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Forward-backward asymmetry of Drell–Yan lepton pairs in pp collisions at $\sqrt{s} = 7\,\text{TeV}$

The CMS Collaboration[*]

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Abstract

A measurement of the forward-backward asymmetry (A_{FB}) of Drell–Yan lepton pairs in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ is presented. The data sample, collected with the CMS detector, corresponds to an integrated luminosity of $5\,\text{fb}^{-1}$. The asymmetry is measured as a function of dilepton mass and rapidity in the dielectron and dimuon channels. Combined results from the two channels are also presented. The A_{FB} measurement in the dimuon channel and the combination of the two channels are the first such results obtained at a hadron collider. The measured asymmetries are consistent with the standard model predictions.

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[*] See Appendix A for the list of collaboration members

The amplitude for the standard model (SM) Drell–Yan process $q\overline{q} \rightarrow Z/\gamma^* \rightarrow \ell^+\ell^-$ contains both the vector and the axial-vector couplings of electroweak bosons to fermions [1, 2]. The differential cross section can be written as

$$\frac{d\sigma}{d\cos\theta^*} = C\left[\frac{3}{8}(1+\cos^2\theta^*) + A_{\mathrm{FB}}\cos\theta^*\right] \tag{1}$$

for a given dilepton invariant mass, at leading order, where θ^* is the emission angle of the lepton (ℓ^-) relative to the quark momentum in the dilepton centre-of-mass frame. Forward and backward events are defined by $\cos\theta^* > 0$ and < 0, respectively, and the asymmetry parameter A_{FB} is defined as

$$A_{\mathrm{FB}} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}, \tag{2}$$

where σ_F and σ_B are the total cross sections for forward and backward events. Within the SM, the parameters C and A_{FB} depend on the vector and axial-vector couplings of the quarks and leptons to the Z boson and on the electric charge of the fermions.

The Drell–Yan cross section is modified by higher-order quantum chromodynamic (QCD) and radiative electroweak corrections. The electroweak corrections are negligible except near the Z peak. At dilepton masses near the Z peak, A_{FB} is predicted to be small because of the small value of the lepton vector coupling in the SM, and is sensitive to the electroweak mixing parameter $\sin^2\theta_{\mathrm{W}}$. Our measurement of $\sin^2\theta_{\mathrm{W}}$ with a maximum-likelihood fit technique based on a smaller data set was reported in Ref. [3]. Above and below the Z peak, A_{FB} exhibits a characteristic energy dependence governed by virtual photon and Z interference. Deviations from the SM prediction for A_{FB} may indicate the existence of particles beyond the standard model [4–11]. For example, a new gauge boson Z' is expected to cause A_{FB} to approach zero at the mass of the Z'. Studying A_{FB} at high mass is particularly useful in a search for resonances that might be missed by a search using the dilepton mass spectrum alone.

To study the forward-backward asymmetry, we use the Collins–Soper frame [12], in which θ^*_{CS} is defined to be the angle between the lepton momentum and the axis that bisects the angle between the direction of one proton and the direction opposite to the other proton in the centre-of-mass frame of the dilepton. Use of this frame reduces the uncertainties due to the unknown transverse momentum of the incoming quarks. The sign of the longiudinal boost of the dilepton system is used to define the orientation of the Collins–Soper frame. The angle θ^*_{CS} is calculated from quantities measured in the lab frame as

$$\cos\theta^*_{\mathrm{CS}} = \frac{Q_z}{|Q_z|}\frac{2(P_1^+P_2^- - P_1^-P_2^+)}{|Q|\sqrt{Q^2+Q_T^2}}, \tag{3}$$

where Q is the four-momentum of the dilepton and Q_T and Q_z are the transverse and longitudinal components of the dilepton momentum with respect to the beam axis; P_1 (P_2) represents the four-momentum of the lepton (antilepton); and $P_i^{\pm} = (P_i^0 \pm P_i^3)/\sqrt{2}$. The quark direction is not determined a priori at the Large Hadron Collider (LHC) [13] because both beams consist of protons. However, because the antiquark is necessarily a sea quark, on average we expect it to carry less momentum than the valence quark, and therefore the dilepton system is usually boosted in the direction of the valence quark [5, 14, 15]. This assumption is taken into account by including the sign of the longitudinal boost in the definition of $\cos\theta^*_{\mathrm{CS}}$.

The raw A_{FB} measurement is distorted compared to the parton-level asymmetry, mainly because of the dilepton mass resolution of the detector and final-state electromagnetic radiation

(FSR). The asymmetry is further distorted by the detector acceptance and diluted by the imperfect knowledge of the quark direction at the LHC. In this Letter we present the raw A_{FB} and compare it to reconstructed $Z/\gamma^* \to \ell^+\ell^-$ Monte Carlo (MC) events. We also unfold the A_{FB} measurements to the electroweak vertex (Born level), taking into account the FSR, mass resolution, and other detector effects. The results are not corrected for the dilution effects due to the acceptance and unknown quark direction because such corrections require information that is not directly observable.

This analysis is based on a data sample of $5\,\mathrm{fb}^{-1}$ collected with the Compact Muon Solenoid (CMS) detector in 2011 at a centre-of-mass energy of 7 TeV. A detailed description of the CMS detector can be found in [16]. The central feature of the CMS detector is a 3.8 T superconducting solenoid of 6 m internal diameter. The silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL), and the brass/scintillator hadron calorimeter are located inside this solenoid. Muons are measured in the pseudorapidity window $|\eta| < 2.4$ using the tracker and the muon system, which is instrumented with detection planes of three complementary technologies embedded in the steel return yoke of the magnet: drift tube chambers (DT), cathode strip chambers (CSC), and resistive plate chambers (RPC) [17]. Pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$, where the polar angle θ is measured with respect to the anticlockwise-beam direction. The DT technology is used in the barrel ($|\eta| < 1.2$), and CSC in the endcaps ($0.9 < |\eta| < 2.4$). These are complemented by an RPC system that covers both regions up to $|\eta| < 1.6$. Electrons are detected as energy clusters in the ECAL and as tracks in the silicon tracker. The ECAL consists of nearly 76 000 lead tungstate crystals, which provide coverage in pseudorapidity $|\eta| < 1.5$ in the barrel region and $1.5 < |\eta| < 3.0$ in the two endcap regions.

The signal ($\mathrm{Z}/\gamma^* \to \mu^+\mu^-, \mathrm{e}^+\mathrm{e}^-$) and the $\mathrm{Z} \to \tau\tau$ process, which is considered as a background in this analysis, are simulated using POWHEG at next-to-leading order (NLO). Parton showering is simulated using PYTHIA v6.4.24 [18] with tune Z2, while the NLO parton distribution function (PDF) is CT10 [19]. The W+jets and $\mathrm{t\bar{t}}$ background events are generated using MADGRAPH [20] and PYTHIA; the TAUOLA package is used to describe τ decays [21]. Event samples of WW, WZ, ZZ, and QCD multijet backgrounds are generated using PYTHIA. The generated events are processed with the GEANT4-based [22, 23] CMS detector simulation and reconstructed with the same software as the collision data. The signal MC samples include pileup conditions (multiple pp interactions occurring in the same bunch crossing) matching those observed in the 2011 data sample.

For data taken in the earlier part of 2011, the dimuon analysis is based on triggers that select events containing at least two muons, each with transverse momentum p_{T} of at least 6 or at least 7 GeV, depending on the running period. For the later running period, the triggers select events containing two muons, one with $p_{\mathrm{T}} > 13\,\mathrm{GeV}$ or $17\,\mathrm{GeV}$ and the other with $p_{\mathrm{T}} > 8\,\mathrm{GeV}$. Within a CSC or DT muon chamber, the hits in the multiple detection layers are fitted to a straight line representing a segment of the muon track. In the offline analysis, tracks reconstructed from hits in the silicon tracker are matched to tracks reconstructed from muon segments alone, and then the individual hits in the tracker and muon detectors are refitted to an overall track. In addition, to increase the acceptance for low momentum muons that may not penetrate deeply into the muon system, tracks from the silicon tracker are extrapolated into the muon system and any that match at least one muon chamber track segment are taken to be muon candidates. In both cases, multiple scattering and energy loss are taken into account as muons traverse the CMS detector. Well-reconstructed muons are selected by requiring (1) at least 10 hits in the tracker, including at least one in the pixel detector; (2) at least one segment in the muon system; (3) a normalized $\chi^2 < 10$ for the overall muon fit (if used); and (4) a transverse distance of closest approach to the beam axis of less than 2 mm. Cosmic ray muons that traverse CMS close to the interaction point can appear as back-to-back dimuons, but these are removed by requiring the muons to have an acollinearity greater than 2.5 mrad. Each muon is required to be isolated from other charged tracks based on tracker information alone. No attempt is made to use radiated photons detected in ECAL to correct muon energies for FSR. The unfolding procedure corrects for the effect of FSR on A_{FB} on a statistical basis. More details on muon reconstruction and identification can be found in Ref. [24]. Trigger efficiency factors are calculated and applied for different data-taking periods. Each muon is required to be within the acceptance of the muon system ($|\eta| \leq 2.4$) and have $p_{\mathrm{T}} > 20\,\mathrm{GeV}$. Events are selected in which opposite-charge muon pairs meet the above requirements.

Dielectron candidates are selected online by requiring two ECAL clusters, each with transverse energy E_{T} exceeding a threshold value. Offline reconstruction of electrons starts by building superclusters in the ECAL in order to collect the energy radiated by bremsstrahlung in the tracker material, following the procedure described in Ref. [25]. A specialized tracking algorithm is used to accommodate changes of curvature due to bremsstrahlung. Superclusters are then matched to electron tracks. Electron candidates are required to have a minimum supercluster E_{T} of $20\,\mathrm{GeV}$ after ECAL energy-scale corrections. Electrons are restricted to the same phase space as the muons, defined by $p_{\mathrm{T}} > 20\,\mathrm{GeV}$ and $|\eta| < 2.4$, for an unambiguous comparison and combination of the two channels. In order to avoid the inhomogeneous response at the interfaces between the ECAL barrel and endcaps, electrons are further required to fall within the pseudorapidity ranges $|\eta| \leq 1.44$ or $1.57 < |\eta| < 2.40$. Electrons are identified by means of shower shape variables, and electron isolation criteria are based on a variable that combines the tracker and calorimeter measurements. Electrons arising from photon conversions are suppressed by requiring that there be no missing tracker hits before the first hit on the reconstructed track matched to the electron, and also by rejecting a candidate if it forms a pair with a nearby track that is consistent with a conversion. More details on electron reconstruction and identification can be found in Ref. [26]. Energy scale, resolution, and efficiency factors are calculated and applied for different data-taking periods. Energy scale and resolution factors are derived using χ^2 tests, taking the MC dielectron mass distribution as a constraint. Events are selected in which opposite-charge electron pairs meet the above requirements.

For both lepton channels, the main sources of background are $\mathrm{Z} \to \tau\tau$ and QCD dijets for the low mass region and $\mathrm{t\bar{t}}$ for the high mass region. Diboson (WW, WZ, and ZZ) and inclusive W production processes are lesser sources of background. Because some QCD jets can pass the electron identification criteria, the QCD background contribution is non-negligible in the dielectron channel below the Z peak. Electroweak backgrounds are estimated using MC samples. For both channels, QCD background is estimated from the data under the assumption that same-sign and opposite-sign electron pairs are equally probable because the misidentification of a charged particle in a jet as a lepton or antilepton is equally likely. For both channels, backgrounds are estimated for forward and backward events separately and subtracted bin by bin. The total background contribution to the data ranges from 0.17% to 0.21% in the dimuon channel and from 0.68% to 0.80% in the dielectron channel.

All results are given in the phase-space region defined by $p_{\mathrm{T}}(\ell) > 20\,\mathrm{GeV}$ and $|\eta(\ell)| < 2.4$. We calculate the $\cos\theta^*_{\mathrm{CS}}$ distributions in ten bins of dilepton mass M and four bins of rapidity $|y|$, the limits of which are defined to be $M = 40, 50, 60, 76, 86, 96, 106, 120, 150, 200$, and $2000\,\mathrm{GeV}$ and $|y| = 0, 1.00, 1.25, 1.50$, and 2.40. Rapidity is defined as $y = \frac{1}{2}\ln[(E + Q_z)/(E - Q_z)]$, where E and Q_z refer to the energy and the third component of the momentum of the dilepton, respectively.

The forward-backward asymmetry is diluted by the events in which the assumed quark and antiquark directions are incorrect. The asymmetry is further reduced by the acceptance requirements. No corrections are applied for either of these effects. The $|y| < 1$ bin has the largest asymmetry dilution due to the unknown quark direction, but the smallest acceptance effect. The next two bins, $1.00< |y| <1.25$ and $1.25< |y| <1.50$, have the largest asymmetry. The highest rapidity bin, $1.50< |y| <2.40$, is least affected by the unknown quark direction but suffers a large acceptance reduction resulting in a smaller asymmetry compared to other $|y|$ bins.

To correct for FSR, mass resolution, efficiencies, and other detector effects, we unfold the forward and backward mass spectra in each $|y|$ bin. The unfolding procedure is performed using a matrix inversion technique [27]. The unfolding is performed with response matrices that provide a mapping between the corrected and measured numbers of events in each mass and rapidity bin:

$$N_j^{\text{meas}}(F,k) = \sum_{i=1}^{10} R_{ji}^{FF}(k)\, N_i^{\text{corrected}}(F,k) \left[\begin{array}{l} j = 1,\ldots,10 \\ k = 1,\ldots,4 \end{array} \right. \tag{4}$$

$$N_j^{\text{meas}}(B,k) = \sum_{i=1}^{10} R_{ji}^{BB}(k)\, N_i^{\text{corrected}}(B,k) \left[\begin{array}{l} j = 1,\ldots,10 \\ k = 1,\ldots,4 \end{array} \right. . \tag{5}$$

In these equations, $N_j(F,k)$ and $N_j(B,k)$ refer to the number of forward (F) and backward (B) events within the acceptance ($p_T > 20\,\text{GeV}$ and $|\eta| < 2.4$) in each mass bin j for the rapidity bin k; $R_{ji}^{FF}(k)$ is the response matrix describing the transfer of forward events from generated mass bin i to observed mass bin j, while $R_{ji}^{BB}(k)$ is the response matrix for the backward events. We construct the response matrices for unfolding the reconstructed forward and backward mass spectra in each $|y|$ bin to the Born level. The response matrices are calculated using MC events before and after simulation of FSR and the detector effects. Therefore they account for the FSR and mass resolution as well as the efficiency within the detector acceptance. In the dielectron channel, the gap in ECAL in the pseudorapidity range of $1.44< |\eta| <1.57$ is treated as an inefficiency and corrected by the unfolding procedure. The response matrices that represent the forward generated but backward reconstructed events (and vice versa) have a negligible contribution and are not used in this study, but the effect of this approximation is taken into account in the systematic uncertainties. The unfolded values are obtained by inverting the above equations. The corresponding uncertainties are calculated taking into account the correlations due to the unfolding procedure. The estimated uncertainties are verified by applying the procedure to a large number of independent MC samples. These MC samples are also used to check whether there is a bias in the A_{FB} values obtained through unfolding, and the maximum difference in A_{FB} is found to be 0.03.

Systematic uncertainties are estimated in each M-$|y|$ bin using MC events for both the raw and the Born level analyses. All systematic uncertainties are assumed to be independent and are combined in quadrature.

Although the background is small in the Drell–Yan process, uncertainties in the background estimation lead to systematic errors in the final results. We take a conservative approach and assume that this small background is uncertain by 100%, and therefore scale the background up and down by 100% and repeat the analysis. The largest difference from the nominal A_{FB} is found to be 0.09 in the highest mass bin, which contains the fewest number of events. The systematic uncertainty in the background estimate in all other bins is smaller than 0.005.

To quantify possible systematic uncertainties that could arise from the modelling of FSR in PYTHIA, we examine the events that show the largest change in lepton momentum pre- and post-radiation. The PYTHIA description of FSR agrees with data to within ±5%, so we reweight by ±5% the events for which the difference of the momenta of a lepton pre- and post-radiation is larger than 1 GeV. The distributions obtained from the reweighted events are used to obtain new values for A_{FB}. Even such a large change in event weights results in a change in the value of A_{FB} of less than 0.002, except in the highest mass bin for which the change is 0.022. These changes in the value of A_{FB} are assigned as systematic uncertainties arising from uncertainty in the modelling of FSR.

The systematic uncertainties that could arise from imperfections in the detector alignment are studied using MC samples with different assumed tracker reconstruction geometries (basic distortions) based on the cylindrical symmetry of the tracker system [28]. The differences between the A_{FB} values obtained with the ideal geometry and the other scenarios are evaluated. For each M-$|y|$ bin, the maximum difference calculated using the different geometries is taken as the alignment uncertainty. The bins around the Z peak have the largest uncertainties, ranging up to 0.061 in A_{FB}.

In the dielectron channel, the uncertainties obtained from the χ^2 minimization used to obtain the energy-scale and resolution factors are used to modify the energy scale and hence calculate the associated uncertainties. In the dimuon channel, no energy scale or resolution factors are applied, but to account for a possible scale uncertainty the energy scale is changed by 0.1% and the analysis is repeated. The resulting mass shift is found to be negligible. The largest systematic uncertainty due to energy scale and resolution in both channels is found to be 0.019 in A_{FB}.

The trigger efficiency uncertainties are estimated by comparing the results before and after trigger scale factors are applied for both channels. The uncertainties due to pileup are estimated by comparing results with different pileup multiplicity profiles for both channels. The efficiency uncertainties are found to be smaller than 0.005 and the pileup reweighting uncertainties smaller than 0.026 in A_{FB}.

The resulting total experimental systematic uncertainty is at most 0.09 in A_{FB}; however, for most of the bins the total experimental uncertainty is less than 0.02.

The total experimental systematic uncertainty does not include the PDF or α_s uncertainties. To determine these, we follow the recommendation of the PDF4LHC working group [29, 30]. At the NLO level, the recommendation is to reweight a sample generated with the CT10 PDF set [19, 31] to obtain samples that mimic the NNPDF2.1 [32] and MSTW2008 [33] PDFs. The internal degrees of freedom of each PDF set are varied. Samples corresponding to different $\alpha_s(M_Z)$ assumptions are obtained in a similar manner. The value of A_{FB} is calculated in each M-$|y|$ bin for each variation. The resulting variations in A_{FB} are combined to obtain the PDF uncertainty, following the PDF4LHC prescription. The largest uncertainty is found to be 0.012.

The measured and expected raw A_{FB} values, plotted versus M in each $|y|$ bin, are shown in Fig. 1 for the dimuon channel and in Fig. 2 for the dielectron channel. The raw A_{FB} distributions are calculated using background-subtracted data and are not unfolded for detector effects and FSR. They represent independent measurements with independent experimental systematic effects. The unfolded and combined A_{FB} distributions at the Born level are displayed in Fig. 3. The reversal of sign near the Z peak is due to the change of sign of the Z-γ^* interference term. All these distributions are in agreement with the SM expectations and there is no indication of non-SM physics.

In summary, we have presented a measurement of the forward-backward asymmetry A_{FB} for opposite-charge lepton pairs produced via an intermediate Z/γ^* at $\sqrt{s} = 7\,\mathrm{TeV}$ in the CMS experiment, based on a sample of pp collisions corresponding to an integrated luminosity of 5 fb^{-1}. The asymmetry is studied as a function of the dilepton rapidity and the dilepton mass M for $M > 40\,\mathrm{GeV}$. The raw asymmetries for both dimuons and dielectrons and the unfolded and combined measurement at the Born level are presented. We find both the raw and the unfolded A_{FB} distributions to be consistent with the standard model predictions. The A_{FB} measurement in the dimuon channel and the combination of the two channels are the first such results obtained at a hadron collider.

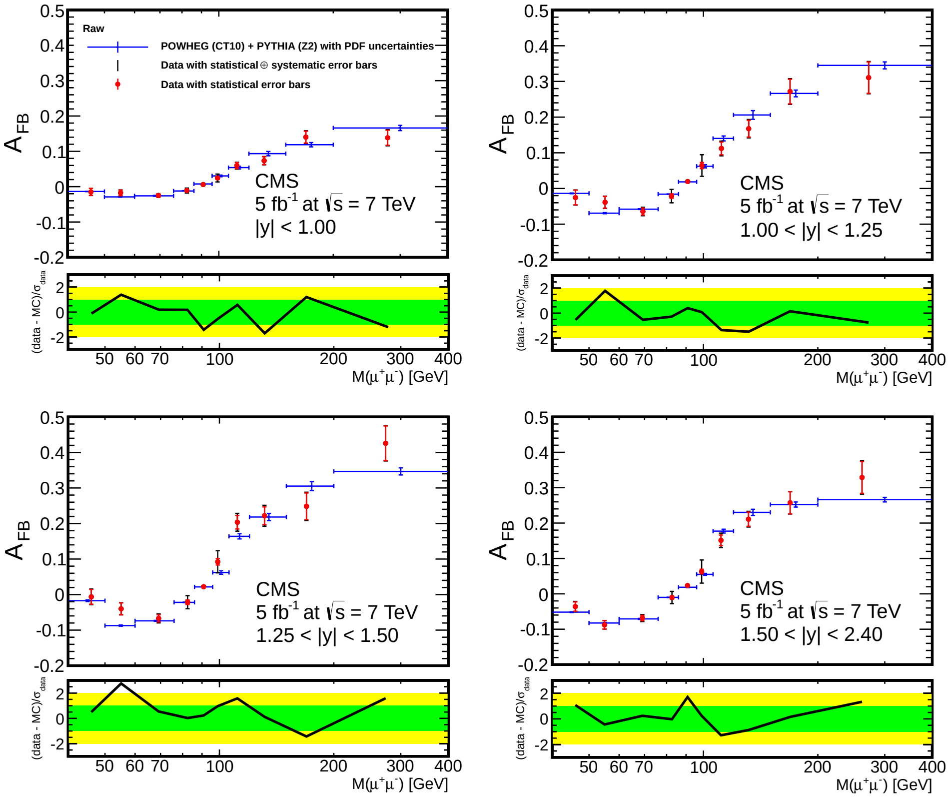

Figure 1: The raw A_{FB} measurement in the dimuon channel in four $|y|$ bins for $p_{\mathrm{T}}(\mu) > 20\,\mathrm{GeV}$ and $|\eta(\mu)| < 2.4$. The data points are shown with both statistical error bars and combined statistical and systematic error bars. The error bars on the MC points are the PDF uncertainties. The MC statistical errors are of the same order of magnitude as the PDF uncertainties. The horizontal extent of the error bars indicates the bin width (except for the last bin, which is truncated at 400 GeV). Beneath each plot is shown the difference between data and MC, normalized by the combined statistical and systematic uncertainty. The green and yellow bands indicate the 1σ and 2σ differences between the data and the theoretical predictions.

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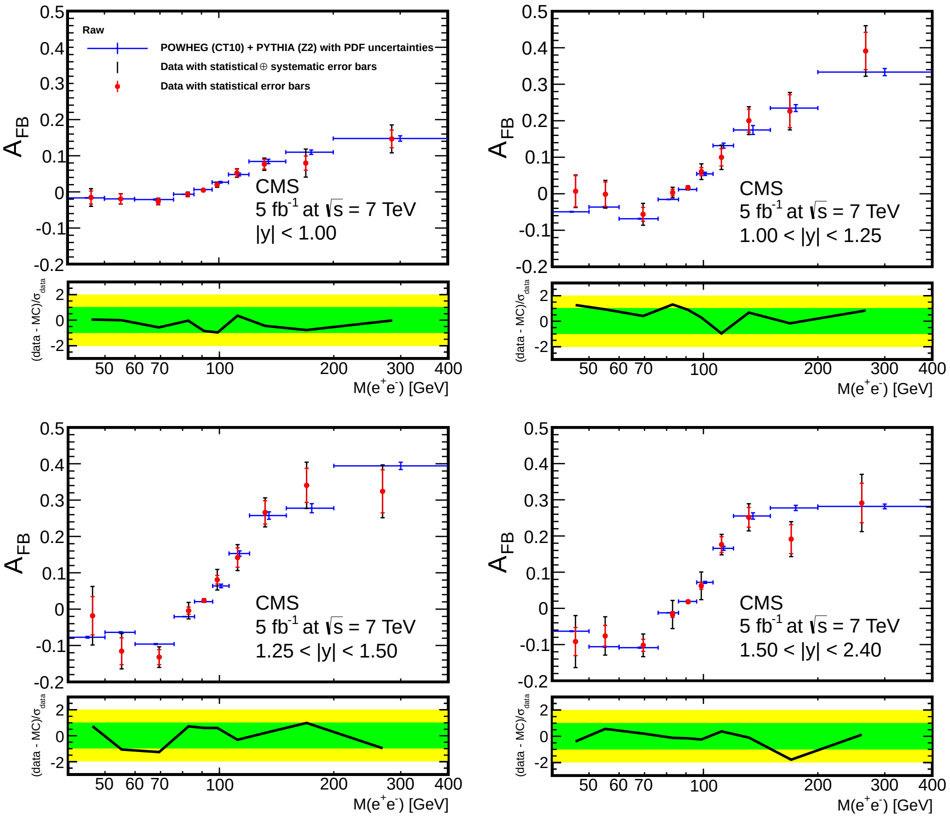

Figure 2: The raw A_{FB} measurement in the dielectron channel in four $|y|$ bins for $p_{\text{T}}(\text{e}) > 20\,\text{GeV}$ and $|\eta(\text{e})| < 2.4$. The data points are shown with both statistical error bars and combined statistical and systematic error bars. The error bars on the MC points are the PDF uncertainties. The MC statistical errors are of the same order of magnitude as the PDF uncertainties. The horizontal extent of the error bars indicates the bin width (except for the last bin, which is truncated at 400 GeV). Beneath each plot is shown the difference between data and MC, normalized by the combined statistical and systematic uncertainty. The green and yellow bands indicate the 1σ and 2σ differences between the data and the theoretical predictions.

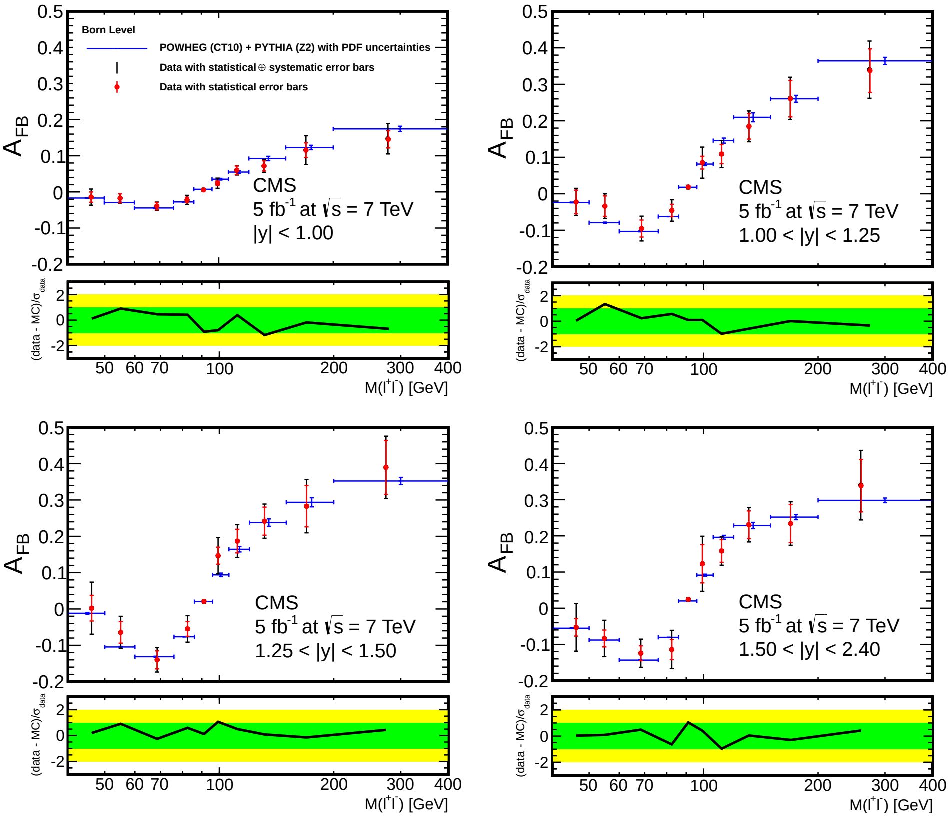

Figure 3: The unfolded and combined ($\mu^+\mu^-$ and e^+e^-) measurement of A_{FB} at the Born level in four $|y|$ bins for $p_T(\ell) > 20\,\text{GeV}$ and $|\eta(\ell)| < 2.4$. The data points are shown with both statistical error bars and combined statistical and systematic error bars. The error bars on the MC points are the PDF uncertainties. The MC statistical errors are of the same order of magnitude as the PDF uncertainties. The horizontal extent of the error bars indicates the bin width (except for the last bin, which is truncated at 400 GeV). Beneath each plot is shown the difference between data and MC, normalized by the combined statistical and systematic uncertainty. The green and yellow bands indicate the 1σ and 2σ differences of data from theory predictions.

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References

[1] S. D. Drell and T.-M. Yan, "Massive Lepton-Pair Production in Hadron-Hadron Collisions at High Energies", *Phys. Rev. Lett.* **25** (1970) 316, `doi:10.1103/PhysRevLett.25.316`.

[2] S. D. Drell and T.-M. Yan, "Partons and their applications at high energies", *Annals of Physics* **66** (1971) 578, `doi:10.1016/0003-4916(71)90071-6`.

[3] CMS Collaboration, "Measurement of the weak mixing angle with the Drell–Yan process in proton-proton collisions at the LHC", *Phys. Rev. D* **84** (2011) 112002, `doi:10.1103/PhysRevD.84.112002`.

[4] D. London and J. L. Rosner, "Extra Gauge Bosons in E_6", *Phys. Rev. D* **34** (1986) 1530, `doi:10.1103/PhysRevD.34.1530`.

[5] J. L. Rosner, "Off-Peak Lepton Asymmetries from New Z's", *Phys. Rev. D* **35** (1987) 2244, `doi:10.1103/PhysRevD.35.2244`.

[6] M. Cvetič and S. Godfrey, "Discovery and Identification of Extra Gauge Bosons", in *Electroweak Symmetry Breaking and New Physics at the TeV Scale*, T. L. Barklow, S. Dawson, H. E. Haber et al., eds. World Scientific, 1995. `arXiv:hep-ph/9504216`.

[7] J. L. Rosner, "Forward-Backward Asymmetries in Hadronically Produced Lepton Pairs", *Phys. Rev. D* **54** (1996) 1078, `doi:10.1103/PhysRevD.54.1078`.

[8] A. Bodek and U. Baur, "Implications of a 300–500 GeV/c^2 Z′ boson on $p\bar{p}$ collider data at $\sqrt{s} = 1.8$ TeV", *Eur. Phys. J. C* **21** (2001) 607, `doi:10.1007/s100520100778`.

[9] CDF Collaboration, "Search for New Gauge Bosons Decaying into Dileptons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **79** (1997) 2192, `doi:10.1103/PhysRevLett.79.2192`.

[10] CDF Collaboration, "Limits on Quark-Lepton Compositeness Scales from Dileptons Produced in 1.8 TeV $p\bar{p}$ Collisions", *Phys. Rev. Lett.* **79** (1997) 2198, `doi:10.1103/PhysRevLett.79.2198`.

[11] H. Davoudiasl, J. L. Hewett, and T. G. Rizzo, "Phenomenology of the Randall–Sundrum Gauge Hierarchy Model", *Phys. Rev. Lett.* **84** (2000) 2080, `doi:10.1103/PhysRevLett.84.2080`.

[12] J. C. Collins and D. E. Soper, "Angular Distribution of Dileptons in High-Energy Hadron Collisions", *Phys. Rev. D* **16** (1977) 2219, `doi:10.1103/PhysRevD.16.2219`.

[13] L. Evans and P. Bryant, "LHC Machine", *JINST* **03** (2008) S08001, `doi:10.1088/1748-0221/3/08/S08001`.

[14] P. Fisher, U. Becker, and J. Kirkby, "Very high precision tests of the electroweak theory", *Phys. Lett. B* **356** (1995) 404, `doi:10.1016/0370-2693(95)00714-V`.

[15] M. Dittmar, "Neutral current interference in the TeV region: The experimental sensitivity at the CERN LHC", *Phys. Rev. D* **55** (1997) 161, `doi:10.1103/PhysRevD.55.161`.

[16] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004, `doi:10.1088/1748-0221/3/08/S08004`.

[17] CMS Collaboration, "CMS MUON Technical Design Report", CMS TDR CERN-LHCC-97-032; CMS-TDR-003, (1997).

[18] T. Sjöstrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 physics and manual", *JHEP* **05** (2006) 026, `doi:10.1088/1126-6708/2006/05/026`.

[19] H.-L. Lai, M. Guzzi, J. Huston et al., "New parton distributions for collider physics", *Phys. Rev. D* **82** (2010) 074024, `doi:10.1103/PhysRevD.82.074024`.

[20] J. Alwall, P. Demin, S. de Visscher et al., "MadGraph/MadEvent v4: the new web generation", *JHEP* **09** (2007) 028, `doi:10.1088/1126-6708/2007/09/028`.

[21] N. Davidson, G. Nanava, T. Przedzinski et al., "Universal Interface of TAUOLA Technical and Physics Documentation", (2010). `arXiv:1002.0543`.

[22] S. Agostinelli et al., "Geant4–a simulation toolkit", *Nucl. Instrum. Meth. A* **506** (2003) 250, `doi:10.1016/S0168-9002(03)01368-8`.

[23] J. Allison et al., "Geant4 developments and applications", *IEEE Transactions on Nuclear Science* **53** (2006) 270, `doi:10.1109/TNS.2006.869826`.

[24] CMS Collaboration, "Performance of muon identification in pp collisions at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-MUO-10-002, (2010).

[25] S. Baffioni, C. Charlot, F. Ferri et al., "Electron reconstruction in CMS", *Eur. Phys. J. C* **49** (2007) 1099, `doi:10.1140/epjc/s10052-006-0175-5`.

[26] CMS Collaboration, "Electron Reconstruction and Identification at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).

[27] V. Blobel, "An unfolding method for high-energy physics experiments", in *Conference on Advanced Statistical Techniques in Particle Physics, Durham, England*, p. 258. 2002. `arXiv:0208022`.

[28] CMS Collaboration, "Alignment of the CMS Silicon Tracker during Commissioning with Cosmic Rays", *JINST* **05** (2010) T03009, `doi:10.1088/1748-0221/5/03/T03009`.

[29] S. Alekhin et al., "The PDF4LHC Working Group Interim Report", (2011). `arXiv:1101.0536`.

[30] M. Botje, J. Butterworth, A. Cooper-Sarkar et al., "The PDF4LHC Working Group Interim Recommendations", (2011). `arXiv:1101.0538`.

[31] P. M. Nadolsky, H.-L. Lai, Q.-H. Cao et al., "Implications of CTEQ global analysis for collider observables", *Phys. Rev. D* **78** (2008) 013004, `doi:10.1103/PhysRevD.78.013004`.

[32] R. D. Ball, L. Del Debbio, S. Forte et al., “A first unbiased global NLO determination of parton distributions and their uncertainties”, *Nucl. Phys. B* **838** (2010) 136, `doi:10.1016/j.nuclphysb.2010.05.008`.

[33] A. D. Martin, W. J. Stirling, R. S. Thorne et al., “Parton distributions for the LHC”, *Eur. Phys. J. C* **63** (2009) 189, `doi:10.1140/epjc/s10052-009-1072-5`.

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