Performance of the ATLAS Trigger with Proton Collisions at the LHC

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The ATLAS Detector

Muon chambers
Toroid magnets
Solenoid magnet
Semiconductor tracker
Transition radiation tracker
Pixel detector
LAr electromagnetic calorimeters
LAr hadronic end-cap and forward calorimeters
Tile calorimeters

$\mu$, $\nu$ = 27 GeV $\eta(\mu) = 0.7$
$\mu$, $\nu$ = 45 GeV $\eta(\mu) = 2.2$
$M_{\mu\mu} = 87$ GeV

$Z+\mu\mu$ candidate in 7 TeV collisions
The ATLAS Trigger

Level 1 (LVL1)
- Fast Custom-built electronics

Level 2 & Level 3 (Event Filter):
- Software based running on large PC farm

Level-2:
- Fast custom algorithms
- Reconstruction mainly in Regions of Interest (RoI) => limited data access

Level 3 = Event Filter (EF)
- Offline tools inside custom wrappers,
- Access to full event information
# Trigger Selection

## Trigger chain:
- Sequence of reconstruction and selection algorithms (~10 per chain)
- Chains for each trigger physics object and threshold i.e.

<table>
<thead>
<tr>
<th>Trigger physics objects</th>
<th>Lowest $p_T$ or $E_T$ Thresholds (GeV)</th>
<th>LVL1</th>
<th>HLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron/photon</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tau</td>
<td></td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Muon</td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Missing energy (MET)</td>
<td></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Jet</td>
<td></td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Total energy (SumET)</td>
<td></td>
<td>10</td>
<td>90</td>
</tr>
</tbody>
</table>

Also chains for B-tagged jets & B-physics signatures

## Trigger menu:
- Collection of trigger signatures: ~200-500 chains in current menus
- Also defines pre-scale factors
- Evolves to match LHC luminosity & physics requirements

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**Talk(Track 13): The ATLAS High Level Trigger Configuration and Steering Software: Experience with 7 TeV Collisions: S. George**
Trigger Commissioning & Evolution

Commissioning with cosmics, single-beam 2008 & 2009:

- Initial timing in of Level-1 signals, ready for first collisions

First Collisions: Dec 2009: 900 GeV; Mar 2010: 2.36 TeV; April & May 2010: 7 TeV

- Level-1 active
- HLT running online in monitoring mode - no HLT rejection*:
  - Validation of HLT ready to activate when needed
  - Online beam-spot determination using Level-2 Tracking

Progressive activation of HLT:

- Prescale sets pre-generated covering fixed luminosity ranges:
  - Can be updated before or during the run to match machine conditions.

Minimum Bias Trigger

• Minimum Bias Scintillators (MBTS) installed in each end-cap (2.09 < |η| < 3.84)
• Primary Minimum Bias trigger MBTS_1:
  - at least 1 counter above thresh & filled LHC bunch
• Efficiency 99.7% for collisions with one track with \( p_T > 500 \) MeV
• Time Difference between forward and backward counters signal collisions events:

Poster: Minimum Bias Trigger in ATLAS: R. Kwee
Jet Triggers

For: QCD multijet prodn., W->τν, SUSY, top, generic searches (pp → XX, X → jj), VBF

- Currently triggering based on Level-1:
  - Sums $E_T$ in the EM and Hadronic Calorimeters
  - Sliding window of up to 0.8x0.8 in $η\times\phi$ with 0.2 step
  - Thresholds well modelled by MC
  - 100% effic. above turn-on

Level-1 effic. v. $η$ for offline jet $p_T > 60$ GeV

Effic. v. $p_T$ for offline jet to pass Level-1 trigger

*Level-1 & HLT use EM Energy scale*
**e & γ Triggers**

3-20 GeV for b/c/tau decays, SUSY, turn-on curves
20-100 GeV for W/Z/top/Higgs physics
> 100 GeV for exotics

Level-1 Trigger based on Calo. energy in:
- $E_T$ within central core : $\Delta \eta \Delta \phi$=0.2x0.2
- Can require EM and Hadronic isolation
  - Close to 100% efficient above turn-on
  - Efficiency well modelled by Simulation

HLT Rejection enabled when L1_EM2>~200Hz
$L > \sim 1.5 \times 10^{29}\text{cm}^{-2}\text{s}^{-1}$
**e & γ : HLT**

- HLT uses full granularity calo. to calculate $E_T$ & cluster shape parameters e.g.

$$R_\eta = \frac{E(3 \times 7)}{E(7 \times 7)}$$

**Cell units:**

$\Delta \eta \times \Delta \phi = 0.025 \times 0.025$

- Additional rejection achieved by matching calorimeter clusters to Inner Detector Tracks

![Graph showing $R_\eta$ distributions for data and MC, peaked towards 1 for e](image)

![Graph showing Level-2 and Event Filter Tracking efficiency vs. $p_T$](image)
Level-1 Muon

Low $P_T$: J/$\Psi$, $\Upsilon$ and B-physics
High $P_T$: H/Z/W/tau $\rightarrow$ $\mu$

Level-1 Muon Trigger:
- Barrel: Resistive Plate Chambers
- Endcap: Thin Gap Chambers

• Performance evaluated w.r.t. offline
  ⇒ Close to nominal efficiency
  ⇒ Good agreement with Simulation

Barrel effic. w.r.t. Offline for data & MC

RPC

Includes ~20% inefficiency due to support structures etc.

TGC

Endcap efficiency w.r.t. Offline
HLT Muon Trigger

Stand-alone: Muons reconstructed at the HLT including information from the precision muon detectors
- Effic. > 98% w.r.t. Level-1 for muons $p_T > 4$ GeV
- Good agreement with Simulation

Combined: Muon track segment combined with inner detector track

**ATLAS Preliminary**
$\sqrt{s} = 7$ TeV, Data 2010

**Level-2 Muon stand-alone effic. w.r.t. Level-1**

**Level-2 Combined effic. w.r.t. Level-1**
**Tau Trigger**

- Dedicated trigger for taus decaying to one or more hadrons
- Level-1: calculates $E_T$ using e.m. and hadronic calo in core ($\Delta\eta \times \Delta\phi = 0.2 \times 0.2$)
  - can require isolation
- HLT: Tau identified by well collimated calo. cluster with small no. of associated tracks

Poster: Performance of the ATLAS tau trigger with 7 TeV collision data at the LHC: M. Shamim
**Missing $E_T$ Trigger**

For: $W \rightarrow \tau\nu$, BSM, SUSY, orthogonal trigger for efficiency studies.

Level-1: Missing $E_T$ and Sum $E_T$ calculated based on Calorimeter Cells

Level-2: Add muon information

Event Filter: Recalculate using Calo. & Muon

10 GeV threshold running un-prescaled to $L \sim 10^{30}$ cm$^{-2}$ s$^{-1}$

Menu also includes combined triggers:

- e.g. tau + Missing $E_T$

Event Filter Sum $E_T$ v. offline Sum $E_T$

**Comparision of Event Filter Missing ET in 7 TeV Data with Simulation**

- Good agreement of Missing $E_T$ turn-on with MC
- Good agreement of Online and offline quantities

**ATLAS Preliminary**

- 5 GeV Threshold
- 20 GeV Threshold

**ATLAS Preliminary**
Summary

• The ATLAS Trigger has been successfully commissioned:
  ▶ Instrumental in delivering data for first physics

  • Very inclusive Level-1 based trigger to start
  • Evolving to track LHC luminosity:
    ⇒ HLT ready for activation when needed
    ⇒ Several HLT triggers now active
  • Generally excellent agreement with Offline & MC
  • Continued evolution matching lumi. & physics:
    • pre-scale lower thresholds
    • move from loose to medium HLT cuts
    • use of isolation requirements
    • higher multiplicity & multi-object triggers
    • Add. Triggers: Jets with B-tagging, B-physics
  • Perf. with pile-up confirmed using Data & MC

=> The ATLAS trigger is ready and able to meet the challenges ahead and deliver the data for physics in 2010/11 and beyond.
Backup
Level-1 Trigger

- Timing of LVL1 triggers determined to 5-10ns using splash events
Triggers for Onia & B-Physics

- Onia & Physics analysis uses Min. Bias (early data) and Single Muon triggers
- When single muon rate becomes too high - use Dimuon Triggers:
  - Two Level-1 muons confirmed at HLT, or
  - Single Level-1 muon + second muon found at the HLT:
- Find Inner Detector tracks in large RoI at Level-2
- Extrapolate to associate Muon Spectrometer hits

=> Increased efficiency at low $p_T$
ID Tracking & Online Beamspot Measurement

For events with a MBTS Trigger:
• Fast Level-2 tracking reconstructs tracks in full Inner Detector
• Primary Vertex reconstructed
⇒ Online measurement of beam position
⇒ Information fed back to LHC
⇒ Can be used in trigger, e.g. Impact parameter based B-jet tagging
Activating the e & $\gamma$ HLT triggers

Trigger Rates v. time with active HLT e & $\gamma$ selections
First $W \rightarrow \nu v$ candidate in ATLAS

**L2 trigger**

Electron candidate

Missing $E_T$

$P_T(e^+) = 34$ GeV

$\eta(e^+) = -0.42$

$M_T = 57$ GeV

$E_{T,\text{Miss}} = 26$ GeV

Offline reconstruction