Inclusive $b$-jet Production at ATLAS

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Content

• Motivation
• ATLAS Detector – Overview
• SV0 $b$-tagging + calibration
• Inclusive cross section of $b$-jets$^{(*)}$
• Di-jet cross section of $b$-jets

$^{(*)}$ Definition:

$b$-jet $[bi:-dʒɛt]$, jet containing a hadron with a $b$ or an anti-$b$ quark
Heavy flavor production

• New energy frontier as excellent testing ground
  
  • Heavy flavor production ...
    
    ▪ ... measurements allow tests of theoretical QCD prediction at NLO
    ▪ ... has large theoretical uncertainties
    ▪ ... is an important background in many searches
    ▪ ... measurement constrains heavy flavor component of proton PDF

• Heavy flavor results from ATLAS:
  
  • Inclusive and di-jet cross section of $b$-jets
  
  • $J/\psi$ and $\Upsilon(1S)$ production (see talk by K. Reeves)
  
  • Top quark (see talks by R. Calkins & D.B.Ta)
  
  • $B$ and $D$ production (see talk by E. Rossi)
ATLAS Detector

Muon Detectors

Tile Calorimeter

Liquid Argon Calorimeter

Toroid Magnets

Solenoid Magnet

SCT Tracker

Pixel Detector

TRT Tracker
ATLAS Detector

- Inner Detector
  - excellent tracking
  - \(b\)-tagging
  - vertexing
- Calorimeter
  - triggering jets
- Muon Spectrometer
  - calibration of \(b\)-tagging
  - muon tracks
Data Taking and Trigger

• Data taking: Mar – Aug 2010
  • Proton-proton collisions at $\sqrt{s} = 7$ TeV
  • Integrated Luminosity: $3.0 \pm 0.1$ pb$^{-1}$
• Trigger
  • Searching for $b$-jets in the range $20 \text{ GeV} < p_T < 260 \text{ GeV}, |y| < 2.1$
  • Level-1 jet trigger + MinBias trigger for low $p_T$ jets
  • Triggers thresholds chosen, to have fully efficient triggers
  • Trigger efficiency $> 98$
• Reconstruction
  • Reconstruct PV, reconstruct jet from topological clusters
  • Anti-$k_t$ algorithm with radius $R = 0.4$
  • Reconstruction and selection efficiency for $b$-jets $> 99$
**b-tagging: SV0 b-tagging**

- Reconstruction of secondary vertex using tracks associated to calorimeter jet
- Merge two-track vertices (each not compatible with the PV) into common vertex
- Remove tracks with large $\chi^2$ contribution...
- ... until several criteria (*) are fulfilled
- Signed decay length (in 3D) significance $L/\sigma(L)$ is the $b$-tagging weight

(*) Criteria:
- vertex mass < 6 GeV
- each track $\chi^2 < 7$
**b-tagging: SV0 b-tagging**

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![Tracks from b decays](tracks_from_b_decays.png)

![Prompt tracks](prompt_tracks.png)

(ATLAS-CONF-2010-099)
**b-tagging: example**

- Top pair e-mu di lepton candidate, two $b$-jet cones
**b-tagging: example**

- Top pair e-\(\mu\) di lepton candidate, two \(b\)-jet cones
**b-tagging calibration**

(ATLAS-CONF-2010-099)

- Select events with muon, calculate $p_T^{rel}$, transverse momentum relative to jet
- Harder spectrum for $b$-jets
- Idea: create template spectra, fit to data to obtain $b$-tagging efficiency
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- templates of jets before some cut on $b$-tagging weight

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*ATLAS Preliminary*
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(ATLAS-CONF-2010-099)

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![Graph Image](image.png)

- template for light flavors and $c$-jets and $b$-jets
- templates of jets before some cut on $b$-tagging weight

... and after
**b-tagging calibration**

(ATLAS-CONF-2010-099)

- Fitting templates by adjusting templates to data in a binned maximum likelihood fit
- Data vs. fit before any cut
**b-tagging calibration**

(ATHLAS-CONF-2010-099)

- Fitting templates by adjusting templates to data in a binned maximum likelihood fit
- Data vs. fit before and after cut on $L/\sigma(L) > 5.72$

- Cut $L/\sigma(L) > 5.72$: 50% b-tagging efficiency in simulated $tt$ events
Measurement: Inclusive $b$-jet cross section at $\sqrt{s} = 7$ TeV

(ATLAS-CONF-2011-056)

- $b$ jet cross section ($20 \,\text{GeV} < p_T < 260 \,\text{GeV}, \,|y| < 2.1$)

\[
\frac{d^2\sigma_b}{dp_Tdy} = \frac{1}{\Delta p_T \Delta y} \frac{N_b \cdot \text{frac}_b}{\varepsilon_{\text{trig}} \cdot \varepsilon_{\text{sel}} \cdot \varepsilon_{\text{btag}} \cdot \mathcal{L}} \times C
\]

- $bb$ di-jet cross section ($\text{di-jet mass} \, M < 670 \,\text{GeV}, \,|y| < 2.1$)

\[
\frac{d\sigma_{b\bar{b}}}{dM} = \frac{1}{\Delta M} \frac{N_{b\bar{b}} \cdot \text{frac}_{b\bar{b}}}{\varepsilon_{\text{trig}} \cdot \varepsilon_{\text{sel}} \cdot \varepsilon_{\text{btag},2} \cdot \mathcal{L}} \times C
\]

- Trigger: level 1 jet trigger, MBTS trigger (for low jet $p_T$)
Measurement: Inclusive b-jet cross section at \( \sqrt{s} = 7 \) TeV

\[
\frac{d^2\sigma_b}{dp_T dy} = \frac{1}{\Delta p_T \Delta y} \frac{N_b \cdot \frac{b}{\epsilon}\epsilon_{\text{trig}} \cdot \epsilon_{\text{sel}} \cdot \epsilon_{b\text{tag}} \cdot \mathcal{L}}{\cdot C}
\]

Number of events tagged by SV0 b-tagging algorithm...

... and fraction of those events, which are b-jets

Efficiencies: trigger (> 98%), jet reconstruction and selection, b-tagging

Integrated luminosity for triggers: \( 3.0 \pm 0.1 \) pb\(^{-1}\)

bin-by-bin unfolding correction applied, to compare to “truth b jets”, true b-hadron within R=0.3
Measurement: Inclusive $b$-jet cross section at $\sqrt{s} = 7$ TeV

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Number of $b$-tagged events...

- Weight of SV0 b-tagger: signed decay length significance $L/\sigma(L)$

- Excess in data: tracking performance difference between data and MC.

- But: affects light jets with small SV0 weight.

- Next: what is the fraction of $b$-jets in data?

- Like before, MC derived templates fitting to data

\[ L/\sigma(L) > 5.72 \]
... and fraction of $b$-jets

- SV0 vertex mass
- Templates of light, charm and $b$-jets (single jets)
  - Log-likelihood fit to data, stat. uncertainty in data and MC templates
  - two example fits...
- Sum of SV0 vertex mass
- Templates of $b$ and non-$b$ jets (di-jets)

**Figure:**
- **Single $b$-jet:**
  - SV0 mass for weight $> 5.72$ [GeV]
  - $40 \text{ GeV} \leq p_T < 60 \text{ GeV}, 0.0 \leq |y| < 0.3$
  - ATLAS Preliminary
  - $n_l = 270^{+53}_{-49}$
  - $n_c = 519^{+105}_{-96}$
  - $n_b = 1197^{+96}_{-88}$
  - $\chi^2/\text{DoF} = 19.7/23$
  - Fit prob. = 0.66

- **Di-jets:**
  - Sum vertex mass [GeV]
  - $\chi^2/\text{DoF}: 65.0/23$
  - b-frac: $0.75 \pm 0.02$
  - Data10, b-template, not b-template
**b-tagging efficiencies**

- Efficiency estimated using $p_T^{rel}$ method using sample with muons

![Graph showing b-tagging efficiencies vs. Jet $p_T$ and b$b$ dijet mass](ATLAS-CONF-2011-056)
Inclusive $b$-jet cross section

- Main uncertainties: jet energy scale and $b$-tagging efficiency and purity
- POWHEG (NLO): broad agreement, but drop steeper in MC
- Pythia (LO): normalization scaled by 0.52 (note expected to get norm. correct), shape well described

(Atlas-CONF-2011-056)
Ratio of $b$- to any jet cross section

- Main uncertainties: $b$-tagging efficiency and purity
- POWHEG (NLO): underestimates fraction of $b$-jets by approx. 30% ($\approx 1\sigma$)
- Pythia (LO) is closer

Inclusive $bb$ di-jet cross section

- Analysis dominated by statistics
- Pythia 6 (LO): shape well described
- POWHEG (NLO): somehow higher $bb$ cross section predicted
Conclusions

• Inclusive $b$-jet cross section measured as a function of jet transverse momentum and rapidity, based on secondary vertex method
• Inclusive $b\bar{b}$ di-jet cross section measured as a function of the invariant di-jet mass
• Measurements dominated by uncertainties of...
  • $b$-jet energy scale, $b$-tagging
• Unfolding corrections to compare with Pythia (LO) and POWHEG (NLO)
  • Shape of differential distribution rather well described
  • POWHEG underestimates ratio of $b$-jets to inclusive jets by 30%

  • more details:
Outlook

• Coming soon, same analysis with all 2010 data

• 2011 data
  • improved $b$-tagging, e.g. identify two $b$’s in one jet
  • improvement in handling close-by pixel hits
  • improvement in reconstructing high-$p_T$ $b$-jets

• more details:
Backup

- Track & vertex reconstruction:
  - $p_T > 400$ MeV, 6 silicon cluster requirements
  - 10 tracks in the primary vertex
  - Iterative secondary vertex reconstruction
- Jet reconstruction:
  - Starting with topological clusters
  - Anti-kT algorithm with R=0.4
- Muon reconstruction
  - Combined muon reconstruction, starting from stand-alone muons
  - Combination of muon tracks and Inner Detector tracks
Backup

• Fractional systematic uncertainties in single $b$-jet cross section
Backup

- Systematics in $b$-tagging

<table>
<thead>
<tr>
<th>Source</th>
<th>Relative Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$25 &lt; p_T^{jet} &lt; 40$ GeV</td>
</tr>
<tr>
<td>Modelling of the $b$-hadron direction</td>
<td>6%</td>
</tr>
<tr>
<td>Non-$b$-jet templates</td>
<td>6%</td>
</tr>
<tr>
<td>Jet $p_T$ spectrum</td>
<td>6%</td>
</tr>
<tr>
<td>Scale factor for inclusive $b$-jets</td>
<td>5%</td>
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<td>$p_T^{rel}$ template statistics</td>
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<tr>
<td>Modelling of $b$-decays</td>
<td>1.3%</td>
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<tr>
<td>Fake muons in $b$-jets</td>
<td>0.7%</td>
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<tr>
<td>Jet energy scale</td>
<td>0.2%</td>
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<tr>
<td>Modelling of $b$-production</td>
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</tr>
<tr>
<td>Fragmentation</td>
<td>0.1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12%</strong></td>
</tr>
</tbody>
</table>
Backup

• Mistag rate in $b$-tagging
Backup

- Discrepancy between Data and MC, closer look at vertex mass...