Analysis of $Z \to l^+l^-$ Polarization at CMS

Nhan Viet Tran on behalf of the CMS collaboration
Department of Physics and Astronomy, Johns Hopkins University,
3400 N. Charles St., Baltimore, MD 21218, USA

With approximately 35 pb^{-1} of LHC proton-proton collision data collected by CMS we study the Drell-Yan process $q\bar{q} \to Z \to l^+l^-$. Differential cross sections with respect to the invariant mass, rapidity, and transverse momentum are presented. The forward-backward asymmetry is measured as a function of the di-lepton invariant mass, and an analysis of the fully differential distribution leads to the measurement of the Weinberg weak-mixing angle.

1 Introduction

In the process $q\bar{q} \to Z/\gamma^* \to l^+l^-$, both the vector and axial vector couplings of electroweak bosons to fermions are present. In the Standard Model (SM), these couplings depend on the electroweak mixing angle, θ_W. This results in a forward-backward asymmetry, A_{FB}, in the number of Drell-Yan lepton pairs. In addition to being sensitive to the electroweak mixing angle, any deviation of the A_{FB} from the SM can be a sign of new physics from new gauge bosons, supersymmetry, or extra dimensions. The measurement of the A_{FB} can also improve QCD measurements and constrain Parton Distribution Functions (PDFs). The A_{FB} and $\sin^2\theta_W$ measurements by CDF[1] and D0[2] are given for reference. In addition to the traditional method of measuring $\sin^2\theta_W$ via the asymmetry, we also considering the measurement of the weak mixing angle via a multivariate likelihood analysis. Full information about the Drell-Yan process is parameterized as a function of the di-lepton rapidity Y, the di-lepton invariant mass m_{ll}, and the di-lepton decay angle θ^*_{CS} defined in the Collins-Soper frame[3] to reduce the effect of di-lepton transverse momentum.

The angular distribution for the Drell-Yan process is given in a simplified form as:

$$\frac{d\sigma}{d\cos\theta^*_{CS}} = A(1+\cos^2\theta^*_{CS}) + B\cos\theta^*_{CS} \tag{1}$$

Because the LHC is a pp collider, the quark direction is unknown and the definition of the Collins-Soper frame is defined using the boost direction of the di-lepton pair. This introduces a dilution of the asymmetric term since we can only determine the quark direction on a statistical basis. The forward-backward asymmetry is defined as

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} = \frac{3B}{8A} \tag{2}$$

where N_F (N_B) is the number of forward (backward) events. The A_{FB} is measured as a function of the di-lepton invariant mass where typically the slope of this quantity is sensitive to the electroweak mixing angle.

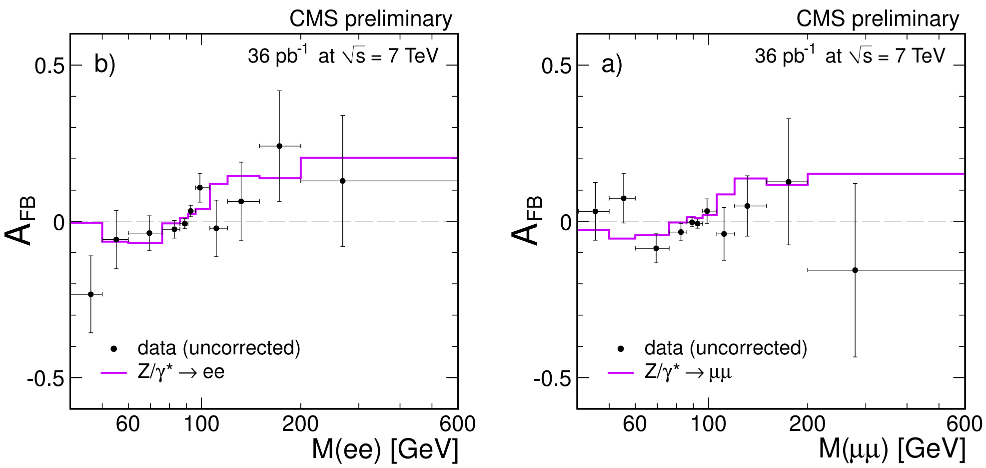

Figure 1: Uncorrected A_{FB} for the di-electron channel (left) and the di-muon channel (right).

Without applying any corrections, the uncorrected A_{FB} measurement is distorted from the original parton-level asymmetry because of bin-to-bin migration due to finite resolution of the detector and QED final state radiation (FSR). Moreover, the A_{FB} is further distorted by the detector acceptance and by the unknown quark direction at the LHC.

As an illustration of the multivariate analysis of the Drell-Yan process, we take the Standard Model description of electroweak interactions and PDFs in the proton as well-established and allow only the effective electroweak mixing angle θ_{eff} to be unconstrained, which is the same for both leptons and light quarks with the current precision of this analysis. We illustrate this method with analysis in the di-muon channel process. The choice of $\mu^+\mu^-$, as opposed to e^+e^- , is motivated by the simpler description of detector and background effects in this first study; however, we do not expect any limitation in the method for future application to other final states.

The formalism is built as an analytic description of the process at leading order where (next-to-)next-to-leading order effects are considered as corrections to the model. The description of the $pp \to Z/\gamma^* \to \mu^+\mu^-$ process is given by a probability distribution function of the triple differential cross-section in the observables , $P_{pp}(m_{ll}, Y, \cos\theta^*_{CS}; \sin^2\theta_{\text{eff}})$. This includes effects from PDFs, the partonic luminosity and the dilution, which requires an analytical parameterization of the PDFs. Then detector effects such as resolution and FSR, $R(m_{ll})$, and acceptance, $G(m_{ll}, Y, \cos\theta^*_{CS})$, are included such that we have the final description of the signal probability distribution function,

$$P_{sig}(m_{ll}, Y, \cos\theta^*_{CS}; \sin^2\theta_{\text{eff}}) = [P_{pp}(m_{ll}, Y, \cos\theta^*_{CS}; \sin^2\theta_{\text{eff}}) \times R(m_{ll})] \times G(m_{ll}, Y, \cos\theta^*_{CS}) \quad (3)$$

Information about the electroweak mixing angle is contained in the correlated three-dimensional shapes of the observables. The motivation for the introduction of the method is the improvement in statistical sensitivity; the increase in sensitivity is approximately 40% over traditional methods. Further details of the measurements of both A_{FB} and $\sin^2\theta_{\text{eff}}$ can be found in the public CMS results [4].

2 Measurement of A_{FB}

In these proceedings, we present the uncorrected A_{FB} vs. di-lepton mass and compare it to events generated with the POWHEG Next-to-Leading Order (NLO) generator and with detailed GEANT-based CMS simulation and reconstruction. Selection of both reconstructed electrons

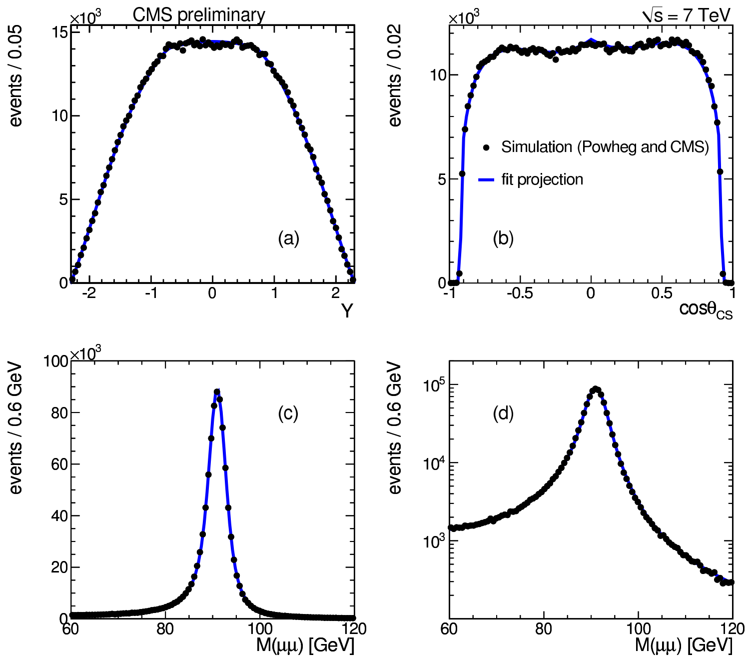

Figure 2: Projections of the fit model on simulation for the observables (a) rapidity, (b) $\cos\theta^*_{CS}$, and (c)/(d) di-lepton mass.

and muons require standard isolation and quality requirements which are detailed in the inclusive W and Z boson measurements at CMS [5]. The muons are required to have a $p_T > 20$ GeV and a pseudorapidity $|\eta| < 2.1$. The electrons are required to have an $E_T > 20$ GeV after energy scale corrections and $|\eta| < 2.5$ excluding the region from $1.442 < |\eta| < 1.560$. The uncorrected forward-backward asymmetry is given in Fig. 1 for the 2010 CMS dataset with an integrated luminosity of 36 pb^{-1}. The expectation from simulation is also given in Fig. 1; and for the given data sample, we observed agreement between the simulation and data.

3 Measurement of $\sin^2\theta_{\rm eff}$

For the measurement of $\sin^2\theta_{\rm eff}$, we perform a single parameter fit to extract the value of the electroweak mixing angle. The same isolation and quality requirements on the muons from the A_{FB} measurement are used. Looser phase space cuts are made in the Collins-Soper frame on the muons to increase sensitivity and accommodate the analytical acceptance, $p_T(CS) < 18$ and $|\eta|(CS) < 2.3$. In addition, there is a cut on the di-lepton transverse momentum to decrease contributions from next-to-leading order effects, $p_T(l^+l^-) < 25$ GeV. The fit value from simulation $\sin^2\theta_{\rm eff} = 0.2306 \pm 0.0004$ is in good agreement with the generated value $\sin^2\theta_{\rm eff}(\text{gen}) = 0.2311$. The fit result is shown in Fig. 2. In addition, we run 400 toy experiments and find the expected statistical error should be 0.0078. The pull distributions are found to be in good agreement with a unit Gaussian centered at zero.

The leading systematics come from the alignment and resolution model, the FSR modeling, and the PDF uncertainties. We also consider contributions from the LO model and initial state radiation, the fit model, and QCD background. The total systematic uncertainty is 0.0036 though these estimates are conservative and sometimes statistically limited. The total systematic uncertainty is less than the statistical errors.

With the CMS 2010 data sample of 40 pb^{-1}, we make a measurement of the weak mixing

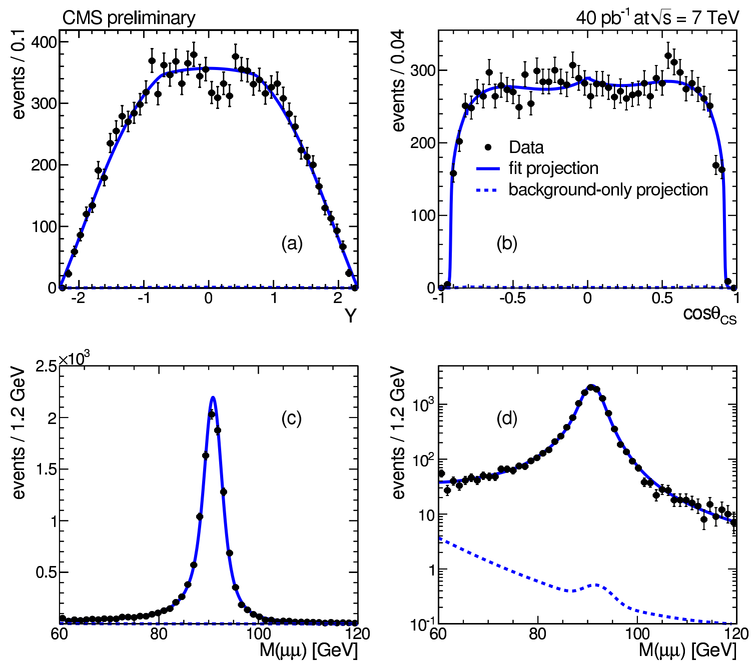

Figure 3: Projections of the fit model on CMS 2010 data for the observables (a) rapidity, (b) $\cos\theta^*_{CS}$, and (c)/(d) di-lepton mass.

angle. The fit value was kept blinded until evaluating all systematics and the final fit result is

$$\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0077(\text{stat.}) \pm 0.0036(\text{sys.}) \tag{4}$$

A final cross-check of the goodness-of-fit is found to be in agreement with simulation.

4 Summary

We have presented the measurement of the forward-backward asymmetry for the Drell-Yan process in pp collision at $\sqrt{s} = 7$ TeV. We have also presented the measurement of the effective electroweak mixing angle based on a multivariate likelihood fit which results in a value of $\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0077 \pm 0.0036$. We find both the A_{FB} distributions and the $\sin^2\theta_{\text{eff}}$ measurement to be consistent with the Standard Model predictions within uncertainties.

References

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