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COMPARISON OF MOMENTS FROM THE VALENCE STRUCTURE FUNCTION
WITH QCD PREDICTIONS

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ABSTRACT

We present moments (both ordinary and Nachtmann) of the nucleon valence structure function measured in high Q^2 ν Fe scattering, supplemented by data from deep inelastic eD scattering. These data seem to agree with QCD predictions for vector gluons. The QCD parameter Λ is found to be of the order 0.5 GeV.

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High Q^2 data from deep inelastic lepton nucleon scattering are particularly relevant for tests of quantum chromodynamic field theory of strong interactions (QCD). Substantial variations of the structure functions with Q^2 have been observed in deep inelastic electron¹⁾, muon²⁾ and neutrino^{3,4)} scattering. Threshold effects (e.g. onset of charm production) have not been sufficient to explain these deviations, particularly at large x , whereas such scaling violations are expected from QCD.

In this letter we report on an analysis of moments of the valence structure function xF_3 in a Q^2 range from 6.5 to 75.0 (GeV/c)². We use the data from the CDHS neutrino experiment⁴⁾ performed in the narrow-band beam at the CERN SPS in 1977 together with part of the data obtained in eD scattering at SLAC¹⁾. In recent work, based on BEBC/GGM neutrino data³⁾, the authors observe quantitative agreement with QCD. On the other hand tests of QCD are more relevant at large values of Q^2 because there the predictions of the theory are more reliable. Higher order corrections are less important and target mass effects are inversely proportional to Q^2 . The contribution from elastic events is negligible in the Q^2 region used in this analysis.

The moments of the structure function xF_3 are defined:

$$M(N, Q^2) = \int_0^1 x^{N-2} \cdot xF_3(x, Q^2) dx \quad (1)$$

where x is the Bjorken scaling variable $x = Q^2/2M\nu$. QCD makes simple predictions⁵⁾ for the variation with Q^2 of these moments. According to this theory the moments develop with Q^2 as

$$M(N, Q^2) \propto \left[\ln \frac{Q^2}{\Lambda^2} \right]^{-d_N} \quad (2)$$

where Λ is an arbitrary parameter and d_N (the "anomalous dimension") is a constant depending only upon the number of flavours N_f :

$$d_N = \frac{4}{33 - 2N_f} \left[1 - \frac{2}{N(N+1)} + 4 \sum_{j=2}^N \frac{1}{j} \right] \quad (3)$$

Expression (2) is valid in the limit $Q^2 \gg \Lambda^2$ and $Q^2 \gg M^2$, where M is the nucleon mass. Nachtmann has shown⁶⁾ that at low Q^2 , the kinematical target mass effects, of the order of Q^2/M^2 can be in part accounted for if the definition (1) for the moments is replaced by

$$\hat{M}(N, Q^2) = \int_0^1 \frac{\xi^{N+1}}{x^3} xF_3(x, Q^2) \frac{1 + (N+1)\sqrt{1 + 4M^2x^2/Q^2}}{N+2} dx \quad (1')$$

where $\xi = \frac{2x}{1 + \sqrt{1 + 4M^2x^2/Q^2}}$.

The two definitions (1) and (1') are equivalent at high Q^2 but differ appreciably at lower Q^2 , especially for the higher moments.

In the following, the results are presented for both the simple and the Nachtmann moments. The difference in the two results may be a measure of the uncertainty in the prediction of the theory, at least as far as the target mass effect is concerned.

For fixed Q^2 the measurements do not cover the whole domain $0 < x < 1$. No data are available at small x and large Q^2 because of the upper limit in the available neutrino energy, and at large x and small Q^2 because of limited experimental resolution. The deficiency at large x and small Q^2 can in large measure be overcome by supplementing our neutrino measurements with the precise data available from deep inelastic electron deuteron scattering.

The use of eD-data together with neutrino data is justified by the quark parton model. For the large x region used, the sea contribution to the structure function F_2^{eD} is negligible⁴⁾ and the simple relation between the structure function

$$xF_3^{\text{vN}} = \frac{9}{5} F_2^{\text{eD}} \quad (x \geq 0.4)$$

is valid. There is also experimental evidence for this relation in the region of overlap of the two experiments at small Q^2 ⁴⁾. Furthermore we used the more precise data for F_2^{vN} instead of xF_3^{vN} for $x > 0.4$.

Even with the combined sample one has to extrapolate xF_3 to the limits $x = 0$ and $x = 1$. This is done by parametrizing the structure function as $x^\alpha(1-x)^\beta$. To clarify this extrapolation Table 1 gives the fraction of the moments which is effectively measured at different Q^2 . For the further analysis, we leave out the first moments at large Q^2 and large N moments ($N \geq 7$), for which the corrections are larger than 25%.

The first test of QCD follows from equation (2). If one plots the logarithm of a moment $M(i, Q^2)$ against the logarithm of another moment $M(j, Q^2)$, the points are expected to fall on a straight line with slope d_i/d_j independent of Λ and the number of flavours. Figure 1 shows this correlation for M_3 vs M_5 and M_4 vs M_6 for both definitions of the moments (1) and (1'). In all cases the data are consistent with a linear dependence. The slope allows a test of the vector or scalar nature of gluons. The various slopes are listed in Table 2 and compared with previous results from BEBC/GCM and the predictions of QCD for vector gluons as well as for a scalar gluon theory. There is good agreement between both measurements (Fig. 2) and the QCD predictions, furthermore vector gluons are favoured over scalar gluons.

An additional independent test of QCD can be obtained by rewriting equation (2) as follows:

$$[M(N, Q^2)]^{-1/d_N} \propto (\ln Q^2 - \ln \Lambda^2). \quad (3)$$

Here the $(-1/d_N)^{\text{th}}$ powers of the N^{th} moments are expected to lie along straight lines when plotted against $\ln Q^2$ and all lines should have a common intercept which is $\ln Q^2 = \ln \Lambda^2$. In Fig. 3 it can be seen that this linear relation (3) is satisfied by the data for both definitions of the moments, however the slopes and also the intercepts are substantially different for the two definitions. For Λ the results are:

$$\begin{aligned} \Lambda_{\text{ordinary}} &= 0.60 \pm 0.15 \text{ GeV} \\ \text{and} \quad \Lambda_{\text{Nachtmann}} &= 0.33 \pm 0.10 \text{ GeV}. \end{aligned}$$

In this analysis we have assumed four quark flavours. Since part of the data is below the charm production threshold, we have repeated the determination for three flavours, which would give a 60 MeV increase for Λ . A further possible uncertainty, the relative normalization of ν and the eD experiments, could change Λ by, at most, 10%. Finally the data are not corrected for Fermi-motion, which could also introduce a shift in Λ of the order of 10%.

In a completely different analysis of the neutrino data which avoids the moment extrapolation as well as the low Q^2 , large x eD-data, and is therefore much less bothered by target mass effects, we obtain the value $\Lambda = 0.47 \pm 0.20 \text{ GeV}^7$, including systematic errors.

In conclusion, the Q^2 behaviour of the moments of the valence structure function xF_3 is in good agreement with the predictions of QCD in a Q^2 range relevant to this theory. The ratio of the anomalous dimension for vector gluons has been verified and Λ has been measured to be of the order of $0.5 \pm 0.2 \text{ GeV}$.

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TABLE 1

Measured fraction of moments (in %).
Moments in the outlined area only are used.

Q^2 N = (GeV/c) ²	2	3	4	5	6	7
4.0	83	70	53	40	26	15
6.5	95	94	90	84	77	70
10.0	95	94	90	84	77	71
21.0	81	92	90	85	79	72
45.0	56	78	85	84	79	72
75.0	34	58	72	77	76	71
120.0	18	36	52	61	65	65

TABLE 2

Ratios of anomalous dimensions

	This experiment	BEBC/GGM		Theory	
	$\int x^{N-2} xF_3 dx$	Nachtmann moments	Nachtmann moments	Vector	Scalar
d_3/d_5	1.58 ±0.12	1.34 ±0.12	1.50 ±0.08	1.46	1.12
d_4/d_6	1.34 ±0.07	1.18 ±0.09	1.29 ±0.06	1.29	1.06
d_3/d_6	1.76 ±0.15	1.38 ±0.15	---	1.62	1.21

TABLE 3

Values of Λ from different moments

N =	3	4	5	6
Ordinary $\Lambda =$ moments (GeV)	0.54 ±0.13	0.57 ±0.13	0.62 ±0.11	0.65 ±0.11
Nachtmann $\Lambda =$ moments (GeV)	0.35 ±0.13	0.36 ±0.12	0.32 ±0.10	0.27 ±0.10

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FIGURE CAPTIONS

Fig. 1: Ordinary and Nachtmann moments for different Q^2 values. The straight lines are fits to the data with fixed slopes, predicted from QCD (vector gluons).

a) $M_N(Q^2) = \int_0^1 x^{N-2} xF_3 dx$, M_3 versus M_5 . The correlation between the moments is indicated by the error ellipse.

b) M_4 versus M_6 .

c) Nachtmann moments $\tilde{M}_N$, $\tilde{M}_3$ versus $\tilde{M}_5$.

d) $\tilde{M}_4$ versus $\tilde{M}_6$.

Fig. 2: Nachtmann's moments from this experiment together with BEBC/GCM³ data and the QCD vector gluon lines. The errors of BEBC/GCM are uncorrelated.

Fig. 3: Ordinary and Nachtmann moments as a function of Q^2 . The straight lines are fits with a common intercept.

a) $M^{-1/dN}$ versus Q^2 for $N = 3, 4, 5$ and 6 .

b) $\tilde{M}^{-1/dN}$ versus Q^2 for $N = 3, 4, 5$ and 6 .

Fig. 1

Fig. 2

Fig. 3