Associative open charm photoproduction $\gamma + N \to Y_c + \overline{D}_c(\overline{D}^*_c)$, $Y_c = \Lambda_c^+$ or Σ_c

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We analyze polarization effects in associative photoproduction of pseudoscalar ($\overline{D}_c$) and vector ($\overline{D}^*_c$) charmed mesons in exclusive processes $\gamma + N \to Y_c + \overline{D}_c$, $Y_c = \Lambda_c^+$, Σ_c. We calculate the differential cross section and all polarization observables in framework of an effective Lagrangian approach. In case of collinear kinematics it is possible to give model independent predictions for polarization observables in case of $\overline{D}_c$ production, and the analysis for $\overline{D}^*_c$ is largely simplified.

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1 Motivation

Photoproduction of charmed particles on nucleons has been studied since more than twenty years, mostly through inclusive reactions, in the photon energy range $E_\gamma = 20 \div 70$ GeV, i.e. far from the threshold region. The production mechanism usually assumed is the photon-gluon fusion mechanism (PGF), $\gamma + G \to c + \overline{c}$ [1], and, in this frame, $\overline{D}_c$ and $\overline{D}^*_c$ production are related to the gluon content of the nucleon: polarized reactions are a tool to measure the spin content of the nucleon which is carried by the gluons.

However, the calculation of the properties of the produced charmed mesons and baryons produced from PGF is not straightforward, as it involves assumptions on the hadronization process and the knowledge of fragmentation functions. Whereas it is possible to reproduce the inclusive cross section, the particle/antiparticle ratio, observed in the experiments, in particular near threshold, cannot be reproduced by PGF.

In principle, other mechanisms (of non-perturbative nature) should also be taken into account, such as, for example, the diffractive production of $D_c\overline{D}_c$ or $\Lambda_c D_c$ pairs, through Pomeron exchange. Different hadronic exchanges can also occur [2]. We discuss here the simplest two body reactions $\gamma + N \to Y_c + \overline{D}_c$ ($\overline{D}^*_c$), among which the reaction $\gamma + p \to \Lambda_c^+ + \overline{D}^0_c$ has the lowest threshold ($E_{thr} = 8.9$ GeV).

The differential cross section and the polarization observables for these processes can be calculated in terms of hadronic exchanges in s, t and u channels. The effective Lagrangian approach gives a very convenient frame for this study, since all the observables can be calculated with the help of few parameters, which have a definite physical meaning.

2 Model independent considerations

Let us consider the reaction: $\gamma + p \to \Lambda_c^+ + \overline{D}^0$, the spins involved are $1 + 1/2 \to 1/2 + 0$. In collinear kinematics, due to the conservation of the spin projection, the collision of γ and p with parallel spins can not take place for collinear regime. Therefore, the asymmetry in the collision of circularly polarized photons with a polarized target, takes its maximum value. This result holds for any process of pseudoscalar and scalar meson photoproduction on a nucleon target (if the final baryon has spin 1/2) and it is independent on the $\mathcal{P}$-parity of produced meson. It is a model independent result, based uniquely on the assumption of the spins of the particle, the conservation of helicity in collinear kinematics, and applies also to threshold.

We will use the standard parametrization [3] of the spin structure for the amplitude of pseudoscalar meson photoproduction on the nucleon:

$$\mathcal{M}(\gamma N \to Y_c \overline{D}_c) = \chi_2^\dagger \left[i\vec{\sigma}\cdot\vec{e} f_1 + \vec{\sigma}\cdot\hat{\vec{q}}\vec{\sigma}\cdot\hat{\vec{k}}\times\vec{e} f_2 + i\vec{e}\cdot\hat{\vec{q}}\vec{\sigma}\cdot\hat{\vec{k}} f_3 + i\vec{\sigma}\cdot\hat{\vec{q}}\vec{e}\cdot\hat{\vec{q}} f_4 \right] \chi_1, \tag{1}$$

where $\hat{\vec{k}}$ and $\hat{\vec{q}}$ are the unit vectors along the three-momentum of γ and $\overline{D}_c$; f_i, i=1,4, are the scalar amplitudes, which are functions of two independent kinematical variables, the square of the total energy s and $\cos\vartheta$, where ϑ is the $\overline{D}_c$–meson production angle in the reaction center of mass (CMS) with respect to the direction of the incident photon, χ_1 and χ_2 are the two-component spinors of the initial nucleon and the produced Y_c-baryon.

Note that the pseudoscalar nature of the $\overline{D}_c$–meson is not experimentally confirmed up to now. One can show, in a model independent way, that for the reaction $\gamma + p \to \Lambda_c^+ + \overline{D}^0$, the triple polarization correlation coefficient is sensitive to the relative parity $P(N\Lambda_c D)$ [4].

In collinear kinematics, the spin structure (1) depends on $P(N\Lambda_c D)$:

$$\mathcal{F}_{col}^{(-)} = \vec{\sigma}\cdot\vec{e} f_{col}^{(-)},\ \mathcal{F}_{col}^{(+)} = \vec{\sigma}\cdot\vec{e}\times\hat{\vec{k}} f_{col}^{(+)}, \tag{2}$$

where $f_{col}^{(\pm)}$ is the collinear amplitude for $P(N\Lambda_c D) = \pm 1$. Due to the presence of a single allowed amplitude in collinear kinematics, all polarization observables have definite numerical values, which are independent on the model chosen for $f_{col}^{(\pm)}$.

The dependence of the Λ_c polarization on the polarization of the colliding particles, can be written as:

$$-(\vec{e}\cdot\vec{e})(\vec{P}_1\cdot\vec{P}_2) + 2(\vec{e}\cdot\vec{P}_1)(\vec{e}\cdot\vec{P}_2),\ \text{ if }\ P(N\Lambda_c D) = -1,$$

$$(\vec{e}\cdot\vec{e})[(\vec{P}_1\cdot\vec{P}_2) - 2(\hat{\vec{k}}\cdot\vec{P}_1)(\hat{\vec{k}}\cdot\vec{P}_2)] - 2(\vec{e}\cdot\vec{P}_1)(\vec{e}\cdot\vec{P}_2),\ \text{if}\ P(N\Lambda_c D) = +1, \tag{3}$$

where $\vec{P}_1$ and $\vec{P}_2$ are the polarization vectors for the initial and final baryons.

One can see from (3), that only the linear photon polarization affects the triple polarization correlations in $\vec{\gamma} + \vec{p} \to \vec{\Lambda}_c^+ + \overline{D^0}$, due to the P-invariance of the electromagnetic interaction of charmed particles. Let us define the coordinate system for the considered collinear kinematics with the $z-$axis along $\hat{\vec{k}}$ and the $x-$ axis along the vector $\vec{e}$ of the photon linear polarization. From(3) one can find a connection between the components of the vectors $\vec{P}_1$ and $\vec{P}_2$ for the different $P(N\Lambda_c D)$, assuming, for simplicity, that initially one has 100% linearly polarized photons:

$$P_{2x} = +P_{1x},\ P_{2y} = -P_{1y},\ P_{2z} = -P_{1z},\ \text{ if }\ P(N\Lambda_c D) = -1,$$

$$P_{2x} = -P_{1x},\ P_{2y} = +P_{1y},\ P_{2z} = -P_{1z},\ \text{if}\ P(N\Lambda_c D) = +1, \quad (4)$$

One can see that both transversal components of the Λ_c-polarization are sensitive to $P(N\Lambda_c D)$, through the relative sign between P_{2i} and P_{1i}:

$$P_{2x} = -P(N\Lambda_c D)P_{1x},\ P_y = P(N\Lambda_c D)P_y, \quad (5)$$

whereas $P_{2z} = -P_{1z}$ for any value of $P(N\Lambda_c D)$.

Therefore, the relations (5) allow one to determine, in a model-independent way, the $D-$meson P-parity. This is a model independent result, which holds for any nucleon photoproduction of a spin 1/2 baryon and a spin zero meson. It requires the assumption on P-parity conservation in $\gamma + p \to \Lambda_c^+ + \overline{D^0}$ and helicity conservation in the collinear regime.

The measurement of the triple polarization correlations in $\vec{\gamma}+\vec{p} \to \vec{\Lambda}_c^+ + \overline{D^0}$, can be in principle realized by the Compass collaboration [5]. The Λ_c-polarization can be measured through the numerous weak decays of the Λ_c^+-hyperon, for example $\Lambda_c^+ \to \Lambda + e^+ + \nu_e$ [6], which is characterized by a large decay asymmetry. Such experiment does not need very large statistics, only well identified events, because only the relative sign of the transversal components of the polarization of the target proton and the produced Λ_c^+-hyperon is important for the determination of the $P(N\Lambda_c D)$-parity. The energy of the photon beam has not to be necessarily monochromatic.

3 Charmed pseudoscalar meson production

The differential cross section and all polarization observables can be calculated from Eq. (1). The full derivation can be found in [7].

Here we focuss on the observables which are accessible with circular polarized photon beams. Due to the P-odd nature of the photon helicity, single spin observables vanish.

The amplitudes can be calculated in framework of an Effective Lagrangian Approach (ELA).

Circular polarization manifests itself only in double spin (or more) polarization phenomena, as, for example, the correlation polarization coefficients of photon beam and proton target, $\vec{\gamma} + \vec{p} \to \Lambda_c^+ + \overline{D}_c^0$, or the polarization of the final Λ_c-hyperon in $\vec{\gamma}+p \to \vec{\Lambda}_c^+ + \overline{D}_c^0$. Note that in both cases, the components of the target polarization and the Λ_c^+ polarization lie in the reaction plane, due to the P-invariance. Note also, that all these polarization observables are T-even, i.e. they may not vanish even if the amplitudes of the considered process are real functions of kinematical variables. The charm particle photo and electroproduction at high energy is usually interpreted in terms of photon-gluon fusion, $\gamma+G \to c+\overline{c}$ (Fig. 1a). Near threshold, another possible mechanism, based on the subprocess $q+\overline{q} \to G \to c+\overline{c}$ (Fig. 1b) should also be taken into account, as it was done for πN-collisions [8]. In case of exclusive reactions, $\gamma + N \to Y_c + \overline{D}_c$ ($\overline{D}_c^*$), $Y_c = \Lambda_c, \Sigma_c$, the mechanism in Fig. 1b is equivalent to the exchange of a $\overline{c}q$-system, in t-channel (Fig. 1c). The importance of the annihilation mechanism has been investigated in [9] to explain the forward charge asymmetry in γp-collisions. The mesonic equivalent of such exchange is the exchange of pseudoscalar $\overline{D}_c$ and (or) vector $\overline{D}_c^*$ mesons, in the t-channel of the considered reaction. In order to insure the gauge invariance, baryonic exchanges in s- and u-channels have to be added, too.

To take into account the virtuality of the exchanged hadrons, form factors (FFs) are introduced in the pole diagrams. These terms decrease essentially the differential cross section, at large values of $|t|$ or $|u|$, and therefore the total cross section, especially in the near threshold region. The role of FFs is essential for such approach, as it has been proved in the analysis of vector meson or strange particle production in $NN-$ and $\Delta N-$collisions [10], but polarization phenomena are, in principle, less sensitive to FFs. Moreover, in the limiting case of $s+u+t(D_c)$ contributions (without D_c^*) or only vector D_c^*-exchange, one can see that polarization observables are independent on any phenomenological FFs, for any kinematics. Other ingredients of the model are the strong coupling constants, which involve one nucleonic vertex, $g_{NY_c\overline{D}_c}$, $g_{NY_c\overline{D}_c^*}$, and the anomalous magnetic moments κ_{Y_c}, $Y_c = \Lambda_c$ or Σ_c. Six coupling constants (three for $\gamma+N \to \Lambda_c+\overline{D}_c$ and three for $\gamma+N \to \Sigma_c+\overline{D}_c$) enter in the calculation of the different observables and therefore in their E_γ and $\cos\vartheta$ dependences, for all the possible exclusive reactions of associative charm particle photoproduction, $\gamma+N \to Y_c+\overline{D}_c$. Note that the same coupling constants enter in the description of charmed particle production in $\pi N-$ collisions: $\pi+N \to Y_c+\overline{D}_c$, $NN-$collisions: $N+N \to N+Y_c+\overline{D}_c$ and in the interaction of charmed particles with nucleons in heavy ion collisions, $D_c+N \to Y_c+P(V)$, $Y_c+N \to N+N+D_c$...

The lack of experimental data about these processes does not allow to fix these coupling constants. Therefore we rely on $SU(4)$ symmetry, and connect the necessary coupling constants with the corresponding constants for strange particle production: $g_{N\Lambda(\Sigma)K}$, $g_{N\Lambda(\Sigma)K^*}$, $\kappa_{N\Lambda(\Sigma)K^*}$, which have been determined in the analysis of experimental data on associative strange particles photo- and electroproduction [12]. We fix the cut-off parameters on the charm photoproduction data. Any fitting procedure induces a strong correlation between the cut-off parameters, therefore the solution is not unique. We also consider two other possiblities, either assuming that $SU(4)$-symmetry is strongly violated for the strong coupling constants, or taking the $SU(6)$ values of the corresponding coupling constants for the vertex $N \to \Lambda + K^*$. The model can predict the energy behavior of the total cross section for $\gamma^* + N \to Y_c + D_c$ (for proton and neutron targets), for all three versions. Therefore we normalize the total cross section for $\gamma + p \to \Lambda_c^+ + \overline{D}_c^0$, to the measured cross section of open charm photoproduction at $E_\gamma = 20$ GeV [13], where it was found that about 70 % of the total cross section can be attributed to $\gamma + p \to \Lambda_c^+ + \overline{D}_c^0$. This condition constrains very strongly the parameters for all versions of the model, as this reaction has the largest cross section. Once the parameters have been fixed, one can predict all polarization observables not only for $\gamma + p \to \Lambda_c^+ + \overline{D}_c^0$, but also for any exclusive reaction $\gamma + N \to Y_c^+ + \overline{D}_c$.

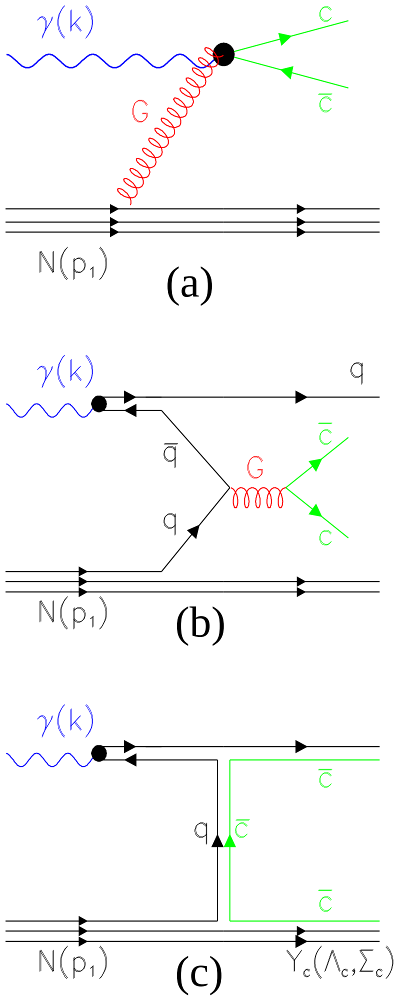

Fig. 1 Feynman diagrams for associative charm production in γN-collisions: (a) the subprocess of photon-gluon fusion $\gamma + G \to c + \overline{c}$; (b) the subprocess of $q + \overline{q}$-annihilation, $q + \overline{q} \to c + \overline{c}$; (c) $t-$channel exchange by $\overline{D}_c$ and $\overline{D}_c^*$ for $\gamma + N \to Y_c + \overline{D}_c(\overline{D}_c^*)$.

The energy dependence of the total cross section for the six exclusive processes $\gamma + N \to Y_c + \overline{D}_c$, is very different, in all photon energy range, see Fig. 2. For $E_\gamma \geq 40$ GeV, the predicted energy dependence of the total cross section becomes flat, up to $E_\gamma = 250$ GeV. One can conclude that, in this energy range, the simplest exclusive photoproduction reactions $\gamma + N \to Y_c^+ + \overline{D}_c$ contribute less than 10 % to the total cross section of open charm photoproduction. This estimation does not contradict the existing experimental data and is in agreement with the measured Λ/Λ_c asymmetry (in sign and value).
The largest cross section on the neutron target belongs to the process $\gamma + n \to \Sigma_c^0 + \overline{D}^0$, the D^- production being essentially suppressed. The D^- production is also small in the γp interaction, $\gamma + p \to \Sigma_c^{++} + D^-$, in agreement with the experiment [16]. Large isotopic effects are an expected property of ELA approach, because the relative values of s, u, and t-channel contributions are different for the different channels. Estimations of associative charm photoproduction cross sections, which have been done from experiments [13, 16, 18], are reported as open symbols in Fig. 2. Polarization effects are generally large (in absolute value), characterized by a strong $\cos\vartheta$-dependence, which results from a coherent effect of all the considered pole contributions. Large isotopic effects are especially visible in the $\cos\vartheta$-distributions for all these observables [7].

In the considered model, the asymmetry Σ_B is positive in the whole angular region, in contradiction with the predictions of PGF [19] and in agreement with the SLAC data [13].

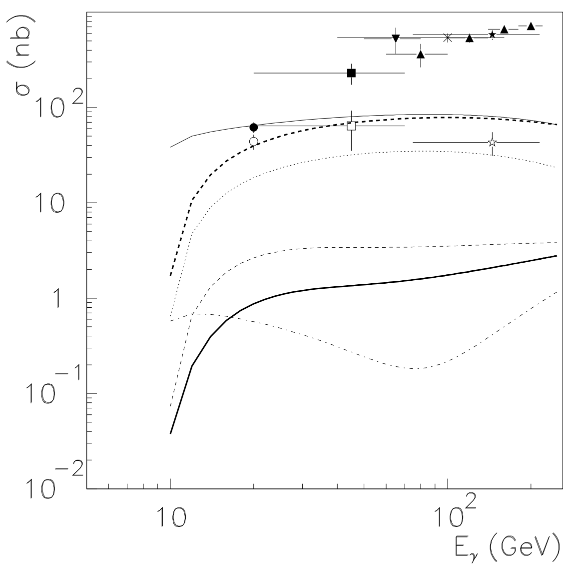

Fig. 2 E_γ-dependence of the total cross section for photoproduction of charmed particles. The curves correspond to different reactions: $\gamma + p \to \Lambda_c^+ + \overline{D}^0$ (solid line), $\gamma + p \to \Sigma_c^{++} + D^-$ (dashed line), $\gamma + p \to \Sigma_c^+ + \overline{D}^0$ (dotted line), $\gamma + n \to \Lambda_c^+ + D^-$ (dot-dashed line), $\gamma + n \to \Sigma_c^+ + D^-$ (thick solid line), $\gamma + n \to \Sigma_c^0 + \overline{D}^0$ (thick dashed line). The data correspond to the total charm photoproduction cross section from [14] (reverse triangle), [16] (square), [17] (asterisk), [18] (star), [15] (triangles), [13] (circle). Open symbols are from [13] (open circle), from [16] (open square), and from [18] (open star).

4 Charmed vector meson production in collinear kinematics

$\overline{D}^*$-production is the main channel for $\gamma + N \to$ charm $+X$ [20, 13, 16, 17, 18], so that the ratio between the vector (V) and the total $\overline{D}^*$ contribution to the total cross section is in agreement with the spin quark rule $V/(P+V) \simeq 0.75$, where P is the pseudoscalar contribution. The relative role of the charged and neutral D-meson photoproduction depends, on one side, on the relative cross sections for the $D^{*\pm}$ and D^{*0} photoproduction, and, from another side, on the branching ratio for the decays $D^* \to D + \pi$ (for different charge combinations).

For the exclusive processes $\gamma + N \to Y_c + \overline{D}^*$ in collinear kinematics, the helicity conservation and the P-invariance of electromagnetic interaction allow to reduce the number of amplitudes to three, which are functions of a single kinematical variable, the photon energy E_γ. In the general case, such processes are characterized by a set of twelve independent amplitudes, which are complex functions of two kinematical variables. Therefore the theoretical analysis is largely simplified in collinear kinematics and the matrix element for any process $\gamma + N \to Y_c + \overline{D}^*$ can be written as:

$$\mathcal{M}(\gamma N \to Y_c \overline{D}^*) = \chi_2^\dagger \left[\vec{\epsilon} \cdot \vec{U^*} f_1 + i\vec{\sigma} \cdot \hat{\vec{k}} \vec{\epsilon} \times \hat{\vec{k}} \cdot \vec{U^*} f_2 + i\vec{\sigma} \cdot \vec{\epsilon} \times \hat{\vec{k}} \vec{U^*} \cdot \hat{\vec{k}} f_3 \right] \chi_1, \quad (6)$$

where $\vec{\epsilon}$ and $\vec{U}$ are the three-vectors of the photon and of the $\overline{D}^*$-meson polarizations, with the condition $\epsilon \cdot \hat{\vec{k}} = 0$, and f_i, i=1,3, are the collinear amplitudes, functions of E_γ. Eq. (6) holds for any reaction mechanism. Using this parametrization, one can find for the differential cross section [21]:

$$\frac{d\sigma}{dt} = \mathcal{N}\left[|f_1|^2 + |f_2|^2 + \frac{E_v^2}{m_v^2}|f_3|^2\right], \tag{7}$$

where $\mathcal{N}$ is a normalization factor, E_v (m_v) is the energy (mass) of the produced vector meson:

$$E_v = \frac{s + m_v^2 - M^2}{2W},\ s = W^2 = m^2 + 2mE_\gamma, \tag{8}$$

where m (M) is the nucleon (Y_c-hyperon) mass, E_γ is the photon energy in the laboratory (Lab) system.

The $\overline{D}^*$-mesons, produced in collinear kinematics, are generally polarized, (with tensor polarization) even in collisions of unpolarized particles:

$$\mathcal{D}\rho_{11} = \frac{|f_1|^2 + |f_2|^2}{2},\ \mathcal{D} = |f_1|^2 + |f_2|^2 + \frac{E_v^2}{m_v^2}|f_3|^2 \tag{9}$$

with the normalization condition: $2\rho_{11} + \rho_{00} = 1$. The non-diagonal elements for ρ_{ab} are equal to zero, in collinear regime. All other single-spin polarization observables, vanish for the considered reactions, for any photon energy and for any reaction mechanism, due to the axial symmetry of collinear kinematics. An interesting set of double-spin polarization observables can be measured, for the reactions $\gamma + N \to Y_c + \overline{D}^*$:

- **the asymmetry** A_z in the collision of circularly polarized photon beam with a polarized nucleon target, in the $\hat{\vec{k}}$-direction, which we choose as the z-direction:

$$A_z\mathcal{D} = -2Re\ f_1 f_2^* - |f_3|^2 \frac{E_v^2}{m_v^2}. \tag{10}$$

- In the collision of circularly polarized photons with unpolarized target, the Y_c-hyperon can be longitudinally polarized, and **the polarization** P_z is:

$$P_z\mathcal{D} = -2Re\ f_1 f_2^* + |f_3|^2 \frac{E_v^2}{m_v^2}. \tag{11}$$

- The non zero components of **the depolarization tensor,** D_{ab} ($a, b = x, y, z$), describing the dependence of the b-component of the Y_c-polarization on the a-component of the target polarization, can be written as:

$$D_{zz}\mathcal{D} = |f_1|^2 + |f_2|^2 - |f_3|^2 \frac{E_v^2}{m_v^2},\ D_{xx}\mathcal{D} = D_{yy}\mathcal{D} = |f_1|^2 - |f_2|^2. \tag{12}$$

One can see that these observables are not independent, and the following relations hold, at any photon energy and for any reaction mechanism: $D_{zz} = -1+4\rho_{11}$, $A_z - P_z = -2 + 4\rho_{11}$.

For the numerical estimations it is necessary to know the following magnetic moments of charmed baryons and $D^* \to D + \gamma$ electromagnetic transitions: $\kappa(Y_c)$, $\kappa(D^{*-}D^{*-}\gamma)$, $\kappa(D^{*0}D^0\gamma)$.

The quark model gives prescriptions which relate the magnetic moments of the charmed hyperons to the magnetic moments of the charmed quarks, μ_q, $q = u, d$, or c. The quark model can also be used for the prediction of the transition magnetic moments (again in terms of quark magnetic moments). The signs, in particular, are very important in the analysis of the isotopic effects for these reactions, which are large in the present model, near threshold, due to the strong interference of the different contributions.

Finally, to fix the strong coupling constants we use the existing information on the corresponding coupling constants for strange particles, which can be determined from the analysis of the data on photo and electroproduction of Λ and Σ-hyperons on protons.

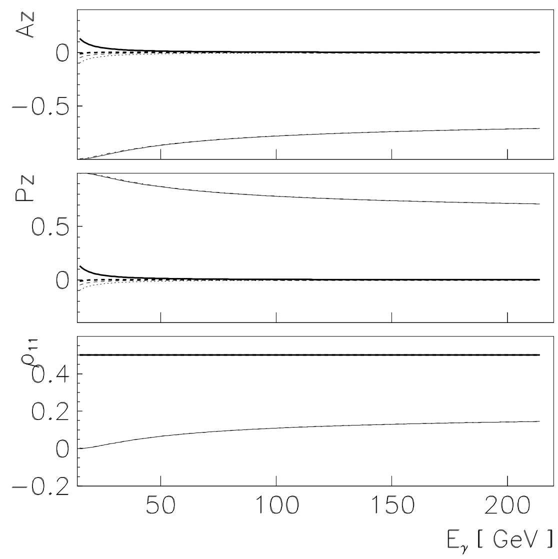

Fig. 3 Predictions for different polarization observables: asymmetry A_z (top), polarization P_z (center) and ρ_{11} (bottom), for the six considered reactions as a function of E_γ: $\gamma+p \to \Lambda_c^+ + \overline{D}^{*0}$ (solid line), $\gamma+p \to \Sigma_c^+ + \overline{D}^{*0}$ (dashed line), $\gamma+p \to \Sigma_c^{++} + D^{*-}$ (dotted line), $\gamma+n \to \Lambda_c^+ + D^{*-}$ (dash-dotted line), $\gamma+n \to \Sigma_c^+ + D^{*-}$ (thick solid line), $\gamma+n \to \Sigma_c^0 + \overline{D^{*0}}$ (thick dashed line).

One can see, that in the considered model, the Λ_c-production has the largest reduced cross section. The fact that all four reactions $\gamma + N \to \Sigma_c + \overline{D}^*$ are one order of magnitude smaller, is due to the difference between the values of the coupling constants for the $N \to \Lambda_c\overline{D}^*$ and $N \to \Sigma_c\overline{D}^*$-vertices. This is also the reason of the difference of the polarization observables for Λ_c and Σ_c-photoproduction (Fig. 3). Note that none of the polarization observables depends on the form factor and on the coupling constant $g_{NY_cD^*}$. The density matrix element is almost independent on energy (Fig. 3, bottom), and $\rho_{11} \simeq 0.5$ for $\gamma + N \to \Lambda_c+\overline{D}^*$, whereas $\rho_{11} \le 0.2$ for $\gamma + N \to \Sigma_c + \overline{D}^*$.

The maximal value of ρ_{11} produces a $\sin^2\theta$-distribution of the emitted D-meson, through the decay $D^* \to D+\pi$ (θ is the angle between the $\vec{k}$-direction and the direction of the D-meson three momentum in the $\overline{D}^*$-rest system). Such θ-dependence results in a depletion of D-meson production at small angles, which should be observed, for example, in the COMPASS experiment.

The large negative values of the asymmetry A_z, for $\vec{\gamma}+\vec{N} \to \Lambda_c^+ + \overline{D}^*$, are near the limiting value $A_z = -1$; more exactly, $|A_z| \geq 0.8$, for $E_\gamma \leq 100$ GeV.

5 Summary

We considered the exclusive photoproduction of charmed vector mesons, $\gamma + N \to Y_c + \overline{D}(\overline{D}^*)$, and calculate the differential cross section and the polarization observables in framework of an effective Lagrangian approach.

The strong coupling constants for the vertices $N \to Y_c + \overline{D}$ and $N \to Y_c + \overline{D}^*$ can be related through SU(4) symmetry with the corresponding coupling constants for strange particles, i.e. for the vertices $N \to Y + K$ and $N \to Y + K^*$, $Y = \Lambda$ or Σ-hyperon, which are known from the analysis of experimental data concerning photo- and electroproduction of strange particles. The electromagnetic characteristics of charmed particles, such as the magnetic moments of the charmed Y_c-hyperons and the transition magnetic moments for the decays $D^* \to D+\gamma$ have been estimated in framework of the quark model. Phenomenological form factors have been introduced to take into account the virtuality of the exchanged particles.

The reaction $\gamma + N \to Y_c + \overline{D}(\overline{D}^*)$ has been analyzed in collinear kinematics, where the differential cross section is large and the spin structure of the matrix element is essentially simplified. We analyzed the single and double-spin polarization phenomena, in a general form, in terms of three independent collinear amplitudes.

The smooth behavior of the total cross section as a function of the energy, for $\gamma + p \to Y_c + \overline{D}_c$, results from the spin one nature of the $\overline{D}^*$ exchange. The model gives robust predictions for the polarization effects. In particular we find large and negative values of the asymmetry A_z (for the collision of a circularly polarized photon beam with a longitudinally polarized nucleon target) for $\Lambda_c^+\overline{D}^*$-production on proton and neutron targets (which is a factor ten larger in comparison of Σ_c-production).

Contributing for about 10 % to the total cross section of open charm photoproduction on nucleons (for $40 \leq E_\gamma \leq 250$ GeV), the exclusive process $\gamma+p \to \Lambda_c^+ + \overline{D}_c^0$ may represent an important background in the interpretation of possible polarization effects in the $\gamma + N \to X$ +charm processes. This refers especially to the A_z asymmetry in $\vec{\gamma} + \vec{N} \to X$ +charm, which can reach large and positive values for associative charm production.

6 Aknowledgments

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References

[1] L. M. Jones and H. W. Wyld, Phys. Rev. D **17**, 759 (1978); H. Fritzsch and K. H. Streng, Phys. Lett. B **72**, 385 (1978); V. A. Novikov, M. A. Shifman, A. I. Vainstein and V. I. Zakharov, Nucl. Phys. B **136**, 125 (1978) [Yad. Fiz. **27**, 771 (1978)];

[2] M. P. Rekalo, Ukr. Fiz. Journ. 22 (1977) 1602; M. P. Rekalo and E. Tomasi-Gustafsson, Phys. Lett. B **500**, 53 (2001).

[3] G. F. Chew, M. L. Goldberger, F. E. Low and Y. Nambu, Phys. Rev. **106**, 1345 (1957).

[4] M. P. Rekalo and E. Tomasi-Gustafsson, Phys. Rev. C **67**, 038501 (2003).

[5] G. Baum *et al.* [COMPASS Coll.], CERN-SPSLC-96-14

[6] K. Hagiwara *et al.*, Phys. Rev. **D 66**, 010001 (2002).

[7] E. Tomasi-Gustafsson and M. P. Rekalo, Phys. Rev. D **69**, 094015 (2004).

[8] J. Smith and R. Vogt, Z. Phys. C **75**, 271 (1997).

[9] V. O'Dell *et al.* [SLAC Hybrid Facility Photon Coll.], Phys. Rev. D **36**, 1 (1987).

[10] M. P. Rekalo and E. Tomasi-Gustafsson, Phys. Rev. C **67**, 044004 (2003).

[11] H. Haberzettl, Phys. Rev. C **56**, 2041 (1997); H. Haberzettl, C. Bennhold, T. Mart and T. Feuster, Phys. Rev. C **58**, 40 (1998).

[12] M. Guidal, J.M. Laget, M. Vanderhagen, Nucl. Phys. **A627**, 645 (1997).

[13] K. Abe *et al.* [SLAC Hybrid Facility Photon Coll.], Phys. Rev. D **33**, 1 (1986).

[14] D. Aston *et al.*, Phys. Lett. B **94**, 113 (1980).

[15] J. J. Aubert *et al.* [European Muon Coll.], Nucl. Phys. B **213**, 31 (1983); Phys. Lett B **167**, 127 (1986).

[16] M. I. Adamovich *et al.* [Photon Emulsion Coll.], Phys. Lett. B **187**, 437 (1987).

[17] M. P. Alvarez *et al.* [NA14/2 Coll.], Phys. Lett. B **246**, 256 (1990); Phys. Lett. B **278**, 385 (1992); Z. Phys. C **60**, 53 (1993).

[18] J. C. Anjos *et al.* [Tagged Photon Spectrometer Coll.], Phys. Rev. Lett. **62**, 513 (1989).

[19] D. W. Duke and J. F. Owens, Phys. Rev. Lett. **D44**, 1173 (1980).

[20] M. Derrick *et al.* [ZEUS Coll.], Phys. Lett. B **349**, 225 (1995); S. Aid *et al.* [H1 Coll.], Nucl. Phys. B **472**, 32 (1996). K. Sliwa *et al.*, Phys. Rev. D **32**, 1053 (1985). J. M. Link *et al.*, [FOCUS Coll.] Phys. Lett. B **566**, 51 (2003).

[21] E. Tomasi-Gustafsson and M. P. Rekalo, arXiv:hep-ph/0401156, to be published in Eur. Phys. J. A