Test Beam Performance Measurements of Novel Thin Gap Detectors for the ATLAS Experiment Upgrade

2015 CAP Congress
Edmonton, AB

Sébastien Rettie, University of British Columbia & TRIUMF
on behalf of the ATLAS New Small Wheel Group
Outline

• Motivation
• The New Muon Small Wheel Upgrade
  • small-strip Thin Gap Chambers (sTGC)
• Full-size Prototype Test Beam at FNAL
  • Experimental Setup
  • Results
• Summary and Outlook
Harsher Conditions at the LHC

LHC / HL-LHC Plan

- 2011: 7 TeV
- 2012: 8 TeV
- 2013-2014: Splice consolidation button collimators R2E project
- 2015-2016: Experiment beam pipes
- 2017: EYETS SPS CC
- 2018-2019: LS2, injector upgrade cryogenics Point 4 dispersion suppression collimation
- 2020-2021: LS3, HL-LHC installation
- 2022: Experiment upgrade phase 1
- 2023-2024: Experiment upgrade phase 2
- 2025: 300 fb⁻¹ luminosity

- 30 fb⁻¹ luminosity
- 150 fb⁻¹ luminosity
- 3000 fb⁻¹ luminosity
Harsher Conditions at the LHC

LHC / HL-LHC Plan

We are here!

- LS1: 13-14 TeV
  - splicing consolidation
  - button collimators
  - RRE project
  - experiment beam pipes
  - nominal luminosity
  - 30 fb⁻¹

- EYETS: 14 TeV
  - SPS CC
  - injector upgrade
  - cryogenics Point 4
  - dispersion suppression
  - collimation
  - experiment upgrade phase 1
  - 150 fb⁻¹

- LS2: 14 TeV
  - cryolimit interaction regions
  - radiation damage
  - 2 x nominal luminosity

- LS3: 14 TeV
  - HL-LHC installation
  - 5 to 7 x nominal luminosity
  - experiment upgrade phase 2
  - 300 fb⁻¹

- 7 TeV
- 8 TeV

- 2011: 75% nominal luminosity
- 2015: nominal luminosity
- 2035: 3000 fb⁻¹ luminosity

June 17, 2015
Sébastien Rettie - 2015 CAP Congress
ATLAS subsystems level 1 readout bandwidth: 100 kHz.

Allowed level 1 bandwidth for muon triggers: 20 kHz.

Two options:

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Trigger Bandwidth Limitations in ATLAS

- ATLAS subsystems level 1 readout bandwidth: 100 kHz.
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- Two options:
  - Reduce number of events with real muons, but miss interesting events (e.g. $H \rightarrow \tau\tau$ with one $\tau$ decaying into a muon).
  - Improve the trigger system: New Small Wheel (NSW)!

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• NSW will only keep A tracks.
• B tracks will be rejected because there is no matching track in the NSW.
• C tracks will be rejected because the NSW track does not point to the interaction point.
The New Muon Small Wheel (NSW)

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Fake (unwanted) triggers
small-strip Thin Gap Chambers (sTGC)

- Gas mixture flows in sTGC: n-pentane / CO$_2$ (45% / 55%).
- Cathode: Pads and Strips.
- Anode: Wires.
- Readout the **pads** for **triggering**.
- Readout the **strips** and **wires** for **tracking**.
- Signal related to charge deposited on pads and strips.
- 64 channels per readout chip (VMM).
“Module -1”

- "Module -1"
- Prototype sector of the NSW
- Composed of 4 sTGC layers
- 32 GeV pion beam
- Pixel Telescope
- Module -1

- Readout (VMM1)
- Motion Table

**Fermilab Test Beam (May 2014)**

**Layout (not to scale)**

- EUDET Telescope (pixel)
- sTGC (4 layers)
Fermilab Test Beam (May 2014)

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EUDET Telescope (pixel)

sTGC (4 layers)

Fermilab Test Beam (May 2014)
• Each telescope plane has $\sim 5 \mu m$ resolution
• 6 telescope planes total

Residual wrt Pixel Telescope

$\sigma = 43.4 \pm 0.8 \mu m$

ATLAS Work in progress
- Each telescope plane has ~5 µm resolution
- 6 telescope planes total
• Each telescope plane has \( \sim 5 \, \mu m \) resolution
• 6 telescope planes total
“S-shape” Correction

- Y-axis: difference between strip cluster mean and pixel track cluster
- X-axis: difference between strip cluster mean and closest gap
- Deviation of the expected hit position from the measured one depends on the hit position
- Differential non-linear effect
“S-shape” Correction

- Y-axis: difference between strip cluster mean and pixel track cluster
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![Graphs showing before and after effects of the S-shape correction.](image)

ATLAS Work in progress
“S-shape” Correction

- Y-axis: difference between strip cluster mean and pixel track cluster
- X-axis: difference between strip cluster mean and closest gap
- Deviation of the expected hit position from the measured one depends on the hit position
- Differential non-linear effect
• Some runs have beam hitting module -1 wire support or spacer button.

• \( \left( y_{\text{STGC,Li}} - y_{\text{STGC,Lj}} \right) / \sqrt{2} \)

\[ \sigma = 40.8 \pm 0.6 \ \mu m \]
sTGC-telescope Analysis Results

- Nominal
- Special
  - “Per channel” pedestal corrections not available for layer 1.
  - Dead channel for run D layer 2.
  - Wire support and button in tested region for run E layers 2 and 3.
• ⧫ Nominal
• ⧬ Special
  • Wire support in tested region for runs E, G, J, K, L, N.
• Use pairwise residuals.
• Apply the “s-shape” correction extracted with the pixel telescope.
• Different runs probe different parts of the module -1.
• ♦ Nominal
• ♣ Special
  • Wire support in tested region for runs E, G, J, K, L, N.
• Use pairwise residuals.
• Apply the “s-shape” correction extracted with the pixel telescope.
• Different runs probe different parts of the module -1.
• The NSW is a key Phase-1 upgrade.
• Achieved spatial resolution of “module -1” around 50 μm; well within design requirement of 100 μm.
• NIM paper in preparation.
• Next steps: Construct a Canadian prototype and test it.
Thank you!

Merci!
Backup
The New Muon Small Wheel (NSW)

- **International effort**
  - **Canada**
    - 32 quadruplets + 8 spares
  - **Chile**
    - 32 quadruplets + 4 spares
  - **China**
    - 32 quadruplets + 4 spares
  - **Israel**
    - 64 quadruplets + 8 spares

- **TRIUMF**
  - Cathode board production: graphite spraying and chamber wall assembly.
  - Quality control for all received parts.

- **Carleton**
  - Anode wire winding and quadruplet assembly.

- **McGill**
  - Cosmic ray testing.
Residuals

Layer 1 Inclusive Residuals
\[ \sigma = 23.8 \pm 0.4 \, \mu m \]

Layer 2 Inclusive Residuals
\[ \sigma = 34.4 \pm 0.5 \, \mu m \]

Layer 3 Inclusive Residuals
\[ \sigma = 33.2 \pm 0.5 \, \mu m \]

Layer 4 Inclusive Residuals
\[ \sigma = 23.5 \pm 0.4 \, \mu m \]

Layer 1 Exclusive Residuals
\[ \sigma = 78.4 \pm 1.2 \, \mu m \]

Layer 2 Exclusive Residuals
\[ \sigma = 50.1 \pm 0.8 \, \mu m \]

Layer 3 Exclusive Residuals
\[ \sigma = 47.7 \pm 0.7 \, \mu m \]

Layer 4 Exclusive Residuals
\[ \sigma = 75.5 \pm 1.2 \, \mu m \]
Residuals

Layer 3 Inclusive Residuals

\[ \sigma = 33.2 \pm 0.5 \, \text{\(\mu\)m} \]

Layer 3 Exclusive Residuals

\[ \sigma = 47.7 \pm 0.7 \, \text{\(\mu\)m} \]

**ATLAS Work in progress**

**Inclusive residual**

**ATLAS Work in progress**

**L3S3 Inclusive Residuals [mm]**

**L3S3 Exclusive Residuals [mm]**

**L1S3 Inclusive Residuals [mm]**

**L1S3 Exclusive Residuals [mm]**
• Runs having good data that is analyzable
• All layers free of support structures
Run 335

\[
\frac{\langle y_{L1} - y_{L2} \rangle}{\sqrt{2}} [\text{mm}]
\]

\[
\sigma = 41.6 \pm 0.6 \mu \text{m}
\]

\[
\frac{\langle y_{L1} - y_{L3} \rangle}{\sqrt{2}} [\text{mm}]
\]

\[
\sigma = 40.6 \pm 0.7 \mu \text{m}
\]

\[
\frac{\langle y_{L2} - y_{L4} \rangle}{\sqrt{2}} [\text{mm}]
\]

\[
\sigma = 38.2 \pm 0.6 \mu \text{m}
\]

\[
\frac{\langle y_{L3} - y_{L4} \rangle}{\sqrt{2}} [\text{mm}]
\]

\[
\sigma = 40.8 \pm 0.6 \mu \text{m}
\]

\[
\frac{\langle y_{L2} - y_{L3} \rangle}{\sqrt{2}} [\text{mm}]
\]

\[
\sigma = 39.8 \pm 0.6 \mu \text{m}
\]

ATLAS Work in progress
• Layer 2 is being hit on support structure
Run 323

- Residuals are systematically worse for pairing with layer 2.
Fake Muons in ATLAS

- Fakes come mostly from activation in the end-cap toroid.
• Require $\chi^2 < 10$
• Allows for very straight tracks
• Removes most multiple scattering events.
• From previous test beam efforts.
• For difference HV values.
Event Selection

• Clustering
  • Only select cluster having 3, 4, or 5 hits
  • Require max bin of cluster not be next to zero bin
  • Require all bins close to max bin: \( (bin - bin_{max}) < 2 \)
• Require all 4 layers be hit
• At most two 3-hit clusters in event
• TDO Cuts
• Corrections
  • “Per channel” pedestals applied, except for layer 1
  • -0.5 strip length offset for L2 and L4 by construction
  • \( corr = -A \cdot \sin(2\pi \cdot y_{rel}) \)
  • \( A \) depends on size of cluster and layer of module -1
  • \( y_{rel} = mean_{cluster} - TMath::Nint(mean_{cluster}) \)
• The instantaneous luminosity is a measure of how many particles (blue) pass through a surface of unit area (yellow) in unit time (not shown.)
What is an inverse femtobarn?

• Measurement of particle-collision events per femtobarn; a measure of both the collision number and the amount of data collected.

• One inverse femtobarn corresponds to approximately 100 trillion \((10^{12})\) proton-proton collisions.

• Luminosity: ratio of the number of expected events detected per unit time to the interaction cross-section.
How Avalanches Form

a. Electron is attracted to anode.
b. Avalanche multiplication starts due to high E field.
c. Lateral diffusion; Coulomb repulsion between same-charge particles.
d. Drop-like avalanche is formed around the anode wire.
e. Electrons are collected rapidly (~1 ns) and ions drift towards cathode. This generates the signal at the electrodes.
• $\eta = -\ln[\tan(\theta/2)]$
• NSW coverage is
  • $1.3 < \eta < 2.7$
  • $15 < \theta < 40$
• ATLAS is a multipurpose particle detector
The ATLAS Detector at the LHC

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The ATLAS Detector at the LHC

- ATLAS is a multipurpose particle detector
- Endcap muon detectors
• ATLAS is a multipurpose particle detector
• Endcap muon detectors
What Now?

- Higgs Precision Measurements
- Beyond the Standard Model Physics Searches
- SUSY, Extra dimensions, etc.
- All these searches need higher energy collisions, and more data

ATLAS SUSY Searches* - 95% CL Lower Limits

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ATLAS Preliminary
$\sqrt{s} = 7, 8$ TeV
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ATLAS Exotics Searches* - 95% CL Exclusion

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*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.
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