AC

cea
CEA/SACLAY
DSM

SW0716

DAPNIA/SPhN-97-12

01/1997

Double polarization observables in Virtual Compton Scattering

M. Vanderhaeghen

DAPNIA

Département d'Astrophysique, de Physique des Particules, de Physique Nucléaire et de l'Instrumentation Associée
CEA/Saclay F-91191 Gif-sur-Yvette Cédex

Submitted to Physics Letters B

Double polarization observables in Virtual Compton Scattering

Marc Vanderhaeghen

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

(January 29, 1997)

Abstract

The polarized $p(\vec{\epsilon}, \epsilon' \vec{p})\gamma$ reaction is studied below pion production threshold. Calculations within an effective Lagrangian formalism for the Virtual Compton Scattering double polarization observables are done for kinematics accessible at MAMI, MIT-Bates and TJNAF. A model independent interpretation of the nucleon structure effect is given by expressing these double polarization observables in terms of the generalized polarizabilities introduced by Guichon et al..

PACS : 13.40.-f, 13.60.Fz, 14.20.Dh

Typeset using REVTeX

Virtual Compton Scattering (VCS) in different kinematical domains has recently seen [2] an increased activity on both the theoretical and experimental side. Below pion production threshold, VCS has been proposed [1] as a tool complementary to real Compton scattering and elastic scattering to study the structure of the nucleon. Experimentally, VCS is accessed through the $p(\epsilon, \epsilon'p)\gamma$ reaction. First evidence for $p(\epsilon, \epsilon'p)\gamma$ events from the proton at SLAC has been reported in Ref. [3]. To extract nucleon structure information from VCS below pion production threshold, a considerable experimental effort is taking place both at MAMI [4] [5] at lower Q^2 and TJNAF [6] at higher Q^2 . On the theoretical side, various model calculations [1] [7] [8] [9] address the nucleon structure information accessible through VCS.

In Ref. [1], this nucleon structure information was formalized by introducing q -dependent generalized polarizabilities which were denoted as $P^{(\rho' L', \rho L)S}(q)$. In this notation, ρ (ρ') refers to the electric (2), magnetic (1) or longitudinal (0) nature of the initial (final) photon. L (L') represents the angular momentum of the initial (final) photon whereas S differentiates between the spin ($S = 1$) and non spin-flip ($S = 0$) character of the electromagnetic transition. If one restricts oneself to the dipole approximation for the outgoing photon, angular momentum and parity conservation yield ten functions of the virtual photon three-momentum q . Of these, there are three spin-independent ($S = 0$) and seven spin-dependent ($S = 1$) functions. It was shown in Ref. [10] that the charge conjugation symmetry combined with crossing symmetry yield additional constraints on the VCS amplitude. In particular, for the spin-independent ($S = 0$) part of the amplitude, this symmetry was shown [8] [10] to yield one relation between the three spin-independent polarizabilities of Ref. [1]. Three additional relations are expected between the spin-dependent polarizabilities [11].

If one wants to extract these polarizabilities from experiment, an unpolarized experiment is not sufficient. To separate the polarizabilities, one has to resort to polarization observables. Below pion production threshold, the amplitude is purely real. Consequently all single polarization observables are zero and one has to resort to double polarization observables to extract new information. Experimentally, at existing high duty cycle electron facilities with a polarized electron beam such as at MAMI, MIT-Bates and TJNAF, double polarization VCS experiments can be performed by using either a polarized target or by measuring the recoil polarization of the outgoing nucleon with a focal plane polarimeter.

We investigate in this Letter what can be learned from these double polarization observables. For this sake, model predictions for these observables will be given based on the effective Lagrangian formalism of Ref. [7]. Afterwards, a model independent interpretation will be given based on the low energy expansion formalism of Ref. [1] in terms of generalized polarizabilities. In particular, the formula relating the double polarization observables to the polarizabilities will be given.

The double polarization asymmetry where the incident electron is polarized (with helicity $h = \pm \frac{1}{2}$) and where the polarization of the final nucleon is measured, is given by [12]

$$\Sigma^{(i)} = \frac{[\sigma_{h=+\frac{1}{2}, s'_i \uparrow} - \sigma_{h=+\frac{1}{2}, s'_i \downarrow}] - [\sigma_{h=-\frac{1}{2}, s'_i \uparrow} - \sigma_{h=-\frac{1}{2}, s'_i \downarrow}]}{[\sigma_{h=+\frac{1}{2}, s'_i \uparrow} + \sigma_{h=+\frac{1}{2}, s'_i \downarrow}] + [\sigma_{h=-\frac{1}{2}, s'_i \uparrow} + \sigma_{h=-\frac{1}{2}, s'_i \downarrow}]}, \quad (1)$$

where s'_i is the projection of the final proton spin along the direction i ($i = x, y, z$, for conventions see Fig.1). In Eq.(1), σ stands for the fivefold differential $p(\epsilon, \epsilon'p)\gamma$ cross section $d\sigma/(d\Omega'_e)_{Lab} d|\vec{k}'|_{Lab} (d\Omega'_p)_{CM}$, where the kinematical variables are taken as in Ref. [1] to be the outgoing electron angles and momentum ($|\vec{k}'|_{Lab}$) in the Lab system and the outgoing

proton angles in the $(\gamma^* + p)$ CM system. In Fig.1 the $p(\vec{\epsilon}, \epsilon' \vec{p})\gamma$ reaction is displayed for the case where the angle between the electron and hadron plane is taken to be $\Phi = 0^\circ$. Similarly to Eq.(1), one can also define the double polarization observable for an incident polarized electron and where the target proton is polarized along direction i . In this latter case, the same definition for the asymmetry as Eq.(1) holds with the replacement of s'_i by the target proton spin projection s_i .

From the experimental point of view, the measurement of an asymmetry such as Eq.(1), has the advantage over an absolute cross section measurement that no absolute normalization is required. Furthermore, it was found in Ref. [13] that the radiative corrections to the VCS (which were calculated exactly in lowest order in Ref. [13]) are not at all negligible compared to the nucleon structure effect one hopes to extract from the $p(\epsilon, \epsilon' p)\gamma$ reaction. In this respect, an asymmetry measurement turns out to be promising as the effect of the radiative corrections on this observable was found to be much smaller over most of the photon angular range compared to the relative effect of the radiative corrections on the cross sections.

To provide an estimate of the VCS asymmetries (Eq.(1)), the relativistic effective Lagrangian model of Ref. [7] is used. In this model, the $p(\epsilon, \epsilon' p)\gamma$ reaction below pion production threshold was described in terms of Bethe-Heitler (BH), Born and non-Born diagrams. For the non-Born diagrams, a tree-level calculation was performed consisting of exchanges of the resonances $\Delta(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $S_{31}(1620)$, $S_{11}(1650)$ and $D_{33}(1700)$ in the s - and u -channel and the exchanges of the π^0 and σ in the t -channel. The model was tested against available data for real Compton scattering below pion threshold. It was found to give a prediction for the magnetic polarizability which is in agreement with the experimental value [14] but underestimates (by about 40%) the value of the electric polarizability. This is probably due to the tree-level nature of the calculation of Ref. [7], where non-resonant πN intermediate states were neglected. It was found that the dominant contributions in this effective Lagrangian calculation were given by the Δ , D_{13} and σ -exchange contributions. The Δ contributes mainly to magnetic transitions whereas the D_{13} and σ -exchanges give the most important contributions to the electric transitions. Due to the underestimation of the electric polarizability in this tree-level model, it is therefore instructive to show separately the results for the Δ and $D_{13} + \sigma$ contributions when making model predictions for the $p(\epsilon, \epsilon' p)\gamma$ double polarization asymmetries.

Results for double polarization VCS asymmetries are shown in Figs.2-4. In Fig.2 the double polarization asymmetry where the recoil proton polarization is measured either along the x - or z - directions (see Fig.1) is shown at $q = 600 \text{ MeV}/c$. It is seen that the asymmetry where the final proton is polarized parallel to the virtual photon yields a large value (between 0.6 and 0.7). For both polarization directions it is furthermore seen that the Δ and $D_{13} + \sigma$ contributions yield a large and opposite effect to the asymmetry relative to the BH + Born result. A similar large and opposite effect is seen in Fig.3 for the corresponding asymmetries at the larger value $q = 1.059 \text{ GeV}/c$ accessible at TJNAF. For the asymmetry where the final nucleon is polarized parallel to the virtual photon, it is seen that the larger value of ϵ (which is the polarization of the virtual photon in the standard notation used in electron scattering) in the kinematics of Fig.3, yields a qualitative different result for the Δ and $D_{13} + \sigma$ contributions compared to those of Fig.2, which points to the interest to measure these asymmetries at different values for ϵ . The ϵ -dependence is also shown in Fig.4, where

the VCS double polarization asymmetry for a polarized target is shown at $q = 450 \text{ MeV}/c$ (accessible at MAMI or MIT-Bates) for two values of ϵ . The Δ and $D_{13} + \sigma$ contributions show a clearly different angular behaviour in Fig.4. Furthermore the magnitude of this asymmetry varies rather strongly with ϵ .

In order to give a model independent interpretation of the nucleon structure effect in the $p(\epsilon, \epsilon' p)\gamma$ reaction below pion threshold, a low energy expansion (in the outgoing photon three-momentum q') of the amplitude in terms of generalized polarizabilities was proposed in Ref. [1]. This yields for the unpolarized differential laboratory cross section the expansion

$$\frac{1}{4}[\sigma_{h=+\frac{1}{2}, s'_1 \uparrow} + \sigma_{h=+\frac{1}{2}, s'_1 \downarrow} + \sigma_{h=-\frac{1}{2}, s'_1 \uparrow} + \sigma_{h=-\frac{1}{2}, s'_1 \downarrow}] = K_1 \left\{ \frac{\mathcal{M}_{-2}}{q'^2} + \frac{\mathcal{M}_{-1}}{q'} + \mathcal{M}_0 + O(q') \right\}. \quad (2)$$

The phase space factor K_1 in Eq.(2) is given by

$$K_1 = \frac{1}{(2\pi)^5} \frac{1}{64 M_N} \frac{s - M_N^2}{s} \frac{|\vec{k}'|_{Lab}}{|\vec{k}|_{Lab}}, \quad (3)$$

where s is the square of the CM energy in the $(\gamma^* + p)$ system, $|\vec{k}|_{Lab}$ ($|\vec{k}'|_{Lab}$) is the incident (final) electron momentum in the Lab system and M_N is the nucleon mass. The coefficients $\mathcal{M}_{-2}$ and $\mathcal{M}_{-1}$ are completely determined by the BH+Born amplitude which is exactly calculable from the on-shell proton electromagnetic form factors. The coefficient $\mathcal{M}_0$ of the unpolarized squared amplitude of Eq.(2) results from the interference of the BH+Born amplitude and the non-Born VCS amplitude respectively. Its expression in terms of polarizabilities was given for the first time in Ref. [1] :

$$\begin{aligned} \mathcal{M}_0 &= \mathcal{M}_0^{BH+Born} \\ &= 2 K_2 \left\{ v_1 [\epsilon P_{LL}(q) - P_{TT}(q)] + v_2 \sqrt{2\varepsilon(1+\varepsilon)} P_{LT}(q) + v_3 \sqrt{2\varepsilon(1+\varepsilon)} P'_{LT}(q) \right\}. \end{aligned} \quad (4)$$

where the kinematical factor K_2 is given by

$$K_2 = \epsilon^6 \frac{q}{Q^2} \frac{2M_N}{1-\varepsilon} \sqrt{\frac{2E_q}{E_q + M_N}}. \quad (5)$$

In Eq.(5), E_q represents the energy of a nucleon with momentum q (which is the three-momentum of the virtual photon). The functions v_1 , v_2 and v_3 in Eq.(4) contain the angular dependence and are given by

$$\begin{aligned} v_1 &= \sin \Theta \left(\omega'' \sin \Theta - k_T \omega' \cos \Theta \cos \Phi \right), \\ v_2 &= - \left(\omega'' \sin \Theta \cos \Phi - k_T \omega' \cos \Theta \right), \\ v_3 &= - \left(\omega'' \sin \Theta \cos \Theta \cos \Phi - k_T \omega' \left(1 - \sin^2 \Theta \cos^2 \Phi \right) \right). \end{aligned} \quad (6)$$

where Θ and Φ are the photon polar and azimuthal angles in the $(\gamma^* + p)$ CM system. The expressions for the kinematical quantities ω'' , k_T and ω' can be found in Ref. [1]¹. The q -dependent nucleon structure functions P_{LL} , P_{TT} , P_{LT} and P'_{LT} in Eq.(4) are given by

¹In Ref. [1] there is a misprint in Eq.(119) for ω , which should be corrected as $\omega = \left[-q' \left(\frac{1}{p \cdot q'} + \frac{1}{k \cdot q'} \right) \right]_{q'=0}$.

$$\begin{aligned}
P_{LL}(q) &= -\sqrt{6} \, 2M_N \, G_E \, P^{(01,01)0}(q) , \\
P_{TT}(q) &= G_M \frac{3}{2} \left[2q^0 P^{(01,01)1}(q) + \sqrt{6}q^2 \hat{P}^{(01,1)1}(q) + \sqrt{2}q^2 P^{(01,12)1}(q) \right] , \\
P_{LT}(q) &= G_M \frac{\sqrt{3}}{2} \frac{Q}{q} \left[P^{(11,00)1}(q) + \frac{q^2}{\sqrt{2}} P^{(11,02)1}(q) \right] + \sqrt{\frac{3}{2}} \left(\frac{M_N q}{Q} \right) G_E P^{(11,11)0}(q) , \\
P'_{LT}(q) &= -G_M \frac{3}{2} Q P^{(01,01)1}(q) + \sqrt{\frac{3}{2}} \left(\frac{M_N}{Q} \right) G_E \left[2q^0 P^{(01,01)0}(q) + \sqrt{6}q^2 \hat{P}^{(01,1)0}(q) \right] . \quad (7)
\end{aligned}$$

where G_E and G_M are the electric and magnetic nucleon form factors which are functions of Q^2 . Remark that only eight polarizabilities enter in the expression of the unpolarized squared amplitude (Eqs.(4) and (7)).

Similarly to Eq.(2) for the unpolarized differential cross section, an expansion is given in this Letter for the polarized cross section difference which appears in the double polarization asymmetry of Eq.(1) (initial electron with helicity $h = \pm \frac{1}{2}$, outgoing proton polarized along the direction i) :

$$\sigma_{h,s'_i \uparrow} - \sigma_{h,s'_i \downarrow} = K_1 \left\{ \frac{\mathcal{M}_{-2}^{(i)}}{q'^2} + \frac{\mathcal{M}_{-1}^{(i)}}{q'} + \mathcal{M}_0^{(i)} + O(q') \right\} . \quad (8)$$

For the case where the outgoing proton is polarized parallel to the virtual photon direction (i.e. along the z -axis), we find

$$\begin{aligned}
\mathcal{M}_0^{(z)} &= \mathcal{M}_0^{(z) BH+Born} \\
&= 4(2h) K_2 \left\{ v_1 \sqrt{1-\varepsilon^2} P_{TT}^z(q) + v_2 \sqrt{2\varepsilon(1-\varepsilon)} P_{LT}^z(q) + v_3 \sqrt{2\varepsilon(1-\varepsilon)} P_{LT}'^z(q) \right\} . \quad (9)
\end{aligned}$$

where the angular dependent coefficients v_1, v_2 and v_3 are the same as those that appear in the unpolarized cross section of Eq.(4). The nucleon structure functions P_{TT}^z , P_{LT}^z and $P_{LT}'^z$ are given by

$$\begin{aligned}
P_{TT}^z(q) &= -P_{TT}(q) , \\
P_{LT}^z(q) &= G_M \frac{\sqrt{3}}{2} \frac{Q}{q} \left[P^{(11,00)1}(q) + \frac{q^2}{\sqrt{2}} P^{(11,02)1}(q) \right] \\
&\quad - \left(\frac{2M_N}{Q} \right) G_E \frac{3}{4} \left[q P^{(11,11)1}(q) - \sqrt{\frac{3}{2}} q^0 q P^{(11,02)1}(q) - \sqrt{\frac{5}{2}} q^3 \hat{P}^{(11,2)1}(q) \right] , \\
P_{LT}'^z(q) &= -G_M \frac{3}{2} Q P^{(01,01)1}(q) \\
&\quad - \left(\frac{2M_N}{Q} \right) G_E \frac{3}{4} \left[2q^0 P^{(01,01)1}(q) + \sqrt{6}q^2 \hat{P}^{(01,1)1}(q) - \sqrt{2}q^2 P^{(01,12)1}(q) \right] . \quad (10)
\end{aligned}$$

Two independent structure functions P_{LT}^z and $P_{LT}'^z$ appear, which contain the two spin-dependent polarizabilities that are not present in the expression Eq.(7) for the unpolarized squared amplitude.

If the outgoing proton is polarized along the x -axis (i.e. perpendicular to the virtual photon direction and parallel to the reaction plane),

$$\begin{aligned}
\mathcal{M}_o^{(x)} &= \mathcal{M}_o^{(x) BH+Born} \\
&= 4 (2h) K_2 \left\{ v_1^x \sqrt{2\varepsilon(1-\varepsilon)} P_{LT}^\perp(q) + v_2^x \sqrt{1-\varepsilon^2} P_{TT}^\perp(q) \right. \\
&\quad \left. + v_3^x \sqrt{1-\varepsilon^2} P_{TT}'^\perp(q) + v_4^x \sqrt{2\varepsilon(1-\varepsilon)} P_{LT}'^\perp(q) \right\} , \tag{11}
\end{aligned}$$

where the angular dependent coefficients v_1^x , v_2^x , v_3^x and v_4^x are given by

$$\begin{aligned}
v_1^x &= \sin \Theta \cos \Phi \left(\omega'' \sin \Theta - k_T \omega' \cos \Theta \cos \Phi \right) , \\
v_2^x &= - \left(\omega'' \sin \Theta - k_T \omega' \cos \Theta \cos \Phi \right) , \\
v_3^x &= - \cos \Theta \left(\omega'' \sin \Theta - k_T \omega' \cos \Theta \cos \Phi \right) , \\
v_4^x &= k_T \omega' \sin \Theta \sin^2 \Phi . \tag{12}
\end{aligned}$$

For in-plane kinematics (i.e. $\Phi = 0^\circ$), the coefficients of Eq.(12) reduce to $v_1^x \rightarrow v_1$, $v_2^x \rightarrow v_2$, $v_3^x \rightarrow v_3$ and $v_4^x \rightarrow 0$. The nucleon structure functions $P_{LT}^\perp$, $P_{TT}^\perp$, $P_{TT}'^\perp$ and $P_{LT}'^\perp$ are given by

$$\begin{aligned}
P_{LT}^\perp(q) &= \frac{r G_E}{2 G_M} P_{TT}(q) - \frac{G_M}{2 r G_E} P_{LL}(q) , \\
P_{TT}^\perp(q) &= \frac{G_M}{r G_E} [P_{LT}^z(q) - P_{LT}(q)] , \\
P_{TT}'^\perp(q) &= \frac{G_M}{r G_E} [P_{LT}'^z(q) - P_{LT}'(q)] , \\
P_{LT}'^\perp(q) &= \left\{ - r G_E \frac{3}{4} \left[q P^{(11,11)1}(q) + \sqrt{\frac{3}{2}} q^0 q P^{(11,02)1}(q) + \sqrt{\frac{5}{2}} q^3 \hat{P}^{(11,2)1}(q) \right] \right. \\
&\quad \left. + G_M \frac{\sqrt{3}}{2} \frac{Q}{q} [P^{(11,00)1}(q) - \sqrt{2} q^2 P^{(11,02)1}(q)] \right\} , \tag{13}
\end{aligned}$$

where r is defined by $r = 2M_N/Q$. Remark that this observable yields one new structure function $P_{LT}'^\perp$. The other functions of Eq.(13) can be written as linear combinations of those of Eqs.(7) and (10). This new structure function $P_{LT}'^\perp$ can only be accessed by an out-of-plane experiment as $v_4^x \rightarrow 0$ for $\Phi \rightarrow 0^\circ$.

If the outgoing proton is polarized along the y -axis (i.e. perpendicular to the virtual photon direction and perpendicular to the reaction plane),

$$\begin{aligned}
\mathcal{M}_o^{(y)} &= \mathcal{M}_o^{(y) BH+Born} \\
&= 4 (2h) K_2 \left\{ v_1^y \sqrt{2\varepsilon(1-\varepsilon)} P_{LT}^\perp(q) + v_2^y \sqrt{1-\varepsilon^2} P_{TT}^\perp(q) \right. \\
&\quad \left. + v_3^y \sqrt{1-\varepsilon^2} P_{TT}'^\perp(q) + v_4^y \sqrt{2\varepsilon(1-\varepsilon)} P_{LT}'^\perp(q) \right\} , \tag{14}
\end{aligned}$$

where the angular dependent coefficients v_1^y , v_2^y , v_3^y and v_4^y are given by

$$\begin{aligned}
v_1^y &= \sin \Theta \sin \Phi \left(\omega'' \sin \Theta - k_T \omega' \cos \Theta \cos \Phi \right) , \\
v_2^y &= k_T \omega' \cos \Theta \sin \Phi , \\
v_3^y &= k_T \omega' \sin \Phi , \\
v_4^y &= - k_T \omega' \sin \Theta \sin \Phi \cos \Phi . \tag{15}
\end{aligned}$$

This observable is zero for in-plane kinematics ($\Phi = 0^\circ$), as all angular coefficients of Eq.(15) are proportional to $\sin \Phi$. A comparison of Eqs.(11) and (14) reveals that the same nucleon structure functions appear for the two polarization directions perpendicular to the virtual photon direction.

For the target nucleon polarization asymmetry, relations similar to Eqs.(9), (11) and (14) can be derived. For instance, for the polarization observable where the target proton is polarized along the virtual photon direction (z -axis), the expression for $\mathcal{M}_o^{(z)} = \mathcal{M}_o^{(z) BH+Born}$ is given by replacing G_M by $-G_M$ in Eq.(9).

We studied in this Letter the polarized $p(\vec{e}, e'\vec{p})\gamma$ reaction below pion production threshold. An effective Lagrangian model was used to give predictions for the VCS double polarization observables for kinematics accessible at MAMI, MIT-Bates and TJNAF. We presented a model independent interpretation of the nucleon structure effect by expressing these double polarization observables in terms of the generalized polarizabilities of Ref. [1]. It was found that the unpolarized cross section and the double polarization observables where both the incident electron is polarized and the recoil nucleon polarization is measured provide seven independent structure functions in a low energy expansion for the outgoing photon energy. An experimental measurement of these double polarization observables holds therefore promise to disentangle the nucleon polarizabilities.

The author thanks P. Guichon for useful discussions and a critical reading of the manuscript. This work was supported by the French Commissariat à l'Energie Atomique and in part by the EU/TMR contract ERB FMRX-CT96-0008.

REFERENCES

- [1] P.A.M. Guichon, G.Q. Liu and A.W. Thomas, Nucl.Phys. **A591** (1995) 606.
- [2] Proceedings of the workshop VCS96, Ed. V. Breton, Clermont-Ferrand, 1996.
- [3] J.F.J. van den Brand, Phys.Rev.D **52** (1995) 4868.
- [4] MAMI proposal (1995), spokespersons N. d'Hose and Th. Walcher.
- [5] Virtual Compton Scattering at MAMI, D. Lhuillier et al., in Proceedings of the XIV International Conference on Particles and Nuclei, PANIC96, Williamsburg, 22-28 May 1996.
- [6] CEBAF proposal, E-93-050, spokespersons P.Y. Bertin, P.A.M. Guichon and C. Hyde-Wright.
- [7] Marc Vanderhaeghen, Phys.Lett.B **368** (1996) 13.
- [8] A. Metz and D. Drechsel, Z.Phys. **A356** (1996) 351.
- [9] T.R. Hemmert, B.R. Holstein, G. Knöchlein and S. Scherer, in Proceedings of the workshop VCS96, Ed. V. Breton, Clermont-Ferrand, 1996.
- [10] D. Drechsel, G. Knöchlein, A. Metz and S. Scherer, preprint MKPH-T-96-20, nucl-th/9608061.
- [11] Andreas Metz, private communication.
- [12] A. Bartl and W. Majoretto, Nucl.Phys. **B62** (1973) 267.
- [13] M. Vanderhaeghen, D. Lhuillier, D. Marchand and J. Van de Wiele, article in preparation.
- [14] B.E. MacGibbon et al., Phys.Rev.C **52** (1995) 2097.

FIGURES

FIG. 1. Outline of the kinematics for the $p(\bar{e}, e'\tilde{p})\gamma$ reaction.

$$q = 600 \text{ MeV}/c, q' = 120 \text{ MeV}/c, \varepsilon = 0.61$$

FIG. 2. VCS double polarization asymmetry (polarized electron, recoil proton polarization along either the x - or z -directions) in MAMI kinematics ($Q^2 = 0.33 \text{ GeV}^2$) as function of the CM angle between real and virtual photon. The BH + Born contribution is shown by the dashed lines. The result of the BH + Born + Δ contribution is shown by the dotted lines, whereas the BH + Born + D_{13} + σ contribution is shown by the dashed-dotted lines. The total effect in the model is shown by the full lines.

$$q = 1.059 \text{ GeV}/c, q' = 120 \text{ MeV}/c, \varepsilon = 0.9475$$

FIG. 3. VCS double polarization asymmetry (polarized electron, recoil proton polarization along either the x - or z -directions) in TJNAF kinematics corresponding with $Q^2 = 1. \text{ GeV}^2$. Curve conventions as in Fig.2.

$$\mathbf{q} = 450 \text{ MeV/c}, \mathbf{q}' = 120 \text{ MeV/c}, \Phi_{\gamma\gamma} = 0^\circ$$

FIG. 4. VCS double polarization asymmetry (polarized electron, target proton polarized along either the x - or z -directions) for in-plane kinematics and for two values of ϵ . Curve conventions as in Fig.2.