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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The 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}. A much more detailed study of this final state has been carried out during 2012 and 2013 leading to a results published during spring 2014 [2] based on a data set of 4.6 fb^{-1} collected during 2011 in pp collisions at $\sqrt{s} = 7$ TeV.

The production of a Z boson with at least one b-jet or at lest two b-jets are interesting processes predicted by the Standard Model of particle physics. The theoretical predictions of the total and differential cross sections for these processes depend on several non trivial problems affecting the corresponding QDC calculation, among them the b-mass treatement in the parton shower (PS) and in the matrix element (ME) and the description of the b-content of the proton. The Zb and the the Zbb final states are reached through a different processes and therefore they test the predictions on different complementary aspects. The inclusive Zb production is particularly interesting because it is a b-initiated process and therefore it is useful for the study of the compatibility of the two calculation techniques which implement the description of the b-quark as an intrinsic proton constituent (5-flavor number schema, 5FNS) or describe the initial state proton as produced by the splitting in $b\bar{b}$ of a gluon from the proton (4-flavor number schema, 4FNS). The predictions for Zbb production are not sensitive to the choice of FNS, since the leading subprocesses do not involve a b-quark in the initial state, but depend on the modeling of gluon splitting to $b\bar{b}$ in ME and PS.

State-of-the-art generators and tools have been used to derive theory predictions for the observables measured by ATLAS. They are: MCFM, implementing fixed order calculations based on NLO ME both for Zb and Zbb on 5FNS in the mass-less b-quark approximation, aMC@NLO providing particle-level predictions by merging the PS from Herwig++ to NLO matrix elements (two ME have been used a NLO ME for Zbb in 4FNSN with a complete treatment of the b-quark mass and a NLO ME for Z+jet in 5FNS and in the massless b-quark approximation) and the multi-parton LO Monte Carlo ALPGEN and

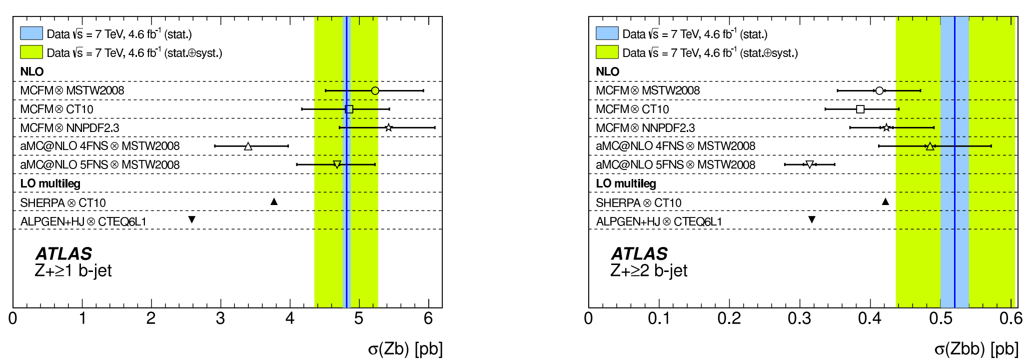

Figure 1. Cross-sections for (left) Z+≥1b-jet, and (right) Z+≥2b-jets. The measurement is shown as a vertical blue line with the inner blue shaded band showing the corresponding statistical uncertainty and the outer green shaded band showing the sum in quadrature of statistical and systematic uncertainties. Comparison is made to NLO predictions from MCFM interfaced to different PDF sets and aMC@NLO interfaced to the same PDF set in both the 4FNS and 5FNS. The statistical (inner bar) and total (outer bar) uncertainties are shown for these predictions, which are dominated by the theoretical scale uncertainty calculated as described in the text. Comparisons are also made to LO multi-legged predictions from ALPGEN+HERWIG+JIMMY and SHERPA; in this case the uncertainty bars are statistical only, and smaller than the marker.

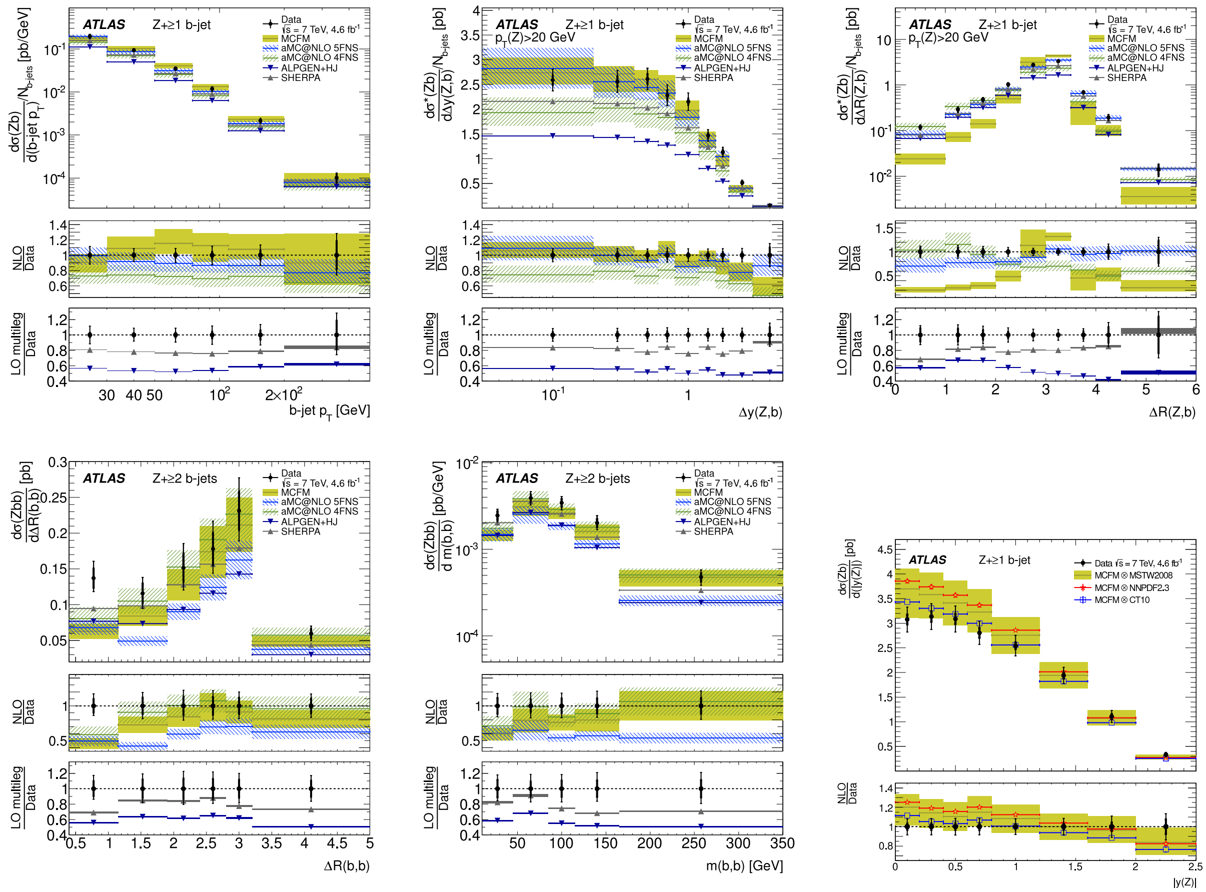

Figure 2. Differential cross sections for the Z+≥1b-jet (top); from left to right, the measured distributions of the following kinematic variables are shown: the b-jet transverse momentum, the absolute difference in rapidity and the distance $\Delta\mathrm{R}(\mathrm{Z}, \mathrm{b}-\mathrm{jet}) = \mathrm{sqrt}(\Delta\phi^2 + \Delta\mathrm{y}^2)$ between the Z boson the b-jet of highest p_T in the event. Differential cross sections for the Z+≥2b-jets (bottom, left and center) as a function of the separation between the two b-jets, $\Delta\mathrm{R}(\mathrm{b}, \mathrm{b})$, and of the invariant mass of the two b-jets. The bottom-right plot shows the rapidity distribution of the Z boson in the inclusive Z+≥1b-jet selection, superimposed with the predictions from MCFM interfaced to three different sets of NLO Parton Density Functions.

SHERPA with jet multiplicities up to 5 and 4 respectively. The features of these generators have been described in a contribution to the 2013 Activity Report and are extensively discussed and referenced in [3] and [4] along with the strategy of the ATLAS measurement. The measured total fiducial cross sections, compared to theory predictions, are shown in Fig.1 for Zb (left) and Zbb (right).

The predictions from the leading order generators fail to describe data since they are reported without applying any correction for the missing higher order contributions (k-factors). Its interesting to notice that NLO predictions from MCFM and from aMC@NLO in 4FNS are in agreement with the measurement of the Zbb production cross section within experimental errors. In particular, the aMC@NLO 4FNS provides the best description of the data for the Z+≥2b-jets selection. It is expected to describe well also the Z+≥1b-jet cross section, but the prediction is this case is more than two experimental standard deviations lower than the measurement. On the other hand, aMC@NLO in 5FNS and MCFM, in spite of the mass-less b-quark approximation, successfully predict the rate of inclusive Zb production, suggesting the relevance of the terms resummed in the DGLAP approach when a PDF for the b-quark is used. These measurements, therefore, provide and handle to clarify the role and equivalence of the flavour number schema used of the theory predictions for b-initiated processes.

In Fig.2 several differential cross sections are shown both for the Z+≥1b-jet and the Z+≥2b-jets selection. In general, the shape of the kinematic variables is well predicted by the generators, with a few expected exceptions. The angular variables, in particular, cannot be well modelled by fixed order predictions which do not foresee final state multiplicity above the value dictated by the perturbative order of the calculation; therefore the ϕ distributions of partons is not well reproduced; this is reflected for example in the $\Delta\mathrm{R}(\mathrm{Z},\mathrm{b})$ distribution reported in 2. An interesting distribution is, in the case of the Z+$\geq$2b-jets selection, the $\Delta\mathrm{R}(\mathrm{b},\mathrm{b})$ (bottom left of Fig. 2) where an excess of data over theory is observed, suggesting a bad modelling of the gluon splitting to $b\bar{b}$. The plot at the top bottom shows the rapidity distribution of the Z boson in events whet are least one b-jet is observed compared with MCFM interfaced to three different sets of parton density functions: MSTW2008, NNPDF2.3 and CT10. The difference in the central value for the prediction induced by the choice of PDF set can be clearly seen, however it is small compared to the dominant theory error represented by the dependence of the prediction on the factorization and renormalization scales.

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