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Reevaluation of the Gottfried sum


(New Muon Collaboration)

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We present a new determination of the nonsinglet structure function $F_2^n - F_2^n$ at $Q^2 = 4$ GeV$^2$ using recently measured values of $F_2^p$ 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 $\frac{3}{2}$.

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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

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

(1)

The ratio $F_2^d/F_2^n$, defined as $2F_2^d/f_2^n - 1$, was taken from the precise NMC measurements of the ratio $F_2^d/F_2^n$ 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 $F_2^n$. These are the first accurate measurements at low $x$; in this region the results for $F_2^n$ differ significantly from the parametrization used in Ref. [1]. A new parametrization of $F_2^n$ 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 $F_2^n$ parametrization and newly determined values of the ratio $F_2^d/F_2^n$. 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 $F_2^p$ 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 $F_2^p$ for $x < 0.07$ [2]. The value of $F_2^p$ affects the result for the nonsinglet structure function both through the factor in Eq. (1), and via its influence on the ratio $F_2^d/F_2^n$ 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 $F_2^n$ 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 $F_2^n$ taken directly from the parametrization [2], to evaluate $F_2^n - F_2^n$ according to Eq. (1). No corrections were applied for target mass, higher twist, or nuclear effects, as discussed in Ref. [1].

The results for $F_2^n - F_2^n$ 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 $F_2^p$ used in the present evaluation. The causes of the differences between the $F_2^n - F_2^n$ 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

$$S_G(0.004 - 0.8) = 0.221 \pm 0.008 \text{(stat)} \pm 0.019 \text{(syst)}.$$

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 $F_2^n$, the correlation between them was taken fully into account. The

<table>
<thead>
<tr>
<th>$x_{\text{min}} - x_{\text{max}}$</th>
<th>$F_2^n$</th>
<th>$F_2^d/F_2^n$</th>
<th>$F_2^n - F_2^n$</th>
<th>$S_G$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.004 - 0.100</td>
<td>0.413 ± 0.020</td>
<td>0.976 ± 0.017</td>
<td>0.010 ± 0.007</td>
<td>0.221 ± 0.008</td>
</tr>
<tr>
<td>0.010 - 0.020</td>
<td>0.394 ± 0.016</td>
<td>0.963 ± 0.011</td>
<td>0.015 ± 0.004</td>
<td>0.213 ± 0.005</td>
</tr>
<tr>
<td>0.020 - 0.040</td>
<td>0.378 ± 0.013</td>
<td>0.927 ± 0.007</td>
<td>0.029 ± 0.003</td>
<td>0.203 ± 0.004</td>
</tr>
<tr>
<td>0.040 - 0.060</td>
<td>0.365 ± 0.012</td>
<td>0.919 ± 0.007</td>
<td>0.031 ± 0.003</td>
<td>0.183 ± 0.004</td>
</tr>
<tr>
<td>0.060 - 0.100</td>
<td>0.350 ± 0.012</td>
<td>0.881 ± 0.006</td>
<td>0.044 ± 0.002</td>
<td>0.171 ± 0.003</td>
</tr>
<tr>
<td>0.100 - 0.150</td>
<td>0.331 ± 0.011</td>
<td>0.836 ± 0.007</td>
<td>0.059 ± 0.003</td>
<td>0.149 ± 0.003</td>
</tr>
<tr>
<td>0.150 - 0.200</td>
<td>0.310 ± 0.010</td>
<td>0.812 ± 0.009</td>
<td>0.064 ± 0.003</td>
<td>0.125 ± 0.003</td>
</tr>
<tr>
<td>0.200 - 0.300</td>
<td>0.274 ± 0.008</td>
<td>0.740 ± 0.008</td>
<td>0.082 ± 0.003</td>
<td>0.107 ± 0.003</td>
</tr>
<tr>
<td>0.300 - 0.400</td>
<td>0.214 ± 0.006</td>
<td>0.637 ± 0.012</td>
<td>0.095 ± 0.004</td>
<td>0.074 ± 0.003</td>
</tr>
<tr>
<td>0.400 - 0.500</td>
<td>0.152 ± 0.005</td>
<td>0.497 ± 0.019</td>
<td>0.102 ± 0.005</td>
<td>0.047 ± 0.002</td>
</tr>
<tr>
<td>0.500 - 0.600</td>
<td>0.101 ± 0.002</td>
<td>0.502 ± 0.038</td>
<td>0.067 ± 0.007</td>
<td>0.025 ± 0.002</td>
</tr>
<tr>
<td>0.600 - 0.800</td>
<td>0.048 ± 0.001</td>
<td>0.382 ± 0.058</td>
<td>0.043 ± 0.006</td>
<td>0.012 ± 0.002</td>
</tr>
</tbody>
</table>
FIG. 1. The difference $F^p_G - F^n_G$ (full symbols and scale to the right) and $\int_x (F^p_G - F^n_G) dx / x$ (open symbols and scale to the left) at $Q^2 = 4 \text{ GeV}^2$, 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 $F^p_G - F^n_G$ 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 $0.001 \pm 0.001$. 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 $0.013 \pm 0.005$ (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 $F^p_G - F^n_G$ 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 $F^p_G/F^n_G$ at low $x$, which rapidly reduces the accuracy of $F^p_G - F^n_G$. For this reason a precise determination of the Gottfried sum from the NMC data is restricted to $Q^2$ around $4 \text{ GeV}^2$.

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