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SOME INFORMATION PROVIDED BY 600 MEV/C π - INTERACTIONS IN FREON

1. Introduction

The analysis of the events obtained in the CERN HLBC during the neutrino experiment have raised a number of questions concerning the behaviour of pions in heavy nuclei such as those contained in Freon CF_3Br [(1)]. In order to know what level of confidence to put on the identification and measurements of the neutrino events, it should be of interest to obtain some information on this matter.

The most important information would be those which could permit to evaluate the contamination of other processes in the non-pionic and one-pionic events, the nature of the "ambiguous events", etc... These are clearly the rates of various processes such as pion-interaction, charge-exchange and absorption, as well as a determination of the energy loss and momentum transfer.

The purpose of this note is, in this respect, to present some information obtained by an analysis of 600 Mev/c π - interactions in CF_3Br. These pictures obtained in 1962 in the CERN HLBC have already provided an interaction length, for all interactions and scatters larger than 2^o comprised between 70 and 102 cm [(2)].

This is thought to constitute a tool for neutrino picture analysis and must not be considered as a complete self-consistent experiment.

2. Rates of various processes of π - interactions

A number of 294 π - interactions occurring in a given fiducial volume of the chamber have been taken. The volume has been chosen such as to provide an optimum identification : positive and negative pions as well as protons clearly identified (at momenta $<$ 600 mev/c one is sure of recognizing protons from π^+, by range-momentum and by ionization), and the detection efficiency for π^o taken to be 1. (The probability of seeing at least one γ from a π^o is 1 in this volume).

The vents have been classified into the following categories :

2.1 So-called "pi-scattering", the scattering angle taken to be more than 10°, and no apparent difference in the primary and secondary momenta (by curvature measured on table with templates). Then it is a process :

$$\pi^- \longrightarrow \pi^- \qquad |\vec{p_i}| - |\vec{p_f}| \leqslant 100 \text{ Mev/c}$$

2.2 π^- interactions of the type :

$$\pi^- \longrightarrow \pi^- + n\,p \qquad (n = 0, 1, 2, ...)$$

in which, for the case $n = 0$ ($\pi^- \longrightarrow \pi^-$ only) the difference with 2.1 type is in the large difference in initial and final momentum ($p_i - p_f > 100$ Mev/c, by template).

2.3 π^- charge exchange of the type :

$$\pi^- \longrightarrow \pi^0 \text{ (1 or 2 } \gamma\text{'s)} + np \quad (n = 0, 1, 2 ...)$$

2.4 π^- interactions with creation of an additional π :

$$\pi^- \longrightarrow \pi^{\pm,0} + \pi^- + n\,p \qquad (n = 0, 1, 2 ...)$$

2.5 π^- absorptions giving no further π^- or π^0, but only recoil protons from the broken nucleus

$$\pi^- \longrightarrow n\,p \qquad (n = 0,1, 2...)$$

In table I are tabulated the rates of these processes together with their relative ratios.

TABLE 1 DESCRIPTION OF 294 π^- INTERACTIONS OF 600 MEV/C

Type		Nr. of events	rel. rates %	
$\pi^- \rightarrow \pi^- + n\ p$	type 2.1	75	.26	.57
	type 2.2	93	.31	
$\pi^- \rightarrow \pi^0 + n\ p$	ch. exch.	35	.12	
$\pi^- \rightarrow \pi^- + \pi^{\stackrel{+}{0}} + np$	π. prod.	14	.05	
$\pi^- \rightarrow n\ p$	absorption	77	.26	

3. Energy and momentum loss

3.1 A sample of these interactions has been measured in order to evaluate the momentum and energy losses. We have restricted the measurements to the two types described in 2 as 2.2 and 2.5 : they correspond to the events in which the accuracy of momentum measurements is optimum : no charge exchange interactions have been taken, as they are subject to important errors in the π^0 or γ - rays measurements. Actually the two processes of importance for our purpose are $\pi^- \rightarrow \pi^- + np$, that is types 2.1, 2.2, and π^- absorption, that is 2.5. The known ratios of 2.1 and 2.2 will allow to give the total information on 2.1 and 2, knowing only the measurement results of 2.2. (2.1 would be subject to larger errors than 2.2, due to those on the secondary pion of larger momentum).

The measured events correspond to a measured primary momentum the distribution of which is given in Fig. 1. Events with visible scatters before the interaction apex have been rejected from scanning as well as from measurements, then we know that there is no systematic effect to reduce the momentum (except for a few percent) other than the ionization loss.

The path crossed by the incident particles corresponds practically to a momentum loss of about 90 Mev/c. Then, one can take as a given value of the primary momentum 510 Mev/c. (The pions from the beam are known to come into the chamber with a well-defined momentum of 600 Mev/c).

One can then measure the secondary particles and calculate the "visible" energy and momentum of the interaction (the visible energy being : E_{vis} = total energy of secondary pion + kinetic energy of protons), and work out the energy and momentum losses :

$$\Delta E = E_i - E_{vis}$$

$$|\overrightarrow{\Delta p}| = |\overrightarrow{p_i} - \overrightarrow{p_{vis}}|$$ where p_i and E_i stand for the incident pion

The distribution s are given in Fig. 2 : a) for the 2.2 type

b) for the 2.5 type

3.2 To the results of the process of type 2.2, one can add the process of type 2.1 in the following way : one knows the relative rates of 2.1 and 2.2, and that in 2.1 : $\Delta E < 100$ Mev

$100 \leqslant |\Delta p| \leqslant 300$ Mev/c

From the observation of the angles in 2.1, one can put half events in 100 - 200 Mev/c and 200 - 300 Mev/c channels.

Then one gets the distributions for the whole process :

$$\pi^- \rightarrow \pi^- + n\,p \qquad (n = 0, 1, 2 \ldots) \text{ in fig. 3}$$

Fig. 4 reproduces Fig. 2a for the process

$$\pi^- \rightarrow n\,p \qquad (n = 0, 1, 2 \ldots)$$

It then can be seen from Fig. 3 and 4 that in the pi-interactions in which the π is not destroyed nor charge-exchanged, the energy is rather conserved with a non-negligible tail, and that the momentum is substantially changed mainly in its direction. Fermi motion can explain only part of it, i.e. events in the lower regions ($\Delta E < 30$ Mev, $|\vec{\Delta_p}| < 250 - 300$ Mev/c).

4. Unbalance and "missing neutrons"

One can try to explain the missing energy and momentum when they are no more compatible with Fermi motion by assuming that one (or more) missing neutron are responsible. One can compare the mass of a missing particle the momentum of which is $\vec{\Delta_p}$ and the kinetic energy ΔE. It is represented in Fig. 5.

As is seen for these unbalanced events (of type 2.2 and 5) one clearly cannot explain the unbalance by a unique missing neutron, which shows that the process occurring in the nucleus is complex.

A plot of longitudinal unbalance along the incident direction, versus the transverse one for those events is given in Fig. 6.

(The events of type 2.1, which represent about one half of the $\pi^- \rightarrow \pi^- + np$ interactions would lie in the circle of 300 Mev/c radius; for these there is no need for any missing particle, everything being compatible with Fermi motion).

5. Production of the pi-nucleon resonance N^* (1238 Mev)

If one takes into account the width of the N^* and the maximum Fermi motion then with the incident pions used in this experiment, one is practically at the limit for direct N^* production. However, one might expect that a fraction of the interactions can occur via N^* directly or after some slowing down of the pion.

One can try to detect N^* in the π- nucleon invariant masses, or in the "final state" mass M^* (if one takes the reaction $\pi^- + N \rightarrow M^*$, then one has $M^* = \sqrt{(E_{vis} + M)^2 - p_{vis}^2}$). Figures 7 and 8 represent these two distributions and do not show any concentration in the 1238 Mev region.

Another possible method is to consider the allowed region for the secondary π^- if produced via N^*. (The shaded region corresponds to 2.1 type).

One can say that it is not in contradiction with some N^* production with a forward - backward symmetry consistent with parity conservation, and the distribution in this case would be in $1 + 3 \cos^2 \theta^*$ which would correspond to a polarized N^* in a m = 1/2 state.

6. Acknowledgements

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D.C. Cundy
M. Paty

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Distribution : (open)

Scientific staff of N.P.A. Division

References

(1) Neutrino HLBC group : NPA/Int. 63-23; NPA/Int. 63-34; International Conference of Sienna 1963; (p. 555); preprint NPA/Int. 64-15

(2) K. Soop - Internal report to be published

Figure captions

1) Measured incident pion momentum
2) Energy and momentum releases for measured events
3) Energy and momentum losses for $\pi^- \rightarrow \pi^-$ + n p interactions
4) Energy and momentum losses for π^- absorptions
5) Mass of "missing byryon" distribution
6) Longitudinal vs transverse momentum unbalance
7) Pi-proton invariant mass distribution
8) Final state mass M^* distribution
9) Momentum of secondary pion distribution

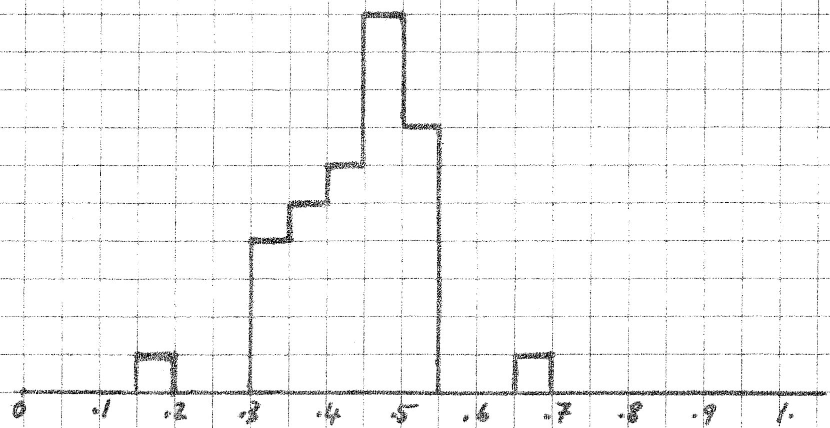

FIG 1 – MEASURED INCIDENT MOMENTUM

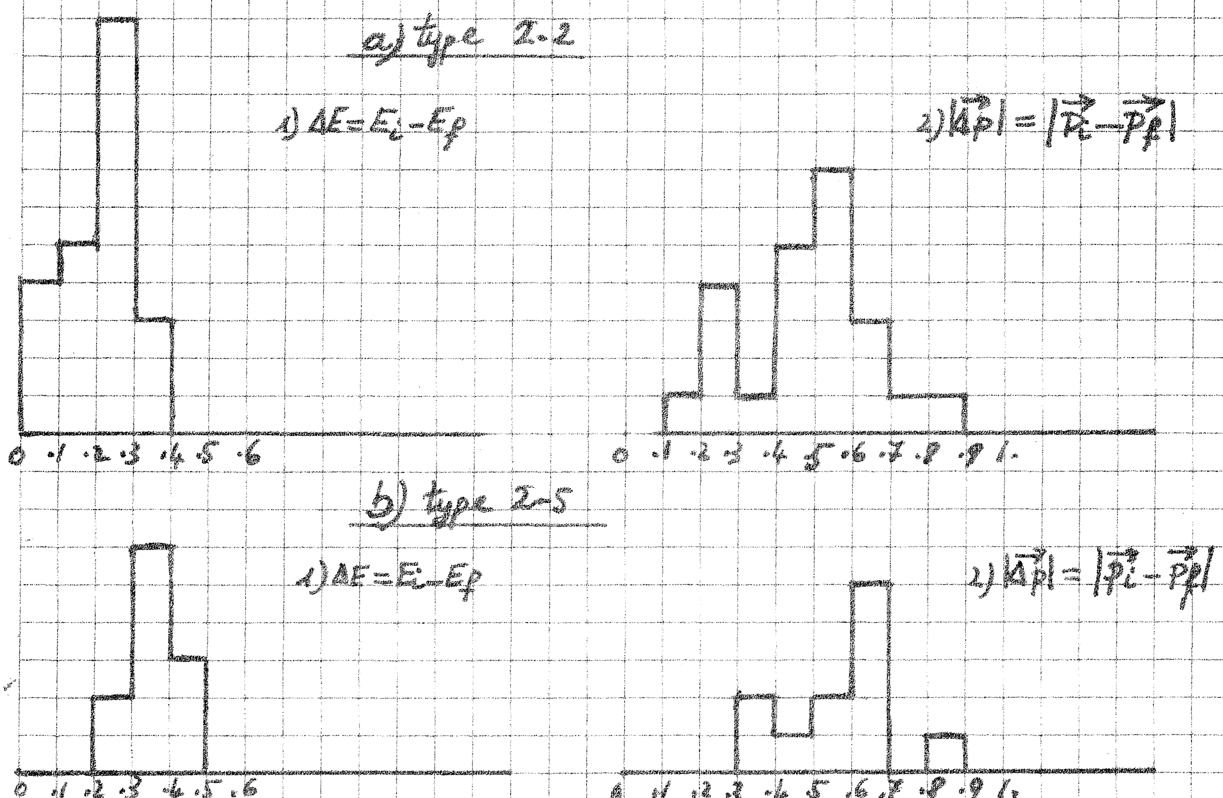

FIG 2 – ENERGY AND MOMENTUM RELEASE
FOR MEASURED EVENTS WITH FIXED $P(\pi)$

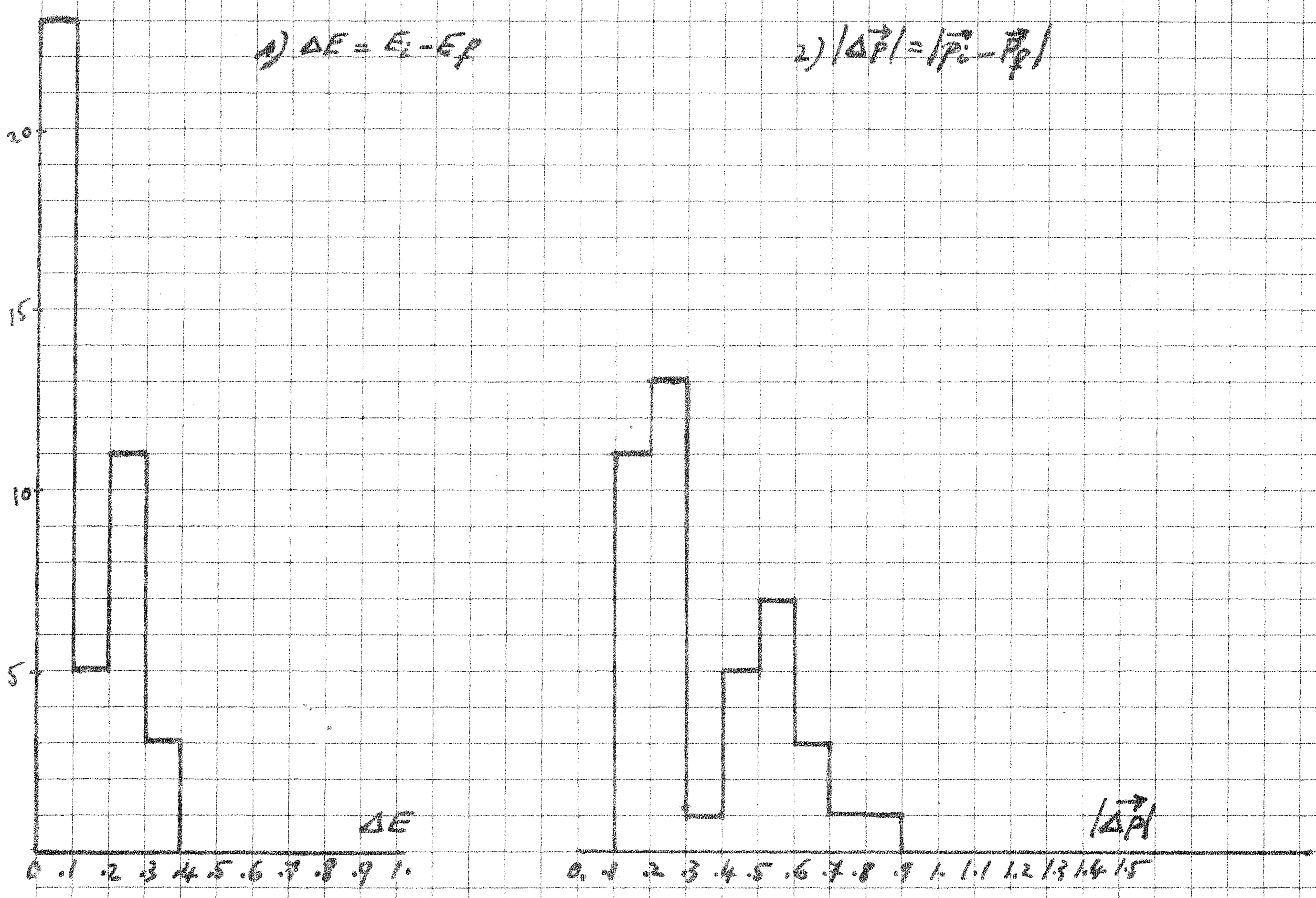

FIG 3 - ENERGY AND MOMENTUM LOSSES IN π^- INTERACTIONS OF THE TYPE $\pi^- \to \pi^- + np$.

FIG 4 - ENERGY AND MOMENTUM LOSSES IN π^- ABSORPTIONS (OF THE TYPE π^- + nucleus $\to$ n protons)

FIG 5 – MASS OF "MISSING BARYON" DISTRIBUTION FOR MEASURED EVENTS

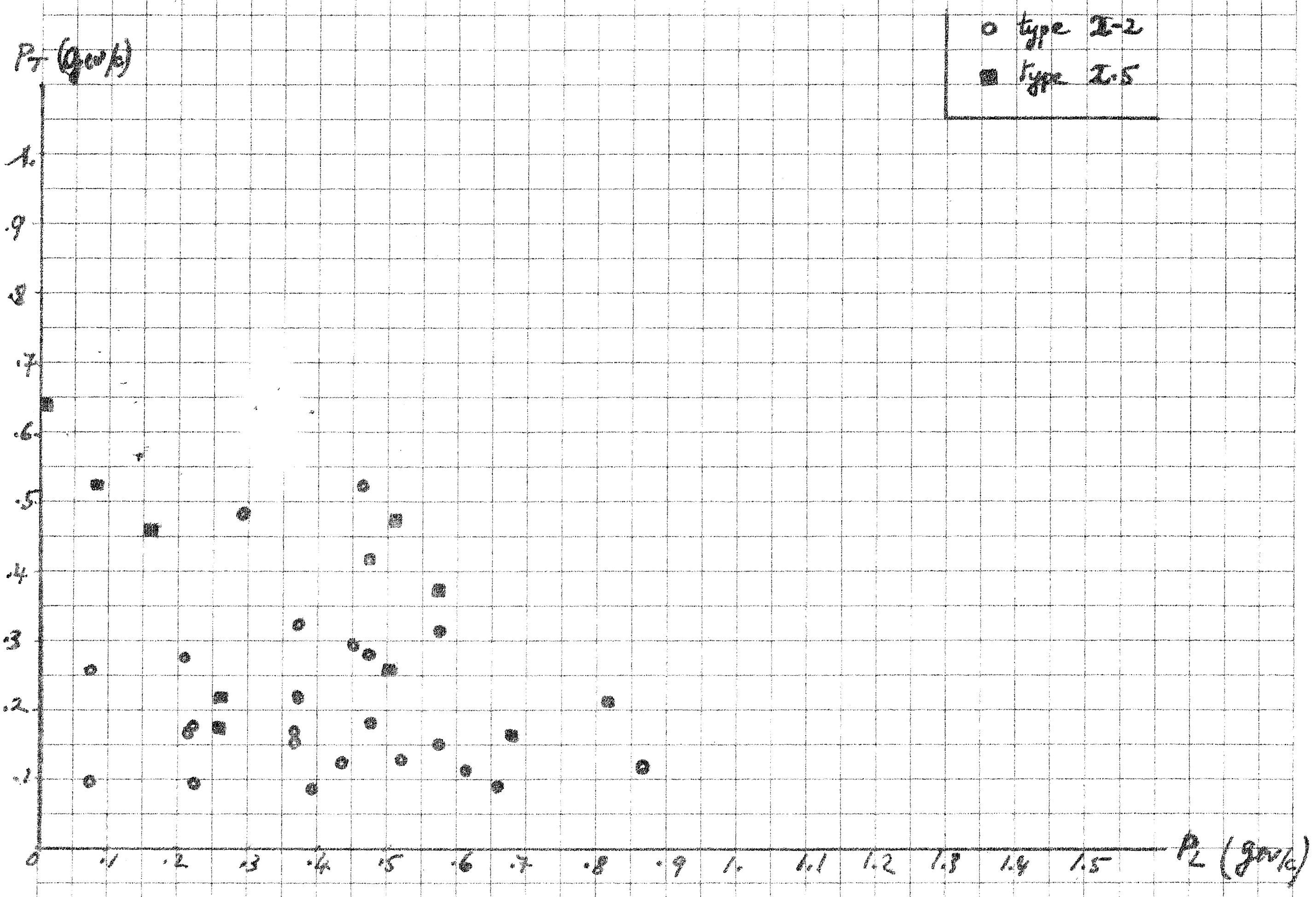

FIG 6 – PLOT OF LONGITUDINAL VS TRANSVERSE MOMENTUM UNBALANCE (MEASURED EVENTS)

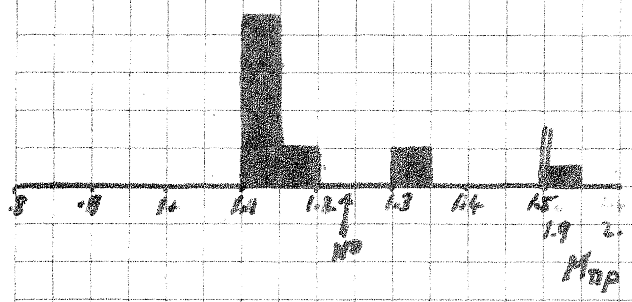

fig 7. PI- PROTON MASS

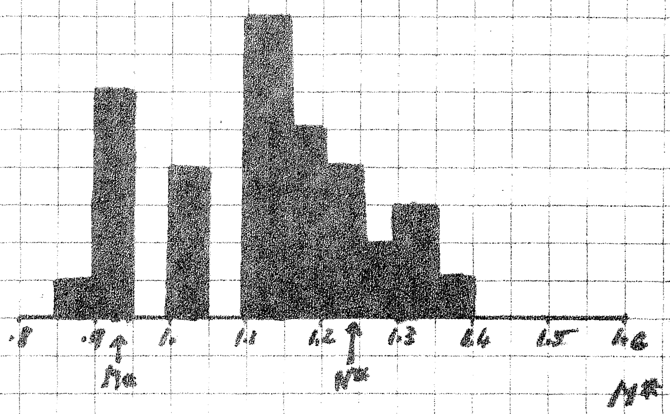

fig 8. FINAL STATE MASS M*

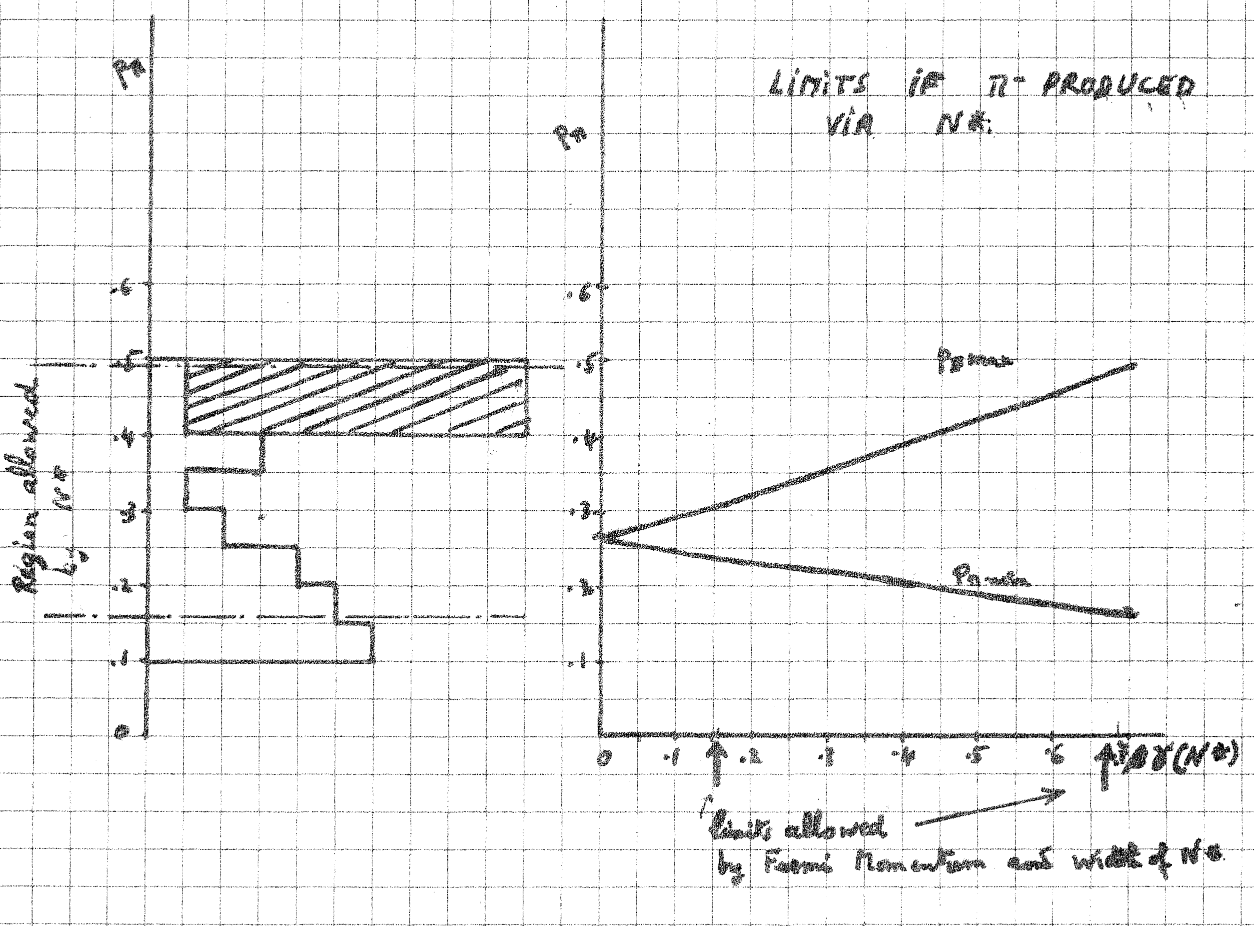

fig 9. MOMENTUM OF PRODUCED PI -.