ONLINE TRACK-BASED PILEUP SUBTRACTION FOR THE ATLAS HL-LHC UPGRADE

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INTRODUCTION

➤ 3000 fb-1 of data will be provided by the HL-LHC during Run 4.

➤ Increased signal rates and extreme contamination by multiple hadronic interactions (pileup).

➤ Main detector upgrade: new inner tracker (ITk) with extended $\eta$ coverage (now $|\eta| < 2.4$).

➤ Major TDAQ upgrade required to handle the enormous input rates. Current trigger system needs powerful pileup mitigation.

➤ Presentation topics:
  ➤ Overview of the plans for the upgrade of the ATLAS TDAQ system.
  ➤ Performance study about the utilisation of online tracking in the new DAQ system.
PHYSICS PLANS FOR THE HL-LHC

- So far no direct hints for SUSY, Exotics or new physics at the tera-scale. 😞
- New physics might be missing at this energy or produced with low cross-section → HL-LHC
- The new ATLAS trigger has to be optimised for:
  - Challenging physics channels uncovered by the current exclusion limits (EW SUSY, Higgsinos, etc.)
  - Measurements of Higgs couplings: $H \rightarrow bb/cc$ (fermions), $HH \rightarrow bbbb$ (self interaction), etc.

![Graph showing ATLAS simulation preliminary results for different processes involving Higgs self-interaction.](image)
Two trigger layouts under discussion:

1. **L0-only hardware architecture:**
   - **L0:** output rate 1MHz
   - **Event Filter:** output rate 10kHz

2. **L0/L1 hardware architecture:**
   - **L0:** output rate 2-4MHz
   - **L1:** output rate 800-600kHz
   - **Event Filter:** output rate 10kHz

Hardware tracking becomes an important component of the trigger upgrade:

- **Regional tracking,** within "regions of interest" defined by calo & muons, provided by EFTrack.
- **Full-scan tracking,** provided by FTK++.
- Both based on the same hardware for flexibility and adaptability.
- EFTrack moves to L1Track in the possible system evolution.
OVERVIEW OF TDAQ PLANS FOR THE ATLAS UPGRADE

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OFFLINE JET/MET RECONSTRUCTION AND PILEUP SUPPRESSION

- **Missing Transverse MomEntum ideally reconstructed as**

\[ E_T^{\text{miss}} = - \sum \vec{p_T}^e - \sum \vec{p_T}^\gamma - \sum \vec{p_T}^\tau - \sum \vec{p_T}^\mu - \sum \vec{p_T}^{\text{jet}} \]

- **Hard Term**
- **Soft Term**
- **(Track-based) Soft Term**

- **Offline Jet pileup suppression mainly applied through:**
  - Track activity in jets.
  - Primary vertex association.

- **Primary vertex reconstruction is a fundamental tasks for pileup jet suppression.**
PILEUP SUPPRESSION WITH TRACKS AT L1

- **L1-based pileup suppression:**
  - Offline PV finding requires a long computational time.
  - A simplified PV finding has to be considered.

- On average, only 10% of the ITk volume can be read out at L0 output rate (⇒ regional tracking at L1). This requirement is satisfied for the jet momentum regime relevant to triggering (40-50 GeV).

- **L1 PV finding idea:**
  - Split the beam line into a set of segments with length $dZ$.
  - Identify the Hard Scatter segment (HS) and the Hard Scatter jets using RoI tracks.

![Graph showing Pileup Suppression with Tracks at L1](image.png)
MET TRIGGERS AND BACKGROUND RATES (1)

➤ MET trigger rates and performance are very sensitive to pileup.
   ⇒ Important improvements expected with use of tracking based on observations in offline MET reconstruction.

➤ MET triggering is based on MHT.

➤ Without tracking available, a trigger decision is made by using all the jets in the event.

\[
MHT = - \sum_{HS	ext{ jets}} \vec{p}_T
\]

No track-based PU suppression

Track-based PU suppression
Today, MET triggers are very pileup dependent.

Important improvements expected from L1Track.

Without tracking available, a trigger decision is made by looking at MHT.

Can we use tracking to identify the HS jets?

\[
\text{MHT} = \sum_{\text{jets}} p_T \quad [\text{GeV}]
\]

Work in Progress

ATLAS = 14 TeV
HL-LHC Trigger, \( \sqrt{s} = 14 \text{ TeV} \)
Jet \( p_T > 40 \text{ GeV}, \langle \mu \rangle = 200 \)
Dijet JZ0
MHT(50 kHz) = 216.6 GeV
MHT(500 kHz) = 153.0 GeV

Threshold reduced by 50 GeV.

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<table>
<thead>
<tr>
<th>Quantity</th>
<th>L0-only scenario</th>
<th>L0+L1Track scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0 total output rate</td>
<td>1 MHz</td>
<td>2-4 MHz</td>
</tr>
<tr>
<td>L0 MET rate</td>
<td>( \sim 50 \text{ kHz} ) (216.6 GeV)</td>
<td>( \sim 500 \text{ kHz} ) (153 GeV)</td>
</tr>
<tr>
<td>L1 MET rate</td>
<td>( \sim 25 \text{ kHz} ) (112 GeV)</td>
<td></td>
</tr>
</tbody>
</table>

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No track-based PU suppression

Track-based PU suppression

ATLAS Work in Progress
HL-LHC Trigger, \( \sqrt{s} = 14 \text{ TeV} \)
Jet \( p_T > 40 \text{ GeV}, \langle \mu \rangle = 200 \)
Dijet JZ0
MHT(25 kHz) = 112.4 GeV
EFFICIENCIES ON SIGNAL

➤ Lower background rates result in an increased signal acceptance.

➤ MET triggers play a fundamental role in SUSY and other Exotics searches, as well as measurements of challenging Higgs channels, e.g. $ZH \rightarrow \nu\nu bb$.

➤ $ZH$ production has a very low cross section.

➤ Improvements to the true MET 95% efficiency have been observed for L1Track with respect to L0-only using $ZH \rightarrow \nu\nu bb$ samples.
SUMMARY AND OUTLOOK

- Many activities to be ready for the ATLAS HL-LHC upgrade.
- Due to the high luminosity peak, very efficient pileup suppression at trigger level will play a fundamental role for a successful ATLAS physics program.
- Promising results (**all work in progress**) have been observed for MET based signatures.
- Right now, signal acceptance of $ZH \rightarrow \nu \nu bb$ can be improved by a factor of 2-4 using tracks in an evolved ATLAS TDAQ architecture.

**On-going studies:**
- Check impact of L1Track on Multijet signatures ⇒ key trigger selection for $HH \rightarrow 4b$.
- Include Event Filter studies using a Track-based Soft Term analogous to the offline MET definition.
- Targeting ATLAS TDAQ TDR scheduled for the end of 2017.
BACKUP
TRIGGERS AND HARDWARE TRACKING

➤ The Fast Tracker (FTK) is already providing online tracks to the current ATLAS High Level Trigger (HLT).

➤ Hardware tracking:
  • Micro-second scale track reconstruction.
  • Massive parallelisation through FPGAs.
  • Based on predefined patterns loaded in FPGAs memory (associative memory).

➤ For L1Track, only the ITk modules which are readable at the L1 rate can be used (strips + outermost pixel layer).
## LO-ONLY RATES

<table>
<thead>
<tr>
<th>Trigger selection</th>
<th>2016 offline threshold (GeV)</th>
<th>Phase II offline threshold (GeV)</th>
<th>L0 (kHz)</th>
<th>Output EF (kHz)</th>
<th>Physics case</th>
</tr>
</thead>
<tbody>
<tr>
<td>isolated single e</td>
<td>27</td>
<td>22</td>
<td>200</td>
<td>1.8</td>
<td>WH, ZH, ttbar, EWK SUSY</td>
</tr>
<tr>
<td>single μ</td>
<td>27</td>
<td>20</td>
<td>40</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>single γ</td>
<td>145</td>
<td>120</td>
<td>66</td>
<td>0.3</td>
<td>GMSB SUSY, QCD</td>
</tr>
<tr>
<td>forward e</td>
<td>35</td>
<td></td>
<td>40</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>di-γ</td>
<td>40,30</td>
<td>25</td>
<td>8</td>
<td>0.2</td>
<td>H→γγ, HH→bbγγ</td>
</tr>
<tr>
<td>di-e</td>
<td>18</td>
<td>15</td>
<td>90</td>
<td>0.1</td>
<td>H→ττ, compressed EWK SUSY</td>
</tr>
<tr>
<td>di-μ</td>
<td>15</td>
<td>11</td>
<td>20</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>e-μ</td>
<td>8,25 / 18,15</td>
<td>15</td>
<td>65</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>single τ</td>
<td>160</td>
<td>150</td>
<td>20</td>
<td>0.3</td>
<td>W'→τν, Z', heavy Higgs</td>
</tr>
<tr>
<td>di-τ</td>
<td>40,30</td>
<td>40,30</td>
<td>200</td>
<td>0.3</td>
<td>H→ττ, HH→bbττ, SUSY di-τ</td>
</tr>
<tr>
<td>single jet w/ a tight b-jet</td>
<td>235</td>
<td>180</td>
<td>60</td>
<td>0.6</td>
<td>Exotics, QCD.</td>
</tr>
<tr>
<td>single jet</td>
<td>420</td>
<td>375</td>
<td></td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>large-R jet</td>
<td>460</td>
<td>375</td>
<td>35</td>
<td>0.4</td>
<td>G→HH, ttbar resonance</td>
</tr>
<tr>
<td>four-jet w/ two tight b-jets</td>
<td>45</td>
<td>75</td>
<td>50</td>
<td>0.6</td>
<td>(G→)HH→4b, RPV SUSY, VBF Higgs</td>
</tr>
<tr>
<td>four-jet</td>
<td>110</td>
<td>100</td>
<td></td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>HT w/ a tight b-jet</td>
<td>300</td>
<td>500</td>
<td>60</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>MET</td>
<td>200</td>
<td>200</td>
<td>50</td>
<td>0.5</td>
<td>Compressed SUSY, ZH→vvh, exotics, LLPs</td>
</tr>
<tr>
<td>jet &amp; MET w/ a tight b-jet</td>
<td>140, 125</td>
<td></td>
<td>60</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>forward jet</td>
<td>280</td>
<td>180</td>
<td>30</td>
<td>0.3</td>
<td>QCD, VBF</td>
</tr>
</tbody>
</table>

**Final Totals:**
- 1MHz
- 10kHz

**Final totals:**
- properly account for overlaps;
- include backup and supporting as well as other primary triggers.