Measurement of the cross-section for b-jets produced in association with a Z boson at $\sqrt{s} = 7$ TeV with the ATLAS detector

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A measurement is presented of the inclusive cross-section for b-jet production in association with a Z boson in pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV. The analysis uses the data sample collected by the ATLAS experiment in 2010, corresponding to an integrated luminosity of approximately 36 pb^{-1}.

The production of Z bosons in association with jets at hadron colliders has long been used as a testing ground for perturbative QCD (pQCD) calculations. Previous measurements of this process have been produced at the Fermilab Tevatron $p\bar{p}$ collider by the CDF and D0 collaborations. The production of one or more b-jets in association with a Z boson is a significant background to many important searches at the LHC, such as the Standard Model Higgs search, SUSY searches and searches for other physics beyond the Standard Model. A measurement of Z plus b-jets production therefore directly improves the understanding of this process, and consequently the ability to accurately model this background. In pp collisions Zb production can proceed via diagrams involving b-quark from the sea in the initial state or diagrams where a $b\bar{b}$ pair is explicitly produced in strong interactions. The measurement, discussed in full detail in [1], is compared to the next-to-leading order (NLO) calculation [2], implemented in the MCFM program, using massless b-quarks, with initial b-quarks taken from a b-PDF. MCFM is not interfaced to parton shower/hadronisation packages, and does not include multiple parton interaction (MPI), i.e. processes where the Z boson and b-jets are produced in two different parton-parton collisions in the same proton-proton interaction. The ALPGEN and SHERPA Monte-Carlo (MC) generators, implementing leading order (LO) calculations of this process using massive b-quarks and accounting for MPI, are used for the full simulation of the signal events, from parton shower and hadronization (emulated with the Herwig program) up to the detector response (with Geant4) for the determination of the acceptance and efficiency of the selection. The Z boson is identified by its decay into a pair of high transverse momentum, opposite sign electrons or muons, and the Z and b-jets are reconstructed within the allowed fiducial coverage of the detector. The inclusive cross-section for b-jet production in association with a Z boson, σ_b, is quoted per lepton channel, within this fiducial coverage.

The dominant background comes from Z + jets events, with the Z decaying into electrons, muons or tau leptons, where one jet is a *light* or c-jet which has been incorrectly tagged as a b-jet. These events are simulated using the same generators as the signal. Other background processes considered include $t\bar{t}$ pair production simulated by MC@NLO, $W(\rightarrow l\nu)$ + jets simulated by PYTHIA, $WW/WZ/ZZ$ simulated by ALPGEN, and single-top production simulated by MC@NLO.

The event selection is based on the search for a pair of good quality opposite sign electrons or muons with $p_T > 20$ GeV and $|\eta| < 2.4$ for muons, while $|\eta| < 2.47$ for electrons and with invariant mass of the lepton pair in the range $76 < m_{ll} < 106$ GeV. Jets are reconstructed from clusters of electromagnetic and hadronic calorimeter cells using an anti-k_t algorithm with a resolution parameter of 0.4. To avoid double-counting electrons and muons as jets, jets with $\Delta R < 0.5$ to either of the leptons coming from the Z pair are removed. Events are selected requiring at least one jet with $p_T > 25$ GeV and $|y| < 2.1$. A jet is considered as b-tagged if the SV0 algorithm reconstructs a secondary vertex from charged particle tracks contained within the jet and the decay length significance of this secondary vertex is greater than 5.85 (this requirement provides 50% efficiency for tagging b-jets in simulated $t\bar{t}$ events).

In addition, the invariant mass of the charged particle tracks from which the secondary vertex is reconstructed – the SV0-mass – will be used to extract the b-jet fraction on a statistical basis. Table 1 gives the number of data events selected by the consecutive stages of the analysis.

In Fig. 1 the e^+e^- invariant mass distribution for events with at least one jet with $p_T > 25$ GeV and $|y| < 2.1$ b-tagged by the SV0 algorithm.

The jets that are b-tagged by the SV0 algorithm still contain *light* and c-jets. The yield of b-jets

Electron channel		Muon channel	
Criterion	Events	Criterion	Events
2 sel. e	10558	2 sel. μ	13691
Z mass	9230	Z mass	12222
≥ 1 jet	1597	≥ 1 jet	1987
≥ 1 b-tag	64	≥ 1 b-tag	67
$= 1$ b-tag	62	$= 1$ b-tag	63
$= 2$ b-tag	1	$= 2$ b-tag	4
$= 3$ b-tag	1	$= 3$ b-tag	0

Table 1
The number of events selected at various stages of the analysis event selection.

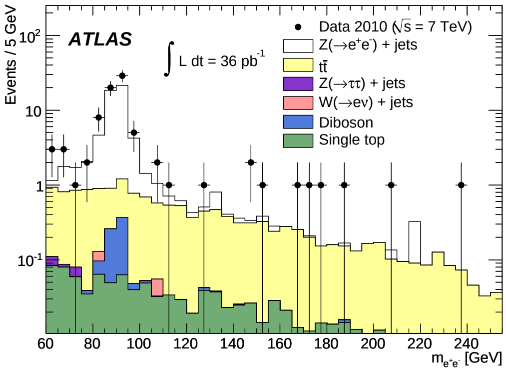

Figure 1. e^+e^- mass distribution for events with at least one b-tagged jet with p_T> 25 GeV and $|y| < 2.1$. The contribution estimated from the simulated MC samples of the signal and various background processes is shown. The small multi-jet background, estimated with a data-driven method, is not shown here.

is thus calculated on a statistical basis, by fitting the expected contributions to the SV0-mass distribution. For the electron and muon channels, templates are obtained from the simulation for the SV0-mass spectrum of each contribution: signal Z + b-jets, Z + *light* jets, Z + c-jets, and all other background processes ($t\bar{t}$, multi-jet, single-top, W + jets, $Z \to \tau^+\tau^-$ and diboson). As the templates for the electron and muon channels are compatible, these channels are treated together and both types of events are entered into one SV0-mass distribution. This spectrum is subjected to a likelihood fit, consisting of a sum containing the fixed contributions of the other background processes and a floating amount of Z + b, Z + *light*, and Z + c-jets. In order to validate the fit procedure, we performed fit closure and linearity tests using pseudo-experiments. In each pseudo-experiment, SV0-mass distributions are constructed using the templates with the same number of events as in the data and varying proportions of the b-jet template, then the fit procedure is performed. The results of teh fit on data give: $N_b = 63.6^{+14.7}_{-13.2}$, $N_c = 59.9^{+13.4}_{-14.0}$ while the other backgrounds, fixed in the fit, are estimated to contribute to 14.5 jets and the light jet contribution is estimated to be compatible with zero.

The particle-level cross-section, σ_b, is defined by the following cuts: for the leptons p_T> 20 GeV and $|\eta| < 2.5$ and di-lepton mass in the range $76 < m_{ll} < 106$ GeV; jets, reconstructed from stable particles using the anti-k_t algorithm with resolution parameter of 0.4 and including muons and neutrinos, must satisfy p_T> 25 GeV, $|y| < 2.1$ and distance from the leptons from Z decay $\Delta R < 0.5$. At particle-level, a jet is considered to be a b-jet if there is a b-hadron with $p_T > 5$ GeV within $\Delta R < 0.3$ of that jet, and only weakly-decaying b-hadrons are considered.

The per lepton channel cross-section is obtained from the experimental measurements using the following formula: $\sigma_b = N_b/(C_e\mathcal{L}_e + C_\mu\mathcal{L}_\mu)$ where N_b is the number of b-jets extracted from the fit to the SV0-mass distribution of b-tagged jets, C_e and C_μ are the acceptance factors for the electron and muon channels respectively, and $\mathcal{L}_e$ and $\mathcal{L}_\mu$ are the respective integrated luminosities for each channel. The C_e and C_μ acceptance factors are determined from the simulated MC samples of the signal process, and correspond to the probability that a particle-level b-jet in a Z event as defined above passes all of the jet and Z event selection criteria at the detector-level. The result $\sigma_b = 3.55^{+0.82}_{-0.74}(\text{stat})^{+0.73}_{-0.55}(\text{syst}) \pm 0.12(\text{lumi})$ pb is found to be in agreement within uncertainties with the prediction from MCFM 3.88 ± 0.58 pb computed using CTEQ6.6 parton distribution functions after correcting for for lepton final state radiation, parton/jet correspondence, underlying event and multiparton interactions, using events from particle-level LO simulations.

The systematic uncertainties affecting the measurement arise both the determination of the acceptance and the modeling of the SV0-mass distribution for b,c and light jets. The main sources of systematic errors are the b-tagging efficiency, the jet energy scale, the modeling of the p_T spectroum of the b-jets and the lepton reconstruction efficiency. In all cases they are evaluated by assessing the disagreement between MC espectations and direct measurements on data.

A similar measurement has recently being produced by the ATLAS experiment by studying b-jets produced in association with a W boson [3].

REFERENCES

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