Measurement of the flavour composition of dijet events in pp collisions with ATLAS

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Introduction

The production of jets containing bottom and charm hadrons

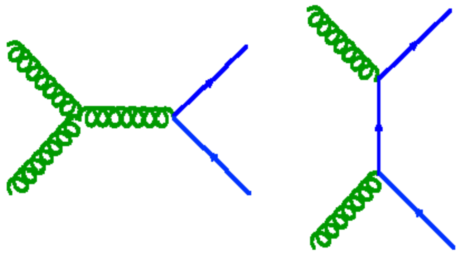
Less influence by low energy hadronisation

➔ Strong interest for understanding QCD.

Three mechanisms of heavy flavour production in a dijet system:

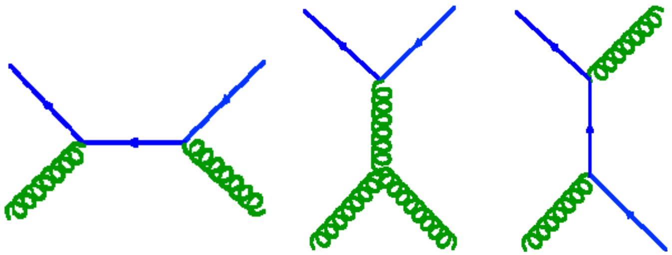
1. Heavy flavour quark pair creation

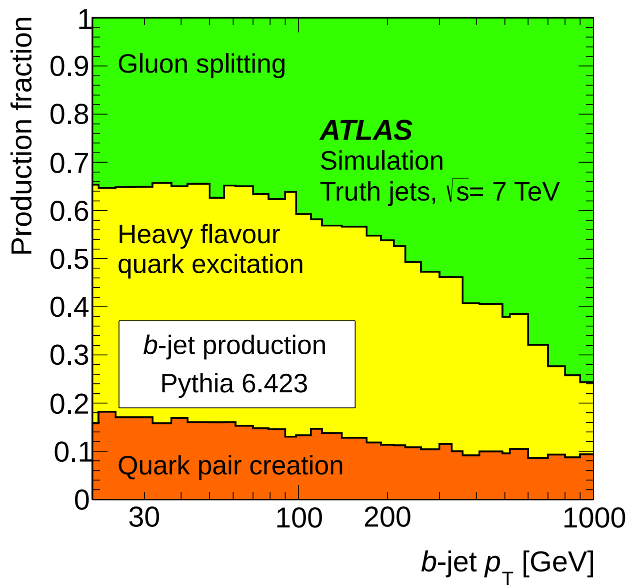
   Two heavy quarks
   in hard interaction
   → pQCD



2. Heavy flavour quark excitation

   Single heavy quark
   in hard interaction
   → PDFs





Pythia MC prediction

3. Gluon splitting

   No heavy quark in hard interaction → non-perturbative QCD

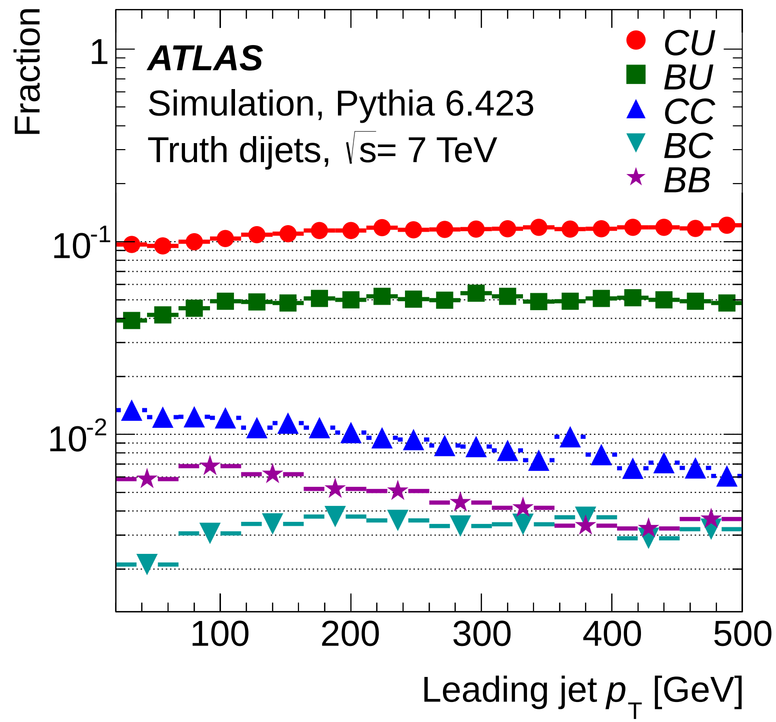
Six flavour composition of dijet events

Six flavour combinations in dijet events:

BB, CC, UU, BU, CU, BC

B: b-jet (a jet includes bottom hadrons) ,
C: c-jet,
U: light-quark jet (u, d, s, g)

- Decrease of BB & CC and increase of BU & CU are expected as a function of jet p_T.



Pythia MC prediction

The analysis aims to measure fractions of the six combinations of dijet events: $f_{BB}, f_{CC}, f_{UU}, f_{BU}, f_{CU}, f_{BC}$

- Jet flavour identification using templates which are derived from kinematics of secondary vertex in a jet. (No jet tagging)

Event reconstruction

ATLAS 2010 pp collision data of 39 pb^{-1} at $\sqrt{s} = 7\text{TeV}$ is analysed.

- Event should have a well reconstructed primary vertex.
- Anti-k_t jets, R=0.4
- p_T>30 GeV, |y|<2.1
- Two leading jets should have azimuthal angular separation of $\Delta\varphi > 2.1$

Measurement is done in leading p_T binning, with minimum p_T cut for subleading jets.

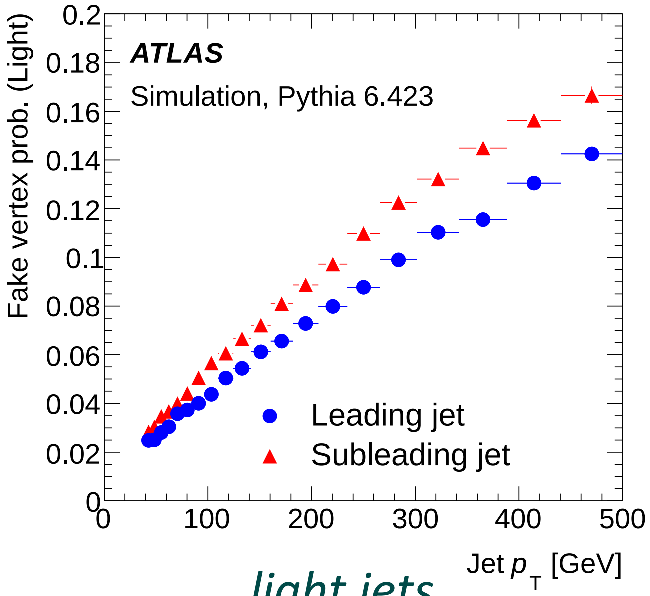
Bin definition

Leading jet p_T (GeV)	40-60	60-80	80-120	120-160	160-250	250-500
Subleading jet p_T (GeV)	30-60	40-80	50-120	75-160	100-250	140-500

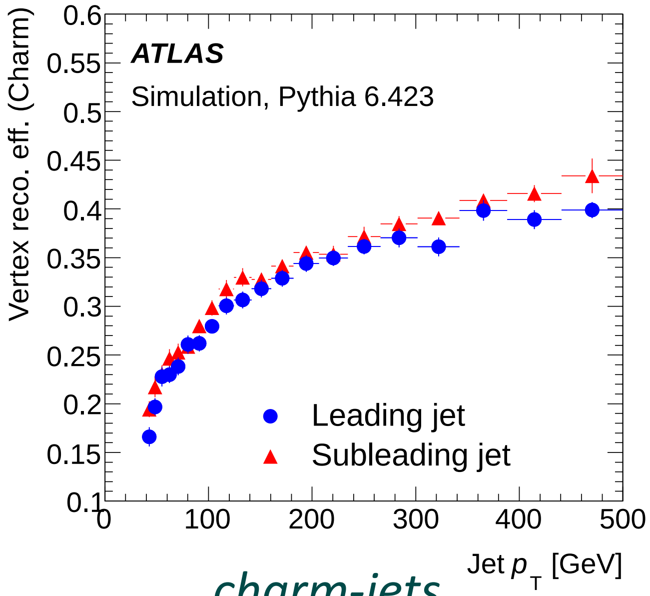
Secondary vertices

- A single secondary vertex is fitted to each jet.
  - A positive decay length and total invariant mass > 0.4 GeV.
- Reconstruction efficiency depends on jet p_T
  - Higher fake vertex reconstruction probability in light jets for subleading jet.
    → will be taken into account in the template fit.

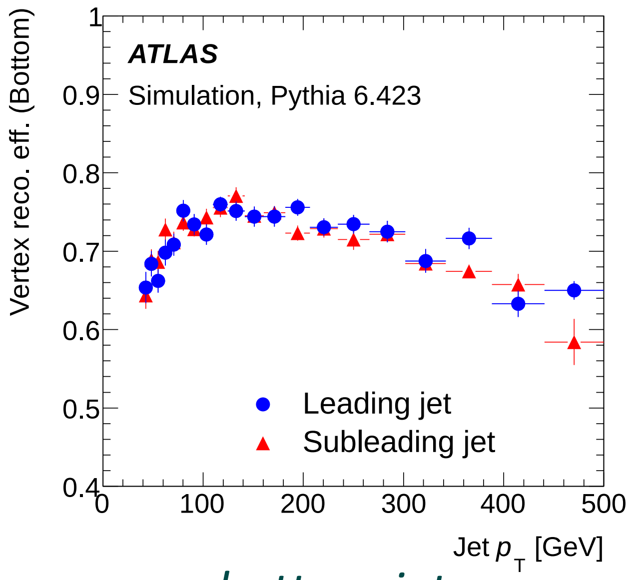
Secondary vertex reconstruction efficiencies



light jets



charm-jets



bottom-jets

Construction of template -1

Templates utilise kinematic information from secondary vertices in jets. Choice of variables is driven by

- Maximal sensitivity to the flavour content
- Minimal dependence on jet p_T and rapidity.
- Minimal dependence on detector resolution.

- Two variables for template fit:

$$\Pi = \frac{m_{\mathrm{vertex}} - 0.4\mathrm{GeV}}{m_B} \cdot \frac{\sum_{\mathrm{vertex}} E_i}{\sum_{\mathrm{jet}} E_i}$$

Product of mass and energy fraction of a secondary vertex.

$$B = \frac{\sqrt{m_B} \cdot \sum_{\mathrm{vertex}} \left|\vec{p}_{T\,i}\right|}{m_{\mathrm{vertex}} \cdot \sqrt{p_{T\,\mathrm{jet}}}}$$

~ relativistic γ factor of a secondary vertex (“Boost”)

i for charged particle, m_{vertex} is invariant mass of the vertex, m_B=5.28 GeV.

- They are transformed to the interval [0,1]:

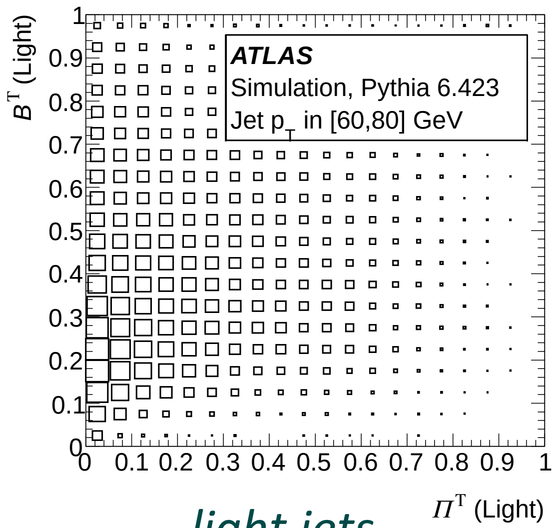
$$\Pi^T = \frac{\Pi}{\Pi + 0.04} \qquad B^T = \frac{B \cdot B}{B \cdot B + 10.}$$

Construction of template -2

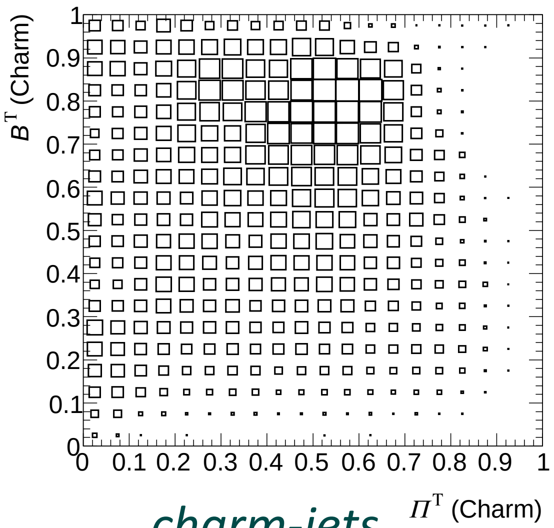
- B^T and Π^T are independent on jet rapidity.
- Π^T has only weak jet p_T dependence.
- B^T is sensitive to the gluon splitting.

2D-template is used.

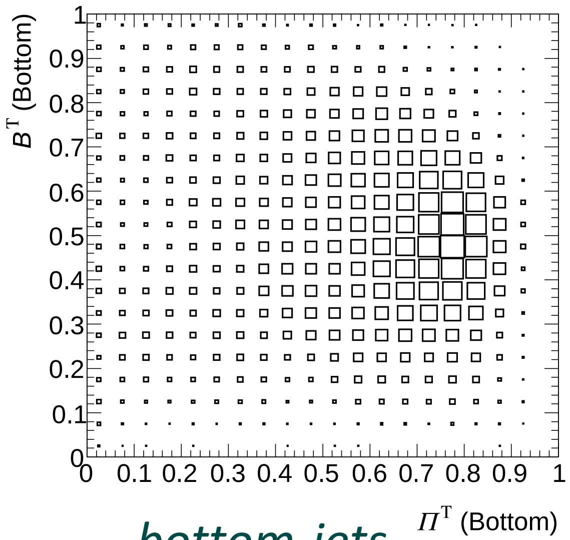
- Light, charm and bottom jets are clearly separated.



light jets



charm-jets



bottom-jets

In addition, template for jets with 2b-quarks are prepared.

- Pythia MC templates are tuned on data, by mixing Pythia events with smeared track impact parameter.

Dijet analysis model

- 9 free parameters in the template fits are
  - $f_{BB}, f_{CC}, f_{BU}, f_{CU}, f_{BC}$: fraction of components in dijet events. ($f_{UU} = 1 - f_{BB} - f_{CC} - f_{BU} - f_{CU} - f_{BC}$)
  - sv_U^L, sv_U^{SL} : Scale factors for fake vertex reconstruction probability for light jets.
  - $A_b = f^L_{BU} / f^{SL}_{BU} - 1$: Bottom dijet flavour asymmetry.
  - b_2 : Parameter for relative mixture of 2b-jet template compared to 1b-jet template.

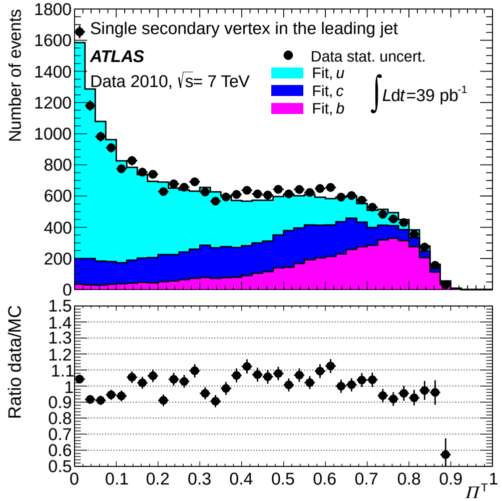
$$B(\Pi^T, B^T) \rightarrow b_2 \cdot B(\Pi^T, B^T) + (1 - b_2) \cdot B_2(\Pi^T, B^T)$$

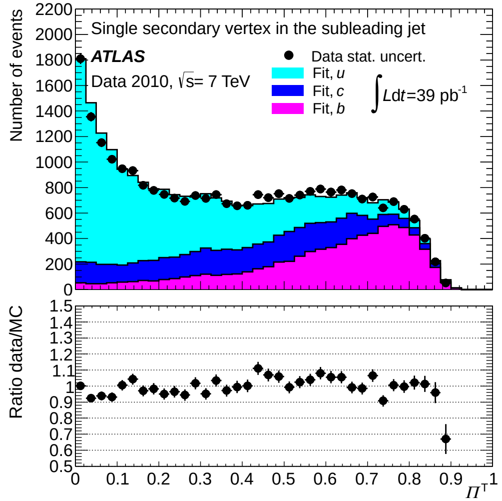
- Fixed parameters
  - v_B, v_C : Secondary vertex reconstruction probabilities for bottom and charm jets are from MC.
  - A_c : Charm dijet flavour asymmetry is fixed to MC prediction.
  - c_2=0 : No additional 2c-jet template.

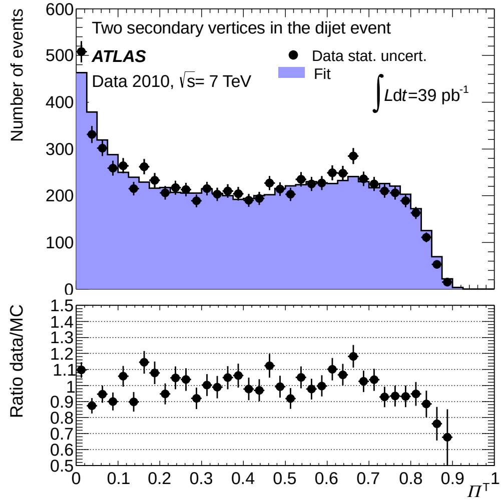
Data fit results

Events with a secondary vertex in leading jet | *Events with a secondary vertex in subleading jet* | *Events with two secondary vertices*

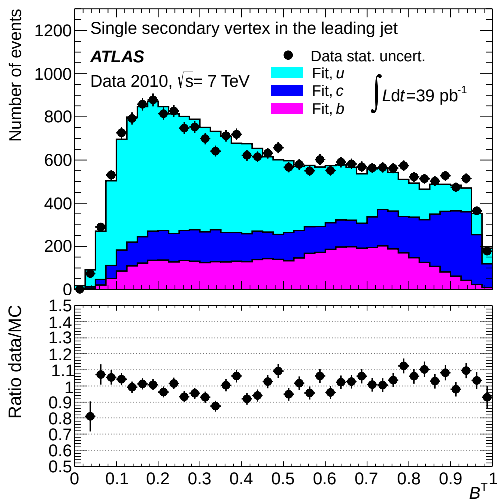
Π^T

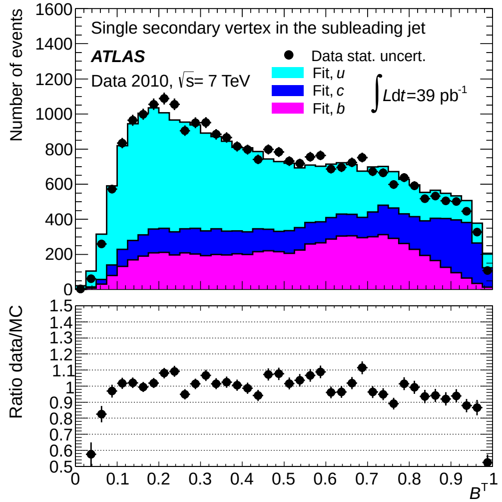


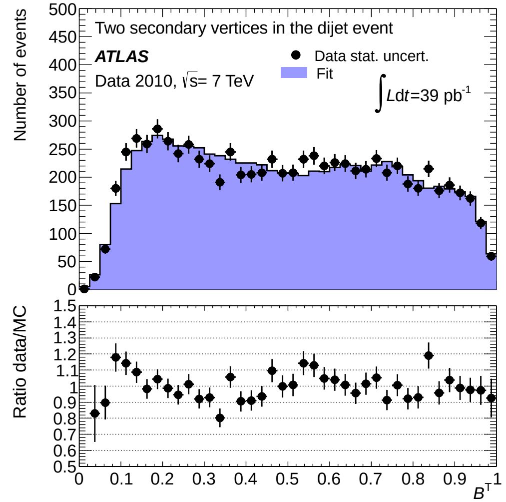




B^T



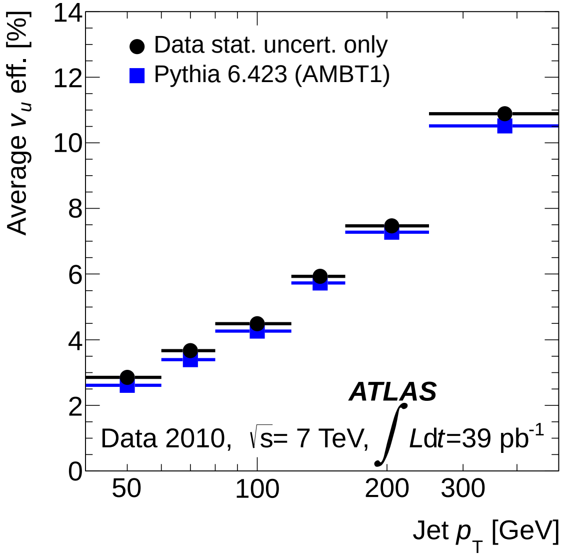




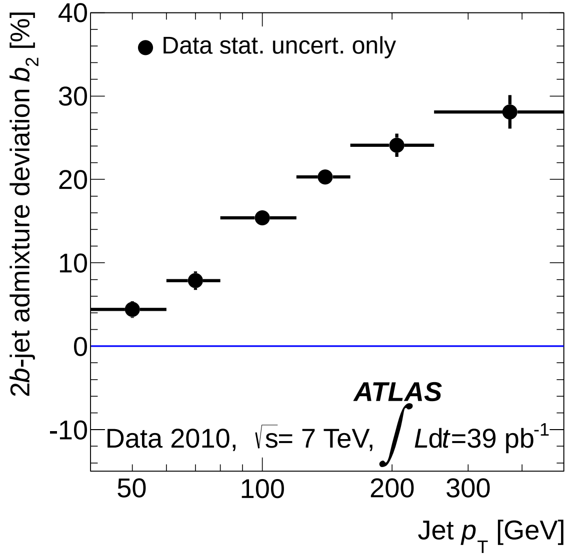
- Data is correctly reproduced by the fit results, within ±10%.

Data fit results

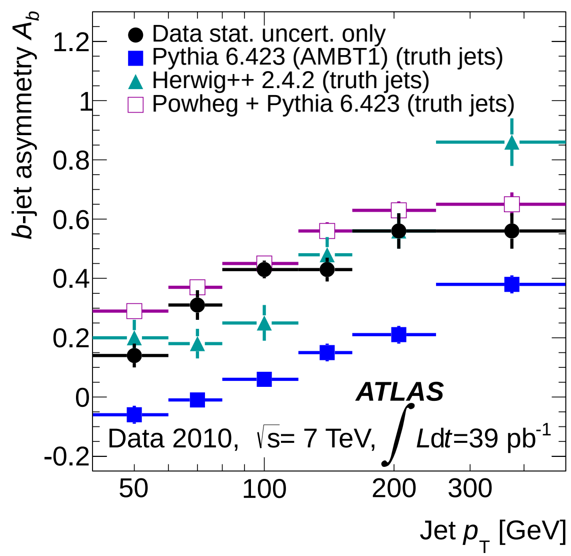
Average v_U



b_2



A_b



- Average fake vertex probability in light jets in data is well reproduced by MC.
- Large contribution of additional 2b-jet template with respect to Pythia. Larger contribution for higher jet p_T.
- Bottom dijet asymmetry is better described by POWHEG (NLO ME) +Pythia than Pythia (LO ME).

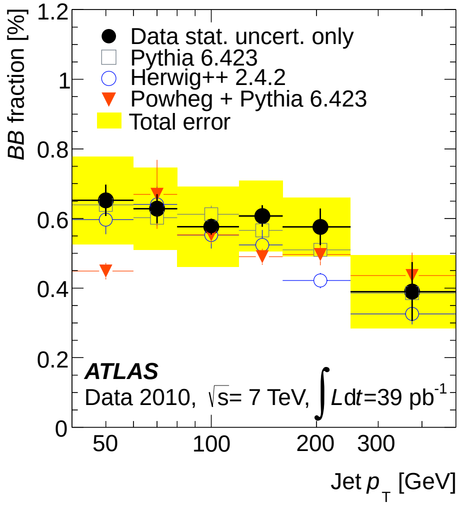
Unfolding and systematic uncertainties

- Unfolding is done by bin-by-bin correction
- Following sources of systematic uncertainties are considered.
  - Pileup effects
  - Jet energy scale (JES) variation
  - v_U, v_C vertex reconstruction efficiencies
  - Template shapes
    - Analysis validation by using Herwig as pseudo-data rather than Pythia.
    - Template created with inclusive jet selection.
  - Imperfection of MC description of jet p_T and rapidity distribution
  - Influence of data-MC difference of track impact parameter accuracy
  - Influence from charm asymmetry (A_C) and 2c-jet (c_2)
  - Unfolding

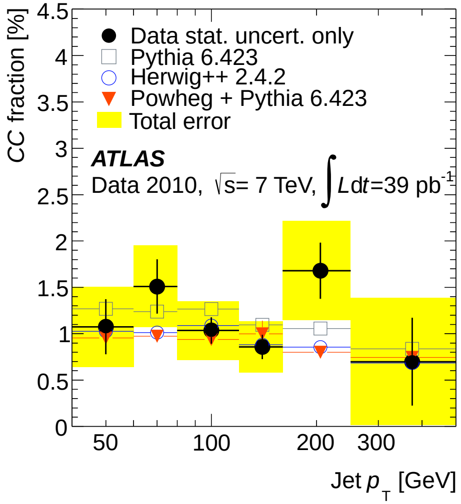
Large contributions from JES and template shapes to the total systematic uncertainties.

Measured flavour composition

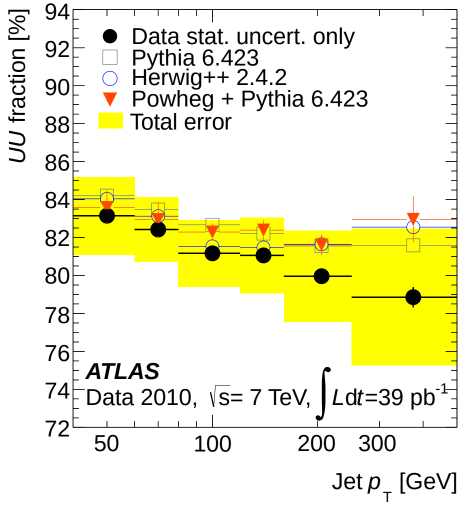
BB



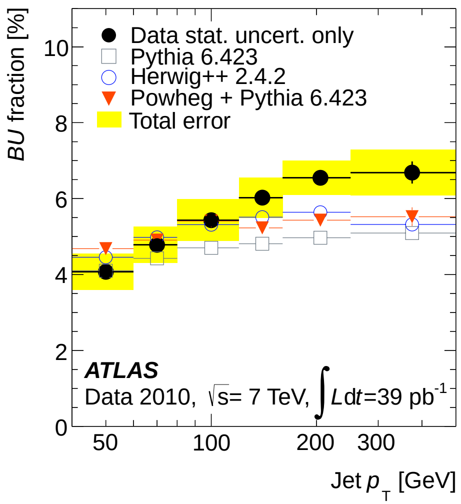
CC



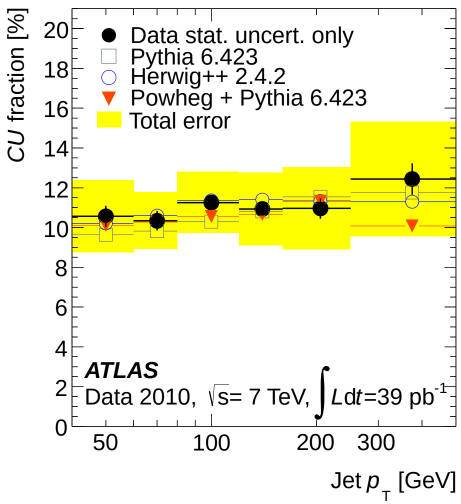
UU



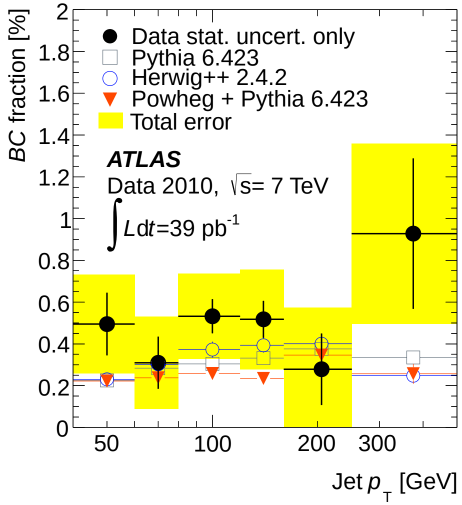
BU



CU



BC



- Measurements are generally reproduced by NLO or LO predictions, except for BU fraction.
- Measured BU fraction is higher than predictions at p_T>100 GeV.

Conclusion

- Analysis of jet flavour composition of dijet events has been performed using ATLAS 2010 pp collision data of 39 pb^{-1}.
  - 6 flavour-combinations of BB, CC, UU, BU, CU, BC.

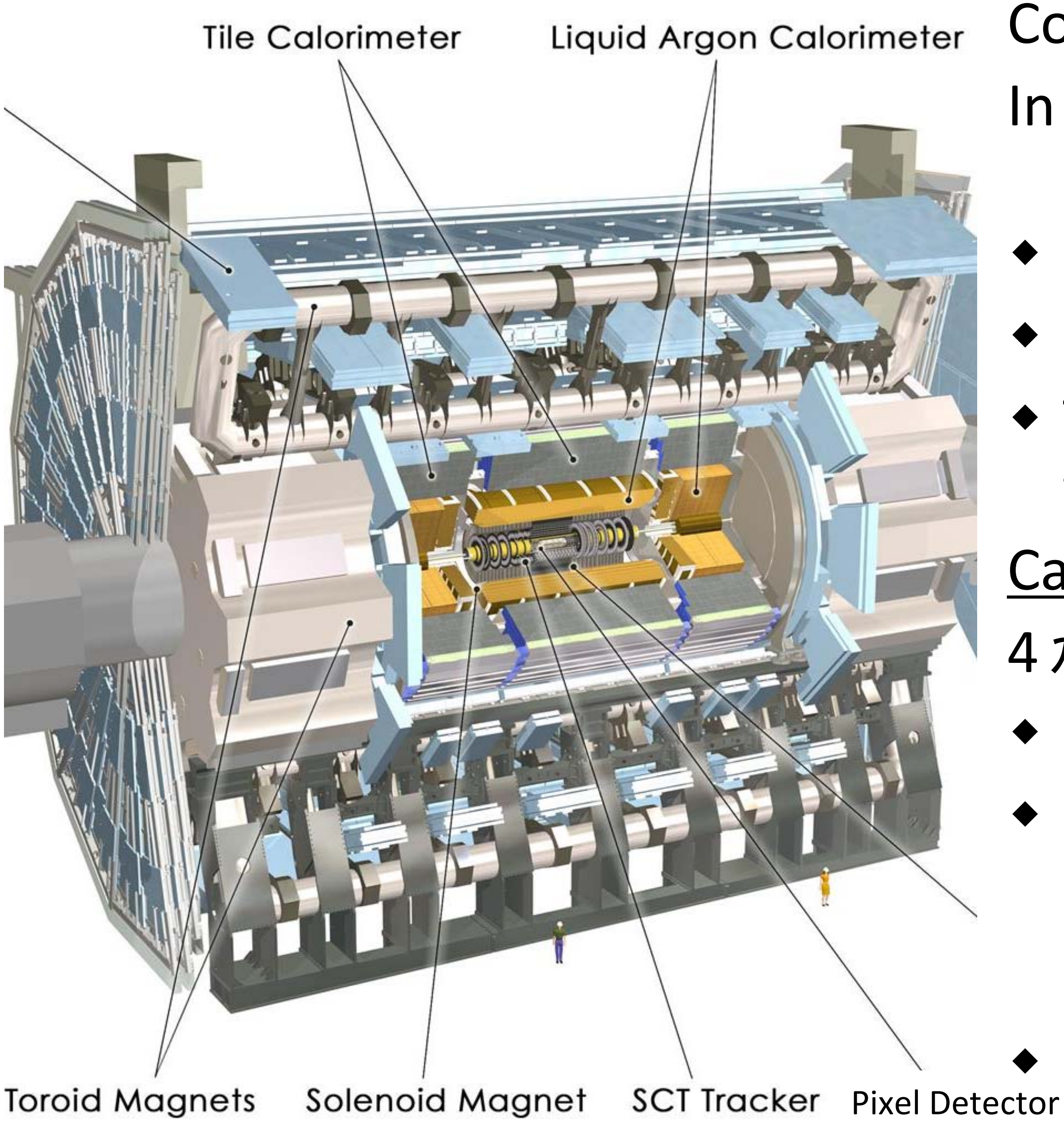
- Kinematic information of secondary vertices in jets are used in templates to separate light, charm and bottom quark.

- Dijet events are analysed using these templates and well described by the template fit.

- Bottom-light flavour composition is found to be larger than the NLO or LO predictions. Other flavour compositions are reproduced by the predictions.

Backup

ATLAS detector



Inner tracker

Covering | η |<2.1

In a solenoidal magnetic filed of 2T

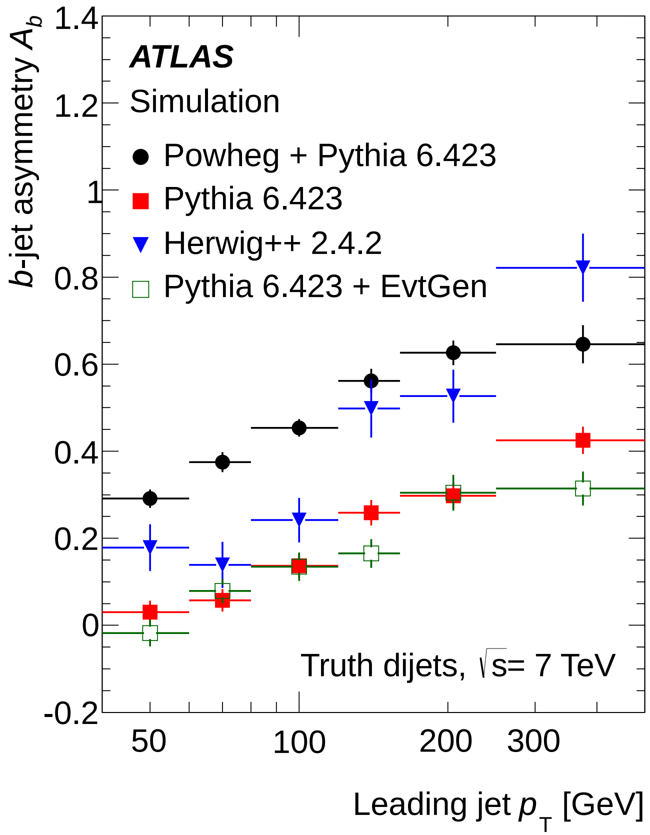
- Silicon pixel detector
- Silicon microstrip detector
- Transition radiation tracker

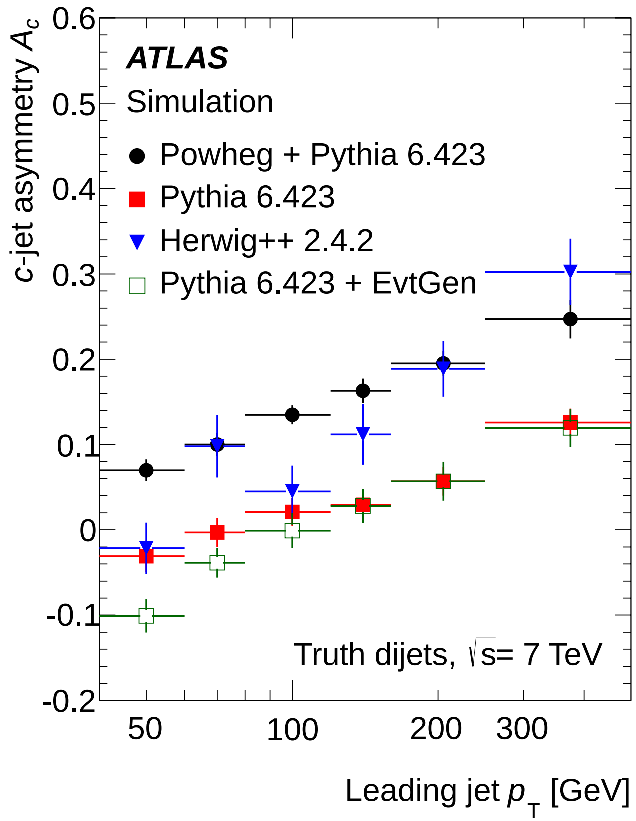
Calorimeter

4 π coverage up to | η |<4.9

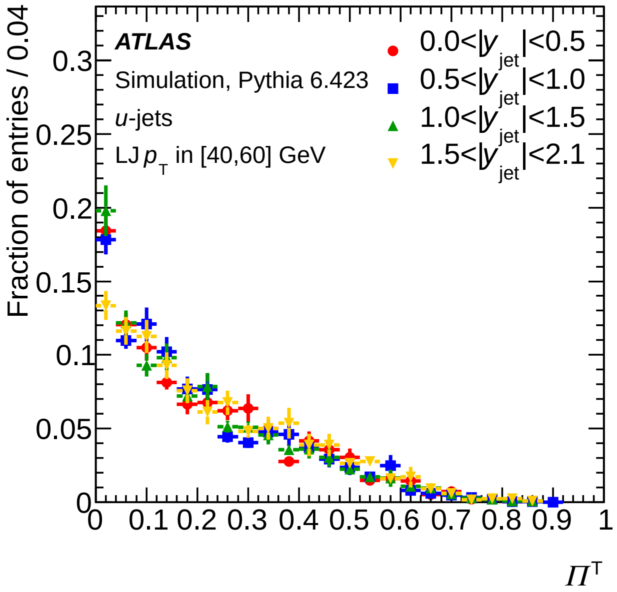
- EM (LAr) | η |<3.2
- Hadron
  - Tile | η |<1.7
  - LAr/Cu 1.5<| η |<3.2
- Forward 3.1<| η |<4.9

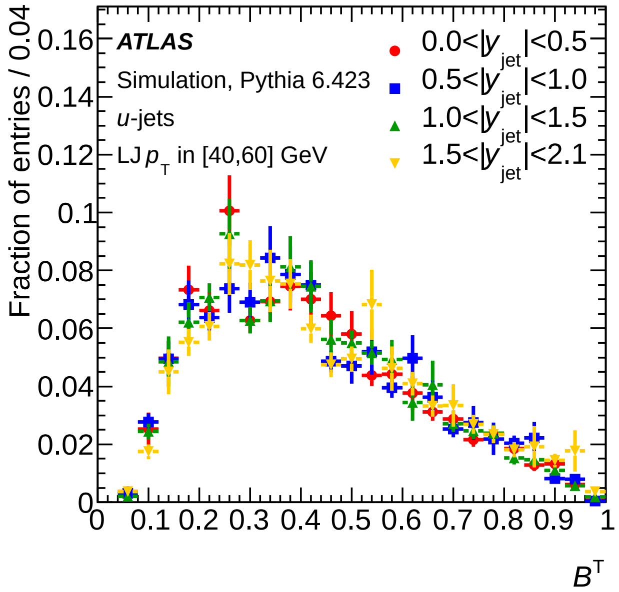
Jet asymmetry

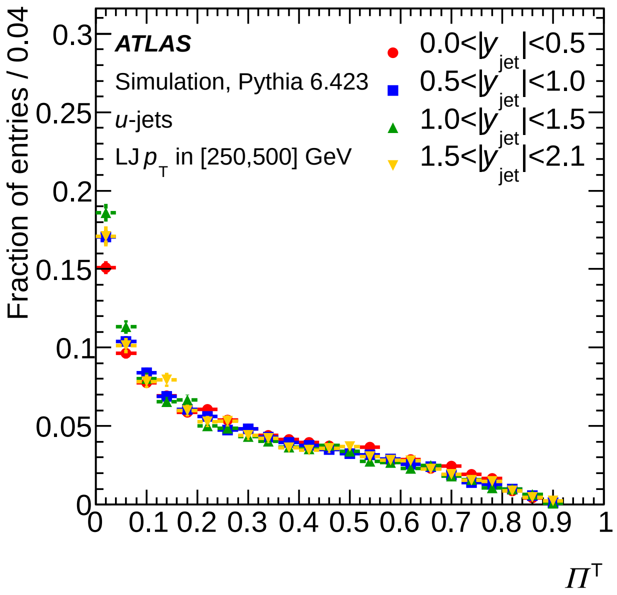


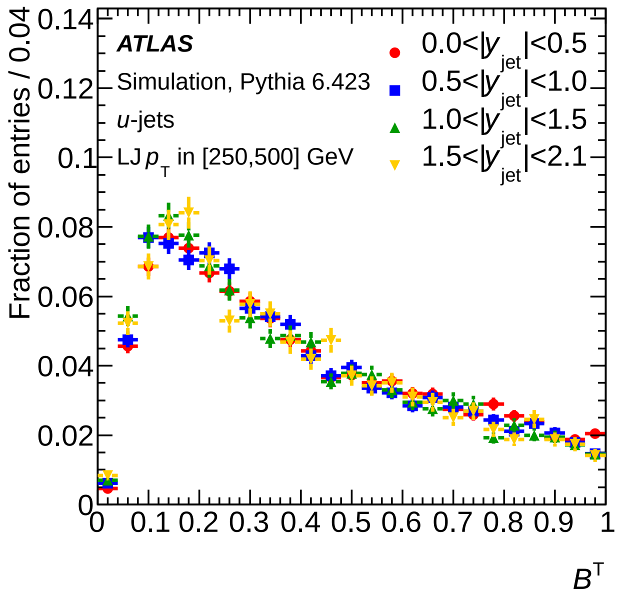


Light jet



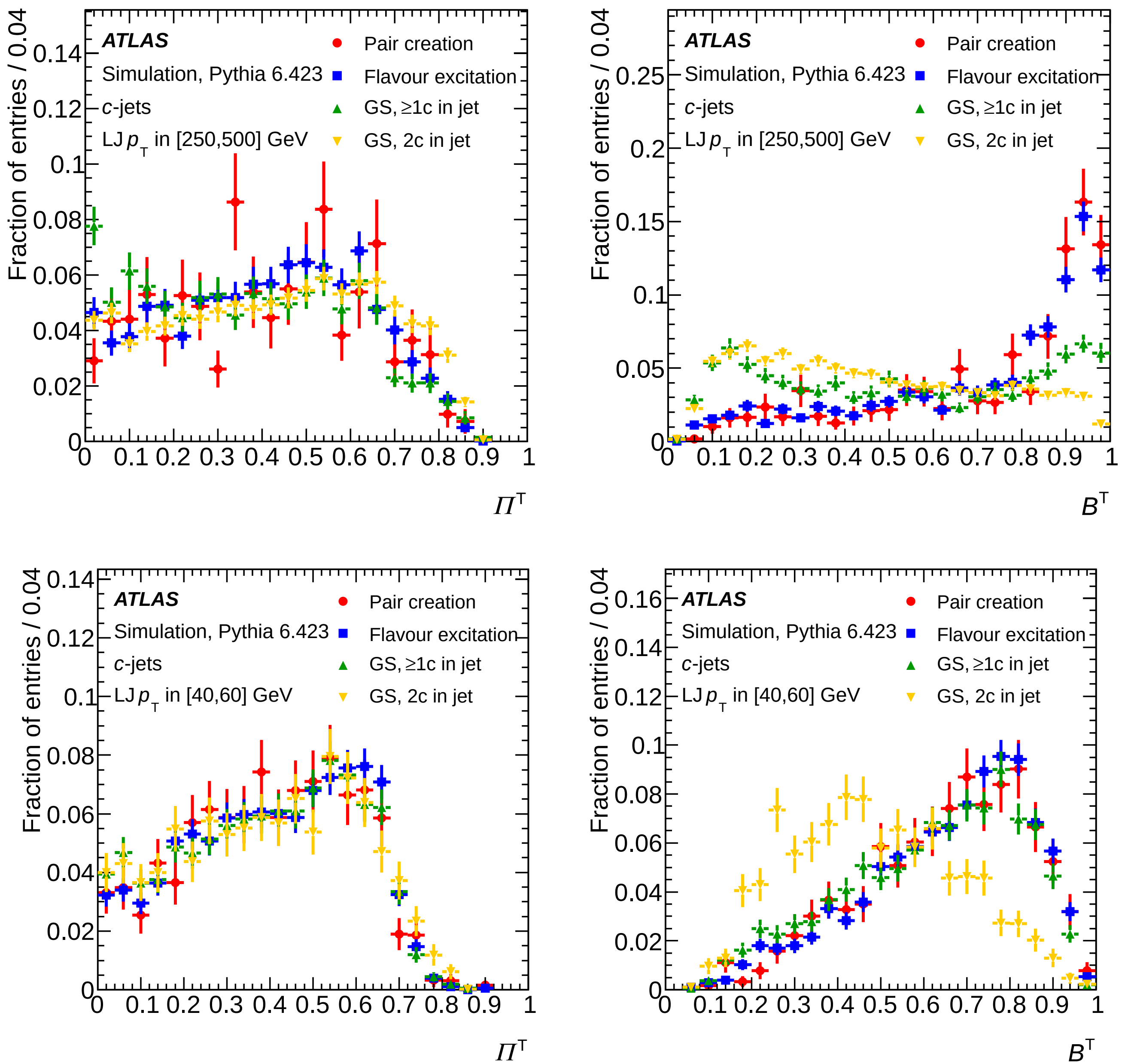




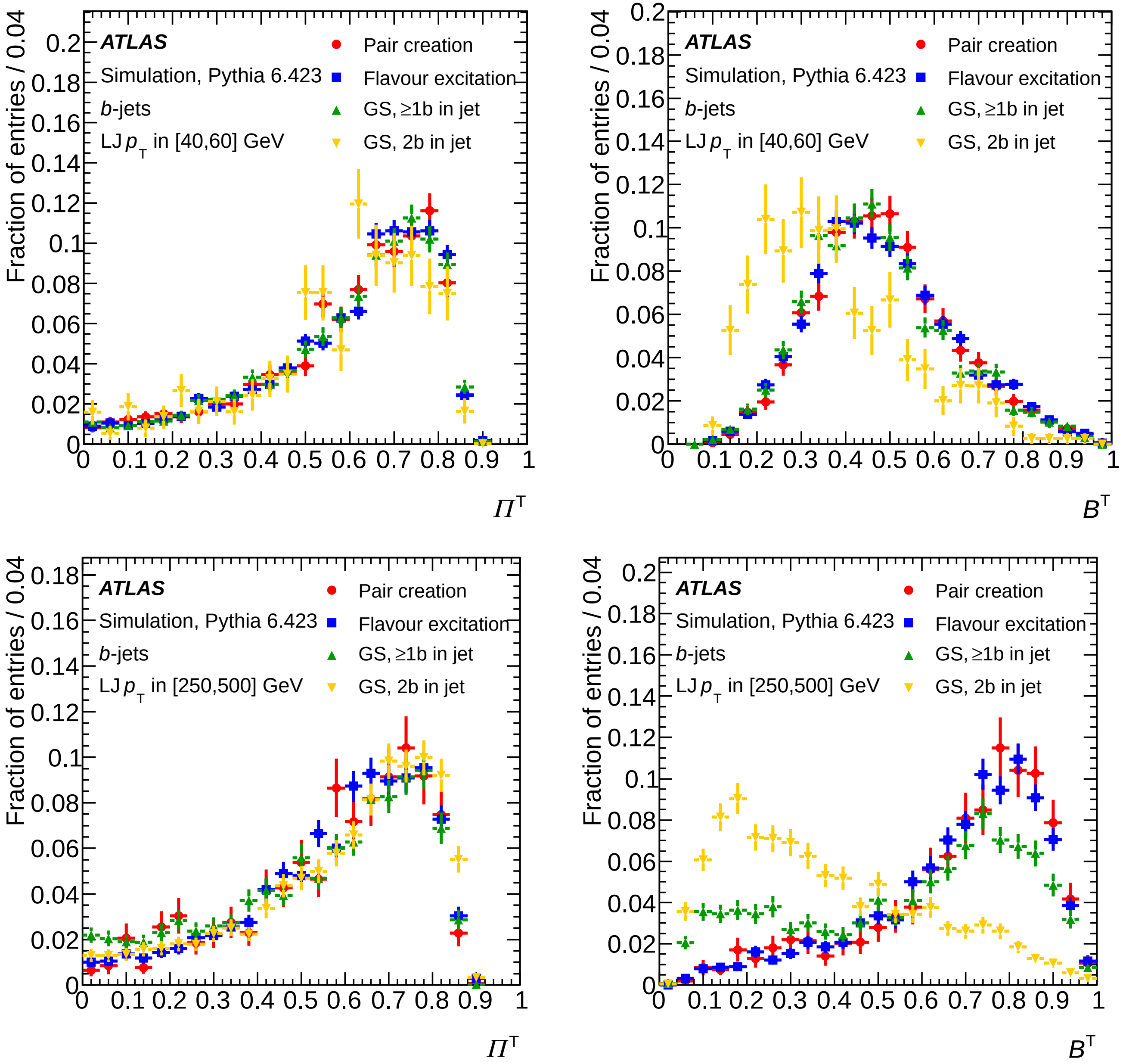


- No rapidity dependence

Charm jet


ATLAS
Simulation, Pythia 6.423
c-jets
LJ p_T in [250,500] GeV
Pair creation
Flavour excitation
GS, ≥1c in jet
GS, 2c in jet
Fraction of entries / 0.04
Π^T
B^T
LJ p_T in [40,60] GeV

Bottom jet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