ON HIGH p_T DIRECT PHOTONS, MESONS AND pQCD *

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Predictions of perturbative QCD (pQCD) for inclusive production of direct photons and mesons at high p_T are tested using new high-statistics measurements from Fermilab experiment E706. Inclusive cross sections are presented for 515 GeV/c π^- and 530 and 800 GeV/c proton beams incident on a Be target, and for the kinematic range $4 < p_T < 10$ GeV/c and central rapidities. Current Next-to-Leading Log (NLL) QCD calculations fail to accommodate the data for usual choices of scales. The data indicate the presence of a substantial effective k_T; a phenomenological model of k_T effects improves the agreement between the calculations and the cross section data.

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1. Introduction

As discussed at this Symposium, electro-weak radiative corrections have been calculated and experimentally tested to an impressive precision. Higher order effects in strong interaction processes are not known to a similar accuracy. Even though pQCD has proven very successful in explaining major characteristics of a wide variety of short distance phenomena, recent data illustrate some limitations of the current theoretical description.

We discuss comparisons of NLL QCD calculations with precision data from Fermilab experiment E706 on large momentum transfer (p_T) production of direct photons and mesons. The direct photon process has long been expected to provide an accurate determination of the distributions of gluons in nucleons and mesons, especially for large values of x. This information has proven difficult to obtain from other measurements. Inclusive

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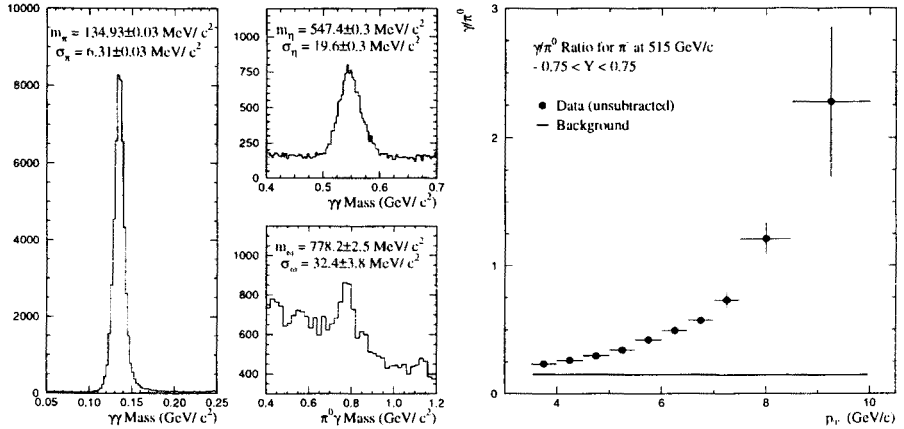

Fig. 1. The three graphs on the left show reconstructed masses of π^0, η and ω mesons in all-photon final states (combined proton beam data). The ratio of single photon to π^0 production for π^- beam data is shown on the right.

meson production at large p_T tests the QCD description of a different mix of hard scattering interactions and provides insights into the parton fragmentation mechanism. These sets of data are not described satisfactorily by NLL QCD calculations using the usual choices of parameters. Resolving the observed discrepancies is of importance for better understanding of both parton distribution and fragmentation functions.

2. The experiment

E706 is designed to measure large p_T production of direct photons, neutral mesons, and associated particles. The apparatus features a large lead and liquid argon electromagnetic calorimeter, and a charged particle spectrometer. The experiment accumulated $\approx$12 events/pb of π^- beam data and $\approx$9 events/pb of proton beam data near 500 GeV/c, and $\approx$11 events/pb of proton beam data at 800 GeV/c, on a combination of Be, Cu, and H targets. A detailed description of the spectrometer and of the analysis procedures can be found in the literature [1].

The excellent quality of the data is illustrated in Fig. 1. The reconstructed masses of π^0, η and ω mesons are in very close agreement with the nominal values. The uncertainty in the calibration of the energy response is less than 0.5% [2]. The direct photon signal is obtained from the yield of single photon candidates that remain after rejection of reconstructed π^0 and η mesons. The residual background, due, primarily, to unreconstructed meson decays, is corrected through a statistical subtraction. Failure to identify

a photon originating from a meson decay can occur if one of the photons from that decay converts in the detector material, leaves the fiducial volume of the calorimeter, or is not reconstructed (typically for low energy photons). Sources of direct photon background have been modelled using the Herwig event generator and a GEANT simulation of the spectrometer response. The total yield of single photon candidates and the background from all sources, both normalized to the π^0 yield, are illustrated in Fig. 1 for the π^- beam data.

Below, we present our highest statistics measurements of the cross sections obtained using Be targets. The nuclear modification of both direct photon and π^0 cross sections can be simply parameterized as A^α, with $\alpha \approx 1.04 \pm 0.02$ for direct photons and 1.11 ± 0.02 for mesons. For the purpose of comparing to our data, a correction factor for this nuclear dependence has been applied to pQCD predictions.

3. Comparisons to QCD

The presence of higher-order QCD effects can be investigated experimentally through studies of processes sensitive to "intrinsic" Fermi motion of partons (k_T) – such motion, presumably, is due to initial state gluon radiation. Data indicate that the amount of radiation is larger than expected from NLL QCD. Previous measurements of direct di-photon production demonstrated a substantial effective k_T [3], and a full resummation calculation was required to reproduce the size of the effect [4].

As shown in Fig. 2, the out-of-plane momentum balance distributions for our $\gamma\gamma$ and $\pi^0\pi^0$ data are bracketed by Pythia simulations with k_T between 1.25 and 1.5 GeV/c. Experimental resolution effects contribute less than 0.2 GeV/c in the di-photon case and ≈ 0.7 GeV/c in the $\pi^0\pi^0$ case. The effective values of k_T smearing depend very weakly on the choice of nuclear target, increasing only by 0.1 GeV/c when measured using the Cu target instead of the H target. Similar k_T's are also indicated by other characteristics of the data. Fig. 3 displays the distribution of charged particles in jets recoiling against isolated photons produced by 800 GeV/c protons on the Be targets. The data are compared to expectations obtained using the BKK fragmentation functions and several choices of k_T; curves corresponding to $1.4 < k_T < 1.6$ GeV/c bracket the data. Also shown in Fig. 3 is the π^0 cross section for the $0.6 < p_T < 5$ GeV/c range, compared to Pythia calculations with various values of effective k_T. A $k_T \approx 1$ GeV/c is required to match the shape of the data.

Since the inclusive cross sections are very rapidly falling with increasing p_T, a k_T smearing could have a large effect on the measured values. It has been suggested [5] that an observed pattern of discrepancies between various

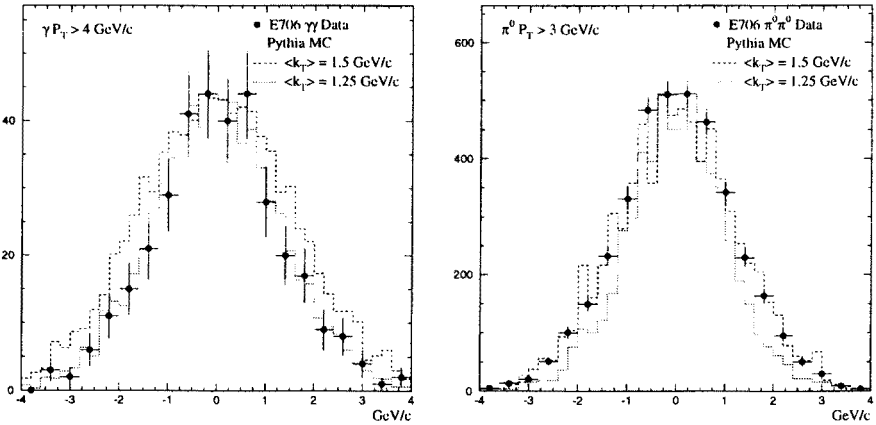

Fig. 2. The out-of-plane momentum balance of unsubtracted $\gamma\gamma$ pairs (left) and of π^0 pairs (right), compared to results from the Pythia generator for two values of k_T.

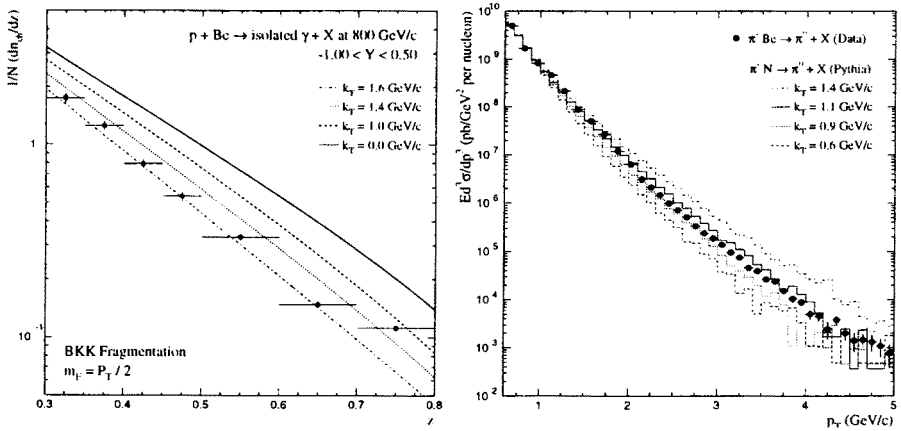

Fig. 3. Left: The distribution of charged particles in jets opposite isolated photons with $p_T > 5.5$ GeV/c in the 800 GeV/c data (z is momentum of particles, rescaled to the photon momentum). Curves are expectations using BKK fragmentation and various k_T values. Right: Comparison of Pythia Monte Carlo for several k_T values with π^0 data.

direct photon experiments and theory could be related to such effects.

Figs. 4 and 5 show comparisons of our direct photon and π^0 inclusive cross sections per nucleon to NLL calculations [6] using ABFKW [7] and CTEQ3m [8] parton distributions, and BKK [9] fragmentation functions. All QCD scales (renormalization, factorization, and, where appropriate,

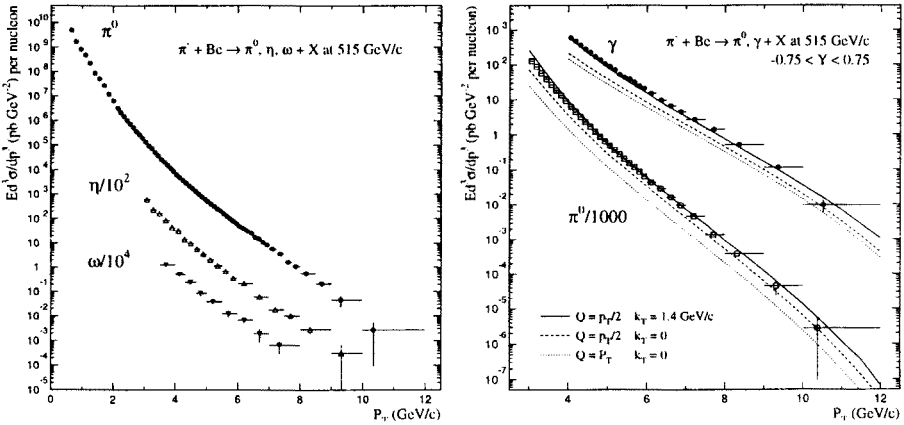

Fig. 4. E706 π^- beam results. Left: Inclusive production of π^0, η and ω mesons. Right: The γ and π^0 production compared to theory using different choices of scales and k_T.

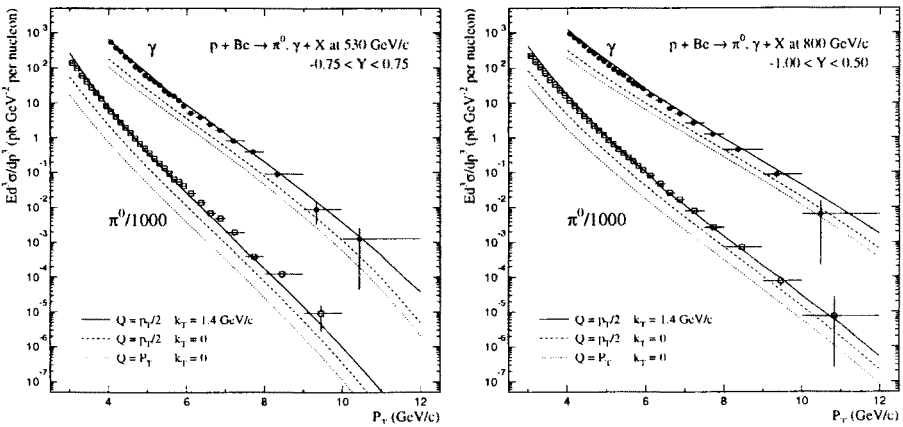

Fig. 5. E706 proton beam results at 530 (left) and 800 GeV/c (right).

fragmentation scales) are set equal. The predictions are very sensitive to the choice of scales, indicating that the NLL calculations are not fully adequate. Neither the $Q = p_T$ nor the $Q = \frac{1}{2}p_T$ choice of scales accommodates the data.

To estimate the impact of the k_T smearing effects on the observed cross sections, we have calculated correction factors for various values of k_T using Leading-Log QCD programs. These corrections were then applied to the NLL predictions. Since such a procedure may double-count contributions

already taken into account in the NLL results, we considered k_T to be a free parameter in the comparisons. As shown in Figs. 4 and 5, good agreement is obtained for both direct photon and π^0 data for $k_T \approx 1.4$ GeV/c.

More theoretical work is needed to sort out alternative explanations (see e.g. [10]) and to achieve a rigorous QCD treatment. A more accurate determination of the gluon distribution at large x would clearly benefit from progress in the theoretical interpretation of our data.

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