The challenge of building large area, high precision small-strip Thin Gap Trigger Chambers for the upgrade of the ATLAS experiment

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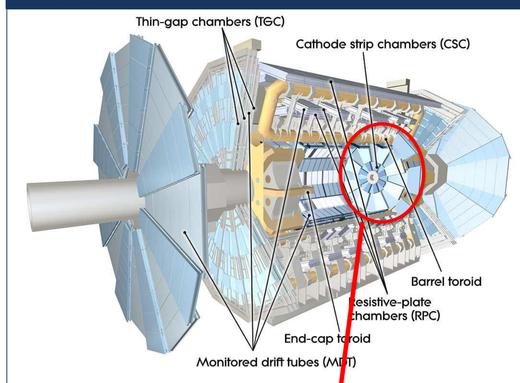
Abstract

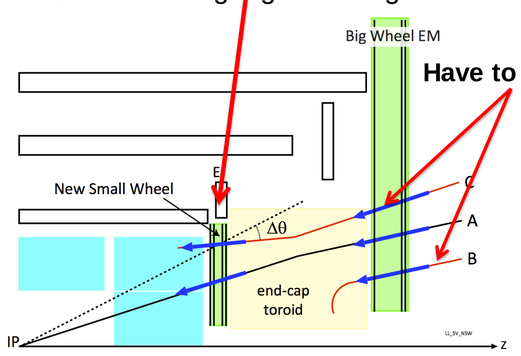
The current innermost stations of the ATLAS muon endcap system must be upgraded in 2018 and 2019 to retain the good precision tracking and trigger capabilities in the high background environment expected with the upcoming luminosity increase of the LHC. Large area small-strip Thin Gap Chambers (sTGC) up to 2 m^2 in size and totaling an active area of 1200 m^2 will be employed for fast and precise triggering. The precision reconstruction of tracks requires a spatial resolution of about 100 μm while the Level-1 trigger track segments needs to be reconstructed with an angular resolution of 1mrad. The upgraded detector will consist of eight layers each of Micromegas and sTGC's detectors together forming the ATLAS New Small Wheels. The position of each strip must be known with an accuracy of 40 μm along the precision coordinate and 80 μm along the beam. On such large area detectors, the mechanical precision is a key point and then must be controlled and monitored all along the process of construction and integration. The precision cathode plane has strips with a 3.2 mm pitch for precision readout and the cathode plane on the other side has pads to produce a 3-out-of-4 coincidence to identify passage of a track in an sTGC quadruplet.

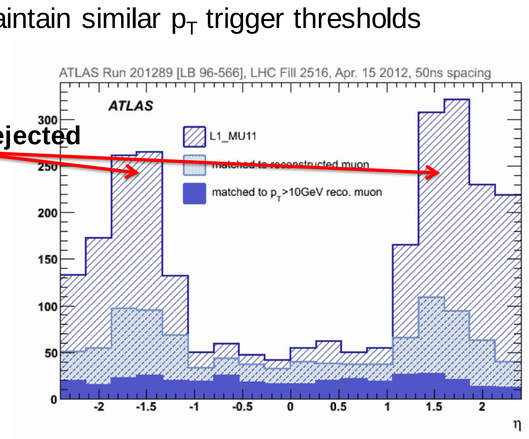
Upgrade of the ATLAS Muon Spectrometer



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. The LHC will deliver beams to the ATLAS detector with a center of mass energy of 13-14 TeV and instantaneous luminosities up to 7x10^{34} cm^{-1}s^{-1}. The end-cap detectors in the small wheel will be replaced during the Phase-1 upgrade (2019-2020). The New Small Wheels (NSWs) will give tracking resolution better than 100 μm and an angular resolution of 1 mrad at the trigger level for the expected rate of 15 kHz/cm^2. The implications of the NSW for muon reconstruction and triggering are:

- ***Momentum resolution better than 10% for muons with p_T ~1 TeV.*** The performance will not degrade for higher background rates.
- ***Significant rejection of fake muons originating from the activation of material in the end-cap toroid.*** The NSWs will allow to maintain similar p_T trigger thresholds to Run 2 while having higher background rates.

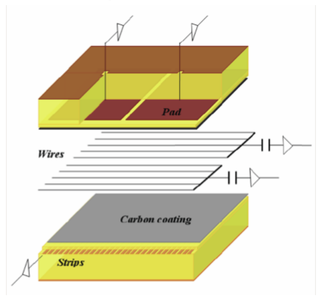




NSW

The two chosen detector technologies for the NSW, Micromegas (MM) and small-strip Thin Gap Chambers (sTGC), are complementary. The sTGC is required to reconstruct track segments online with an angular resolution of better than 1 mrad for triggering purposes, as well as a spatial resolution of about 100 μm for tracks reconstructed offline. The NSW consists of two types of sectors (small and large sectors), and each sector includes eight sTGC detector planes (layers) arranged in two quadruplets (chambers) sandwiching two MM chambers. This layout maximizes the distance between the two main triggering planes and therefore the angular resolution of the track segment measurement.

The sTGC structure consists of a grid of 50 μm gold plated tungsten wires at a potential of 2.9 kV, with a 1.8 mm pitch, sandwiched between two cathode planes 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 100-200 kΩ/□ sprayed on a 100 μm thick G-10 plane. Behind cathode plane there are precision strips (that run perpendicular to the wires) on one side and on the other side there are pads (covering large rectangular surfaces – about 10 cm in R-direction, and from 5 cm to 50 cm in φ-direction depending on R), on a 1.6 mm thick printed circuit board (PCB) with the shielding ground on the opposite side. The strips have a 3.2 mm pitch. The pads are used through a 3-out-of-4 coincidence to identify muon tracks roughly pointing to the interaction point. They are also used to define which strips need to be readout to obtain a precise measurement in the bending coordinate (region of interest), for the online event selection. The azimuthal coordinate is obtained from the wires. The operational gas is a mixture of 55% CO_2 and 45% n-pentane.



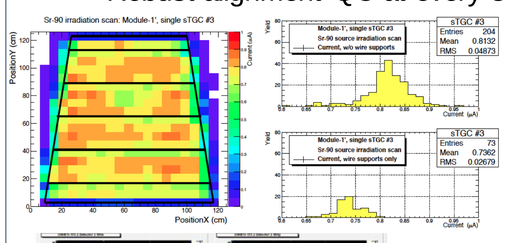
sTGC production

To meet the requirements for robust single-muon triggering, in particular, achieve 1 mrad angular resolution to select muons from IP, sTGC itself has to be precisely constructed

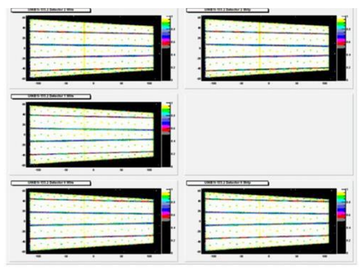
- Strip relative transverse alignment within quadruplet to better than 40 μm
- Strip board relative parallelism within quadruplet to better than 80 μm
- Allow for assembly of stiff wedges with less than 80 μm deformation

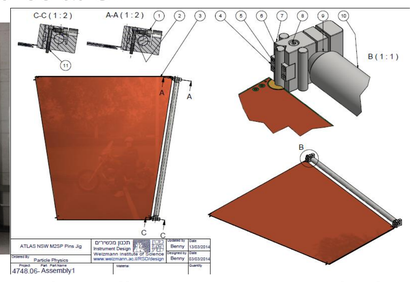
It necessitates careful assembly procedure. This procedure should be focused at:

- Producing a precise strip board to be referenced externally (achieved by machining together the strips with the precision brass inserts)
- Careful alignment of stiff structures (strips + pads boards and wires)
- Robust alignment QC at every step of the quad assembly



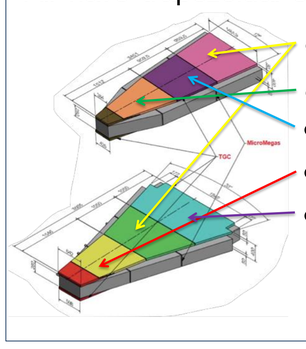
- Robust QA at the single detector level
  - *Use x-ray source to measure gain uniformity*
- Robust QA at the quadruplet level
  - *Measure pad efficiency, strip position using cosmic rays*
  - *Assess full quadruplet performance at high irradiation γ-source at GIF++*





There are six types of sTGC quadruplets - three for the large and small sectors, respectively. All have trapezoidal shapes with dimensions between 1 and 2 m^2. The production of the sTGC detectors will take place at institutions from Canada, Chile, China, Israel and Russia.

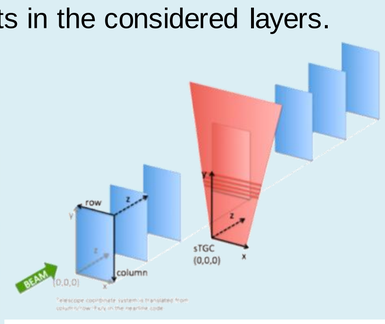
An important step in the preparation for full sTGC production is assembling module-0 at each production site to verify technological readiness of equipment and personnel.

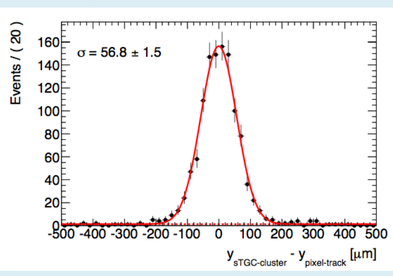


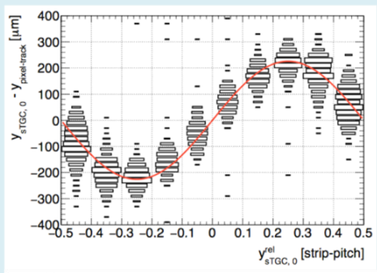
- **Canada**
- **Chile**
- **China**
- **Israel**
- **Russia**

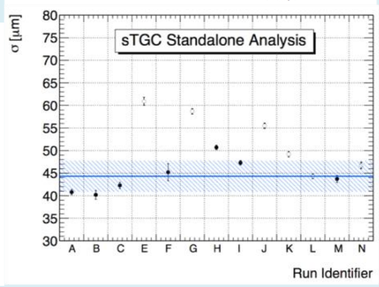
Test Beam Results

An important step in the sTGC development and proving of production procedure was the construction of the full size quadruplet, with dimensions 1.2x1m^2. Beam tests of the full size sTGC prototype have been performed at Fermilab and at CERN. Fermilab test was devoted to the spatial resolution measurement The test utilized a pixel telescope to precisely track the incident point of 32 GeV pions on the sTGC quadruplet and compare it to the measured position in each of the four sTGC detection planes. A moveable x-y table is used to expose different regions of the sTGC detector to the particle beam. At perpendicular incidence, a resolution of about 45 μm has been found to be uniform (within 3 m of RMS) across the tested area of 65X11 cm^2 for the runs where the measurement was not influenced by the presence of mechanical supports in the considered layers.

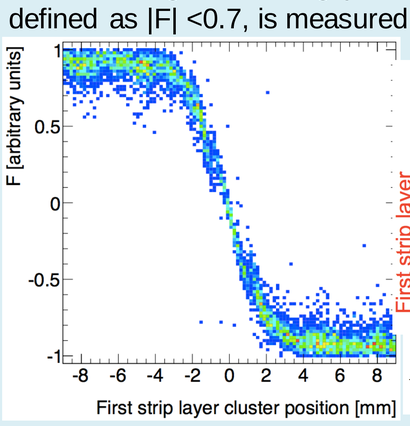


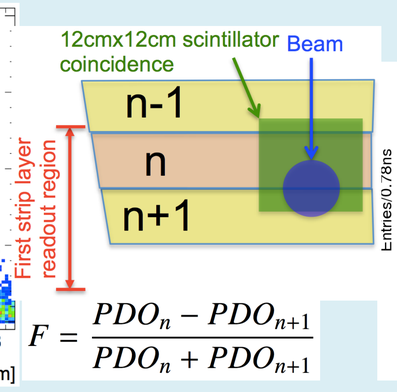




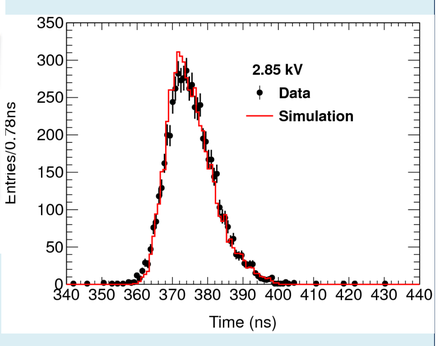


At the CERN test beam, the charge sharing between pads was measured by centering the beam (130 GeV muons) in the transition region between two pads. The charge fraction (F) is defined using the analog peak values (P) of two neighboring pads. The transition region, defined as |F| <0.7, is measured to be about 4 mm.





$$F = \frac{PDO_n - PDO_{n+1}}{PDO_n + PDO_{n+1}}$$



Earlier measured time spectrum demonstrates that 95% of the total events are contained within a 25 ns time window.

Conclusion

The sTGC detectors will provide the Muon NSW with excellent triggering and tracking capabilities. The construction protocol has been validated by test beam measurements on a full-size prototype showing the performance requirements are met.

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