

Resonances in forward $\pi^+\pi^-$ photoproduction on hydrogen

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Abstract. We show that the cross section of the $\Delta(1230)$ production in the $\gamma p \rightarrow p\pi^+\pi^-$ reaction at forward angles and with unpolarized photons can be described in terms of gauge invariant one pion t -channel exchange amplitudes. Proper description of the polarized cross sections requires, however, the inclusion of contributions from the baryon exchanges.

1 Introduction

Photoproduction reactions are a good source of information on the structure and production mechanisms of baryon and meson resonances. In particular, photoproduction of pions on the hydrogen target can be used to study the spectrum of Δ resonances and the exchanges involved in their production. At low energies it can be described by models based on effective Lagrangians [1, 2] while at higher energies the Regge amplitudes are used to describe the data [3, 4]. Moreover, analysis of experiments with linearly polarized photon beams enables to disentangle the contributions of natural and unnatural exchanges in the amplitudes. This is because it was shown in [5, 6] that to leading order in the t/s ratio the cross section for photons polarised parallel (perpendicular) to the production plane receives contributions only from unnatural (natural) exchanges, where naturality is defined as $P(-1)^J$. In our case the production plane is defined by momenta of incident photon and outgoing pion. Thus e.g. the ρ and a_2 are natural exchanges and contribute to σ_{\perp} while π and b are unnatural exchanges and contribute to the σ_{\parallel} only. The analyses of $\gamma p \rightarrow p\pi^+\pi^-$ reaction at photon energies around 10 GeV are currently underway at CLAS12 and GlueX experiments in Jefferson Laboratory [7].

2 Model description

In this analysis we exploit the fact that at forward angles the amplitude based on the dominant π Regge trajectory is very close to the one calculated with the Feynman propagator. Such one pion exchange amplitudes, whose diagrammatic representation is shown in Fig. 1, are known in the literature as Deck amplitudes [8]. It is also known that the one pion exchange amplitudes are not gauge invariant by themselves. Therefore we adapt the approach used

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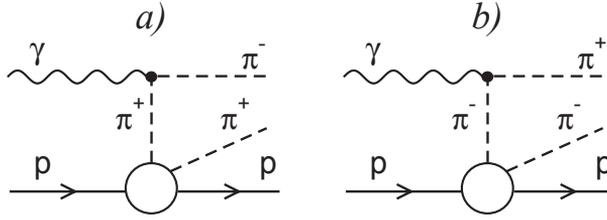


Figure 1. Feynman diagrams for the direct meson photoproduction (Deck mechanism).

in [9] and add the direct photon-proton coupling term to the amplitude to make it gauge invariant. Thus the modified Deck amplitude reads

$$M_{\lambda_2\lambda\lambda_1} = -e \left[\left(\frac{\epsilon_\lambda \cdot k_2}{q \cdot k_2} - \frac{\epsilon_\lambda \cdot (p_1 + p_2)}{q \cdot (p_1 + p_2)} \right) T_{\lambda_1\lambda_2}^+ - \left(\frac{\epsilon_\lambda \cdot k_1}{q \cdot k_1} - \frac{\epsilon_\lambda \cdot (p_1 + p_2)}{q \cdot (p_1 + p_2)} \right) T_{\lambda_1\lambda_2}^- \right], \quad (1)$$

where p_1, p_2, q, k_1 and k_2 are respectively target, recoil, photon, π^+ and π^- 4-momenta, ϵ_λ is photon polarisation vector with helicity λ and λ_1, λ_2 are target and recoil polarisations. Additional terms in two parentheses of Eq. (1) are usually referred to as contact terms, even though they induce nonlocality in the model. The π^+ and π^- scattering amplitudes off proton, $T_{\lambda_1\lambda_2}^+$ and $T_{\lambda_1\lambda_2}^-$ can be expressed in terms of the isospin amplitudes

$$T_{\lambda_1\lambda_2}^+ = T_{\lambda_1\lambda_2}^{\frac{3}{2}}, \quad T_{\lambda_1\lambda_2}^- = \frac{1}{3} (T_{\lambda_1\lambda_2}^{\frac{3}{2}} + 2T_{\lambda_1\lambda_2}^{\frac{1}{2}}). \quad (2)$$

These in turn are given in terms of the standard Lorentz invariant isospin amplitudes [10]

$$T_{\lambda_1\lambda_2}^I = \bar{u}(p_2, \lambda_2) (A^I + \gamma \cdot QB^I) u(p_1, \lambda_1), \quad (3)$$

with $Q = \frac{1}{2}(q \mp k_1 \pm k_2)$, for π^- and π^+ scattering, respectively. Further, we define the scalar functions A^I and B^I in Eq. (3) in terms of phenomenological SAID partial wave amplitudes [11] for respective isospins.

Based on Eq. (1) we define the fixed photon polarisation double differential cross section as

$$\frac{d^2\sigma^{\parallel/\perp}}{d|t|dM_{p\pi}} = \frac{|\mathbf{k}|}{128(q \cdot p)^2} \frac{1}{(2\pi)^3} \sum_{\lambda_2\lambda_1} |M_{\lambda_2\lambda_1}^{\parallel/\perp}|^2, \quad (4)$$

where the relation between linearly polarised photon states and helicity states is

$$\epsilon_x = -\frac{1}{\sqrt{2}}(\epsilon_+ - \epsilon_-) \quad \epsilon_y = \frac{i}{\sqrt{2}}(\epsilon_+ + \epsilon_-). \quad (5)$$

3 Numerical results

In what follows we focus on the small $|t|$ photoproduction cross sections of the lightest $\Delta(1230)$ resonances in two charge states Δ^{++} and Δ^0 . To this end we integrate the $M_{p\pi}$ spectrum defined by Eq. (4) in the mass region around 1.23 GeV.

In Fig. 2 we show the calculation of the unpolarised cross section (ie. the average of polarised cross sections defined in Eq. (4)) for $\gamma p \rightarrow \Delta^{++}\pi^-$ reaction calculated at photon energies $E_\gamma=5, 8$ and 16 GeV and compared with data obtained in SLAC [12, 13]. It is

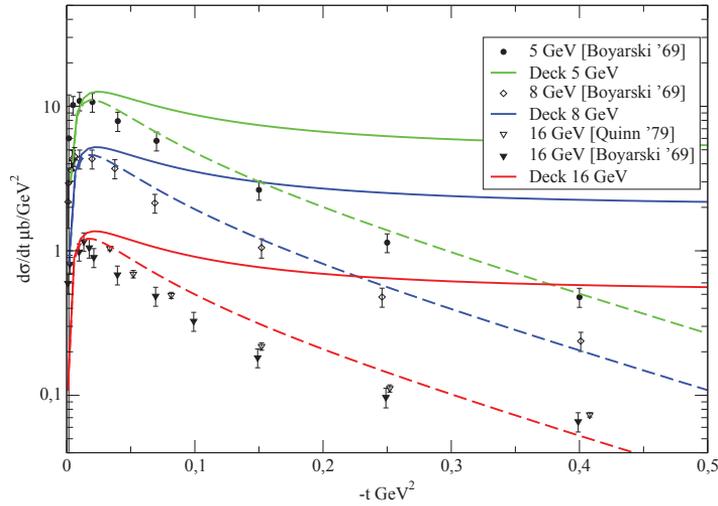


Figure 2. Unpolarised cross sections calculated at photon energies of 5, 8 and 16 GeV. Solid curves - one pion exchange model, dashed curves - one pion exchange model multiplied by Regge factor. (color online)

apparent that the OPE alone (solid lines) is not able to provide good data description for larger momentum transfers. It is usually remedied by including either exponential collimation factor or Regge-like $(s/s_0)^{\alpha(t)}$ factor in the amplitude, where $\alpha(t)$ is the pion Regge trajectory. We choose the latter to make results obtained with our approach comparable to analyses based on Regge amplitudes. It is important to note that the model fairly well reproduces the the cross section at different energies.

In Fig. 3 we show the results of the calculation of cross sections for photons polarized parallel to the production plane for Δ^{++} (left panel) and Δ^0 (right panel), at $E_\gamma=16$ GeV and compare them to measurements described in [13]. The model fairly well describes the

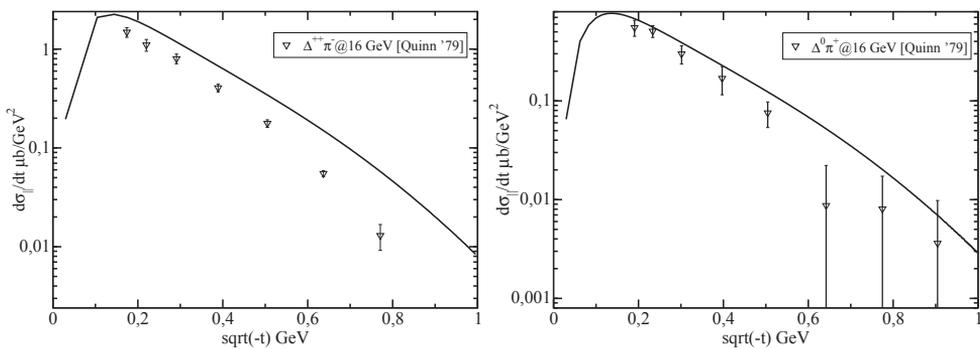


Figure 3. Cross sections for photons polarized parallel to the production plane calculated at $E_\gamma=16$ GeV.

data, especially in the forward region where the effect of the pion propagator is dominating. However, one observes some excess for the Δ^{++} photoproduction. On the other hand, the pure one pion exchange model predicts the perpendicular cross section $d\sigma_\perp/dt$ to be 0 in

contradiction with data obtained in [13]. Therefore, it appears that the t -channel one pion exchange *aka* Deck model is insufficient to properly describe the Δ^{++} and Δ^0 photoproduction for photons polarized both parallel and perpendicular to the production plane. The natural extension is to include the baryon exchanges in the s - and u -channels together with the contact term [14]. Additionally, one can expect some absorption effects to modify basic helicity amplitudes used in the model [15].

4 Conclusions and outlook

We have constructed the extended version of the Deck model, where instead of assuming particular exchanges to describe the $p\pi$ scattering, we use phenomenological partial wave SAID amplitudes. To disentangle the contributions of $\Delta^{++}(1230)$ and $\Delta^0(1230)$ we integrate the $M_{p\pi^+}$ and $M_{p\pi^-}$ spectra in the region around these resonances. The model very well describes the unpolarized cross section $d\sigma/dt$ at different energies from 5 to 16 GeV. Including the Regge factor we are able to describe the cross section even beyond the forward region where the model is supposed to be best suited. The model fairly well describes the $\Delta^{++}(1230)$ and $\Delta^0(1230)$ photoproduction cross section for photons polarized parallel to the production plane, with some excess observed for the $\Delta^{++}(1230)\pi^-$ channel. It fails, however, to describe the perpendicular cross section. We interpret this as a signature of other mechanisms involved in the reaction, like the s - and u -channel baryon exchanges or the effect of contact term.

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