The ATLAS trigger system

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on behalf of the ATLAS collaboration

INFN Trieste

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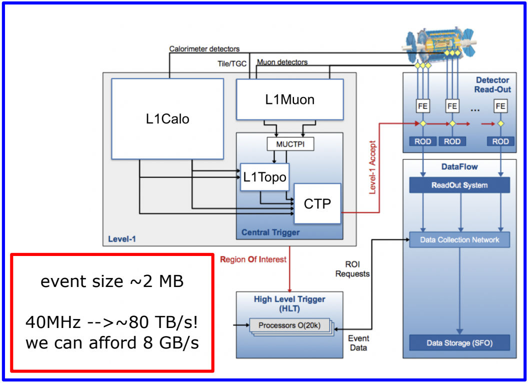
The ATLAS Trigger System



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Multilayered even selection:

- first selection performed by the Level-1 Trigger, providing pointers to Regions of Interest (RoI) in the detector
- RoIs are further explored in the software based High-Level Trigger (HLT) with full detector granularity

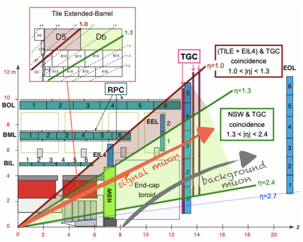
In Run 3: 40 MHz $\rightarrow$ 100 kHz (L1) $\rightarrow$ $\approx$3 kHz (HLT) for full physics events at a fixed latency (detector readout time window) below 2.5 μs
$\rightarrow$ rejection factor of $\approx$20 000

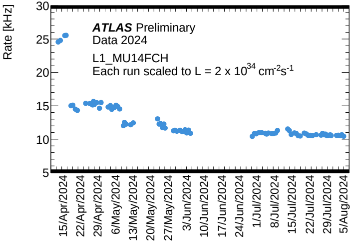
New for Run3: L1 Muon upgrade

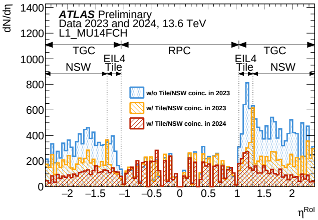
Muon trigger detectors partecipating to the trigger logic:
RPCs, TGCs, NSW ← new detector installed in Run3!

Coincidence patterns within parameterised geometrical "roads" to identify muons

- NSW coincidence activated in all sectors this year
- better discrimination against fake muon background
- ≈ 12 kHz L1 rate reduction!



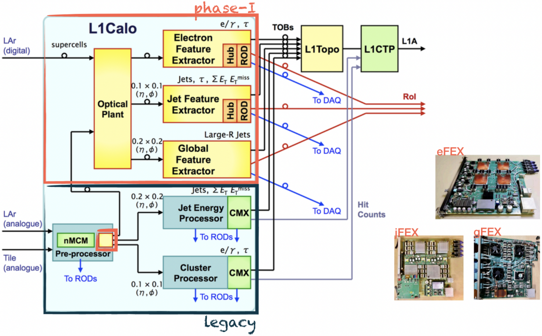




PLOT-TDAQ-2024-08

Uses calorimeter energy deposits as inputs to calculate trigger objects:

- Electrons, photons, taus
- Large and small radius jets
- Missing transverse energy



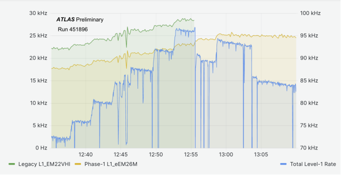
New for Run 3:

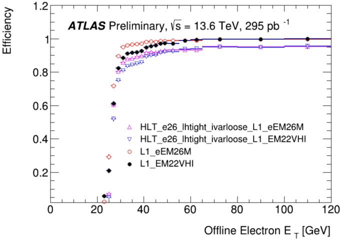
- Feature Extractors (FEXes)
  - eFEX: isolated e/y, taus
  - jFEX: jets, taus, missing transverse energy
  - gFEX: large radius jets, missing transverse energy
- New LAr Super Cells
  - Higher granularity and resolution to increase discrimination power
  - Higher efficiency, better pile-up robustness for EM triggers

New for Run3: L1 Calo upgrade (2)

Commissioning of the new system performed in steps:

- electromagnetic objects for the new Run-3 L1Calo trigger validated at the start of 2023 data-taking
- after tuning, allowed for up to 10 kHz rate reduction and an improved efficiency for isolated electrons
- 2024 data used to fully validate the rest of the system
- last "legacy" Triggers disabled recently
- overall performance improved





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Next: highlight of performance for more calorimeter objects

Improved performance w.r.t. legacy system:

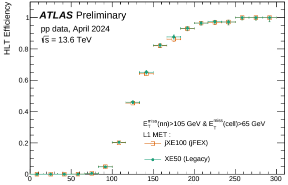
- primary E_T^{miss} trigger in 2024 based on jFEX
- significant effort spent on tuning PU weights
- at $< \mu > \sim 60$, HLT rate reduced by $\sim 20\%$ for chains seeded by jFEX L1 selection

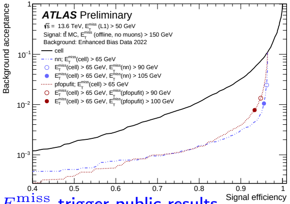
New HLT strategy:

- neural network with three hidden layers
- trained on all the E_T^{miss}, $\sum p_T$ and ϕ values for several E_T^{miss} algorithms (arXiv:2401.06630)
- signal efficiency improved by $\sim 1\%$ point
- reducing the background acceptance by $\sim 22\%$

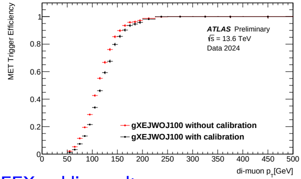
Expected for next year:

- discussing strategy for combining jXE and gXE seeds



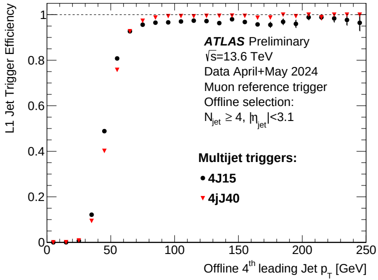


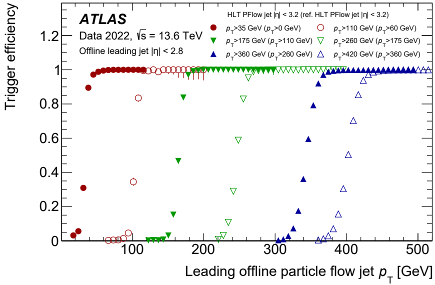
E_T^{miss} trigger public results



gFEX public results

- Phase-I jet identification is provided by jFEX
- higher efficiency of Phase-I system is attributed to a higher granularity
  $\rightarrow$ which allows for better resolution of close-by jets
- at the HLT, multi-jet chains exploit Full Scan tracking now (new for Run 3) and reconstruction is much closer offline Particle Flow jets





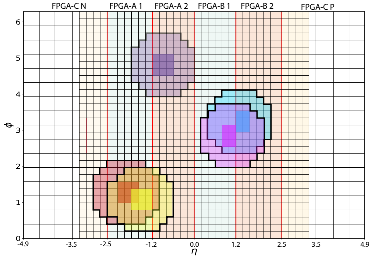
jet trigger public results, JINST 19 (2024) P06029

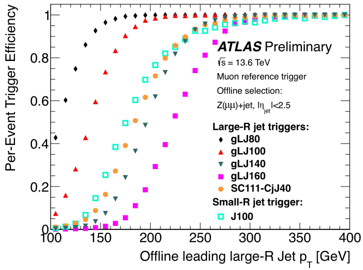
Jets (2)

New opportunities with the Phase-1 system: Large-R jets at L1

- gLJ trigger items are based on large-R jet objects from gFEX
- Jet Finder algorithm responsible to identify jet objects:
  - small block corresponding to small-R jets
  - large-R jets area built with a seeded cone algorithm
  - pile-up correction by subtracting the energy density per trigger tower
- alternative large-R jet object created in L1Topo
  - based on reclustered small-R jets with $p_{\mathrm{T}} > 40$ GeV from jFEX

L1 item	Rate at $L \sim 2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
gLJ140	2.3 kHz
SC111-CjJ40	3.7 kHz
J100	4.3 kHz

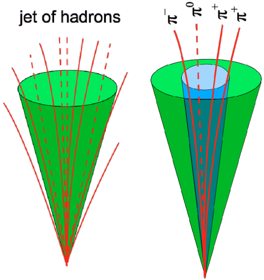


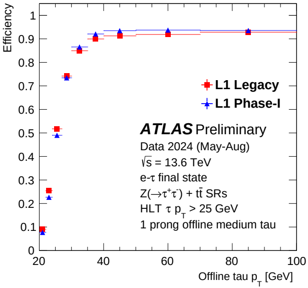


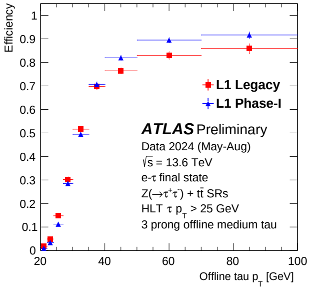
L1calo public results

Tau

- L1-Tau items combine inputs from eFex and jFex systems
- improved isolation thanks to high granularity
- tuning of standalone/combined systems crucial
- calorimetric and tracking information are then combined at the HLT via ML algorithms (RNN)
- current Phase-1 L1 seeded HLT tau trigger performs better to Legacy L1 seeded triggers at plateau







tau trigger public results

Trigger Menu

Many more physics objects identified by the HLT system:

- electrons, photons, and muons
- dedicated triggers for B-physics and light states
- triggers exploiting tracking for unconventional signatures (LLP)

The collection of trigger chains and the corresponding set of rules defining their rates is called Trigger Menu: it defines the Physics program and reach of ATLAS

Design is driven by:

- Physics priorities aiming to record a balanced dataset for analyses
- Representative of major processes
- High efficiency for rare processes
- Supporting triggers for calibration, efficiency measurements. . .

Signature	Rate per stream [Hz]		
	Main	Delayed	TLA
Electron	270		
Photon	120		
Muon	290		
Tau	160		
Missing transverse momentum	140		
Unconventional Tracking	40		
B-physics and light states		240	
Jet	490	460	5000
Jet with *b*-hadrons	190	160	
Combined	240	50	830

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Different menus defined for specific purposes and conditions:

- proton-proton and Heavy Ion physics
- Cosmics data taking or Standby running when no LHC collisions

Trigger Menu optimised with physics coordination to achieve:

- maximum physics output
- keep L1 rate around 95 kHz to minimise deadtime from readout
- total output bandwidth must not exceed 8 GB/s
  - part of the farm dedicated to MC simulation and other ATLAS computing needs
  - space for new ideas/physics needs
- balancing act between rate versus deadtime and system stability

Menu varies with luminosity and time

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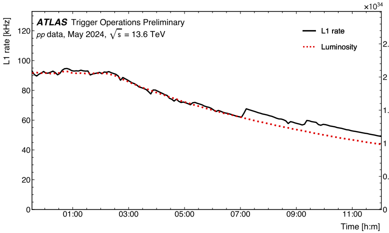
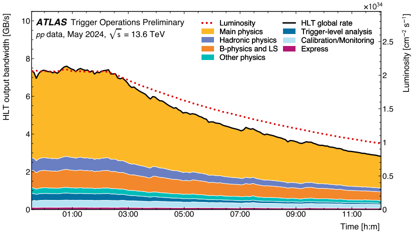
constantly fine-tuned according to running conditions and new developments





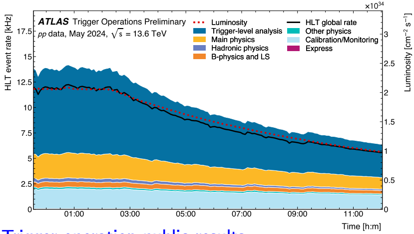
Trigger operation public results

Extended in Run3: usage of delayed streams

- increase in the farm capacity enables a larger recording bandwidth but we can't reconstruct promptly all the events recorded offline
- events in the b-physics and hadronic streams undergo offline reconstruction when resources allow it

Extra data saved with Trigger Level Analysis (TLA)

- only records the Trigger results (much smaller payload)
- possibility to save data at higher rates
- increased physics reach for low energy systems



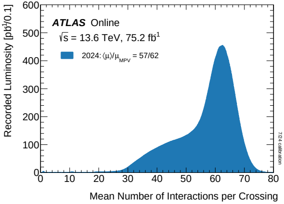
Trigger operation public results

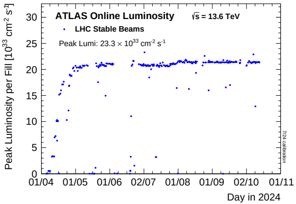
Huge rate reduction achieved in steps during 2024

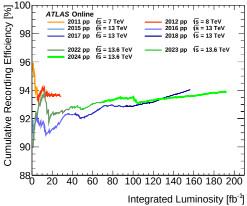
- NSW included in muon trigger coincidence
- full commissioning of Phase-1 L1calo

Allows ATLAS taking data at unprecedented luminosity level!

- stably sustaining 65 interaction per bunch crossing delivered by the LHC
- total L1 rate below 95kHz
- data-taking efficiency > 95%







Luminosity public results

L1 limitations drop as soon as luminosity decrease

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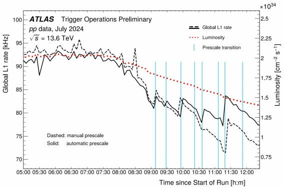
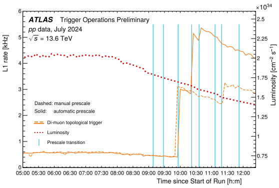
effort to exploit extra available rate

New offfline tool that optimises the available end of fill resources based on a prioritised list of triggers

- iterative data-driven optimisation of the rates
- target L1 rate of 85kHz, 7.5 GB/s HLT bandwidth
- currently used for b-physics and HH triggers, open to new requests
- long term project: real-time optimisations!



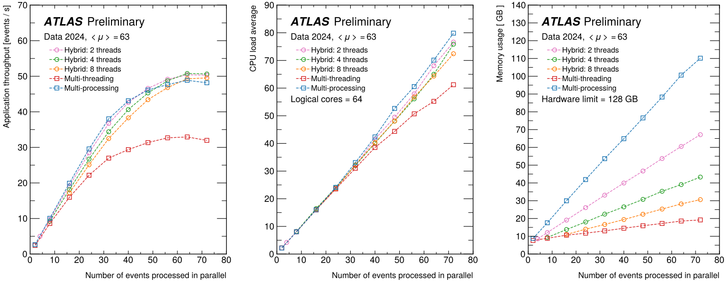


Trigger operation public results

HLT farm and CPU

New for Run 3:
multi-threading to simultaneously process events with a single HLT process

- only a small amount of memory needed for each additional event processing slot (O(180Mb))
- measurements indicate limits due to the the number of threads
- likely reducing the per core performance due to internal locks in sections of the code.



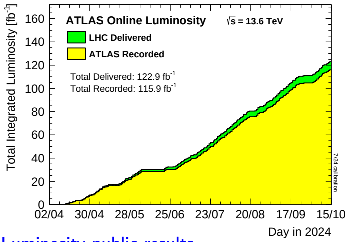
(Measurements performed in a standalone local environment using a machine identical to those used in the ATLAS HLT computing farm during data-taking, running Alma9)

Trigger Core SW public results

Conclusions

Very important year for the ATLAS trigger system

- huge run3 milestone: completion of Phase-1 commissioning!
  - full integration of the NSW in the trigger logic
  - L1calo upgrade fully exploited to maximise physics output from hadronic signatures
- long year of data taking
- good LHC performances
- more than 100 fb-1 collected by ATLAS!
- now preparing for Heavy Ions → new challenges!



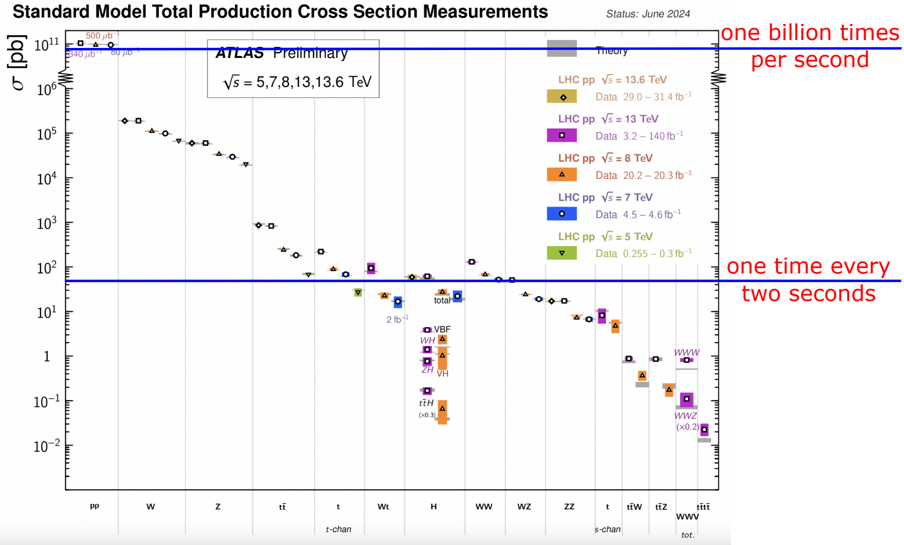
Luminosity public results

And already looking at the future

- up to 200 collisions per bunch crossing expected to be delivered by the HL-LHC
- new inner detector system
- R&D for increased usage GPUs and FPGAa both at hardware and software level
- large number of Machine Learning techniques being explored/investigated
- several talks from ATLAS members covering these topics!

Backup slides

Why do we need a trigger system?



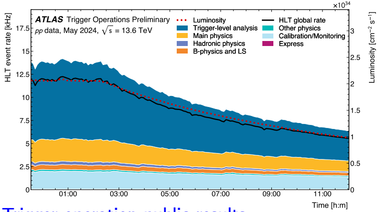
- Fast custom-made software running on CPUs
- Uses offline-like algorithms to reconstruct objects, in steps
  - Fast reconstruction, often guided by RoIs
  - Precision, slower, reconstruction on full detector data
- Applies physics selection
- The data is processed on a computing farm with 60,000 real CPU cores
- CPUs not used by the trigger system, can be used for MC generation and other ATLAS computing needs

Once an event is accepted by the HLT,
it is recorded and processed at Tier-0 and distributed to the GRID for physics analyses

HLT farm and CPU

Several improvements during 2022/2023 to reduce CPU requests:

- overallocation
- ROS prefetching to speed time to access the data from the detector when several RoI are identified
- improved HLT algorithms (full scan tracking, photon isolation. . .)
- multi step selections to avoid running costly algs on all event (ie met)



Trigger operation public results

Currently no limitations for this side!

- part of the farm dedicated to MC simulation and other ATLAS computing needs
- space for new ideas/physics needs