ATLAS High Level Trigger b-tagging with GN2 for 2024 data-taking

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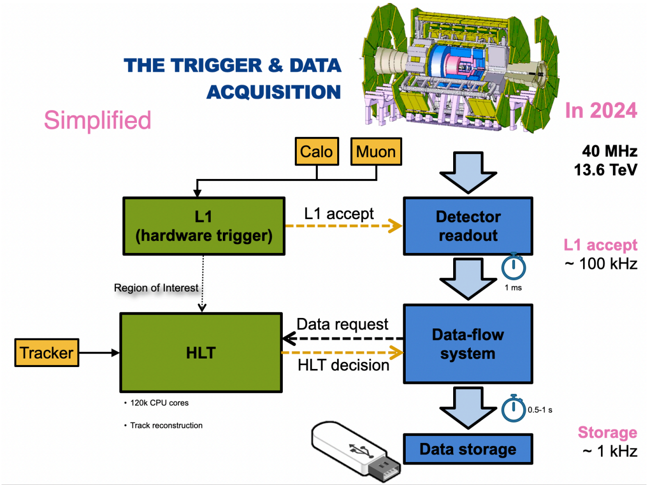
ATLAS EXPERIMENT

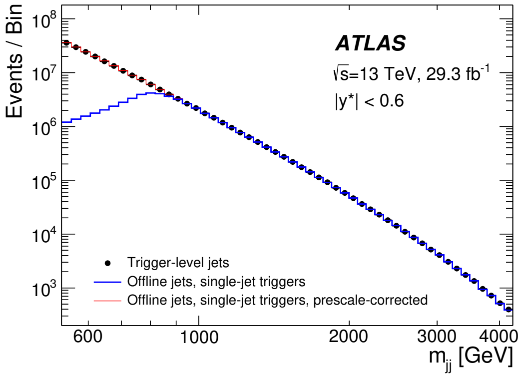
ATLAS Trigger

- Proton bunches cross at 40 MHz and each bunch crossing create 50 events on average
- Saving everything O(3 TB/s) is impossible —> Selection is needed
- ATLAS has a 2 level trigger system to reduce the accepted event rate by step
- In order to make selection with low latency, the trigger reconstruction is different than offline



- Trigger Level Analysis (« Data Scouting » in CMS)

To reduce the data rate, one strategy is to save coarse information only.
This allows to make softer selection and increase statistics in the low energy region.



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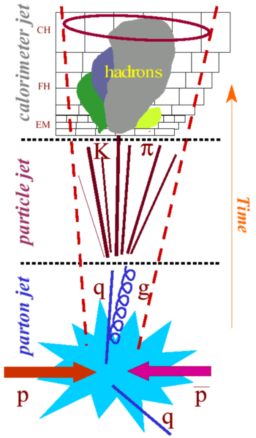
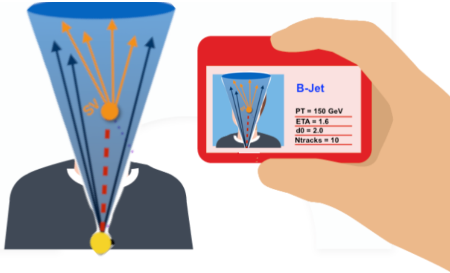
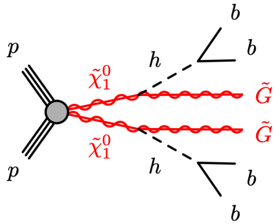


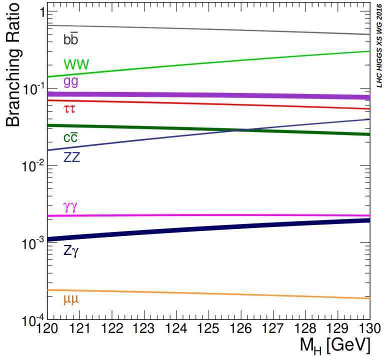
Jets and b-tagging



- In pp collisions, the most common final states are quarks
- Quarks can't propagate isolated —> Hadronisation —> Hadronic Jets
- Hadronic jets can be initiated by different flavour of quarks (by gluon or tau as well)
- Flavour Tagging (FTAG) is the set of methods and techniques used to identify the flavour of a jet



- Many interesting processes produce b-jets e.g. HH→ 4b or beyond SM physics
- Identifying events with b-jets in the final state at trigger level is challenging given the overwhelming QCD background dominated by light jets
- A typical feature of b-jets is existence of secondary vertex and displaced tracks due to long lifetime of B hadrons

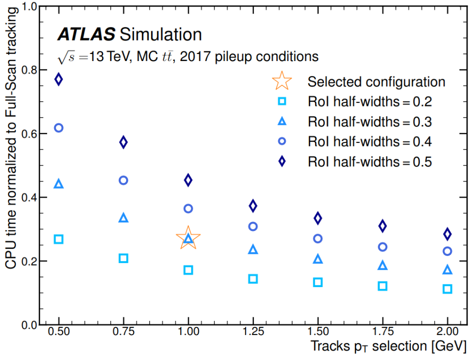


- b-tagging algorithms requires track reconstruction which is CPU intensive

⚠ **Bottleneck for high rate trigger reconstruction**

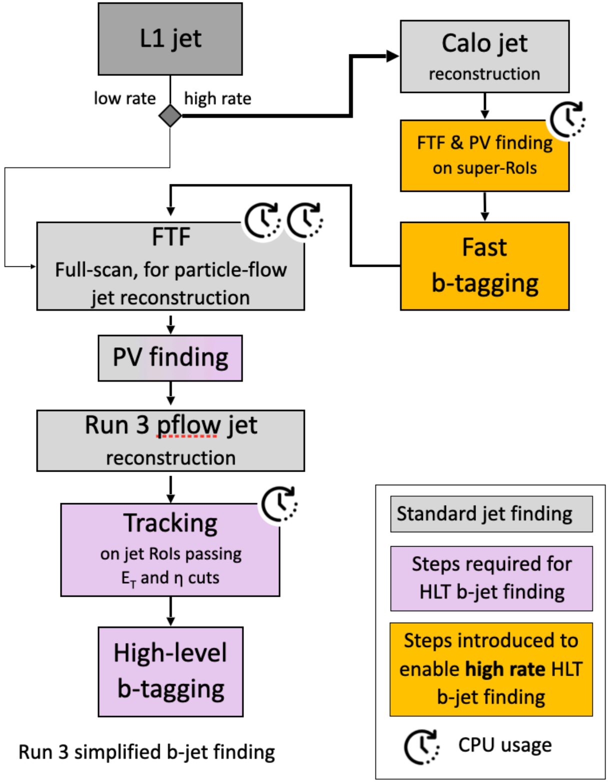
Fast b-tagging at the ATLAS High Level Trigger (HLT)

- Tracking of the full event is too slow to run at L1 output rate
- Solution: run tracking only in a narrow region around the jet axis



- Run b-tagging and reject background before Full detector acceptance tracking

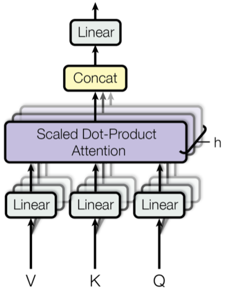
  → Saves CPU, enables complex reconstruction downstream avoids wasting ressources on background events



Run 3 simplified b-jet finding

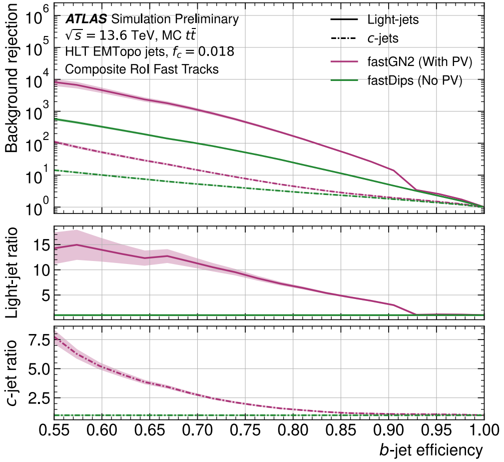
Training of GN2 for HLT b-tagging

- GN2 architecture in HLT:

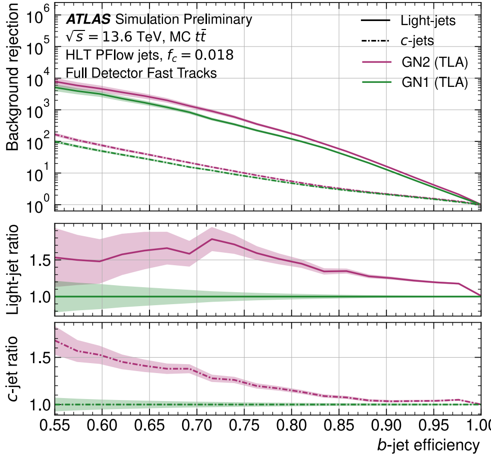


- Training data: 180M jets from MC $t\bar{t}$ samples (with p_T between 20 GeV-250 GeV) and 18M from Z' samples (p_T between 250 GeV-6000 GeV)

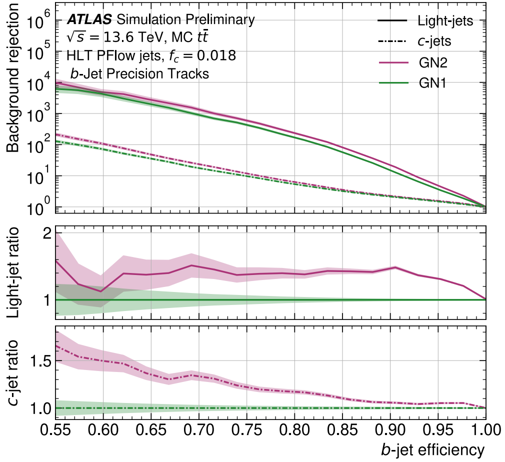
- For all b-tagging steps, GN2 outperforms the taggers that were used in 2023 data-taking



fast b-tagging



TLA b-tagging



Precision HLT b-tagging

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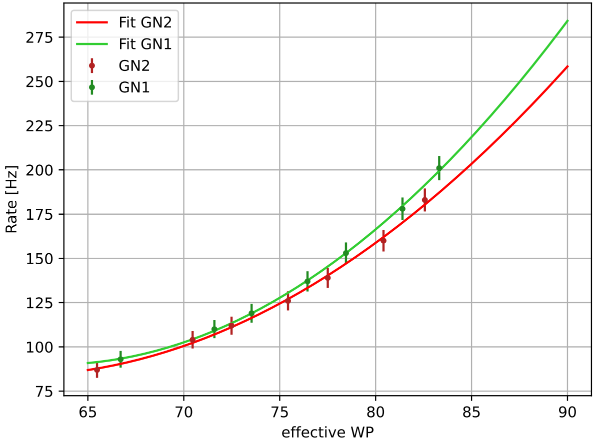
Performance of GN2 in HLT: CPU and Rate reduction



- History of HLT taggers:
  - fastDIPS (running in 2022/2023): Deep NN
  - fastGN1 (developed in 2022): Graph NN
  - fastGN2: Transformer based model

- GN2 has lower rate for same efficiency

Fast b-tagger used in the chain	Mean time per event in HLT [ms]
fastDIPS	1164
fastGN1	941,7
fastGN2	929,2

- fastGN2 used in 2024 data-taking saves 20% of CPU w.r.t. fastDips (used in 2022/2023)
- fastGN2 preselection saves 60% of CPU w.r.t. no preselection case

Outlook and conclusions

- Rejecting background in trigger as early as possible is essential for data-taking nowadays and even more for HL-LHC
    - Fast b-tagging enabled to collect di-Higgs events at a higher rate than ever before!
    - Switching to fastGN2 for 2024 saves 20% of CPU w.r.t. 2023 data-taking

- GN2 taggers were successfully deployed in trigger, following closely offline b-tagging improvements

- The success of fast b-tagging in LHC Run 3 encourages the studies for improving these strategies for HL-LHC
    - Using different inputs/outputs to reach the full potential of transformer based architecture
    - Add another preselection step even more upstream in trigger (L1 b-tagging)

BACK-UP

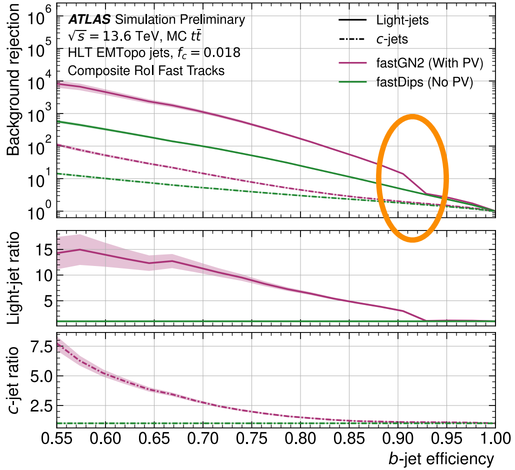
Trigger Level Analysis (TLA) b-tagging

- Bandwidth = Event Rate $\times$ Event Size

- 2 solutions to respect bandwidth limitations
  - Reduce Event Rate: Standard Trigger strategy
  - Reduce Event Size: TLA Strategy

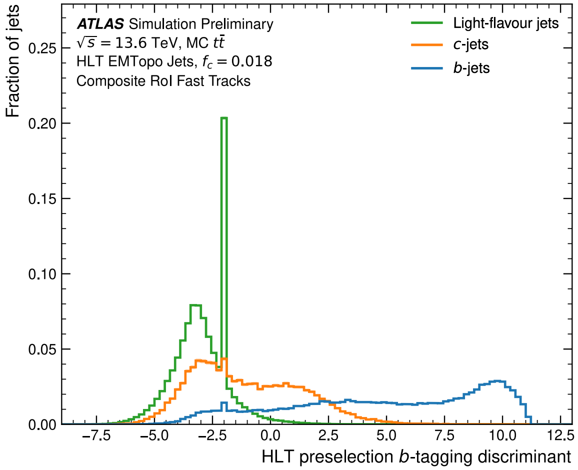
- In TLA, only trigger objects are saved rather than full detector data:
  - Needs dedicated b-tagging reconstruction

Empty jets



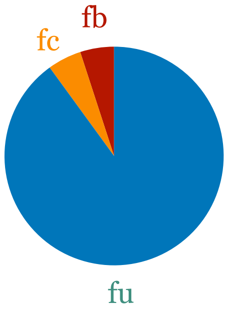
- The knee in the ROC curve corresponds to peaks in the discriminant distribution

- Investigations of the properties of the jets in the peaks showed the latter were mostly jet with N_tracks = 0.



How does GNNs deals with jets with 0 tracks ?

Empty jets



GN1: pu = 1 , pb = pc =0 → Peak at Db = inf and knee at ϵ_b=1

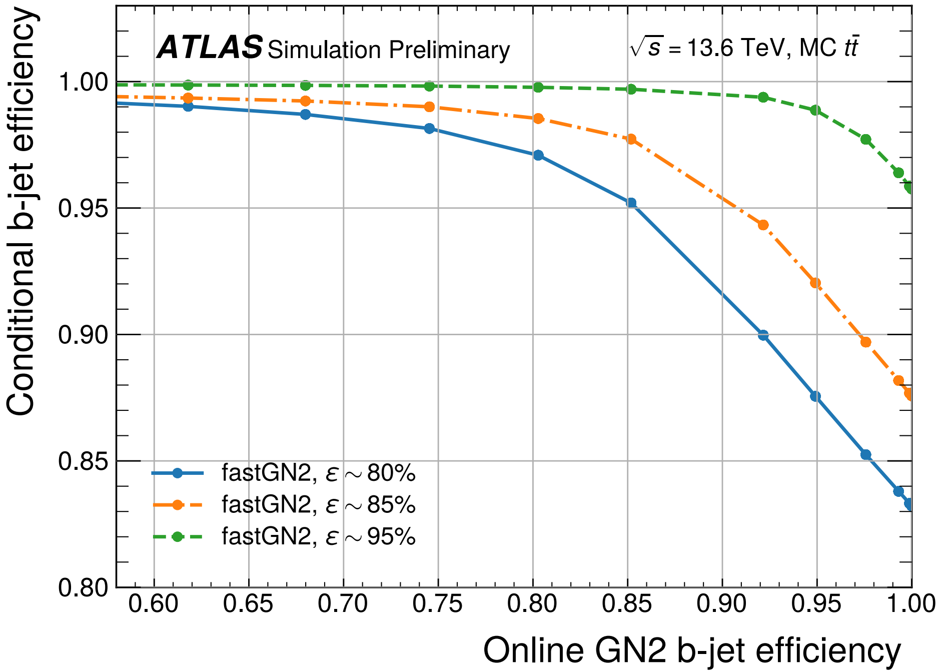
GN2: pu = fu , pb = fb , pc = fc

Performance of GN2 in HLT: Fast b-tagging and Precision tagging overlap

- P(Pass fast b-tagging | Pass Precision b-tagging) for true b-jets

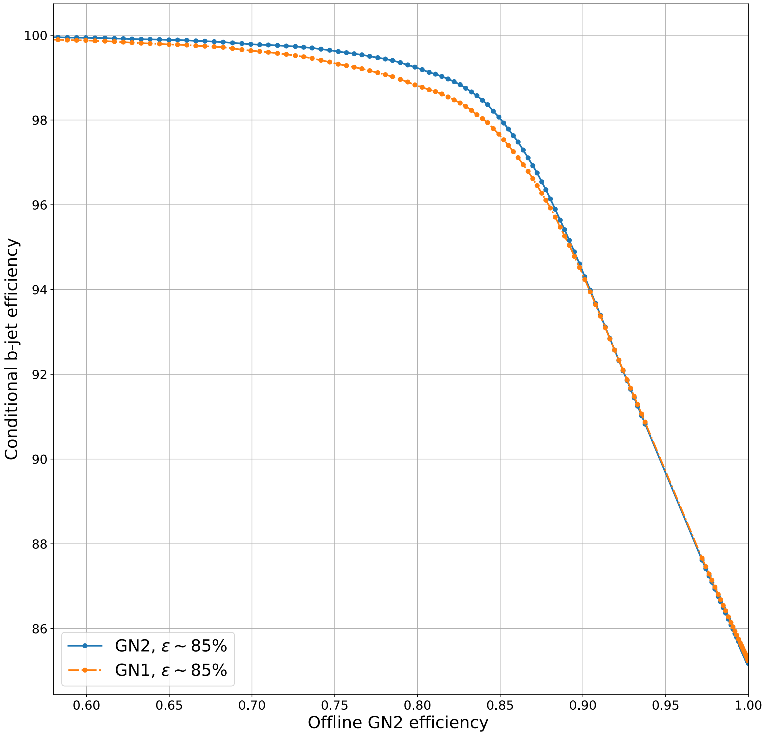
- It means that a jet that is accepted by precision tagging is not likely to be rejected by preselection

  —> What we reject with fast b-tagging is indeed background



Performance of GN2 in HLT: Online and Offline tagging overlap

- P(Pass Online tagging | Pass Offline tagging) for true b-jets
- Using 85% working point for online taggers (WP used in Data-taking)
- A jet tagged as a b-jet offline is more likely to be properly tagged in HLT by GN2 compared to GN1



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