Federal Ministry
of Education
and Research

Gefördert durch
DFG Deutsche Forschungsgemeinschaft

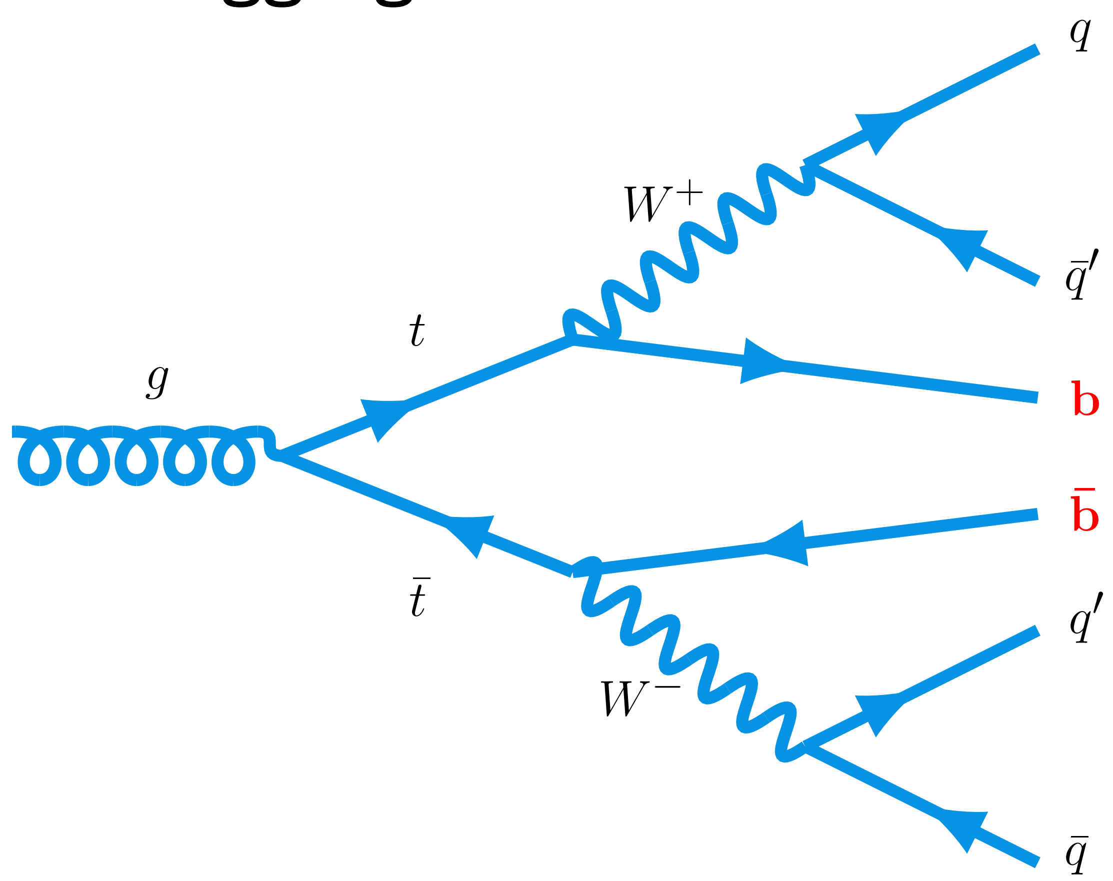
Deep-Neural-Network-based *b*-Tagging as Basis for Improvements in Top Analyses

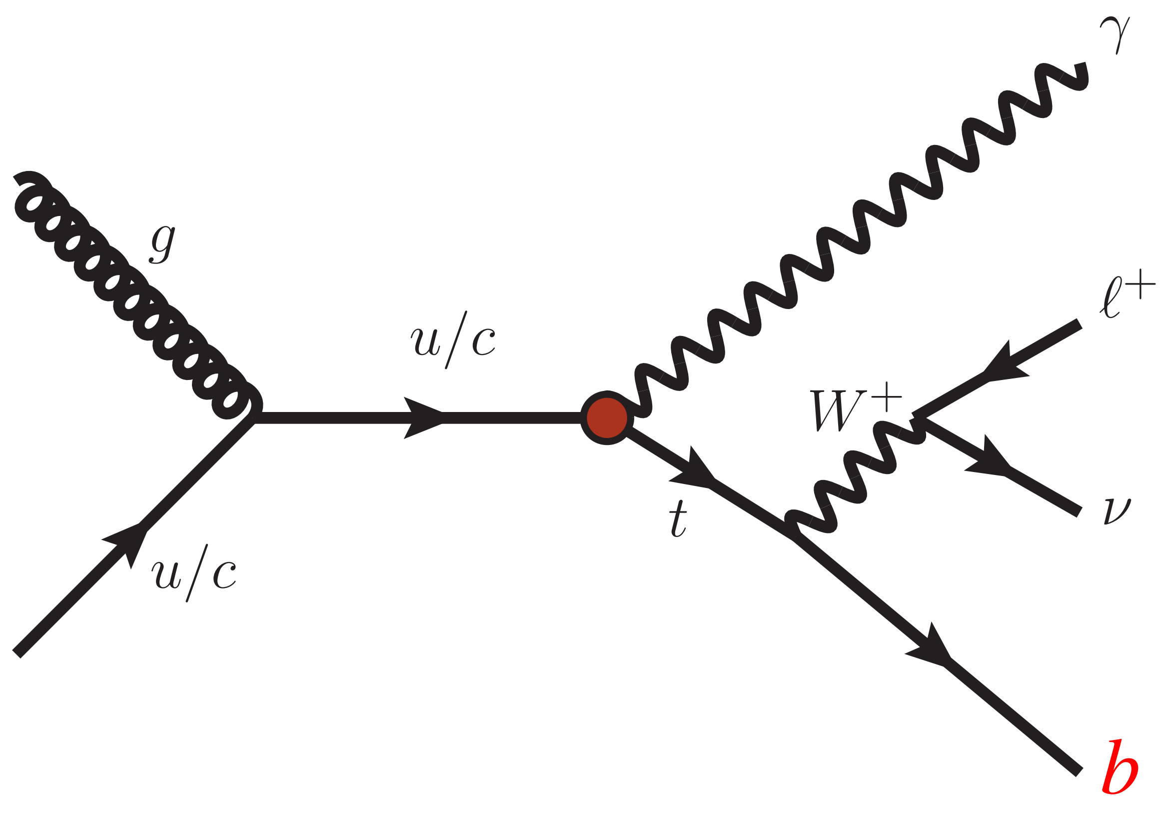
Manuel Guth
on behalf of the ATLAS collaboration

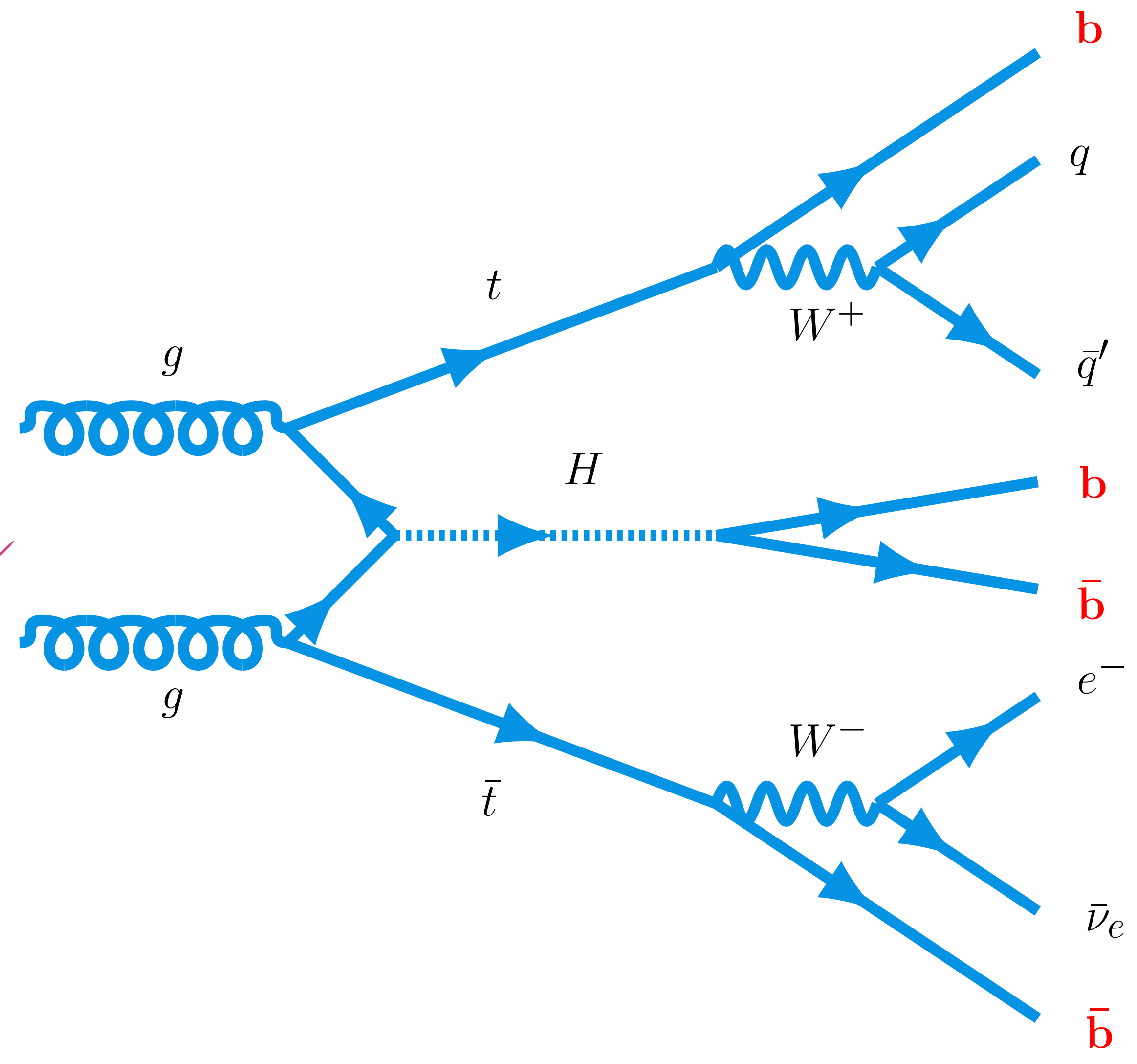
24.09.2019 - 12th International Workshop on Top Quark Physics, Young Scientist Forum

Why is *b*-Tagging crucial for Top-Quark Physics?

- Top quark decays (almost) exclusively into a *W* boson and a *b*-quark $|V_{tb}| = 1.019 \pm 0.025$ (comb. Tevatron & LHC)
  - *b*-tagging essential tool for top-quark analyses







- Besides need of tagging performance also influence on uncertainties
  - e.g. in top-quark decay width measurement Flavour tagging on 4th rank
  - In tt+Z cross section measurement on fifth rank (Phys. Rev. D 99 (2019) 072009)

Source	Impact on Γ_t [GeV]
Jet reconstruction	±0.24
Signal and bkg. modelling	±0.19
MC statistics	±0.14
Flavour tagging	±0.13
E_T^{miss} reconstruction	±0.09
Pile-up and luminosity	±0.09
Electron reconstruction	±0.07
PDF	±0.04
$t\bar{t}$ normalisation	±0.03
Muon reconstruction	±0.02
Fake-lepton modelling	±0.01

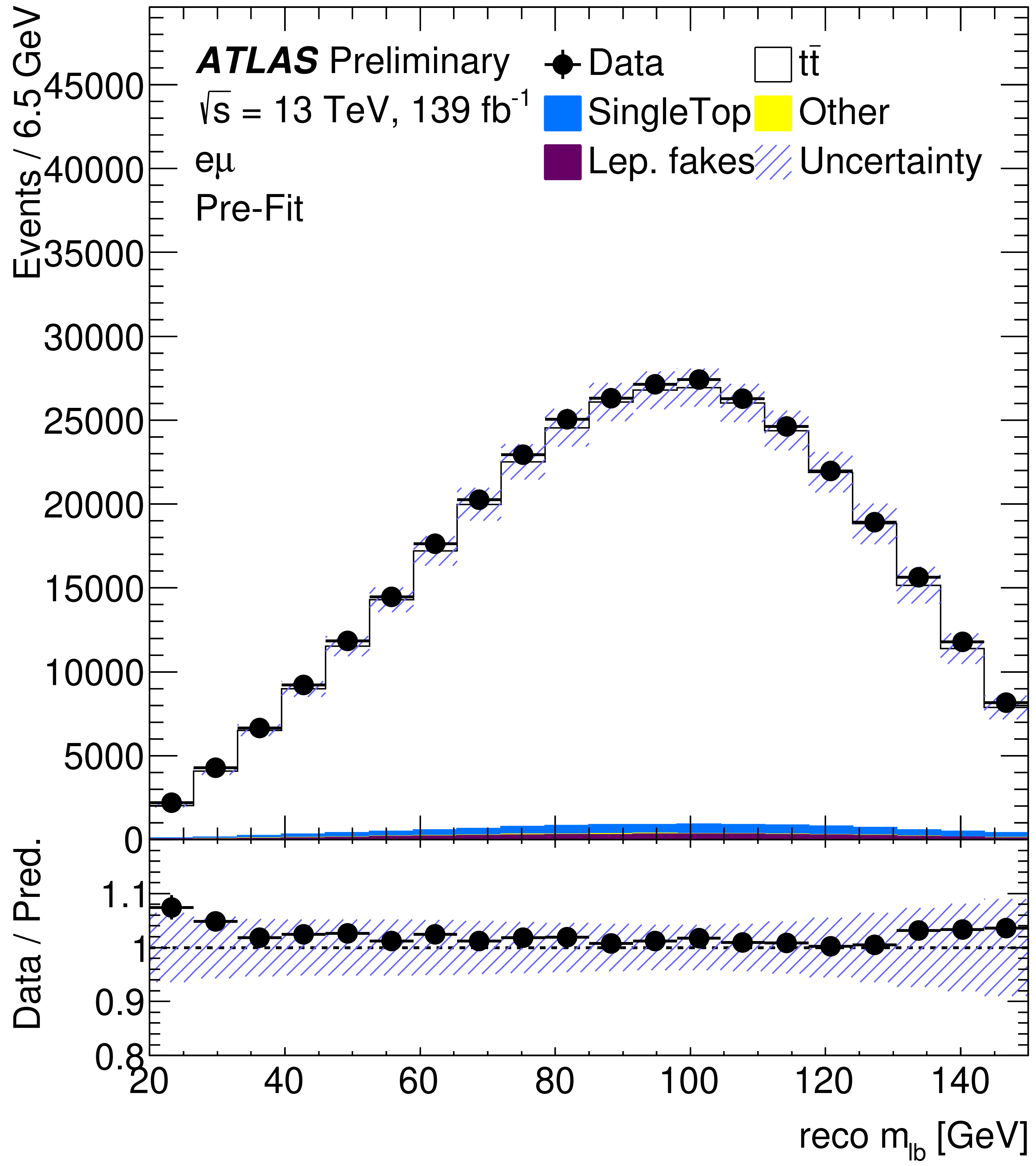
ATLAS-CONF-2019-038

Current EMTopo *b*-Tagging Performance

- *b*-tagging performance already very good for several use-cases
- e.g. top quark decay width measurement (ATLAS-CONF-2019-038)
  - Background contamination already very small

Channel	ee	μμ	eμ
background fraction	6.0 %	3.9 %	4.2 %

2 *b*-jets tagged with 60% working point required

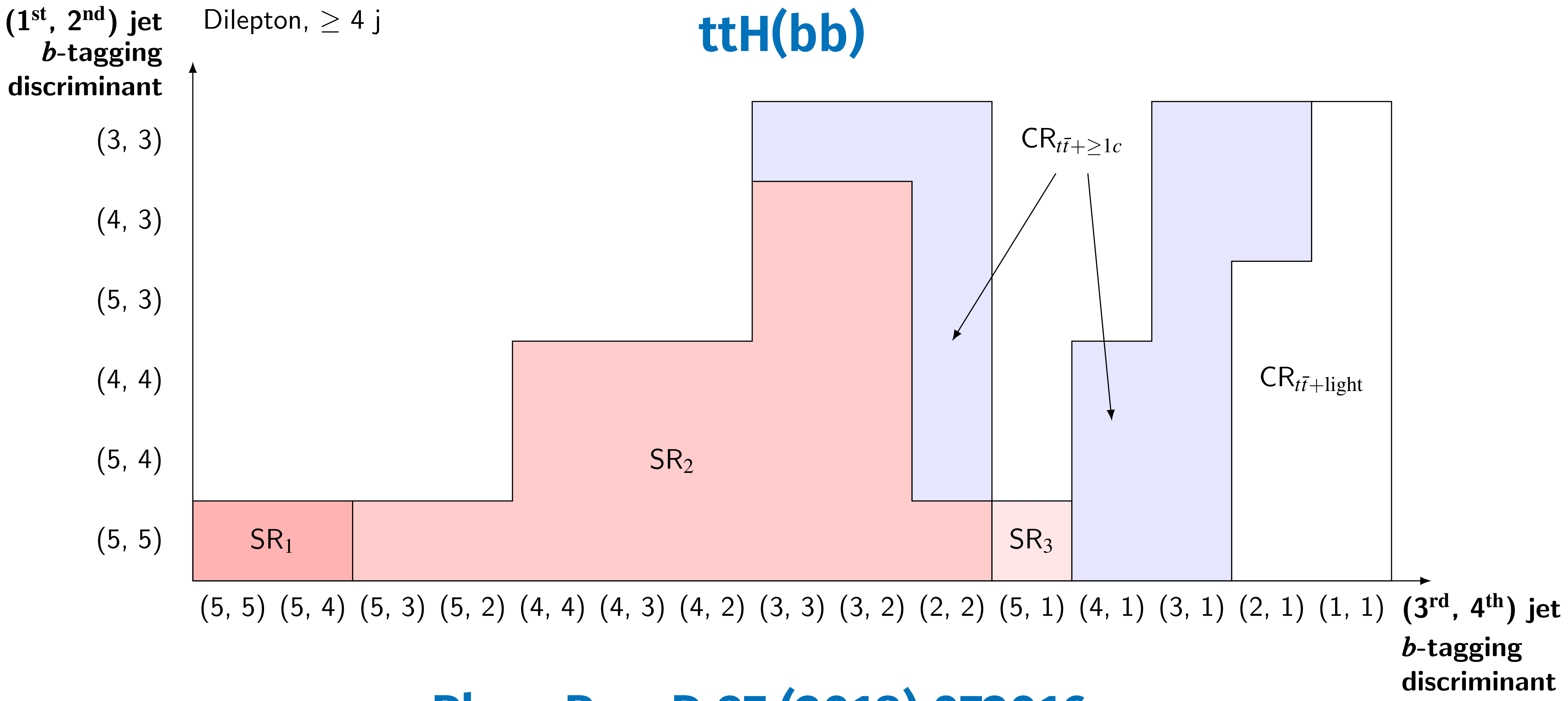


ATLAS-CONF-2019-038

Impact on Signal Purity

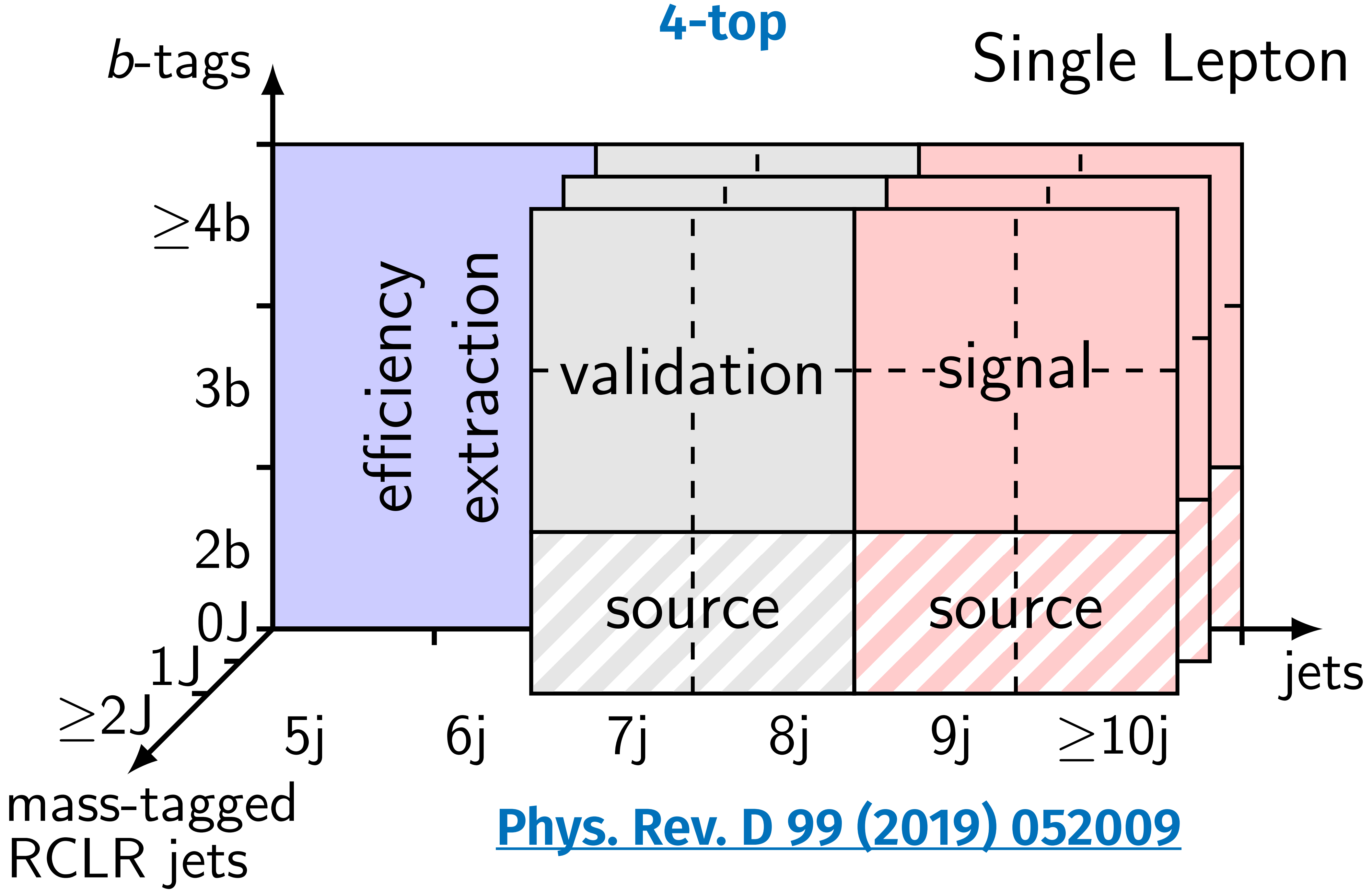
- ttH(bb) and 4-top analyses define their regions depending on the *b*-tagging scores
- Improving *b*-tagging performance allows definition of (signal) regions with higher purity

ttH(bb)



[Phys. Rev. D 97 (2018) 072016]

4-top



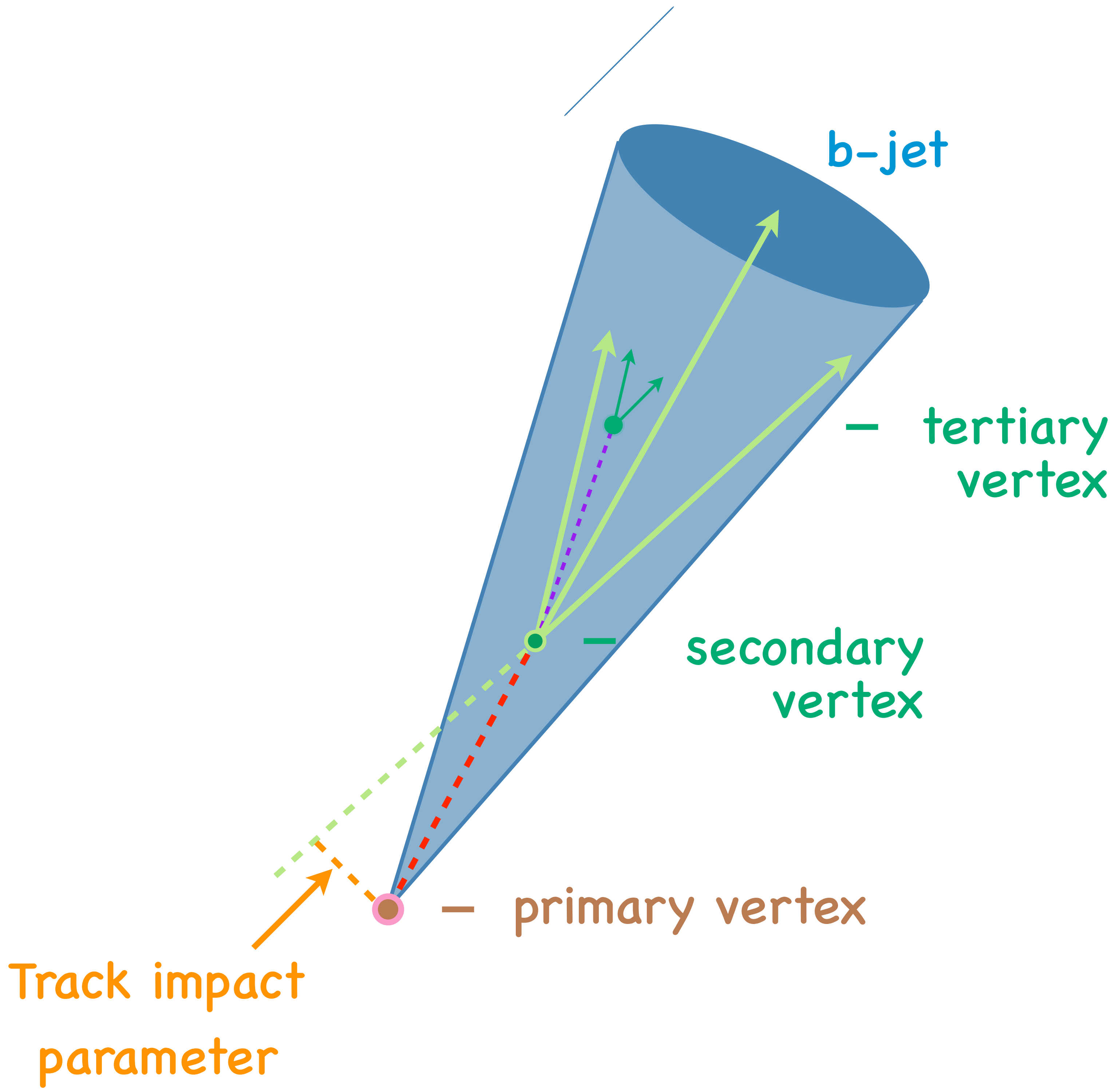
[Phys. Rev. D 99 (2019) 052009]

4 *b*-jets in final states

Baseline Algorithms

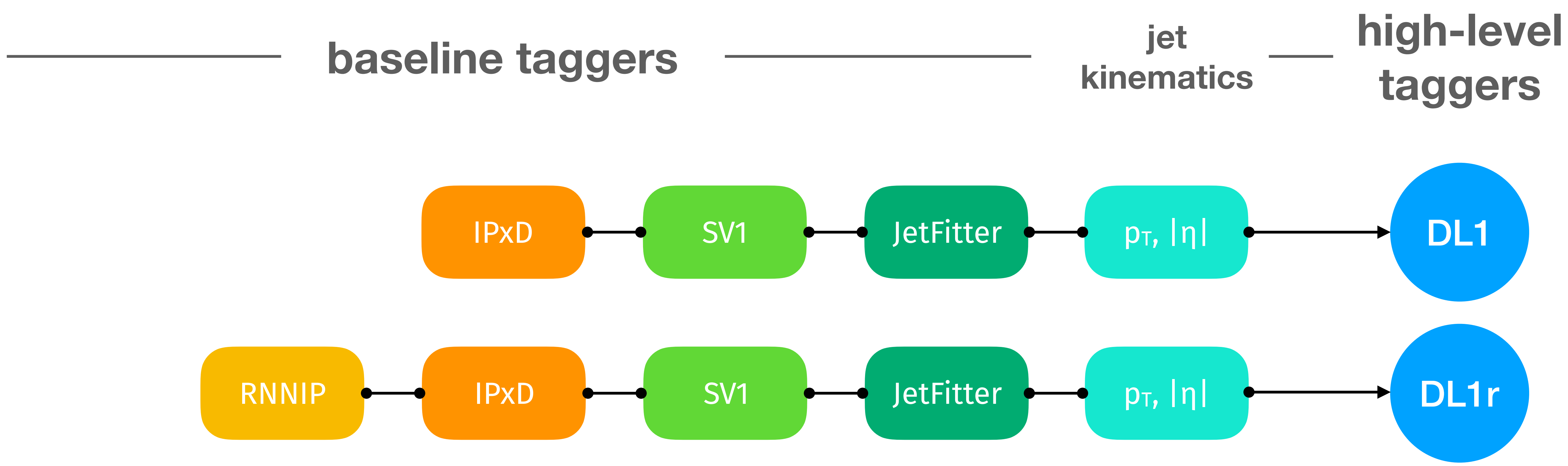
IP based		SV based	
Impact Parameter based (IP2D,IP3D)	NN based on track parameters (RNNIP)	Topological secondary and tertiary vertices (JetFitter)	Inclusive secondary vertex (SV1)

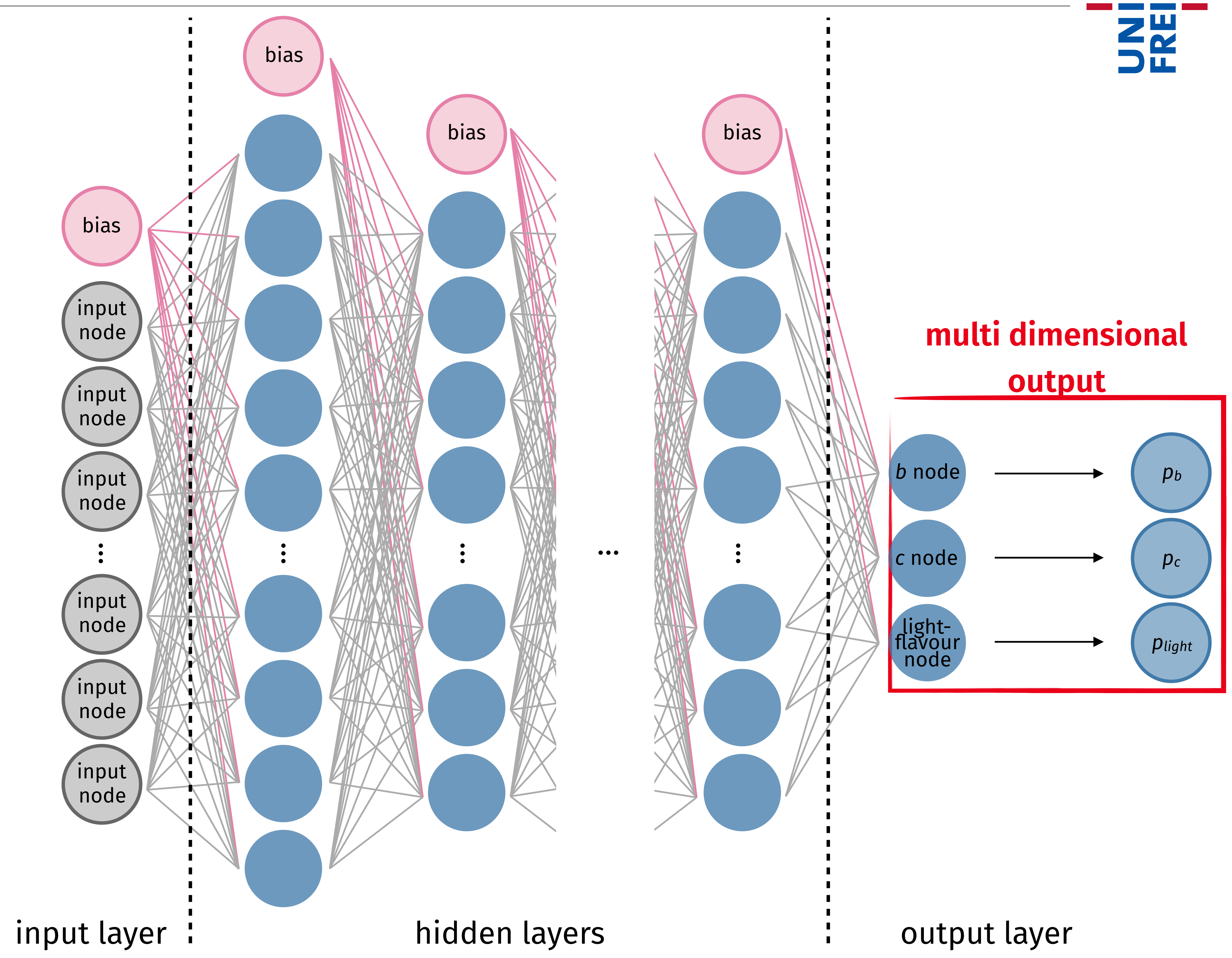
- 2 types of algorithms were designed employing topologies of *b*-hadrons (long lifetime, high mass, large decay multiplicity)
  - Impact parameter based
  - Secondary (tertiary) vertex based



Deep-Learning Flavour Tagger (DL1) - Architecture

- *b*-tagging algorithm based on deep learning
- Multi-class output ➔ allows also *c*-tagging
- 2 different DL1 tagger depending on input algorithms



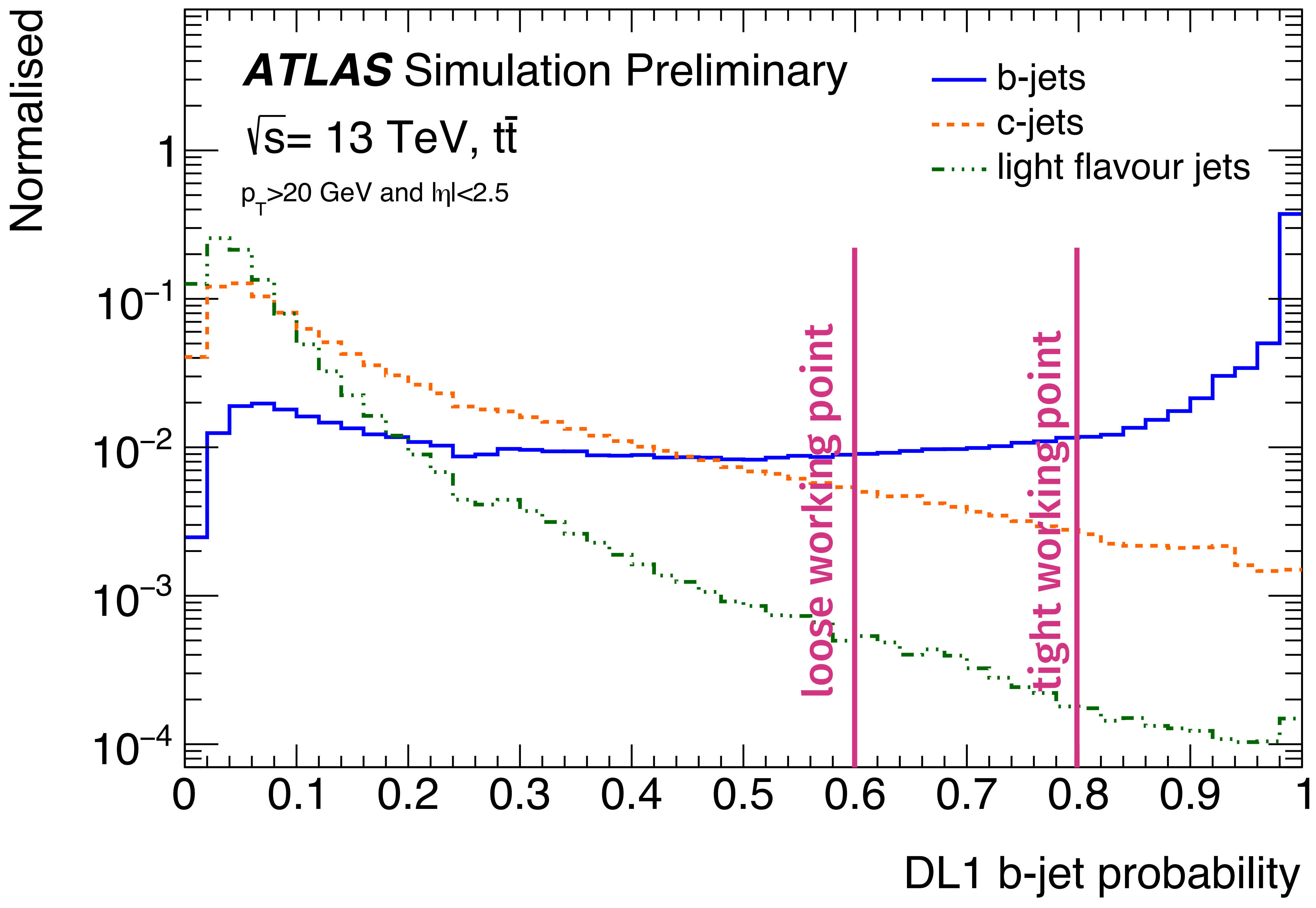


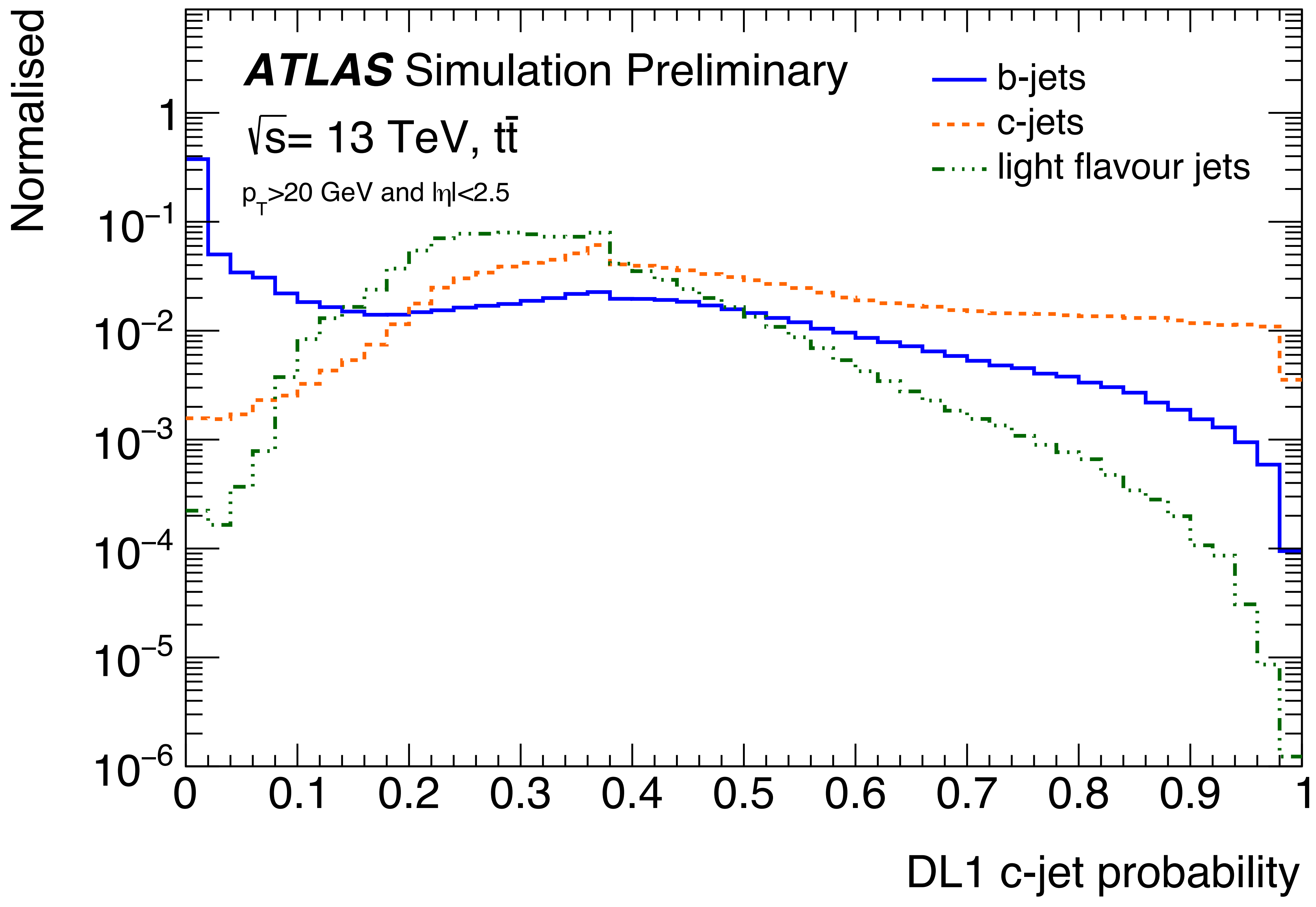
$$\mathrm{DL1}_{score} = \ln\left(\frac{p_b}{f_c \cdot p_c + (1 - f_c) \cdot p_{\text{light-flavour}}}\right)$$

- Compare performance to MV2 algorithm
  - MV2 is a BDT based algorithm trained with the same input

Network Outputs

- Each jet gets probability for being a *b*-, *c*- or light flavour jet
- Definition of working points, which have to be calibrated
  - The lower the *b*-jet efficiency, the better the classification ➔ However less statistics

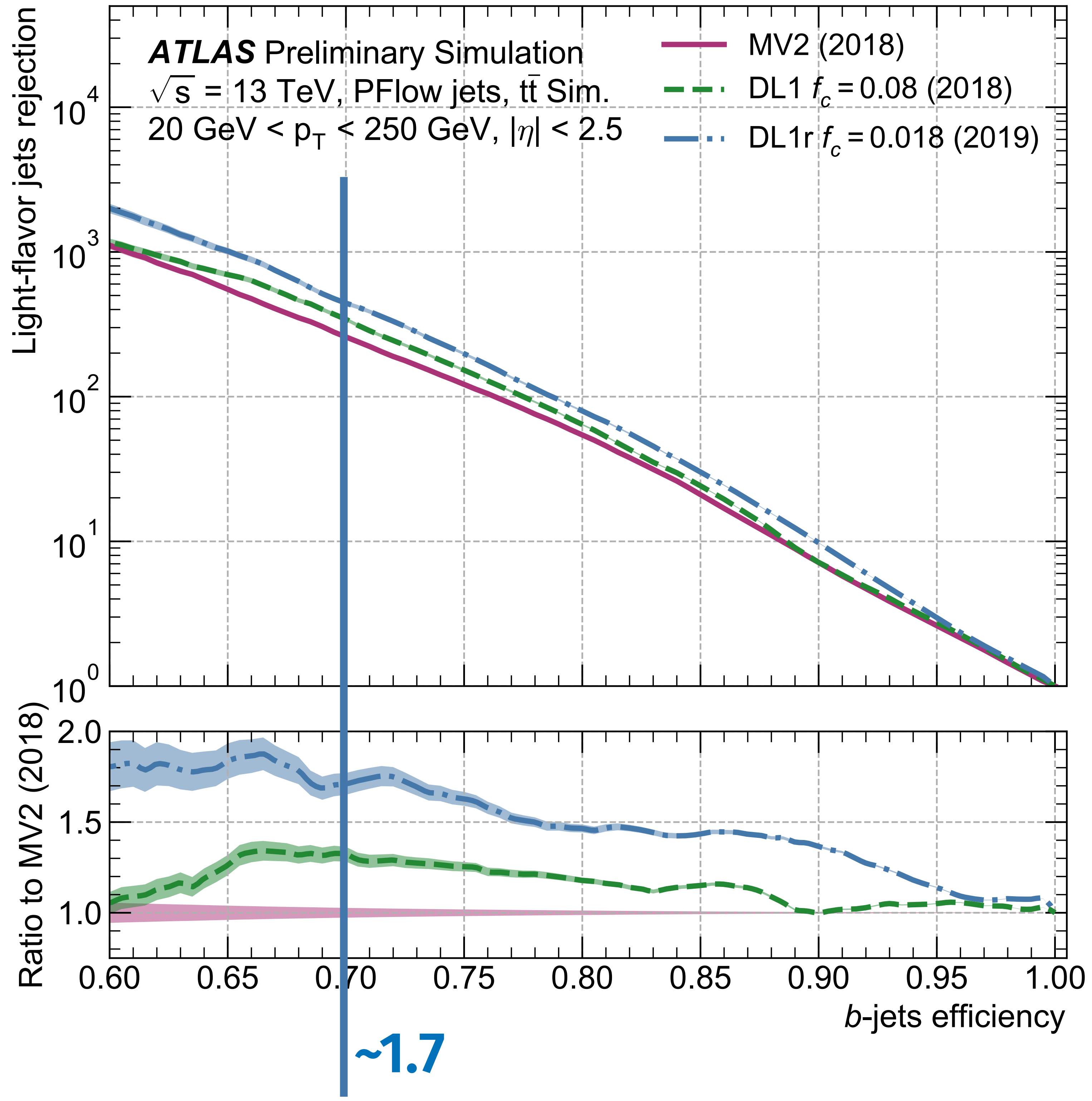


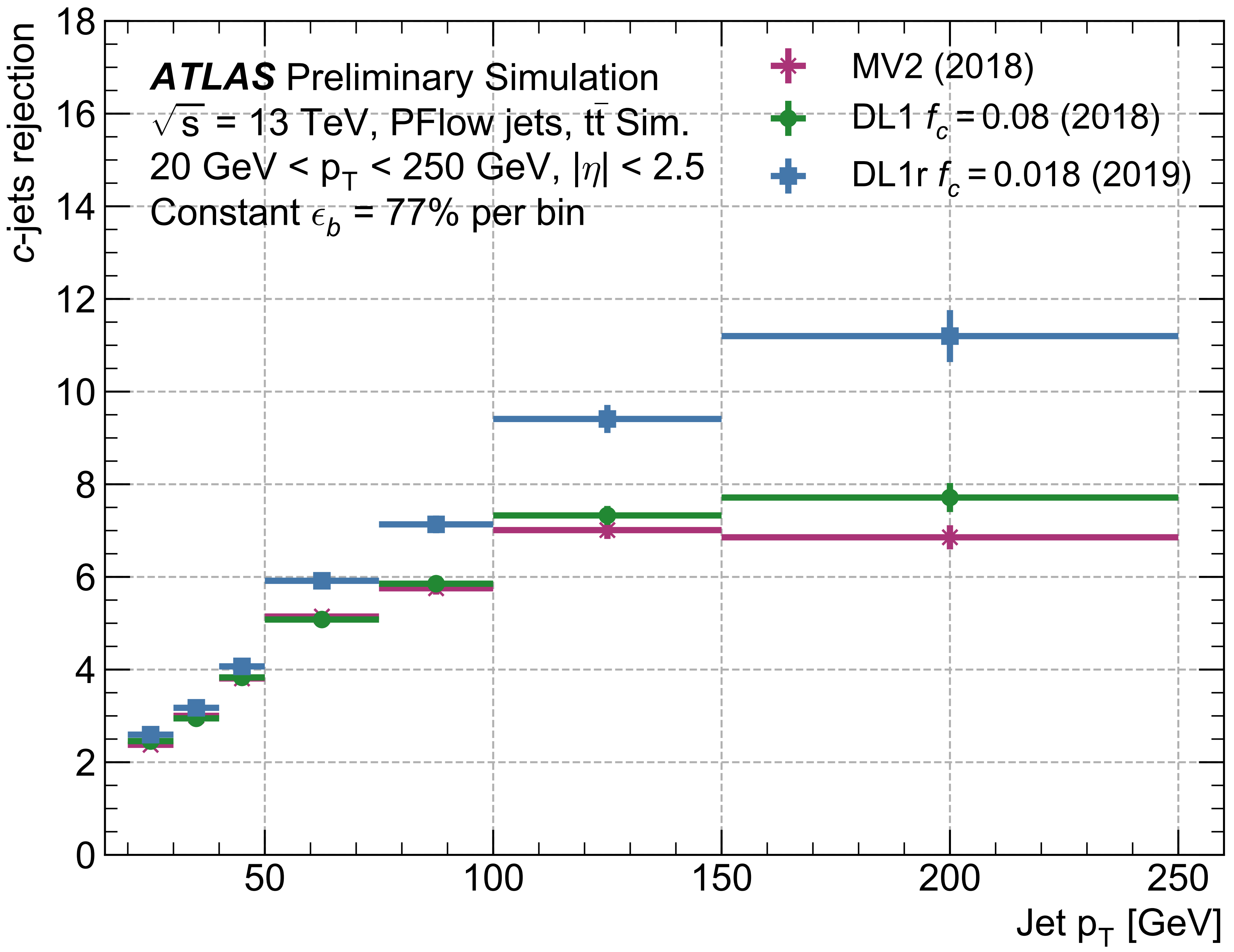


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/FTAG-2019-001/

Improvements with new Algorithm

- ATLAS is moving from EMTopo to particle-flow jet algorithm
- DL1 taggers were retrained with particle-flow jets also using new RNNIP (neural network based on track parameters)





- Impressive *b*-tagging performance improvement: **1.7 for 70%** working point (most 13 TeV top analyses use MV2c10@ 70%)

Summary

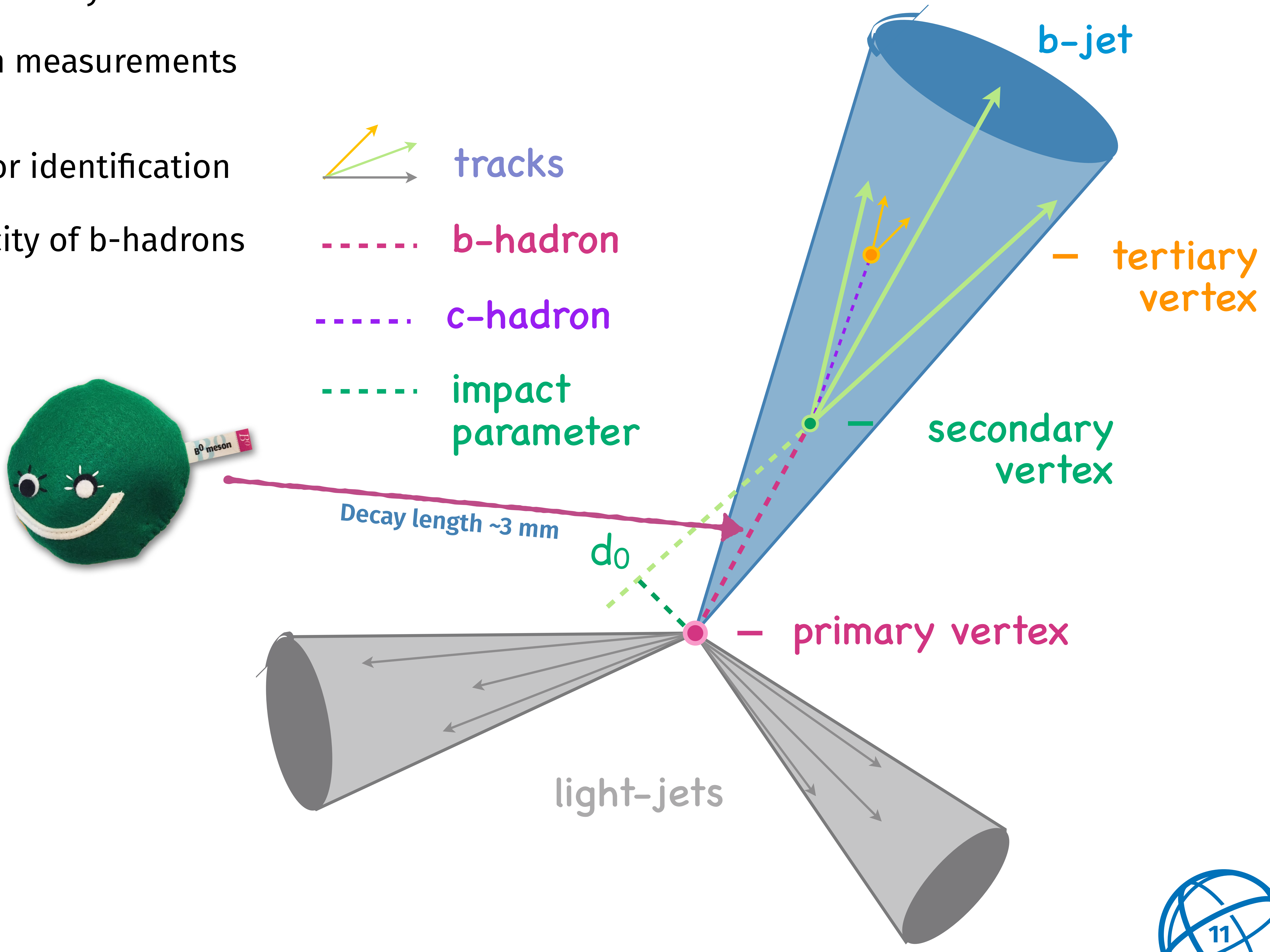
- *b*-tagging essential tool for top analyses
- Sophisticated machine learning techniques allow to further improve *b*-tagging
- New jet collection and dedicated b-tagging algorithms improve performance by:
  - **~1.5 for 70%** working point
  - **~2 for 60%** working point

➥ Better signal-background separation and therefore a purer definition of (signal) regions

Backup

General about b-Tagging

- Heavy-flavour tagging important tool for physics analyses
  - Signal ID, background suppression, precision measurements
- Exploit specific topology of heavy-flavour jets for identification
  - Long lifetime, high mass and decay multiplicity of b-hadrons



Additional Performance Plots new *b*-tagging Trainigs