Measurements of beauty quark production at CMS

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The CMS collaboration has measured the production of b-quarks in pp collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV at the LHC. The measurement of the production cross section for Λ_b baryons are shown and results for jets containing b-quarks and for b-anti-b-pairs decaying into muons are compared to NLO QCD predictions.

1 Introduction

The production of b quarks in proton-proton collisions at the Large Hadron Collider (LHC) is expected to be dominated by gluon-fusion processes. With the center of mass energy of $\sqrt{s} = 7$ TeV, QCD based predictions of the production cross-sections are tested in a new kinematical regime. The CMS detector[1] is well equipped for b-physics in the central rapidity region, $|\eta| \lesssim 2.4$, with muon reconstruction and triggering as well as precise tracking and vertexing for b-tagging and excellent mass resolution. The running period in 2010 with relatively low instantaneous luminosity and negligible pile-up permitted data taking with low trigger thresholds and is very well suited for low p_T production cross section measurements. The single inclusive production of beauty quarks ($pp \to b + X$) has already been measured by CMS through the inclusive $b \to \mu X$ and fully reconstructed B mesons. In this note we present recent measurements of the inclusive b-jet cross section, $b\bar{b}$-pair production and differential cross sections for the production of the b-baryon Λ_b .

2 Inclusive b-jet production

The comparison of jet cross sections with theoretical predictions is less affected by details of the hadronization and decay than measurements based on identified hadrons. On the other hand, the calibration of the b-tagging efficiency introduces a sizeable systematic uncertainty.

The CMS collaboration has recently published two b-jet cross section measurements based on inclusive b-tagged jets and on b-tagged jets with muons[2]. The latter measurement is based on a data sample collected with a single muon trigger while the former is based on inclusive jet triggers. Both measurements reconstruct jets with the anti-kt jet-algorithm with radius parameter $R = 0.5$ applied identified objects (particle flow algorithm). Using simulated events, the reconstructed jet energy is corrected to the corresponding "generator-level" jet by applying the same anti-kt algorithm to all stable particles produced by the event generator. The fraction of events with b-quarks in the samples is increased by b-tagging, requiring the presence of a secondary vertex with a minimum number of tracks and separation from the primary collision vertex.

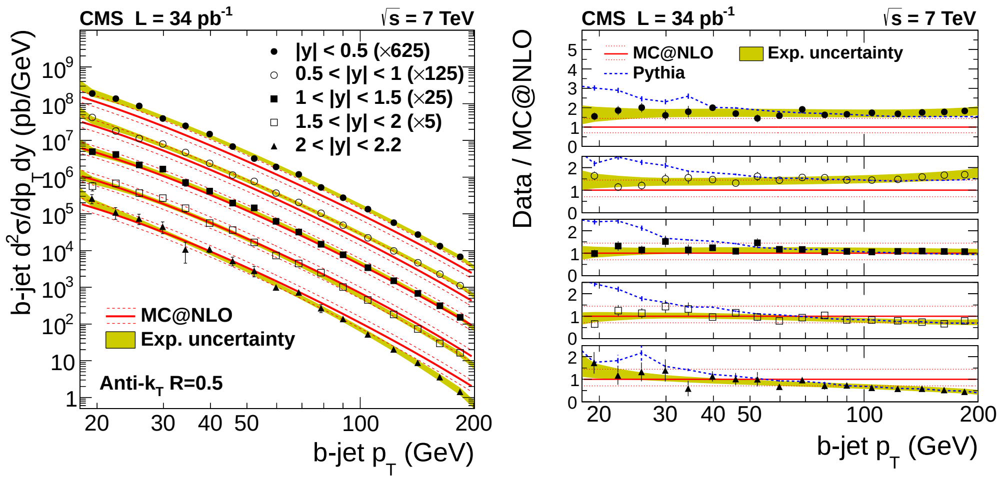

Figure 1: Differential b-jet cross section as a function of jet transverse momentum in five rapidity bins. The symbols with error bars are the measurement. The ratio of data divided by the MC@NLOprediction is shown on the right hand side, the five curves correspond to the rapidity bins from central (top) to forward (bottom).

The jet analysis uses 34 pb^{-1} of data collected in 2010 with a combination of minimum bias and jet triggers. A high purity b-tag requiring a secondary vertex with at least three tracks is used to reject non-b events. The tagging efficiency rises from 5% for the lowest jet transverse momenta (18 GeV) to 56% at 100 GeV The invariant mass of the tracks forming the secondary vertices is higher for jets with b-quarks than for lighter quark and gluon jets. The b-fraction of the tagged sample is determined is a function of jet transverse momentum from fitting the invariant vertex mass distribution with templates obtained from simulated events. The observed purity is of the order of 75%.

The muon analysis uses 3.0 pb^{-1} of data collected early in 2010 for which the muon trigger with a transverse momentum threshold of 9 GeV was not prescaled. The muon-event sample is already b-enriched and a lower purity version of the b-tagging requiring a two-track vertex is applied. This maintains a high tagging efficiency ranging from 50% at 30 GeV to 75% at 100 GeV jet p_T. Muon and b-tagged jet are accepted if their angular separation $\sqrt{\Delta\eta^2 + \Delta\phi^2}$ is 0.3 or less. The transverse momentum of the muon relative to the jet axis, p_T^{rel}, is on average higher for b–jets than for light jets. The b-fraction in the muon sample is determined by fitting the observed $p_T^{\rm rel}$ distribution with templates from simulated events. The cross section for b-jets with a muon with rapidity $|\eta_\mu| < 2.4$ and transverse momentum $p_T^\mu > 9$ GeV has been compared with predictions from PYTHIA and MC@NLO. Total rate and jet p_T spectrum are found to be in good agreement with the MC@NLO prediction. The shape of the rapidity distribution on the other hand is described better by PYTHIA, which overestimates the normalization. A similar observation was made in previous b-production measurements.

Figure (1) shows the double differential jet cross section obtained with the jet-based analysis. The MC@NLO prediction tends to lie below the data for central rapidities, but agrees within the theoretical uncertainties. At high rapidities, the slope of the p_T dependent cross section is not well described by MC@NLO. PYTHIA overestimates the cross section at low p_T but agrees well at high p_T.

The muon acceptance for a jet with rapidity $|\eta| < 2.2$ varies with jet p_T between 5% and 20 %. After correcting for this, the muon cross section is found to be consistent with the jet cross section integrated over rapidities. Both measurements lie above the MC@NLO prediction but are consistent with it within uncertainties.

3 Measurement of $\sigma(pp \to b\bar{b}X \to \mu\mu Y)$

The production of $b\bar{b}$ pairs in pp collisions has been inferred from the detection of lepton pairs from semileptonic b-hadron decays in 27.9 pb^{-1} of data collected with a dimuon trigger[3]. The backgrounds from single b-hadron decays producing two muons, $Z \to \mu\mu$, and Υ decays can be removed by appropriate cuts on the invariant mass, e.g. $m(\mu\mu) > 5$ GeV. Remaining source of muons are charm production (C), prompt muons (P) from Drell Yan events and muons from light hadron decaying to muons inside the detector (D). The precise measurement of the impact parameter of the muon with respect to the collision point, d_{xy}, permits separating these source because of the different lifetimes involved. A fit to the two-dimensional distribution $(d_{xy}(\mu_1), d_{xy}(\mu_2))$ is used to determine the b-fraction of a sample of muon pairs with both muons inside $|\eta| < 2.1$ and $p_T > 4(6)\, GeV$. The impact parameter template for prompt muons is measured in data, using Υ decays, while other templates are obtained from simulated events. The 1d projection of the fit result is shown in figure 2. The result is a very precise measurement with less than 10% systematic uncertainty, dominated by efficiency determination for finding the two muons: 25.7 ± 0.1 (stat.) ± 2.2 (syst.) ± 1.0 (lumi.) nb for $p_T > 4$ GeV and 5.03 ± 0.05 (stat.) ± 0.46 (syst.) ± 0.20 (lumi.) for $p_T > 6$ GeV. The corresponding MC@NLO predictions are 19.7 ± 0.3 (stat.) $^{+6.5}_{-4.1}$ (syst.) nb and 4.40 ± 0.14 (stat.) $^{+1.10}_{-0.84}$ (syst).

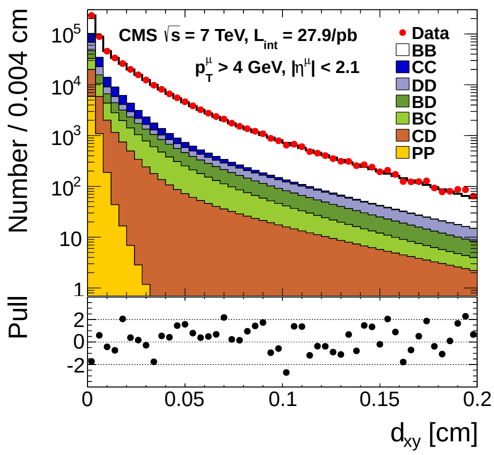

Figure 2: One-dimensional projection of the muon impact parameter fit. Points are data, the histograms show the templates for combinations of muons from b-decays (B) and other sources (see text).

4 Λ_b production

CMS has measured the production of the Λ_b baryon [4] through reconstruction of the decays $\Lambda_b \to \Lambda J/\psi$ followed by $\Lambda \to p\pi$ and $J/\psi \to \mu^+\mu^-$. The measurement is based on 1.9 fb^{-1} of data collected in 2011 using a displaced dimuon trigger. Clean samples of $J\psi$ and Λ candidates are obtained by requiring a good secondary vertex significantly displaced from the collision point. A total of 1252 ± 42 (stat. error only) signal events is found on top of a low background. The rates of $\bar{\Lambda}_b$ and Λ_b are in good agreement with each other, taking into account the expected reconstruction efficiency is 15% lower than for $\bar{\Lambda}_b$ because of the different nuclear interactions of anti-protons.

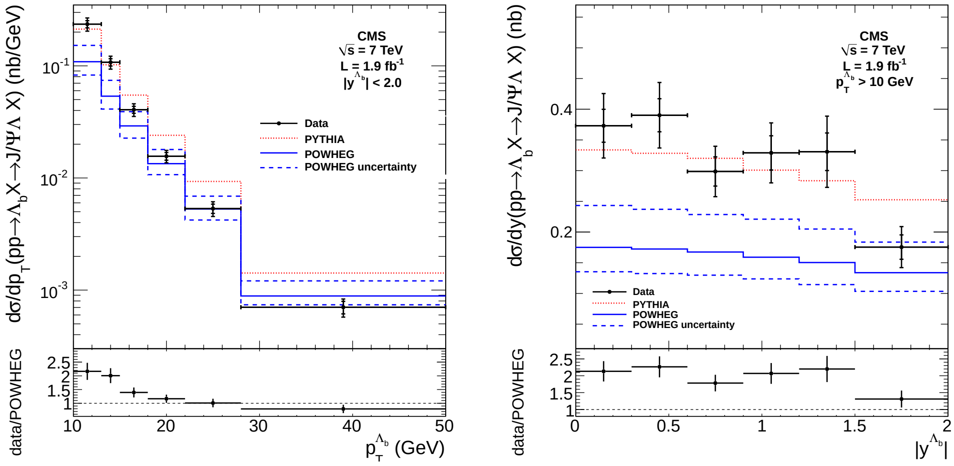

Figure 3: Differential Λ_b cross sections times branching fractions. Error bars and theoretical uncertainties do not contain the contribution from the branching fractions (e.g. 54% from $BR(\Lambda_b \to \Lambda J/\psi)$). The shape of the rapidity distribution (right) is well described by theoretical predictions, while the cross section falls faster as a function of p_T than predicted. The small figures at the bottom show the ratio of the data and POWHEG prediction.

The cross section is found to have a steeper p_T dependence than predicted by calculations. It is also found to be softer than the measured B-meson spectra in a similar pseudorapidity range.

5 Conclusion

Recent CMS results on b-production in pp collisions at $\sqrt{s} = 7$ TeV have been reported and compared with QCD predictions. The NLO-QCD Monte Carlo MC@NLO tends to underestimate inclusive production cross sections but is generally in agreement within the large theoretical uncertainties. The the shape of the rapidity distributions at low p_T and the p_T distribution of jets at high rapidity are not well described. The production of Λ_b baryons has been measured and the p_T spectrum is found to be steeper than predicted and steeper than for B mesons.

6 Bibliography

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