# Estimate of the lower bound of the cross section for the production of supercharged hadrons in strong interactions

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A relation between the lower bound of the cross section for the production of pairs of heavy particles and the cross section for the production of heavy muon pairs is obtained within the framework of the parton model. A scaling law is obtained for the lower bound of the cross section, $\sigma(h_1h_2\to R_1R_2+X) = \sigma_0(M_p/M)^5 f(M^2S)$. It is shown that in the parton model the growth of the total cross section of $PP$ scattering at NAL or ISR energies can be attributed to a threshold effect in the production of $N\bar{N}$ pairs.

1. We discuss in this paper the production of pairs of heavy particles in inclusive reactions

$$NN\to R_1R_2+X$$

at high energies within the framework of the parton model. This problem is timely both in connection with the analysis of the feasibility of experimental searches for supercharged particles, predicted in weak-interaction gauge theories (for a discussion of the properties of supercharged hadrons see[1] and the lecture notes[2]), as well as for the interpretation of experiments on the search for quarks, the negative result of which is usually attributed to the large mass of the quark. Estimates of the cross section for the production of heavy particles are important also for the analysis of the possibility of attributing the increase of the total cross sections at NAL-ISR energies to a "threshold" effect connected with the production of heavy particles.

2. The main premise of the paper is that within the framework of the parton model there exists a relation

$$\sigma_{R_1R_2}(S,M) \gg \frac{16<|T|^2>k_0^3}{a^2<Q_p^2>M^2}\quad \frac{d\sigma_{\mu\mu}(S,M)}{dM}=\sigma_0\left(\frac{m_p}{M}\right)^5 f\left(\frac{M^2}{S}\right) \qquad (1)$$

between the lower bound of the cross section for the production of a pair of heavy particles with total mass $M$, on the one band and the cross section for the production of muon pairs having the same mass. In (1), $\alpha = 1/137$, $k_0\approx 1$ GeV is the characteristic relative momentum of the heavy hadrons of the pair, and $\langle |T|^2\rangle \approx 10^{-2}-10^{-1}$ is the characteristic square of the partial amplitude of the reaction of annihilation of a pair of partons into the produced particles near the threshold

$$p_1p_2\to R_1R_2. \qquad (2)$$

It follows from (1) that the dependence of the cross section for the production of a pair with mass $M$ and total energy squared $S$ is subject to scaling. For numerical estimates at $0.1\lesssim M^2/S\lesssim 0.5$, the scaling function, according to the experimental data of[3], takes the form $f(M^2/S)=\exp(-10M^2/S)$, and the estimated experimental cross section for the production of muon pair is $\sigma_0\approx 0.5-5$ mb.

The derivation of (1) is based on the fact that in the parton model a superneutral pair of particles can be produced in the central region of the inclusive spectrum mainly in a reaction of the annihilation type (2). Near the threshold of the reaction (2), the pair is produced only in an $S$ wave, with a cross section determined in practice by the kinematics:

$$\sigma_{R_1R_2} = 4\pi\lambda^2 <|T|^2> \frac{k_f}{k_{in}}, \qquad (3)$$

where $\langle |T|^2\rangle$ is the effective square of the partial-wave amplitude, and the factor $k_f/k_{in}$ corresponds to suppression of the cross section of the reaction by the phase space.

This pair-production mechanism is perfectly analogous to the Drell-Yan mechanism[4] for the production of heavy muon pairs, when a parton and antiparton annihilate into a muon pair with a cross section

$$\sigma_{p\bar{p}\to\mu\bar{\mu}} = \frac{4}{3}\pi a^2 Q_p^2\frac{1}{M^2}, \qquad (4)$$

where $Q_p$ is the parton charge. Relation (1) is obtained by replacing the cross section (4) in the Drell-Yan formula by the cross section (3), and then cutting off the integral with respect to the invariant mass of the pair at a relative pair-particle momentum $k_0\approx 1$ GeV. It is important that we obtain in this case an estimate of precisely the lower limit of the cross section for the production of the pair, inasmuch as the discussed pair-production mechanism does not interfere with the mechanism of fragmentation of partons into a pair, owing to the difference in the finite parton states.

The foregoing estimate for $\langle |T|^2\rangle$ can be obtained directly from experiment if it is recognized that the production of pairs of heavy resonances near threshold takes place under the same conditions as the reaction (2). A comparison of the available experimental data with formula (3) has shown that the quantity $\langle |T|^2\rangle$ is of the same order in highly diverse reactions, regardless of the values of the strangeness and of the charge in the crossing channel, and does not tend to decrease with increasing total mass. This gives, in our opinion, serious grounds for assuming that $\langle |T|^2\rangle$ is of the same order also for the reactions (2), and will likewise not decrease with mass.

If we represent the reaction $p_1p_2\to R_1R_2$, which proceeds via a gluon in the direct channel, then the independence of $\langle |T|^2\rangle$ of the mass corresponds to the absence of a form factor that decreases with mass in the vertex of the transition of the gluon into the $R_1R_2$ pair at the threshold. This seems natural in the parton model, where the form factor at large momentum transfer is due to the fact that the fast hadron consists of a large number of partons, and where there are no special reasons for the existence of a form factor in the threshold region. There is in addition also a direct experimental indication that the hadron form factor at the threshold is not small. Thus, according to experiment,[5] the proton form factor in the $e^+e^- \to p\bar{p}$ reaction at $S=4.5$ GeV$^2$ is $F_p=0.3$ and is larger by almost one order of magnitude that the dipole estimate.

4. As shown in[1], the most characteristic feature of supercharged hardons is the large partial width of the $\beta$ decays, on the order of unity. Therefore the production of the $R_1R_2$ pair would have in experiment the appearance of an anomalous direct production of the pairs $e^+e^-$, $e^+\mu^-$, $e^-\mu^+$, and $\mu^-\mu^+$ with identical pair cross sections and spectra. Recognizing that with ordinary accelerators one can measure cross sections $\sigma \approx 10^{-38}$—$10^{-37}$ cm$^2$, we find from (1) that it is possible to use the accelerator of the Institute of High Energy Physics to verify the existence of supercharged hadrons with masses up to 4—5 GeV, while the NAL accelerator at 400 GeV can be used to check on hadrons with masses up to 10—12 GeV. In the CERN colliding-beam experiments, at a sensitivity to cross sections $\sigma \approx 10^{-34}$ cm$^2$, one can reach masses on the order of 6 GeV. The corresponding experiments would be of great interest, since the masses of supercharged hadrons have a theoretical upper bound $m_R \lesssim 5$—$7$ GeV (see the review[6]).

We note that these estimates of the sensitivity of the experiments with different accelerators to supercharged nuclei apply also to searches for quarks and colored particles, if their production is suppressed only by large masses, and not by specific strong-coupling mechanisms of the infrared-catastrophe type in theories with gauge colored strong interactions.

5. In the parton model there exists a distinct large parameter of order $10^2$, as a result of which the production of heavy particles with total mass $M$ becomes not suppressed only at $S \gtrsim 10^2M^2$ in nucleon-nucleon collisions. The reason is that, according to the results of neutrino experiments, the density of the antipartons in nucleons is much lower than the density of the partons, down to very small $x \lesssim \bar{x}_0 \approx 0.03$. Consequently the scaling function $f(\tau)$ should increase rapidly with decreasing $\tau$, up to $\tau_0 \approx x_0\bar{x}_0 \approx 10^{-2}$. At $\tau < \tau_0$, the function $f(\tau)$ increases logarithmically, corresponding simply to a logarithmic growth of the multiplicity. For $N\bar{N}$ pair production this means that the asymptotic regime of $N\bar{N}$ pair production is established only at $S \gtrsim 4m_p^2\bar{x}_0^2 \approx 4000$ GeV$^2$, when a parton and antiparton from the equilibrium reservoirs of the colliding nucleons annihilate into an $N\bar{N}$ pair, and when the growth of the total cross section, due to the production of the $N\bar{N}$ pairs, ceases. We see therefore that in the parton model there exists a unique threshold effect for the production of heavy particles with conserved quantum numbers; this effect is connected with the delayed appearance of the antiparton density. If formula (1) is applied to $N\bar{N}$ pair production, even though strictly speaking this formula is valid only at $M \gg 1$ GeV, this explains satisfactorily the order of magnitude of the observed growth of the $p\bar{p}$ cross section.

It is well known for experiment that if antiproton production is subtracted from the total cross section, then the remaining cross section is practically constant. It is also known that antiproton production cannot be described by the Regge approach. In the parton model, as described above, both facts are naturally explained by the delayed appearance of the antiparton density.

Inasmuch as in mesons the antipartons are the commanding partons, it follows that according to the described picture the growth of the total cross sections should begin much earlier in meson-nucleon scattering than in proton-proton scattering. This agrees with the results obtained at NAL (private communication from Professor J. Bjorken). To verify this explanation of the growth of the total cross sections, it would be important to ascertain the degree to which the growth of the cross sections is experimentally connected with the growth of the cross section for the production of $N\bar{N}$ pairs.

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