The ATLAS Muon Spectrometer at the LHC and the HL-LHC

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Focus on stand-alone muon reconstruction.
- Air-core toroid → minimization of multiple scattering.
Fast trigger chambers: RPC, TGC
(<10 ns time resolution, moderate spatial resolution \(\sim\) mm-cm).

High-resolution tracking detectors: CSC, MDT (40 \(\mu\)m spatial resolution).

Optical alignment system with 50 \(\mu\)m resolution.

Pseudorapidity coverage: \(|\eta| < 2.7\).
Muon momentum resolution

**Barrel region**

- ∼4% muon spectrometer stand-alone resolution for $10 \lesssim p_T \lesssim 200$ GeV.

**End-cap region**

- Muon spectrometer crucial to reach 10% momentum resolution at $p_T = 1$ TeV.
ATLAS uses as 3-level trigger system.
The level-1 high $p_T$ muon trigger built out of a coincidence of three RPCs in the barrel or three TGCs in the big end-cap wheel.
Muon momentum estimate from the size of the deviation of hits from an infinite momentum track from the interaction point.
Muons trigger rate dominated by fake triggers in the end-caps caused by charged particle not emerging from the interaction point.

Real muon triggers contaminated with sub-$p_T$-threshold muon due to the reduced momentum resolution caused by the moderate spatial resolution of the trigger chambers.
- New small wheel with high-resolution trigger chambers to reject fake muon triggers and improve momentum resolution at trigger level.
- New TGCs with higher resolution to cope with background at $|\eta| \sim 2.7$.
- New thin-gap RPCs to close acceptance gaps of the barrel muon trigger.
- New sMDT chambers to free space for new RPCs.
- High-\(\eta\) tagger to identify muons up to $|\eta| = 4.0$.
- New on- and off-chamber electronics for new trigger architecture.
New trigger scheme:

- Only two trigger levels: level 0 (L0) and high-level trigger (HLT).
- L0 rate: 1 MHz. L0 latency: 6-10 µs.

⇒ In this scheme all muon chambers have to send their data off to USA15 continuously for further processing.

⇒ New on-chamber (MDT ASD and TDC chips, multiplexers) and off-chamber electronics (trigger logic, Felix) needed!
**The ATLAS 1st level muon trigger at the HL-LHC**

**Processing step**

1. Continuous stream of muon hit data to off-detector trigger logic.  
   **Time after pp collision**: 1 µs

2. Pre-muon-trigger based on coincidences of trigger-chamber hits in the inner, middle, and outer layers.  
   **Time after pp collision**: 2 µs

3. Use of precision NSW and MDT hits for the refinement of muon $p_T$ measurement in regions of interest defined by the trigger chambers.  
   **Time after pp collision**: 3 µs

4. Final muon trigger based on refined momentum measurement.  
   **Time after pp collision**: 6 µs
Single-muon trigger rates at the HL-LHC

Single-muon trigger rates
(estimated from run-I data)

- Unacceptably high rate of run-I 20 GeV muon trigger: \( \sim 150 \text{ kHz} \).
- Removal of fake triggers by including the NSW in the trigger coincidence.
  \( \Rightarrow \) Rate reduced to \( \sim 70 \text{ kHz} \).
- Sharpening of the turn-on curve with MDT data reduces trigger rate to \( \sim 18 \text{ kHz} \).
  \( \Rightarrow \) \( \sim 130 \text{ kHz} \) free for other triggers!