Triggering on LLP signatures at ATLAS

Searches for LLP at the LHC: WS of the LHC LLP community
CERN - 23-25 April 2017

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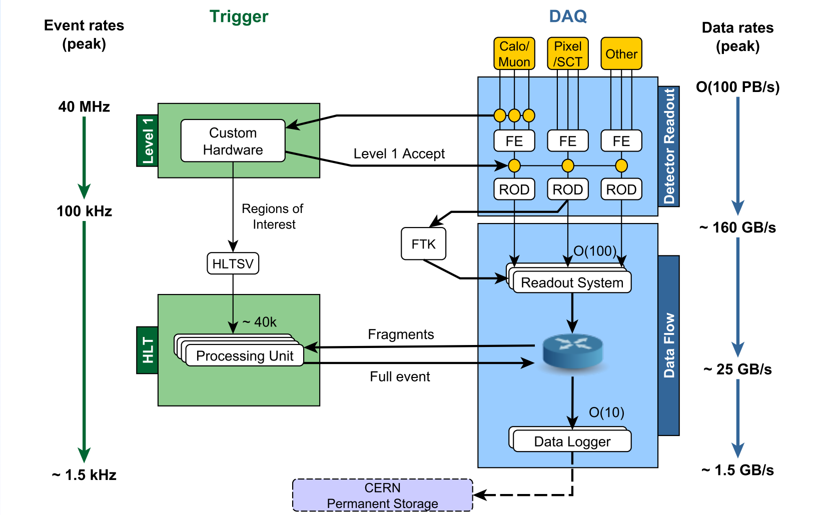
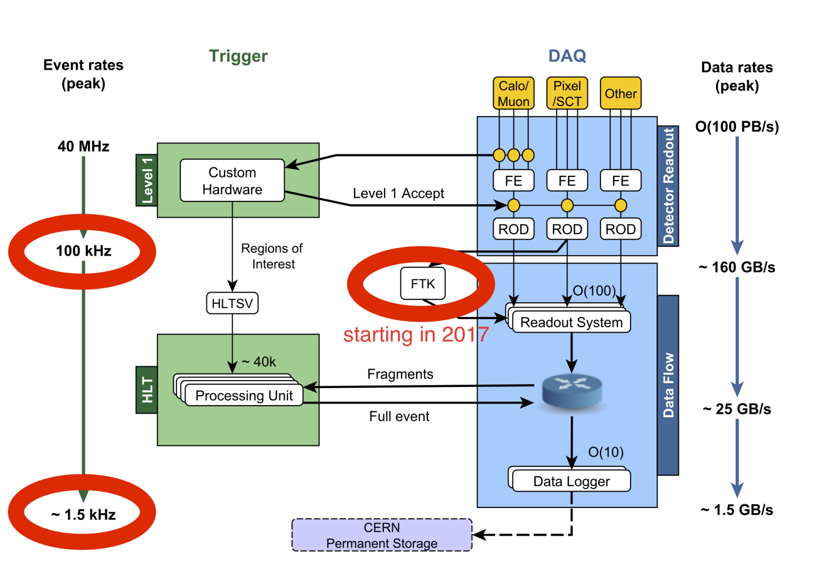
Outline

1. Overview
   - TDAQ system in Run II
   - selected trigger thresholds and trigger operations highlights
2. Trigger strategies
   - overview of trigger strategies in representative LLP searches
   - dedicated LLP triggers
   - LLP trigger in the tracker?
   - other dedicated triggers and search strategies
3. Conclusions

TDAQ system in Run II



TDAQ system in Run II

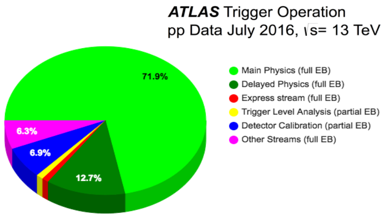


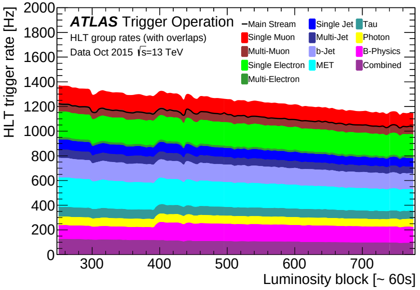
Selected trigger thresholds for lumi $< 10^{34}$

Year	2012		2015		
$\sqrt{s}$	8 TeV		13 TeV		
Peak luminosity	$7.7 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$		$5.0 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$		
	p_T threshold [GeV], criteria				
Category	L1	HLT	L1	HLT	Offline
Single electron	18	24i	20	24	25
Single muon	15	24i	15	20i	21
Single photon	20	120	20	120	125
Single tau	40	115	60	80	90
Single jet	75	360	100	360	400
Single b-jet	n/a	n/a	100	225	235
$E_\mathrm{T}^\mathrm{miss}$	40	80	50	70	180
Dielectron	2×10	2×12,loose	2×10	2×12,loose	15
Dimuon	2×10	2×13	2×10	2×10	11
Electron, muon	10, 6	12, 8	15, 10	17, 14	19, 15
Diphoton	16, 12	35, 25	2×15	35, 25	40, 30
Ditau	15i, 11i	27, 18	20i, 12i	35, 25	40, 30
Tau, electron	11i, 14	28i, 18	12i(+jets), 15	25, 17i	30, 19
Tau, muon	8, 10	20, 15	12i(+jets), 10	25, 14	30, 15
Tau, $E_\mathrm{T}^\mathrm{miss}$	20, 35	38, 40	20, 45(+jets)	35, 70	40, 180
Four jets	4×15	4×80	3×40	4×85	95
Six jets	4×15	6×45	4×15	6×45	55
Two b-jets	75	35b,145b	100	50b,150b	60
Four(Two) (b-)jets	4×15	2×35b, 2×35	3×25	2×35b, 2×35	45
B-physics (Dimuon)	6, 4	6, 4	6, 4	6, 4	6, 4

Actual menu contains $> 1k$ trigger chains

Trigger operations in 2016





- recorded events to events with leptons
- large bandwidth to MET triggers
- more combined triggers compared to previous LHC runs
- delayed stream and trigger-level analysis to overcome CPU and DAQ limitations

Trigger strategies in ATLAS LLP searches

A selection meant to represent the vast LLP search program from the trigger standpoint

⇒ 13 TeV / displaced jets in the HCal / ATLAS-CONF-2016-103
LLP trigger for LLP decays within the calorimeter volume

⇒ 13 TeV / displaced lepton-jets / ATLAS-CONF-2016-042
multi-muon trigger, narrow-scan muon trigger, dedicated trigger as in 1.

⇒ 13 TeV / charged LLP with dE/dx / Phys. Rev. D 93, 112015 (2016)
MET trigger with a 70 GeV threshold

⇒ 13 TeV / charged LLP with dE/dx and ToF in calorimeters / Physics Letters B (2016) 647
MET trigger with a 70 GeV threshold

⇒ 13 TeV / disappearing tracks / ATLAS-CONF-2017-017
MET trigger with thresholds between 70 and 110 GeV

⇒ 8 TeV / displaced jets in the ID and MS / Phys. Rev. D 92, 012010 (2015)
LLP trigger for LLP decays within the MS volume, jet plus MET trigger

⇒ 8 TeV / monopoles and HIP / Phys. Rev. D 93, 052009 (2016)
HIP trigger by looking at high-threshold hits in the TRT

⇒ 8 TeV / multi-track displaced vertex or displaced leptons / Phys. Rev. D 92, 072004 (2015)
muon, photon, jet and MET triggers

⇒ 7 and 8 TeV / stopped LLP decays in the calorimeter / Phys. Rev. D 88, 112003 (2013)
low-threshold calorimeter triggers on empty and unpaired bunches

Some considerations on current trigger strategies

Charged LLP searches dominated by MET triggers

- signatures such as dE/dx or cell timing not exploited at the trigger level

Neutral LLP searches often relying on dedicated triggers

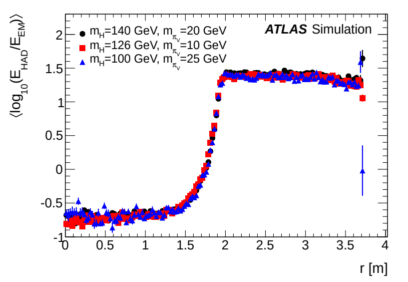
- single-object requirement at the trigger level but not at the analysis level to have the search as background free as possible

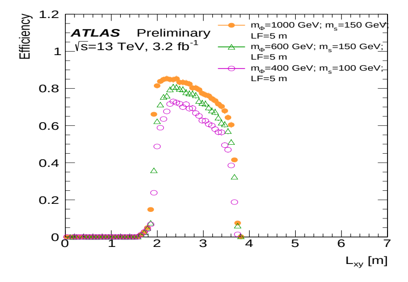
Some more considerations

- real limitation is L1
- associated production not really exploited at the trigger level
- different triggers, and sometimes dedicated triggers, for background estimates needed
- trigger rate not easily predictable whenever is driven by instrumentation or machine effects
- L1 topological selections not exploited
- some dedicated triggers vastly improved between Run I and Run II, two examples in the next slides

LLP trigger: calorimeter-ratio trigger

- tau candidate at L1 with at least 60 GeV
- no tracks above 2 GeV in the jet cone
- $\log(E_{HAD}/E_{EM}) > 1.2$
- beam halo removal using calorimeter cell timing
- log-ratio requirement implemented at L1 for 2017

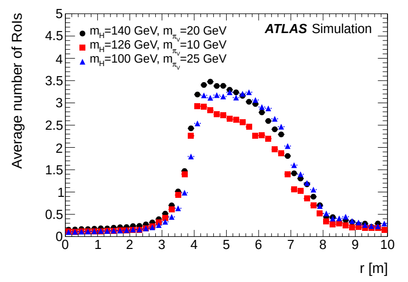


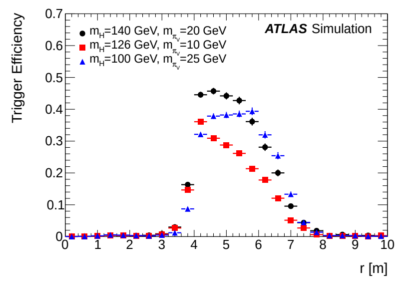


Key feature: Isolated jet with very low EM fraction

LLP trigger: muon RoI cluster trigger

- two muon candidates with at least 10 GeV
- muon cluster asking for 3 (4) muon RoIs in $\Delta R < 0.4$ in the barrel (end-cap) MS
- no tracks above $p_T > 5$ GeV and no jets above $E_T > 30$ GeV around the muon cluster direction





Key feature: Isolated cluster of muon region of interests

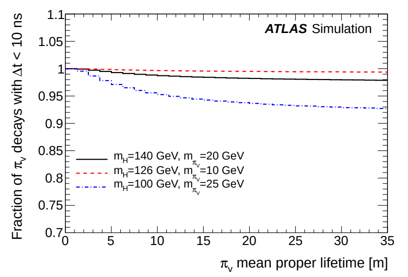
LLP triggers: timing window acceptance

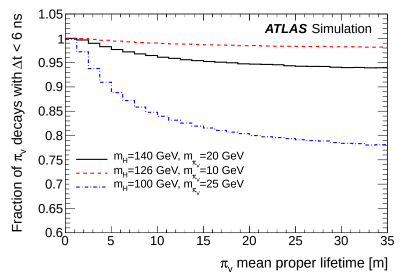
Jet energy within 1% for time shifts up to 12 ns - reference

- $\geq 93\%$ of the π_v decays arrive in the HCal with a $\Delta t < 10$ ns

Muon trigger accurately matches events for $\Delta t < 6$ ns - reference

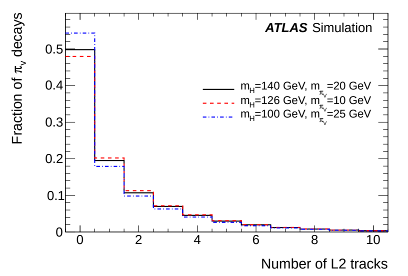
- $\geq 75\%$ of the π_v decays arrive in the MS with a $\Delta t < 6$ ns

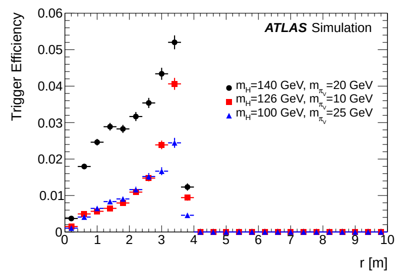




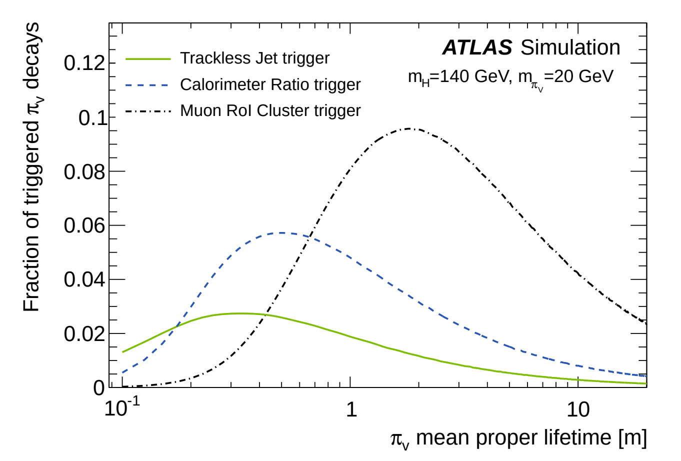
LLP trigger: trackless jet trigger

- muon and jet seeds at L1
- track isolation around the jet axis direction
- implemented in Run I but not used
- FTK allows for reconsidering this triggering option





LLP triggers: expected fraction of events



Nice complementarity among the three triggers

LLP trigger in the tracker?

Explicit displaced vertex reconstruction

- requires efficient tracking at large impact parameters
- prohibitive CPU consumption given the input rate
- possible population of FTK bank with displaced tracks?

b-tagging is not designed for LLP searches

- nevertheless some efficiency is expected and b-tagging algorithms are run at the trigger level

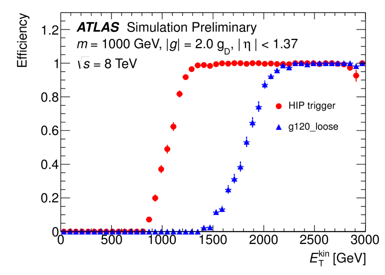
Instead of direct reconstructing displaced vertices, looking for

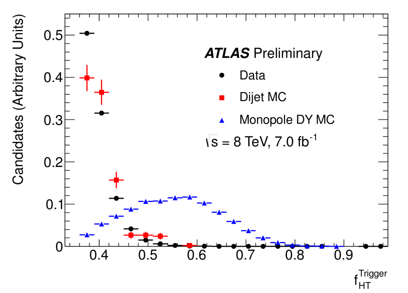
- trackless jet allowing soft-tracks from pile-up
- jets with transverse energy significantly smaller than the sum of tracks
- jets with proportion of hits not associated to tracks

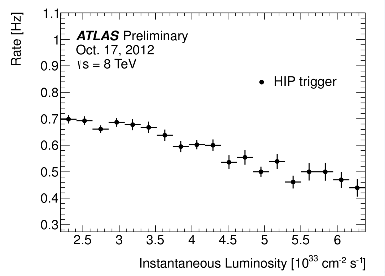
HIP trigger

Specifically designed for monopoles and HIP particles

- EM requirement at L1
- no energy requirement in EM2 as in electron or photon triggers
- instead a requirement on the number and fraction of TRT hits in a narrow region around the L1 seed



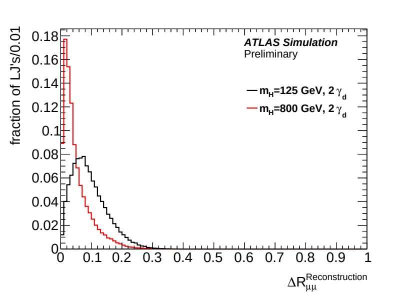




Trigger for collimated leptons

Higgs $\rightarrow 2\gamma_d + X$	Run2 m=125 GeV	Run1 m=125 GeV	Run2 m=800 GeV
Tri-muons	2.0	2.9	2.4
Narrow-scan	10.6	N/A	23.0
Calo-ratio	0.3	2.3	9.7
OR of all	11.9	4.6	32.0

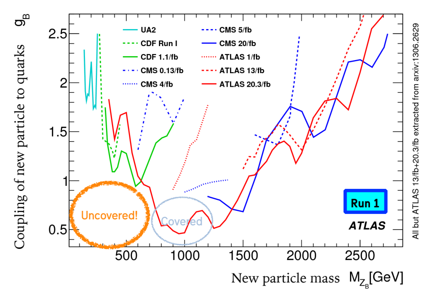
Higgs $\rightarrow 4\gamma_d + X$	Run2 m=125 GeV	Run1 m=125 GeV	Run2 m=800 GeV
Tri-muons	4.9	5.8	7.8
Narrow-scan	8.3	N/A	38.4
Calo-ratio	0.1	0.5	7.4
OR of all	11.8	6.2	44.8

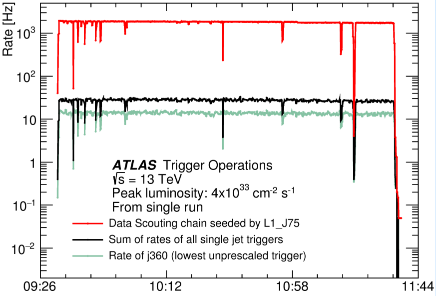


New narrow-scan approach in Run II

- leading muon seeded by a L1 muon
- sub-leading muon without a L1 seed searched at the HLT in a narrow cone by scanning the MS detector

Trigger lessons from ATLAS jet resonance searches





Interest not only on high mass but also on low couplings

- di-jet resonance search with high-p_T ISR jet or photon / ATLAS-CONF-2016-070
- di-jet resonance search with b-tagging at the trigger level / ATLAS-CONF-2016-031
- di-jet search in trigger-level analysis / ATLAS-CONF-2016-030

Conclusions

Lots of thinking in the trigger strategies for LLP searches

- often the main bottleneck for designing new searches
- final choice mostly driven by rate budget and operational constraints

Need to be smart in building triggers and picking up the right ones

- dedicated vs standard, inclusive vs exclusive, threshold vs multiplicity, etc

Dedicated LLP triggers in ATLAS since Run I

- improvements in Run II despite the harsher conditions
- details are not always public

Some final remarks

- MET thresholds will keep raising
- don't forget about triggering on the backgrounds
- (how to best exploit future hardware or even help making upcoming hardware choices)