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EVIDENCE FOR AN ENHANCED NUCLEAR SEA
FROM THE PROTON-NUCLEUS DRELL-YAN PROCESS

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A B S T R A C T

We show that the experimental data for the slope of the rapidity distribution of the Drell-Yan process p on P_t favour the existence of an increase in the sea for a bound nucleon.

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The European Muon Collaboration recently reported ¹⁾ a striking difference between the structure functions of a nucleon in deuterium and iron - the EMC effect. Amongst the many explanations which have been proposed, the pionic model ²⁾⁻⁴⁾ provides a very natural explanation of the enhancement in Fe at small x , as an increase in the non-strange sea. However, this interpretation has been questioned by neutrino experiments ^{5),6)} which claim to see no significant enhancement of the nuclear sea - although their (statistical and systematic) uncertainties are large.

Clearly, it is very important to settle the question of whether or not the nuclear sea is enhanced, and the Drell-Yan (DY) process (in which a $q - \bar{q}$ pair annihilate to form a high mass lepton pair) is an obvious tool. In particular, it is possible to select asymmetric kinematic conditions such that only the sea of the target is probed, and one would expect to be sensitive to any enhancement of it. Unfortunately, this simple idea is complicated in practice by the uncertainty in extrapolating from time-like to space-like values of Q^2 when relating DY with deep-inelastic scattering. This extrapolation involves a factor, usually denoted as K , which cannot be calculated with high precision. Thus only a measurement of the relative cross-sections for DY on (say) Fe and D, in the same asymmetric kinematical conditions, would provide the information we want. At the present time, there is no such data.

An alternative idea, which we consider here, is to analyse the logarithmic derivative of the rapidity distribution,

$$S = \frac{d}{dy} \left(\ln \frac{d^2\sigma}{dM dy} \right)_{y=0} \quad (1)$$

where M is the invariant mass of the dilepton pair. This quantity, which has the desired property of being independent of the K factor, has been measured by Ito et al. ⁷⁾ for protons on Pt ($Z/A = 0.4$, $N/A = 0.6$). The dominant contribution to the DY cross-section is proportional to

$$X = \frac{4}{9} \left[u_p(x_1) \left(0.4 \bar{u}_A(x_2) + 0.6 \bar{d}_A(x_2) \right) + \bar{u}_p(x_1) \left(0.4 u_A(x_2) + 0.6 d_A(x_2) \right) \right] \quad (2)$$

where the subscript refers to the projectile (p), or target (A). [In Eq. (2), we omit, for simplicity, the smaller terms involving d quarks. The actual numerical calculations include all terms - to be specific, we use for the free proton $u_v(x) = 2.2x^{\frac{1}{2}}(1-x)^3$; $d_v(x) = 0.57(1-x)u_v(x)$; $\bar{u}(x) = \bar{d}(x) = 0.2(1-x)^7$.]

With the conventional definition of rapidity (y) :

$$x_1 = \sqrt{x} e^y, \quad x_2 = \sqrt{x} e^{-y} \quad (3)$$

Eq. (2) implies that

$$S = \frac{4}{9} \frac{\sqrt{x}}{X} \left[u'_p \left(0.4 \bar{u}_A + 0.6 \bar{d}_A \right) + \bar{u}'_p \left(0.4 u_A + 0.6 d_A \right) - \bar{u}_p \left(0.4 u'_A + 0.6 d'_A \right) - u_p \left(0.4 \bar{u}'_A + 0.6 \bar{d}'_A \right) \right] \quad (4)$$

where $u'_p \equiv [du_p(x_1)]/dx_1$, etc.

If the quark momentum distributions were unaltered in the nucleus, the interaction between the incident proton and a nuclear proton would give no contribution to S. Then the dominant term is

$$S \simeq \frac{4}{9} \frac{\sqrt{x}}{X} \left(d_p \bar{u}'_p - u_p \bar{d}'_p \right) \quad (5)$$

and the asymmetry between u and d ($u > d$) yields a positive slope. As shown in Fig. 1 (solid curve), while the sign is correct, this effect alone is too small to explain the data. In order to account for the remaining discrepancy, Ito et al.⁷⁾ proposed that there might be a basic asymmetry between the $\bar{u}$ and $\bar{d}$ distributions in the proton. Using $\bar{u}(x) = (1 - x)^{3.5} \bar{d}(x)$, they were able to obtain a reasonable fit.

This asymmetry between $\bar{u}$ and $\bar{d}$ is rather large (e.g., $\bar{u}/\bar{d} = 0.45$ at $x = 0.2$), with $\bar{d}$ dominating the sea beyond $x = 0.2$. Such a large asymmetry does not seem to be present in the $\bar{u}$ and $\bar{d}$ distributions measured directly in ν and $\bar{\nu}$ interactions with H and D. Indeed, the general conclusion seems to be that statistical and systematic uncertainties would permit no more than a 30% difference between $\bar{u}$ and $\bar{d}$ (8).

In the light of the EMC results, we would like to discuss the effect on S of an asymmetry of a different type, namely that between the quark distributions in a free nucleon and one bound in a nucleus. In particular, it is clear from Eq. (4) that an increase in the nuclear sea would tend to increase the slope. (Note that $\bar{u}'$ and $\bar{d}'$ are negative, so the last term in Eq. (4) is positive.) In Fig. 1, we show the effect of a 40% increase in the non-strange nuclear sea (case 1 - dotted curve). As well as giving the small x enhancement seen by EMC (see Fig. 2), such a change clearly improves the agreement with the slope data of Ito et al.

It should now be clear that many combinations of these two effects, namely a basic asymmetry between $\bar{u}$ and $\bar{d}$ on the nucleon and an enhancement of the nuclear sea, can reproduce the DY data. To illustrate this, we also show in Fig. 1 (case 2 - dashed curve) the combined effect of a (maximal) 30% asymmetry between $\bar{d}$ and $\bar{u}$ on the free proton together with an additional 25% enhancement of $\bar{d}$ for a proton ($\bar{d}_A = 1.25 \bar{d}_p$) in the nucleus. Such a preferential enhancement of $\bar{d}$ compared to $\bar{u}$ occurs naturally⁹⁾ in the pionic model because of the virtual process $p \rightarrow n\pi^+$. Clearly, the agreement with the data of Ito et al. is rather good, but the corresponding EMC effect is a little small. Finally, we show as the dot-dash curve (case 3) in Fig. 1 the same calculation with a 45% (rather than 25%) enhancement of $\bar{d}$ for a proton in the nucleus. Once again, the slope of the rapidity distribution is well fit and we also find a sizeable EMC effect (see Fig. 2).

To summarize, given the experimental constraints on the relative size of $\bar{u}$ and $\bar{d}$, the most reasonable explanation of the slope data of Ito et al. is that there is a substantial increase in the nuclear sea. While one cannot give a tight, quantitative limit on the size of this increase, it is certainly consistent with the small x enhancement seen by EMC.

The essential question remaining is whether this increase in the sea is in disagreement with the neutrino data. In particular, the CDHS group has determined the ratio ⁽⁶⁾

$$R = \left(\bar{u} + \bar{d} + 2\bar{s} \right)_{Fe} / 2 \left(\bar{d} + \bar{s} \right)_H \quad (6)$$

to be $R = 1.10 \pm 0.11 \pm 0.07$. For the three cases cited above, we find this ratio to be 1.26, 1.03 and 1.13 respectively. All of these values are compatible with the data. Clearly the sensitivity of Eq. (6) to a small asymmetry between $\bar{u}$ and $\bar{d}$ makes it less valuable as a test for an increase in the sea.

In conclusion, the value of the slope of the rapidity distribution for $p - p_{\perp}$ DY measured by Ito et al. strongly suggests that the nuclear sea is enhanced. This interpretation has the advantage of not requiring a large asymmetry between $\bar{u}$ and $\bar{d}$ as those authors had suggested. In addition, the enhancement required to explain their data is consistent with the increase at small x seen by EMC, and is also compatible with the measurements of CDHS.

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FIGURE CAPTIONS

Fig. 1 : The slope of the rapidity distribution for various assumptions concerning the antiquark distributions.

Fig. 2 : The EMC effect for various assumptions concerning the antiquark distributions. (For the u and d quarks of the sea, we have taken $u^S + d^S = \bar{u} + \bar{d}$.)

Figure 1

Figure 2