Fast b-tagging at the ATLAS Trigger

Lucas Bezio & Stefano Franchellucci

Université de Genève

Working with: Claire Antel, Kostas Axiotis, Quentin Berthet and Anna Sfyrla

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ATLAS EXPERIMENT

OUTLINE

Trigger in ATLAS Experiment

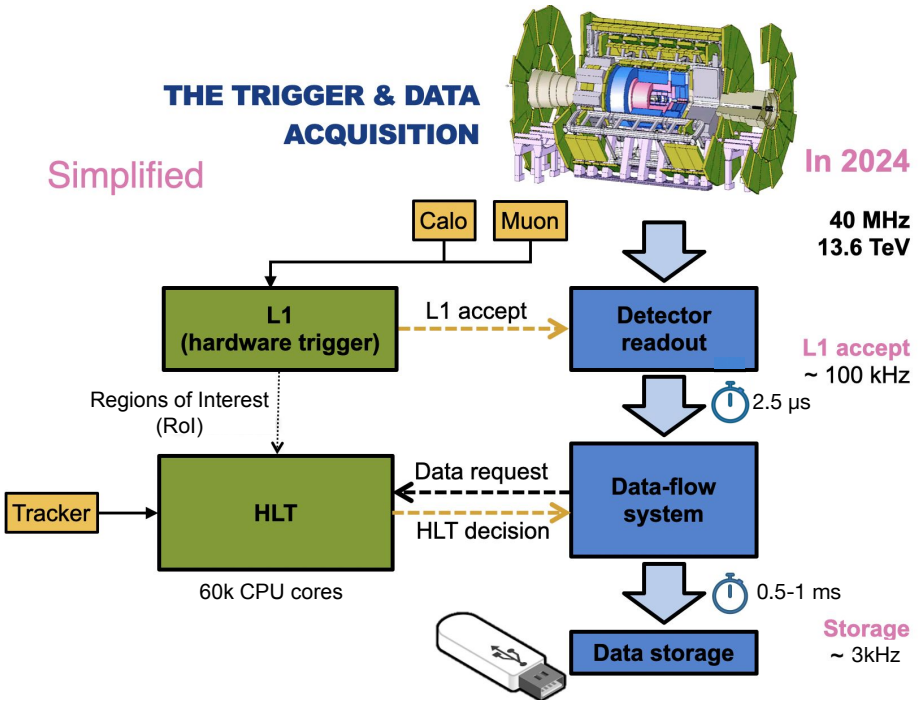
b-tagging

GNN for fast b-tagging

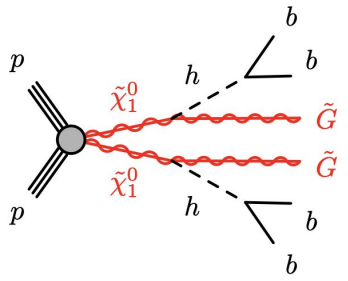
Perspectives for b-tagging in trigger

ATLAS Experiment & Trigger

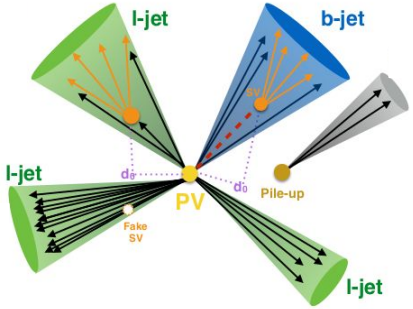
- ATLAS experiment at LHC has to deal with 40 MHz pp collisions, in high pile-up conditions
  - Large event size (~1.5MB)
  - Low rates for “interesting” physics
    - ➽ Need for a robust trigger system!
- ATLAS uses a two level trigger
  - L1: Low latency hardware trigger
  - High Level Trigger (HLT): large set of algorithms for reconstruction / tagging / selections
- Different reconstruction steps for each trigger object (muons, jets, e/gamma)



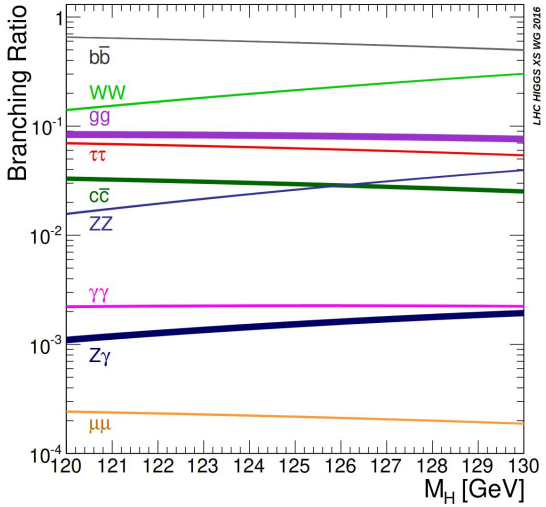
b-tagging



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



Credits: Universität Siegen



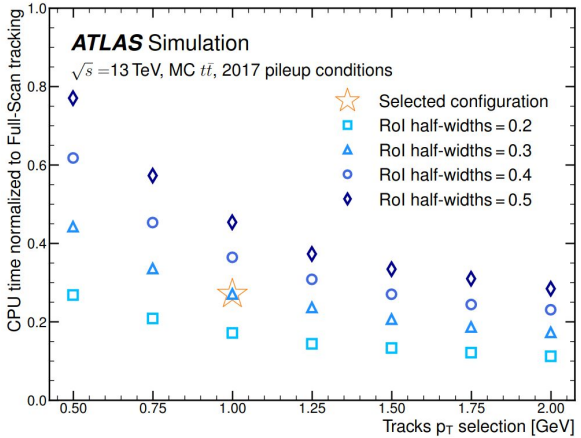
- b-tagging algorithms requires track reconstruction which is CPU intensive

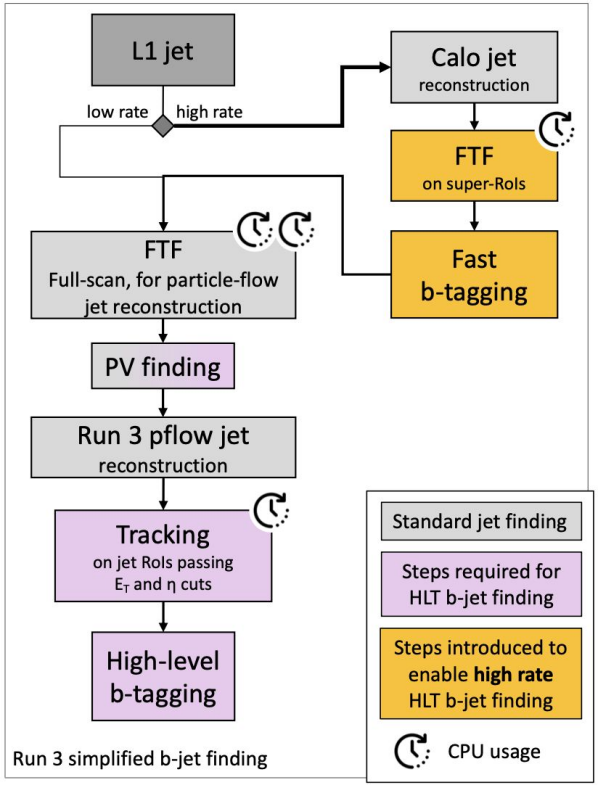
⚠ **Bottleneck for high rate trigger reconstruction**

Fast b-tagging at the HLT

- Reject background as early as possible
- Run b-tagging before Full detector acceptance tracking

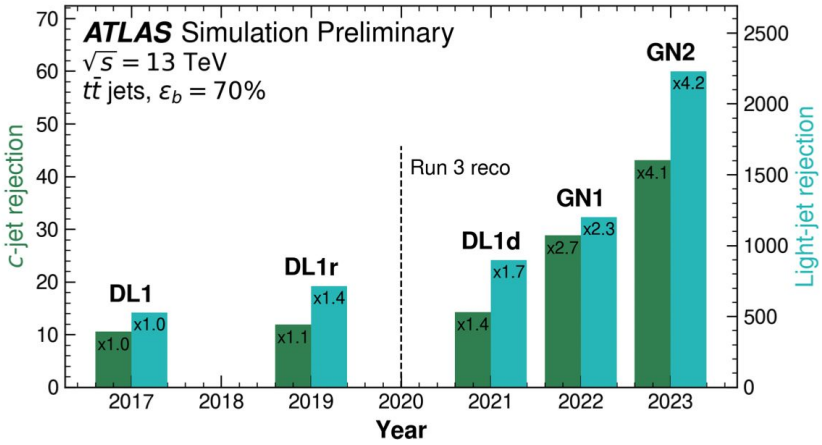
  → Saves CPU, enables complex reconstruction downstream
- Use ML models to infer the flavour of the jet using coarser inputs
  - "*Fast*" tracking only, in narrow regions of interest





Recent history of b-tagging in ATLAS

- First implementation of fast b-tagging was done using a Deep Sets architecture (DIPS)
- Offline analysis showed the success of GNNs for flavour tagging



Run 3 Taggers

DL1d is a combination of DNNs

GN1 is a Graph Attention Network

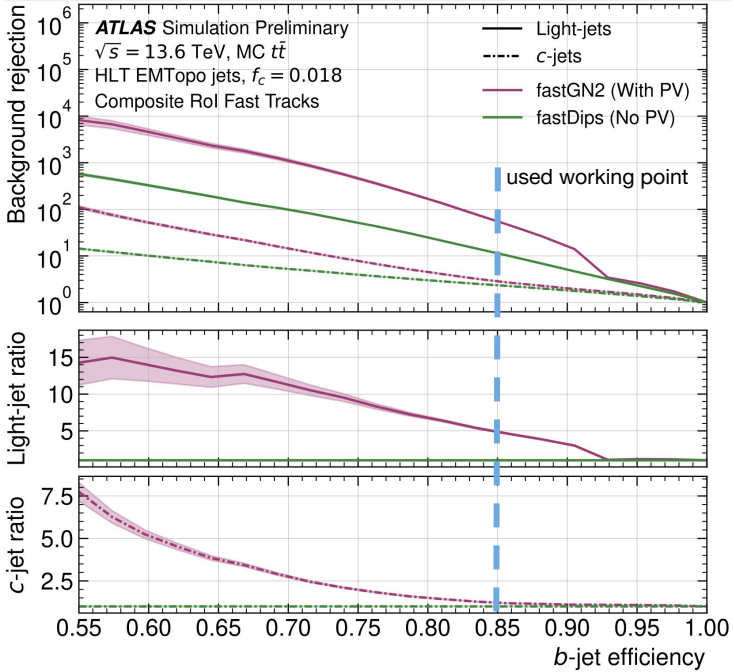
GN2 is based on a Transformer architecture with Multi-Head Attention

GNNs for fast b-tagging

- GN2 models have been trained for trigger b-tagging, currently running for 2024 physics data-taking
- **Factor ~5** improvement in background rejection with GN2 compared to previous implementation
  - PV information also helps to increase performance
- Huge impact on CPU resources
  - **- 20% CPU time** per event savings overall!

Fast b-tagger	Time per event [ms]
fastDips	1164
fastGN2	929,2

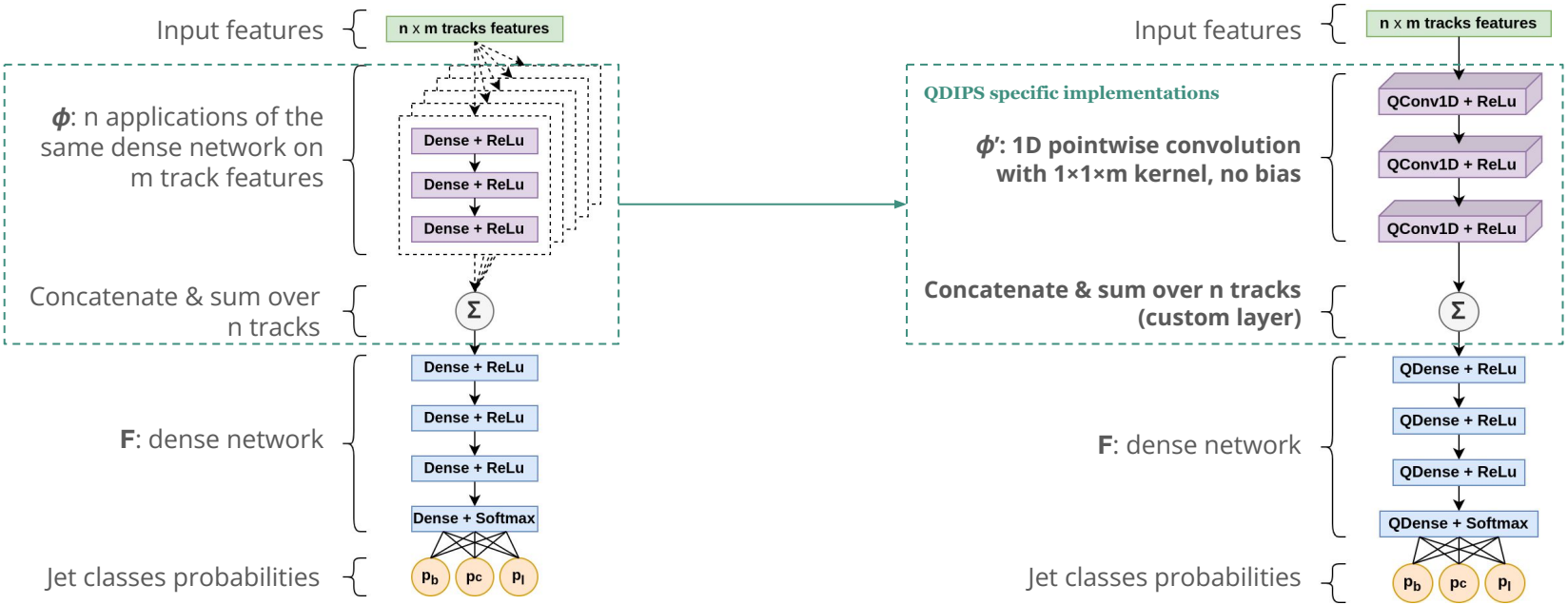
testing same trigger chain, but different taggers



fastDips is the Deep Sets model used for 2022 and 2023

Fast b-tagging for upgrade trigger

- Big restructuring of the trigger system for HL-LHC
- Explorations for fast b-tagging, accelerate with implementation in FPGA
  - Need to quantize weights and slightly adapt the architecture ⇒ **QDIPS**

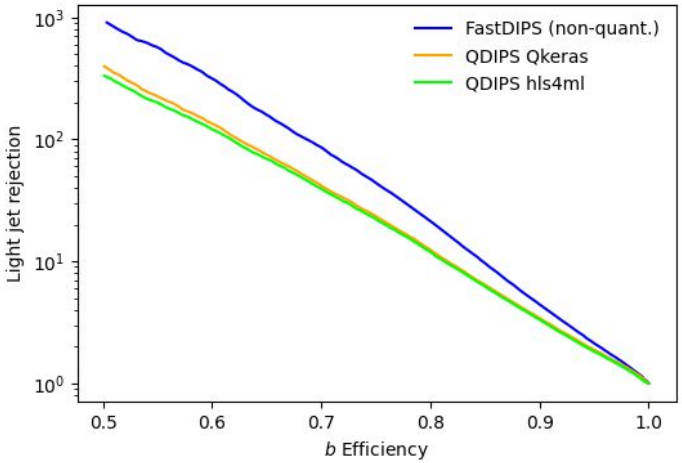


Fast b-tagging for upgrade trigger

- Training with same dataset of fastDIPS
  - Fully implemented and tested model on FPGA

QKeras + hls4ml

- Reducing model size by roughly one order of magnitude at the cost of small loss in performances
- Still work in progress, many possible improvements
  - hope to achieve performances closer to fastDIPS keeping the model small and hardware friendly

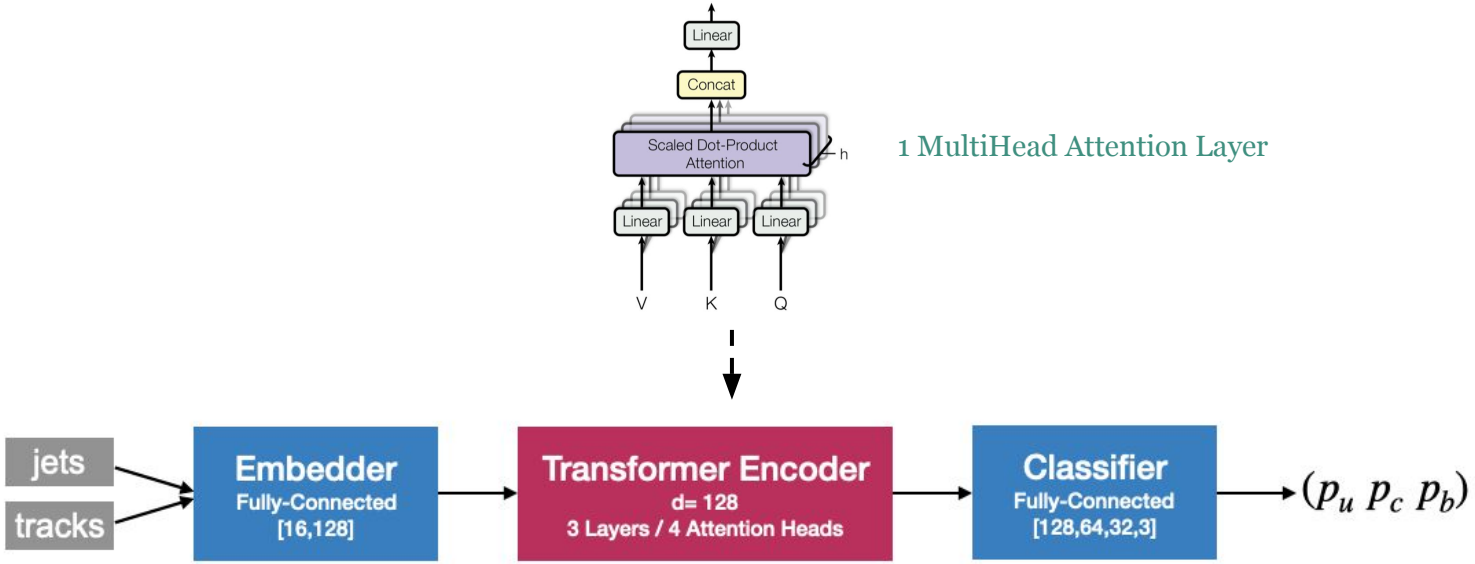


(more on FPGAs in Kostas talk)

Conclusion

- 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!
- More performant 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, e.g. leveraging hardware acceleration

Backup: GN2 in HLT



- Trained with 180M jets from simulated ttbar samples and 18M from Z' sample