to define the nominal strip-pattern. Deviations of up to a few hundred microns relative to nominal are typically measured.

The displacements of sTGC wedges in the ATLAS coordinate system are measured online with an optical alignment system. The system uses BCAMs [3] (Brandeis CCD Angular Monitors) which locate and track the light emitted by fibres installed on the wedges. The BCAMs are positioned at surveyed locations on precision bars installed on the NSW frame. The light fibres are inserted into source plates glued on the surface of the wedges. The source plates are positioned during wedge assembly with a precision jig installed using the sTGC brass inserts as reference.

### 3 X-ray survey

The X-ray survey of the cathode strips is carried out on finished sTGC wedges. The survey aims at measuring the relative misalignments between the modules strip boards and of the source plates relative to the modules. The survey also complements the CMM survey done previously at the cathode board stage.

A gun<sup>2</sup> with a gold target is used to generate X-rays with energies of up to 40 keV with peaks in the 7-15 keV range. The gun is mounted on a precision holder with the source opening pointing perpendicularly to the wedge surface. The holder is fastened on one of the source plates. The holder position is fully constrained with respect to the source plate with a 3-ball alignment system. The complete setup installed on an sTGC wedge is shown in figure 3. A cylindrical brass collimator ( $\varnothing = 1.1$  mm) is inserted in the gun opening to achieve a sharp disk-shaped irradiation spot. Detected photoelectrons are mainly produced from X-rays hitting the copper cladding and anode wires of the gas volumes. Most detected photoelectrons are stopped in the gas volumes and initiate Townsend avalanches picked up by the strips. Between 10 and 20 points are surveyed on each sTGC module of the wedge under test. Each point is associated with one position measurement per gas volume.



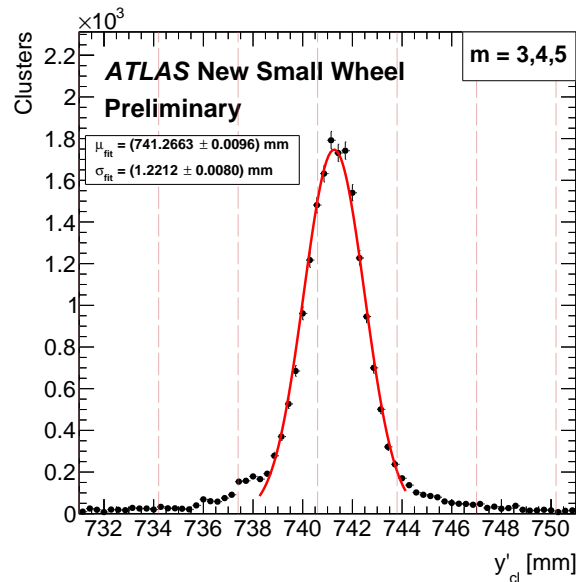
**Figure 3.** Photograph of the X-ray gun used for the survey installed in the holder and fastened onto a source plate of an sTGC wedge. The wedge is horizontal during the survey. © 2020 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.

<sup>2</sup>Amptek Mini-X.

### 3.1 Data taking and analysis

During the survey, the gas volumes of the wedge are flushed with pure CO<sub>2</sub> gas and a bias voltage of 2.925 kV is applied to the anode wires. During X-ray irradiation, the strips are read out using the VMM3 [4], an amplifier-shaper-discriminator ASIC, mounted on prototype front-end boards. The voltage thresholds of the electronic channels are tuned to equalize their hit efficiencies. The data acquisition system uses random triggers to acquire strip hits. A data acquisition run of a few minutes is sufficient for one surveyed point.

Contiguous strip hits within a time window of 75 ns make up charge clusters. Charge clusters made up of 3, 4 or 5 strips are used for analysis. Clusters with larger strip-multiplicities are more likely to be associated with  $\delta$ -ray production which biases the cluster centroid position. The centroid position of the charge clusters is taken as the mean parameter of a Gaussian function fitted to the pulse peak values of the hits. The measured position of individual X-rays is the centroid position of the clusters corrected for the differential non-linearity bias [5]. A typical irradiation profile is shown in figure 4.



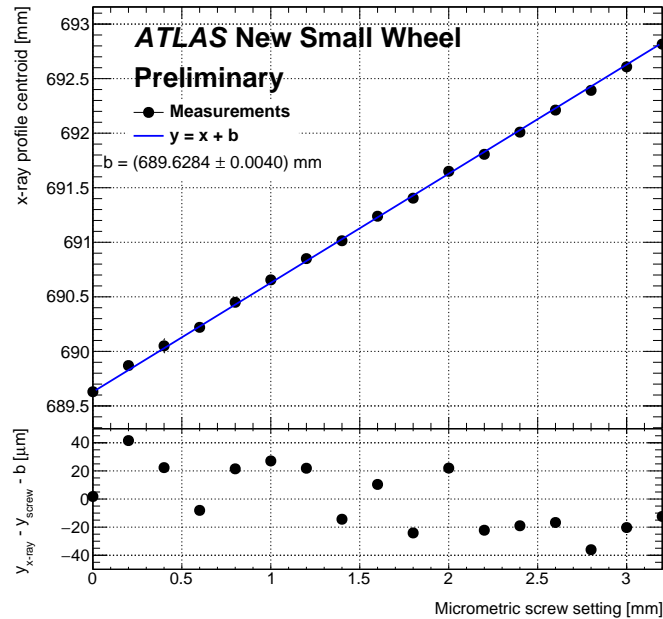
**Figure 4.** Typical distribution of the centroid position of X-ray charge clusters corrected for differential non-linearity. Charge clusters with strip-multiplicities  $m$  of 3, 4 and 5 are selected. The distribution is fitted to a Gaussian function (red line). The pink dashed lines indicate the cathode strip edges [6]. © 2020 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.

The X-ray beam position on each gas volume is corrected for the geometry of the precision holder, the positioning of the source plates, the angle of the collimator, and the angle of the source plate. The measured deviation between the expected beam position and the centroid position of the X-ray irradiation profile corresponds to the local misalignment of the strip-pattern.

The local strip-pattern misalignments are combined with the strip board CMM measurements into a global alignment model. The model uses 4 parameters per gas volume to parameterize a rotation, a constant shift, an elongation, and shears of the strips relative to the brass inserts.

### 3.2 Spatial resolution

The spatial resolution of the technique was obtained by comparing the centroid position of the X-ray irradiation profile to the position of a micrometric screw. During the test, the screw pushes the X-ray holder perpendicularly to the strips. The holder is guided using a square edge glued to the surface of the wedge and positioned using the sources plates as reference. The measurements, shown in figure 5, are consistent with a spatial resolution better than  $40\ \mu\text{m}$ .



**Figure 5.** Position of the X-ray irradiation profile centroid as a function of the micrometric screw position. The measurements are fitted to a first-order polynomial with the slope fixed to unity. The fit residuals, shown in the bottom plot, vary within  $\pm 40\ \mu\text{m}$  [6]. © 2020 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.

## 4 Conclusion

The NSWs, combining the Micromegas and sTGC technologies, will replace the current inner end-cap station of the ATLAS muon spectrometer during the 2019/2020 LHC Long Shutdown. This upgrade aims at improving the online muon identification capabilities of ATLAS. An X-ray survey is carried out as part of the sTGC wedge manufacturing as a mean to obtain the position of the cathode strips relative to the source plates of the NSW optical alignment system. The survey will provide parameters used by the sTGC alignment model to correct for non-conformities of the detector planes strip-patterns. The spatial resolution of the technique was shown to be better than  $40\ \mu\text{m}$  which offers the potential to reconstruct the position of the strips in the NSW to within  $100\ \mu\text{m}$ , the current design target.

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