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STUDY OF THE MULTIPARTICLE PRODUCTION IN THE COHERENT PRODUCTION FOR π^- 340 GeV/c AND $K^\pm$ 70 GeV/c INTERACTION WITH EMULSION NUCLEI

M. El-Nadi
Physics Department, Faculty of Science, Cairo University,
Cairo, Giza, Egypt,

M.N. Yasin El-Bakry * and S. Abd El-Halim **
International Centre for Theoretical Physics, Trieste, Italy.

ABSTRACT

The coherent multiparticle production in π^- (340 GeV/c) and in $K^\pm$ (70 GeV/c) interactions with nuclei is studied using the nuclear emulsion technique.

The mean free path and cross-sections of the three prong events are estimated and compared with other data.

A $\sum_i \sin\theta_i$ analysis, pseudorapidity and azimuthal angular distributions are discussed.

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* Permanent address: Physics Department, Faculty of Science, Cairo University, Cairo, Giza, Egypt.
** Permanent address: Fayoum Branch, Cairo University, Cairo, Giza, Egypt.

I. INTRODUCTION

The coherent event is the type in which interaction takes place with the target nucleus as a whole and remains in its ground state. However, it is pointed out that coherence is possible also when the nucleus goes to a specific excited state/1,2/. The coherent interactions are predominant at small momentum transfer to the target nucleus. The coherent interactions leading to pion production was discussed by many authors /1,3-8/. The coherent production can result from the interaction of the incident hadron with the nuclear field of the target nucleus (diffraction dissociation) as where the interaction with the coulomb field leads to the so called coulomb dissociation/9/. A theoretical analysis of these types has been reported by Marage 171, Drell/10/, Mathews et al.,/11/and Zhizhin et al.,/12/. Bemporad et al.,/13/ concluded that the kinematics of the coherent production process ensures that the three pions remain within the range of strong interaction along their path through the nucleus.

In the present work, the multiplicity as well as the $\sum_i \sin\theta_i$ spectra of white stars (N_h=0 stars) produced in π^- and $K^\pm$ interactions with nucleons enabled the determination of the coherent production cross-section of showers in three prong events in these reactions.

The azimuthal angular distribution of these coherent events and of those due to π^- and $K^{\pm}$-nucleon interactions confirmed the observed results.

2. RESULTS AND DISCUSSION:

A sample of about 1016, 528 and 511 inelastic interactions of 340 GeV/c π^-, 70 GeV/c K^+ and 70 GeV/c K^- with emulsion nucleons and nuclei respectively were collected by along the track scanning in the present work. For these events, the numbers of relativistic charge particles N_s, grey particles N_g, black particles N_b and heavily ionising particles N_h ($N_h=N_g+N_b$) were counted carefully. The separation of π^-, K^+ and K^- -nucleon interactions was carried out giving 420, 90 and 98 clean events respectively. These clean events satisfy the following criteria:

1. Since the nucleus should not break up, there should be no short heavily-ionising tracks, i;e. $N_h= 0$.
2. No single electron tracks (pairs are allowed if they could be Dalitz pairs).
3. Since in coherent events there is no charge exchange, the total multiplicity must be odd.
4. Since the four momentum transfer "t" is small in coherent production (or the nucleus breaks up) the multiplicity must be small. Hence expect peaks in the multiplicity distribution for reactions-on nuclei at 1,3 and possibly 5.

5. Elastic events as well as knock-on and direct electron pair productions are excluded /2,14/.

2.1. Multiplicity distribution:

The multiplicity distribution for clean events of 340 GeV/c π^--meson is presented in figure (1) and that of 70 GeV/c $K^{\pm}$ -mesons in figure (2) . Distinct peaks are clearly observed at multiplicity $N_s= 3$ which are far from the values expected due to multiparticle production processes at the value of $\bar{n}_s$ where $\bar{n}_s \simeq 9$ for π^-(340 GeV/c) nucleon interaction /15/, $\bar{n}_s = 6.1$ for K^+ (70 GeV/c) nucleon interaction /16/ $\bar{n}_s = 5.6$ for K^- (70 GeV/c) nucleon interaction /17/. These peaks can be attributed to the coherent production. Comparing our data for π^-(340 GeV/c) with that for incident proton/2/ at nearly the same momentum (303 GeV/c), the peak at $N_s= 3$ is mor distinct for π^- (Figure 1). The same effect was observed before at 60 GeV/c π^-/18/ and at 67 GeV/c proton/19/. This observation reflects an enhancement for the coherent cross-section in case of π^- meson and could be expcted due to the difference in the rest masses of proton and pion.

N_s distribution for white events for different incident particles at nearly the same incident momentum are presented also in figure (2) . The same enhancement for the peaks at $N_s= 3$ events is observed for all the incident hadrons.

2.2. $\sum_i \sin \theta_i$ analysis :

The parameters $\sum_{i=1}^{3} \sin \theta_i$, representing the degree of collimation of the secondaries, is roughly proportional to the longitudinal-momentum transfer to the target nucleus (θ_i is the angle of emission of the ith particle in the laboratory system).

The coulomb dissociation is more prominent when the charge of the target ncleus is very high. So the main contribution to the coherent cross section is due to the collisions with (Ag Br) for which the longitudinal momentum transfer $q_L \simeq$ 30 MeV/c. Thus for coulomb dissociation, we expect $\sum_{i=1}^{3} \sin \theta_i \leq 0.22$.

On the other hand, the diffraction dissociation is expected to take place with semi transparent nuclei (CNO). In this case (q_L max $\simeq$ 60 MeV/c) and hence the geometrical condition for such events is $\sum_{i=1}^{3} \sin \theta_i \leq 0.43$. These two condition are necessary but not sufficients /10,11,12 and 20/.

We have found 65 (N_s=3) events in case of π^- (340 GeV/c) nucleus interaction (out of 1016 scanned events) having $\sum_{i=1}^{3} \sin \theta_i \leq .043$. For K^+ and K^- (70 GeV/c) emulsion interaction, we have found 23 and 16 events (out of 528 and 511 events) respectively having $\sum_{i=1}^{3} \sin \theta_i \leq 0.43$.

Figures 3 (a)-(c) represent the $\sum_{i=1}^{3} \sin \theta_i$ distributions for these events. In figure (4) we presented the $\sum_{i=1}^{3} \sin \theta_i$ distribution of the coherent events produced from interactions of different hadrons at nearly the same incident momentum. The distributions are collimated at small values of $\sum_{i=1}^{3} \sin \theta_i$ for all the different hadrons.

2.3. Mean Free Path

The results are presented in table (1)

Projectile and momentum / Information	π^- 340 GeV/c	K^+ 70 GeV/c	K^- 70 GeV/c
Total scanned track length (meter)	401	306	266
Total number of inelastic events	1016	528	511
The mean free path $\lambda_{inel.}$ (cm)	39.47±1.24	57.95±2.52	52.05±2.30
The number of white events	420	90	98
The number of coherent events	65	23	16
σ_{coh} (mb)	48.38±5.46	22.44±4.7	18.18±4.43
Beam	H-2 SPS CERN	S-3 SPS CERN	S-3 SPS CERN
Experiment	WA-61 CERN		
Emulsion plate	6 cm X 15 cmX0.06 cm G-5 pelliceles		
Emulsion sensitivity	18 grains /100 μ for the incident beam		

Table (1)

Using the data presented in Caroll et al.,/21/ , we can calculate λ_{cal} according to : $\lambda_{cal} = \frac{1}{n_{eff} \cdot \sigma}$ where n_{eff}: the number of average nuclei, $\sigma = \sigma_0 A^{\alpha}$ and A: the atomic weight of the average emulsion nucleus.

The obtained values are:

$\lambda_{cal} = 45.99 \pm 2.30$ cm for π^- 269 GeV/c,

$\lambda_{cal} = 51.48 \pm 2.60$ cm for K^+ 60 GeV/c and

$\lambda_{cal} = 48.92 \pm 2.50$ cm for K^- 60 GeV/c,

which are in fair agreement with our experimental values within the stated errors (see table 1).

2.4. Coherent production cross-section:

The coherent production cross-section can be calculated experimentaly from the coherent interaction length using the well known formula:

$$\sigma_{coh.} = \frac{1}{\lambda_{coh.} n_{eff}}$$

Where $$\lambda_{coh.} = \frac{\text{total scanned length}}{\text{no. of coherent events}}$$

and n_{eff} is the effective number of atoms per c.c. in the emulsion used.

In table (2) the values of the coherent corss-sections for different incident particles with different incident momenta and different targets are given. The increase of the coherent crossstion with the increase of the energy of the incident hadron is noticable. This may be explained by the increase in the maximum mass of the system that can be produced coherently, which σ is roughly proportional to the square root of the primary energy. This increase in energy thus open new coherent reaction channels.

We can consider it as an important experimental observation from table (2) that: $\sigma_{coh}(K^{\pm}) > \sigma_{coh.}(\pi^-) > \sigma_{coh.}(P)$ at approximately the same incident momentum (70 GeV/c). This is may be due to the role played by the strange mesons, which have a rather small absorption cross-sections in nuclear matter.

Figure (5) shows the coherent cross-section for different hadrons at different momenta ($\sigma_{coh.}$ is divided by $A^{2/3}$ to eliminate the dependence on the mass number of the target nucleus). We notice, from the figure, an increase of $\sigma_{coh}/A^{2/3}$ for all the particles with increasing incident momenta. This increase is more rapid for π^- than for any other hadron, where—as there is no any significant change of $\sigma_{coh}/A^{2/3}$ with increasing Momentum very low value to 200,300 GeV/C for π^- and P respectively .

Table (2)

The coherent cross-sections for different incident hardrons at different momenta in nuclear emulsion and bubble chamber (B.C.) experiments.

Beam	mom. GeV/c	$\sigma_{coh.}/A^{2/3}$	experi.	$\sigma_{coh.}$	Ref.
π^-	6	0.16	B.C.		22
	16	0.32	B.C.		23
	17	0.28±0.04	emulsion	4.9±0.6	24
	45	0.58±0.07	"	9.9±1.1	24
	50	0.76±0.07	"	12.9±1.1	19
	200	1.7±1.00	cosmic		25
	200	1.05	B.C.		26
	340	2.8±0.32	emulsion	48.38±5.46	present work
π^+	4.2	0.157±0.03	B.C.	0.253±0.05	27
	4.5	0.163±0.04	B.C.	0.26±0.07	27
	11.7	0.2±0.063	B.C.	0.32±0.10	27
	15	0.187	B.C.	3.0	13,28,29,30
	23	0.156	B.C.	2.5	31
	40	0.175	B.C.	2.8	32
	156	0.203	B.C.	3.25	33
	200	0.24	B.C.	3.9	34
K^-	5.5	0.1±0.02	B.C.	0.74±0.15	27
	12.7	0.44±0.05	B.C.	3.3±0.40	27
	70	1.06±0.26	emulsion	18.18±4.43	present work
K^+	2.3	0.07±0.01	B.C.		27
	3	0.13±0.014	B.C.		27
	70	1.3±0.32	emulsion	22.44±4.70	present work

Table (2) (Continued)

Beam	mom. GeV/c	$\sigma_{coh.}/A^{2/3}$	Experi.	$\sigma_{coh.}$	Ref.
p	1.825	0.12±0.013	B.C.	0.185±0.02	27
	22	0.23±0.04	B.C.	4.0±0.60	35,36,37,38
	50	0.19±0.05	emulsion	3.3±0.80	39
	67	0.42±0.05	"	7.2±0.90	17
	200	0.658±0.15	"	11.2±2.50	40
	205	0.33	"	5.6	2
	303	0.45	"	7.6	2

Also we notice that the increase of $\sigma_{coh}/A^{2/3}$ with momentum for both K^+ and K^- mesons is nearly the same within the values of the stated errors.

2.5. The Azimuthal angular distribution:

The azimuthal angle ψ can be determined from $\psi = \sin^{-1}\left(\frac{\sin\alpha}{\sin\theta}\right)$ where α is the dip angle and θ is the space angle.

For our analysis a sample of π^- - nucleon, K^+ - nucleon and K^--nucleon interactions (different topoloyies of N_s) were taken. The azimuthal angular distribution was constructed using the method consecutive angles /41,42/. In case of azimuthal isotropy, the probability distribution of ψ for n-prong events is given by:

$$N(\psi)\,d\psi = (n-1)\left(1-\frac{\psi}{2\pi}\right)^{n-2}\frac{d\psi}{2\pi}$$

The observed distributions together with random ones obtained from the above expression for events having different number of prongs (non coherent events) are shown in figures 6 (a)-(c) for π^--nucleon (340 GeV/c), K^+-nucleon (70 GeV/c) and K^--nucleon (70 GeV/c) interactions. It is clear that we can not detect a deviation from the azimuthal isotropy. Figures 7 (a)-(c) illustrate the azimuthal angular distributions for the coherent events with $N_s=3$ for π^- (340 GeV/c), K^+ (70 GeV/c) and K^- (70 GeV/c).

The shapes here are quite different from that of the random ones. These characteristic shapes suggest that these interactions consist of two types of events. One causes the deviation from isotropy and the other giving the isotropic part of the distribution . The events which cause the anisotropic part are due to the diffraction dissociation mechanism.

2.6. **Pseudorapidity distribution:**

The angular distribution of fast particles is presented in terms of the pseudorapidity variable:

$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

where θ is the laboratory space angle of relativistic particles.

Figures 8 (a)-(c) show the pseudorapidity distribution for showers produced in coherent events ($N_s=3$) of 340 GeV/c π^-, 70 GeV/c K^+ and 70 GeV/c K^-- nucleon interactions. These η spectra are shifted towards high rapidity region, that is the projectile fragmentation region. This indicates that the multiparticle production in coherent events is mainly due to projectile fragmentation.

3. **Conclusions**:

(1) The values of the mean free path $\lambda_{int.} = 39.47 \pm 1.24$, 57.95 ± 2.52 and 52.05 ± 2.3? cm for 340 GeV/c π^-, 70 GeV/c K^+ and 70 GeV/c K^- inelastic interactions with nucleons and nuclei, respectively, were obtained.

(2) The multiplicity distributions of the white stars were constracted with distinct peaks at multiplicity $N_s = 3$ clearly observed. These peaks can be taken as evidence for coherent production.

(3) The peak at $N_s = 3$ is more distinct for the case of the incident negative pions than that of protons at nearly the same momentum. This observation reflects an enhancement for the coherent cross-section in case of π^--meson.

(4) The distribution of $\sum_i \sin\theta_i$ for coherent events in three prong topology ($N_s=3$) were displayed showing that the distribution of π^- (340 GeV/c) events is strongly collimated towards very low values of $\sum_i \sin\theta_i$.

(5) The coherent cross-section is increased with the increase of the energy of the incident hadron.

(6) $\sigma_{coh.}(K^{\pm}) > \sigma_{coh.}(\pi^{\pm}) > \sigma_{coh.}(P)$ at approximately the same incident momentum. This is may be due to the role played by the strange mesons.

(7) The azimuthal angular distributions for coherent events (N_S=3) have shapes quite different from that of the random ones. These characteristic shapes suggest the assumption that these interactions consist of two types of events. One causes the deviation from isotropy which is the coherent part and the other gives the isotropic part of the distribution.

(8) The multiparticle production coherent events is mainly due to the projectile fragmentation, as is reflected from the studied pseudorapidity spectra.

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Figure Captions:

Fig.(1) : The multiplicity distribution for 340 GeV/c π^--nucleon events compared with that of 303 GeV/c protons.

Fig. (2) : The multiplicity distribution for white stars (N_h=0) for different incident particles at nearly the same incident momentum.

Fig. (3-a) : $\sum_{i=1}^{3} \sin \theta_i$ - distribution for 65 coherent events produced from the interaction of 340 GeV/c π^--mesons with emulsion nuclei.

Fig.(3-b) : $\sum_{i=1}^{3} \sin \theta_i$ distribution for 23 coherent events produced from the interaction of 70 GeV/c K^+ - mesons with emulsion nuclei.

Fig. (3-c) : $\sum_{i=1}^{3} \sin \theta_i$-distribution for 16 coherent events produced from the interaction of 70 GeV/c K^--mesons with emulsion nuclei.

Fig. (4) : The $\sum_{i=1}^{3} \sin \theta_i$ -distribution for coherent events produced from the interactions of different hadrons at nearly the same incident momentum.

Fig. (5) The coherent cross-section for different hadrons at different incident momenta.

Fig. (7) The azimuthal angular distribution for coherent events (N_s=3) produced from the interaction of different hadrons with emulsion nuclei:

(a) 340 GeV/ c π^-, (b) 70 GeV/c K^+
(c) 70 GeV/ c K^-

Fig. (8) The azimuthal angular distribution of white stars (N_h=0) produced from the interaction of different hadrons with emulsion nuclei:

(a) 340 GeV/ c , (b) 70 GeV/c K^+
(c) 70 GeV/ c K^-.

Fig.(8) The pseudorapidity distribution for the interaction of different hadrons with em ulsion nucleons and for coherent events:

(a) for π^- (340 GeV/c),
(b) for K^+ (70 KeV/c) and
(c) for K^- (70 GeV/c).

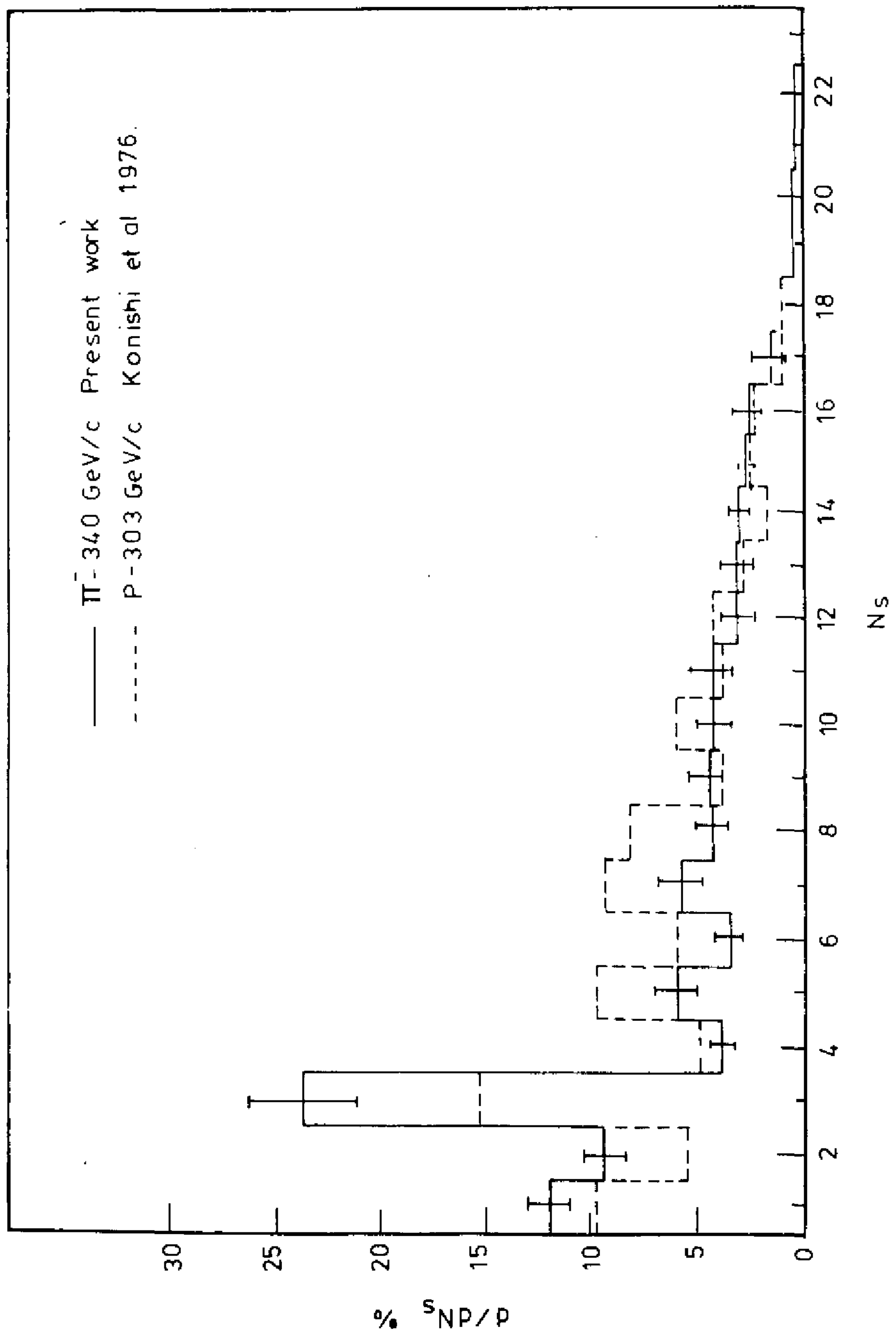
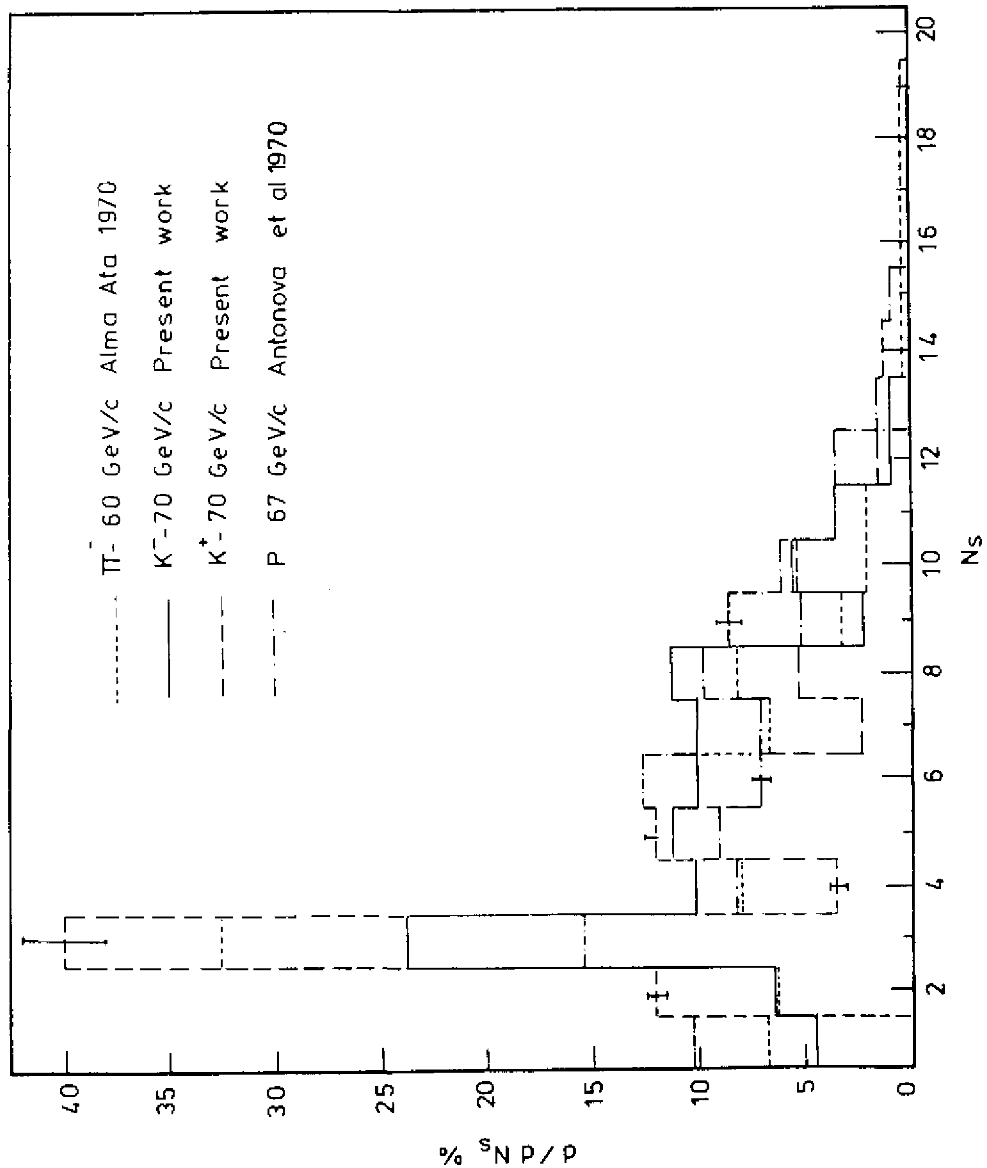

π⁻ 340 GeV/c Present work
P 303 GeV/c Konishi et al 1976.
Ns
% sNP/P

Fig. (1)


π⁻ 60 GeV/c Alma Ata 1970
K⁻ 70 GeV/c Present work
K⁺ 70 GeV/c Present work
P 67 GeV/c Antonova et al 1970
Ns
% sNP/P

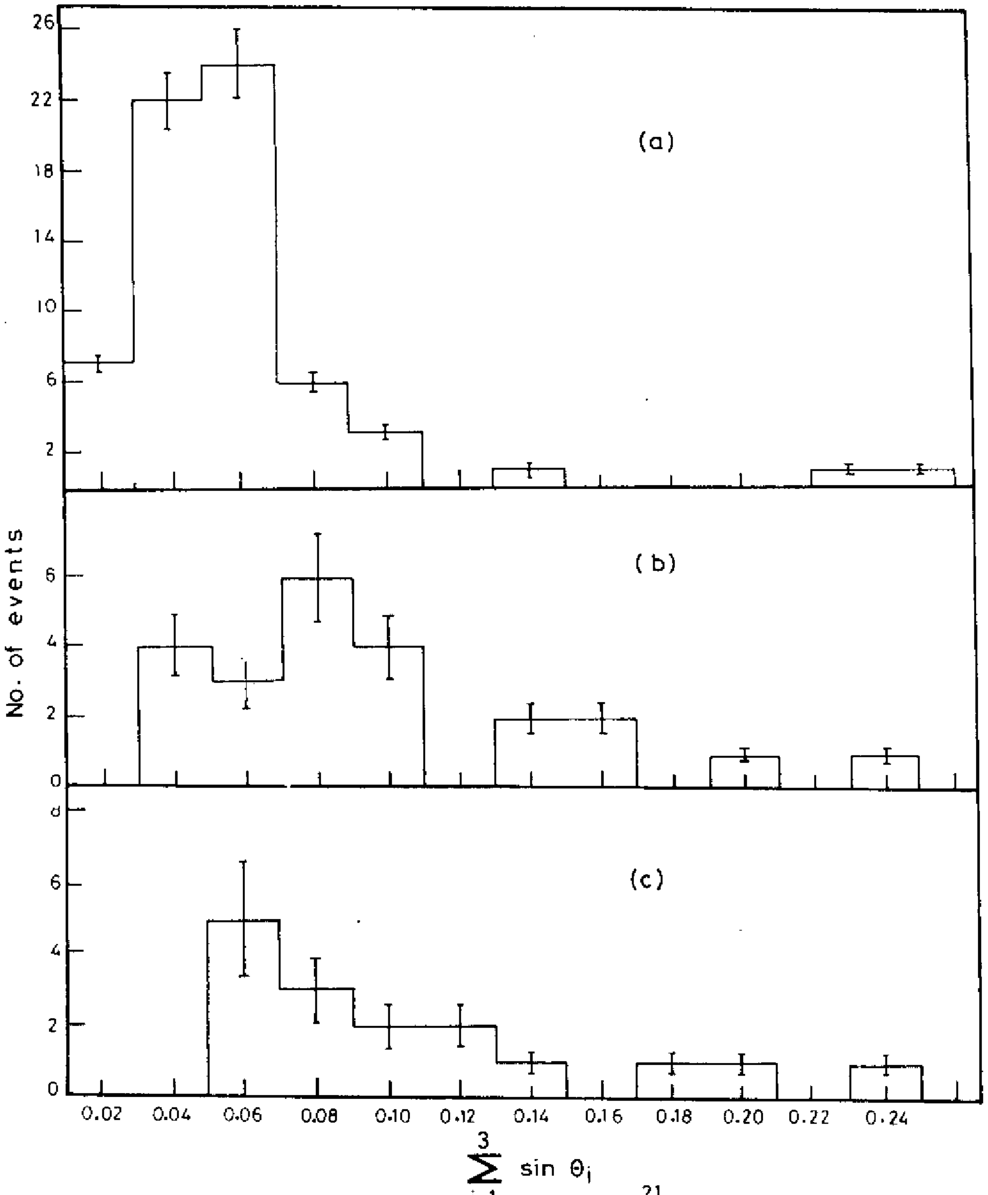

(a)
(b)
(c)
No. of events
0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24
$\sum_{i=1}^{3} \sin \theta_i$

Fig (3)

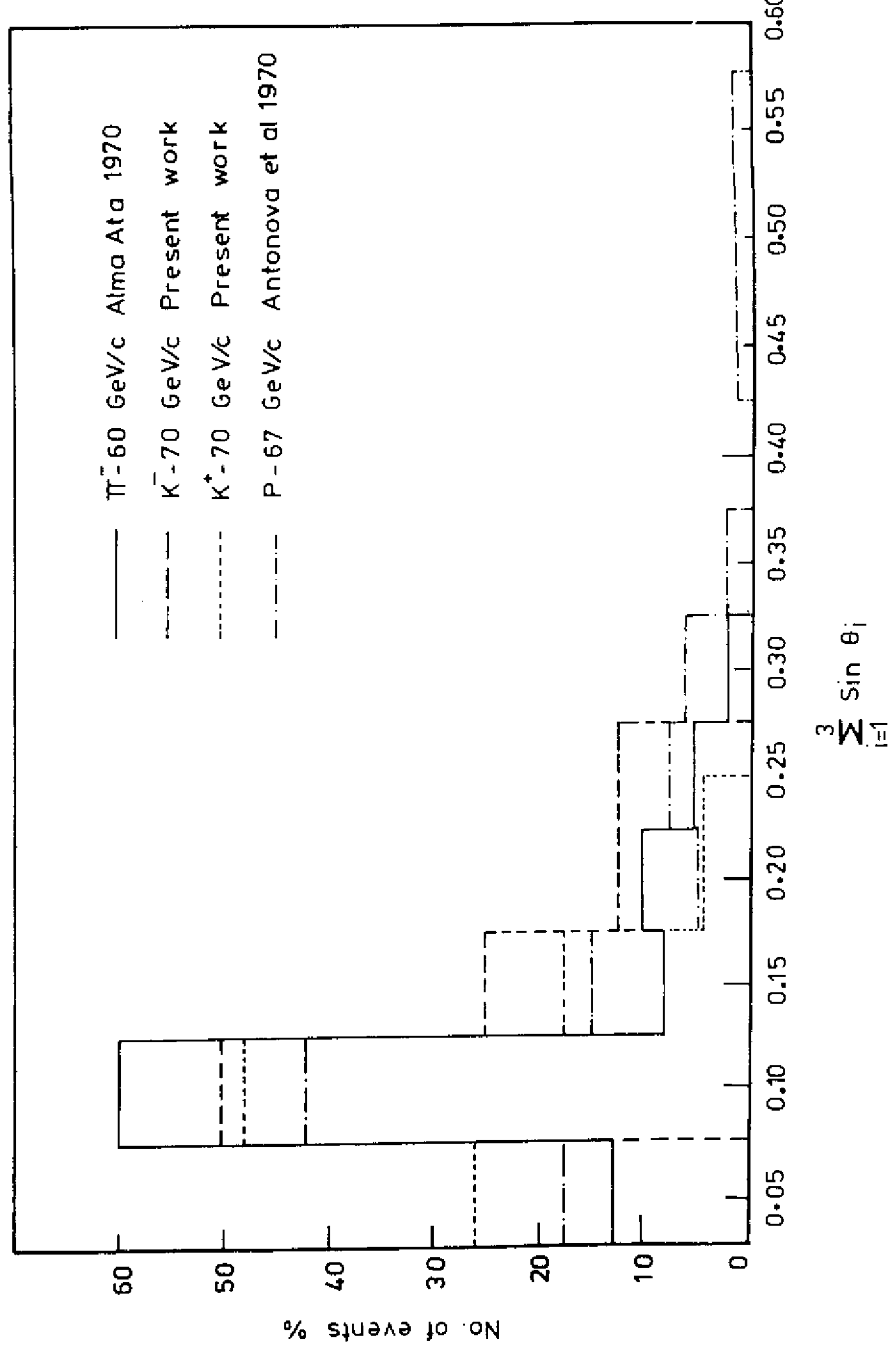
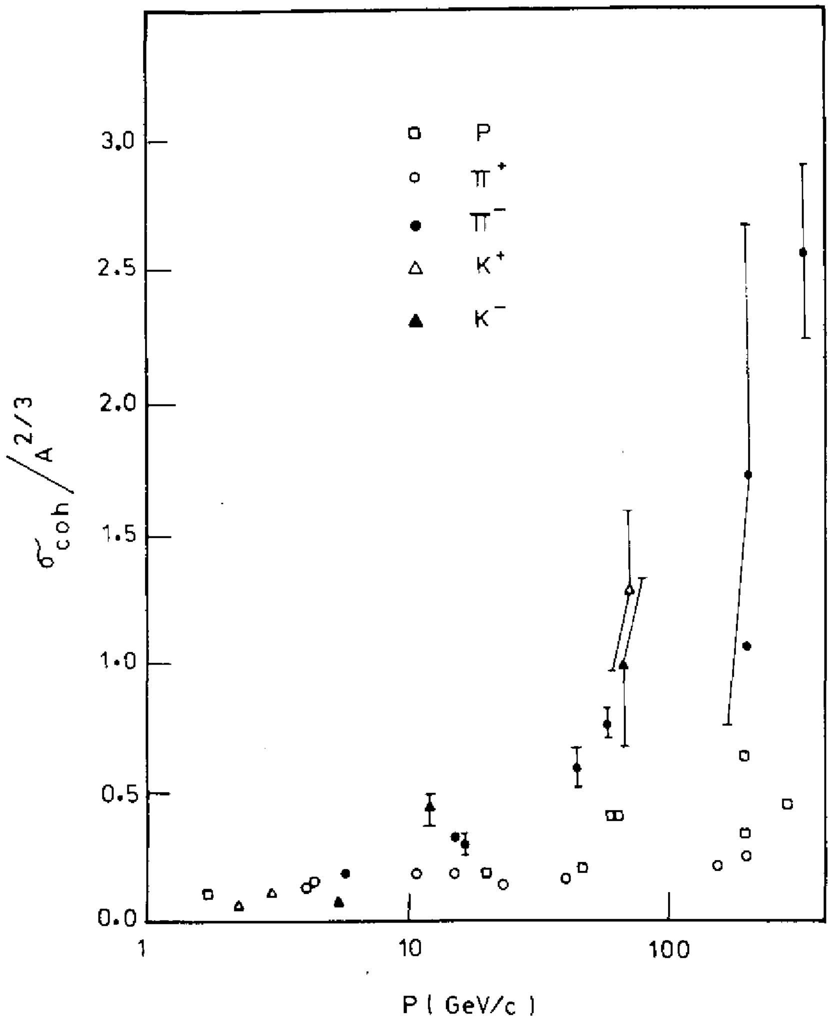
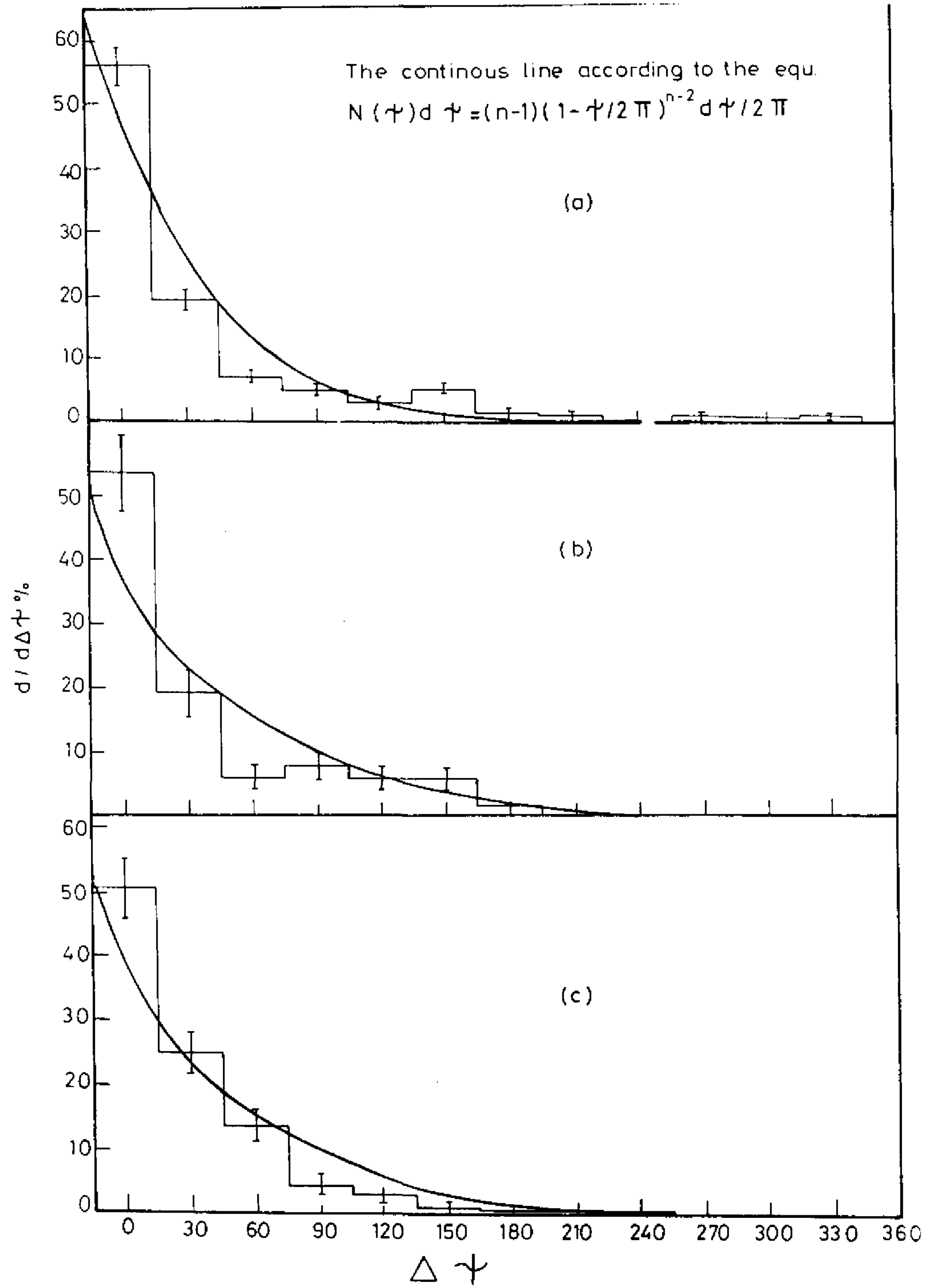

π^--60 GeV/c Alma Ata 1970
K^--70 GeV/c Present work
K^+-70 GeV/c Present work
P-67 GeV/c Antonova et al 1970
No. of events %
$\sum_{i=1}^{3} \sin \theta_i$

Fig.(4)



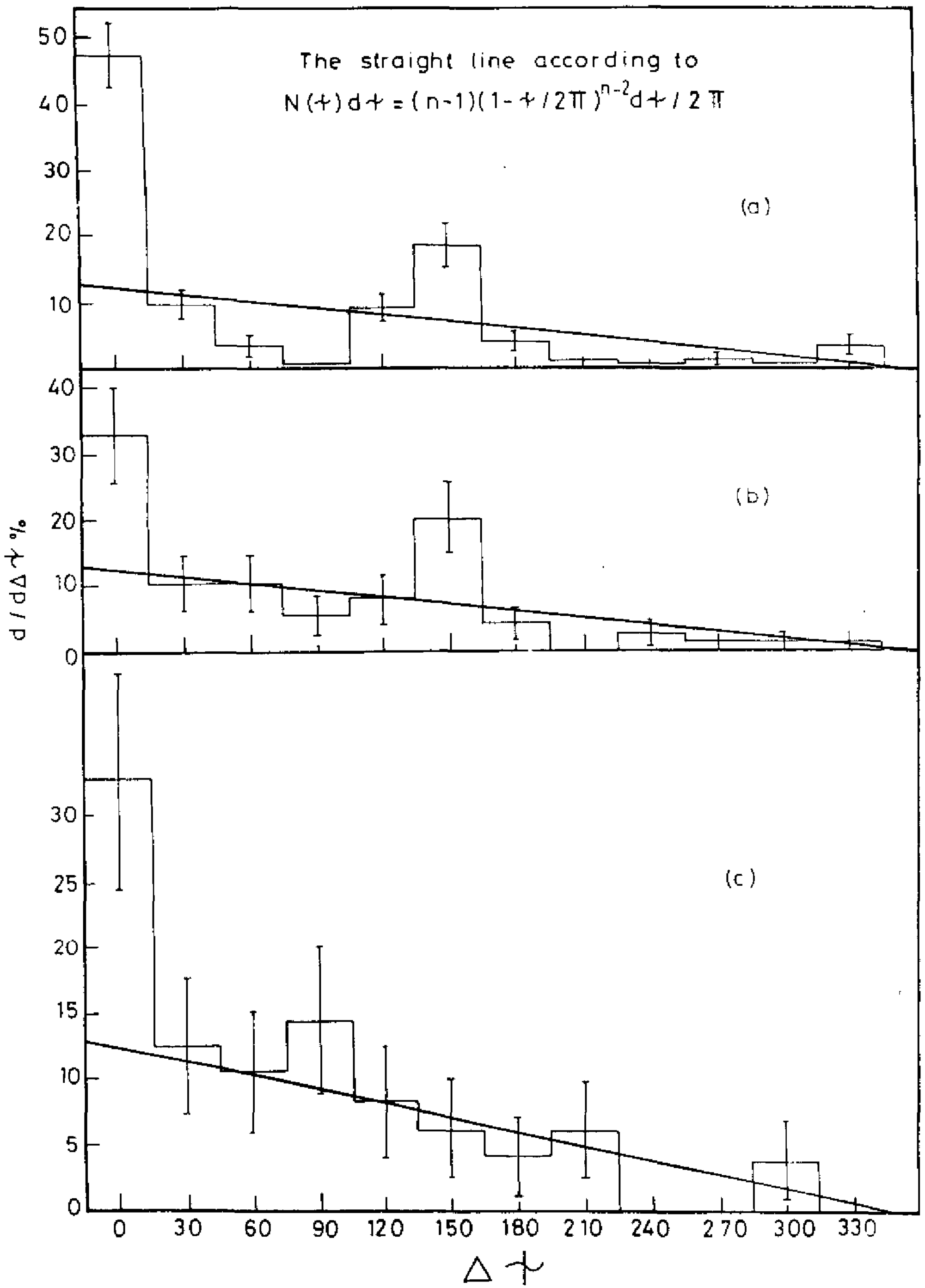
P
π⁺
π⁻
K⁺
K⁻
σ_coh / A^{2/3}
P (GeV/c)

Fig.(5)



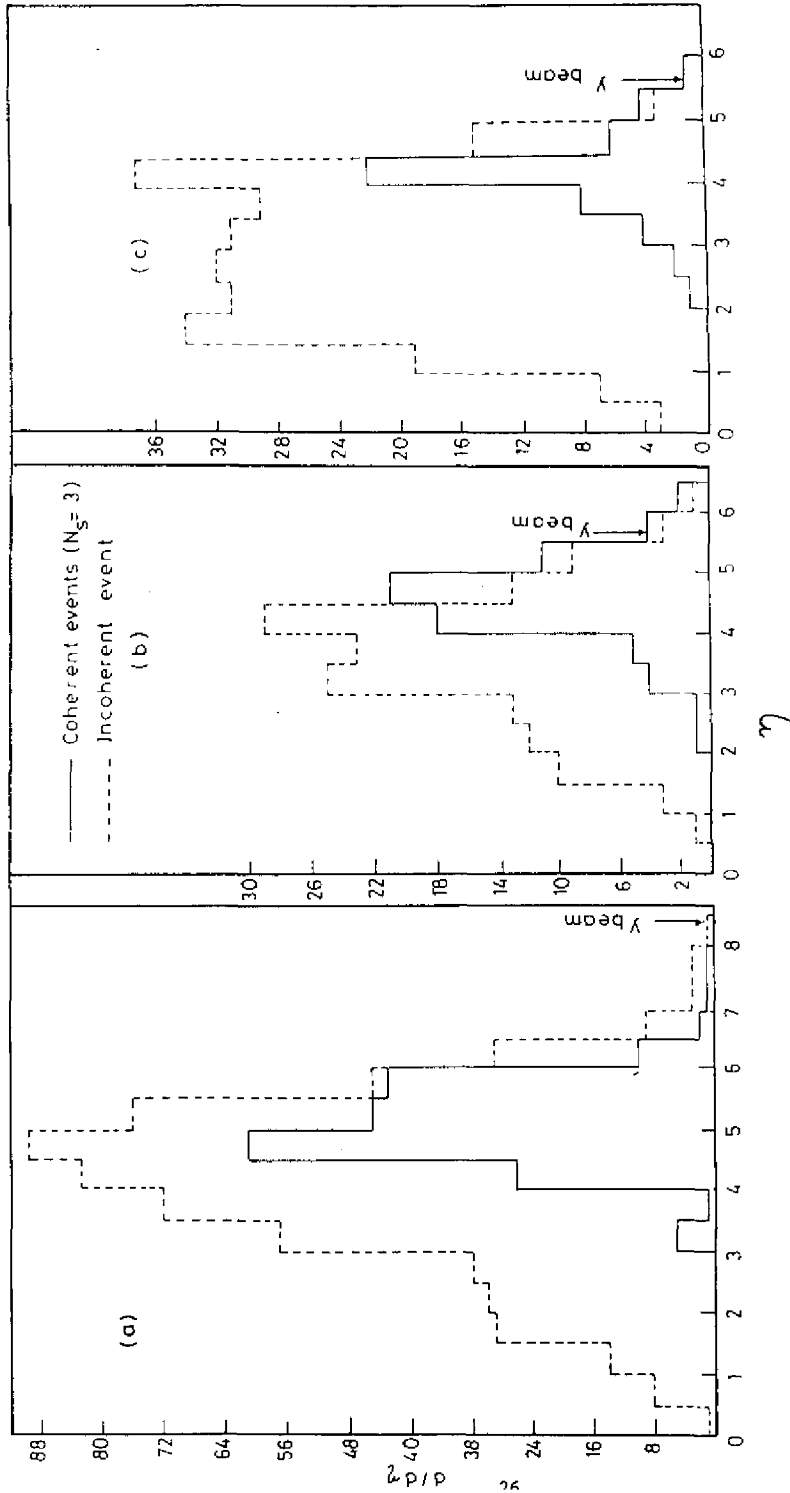
The continous line according to the equ.
N (ψ)d ψ =(n-1)(1- ψ/2 π)^{n-2} d ψ / 2 π
(a)
(b)
(c)
d / dΔψ %
Δ ψ

Fig.(6)



The straight line according to
N(+) d+ = (n-1)(1- + / 2π)^n-2 d+ / 2π
(a)
(b)
(c)
d / dΔ+ %
Δ+

Fig.(7)



γ beam
(a)
(b)
(c)
Coherent events (Ns = 3)
Incoherent event

Fig (8)