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Performance of a full-size small-strip thin gap chamber prototype for the ATLAS new small wheel muon upgrade

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ABSTRACT

The instantaneous luminosity of the Large Hadron Collider at CERN will be increased up to a factor of five with respect to the present design value by undergoing an extensive upgrade program over the coming decade. The most important upgrade project for the ATLAS Muon System is the replacement of the present first station in the forward regions with the so-called New Small Wheels (NSWs). The NSWs will be installed during the LHC long shutdown in 2019/2020. Small-Strip Thin Gap Chamber (sTGC) detectors are designed to provide fast trigger and high precision muon tracking under the high luminosity LHC conditions. To validate the design, a full-size prototype sTGC detector of approximately $1.2 \times 1.0\ \mathrm{m}^2$ consisting of four gaps has been constructed. Each gap provides pad, strip and wire readouts. The sTGC intrinsic spatial resolution has been measured in a 32 GeV pion beam test at Fermilab. At perpendicular incidence angle, single gap position resolutions of about 50 μm have been obtained, uniform along the sTGC strip and perpendicular wire directions, well within design requirements. Pad readout measurements have been performed in a 130 GeV muon beam test at CERN. The transition region between readout pads has been found to be 4 mm, and the pads have been found to be fully efficient.

1. Introduction

The motivation for the luminosity upgrade of the Large Hadron Collider (LHC) is to precisely study the Higgs sector and to extend the sensitivity to new physics to the multi-TeV range. In order to achieve these goals the ATLAS experiment [1] has to maintain its capability to trigger on moderate momentum leptons under more challenging background conditions than those present at the LHC during Run-1 and Run-2. For the Muon Spectrometer (MS) [2], such requirements necessitate the replacement of the forward muon-tracking region called the muon Small Wheel, with new detectors capable of triggering and precision tracking simultaneously. The New Small Wheel (NSW) upgrade [3] is designed to cope with the high background rate (up to $15\ \mathrm{kHz/cm^2}$) that is expected at luminosities between 2 and $7 \times 10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$ during Run-3 and the high luminosity LHC (HL-LHC) runs [4].

Small-Strip Thin Gap Chambers (sTGCs) have been selected as one of the two detector technologies that will be used for the NSW

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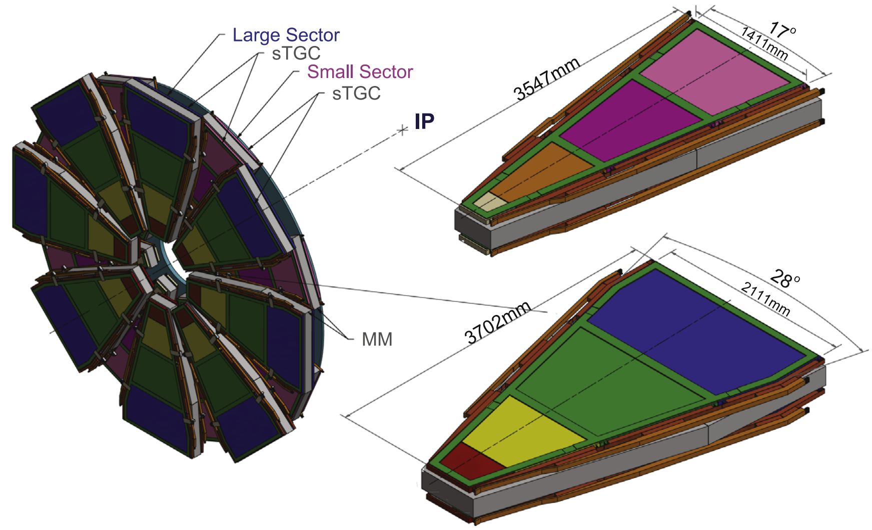

Fig. 1. Schematic diagram of the small and large sectors that make up the New Small Wheel. Each sector consists of two quadruplets of sTGC with eight micromegas (MM) detection planes in between.

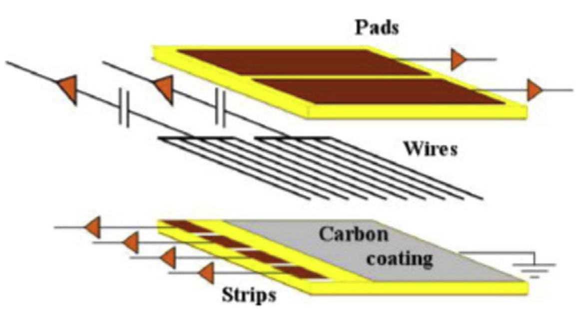

Fig. 2. Schematic diagram of the basic sTGC structure.

upgrade along with micromegas detectors. Fig. 1 shows a schematic diagram of the NSW. The NSW includes eight detection planes (layers) of sTGC arranged in two quadruplets and eight planes of micromegas. The precision reconstruction of tracks for offline analysis requires a spatial resolution of about 100 μm per sTGC layer, and the track segments have to be reconstructed online for triggering purposes with an angular resolution better than 1 mrad. A large collaboration has been established to construct these devices and is composed of members from Canada, Chile, China, Israel and Russia. These precision requirements are challenging to achieve, therefore beam test experiments have been performed to qualify the sTGC assembly procedure.

2. sTGC Technology

The concept of Thin Gap Chambers (TGCs) was developed in 1983 [5] and then used at the OPAL experiment and for the ATLAS end-cap muon trigger system. The basic sTGC structure is shown in Fig. 2. It consists of an array of 50 μm diameter gold plated tungsten wires held at a potential of 2.9 kV, with a 1.8 mm pitch, sandwiched between two cathode planes located at a distance of 1.4 mm from the wire plane. The cathode planes are made of a graphite-epoxy mixture with a typical surface resistivity of 100 or 200 kΩ/□ sprayed on a 100 or 200 μm thick G-10 plane for the inner and outer chambers, respectively. Behind the cathode planes on one side of the anode plane there are copper strips for precise coordinate measurements that run perpendicular to the wires and on the other side of the anode plane there are copper pads used for fast trigger purposes. The copper strips and pads act as readout electrodes. The pads cover large rectangular surfaces on a 1.5 mm thick printed circuit board (PCB) with the shielding ground on the opposite side. The strips have a 3.2 mm pitch, much smaller than the strip pitch of the ATLAS TGC,[1] hence the name 'small-strip TGC' for this technology. The pad occupancy for each colliding bunch of protons in the LHC is expected to be around 1.0–1.3%.

Each sTGC quadruplet consists of four pad-wire-strip planes shown in Fig. 2. The pads are used through a 3-out-of-4 coincidence to identify muon tracks approximately pointing back to the interaction point. They are also used to define a region of interest that determines which group of strips needs to be read out in order to obtain a precise position measurement in the precision coordinate, for the online track reconstruction. The azimuthal coordinate of a muon trajectory is obtained from the wires readout. The operational gas is a mixture of 55% CO_2 and 45% n-pentane. There are six different sizes of sTGC quadruplets, three for each of the large and small sectors. As shown in Fig. 1, all have trapezoidal shapes with surface areas between 1 and 2 m^2.

3. Construction of a large sTGC prototype

A challenge in the construction of large area multi-layer particle detectors is to achieve high precision alignment of the readout strips across layers. The required accuracy in the position and parallelism of the precision strips between planes is 40 μm. This precision is achieved by mechanical machining. The readout strips for an sTGC plane are machined together, in one step, with brass inserts which can be externally referenced. The cathode boards are glued together, separated by chamber walls at the periphery of the boards as well as 7 mm wide T-shaped wire supports and spacer buttons in approximately 20 cm intervals. The detector has been designed such that every charged particle originating from the ATLAS interaction point will traverse at most one support structure in one out of the four sTGC planes.

The resulting individual chambers are glued together, separated by a specially machined frame with a honeycomb structure over the entire surface of each chamber, which is smaller by 100 μm than the gap between chambers. The glue serves as a filler to compensate for small deviations in the thickness of the PCB material. The gluing procedure makes use of the fact that the

[1] The strip-pitch of the TGC varied between 150–490 mm.