On the Kaon' $\bar{s}$ structure function from the strangeness asymmetry in the nucleon

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Abstract. We propose a phenomenological approach based in the meson cloud model to obtain the strange quark structure function inside a kaon, considering the strange quark asymmetry inside the nucleon.

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The experimental data from CCFR and NuTeV collaborations [1] show that the distribution function for strange and anti-strange quark are asymmetric. If we consider only gluon splitting processes, such asymmetry cannot be found, since the quarks generated by gluons should have the same momentum distribution. So, among the models that have been proposed (or considered) to explain the asymmetry, the most popular are based on meson clouds or Λ - K fluctuations [2, 3]. By using this kind of model, we analyze the behavior of some parameterizations for the strange quark distribution $s(x)$, in terms of the Bjorken scale x, and discuss how to estimate the structure function for a constituent quark in a Kaon.

The strange quark distribution in the nucleon sea, as well as the distribution for u and d quarks, can be separated into perturbative and nonperturbative parts. The perturbative part, due to short range fluctuations of the gluon field, cannot contribute to the $s - \bar{s}$ asymmetry. So, the observed asymmetry is expected to result from nonperturbative processes, such as a meson-baryon configuration. In the meson-baryon configuration, there are processes where the nucleon oscillates to a baryon plus a meson, such as,

$$p(uud) \rightarrow \Lambda(uds) + K(u\bar{s}).$$

For instance, the contribution to strange quark distribution comes from the valence s quark in the Λ and the $\bar{s}$ in the kaon. The phenomenological approach we consider here is the same one used in Ref. [4] to explain the $\bar{u} - \bar{d}$ behavior. Instead of π^+ or π^0, we have K^+ or K^0. The formalism is explained in the following. As in [5] we describe the meson composed by a valence quark surrounded by a cloud of partons that is locally colorless and electrically neutral. But the cloud contains some of momentum of the constituent quark. So, the quark in our model have effective degrees of freedom with substructure. The structure function of the constituent quark/antiquark can be extracted

from the Kaon (pion) structure function, assuming that its asymptotic form is dominated by the kaon (pion) light-front wave function. The asymptotic form of the wave function for a massless kaon implies in a constant probability for the valence quark to have a given momentum fraction (see Ref.[5]). The valence distribution of an antiquark $\bar{q}$ inside a meson M can be written as

$$v_{\bar{q}}^M(x, Q^2) = \int_x^1 \frac{dy}{y} P(y, Q^2) F_{q\bar{q}}^M(\frac{x}{y}),$$
(1)

where $F_{q\bar{q}}^M(x)$ is the meson (kaon or pion) structure function for constituent quarks (a bound quark, obtained from the valence wave function, as in [5]). $P(x)$ is the momentum distribution of the valence current quark in the constituent quark. So, we define the valence distribution of antiquark $\bar{s}$ inside the kaon by

$$v_{\bar{s}}^K(x, Q^2) = \int_x^1 \frac{dy}{y} P_{\bar{s}}(y, Q^2) F_{q\bar{s}}^K(\frac{x}{y}),$$
(2)

where q is the $u-$quark for K^+ and $d-$quark for the K^-. Assuming $F_{q\bar{q}}^K(x) = 1$ for the asymptotic form of the valence wave function,

$$v_{\bar{s}}^K(x, Q^2) = \int_x^1 \frac{dy}{y} P_{\bar{s}}(y, Q^2),$$
(3)

and deriving in x, one gets

$$P_{\bar{s}}(x, Q^2) = -x \frac{\partial}{\partial x} v_{\bar{s}}^K(x, Q^2).$$
(4)

The structure function in the nucleon, from the constituent substructure, is given by

$$\bar{q}_{const}(x) = -\int_x^1 \frac{\partial}{\partial z} v^K(z, Q^2)|_{z=x/y} \bar{q}(y) dy,$$
(5)

where $\bar{q}(y)$ inside the integral is a given quark structure function (in this case, for a strange anti-quark). The quark structure function may come from the gluon splitting process, from a parametrization or from another model.

In the proposed model, we need an information about the initial $\bar{s}(x)$ distribution, that we will suppose to be equal the initial $s(x)$, which is a symmetric distribution that comes from the gluon splitting. After the convolution in eq. (5) we obtain a different $\bar{s}(x)$ distribution, that will be $\bar{s}_{const}(x)$. On the other hand, we need an information about the valence quark distribution in the kaon. Hence, using the present formalism, we may isolate the function for the valence quark in the kaon in such a way that

$$\bar{s}_{const}(x) = -\int_x^1 \frac{\partial v_{\bar{s}}^K(z)}{\partial z}|_{z=x/y} \bar{s}(y) dy.$$
(6)

On the other hand,

$$\bar{s}_{const}(x) = -\int_x^1 \frac{d\bar{s}_{const}(y)}{dy} dy$$
(7)

TABLE 1. The coefficients of the "standard fit"

B fit	A_0	A_1	A_2	A_3	A_4	A_5
$s+\bar{s}$	0.04966	0.03510	7.44149	-1.44570	5.13400	0.59659
$s-\bar{s}$	-0.08438	0.18803	2.36708	0.04590	0.0000	0.0000

will give us the equation

$$\int_x^1 \frac{\partial v_{\bar{s}}^K(z)}{\partial z}\Big|_{z=x/y} \bar{s}(y) dy = \int_x^1 \frac{d\bar{s}_{const}(y)}{dy} dy. \tag{8}$$

By working with partial derivatives on the left-hand side of the above equation, we obtain

$$\int_x^1 \left[\frac{-y^2}{x} \frac{\partial v_{\bar{s}}^K(x/y)}{\partial y} \bar{s}(y) - \frac{d\bar{s}_{const}(y)}{dy} \right] dy = 0. \tag{9}$$

From the above, the function $v_{\bar{s}}^K(x)$, the anti-strange structure function in the Kaon, can be extracted numerically.

As described above, some information on the strange (and anti-strange) distribution, as measured in the nucleon, are needed, beside the initial input of the distribution, which is supposed to be symmetric. This initial distribution may come from the gluon splitting processes, a statistical model and some parameterization. With these information, it is possible to isolate the anti-strange valence quark function in the kaon. We performed two test of the model, as explained in the following.

Using the parametrization presented by Olness et al. [6], we isolate $s_{const}(x)$ and $\bar{s}_{const}(x)$ from the $s - \bar{s}$ and $s + \bar{s}$ parameterizations. In order to apply the model, we introduce $s_{const}(x)$ and $\bar{s}_{const}(x)$ in (8) and calculate the structure function of the strange anti-quark in the Kaon. The important point here is the approach to the initial $\bar{s}(x)$ distribution, that we use, $\bar{s}(x) = s_{const}(x)$, that is, we suppose that $s(x)$ keeps a distribution quite similar to the original one obtained from the gluon splitting processes which generate the $s\bar{s}$ pairs. The numerical values of the parameterization are given in Table 1. With the fitting expressions for $s^+(x) = [s(x) \pm \bar{s}(x)][6]$

$$
\begin{aligned}
xs^+(x) &= A_0 x^{A_1}(1-x)^{A_2} e^{A_3 x}(1+e^{A_4})^{A_5} \\
s^-(x) &= s^+(x) \times \tanh\left[A_0 x^{A_1}(1-x)^{A_2}\left(1-\frac{x}{A_3}\right)(1+A_4 x + A_5 x^2)\right],
\end{aligned}
\tag{10}
$$

we can isolate $s(x)$ and $\bar{s}(x)$ using the values given in Table 1.

The momentum distribution shows that, in the Kaon, the anti-strange quark carries the main fraction of the total momentum. This may be a consequence of bigger mass of the $\bar{s}$ in comparison with the u and d quark masses.

In the work of Dahiya and Gupta[7], no strangeness asymmetry in the constituent quarks is assumed. They have used the strangeness distribution function

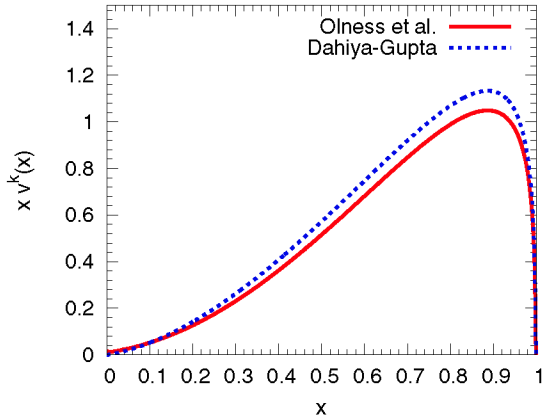$$s(x) = \frac{a}{3}\left[(\varsigma - \beta)^2 + 9\alpha^2\right](1-x)^8 \tag{11}$$

FIGURE 1. The strange anti-quark distribution in the kaon, using the present approach with initial parameterizations of Olness et al. [6] (solid-line) and Dahyia-Gupta [7] (dashed-line).

with $a = 0.13$, $\alpha = \beta = 0.45$ and $\varsigma = 0.10$. In this case, $\bar{s}$ carries out about 56% of total momentum.

In Figure 1, we show the strange antiquark distribution in the kaon, according to the present model, using the initial parameterizations given by Olness et al.[6] and by Dahyia and Gupta [7]. The result is close to the parameterization for the kaon considered in Ref. [8].

In conclusion, we report an approach to estimate the structure function for an constituent quark inside a meson, considering specifically the case of an antiquark strange in the kaon. From our results, we observe that most of the momentum of a kaon is carried out by the anti-strange quark, due to its larger mass in comparison with the u and d quarks.

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