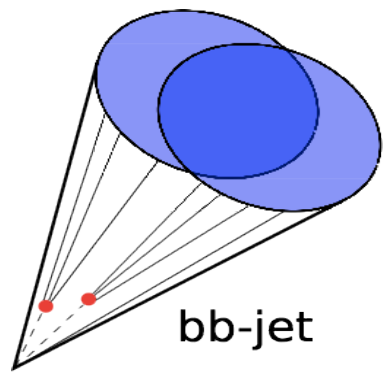
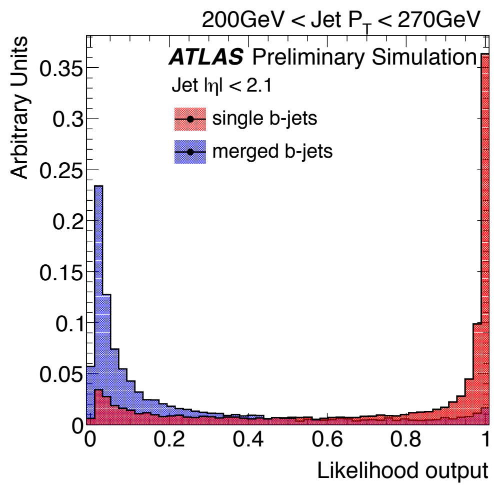
Double B-hadron tagging using jet substructure in ATLAS





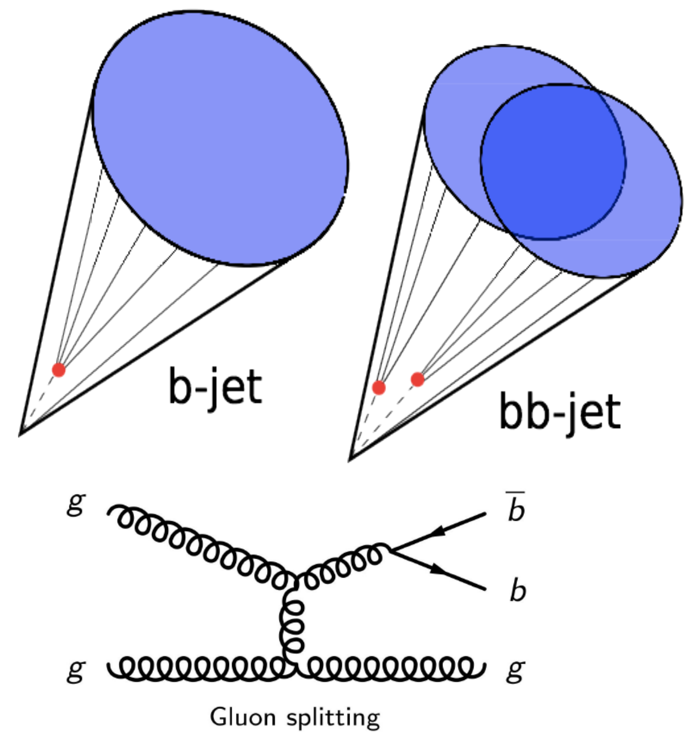
Ariel Schwartzman
SLAC

Berkeley Workshop on Heavy Flavor Production at Hadron Colliders

16-Jan-2013

Introduction

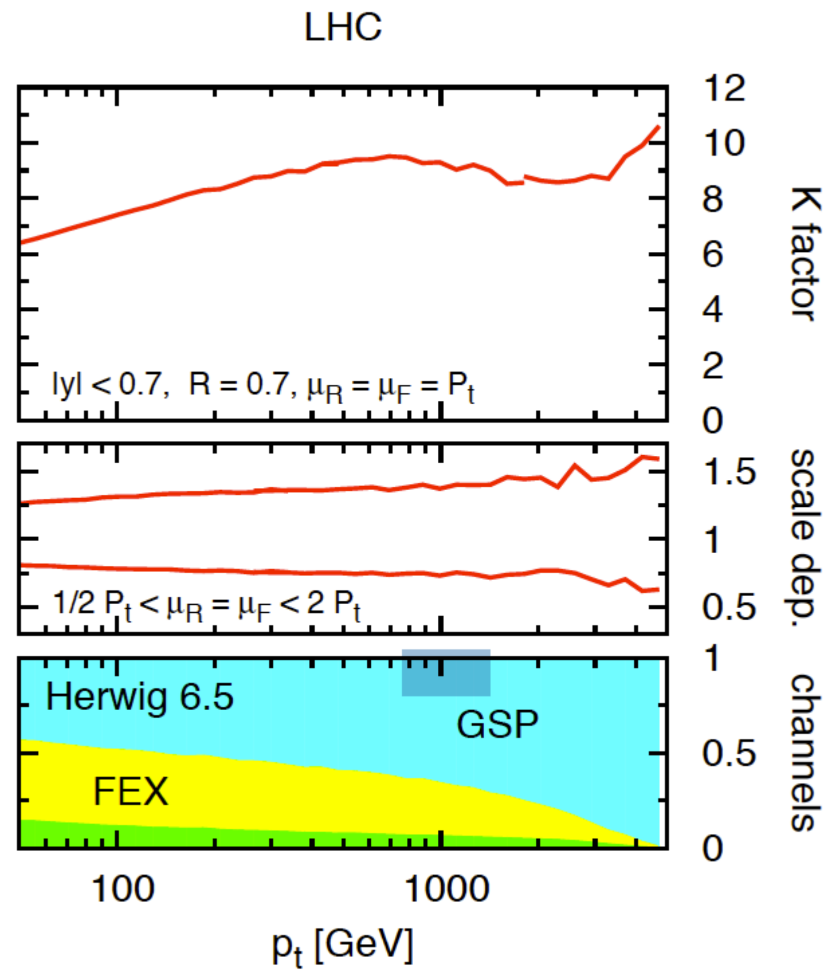
- **Gluons can split to 2 b-quarks at small angles, which can be reconstructed as one single (merged) b-jet**
  - b-tagging algorithms do not provide information on the number of B-hadrons within jets, or on the **net heavy flavor content**
- Tagging and removing these jets can **suppress SM backgrounds to physics searches** (*W(bb)j*), and significantly reduce theoretical uncertainties in cross-section calculations (*A. Banfi's talk*)



- **Developed new technique to identify b-tagged jets containing two B-hadrons** exploiting the distinct b-jet substructure between single and double b-hadron b-jets
  - **ATLAS-CONF-2012-100 (4.7fb^{-1})**

Theoretical motivation

- **Inclusive b-jet spectrum suffers from large theoretical uncertainties**
  - Large K-factors (6-10)
  - LO channel is smaller than NLO gluon splitting and flavor excitation channels due to strong enhancements from collinear logarithms
  - Largest uncertainty from gluon splitting
- **Flavor-k_t algorithm can significantly improve the accuracy of the b-jet cross section by not including the contribution from from double B-hadron jets**
  - Jets that contain equal number of b and anti-b quarks are considered light, such that merged b-jets from gluon splitting do not contribute to the b-jet spectrum



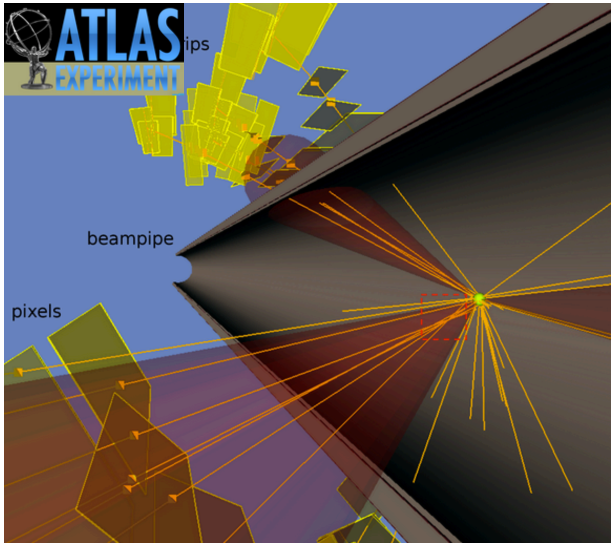
A. Banfi, G. Salam, G. Zanderighi
JHEP 0707:026

Double B-hadron tagging

Two possible approaches:

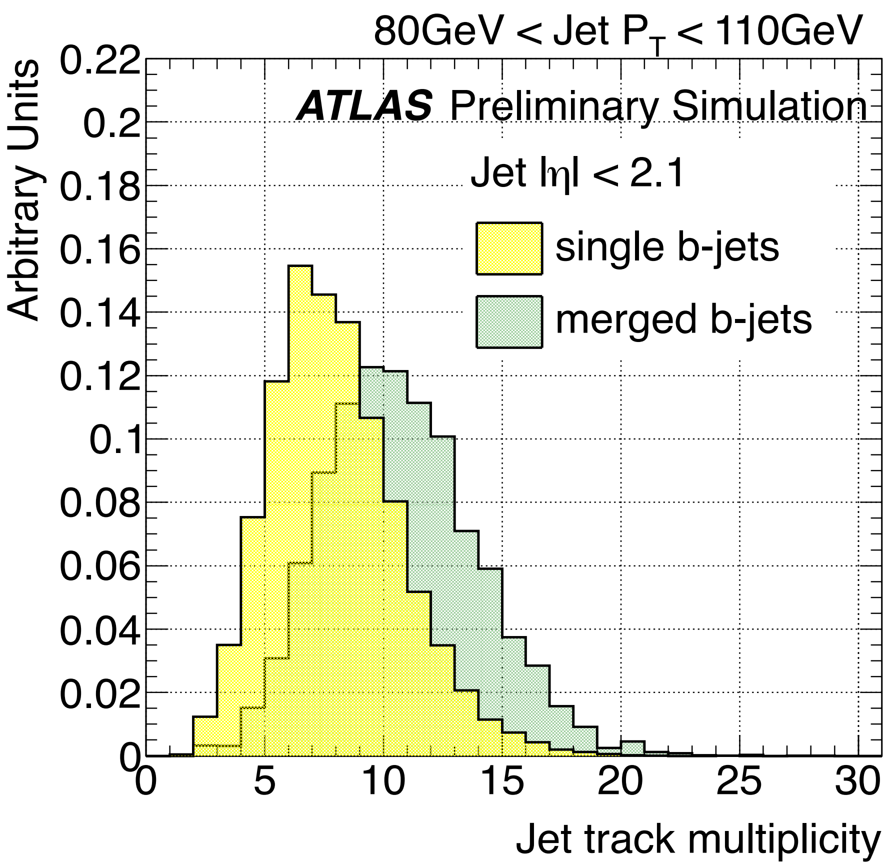
- **Direct reconstruction of two secondary vertices within jets:**
  - Used by CDF [PRD 71 (2005) 092001] and CMS [JHEP 03 (2011) 136]
  - Low reconstruction efficiency due to impact parameter requirements
  - Additional reconstruction inefficiencies at small angular separation between the two B-hadrons
  - Separation between B-B and B-D cascade decays

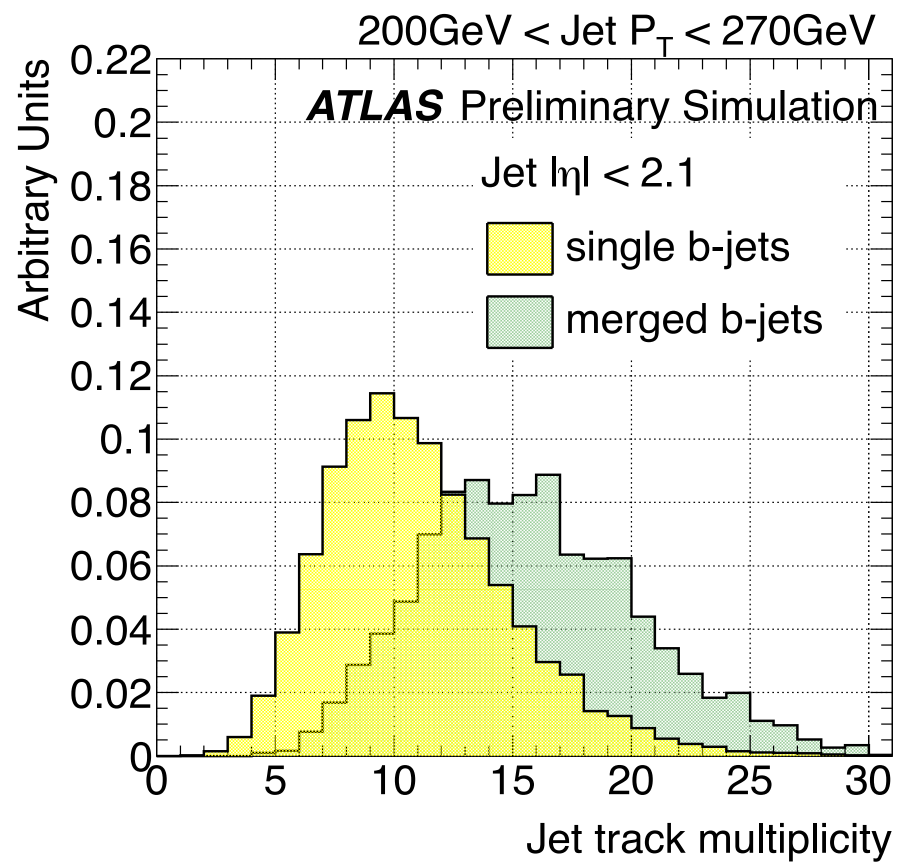
- **Exploit the substructure differences between single and merged b-jets:**
  - One-prong vs. two-prong (track)-jet structure
  - Does not require the presence of two displaced vertices.
  - Anti-k_t R=0.4 jets, b-tagged by the ATLAS MV1 tagger (60% efficiency operational point)
  - Jet substructure observables computed from tracks with p_T>1 GeV
  - Multivariate likelihood trained with Pythia dijet Monte Carlo Samples



Kinematic differences between single and double b-hadron jets (I)

- **Merged b-jets have more tracks (on average) than single b-jets**

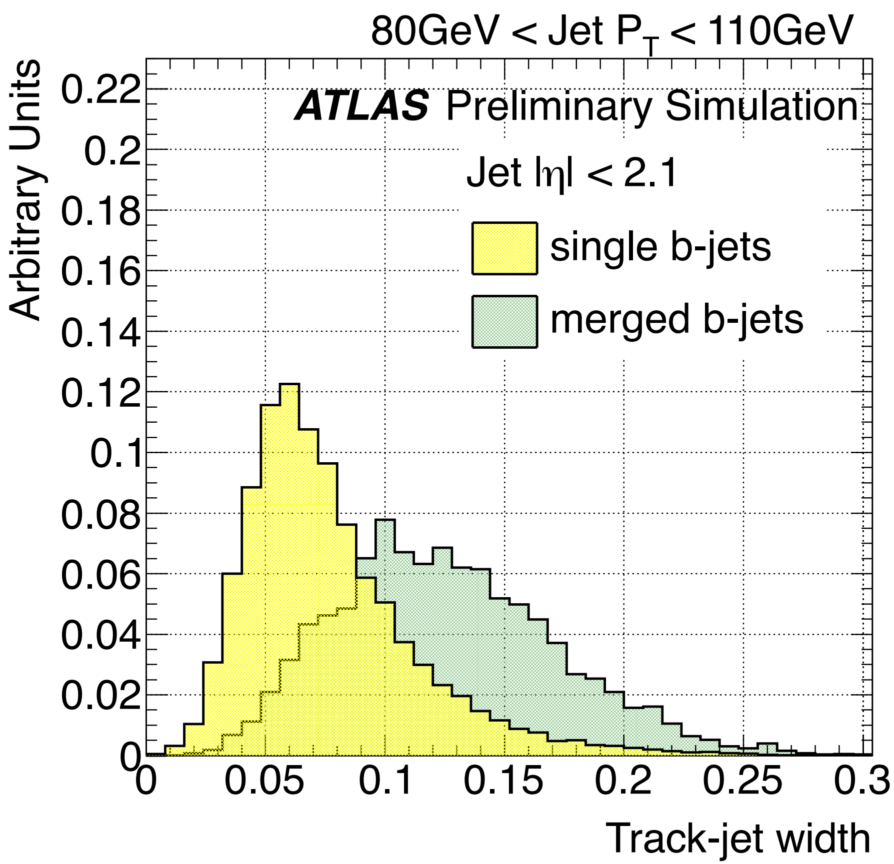


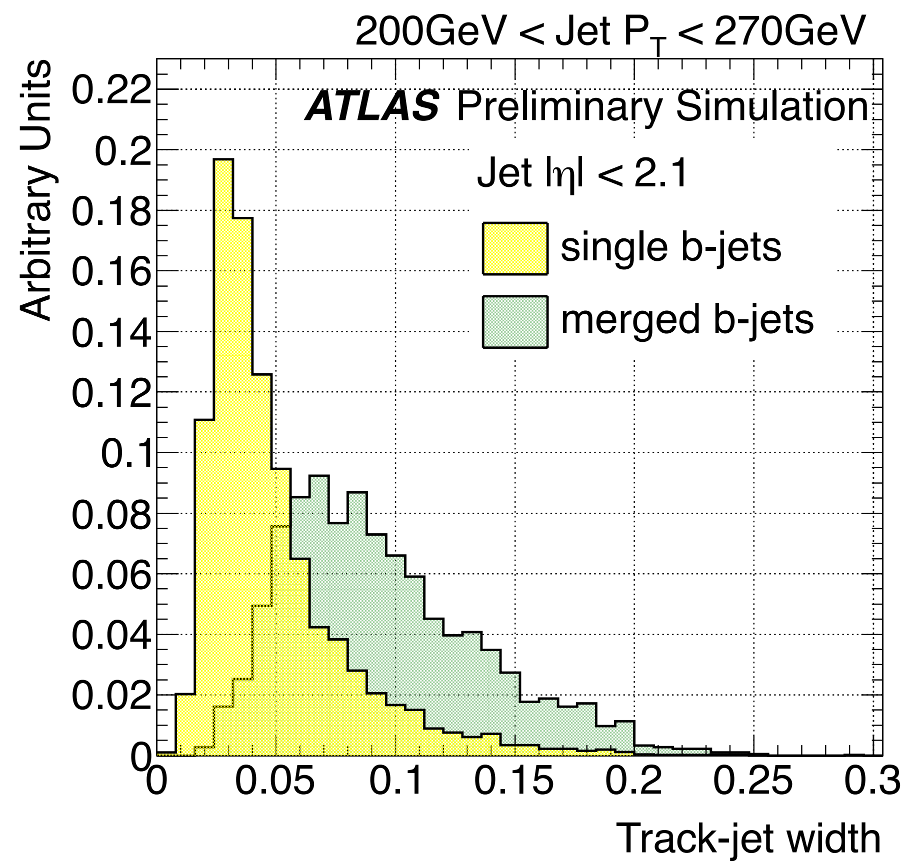


Kinematic differences between single and double b-hadron jets (II)

- **Merged b-jets are wider than single b-jets**

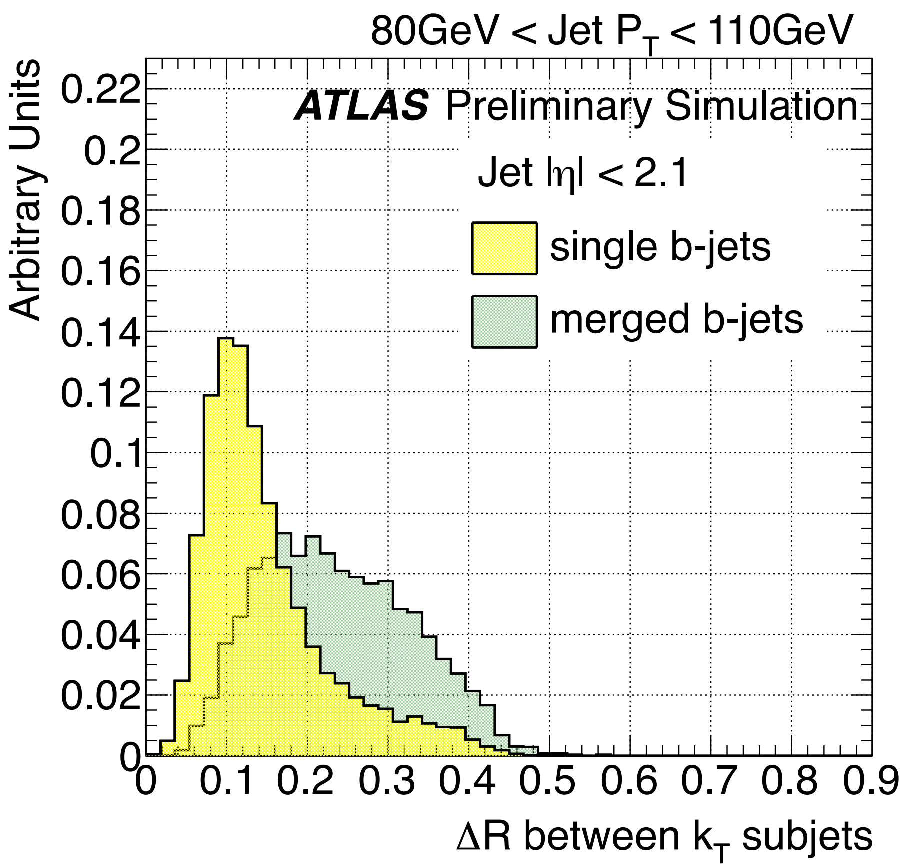
$$width = \frac{\sum_{trk} p_T^{trk} \Delta R(trk, jet)}{\sum_{trk} p_T^{trk}}$$

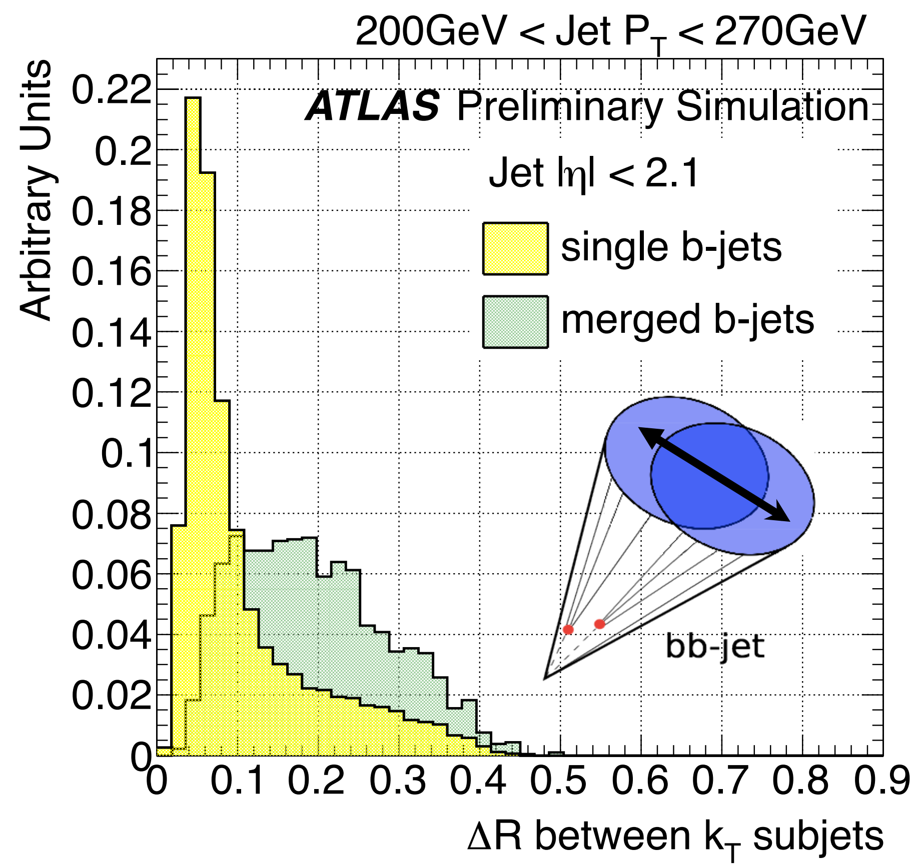




Kinematic differences between single and double b-hadron jets (III)

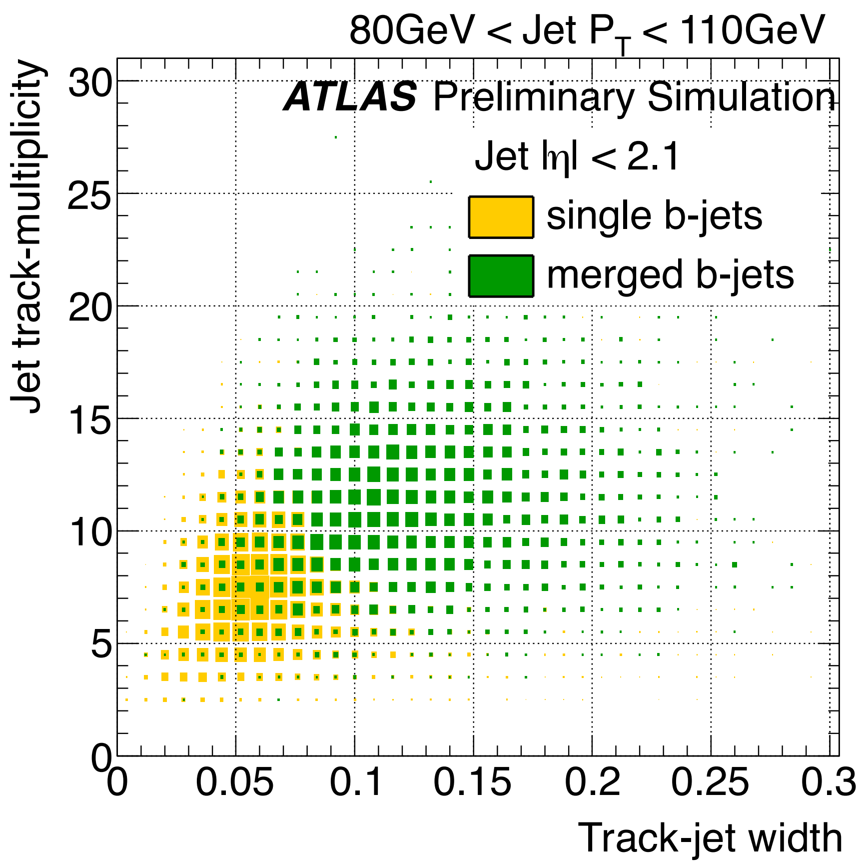
- **DR separation between exclusive k_t subjets**

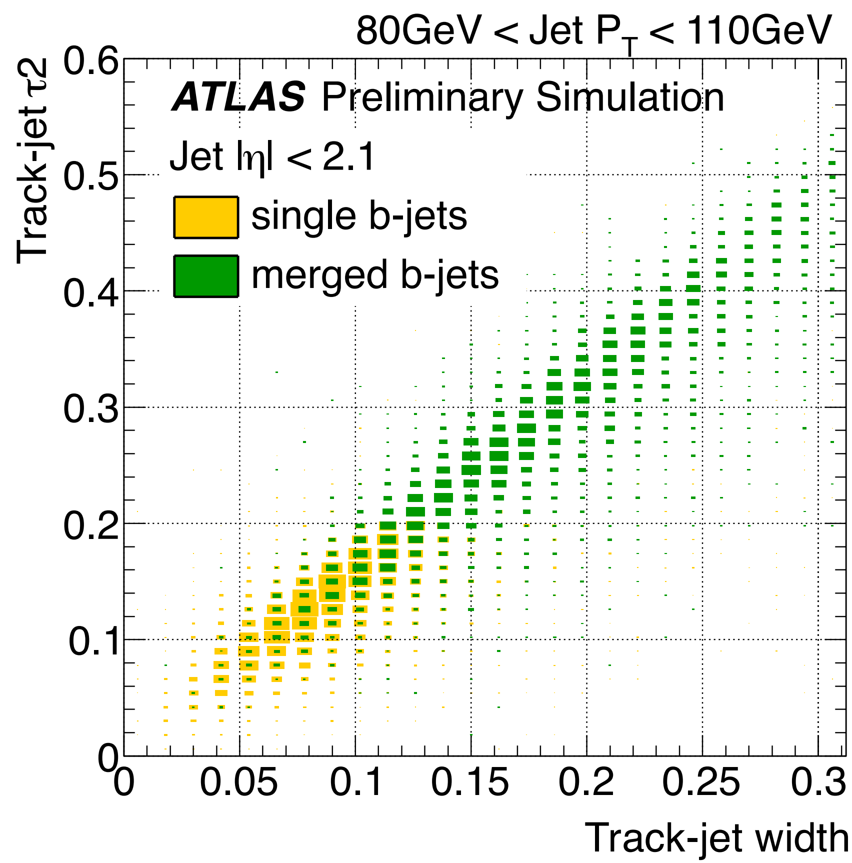




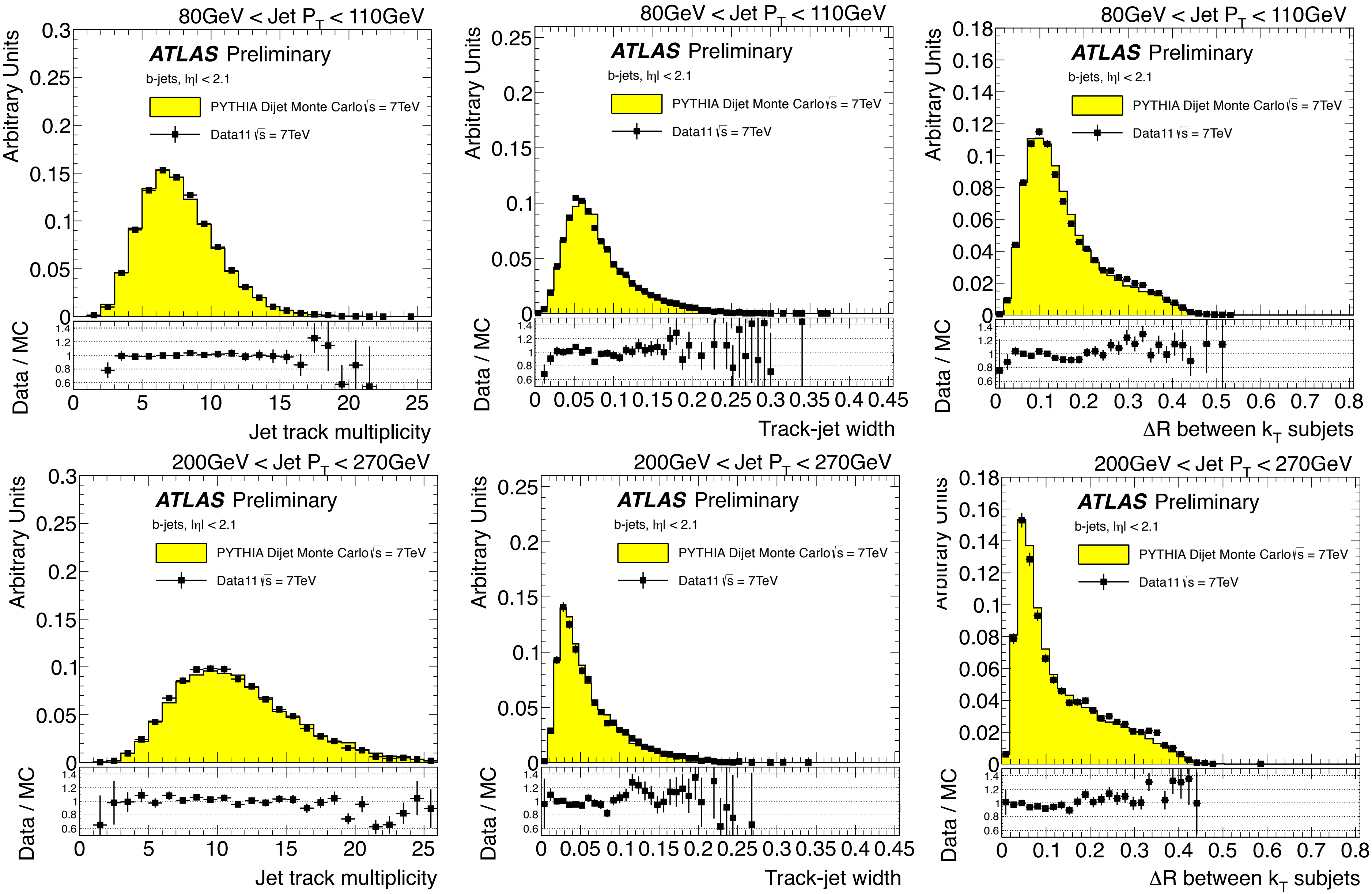
Correlations

- **N-subjettiness τ_2 strongly correlated with jet width**
- Other jet substructure variables (eccentricity, DR between leading tracks, τ_{21}) did not show large discrimination



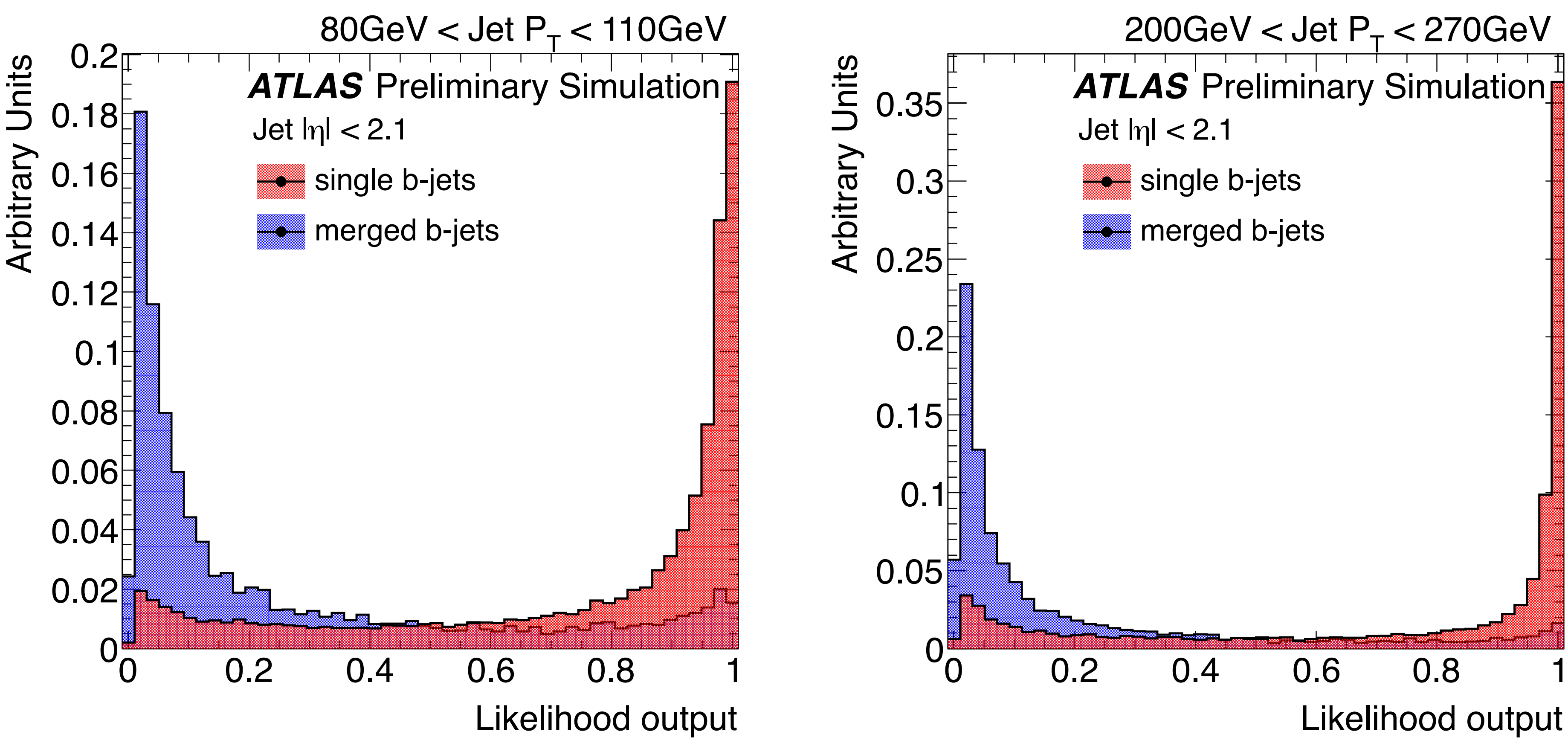


Validation of variables with data



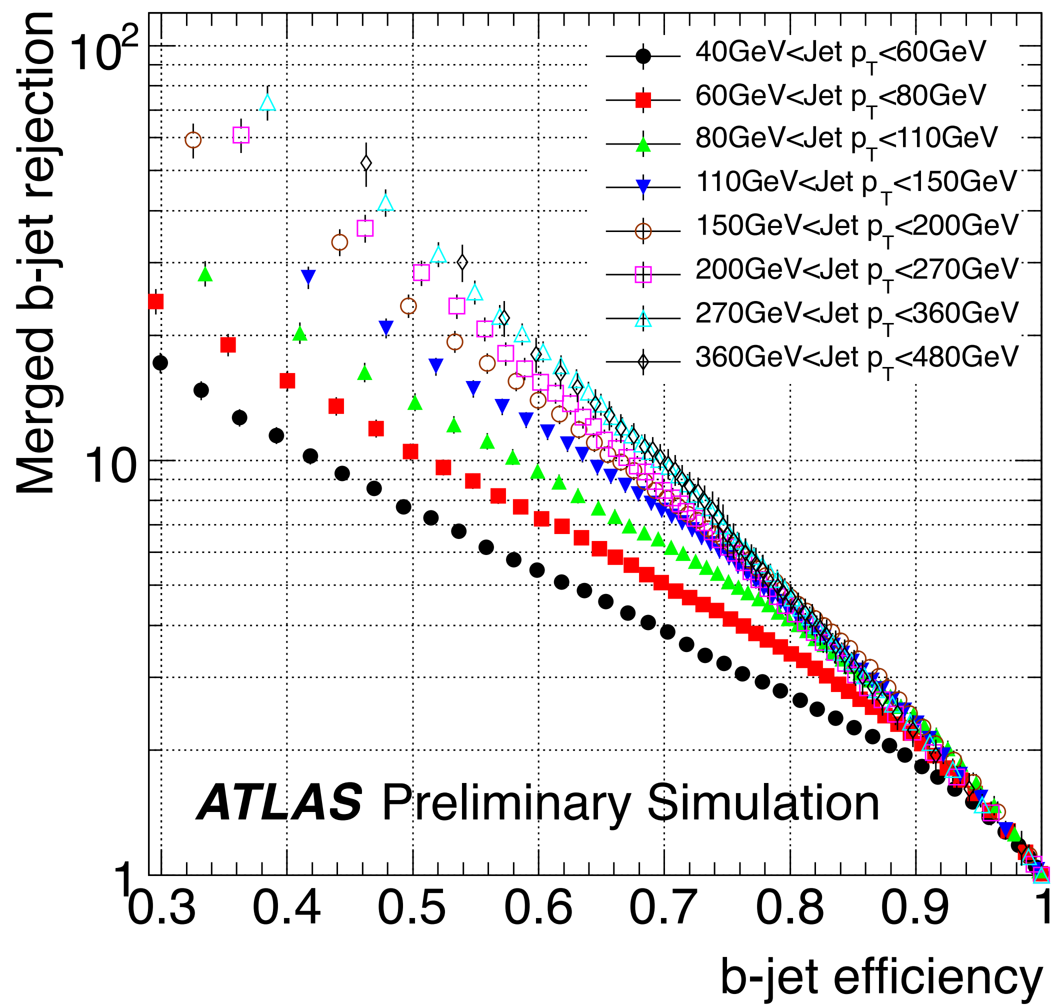
Double B-hadron tagger

- **Multivariate likelihood discriminator:**
  - Jet track multiplicity, Track-jet width, DR between k_t subjets
  - Training performed in bins of jet p_T



Tagging performance

- **Rejection of merged b-jets @ 50% b-jet efficiency:**
  - 8x for jet p_T>40 GeV
  - 30x for jet p_T>200 GeV
- Same likelihood performance for b-jets identified with different b-tagging algorithms (*JetFitter*), and operational points (*70% MV1*)

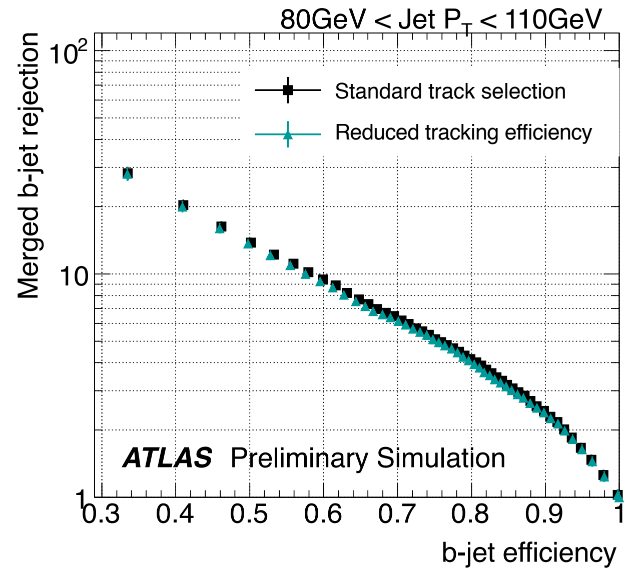


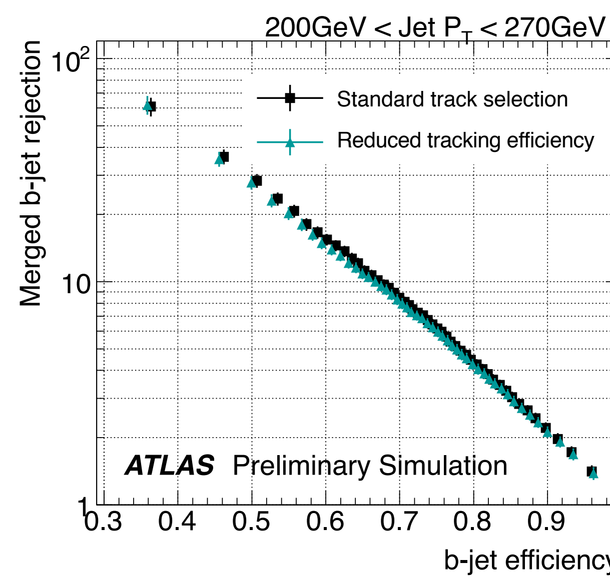
Only statistical errors shown

Systematic uncertainties

- **Evaluate the impact of tracking, b-tagging, and jet energy scale and resolution uncertainties on the tagger performance**
  - merged b-jet rejection uncertainty at 50%-60% single b-jet efficiency

Systematic source	Uncertainty
pile-up	neglible
b-tagging efficiency	neglible
track reconstruction efficiency	4%
track p_T resolution	neglible
jet p_T resolution	6%
jet energy scale	5%



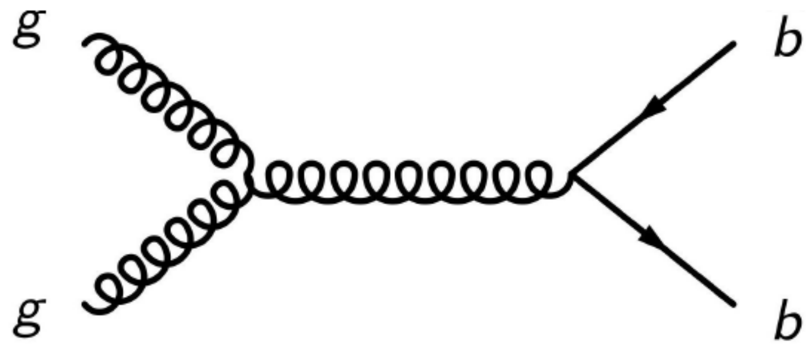


Summary

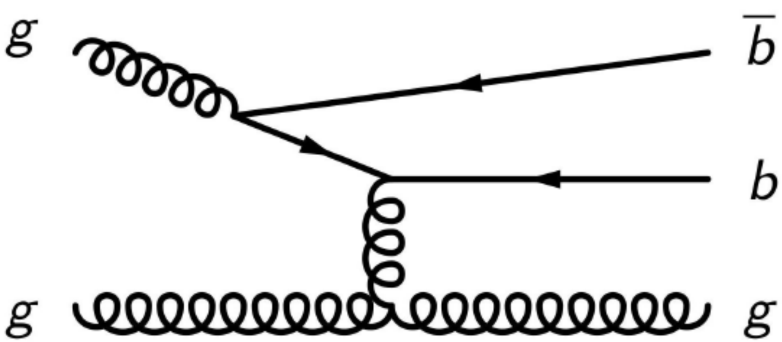
- **ATLAS has developed an algorithm to identify and tag double B-hadron jets using substructure techniques**
  - 20x rejection at 50% b-jet efficiency is achieved for jets with p_T>100 GeV
- **The method exploits the differences in the internal structure between single and merged b-jets produced from gluon splitting**
  - Combines b-tagging with jet substructure techniques
  - Does not require the reconstruction of two displaced vertices
- **Double B-hadron tagging can have multiple applications in physics analyses and enhance the physics precision of the LHC**

Backup slides

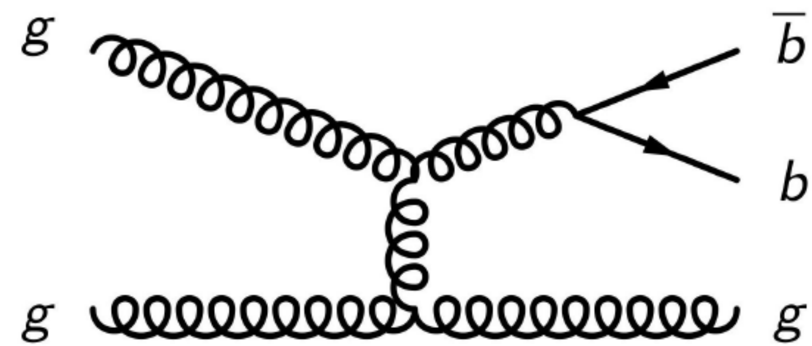
QCD b-quark production



Flavour creation



Flavour excitation



Gluon splitting