KERNFORSCHUNGSZENTRUM

KARLSRUHE

August 1965 KFK 362

SEARCH FOR A HEAVY ELECTRON BY ELECTRON PROTON COINCIDENCE MEASUREMENTS

H. J. Behrend, F. W. Brasse, J. Engler, E. Ganssauge, H. Hultschig
Deutsches Elektronen Synchrotron DESY, Hamburg

S. Galster, G. Hartwig, H. Schopper
Institut für Experimentelle Kernphysik des Kernforschungszentrums
Karlsruhe und der Technischen Hochschule Karlsruhe

GESELLSCHAFT FUR KERNFORSCHUNG M. B. H.
KARLSRUHE

August 1965 KFK 362

SEARCH FOR A HEAVY ELECTRON BY ELECTRON PROTON COINCIDENCE MEASUREMENTS

by

H. J. Behrend, F. W. Brasse, J. Engler,
E. Ganssauge [x)], H. Hultschig

Deutsches Elektronen Synchrotron DESY, Hamburg

and

S. Galster, G. Hartwig, H. Schopper

Institut für Experimentelle Kernphysik des Kernforschungszentrums
Karlsruhe und der Technischen Hochschule Karlsruhe

[x)] On leave from Universität Marburg

Gesellschaft für Kernforschung m. b. H. Karlsruhe
This report is identical with report DESY 65-9
by Deutsches Elektronen Synchrotron, Hamburg

Abstract

A heavy electron, which might explain deviations from quantum electrodynamics, should be produced in inelastic proton scattering. Decaying into electron and gamma it would contribute to electron proton coincidences, if electron and proton are detected under the proper kinematic values. It would produce a peak in this coincidence rate, if one measures along the mass scale of the electron-gamma-system

With the existing apparatus of elastic electron proton scattering for coincidence such measurements have been carried through in the mass region from 500 to 1000 MeV. By comparison with theoretical cross sections for the production of a heavy electron the result is$_2$ that no heavy electron exists in the above mass region, where λ^{-2} is larger than roughly 3000 $\frac{\lambda e}{m_e}$ being the coupling constant of the reaction. A rise in cross section has been observed and could be identified as electroproduction of pions around the isobar 2,19 GeV mass of the pion nucleon system. Cross sections for this reaction are also given.

Table of Contents

1 - General Idea

The measurements on electron pair production done by F.M Pipkin et al[1] showed a considerable deviation from quantum electrodynamics. This induced considerations on the possible existence of a heavy electron published by F.E. Low[2]

The heavy electron could be produced by the reaction

$$e + p \longrightarrow e^{*} + p$$

where the e^{*} decays into $e + \gamma$ with a lifetime of the order of 10^{-21} sec This reaction would show up as a peak in the momentum and angular spectrum of the recoil proton in inelastic electron proton scattering This peak has to be observed on a high background belonging to pion production and radiation. By this method measurements in the mass range from 420 to 570 MeV of the e^{*} have been carried through by a group at Orsay[3] with no evidence for a heavy electron above a certain coupling strength.

The background would be considerably reduced by measuring the proton in coincidence with the decay electron. The counting rate for the above reactions goes down by $d\Omega_{Lab}/d\Omega_{CMe} \cdot \Delta\Omega/4\pi$, with $\Delta\Omega$ being the solid angle of the electron detection apparatus, assuming that the decay of the e^{*} is isotrop in its center-of-mass system. If the energy of the e^{*} is large enough, the decay, however, is very much peaked in the direction of the e^{*}, which means that $d\Omega_{Lab}/d\Omega_{CMe}$ is large

---

1) - R B Blumenthal, D.C Ehn, W L. Faissler, P M Joseph, L J Lanzerotti, F M. Pipkin and D.G Stairs: Phys Rev Lett. 14, 660 (1965)

2) - F.E. Low: Phys. Rev. Lett. 14, 238 (1965)

3) - C Bétourné, H. Nguyen Ngoc, J Perez y Jorba, J Tran Thanh van: Phys Letters 17, 70, 1965; also Intern Symp on Electron and Photon Interactions at High Energies, Hamburg, 1965

4) - F Gutbrodt, D Schildknecht: DESY-Bericht 1965/10.

2 - Cross Sections and Kinematics

The cross section for the above reaction has been calculated [4] with the coupling constant $\frac{\lambda \alpha}{m_{e^*}}$ under the assumption that the e* has a spin 1/2. It shows a strong dependence on angle and mass of the e*, as one may see from figure 1, where cross sections are calculated with $\lambda^2 = 1$. Since the experiment should be carried out with the existing apparatus of elastic electron proton scattering at an internal target, the lower limit of the detection angles was 32° for the electron and 54° for the proton. Because the direction of the e* had to be below 20°, otherwise the proton would not come above 54°, a compromise had to be made between the production angle of the e* and the angle of detection of the electron with respect to the direction of the e*. Both angles want to be as small as possible, whereas their sum has to be at least 32°.

The angle of the e* was chosen to be 10°, the primary energy 4 GeV and the angle of the electron 32°, all three values constant through the total range of mass from 500 to 930 MeV (see figure below). The angle of the proton, the momentum of the proton and of the electron had to be varied according to the exact kinematic values, which are shown in figure 2 (solid lines). The value of $d\Omega_{Lab}/d\Omega_{CM}$ varied from 2.70 at 500 MeV to 5.80 at 900 MeV. All angles are measured in the laboratory system with respect to the direction of the incident electron.

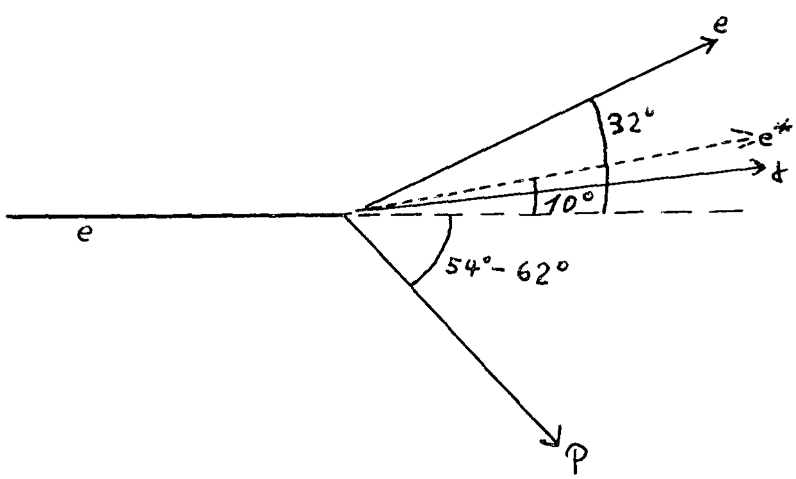


Figure 2 also shows curves for pion electroproduction, when electron and proton are observed. The dashed lines are the momenta of the electron for single and double pion production (threshold, where both pions move in one direction), when momenta of the proton and angle of the electron and proton remain the same as in the case of heavy electron production. Taking into account the momentum acceptance of the spectrometers of about 5 %, on the left side of the scale there is kinematically a good chance of seeing single pion production. However generally the cross section should be too low to see such events above the expected rate of random events. Double pion production via ρ resonances are kinematically excluded as one can see from figure 2.

3. - Apparatus

The apparatus consisted of two single quadrupole spectrometers looking at an internal target in the synchrotron. The spectrometers have been previously used for elastic electron-proton scattering and are described in the corresponding reports [5)]. The CH_2 target was replaced by a liquid hydrogen target. The outside spectrometer 2 was used to detect electrons. In addition to the kinematic counters a shower counter was installed to separate electrons from pions The inside spectrometer detected positive particles. Only at low momenta (roughly below 600 MeV/c) it was possible to separate protons from pions by pulse height discrimination in the last scintillation counter.

4. - Measurements for e^*

a) at 4 GeV

Measurements were made along the kinematic values as indicated above and shown in figure 2. The step width was $0,5^o$ in proton angle ϕ. So with a width of the spectrometer of about 2^o at least 3 points should lie above background if there would be a resonance. In each point $2 \cdot 10^{-2}$ Asec charge in the quantameter were accumulated. The coincidence rates with 5 % (split counters) and 3 % (slat counters) momentum acceptance of the proton spectrometer are shown in figures 3 and 4. Also shown are the random events measured by a second coincidence between the two spectrometers, where one was delayed with respect to the other. The measuring time for one point was about 1 hour.

---

5) - H. J. Behrend, F. W. Brasse, J. Engler, S. Galster, E. Ganssauge, G. Hartwig, H. Hultschig, H. Schopper: DESY 65/3 (KFK 320), 65. Also International Symposium on Electron and Photon Interactions at High Energies, Hamburg, 1965

Nearly through the whole range the coincidence rate is not above the rate of random events. Only at the end of higher mass two points are clearly above background Since it was not possible to get below $54,4^{o}$, at this point the momentum acceptance of the electron spectrometer was opened to about 30 % and the counting rate was taken as a function of the current of the proton spectrometer, leaving the other values fixed. The result is shown in figure 5. (Note that the collected charge is only 10^{-2} Asec). These measurements confirm that there are true coincidences between both spectrometers. The peak would correspond to a mass of 970 MeV of a heavy electron. As was shown in section 2), in this region also pion production could be observed. In this case the peak would belong to a mass of approximately 2,21 GeV of the pion-nucleon system. However, for the measurements in figure 5 one has to keep in mind, that only one parameter is changed and that the kinematic is overdetermined beyond the 30 % momentum acceptance of the electron spectrometer. This means that one has to observe a peak with a maximum width of the 30 %, transformed to the proton side.

b) at 4,5 and 5,5 GeV:

In order to explain the observed coincidence events of such a high rate and with such a steep rise on one side of the kinematic as shown in fig. 3, further measurements were made: one set on the basis of explanation by a heavy electron by changing the primary energy to 4,5 and 5,5 GeV, a second set on the basis of electro pion production by changing the energy to 3,5 GeV.

Figure 6 shows the measurements at 4,5 GeV, where only the momentum of the proton is varied with 30 % momentum acceptance of the electron, as in figure 5 The coincidence rate is smaller by roughly a factor of two than in the corresponding measurement at 4 GeV. The cross section for e^* production, however, stays roughly constant, including the effect that θ_{e^*} is slightly smaller than 10^{o} and that the ratio $d\Omega_{Lab}/d\Omega_{CM}$ gets also smaller. In addition the peak of the curve does not lie at $m_{e^*} = 970$ MeV.

The measurements at 5,5 GeV are shown in figure 7. Here the total kinematic was varied according to m_{e^*}-kinematic as it was done in figure 3. The angle of e^* was kept constant to $7,5^{o}$, the angle of the electron to 32^{o}. The acceptance in momentum for the electron was set to 30 % in order not to lose events due to overdetermination of the kinematic. There are nearly no events around the mass of 970 MeV. Again the calculated cross section is nearly the same as at 4 GeV.

5. - Measurements at 3, 5 GeV for Explanation of the Observed Coincidences by Pion Production

A closer look into the kinematic for pion production in the experiment at 4 GeV shows, that with decreasing proton angle the line of measurements was approaching the line of maximum angles of the proton for different masses of the nucleon pion system defined by the electron spectrometer (figure 8). At the maximum angles the ratio $d\Omega_{lab}/d\Omega_{CM}$ for the proton goes to infinity, which means that the counting rate should be larger in the maximum angle than outside, if the momentum acceptance of the spectrometers is large enough. The curves in figures 3 and 5 show the value $d\Omega_{Lab}/d\Omega_{CM}$, integrated over the spectrometer windows, along the line of measurements, fitted at one point to the counting rate. It shows a rise of the counting rate in general agreement with the observed coincidences. In figure 3, however, the observed rate rises faster than this phase space. The measurements at 4, 5 and 5, 5 GeV are in agreement with this explanation, as shown in figures 8 and 9. The measurement at 5, 5 GeV, where nearly no coincidences were observed, was lying much outside the maximum angles. In the measurement at 4 GeV there might be a contribution to the cross section by the nuclear resonances at 2, 19 and 2, 36 GeV [6], explaining the faster rise of the counting rate.

In order to prove the above explanations another measurement was carried out at 3, 5 GeV, where the kinematic was set to electroproduction of pions around the resonance 2, 19 GeV (figures 10 and 11). Data were taken along the line of maximum angles (figure 12) with no momentum discrimination for the proton ($\Delta p/p$ = 30 %) and outside the maximum angles (figures 13) along lines of constant m_{N*} with $\Delta p/p$ = 5 % of the proton. The figures also contain again the phase space integrated over the spectrometer windows. For constant m_{N*} there is agreement between these curves and the observed coincidences. The rates for the maximum angles, however, show a bump on top of the phase space curve around the resonant masses of 2, 19 and 2, 36 GeV. The resonances might add roughly a factor of two to the cross section of electroproduction.

An explanation of the observed peaked coincidences by means of detecting positive pions instead of protons is kinematically not possible.

---

6) - A. H. Rosenfeld, A. Barbaro-Galtieri, W. H. Barkas, P. L. Bastien, J. Kirz, M. Roos: UCRL-8030-Part I, June 1964

Only multiple production of pions may contribute to the background

5. - Conclusions

a) for heavy electron:

From the measurements at 4 and 5,5 GeV the cross sections $d\sigma/d\Omega_{e*}$ have been calculated and are listed together with the theoretical cross section with $\lambda = 1$ and with the solid angle transformation $d\Omega_{Lab}/d\Omega_{CM,e}$ in table 1. Also listed is the limit of λ^{-2} above which no heavy electron exists between 500 and 1000 MeV mass. This limit corresponds to the cross section calculated from the counting rate of the background.

b) for pion production:

From the measurements at 4 and 3,5 GeV we have extracted cross sections for electroproduction of pions, which are shown in table 2. In order to compare them with photoproduction [7], these cross sections are transformed to $d\sigma/d\Omega'_{p,Photon}$ by the method, described by Berman [8]. These values are also listed in table 2. A second comparison has been made with measurements on electroproduction of pions, where only the electron was detected [9]. For this comparison the values of this report have been integrated over $d\Omega_p$ under the assumption of isotropy in the center of mass system of the isobar (table 2, column 4).

In both cases the cross sections of this report are much higher. However, for the comparison with photoproduction one has to notice that the angles of the pion in the center of mass system of the isobar are much different. On the other hand in this measurement the momentum transfer to the electron is far apart from zero, so that formfactors should make the cross section smaller. Both comparisons suggest a strong anisotropy in the pion-nucleon center of mass system.

Acknowledgements

We thank Dr. H. Joos and Dr. F. Gutbrodt for many useful discussions. Dr. H Pingel contributed the internal hydrogen target. Finally we thank the synchrotron operations group for the full support of our work.

---

7) - R. Alvarez, Z. Bar-Yam, W. Kern, D. Luckey, L. S. Osborne and S. Tazzari, R. Fessel: Phys. Rev. Let. 12, 707 (1964)

8) - S. M. Berman: Phys. Rev. 135, B1249, (1964)

9) - A. A. Cone, K. W. Chen, J. R. Dunning, G. Hartwig, N. F. Ramsey, J. K. Walker, R. Wilson: Phys. Rev. Let. 14, 326 (1965)

Erratum

Through the whole report the ratio $d\Omega_{Lab}/d\Omega_{CMe}$ should be replaced by

$$d\Omega_{CMe}/d\Omega_{Lab}.$$

Figure Captions:

Figure 1 - Calculated cross section for production of heavy electron.

Figure 2 - Kinematic for protom and electron in heavy electron production and pion production.

Figure 3 - Counting rate of coincidences between electron and proton arm along the kinematic shown in figure 2 for heavy electron production with 5 % momentum acceptance in both spectrometers.

Figure 4 - As figure 3 with 3 % proton momentum acceptance

Figure 5 - Counting rate versus proton momentum at the left end of mass scale in figure 3.

Figure 6 - Counting rate versus proton momentum at 4, 5 GeV primary energy, when the other kinematic values are set for m_{e^*} = 0. 97 GeV.

Figure 7 - Counting rate versus proton angle at 5, 5 GeV primary energy with the other kinematic values varied for heavy electron around 0, 97 GeV

Figure 8 - Proton momentum versus proton angle for different masses of the pion nucleon system at 4 GeV.

Figure 9 - As figure 8 for 4, 5 and 5. 5 GeV

Figure 10- Kinematic of the electron for different masses of the pion nucleon system at 3, 5 GeV.

Figure 11- Kinematic of the proton for different masses of the pion nucleon system at 3. 5 GeV

Figure 12- Counting rate along the line of maximum angles in figure 11.

Figure 13 - Counting rate versus proton momentum for constant mass of the pion nucleon system.

Table 1

m_{e^*} [MeV]	500	600	700	800	900	1000
$\frac{d\sigma}{d\Omega_{e^*,\text{theor.}}}$ in 10^{-31} $\frac{cm^2}{ster}$	7.45	5.33	3 52	2.48 (5 5GeV)←	1,84 3,12	←(4GeV) 2,60
$\frac{d^2\sigma}{d\Omega_e, d\Omega_{p,\text{exp.}}}$ in 10^{-33} $\frac{cm^2}{ster^2}$	0.41	0,41	0.41	0,41	0,41 1,10	1 10
$\frac{d\Omega_{e,\text{Lab}}}{d\Omega_{e,\text{CM}}}$	2,70	3,57	4 40	5,16	5.80 4.17	4.37
$\left(\frac{d\Omega\ p}{d\Omega\ e^*}\right)_{\text{Lab}}$	10 2	9,35	8.54	7.94	7,41	6,90
$\frac{d\sigma}{d\Omega_{e^*,\text{exp.}}}$ in 10^{-33} $\frac{cm^2}{ster}$	1,53	1,07	0 80	0,63	0,52 1 95	1,59
λ^{-2}	4900	4900	4400	4000	1600	1600

Table 2

M_{N^*} GeV	q^2 f^{-2}	φ_{π^*}	(1) $\frac{d^3\sigma}{d\Omega_e\, dP_e\, d\Omega_p^*}$ $(10^{-33}\, cm^2/sr^2\, GeV/c)$	(2) $\left(\frac{d\sigma}{d\Omega_p^*}\right)_{P\ell}$ $(\mu b/sr)$	(3) $\left(\frac{d\sigma}{d\Omega_p^*}\right)_{P\ell},\ q^2=0$ $(\mu b/sr)$	(4) $\frac{d^2\sigma}{d\Omega_e\, dP_e}$ $(10^{-32}\, cm^2/sr\, GeV/c)$	(5) $\frac{d^2\sigma}{d\Omega_e\, dP_e}$ $(10^{-32}\, cm^2/sr\, GeV/c)$	E_o GeV
2,1	24,7	30^o	7,2 ± 1,9	51 ± 14	0,2 (φ_{π^*} = 60) 0,3 (φ_{π^*} = 90)	8,9 ± 2,4		3,5
2,2	24,7	28^o	19 ± 5	39 ± 10	0,2 (60^o, 90^o)	24 ± 6	≤ 0,5	3,5
	35,4	32^o	16 ± 2	36 ± 5		21 ± 3		4,0

(1) - results of this measurement (φ^* and $d\Omega_p^*$ measured in CM-system of pion-nucleon)

(2) - transformed to photoproduction [8)]

(3) - results of photoproduction [7)]

(4) - (1) integrated over proton solid angle with isotropic distribution

(5) - electroproduction without coincidences [9)]

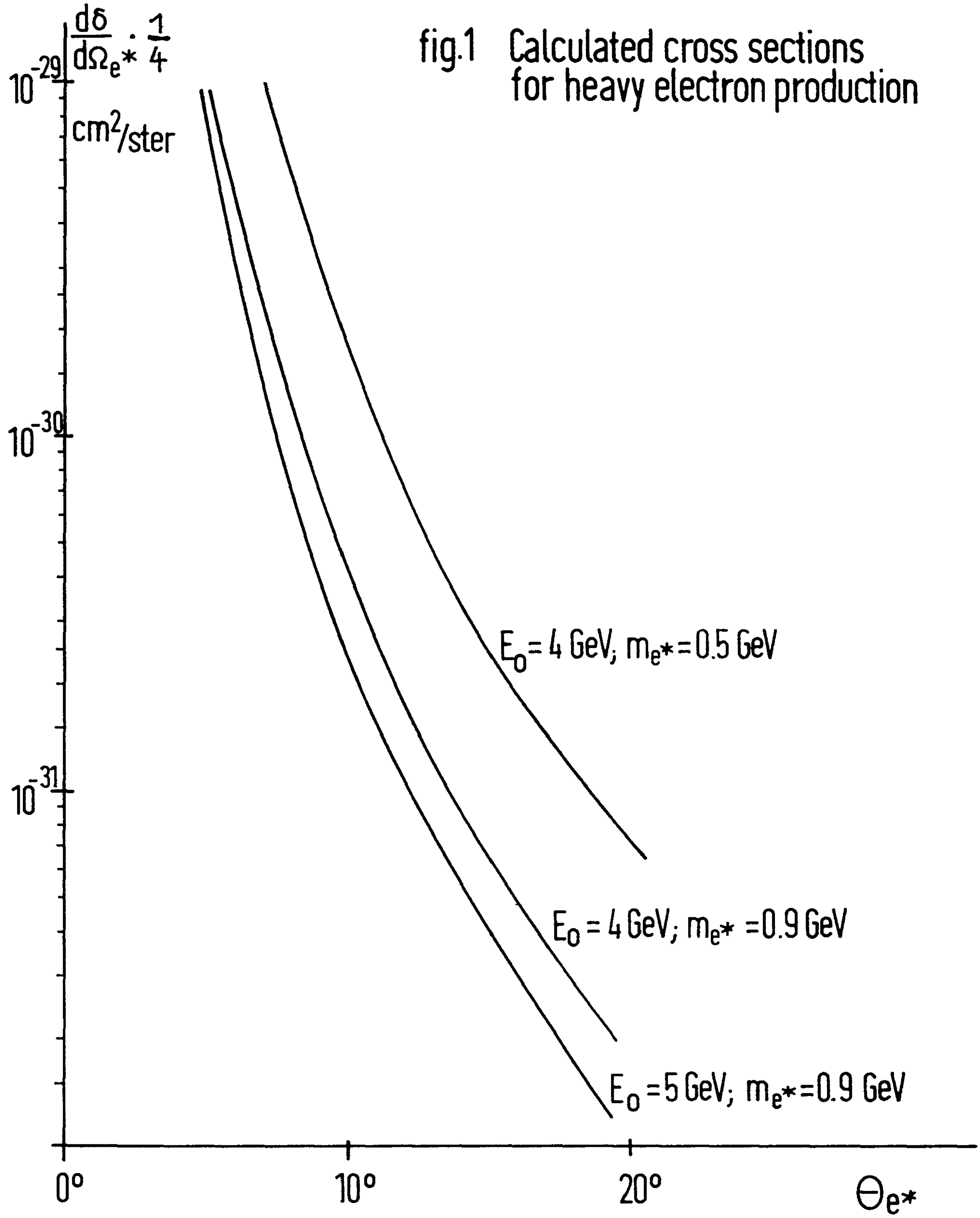


fig.1 Calculated cross sections for heavy electron production

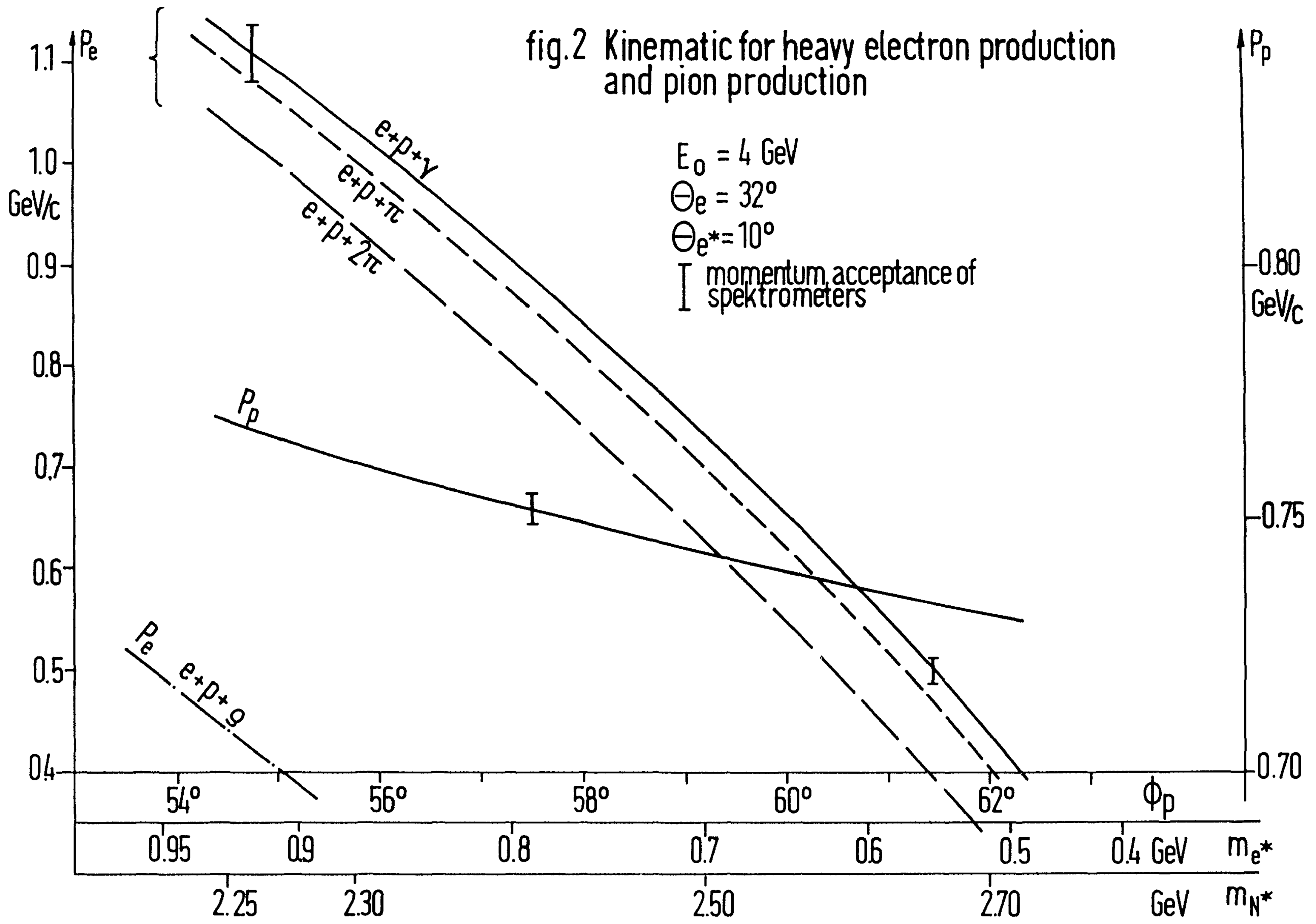
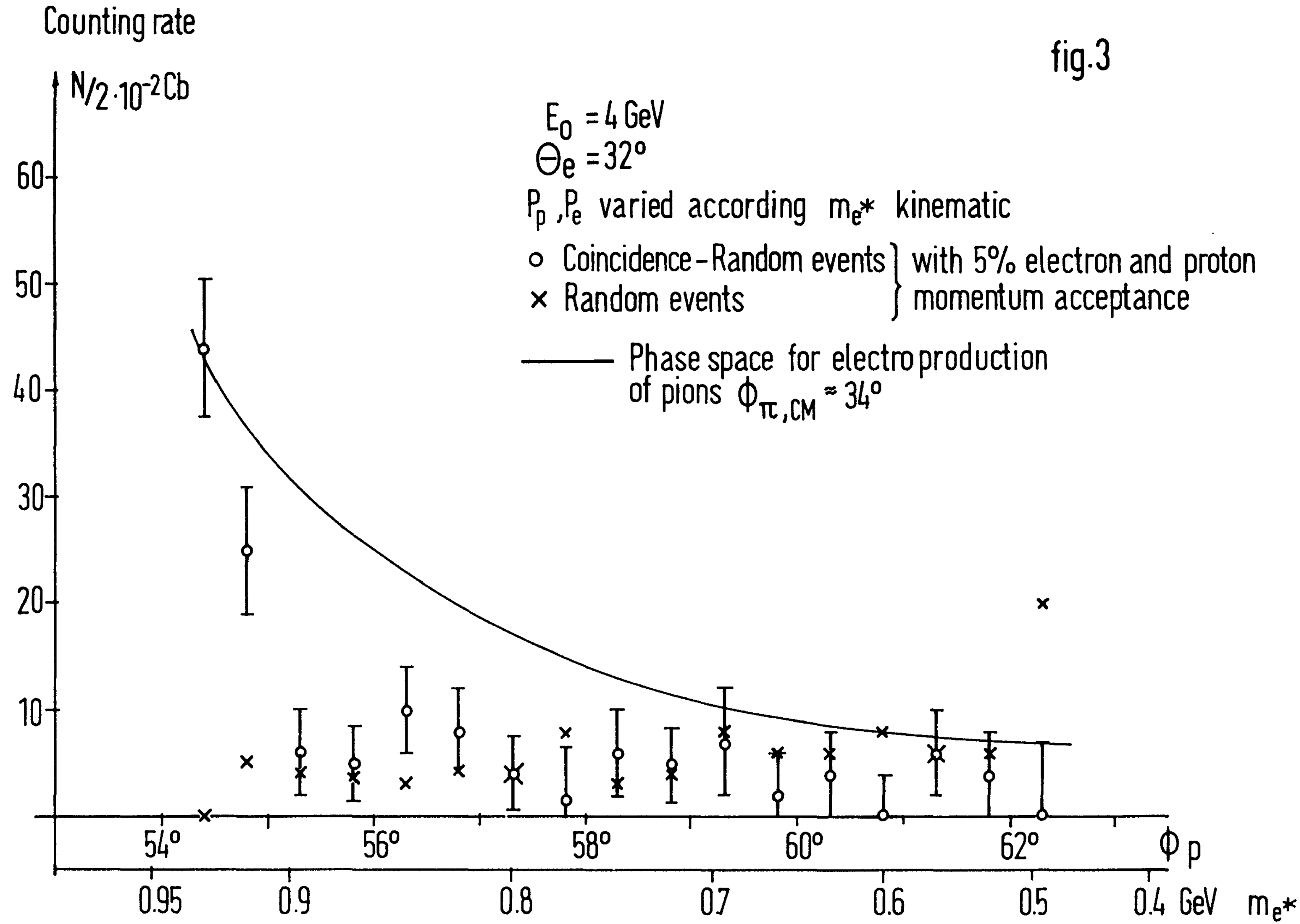


fig.2 Kinematic for heavy electron production and pion production



Counting rate
N/2·10^-2 Cb
E0 = 4 GeV
Θe = 32°
Pp, Pe varied according me* kinematic
○ Coincidence-Random events
× Random events
with 5% electron and proton momentum acceptance
Phase space for electroproduction of pions Φπ,CM ≈ 34°
60
50
40
30
20
10
54°
56°
58°
60°
62°
Φ p
0.95
0.9
0.8
0.7
0.6
0.5
0.4 GeV
me*

fig.3

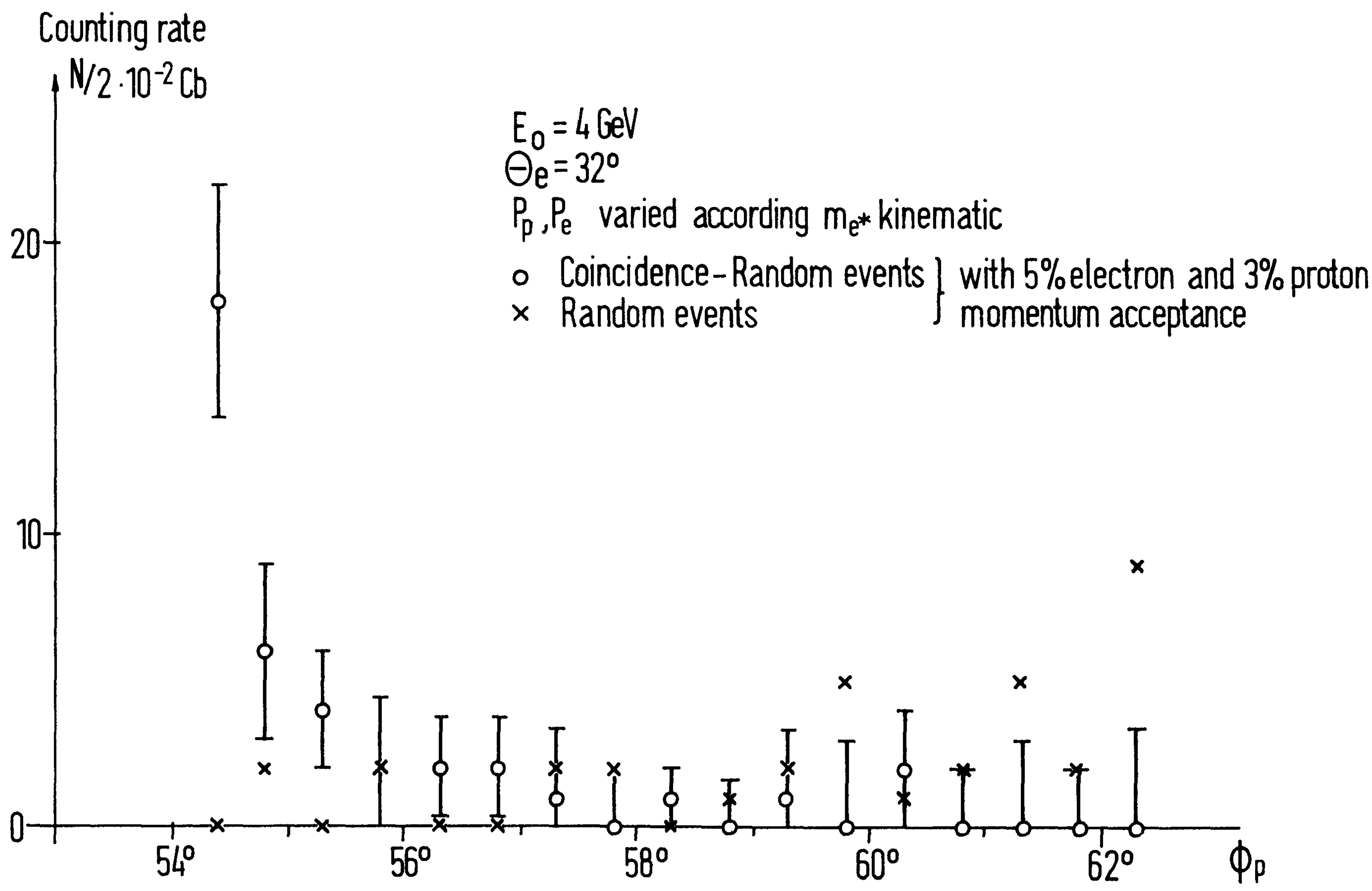
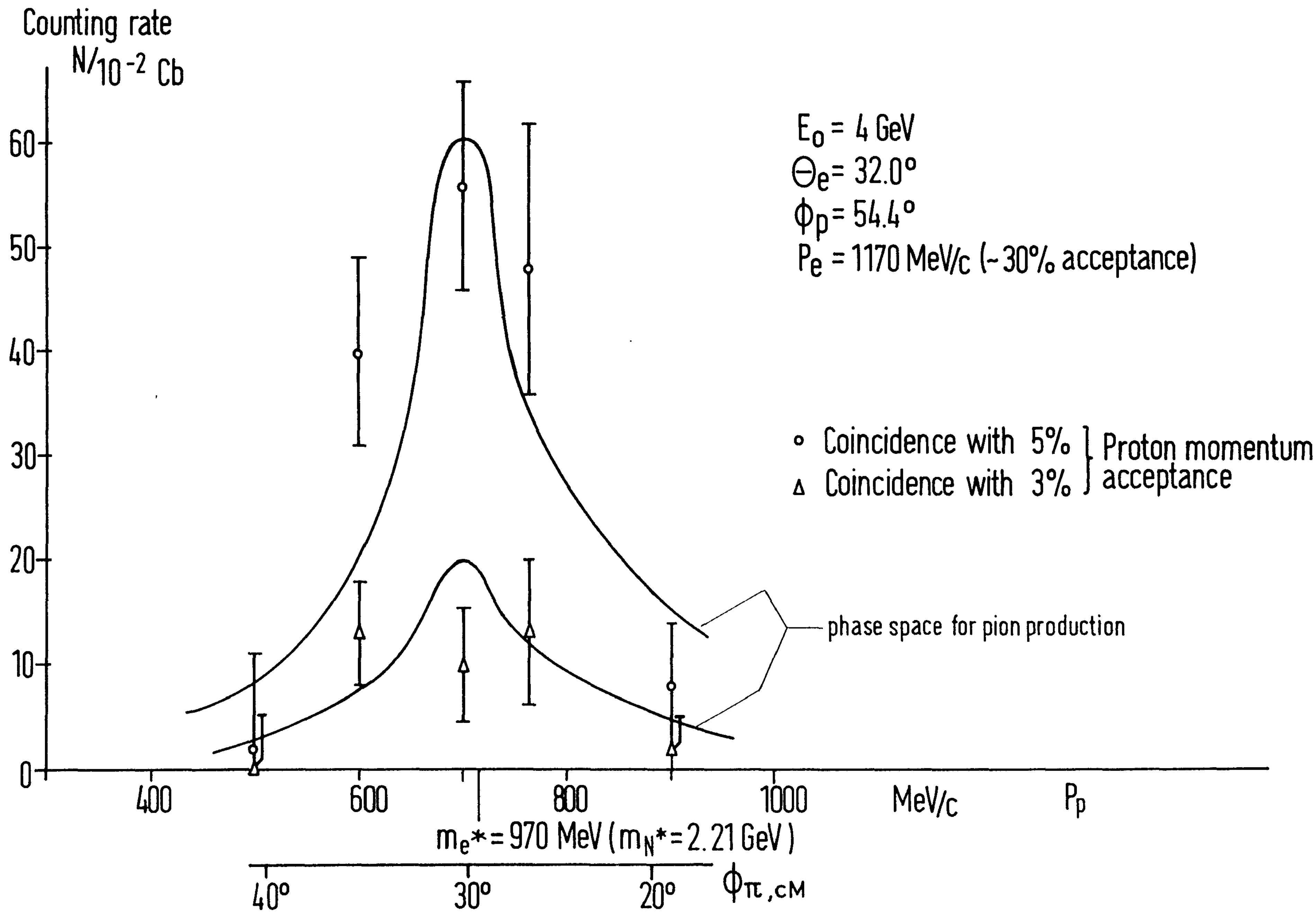

Counting rate
N/2·10⁻² Cb
E0 = 4 GeV
Θe = 32°
Pp, Pe varied according me* kinematic
o Coincidence-Random events
× Random events
with 5% electron and 3% proton momentum acceptance
20
10
0
54°
56°
58°
60°
62°
Φp

fig. 4



Counting rate
N/10 -2 Cb
60
50
40
30
20
10
0
400
600
800
1000
MeV/c
Pp
me* = 970 MeV (mN* = 2.21 GeV)
40°
30°
20°
φπ,cM
E0 = 4 GeV
Θe = 32.0°
φp = 54.4°
Pe = 1170 MeV/c (~30% acceptance)
Coincidence with 5%
Coincidence with 3%
Proton momentum acceptance
phase space for pion production

fig.5

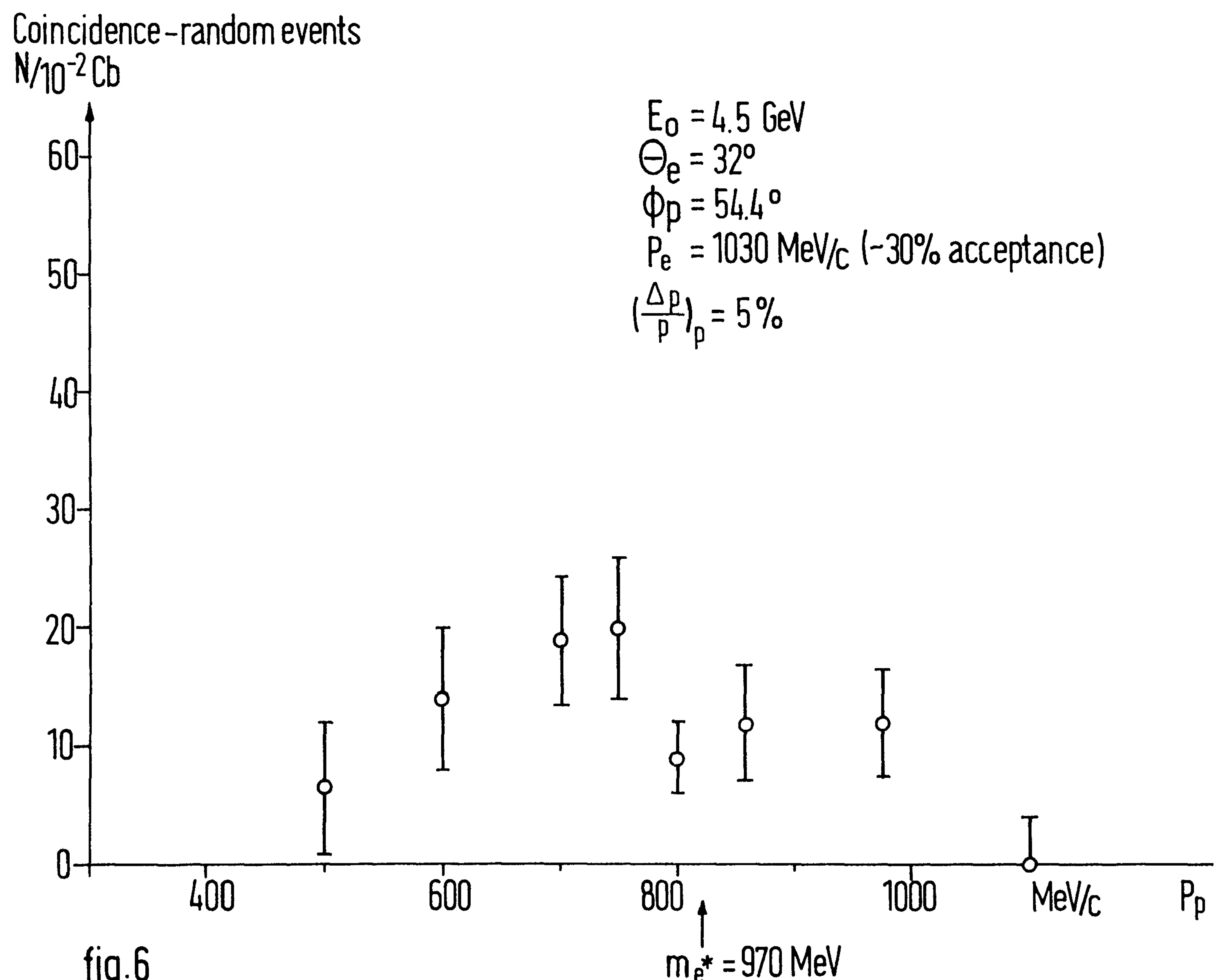
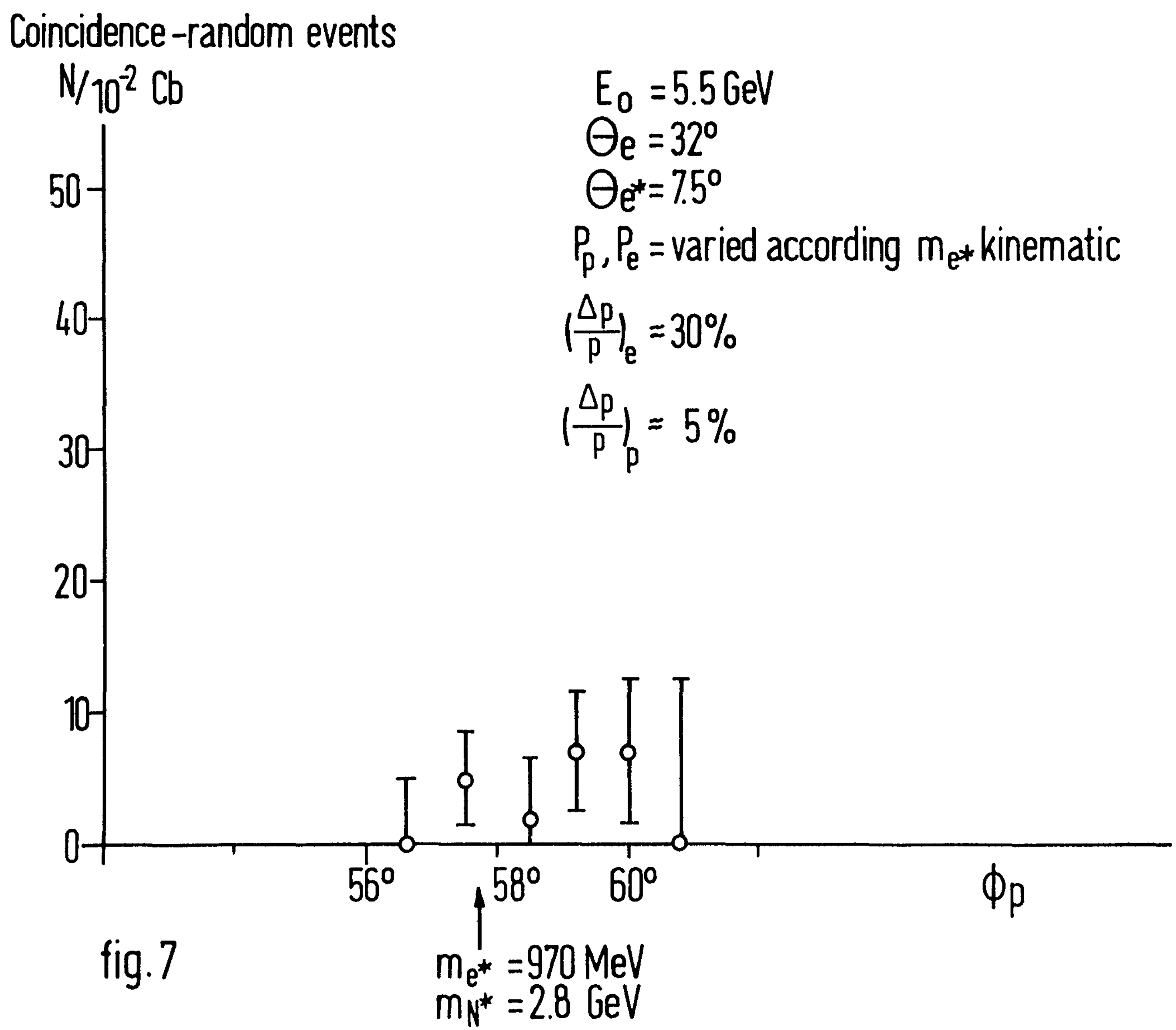

Coincidence-random events
N/10^-2 Cb
E_o = 4.5 GeV
Θ_e = 32°
Φp = 54.4°
P_e = 1030 MeV/c (~30% acceptance)
(Δp/p)_p = 5 %
60
50
40
30
20
10
0
400
600
800
1000
MeV/c
P_p
m_e* = 970 MeV

fig.6



Coincidence-random events
N/10^-2 Cb
E_o = 5.5 GeV
Θ_e = 32°
Θ_e* = 7.5°
P_p, P_e = varied according m_e* kinematic
(Δp/p)_e = 30%
(Δp/p)_p = 5%
50
40
30
20
10
0
56°
58°
60°
Φp
m_e* = 970 MeV
m_N* = 2.8 GeV

fig. 7

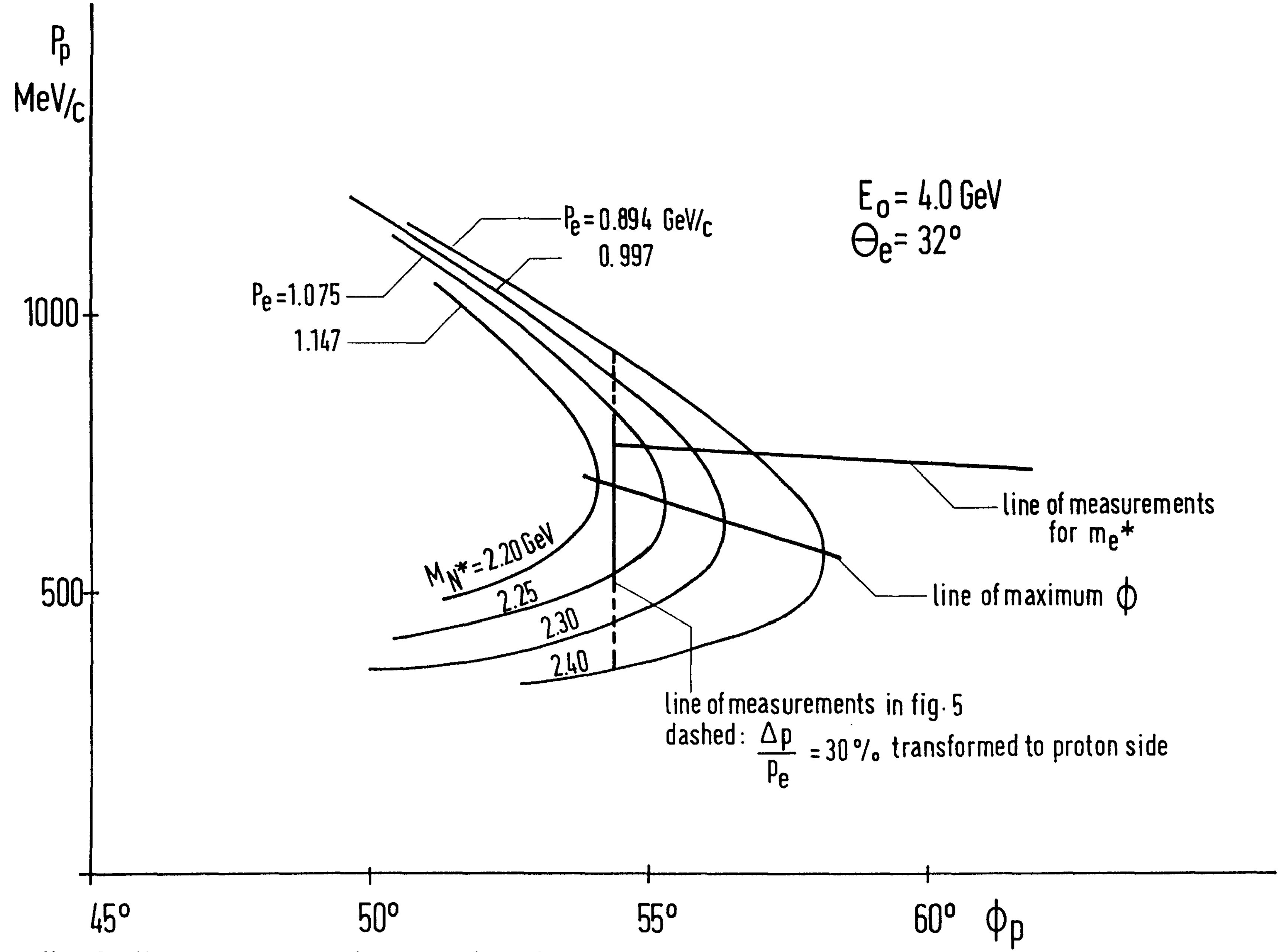


fig. 8 Kinematic for pion production

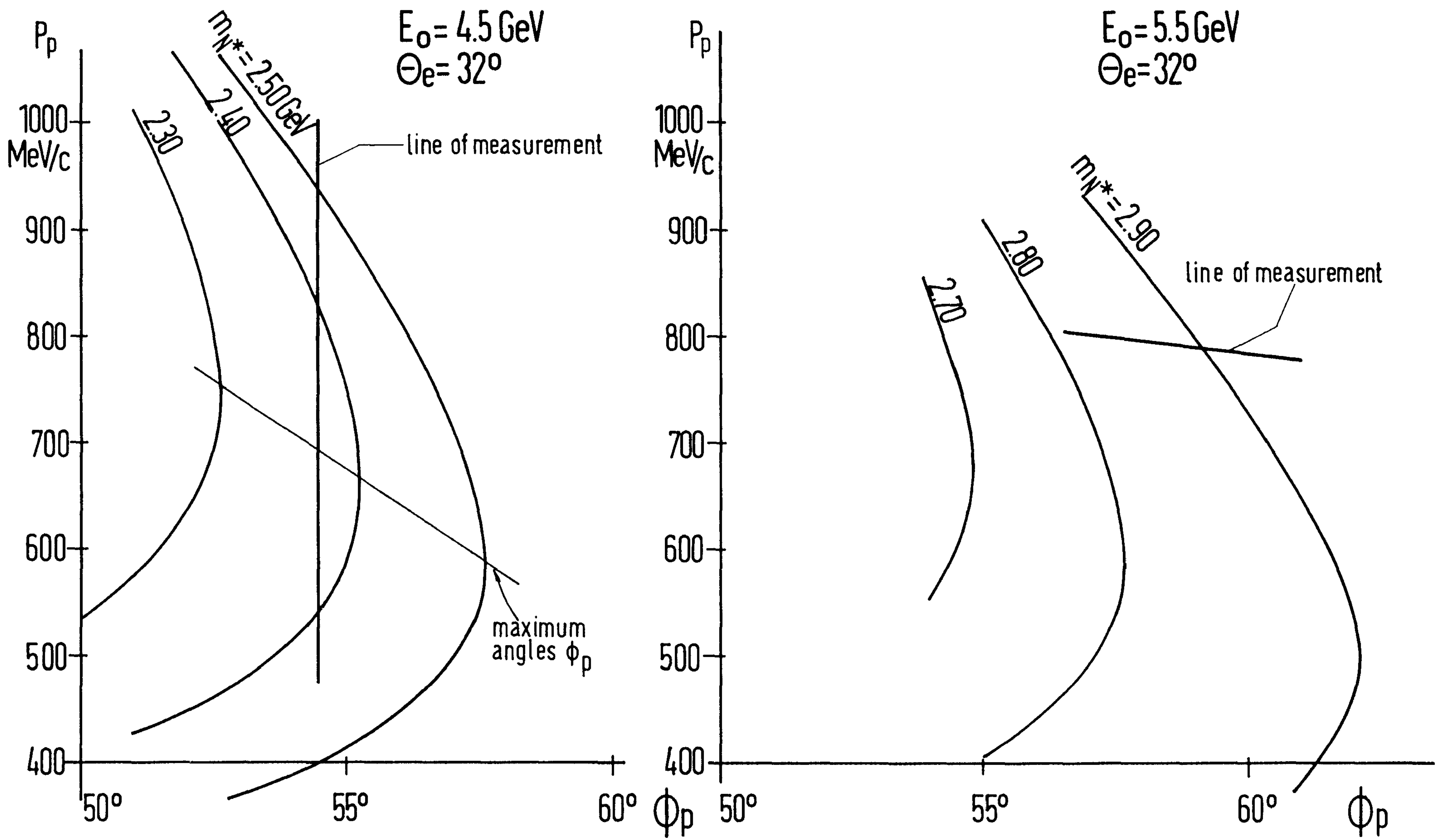


fig. 9 Kinematic for pion production

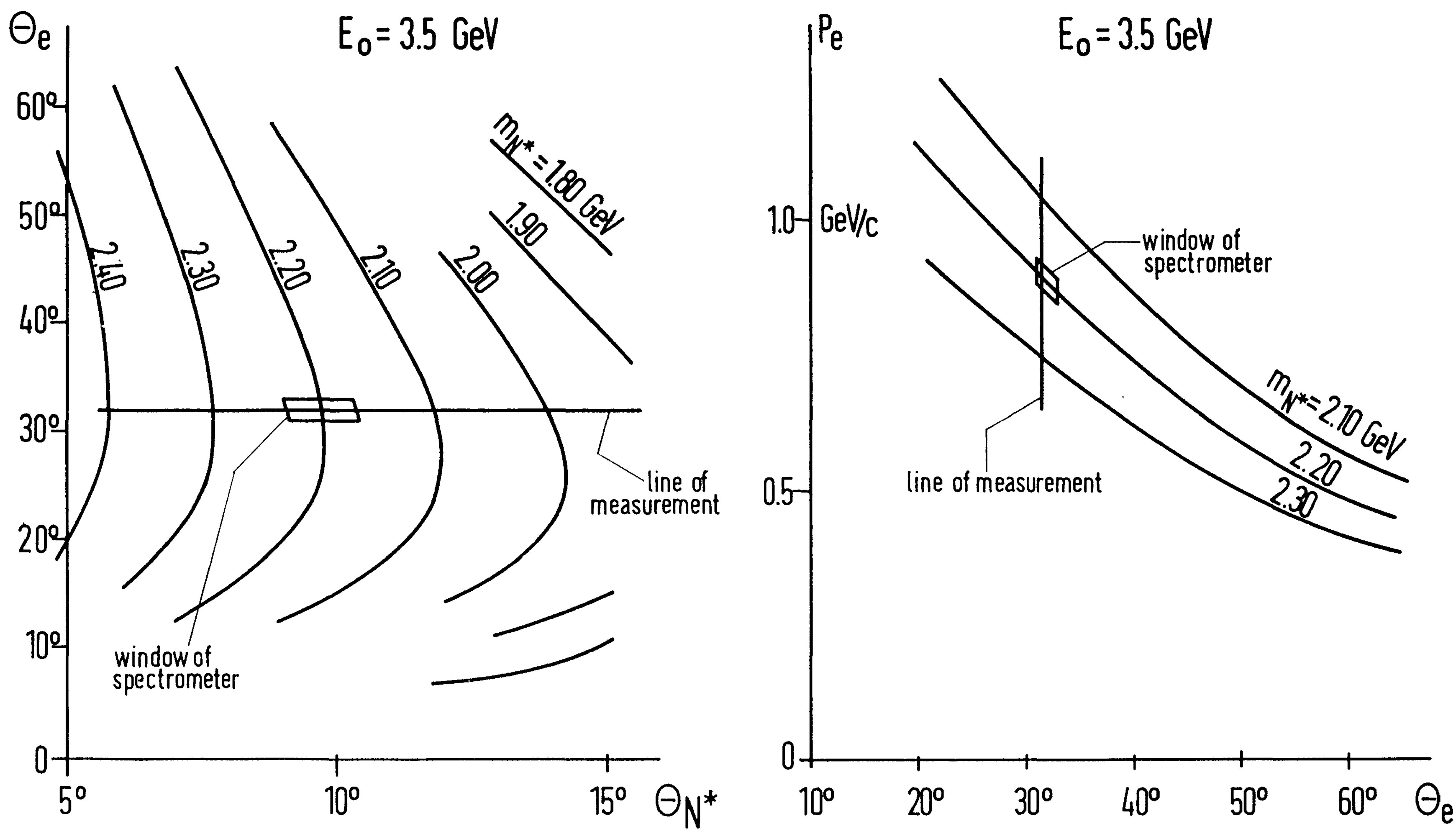


fig. 10 Kinematic for pion production

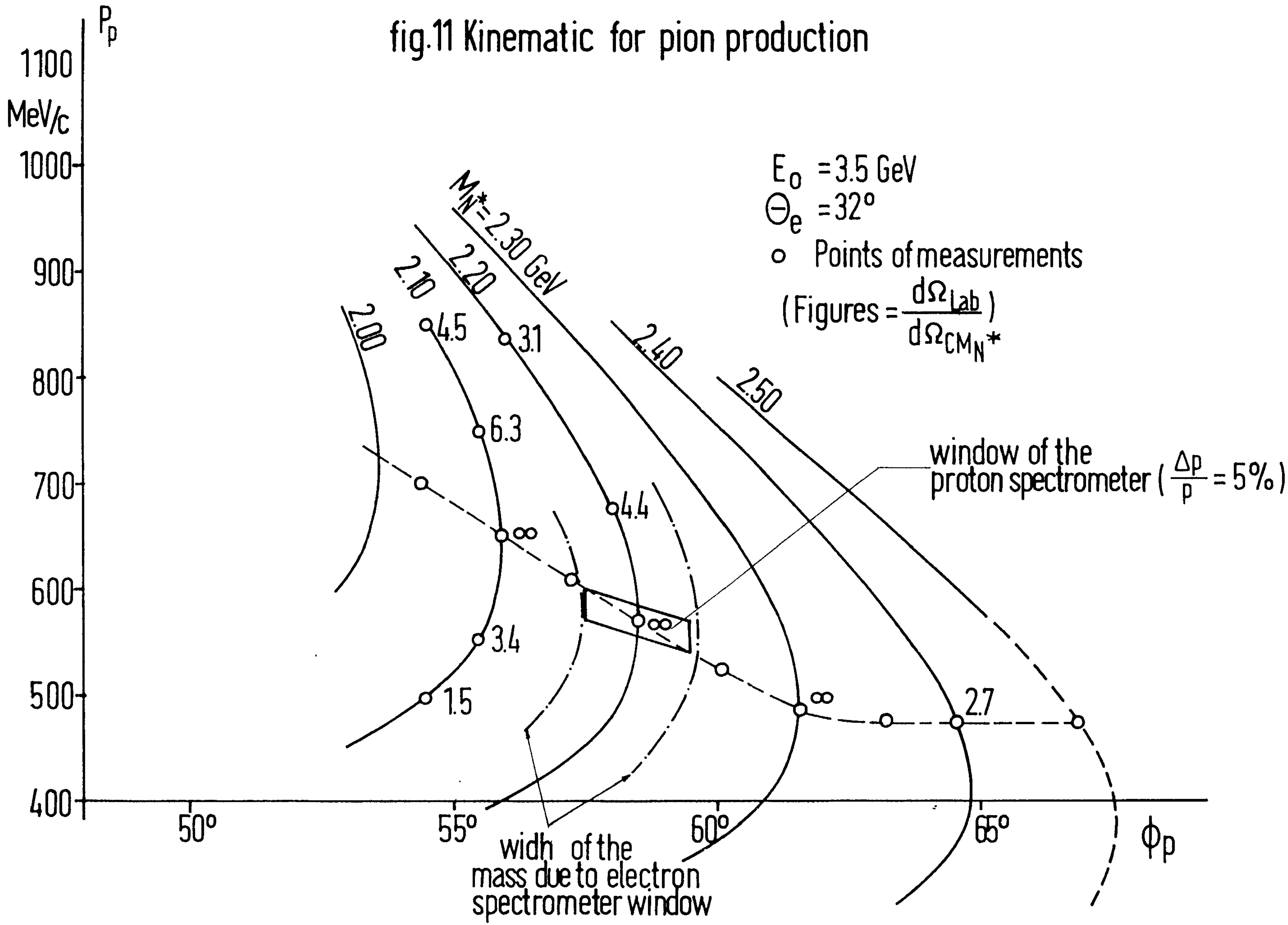


fig.11 Kinematic for pion production
P_p
MeV/c
1100
1000
900
800
700
600
500
400
50°
55°
60°
65°
ϕ_p
E_o = 3.5 GeV
Θ_e = 32°
o Points of measurements
(Figures = $\frac{d\Omega_{Lab}}{d\Omega_{CM_N^*}}$)
M_N^* = 2.30 GeV
2.00
2.10
2.20
2.40
2.50
4.5
3.1
6.3
4.4
3.4
1.5
2.7
∞
window of the proton spectrometer ($\frac{\Delta p}{p}$ = 5%)
widh of the mass due to electron spectrometer window

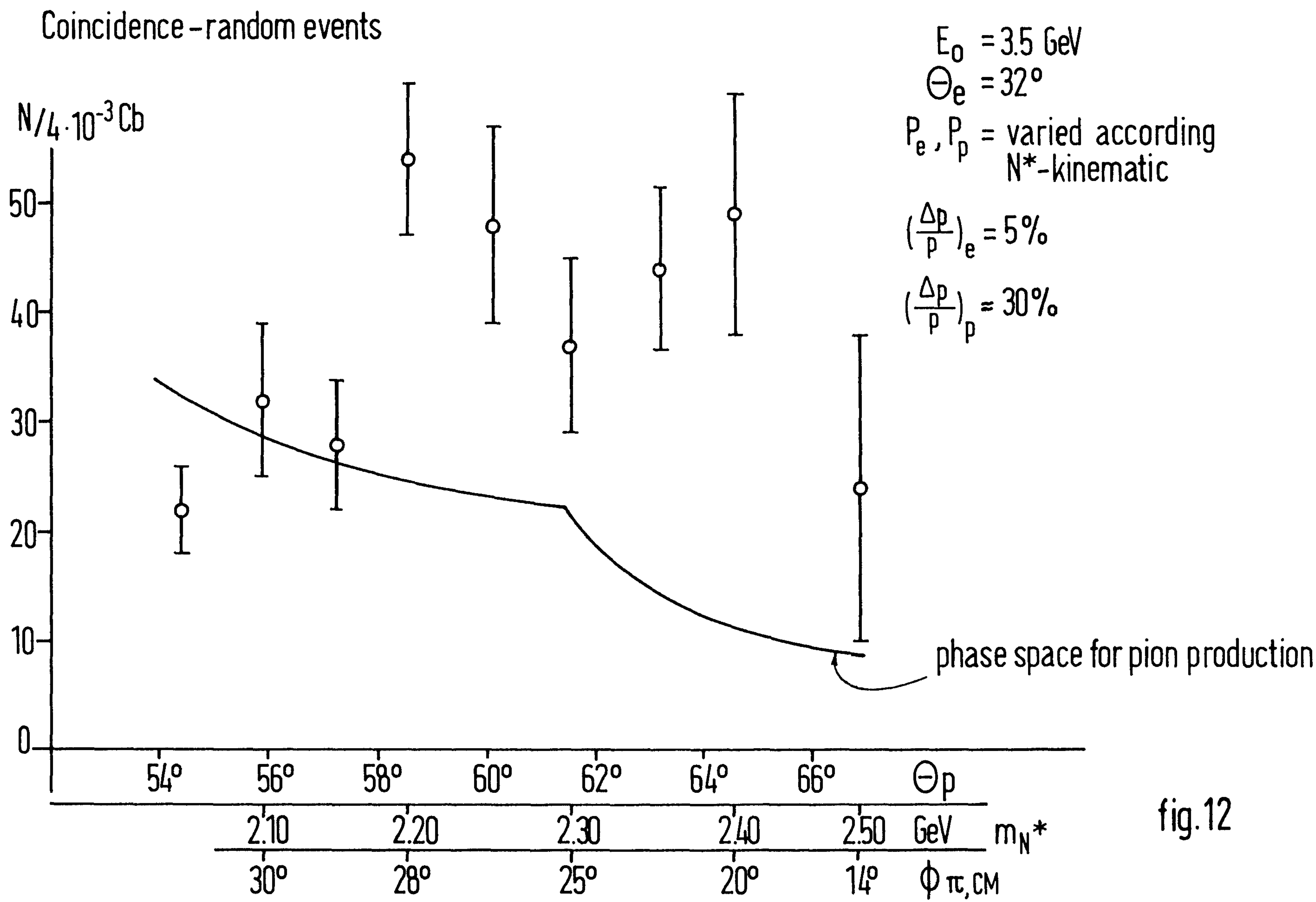

Coincidence - random events
N/4·10^-3 Cb
50
40
30
20
10
0
54°
56°
58°
60°
62°
64°
66°
Θp
2.10
2.20
2.30
2.40
2.50
GeV
mN*
30°
28°
25°
20°
14°
Φ π,CM
E0 = 3.5 GeV
Θe = 32°
Pe , Pp = varied according
N*-kinematic
(Δp/p)e = 5%
(Δp/p)p = 30%
phase space for pion production

fig. 12

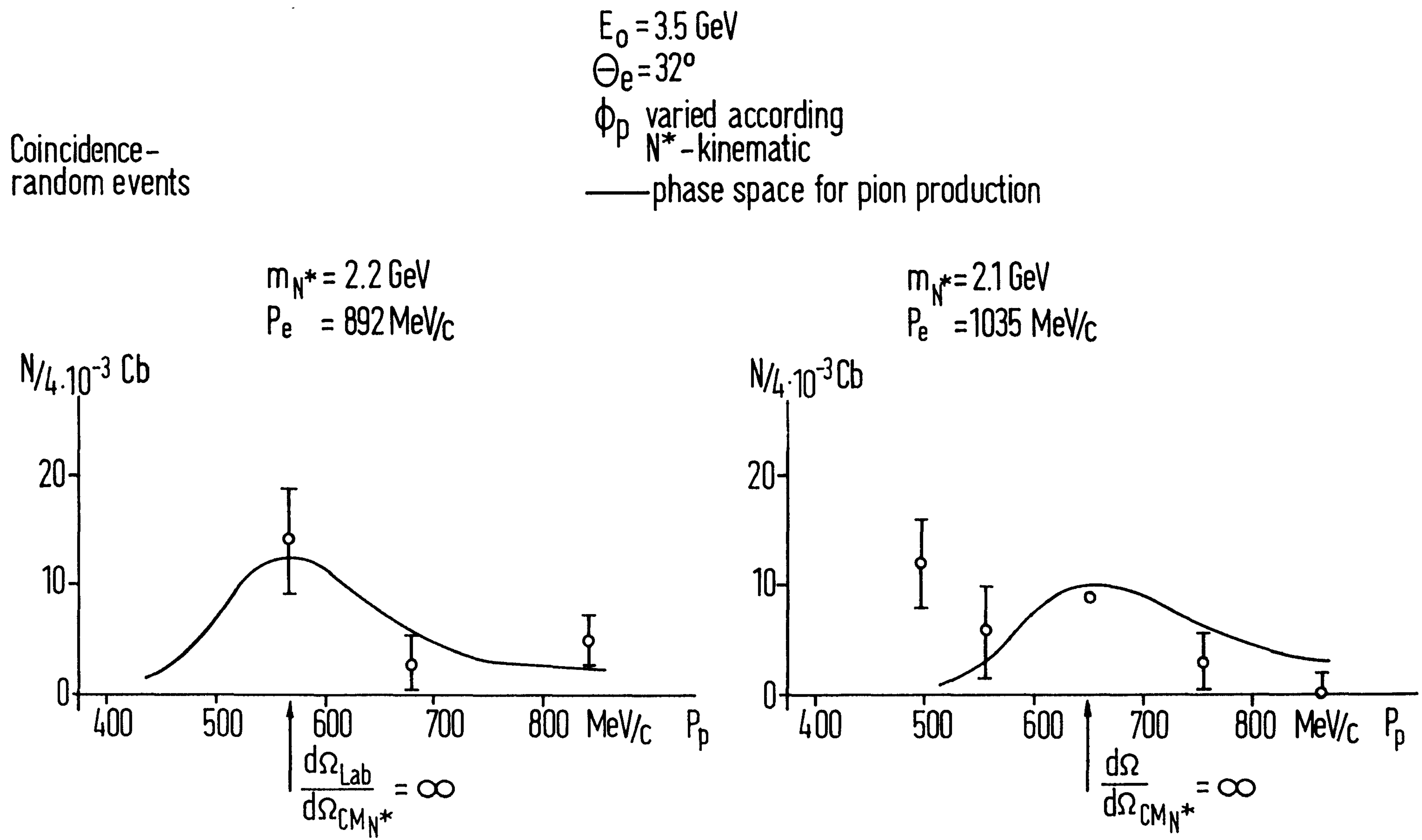

Coincidence-
random events
E0 = 3.5 GeV
Θe = 32°
Φp varied according N*-kinematic
phase space for pion production
mN* = 2.2 GeV
Pe = 892 MeV/c
N/4·10^-3 Cb
20
10
0
400
500
600
700
800
MeV/c
Pp
dΩLab/dΩCMN* = ∞
mN* = 2.1 GeV
Pe = 1035 MeV/c
N/4·10^-3 Cb
20
10
0
400
500
600
700
800
MeV/c
Pp
dΩ/dΩCMN* = ∞

fig.13