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ON THE VARIATION OF CROSS SECTION WITH INCIDENT MOMENTUM OF TWO-BODY REACTIONS AT HIGH ENERGY

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Abstract:

For two-body reactions, the variation of the cross section, σ, with the incident laboratory momentum, p_{in}, is found to be consistent with the relationship, $\sigma = \text{const.}\ p_{in}^{-n}$. The values of the exponent, n, are found to fall into three groups, about 0, a broad group from 1.5 to 2.0 and about 4. The three categories are discussed and some consistency is found with the Regge Pole model.

Results are presented in this letter on the variation of the cross section, σ, with incident laboratory momentum, p_{in}, for two-body reactions of the type

$$A + B \rightarrow C + D \quad . \qquad (1)$$

The results for inelastic reactions are shown in Figures 1 and 2. For reactions involving resonances, the cross sections have often been determined at different momenta by different groups and it may happen that the groups have different methods of analysis and of estimating background. Hence, as can be seen in Figures 1 and 2, the results are sometimes inconsistent. The inconsistencies are particularly important for reactions with double resonance production where the resonances are **wide**, such as $\pi + p \rightarrow N^{*}\rho$, as can be seen in Fig. 1i[1].

At low momenta, cross sections tend to fluctuate because of the occurrence of resonances in the production process. If, to avoid this difficulty and to avoid threshold effects, we consider only higher momenta, say greater than 2 GeV/c, then it can be seen in Figures 1 and 2 that the results may be expressed by the following relation :

$$\sigma = K \, (p_{in} / p_o)^{-n} \qquad (2)$$

where K and n are constants and p_o is a dimensional constant taken as p_o = 1 GeV/c.

The values of the exponent, n, for these and other inelastic two-body reactions, are listed in Table I, together with the range of incident laboratory momentum over which they were calculated and the constant K, which is the cross section extrapolated to p_{in} = 1 GeV/c. In the calculation of the exponents, n, given in Table I, results for momenta of more than 2 GeV/c have been used wherever possible.

The results for reactions 1 to 4 are shown in Figure 4 of Anderson et al.[2]. The results for reactions 5, 6 and 7 are given in the following paper[3]. The reactions of double resonance production 32, 33 and 34 for which the cross section is difficult to determine will not be considered in the following discussion. The values of the cross section for reaction 8 have very large errors and this reaction will also not be considered further.

After making allowance for the uncertainties of the results, there appears to be three groups of values of exponents, one about zero, secondly a broad group of values extending from extreme values of 1.1 to 2.8, and thirdly a group with exponent about 4. We now consider these three categories in turn.

Category 1 may be generalised to include elastic scatters, which are well known to have approximately constant cross section with respect to incident energy, i.e., $n \approx 0$. The surprising result that the cross sections for the inelastic reactions 1 to 7 are approximately constant is discussed in the following paper[3]. There it is suggested that if the reactions can be interpreted in terms of a Feynmann diagram in which a diffraction scattering occurs at one vertex then the cross section will be constant at high energies.

Category 2, consisting of inelastic reactions 8 to 34, has a large range of exponent. A common characteristic of these reactions is that they can be described by a Feynmann diagram in which a single meson is exchanged. For reactions 9 to 22 (and also 8, 32, 33 and 34) this meson has zero strangeness and it can be seen that the exponents tend to group around $n \approx 1.5$. For reactions 23 to 31, the meson has a strangeness of one and the exponents tend to group around $n \approx 2.0$. Hence, we would suggest that category two has two sub-groups with exponents of about 1.5 or 2.0 according to whether the exchanged meson is non-strange or strange, respectively.

Reactions 35, 36 and 37 of category three, all have the characteristic that they do not have, at high energy, a forward diffraction peak ($\theta_{CM} = 0^{\circ}$) but do have a backward peak[4,5]. In terms of Feynmann diagrams, a forward peak would require the exchange of two units of charge, while a backward peak would require exchange of a particle with baryon number $B = 1$. Backward elastic scattering is another reaction which would require exchange of a particle with $B = 1$. As cross sections for backward elastic scattering are not available, we have plotted in Fig. 2d, the values for the differential cross section ($d\sigma/dt$), at 180°[6,7] or near 180°[8,9] for reaction 38. Because of constructive and destructive interference between the isobars produced, the values of $d\sigma/dt$ fluctuate considerably, but it can be seen that if these fluctuations are ignored, a rough fit to the data can be obtained with a line having the equation :

$$(d\sigma/dt)_{180^{\circ}} = 7.3\,(p_{in} / p_o)^{-4.0} . \qquad (3)$$

One of the most striking features of Figures 1 and 2 is that for a given value of p_{in}, similar reactions tend to have the same cross section. Thus at 3 GeV/c, if we consider the 9 reactions (numbers 23 to 31) requiring exchange of a strange meson, 8 of them have approximately the same cross section of about 0.1 to 0.15 mb. It can be seen in Fig. 2c, that ignoring threshold effects, the cross section at a given p_{in} for reaction 37 which requires the exchange of a strange baryon (e.g. Λ^{0}) is similar to that for reactions 35 and 36 where exchange of a non-strange baryon is required.

It is possible to interpret these results in the framework of the Regge Pole model. In this model the differential cross sections are expressed in terms of the square of the total energy, s, but at high energies this is directly proportional to p_{in}. A comparison of these results with the Regge Pole model cannot be made directly, since the model predicts the variation of the differential cross section with s at a fixed value of t, whereas we report here on the total cross sections, σ, integrated over all t-values. In the Regge Pole model, the differential cross section $d\sigma/dt$ is proportional to $s^{2\alpha(t)-2}$. As small t-values yield most of the reaction cross section, the exponent, n, should be approximately equal to $\{2\alpha(0) - 2\}$. If the value of $\alpha(t)$ decreases as t decreases, then the exponent n will be slightly greater than $\{2\alpha(0) - 2\}$. For category 1 reactions, exchange of the Pomeranchuk trajectory is postulated and as $\alpha(0) = 1$, the exponent is expected to be about zero. For the first sub-group of category 2, exchange of the ρ or R trajectory is expected and as $\alpha(0)$ is about 1/2 and as $\alpha(t)$ decreases as t decreases, the exponent n is expected to be slightly greater than one. For the second sub-group of category 2, the K^{*}-trajectory is expected to dominate and as this has a $\alpha(0)$ value slightly less than that for the ρ or for the R trajectory, the value of the exponent n should be slightly greater than for the first sub-group. The trajectories for nucleons, isobars and hyperons are all believed to have negative values of α at $t = 0$, and hence the exponent will be appreciably larger than that for category 2. If for backward elastic scattering of negative pions the differential cross section, $d\sigma/dt$, is plotted against s, the exponent is about 4.5.

In one-meson exchange models, such as the absorption model, one expects different values of the exponent, n, according to whether a pion or a vector meson is exchanged. But the exponent for reactions 9 to 22 show no difference due to the mass or spin of the exchanged particle. For interactions requiring pion exchange, one instead considers in the Regge Pole model the exchange of the R-trajectory. As the R and ρ trajectories are believed to be similar, we would expect similar values of the exponent for all reactions for which the R or ρ trajectory is the dominant one. Hence this may be considered evidence in favour of the Regge Pole model.

This letter is part of a review paper[10] given at the Stony Brook Conference on Two-Body Reactions, April 1966, and a more detailed discussion and further references will be given there.

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FIGURE CAPTIONS

Fig. 1. Variation of the cross section of two-body reactions of category 2 with incident laboratory momentum.

Fig. 2.a)b)c). Variation of the cross section for two-body reactions of category 3, with incident laboratory momentum;

d). Variation with incident laboratory momentum of the differential cross section $d\sigma/dt$, for scattering at 180° in the reaction $\pi^- p \to p\pi^-$.

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TABLE I

REACTION		INCID. MOM^{M} GeV/c.		Constant, K. mb.	Exponent, n
No.		Min	Max		
1	$p + p \rightarrow p + N^{*}(1400)$	10	30	$0.3 \; {}^{+0.4}_{-0.2}$	0.3 ± 0.3
2	$p + p \rightarrow p + N^{*}(1520)$	10	30	$0.25 \; {}^{+1.3}_{-0.15}$	0.1 ± 0.3
3	$p + p \rightarrow p + N^{*}(1690)$	10	30	$0.6 \; {}^{+0.8}_{-0.3}$	0.0 ± 0.15
4	$p + p \rightarrow p + N^{*}(2190)$	20	30	-	0.4 ± 0.9
5	$\pi + p \rightarrow p + A_1 \rightarrow p\pi\pi^{+}\pi^{-}$	4	11	0.1	0
6	$\pi + p \rightarrow p + A_2 \rightarrow p\pi\pi^{+}\pi^{-}$	4	11	0.1.5	0
7	$K + p \rightarrow p + (K\pi\pi)(1320)$	5	10	-	0
8	$n + p \rightarrow p + n$				
9	$\bar{p} + p \rightarrow \bar{n} + n$	3.0	9.0	$11 \; {}^{+22}_{-7}$	1.7 ± 0.3
10	$K^{-} + p \rightarrow K^{0} + n$	2.0	9.5	$2.3 \; {}^{+1.6}_{-1.0}$	1.5 ± 0.2
11	$\pi^{-} + p \rightarrow \pi^{0} + n$	3.07	18.0	$1.1 \; {}^{+0.6}_{-0.4}$	1.3 ± 0.2
12	$\pi^{-} + p \rightarrow n + \eta$	2.9	18.2	$1.2 \; {}^{+0.4}_{-0.2}$	1.5 ± 0.1
13	$\pi^{+} + p \rightarrow N^{*++} + \eta$	2.08	8.0	$2.3 \; {}^{+2.1}_{-1.1}$	2.2 ± 0.2
14	$\pi^{+} + p \rightarrow N^{*++} + \omega$	2.08	8.0	$4.4 \; {}^{+3.6}_{-2.0}$	1.7 ± 0.3
15	$\pi^{+} + p \rightarrow p + \rho^{+}$	4.0	8.0	$3.0 \; {}^{+2.3}_{-1.6}$	1.5 ± 0.5
		2.1	8.0	$15 \; {}^{+14}_{-7}$	2.6 ± 0.4
16	$\pi^{-} + p \rightarrow p + \rho^{-}$	2.75	11.0	$3.2 \; {}^{+1.9}_{-0.7}$	1.5 ± 0.2
17	$K^{+} + p \rightarrow p + K^{*} \rightarrow pK^{0}\pi^{+}$	3.0	5.0	$6.3 \; {}^{+7.7}_{-3.5}$	1.8 ± 0.6
18	$K^{-} + p \rightarrow p + K^{*} \rightarrow pK^{0}\pi^{-}$	2.1	10.1	$6.4 \; {}^{+5.5}_{-2.6}$	1.9 ± 0.5
19	$\pi^{+} + p \rightarrow N^{*++} \pi^{0}$	2.08	8.0	$1.1 \; {}^{+1.1}_{-0.5}$	1.1 ± 0.2
20	$\pi^{+} + p \rightarrow N^{*+} \pi^{+} \rightarrow p\pi^{+}\pi^{0}$	4.0	8.0	$1.2 \; {}^{+1.7}_{-0.7}$	1.3 ± 0.6

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TABLE I (contd.)

No.	REACTION	INCID. MOM^{M} GeV/c. Min	Max	Constant, K. mb	Exponent, n
21	$K^+ + p \rightarrow N^{*++} + K^o$	1.73	5.0	$5.3^{+0.6}_{-0.4}$	1.8 ± 0.2
22	$p + p \rightarrow p + N^*(1238)$	6	15	4^{+7}_{-2}	1.3 ± 0.6
23	$\pi^- + p \rightarrow \Lambda + K^o$ or $\Sigma^o + K^o$	3.0	4.65	$1.3^{+5.0}_{-0.7}$	1.6 ± 1.4
24	$\pi^+ + p \rightarrow \Sigma^+ + K^+$	2.08	8.0	$1.0^{+1.2}_{-0.6}$	2.1 ± 0.5
25	$\pi^+ + p \rightarrow Y^*(1385) + K^+$	2.08	8.0	$1.3^{+1.1}_{-0.6}$	2.6 ± 0.5
26	$K^- + p \rightarrow \Lambda + \pi^o$	2.24	10.1	7^{+6}_{-3}	1.9 ± 0.3
27	$K^- + p \rightarrow \Lambda + \omega$	2.24	10.1	$3.1^{+1.7}_{-1.1}$	2.8 ± 0.3
28	$K^- + p \rightarrow \Sigma^+ + \pi^-$	2.24	3.5	$2.2^{+2.4}_{-1.1}$	2.0 ± 0.5
29	$K^- + p \rightarrow Y^{*+}(1385) + \pi^-$	2.24	10.1	$4.8^{+4.2}_{-2.2}$	2.2 ± 0.25
30	$\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda$	3.0	6.94	$0.9^{+1.0}_{-0.5}$	1.9 ± 0.3
31	$\bar{p} + p \rightarrow \bar{\Lambda}\Sigma^o$ or $\Lambda\bar{\Sigma}^o$	3.0	6.94	$0.6^{+0.8}_{-0.4}$	1.8 ± 0.4
32	$\pi^+ + p \rightarrow N^{*++} + \rho^o$				
33	$\pi^- + p \rightarrow N^{*o} + \rho^o$				
34	$K^+ + p \rightarrow N^{*++} + K^{*o}$				
35	$K^- + p \rightarrow \Sigma^- + \pi^+$	2.24	3.5	$1.9^{+2.4}_{-1.1}$	3.8 ± 0.8
36	$K^- + p \rightarrow Y^{*-}(1385) + \pi^+$	1.65	10.1	$2.5^{+3.0}_{-1.3}$	4.1 ± 0.7
37	$K^- + p \rightarrow \Xi^- + K^+$	2.24	5.0	$5.0^{+4.2}_{-2.3}$	3.5 ± 0.3
38	$(\pi^- + p \rightarrow p + \pi^-)_{180^o}$				

Fig. 1

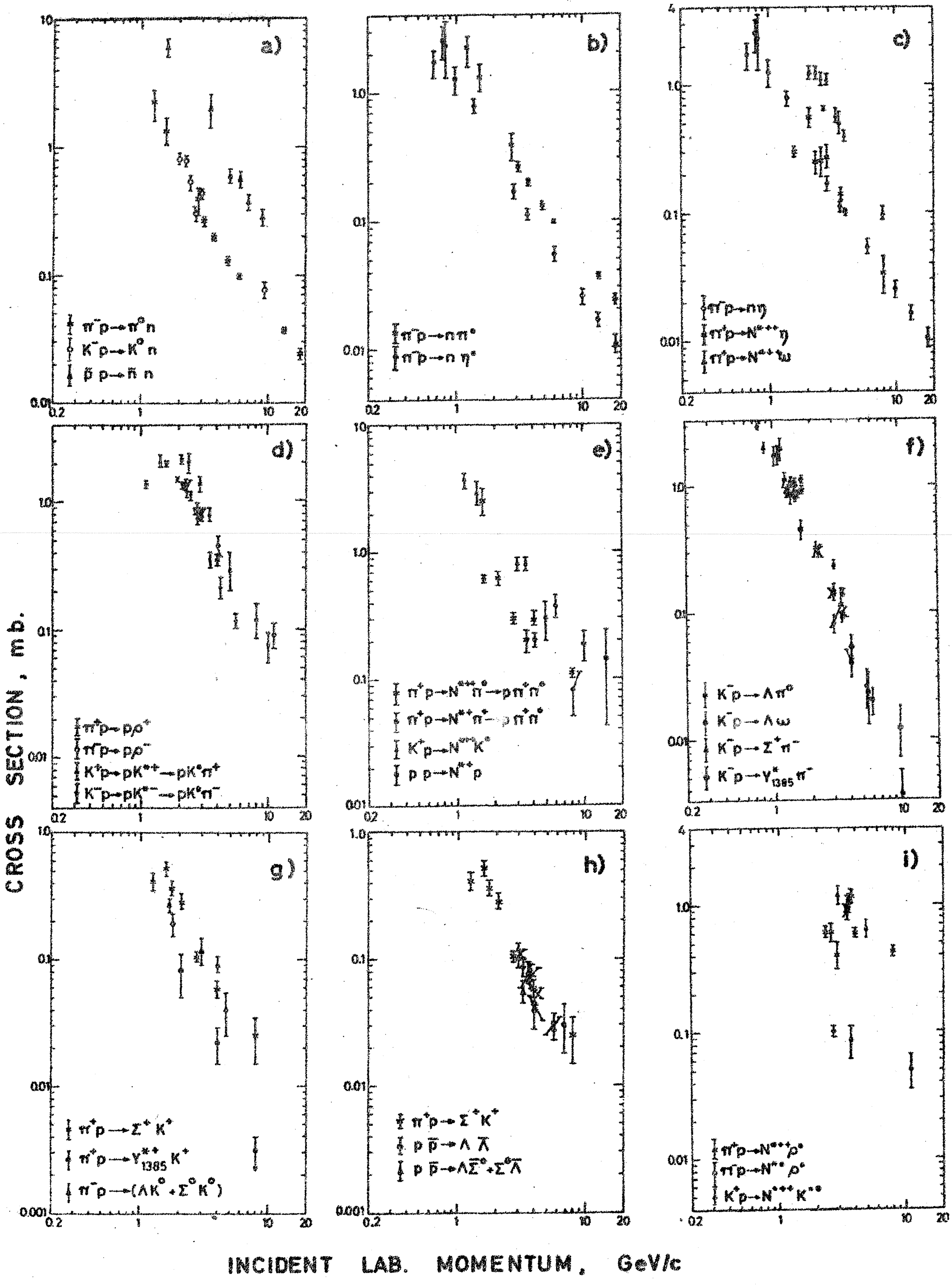

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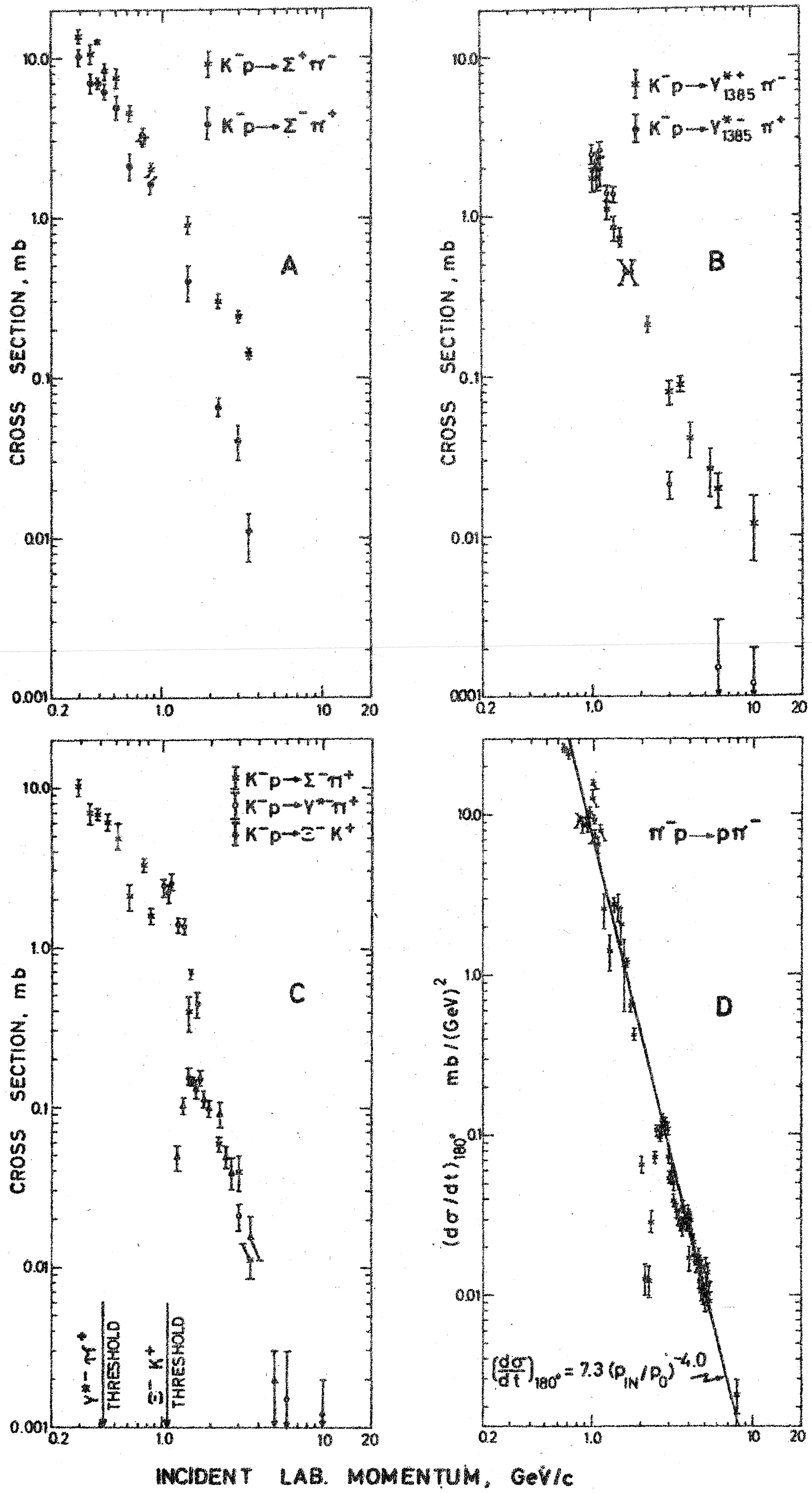
Fig. 2



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