Z. Physik C, Particles and Fields 2, 279–284 (1979)

Zeitschrift für Physik C Particles and Fields


# Shadowing Effect in Inelastic Electron Scattering on $^{12}C$ and $^{27}Al$ Nuclei at Small Four Momentum Transfer

G. Huber, S. Hartwig[1], F. H. Heimlich[2], E. Rössle
Fakultät für Physik der Universität Freiburg i.Br., Federal Republic of Germany

J. Bleckwenn
Deutsches Elektronensynchrotron DESY, Hamburg, Federal Republic of Germany

M. Köbberling, J. Moritz[3], K. H. Schmidt[4], D. Wegener[5], D. Zeller
Kernforschungszentrum und Universität Karlsruhe, Institut für Experimentelle Kernphysik, Karlsruhe, Federal Republic of Germany

P. David, H. Mommsen
Institut für Kern- und Strahlenphysik der Universität Bonn, Federal Republic of Germany

Received 31 July 1979

**Abstract.** The cross section for inelastic electron scattering on $^{12}C$ and $^{27}Al$ has been measured for energy transfers of the virtual photon $\nu < 6.2\,\mathrm{GeV}$ and four momentum transfers $0.075 < Q^2 < 1\,\mathrm{GeV}^2$. The influence of different sources of the radiative corrections is studied in detail. Shadowing effects are observed for both nuclei, which decrease with increasing values of the scaling variable $x$.

## 1. Introduction

The inelastic electron scattering on nucleons and nuclei can be described as an absorption process of virtual photons by hadronic matter. The process is parametrized by the absorption cross section

$$\sigma = \frac{1}{\Gamma_t} \frac{d^2\sigma}{d\Omega dE}. \tag{1}$$

$\Gamma_t$ is the flux of virtual photons, $d^2\sigma/d\Omega dE$ is the measured twofold electron scattering cross section [1]. For real high energetic photons it was shown that the number of effective nucleons $A_{\mathrm{eff}}$ of a nucleus is smaller than its atomic mass number $A$ [2]. This effect, well known for absorption processes where only hadrons are involved [3], has been explained in the framework of the vector meson dominance model to be due to a hadronic component of the photon [4–6]. On the other side it is known from deep inelastic electron scattering that at four momentum transfers $Q^2 > 1\,\mathrm{GeV}^2$ the interaction between the virtual photon and the hadron has a point-like structure. Therefore it is of interest to study the damping of the photon hadronic component by increasing the mass $Q^2$ of the virtual photon [6]. Foregoing experiments have found weak evidence for shadowing effects [7–9]. In order to study this effect in more detail we have measured the inelastic electron scattering cross section on hydrogen, $^{12}C$ and $^{27}Al$ nuclei for four momenta $0.075 < Q^2 < 1\,\mathrm{GeV}^2$ and energies of the virtual photon $\nu < 6.2\,\mathrm{GeV}$ at the DESY synchrotron [10].

## 2. Experimental Set-up and Corrections

The scattered electrons have been detected by a spectrometer consisting of a bending magnet, four wire spark chambers, trigger and particle identifying counters [10, 11]. A pressurized Cerenkov counter and a lead-scintillator sandwich counter have been used to separate scattered electrons from hadrons. Details of the separation procedure are given in [10]. The efficiency of the counters and the acceptance of the set up have been derived directly from the experimental data. The effective target length for the different target materials was chosen to be approximately the same and amounted to $6 \cdot 10^{-3}$ radiation length.

[1] Present address: Batelle Institut e.V., Frankfurt (Main)
[2] Present address: I. Institut für Experimentalphysik, Universität Hamburg
[3] Present address: Siemens AG, München
[4] Present address: Siemens AG, Karlsruhe
[5] Present address: Institut für Physik, Universität Dortmund

0170-9739/79/0002/0279/$01.20

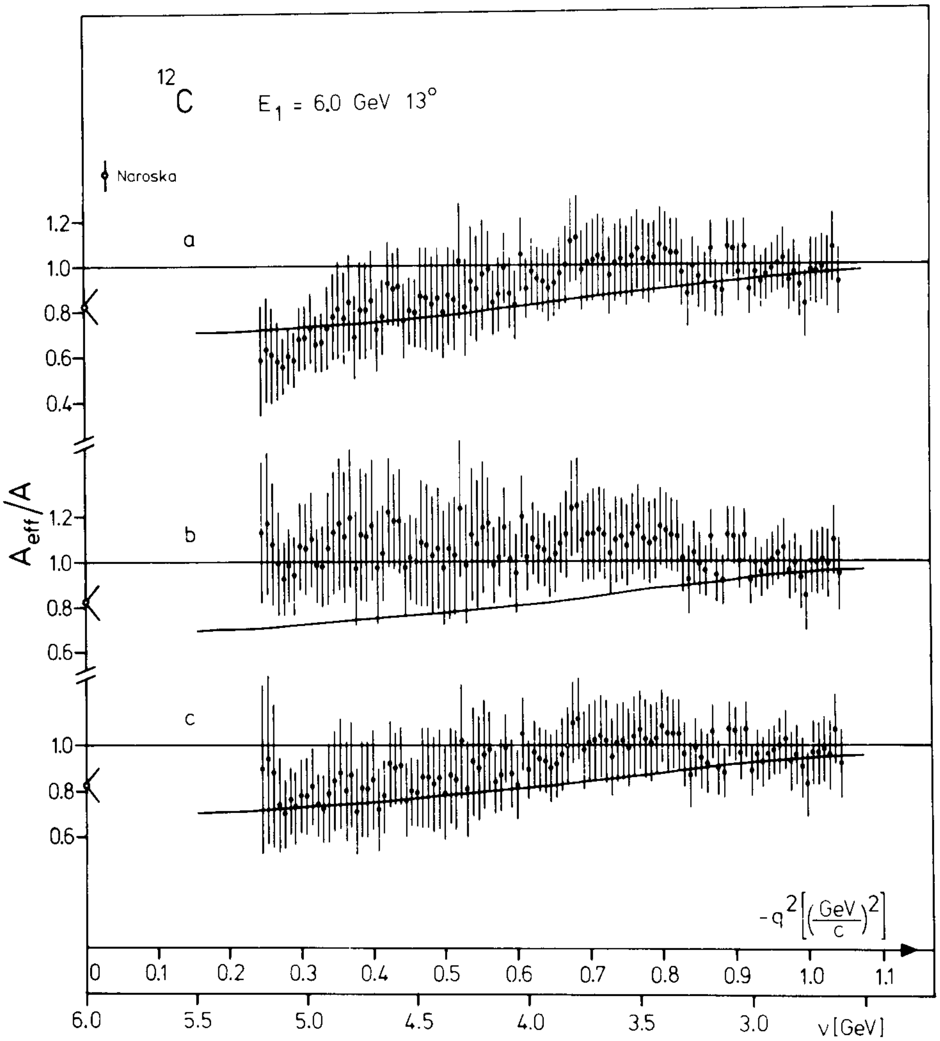


**Fig. 1a–c.** Ratio $A_{eff}/A$ for inelastic electron scattering on $^{12}C$, primary electron energy $E=6\,\text{GeV}$, electron scattering angle $\theta=13°$. The Figs. **a**, **b**, **c** result from different treatment of the radiative corrections (see text). The result for $Q^2=0\,\text{GeV}^2$ is taken from [2]. For comparison the VDM prediction of [4] is included

The intensity of the primary beam was monitored with the help of a Faraday cup and a secondary emission monitor. For each setting of the spectrometer current the full and the empty target rate was determined, typically the latter one amounted to 15% of the full target rate. The contribution of Dalitz pairs (typically 2% of the full target rate) was measured by inversion of the magnetic field direction of the spectrometer. Because of the large momentum acceptance of the spectrometer, at most four settings of the spectrometer current were necessary to cover the full energy range of the scattered electrons for a given primary energy and electron scattering angle. The four intervals were chosen to overlap. The typical statistical errors are 2–4% and the systematic error of the data is 3.5%.

The main corrections, which had to be applied to the raw data, were due to radiative processes. In principle one has to consider for these corrections the radiative tail of the following scattering processes:

I: Elastic electron scattering on the whole nucleus.

II: Other coherent scattering processes such as nuclear level and giant resonances excitation.

III: Quasielastic electron nucleon scattering.

IV: Inelastic scattering on bound nucleons.

We have taken into account the processes I and III. The contributions of the coherent processes II can be neglected because of their smallness [12]. For the inelastic scattering processes IV we assume that no significant difference between the free and bound nucleon case exists. This assumption is supported by the observation, that the electron scattering on nuclei in the resonance region can be described as an incoherent superposition of free nucleon scattering pro-

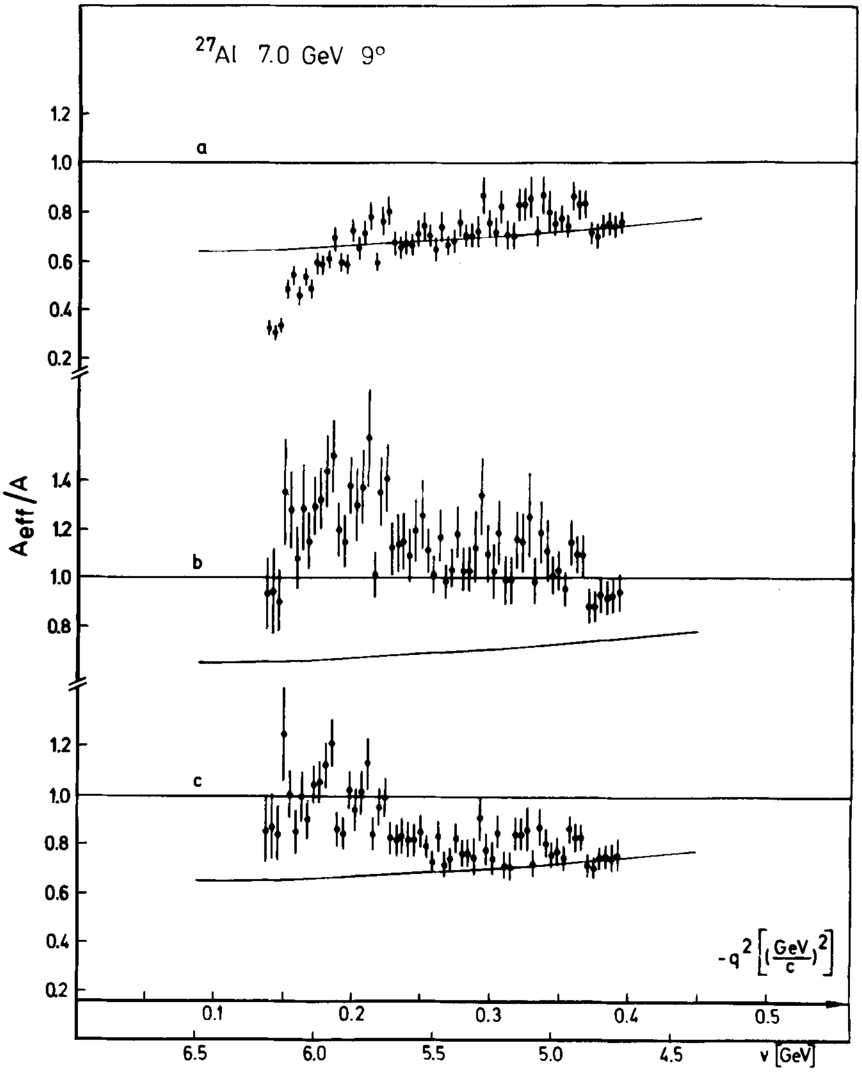


**Fig. 2a–c.** Ratio $A_{eff}/A$ for inelastic electron scattering on $^{27}$Al, $\theta=9°$, $E=7$ GeV. The Figs. **a**, **b**, **c** result from different treatment of the radiative corrections (see text). For comparison the VDM prediction of [4] is included

cesses [13]. From this assumption follows that the contribution IV to the radiative corrections cancels, if one compares the cross section on nuclei with those on hydrogen, under the condition that the target thickness, measured in radiation lengths, is chosen to be the same, in order to have the same contributions from external Bremsstrahlung. This condition was fulfilled in the present experiment.

The calculations have been performed using the formulae of Mo and Tsai [14] for the radiative tail of the elastic electron scattering. We have used the formfactor parametrization of Hofstadter [15] to calculate the radiative tail for elastic electron scattering on $^{12}$C and $^{27}$Al. If necessary the parametrization of the nucleus formfactor has been extrapolated to regions of larger four momentum transfer. For the radiative tail of the elastic scattering on bound nucleons suppression effects according to the Pauli principle have been included [16]. In addition we have checked by comparison of electron and positron scattering data, that the one photon exchange approximation (1) holds in the region of the kinematical variables of the present experiment for electron scattering on nucleons [17] and nuclei [18].

### 3. Results

The number $A_{eff}$ of the effective interacting nucleons has been determined according to the formula:

$$\frac{A_{eff}}{A}=\frac{\sigma_{\gamma A}}{Z\sigma_{\gamma p}+N\sigma_{\gamma n}}, \tag{2}$$

where $\sigma_{\gamma A}$, $\sigma_{\gamma p}$, $\sigma_{\gamma n}$ are the cross sections of the nucleus, the proton and the neutron respectively. $Z$ and $N$ are

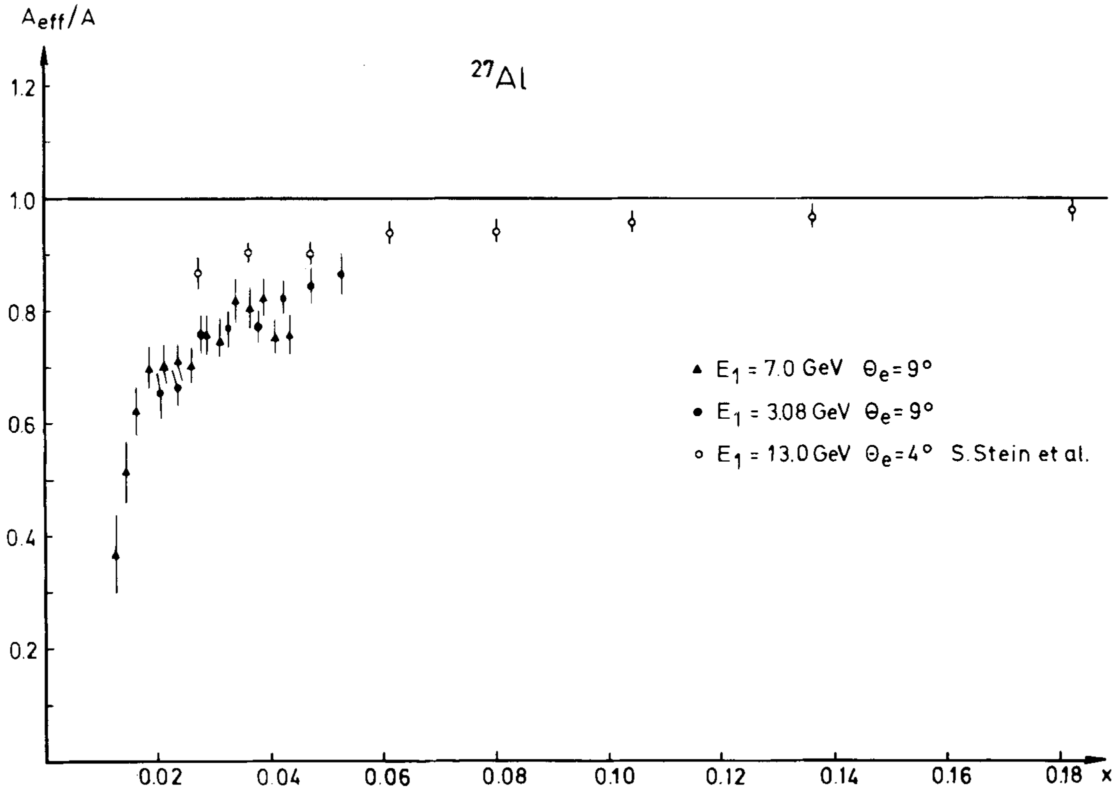


**Fig. 3.** Ratio $A_{\text{eff}}/A$ for $^{27}$Al as a function of the scaling variable $x$. Besides the result of the present experiment ($E=7$ GeV, $E=3.08$ GeV, $\theta=9°$) data of Stein et al. [8] are included for comparison. Radiative corrections according to Fig. 2a are applied

the numbers of protons and neutrons composing the nucleus with mass number $A$.

For the neutron cross section we have used the empirically found relation between neutron and proton cross sections

$$\sigma_{\gamma n}=(1-x')\sigma_{\gamma p}, \quad x'=\frac{Q^2}{2M\nu+M^2}. \tag{3}$$

With this relation, which has been checked by several experiments [19, 20], we get

$$R=\frac{A_{\text{eff}}}{A}=\frac{\sigma_{\gamma A}}{(A-Nx')\sigma_{\gamma p}}. \tag{4}$$

The ratio $R$ is a measure of the shadowing effect.

The influence of different sources of radiative corrections on the ratio (1) has been studied. If the radiative process is not modified by the fact, that for a nucleus part of the possible final states, accessible to a scattered nucleon, are occupied by spectator nucleons, the radiative tail due to the contribution of quasielastic electron nucleon scattering should factorize in the measured inelastic electron nucleus scattering cross section. Therefore this contribution to the radiative corrections should cancel in the ratio (4). If this assumption holds, the only corrections, which have to be taken into account, are due to the radiative tail from elastic electron nucleus scattering. In Figs. 1a and 2a typical result for $^{12}$C and $^{27}$Al nuclei are plotted for the case that the factorization assumption holds. The data show clear evidence for a shadowing effect at small four momentum transfer $Q^2$.

In Fig. 3, the ratio $R=A_{\text{eff}}/A$ is plotted as a function of the scaling variable $x=Q^2/2M\nu$ together with the results of Stein et al. [8]. In both cases radiative corrections based on the factorization assumption of Figs. 1a and 2a were used. The two data sets show clear evidence for shadowing effect. The ratio $R$ of the present experiment seems to be smaller than that of [8]. The strong increase of the shadowing at small values of the scaling variable $x$ is due to the neglection of the Pauli principle. By this neglection only the data below $x=0.03$ are influenced. The effect of the Pauli principle on the ratio $R$ is discussed next.

At small $Q^2$, where the momentum of the struck nucleon after the scattering process is small, the occupation of possible final states by spectator nucleons is important. Because of the Pauli principle, the contribution of the quasielastic radiative tail should decrease compared to the radiative tail of the elastic scattering. In the extremest case the radiative tail contributes to the measured cross-section only for free electron nucleon scattering, while the electron does not radiate for electron bound state nucleon scattering, because all possible final states are occupied. This extreme case is considered, if one applies only radiative corrections due to the elastic electron proton scattering but no corrections due to electron scattering on bound state nucleons. The results for this extreme case are shown in Figs. 1b and 2b. The shadowing effect nearly disappears. A realistic correction should yield results for the ratio $R = A_{eff}/A$ between the two extreme cases of Figs. 1a and 2a and Figs. 1b and 2b respectively.

An approach to the realistic computation of the radiative corrections due to the radiative tail of electron bound state nucleon scattering was given by Bernabeu [16]. He has described the influence of the Pauli principle to the quasielastic electron nucleon scattering by an effective nucleon formfactor. We have used the effective nucleon formfactor, which has been computed by Bernabeu [16] for the $^{12}C$ nucleus, to determine the radiative tail for the quasielastic electron nucleon scattering on $^{12}C$ and $^{27}Al$. The results of this analysis are given in Figs. 1c and 2c, showing a shadowing effect for both nuclei. For comparison the ratio $R$ measured with real photons [2] is included in Fig. 1c. Since we applied the effective nucleon formfactors computed for the $^{12}C$ nucleus also in the case of $^{27}Al$, the systematic error for this nucleus is larger for the lower $Q^2$ values, where the influence of the Pauli principle is strongest.

Figure 4 shows for the $^{12}C$ nucleus the final results taking into account the complete radiative corrections. The plotted points are the statistically weighted mean values of all our $^{12}C$ data lying in the same interval of the scaling variable $x$. The ratio $R$ shows clear evidence for shadowing below $x=0.1$. For comparison the prediction of the generalized vector meson dominance model [5] is included. The calculation reproduces the magnitude of the effect and its $x$ dependence.

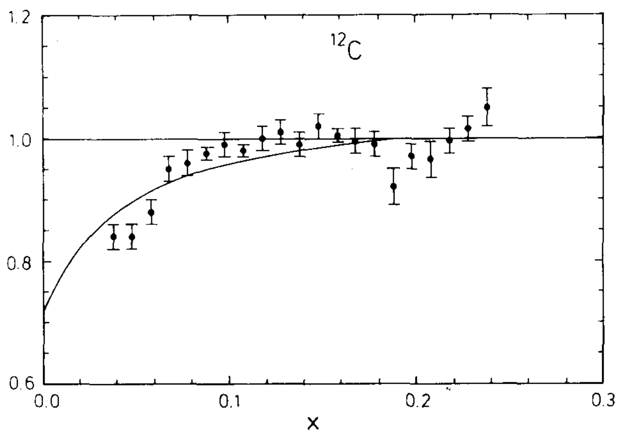


**Fig. 4.** Ratio $A_{eff}/A$ for $^{12}C$ as a function of the scaling variable $x$. For comparison the prediction of the generalized vector meson dominance model [5] is included. Radiative corrections according to Fig. 1c are applied

Similar results to ours have recently been obtained on $^{12}C$ and $^{27}Al$ in a Daresbury experiment [21], while other electroproduction data [7, 8], which show no conclusive evidence for shadowing, have been performed at higher $Q^2$.

## 4. Conclusion

In conclusion we have shown that a shadowing effect exists for the absorption cross section of virtual photons. It increases with decreasing four momentum transfer $Q^2$ [22]. The magnitude of the effect and its $Q^2$ dependence is in agreement with the prediction of the generalized vector dominance model [5]. The important difference of the radiative tails for electron scattering on free and bound nucleons is pointed out.

*Acknowledgement.* We acknowledge the untiring help of Ing. H. Sindt during all stages of the experiment. This work has been supported by the Bundesministerium für Forschung und Technologie.

## References


1. L.N.Hand: Phys. Rev. **129**, 1834 (1963)
2. V.Heynen, H.Meyer, B.Naroska, D.Notz: Phys. Lett. **34** B, 651 (1971)
3. G.Bellettini, G.Cocconi, A.N.Diddens, E.Lillethun, G.Matthiae, J.P.Scanlon, A.M.Wetherell: Nucl. Phys. **79**, 609 (1966)
4. S.J.Brodsky, J. Pumplin: Phys. Rev. **182**, 1794 (1969)
5. D.Schildknecht: Nucl. Phys. B **66**, 398 (1973)
6. A.Suri, D.R.Yennie: Ann. Phys. **72**, 243 (1972)
7. W.R.Ditzler, M.Breidenbach, J.I.Friedmann, H.W.Kendall, J.S.Poucher, E.D.Bloom, R.L.A.Cottrell, D.H.Coward, H.DeStaebler, C.L.Jordan, H.Piel, R.E.Taylor: Phys. Lett. **57** B, 201 (1975)
8. S.Stein, W.B.Atwood, E.D.Bloom, R.L.A.Cottrell, H.DeStaebler, C.L.Jordan, H.G.Piel, C.Y.Prescott, R.Siemann, R.E.Taylor: Phys. Rev. D **12**, 1884 (1975)
9. J.Eickmeyer, S.Michalowski, N.Mistry, R.Talman, K.Uneo: Phys. Rev. Lett. **36**, 289 (1976)
10. G.Huber: Thesis Freiburg University 1976
11. S.Galster, G.Hartwig, H.Klein, J.Moritz, K.H.Schmidt, W.Schmidt-Parzefall, D.Wegener, J.Bleckwenn: Phys. Rev. D **5**, 519 (1972)
12. K.C.Stanfield, C.R.Canizares, W.L.Faissler, F.M.Pipkin: Phys. Rev. C **3**, 1448 (1971)
13. U.Glawe, U.Strohbusch, J.Franz, P.Grosse-Wiesmann, G.Huber, G.Guzielski, G.Mecklenbrauck, W.Mecklenbrauck, E.Roessle: Paper SC.5 presented to the 8th International Conference on High Energy Physics and Nuclear Structure, Vancouver 1979
14. L.W.Mo, Y.S.Tsai: Rev. Mod. Phys. **41**, 205 (1969)
15. R.Hofstadter: Ann. Rev. Nucl. Sci. **7**, 231 (1957)
16. J.Bernabeu: Nucl. Phys. B **49**, 186 (1972)
17. S.Hartwig, F.H.Heimlich, G.Huber, E.Rössle, J.Bleckwenn, M.Köbberling, J.Moritz, K.H.Schmidt, D.Wegener, D.Zeller: Lett. Nuovo Cimento **15**, 429 (1976)

18. S. Hartwig, F.H. Heimlich, G. Huber, E. Rössle, J. Bleckwenn, M. Köbberling, J. Moritz, K.H. Schmidt, D. Wegener, D. Zeller, P. David, H. Mommsen: Phys. Lett. **82** B, 297 (1979)
19. H.W. Kendall: In: Proceedings of 1971 International Symposium on Electron and Photon Interaction at High Energies, Ithaca N.Y. (1971), p. 247
20. G. Miller, E.D. Bloom, G. Buschhorn, D.H. Coward, H. DeStaebler, J. Drees, C.L. Jordan, L.W. Mo, R.E. Taylor, J.I. Friedman, G.C. Hartmann, H.W. Kendall, R. Verdier: Phys. Rev. D **5**, 528 (1972)
A. Bodek, M. Breidenbach, D.L. Dubin, J.E. Elias, J.I. Friedman, H.W. Kendall, J.S. Poucher, E.M. Riordan, M.R. Sogard, D.H. Coward: Phys. Rev. Lett. **30**, 1087 (1978)
J.S. Poucher, M. Breidenbach, R. Ditzler, J.I. Friedman, H.W. Kendall, E.D. Bloom, R.L.A. Cottrell, H. DeStaebler, C.L. Jordan, H. Piel, R.E. Taylor: Phys. Rev. Lett. **32**, 118 (1974)
21. J. Bailey, D.R. Botterill, H.E. Montgomery, P.R. Norton, A. DelGuerra, A. Giazotto, M.A. Giorgi, A. Stefanini, G. Matone: Nucl. Phys. B **151**, 367 (1979)
22. The full data set is available in tabulated form [10]