Beam test of new ATLAS muon detectors at Fermilab

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(University of British Columbia, TRIUMF)
on behalf of all participants

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• Israel
  • Weizmann Institute (G. Mikenberg, M. Shoa, V. Smakhtin)
  • Tel Aviv University (Y. Benhammou, H. Cohen, M. Davies)
  • Technion - Israel Institute of Technology (N. Lupu, A. Vdovin)

• Canada
  • Carleton University (A. Bellerive, T. Koffas, J. Botte, S. Rettie, S. Weber, M. Batygov, P. Gravelle, M. Bowcock)
  • McGill University (B. Vachon, B. Lefebvre, C. Bélanger-Champagne, A. Robichaud-Véronneau)
  • Université de Montréal (L. Gauthier)
  • Simon Fraser University (B. Stelzer, H. Torres, D. Mori)
  • TRIUMF (O. Stelzer-Chilton, E. Perez Codina, S. Viel)

• Collaborators from Chile (Universidad Técnica Federico Santa Maria, Pontificia Universidad Católica de Chile) and China (Shandong University) could unfortunately not be present
Main goal of the sTGC:

Enhance trigger capabilities in the ATLAS Muon Spectrometer for operation at the very high LHC collision rates after 2018.
Experimental setup
Experimental setup

Module -1

40x60 chamber

Pixel telescope

BEAM (32 GeV π at 1 kHz)

Scintillators + PMT

Scintillators + PMT
Experimental setup

- sTGC chambers filled with a mix of 55% CO$_2$ and 45% n-pentane
- Result: a highly-quenching mixture in which electrons drift at high velocities, making possible the use of the sTGC as trigger chambers
Pixel detector hit map with beam

Hit map in the detector local frame of reference

Horizontal

Vertical

10 mm

HitHistLocal_0

Entries 66454
Mean x 10.47
Mean y 5.614
RMS x 4.979
RMS y 2.859
First beam run (including cosmic rays)

- The middle of the Module -1 (S3) is read out for all four layers
- The support structure can be seen

- Online data quality monitoring proves essential to detect synchronization problems, dead and noisy channels to avoid, and to tweak the chamber gain and threshold values
sTGC readout synchronization

- This and next slides: **Preliminary results for Module -1**
  
  - Observed synchronization between layers read out:
    - More work is necessary to fully understand the synchronization patterns

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2D: Coincidence rates for clusters and pads

With Respect to Layer

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- L4P
- L3P
- L2P
- L1P
- L4S3
- L3S3
- L2S3
- L1S3
Example selected event from Module -1

Layer 1: 4 hits
Layer 2: 5 hits
Layer 3: 3 hits
Layer 4: 5 hits
sTGC cluster centre correlations, uncorrected
sTGC cluster centre corrections

- **Rotate** and **zoom**
  - Sine wave structure clearly visible

- **Fit**: \( f(y_1) = a \sin(2\pi (b y_1 + d)) + c \)

- **Apply** correction
sTGC cluster centre corrections

- **Rotate** and zoom
  - Sine wave structure clearly visible
- **Fit:** $f(y_1) = a \sin(2\pi (b y_1 + d)) + c$
- **Apply** correction

Reason for sine wave structure: cluster means are biased toward strip centres
sTGC cluster centre correlations, uncorrected
sTGC cluster centre correlations, corrected
sTGC cluster centre correlation projections
First indication of the sTGC resolution: $\sigma_{L1 - LX} / \sqrt{2}$

- Layer 1 vs. Layer 2: $0.032 \text{ strip} \times 3.2 \text{ mm/strip} / \sqrt{2} \sim 70 \mu m$
- Layer 1 vs. Layer 3: $0.039 \text{ strip} \times 3.2 \text{ mm/strip} / \sqrt{2} \sim 90 \mu m$
- Layer 1 vs. Layer 4: $0.031 \text{ strip} \times 3.2 \text{ mm/strip} / \sqrt{2} \sim 70 \mu m$

The sine wave corrections are also applied in the following slides.
sTGC standalone tracks

Calculate residuals:

\[ \Delta y = y_{\text{hit}} - y_{\text{track}} \]
sTGC inclusive residuals

\( \sigma_{\text{inc}} = 43 \, \mu\text{m} \)

\( \sigma_{\text{inc}} = 62 \, \mu\text{m} \)

\( \sigma_{\text{inc}} = 84 \, \mu\text{m} \)

\( \sigma_{\text{inc}} = 54 \, \mu\text{m} \)
sTGC standalone tracks (3 out of 4)
sTGC exclusive residuals

\[ \sigma_{\text{exc}} = 139 \, \mu m \]

Entries: 3377
Mean: -0.003302
RMS: 0.1763
Underflow: 10
Overflow: 15
\[ \chi^2 / \text{ndf} = 163.9 / 81 \]
Constant: 183.2 ± 4.3
Mean: -0.008695 ± 0.002462
Sigma: 0.1389 ± 0.0022

\[ \sigma_{\text{exc}} = 88 \, \mu m \]

Entries: 3377
Mean: 0.001911
RMS: 0.1217
Underflow: 6
Overflow: 6
\[ \chi^2 / \text{ndf} = 158.1 / 69 \]
Constant: 290.2 ± 7.0
Mean: 0.005491 ± 0.001558
Sigma: 0.08817 ± 0.00145

\[ \sigma_{\text{exc}} = 119 \, \mu m \]

Entries: 3377
Mean: -0.004456
RMS: 0.1519
Underflow: 11
Overflow: 16
\[ \chi^2 / \text{ndf} = 126.8 / 74 \]
Constant: 216.5 ± 5.0
Mean: -0.004512 ± 0.002097
Sigma: 0.1189 ± 0.0018

\[ \sigma_{\text{exc}} = 175 \, \mu m \]

Entries: 3377
Mean: 0.003539
RMS: 0.2036
Underflow: 27
Overflow: 25
\[ \chi^2 / \text{ndf} = 122.7 / 90 \]
Constant: 146.4 ± 3.4
Mean: 0.005376 ± 0.003095
Sigma: 0.1747 ± 0.0026
sTGC standalone resolution

<table>
<thead>
<tr>
<th>Layer</th>
<th>L1S3</th>
<th>L2S3</th>
<th>L3S3</th>
<th>L4S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive resolution</td>
<td>43 ± 1 µm</td>
<td>62 ± 1 µm</td>
<td>84 ± 1 µm</td>
<td>54 ± 1 µm</td>
</tr>
<tr>
<td>Exclusive resolution</td>
<td>139 ± 2 µm</td>
<td>88 ± 1 µm</td>
<td>119 ± 2 µm</td>
<td>175 ± 3 µm</td>
</tr>
</tbody>
</table>

- The sTGC standalone resolution is given by $\sigma = \sqrt{\sigma_{inc} \times \sigma_{exc}}$
  - Uncertainties on the incl. and excl. resolution values are statistical only

Resolution calculation procedure reference:
DOI: 10.1016/j.nima.2004.08.132
sTGC angular resolution

- Angular resolution:
  \[ \sigma_\theta = 2.8 \text{ mrad} \]
  \[ \sigma_y \sim \sigma_\theta \times 34 \text{ mm} \]
  \[ \sim 100 \mu\text{m} \]

- All three methods yield comparable results for the sTGC standalone resolution
Combined pixel and sTGC tracks

![Graph showing combined pixel and sTGC tracks]
sTGC residuals wrt pixel track

Very preliminary: multiple-scattering effects and mis-alignment not corrected
Conclusion

- The ATLAS sTGC test beam at Fermilab is a success!
  - Thanks to all who participated, and to the FTBF for their hospitality

- Preliminary results for the Module -1 resolution: $\sigma \sim 70$-100 $\mu$m
  - Coming up: detailed analysis of all runs, including data with the 40x60 chamber
    - Will require corrections for mis-alignment and multiple-scattering effects (using a 3+3 pixel fit, or better)
  - Quantify resolution and deformations using data taken at different points in the Module -1

- Measured good detector efficiency
  - Small inefficiencies observed for pads, to be investigated
BONUS SLIDES
sTGC event selection

- Hit selection
  - Remove noisy channels
  - Time Digital Output window: 2300-3300

- Cluster selection
  - 3 to 5 hits per cluster
  - All cluster channels within 2 strips of mode
  - Channel mode of cluster not next to channel with zero amplitude

- Event selection
  - Four out of four layers
  - At most 2 clusters with only 3 channels
Event synchronization