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 of the inclusive total 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 was published [1] by the ATLAS experiment with the 2010 data set, corresponding to an integrated luminosity of about 35 pb^{-1}. An extension of such measurement with the whole statistics of data available at $\sqrt{s} = 7$ TeV is being prepared for publication these days. It provides measurements of various differential cross sections related to the final state with a Z boson and at least one b-jet. Since the measurements are close to be released by the collaboration we refrain from presenting here final results, but we discuss the theory predictions that are available for comparison with the data. The rather large differences between predictions will clearly show the relevance of the forthcoming measurement which will be affected by a total relative experimental uncertainty between 10 and 15%. The analysis is documented in the ATLAS internal documents [2] and [3] where an extensive list of references is given.

A next-to-leading order prediction is obtained from MCFM using the five-flavor MSTW2008 PDFs. MCFM is a parton level pQCD calculation, with partons clustered into jets in the final state, which allows event generation for a flexible implementation of the kinematic requirements defining a fiducial signal. In this case, leptons and jets are required to have $p_{\mathrm{T}} > 20$ GeV and to be produced at $|\eta| < 2.5$ and $|y| < 2.4$, respectively. In addition, the di-lepton invariant mass has to be in the range $76 - 106$ GeV. Lepton-jet overlap removal criteria are applied consistently with the particle level selection and the jets are accepted as b-tagged if they match a b-parton according to the same criteria applied to B hadrons. The MCFM Monte Carlo capability is exploited to obtain a break-down of the predicted cross section, passing the acceptance requirements, into the various intervals of the differential distributions measured in data.

Another theory prediction with a NLO accuracy of the matrix element but based on the four-flavor calculation scheme has been considered for comparison to the data: the aMC@NLOMC with PDF set MSTW2008(N)LO_nf4 . A set of 10^6 parton-level simulated events representing Zbb production in pp collisions at $\sqrt{s} = 7$ TeV has been produced using the same values of the factorization and renormalization scales of the MCFM predictions and consistent values of the electroweak parameters. No kinematic cuts have been applied at generator level to the b-partons, which are treated as massive. As a consequence the sample is, in principle, suitable to describe the $Z + b$ inclusive data sample, as well as the Zbb sample. Events from aMC@NLO need to be showered in order to predict physical observables. The showering, performed with the HERWIG++ MC, brings, as extra benefit, the resummation to all orders of many classes of large logarithms that appear in the cross section. The generator used for the showering allow the emulation of fragmentation, hadronization, hadron decays, secondary partonic interactions overlaid to the main scattering (multi-parton interactions, MPI) and final state radiation from leptons.

The aMC@NLO generator has been used also to produce a sample of 5×10^6 events with lepton pairs and at least one jet, using a five-flavor calculation scheme in the mass-less approximation for the b-quark. The choice of the PDF set and the setting of the dynamic scales have been done in such a way to ensure coherence with the fixed order MCFM prediction. Showering, fragmentation, hadronization and MPI have been obtained with HERWIG++ .

The estimate of the theory uncertainty obtained with MCFM is expected to represent correctly the theory uncertainty on the predictions from aMC@NLO, because the two calculations are performed at the same perturbative order, using the same PDF set and the same values for the factorization and renormalization scales.

In addition to the NLO generators, the LO multi-leg Monte Carlo ALPGEN and SHERPA , implementing respectively the four-flavor and five-flavor number schemas, have been compared to data. The ALPGEN prediction has been obtained using the ATLAS fully simulated samples. A custom production of events has been run with SHERPA 1.4.1, using the CT10 PDF set. In the SHERPA multi-parton Monte Carlo both matrix element and parton shower can lead to b-jet production in the final state and all overlaps are internally removed.

Cross section (fb)	MCFM(mstw2008) × Corr.	aMC@NLO Zbb (4f)	aMC@NLO Zj (5f)
$\sigma(Zb)$	$5230 \pm 33(stat) + 685 - 709(syst)$	3394 ± 18	4679 ± 36
$\sigma(Zb) \times N_{b-jet}$	$5463 \pm 36(stat) + 735 - 743(syst)$	3906 ± 20	5010 ± 37
$\sigma^{\star}(Zb) \times N_{b-jet}$	$4331 \pm 33(stat) + 401 - 479(syst)$	3286 ± 18	4225 ± 35
$\sigma(Zbb)$	$413 \pm 8(stat) + 57 - 58(syst)$	485 ± 7	314 ± 9

Cross section (fb)	PDF	MCFM	stat.error	α_s error		R_f, R_μ error		pdf-error		Corr. error
$\sigma(Zb)$	MSTW2008	5230	33	+106	-142	+666	-687	+121	-99	+109
$\sigma(Zb) \times N_{b-jet}$	MSTW2008	5463	36	+122	-147	+715	-722	+116	-97	+111
$\sigma^{\star}(Zb) \times N_{b-jet}$	MSTW2008	4331	33	+103	-145	+376	-449	+92	-78	+63
$\sigma(Zbb)$	MSTW2008	413	8	+10	-22	+56	-54	+7	-6	+7
$\sigma(Zb)$	CT10	4854	26	+60	-108	+550	-651	+141	-147	106
$\sigma(Zb) \times N_{b-jet}$	CT10	5073	30	+63	-112	+613	-683	+131	-136	110
$\sigma^{\star}(Zb) \times N_{b-jet}$	CT10	4028	31	+51	-87	+321	-424	+105	-107	59
$\sigma(Zbb)$	CT10	386	4	+18	-13	+49	-45	+15	-15	6
$\sigma(Zb)$	NNPDF23	5424	19	+69	-89	+647	-691	-89	+89	109
$\sigma(Zb) \times N_{b-jet}$	NNPDF23	5664	32	+71	-88	+700	-726	-79	+79	113
$\sigma^{\star}(Zb) \times N_{b-jet}$	NNPDF23	4491	26	+55	-68	+361	-444	-62	+62	65
$\sigma(Zbb)$	NNPDF23	423	9	+16	-11	+64	-49	-6	+6	7

Cross section (fb)	SHERPA	ALPGEN	PYTHIA
$\sigma(Zb)$	3770.0 ± 7.7	2581.1 ± 6.8	3331.5 ± 2.6
$\sigma(Zb) \times N_{b-jet}$	4208.4 ± 8.0	2924.0 ± 7.2	3696.1 ± 2.8
$\sigma^{\star}(Zb) \times N_{b-jet}$	3642.9 ± 7.3	2376.9 ± 5.8	3197.9 ± 2.6
$\sigma(Zbb)$	421.6 ± 2.3	316.9 ± 1.8	356.1 ± 1.4

Table 1
Theory predictions for the total fiducial cross sections in comparison. All predictions are at particle level, hence MCFM is corrected for non-perturbative QCD effects (fragmentation and multi-parton interactions) and QED radiation effects. Errors from the MC statistics are quoted for all generators. For MCFM the sum in quadrature of all systematic theory uncertainties discussed in the text is also reported in the top table, while the breakdown into the various components is shown in the middle table for a few choices of the PDF set. The notation $\sigma(Zbb)$, $\sigma(Zb)$, $\sigma(Zb) \times N_{b-jet}$ and $\sigma^{\star}(Zb) \times N_{b-jet}$ are used to refer to the Zbb and Zb inclusive cross section, to the b-jet cross section in events with at least one b-jet and to the b-jet cross section in events with at least one b-jet and Z transverse momentum greater than 20 GeV.

The NLO theory predictions discussed above need to be corrected before being ready for a comparison with data. The data measurements are defined based on a particle-level signal definition quite close to the experimentally accessible observables, therefore, cannot be directly compared to the parton-level MCFM prediction. In addition, the signal definition does not try to disentangle the cross section from independent production of Z and $b(b)$ from two parton interactions in the same pp scattering, that will be referred as double parton interactions (DPI), from the processes where the $Zb(b)$ final state is produced in a single parton scattering.

A comparison of the theory predictions for total cross sections corresponding to the two selections, inclusive cross section of b-jet produced in association with Z (per b-jet and per event) and Zbb cross section (per event), are summarized in table 1. The prediction on the inclusive Zb cross section from aMC@NLO appears very sensitive to the flavor-number scheme adopted in the calculation. The prediction based on the 5-flavor number schema agree with the MCFM-based prediction within -10.5%, -8.3% and -2.5% respectively for $\sigma(Zb)$, $\sigma(Zb) \times N_{b-jet}$ and $\sigma(Zb)^{\star} \times N_{b-jet}$, corresponding to deviations of $-4.6\sigma, -3.7\sigma$ and -1.3σ. The differences observed can be ascribed to the different ways the predictions are extracted out of a NLO matrix element: the MCFM parton-level prediction is corrected for the non-perturbative effects with a custom procedure while the aMC@NLO matrix element is matched to a parton-shower program which allows also the modeling of the non-perturbative effects. In addition, there are subtle differences in the implementation of the matrix element calculation related to the tretement of the b-quark mass.

In conclusions, theory predictions have been prepared for comparison with fortcoming data. The data precision will give some quantitative indications on the most accurate prediction in terms of total rate and shape of the kinematic variables.

REFERENCES

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