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Associated production of heavy flavors and W, Z bosons at CMS

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Abstract. The mechanism of production of heavy-flavoured jets, originated by the hadronization of b or c quarks, in association with vector bosons, W or Z, in the Standard Model is of primary importance. The study of events with one or two well-identified and isolated leptons accompanied by b-jets or displaced secondary vertices is therefore crucial to refine the theoretical calculations in perturbative QCD, as well as validate associated predictions from simulation. The understanding of these processes is furthermore required by Higgs and Beyond the Standard Model searches with similar final states. Using the LHC proton-proton collision data collected at a center of mass energy of 7 TeV by the CMS detector, measurements of the W+b, W+c, Z+b and Z+B hadrons cross sections are presented, comparing experimental data with several theoretical predictions in quantum chromodynamics.

1. Introduction

The associated production of vector bosons V (V=W,Z) and heavy flavoured quarks (HF) in proton-proton collisions at LHC is of prime interest in the physics program of the CMS experiment [1]. This process is important for several physics aspects. First of all in perturbative QCD (pQCD) studies, where direct measurement on the quark content of the proton and parton density functions (PDF) can be made through the measurement of the production cross sections. The prediction in pQCD for the strange quark content of the proton can be probed by the W+c production, and the different interpretation of the b quark density inside the proton can be tested in the Z+b measurements. Higher order pQCD effects can also be studied. From the Standard Model point of view, the W, Z + heavy flavours production allows to understand the background component in the associated production of the Higgs boson together with a vector boson. Furthermore, many Beyond the Standard Model searches (such as supersymmetric bottom partners, new Higgs bosons, 4^{th} generation of heavy quarks) have a similar topology with respect to the V+HF production, and thus the control on their backgrounds might be highly improved by means of these measurements.

2. W+b and W+c differential cross section at 7 TeV

2.1. Associated production of W boson and c quarks

The W+c production in proton-proton collisions allows to directly probe the strange quark content of the proton. The cross section measurement is made with an integrated luminosity of 5 fb^{-1} with a center of mass energy of 7 TeV [2]. The selection is made by requiring an isolated lepton (electron, muon) with high momentum (p_T) within the pseudorapidity (η) of $|\eta|<2.1$ coming from a W boson

decay. The c-jets are reconstructed exploiting the decays of charmed mesons and reconstructing the displaced secondary vertex of the charm quark. The transverse momentum of the c-jet is then required to be greater than 25 GeV in the pseudorapidity range of $|\eta|<2.5$. Selected events are then combined with the integrated luminosity and the efficiency for the leptons and jets identification in order to give the cross section, after the background subtraction. Results are compared to the theoretical predictions of the next-to-leading order event generator MCFM [3]. Several PDF sets have been used including MSTW08 [4], CT10 [5], NNPDF23 [6]. The main systematic uncertainty for this measurement comes from the jet energy scale. Results for the combination of electron and muon final states are presented in Fig.1, showing good agreement between measured data and the theoretical predictions. The measured cross section shows no discrepancy between data and the theoretical predictions of the different strange quark and anti-quark parton distribution functions, which are probed at an energy significantly higher than those of the previous experiments.

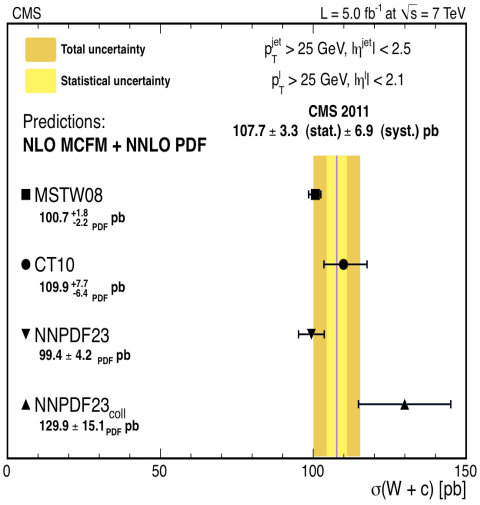

Figure 1. Comparison of the theoretical predictions for the W+c production cross section computed with MCFM and several sets of PDFs with the average of the experimental measurements, combining the electron and muon final states.

2.2. Associated production of W boson and b quarks

The production of W bosons in association with b quarks is studied using proton proton collisions at 7 TeV with the CMS experiment at the LHC [7] in a data sample corresponding to an integrated luminosity of 5.0 fb^{-1}. The W+b events are selected in the $W\rightarrow\mu\nu$ decay mode with a muon of $p_T > 25$ GeV and $|\eta|<2.1$, and exactly two b-tagged jets with $p_T > 25$ GeV and $|\eta|<2.1$. The measured particle-level cross section times the $W\rightarrow\mu\nu$ branching ratio is $0.53\pm 0.05(stat) \pm 0.10$ (sys) ± 0.01 (lumi) pb, in agreement with the Standard Model prediction. The cross section is unfolded to the level of final-state particles, and in the fiducial regime, requiring a muon with $p_T(\mu)>25$ GeV and $|\eta(\mu)|<2.1$ and exactly two particle jets, reconstructed using the anti-k_T jet algorithm with $\Delta R=0.5$ and with $p_T(bjet)>25$ GeV and $|\eta(bjet)|<2.1$, and each containing at least one b hadron with $p_T(B)>5$ GeV.
A correction factor to bring the hadron level to the level of final partons (before hadronization) is applied, computed with the MADGRAPH event generator [8]. The cross section is measured from the reconstructed objects unfolded to the level of final-state particles, corresponding to events with a muon and two particle jets matching the kinematic criteria defined above, requiring the particle jets to

be matched to b hadrons. The corrected cross section is compared to the NLO cross section calculated with the MCFM event generator. The NLO cross section computed with MCFM is 0.52 ± 0.03 pb. This cross section is evaluated using the MSTW2008 NNLO PDF set, and setting the renormalization and factorization scales to $\mu(F) = \mu(R) = m_W + 2m_b$.

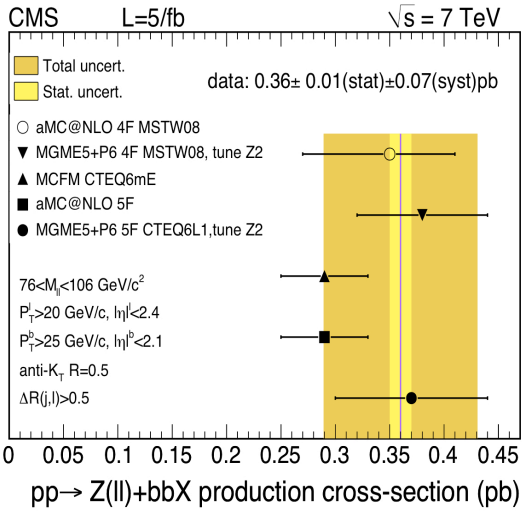

Figure 2. The inclusive Z+bb production cross section measurement compared with the theoretical expectations of the 4- and 5-flavour schemes tree level MADGRAPH calculations, the 5FS aMC@NLO, MCFM. Measurements are presented together with the relative statistical and statistical plus systematic uncertainty.

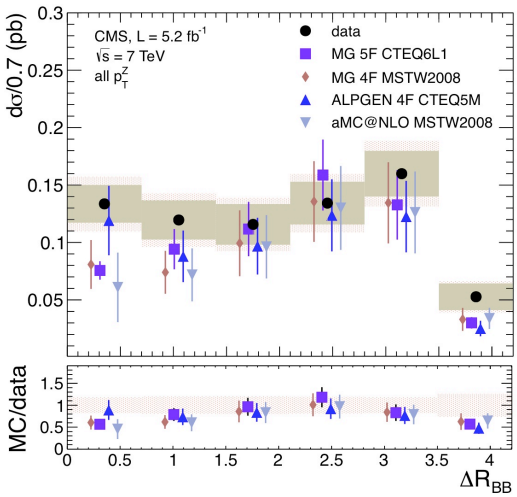

Figure 3. Differential Z+B hadrons production cross section as a function of the angular separation of the two B hadrons in the η-φ space, ΔR, compared with the 4- and 5-flavour schemes MADGRAPH event generator at tree level, aMC@NLO, ALPGEN 4FS.

3. Z+b and Z+B hadrons cross section at 7 TeV

3.1. Associated production of a Z boson and b jets

The production cross section for the process involving a Z boson decaying into two leptons (electrons and muons) in association with one or more b jets is measured in proton-proton collisions at a centre-of-mass energy of 7 TeV [9]. The data were recorded in 2011 data-taking with the CMS detector and correspond to an integrated luminosity of 5 fb^{-1}. The Z boson is selected from isolated, high momentum dilepton pairs in the invariant mass range of 76-106 GeV within the pseudorapidity range of 2.4. The b-jets are identified by means of a discriminator based on secondary vertex measurements and are selected if they have at least 25 GeV and pseudorapidity less than 2.1. The Z+b-jets cross sections are measured for a Z boson produced with exactly one or at least two b jets. The measured cross sections are compared to several theoretical predictions, and the data show better agreement with the 5-flavour scheme, where b quarks are assumed massless. The measured data are compared with the predictions from the tree-level calculation by MADGRAPH event generator rescaled to the next-to-next to leading order precision, with MSTW08 parton density function set using the PYTHIA parton shower simulation. The comparison with aMC@NLO [10] (both in the 4 and 5-flavour schemes) and MCFM event generators is also performed, using respectively MSTW08 and CTEQ6mE parton density function sets. Results are presented in Fig.2.

3.2. Associated production of Z boson and B hadrons

The inclusive and differential cross sections as function of the angular separation between B hadrons produced in association with a Z boson are measured in proton-proton collisions at a center of mass energy of 7 TeV using an integrated luminosity of 5 fb^{-1} [11]. The B hadrons are identified by means of their displaced secondary vertex only, which allows to study B-hadron pair production even at small angular separation. The differential cross section as function of the angular separation and as a function of the Z boson transverse momentum are compared to several calculations made at tree-level and NLO precisions. MADGRAPH in the 4- and 5- flavour schemes, ALPGEN and aMC@NLO in the 4-flavour scheme have been tested. The Z boson candidates are selected requiring two isolated charged leptons with high transverse momentum, making an invariant mass in the Z boson mass range, 81 to 111 GeV, and of two B hadrons with a transverse momentum greater than 15 GeV inside the pseudorapidity range of 2.0. The measurements of the differential cross section are presented in Fig.3, showing the comparison between measured data and the above mentioned theoretical predictions. The cross section result shows a discrepancy in the collinear region ($\Delta R<1$), which is dominated by diagrams $q \rightarrow ZbbX$, involving the contribution of the gluon splitting process initiated by a quark q. In this region only ALPGEN is able to describe data, while the other predictions underestimate the cross section.

Conclusions

Standard Model W, Z boson measurements in association with heavy flavours in LHC proton-proton collision at a center of mass energy of 8 TeV with the CMS experiment have been presented. Results on the W+c process cross section, W+b jets differential cross sections, Z+b jets and Z+B hadrons have been measured and compared with different theoretical expectation from several Monte Carlo generators and PDF tunings, up to the NNLO precision in perturbative QCD when available.

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