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PROPOSAL TO SEARCH FOR CHARMED PARTICLES AND ELECTRONS PAIRS AT THE ISR

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INTRODUCTION

Several groups[1,2,3] have reported an unexpectedly large cross section for the production of single leptons with large transverse momenta. At the ISR, the observed leptons are electrons, and the ratio e/π, in the transverse momentum range of 1.6 to 3.5 GeV/c is $1.2\ 10^{-4}$. At NAL, both muons and electrons have been observed with ratios e/π and μ/π equal to $0.8\ 10^{-4}$. It is notable that the ratio of leptons to pions does not depend very strongly on the total CM energy. If these leptons result from the decay of a heavy particle, its mass cannot be larger than about 5 GeV, otherwise these ratios would be energy dependent. Furthermore the lepton transverse momentum spectrum is seen to decrease sharply from 1.6 GeV/c to 3 GeV/c. A single particle of mass M decaying into a lepton pair would generate a maximum in this spectrum located at M/2. The mass of such a parent particle should therefore lie below roughly 3.5 GeV. Fig.1 shows a transverse momentum distribution of an electron due to a mass of 4 GeV.

On the other hand, the e/μ ratios of the order of 1 suggest, within the assumption of lepton pair decay, a mass of the parent particle larger than 700 MeV.

If the leptons were produced by pairs the previous discussion shows that the mass of the pair should lie between 0.7 and 3.5 GeV. This points to the region of known vector mesons.

The observed e spectra can be accomodated by production cross sections such that $\sigma_{\rho^\pm} = \sigma_{\emptyset_0} = \sigma_\omega = 1.1\ \sigma_\pi$, where σ_π is the pion cross section excluding π generated by the ρ, ω and $\emptyset$ decay. The present experimental limits on $\emptyset$ production[1] render such high cross section unlikely.

Two main sources of electrons remain as likely candidates : either new mesons of high mass, or some new process such as charmed[4,5] particle production.

In either case a better understanding of this phenomenon would be obtained from the study of the particles produced in association with the electron. This is the aim of the present proposal.

The CCRS experiment performed at the CERN ISR was successful in detecting directly produced electrons as it was able to reject converted photons and hadrons to the level of 10^{-5} with respect to hadrons. A spectrometer utilizing momentum measurement with a magnet, electron energy determination with lead glass detectors, and an air-filled Cerenkov achieved the rejection factor of 10^5. The Cerenkov itself gave a rejection of 10^3 against hadrons.

We propose to retain these features of the CCRS experiment, but to increase the solid angle to achieve a better acceptance for associated production. Two identical spectrometers are placed in opposition and as close as possible to the ISR beam pipes yielding a solid angle of 0.9 ster. in each spectrometer. The product of the solid angles of both spectrometers is 70 times larger than in the CCRS experiment.

Each arm is well suited to the detection of electrons, and of neutral strange particles through the decays $K_S \rightarrow \pi^+ \pi^-$ and $\Lambda \rightarrow p\, \pi$. This permits a search for charmed particles through the following correlations ($\pi - K_S$ or $\pi - \Lambda$) ; ($e - K_S$ or $e - \Lambda$).

The former corresponds to the hadronic decay of the type $D \rightarrow \pi\, K_{OS}$ and would be characterized by a peak in the mass distribution above a $\pi\, K_{OS}$ continuum.

The latter corresponds to semi-leptonic decays of the type $D \rightarrow e\, K\, \nu$ or $e\, K\, \nu + n\, \pi$ or $B_C \rightarrow e\, \Lambda\, \nu$ or $e\, \Lambda\, \nu + n\, \pi$.

The presence of an electron in the final state avoids the complications due to the copious hadron production. The mass spectrum of the electron-strange particle pair would show an enhancement at masses less than but near to the charmed parent mass.

The large horizontal acceptance (± 47°) of the spectrometers also allows an efficient search for mesons such as those recently detected at BNL and Spear [6,7] which decay into electrons pairs. The rejection against hadrons pairs is of the order of 10^{10}.

In addition to the investigation of the rare but topical processes discussed above, the proposed apparatus will be a very useful tool for research into non-strange hadronic processes. Appendix I discusses some of the possibilities for these studies.

EXPERIMENTAL SET-UP

The experimental apparatus is shown in Fig.2. It consists of two identical spectrometers.

1) Magnets.

The Saclay magnets previously used in the CCRS experiment will be centered 0.6 m from the intersect. The magnet aperture is 1.5 x 0.4 x 0.4 m^3. The field integral of 0.3 Tesla-m corresponds to a transverse momentum of 103 MeV/c. The magnetic fields will be in opposite directions to each other minimizing the magnetic field in the region of the beams. Calculations performed by the ISR division have shown that it is possible to shield the beams adequately against the remaining magnetic field.

2) Cerenkov counters.

The Cerenkov counters will be filled with air at atmospherique pressure corresponding to a threshold of 5.6 GeV/c for pions. They countain 12 cells, covering the full magnet aperture; each cell is defined by an elliptical miror focusing the entire diamond onto the photocathode of a 58 DVP tube. The active Cerenkov length is 90 cm. The construction is similar to that used in experiment R 105.

3) Chambers.

As the magnets give a bend only in the horizontal plane good spatial resolution is needed in this plane in order to achieve a good momentum measurement. In the horizontal plane the lever arm for track measurement is 20 cm on each side of the magnets, while in the vertical direction it is 1.5 m. This requires different designs for the chambers measuring horizontal (x) and vertical (y) coordinates.

In addition, in order to match the magnet aperture, the chamber size increases from 0.60 x 0.30 m^2 in front of the magnet to 2.7 x 1.0 m^2 behind it. This implies different designs for the two sets of chambers.

In the front, 4 drift chambers with a 1 cm drift space measure the x coordinates to a precision of ± 0.2 mm. The sense wires of these chambers are short (30 cm at most), which permits the use of double wires (∼ 0.2 mm apart) to resolve left-right ambiguities[8]. The fringe field in the chamber closest to the magnet never exceeds 1.8 kG and is sufficiently homogeneous to permit an easy compensation. In the other chambers the field is always below 1 kG, which requires no compensation.

The measurement of y coordinates in front of the magnet is performed with 2 proportional chambers. A 2 mm wire spacing is sufficient for the accuracy required, corresponding to a total of 300 wires in each arm.

The large horizontal dimension (2.7 m) of the chambers behind the magnet forbids the use of thin horizontal wires to measure the y coordinates. For this reason we use 3 drift chambers with vertical sense wires (2 cm drift space) with delay lines to measure the x and y coordinates simultaneously [9]. The propagation velocity in the delay lines has been measured to be 1.5 ns/cm, corresponding to a precision in y of 3 to 4 mm. The simultaneous measurement of x and y in each of the 3 chambers solves the difficulties of multitrack reconstruction in space. The most important information is given by the x coordinate, and therefore we take no risk by using this new technique to measure the y coordinate.

4) Lead Glass Arrays.

The lead glass Cerenkov counters are arranged in two large arrays behind the spectrometers and match the magnet apertures. The design is similar to that previously used in several ISR experiments. The cellular arrangement (15 cm cell width) provides a position measurement with an accuracy of ± 3 cm. The energy deposited in each block (15 radiation lengths deep) is known to a precision of ± 5 % at 1 GeV, varying approximately as the inverse root of the energy. The requirement that the electron momentum measured in the magnet matches the energy measurement in the corresponding region of the lead glass counter gives a further rejection factor of 10^2 against hadrons.

Adequate shielding from the beam background avoids deterioration of the optical quality of the glass. Standard techniques (Am sources imbedded in Na I scintillators, and photodiodes) are used to monitor the energy calibration. A one radiation length thick iron plate in front of each lead glass detector serves the dual purpose of shielding against the stray magnetic field and providing further rejection against hadrons of the order of 3 to 4 by pulse height measurement in an array of scintillators H_3 behind it.

5) Hodoscopes.

Each spectrometer is equipped with three hodoscope banks, H_1, H_2 and H_3. The width of the scintillation counters are 5, 10, 15 cm respectively. Pulse height measurements are made for the scintillation counters H_1 and H_3. The pulse height measurement in H_1 is used to reject converted gamma rays and Dalitz pairs ; the pulse height measurement in H_3 which is located after one radiation length of steel gives an additional rejection against hadrons. Fig.3 shows a pulse height spectrum for hadrons, and for electrons taken by the H_3 counters of the CCRS experiment.

RESOLUTION

The angular resolution provided by the chambers is 1 millrad in the horizontal plane, and 3 millrad in the vertical. The momentum resolution in the magnetic spectrometer is dominated by multiple scattering below 2 GeV/c and is nearly flat at 3 %. Above 2 GeV/c the resolution decreases to a value of 15 % at 10 GeV/c. On the other hand, the lead glass detector resolution for electrons is improving with momentum. Therefore, the mass resolution $\Delta m/m$ for electrons pairs is always better than 5 % at any mass.

TRIGGERS

a) Triggers requiring an electron.

The basic electron trigger is a coincidence between the hodoscopes H_1 H_2 H_3 and a Cerenkov signal. To reduce the trigger rate a minimum energy deposition is also required in the lead glass blocks corresponding to the Cerenkov cell. The energy threshold will be chosen as low as is compatible with dead time.

- Electron pairs : For this case, two single electron triggers are in coincidence. An energy threshold as low as 1 GeV suffices to maintain a low trigger rate at even the highest ISR luminosity. Note that if the two electrons are in one arm, two different Cerenkov cells and their associated lead glass pulse heights are required.

- Strange particles : As a trigger for strange particles we require two additional charged particles other than the electron, corresponding to a possible two body decay. The strangeness will be verified by an off-line mass reconstruction ; the decay vertex must be different than the primary interaction vertex. The requirement of an electron in this trigger should limit the rate to a manageable level.

b) Hadrons.

As a complement to the investigations of electron-strange particle correlations, we will also study pion-strange particle correlations. According to the preceding argument, the minimum trigger for this would be that 3 different H_3 scintillation counters have fired. However, this trigger is surely too loose. Therefore, we envisage the use of the drift chamber signals in a hardware (or online software) decision to reduce the trigger rate. As an example, the sense wires can be used as a fine sampling hodoscope and a minimum transverse momentum requirement can be imposed by demanding the excited sense wires be approximately aligned in space. For a Λ^0 trigger, we note that the momentum of the proton and the pion in the Λ^0 rest frame is 100 MeV/c and that each spectrometer has a field integral equivalent to 103 MeV/c. Therefore, requiring two parallel tracks after the magnet will enrich the trigger sample with Λ's.

Fig.4 shows the mass spectrum of two particles obtained in the CCRS experiment assuming the particle with the largest momentum to be a proton and the other one to be a pion. A clear peak is seen at the Λ mass, demonstrating that the proposed method is sufficient to recognize Λ's. Fig.5 shows (CCRS) data assuming the two particles are pions ; the $K_{OS} \rightarrow \pi^+ \pi^-$ is identified by a mass peak at 500 MeV.

In the above discussion it has been tacitly assumed that the pion not produced by strange decay is charged. Using the lead glass counters a trigger including π^0's is easily obtained by observing one or both of the decay photons.

RATE ESTIMATION

For the estimation of trigger rates, it is assumed that the apparatus will be installed in the low beta intersection I7, where a luminosity of $3\ 10^{31}$ is expected. In 100 hours, an integrated luminosity of 10^{37} is obtained, yielding 30000 single electrons with p_T larger than 1.5 GeV/c within the proposed solid angle.

The number of electron pairs or electron-strange particle pairs expected depends on the production mechanism. For a simple model with minimal assumptions, we suppose these pairs result from the decay of a single heavy object whose rapidity distribution is similar to that of antiprotons. The transverse momentum distribution is assumed to be

$$\frac{d\sigma}{dp_T^2} \approx \frac{1}{(1+p_T^2)^4} \quad e^{-\frac{26p_T}{\sqrt{s}}}$$

With these assumptions, one can estimate the fraction of the time R that a second particle is seen, given that an electron has been detected.

For electron pairs the ratio R is shown in Table 1 as a function of the pair mass for the cases that the two electrons are detected in the same or different spectrometers.

To estimate R for an electron-strange particle decay of a charmed particle, we assume that the decay $D \rightarrow K\ e\ \nu$ behaves similarly to $K \rightarrow \pi\ e\ \nu$. Then, for a 2 GeV charmed mass the ratio R is 0.25 for detecting both the electron and strange particle in the same spectrometer. For a 4 GeV mass R is roughly 0.2 for detection in either one or both spectrometers.

It is to be emphasized that the ratio R does not depend very strongly on the rapidity assumption. If we detect an electron with large transverse momentum coming from the decay of a heavy object then the C.M. rapidity of the other decay products is automatically restricted to the central region where the acceptance of the proposed apparatus is large.

As mentioned previously, 30000 single electrons of more than 1.5 GeV/c can be detected in 100 hours and therefore a ratio R as low as 1 % gives 300 pairs. For all masses considered this ratio is greater than 1 %. For masses above 3 GeV the ratio for electron pairs is close to 100 %.

In other words, with an apparatus of 1.8 steradians solid angle, if no electrons pairs are found in 100 hours running time, very strong limits can be placed on the hypothesis of heavy particle decays.

Since we wrote our letter of intent a 3 GeV meson has been found at Brookhaven and SLAC[6,7]. The question to answer is : "Are all the single electrons observed at large transverse momentum due to this particle or a series of these particles ?" We believe that the proposed equipment is well suited to answer this question.

It should not be forgotten that charmed meson can decay via the mode D → K π. In this case, the charmed particle manifests itself as a bump in the K π mass distribution. The detection of the signal is not limited by the luminosity, but by the background from hadronic correlation between pions and kaons. Fig.6 shows the mass spectrum for charged pairs reconstructed as pion-kaon pairs. Assuming the pion-K_S^0 correlation is the same but the yield 10 times less and a mass resolution $\frac{\Delta m}{m}$ of 5 %, a cross section of the order of 10^{-32} cm^2 for charmed particle can be seen. With the proposed set-up K_S^0 π^0 and K_S^0 $\pi^{\pm}$, as well as $\Lambda\pi^0$, $\Lambda\pi^{\pm}$, can be studied. In any case, the correlation of pions with strange particles must be studied in order to compare it to electron-strange particle correlations.

CONCLUSION

The proposed experiment is designed for detailed investigation into the origin of the electrons directly produced with large transverse momentum.

It utilizes proven techniques; the principle innovation is to increase the acceptance by 2 orders of magnitude. In addition, it features good efficiency for strange particle detection, which allows the search for new mesons and/or charmed particles via their leptonic, semi-leptonic or hadronic decay modes. If new particles are produced in pairs, we can use the leptonic decay of one to define an enriched event sample in which to study the hadronic decays of the other.

The experiment is well suited to enlarge upon the recent discoveries at BNL and Spear. We shall be able to detect their mesons, and extend the search of new particles to higher masses.

At the same time this apparatus is well suited to study hadronic correlation in a large p_T range.

The experiment is compatible with installation in a low beta section, where it would profit from the increased luminosity.

The lead glass and the Cerenkovs will be ready before the chamber assembly is completed. With the two first elements, we may begin the study of the electron pairs but with a reduced rejection against hadrons.

If a favorable ISRC decision is taken in December, the construction of the apparatus would start immediately and the experiment could commence in summer 1975.

TABLE I

Ratio R (defined in page 7) for electrons pairs.

Mass	both electrons in one spectrometer	one electron in each arm
0.5	0.22	0
1	0.03	0
1.5	0.01	0.1
2	0.001	0.43
3	0	0.7
4	0	0.8

Appendix I

CORRELATION STUDIES

The study of angular correlations at FNAL and ISR has shown the existence of a short range term, with properties suggestive of neutral cluster production with low internal multiplicities. The configuration ($\pi^+ \pi^- \pi^0$) is often regarded as a good candidate for such clusters.

The proposed set-up is well suited to study the invariant mass distribution of such triplets and measure the contribution of known meson decays, such as $\eta \rightarrow \pi^+ \pi^- \pi^0$, $\omega \rightarrow \pi^+ \pi^- \pi^0$, etc... The large rapidity acceptance of the magnetic spectrometers (more than 2 units) permits an efficient detection of centrally produced $\pi^+\pi^-$ pairs. Depending upon the mass M^* and transverse momentum $p_\perp^*$ of the ($\pi^+ \pi^- \pi^0$) triplet, the neutral pion can be observed in the lead glass array on the same side as the $\pi^+\pi^-$ pair, or opposite to it.

The addition of a lead glass array between both magnets, at 90° to the beam plane, fills the gap between these extreme configurations, corresponding to the range $\frac{1}{2} \lesssim \frac{M^*}{p_\perp^*} \lesssim \frac{3}{2}$. For transverse momenta above 1 GeV/c and masses below 2 GeV/c^2, the three pions are efficiently detected in a same arm : we find that a cluster produced uniformly between rapidities -1 and +1, and decaying according to pure phase space, is detected with an efficiency of 2.5 %.

The large acceptance of the spectrometers also permits us to extend the momentum correlation measurements previously performed by the CCRS collaboration to a much larger rapidity range in the high transverse momentum region. In particular it will allow us to study whether the similarity observed between the back to back and alongside configurations persists at rapidity differences of the order of one unit.

In addition, the azimuthal dependence of the rapidity and transverse momentum correlations can be studied for the charged-neutral and neutral-neutral configurations.

References

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9 A. Breskin et al, Nuclear Instrument and Methods, 119 (1974) 1-5.

Figure captions.

1) Single electron transverse momentum spectrum for a 4 GeV meson mass.

2) Top view of the experimental set-up.

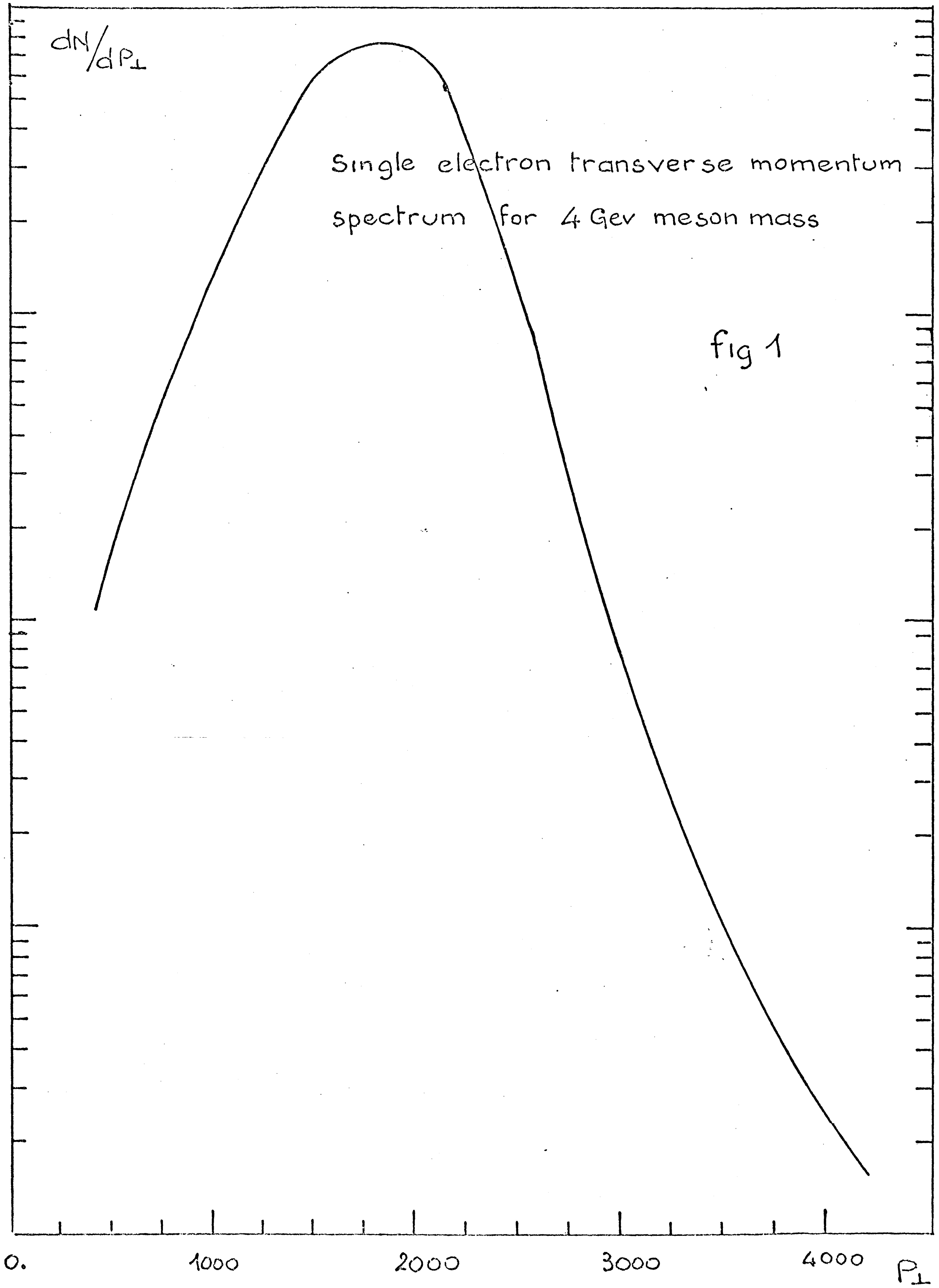
3) Pulse height distribution in H_3 located behind 1RL of steel for electrons and hadrons above 1.5 GeV/c momentum.

4) π p invariant mass distribution.

5) $\pi^+ \pi^-$ invariant mass distribution.

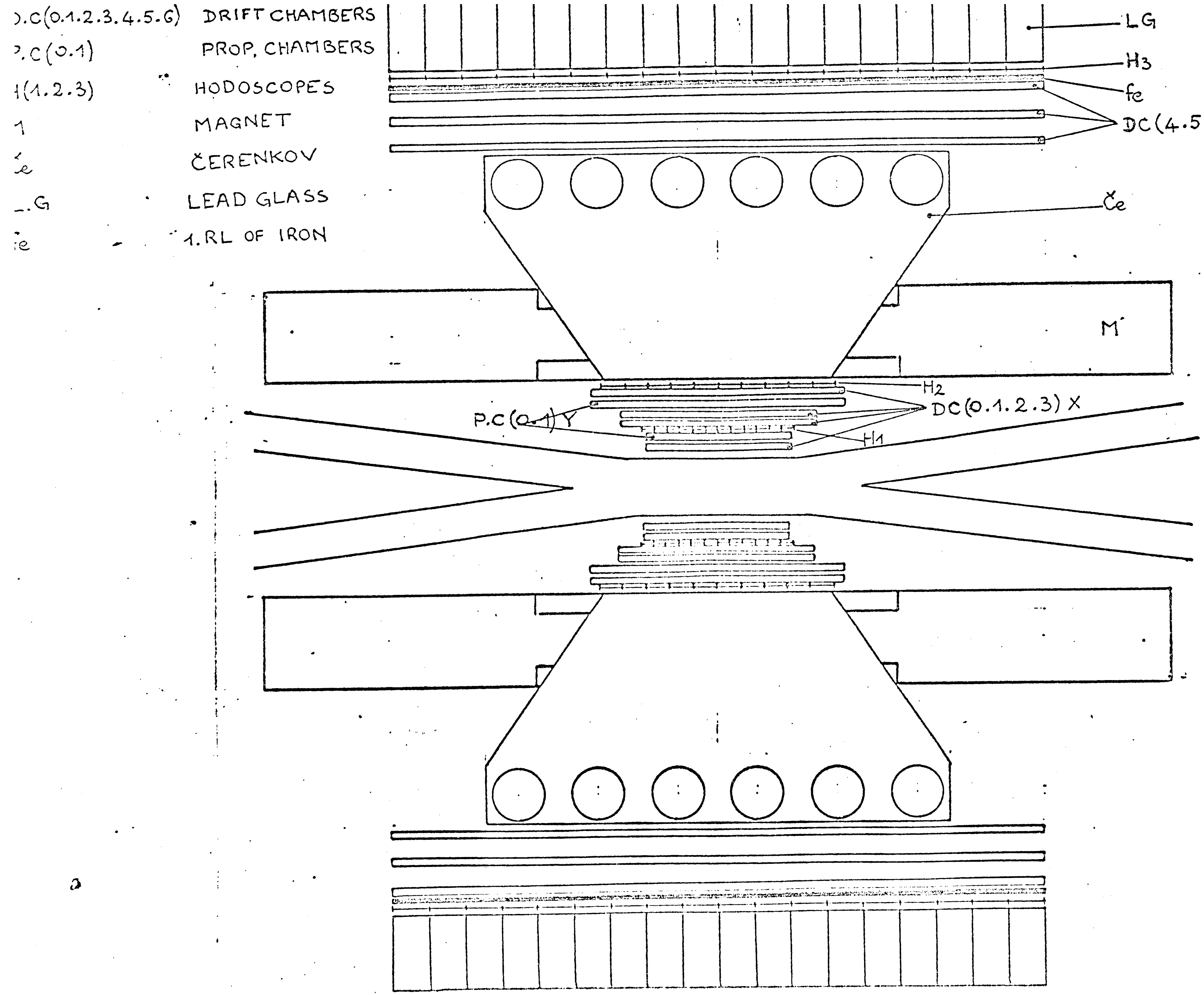
6) Mass spectrum of charged pairs reconstructed as $\pi^\pm K^\mp$ pairs.

Fig.3 to 6 are experimental data from CCRS.



dN/dP⊥
Single electron transverse momentum spectrum for 4 Gev meson mass
0.
1000
2000
3000
4000
P⊥

fig 1


).C(0.1.2.3.4.5.6) DRIFT CHAMBERS
?.C(0.1) PROP, CHAMBERS
{(1.2.3) HODOSCOPES
1 MAGNET
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ie 1.RL OF IRON
LG
H3
fe
DC(4.5.6) X,Y
Če
M
H2
DC(0.1.2.3) X
P.C(0.1) Y
H1

fig 2

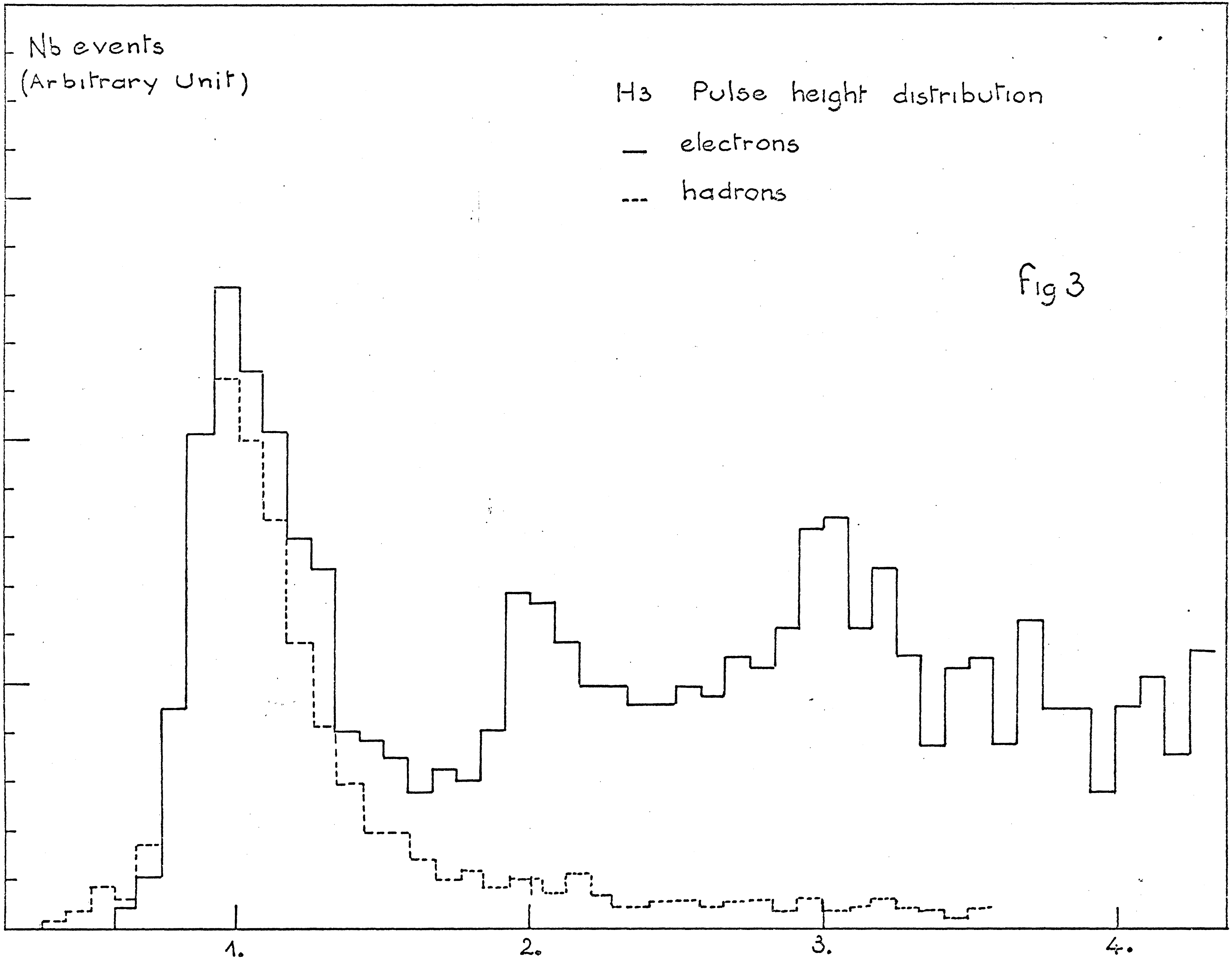
Nb events
(Arbitrary Unit)
H3 Pulse height distribution
— electrons
--- hadrons
1.
2.
3.
4.

Fig 3

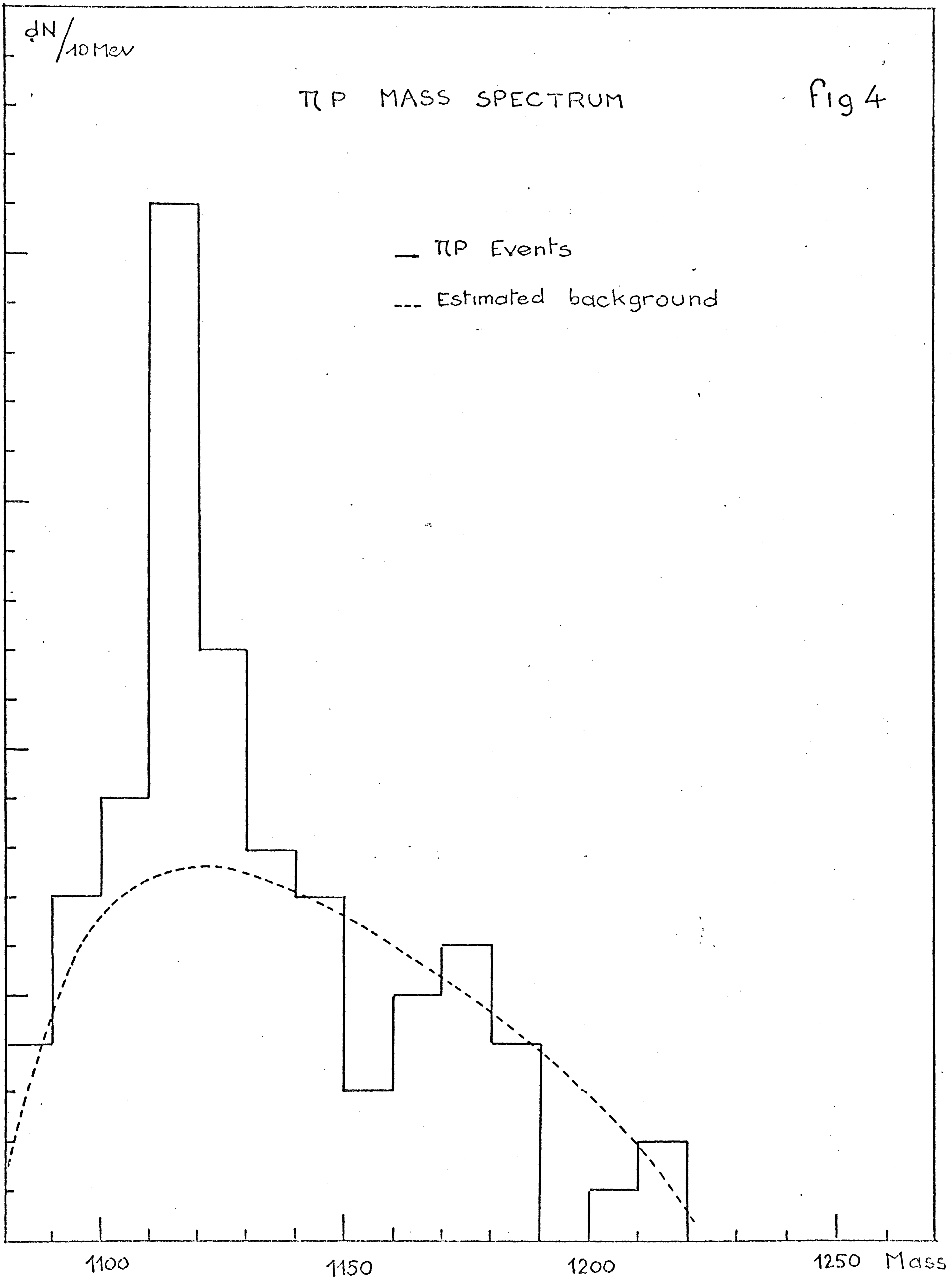
fig 4

πP MASS SPECTRUM

ππ MASS SPECTRUM

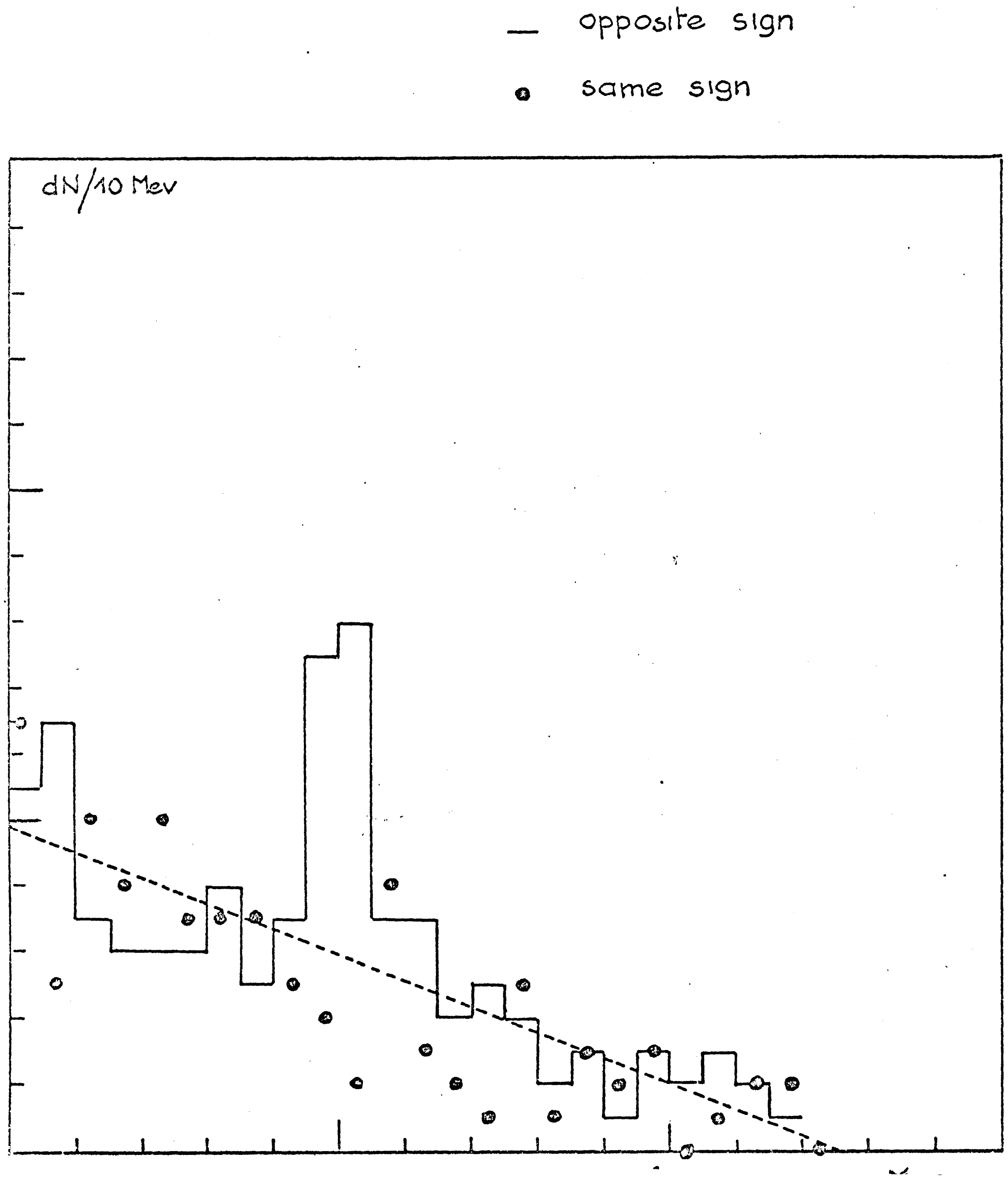

Fig 5

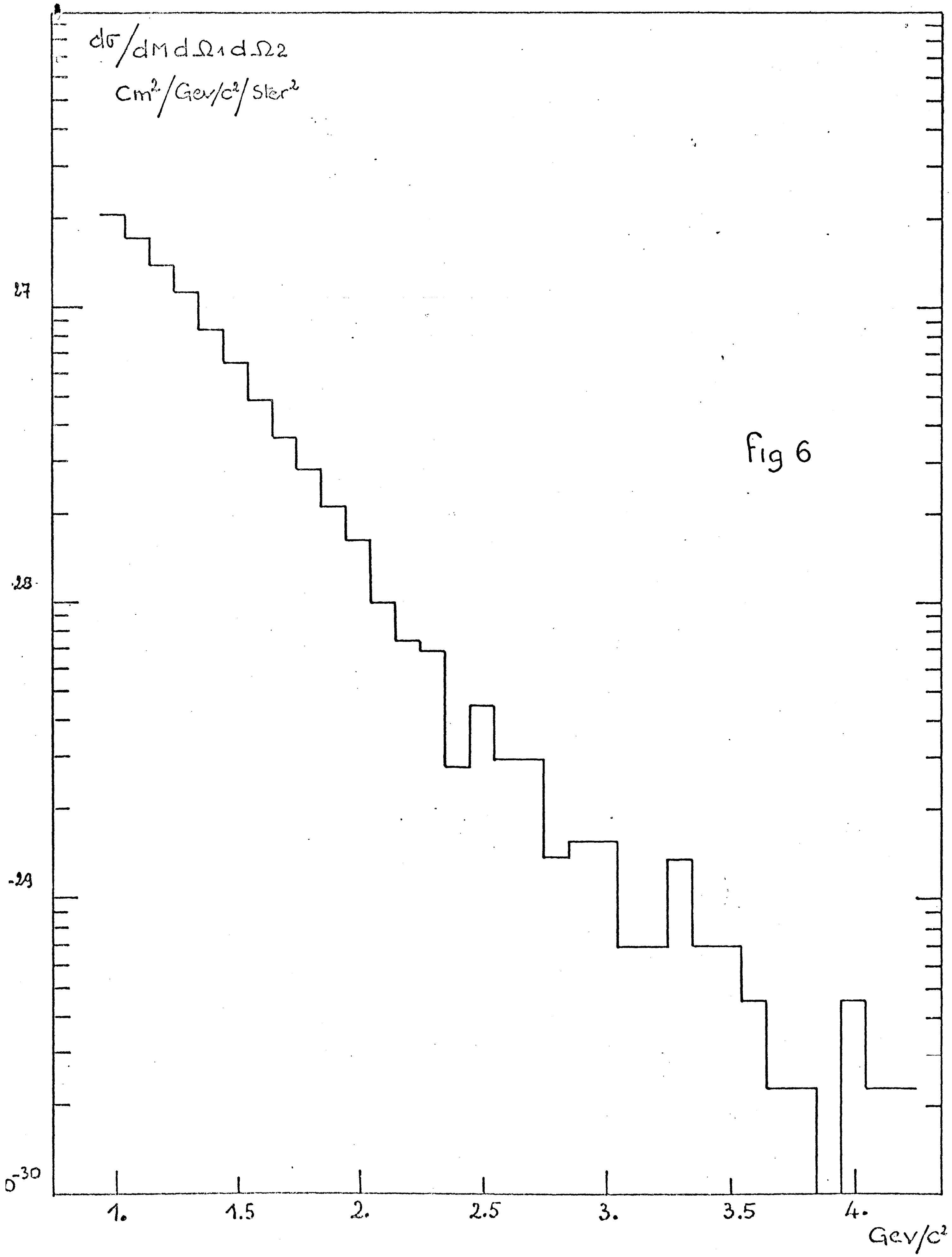

fig 6