The ATLAS Trigger System

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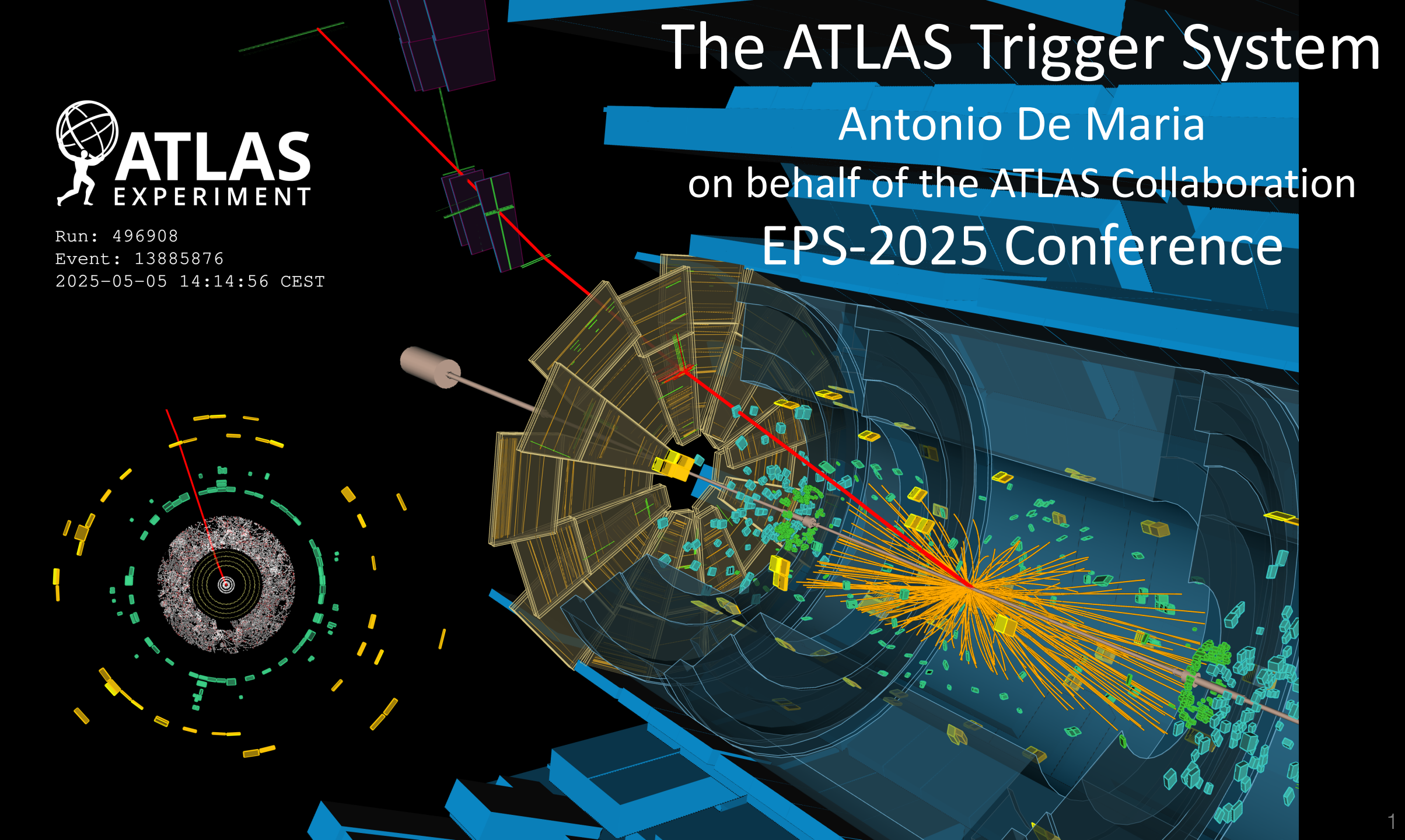
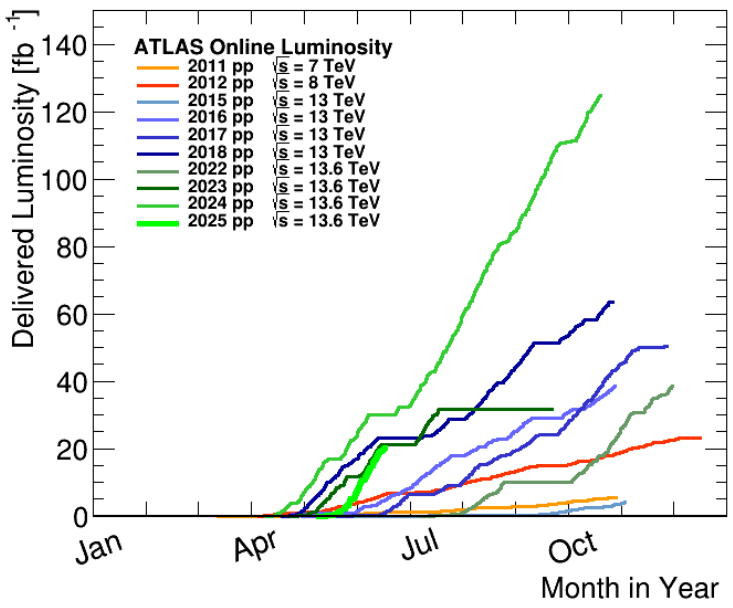
on behalf of the ATLAS Collaboration

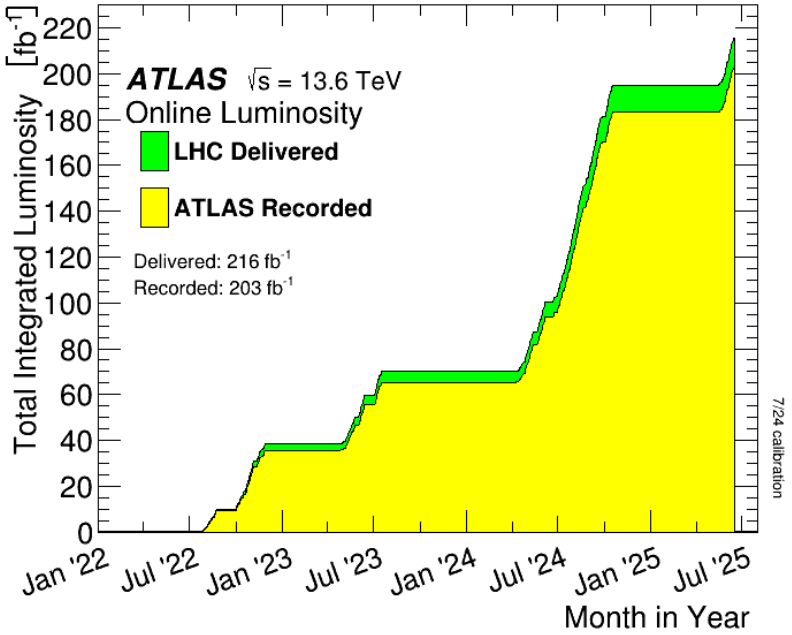
EPS-2025 Conference

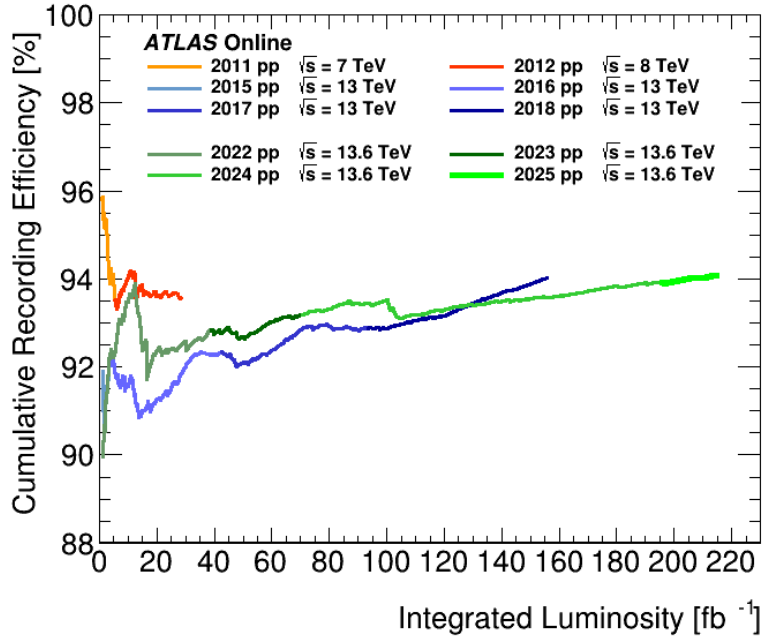


ATLAS data taking status towards 2025

- 2024 was a very productive year for LHC/ATLAS, with a collected dataset of 118 fb^{-1}
- In total, collected over 203 fb^{-1} in Run 3, way more with respect to Run 2 (147 fb^{-1})
- Running at peak luminosity ~ $2.2 \cdot 10^{34} cm^{-2} s^{-1}$, with an average number of interactions per bunch crossing $< \mu > \sim 64$
- Recording efficiency ~ 94%, increasing as data-taking continues:
  - Careful follow-up of all issues causing dead-times
  - Continuously improving all systems to be more robust against failures/mistakes

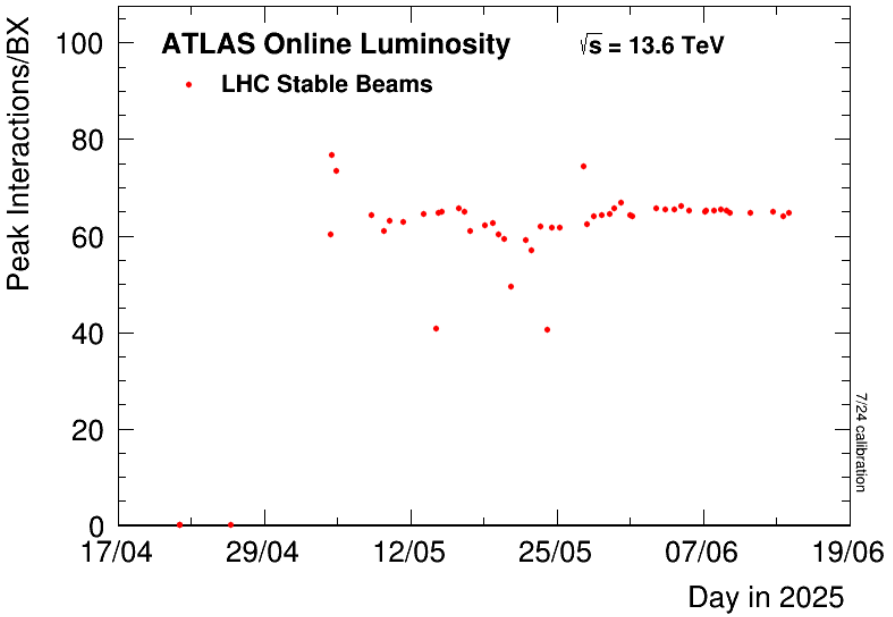


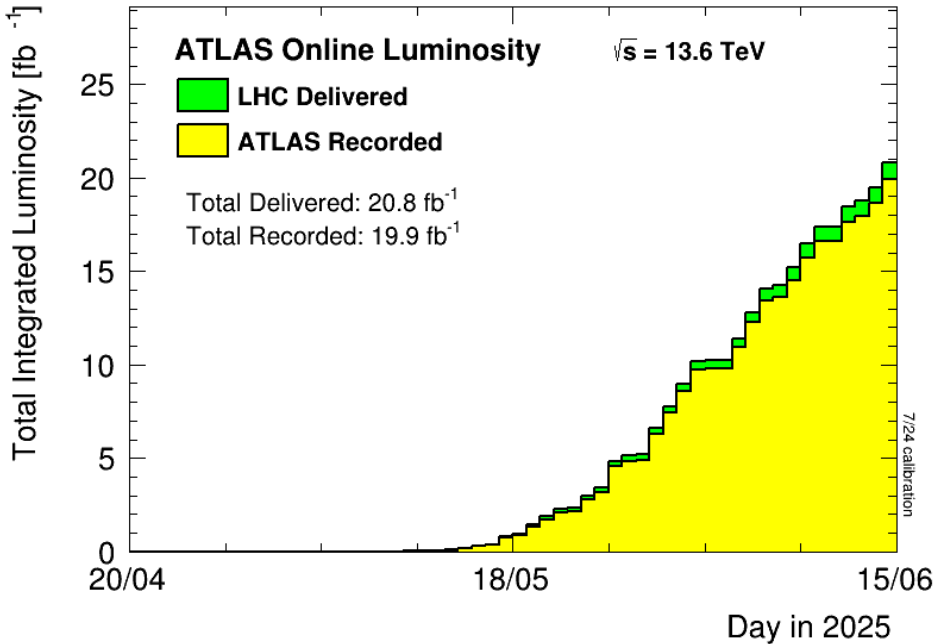


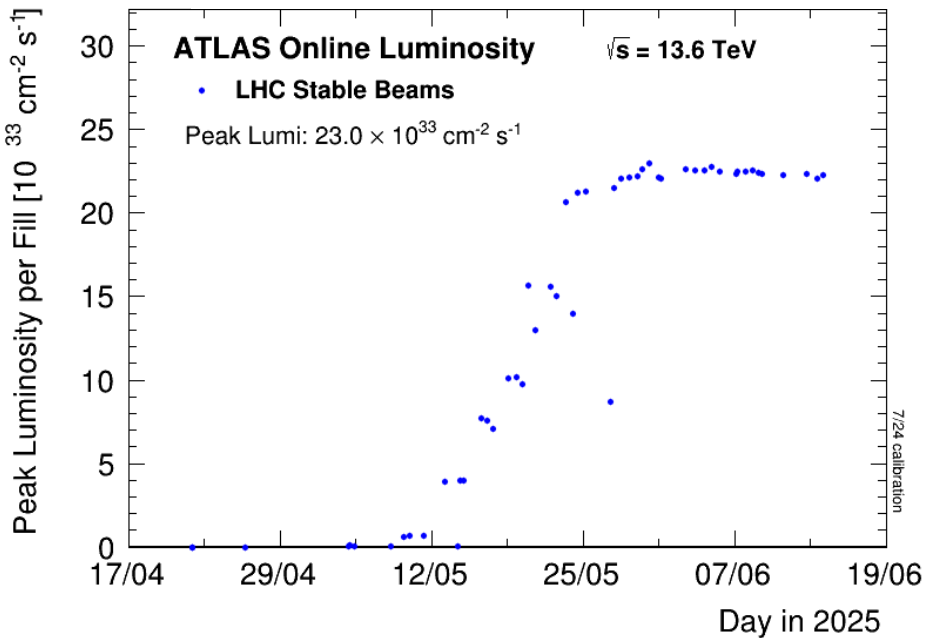


2025 data taking first results

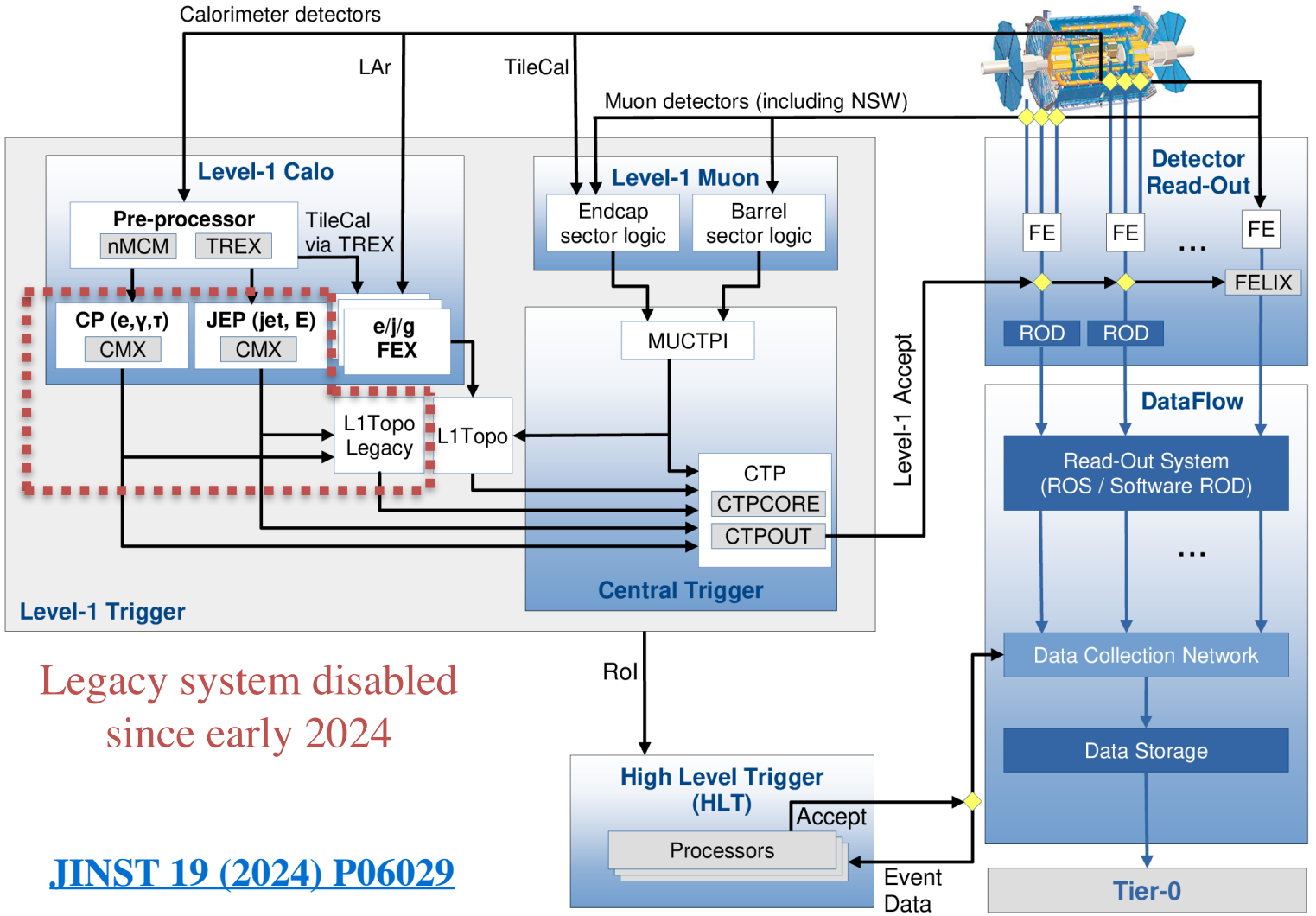
- Already collected ~20 fb^{-1} running also at higher peak luminosity with respect to last year
- Luminosity "levelling" allow to keep a constant pileup over time
  - Target set at the performance limit of the detector to ensure high efficiency
- Detector operational fraction in most of the systems close to 100%







The ATLAS trigger system



Legacy system disabled since early 2024

[JINST 19 (2024) P06029]

LHC collision rate & event size

40 MHz — 3.0 MB

Level-1 accept rate

100 kHz — 300 GB/s

HLT output to storage

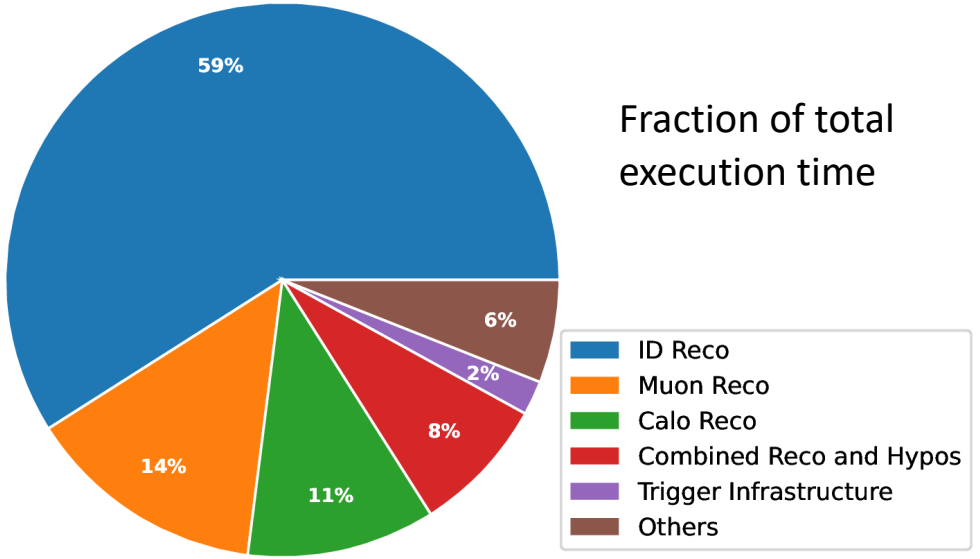
3 kHz — 6 GB/s

- Level-1: hardware based, limited by detector readout. Performs initial object reconstruction and event selection
- High Level Trigger (HLT): access events filtered by Level-1 and perform more sophisticated event reconstruction/selection. Reaching 3 kHz output to storage for full event-building

- Crucial to filter and record only "interesting" events to fulfil the ATLAS Physics programme

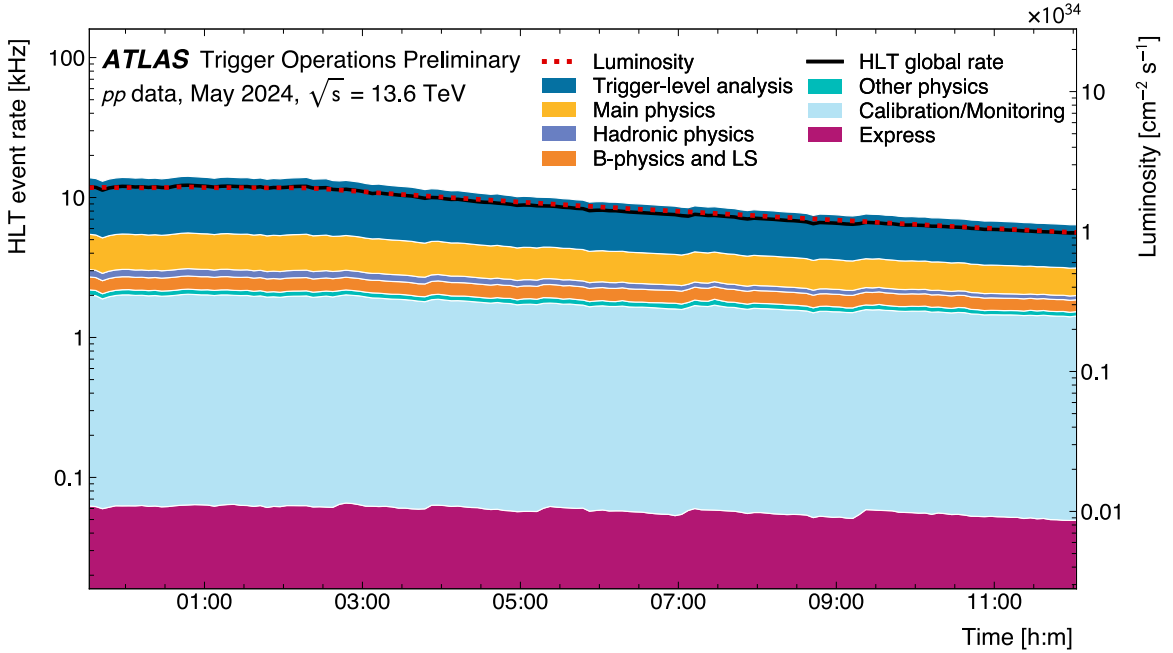
The ATLAS trigger menù

- The trigger menù is designed to cover all signatures like electrons, muons, photons, taus, jets relevant both for SM measurements and BSM searches
- Different triggers for the different streams to ensure maximum complementarity for different physics measurements
- Most of the reconstruction time taken by Inner Detector reconstruction (tracking), followed by Muon reconstruction



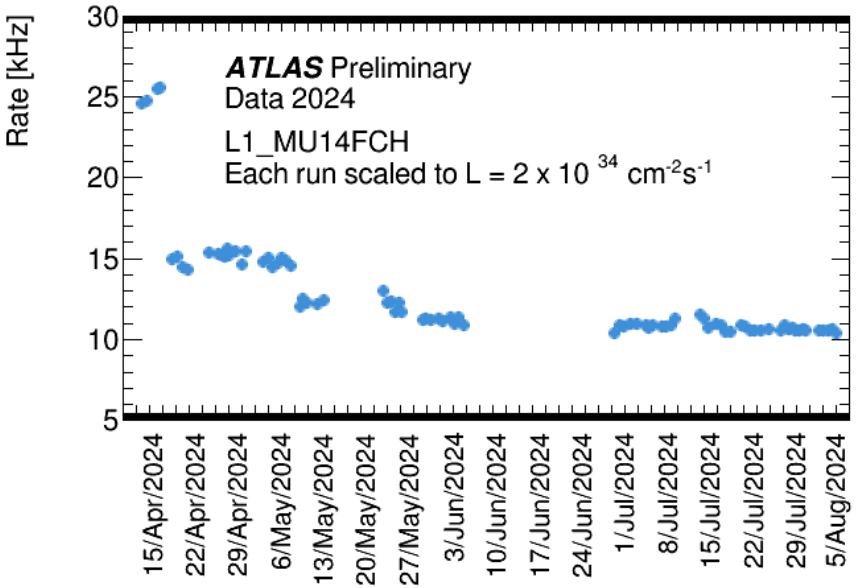
Fraction of total execution time

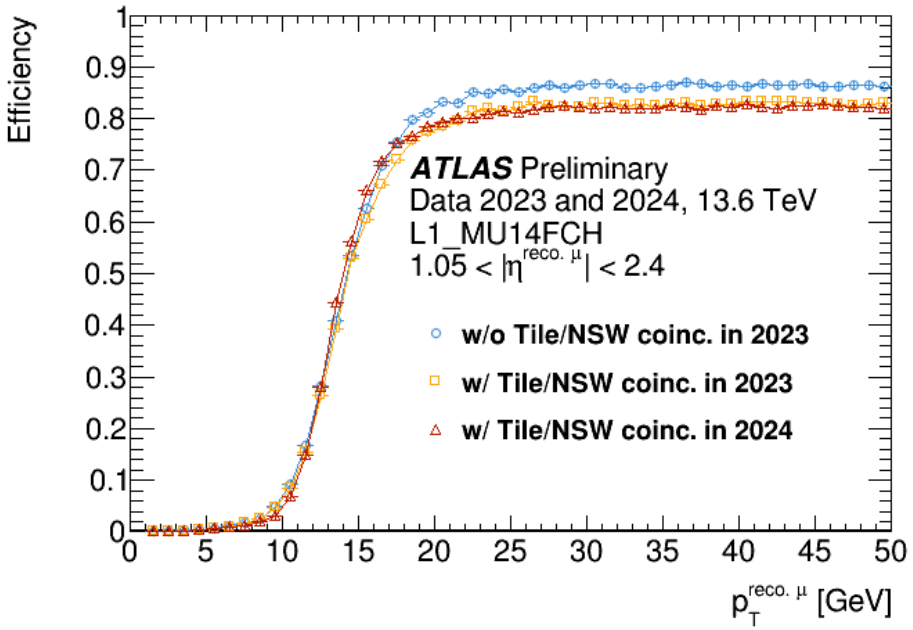
Signature	Rate per stream [Hz]		
	Main	Delayed	TLA
Electron	270		
Photon	120		
Muon	290		
Tau	160		
Missing transverse momentum	140		
Unconventional Tracking	40		
B-physics and light states		240	
Jet	490	460	5000
Jet with *b*-hadrons	190	160	
Combined	240	50	830

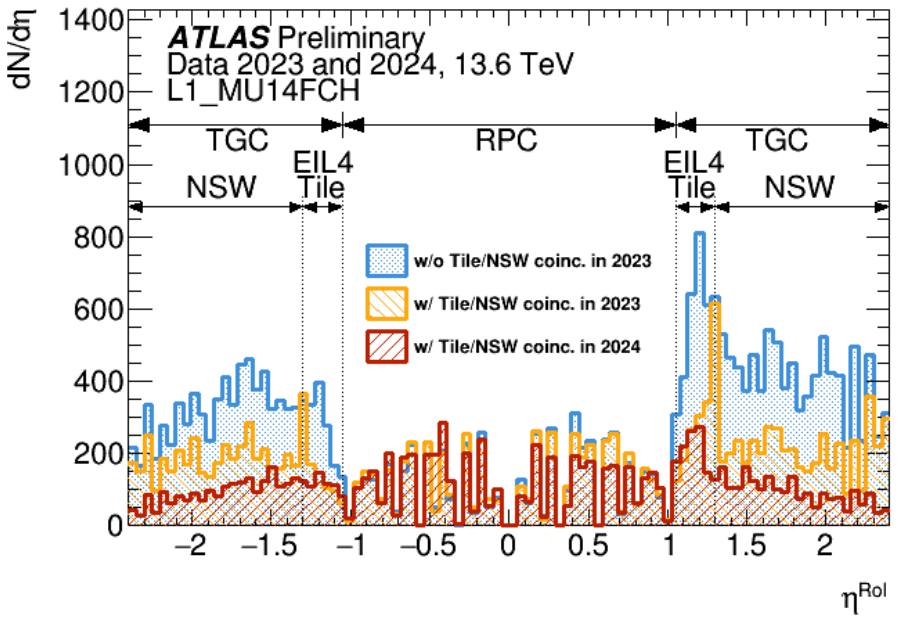


Level 1 Muon performance with New Small Wheels

- Inner coincidence in 2024 allowed to reach the expected luminosity compatible with maximum L1 rate and dead time
- Overall rate reduction of 15 kHz, including the contribution from the Tile Muon Trigger
- More on this in the talk by T. Saito

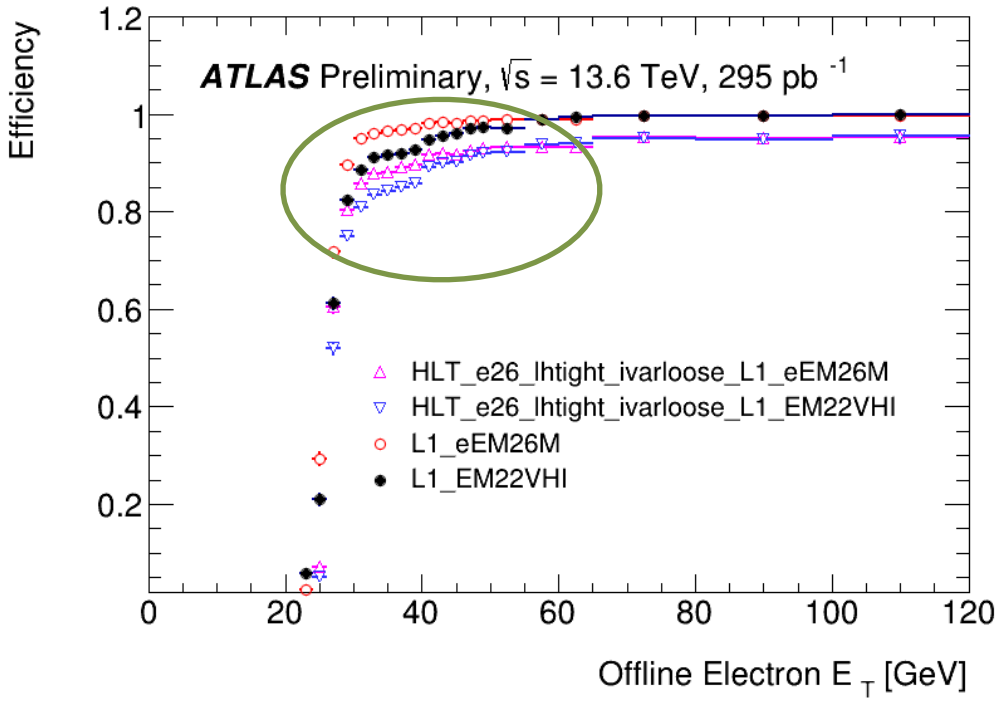


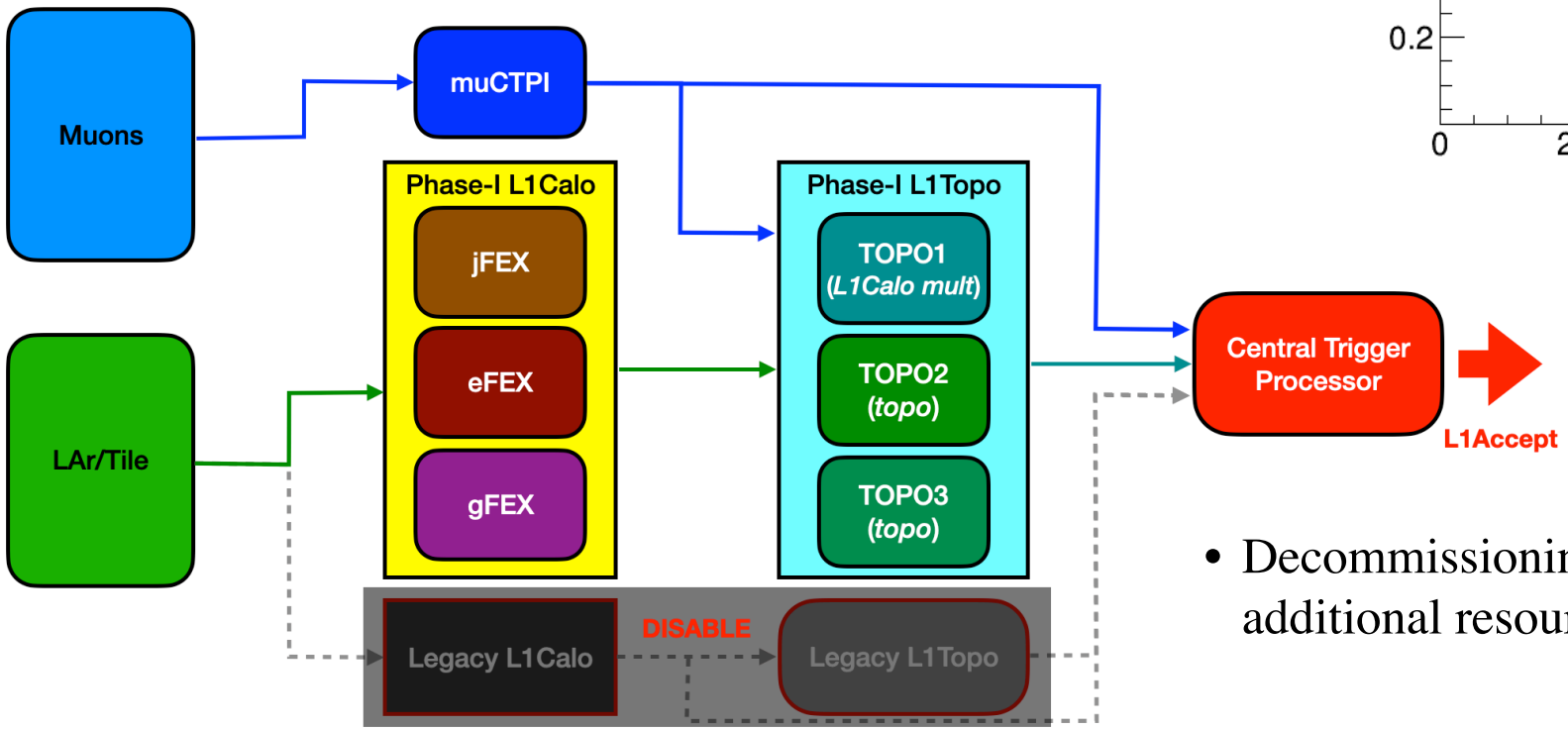




Level-1 Calo updates

- Level-1 (L1) Calo migration to Phase-I FPGA based system completed:
  - Improvements over Legacy L1 system already seen in 2023 data taking for electron trigger
- Tau/Jet triggers migration/validation finished in early 2024:
  - Longer time scale due to trigger object complexity and sizeable amount of data to be collected for proper validation

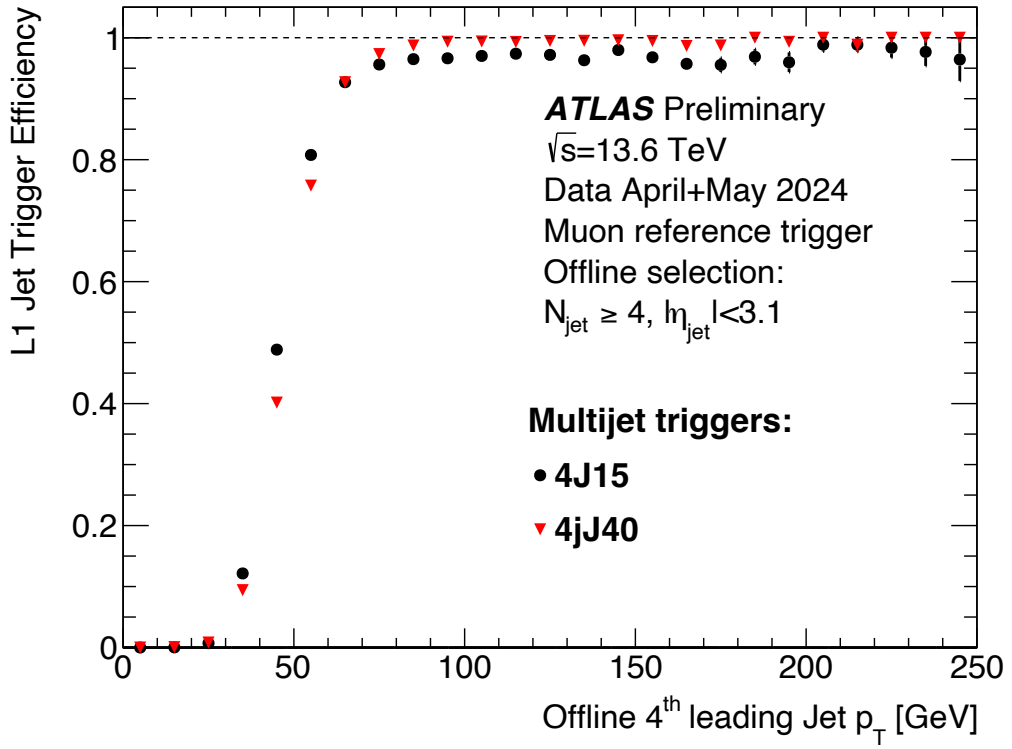


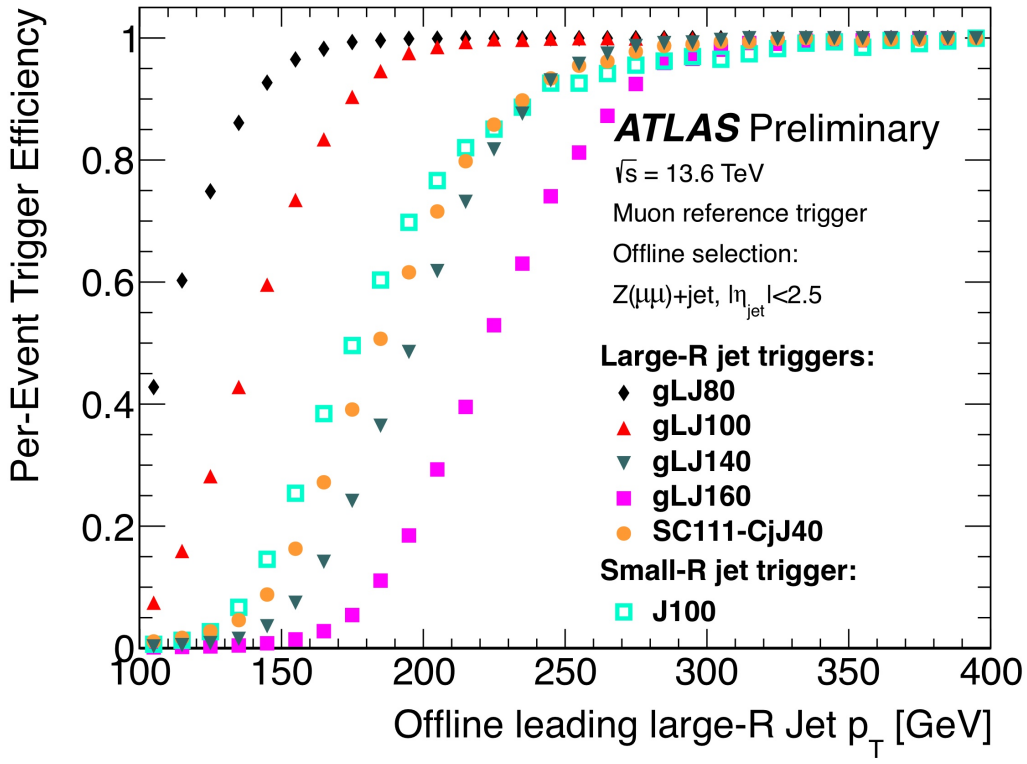


- Decommissioning of Legacy L1 system provides additional resources for next trigger developments

Jet trigger updates

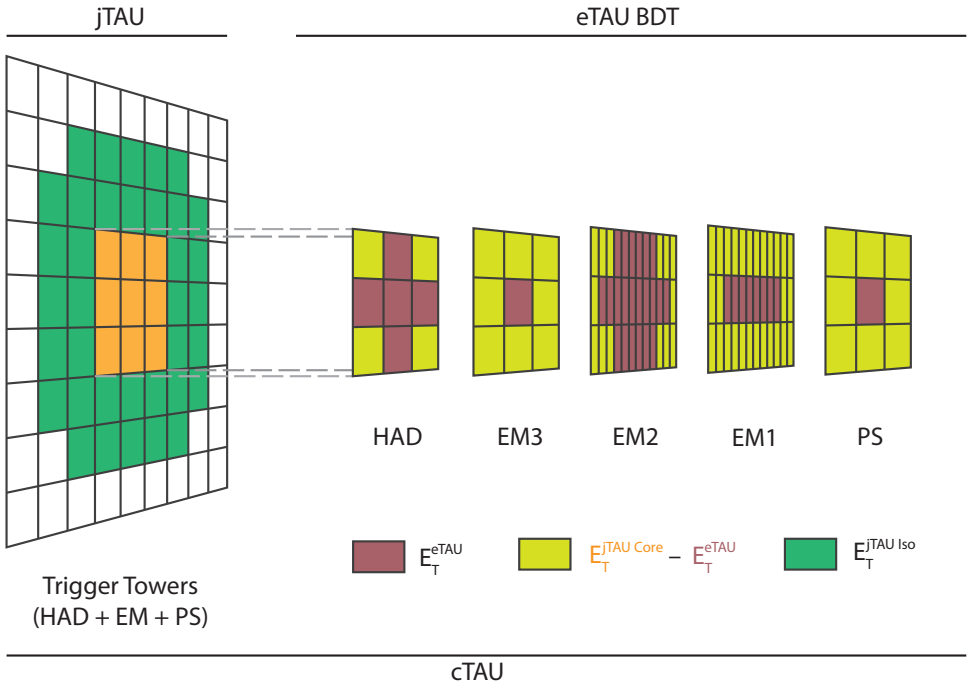
- Use different FEX boards to cover different jet reconstruction
- jFEX: used for small R-jets (R=0.4); allows to better resolve 2 close-by jets improving the efficiency for multi-jet triggers with respect to the legacy Level-1 system
- gFEX: used for large R-jets (R=0.9); improvements using Phase-1 system allows better efficiency and better calibration capability





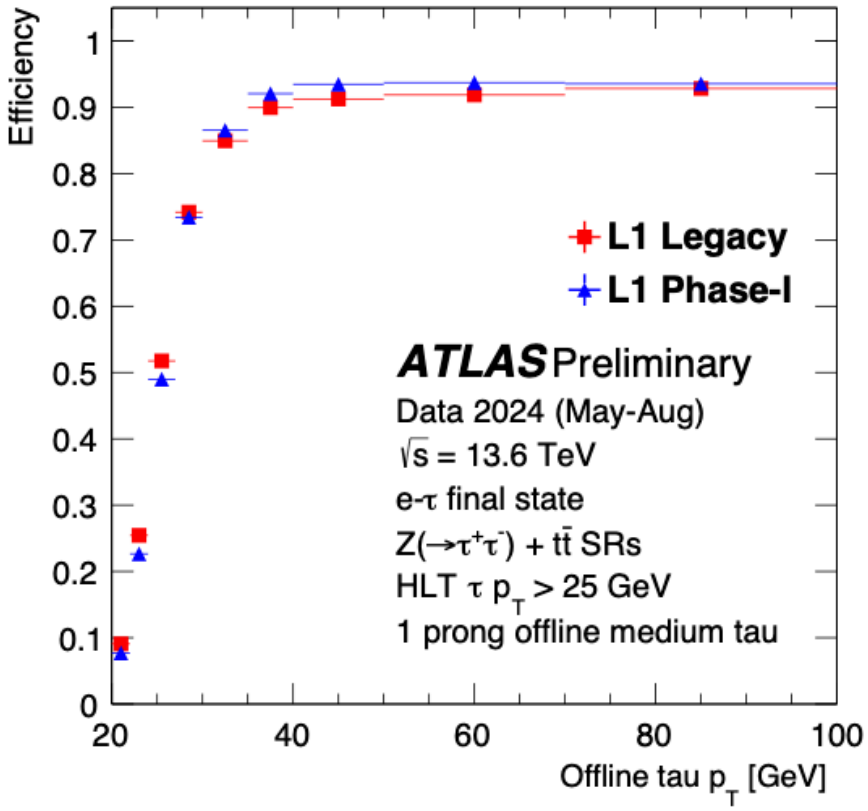
Phase-I L1 Tau performance

- L1-Tau involves L1 Topo matching of inputs from eFex and jFex systems for high trigger efficiency at low rate
  - Continuous tuning of standalone/combined systems is crucial to get best performance
  - Current Phase-1 L1 seeded HLT tau trigger performs better than Legacy L1 seeded triggers
    - Important to get more "good" data at low pt regime for BSM/Di-Higgs searches



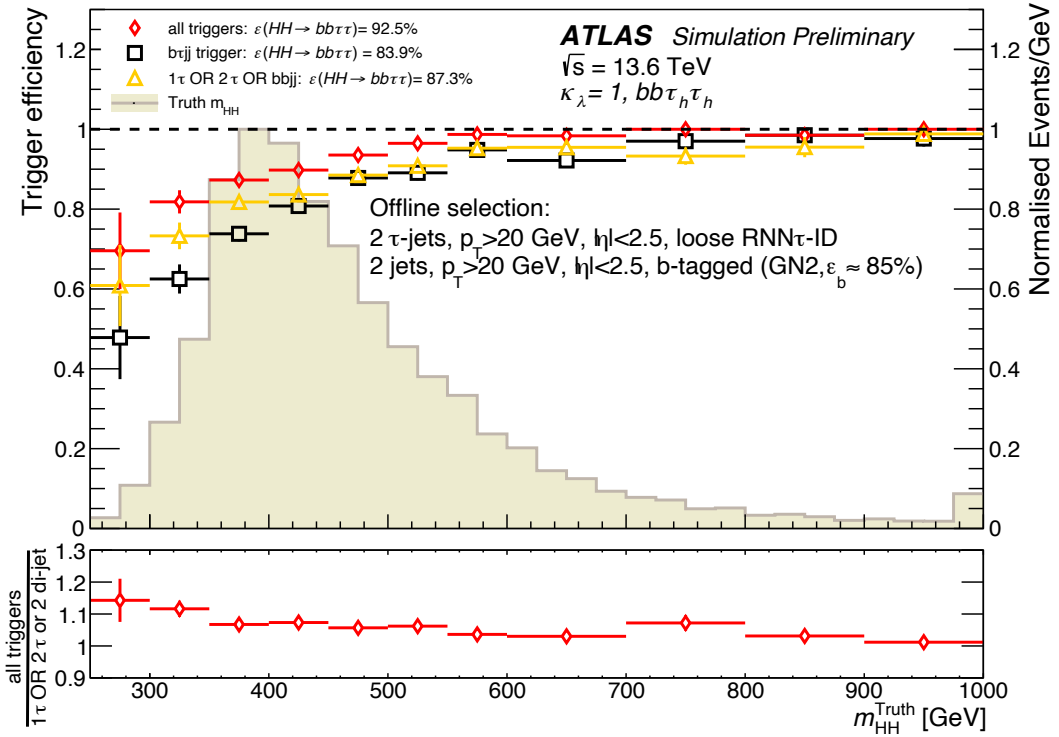
Isolation condition: (if matched)

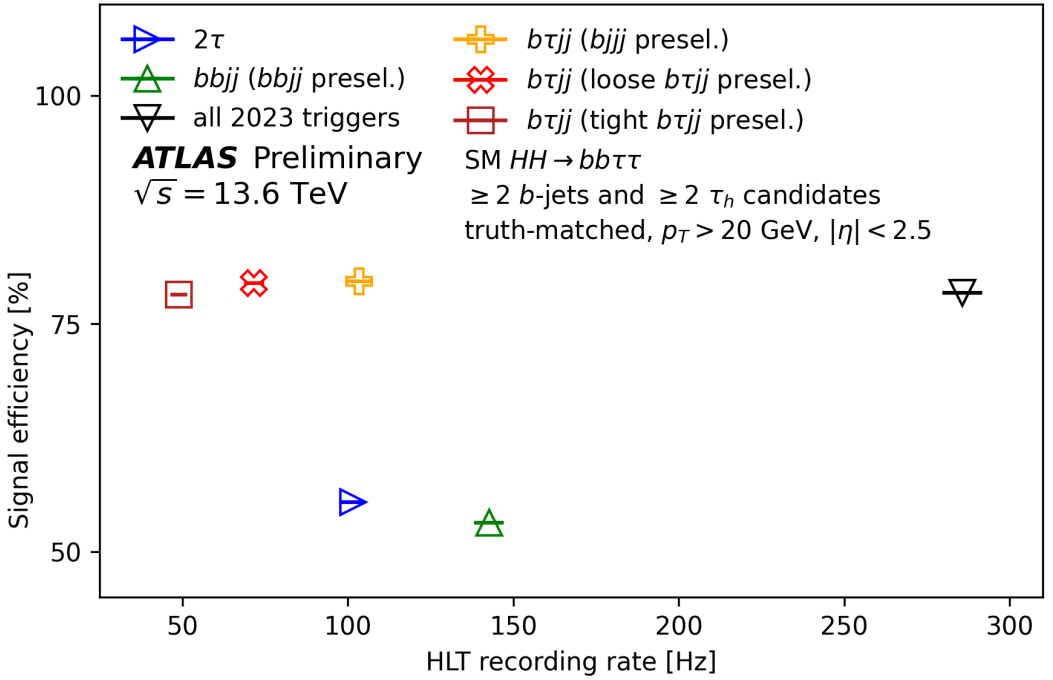
$$\frac{E_T^{jTAU\ Iso} + \alpha\,(E_T^{jTAU\ Core} - E_T^{eTAU})}{E_T^{eTAU}} < r$$



New b+tau triggers

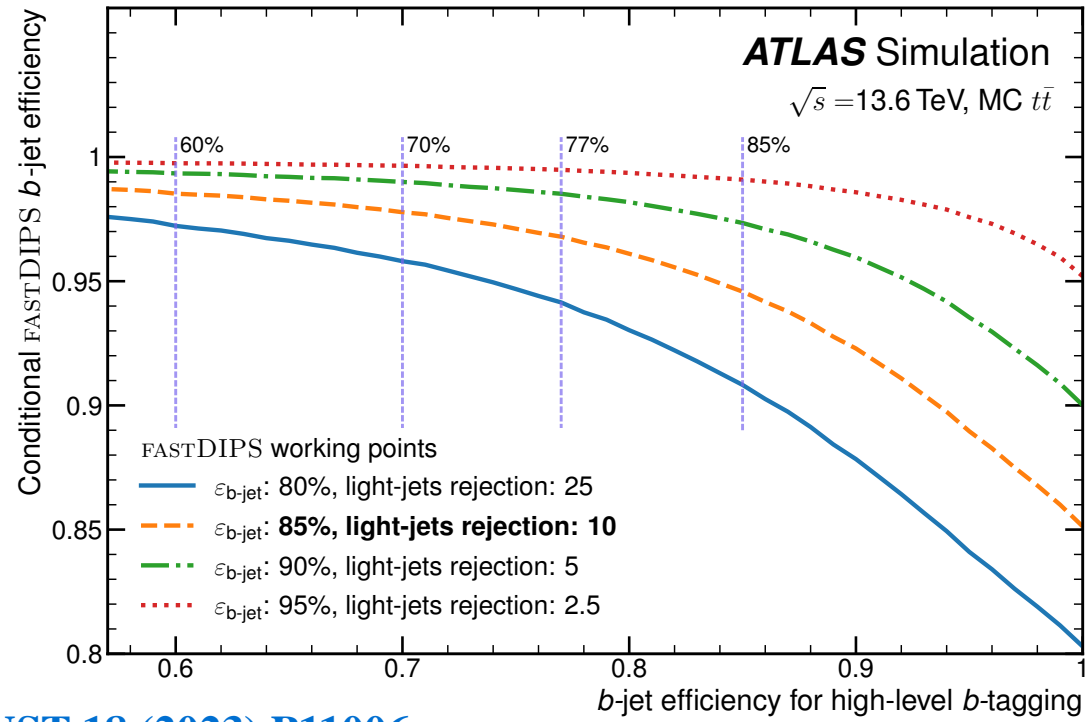
- Strongly motivated by Di-Higgs search in bbtautau final state, one of the golden channels in the latest Run2 ATLAS Di-Higgs search combination (Phys. Rev. Lett. 133 (2024) 101801)
- New trigger using b+tau selection at HLT allows to increase analysis acceptance in particular for low Di-Higgs mass region, recovering low pt phase space region
  - Dedicated "pre-selection" stage at HLT allows to keep tracking rate at sustainable level
- This trigger was introduced in 2024 and now stable part of the ATLAS trigger menù



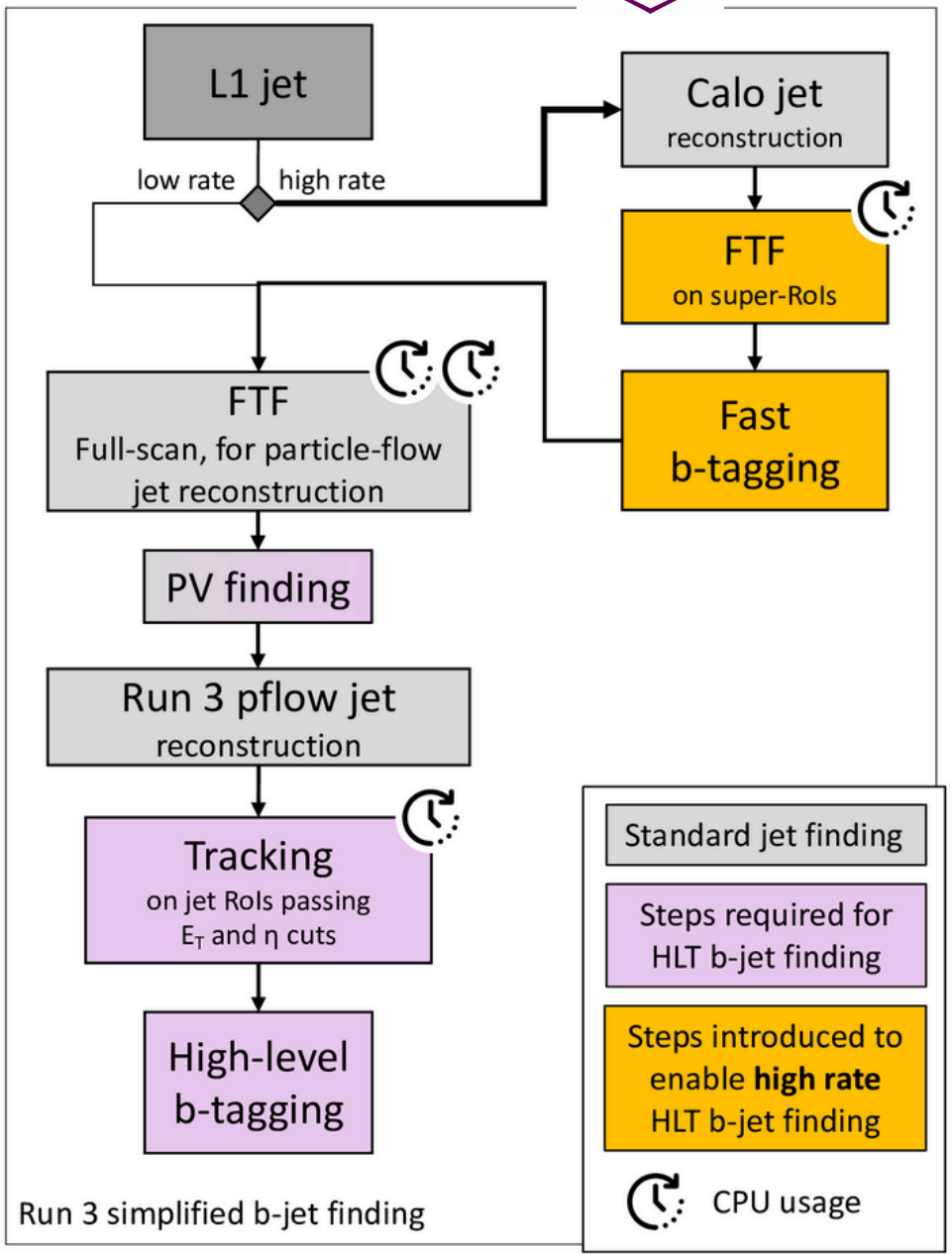


Bjet trigger object reconstruction

- Fast b-tagging provides a rejection factor of 5-10 for events entering the precision b-tagging algorithms
- Fast track finder (FTF) over full detector acceptance ("full-scan"); followed by PFlow jet reconstruction
- Precision tracking around PFlow jets, mimicking similar condition as offline b-jet tagging

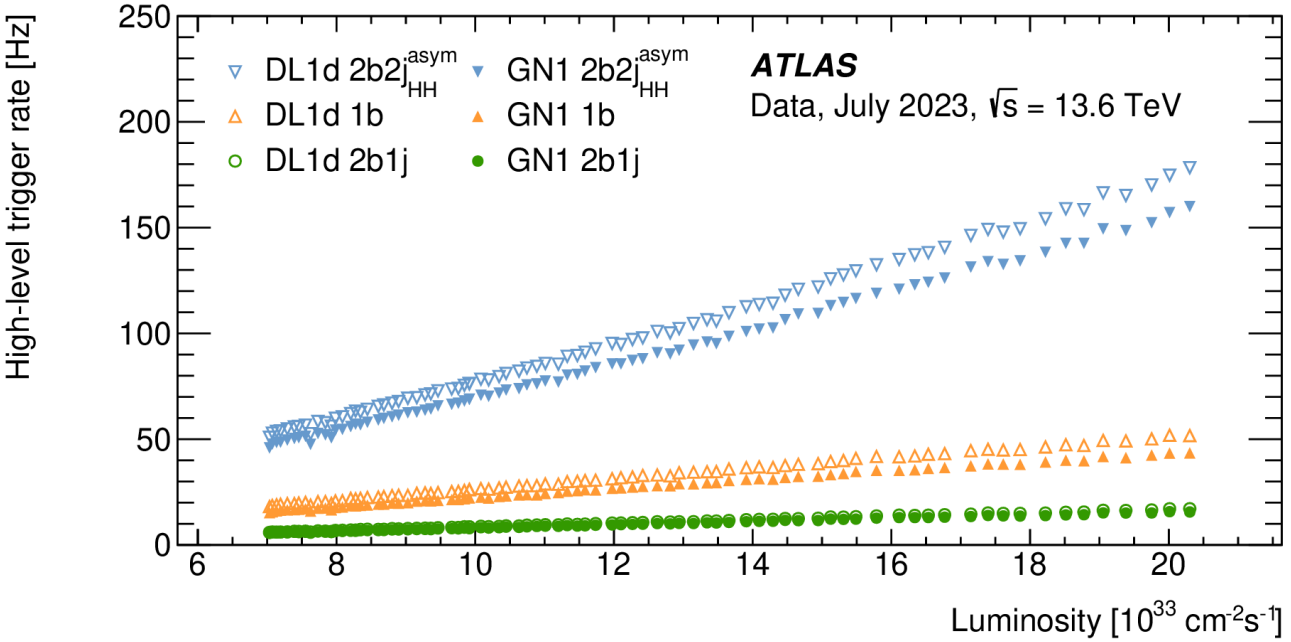


[JINST 18 (2023) P11006]

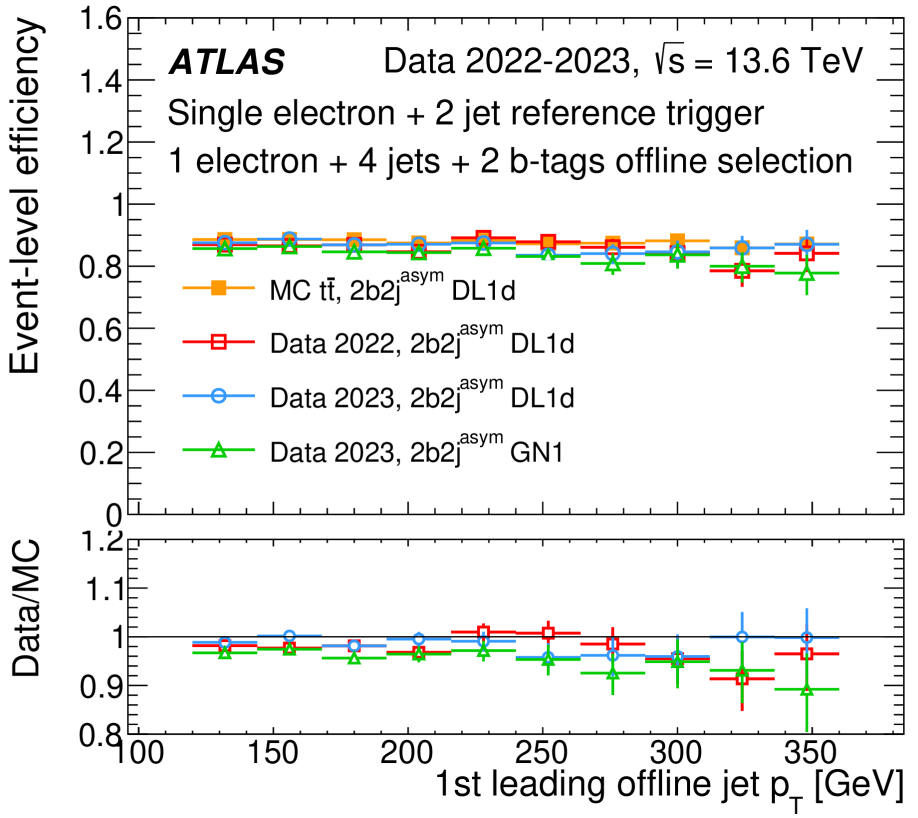


Bjet trigger object identification

- Graph Neural Network (GNN) is used both in fast b-tagging and at the last identification step at HLT level
  - provides improvements over previous tagging method (DL1d) reducing the trigger rates at the similar efficiency level
  - factor two improvement in light-flavour rejection
- Increase in signal efficiency for bbtautau of up to a factor 1.7 relative to Run 2

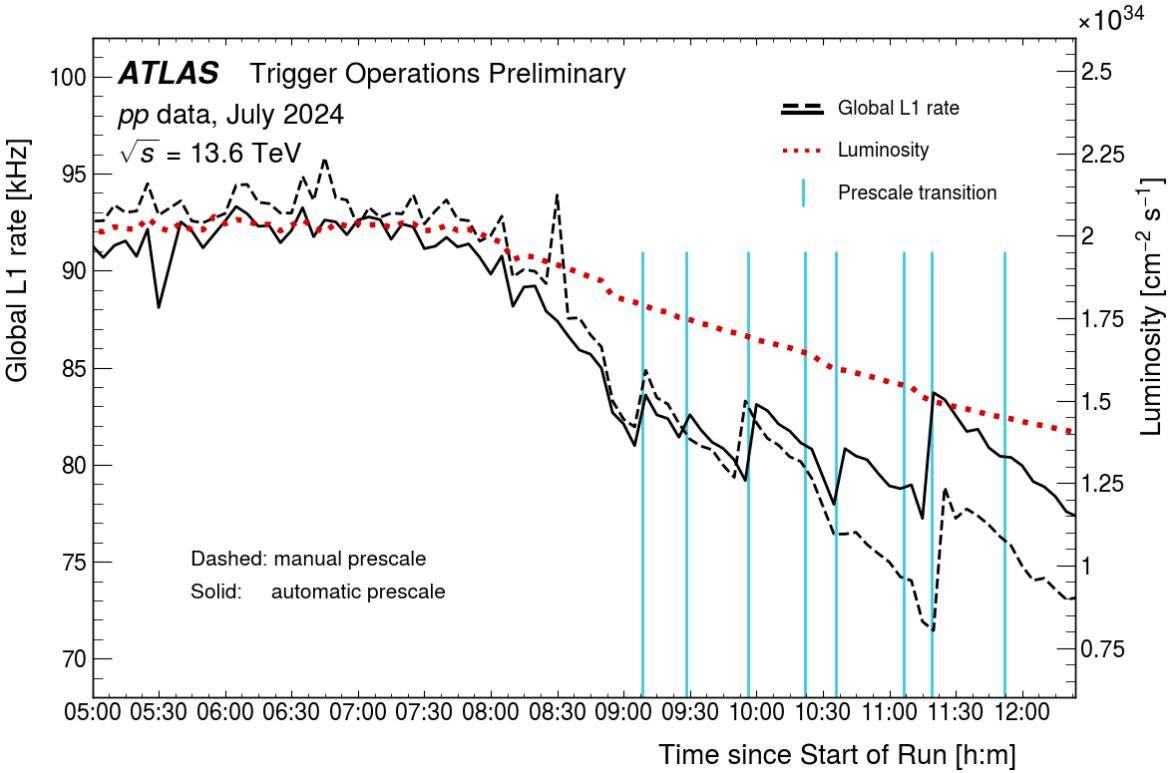


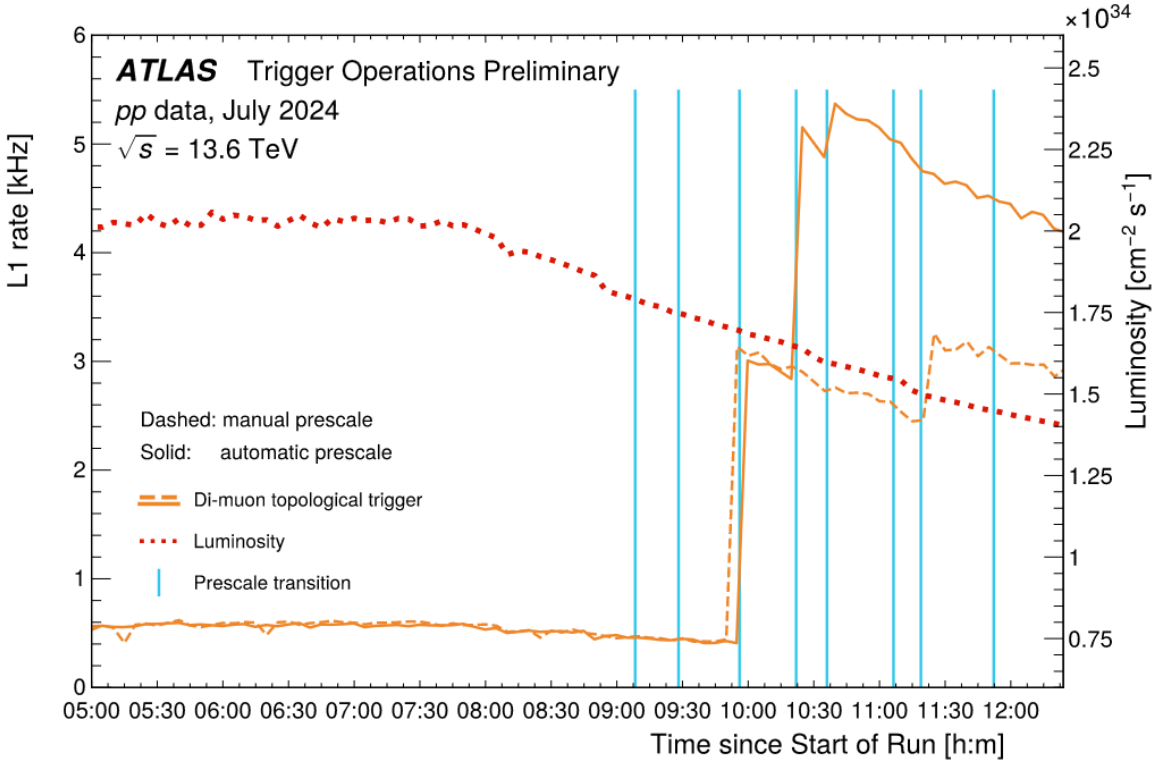
[JINST 20 (2025) P03002]



End of fill trigger automatised optimisation strategy

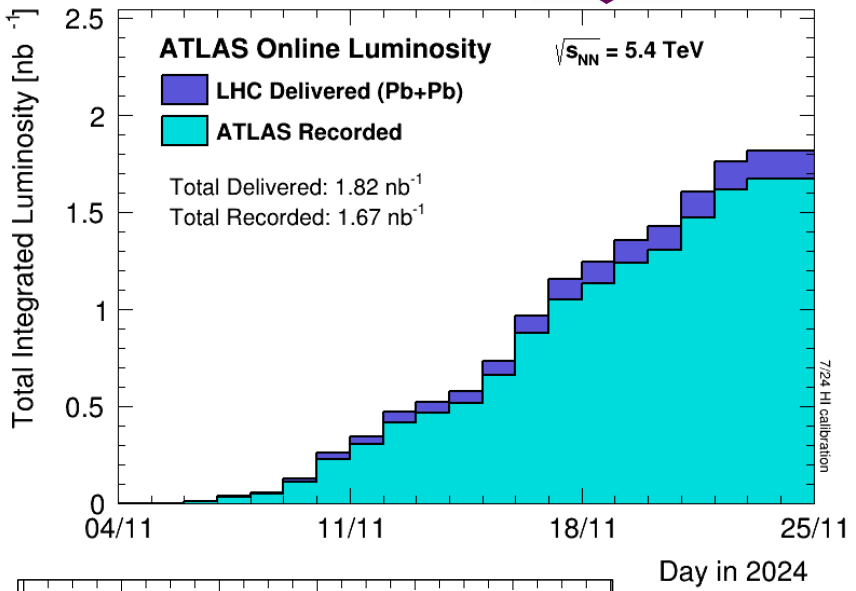
- As a run progresses the delivered luminosity decreases since less colliding protons in each bunch
  - Luminosity levelling is no longer effective
- Due to the lower luminosity, the rate of the various triggers drops creating “space” towards the end of run
  - Increase the rate of previously pre-scaled trigger chains based on physics-driven priority (e.g. Di-Higgs, BLS)

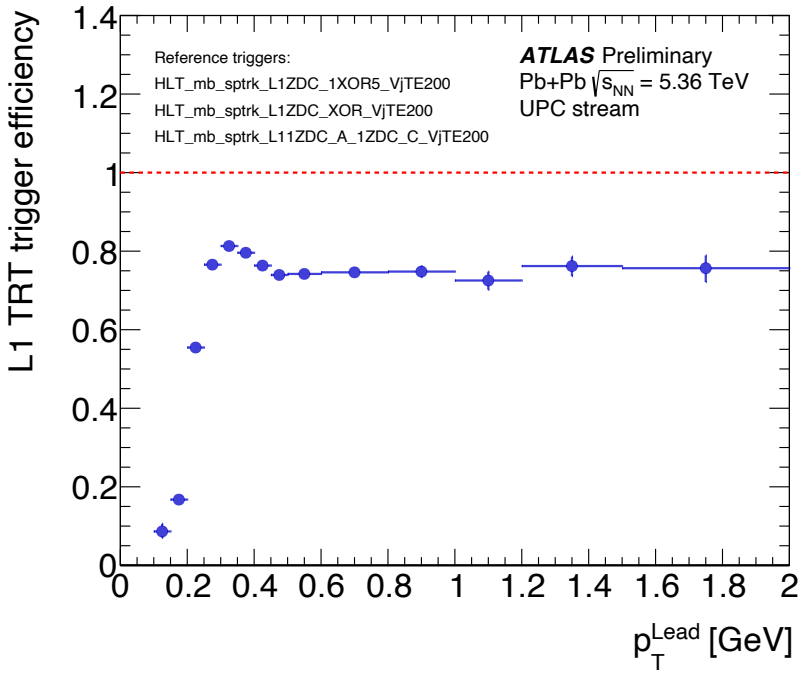


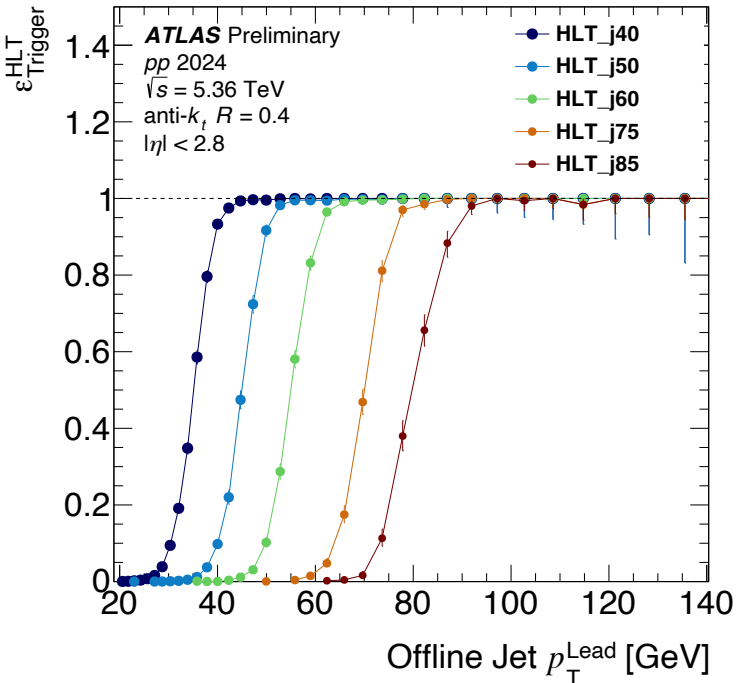


Heavy Ion

- In 2024 recorded 1.73 nb^{-1} with a data quality efficiency of ~98%; also for Heavy Ion switch to use exclusively Phase-1 L1 system
- Good HLT jet efficiency important to study for example the jet quenching
- Good L1 TRT trigger efficiency important to study Minimum Bias (MB) and Ultra Peripheral Collisions (UPC)

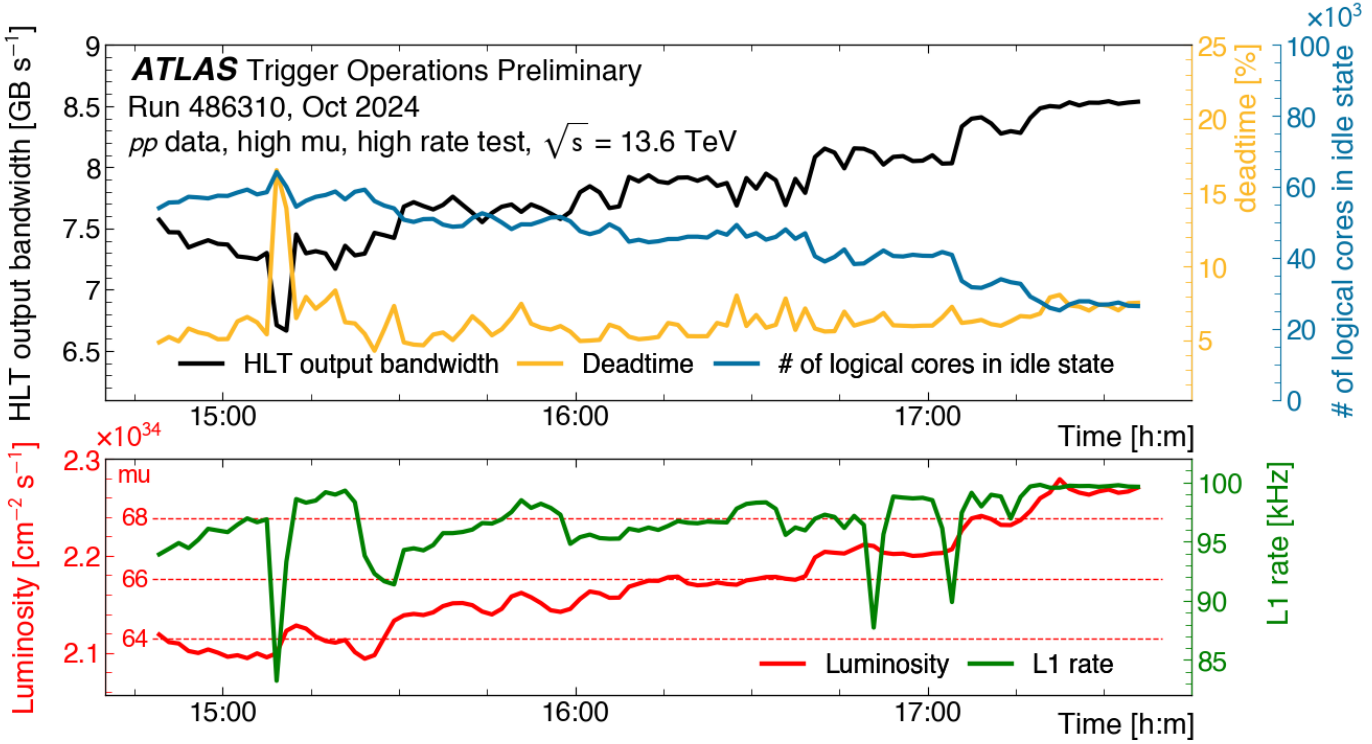






Trigger Performance at high < μ >

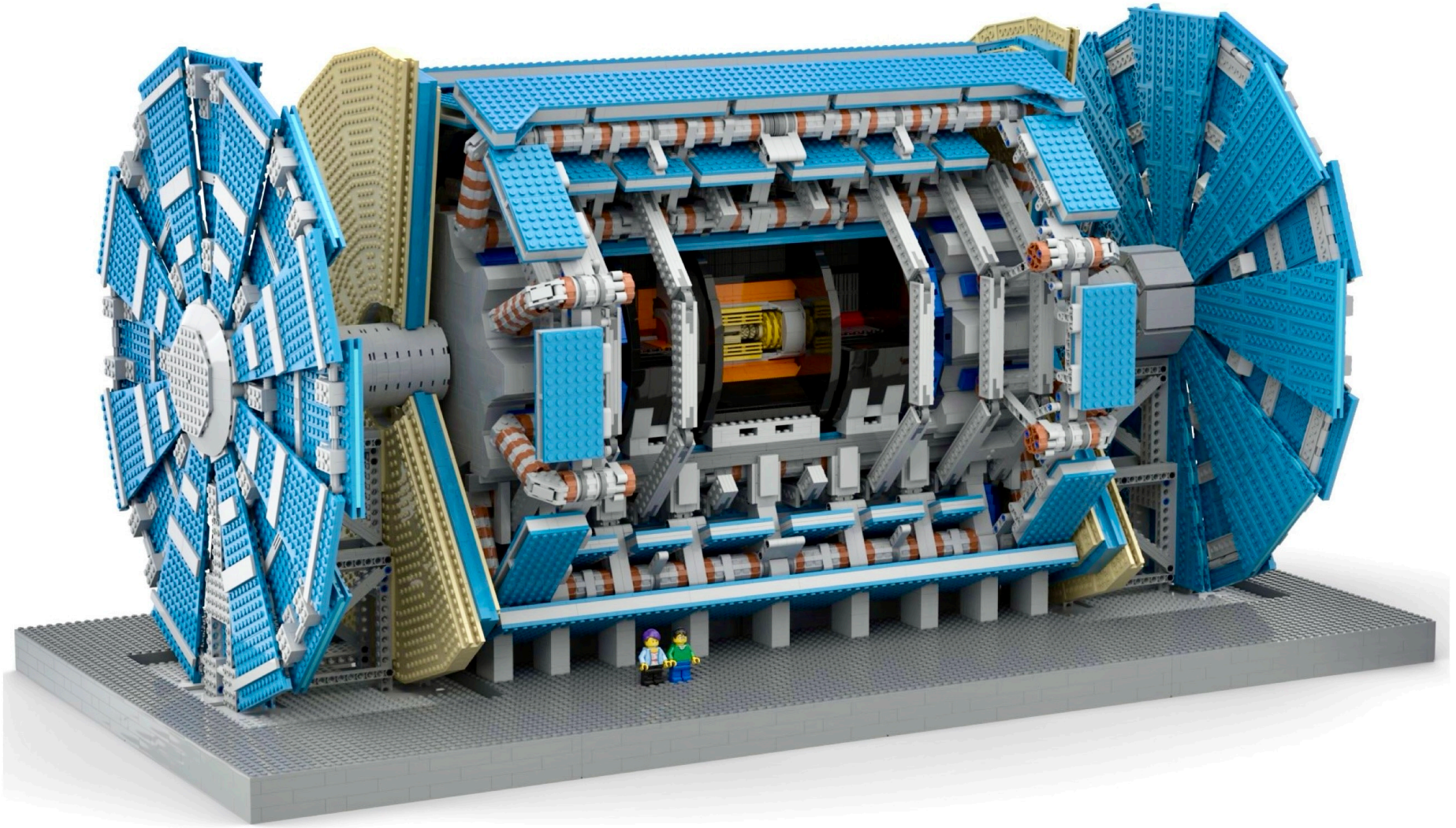
- Following LHC plans for machine developments towards HL-LHC, special runs with high <μ> and high rate in held in October 2024
- The HLT output bandwidth increases as a function of <μ>, scaling both with the rate of accepted events in all streams, and with the increased event size due to the higher occupancy.
- Dead-time increased with the L1 rate from about 4.5% to 8%, mainly due to the "complex dead-time" *
  - No "busy" signal observed from the sub-detector readout up to <μ> = 69



* dead-time used to prevent buffer overflows in the front ends.

Summary

- 2024 was very productive year for LHC/ATLAS; 2025 data taking started smoothly
- The ATLAS trigger system is crucial to filter and record only “interesting” events to fulfil the ATLAS Physics programme
- Several updates at Level-1
  - Level-1 Muon: New Small Wheel efficiency improvement leads to lower rates and better background rejection
  - Level-1 Calo: full migration to Phase-1 system in 2024, giving additional resources for next trigger developments
- New triggers (b+tau) and improvements (b-jet identification) at HLT level to help physics analyses to increase signal acceptance
- Tests done at high $\langle\mu\rangle$ and high rate indicate that it’s possible to run at $\langle\mu\rangle=69$ without significant “busy” signal from the detector



Thanks a lot for your attention