ATLAS Trigger
in view of LLP Triggering

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ATLAS Run-3 Trigger

- Two-level trigger system
  -- Level-1 (L1): 40 MHz \rightarrow \sim 100 \text{ kHz}
    * By custom-made electronic, fully synchronized
    * Topological selection by L1Topo
  -- High Level Trigger (HLT)
    * \sim 100 \text{ kHz} \rightarrow \sim 1-2 \text{ kHz}
    * Computing farm, running custom and \sim offline reconstruction software

- Limitation
  -- L1 output rate in Run-2: \sim 86 \text{ kHz} \@ 2 \times 10^{34} /\text{cm}^2/\text{s}
  -- HLT farm CPU in Run-2: \sim 30-40 \text{ kCores}
    (= with 100 kHz input, process time < \sim 300-400 \text{ ms})
  -- HLT recording rate in Run-2: 1.75 \text{ kHz} \@ 2 \times 10^{34} /\text{cm}^2/\text{s}
ATLAS Run-3 Trigger [What’s New]

- **L1Calo**
  - Trigger readout becomes fully digitized and finer granular ("super cell")
  - Improved e/γ, τ, jet, E_{T}^{miss} with new hardwares (eFEX, jFEX, gFEX)
  - Large-R jet reconstruction available

- **L1Muon (Endcap)**
  - 6→15 thresholds p_{T} measurement
  - Charge information available

- **HLT**
  - Multi-threaded to reduce the memory requirements of parallel event processing
  - Some more CPUs to allow software full-scan tracking on subset of L1-accept triggers
ATLAS Trigger Menu in Run-2 (2018)

- Inclusive and generic triggers, e.g.
  - single isolated $\mu > 26$ (27) GeV
  - $E_T^{miss} > 110$ (200) GeV
  - Typical offline

- Dedicated triggers, targeting specific signature/physics
  - e.g. LLP triggers

- Trigger-level Analysis (TLA)
  - High recording rate with trigger objects information only, e.g. low-mass di-jet resonance search

- Delayed stream
  - Separate recording with deferred offline processing e.g. B-physics

Run-3 menu strategy would probably be not too far different from Run-2
LLP Signatures
LLP Signatures and **Run-2 Triggers**

**Dedicated LLP triggers**
- Disappearing tracks $E_T^{\text{miss}}$
- Multi-track vertices in ID
  - **Muon**
- Emerging jets Multi-jets
- Trackless, displaced jets “Calo-ratio”
- Multi-track vertices in MS “MS vertex”
- Displaced lepton, lepton-jets
  - ”MS-only”, “Narrow scan”

**Conventional triggers**
- Lepton/jets from associated production and/or ISR
- $E_T^{\text{miss}}$ from invisible particles and/or muon
  ($E_T^{\text{miss}}$ at Run-2 trigger was based on calorimeter-only)

**Calo-ratio**

**HIP**
**Dedicated LLP triggers**

- “Calo-Ratio” : low EM (vs. Had) fraction jet
  - Target: LLP decays in Had Calo

- “MS vertex” : muon clusters in Muon Spectrometer (MS)
  - Target: Hadronic LLP decays in MS

**Used in neutral LLP search 13 TeV**

Complementary coverage in decay length

In Run-3 menu, these will likely stay with some adjustments, e.g. L1 seed for Calo-Ratio
Dedicated LLP triggers -cont’d-

- “MS-only”
  -- MS tracks w/o explicitly requiring to match to ID track

- “Narrow scan”
  -- Pairs of collimated “MS-only” muons

Used in search for light neutral particles decaying into collimated leptons or light hadrons, 13 TeV

In Run-3, these trigger may need adjustment (e.g. to reduce CPU) with possible improvements in efficiency (e.g. lowering $p_T$ threshold)
Dedicated LLP triggers -cont’d-

• “HIP”
  -- Large fraction of high threshold of TRT (Transition Radiation Detector) hits
  -- Target: heavily charged LLPs

  Used in search for magnetic monopole and stable high-electric-charge object, 13 TeV


In Run-3, “HIP” trigger may need adjustment to the data taking condition in Run-3 (e.g. hit occupancy at high pileup condition).

• “Late Muon”
  -- L1: Jet or $E_T^{\text{miss}}$ with muon in next bunch-crossing (BC), with L1Topo

• ”Empty bunch”
  -- Non p-p collision bunches, separated by > +-5 BCs to any colliding BCs
  -- Target: stopped LLPs

In Run-3, Late Muon can be improved by making use of upgraded L1Muon / Topo
New LLP triggers feasibility in Run-3?

[Personal Remarks]

- Disclaimer: below are personal remarks (to stimulate discussion / inspiration)

- As the resources (L1 rate, HLT CPU) are limited, new triggers would be ideal if:
  - target phase-space / topology is really uncovered by the other triggers
  - well motivated by theory

- Can we extend reach with dedicated LLP triggers, over conventional triggers?
  - Is there interesting phase space that is not yet explored due to topology assumptions by using conventional triggers (e.g. low $E_{T}^{\text{miss}}$, no ISR, no leptons)?

For example, tracking signatures direct detection in trigger (e.g. disappearing track, displaced vertex) useful? Although:
  * HLT farm is very CPU limited; impossible to run complicated offline tool as it is
  * It can be only on subset of L1 triggers

Conventional triggers
-- Lepton/jets from associated production and/or ISR
-- $E_{T}^{\text{miss}}$ from invisible particles and/or muon ($E_{T}^{\text{miss}}$ at Run-2 trigger was based on calorimeter-only)

Multi-track vertices in ID Muon
Disappearing tracks $E_{T}^{\text{miss}}$
Emerging jets Multi-jets
Disappearing lepton-jets ‘Narrow scan’
New LLP triggers feasibility in Run-3?
[Personal Remarks] -cont’d-

- Disclaimer: below are personal remarks (to stimulate discussion / inspiration)

- Any uncovered topology?
  -- Hadronic decays in EM calo (after ID) etc?

- Any uncovered phase-space?
  -- Lower $p_T$ object (e.g. lower $p_T$
    Calo-Ratio, lower $p_T$ muon, etc.)

- Any trigger-level analysis (TLA) application also for LLPs?
  Non-LLP example low-mass di-jet resonance search
  High rate = down to lower mass, $p_T$ …

Any ideas highly welcome! = It’s still not too late to start up new trigger R&D (in my personal view)
Summary

- Major upgrades in ATLAS Trigger, both on L1 and HLT, are actively under way, toward Run-3

- Many LLP signatures are covered by several dedicated triggers, for example for neutral LLP decays hadronic calorimeter or later, as well as by conventional triggers such as inclusive $E_T^{\text{miss}}$ trigger

- Ideal if we could expand / enhance physics sensitivity for LLP search by exploiting new / improved triggers at Run-3
Backup Slides
Run-1 ATLAS Trigger

HLT (software-based) is sub-divided into L2 (before event building, “fast”) and Event Filter (after event building, “precision”)

ATLAS Data
Trigger Info

ATLAS Event
1.5 MB/25 ns

1.6 MB/50 ns

112 (150) GB/s

110 GB/s

7.5 GB/s

~ 6 GB/s

~ 450 MB/s

~ 10%

75 ms

~ 40 ms

~ 4 sec

< 2.5 µs

20 MHz

40 MHz

40 MHz

Regions Of Interest

High Level Trigger

Event Filter

Level 2

L1 Accept

40 MHz

Calo/Muon Detectors

Other Detectors

Detector Read-Out

ROI data (~2%)

L2 Accept

EF Accept

Event Filter

Data Collection Network

Back-End Network

SubFarmInput

SubFarmOutput

Event Builder

Data Flow

~10%

~40 ms

75 ms

~4 sec

1 s

300 Hz

700 Hz

~ 4 kHz

70 kHz

75 (100) kHz

~ 20 MHz

40 MHz

Typical 2012

Typical 2012
Explicit division of HLT (software-based) is removed, to allow for more flexibility.
(Run-3 is same, in architecture point of view, with upgrades in components)
calRatio: 2015-2016

- Targets LLP decays in HCal
  - High ratio of energy deposited in HCal to energy deposited in the ECal
  - Narrow shower
  - No associated activity in the tracker
- L1
  - High-$E_T$: 60 GeV $\tau$ trigger
  - Low-$E_T$: 30 GeV $\tau$ trigger w/ no $\geq$3 GeV ECal deposits nearby
    - Exploits L1Topo capabilities - Introduced in mid-2016
- HLT
  - Tracking performed in RoIs around jets with $E_T > 30$ GeV and $E_{EM}/E_H < 0.06$
    - Veto presence of tracks with $p_T > 2$ GeV within $\Delta R(\text{jet}) < 0.2$
  - Veto Beam-Induced Background (BIB) via cell timing/position
  - Offline strategy: use MVAs to discriminate against QCD and BIB background
calRatio: Run 3

• Lowest un-prescaled single-tau trigger threshold raised to 100 GeV in 2017

• Recovering lost efficiency by also accepting 30 GeV L1 τ with $E_{EM}/E_H < 0.1$

• Future developments:
  • Cluster-level pileup removal
  • Port MVAs from offline to trigger
Muon RoI cluster

- Targets hadronic LLP decays in the MS
  - Resulting charged hadrons will be reconstructed as a cluster of muons
- L1: 2 muons with $p_T > 10$ GeV
- HLT: require at least 3 (4) L1 muons within $\Delta R < 0.4$ in barrel (endcaps)
- Offline strategy: reconstruct vertex from MS “tracklets”
- Trigger expected to remain throughout Run 3
Muon Narrow Scan

- Targets decays to collimated muons between IBL and MS
- L1: muon with $p_T > 20$ GeV
- HLT
  - Require reconstruction of L1 muon as as standalone MS muon
  - Scan within $\Delta R < 0.5$ for 2nd standalone MS muon (variable $p_T$ threshold)
- Offline strategy:
  - Use MVA to discriminate against cosmic muon background
  - Require $\geq 2$ “dark photon jets” with $\geq 2$ muons each (also an electron/pion channel which uses the calRatio trigger)
- Run 3:
  - Scan is slow, making rate somewhat high (even in 2016)
  - Increasing 2nd muon $p_T$ threshold significantly reduces H(125) efficiency
  - Work ongoing to improve efficiency for Run 3