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Coherent Production of Particles by 200 GeV/c Protons in Nuclear Emulsion*

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ABSTRACT

The coherent production of particles by 200 GeV protons was observed in nuclear emulsion. The cross section of three-prong events by this process was evaluated from the data obtained in 400 meters of along-the-track scanning.

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Until the present time, there have been no experimental data available for the inelastic coherent production of particles in proton-nucleus reactions in 200 GeV proton primary energy. It is important to know the cross section of the coherent production at high energy because the particle production via this process seems to increase with energy, while the particle production via multiparticle production process also becomes a predominant feature at this energy.

A number of papers on the coherent production by pions in lower energy regions have been published[1,2,3,4]. However, little is known about the process at very high energy, in particular, for the cross section of dissociation of particles by protons. The production of particles by the coherent process may be attributed to Coulomb dissociation or diffraction dissociation in which the later occurs mainly with nuclear fields. However, complete separation of these two processes in the experiment is not possible as will be discussed later. Therefore, these two processes will be treated together as the coherent process in this article.

As demonstrated in earlier theoretical speculation[5] on the possibility of the above process, the cross section of the dissociation of particles may be proportional to Ep in the case of diffraction dissociation and proportional to LnEp in the case of Coulomb dissociation, where Ep is the incident energy of the particle in the lab system.

For a proton projectile, the final state of particles via this process typically forms an odd number of charged particles so as to conserve the initial quantum state of the particle. The probable reactions will be:

$P + A \rightarrow P\pi^0 + m\pi^0 + A$	1 prong
$\rightarrow n\pi^0 + m\pi^0 + A$	1 prong
$\rightarrow \pi^+\pi^- + m\pi^0 + A$	3 prongs
$\rightarrow n\pi^+\pi^+\pi^- + m\pi^0 + A$	3 prongs
$\rightarrow p\pi^+\pi^-\pi^+\pi^- + m\pi^0 + A$	5 prongs
$\rightarrow n\pi^+\pi^+\pi^-\pi^+\pi^- + m\pi^0 + A$	5 prongs

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etc., where A is a target nucleus in its ground state and m = 0, 1, 2, 3...

We have exposed a small stack of Ilford G_5 nuclear emulsion to a beam of 200 GeV/c protons with a flux of $2 \cdot 10^4$ protons/cm^2 at NAL. By "along-the-track" scanning method, 400.3 meters of proton track were scanned and 1244 interactions were found. Out of this, 227 interactions were classified as white stars[6] which consist of only relativistic particles, except in some cases the recoil target proton appears with non-relativistic velocity.

As seen in Fig. 1, the multiplicity distribution for these white stars exhibits a high peak at multiplicity three. The white stars used in Fig. 1 are only those events which have neither an Auger electron nor a recoil nucleus (we defined a recoil nucleus as $\geq$ 3 grains forming a stub or a track at the vertex point. Therefore, these events can be considered as proton-nucleon interactions. There is no reason for the abundance of 3-prong events in the multiparticle process in this energy region. It is known that the average multiplicity of the interaction, due to multiparticle production process, is about 8 at this energy, and the distribution obeys roughly a Poisson type[8] distribution as shown in Fig. 1. This peak in dotted line indicates that a considerable number of dissociation products are yielded at this energy.

By the present experimental method, the diffraction of a single track was not detected, but all reactions with ≥ 2-prong final states were recorded. The production of ≥ 5 prongs via the coherent process would be much less[2,7] than that of 3 prongs. Besides, the multiparticle production process yields a great fraction at ≥ 5-prong events at this energy. Therefore, in the present analysis we will deal with 3-prong coherent events mainly with some discussion of 5-prong reactions later.

With the kinematical consideration[9] of the conservation of energy and momentum of the process, the following relation is obtained

$$\sum_{i=1}^{3} \sin \theta_i \leq q_{\ell\, max}/m_\pi = A^{-1/3} \qquad (1)$$

where $q_{\ell\, max}$ is the maximum longitudinal momentum transfer in the process and is of order of the inverse of the radius of the target nucleus, $m_\pi A^{-1/3}$; θ_i is the space angle of ith particle in the final state. The above relation gives some measure to differentiate between trident reactions produced via the coherent process and those produced via the multiparticle production process. In the nuclear emulsion the lightest nucleus is carbon where diffraction dissociation mainly occurs; the heaviest is silver where Coulomb dissociation dominates. Thus, the parameter $\sum_{i=1}^{3} \sin \theta_i$ expressed in the relation (1) becomes 0.43 for carbon nucleus and 0.21 for silver nucleus as the upper limits. We set 0.43 as the upper limit for the criterion of the coherent process. This criterion is used for both the diffraction process and the Coulomb process since it is not possible to differentiate between the two processes at $\sum_{i=1}^{3} \sin \theta_i \leq 0.21$.

Since the space resolution in nuclear emulsion is very high, we made angular measurements of all the tracks in the trident events and thus $\sum_{i=1}^{3} \sin \theta_i$ of individual events were evaluated. Out of 46 trident events,

5 were rejected because the vertex was not clean; 38 events fell in the region of $\sum_{i=1}^{3} \sin \theta_i \leq 0.43$; 3 were > 0.43. By taking measurements on the scatterings of all the tracks, 13 events were identified as the type having an electron pair associated with proton projectile which give a cross section of ∿7mb for electron pair production at this energy. Those events were removed from the data. Thus 25 trident events are attributed to the coherent process. The distribution of values of $\sum_{i=1}^{3} \sin \theta_i$ for these 25 events is shown in Fig. 2.

Not all of these 25 events are necessarily due to the coherent process as the criterion gives only the upper limit. A contamination from the reaction $pn \rightarrow p\pi^+\pi^-n$ may be possible. If all of these 25 tridents are removed from the multiplicity distribution shown in Fig. 1, a dip appears at multiplicity three. The Poisson distribution curve on the whole data in Fig. 1 indicates that 21 tridents belong to the coherent events. The interaction length for trident production via the coherent process for the present experiment turned out to be

$$\lambda_{3,coh} = 400.3 \text{ meters}/21 = (19.1 \pm 4.2) \text{ meters}$$

in the nuclear emulsion. The errors above and following are statistical. This value can be compared with the results[10,11] obtained in nuclear emulsions for lower energies. Figure 3 shows the interaction length of trident production by the coherent process as a function of the primary energy of the particles. Some of the data for pions seen in Fig. 3 are from refs. [1,2,7,12.] The data for protons at 200 GeV were obtained from the present experiment. The energy dependence of the interaction length is clearly seen, though the trend appears to be different for those induced

by pions and those induced by protons. This difference could be expected because of the difference in absorption of the waves.

To compare this interaction length to those obtained in other experiments, one needs to apply a certain normalization to the interaction length regarding the nucleus concerned. First, we express the interaction length in terms of the cross section for the emulsion. Since this process involves only the nuclei, we calculated the cross section by the following relation:

$$\sigma_{coh}(mb) = \frac{1}{N' \lambda_{coh}} = \frac{214}{\lambda(m)} ,$$

where $N' = N_o - N_H$ and is the number of nuclei in a cubic centimeter and is $4.683 \cdot 10^{22}$ for the Ilford G_5 emulsion[13]. N_o and N_H are the numbers of all atoms and of hydrogen per cm^3 of the nuclear emulsion. Thus, our $\sigma_{3,coh}$ becomes (11.2 ± 2.5) mb. This figure cannot be compared with other experiments unless normalized by A-dependency. From bubble-chamber experiments[4], the cross section of the coherent process seems to increase in proportion to $A^{2/3}$ of the target nucleus. By taking <A> = 24.56[13] for our emulsion, the value $\sigma_{coh}(mb)/A^{2/3}$ in the present experiment becomes (1.33 ± 0.29) mb. This value is shown in Fig. 4, together with those of other experiments. The cross section increases relatively fast with an increase in the primary energy. As seen in Fig. 4, the rate of the increase in the cross section is faster than $\ln Ep$ and is almost linear to Ep.

Five-prong events produced via the coherent process are not fully analyzed yet. From partial analysis of 5-prong events, we see that 3 out of 14 five-prong events fall in the region of $\sum_{i=1}^{3} \sin\theta_i \leq 0.43$. The corresponding number of coherent tridents within the same sample is 11 out of 17. The cross section for 5-prong coherent events seems to be

about 1/4 that of the 3-prong coherent events. However, the statistics are not high for 5-prong events, thus further investigation is needed on this problem.

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6 White stars are those primary events in which there may be zero ($N_h = 0$) or one ($N_h = 1$) black or grey track present along with all the light tracks. For p-p interactions we shall accept an event with $N_h = 1$ if the grey or the black track is in the forward hemisphere in the laboratory system. The nomenclature for black, grey and light tracks is as follows: light track, $g \leq 1.5\ g_o$; grey tracks, $1.5\ g_o < g < 2.5\ g_o$; black tracks, $g \geq 2.5\ g_o$, where g_o and g are the grain densities of the beams and secondary tracks.

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FIGURE CAPTIONS

Fig. 1 Multiplicity distribution of proton-nucleon interactions by 200 GeV/c protons. Theoretical curve fitted is a compound Poisson[8] distribution.

Fig. 2 The $\sum_{i=1}^{3} \sin \theta_i$ distribution of trident events. The vertical line at $\sum_{i=1}^{3} \sin \theta_i = 0.43$ is the upper limit for the coherent events.

Fig. 3 Interaction length of 3-prong and 5-prong coherent events as a function of primary energy. Numbers in the figures are references for the data referred. Our results are shown at *.

Fig. 4 Normalized cross section of trident production by the coherent process.

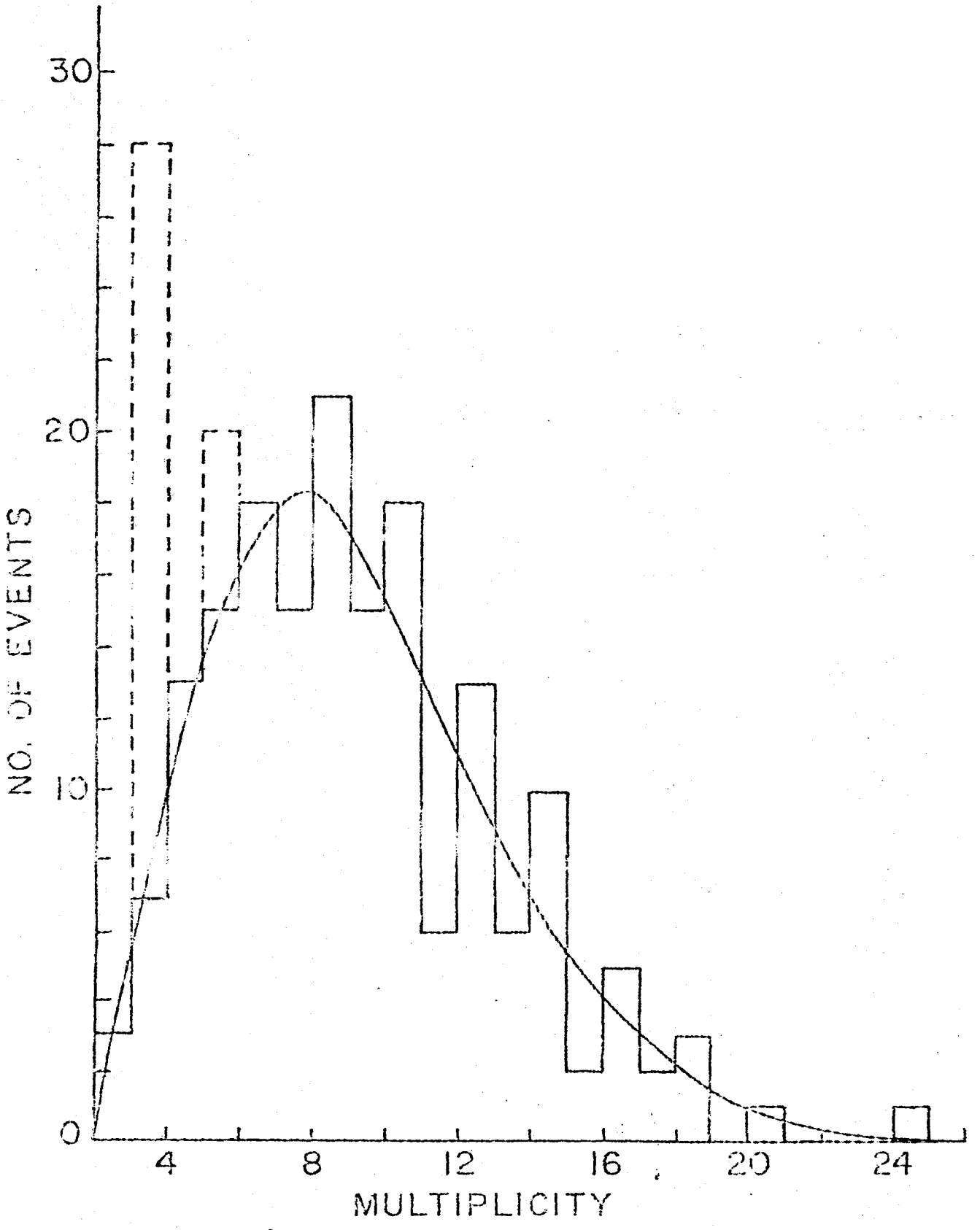


Figure 1

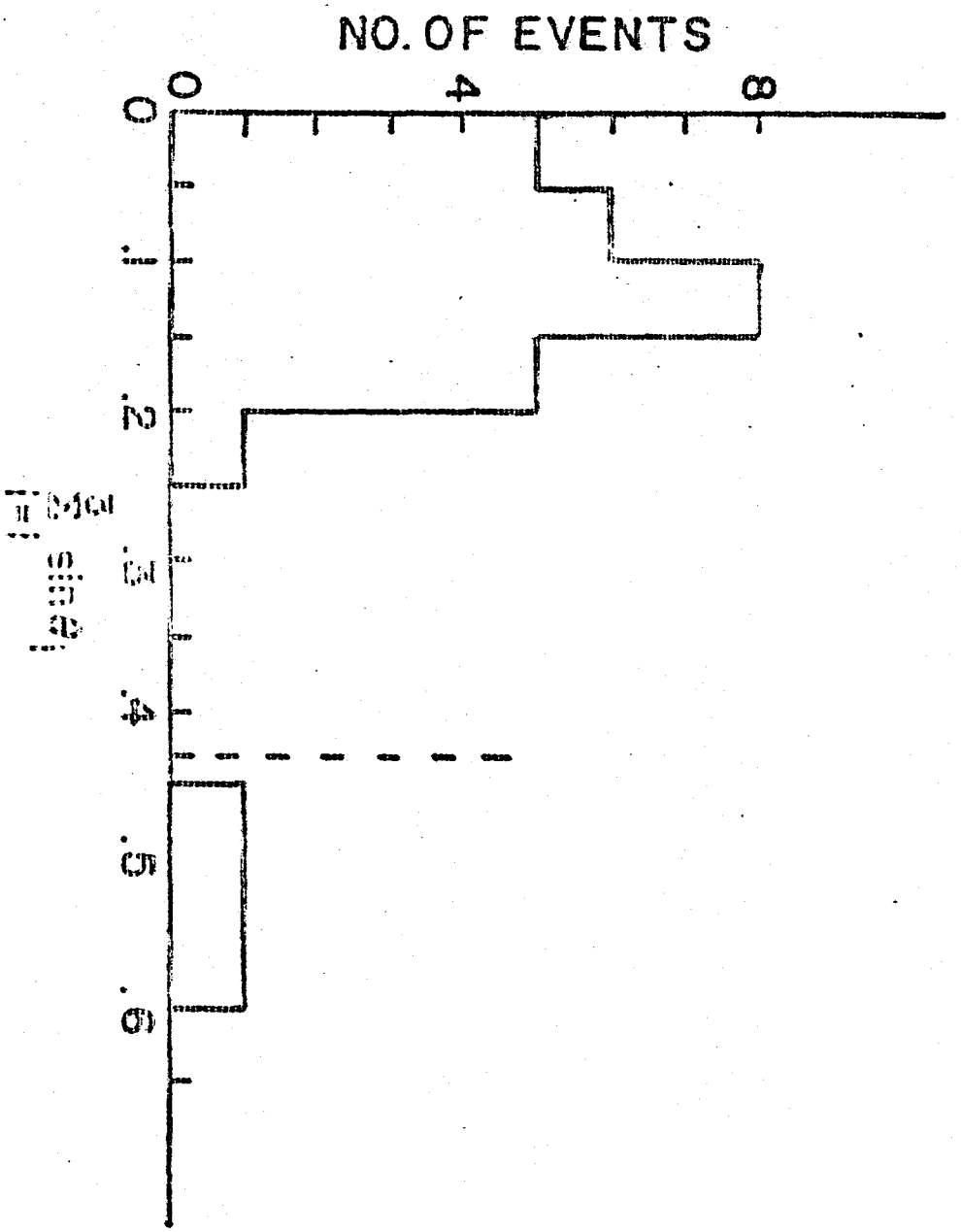
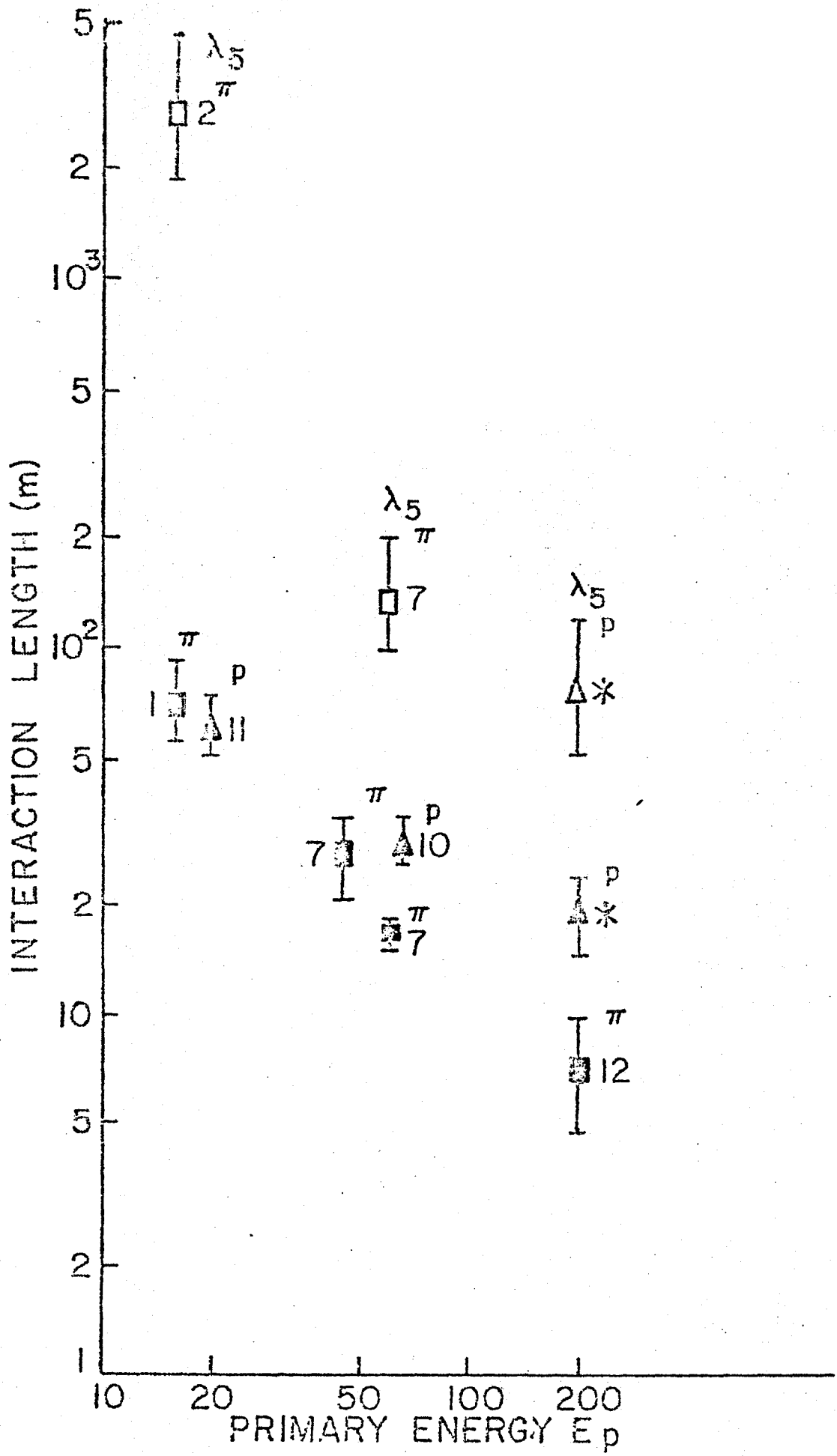


Figure 2



INTERACTION LENGTH (m)
PRIMARY ENERGY Ep
5
2
10³
5
2
10²
5
2
10
5
2
1
10
20
50
100
200
λ5
π
2
π
1
p
11
λ5
π
7
π
7
p
10
π
7
λ5
p
*
p
*
π
12

Figure.3

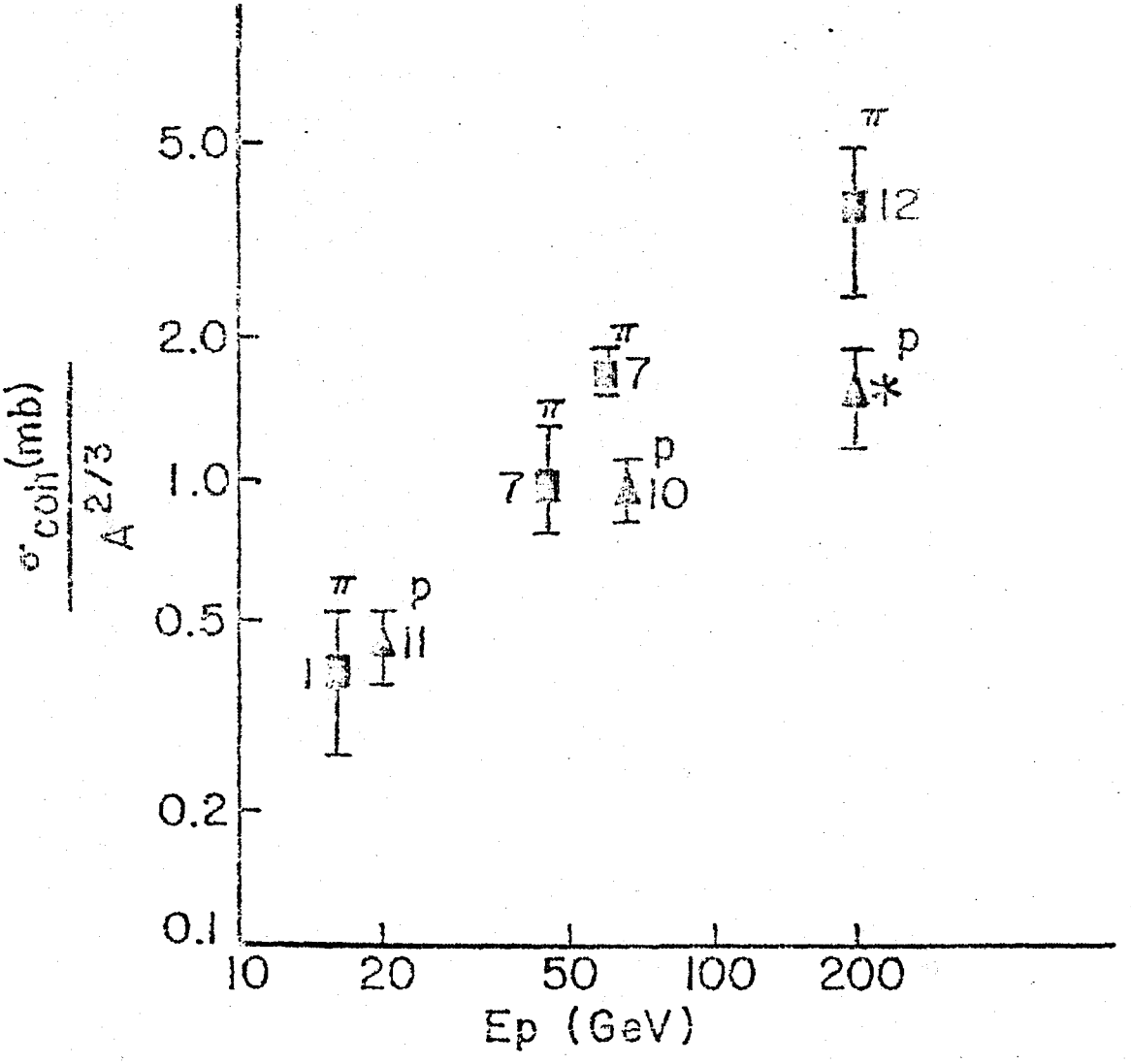

5.0
2.0
1.0
0.5
0.2
0.1
$\frac{\sigma_{coh}(mb)}{A^{2/3}}$
10
20
50
100
200
Ep (GeV)
π
p
1
11
7
10
12

Figure 4