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Inelastic Cross Sections for Proton-Nucleus Collisions at 205 GeV/c in Nuclear Emulsion

by

S.Konishi, O.Kusumoto, H.Okabe, S.Ozaki and M.Teranaka

Osaka City University, Osaka, Japan

G.Fujioka, H.Fukushima, M.Igarashi, K.Kobayakawa,

M.Miyagaki, Y.Tsuzuki and H.Yamasaki

Kobe University, Kobe, Japan

M.Ohta and T.Konishi

Kinki University, Higashi-Osaka, Japan

J.Yokota

Science Education Institute of Osaka Prefecture, Osaka, Japan

S.Mikamo

Institute for Nuclear Study, University of Tokyo, Tokyo, Japan

K.Kitayama

Wakayama Medical College, Wakayama, Japan

Abstract

A stack of the nuclear emulsion was exposed to the 205 GeV/c proton beam at NAL. By along-the-track scanning of 1060 m, 2963 inelastic proton-nucleus collisions are obtained. The cross section for the inelastic interaction, its mass number dependence and the cross section for the coherent production are studied.

In this note, some features of the inelastic cross sections for the proton-nucleus collisions at 205 GeV/c in nuclear emulsion are reported.

An emulsion stack of Ilford K5 pellicles of 34 sheets, each of which has a size of 15 cm x 7.5 cm x 600 μm was exposed to the 205 GeV/c proton beam at the National Accelerator Laboratory. The nominated momentum divergence of this proton beam was $\pm$ 0.1 %. The mean grain density of the 205 GeV/c protons after processing was 24.3 $\pm$ 0.3 grains per 100 μm.

Along-the-track scanning was performed over the track length of 1060 m and then 2963 inelastic proton-emulsion nucleus collisions were detected. In this detection, the events of the type of 0 + 1 and 0 + 2[1] in which the scattered angle of the proton is less than 5 mrad are excluded. In the 0 + 2 events, the particle with smaller scattered angle is assumed to be the surviving proton. By this selection of the scattered angle, the elastic events are reasonably excluded because of the sharp decrease of the cross section with the scattered angle[2]. The missing rate for the inelastic 0 + 1 and 0 + 2 events due to the 5 mrad cut might be estimated using the result of the bubble chamber analysis for the 205 GeV/c proton-proton interactions[3] under the assumption that the cross section for the proton-neutron interaction is the same as the proton-proton one. According to this estimation, the detected numbers for these two types of events are respectively about half of the expected ones. These corrections are not applied since, as will be shown later, the events of the type of $0 + n_s$ do not strictly correspond to the elementary processes except for the proton-hydrogen nucleus collision.

The electromagnetic interactions of the incoming proton, that is, konck-on process and electron-positron pair creation, contaminate the 0 + 2 and 0 + 3 events. The electrons with energies less than several tens of MeV are easily detected. The knock-on events with electrons of higher energies are almost completely excluded by the 5 mrad cut. The direct pair creation is identified by inspecting the scattering behavior of the associating electron or positron. The number of events thus excluded as the direct pair creation is consistent with King's result[4].

After correcting these electromagnetic events, the foregoing total number of events are obtained, among which 436 are $0 + n_s$. The mean free paths for the total inelastic and $0 + n_s$ events are respectively 35.8 ± 0.7 cm and 2.7 ± 0.1 m. It should be noted that the mean free path for the total inelastic events is somewhat shorter than those obtained below 70 GeV[5]. When we express the cross section for the proton-nucleus collision as $\sigma_0 A^{\alpha}$, where A is the mass number and σ_0 the cross section for the elementary proton-nucleon collision which is assumed to be the same as that for the 205 GeV/c proton-proton collision, then, α turns out to be 0.76 ± 0.11. In this computation, the coherent events are included. In the case that the coherent events are excluded, the value of α lies within the region of the present uncertainty since, as will be shown later, the number of the coherent events is relatively small. This result shows that the A-dependence of the cross section for the proton-nucleus collision might be somewhat stronger than that shown by $A^{2/3}$.

Fig. 1 shows the multiplicity distribution of charged particles for the events of $0 + n_s$. The dotted parts show the coherent production which will be mentioned in the subsequent paragraph. The hatched parts show the dirty events which mean the events with electrons (mostly one) and/or a track of its length less than 3 μm. The rest is the clean event. The mean n_s for the total, clean and dirty events of $0 + n_s$ are respectively 8.1 ± 0.4, 7.4 ± 0.4 and 9.4 ± 0.8. From the above definition, the dirty events are not pure elementary processes. Accordingly, the mean n_s for the total events of $0 + n_s$ shows the systematic deviation towards higher value than that expected from the result of the proton-proton collision.

The coherent production is defined as the diffractive dissociation of the incident proton induced by the proton-nucleus collision where the whole nucleons inside the target nucleus collide coherently with the proton[6]. From this definition and the energy-momentum conservation of this process, the coherent production is characterized by the following relation[7],

$$\sum_i m_i \sin\theta_i \lesssim q_{\parallel} \lesssim m_\pi / A^{\frac{1}{3}} \quad (1)$$

where m_i and θ_i are the mass and the emitted angle of the i-th outgoing particle and m_π is the pion mass. $q_{\parallel}$ is the momentum transfer of the proton parallel to its initial direction. In this work, the relation (1) is employed as the selection criterion to discriminate the coherent event. Different from the pion-nucleus collision, the factor m_i should be needed to select the coherent events induced by the proton-nucleus collision. To derive the value of $\sum_i m_i \sin\theta_i$, we assume that the smallest angle is the one for the proton. The dirty events with slow electrons cannot be the candidates for the coherent process, since in this process the target nucleus is left in the ground state. The dirty event with a track shorter than 3 μm is also excluded in this analysis.

In Fig. 2a, the distribution of $\sum_i m_i \sin\theta_i$ (hereafter denoted by q_{min}) thus obtained for the events of 0 + 3 is shown. The hatched portions show the dirty events. The distribution of q_{min} for the clean events has a clear peak at small q_{min}. This q_{min} value is in the region assigned by the criterion $q_{\parallel} \lesssim m_\pi / A^{\frac{1}{3}}$, because the value of $m_\pi / A^{1/3}$ is 0.03 GeV for heavy nuclei (Ag and Br) and 0.06 GeV for light nuclei (C, N and O). However, in this coherent q_{min} region, the incoherent events like the clean event induced by the proton-peripheral neutron collision are included. The rate of these incoherent events included in the coherent q_{min} region is estimated using the rate of the clean to dirty events in the incoherent q_{min} region as,

$$(\text{the number of dirty events at } q_{min} < m_\pi/A^{1/3}) \times \frac{(\text{the number of clean events at } q_{min} \geq m_\pi/A^{1/3})}{(\text{the number of dirty events at } q_{min} \geq m_\pi/A^{1/3})} \quad (2)$$

In practice, we use 0.06 GeV as the $m_\pi/A^{1/3}$ value. Thus, we obtain the number of the coherent events of 0 + 3 to be 17 $\pm$ 12. The corresponding mean free path is 62^{+172}_{-26} m. In Figs. 2b and 2c, the q_{min} distributions for the events of 0 + 5 and 0 + 7 are shown. By the same procedure as the case of 0 + 3, the coherent events of 0 + 5 and 0 + 7 are obtained respectively as 13 $\pm$ 6 and 6 $\pm$ 5. The corresponding mean free paths are 80^{+77}_{-26} m for 0 + 5 and 179^{+743}_{-80} m for 0 + 7. The relatively large error associated with each value of the mean free path is due to the statistics of the events used to evaluate the relation (2). Among these results, the mean free path for the 0 + 3 coherent event seems to be somewhat large in comparison with the result obtained by other authors[8], though the selection criteria are different. In Fig. 3, the cross sections for the coherent productions at various proton energies obtained so far by emulsion analyses[5] are shown. In other analyses, the different selection criteria are adopted. Therefore, there should be some problems to compare our results directly with those of other authors, among which the difference between the selection criteria of $\sum_i m_i \sin\theta_i$ and $\sum_i \sin\theta_i$ would be the main problem. If the same selection of $\sum_i \sin\theta_i \lesssim A^{-1/3}$ as other authors is applied to our data, we obtain the mean free paths of 41 m for 0 + 3 and of 72 m for 0 + 5. By comparing these values with those obtained before, it will be said that the difference between two methods is not so serious. Therefore, it could be said that Fig. 3 shows the energy dependence of the cross section for the coherent production. In this figure, the cross section for the 0 + 3 coherent event seems to reveal a tendency to rather decrease or flatten (taking into account of the difference of the selection criteria) in the energy region between 70 and 200 GeV, while the cross section for the 0 + 5 event continues to rise.

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References

1 The notation 0 + 1 or so is the same one employed usually in emulsion analysis, that is, the number of evaporated and slow charged particles whose track lengths are larger than 3 μm, N_h, plus the number of fast charged particles, n_s. The word fast or slow corresponds to the velocity more than or less than about 0.7 of the light velocity.

2 V. Bartenev et al., Phys. Rev. Lett. 31 1088 (1973)

3 G. Charlton et al., Phys. Rev. Lett. 29 515 (1972)

4 J. E. Butt and D. T. King, Phys. Rev. Lett. 31 904 (1973)

5 M. G. Antonova et al., Phys. Lett. 39B 282 (1972)

6 J. J. Veillet, CERN 68-7 1 537 (1968); K. Gottfried, Th. 1564-CERN (1972); L. Van Hove, Th. 1746-CERN (1973)

7 The energy-momentum conservation gives

$$q_{\parallel} = \sum_i (E_i - P_{\parallel i}) - (E_0 - P_0) + \nu ,$$

where E_i and $P_{\parallel i}$ are the energy and momentum parallel to the incident direction for the i-th outgoing particle. E_0 and P_0 are the energy and momentum of the projectile proton. ν is the transfer energy to the target nucleus. In the diffractive dissociation, θ_i is expected to be small enough, then,

$$E_i - P_{\parallel i} = \frac{m_i^2}{2P_i} + \frac{P_i}{2}\sin^2\theta_i ,$$

where P_i is the momentum of the i-th outgoing particle. Therefore, $q_{\parallel}$ has a minimum value at $\nu = 0$ and $P_i \sin\theta_i = m_i$ and then,

$$q_{\parallel} \gtrsim \sum_i m_i \sin\theta_i .$$

From the definition of the coherent production, the condition of $qR \lesssim 1$ should be fulfilled, where q is the momentum transfer to the target nucleus and R the nuclear radius. Then we get,

$$m_\pi / A^{\frac{1}{3}} \gtrsim q_{\parallel} \gtrsim \sum_i m_i \sin\theta_i$$

8 Z. V. Anzon et al., Conference Papers of the 13th International Conference on Cosmic Rays 2063 (1973)

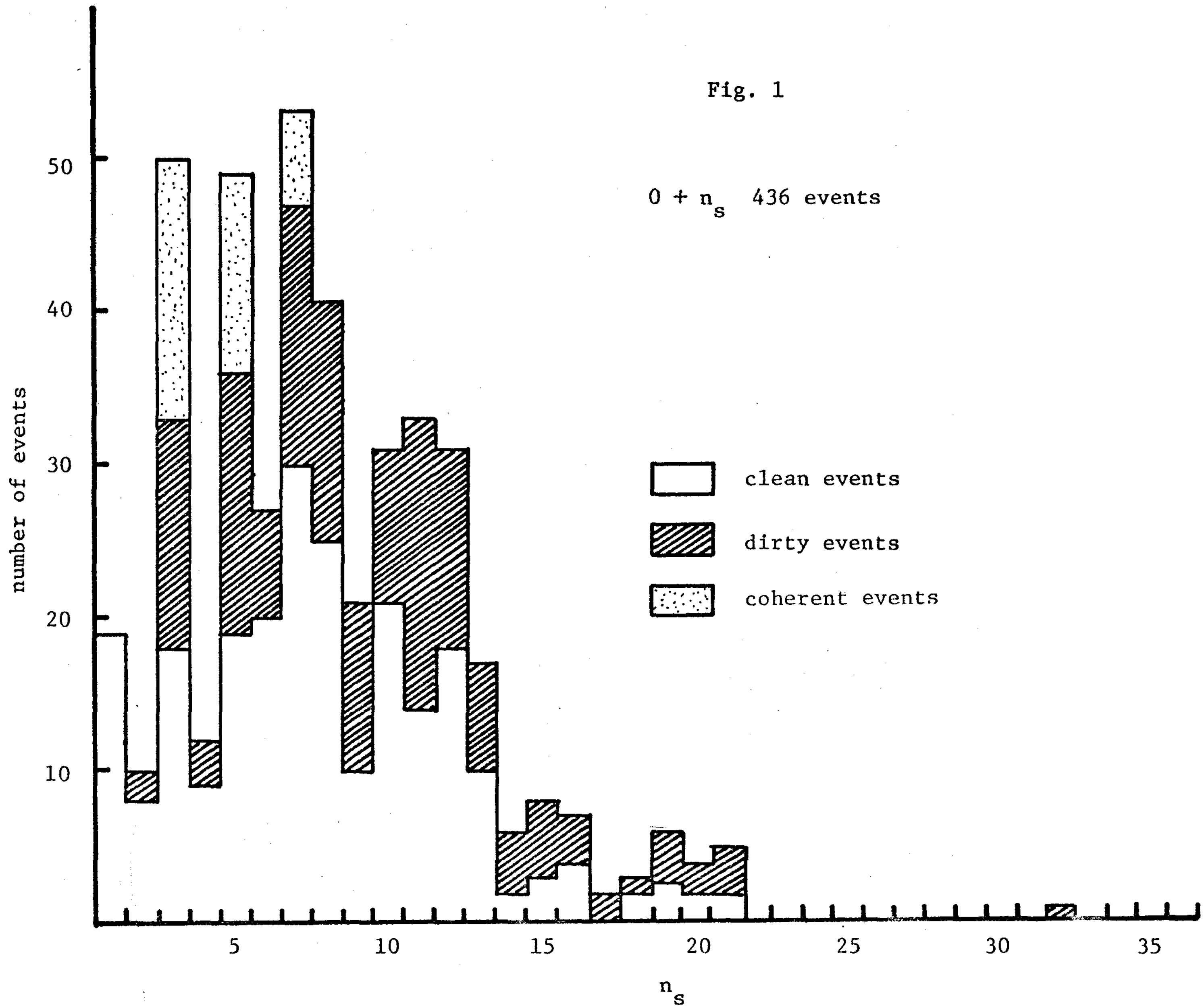
Figure Captions

Fig. 1 Multiplicity distribution of charged particles for the events of $0 + n_s$.

Fig. 2 Distribution of $\sum_i m_i \sin\theta_i$. a, b and c show the distributions for the events of 0 + 3, 0 + 5 and 0 + 7. A few events whose values of $\sum_i m_i \sin\theta_i$ are larger than 0.30 are not shown.

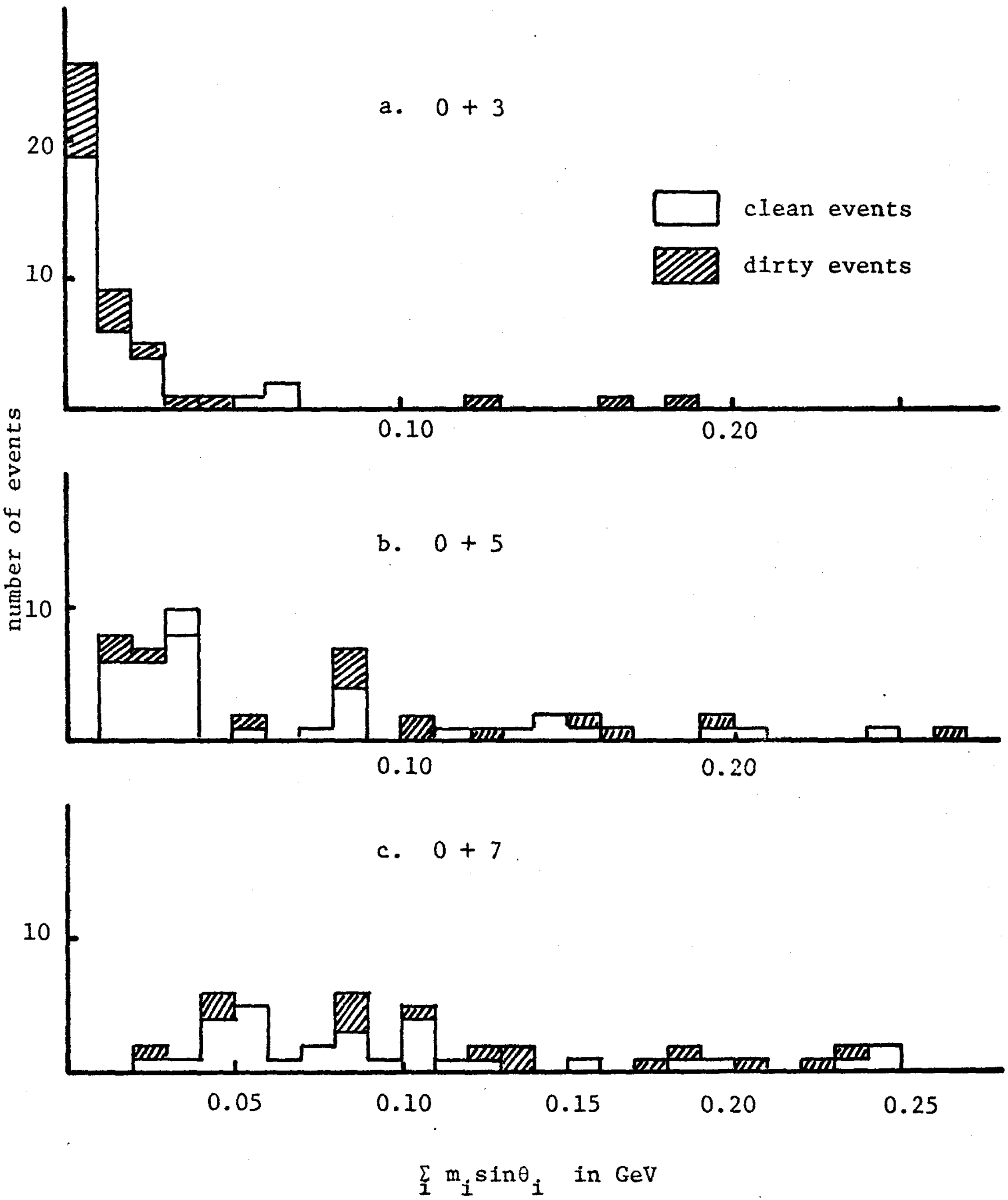
Fig. 3 Cross sections for the coherent productions induced by the protons with various energies in emulsion. Abscissa is the momentum of the incident proton in the Laboratory frame. Ordinate is the cross section divided by the mean value of $A^{2/3}$ of emulsion nuclei. Three points at P_{lab} = 205 GeV/c are due to our experiment. Other points are quoted from Reference 5. Two curves show the results obtained so far by π^- in emulsion.

Fig. 1



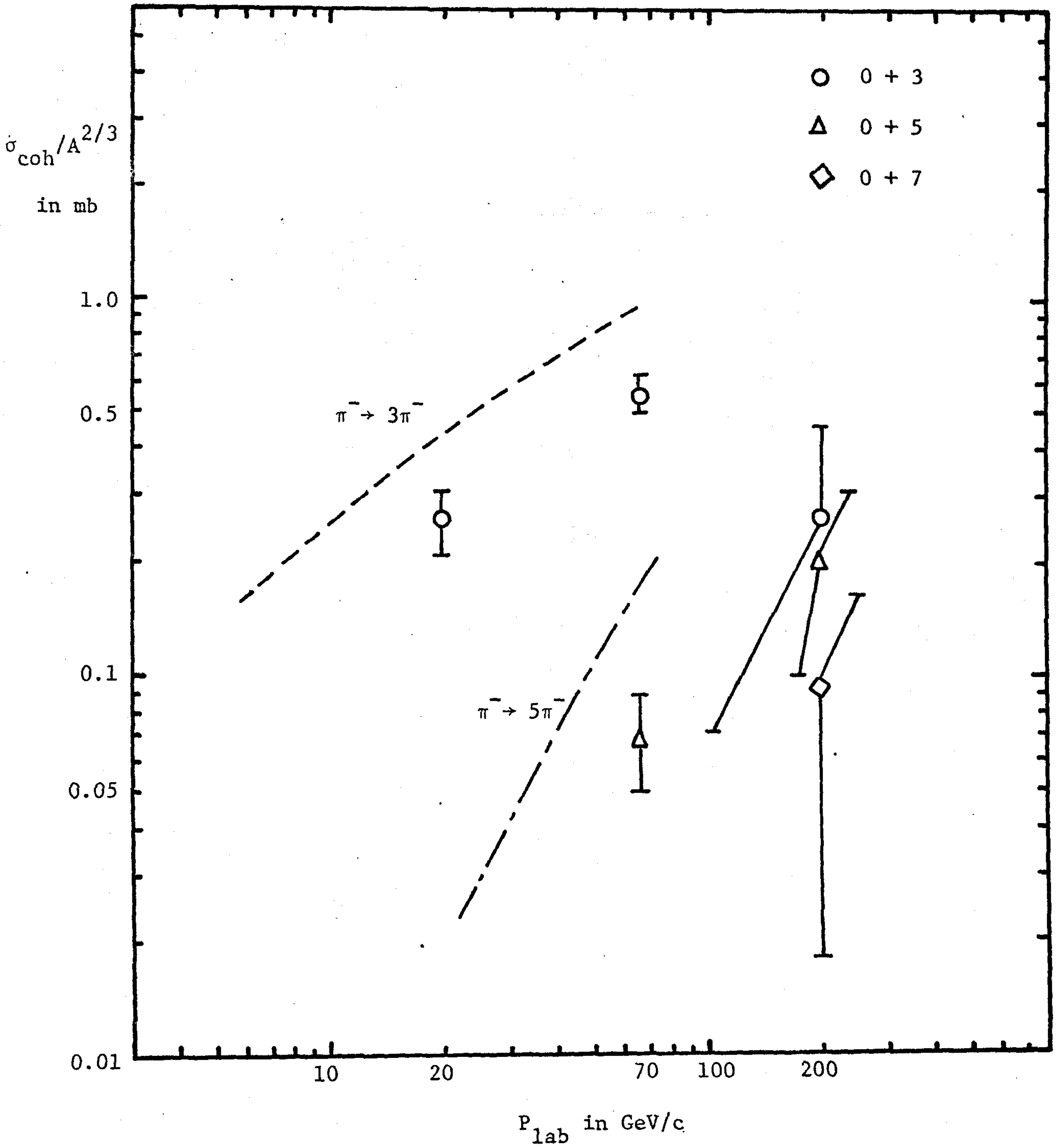
0 + n_s 436 events
clean events
dirty events
coherent events
number of events
10
20
30
40
50
5
10
15
20
25
30
35
n_s

Fig. 2



a. 0 + 3
clean events
dirty events
20
10
0.10
0.20
number of events
b. 0 + 5
10
0.10
0.20
c. 0 + 7
10
0.05
0.10
0.15
0.20
0.25
$\sum_i m_i \sin\theta_i$ in GeV

Fig. 3



$\sigma_{coh}/A^{2/3}$
in mb
1.0
0.5
0.1
0.05
0.01
10
20
70
100
200
P_{lab} in GeV/c
0 + 3
0 + 5
0 + 7
$\pi^- \to 3\pi^-$
$\pi^- \to 5\pi^-$