Charm Photoproduction with Linearly Polarized Photons

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The photoproduction of charmed particles by polarized photons is calculated in perturbative quantum chromodynamics. For vector gluons the resulting linearly polarized photon asymmetry is found to be large and negative, therefore providing a distinctive test of the proposed production mechanism. Predictions are also given for scalar and pseudoscalar gluons and the magnitude of the cross section is discussed.

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Polarization data have historically provided stringent tests for models of high-energy scattering processes. Accordingly, it is not surprising that much interest has centered around obtaining polarization predictions based on quantum chromodynamics (QCD).[1] However, the predictions for most single polarization observables have been very small. This occurs because such observables require an interference between helicity-flip and -nonflip amplitudes and the former vanish for massless quarks in the tree approximation.[2] Nonzero polarizations can be obtained by calculating higher-order loop diagrams, but the results are then suppressed by powers of the strong coupling constant.[3] Furthermore, polarizations calculated at the parton level are, in general, decreased by effects associated with the transformation to the hadron level via fragmentation and distribution functions.

The problems listed above may be neatly circumvented by considering the production of charmed particles by polarized photons. The pointlike nature of the quark-photon interaction ensures that there is no loss of polarization due to an intervening distribution function. The large charm-quark mass results in a significant linearly polarized photon asymmetry using just lowest-order QCD diagrams. Finally, the asymmetry is expected to be insensitive to the fragmentation of charmed quarks into charmed hadrons, provided that the transverse momentum exceeds that usually associated with fragmentation processes, e.g., $\langle k_T \rangle \simeq 300$ MeV/c. These points will each be discussed in detail below.

For parity-conserving processes there is no polarized-photon asymmetry associated with circularly polarized photons since the cross sections for helicity +1 and −1 photons are equal. Thus, one must consider correlations between the photon helicity and the spin of either the target or one of the final-state hadrons. On the other hand, with linearly polarized photons the cross sections for photons polarized in the x and y directions, denoted by σ_x and σ_y, respectively, can differ. For a process with an incoming photon momentum $\vec{k}$ and a detected final-state particle with momentum $\vec{k}'$ the coordinate system is defined with the z axis along $\vec{k}$ and the y axis normal to the production plane along $\vec{k}\times\vec{k}'$. The polarized-photon asymmetry, Σ, and the unpolarized cross section, σ, are then defined by $\Sigma=(\sigma_y-\sigma_x)/(\sigma_y+\sigma_x)$ and $\sigma=(\sigma_x+\sigma_y)/2$.

The dominant lowest-order QCD subprocess involving a pointlike quark-photon vertex is expected to be $\gamma g \to c\bar{c}$. The related subprocess, $\gamma c \to gc$, is expected to make a much smaller contribution as a result of the relative magnitudes of the gluon and c-quark distributions in the target nucleon. Additional contributions from subprocesses involving the fragmentation of the photon are expected to be suppressed since some of the photon energy is lost to the beam fragments and is not then available for the production of charmed particles.[4]

The differential cross sections for photons polarized in the x or y directions are calculated to be

$$d\sigma_x/d\hat{t}=(4\pi\alpha\alpha_s/9\hat{s}^2)[A-8B(1+B)], \tag{1a}$$

$$d\sigma_y/d\hat{t}=(4\pi\alpha\alpha_s/9\hat{s}^2)A, \tag{1b}$$

where

$$A=(\hat{t}-m^2)/(\hat{u}-m^2)+(\hat{u}-m^2)/(\hat{t}+m^2)$$

and

$$B=m^2/(\hat{t}-m^2)+m^2/(\hat{u}-m^2).$$

Here a caret has been used to denote the Mandelstam variables for the subprocess. For scalar gluons A is replaced by $A+2$ and the coefficient of the B term is changed from −8 to +16. For pseudoscalar gluons the x and y cross sections are equal and are given by Eq. (1a) with A replaced by $A+2$ and the second term deleted.

In the approximation that the photon and the intial gluon are collinear in the overall center-of-mass system the invariant cross section for the production of a c or $\bar{c}$ jet is given simply by

$$E\frac{d^3\sigma_i}{dp^3}=\frac{2}{\pi}xG(x,Q^2)\frac{d\sigma_i}{d\hat{t}}\frac{1}{1-\rho_Te^y},\quad i=x,y, \tag{2}$$

where y is the center-of-mass rapidity of the jet,

$$x=\frac{\rho_Te^{-y}}{1-\rho_Te^y},\quad \rho_T=\frac{(m^2+p_T^2)^{1/2}}{2P},\quad P=\frac{(s-M^2)}{2\sqrt{s}},$$

with the target mass denoted by M. The subprocess Mandelstam variables are given by $\hat{s}=4xP^2$ and $\hat{t}=m^2-4P^2\rho_Te^{-y}$ with $\hat{s}+\hat{t}+\hat{u}=2m^2$. The factor of 2 in Eq. (2) reflects the fact that in the fully inclusive jet cross section either a c or a $\bar{c}$ can be detected. Under the assumption that each jet fragments into one charmed particle, i.e., with neglect of additional $c\bar{c}$ pairs formed in the fragmentation process, Eq. (2) can be integrated over the allowed p_T and rapidity range to obtain the total inclusive cross section for producing charmed particles.

For the purpose of obtaining numerical estimates a charmed-quark mass of 1.5 GeV/c^2 has been used. The kinematic boundary has been calculated with a D-meson mass of 1.86 GeV/c^2 and the target-nucleon mass has been retained. The strong running coupling constant has been taken to be $\alpha_s(Q^2)=12\pi/25\ln(Q^2/\Lambda^2)$ with $\Lambda=0.4$ GeV/c and $Q^2=\hat{s}$. Two gluon distributions have been used corresponding to the forms given by Owens and Kimel[5] and by Feynman, Field, and Fox.[6] At $Q_0^2=4$ (GeV/c)^2 the input parametrizations are $xG(x,Q^2)=2.672(1-x)^5$ and $0.892(1+9x)(1-x)^4$, respectively. The Q^2 dependence has been calculated as in Ref. 5.

In Fig. 1 predictions are given for $d\sigma/dy$ and Σ integrated over the region $p_T\geq 1$ for photon momenta of 20 and 200 GeV/c. The cross-hatched area indicates the uncertainty resulting from the two different gluon distributions. The flatter distribution gives a larger cross section near threshold and a smaller cross section asymptotically than does the steeper one. Integrating over y in the figure gives cross sections of 5 (15) and 622 (546) nb for the solid (dashed) curves at 20 and 200 GeV/c, respectively. For comparison, the corresponding cross sections integrated over all p_T are 35 (77) and 1220 (954) nb. These results are compatible with the predictions for the $c\bar{c}$ pair cross section given by Jones and Wyld[7] and by Gluck and Reya.[8]

The asymmetry shown in the figure is quite

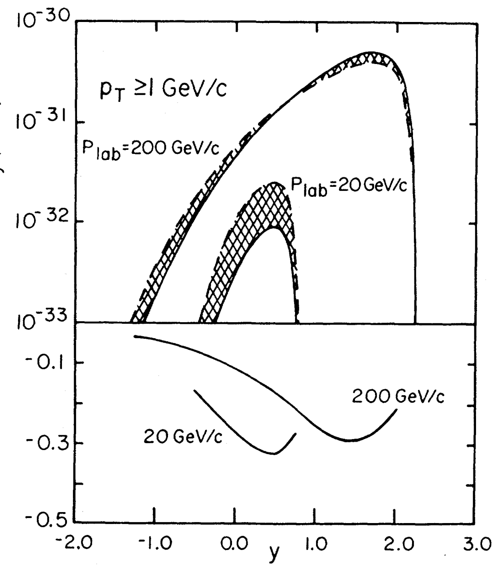

FIG. 1. Predictions for $d\sigma/dy$ and Σ in charm photoproduction at photon momenta of 20 and 200 GeV/c. The solid and dashed lines correspond to the $(1-x)^5$ and $(1+9x)(1-x)^4$ gluon distribution forms, respectively.

large over the same region where the cross section is large. According to Eqs. (1) and (2) the asymmetry is proportional to B and, hence, at fixed ρ_T and y it decreases with increasing s as m^2/s. However, if y is increased as s increases the curves in the figure show that the maximum asymmetry is a slowly varying function of x. This asymmetry should, therefore, be measurable over a large energy range.

The asymmetry for scalar gluons is also large and it has the opposite sign while the result for pseudoscalar gluons is zero. A measurement of the asymmetry can, therefore, aid in providing a determination of the spin of the gluon.

The restriction to $p_T\geq 1$ GeV/c in the figure has been made for several reasons. First, the asymmetry, Σ, measures a correlation between the photon polarization vector and the event plane containing the c and $\bar{c}$ jets. This plane will also coincide approximately with that plane which contains the charmed particles, provided that the p_T of the detected charmed particle is greater than the average transverse momentum associated with the fragmentation process. For small values of p_T we expect that the correlation will be smeared by the fragmentation process and, accordingly, that Σ will go to zero. Of course, the asymmetry has a kinematic zero[9] at $p_T=0$ and vanishes as p_T^2. The second reason for requiring

$p_T \geq 1$ GeV/c is that charmed hadrons from vector-dominance processes, which are expected to be primarily diffractive, should be produced preferentially at modest p_T values and their influence can be minimized by making such a cut.

The cross-section estimate obtained using Eq. (2) ignores two potentially important effects: the enhancement from parton k_T-smearing effects and the suppression due to the charmed-quark fragmentation function. These effects are the most significant for the cross section at fixed large p_T values, but they are less important when a large range of p_T is integrated over as was done above. Furthermore, the two effects will tend to offset each other. Accordingly, we believe that the cross-section estimates given previously should be reasonably reliable.

We have shown that lowest-order QCD predicts a large linearly polarized photon asymmetry for charmed-particle photoproduction. Linearly polarized photon beams exist at Stanford Linear Accelerator Center and at CERN and one could be constructed at Fermilab. Charmed-particle searches will be performed in the near future at each of these facilities and we strongly urge that a linearly polarized photon beam be used.

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[1]D. Sivers, in *High Energy Physics with Polarized Beams and Polarized Targets—1979*, edited by G. H. Thomas, AIP Conference Proceedings No. 51 (American Institute of Physics, New York, 1979).

[2]G. L. Kane, J. Pumplin, and W. Repko, Phys. Rev. Lett. 41, 1689 (1978).

[3]A. Devoto *et al.*, Phys. Rev. Lett. 43, 1062 (1979).

[4]J. F. Owens, Phys. Rev. D 21, 54 (1980).

[5]J. F. Owens and J. D. Kimel, Phys. Rev. D 18, 3313 (1978).

[6]R. P. Feynman, R. D. Field, and G. C. Fox, Phys. Rev. D 18, 3320 (1978).

[7]L. M. Jones and H. W. Wyld, Phys. Rev. D 17, 759 (1978).

[8]M. Glück and E. Reya, Phys. Lett. 79B, 453 (1978).

[9]G. R. Goldstein and J. F. Owens, Nucl. Phys. B103, 145 (1976).

Spin from Isospin in SU(5)

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The possibility of the charge-monopole systems with half-integer spin in the grand unified SU(5) model is investigated and found to occur.

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Several years ago it was noticed[1] that quantum excitations of an isospin-$\frac{1}{2}$ field in the presence of a 'tHooft–Polyakov monopole produced a field configuration with half-integer angular momentum. The particular case considered was a Yang-Mills SU(2) gauge theory spontaneously broken by a Higgs triplet in the adjoint representation, and containing an auxiliary Higgs doublet in the fundamental representation. The net angular momentum of the monopole-isodoublet system is a half-integer, even though the Lagrangian contains no fermionic field operators. If this system has a bound state, it is expected to obey Fermi statistics.[2]

It is of interest that the phenomenologically realistic SU(5) theories contain just the ingredients to produce this phenomenon. In the Georgi-Glashow SU(5) model[3] a two-stage symmetry breaking scheme

$$SU(5) \to SU(3)_c \otimes SU(2) \otimes U(1) \to SU(3)_c \otimes U(1)_{em}$$

is achieved by introducing a 24-plet of real Higgs fields φ and a quintuplet of complex Higgs fields H which develop vacuum expectation values via an appropriate potential $V(\varphi, H)$. The first stage is effected by the 24-plet (which is heavier than the quintuplet) and occurs at a higher temperature. In the following we will consider the theory in the phase defined by $SU(3)_c \otimes SU(2) \otimes U(1)$, i.e., at a temperature above the phase transition where $SU(2) \otimes U(1) \to U(1)_{em}$. This theory admits monopole solutions composed of the Yang-Mills and adjoint Higgs field. As shown by Kibble and others,[4] these monopoles are produced as physi-

