ATLAS jet trigger system: overview and performance at the beginning of Run 3

Ondřej Theiner on behalf of the ATLAS Collaboration

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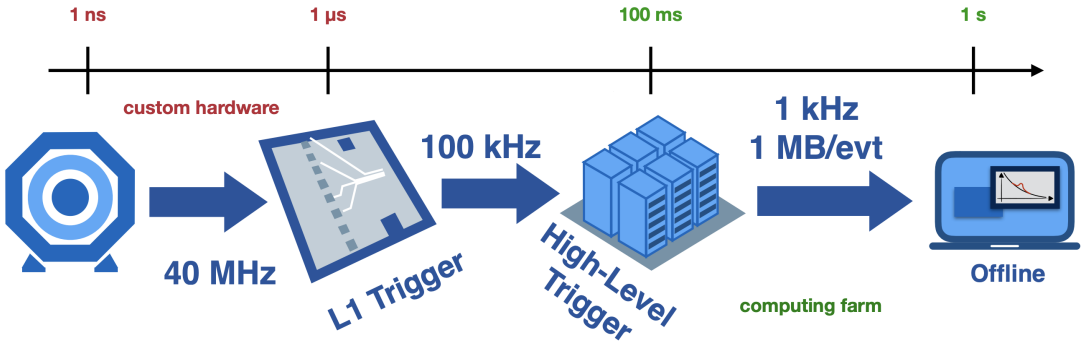
ATLAS trigger system - general overview

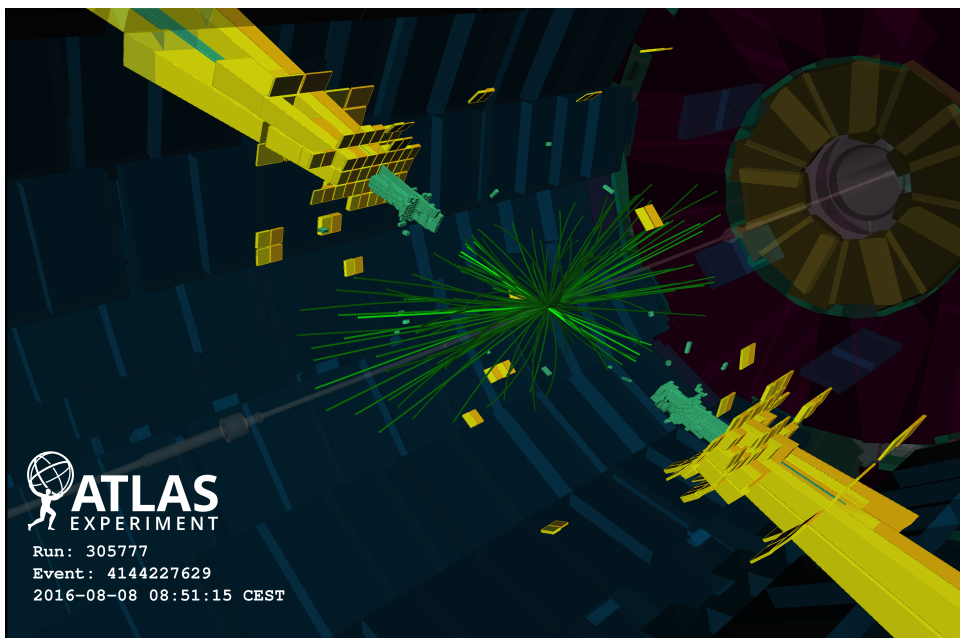
- If all events were saved - ∼1 PB of data in 10 seconds of data taking
  - not feasible → use trigger system to record only **interesting events**
- ATLAS has two level trigger system
  - **Level-1 (L1) trigger**:
    - hardware based
    - reduces 40 MHz to 100 kHz, decision made within 2.5 μs
    - high-p_{T} muons, electrons, photons, jets, large E_T^{miss}
  - **High Level Trigger (HLT)**:
    - more sophisticated algorithms (tracking, PFlow, jet reconstruction), higher latency ($\mathcal{O}(100)$ ms)
    - reduces 100 kHz down to 3 kHz



Source: [9]

Jets in ATLAS

- **Collimated bursts of hadrons** produced by the hadronisation of quarks and gluons
- Reconstructed by using calorimeter clusters and charged particle tracks as inputs
  - jets are formed by clustering inputs together (different strategies)
  - **small-R jets** R = 0.4, **large-R jets** R = 1.0
- Associated with many interesting Standard Model (SM) and Beyond Standard Model (BSM) processes
  - the **most common** signature **at the LHC** → powerful jet triggers essential for all physics purposes



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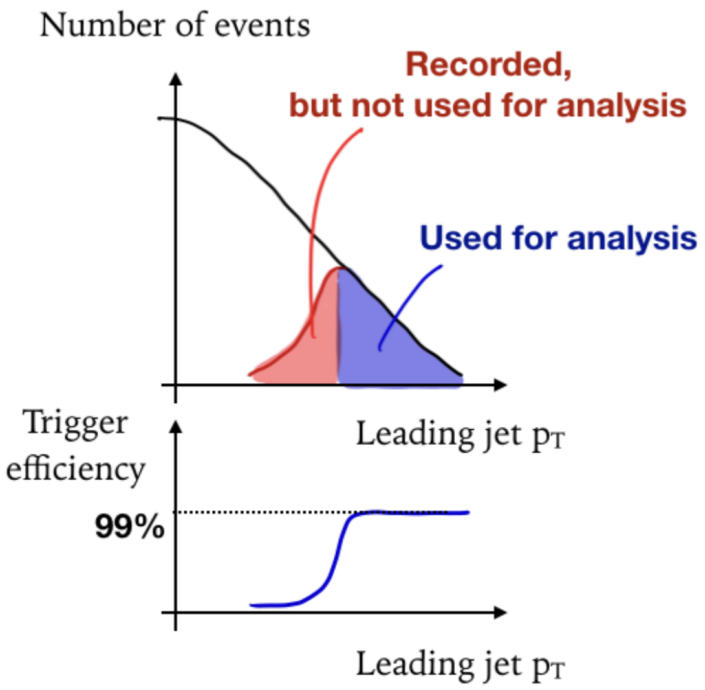
Trigger efficiency

- Way to assess the performance of trigger is to study **trigger efficiency**
- Computed with respect to the reference trigger which is chosen to be fully efficient in the studied region
- The **sharper the turn-on** (rising slope), the less unused data → **better** performing trigger



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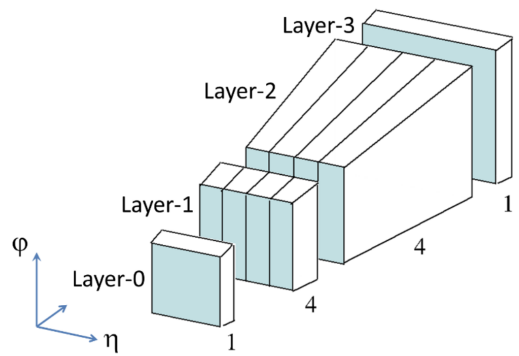
Level-1 Trigger

ATLAS jet trigger in Run 3

L1 calorimeter trigger (L1Calo)

- Jet trigger at Level-1 based on the information from the calorimeter
- **Upgrade** of the system between Runs 2 and 3
  - Runs 1 and 2 - trigger towers 0.1×0.1 in $\eta - \phi$
  - Run 3 finer-granularity input from LAr - SuperCells (10 in one trigger tower)
  - trigger towers distributed to **Feature Extractor (FEX)** processor
- FEX has electromagnetic (eFEX), jet (jFEX) and global (gFEX) feature extractors
  - jFEX and gFEX used for jet triggers

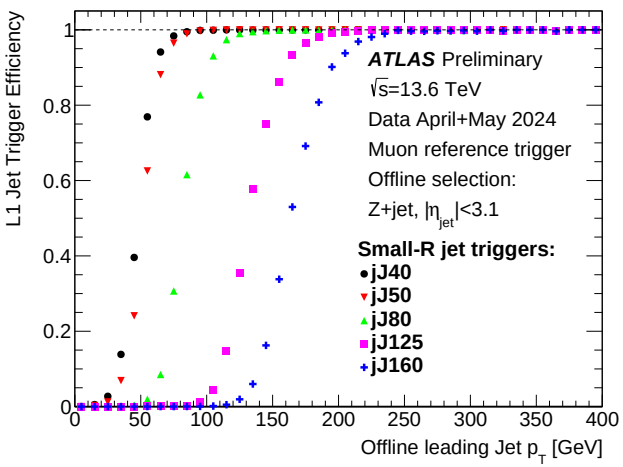


Schema of 0.1×0.1 trigger tower formed by ten SuperCells. [7]

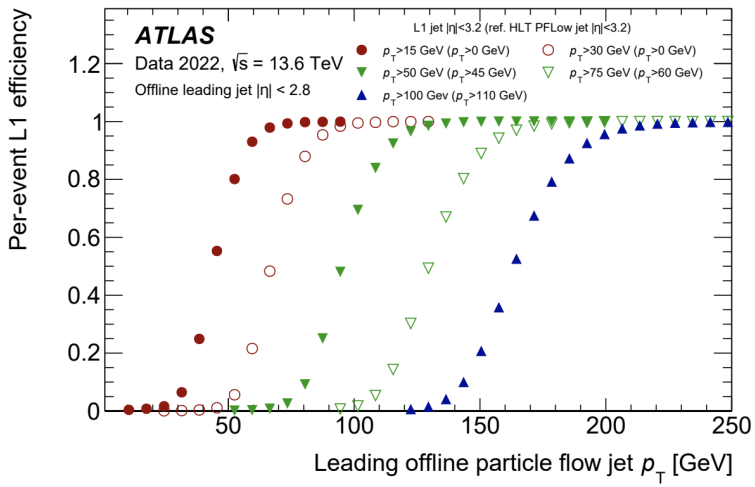
ATLAS jet trigger in Run 3

L1 jet trigger

- **Jet Feature Extractor (jFEX)**
  - reconstructs small-R jets, sliding-window algorithm
  - similar performance to L1Calo from Run 2 in single jets
  - higher efficiency in multi-jet triggers due to better resolution of close-by jets
- **Global Feature Extractor (gFEX)**
  - coarser granularity compared to jFEX → large-R jets
- jJ40 → jFEX jet, gLJ80 → gFEX . . . , number is a jet p_{T}



L1Calo single jet trigger efficiencies for the Phase-I system (Run 3). [4]



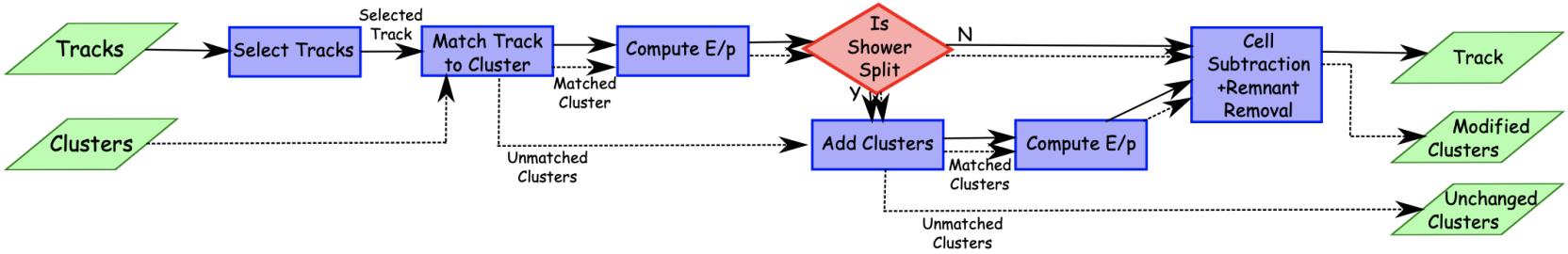
Efficiency of the legacy L1 single jet triggers. [7]

High-Level Trigger

Jet reconstruction for the HLT

Particle Flow jets

- Tracks are extrapolated to calorimeter and are matched to clusters
- Computing E/p
  - deposited energy $< E_{dep} >= p^{trk} < E^{clus}_{ref}/p^{trk}_{ref} >$
- Cell energy subtraction
- Positive energy topo-clusters surviving the energy subtraction are used for anti-k_t jet clustering algorithm (R = 0.4)

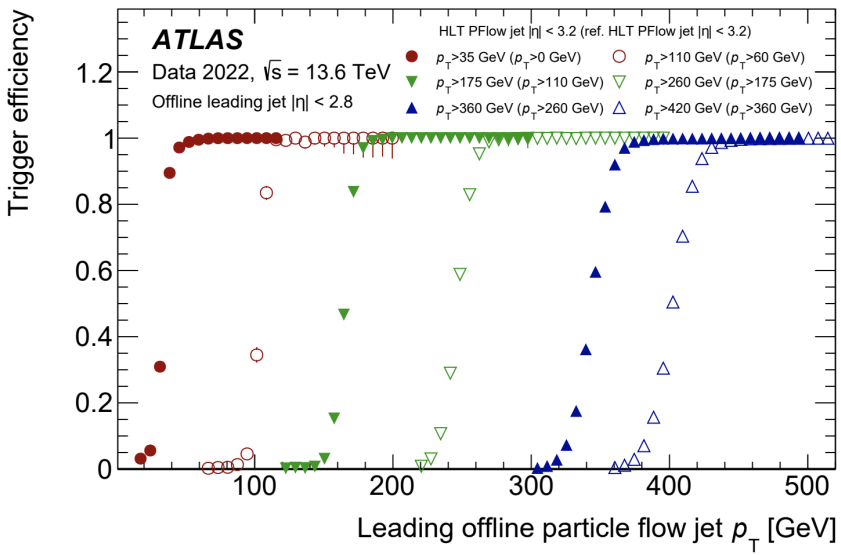


Source: [6]

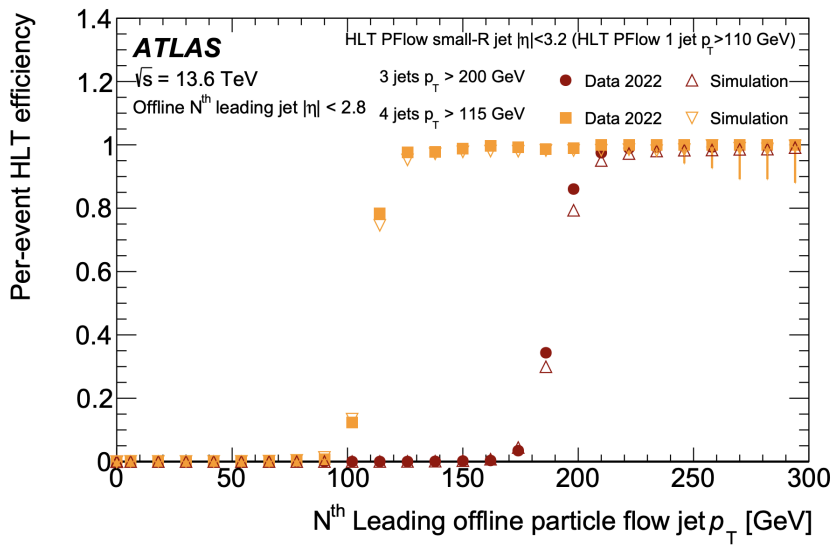
ATLAS jet trigger in Run 3

HLT jet trigger

- Triggers based on **Particle Flow Objects (PFO)** thanks to great tracking capability
  - Run 2 triggers used information only from topo-clusters
- Full scan tracking run after preselection stage to reduce CPU costs
- PFO - matching tracks to topo-clusters based on extrapolated track and cluster location
- Calibration → directly controls the shape of trigger efficiency turn on curves



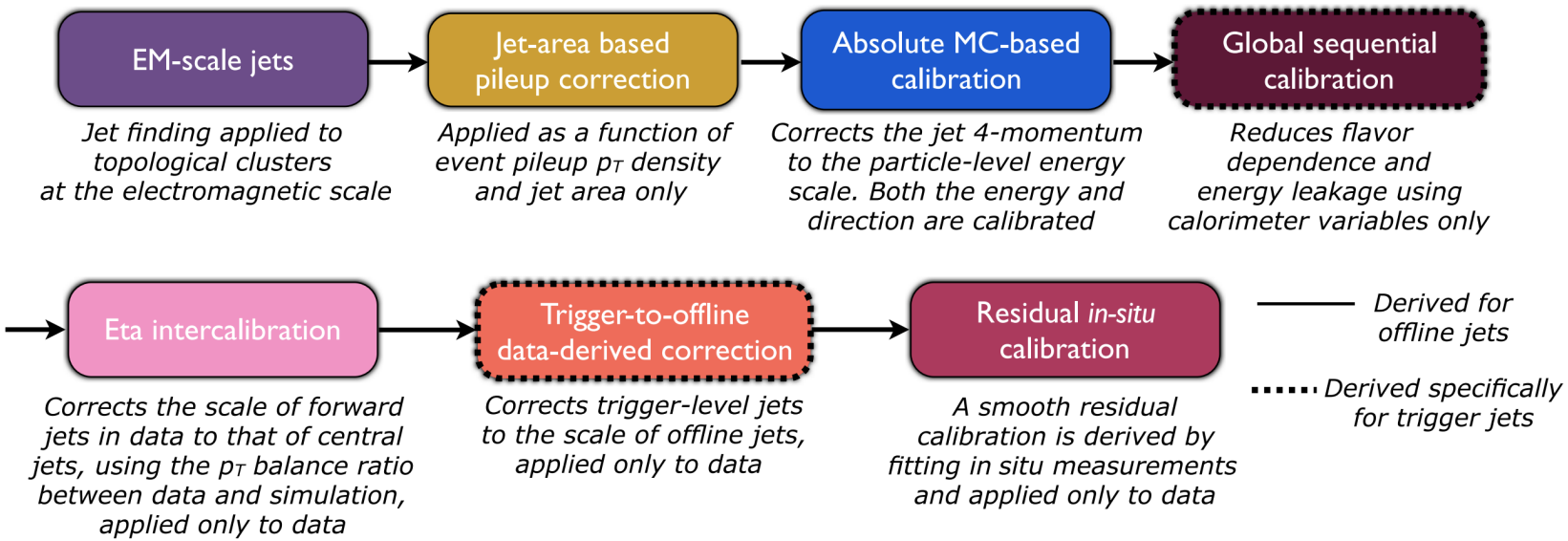
Single jet HLT efficiencies for jets in the central region. [7]



Multi-jet trigger efficiency at the HLT. [7]

HLT jet calibrations

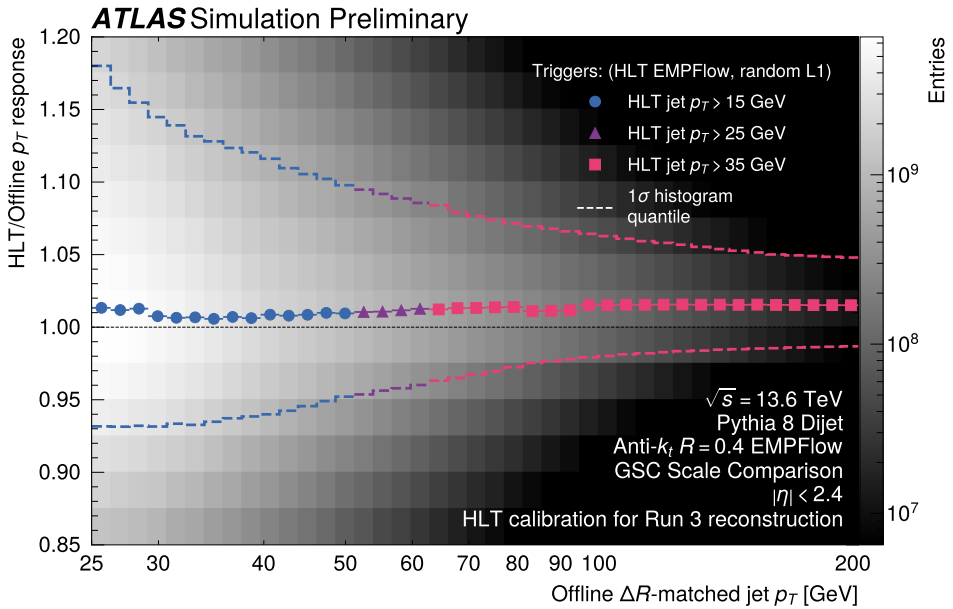
- **Response** of the detector for **HLT jets** with **different** p_{T} is different compared to **offline jets** at EM-scale→ need for the **calibration**
  - ideally we want to get the same response as for offline jets
  - we want distribution HLT/offline $\mu \approx 1$ with small σ



Steps of the HLT jet energy scale calibration [5]

Performance of the trigger-level jet calibrations

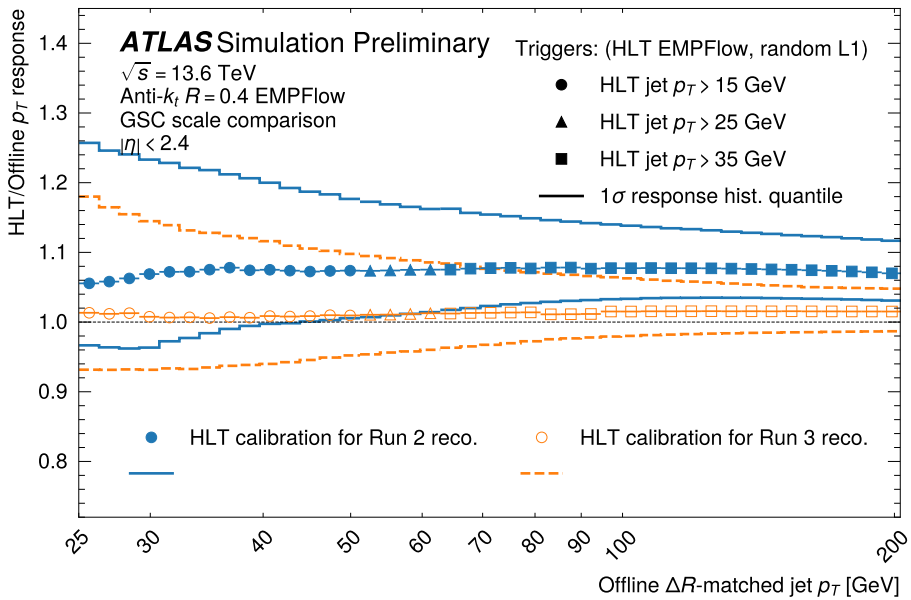
- HLT jets are corrected with an offline jet calibration configured for Run 3 reconstruction
- Good trigger-level calibration crucial for well-performing trigger
- Dijet Monte-Carlo HLT/offline response
  - **distribution** of **HLT/offline response** for different p_{T} bins is computed
  - each bin is fitted Gaussian and **mean** (full points in the graph) is estimated
  - boundaries of **1σ quantile** are drawn (dashed lines)



HLT jet calibration performance for 2023 [4]

Comparison of the HLT jet calibrations during 2022 and 2023

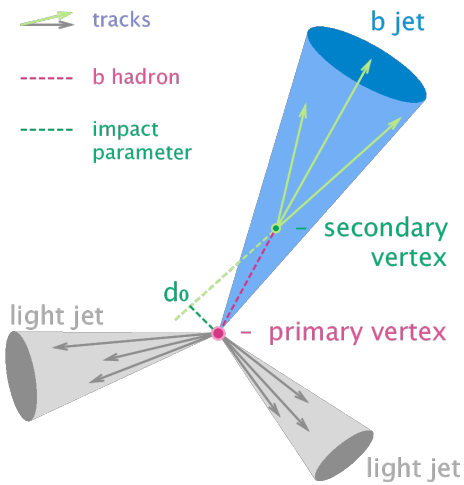
- At the **beginning of Run 3** HLT used Run 2 and offline used Run 3 **calibrations**
  - HLT/offline response 5-7% above unity
- **2023** - improvement by applying the **same calibration** to the HLT and offline reconstruction
  - narrower 1σ bands and mean response closer to 1
  - this can help achieving sharper trigger efficiency turn on



Comparison between HLT jet calibration using Run 2 (blue) and Run 3 (orange) reconstruction [4]

b-jet triggers

- *b*-jet triggers crucial for precision measurements and searches
- ***b*-tagging** requires **precise tracking** and dedicated approach
  - inputs are reconstructed tracks and jets, and primary vertex position
- Identification done in two steps
  - fast *b*-tagging is run on tracks inside super-Regions of Interest
  - final *b*-tagging algorithm
    - low level presel.: fastDIPS → fastGN2; higher level: DL1d → GN1 → GN2



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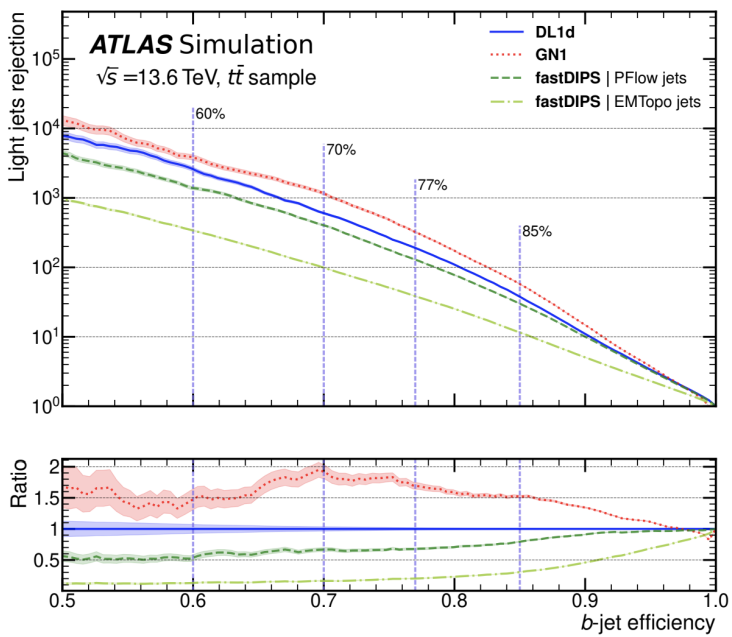
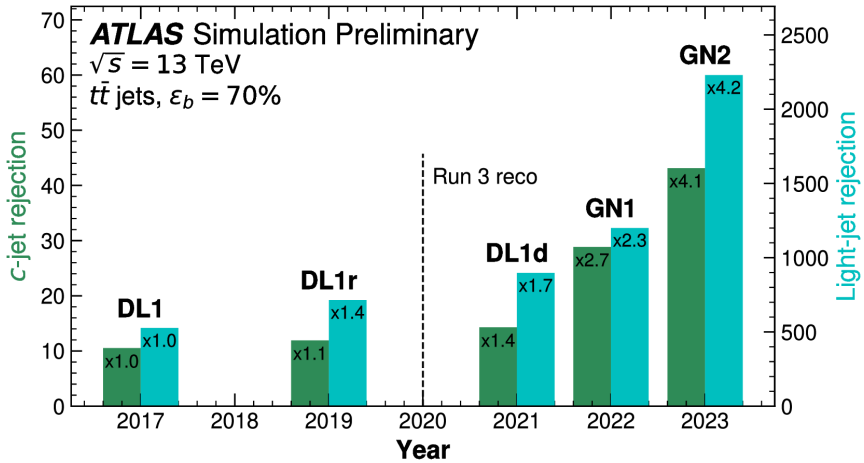


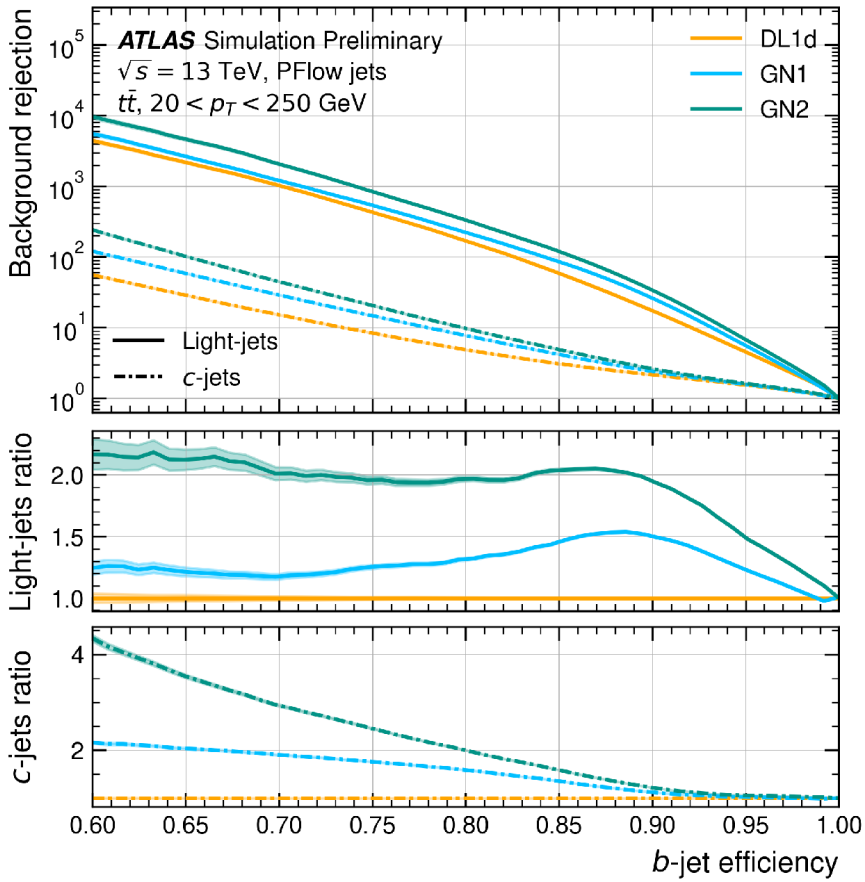
Light jets rejection by different *b*-tagging algorithms [7]

Comparison of b-jet taggers used in Run 3

- Continuous improvement of b-tagging algorithms used in ATLAS



The c-jet and light-jet rejection of different ATLAS flavour tagging algorithms in $t\bar{t}$ Monte-Carlo samples. [2]



The c-jet and light-jet rejections as a function of the b-jet tagging efficiency for jets in a $t\bar{t}$ sample. [2]

Conclusion

- Efficient jet trigger system helps targeting many interesting SM and BSM processes
- Several improvements to the jet trigger system with respect to Run 2
  - L1: gFEX and jFEX
  - HLT: PFlow jets
- Improvements to the trigger-level jet calibration
- Better b-tagging capability thanks to the graph neural networks GN1, and currently GN2
- b-tagging preselections (fastDIPS, fastGN2) introduced in Run 3 allowed for better b-tagging triggering

References

[1] Amerl, Max: The ATLAS Jet Trigger in Run-3, URL https://indico.jlab.org/event/459/contributions/11409/attachments/9379/13601/CHEP2023Slides_MAmerl_TheATLASJetTriggerInRun3.pdf (CHEP2023)

[2] ATLAS Collaboration : *Jet Flavour Tagging With GN1 and DL1d. Generator dependence, Run 2 and Run 3 data agreement studies*. – URL https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/FTAG-2023-01/

[3] ATLAS Collaboration : *Particle-hunting at the energy frontier*. – URL https://atlas.cern/updates/briefing/particle-hunting-energy-frontier

[4] ATLAS Collaboration : *Public Jet Trigger Plots for Collision Data*. – URL https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetTriggerPublicResults#2022_pp_data

[5] ATLAS Collaboration : Jet energy scale measurements and their systematic uncertainties in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector. In: *Physical Review D* 96 (2017), Nr. 7. – URL http://dx.doi.org/10.1103/PhysRevD.96.072002

[6] ATLAS Collaboration : Jet reconstruction and performance using particle flow with the ATLAS Detector. In: *The European Physical Journal C* 77 (2017), Juli, Nr. 7. – URL http://dx.doi.org/10.1140/epjc/s10052-017-5031-2. – ISSN 1434-6052

[7] ATLAS Collaboration : *The ATLAS Trigger System for LHC Run 3 and Trigger performance in 2022*. 2024. – URL https://arxiv.org/abs/2401.06630

[8] Bartosik, Nazar: B-tagging. . – URL https://en.wikipedia.org/wiki/B-tagging

[9] Summers, S.: *Fast Machine Learning at the Edge for HEP Experiments*. – URL https://indico.cern.ch/event/1389765/attachments/2815819/4915639/sps_ds_8-3-24.pdf