Commissioning of the ATLAS Muon High Level Trigger with beam collisions at the LHC

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The ATLAS Detector

is designed for physics in p-p (and heavy ion) collision at LHC.

It consists of many sub-detectors.

• Inner Detector (ID):
  – Charged particle measurement

• Calorimeter (CAL):
  – Energy measurement of particles

• Muon Spectrometer (MS):
  largest sub-detector to detect & reconstruct muons
  – Barrel & Endcap Toroid Magnets: Bend muon tracks → momentum measurement
  – Trigger Chambers: Resistive Plate Chambers (RPC), Thin Gap Chambers (TGC)
  – Precision Chambers: Monitored Drift Tubes (MDT), Cathode Strip Chambers (CSC)
The ATLAS Trigger System

- **Level 1 Trigger (L1)**
  - Custom-made hardware based
  - ~75kHz → Readout Buffer
  - Geometrical info → HLT

- **High Level Trigger (HLT)**
  - Level 2 & Event Filter
  - Fully software based

- **Level 2 (L2)**
  - Fast & simple algorithm
  - Request the data around the region identified by L1 to Readout System
  - ~3kHz → Event Builder

- **Event Filter (EF)**
  - Complete event data accessible
  - Make use of the Offline reconstruction algorithm
  - ~200Hz → Recorded
Commissioning of the ATLAS Muon Trigger with beam collisions

In this talk, the ATLAS Muon trigger is evaluated in the following aspects:

• Trigger efficiency
• Residual of $p_T$ (transverse momentum)
• Trigger rates

for each of the 3 levels of the trigger

• Offline good muons are selected as a reference
  - Cut on momentum
    • momentum $>$ 4 GeV, $p_T >$ 2 GeV
  - Enough hits in ID
    • # silicon tracker hits $>$ 5, # pixel hits $>$ 0
  - Good matching between ID & MS track
    • match $\chi^2 <$ 50

Contents:
1. Level 1 Muon Trigger
2. Level 2 Muon Trigger
3. Event Filter Muon Trigger
4. Trigger Rates

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Data Sample

- Data taken from p-p collision at $\sqrt{s} = 7$TeV between April and July 2010
  \[ \text{Integrated Luminosity of } \sim 94 \text{nb}^{-1} \]
  (with requirement detectors were in operation)
  \[ \text{for Level 1 study} \]
  \[ \text{for Level 1 study} \]
- Trigger Requirement
  - For Level 1 study: **Independent trigger**
    - Level 1 Minimum Bias trigger
      (cross-checked using Level 1 Calorimeter Trigger)
  - For HLT study: **Level 1 muon Trigger**
    - HLT was running but not rejecting the events
- Events selection
  - vertex with at least 3 tracks & $|z_{\text{vertex}}| < 150$ mm
  \[ \text{Reject the background e.g. cosmic-ray induced event} \]
Level 1 Muon Trigger
Level 1 Muon Trigger

- Dedicated Trigger Chamber
  - Barrel ($|\eta| < 1.05$)
  - Resistive Plate Chamber (RPC)
  - Endcap ($|\eta| > 1.05$)
    Thin Gap Chamber (TGC)
- RPC and TGC have several layers, which form coincidences for muon detection
- Toroidal magnetic field induces $\Delta \eta$ differences between layers in coincidence, which allows $p_T$ measurement
Level 1 Muon Trigger Efficiency

- Efficiency defined as

\[
\frac{\text{# offline muons triggered by Level 1}}{\text{# offline muons}}
\]

*An offline muon was regarded to be triggered if it matches to L1 muon in \(\eta-\phi\) plane*

- Plateau efficiency is obtained
  - Barrel: \(~73\%\), Endcap: \(~90\%\)
  - Efficiency at Barrel is lower than at Endcap because of geometrical acceptance (detector feet, Toroid Magnets support structure)
Level 2 Muon Trigger
Level 2 Muon Trigger

- Level 2 Muon Trigger consists of 3 sub-algorithms
  - **Stand-alone Muon** Reconstruction
    - In addition to Trigger Chambers, Precision Chambers (MDT) are used
    - Fast pattern recognition & drift time fit on MDT tubes
    - Look-Up Table for $p_T$ determination
  - **Combined Muon** Reconstruction
    - Back-extrapolate Stand-alone track and combine it to Inner Detector track
    - Refine track parameter by adding ID track information
    - Rejection of background
      - Decay of $\pi/K$ in flight
      - Cosmic ray induced event
  - **Isolated Muon** Finder (*not covered in this talk)
    - Uses Calorimeter and Inner Detector information to find isolated muon
      - At LHC, muons mainly come from heavy flavor jets.
      - Isolated Muon finder is deployed to retain high efficiency (lower $p_T$ threshold) for muons from e.g. W/Z/$\tau$
**Level 2 Muon Trigger Efficiency**

- **Relative** efficiency defined as
  - *Standalone*: \( \frac{\text{# muons triggered by L2 Stand-alone}}{\text{# muons triggered by L1}} \)
  - *Combined*: \( \frac{\text{# muons triggered by L2 Combined}}{\text{# muons triggered by L2 Stand-alone}} \)

- Good performance
  - High plateau efficiency
  - Sharp turn-on curve

- Good agreement between data and MC

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Eff. of **Stand-alone:**
- **Barrel** \( (|\eta|<1.05) \)
- **Endcap** \( (|\eta|>1.05) \)

*ATLAS Preliminary* 
\( \sqrt{s}=7 \text{ TeV}, \text{ Data 2010} \)
Performance of Level 2 algorithm

Residual of $p_T$ wrt.
Offline defined as:
$$r = \frac{1}{p_T^{off}} - \frac{1}{p_T^{L2}}$$

Gaussian fit performed on Residual distribution

- Stand-alone: Shift of mean
- Slightly worse resolution in data than MC
  → Under investigation

Combined: smaller sigma (1~2%) than Stand-alone (≈10%)
(at $p_T$ 2~20 GeV) due to additional ID track information

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Event Filter Muon Trigger
Event Filter Muon Trigger

- Event Filter Muon Trigger consists of
  - **Stand-alone** reconstruction
    - Find the hit segments in Muon Spectrometer and build the track
    - Back-extrapolate the track from Muon Spectrometer to Interaction Point
      » take Calorimeter info into account for scattering & energy loss
  - **Combined** reconstruction
    - “Outside-in” Algorithm
      - Combine the Stand-alone track with the Inner Detector track
    - “Inside-out” Algorithm
      - Start from Inner Detector track around L2 muon
      - Extrapolate it to Muon Spectrometer to find hits
Event Filter Muon Trigger Efficiency

- **Relative efficiency** defined as:
  - **Standalone:** 
    - # muons triggered by EF Stand-alone
    - # muons triggered by L2 Stand-alone
  - **Combined:** 
    - # muons triggered by EF Combined
    - # muons triggered by L2 Combined

  - Good performance
    - High plateau efficiency
    - Sharp turn-on curve
  - Good agreement between data and MC

* data-MC comparison not yet performed for “Inside-out”

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Performance of Event Filter algorithm

Residual of $p_T$ wrt. Offline:

$$ r = \frac{1}{P_T^{off}} - \frac{1}{P_T^{EF}} $$

- Slight difference between data and MC $\rightarrow$ On-going Investigation
  - e.g. refine alignment of Muon Spectrometer
- Sigma $\sim 1\%$ (at $p_T$ 2$\sim$30 GeV)
  - Well refined measurement wrt. Offline compared to L2 (Stand-alone: $\sim 10\%$, Combined: 1$\sim$2\%)
Trigger Rate
Trigger Rate Study

- Trigger rate must be retained within the limit of DAQ system, while Physics Analysis needs sufficient trigger efficiency
  → Trigger rate is important information

- Fit on data is performed with the equation:
  \[ r = c_1 L + c_0 N_{BC} \]
  - \( L \): Instantaneous luminosity
    - Collision component
  - \( N_{BC} \): number of bunches open to the trigger
    - Accidental component (e.g. cosmic)
  → Fit describes data well
Trigger Rate Reduction in HLT

Rate of L2 & EF relative to L1, obtained from data (rejection power)

- Combined trigger has more rejection power than Stand-alone trigger
  - Background rejection
  - Better $p_T$ resolution

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Summary

• Commissioning of the ATLAS Muon Trigger was done with ~94nb$^{-1}$ beam collision data
  – Trigger efficiency relative to Offline muon
  – Residual of $p_T$ between Trigger algorithm and Offline
• Trigger performance was well verified
  – Reasonable turn-on curves with good plateau efficiency
  – Generally good agreement with MC
    • Some discrepancy indicates current status of tuning, which will be investigated with future study
• Trigger Rate was measured at each level of the muon trigger
backups
Level 1 RPC efficiency

- Comparison to MC
  - minimum bias MC
  - single muon MC
- Good agreement between data and MC
Level 2 Standalone Muon Reconstruction

- In addition to Trigger Chamber, Precision Chamber is used
  - Monitored Drift Tube (MDT)
- Find the MDT hits around the Level 1 hits

\[ p_T \text{ is measured as} \]
- **Barrel**: \( p_T = [A]R + [B] \)
- **Endcap**: \( 1/p_T = [A]\alpha + [B] \)

where \( \eta - \phi \text{ binned Look-Up Table} \)
define coefficient \([A] \& [B]\)

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Level 2 Combined Muon Reconstruction

- Inner Detector track is combined to Muon Spectrometer Standalone track
  - Rejection of background
    - decay of $\pi/K$ in flight
    - cosmic shower
  - Refining track parameter resolution
- Back-extrapolate Standalone track to Interaction Point
- Gather match candidate of Inner Detector track
- Find the best match Inner Detector track with $\chi^2_{\text{match}}$
  - $\chi^2_{\text{match}}$: taken with $p_T$, $\eta$, $\phi$
    between Inner Detector track and Standalone track
- Muon $p_T$ is refined to the weighted mean of Inner Detector track $p_T$ and Standalone track $p_T$
Level 2 Isolated Muon Finder

- At LHC, muons mainly come from heavy flavor jets.
- Isolated Muon finder is deployed to retain high efficiency (with low $p_T$ threshold) for muons from e.g. W/Z/\(\tau\)

- Calo based Isolation
  - Define Inner and Outer Cone (for electromagnetic calorimeter and hadronic calorimeter separately)
  - Calculate the sum of $E_T$ of calorimeter located outside the Inner Cone and inside the Outer Cone, to be used for judgment of isolation

- ID track based Isolation
  - Collect the Inner Detector track in a cone of $\Delta R < 0.2$ around the muon
  - Calculate the ratio $\Sigma p_{T,ID\text{track}} / p_{T,muon}$, to be used for judgment of isolation
Performance of L2 Isolated Muon Finder

- Input variables: agreement between data and MC is fair

  - sum of $p_T$ of Inner Detector tracks around muon in $\Delta R < 0.2$
  - sum of $E_T$ at ECAL in $0.07 < \Delta R < 0.4$
  - sum of $E_T$ at HCAL in $0.1 < \Delta R < 0.4$

- $\Sigma p_{T,track} / p_{T,muon} < 0.01$
- $\Sigma E_{T,ECAL} < 5.5$ GeV
- $\Sigma E_{T,HCAL} < 7$ GeV

is applied to check $p_T$ distribution

- Reasonable agreement between data and MC

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Event Filter Standalone Muon Trigger Efficiency

- **Relative** efficiency is defined as
  \[
  \frac{\text{# muons triggered by Event Filter MS}}{\text{# muons triggered by Level 2 MS}}
  \]

- Good performance
  - plateau efficiency > 99%

- Rejection at low $p_T$ region not so powerful, indicating Level 1 & Level 2 are already selective

- Good agreement between data and MC
Event Filter Combined Muon Trigger Efficiency

- **Relative** efficiency is defined as
  \[
  \frac{\text{# muons triggered by Event Filter CB}}{\text{# muons triggered by Level 2 CB}}
  \]

- Good performance
  - plateau efficiency > 99%

- Rejection at low $p_T$ region not so powerful, indicating Level 1 & Level 2 are already selective

- Good agreement between data and MC

- Sharpest turn-on curve obtained with the help of almost offline-like reconstruction at Event Builder
Event Filter “Inside-out” Algorithm Trigger Efficiency

- **Relative** efficiency is defined as
  
  \[
  \frac{\text{# muons triggered by “Inside-out”}}{\text{# muons triggered by Level 2 CB}}
  \]

- Good performance evaluated on data
Trigger Rate Extrapolation to Higher Luminosity

- baseline information to be used for future
The Muon System in the ATLAS Detector

- Trigger Chambers
  - Resistive Plate Chambers (RPC)
  - Thin Gap Chambers (TGC)

- Precision Chambers
  - Monitored Drift Tubes (MDT)
  - Cathode Strip Chambers (CSC)