The ATLAS Level-1 Topological Trigger Performance in Run 2

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ATLAS Run 2 Operations

- Recorded integrated luminosity:
  - In 2015: 3.5 fb$^{-1}$
  - In 2016: 29.5 fb$^{-1}$

- Data taking efficiency in 2015/2016:
  - 92.1% / 92.4%

- Peak luminosity during stable beams and $\langle \mu \rangle$:
  - In 2015: $5.0 \times 10^{33}$ cm$^{-2}$s$^{-1}$ / 13.7
  - In 2016: $13.2 \times 10^{33}$ cm$^{-2}$s$^{-1}$ / 23.2

The trigger system is tuned according to beam conditions.
• High-precision silicon and straw-tube gaseous detectors
• Fine-granularity/longitudinally segmented calorimeter
• Air-core toroid muon spectrometer

The ATLAS detector

25 m

46 m

~7000 Tons
Two-level trigger system:

- **Level-1 (L1)**
  - Custom-made electronics
  - From 40 MHz to 100 kHz
  - Fixed latency: 2.5 µs
  - Finds regions of interest (RoI) using coarse detector information

- **High Level Trigger (HLT)**
  - Software-based computer farm
  - From 100 kHz to ~1 kHz
  - Average latency: ~400 ms
  - Fast offline-like algorithms running mostly on L1 RoIs
Level-1 trigger in Run 2

- **L1 upgrades during the Long Shutdown 1:**
  - Many electronic modules were upgraded with new firmware
  - New custom-made electronics were introduced to the L1 system

- **CMX: Common Merger eXtended**
  - Provides Trigger Objects to L1Topo and multiplicities/thresholds to CTP

- **MUCTPI to Topo Interface**
  - New interface module between L1 Muon and L1Topo

- **L1Topo: Level-1 Topological Trigger**
  - Calculates event topological variables used to generate triggers
  - Combines information from L1Calo and L1Muon systems
Motivation for the L1 Topological trigger

$H \rightarrow \tau_{\text{had}} \tau_{\text{had}}$

ZH $\rightarrow \nu \bar{\nu} b \bar{b}$

Non-L1Topo triggers rate versus luminosity

High trigger rate even when requiring additional jets

Topological variables distribution for signal and background

By requiring close-by taus bkg events are removed

ATLAS Simulation

$\sqrt{s} = 14 \text{ TeV}$

VBF $H \rightarrow \tau_+ \tau_-$

$Z \rightarrow \tau_+ \tau_-$

Minimum Bias

ATLAS Simulation

Events with at least two L1 central jets

Requiring a minimum distance bw MET & jets
Technical description of L1Topo

- **L1Topo module:**
  - AdvancedTCA 6U module
  - 22 layers PCB
  - Includes 3 FPGAs
    - 2 Xilinx Virtex 7 for event processing
    - 1 Kintex 7 for control and readout
  - Processes 1 Tb/s with a latency budget of 150 ns

- **L1Topo system:**
  - Two double-size L1Topo processor modules inside one ATCA crate
  - Dedicated hardware built to convert the input data into the required format
L1Topo functionality description

- **L1Topo functionality:**
  - Receives different types of Trigger Objects: muons, electrons, taus, jets, $E_T^{\text{miss}}$
  - Executes up to 128 algorithms (64 per board) in 75 ns
    - Algorithms are configurable and programmed in VHDL
  - Provides readout information to the Data Acquisition system and trigger decisions to the Central Trigger Processor
L1 Topological triggers in Run 2

- Many possibilities of L1 topological selections: angular/position/event kinematics

<table>
<thead>
<tr>
<th>Physics channel target</th>
<th>Input objects</th>
<th>Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>H → ττ</td>
<td>tau_had, jets</td>
<td>Δη, Δφ, ΔR, disambiguation</td>
</tr>
<tr>
<td>SUSY, ZH → νν b̅b̅</td>
<td>jets, miss E_T</td>
<td>H_T, min Δφ</td>
</tr>
<tr>
<td>B-physics</td>
<td>muons</td>
<td>ΔR, Mass</td>
</tr>
<tr>
<td>W → eν</td>
<td>electrons, jets, miss E_T</td>
<td>min Δφ, m_T</td>
</tr>
<tr>
<td>Long-lived particles</td>
<td>late muons, miss E_T</td>
<td>muon in the following bunch</td>
</tr>
</tbody>
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Commissioning and validation process

• General method:
  - Compare L1Topo algorithms decisions between hardware (hw) and expectation (sim)

• Standalone validation of firmware:
  - Simulating the VHDL code
  - Processing well-defined input data through the hardware via a playback mechanism

• Online validation:
  - Generating hot towers in pre-defined regions of the detector to check algorithms output
  - Running the C++ simulation of algorithms online at the HLT
    - Plots comparing hardware and simulated decisions are available online
    - Detailed analysis is performed offline

Hardware and simulated decisions are in good agreement
L1Topo commissioning: HT triggers

- L1 HT150 / HT190 topological triggers: $\Sigma p_{jett} > 150 / 190$ GeV
  - Good agreement between hardware and simulation trigger rates versus luminosity
  - Sharp HT trigger efficiency turn-on curve with respect to offline-calculated HT
L1Topo performance: di-tau triggers

**L1 di-tau topological trigger rate:**
- The topological trigger adds a $\Delta R$ requirement to the di-tau trigger:
  - $\Delta R(\tau,\tau) < 2.8$
- The rate is reduced by a factor of ~2 w.r.t. the di-tau+jets non-topo trigger

**L1 di-tau topological trigger efficiency:**
- The trigger efficiency with respect to $\Delta R$ is 100% up to $\Delta R \sim 2.5$
- The offline analysis requires $\Delta R < 2.5$
L1Topo performance: di-muon triggers

- L1 di-muon topological trigger:
  - $2\mu \ p_T>6$ GeV & $2<M(\mu\mu)<9$ GeV & $0.2<\Delta R<1.5$
  - It reduces the trigger rate by a factor of ~4 w.r.t. the non-topo 2MU6 trigger
  - It does not bias $m_{\mu\mu}$ around the $B_S$ meson mass
  - Allows to keep B-physics analyses in ATLAS

2µ non-topo triggers effect to the $m_{\mu\mu}$ distribution

2µ non-topo and topo triggers rate versus time

2µ non-topo and topo triggers effect to $m_{\mu\mu}$
Summary and outlook

- To cope with the increase of energy and luminosity in Run 2, ATLAS upgraded both the Level-1 and High Level triggers during the Long Shutdown 1

- A new topological trigger system was built and installed at Level-1
  - It allows to select events by combining L1 calorimeter and L1 muon objects

- Commissioning of the L1 topological system took place early in Run 2

- Validation studies show a very good agreement between hardware and simulation topological trigger decisions

- Initial performance results show that topological triggers increase acceptance for physics channels

- More topological triggers are to be expected in the run in 2017
THANK YOU!