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EVIDENCE FOR A NEW $\pi^+ \pi^-$ RESONANCE AT 1.67 GeV

CERN - Ecole Polytechnique Collaboration

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INTRODUCTION

Our two collaborations have investigated the $\pi^+ \pi^-$ mass system in the following reactions:

CERN, E.P. $\pi^+ d \longrightarrow p\ p\ \pi^+\ \pi^-$ at 6.0 GeV/c (in Saclay 81cm DBC)

O.M.S. $\pi^- p \longrightarrow n\ \pi^+\ \pi^-$ at 8.0 GeV/c (in EP HLBC with H_2 target).

These two reactions are charge symmetrical. Having observed comparable features in the 1.65 GeV region, we have decided to publish together.

The experimental analysis and results for each collaboration are presented separately and a common conclusion will summarize the situation.

1) C - E.P. Collaboration - π^+ d at 6 GeV/c

68.000 pictures have been taken at CERN with the 81 cm Saclay bubble chamber filled with deuterium.

From complete scanning, we have selected 1,262 events of the type $\pi^+ d \longrightarrow p p \pi^+ \pi^-$. This sample is made of 468 four-prongs (both protons visible) and 794 three-prongs (invisible spectator proton). Protons were identified by ionisation up to momenta of 1.3 GeV/c; this cut-off in the momentum recoil corresponds to a momentum transfer $\Delta^2 \geqslant 1.25$ (GeV/c)^2; we checked that only few events lie above that limit.

In the three-prong sample the fits are only one constraint. Further separation from events with additional π^0 was performed by checks on unfitted quantities taking into account the Hulten distribution of the unseen proton. Residual contamination is lower than 3 o/o and affects in no particular way the events lying in the mass region to be discussed in this paper.

The $\pi^+ \pi^-$ effective mass distributions for 3 and 4 prongs respectively show no significant differences; the two samples have been added. However, 4-prong events with spectator proton faster than .3 GeV/c were removed, since they can hardly be attributed to an interaction on a quasi-free neutron.

Fig. 1 shows the distribution of the 1,046 remaining events. Besides important ρ and f^0 productions an enhancement is observed at about 1.65 GeV. The shaded events have a momentum transfer Δ^2 lower than 0.2 (GeV/c)^2.

The enhancement cannot be attributed to a reflection of N^* production: when removing events in the N^* mass region (up to 1.6 GeV π-p mass), the enhancement remains.

The statistical significance of the peak, assuming a modified phase space weighted by the observed momentum transfer distribution, is of the order of three standard deviations, about 35 events above background.

The variation of the asymmetry parameter (F-B)/(F+B) with the effective two-pion mass is shown in Fig. 2. The general behaviour is quite as expected: the asymmetry is positive in the ρ region, it vanishes at the f^0 mass and then rises again; this rise corresponds to the predominance in the high mass region of a peripheral process for which the incident π^+ conserves most of its momentum. However, there is an indication that in the 1.6 GeV mass region the rise is perturbed: on the plot, one point lies off the otherwise smooth line by 2.2 standard deviations. This constitutes independent indication in favour of a resonance in that region.

Estimation of the cross section, is not an easy matter. The mass distribution after Δ^2 cut (shaded events Fig. 1) suggests that most events in the region 1.6 to 1.8 GeV belong to one single structure. This affords an upper limit estimation of the cross section $\sigma = 61 \pm 8$ μ barns (statistical errors). On the other hand, taking into account only the events above the modified phase space, we obtain a somewhat lower estimate of the cross section $\sigma \approx 35 \pm 9$ μb (35 events); assuming that resonant events are forward-backward symmetric, this value is confirmed from the angular distribution in the 1.6 - 1.8 mass region in which, in addition to a strong forward peak, about 40 events contribute to a flat distribution.

The central value of the mass is 1.66 ± 0.04 GeV (the error includes possible systematic shifts due to the neighbouring f^o production and to the shape of the factorised phase space). Full width estimation is 0.17 ± 0.04 GeV.

I-spin 0,1 and 2 assignments for the postulated resonance, gives expected cross sections for the neutral mode (π^o π^o) which are respectively 1/2, 0 and 2 times the charged one; (i.e. 18 ± 5 0 , 70 ± 18 μbarn, using our lowest cross section estimation for the charged mode). No accumulation in the corresponding mass region was observed in the events of type $\pi^+ d \longrightarrow$ p p + neutrals (Ref.1), from which data we can infer an upper limit to the cross section of 35 μbarns. We therefore conclude that I-spin 2 is highly improbable.

2) OMS Collaboration - π^- p at 8 GeV/c

This experiment was performed in the EP heavy liquid bubble chamber[2] (100 x 50 x 50 cm), (B = 20.3 K gauss) used with a new technique: A liquid H_2 target[3] was mounted inside the chamber which was filled with C_2F_5Cl (X_o = 25 cm). The purpose of this was to combine the advantages of a pure proton target with high gamma detection efficiency ($\gtrsim$ 85 o/o). The incident 8 GeV/c π^- pencil beam, after traversing the target (20 cm long) escaped through a narrow vacuum tube. This tube allows a beam intensity sufficiently high to obtain one H_2 interaction per picture without confusing interactions in the liquid.

220.000 pictures were taken in these conditions. These pictures were completely scanned for beam interactions in the target and only two-prong events with no gammas and no stopping proton ($p \lesssim 650$ MeV/c) were considered. These events were geometrically fitted to find the interaction point. Those in hydrogen were then kinematically fitted to the two hypothesis:

$\pi^- p \longrightarrow \pi^+ \pi^- n$ - A

$\pi^- p \longrightarrow \pi^- p$ - B

Only events which fit A alone have been kept. Events which fit both hypothesis are 16 o/o of the total and have been rejected. In the final sample the number of A events thus missed is 7 o/o and there are less than 2 o/o elastic scattering remaining. This was estimated from the unfitted missing mass distribution and from the observed elastic events with stopping proton. Both types correspond to large mass events ($\gtrsim$ 2,000 MeV in most cases) and also large momentum transfer events. Thus this does not perturb our distribution of mass or asymmetry below 2 GeV.

The background of $\pi^- p \longrightarrow \pi^+ \pi^- n + X \pi^o$ events is also negligible ($\lesssim$ 2 o/o) due essentially to high γ detection efficiency.

Thus we are left with 604 events.

The $\pi^+ \pi^-$ invariant mass distribution for the total sample is plotted in Fig. 3a. We observe the ρ_o and f_o resonances and an enhancement at 1675 MeV. No indication of N^* production is observed, thus this effect appears not to be correlated to the N^*. By taking events with low momentum transfer ($\Delta^2 \lesssim 0.3$ GeV^2) essentially only background is removed (fig. 4a). The enhancement then corresponds to $\sim$ 2,5 standard deviations above the neighbouring intervals and to $\sim$ 3,5 standard deviations above a phase space curve modified by a factor $e^{-A\Delta^2}$ (A = 8.0 GeV^{-2}) and Breit-Wigner distributions for ρ_o and f_o (solid curve). The dotted curve contains in addition a Breit-Wigner distribution at a mass of 1675 MeV and with a width of 200 MeV. This curve fits reasonably well with a very low proportion of phase space.

Another indication is given by the distribution of the forward-backward asymmetry of the $\pi\,\pi$ scattering angle in the $\pi^+\,\pi^-$ CMS. This distribution (Fig. 3b, 4b) is consistent with previous results in the ρ_o and f_o region. After the f_o, the slow rise to 1 previously observed at lower energy[4] and expected from high energy diffraction effects is suddenly stopped as the asymmetry drops down in the region of the above mentioned enhancement, then climbing again at higher masses. In this region, the minimum of the asymmetry lies 2 to 3 standard deviations from the crest on either side and is compatible with zero.

The coincidence of these two phenomena in the same mass region supports the hypothesis of a new resonance, produced peripherally as ρ_o and f_o. Its parameters are found to be:

$$M = (1675 \pm 35)\ \text{MeV}$$

$$\Gamma = (200 \pm 50)\ \text{MeV}$$

$$\sigma\,(\pi^- p \rightarrow 1675 + n) = (100 \pm 25)\ \mu\text{b}.$$

CONCLUSION

The experiment described above show two striking common features in the $\pi^+ \pi^-$ system around 1,65 GeV: a peak in the mass spectrum and a discontinuity in the variation of the forward-backward asymmetry. (These two effects are experimentally uncorrelated). None of these observations alone has a very high statistical significance; however, their recurrence in experiments made at different incident energies and involving different techniques, appears sufficient to exclude any explanation based on statistical fluctuations. Besides, these energy independent effects concern events produced at low momentum transfer. Their most sensible explanation is to attribute them to a resonance peripherally produced which we propose to call g.

Mass and full width best estimations are:

$M = 1.67 \pm 0.03$ GeV $\qquad\qquad \Gamma = 0.18 \pm 0.04$ GeV.

Isospin 2 is ruled out with high probability from the upper limit estimate of the 2 π^0 decay cross-section in the π^+ d experiment. From lack of statistics, both isospin 0 and 1 remain possible. We have for the time no information concerning spin and parity.

Note

The Saclay Orsay Bologna Collaboration has studied the 4.5 GeV/c π^+ interactions on deuterium. Features closely ressembling ours are observed, although the incident energy lies just above the 1.65 GeV production threshold. We kindly thank the authors for this information.

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FIGURE CAPTIONS

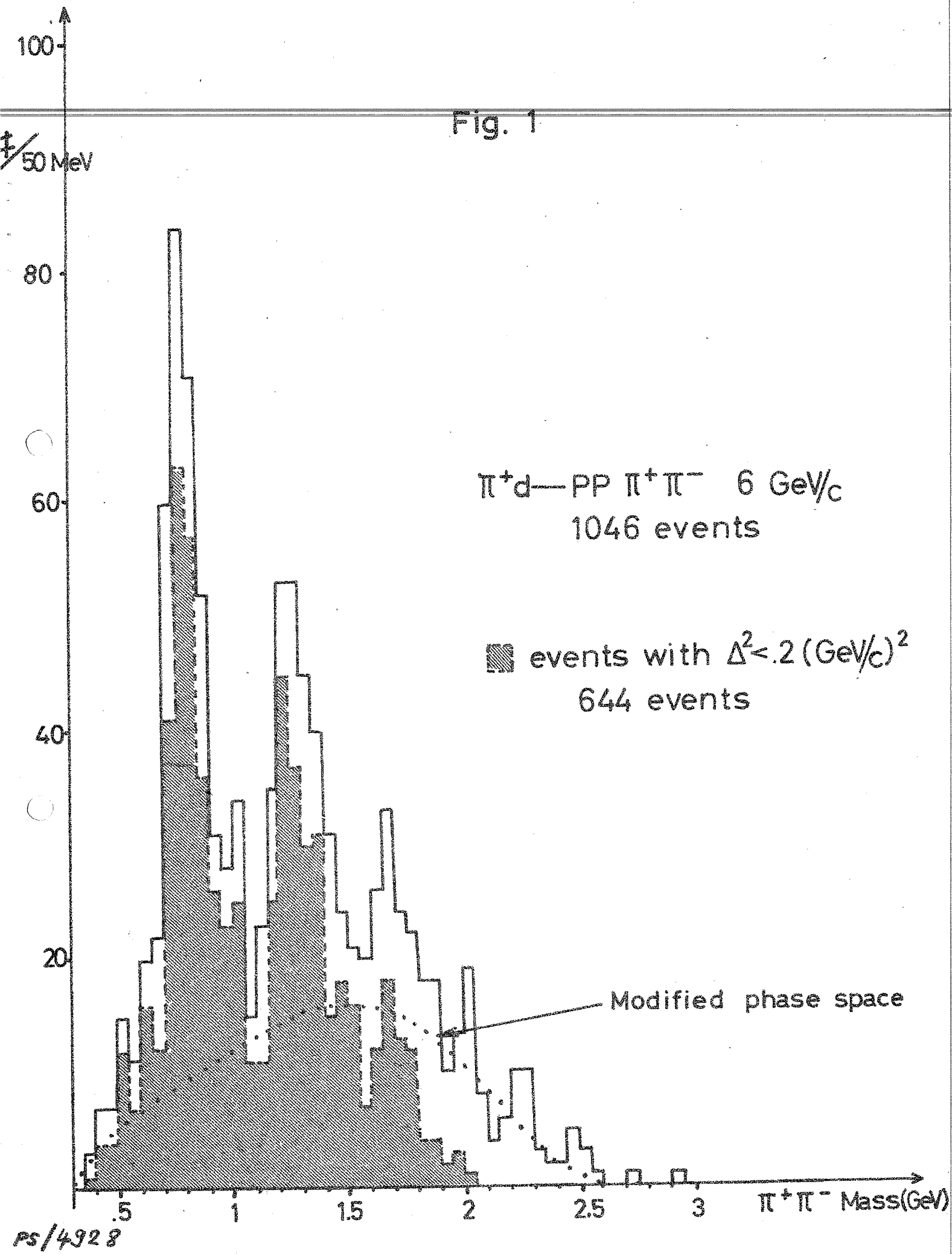
Fig. 1 Invariant mass $\pi^+ \pi^-$ in reaction $\pi^+ d \rightarrow p\ p\ \pi^+\ \pi^-$.
The shaded area corresponds to a quadrimomentum transfer to the $\pi^+\pi^-$ system lower than 0.2 $(GeV/c)^2$.

Fig. 2 Forward-backward asymmetry parameter of the outgoing π^+ in the $\pi^+\pi^-$ c.m. system, relative to incident π^+.

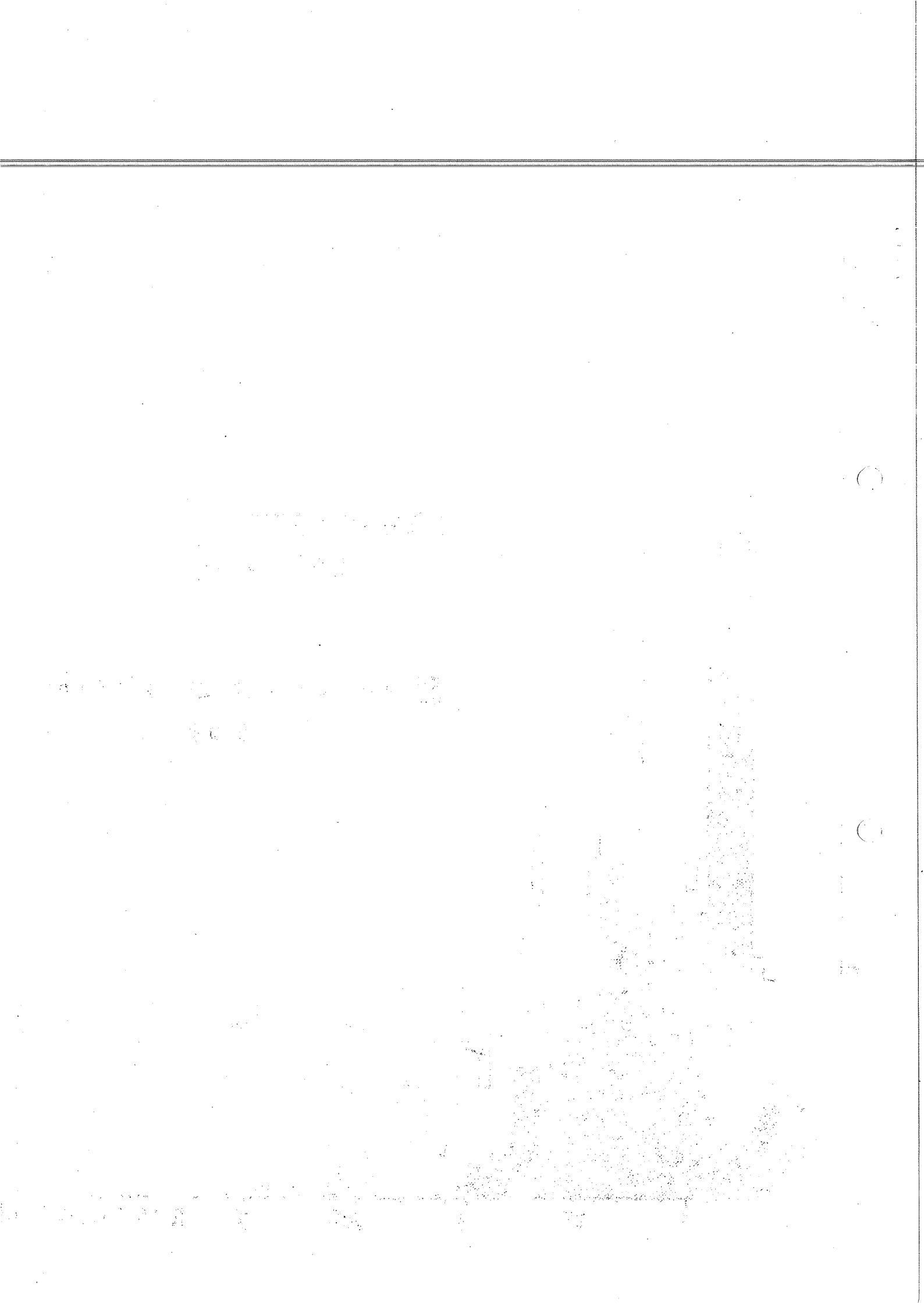
Fig. 3 Total sample
a) $\pi^+\pi^-$ mass plot for the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$
b) Forward-backward asymmetry of the outgoing π^- in the $\pi^+ \pi^-$ c.m. system relative to incident π^-.

Fig. 4 $\Delta^2 < 0.3\ (GeV)^2$, same distributions as Fig. 3.

Fig. 1


A
100
80
60
40
20
ℓ/50 MeV
π⁺d—PP π⁺π⁻ 6 GeV/c
1046 events
events with Δ²<.2 (GeV/c)²
644 events
Modified phase space
.5
1
1.5
2
2.5
3
π⁺π⁻ Mass(GeV)

PS/4928



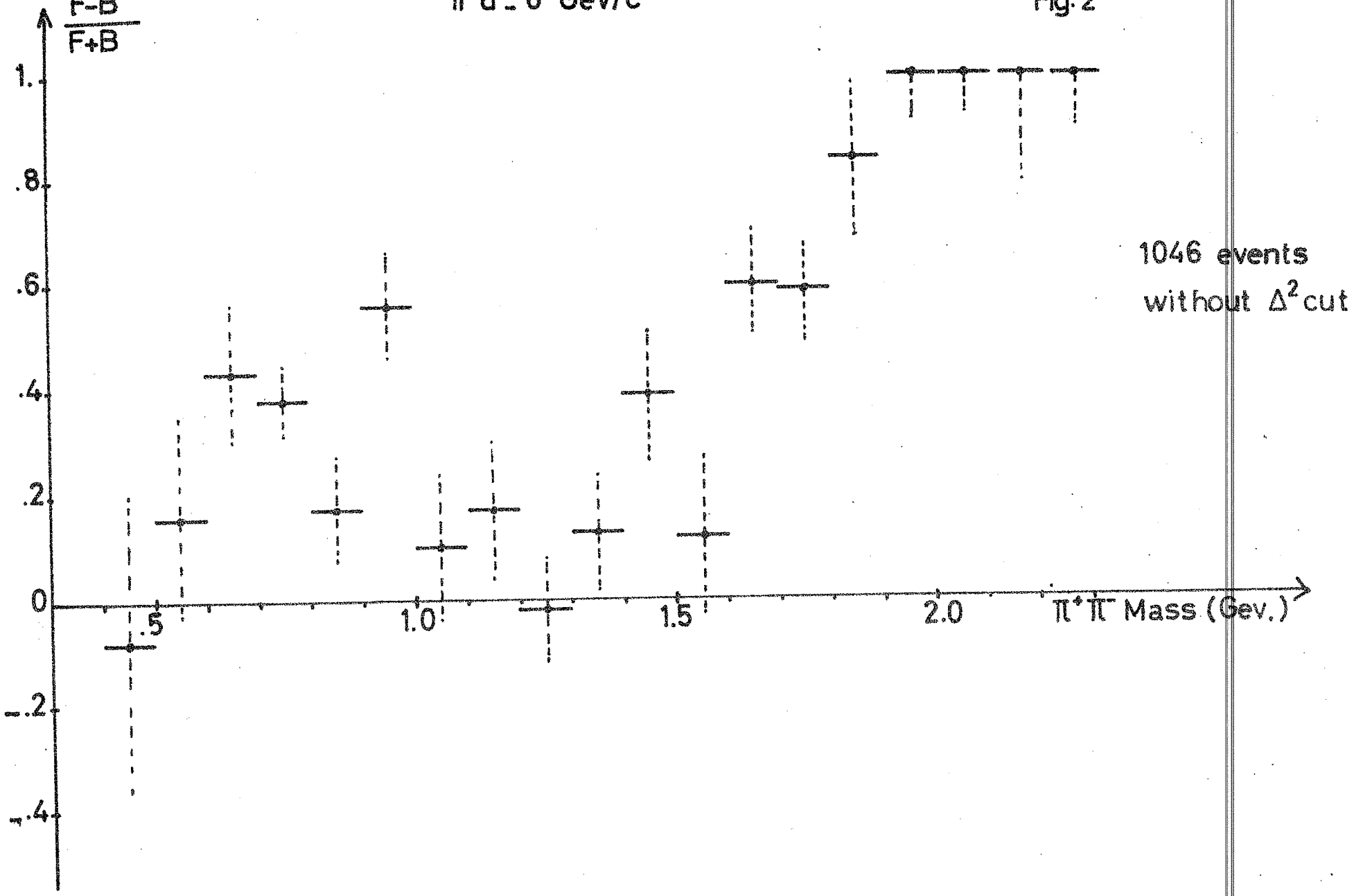
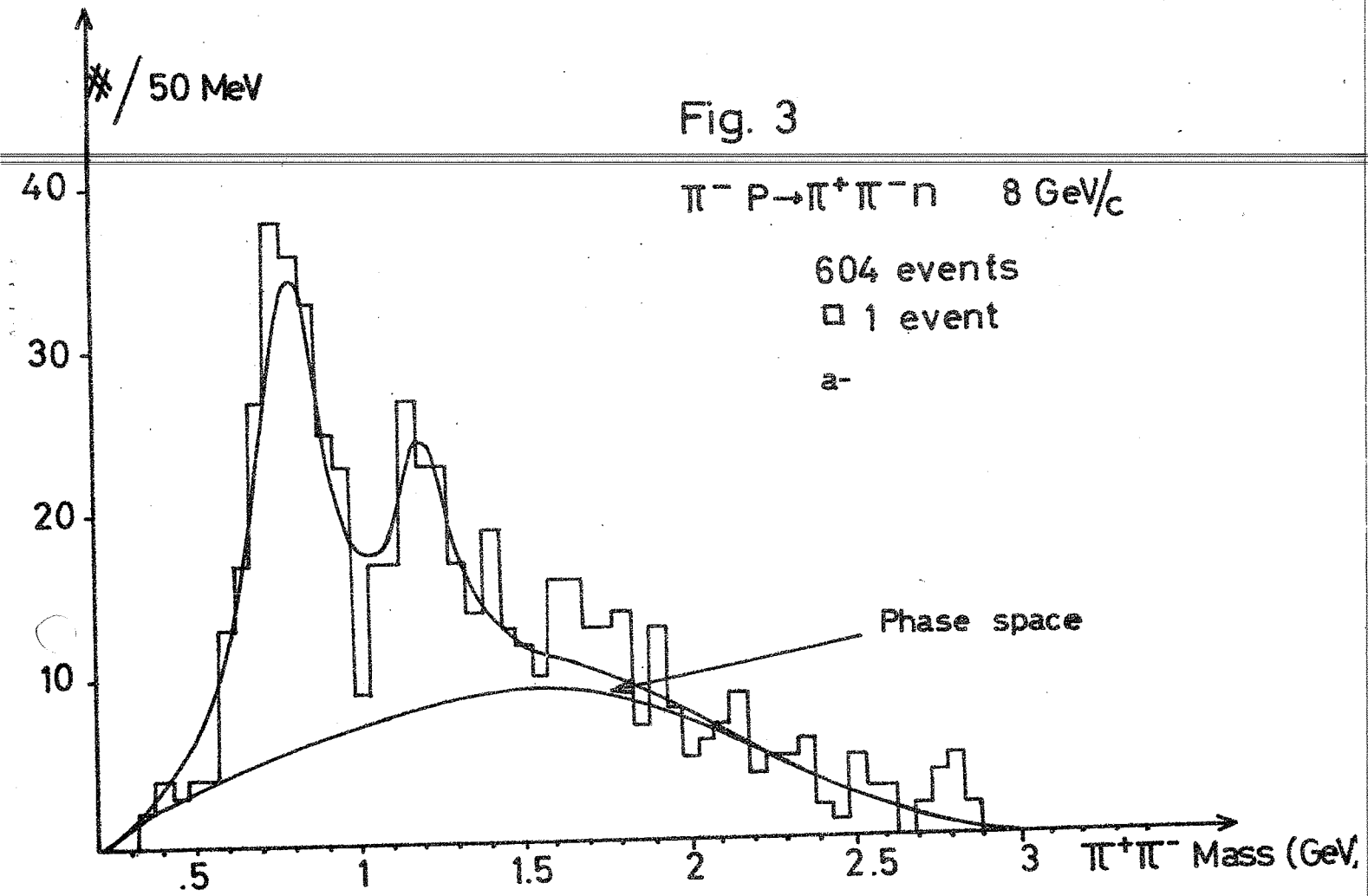
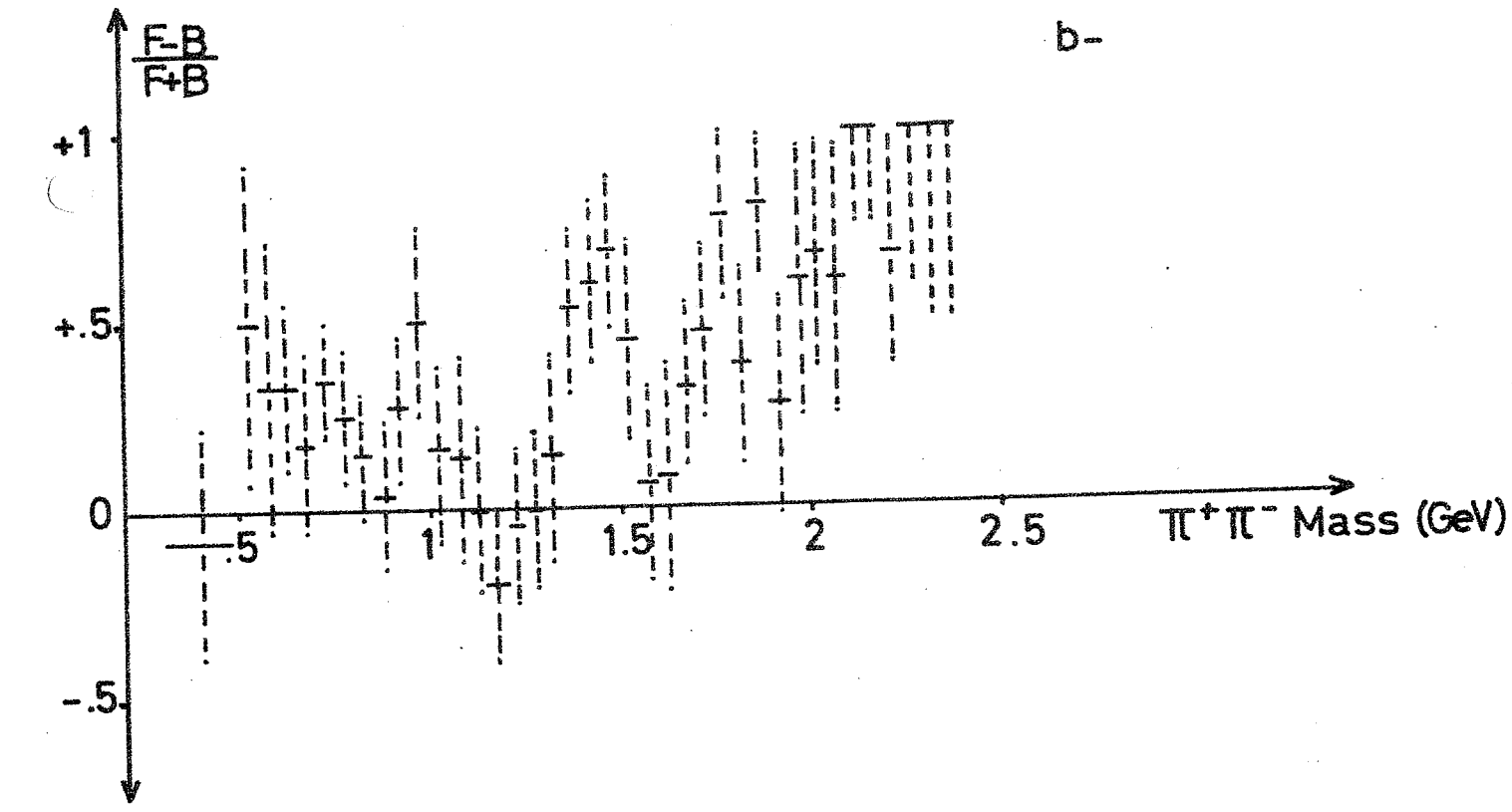

$\pi^+ d$ _ 6 Gev/c
Fig. 2
F-B / F+B
1.
.8
.6
.4
.2
0
-.2
-.4
.5
1.0
1.5
2.0
$\pi^+\pi^-$ Mass (Gev.)
1046 events
without Δ^2 cut

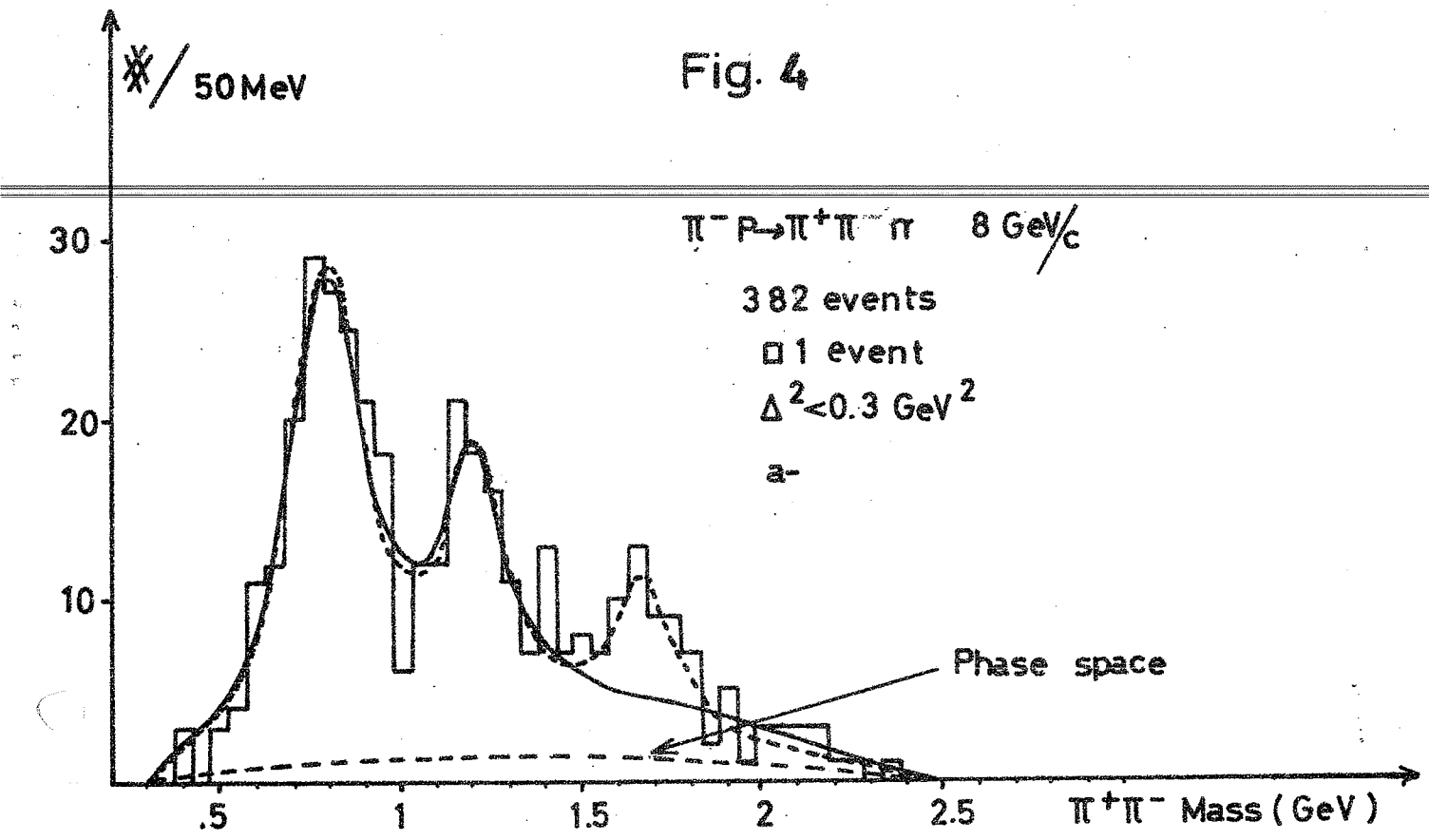
Fig. 3

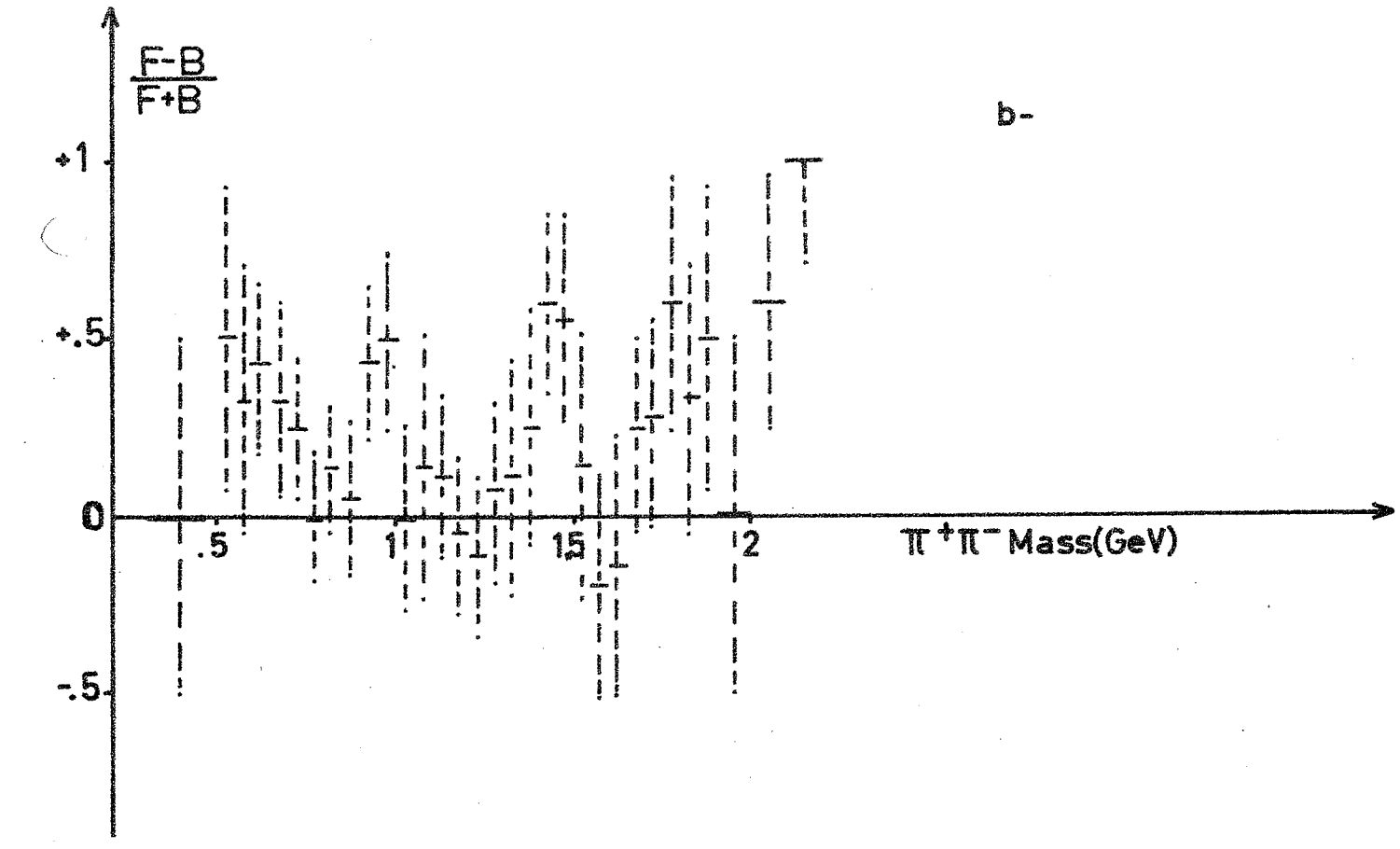

*/ 50 MeV
40
30
20
10
$\pi^- P \to \pi^+ \pi^- n$ 8 GeV/c
604 events
1 event
a-
Phase space
.5
1
1.5
2
2.5
3
$\pi^+\pi^-$ Mass (GeV)


F-B / F+B
b-
+1
+.5
0
-.5
.5
1
1.5
2
2.5
$\pi^+\pi^-$ Mass (GeV)

PS/4928

Fig. 4


*/ 50 MeV
30
20
10
$\pi^- P \to \pi^+ \pi^- n$ 8 GeV/c
382 events
□ 1 event
$\Delta^2 < 0.3$ GeV^2
a-
Phase space
.5
1
1.5
2
2.5
$\pi^+\pi^-$ Mass (GeV)


F-B / F+B
b-
+1
+.5
0
-.5
.5
1
1.5
2
$\pi^+\pi^-$ Mass(GeV)

PS/4928