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1) ABSTRACT

The cross section for elastic electron-proton scattering has been measured in the four momentum transfer region  $q^2 = 18$  to  $40 \text{ f}^{-2}$  at electron scattering angles from  $54^\circ$  to  $75^\circ$ .

A polyethylen target was used in the internal beam of the Deutsches Elektronen Synchrotron at Hamburg. Electron-proton coincidences were observed by using two quadrupole spectrometers. In contrast to single arm measurements the separation of elastic and inelastic events is achieved here mainly by defining the directions of scattered electrons and recoil protons, whereas the momentum analysis is only used as an additional means to reduce the background. In the present coincidence arrangement the range of momentum transfer is rather limited by the accessible angles of electrons and protons. The two quadrupole spectrometers are designed to be used either separately for single arm measurements with a liquid hydrogen target or one in coincidence with a differential Cerenkov proton counter at small angles.

The results obtained are preliminary. The cross sections corrected for bremsstrahlung and hydrogen loss of the  $\text{CH}_2$ -target are roughly consistent with results calculated from known form factors.

## 2) APPARATUS

The coincidence arrangement is shown in figure 1.

### a) Target

A 2 mm high, 5 mm long polyethylen target was exposed to a flux of about  $3 \cdot 10^{10}$  electrons per burst of the internal beam. During the irradiation the target loses hydrogen. The hydrogen loss has been measured as a function of the integral irradiation monitored by a quantameter <sup>+)</sup> .

After some hours an asymptotic loss of 30 % was reached. In figure 2 the coincidence rate of electron-hydrogen scattering is shown versus the collected charge of the monitor.

For some runs the apparatus was only adjusted with an irradiated target, but the data collection was done with a fresh one.

A carbon target was used to correct for the electron carbon scattering. For the singles rate this contribution was roughly 70 % of the total rate and was reduced to less than 10 % by coincidence measurements.

### b) Spectrometer

Two spectrometers with quadrupoles, vacuum chambers, counterbanks and a Cerenkov counter in the electron arm is arranged on two carriages, whose angles were viewed by means of a TV camera accurate to  $\pm 0.07^\circ$ .

The electron spectrometer has half a quadrupole (DESY type QC/2) with an iron mirror plate. Both quadrupoles

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<sup>+)</sup>  A chemical analysis of the target is not reliable since the hydrogen loss is not uniform over the volume.

are focussing vertically.

The useful solid angle of 5.60 mster for coincidence measurements was defined by the electron arm .

From the total aperture 26 % were shadowed by a central lead plug. The apertures, defined by lead collimators at the entrance of each quadrupole were chosen small enough so that no elastically scattered particle hits the pole faces. This was checked by floating wire measurements <sup>+) ++)</sup>.

The scintillation counter bank is shown in figure 1. Because of field aberrations the scintillators are divided in the defocussing plane of the quadrupoles into two straight sections in order to fit the image line as determined from floating wire- or  $\alpha$  measurements <sup>++)</sup> <sup>+++)</sup>. Each section is in optical contact with a 56 AVP tube. To compensate for the variation of momentum with the scattering angle across the spectrometer aperture the counter banks were tilted.

With respect to the effects mentioned above the scintillators (NE 102 A) were sufficiently oversized, so that they do not limit the acceptance of the spectrometers in any position. The counter bank was adjustable also in vertical direction remotely from the counting room.

The momentum resolution of the electron spectrometer as measured with an  $\alpha$ -source Po 210, is <sup>+++)</sup> :

2.4 % halfwidth with one of the 4 momentum defining counters 2 x 20 mm<sup>2</sup>,  
5 % " " the two split counters in a distance of 12.5 cm.

In figure 3 the resolutions curves from the scattering experiment are shown for a momentum defining counter

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<sup>+) E.Ganszaug, DESY Ber. F21-3, Hamburg 24-9-64  
<sup>++) H.Hultschig, DESY Ber. F21-2, Hamburg 3-7-64  
<sup>+++)</sup> H.J.Behrend, DESY Ber. F21-1, Hamburg 12-5-64</sup></sup>

and the split counters with and without the proton coincidence.

For the proton arm a momentum resolution of about 30 % was sufficient.

### c) Cerenkov Counter

To separate contributions from pions a 0.3 m long threshold Cerenkov counter with a gas filling of Frigen 13 ( $\text{CF}_3\text{Cl}$ ) at maximal 9 atmospheres was used. The optical system consists of 5 spherical mirrors which concentrate the Cerenkov radiation on five 56 UVP tubes in optical contact with quartz glass windows in the tank. The spherical mirrors were manufactured by pressing lucite and cover it with a thin aluminium layer, coated for protection with quartz<sup>+)</sup> . The efficiency of the Cerenkov counter at a pressure of 9 atmospheres was near 100 % as shown in figure 7. The efficiency was measured with and without using the Cerenkov counter in the coincidence logic. To compare with the measured points, two curves are plotted. They are calculated for two different numbers of photoelectrons produced by Cerenkov radiation, which is proportional to the gas pressure P.

### d) Fast Logic

A block diagram of the electronics is shown in figure 4. The 3 nsec rise time of the photo tube pulses was not worsened appreciably by using 150 m of transfer cables, 3/8" thick. The time resolution was 13 nsec halfwidth. The average pulse height produced by minimum ionizing particles was about 0.7 Volt. During the run the pulse-

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<sup>+)</sup>  S.Galster, G.Hartwig ; - Bericht über einen Schwellen-Cerenkov-Zähler. (to be published)

height spectrum of each counter was cyclically checked. Random coincidences between the two spectrometers as measured with a 30 nsec delay or a time to pulse height converter, were kept below 5-10 %. For single arm measurements randoms were also registered.

e) Monitoring

The incident electrons producing bremsstrahlung in the target (0.0095 radiation length) were monitored by a 13 plate, argon filled quantameter <sup>+)</sup> . The density of CH<sub>2</sub> was determined as 0.95 gram/cm<sup>3</sup>, and a radiation length of X<sub>CH<sub>2</sub></sub> = 50.0 gram/cm<sup>2</sup> was used. The latter was derived from X<sub>carbon</sub> = 45.7 gram/cm<sup>2</sup> and X<sub>H<sub>2</sub></sub> = 64.4 gram/cm<sup>2</sup> <sup>++)</sup> in the complete screening limit.

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<sup>+)</sup> R.R.Wilson  
<sup>++)</sup>K.W.Chen

Nucl.Instr.and Meth. 1, 101 (1957)  
Harvard Univ., Cyclotron Laboratory  
Internal Memorandum dated 1-9-63



### 3) CALIBRATIONS AND TESTS

#### a) Incident Energy

Since there was no exact calibration of the synchrotron, the incident energy was determined from the angles of the recoil protons and the scattered electrons.

As an example the variation of the coincidence rate with the proton angle  $\phi$  at a fixed electron angle is shown in figure 5. The angles were accurate to  $\pm 0.07^\circ$ .

Both angles, weighted by the cross section across the spectrometer acceptance, were used to calculate the primary energy to better than  $\pm 1.2\%$ .

For the low energies (1-2 BeV) used in these measurements the spill started around 0.7 msec before  $\frac{dB}{dt} = 0$  with a duration of about 0.3 msec. In addition a shift of typically  $\pm 0.1$  msec during the run was observed.

Both induced a spread of  $\pm 0.4\%$  of the incident energy, which was included in the uncertainty of the fourmomentum transfer.

#### b) Solid Angle

During the data collection the solid angle of the coincidence apparatus was defined by the electron arm only. To check this, the aperture of the proton spectrometer was varied. The coincidence rate versus vertical and horizontal slit position is plotted in figure 6. The breaks in the curve 6a) arise from the shape of the spectrometer apertures, which are drawn for this case in a sub-figure. There the electron aperture is projected with respect to kinematics into the direction of the proton acceptance.

### c) Counter Efficiency and Dead Time

The system was operated so, that all counters, except for the slat counters, had approximately 100 % efficiency. This was checked by observing the pulse height spectra or rising the discriminator levels by 6 db. A good test comes also from measuring the increase in the counting rate, when alternately each counter was taken out of the logic. Because of the coincidence arrangement this method was also applicable to the Cerenkov counter at low incident energies. For all tests no effect was found within a statistical error of less than  $\pm 3\%$ . The efficiency of the Cerenkov counter as a function of the gas pressure is shown in figure 7.

Electronic dead time effects were checked firstly by reducing the incident electron flux by a factor of 5 and secondly the dead time of each discriminator was increased by a factor of 6. Both methods showed no change in the counting rate within an error of  $\pm 3\%$ .

### d) Momentum Acceptance

The resolution curve of the OR coincidence rate as plotted in figure 3, shows a small flat top. To proof that the momentum acceptance covers all elastically scattered electrons, the momentum resolution of the electron-spectrometer was changed from 5% to about 30% by adding the split counter rate. Thereby advantage was taken of the coincidence method as the inelastic contributions were negligible. After subtraction of the carbon background for both momentum acceptances the coincidence rate was equal within a statistical error of typically 3%. A correction of 3% only was applied for the different radiative corrections, since phase space accepted by this coincidence apparatus was defined essentially by the proton solid angle and not by the momentum resolution of the electron spectrometer.

#### 4) RESULTS

The preliminary cross sections obtained by coincidence measurements at incident energies from 0.9 to 1.3 BeV at scattering angles  $54^\circ$  to  $74^\circ$  are listed in table I and plotted in figure 3.

For comparison two curves are drawn constructed from CEA <sup>+)</sup>  and Cornell <sup>++)</sup>  form factor fits. A summary of correction factors applied on the data and the systematic errors involved in the experiment are listed in table II and III respectively. The radiative corrections are calculated for coincidence measurements taking into account the special parameters of the apparatus <sup>+++)</sup>.

In figure 9 the electromagnetic formfactors were extracted, assuming  $G_E = G_M/2.79$  <sup>+)</sup> , or by combining with other formfactors <sup>++)</sup> .

#### 5) FURTHER MEASUREMENTS

For measurements at higher energies a liquid hydrogen target is under construction.

Till now the region of  $q^2$  was limited by the angles of both of the spectrometers (electron angle  $54^\circ$  to  $145^\circ$ ; proton angle  $31^\circ$  to  $90^\circ$ ). For coincidence work at higher momentum transfer a differential gas Cerenkov counter will be used to detect the recoil protons in extreme forward directions. Also one of the spectrometers will be furnished with a shower counter for single arm measurements at electron angles from  $30^\circ$  to  $90^\circ$ .

Acknowledgments : The authors wish to thank Drs. J. Bucher, U. Meyer-Berkhout, H. Pingel and K. Steffen for help and discussions in the earlier phases of the experiment.

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<sup>+)</sup> W. Chen et al., Phys. Rev. Letters 13, 631 (1964)  
<sup>++)</sup> M. W. Kirson, J. S. Levinger (Preprint)  
<sup>+++)</sup> Kohaupt private communication

Table I      Electron Proton Scattering Cross Section

$q^2 [r^{-2}]$	$\theta^\circ$	$\phi^\circ$	$E_0 [\text{BeV}]$	$\frac{d\sigma}{d\Omega} \cdot 10^{-32}$
18.2	54.2	41.35	1.14	0.82 ± 0.01 <sup>+) </sup>
18.3	54.1	41.3	1.15	0.81 ± 0.02
18.9	54.1	41.2	1.160	0.78 ± 0.02
19.4	54.2	40.9	1.18	0.72 ± 0.01
19.5	73.0	33.8	0.96	0.30 ± 0.02
19.9	73.5	33.35	0.97	0.29 ± 0.01
23.4	64.9	35.1	1.16	0.227 ± 0.005
25.3	70.0	32.1	1.16	0.171 ± 0.01
31.5	54.1	36.0	1.59	0.113 ± 0.007
31.6	64.4	32.2	1.42	0.074 ± 0.006
32.0	54.1	35.9	1.60	0.144 ± 0.008
32.5	64.3	32.2	1.44	0.096 ± 0.007
38.3	54.2	33.8	1.81	0.059 ± 0.004
41.0	54.1	31.05	1.83	0.049 ± 0.001

<sup>+)</sup>  statistical errors

Table II Correction Factors

1) Hydrogen loss	of a 'new' target	: 1.02
	of an irradiated target	: 1.53
2) Bremsstrahlung		: 1.19-1.20
3) Quantameter		: 1.00
4) Overall counter efficiency		: 1.00

Table III Systematical Errors

1) Quantameter	$\pm 10 \%$	(estimated, not calibrated)
2) Target new	$\pm 1 \%$	
irradiated	$\pm 5 \%$	
3) Overall scintillation counter efficiency	4 %	
4) Dead time	3 %	
5) Cerenkov counter efficiency	3 %	
Total		$\pm 14 \%$ (for an irradiated target)

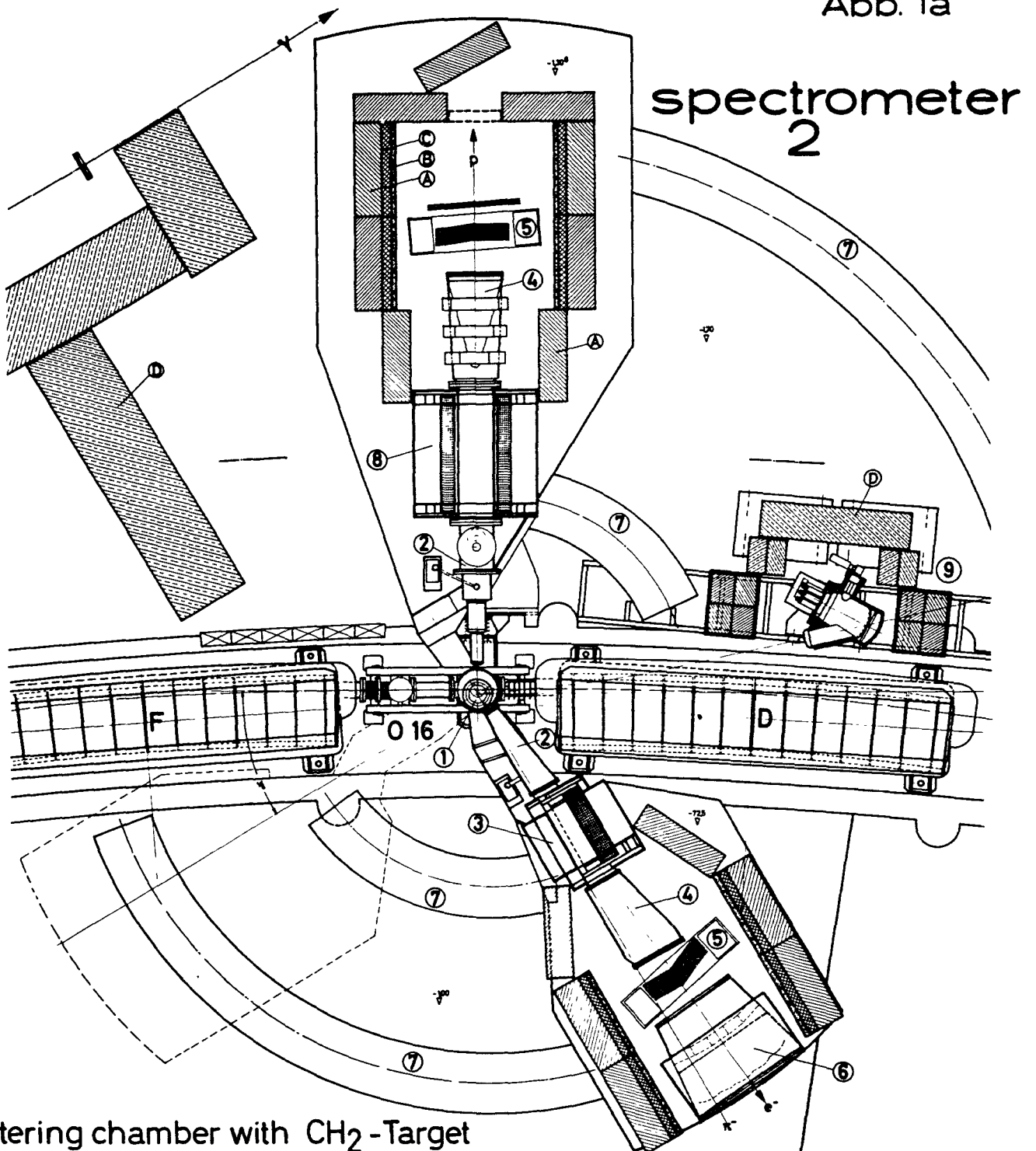
Uncertainty in the value of  $q^2$ : +)

	$q^2 = 20 \text{ f}^{-2}$	$q^2 = 40 \text{ f}^{-2}$
1) $\pm 1.6 \%$ incident energy	$\pm 2.5 \%$	$\pm 2.3 \%$
2) $\pm 0.07^\circ$ electron angle	$\pm 0.2 \%$	$\pm 0.2 \%$
Total (added in square)		$\pm 2.3 \%$

+) an electron scattering angle of  $60^\circ$  was assumed

Table of Figures :

<u>Figure 1</u>	Experimental Arrangement
<u>Figure 2</u>	Hydrogen Loss of the CH <sub>2</sub> Target
<u>Figure 3</u>	Momentum Resolution Curves
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<u>Figure 5</u>	Proton Angle
<u>Figure 6</u>	Solid Angle
<u>Figure 7</u>	Cerenkov Counter Efficiency
<u>Figure 8</u>	Experimental Results
<u>Figure 9</u>	Form Factors

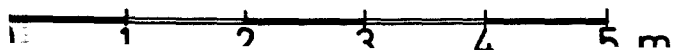


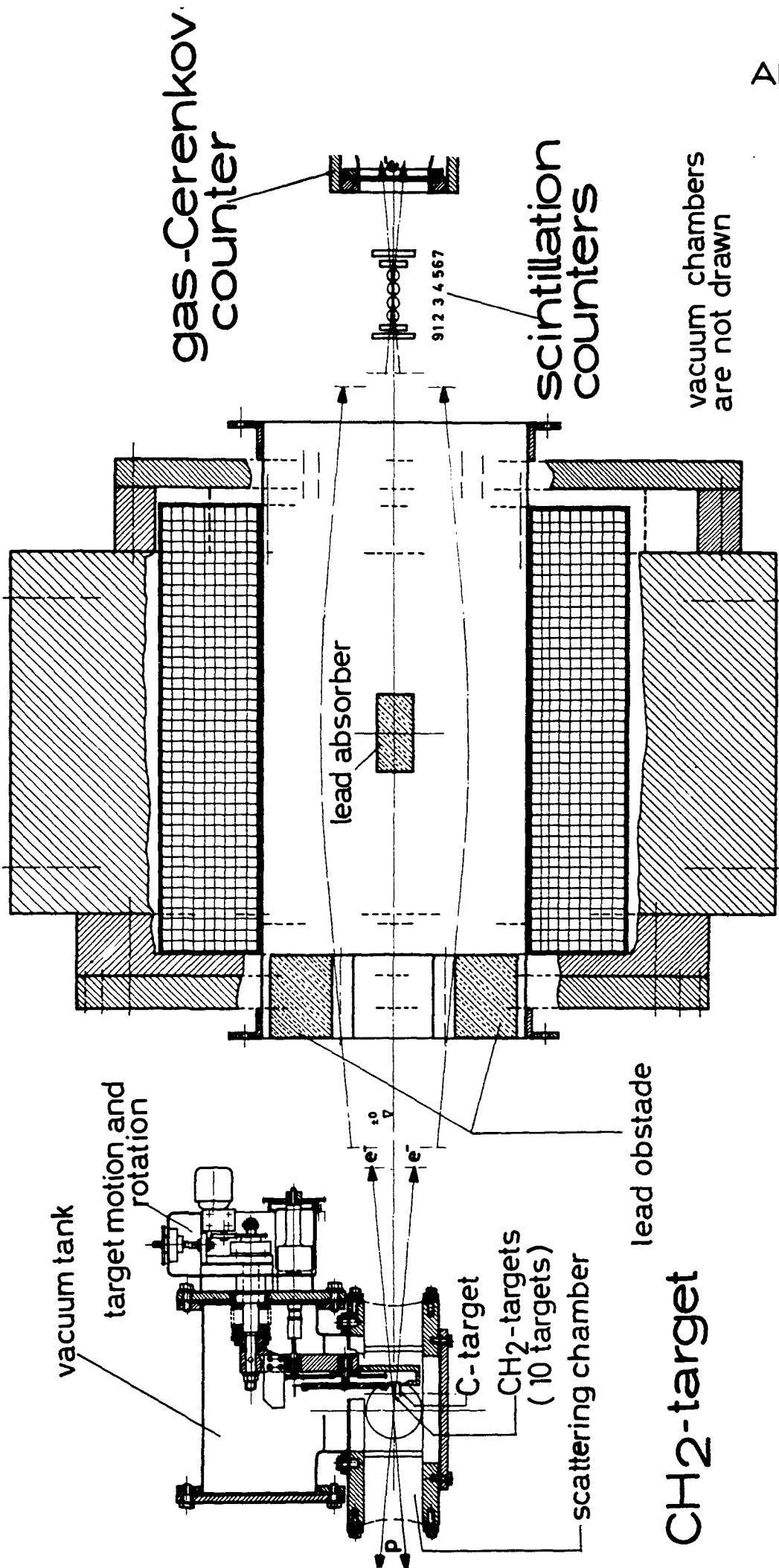
- 1 scattering chamber with CH<sub>2</sub>-Target
- 2 front vacuum chamber
- 3 halved quadrupole magnet QC/2
- 4 back vacuum chamber
- 5 scintillation counters
- 6 gas-Cerenkov-counter (threshold counter)
- 7 carrers for carriages
- 8 quadrupole magnet QA
- 9 differential gas-Cerenkov-counter for measuring the recoil protons in coincidence with spectrometer I. Counter and shielding movable

**spectrometer 1**

- A iron blocks
  - B B<sub>4</sub>C-CH<sub>2</sub>-plates
  - C lead blocks
  - D concrete blocks
- } shielding

e<sup>-</sup>. p-scattering on internal target,  
1<sup>st</sup> generation





gas-Cerenkov counter

scintillation counters

vacuum chambers are not drawn

lead absorber

912 3 4 567

target motion and rotation

vacuum tank

C-target

CH<sub>2</sub>-targets (10 targets)

scattering chamber

lead obstade

CH<sub>2</sub>-target

0 10 20 30 40 50 cm

quadrupole magnet QC/2

Vertical cut through quadrupole spectrometer 1



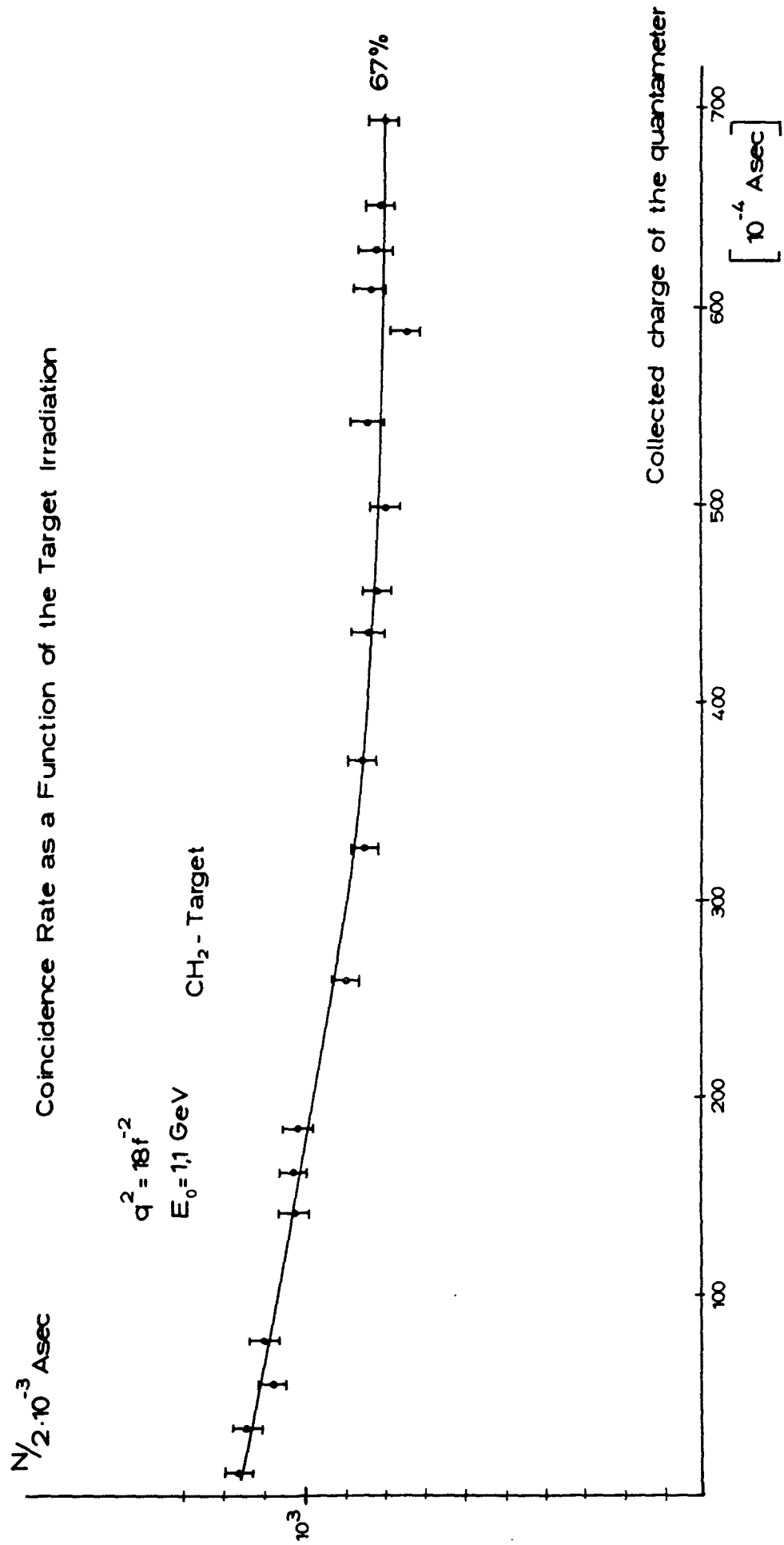
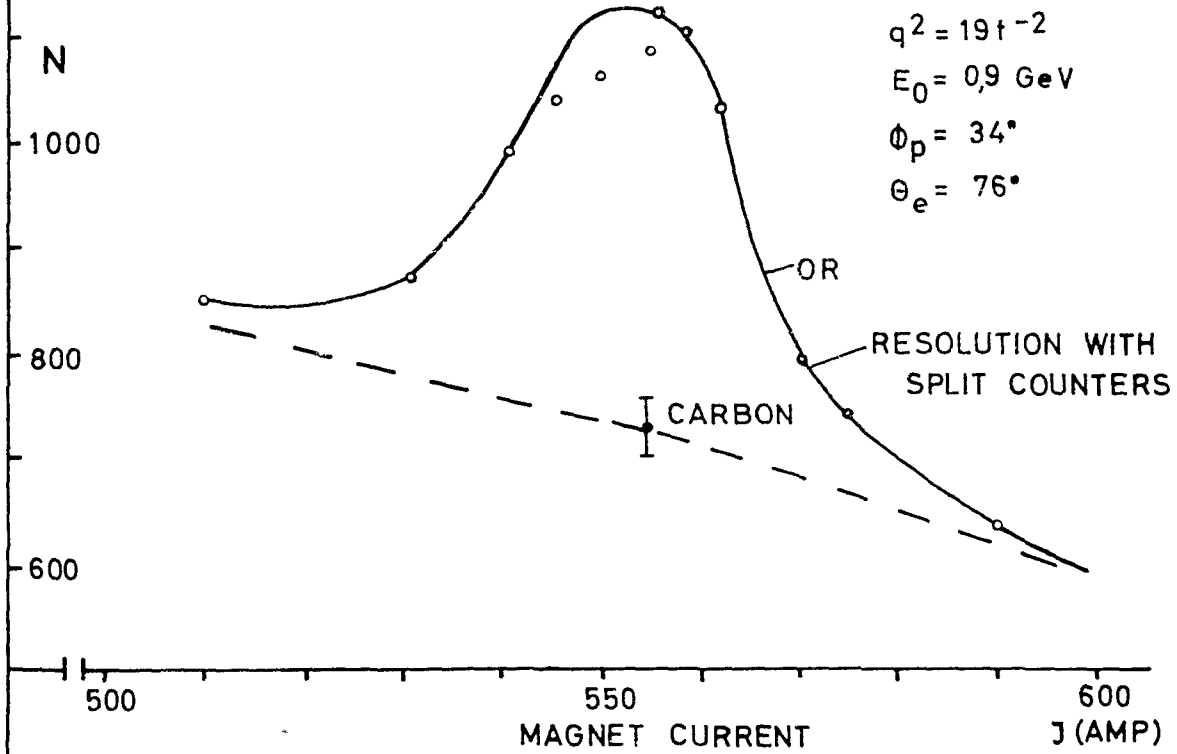


Fig. 2

# ELECTRONSPECTRA

Fig. 3



# ELECTRONSPECTRA IN COINCIDENCE WITH THE PROTON ARM

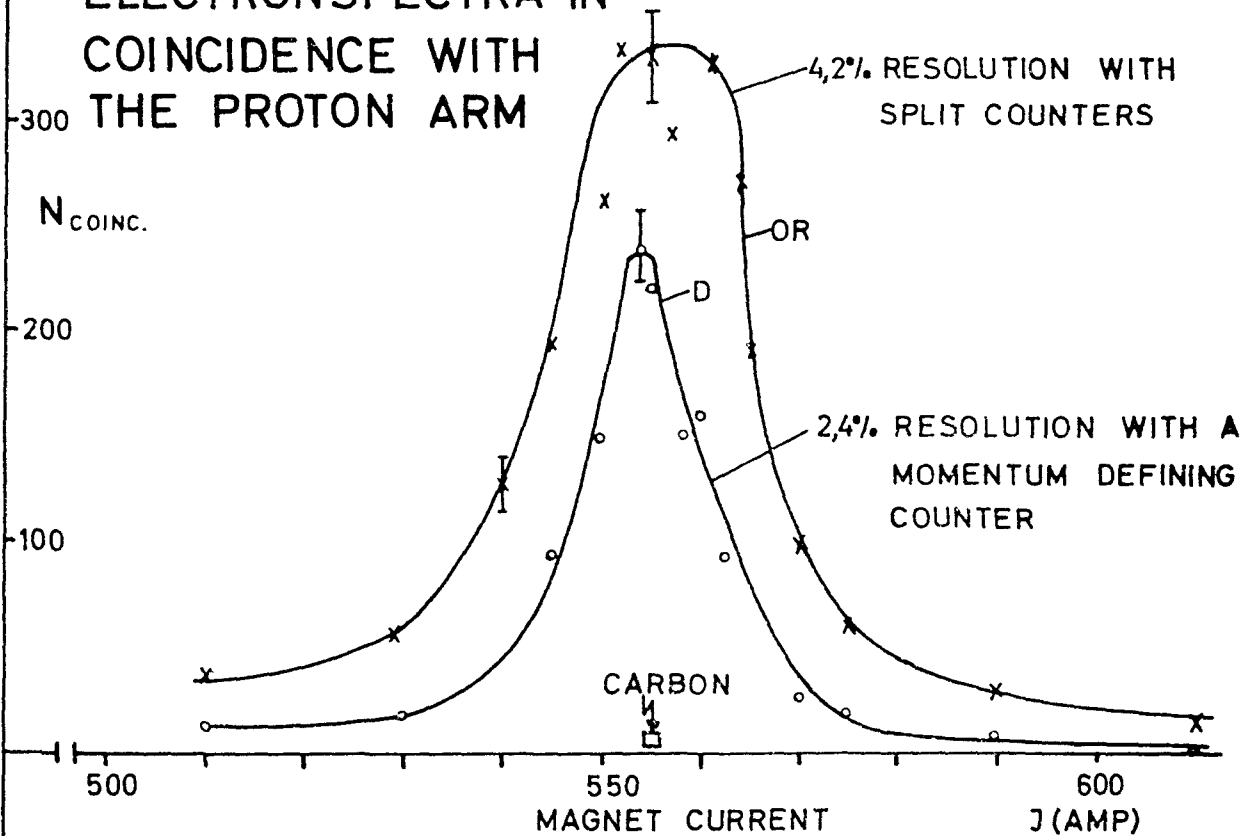
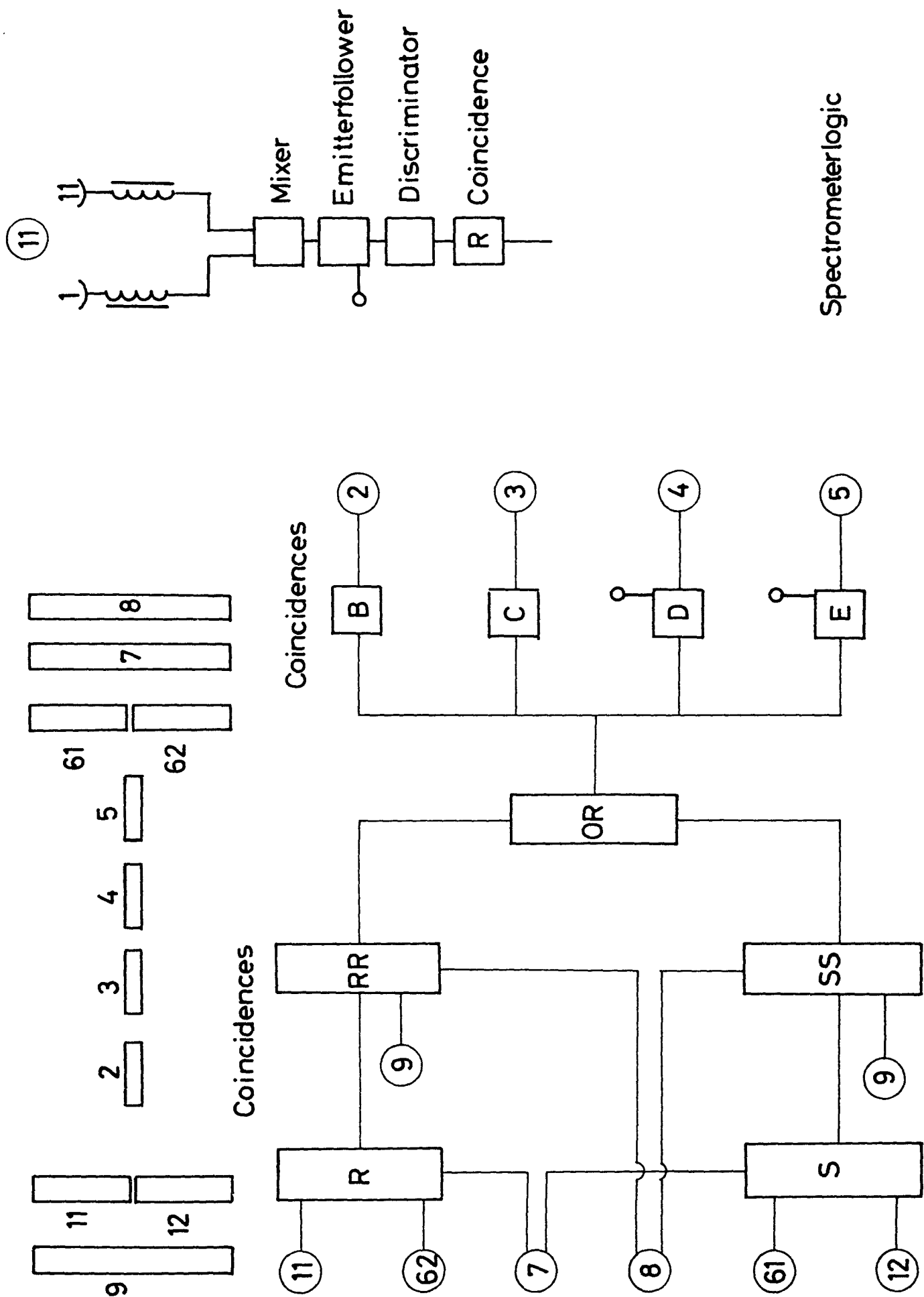


Fig.4



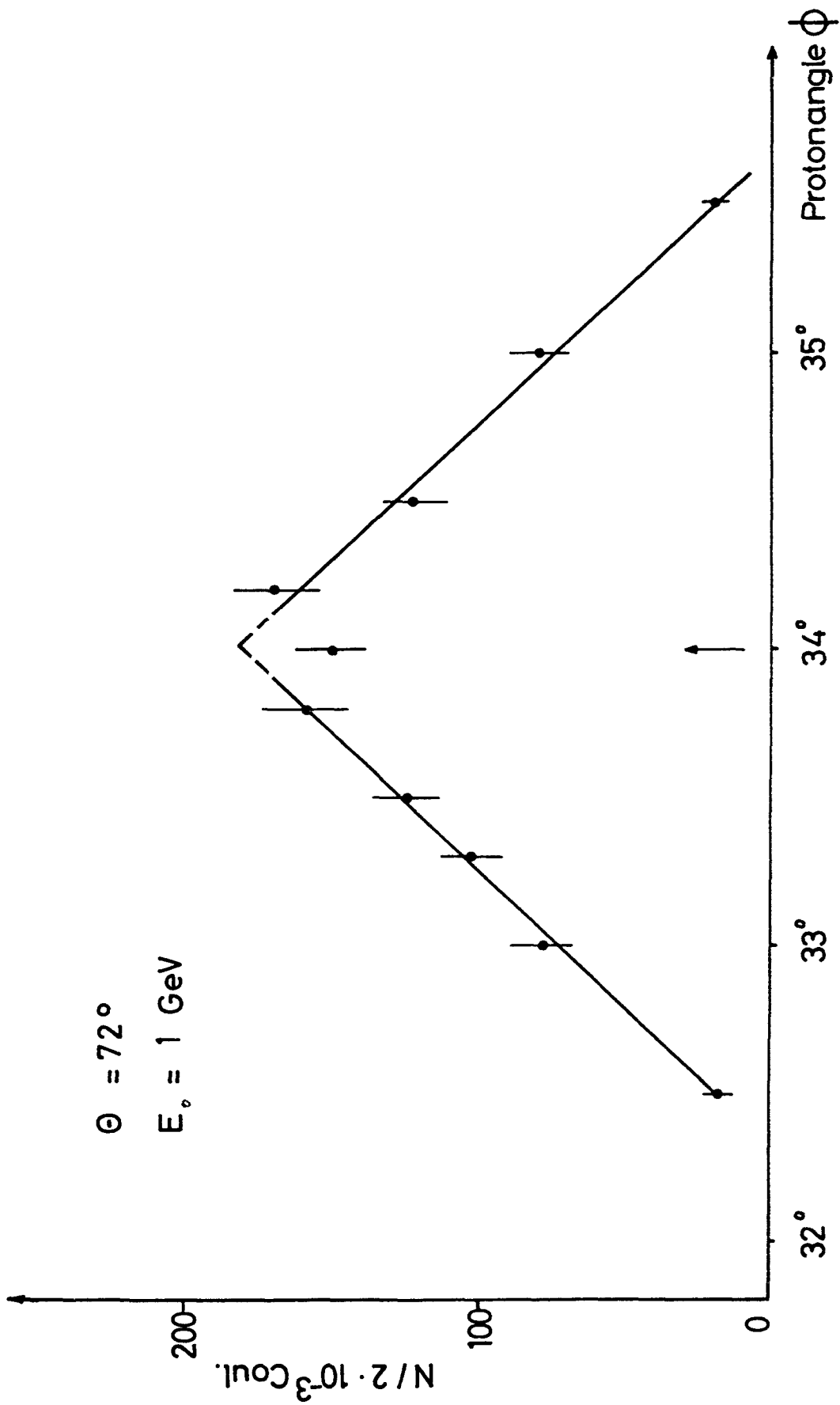
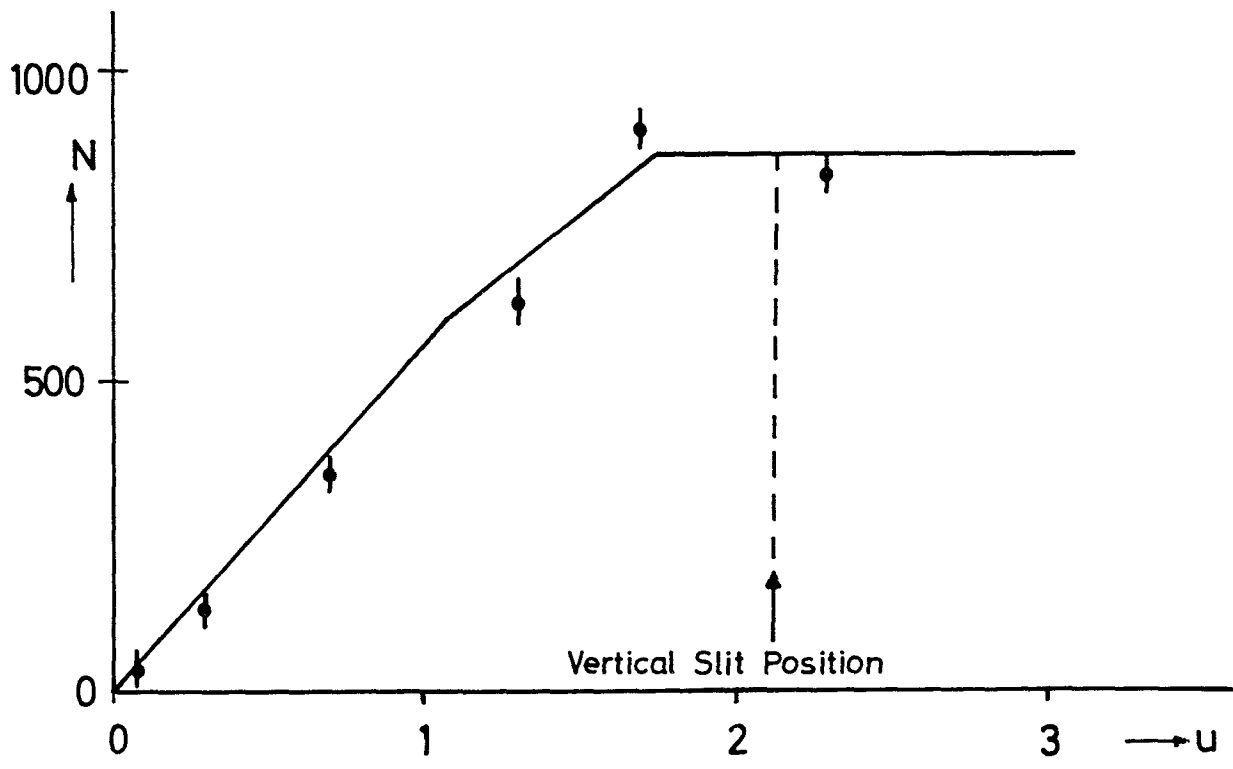
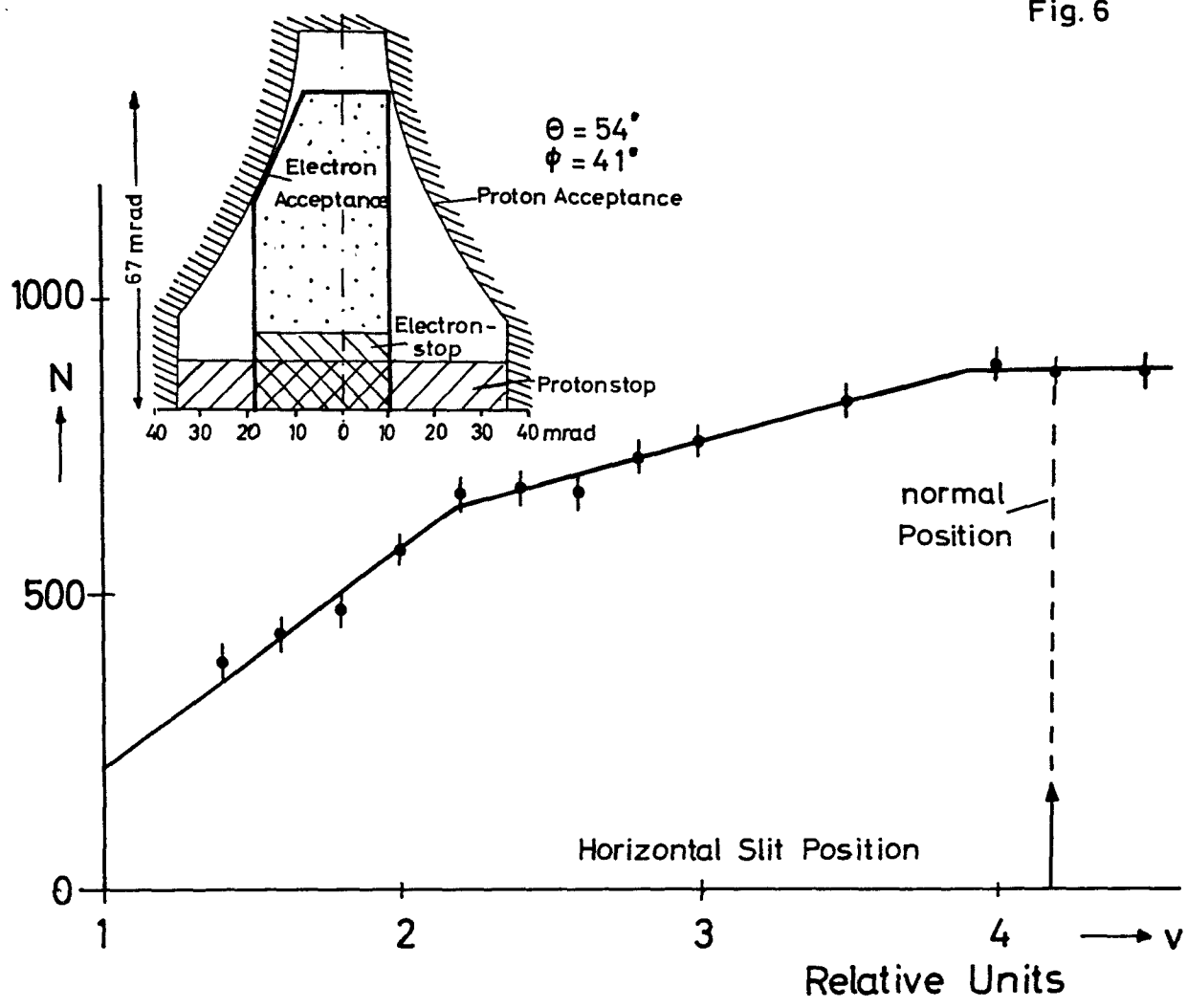


Fig. 5

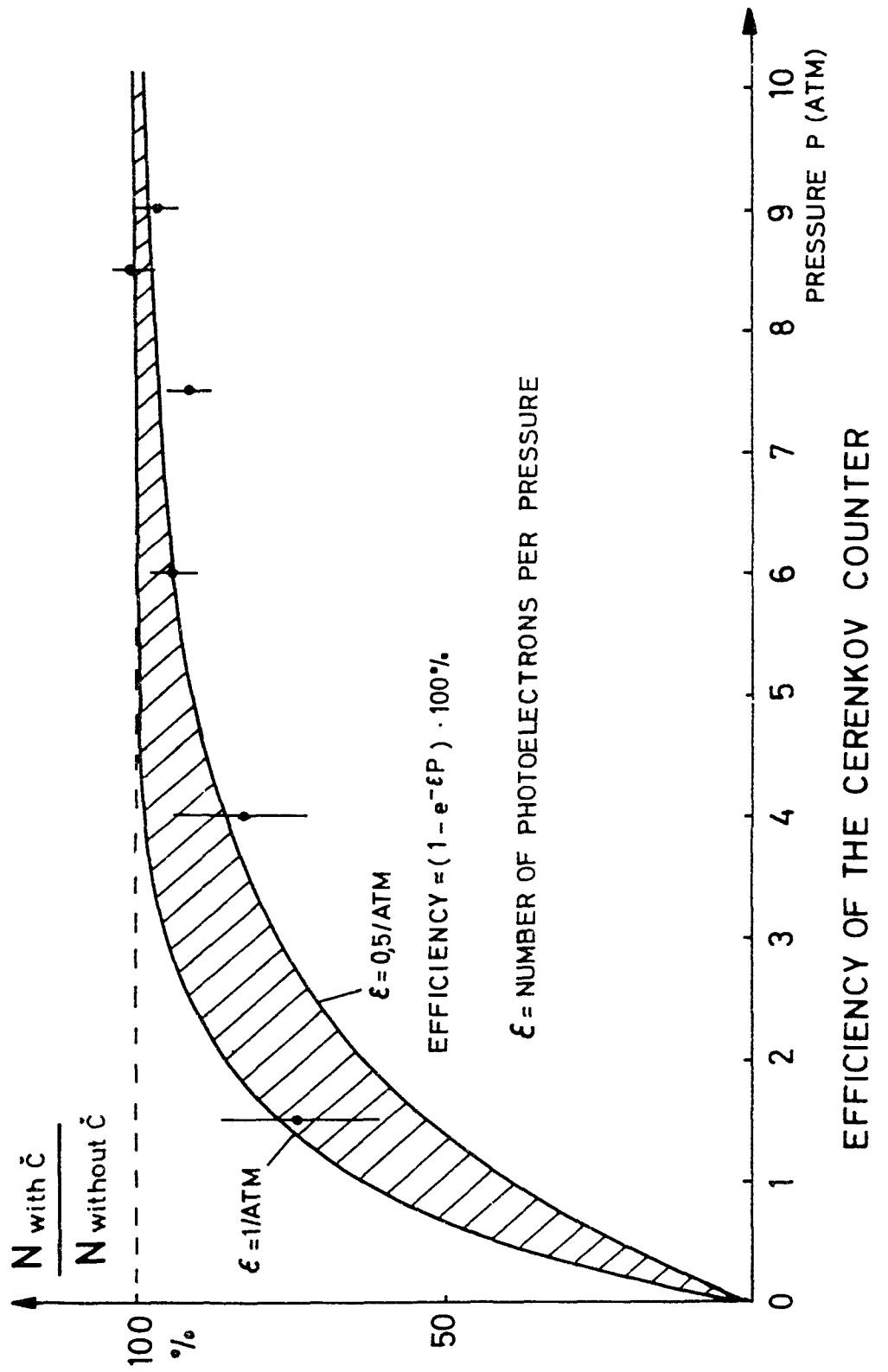
Coincidence Rate as a Function of the Protonangle.

Fig. 6



Coincidence Rate as a Function of the Slit Position in the Protonarm.

Fig.7



EFFICIENCY OF THE CERENKOV COUNTER

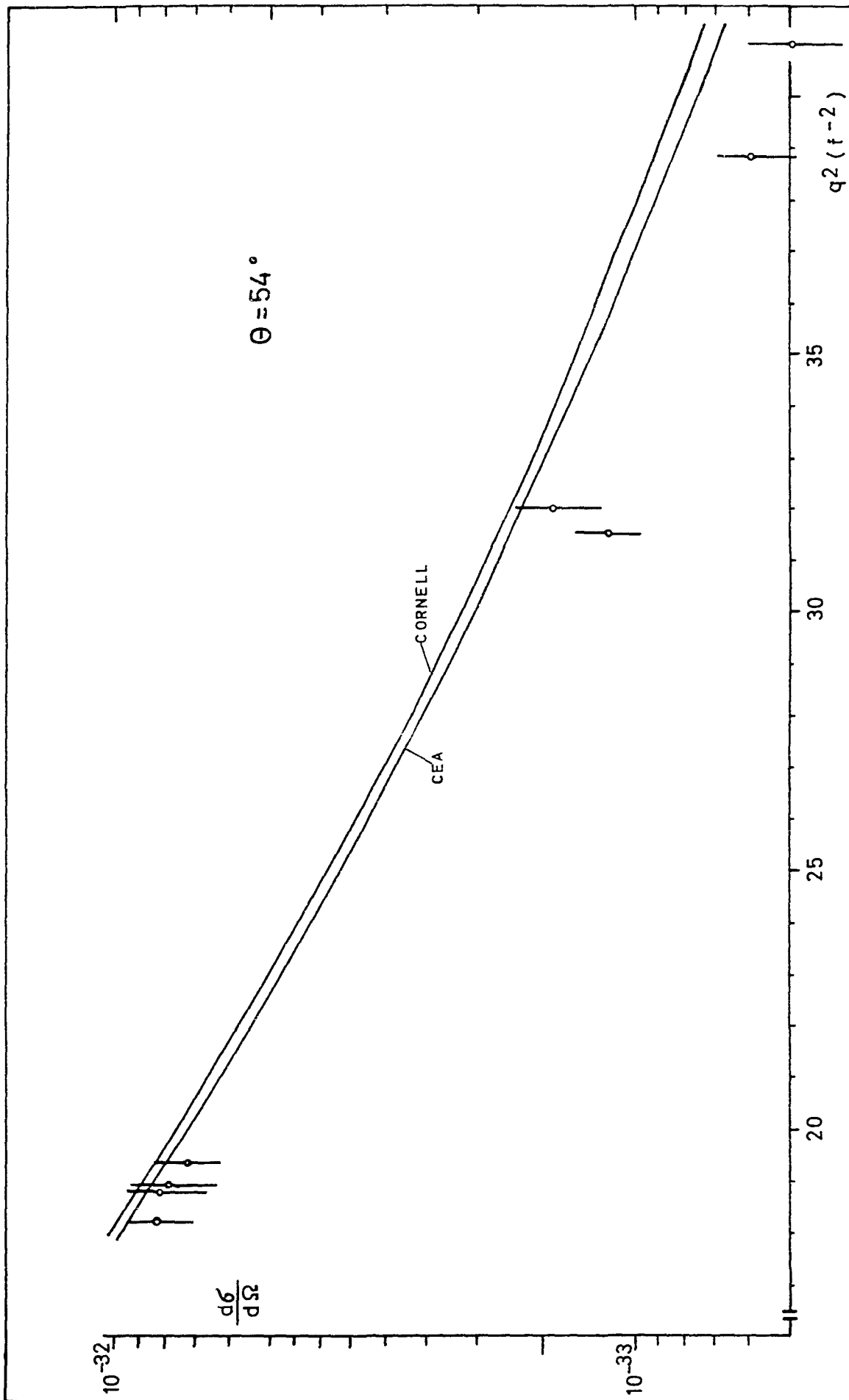


Fig. 8

ELECTRON PROTON SCATTERING CROSS SECTION

PLOTTED ARE SYSTEMATICAL AND STATISTICAL ERRORS

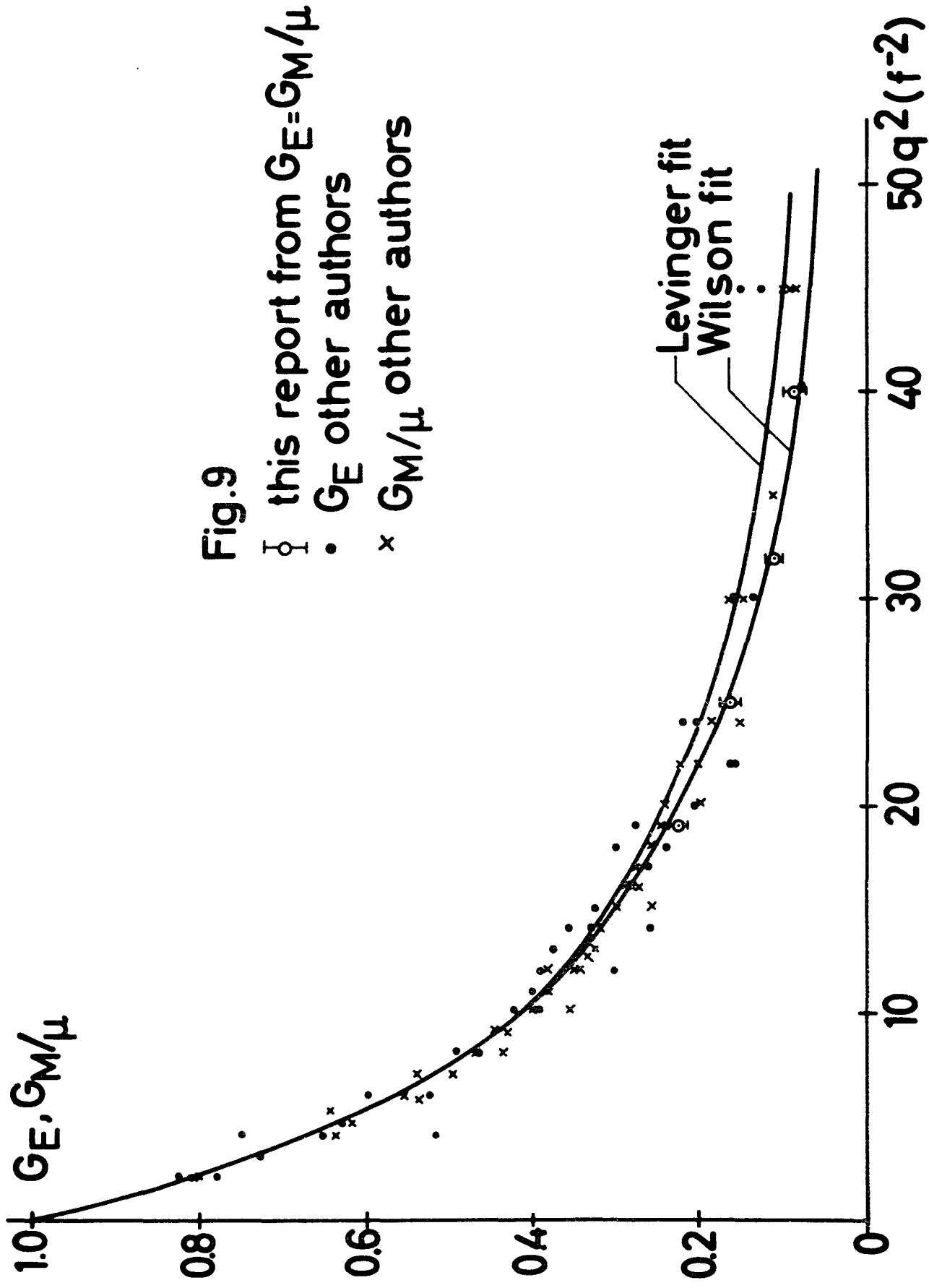


Fig.9

- this report from  $G_E = G_M / \mu$
- $G_E$  other authors
- ×  $G_M / \mu$  other authors