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全国会员代表大会暨学术年会

Identify the heavy flavour jet using the High Level Trigger information with the ATLAS detector

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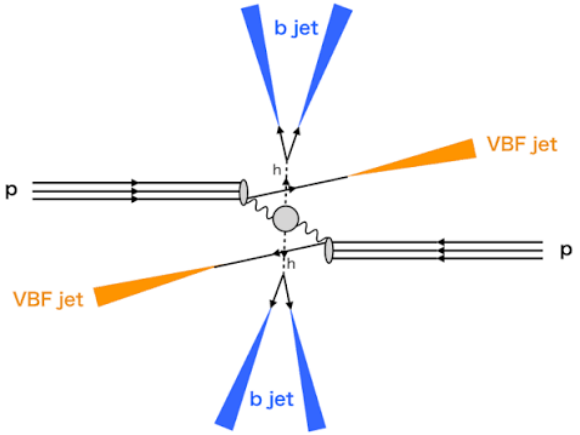
Introduction

- b-jet is an important signature in many physics analyses (e.g. ttbar, H→bb, HH→4b/bb$\tau\tau$)
- b-jet tagging algorithm explore the b-hadron decay properties to identify the b-originated jet
  - Offline b-tagging information is useful to suppress the large QCD multijet events with light/c-flavour jets
- With an increased instantaneous luminosity, offline b-tagging is not enough,
- New phase space exploration limited by jet kinematic in trigger-level (online)
- Implementing b-tagging information in trigger-level is essential for processes for full hadronic final state with b-quarks.



Bunch crossings

40 MHz

L1 trigger

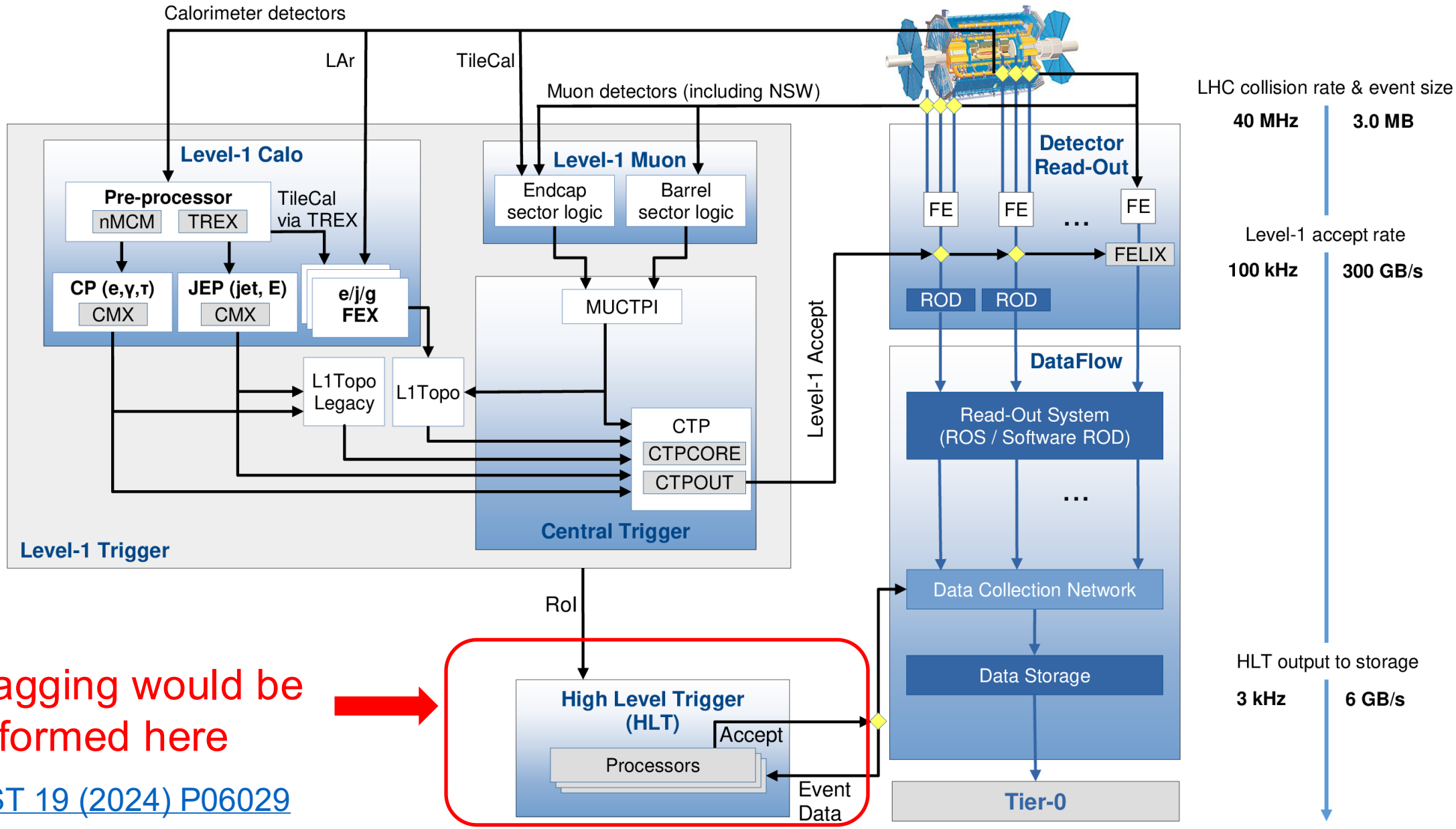
< 100 kHz

HLT

~190 Hz

Main physics stream (b-jet trigger)

ATLAS trigger system



B-tagging would be performed here

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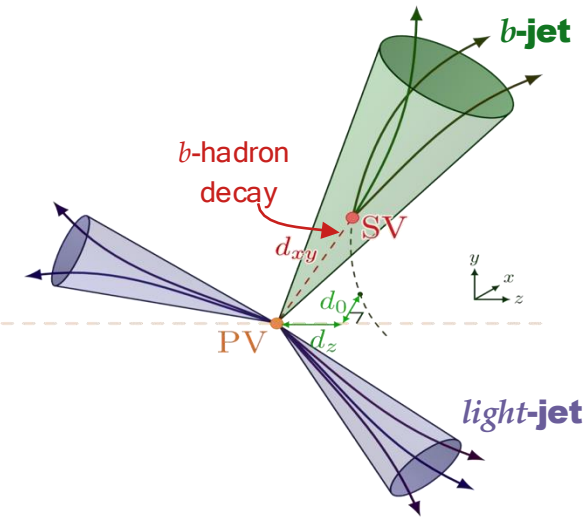
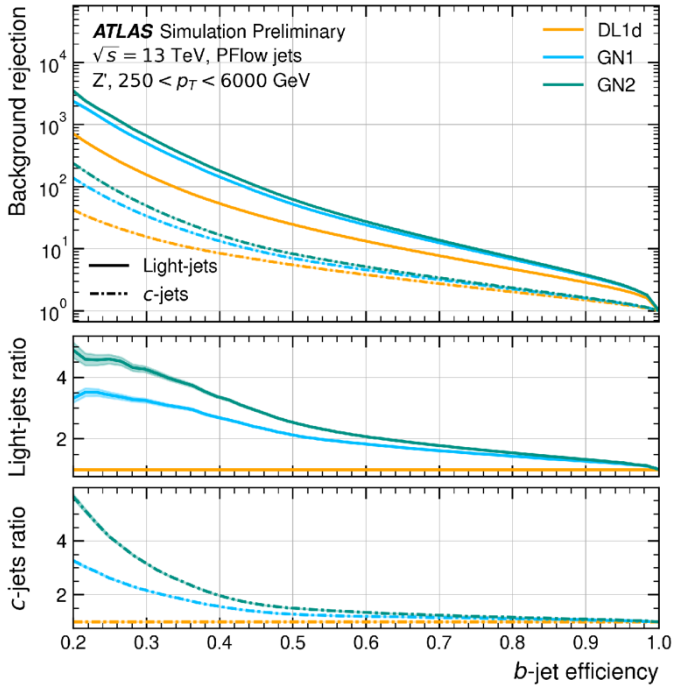
b-tagging in ATLAS

- B-tagging algorithm exploits the b-hadron decay properties
  - Hard b-quark fragmentation with ~70% energy goes to b-hadron
  - Relative long lift time: ~1.5ps
  - High multiplicities
  - Displaced secondary vertex (~3mm for p_T~50GeV b-hadron)
  - Tracks with large impact parameters
- Several identification algorithm since run1
  - Machine learning is the key technique
- Similar techniques also used for c-jet tagging and tau-lepton identification



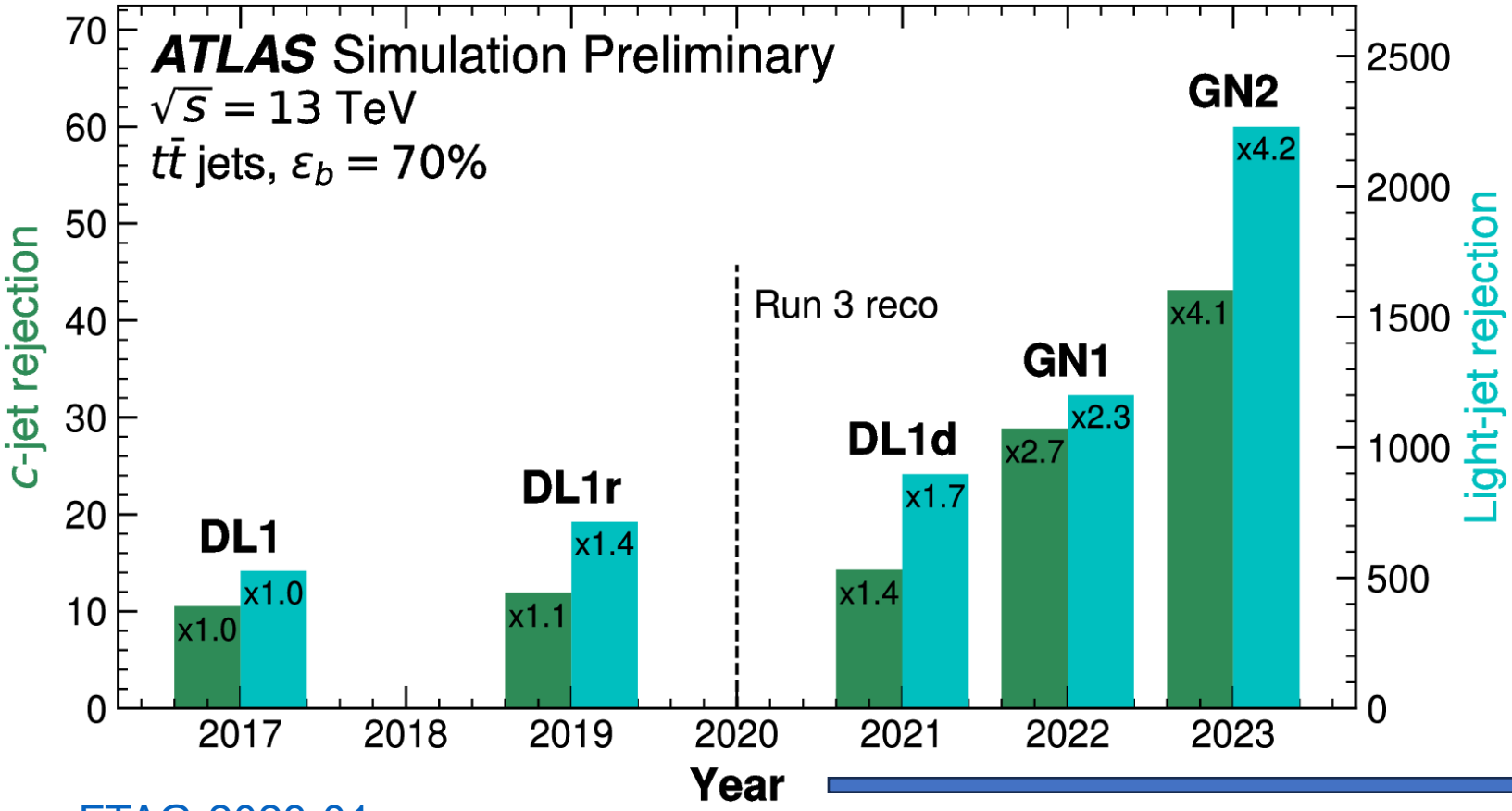


More in Bingxuan's Talk

Flavour tagging algorithm development

- The flavour tagging algorithm evolve dramatically during Run3
- The online also keep pace with the offline effort

More in Bingxuan's Talk



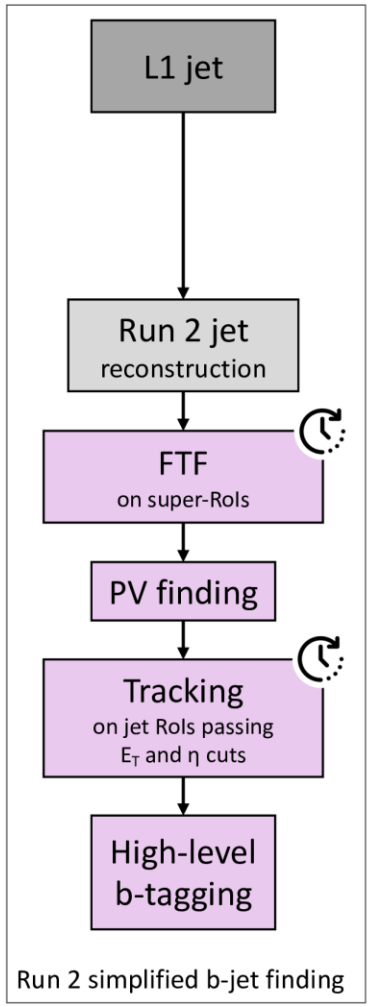
DL1d = Combination of DNNs
GN1 = Graph Attention Network
GN2 = Transformer architecture with Multi-Head Attention

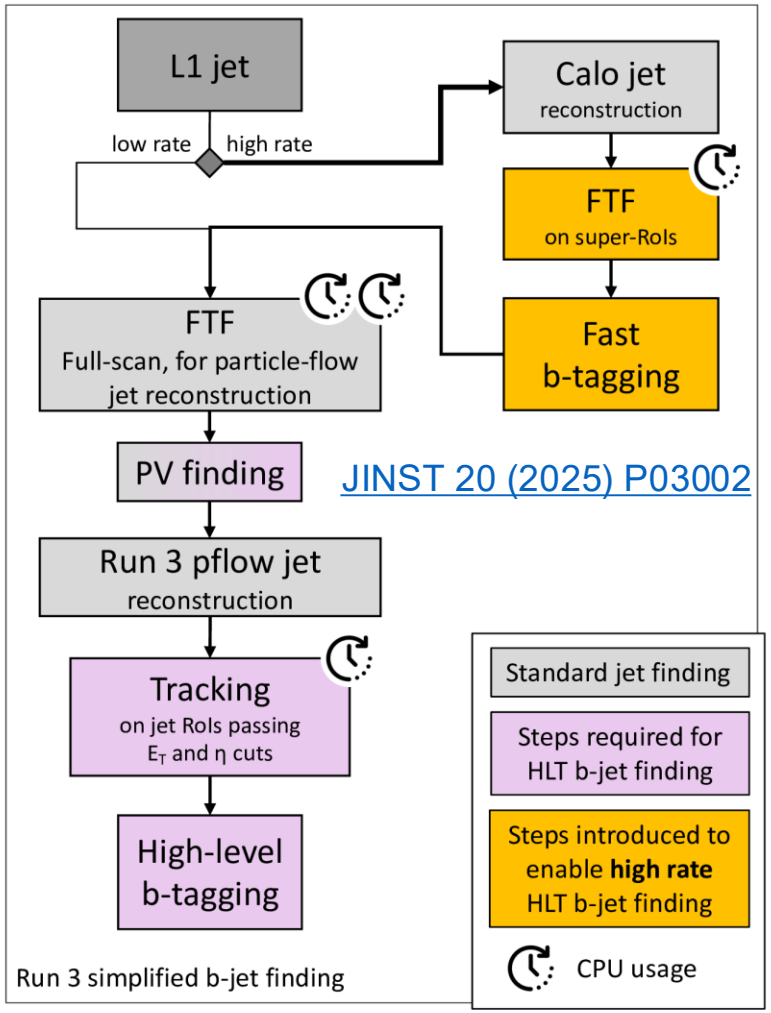
FTAG-2023-01

2022 ***2023*** ***2024, 2025, 2026*** *Online implementation*

b-jet trigger work flows

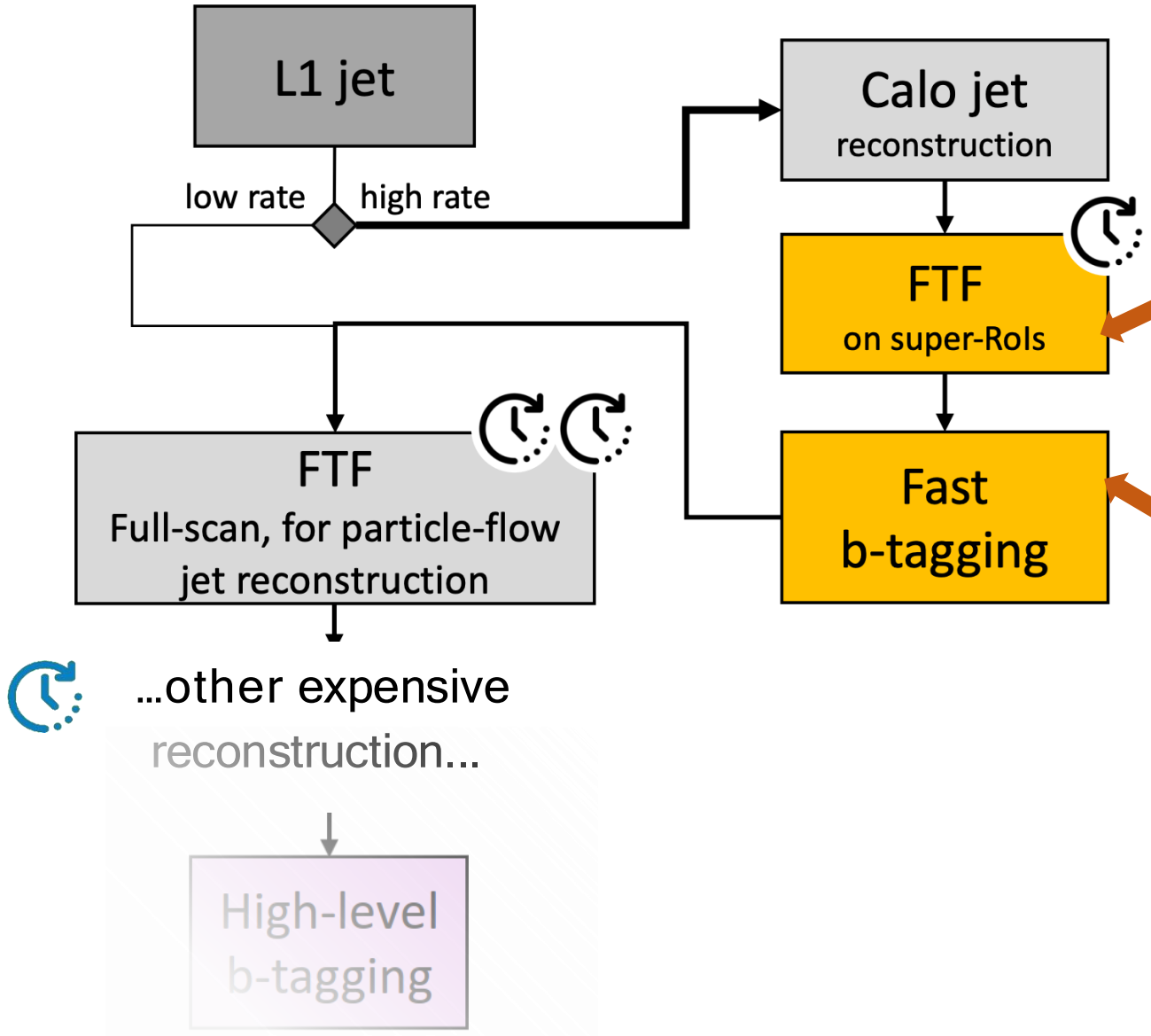
- Several novel items implemented in Run3 HLT compared to Run2
- b-jet trigger workflow
  - L1 jet or L1Topo seeds
  - Full detector acceptance (Full Scan) tracking NEW
  → *Better tracking efficiency*
  - Particle flow (Pflow) reconstruction NEW
  → *Better resolution at low p_T*
  - Precision tracking around Pflow jets
  - Perform b-tagging with advanced ML techniques NEW
  → *Better rejection, better align with offline*





High-precision and full scan tracking is very CPU intensive and time consuming
→ *Fast b-tagging with ROI scan as preselection*

Fast b-tagging preselection



- Fast track finder (FTF) algorithm in limited regions of interest (ROI)

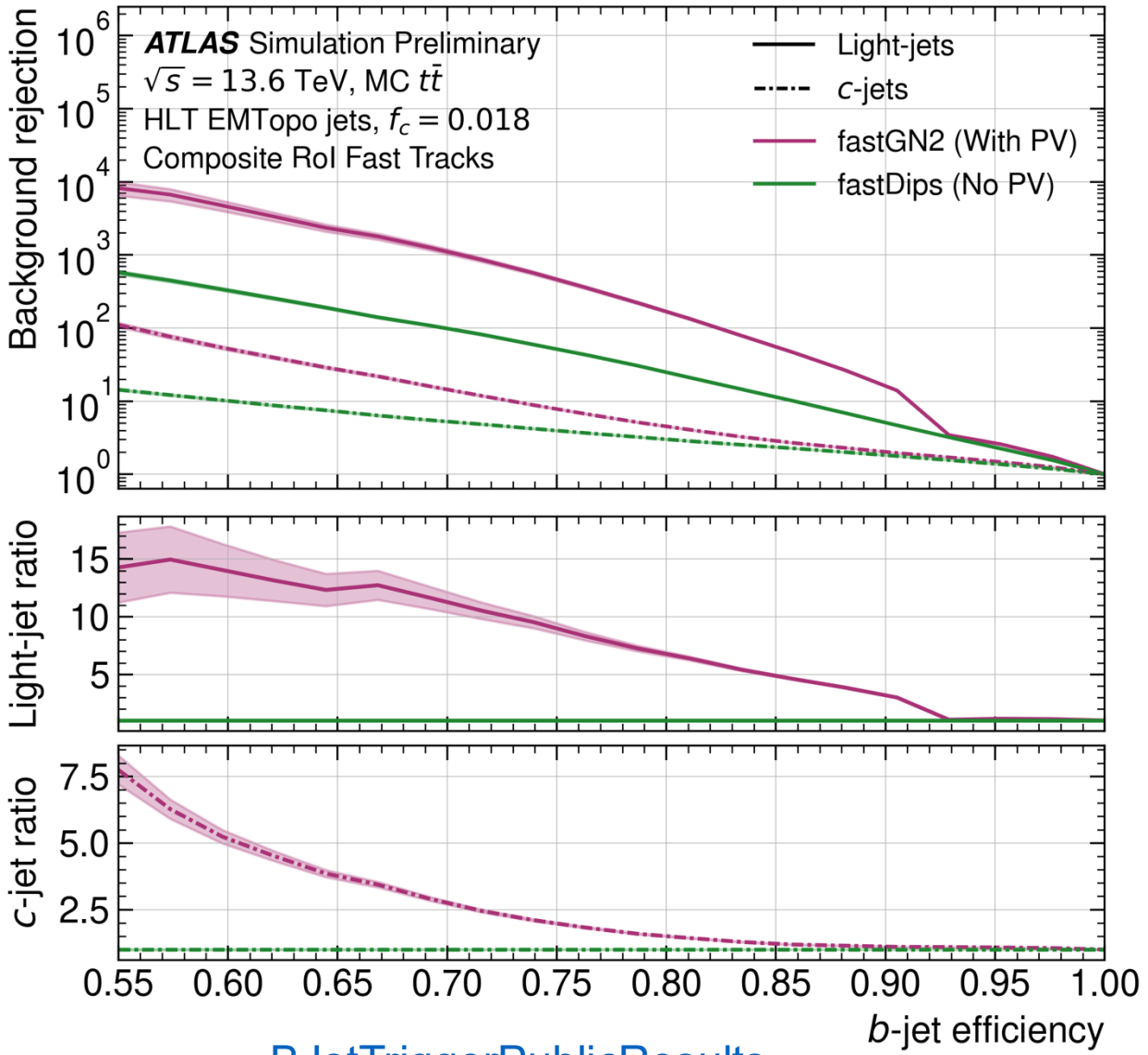
- ML-based algorithm to filter events containing b-jets
- Using DeepSets architecture (fastDIPS) in 2022 and 2023
- Move to GN architecture (fastGN2) since 2024

Fast b-tagging performance

- Preselection tagger get upgraded with GN2 architecture
- A factor of 5 improvement in background rejection with fastGN2 vs fastDIPS
  - PV information also helps to increase the performance
- Some impact on CPU consumption

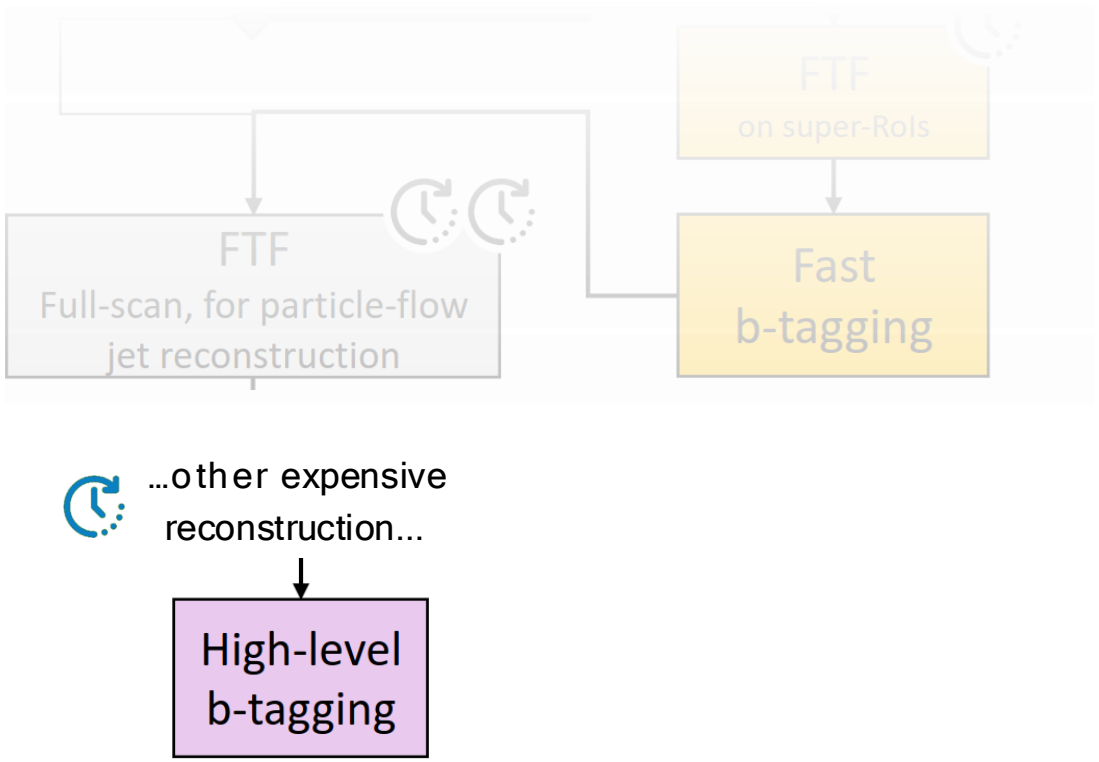
Tagger	Time per event
fastDIPS	1164 ms
fastGN2	929 ms

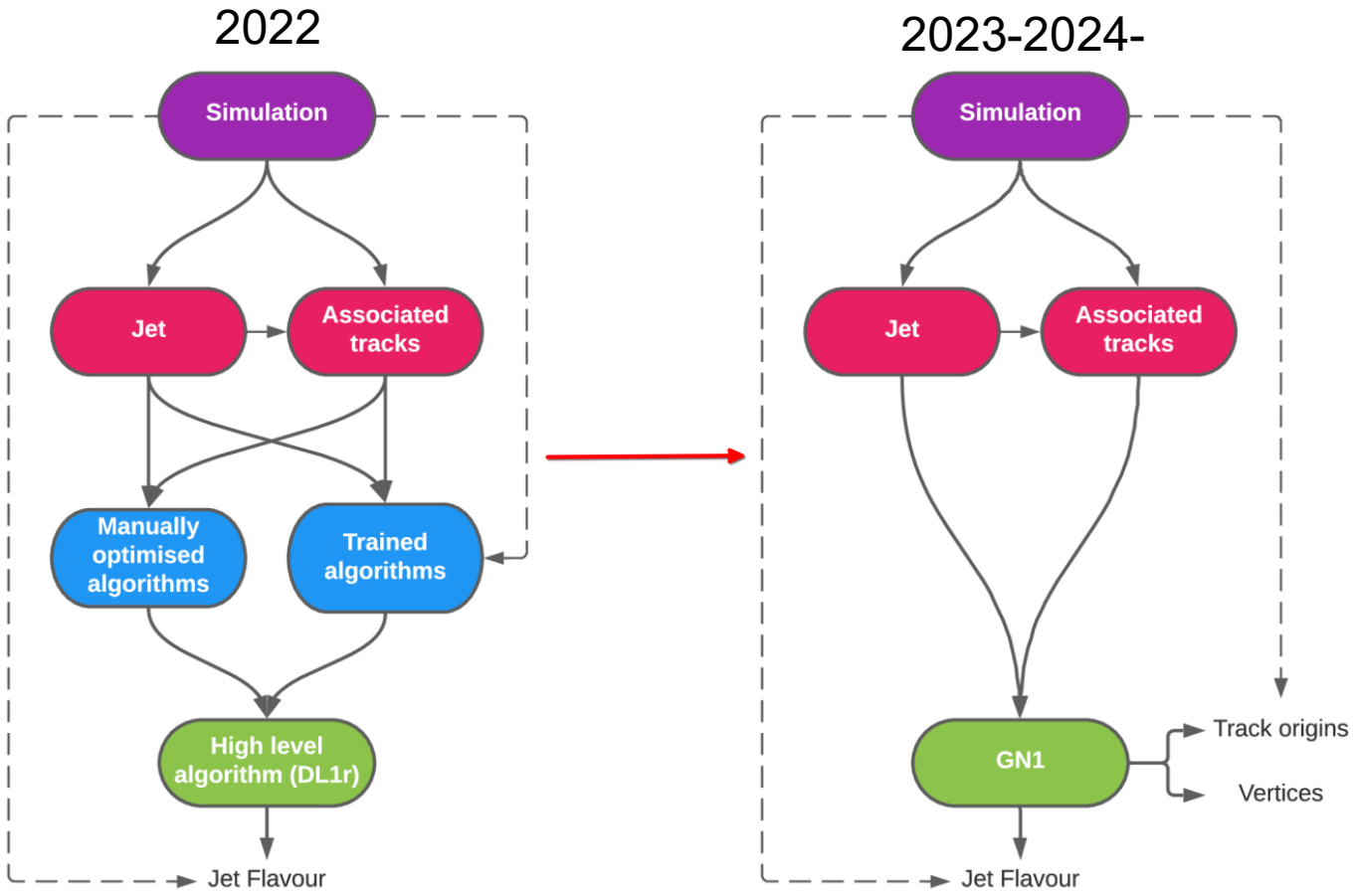
Decreased by ~20%



BJetTriggerPublicResults

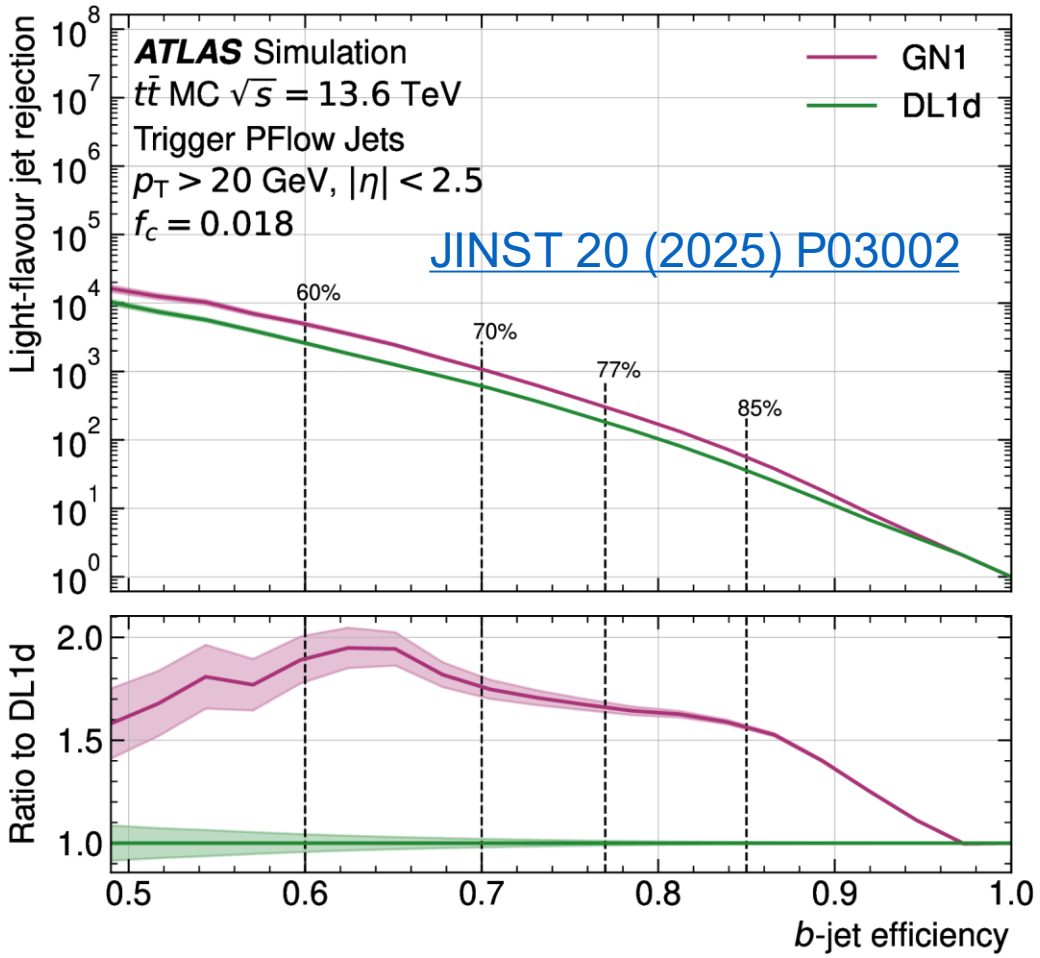
Precision b-tagger

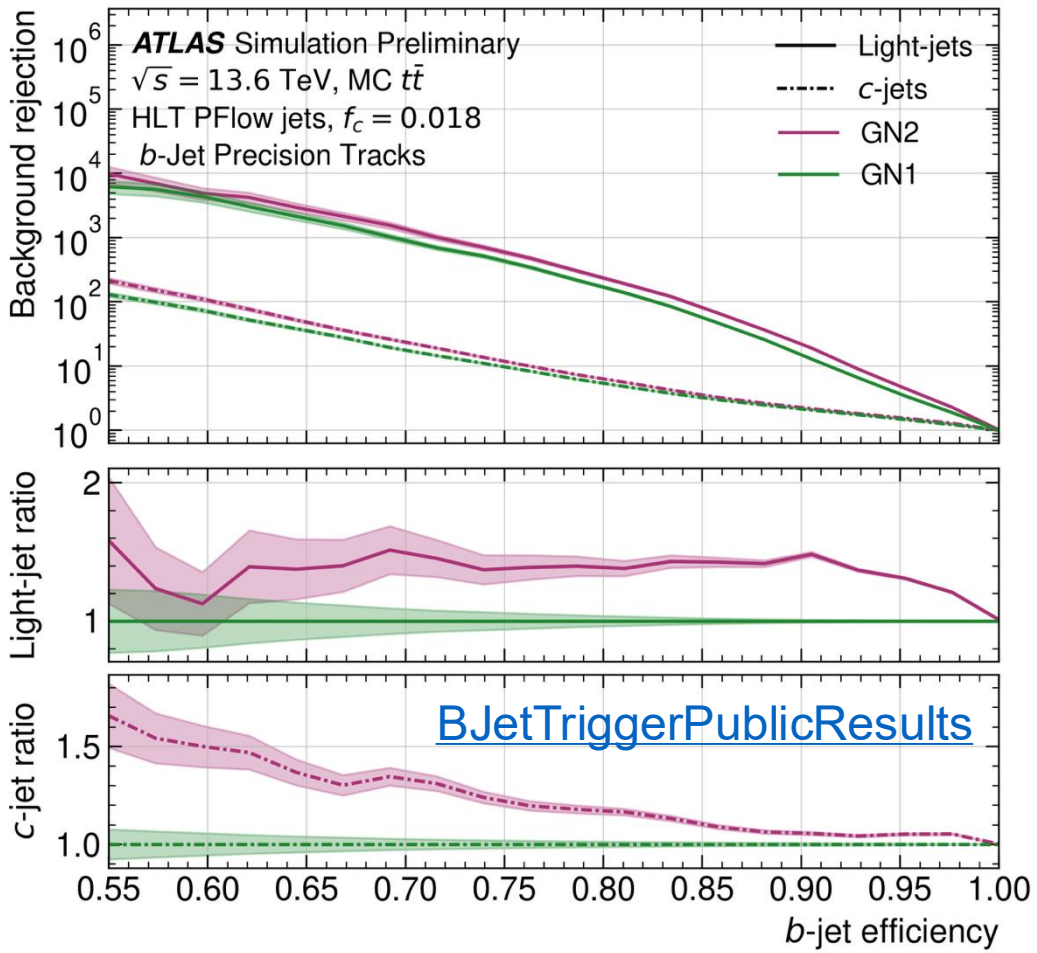




- At begin of run3, online b-tagging use 2-stage approach (same in run2)
  - Use low-level variables (e.g. tracks) for b-hadron specific reconstruction (e.g. IP, SV …)
  - Train BDT, DNN with pre-reconstructed variables (e.g. MV2, DL1d tagger)
- Move to GN1/2 tagger: using jet and track features directly

Comparison of tagger performance





Increased Light jet rejection @77% -jet efficiency:

DL1d
Combination of DNNs

+75% →

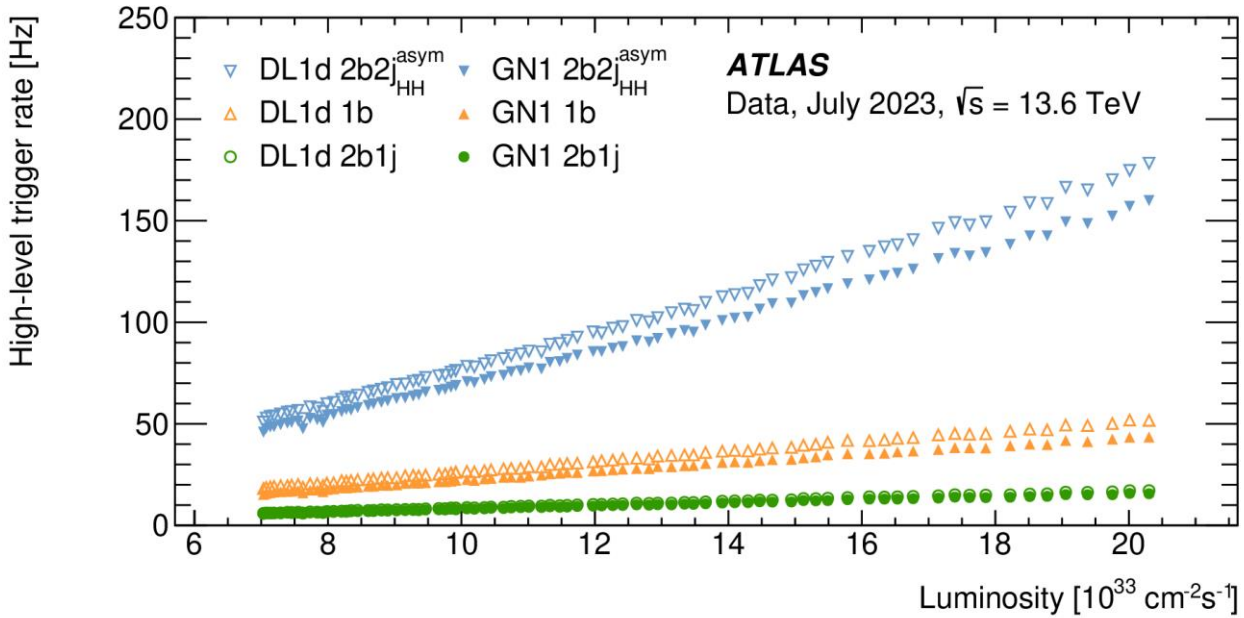
GN1
Graph Attention Network

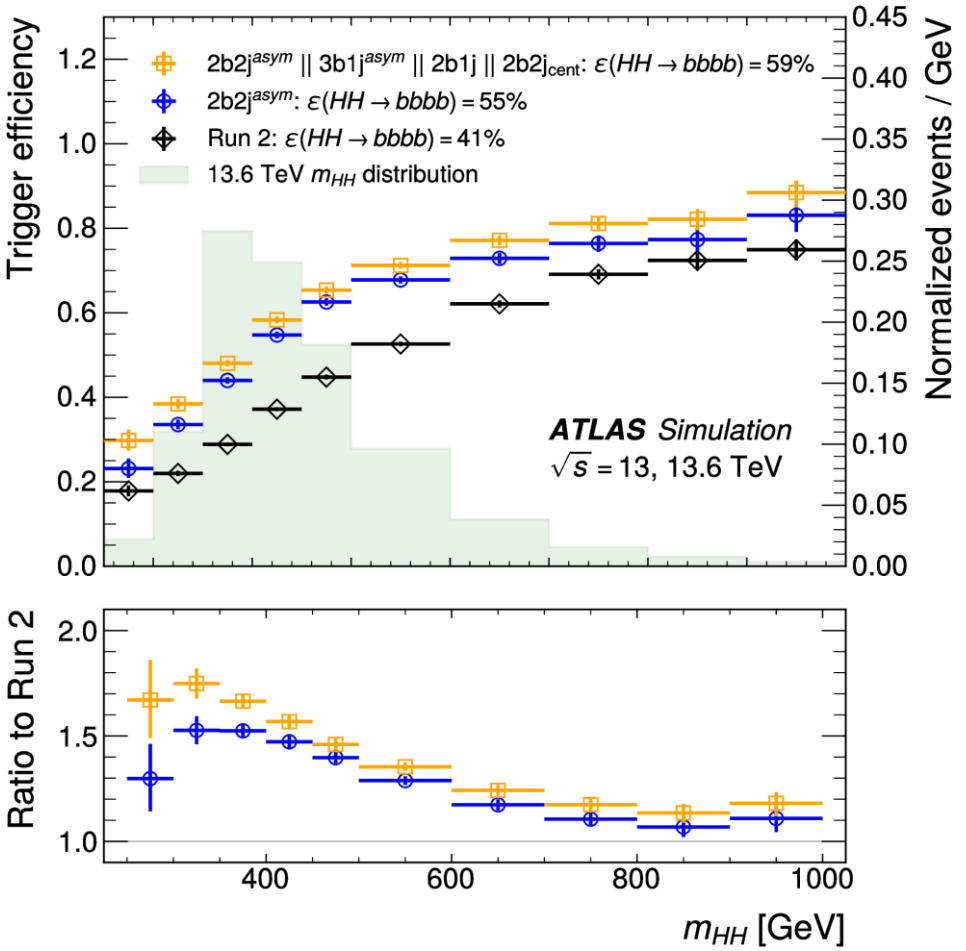
+50% →

GN2
Transformer-based Architecture

B-jet trigger chains

- Various trigger chains with online b-tagging
  - General purpose chains:
    - combination of n-bjet and n-jet
  - Physics specified chains
    - DiHiggs: Soft asymmetric p_T cuts, 2 or 3 b-tagged jets
    - SUSY search: bjet+E_T^{miss}
    - Vector boson fusion: Forward jets+Central b-jets



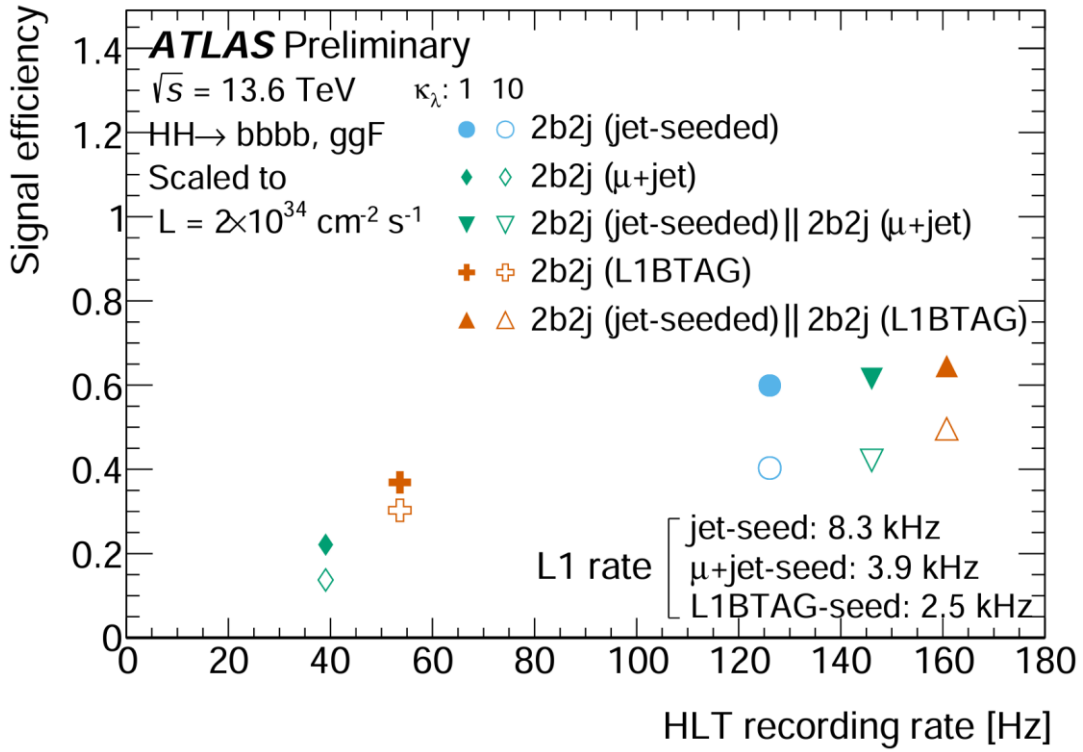


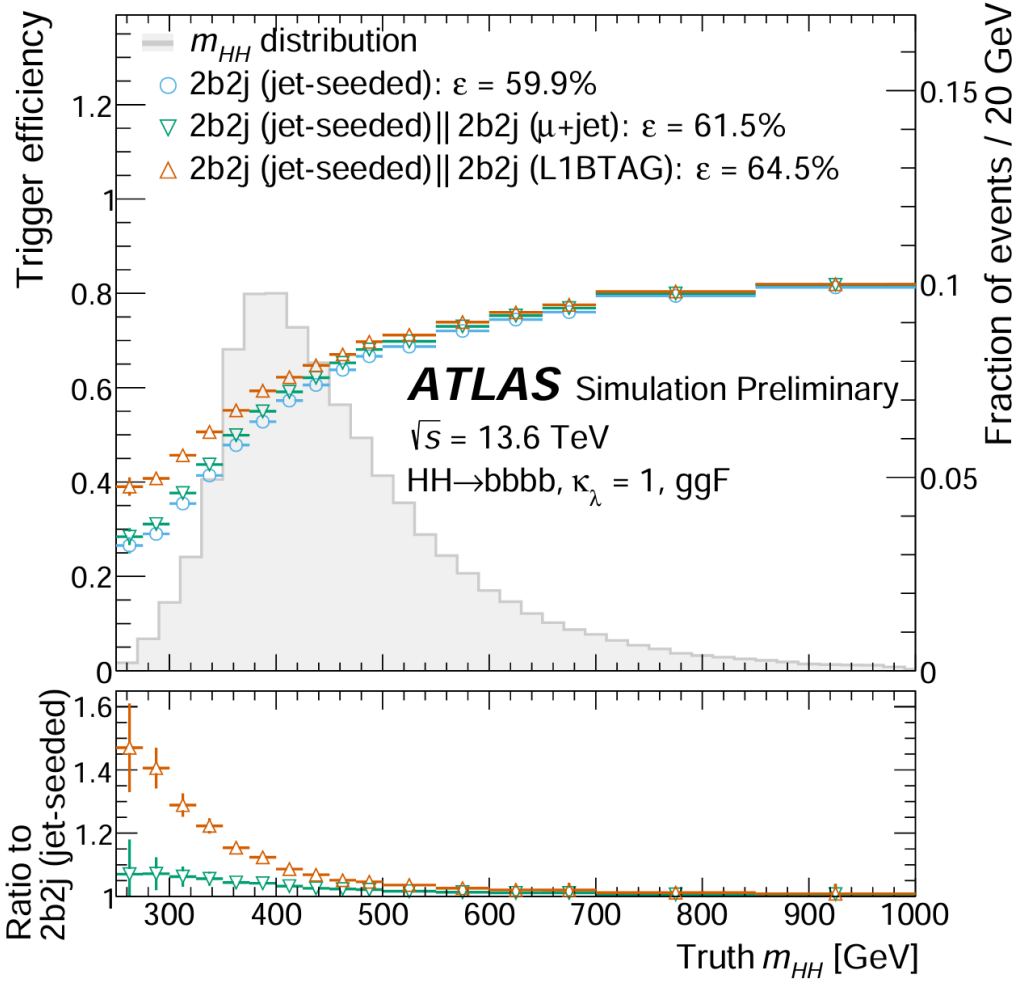
JINST 20 (2025) P03002

L1BTAG chains

- 20% of b-hadron decay chain with muons
- L1Topo item with μ+jet added in Run3 (no ΔR match)
- New L1BTAG algorithm deployed in 2025
  - ΔR match between L1MU and L1Jet
  - Better efficiency in low pt region

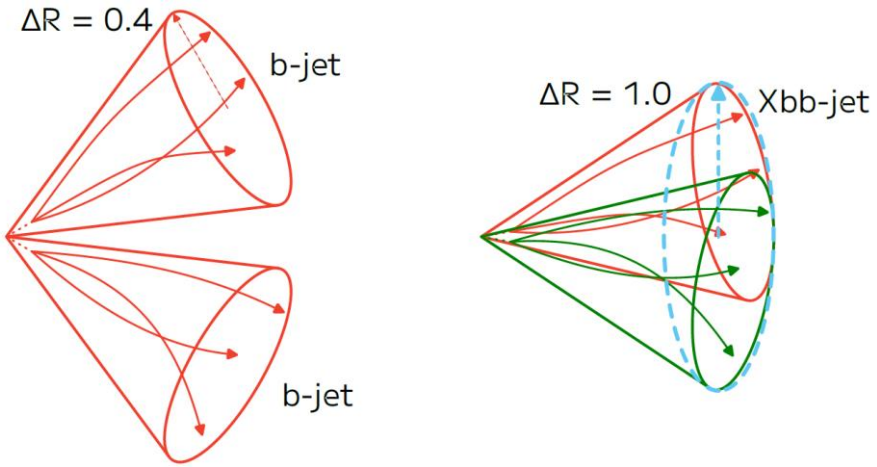
BJetTriggerPublicResults

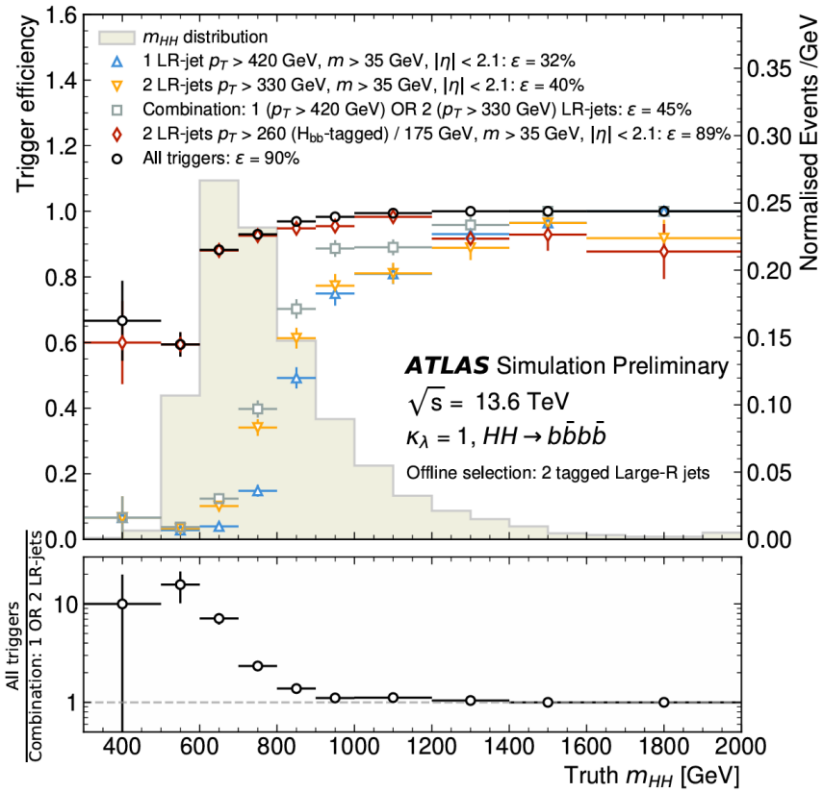


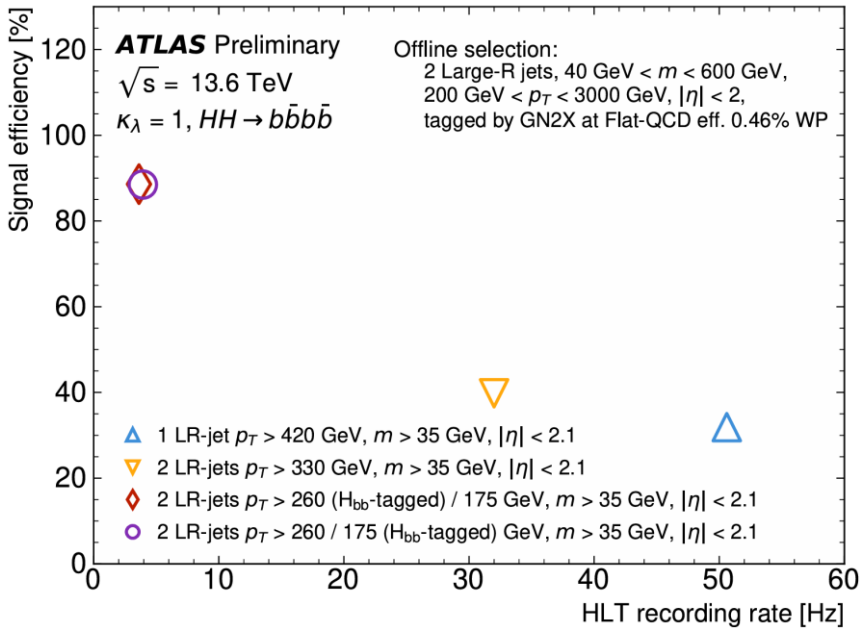


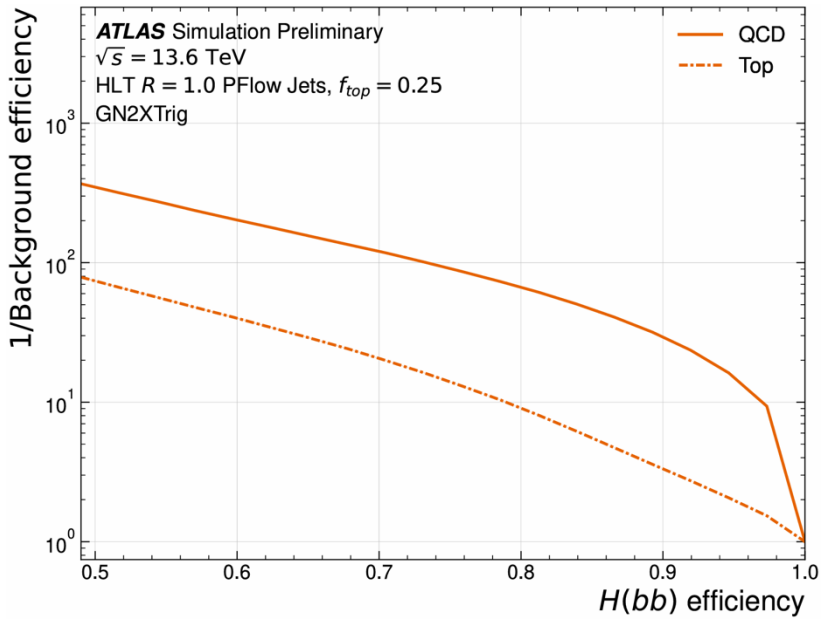
X→bb trigger

- Beside the small-R b-jet trigger, large-R Jet X→bb tagger also implemented in trigger-level in 2025
- Model use transformer-based architecture following the offline GN2X tagger and retrained with HLT information
- Better efficiency in low p_T region









[BJetTriggerPublicResult]

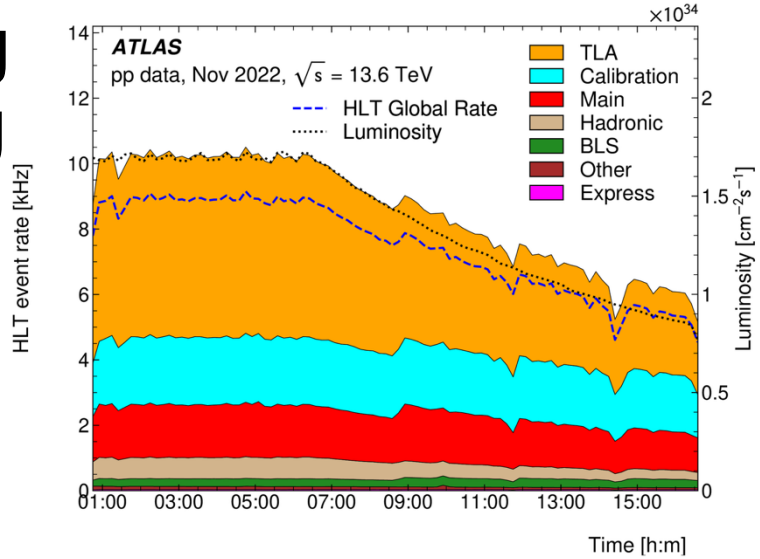
b-tagging in TLA

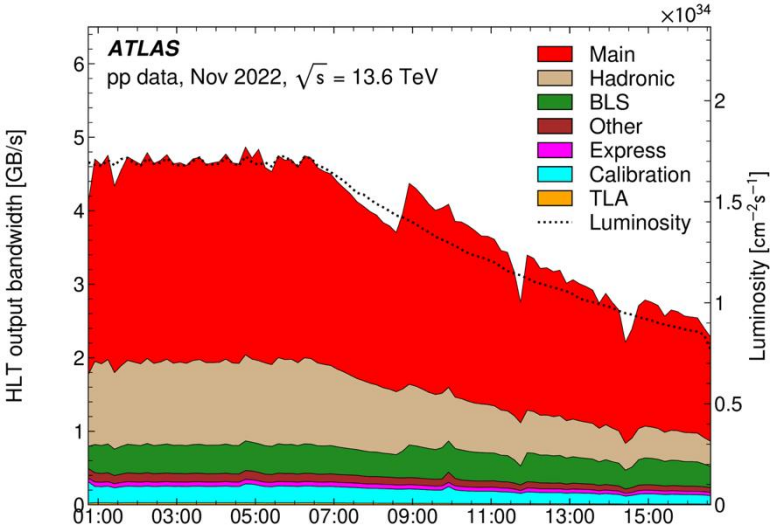
- Online b-tagging allow to include flavour tagging in trigger-level analysis (TLA), like data scouting in CMS
- TLA stores only trigger-level objects (without RAW data)
  - Allow to select events at low threshold without significantly increasing the bandwidth

↑ Event rate x ↓ Event size = Bandwidth

Physics Stream :	1.7 kHz	x	1.5 MB	=	3 GB/s
TLA Stream :	6.0 kHz	x	4.5 kB	=	27 MB/s

- TLA use fastDIPS in 2022, GN1 in 2023 and GN2 since 2024





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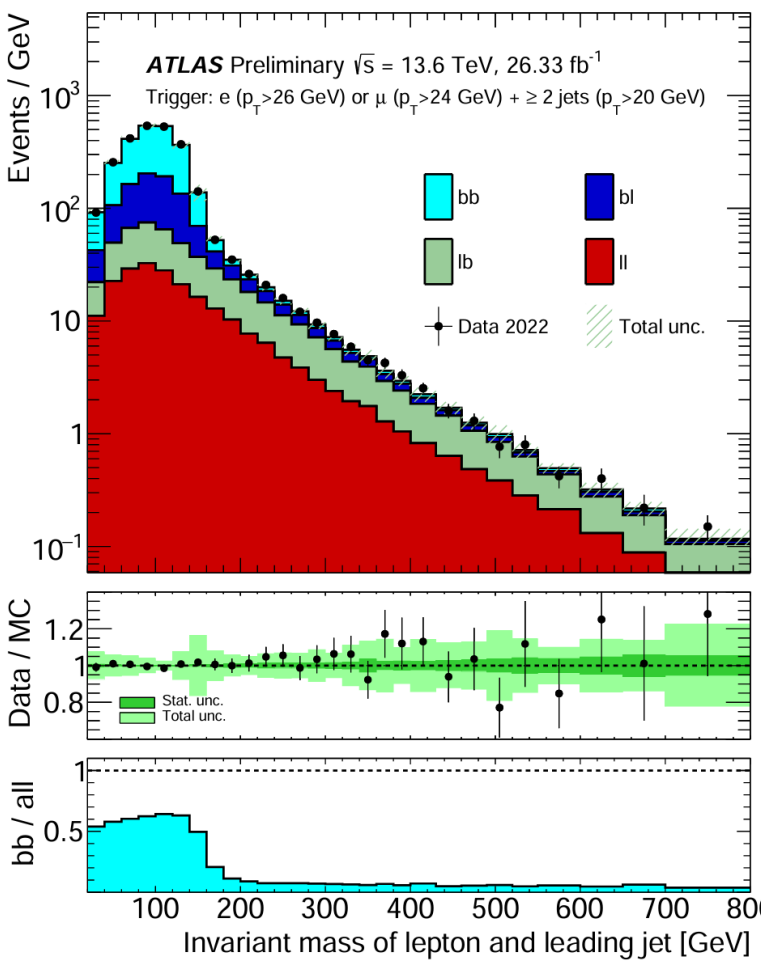
Calibration

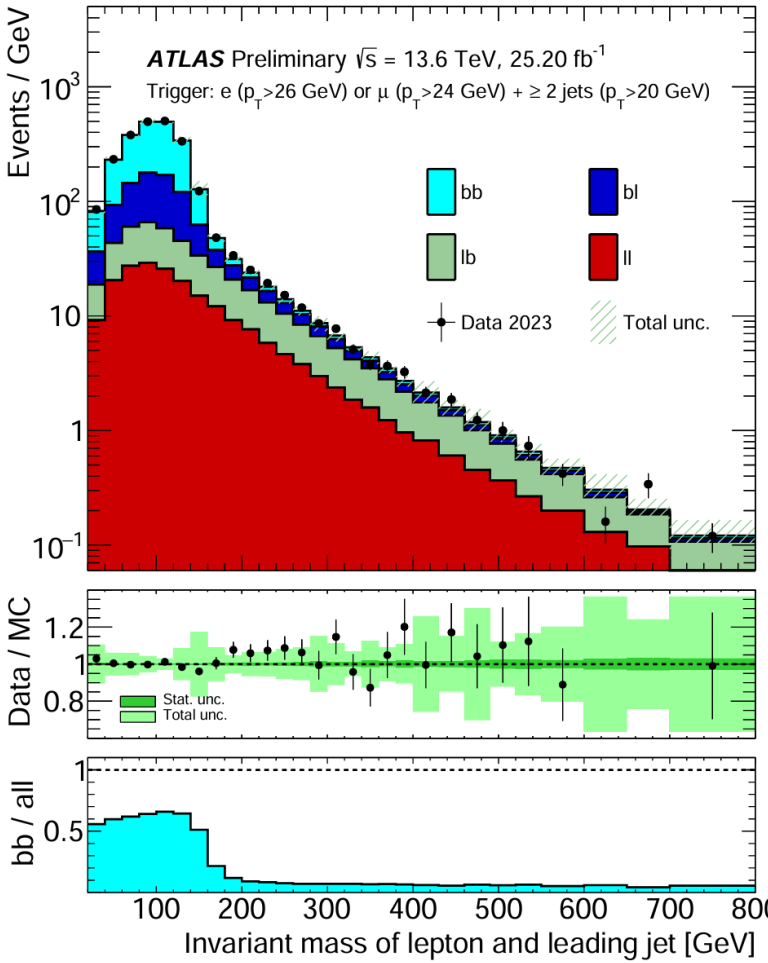
- The online b-tagging efficiency measured with di-lepton $t\bar{t}$ events
- similar as the offline measurement

→ share the same framework as the offline

- PDF method, simultaneously extracting efficiency and flavour composition
- Scale factor close to be unity



2022 data



2023 data

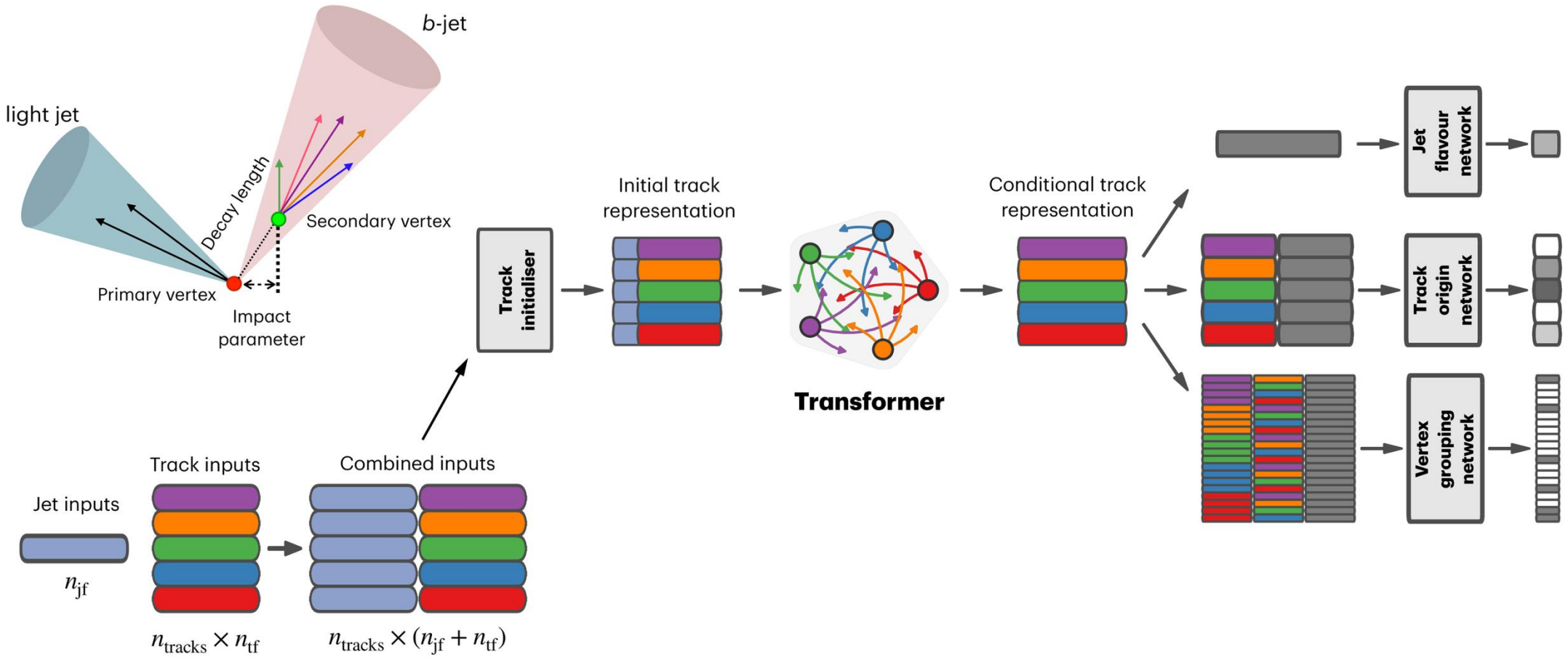
BJetTriggerPublicResult

Summary

- b-jet is an important signature in many physics processes to suppress large QCD background
- Implement b-tagging in trigger-level help to explore new phase-space
- Benefit from offline b-tagging development, online b-jet trigger performance improved significantly
- Large-R tagger also implemented in Run3 data taking to reduce jet p_T threshold in trigger-level
- Expected more excited physics results with Run3 dataset using updated b-jet trigger algorithm

Backup

GN2


b-jet
light jet
Decay length
Secondary vertex
Primary vertex
Impact parameter
Track initialiser
Initial track representation
Transformer
Conditional track representation
Jet flavour network
Track origin network
Vertex grouping network
Track inputs
Combined inputs
Jet inputs
n_{jf}
$n_{\text{tracks}} \times n_{\text{tf}}$
$n_{\text{tracks}} \times (n_{\text{jf}} + n_{\text{tf}})$