CBPF-NF-003/98

Strange / anti-strange asymmetry in the nucleon sea

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Abstract

We derive the nucleon sea-quark distributions coming from a meson cloud model, in order to argue for a strange-antistrange asymmetry in the nucleon sea.

Key-words: Meson cloud model; Asymmetric sea; Strangeness.

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Motivation

According to the Quark Parton Model, with its subsequent improvements coming from Quantum Chromodynamics, it is known that hadrons are built up from a fixed number of valence quarks plus a fluctuating number of gluons and sea quark anti-quark pairs. As the momentum scale rises up these are mainly generated perturbatively and in consequence, quarks and anti-quarks have the same probability and momentum distributions inside the hadron. Despite of this, a small fraction of the sea may be associated to non-perturbative processes raising the possibility of generating *unequal* quark and anti-quark distributions, which in the case of the charmed sea could explain recent experimental measurements at Hera by H1 [1] and ZEUS [2] as was discussed in Refs. [3, 4]. Let us mention also that the present status of the experimental data does not exclude the possibility of asymmetric strange / anti-strange sea distributions in the nucleon (see e.g. [5, 6] and Refs. therein).

The question of a nonperturbative asymmetry in the nucleon sea has been addressed by a number of authors. The most significant framework to discuss this issue appears to be the Meson Cloud Model. In this context, it is assumed that the nucleon can fluctuate to a meson-baryon bound state with a small probability. Non-perturbative sea-quark distributions are then associated with the valence quark and anti-quark distributions inside the baryon and the meson respectively [6, 7]. In Ref.[5], intrinsic sea quark and anti-quarks are rearranged with valence quarks using simple two body wave functions so as to form a meson-baryon bound state, thus falling into the meson cloud model. Finally, let us mention the approach of Ref. [8] where the different interactions experienced by the perturbatively generated quark and anti-quark are simulated by giving different masses to each of them. Consequently, different distributions are obtained for sea quark and anti-quarks.

Based on some well established schemes concerning hadronic processes, we propose in turn, a phenomenological approach involving both effective and perturbative calculation which enables a description of the nucleon-meson-baryon vertex. Once meson and baryon densities are derived, we compute the non-perturbative contribution to the strange sea of the nucleon, by means of simple convolution forms.

Strange meson-baryon fluctuation

We start by considering a simple picture for the ground-state of the nucleon as being formed by three dressed valence quarks or *valons* which carry all its momentum, with normalized valon distribution given by [9]

$$v\left(x\right)=\frac{105}{16}\sqrt{x}\left(1-x\right)^{2}. \tag{1}$$

For the sake of simplicity, we will not distinguish between u and d valon densities, so identical momentum distribution will be assumed.

In order to get a sea $q\bar{q}$ pair suitable to produce a fluctuation of the nucleon to a meson-baryon bound state, the simplest next step is to consider that each dressed quark can emit a gluon which before interacting with another valon, decays perturbatively into a quark anti-quark pair. One can then estimate the probability of having such a perturbative $q\bar{q}$ pair using splitting functions à la Altarelli-Parisi [10]

$$P_{gq}(z) = \frac{4}{3}\frac{1+(1-z)^2}{z}, \qquad P_{qg}(z) = \frac{1}{2}\left(z^2+(1-z)^2\right). \tag{2}$$

These are the probability densities respectively associated with the emission of a gluon by a valence quark, and the emission of a $q\bar{q}$ pair by a gluon. Hence,

$$g(x) = \alpha_{strong}\int_x^1 \frac{dy}{y} P_{gq}\left(\frac{x}{y}\right) v(y) \tag{3}$$

is the distribution of a gluon coming out from a valon and

$$q(x) = \bar{q}(x) = \alpha_{strong}\int_{x+a}^1 \frac{dy}{y} P_{qg}\left(\frac{x}{y}\right) g(y) \tag{4}$$

is the joint probability density of obtaining a quark or anti-quark coming from subsequent decays $v \to v + g$ and $g \to q + \bar{q}$.

We have introduced the cut-off a in eq.(4) so as to suppress the divergency at $x = 0$ in the gluon distribution (3). In addition, it is suitable in order to control the flavor to be produced at the $gq\bar{q}$ vertex. By requiring that the sea quark distributions generated by gluon splitting lay below the experimental ones, we need $a = .025$ to get a reasonable initial strange distribution.

So far, this mechanism produce of course just identical q and $\bar{q}$ distributions, thus, no $q/\bar{q}$ asymmetry is present, at this stage, in the nucleon sea.

The next step concerns effective models as it involves non-perturbative soft processes. We shall assume that once the sea quark and anti-quark are created, they can interact with the remaining valons in the nucleon, so as to form the most energetically favored meson-baryon fluctuations which we will describe by means of recombination models. The probability density of having a meson inside the nucleon is thus given by [11]

$$xP_M(x) = \int_0^x dy \int_0^{x-y} dz F(y,z) R(x,y,z) \tag{5}$$

where $F(y,z)$ is the two-quark distribution

$$F(y,z) = \beta\, y v(y)\, z\bar{q}(z)(1-y-z) \tag{6}$$

and $R(x,y,z)$ is the recombination function associated with the in-nucleon meson formation

$$R(y,z) = \alpha \frac{yz}{x^2}\delta\left(1 - \frac{y+z}{x}\right). \tag{7}$$

As we are assuming that the nucleon has indeed fluctuated to a meson-baryon bound state, we shall require that

$$\int_0^1 dx P_M(x) = 1 \tag{8}$$

thus fixing the value of the product $\alpha\beta$. Now, $P_M(x)$ is a well-behaved probability density for a meson with a momentum fraction between x and $x+dx$ inside the splitted nucleon. As for the baryon distribution, the simplest way to fulfill the momentum correlation within the fluctuation, is to assume that it is given by [4]

$$P_B(x) = P_M(1-x) \tag{9}$$

then

$$\int_0^1 dx\,[xP_B(x) + xP_M(x)] = 1 \tag{10}$$

is automatically satisfied as expected. For completeness, we have also computed the baryon probability using a recombination scheme along the lines of ref.[12], but due to proper limitations of the model, eq.(10) is only verified up to a 90%.

In Fig.1 we show our calculated meson and baryon probabilities for the two choices, namely, $P_B(x)$ as given by eq.(9) and recombination, respectively. The obtained hadronic probabilities are alike the meson and baryon distributions given in ref.[4].

Let us stress that with our approach we are able to predict the meson and baryon probability shapes inside the nucleon, whereas in the usual meson cloud model these are directly introduced at the nucleon meson baryon vertex by means of *ad-hoc* hadronic form factors [6].

Strange sea quark / anti-quark asymmetry

Once we have determined the meson and baryon probability densities in the excited nucleon configuration, we can compute the non-perturbative strange and anti-strange sea distributions by

$$xs^{NP}(x) = \int_x^1 dy P_B(y)\ (x/y)s_B(x/y) \tag{11}$$

$$x\bar{s}^{NP}(x) = \int_x^1 dy P_M(y)\ (x/y)\bar{s}_M(x/y), \tag{12}$$

where the sources $xs_B(x)$ and $x\bar{s}_M(x)$ are primarily the momentum distributions of the valence quark and anti-quark in the baryon and meson respectively.

A delicate point in the calculation is the lack of such valence distributions in the literature. Since one has no better, we shall propose the following

$$\bar{s}_M(x) = 12x^2(1-x), \tag{13}$$

and

$$s_B(x) = 30x^2(1-x)^2 \tag{14}$$

in order to take into account the mass of the strange quarks, which carries a large amount of momentum in the hadronic states. Let us note that the distribution of eq.(13) is similar to the $\bar{s}$ distribution in the K given in ref.[13], whereas the s distribution in the Λ was chosen in such a way that the s-quark carries approximately half the momentum of the hyperon. Evidently, eq.(12) expresses the joint probability of finding a $\bar{s}$ quark inside the in-nucleon K meson obtained by recombination, and eq.(11) provides the probability of an s inside an in-nucleon Λ or Σ (see e.g. [6]).

As we show in Fig.2, the present analysis leads to a noticeable prediction of the non-perturbative strange and antistrange distributions in the nucleon sea. The corresponding $s/\bar{s}$ asymmetry, defined by

$$A(x) = \frac{s^{NP}(x) - \bar{s}^{NP}(x)}{s^{NP}(x) + \bar{s}^{NP}(x)} , \tag{15}$$

is shown in Fig.3.

Clearly, the origin of such an asymmetry in the strange sea of the nucleon is due to the fact that the strange and the anti-strange quarks are in different hadronic configurations.

Summary and discussion

By means of a model involving both effective and perturbative calculations, we have obtained a sensible prediction for the $s/\bar{s}$ non-perturbative distributions in the nucleon sea. We based our approach on a valon description of the ground state of the nucleon, which perturbatively produces sea quark/anti-quark pairs and subsequently fluctuate into a hadronic bound state by recombination with the remaining valons.

One should notice however, that the non-perturbative quark and anti-quark distributions are strongly dependent on the form of the valence quark and anti-quark distributions assumed for the in-nucleon baryon and meson respectively. So, although the model is reliable in predicting different distributions for sea quark and anti-quarks, their exact shape remain unknown until we have more confident results for the valence density inside strange hadrons.

In any case, the model predicts an excess of quarks over anti-quarks in the nucleon's sea carrying a large fraction of the nucleon's momentum, as we show in Fig.3. This prediction should be independent of the exact form of the strange and anti-strange distributions inside the in-nucleon baryon and meson respectively since the in-nucleon baryon carries a large fraction of the nucleon's momentum and, conversely, the meson is found to have a small fraction of it.

Another point which deserves a comment is the absolute magnitude of the non-perturbative contribution to the sea. In this approach, the normalization of the non-perturbative strange and anti-strange component is proportional to the probability of the fluctuation of the nucleon to a strange meson-baryon state, which is not given by the meson cloud model. An upper bound for that normalization might be obtained by comparison with experimental data.

The present analysis can be extended with no problems so as to study non-perturbative contributions to other flavors. We hope to report on this point in a future communication.

Acknowledgments

We thank Centro Brasileiro de Pesquisas Físicas (CBPF) for the warm hospitality extended to us during this work. H.R.C. was supported by CLAF and the Brazilian Agency for Scientific Research (CNPq). J.M. was supported by Fundação de Amparo à Pesquisa do Estado de Rio de Janeiro (FAPERJ). H.R.C. wish to acknowledge the valuable financial support of the Organizing Comitee of *Quark Matter '97, University of Tsukuba, Japan*, for raising the opportunity of many useful conversations during the conference.

References

[1] H1 Colaboration, C. Adloff *et al.*, DESY 97-024, hep-ex/9701212.

[2] ZEUS Collaboration, J. Breitweg *et al.*, DESY 97-025, hep-ex/9702015.

[3] J.F. Gunion and R. Vogt, UDC 97-14, LBNL 40399, hep-ph/9706252.

[4] W. Melnitchouk and A.W. Thomas, University of Adelaide preprint ADP-97-25/T260 (1997), hep-ph/9707387.

[5] S.J. Brodsky and B.Q. Ma, Phys. Lett. **B381**, 317 (1996). B.Q. Ma and S.J. Brodsky, SLAC-PUB-7501 hep-ph/9707408.

[6] A. Signal and A.W. Thomas, Phys. Lett. **B191**, 205 (1987).

[7] J.D. Sullivan, Phys. Rev. **D5**, 1732 (1972).

[8] X. Ji and J. Tang, Phys. Lett. **B362**, 182 (1995).

[9] R.C. Hwa, Phys. Rev. **D22**, 759 (1980).

[10] F. Halzen and A.D. Martin, *Quarks & Leptons: an introductory course in modern particle physics*, John Willey & Sons, 1982, p.211.

[11] K.P. Das and R.C. Hwa, Phys. Lett **B68**, 459 (1977).

[12] J. Ranft, Phys. Rev. **D18**, 1491 (1978).

[13] J.T. Londergan, G.Q. Liu and A.W. Thomas, Phys. Lett. **B380**, 393 (1996).

Figure Captions

Fig. 1: Meson and baryon probability densities in the nucleon. Full line is the strange meson distribution in the nucleon. Dashed line shows the strange baryon distribution obtained from eq.(9) whereas point dashed line is the prediction as given by recombination models.

Fig. 2: s and $\bar{s}$ non-perturbative distributions in the nucleon. Full line is the anti-strange distribution inside the nucleon. Dashed line is the strange distribution obtained from the baryon probability density calculated according to eq.(9) and point dashed line is the prediction coming from P_B as given by the recombination model for three quarks.

Fig. 3: $s/\bar{s}$ asymmetry as a function of the strange quark momentum fraction. The asymmetry curve shown was calculated using the strange distribution given by the convolution of P_B of eq.(9) with the strange distribution in the baryon of eq.(14). A similar curve is obtained using P_B as given by recombination models.

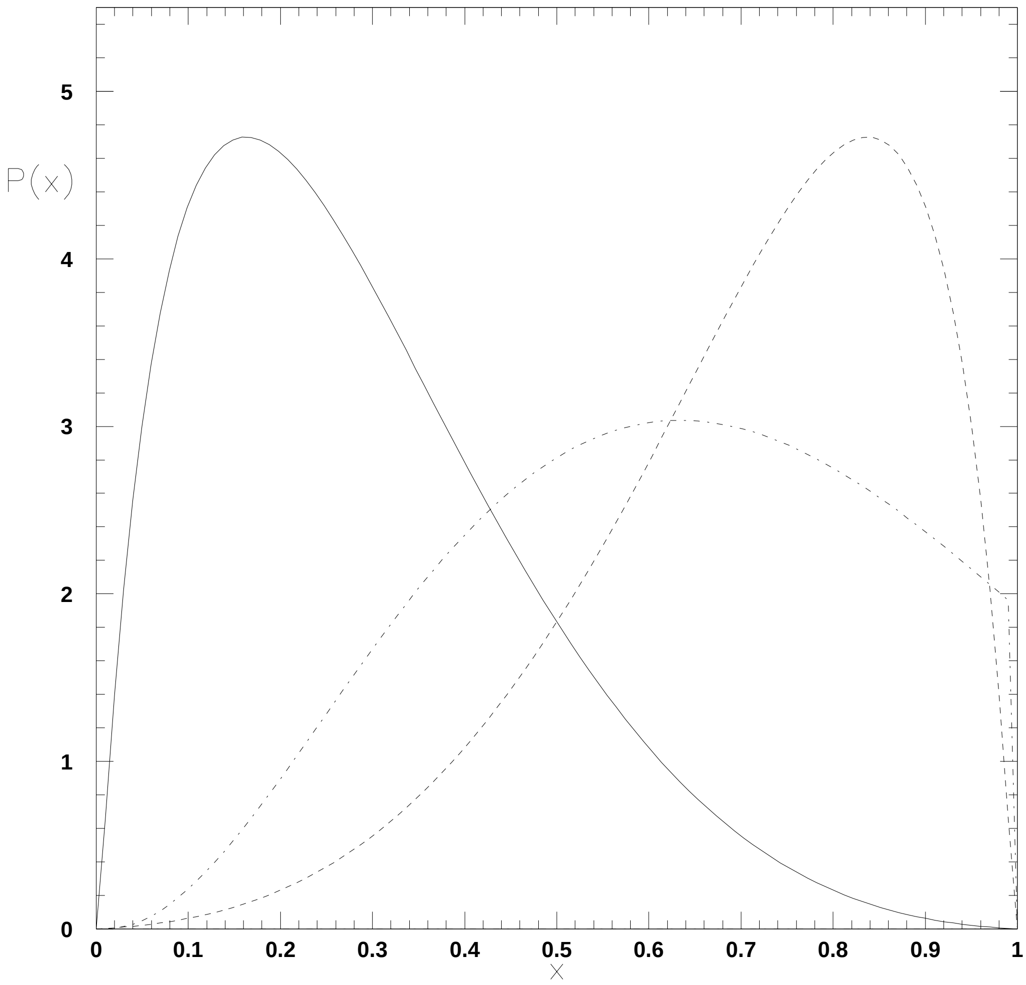

Figure 1:

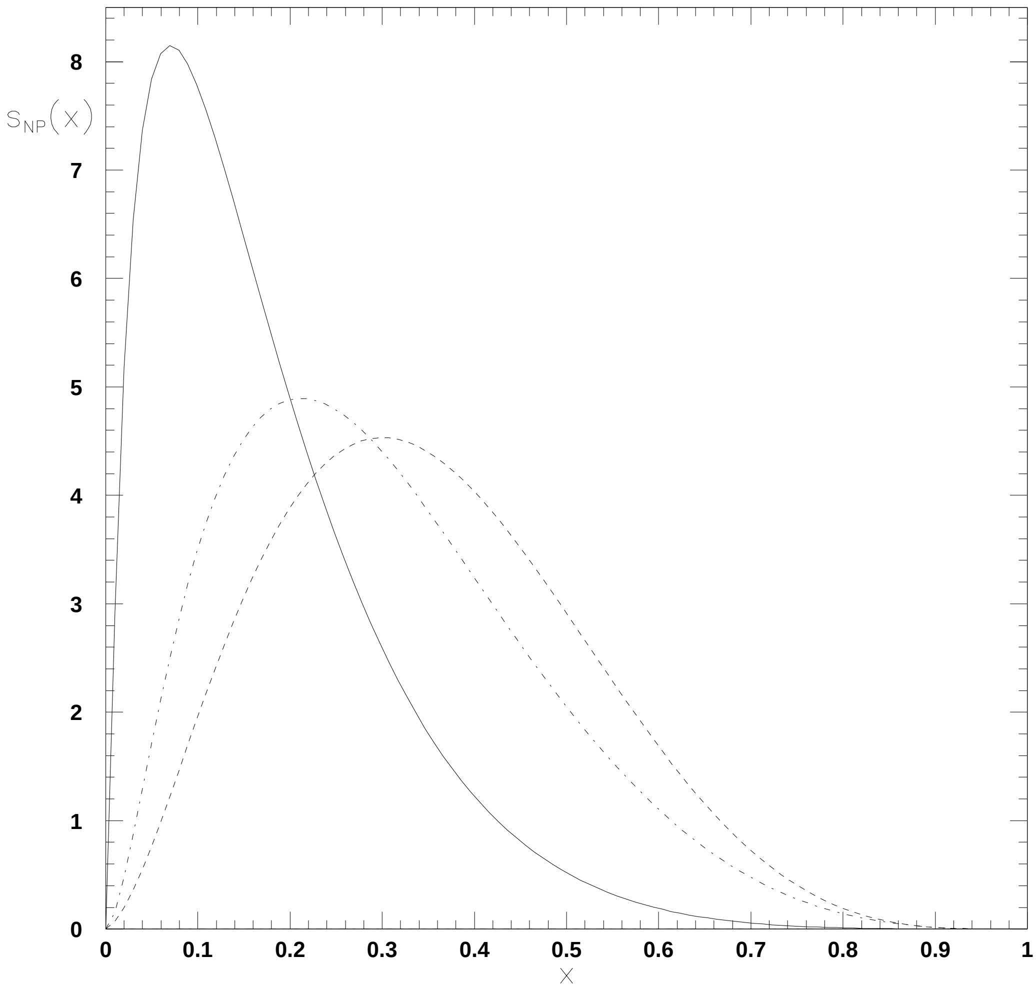

Figure 2:

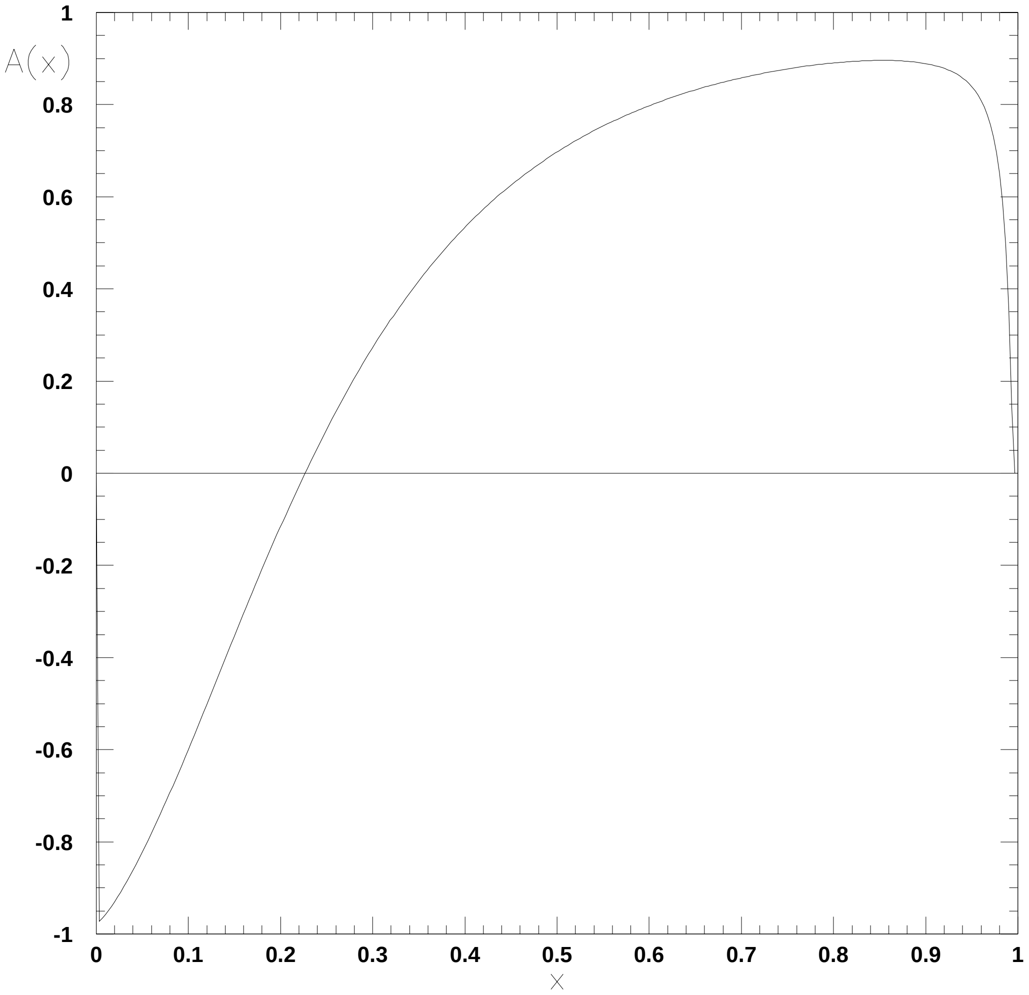

Figure 3: