Recent progress of research on ϕ photoproduction at LEPS

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Photoproduction of the ϕ meson is one of the main research fields of the LEPS experiment. Utilizing a highly polarized laser-electron-photon (LEP) beam, we have been studying the photoproduction mechanism of the ϕ meson. In this report, we present the results of two measurements for which the data analyses were recently finished: 1) ϕ photoproduction on the proton at $E_\gamma = 1.5-2.9$ GeV, and 2) coherent ϕ photoproduction from ^{4}He at $E_\gamma = 1.7-2.4$ GeV.

I. ϕ photoproduction as a tool to study the Pomeron

The Pomeron is introduced to explain hadron-hadron scatterings at high energies. The Pomeron exchange process is universal for all the hadronic reactions, and well explains energy dependences of total cross sections for various hadron scatterings at $\sqrt{s} > 10$ GeV. On the other hand, the Pomeron behavior at low energies is not well known because the Pomeron exchange process is usually hidden by large contributions from quark exchange processes at low energies (Fig. 1). However, the quark exchange processes [Fig. 1 (right)] are suppressed in the ϕ photoproduction

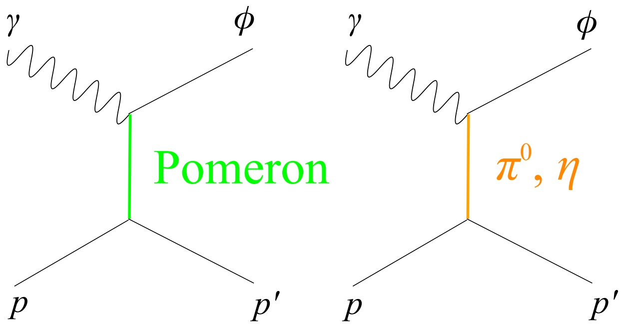

FIG. 1. t-channel Pomeron (left) and π^0, η (right) exchanges.

(OZI rule [1, 2]). Therefore, the ϕ photoproduction is a unique tool to study the Pomeron behavior at low energies.

II. Bump structure in the energy dependence of $(d\sigma/dt)_{t=t_{\min}}$

The SPring-8/LEPS Collaboration has been studying the ϕ photoproduction near the threshold region at forward angles in a systematic manner. In LEPS 2005 measurement ($E_\gamma = 1.57-2.37$ GeV) [3], we observed an interesting bump structure in the energy dependence of the differential cross section for the $\gamma p \to \phi p$ reaction at zero degrees $(d\sigma/dt)_{t=t_{\min}}$. This bump structure ($E_\gamma \sim 2.1$ GeV) cannot be explained by the simple t-channel Pomeron, π^0, and η exchange model (Fig. 1), and its origin is still an open question.

To resolve the origin of the bump structure, measurements covering a wider E_γ range and using various target nuclei are necessary. In this report, we present two recent measurements: 1) ϕ photoproduction on the proton where the energy range is extended up to $E_\gamma = 2.9$ GeV, and 2) coherent ϕ photoproduction from ^{4}He at $E_\gamma = 1.7-2.4$ GeV.

It is expected that when the energy E_γ increases, the simple Pomeron$+\pi^0+\eta$ model works, but its lower limit is not known. The measurement with the extended E_γ range provides important information on the infimum. On the other hand, using the coherent ϕ photoproduction from ^{4}He, we can approach the bump structure problem from a different perspective. Here, the "coherent ϕ photoproduction" means the reaction where the target particle remains intact in the final state, i.e., $\gamma^4\text{He} \to \phi^4\text{He}$. Thanks to the spin parity $J^P = 0^+$ of the ^{4}He nucleus, t-channel exchanged particles in the coherent ϕ photoproduction are limited to natural parity particles, i.e., $P = (-1)^J$. In other words, t-channel π^0 and η exchanges [Fig. 1 (right)] are prohibited, and the coherent ϕ photoproduction works as a Pomeron filter. In this sense, the coherent ϕ photoproduction from ^{4}He is an important reaction to study the Pomeron behavior at low energies.

III. Experiment

The experiments were carried out at SPring-8/LEPS beamline. Linearly polarized photons with energies up to 2.9 GeV (2.4 GeV) and the maximum intensity of 2×10^5 cps (2×10^6 cps) were produced using the Compton backscattering technique [4] with deep-ultraviolet (ultraviolet) lasers. The photons impinged on the target and ϕ mesons were produced. The K^+K^- pair from the ϕ-meson decay was detected by the LEPS spectrometer as shown in Fig. 2. For details of the experiment, see Ref. [5].

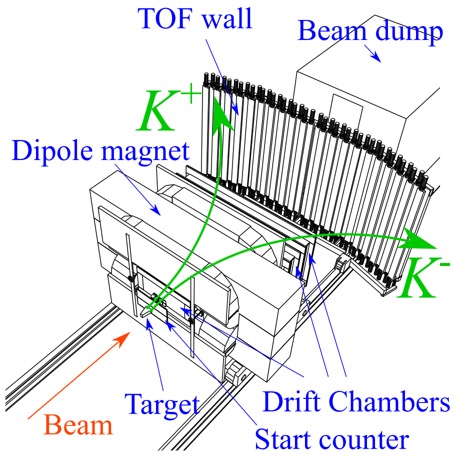

FIG. 2. LEPS spectrometer.

Figure 3 (left) shows K^+K^- invariant mass distributions $M(K^+K^-)$. Clear peaks corresponding to the ϕ meson are seen on top of the background. Figure 3 (right) shows K^+K^- missing mass distributions $MM(K^+K^-)$. The top panel shows the missing mass distribution for the $p(\gamma, K^+K^-)X$ reaction. The proton peak is seen along with background events in which additional pions are produced. The lower panel shows the missing mass distribution for the ^{4}He$(\gamma, K^+K^-)X$ reaction. The black dots represent real data points. A peak corresponding to coherent events is seen at around the mass of a ^{4}He nucleus (3.727 GeV/c^2). Also, incoherent events are seen on the higher side ($MM(K^+K^-) \sim 3.8$ GeV/c^2). The red and green histograms are the coherent and incoherent processes obtained by Monte Carlo simulations, respectively. The black histogram represents the sum of these coherent and incoherent distributions.

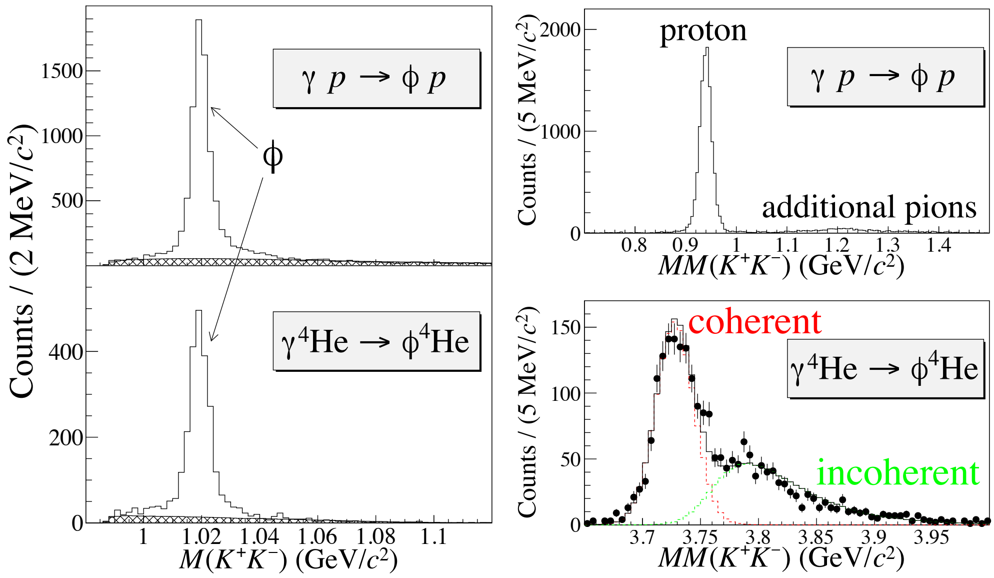

FIG. 3. Left: K^+K^- invariant mass distributions $M(K^+K^-)$. The hatched histograms represent the background distributions obtained by Monte Carlo simulations. Right: Missing mass distributions $MM(K^+K^-)$. See text for details.

IV. Decay asymmetry

We can disentangle the Pomeron exchange process [Fig. 1 (left)] and the pseudoscalar exchange process [Fig. 1 (right)] by measuring the decay asymmetry with a linearly polarized photon beam. Figure 4 (left) shows decay patterns for t-channel natural- and unnatural-parity exchanges when the ϕ meson is emitted at zero degrees. For the natural (unnatural) parity exchange, the decay plane is concentrated in a direction parallel (perpendicular) to the photon polarization vector.

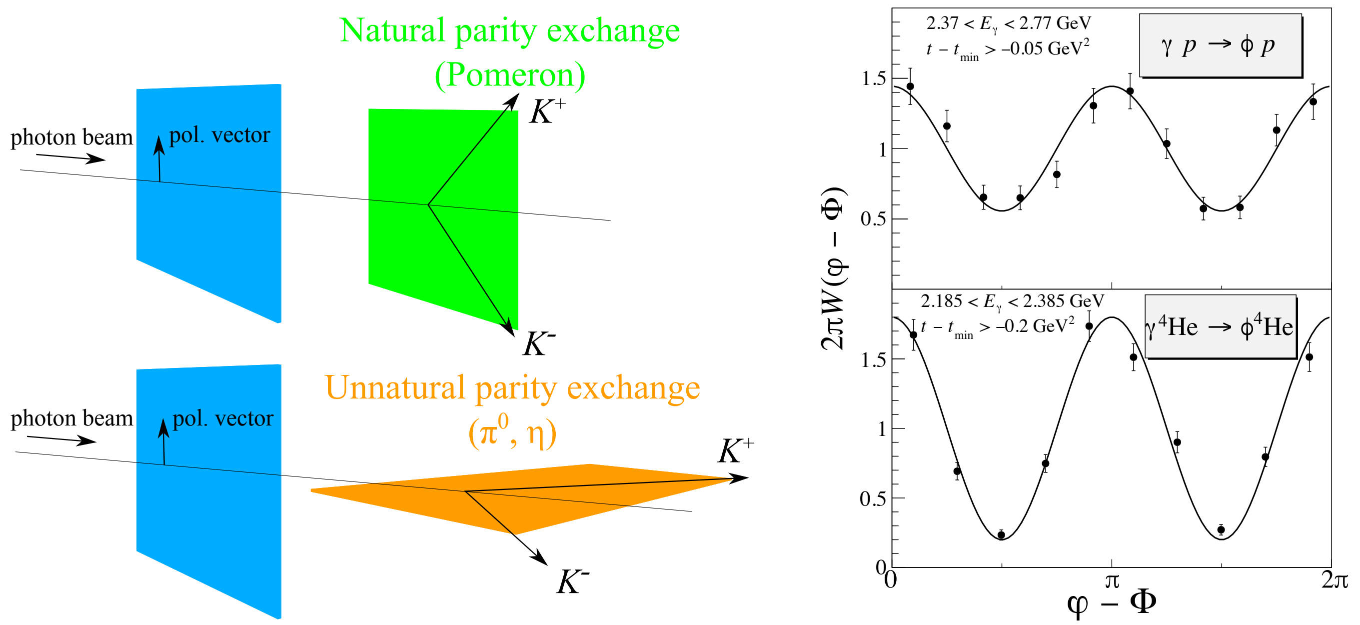

FIG. 4. Left: Decay patterns for t-channel natural- and unnatural-parity exchanges. Right: Decay asymmetry $2\pi W(\varphi - \Phi)$ [6, 7]. See text for details.

Figure 4 (right) shows the decay asymmetry $2\pi W(\varphi - \Phi)$, where $\varphi - \Phi$ is an angle between the polarization vector of the incident photon and the K^+K^- decay plane. In both cases of the proton and ^{4}He target, $2\pi W(\varphi - \Phi)$ achieve maxima at $\varphi - \Phi = 0, \pi$, indicating that the Pomeron exchange process is dominant. Almost 100% Pomeron exchange process is observed in the $\gamma^4\text{He} \to \phi^4\text{He}$ reaction, while about 20% contribution of the pseudoscalar exchange process is observed in $\gamma p \to \phi p$.

V. Energy dependence of $(d\sigma/dt)_{t=t_{\mathbf{min}}}$

The energy dependence of $(d\sigma/dt)_{t=t_{\rm min}}$ is shown in Fig. 5. The top panel shows the results for the $\gamma p \to \phi p$ reaction. The open circles represent the LEPS 2005 results, and the solid circles this work [6]. We used data points above $E_\gamma = 2.57$ GeV to determine the Pomeron strength factor. The theoretical calculation of the Pomeron+$\pi^0 + \eta$ model is shown as a green solid curve. This study revealed that the Pomeron+$\pi^0 + \eta$ model consistently describes the cross sections and decay asymmetries in the E_γ region above 2.37 GeV. Also, we observed a $20 - 30$% excess over the model prediction below $E_\gamma = 2.27$ GeV.

The lower panel shows the results for the $\gamma^4\text{He} \to \phi^4\text{He}$ reaction. The blue curve represents the Pomeron exchange model, and the yellow curve is the Pomeron and daughter Pomeron exchange model [8]. In both cases, the overall strengths were determined using the measured $(d\sigma/dt)_{t=t_{\rm min}}$. The model including the daughter Pomeron reproduces the data relatively well. To distinguish models, precise measurements at higher energies are desired.

VI. Summary

The reactions $\gamma p \to \phi p$ at $E_\gamma = 1.5 - 2.9$ GeV and $\gamma^4\text{He} \to \phi^4\text{He}$ at $E_\gamma = 1.7 - 2.4$ GeV were measured at SPring-8/LEPS beamline. The measurement with the proton target revealed that the Pomeron+$\pi^0 + \eta$ model works

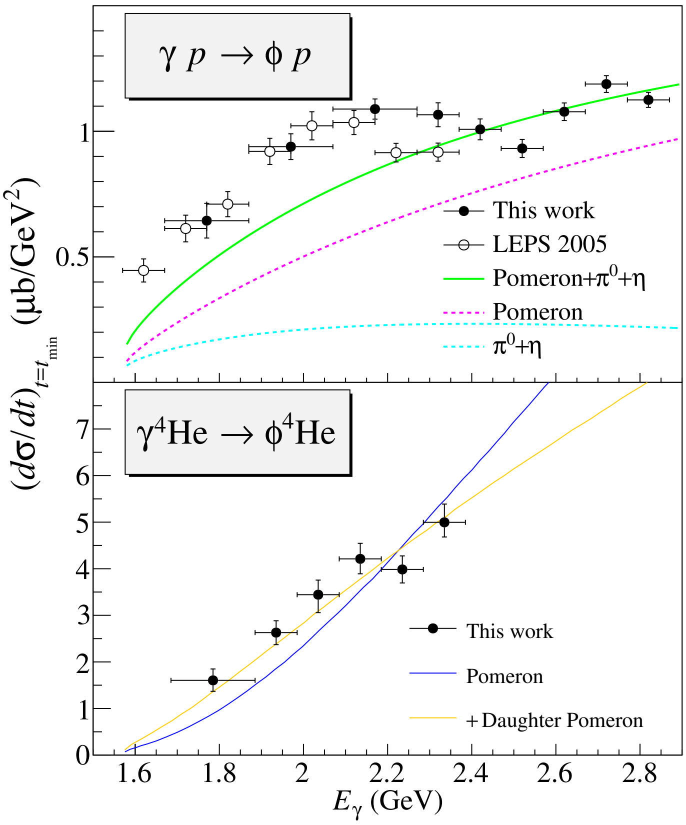

FIG. 5. Energy dependence of $(d\sigma/dt)_{t=t_{\min}}$ [6, 7].

above $E_\gamma = 2.37$ GeV. In the lower energy region, an excess over the model prediction is observed in the energy dependence of the differential cross sections at zero degrees. The measurement of the $\gamma^4\mathrm{He} \to \phi^4\mathrm{He}$ reaction shows that the reaction works as a Pomeron filter, and indicates contributions of natural parity exchanges other than the Pomeron. Further careful studies are necessary to clarify the nature of the bump structure, and an analysis of the ϕ photoproduction from the deuteron is in progress as a next step.

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