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Measurement of photon pair production cross section at D0

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Abstract. A recent D0 measurement [1] of direct photon pair production cross sections using 4.2 fb^{-1} of data is presented. The single differential cross sections are measured as a function of the diphoton mass, the transverse momentum of the diphoton system, the azimuthal angle between the photons, and the polar scattering angle of the photons. In addition, we measure double differential cross sections considering the last three kinematic variables in three diphoton mass bins. The results are compared with different perturbative QCD predictions and event generators.

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INTRODUCTION

At a hadron collider, the direct photon pair (DPP) production with large diphoton invariant mass ($M_{\gamma\gamma}$) constitutes a large and irreducible background to searches for the Higgs boson decaying into a pair of photons, for both the Fermilab Tevatron and the CERN LHC experiments. DPP production is also a significant background in searches for new phenomena with heavy resonances decaying into a photon pair [2, 3]. Thus, precise measurements of the diphoton differential production cross sections for various kinematic variables and their theoretical understanding are extremely important.

In addition, DPP production is interesting in its own right, and is used to check the validity of the predictions of perturbative quantum chromodynamics (pQCD) and soft-gluon resummation methods implemented in theoretical calculations. Measurements involving the diphoton final state have been previously carried out at fixed-target and collider experiments. However, the large integrated luminosity accumulated by the D0 experiment in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron Collider allows us to perform precise measurements of several observables in kinematic regions previously unexplored, as well as, for the first time, the measurement of double differential cross sections for this process.

DATA SELECTION

A new D0 measurement [1] presents the DPP production cross sections that are obtained using data collected by the D0 experiment from August 2006 to June 2009. The cross sections are measured differentially as a function of $M_{\gamma\gamma}$, the diphoton transverse momentum ($p_T^{\gamma\gamma}$), the azimuthal angle between the photons ($\Delta\phi_{\gamma\gamma}$), and the cosine of

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the polar scattering angle of the photon in the frame with no net transverse momentum of the diphoton system, defined as $\cos\theta^* = \tanh[(\eta_1 - \eta_2)/2]$, where $\eta_{1(2)}$ is the pseudorapidity of the highest (next-to-highest) p_T photon. These kinematic variables probe different aspects of the DPP production mechanism. For instance, the shapes of the $p_T^{\gamma\gamma}$ and $\Delta\phi_{\gamma\gamma}$ distributions are mostly affected by initial state gluon radiation and fragmentation effects. In addition, the $M_{\gamma\gamma}$ spectrum is particularly sensitive to potential contributions from new phenomena. The $\cos\theta^*$ distribution probes PDF effects and the angular momentum of the final state. The measured cross sections are compared to theoretical predictions from RESBOS [4], DIPHOX [5], and PYTHIA [6].

Events are selected by requiring two photon candidates with transverse momentum $p_T > 21$ (20) GeV for the highest (next-to-highest) p_T photon candidate and pseudorapidity $|\eta| < 0.9$, for which the trigger requirements are $>96\%$ efficient. The two photon candidates are also required to be spatially separated from each other by a distance in $\eta - \phi$ space $\Delta R > 0.4$ and to satisfy $M_{\gamma\gamma} > p_T^{\gamma\gamma}$. The latter requirement is satisfied by the majority of DPP events and, together with the photon isolation requirements, allows significant suppression of the contribution from the fragmentation diagrams, thus restricting the data-to-theory comparison to the region where the theoretical calculations should have smaller uncertainties [4].

After imposing all requirements, 10938 events with diphoton candidates are selected in data. This sample includes instrumental background contributions from γ+jet and dijet production, where a jet is misidentified as a single photon. An additional smaller background contribution results from Z-boson/Drell-Yan production events $Z/\gamma^* \to e^+e^-$ in which both electrons are misidentified as photons. The total number of DPP events after subtraction of all background events is found to be $N_{\gamma\gamma} = 7307 \pm 312(\text{stat.})$, corresponding to an average DPP purity of $\approx 67\%$. The largest kinematic dependence of the DPP purity is in terms of $M_{\gamma\gamma}$, with a variation between $\approx 60\%$ at $M_{\gamma\gamma} \approx 40$ GeV and close to 100% for $M_{\gamma\gamma} > 200$ GeV. As a function of the other kinematic variables, the DPP purity varies in the $(60-70)\%$ range.

RESULTS

Figure 1 shows a comparison of the measured differential cross sections to the theoretical predictions from RESBOS, DIPHOX, and PYTHIA. There is a common 7.4% normalization uncertainty, not shown on the data points. The predictions from RESBOS, and DIPHOX use the CTEQ6.6M PDF set [7] and renormalization, factorization, and fragmentation scales $\mu_R = \mu_F = \mu_f = M_{\gamma\gamma}$, while PYTHIA uses the Tune A settings. Theoretical predictions are obtained using the following selections: two photons with $p_T > 21(20)$ GeV, $|\eta| < 0.9$, $30 < M_{\gamma\gamma} < 350$ GeV, $M_{\gamma\gamma} > p_T^{\gamma\gamma}$, $\Delta R > 0.4$, $\Delta\phi_{\gamma\gamma} > 0.5\pi$, and isolated by $E_T^{\text{iso}} = E_T^{\text{tot}}(0.4) - E_T^{\gamma} < 2.5$ GeV, where $E_T^{\text{tot}}(0.4)$ is the total transverse energy within a cone of radius $R = 0.4$ centered on the photon, and E_T^{γ} is the photon transverse energy.

The results obtained show that none of the theoretical predictions considered is able to describe the data well in all kinematic regions of the four variables. RESBOS shows the best agreement with data, although systematic discrepancies are observed at low $M_{\gamma\gamma}$, high $p_T^{\gamma\gamma}$, and low $\Delta\phi_{\gamma\gamma}$. However, the agreement between RESBOS and data is

fair at intermediate $M_{\gamma\gamma}$ ($50-80$ GeV), and good at high $M_{\gamma\gamma}$ (>80 GeV). The large discrepancy between RESBOS and DIPHOX in some regions of the phase space is due to absence of all-order soft-gluon resummation and accounting $gg \to \gamma\gamma$ contribution just at LO in DIPHOX.

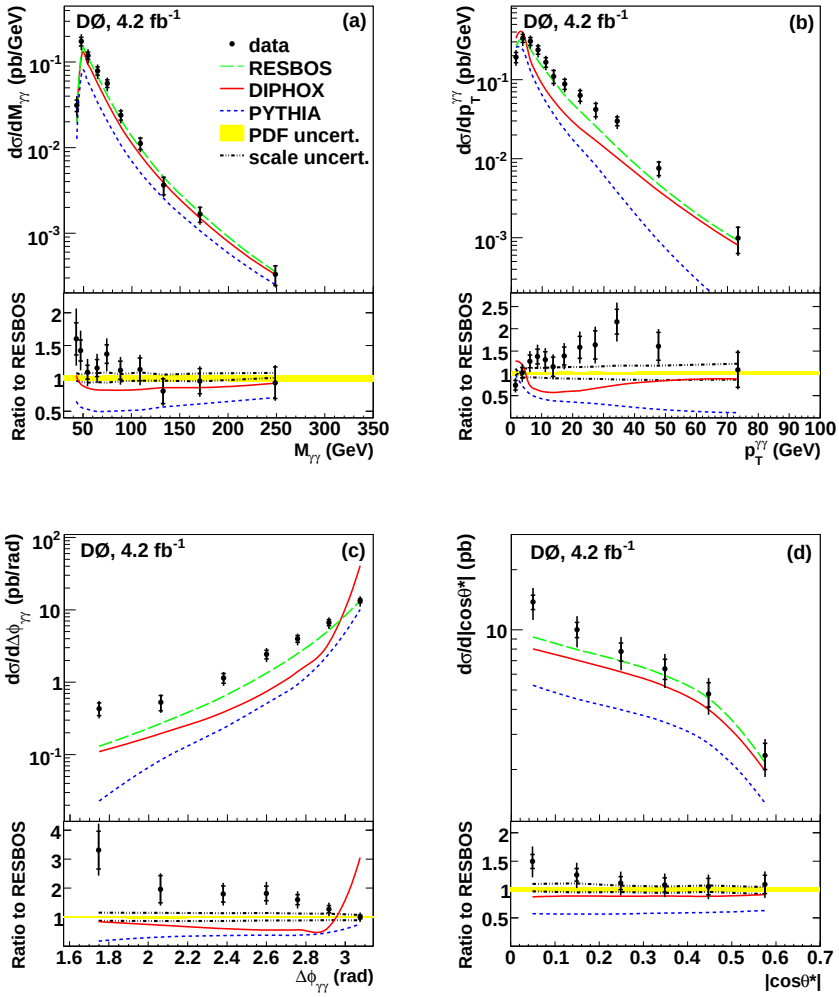

FIGURE 1. The measured differential diphoton production cross sections as functions of (a) $M_{\gamma\gamma}$, (b) $p_T^{\gamma\gamma}$, (c) $\Delta\phi_{\gamma\gamma}$, and (d) $|\cos\theta^*|$. The data are compared to the theoretical predictions from RESBOS, DIPHOX, and PYTHIA. The ratio of differential cross sections between data and RESBOS are displayed as black points with uncertainties in the bottom plots. The inner line for the uncertainties in data points shows the statistical uncertainty, while the outer line shows the total (statistical and systematic added in quadrature) uncertainty after removing the 7.4% normalization uncertainty. The solid (dashed) line shows the ratio of the predictions from DIPHOX (PYTHIA) to those from RESBOS. In the bottom plots, the scale uncertainties are shown by dash-dotted lines and the PDF uncertainties by shaded regions.

Further insight on the dependence of the $p_T^{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, and $|\cos\theta^*|$ kinematic distributions on the mass scale can be gained through the measurement of double differential cross sections. For this purpose, the differential cross sections as functions of $p_T^{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, and $|\cos\theta^*|$ are measured in three $M_{\gamma\gamma}$ bins: $30-50$ GeV, $50-80$ GeV and $80-350$ GeV. The measured cross sections for $p_T^{\gamma\gamma}$, as an example, in the three mass bins are

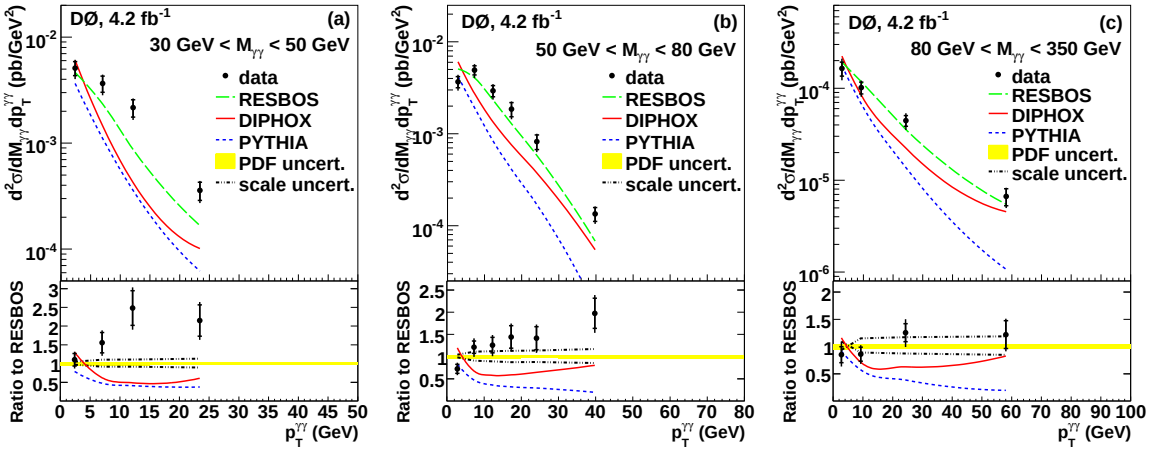

FIGURE 2. The measured double differential diphoton production cross sections as functions of $p_T^{\gamma\gamma}$in the three mass bins: (a) for $30 < M_{\gamma\gamma} < 50$ GeV, (b) for $50 < M_{\gamma\gamma} < 80$ GeV and (c) for $80 < M_{\gamma\gamma} < 300$ GeV.

presented in Figure 2 and compared to the theoretical predictions. These results confirm that the largest discrepancies between data and RESBOS for each of the kinematic variables originate from the lowest $M_{\gamma\gamma}$ region ($M_{\gamma\gamma} < 50$ GeV). This is the region where the contribution from $gg \to \gamma\gamma$ is expected to be largest [1]. The discrepancies between data and RESBOS are reduced in the intermediate $M_{\gamma\gamma}$ region ($50-80$ GeV), and a quite satisfactory description of all kinematic variables is achieved for the $M_{\gamma\gamma}>$ 80 GeV region, the relevant region for the Higgs boson and new phenomena searches. It remains to be seen whether the addition of NNLO corrections to RESBOS, as done in [8], will improve the description of the high $p_T^{\gamma\gamma}$ (low $\Delta\phi_{\gamma\gamma}$) spectrum at low $M_{\gamma\gamma}$.

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