Two pion electroproduction *

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We have extended a model for the $\gamma N \to \pi\pi N$ reaction to virtual photons and selected the diagrams which have a Δ in the final state. The agreement found with the $\gamma_v p \to \Delta^0\pi^+$ and $\gamma_v p \to \Delta^{++}\pi^-$ reactions is good. The sensitivity of the results to $N\Delta$ transition form factors is also studied. The present reaction, selecting a particular final state, is an extra test for models of the $\gamma_v N \to \pi\pi N$ amplitude.

1. Introduction

The $\gamma N \to \pi\pi N$ reaction in nuclei has captured some attention recently and has proved to be a source of information on several aspects of resonance formation and decay as well as a test for chiral perturbation theory at low energies. A model for the $\gamma p \to \pi^+\pi^- p$ reaction was developed in [1] containing 67 Feynman diagrams by means of which a good reproduction of the cross section was found up to about $E_\gamma \simeq 1$ GeV.

A more reduced set of diagrams, with 20 terms , was found sufficient to describe the reaction up to $E_\gamma \simeq 800$ MeV [2] where the Mainz experiments are done [3,4,5].

The extension of this kind of work to virtual photons should complement the knowledge obtained through the (γ,2π) and the related reactions. The coupling of the photons to the resonances depends on q^2 and the dependence can be different for different resonances. Hence, the interference of different mechanisms pointed above will depend on q^2 and with a sufficiently large range of q^2, one can pin down the mechanism of (γ,2π) with real or virtual photons with more precision than just with real photons, which would help settle the differences between present theoretical models.

However, there are already interesting two pion electroproduction experiments selecting Δ in the final state. The reactions are, $ep \to e'\pi^-\Delta^{++}$ and $ep \to e'\pi^+\Delta^0$ [6]. It is thus quite interesting to extend present models of $(\gamma, 2\pi)$ to the realm of virtual photons and compare with existing data. In our paper [7] we do so, extending the model of ref.[2] to deal with the

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electroproduction process. This model is flexible enough and one can select the diagrams which contain $\Delta\pi$ in the final state in order to compare directly with the measured cross sections.

The extension of the model requires three new ingredients: the introduction of the zeroth component of the photon coupling to resonances (calculations where done in [2] in the Coulomb gauge, ϵ^0, where the zeroth component is not needed), the implementation of the q^2 dependence of the amplitudes, which will be discussed in forthcoming sessions, and the addition of the explicit terms linked to the $S_{1/2}$ helicity amplitudes which vanish for real photons.

Experiments on $(\gamma_v, 2\pi)$ are presently being done in the Thomas Jefferson Laboratory [8], both for $N\Delta$ and $N\pi\pi$ production.

2. Model for $eN \to e'\Delta\pi$

We will evaluate cross sections of virtual photons integrated over all the variables of the pions and the outgoing nucleon. In this case the formalism is identical to the one of inclusive $eN \to e'X$ scattering [9,10] or pion electroproduction after integrating over the pion variables [11,12]. For the model of the $\gamma_v N \to \Delta\pi$ reaction we take the same diagrammatic approach as in ref.[2] and select the diagrams which have a Δ in the final state. The diagrams which contribute to the process are depicted in fig.1

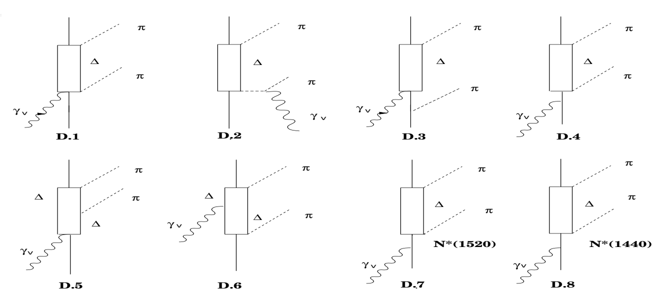

Fig.1

Fig. 1. Feynman diagrams used in the model for $\gamma_v p \to \pi\Delta$

We follow the paper from Devenish et al. [13] in our approach to electromagnetic transitions for Roper and $N^*(1520)$ resonances. As we are working with virtual photons we need to care about these couplings and hence include terms which vanish for real photons.

Gauge invariance is one of the important elements in a model involving photons and implies that

$$T^\mu q_\mu = 0 \tag{1}$$

However, as discussed in the study of the $eN \to e'N\pi$ reaction in [14], and as can be easily seen by inspection of the diagrams and the amplitudes, the constraint of eq. (1) still requires the equality of four electromagnetic form factors,

$$F_1^p(q^2) = F_1^\Delta(q^2) = F_{\gamma\pi\pi} = F_c(q^2) \tag{2}$$

The form factors of eq. (2) are respectively the γNN, $\gamma\Delta\Delta$, $\gamma\pi\pi$ and $\gamma\Delta N\pi$ ones. These form factors are usually parametrized in different forms, except for $F_1^p(q^2)$ and $F_1^\Delta(q^2)$ which are taken equal, as it would come from ordinary quark models.

Although the model is gauge invariant with the prescription of eq. (2) there is the inconvenience that the results depend upon which one of the three form factors we take for all of them.

We should note however, that the dominant term, by large, is the Δ Kroll Ruderman and pion pole terms. This is also so in the test of gauge invariance where the two terms involving the $F_1^p(q^2)$ form factor in diagrams D4, D6 give only recoil contributions of the order of $O(p_\pi/m)$ in eq. (1). This justifies the use of $F_c(q^2)$ or $F_{\gamma\pi\pi}(q^2)$ for all the form factors.

There is, however, another way to respect gauge invariance, while at the same time using different form factors which is proposed in [15] and to which we refer in what follows as Berends et al. approach.

3. Results and conclusions

We have tested our results [7] with the experimental data of refs. [6,11]. We show the cross section of $\gamma_v p \to \Delta^{++}\pi^-$ and $\gamma_v p \to \Delta^0\pi^+$ ($\Delta^0 \to \pi^- p$), as a function of W, the virtual photon-proton ($\gamma_v p$) center of mass energy, and for different values of Q^2. We have made different calculations. One of them corresponds to using all form factors equal (which we set to $F_{\gamma\pi\pi}$) with two different values of λ_π^2, 0.5 GeV^2 and 0.6 GeV^2. In [7] we see that the cross section increases by about 10 % when going from λ_π^2=0.5 GeV^2 and λ_π^2=0.6 GeV^2. We also show the results taking F_1^p, F_1^Δ and setting $F_c = F_{\gamma\pi\pi}$ with λ_π^2=0.6 GeV^2. This latter calculation is not gauge invariant. However we see that the deviation with respect to the gauge invariant one assuming all form factors equal is very small [7]. This reflects the fact that the relevant terms in the model are those involving $F_{\gamma\pi\pi}$ and F_c, the pion pole and Δ Kroll Ruderman terms.

We also evaluate the cross section using Berends gauge invariant approach with different form factors [15]. We show the results in fig. 2. The continuous line in the figure is obtained with this prescription using F_1^p, F_1^Δ but setting $F_c = F_{\gamma\pi\pi}$ with $\lambda_\pi^2 = 0.5$ GeV^2.

We see that these results are remarkably similar to those where F_c and $F_{\gamma\pi\pi}$ had the same values as here but F_1^p, F_1^Δ were set equal to $F_{\gamma\pi\pi}$ in order to preserve gauge invariance.

The dotted line in fig. 2 corresponds to the same parametrization for F_c as for $F_{\gamma\pi\pi}$ but parameter λ_c^2= 0.8 GeV^2. This shows the sensitivity of the results to F_c which appears in the dominant Kroll-Ruderman term.

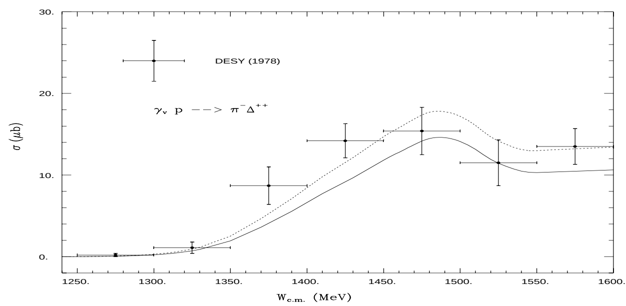

Fig. 2. Cross sections from $\gamma_v p \rightarrow \Delta^{++}\pi^-$ with Berends formalism included. Continuous line: $F_1^p, F_1^\Delta, F_{\gamma\pi\pi} = F_c$ with $\lambda_\pi^2 = 0.5\ GeV^2$. Dotted line: same as continuous line with the parameter for $F_{\gamma\pi\pi}$ 0.5 GeV^2 and for F_c is 0.8 GeV^2.

In summary we could remark the following points: We have shown in [7] that the peak in the cross section is due to an interference between the Δ Kroll Ruderman term and the $N^*(1520)$ excitation process followed by $\Delta\pi$ decay. Different sets of form factors have been used in our model in order to show the sensitivity of the results to these changes. These tests should be useful in view of the coming data and the possibility to extract relevant information from them. We have calculated the separation of the transverse and longitudinal cross sections and found that the transverse one largely dominates the cross sections. Finally, it is also interesting to note that the present model is just part of a more general $\gamma_v N \rightarrow \pi\pi N$ model which selects only the terms where a πN pair of the final state appears forming a Δ state.

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