The New Small Wheel Upgrade Project of the ATLAS Experiment

37th ICHEP, Valencia, July 4th 2014
Bernd Stelzer (SFU)
on behalf of the ATLAS Muon Collaboration
The **New Small Wheel (NSW)** upgrade is motivated primarily by the **high background rate** that is expected at \( L = 2 - 5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1} \) during LHC Run-3 and HL-LHC.

→ Replace SW with **fast, high rate, precision** detectors

- BCID up to 15 kHz/cm\(^2\) <100 \( \mu \text{m} \)/plane
- **new** structure and JD shielding

Coverage:

\[ 1.2 < |\eta| < 2.7 \]
Motivation

• Forward muon triggers have currently high fake rate
  ➢ Simply raising muon trigger $p_T$ thresholds to reduce the trigger rate results in significant physics loss

• SW chambers can’t cope with rates up to 15 kHz/cm$^2$
  ➢ For high $p_T$ muons, resolution is dominated by the muon
  ➢ Require segments in all three muon stations
    Losing SW $\rightarrow$ losing muons

Example:
(single lepton trigger)

\[ VBF \rightarrow \tau_{lep} \tau_{had} \]
Enhanced ATLAS Muon Trigger with NSW

NSW will provide improved trigger for forward muons and improved tracking

New (fast) precision tracker in NSW that works up to the ultimate luminosity, with some safety margin ($7 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$)

Kill the fake triggers by requiring high quality ($\sigma_\theta \sim 1\text{mrad}$) pointing segments in NSW
NSW Detector Layout

NSW will utilize two detector solutions:
- Small strip Thin Gas Chambers (sTGC) as primary trigger
- Micromegas (MM) for primary precision tracker

- 16 Sectors per wheel (8 large, 8 small)
- 8 detection layers per sector for each technology, subdivided into 2 quadruplets each
- Position determination of the precision coordinate readout elements better than 30-40 μm
sTGC-Technology

Based on proven ATLAS TGC technology
- Fast, thin gap wire chambers (2.8 mm gap)
- Used for the endcap trigger

New sTGC specifications:
- Lower cathode resistance - for high rate
- Pads - online trigger tower
- Strip charge readout - precision coordinate (3.2 mm pitch)
- Wire readout - coarse $\phi$ coordinate

Pad coincidence (3 out of 4) defines RoI

Extensive testing of sTGC prototype detectors (40x60 cm) in 2010-2014

Operating voltage: 2.9 kV.
Use of a self-quenching gas (55% CO$_2$, 45% n-pentane)

Bernd Stelzer (SFU) ICHEP 2014
Production of sTGC

First Module-1 produced and tested. *Full (site wide) production starting in 2015.*
Module-1 of sTGC Detectors

- First full size (1x1.2m) sTGC quadruplet at Weizmann

- Precision requirements on production methods
  - Readout strips machined together with precision brass insert that can be externally referenced
  - Strip precision between planes better than 40 μm
  - Cathode boards flat and parallel to better than 80 μm (using honeycomb filler)
Fermilab Test Beam (2014)

Fermilab sTGC Test Beam

Setup: sTGC quadruplet in between pixel telescopes

30 GeV pion beam from Tevatron Main Injector

• Tests verifying construction methods for assembly precision
• Uniformity of large scale sTGC detectors and resolution
• Verification of prototype of final NSW front-end chip (VMM-1)
• Pad / strip efficiency measurements

sTGC residual using “3 out of 4” tracks

88 ± 1 μm

preliminary
Micromegas Technology

- Parallel plate chambers where the amplification takes place in a **thin amplification gap** (128μm) separated from the drift gap by a fine micromesh.

- Read-out strips (~0.5 mm pitch) covered by resistive strip layer.

- Novel technology with excellent high rate capability due to thin amplification gap and small space charge effects.

- Primary Precision Tracker with spatial resolution better than 100 μm **independent** of track incident angle.
Production of Micromegas

Four types of Micromegas quadruplets

All with trapezoidal shapes, dimensions between 2-3 m²

Full site wide production starting in 2015.
Micromegas Prototypes

• Several prototypes with dimensions up to 1 x 2.4 m² have been constructed
• Precision requirements on production methods
  ◇ Position of read-out strip along precision coordinate better than 30 μm
  ◇ Position of each plane perpendicular to chamber surface better than 80 μm

• Prototype (1.2x0.5 m²) will be installed in ATLAS (in July)
  ◇ 4 layers (2 eta and 2 stereo)
  ◇ Pitch 0.425mm
  ◇ 1024 strips per plane
  ◇ All panels finished
• 3 additional prototypes
  ◇ Qualify procedures

Drift panel for SM1

mesh stretching

a single wedge full size mechanical prototype
Readout Electronics

• The NSW will feature ~2.5 M readout channels!
• A newly developed VMM chip is a 64-channel front-end ASIC, common for both technologies
• Charge measurement $\leq 2$ pC with 1 fC rms.
• Time measurement with $\leq 1$ ns rms at 100 ns.
• Adjustable gain (0.5 – 16 mV / fC)
• Test pulser

• 2nd generation VMM2, available in 2014
• Fixes issues of first version
• Significant step-up in complexity
  ◇ 5 M transistors (13.5 x 8.4 mm$^2$) using 130nm, 1.2V CMOS
• Includes 10-bit amplitude/time digitizer + 6-bit fast amplitude digitizer (40ns)
ICHEP 2014

We are here

Bernd Stelzer (SFU)
Summary

• The New Small Wheel will make significant and necessary improvements to enable triggering and tracking for muons in the forward region of the ATLAS with a reasonable safety margin

• Crucial upgrade to maintain ATLAS physics program for Run-3 and beyond

• Production of New Small Wheel chambers will start in 2015
L1 rate is very high in the endcap
Total L1 bandwidth = 100 kHz (single muon ~ 20 kHz)

L1 rate estimate at 14 TeV, $L = 3 \times 10^{34}$
Single muon rate (kHz)

<table>
<thead>
<tr>
<th></th>
<th>Mu20</th>
<th>Mu40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without NSW</td>
<td>60</td>
<td>29</td>
</tr>
<tr>
<td>With NSW</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>NSW + phase-0</td>
<td>17</td>
<td>8</td>
</tr>
</tbody>
</table>

Release ~40 kHz of L1 bandwidth for other useful L1 inputs while maintaining low $p_T$ threshold
Additional sTGC Parameters

![Graph showing relationships between strip pitch and arrival time with labeled parameters.]
Calculated deformation of a Large (left) and a Small (right) wedges at 0.75° inclination. All deformations are below 50 μm for the wedges.
<table>
<thead>
<tr>
<th>Item/Parameter</th>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh</td>
<td>Stainless steel</td>
<td>325 lines/inch</td>
</tr>
<tr>
<td></td>
<td>separate from readout board</td>
<td></td>
</tr>
<tr>
<td>Amplification gap</td>
<td></td>
<td>128 µm</td>
</tr>
<tr>
<td>Drift/conversion gap</td>
<td></td>
<td>5 mm</td>
</tr>
<tr>
<td>Resistive strips</td>
<td>Interconnected</td>
<td>R = 10–20 MΩ hm/cm</td>
</tr>
<tr>
<td>Readout strip pitch</td>
<td></td>
<td>0.425–0.445 mm</td>
</tr>
<tr>
<td>Stereo angle</td>
<td>4/8 layers</td>
<td>±1.5°</td>
</tr>
<tr>
<td>Total number of strips</td>
<td></td>
<td>2.1 M</td>
</tr>
<tr>
<td>Gas</td>
<td>Ar:CO₂</td>
<td>93:7</td>
</tr>
<tr>
<td>HV on resistive strips</td>
<td>positive polarity</td>
<td>550 V</td>
</tr>
<tr>
<td>Amplification field</td>
<td></td>
<td>40 kV/cm</td>
</tr>
<tr>
<td>Drift field</td>
<td></td>
<td>600 V/cm</td>
</tr>
</tbody>
</table>
(a): integrated sTGC–MM sector. The four possible mount points are indicated by the red circles. The arrows give an example of the degrees of freedom of translations of the three used kinematic bearings.

(b): cut though the sTGC–MM station at a kinematic double bearing.

(c): detail of the sTGC mounted to the MM frame. Visible is the bar connecting the two sTGC wedges to the MM frame and the double kinematic bearing. The arrows indicate the possible adjustment of the sTGC wedges on the connecting bar.