TENSOR MESON PHOTOPRODUCTION ON PROTON THROUGH THE FINAL STATE MESON–MESON INTERACTIONS*

Łukasz Bibrzycki

State School of Higher Education in Oświęcim
Kolbego 8, 32-600 Oświęcim, Poland

Robert Kamiński

The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences
Division of Theoretical Physics
Radzikowskiego 152, 31-342 Kraków, Poland

(Received July 3, 2013)

For the $\pi^+\pi^-$ effective masses of 1.0–1.5 GeV, the $\gamma p \to \pi^+\pi^- p$ reaction is influenced by the $f_2(1270)$ photoproduction. We present introductory results on the model describing the $f_2(1270)$ photoproduction as a final state $\pi\pi$ interaction effect. We have calculated Born cross sections for $f_2(1270)$ helicities $M = -1, 0, +1$ and found that our model is in agreement with experimental observation that the cross section is dominated by the partial wave corresponding to $M = 0$. The projection of $\pi\pi$ angular momentum on the spin quantisation axis is entirely determined by Born amplitudes.

DOI:10.5506/APhysPolBSupp.6.833
PACS numbers: 13.60.Le, 13.75.Lb

1. Introduction

Analysis of the resonances in the $\pi\pi$ system photoproduced in the S- and D-waves is difficult from both experimental and theoretical point of view. Due to small photoproduction cross sections and possible background contributions the interpretation of $\pi\pi$ mass distributions in terms of resonance amplitudes is not straightforward. Valuable information on the S- and D-wave amplitudes can be obtained from the analysis of interference patterns of these amplitudes with dominant P-wave amplitude. This can be

* Presented at the Workshop "Excited QCD 2013", Bjelašnica Mountain, Sarajevo, Bosnia–Herzegovina, February 3–9, 2013.

conveniently performed by using the moments of pion angular distribution or spin density matrix elements. The moments analysis was successfully employed to extract the $f_0(980)$ and $a_0(980)$ from the photoproduced $K\overline{K}$ spectrum [1] and $f_0(980)$ from the $\pi^+\pi^-$ spectrum [2, 3]. The amplitude of the $f_2(1270)$ photoproduction is the necessary ingredient to properly describe the partial wave interference pattern observed in moments measured by CLAS experiment at JLab [2] for $\pi\pi$ effective masses above 1 GeV.

So far, the electromagnetic processes involving tensor mesons were described in terms of the combined tensor meson dominance and vector meson dominance models [4–6], Regge inspired exchange models [7] or effective field theories [8, 9]. None of these approaches can, however, be treated as properly tested in tensor meson photoproduction reactions.

2. Model for the $\pi^+\pi^-$ photoproduction

In our model, we consider the tensor meson photoproduction as a two stage processes. In the first stage, a pair of pions is photoproduced. According to Regge phenomenology, this process at high energies should be dominated by t-channel ρ and ω exchanges. In the second stage, pions undergo final state interactions which may result in the resonance creation. This two stage process is schematically drawn in Fig. 1. The model preserves

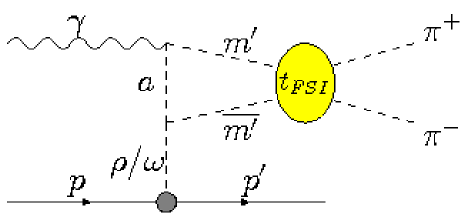

Fig. 1. Diagram of two pion photoproduction with final state interactions, where a denotes π, ρ or ω.

important features of the $\pi\pi$ scattering amplitudes like 2-particle unitarity, proper analytical structure, crossing symmetry and embeds them seamlessly in the framework of the photoproduction amplitude. Our formalism is inspired by reference [10] but we specialize the results to the case of two pions photoproduced in the D-wave. Details of the final state scattering amplitude are described in [11–13]. The calculations are performed in the helicity system which is the center of the mass system of two photoproduced pions. In this system, the z-axis is directed opposite to final proton momentum $\boldsymbol{p}'$, y-axis is perpendicular to the production plane and x-axis versor is defined as $\hat{x} = \hat{y} \times \hat{z}$. We describe the initial state $\pi\pi$ photoproduction in terms of Born amplitudes derived from the phenomenological Lagrangian

$$\mathcal{L} = \mathcal{L}_{\pi\pi\gamma} + \mathcal{L}_{\rho\pi\gamma} + \mathcal{L}_{\omega\pi\gamma} + \mathcal{L}_{\rho\pi\pi\gamma} + \mathcal{L}_{\rho\pi\pi} + \mathcal{L}_{\rho\pi\omega} + \mathcal{L}_{\omega NN} + \mathcal{L}_{\rho NN} \,, \quad (1)$$

where individual terms of Eq. (1) are defined in [10]. The diagram representation of amplitudes obtained from this Lagrangian is shown in Fig. 2 and they have a general form of

$$V_{m\overline{m}} = \sum_{r=\mathrm{I,II}} \overline{u}\left(p', s'\right) J_{r,m\overline{m}} \cdot \varepsilon\left(q, \lambda_\gamma\right) u(p, s) \,, \quad (2)$$

where $J_{r,m\overline{m}}$ is the hadronic current, $u(p,s)$ and $\overline{u}(p',s')$ — wave functions of the initial and final proton respectively and ε — polarisation vector of the incident photon. In Eq. (2), $r = \mathrm{I}$ corresponds to the sum over diagrams, where $a = \pi$ in Fig. 2 (including the contact diagram) and $r = \mathrm{II}$ corresponds to the sum of diagrams with $a = \rho$ or ω. The amplitude defined in Eq. (2) is then D-wave projected using the formula

$$V^{2M}_{m\overline{m}} = \frac{1}{\sqrt{4\pi}} \int d\Omega Y^{2\,*}_M(\Omega) V_{m\overline{m}} \,. \quad (3)$$

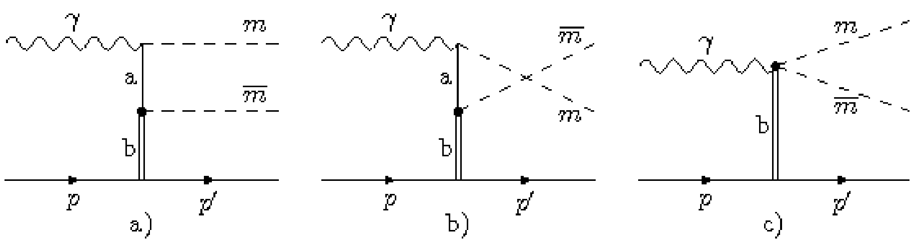

Fig. 2. Structure of diagrams corresponding to Born photoproduction amplitudes.

Details of the partial wave expansion procedure are given in [14]. Complete (*i.e.* including the final state interactions) amplitude of the D-wave $\pi^+\pi^-$ photoproduction reads

$$\left\langle \lambda' M \right| A_{\pi^+\pi^-} \left|\lambda_\gamma \lambda\right\rangle = \left\langle \lambda' M \right| \hat{V}_{\pi^+\pi^-} \left|\lambda_\gamma \lambda\right\rangle + 4\pi \sum_{m'\overline{m}'} \int_0^\infty \frac{k'^2 dk'}{(2\pi)^3}$$
$$\times F\left(k, k'\right) \left\langle \pi^+\pi^- \right| \hat{t} \left| m'\overline{m}' \right\rangle G_{m'\overline{m}'}\left(k'\right) \left\langle \lambda' M \right| \hat{V}_{m'\overline{m}'} \left|\lambda_\gamma \lambda\right\rangle , \quad (4)$$

where $\hat{V}$ is the Born amplitude of the $\pi^+\pi^-$ or $\pi^0\pi^0$ photoproduction, $\hat{t}$ is the $\pi\pi$ scattering amplitude which is discussed in [13], $\lambda, \lambda', \lambda_\gamma$ and M are, respectively, the helicities of the initial and final proton, photon helicty and projection of the $\pi\pi$ system angular momentum on the spin quantisation axis z (which can be identified with $f_2(1270)$ helicity). $\hat{G}$ is the propagator of the intermediate pion pair and $F(k,k')$ is the form-factor needed to regularize divergent mesonic loop of diagram shown in Fig. 1. Our present analysis is limited to the on-shell part of the amplitude defined by Eq. (4) so after momentum integration it can be recast in terms of isospin $\pi\pi$ amplitudes as

$$\left\langle \lambda' M \right| \hat{A}_{\pi^+\pi^-} |\lambda_\gamma \lambda\rangle = \left[1 + i r_\pi \left(\tfrac{2}{3} t_{\pi\pi}^{I=0} + \tfrac{1}{3} t_{\pi\pi}^{I=2}\right)\right] \left\langle \lambda' M | \hat{V}_{\pi^+\pi^-} | \lambda_\gamma \lambda \right\rangle + \tfrac{1}{3}\left[i r_\pi \left(-t_{\pi\pi}^{I=0} + t_{\pi\pi}^{I=2}\right)\right] \left\langle \lambda' M | \hat{V}_{\pi^0\pi^0} | \lambda_\gamma \lambda \right\rangle , \quad (5)$$

where $r_\pi = -k M_{\pi\pi}/8\pi$. The first term in Eq. (5) describes fully elastic rescattering, while the second term is the recharging term with a pair of neutral pions in the intermediate state converted to $\pi^+\pi^-$ in the final state.

3. Results

We have calculated the double differential cross section using the same formula as in [10]. Out of 40 spin amplitudes describing the D-wave $\pi\pi$ photoproduction only 20 are independent due to amplitude invariance under parity transformation. So we choose the photon helicity $\lambda_\gamma = +1$ as a reference helicity and refer to amplitudes corresponding to various M as no flip, single flip (either up or down), double flip amplitudes and so forth. From Eq. (4), we see that strengths of the photoproduction amplitudes with

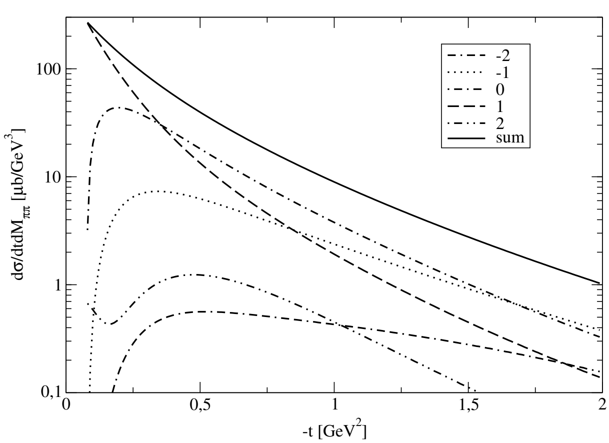

Fig. 3. Born cross sections for $\pi^+\pi^-$ photoproduction at $E_\gamma = 3.5$ GeV and $M_{\pi\pi} = 1.27$ GeV for different angular momentum projections (see the legend).

different M *entirely* depend on the Born amplitudes and that final state interactions modulate these amplitudes uniformly. The full photoproduction amplitude consists of the terms proportional to $V_{\pi^+\pi^-}$ and $V_{\pi^0\pi^0}$. We show Born cross sections of the $\pi^+\pi^-$ and $\pi^0\pi^0$ photoproduction in Figs. 3 and 4. While the $\pi^+\pi^-$ photoproduction is dominated by contributions of $M = +1$,0 and -1 (dashed, dot-dashed and dotted curves in Fig. 3), the $\pi^0\pi^0$ photoproduction has strong contributions of partial waves corresponding to $M = \pm 2$ (dot-dot-dashed and dash-dash-dotted curves in Fig. 4). It can

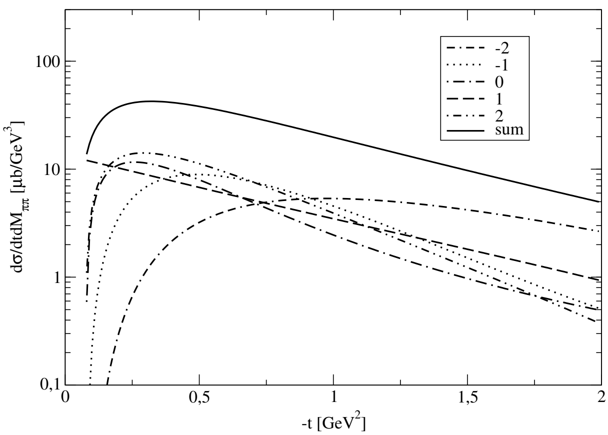

Fig. 4. Born cross sections for $\pi^0\pi^0$ photoproduction at $E_\gamma = 3.5$ GeV and $M_{\pi\pi} = 1.27$ GeV for different angular momentum projections (see the legend).

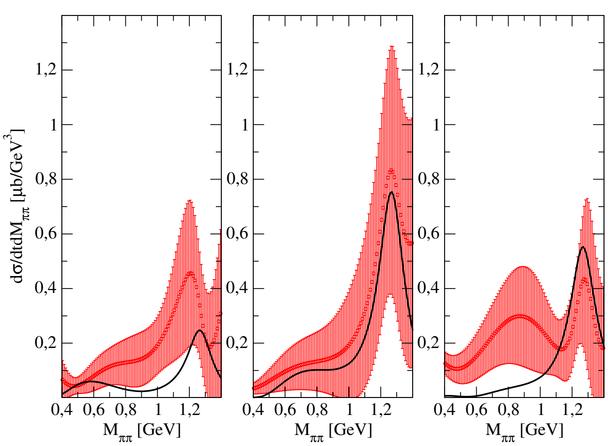

Fig. 5. (color online) Model prediction (solid line) of $\pi^+\pi^-$ mass distribution for $M = -1$ (left panel), $M = 0$ (middle panel) and $M = +1$ (right panel) at $E_\gamma = 3.3$ GeV and $-t = 0.55$ GeV^2 compared to CLAS data.

be understood as a consequence of double vector meson exchange as the Born amplitudes for $\pi^0\pi^0$ photoproduction are only type II amplitudes. On the other hand, the Born amplitudes for $\pi^+\pi^-$ photoproduction have both type I and type II contributions with dominating type I contribution. In Fig. 5, we show the mass distributions for $M = -1,0,+1$ compared with the corresponding CLAS data [2]. The model reproduces the fact that mass distribution is dominated by $M = 0$. The resonance line asymmetry and its shift towards lower masses observed in the experiment may be attributed to the interference of the resonant D-wave amplitude with contribution of other mechanisms involving pion–nucleon rescattering (Drell mechanism). These features will be subject of further studies.

4. Summary

The model properly predicts relative strengths of different partial waves which are entirely determined by the Born amplitudes. The ultimate check of model predictions will be the calculation of moments of pion angular distribution and comparison with moments measured by CLAS experiment.

This work has been supported by the Polish Ministry of Science and Higher Education (grant No N N202 236940).

REFERENCES

[1] Ł. Bibrzycki, L. Leśniak, A.P. Szczepaniak, *Eur. Phys. J.* **C34**, 335 (2004).
[2] M. Battaglieri *et al.*, *Phys. Rev.* **D80**, 072005 (2009).
[3] Ł. Bibrzycki, L. Leśniak, *EPJ Web Conf.* **37**, 09009 (2012).
[4] B. Renner, *Nucl. Phys.* **B30**, 634 (1971).
[5] M. Suzuki, *Phys. Rev.* **D47**, 1043 (1993).
[6] Y. Oh, T.-S.H. Lee, *Phys. Rev.* **C69**, 025201 (2004).
[7] A. Ahmadzadeh, R.J. Jacob, *Phys. Rev.* **160**, 1359 (1967).
[8] D. Toublan, *Phys. Rev.* **D53**, 6602 (1996).
[9] F. Giacosa *et al.*, *Phys. Rev.* **D72**, 114021 (2005).
[10] Ch.-R. Ji *et al.*, *Phys. Rev.* **C58**, 1205 (1998).
[11] R. Garcia-Martin *et al.*, *Phys. Rev.* **D83**, 074004 (2011).
[12] R. Kamiński, *Phys. Rev.* **D83**, 076008 (2011).
[13] R. Kamiński, *Acta Phys. Pol. B Proc. Suppl.* **6**, 743 (2013), this issue.
[14] Ł. Bibrzycki, R. Kamiński, in preparation.