# $F_2^N$ at Low $Q^2$

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There are several examples in nature where a force can appear to have a different behavior depending on the distance over which it acts. The Coulomb force between the electrons and the nucleus of an atom has a strength that falls off with the square of the distance between these charges, while at larger distances electrically neutral atoms attract each other via Van der Waals forces which fall off as the sixth power of the distance between them. Yet, the apparently different Coulomb and Van der Walls forces are manifestations of the same fundamental theory of electromagnetism. Similarly, the strong nuclear force which binds the quarks in hadrons can be calculated via QCD at short distance scales. But, we have not thus far been able to describe using QCD the forces at distances comparable to the size of hadrons.

The fundamental nucleon structure function $F_2$ may be studied in the transition region between distances comparable to, and small with respect to, the size of the proton using $Q^2$ as a measure of the wavelength of the virtual photon probe. This quantity has been measured over several orders of magnitude in $Q^2$ and $x$, and is well understood at high $Q^2$ in terms of logarithmic scaling violation. However, at low $Q^2$, there is almost no data in the region $Q^2 < 1$ (GeV/c)$^2$ and $0.005 < x < 0.2$. Moreover, data at low $Q^2$ and very low $x$ from DESY indicate that $F_2$ falls proportionally to $Q^2$. This latter is a reflection of fundamental symmetries and conservation laws. At it's most basic level, the $F_2$ structure function parameterizes the coupling between a point-like photon and a charged quark. Conservation of the electromagnetic current that generates the photon requires $F_2$ to vanish as the virtuality of the photon goes to zero.

An energy-upgraded Hall C, with a high momentum, small angle spectrometer, will extend the measured $F_2$ range to a to a region of relatively high $W$ where the drop-off in $F_2$ has been observed, and where the short distance scale QCD appears to be failing.

The proton and neutron structure functions $F_2^N$ are fundamental to our understanding of physics at the nucleon scale. Fig. 1 shows a set of the world proton structure function data $F_2^p$ as a function of $Q^2$, binned in $x$ [1].

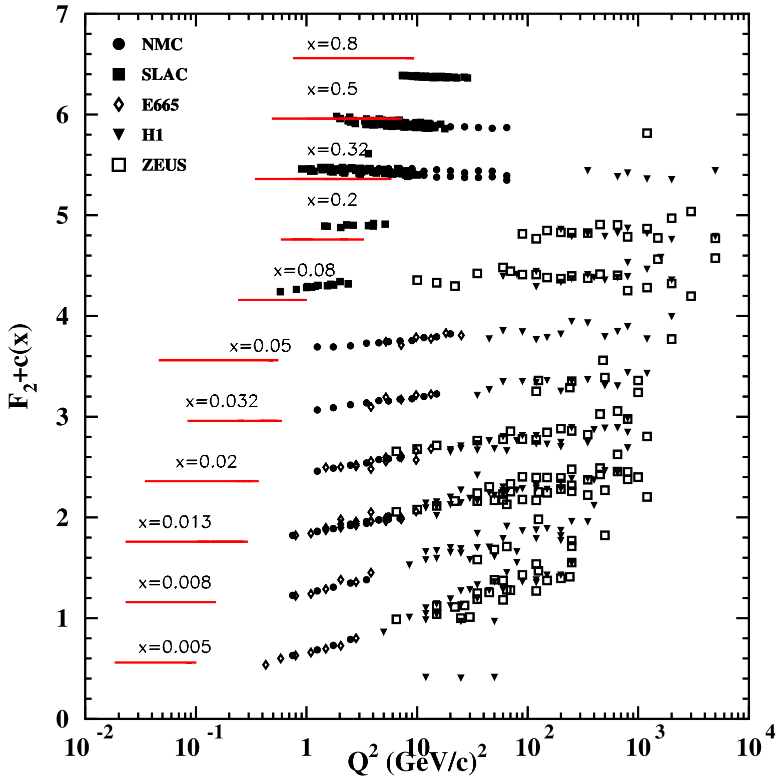


Figure 1: $F_2^p$ as a function of $Q^2$ for several values of $x$. The symbols indicate various experiments [1]. The solid lines indicate the region that will be accessible in Hall C at JLab. For plotting clarity each $x$ bin is offset by a constant.

In the high $Q^2$ regime, perturbative Quantum Chromodynamics (pQCD) calculations of leading order (LO) and next–to–leading order (NLO) terms together with target mass corrections reproduce the data very well. At values of $x$ from 0.005 to about 0.2, however, there are almost no data in the region $Q^2 < 1$ (GeV/c)$^2$. The solid lines represent the kinematic coverage that will be accessible with an electron beam of up to 11 GeV and a spectrometer that can reach a 5.5° angle. The objective of this experiment is to obtain data that will cover both the resonance region (low $x$) and the deep inelastic scattering (DIS) region (moderate $x$) at low $Q^2$.

Fig. 2 shows proton structure function data as a function of $x$, for several values of $Q^2$ between 0.1 and 3 (GeV/c)$^2$. The deep inelastic scattering data originate from different experiments from SLAC, CERN, FNAL, and DESY [1], while the data in the resonance region were obtained at SLAC [2] and Jefferson Lab [3]. The solid curves indicate the next–to–leading order calculations of Gluck, Reya, and Vogt (GRV) [4, 5]. As one can see the pQCD–based calculation agrees well with the data for $Q^2 = 0.9$ and 3 (GeV/c)$^2$. In the proton resonance region, the resonances oscillate around the DIS curve, exhibiting the local duality observed by Bloom and Gilman in 1968 [6].

Turning our attention to the bottom two panels of Fig. 2, $Q^2 = 0.3$ and 0.1 (GeV/c)$^2$, we first note the paucity of data: there are only sparse data from FNAL, the recent DESY data, and the resonance region data. The DESY data exhibit a very strong $Q^2$ dependence of $F_2^p$ at very small $x$. One interpretation of this effect is that at these low values of $Q^2$ we see a transition from the parton model to the real photon point at $Q^2 = 0$, rather than a breakdown of the parton model. On the other hand, the nucleon resonance data, at $x \approx 0.1$, do not exhibit such a drastic collapse in $Q^2$, and stay fairly constant. The structure function data in this region still seem to oscillate around one $Q^2$-independent global curve, showing a rather shallow $Q^2$ dependence, mimicking a valence–like quark distribution [7].

The objective of the proposed experiment is to extend the existing Jefferson Lab data down in both $Q^2$ and $x$, in the region where a drop off in $F_2$ has been observed and the parton model appears to be failing. This experiment will take advantage of the high energy electron beam (up to 11 GeV) and of the very forward angle that can be reached by the Super-HMS (5.5°) in Hall C. Over the kinematic range proposed, the rates are very high (1 kHz and higher for 10 to 50 $\mu$A beam currents). Thus, the statistical uncertainty for measuring inclusive electron scattering cross section will be 1% or better. The present experiment will provide a large volume of high precision data which will aid efforts to develop global descriptions of the inclusive electron–nucleon scattering in the low $Q^2$ region. In addition, the resonance region data will allow studies of Bloom–Gilman (or quark–hadron) duality, at low values of $Q^2$.

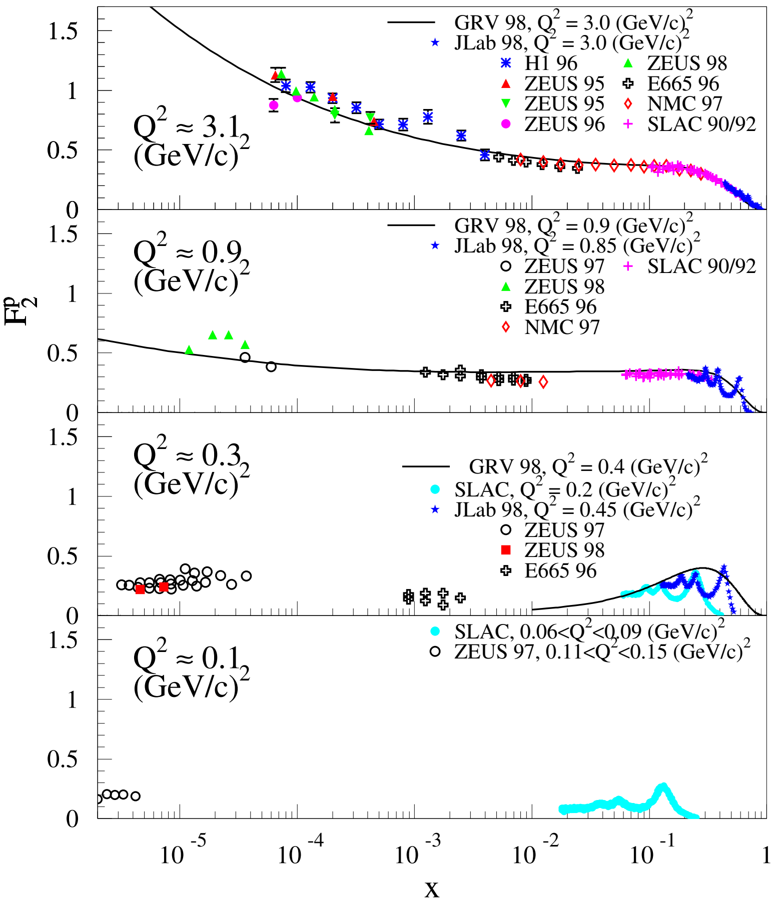


Figure 2: $F_2$ as a function of $x$ for four values of $Q^2$, with a logarithmic $x$ scale. The symbols indicate various experiments, as cited in the text. The solid curves in the top two panels represent the calculated distributions from the GRV collaboration [4, 5], evolved from $Q^2 = 0.4$ (GeV/c)$^2$. The solid curve in the third panel represents the input distribution itself.

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