ATLAS Muon Trigger for HL-LHC

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with inputs from
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Introduction

- Proposed ATLAS Phase-II hardware trigger
  - Level-0 trigger with 500 kHz and 6 $\mu$s latency.
  - Level-1 trigger with 200 kHz and 20 $\mu$s latency.

- Concept of the ATLAS Phase-II muon trigger
  - Keep Level-1 muon $p_T$ threshold of 20 GeV for retaining acceptance for various physics processes.
  - Trigger logic based on the trigger chambers (RPCs and TGCs) remains at Level 0. Electronics modified.
  - Additional constraint based on precision tracking chambers (MDTs) at Level 0 or Level 1 proposed.
Contents of this presentation

1. **MDT-based** Level-0/1 muon trigger
   - Performance estimation with method overview
   - Proposed schema of electronics

2. **Barrel** Level-0 muon trigger
   - Proposed scheme of electronics

3. **Endcap** Level-0 muon trigger
   - Proposed scheme of electronics
I. MDT-based Level-0/1 muon trigger
• Monitored Drift Tube ("MDT") for precision tracking.

• MDT-based trigger: candidate of the Phase-II Level-0/1 muon triggers. Exploit precision angular resolution.

• MDT covers a wide range in both barrel and endcaps.

"Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment", CERN-2012-022.
Strategy for a performance estimation

Level-1 trigger rate after the Phase-I upgrade has been estimated in TDR for Phase-I upgrade of TDAQ [CERN-LHCC-2013-018].

An MDT-based requirement is additionally applied for the Level-1 candidates which satisfy the requirements for the Phase-I upgrade.

Using 2012 data, 8 TeV, 25 nsec. No higher-level triggers applied. No event filters applied.

Level-1 entries after Phase-I upgrade.
Region mask

(Optional for Phase-0/I upgrades.)

Before including MDT-based requirement, we mask some regions in which the magnetic-field integral is small ("region mask").

By introducing the region mask, Level-1 trigger rate is expected to reduce to about 90%, while an acceptance of 99% is retained.
Overview of an MDT-based requirement

Use a polar-angle difference $\beta$ of the segments between:

- outer and middle stations in the barrel,
- middle and inner stations in the endcap.

For estimating the performance, offline segments are selected in $\sqrt{(d\eta)^2 + (d\phi)^2} < 0.1$ from each Level-1 region of interest. A combination is selected so that $|\beta|$ becomes the smallest.
Level-1 muon candidates depending on $|\beta|$ and $1/p_T$ after Phase-I requirements

A large correlation between $|\beta|$ and offline $1/p_T$ indicates a good separation of $p_T$ region, e.g. $p_T > 20$ GeV, by a requirement on $|\beta|$. Requirement on $|\beta|$ determined depending on the regions divided by $\eta$ and $\varphi$ (24 regions in total), so that the efficiency for the candidates with offline $p_T > 20$ GeV becomes $> 95\%$ in each region.
Level-1 muon candidates as a function of $\eta$

- Region mask rejects $\sim 10\%$ of the Level-1 candidates.
- MDT-based requirement rejects $\sim 50\%$ of the Level-1 candidates.
Distributions of offline $p_T$ and relative efficiency

Candidates with offline $p_T > 20$ GeV well selected.

More explanation about this performance estimation:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1MuonTriggerPublicResults
Fast segment reconstruction

- At a Level-0/1 trigger level, full track information cannot be used.
- Algorithm at Level-0/1 based on shift registers or FIFO proposed; this method provides binary hit-time information for each tube.
- Timing and region information from trigger chambers planned to be used for constraining segment reconstruction.
- Expect a ~1 mrad level resolution.

**Input:** hit signal synchronized with a clock.

Histogram with projected hit positions. At the time and in the region specified by trigger chambers.
Overview of the proposed schema for MDT-based trigger electronics

- Will focus on two proposed schema for electronics.

1. “RoI-based” scheme to send MDT data after selection based on regions of interest transferred from RPC/TGC to off-detector.
   - Less MDT information sent to off-detector (less fibers).
   - More latency due to the time of sending RoI to MDT frontend.

2. An alternative scheme to send all MDT data to off-detector.
   - Less latency since no transfer of RoI to MDT frontend.
   - More MDT information sent to off-detector (more fibers).

Bunch-crossing timing and region of interests from RPC/TGC used for constraining segment reconstruction at MDT in both schema.
“Rol-based” scheme for MDT-based trigger

**Existing MDT R/O structure**

```
<table>
<thead>
<tr>
<th>24</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD</td>
<td>TDC</td>
</tr>
<tr>
<td>TDC</td>
<td>24 FIFOs</td>
</tr>
<tr>
<td>24 FIFOs</td>
<td>R/O buff's &amp; formatting</td>
</tr>
<tr>
<td>R/O buff's &amp; formatting</td>
<td>FPGA</td>
</tr>
<tr>
<td>FPGA</td>
<td>Data</td>
</tr>
<tr>
<td>Data</td>
<td>TTC, JTAG</td>
</tr>
</tbody>
</table>
```

**Logic for the MDT trigger**

```
<table>
<thead>
<tr>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC</td>
</tr>
</tbody>
</table>
```

**on-detector**

```
<table>
<thead>
<tr>
<th>CSM board</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSM R/O part</td>
</tr>
<tr>
<td>Data</td>
</tr>
</tbody>
</table>

TTC, DCS

**off-detector**

```
<table>
<thead>
<tr>
<th>DCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC</td>
</tr>
</tbody>
</table>

MROD

ROB

ROS

**“Look back” based on RPC/TGC information. Send only interested MDT data to off-detector.**

**RPC/TGC information sent to MDTs.**

```
<table>
<thead>
<tr>
<th>UX15</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA15</td>
</tr>
</tbody>
</table>

SL: Trigger logic of one Sector

high-p_T selection

<1kHz<br><100 Hz<br><200Hz<br><50kHz<br>~20kHz<br>~50kHz<br>~500 kHz<br>~20kHz<br><50kHz<br><200Hz<br><100 Hz<br><1kHz<br><20 Hz<br><200Hz<br><50kHz<br>~20kHz<br>~50kHz<br>~500 kHz<br>~20kHz<br>~50kHz<br><200Hz<br><100 Hz<br><1kHz<br><20 Hz<br><200Hz

RPC or TGC chambers in a Trigger Sector

Primary trigg. data

40 MHz

400 SL's

Fr. Calorimeters & Tracker

0.2 MHz

L1 trig. (0.2 MHz)

CTP

CTP

CTP

CTP

L0 trig. 

400 SL’s

USA15

UX15

LVL1

LVL0
Alternative scheme for MDT-based trigger

- MDT data sent to off-detector w/o selection based on TGC/RPC Info.
- While data are merged, zero-suppressed, and encoded, more fibers are needed with respect to the “RoI-based” scheme. Estimated $\#_{\text{fibers}} \lesssim 5000$.
- Expected latency: $< 4 \mu\text{sec}$, safely smaller than Level-0 latency of 6 $\mu\text{sec}$. 

(Similar logic for RPC.)
2. Barrel Level-0 muon trigger
Current L1 muon barrel trigger system

- Pads take a coincidence between layers, selects candidates in $\eta$ and $\phi$ independently, and associates candidates to regions of interest.
- Sector Logic selects muon candidates with a scheme based on coincidence windows, and sends trigger signal to MuCTPi.
Phase-II L0 muon barrel trigger system

- Front-end cabling not replaced.
- Pad box replaced by DCT box.
  - Simple logic in DCT.
  - Time-over-threshold measurement considered for improving resolution.
- A proposal: installing RPCs in inner station.
- ROI-based scheme maintained.
- Most of the trigger algorithm in SL, providing flexibility, easier operation and maintenance, and less radiation.
- Information probably transferred to the MDT trigger electronics.
3. Endcap Level-0 muon trigger
Current L1 muon endcap trigger system

**PS-Board (on chambers)**
- Patch-Panel ASIC (PP)
  - LVDS Rx, variable delay, BCID,
  - Test pulse generator
- Slave Board ASIC (SLB)
  - Trigger logic,
  - L1-Buffer (3.2 μs ), Readout

**HSC Crate (on Big Wheel)**
- H-pT Board, H-pT ASIC
  - Trigger Logic
- Star Switch Board (SSW)
  - Readout
- HSC
  - Crate controller

**VME Crate (USA15)**
- Sector Logic (SL)
  - wire-strip coin.
  - pT calculation
- ROD
  - Readout
- CCI
  - front-end controller

Coincidence-window scheme in SL.
Phase-II L0 muon endcap trigger system

• ASIC’s for PS-Board:
  • LVDS Rx, variable delay, BCID, and test pulse generator.
  • Zero-suppress and encoding logic of hit signals and interface to GBT.
• Module with FPGAs for trigger and readout located off-detector.
  • Most of the trigger algorithm located off-detector, providing flexibility, easier operation and maintenance, and less radiation.
• Information for MDT trigger sent from Sector Logic (“SL”).
• Receive Level-1 accepts. Long Level-1 buffer (no separate Level-0 buffer).
Conclusion

• **MDT-based trigger** is a candidate of the Level-0/1 muon triggers for HL-LHC at ATLAS.

• **Trigger rate** is estimated to reduce to about 50% based on a data sample for 8 TeV and 25 nsec.

• **RPC/TGC information** for constraining tracking at MDT.

• **RPC/TGC electronics** will be replaced.

• Most of the trigger logic will be located off-detector; increased algorithm flexibility, easier operations and maintenance, and less radiation.