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CHARGE EXCHANGE AND THE REACTION $\bar{p} + p \rightarrow \bar{n} + n + \pi^+ + \pi^-$ OF 3.0, 3.6 AND 4.0 GeV/c ANTIPROTONS

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Photographs from the 81 cm Saclay hydrogen bubble chamber operating in 3.0, 3.6 and 4.0 GeV/c separated antiproton beams from the CERN proton synchrotron were used to study the reactions:

$$\bar{p} + p \longrightarrow \bar{n} + n \qquad (1)$$
$$\bar{p} + p \longrightarrow \bar{n} + n + \pi^+ + \pi^- \qquad (2)$$

The slope of the t-distribution for charge exchange is shown to be less than that for elastic scattering and the value of $(d\sigma/dt)$ at $t = 0$ is shown to be about the same as for the reaction $p + n \rightarrow n + p$, as would be expected from some models of crossing symmetry. For (2) the production of double isobars is found to be much less frequent than in the related reaction $\bar{p} + p \rightarrow \bar{p} + p + \pi^+ + \pi^-$, possibly due to the requirement of exchanging 2 units of charge in the former case. An enhancement is observed in the $(n\pi^+\pi^-)$ and $(\bar{n}\pi^+\pi^-)$ systems which could be attributed to the 1688 MeV isobar which is shown to decay partially by the (3/2,3/2) isobar.

68,000 photographs of 3.0 and 3.6 GeV/c antiprotons were scanned twice for reactions (1) and (2) and, in addition, 19,000 photographs of 4.0 GeV/c were scanned twice for reaction (2). Events with associated K-mesons were rejected. 578 neutral "stars" with an odd number of prongs were found downstream from a zero or two-prong antiproton interaction. Reactions (1) and (2) must be separated by measurement and

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simultaneous kinematic fit of interaction and star, from the reactions where one or more additional π^0 are produced at the interaction, and from the spurious events arising by the chance coincidence of an anti-proton interaction in the chamber and of a star produced by an anti-neutron coming from outside.

An important feature of the analysis was the use of the reaction

$$p + \bar{p} \longrightarrow p + \pi^- + \bar{n} \qquad (3)$$

previously reported[1]. Events of reaction (3) which had an anti-neutron star apparently associated with them, were used in two ways: (a) as a measure of the detection efficiency of anti-neutrons for the various types of anti-neutron reactions and (b) a possible contamination in the charge exchange reaction of events with additional neutral pions was evaluated by amputating the two charged tracks of the proton and π^- and then attempting a fit of the resulting zero prong plus anti-neutron star to the charge exchange reaction.

Details of the procedure and of classification of the antiproton and antineutron interactions are reported elsewhere[2]. It is shown that the contamination of reactions (1) and (2) by similar reactions with an additional π^0 is less than $10^0/o$. Finally, 30 events of reactions (1) and 91 events of reaction (2) were used.

The charge exchange cross-section was found to be 2.0 ± 0.6 mb and a cross-section of 2.0 ± 0.7 mb was obtained for reaction (2).

The distribution of $-t$, the square of the four-momentum transfer, are shown in Fig. 1 for the elastic[3] and the charge exchange scattering of antiprotons as obtained in the present experiment. It can be seen that the charge exchange cross-section has a much broader forward peak. At 1.61 GeV/c[4] similar results were found.

A one-pion exchange model calculation with inclusion of absorption effects, has been made by Kingland[5] who found good agreement with the present experimental results, as can be seen in Fig. 1. Also, the energy dependence of the charge-exchange cross-section agrees reasonably with the predictions of one-pion-exchange model (Fig. 2).

In Fig. 1, is also shown the differential cross-section for the neutron-proton charge exchange reaction $p + n \rightarrow n + p$ studied by Palevsky et al.[6]. It can be seen that in the limit of small $-t$ values, the differential cross-sections tend to become equal. Such behaviour of these two processes at high energy was predicted by Bialas and Czyzewski[7] on the basis of crossing symmetry and analycity of amplitudes.

Reaction (2) may be compared with the reaction

$$\bar{p} + p \longrightarrow \bar{p} + p + \pi^+ + \pi^- \tag{4}$$

which is dominated by the production of the isotopic-spin-favoured combinations $(p\pi^+)$ and $(\bar{p}\pi^-)$ of the (3/2,3/2) isobar. Thus, reaction (4) proceeds through double isobar production[8][9]

$$\bar{p} + p \longrightarrow N^{*++} + (\overline{N^{*++}}) \longrightarrow \bar{p} + p + \pi^+ + \pi^- \tag{5}$$

in 55°/o and 58°/o of the cases for 3.25 and 3.6 GeV/c incident antiprotons, respectively. For reaction (2), the $(n\pi^-)$ and $(\bar{n}\pi^+)$ states of the isobar are similarly favoured by isotopic spin. They are indeed found as shown by Fig. 3A. A fit to a Breit-Wigner distribution and a phase space background indicates that 43 ± 10°/o of the events proceed via the production of one isobar. No corresponding enhancement is found in the $(n\pi^+)$ and $(\bar{n}\pi^-)$ effective mass distributions, these combinations having a smaller contribution of the $I = 3/2$ amplitude. A search for events showing double isobar production

$$\bar{p} + p \longrightarrow N^{*-} + \overline{(N^{*-})} \longrightarrow \bar{n} + n + \pi^+ + \pi^- \qquad (6)$$

gave a negative result (Fig. 3B). That isobars are produced frequently singly, but not doubly as in reaction (6) can be understood by observing that, whereas reaction (5) can proceed by the exchange of one unit of charge, reaction (6) requires the exchange of two. The small value of the cross-section for reaction (6) can be related by SU 3 to the smallness of Ω^- production cross-section by antiprotons[10].

The effective mass distribution for the $(n\pi^+\pi^-)$ and $(\bar{n}\pi^+\pi^-)$ combinations is shown in Fig. 4. There is a peak near 1700 MeV which may be assumed to be one or more of the isobars of mass about 1688 MeV[11]. A fit to the distribution indicates that in 48 $\pm$ 14°/o of the reactions an 1690 MeV isobar is formed.

A question of some interest is whether this isobar decays by a cascade process, that is $N^{**} \longrightarrow N^* + \pi \longrightarrow N + \pi + \pi$. In Fig. 5, the distribution of the $(n\pi^-)$ and $(\bar{n}\pi^+)$ effective masses for events in the 1690 peak is shown, which indicates that in about 50°/o of the cases the (3/2,3/2) isobar is formed. Taking events with $(n\pi^+\pi^-)$ and $(\bar{n}\pi^+\pi^-)$ masses higher and lower than the 1688 MeV isobar, there is appreciably less indication of decay by the formation of the $N^*_{3,3}$ isobar, but with the limited statistics available, this background is such that it is not possible to say what percentage of the 1690 MeV isobar events decay through the $N^*_{3,3}$ isobar. Evidence for this cascade decay was also found for other charge states of the 1688 isobar in two other experiments[12,13]. In reaction (3) no indication was found of production of ρ-mesons.

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Figure Captions

Fig. 1 Differential cross-sections as a function of $-t$, the square of the four-momentum transfer. The errors are statistical.

Fig. 2 Total change-exchange cross-section as a function of laboratory momentum. The line drawn is the $(p_{lab})^{-2}$ dependence of the cross-section predicted approximately by the O.P.E. model and normalised using the cross-section of 1.5 mb at 3.0 GeV/c obtained from the calculation of Ringland[5].

Fig. 3 (A) Effective mass distributions of all $(\pi^{+}\bar{n})$ and $(\pi^{-}\bar{n})$ combinations.
(B) If one of the $(\pi^{+}\bar{n})$ or $(\pi^{-}n)$ combinations has a mass near that of the $N^*_{3,3}$ isobar, then the effective mass of the other combination is plotted.

Fig. 4 $(\pi^{+}\pi^{-}n)$ and $(\pi^{+}\pi^{-}\bar{n})$ effective mass distribution.

Fig. 5 If the $(\pi^{+}\pi^{-}n)$ effective mass is near 1688 MeV, then the $(\pi^{-}n)$ effective mass is plotted and if the $(\pi^{+}\pi^{-}\bar{n})$ effective mass is near 1688 then the $(\pi^{+}\bar{n})$ effective mass is plotted.

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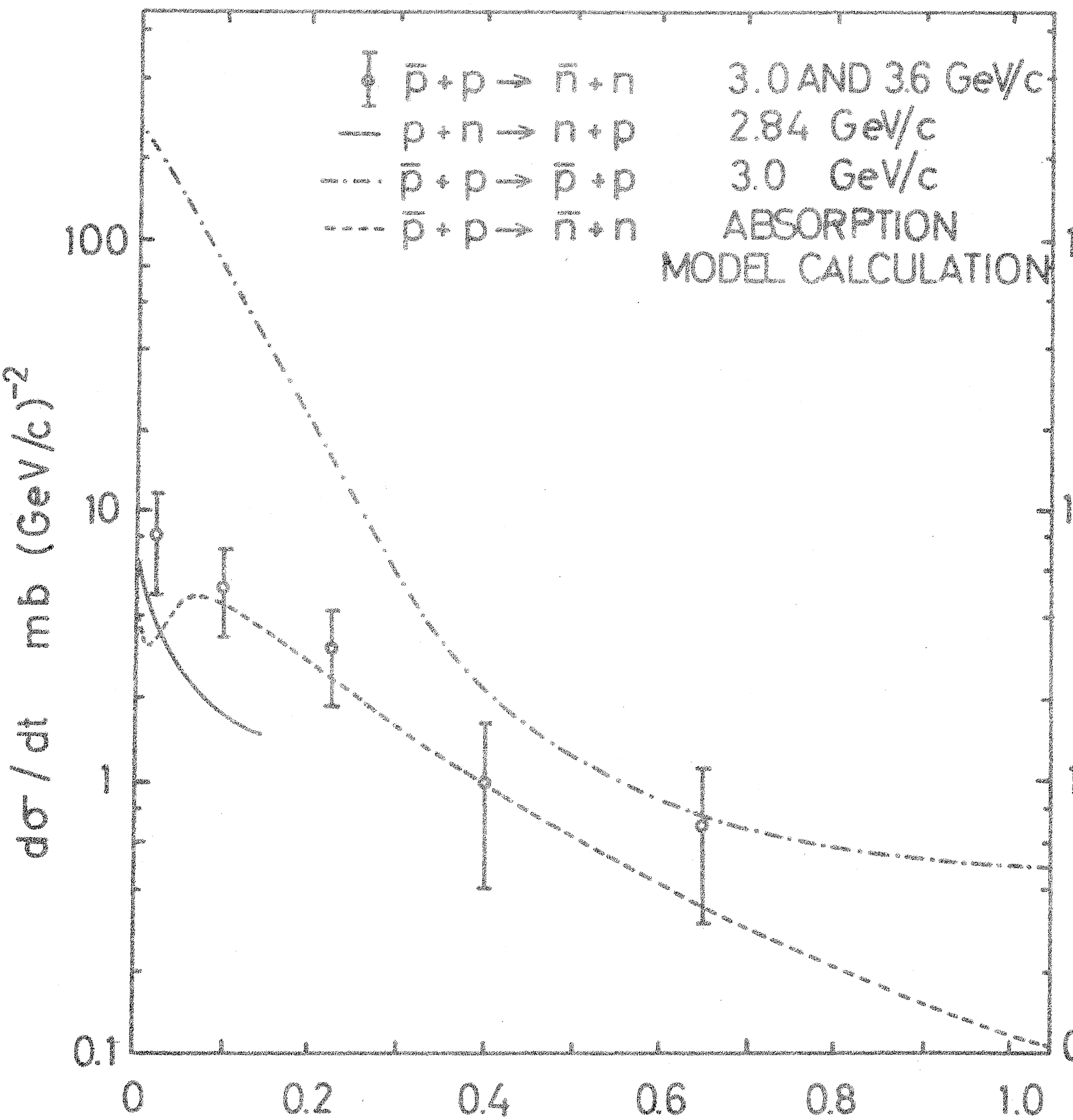
p̄ + p → n̄ + n 3.0 AND 3.6 GeV/c
p + n → n + p 2.84 GeV/c
p̄ + p → p̄ + p 3.0 GeV/c
p̄ + p → n̄ + n ABSORPTION MODEL CALCULATION
100
10
1
0.1
0
0.2
0.4
0.6
0.8
1.0
dσ / dt mb (GeV/c)$^{-2}$
-t , (GeV/c)^2

FIG.1

25611

80957

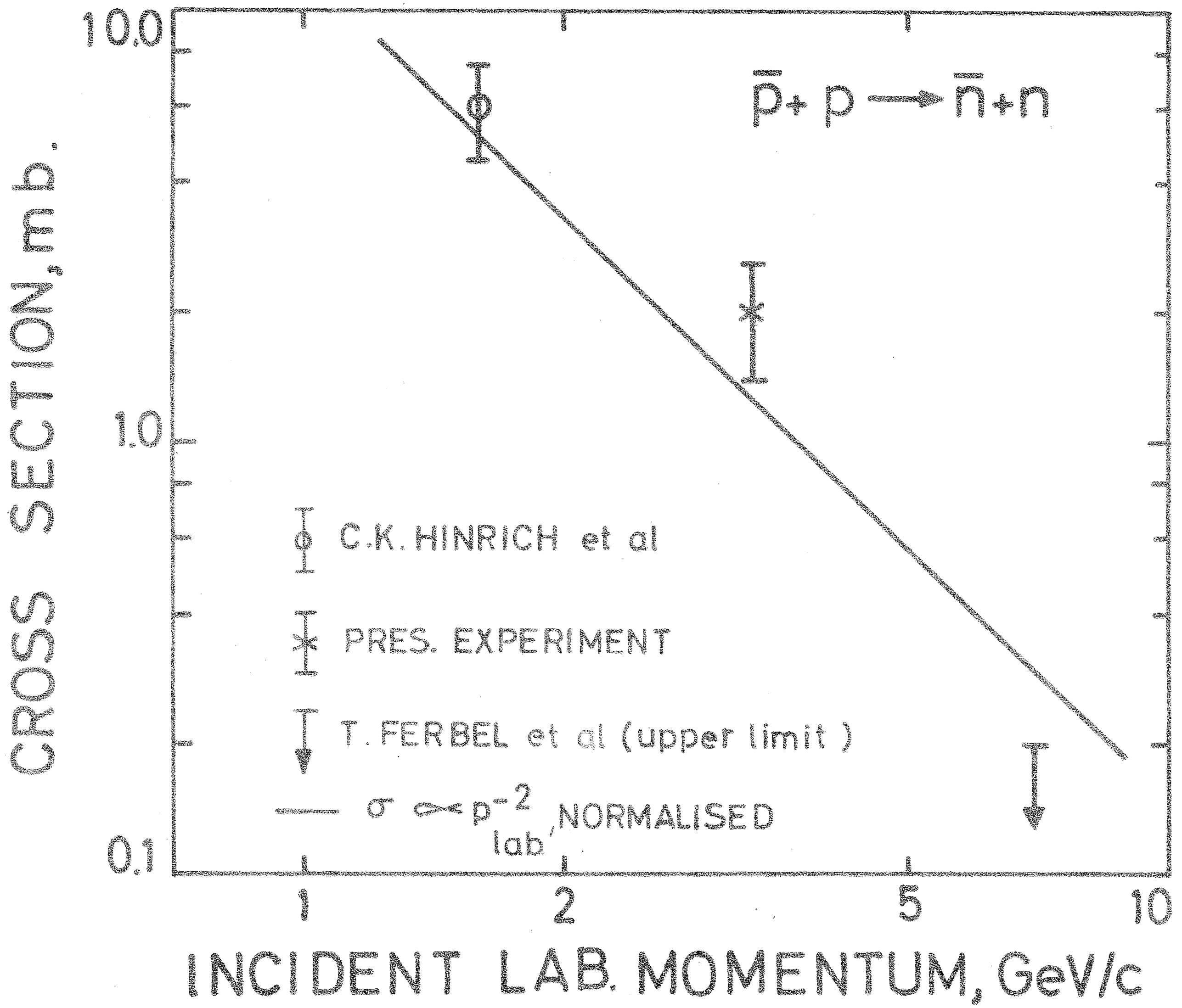

FIG.2 25608

$\bar{p}+p \longrightarrow \bar{n}+n+\pi^{+}+\pi^{-}$

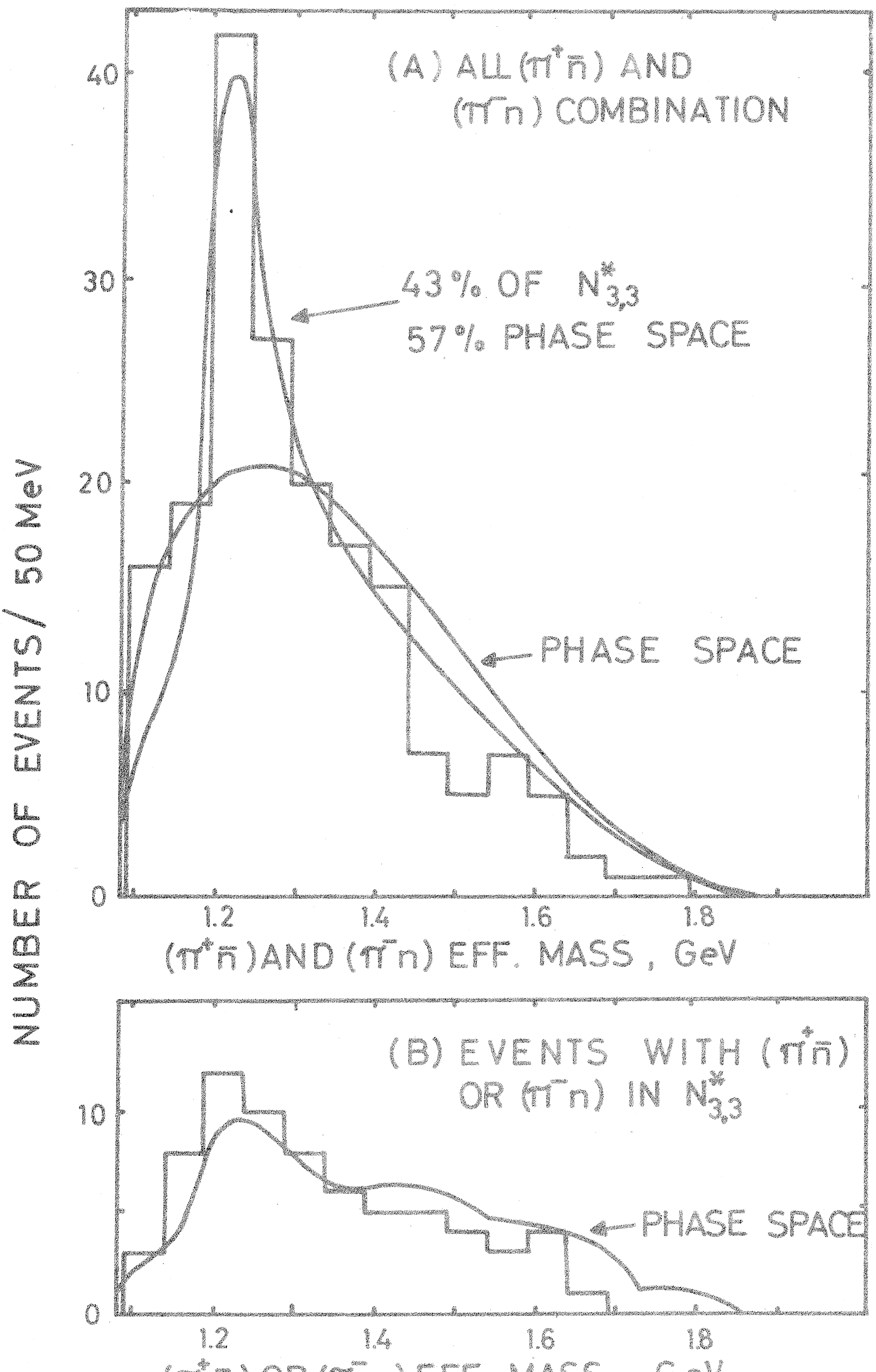

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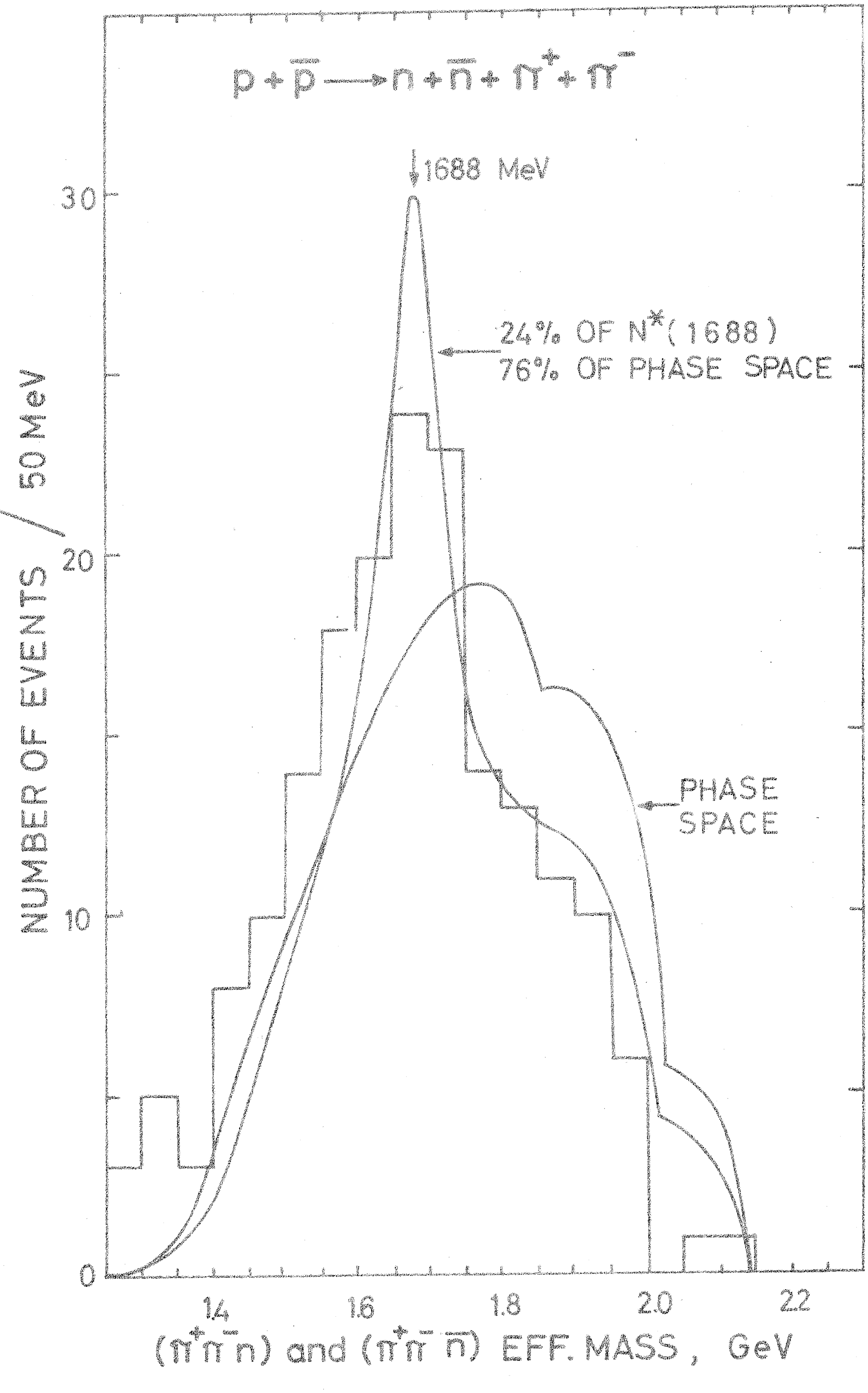
FIG. 3


$p + \bar{p} \longrightarrow n + \bar{n} + \pi^+ + \pi^-$
1688 MeV
24% OF N^*(1688)
76% OF PHASE SPACE
PHASE SPACE
NUMBER OF EVENTS / 50 MeV
0
10
20
30
1.4
1.6
1.8
2.0
2.2
$(\pi^+\pi^- n)$ and $(\pi^+\pi^- \bar{n})$ EFF. MASS , GeV

25617

FIG. 4

$p + \bar{p} \rightarrow n + \bar{n} + \pi \; + \pi^-$

IF $1.60 < \pi^+\pi^- n < 1.75$ GeV, PLOT $\pi^- n$
IF $1.60 < \pi^+\pi^- \bar{n} < 1.75$ G V, PLOT $\pi^+ \bar{n}$

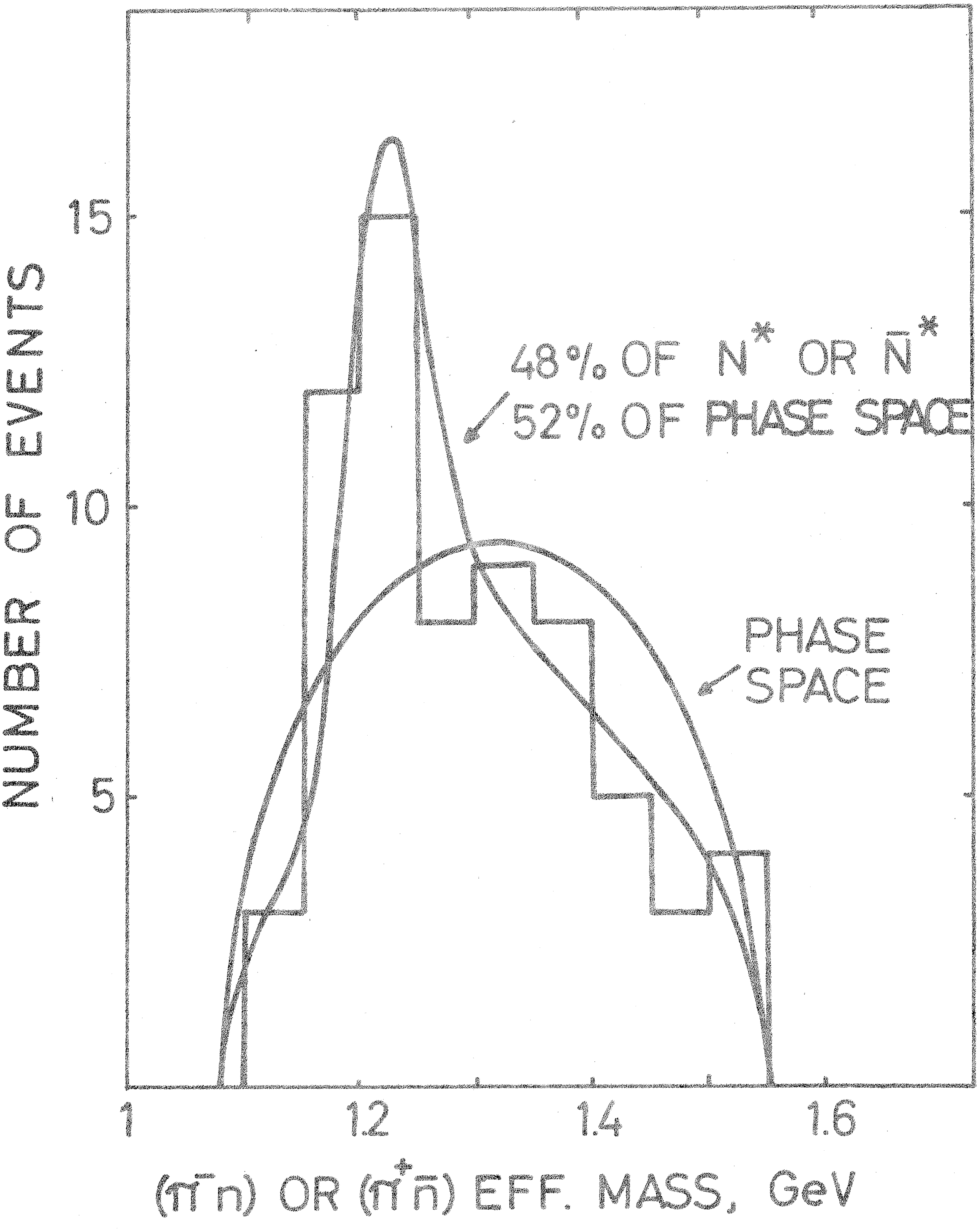


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FIG. 5