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Electroproduction of mesons in a chiral quark model

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Motivation This work is a continuation of a joint project on the description of baryon resonances performed by the Coimbra group (Manuel Fiolhais, Luis Alvarez Ruso, Pedro Alberto) and the Ljubljana group (Simon Širca and B. G.)

The pion- and photon-induced meson production on nucleons are important tools to study the hadron dynamics in the first and second resonance region. One of the main challenges is to understand the interplay of quark and meson degrees of freedom. While several models of nucleon excited states spanning from the non-relativistic models based solely the quark degrees of freedom to models involving only mesonic degrees of freedom are able to successfully describe the pion elastic and non-elastic scattering in the resonance region, electro-production of mesons represents a much more severe test which may be able to disentangle the properties originating in the (valence, constituent) quark degrees of freedom from those of the meson cloud. One of the most widely recognized example is electro-excitation of the $\Delta(1232)$ resonance where the pion cloud contributes $\sim 45\,\%$ to the magnetic dipole amplitude, and strongly dominates the electric quadrupole amplitude. Similarly, the behaviour of the pion electro-excitation amplitude in the Roper region can be explained by assuming a relatively strong contribution of the pion cloud. However, in the second resonance region, such a conclusion is less transparent because of the presence of other channels. To avoid ambiguities, we need to develop a method in which the strong and the EM processes are treated in a unified approach without too many adjustable parameters.

The method In order to study the interplay of quark and meson degrees of freedom, we have developed a method that incorporates the nucleon and its excited states calculated in different chiral quark models into a coupled channel approach involving different meson-baryon channels as well as the photon-nucleon channel. The conceptual foundations of our approach in chiral quark models date back to the paper [1], in which we demonstrated the above mentioned importance of the pion cloud in electro-production of pions in the region of the $\Delta(1232)$.

In [2] we have generalized our approach used in our previous studies of the resonances (see e.g. [1], [3], [4] and [5]). The generalized method incorporates excited baryons represented as quasi-bound quark-model states into a coupled channel framework using the K-matrix formalism. It can be applied to meson scattering as well as to electro and weak-production of mesons. Our method assumes a class of chiral quark models in which mesons couple linearly to the quark. In such a case it is possible to write down an exact expression for the K matrix (and, consequently, for the T matrix) in terms of the principal-value states corresponding to the meson-baryon channels possessing the proper asymptotic behaviour. The construction respects the symmetry of the K matrix and hence ensures the unitarity of the S matrix.

The strong and the weak points The main *advantages* of our method can be summarized in

- Baryons are treated as composite particles from the very beginning; the strong and electro-weak form-factors are derived from baryon internal structure and not inserted a posteriori; as a consequence the method introduces a much smaller number of free parameters.
- The physical resonances appear as linear superpositions of bare resonances.
- The bare quark-meson and quark-photon vertices are modified through meson loops as well as through mixing of resonances and coupling to the background.
- The meson cloud around baryons is included in a consistent way also in the asymptotic states.
- The method yields a symmetric K matrix and hence respects the unitarity of the S matrix.

The present *limitations* of the method are primarily the absence of meson-meson interaction and the nucleon-meson four-point interaction which can be introduced only in an approximate way. This is a consequence of our assumption about the meson-quark interaction discussed above. Our method is therefore primarily intended to describe the processes in the region of resonances rather than in the energy region close to the threshold where other methods are anyway superior.

The Roper resonance In [2] and [6] we have considered the scattering and the pion electro-production in the region of the N(1440) and of its $I = \frac{3}{2}$ partner, the $\Delta(1600)$. As the underlying quark model we have taken the Cloudy bag Model, primarily because of its simplicity. A good agreement with the observed scattering amplitude and the M_{1-} electro-production amplitude is found provided the $\pi\Delta$ and the σN channels of comparable strength are included in the multichannel calculation. The results strongly support the hypothesis that the pion cloud plays an important role in the case of the electro-excitation of $N^*(1440)$ resonance, especially in the region of low Q^2 (long-range effects). In this region the quark contribution is small and positive, while the pion contribution and the vertex corrections due to meson loops are large and negative. At intermediate Q^2, these two effects are responsible for the zero crossing of the amplitude. At higher Q^2 (short-range physics) the quark core takes over, rendering the amplitude positive.

The S11 resonances In recent years there have been substantial efforts to understand the peculiar nature of the lightest of the S11 resonances, the $N(1535)$, due to its position just above the ηN threshold and the large branching ratio to the ηN channel. The extension of the approach to the low-lying negative-parity resonances requires the inclusion of new channels involving the s- and d-wave pions, the η and the ρ mesons, and the $K\Lambda$ channel. In [7–9] we have used an SU(3) extension of the Cloudy Bag Model taking f_η and f_K from the meson sector, while for the other model parameters we have used the same values as in the case of the positive-parity resonances, adding only the mixing parameter between the two bare-quark states corresponding to $N(1535)$ and $N(1650)$, and their bare masses. We have obtained a good overall agreement with the available experimental results for the partial widths of the $N(1535)$ and the $N(1650)$ resonances as well as for the pion, η-meson and kaon electroproduction amplitudes. In particular, the excellent agreement with the data for η production strongly supports our conjecture about the dominance of the genuine three-quark configuration in the $N^*(1535)$ state. While the cross-section for pion-induced production of K^+ appears to be over-estimated in our model, the photo-production amplitude is smaller than predicted by phenomenological analyses. This discrepancy remains an open question and represents a challenge for further investigation.

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