Neutron structure function moments at leading twist

M. Osipenko*, S. Simula†, S. Kulagin**, G. Ricco‡ and CLAS Collaboration§

Abstract. The experimental data on $F_2$ structure functions of the proton and deuteron were used to construct their moments. In particular, recent measurements performed with CLAS detector at Jefferson Lab allowed to extend our knowledge of structure functions in the large-$x$ region. The phenomenological analysis of these experimental moments in terms of the Operator Product Expansion permitted to separate the leading and higher twist contributions. Applying nuclear corrections to extracted deuteron moments we obtained the contribution of the neutron. Combining leading twist moments of the neutron and proton we found $d/u$ ratio at $x \to 1$ approaching 0, although $1/5$ value could not be excluded. The twist expansion analysis suggests that the contamination of higher twists influences the extraction of the $d/u$ ratio at $x \to 1$ even at $Q^2$-scale as large as 12 (GeV/c)$^2$.

Keywords: nucleon structure functions, moments, twist expansion

PACS: 13.60.Hb, 12.38.Lg, 24.85.+p

DATA ANALYSIS

QCD through the Operator Product Expansion (OPE) allows to relate measurable moments of nucleon structure functions to the series of local operators, so called twists. The Leading Twist (LT) (first term in the series) represents the asymptotic freedom domain. This term is completely determined by perturbative calculations and Lattice simulations. Higher Twists (HT) (all further terms) describe the virtual photon scattering off interacting partons. The complexity of this interaction and therefore of corresponding QCD operators increases with twist order. Calculations of these terms have been performed only in a few cases.

The experimental data on the structure function moments were obtained recently for the proton and deuteron in Refs. [1] and [2], respectively. Moments were extracted from a combined analysis of the structure functions $F_2$ measured at CLAS and other world data on the inclusive lepton-nucleon scattering. This was performed by integrating experimental data points independently at each fixed $Q^2$ value. Hence, the obtained $Q^2$-evolution of the moments is not affected by any model dependence and can be directly compared to pQCD predictions. Example of measured moments is shown in Fig. [1]

---

1 Lattice simulations up to now are limited to a few lower moments
FIGURE 1. Total experimental $n = 6$ moments of the proton (full triangles) and deuteron per nucleon (open squares) structure functions $F_2$. 

one can see the proton and deuteron moments have similar $Q^2$-behavior, but different absolute value. Indeed, in the QCD at the LT two moments should have the same $Q^2$-evolution. This observation suggests that the duality is valid for both targets and the contribution of nuclear HTs\(^2\) is small in the covered $Q^2$-range.

We analyzed these experimentally extracted moments of the proton and deuteron structure functions $F_2$\(^{1,2}\) to separate LT and HT terms. This was performed by fitting the data with the following expression:

$$M_n(Q^2) = \int_0^1 dx x^{n-2} F_2(x, Q^2) = LT_n(\alpha_S) + \sum_{\tau=4}^k a^n_\tau \left( \frac{\alpha_S(Q^2)}{\alpha_S(\mu^2)} \right)^{\gamma^2_n} \left( \frac{\mu^2}{Q^2} \right)^{\tau - 2},$$ \hfill (1)

where $\alpha_S$ is the running coupling constant, $\mu^2$ is an arbitrary scale (taken to be 10 (GeV/c)^2), $a^n_\tau$ is the matrix element of corresponding QCD operators, $\gamma^2_n$ is the anomalous dimension, $\tau$ is the order of the twist and $k$ is the maximum HT order considered. The number of HT terms ($k$) in the expansion is of course arbitrary because we don’t know at which $1/Q^2$ power the series converges. This prevents an evaluation of each separate HT term from the data. Instead, \textit{the total contribution of HTs can be extracted with good precision}. In Fig. 2 one can see that taking two, three or four HT terms in Eq. 1 does not change the total HT contribution. Moreover, this result was expected because the total HT contribution represents simply the difference between the data and calculated LT.

Extracted LT components of the proton and deuteron moments can be combined now to obtain moments of the neutron structure function $F_2$. In the Euclidean space of moments the convolution of the nuclear Impulse Approximation (IA) transforms into

\(^2\) nuclear higher twists are mostly related to Final State Interactions of the nucleon in the nucleus
FIGURE 2. Total higher twist contribution in $n = 8$ moment obtained with the present procedure for different number of terms in the OPE series (see Eq. 1): solid line - two HT terms, dashed line - three HT terms, dotted line - four HT terms.

a product of moments. This allows for a simple extraction of neutron moments from the following algebraic relation:

$$M_n^p(Q^2) = \frac{2M_n^D(Q^2)}{N_n^D} - M_n^p(Q^2),$$

where $M_n^p$, $M_n^n$ and $M_n^D$ are moments of the proton, neutron and deuteron, respectively. $N_n^D$ is the moment of the nuclear momentum distribution $f_D$ i.e. the structure function of the deuteron composed of point-like nucleons (see Ref. [3] for details). This nuclear structure function $f_D$ was obtained from the data on the deuteron wave function.

The data on proton and neutron moments can be used to study the contribution of $u$ and $d$ quarks in the proton at $x \rightarrow 1$. Assuming that $u$ and $d$ quark distributions in the proton and neutron are the same $^3$ the $d/u$ ratio at the leading twist accuracy can be related to the ratio of neutron to proton structure functions $F_2^n/F_2^p(x \rightarrow 1)$. This ratio, in turn, is equal to the ratio of moments of these structure functions $M_2^n/M_2^p(n \rightarrow \infty)$. The latter equality requires only that $F_2^n/F_2^p(x \rightarrow 1) \rightarrow a^{p,n}(1-x)^{b^{p,n}}$, which follows from the analyticity of the forward Compton amplitude in OPE. Instead, the existence of a finite $F_2^n/F_2^p(x \rightarrow 1)$ limit guarantees that exponents $b^p$ and $b^n$ are exactly the same. We constructed these ratios of moments and results are shown in Fig. 3. As one can see our data tend to the “standard” $1/4$ value used in most of parton distribution fits. This value corresponds to the vanishing $d/u$ ratio. However, the precision of our data does not allow to exclude $3/7$ value corresponding to $d/u$ ratio $1/5$. In the Fig. 3 one also can see the impact of the HT contribution on the ratio at $Q^2 = 12$ (GeV/c)$^2$. The previous analysis [4] performed in the $x$-space showed that applying similar nuclear corrections the ratio of

$^3$ though the number of $u$ and $d$ quarks is of course different
structure functions $F_2^n/F_2^p (x \rightarrow 1)$ goes to $3/7$ at $Q^2 = 12 \text{ (GeV/c)}^2$. No corrections on the possible HT contamination has been applied in this article, assuming that at such large $Q^2$ they are negligible. Therefore, if instead of LT part we take measured inelastic moments, containing also HT terms, and construct the same ratios we should confirm the result from Ref. [4]. Indeed, in the Fig. 3 one can see that the ratio of moments including HTs tends to $3/7$ at largest $n$ ($n = 12$ corresponds to $x$ values about 0.75). This result could also be deduced from the isospin independence of HTs observed in the Ref. [3].

CONCLUSIONS

We obtained the experimental data on moments of proton and deuteron structure function $F_2$. In these data contributions of the leading and higher twists were separated via OPE analysis. By combining the proton and deuteron moments and applying nuclear corrections we extracted moments of the neutron structure function $F_2$. The ratio of the neutron and proton moments at large $n$ is related to the ratio of $d$ and $u$ quark contributions in the proton at large-$x$. The obtained ratio is consistent with the asymptotic limit $d/u \rightarrow 0$ at $x \rightarrow 1$, which originates from the dominance of soft, non-perturbative physics at large-$x$. Nevertheless the alternative value of $1/5$, derived from helicity conservation arguments, is not excluded. The HT contamination to the ratio, if not subtracted as in the present analysis, influences significantly the extracted $d/u$ ratio also at large $Q^2$-values.

REFERENCES

1. M. Osipenko, et al., Phys. Rev. D67, 092001 (2003).
2. M. Osipenko, et al., Phys. Rev. C73, 045205 (2006).
3. M. Osipenko, et al., Nucl. Phys. A766, 142 (2006).
4. W. Melnitchouk, and A. Thomas, *Acta Phys. Polon.* **B27**, 1407 (1996).