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# Quasielastic Electron-Deuteron Scattering at Four Momentum Transfers in the Range $0.25\ (\frac{GeV}{c})^2 < q^2 < 0.85\ (\frac{GeV}{c})^2$

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# Quasielastic Electron - Deuteron Scattering at Four Momentum Transfers in the Range

$$0.25 \left(\frac{GeV}{c}\right)^2 < q^2 < 0.85 \left(\frac{GeV}{c}\right)^2$$

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Summary

In an e-d scattering experiment the process e+d→e+p+n has been studied. The scattered electrons and the recoil protons were detected with a coincidence apparatus. Within the experimental error of 6 % the measured cross sections $d^2\sigma/d\Omega dE_3$ are in good agreement with the predictions of the Durand theory. The measured angular distributions of the recoil protons agree with theoretical predictions of McGee. There is no evidence for final state interactions or meson currents. The square of the neutron formfactor $G_{EN}^2$ was evaluated.

Zusammenfassung

In einem e-d Streuexperiment wurde der Prozess e+d→e+p+n untersucht. Mit einer Koinzidenzapparatur wurden die gestreuten Elektronen und die Rückstoßprotonen nachgewiesen. Die gemessenen Wirkungsquerschnitte $d^2\sigma/d\Omega dE_3$ des Elektronenspektrums stimmen innerhalb der Fehlergrenze von 6 % mit der Theorie von Durand überein. Die Winkelverteilung der Rückstoßnukleonen wird durch die Theorie von McGee wiedergegeben. Einflüsse von Endzustandswechselwirkungen und Mesonenströmen wurden nicht nachgewiesen. Aus den gemessenen Wirkungsquerschnitten wurde das Quadrat des elektrischen Neutronformfaktors berechnet.

| $q^2$ $(\frac{GeV}{c})^2$ | $G_{EN}^2$ | $\Delta G_{EN}^2$ |
|---|---|---|
| 0.26 | 0.0046 | ±0.016 |
| 0.34 | 0.0029 | ±0.012 |
| 0.45 | 0.0069 | ±0.011 |
| 0.81 | 0.0034 | ±0.008 |

## Introduction

In this report we present the results of a quasielastic electron-deuteron scattering experiment which was performed at DESY (Hamburg). A theory relating the cross section to the neutron formfactor was given by Durand III [1]. It was the object of the coincidence experiment to test this theory by comparing the experimental and theoretical twofold and threefold cross sections and to give an upper limit for the contribution of meson currents and final state interactions. Moreover the electric neutron formfactor was determined.

## II. Apparatus

Electrons with an energy of $E_1$=2.5 GeV and 2.7 GeV of the slowly ejected beam at DESY were focussed on a liquid deuterium target of 3 cm diameter (fig. 1).

Angle and momentum of the scattered electrons and the angular distribution of the recoil protons were measured in coincidence.

The electron spectrometer (fig. 1) consists of a bending magnet with a homogeneous field, four digitized wire spark chambers with core read-out [2] and a counter array which separates electrons from other particles.

The angular distribution of the recoil protons was measured with a scintillation-counter hodoscope. It consisted of 12 horizontal and 12 vertical scintillation counters which formed a hodoscope of 12 by 12 elements subtending a solid angle of $30^{\circ}\times30^{\circ}$ around the direction of the virtual photon emitted in the scattering process. Pulse-height-analysis was performed in a third plane with four 5 cm thick quadratic counters.

A lead foil of 1 mm in front of the hodoscope absorbed the low energy electron- and $\gamma$-ray-background.

All experimental data were stored by a computer CDC 1700 on line [3]. (a detailed description of the apparatus was given in a preceding paper [4]).

Results

Data were taken at four different four momentum transfers $q^2=0.26(\frac{GeV}{c})^2$, $q^2=0.34(\frac{GeV}{c})^2$, $q^2=0.45(\frac{GeV}{c})^2$ and $q^2=0.81(\frac{GeV}{c})^2$. The measured twofold cross sections have been corrected for target empty rates, efficiency of the scintillation counters and spark chambers and dead time of the electronics. The contribution of the elastic electron-deuteron scattering was determined experimentally [5] and subtracted from the measured spectra. The measured coincidence cross sections have been corrected for the efficiency of the proton hodoscope, which was determined by elastic electron-proton scattering, and for the absorption by the lead foil and the scintillation counters. The contribution of recoil protons missing the hodoscope was calculated using the theory of McGee [6]. In table I the corrections and errors are listed.

Electron spectra

The measured electron cross sections $d^2\sigma/d\Omega dE_3$, compiled in table II, were compared with the theoretical predictions of Durand III [1]. For this purpose the proton formfactors and the magnetic neutron formfactor were calculated using a four pole fit [7] and the scaling law. A Hulthén wave function [8] was used with a 4 % D state probability.

The radiative corrections were computed using the formulae given by Mo and Tsai [9]. The corrected theoretical curves were folded with a Gaussian distribution taking into account the finite energy resolution of the spectrometer [10]. In figs. 2 - 5 the results of this calculation and the measured electron spectra are shown.

The theoretical and the experimental cross sections are in good agreement especially at the high energy tail of the spectra. One gets a $\chi_F^2 \simeq 1$. Small deviations for low energies arise from inelastic contributions.

Angular distribution of recoil protons

A more sensitive experimental test of the electrodisintegration of the deuteron can be made by comparing the theoretical and experimental angular distributions of the recoil protons. The influence of radiative corrections was taken into account using formulae of Mo and Tsai [9]. Taking all 144 elements of the hodoscope, the average value of $\chi_F^2$ is approximately 1 in the whole kinematical region covered by this experiment. The systematical errors are 1.5 %, the statistical errors vary from 2.5 % in the maximum to 25 % at the outer regions.

Fig. 6 shows the experimental counting rate plotted for 12 hodoscope elements in a one dimensional cut parallel to the scattering plane. The statistical error bars and the horizontal width of the hodoscope elements are given. Fig. 7 shows a similar cut perpendicular to the scattering plane. In figs. 6 and 7 the solid curves are the calculated theoretical counting rates.

As there exist no discrepancies between theoretical and experimental data (electron spectra and distributions of the recoil protons) we conclude that the theories of Durand and McGee describe the quasielastic e-d-scattering process very well in the covered kinematical region. Moreover, the influence of meson currents and final state interactions can be excluded as well as a deuteron pole term contribtution within the experimental error of about 6 %.

## 3. Electric neutron formfactor

The values of the electric neutron formfactor were calculated using the formula [1]

$$R = \frac{\left.\frac{d^2\sigma}{d\Omega_3 dE_3}\right|_N}{\left.\frac{d^2\sigma}{d\Omega_3 dE_3}\right|_P} \approx \frac{\frac{G_{EN}^2 + \tau G_{MN}^2}{1+\tau} + 2\,\tau G_{MN}^2\, tg^2\,(\Theta_e/2)}{\frac{G_{EP}^2 + \tau G_{MP}^2}{1+\tau} + 2\,\tau G_{MP}^2\, tg^2\,(\Theta_e/2)}$$

$G_{EP}$, $G_{MP}$, $G_{EN}$, $G_{MN}$ are the electric and magnetic formfactors of proton and neutron,

$\tau = \frac{q^2}{4m^2}$ ; m = nucleon mass.

The ratio R was determined using the total differential cross section of quasielastic electron-deuteron scattering and the differential cross section for quasielastic electron-proton scattering.

For these calculations only events were taken, when the energy of the scattered electrons was within the range of ± 25 MeV near the peak energy.

The coincidence rate has a systematical error of about ± 2 %, the error of the electron rate is negligible in the determination of the ratio R. $G_{EP}$, $G_{MP}$ and $G_{MN}$ were computed using the four pole fit formula [7] and the scaling law. The results of this experiment for the ratio R and the electric neutron formfactor $G_{EN}$ are listed in table III and shown in figure 8.

The values of $G_{EN}$ differ from zero but are consistent with zero within the errors. These results are in agreement with our elastic e-d data [5] and with measurements of Albrecht et al. [11] and Bartel et al. [12].

## Acknowledgements

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\+ now at Bundesministerium für Bildung und Wissenschaft, Bonn

++ now at CERN, Geneva

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Table I

Corrections and errors of the cross sections

| | Correction | Error |
|---|---|---|
| target | | 0.5 % |
| intensity of primary beam | | 1.0 % |
| electron scattering angle | | 0.2 % |
| solid angle | | 1.0 % |
| primary energy | | 1.0 % |
| shower counter efficiency | 0.5 % | 0.1 % |
| spark chamber efficiency | 1 % | 0.5 % |
| protons missing the hodoscope | 1%-6% | |

Table IIa

Cross sections of quasielastic electron-deuteron scattering

$E_1 = 2.7$ GeV $\qquad \theta_e = 21^{\circ}$

| $E_3$ \|GeV\| | $\frac{d^2\sigma}{d\Omega_3 dE_3}$ $\left\|\frac{\mu b}{\text{sterad GeV}}\right\|$ | $\Delta\sigma$ $\left\|\frac{\mu b}{\text{sterad GeV}}\right\|$ |
|---|---|---|
| 2.199 | 0.226 | ±0.007 |
| 2.204 | 0.269 | ±0.007 |
| 2.209 | 0.286 | ±0.007 |
| 2.214 | 0.334 | ±0.008 |
| 2.219 | 0.336 | ±0.008 |
| 2.224 | 0.379 | ±0.009 |
| 2.229 | 0.404 | ±0.009 |
| 2.234 | 0.458 | ±0.009 |
| 2.239 | 0.495 | ±0.010 |
| 2.244 | 0.508 | ±0.010 |
| 2.249 | 0.564 | ±0.010 |
| 2.254 | 0.554 | ±0.010 |
| 2.259 | 0.592 | ±0.011 |
| 2.264 | 0.571 | ±0.010 |
| 2.269 | 0.551 | ±0.010 |
| 2.274 | 0.544 | ±0.010 |
| 2.279 | 0.514 | ±0.010 |
| 2.284 | 0.485 | ±0.010 |
| 2.289 | 0.417 | ±0.009 |
| 2.294 | 0.379 | ±0.009 |
| 2.299 | 0.317 | ±0.008 |
| 2.304 | 0.288 | ±0.007 |
| 2.309 | 0.224 | ±0.007 |
| 2.314 | 0.226 | ±0.007 |

Table IIb

Cross sections of quasielastic electron-deuteron scattering

$E_1$ = 2.7 GeV $\theta_e = 15^\circ$

| $E_3$ \|GeV\| | $\frac{d^2\sigma}{d\Omega_3 dE_3}$ $\left\|\frac{\mu b}{\text{sterad GeV}}\right\|$ | $\Delta\sigma$ $\left\|\frac{\mu b}{\text{sterad GeV}}\right\|$ |
|---|---|---|
| 2.397 | 2.05 | ±0.05 |
| 2.402 | 2.26 | ±0.05 |
| 2.407 | 2.58 | ±0.05 |
| 2.412 | 2.89 | ±0.06 |
| 2.417 | 3.19 | ±0.06 |
| 2.422 | 3.70 | ±0.07 |
| 2.427 | 4.08 | ±0.07 |
| 2.432 | 4.58 | ±0.07 |
| 2.437 | 4.94 | ±0.08 |
| 2.442 | 5.01 | ±0.08 |
| 2.447 | 5.94 | ±0.08 |
| 2.452 | 6.14 | ±0.08 |
| 2.457 | 6.00 | ±0.08 |
| 2.462 | 5.39 | ±0.08 |
| 2.467 | 5.32 | ±0.08 |
| 2.472 | 4.86 | ±0.07 |
| 2.477 | 4.25 | ±0.07 |
| 2.482 | 3.54 | ±0.06 |
| 2.487 | 3.06 | ±0.06 |
| 2.492 | 2.25 | ±0.05 |
| 2.497 | 2.07 | ±0.05 |
| 2.502 | 1.74 | ±0.04 |
| 2.507 | 1.34 | ±0.04 |
| 2.512 | 1.07 | ±0.03 |

Table IIc

Cross sections of quasielastic electron-deuteron scattering

$E_1 = 2.5$ GeV $\qquad \Theta_e = 14^\circ$

| $E_3$ \|GeV\| | $\frac{d^2\sigma}{d\Omega_3 dE_3}$ $\left\|\frac{\mu b}{\text{sterad GeV}}\right\|$ | $\Delta\sigma$ $\left\|\frac{\mu b}{\text{sterad GeV}}\right\|$ |
|---|---|---|
| 2.245 | 3.40 | ±0.11 |
| 2.250 | 3.51 | ±0.11 |
| 2.255 | 4.05 | ±0.12 |
| 2.260 | 4.74 | ±0.13 |
| 2.265 | 4.72 | ±0.13 |
| 2.270 | 5.90 | ±0.14 |
| 2.275 | 6.27 | ±0.15 |
| 2.280 | 7.39 | ±0.16 |
| 2.285 | 8.81 | ±0.17 |
| 2.290 | 9.99 | ±0.19 |
| 2.295 | 11.17 | ±0.20 |
| 2.300 | 11.70 | ±0.20 |
| 2.305 | 13.40 | ±0.21 |
| 2.310 | 13.36 | ±0.21 |
| 2.315 | 13.31 | ±0.21 |
| 2.320 | 12.81 | ±0.21 |
| 2.325 | 12.92 | ±0.21 |
| 2.330 | 10.29 | ±0.19 |
| 2.335 | 8.96 | ±0.18 |
| 2.340 | 7.43 | ±0.16 |
| 2.345 | 5.94 | ±0.14 |
| 2.350 | 4.34 | ±0.12 |
| 2.355 | 3.51 | ±0.11 |
| 2.360 | 2.91 | ±0.10 |
| 2.365 | 2.39 | ±0.09 |
| 2.370 | 1.63 | ±0.07 |

Table IId

Cross sections of quasielastic electron-deuteron scattering

$E_1 = 2.5$ GeV $\quad\quad \Theta_e = 12^\circ$

| $E_3$ \|GeV\| | $\frac{d^2\sigma}{d\Omega_3 dE_3}$ $\left\|\frac{\mu b}{\text{GeV sterad}}\right\|$ | $\Delta\sigma$ $\left\|\frac{\mu b}{\text{GeV sterad}}\right\|$ |
|---|---|---|
| 2.294 | 7.56 | ±0.35 |
| 2.299 | 8.17 | ±0.37 |
| 2.304 | 10.23 | ±0.41 |
| 2.309 | 10.80 | ±0.42 |
| 2.314 | 11.70 | ±0.44 |
| 2.319 | 12.99 | ±0.46 |
| 2.324 | 18.09 | ±0.55 |
| 2.329 | 18.47 | ±0.55 |
| 2.334 | 22.33 | ±0.61 |
| 2.339 | 26.40 | ±0.66 |
| 2.344 | 29.55 | ±0.70 |
| 2.349 | 31.88 | ±0.73 |
| 2.354 | 34.19 | ±0.75 |
| 2.359 | 34.86 | ±0.76 |
| 2.364 | 34.86 | ±0.76 |
| 2.369 | 31.37 | ±0.72 |
| 2.374 | 26.67 | ±0.66 |
| 2.379 | 21.20 | ±0.59 |
| 2.384 | 16.86 | ±0.53 |
| 2.389 | 13.92 | ±0.48 |
| 2.394 | 9.52 | ±0.40 |
| 2.399 | 7.74 | ±0.36 |
| 2.404 | 5.84 | ±0.31 |
| 2.409 | 4.40 | ±0.27 |

Table III

Ratio R of quasielastic electron-neutron and electron-proton scattering and the elastic neutron form factor

| $q^2 \left\| (\frac{GeV}{c})^2 \right\|$ | R | $G_{EN}^2$ |
|---|---|---|
| 0.26 | 0.18±0.04 | 0.0046±0.016 |
| 0.34 | 0.21±0.03 | 0.0029±0.012 |
| 0.45 | 0.24±0.04 | 0.0069±0.011 |
| 0.81 | 0.32±0.05 | 0.0034±0.008 |

## Figure Captions

Figure 1 Experimental set-up.

2-5 Measured energy-spectra of the scattered electrons. The solid lines are curves which were computed with formulae taken from references 1, 7, 8, 9.

6 Measured angular distribution of the recoil protons for 12 hodoscope elements in a one dimensional cut parallel to the scattering plane. The solid lines are curves which were computed with formulae from references 6 - 9.

7 Measured angular distributions for 12 hodoscope elements perpendicular to the scattering plane. See fig.6.

8 Electric neutron formfactor $G_{EN}(q^2)$.

▲ Albrecht et al. [11],
▼ W. Bartel et al. [12],
○ S. Galster et al. [5],
X this work.

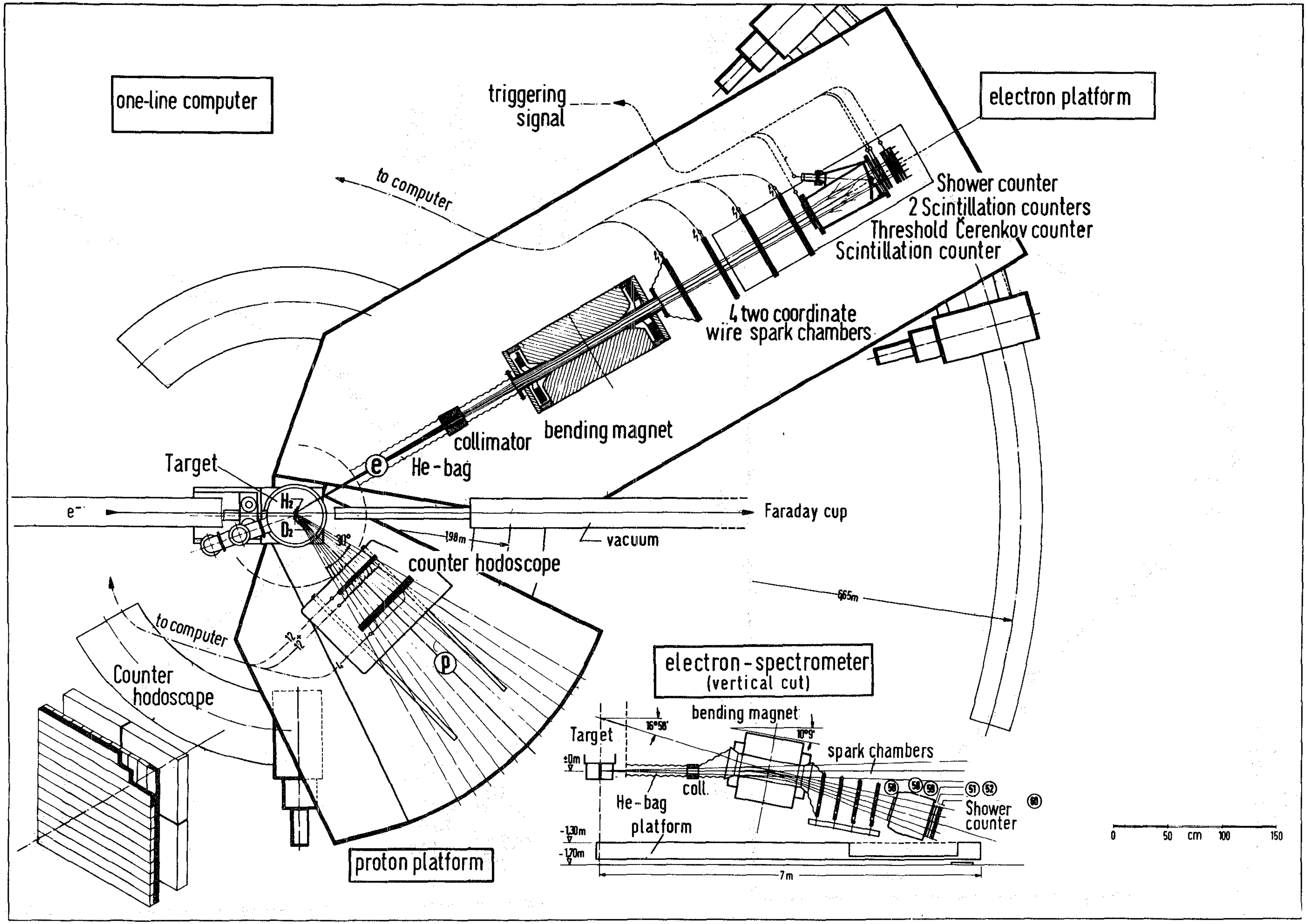
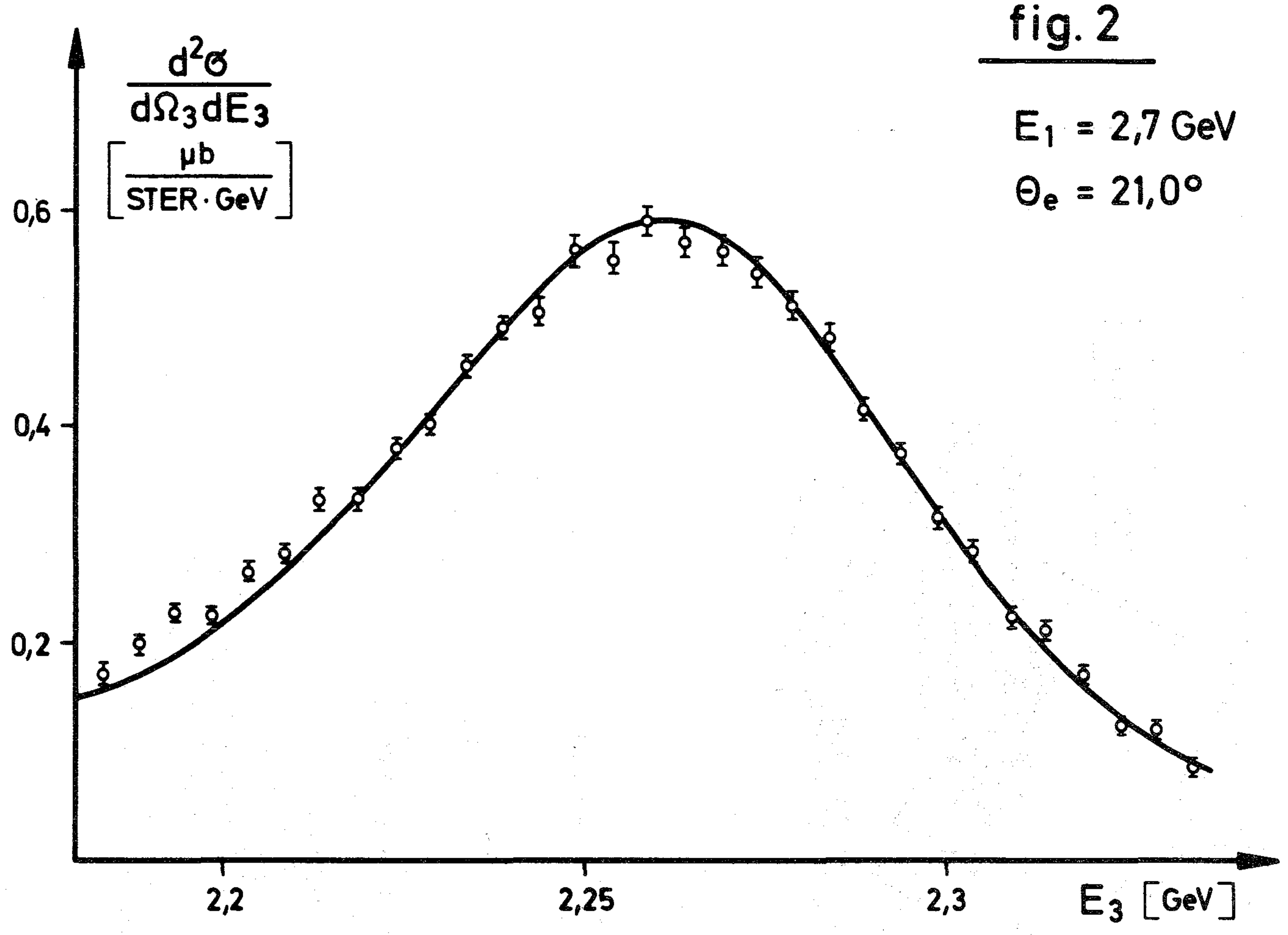

one-line computer
triggering signal
electron platform
to computer
Shower counter
2 Scintillation counters
Threshold Čerenkov counter
Scintillation counter
4 two coordinate wire spark chambers
bending magnet
collimator
He-bag
Target
$H_2$
$D_2$
e⁻
Faraday cup
vacuum
1.98m
30°
counter hodoscope
6.65m
to computer
Counter hodoscope
p
electron-spectrometer (vertical cut)
bending magnet
16°58'
10°9'
Target
spark chambers
±0m
coll.
He-bag
platform
Shower counter
-1.30m
-1.70m
7m
proton platform
0 50 cm 100 150

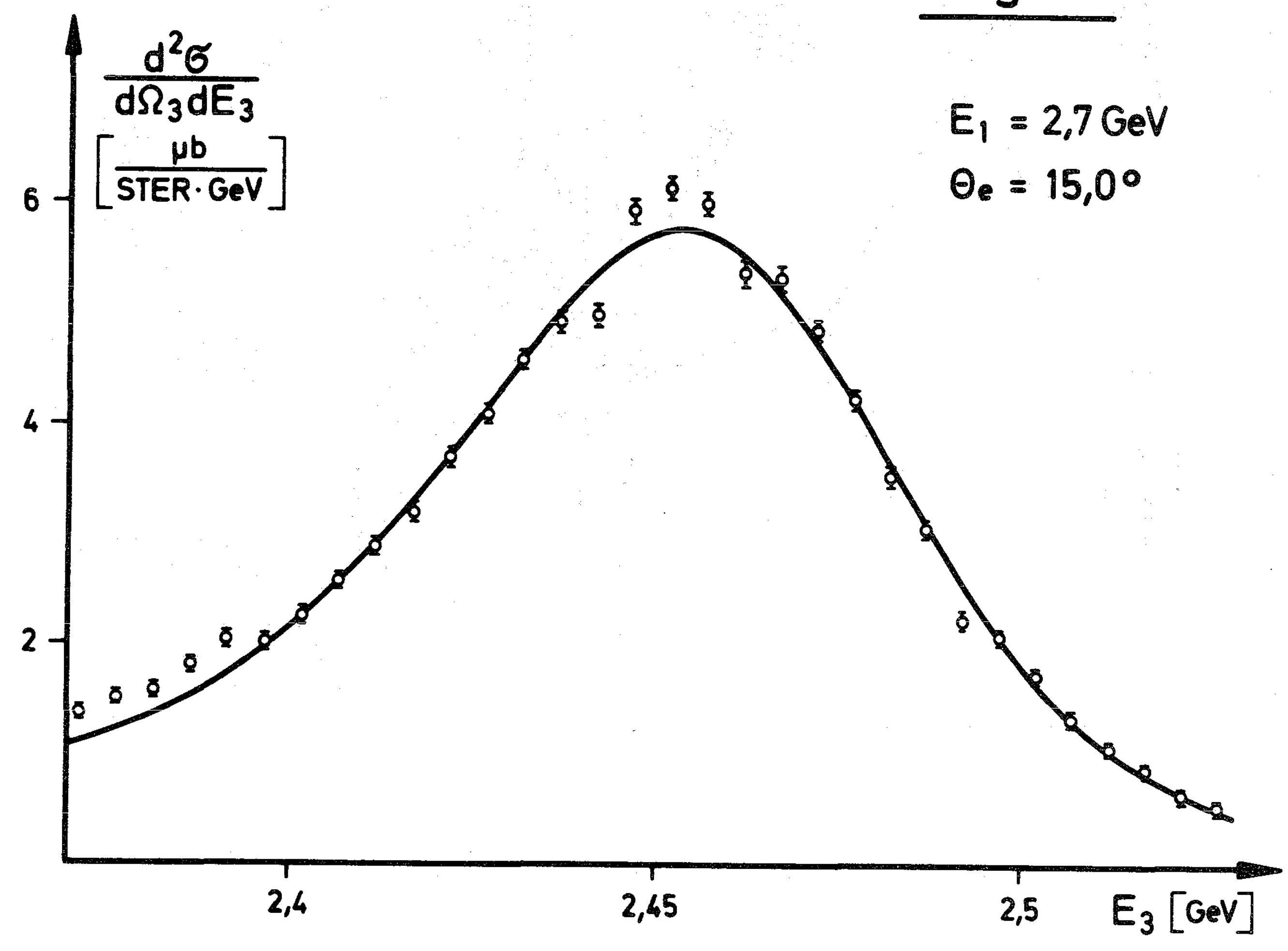
fig. 1

fig. 2



E1 = 2,7 GeV
Θe = 21,0°
d²σ / dΩ3dE3 [μb / STER·GeV]
0,6
0,4
0,2
2,2
2,25
2,3
E3 [GeV]


fig. 3



E1 = 2,7 GeV
Θe = 15,0°
d²σ / dΩ3dE3 [μb / STER·GeV]
6
4
2
2,4
2,45
2,5
E3 [GeV]

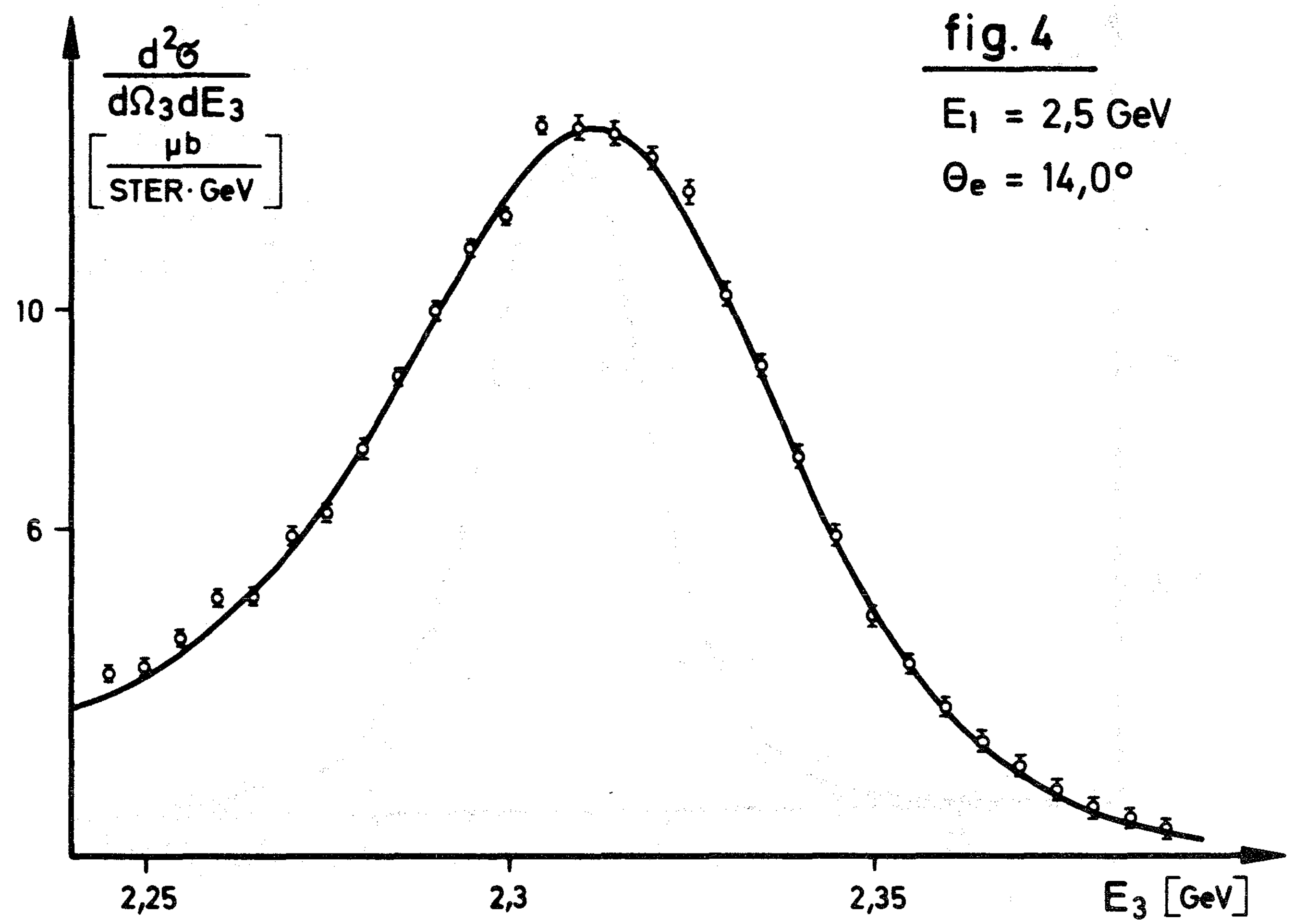


fig. 4
$E_1$ = 2,5 GeV
$\Theta_e$ = 14,0°
$\frac{d^2\sigma}{d\Omega_3 dE_3}$ [$\frac{\mu b}{STER \cdot GeV}$]
10
6
2,25
2,3
2,35
$E_3$ [GeV]

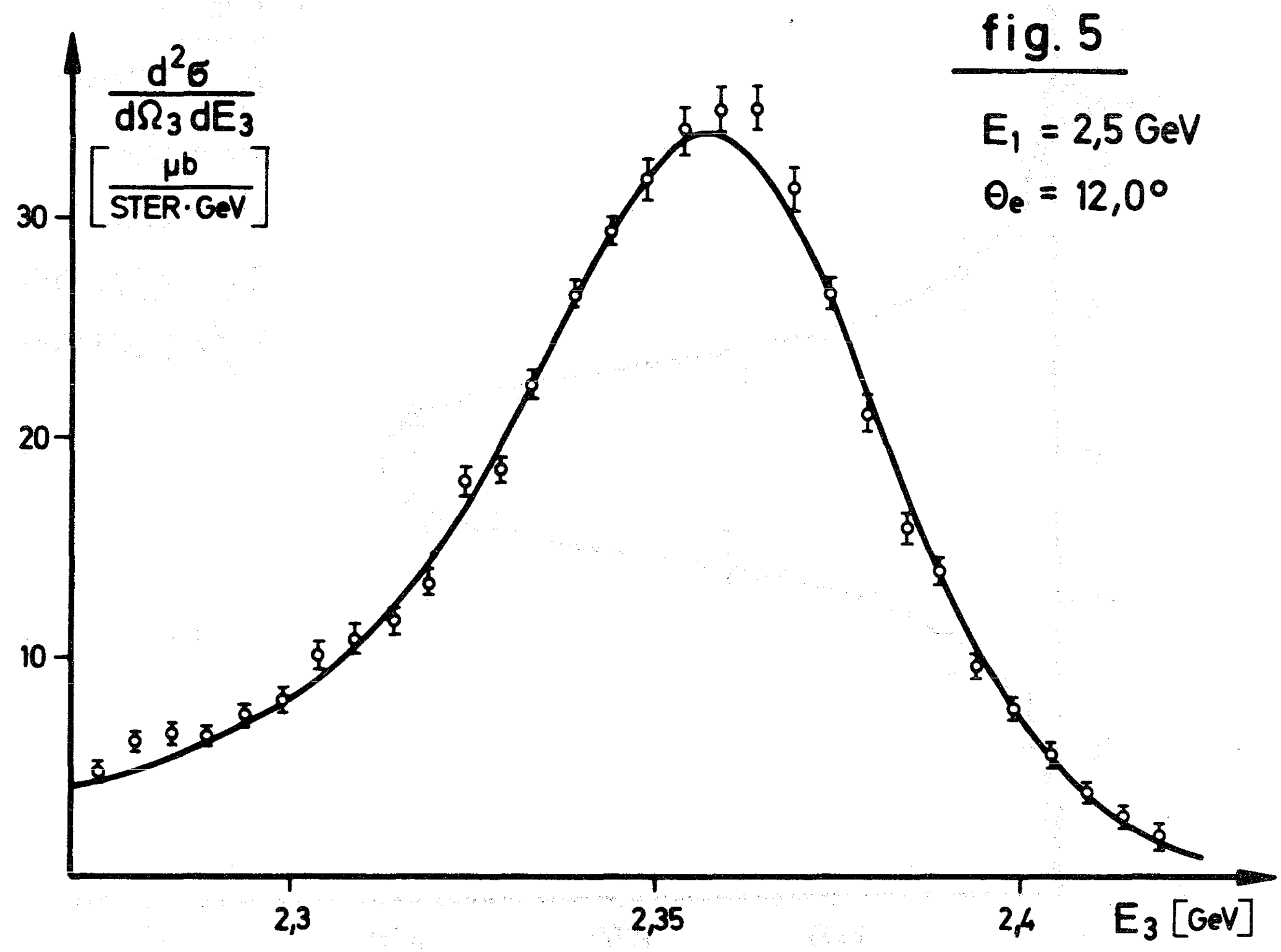



fig. 5
$E_1$ = 2,5 GeV
$\Theta_e$ = 12,0°
$\frac{d^2\sigma}{d\Omega_3 dE_3}$ [$\frac{\mu b}{STER \cdot GeV}$]
30
20
10
2,3
2,35
2,4
$E_3$ [GeV]

fig. 6

$E_1 = 2{,}7$ GeV
$\Theta_e = 15{,}0°$
$E_3^1 = 2{,}435$ GeV
$E_3^2 = 2{,}555$ GeV

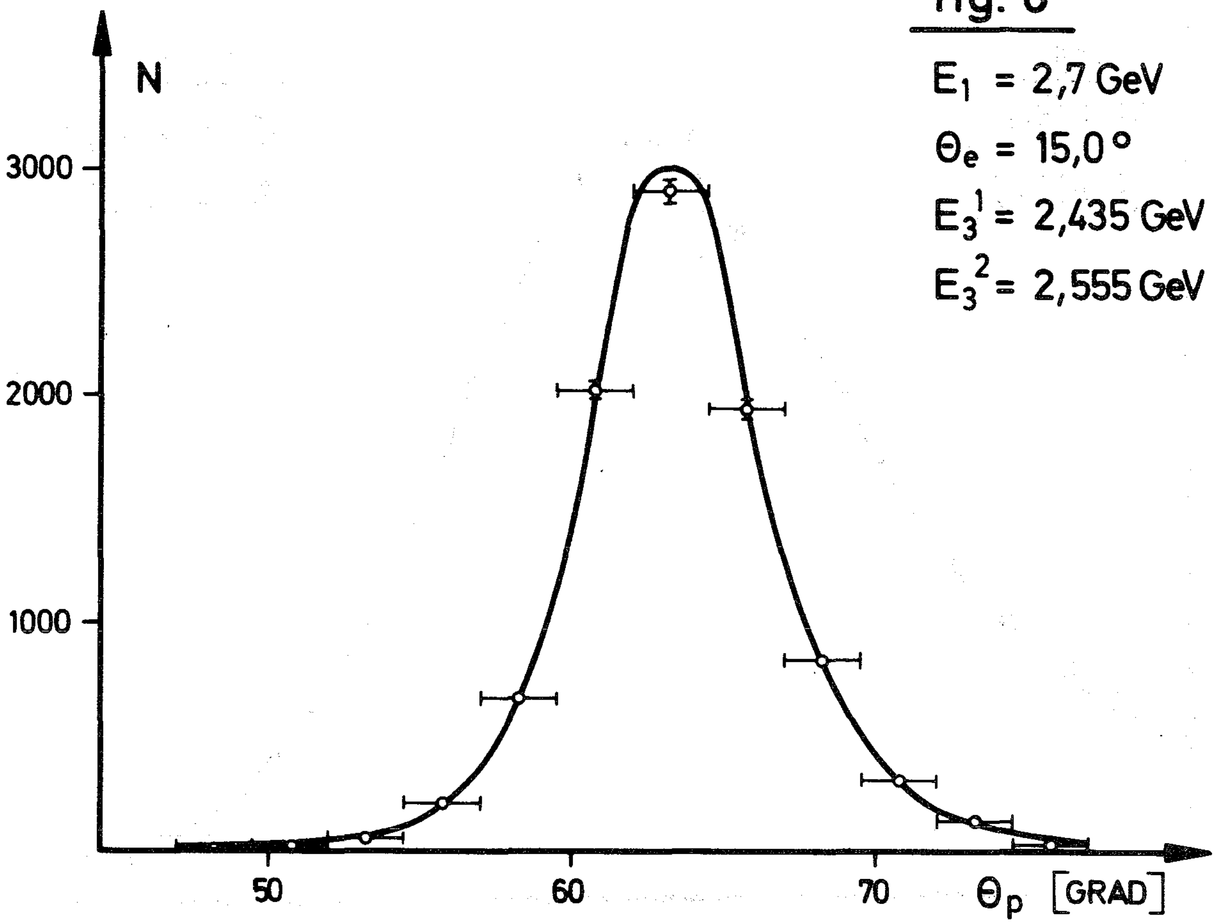
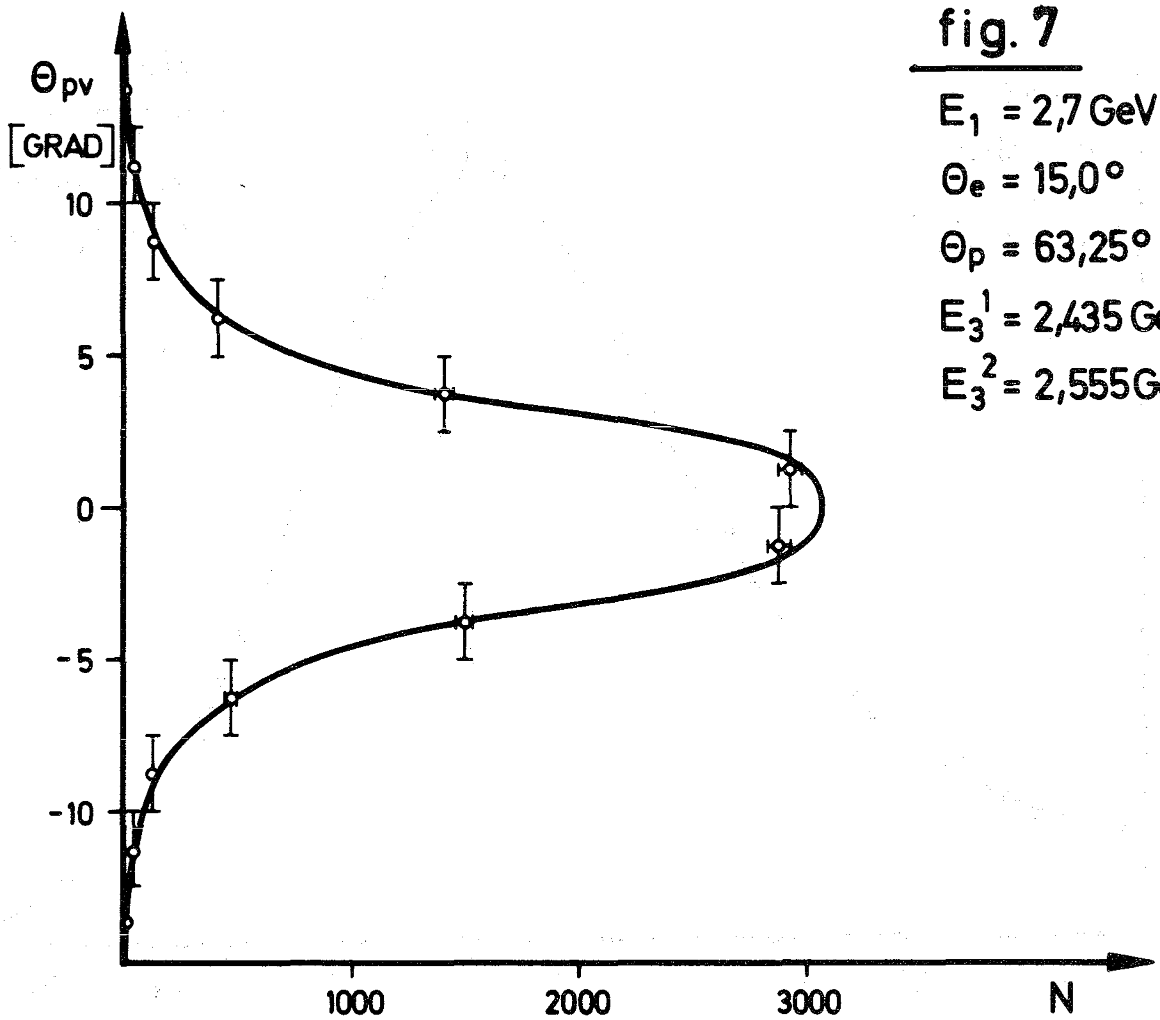



fig. 7

$E_1 = 2{,}7$ GeV
$\Theta_e = 15{,}0°$
$\Theta_p = 63{,}25°$
$E_3^1 = 2{,}435$ GeV
$E_3^2 = 2{,}555$ GeV



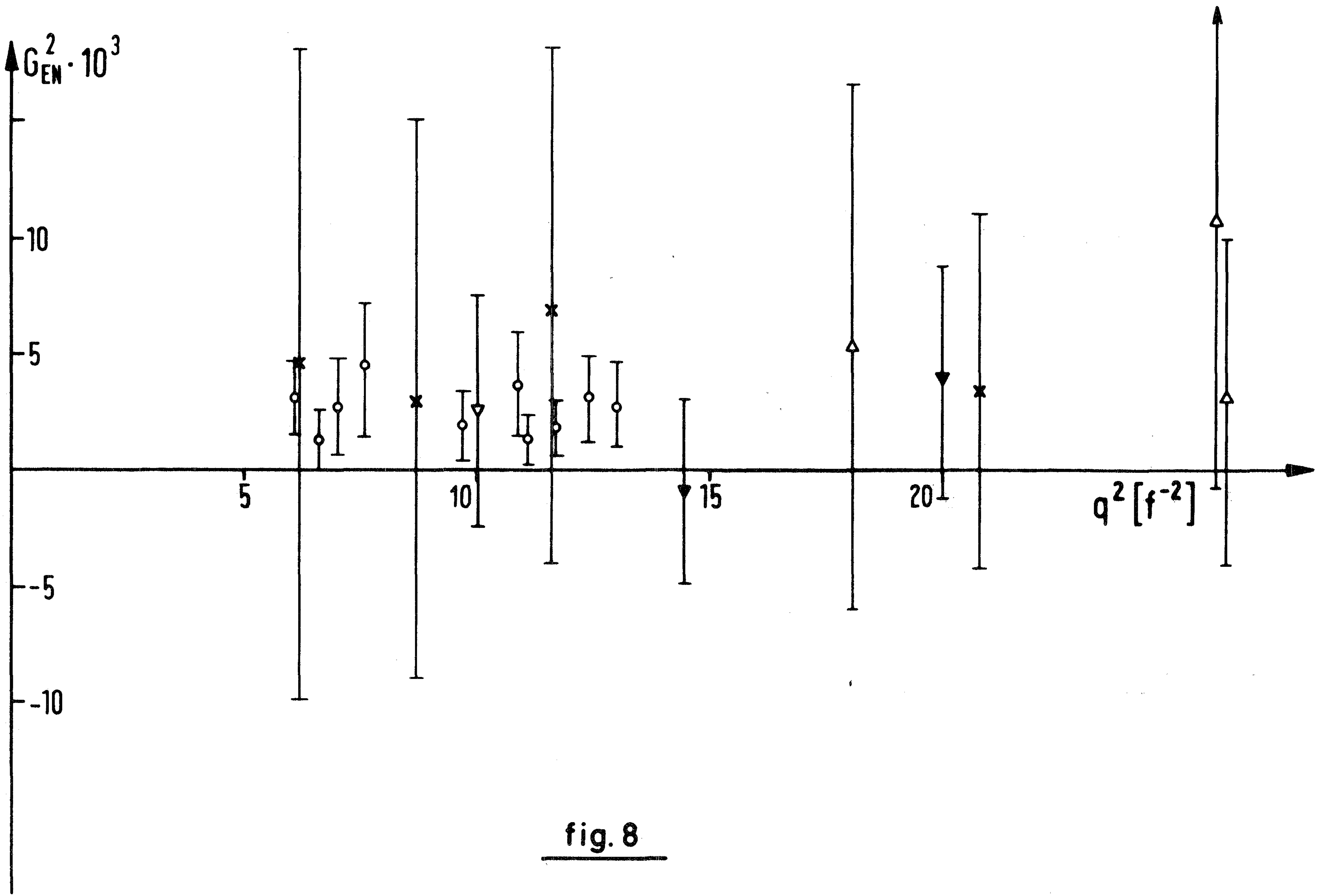



fig. 8