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THE TOTAL CROSS-SECTION OF (5π)-NUCLEON COLLISION

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ABSTRACT

Coherent 5π production on nine nuclear targets has been studied at 40 GeV incident energy at the Serpukhov accelerator (CERN-Serpukhov experiment No. 5). The collision cross-section of the 5π system on the nucleon has been determined in the frame of the Kölbig-Margolis-Glauber model; its value, < 10 mb, is definitely lower than the (3π)-nucleon cross-section at the same energy.

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The (5π)-nucleon interaction cross-section has been measured, until now, in only one experiment [1], carried out with a pion beam of 16.1 GeV/c. In that experiment its value (∿ 17 mb) suffers from large random (±5 mb) and systematic ($^{+8}_{-7}$ mb) errors, and it is lower than the (3π)-nucleon cross-section obtained at the same energy (∿ 25 mb). Further and improved measurements are needed to confirm the decrease of the cross-section with the increase in the complexity of the meson state, which should throw new light on the problem of the absorption in nuclear matter.

The interaction cross-sections of meson states on nucleon are obtained, by means of the Kölbig-Margolis-Glauber model [2], from the dependence of the coherent production on the atomic weight of the nuclear targets. This model simplifies the interaction mechanism too much, because it assumes that the production process is instantaneous and point-like (see, for instance, the discussion included in ref. 3). Nevertheless, a comparative analysis of the absorption suffered by different particle states is possible by means of the KMG model, even if the absolute value of the collision cross-sections on the nucleon has to be considered less reliable.

In this letter we show results concerning the (5π)-nucleon cross-section and its comparison with the (3π)-nucleon cross-section obtained at the same energy. The data have been collected in the 40 GeV/c beam of the Serpukhov accelerator, using nine different targets (Be, C, Al, Si, Ti, Cu, Ag, Ta, and Pb). The experimental set-up is described elsewhere [3]. The geometrical acceptance of the apparatus is almost independent of t' [at least up to 0.5 $(\mathrm{GeV/c})^2$] and decreases smoothly from 75% to 55% when $M_{5\pi}$ ranges from 1.8 to 3.0 $\mathrm{GeV/c^2}$. The inefficiency of the pattern recognition program has been evaluated by analysing a sample of events with an interactive graphic system [4]. An estimate of the over-all inefficiency of the reconstruction chain gives ∿ 25%, almost independent of t' and $M_{5\pi}$. From a total of ∿ 500,000 triggers, which includes a "majority 2" requirement, a sample of ∿ 15,000 events has been selected, where five charged pions are produced.

The differential cross-sections for the different targets exhibit a clear diffractive behaviour. A t' cut corresponding to the first dip of the t' distribution enriches the samples of coherent events (coherent samples): owing to the steepness of the t' slopes for the coherent interactions on nuclear targets, the incoherent background is reduced, in the coherent samples, to $\sim$ 12% for Be and decreases with increasing atomic weight until it reaches $\sim$ 2% for Pb. The 5π mass distribution for the events of the coherent samples is presented in fig. 1, where all the events of different nuclear targets are plotted together. The differential cross-sections for two typical targets (the lightest and the heaviest ones) and for two different intervals of the produced 5π mass are presented in fig. 2*). The first diffractive maximum and the flatter part due to the incoherent contribution are clearly visible.

The comparison of the data with the Kölbig-Margolis-Glauber model, in order to extract the (5π)-nucleon cross-section, can be carried out using either the differential cross-sections or the total coherent cross-sections. The details of the model are given in table 1, where $d\sigma_C/dt'$ and $d\sigma_I/dt'$ are the differential cross-sections for the coherent and the incoherent contributions, respectively [$d\sigma_I/dt'$ is corrected with the factor $S(t',M,A)$ to account for the experimental bias introduced in the incoherent events by counters surrounding the target]; σ_1 is the total cross-section of the incident pion on the nucleon; σ_2 is a parameter which reproduces the absorption in nuclear matter and, in the hypothesis of the model, is the cross-section of the five-pion system on the nucleon; α_1 and α_2 are the ratios of the real to imaginary parts of the forward elastic scattering amplitudes of the pion on the nucleon and of the five-pion system on the nucleon, respectively; a and c are the two parameters of the Fermi distribution of the nuclear density; M is the invariant mass of the produced system. The form factor $F(t',M)$ includes also the phase factor $\{\exp[i\chi_{Coul}(b)]\}$ accounting for the elastic scattering of the incoming and outgoing particles in the nuclear Coulomb

*) The mass and angular distributions are not corrected for the geometrical acceptance.

field: its contribution is very small. The slope B is obtained by fitting $d\sigma/dt'$ with an exponential function for the events of all the targets plotted together in the high-t' region, where the coherent contribution is negligible.

The fit on the differential cross-sections is carried out with $d\sigma/dt' = d\sigma_C/dt' + d\sigma_I/dt'$ on the full range of t'. For the comparison with the total cross-sections, the experimental values, once the incoherent background is subtracted, are fitted with $\sigma_C = \int_0^{t'} d\sigma_C/dt'$, integrated either up to the first diffractive minimum (t'^*) or over the full t' range. The incoherent contribution is subtracted from the experimental differential cross-sections using the $d\sigma_I/dt'$ formula shown in table 1. More details on the procedure used in the comparison with the Kölbig-Margolis-Glauber model are given in ref. 3, where this analysis is applied in the same way to the 3π system.

The comparison between the total coherent cross-sections and the theoretical model is shown in fig. 3. The σ_2 values obtained by fitting either $d\sigma/dt'$ versus A or σ_C versus A are shown in table 2. The statistical errors correspond to changing the χ^2 of the fit by one. The systematic errors are the maximum fluctuations of the σ_2 values, obtained by removing in turn, from the fitted experimental points, the cross-section corresponding to one nuclear target. The results of the fits are stable and consistent with each other, within the errors; they are very weakly influenced by different assumptions for α_2 in the range (-0.5 to +0.5); the best fit values included in table 2 are obtained with $\alpha_2 = 0.0$. The (5π)-nucleon cross-section determined in this analysis is lower than 10 mb, independently of the procedures used in the fits. This value is definitely lower than the (3π)-nucleon cross-section obtained at the same energy in the same experiment [3], which fluctuates around 17 mb, with over-all errors not exceeding $\sim$ 3 mb.

A comparative analysis of the results obtained for 3π and 5π production at 40 GeV/c and 16.1 GeV/c [1] leads to the following conclusions:

i) The (5π) states are less absorbed in nuclear matter than the (3π) states.

ii) The (5π)-nucleon cross-section tends to decrease with increasing incident energy, as already found for the (3π)-nucleon cross-section.

iii) The absorption of the (5π) states seems to decrease with increasing mass. This behaviour is a general tendency of all the particle states, both mesonic and baryonic, even if it is not clearly found by the results obtained on the (5π) states at 40 GeV/c [3].

REFERENCES

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Table 1

Details of the model

$$\frac{d\sigma}{dt'} = \frac{d\sigma_C}{dt'} + \frac{d\sigma_I}{dt'} \quad \begin{cases} \dfrac{d\sigma_C}{dt'} = C_0(M)\, A^2 |\tilde{F}(t',M)|^2 \\[2ex] \dfrac{d\sigma_I}{dt'} = I_0(M,A) S(t',M,A)\, C_0(M)\, e^{-B(M)t'} \end{cases}$$

$$\tilde{F}(t',M) = 2\pi \int_{-\infty}^{+\infty} dz \int_0^{+\infty} db\, b \exp\left[i\frac{M^2 - m_\pi^2}{2p} z\right] J_0(\sqrt{t'}b)\rho(b,z) \exp\left[i\chi_{Coul}(b)\right]$$

$$\times \exp\left[-(1-i\alpha_1)\frac{1}{2}\sigma_1 T_1(b,z)\right] \exp\left[-(1-i\alpha_2)\frac{1}{2}\sigma_2 T_2(b,z)\right]$$

$$T_1(b,z) = \int_{-\infty}^{z} A\rho(b,z')\, dz' \; ; \quad T_2(b,z) = \int_{z}^{\infty} A\rho(b,z')\, dz'$$

$$\rho(r) = \rho_0\left[1 + \exp\frac{r-c}{a}\right]^{-1} \; ; \quad \int \rho(\vec{r})\, d^3\vec{r} = 1$$

$$\chi_{Coul}(b) = \frac{27}{137}\left\{\ln(pb) + 4\pi\int_b^{\infty} \rho(r)\left[\ln\left(\frac{r}{b} + \sqrt{\frac{r^2}{b^2} - 1}\right) - \sqrt{1 - \frac{b^2}{r^2}}\right] r^2\, dr\right\}$$

<u>Fixed parameters</u>

$\sigma_1 = 23.7$ mb $\qquad \alpha_1 = -0.15$

$B = 5.5\ (\mathrm{GeV}/c)^{-2}$

$c = 1.12\ \mathrm{fm} \times A^{1/3}$

$a = 0.545$ fm

α_2 is fixed, but a few different values are used: -0.5, 0, $+0.5$

<u>Free parameters</u> $\quad I_0,\ C_0,\ \sigma_2$

Table 2

Best-fit values

$M_{5\pi}$ interval (GeV)	Upper limit of the fit	Fit on $d\sigma/dt'$ versus A			Fit on σ_C versus A		
		σ_2 (mb)	$\Delta\sigma_2$ stat.	$\Delta\sigma_2$ syst.	σ_2 (mb)	$\Delta\sigma_2$ stat.	$\Delta\sigma_2$ syst.
1.6–2.2	$t' = t'^*$	9.7	±0.15	+2.5 −1.3	8.8	±0.15	+2.5 −1.3
	$t' = 0.5\ (\mathrm{GeV}/c)^2$	9.6	±0.15		10.1	±0.20	
2.2–3.0	$t' = t'^*$	7.1	±0.25	+2.5 −1.3	5.5	±0.16	+2.5 −1.3
	$t' = 0.5\ (\mathrm{GeV}/c)^2$	7.9	±0.25		9.4	±0.18	

Figure captions

Fig. 1 : The 5π invariant mass distribution for the samples with t' lower than the first diffractive minimum.

Fig. 2 : The differential cross-sections versus t' for Be and Pb targets and for 5π mass interval 1.6-2.2 GeV: the vertical bars represent the statistical errors.

Fig. 3 : Total coherent cross-sections of 5π production for different nuclear targets and for two mass intervals: 1.6-2.2 and 2.2-3.0 GeV. The vertical bars represent the statistical errors. The full lines are the result of the fit on σ_C versus A with the Kölbig-Margolis-Glauber equation integrated in t' up to the first diffractive minimum. The best fit values for σ_2 are 8.8 ± 0.15 mb and 5.5 ± 0.16 mb for the 5π mass intervals 1.6-2.2 and 2.2-3.0 GeV, respectively.

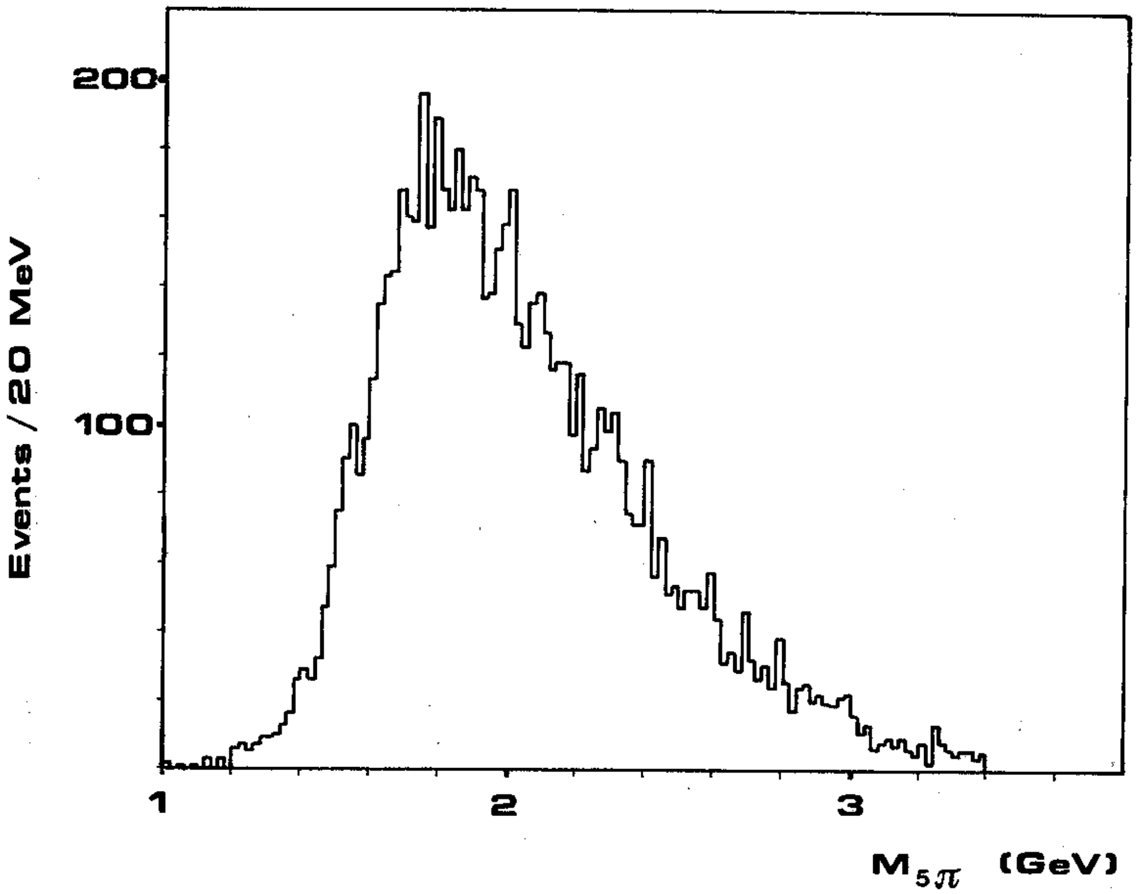
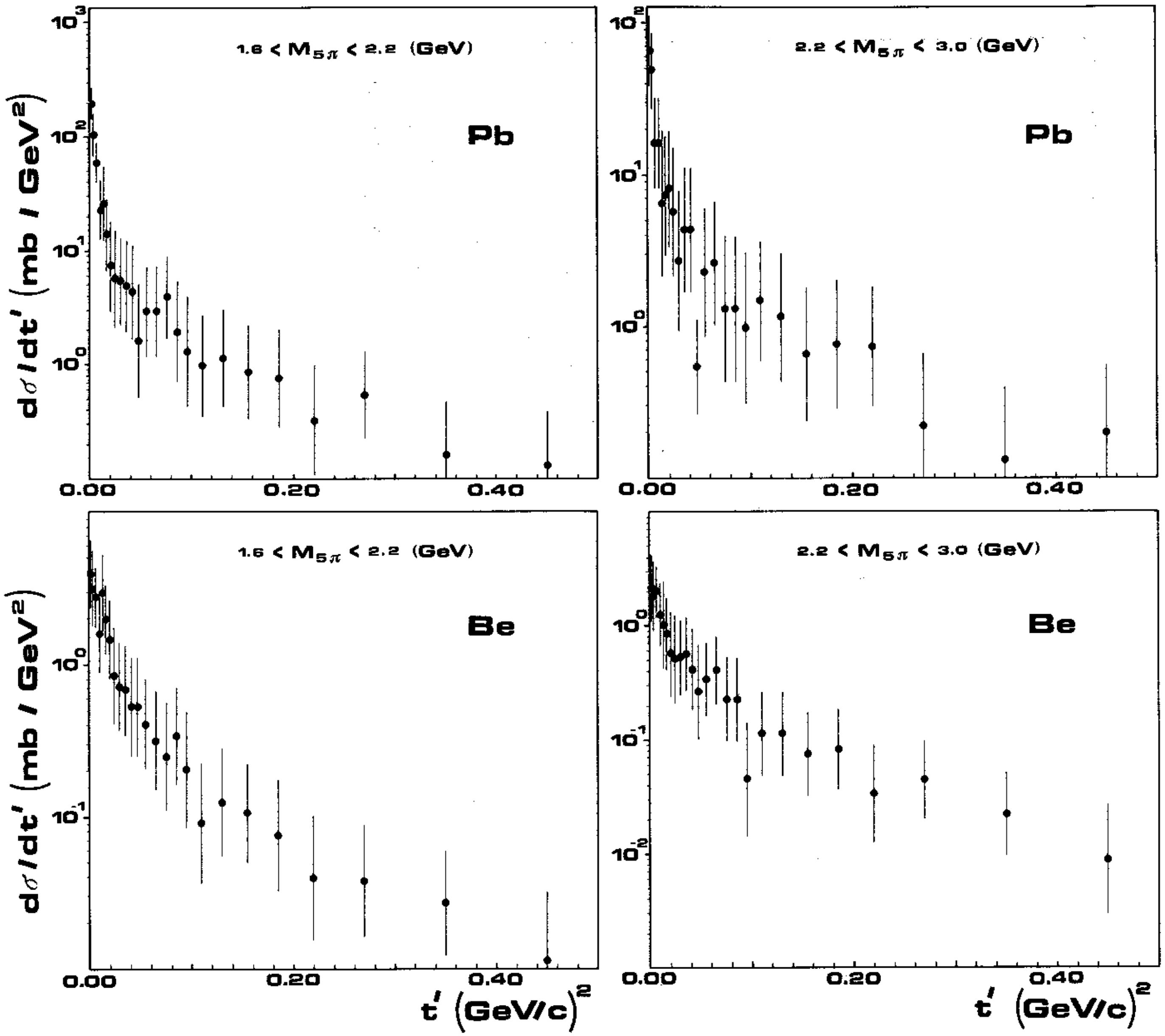


Fig. 1



$d\sigma/dt'$ (mb / GeV^2)
1.6 < $M_{5\pi}$ < 2.2 (GeV)
2.2 < $M_{5\pi}$ < 3.0 (GeV)
Pb
Be
0.00
0.20
0.40
t' (GeV/c)^2

Fig. 2

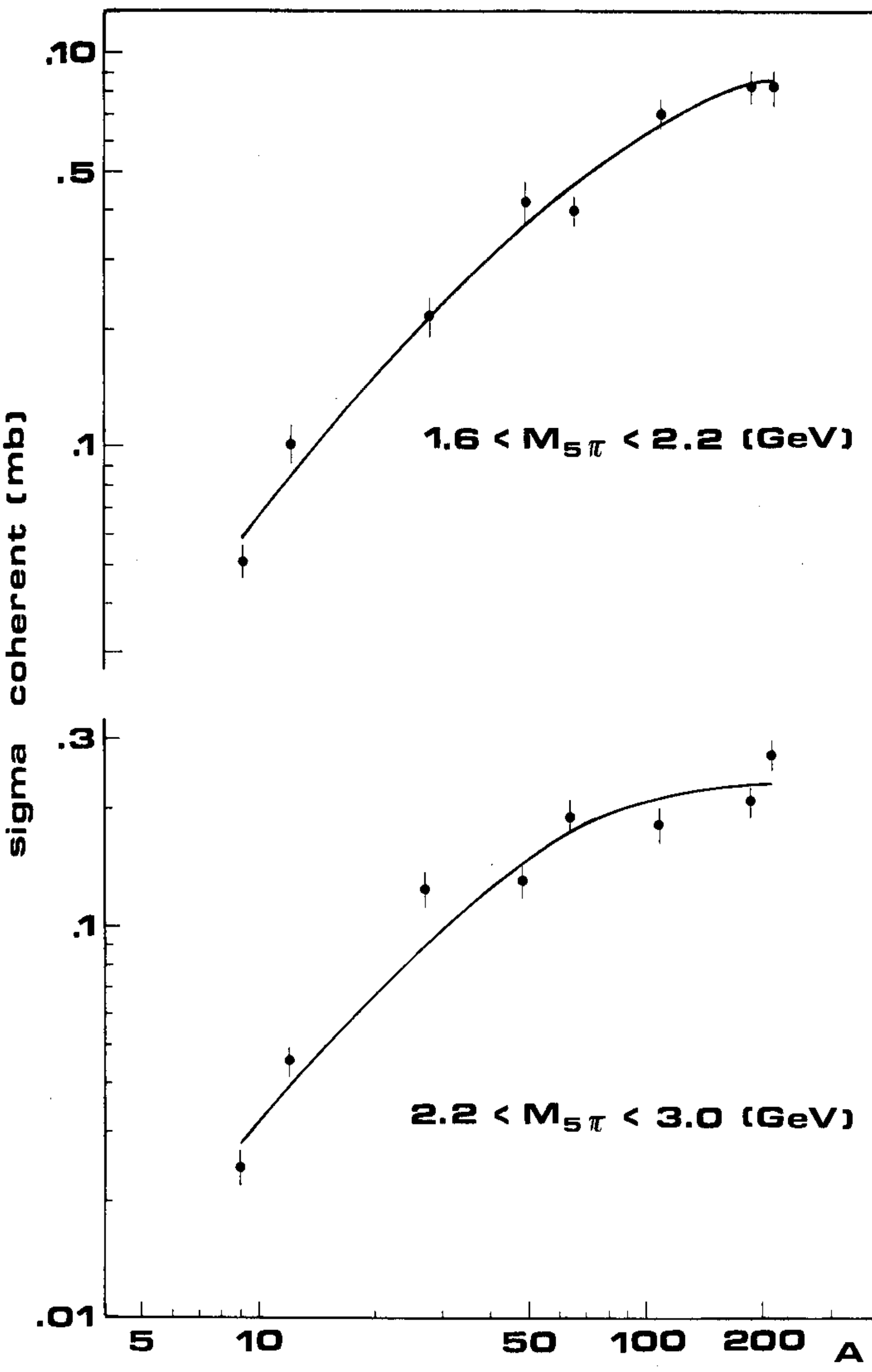

.10
.5
.1
.3
.1
.01
sigma coherent (mb)
1.6 < $M_{5\pi}$ < 2.2 (GeV)
2.2 < $M_{5\pi}$ < 3.0 (GeV)
5
10
50
100
200
A

Fig. 3