New Trigger Strategies Discussion

Perimeter Institute HL-LHC Workshop

June 8, 2015

Eva Halkiadakis,
Matt Strassler,
Gordon Watts

Discussion of triggers in HL-LHC environment

- What do we expect to face?
- What are new capabilities?
- What have we done in the past?
- How do we prevent interesting new physics from slipping through the triggering cracks?
- When do we panic?

LHC program

2010-2012	2013-2014	2015- 2018	2018-2019	2019-2022	2023-2025	2025-203X
Run1: 7-8TeV	LS1	RunII: 13TeV	LS2	Run3: 14TeV	LS3	HL-LHC 14 TeV
25fb^{-1}	Phase 0 upgrade	~120fb^{-1}	Phase 1 upgrade	~300fb^{-1}	Phase 2 upgrade	~3000fb^{-1}
PU 20 (50ns)		PU 20-40 (50ns, 25ns)		PU 50-80		PU 140-200
7×10^{33} $cm^{-2} s^{-1}$		~1×10^{34} $cm^{-2} s^{-1}$		~2×10^{34} $cm^{-2} s^{-1}$		~5×10^{34} $cm^{-2} s^{-1}$

You are here

You are heading here

HL-LHC Trigger Upgrades

ATLAS TDR:
http://cds.cern.ch/search?ln=en&cc=LHCC+Public+Documents&sc=1&p=atlas&action_search=Search&op1=a&m1=a&p1=&f1=

CMS technical proposal:
https://cds.cern.ch/record/2020886

- New Track Trigger at L1
- Upgrades to the detector readout, L1 trigger and HLT systems

- L1 read-out: up to 750kHz-1MHz -- Compared to current 100kHz
- Up to 7.5 kHz permanent event storage rate -- Compared to the current 0.5 to 1 kHz

- For 140 PU, at least 1500 kHz of L1 acceptance rate would be required to maintain the same physics acceptance as outlined for Phase-I.
- For an environment of 200 PU the same L1 menu would require almost 4000 kHz.

  → Beyond the technical feasibility of upgrades

- Adding tracking information to L1 trigger objects substantially reduces these rates to about 260(500) kHz for the same beam conditions of 140(200) PU.

ATLAS – with and without a L1 Track Trigger

Object(s)	Trigger	Estimated Rate	
		no L1Track	with L1Track
e	EM20	200 kHz	40 kHz
γ	EM40	20 kHz	10 kHz*
μ	MU20	$>$ 40 kHz	10 kHz
τ	TAU50	50 kHz	20 kHz
ee	2EM10	40 kHz	$<$ 1 kHz
$\gamma\gamma$	2EM10	as above	$\sim$5 kHz*
$e\mu$	EM10_MU6	30 kHz	$<$ 1 kHz
$\mu\mu$	2MU10	4 kHz	$<$ 1 kHz
$\tau\tau$	2TAU15I	40 kHz	2 kHz
Other	JET + MET	$\sim$ 100 kHz	$\sim$ 100 kHz
Total		$\sim$ 500 kHz	$\sim$ 200 kHz

Factor of 4 to
5 reduction
in rate

Overall Rates

ATLAS

	Capabilities	Accept Rate
Level 0	Calo/Muon	1 MHz
Level 1	Calo/Muon/Tracking (RoI)	200 kHz
HLT	Software	3kHz – 10 kHz

CMS

	Capabilities	Accept Rate
Level 1	Calo/Muon/Tracking	1 MHz
HLT	Software	3kHz – 10 kHz

ATLAS and CMS trigger upgrades

CMS Trigger Upgrade

22

Trigger/DAQ systems

- New L1-trigger will build on the Phase 1 architecture, adding tracking (from outer tracker) into all trigger objects, with increased granularity (EB at crystal level), and will be able to operate up to 1 MHz
  - Match leptons with high momentum resolution tracks
  - Provide isolation of e, γ, μ or τ candidate
  - Provide track vertex association to reduce pileup effect in multiple object triggers, e.g. in lepton plus jet triggers (investigating pixel implementation in trigger)

Preliminary studies of L1-trigger rate reduction with track-trigger

Trigger, Threshold	Algorithm	Rate reduction	Full eff. at the plateau	Comments
Single Muon, 20 GeV	Improved Pt, via track matching	~ 13 (central region)	~ 90 %	Tracker isolation may help further.
Single Electron, 20 GeV	Match with cluster	> 6 (current granularity) >10 (crystal granularity) (| η | < 1)	90 %	Tracker isolation can bring an additional factor of up to 2.
Single Tau, 40 GeV	CaloTau – track matching + tracker isolation	O(5)	O(50 %) (for 3-prong decays)	Work in progress to improve efficiency
Single Photon, 20 GeV	Tracker isolation	40 %	90 %	Probably hard to do much better.
Multi-jets, HT	Require that jets come from the same vertex			Performances depend a lot on the trigger & threshold.

Taken from:
https://indico.cern.ch/event/272893/contribution/6/material/slides/0.pdf

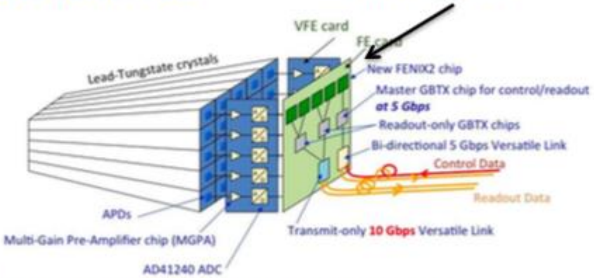
CMS Trigger upgrade

Trigger/DAQ systems

23

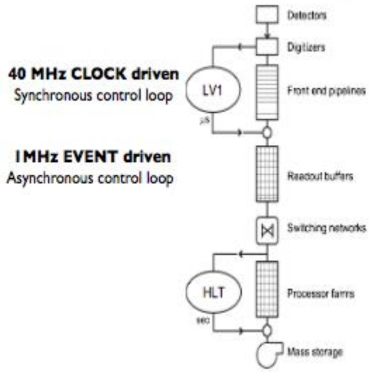
- New L1 trigger requires replacement of ECAL Barrel FEE
  - Allow 10 μs latency (limited by CSC RO)
  - Allow L1 rate up to 1 MHz to maintain trigger menu for objects or regions where the track trigger is less efficient
  - Provide crystal granularity (track match)
  - Improved APD spike rejection

New EB FE board



Note: this upgrade must happen concurrently to the tracker replacement in LS3

- The DAQ and HLT will be upgraded for up to 1 MHz into HLT and 10 kHz out to maintain ~ to current rejection factor



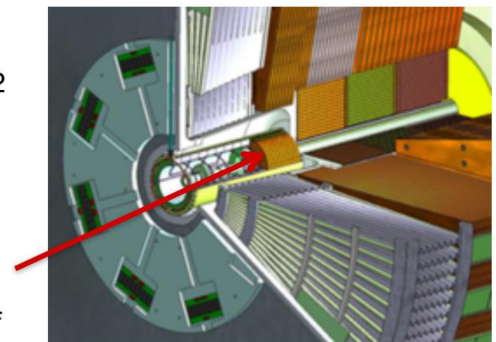
- "Moore's Law" (CPUs, networks, storage) over 10 years suggests that "normal technology improvements" will handle this, including offline

Taken from:
https://indico.cern.ch/event/272893/contribution/6/material/slides/0.pdf

ATLAS Calorimeter Electronics Upgrade

Calorimeter

- Tile Calorimeters
  - No change to detector needed
  - Full replacement of front-end and back-end electronics to cope with higher initial event-rates and higher radiation levels
    - New read-out architecture: Full digitisation of data at 40MHz and transmission to off-detector system, digital information to level L1/L0 trigger
- LAr Calorimeter
  - Replace front-end and back-end electronics
    - Ageing, radiation limits, compliance with Phase-2 L0/L1 trigger rates and latencies.
    - Fully digital 40 MHz readout → finest granularity trigger input (L0/L1)



- Replace Forward calorimeter (FCal) if required
  - Install new sFCAL in cryostat or miniFCAL in front of cryostat if significant degradation in current FCAL or if finer granularity mandated by physics requirements at HL-LHC

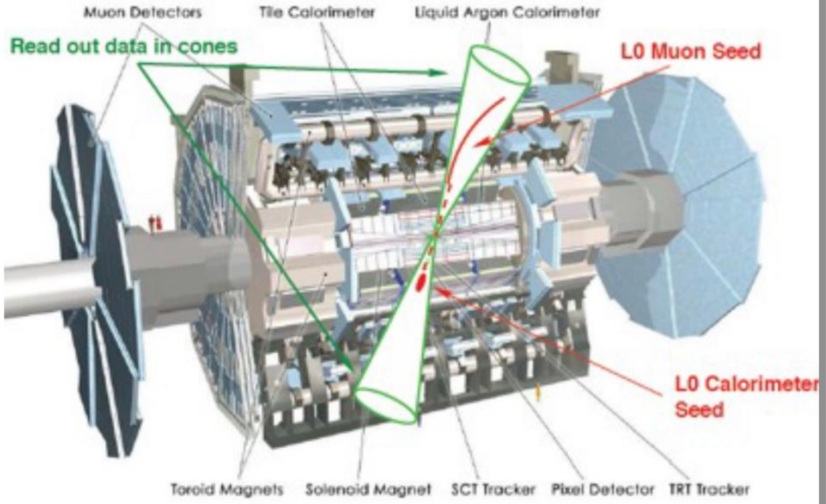
Upgrade occurs over both Phase I and Phase 2

- Digitize full Cal on each crossing
- Level 0 and Level 1 now have access to shower shape information

ATLAS Track Trigger @ HL-LHC

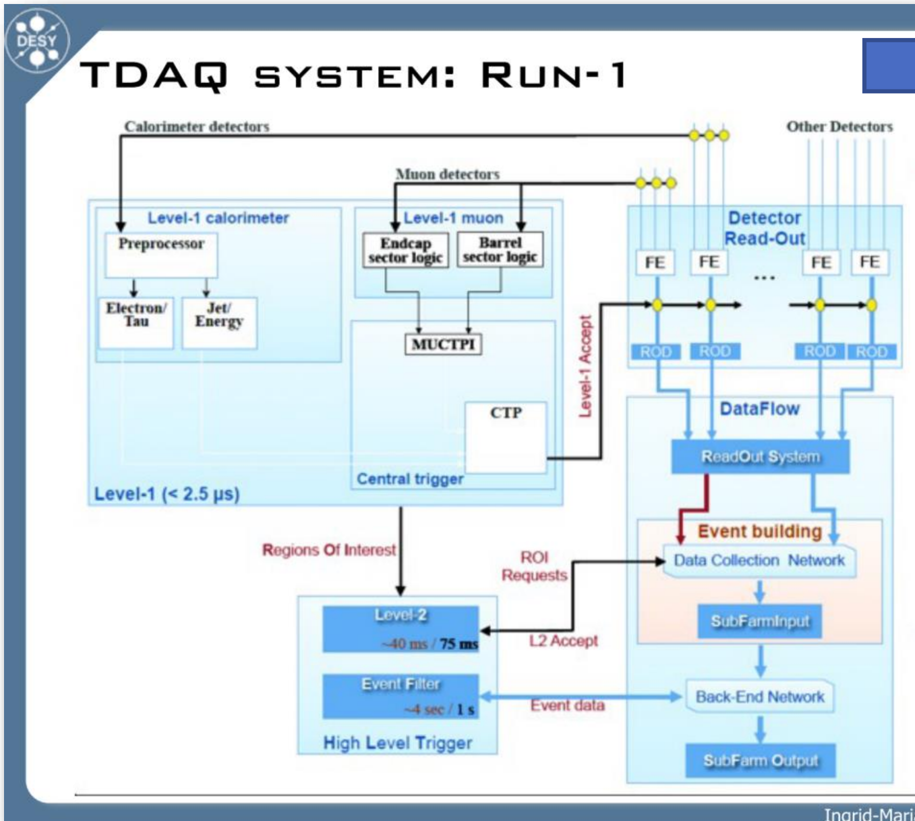
L1 Track Trigger

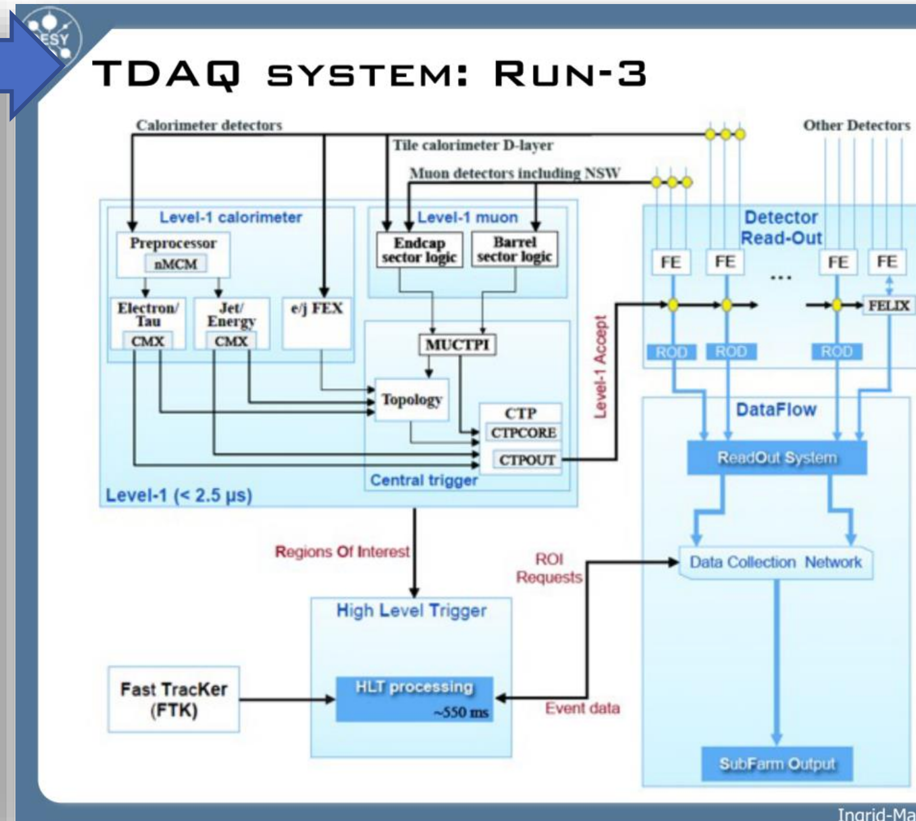
- Adding tracking information at Level-1 (L1)
  - Move part of the High Level Trigger (HLT) reconstruction into the early stage of trigger
  - Goal: keep thresholds on p_T of triggering leptons and L1 trigger rates low
- Triggering sequence
  - L0 trigger (Calo/Muon) reduces rate within ~6 μs to 1 MHz and defines RoIs
  - L1 track trigger extracts tracking info inside RoIs from readout electronics
- Challenge
  - Finish processing within the latency constraints
  - Requires changes to electronics feeding trigger system



- RoI based track reconstruction planned
- Full detector possible; studies ongoing now.

ATLAS: Trigger Evolution





CMS: Estimated total L1 Menu Rate

Table 6.1: Level-1 Menu using algorithms that include track trigger capabilites. The beam conditions are $\sqrt{s}$ = 14 TeV, and $L = 5.6 \times 10^{34}$ cm^{-2}s^{-1} with a bunch spacing of 25 ns and pileup of 140. The rate for each algorithm is given along with the total rate, which accounts for overlaps between algorithms. For algorithms that depend on more than one object, the thresholds are listed in the order corresponding to the algorithm name. Objects which use Level-1 tracking are indicated with "(tk)". From Run-I data, we estimated that our sample menu of 20 triggers accounts for approximately 70% of the total Level-1 rate. The last line of the table presents the total estimated rate when we scale for the remaining 30%. No additional safety factor for uncertainties in our extrapolations has been applied.

$L = 5.6 \times 10^{34}$ cm^{-2}s^{-1} $\langle PU \rangle = 140$	Level-1 Trigger with L1 Tracks	
Trigger Algorithm	Rate [kHz]	Offline Threshold(s) [GeV]
Single Mu (tk)	14	18
Double Mu (tk)	1.1	14 10
ele (iso tk) + Mu (tk)	0.7	19 10.5
Single Ele (tk)	16	31
Single iso Ele (tk)	13	27
Single γ (tk-veto)	31	31
ele (iso tk) + e/γ	11	22 16
Double γ (tk isol)	17	22 16
Single Tau (tk)	13	88
Tau (tk) + Tau	32	56 56
ele (iso tk) + Tau	7.4	19 50
Tau (tk) + Mu (tk)	5.4	45 14
Single Jet	42	173
Double Jet (tk)	26	2@136
Quad Jet (tk)	12	4@72
Single ele (tk) + Jet (tk)	15	23 66
Single Mu (tk) + Jet (tk)	8.8	16 66
Single ele (tk) + H_T^{miss} (tk)	10	23 95
Single Mu (tk) + H_T^{miss} (tk)	2.7	16 95
H_T (tk)	13	350
Rate for above Triggers	180	
Est. Total Level-1 Menu Rate	**260**	

ATLAS Goals are similar

CMS technical proposal: https://cds.cern.ch/record/2020886

What has worked in the past?

- Beyond having standard single object triggers, CMS and ATLAS have implemented:

  - Data scouting: save only a small subset of the event content (e.g., only the HLT-level jet objects)

  - Data parking: send events from the HLT to tape without reconstructing them, analyze later.

  - Multi-object triggers

To discuss …

- Entirely different trigger concepts?

- Are there holes in trigger strategy? Can we anticipate this before Run II conclusions?

- Different trigger strategies:
  - Assuming we find new physics in Run II
    - Would trigger strategy change depending on flavor of new physics?
  - Assuming we have yet to find new physics in Run II

- Thoughts/comments?