OPERATION AND PERFORMANCE OF THE ATLAS L1CALO AND L1TOPO TRIGGERS IN RUN 2 AT THE LHC

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DPF 2017
INTRODUCTION

TRIGGERING AT HADRON COLLIDERS

- LHC pp collision rate is ~1 GHz
  - 40 MHz bunch crossing rate
  - ~25 interactions per bunch crossing in 2016
- Interesting physics is produced at a rate 6-8 orders of magnitude lower… or even less often!
- We need triggers to select interesting events to record and analyze offline

arXiv:0812.2341
INTRODUCTION

TRIGGERING AT HIGH LUMINOSITY

- The LHC has surpassed its design luminosity!
- Average of ~32 interactions per bunch crossing in 2017
  - 40-50 at start of fill
- Pile-up leads to increased trigger rates
  - In-time pile-up: multiple interactions per bunch crossing
  - Out-of-time pile-up: overlapping signals from adjacent bunch crossings
- Need to employ strategies to mitigate pileup effects without raising trigger thresholds

$Z \rightarrow \mu\mu$ event with 25 reconstructed vertices

Luminosity public results

Design lumi: $10^{34}$ cm$^{-2}$s$^{-1}$

Peak Lumi: $16.8 \times 10^{33}$ cm$^{-2}$s$^{-1}$

Delivered Luminosity [$pb^{-1}$/0.1]

Mean Number of Interactions per Crossing

Luminosity public results

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INTRODUCTION

THE ATLAS TRIGGER SYSTEM

40 MHz

Detector readout limitation!

1 kHz

(~GB/s)

See talks by:
- C. Bernius (Trigger)
- H. Russell (Trigger menu)

This talk

Region of Interest

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**LEVEL-1 CALORIMETER TRIGGER**

**L1CALO TRIGGER IN RUN 2**

*Preprocessor*
- New multi-chip modules (nMCM)
- Look-up tables (LUT): CP & JEP
- Digitization
- Fine timing
- Bunch-crossing ID
- Noise suppression
- Pedestal correction
- $E_T$ calibration

*Cluster Processor & Jet Energy Processor*
- EM & jet cluster algorithms
- New EM/$\tau$ isolation scheme
- Identify trigger objects (TOBs)

*Extended Common Merger Modules*
- New for Run 2!
- Extended $\eta$-dependent thresholding
- Threshold multiplicities to CTP
- TOBs to L1Topo

*L1Topo*
- New for Run 2!
- Topological selection using trigger objects (TOBs) from L1Calo & L1Muon

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OBJECT SELECTION AND REGIONS OF INTEREST

- Local maxima determined using a sliding window algorithm
- Energy sums compared to a variety of $\eta$-dependent thresholds
  - ~2x as many as in Run 1
  - 16 EM, 16 tau, 25 jet, 16 sum $E_T$, 16 missing $E_T$, 8 missing $E_T$ significance
- Regions of Interest (RoI) identified and sent to the high-level trigger
  - EM / tau: 2x2 trigger towers ($\Delta\eta \times \Delta\phi = 0.2 \times 0.2$)
  - Jets: 4x4 jet elements ($\Delta\eta \times \Delta\phi = 0.8 \times 0.8$)
Many interesting physics signatures involve isolated electrons or photons (e.g. $Z\rightarrow ee$, $H\rightarrow \gamma\gamma$)

Isolation selection: require energy in the vicinity of the EM cluster to be below a given threshold

- EM: ring around local maximum
- Hadronic: inner core behind local maximum
- $E_T$- dependent thresholds with steps of 0.5 GeV

Adding EM isolation requirement:

- 45% rate reduction, only 2% efficiency loss for single electron trigger in 2016

Retuned “medium” isolation thresholds for 2017 for additional improvements

- 11% rate reduction, only 1% efficiency loss for L1_EM24VHIM!
PPM IMPROVEMENTS: PEDESTAL CORRECTION

- Calorimeter pulses are longer than one bunch crossing
- Overlapping signals from adjacent bunch crossings cause baseline shift for L1Calo input signal
  - Increased rates at the beginning of the bunch train
  - Missing $E_T$ trigger rates increase non-linearly with luminosity
- Improved preprocessor modules apply dynamic pedestal correction by calculating and subtracting the average input
PPM IMPROVEMENTS: FILTERS & NOISE CUTS

- Reoptimized autocorrelation filters / noise cuts for improved high-pileup performance
  - Filter coefficients take into account correlations between bunch crossings
- Also reoptimized EM noise cuts for improved TE turn-on at low pileup (2016 p-Pb run)!

ATLAS Preliminary L1Calo public results
How do we handle rate limitations as we exceed the LHC’s design luminosity?

- Prescale?
- Raise thresholds?

Traditional strategies risk throwing away interesting events

- Particularly critical for new physics searches and studies of rare processes

Instead, apply real-time kinematic and angular cuts at level-1

Increase signal purity and reduce trigger rates without losing interesting physics
LEVEL-1 TOPOLOGICAL TRIGGER

L1TOPO COMMISSIONING

- Can run up to 128 algorithms on four FPGAs in 75 ns (3 bunch crossings)
- Combines info from L1Calo and L1Muon trigger objects (TOBs)
  - Muons, electrons/photons, taus, jets, energy sums
  - \((\eta, \phi)\) coordinates, \(p_T\), \(E_T\), \(E_T^{\text{miss}}\), isolation
- Installation/commissioning in 2015/2016
  - Algorithm validation: hardware/simulation comparisons
  - Test patterns in ATLAS with artificial “hot towers”
  - Validation of timing, readout stability at 100 kHz
  - Online/offline monitoring of timing, simulation/transmission
- First high-priority L1Topo trigger items enabled in Sept. 2016 (tau, B-physics)
- 2017: more items enabled, some of which are now primary triggers
- Commissioning of remaining algorithms continues
L1Topo allows us to probe a wide range of physics signatures using a variety of algorithms.

The following is just a brief overview!

<table>
<thead>
<tr>
<th>Physics signature</th>
<th>Input objects</th>
<th>Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow \tau\tau$</td>
<td>$\tau$, jets</td>
<td>$\Delta \eta$, $\Delta \phi$, $\Delta R$, disambiguation</td>
</tr>
<tr>
<td>SUSY, $ZH \rightarrow v\bar{v} bb$</td>
<td>jets, $E_T^{miss}$</td>
<td>$H_T$, min $\Delta \phi$</td>
</tr>
<tr>
<td>B-physics</td>
<td>muons</td>
<td>$\Delta R$, invariant mass</td>
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<tr>
<td>Long-lived particles</td>
<td>muons, $E_T^{miss}$</td>
<td>late muons (in next bunch crossing)</td>
</tr>
<tr>
<td>Lepton flavour violation</td>
<td>muons, EM clusters</td>
<td>$\Delta R$</td>
</tr>
</tbody>
</table>
PHYSICS IMPACT

- SM Higgs $\rightarrow \tau\tau$ trigger with $\Delta R(\tau,\tau)$ requirement is fully efficient in the signal region!

- B-physics dimuon trigger with $\Delta R(\mu,\mu)$ and invariant mass requirements reduces trigger rate by a factor of 4, with only 12% efficiency loss!
SUMMARY

A MULTI-PRONGED APPROACH TO PILEUP MITIGATION IN RUN 2

- LHC conditions are becoming more challenging as we surpass the design luminosity!
- The L1Calo trigger employs a variety of strategies to mitigate the effects of increasing pileup on the rates and efficiency
- New for Run 2, the L1Topo trigger allows us to improve signal purity and reduce trigger rates while retaining interesting physics events