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Electromagnetic Associated Strangeness Production and Hadrons Form Factors

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Abstract. A formalism, based on an isobaric approach, via Feynman diagrammatic technique, including the nucleonic (spin $\leq 5/2$), hyperonic (spin $1/2$) and the kaonic resonances is developed. Using this formalism, a thorough investigation of *all* the electromagnetic strangeness processes, for which experimental results are available, is performed and satisfactory agreement with the data is obtained. The reaction mechanism is found to include a reasonable number of baryonic resonances, with the extracted main kaon-hyperon-nucleon coupling constants in agreement with the SU(3)-symmetry predictions. The sensitivity of this model to the form factors of the relevant hadrons is emphasized.

1 Introduction

Using a phenomenological approach based on an isobaric model including s , u , and t -channels, we have performed a thorough study of the associated strangeness electromagnetic production [1, 2], namely the following reactions:

$$\gamma p \rightarrow K^+ \Lambda, K^+ \Sigma^0, K^0 \Sigma^+; E_{\gamma}^{lab} \leq 2.1 \text{ GeV},$$

$$e p \rightarrow e' K^+ \Lambda, e' K^+ \Sigma^0,$$

$$K^- p \rightarrow \gamma \Lambda, \gamma \Sigma^0, \text{branching ratios with stopped kaons.}$$

Here, we focus on the sensitivity to the hadronic form factors of the reactions $ep \rightarrow e' K^+ \Lambda$, in the few GeV region. The virtual photon has a longitudinal part besides the transverse component, and offers the possibility of vary independently the energy and momentum transfers. In this respect, the electrons are a finer probe for the strangeness realm. At the present time, the data in this field are scarce [3], but the foreseen experiments [4] at CEBAF are expected to produce much copious and accurate data in a near future.

2 Model

Our formalism is based on an isobaric approach using Feynman diagrammatic technique. To determine the reaction mechanism, two interconnected questions need to be addressed: which resonances are exchanged and what are the corresponding coupling constants? These latter are free parameters and their values are extracted through a least-squares fitting procedure. In our investigation, we have used all the roughly 500 available data points for the seven reactions mentioned in the Introduction, and examined the possible contributions of some 30 resonances. A model is obtained containing, besides extended Born terms, the following exchanged particles:

s -channel: $P_{11}(1440)$, $P_{13}(1720)$, $D_{15}(1675)$,
 u -channel: $\Lambda(1405)$, $\Lambda(1670)$, $\Lambda(1810)$, $\Sigma(1660)$,
 t -channel: $K^*(892)$, $K_1(1280)$.

In addition, the values of the two main coupling constants g_{KAN} and g_{KEN} , are in agreement with the broken $SU(3)$ -symmetry constraints.

3 Form Factors

In the electroproduction reaction, the virtual photons probe the electromagnetic structure of the involved hadrons. This is taken into account in phenomenological models by incorporating appropriate form factors for each hadron. In the present work, we have selected some parametrizations proposed in the literature, without trying to re-adjust the parameters. We now describe briefly the form factors introduced at the relevant vertices .

3.1 Baryonic Form Factors

At the γpp vertex, we have to consider the two form factors of the proton, namely F_1^p and F_2^p , which are related to the electric (G_E^p) and magnetic (G_M^p) form factors:

$$F_1^p = \frac{1}{1-\tau}(G_E^p - \tau G_M^p) \quad , \quad F_2^p = \frac{1}{\kappa_p(1-\tau)}(G_M^p - G_E^p) \quad (1)$$

with $\tau = \frac{Q^2}{4M^2}$, and κ_p the anomalous magnetic moment of the proton. These form factors have been extensively studied in the literature. We have retained the model developed by Gari and Krümpelmann [GK] in Ref. [5] in its most recent version [6] which gives a good agreement with the available data. The basis of this approach is the extended vector meson dominance (EVMD) model, combining the vector meson dominance (VMD) hypothesis (appropriate at low Q^2) with the perturbative QCD approach describing the spacelike region. At the $YY\gamma$ vertices ($Y \equiv \Lambda, \Sigma^0$), we have used the two form factors of the neutron ($F_1^Y = F_1^n$, $F_2^Y = F_2^n$) as parametrized by GK [5, 6]. For the nucleonic (hyperonic) resonances, we choose the second Dirac form factor of the proton (neutron).

3.2 Kaonic Form Factors

The form factor of the K^+ has not been studied as extensively as the nucleon one. Moreover, the available experimental data are restricted to the low energy domain ($-Q^2 < 0.15 \text{ GeV}^2$), which makes difficult to choose a model valid in the whole energy range considered in the present work. We have adopted the VMD model as proposed by Williams [7]: $F_{K^+} = (F_{i_s} + F_{i_v})/2$, where the isoscalar and isovector parts are expressed in terms of the appropriate mesons contributions:

$$F_{i_s}(Q^2) = \sum_{v=\phi,\omega} F_v(Q^2) \left(\frac{g_v}{f_v} \right) \frac{M_v^2}{M_v^2 + Q^2 - iM_v\Gamma_v} \quad (2)$$

$$F_{i_v}(Q^2) = F_\rho(Q^2) \left(\frac{g_\rho}{f_\rho} \right) \frac{M_\rho^2}{M_\rho^2 + Q^2 - iM_\rho\Gamma_\rho} \quad (3)$$

The free parameters are determined by the known $\phi \rightarrow K^+ K^-$ decay width, plus the two normalization constraints $F_{K^+}(Q^2 = 0) = 1$, $F_{K^0}(Q^2 = 0) = 0$. The values obtained by Williams lead to a K^+ charge radius $\langle r_{K^+}^2 \rangle = 0.335 \text{ fm}^2$, in good agreement with the experimental value [8] : $0.34 \pm 0.05 \text{ fm}^2$.

For the K^* and $K1$ kaonic resonances, we have chosen the simplified VMD model used by Adelseck [9]. A monopole form factor was assumed: $F(Q^2) = 1/(1 + Q^2/\Lambda^2)$, and Λ_{K^*} and Λ_{K1} were adjusted to give the best fit to the electroproduction data.

4 Results and discussion

In this contribution, using the reaction mechanism [2] outlined in Section 2, we report on the results corresponding to the baryonic form factors by Gari and Krümpelmann published in 1985 [Ref. 5] and 1992 [Ref. 6], hereafter referred to as GK85 and GK92, respectively. For the t -channel exchanged particles, namely K , K^* , $K1$, the expressions by Adelseck [9], and Williams [7] are used. Figure 1 shows these kaonic form factors.

• Fig. 1 Form factors for Kaon, K^* and $K1$

The existing data [8] concern only the Kaon form factor and the 25 data points are in the range $-Q^2 \simeq 0.02 \div 0.1 \text{ (GeV/c)}^2$. For the sake of clarity, we show in Fig.1 only a few of them including the extreme Q^2 values.

Figure 2 shows our results for the cross section $d\sigma_{UL} \equiv d\sigma/d\Omega_K = \sigma_U + \varepsilon_L \sigma_L$, and the ratio $R = \sigma_L/\sigma_U$, with σ_U and σ_L the differential cross sections for an unpolarized incident photon beam, and a longitudinally polarized virtual photon, respectively; ε_L is the longitudinal polarization parameter. The curves, at $W = 5.02 \text{ (GeV/c)}^2$ and $\varepsilon = 0.7$, come from reaction mechanisms with the same exchanged particles [2], and differ in the expressions for the form factors. For each form factor combination, the free parameters (coupling constants) have been refitted to all the relevant data points. In Fig. 2, the curve (a) corresponds to our model as mentioned in Section 2, for which the reaction mechanism (set of exchanged particles and values of couplings) has been optimized. The form factors for baryons are from GK92, for Kaon from Williams (W), and for K^* and K_1 from Adelseck (A). This model called SL (for Saclay-Lyon) is identified as the following combination for form factors: GK92-WAA. The curve (b) is the same as SL, except that it does not contain the K_1 -exchange. The curves (c) to (e) incorporate the same resonances as the SL model but differ in the form factors, namely (c): GK92-WAW, (d): GK92-WWW, (e): GK85-WWW.

• Fig. 2 Cross section $d\sigma_{UL} \equiv d\sigma/d\Omega_K = \sigma_U + \varepsilon_L \sigma_L$ (in $\mu\text{b/GeV}^2$) as a function of momentum transfer at $t = -0.1 \text{ (GeV/c)}^2$, and the ratio $R = \sigma_L/\sigma_U$ as function of Mandelstam variable t at $Q^2 = -1. \text{ (GeV/c)}^2$, curves are explained in the text. Curve (a) is divided by a factor of 2.

We emphasize that all these curves have been obtained by fitting the complete set of data (photoproduction, electroproduction, and radiative capture) producing reasonable reduced χ^2 s; for the $K\Lambda$ channels the values are: 1.73 for (a), 2.47 for (b), and 2.22 for the three others (c to e). Nevertheless, removing K_1 from the model leads to large coupling constants for the $\Lambda(1810)$,

and $\Sigma(1660)$ resonances as expected from the duality hypothesis [11], showing the need for higher spin hyperonic resonances [2] if the t -channel terms are discarded.

For the cross section $d\sigma_{UL}$, our optimized model SL (curve *a*) gives the best agreement with the data. The other curves (*b* - *e*) compare equally to the data and differ from the SL model at low $-Q^2$. At this level, different choices of the form factors do not lead to significant effects on the cross section. However, the ratio between the two components of this observable offers very interesting features (Fig. 2B), showing drastic differences according to the included form factors sets. The SL gives a large and monotonously increasing ratio. Switching off the K1 exchange (curve *b*) presents the opposite trend. Putting back the K1 and using for this resonance the expression obtained by Williams [7] rather than by Adelseck [9] produces the curve *c* which is much flatter than in the case of the SL model. Doing in addition the same substitution for the K^* (curve *d*) leaves the magnitude almost unchanged but reverses the curvature. Keeping these kaonic form factors and using GK85 instead of GK92 for the hadrons form factors leads to a minimum around $-t \simeq 1. (GeV/c)^2$. This latter shape is comparable to the one produced by Williams-Ji-Cotanch model [10, 4]. In summary, the longitudinal and transverse electroproduction cross sections show sizable sensitivities to the choice of hadrons form factors. The upcoming results from CEBAF [4] will therefore play a crucial role in our knowledge of some fundamental properties of the hadrons.

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