Fermi National Accelerator Laboratory

FERMILAB-Pub-78/80-EXP
7100.104

(Submitted to Phys. Letters)

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ABSTRACT

Absorption cross sections of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ have been measured on targets of Li, C, Al, Cu, Sn and Pb at 60, 200, and 280 GeV/c.

We have measured absorption cross sections of $\pi^{\pm}$, $K^{\pm}$, p and $\overline{p}$ on lithium, carbon, aluminum, copper, tin, and lead at 60, 200, and 280 GeV/c. The data were taken using the same equipment as for measurements of total cross sections on hydrogen and deuterium, and experimental details have been described elsewhere.[1] The major difference for this experiment was to reduce the distance from the targets to the transmission counters in order to obtain the larger solid angles required for absorption measurements on nuclei. Several measurements of absorption cross sections have been carried out previously at lower momenta,[2-5] with the most extensive being those obtained at Serpukhov between 7 and 60 GeV/c.[3,4]

The targets used in this experiment all had a thickness of approximately 0.2 absorption lengths. Typical examples of the partial cross sections obtained from the individual transmission counters are shown in Fig. 1 as a function of t_i, where t_i is the square of the maximum 4-momentum transfer detected by the i^{th} transmission counter. We follow previous experiments[3-5] in obtaining the absorption cross section σ_a by extrapolating the partial cross sections $\sigma(t_i)$ measured in the range $0.1 < -t < 0.25$ $(GeV/c)^2$ to $t = 0$ using the expression

$$\sigma(t_i) = \sigma_a \exp(At_i) \quad ;$$

this form gives a good fit to the data in the t_i range used. The t_i range measured here is considerably larger than in previous experiments, and we see that for $-t_i$ larger than 0.25 such a simple form would not be adequate to describe the data.

At small values of $-t_1$, the partial cross sections rise due to Coulomb scattering, coherent scattering from the whole nucleus, and "quasi-elastic" scattering from individual nucleons in the nucleus. The first two affect partial cross sections only at values of $-t_1$ smaller than 0.1; the quasi-elastic scattering is mostly at smaller $-t_i$ values, but a correction has to be made to the individual partial cross sections to account for the remainder, as shown in Fig. 1. The correction is calculated using the empirical expression of Bellettini et al;[6] although this was derived for light nuclei only and there are questions about its form,[7] we have used it here since in the region of our fit the correction to any data point is always less than 5%. In calculating the correction, the required data on hadron-nucleon elastic scattering were taken from Ayres et al.[8] Our final result, σ_a, is

$$\sigma_a = \sigma_{total} - \sigma_{coherent\ nucleus} - \sigma_{quasi\text{-}elastic} .$$

Note that in previous experiments on absorption cross sections, the correction for quasi-elastic scattering has not always been made.

Statistical errors in our absorption cross sections were generally less than ±1%; we have added in quadrature an estimated systematic error of ±3% to account for uncertainty in the extrapolation procedure, uncertainty in the muon contamination of the pion and kaon beams, uncertainties in the target densities, and uncertainties in the quasi-elastic scattering correction.

Our results for σ_a are given in Table I, and some of the data are shown in Fig. 2, together with results from Refs. 3 and 4. We can make the following observations:

(1) At 60 GeV/c, we can compare our data with those of Refs. 3 and 4. In general, the agreement for heavy nuclei is good; for the light nuclei, there is agreement for some incident particles and disagreement for others, with the data of Refs. 3 and 4 being up to 14% larger than ours. We know of no reason for this discrepancy.

(2) As at lower momenta, the data for any given incident particle and momentum were found to be well fitted by the expression

$$\sigma_a(A) = \sigma_o A^{\alpha} ,$$

where A is the atomic weight of the target nucleus. Some examples of this are shown in Fig. 3, and the fitted values of the parameters σ_o and α are given in Table I.

(3) All of the absorption cross sections are close to momentum independent over the range 60 to 280 GeV/c, as seen in Fig. 2, but almost all show some small momentum variation. The parameters σ_o and α show momentum dependence; for all incident particles except antiprotons, the value of σ_o increases by up to 10% as the momentum increases from 60 to 280 GeV/c, with the largest increase for K^+. For antiprotons, σ_o decreases with increasing momentum. This behavior is similar to that of the corresponding hadron-proton total sections. In Fig. 4, for each particle and momentum, we plot the value of σ_o against the corresponding hadron-proton total cross section σ_h;[1] we see that σ_o rises monotonically with σ_h. Also in Fig. 4 we show α as a function of σ_h; the data are consistent with α approaching 2/3 for large values of σ_h as would be expected for an opaque nucleus.

(4) Absorption cross sections for π^+ and π^- are almost equal, as is expected from charge symmetry and the closenss of the $\pi^{\pm}p$ total cross sections.

(5) It has been noted previously that the multiple scattering model of Glauber[9] gives a good description of the interaction of high energy hadrons in nuclear matter, and can be used to relate absorption cross sections in nuclei to the corresponding hadron-nucleon total cross sections.[4,10] A preliminary comparison using this set of absorption cross section data and our hadron total cross sections[1] also shows satisfactory agreement.[11]

We wish to thank L. W. Jones for many useful conversations on absorption cross sections, and the staff of the Fermilab Meson Laboratory for their assistance.

This work was supported by the U. S. Department of Energy.

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TABLE I. Absorption Cross Sections Measured in This Experiment

Momentum (GeV/c)	Particle	Absorption Cross Section (mb) Li	C	Al	Cu	Sn	Pb	σ_o (mb)	α
60	K^+	94 ± 3	144 ± 4	280 ± 9	556 ± 17	890 ± 27	1360 ± 42	20.37 ± 0.80	0.791 ± 0.010
	K^-	102 ± 3	153 ± 5	299 ± 9	583 ± 18	933 ± 29	1414 ± 45	22.56 ± 0.90	0.779 ± 0.010
	π^+	113 ± 3	168 ± 5	323 ± 10	627 ± 19	992 ± 30	1480 ± 44	25.64 ± 1.00	0.764 ± 0.010
	π^-	113 ± 3	169 ± 5	324 ± 10	625 ± 19	989 ± 30	1478 ± 44	25.86 ± 1.00	0.762 ± 0.010
	p	154 ± 5	222 ± 7	409 ± 12	764 ± 23	1179 ± 35	1730 ± 52	37.99 ± 1.48	0.719 ± 0.010
	$\bar{p}$	170 ± 5	242 ± 7	439 ± 13	794 ± 24	1218 ± 38	1805 ± 56	43.50 ± 1.73	0.698 ± 0.010
200	K^+	99 ± 3	150 ± 5	293 ± 9	578 ± 18	902 ± 28	1401 ± 44	21.89 ± 0.87	0.782 ± 0.010
	K^-	102 ± 3	154 ± 5	301 ± 9	581 ± 18	938 ± 29	1401 ± 44	22.69 ± 0.90	0.777 ± 0.010
	π^+	114 ± 3	171 ± 5	325 ± 10	629 ± 19	1001 ± 30	1485 ± 45	26.08 ± 1.02	0.762 ± 0.010
	π^-	113 ± 3	170 ± 5	325 ± 10	625 ± 19	986 ± 30	1467 ± 44	26.17 ± 1.01	0.759 ± 0.010
	p	156 ± 5	225 ± 7	416 ± 12	774 ± 23	1199 ± 36	1765 ± 53	38.52 ± 1.50	0.719 ± 0.010
	$\bar{p}$	163 ± 5	236 ± 7	435 ± 14	772 ± 24	1239 ± 40	1793 ± 58	41.08 ± 1.67	0.710 ± 0.011
280	K^+	101 ± 3	153 ± 5	288 ± 10	567 ± 19	923 ± 33	1377 ± 50	22.26 ± 0.97	0.775 ± 0.012
	K^-	104 ± 3	157 ± 5	296 ± 10	578 ± 19	909 ± 32	1430 ± 50	23.21 ± 0.99	0.771 ± 0.011
	π^+	115 ± 4	171 ± 5	328 ± 10	612 ± 19	980 ± 31	1447 ± 47	26.93 ± 1.08	0.751 ± 0.011
	π^-	114 ± 3	171 ± 5	326 ± 10	624 ± 19	986 ± 30	1460 ± 44	26.57 ± 1.03	0.755 ± 0.010
	p	156 ± 5	225 ± 7	415 ± 12	769 ± 23	1194 ± 36	1752 ± 53	38.59 ± 1.50	0.718 ± 0.010
	$\bar{p}$	166 ± 6	239 ± 8	422 ± 15	782 ± 29	1236 ± 51	1856 ± 77	41.05 ± 1.91	0.713 ± 0.013

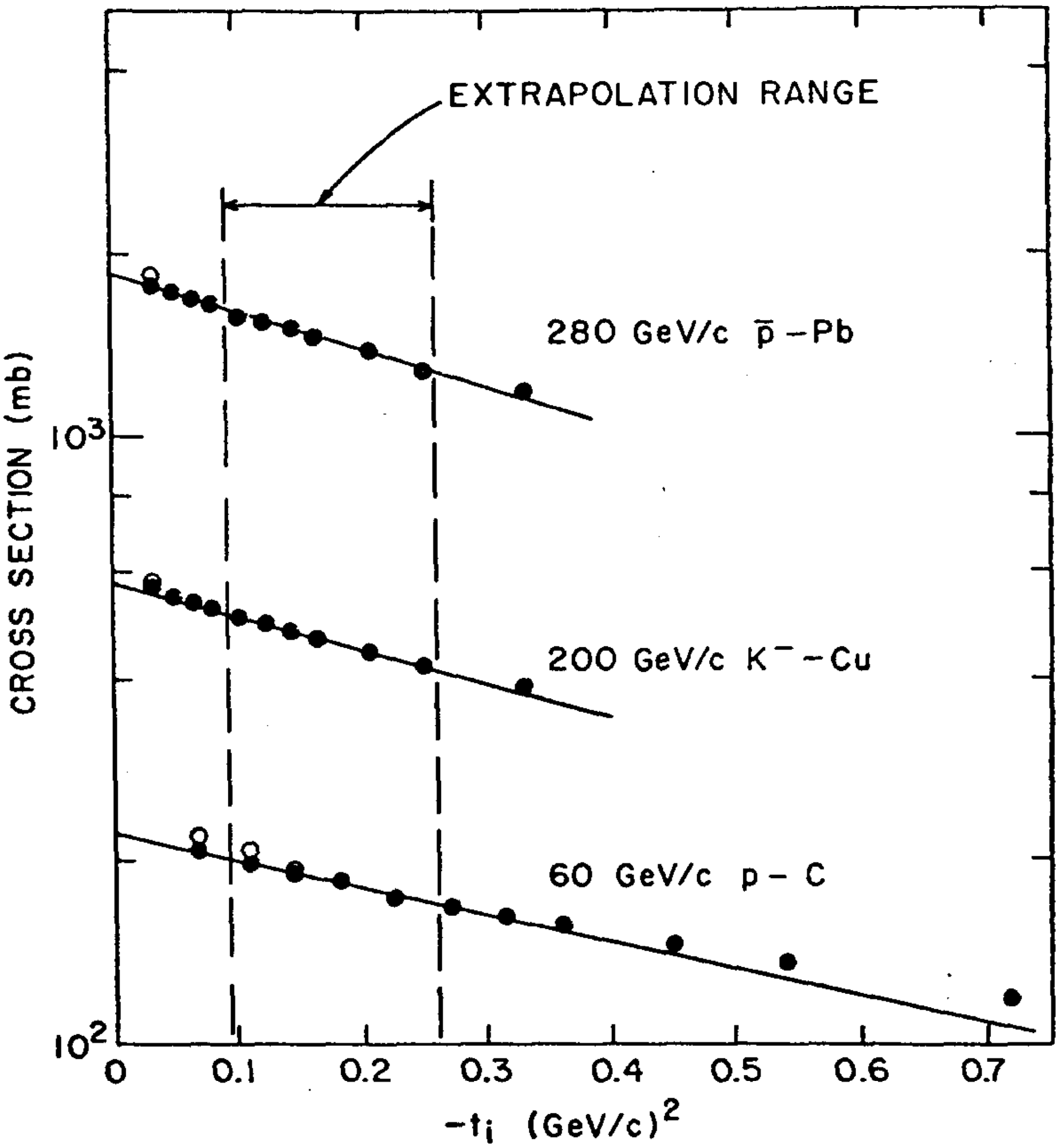

Fig. 1. Examples of partial cross sections obtained in this experiment. The open circles are the experimental data; the closed circles are the data after applying the correction for quasi-elastic scattering. The range used in the extrapolation, and the fits obtained, are also shown.

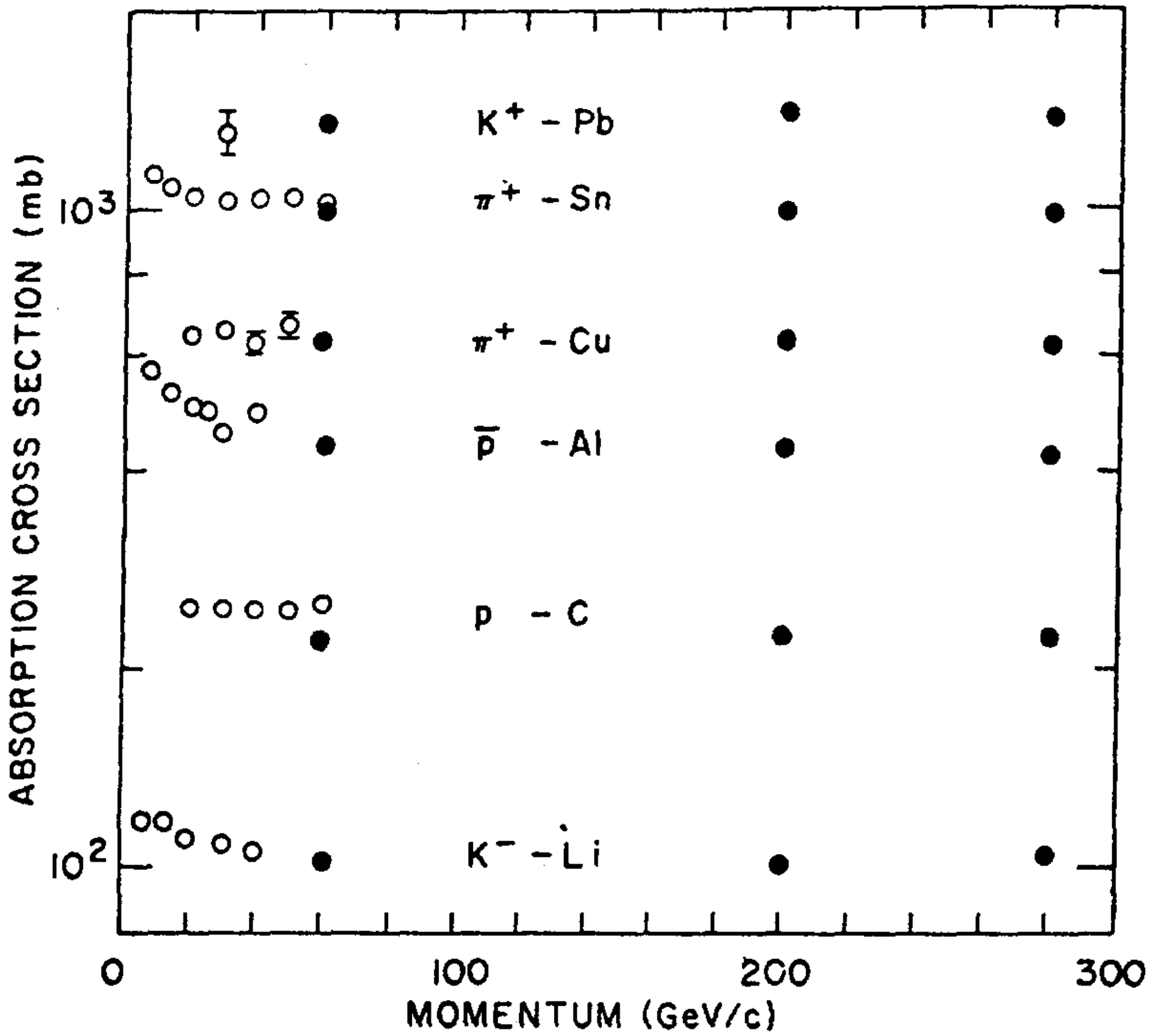

Fig. 2. Some results from this experiment, together with data from Refs. 3 and 4.

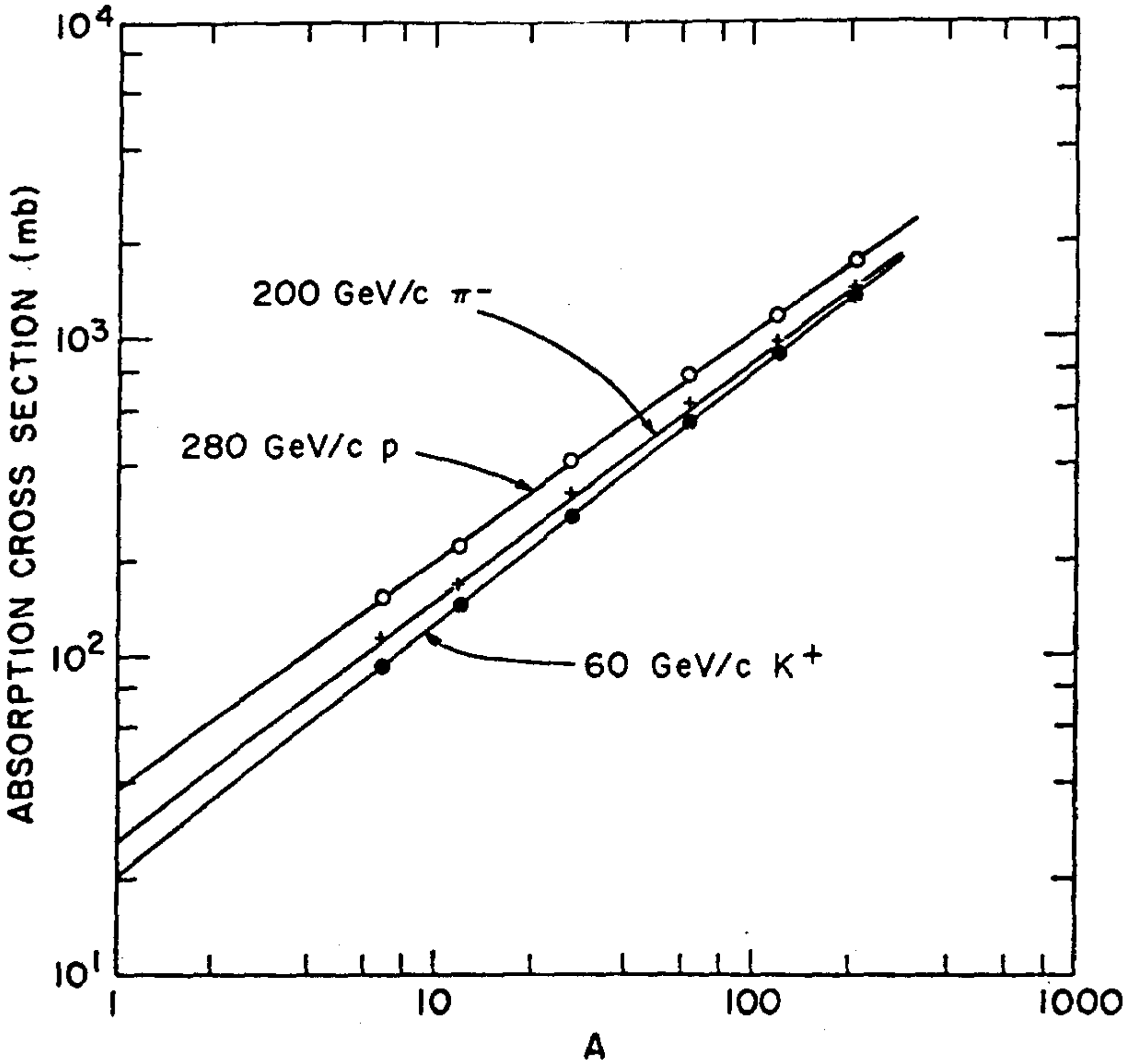

Fig. 3. Some results from this experiment as a function of atomic weight. Fits to the form $\sigma_a(A) = \sigma_0 A^\alpha$ are shown.