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HYPERON AND KAON PRODUCTION BY 24.5 GeV/c PROTONS ON PROTONS

by

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Abstract

An analysis is given of strange particle production in collisions of 24.5 GeV/c protons with protons (c.m.s. total energy = 6.72 GeV). It is based on 50'000 pictures taken with the CERN 30 cm hydrogen bubble chamber. Comparison is made with an experiment on π^- - p interactions at 16 GeV/c in the same chamber. The low transverse momenta previously found are confirmed - only positive hyperons have high transverse momenta. Partial cross-sections are given.

Introduction

Strange particle production in high energy proton-proton collisions has been studied using the CERN 30 cm hydrogen bubble chamber (in a magnetic field of 15.5 kg). The chamber was exposed in a proton beam of momentum 24.5 ± 0.6 GeV/c. This momentum was calculated from the geometry of the beam and was verified by floating wire measurements. The beam consisted of protons scattered at small angles ($\sim$40 mr) from an aluminium target. Because of the small angle, the beam passed through the fringing field of several magnet sections giving a marked focusing effect. The intensity was chosen to give $\sim$10 protons/picture. There was no appreciable contamination.

A total of 50'000 pictures were taken of which 37'000 were studied at CERN and 13'000 in Pisa. The analysis was done in the same way as in the study of strange particles production in hydrogen by negative π mesons of 16 GeV/c[1]. The films were scanned twice and the scanning efficiency assuming random loss of events was 99 o/o for V^0 and 85 o/o for $V^{\pm}$. The results of identification are shown in Tables 1 and 2. No antihyperons or well identified Ξ^- were found.

TABLE 1

Identification of the observed neutral strange particles

	Λ^0	K^0	$\tilde{\Lambda}^0$	K or Λ	K or $\tilde{\Lambda}$	Λ^0 or ep	Λ^0 or ep	K or ep
CERN	39	118	0	30	9	7	5	1
						(taken as electron pairs)		
PISA	16	40	0	17	6	(not recorded)		

TABLE 2

Identification of the observed charged strange particles

	Σ^+_π	Σ^+_p	Σ^-_π	K	Not identified
CERN	61	11	22	9	6
PISA	24	4	9	1	4

Selection of unbiassed sample of neutral V particles

The p-p system is symmetrical so we need to consider only one hemisphere in the production c.m.s. The backward hemisphere corresponds to slower particles in the laboratory system, which are easier to detect and measure. This suggests using only the backward hemisphere.

For Λ^0 particles the efficiency may also depend on θ^{**}, the proton emission angle in the decay c.m.s. Table 3 shows a splitting of events into forward and backward emission.

TABLE 3

Distribution of Λ^0 particles in the production and decay c.m.s.

No. of events	Backward production in p-p c.m.s. $\cos\theta^{**} < 0$	$\cos\theta^{**} > 0$	Forward production in p-p c.m.s. $\cos\theta^{**} < 0$	$\cos\theta^{**} > 0$
Observed	31	18	1	10
Corrected for decay probability	44.9	26.1	2.4	44.5
Total	71.0		46.9	

θ^{**} is the angle of the decay proton in the Λ^0 c.m.s.

Because of symmetry in p-p c.m.s. the four numbers in the middle row should be equal, provided there is no longitudinal polarization.

There is a definite indication of loss of events with backward proton decay and forward production corresponding to a small decay angle in the laboratory system*. There is also a slight indication of loss of events with cos $\theta^{**} > 0$ and backward production. This latter effect could be understood, because the Λ^0 decay in this region has a wide opening angle and rather short π^- track. However, no such effect was found in Λ^0 produced in interactions of 16 GeV/c π^- mesons (1), suggesting that the observed asymmetry is due merely to statistical fluctuation.

These effects can be seen in greater detail in Fig. 1, where one should find vertical bands with uniform population since $\vec{P}_{lab}$ and cos θ^{**} are independent (provided there is no longitudinal polarization).

The analysis of the K^0 sample was also done using the particles emitted backwards in the p-p c.m.s., although in this case the difference in accuracy of measurement and ease of detection between forward and backward emission is not so large since all K^0 mesons have small momentum in the p-p c.m.s. In addition they are easier to find in the scanning, the opening angle being, on average, twice as large as for Λ^0's.

Selection of an unbiassed sample of charged strange particles

The decay branching ratio $\frac{\sum p}{\sum \pi}$ is 1, whereas 1/6 was found. This is clearly due to the difficulty in finding small angle Σ_p decays. It is not due to K decays being taken as Σ_π decays. It is shown in the next section that the contamination by K mesons is small. Only Σ_π decays are considered in the following analysis. The scanning efficiency for charged hyperons decaying into charged π mesons has been investigated by four methods.

* In the experiment with 16 GeV/c π^- mesons[1)], the momentum of the Λ^0 produced was not higher than 6 GeV/c. It is seen from Fig. 1 that no appreciable loss occurs in this case.

1. Comparison of repeated scans (85 o/o)
2. Plotting ψ, the azimuthal angle of the decay plane (no visible effect, but the method needs large statistics. Also each camera should be considered separately).
3. By comparing the forward and backward hemispheres of the production in the p-p c.m.s. which should be identical (as for neutral V's). Each event emitted backwards was folded round $\cos \theta^* = 0$ thus making the distribution symmetrical, and the corresponding laboratory momentum and probability to decay within the chamber was worked out. The expected numbers, if the distribution were symmetrical, were compared with those actually found. The result of this method is given in Fig. 2. The points show the ratios of the number of Σ's actually found to the number of Σ's expected to decay in the chamber in that momentum range. This shows that for backward production, which gives hyperons of < 5 GeV/c, the detection probability is ~ 100 o/o.
4. By calculating the loss incurred by assuming that no event with decay angle $< 2.5^{\circ}$ is observed.

Methods 3) and 4) lend themselves to calculation of efficiency as a function of momentum. The correction from method 4) does not completely account for the loss observed in method 3).

These results have been used in the 16 GeV/c analysis, where one wished to compare the forward and backward hemispheres. In the present analysis, however, only the backward hemisphere is considered, and the efficiency is taken to be 100 o/o.

Kinematics of production

In fig. 3a, b, c and d, the $p_T - p_L^*$ diagrams are shown. These are the distributions of hyperons and K^o-mesons in the plane of transverse and longitudinal momentum in the p-p c.m. system.

The distributions are very similar to those from the interactions of 16 GeV/c π^- mesons with protons[1]. The hyperons are collimated along the direction of the incident particles (i.e. spread in a narrow band along the p_L^* axis). The K^o - mesons have lower mean momentum in the p-p c.m.s. and are emitted more isotropically. In the 16 GeV/c π^- - p experiment, the K^o - mesons showed a slight preference to forward emission, ~~due to production in conjunction with~~ [redacted]. Here they are symmetric about $p_L^* = 0$, as they must be. The average values of transverse momentum are also similar, as seen in Table 4 and Figs. 4a, b, c and d. The only exception is Σ^+. In particular the average transverse momentum is remarkably high. It cannot arise from contamination of K^+ in the Σ^+ sample, since nearly all the expected K-mesons were found (7 identified among 10 expected) and the calculated lifetime of the V^+ was (0.97 ± 0.15) 10^{-10} sec., close to τ_{Σ^+}.

TABLE 4

Average transverse momenta

	24.5 GeV/c p + p	16 GeV/c π^- + p
Λ^o	396 $\pm$ 50 MeV/c	460 $\pm$ 40 MeV/c
Σ^+	950 $\pm$ 100 MeV/c	650 $\pm$ 90 MeV/c
Σ^-	510 $\pm$ 70 MeV/c	650 $\pm$ 80 MeV/c
K^o	373 $\pm$ 33 MeV/c	410 $\pm$ 30 MeV/c

In the $\pi^- p$ interactions at 10 GeV/c [2] accurate measurements of transverse momentum, not only for the above particles but also for π and Ξ, showed a variation of p_T with mass. Except for the Σ^+, the above results are consistent with this variation, within the rather large widths of the p_T distributions.

The $p_T - p_L^*$ plot indicates that in proton-proton interactions with hyperon production there is a significant part of non statistical but rather peripheral like processes. Events close to the semicircle have small inelasticity and some Σ^+ events tend to be closer than the Σ^- and Λ^0 (higher p_T and wider variation of p_L).

The momentum distribution of the Σ^- in the p-p c.m.s. agrees fairly well with that predicted by Hagedorn [3], whereas the Σ^+ do not (see Fig. 5). In addition, the charged prong multiplicity in interactions producing Σ^- is slightly higher. We find the following mean multiplicities for charged particles, not including the strange particle :

For interactions associated with	Λ^0	3.7 ± 0.6
" " " "	Σ^+	3.9 ± 0.3
" " " "	Σ^-	4.5 ± 0.4
" " " "	K^0	4.5 ± 0.3

The complete lack of antiparticles is, of course, in disagreement with statistical theory.

As only one of the strange particles is normally seen, more detailed analysis is difficult. As has been previously noted [1], the complexity of the interactions makes a four-momentum transfer analysis of doubtful use.

Cross Sections

In order to deduce the cross sections for strange particle production they were normalised to a total cross section of 39.6 ± 1.7 mb. (This is not the value found directly from the same pictures but the more accurate value from a counter experiment by von Dardel et al [4].)

The sample of events taken to be Λ^o consisted of two parts, those where the identification was unambiguous and those where K^o could not be excluded ("K or Λ events"). The number of K's in the (K or Λ) class must be equal to the number of K's in the (K or $\tilde{\Lambda}$) class. (By consideration, for example, of the α-p_T diagram). The extent of K contamination can not only be deduced, but can also be subtracted from the distributions for Λ^o. The same is true for Λ contamination in K + (K or Λ) sample. Since the number of $\tilde{\Lambda}^o$ is very small, this amounts to taking the Λ^o sample as:

$$\Lambda^o_{\text{identified}} + (K \text{ or } \Lambda) - (K \text{ or } \tilde{\Lambda}) = 87$$

and the K^o sample as:

$$K^o_{\text{identified}} + 2\,(K \text{ or } \tilde{\Lambda}) = 188$$

Using only particles emitted backwards in the proton-proton c.m.s., and adding events to the cos θ^{**} distribution so as to create symmetry, the cross sections given in Table 5 have been found:

TABLE 5

Partial cross-sections

	Present work 25 GeV/c p-p	16 GeV/c π^- 1)
$\sigma_{\Lambda^o \Sigma^o}$	1.13 ± 0.20 mb*	0.68 ± 0.10 mb
σ_{K^o}	2.74 ± 0.25 mb	2.86 ± 0.24 mb
σ_{Σ^+}	1.60 ± 0.20 mb	0.36 ± 0.06 mb
σ_{Σ^-}	0.40 ± 0.08 mb	0.28 ± 0.05 mb
σ_{Ξ^-}	< 50 μb	< 50 μb
σ_{YK}	3.1±0.3 mb	1.32 ± 0.15 mb
$\sigma_{K\bar{K}}$	-	2.21 ± 0.25 mb

* This value would be 19 o/o lower if the cos θ^{**} distribution were not symmetrized.

In the case of π^- - p interactions we start from a neutral system and so it is reasonable to assume that the $K\bar{K}$ channels are equal for different charge states and the (YK) and ($K\bar{K}$) production can then be separated [1].

In the pp case, the same assumption leads to the values [redacted] $\sigma_{K\bar{K}} = 1.2 \pm 0.3$ mb. However there is no reason for this assumption to be true, and insufficient data to check it.

The production of Y^0 is, as one might expect, about twice as abundant as in π-p collisions.

The charge ratio: $$\frac{p + p \longrightarrow \Sigma^+}{p + p \longrightarrow \Sigma^-} = 4.0 \pm 0.9.$$

The corresponding ratio for 16 GeV/c π^- + p reactions is 1.3 ± 0.3. The difference is due almost entirely to a much larger cross section for Σ^+ production in the 25 GeV/c p + p reactions (1.60 ± 0.2 mb compared with 0.36 ± 0.06 mb for pions). The cross section for Σ^- production (0.40 ± 0.10 mb) is almost the same as for the reactions of 16 GeV/c π^- mesons (0.28 ± 0.05 mb). Since the mean multiplicity of charged secondaries is ~ 5, the average p-p interaction will have 3.5 positive and 1.5 negative particles. One would expect a proton to be changed to a positive hyperon more easily than a negative, and this is borne out by the charge ratio being greater than 3.5/1.5 = 2.3.

CONCLUSIONS

The low transverse momentum found in other high energy experiments is confirmed for all particles except positive hyperons, which show a higher value. The cross section for the production of neutral K-particles is the same as in high energy π^- - p interactions. Positive hyperons, however, show a very high cross section.

Again, both statistical-like and peripheral-like features can be found, with no clear distinction between them. The symmetry of the pp system allows precise checks of scanning efficiency, which, in particular, confirm results obtained from 16 GeV/c π^- p interactions.

Acknowledgments

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Proceedings of Aix-en-Provence Conference, Session F, Vol.1, p. 287.

Figure Captions

Fig. 1

Distribution of Λ^o decays in the p_{lab} - cos θ^{**} plans. θ^{**} is the angle of decay of the proton in the c.m.s. of Λ^o. The non-uniform population around cos θp^{**} = 0 and large $(p_{\Lambda^o})_{lab}$, shows the effect of scanning inefficiencies. The solid curves are for constant decay angle in the laboratory.

Fig. 2

Scanning efficiency for Σ_π decays as a function of laboratory momentum of the hyperon.

Fig. 3

The p_T - p_L^* plots for a) Λ^o

b) Σ^+ } Only the backward hemisphere

c) Σ^- } is used in further analysis

d) K^o

p_L^* is in the p-p c.m.s. The blackness of the circle shows the multiplicity of the interaction, and its area is proportional to the statistical weight.

Fig. 4

The p_T distribution for a) Λ^o

b) Σ^+ } produced backwards

c) Σ^- } in the c.m.s.

d) K^o

The dotted line indicates observed numbers and the full line corrected numbers.

Fig. 5

The distribution of momentum in the p-p c.m.s. for a) Σ^- and b) Σ^+ compared to that predicted by the statistical theory of Hagedorn[3].

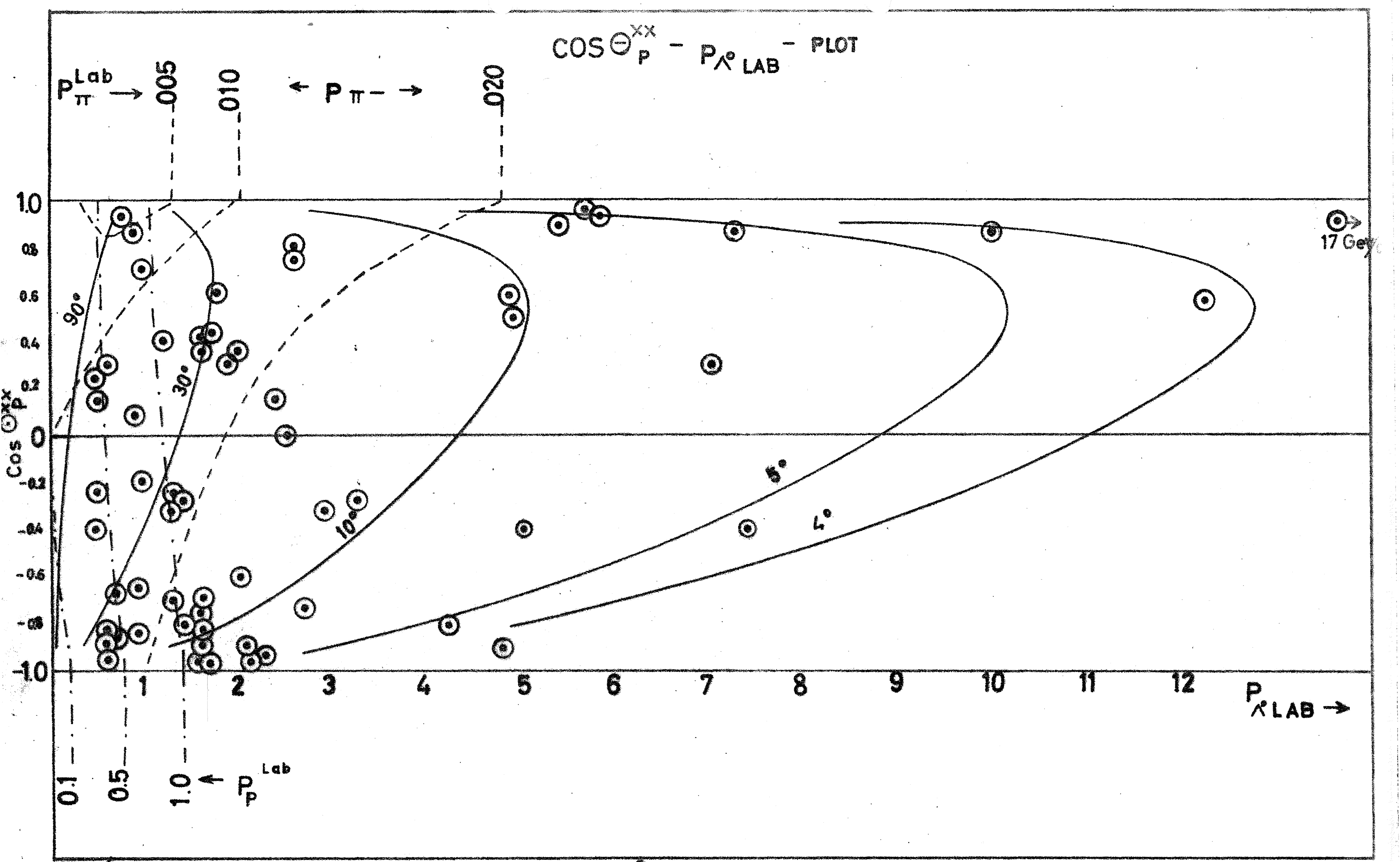
COS Θ_P^{xx} - $P_{\Lambda^0 LAB}$ - PLOT
P_π^{Lab} →
005
010
← P_π →
020
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
Cos Θ_P^{xx}
90°
30°
10°
5°
4°
17 GeV
1
2
3
4
5
6
7
8
9
10
11
12
$P_{\Lambda^0 LAB}$ →
0.1
0.5
1.0
← P_P^{Lab}

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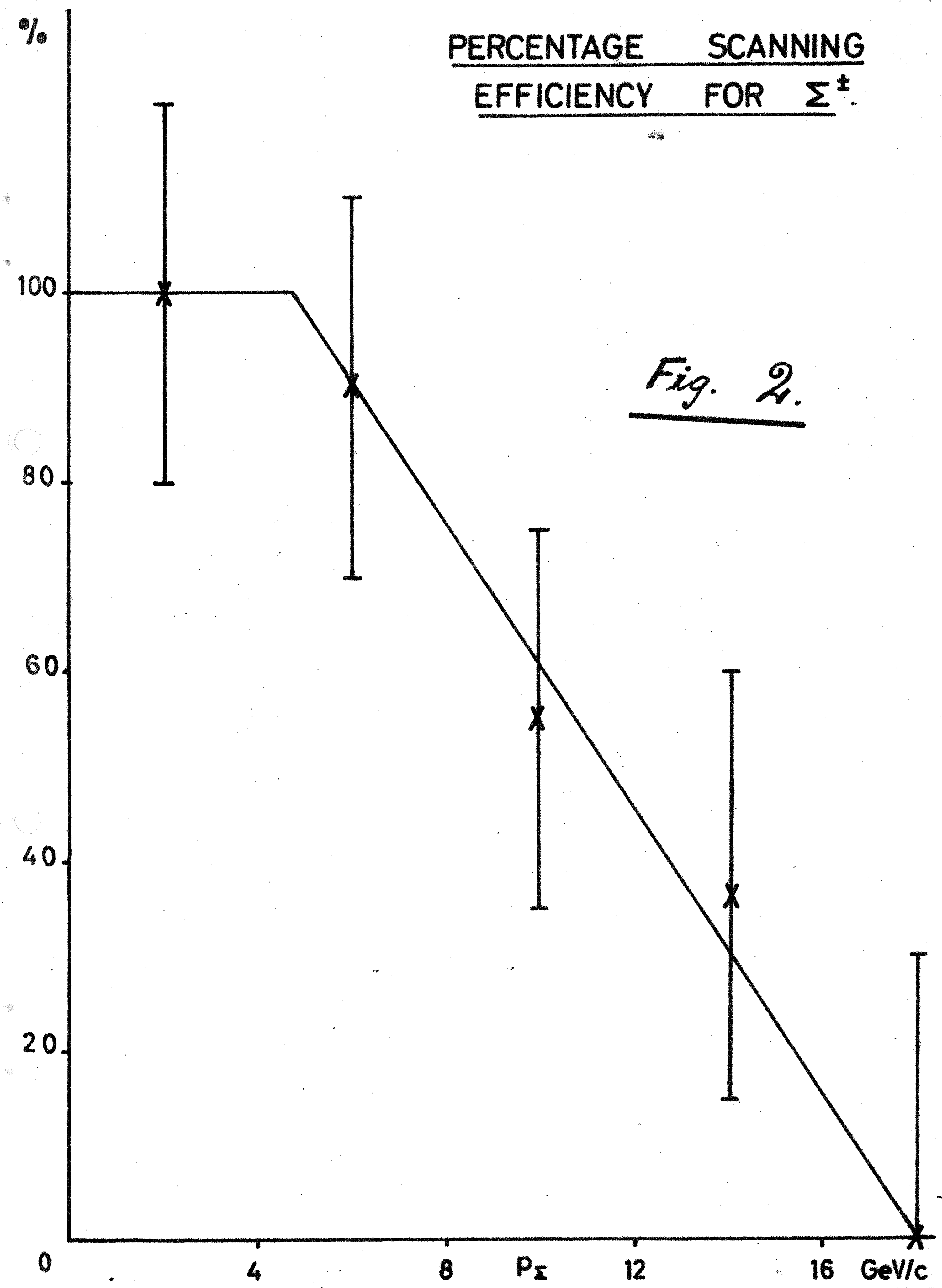
Fig. 1.



PERCENTAGE SCANNING EFFICIENCY FOR Σ±.
Fig. 2.
%
100
80
60
40
20
0
4
8
PΣ
12
16
GeV/c
PS/3370

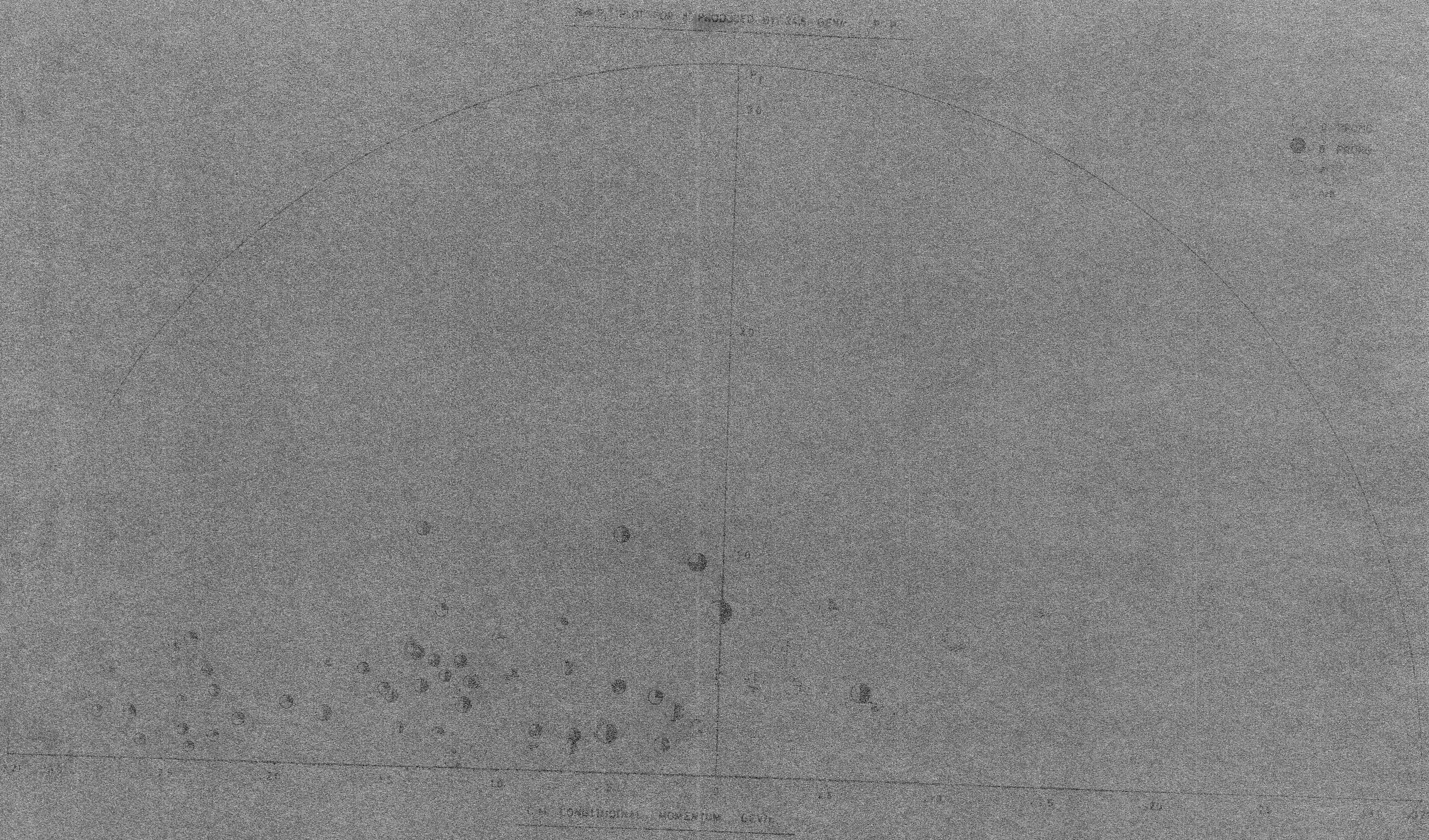


Fig. 3 a)

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$P_T - P_L^{\circ}$ FOR Σ_{π}^{+} PRODUCED BY 24.5 GeV/c p – p.

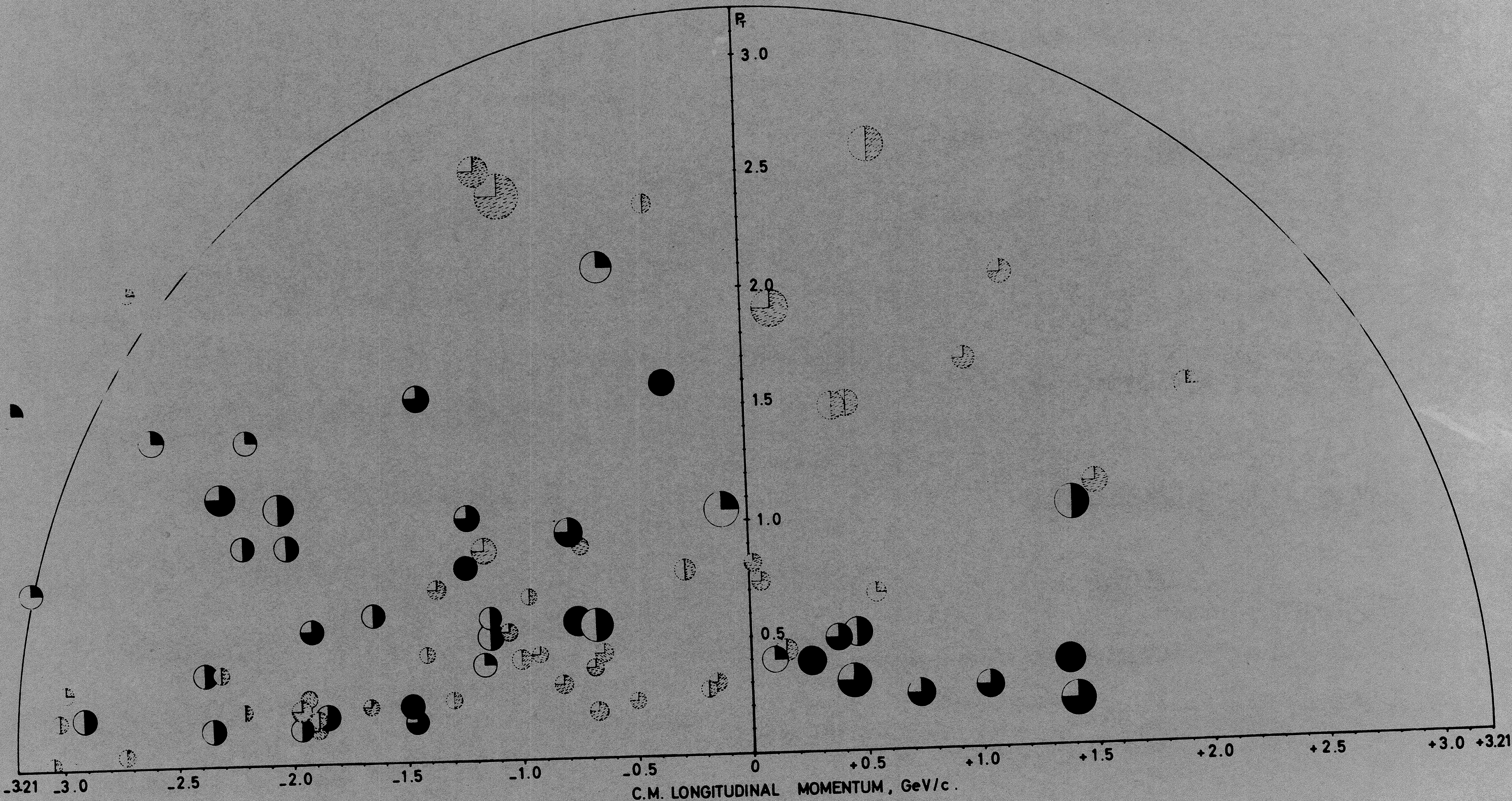

Fig. 3b).

$P_T - P_L^*$ FOR Σ^-_π PRODUCED BY 24.5 GeV/c p-p.

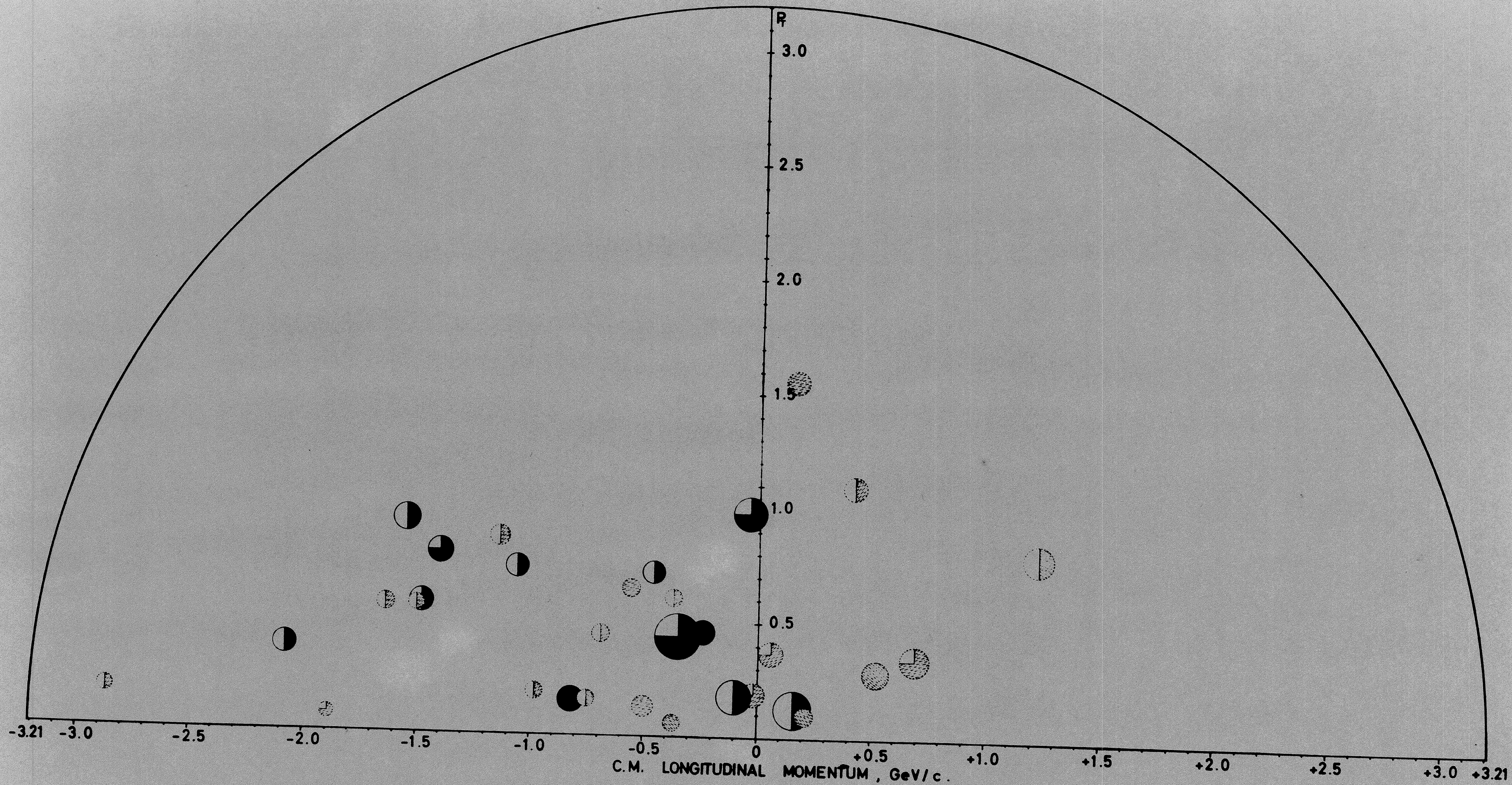

Fig. 3c).

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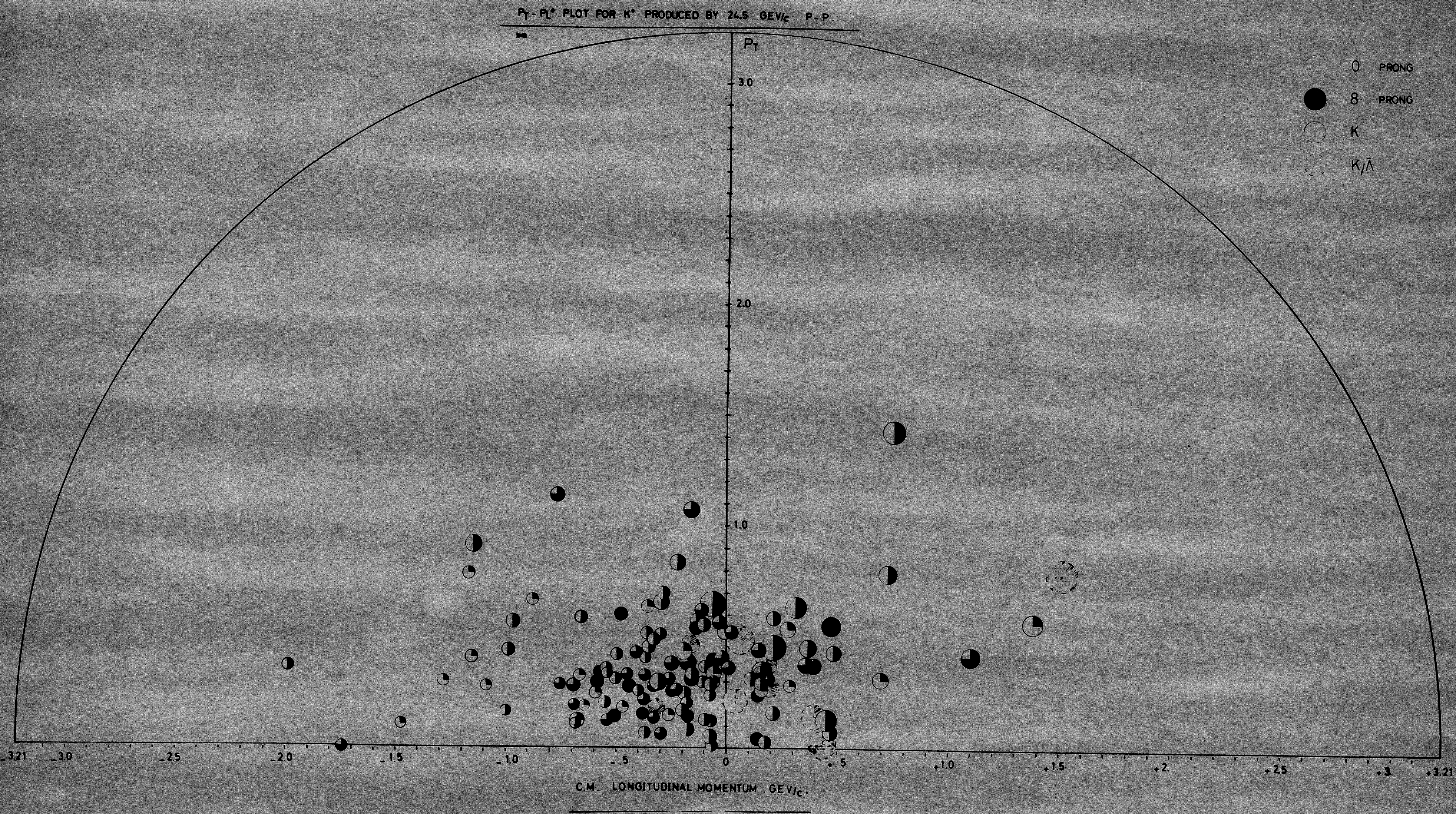

PT - PL* PLOT FOR K° PRODUCED BY 24.5 GEV/c P - P.
PT
3.0
2.0
1.0
0 PRONG
8 PRONG
K
K/Λ̄
-3.21
-3.0
-2.5
-2.0
-1.5
-1.0
-.5
0
+.5
+1.0
+1.5
+2.
+2.5
+3
+3.21
C.M. LONGITUDINAL MOMENTUM . GEV/c .

Fig 3d)

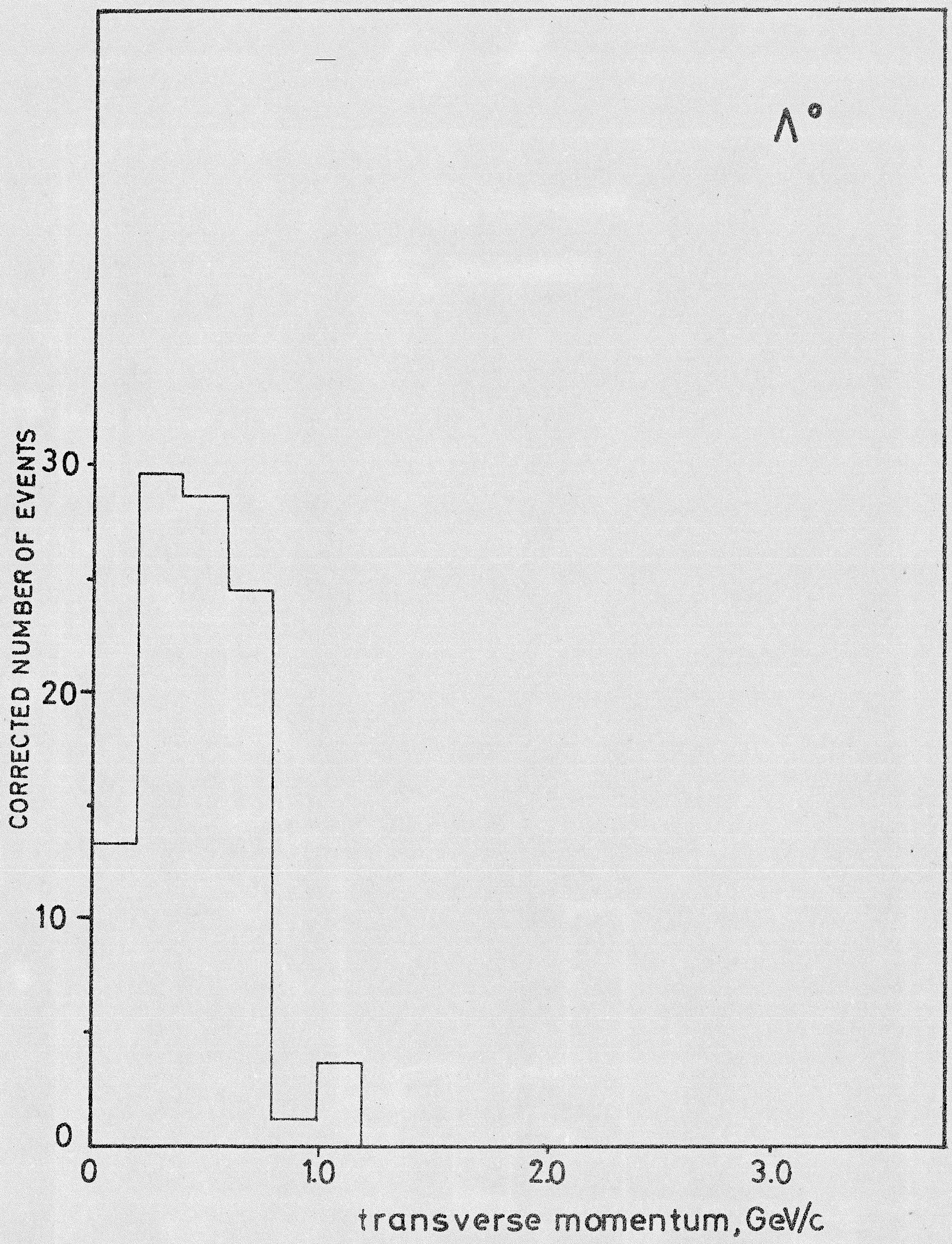
Λ°
CORRECTED NUMBER OF EVENTS
30
20
10
0
0
1.0
2.0
3.0
transverse momentum, GeV/c

Fig 4a

Fig. 4 b)

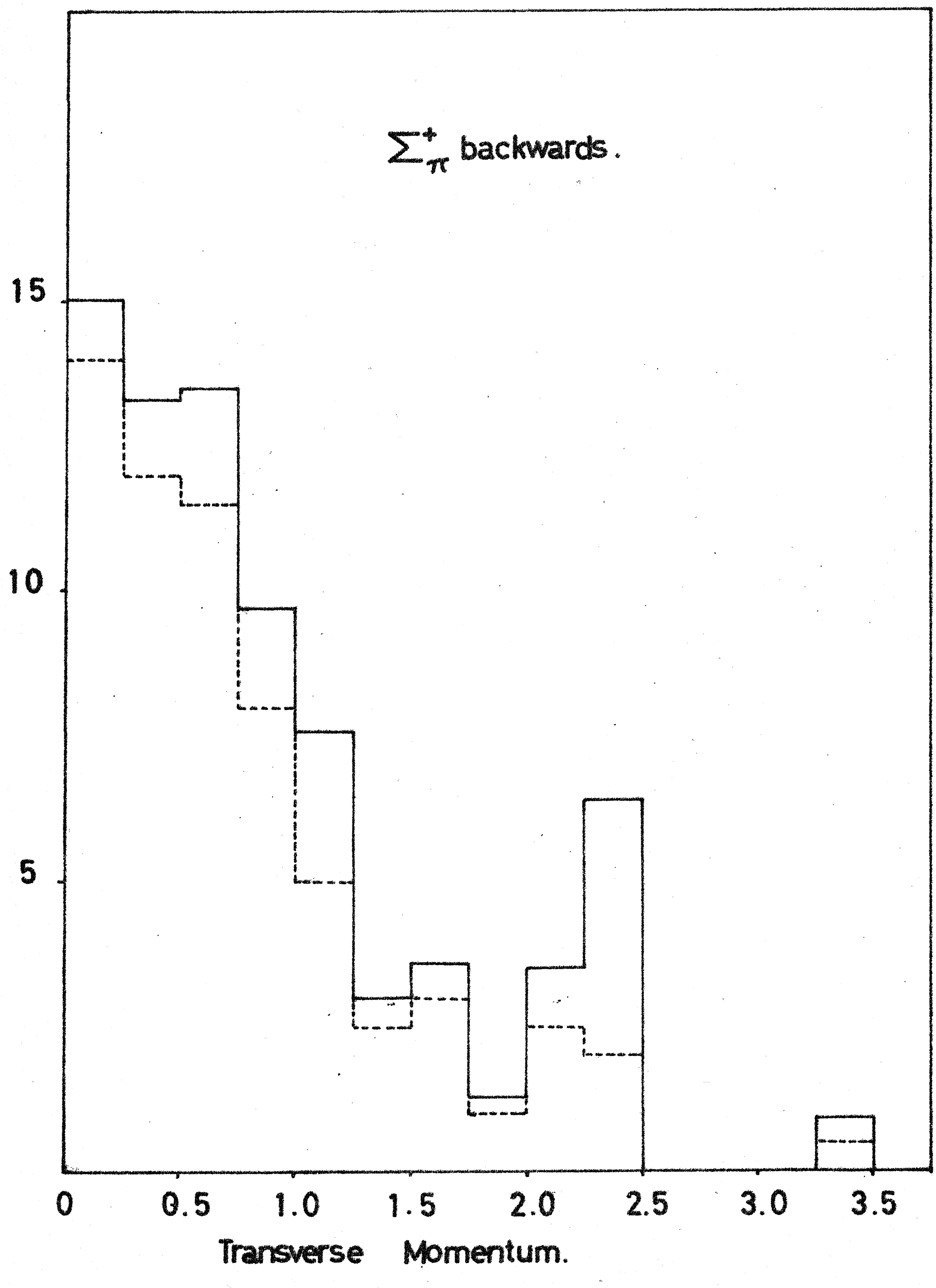

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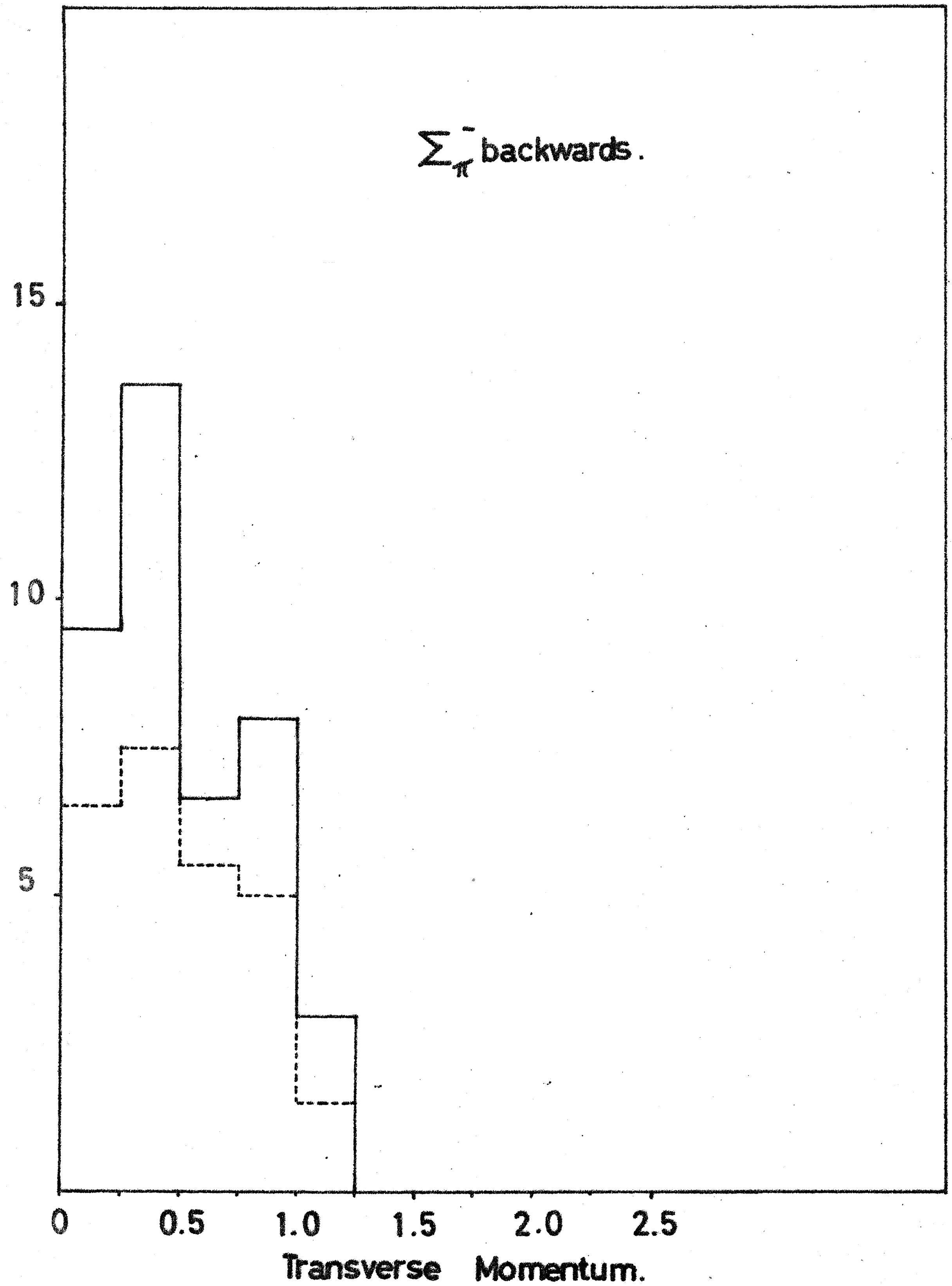
Fig. 4c)



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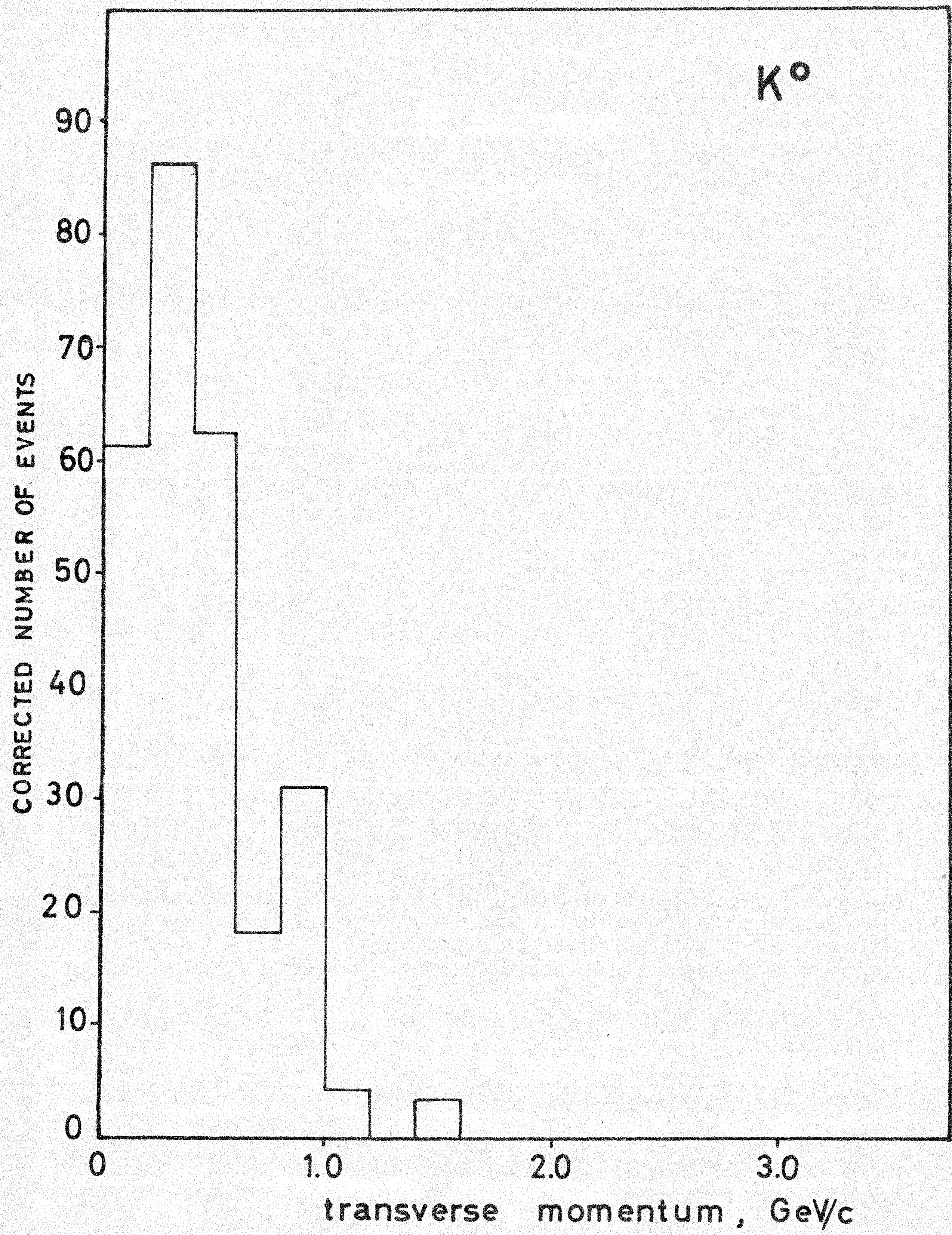
K°
CORRECTED NUMBER OF EVENTS
0
10
20
30
40
50
60
70
80
90
0
1.0
2.0
3.0
transverse momentum , GeV/c

Fig 4d)

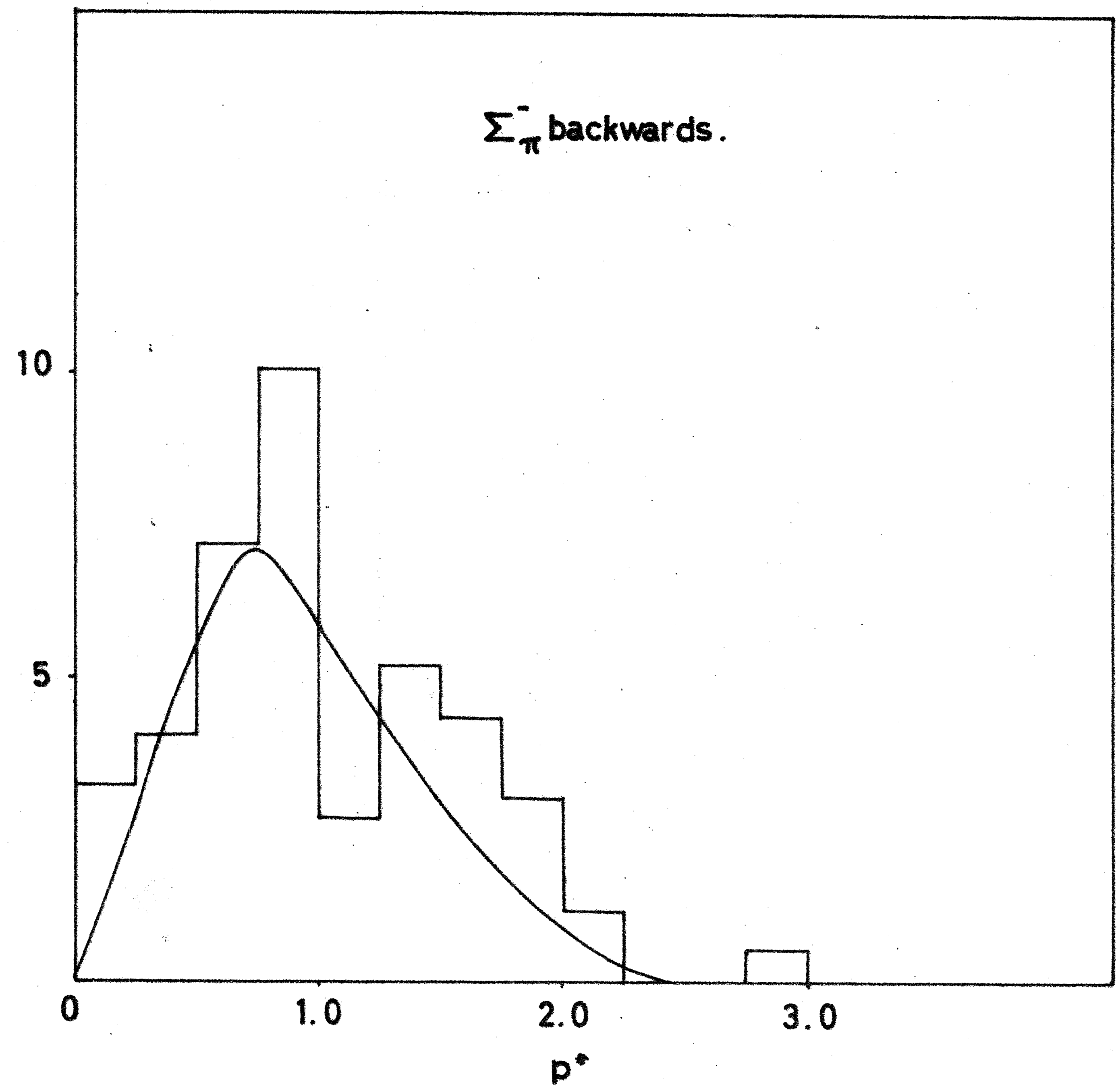

Fig. III. 5a)

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Fig. 12.

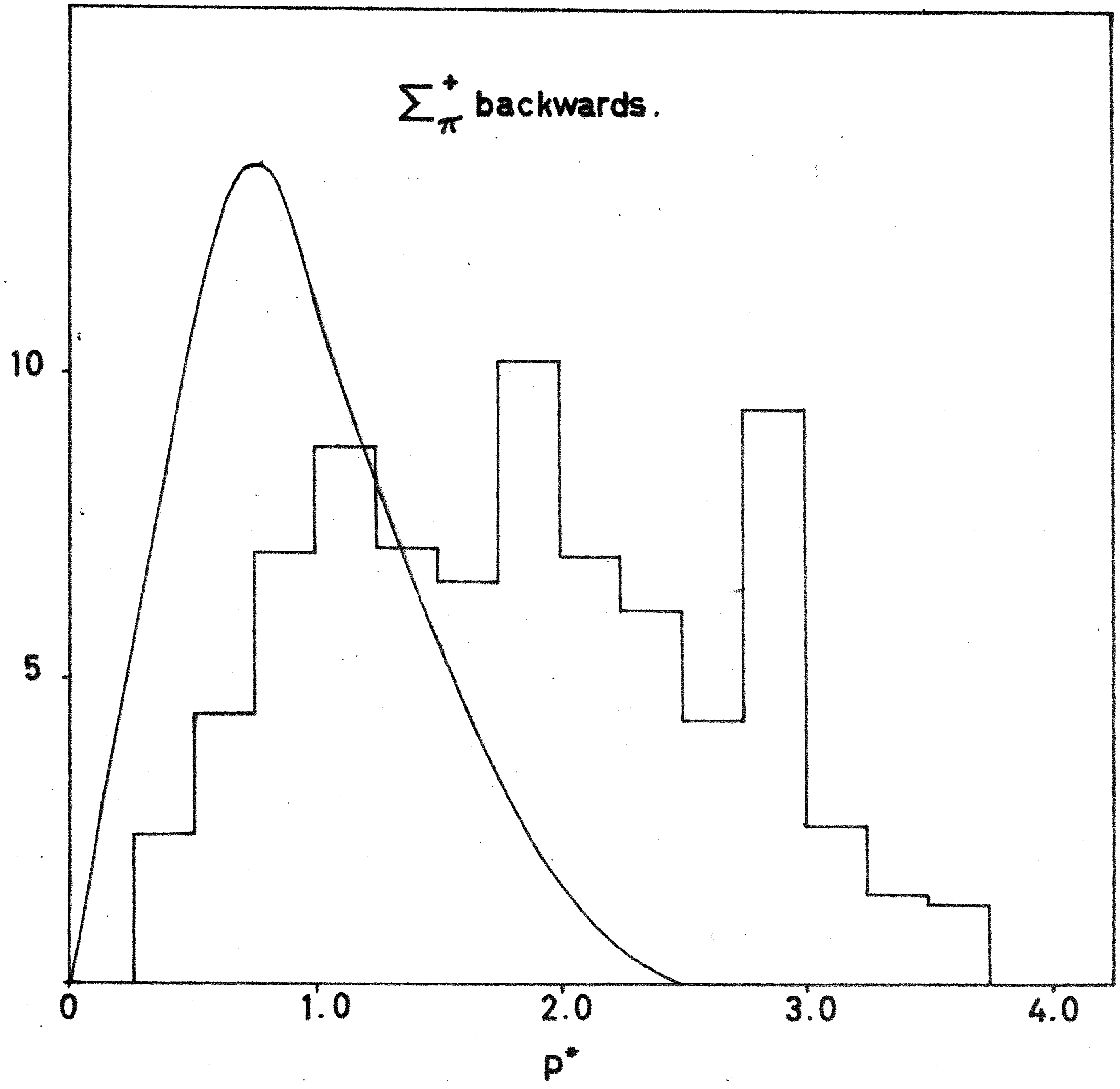

Fig 5b

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