Letter of Intent

Double Polarization Observables in ϕ Photoproduction using a Polarized Target

F. Klein[1], D. Tedeschi[2], M. Wood[2], D. Sober[1], H. Crannell[1]

[1] The Catholic University of America, Washington, DC 20052
[2] University of South Carolina, Columbia, SC 29208

Abstract

ϕ photoproduction is known to be dominated by t-channel processes, especially diffractive production. Nevertheless, predictions show that contributions of direct knockout mechanisms arising from the possible hidden strangeness content of the nucleon can be measured via double polarization observables involving a polarized target. We propose to measure double polarization observables that are predicted to be very sensitive to the strangeness content of the proton due to the spin structures of the amplitudes associated with contributing mechanisms.

The high quality of the CEBAF electron beam with up to 75 % beam polarization, the recently installed coherent bremsstrahlung facility promising high linear polarization (85–95 %), and the low divergence of the photon beam on target, in combination with the large angular coverage of the CLAS detector form an optimal ensemble to perform this measurement. The experiment will use linearly polarized as well as circularly polarized photon beams at energies between 1.8 and 3.0 GeV.

1 Introduction

One of the most controversial problems in hadron physics over the last 15 years has been the spin content of the nucleon. Experiments in polarized deep inelastic scattering showed that one can probe the composition of the nucleon's spin only via fixing the spin orientation of input particles, i.e. beam and target polarization. Analyses of these measurements revealed that only 22–24% of the nucleon's spin is carried by valence quarks. Based on analyses of the pion-nucleon sigma term [1], polarized deep-inelastic lepton-proton scattering [2], and low energy elastic neutrino-proton scattering [3] it was considered that strange sea quarks play a significant role in the nucleon structure [4]. However, it has also been argued that such experimental results could be understood with little or no strangeness in the nucleon [5].

Several groups studied other processes that might be directly related to the strangeness content of the nucleon [7, 6]. One of them is ϕ meson production from the proton [6, 14, 15]. Since the ϕ meson is a nearly pure $s\bar{s}$ state because of ideal mixing with the ω meson, its coupling to the proton is suppressed through the OZI rule. On the other hand, experiments on vector meson production through $\bar{p}p$ annihilation at rest [9] reported a strong violation of the OZI rule. It could be accounted for by the presence of an intrinsic $s\bar{s}$ component in the nucleon wave function [4, 10]. Other theorists claimed that the OZI violation could be explained through modified meson exchange models [11, 12] without any strangeness content of the nucleon.

In the reaction $\gamma p \to \phi p$ the contribution from the hidden strangeness of the proton arises through the direct knockout process. Henley *et al.* [13] calculated the contribution from knockout process to the ϕ electroproduction cross section, and found it comparable to that of VDM with an assumption of a 10–20% strange sea quark admixture in the proton wave function. They used non-relativistic quark model wave functions for the hadrons which are not very accurate in the kinematical region of ϕ meson photo- and electroproduction. Improved calculations by Titov *et al.* [14] using a a relativistic harmonic oscillator quark model show that the relativistic corrections are important. As a result, the cross section of the direct knockout mechanism for electroproduction is comparable to that of VDM at moderate Q^2 with less than 5% admixture of strange sea quarks in the proton, and for photoproduction with less than 2% admixture.

The differential cross section and the beam asymmetry measurements underway in Hall B [16] will provide information on the ratio of the VDM amplitude to other amplitudes by deducing the parity of the contributions from azimuthal distributions. However, it is experimentally very difficult to further disentangle the mechanisms from the data since OBE processes (π and η exchange) and strangeness knockout have the same parity. It is more advantageous to measure polarization observables which reveal the different spin structures of the various amplitudes [13, 14, 17]. Titov *et al.* [14, 15] have shown that some double polarization observables are indeed very sensitive to the hidden strangeness content of the proton. Their calculations include a gauge invariant description of the quark-Pomeron interaction for the VDM amplitude, OBE processes, and direct knockout of an $s\bar{s}$ (or uud) cluster in the proton.

2 Polarization Observables

In the framework of VDM [20, 21] the incoming photon first dissociates into a $q\bar{q}$-pair which is almost on the mass-shell of one of the vector mesons (e.g. ϕ-meson), and then scatters diffractively off the nucleon through Pomeron exchange, as shown in Fig. 1 (*left*). Experimental observations for vector-meson production, small-t elastic scattering, and diffractive dissociation indicate that the Pomeron behaves like a $C = +1$ isoscalar photon [22, 23]. The microscopic model for vector meson photo- and electro-production applied in our calculations is based on the Pomeron–photon analogy at high energies as proposed by Donnachie and Landshoff [24] who described the Pomeron successfully in terms of a non-perturbative two-gluon exchange model [25].

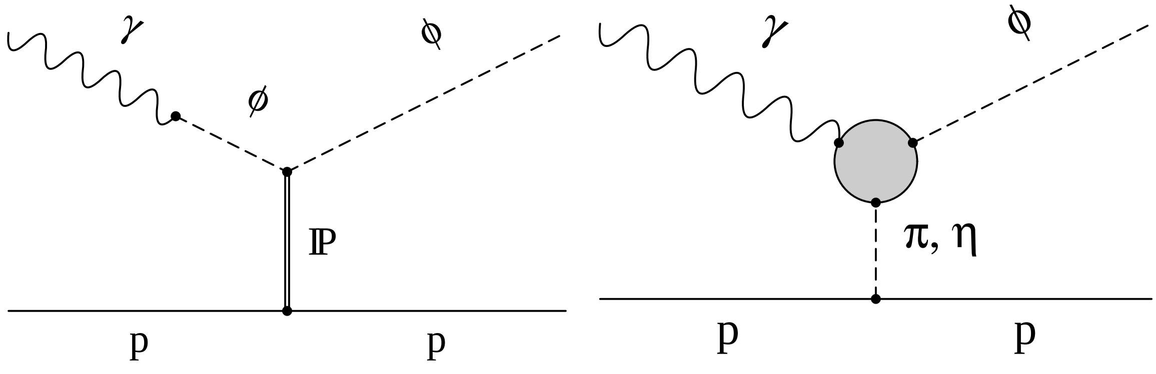

Figure 1: Diffractive ϕ production through Pomeron exchange (*left*) and one-boson-exchange process in ϕ production (*right*).

At low photon energy, one-boson-exchange diagrams like π and η exchange in Fig. 1 (*right*) give non-negligible contributions. The t-channel exchange of η is expected to give contributions of the same order of magnitude as the π-exchange, except in forward direction due to the heavier mass of the η-meson.[1]

[1]For this consideration, the ηNN coupling is taken into account. There can be cancellation between the two because $g_{\eta NN}/g_{\pi^0 NN} < 0$.

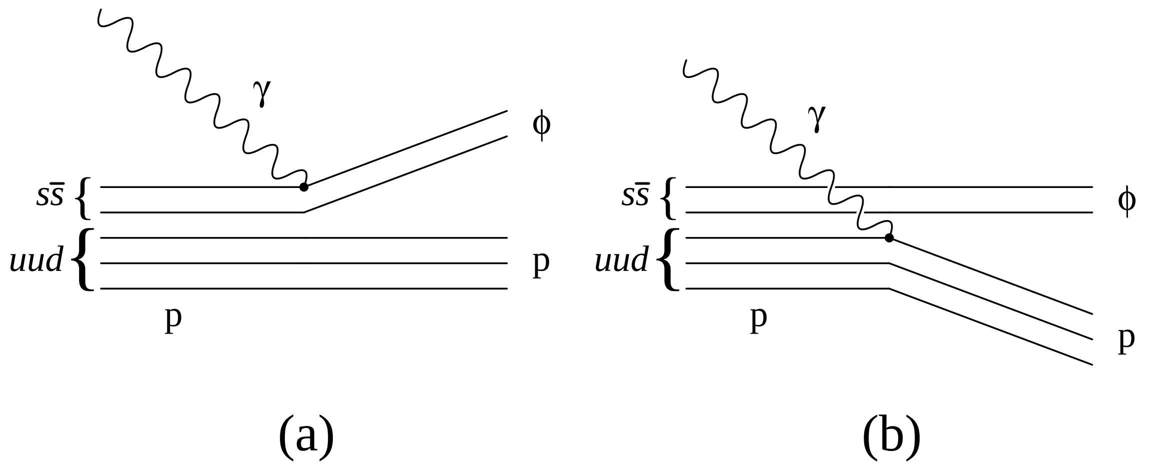

Figure 2: $s\bar{s}$ knockout (a) and uud knockout (b) as OZI evasive contributions to ϕ photoproduction [15].

Assuming that the proton contains a 5-quark component ($uuds\bar{s}$), the incoming photon may interact with this 5-quark component by direct knockout as shown in Fig. 2. This process can be classified, according to the struck quark-cluster, into $s\bar{s}$- and uud-knockout. In order to investigate the effects from the hidden strangeness content of the proton in ϕ photoproduction, the proton wave function is parametrized [15] in Fock space as

$$|\,p\rangle = A_0|\,uud\rangle + \sum_X A_X|\,uudX\rangle + \sum_X B_X|\,uuds\bar{s}X\rangle, \tag{1}$$

where X denotes any combination of gluons and light quark pairs of u and d quarks. The strength of the $s\bar{s}$ admixture ($|B_X|^2$) is estimated by isolating the OZI evasion processes. To compensate for the negative parity of the $s\bar{s}$ cluster, only the odd orbital excitations in the wave function of relative motion between uud and $s\bar{s}$ clusters are allowed.

The calculations show that beam asymmetry Σ_x and tensor polarization observables $V_{z'z'}$, $V_{z'x'}$, $V_{x'x'y'y'}$ are not sensitive for knockout processes except in the very backward direction where the VDM parametrization is questionable, and count rates are the lowest. The most sensitive observables[2] are the double polarization observables $C^{\rm BT}_{zz}$, $C^{\rm BT}_{zx}$, $C^{\rm BT}_{yz}$, and $C^{\rm BT}_{yx}$ involving circularly (B$\rightarrow z$) and linearly (B$\rightarrow y$) polarized photon beam in combination with longitudinally (T$\rightarrow z$) and transversely (T$\rightarrow x$) polarized targets (cf. Fig. 3).

We take into consideration that other processes like rescattering effects may play an important role in the interpretation of the data. In $\bar{p}p$ annihilation it was e.g. shown that the large rate for

[2]We do not refer to polarization observables involving recoil polarization (which can be measured by means of a proton polarimeter) or vector polarization of ϕ (which is only measurable via the spin transfer in leptonic decays).

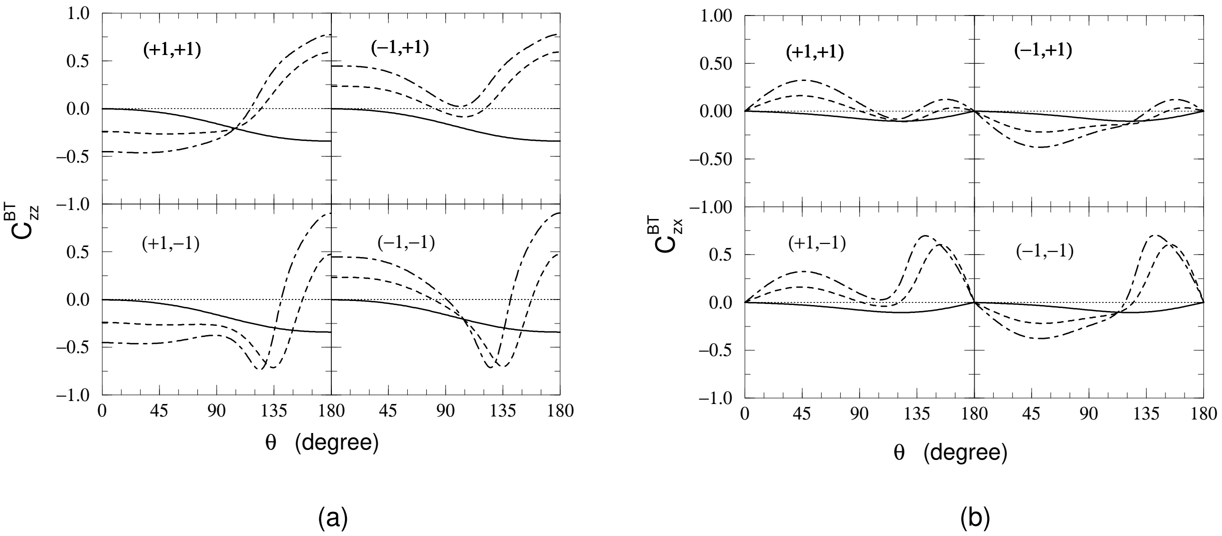

Figure 3: The double spin asymmetry (a) $C^{\rm BT}_{zz}(\theta)$ and (b) $C^{\rm BT}_{zx}(\theta)$ at E_γ = 2.0 GeV for VDM and OPE processes (solid lines), 0.25% (dashed lines), and 1.0% (dot-dashed lines) $s\bar{s}$ admixture. The phases (η_0, η_1) between the $s\bar{s}$ and uud knockout processes are explicitly given in each graph [15].

$\bar{p}p \to \phi\pi$ which is OZI-violating can be explained by the rescattering of the two kaons produced in $\bar{p}p \to$ K*K [27]. Here the rates for the two reactions are similar im magnitude.
Such effects may also play a role in the photoproduction of ϕ-mesons where the process allowing the rescattering of two kaons into a ϕ, namely $\gamma p \to \Lambda(1520)K^+$ has also the same order of magnitude than the ϕ-photoproduction itself.
The final state pK^+K^- can be reached via ϕ-photoproduction but also via the reaction shown in Fig. 4. Here, in a first step, the $\Lambda(1520)$ is produced together with a K^+, the $\Lambda(1520)$ decays via pK^-, and the K^- then rescatters with the K^+ into a ϕ.

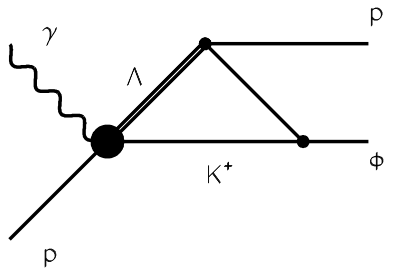

Figure 4: ϕ-meson photoproduction via rescattering with $\Lambda(1520)K^+$ in the intermediate state.

Such rescattering effects have been calculated in the framework of the dispersion relation technique [28]. It was shown that they lead to contributions in single and double polarization observables. These are of similar magnitude than the knockout-processes but their shape is different. Rescattering only contributes to the backward scattering region ($\theta > 90°$). Fig. 5 show that, especially for polarization observables C^{BT}_{ij} involving polarized beam and polarized target, the contributions are rather limited and clearly differ from those shown in Fig. 3.

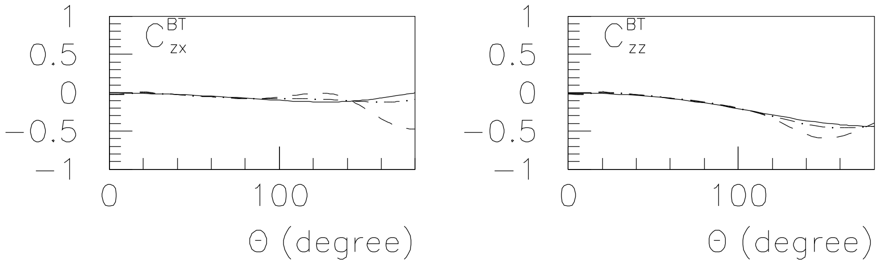

Figure 5: Double polarization observables C^{BT}_{zx} and C^{BT}_{zz} for ϕ-meson photoproduction. The *solid* curve represents diffractive scattering (Pomeron exchange), the *dashed* and *dot-dashed* lines show the contributions from rescattering in case of exponential and linear differential cross section for $\Lambda(1520)$ photoproduction. Taken from [28].

We will propose measurements of C^{BT}_{zz} and C^{BT}_{zx} in Hall B using circularly polarized photons and a polarized target as well as C^{BT}_{yz} and C^{BT}_{yx} using linearly polarized photons and a polarized target. A frozen spin target based on proven techniques (described in the next section) can provide the necessary polarization and count rates for these measurements.

3 Frozen Spin Polarized Target for CLAS

We propose to build a frozen spin target for use in photon-induced experiments with CLAS. The dynamically polarized target used for electron-beam experiments has the disadvantage that is requires the target to be located inside a strong (≈ 5 T) and very uniform (ΔB/B$\approx 10^{-4}$) magnetic field. The magnet needed to produce this field occupies a major fraction of the space around the target sample, leaving only a relatively small acceptance for outgoing particles, and the useful acceptance for low-momentum charged particles may be further reduced by large deflections in the magnetic field. For experiments using a large-aperture spectrometer like CLAS in conjunction with a tagged photon beam, which deposits negligible energy in the target, a more attractive option is to use a frozen spin polarized target.

In a frozen spin target, the material is polarized in the standard way with microwave irradiation in a high magnetic field. Then, with the microwaves off, the temperature of the material is lowered as much as possible, so that the relaxation time of the polarization becomes very long, hence the term "frozen spin". The value of the relaxation time is a strong function of the ratio B/T where B is the value of the magnetic holding field and T the material temperature. By operating at a sufficiently low temperature, it is possible to reduce the holding field to $< 0.5T$ and modest uniformity, while still preserving a high polarization for times acceptable for running the experiment.

The low holding field can be supplied either by the fringe field of the polarizing magnet or by another magnet, the geometry of which can be tailored to the particular experiment to provide a much larger acceptance than obtainable with a high-field magnet. For example, the polarized target for the Bonn–Mainz GDH experiments [29] uses a longitudinal holding field produced by a very thin (500μm) supperconducting solenoid located within the target cryostat which offers virtually no obstruction to the outgoing particles. Another arrangement may be solenoids in a certain distance from the target along the beam axis which do not obstruct the geometrical acceptance of the spectrometer. For transverse polarization, a suitable holding field could be produced by a pair of superconducting Helmholtz coils parallel to the beam axis, also contained within the target cryostat. Figure 6 shows a rough sketch of the holding magnets envisioned for CLAS. The coils could be positioned as much as possible within the shadows of the CLAS torus, to minimize he loss of acceptance.

A "standard" frozen spin target such as the Bonn–target uses butanol as target material. Another possible target material is polyethylene doped with TEMPO, which has similar dilution factor and polarization properties but allows a more accurate measurement of the effective thickness of the target beads. For the purpose of rate calculations, we propose to construct a cylindrical CH_2 target of 40 mm length and 20 mm diamter, with a density of 0.9 g/cm^3 and a free proton density of 0.8×10^{22} protons/cm^3.

A dilution refrigerator is used to provide the lowest temperatures and reasonable cooling power when polarizing. Typical values [30] would be 50 mK for frozen spin operation and 200–400 mK with ≈ 50 mW cooling power when polarizing. the University of Virginia (UVa) has the capability of providing such a refrigerator which can be assembled from major components currently in its laboratory. This dilution refrigerator was fabricated at CERN but never assembled; however, three others of the same design have been used very successfully in other experiments at the CERN PS and LEAR.

Other typical parameters for the system are [31]:

a 2.5 T polarizing magnet, microwave frequency of 70 GHz to polarize, and a standard Liverpool Q-meter would measure the polarization to a precision of about 3 %. For a butanol target, proton

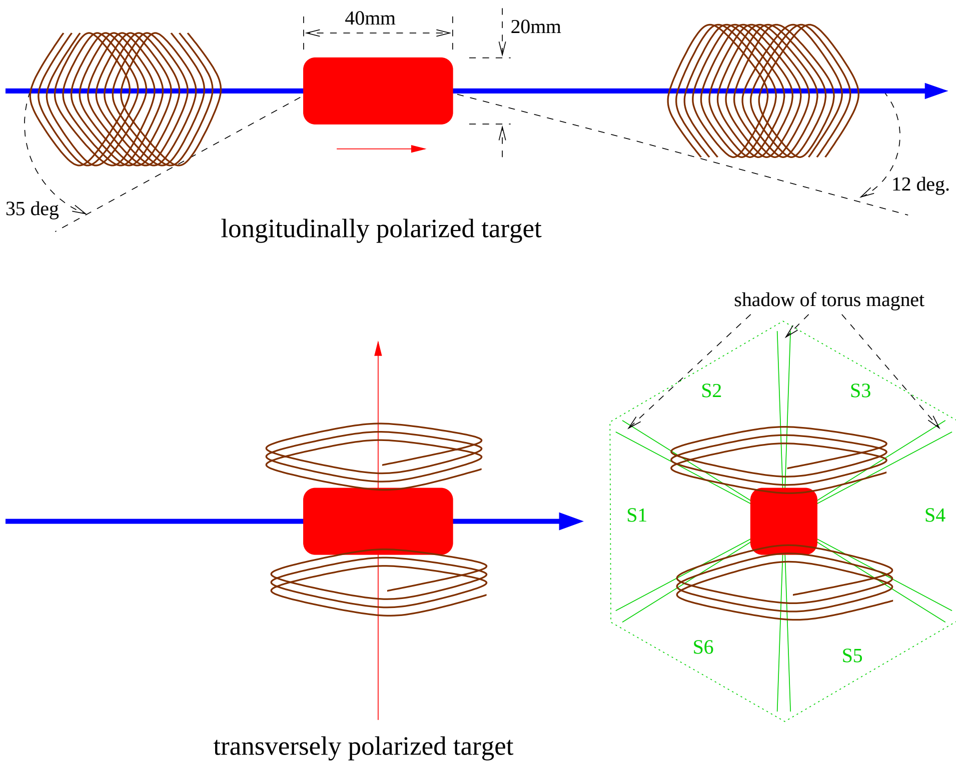

Figure 6: Sketch of the frozen spin target for CLAS.

polarizations of about 90 % with hold times of around 200 hours are achievable, while deuteron polarizations for deuterated butanol could reach 50 % with long hold times.

This target system could efficiently be produced by a collaboration between the Jefferson Lab target group and UVa, and – especially if transverse polarizations are accommodated, would be a flexible facility for a wide range of polarization experiments with CLAS.

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