ATLAS Muon Spectrometer Upgrades for the High Luminosity LHC

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LHC Timeline



ATLAS Muon Spectrometer

ATLAS is a general purpose detector at the LHC with an dedicated muon detection system





ATLAS Muon Spectrometer is realized by different gas detector technologies. Different technologies for trigger and tracking

- RPC and MDT in the barrel region, $|\eta| < 1.05$
- TGC and CSC, MDT in the endcap region, $|\eta| > 1.05$

Limitations of the current Small Wheel

- The fake rate of the current muon triggers is too high for Run III
- Current Small Wheel chambers cannot cope with the expected rates



• New small wheel upgrade is primarily motivated by the high rates that are expected for the higher luminosity running in Run 3 and beyond



New Small Wheel Upgrade

- <u>New (fast) precision tracker</u> (~100µm per plane) that will work up to the ultimate luminosity with some safety margin (NSW upgrade)
- <u>Reject the fake trigger signals</u> by requiring high quality (~1mrad) pointing segments (NSW upgrade)





New Small Wheel layout

NSW will utilize two detector solutions

- Small strip thin gap chambers (sTGC) for primary trigger
- Resistive strip Micromegas (MM) for primary precision tracker
- Both detector technologies are capable of both actions (fully redundant system)



General Layout

- 16 Sectors per wheel (8 large and 8 small)
- 8 detection layers per sector for each technology, subdivided into 2 quadruplets each
- Position determination of the precision coordinate: $<30 40 \mu m$



Resistive strip Micromegas

- High rate capable planar gaseous detector technology
- Readout boards from standard industry PCB production
- Discharge insensitive by additional resistive strip
- 2nd coordinate measurements by stereo strips



- Use non-bulk technique (<u>floating mesh</u>) that uses also pillars to keep the mesh at a defined distance from the board
- mesh is integrated with the drift-electrode panel and placed on the pillars when the chamber is closed
 - Allows to build very large chambers using standard PCB





MM medium size prototype

The prototype (MMSW) that adopts the general design foreseen for the Micromegas detectors in the NSW project has been constructed

- Quadruplet structure with two double sided readout
- Readout of 1024 strips per plane with pitch 415um.
 Strips are rotated on two planes to measure the second coordinate
- A pattern of 128um high support pillars to define the position of the mesh
- Readout strips covered with kapton foil with sputtered resistive strips
- MMSW has been extensively studied during the test beam campaigns.
 - Measured resolution for first and second coordinate are well within specifications
 - Efficiency ≈98% for all the layers (2% inefficiency caused by the pillars)







Small strip thin gap chambers

Based on TGC technology already operational in ATLAS

- Used for muon endcap triggering
- Fast, thin gap wire chambers (2.8mm gap)

New specification with

- Strips, width/pitch: 2.7 / 3.2 mm, for precise measurement of polar coordinate
- Wires, 1.8 mm pitch, for coarse azimuthal coordinate measurement
- Pads, 8cm pitch, to identify regions of interest for trigger
- Cathode planes with graphite-epoxy mixture on G10 plane
- Gas mixture, 55% CO2 45% n-pentane
- High voltage 2.9kV



sTGC Prototypes and Testbeam Campaings

- Module-1, the first full size prototype (1×1.2 m) built at Weizmann
- Module-0 being produced by all sites
- To qualify materials, tackle construction problems and gain experiences for mass production
- Both at FNAL and at CERN
 - Verification of construction methods
 - Uniformity of large scale detectors
 - Efficiency and resolution studies



Sr-90 irradiation scan: Module-1', single sTGC #4



Motivations for muon Phase – II upgrades

Increased instantaneous luminosity, 7×10³⁴cm⁻²s ⁻¹, at the HL-LHC results in the expected mean number of interactions per bunch crossing ~200

- How to maintain spatial resolution and tracking efficiency in a high rate environment
- How to cope with higher occupancies and increased L1 trigger rate
- How to keep a high level of high p_T tracks finding at low rate of fake triggers

While keeping low the p_T thresholds for the single lepton trigger

Phase – II upgrade

Split the current (and phase-I) L1 trigger architecture in two (L0 and L1), enlarging the latencies (3us vs 6us and 30us)

- Base the L0 to the current L1
- Use track information in L1 to reduce rate even further.



- New muon spectrometer front-end electronics is needed.
- Use this opportunity to improve the p_T resolution at L1 (or even L0) using tracking chamber information
- Upgrade the detectors of the trigger system

Upgrade of the barrel muon trigger system

- Current RPC detectors are not designed for the integrated charge they will accumulate during HL-LHC operation.
- In order to survive, the gas gain will be lowered leading to lower efficiencies
- By adding another layer of RPC, thinner version with better rate capabilities, we can bypass the inefficiency problem



 As an added bonus we can increase the acceptance of the muon trigger system from 75% to >90%



Sharpening high p_T threshold

Currently precision and trigger chambers in Muon Spectrometer have independent readout, merged only in L2.

Introduce a second fast readout path in the precision chambers. Do not use the full resolution of the TDC in order to stay in latency budget.

Even in reduced time resolution the "binning" of the precision chambers is better than the "binning" of the trigger chambers







Summary

- LHC luminosity upgrades will pose challenges to the performance of the ATLAS Muon Spectrometer
- ATLAS is preparing two upgrades to the Muon Spectrometer, coinciding with the Long Shutdown periods.
- NSW upgrade is on schedule for LS2 installation.
 - Both detector technologies have produced preproduction pieces and mass production is ready to start
- Phase II projects are passing from R&D to implementation of demonstrators. Different scenarios still on the table. An initial design review is being prepared for next year.

Production Sites

MM production is distributed over several university groups with some components delivered by industry.

- All production sites are ready with the basic equipment
- Tooling & quality control for the chamber construction under preparation
- Module 0s starting to appear beginning of autumn.





sTGC production also distributed within the ATLAS Muon Community

- Module-0, module-1 already produced and tested
- Production is starting

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LOI
LS2
LS3

LHC startup, 900 GeV	L		
7 + 8 TeV, L=6x10 ³³ /cm ² s, Bunch spacing 50 ns		~25 1/fb	RUNI
Go to design energy, nominal luminosity			
13 - 14 TeV, L~1x10 ³⁴ /cm²s, bunch spacing 25 ns		75 - 100 1/fb	RUN II
Injector + LHC Phase-1 upgrade to ultimate design luminosity		_	
14 TeV, L~2x10 ³⁴ /cm²s, bunch spacing 25 ns		~300 1/fb	RUN III
HL-LHC Phase-2 upgrade: Interaction region, crab cavities?			
14 TeV, L=5x10 ³⁴ /cm ² s, luminosity levelling		~3000 1/fb	RUN IV