Measurement of Charged-Hadron Multiplicities in Deep-Inelastic Electron-Proton Scattering*

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We report measurements of the charged-hadron multiplicity for electrons scattered by protons at momentum transfers up to $Q^2=8$ GeV^2, and for s up to 14 GeV^2. The multiplicity is consistent with a simple ln$s$ behavior, with little or no Q^2 dependence above $Q^2=1.4$ GeV^2.

Much of the recent interest in hadron collisions at high energy has focused on global features of the final states, such as the dependence of the average charged-hadron multiplicity on the squared c.m. energy s and the relative yields in the various multiplicities. We can expect the same kind of global information to be even more interesting for the hadron final states in deep-inelastic electron scattering, since the final-state multiplicities and inclusive spectra in the virtual-photon-nucleon collision can vary with the virtual-photon mass squared, $q^2=-Q^2<0$, as well as with s. Although the models which are still surviving tend to have rather similar predictions for hadron collisions, their predictions, for the electroproduction final states can be quite different.[1]

The extracted electron beam from the Cornell synchrotron passed through a 2.6-cm liquid-hydrogen target and on to a secondary-emission monitor. Scattered electrons were detected in a spectrometer consisting of a bending magnet, eight proportional wire chambers, three planes of scintillation counters, and a lead-Lucite shower telescope. The scattered electron aperture covered a solid angle of 30 msr and extended from 9° to 20° in some of the data runs, and from 14° to 25° in other runs with the detectors moved farther from the beam line. The rms resolution in Q^2 and s was typically 0.5 and 2 GeV^2, respectively.

A single-layer array of 68 scintillation counters completely enclosed the target, except for a 3° forward cone and a 20° backward cone. With every electron trigger we recorded the status of each scintillator, and for coincidence counts, the pulse height and time relative to the electron signal. Random triggers simultaneously sampled the accidental coincidences in the hadron scintillators.

For an event to be accepted in the analysis, rather stringent cuts were made on the shower-counter pulse heights relative to the reconstructed electron momentum. This effectively eliminated any contribution from π^- but also reduced the efficiency for counting low-momentum (high-s) electrons. However, no bias is introduced into the measurement of the hadron multiplicities. In order to be even more confident that we have removed all π^- triggers, we have excluded from the data sample all events with $s>16$ GeV^2. No hadron detector information was ever used in accepting or rejecting events.

The 0.013-mm Kapton target wall was responsible for 5% of the observed electron rate and produced a mean multiplicity only slightly higher than did the hydrogen. This was easily corrected, using empty-target data runs.

The electron can lose energy by radiation either in the deep-inelastic process itself[2] or in the various pieces of material through which the scattered electron must pass before being detected. This shifts by varying amounts the apparent values of Q^2 and s relative to the true values for the

TABLE I. Sources of error in measured multiplicity and estimates of their effects for the $\overline{Q}^2=2.3$-GeV^2, $\overline{s}=9.6$-GeV^2 data bin, for events with an assumed true charged multiplicity of 3. $\Delta\bar{n}_3$ is the effect on the average multiplicity.

	$\Delta\bar{n}_3$
Absorption losses	−0.14
π^0 decay and conversion	0.03
δ rays, γ conversions	0.14
Geometric losses	−0.34
K^0, Λ charged decays	0.09
Accidental coincidences	0.64

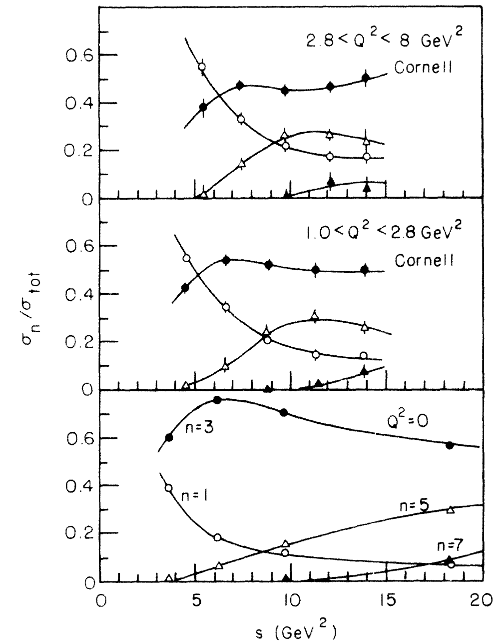

FIG. 1. s dependence of σ_n/σ_{tot}, the fraction of events with corrected charged-hadron multiplicity n, for several ranges in Q^2. Photoproduction data ($Q^2=0$) are from Ref. 4. The curves are merely drawn to connect corresponding points.

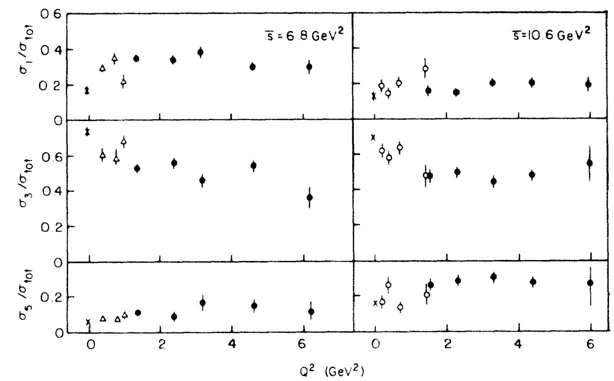

FIG. 2. Q^2 dependence of σ_n/σ_{tot} for two ranges in s. Also shown for comparison are data of Ref. 5 (triangles), Ref. 6 (open circles), and Ref. 4 (crosses).

scattering reaction. Multiple scattering, finite target size, and wire-chamber resolution have a similar effect. For each Q^2, s bin in the data we calculated by Monte Carlo methods the true average Q^2 and s to use in plotting and fitting the multiplicity results for that bin.

Table I lists the important sources of error in the observed multiplicities. Their effects have been evaluated using separate Monte Carlo calculations for each Q^2, s bin and true charged-hadron multiplicity n. Events of charged multiplicity n (always an odd number) were simulated with the known particle momentum distributions[3] and satisfying overall charge, momentum, and energy conservation, then propagated through the experimental apparatus taking account of the effects listed in Table I, to determine the expected observable multiplicity distribution $f_n(n_{obs})$ (n_{obs} ranges over all nonnegative integers, and the f_n summed over all n_{obs} are normalized to 1). For each of the Q^2, s bins we fitted the experimental charged multiplicity distribution $f_{exp}(n_{obs})$ by a linear superposition of predicted distributions $\sum_n a_n f_n(n_{obs})$ to get the contribution $\sigma_n/\sigma_{tot} = a_n$ of each true multiplicity. Reasonable variations in the input assumptions in the Monte Carlo calculation do not significantly affect the multiplicity corrections.

Since the accidental subtraction was rather large (~30%), we required that the net mean multiplicity be independent of beam intensity. This was confirmed experimentally over the entire Q^2, s range and over a range of incident electron intensity from 6×10^7 to 10^9 sec^{-1}. Also, as a check on the Monte Carlo calculations, we took some data with various absorbers between the target and scintillators. The corrected multiplicities were the same within statistical errors.

Figure 1 shows our corrected relative cross sections for one-, three-, five-, and seven-prong events as a function of s for two ranges in Q^2, compared with photoproduction data.[4] The three-prong cross section is less prominent in electroproduction than photoproduction. The onset of this effect at low Q^2 is shown more clearly in Fig. 2. Figure 3 shows the measured values of the corrected average charged-hadron multiplicity $\bar{n}$ as a function of Q^2 for several s values, compared with DESY[5] and SLAC[6] data. The data of this experiment at $Q^2 \geq 1.4$ GeV^2 join on well with the track-chamber data at $Q^2 \leq 1.4$ GeV^2. At each fixed Q^2 the s dependence follows the form $\bar{n} = a + b\ln s$, as it does in photoproduction. Any rapid Q^2 dependence, on the same order as the s dependence, is completely ruled out by our data. In particular, any scaling behavior of the form $\bar{n} = a + b\ln\omega$ is incompatible with this experiment.[7] A best fit to the Q^2 dependence in our data ($\chi^2 = 1.0$ per degree of freedom) is

$$\bar{n} = (-0.40 \pm 0.03) + (1.61 \pm 0.04)\ln s + (-0.11 \pm 0.03)\ln Q^2.$$

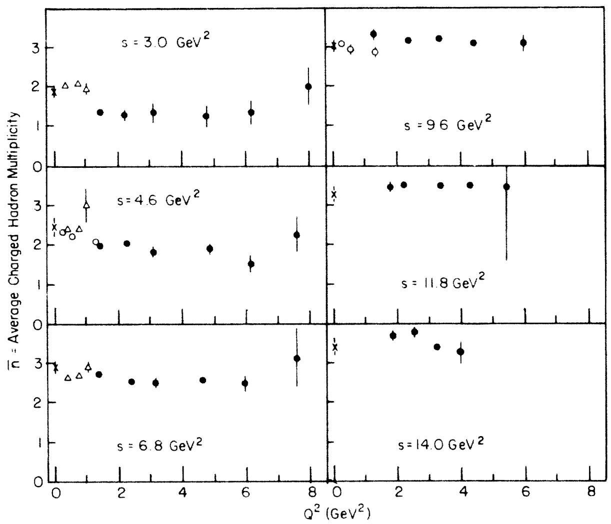

FIG. 3. The corrected average charged-hadron multiplicity plotted as a function of Q^2 for several ranges of s. The indicated errors are statistical only. The systematic error arising from uncertainties in the Monte Carlo input is estimated at 0.13 in the mean multiplicity. For comparison we have also plotted data of Ref. 5 (triangles), Ref. 6 (open circles), and Ref. 4 (crosses). Data at nearby values of s have been scaled to the quoted s value using the best-fit $a + b$ ln$s$ dependence. Photoproduction data at $s = 4.6$, 11.8, and 14.0 GeV^2 are interpolated using the fit given in Ref. 4.

This shows a barely significant decrease with Q^2; the higher values of $\bar{n}$ at $Q^2 \approx \text{GeV}^2$ in Fig. 3 carry very little statistical weight. In fact

$$\bar{n} = (-0.37 \pm 0.07) + (1.55 \pm 0.04)\ln s$$

is almost as good a fit to all our data ($\chi^2 = 1.3$ per degree of freedom). This latter fit is close to the dependence observed in photoproduction[4] and, indeed, in all hadronic collisions.

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[1]See, for example, P. Carruthers and Minh D.-v., Phys. Lett. 44B, 507 (1973); T. T. Chou and C. N. Yang, Phys. Rev. D 4, 2005 (1971); J. D. Bjorken and J. Kogut, Phys. Rev. D 8, 1341 (1973); R. N. Cahn, J. W. Cleymans, and E. W. Colglazier, Phys. Lett. 43B, 323 (1973); S. D. Drell, D. J. Levy, and T. M. Yan, Phys. Rev. Lett. 22, 744 (1969); S. S. Shei and D. M. Tow, Phys. Rev. Lett. 26, 470 (1971).

[2]Radiation during scattering is calculated using the equivalent-radiator approximation: L. W. Mo and Y. S. Tsai, Rev. Mod. Phys. 41, 205 (1969). The contribution to the one-prong events from radiative elastic scattering varies from 0 to 10% and is subtracted from the data.

[3]For a recent review of the data see F. Brasse, in Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, Bonn, 1973 (to be published). An estimate of the contribution from decays of neutral strange particles based on the data of V. Eckardt *et al.*, in Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, Bonn, 1973 (to be published), is also included in the calculation (see Table I).

[4]K. C. Moffeit *et al.*, Phys. Rev. D 5, 1603 (1972).

[5]Eckardt *et al.*, Ref. 3.

[6]J. Ballam *et al.*, in Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, Bonn, 1973 (to be published).

[7]Scaling in ω' [E. D. Bloom and F. J. Gilman, Phys. Rev. D 4, 2901 (1971)] and in ω_W [V. Rittenberg and H. R. Rubinstein, Phys. Lett. 35B, 50 (1971)] are also incompatible with the data.