A dependence of pair production of hadrons with large P_T

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The A dependence of the production of pairs of charged hadrons has been measured. When the A dependence of the invariant cross section is approximated by a function A^{α_2}, the exponent α_2 does not exceed unity anywhere in the P_T range from 0.46 to 2.27 GeV/c. The exponent α_2 is found to depend on the nature of the particles.

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Nearly a decade after the discovery of the effect, opinion is still divided on the explanation for the anomalous A dependence of the cross sections for the production of single particles with large P_T, i.e., with an exponent α greater than unity in an A^{α} parametrization of the cross sections. The models which seem most convincing are those which attribute the anomalous A dependence to a rescattering of partons in the

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nucleus. There is accordingly much interest in studying the A dependence of the cross sections for the production of symmetric pairs of hadrons, by which we mean pairs which have equal and oppositely directed transverse momenta. The effect of rescattering is at its smallest for such pairs, and we would expect the exponent on A to be unity, as it is for other hard processes.

The present measurements were carried out with a two-arm focusing spectrometer,[1] whose arms make an angle of 160 mrad with the axis of the proton beam; in the c.m. frame of the two nucleons, the corresponding angle for relativistic particles is $\theta_{\text{c.m.}} = 90°$ (the angle between the hadrons is 180°). We studied the yields of pairs of positively charged hadrons at $P_T = 0.5$–2.3 GeV/c; only for π mesons were the corresponding values of $\theta_{\text{c.m.}}$ essentially equal to 90°; for K mesons these angles varied from 120° to 93°, and for protons from 155° to 95°. In the experiments we used a proton beam extracted slowly from a 70-GeV proton accelerator with an intensity of 10^{10} to 10^{12} per cycle. The beam was monitored by secondary-emission chambers with an absolute accuracy of $\pm 6\%$ and a relative accuracy of $\pm 1\%$. Measurements were taken with Be, Cu, and Pb targets with a thickness equal to 0.02 of a nuclear interaction length. Each arm of the spectrometer spanned a momentum interval $\Delta p/p = 20\%$. The momenta of the particles were measured within $\pm 1\%$ on the basis of their deflection in a magnetic field in drift chambers. The particles were identified at $P < 5$ GeV/c on the basis of their time of flight, while at higher momenta they were identified by two threshold Cerenkov counters.

Cases of pair production of particles were distinguished from the random-coincidence background by a time-analysis system containing six timing scintillation counters, three in each arm of the spectrometer. The resolution of the time-analysis system was 0.4 ns (full width at half-maximum). To optimize the statistical data base, we kept the ratio of the effect to the background under the peak at the level of 0.5 of the change in the intensity of the proton beam.

We approximated the A dependence of the invariant cross sections by a function A^{α_2}. Most of the data were obtained from Be and Pb nuclei. At $P_T = 1$ GeV/c we took measurements for three nuclei for a check of the validity of this approximation. The results of this check (Fig. 1) show that the power law holds well at this measurement accuracy.

The values found for α_2 in this manner are shown in Fig. 2a as a plot against $m' = P_{T_1} + P_{T_2}$. Shown for comparison are data from Refs. 2 and 3. At $P_T > 1$ GeV/c the values of α_2 are approximately equal to unity, in agreement with the results of Ref. 2. We simultaneously measured the emission of single hadrons with this apparatus; the behavior of the corresponding exponent for these processes, α_1, is shown in Fig. 2b. It should be noted that the behavior of α_1 as a function of P_T is essentially the same in these studies, although the results of Ref. 3 do not conform to the general trend in the data on pair production.

The new experimental data agree with the results of Ref. 4, where a study was made of the A dependence of the production of pairs of π^0 mesons at a proton energy of 70 GeV. Taken together, all the results show that the value of α_2 for symmetric pairs is consistent with unity for m' from 1 to 10 GeV/c. This conclusion agrees well

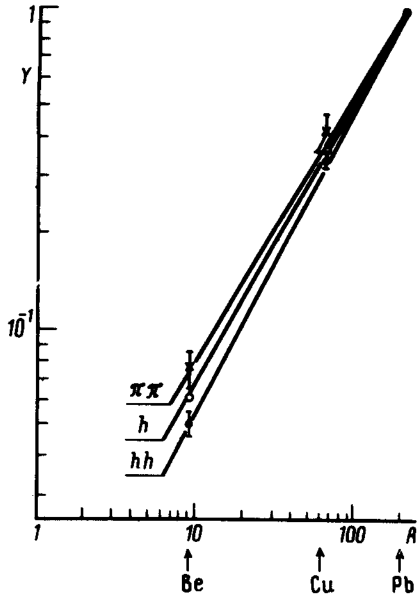

FIG. 1. Cross sections (Y) for particle production in Be and Cu nuclei at $P_T = 0.98$ GeV/c. The cross sections are normalized by dividing by the Pb cross section. Filled circles—hh pairs $\alpha_{\mathrm{Pb/Be}} = 0.950 \pm 0.026$; $\alpha_{\mathrm{Cu/Be}} = 0.985 \pm 0.042$), crosses—$\pi\pi$ pairs; open circles—single hadrons ($\alpha_{\mathrm{Pb/Be}} = 0.89 \pm 0.01$; $\alpha_{\mathrm{Cu/Be}} = 0.91 \pm 0.01$).

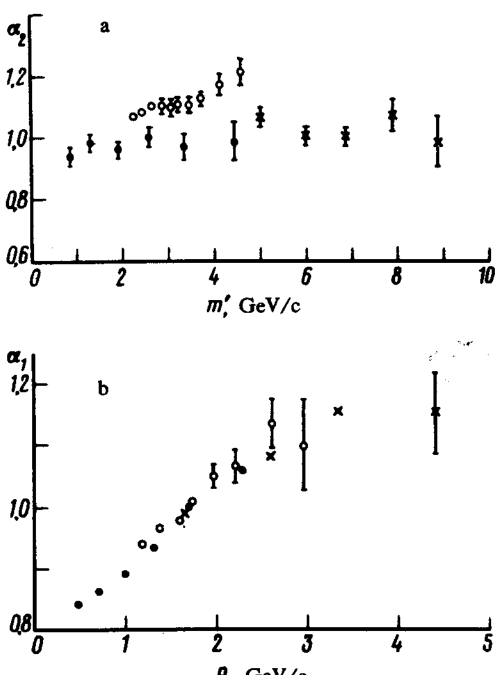

FIG. 2. a: m' dependence of the exponent α_2. b: P_T dependence of α_1. Filled circles—h^+h^+, 70 GeV, results of the present study; open circles—h^+h^-, 400 GeV, data of Ref. 3; crosses—h^+h^-, 400 GeV, data of Ref. 2.

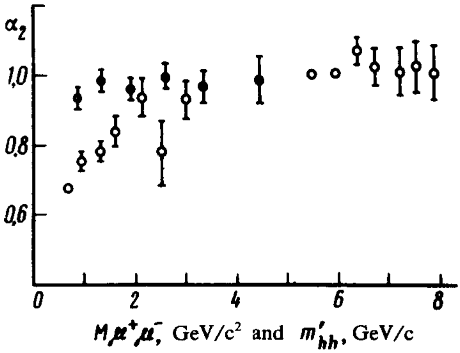

FIG. 3. Comparison of the values of α_2 for symmetric pairs of hadrons (filled circles) with the data from Refs. 6 and 7 on $\mu^+\mu^-$ pairs (open circles).

with the model which attributes the anomalous A dependence to a rescattering of partons in the nucleus.[5]

It is interesting to note that α_2 is rapidly approaching unity. If we take the approach to unity as evidence of a hard collision regime, we conclude that this regime sets in at $P_T = 2$ GeV/c for the inclusive production of single hadrons, while it sets in at $P_T = 0.5$–1 GeV/c for pair production. The data on the A dependence of the production of $\mu^+\mu^-$ pairs, shown along with data from the present study in Fig. 4, demonstrate an approach to unity at $M = 2$–3 GeV/c. It should be noted, however, that in the detection of hadron pairs the fragmentation of partons may cause the transverse-momentum scale and thus m' to shift toward lower energies. Furthermore, soft quarks of the sea play an important role in the production of $\mu^+\mu^-$ pairs. These

TABLE I. The exponents α_2 for various pairs.

P_T, GeV/c	hh	$\pi\pi$	πK	πp	Kp	pp
0,46	0,940 ±0,025	0,91 ±0,03	0,97 ±0.13	0,99 ±0,07	0.81 ±0,22	1.14 ±0,28
0.69	0,986 ±0.030	0,89 ±0,04	1.08 ±0.11	1,05 ±0,05	0,84 ±0,13	1,23 ±0,17
0,98	0,960 ±0.022	0,85 ± 0,04	1,07 ±0,09	0,96 ±0,03	1,10 ±0,09	1.11 ±0,08
1,34	0,997 ±0,031	0,88 ±0,08	0,81 ±0,11	1,03 ±0.05	1,01 ±0,10	1,10 ±0,07
$0.46 \leqslant P_T \leqslant 1,34$	0.966 ±0.013	0,89 ±0,02	0,99 ± 0,05	0,99 ±0.02	1,00 ±0,06	1,11 ±0,05

qualitative considerations suggest that α_2 would approach unity earlier for pairs of hadrons than for $\mu^+\mu^-$ pairs.

Table I shows the values of α_2 for various pairs of particles. Since there is no significant m' dependence of the values of α_2 in the range measured, we also show data averaged over the range $1 \leqslant m' \leqslant 3$ GeV/c. Although the values of α_2 are approximately equal to unity, the values for the combinations πK, πp, Kp, and, especially, pp are larger than that for $\pi\pi$. If we can attribute some of the decrease in $\alpha_{2\pi\pi}$ from unity to a partial absorption of the secondary hadrons in the nucleus, it is more difficult to explain the higher values of α_2 for the other combinations. It may be that there are important differences in the c.m. production angle for the particles of different masses. The data of Ref. 3, corresponding to $\theta_{\text{c.m.}} = 110 \pm 10°$, lead to higher values of α_2. In Ref. 2, however, there is an indication of the same dependence of α_2 on the particle species, although the production angle remains essentially constant at these P_T.

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