Studies of cosmic ray events in ATLAS sTGC muon chamber prototypes

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Outline

1. Project Overview
   - ATLAS New Small Wheel Upgrade Project
   - McGill sTGC Testbench

2. Analysis of Cosmic-Ray Data with a sTGC Detector
   - Definitions
   - Multi-Cluster Event Analysis
   - Cosmic Ray Event Categorization
Motivation: (Run-1) High $\mu$ fake rate in forward region of ATLAS $\Rightarrow$ New detector needed for triggering Run-3 (see I. Trigger’s talk)
- Current Small Wheel (SW) uses Thin Gap Chamber (TGC) detectors
- Small-strip Thin Gap Chambers (sTGC) technology developed for New Small Wheel (NSW)
- Canada involved in production of 1/4 of the sTGC
TGC Structure

- **Wires [x axis]**
  - Wire pitch: 1.8 mm
- **Strips [y axis]**
  - Strip pitch: 3.2 mm
- **Pads [xy axis]**
  - Laid in tiles
  - 28 channels on layers 1, 3
  - 40 channels on layers 2, 4
- **Z axis**: 4 layers (quadruplet)

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McGill sTGC Testbench

- McGill responsible for quality assurance / performance characterization of Canadian sTGC modules
- Goal: measure hit efficiency and spatial resolution of sTGC planes
- Relies heavily on track reconstruction: my project is to better understand the nature of Cosmic Ray events recorded by sTGC quadruplet through track reconstruction

3D data available from detector, but my study only uses 2D information for tracking (strips, layers)

McGill sTGC Testbench

- 3D data available from detector, but my study only uses 2D information for tracking (strips, layers)
McGill currently uses an ATLAS sTGC prototype to validate quality control measurements

- Designed by Weizmann Institute Group
- Built by sTGC Canadian Group (TRIUMF & Carleton U) in Israel
- Tested at Fermilab

*NIM A817 (2016) 85-92*
GAS SYSTEM | HODOSCOPE (sTGC Prototype) | LOADING STATION | SLOW CONTROL

- Gas System provides n-pentane:CO₂ mixture of 45%:55% by volume
- Slow Control system in place to ensure lab safety
- McGill group published paper to JINST about development and characterization of these two components:
  - JINST 12(04):P04027, 2017
Cosmic Ray Detection

- Trigger on the scintillators.
- sTGC quadruplet has 4 layers.

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Definitions for Multi-Cluster Track Analysis

A Hit

A Cluster

Contiguous hits form a cluster

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Motivation for Multi-Cluster Event Analysis

- Current sTGC analysis algorithm only does tracking using layers with at most one cluster
- We find that $\sim 4\%$ cosmic muons produce $\geq 2$ clusters in at least one of the layers
- Want to categorize multi-cluster events to know what we throw out of the analysis
  - $\geq 2$ muons
  - delta-ray
  - spurious hits / false signals / other

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Current algorithm for multi-tracking is the following:

- Separate clusters with 2 maxima into two individual clusters (if needed)
- Try every possible combination of hits in an event to form a track containing a hit on every layer
- Compare every track that contains 2 common hits and keep the track with smallest $\chi^2$
- For tracks with a common cluster, re-fit excluding this cluster.
Different Event Categories (1/3)

Single track with 3 layers

\[
\begin{align*}
\chi^2/\text{ndf} &= -0.0217 \\
(MG0148)
\end{align*}
\]

Single track with 4 layers

\[
\begin{align*}
\chi^2/\text{ndf} &= 0.0008 \\
(MG0148)
\end{align*}
\]

These events are used for efficiency and resolution measurements for the sTGC
Different Event Categories (2/3)

1 track, double cluster

2 tracks

These events are not used for sTGC characterization
Different Event Categories (3/3)

3+ tracks

No tracks

These events are not used for sTGC characterization
Categorization of Cosmic Ray Events

- Single cluster event, 1 track, 3 layers: 33.1%
- Single cluster event, 1 track, 4 layers: 60.7%
- Double cluster event, 1 track: 4.5%
- 2 tracks: 1.5%
- ≥ 3 tracks: 0.2%

~ 480,000 events

Categorizing events provides better understanding of data composition and event reconstruction.
Summary and Outlook

- Testing facility physically located at McGill now fully operational, currently uses 40x60 cm$^2$ sTGC prototype
- The analysis of cosmic muon data is functional, extended the code to include multi-cluster tracking
- This process was useful to develop a better understanding of the sTGC data and to improve the track reconstruction
- First sTGC modules are expected to arrive at McGill during the summer

Thanks!
Backup slides
Canadian sTGC Production

- QA/QC on received parts (frames, wire supports, spacer buttons)
- Resistive layer coating (graphite spraying)
- Assembly of cathode boards (half gaps)

- Anode wire winding
- Gap / doublet / quadruplet assembly
- Adaptor board mounting
- Shipment of quads to McGill

Cosmic ray testing Shipment to Geneva
sTGC Data Acquisition

- Currently using first generation prototype of front end electronics (VMM1 ASIC)
  - 8 chips available (64 readout channels each) with associated interface cards for digitization and data formatting

- Cosmic data processed for event building and data quality into ROOT trees
  - Same format as Fermilab testbeam 2014 (same electronics)
  - Main analysis package applies channel mapping and cuts, performs strip channels clustering and tracking, and finally computes various efficiencies and resolutions
  - Extensively used and tested, stable since May 2016
  - Will use VMM2 instead of VMM1 for testing at McGill

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Cluster with 2 Maxima Separation Algorithm Demo

Before and after algorithm. Notice the cluster in the [120-140]mm range is continuous, but contains 2 bumps.
Cluster Cleaning Cuts

Before applying multi-tracking algorithm, these cuts are applied on clusters (strips, y-axis):

- Cluster must contain $\geq 3$ strip hits
- Cluster cannot "touch" either extremity of the strips layer
- The leftmost and rightmost strip hits of a cluster cannot contain the peak
Categorization of Multi-Cluster Events

Same figure as previous pie chart, but includes events where tracking failed 10^6 events

- < 3 layers with hits before cluster cut: 41.3%
- < 3 layers with hits after cluster cut: 10.7%
- Enough layers with hits, no track: 0.1%
- Single cluster event, 1 track, 3 layers: 15.9%
- Single cluster event, 1 track, 4 layers: 29.1%
- Double cluster event, 1 track: 2.2%
- 2 tracks: 0.7%
- ≥ 3 tracks: 0.1%

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Relation between number of tracks and clusters for different layers

- The number of tracks roughly follows the number of hits on a layer
- Events with high number of tracks are rarer
- Statistics look similar on different layers
- \( \Rightarrow \) follows expectations
Comparison with Simulation

Geant MC Simulation (cut for $\delta$-ray)

Data from run MG0148

Very preliminary results, work in progress