Simulation of the ATLAS New Small Wheel (NSW) System

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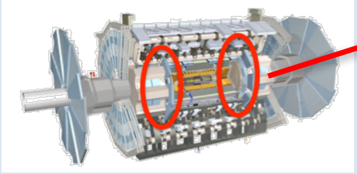
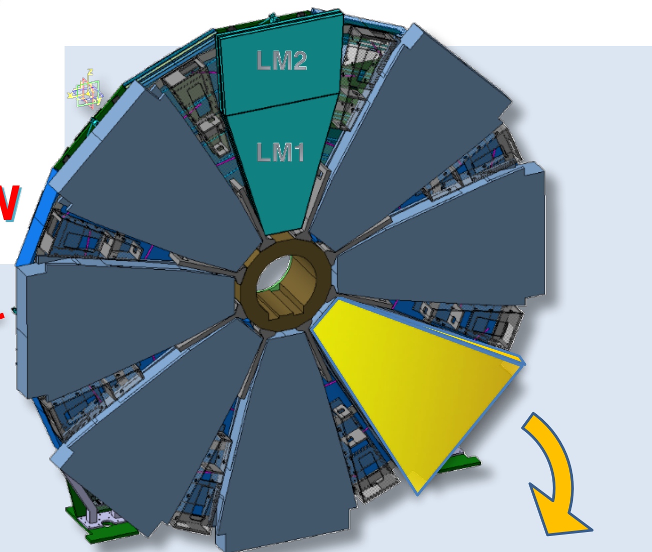
ATLAS Upgrade and NSW Installation

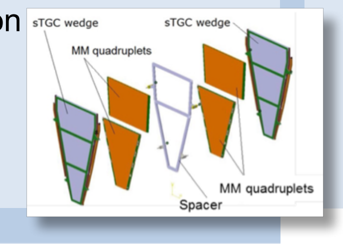
NSW





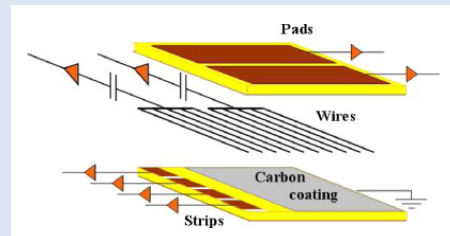
LHC peak luminosity will increase to $3\times10^{-34}\ \mathrm{cm^{-2}s^{-1}}$ in Run3 (2021~).
A serious limitation on the ATLAS performance in the endcap region
- Degradation of muon tracking efficiency
- Unacceptable rate of fake Level-1 muon triggers

ATLAS replaces endcap muon detector with New Small Wheel (NSW) and upgrades muon system in 2019-2020.



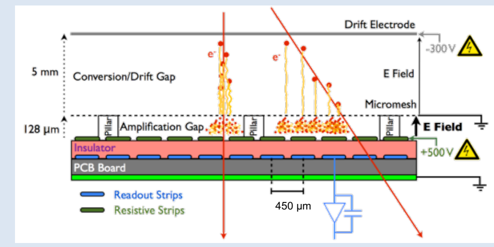
2 Detectors of NSW

Small-strip TGC (sTGC)



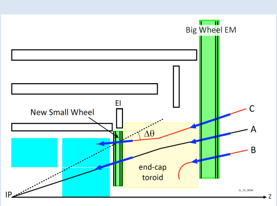
- Lower cathode resistance for high hit environment
- Fine readout strip pitch (3 mm)
- Readout channels : 280k (strip) + 46k (pad) + 28k (wire)

Micromegas (MM)

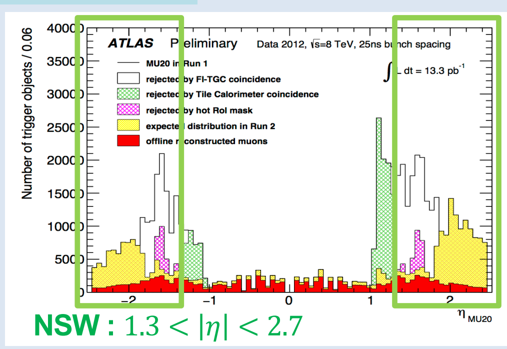


- Drift and amplification gaps separated by mesh.
- Fine strip pitch ~450 μm
- Resistive anode to suppress spark
- Readout channels: ~2.1 M
- Using only the fastest signal for trigger in front-end ASIC(VMM) (1 VMM = 64 ch)

Trigger Rate Reduction using NSW

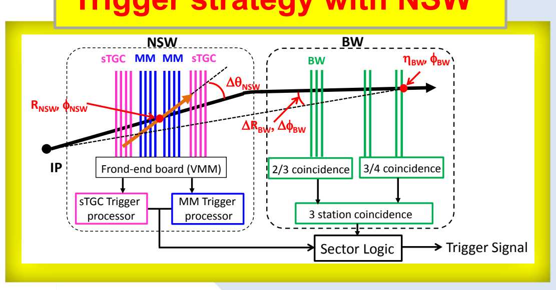


Fake Level-1 muon triggers are mainly caused by particles generated in the material before Big Wheel (BW), main endcap muon detector.



NSW : $1.3 < |\eta| < 2.7$

Trigger strategy with NSW



Such fake triggers can be suppressed by a coincidence with NSW, and Level1 muon trigger rate will be reduced to 1/4.

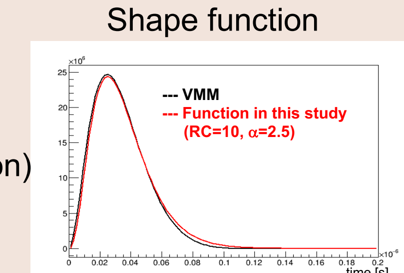
BW only 51 kHz ⇨ BW+NSW+Tile Calo. 13 kHz at $L\sim3\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$

Simulation of MM output signals

Detector Simulation

- Calculate energy deposition and ionization by Geant4
- Simulate electron drift (transverse, longitudinal diffusion)
- Simulate Lorentz angle in the ATLAS magnetic field
- Amplify electrons according to Polya distribution

Validation on Shape function

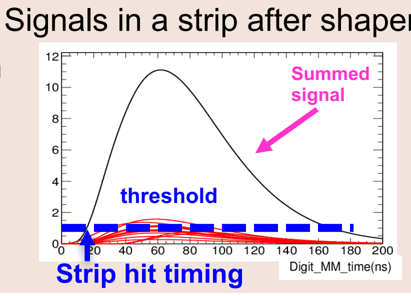


No significant difference

Electronics Simulation

- Pulse shape based on the function which is taken from ideal VVM specification
- Sum up pulses from all drift electrons in a strip
- Strip hit timing is recorded when the signal surpasses the threshold.
- Simulate the VMM dead time of 40 ns

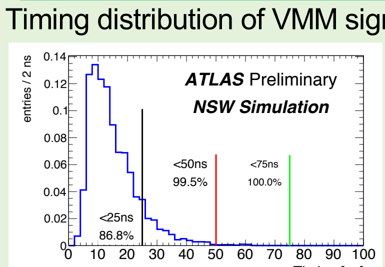
Signals in a strip after shaper



Results of Micromegas Trigger Performance Study

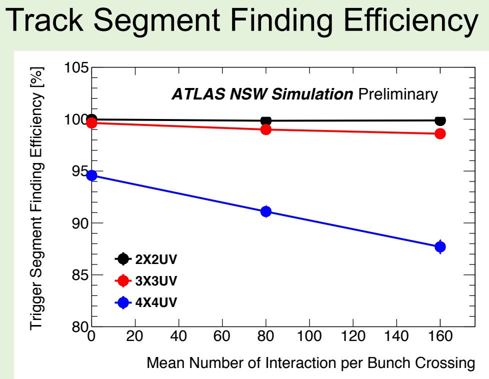
Segment finding efficiency

Timing distribution of VMM signal



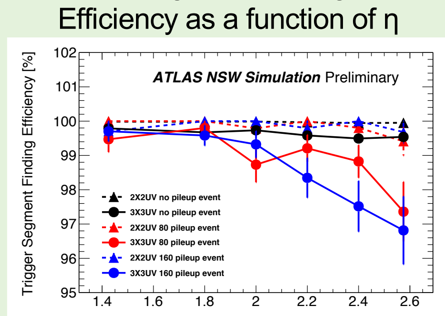
In 50 ns window, equivalent to 2 bunch crossings (BC), 99.5 % is collected and that is sufficient.

Track Segment Finding Efficiency



Pileup (mean number of interactions/BC)
- 80 (Run-3)
- 160 (Run-4, HL-LHC)

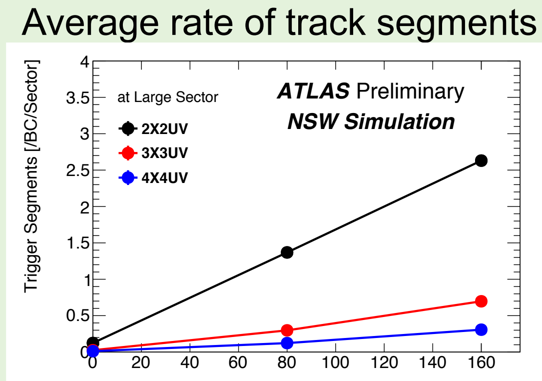
Track Segment Finding Efficiency as a function of η



The efficiency of track segment finding for true muons that penetrate all the 8 MM layers are shown for different track segments finding conditions: required number of eta (X) and stereo (UV) hits [1] (inclusive) within a common slope (R/Z) window.
Track segment finding efficiency decreases due to VMM dead time in high pileup conditions of high background (BG) hit rate.
As coincidence threshold, 3X3UV and 2X2UV are reliable.
Even in the innermost region of high BG hit rate, the inefficiency is at most 3 %.

Trigger link occupancy

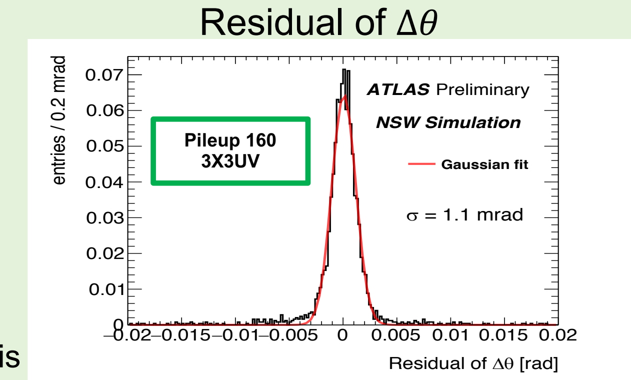
Average rate of track segments



With the reserved bandwidth of data transmission, the NSW trigger electronics can send out up to 8 track segments per BC per sector to downstream.
The occupancy is small enough with regard to the bandwidth limitation in the trigger performance at coincidence threshold 3X3UV and 4X4UV.

Resolution

Residual of $\Delta\theta$



The resolution is shown for the 3 parameters $\Delta\theta$, $\eta(R)$, ϕ, which will be sent to downstream.
The $\Delta\theta$, η, and ϕ are obtained by an analytical formula based on a χ^2 minimization algorithm, which is to be implemented as a fixed latency logic.

	Resolution	Requirement
$\sigma(\Delta\theta)$	1.1 mrad	1 mrad
$\sigma(\eta)$	4.7×10^{-5}	5×10^{-3}
$\sigma(\phi)$	1.9 mrad	20 mrad

Residual is defined as the difference between the track segment, as reconstructed by the MM trigger logic, and the true muon direction from the simulation in the 160 pileup condition.
The resolutions are found to be 1.1 mrad for $\Delta\theta$, 4.7×10^{-5} for η, and 1.9 mrad for ϕ, respectively.
In the 3 parameters, the resolution meets the requirement.

Conclusion

NSW upgrade is crucial to reduce trigger rate for future.
We evaluated MM trigger performance with single muon + high pile up background.
50 ns time window is available.
Track segment finding efficiency is still sufficient in high pileup and high hit region at both 2X2UV and 3X3UV coincidence thresholds.
The resolution meets the requirement and occupancy is negligible.
The study shows the MM trigger will be competent in the high BG rate condition for future LHC operation.

[1] CERN-LHCC-2013-006 (2013), ATLAS Collaboration, ATLAS New Small Wheel Technical Design Report.

ATLAS EXPERIMENT