Upgrade of the ATLAS Level-1 Trigger with an FPGA based Topological Processor

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on behalf of the ATLAS collaboration
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Overview

• Introduction
  – The LHC and ATLAS
    • Running conditions 2012/2015
  – The Level-1 Trigger
• Level-1 Topological Trigger
  – Prototype Specifications
  – Tests and first results
• Summary
Introduction To ATLAS

Right handed coordinate system
x-coordinate toward LHC ring
pseudorapidity, $\eta = \ln(\tan(\theta/2))$

Inner Detector:
Tracking to identify charged particles

Muon Systems:
Tracking to identify muons, magnets to bend trajectory

Electromagnetic and Hadronic Calorimeters:
Energy deposition of EM and Hadronic particles
<table>
<thead>
<tr>
<th>2012 Performance</th>
<th>2015 Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunches</td>
<td>1331</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>50 ns</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$7.5 \times 10^{33}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Pile-up</td>
<td>~20</td>
</tr>
<tr>
<td>Energy (COM)</td>
<td>8 TeV</td>
</tr>
</tbody>
</table>

- Through 2012: 50 ns BCs $\rightarrow$ ~20 interactions/BC
- ~3x luminosity in 2015
- Standard $p_T/E_T$ requirements 2012
  - higher thresholds $\rightarrow$ loss of physics
  - not sufficient rate reduction 2015
- New approach needed
# Trigger Menu 2012/2015

<table>
<thead>
<tr>
<th>Trigger Type</th>
<th>L1 Item</th>
<th>Offline Threshold [GeV]</th>
<th>Rate [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single electron/photon</td>
<td>EM30(EM18VH) EM30</td>
<td>45(25) 100</td>
<td>7.5(20.5) 7.5</td>
</tr>
<tr>
<td>Single muon</td>
<td>MU15</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Single tau</td>
<td>TAU40</td>
<td>120</td>
<td>4</td>
</tr>
<tr>
<td>Single jet</td>
<td>J75</td>
<td>165</td>
<td>2</td>
</tr>
</tbody>
</table>

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</tr>
</thead>
<tbody>
<tr>
<td>Single electron/photon</td>
<td>EM40H(EM28H) EM50</td>
<td>50(33) 60</td>
<td>7(28) 9</td>
</tr>
<tr>
<td>Single muon</td>
<td>MU20</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Single tau</td>
<td>TAU60</td>
<td>150</td>
<td>10</td>
</tr>
<tr>
<td>Single jet</td>
<td>J100</td>
<td>250</td>
<td>4.9</td>
</tr>
</tbody>
</table>

8 TeV, 1x10\(^{34}\) cm\(^{-2}\)s\(^{-1}\)

14 TeV, 2x10\(^{34}\) cm\(^{-2}\)s\(^{-1}\)
The Level 1 Trigger

The task of Level 1: reduce rate from ~40 MHz to ~70 kHz in 2012 2015 L1 up to ~100 kHz

How is it done: custom built hardware information on Regions Of Interest (ROIs)

Three systems: L1 Muon, L1 Calorimeter (L1Calo), Central Trigger Processor (CTP) L1 sends information to CTP which makes the decision latency ~2.5 μs

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L1Topo: A Solution to the Rate

What is L1Topo?
Online trigger decision based on event topology

Examples

- $\Delta \Phi, \Delta \eta$
- Isolation, overlap removal, b-tagging...
- $H_T, M_{\text{eff}}$
- Fat jets
- Transverse Mass, $\Delta \Phi(\text{jet}, E_T)$

TOB: Trigger OBject data

A Physics case... $H \rightarrow \tau \tau$
A Physics Case: \( H \rightarrow \tau \tau \)

L1: \( \tau \) thresholds (e+\( \tau \)/\( \mu +\tau \)/\( \tau +\tau \) triggers) 40/40/80 GeV

30% efficiency loss for semileptonic \( \tau \), 100% loss for hadronic \( \tau \)
A Physics Case: $H \rightarrow \tau \tau$

How can this be saved?
Topological Trigger!

Example 1: $\Delta \eta (\tau, \tau) < 2$ and tight isolation
L1 rate reduced $\sim 2$ - preliminary

Example 2: $\Delta \eta (\text{jet, jet}) > 2.5$
L1 rate reduced $\sim 15$ – preliminary

This would be enough to stabilize thresholds at current levels
L1Calo Current System

PPM : PreProcessing (BCID, Calibration)
CPM : Cluster Finding (e/γ/τ)
JEM : Jet Finding (Jets, MET)
CMM : Hit Merging

Calorimeter

PPM
PreProcessor Modules
MCM
(124 modules)

CPM
ClusterProcessor
(56 modules)

JEM
(32 modules)

CMM
Merging
(8 modules)

CMM
Merging
(4 modules)

Info to CTP:
Jet multiplicities
e/γ,τ/had multiplicities
MET, ET

Readout (20 modules) & Control
(48 modules)

CTP
Level-1 Central Trigger Processor
(11 modules)

Muon
L1Calo + L1 Topological Processor

- Increase bandwidth to allow transfer of TOBs (ROI information)
- JEM/CPM firmware, CMM replacement: CMX
- Rate increase on backplane to CMX
L1Calo + L1 Topological Processor

Design Challenges
- input b/w
- short latency
- processing power

Increase bandwidth to allow transfer of TOBs (ROI information)
JEM/CPM firmware, CMM replacement: CMX

rate increase on backplane to CMX

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RX/TX: Input - 160 optical fibres from CMX and L1 Muon
AVAGO MiniPOD 120 GB/s transceivers

A and B:
2 Xilinx Vertex 7 FPGAs
XC7VX690T
(first prototype: XC7VX485T)

C: Non-real-time Module control FPGA

X: FMC Extension Module for RODs

I: IPMC Module
L1Topo Prototype Module
L1Topo Prototype Module

Prototype Specifications

- Fully ATCA compliant
- 18 MiniPOD sockets via 48-way backplane connectors
- Vertex 7 FPGAs
  - XC7VX690T
  - first prototype: XC7VX485T
- Module control via a large “Kintex” FPGA
- Output to CTP
  - 12-way optical
  - 32-way electrical (LVDS)
- Embedded ROD on control FPGA – up to 12 DAQ/RoI fibers
- Beyond the prototype
  - larger capacity, more IO
  - 56 vs. 80 links
High Speed Link Test

• Eye measurement @10.26 GB/s
• miniPOD RX (left), miniPOD TX (right)
Real Time High Speed Links Tests

- 136 BER scans (bathtub),
  - 14 Avago minipod RX, 2 Avago TX connected
- Measure EFR (Error Free Region) @10.26 Gb/s
- Left tail entirely due the reworked FPGA (U1)

UI: Unit Interval → width of a single data bit on the serial stream (percentage of nominal eye width)
Algorithm Implementation on FPGA

~40% resources used
latency: 3BX
Resource Usage vs TOB number

Implementation, timing analysis on XC7V690T

- Jets
- Muons
- e/γ/τ

Input channels

Resource use

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Wrapping up…

ATLAS trigger system
Future runs not sufficient to base decisions solely on $p_T/E_T$
Solution: Topological Trigger future of trigger system
FPGA based algorithms
Prototype tests going well, soon full production chips with more logic capacity, IO, and links
Thank you!