

# Photoproduction of the Scalar Meson $f_0(500)$

Jehee LEE<sup>1</sup> and Hui-Young RYU<sup>2</sup> and Byung-Geel YU<sup>3</sup> and Hyun-Chul KIM<sup>1</sup>

<sup>1</sup> *Department of Physics, Inha University, Incheon 22212, Korea*

<sup>2</sup> *Department of Physics, Kyungpook National University, Daegu 702-701, Korea*

<sup>3</sup> *Research Institute for Basic Sciences, Korea Aerospace University, Goyang 412-791, Korea*

*E-mail: jehee.lee@inha.edu, hchkim@inha.ac.kr*

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In the present talk, we report a recent investigation on photoproduction of the  $\gamma N \rightarrow f_0(500)N$  within a framework of the effective Lagrangian. We include the nucleon resonances with spin 1/2 in the  $s$  channel. The coupling constants have been determined by assuming that the decay process  $N^* \rightarrow (\pi\pi)_{I=0, J=0}N$  can be regarded as  $N^* \rightarrow f_0(500)N$ . We discuss the numerical results for the total cross sections and possible extension of the present work.

**KEYWORDS:** Photoproduction,  $f_0(500)$ , Effective Lagrangian approach

## 1. Introduction

Understanding the structure of the scalar meson  $f_0(500)$  has been one of the most important issues in hadronic physics well over decades. The usual  $q\bar{q}$  meson structure is not enough to describe properties of the  $f_0(500)$ , which implies the complexity of its structure. Moreover, its production mechanism is still not much known. In the meanwhile, the CLAS Collaboration has reported the first analysis of the  $S$ -wave photoproduction of  $\pi^+\pi^-$  pairs in the region of the  $f_0(980)$  at photon energies between 3.0 and 3.8 GeV and momentum transfer squared  $-t$  range between  $0.4 \text{ GeV}^2$  and  $1 \text{ GeV}^2$  [1, 2]. While the differential cross section for the  $\gamma p \rightarrow \pi^+\pi^-p$  process in the  $S$ -wave shows an evident signal for the  $f_0(980)$  production, the  $f_0(500)$  was not seen clearly. However, there is a hint for the existence of  $f_0(500)$  in the  $\pi^+\pi^-p$  photoproduction measured at different kinematic conditions [1]. Thus, it is of great interest to study theoretically the production mechanism of the  $f_0(500)$  scalar meson.

In this talk, we will present the results of a recent work on photoproduction of  $f_0(500)$ , based on an effective Lagrangian approach. We consider the  $\rho$ -meson exchange in the  $t$ -channel and the nucleon and its resonances with spin 1/2 in the  $s$ -channel. The coupling constants of the  $NN^*f_0(500)$  are determined by assuming that the decay modes  $N^* \rightarrow (\pi\pi)_{S\text{-wave}}^{I=0}N$  are regarded as  $N^* \rightarrow f_0(500)N$ . It is a reasonable assumption, because  $f_0(500)$  is the most dominant one in the scalar-isoscalar channel of  $\pi\pi$  scattering. We also include the  $u$ -channel contribution. In order to reduce the ambiguity in the present approach, we fix the cut-off parameters to be around 1.8 GeV. Since the  $f_0(500)$  has a very broad width, one cannot fix the exact threshold energy. However, we found that the general feature of the production mechanism is not much changed as the mass of the  $f_0(500)$  meson is varied. Thus, we will take the  $f_0(500)$  mass to be 500 MeV.

The structure of the present talk is summarized as follows: In Section 2, we discuss the general formalism for  $f_0(500)$  photoproduction. In Section 3, we present the numerical results of the total and differential cross sections for the  $\gamma N \rightarrow f_0(500)N$  and discuss them. We summarize and give an outlook for the present work in the final Section.

## 2. Formalism

We start with the effective Lagrangians for the  $\gamma N \rightarrow f_0(500)N$  process. In addition to the  $\rho$ -meson exchange in the  $t$  channel, we consider the following nucleon resonances:  $N(1440, 1/2^+)$ ,  $N(1535, 1/2^-)$ ,  $N(1650, 1/2^-)$ , and  $N(1710, 1/2^+)$  in the  $s$ -channel. The  $u$ -channel is also included. The effective Lagrangians are given as [3–5]

- photon vertices

$$\mathcal{L}_{\gamma NN} = -\bar{N} \left( e\gamma_\mu A^\mu - \frac{e\kappa_N}{2m_N} \sigma_{\mu\nu} \partial^\nu A^\mu \right) N, \quad (1)$$

$$\mathcal{L}_{\gamma\rho f_0} = \frac{g_{\gamma\rho f_0}}{m_\rho} \left[ \partial_\mu A_\nu \partial^\mu \rho^\nu - \partial_\mu A_\nu \partial^\nu \rho^\mu \right] f_0, \quad (2)$$

$$\mathcal{L}_{\gamma NN^*} \left( \frac{1^\pm}{2} \right) = \pm \frac{ef_1}{2m_N} \bar{N}^* \partial^\nu A^\mu \sigma^{\mu\nu} \Gamma^{(\mp)} N, \quad (3)$$

- strong vertices

$$\mathcal{L}_{\rho NN} = -g_{\rho NN} \bar{N} \left[ \gamma_\mu \rho^\mu - \frac{\kappa_\rho}{2m_N} \sigma^{\mu\nu} \partial_\nu \rho_\mu \right] N, \quad (4)$$

$$\mathcal{L}_{f_0 NN} = g_{f_0 NN} f_0 \bar{N} N, \quad (5)$$

$$\mathcal{L}_{f_0 NN^*} \left( \frac{1^\pm}{2} \right) = \pm g_{f_0 NN^*} f_0 \bar{N} \Gamma^{(\mp)} N^*, \quad (6)$$

where  $N^*$  denote the nucleon resonances with the corresponding spins and parities given, and  $A_\mu$ ,  $N$ ,  $\rho$ , and  $f_0$  indicate the photon, the nucleon, the  $\rho$  meson, and the  $f_0(500)$  meson fields, respectively.  $\Gamma^{(\pm)}$  is defined as

$$\Gamma^{(\pm)} = \begin{pmatrix} \gamma^5 \\ 1 \end{pmatrix}. \quad (7)$$

Parameters used in the present work are summarized in Table I. The coupling constants in the

**Table I.** The coupling constants and the cut-off masses. In the second row the coupling constants for the  $N^*$  resonances are listed.

$\kappa_p$	$g_{\rho NN}$	$g_{f_0 NN}$	$\Lambda$				
1.79	3.11	0.56	0.8 GeV				
$f_{\gamma NN(1440)}$	$f_{\gamma NN(1535)}$	$f_{\gamma NN(1650)}$	$f_{\gamma NN(1710)}$	$g_{f_0 NN(1440)}$	$g_{f_0 NN(1535)}$	$g_{f_0 NN(1650)}$	$g_{f_0 NN(1710)}$
0.47	0.81	0.28	-0.24	$\pm 3.59$	$\pm 0.33$	$\pm 0.37$	$\pm 0.53$

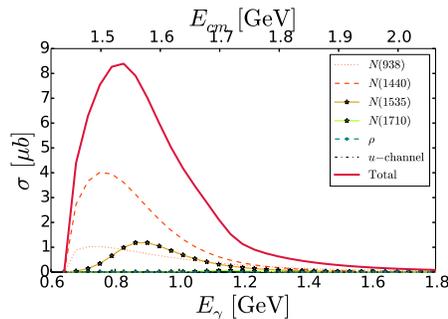
photon vertices are determined by using the experimental data for the helicity amplitudes given by the Particle Data Group [9]. The coupling constants involving the strong vertices are calculated by using the relations between the partial decay widths and the partial amplitudes. However, since  $f_0(500)$  has a very broad width, it is not possible to determine its coupling constants directly. Thus, we need to make an assumption. We will take upon  $\pi^+\pi^-$  pairs in the scalar-isoscalar channel as the  $f_0(500)$  meson such that we are able to determine the strong coupling constants for the  $N^* \rightarrow f_0 N$  decays.

The form factor at the baryon-baryon-meson vertices in the  $s$ -channel is expressed as [10]

$$f_B(p^2) = \frac{\Lambda^4}{\Lambda^4 + (p^2 - m_R^2)^2}, \quad (8)$$

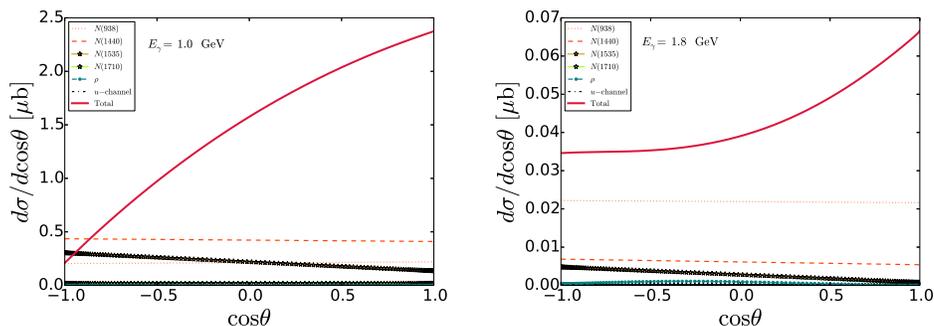
where  $p$  is the off-shell momentum of the process, and  $\Lambda$  indicates a cutoff parameter. We will use the same value of the cut-off parameter to reduce the ambiguity in the parameters. The problem of the gauge invariance arising from form factors is handled as usual.

### 3. Numerical result



**Fig. 1.** Total cross section for the  $\gamma N \rightarrow f_0(500)N$  reaction.

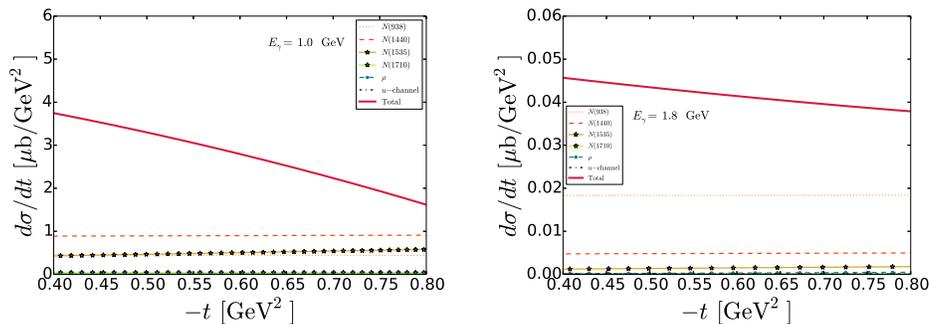
In Fig. 1 we show the total cross section for the  $\gamma N \rightarrow f_0(500)N$  process with each contribution depicted. Interestingly, the  $\rho$ -meson exchange in the  $t$ -channel is almost negligible in the effective Lagrangian approach. The most dominant contribution comes from  $N^*(1440)$  due to large values of its strong coupling constant listed in Table I. The nucleon exchange enhances the cross section near the threshold region, while the  $N^*(1535)$  become effective around  $E_\gamma = 0.9$  GeV. The  $u$ -channel contribution is negligibly small.



**Fig. 2.** Differential cross sections for the  $\gamma N \rightarrow f_0(500)N$  reaction as a function of  $\cos\theta$  at two different photon energies, i. e.  $E_\gamma = 1.0$  GeV and  $E_\gamma = 1.8$  GeV in the left and right panels, respectively.

Figure 2 draw the results of the differential cross section as a function of  $\cos\theta$  with two photon energies  $E_\gamma = 1.0$  GeV (left panel) and  $E_\gamma = 1.8$  GeV (right panel), respectively. We can find similar tendencies in the differential cross sections: the  $N^*(1440)$  is the most dominant one. As  $E_\gamma$  increases the strength of the differential cross section drastically decreases, as expected from the results of the total cross section. The results of the differential cross section shows in general the enhancement in the forward direction. However, when  $E_\gamma$  becomes large, those in the backward direction come into play.

We also present the results of the differential cross section as a function of the momentum transfer in Fig. 3. The  $t$  dependence gets weaker as  $E_\gamma$  increases.



**Fig. 3.** Differential cross sections as a function of the momentum transfer. Notations are the same as in Fig. 2.

#### 4. Summary and discussion

In the present talk, we presented the results of a recent work on  $f_0(500)$  photoproduction off the nucleon. We considered the  $N^*$  resonances with spin 1/2 together with the  $\rho$  meson and nucleon exchanges in the  $t$  and  $u$  channels, respectively. We found that the  $N^*(1440)$  is the most dominant one and the nucleon and the  $N^*(1535)$  makes contributions to the regions near the threshold and the lower photon energies, respectively. We found that as the photon energy increases the differential cross section becomes slowly enhanced in the backward direction.

Since the  $f_0(980)$  scalar meson is also found in the scalar-isoscalar  $\pi\pi$  interaction, it is of significant importance to treat both the  $f_0(500)$  and  $f_0(980)$  on an equal footing. Since the threshold energy for  $f_0(980)$  photoproduction is close to 2 GeV, the relevant  $N^*$  resonances do not exist for the description of the  $\gamma N \rightarrow f_0(980)N$ . Moreover, it is also of interest to the reggeized  $\rho$ -meson exchange in describing  $f_0(980)$  photoproduction because of its higher threshold energy. The corresponding work will appear elsewhere.

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