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Measurement of direct photon production at Tevatron fixed target energies

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FOR THE E706 COLLABORATION

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Measurements of the production of high-p_T direct photons by a 515 GeV/c π^- beam and 530 and 800 GeV/c proton beams in interactions with Be and H_2 targets are presented. The data span the kinematic ranges of $3.5 < p_T < 12$ GeV/c in transverse momentum and 1.5 units in rapidity. The inclusive direct-photon cross sections are compared with NLO pQCD calculations and expectations based on a phenomenological parton-k_T model.

Keywords: E706; QCD; direct photon, gluon.

Direct-photon measurements provide potential constraints on the gluon PDF, particularly at large x. This is especially relevant since recent global PDF fits have instead used jet data from Tevatron Run I to constrain the large-x gluon—thereby possibly incorporating new physics effects into the PDF.[1,2] Inclusion of direct-photon data in the global fits would provide additional constraints on the gluon distribution, independent of the jet data from the Tevatron, thereby enhancing the discovery potential of the jet data being acquired in Tevatron Run II.

Fermilab E706 is a fixed-target experiment designed to measure the production of direct photons, neutral mesons, and associated particles at high-p_T.[3,4,5,6] Our high-precision direct-photon cross-section measurements,[4] as illustrated in Fig. 1 (left), as well as our π^0 cross-section measurements,[5] are not satisfactorily described by the available NLO pQCD calculations. NLO pQCD has significantly improved agreement with data (and reduced scale dependence) when compared to ratios of direct-photon cross sections. The ratio of the 800 to 530 GeV/c direct-photon cross sections is presented as a function of $x_T = 2p_T/\sqrt{s}$ in Fig. 1 (right). The broad band for the NLO theory in the figure is bounded by $\mu = p_T/3$ and p_T; the inner band represents the PDF uncertainty. The dotted curves show the results of LO pQCD calculations for $\mu = p_T/2$. There is relatively little difference between the LO and NLO curves in Fig. 1 (right) since the numerator and denominator have the same beam particle.

Discrepancies between pQCD calculations and other measurements of high-p_T

direct-photon and π^0 production have also been observed[7] and are attributed to the effect of initial-state soft-gluon radiation. The importance of including gluon emission through the resummation formalism has long been recognized, however, these calculations have only recently been considered for inclusive direct-photon production.[8] While these developments are encouraging, the calculations are still incomplete. In the absence of a rigorous treatment, a phenomenological prescription[3,7] is used in the following comparisons of pQCD with our data. In this approach, soft-gluon radiation is parameterized in terms of an effective $\langle k_T \rangle$ that provides an additional transverse impulse to the incoming partons. Since the hard-scattering cross sections fall steeply as functions of p_T, the net effect of this additional transverse impulse is to enhance high-p_T yields. The $\langle k_T \rangle$ values are representative of values that describe kinematic distributions observed in production of high-mass $\pi^0\pi^0$, $\gamma\pi^0$, and $\gamma\gamma$ systems.[3,9] The k_T-enhanced NLO calculations are compared to our direct-photon measurements in Fig. 1 (left), and provide a much improved description of our data relative to the NLO calculations.

Results of k_T enhanced NLO pQCD calculations using CTEQ6.1M PDF[1] are compared to our direct-photon measurements for incident protons in Fig. 2 (left). The CTEQ6.1 PDF uncertainty bands are also shown in that figure. While the uncertainties associated with the PDF are small at low x_T, they are significantly larger than the uncertainties in data at moderate and high x_T, and are dominated by the uncertainty in the gluon distribution. There is also a large variation in the central value of several PDF sets, as illustrated in Fig. 2 (right). The major difference between the CTEQ5M[10] and CTEQ6.1M PDF is that CTEQ6.1M has a much harder gluon (motivated by measurements of the inclusive jet cross section at the Tevatron collider). Cross sections calculated using MRST2003C PDF[11] are similar to results using CTEQ5M PDF. Calculations with PDF that have softer gluons provide a better description of our data at high p_T.

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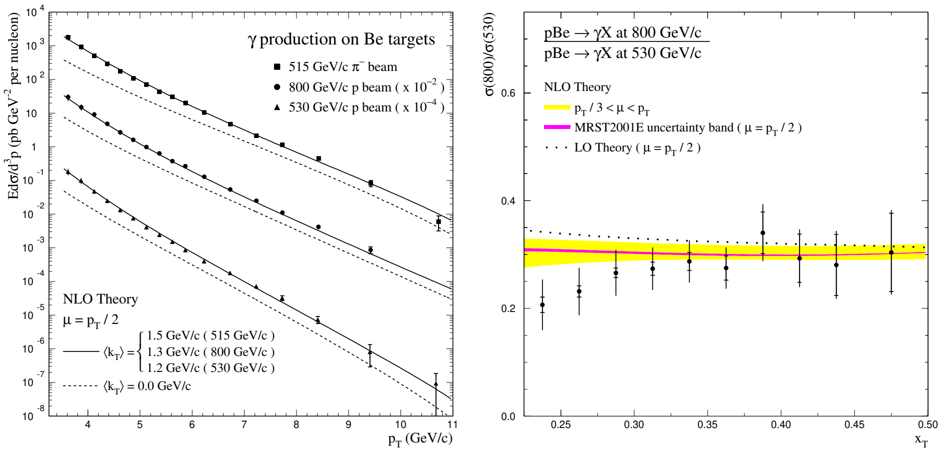

Fig. 1. Left: invariant differential cross sections per nucleon for direct-photon production as functions of p_T, averaged over rapidity, for 515 GeV/c π^- and 800 and 530 GeV/c proton beams incident upon Be. Overlaid on the data are NLO pQCD and k_T-enhanced NLO pQCD calculations. GRV92 PDF were used in the incident π^- calculations, while CTEQ5M PDF were used in the incident proton calculations. Right: The ratio of 800 GeV/c to 530 GeV/c proton beam direct-photon cross sections as a function of x_T. The dotted curve shows the results of LO pQCD calculations using the CTEQ5L PDF and $\mu = p_T/2$. Shaded bands illustrate the results from NLO pQCD calculations. The outer band is bounded by $\mu = p_T/3$ and $\mu = p_T$; the inner band by the uncertainty of the MRST2001E PDF set.

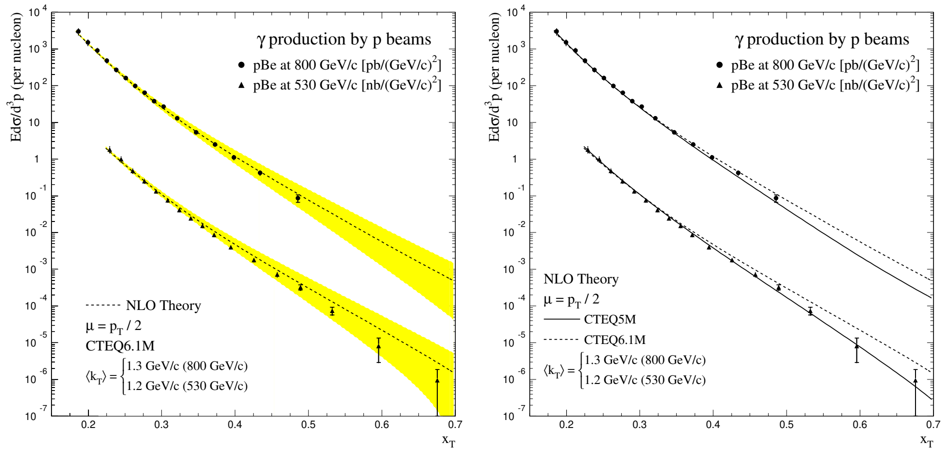

Fig. 2. Invariant differential cross sections per nucleon for direct-photon production as functions of x_T in pBe interactions at 800 and 530 GeV/c. Left: Overlaid on the data are k_T-enhanced NLO pQCD calculations. The shaded region represents the uncertainty band associated with the CTEQ6.1M PDF set. Right: Overlaid on the data are k_T-enhanced NLO pQCD calculations using CTEQ5M and CTEQ6.1M PDF.