ATLAS New Small Wheel (NSW) small-strip Thin Gap Chamber (sTGC) simulation in Athena

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Outline

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Why Upgrade? Harsher Conditions at the LHC

Upgrade ATLAS to increase data acquisition rate

- Accelerate the study of the Higgs, the standard model and new physics

Increased Rate due to higher Luminosity, more Energy and smaller Bunch Spacing (25 ns)
Collecting the data

ATLAS collision rate:

- **Original**: 25 every 50 ns
- **Future**: 50-100 every 25 ns

Collisions in one event in ATLAS

- With current **Muon Small Wheel** the trigger cannot handle Run 3 rate
- Key **trigger** selection looks for energetic **muons**
- Trigger designed for original luminosity of $1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- The **High Luminosity LHC** trigger will need to handle luminosity of $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- To collect interesting events we need to **enhance** ATLAS trigger capability

Run 3 will have even more collisions!
The **Small Wheels** are the most forward muon chambers ➔ highest event rate
Why a New Small Wheel at ATLAS?

Fake muon triggers are overwhelming in the end cap regions.

Magnetic Field

Current trigger relies mainly on the Big Wheel

Difficult to distinguish between A, B and C above

The NSW will simultaneously improve tracking performance and reduce fake rate by an order of magnitude.
New Small Wheel Technologies

The **NSW** must provide angular resolution of $<1$ mrad or less to the IP, and so a spatial resolution of $<100$ um per layer, in $<1$ μs.

To satisfy the requirements, use two separate technologies:

1. **sTGC** (in color below) as the primary trigger (*very fast*)
2. **MicroMegas** (in grey) as the primary tracker (*high-resolution*)

sTGC’s are the outer chambers ➔ longer lever arm ➔ **better angular resolution**
The small-strip Thin Gap Chamber (sTGC)

Gas: pentane / CO₂ (45% / 55% vol.)
2.8 mm gas gap

Anode: wires (at 2900 V) 1.8 mm pitch
Cathode: pads and strips, 3.2 mm pitch

Resistive layer: mitigates 10kHz/cm² rate protection against discharge

Pads: for triggering and to determine areas of interest for strip readout
Strips: for tracking in the precision coordinate (η)
Single-hit strip spatial resolution

$$\sigma = 45 \pm 8 \, \mu m$$  All runs – All layers

Resolution determined with respect to precise pixel telescope measurements ($y_{pix}$)
Simulation Geometry Validation

Important to have **accurate geometry** for digitization results to be correct

We took the approach of simulating a **hit** on every **pad** of every **layer**

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Ensure that the simulation returns the correct **pad** every time

Geometry is defined by the **NSW xml**:

MuonSpectrometer/MuonG4/NSW_Sim/trunk/data/stations.v1.73.xml

And by the package:

MuonReadoutGeometry-03-03-03
Visualization of pad geometry was implemented to understand, categorize and fix geometry problems.

Before fix

GL1C1 Layer 1

Green circles are input hit positions, Blue crosses are the digitized position, Red crosses are positions returned more than once (Wrong pad!)
Half of the layers were inverted in the geometry -> hits created on the wrong pad

After fix

Green circles are input hit positions, Blue crosses are the digitized position
sTGC signal simulation

- Simulate **full waveform** of signal on strips after the VMM readout chip
- Study of time delay associated with the **resistive layer** (carbon coating)
- Allows for **detailed** trigger simulation
- Investigate pad trigger **efficiency**
sTGC signal simulation

Shaped and amplified sTGC electronic signal versus time

Strip main (middle)  Strip (1st neighbor)  Strip (2nd neighbor)

The charge signal time profile is different on each strip
This will be reflected in the simulation
**sTGC timing simulation**

**Need to assign BCID**: detector electronics will determine which bunch crossing (BC) a digitized hit corresponds to

Start with a **global hit time** for Geant4 and account for several **Physical timing effects**:

- Time of flight (ToF) = (global hit position)/(speed of light)
- Detector Jitter (Jd): *statistical* fluctuation from **charge drift time**
- Electronic Jitter (Je): *statistical* fluctuation of **readout electronics**
- Strip propagation time (SPT): time for signal to **propagate to the readout** down a strip

\[
\text{Digit time} = \text{global hit time} - \text{ToF} + J_d + J_e + SPT
\]

Then BCID is determined:

- \(-25\) ns < (Digit time) < \(5\) ns \(\Rightarrow\) **Previous BC**
- \(0\) ns < (Digit time) < \(30\) ns \(\Rightarrow\) **Current BC**
- \(25\) ns < (Digit time) < \(55\) ns \(\Rightarrow\) **Next BC**

Matching window
sTGC Deadtime Simulation

Hit deposited on sTGC channel

Charge is converted by ADC in VMM readout chip.
- Takes \(~250\) ns for strip channel (precise 10 bit ADC)
- \(~140\) ns for pad channel (6 bit ADC)

2\textsuperscript{nd} hit arrives within digitization time window \(\Rightarrow\) channel is dead

Must simulate with pile-up to study the effect of this deadtime!
Pile-up Digitization

Pile-up events are sourced from separate input samples
2 types of pile-up events: **low pT** (abundant) and **high pT** (rare)

Pile-up events are included from a set number of BC before and after the current BC

For sTGC the electronics deadtime of the **strip** digitization is \(~250\) ns
-> Need to consider pile-up from at least 10 BC (225 ns)

Bunch structure will affect deadtime

More time between filled bunches
-> less deadtime due to pile-up

Code for pile-up deadtime is *in place and functional*; need to determine parameters and validate
Summary and Conclusion

- LHC upgrades provide the opportunity to really improve our knowledge of the Higgs boson, the Standard Model and the search for new physics.
- However, in its current state ATLAS would be unable to take full advantage of these opportunities.
- The first full scale sTGC module meets the specification with single-hit spatial resolution ($\sigma = 45 \pm 8 \mu m$).
- sTGC digitization simulation is underway to test whether pile-up induced electronics deadtime will be acceptable.
Backup
**sTGC deadtime simulation**

**Pad deadtime structure**

- **80 ns**
- **60 ns**
- **140 ns** deadtime

  - **Time over threshold**
  - Allows strips to be read out

  - **Digitize pad charge via 6 bit ADC**

**Strip deadtime structure**

- **30 ns**
- **220 ns**
- **250 ns** deadtime

  - **Strip signal peaking time**

  - **Digitize strip charge via 10 bit ADC**

**Neighbor on mode** will add another strip on each end of the cluster.
strips activated by **neighbor on mode** will be dead for ~250 ns as well.

Neighboring strip channels will be delayed, time for the charge to diffuse in the resistive layer ——> **longer deadtime**
Rough estimation:
Inelastic cross section assumed: 70 mb
HL-LHC luminosity assumed: $7.0 \times 10^{34}$ Hz/cm$^2$

Event rate = Luminosity * Cross section.

$$ (70 \times 10^{-27} \text{ cm}^2) \times (7.0 \times 10^{34} \text{ Hz/cm}^2) = 4900 \text{ MHz} $$

Head-on meetings between bunches at every collision point occur every 25 ns $\Rightarrow$ 40 MHz

But, the entire ring is not filled with bunches

$$ \langle \text{crossing rate} \rangle = \text{number of bunches} \times \text{revolution frequency} = 2808 \times (3 \times 10^8 \text{ m/s}) / (26.73 \times 10^3 \text{ m}) = 31.5 \text{ MHz} = 1/(31.7 \text{ ns}) $$

Thus, the average bunch spacing in the LHC in real life is $\sim 32$ ns (4900 MHz/31.5 MHz) $\approx$ 160 events per bunch crossing