The Canadian Contribution to the ATLAS New Small Wheels

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### Path to the High Luminosity LHC

<table>
<thead>
<tr>
<th>Year</th>
<th>LS1</th>
<th>LS2</th>
<th>LS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>splice consolidation</td>
<td>Diodes Consolidation</td>
<td>HL-LHC installation</td>
</tr>
<tr>
<td>TeV</td>
<td>button collimators R2E project</td>
<td>LIU Installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 TeV</td>
<td>13 - 14 TeV</td>
<td>14 TeV</td>
</tr>
<tr>
<td></td>
<td>8 TeV</td>
<td>13 TeV</td>
<td>energy</td>
</tr>
</tbody>
</table>

#### Run 1
- LS1: splice consolidation button collimators R2E project
- LS2: Diodes Consolidation LIU Installation
- LS3: HL-LHC installation

#### Run 2
- LS1: 13 TeV
- LS2: 13 - 14 TeV
- LS3: 14 TeV

#### Run 3
- LS1: cryolimit interaction regions
- LS2: inner triplet radiation limit
- LS3: 5 to 7.5 x nominal Lumi

#### Run 4 - 5...
- LS1: 30 fb⁻¹
- LS2: 190 fb⁻¹
- LS3: 350 fb⁻¹

### Long shutdown 2 (2019–2021):
- \( \mathcal{L} = 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \) for the entirety Run-3

### Long shutdown 3 (2025–2027):
- \( \mathcal{L} = 2 \times 10^{34} \rightarrow 5 \times 7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)

Such an intense environment presents challenges for the experiments that use the collisions provided by the LHC.

During long shutdown 2, improvements – called Phase-1 upgrades – to the ATLAS detector are ongoing.

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At high luminosities, the trigger rate would exceed the readout bandwidth of the ATLAS data acquisition system.

In the end-caps, most “muons” firing the trigger would in fact be background hits from particles created in the material between the inner and middle stations.

To solve this problem, the plan is to use the inner station to distinguish muons from these fake “muons”.

The current small wheel is unable to perform tracking efficiently.

![Diagram of ATLAS Muon Spectrometer and High Luminosity System](image)
The ATLAS New Small Wheel

The New Small Wheel (NSW) will use two different gas detector technologies: sTGCs primarily for triggering and Micromegas (MM) primarily for precision tracking.

**Design/Requirements:**

- Substantially reduce the fakes trigger rate at L1;
- Reconstruct online muon tracks with 95% efficiency;
- Excellent spatial and angular resolutions: $< 50 \mu m$ for offline momentum reconstruction and $< 1$ mrad for online matching with Big Wheel;
- Operate for the entirety of the HL-LHC.

Canada is contributing to the construction of 54 (of 216) sTGC modules (“quadruplets”).

Other sTGC construction site countries are Chile, China, Israel, and Russia.
Small-Strip Thin Gap Chamber Technology

sTGC Chambers:
- Multiwire ionization chambers operated with a pentane-CO₂ gas mixture;
- Operating voltage of 2.8 kV.

Wires:
- Acting as our anode, wires provides a coarse measurement of the trajectory in the $\phi$- or azimuthal-direction.
- Sandwiched between two cathode planes with a distance of 1.4 mm between the anode and cathode.

Strips:
- On one of the cathode planes, strips have a pitch of 3.2 mm;
- Used to provide precision measurements of muon trajectory in the $\eta$-direction.

Pads:
- On the other cathode plane are pads, which are used to trigger readout of the strip in a localized region of the detector.
  -> Each quadruplet module consists of 4 pad-wire-strip planes.
The Canadian sTGC Construction Project

- Commercially made circuit boards etched with copper strips and pads are coated with graphite.
- Boards are then shipped to Carleton University, Ottawa.

- Anode wires are strung, and gaps and quadruplets are assembled.
- Adapter boards are mounted.
- Finished modules are sent to McGill University, Montreal.

- Detectors are characterized and tested for quality and performance using cosmic muons.
- They are then shipped to CERN, Geneva, where they are formed into wedges that will make up the NSW.
Construction
Quality assurance / quality control tests are performed throughout the construction process. Tests include:

- High voltage tests at the singlet, doublet, quadruplet stages to check for sparks, shorts, and leakage currents;
- X-ray scans to measure gain uniformity of single gaps and to probe internal structure;
- Electrical connectivity checks of the readout channels;
- Gas leakage checks to ensure no leaks, e.g. from a crack, are present;
- Readout noise using prototype front-end boards;
- Cosmics testing to measure efficiency and resolution of finished quadruplets, and the relative misalignment of individual gaps.

Detectors that pass all tests are shipped to CERN where they are assembled into wedges then sectors to be installed into the NSW.
Canadian Production

Number of modules

Date

Received at McGill

Shipped from McGill
sTGC Performance

CERN Test Beam:
- Pad charge distribution studies at H8 beam-test area (top left).
- Pad charge distribution studies in GIF++ using a muon beam in the presence of high rate photon background (top right).
- Residual distributions of reconstructed perpendicular tracks (bottom left). For more details, see poster by Lia Formenti.
- In-situ measurement of the sTGC strip spatial resolution as a function of the applied high-voltage using a low-rate muon beam in the H8 beam-test area (bottom right).

NSW Public Results
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Sector Installation and Commissioning

- Construction of sTGC and Micromegas modules for both NSW-A and C is nearing completion.
- Sector assembly, installation, and commissioning well underway (with major contributions from Canadians).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Type</th>
<th>Date of installation</th>
<th>Commissioning status</th>
</tr>
</thead>
<tbody>
<tr>
<td>A14</td>
<td>Small</td>
<td>11/12/2020</td>
<td>Ongoing</td>
</tr>
<tr>
<td>A12</td>
<td>Small</td>
<td>16/12/2020</td>
<td>Complete</td>
</tr>
<tr>
<td>A16</td>
<td>Small</td>
<td>11/01/2021</td>
<td>Complete</td>
</tr>
<tr>
<td>A10</td>
<td>Small</td>
<td>17/12/2020</td>
<td>Complete</td>
</tr>
<tr>
<td>A08</td>
<td>Small</td>
<td>18/01/2021</td>
<td>Complete</td>
</tr>
<tr>
<td>A02</td>
<td>Small</td>
<td>25/01/2021</td>
<td>Complete</td>
</tr>
<tr>
<td>A06</td>
<td>Small</td>
<td>11/09/2020</td>
<td>Complete</td>
</tr>
<tr>
<td>A04</td>
<td>Small</td>
<td>08/02/2021</td>
<td>Complete</td>
</tr>
<tr>
<td>A13</td>
<td>Large</td>
<td>27/04/2021</td>
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<tr>
<td>A01</td>
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<tr>
<td>A03</td>
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<td>26/05/2021</td>
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</tr>
<tr>
<td>A05</td>
<td>Large</td>
<td>28/05/2021</td>
<td>To be started</td>
</tr>
</tbody>
</table>

Commissioning of NSW-A expected to be completed by June 17.
Conclusions

- Inclusion of the NSW into the ATLAS detector is imperative in order to maintain high trigger efficiency and momentum resolution in the high luminosity environment of the LHC and HL-LHC for years to come.

- Production of both sTGC and Micromegas modules is nearly complete while sector assembly at CERN has kept pace.

- Canada has played a key role in the NSW project, from construction of sTGC modules to contributing to vital NSW operations at CERN.

Status of NSW-A:

- All 8 small sectors installed; all 8 large sectors installed.
- Commissioning well underway.
- Expected to be completed by 29/07/2021.
- NEWS: ATLAS has given the green light for installation.

Status of NSW-C:

- Three small sectors installed; large sectors yet to be assembled.
- With the experience gained from NSW-A, commissioning expected to be streamlined.
- Must be completed by 21/10/2021 to be installed during this shutdown.