FLAVOUR TAGGING WITH THE ATLAS DETECTOR AT THE HL-LHC

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High-Luminosity Large Hadron Collider (HL-LHC)

Benefits and Challenges

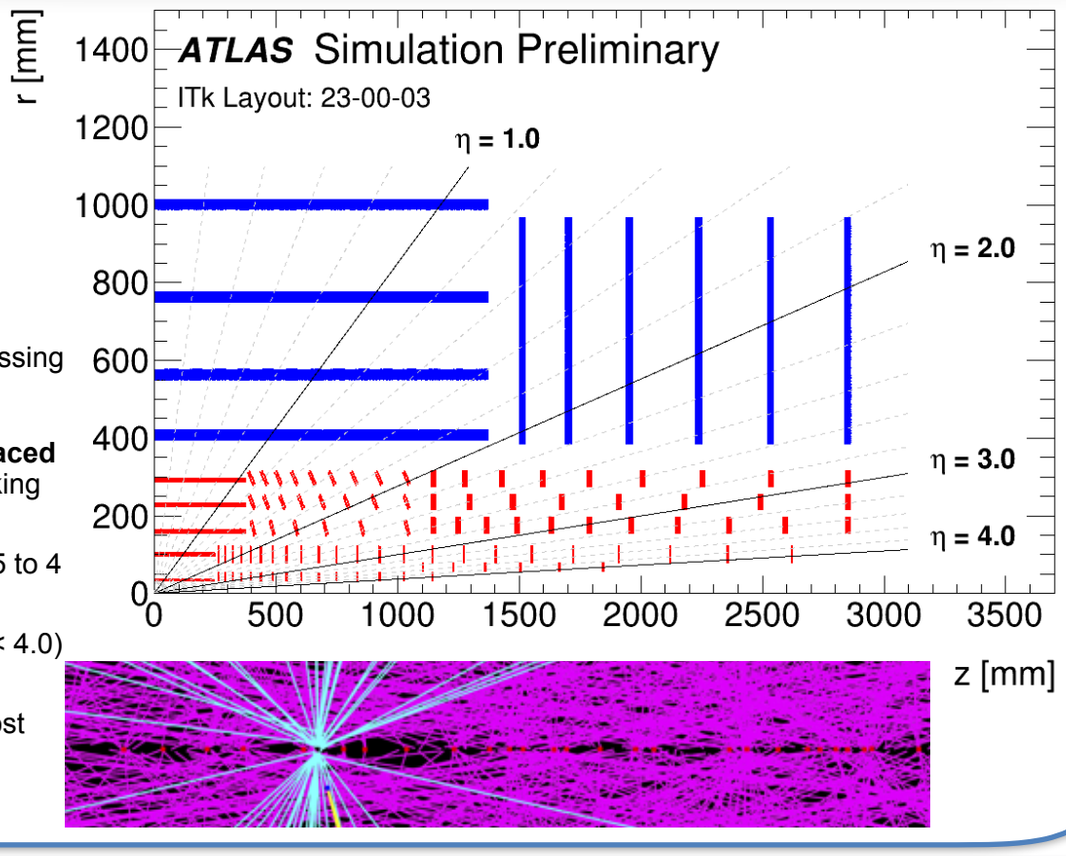
✅ Increased instantaneous luminosity up to 7.5 x 10^{34} cm^{-2} s^{-1}

✅ Larger integrated luminosity; 10x more data than what is collected during Run 1-3

❌ More pile-up; ~200 interactions per bunch crossing

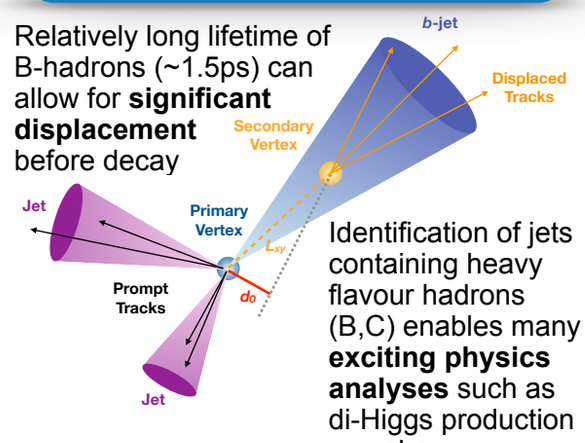
Inner Tracker (ITk) Upgrade

- Current ATLAS Inner Detector (ID) will be **replaced by a new Inner Tracker (ITk)** to maintain tracking performance in harsh HL-LHC conditions
- Extended forward pseudo-rapidity (|η|) from 2.5 to 4 provides **increased tracking acceptance**
- All-silicon design consisting of inner **pixel** (|η| < 4.0) and outer **strip** (|η| < 2.7) sub-detectors
- Latest ITk layout design 23-00-03 with innermost pixel layer closer to beam pipe (R = 34mm)

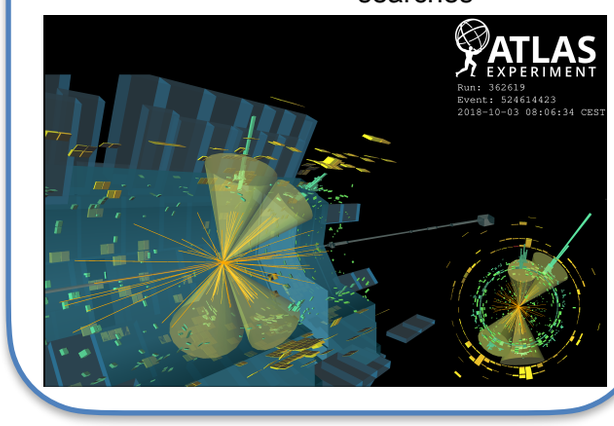


Flavour Tagging

Relatively long lifetime of B-hadrons (~1.5ps) can allow for **significant displacement** before decay



Identification of jets containing heavy flavour hadrons (B,C) enables many **exciting physics analyses** such as di-Higgs production searches



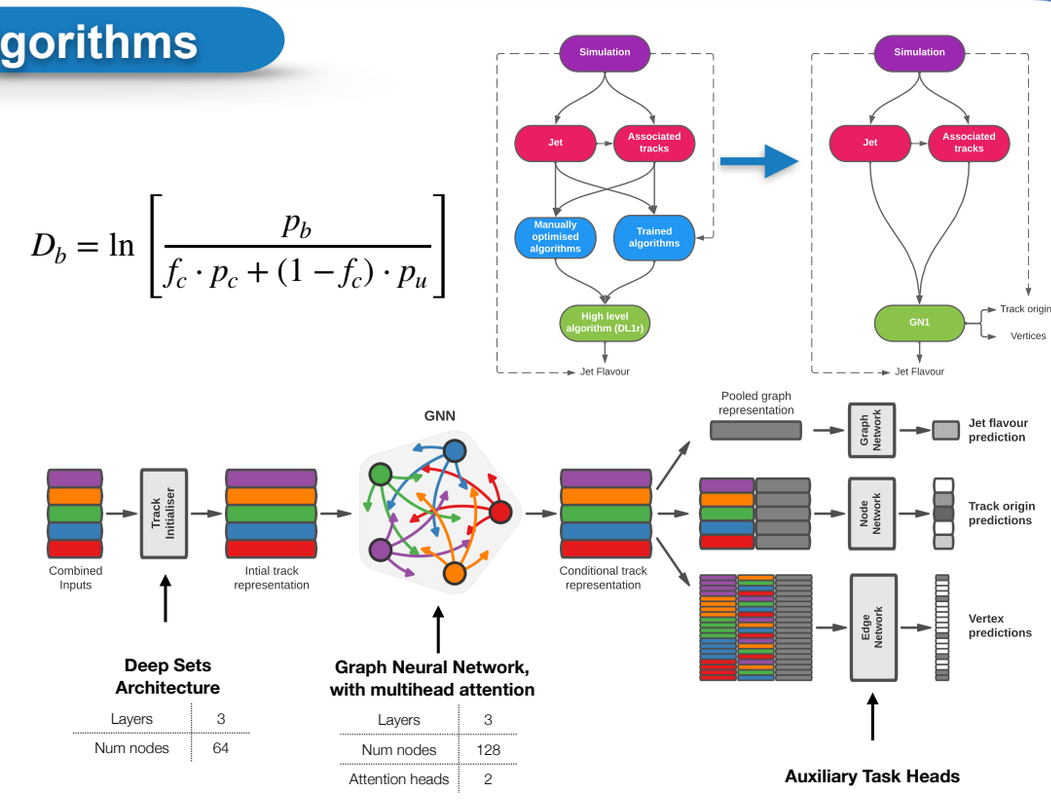
Flavour Tagging Algorithms

Jet Input
p_T
η
Track Input
q/p
$d\eta$
$d\phi$
d_0
$z_0 \sin\theta$
$\sigma(q/p)$
$\sigma(\theta)$
$\sigma(\phi)$
$s(d_0)$
$s(z_0 \sin\theta)$
nPixHits
nStripHits
nInnermostPixHits
nNextToInnermostPixHits
nInnermostPixShared
nInnermostPixSplit
nPixShared
nPixSplit
nStripShared
nPixHoles
nStripHoles

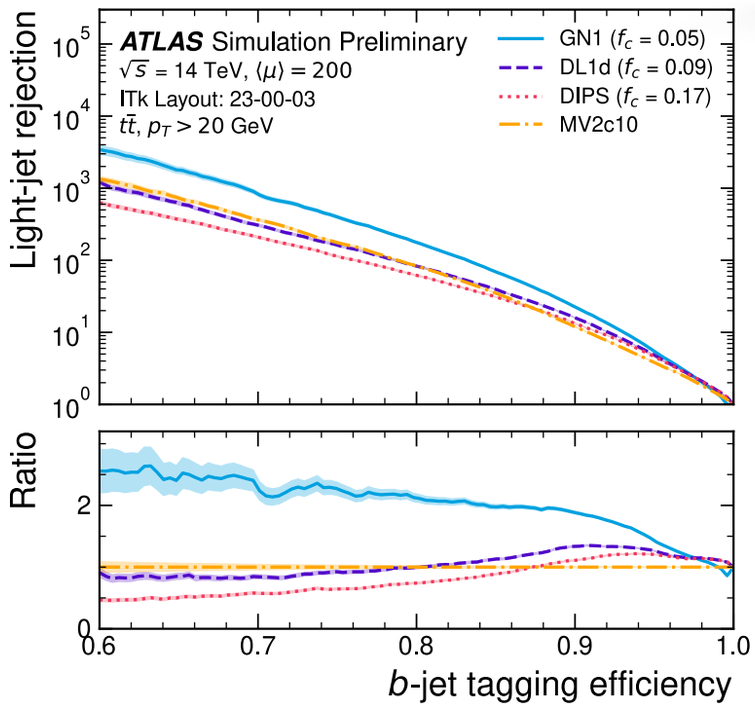
- Previous flavour tagging algorithms relied on “two-tiered” approach, where the outputs from manually optimised low-level taggers were fed into high-level taggers
- New approach based on graph neural networks (GNNs): **no need for manually optimised low-level algorithms!**
- GN1 trains jet flavour, vertexing, and track origin tasks **simultaneously**
- Single algorithm is easy to maintain and tune for specific use-cases, e.g. high-p_T flavour tagging
- Naturally suited for variable number of unordered input tracks

$$D_b = \ln\left[\frac{p_b}{f_c \cdot p_c + (1 - f_c) \cdot p_u}\right]$$

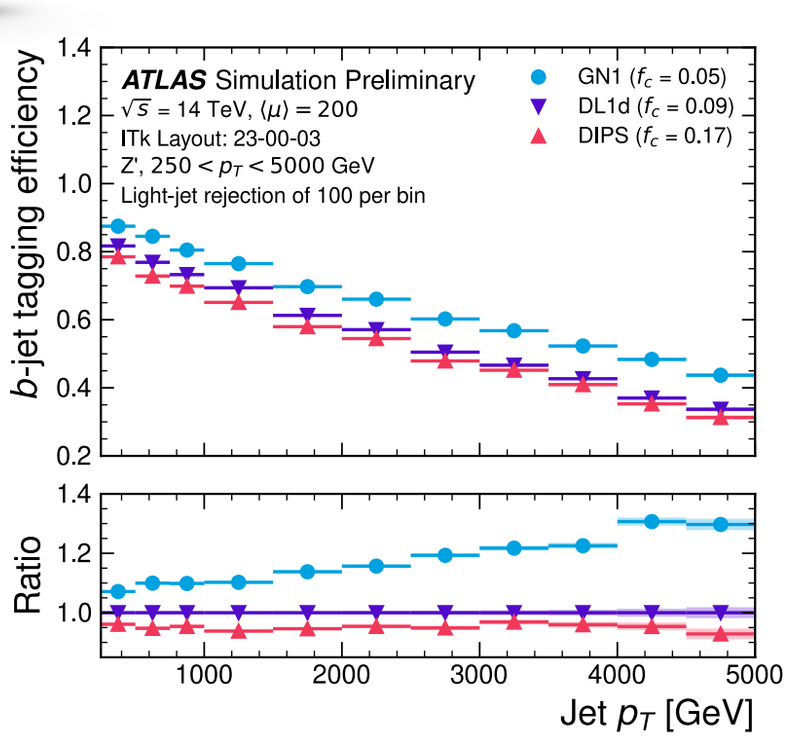
Requirements	Pseudorapidity interval		
	$\lvert\eta\rvert < 2.0$	$2.0 < \lvert\eta\rvert < 2.6$	$2.6 < \lvert\eta\rvert < 4.0$
pixel + strip hits	≥ 9	≥ 8	≥ 7
pixel hits	≥ 1	≥ 1	≥ 1
pixel + strip holes	≤ 2	≤ 2	≤ 2
p_T [MeV]	> 900	> 500	> 500
$\lvert d_0\rvert$ [mm]	≤ 2.0	≤ 2.0	≤ 3.5
$\lvert z_0 \sin\theta\rvert$ [mm]	≤ 5.0	≤ 5.0	≤ 5.0



Expected Performance



- Previous generation of taggers used for comparison: MV2c10 (Boosted Decision Tree), DIPS (Deep Sets), DL1d (Deep Neural Network)
- GN1 all-in-one tagger **outperforms current taggers** over a broad range of phase space and provides excellent performance in in the harsh HL-LHC environment
- Limited statistics for HL-LHC training (4M jets vs. 30M jets used for baseline model); **expect further improvements** with enlarged training dataset
- 2x improvement in light-jet rejection for the 70% $t\bar{t}$ working point compared to previous taggers
- GN1 improves flavour tagging performance in all regions of phase space, including the high p_T regime



Summary & Outlook

- GN1 flavour tagging algorithm provides excellent flavour tagging performance in in the harsh HL-LHC environment
- Training procedure used for current detector configuration easily adapted to ITk geometry and increased tracking acceptance
- Next generation of flavour tagging algorithms will include updated architecture, optimized training, and enlarged training dataset

References

- ATL-PHYS-PUB-2022-027
- ATL-PHYS-PUB-2022-047
- TRIG-2018-08
- ATLAS-CONF-2022-035

Bourses postdoctorales Banting Postdoctoral Fellowships