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Reevaluation of the Gottfried sum

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We present a new determination of the nonsinglet structure function $F_2^p - F_2^n$ at $Q^2=4$ GeV^2 using recently measured values of F_2^d and F_2^n/F_2^p. A new evaluation of the Gottfried sum is given, which remains below the simple quark-parton model value of $\frac{1}{3}$.

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In 1991 the New Muon Collaboration (NMC) published an evaluation of the Gottfried sum $S_G=\int(F_2^p-F_2^n)dx/x$ which showed that the simple quark model expectation of 1/3 was not reached [1]. In that analysis the nonsinglet structure function was obtained as

$$F_2^p-F_2^n=2F_2^d(1-F_2^n/F_2^p)/(1+F_2^n/F_2^p). \quad (1)$$

The ratio F_2^n/F_2^p, defined as $2F_2^d/F_2^p-1$, was taken from the precise NMC measurements of the ratio F_2^d/F_2^p at 90 and 280 GeV, and the deuteron structure function in Eq. (1) was taken from a global fit to the results of earlier experiments.

Recently the NMC has published [2] its own values of F_2^p and F_2^d. These are the first accurate measurements at low x; in this region the results for F_2^d differ significantly from the parametrization used in Ref. [1]. A new parametrization of F_2^d using the NMC, SLAC, and BCDMS data was included in Ref. [2].

We report here a reevaluation of $F_2^p-F_2^n$ and S_G, using the new F_2^d parametrization and newly determined values of the ratio F_2^n/F_2^p. The latter were determined from the data set reported in Ref. [3], but with the radiative corrections applied using the new F_2^d parametrization, and following the method of Akhundov *et al.* [4]. In addition, a more precise calibration for the scattered muon momentum was applied to the 90 GeV data. The data set of Ref. [3] is slightly more extensive than that used in Ref. [1].

At small values of x the changes in $F_2^p-F_2^n$ reported here, relative to the values in Ref. [1], are due to the changed values of F_2^d which have increased by up to 18% at $x=0.007$ (compared to a systematic error of 7% given in Ref. [1]). It may be noted that most previous structure function parametrizations underestimated F_2^d for $x<0.07$ [2]. The value of F_2^d affects the result for the nonsinglet structure function both through the factor in Eq. (1), and via its influence on the ratio F_2^n/F_2^p through the radiative corrections. This is because the term $(1-F_2^n/F_2^p)$ in Eq. (1) is close to zero at low x. At large values of x the changes in $F_2^p-F_2^n$ are caused by the new momentum calibration.

The method of determining $F_2^p-F_2^n$ used here and in Ref. [1] gives more accurate results than can be obtained from the values of F_2^p and F_2^d given in Ref. [2]. This is because it takes advantage of the NMC experiment's ability to make precise measurements of cross-section ratios [3], in which more data, covering a larger Q^2 range, can be used. This leads to smaller systematic and statistical errors on S_G.

The results presented here are evaluated at $Q^2=4$ GeV^2; this value of Q^2 was chosen as it is covered by the F_2^n/F_2^p data over the range $0.004<x<0.5$. The values of F_2^n/F_2^p were obtained from fits to the data, linear in ln(Q^2), at each interval of x, as in Ref. [1]. These were then used, together with the values of F_2^d taken directly from the parametrization [2], to evaluate $F_2^p-F_2^n$ according to Eq. (1). No corrections were applied for target mass, higher twist, or nuclear effects, as discussed in Ref. [1].

The results for $F_2^p-F_2^n$ are given in Table I and in Fig. 1, where they are compared to those published in Ref. [1]. Table I also gives the values of F_2^n/F_2^p and F_2^d used in the present evaluation. The causes of the differences between the $F_2^p-F_2^n$ values presented here and those of Ref. [1] have been discussed above. The value of the Gottfried sum at $Q^2=4$ GeV^2 over the interval $0.004<x<0.8$ is found to be

$$S_G(0.004-0.8)=0.221\pm0.008(\text{stat})\pm0.019(\text{syst}).$$

The systematic error has been reevaluated. For the radiative corrections we have now followed the prescription given in Ref. [3] which leads to an uncertainty of 0.011. In combining this with the uncertainty (systematic and statistical) in F_2^d the correlation between them was taken fully into account. The

TABLE I. The values of F_2^d, F_2^n/F_2^p, $F_2^p-F_2^n$ and $S_G(x_{\min}-0.8)$ at $Q^2=4$ GeV^2. The errors on F_2^d are the estimated total uncertainties and those on F_2^n/F_2^p, $F_2^p-F_2^n$ and $S_G(x_{\min}-0.8)$ are statistical only.

$x_{\min}-x_{\max}$	F_2^d	F_2^n/F_2^p	$F_2^p-F_2^n$	S_G
0.004−0.010	0.413±0.020	0.976±0.017	0.010±0.007	0.221±0.008
0.010−0.020	0.394±0.016	0.963±0.011	0.015±0.004	0.213±0.005
0.020−0.040	0.378±0.013	0.927±0.007	0.029±0.003	0.203±0.004
0.040−0.060	0.365±0.012	0.919±0.007	0.031±0.003	0.183±0.004
0.060−0.100	0.350±0.012	0.881±0.006	0.044±0.002	0.171±0.003
0.100−0.150	0.331±0.011	0.836±0.007	0.059±0.003	0.149±0.003
0.150−0.200	0.310±0.010	0.812±0.009	0.064±0.003	0.125±0.003
0.200−0.300	0.274±0.008	0.740±0.008	0.082±0.003	0.107±0.003
0.300−0.400	0.214±0.006	0.637±0.012	0.095±0.004	0.074±0.003
0.400−0.500	0.152±0.005	0.497±0.019	0.102±0.005	0.047±0.002
0.500−0.600	0.101±0.002	0.502±0.038	0.067±0.007	0.025±0.002
0.600−0.800	0.048±0.001	0.382±0.058	0.043±0.006	0.012±0.002

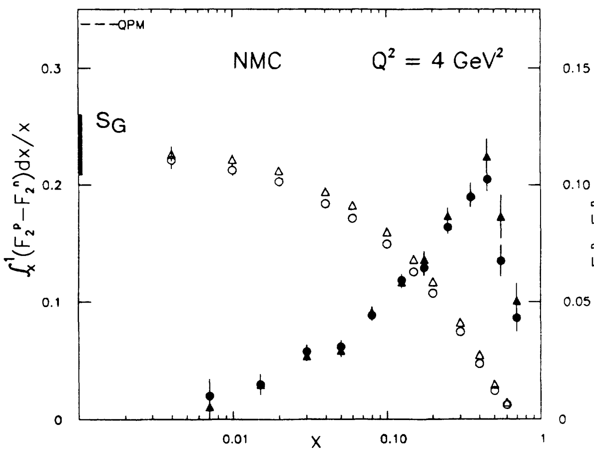

FIG. 1. The difference $F_2^p - F_2^n$ (full symbols and scale to the right) and $\int_x^1 (F_2^p - F_2^n)dx/x$ (open symbols and scale to the left) at $Q^2=4$ GeV^2, as a function of x from the present reevaluation (circles) and from Ref. [1] (triangles). The extrapolated result S_G from the present work and the prediction of the simple quark-parton model (QPM) are also shown.

uncertainty from the momentum calibration is reduced compared to that given in Table 2 of Ref. [1], while the other contributions are unchanged.

To evaluate the contributions to S_G from the unmeasured regions at high and low x, extrapolations of $F_2^p - F_2^n$ to $x=1$ and $x=0$ were made using the same procedures as described in Ref. [1]. The contribution from the region $x>0.8$ is 0.001 ± 0.001. For the region $x<0.004$, the expression ax^b, appropriate for a Regge-like behavior, was again fitted to the data in the range $0.004<x<0.15$ and extrapolated to $x=0$. The fit yields the values $a=0.20 \pm 0.03$ and $b=0.59 \pm 0.06$ and a contribution to S_G of 0.013 ± 0.005 (stat) for $x<0.004$. The quality of the fit is as good as that in Ref. [1] and the result is insensitive to the upper limit of the fitted range (up to $x=0.40$).

Summing the contributions from the measured and unmeasured regions we obtain for the Gottfried sum

$$S_G = 0.235 \pm 0.026.$$

The error is the result of combining the statistical and systematic errors in quadrature, and including the effect of the (correlated) systematic uncertainties on the extrapolations of $F_2^p - F_2^n$ to $x=1$ and $x=0$. This new value of S_G agrees well with that in Ref. [1]. However, the total error given here is larger than that quoted in Ref. [1] due to the more extensive examination of the systematic uncertainties. Nevertheless, the result for S_G is significantly below the simple quark-parton model value of 1/3, so that the conclusions of Ref. [1] are unchanged.

The evaluation of the Gottfried sum at higher Q^2 requires large extrapolations of the measured values of F_2^n/F_2^p at low x, which rapidly reduces the accuracy of $F_2^p - F_2^n$. For this reason a precise determination of the Gottfried sum from the NMC data is restricted to Q^2 around 4 GeV^2.

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