PHOTON PRODUCTION AT THE FERMILAB TEVATRON

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The DØ and CDF experiments at the Fermilab Tevatron have recently measured photon production cross sections in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. An improved measurement of the isolated single photon production cross section with an increased data sample is presented and compared to NLO QCD predictions. Also, a new measurement of the production of $\gamma + \mu$ events is discussed and compared with NLO QCD predictions.

1 Introduction

Direct production of photons in $p\overline{p}$ collisions can be a useful tool for testing the predictions of Quantum Chromodynamics (QCD) with few of the ambiguities associated with jet production and fragmentation.[1] At leading order, photons are produced through Compton scattering, $g+q \rightarrow q+\gamma$ or through annihilation processes, $q + \overline{q} \rightarrow g + \gamma$, allowing the quark and gluon content of the proton to be probed. Previous measurements of direct photon production have reported an excess of production at low photon transverse energies, E_T^{γ}.[2,3]

2 Data Analysis

2.1 Photon Selection

Both DØ[4] and CDF[5] use electromagnetic (EM) calorimeters to identify isolated photon candidates. The DØ calorimeter is a liquid argon uranium calorimeter with an energy resolution of $(15/\sqrt{E}+0.3)\%$ for electromagnetic showers. It is divided into four longitudinal electromagnetic sections of 2, 2, 7, and 10 radiation lengths, respectively. The Central Cryostat (CC) covers the pseudorapidity region $|\eta| \leq 0.9$ and the Forward Cryostat (EC) covers the region from $1.6 \leq |\eta| \leq 2.5$, where pseudorapidity is defined as $\eta = -\ln\tan(\theta/2)$ where θ is the polar angle with respect to the proton beam.

The CDF lead-scintillator EM calorimeter has an energy resolution of $(13.5/\sqrt{E} + 1.7)\%$ for electromagnetic showers. A very accurate measurement of the transverse development of the shower is provided by a central EM Strip Chamber (CES) which is placed at the longitudinal position of the shower where it is expected to have its largest transverse profile. In addition, a 1.1 radiation length Central Preradiator (CPR) is placed immediately in front of the calorimeter in the region $|\eta| < 1.1$.

Photon selection is similar for both experiments. Isolated photon candidates are identified in the EM calorimeters. For DØ, the isolation criteria requires that the energy deposited in a cone of azimuthal-pseudorapidity radius $0.2 < R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$ be less than 2.0 GeV. CDF requires that in a cone of $R < 0.4$ around the photon cluster center, there is less than 1 GeV of energy not associated with the cluster towers. Electrons are rejected by requiring that no charged track point to the EM cluster from the central tracking chamber. Reconstructed shower shapes must match single photon shower shapes from test beam data in the EM calorimeter for DØ and in the CES for CDF. CDF requires that there is only one EM cluster with $E_T > 1$ GeV/c in the CES, and DØ requires that $\geq 96\%$ of the shower energy be in the EM region of the calorimeter. Both experiments identify photons with E_T dependent efficiencies. Both detectors also apply an azimuthal cut to ensure that the showers are well contained in the active calorimeter volume.

2.2 Photon Identification and Purity

The primary backgrounds to single photon production are photons produced from $\eta^0 \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$ decays. When the two photons have high enough E_T they appear as a single cluster in the EM calorimeter. The fraction of photon candidates which arise from this background must be determined as a function of E_T so that the production cross section can be adjusted accordingly.

The DØ collaboration exploits the longitudinal segmentation of the colorimeter to differentiate single photons from double photons. Because the two photons from meson decay have a higher probability of beginning to shower early in the EM calorimeter, the ratio of energy in the first longitudinal EM section (E_1) to the total EM energy (EM_{total}) can be used as a discriminant.

Distributions of the variable $\log(EM_1/EM_{total})$ are created from Monte Carlo simulations of meson decay and of single photon interactions in the DØ calorimeter. The data is then fit to a linear combination of the Monte Carlo signal plus background distributions. The shapes of the Monte Carlo distributions are fixed and fitting is done with only one free parameter, the fraction of signal events in the data, normalization to the total number of data events. As a check of the reliability of the Monte Carlo, the response of the EM calorimeter to electrons in the data from $W \to e\nu$ were compared to the Monte Carlo predictions and found to agree.

The CDF collaboration uses two methods for determining the fraction of single photon events. For photons with $E_T < 36$ GeV/c, the "Profile" method is used which compares shower shapes in the CES to shower shapes from test beam electrons. For photons with $E_T > 36$ GeV/c, the "Conversion" method is used which relies on the greater probability of photons from meson decay converting in the CPR than the single photon signal.

2.3 CDF Calibration

It is expected and necessary that in regions of E_T^γ where both the conversion method and the profile method are applicable, the two methods should produce the same cross section. Although this was the case for a subset of data taken in 1992-1993 (Run 1a),[3] it was, initially, not true for the data taken in 1994-1995, (Run 1b). Not only did the two methods disagree with each other, but the cross section from Run 1b alone did not agree with the cross section from Run 1a alone. Consequently, a new calibration of the photon response in the CES and the CPR had to be done. This calibration was accomplished using photons from the decay $\rho^\pm \to \pi^\pm\pi^0 \to \pi^\pm\gamma\gamma$. Efficiencies measured from data were compared with those expected from Monte Carlo simulations. The measured efficiency was 0.458 ± 0.009 (0.886 ± 0.006) for the profile (conversion) method compared to the Monte Carlo prediction of 0.472 (0.838), resulting in a necessary correction of -2.97% (+3.34%). After applying these corrections both problems were resolved. The cross section from the profile method agreed with the cross section from the conversion method, and the Run 1a cross section agreed with the Run 1b cross section. The origin of this calibration discrepancy is not yet known, and is still under investigation. It is the predominant contribution to the 14% normalization error in the cross section.

3 Single Photon Results

3.1 Inclusive Photon Cross Section

Both DØ and CDF have measured the photon inclusive cross section in the central region, $|\eta| \leq 0.9$. In addition, DØ has measured the cross section in the forward region, $1.6 \leq |\eta| \leq 2.5$. The preliminary results presented are from data taken in Run 1b, representing 95 pb^{-1} for DØ, and 87 pb^{-1} for CDF. The resulting cross sections are compared to NLO predictions of Baer, Ohnemus, and Owens with CTEQ4M parton distributions in Fig. 1 and Fig. 2. [6] The DØ cross section agrees with theory at higher E_T, but still shows some excess production at low E_T.

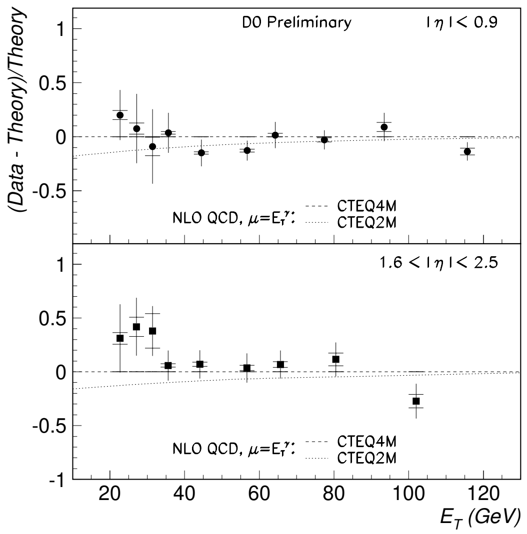

Figure 1: DØ single photon cross section.

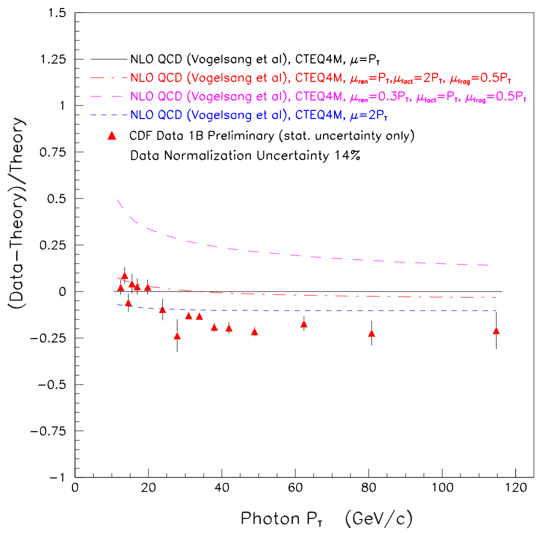

Figure 2: CDF single photon cross section.

The CDF result is compared to variations on the model made by Vogelsang, including independently changing the renormalization scale, the fragmentation scale, and the factorization scale. [7] Previously published CDF results from Run 1a showed a slightly different comparison to the theoretical predictions [3] which comes from three sources. First, earlier results used an isolation cut of $R = 0.7$ rather than $R = 0.4$. The new cut increases the normalization of the cross section by 10%. Second, the Monte Carlo cutoff for 2-to-3 body interactions was lowered, which increased the cross section normalization by 5%. Finally, comparing the data to CTEQ4M instead of CTEQ2M decreases the slope of the cross section by 15%. The CDF result continues to show a discrepancy between data and theory in shape and normalization. Modifications by Vogelsang can improve the agreement between either the shape of the distributions or the absolute normalization, but can not bring agreement between data and theory over the entire E_T region, even when considering the 14% normalization uncertainty of the data. Recent comparison of the data to a theoretical model which includes Gaussian smeared initial state "k_T" radiation shows agreement between the shapes of the distributions, but still some normalization discrepency.

3.2 CDF Photon + Muon

A measurement of the production of a photon plus a muon can probe the charm content of the proton via the reaction $cg \to c\gamma \to \gamma\mu X$. The primary NLO correction comes from the process $gg \to c\bar{c} \to c\bar{c} + \gamma \to \gamma\mu X$ where the photon is produced from c quark final state radiation.

Photons are selected using the same criteria mentioned above, except that the momentum of the photon is limited to $12 \leq P_T^\gamma \leq 40$ GeV/c so that the profile identification method can be used. Muons are identified in the central region, $|\eta| \leq 1.0$ by matching a track in the central tracking chamber with momentum $P_T^\mu \geq 4.0$ GeV/c to a track in the muon chambers. After selecting events, the primary background comes from either K/π decays in flight, or from hadrons which "punch-through" into the muon chambers and, thus appear to be muons. Background estimations using a Monte Carlo simulation of the detector are shown in Fig. 3.

Results for the production cross section, shown in Fig. 4, are compared with a NLO calculation and to a Pythia Monte Carlo. Pythia falls below the data, but does not include Bremsstrahlung radiation. The data are consistent with NLO predictions.

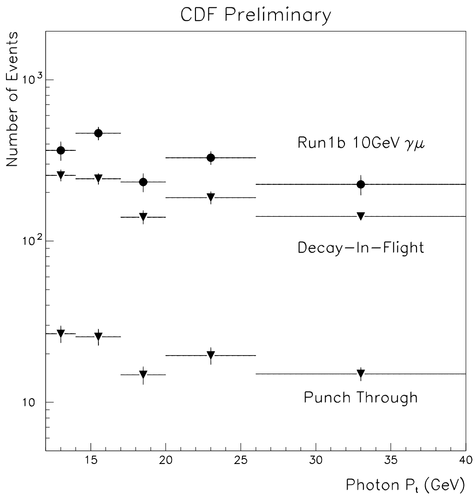

Figure 3: CDF $\gamma + \mu$ background estimations.

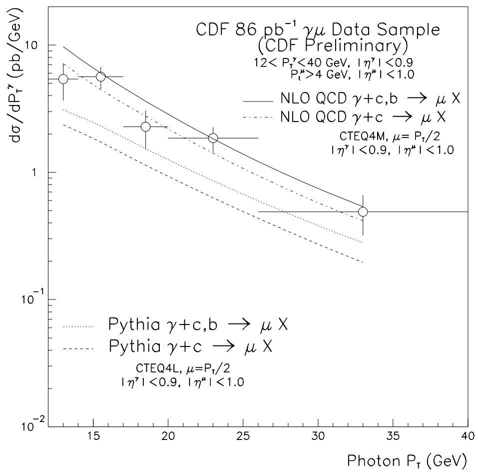

Figure 4: CDF $\gamma + \mu$ cross section.

Conclusions

Photon production in $p\bar{p}$ collisions continues to be a fruitful arena for exploring QCD. Although DØ and CDF measurements of the single photon production cross section are consistent, DØ data seems to agree with NLO QCD while the CDF measurement shows disagreement between the shape and/or absolute normaliziation. This discrepancy can not be resolved by simply changing the theory scales. Measurements of the production of $\gamma + \mu$ imply a charm content of the proton which is in agreement with NLO QCD.

References

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