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Measurement of the transverse momentum distribution of Z bosons decaying to dimuons in pp collisions at $\sqrt{s}$ =8 TeV

SangEun Lee[a], Nadeesha Wickramage[b], on behalf of the CMS collaboration

[a] *Kyungpook National University*
[b] *Tata Inst. of Fundamental Research*

Abstract

A measurement of the transverse momentum distribution of Z bosons decaying to dimuons in pp collisions at $\sqrt{s}$=8 TeV is reported. The results are obtained using a data sample collected by the CMS experiment at the LHC, corresponding to an integrated luminosity of 18.4 pb^{-1}. An overall agreement with the theoretical predictions is observed, however no single model can reproduce the transverse momentum distributions over the whole accessible range.

Keywords: Z boson, transverse momentum, cross section

1. Introduction

The production of W and Z bosons in hadron collisions, which are typically identified through their leptonic decays, are very useful candles at the LHC. They are theoretically described very well within the framework of the standard model (SM). The total and the differential cross sections for the Drell–Yan process have been calculated up to the next-to-next-to-leading order (NNLO) in the perturbation theory [1, 2], providing one of the most accurate theoretical predictions of the SM which can be tested at the Large Hadron Collider (LHC).

At the LHC energies, a good fraction of the Drell–Yan ($q\bar{q} \rightarrow \ell^+\ell^-$) events have the dilepton system boosted in the transverse direction due to initial-state radiation and the underlying event activities accompanying the hard interaction. Consequently, the dilepton system has a non-zero component of the transverse momentum (q_T), which can be calculated using the gluon resummation or perturbative QCD techniques for low and high values of q_T respectively [3]. Thus, the measurement of the q_T distributions of the Z boson provides additional information about the dynamics of proton collisions at high energies. Since the underlying events affect the low q_T region a study of the spectrum towards the lower end helps in discriminating models with different parametrizations for the underlying event in proton-proton collisions. Similarly the higher end of the momentum distribution potentially indicates the need for accounting the higher order quantum corrections in the theoretical calculation.

At LHC, both the Compact Muon Solenoid (CMS) [4] and ATLAS experiments have reported measurements of the Z boson q_T spectrum at $\sqrt{s}$= 7 TeV [5, 6]. In this paper, we report a measurement of the q_T distribution of Drell-Yan process decaying into dimuons. The results are obtained using a data sample recorded by the CMS experiment at the LHC in 2012, corresponding to an integrated luminosity of 18.4pb^{-}. This dataset was recorded with a special LHC configuration of low instantaneous luminosity intended to provide data with a reasonably small number of multiple collisions, on an average 5, at each bunch crossing (pile up). Moreover, these beam conditions match with the experimental environment prevalent during the data taking period of 2010 where the average event pile up was also about 5. This allows a direct and interesting comparison between the results obtained at $\sqrt{s}$ =7 TeV and the ones at $\sqrt{s}$ =8 TeV. The dimuon mass is restricted in a mass range from 60 to 120 GeV. Restricting the dimuon mass around the Z range provides a clean sample of signal events with very little contamination from the background processes. A high efficiency low p_T single muon trigger was used in order to have a reliable description of the low q_T portion of the spectrum, which is dominated by single hard-gluon emission. The present measurement covers a large range in transverse momentum, up to several hundred GeV which is relevant in other interesting physics processes at LHC.

2. Results

The perturbative QCD calculations are expected to provide a reliable prediction for the higher end of the spectrum which is dominated by single and hard gluon emission. For the lower values of q_T the shape of the distribution is determined by multiple soft gluon radiations and other non-perturbative effects, which are simulated by MC generators through the combination of the parton showering and parametrized models of underlying events.

For the measurement of the differential q_T spectrum, the data are normalized to the cross section integrated over the acceptance region, $|\eta| < 2.1$ and $p_T > 20$ GeV for both muons. The measurement of the normalized differential cross section is displayed in Fig. 1 as a function of q_T. The theoretical uncertainty accounts for the dependence of the cross section on the factorization and the renormalization scales and CT10 PDF [7]. Comparisons have been made separately between the data and the predictions of the MADGRAPH [8] event generator with the Z2star tune [9] for underlying event modeling and Pythia 6 [10] for hadronization.

The low q_T region is affected by the underlying event activity in the hadronic collision which is a non-perturbative QCD processe modeled in PYTHIA in terms of few parameters. Several sets of values for these parameters, called "tunes", are available for the LHC, including the Z2star, P0 [11], D6T [12], and 4C [13]. The shapes predicted by PYTHIA with these tunes are compared to the measurement in Fig. 2, where the best data and theory agreement is achieved with PYTHIA Z2star.

In Fig. 3, the measured normalized differential distribution is compared to the prediction of POWHEG [14] as well as the "Fully Exclusive W, Z Production through NNLO in Perturbative QCD" (FEWZ) package version 3.1 [15] for $q_T > 20$ GeV and $|\eta| < 2.1$, calculated at $O(\alpha_s^2)$. The FEWZ calculation uses the effective

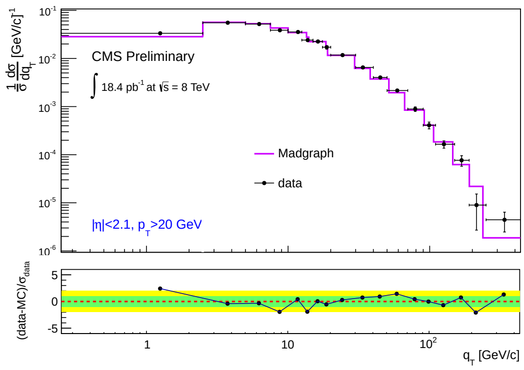

Figure 1: Data compared to MADGRAPH event generator interfaced with same Z2star tune. The uncertainties associated with the data correspond to the statistical and systematic uncertainties summed in quadrature. The horizontal lines indicate the bin boundaries and the data points are positioned at the average of the bins. The lower portion of the figure shows the difference between the data and the simulation predictions divided by the uncertainty (statistical and systematic) on the data, σ_{data}. The green (inner) and yellow (outer) bands are the ranges corresponding to $\pm1\sigma$ and $\pm2\sigma$ experimental uncertainties.

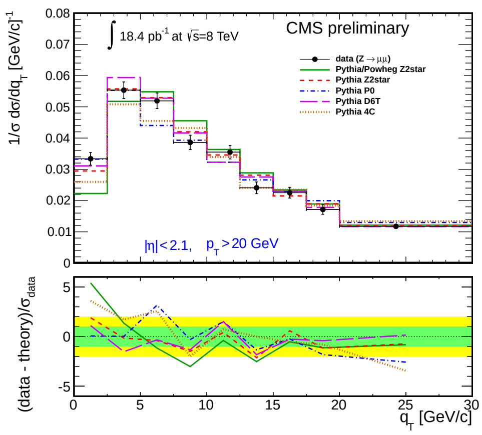

Figure 2: The transverse momentum distribution of the dimuon system from Z boson decay in data (points) compared with the predictions of various tunes in PYTHIA as well as of POWHEG interfaced with PYTHIA using the Z2star tune (green). The error bars on the points represent the statistical and systematic uncertainties summed in quadrature on the data and data points are positioned at the average of the entries in the bins. The lower portion of the figure shows the difference between the data and the simulation predictions divided by the uncertainty (statistical and systematic) on the data, σ_{data}. The green (inner) and yellow (outer) bands are the ranges corresponding to $\pm1\sigma$ and $\pm2\sigma$ experimental uncertainties.

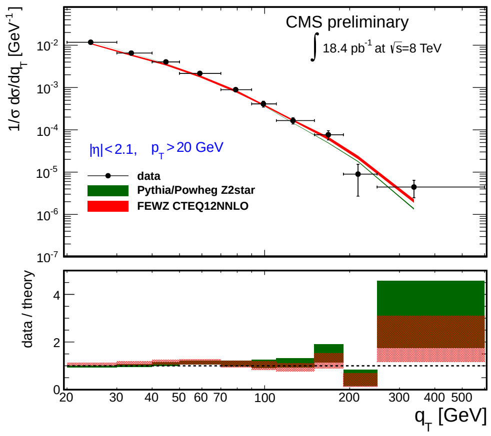

Figure 3: The normalized differential cross section of transverse momentum of the dimuon system from Z boson decay in data (points) compared with the predictions from POWHEG and FEWZ for $q_T > 20$ GeV. The horizontal lines indicate the bin boundaries and the data points are positioned at the average of the entries in the bins. The bands in the upper plot represent the uncertainty on the predictions from factorization and renormalization scales and PDFs. The lower plot shows the ratio between the data and the theory predictions. The bands in the lower plot represent one standard deviation range for combined theoretical and experimental uncertainties.

dynamic scale defined as $\sqrt{M_Z^2 + \langle q_T \rangle^2}$ rather than the fixed scale determined by the mass of the Z boson. At present the statistical uncertainty in data in the high q_T region is unable to discriminate different modeling of the hard-scatter.

3. Summary

A measurement of the shape of the differential cross section for the transverse momentum of the Drell–Yan muon pairs in the Z boson mass region between 60 and 120 GeV has been reported as a function of the dimuon transverse momentum within a restricted acceptance for the muons, $p_T > 20$ GeV and $|\eta| < 2.1$. The results are obtained using a data sample of proton-proton collisions collected by the CMS experiment at the LHC at a $\sqrt{s}$= 8 TeV recorded in the year 2012 with a dedicated LHC configuration meant for reasonably low number of multiple interactions per bunch crossing. The amount of data used here corresponds to an integrated luminosity of $18.4 pb^{-1}$. The measured transverse momentum distribution are compared to predictions based on Madgraph+Z2star, POWHEG+Z2star, Pythia+Z2star/P0/D6T/4C, and the FEWZ MC tool. The low momentum region discriminates the models of soft interaction including the showering scheme. Our results show only a moderate agreement between data and POWHEG PYTHIA Z2star for q_T below 20 GeV, whereas the description of PYTHIA with Z2star tune seem more satisfactory. On the high q_T side of the spectrum, we observe better agreement with the predictions from MADGRAPH generator. However, in the range of q_T beyond 100 GeV, the accuracy in data is not sufficient to significantly discriminate among available theoretical calculations of varying accuracy.

In conclusion, our study shows that the PYTHIA generator with Z2star tune is able to describe data well in low q_T region, while MADGRAPH predictions are in general good agreement with data at high q_T.

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