b-jet Trigger at ATLAS

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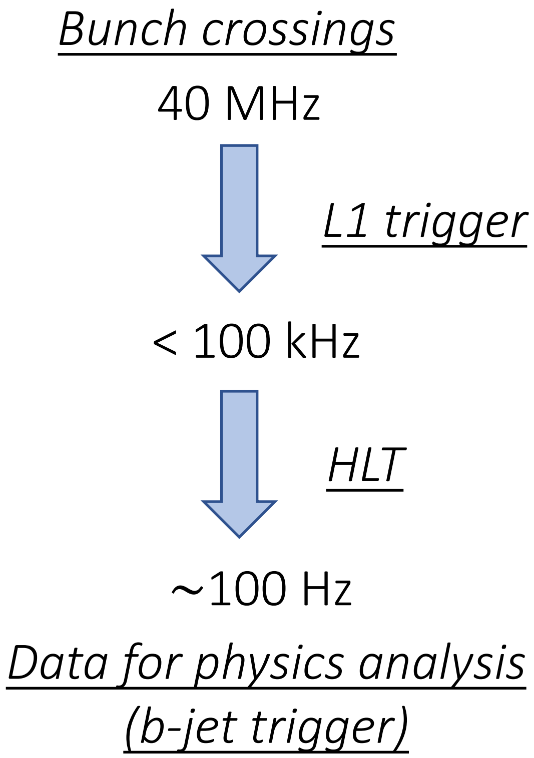
On behalf of the ATLAS b-jet trigger group

HHH workshop Dubrovnik 2023

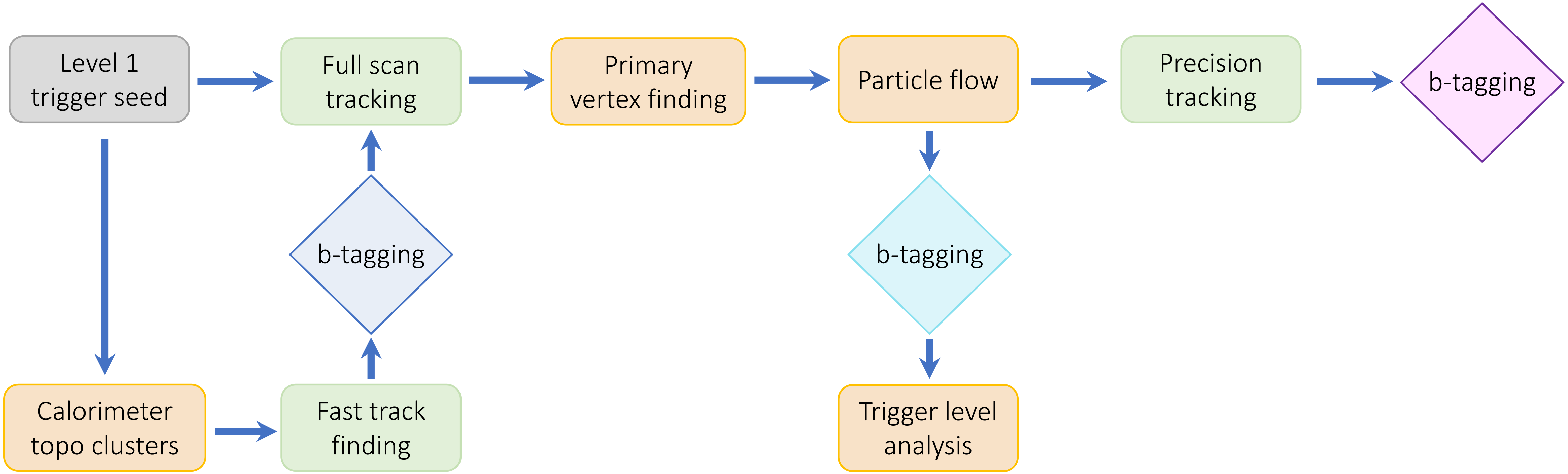
Overview

- b-jets are important in many physics searches (e.g. $HH \rightarrow b\bar{b}b\bar{b}$)
- b-tagging algorithms exploit the b-hadron decay properties to identify b-jets
  - Used in multiple stages in the b-jet trigger preselection
  - With many updates in Run 3!
- $HH \rightarrow b\bar{b}b\bar{b}$ trigger strategy update
  - Gain in efficiency from delayed stream
- Challenges in HL-LHC and HHH searches
  - Specific kinematic phase space currently not within reach?
  - More final-state specific triggers?



b-jet trigger preselection

- Precision b-tagging requires precise tracking information to reconstruct secondary vertices → CPU intensive!
  - Can utilize b-tagging at earlier stages for pre-select candidates for full scan tracking
- Significant improvement in the ability to reject background from b-tagging



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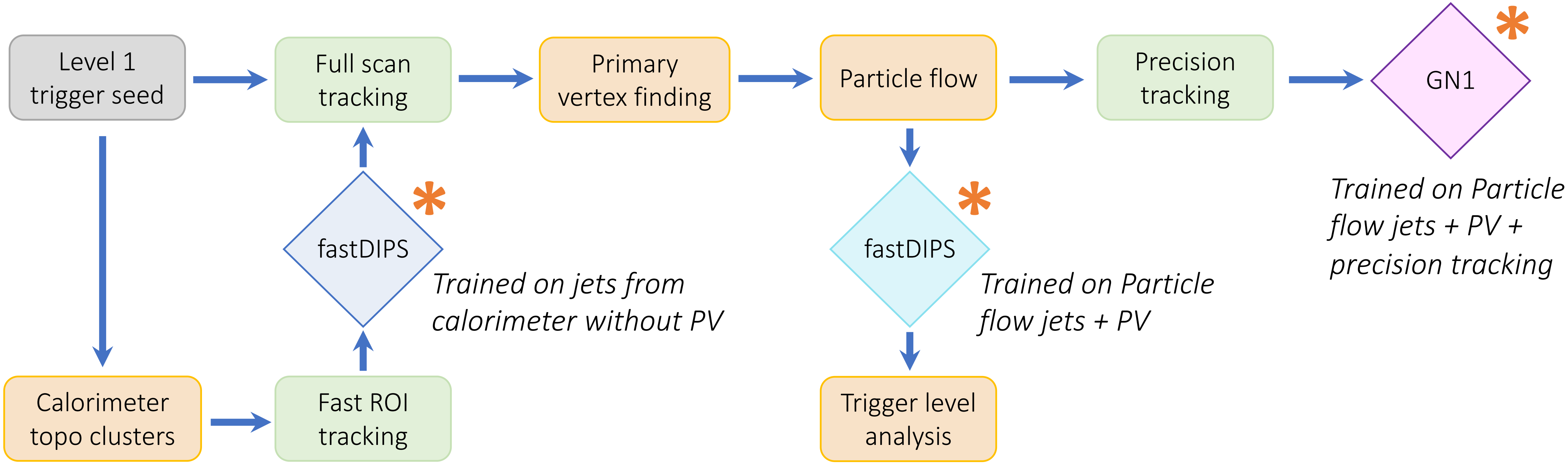
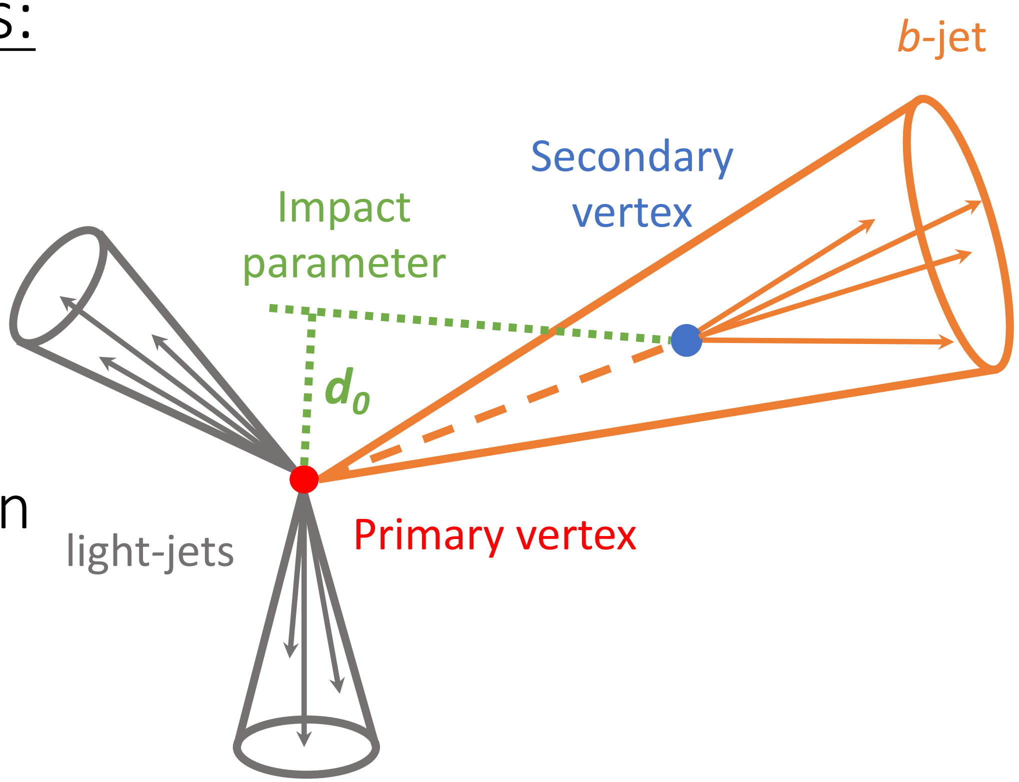


b-tagging algorithm

b-tagging exploits the b-hadron decay properties:

- Hard *b*-quark fragmentation
  - ∽70% of the *b*-quark energy goes to the B-hadron
- Relatively long lifetime: ∽1.5ps
- Displaced secondary vertex
- Large transverse impact parameter (d_0) in B-hadron decay tracks
- Large decay multiplicity



Objective:

- Classify jets originating from b-quarks, c-quarks and light-flavour quarks

Update to GN1

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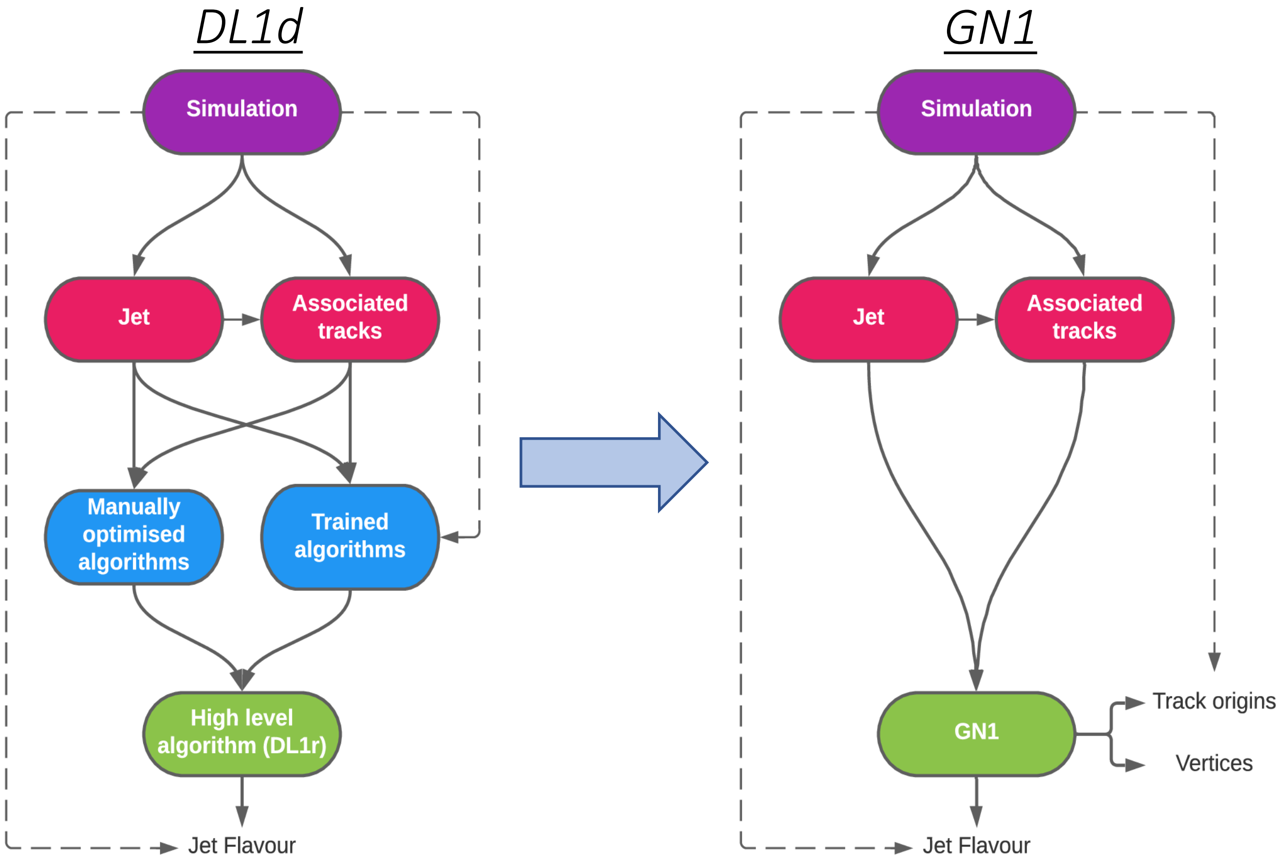
DNN → GNN (represents jets with variable number of unordered tracks naturally)

- Previously: DL1d relies on "low-level" algorithms
- Now: GN1 – a single algorithm
  - o Uses auxiliary tasks to learn jet substructure
  1. Group tracks from common vertices
  2. Predict physics origins of tracks
- Benefits:
  - o Better background rejection
  - o No "low-level" algorithms to retune/maintain
  - o Useful auxiliary tasks outputs



GN1 performance

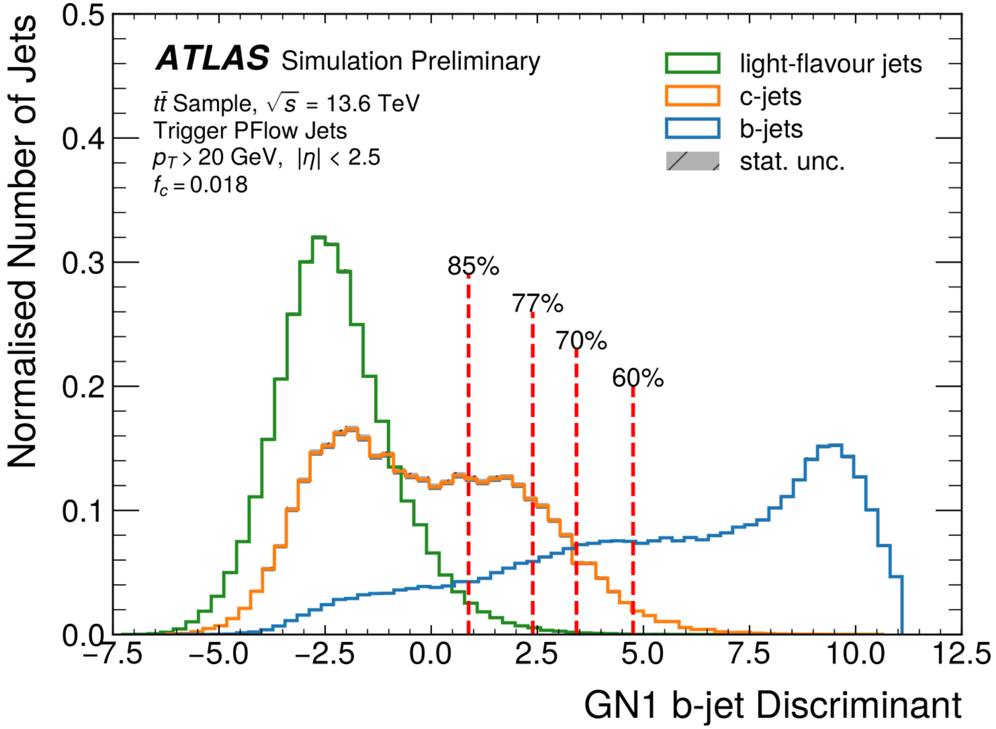
GN1 public results

Combine the GNN outputs p_b, p_c, p_{light} into a single discriminant:

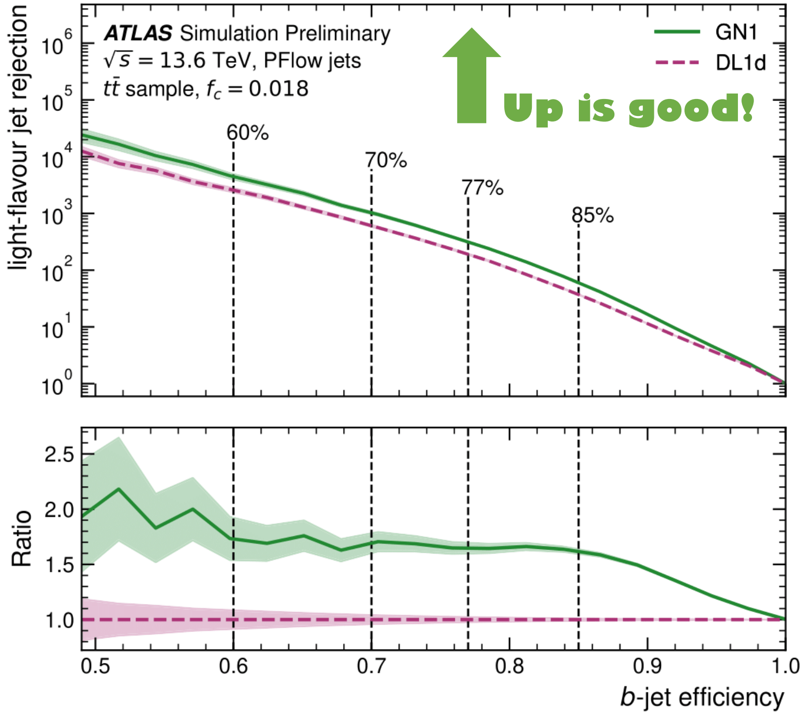
$$D_b = \log\left(\frac{p_b}{(1-f_c) * p_{light} + f_c * p_c}\right)$$

f_c - effective charm fraction

Define working points for b-jet efficiency:



Evaluate background rejection:

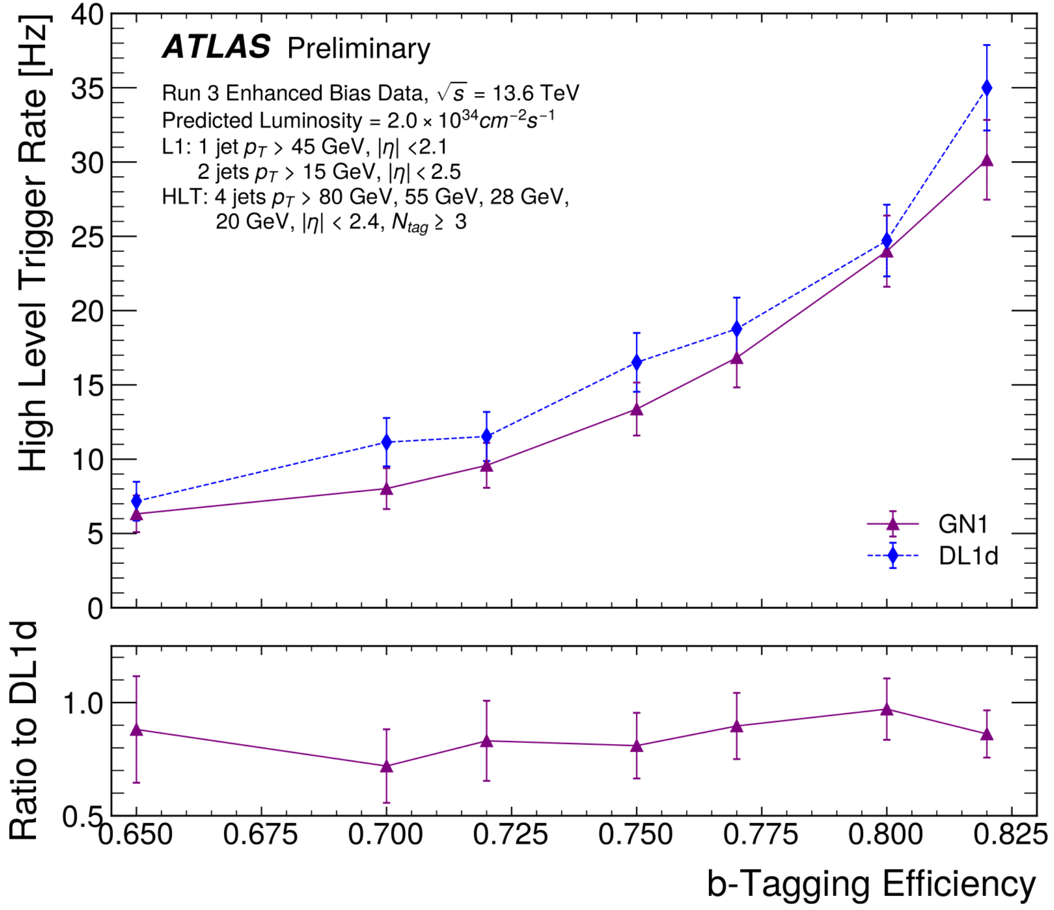


GN1 trigger rates

GN1 public results

Higher background rejection means lower trigger rates!

- Rates estimated by rerunning the Run 3 HH4b trigger on Run 3 Enhanced Bias data
- Replacing DL1d with GN1 in the same trigger
- At most a 20% reduction in readout rate → highly relevant in HL-LHC

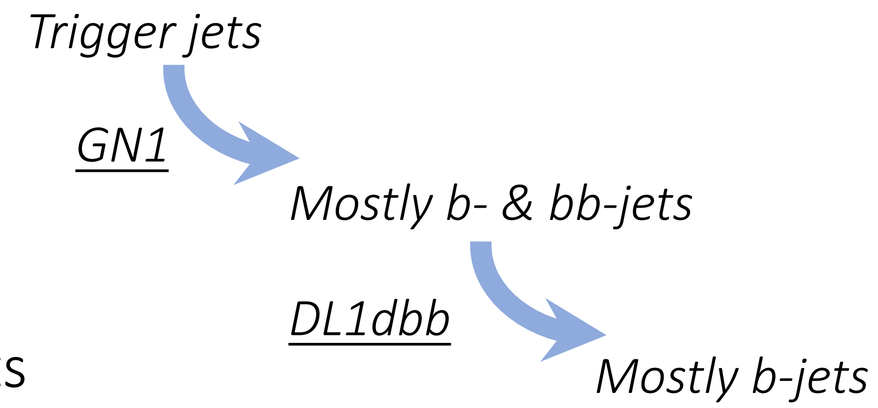


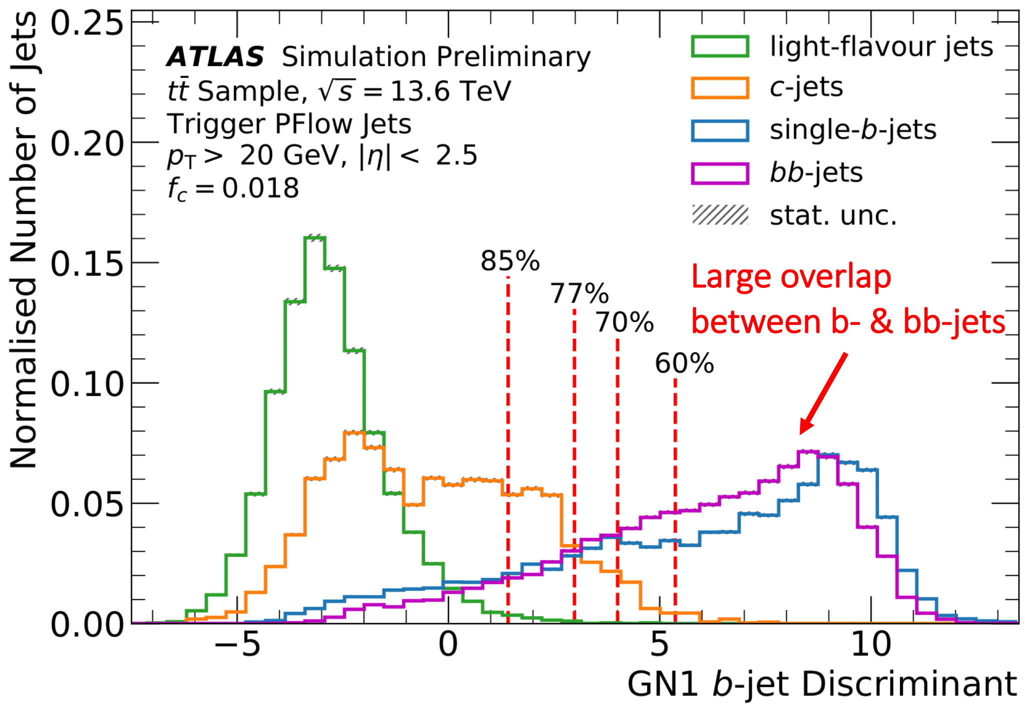
$g \rightarrow b\bar{b}$ rejection – DL1dbb

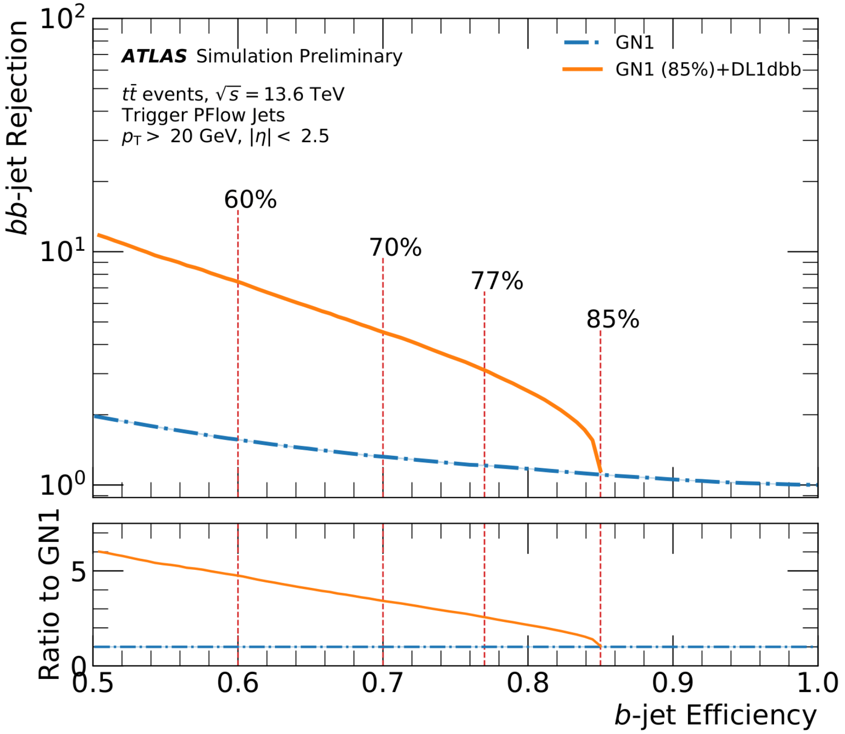
DL1dbb public results

Rejecting bb-jets from $g \rightarrow b\bar{b}$ splitting can further reduce readout rates

- Currently bb-jets are identified as b-jets by GN1
- DL1dbb – a dedicated DNN to separate b-jets and bb-jets





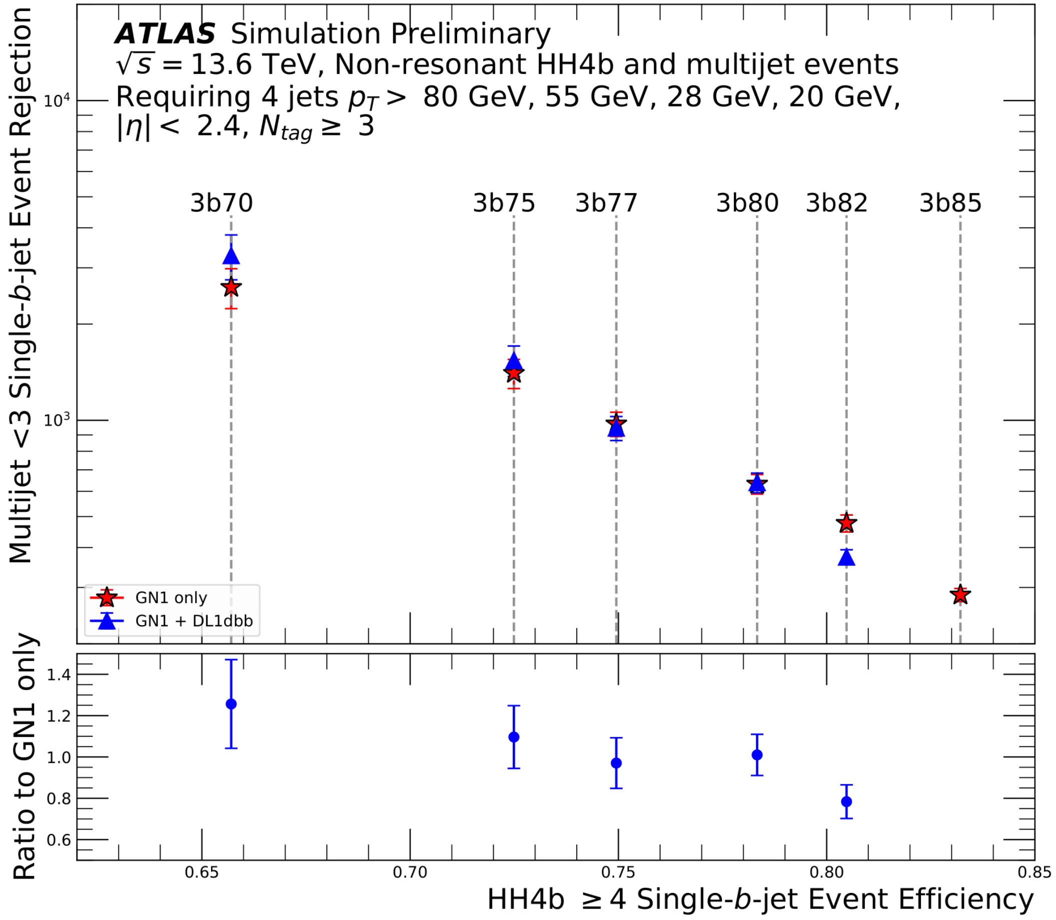


DL1dbb performance

[DL1dbb public results]

Combining GN1 + DL1dbb:

- Higher background rejection while maintaining HH4b signal efficiency
- Most significantly at tighter GN1 b-tagging working points
- Reduce readout rates, and maintain high signal purity for final states with multiple b-jets



FastDIPS algorithm

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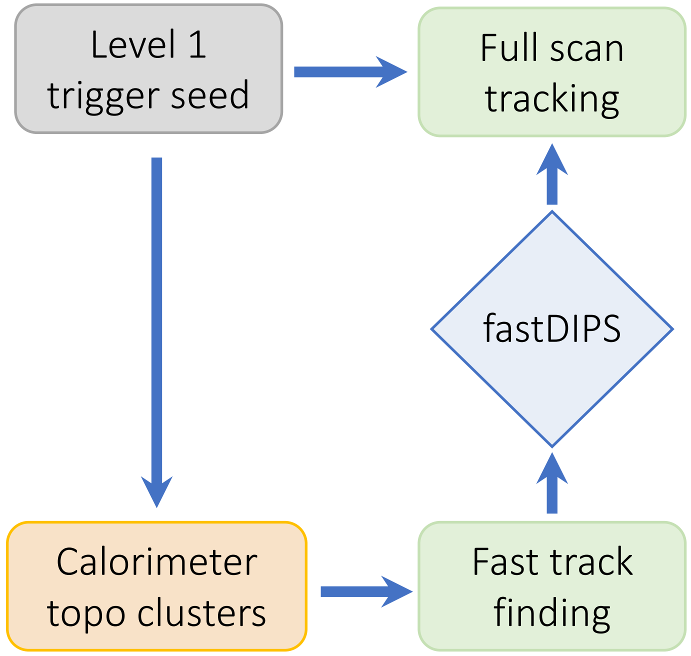
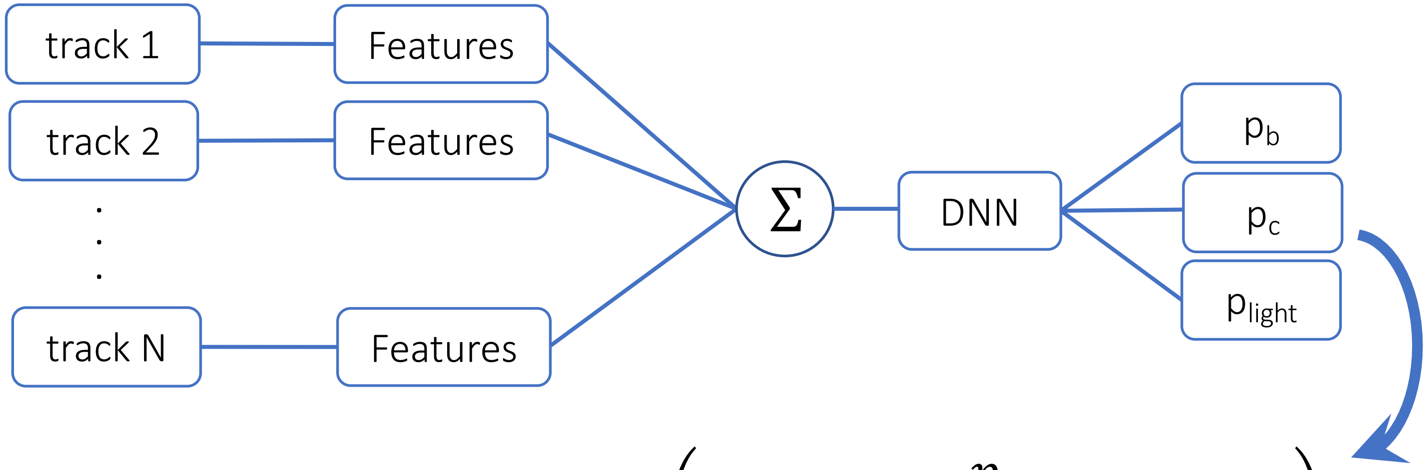
- Run 3 triggers use full scan tracking to reconstruct PFlow objects
  - Better reconstruction but CPU intensive
- Fast track finding + fastDIPS: reduces tracking to high-energetic jets only



FastDIPS architecture – deep sets network

DIPS paper



$$D_b = \log\left(\frac{p_b}{(1-f_c) * p_{light} + f_c * p_c}\right)$$

FastDIPS pre-selection

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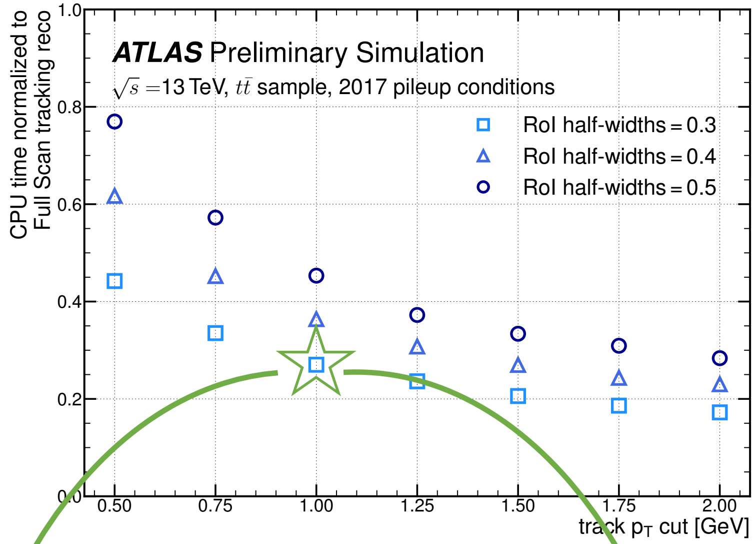
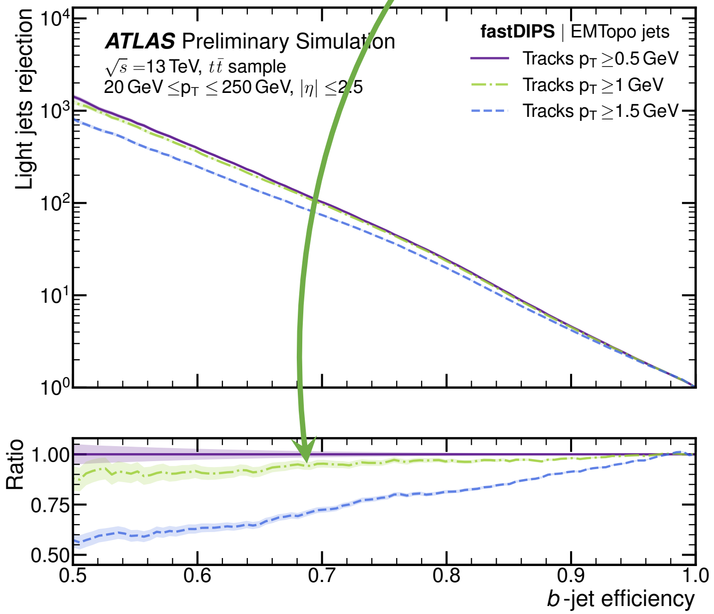
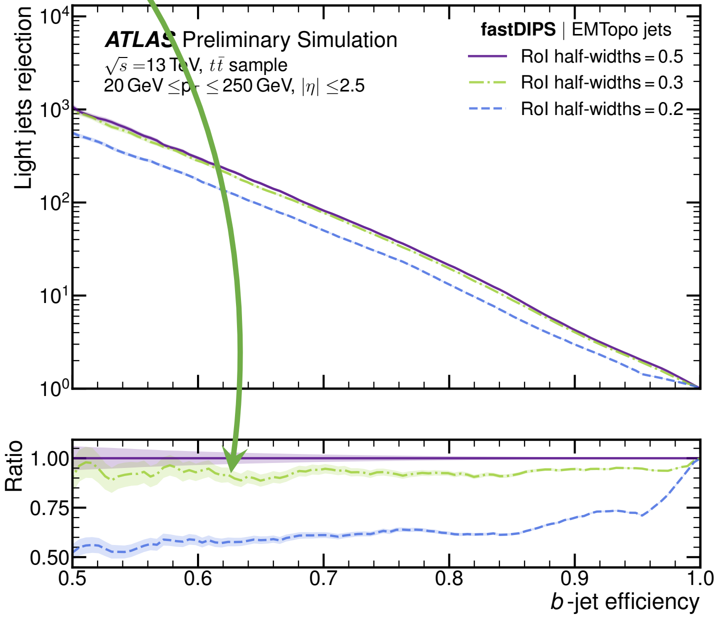
RoI width for fast track finding – 0.5 to 0.3
Track p_T threshold – 0.5 to 1 GeV



Fast tracking finding + FastDIPS – 30% of CPU cost





Smaller RoI width + higher track p_T cut:

no large degradation in light-jet rejection

FastDIPS pre-selection

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Impact on $HH \rightarrow b\bar{b}b\bar{b}$ signal acceptance:

- From tightening the working point on fastDIPS from 85% to 80%
  - Very small impact on $HH \rightarrow b\bar{b}b\bar{b}$ signal trigger acceptance (-2%)
  - But reduces the rates of event-wide tracking significantly
- CPU reduction will be highly relevant in HL-LHC data-taking

ATLAS Preliminary

Trigger selection	Presel. rejection factor on top of L1	$HH \rightarrow b\bar{b}b\bar{b}$ relative trigger acceptance
L1 + presel. (85% WP) + selection ($HH \rightarrow b\bar{b}b\bar{b}$)	5	0.98
L1 + presel. (80% WP) + selection ($HH \rightarrow b\bar{b}b\bar{b}$)	10	0.96

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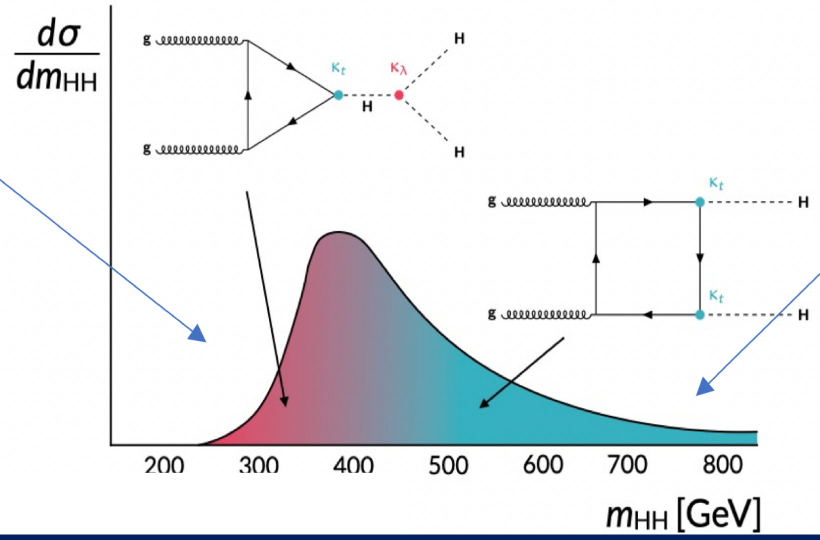
Run 3 $HH \rightarrow 4b$ trigger strategy

- $HH \rightarrow 4b$ is challenging due to all-hadronic final state
  - Analysis operates on trigger turn-on region
  - Several multi-jet triggers for acceptance across m_{HH}

Non-resonant analysis:

***2b2j** – 2 35GeV b-tagged jets* *
+ 1 35GeV extra jet

***2b1j –** 2 55 GeV b-tagged jets*
+ 1 100-150 GeV extra jet



Run 3 $HH \rightarrow 4b$ trigger strategy

[Run 3 expected HH4b trigger performance]

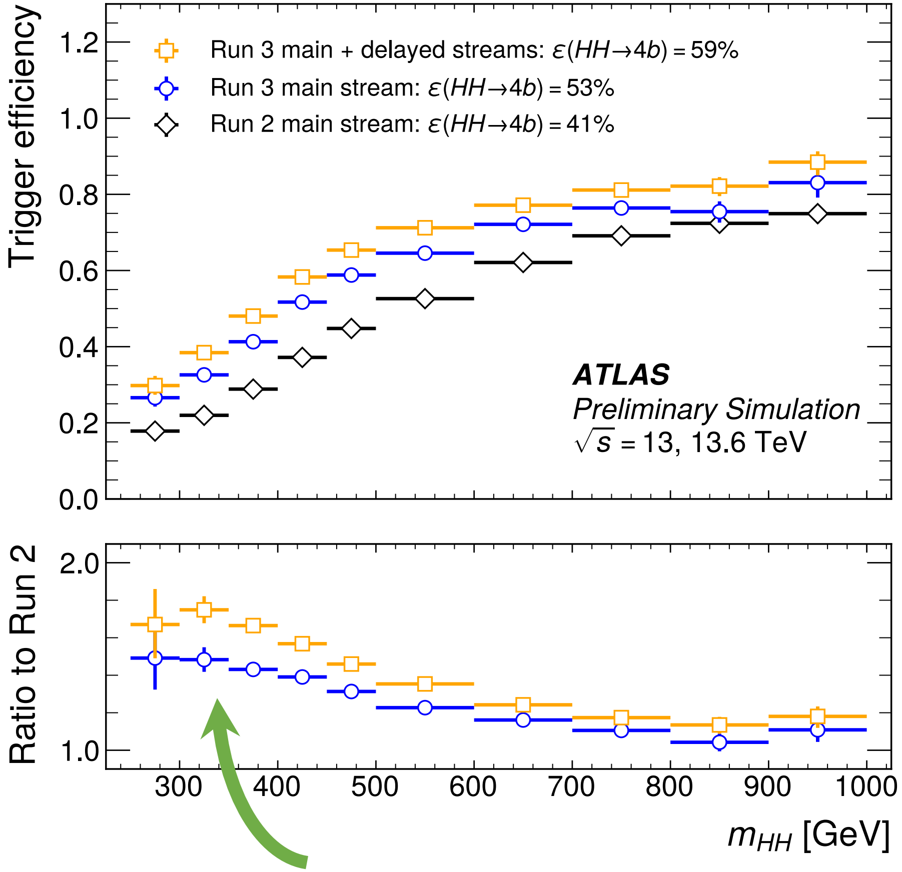
Changes in L1:

Run 2:

- Sensitivity limited by requiring 4 jets with p_T > 15 GeV
- Plateaus at 65 GeV in offline → low acceptance for the 4th soft jet

Run 3:

- Pre-selection upgrade allows for more L1 accept rates
  → requiring 2 jets p_T > 15 GeV, 1 jet p_T > 45 GeV
  → lower L1 threshold for 4th soft jet



Largest improvement in the low m_{HH} region

Run 3 $HH \rightarrow 4b$ trigger strategy

Run 3 expected HH4b trigger performance

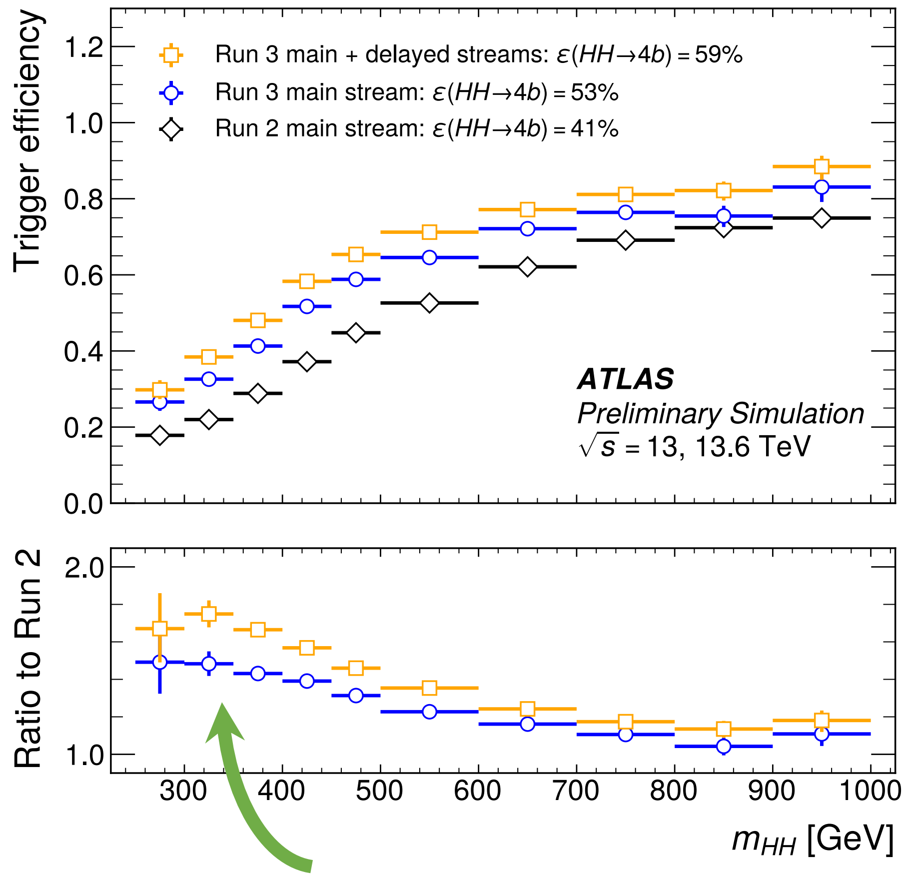
Changes in HLT:

Run 2:

- Symmetric triggers: same p_T cut on triggered jets ($p_T > 35$ GeV)

Run 3:

- Asymmetric trigger: different p_T cuts on triggered jets ($p_T > 80$ GeV, 55 GeV, 28 GeV, 20 GeV)
  → reduces trigger rates
- Delayed stream – events stored for later reconstruction

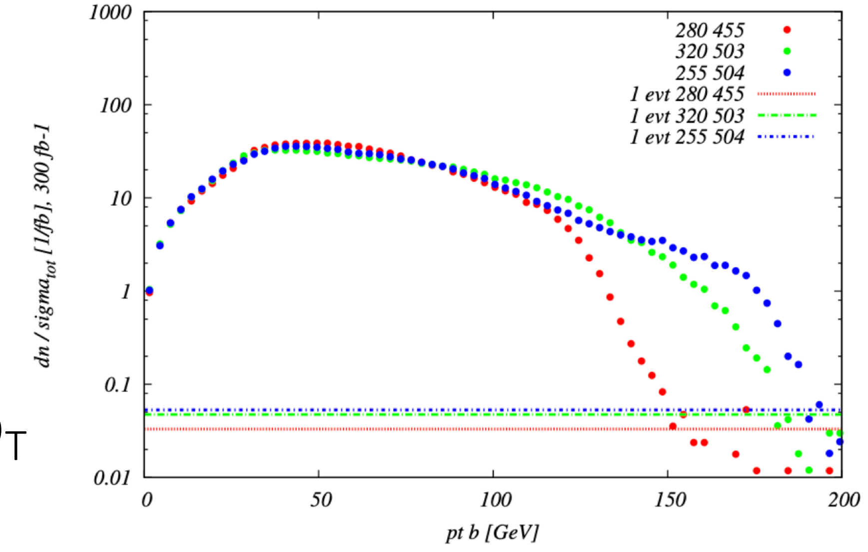


Largest improvement in the low m_{HH} region

Conclusion & HHH trigger challenges

- Upgrades to reduce readout rates and maintain signal purity are highly relevant for HL-LHC, where HHH signatures might become accessible
- Upgrades in $HH \rightarrow 4b$ trigger strategies also relevant for HHH
- However HHH signatures are more challenging
  - o More b-quarks in the final states ($HHH \rightarrow 6b$)
  - o Softer b-quarks in the final states in many BSM models → Tania will give an overview on a range of models

TRSM BP3 b P_T distribution

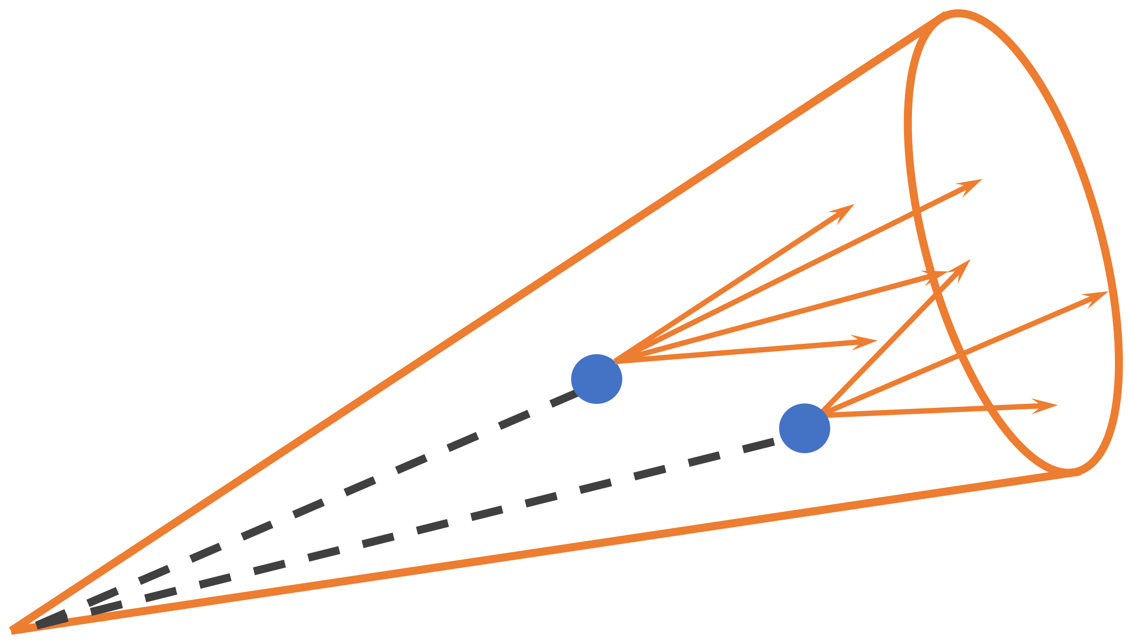


<u>Challenges to consider:</u>

- Challenges to calibrate b-tagging for b-jets at very low p_T
- How much can we rely on delayed stream in HL-LHC?
- More final-state-specific trigger strategies for more complex signatures?

Backup

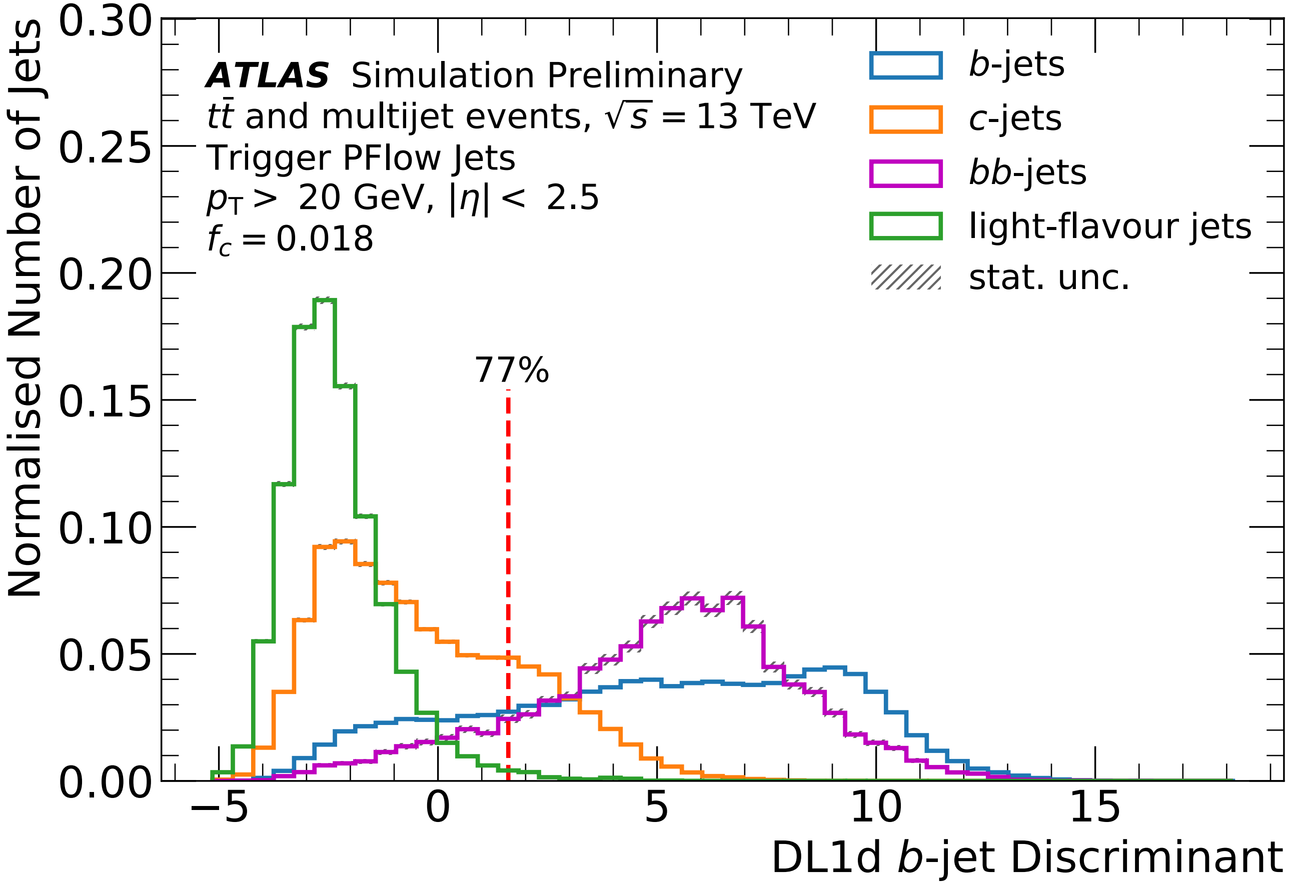
bb-jet features



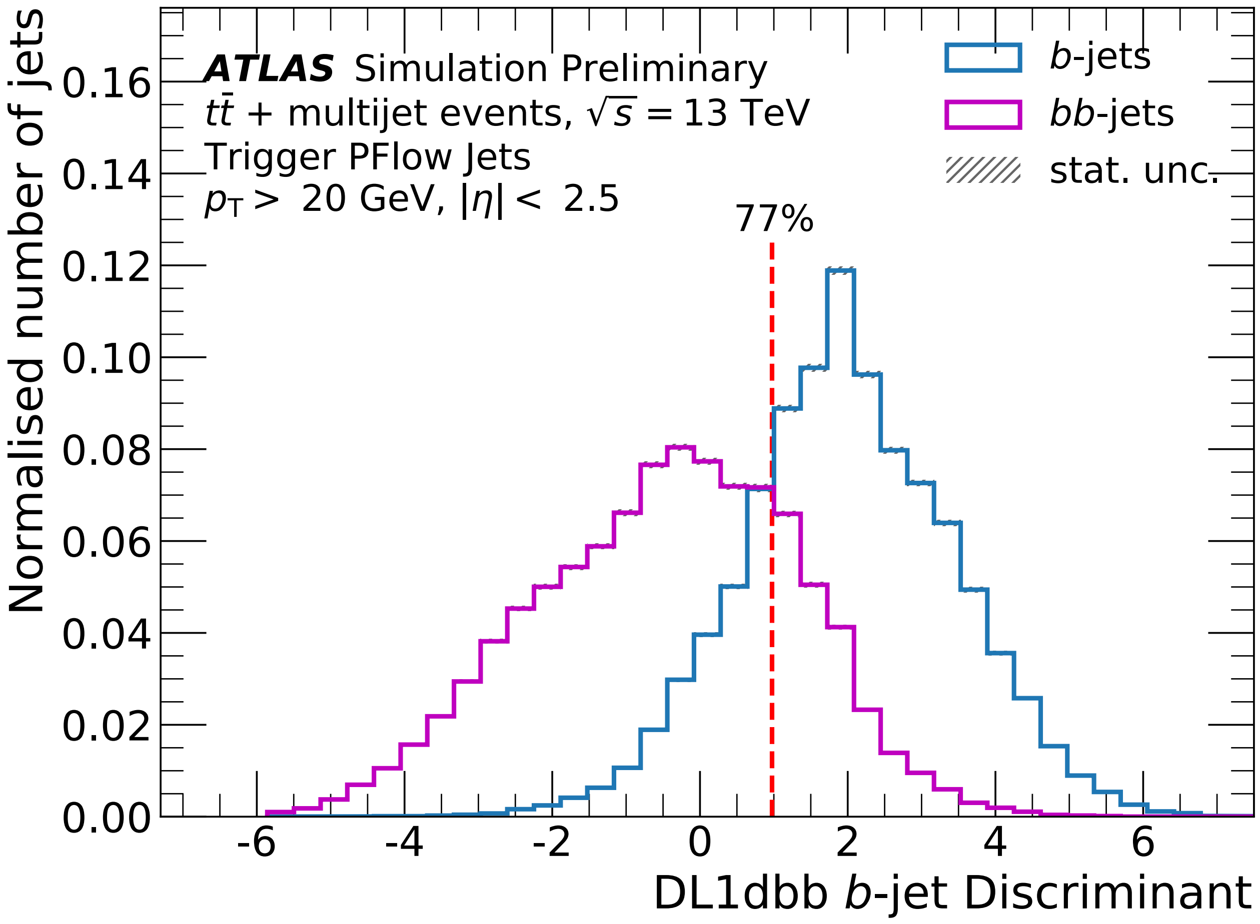
Compared to *b*-jets:

- Contains 2 *b*-hadrons instead of 1
- Larger track multiplicity within the jet cone
- Lower fraction of energy carried by tracks from *b*-hadron decay
- Larger jet width

DL1d discriminant



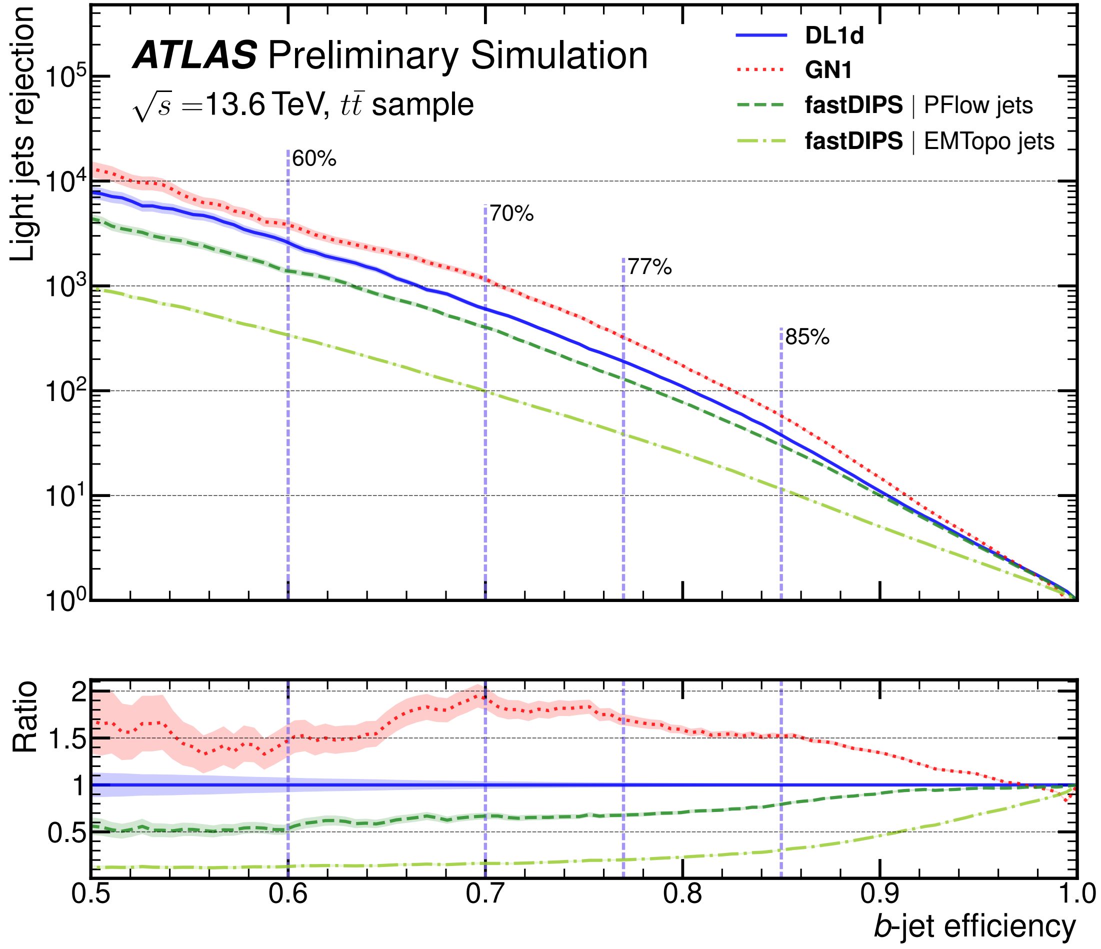
DL1dbb discriminant



fastDIPS performance

fastDIPS | EMTopo jets is not trained with any primary vertex info

- However still decent performance in light-jet rejection compared to precision b-tagging algorithms



L1 jet turn-on

3J15 at L1 plateaus at 65 GeV for offline jet

- L1 jet energy resolution is low, therefore jet E_T at L1 spreads more widely at offline jet p_T
- The 65 GeV threshold limits the acceptance of the 4th soft jet in the HH4b signal