PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 79, No. 4
October 2012
pp. 937–940

Measurement of the Drell–Yan differential cross-section $d\sigma/dM$ at $\sqrt{s} = 7$ TeV

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Abstract. The Drell–Yan differential cross-section is measured in proton–proton collisions at $\sqrt{s} = 7$ TeV, from a data sample collected with the CMS detector at the LHC and corresponding to an integrated luminosity of 36 ± 1.4 pb^{-1}. The measured cross-section is normalized to the cross-section of the Z-peak region, for both dimuon and dielectron final state, in the dilepton invariant mass range of 15–600 GeV/c^2. The normalized cross-section values are quoted in the full phase-space and within the detector acceptance. The effect of final-state radiation is also studied and the measurements are correted for this. The measurements are compared to the theoretical predictions and are found to be in good agreement.

Keywords. Hadron–hadron collider; Drell–Yan; compact muon solenoid.

PACS Nos **12.15.−y; 13.85.Qk**

1. Introduction

The production of lepton pairs in hadron–hadron collisions via the Drell–Yan (DY) process is described in the Standard Model (SM) by the s-channel exchange of γ^*/Z. Theoretical calculations of the differential cross-section $d\sigma/dM_{ll}$, where M_{ll} is the dilepton invariant mass, are well established up to next-to-next-to-leading order (NNLO) [1–3]. Therefore, comparisons between calculations and precise experimental measurements provide stringent tests of perturbative quantum chromodynamics (QCD) and significant constraints on the evaluation of the parton distribution functions (PDFs). Furthermore, the DY process also forms an irreducible background to the search for physics beyond the SM in high mass lepton pairs. This means that in searching for new particles such as Z' for the indications of extra dimensions, the contribution of the DY process needs to be measured with high precision. We are presenting here the measurement of the differential DY cross-section in proton–proton collisions at $\sqrt{s} = 7$ TeV, based on dimuon and dielectron data samples collected in 2010 by the compact muon solenoid (CMS) experiment [4] at the Large Hadron Collider (LHC). The cross-section is calculated as

$$\sigma = \frac{N_{\mathrm{U}}}{A\mathcal{L}\epsilon\rho}, \tag{1}$$

DOI: 10.1007/s12043-012-0409-z; ***e*Publication: 6 October 2012**

where N_U is the unfolded background-subtracted yield, corrected for detector resolution. The values of the acceptance A and the efficiency ϵ are estimated from simulation, while ρ is a factor that accounts for the differences in the detection efficiency between data and simulation. The cross-section in each mass bin has been normalized to the cross-section of Z peak region ($60 < M_{ll} < 120$ GeV/c^2), and is independent of integrated luminosity. The details about the DY cross-section measurement can be found in ref. [5].

2. Event selection and backgrounds

The analysis presented in this paper is based on dilepton data samples selected by inclusive single-lepton triggers with p_T thresholds ranging between 9 and 15 GeV for muons and between 15 and 17 GeV for electrons, depending on the instantaneous luminosity. Muons passing the standard CMS muon identification and quality criteria [6,7], both fitting to a common vertex, with opening angle different from π by more than 5 mrad, are also required to pass an isolation requirement based on the relative transverse energy deposited in the HCAL and transverse momenta of tracks around each of the muons. Electron identification criteria based on shower shape and track-cluster matching are applied to the reconstructed candidates [8]. Isolation requirements are imposed on each electron, based on the relative transverse energy deposited in the ECAL and the HCAL and transverse momenta of tracks around each of the electrons.

The top quark pair and diboson processes are the dominant backgrounds at high dilepton invariant mass, while at invariant masses below the Z peak, DY production of $\tau^+\tau^-$ pairs becomes the dominant background. At low dilepton mass, QCD multijet events are the dominant background.

3. Results and discussion

The effects of the detector resolution on the observed dilepton spectra are corrected through an unfolding procedure. This procedure is sufficient in the analysis reported in this paper because the response matrix is non-singular and nearly diagonal. Two extra dilepton invariant mass bins are included in the unfolding procedure, to account for events observed with $M_{ll} < 15$ GeV or $M_{ll} > 600$ GeV. The unfolded spectra is then corrected for the geometric and kinematic acceptance A, defined using the simulated leptons after the final-state radiation (FSR) simulation, as $A = N_{acc}/N_{gen}$ where N_{gen} is the number of generated events and N_{acc} is the corresponding number of events passing the standard p_T and η lepton requirements, in each dilepton invariant mass bin. The DY cross-section σ_i per invariant mass bin has been calculated using eq. (1). In order to provide a measurement independent of the luminosity uncertainty and to reduce many systematic uncertainties, σ_i is normalized to the cross-section in the Z region, σ_{ll}, defined as the DY cross-section in the invariant mass region $60 < M_{ll} < 120$ GeV. The result of the analysis is presented as the ratio

$$R^i_{\text{post-FSR}} = \frac{N^i_U}{A_i * \text{FSR}_i} \Bigg/ \frac{N^{\text{norm}}_U}{A_{\text{norm}} * \text{FSR}_{\text{norm}}}, \tag{2}$$

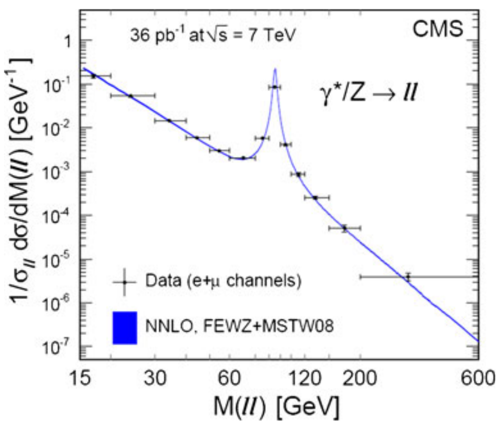

Figure 1. DY invariant mass spectrum, normalized to the Z resonance region, $r = (1/\sigma_{ll})(\mathrm{d}\sigma/\mathrm{d}M_{ll})$, as measured and as predicted by NNLO calculations, for the full phase-space. The vertical error bar indicates the experimental (statistical and systematic) uncertainties summed in quadrature with the theory uncertainty resulting from the model-dependent kinematic distributions inside each bin. The horizontal bars indicate bin sizes and the data points inside are placed according to ref. [9]. The width of the theory curve represents theoretical uncertainties which do not exceed few per cent.

where N_{U}^{i} is the number of events after the unfolding procedure and FSR_i is the correction factor to take into account the effect of final-state-radiation on the dilepton mass spectra. It has been calculated by dividing the invariant mass after FSR by the corresponding quantities before FSR. The acceptances A_i have been already defined earlier; $N_{\mathrm{U}}^{\mathrm{norm}}$, A_{norm} and $\mathrm{FSR}_{\mathrm{norm}}$ refer to the quantities in the Z peak region. The results are also normalized to the invariant mass bin widths, M_i, defining:

$$r_i = \frac{R_i}{\Delta M_i}. \qquad (3)$$

Assuming lepton universality, the dimuon and dielectron results for r_i are combined in a weighted average, using as weights the inverse of the respective squared total uncertainties, where the statistical and systematic uncertainties are added in quadrature. Figure 1 compares the measured (combined) results for the shape r with the prediction from the FEWZ NNLO calculations, performed with the MSTW2008 PDF set [9]. The measurements are very well reproduced by the theoretical calculations.

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