Virtual Compton scattering at low energy and the generalized polarizabilities of the nucleon

H. Fonvieille

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VIRTUAL COMPTON SCATTERING AT LOW ENERGY AND THE GENERALIZED POLARIZABILITIES OF THE NUCLEON

H.FONVIEILLE,

for the Jefferson Lab Hall A Collaboration
and the VCS Collaboration

Laboratoire de Physique Corpusculaire IN2P3/CNRS
Université Blaise Pascal - Clermont II
63170 AUBIERE Cedex, FRANCE

We present a particular kind of $(e, e'p)$ experiments, which has opened a new field of investigation of nucleon structure in the last ten years. The exclusive photon electroproduction process $p(e, e'p)\gamma$ is used to study Virtual Compton Scattering (VCS) off the proton: $\gamma^* p \to \gamma p$. In the low energy domain, this process gives access to new observables called the Generalized Polarizabilities. They are fundamental properties of the nucleon, characterizing the deformation of its internal structure under an applied electromagnetic field. Dedicated experiments have been performed at MAMI, Jefferson Lab and MIT-Bates. This contribution summarizes the results obtained so far and future prospects in the field.

1 The Generalized Polarizabilities

The electric and magnetic polarizabilities α_E and β_M of Real Compton Scattering (RCS) [1] are a measure of the deformation of the nucleon structure under an applied EM field. The Generalized Polarizabilities (GPs), first introduced by P.Guichon *et al.* [2], generalize this concept to the case of an incoming virtual photon. The GPs measure the electromagnetic deformation locally inside the nucleon, with a scale given by the virtuality Q^2, and they can be seen as "deformed form factors". The full formalism [3,4] leads to six independent GPs at lowest order, including the electric and magnetic GPs $\alpha_E(Q^2)$ and $\beta_M(Q^2)$, and four spin-flip GPs. The quantities that are determined from an unpolarized $p(e, e'p)\gamma$ experiment are two combinations of GPs called the VCS structure functions $P_{LL} - \frac{1}{\epsilon} P_{TT}$ and P_{LT} , at a given four-momentum transfer squared Q^2.

2 Experiments

Dedicated VCS experiments have been performed at MAMI [5] ($Q^2 = 0.33$ GeV^2), JLab [6] ($Q^2 = 0.92$ and 1.76 GeV^2) and Bates [7] ($Q^2 = 0.05$ GeV^2). They detect the outgoing electron and proton in magnetic spectrometers and reconstruct the photon kinematics by the missing-particle technique. These are difficult experiments, requiring performant electron machines (high luminosity and duty cycle) and high resolution spectrometers. Photon electroproduction cross sections are small, and background events numerous. The smallness of the "Polarizability signal" implies an accurate determination of experimental cross sections, via a careful Monte-Carlo study.

3 Analysis Methods and Results

A first method to analyze the data is to measure the deviation of the $p(e,e'p)\gamma$ cross section to the so-called Bethe-Heitler+Born cross section, given by the low-energy expansion (LEX) [3]. This deviation is expressed in terms of the VCS structure functions, which can then be fitted to the experiment. The method is valid for kinematics below the pion production threshold ($\sqrt{s}_{\gamma p} \leq m_N + m_\pi$). A second method is based on the Dispersion Relation (DR) model of B.Pasquini *et al.* [8] and is applicable to kinematics extending in the $\Delta(1232)$ resonance region. The free parameters of the model are fitted to the measured $p(e,e'p)\gamma$ cross sections, yielding the value of the electric and magnetic GPs $\alpha_E(Q^2)$ and $\beta_M(Q^2)$, as well as the VCS structure functions. The first method has been applied in the MAMI and JLab experiments. In the JLab experiment, the resonance region was scanned for the first time in the photon electroproduction channel, allowing also the application of the second method to extract polarizabilities.

From the first VCS experiment of MAMI at low Q^2, one found that the Chiral Perturbation Theory to order (p^3) [9] agreed well with the measured structure functions $P_{LL} - \frac{1}{\epsilon} P_{TT}$ and P_{LT}. Figure 1 gives a representation of the presently available experimental results. In this figure, the electric and magnetic GPs are determined in the framework of the DR model, either by a direct DR analysis of the data [10], or by a LEX analysis of the data [5,11] followed by a subtraction of the spin-flip GPs evaluated in the DR model. The curves are the calculation of this model for two different sets of values of its free parameters ($\Lambda_\alpha, \Lambda_\beta$). The Q^2-dependence of the electric GP $\alpha_E(Q^2)$ appears to be non-trivial, since there is no unique DR curve going through all the points. Measurements tend to confirm the extremum of $\beta_M(Q^2)$ which is predicted by most models in the low-Q^2 region. This turn-over reflects the competing effects of para- and dia-magnetism in the magnetic polarizability. The expected Bates measurement [7] is of great interest in this regard.

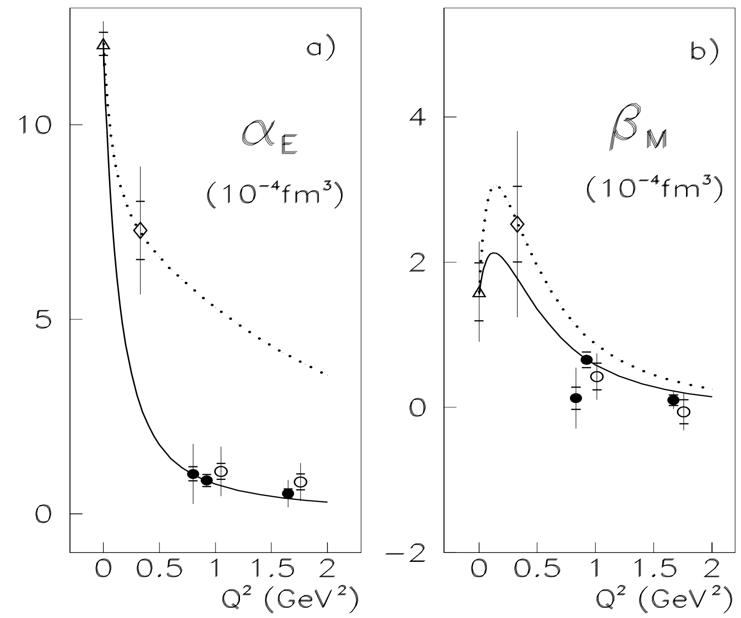

Figure 1: World results on the electric (a) and magnetic (b) Generalized Polarizabilities. The data points at Q^2=0 are from the TAPS experiment [1], the ones at Q^2 = 0.33 GeV^2 are from MAMI[5] and the other ones are from the JLab VCS E93-050 experiment including both analysis methods[11,10]. Some JLab points have been shifted in abscissa for clarity. The curves are the calculation of the DR model for two different sets of values of its free parameters: Λ_α= 0.70 GeV, Λ_β= 0.63 GeV (solid), Λ_α= 1.79 GeV, Λ_β= 0.51 GeV (dotted).

4 Future prospects and conclusions

Table 1 summarizes the foreseen experiments in the field of VCS at low energy. Most projects aim at a deeper disentangling of the individual GPs, by polarization measurements or Rosenbluth-type separations. A recent ($\vec{e}p \to ep\gamma$) experiment was performed at MAMI [12] with a polarized beam. It gives access to the beam spin asymmetry, testing the imaginary part of the VCS amplitude.

Virtual Compton Scattering is an active field of research; Generalized Polarizabilities are new observables providing an original way to study nucleon structure, and there is an ongoing effort to learn more about them both experimentally and theoretically. Experiments make use of low and high energy machines, of polarization degrees of freedom, and they exploit the versatility of methods to extract GPs at low and high Q^2. These observables are also predicted by many theoretical approaches[9,13,14,15,8,16], ..., most calculations being valid at rather low Q^2. In that view the results of the JLab VCS E93-050 experiment should stimulate new calculations of the GPs at high Q^2.

Table 1: Prospects of VCS at low energies. SSA (DSA) = single (double) spin asymmetry.

type of experiment	measure		observables	$\sqrt{s}$	Q^2 (GeV^2)
double polarization	DSA	$\rightarrow$	separate the six lowest-order GPs	$< \pi N$	0.2-0.3
polarized beam	SSA $d^5\sigma$	$\rightarrow$ $\rightarrow$	test Im(VCS) $P_{LL} - \frac{1}{\epsilon} P_{TT}$ and P_{LT}	Δ	≤ 4
unpolarized (several ϵ)	$d^5\sigma$	$\rightarrow$	separate P_{TT} and P_{LL}	$< \pi N$	0.2-0.3

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[1] V. Olmos de León *et al.*, Eur. Phys. J. A 10 (2001) 207 and references therein.

[2] P.A.M. Guichon, G.Q. Liu and A.W. Thomas, Nucl. Phys. A 591 (1995) 606.

[3] P.A.M. Guichon and M. Vanderhaeghen, Prog. Part. Nucl. Phys. 41 (1998) 125.

[4] D. Drechsel *et al.*, Phys. Rev. C 55 (1997) 424; Phys. Rev. C 57 (1998) 941.

[5] J. Roche *et al.*, Phys. Rev. Lett. 85 (2000) 708.

[6] P.Y. Bertin, C. Hyde-Wright, P. Guichon *et al.*, CEBAF Proposal PR93050 (1993). http://hallaweb.jlab.org/experiment/E93-050/vcs.html

[7] J. Shaw, R. Miskimen *et al.*, MIT-Bates Proposal E97-03 (1997).

[8] B. Pasquini *et al.*, Eur. Phys. J. A 11 (2001) 185; D. Drechsel, B. Pasquini and M. Vanderhaeghen, Phys. Rept 378 (2003) 99.

[9] T. Hemmert *et al.*, Phys. Rev. D 62 (2000) 014013.

[10] G. Laveissière *et al.*, hep-ph/0312294, submitted to PRL.

[11] S. Jaminion *et al.*, hep-ph/0312293, submitted to PRL.

[12] H. Merkel, N. D'Hose, spokespersons, MAMI Proposal (2000).

[13] C.W. Kao and M. Vanderhaeghen, Phys. Rev. Lett. 89 (2002) 272002.

[14] G.Q. Liu, A.W. Thomas and P.A.M. Guichon, Austral. J. Phys. 49 (1996) 905; B. Pasquini, S. Scherer and D. Drechsel, Phys. Rev. C 63 (2001) 025205.

[15] A. Metz and D. Drechsel, Z. Phys. A 356 (1996) 351; Z. Phys. A 359 (1997) 165.

[16] M. Vanderhaeghen, Phys. Lett. B 368 (1996) 13.