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HYPERON RESONANCES IN RADIATIVE KAON CAPTURE*

Tim Van Cauteren†, Pieter Vancraeyveld, Jan Ryckebusch

Department of Physics and Astronomy, Ghent University
Proeftuinstraat 86, 9000 Gent, Belgium

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We use crossing symmetry to extend our Regge model for electromagnetic kaon production from the proton to the case of radiative kaon capture. Our model is based on the exchange of the $K(494)$ and $K^*(892)$ Regge trajectories in the t-channel. We use the parameters fitted to describe the $p(\gamma, K^+)Y$ reaction to make predictions for the $p(K^-, \gamma)Y$ process. The differential crosss-sections of the latter for kaon momenta of 520 and 750 MeV/c show a satisfactory agreement with data from the Crystal Ball Collaboration.

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Mapping out the properties (masses, coupling strengths, excitation energies, ...) of baryon resonances will tell us a great deal about the dynamics of QCD in the confinement region. Many resonance models, for example, predict a denser baryon spectrum than experimentally observed [1–4]. Particularly interesting channels are those involving the production of a kaon ($K\Lambda$ or $K\Sigma$) because they also allow access to the strangeness content of the baryons.

Over the last years, we have developed a *Regge-plus-resonance* (RPR) model for kaon electro- and photoproduction from the nucleon [5–7]. The model can be extended straightforwardly to describe the radiative kaon capture processes, using crossing symmetry. In the latter process, hyperon resonances can be excited. Therefore, the two different reactions offer an opportunity of studying both the nucleon and the hyperon spectrum in a single framework.

The RPR model provides the amplitude $\mathcal{M}(k, p; p_Y, p_K)$ for the kaon production process. Here, k, p, p_Y and p_K are the photon, proton, hyperon and kaon fourmomenta, respectively. The amplitude comprises a sum of

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† Corresponding author: `timvancauteren@gmail.com`

terms corresponding to the exchange of t-channel kaon Regge-trajectories and s-channel nucleon/delta resonances as depicted in Fig. 1. The t-channel Regge-trajectory exchange results in a smooth *background* behaviour of the amplitude, while the s-channel resonance exchanges allow for structure in the differential cross-sections and other observables.

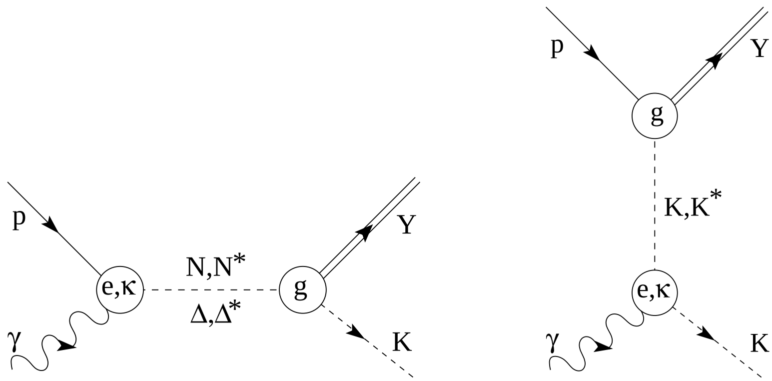

Fig. 1. The left panel shows the Feynman diagram for s-channel exchange (nucleon, delta and their resonances) in the kaon production process. The right panel shows the same for t-channel exchange (kaon and kaon resonances), where the Feynman propagator is replaced by a Reggeized propagator in our model. Each diagram contributes with a strength proportional to the product of a strong coupling (g) and an electromagnetic coupling (e or κ).

In the case of electromagnetic (EM) production of a positively charged kaon and a neutral hyperon ($Y = \Lambda, \Sigma^0$), the background consists of the two trajectories with the $K(494)$ and the $K^*(892)$ as first materializations [5]. The contribution of a kaon trajectory is computed as if only the first materialization is exchanged, but with the denominator in the Feynman propagator ($1/(t - m^2_{K^{(*)}})$) replaced by the Reggeized propagators for high s and small $|t|$

$$\mathcal{P}^{K^+}_{\text{Regge}}(s,t) = \left(\frac{s}{s_0}\right)^{\alpha_{K^+}(t)} \frac{1}{\sin(\pi\alpha_{K^+}(t))} \times \left\{ \begin{array}{c} 1 \\ e^{-i\pi\alpha_{K^+}(t)} \end{array} \right\} \frac{\pi\alpha'_{K^+}}{\Gamma(1+\alpha_{K^+}(t))}, \tag{1}$$

$$\mathcal{P}^{K^{*+}}_{\text{Regge}}(s,t) = \left(\frac{s}{s_0}\right)^{\alpha_{K^{*+}}(t)} \frac{1}{\sin(\pi(\alpha_{K^{*+}}(t)-1))} \times \left\{ \begin{array}{c} 1 \\ e^{-i\pi(\alpha_{K^{*+}}(t)-1)} \end{array} \right\} \frac{\pi\alpha'_{K^{*+}}}{\Gamma(\alpha_{K^{*+}}(t))}. \tag{2}$$

Here, $\alpha_{K^+}(t) = \alpha'_{K^+}(t - m^2_{K^+})$ and $\alpha_{K^{*+}}(t) = 1 + \alpha'_{K^{*+}}(t - m^2_{K^{*+}})$ with trajectory slopes $\alpha'_{K^+} = 0.70\,\text{GeV}^2$ and $\alpha'_{K^{*+}} = 0.85\,\text{GeV}^2$. Furthermore, we are only considering strongly degenerate kaon trajectories, which gives rise to a constant or rotating phase factor in the above expressions [5,6]. Previous studies [6,7] have shown that a rotating phase for both K and K^* trajectories yields optimal results for $K\Lambda$ production, and that a rotating (constant) phase for the K (K^*) trajectory is the best choice for $K\Sigma$ production. The background terms stemming from the above procedure do not give rise to a gauge invariant amplitude. This is remedied by including the electric part of the Feynman amplitude describing the exchange of a ground-state nucleon in the s-channel [5,8].

The Regge-model description given by the exchange of the two kaon trajectories and the electric s-channel term turns out to be extremely efficient. Indeed, the model has only three fitting parameters: g_{pK^+Y} is the coupling at the strong pK^+Y vertex, and $g^{v,t}_{pK^{*+}Y}$ are the vector and tensor couplings at the strong $pK^{*+}Y$ vertex. These coupling constants are fitted to the data at high energies, where no resonant structures are observed. For the $p(\gamma, K^+)\Lambda$ reaction [6], our optimal Regge model has been labelled Regge-2. In our analysis of the $K\Sigma$ channels [7], two models coined Regge-3 and Regge-4 (which most noticeably differ in the sign of $g^t_{pK^{*+}\Sigma^0}$) yield an equally satisfying description of the data. Simply extrapolating these Regge models to intermediate energies leads to an amazingly good description of the general features of the kaon production observables in the resonance region, considering that the Reggeized propagators of Eqs. (1), (2) are asymptotic expressions for high s and small $|t|$ [5,9].

The structures seen in the kaon production differential cross-sections obviously cannot be explained by the Regge model. Therefore, the Regge model is supplemented with individual s-channel terms describing the exchange of nucleon/delta resonances. These terms are given by their Feynman amplitude, in which the denominator incorporates the finite lifetime of the resonance $s - M^2_{N^*} + i\varepsilon \rightarrow s - M^2_{N^*} + iM_{N^*}\Gamma_{N^*}$. A phenomenological form factor for the resonance is introduced at the strong vertex. For this, we assume a Gaussian functional dependence $\exp\left[-\frac{(s-M^2_{N^*})^2}{\Lambda^4_{\text{res}}}\right]$ with one value for the cutoff $\Lambda_{\text{res}} \simeq 1.6$ GeV for all resonances.

Fig. 2 shows the crossing symmetry between kaon production (the left panel) and kaon capture (the right panel). The amplitude $\mathcal{M}$ for the kaon capture process is the analytic continuation (AC) of the amplitude for the kaon production process, with the signs of the kaon and photon momenta reversed:

$$\mathcal{M}^{Kp\rightarrow\gamma Y}(p_K, p; p_Y, k) = \mathcal{M}^{\gamma p\rightarrow KY}_{\text{AC}}(-k, p; p_Y, -p_K)\,. \quad (3)$$

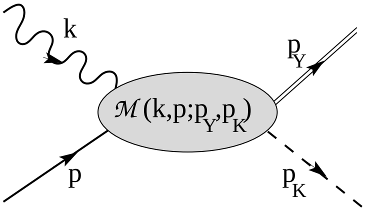

Fig. 2. The left panel shows the amplitude for kaon production as a function of the particles' fourmomenta. The right panel shows the amplitude for the kaon capture process, which is the analytic continuation of the amplitude from the left figure with the signs of photon and kaon momenta reversed.

Crossing symmetry interchanges the roles of the Mandelstam-s and -u variables. The Mandelstam-t variable remains the same, as do the contributions to the amplitude that arise from t-channel exchange. Therefore, one can apply the Regge models as introduced above, to the description of radiative kaon capture, without introducing or adjusting any parameters. However, the s/u-interchange means that deviations between Regge model results and data should be attributed to hyperon exchange contributions.

The Crystal Ball Collaboration has measured the radiative kaon capture process at the AGS at Brookhaven for kaon momenta ranging from $\sim$ 520 MeV/c to 750 MeV/c. Analysis of this data is underway, but some preliminary results can be found in [10]. In Fig. 3, one sees the results for the $K^-p \to \gamma\Lambda$ at kaon momenta 520 MeV/c and 750 MeV/c as a function of the c.o.m. angle θ^*_γ between the incoming kaon and the outgoing photon. The agreement of our predictions with the data from [10] is clearly satisfactory.

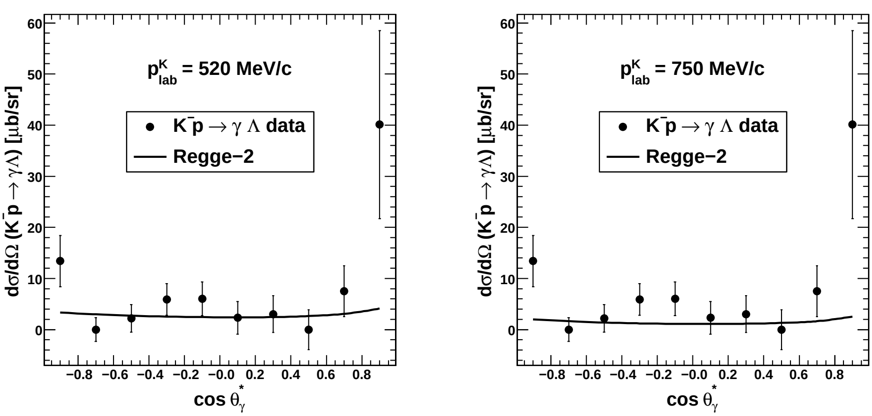

Fig. 3. Regge model predictions for the $K^-p \to \gamma\Lambda$ process are shown for $p_K =$ 520 MeV/c (left panel) and $p_K = 750$ MeV/c (right panel). Data are from Ref. [10].

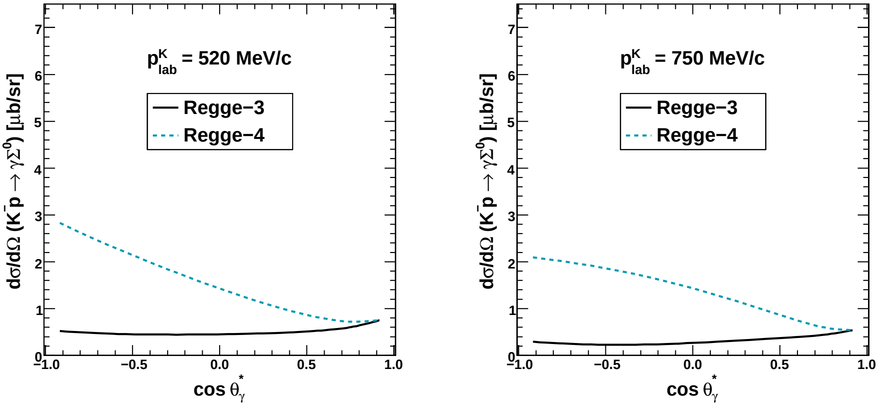

Fig. 4. The same as in Fig. 3, but for the $K^-p \to \gamma\Sigma^0$ process and for the two Regge model variants discussed in the text.

For the $K^-p \to \gamma\Sigma^0$ process, we show the predictions of two Regge model variants for the differential cross-sections in Fig. 4. They are similar for forward angles, but diverge for moderately forward and backward angles. The background contributions are clearly less forwardly peaked in the $\gamma\Sigma^0$-channel than in the $\gamma\Lambda$-channel.

Summarizing, we have used crossing symmetry to extend our Regge model for EM kaon production to radiative kaon capture. The three parameters of the $p(\gamma, K^+)Y$ model were kept fixed and no extra parameters were introduced, making the results for the kaon capture reaction pure predictions. For the $\gamma\Lambda$-channel, the differential cross-sections are of the same order as the preliminary data. Therefore, we only expect moderate contributions from hyperon resonance exchange terms. For the $\gamma\Sigma^0$-channel, we await the data analysis from the Crystal Ball Collaboration.

As a next step, we intend to include Y^* exchange terms into our $p(K, \gamma)Y$ model along similar lines as we included N^* and Δ^* terms in the RPR model for the $p(\gamma, K)Y$ process. Not only would this allow us to give a better description of the data, it would also make it possible to extract the ratio of electromagnetic couplings to the $\gamma\Lambda/\gamma\Sigma^0$-channels for a specific hyperon resonance. This ratio can be compared with predictions from models for hadron structure.

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