MEASUREMENT OF $R = \sigma_L/\sigma_T$ IN DEEP INELASTIC MUON-PROTON SCATTERING

The European Muon Collaboration

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Abstract

The ratio $R = \sigma_L/\sigma_T$ of the longitudinal to the transverse photon absorption cross section has been determined from deep inelastic muon-proton scattering at incident energies of 120, 200 and 280 GeV. The results are given as a function of the variables x , Q^2 and ν of the interaction. In the kinematic range $60 < \nu < 160$ GeV at $\langle Q^2 \rangle = 22.5$ GeV² an average value of $R = 0.00 \pm 0.10$ has been obtained.

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In previous publications [1] the EMC presented measurements of the structure function $F_2(x, Q^2)$ in deep inelastic muon-nucleon scattering. The observed scaling violation of $F_2(x, Q^2)$ was compared with the predictions of Quantum Chromodynamics (QCD) and was used to determine the value of the scale parameter Λ of this theory [2].

The structure function $F_2(x, Q^2)$ is related to the measured cross section through

$$\frac{d^2\sigma}{dQ^2 dx} = \frac{4\pi\alpha^2}{Q^4} \frac{F_2(x, Q^2)}{x} \left[1 - y - \frac{Mxy}{2E} + \frac{y^2(1+4M^2x^2/Q^2)}{2(1+R(x, Q^2))} \right].$$

Q^2 is the square of the four-momentum transfer, E is the beam energy, y is ν/E , where ν is the energy transfer and x is the Bjorken scaling variable $Q^2/2M\nu$. $R(x, Q^2)$ is the ratio of the absorption cross sections σ_L and σ_T for longitudinally and transversely polarised virtual photons and can be written in terms of the structure functions F_1 and F_2 as

$$R = \sigma_L / \sigma_T = \frac{(1+4M^2x^2/Q^2)F_2 - 2xF_1}{2xF_1},$$

$$F_1 = \frac{2M\nu - Q^2}{8\pi^2\alpha} \sigma_T,$$

$$F_2 = \frac{2M\nu - Q^2}{8\pi^2\alpha} \frac{\nu}{M} \frac{Q^2}{Q^2 + \nu^2} (\sigma_T + \sigma_L).$$

The results for $F_2(x, Q^2)$ extracted from $d^2\sigma/dQ^2 dx$ depend on the value of R , with the influence of R increasing with y . Since for a given beam energy the variable y at fixed x is related to Q^2 , different values of R change the observed Q^2 -dependence of $F_2(x, Q^2)$. Therefore an experimental knowledge of the quantity R is necessary to determine the structure function $F_2(x, Q^2)$ in a complete way*. Previous measurements of R have been made in very different kinematic ranges in electron-proton [3] and muon-proton [4] scattering.

In the parton model the magnitude of R reflects the spin of the constituents in the nucleon. Neglecting small mass effects and transverse momentum components, helicity conservation requires $R = 0$ for partons with spin $1/2$ and $R = \infty$ for partons with spin zero. Taking into account a transverse momentum,

*) In ref. [1] values of F_2 were given for assumed values of $R = 0$ and $R = 0.2$.

p_T , of the quarks, R is given by $R = 4\langle p_T^2 \rangle / Q^2$ [5]. Contributions to p_T can be due to an intrinsic transverse momentum of the order of a few hundred MeV, but can also be induced by gluon bremsstrahlung and quark-antiquark pair creation. The latter effects can be calculated in the framework of perturbative QCD and give values for R proportional to the strong coupling constant $\alpha_s(Q^2)$ [6].

For the experimental determination of R , in addition to the results obtained with the hydrogen target at incident energies of 120 and 280 GeV [1], data taken at 200 GeV beam energy [7] were used. The measured cross section was evaluated in bins of Q^2 and ν and written as

$$\frac{d^2\sigma}{dQ^2 d\nu} = \Gamma_T [\sigma_T(Q^2, \nu) + \epsilon \sigma_L(Q^2, \nu)] = \Gamma_T \sigma_T (1 + \epsilon R),$$

where Γ_T is the flux of transverse virtual photons and ϵ the polarisation parameter, given by

$$\Gamma_T = \frac{\alpha}{4\pi M} \frac{2M\nu - Q^2}{Q^2} \frac{1}{E^2} \frac{1}{1 - \epsilon},$$

$$\epsilon = \frac{1 - y - Q^2/4E^2}{1 - y + y^2/2 + Q^2/4E^2}.$$

The value of R can then be determined from a straight line fit to the quantity $1/\Gamma_T \cdot d^2\sigma/dQ^2 d\nu$, measured at fixed Q^2 and ν but at different values of ϵ , i.e. different beam energies.

For the evaluation of R the relative normalisation of the data sets at different energies is of great importance. Comparing the results for $1/\Gamma_T \cdot d^2\sigma/dQ^2 d\nu$ at low ν , where ϵ is close to 1 for all three primary energies, allows a determination of the relative normalisation. Shifts of -0.5% for the data at 120 GeV and of -2.5% for the data at 200 GeV beam energy were applied relative to the data at 280 GeV incident muon energy. These shifts are well inside the statistical and systematic uncertainties for the normalisation of the individual data sets.

In fig. 1 typical straight line fits of $(\sigma_T + \epsilon\sigma_L)$ versus ϵ are shown in the range $80 \leq \nu \leq 100$ GeV for different values of Q^2 . The total error shown for each measured cross section is the quadratic sum of the

statistical and systematic error for which the contributions from the individual systematic error sources [1] and an additional 3% normalisation uncertainty were added quadratically. The statistical contribution alone is indicated by the inner error bar. To avoid large systematic effects the whole analysis for R was restricted to a kinematical region with systematic errors $\leq 5\%$ (excluding the normalisation uncertainty) for the measured cross section.

In total σ_T , σ_L and R were determined for 14 different (Q^2, ν) bins in the region $60 \leq \nu \leq 100$ GeV and $8 \leq Q^2 \leq 55$ GeV² with data from three incident energies and for 27 different (Q^2, ν) bins in the region $100 \leq \nu \leq 160$ GeV and $10 \leq Q^2 \leq 145$ GeV² with data from beam energies of 200 GeV and 280 GeV. In fig. 2 σ_T and σ_L are shown as a function of Q^2 for the region $80 \leq \nu \leq 100$ GeV. Relative to the transverse cross section the longitudinal cross section is small and consistent with zero everywhere.

To obtain R as a function of each of the kinematical variables Q^2 , ν and x several individual results for R were combined to increase the statistical accuracy. Fig. 3a) shows R as a function of ν averaged over $8 \leq Q^2 \leq 145$ GeV² with $\langle Q^2 \rangle = 22.5$ GeV² and fig. 3b) as a function of Q^2 averaged over $60 \leq \nu \leq 160$ GeV with $\langle \nu \rangle = 100$ GeV. Within the errors R does not depend strongly on either Q^2 or ν . In fig. 4 R is given for different values of x with $\langle Q^2 \rangle$ increasing from ~ 10 GeV² at $x = 0.05$ to ~ 55 GeV² at $x = 0.30$. Within the statistical and systematic uncertainties no difference is visible between the results for R from the region $60 \leq \nu \leq 100$ GeV with data from three different energies and the results from the region $100 \leq \nu \leq 160$ GeV, where only 200 GeV and 280 GeV data contribute.

Since the values for R show no significant dependence on the kinematic variables considered, a global determination of R over the whole kinematical region was made resulting in a value of $R = 0.00 \pm 0.035$ (stat.) ± 0.095 (syst.) and a χ^2 (stat.) of 64.8 for 54 degrees of freedom.

In fig. 4 the QCD prediction for R in leading order [6] assuming a value of $\Lambda = 160$ MeV [2] is given for comparison. Since at fixed x the theoretical results show no large variation over the ν range covered, only the curve corresponding to $\nu = 100$ GeV is displayed. In the calculation, a Q^2 -dependent

parameterisation for the gluon distribution was used [8] and mass effects for the charm quark contribution to the longitudinal structure function were taken into account [9]. The experimental results confirm the small value for R predicted by the quark-parton model and QCD. With respect to the comparison with theoretical calculations it should be noted that the systematic errors between neighbouring points are strongly correlated.

In conclusion the ratio $R = \sigma_L/\sigma_T$ has been determined in deep inelastic muon-proton scattering from cross section measurements at three different incident muon energies. Within the statistical and systematic uncertainties R shows no variation with the kinematic variables Q^2 , ν or x . An average value of $R = 0.00 \pm 0.10$ for $\langle Q^2 \rangle = 22.5 \text{ GeV}^2$ and $\langle \nu \rangle = 100 \text{ GeV}$ has been obtained, where the error is mainly systematic. This result is in reasonable agreement with the predictions of the quark-parton model and QCD.

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FIGURE CAPTIONS

- Fig. 1 Straight line fits to $(\sigma_T + \epsilon\sigma_L)$ versus ϵ for different kinematical bins. Statistical errors are given separately by the inner bars.
- Fig. 2 σ_T and σ_L as a function of Q^2 for $80 \leq \nu \leq 100$ GeV. Statistical errors are given separately by the inner bars.
- Fig. 3 a) R averaged over Q^2 as a function of ν .
b) R averaged over ν as a function of Q^2 .
Statistical errors are given separately by the inner bars.
- Fig. 4 R as a function of the Bjorken variable x .
Statistical errors are given separately by the inner bars.
Dashed line: leading order QCD prediction [6,9].

Fig. 1

Fig. 2

Fig. 3

Fig. 4