PHOTO- AND ELECTROPRODUCTION OF THE ETA AND ETA-PRIME MESONS

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ABSTRACT
We discuss the eta and eta prime photo- and electroproduction as a way to probe the nucleon resonance structure.

1. Introduction

The Blaubeuren symposium of summer, 1995 has been a gathering bathed in the excitement generated by the eta physics. We have had two plenary sessions dedicated to this subject and many fine contributions. Of particular interest has been the recent experiments done at Mainz and Bonn facilities. The Mainz photoproduction data are very precise.

On the theory side, Benmerrouche and Mukhopadhyay laid out some time ago an effective Lagrangian approach (ELA), which emphasizes the tree-level structure of the photoproduction reaction

\[ \gamma + p \rightarrow p + \eta, \]  

(1)
clearly dominated by the excitation of the N\(^\ast\)(1535) resonance. Our recent work has dealt with all then available data, most of which are in the higher energy region \(E_\gamma \geq 900\, \text{MeV}\). The publication of the precise Mainz data along with the less precise ones from Bates and Bonn, has necessitated a revisit of our ELA. This is what our report here is about.

The electroproduction of eta

\[ e + p \rightarrow e' + p + \eta \]  

(2)
involves older data base. Our result essentially coincides with the thesis of Benmerrouche. We have not been able to reproduce the non-isotropic angular distributions reported at low \(Q^2\) from Bonn. These data must be confirmed. New data are urgently needed for the reaction (2).

Our work on the theory of eta prime photoproduction, just about to come out in print, is the first theoretical paper on this subject, based on the old data base dating back to 1968. As such, it is exploratory in nature. There is no experimental work to guide us into the domain of eta prime electroproduction and we shall not discuss that any further. There exists an approved proposal on eta prime photoproduction at CEBAF.

We note with anticipation new theoretical efforts to build on the coupled-channel analysis by Tanabe and Bennhold. Confusions about the disputed data base on the strong
sector, discussed at this conference in a hot debate between Bennhold and Svarc, do not allow us to draw any firm conclusions on the unitarity and coupled-channel effects, as yet, contrary claims notwithstanding. This symposium has featured these concerns in spirited discussions.

2. Basic issues

In the context of the $\eta$ and $\eta'$ photo- and electroproduction, basic questions mirror those of the pi-zero production. Some of these are:

1. What are the nature of the meson-nucleon couplings? How large are the meson-nucleon coupling “constants”?

2. Are there any “low-energy” theorems near thresholds of the eta and eta prime photoproduction?

3. What are the key contributions at the tree level? How important are the roles of the various $N^*$ excitations?

4. How big are the form factor effects? What are the exact forms of these form factors?

5. How large are the effects from unitarity?

We discuss some of these issues here. Others are picked up later.

On the eta-nucleon coupling constant $g_\eta$ for the pseudoscalar meson-nucleon coupling, one can give rather broad range of values, using the SU(3) or SU(6)$_W$ symmetry arguments. These bands imply $g_\eta$ considerably smaller than the value of $g_\pi$. Using quark model arguments, we can calculate these ranges for $g_{\eta'}$ as well. Similarly, the t-channel vector meson exchanges can be constrained by using suitable constraints on the vector meson-nucleon couplings.

Another important point is the handling of the spin-3/2 baryon resonances, which involves proper treatment of spin-3/2 propagators, often poorly done in the literature. In view of our recent discussion of it, we shall not elaborate this any further. Suffice to say that it gives contribution in the spin-1/2 sector, which can be quite important, but is often neglected. We also note that no comparable treatments are available in the literature on the higher spin baryon resonances. Fortunately, their roles in the present context are rather marginal.

3. Our analysis of the Mainz photoproduction data

The eta photoproduction data from Mainz obtained by Krusche et al. have very small statistical and systematic errors. Our ELA fit to this data yields excellent agreement (samples are in Fig.1). The same fit agrees with the recent data of Dytnan et al. from the Bates laboratory at $E_\gamma = 753\text{MeV}$, but disagrees with the latter at $E_\gamma = 729\text{MeV}$. Our tree-level ELA describes very well the total cross-section data of Mainz, Bonn and the Bates data point at $E_\gamma = 753\text{MeV}$.

We can extract from the Mainz data an electrostrong parameter characteristic of the $N^*(1535)$ excitation and decay. This quantity, defined by Benmerrouche and Mukhopadhyay, is conservatively estimated to be

$$\xi = (2.20 \pm 0.15) \times 10^{-4}\text{MeV}^{-1}. \quad (3)$$
Recent estimates in the quark model by Capstick and Roberts\cite{17} has yielded a value of this parameter about half of the above, while Li, in a recent preprint\cite{18}, extracts a figure within the order of magnitude of Eq.(3). Clearly, this is a fundamental baryon property that should be ultimately computed reliably via QCD.

Other inferences from the Mainz data are as follows:

(1) We cannot determine precisely $g_{\eta NN}$ within our ELA, given the relatively small role nucleon Born terms play. Our extracted range is in fair agreement with SU(3).

(2) The vector meson sector compensates for the other non-resonant contributions, thereby playing a useful role.

(3) The $N^*(1520)$ [$D_{13}$] resonance also plays some role that we can discern. The measured angular distributions at higher energies ($E_\gamma \geq 780\text{MeV}$) require the presence of this resonance. At energies higher than $E_\gamma = 900\text{MeV}$, other resonances become important.

4. Our analysis of the data on electroproduction of the etas

The data, rather old, show generally flat angular distributions, indicating the dominance of the $N^*(1535)$ excitation. The data of Brasse et al\cite{7} continue to be flat for $Q^2 \leq 3\text{GeV}^2$. 

Figure 1: Our effective Lagrangian approach description of the Mainz eta photoproduction data on proton (a) $E_\gamma = 716\text{MeV}$ (b) $E_\gamma = 783\text{MeV}$. The main parameter fitted here is $\xi$ of $N^*(1535)$[see text].
5. Photoproduction of the eta prime meson

The data come from the venerable ABBHHM collaboration\[11\] from 1968 and are of poor quality. Our ELA analysis\[10\] is motivated by the quark model calculation of Capstick and Roberts\[17\], who give us a first look at the prediction of the electromagnetic excitation strength in the quark model.

The physics of $\eta'$ is interesting for many reasons: $\eta_1$-$\eta_8$ mixing angle\[13\], chiral U(1) problem\[20\], the U(4)$\supset$SO(4) dynamical symmetry\[21\], just to mention a few. We have found another wrinkle: the importance of s- and u-channel form factors, without which the cross-section violates unitarity very badly. The form factors we use are:

$$F(s) = 1/ \left[ 1 + \frac{(s - M_R^2)^2}{\Lambda^4} \right]$$

where $\Lambda^2$ is of the order of $1 GeV^2$, $M_R$ is the resonance mass. Similar forms can be used in the u-channel. Of course, we must respect gauge invariance.

Our fit of the ABBHHM data (Fig.2) is quite satisfactory, given the quality of the data. The surprising feature, about which we should hopefully hear more in the next conference, is the important role of the $D_{13}$ resonance, $N^*(2080)$, which is strongly excited in the quark model estimate by Capstick and Roberts.
6. Concluding remarks

The eta and eta prime photoproduction studies have ushered an exciting frontier of the hadron physics involving N* resonances. We have obtained the first careful look at the properties of N*(1535) from the precise Mainz data on photoproduction of eta mesons. The photoproduction of eta prime promises to yield new valuable information on the electrostrong properties of the N*(2080) resonance, about which we know very little. New neutron data from Mainz and polarization studies from Bonn for eta photoproduction, together with the advent of CEBAF, should bode well for the future of this field.

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