Measurement of the Single and Double Spin Asymmetry in Polarized Virtual Compton Scattering at MAMI (Mainz).

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Outline



Introduction

- Virtual Compton Scattering
- Experimental setup: Hall A1 @ MAMI

2 VCS Below Pion Threshold: Recoil Proton DSA

- Theoretical Framework
- Preliminary Results

3 VCS Above Pion Threshold: Beam SSA

- Theoretical Framework
- Preliminary Results



The $p(e, e'p')\gamma$ -reaction

VCS accessed by $p(e, e'p')\gamma$ -reaction



- Bethe-Heitler + Born \rightarrow QED + form factors
- VCS non-Born → Nucleon structure (10% of cross section below π production threshold)

$$\frac{\mathrm{d}^{5}\sigma}{\mathrm{d}k'_{\mathrm{lab}}\mathrm{d}\Omega_{e'\mathrm{lab}}\mathrm{d}\Omega_{\gamma\gamma\mathrm{cm}}}(q_{\mathrm{cm}},q'_{\mathrm{cm}},\varepsilon,\theta_{\gamma\gamma\mathrm{cm}},\varphi)$$

The $p(e, e'p')\gamma$ -reaction

VCS accessed by $p(e, e'p')\gamma$ -reaction



@ threshold: the real photon \approx static electromagnetic field

Interpretation

VCS off the proton @ threshold = elastic electron scattering off a proton, deformed by the (static) external electromagnetic field of the outgoing photon

~ Generalized Polarizabilities (GPs)

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Low energy behaviour of the non-Born VCS scattering amplitude: \rightarrow studied using multipole expansion¹

Six independent lowest order dipoles ~> GPs (Q²-dependent)

- 2 Scalar GPs $\longrightarrow \alpha_E$ and β_M (for $Q^2 \rightarrow 0$: RCS)
- 4 Spin GPs

Interpretation

GPs = extension of the polarizabilities obtained by RCS and they measure the polarizability locally inside the nucleon with a distance scale given by Q^2 .

SSA and DSA in VCS @ $\pi\text{-threshold}$

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Experimental Setup - Overview MAMI-A1

SSA : $\vec{e}p \rightarrow ep\gamma$

DSA: $\vec{e}p \rightarrow e\vec{p}\gamma$

- Polarized electron beam: 855 MeV and 20µA
- Beam polarization up to 85%
- Liquid hydrogen target
- → High luminosity
 - 2 High resolution magnetic spectrometers (^{Δp}/_p ≈ 10⁻⁴)
 → detect proton and electron (small acceptance)
 → γ: missing mass reconstruction
 - Low cross section
 - Proton Focal Plane polarimeter (low efficiency)
- → High luminosity is necessary



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- \rightarrow High luminosity
 - 2 High resolution magnetic spectrometers $(\frac{\Delta p}{p} \approx 10^{-4})$ \rightarrow detect proton and electron (small acceptance)
 - $\rightarrow \gamma$: missing mass reconstruction
 - Low cross section
 - Proton Focal Plane polarimeter (low efficiency)
- \rightarrow High luminosity is necessary

VCS Below π^0 -threshold: Low Energy Theorem

LET = expansion of the observables in q'_{cm} for low q'_{cm}

Unpolarized cross section

$$\mathrm{d}^{5}\sigma = \mathrm{d}^{5}\sigma^{\mathrm{BH}+\mathrm{B}} + \phi \mathbf{q}_{\mathrm{cm}}^{\prime} \Psi_{0} + \mathcal{O}(\mathbf{q}_{\mathrm{cm}}^{\prime 2})$$

 $\Psi_0 \rightarrow 2$ linear combinations of GPs

Single spin asymmetry = 0

Double spin asymmetry (recoil proton and beam helicity):

$$P_{i} = \frac{d^{5}\sigma_{i}^{\uparrow} - d^{5}\sigma_{i}^{\downarrow}}{d^{5}\sigma_{i}^{\uparrow} + d^{5}\sigma_{i}^{\downarrow}} = \frac{\Delta d^{5}\sigma_{i}}{2d^{5}\sigma} \qquad (i = x, y, z)$$
$$\Delta d^{5}\sigma_{i} = \Delta d^{5}\sigma_{i}^{BH+B} + \phi q_{cm}^{\prime} \Delta \Psi_{0,i} + \mathcal{O}(q_{cm}^{\prime})^{2})$$
$$_{i} \rightarrow 6 \text{ linear combinations of GPs}$$



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 $\Delta \Psi_0$

Overview Double Polarized VCS



- Below π^0 -production threshold
- In plane kinematics
- 2 different settings

Status of the analysis:

- Unpolarized cross section: \approx finished
- Recoil proton DSA: not completed yet



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SSA and DSA in VCS @ *π*-threshold

New preliminary result ($\varepsilon = 0.645$):

$$P_{LL} - P_{TT} / \varepsilon = 21.9 \pm 1.8 \pm 0.3 \pm 3.5 \text{ GeV}^{-2}$$
$$P_{LT} = -4.1 \pm 0.6 \pm 0.9 \pm 1.1 \text{ GeV}^{-2}$$

(no detector efficiency correction)

Previous measurement ($\varepsilon = 0.62$)²:

$$\begin{array}{rcl} {\cal P}_{\rm LL} - {\cal P}_{\rm TT}/\varepsilon &=& 23.7 \pm 2.2 \pm 0.6 \pm 4.3 \ {\rm GeV}^{-2} \\ {\cal P}_{\rm LT} &=& -5.0 \pm 0.8 \pm 1.1 \pm 1.4 \ {\rm GeV}^{-2} \end{array}$$

²Roche J., *et al.*, *Phys.Rev.Lett.*, 85, 708, 2000.

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SSA and DSA in VCS @ *π*-threshold



Double Polarization Asymmetry - Analysis Method

- Statistics are low (cross section, polarimeter efficiency, ...)
- Maximum Likelihood fit to the complete dataset
- Direct fit of the GPs to the data
- $\bullet~$ Unpolarized analysis $\rightarrow~$ constraint on the fit
- Goal: extraction of the 6 GPs

VCS Above π^0 -threshold: DR model

VCS amplitude becomes complex above π^0 -threshold



Beam single spin asymmetry

$$A = \frac{\mathrm{d}^5 \sigma^{\uparrow} - \mathrm{d}^5 \sigma^{\downarrow}}{\mathrm{d}^5 \sigma^{\uparrow} + \mathrm{d}^5 \sigma^{\downarrow}} \neq 0$$

Numerator = proportional to the imaginary part of the VCS amplitude



VCS Above π^0 -threshold: DR model

- SSA = direct test of Im(VCS)
- Dispersion Relation (DR) model for VCS³ is the only model
- Model uses πN multipoles dominant in the Δ (1232) region (MAID) in addition to the formfactors
- Two free parameters: Λ_α and Λ_β
 Asymptotic behaviour electric and magnetic GP.

³Pasquini B. *et al*, *Eur. Phys. J.*, A 11, 185, 2001.

SSA and DSA in VCS @ π -threshold

Overview VCS SSA



- Above π⁰-production threshold
- Out of plane kinematics $(\varphi = 220^{\circ})$
- 3 different settings

Status of the analysis: Beam SSA: \approx finished

 $A \approx K \sin \varphi$. (DR model)

Likelihood fit in each θ -bin including the treatment of random coincidences.

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Preliminary Results Single Spin Asymmetry



 $Q^2 = 0.35 \text{ GeV}^2/c^2$, W = 1.19 GeV/c, $\varepsilon = 0.48$ and $\varphi = 220^{\circ}$.

Agreement with theoretical calculation. Small sensitivity to the free parameters.

Preliminary Results Single Spin Asymmetry



 $\mathsf{Q}^2=0.35~\mathsf{GeV}^2/c^2,~W=1.19~\mathsf{GeV}/c,~arepsilon=0.48$ and $arphi=220^\circ.$

Good agreement with MAID^a and DMT^b model.

^aDrechsel D. *et al*, *Nucl. Phys.*, A 645, 145, 1999. ^bKamalov S. *et al*, *Phys. Rev. Lett.*, 83, 4494, 1999.

Summary

First measurement of DSA in VCS

- Below π^0 production threshold
- DSA-analysis not completed yet
- Unpolarized results in agreement with the previous experiment
- The 6 GPs of the proton

Pirst measurement of SSA in VCS

- Above π^0 production threshold
- Preliminary result SSA in photon and pion electroproduction
- Qualitative agreement with theory
- Description of some of the pion-nucleon multipoles might be improved.

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