MEASURABILITY OF THE PROTON STRUCTURE FUNCTIONS AT VERY HIGH x AT HERA II*

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In this paper we address a question of measuring a proton Structure Functions (SF) at Bjorken $x \sim 1$. A new method which allows for a measurement of SF at high x to be done with large data samples is proposed. Expected measurements after HERA luminosity upgrade are estimated using a Monte Carlo simulation. This shows that $\sim 30\%$ precision can be achieved for the highest x-bins with $1\mathrm{fb}^{-1}$ of data in so far experimentally unconstrained region. Impact of this measurement on constraining the fundamental physics is discussed. A measurement with proton beam energy lowered to half (460 GeV) is discussed as well.

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1. Structure functions at very high x

In DIS regime the structure functions can be expressed in terms of the parton distribution functions (PDF). The distributions fall down very quickly as $x \to 1$ which makes the measurement difficult both because of limited statistics and large migrations from lower x regions.

For $x > 0.5$ the relative uncertainties on PDFs exceed 30% [1] and grow with x. It was shown [2] that there is an extra uncertainty associated with the parametrization function assumption. The existing data allow for a big enhancement of PDFs at $x > 0.7$ and can even become infinite at $x = 1$.

The highest measured data points $x = 0.75$ in DIS regime come from the BCDMS collaboration [3]. Other published data sets are either in the resonance at low $W \sim 1$–2 GeV (SLAC) or being performed on heavy targets (CCFR) and cannot be reliably related to the proton PDFs at high x. The highest x data points measured at HERA are at $x = 0.65$ [4,5].

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2. HERA kinematics at very high x

HERA is an electron proton collider with beam energies $E_e = 27.5\,\mathrm{GeV}$ and $E_p = 920\,\mathrm{GeV}$. For very high x the struck quark carries a big part of the protons energy and all the system is boosted in the forward direction. The electrons are scattered in large angles with high energies up to $x = 1$ and the efficiency for their detection is close to 100%. In addition electrons provide a good resolution on the momentum transfer Q^2. However, the resolution on x is very poor[1] for $x > 0.1$ and there is no distinction between large and medium x. The hadronic energy in a form of high energy jet escapes the detector down the beam pipe above some x for a given Q^2 (red curve in Fig. 1); the acceptance for hadrons becomes zero. Using jet, however, leads to a very precise measurement of x with a low sensitivity to the initial state radiation.

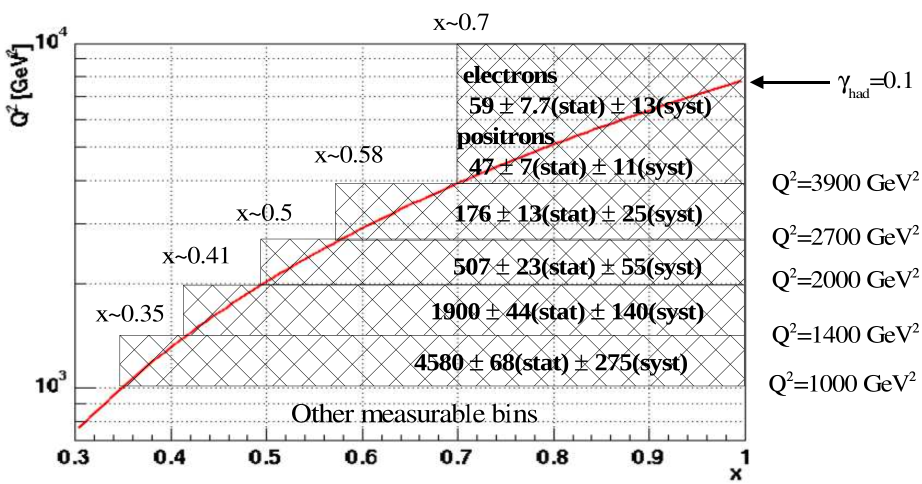

Fig. 1. Expected number of measured events for $1\mathrm{fb}^{-1}$ of data with $Ep = 920\,\mathrm{GeV}$

The kinematics and standard methods used to reconstruct kinematical variables x and Q^2 are reviewed in more detail in [6]. None of the standard methods is, however, suitable for measuring SF at very high x.

3. Proposed method

The proposed method for measuring structure function combines the property of high acceptance and good Q^2 resolution from the electron method with the good resolution on x from the jet. The steps for data selection are as follows:

[1] For $x = 0.7$ and $Q^2 = 2500\,\mathrm{GeV}^2$ the resolution on x with electron method is $\delta(x) = 0.16$.

(1) Select all the events in a given Q^2 range $Q^2_{\rm min} < Q^2 < Q^2_{\rm max}$ by the electron method.

(2) Throw away all the events with x measured using jet to be lower than specified value $x_{\rm min}$.

This value must be in a region of the detector with good reconstruction for jets for all Q^2 in a given range. What is left are the events with x higher that the cut.

In this way an integral of the cross-section over the bin $x_{\rm min} < x < 1.$ and $Q^2_{\rm min} < Q^2 < Q^2_{\rm max}$ can be measured.

4. Expected measurements at HERA II

The expected numbers of events were estimated using a Monte Carlo simulation program. Events are generated according to Born-level cross-sections[2]. The detector was assumed to have simple Gaussian type resolution with parameters of the ZEUS detector [4]. The jet is assumed to be well contained for angles $\gamma_{\rm had} > 0.1$. The main source of systematic errors is the uncertainty on the hadronic energy scale ($\delta E_{\rm had} = 2\%$).

The expected number of events to be measured for integrated luminosity of $\mathcal{L} = 1{\rm fb}^{-1}$ as is expected after HERA upgrade are shown in Fig. 1. For very high Q^2 bin there is about 15% difference on the cross-sections for electrons and positrons due to interference of the photon and Z boson exchange. For lower Q^2 the bins could be combined in order to enhance the statistics. The purities are $\approx$ 70% and efficiencies are $\approx$ 80%. The largest source of the migrations comes from the misreconstruction of Q^2 to be higher for events with ISR. This effect should be, however, well simulated in the Monte Carlo. The migrations across the x boundary are the largest for the highest x bin ($\sim$ 10%) and drop down to $\sim$3–5% for bins starting at lower x. Except for the highest x and Q^2 bin the migrations across Q^2 boundary dominate.

For the highest x bin ($x > 0.7$) which is the most interesting for resolving possible anomaly at $x \sim 1$ the relative precision is $\approx$ 30%. The differences between predictions of different CTEQ4 and MRS99 sets of parton distributions are of the order of 10%. These, however, do not include the uncertainties due to parametrization assumption. However, other parameterizations allowed by existing data [2] allow for an enhancement by a factor of 6! Therefore, the PDFs at high x can be constrained by experiments at

[2] Radiative corrections and higher twist effects may be large in this region of phase-space.

HERA after luminosity upgrade. In addition the effect of higher twist contributions and radiative corrections may be large in this region and can be constrained.

For bins starting at lower x the relative precision of the measurement is increased. On the other hand the cross-section is a steeply falling function of x and the number of events in the bin is dominated by lower values of x in that bin. A resolution on the possible anomaly at $x \sim 1$ is, therefore, reduced.

It would be an advantage for this measurement if the proton energy could be lowered to half (460 GeV) of its present value. The quarks in the interaction are not as energetic and the boost to forward region is not that pronounced. The access to large x starts at lower Q^2 values and the cross-sections are higher. On the other hand the expected luminosity is lower hence an integrated luminosity of 100 pb^{-1} was assumed for this study which would correspond to 1 year of data taking. The results are shown in the Fig. 2. The difference between the cross-sections for electrons and positrons is small in this case. Expected precision of the measurement is similar to that of 1fb^{-1} of running with nominal proton energy.

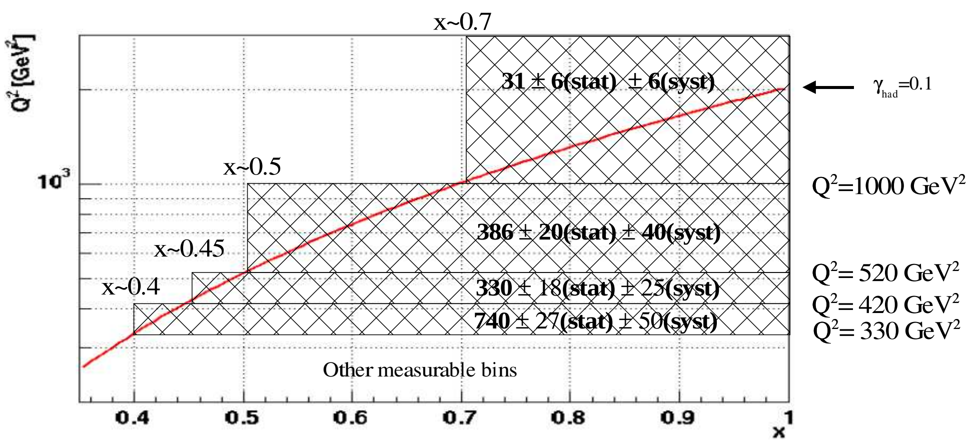

Fig. 2. Expected numbers of events for 100 pb^{-1} of data with $Ep = 460\,\mathrm{GeV}$.

5. Conclusions

A new method to measure proton structure functions at very high x is proposed. It is shown that a $\sim 30\%$ precision can be achieved for the bin $0.7 < x < 1$ and $Q2 > 3900\,\mathrm{GeV}^2$ with 1fb^{-1} of data. With such precision the structure functions can be constrained in this so far unexplored part of the phase-space. The implications on physics range from discriminating between different parameterizations of parton distributions to constraining higher twist effects and radiative correction. In addition a good knowledge of proton structure at large x will help to understand the searches and measurements at proton colliders like Tevatron or LHC.

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