hep-ph/9904511 30 Apr 1999

Electroproduction of strangeness above the resonance region.

M. Guidal [a], J.-M. Laget [b] and M. Vanderhaeghen[c]
[a] *IPN Orsay, F-91406 Orsay, France*
[b] *CEA/Saclay, DAPNIA/SPhN, F-91191 Gif-sur-Yvette Cedex, France*
[c] *University Mainz, D-55099 Mainz, Germany*

(April 30, 1999)

A simple and elegant model, based on Reggeized t-channel exchanges is successful in reproducing the main features of all existing data of the reactions $ep \to e'K^+\Lambda$ and $ep \to e'K^+\Sigma$. In particular, the original way gauge invariance is taken into account is found to be essential to describe the ratio between the Coulomb and the Transverse cross-sections at large Q^2 that has been measured recently at JLab.

Strangeness production is undergoing a renewed interest in view of the numerous data which are currently coming out of electron accelerators like CEBAF at Jefferson Lab and ELSA at Bonn. It offers us with an original way to probe hadronic matter. Not only the study of the Hyperon-Nucleon interaction is a mandatory complement to the study of the Nucleon-Nucleon interaction, but the implantation of an impurity (the strange quark or a Hyperon) in a hadronic system is a formidable tool to study its properties. However, the elementary processes of photo- and electroproduction of kaons off the nucleon should be mastered.

At low energy, within about 1 GeV above threshold, many resonances may contribute in the s-channel and fits to the scarce data are generally obtained at the expense of many free parameters [1], [2]. At higher energy, Regge phenomenology provides us with an elegant and simple way to account for the analyticity and unitarity of the amplitude with almost no free parameters [3], [4].

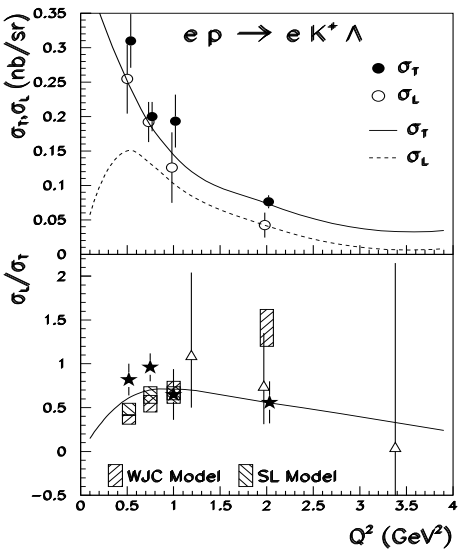

FIG. 1. Q^2 dependence of σ_T and σ_L (upper plot) and σ_L/σ_T (lower plot) for the $\gamma^* + p \to K^+ + \Lambda$ reaction, at W = 1.84 GeV. Experimental data points are from : (•, ○, ★) : [6] and (△) : [11]. Besides our calculation, on the lower panel are also shown the models of Ref. [1], [2]. The WJC prediction is $\approx$ 3.5 (off scale) for Q^2 =2. (GeV/c)^2.

Our Regge model is fully described in Refs. [3], [4] for the *photoproduction* of pions and kaons on the nucleon above the resonance region (above $E_\gamma \approx 2$ GeV), and in Ref. [5] for the *electroproduction* of pions. It is based simply on two "Reggeized" t-channel exchanges (π and ρ trajectories for pion production, K and K^* trajectories for kaon production). An original and essential feature of this model is the way gauge invariance is restored for the π (K) t-channel exchanges by proper "reggeization" of the s-channel nucleon pole contribution. This was found to be the key element to describe numerous features of the experimental data (for instance, the π^+/π^- ratio, the forward peaking of the charged pion differential cross section, the photon asymmetry, etc...).

As in Ref. [5], we extend the model of kaon photoproduction to electroproduction by multiplying the separately gauge invariant K and K^* t-channel diagrams by a monopole form factor :

$$F_{K,K^*}(Q^2) \;=\; \left[1 + Q^2/\Lambda^2_{K,K^*}\right]^{-1} \;, \qquad (1)$$

with $Q^2 = -q^2$, where q is the spacelike virtual photon four-momentum. The mass scales Λ_K and Λ_{K^*} are chosen to be $\Lambda^2_K = \Lambda^2_{K^*} = 1.5$ GeV^2, in order to fit the high Q^2 behavior of σ_L and σ_T in Fig. 1. We keep the same coupling constants at the $(K, (\Lambda, \Sigma), N)$ and $(K^*, (\Lambda, \Sigma), N)$ vertices as in the photoproduction study [4], which were found to describe all existing high energy data, i.e. :

$$\begin{aligned} &\frac{g^2_{K\Lambda N}}{4\pi} = 10.6 \;,\; g_{K^*\Lambda N} = -23. \;,\; \kappa_{K^*\Lambda N} = 2.5, \\ &\frac{g^2_{K\Sigma N}}{4\pi} = 1.6 \quad ,\; g_{K^*\Sigma N} = -25. \;,\; \kappa_{K^*\Sigma N} = -1. \end{aligned} \qquad (2)$$

The magnitudes and signs ($g_{K\Lambda N} < 0$ and $g_{K\Sigma N} > 0$) of the K strong coupling constants are in agreement with SU(3) constraints (broken to about 20%). The signs of the K^* strong coupling constants are also in accordance with SU(3).

It turns out that the recent measurement [6], at Jefferson Lab, of the ratio between the Coulomb (σ_L) and the Transverse (σ_T) cross-sections of the $p(e, e'K^+)\Lambda$ reaction clearly favors the Regge model over the resonance models, already in the CEBAF energy range. Fig. 1 shows the comparison of the Regge model with the data. Particularly interesting is the behavior at large Q^2 of the σ_L/σ_T ratio which decreases as the data, in contrast to two recent theoretical resonances models [1], [2]. Our Regge model suitably reproduces the trend of this ratio. The reason is that, due to gauge invariance, the t-channel kaon exchange and the s-channel nucleon pole terms are indissociable and must be treated on the same footing. In our model [3], [4], they are Reggeized in the same way and multiplied by the same electromagnetic form factor. This approach clearly differs from traditional ones [1], [2] where a different form factor is assigned to the t- and s-channel diagrams (monopole and a dipole forms respectively -with also different mass scales-, in general). This explicitly breaks gauge invariance and the introduction of a purely phenomenological and ad-hoc counter-term is

needed to restore it. Whatever particular way this procedure is done, it produces a -linearly- rising ratio σ_L/σ_T with Q^2 in contrast to the data.

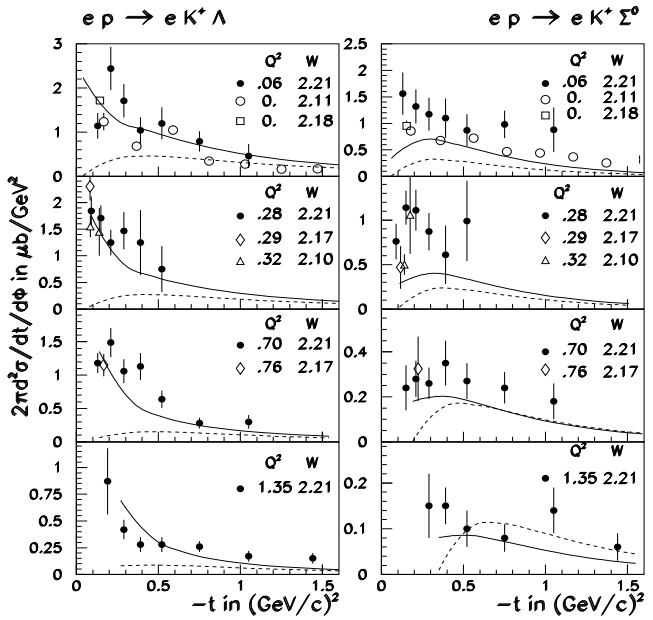

FIG. 2. t dependence of the $\gamma^* + p \to K^+ + \Lambda$ (left) and $\gamma^* + p \to K^+ + \Sigma$ (right) differential electroproduction cross section $2\pi d^2\sigma/dtd\Phi$ for different Q^2 values. The solid line shows the K+K^* exchanges, the dashed line shows the K^* exchange only. Displayed data correspond approximately to the same W and Q^2 ranges (units for the figure are in GeV/c and (GeV/c)^2 respectively) ; (•) : [8], (○) : [7], (□) : [9], (◇) : [10], (△) : [12].

The Regge model reproduces also fairly well the -scarce- data prior to Jefferson Lab. Fig. 2 shows the t-dependence of the $\gamma^*+p \to K^+ + \Lambda$ and $\gamma^*+p \to K^+ + \Sigma$ differential electroproduction cross section $2\pi d^2\sigma/dtd\Phi$ for different Q^2 values. The latest [7] and older [9] Bonn data for photoproduction are also shown for reference. At Q^2=.06 GeV^2, there is essentially no influence of the form factors. Therefore, without any additional parameter, a straightforward extension of the photoproduction model gives the correct t-dependence and magnitude of the data. As in the photoproduction study, the Λ and Σ channels show a different behavior at forward angles : the differential cross section decreases towards 0 for the latter one whereas it tends to peak for the former one. According to [4], this "peaking" for the Λ channel is due to the dominance of the gauge invariant K exchange at small t. Because of the weaker $g_{K\Sigma N}$ coupling constant relative to the $g_{K\Lambda N}$ coupling constant, the K^* exchange contribution -which has to vanish at forward angles due to angular momentum conservation- dominates the Σ channel, which reflects into a decrease of the differential cross section at forward angles. This decrease at small t is attenuated at larger Q^2 due to the "shift" of t_{min} with Q^2.

The Brauel et al. data of Fig. 2 were integrated in Φ between 120^o and 240^o [8] ; so was the model in order to correctly take into account the influence of the σ_{TT} and σ_{TL} terms which is found not to be negligible. Fig. 2 shows furthermore the destructive interference between the K and K^* exchange mechanisms for the Σ channel found at large angles, which was also noticed before in the photoproduction study [4].

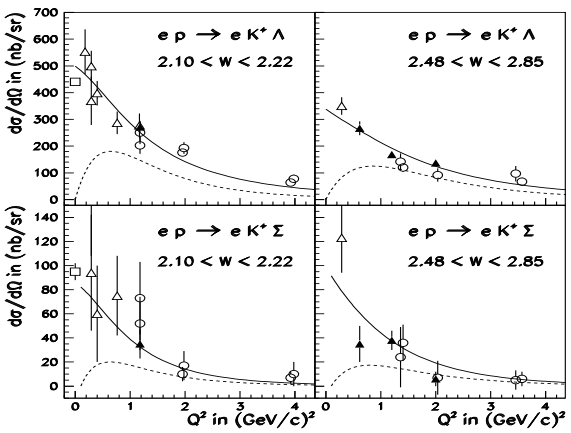

FIG. 3. Q^2 dependence of the $\gamma^* + p \to K^+ + \Lambda$ (upper plots) and $\gamma^* + p \to K^+ + \Sigma$ (lower plots) differential cross section $d\sigma/d\Omega$ for 2 energy bins. Solid lines : $d\sigma_T/d\Omega$, dashed line : $d\sigma_L/d\Omega$. Displayed data correspond approximately to the same W and θ ranges ; (△) : [13], (○) : [10], (▲) : [14], (□) : [9]. This latter point has been renormalized (see text for details).

This Q^2 dependence is confirmed by Fig. 3 which shows the differential cross section $d\sigma/d\Omega$ at θ_{CM}=8^o as a function of Q^2 for 2 energy bins. In fact, commonly, this observable has been plotted at a single averaged W value ($< W >$=2.15 GeV) where a $\mid p^*_K \mid /W/(s - m_p^2)$ dependence was used for the extrapolation of the lower and higher measured W values [10]. Fig. 3 shows that this procedure is approximately right for the Λ channel which shows roughly a $\frac{1}{s}$ behavior, but is not appropriate for the Σ channel which shows a rather constant behavior in this energy domain. Indeed, it is well known that a Regge amplitude proportional to $s^{\alpha(t)}$ leads to a differential cross-section $\frac{d\sigma}{dt} \propto s^{2\alpha(t)-2}$ and therefore $\frac{d\sigma}{d\Omega} \propto s^{2\alpha(t)-1}$. For

a K-meson exchange dominated mechanism (such as the Λ channel at forward angles, see fig. 2) with $\alpha_K(0) \approx$ -0.14, this implies $\frac{d\sigma}{d\Omega} \propto s^{-1.28}$. And for a K^*-meson exchange dominated mechanism (such as the Σ channel) with $\alpha_{K^*}(0) \approx .5$, we have $\frac{d\sigma}{d\Omega} \propto s^0$.

Note that the photoproduction point of [9] has been renormalized. This data was taken at θ_{CM}=25^o ($t \approx$-.15 GeV^2). It has been extrapolated to 8^o ($t \approx$-.06 GeV^2) to allow a consistent comparison with the other data. We did so by using the t-dependence of our model. From Fig. 2, it can be seen that this implies an *upscaling* (of $\approx$ 1.2) of the Λ photoproduction point and a *downscaling* (of $\approx$ 2.4) of the Σ photoproduction point. This leads to a very different figure and conclusion than in Ref. [10] (see figures 6 and 7 of Ref. [10]) : firstly, the Q^2 dependence of the Σ channel is not steeper than for the Λ channel and, secondly, there is no particular evidence of a rise with Q^2 of the Λ cross-section which would have indicated a strong contribution of σ_L. This latter contribution is seen to account for less than half of the cross section.

It is remarkable that the value of the cut-off mass, Λ_K^2=$\Lambda_{K^*}^2$=1.5 GeV^2, deduced from the Jefferson Lab experiment leads also to a correct Q^2 dependence for the world set of previous data, both in the Λ and the Σ channels. It appears, however, to be quite large, resulting in a rather flat form factor. Indeed, the effective charge radius corresponding to Λ_K^2=1.5 GeV^2 is : $< r_K^2 > \equiv -6\frac{dF_K}{dQ^2}\mid_{(Q^2=0)} = \frac{6}{\Lambda^2} \approx$.16 fm^2. This has to be compared to the value measured by direct scattering of kaons on atomic electrons at the CERN SPS which yielded $< r_K^2 >$=.34 fm^2 [16]. However, we found [5] a good agreement between the pion form factor mass scale (Λ_π^2 =.462 GeV^2, i.e. $< r_\pi^2 >$= .52 fm^2) deduced from a study similar to the one in this article and the value measured by direct scattering of pions on atomic electrons at the CERN SPS : $\approx$.44 fm^2 [17]. An interpretation of this discrepancy for the kaon case can be that, the kaon pole being far from the physical region, the form factor used in this kind of model does not represent the properties of the kaon itself but rather the properties of the whole trajectory. This has to be kept in mind when trying to extract the kaon electromagnetic form factor from these channels. Indeed, when the exchanged kaon is further off-shell, instead of being sensitive to the kaon form factor, one might in fact measure a transition form factor between the kaon and an orbital excited state lying on the kaon Regge trajectory.

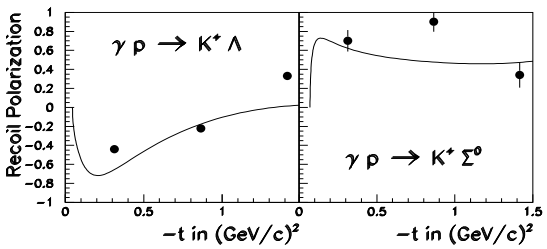

FIG. 4. t dependence of the Λ and Σ recoil polarizations recently measured at Bonn in photoproduction [7].

We now turn to polarization observables. We first show on Fig. 4 that the Λ and Σ single recoil polarizations recently measured at Bonn [7] in photoproduction are reasonnably predicted by our model at forward angles (At larger angles, other contribution besides t-channel exchanges are expected to contribute : u-channel exchanges, resonances contributions at low energies, etc...). It is the interference between the K and K^* trajectories -arising from the $e^{i\alpha_{K,K^*}(t)}$ signature term in the K and K^* Regge propagators, see Ref. [4]- which produces the non-zero polarization in the present model. The negative (positive) Λ (Σ) recoil polarization is directly related to the relative sign of the $g_{K^*N\Lambda}$ couplings with respect to the K ($g_{K\Lambda N} < 0$ and $g_{K\Sigma N} > 0$ whereas $g_{K^*(\Lambda,\Sigma)N}$ are both negative).

At Jefferson Lab, with electron beams, double polarization observables will soon be accessed for the first time [18]. These will put further stringent constraints on the models and will allow to disentangle the contributions of the K and the K^* exchange. Typical behaviors for kinematics accessible at Jefferson Lab (E_e = 6 GeV, $\theta_{e'}$ = 13 °, E_{γ^*} = 2.643 GeV) are shown in Fig. 5 for Φ=0 and 180 degrees (The definitions and the notations are given in Appendix A of Ref. [15], and the z-axis is chosen along the direction of the virtual photon). If only one trajectory is retained the induced polarization P_Y° (unpolarized electrons) vanishes: it is different from zero when the two trajectories interfere. It is worth noting that P_Y°, which is the "extension" to *electroproduction* of the *photoproduction* recoil polarization of Fig. 4, is now positive (at Φ=0 degrees). Indeed, in photoproduction, this observable is sensitive only to σ_T^Y whereas in electroproduction the additionnal σ_L^Y, σ_{TT}^Y and σ_{TL}^Y cross sections enter. These latter contributions come with an oppposite sign with respect to σ_T^Y here. The sideways (P_X') and longitudinal (P_Z') transfered polarizations indicate the relative amount of K and K^* exchanges. The strong Φ dependence evidenced on Fig. 5 can also be used to disentangle the various contributions. At large transfers, it was noted that, in Deep Inelastic Scattering,

the strange quark can be used to follow the spin transfer from the probe to the emitted Λ. It will be interesting to compare such approaches to our Regge calculations.

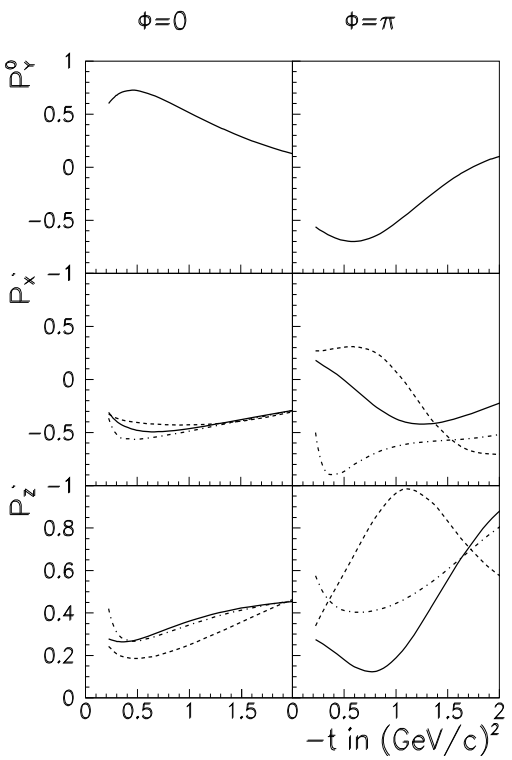

FIG. 5. The t dependence of the three Λ polarizations which do not vanish in coplanar kinematics, for E_e=6 GeV, W=2.2 GeV and Q^2=1 GeV^2. Dashed lines: K exchange only. Dash-dotted lines: K^* exchange only. Full lines: complete model. Left panels : Φ=0. degrees, right panels : Φ=180. degrees

To conclude, this simple and elegant Regge trajectory exchange model accounts fairly well for the whole set of available data and the rather accurate first measurement at Jefferson Lab. Since the model depends on very few parameters, the forthcoming data from Jefferson Lab will constitute a stringent test (that may eventually call for a more fundamental partonic description). Nevertheless, it provides already a good starting point to compute and analyze strangeness production in nuclei.

[1] R.A. Williams, C.R. Ji and S.R. Cotanch, Phys. Rev. C **46**, 1617 (1992).

[2] J. C. David et al., Phys. Rev. C **53**, 2613 (1996).

[3] M. Guidal, J.-M. Laget and M. Vanderhaeghen, Phys. Lett. B **400**, 6. (1997).

[4] M. Guidal, J.-M. Laget and M. Vanderhaeghen, Nucl. Phys. A **627**, 645 (1997).

[5] M. Vanderhaeghen, M. Guidal and J.-M. Laget, Phys.Rev. C **57**, 1454 (1998).

[6] G. Niculescu et al., Phys. Rev. Lett. **81**, 1805 (1998).

[7] M.Q. Tran et al., Phys. Lett. B **445**, 20 (1998).

[8] P. Brauel et al., Z. Phys. C **3**, 101 (1979).

[9] P. Feller et al., Nucl. Phys. B **39**, 413 (1972).

[10] C. J. Bebek et al., Phys. Rev. D **15**, 594 (1977).

[11] C. J. Bebek et al., Phys. Rev. D **15**, 3082 (1977).

[12] T. Azemoon et al., Nucl. Phys. B **95**, 77 (1975).

[13] C. N. Brown et al., Phys. Rev. Lett. **28**, 1086 (1972).

[14] C. J. Bebek et al., Phys. Rev. Lett. **32**, 21 (1974) .

[15] J.-M. Laget, Nucl. Phys. A **579**, 333 (1994).

[16] S. R. Amendolia et al., Phys. Lett. B **178**, 435 (1986).

[17] S. R. Amendolia et al., Phys. Lett. B **B146**, 116 (1984).

[18] JLab proposals, E99-006, D. Carman et al., E98-101, O. Baker et al. .