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Research Article

Angular Dependence of ϕ Meson Production for Different Photon Beam Energies

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The dependence of ϕ-meson photoproduction on the polar angle is investigated in the framework of a multisource thermal model. We present a detailed comparison between our results and experimental data of the neutral decay mode in the reaction $\gamma p \rightarrow p\phi(K_S K_L)$. The results are in good agreement with the experimental data. It is found that the movement factor b_z increases linearly with the photon beam energies.

1. Introduction

More than 20 years ago, strangeness enhancement was predicted to be a unique signature of the quark-gluon plasma (QGP) formation in high energy collisions [1]. So far, many experimental results from the Super Proton Synchrotron (SPS) and Relativistic Heavy Ion Collider (RHIC) have shown the enhancement of strange particles [2]. At low photon energies, strangeness production starting from threshold is also helpful to understand underlying photoproduction mechanisms because it is far below the region of perturbative Quantum Chromodynamics (QCD) and is an energy domain well above the region controlled by low energy theorems [3–5]. As a particle with hidden strangeness, ϕ meson can be produced without an associated hyperon. Recently, in the reaction $\gamma p \rightarrow p\phi(K_S K_L)$, a photoproduction cross-section of the ϕ meson in its neutral decay mode was measured by the CLAS Collaboration. The experiment is conducted by a tagged photon beam of energy $1.65 \leq E_\gamma \leq 3.6$ GeV on a liquid hydrogen target at the Thomas Jefferson National Accelerator Facility (TJNAF) [6].

In order to explain the abundant experimental data, some phenomenological models of initial-coherent multiple interactions and particle transport were proposed and developed in recent years [7–12]. The dynamics of the system evolution has been studied by the azimuthal anisotropy of final-state particles produced in high energy collisions. In our previous work [13], the multisource thermal model has been used to describe the elliptic flows of final-state hadrons produced in nucleus-nucleus collisions at RHIC energies. It involves the anisotropic expansion of the participant area in the transverse momentum space. The model is successful in the description of (pseudo)rapidity and multiplicity distributions of produced particles [14]. In the present work, we focus our attention on the dependence of ϕ meson photoproduction on the polar angle. A purpose of this paper is to check whether the model can fit the angular dependence of ϕ meson photoproduction.

The paper is organized as follows: in Section 2, the multisource thermal model is introduced; in Section 3, we present our results, which are compared with the experimental data; at the end, we provide discussions and conclusions in Section 4.

2. Angular Distribution in the Multisource Thermal Model

According to the multisource model [14], some emission sources of ϕ mesons are assumed to be formed in the reaction

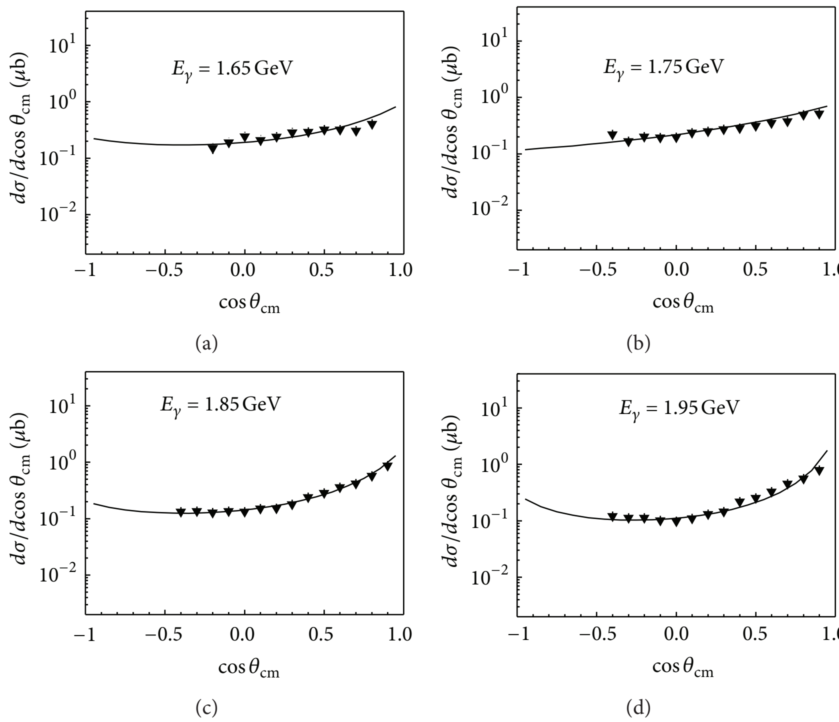

FIGURE 1: The $\cos\theta_{cm}$ dependence of ϕ meson differential cross-section for different photon beam energy $1.65 \leq E_\gamma \leq 1.95$ GeV. The scattered symbols represent the experimental data. The solid lines are the calculated results.

process. Each source is considered to emit particles isotropically in a source rest frame. Let the incident beam direction be oz-axis and let the reaction plane be the xoz plane, which is scanned by the vector of the beam direction and impact parameter. In the source rest frame, the momentum components P'_x, P'_y, and P'_z of a considered particle have the same Gaussian distributions with a width σ. Then, a transverse momentum $P'_T = \sqrt{P'^2_x + P'^2_y}$ obeys a Rayleigh distribution.

Due to the interactions among the emission sources, the sources will depart from isotropic emissions at the direction of z. The corresponding momentum component P_z of the particle is

$$P_z = a_z P'_z + b_z, \quad (1)$$

where a_z and b_z indicate a deformation and movement of the emitted source, respectively. As a standard treatment in the Monte Carlo calculation, the random variable P_T and P_z are

$$P_T = \sigma\sqrt{-2\ln R_1},$$
$$P_z = a_z\sigma\sqrt{-2\ln R_2}\cos(2\pi R_3) + b_z, \quad (2)$$

where R_1, R_2, and R_3 are random variables distributed in [0, 1]. So the polar angle is given by

$$\theta = \arctan\frac{P_T}{P_z} = \arctan\frac{\sqrt{-2\ln R_1}}{a_z\sqrt{-2\ln R_2}\cos(2\pi R_3) + b_z}. \quad (3)$$

Generally speaking, $a_z > 1$ denotes the expansion of the emission source along the oz-axis and $b_z > 0$ or $b_z < 0$ denotes the movement of the source along the positive or negative axes.

3. Comparison with the CLAS Results

The $\cos\theta$ dependences of ϕ meson differential cross-section $d\sigma/d\cos\theta$ over a photon beam energy range from 1.6 GeV to 2.8 GeV is presented in Figure 1, which is plotted for 0.1 GeV photon energy bins. The symbols denote the experimental data of the photoproduction cross-section of the ϕ meson produced in its neutral decay mode in the reaction $\gamma p \rightarrow p\phi(K_S K_L)$. The $d\sigma/d\cos\theta$ increases with $\cos\theta_{cm}$ for the photon energy range $1.65 \leq E_\gamma \leq 1.95$ GeV. The solid lines denote the results calculated by the multisource model. One can see that the results are in agreement with the experimental data in the whole observed $\cos\theta$ region for the four energy bins. The values of a_z and b_z are obtained by fitting the data. The b_z increases linearly with the incident photon energies. In order to see the structure of the sources corresponding to different parameter values, the expansions and deformations of the modeling source are shown in Figure 6(a).

In Figure 2, we show the ϕ meson differential cross-section $d\sigma/d\cos\theta$ as a function of $\cos\theta_{cm}$. The symbols indicate the experimental data for the photon beam energy bins $2.05 \leq E_\gamma \leq 2.35$ GeV. The solid lines indicate the results calculated by the multisource thermal model. In the calculation, we take the different expansion and

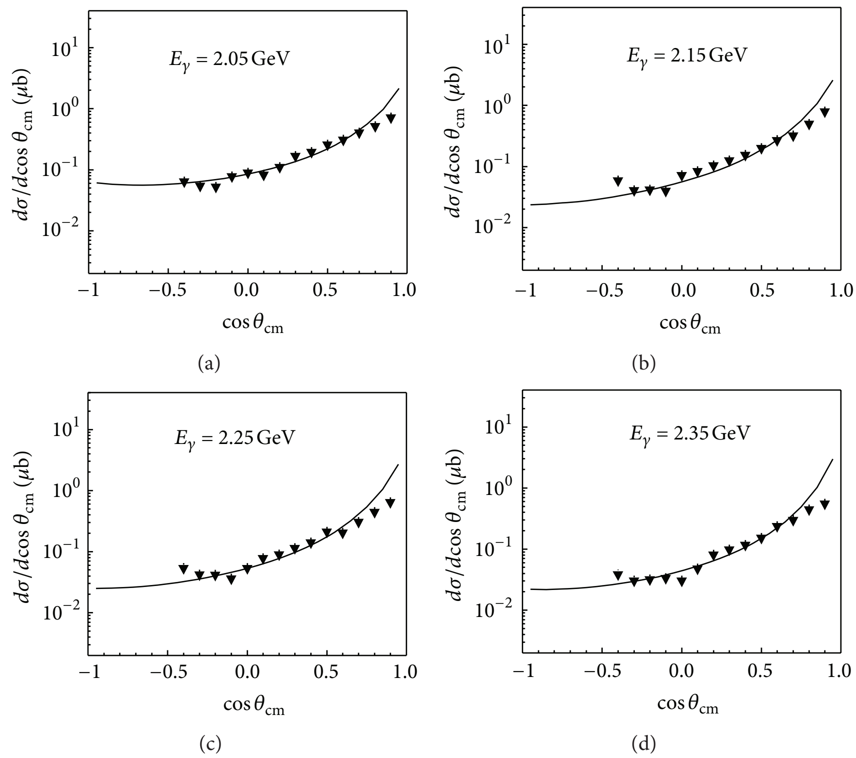

FIGURE 2: Same as Figure 1, but for the photon energy range $2.05 \le E_\gamma \le 2.35$ GeV.

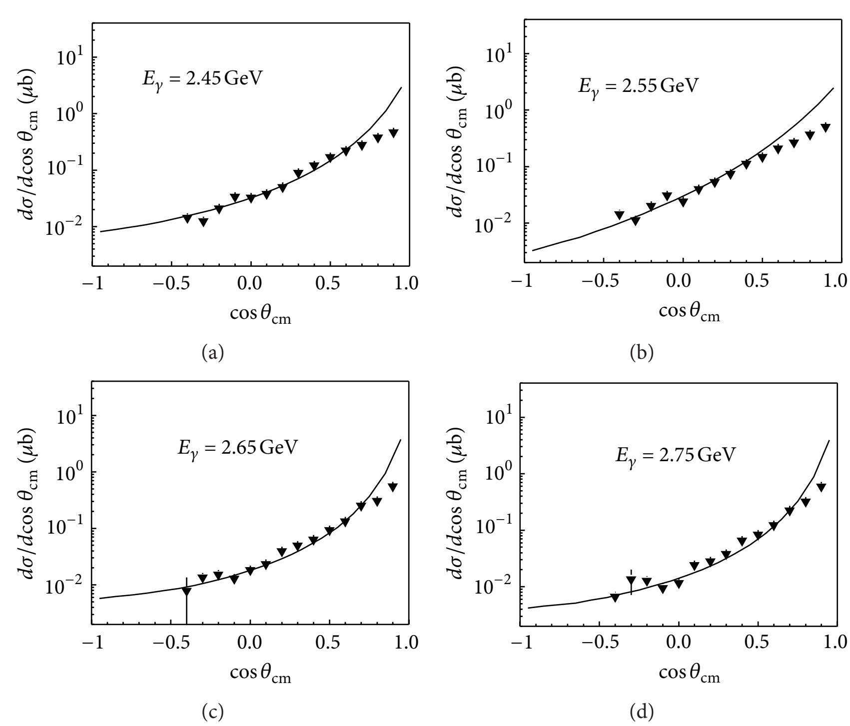

FIGURE 3: Same as Figure 1, but for the photon energy range $2.45 \le E_\gamma \le 2.75$ GeV.

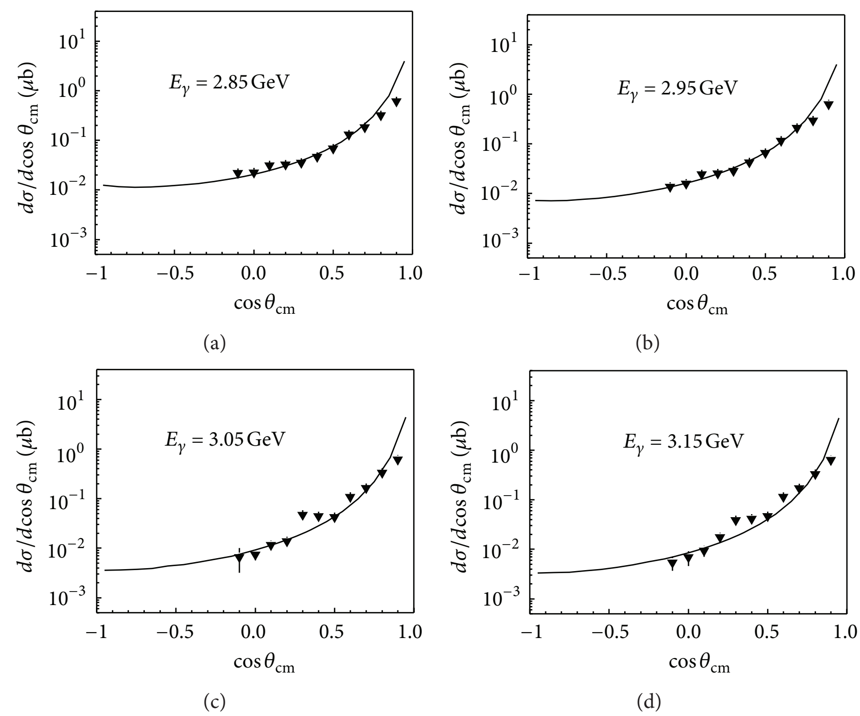

FIGURE 4: Same as Figure 1, but for the photon energy range $2.85 \le E_\gamma \le 3.15$ GeV.

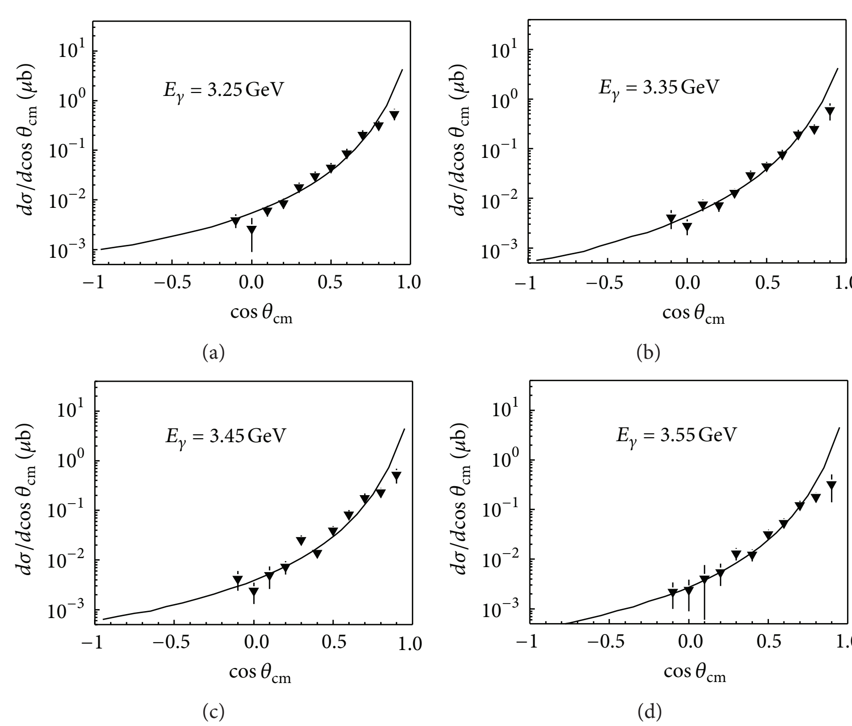

FIGURE 5: Same as Figure 1, but for the photon energy range $3.25 \le E_\gamma \le 3.55$ GeV.

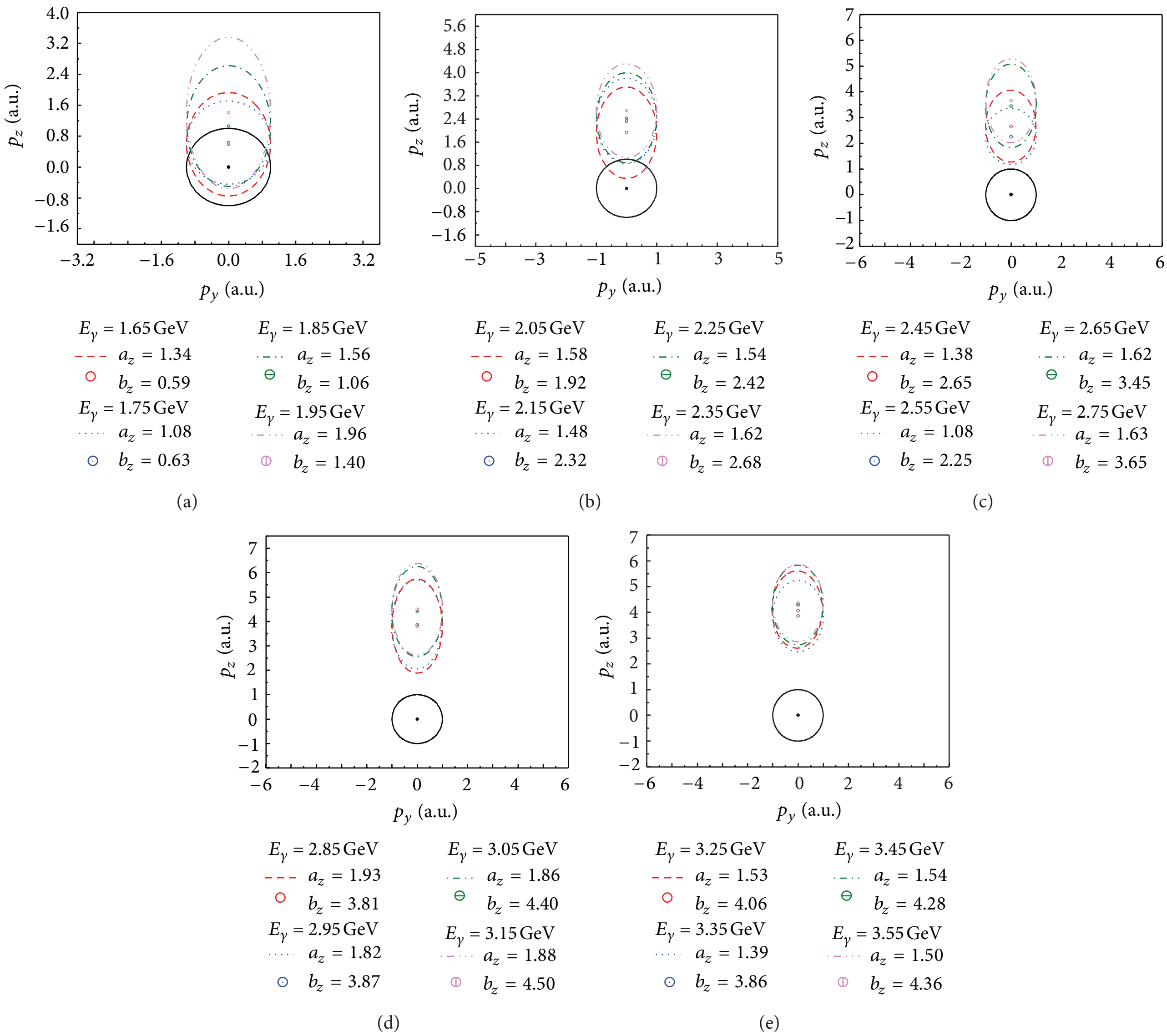

FIGURE 6: The source deformations and movements in the reaction plane corresponding to the different photon beam energies E_γ.

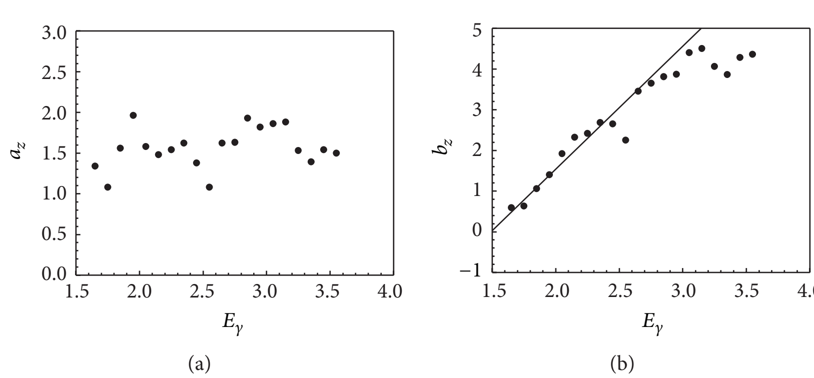

FIGURE 7: The dependence of a_z and b_z on the photon beam energies E_γ. The symbols represent the parameter values used in Figures 1–5. The solid lines are the fitted results.

deformation sources as marked in Figure 6(b). Figures 3, 4, and 5 are detailed comparisons between the results and the experimental data for $2.45 \leq E_\gamma \leq 2.75$ GeV, $2.85 \leq E_\gamma \leq 3.15$ GeV, and $3.25 \leq E_\gamma \leq 3.55$ GeV, respectively. The results are also in agreement with the data from the CLAS Collaboration. The corresponding anisotropic sources are given in Figures 6(c)–6(e).

The parameters a_z and b_z obtained in the above comparisons are given in Figure 7. The value of a_z is around 1.5 and has no obvious regularity. Except for a saturation region, the values of b_z exhibit a linear dependence on the photon beam energies, which are best fitted by the function $b_z = (3.02 \pm 0.04)E_\gamma - (4.5 \pm 0.08)$. The movement of the sources along the positive z direction increases approximately with increasing photon beam energy.

4. Discussions and Conclusions

In the framework of the multisource thermal model, we have investigated the differential cross-section versus the polar angle of ϕ meson photoproduction on hydrogen in the neutral decay mode. The incident photon beam energy range is 1.65–3.55 GeV. The results calculated in the model approximately agree with the data of the CLAS Collaboration. In the above discussions, the deformation and movement of the sources are obtained by fitting the experimental data. The local sources of the final-state particles are formed in the reaction plane. Their interactions, which are related to the matter in the sources, result in the anisotropic expansion and the movement along the direction of the beam [12]. For the longitudinal structure of the sources, $a_z > 1$ presents a longitudinal expansion of the source along oz-axis. When $b_z \neq 0$, the source has a movement along oz-axis. The model involves the anisotropic expansion of the participant area in the transverse momentum space. Therefore, the multisource thermal model can be used to study the elliptic flow of charged hadrons produced in high energy collisions at RHIC energies. The analysis of the elliptic flow shows that the expansion factor is characterized by the impact parameter, which is related to participating nucleons. Moreover, the system expansion can be quantified in the momentum space. In the description of (pseudo)rapidity and multiplicity distributions for the final-state particles [14], this model is also successful.

All final-state particles are emitted from the sources formed in the reaction. The polar angle distributions can be obtained by the statistical method. The movement factor b_z used in the calculation exhibits a linear dependence on the photon beam energy $E_\gamma < 3.0$ GeV. Our previous work mostly described particle production in intermediate energy and high energy collisions. In the description of ϕ meson photoproduction in the reaction $\gamma p \rightarrow p\phi(K_S K_L)$, this work is a good attempt.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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