EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL FOR AN EXPERIMENT WITH OMEGA :

ππ SCATTERING LENGTHS

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1. PHYSICS INTEREST AND SUMMARY

We propose a short experiment on the $\pi^{\mp}p\to\pi^{\mp}\pi^{+}n$ reactions near the $\pi\pi$ threshold. The experimental effort required would essentially be an integral part of the development of approved Omega trigger systems. An originality of the experiment is the use of the Čerenkov counter as a veto against some of the most important sources of background.

Weinberg's elegant and apparently definitive theory [1] fixes the $\pi\pi$ scattering lengths as $a_o = \frac{7\mu}{32\pi F_\pi^2} = .16\ \mu^{-1}$, $a_2 = -\frac{2}{7}\ a_o = -.048\ \pi^{-1}$. Experiments, based both on direct evidence from Ke4 decays [2] and on $\pi p\to\pi\pi N$ data interpreted through One Pion Exchange [3], favor larger values for both scattering lengths, although not convincingly (Fig. 1).

Regarding $\pi N\to\pi\pi N$ above $M_{\pi\pi}$ = 500 MeV, unitarized Weinberg-type and other theories [4] as well as experiments all essentially agree with each other; the sensitive region is mostly between threshold and $M_{\pi\pi}$ = 400 MeV, where the cross section is very low.

We request a total of 5 days of beam at Omega, at a momentum of 3.2 GeV/c, in order to obtain some 8000 events below $M_{\pi\pi}$ = 500 MeV, for each of the two reactions $\pi^-p\to\pi^-\pi^+n$ and $\pi^+p\to\pi^+\pi^+n$. The results of a short test run show that this goal is realistic. A Chew-Low extrapolation with conformal mapping [5] combined with the study of the Coulomb interference in the $\pi^{\mp}\pi^{+}\to\pi^{\mp}\pi^{+}$ channel [6], will help to obtain the s-wave $\pi\pi$ phase shifts in magnitude and sign (Fig. 2).

The comparable efforts known to us in this field are the improved Ke4 experiment which is under way [7] and which uses somewhat different assumptions, and the CERN-Munich experiment at 7 GeV/c [8], with similar statistics in the $\pi^-\pi^+n$ channel only.

Concerning the latter, we wish to point out that experiments at different momenta are needed in order to exclude possible N* effects.

Regarding instrumentation, the proposed experiment is a natural first step in the development of the multiplicity trigger based on multiwire proportional chambers.

2. THE PROPOSED EXPERIMENT

The proposed layout is shown in Fig. 3a. The Omega field is reduced to 6 kGs (1600 A). Two tracks in the porportional chamber MWPC 1 (20 x 20 cm^2, 1 mm pitch, y and z planes) are required. This is done using the multiplicity logics developed for the K^{*o} trigger. In addition, the forward hodoscopes, which are placed together with the Čerenkov counter on the beam path, select a like pion, i.e. a particle of the same sign as the incoming pion and of at least half the beam momentum. The selectivity of the trigger is greatly improved thanks to two anticoincidence devices : the Čerenkov, whose threshold for pions with isobutane is at 2.7 GeV/c, rejects all like pions between some 2.75 GeV/c and the beam momentum (3.2 GeV/c), with 99.8% efficiency, thereby excluding elastic scattering, quasi-elastic scattering and π-e scattering. Secondly, a simple anticoincidence shield around the target excludes the events of higher charged multiplicity.

The geometrical acceptance for this set-up is high at low mass, and decreases at higher mass where the cross section is bigger (see Fig. 5). Fig. 4 shows the part of the $\pi\pi N$ Dalitz plot under study, with the important N* bands clearly excluded by our set-up. The fact that we accept only forward decays ($\cos\theta_J > 0$) in the $\pi^-\pi^+$ rest frame will make the measurement of the (small) p-wave phase shift unreliable, but is adequate for the Coulomb interference effects (see e.g. Fig.1 of ref. 6a which shows the computed effect in the physical region).

3. CROSS SECTIONS AND RESULTS FROM THE TEST RUN

We had Omega for six hours during the October 1972 run for a test with the set-up shown in Fig. 3b. Instead of the MWPC we used a 30 x 30 cm counter which detected the π^+ in $\pi^- p \to \pi^- \pi^+ n$. We used also a rather insufficient veto screen against high multiplicity events. During the last hour we recorded 10000 triggers. From these, and using computed acceptance and estimated counter efficiencies, we found the following cross sections at 3.2 GeV/c :

$$\sigma(M_{\pi\pi} < 400 \text{ MeV}/c^2) = 2 \pm 1 \ \mu b \ \text{(10 events)}$$
$$\sigma(M_{\pi\pi} < 500 \text{ MeV}/c^2) = 12 \pm 5 \ \mu b \ \text{(25 events)} \qquad \Delta^2 < 0.1 \text{ GeV}^2$$

This has to be compared with the value derived from Weinberg's theory and OPE with Dürr-Pilkuhn form factors :

$$\sigma(M_{\pi\pi} < 400 \text{ MeV}/c^2) = 2 \ \mu b \qquad \Delta^2 < 0.1 \text{ GeV}^2$$

and also to previous experimental results [9] extrapolated to our energy :

$$\sigma(M_{\pi\pi} < 400 \text{ MeV}/c^2) = 4.7 \pm 1 \ \mu b$$

and

$$\sigma(M_{\pi\pi} < 500 \text{ MeV}/c^2) = 15 \pm 2 \ \mu b$$

The $\pi\pi$ mass spectrum before and after a fit to the reaction $\pi^- p \to \pi^- \pi^+ n$ is shown in Fig. 6. One can see that the events due to K^o decays are correctly eliminated. Fig. 7 shows that by requiring a double hit in the MWPC we will essentially **reduce** the ρ **region**.

A possible contamination may come from η's decaying into $\pi^- \pi^+ \gamma$ ($\eta^o \to \pi^+ \pi^- \pi^o$ events are easily eliminated by the fit;

see Fig. 8 which shows the plot of the missing mass versus the $\pi\pi$ mass). The $\pi^+\pi^-\gamma$ contamination, which is 5-10% depending on the resolution finally achieved, can be easily computed and corrected for, from the known η production cross section and decay Dalitz plot. The observed missing mass distribution just above the η mass checks with this estimate.

4. EVENT RATE, TRIGGER RATE AND BEAM TIME REQUIREMENTS

From the experience with the test run, and the improvements foreseen, we estimate a trigger rate of $1\ 10^{-4}$ for the described set-up. From a beam of 200'000 π/burst, hitting 30 cm of liquid H_2, and taking into account a dead time of 20 msec, we expect 10 triggers/burst.

Assuming (pessimistically) a $\pi^-\pi^+n$ cross section of 2 μb, a detection efficiency of 40% (forward hemisphere only, in the $\pi\pi$ system), and a security factor of π, we expect to detect 3000 events with $M_{\pi\pi} < 400$ MeV (or 8000 events with $M_{\pi\pi} <$ 500 MeV) during a two days run.

The $\pi^+\pi^+n$ cross section is about a factor of 2 smaller, but the efficiency doubles (there is always one π^+ in the forward hemisphere). A comparable number of events is therefore expected from a further two days.

We request therefore a total of five days running time at Omega, at ± 3.2 GeV/c, namely 1/2 day in June 1973 when the MWPC multiplicity logics will be ready, and the main run of 2 x 2 days , preceded by some checking time, in August or October 1973.

The total number of triggers would be between $0.5\ 10^6$ and $1\ 10^6$. Some 150 h 6600 equivalent of computer time would be needed, partly at CERN and mainly in Paris.

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9) G. Laurens, thesis, Note CEA-N-1497 (1971).
(Data : 2.77 GeV/c. Quoted values are for 3.2 GeV/c, assuming a P_{Lab}^{-2} dependence of the cross sections).

FIGURE CAPTIONS

Fig. 1 : $\pi\pi$ s-wave phase shifts : a. δ_0^0 ; b. δ_0^2.
Curves from Ref. 4a.

Fig. 2 : The method : the unknown nuclear $\pi\pi$ scattering (a) and the known Coulomb scattering (b) contributions interfere and can be obtained by extrapolation to the pion pole. The diagram (c) is hoped not to contribute in the kinematical region considered.

Fig. 3a) : Proposed layout of the experiment.
b) : Layout of the test done in October.

Fig. 4 : $\pi\pi N$ Dalitz plot at 3.2 GeV/c, and acceptance of our set-up for small Δ^2.

Fig. 5 : Geometrical acceptance of the proposed set-up of Fig.3a).
Dotted curve : generated phase space ($\pi^-\pi^+$: events with $p_{\pi^-} > p_{\pi^+}$ only);
Solid histogram : events accepted by the proposed trigger system.

Fig. 6a) : $M\pi\pi$ for all two prongs events of the October run.
6b) : $M\pi\pi$ for events fitting the reaction $\pi^- p \rightarrow n\pi^+\pi^-$.

Fig. 7 : $M\pi\pi$ for those mong the unfitted October events which have both pions passing through the MWPC.

Fig. 8 : Plot of the missing mass versus the effective $\pi\pi$ mass for events fitting the reaction $\pi^- p \rightarrow \pi^-\pi^+ n$.

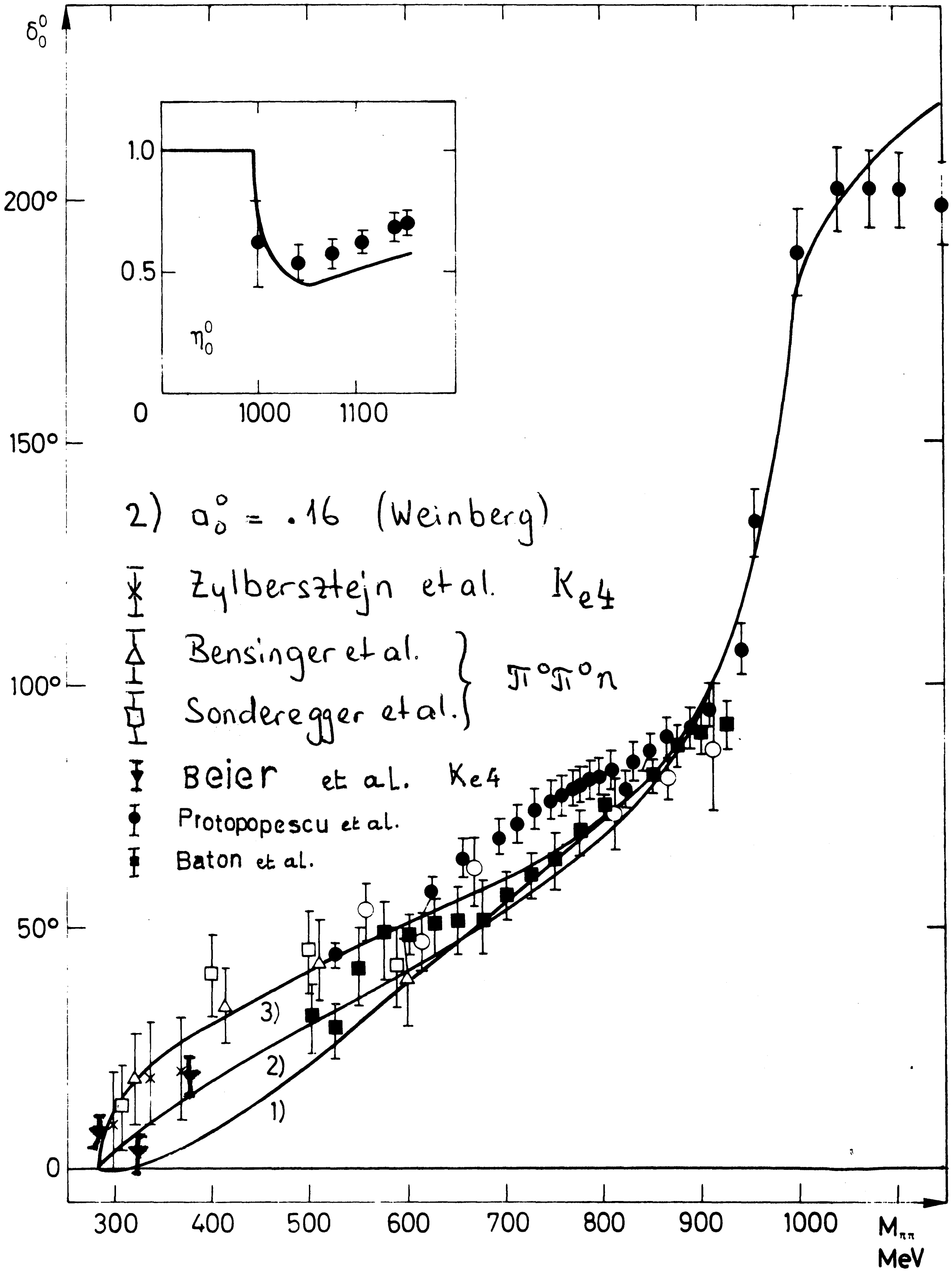

δ_0^0
200°
150°
100°
50°
0
300
400
500
600
700
800
900
1000
$M_{\pi\pi}$ MeV
1.0
0.5
η_0^0
0
1000
1100
2) a_0^0 = .16 (Weinberg)
Zylbersztejn et al. K_{e4}
Bensinger et al.
Sonderegger et al.
$\pi^0\pi^0 n$
Beier et al. K_{e4}
Protopopescu et al.
Baton et al.
3)
2)
1)

FIG. 1 a

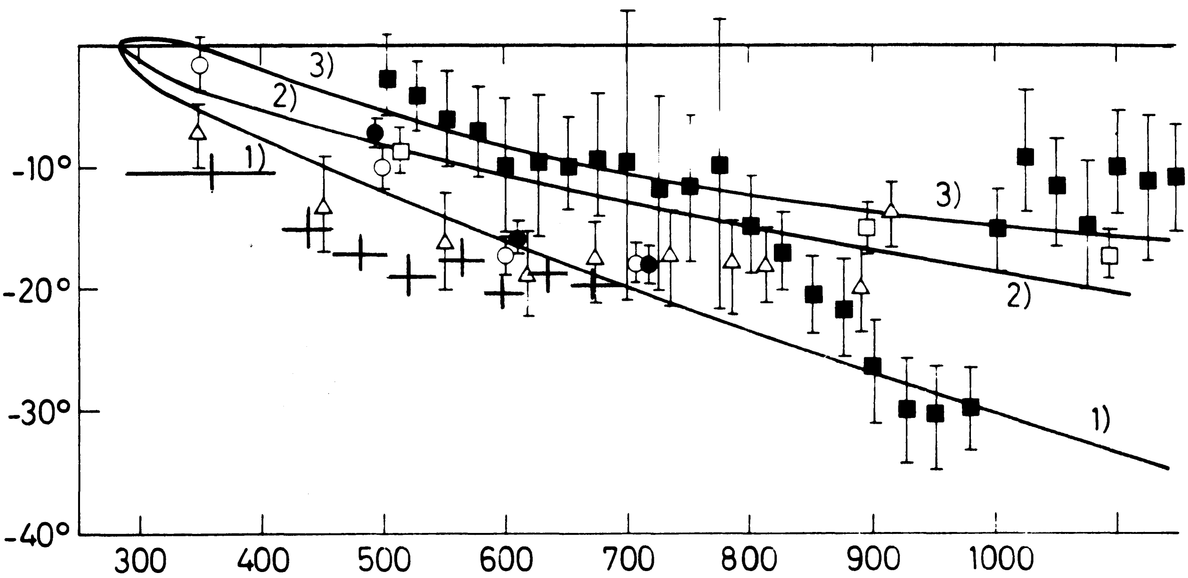


FIG.1b

2) $a_0^2 = -.048$ (Weinberg)

■ Baton et al.

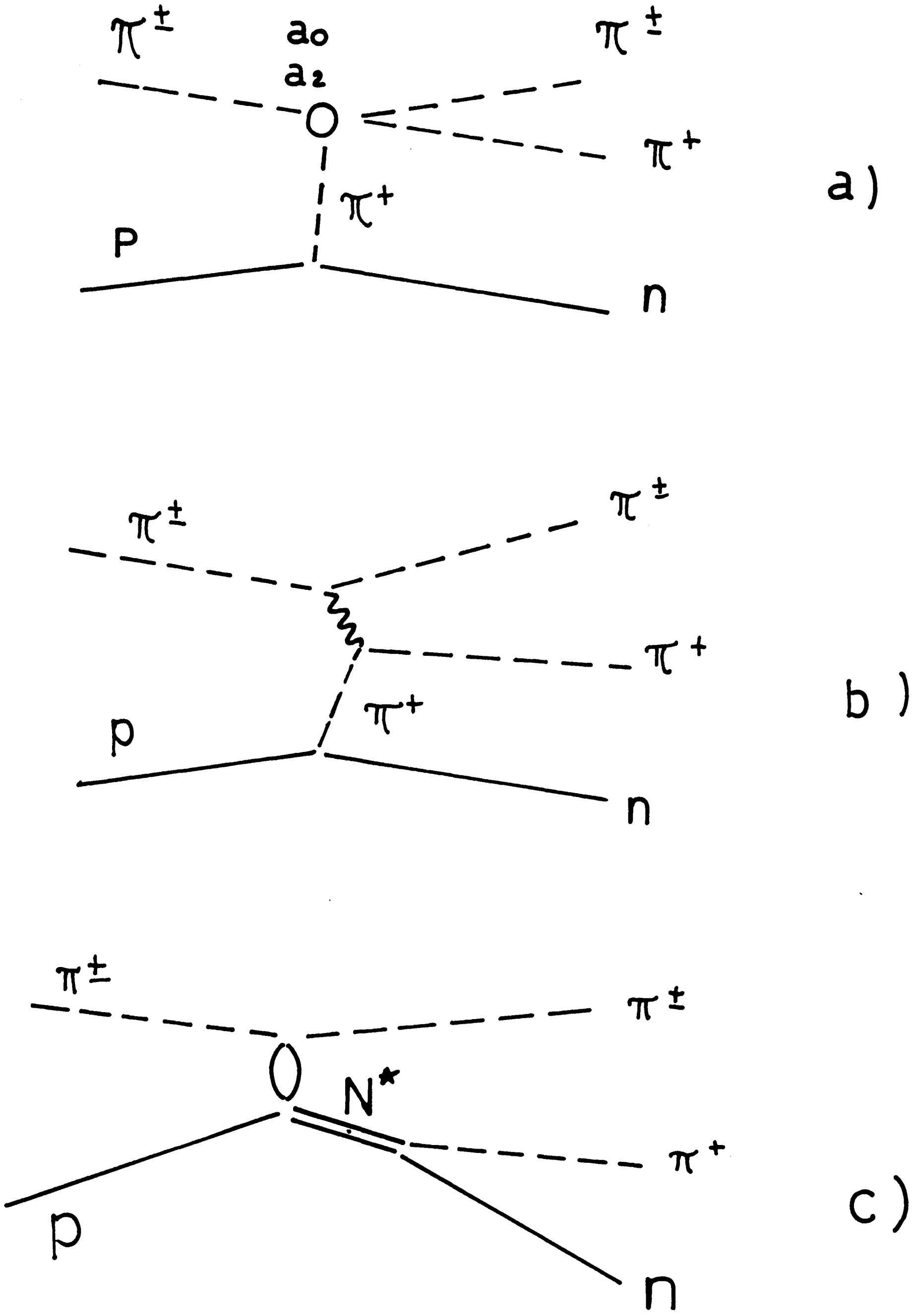
○ Colton et al

□ Katz et al.

△ Walker et al.

+ Sander et al

fig. 2



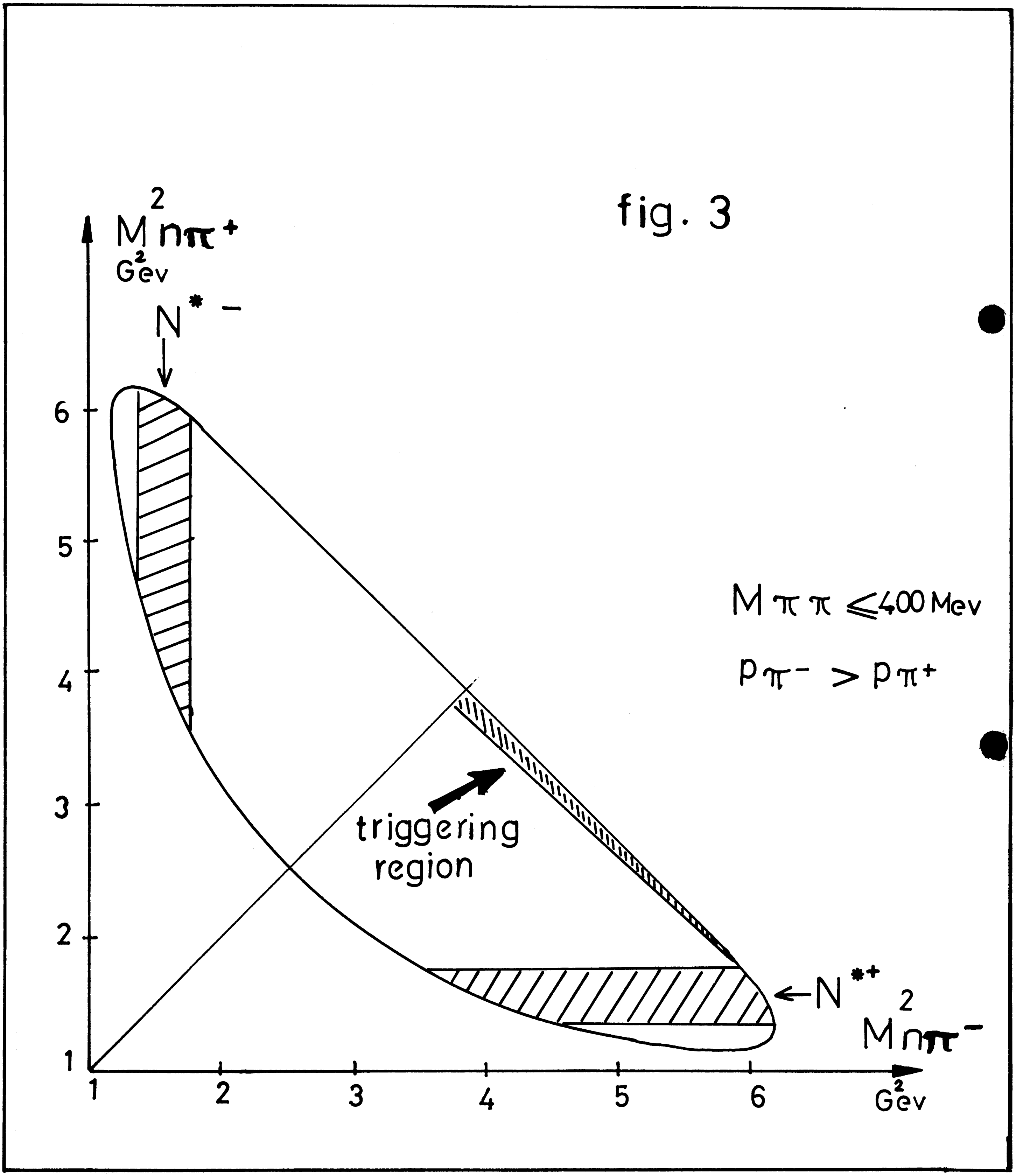


fig. 3
$M^2_{n\pi^+}$ Gev^2
N^{*-}
$M\pi\pi \leqslant 400$ Mev
$p_{\pi^-} > p_{\pi^+}$
triggering region
N^{*+}
$M^2_{n\pi^-}$ Gev^2
1
2
3
4
5
6

fig. 4a

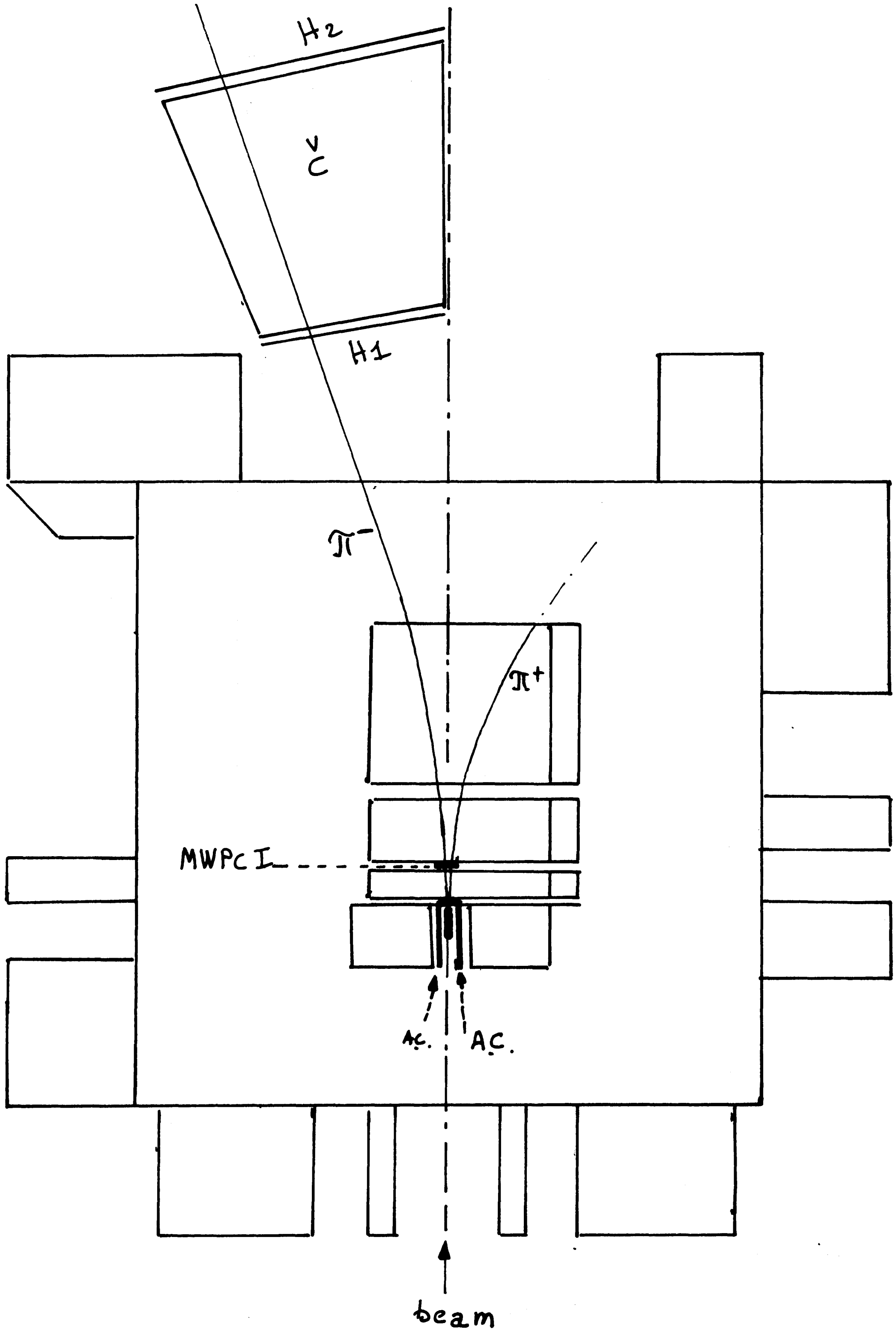
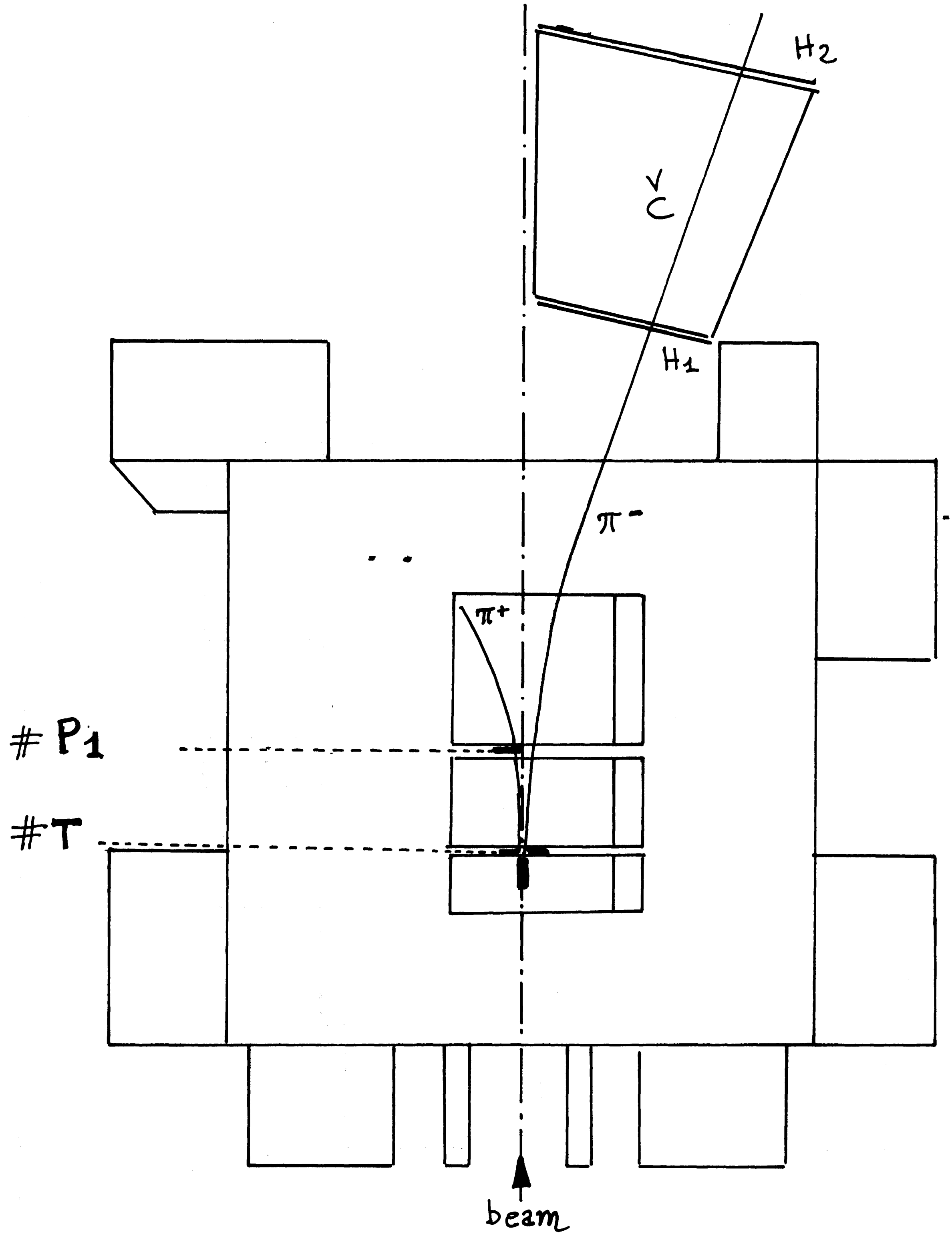


fig. 4 b



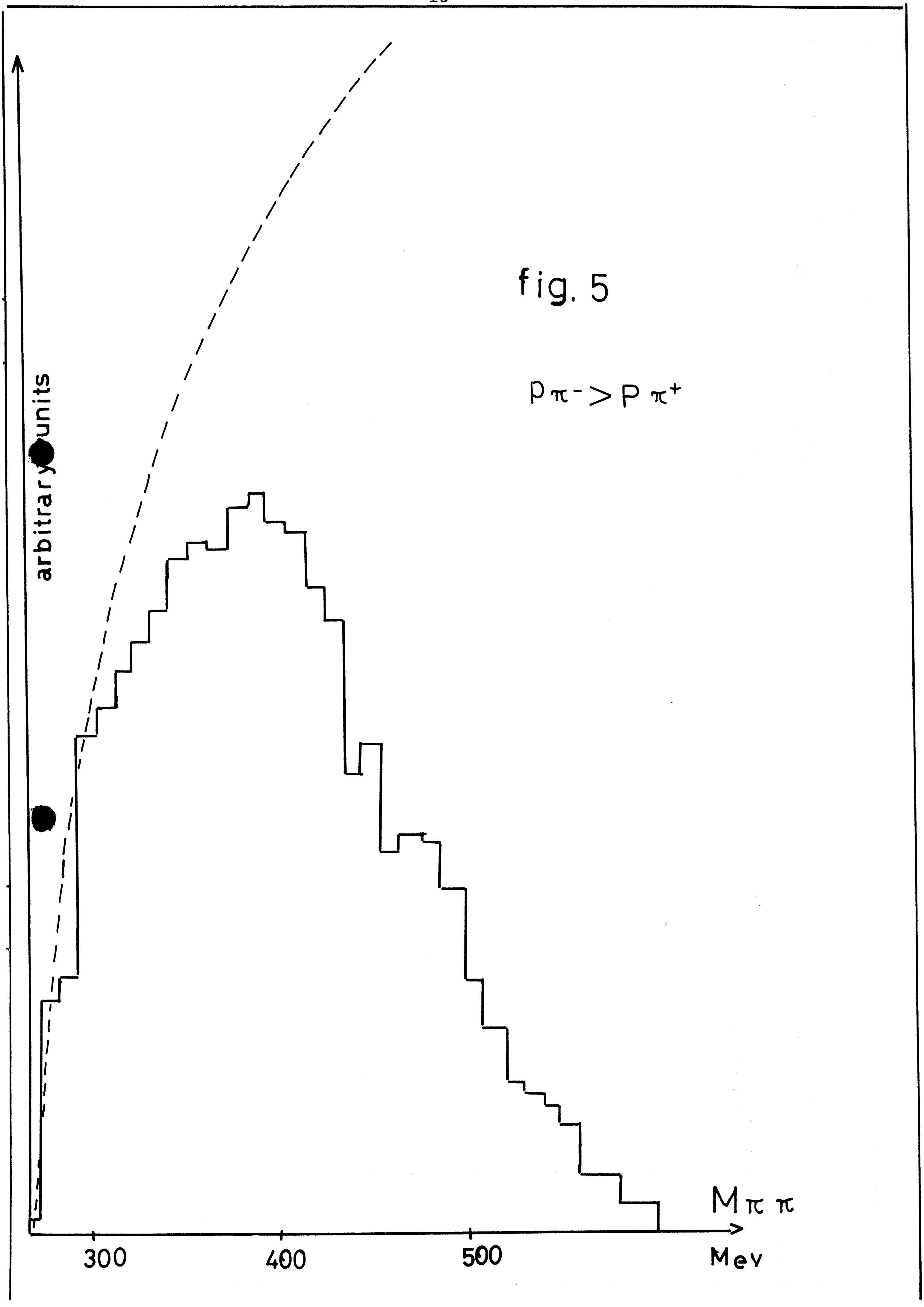


fig. 5
$p\pi^- \to p\pi^+$
arbitrary units
$M\pi\pi$
300
400
500
Mev

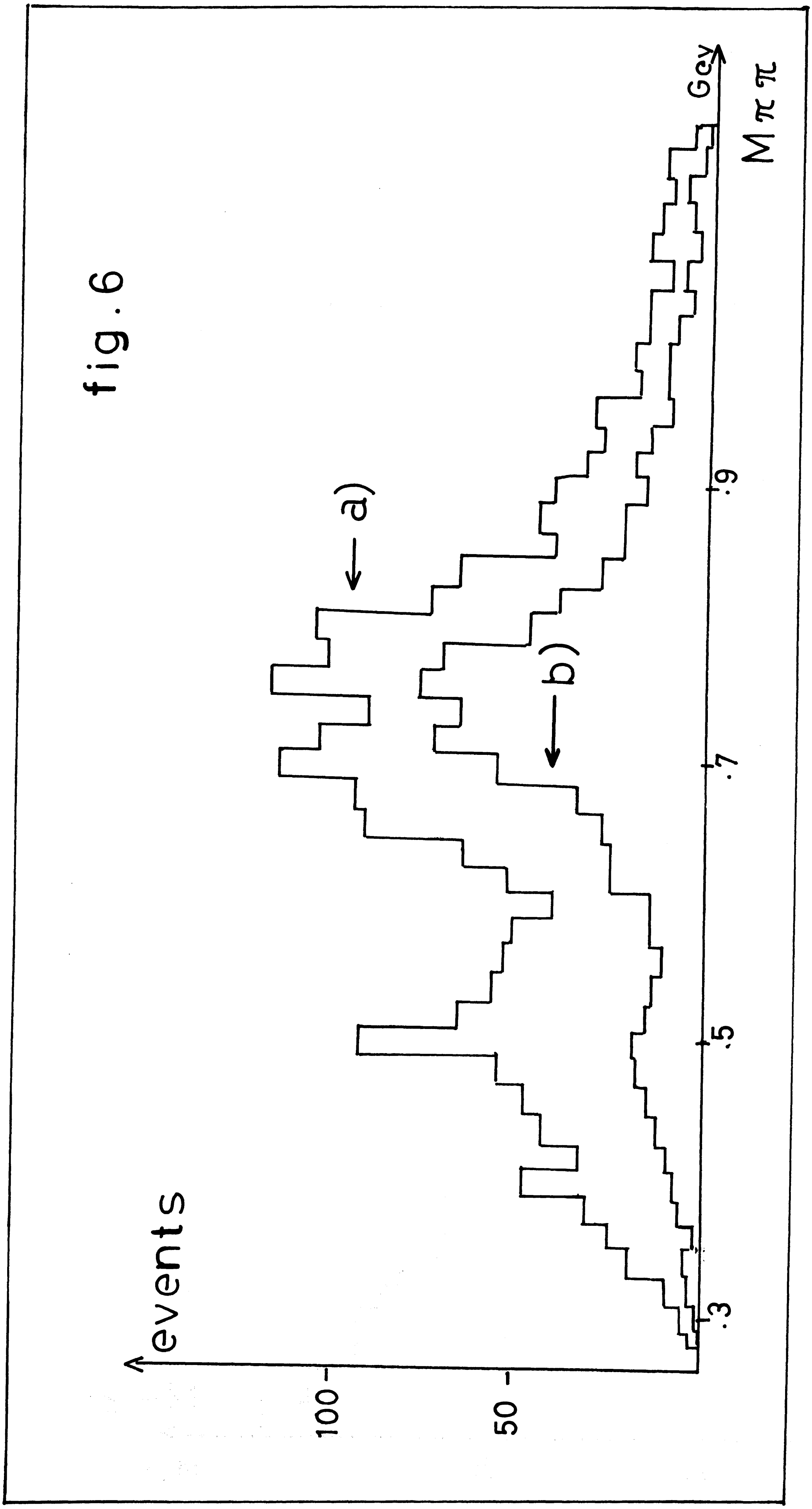


fig. 6

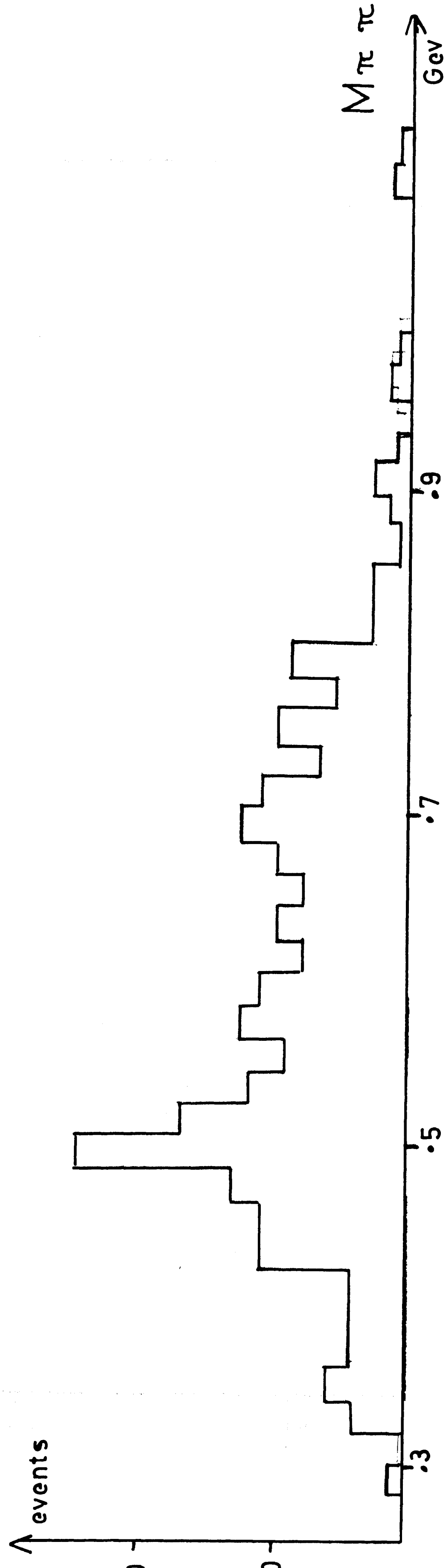


fig. 7

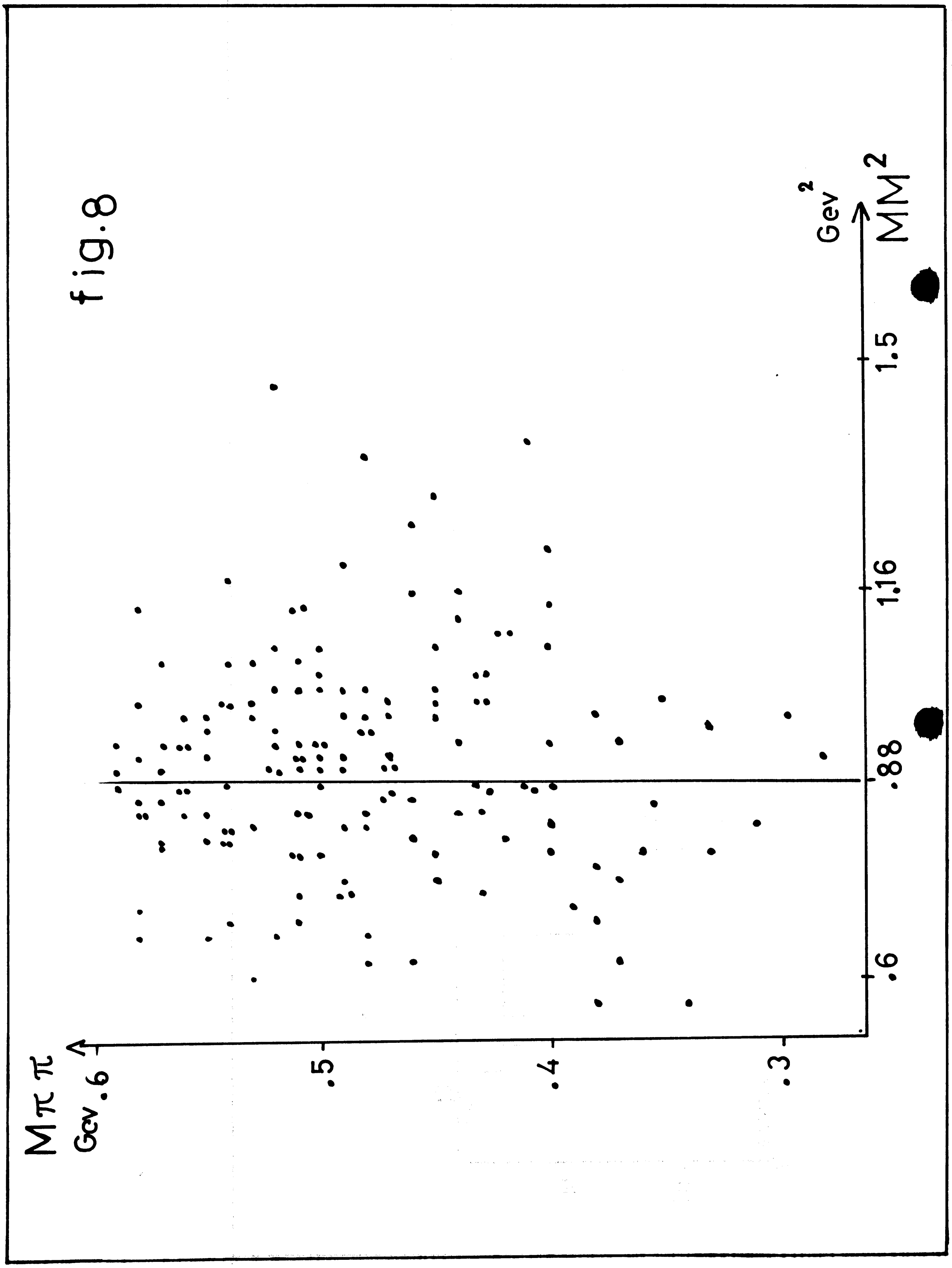


fig.8