# PHYSICAL REVIEW D

## PARTICLES AND FIELDS

**THIRD SERIES, VOLUME 50, NUMBER 1** **1 JULY 1994**


## RAPID COMMUNICATIONS

*Rapid Communications are intended for important new results which deserve accelerated publication, and are therefore given priority in editorial processing and production. A Rapid Communication in* **Physical Review D** *should be no longer than five printed pages and must be accompanied by an abstract. Page proofs are sent to authors, but because of the accelerated schedule, publication is generally not delayed for receipt of corrections unless requested by the author.*

# Reevaluation of the Gottfried sum


M. Arneodo,[13,a] A. Arvidson,[14] B. Badelek,[16] M. Ballintijn,[9] G. Baum,[1] J. Beaufays,[9,b] I. G. Bird,[9,c] P. Björkholm,[14] M. Botje,[12,d] C. Broggini[8,e] W. Brückner,[4] A. Brüll,[3,f] W. J. Burger,[12,g] J. Ciborowski,[16] R. van Dantzig,[9] A. Dyring,[14] H. Engelien,[3,h] M. I. Ferrero,[13] L. Fluri,[8] U. Gaul,[4] T. Granier,[10] D. von Harrach,[4,i] M. van der Heijden,[9,d] C. Heusch,[11] Q. Ingram,[12] K. Janson-Prytz,[14,j] M. de Jong,[9] E. M. Kabuss,[4,i] R. Kaiser,[3] T. J. Ketel,[9] F. Klein,[6] S. Kullander,[14] U. Landgraf,[3] T. Lindqvist,[14] G. K. Mallot,[6,2] C. Mariotti,[13,k] G. van Middelkoop,[2,9] A. Milsztajn,[10] Y. Mizuno,[4,l] J. Nassalski,[15] J. Oberski,[9] D. Nowotny,[4,m] A. Paic,[8] C. Peroni,[13] B. Povh,[4,5] R. Rieger,[6,n] K. Rith,[4,o] K. Röhrich,[6,p] E. Rondio,[15] L. Ropelewski,[16] A. Sandacz,[15] D. Sanders,[9,q] C. Scholz,[4] R. Schumacher,[12,r] R. Seitz,[6] F. Sever,[9,s] T.-A. Shibata,[5] M. Siebler,[1] A. Simon,[4] A. Staiano,[13] M. Szleper,[15] Y. Tzamouranis,[4,q] M. Virchaux,[10] J. L. Vuilleumier,[8] T. Walcher,[6] R. Windmolders,[7] A. Witzmann,[3] and F. Zetsche[4]

(New Muon Collaboration)

[1]*Bielefeld University, Universitätstrasse 25, D-33501, Bielefeld, Germany*
[2]*CERN, CH-1211, Geneva 23, Switzerland*
[3]*Freiburg University, Hermann-Herder-Strasse 3, D-79104 Freiburg, Germany*
[4]*Max-Planck Institut für Kernphysik, Postf. 103980, D-69029, Heidelberg, Germany*
[5]*Heidelberg University, D-69120, Heidelberg, Germany*
[6]*Mainz University, D-55099, Mainz, Germany*
[7]*Mons University, Mons, Hainaut, Belgium*
[8]*Neuchâtel University, Neuchâtel, Switzerland*
[9]*NIKHEF-K, P.O. Box 41882, NL-1009DB, Amsterdam, The Netherlands*
[10]*DAPNIA/SPP, CEN-Saclay, F-91191 Gif-sur-Yvette, France*
[11]*University of California, Santa Cruz, California, 95064*
[12]*Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland*
[13]*Torino University, Via Pietro Giuria 1, 10125, Torino, Italy and Istituto Nazionale di Fisica Nucleare, Torino, Italy*
[14]*Uppsala University, S-75121, Uppsala, Sweden*
[15]*Soltan Institute for Nuclear Studies, Warsaw, Poland*
[16]*Warsaw University, Warsaw, Poland*


(Received 28 July 1993; revised manuscript received 1 March 1994)


[a]Now at Dipartimento di Fisica, Università della Calabria, I-87036 Arcavacata di Rende (Cosenza), Italy.
[b]Now at Trasys, Brussels, Belgium.
[c]Now at CERN, 1211 Geneva 23, Switzerland.
[d]Now at NIKHEF-H 1009 DB Amsterdam, The Netherlands.
[e]Now at University of Padova, 35131 Padova, Italy.
[f]Now at MPI für Kernphysik, 69029 Heidelberg, Germany.
[g]Now at Université de Genève, 1211 Genève 4, Switzerland.
[h]Now at LHS GmbH, 63303 Dreieich, Germany.
[i]Now at University of Mainz, 55099 Mainz, Germany.
[j]Now at DESY, 2000 Hamburg 52, Germany.
[k]Now at INFN Istituto Superiore di Sanita, 00161 Rome, Italy.
[l]Now at Osaka University, 567 Osaka, Japan.
[m]Now at SAP AG, Walldorf, Germany.
[n]Now at Ploenzke Informatik, Mannheim, Germany.
[o]Now at University of Erlangen-Nuernberg, 91058 Erlangen, Germany.
[p]Now at IKP2-KFA, Jülich, Germany.
[q]Now at University of Houston, TX 77204-5504.
[r]Now at Carnegie Mellon University, Pittsburgh, PA 15213.
[s]Now at ESRF, 38043 Grenoble, France.


 

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 $\frac{1}{3}$.

PACS number(s): 13.60.Hb, 11.55.Hx

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 $S_G(x_{\text{min}}-0.8)$ 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 $S_G(x_{\text{min}}-0.8)$ are statistical only.

| $x_{\text{min}}-x_{\text{max}}$ | $F_2^d$ | $F_2^n/F_2^p$ | $F_2^p-F_2^n$ | $S_G$ |
|---|---|---|---|---|
| 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 |

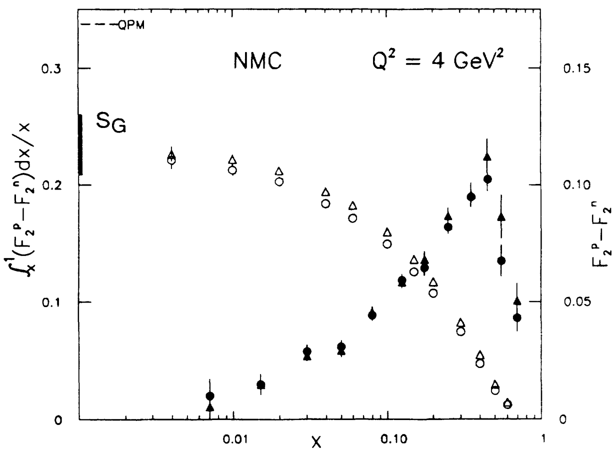


FIG. 1. The difference $F_2^p - F_2^n$ (full symbols and scale to the right) and $\int_x^1 (F_2^p - F_2^n) dx/x$ (open symbols and scale to the left) at $Q^2 = 4$ GeV$^2$, as a function of $x$ from the present reevaluation (circles) and from Ref. [1] (triangles). The extrapolated result $S_G$ from the 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 $0.001 \pm 0.001$. 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 $F_2^p - F_2^n$ 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$^2$.

Bielefeld University, Freiburg University, Max Planck Institut Heidelberg, Heidelberg University, and Mainz University were supported by Bundersministerium für Forschung und Technologie. NIKHEF-K was supported in part by FOM, Vrije Universiteit Amsterdam and NWO. Soltan Institute for Nuclear Studies and Warsaw University were supported by KBN Grant No. 2 0958 9101. The work of D.S. was supported by the NSF and DOE.

[1] New Muon Collaboration, P. Amaudruz *et al.*, Phys. Rev. Lett. **66**, 2712 (1991).
[2] New Muon Collaboration, P. Amaudruz *et al.*, Phys. Lett. B **295**, 159 (1992); Report No. CERN-PPE/92-124, 1992 (unpublished); erratum (unpublished); erratum (unpublished).
[3] New Muon Collaboration, P. Amaudruz *et al.*, Nucl. Phys. **B371**, 3 (1992).
[4] A. A. Akhundov *et al.*, Sov. J. Nucl. Phys. **26**, 660 (1977); **44**, 988 (1986); JINR-Dubna Report No. E2-10147, 1976 (unpublished); No. E2-10205, 1976 (unpublished); No. E2-86-104, 1986 (unpublished); D. Bardin and N. Shumeiko, Sov. J. Nucl. Phys. **29**, 499 (1979).