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Flavor Asymmetry $\bar{u} - \bar{d}$ in the Nucleon

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Flavor asymmetry $\bar{u} - \bar{d}$ in the nucleon

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Abstract

We give a brief summary of the Gottfried sum rule and a flavor asymmetric distribution $\bar{u}-\bar{d}$ in the nucleon. First, experimental history of the sum-rule studies is discussed. Second, future prospects for studying the asymmetry at Fermilab and RHIC are discussed. We also comment on possible nuclear modification.

1. Introduction

Unpolarized parton distributions in the nucleon are now well understood by analyzing abundant high-energy experimental data. However, light antiquark distributions had been considered flavor symmetric until rather recently. It is because u and d quark masses are very small compared with typical $\sqrt{Q^2}$ in deep inelastic processes. Therefore, equal mounts of $u\bar{u}$ and $d\bar{d}$ pairs are produced perturbatively through gluon splitting. Although it was somewhat suggested in the SLAC data in 1970's, the NMC conclusion of the $\bar{u}/\bar{d}$ asymmetry in 1991 was surprising.

As far as theory is concerned, there are several proposed models for explaining the NMC result. Those include Pauli-blocking mechanism, mesonic clouds, diquark model, and so on. These ideas are not discussed in this paper due to lack of space. Interested reader may read a summary paper in Ref. [1].

In spite of the NMC suggestion, it is still not obvious whether the Gottfried sum rule is in fact violated due to a possible small-x contribution. Therefore, independent experimental information is necessary for finding an accurate $\bar{u} - \bar{d}$ distribution. The NA51 Drell-Yan experiment in 1994 suggests a large flavor asymmetry, which is consistent with the NMC finding. Right now, the Drell-Yan experiment is in progress at the Fermilab, and we expect to have much detailed results in the near future. On the other hand, the other hadron collider RHIC should also be able to provide information on the asymmetry.

In this paper, we first discuss experimental history of the Gottfried sum rule and its relation to the flavor asymmetry $\bar{u} - \bar{d}$ in section 2. Then, Drell-Yan and W production processes are explained in sections 3 and 4 for finding the asymmetry at Fermilab or RHIC.

occur more frequently than the $u\bar{u}$. It means that a finite $\bar{u}/\bar{d}$ asymmetry is produced even if it is symmetric ($\bar{u} = \bar{d}$) in the nucleon. We show the $\bar{u} - \bar{d}$ distributions, which are created by the recombinations in Fig. 3. The detailed calculations are explained in Ref. [3]. Depending on the flavor distribution in the nucleon, the results show interesting nuclear modification effects. They are calculated at Q^2=4 GeV^2; however, the modification should be larger at smaller Q^2 because of higher-twist nature. Therefore, the nuclear effects are typically a few or several % in comparison with the $\bar{u} - \bar{d}$ distribution which is suggested by the NMC data. It is important to test the nuclear modification by the Drell-Yan experiments for nuclear targets.

4. W production

W production is investigated for measuring $\bar{u} - \bar{d}$ by several people [1]. Here, we discuss this topic based on Peng-Jansen studies [4]. The dominant subprocess of producing W^+ is $u + \bar{d} \to W^+$, so that the $\bar{d}$ distribution could be extracted from W^+ production data. On the other hand, the dominant process of W^- production is $d + \bar{u} \to W^-$, and $\bar{u}$ information can be obtained instead of $\bar{d}$. This difference makes it possible to find the asymmetric distribution $\bar{u} - \bar{d}$. The W^+ production cross section is given by

$$\frac{d\sigma_{p+p\to W^+}}{dx_F} \propto \cos^2\theta_c \left[u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)\right] + \sin^2\theta_c \left[u(x_1)\bar{s}(x_2) + \bar{s}(x_1)u(x_2)\right] \quad . \tag{4}$$

Because the Cabbibo angle θ_c is small, the $\sin^2\theta_c$ terms are neglected for simplicity in the following discussions. Then, the processes of producing W^+ are $u(x_1) + \bar{d}(x_2) \to W^+$ and $u(x_2) + \bar{d}(x_1) \to W^+$. The W^- cross section is calculated in the similar way, and we obtain the $W^\pm$ production ratio

$$R_{p+p}(x_F) \equiv \frac{d\sigma_{p+p\to W^+}/dx_F}{d\sigma_{p+p\to W^-}/dx_F} = \frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)} \quad . \tag{5}$$

At large x_F (large x_1), the antiquark distribution $\bar{q}(x_1)$ is very small, so that the above equation becomes $R_{p+p}(x_F \gg 0) \approx [u(x_1)/d(x_1)][\bar{d}(x_2)/\bar{u}(x_2)]$, which is directly proportional to the $\bar{d}/\bar{u}$ ratio. On the other hand, we have $R_{p+\bar{p}}(x_F \gg 0) \approx [u(x_1)/d(x_1)][d(x_2)/u(x_2)]$ in the $p + \bar{p}$ reaction case. In the $x_F = 0$ region, even though the $p + p$ ratio is still sensitive to the flavor asymmetry: $R_{p+p}(x_F = 0) = [u(x)/d(x)][\bar{d}(x)/\bar{u}(x)]$, the $p + \bar{p}$ ratio is independent: $R_{p+\bar{p}}(x_F = 0) = 1$. Therefore, the $p + \bar{p}$ reaction is not a good way for finding the flavor asymmetry. This situation is clearly shown in Fig. 4, where the $W^\pm$ production ratio is calculated in the $p + p$ and $p + \bar{p}$ cases.

The $W^{\pm}$ ratios in the $p+p$ and $p+\bar{p}$ reactions are evaluated at $\sqrt{s}$=500 GeV by using various parametrizations for the parton distributions [4]. The distributions are evolved to the scale $Q^2 = M_W^2$. The figures a) and b) show the $p+p$ and $p+\bar{p}$ results respectively. The dashed curve indicates results of using the flavor symmetric ($\bar{u} = \bar{d}$) DO1.1 distributions. Others are the results for flavor asymmetric distributions (MRSD0$-'$, CTEQ2pM, ES, EHQ). As we expected, the $p+p$ reaction is sensitive to the light antiquark flavor asymmetry not only in the large x_F region but also in the $x_F \approx 0$ region. On the other hand, the $p+\bar{p}$ reaction is almost insensitive to the asymmetry. The dependence appears only in the very small x_F region.

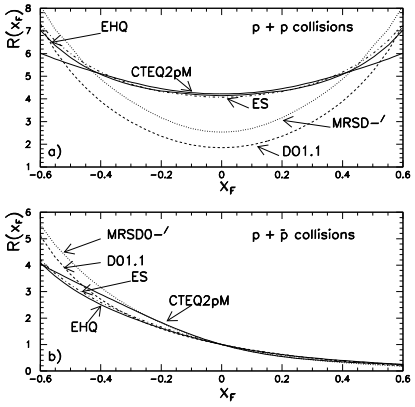

Fig.4 W production in $p+p$ and $p+\bar{p}$ reactions (taken from Ref. [4]).

There are other possibilities such as Z and quarkonium production processes for finding the $\bar{u} - \bar{d}$ distribution. These topics as well as theoretical ideas are summarized in Ref. [1]. The flavor symmetry is an interesting topic for future investigations. It is currently being studied at Fermilab and should be investigated at RHIC. Furthermore, the asymmetry in polarized parton distributions ($\Delta\bar{u}/\Delta\bar{d}$) is an unexplored subject, which will be studied for example at RHIC-SPIN.

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