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Photoproduction of charmed vector mesons, $\gamma+N\to\mathcal{B}_c+\overline{D^*}$, with $\mathcal{B}_c=\Lambda_c$ or Σ_c

Michail P. Rekalo*
Physics Department, Middle East Technical University, Ankara 06531, Turkey

Egle Tomasi-Gustafsson
DAPNIA/SPhN, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France

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The energy and the angular dependences of associative vector charmed D^*-meson photoproduction, $\gamma+N\to\mathcal{B}_c+\overline{D^*}$, with $\mathcal{B}_c=\Lambda_c$ or Σ_c, have been predicted in the framework of the pseudoscalar D-meson exchange model. The behavior of the cross section is driven by phenomenological form factors, which can be parametrized in terms of two independent parameters. The predicted values of the cross section are sizable enough to be measured in the near threshold region.

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I. INTRODUCTION

It is well known that, due to the small mass difference between the vector $D^*(2.010)^{\pm}$, $D^*(2.007)^0$, and the pseudoscalar $D^{\pm}$, D^0 charmed mesons, the radiative decay $D^*\to D+\gamma$ is very important for the neutral D^0 (BR$\simeq$40%) where it is negligible for the charged $D^{*\pm}$ (BR$\simeq$1%), in comparison with the pion decay $D^{*\pm}\to D+\pi$. Therefore, the absolute value of the transition magnetic moment (TMM) for the decay $D^*\to D+\gamma$ allows us to determine the value of the radiative width $\Gamma(D^*\to D\gamma)$ for the neutral and charged vector mesons, and, consequently, to find the total widths of the vector D^* meson. Only recently, the CLEO Collaboration measured the total width for D^{*+} [1]:

$$\Gamma(D^{*+})=(96\pm4\pm22)\ \text{keV}.$$

Using the known value for the branching ratio of the radiative decay $\Gamma(D^{*+})\to D^*+\gamma$ [2],

$$\text{BR}(D^*\gamma)=(16.8\pm0.42\pm0.49\pm0.03)\%,$$

one can find the width $\Gamma(D^{*+}\to D^*+\gamma)$ and the corresponding TMM. In contrast, only the upper limit is known for the total width of the neutral D^{*0}: $\Gamma(D^{*0})\leqslant 2.1$ MeV [3].

These TMM's, which are generally different for the quoted decays $D^{*\pm}\to D^{\pm}+\gamma$ and $D^{*0}\to D^0+\gamma$, are particularly interesting for testing the predictions of many theoretical approaches [4–19], such as, for example, the quark model, dispersion sum rules, or heavy quark effective theory (HQET). Knowledge of these magnetic moments can also allow us to predict the branching ratio for the conversion decay $D^*\to D+e^++e^-$ [19].

The standard method to determine the radiative widths $\Gamma(D^*\to D\gamma)$ through the Primakoff effect, which has been successfully used for the decays $\rho\to\pi+\gamma$ and $A\to\pi\gamma$, cannot be applied here, due to the short decay time of the D meson [$\tau(D)\simeq10^{-13}$ s [3]]. In order to study these TMM's a unique way is represented by the associative photoproduction of charmed particles, for example, by the process $\gamma+p\to\Lambda_c$ $(\Sigma_c)+\overline{D_c}$, near threshold. The large threshold ($E_\gamma\simeq9$ GeV) will allow us to investigate these reactions, after the upgrade of the electron accelerator at the Jefferson Laboratory (JLab) [20].

The cross section for such processes, in the near threshold region, has been estimated in the framework of the effective Lagrangian approach (ELA) and the predicted values are sizable enough to be experimentally accessible [21]. Moreover, it was shown that the angular dependence of the differential cross section and the Σ asymmetry (with linearly polarized photons), for the reaction $\gamma+p\to\Lambda_c+\overline{D_c^0}$, are sensitive to the value of the TMM of the Λ_c hyperon.

The ELA has been used recently in other studies of charm particle production, such as $J/\psi+\pi(\rho)\to D+\overline{D}(D^*)$ or $J/\psi+N\to\Lambda_C+\overline{D}$ [22–25].

Our aim here is to consider the processes of associative charm production of vector mesons and to study the sensitivity of the differential and total cross sections to the TMM in the $D^*\to D$ vertex in the case of pseudoscalar D exchange.

II. D EXCHANGE IN $\gamma+N\to\mathcal{B}_c+\overline{D^*}$

The processes $\gamma+N\to\Lambda_c(\Sigma_c)+\overline{D^*}$ are the simplest two-body reactions of photoproduction of the charmed vector $D^*(2010)$ meson on nucleons. Their threshold is high: $E_\gamma=9.361\,(10.144)$ GeV for Λ_c (Σ_c) production.

In order to discuss the reaction mechanism for the reaction $\gamma+N\to\mathcal{B}_c+\overline{D^*}$ (with $\mathcal{B}_c=\Lambda_c$ or Σ_c) in the near threshold region, we will proceed by analogy with other vector meson photoproduction processes, such as $\gamma+N\to N+V, V=\rho,\omega,\phi$, and $\gamma+N\to K^*+\Lambda$ (Σ). In the case of neutral vector meson photoproduction the diffractive mechanism dominates at large photon energies. It is characterized by specific properties such as an energy independent cross section and an exponential decrease of the differential cross sec-

*Permanent address: National Science Center KFTI, 310108 Kharkov, Ukraine.

tion with momentum transfer squared t. In the near threshold region other mechanisms are more important: in the case of ω photoproduction the one-pion exchange dominates, whereas in the case of ρ photoproduction, due to the small $\rho\pi\gamma$ coupling constant, the scalar σ exchange [26] has to be considered. Taking the coupling constant $g_{\rho\sigma\gamma}$ as a fitting parameter, it is possible to reproduce the t dependence of the differential cross section for the process $\gamma+p\to p+\rho^0$ in the near threshold region. However, a direct measurement of the $\rho\to\sigma^0\gamma$ decay [27] gives an experimental value of the $g_{\rho\sigma\gamma}$ constant smaller than the fitted value [26], which is necessary to reproduce the absolute value of the differential cross section for the process $\gamma+p\to p+\rho^0$ at $E_\gamma\leqslant 2$ GeV. One could still reproduce the data by increasing the value of the coupling constant for the σNN vertex.

In the case of $\rho^{\pm}$- or K^*-meson photoproduction, the diffractive mechanism is forbidden, for any kinematical condition. This applies also to the process $\gamma+N\to\mathcal{B}_c+\overline{D^*}$. For this last process we can conclude that the pseudoscalar D exchange has to dominate, in analogy with π or K exchange for $\gamma+p\to p+\omega$ or $\gamma+p\to K^*+\Lambda$ (Σ).

In principle, in addition to meson exchange, other mechanisms can occur. For example, nucleon resonances N^* strongly contribute in the resonance region, for strange particle or vector meson photoproduction [28]. On the contrary, the threshold for the process $\gamma+N\to\mathcal{B}_c+\overline{D^*}$ is so large that there is no physical reason to include these processes. One might consider, for $\gamma+p\to\Lambda_c+\overline{D^*}$, the one-baryon exchange in the s and u channels as was done in [21] for the photoproduction of pseudoscalar D mesons, $\gamma+N\to\mathcal{B}_c+\overline{D}$. However, we will not include the calculation of these two diagrams in our model. The reason is that these contributions contain at least two unknown coupling constants in the vertex $N\mathcal{B}_c\overline{D^*}$ [corresponding to the Dirac (vector) and Pauli (tensor) interactions], essentially decreasing the predictive power of the model. Moreover, previous experience with similar diagrams in the case of the processes $\gamma+N\to N+\rho(\omega)$ showed that these contributions are not essential in the differential and total cross sections.

III. PHOTOPRODUCTION OF VECTOR MESONS, $\gamma+N\to\mathcal{B}_c+\overline{D^*}$, WITH $\mathcal{B}_c=\Lambda_c$ OR Σ_c

The TMM's for $D^*\to D+\gamma$ decays determine the matrix element for the exclusive process $\gamma+N\to\mathcal{B}_c+\overline{D^*}$, when pseudoscalar D exchange [Fig. 1(a)] is considered in complete analogy with π exchange for the process $\gamma+N\to N+V^0$, $V^0=\rho$ or ω. The pseudovector D^*-meson photoproduction seems preferable to the pseudoscalar D-meson photoproduction for determination of the coupling constant $g_{D^*D\gamma}$, because, in the first case, there is only one strong coupling constant $g_{N\mathcal{B}_cD}$ instead of two (for the process $\gamma+N\to\mathcal{B}_c+\overline{D}$).

The matrix element for $\gamma+N\to\mathcal{B}_c+\overline{D^*}$, in the framework of D exchange, can be written in the following form:

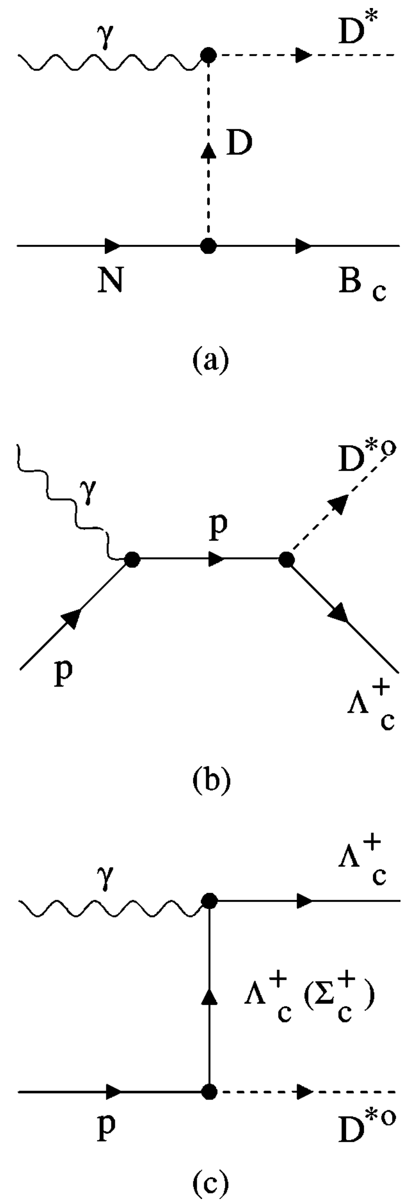

FIG. 1. Feynman diagrams for D^* photoproduction: (a) D exchange for $\gamma+N\to\mathcal{B}_c+\overline{D^*}$; (b) s-channel proton exchange for $\gamma+p\to\Lambda_c^++\overline{D^{0*}}$; (c) u-channel Λ_c^+ (Σ_c^+) exchange for $\gamma+p\to\Lambda_c^++\overline{D^{0*}}$.

$$\mathcal{M}_t(\gamma N\to\mathcal{B}_c\overline{D^*})=\frac{ie}{m_{D^*}}\frac{g_{D^*D\gamma}}{t-m_D^2}g_{N\mathcal{B}_cD}\overline{u}(p_2)\times\gamma_5 u(p_1)\epsilon_{\alpha\beta\gamma\delta}e_\alpha k_\beta U_\gamma q_\delta, \quad (1)$$

where $U_\gamma(e_\alpha)$ is the four-vector of the produced D^*-meson (initial γ) polarization, $U\cdot q=0$ $(e\cdot k=0)$, k and q are the four-momenta of γ and D^*, $t=(k-q)^2$, m_D (m_D^*) is the mass of the D (D^*) meson, and $g_{D^*D\gamma}$ $(g_{N\mathcal{B}_cD})$ is the coupling constant for the vertex $D^*\to D\gamma$ $(N\to\mathcal{B}_cD)$.

After summing over the polarizations of the final particles ($\overline{D^*}$ and $\mathcal{B}_c$) and averaging over the polarizations of the

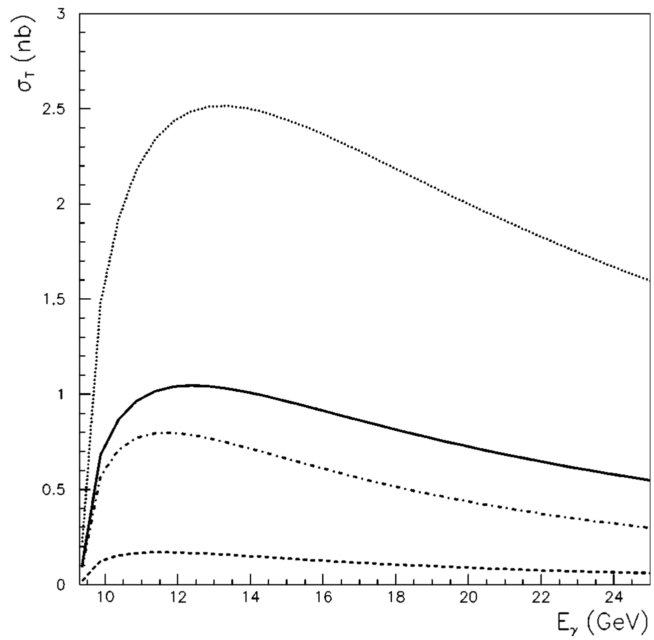

FIG. 2. Energy dependence of the total cross section $\sigma_T = \int \sigma(\vartheta) d\Omega$, for the reaction $\gamma + p \to \Lambda_c^+ + \overline{D^{*0}}$. Different curves correspond to different values of n and Λ: $n=1$ and $\Lambda=2$ (solid line), $n=2$ and $\Lambda=2$ (dashed line), $n=1$ and $\Lambda=3$ (dotted line), $n=2$ and $\Lambda=3$ (dash-dotted line).

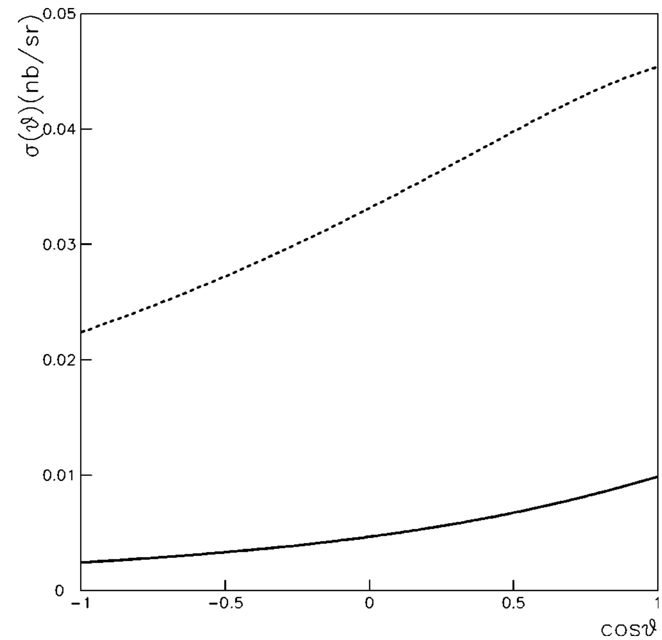

FIG. 3. $\cos\vartheta$ dependence of the differential cross section $\sigma(\vartheta) \equiv (d\sigma/d\Omega)/(g^2_{N\mathcal{B}_cD} g^2_{D^*D\gamma})$ for the reaction $\gamma + p \to \Lambda_c^+ + \overline{D^{*0}}$ at $E_\gamma = 11$ GeV for $\Lambda = 2$ (solid line) and $\Lambda = 3$ (dashed line).

initial particles (γ and N) one finds the following expression for the differential cross section of $\gamma + N \to \mathcal{B}_c + \overline{D^*}$:

$$\frac{d\sigma}{d|t|} = \frac{\alpha}{16} g^2_{N\mathcal{B}_cD} \frac{g^2_{D^*D\gamma}}{(s-m^2)^2} \frac{(M-m)^2 - t}{m^2_{D^*}} \times \left(\frac{t - m^2_{D^*}}{t - m^2_D} \right)^2 F^2(t),$$

where $s = (k+p_1)^2$ and $M(m)$ is the $\mathcal{B}_c(N)$ mass. Following the analogy with one-pion exchange, it is necessary to introduce in the expression of the cross section a t-dependent form factor $F(t)$, normalized to unity, for $t = m^2_D$:

$$F(t) = \frac{1}{[1 - (t - m^2_D)/\Lambda^2]^n}, \tag{2}$$

where $n=1$ or 2 and Λ is a cutoff parameter. Such form factors are necessary ingredients of this phenomenological model and are introduced in order to improve the t behavior of the differential cross section, in the region of large values of $|t|$. In numerical estimations we will use values of Λ in the range between 1 and 3 GeV.

The energy dependence of the total cross section is reported in Fig. 2 for $\gamma + N \to \Lambda_c^+ + \overline{D^*}$. We see that this cross section sharply increases at threshold and has a maximum around 10 GeV. The position of this maximum depends slightly on the choice of the form factor.

In the near threshold region, t is not a good physical variable, as $|t_{min}(\cos\vartheta = 1)| \simeq m^2_D \simeq 4$ GeV^2; therefore the differential cross section $d\sigma/d\Omega$ is preferable. This observable is reported in Fig. 3 for $n=2$, considering two different values for the parameter Λ, $\Lambda = 2$ and 3 GeV.

Note that in the framework of the considered model, for $\gamma + N \to \mathcal{B}_c + \overline{D^*}$ the absolute value of the cross section is determined by the product $g_{D^*D\gamma} g_{N\mathcal{B}_cD}$ of the electromagnetic and strong coupling constants, whereas the shape of the t dependence of the differential cross section and the energy behavior of the total cross section are driven only by the parameters of the phenomenological form factors, n and Λ, which can therefore be determined from the experimental data, when available. Having determined the correct form factor, the product of the coupling constants $g_{D^*D\gamma} g_{N\mathcal{B}_cD}$ can be derived from the absolute value of the differential cross section (for fixed values of $\cos\theta$ and E_γ). Finally, the ratio of cross sections on proton and neutron targets will help to determine separately the electromagnetic and strong coupling constants:

$$\frac{d\sigma(\gamma n \to \overline{D^{*-}} \Lambda_c^+)}{d\sigma(\gamma p \to \overline{D^{*0}} \Lambda_c^+)} = \frac{g^2_{D^{*-}D^-\gamma}}{g^2_{D^{*0}D^0\gamma}}. \tag{3}$$

The results of the SLAC experiment [29] concerning open charm photoproduction at $E_\gamma = 20$ GeV constrain the values of the coupling constants and the choice of the form factor $F(t)$. At this energy, it is found that the probability of D^* production per charm event is 0.17 ± 0.11. The total cross section for charm photoproduction being 56 nb, the upper limit for the cross section of $\gamma + p \to \Lambda_c^+ + \overline{D^{*0}}$ can be estimated to be of the order of 10 nb.

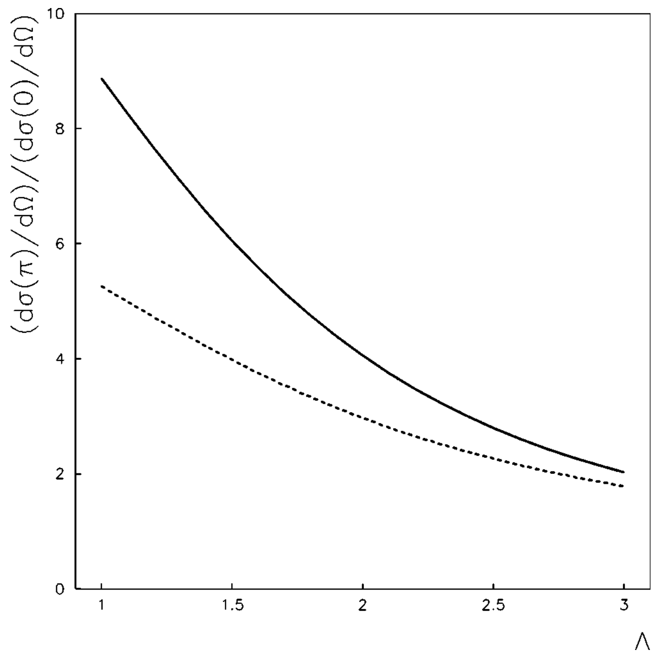

FIG. 4. Dependence of the backward-forward asymmetry for the processes $\gamma+p\to\Lambda_c^+ +\overline{D^{*0}}$ (solid line) and $\gamma+p\to\Sigma_c^+ +\overline{D^{*0}}$ (dashed line) as a function of Λ at $E_\gamma=11$ GeV.

So, from our calculation (see Fig. 3) we can estimate the product of the strong and electromagnetic coupling constants, $R=g^2_{D^{*0}D^0\gamma}g^2_{N\Lambda_cD}$, for different choices of the phenomenological form factor $F(t)$: $R_{expt}\leqslant 20$ (for $n=2$ and $\Lambda=3$ GeV), and $R_{expt}\leqslant 100$ (for $n=2$ and $\Lambda=2$ GeV). These numbers may be compared with some conservative theoretical estimates for the value R.

Taking into account that most theoretical predictions [4–19] are consistent with the value of the radiative width $\Gamma(D^{*0}\to D^0\gamma)\geqslant 10$ keV, one can deduced a ‘‘theoretical’’ value for the ratio R, $R_{th}\geqslant 1300$, i.e., $R_{th}\gg R_{expt}$, for any parametrization of the form factor $F(t)$. In particular the value $n=1$ should be excluded; for $n=2$ the smallest value of the cutoff parameter λ seems preferable. But even for $n=2$ and $\Lambda=2$ GeV, we find $g_{N\Lambda_cD}<1$, in large disagreement with SU(4), which predicts the same value for the coupling constants $g_{N\Lambda_cD}$ and $g_{N\Lambda K}$. This last constant has been estimated from analysis of the processes of photoproduction of strange particles on nucleons [30] to be in the interval $13.2\leqslant|g_{N\Lambda K}|\leqslant 15.7$. QCD sum rules [31] predict a smaller value for this constant, $g_{N\Lambda K}=6.7\pm 2.1$. Note that most calculations for processes like $J/\psi+N\to\Lambda_c+D$ in connection with the interpretation of the quark gluon plasma rely on SU(4) symmetry [32].

Taking the form factor with $n=2$ and $\Lambda=2$ GeV, we predict a maximal value of the cross section for $\gamma+p\to\Lambda_c^+ +\overline{D^{*0}}$ of 20 nb, in the near threshold region. The upgraded JLab, with a tagged photon beam of luminosity $\mathcal{L}=10^{-29}$–10^{-30} cm^{-2} s^{-1}, can investigate such processes.

In Fig. 4 we show the sensitivity of the backward-forward asymmetry to Λ, for $n=2$.

In order to test the proposed model, polarization phenomena in $\gamma+p\to\Lambda_c^+ +\overline{D^{*0}}$ will be very useful. Polarization effects can easily be predicted. For example, the beam asymmetry Σ induced by linear polarization of the photon beam vanishes, for any choice of the phenomenological form factors and for any values of the coupling constants, independent of kinematical conditions. The polarization of the produced D^* is characterized by a single nonzero element of the density matrix, $\rho_{11}=1/2$, with a $\sin^2\theta_D$ distribution for $D^*\to D+\pi$, where θ_D is the angle between the three-momenta of D and the initial γ, in the $\overline{D^*}$ rest frame system. Because of the fact that the D-exchange amplitudes are real, all T-odd polarization effects are identically zero. However, these observables do not vanish, if one takes into account the strong final $\overline{D^*}\Lambda_c$ interaction, which might play a role near the reaction threshold. Another source of T-odd effects is the unitarity condition in the s channel, due to the large number of possible intermediate states in $\gamma+p\to\Lambda_c+\overline{D^*}$, even in the threshold region.

IV. ESTIMATION OF BARYON-EXCHANGE CONTRIBUTIONS

The matrix elements for the s- and u-channel baryon exchange [Fig. 1(b) and Fig. 1(c)] for the process $\gamma+p\to\Lambda_c^+ +\overline{D^{*0}}$ can be written in the following form:

$$\mathcal{M}_s=\frac{e}{s-m^2}\overline{u}(p_2)\left(g_V\hat{U}+g_T\frac{\hat{U}\hat{q}}{m+M}\right)\times(\hat{f}_1+m)\left(\hat{\epsilon}-\kappa_p\frac{\hat{\epsilon}\hat{k}}{2m}\right)u(p_1), \quad (4)$$

$$\mathcal{M}_u=\frac{e}{u-M^2}\overline{u}(p_2)\left(\hat{\epsilon}-\kappa_\Lambda\frac{\hat{\epsilon}\hat{k}}{2M}\right)\times(\hat{f}_2+M)\left(g_V\hat{U}+g_T\frac{\hat{U}\hat{q}}{m+M}\right)u(p_1), \quad (5)$$

where $f_1=k+p_1$, $f_2=k-p_2$, $s=f_1^2$, $u=f_2^2$, g_V and g_T are the vector and tensor coupling constants for the $N\Lambda_cD^*$ vertex, and κ_p and κ_Λ are the anomalous magnetic moments of the proton and Λ_c^+ hyperon. Note that the sum of these contributions, $\mathcal{M}_s+\mathcal{M}_u$, satisfies the gauge invariance of the electromagnetic interaction for any values of the coupling constants g_V and g_T, and for any value of κ_p and κ_Λ as well.

In the u channel another baryon exchange, Σ_c^+ [Fig. 1(c)] is possible. This contribution to the total matrix element is determined by two additional combinations of fundamental constants, namely, $\kappa_{\Lambda_c\Sigma_c}g'_V$ and $\kappa_{\Lambda_c\Sigma_c}g'_T$, where g'_V and g'_T are the vector and tensor coupling constants for the $N\Sigma_cD^*$ vertex and $\kappa_{\Lambda_c\Sigma_c}$ is the magnetic moment of the $\Lambda_c\to\Sigma_c$ magnetic transition, the charm analogue of the well-known $\Lambda^0\to\Sigma^0$ transition for strange hyperons.

So, generally, the baryon exchanges for $\gamma+p\to\Lambda_c^+ +\overline{D^{*0}}$ are characterized by four unknown coupling constants, g_V and g_T for the $N\Lambda_cD^*$ vertex and g'_V and g'_T for the $N\Sigma_c D^*$ vertex. In principle, SU(4) symmetry allows one to relate these constants to the corresponding coupling constants for strange particles: $g_{p\Lambda K^*}$ and $g_{p\Sigma K^*}$. However, this is meaningless, because, as we proved above, SU(4) symmetry is strongly violated for $g_{p\Lambda K}$ and $g_{p\Lambda_c\bar{D}}$ coupling constants. Moreover, the coupling constants for $g_{p\Lambda K^*}$ and $g_{p\Sigma K^*}$ vertexes are not well determined experimentally, although their value can be estimated on the basis of models for strange particle photoproduction, $\gamma+p\to Y+K$, $Y=\Lambda$ or Σ.

Therefore, in order to simplify our estimation we will neglect the u-channel Σ^+ exchanges (due to the relatively small difference in masses of the Λ_c^+ and Σ_c^+ hyperons, it is in principle possible to use an effective contribution, renormalizing the product of the coupling constants $\kappa_\Lambda g_V$ and $\kappa_\Lambda g_T$), and we shall neglect the tensor contributions to the electromagnetic and strong vertices. Moreover, we will compare the relative roles of the D contribution and the baryon contributions at the level of amplitudes (not of observables). This comparison can be done in exact form, in the threshold region, where the final particles are produced in the S state. The conservation of angular momentum and P parity allows three multipole transitions:

$$E1\to\mathcal{J}^P=1/2^- \quad \text{and} \quad 3/2^-, \quad M2\to\mathcal{J}^P=3/2^-$$

with the following spin structure of the threshold matrix element:

$$\mathcal{M}_{th}=\phi_2^\dagger[F_1\vec{\epsilon}\cdot\vec{U}+iF_2\vec{\sigma}\cdot\vec{\epsilon}\times\vec{U}+iF_3\vec{\sigma}\cdot\vec{\epsilon}\times\hat{k}]\phi_1, \quad (6)$$

where $\vec{\epsilon}$ ($\vec{U}$) is the three-vector of the photon (D^*-meson) polarization, $\hat{k}$ is the unit vector along the photon three-momentum, ϕ_1 and ϕ_2 are the two-component spinors of the initial and final Λ_c^+ hyperons, and F_1–F_3 are the threshold amplitudes, which are functions of the total energy W (with $s=W^2$).

Note that the representation (6) is the most general model independent parametrization of the spin structure for the threshold matrix element of the process $\gamma+p\to\Lambda_c^+ +\overline{D^{*0}}$. Far from the threshold, the spin structure of the matrix element for vector meson production on nucleons generally contains 12 independent combinations of the vector polarizations $\vec{\epsilon}$ and $\vec{U}$ and of the two-component spinors ϕ_1 and ϕ_2. Let us rewrite the expression (6) in terms of the spin structures corresponding to the three multipole transitions:

$$\mathcal{M}_{th}=\phi_2^\dagger[e_1(\vec{\epsilon}\cdot\vec{U}-i\vec{\sigma}\cdot\vec{\epsilon}\times\vec{U}) +e_3(2\vec{\epsilon}\cdot\vec{U}+i\vec{\sigma}\cdot\vec{\epsilon}\times\vec{U}) \quad (7)$$

$$+im_3(\vec{\sigma}\cdot\vec{\epsilon}\times\hat{k}\hat{k}\cdot\vec{U}+\vec{\sigma}\cdot\hat{k}\vec{\epsilon}\times\hat{k}\cdot\vec{U}.)]\phi_1, \quad (8)$$

where e_1 and e_3 are the multipole amplitudes corresponding to the absorption of the electric dipole γ quantum, with production of final particles in states with $\mathcal{J}^P=1/2^-$ and $3/2^-$, respectively, and m_3 is the multipole amplitude for the absorption of the magnetic quadrupole γ quantum, corresponding to a $\mathcal{J}^P=3/2^-$ final state.

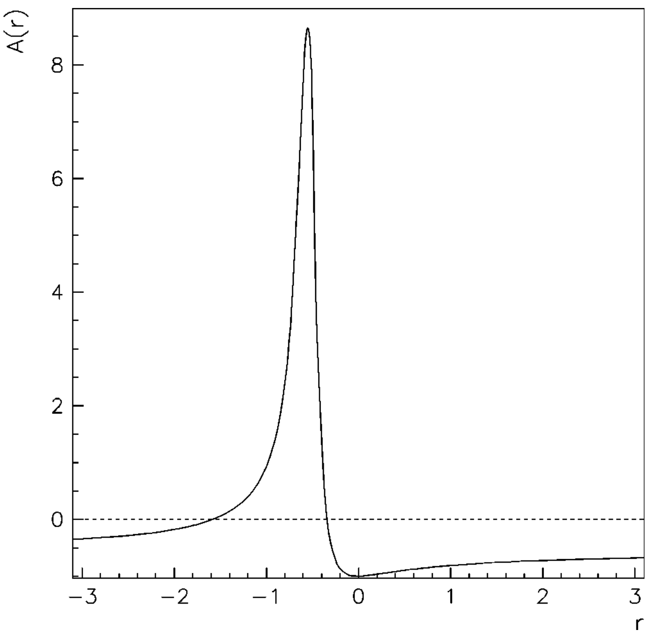

FIG. 5. Dependence of A on the parameter r; see Eq. (10).

Using the expressions (1), (4), and (5) for the matrix elements $\mathcal{M}_t$, $\mathcal{M}_s$, and $\mathcal{M}_u$, one can find the following formulas for the multipole amplitudes e_1, e_3, and m_3 (in the framework of the model considered):

$$e_1=\frac{eg^*}{6}\sqrt{\frac{M}{W}}\left(\frac{W-m}{m_{D^*}}+r\frac{m+3M}{M}\right),$$

$$e_3=-\frac{eg^*}{12}\sqrt{\frac{M}{W}}\left(\frac{W-m}{m_{D^*}}+r\frac{m+3W}{M}\right), \quad (9)$$

$$m_3=\frac{eg^*}{4}\sqrt{\frac{M}{W}}\left(\frac{W-m}{m_{D^*}}-r\frac{m-W}{M}\right),$$

where $g^*=g_{D^0*D^0\gamma}g_{p\Lambda_c D}$ and $r=2g_v/g^*$. These formulas explicitly show the spin structure of all considered diagrams at threshold. One can see also that these diagrams interfere in the differential cross section as well as in polarization effects. The s-channel diagram contributes to the e_1 amplitude only.

The main problem is the value of the parameter r, i.e., the ratio of the coupling constants for the $N\Lambda_c D$ and $N\Lambda_c D^*$ vertices. In principle, the ratio r could be estimated in the framework of SU(4) symmetry, connecting the coupling constants for the $N\Lambda_c D(D^*)$ and $N\Lambda K(K^*)$ vertices, but the existing estimations of the coupling constants for the K (K^*) meson are strongly model dependent, and may take values in a wide interval. Moreover, SU(4) symmetry is essentially violated. Therefore, any quantitative, rigorous estimation of the baryon-exchange contributions to the different observables for $\gamma+p\to\Lambda_c^* +\overline{D^{*0}}$ cannot presently be done.

However, the parameter r can be experimentally determined in future, from a study of the angular dependence of the decay products in $D^*\to D+\pi$ (D^* is a self-analyzing particle). Even in collisions of unpolarized particles $\gamma+p\to\Lambda_c^+ + \overline{D^{*0}}$, D^* is polarized near threshold. The normalized density matrix for D^*, produced in the S state, can be written in the following form:

$$\rho_{ab}=k_a k_b+\rho(\delta_{ab}-3\hat{k}_a\hat{k}_b),$$

where the real dynamical parameter ρ determines the angular dependence in $D^*\to D+\pi$:

$$W(\theta_D)=\rho(1+A\cos^2\theta_D)$$

with

$$A=\frac{1-3\rho}{\rho}=-1+\Delta, \tag{10}$$

and Δ can be written in terms of the multipole amplitudes as

$$\Delta=2\frac{|e_1-e_3-m_3|^2}{|e_1+2e_3|^2+|e_1-e_3+m_3|^2}.$$

In the model considered, Eqs. (9), A depends only on the ratio r (see Fig. 5) with an essential sensitivity to r, in particular in the region where r is negative. Note that at $r=0$ (for D exchange only) we have $A=-1$, i.e., the expected $\sin^2\theta_D$ dependence.

V. CONCLUSIONS

We have calculated the differential and total cross sections for associative charm photoproduction of vector $\overline{D^*}$, through a pseudscalar D-meson exchange model, in analogy with light vector meson (ρ,ω) and strange K^* photoproduction.

We introduced phenomenological form factors with a larger cutoff parameter in comparison with the usual value for ρ,ω meson photoproduction. We found large sensitivity of the differential and total cross sections for $\gamma+p\to\Lambda_c+\overline{D^*}$ to the value of the cutoff parameter.

Finally, we found sizable values for the cross section in the threshold region and predicted the energy dependence for these reactions, which will be experimentally accessible in the near future. The existing experimental data on charm photoproduction at $E_\gamma=20$ GeV allow one to constrain the value of the $g_{N\mathcal{B}_cD}$ coupling constant and the parameters of the phenomenological form factor $F(t)$ as well.

The baryon contributions have also been estimated in terms of one parameter r, which can be experimentally determined through the measurement of the angular dependence of the D^*-decay products.

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