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Meson cloud and nucleon strangeness: An update

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Abstract. We use a version of the meson cloud model, including kaon, κ and K^* contributions, to estimate the electric and magnetic strange form factors of the nucleon. We compare our results with the recent measurements of the strange-quark contribution to parity-violating asymmetries in electron-proton scattering experiments.

PACS. 14.20.Dh Protons and neutrons – 12.40.-y Other models for strong interactions – 24.85.+p Quarks, gluons, and QCD in nuclei and nuclear processes

The strange component of the nucleon sea has been intensely investigated in the last years and there are new experimental and theoretical results. On the experimental side we have the low-energy parity-violating experiments carried out at TJNAF, where it was possible to measure the strange electric and magnetic form factors of the nucleon. The first measurements of these quantities (and combinations of them) were performed by the SAMPLE [1] and HAPPEX [2] Collaborations at TJNAF. The very recent results from SAMPLE [3], HAPPEX [4], A4 (at MAMI) [5] and G0 [6] Collaborations, provide information on the nucleon strange vector form factors over the range of momentum transfers $0.12 \leq Q^2 \leq 1.0\,\mathrm{GeV}^2$. The data indicate non-trivial, Q^2-dependent, strange-quark distributions inside the nucleon, and present a challenge to models of the nucleon structure.

On the theoretical side, there were new lattice QCD calculations of the strange magnetic [7] and electric [8] form factors. There are discrepancies between theory and experiment which deserve further investigation. For example, the measured strange magnetic moment is positive, whereas the lattice calculations point to a negative value. In this context, a further theoretical insight on the problem might come from chiral perturbation theory. Unfortunately, as it was shown in [9], in ChPT the matrix elements of the strangeness current depend on a new low-energy constant, which cannot be determined from fitting other data. Thus, for the observables discussed here, ChPT has no predictive power.

In the low-energy regime the strange component of the nucleon sea is expected to have a nonperturbative origin. One of the possible nonperturbative mechanisms of strangeness production is given by the meson cloud [10]. In this model the physical nucleon contains virtual meson-baryon components, which "dress" the bare nucleon. The meson cloud mechanism provides a natural explanation for symmetry breaking in parton distributions [11]. Already in the first kaon-cloud models the nucleon strangeness distribution was generated by fluctuations of the "bare" nucleon into kaon-hyperon intermediate states which were described by the corresponding one-loop Feynman graphs [12]. Since then, some concerns have been raised in the literature regarding the implementation of the loop model of the nucleon. In particular, regarding the omission of contributions from higher-lying intermediate states in the meson-hyperon fluctuations [13,14]. While the effects of heavier hyperons, such as the Σ^*, have been shown to be negligible [14], the contribution of the K^*-Y pairs were found to be large [13]. Nevertheless, the results of [15] pointed to a "slow convergence" of the intermediate-state sum.

In view of the recent data mentioned above we think that it is interesting to update our previous calculations of the strange form factors with the meson cloud model. In a recent work [16] we have computed the momentum dependence of the strange vector form factors in the loop model at momentum transfers $0 \leq Q^2 \leq 3\,\mathrm{GeV}^2$ and compared our results with the measurements from the G0 Collaboration [6]. In the present work we extend our previous calculation, including, for the first time, the recently observed [17] strange scalar meson, κ, in the cloud and analyze new data on the strange form factors.

The nucleon matrix element of the strangeness current is parametrized by two invariant amplitudes, the Dirac and Pauli strangeness form factors $F_{1,2}^{(s)}$:

$$\langle N|\bar{s}\gamma_\mu s|N\rangle = \bar{U}\left[F_1^{(s)}(Q^2)\gamma_\mu + i\frac{\sigma_{\mu\nu}q^\nu}{2m_N}F_2^{(s)}(Q^2)\right]U\,, \tag{1}$$

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where $U(p)$ denotes the nucleon spinor and $F_1^{(s)}(0) = 0$, due to the absence of an overall strangeness charge of the nucleon. The electric and magnetic form factors are defined through $G_E^{(s)}(Q^2) = F_1^{(s)}(Q^2) - \frac{Q^2}{4m_N^2} F_2^{(s)}(Q^2)$ and $G_M^{(s)}(Q^2) = F_1^{(s)}(Q^2) + F_2^{(s)}(Q^2)$.

We consider a hadronic one-loop model containing K, K^* and κ mesons as the dynamical framework for the calculation of these form factors. This model is based on the meson-baryon effective Lagrangians

$$\mathcal{L}_{KB} = -g_{ps}\bar{B}i\gamma_5 BK, \tag{2}$$

$$\mathcal{L}_{K^*B} = -g_v\left[\bar{B}\gamma_\alpha BK^{*\alpha} - \frac{\kappa_{tv}}{2m_N}\bar{B}\sigma_{\alpha\beta}B\partial^\alpha K^{*\beta}\right], \tag{3}$$

$$\mathcal{L}_{\kappa\mathcal{B}} = -g_s\bar{B}B\kappa\,, \tag{4}$$

where B $(= N, \Lambda, \Sigma)$, K, $K^{*\alpha}$ and κ are the baryon, kaon, K^* (vector meson) and the strange scalar meson, respectively. In the above expression $m_N = 939\,\mathrm{MeV}$ is the nucleon mass and κ_{tv} is the ratio of tensor to vector coupling, $\kappa_{tv} = g_t/g_v$. In order to account for the finite extent of the above vertices, the model includes form factors from the Nijmegen NY potential [18] at the hadronic KNY and K^*NY $(Y = \Lambda, \Sigma)$ vertices, which have the monopole form

$$F(k^2) = \frac{m_M^2 - \Lambda_M^2}{k^2 - \Lambda_M^2} \tag{5}$$

with meson momenta k and the physical meson masses $m_K = 495\,\mathrm{MeV}$, $m_{K^*} = 895\,\mathrm{MeV}$ and $m_\kappa = 800\,\mathrm{MeV}$.

Since the nonlocality of the meson-baryon form factors (5) gives rise to vertex currents, gauge invariance was maintained in [13] by introducing the photon field via minimal substitution in the momentum variable k [19]. The resulting nonlocal seagull vertices are given explicitly in [13,15].

The diagonal couplings of $\bar{s}\gamma_\mu s$ to the strange mesons and baryons in the intermediate states are straightforwardly determined by current conservation, *i.e.* they are given by the net strangeness charge of the corresponding hadron. The nondiagonal (*i.e.* spin-flipping) couplings of the strange current in the vertices γ-K-K^* and γ-κ-K^* have been discussed in [13] and, more recently, in [20]. The other couplings in the effective Lagrangians are taken from the Nijmegen NY potential [18]: $g_{ps}/\sqrt{4\pi} = -4.005$, $g_v/\sqrt{4\pi} = -1.45$, $g_s = -10.0$, $\kappa_{tv} = 2.43$. In phenomenological potential models, as the Nijmegen [18] or Bonn-Jülich [21], the couplings and cut-off parameters are determined simultaneously. In fact, some coupling constants may be calculated with QCD sum rules, as, for example, in [22], where a smaller value of g_{ps} was found. In our numerical analysis, we shall fix the couplings to the numbers given above but we shall vary all the cut-off parameters in the interval $0.9\,\mathrm{GeV} \le \Lambda \le 1.1\,\mathrm{GeV}$, which encompasses the numbers obtained in refs. [18] and [21]. After some calculations we discovered that the contribution from κ to all the observables considered here tends to cancel the contribution of K and K^*, which add together. Since increasing the cut-off leads to an enhancement in the contribution of the corresponding meson, there are two extreme

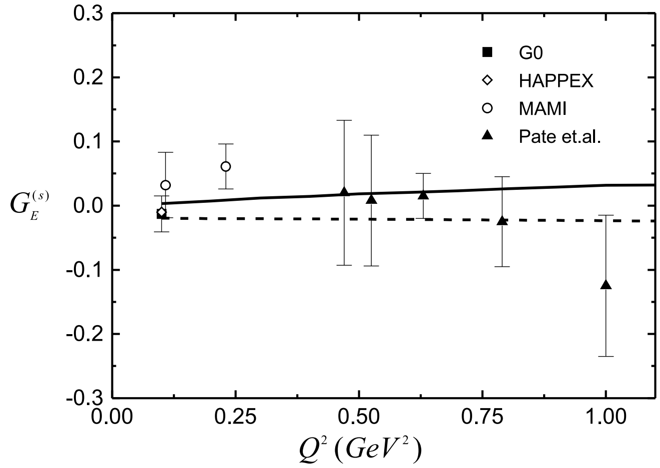

Fig. 1. The strange electric form factor G_E^s. The solid line shows our results with $\Lambda_K = \Lambda_{K^*} = 0.9\,\mathrm{GeV}$ and $\Lambda_\kappa = 1.1\,\mathrm{GeV}$. The dashed line represents the choice $\Lambda_K = \Lambda_{K^*} = 1.1\,\mathrm{GeV}$ and $\Lambda_\kappa = 0.9\,\mathrm{GeV}$.

choices: I) $\Lambda_K = \Lambda_{K^*} = 0.9\,\mathrm{GeV}$ and $\Lambda_\kappa = 1.1\,\mathrm{GeV}$ and II) $\Lambda_K = \Lambda_{K^*} = 1.1\,\mathrm{GeV}$ and $\Lambda_\kappa = 0.9\,\mathrm{GeV}$. The first one maximizes the role played by κ, whereas the last one maximizes the joint contribution of K and K^*.

In fig. 1 we show the strange electric form factor G_E^s obtained with the loop model obtained by using choice I (solid line) and choice II (dashed line). Our final result for G_E^s is the area between these two "boundary" lines, since we cannot be more precise about the value of the Λ's. We see that the agreement with data points from refs. [4–6] and also from ref. [23] is reasonable.

One should keep in mind that the cut-off value $\Lambda_{K^*} = 0.9\,\mathrm{GeV}$, is very close to the K^* mass. As a consequence, for this cut-off value the contributions from the K^* and the K/K^* and κ/K^* transitions are completely negligible relative to the kaon contribution. Using a bigger value for Λ_{K^*} makes the agreement with data worse. It is interesting to observe that the authors of [20], studying K^* photoproduction with a meson exchange model with the same Nijmegen form factors reached the same conclusion!

In fig. 2 we show the strange magnetic form factor G_M^s obtained with the loop model using choice I (solid line) and choice II (dashed line). Our final result for G_M^s is the area between these two lines. We see that the agreement with data points from refs. [4–6,23] is acceptable when the κ component is large but is very poor when it is small. In any case, however, our model cannot reproduce the strange magnetic moment $G_M^s(0)$. In order to have a better idea of the role played by the meson κ, in fig. 3 we replot the solid line of fig. 2 splitting it into its components given by the κ contribution (dashed line) and the $K+K^*$ contribution (dotted line). We clearly see that the inclusion of κ in the calculation compensates the $K+K^*$ contribution and improves the agreement with data.

In summary, we have calculated the electric and magnetic strange form factors of the nucleon with a version of the meson cloud model, which includes kaon, κ and K^* contributions. In contrast to other situations, in the

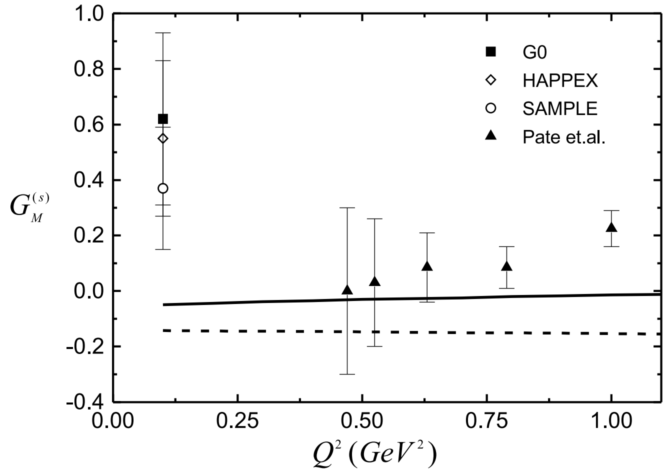

Fig. 2. The strange magnetic form factor G_M^s. The solid line shows our results with $\Lambda_K = \Lambda_{K^*} = 0.9\,\text{GeV}$ and $\Lambda_\kappa = 1.1\,\text{GeV}$. The dashed line represents the choice $\Lambda_K = \Lambda_{K^*} = 1.1\,\text{GeV}$ and $\Lambda_\kappa = 0.9\,\text{GeV}$.

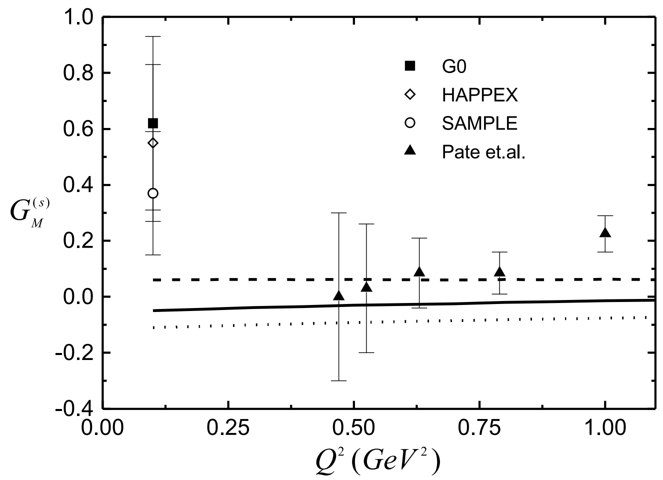

Fig. 3. The dashed (dotted) line shows the contribution of κ $(K + K^*)$ to the strange magnetic form factor G_M^s. The solid line shows the sum, which also corresponds to the solid line of fig. 2.

present case the K^* contribution did not cancel the kaon contribution. The κ contribution gives opposite results to the other strange mesons and improves the description of data.

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