Inclusive b -jet Production in ATLAS

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Abstract. The production of high- p_T b -jets at the Large Hadron Collider LHC is an important process probing perturbative QCD at next-to-leading order. High- p_T b -jets also form a significant background to many Standard Model and Beyond the Standard Model physics channels at the LHC. Measurements of the inclusive differential and dijet cross section of b -jets in proton-proton collisions at $\sqrt{s} = 7$ TeV, using data collected with the ATLAS experiment corresponding to an integrated luminosity of 3 pb^{-1} is presented. These results are compared to NLO QCD predictions.

Keywords: ATLAS, b -jet production, QCD

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INTRODUCTION

The new energy regimes available with the LHC provide an excellent testing ground for probing production of b -jets in proton-proton collisions using perturbative QCD (pQCD). The measurement of the b -jet production cross section not only is a test of theoretical predictions in pQCD, but also can be used to constrain the heavy flavour content in proton PDFs. Furthermore, understanding a substantial fraction of background events in many searches for physics beyond the Standard Model depends on the precise measurements of the inclusive b -jet cross section.

In this paper details of the b -jet cross section measurements with the ATLAS detector [1] at the LHC are highlighted. The identification of b -jets is described in the first part, results on the cross section measurements are summarised in the second part. The next-to-leading order (NLO) calculations in pQCD have been used to produce particle final states, which have been compared to data.

TRIGGER AND RECONSTRUCTION

All results presented in this paper are based on data that have been collected between March and August 2010 at the ATLAS detector, corresponding to an integrated luminosity of about 3.0 pb^{-1} of proton-proton collisions at $\sqrt{s} = 7$ TeV. Events are triggered by a combination of Level-1 jet triggers and a minimum bias trigger for low- p_T jets, resulting in a trigger efficiency for b -jets of more than 98 %. Jets are reconstructed using the anti- k_t algorithm [2] with a radius of $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$. Depending on the jet p_T , the systematic uncertainty on the jet energy scale varies between 5 % and 9 %, the reconstruction and selection efficiency of b -jets is above 99 % [3].

Jets originating from b - or $\bar{b}$ -quarks are identified by b -tagging algorithms. The lifetime of B hadrons of about 1.5 ps and consequently a typical flight time of a few millimetres leads to a jet topology with a displaced secondary vertex. The SV0 b -tagging algorithm [4] explicitly tries to reconstruct a displaced vertex by taking into account all particle tracks and muons associated to a jet. From those tracks, two-track vertices are built and merged into one common vertex. Two-track vertices compatible with the primary vertex or the radii of one of the three Pixel Detector layers are removed. From the common vertex, tracks contributing with a large χ^2 are iteratively removed, until the reconstructed vertex fulfils several quality criteria, e.g. the largest χ^2 contribution from any track is 7 or less and the invariant vertex mass is required to be less than 6 GeV.

The final output of the SV0 tagging algorithm is the signed decay length significance $L/\sigma(L)$, which is used as b -tagging weight, where L is the signed decay length and $\sigma(L)$ its error. The b -tagging weight distribution is shown in the Figure 1 (left) for three different kinds of jets: b -jets, c -jets and light flavoured jets. The b -tagging efficiency is determined in a sub-sample of the data, containing at least one muon with $p_T > 4 \text{ GeV}$ associated to a jet. Muons originating from B hadrons have a harder p_T^{rel} spectrum than non- b -jets, where p_T^{rel} is the momentum component perpendicular to the axis of an associated jet. Template p_T^{rel} spectra are created for b - and non- b -jets using simulated

data and fitted to the data using a binned maximum likelihood fit. The relative contributions of the templates in the fit correspond to the b -tagging efficiency, as shown in the Figure 1 (right) for events with $L/\sigma(L) > 5.72$. This cut corresponds to a b -tagging efficiency of 50% in simulated events and is also used in the cross section measurement. More details on the p_T^{rel} template fit method can be found in [5].

FIGURE 1. *Left:* The SV0 signed decay length significance $L/\sigma(L)$ for simulated events. *Right:* The result of a template fit to the p_T^{rel} distribution for jets with $40\text{ GeV} < p_T(\text{jet}) < 60\text{ GeV}$. Figures taken from [5].

MEASUREMENT OF THE b -JET PRODUCTION CROSS SECTION

The differential cross sections for inclusive b -jets in bins of jet transverse momentum p_T and rapidity y and for pairs of b -jets (dijets) in bins of the dijet mass M can be written as

$$\frac{d^2\sigma_b}{dp_T dy} = \frac{1}{\Delta p_T \Delta y} \frac{N_b \cdot \text{frac}_b}{\epsilon_{trig} \cdot \epsilon_{sel} \cdot \epsilon_{btag} \cdot \mathcal{L}} \times C, \quad \frac{d\sigma_{bb}}{dM} = \frac{1}{\Delta M} \frac{N_{bb} \cdot \text{frac}_{bb}}{\epsilon_{trig} \cdot \epsilon_{sel} \cdot \epsilon_{btag,bb} \cdot \mathcal{L}} \times C, \quad (1)$$

where N_b is the total number of b -jets tagged by the SV0 algorithm and frac_b is the fraction of true b -jets determined by applying a Monte Carlo template fit to the spectrum of the invariant mass of the secondary vertex. N_{bb} is the number of events with two b -jets and frac_{bb} is the fraction of events with two true b -jets, determined by a template fit of the sum of the two secondary vertices. ϵ_{trig} and ϵ_{sel} are the trigger and jet reconstruction efficiencies, ϵ_{btag} ($\epsilon_{btag,bb}$) is the b -tagging efficiency for b -jets (dijets) and $\mathcal{L}$ is the total integrated luminosity. Finally, C is a bin-by-bin unfolding correction applied to the cross section taking into account bin migrations between reconstructed jet p_T and the p_T of a truth jet containing a true B hadron. All above values have been measured in bins of p_T and y or in bins of the dijet mass M . The following measurements are compared to predictions from Pythia 6 and NLO calculations derived by POWHEG.

Figure 2 (left) shows the inclusive double-differential b -jet cross section as a function of p_T and $|y|$, in the range $20\text{ GeV} < p_T < 260\text{ GeV}$ and for $|y| < 2.1$. As Pythia is a leading-logarithmic parton power shower generator, it is not expected to get the normalisation correct [3], therefore the Pythia results are scaled by a factor of 0.52. While both cross sections from Pythia and POWHEG fall more quickly than the measured one, the model shapes are consistent with data within indicated uncertainties. The systematic uncertainty is dominated by the b -jet energy scale followed by uncertainties due to the determination of b -tagging efficiency and purity.

The ratio of b -jet to inclusive jet cross section is shown in the Figure 2 (right), again as a function of jet p_T and $|y|$. The b -jet fraction is underestimated by POWHEG by approximately 30 %, corresponding to about 1σ of the systematic uncertainty, whereas the Pythia predictions are closer to the measured ratio. As the jet scale uncertainty largely cancels in the ratio, the dominant uncertainties arise from b -tagging efficiency and purity determination.

Figure 3 shows the differential $b\bar{b}$ dijet cross section as a function of the dijet mass M . Both b -jets are required to have a transverse momentum of $p_T > 40\text{ GeV}$ and to be within $|y| < 2.1$ in order to be fully reconstructed. With the same scaling factor of 0.52, the measured data is well described by Pythia, whereas it can be seen, that POWHEG overestimates the $b\bar{b}$ cross section at lower dijet mass. The systematic uncertainty of this measurement is dominated by the determination of the b -tagging efficiency, followed by jet scale uncertainty.

FIGURE 2. Inclusive double-differential b -jet cross section (*left*) and ratio of b -jet to inclusive jet cross section (*right*) as a function of jet p_T for different bins of rapidity. Data is compared to Pythia predictions (rescaled by a factor of 0.52) and to POWHEG. Figures taken from [3].

FIGURE 3. The $b\bar{b}$ dijet cross section as a function of the dijet mass M for b -jets with $p_T > 40 \text{ GeV}$ and $|y| < 2.1$, compared to Pythia (rescaled by a factor of 0.52) and POWHEG predictions. Figure taken from [3].

CONCLUSION

The differential inclusive and dijet cross section of b -jets has been measured at ATLAS using the SV0 b -tagging algorithm and compared to predictions of Pythia and with the NLO QCD calculations performed within a framework of the POWHEG generator. This paper was supported by the Austrian Ministry of Science and Research BM.WF and the Austrian Science Fund FWF project P22982. Copyright CERN for the benefit of the ATLAS collaboration.

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