ATLAS Trigger
in view of LLP Triggering

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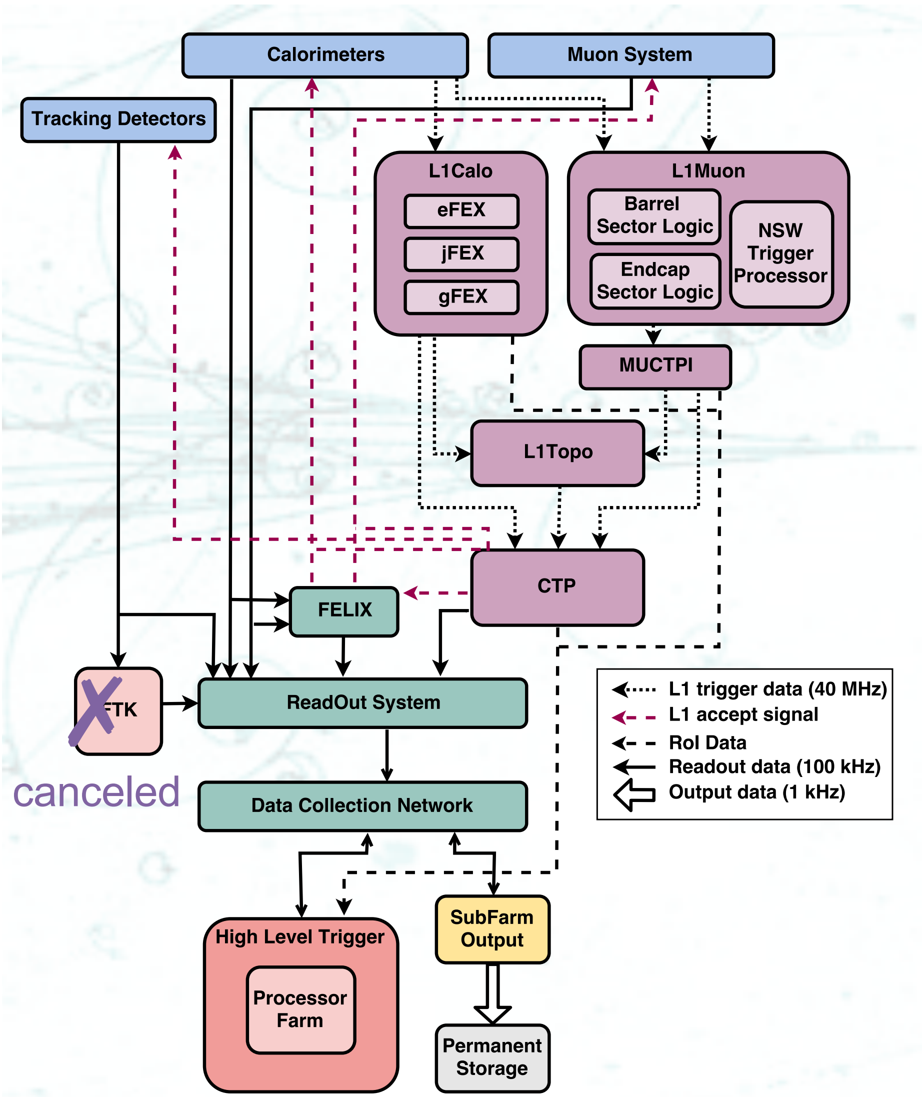
on behalf of the ATLAS Collaboration

Searching for long-lived particles at the LHC
7th Workshop of the LHC LLP Community
27 May, 2020

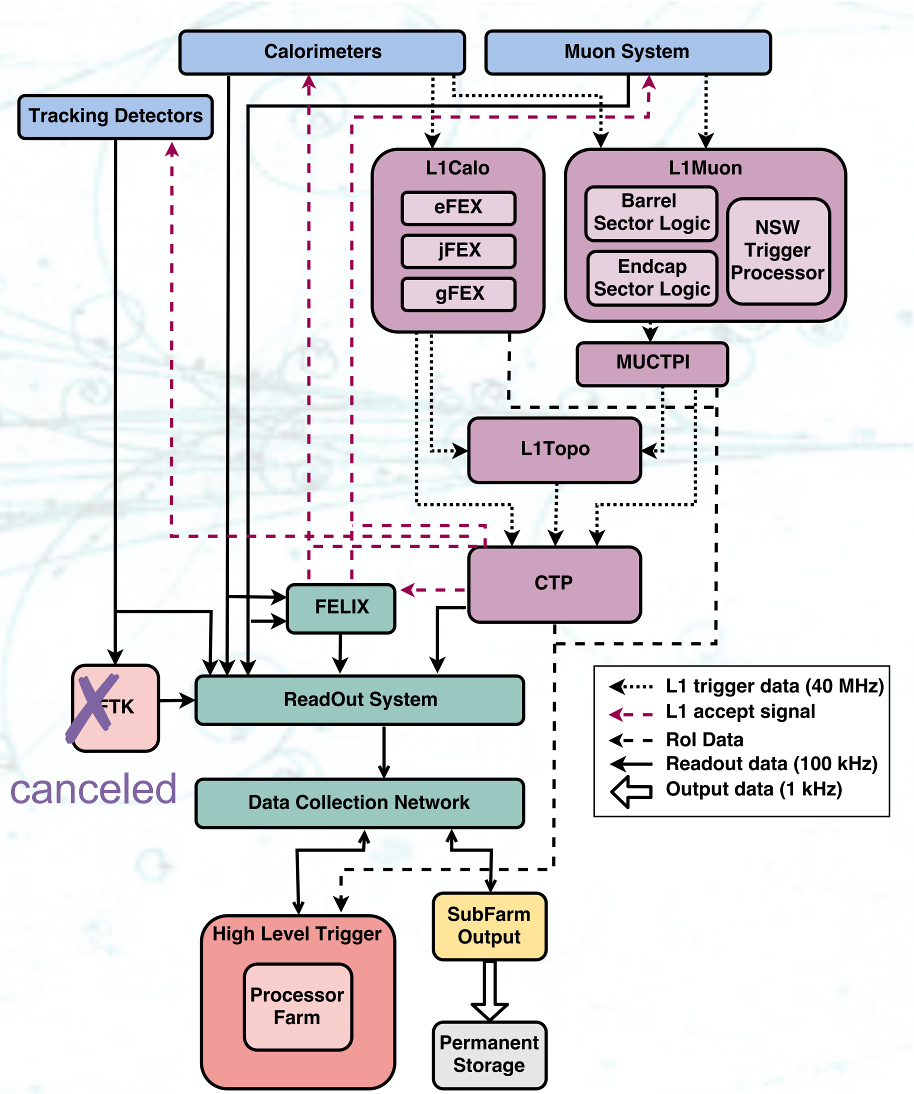
ATLAS Run-3 Trigger



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

- Limitation
  -- L1 output rate
  in Run-2: ~86 kHz @ 2×10^{34} /cm^2/s
  -- HLT farm CPU
  in Run-2: ~30-40 kCores
  (= with 100 kHz input, process time < ~300-400 ms)
  -- HLT recording rate
  in Run-2: 1.75 kHz @ 2×10^{34} /cm^2/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)

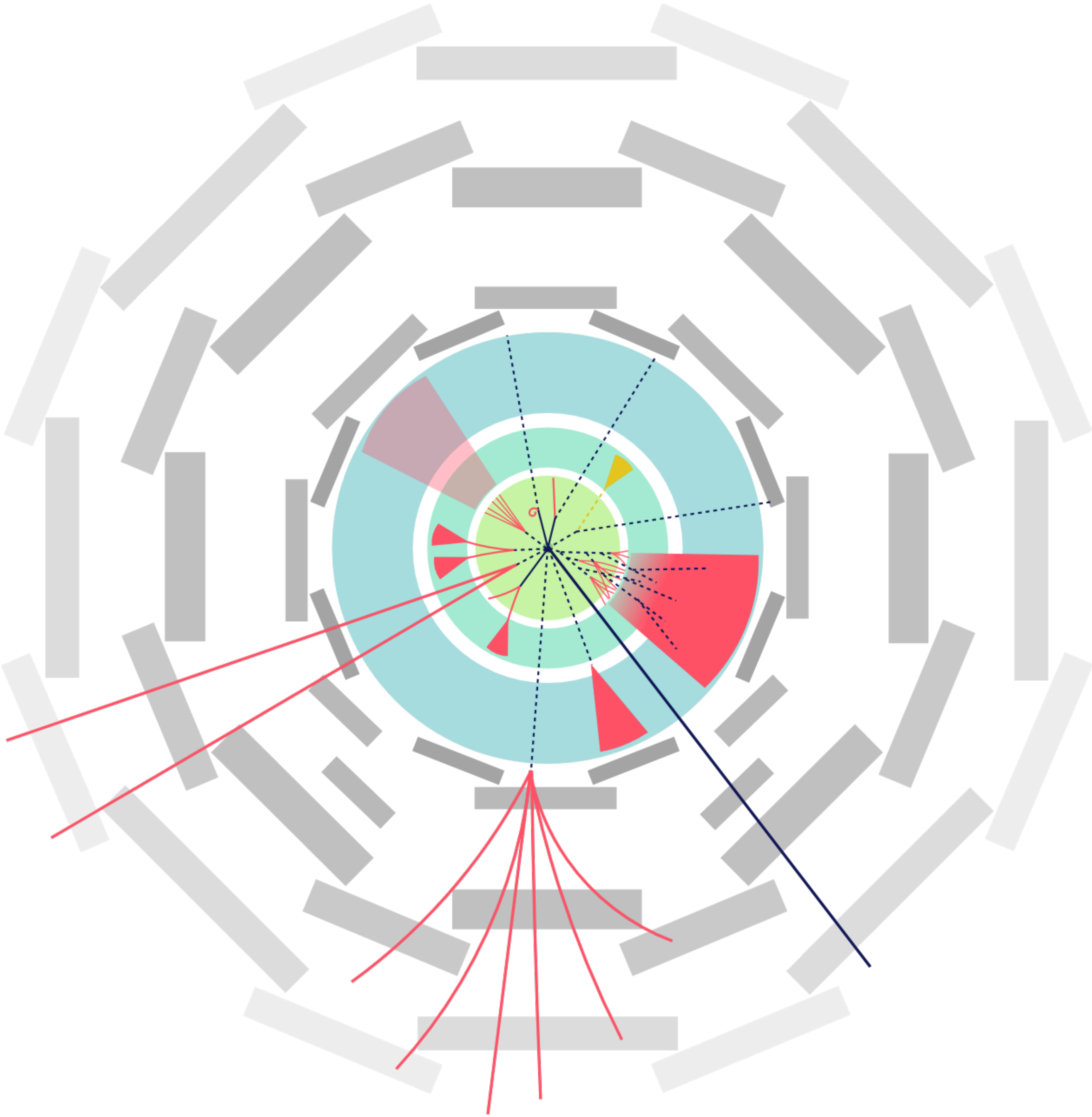
ATL-DAQ-PUB-2019-001

Trigger	Typical offline selection	Trigger Selection L1 [GeV]	Trigger Selection HLT [GeV]	L1 Peak Rate [kHz]	HLT Peak Rate [Hz]
				L=2.0×10[34] cm^{-2}s^{-1}	
Single leptons	Single isolated μ, $p_T > 27$ GeV	20	26 (i)	16	218
	Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	31	195
	Single μ, $p_T > 52$ GeV	20	50	16	70
	Single e, $p_T > 61$ GeV	22 (i)	60	28	20
	Single τ, $p_T > 170$ GeV	100	160	1.4	42
Two leptons	Two μ, each $p_T > 15$ GeV	2×10	2×14	2.2	30
	Two μ, $p_T > 23, 9$ GeV	20	22, 8	16	47
	Two very loose e, each $p_T > 18$ GeV	2×15 (i)	2×17	2.0	13
	One e & one μ, $p_T > 8, 25$ GeV	20 (μ)	7, 24	16	6
	One loose e & one μ, $p_T > 18, 15$ GeV	15, 10	17, 14	2.6	5
	One e & one μ, $p_T > 27, 9$ GeV	22 (e, i)	26, 8	21	4
	Two τ, $p_T > 40, 30$ GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5.7	93
	One τ & one isolated μ, $p_T > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	2.4	17
	One τ & one isolated e, $p_T > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	4.6	19
Three leptons	Three very loose e, $p_T > 25, 13, 13$ GeV	20, 2×10	24, 2×12	1.6	0.1
	Three μ, each $p_T > 7$ GeV	3×6	3×6	0.2	7
	Three μ, $p_T > 21, 2\times5$ GeV	20	20, 2×4	16	9
	Two μ & one loose e, $p_T > 2\times11, 13$ GeV	2×10 (μ)	2×10, 12	2.2	0.5
	Two loose e & one μ, $p_T > 2\times13, 11$ GeV	2×8, 10	2×12, 10	2.3	0.1
Signle photon	One loose γ, $p_T > 145$ GeV	24 (i)	140	24	47
Two photons	Two loose γ, each $p_T > 55$ GeV	2×20	2×50	3.0	7
	Two γ, $p_T > 40, 30$ GeV	2×20	35, 25	3.0	21
	Two isolated tight γ, each $p_T > 25$ GeV	2×15 (i)	2×20 (i)	2.0	15
Single jet	Jet ($R = 0.4$), $p_T > 435$ GeV	100	420	3.7	35
	Jet ($R = 1.0$), $p_T > 480$ GeV	111 (topo: $R = 1.0$)	460	2.6	42
	Jet ($R = 1.0$), $p_T > 450$ GeV, $m_{jet} > 45$ GeV	111 (topo: $R = 1.0$)	420, $m_{jet} > 35$	2.6	36
b−jets	One b ($\epsilon = 60\%$), $p_T > 285$ GeV	100	275	3.6	15
	Two b ($\epsilon = 60\%$), $p_T > 185, 70$ GeV	100	175, 60	3.6	11
	One b ($\epsilon = 40\%$) & three jets, each $p_T > 85$ GeV	4×15	4×75	1.5	14
	Two b ($\epsilon = 70\%$) & one jet, $p_T > 65, 65, 160$ GeV	2×30, 85	2×55, 150	1.3	17
	Two b ($\epsilon = 60\%$) & two jets, each $p_T > 65$ GeV	4×15, $\lvert\eta\rvert < 2.5$	4×55	3.2	15
Multijets	Four jets, each $p_T > 125$ GeV	3×50	4×115	0.5	16
	Five jets, each $p_T > 95$ GeV	4×15	5×85	4.8	10
	Six jets, each $p_T > 80$ GeV	4×15	6×70	4.8	4
	Six jets, each $p_T > 60$ GeV, $\lvert\eta\rvert < 2.0$	4×15	6×55, $\lvert\eta\rvert < 2.4$	4.8	15
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	5.1	94
B-physics	Two μ, $p_T > 11, 6$ GeV, $0.1 < m(\mu,\mu) < 14$ GeV	11, 6	11, 6 (di-μ)	2.9	55
	Two μ, $p_T > 6, 6$ GeV, $2.5 < m(\mu,\mu) < 4.0$ GeV	2×6 (J/ψ, topo)	2×6 (J/ψ)	1.4	55
	Two μ, $p_T > 6, 6$ GeV, $4.7 < m(\mu,\mu) < 5.9$ GeV	2×6 (B, topo)	2×6 (B)	1.4	6
	Two μ, $p_T > 6, 6$ GeV, $7 < m(\mu,\mu) < 12$ GeV	2×6 (Υ, topo)	2×6 (Υ)	1.2	12
Main Rate B-physics and Light States Rate				86	1750 200

- Inclusive and generic triggers, e.g.
  - -- single isolated e/μ > 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.x. B-physics

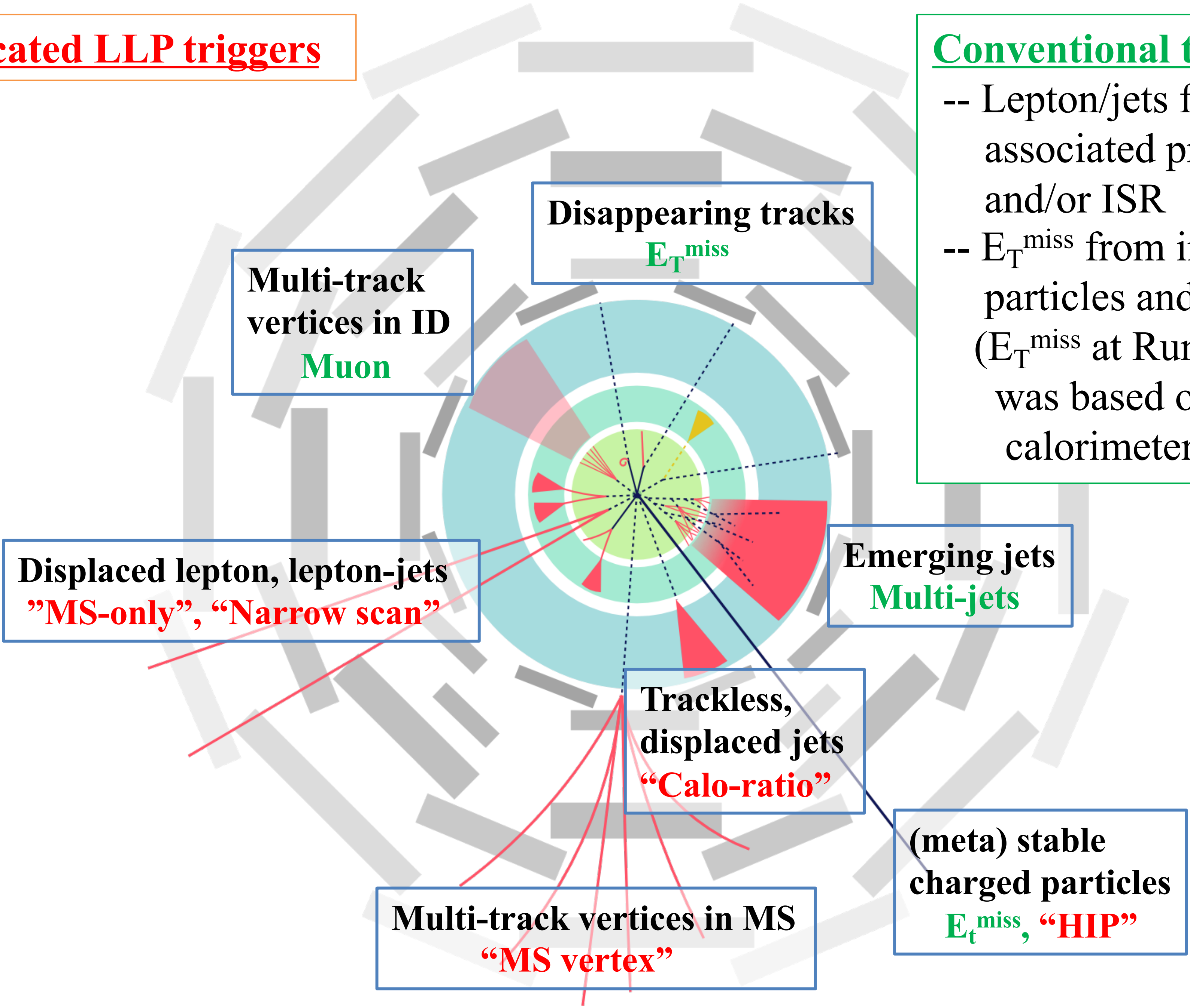
Run-3 menu strategy would probably be not too far different from Run-2

LLP Signatures



LLP Signatures and Run-2 Triggers

Dedicated LLP triggers

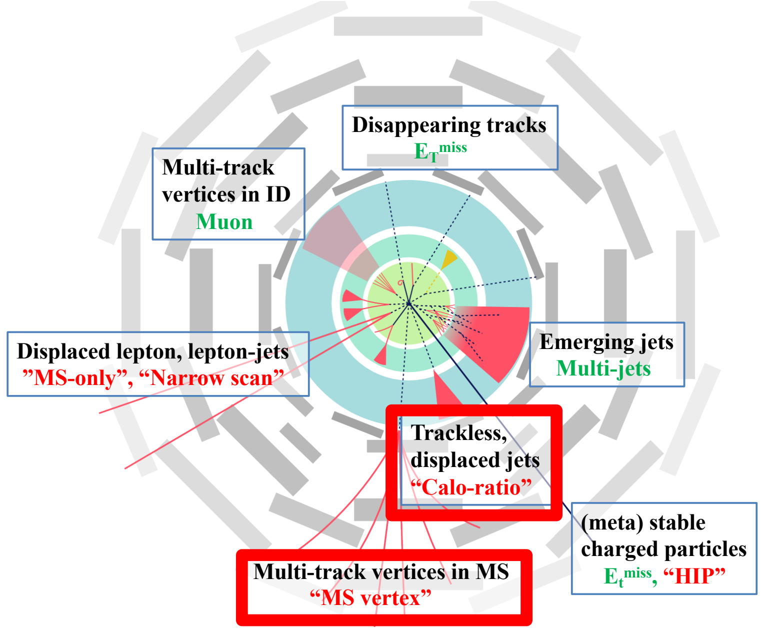


Conventional triggers

-- Lepton/jets from associated production and/or ISR

-- E_T^{miss} from invisible particles and/or muon (E_T^{miss} at Run-2 trigger was based on calorimeter-only)

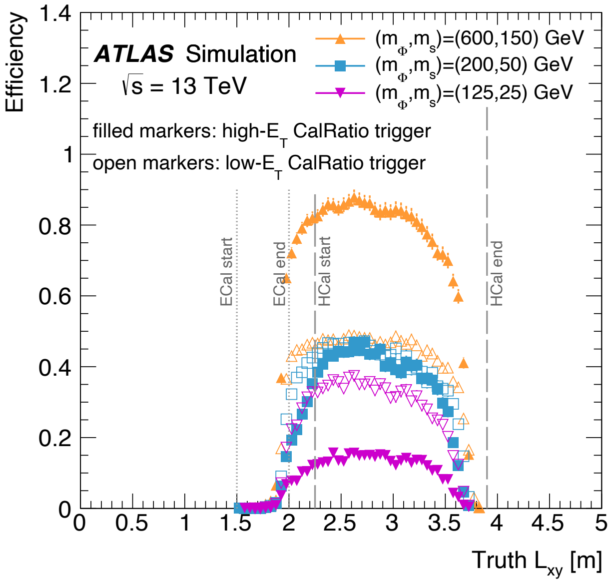
Dedicated LLP triggers



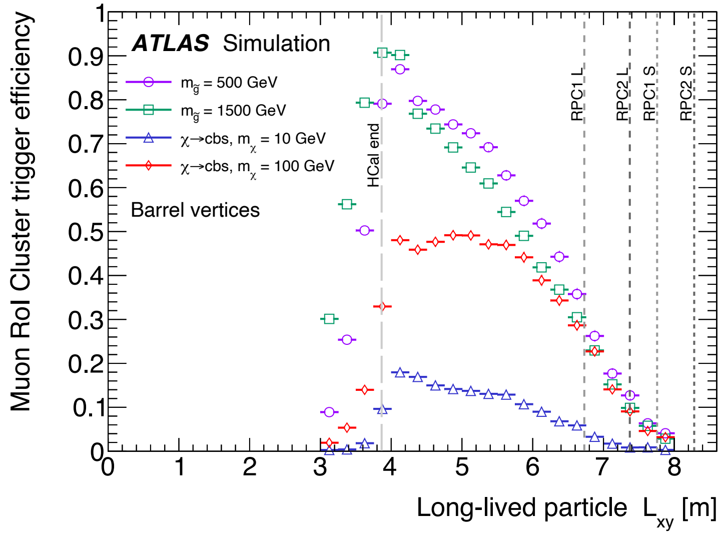
- "Calo-Ratio" : low EM (vs. Had) fraction jet
  → Target: LLP decays in Had Calo
- "MS vertex" : muon clusters in Muon Spectrometer (MS)
  → Target: Hadronic LLP decays in MS

Used in neutral LLP search 13 TeV
Complementary coverage in decay length

Eur. Phys. J. C 79 (2019) 481

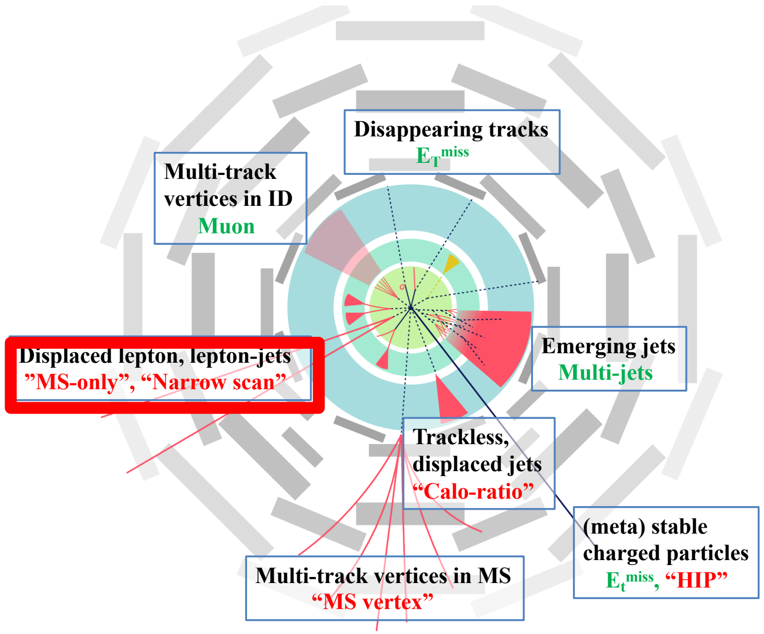


Phys. Rev. D 99, 052005 (2019)



In Run-3 menu, these will likely stay with some adjustments, e.g. L1 seed for Calo-Ratio

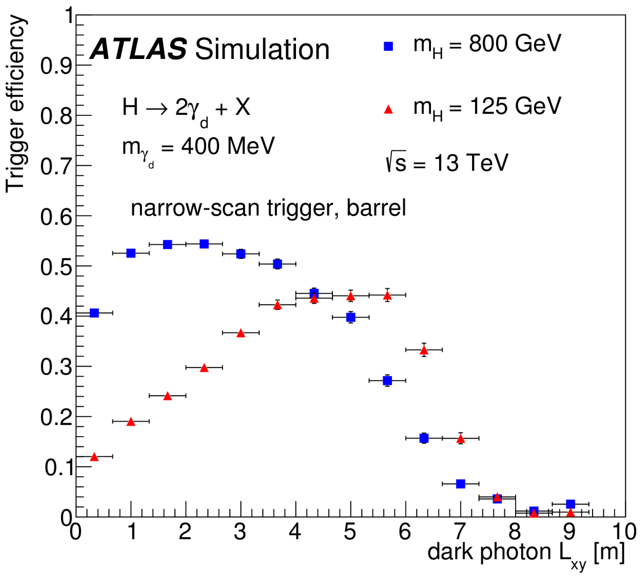
Dedicated LLP triggers -cont'd-



- "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



arXiv:1909.01246 (accepted by EPJC)

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-

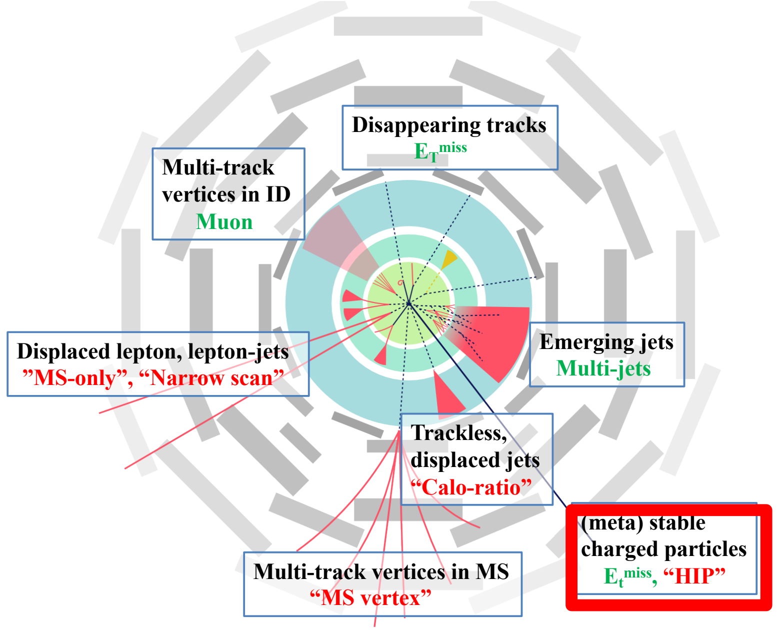
- "HIP"
  - -- Large fraction of high threshold of TRT (Transition Radiation Detector) hits
  - -- Target: heavily charged LLPs

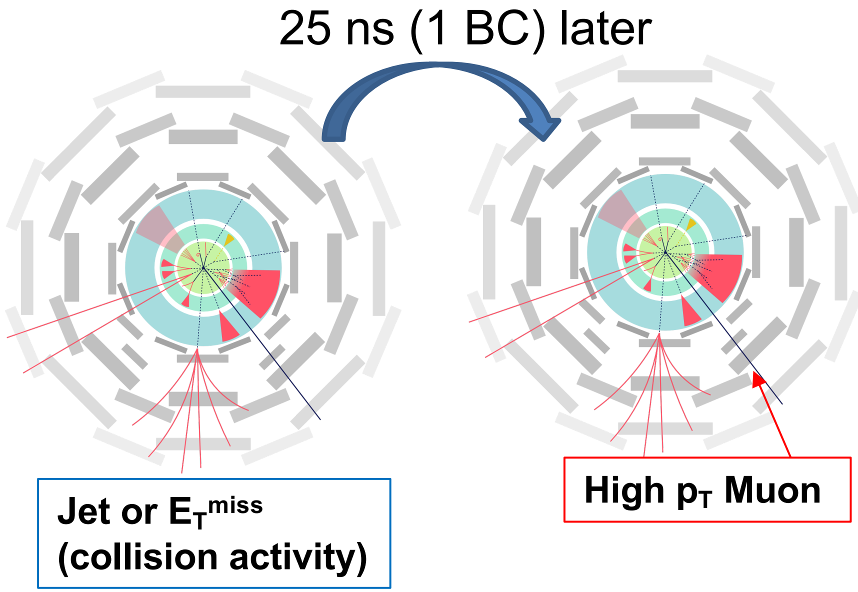
Used in search for magnetic monopole and stable high-electric-charge object, 13 TeV

Phys. Rev. Lett. 124, 031802 (2020)

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^{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

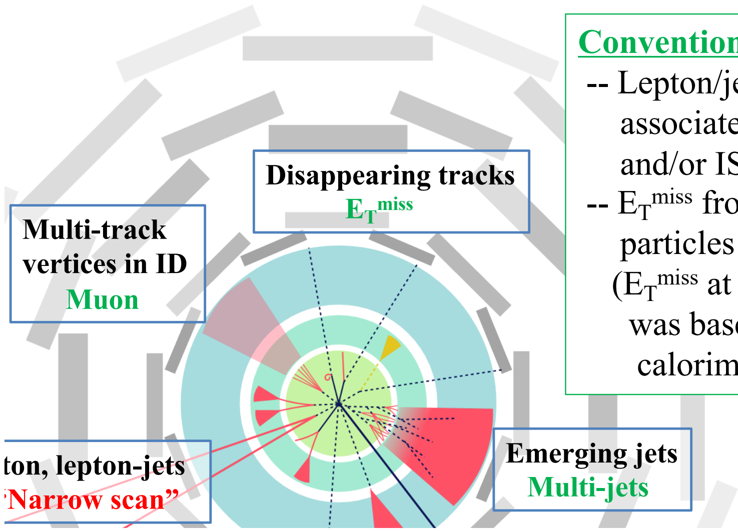
New LLP triggers feasibility in Run-3 ?
[Personal Remarks]

- 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^{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



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New LLP triggers feasibility in Run-3 ? [Personal Remarks] -cont'd-

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

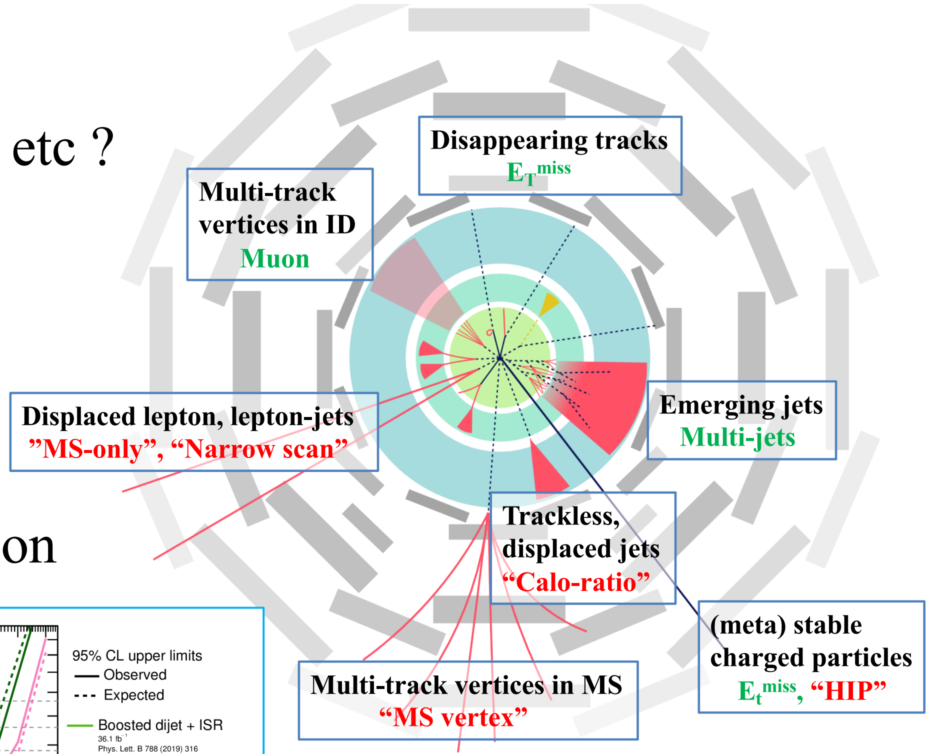
- Any uncovered topology?
  -- Hadronic decays in EM calo (after ID) etc ?

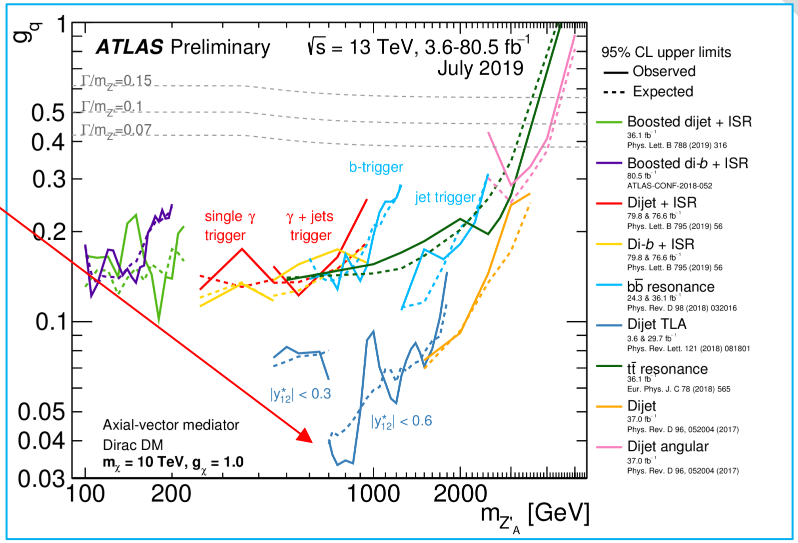
- Any uncovered phase-space?
  -- Lower p_T object (e.g. lower p_T Calo-Ratio, lower p_T muon, etc.)

- 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 …





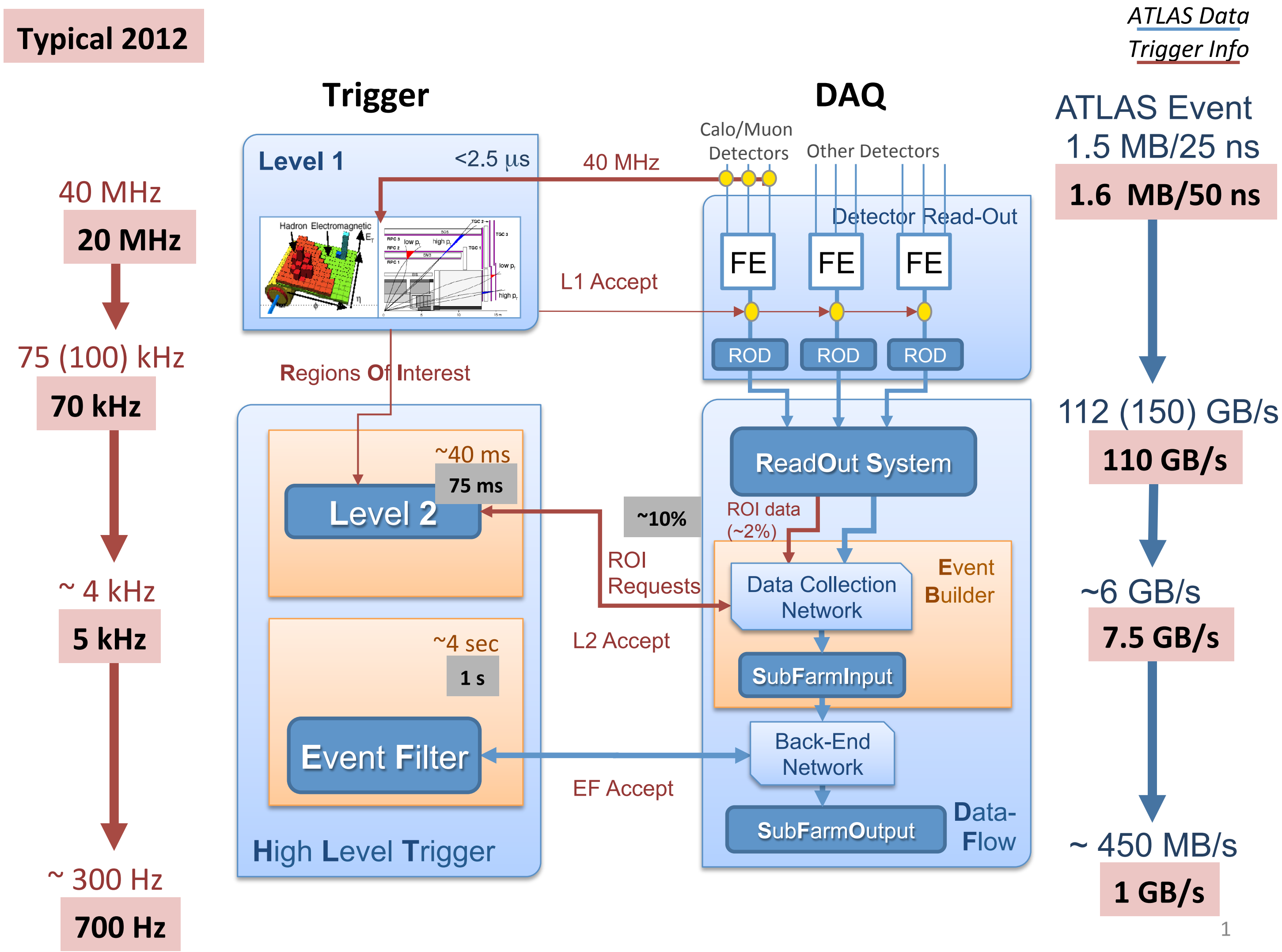
Any ideas highly welcome!
= It's still not too late to start up new trigger R&D (in my personal view)

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^{miss} trigger
- Ideal if we could expand / enhance physics sensitivity for LLP search by exploiting new / improved triggers at Run-3

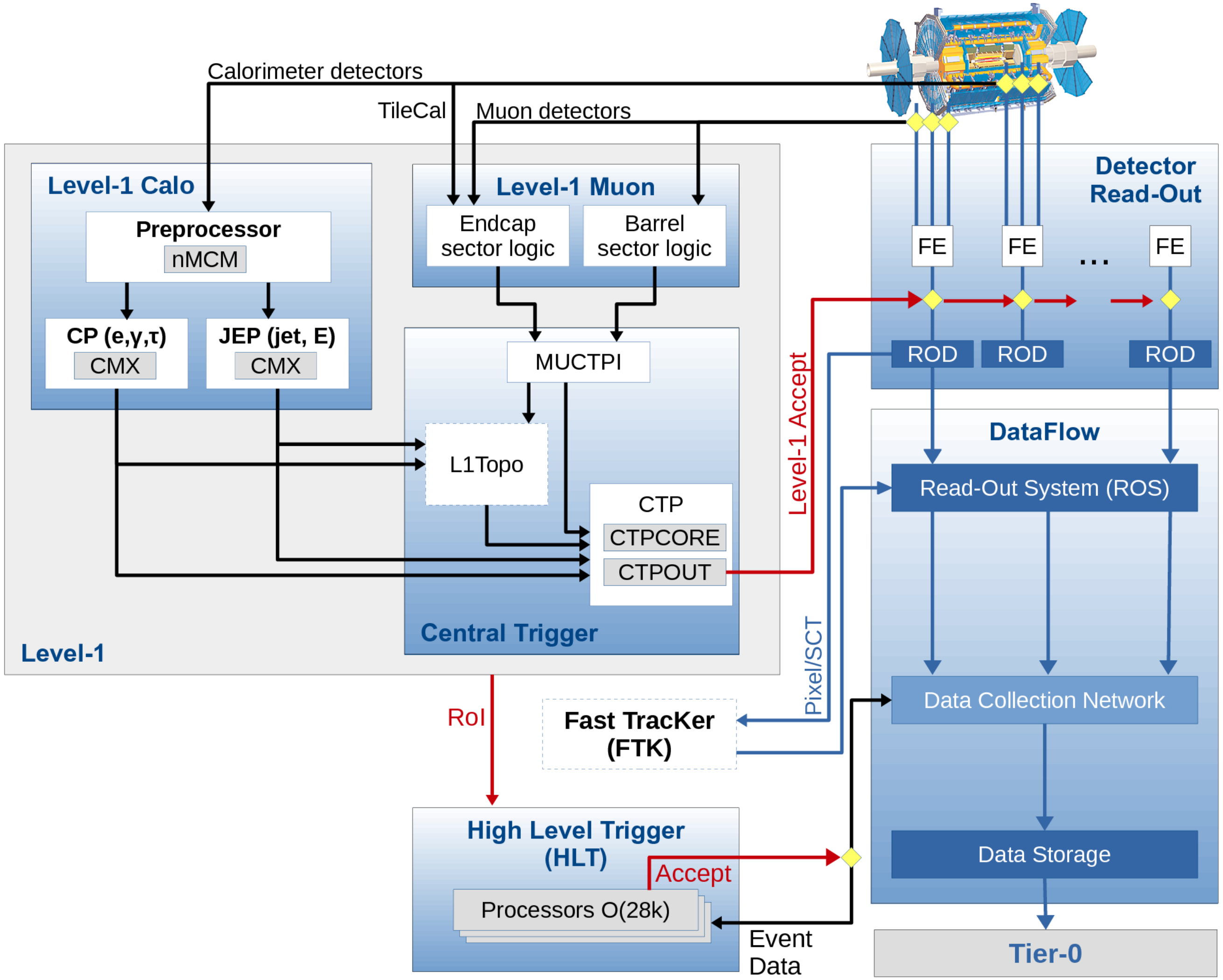
Backup Slides

Run-1 ATLAS Trigger



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

Run-2 ATLAS Trigger

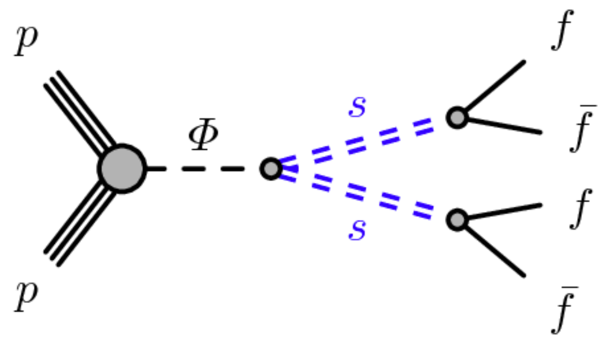


Explicit division of HLT (software-based) is removed, to allow for more flexibility.
(Run-3 is same, in architecture point of view, with upgrades in components)

J. Stupak's talk at previous LLP WS (Nov 2019)

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 τ trigger
  - Low-E_T: 30 GeV τ trigger w/ no ≥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



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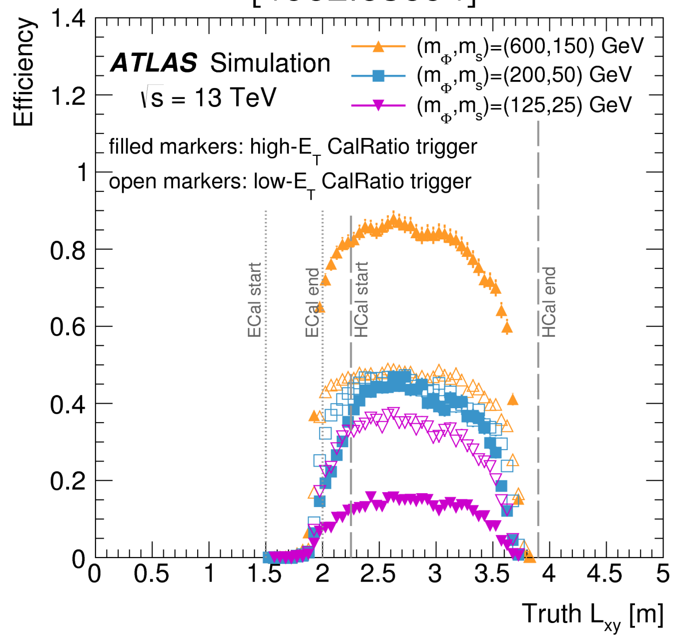
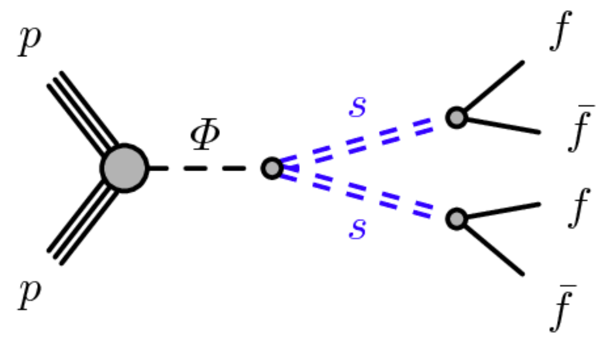


J. Stupak's talk at previous LLP WS (Nov 2019)

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



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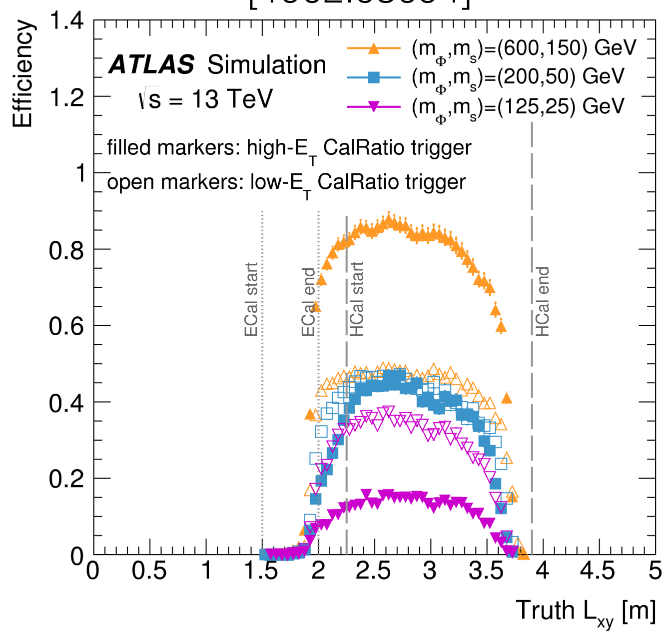
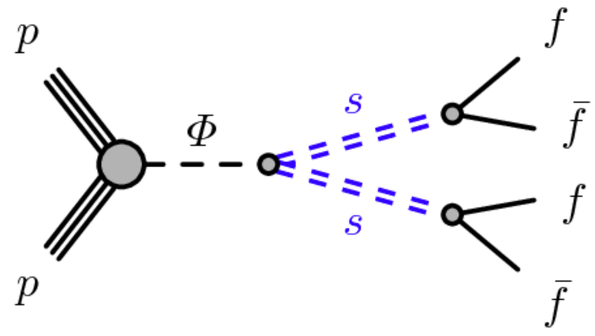


Muon RoI cluster

- 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



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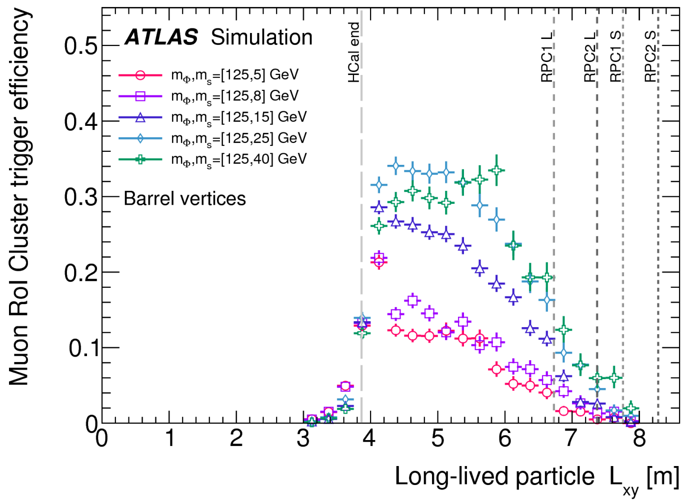
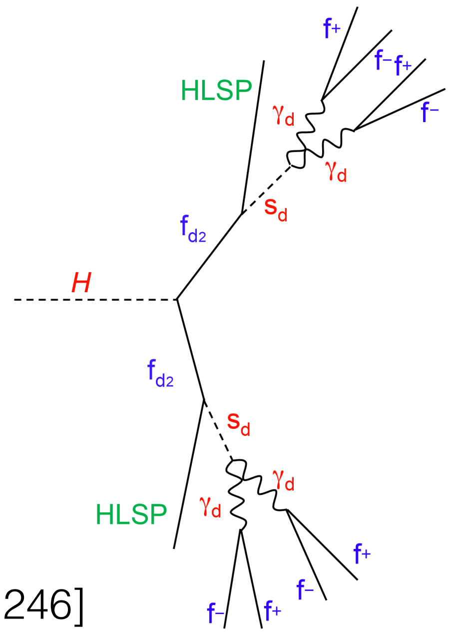


J. Stupak's talk at previous LLP WS (Nov 2019)

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 ΔR < 0.5 for 2nd standalone MS muon (variable p_T threshold)
- Offline strategy:
  - Use MVA to discriminate against cosmic muon background
  - Require ≥2 "dark photon jets" with ≥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



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