φ-MESON PHOTOPRODUCTION AND STRANGENESS OF THE NUCLEON

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The polarization observables in φ photoproduction are suggested for probing the nucleon strangeness. Based on models for φ photoproduction, some double polarization observables are shown to be very sensitive to the strangeness content of the proton because of the different spin structures of the amplitudes associated with different mechanisms.

The possible existence of hidden strangeness in the nucleon has been one of the most controversial problems in hadron physics. Some experimental results have been interpreted as signatures of hidden strangeness of the nucleon but it has been also claimed that these experiments could be understood with little or null strangeness in the nucleon. It will be interesting, therefore, to study other processes that might be related directly to the hidden nucleon strangeness. One of them is to use φ production from the proton. Since the φ is nearly pure s̅s state, its coupling to the proton is suppressed by the OZI rule. Then the idea is that studying the strange sea quark contribution through the OZI evasion processes may give informations about the hidden strangeness of the nucleon.

In this work, we discuss φ photoproduction process from the proton targets (Fig. 1). We define k, q, p, and p' as the four-momenta of the photon, φ-meson, target proton, and recoiled proton, respectively, and t = (p - p')² and W² = (p + k)². The scattering angle in c.m. frame is denoted by θ. In this case, the main contribution to the cross section is from the diffractive production process of vector-meson dominance (VDM), and the one-pion-exchange (OPE) process comes in as a correction to VDM. This OPE process is possible because of the φ-π-γ coupling, and represents the contributions from the (small) non-strange quark components of the φ-meson.

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In addition to these processes, the contribution from the hidden strangeness of the proton arises through the direct knockout process. For this purpose, we write the proton wave function in Fock space as

$$|p\rangle = A [\{uud\}^{1/2} + \sum_{j,s=0,1/2} b_{j,s} [[\{uud\}^{1/2} \otimes \{L\}^{j,c} \otimes \{s\bar{s}\}^{j,s}]^{1/2}], \quad (1)$$

where the superscripts denote the spin of each cluster and \((b_0, b_1)\) correspond to the amplitudes of the \(s\bar{s}\) cluster with spin 0 and 1, respectively. Then the strangeness admixture of the proton is \(B^2 = b_0^2 + b_1^2\). The symbol \(\otimes\) represents vector addition of the cluster spin and the orbital angular momentum \(L\) (\(\ell = 1\)). The purpose of this study is to extract an information about \(B^2\), if it is nonzero, through \(\phi\) photoproduction from the proton targets.

In Ref. 6, Henley et al. calculated the contribution of the knockout process in \(\phi\) electroproduction cross section using nonrelativistic harmonic oscillator quark model and found it comparable to that of VDM with an assumption of \(B^2 = 10\%\). This work was improved by Titov et al. with the use of a relativistic harmonic oscillator quark model and leads to the conclusion that a theoretical upper bound of \(B^2\) would be less than 5\%. In Fig. 2, we give our results for the cross section for \(\phi\) photoproduction. As can be seen from Fig. 2, it is not easy to distinguish the mechanisms from the cross section measurements because their respective contributions have similar dependence on the momentum transfer.

It is, therefore, required to find other quantities which are very sensitive to the nucleon strangeness and we found that some double polarization observables in \(\phi\) photoproduction could be very useful tools to study the nucleon strangeness. Having the helicity amplitudes of each process, we can compute various polarization observables using the formalism developed, e.g., in Ref. 10. In Fig. 3, as a typical example, we show our results for the double polarization observable \(C_{\lambda\lambda}^{\phi}\) where both the photon and the target proton are polarized along the direction of the photon.
Figure 2. Unpolarized differential cross section $d\sigma/dt$ of $\phi$ photoproduction at $W = 2.155$ GeV. The solid, dotted, dashed, and dot-dashed lines give the cross section of VDM, OPE, $s\bar{s}$-knockout, and $uud$-knockout, respectively, with strangeness admixture $B^2 = 1\%$ assuming $|b_0| = |b_1|$. The experimental data are from Ref. 8.

momentum;

$$C_{zz}^{BT} \equiv \frac{d\sigma_{\uparrow\uparrow} - d\sigma_{\uparrow\downarrow}}{d\sigma_{\uparrow\uparrow} + d\sigma_{\uparrow\downarrow}},$$

(2)

where $d\sigma$ represents $d\sigma/dt$ and the arrows denote the photon beam and target proton helicities. One can find that this quantity is very sensitive to the hidden nucleon strangeness $B^2$. At forward scattering angles, $C_{zz}^{BT}$ approaches zero with $B^2 = 0$, but even with $B^2 = 1\%$ its magnitude is as large as 0.45.

This remarkable sensitivity of $C_{zz}^{BT}$ on $B^2$ comes from the different spin structures of the associated amplitudes. At forward scattering angle limit, the helicity amplitudes read

$$H^{VDM} \rightarrow -iM_0^{VDM}\delta_{\lambda_f \lambda_i} \delta_{\lambda_\phi \lambda_\gamma},$$

$$H^{OPE} \rightarrow -M_0^{OPE}(2\lambda_f \lambda_i)\delta_{\lambda_f \lambda_i} \delta_{\lambda_\phi \lambda_\gamma},$$

$$H^{ss} \rightarrow -iM_0^{ss}(2\lambda_f \lambda_i)\delta_{\lambda_f \lambda_i} \delta_{\lambda_\phi \lambda_\gamma},$$

(3)

where the helicities of the target and recoiled proton, photon beams, and $\phi$-meson are denoted respectively by $\lambda_i, f, \gamma, \phi$. The relevant amplitudes of each process are given by $M_0^{VDM}$, etc. The $uud$-knockout is suppressed at forward scattering angles and we can ignore it in this region. Then the above analysis gives

$$C_{zz}^{BT} \simeq -2\eta_0 \sqrt{\sigma^{ss}/\sigma^{VDM}},$$

(4)

where $\eta_0$ is the phase of $b_0$. This shows that the above quantity is very sensitive to $\sigma^{ss}$ as verified by numerical calculations given in Fig. 3.
As a summary, we found that some double polarization observables in $\phi$ photoproduction could be very useful for investigating the hidden strangeness of the nucleon. The optimal range of the initial photon energy to measure $B^2$ would be around 2-3 GeV, which can be reached by the current electron facilities, and several experiments have been proposed at JLab and RCNP to measure these quantities.

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