T-odd polarization observables in the photoproduction of charmed particles near threshold

Michail P. Rekalo *

Middle East Technical University, Physics Department, Ankara 06531, Turkey

Egle Tomasi-Gustafsson

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

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Abstract

The imaginary part of the matrix element for associative charm particle photoproduction, $\gamma + N \to \Lambda_c + \overline{D}$, has a definite spin structure, near the reaction threshold, being characterized by a single parameter. This allows us to predict, in the framework of an effective Lagrangian approach, the energy and the angular dependence of T-odd polarization observables such as the analyzing power in the reaction $\gamma+\vec{p} \to \Lambda_c+\overline{D}$ and the polarization of the Λ_c hyperon, produced in the collision of unpolarized particles. We find sizeable values for these observables, which can be measured experimentally.

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

I. INTRODUCTION

Associative charmed particles photoproduction processes, $\gamma+N\to\mathcal{B}_c+\overline{D}$, with $\mathcal{B}_c=\Lambda_c$ or Σ_c can be viewed, similarly to pion or strange particle photoproduction, as belonging to the same class of reactions: $\gamma+N\to\mathcal{B}+\mathcal{P}$, where $\mathcal{B}$ is a baryon, with spin $\mathcal{J}$ and parity P equal to $\mathcal{J}^P=1/2^+$, ($\mathcal{B}=N$, Λ, Σ, Λ_c, or Σ_c) and $\mathcal{P}$ is the corresponding pseudoscalar meson ($\mathcal{P}=\pi$, η, K, D).

Such similarity allows to apply the effective Lagrangian approach (ELA), which has been so successful in the description of processes of photoproduction of light mesons, π, η or K.

The intense N^*-excitation in the s-channel, which has to be taken into account in the resonance region for $\gamma+N\to N+\pi$ (η or K) processes, induces complex amplitudes with rich T-odd polarization phenomena in such processes. In this respect the situation is different for open charm photoproduction, due to the very high reaction threshold ($E_{thr}>$ 8 GeV), where the nucleon resonances excitation (with masses $m_{\Lambda_c}+m_D>4.1$ GeV) seem very improbable.

In the near-threshold region for $\gamma+N\to\mathcal{B}_c+\overline{D}$, in the framework of the ELA description, all the amplitudes are real, in evident contradiction with unitarity, which requires a non vanishing imaginary part in the matrix element. Generally the application of the unitarity condition for $\gamma+N\to\mathcal{B}_c+\overline{D}$ at so large energies is very complicated. However in the near threshold region, it is possible to predict the spin structure of the imaginary part of the amplitudes and parametrize the numerous and complicated contributions to the unitarity condition with the help of one parameter, only.

In this paper we study different T-odd effects in the processes $\gamma+N\to\Lambda_c+\overline{D}$, in framework of a model which unifies the ELA with unitarity, in the threshold region. We predict the angular and the energy dependence of the analyzing power and the Λ_c-polarization (in collisions of unpolarized particles) and analyze its sensitivity to the effective imaginary part.

II. THE UNITARITY CONDITION

As the threshold energy for the process $\gamma+N \to \Lambda_c+\overline{D}$, is very large, many multiparticle states can contribute, in the intermediate state, to the unitarity condition (for example $N+n\pi$, where $n \leq 23$ is the number of pions which are allowed). Looking forward an exact calculation of such contributions to the imaginary part of the amplitude for $\gamma+N \to \Lambda_c+\overline{D}$, is certainly very difficult, if not possible at all. In order to find an adequate solution to this problem, let us focus, instead, on the most simple term, the two-particle $J/\psi + N$-contribution to the unitarity chain (Fig. 1): $\gamma+N \to J/\psi+N \to \Lambda_c+\overline{D}$. The main property of this contribution is the absence of OZI-suppression [1] in the transition $J/\psi+N \to \Lambda_c+\overline{D}$, due to the presence of hidden charm in the initial state, so that the reaction proceeds through the possible mechanism illustrated in Fig. 2.

Moreover, the contribution of the $J/\psi+N$ intermediate state can be easily parametrized in the near threshold region, for $\gamma + N \to \Lambda_c + \overline{D}$, where the main contribution is given by the S-state D-meson photoproduction, with $\mathcal{J}^P = 1/2^-$. In the center of mass system (CMS), one can find for the spin structure of the matrix element the following expression:

$$\mathcal{M}^{(s)}(\gamma N \to \Lambda_c\overline{D}) = f(\gamma N \to \Lambda_c\overline{D})\chi_2^\dagger\vec{\sigma}\cdot\vec{e}\chi_1,$$

where χ_1 and χ_2 are the two-component spinors of the initial nucleon and the final Λ_c baryon, $\vec{e}$ is the three-vector of the photon polarization, and $f(\gamma N \to \Lambda_c\overline{D})$ is the S-wave multipole amplitude for $\gamma + N \to \Lambda_c + \overline{D}$.

In the same way the following spin structure can be written for the corresponding matrix elements of the processes $\gamma+N \to J/\psi+N$ and $J/\psi+N \to \Lambda_c+\overline{D}$, in the state $\mathcal{J}^P = 1/2^-$:

$$\mathcal{M}(\gamma N \to J/\psi N) = f(\gamma N \to J/\psi N)\chi^\dagger\left(\vec{e}\cdot\vec{U} + i\vec{\sigma}\cdot\vec{e}\times\vec{U}\right)\chi_1,$$

$$\mathcal{M}(J/\psi N \to \Lambda_c\overline{D}) = f(J/\psi N \to \Lambda_c\overline{D})\chi_2^\dagger\vec{\sigma}\cdot\vec{U}\chi,$$

where χ is the two-component spinor of the nucleon in the intermediate $J/\psi + N$-state and $\vec{U}$ is the three-vector of the J/ψ-polarization. After averaging over the polarizations of the intermediate $J/\psi + N$ system, one can find:

$$\mathcal{I}mf(\gamma N \to \Lambda_c \overline{D}) = \mathcal{R}ef(\gamma N \to J/\psi N) f(J/\psi N \to \Lambda_c \overline{D}), \tag{1}$$

when the matrix element is normalized as:

$$\frac{d\sigma}{d\Omega}(ab \to cd) = \frac{q_f}{q_i} \frac{|\mathcal{M}(ab \to cd)|^2}{64\pi^2 s},$$

where q_i and q_f are the three-momenta in the initial and final states of the process $a + b \to c + d$ and s is the square of the total energy of the $a + b$ system.

Even in the simple case of Eq. (1), the calculation of $\mathcal{I}mf(\gamma N \to \Lambda_c \overline{D})$ can not be done with the necessary accuracy, because we need an adequate model for the description of the processes $\gamma + N \to J/\psi + N$ and $J/\psi + N \to \Lambda_c + \overline{D}$, in the state $\mathcal{J}^P = 1/2^-$. There are no experimental data to constrain and test such model. If the process $\gamma + N \to J/\psi + N$, can, in principle, be studied (in the near threshold region) after the planned upgrade of Jlab, or at the future ELFE machine, the process $J/\psi + N \to \Lambda_c + \overline{D}$ can be studied in an indirect way, only, from the behavior of the J/ψ-meson in nuclear matter. This problem is very actual for the understanding of the the quark-gluon plasma transition in high energy ion-ion collisions [2–5].

Due to the absence of good data and/or good model, for the processes $\gamma + N \to J/\psi + N$ and $J/\psi + N \to \Lambda_c + \overline{D}$, it seems preferable to us to write the corresponding imaginary part of the S-wave amplitude for $\gamma + N \to \Lambda_c + \overline{D}$ as :

$$\mathcal{I}mf_1 = \mathcal{C}, \tag{2}$$

where $\mathcal{C}$ is a dimensionless constant (which sign and absolute value can not be determined by modern theories). The assumption about the energy independence of the imaginary part, $\mathcal{C}$, seems a reasonable hypothesis only in the near threshold region, in absence of resonance contributions to the S-wave. We shall use the standard expression of the spin structure of the general matrix element of $\gamma + N \to \Lambda_c + \overline{D}$ (in the CMS) [6]:

$$\mathcal{M}(\gamma N \to \Lambda_c \overline{D}) = \chi_2^\dagger \mathcal{F} \chi_1,$$

$$\mathcal{F} = i\vec{\sigma} \cdot \vec{e} f_1 + \vec{\sigma} \cdot \hat{\vec{q}} \vec{\sigma} \cdot \hat{\vec{k}} \times \vec{e} f_2 + i\vec{e} \cdot \hat{\vec{q}} (\vec{\sigma} \cdot \hat{\vec{k}} f_3 + \vec{\sigma} \cdot \hat{\vec{q}} f_4), \tag{3}$$

where $\hat{\vec{k}}$ and $\hat{\vec{q}}$ are the unit vectors along the three-momentum of the initial γ and final $\overline{D}$-meson, $f_1 - f_4$ are the scalar amplitudes, which are functions of two independent variables, s and $\cos\theta = \hat{\vec{k}} \cdot \hat{\vec{q}}$.

It follows that, in the considered approach, we can not determine the constant $\mathcal{C}$, but we can derive the spin structure, $\vec{\sigma} \cdot \vec{e}$, of the imaginary contribution to the matrix element in the near threshold region. But the solution of the unitarity condition that we proposed in Eq. (2), is correct, not only for the considered two-particle contribution, $J/\psi + N$, but also for all other complicated intermediate states. Therefore Eq. (2) can be considered as the general solution of the unitarity condition for a state $\mathcal{J}^P = 1/2^-$. The expectation (which has no deep justification) that the $J/\psi + N$ intermediate state has to be dominant among the numerous possible mesonic contributions, can be tested, in principle, through the following relation between the imaginary parts of different channels: $\mathcal{C}(\gamma p \to \Sigma_c^{++} D^-) = \sqrt{2}\mathcal{C}(\gamma p \to \Sigma_c^+ \overline{D^0})$, which results from the zero isospin of the J/ψ-meson. The possible deviation from this relation can be considered an indication of the relative role of $J/\psi + N$ and many-meson contributions to the unitarity condition.

If we unify now the considered mechanism of generating an imaginary part to the amplitude f_1, Eq. (2), with the ELA approach which has been considered in [7,8], we have now a model which naturally generates different T-odd phenomena for the process $\gamma + N \to \Lambda_c + \overline{D}$, in the near threshold region. These polarization observables are expected to be sensitive to the value and the sign of the single phenomenological parameter $\mathcal{C}$.

Note that such straightforward unification of the real Born contribution with the imaginary part of the amplitude f_1 does not violate the general theorem of Christ and Lee [9], concerning multipole amplitudes (for any value of $\mathcal{C}$) and therefore does not violate the T-invariance of hadron electrodynamics. This derives from the fact that the imaginary part is present only in the particular state with $\mathcal{J}^P = 1/2^-$, which can be excited in $\gamma + N \to \Lambda_c + \overline{D}$ only in one multipole amplitude, corresponding to E1 absorption. This insures that all polarization phenomena, in particular the T-odd ones, are derived in a correct and consistent form. One can see that all the multipole amplitudes, besides the S-wave one, are real functions of the energy. This is a typical property of ELA and can only be justified in the threshold region, for $\gamma + N \to \Lambda_c + \overline{D}$.

III. T-ODD EFFECTS

The simplest T-odd observables, in the processes $\gamma + N \to \Lambda_c + \overline{D}$, are $\mathcal{A}_n$, the analyzing power in $\gamma + \vec{p} \to \Lambda_c + \overline{D}$, (induced by the polarization of the proton target) and $\mathcal{P}_n$, the Λ_c polarization in the collision of unpolarized particles (note that the Λ_c, like the usual Λ-hyperon, is a 'self-analyzing' particle: its polarization can be measured through the angular distribution of its decay products). These observables are expressed in terms of the scalar amplitudes (3) as follows:

$$\mathcal{A}_n \left(\frac{d\sigma}{d\Omega}\right)_0 = \sin\vartheta \mathcal{I}m \left(-f_1 f_3^* - \cos\vartheta f_1 f_4^* + f_2 f_4^* + \cos\vartheta f_2 f_3^* + \sin\vartheta^2 f_3 f_4^*\right), \quad (4)$$

$$\mathcal{P}_n \left(\frac{d\sigma}{d\Omega}\right)_0 = \sin\vartheta \mathcal{I}m \left(-f_1 f_2^* + f_1 f_3^* + \cos\vartheta f_1 f_4^* - \cos\vartheta f_2 f_3^* - f_2 f_4^* - \sin\vartheta^2 f_3 f_4^*\right).$$

In the numerical calculations we shall use a model, where the amplitudes f_2, f_3 and f_4 are real as a result of ELA and only the amplitude f_1 is complex, being the sum of the real Born contribution and the imaginary contribution of the contact term, from the unitarity condition.

Therefore, in this model, Eqs. (4) can be simplified in the following form:

$$\mathcal{A}_n = -2\sin\vartheta \frac{(f_3 + \cos\vartheta f_4)\mathcal{I}m f_1}{B + A\sin^2\vartheta},$$

$$\mathcal{P}_n = 2\sin\vartheta \frac{(2f_2 + f_3 + \cos\vartheta f_4)\mathcal{I}m f_1}{B + A\sin^2\vartheta},$$

where A and B are quadratic combinations of the amplitudes f_i [8]:

$$A = |f_3|^2 + |f_4|^2 + 2\mathcal{R}e f_2 f_3^* + 2\mathcal{R}e (f_1 + \cos\vartheta f_3) f_4^*,$$

$$B = 2\left(|f_1|^2 + |f_2|^2 - 2\cos\vartheta \mathcal{R}e f_1 f_2^*\right).$$

IV. THE ELA APPROACH

As an example, we consider the simplest reaction of charm photoproduction: $\gamma + p \to \Lambda_c + \overline{D^0}$, Fig. 3. In our calculations we use the pseudoscalar coupling for the $N\Lambda_c\overline{D}$-vertex. The difference between the pseudoscalar and the pseudovector coupling has been widely discussed in the literature, as an evident example of off-mass shell effects. Here we consider another kind of off-mass shell effects, due to different possible parametrizations of the electromagnetic vertexes, γNN or $\gamma\Lambda_c\Lambda_c$.

In the calculation of the scalar amplitudes f_i, for the Born diagrams (Fig. 2) we can use a possible 'non-standard' parametrization of the electromagnetic vertexes for N and Λ_c, in the following form:

$$\mu\hat{e} - \kappa\frac{e\cdot(p_1+p_2)}{2m}, \tag{5}$$

where κ and μ are the anomalous and total magnetic moments of baryon, p_1 and p_2 are the four-momenta of the initial and final baryon in the vertex $\gamma N(p_1) \to N(p_2)$. This will allow us to study off-mass shell effects for the considered processes induced by the different possible parametrizations of the baryonic electromagnetic current. When both baryons are on mass shell, this form is equivalent to the standard Dirac+Pauli parametrization of the electromagnetic current: $Q\hat{e} - \kappa\frac{\hat{e}\hat{k}}{2m}$, where Q is the electric charge of the baryon (in units e).

Note that such effects, induced by different parametrizations of the $NN\pi$-vertex (pseudoscalar or pseudovector variants), have been intensively studied for pion photo-and electroproduction on nucleons in the near theshold region. Similar effects for the electromagnetic vertex [10–12] are of a particular interest in connection with the gauge invariance of hadronic electromagnetic interactions [12]. Let us analyse this problem in the framework of the considered model.

The question is now if it is possible to use the form (5) in the calculation of Born diagrams with respect to the requirement of gauge invariance. These two parametrizations will certainly generate different matrix elements. Let us consider the $s-$channel contribution (in the standard form):

$$\mathcal{M}_s = e\frac{g_{N\mathcal{B}_c\overline{D}}}{s-m^2}\overline{u}(p_2)\gamma_5(\hat{p}+m)\left[Q_N\hat{\epsilon}-\frac{\hat{\epsilon}\hat{k}}{2m}\kappa_N\right]u(p_1),$$

It is possible to transform $\mathcal{M}_s$ in terms of the vertex (5):

$$\mathcal{M}_s = e\frac{g_{N\mathcal{B}_c\overline{D}}}{s-m^2}\overline{u}(p_2)\gamma_5(\hat{p}+m)\left[\mu_N\hat{\epsilon}-\frac{\epsilon\cdot p_1}{m}\kappa_N\right]u(p_1). \tag{6}$$

$$+\frac{\kappa_N}{2m}\overline{u}(p_2)\gamma_5\hat{\epsilon}u(p_1)eg_{N\Lambda_c D},\ p=p_1+k,$$

where $g_{N\Lambda_c\overline{D}}$ is the pseudoscalar constant of the $N\Lambda_c\overline{D}$-vertex, and m is the nucleon mass. One can see that the two electromagnetic vertexes correspond to two different matrix elements, and the difference, $\Delta\mathcal{M}$, depends on the anomalous magnetic moment of the nucleon κ_N. In Eq. (6) the Pauli contribution contains three different terms, only their sum satisfies the gauge invariance. Note also that the representation (6) has the practical advantage to decrease the number of γ-matrixes, giving a simpler expression for the scalar amplitudes f_i.

Applying the same procedure to the u-channel contribution, we finally obtain for the total matrix element of the $\gamma+p\to\Lambda_c+\overline{D^0}$ process:

$$\mathcal{M}=\mathcal{M}_s'+\mathcal{M}_u'+\mathcal{M}_c, \tag{7}$$

where $\mathcal{M}_s'$ and $\mathcal{M}_u'$ are the new simpler forms for s- and $u-$channels and $\mathcal{M}_c$ is the contact-like contribution, induced by the anomalous magnetic moments of the initial and the final baryons:

$$\mathcal{M}_c = eg_{N\Lambda_c\overline{D}}\left(\frac{\kappa_N}{2m}-\frac{\kappa_\Lambda}{2M}\right)\overline{u}(p_2)\gamma_5\hat{\epsilon}u(p_1). \tag{8}$$

Finally we obtain for $\mathcal{M}_u'$

$$\mathcal{M}_u = e\frac{g_{N\Lambda_c\overline{D}}}{u-M^2}\overline{u}(p_2)\left(\mu_\Lambda\hat{\epsilon}-\frac{\epsilon\cdot p_2}{M}\kappa_\Lambda\right)u(p_1). \tag{9}$$

The scalar amplitudes, corresponding to the matrix element (7), can be written as:

$$f_i=\sqrt{(E_1+m)(E_2+M)}\left[f_{i,s}+f_{i,u}+f_{i,c}\right],$$

with the following simple expressions for the different contributions:

$$f_{1,s} = eg_{N\Lambda_c\overline{D}}\frac{\mu_N}{W+m}, \quad f_{2,s} = -eg_{N\Lambda_c\overline{D}}\frac{\mu_N}{W+m}\frac{q}{E_2+M}, \qquad f_{3,s} = f_{4,s} = 0,$$

$$f_{1,u} = eg_{N\Lambda_c\overline{D}}\mu_\Lambda\frac{W-m}{u-M^2},$$

$$f_{2,u} = -eg_{N\Lambda_c\overline{D}}\mu_\Lambda\frac{W-m}{u-M^2}\frac{q}{E_2+M},$$

$$f_{3,u} = eg_{N\Lambda_c\overline{D}}\frac{q}{u-M^2}\left[2\mu_\Lambda + \frac{\kappa_\Lambda}{M}(W+m-2M)\right],$$

$$f_{4,u} = eg_{N\Lambda_c\overline{D}}\frac{E_2-M}{u-M^2}\left[-2\mu_\Lambda + \frac{\kappa_\Lambda}{M}(W-m+2M)\right],$$

$$f_{1,c} = eg_{N\Lambda_c\overline{D}}\left(-\frac{\kappa_N}{2m}+\frac{\kappa_\Lambda}{M}\right),$$

$$f_{2,c} = eg_{N\Lambda_c\overline{D}}\left(-\frac{\kappa_N}{2m}+\frac{\kappa_\Lambda}{M}\right)\frac{W-M}{W+M}\frac{q}{E_2+M},$$

$$f_{3,c} = f_{4,c} = 0,$$

These analytical formulas are simpler, in comparison with the standard ELA calculations.

V. DISCUSSION OF THE NUMERICAL RESULTS AND CONCLUSIONS

Using the above described model, (ELA and parametrization of imaginary part in S-wave), let us calculate the T-odd polarization observables, A_n and P_n. The main parameters are the magnetic moment of the Λ_c-hyperon, the coupling constant $g_{N\Lambda_c\overline{D}}$ of the pseudoscalar meson-baryon vertex and the phenomenological constant $\mathcal{C}$ as the value of the S-wave imaginary part.

The value of the magnetic moment of the charmed baryons can be predicted in the framework of the different approaches: SU(4)-symmetry [13,14], quark model [15,16], MIT bag model [17], topological soliton [18], heavy quark (hadron) chiral perturbation theory [19,20]... In principle, the SU(4)-symmetry can also be used to relate the $g_{N\Lambda_c\overline{D}}$ and the $g_{N\Lambda K}$ coupling constants. The main problem here is the absolute value and the sign of the phenomenological imaginary part $\mathcal{C}$. One can easily see that all polarization observables, for the considered reaction, such as the T-odd A_n and P_n, depend only on the ratio of constants: $r = \mathcal{C}/g_{N\Lambda_c\overline{D}}$, for a known value of the Λ_c magnetic moment [13–20].

The Σ_B-asymmetry, being a T-even observable, does not depend on the sign of r and decreases with increasing $|r|$. The observables A_n and P_n are odd functions of r; in the region $|r| \leq 1$ their absolute values are increasing functions of $|r|$. One can see from Fig. 4, that nonzero values of Σ_B and A_n are due to the u-channel diagram. The $s-$channel alone gives a vanishing contribution. But this contribution acts through the denominator, as a 'dilution' factor for A_n and changes the sign of Σ_B (due to the interference term). On the other hand, the s-channel contribution is important for the observable P_n.

The large absolute value of the Σ_B-asymmetry (with negative sign) for associative charm production, has been also predicted in the framework of photon-gluon fusion [21]. In principle the gluon-fusion mechanism can be extrapolated up to the reaction threshold for J/ψ-photoproduction [22]. However such mechanism can not induce T-odd polarization observables. Following a quark-diquark model, the polarization of the Λ_c-hyperon in the reaction $\gamma + p \to \Lambda_c^+ + \overline{D^0}$ vanishes [23].

The observables A_n and P_n have opposite sign, (Fig. 5), which is a property of the considered model. The sensitivity of these observables to r, as well as their sizeable value make interesting the possibility of their measurement.

The large Λ_c polarization ($|P_n| \simeq 0.3$) near the reaction threshold can be measurable. As all different decays of the Λ_c-hyperon are induced by weak interaction (with strong violation of the P-invariance) there are many ways to measure this polarization, through the determination of the decay asymmetry. Note also that the large value of $|P_n|$ near threshold for $\gamma + p \to \Lambda_c + \overline{D}$ and the relatively large cross section predicted by this model, can allow, in principle, to determine the magnetic moment of the Λ_c-hyperon, through the possible precession of the Λ_c-spin in crystals [24].

The sensitivity of these observables to μ_{Λ_c} is shown in Fig. 6, where we report the value of A_n and P_n for $\theta = 90^0$. Note that the analyzing power A_n at $\theta = 90^0$ is decreasing in absolute value for $\mu_{\Lambda_c} \to 0$, whereas the absolute value of the Λ_c-polarization is increasing (for any value of r, $r \leq 1$) for small values of $\mu_{\Lambda_c} \leq 0.5$, which are consistent with skyrmion topological approaches and quark models as well.

Our analysis for $\gamma + p \to \Lambda_c^+ + \overline{D^0}$ shows that the imaginary part of the threshold amplitude has to be considered an important ingredient of ELA, originating large T-odd polarization observables.

REFERENCES

[1] S.Okubo, Phys. Lett. **5**, 165 (1963);

G. Zweig, CERN Reports TH401 and TH412 (1964);

J. Iizuka, K. Okada, and O. Shito, Prog. Theor. Phys. Suppl. **37**, 38 (1966).

[2] S. G. Matinyan and B. Muller, Phys. Rev. C 58 (1998) 2994.

[3] K. L. Haglin, nucl-th/9907034 (1999).

[4] Z. Liu and C. M. Ko, nucl-th/9912046 (1999).

[5] Z. Lin, C. M. Ko and B. Zhang, Phys. Rev. C 61 (2000) 024904.

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

[7] M. P. Rekalo, Ukr. Fiz. Journ. 22, 1602 (1977).

[8] M. P. Rekalo and E. Tomasi-Gustafsson, Phys. Lett. B 500, 53 (2001).

[9] N. Christ and T. D. Lee, Phys. Rev. **143**, 1310 (1966).

[10] A. M. Bincer, Phys. Rev. **118**, 855 (1960).

[11] H. W. Naus, J. H. Koch and J. L. Friar, Phys. Rev. C **41**, 2852 (1990).

[12] J. W. Bos, S. Scherer and J. H. Koch, Nucl. Phys. A **547**, 488 (1992).

[13] A. L. Choudhury and V. Joshi, Phys. Rev. **D13**, 3115 (1976).

[14] A. L. Choudhury and V. Joshi, Phys. Rev. **D13**, 3120 (1976).

[15] D. B. Lichtenberg, Phys. Rev. **D15**, 345 (1977).

[16] S. N. Jena and D. P. Rath, Phys. Rev. **D34**, 196 (1976).

[17] S. K. Bose and L. P. Singh, Phys. Rev. **D22**, 773 (1980).

[18] Y. Oh, D.-P. Min, M. Rho, N. N. Scoccola, Nucl. Phys. **A534**, 493 (1991).

[19] M. J. Savage, Phys. Lett. B 326, 303 (1994).

[20] M. C. Banuls, I. Scimemi, J. Bernabeu, V. Gimenez and A. Pich, Phys. Rev. D **61**, 074007 (2000). Phys. Rev. **D61**, 074007 (2000).

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

[22] S. J. Brodsky, E. Chudakov, P. Hoyer and J. M. Laget, Phys. Lett. B **498**, 23 (2001).

[23] J. Berthot, P. Y. Bertin, V. Breton, G. Fournier, Z. Meziani, J. Mougey and M. Potokar, 'The ELFE project: physics with a 15-GeV to 30-GeV high intensity continuous beam electron accelerator. Proceedings, workshop, Mainz, Germany, Oct. 7-9, 1992', ed. by J. Arvieux, (ed.), E. De Sanctis, (ed.) (Mainz U., Inst. Phys.), p. 309.

[24] V. M. Samsonov, Nucl. Instrum. Meth. B **119**, 271 (1996).

FIGURES

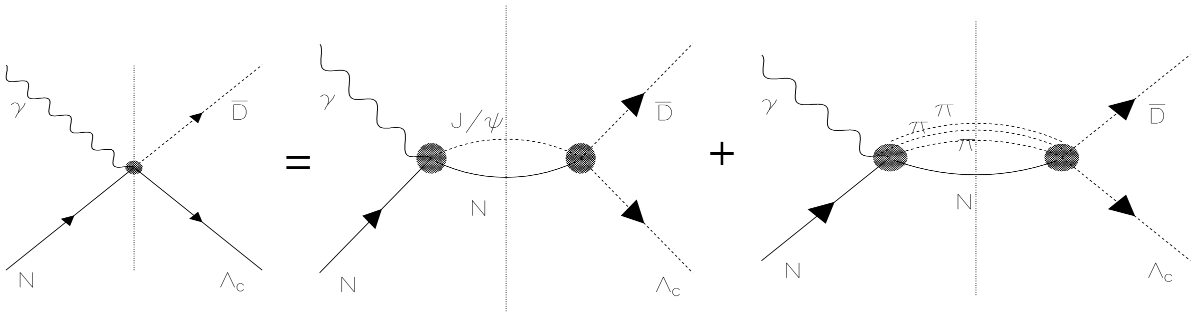

FIG. 1. The unitarity condition for $\gamma + N \to \Lambda_c + \overline{D}$: the vertical line denotes $\mathcal{I}mF(\gamma N \to \Lambda_c \overline{D})$ whereas, in the right side, it crosses the real particles in the intermediate state.

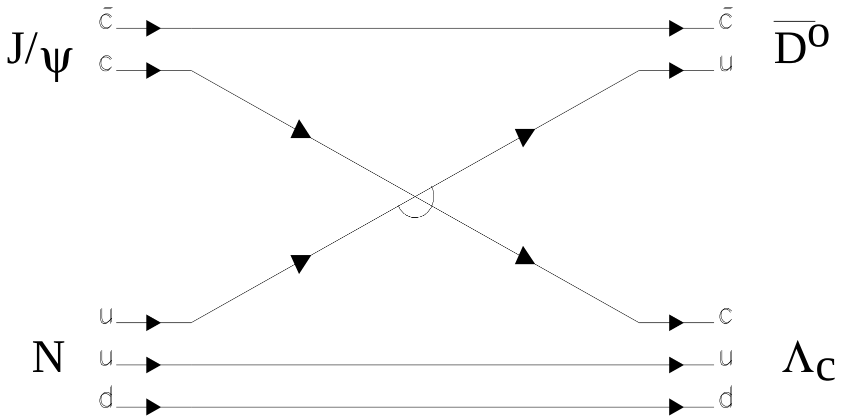

FIG. 2. Feynman diagram for $J/\psi + N \to \Lambda_c + \overline{D^0}$ through quark exchange

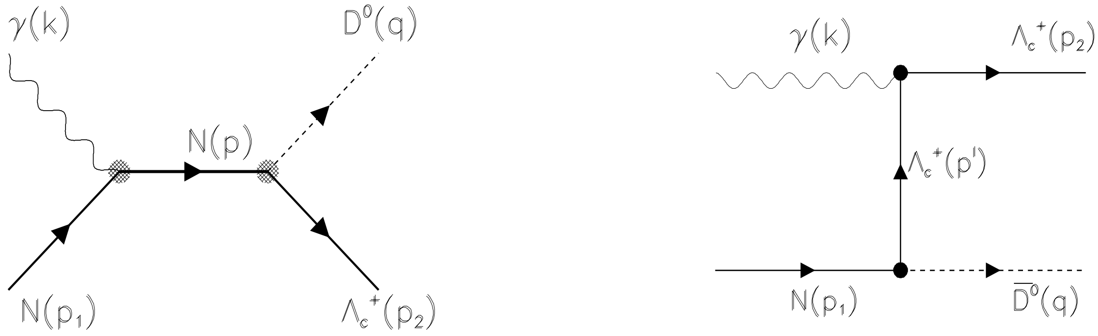

FIG. 3. Feynman diagrams of Born approximation for $\gamma + p \to \Lambda_c^+ + \overline{D^0}$.

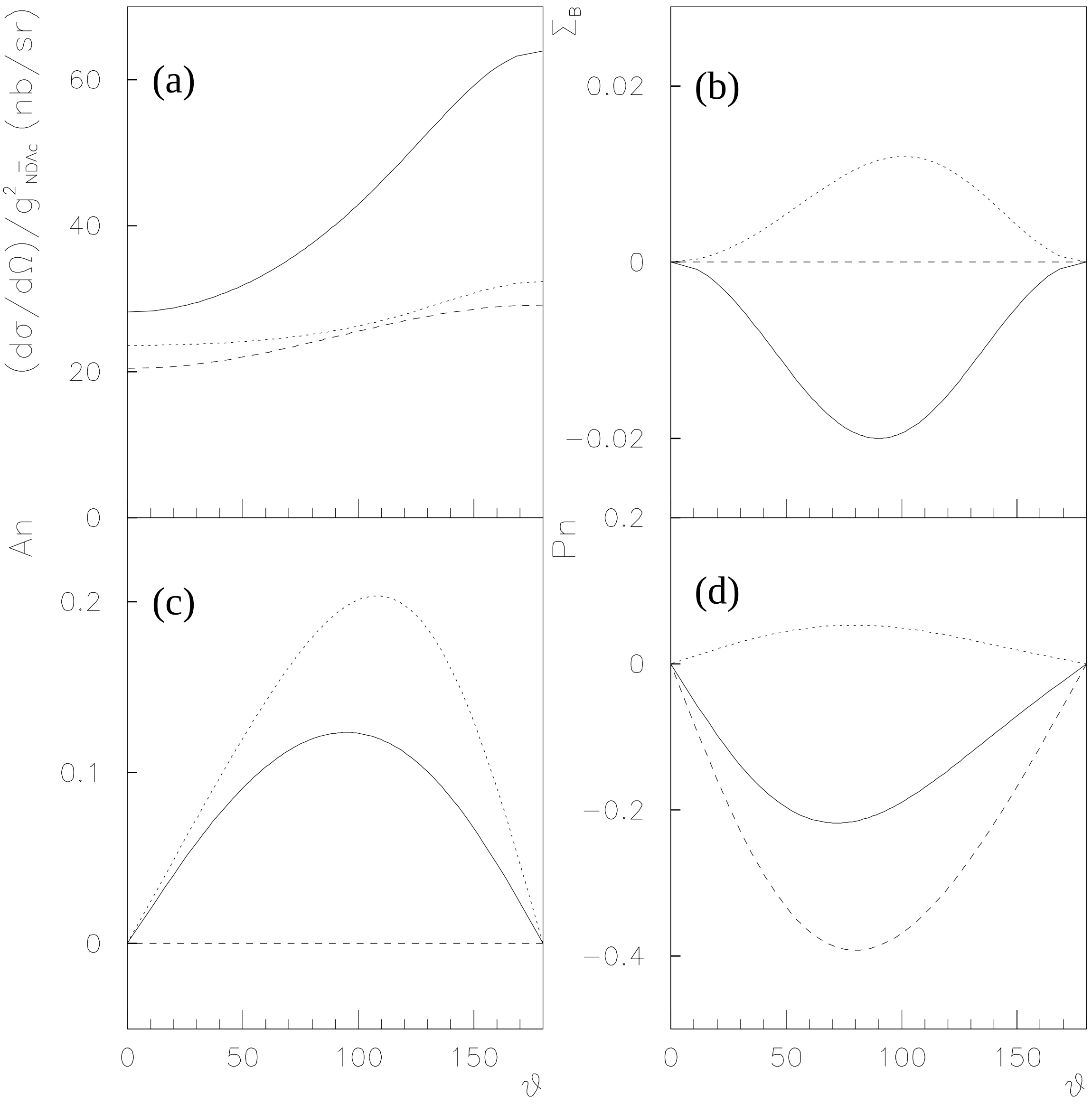

FIG. 4. θ-dependence of the differential cross section (a), and single spin polarization observables: beam asymmetry (b), analyzing power (c) and polarization (d) for the reaction $\gamma + p \to \Lambda_c^+ + \overline{D^0}$, r=1 and $E_\gamma = 11$ GeV. The dashed, dotted and solid lines correspond to u, s, and $u+s$ contributions, respectively.

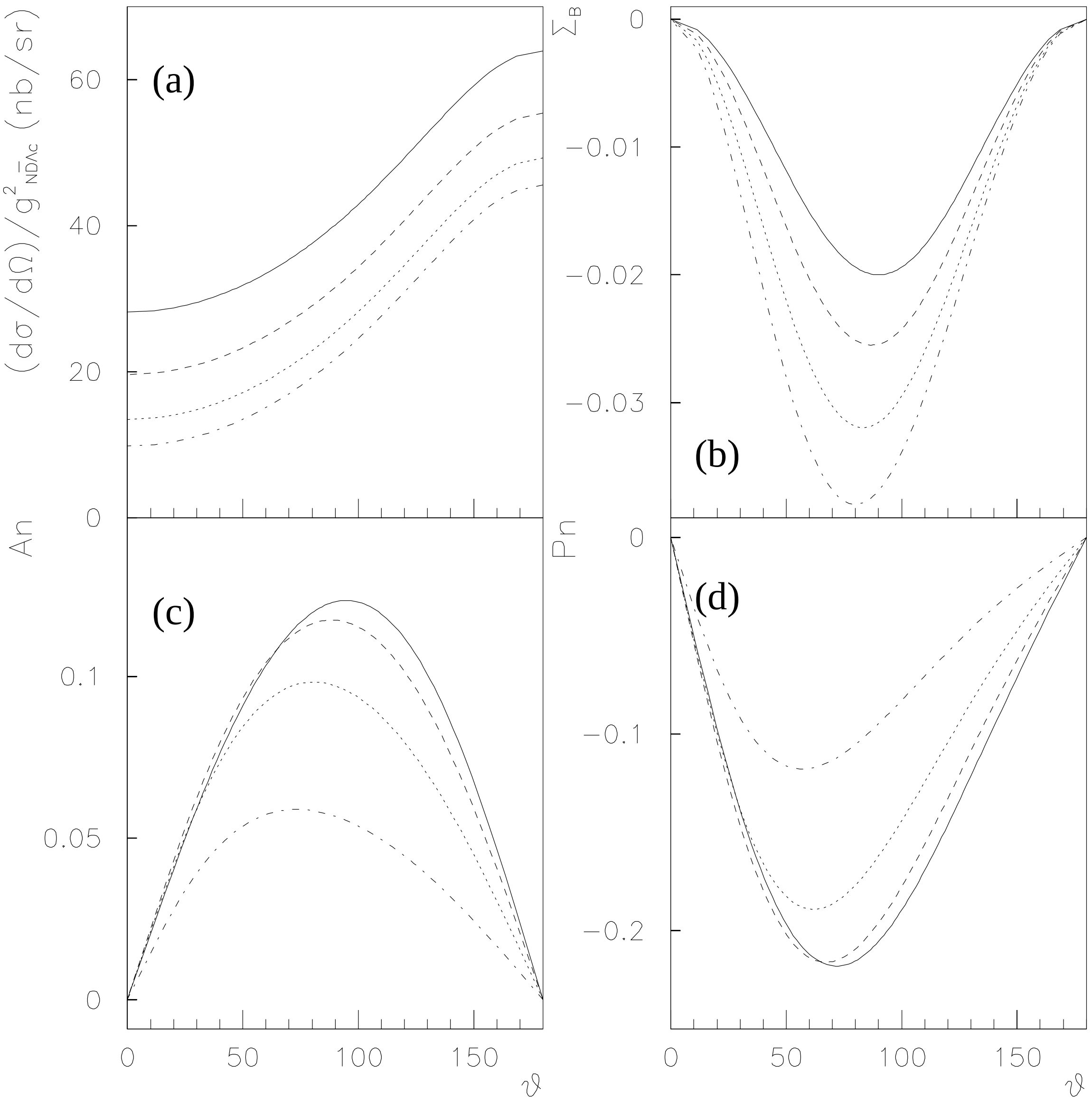

FIG. 5. θ-dependence of the differential cross section (a), and single spin polarization obser-avbles: beam asymmetry (b), analyzing power (c) and polarization (d) for different values of the ratio $r = \mathcal{C}/g_{N\Lambda_c\overline{D}}$. The solid, dashed, dotted and dashed-dotted lines correspond to r=1.0, 0.75, 0.5 and 0.25, respectively.

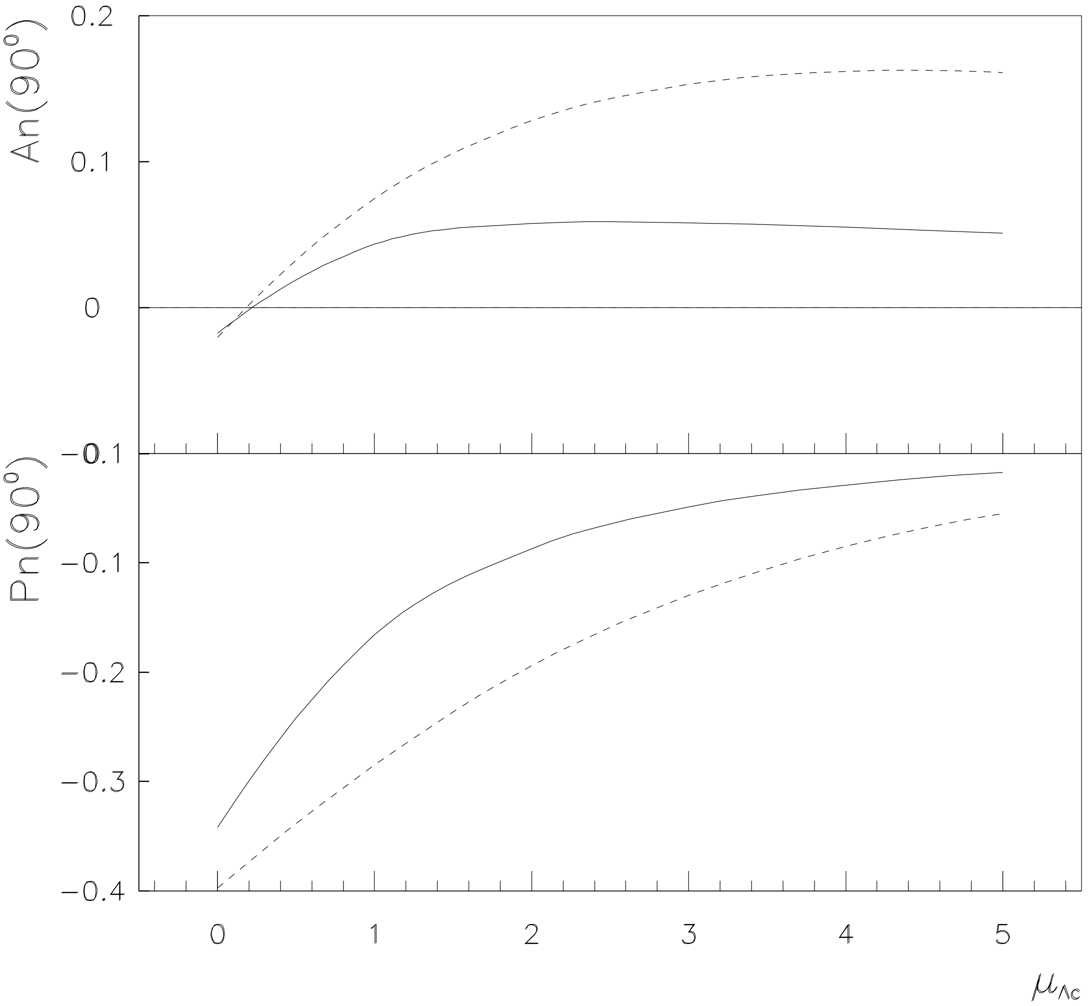

FIG. 6. Dependence of the analyzing power (top) and polarization (bottom) at $\theta = 90^0$, as a function of the Λ magnetic moment, for $r = 0.25$ (solid line) and $r = 1$ (dashed line).