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Study of the proton structure by measurements of polarization transfers in real Compton scattering at JLab

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Abstract.
A preliminary analysis of polarization-transfer data at large scattering angle (70^o), obtained in an experiment of real Compton scattering on proton, performed in Hall-C of Jefferson Lab, is presented. It is also discussed the relevance of this kind of experiments for shedding light on the non-perturbative structure of the proton, at low energy, and on the transition from the non-perturbative regime to the perturbative one, that occurs at high energy. Moreover, the possibility to extract Compton form factors and the Generalized Parton Distributions, one of the most promising theoretical tool to determine the total angular momentum contribution of quarks and gluons to nucleon spin, is emphasized.

1 Introduction

Real Compton scattering (RCS) performed at wide scattering angle (also called WACS) in the center of mass frame, is a powerful probe for investigating the structure of the nucleon in the hard scattering limit: the coupling of the hadron to two real photons allows one to access information which are not available from DIS and could be complementary to the ones extracted from ep-scattering (see, e.g., Ref. [1] for a recent discussion of the relevance of WACS).
For RCS on proton, the hard scale is reached when the Mandelstam variables s, $-t$, and $-u$ are all large compared to the proton mass or, equivalently, when the transverse momentum transfer $p_\perp$ is large (the WACS regime). Under such conditions the transition amplitude is expected to factorize into the convolution of i) a perturbative hard scattering amplitude, which involves the coupling of the external photons to the active quarks, and ii) an overlap of initial and final soft (non-perturbative) wave functions, which describe the coupling of the active quarks to the proton. Schematically this can be written as:

$$T_{if}(s,t) = \Psi_f \otimes K(s,t) \otimes \Psi_i \tag{1}$$

where $K(s,t)$ is the perturbative hard scattering amplitude and the Ψ's are the soft wave functions. In recent years, various factorization schemes, differing in the number of active constituents participating

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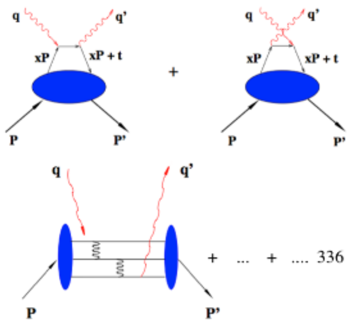

Figure 1. Upper Panel: handbag (left) and crossed (right) diagrams for WACS. (see text). Lower panel: two-gluon exchange pQCD diagram (plus about 336 similar) for WACS (see text).

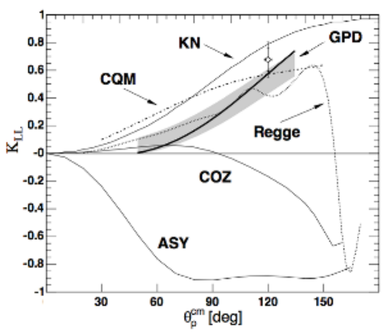

Figure 2. Longitudinal polarization transfer in the WACS process versus the scattering angle in CM. The point is the result of E99-114 at an incident photon energy of 3.2 GeV [10], discussed in the text. The curves represent theoretical prediction based on: KN (Klein-Nishina) for the asymmetry in the hard subprocess; GPD, shown as a gray band, for the handbag approach using GPD's [12]; CQM for the handbag approach using constituent quarks [13]; Regge for a Regge exchange mechanism [11]; and COZ and ASY for pQCD calculations [14] using the asymptotic (ASY) or Chernyak-Ogloblin -Zhitnitsky (COZ) distribution amplitudes.

to the hard scattering subprocess, have been applied to WACS. The two most developed frameworks adopted for analyzing WACS are: i) the "handbag" mechanism [2, 3], which involves only one active constituent, see Fig.1 (upper panel); ii) the "perturbative QCD" (pQCD) approach [4–6], characterized by the two hard-gluon exchange, which involves three quarks, see Fig.1 (lower panel).
In the handbag mechanism, the hard physics is contained in the scattering from a single active quark, i.e. Compton scattering from a structureless spin-1/2 particle, while the soft physics is contained in the wave function describing how the active quark couples to the proton. This coupling is described in terms of Generalized Parton Distributions (GPD's) [7, 8]. In the pQCD approach all three valence quarks are active participants in the hard subprocess, which is effected by the exchange of two hard gluons, while the soft physics is contained in the valence quark distribution. In principle, in any kinematic regime, both mechanisms contribute to the scattering amplitude: at high energy, the pQCD mechanism is expected to dominate, but it is not fully clear how the transition to the purely pQCD occurs; whereas at low energy, WACS is likely dominated by the non-perturbative mechanism. Within this scenario, experiment E99-114 [9] was undertaken to study the WACS reaction. A measurement was made at a single kinematic point, of the longitudinal polarization transfer of longitudinal polarized incident photons to the recoil proton:

$$K_{LL} = \frac{\frac{d\sigma(\uparrow\uparrow)}{dt} - \frac{d\sigma(\uparrow\downarrow)}{dt}}{\frac{d\sigma(\uparrow\uparrow)}{dt} + \frac{d\sigma(\uparrow\downarrow)}{dt}} \tag{2}$$

where the first arrow refers to the incident photon helicity and the second to the recoil proton polarization. The JLab E99-114 experiment has produced a remarkable result [10] shown in Fig.2: K_{LL} is consistent with the handbag and Regge exchange predictions [11], while it is completely inconsistent with predictions based on pQCD. This result has given a strong confidence on the mechanism involving only a single quark in WACS, at least at the experimental energy investigated. Indeed, the longitu-

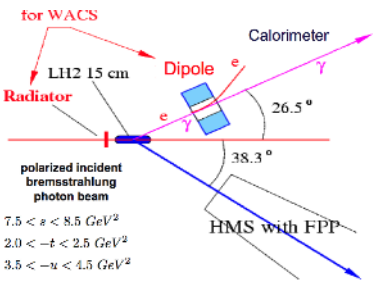

Figure 3. Experimental setup of Hall-C WACS. A polarized photon beam, produced by bremsstrahlung of a polarized electron beam crossing a 6% copper radiator, is scattered from a liquid hydrogen target, transferring polarization to the recoiling protons. These protons are detected in a High-Momentum Spectrometer (HMS), used to reconstruct their kinematics. A focal plane polarimeter (FPP), measures the polarization of the recoiling protons: two blocks of CH_2 are used as analyzers, and tracking detectors are placed after each block to measure the azimuthal asymmetry in the angular distribution of the scattered protons by spin-orbit coupling in the blocks. The scattered photon is detected in a large acceptance electromagnetic calorimeter. Scattered electrons can also reach the calorimeter and constitute one of the main sources of background that are largely identified by a dipole magnet in front of the calorimeter.

dinal polarization is nearly as large as the one expected for the scattering from a free quark. However, further experimental investigations are needed, since the E99-114 measurement was performed at a single kinematic point, and it is possible that the factorization regime was not fully reached, given $u = -1.1(GeV/c)^2$ with that experimental set-up. It is therefore essential to verify E99-114 findings with new measurements, over a broader kinematic range, especially for higher photon energies. For this purpose, in the JLab Hall-C the WACS experiment was performed at different scattering angles. The main goal of the WACS experiment is the measurement of the polarization transfer asymmetries, Eq.(2), sensitive to WACS form factors (FF's) and, in turn, to GPD's.

2 Hall-C WACS Experiment

The JLab WACS experiment E99-114 [9], demonstrated the feasibility of the experimental technique and produced remarkable results, that were the driving force toward a second experiment E07-002, whose setup is summarized in Fig.3; the experiment ran in 2008 in Hall C. The analysis of the collected data can be divided into two parts: i) selection of WACS events and ii) extraction of polarization asymmetries. The WACS channel is selected taking advantage of the 2-body kinematics (Compton scattering), implementing several discriminating variables to increase signal over background ratio. One of the most sensitive variable is the difference between the predicted and observed y-coordinate (δy) in the calorimeter of the photon candidate, since the presence of the magnetic field deflects most of the electrons. Therefore, the main backgrounds to WACS remain basically the pion photo-production, when the di-photon decay is misidentified as one photon, and Bethe-Heitler events, when a radiative photon in ep-scattering is emitted before the magnet. The polarization transfer, expressed in the proton rest frame (helicity rest frame for WACS), is measured through the Maximum Likelihood (ML) method. The likelihood is obtained by collecting all the events that passed the selection criteria of the analysis i). Furthermore, event by event, different aspects have been considered, among these the precession of the proton velocity and spin due to the magnetic dipole field in the HMS, and also the azimuthal asymmetry caused by spin-orbit coupling in the analyzers at focal plane polarimeter (FPP) (the difference of helicity correlated distributions corresponds to the 'true' physical asymmetry, whereas the sum is related to the 'false' instrumental asymmetry) and, finally, back-propagating all these informations to the proton rest frame. Details of the polarization extraction and of Hall-C FPP can be found in [15].

In order to extract the polarization transfer for the WACS signal, K_{LL}^{RCS}, one must take into account the background contamination. Indeed, the WACS events of interest are located in a small elliptical region around $\delta x = \delta y = 0$ in the calorimeter, but in this region we can extract only K_{LL}^{tot}, to which contribute not only WACS but also pion (mostly) background events. The dilution factor in this region, therefore, will be $f = N_{RCS}/N_{tot}$ (~36%) that can be estimated by studying the shape of δy. In the reasonable hypothesis of uniform background polarization K_{LL}^{π}, this latter term can be extracted outside the region where the WACS signal is present. The final longitudinal polarization transfer, in the light of these considerations, can be written as:

$$K_{LL}^{RCS} = \frac{1}{f}\left[K_{LL}^{tot} - (1-f)K_{LL}^{\pi}\right] \tag{3}$$

According to preliminary results, the polarization transfer seems to be consistent with GPD‘s based and Regge predictions, within the uncertainty.

3 Conclusions

The analysis of the polarization transferred to the recoil proton in WACS at θ_p^{cm}=70°, Q^2= 2.1 GeV^2, and incident mean energy of 3.8 GeV is in progress. The preliminary results appear consistent with GPD's based and Regge predictions. This is not sufficient yet to exclude pQCD COZ model, but it is another preliminary indication that the handbag approach seems to be the dominant mechanism at the energy of the experiment. The optimization of the WACS-selection cuts, together with a full study of the systematics are underway. The larger beam energies available at Jefferson Lab in the coming years will permit new measurements of the differential cross section in Compton scattering at higher incident energies, in order i) to clarify in more detail how the factorization is realized and ii) to test QCD based theories and to have an important input for the two-photon exchange calculations and GPD models.

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