DEEP INELASTIC SCATTERING AND QCD

Workshop Participants

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Two aspects of deep-inelastic scattering may be distinguished. At the purely **inclusive level**, the cross sections may be expressed in terms of hadron structure functions $F_i(x,Q^2)$ whose dependence on Q^2 is of great interest in QCD. Second, there is the **hadron vertex itself**. Analyses of the final state hadron distributions at Tevatron energies should provide a wealth of information of relevance to constituent scattering models and important tests of QCD. We discuss both of these issues.

1. Inclusive

An obvious advantage of the Tevatron is that the accessible range in Q^2 is extended to $Q^2 \simeq 600$ GeV^2, roughly a factor of two above that of existing machines. In principle, therefore, the measurements of $F_1(x,Q^2)$, $F_2(x,Q^2)$, and $F_3(x,Q^2)$ can be extended in Q^2 far beyond present limits. According to QCD expectations, $F_2(x,Q^2)$ (for $x \gtrsim 0.3$) should fall off slowly with increasing Q^2. Once Q^2 is large enough that all inverse-power, higher-twist terms ($\propto 1/Q^2$) have died out, theory predicts that $F_i(x,Q^2)$ should fall as $1/\ln Q^2$. One possible extrapolation[1] to large Q^2 is shown in Fig. 1.

In typical electronic experiments, statistical errors are negligible, but systematic problems may limit one's ability to ascertain whether there is a measureable decrease of $F_i(x,Q^2)$ with Q^2 at large Q^2 ($Q^2 \gtrsim 100$ GeV^2) or, if so, to place stringent limits on the QCD scale parameter Λ in $\alpha_s \propto 1/\ln(Q^2/\Lambda^2)$. The goal is to determine whether asymptotic freedom is consistent with Nature. To do so, one must establish that the structure functions fall monotonically with increasing Q^2. Setting aside our faith in gauge theories for an instant, it is amusing to recall that not so long ago most physicists expected that hadron-hadron total cross sections would approach constant values or would continue to fall as energies were increased. Will experimenters find that the $F_i(x,Q^2)$ cease to decrease in the Tevatron range and instead begin to grow?

"New" problems in addition to systematic errors must be faced in the region $Q^2 \gtrsim 200$ GeV^2. For $\mu N \to \mu' X$, these include **weak-electromagnetic interference**, due to Z^0 exchange. The interference induces a Q^2 dependence which is different for μ^+ and μ^- scattering. The effect does not depend strongly on x; it begins to be significant above $Q^2 \simeq 50$ GeV^2.

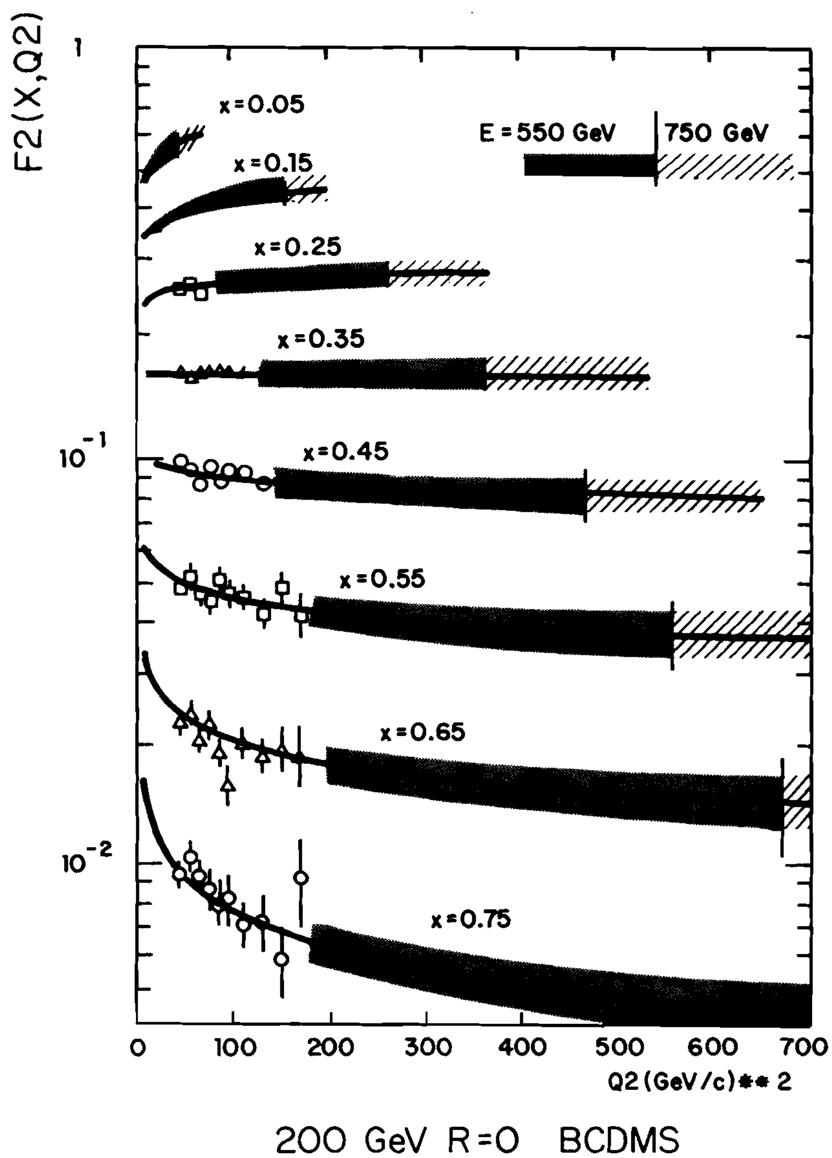

Fig. 1. Data of the Bologna-CERN-Dubna-Munich-Saclay collaboration on $\mu N \to \mu' X$ at the CERN SPS along with a QCD extrapolation of the expectd behavior of $F_2(x,Q^2)$. This figure is taken from Tevatron proposal 648. The bands show the estimated systematic uncertainties.

For both $\mu N \to \mu' X$ and $\nu N \to \mu X$, there are difficulties associated with **heavy-flavor thresholds.** The onset of charm, bottom, and top production contributes to an increase of the $F_i(x,Q^2)$ with Q^2 in the low x region.[2] These effects must be subtracted. Fortunately, the effects can be measured in an apparatus with good multimuon detection efficiency.

For $\nu N \to \mu X$, effects associated with the W propagator $(1 + Q^2/M_W{}^2)^{-1}$ become significant in the Tevatron range of Q^2.

In analyses of both νN and μN data, electromagnetic radiative corrections induce a significant dependence on Q^2 which varies strongly with x.

Most of the above "problems" are interesting physical effects in their own right. However, from the point of view of the Q^2 dependence of structure functions, they are sources of error to be identified and subtracted before comparison with QCD predictions.

The **experimental** determination of the value of $R(x,Q^2) \equiv \sigma_L/\sigma_T$ is of substantial importance in both ν and μ experiments. Assumptions about the value of R are known to affect statements about the Q^2 dependence of $F_2(x,Q^2)$. Moreover, R provides a good test of QCD in more than one way. Because of helicity conservation, one predicts that R = 0 at the simplest Born approximation level of the parton model. However, higher twist effects[3] supply a non-zero value of R, principally at large x, and higher-order gluonic radiation effects[2] generate a significantly large value of R at small x. The dependence on Q^2 is different for the higher-twist $(1/Q^2)$ and higher-order $(1/\ln Q^2)$ terms.

In μ and ν experiments, the determination of $R(x,Q^2)$ requires data over a large range in y. For fixed values of x and Q^2, y varies inversely with the value of the incident lepton energy E_ℓ. In ν experiments, a range of E_ℓ is supplied naturally in both wide-band and narrow-band beams. For muons, however, the measurement of R requires data at several different values of E_μ. At the Tevatron, μ beams are foreseen at energies of 280, 550, and 750 GeV. A good determination of R_μ should be possible.

The extraction of both singlet and non-singlet structure functions in μN experiments requires data from hydrogen and deuterium targets.

Hadron Final States

For the first time, Tevatron energies will increase the range of W sufficiently to allow unambiguous separation of the current and target fragmentation regions in the hadronic final state. Here, W is the total energy of the hadrons (X) in $\nu N \to \mu' X$ or $\nu N \to \nu' X$. The hadron correlation length in rapidity is known to be roughly 2 units. **Clean separation** of hadrons associated with the "struck quark" from those associated with the residual target debris therefore requires $Y = \ell n\ s \geq 4$, or $W = (s)^{1/2} \gtrsim 10$ GeV.

As shown in Fig. 2, a statistically very significant sample of events with $W^2 \gtrsim 100\ \mathrm{GeV}^2$ should be obtained in Tevatron experiments, at least with muon beams.[4] We list some of the interesting measurements to be made.

i) The fragmentation functions $D(z,Q^2)$ can be determined cleanly in the time-like region $Q^2 < 0$ over a wide range of Q^2. The universality and factorization properties of this function are of great interest: viz., is it the same as $D(z,Q^2)$ determined in e^+e^- annihilation at $Q^2 > 0$. The Q^2 evolution of $D(z,Q^2)$ is predicted by QCD. At low Q^2, higher-twist effects should dominate the Q^2 variation, while logarithmic dependence sets in at high Q^2 (first order, higher-order,...).

ii) Are there significant correlations between the x and z dependences and/or the y and z dependences of the cross section? Higher-order QCD calculations suggest that the double moments do not factor;[5] thus, (x,z) correlations are expected at some level. The y and z dependences are correlated through higher-twist phenomena,[6] as was observed recently in Gargamelle data[7]

$$D(z,y,Q^2) \simeq f(z) + \frac{c}{Q^2}\,(1-y),$$

where $c \simeq 0.75\ \mathrm{GeV}^2$.

iii) Investigations can be made of the fragmentation of the "diquark" system in the target fragmentation region[8] and in the current fragmentation region.[3]

iv) The phenomenon of jet broadening can be studied in the current fragmentation region. The value of $\langle p_T^2 \rangle$ is expected to increase with Q^2 in a well defined way in QCD, associated with gluonic radiation. Higher-twist phenomena[6] also lead to an increase of $\langle p_T^2 \rangle$ with z at fixed Q^2. It should be possible to separate these two effects cleanly through their different dependence on Q^2.

Perhaps the most interesting phenomenon to be observed will be the expected multijet structure in the current fragmentation region. For events with $W \gtrsim 20$ GeV, it should be possible to see clear **two-jet patterns** corresponding to $\gamma^* q \to qg$, and $\gamma^* g \to q\bar{q}$. These **two-jet** patterns are the analogues of the three jet patterns ($\gamma^* \to qqg$) identified for $W \simeq 30$ GeV in PETRA experiments.

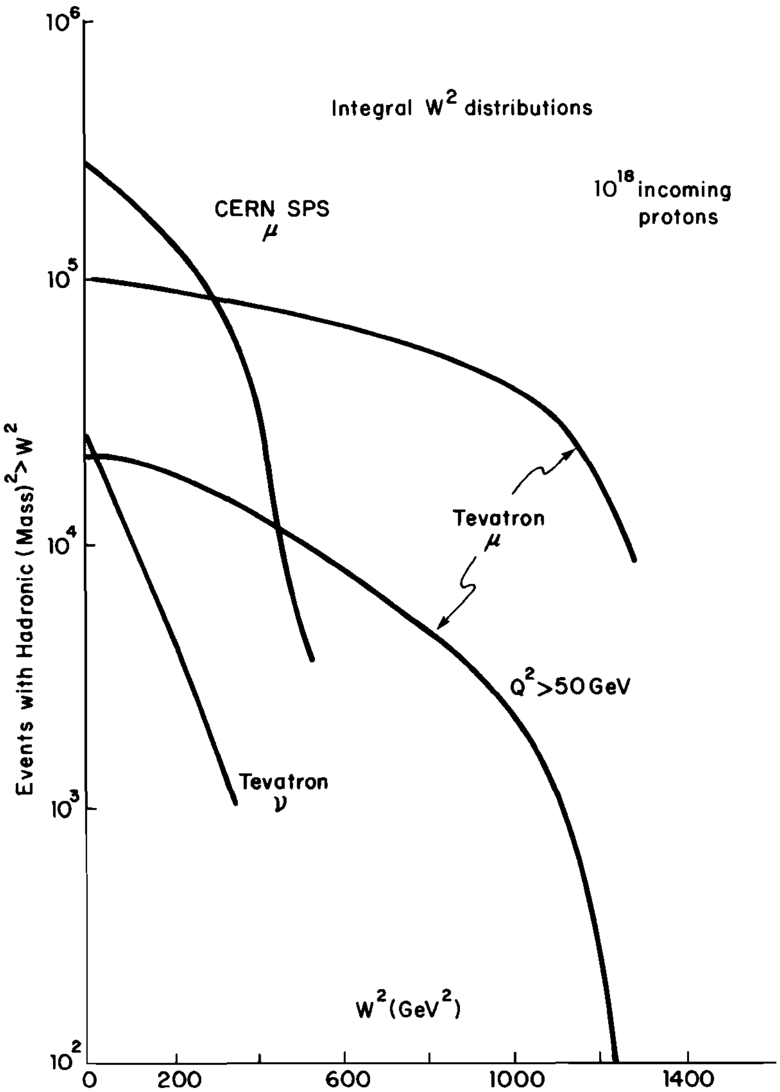

Fig. 2. The number of events expected with squared hadronic energy greater than W^2 for a) all Q^2, and b) $Q^2 > 50$ GeV^2, in deep inelastic muon scattering with the Fermi National Accelerator Laboratory tevatron muon beam. The vertex detector is a 2 m streamer chamber containing a 1 m liquid H_2 target, as described in Tevatron proposal 658.

Once the relevant data sample is in hand, one can envisage measurements of $\alpha_S(Q^2)$, the determination of angular distributions intimately connected with the value of the gluon spin, and so forth. Note that these jet studies will be carried out for values of $Q^2 < 0$, as distinct from the $Q^2 > 0$ domain of e^+e^- studies.

References

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