Nuclear Physics

ϕ-MESON PHOTOPRODUCTION NEAR THE THRESHOLD

The ultimate building blocks of subatomic particles (hadrons) are quarks and gluons. Quantum chromodynamics (QCD) describes how hadrons are formed from quarks and gluons. Gluons serve as the glue between quarks (q) and anti-quarks ($\bar{q}$) to form a hadron. A particle made of three quarks is called a baryon. A particle made of a quark and an anti-quark is called a meson. There are six flavors to distinguish different types of quarks, i.e. up, down, strange, charm, beauty and top. An example of a baryon is a proton which is made of two up quarks and a down quark.

Most hadrons are made of three quarks qqq or a quark anti-quark pair $q\,\bar{q}$. However QCD does not rule out the existence of baryons made of more than three quarks, mesons made of more than two quarks and particles made of only gluons (glueball). An example of such exotic hadrons is a penta-quark particle, Θ^+, found by the LEPS collaboration at beamline **BL33LEP** and in other experiments [1].

Other than penta-quark states, there has been much effort in the search for the glueball state for many years. There are some candidates for the glueball state although no clear experimental confirmation has been made. In 1997, Nakano and Toki suggested that diffractive ϕ-meson photoproduction near threshold may be sensitive to the possible existence of a glueball with spin-parity $J^P=0^+$ [2]. In diffractive photoproduction, ϕ-mesons are predominantly produced by a conversion from a photon (vector meson dominance). Therefore, the incident photon beam can be viewed as a virtual ϕ-meson beam. Interactions of ϕ-mesons with the target protons can be intensively studied in this reaction. Note that the quark configuration of a ϕ-meson is almost purely a strange quark and an anti-strange quark. Thus, exchanges of quarks are highly suppressed in this reaction because no net strange quark is contained in protons (OZI rule). The reaction is expected to be dominated by exchanges of multi-gluons. In the other low-energy hadronic reactions, the contribution from quark exchanges is usually large enough to hide multi-gluon exchange processes. Thus, ϕ-meson photoproduction is an ideal reaction for studying the multi-gluon exchange processes.

Historically, the ϕ-meson photoproduction reaction has been measured mainly at high photon energies. The slow increase of cross section with the total energy was successfully interpreted by a dominant contribution from the Pomeron exchange process. The Pomeron exchange process is explained in terms of a multi-gluon exchange in QCD. The contribution from the Pomeron exchange process is predicted to be almost constant near the threshold. In this regard, the presence of the 0^+ glueball exchange process may lead to a non-monotonic behavior of the energy dependence of the cross section in the near-threshold region.

The concept of the Pomeron was originally introduced in the high-energy limit. There is no justification that the same picture can be applied to the low-energy process. Consequently, the low-energy ϕ-meson photoproduction reaction can also provide information on how the Pomeron exchange process behaves at low energies.

We obtained data using a liquid hydrogen target with linearly polarized photons at beamline BL33LEP. ϕ-Meson photoproduction was identified through K^+K^- decay mode. Details of the experiment and data analysis are described in Ref. [3]. Figure 1 shows the energy dependence of the differential cross section at the forwardmost production angle, $d\sigma/dt_{t=-|t|min}$ [3,4]. The energy dependence of $d\sigma/dt_{t=-|t|min}$ shows a non-monotonic behavior, i.e., a peak structure appears at around photon energy E_γ = 2 GeV. The data was compared with a model which includes the Pomeron exchange and π, η-meson exchange processes without the 0^+ glueball exchange process [5] (dashed curve). The model does not describe the data points in this energy region.

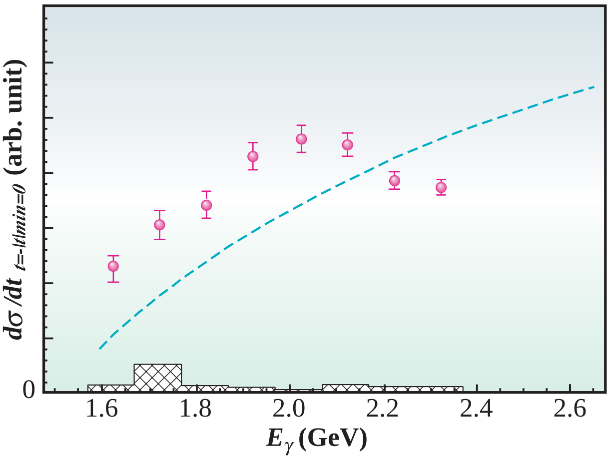

Fig. 1. Differential cross section at t = -$|t|_{min}$. The hatched histogram indicates systematic errors. The prediction based on the Pomeron exchange process and π, η-meson exchange process in ref. [5] is shown by the dashed curve.

To understand the cause of the peaking structure in the cross section, ϕ-meson decay angular distributions were measured at forward angles ($-0.2 < t+|t|_{min} < 0$ GeV^2) in two different energy ranges: $1.973 < E_\gamma < 2.173$ GeV (near the cross section peak) and $2.173 < E_\gamma < 2.373$ GeV (above the cross section peak). The ϕ-meson decay angular distributions, $W(\cos\theta, \phi, \Phi)$, have rich information on the underlying production mechanism. The angles θ, ϕ and Φ stand for the K$^+$ polar angle, the K$^+$ azimuthal angle and the azimuthal angle of the photon polarization vector.

Figure 2 (left panel) shows the angular distribution $W(\cos\theta)$. In both energy ranges, $W(\cos\theta)$ follows $3/4 \sin^2\theta$, which indicates the dominance of a spin conserving process, such as the Pomeron exchange process, π, η-meson exchange and 0$^+$ glueball exchange. Figure 2 (right panel) shows the $W(\phi-\Phi)$ distribution. In both energy ranges, the ϕ-meson exhibits preferential decay in parallel to the direction of photon polarization. This implies that the contribution of the unnatural parity exchange (π, η-meson exchange) is not dominant. The relative contribution between natural parity exchange and unnatural parity (π, η-meson) exchange is nearly the same for the two energy bins. Taking into account that the contribution from the Pomeron exchange is expected to be almost constant in this energy range, the peaking structure of the cross section cannot be explained by only unnatural-parity exchange processes. A possible explanation of this effect might be related to the 0$^+$ glueball exchange. However, a fit suggested in ref. [2] failed to reproduce the peaking structure with the proposed set of parameters. Further measurement in a wider energy range using different targets, as well as theoretical studies, would help to better understand the underlying mechanism of the peaking structure.

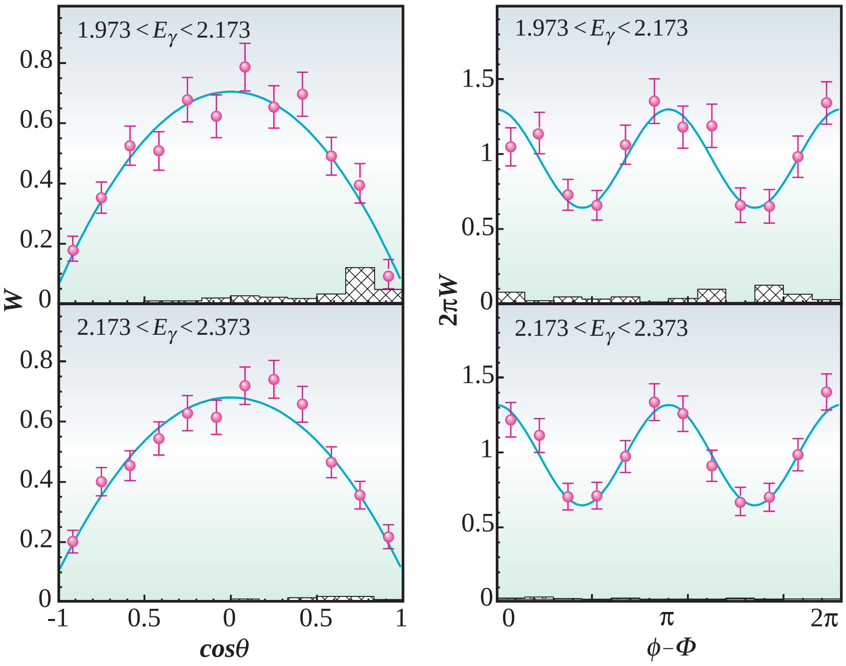

Fig. 2. ϕ-meson decay angular distributions in two beam energy ranges. The hatched histograms indicate systematic errors. Solid curves show fits to the distributions.

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