The ATLAS Run-2 Trigger Menu: Design, Performance and Operational Aspects

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on behalf of the ATLAS Collaboration

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Introduction

- Sucessfull start of Run-2 in 2015

  → **3.2 fb^{-1}** of pp data recorded for physics

- In 2016: → record peak luminosity of **10.8 x 10^{33} cm^{-2} s^{-1}**, peak interactions/bunch crossing **μ = 38**

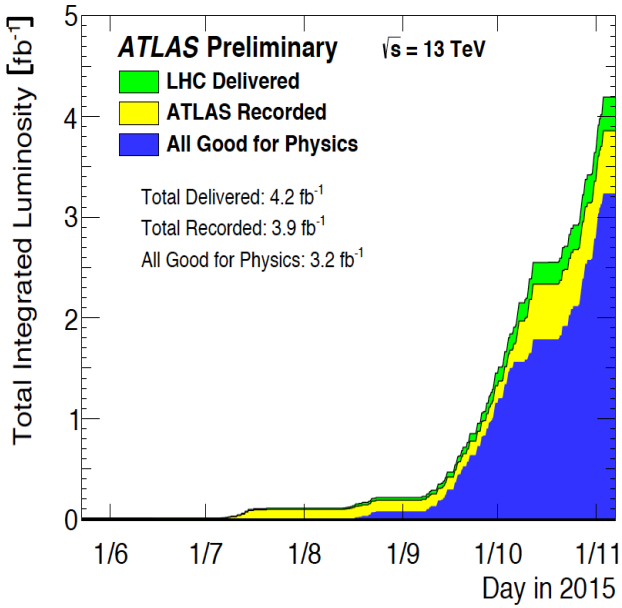
  → already recorded > **9.7 fb^{-1}** of pp data

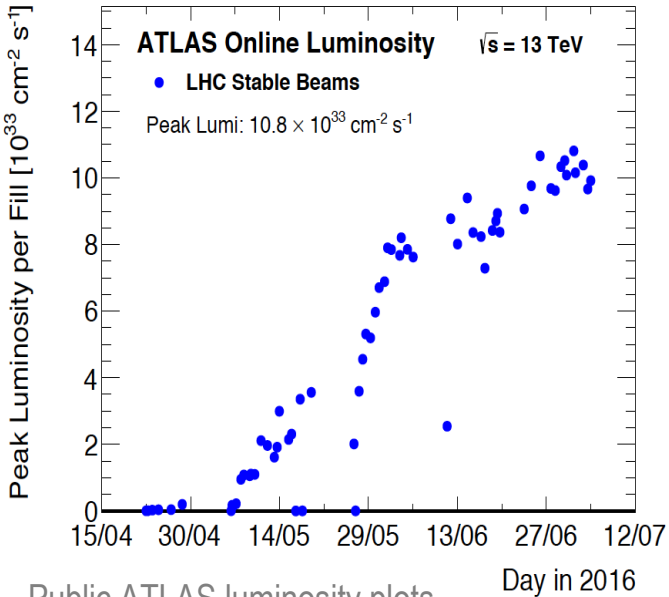
- Challenging conditions for the trigger system

	bunch spacing	√s	luminosity	< μ >
Run-1	50 ns	8 TeV	~8 e33	40
Run-2	25 ns	13 TeV	**1-2 e34**	25-**50**

- Many improvements of the TDAQ system for Run-2:
  - several upgrades/additions on hardware side
  - unified High Level Trigger (HLT) architecture
  - increased bandwidth:

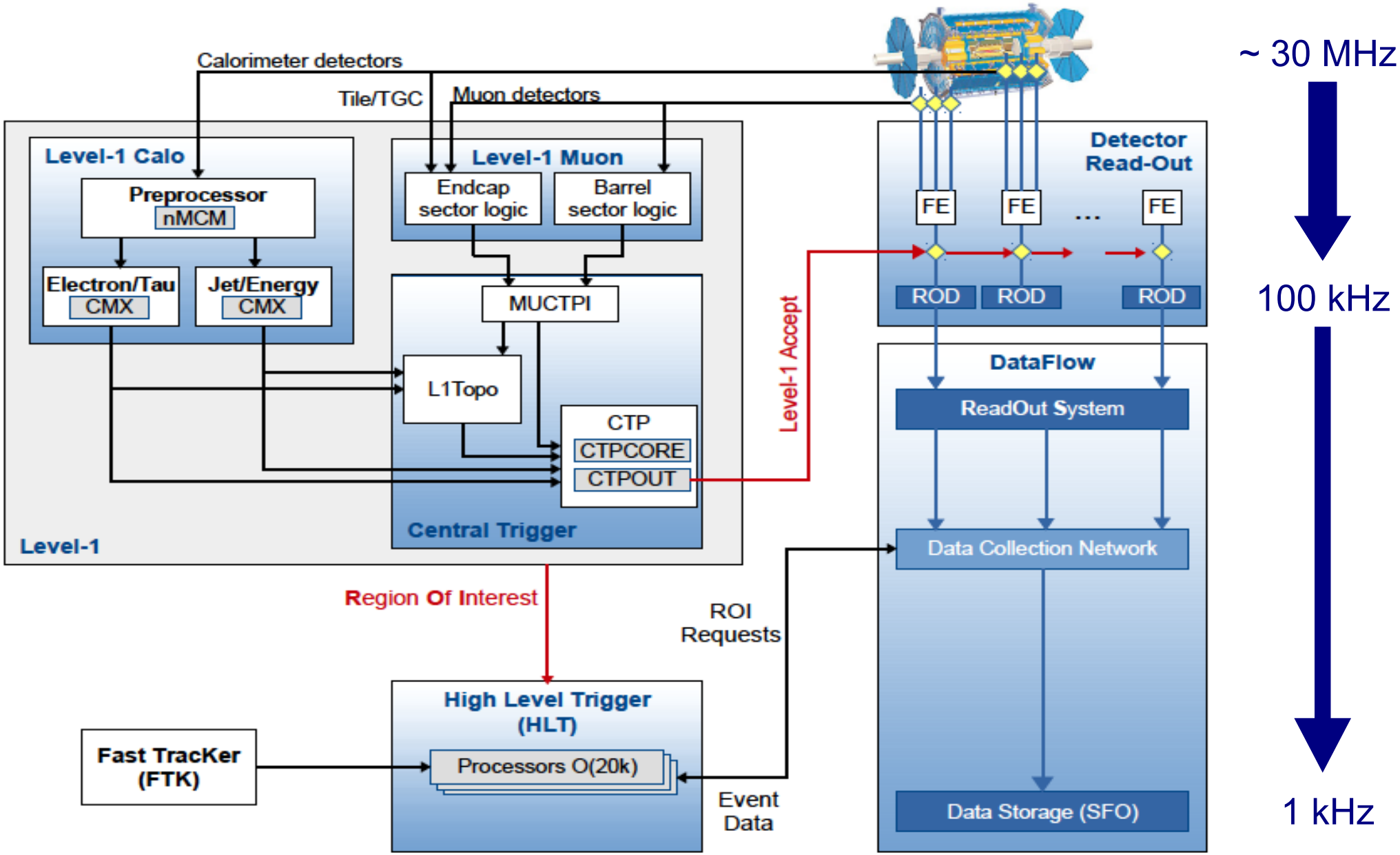
    L1: 75 (2012) → **100 kHz, HLT: 400** (2012) → **1000 Hz**





Public ATLAS luminosity plots

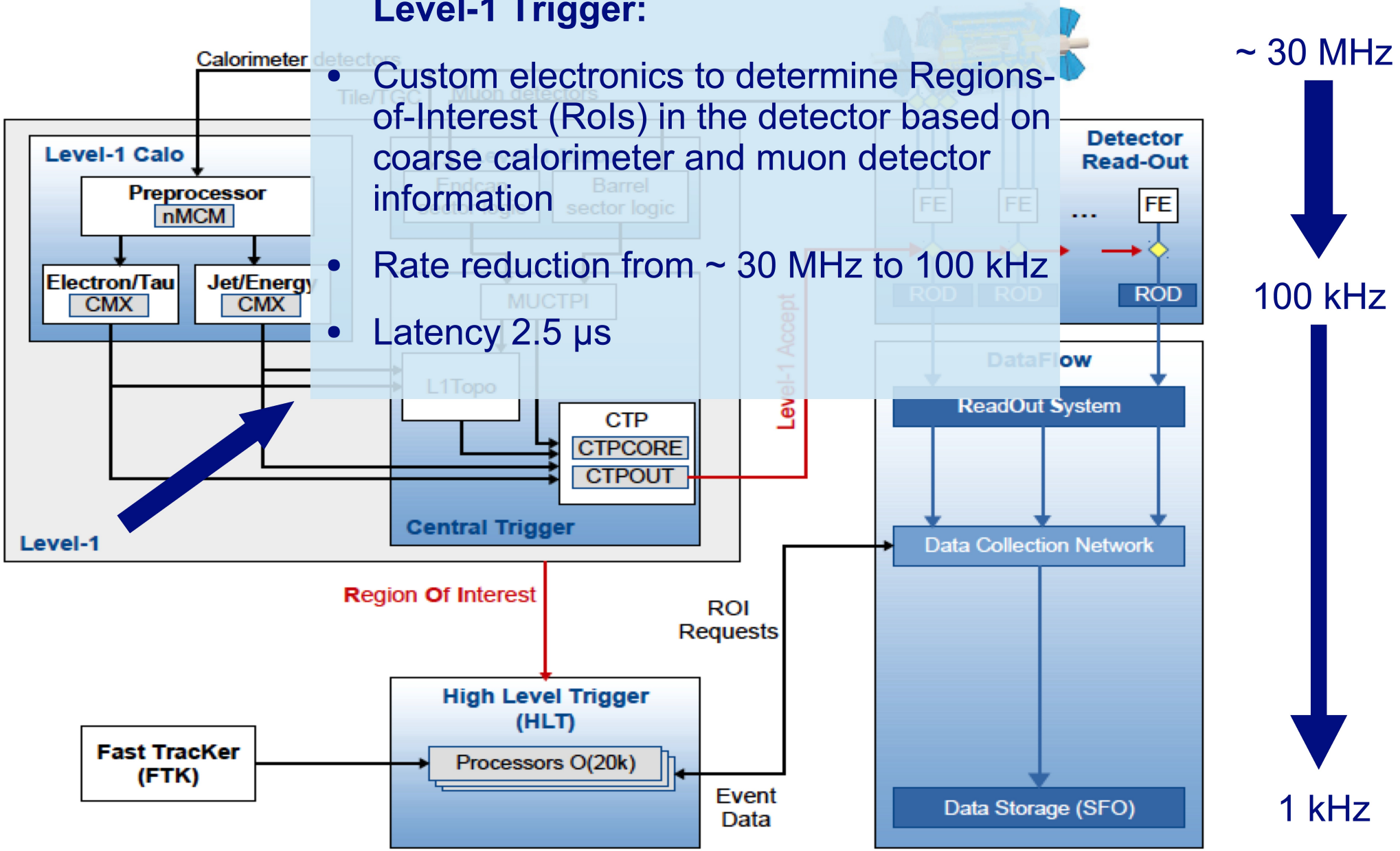
ATLAS Trigger System



ATLAS Trigger System

Level-1 Trigger:

- Custom electronics to determine Regions-of-Interest (RoIs) in the detector based on coarse calorimeter and muon detector information
- Rate reduction from ~ 30 MHz to 100 kHz
- Latency 2.5 μs



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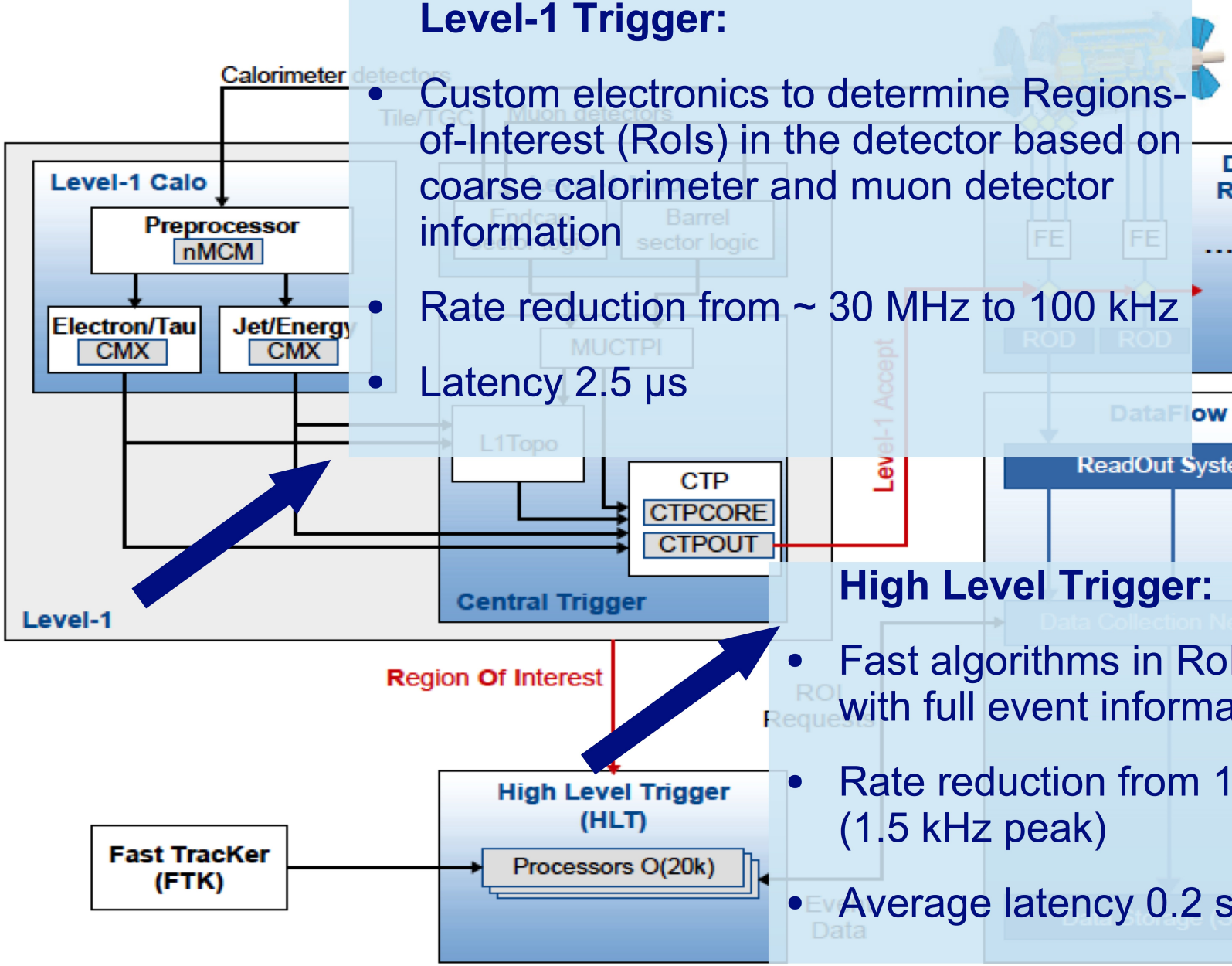


~ 30 MHz

100 kHz

1 kHz

High Level Trigger:

- Fast algorithms in RoIs, offline-like ones with full event information
- Rate reduction from 100 kHz to ~ 1 kHz (1.5 kHz peak)
- Average latency 0.2 s

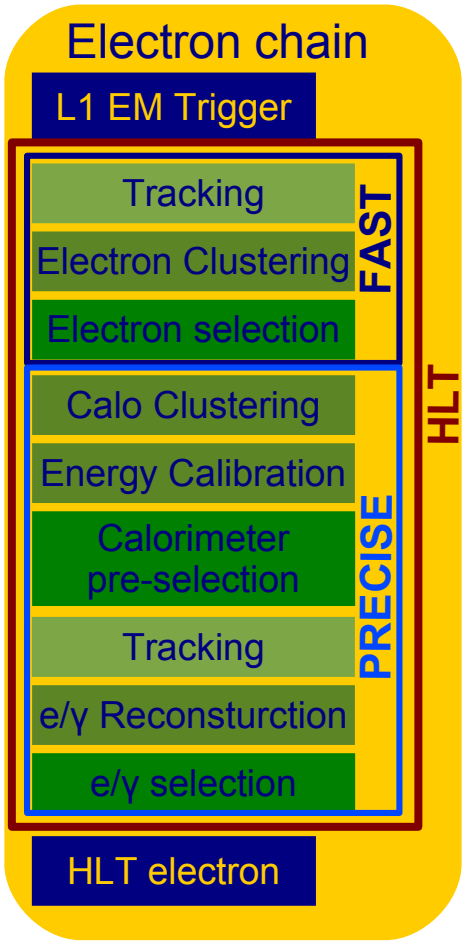
Trigger Menu

Level 1 Trigger

- first and simple preselection of events based on information of subdetector system
  - calorimeter triggers and muon triggers
  - e.g. XE50, J400, TAU40, EM22, MU20
  - all kinds of combinations (e.g. EM7_MU10)

High Level Trigger

- HLT algorithms activated if the assigned L1 trigger(s) passed
  - access to the full event information
  - designed to be as close to offline as possible



- The sequence of Level 1 and HLT algorithms → trigger chain
- Trigger Menu: full set of trigger chains with prescale factors depending on luminosity

The trigger menu consists of > 400 L1 triggers and ~ 2000 HLT triggers

Trigger Menu in 2015

Closely related chains are grouped in **Trigger Signatures**:

e/gamma

muons

taus

jets

missing energy

b-jets

B-physics

Trigger	Typical offline selection	Trigger Selection		Level-1 Peak Rate (kHz)	HLT Peak Rate (Hz)
		Level-1 (GeV)	HLT (GeV)	$L = 5 \times 10^{33}$ cm^{-2}s^{-1}	
Single leptons	Single iso μ, $p_T > 21$ GeV	15	20	7	130
	Single e, $p_T > 25$ GeV	20	24	18	139
	Single μ, $p_T > 42$ GeV	20	40	5	33
	Single τ, $p_T > 90$ GeV	60	80	2	41
Two leptons	Two μ's, each $p_T > 11$ GeV	2	2 × 10	0.8	19
	Two μ's, $p_T > 19, 10$ GeV		18, 8	7	18
	Two loose e's, each $p_T > 15$ GeV	2 ×	2 × 12	10	5
	One e & one μ, $p_T > 10, 26$ GeV	20 (μ)	7, 24	5	1
	One loose e & one μ, $p_T > 19, 15$ GeV	15, 10	, 24	0.4	2
	Two τ's, $p_T > 40, 30$ GeV	20, 12	25	2	22
	One τ, one μ, $p_T > 30, 15$ GeV	12, 10 (+jets)	14	0.5	10
	One τ, one e, $p_T > 30, 19$ GeV	12, 15 (+jets)	17	1	3.9
Three leptons	Three loose e's, $p_T > 19, 11, 11$ GeV	15, 2 × 7	17, 2 ×	3	< 0.1
	Three μ's, each $p_T > 8$ GeV	3 × 6	3 ×	< 0.1	4
	Three μ's, $p_T > 19, 2 \times 6$ GeV	15	18, 2 ×	7	2
	Two μ's & one e, $p_T > 2 \times 11, 14$ GeV	2 × 10 (μ's)	2 × 10,	0.8	0.2
	Two loose e's & one μ, $p_T > 2 \times 11, 11$ GeV	2 × 8, 10	2 × 12, 10	3	< 0.1
One photon	one γ, $p_T > 125$ GeV	22	120	8	20
Two photons	Two loose γ's, $p_T > 40, 30$ GeV	2 × 15	35, 25	1.5	12
	Two tight γ's, $p_T > 25, 25$ GeV	2 × 15	2 × 20		7
Single jet	Jet ($R = 0.4$), $p_T > 400$ GeV	100	360		18
	Jet ($R = 1.0$), $p_T > 400$ GeV	100	360		23
E_T^{miss}	$E_T^{miss} > 180$ GeV	50	70	0.7	55
Multi-jets	Four jets, each $p_T > 95$ GeV	3 × 40	4 × 85	3	20
	Five jets, each $p_T > 70$ GeV	4 × 20	5 × 60	0.	15
	Six jets, each $p_T > 55$ GeV	4 × 15	6 × 45	1.0	
b–jets	One loose b, $p_T > 235$ GeV	100	225	0.9	35
	Two medium b's, $p_T > 160, 60$ GeV	100	150, 50	0.9	9
	One b & three jets, each $p_T > 75$ GeV	3 × 25	4 × 65	0.9	11
	Two b & two jets, each $p_T > 45$ GeV	3 × 25	4 × 35	0.9	9
b–physics	Two μ's, $p_T > 6, 4$ GeV plus dedicated b-physics selections	6, 4	6, 4	8	52
Total				70	1400

~ 2000 trigger chains

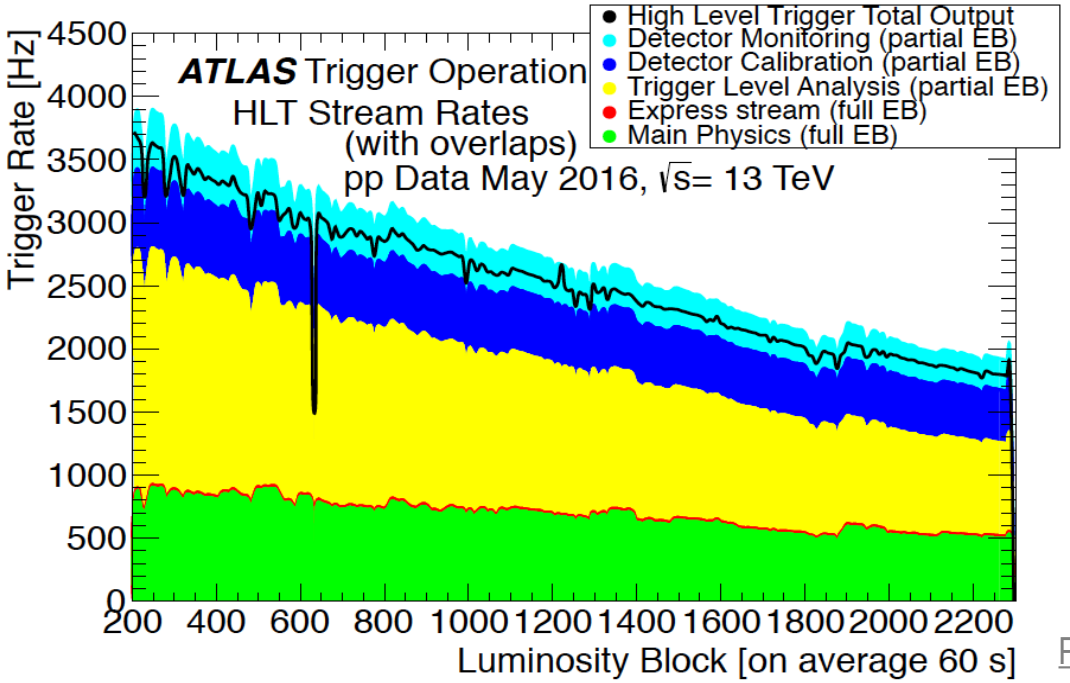
Menu Design Strategy

- The trigger selection needs to respect all bandwidth limitations

  → driven by the physics priorities of ATLAS

  - broad physics program (from SM measurements to BSM searches)
  - **most bandwidth** is given to **generic triggers**
  - additional multi-object and dedicated triggers

  → trigger selection must also satisfy the need for calibration and other requirements

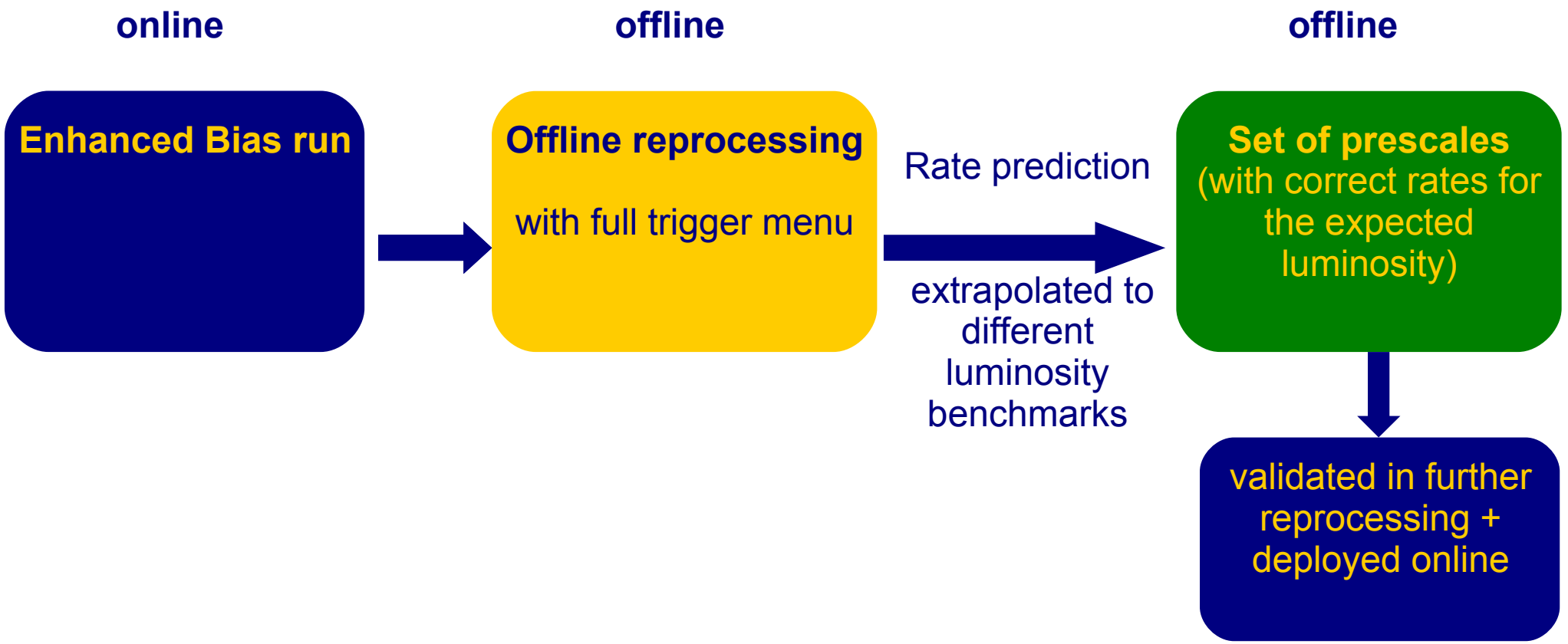


Public ATLAS trigger operation plots

Rate predictions

- Trigger menu is designed for different luminosity points

  (in 2016 for 0.5, 0.7, 1, **1.2 and 1.5 x 10^{34} cm^{-2} s^{-1}**) → needs **precise** rate predictions
- **Enhanced Bias** dataset: special set of only Level 1 triggers with low thresholds



Trigger Menu Operations

- Primary triggers are kept stable by preparing benchmark luminosity menus

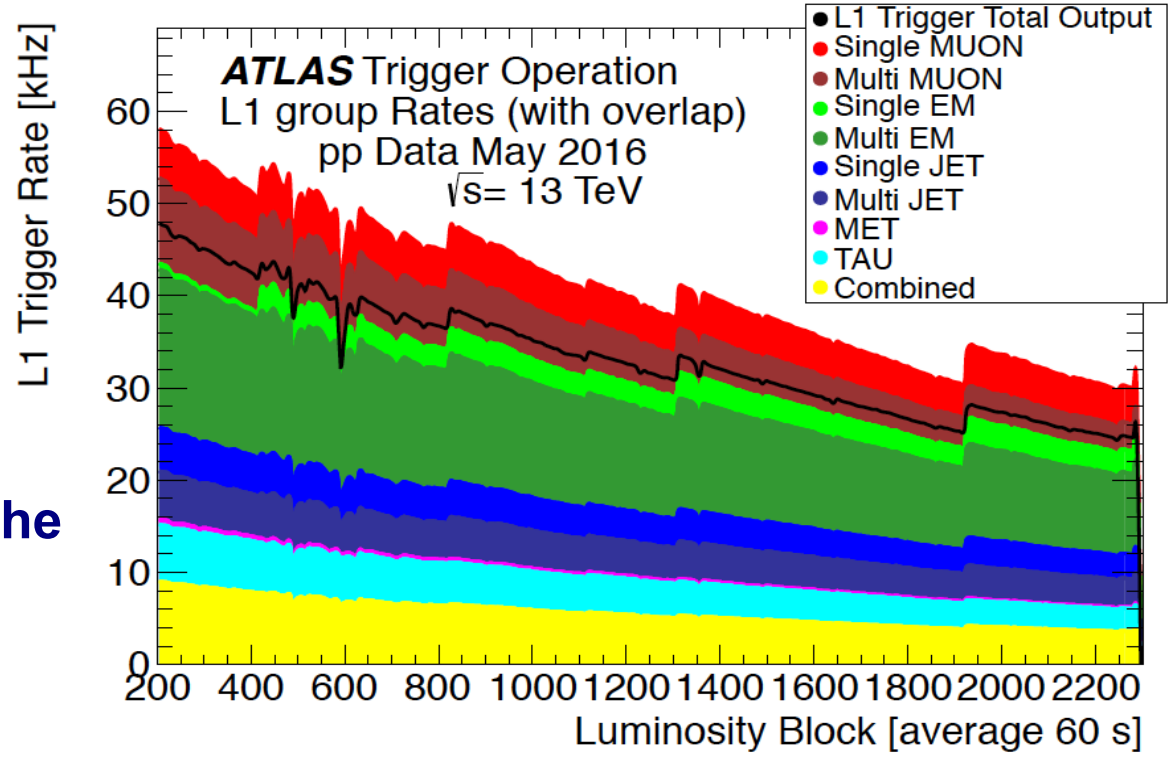
  → in 2016 for 0.5, 0.7, 1, **1.2 and 1.5 x 10^{34} cm^{-2} s^{-1}**

  → highly desirable for physics analysis

- during the run trigger prescale sets are adjusted to decreasing instantaneous luminosity

  → in steps of ~5 x 10^{32} cm^{-2} s^{-1}

- supporting and monitoring triggers are kept at a constant output rate



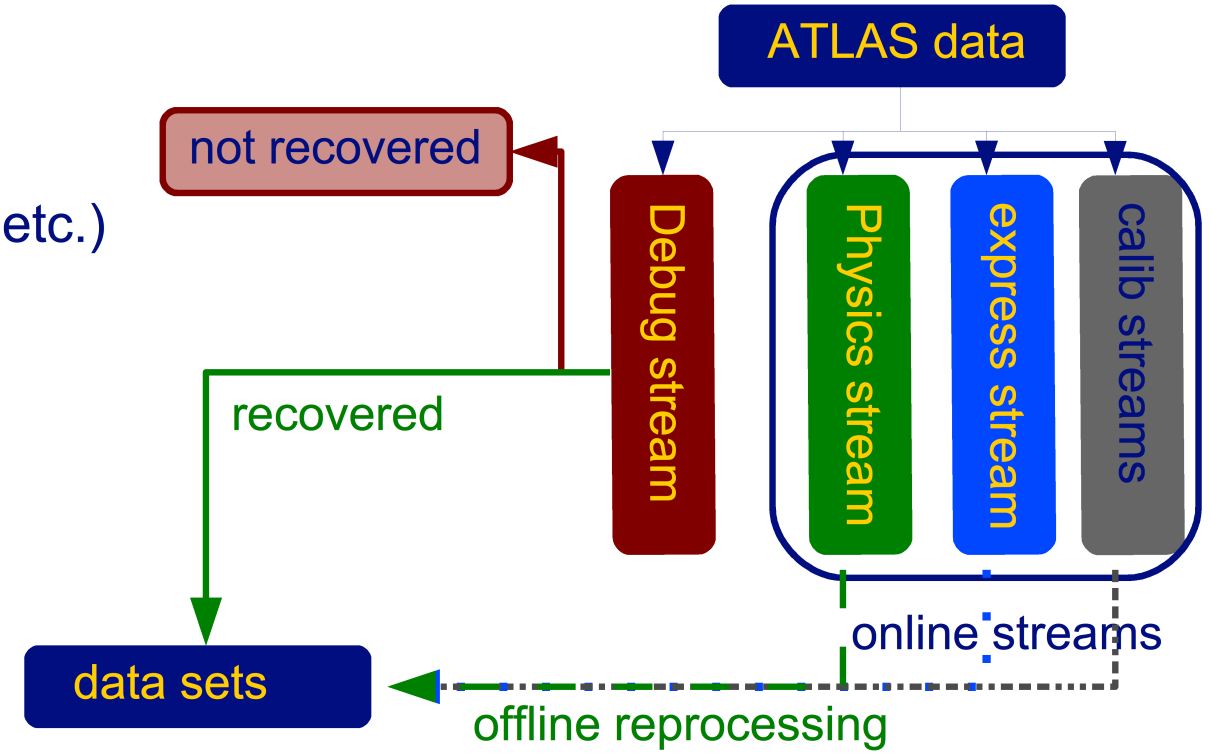
Very smooth operations since the beginning of 2016!

- ~ 35k CPUs, no serious amount of crashes

Trigger System Monitoring

- Monitoring of the trigger system is extremely important

  → needs to provide the ability to discover any problems immediately
- **Online monitoring:** immediate check of all trigger rates both at Level 1 and at HLT
- **Offline monitoring:** data quality framework for the reprocessed data
- **Debug stream:**
  recovery of events without
  trigger decision (due to time-outs etc.)



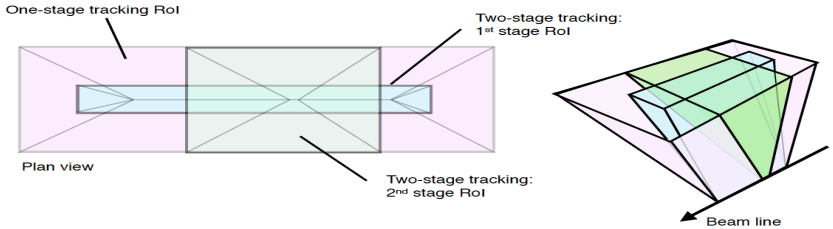
Trigger Performance - HLT Tracking

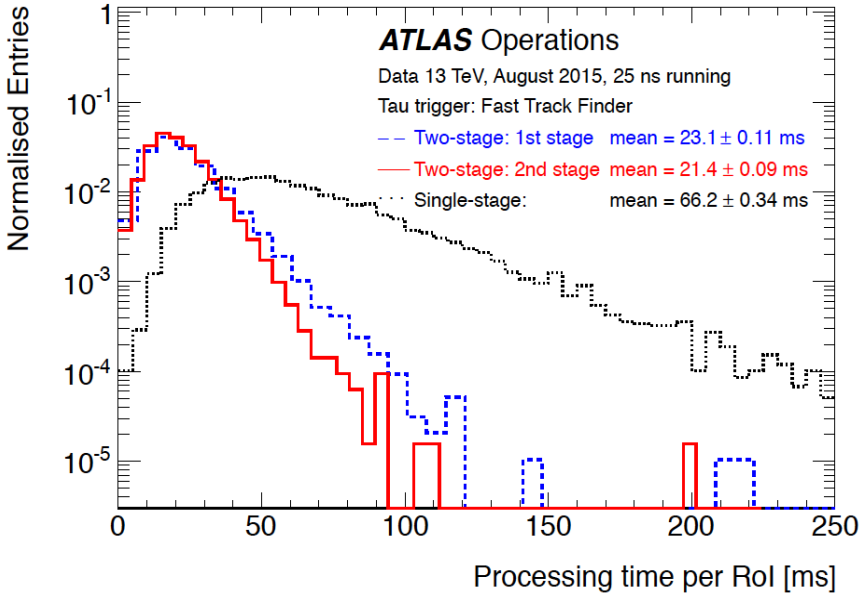
- Fast and precision tracking is combined on the same machine in steps
- **Fast tracking**: pattern recognition and data preparation

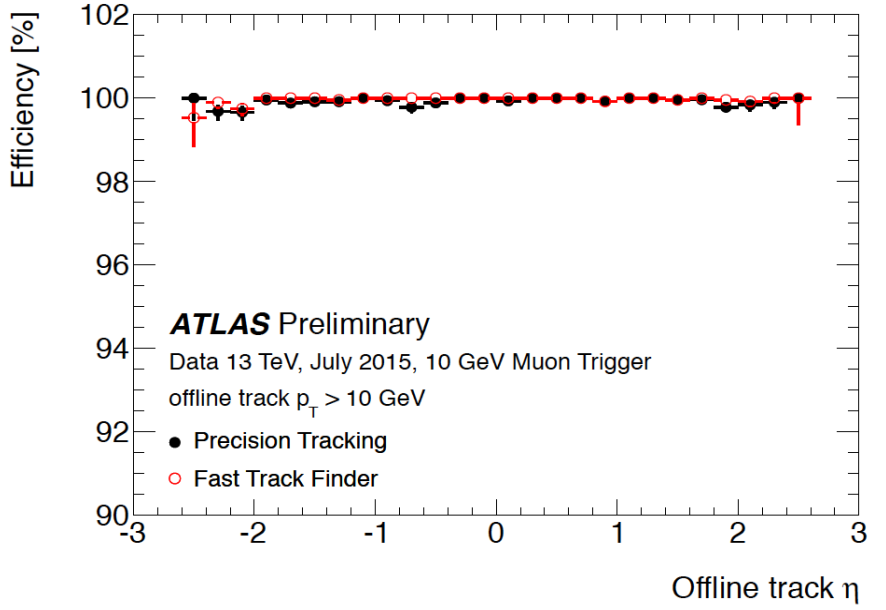
  → run only once
- **Precision tracking**: refined tracking that is run later

  → using the result of the fast tracking as input

- **increased speed by almost a factor of 3**
- tracking efficiency larger than 99%





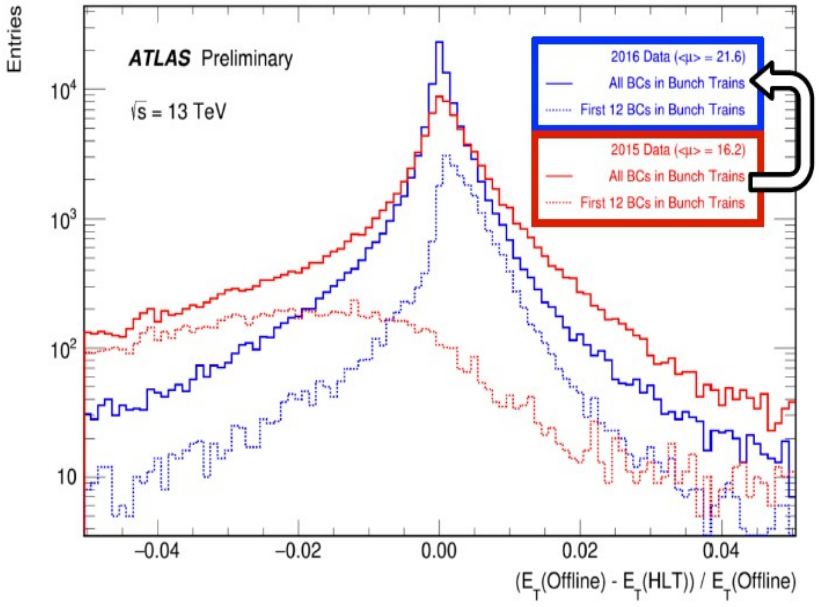


Trigger Performance - HLT Calo and E_T^{miss}

HLT Calorimeter: improved cluster energy resolution

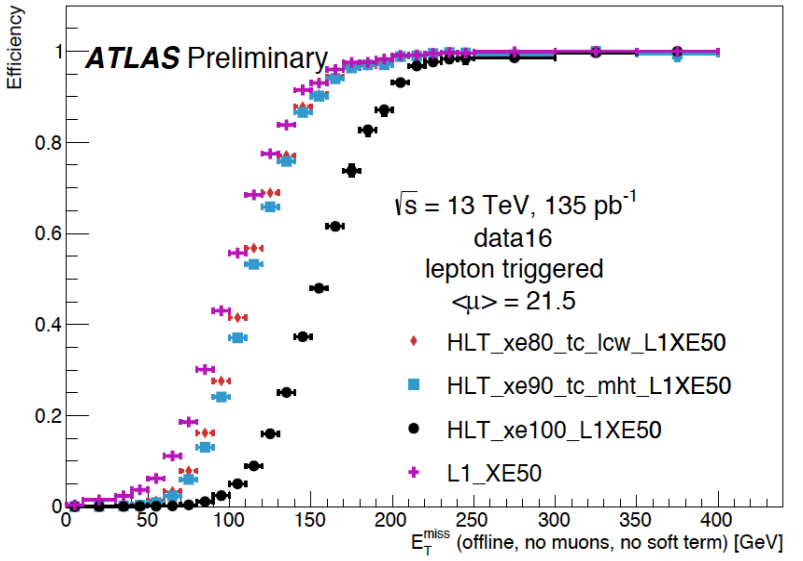
- more robust against out-of-time pile-up

  → using BCID/<μ>-based energy corrections at cell level



Missing transverse energy:

- cell-based
- topocluster: similar to offline E_T^{miss}, hadronic calibration of cells
  - variants with different pile-up suppression
- mht: based on jets
- in 2015 all algorithms running with the same threshold
- in 2016 **mht** lowest unprescaled threshold

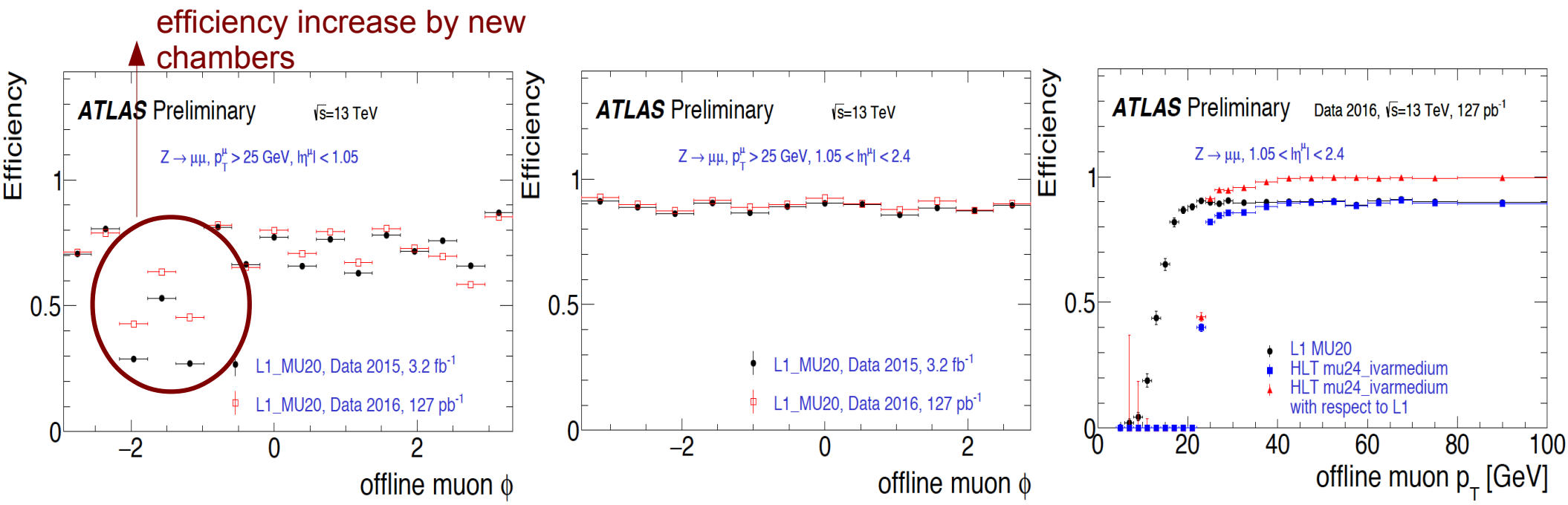


Trigger Performance - Muons

- **Level 1**
  - better coverage thanks to **new chambers in the barrel region**
  - new coincidence logic in forward region to suppress background

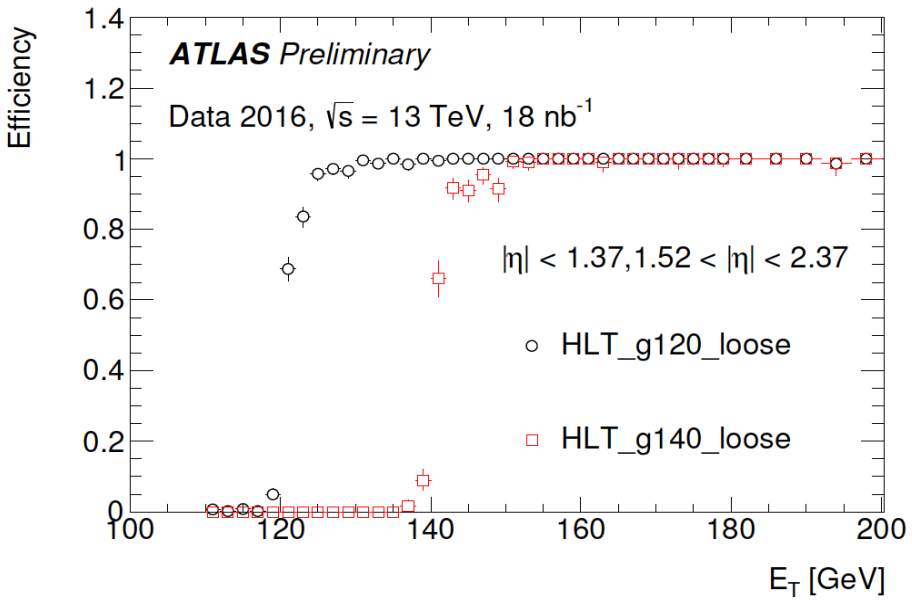
HLT

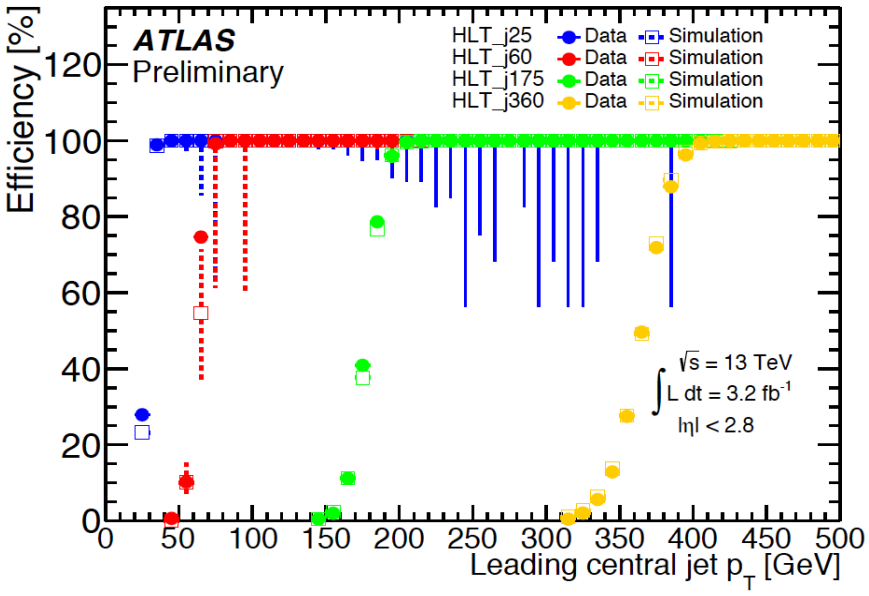
- combination of inner detector and muon spectrometer tracks
- offline-like algorithms for final selection

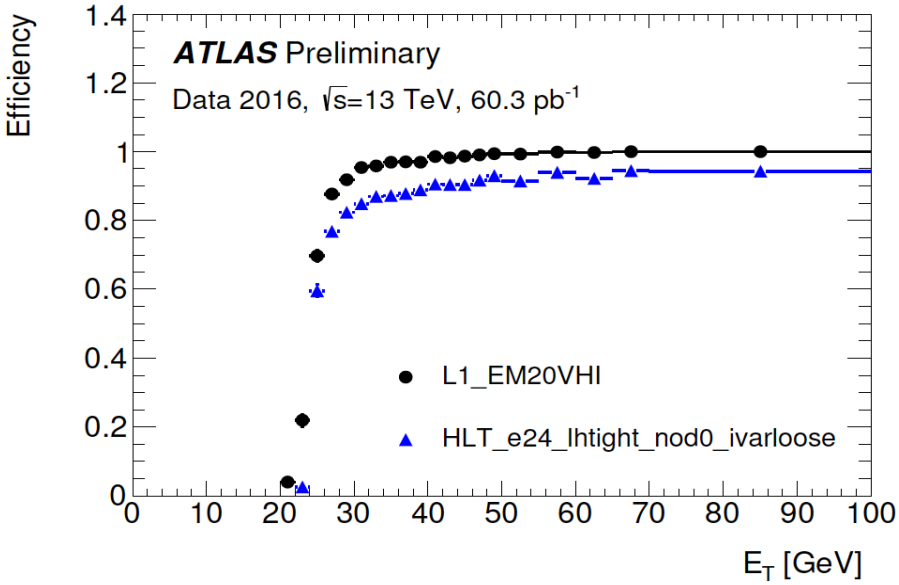


Trigger Performance - Electrons/γ + Jets

- good performance of all triggers
- increased thresholds and isolation requirements in 2016



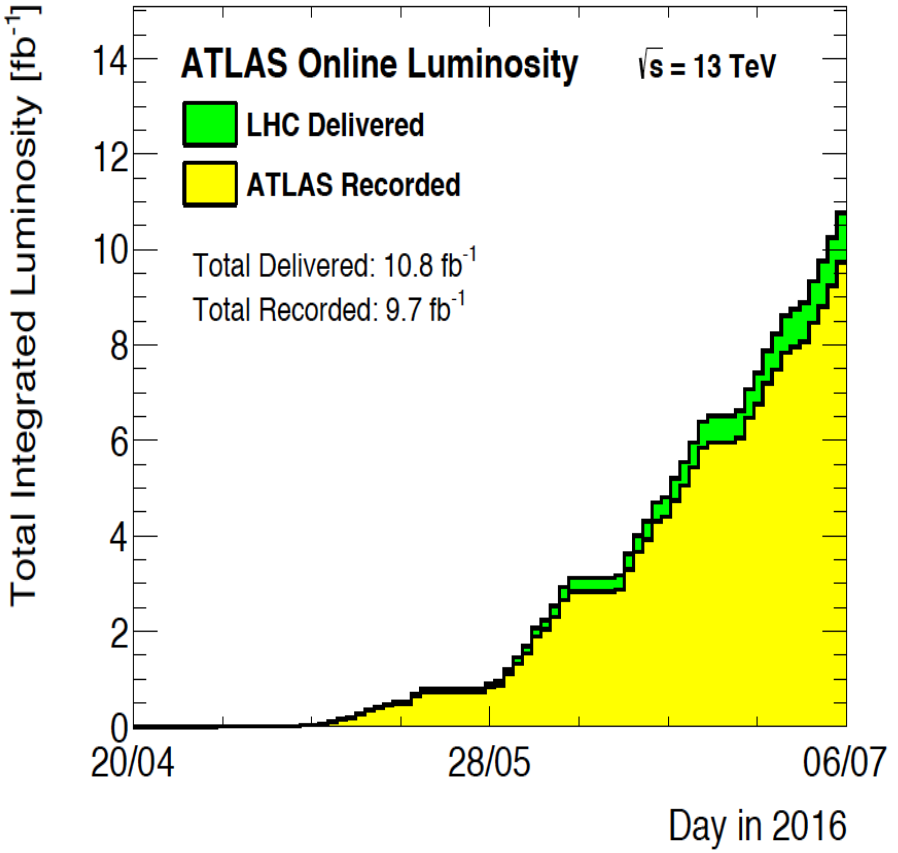




Summary

- Sucessful start of Run-2 in 2015
- Several updates of trigger hardware and software for Run-2
- Sophisticated monitoring at all stages
- Trigger menu prepared for the challenges of 2016 data-taking
  - good performance so far

Ready for much more data this year!



Backup

Trigger Performance - Electrons/Photons

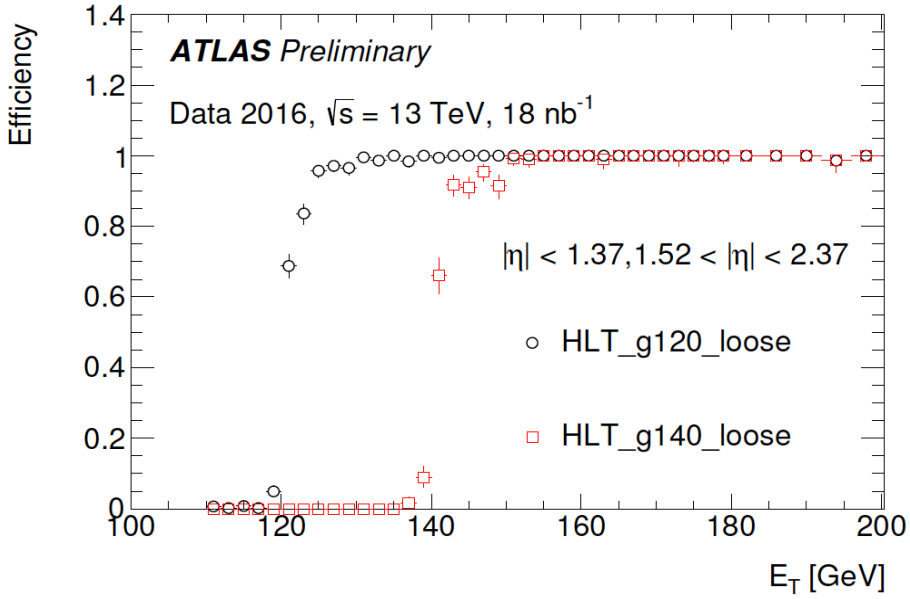
- **Level 1** applies an E_T based veto against energy deposited in the hadronic calorimeter
  - isolation requirement for electrons

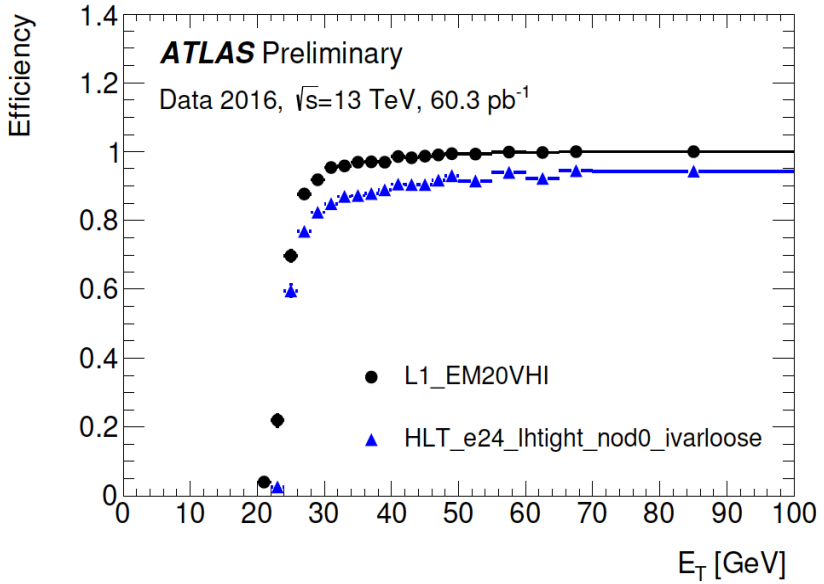
HLT

- MVA based energy calibration of the electromagnetic clusters
- **electrons:** combination of calorimeter and tracking information

  → identification based on a likelihood method using the electromagnetic shower shape and tracks as input
- **photons:** based on calorimeter information only

  → cut-based identification criteria
- both available for different identification requirements (loose → medium → tight)

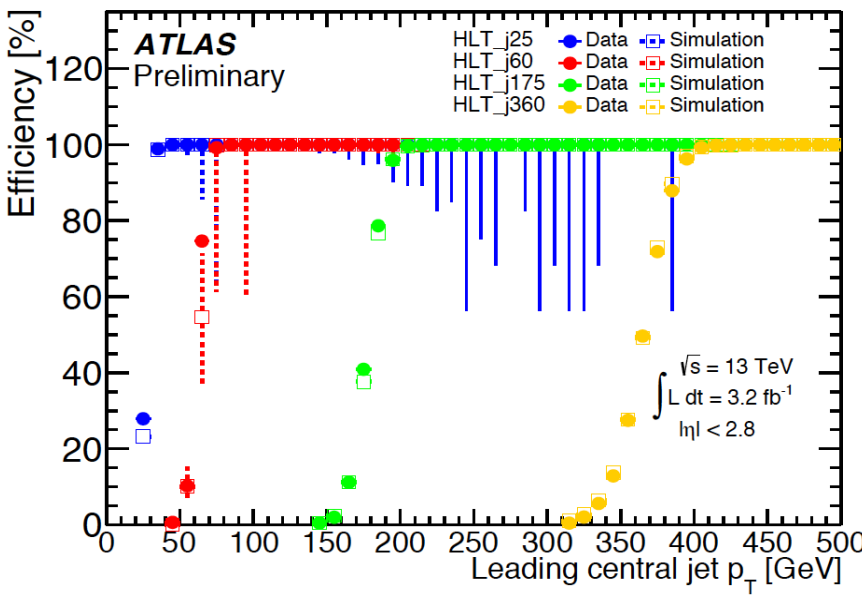


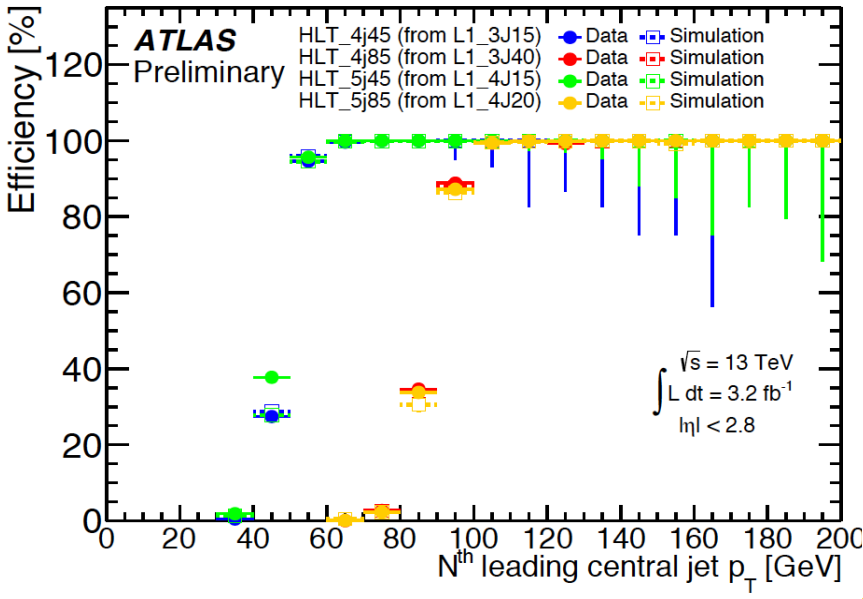


Trigger Performance - Jets

- **Level 1**: sliding window algorithm on calorimeter towers
  - seperate triggers for central (η <3.2) and forward (3.1 < η < 4.9) region
- **HLT:** jet trigger algorithms very similar to offline

  → very good performance
- several configurations available: (default)
  - **η range** - [0,3.2], [0,2.4], [0,4.9], [3.2,4.9]
  - **jet cluster algorithm** - anti-k_t R=0.4 or R=1.0
  - **constituent energy scale** - no weights, local cluster weight
  - **jet energy scale** - calibration factors and pile-up subtraction, calibration factors only, pile-up subtraction only, no calibration
  - **calorimeter read-out** - full scan, partial scan





Online Monitoring

- It includes the following tools to monitor the performance of the trigger w.r.t the trigger menu and algorithms running online:

  Online**H**istogram**P**resenter - **OHP**

  - provides visualisation of incoming data against a reference, also available remotely

  Trigger**R**ate**P**resenter - **TRP**

- displays trigger rates for the ongoing run at P1, also availble remotely

  → one of the most important tools for the control room shifter

  → several overview panels, can plot each L1 item/ HLT chain/ stream seperately

Online Monitoring

- It includes the following tools to monitor the performance of the trigger w.r.t the trigger menu and algorithms running online:

  Online**H**istogram**P**resenter - **OHP**

  Trigger**R**ate**P**resente**r - TRP**

  Data**Q**uality**M**onitoring**F**ramework - **DQMF**

  - sophisticated tool for online data quality assessment
  - analyses histograms through user-defined (=signature) algorithms

    → displays DQ flag in red, yellow or green based on algorithm result

    → red flag: serious problem that needs to be checked, green flag: all is fine
  - the individual flags of checked histograms are combined into weighted status flags of the various sub-groups and the overall trigger system

Offline Monitoring

- Provides framework for data quality assessment
  - the trigger data quality is based on the express stream (~10 Hz of data)
  - if there are any deficiencies in the trigger algorithms defects are set

    → they provide important information to physics analyses about data taking conditions

- New development: **M**enu **a**ware **M**onitoring - **MaM**
  - offline monitoring of reprocessed data needs to be correct to allow the data quality assessment

  - links the offline monitoring configuration to the trigger menu configuration of a run

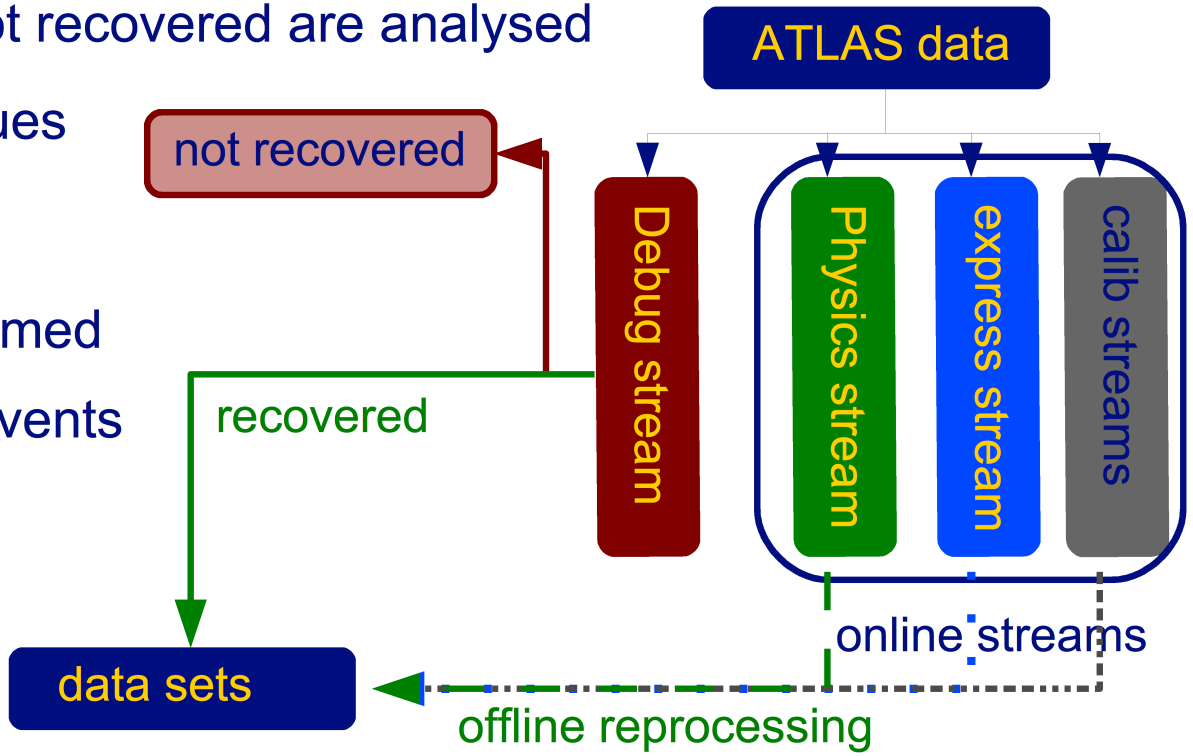
    → during reprocessing the correct configuration is automatically read from the DB

    → very flexible system, makes fast changes of monitoring configuration easy and possible

Offline Monitoring

Debug stream

- If the trigger fails to make a decision for an event due to various reasons, it goes to the debug stream
- most of these events can be recovered offline where there are no constraints on processing times on the algorihtms

  → recovered events are treated like online accepted ones
- small amount of events that are not recovered are analysed
  - often correlated to general issues with data/DAQ
  - if there are issues in a trigger algorithm, developers are informed
  - bugs leading to unrecovered events need to be fixed promptly

  → loss of data