# Exclusive electromagnetic production of strangeness on the nucleon: Regge analysis of recent data

M. Guidal,[1] J.-M. Laget,[2] and M. Vanderhaeghen[3]
[1]*IPN Orsay, F-91406 Orsay, France*
[2]*CEA/Saclay, DAPNIA/SPhN, F-91191 Gif-sur-Yvette Cedex, France*
[3]*University Mainz, D-55099 Mainz, Germany*
(Received 11 August 2003; published 10 November 2003)

In view of the numerous experimental results recently released, we provide in this paper an update on the performance of our simple Regge model for strangeness electroproduction on the nucleon. Without refitting any parameters, a decent description of all measured observables and channels is achieved. We also give predictions for spin transfer observables, recently measured at Jefferson Lab, which have high sensitivity to discriminate between different theoretical approaches.

DOI: 10.1103/PhysRevC.68.058201 PACS number(s): 13.60.Le, 12.40.Nn

Regge theory provides a simple and elegant framework to describe exclusive hadronic reactions above the resonance region [1–3]. We have presented in Refs. [4–7] a Regge model for meson photoproduction and electroproduction reactions, which is based on the exchange of one- or two-meson Regge trajectories in the $t$ channel. The very few free parameters used in this approach are the coupling constants of the first particle materialization of the Regge trajectory at the hadronic vertices along with the mass scales of monopole form factors at the electromagnetic vertices in the case of electroproduction. Basically, all available observables are decently and "economically" described by this approach for a plethora of elementary channels: photoproduction and electroproduction on the nucleon of $\pi^{0,\pm}$ and $K^+$ as well as $\rho^0, \omega, \phi, \gamma$ [8,9] and $\eta, \eta'$ [10]. Surprisingly, in some cases, data down to $W<2$ GeV center of mass energies, therefore supposedly in the resonance region, can be successfully described: this could be interpreted as a manifestation of the reggeon-resonance duality hypothesis [11]. Why this duality seems to work for some channels and not for some others still remains an open question.

Recently, numerous experimental data have been released by the Jefferson Lab, ELSA, GRAAL, and SPRING8 facilities in the kaon production sector. This motivates the study which compares the Regge model to these new observables and channels, without any change of the parameters. Our model is fully described in Refs. [4–7]. In these works, we found that, for strangeness electromagnetic production, it allows one to describe the $\gamma^{(*)}+p\to K^+ +\Lambda$ and $\gamma^{(*)}+p\to K^+ +\Sigma$ reactions through the exchange of only two trajectories in the $t$ channel: $K$ and $K^*$. The coupling constants at the $[K,(\Lambda,\Sigma),N]$ and $[K^*,(\Lambda,\Sigma),N]$ vertices were derived and fitted from the photoproduction study [4,5] where all existing high energy data could be satisfactorily described:

$$g_{K\Lambda N}=-11.54, \quad g_{K^*\Lambda N}=-23.0, \quad \kappa_{K^*\Lambda N}=2.5,$$

$$g_{K\Sigma N}=4.48, \quad g_{K^*\Sigma N}=-25.0, \quad \kappa_{K^*\Sigma N}=-1.0. \qquad (1)$$

In the electroproduction case, the other parameters of the model are the two (squared) mass scales of the monopole form factors at the $\gamma, K, (K, K^*)$ vertices, both of which were taken equal to 1.5 GeV$^2$ [7] in order to fit the high $Q^2$ behavior of the data.

Finally, let us recall that one essential feature of the model is the way gauge invariance is restored for the $t$-channel $K$ exchange by proper "Reggeization" of the $s$-channel nucleon pole contribution. As detailed further below, this is the key element to describe the slow decrease with $Q^2$ of the $R=\sigma_L/\sigma_T$ ratio for the $K^+\Lambda$ channel, a feature which was found to be difficult to accommodate in all other approaches.

These data, first published in Ref. [12], have actually been recently reanalyzed [13] by the JLab Collaboration E93018. We compare in Fig. 1 the Regge model predictions [7] with these new $Q^2$ dependence for the experimental transverse $(\sigma_T)$ and longitudinal $(\sigma_L)$ cross sections, along with their ratio $R$, for both the $\Lambda$ and $\Sigma$ channels. The corrections due to the new analysis are non-negligible for the absolute values of the longitudinal and transverse cross sections and affect significantly the slopes of the $Q^2$ dependences. Our (unchanged) model gives now a much better description of $\sigma_L$ but it significantly underestimates $\sigma_T$ at large $Q^2$ for both channels. However, the ratio $R$ is still very well reproduced and displays a slow decrease as $Q^2$ increases.

The curves in the lower panels of Fig. 1 illustrate that the origin of the decrease with $Q^2$ of the ratio $R$ is actually not, so much, the result of the Regge treatment of the $K$ and $K^*$ $t$-channel propagators but, rather, as mentioned before, of the particular way gauge invariance is restored (i.e., by Reggeizing the nucleon $s$-channel and kaon $t$-channel diagrams and assigning to them the *same* electromagnetic form factor). The Reggeization is nevertheless necessary to ensure a correct normalization of $\sigma_T$ and $\sigma_L$ as standard Feynman propagators would produce cross sections higher by factors of 2–5 at these energies.

A better agreement with these new data could certainly be achieved by changing the values of the $K$ and $K^*$ form factor mass scales but this would destroy the nice agreement with the other kaon electroproduction data [14–20], for which $W>2.1$ GeV and which are presented in Ref. [7]. We prefer to interpret this discrepancy as room for potential additional processes at these lower energies ($W$=1.84 GeV), such as $s$-channel resonances. Indeed, it has already been observed

 

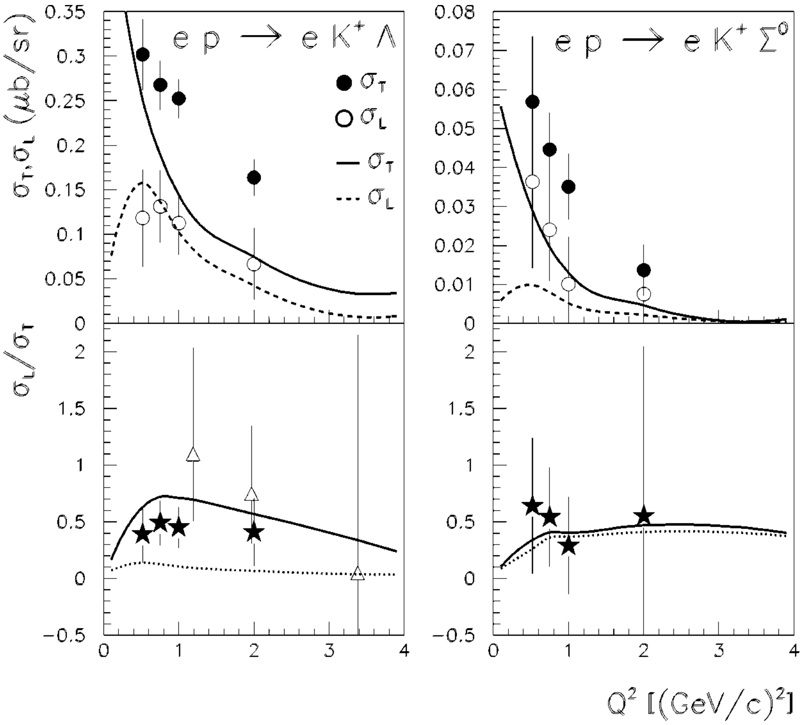


FIG. 1. $Q^2$ dependence of the forward ($\theta_K^{\mathrm{c.m.}}=0$) $\sigma_T$ and $\sigma_L$ (upper panels) and of their ratio $R=\sigma_L/\sigma_T$ (lower panels) for the $\gamma^*+p\rightarrow K^++\Lambda$ reaction (left panels) and $\gamma^*+p\rightarrow K^++\Sigma$ reaction (right panels), at $W=1.84$ GeV. Experimental data points are from Refs. [13] (•, ∘, ⋆) and [14] (△). For the lower panels, the full curve is the model with Reggeized $K$ and $K^*$ $t$-channel exchanges, whereas the dotted curve has standard Feynman poles for the $K$ and $K^*$ propagators.

that the well known nucleon resonances have larger transverse photocouplings than longitudinal ones [21,22].

Figure 2 shows the $Q^2$ dependence of the $\Sigma/\Lambda$ ratio for both transverse and longitudinal cross sections. Again, a good agreement with the data is found without any additional refitting of the parameters of the model. In our $t$-channel approach, only the kaon exchange contributes to $\sigma_L$ (such as

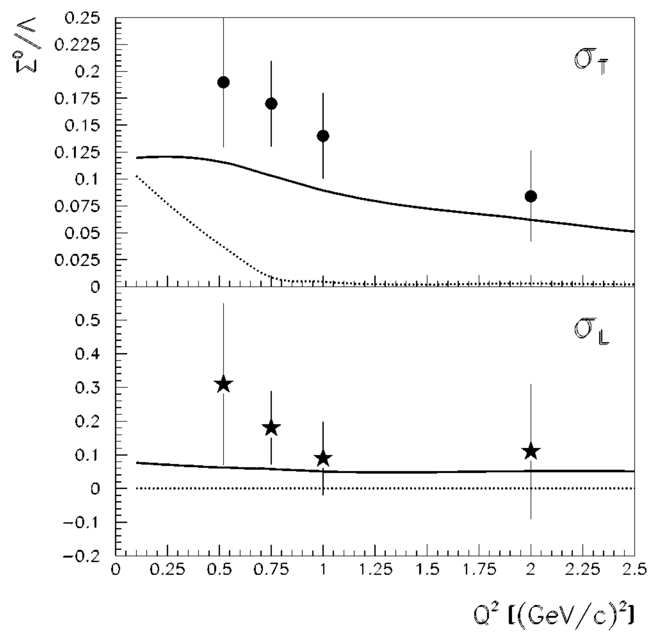


FIG. 2. $Q^2$ dependence of the ratio of the $\gamma^*+p\rightarrow K^++\Sigma$ to the $\gamma^*+p\rightarrow K^++\Lambda$ forward ($\theta_K^{\mathrm{c.m.}}=0$) differential cross sections at $W=1.84$ GeV. Upper panel, transverse cross section; lower panel, longitudinal cross section. Full curve, $K+K^*$ exchanges; dotted curve, only $K^*$ exchange. Experimental data points are from Ref. [13].

for the pion form factor in pion electroproduction, the best way to access the kaon form factor at intermediate and large $Q^2$ is to isolate $\sigma_L$, as it is mostly insensitive to $K^*$ exchange). This is why the $\Sigma/\Lambda$ ratio for $\sigma_L$ is basically constant in our model. However, for the transverse part of the cross section, $K$ and $K^*$ contribute with different weights for the $\Lambda$ and $\Sigma^0$ channels and, therefore, the $\Sigma/\Lambda$ ratio is no longer constant for $\sigma_T$.

Figure 3 displays the photoproduction data with, in particular, the latest results from the JLab/CLAS Collaboration [23] which are about 20–25 % above the previous Bonn/Saphir data [24]. For the $\Lambda$ channel, there are structures in the experimental data ("bumps" around $W\approx1.75$ GeV and 1.95 GeV) which hint towards $s$-channel resonance excitations and which our model can obviously not reproduce as it is purely a $t$-channel model; however, the JLab experimental data (for the forward angles) lies now, on average, very close to the Regge model, unchanged from Refs. [4,5]. This supports, at the 10–15 % level and for this channel, the concept of a global duality between the sum of all $t$-channel exchanges and all $s$-channel excitations.

As for the $\Sigma^0$ channel, the Bonn/Saphir data [24] largely exceed the calculation of our model. The data point to a prominent $s$-channel resonance structure around $W\approx1.9$ GeV. It would be interesting to explore the kinematical region $W>2.1$ GeV to see if our model overestimates the experimental data which would therefore make up for the underestimation of our model in the $W<2.1$ GeV and which would restore, on average, the duality idea. This high energy domain can be explored by the JLab CLAS Collaboration up to $E_\gamma\approx6$ GeV(W$\approx$3.5 GeV).

The $K^0\Sigma^+$ channel can be calculated in a straightforward way, without any additional parameter by taking into account only the $K^{0*}$ $t$-channel exchange (as a real photon cannot elastically couple to the neutral spinless $K^0$) and using

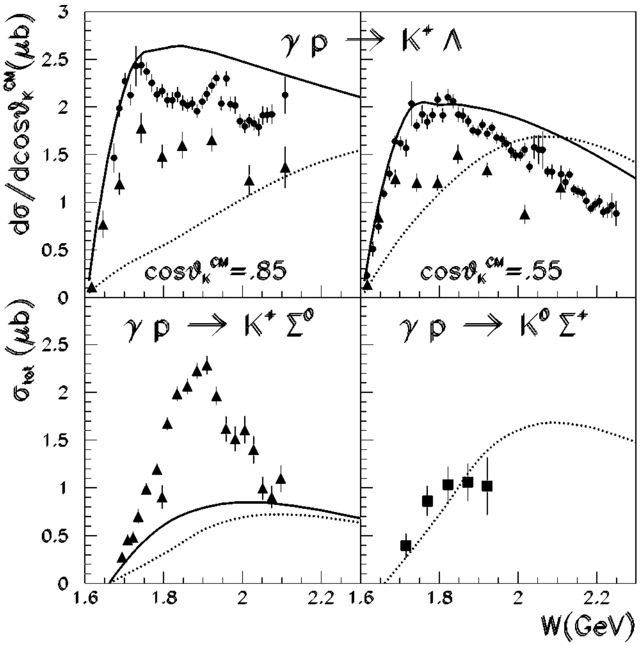


FIG. 3. $W$ dependence of the $\gamma+p\to K^{+}+\Lambda$ *differential* cross section at $\cos(\theta_K^{\mathrm{c.m.}})\approx 0.85$ and $\cos(\theta_K^{\mathrm{c.m.}})\approx 0.55$ (left and right upper panels respectively) and of the $\gamma+p\to K^{+}+\Sigma$ and $\gamma+p\to K^{0}+\Sigma^{+}$ *total* cross sections (left and right lower panels respectively). Full curve: $K$+$K^*$ exchanges; dotted curve: only $K^*$ exchange. Experimental data points are from Refs. [23] (circles), [24] (triangles), and [25] (squares).

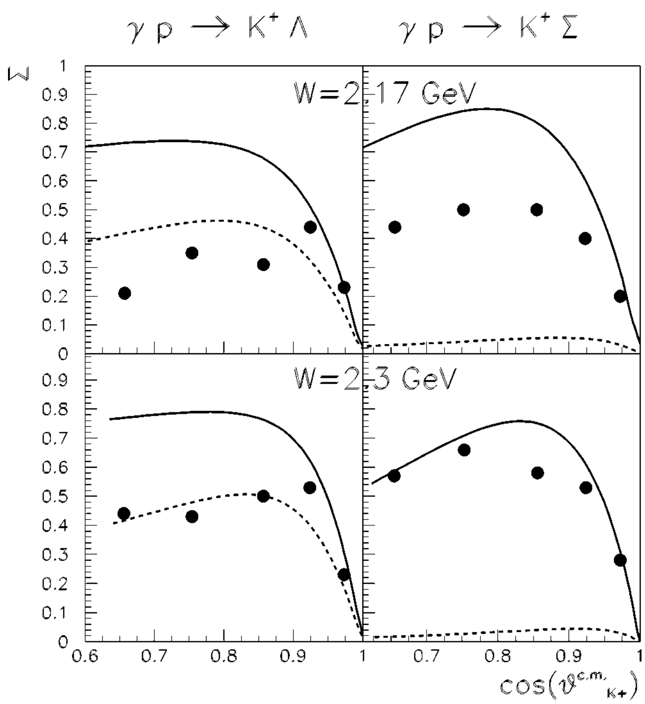


FIG. 4. $\cos(\theta_{K^+}^{\mathrm{c.m.}})$ dependence of the photon asymmetry for the $\gamma+p\to K^{+}+\Lambda$ (left) and $\gamma^{*}+p\to K^{+}+\Sigma$ (right) processes at $W=2.17$ GeV (or $E_\gamma=2.05$ GeV) and $W=2.3$ GeV (or $E_\gamma=2.35$ GeV). Experimental data points are from Ref. [26]. Full curve, $K$+$K^*$ exchanges; dashed curve, $K$ exchange.

$$g^2_{\gamma K^0 K^{*0}} = g^2_{\gamma K^+ K^{*+}}\Gamma_{K^{*0}\to\gamma K^0}/\Gamma_{K^{*+}\to\gamma K^+} \approx 2.3 g^2_{\gamma K^+ K^{*+}} \quad (2)$$

with the radiative widths taken from Ref. [21]. Figure 3 shows a very nice agreement between our calculation and the Bonn/Saphir data of Ref. [25] which can be interpreted as an absence of $s$-channel excitation in this channel (which brings a constraint on the isospin of the *hinted* resonance around $W\approx 1.9$ GeV decaying into the $\Sigma^0$ channel). If the $\Sigma^+$ channel is indeed produced by pure $t$-channel exchange, these data provide us with a strong constraint (and in our case, a nice confirmation) of the strength of the $K^*$ exchange, which is the only allowed leading Regge trajectory and whose coupling constants have been derived independently [5].

Turning now to polarization observables, Fig. 4 shows the photon asymmetry recently measured by the Spring-8 Collaboration at the LEPS facility [26] in photoproduction for both $\Lambda$ and $\Sigma$ channels. The general trend of the data is reproduced by the model, in particular, the sharp rise of the beam asymmetry at very forward angles (indication of the dominance of the natural parity $K^*$ exchange). At smaller center of mass energies and larger angles, the discrepancies between theory and data become more pronounced. This should not come as a surprise as the Regge theory is essentially valid at high energies and forward angles. It is nevertheless certainly of great interest to probe the limits of this model through such data. Let us also remind that the Regge

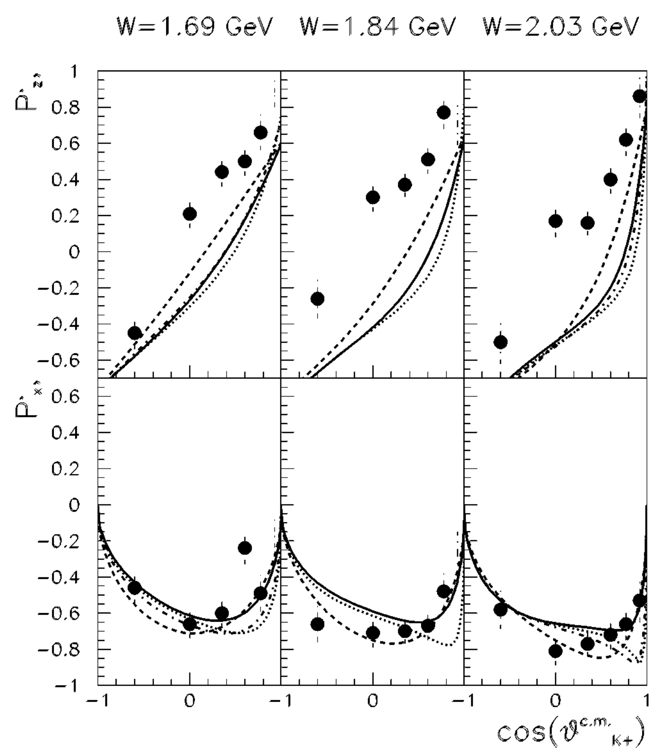


FIG. 5. $\cos\theta_{K^+}^{\mathrm{c.m.}}$ dependence of the transferred $\Lambda$ polarization in $e+p\to e'+K^{+}+\Lambda$ (left) for $E_e=2.5$ GeV and $\langle Q^2\rangle=0.8$ GeV$^2$. Full curve: $K$+$K^*$ Reggeized exchange. Dashed curve: $K$ Reggeized exchange. Dotted curve: $K^*$ Reggeized exchange. Dash-dotted curve: $K$+$K^*$ standard Feynman pole exchange. Experimental data points are from Ref. [27].

model describes well at forward angles the magnitude and the sign of the $\Lambda$ and $\Sigma$ recoil polarizations [7].

An electroproduction experiment at JLab [27] has measured for the first time the transferred polarization from a longitudinally polarized beam to the $\Lambda$ recoil hyperon in the exclusive reaction $e+p\rightarrow e'+K^{+}+\Lambda$. We show in Fig. 5 the only two transferred polarization components $P'_{x'}$ and $P'_{z'}$,[1] which are nonzero when integrated over $\Phi$, the azimuthal angle between the leptonic and the hadronic planes. The longitudinal spin transfer component $P'_{z'}$ is well reproduced at the very forward angles. The sideways component spin transfer component $P'_{x'}$ is well reproduced over the full angular range.

We have plotted, along with the standard $K+K^*$ Reggeized exchanges which constitute our full model, the individual contributions of the Reggeized $K$ and $K^*$ exchanges. We also show the calculation carried out with standard Feynman propagators of the type $1/(t-m^2_{(K,K^*)})$, instead of Regge propagators of the type $s^{\alpha(K,K^*)(t)}$. It can be seen that these observables are actually barely sensitive to these variations and that basically any model based on $K$ and/or $K^*$ $t$-channel exchange, whatever is the chosen prescription (Feynman- or Regge-type pole), gives a decent description of the data. However, it should be noted that, when introducing $s$-channel resonance processes (see, for instance, the isobaric models cited in Ref. [27]), such double polarization observables are very sensitive to resonance properties and allow one to discriminate rather precisely between various sets of nucleon resonances participating in the reaction.

In summary, the latest experimental results released in the domain of open strangeness electromagnetic production on the nucleon confirm that our "simple" Regge model surprisingly reproduces the gross features of the data, even for $W<2$ GeV. It thus provides an economical description and a simple explanation of the data, hinting that a sort of reggeon-resonance duality is at work here; where it fails, it gives a useful hint that mechanisms other than simple $t$-channel mechanisms are necessary. In the difficult task of putting into evidence new nucleon resonances in the strangeness channel which are overlapping or hidden into large backgrounds, this sort of clue, i.e., the contribution of nonresonant $t$-channel and Born mechanisms, is certainly much needed.

This work was supported in part by the French CNRS/IN2P3, the French Commissariat à l'Energie Atomique, the Deutsche Forschungsgemeinschaft (Grant No. SFB443), and the European Commission IHP program (Contract No. HPRN-CT-2000-00130).

[1] $x'$ and $y'$ refer to the Cartesian coordinates in the $\gamma^*$-$p$ center of mass frame with the $z$ axis along the direction of the produced kaon.

[1] T. Regge, Nuovo Cimento **14**, 951 (1959).
[2] T. Regge, Nuovo Cimento **18**, 947 (1960).
[3] J. K. Storrow, Phys. Rep. **103**, 317 (1984).
[4] M. Guidal, J.-M. Laget, and M. Vanderhaeghen, Phys. Lett. B **400**, 6 (1997).
[5] M. Guidal, J.-M. Laget, and M. Vanderhaeghen, Nucl. Phys. **A627**, 645 (1997).
[6] M. Guidal, J.-M. Laget, and M. Vanderhaeghen, Phys. Rev. C **57**, 1454 (1998).
[7] M. Guidal, J.-M. Laget, and M. Vanderhaeghen, Phys. Rev. C **61**, 025204 (2000).
[8] J.-M. Laget, Phys. Lett. B **489**, 313 (2000).
[9] F. Cano and J.-M. Laget, Phys. Lett. B **551**, 317 (2003).
[10] W.-T. Chiang, S. N. Yang, L. Tiator, M. Vanderhaeghen, and D. Drechsel, Phys. Rev. C **68**, 045202 (2003).
[11] R. Dolen, D. Horn, and C. Schmidt, Phys. Rev. **166**, 1768 (1968).
[12] G. Niculescu *et al.*, Phys. Rev. Lett. **81**, 1805 (1998).
[13] R. M. Mohring *et al.*, Phys. Rev. C **67**, 055205 (2003).
[14] C. J. Bebek, C. N. Brown, R. V. Kline, F. M. Pipkin, S. W. Raither, L. K. Sisterson, A. Browman, K. M. Hanson, D. Larson, and A. Silverman, Phys. Rev. D **15**, 3082 (1977).
[15] P. Brauel, T. Canzler, D. Cords, R. Felst, G. Grindhammer, M. Helm, W.-D. Kollmann, H. Krehbiel, and M. Schädlich, Z. Phys. C **3**, 101 (1979).
[16] P. Feller, D. Menze, U. Opara, W. Schulz, and W. J. Schwille, Nucl. Phys. **39**, 413 (1972).
[17] C. J. Bebek, C. N. Brown, P. Bucksbaum, M. Herzlinger, S. D. Holmes, C. A. Lichtenstein, F. M. Pipkin, S. W. Raither, and L. K. Sisterson, Phys. Rev. D **15**, 594 (1977).
[18] T. Azemoon, I. Dammann, C. Driver, D. Lüke, G. Specht, K. Heinloth, H. Ackermann, E. Ganssauge, F. Janata, and D. Schmidt, Nucl. Phys. **B95**, 77 (1975).
[19] C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, and F. M. Pipkin, Phys. Rev. Lett. **28**, 1086 (1972).
[20] C. J. Bebek *et al.*, Phys. Rev. Lett. **32**, 21 (1974).
[21] Particle Data Group, K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002).
[22] V. Burkert *et al.*, Phys. Rev. C **67**, 035204 (2003).
[23] J. W. C. McNabb *et al.*, nucl-ex/0305028.
[24] M. Q. Tran *et al.*, Phys. Lett. B **445**, 20 (1998).
[25] S. Goers *et al.*, Phys. Lett. B **464**, 331 (1999).
[26] R. G. T. Zegers *et al.*, Phys. Rev. Lett. **91**, 092001 (2003).
[27] D. Carman *et al.*, Phys. Rev. Lett. **90**, 131804 (2003).