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ABSORPTION OF PARTICLES IN NUCLEAR MATTER DURING TUNNELLING FROM VACUUM

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1. A widely accepted picture of hadronization of departing colour charges is the model of colour strings (tubes) [1-3]. Here $q\bar{q}$ pairs are created from vacuum by tunnelling through the potential barrier formed by the external colour field. The pair appears at a relative distance $2m_q/\kappa$, where $\kappa \approx 1$ GeV/fm is the string tension. This is the consequence of "soft" hadronization, i.e., the energy is transferred slowly by the external colour field acting on colour charged virtual quarks. $N\bar{N}$ pairs are created in the same way [2,4] and are formed at a relative distance $2m_N/\kappa \approx 2$ fm. It is interesting to note that in the lab.frame N and $\bar{N}$ are created at different moments of time and at different distances from the interaction point. For example, in the reaction $pp \to ppN\bar{N}$ at the threshold energy $E \approx 6.6$ GeV one of the created particles (N or $\bar{N}$) is formed at a distance $x_1 \approx m_N/\kappa \approx 1$ fm, the second one at $x_2 \approx 5m_N/\kappa \approx 5$ fm. Consequently, if the process takes place on a nucleon of a nucleus, one of the produced particles appears from beneath the barrier outside the boundary of the nucleus. One may ask whether the particle is not absorbed by nuclear matter during the tunnelling.

2. It turns out that the absorption of particles under the potential barrier is strongly suppressed. Let us consider the quantum-mechanical problem of a particle passing through a potential barrier, when the potential has an imaginary part. The wave function of the particle in the quasiclassical approximation is given by $\Psi(x) \propto \exp\left(\frac{i}{h}\int^{x} dx' \sqrt{2m[E - V(x') + iW(x')]}\right)$.

For small $W(x)$ we have

$$\Psi(x) \propto \exp\left[\frac{i}{h}\int^{x} p(x')dx' - \frac{1}{h}\int^{x} W(x')m\frac{dx'}{p(x')} + \frac{i}{h}\int^{x}\frac{m^2W^2(x')}{2p^3(x')}dx' - \ldots\right].$$

Here $p(x) = \{2m[E - V(x)]\}^{1/2}$ is the quasiclassical momentum. The first term in the exponent gives a phase outside the barrier and an exponential fall-off under the barrier. The second term leads to an exponential damping (absorption) outside the barrier, while below the barrier it gives a phase shift only. Hence, absorption under the barrier appears only in the second order of $W(x)$. This conclusion obviously follows from the interpretation of the under-barrier penetration as movement in imaginary time. Note that the use of approximation of a complex potential is not essential here. The same effect appears in solving the hermitian manychannel problem.

3. In the experiment [5,6] on $\bar{p}$ formation off nuclei at the incident momentum 10 GeV/c, an anomalous A-dependence has been observed with an exponent $\alpha = 0.57 \pm 0.04$. This may indicate a weak absorption of created $\bar{p}$'s by the nuclear matter. Since the momentum of $\bar{p}$ is about 1 GeV/c, the formation length calculated by the standard parton model turns out to be about 0.5 fm.

The observed effect may be related to the above results. Probability of the $N\bar{N}$ pair creation in the nuclear matter is suppressed by the factor $\exp(-W^2\gamma/\kappa)$ as compared with creation in vacuum, where $\gamma \approx 2.5$ is the Lorentz dilation factor; $W \approx \sigma\rho/2$, $\rho \approx 0.16\ fm^{-3}$ is the nuclear density, $\sigma \approx 60$ mb is the $\bar{N}N$ annihilation cross section. Hence, the nuclear matter suppresses the probability of $N\bar{N}$ creation only by about 10%. On the other hand at the usual absorption cross section during the tunnelling this probability would be suppressed by an order of magnitude.

At energies near the threshold value it is a good approximation to assume that a half of the $\bar{p}$'s is created near the interaction point while the other half is born outside the nucleus. The cross section of the process can be written as

$$\sigma_A(\bar{p}) = \frac{1}{2}\sigma_N(\bar{p})\left(\frac{\sigma_{in}^{\bar{p}A} - \sigma_{in}^{pA}}{\sigma_{in}^{\bar{p}N} - \sigma_{in}^{pN}} + \frac{\sigma_{in}^{pA}}{\sigma_{in}^{pN}}\right).$$

Here σ_{in} is the cross section of the corresponding inelastic scattering. A-dependence of the 1st term in the brackets is $A^{1/3}$, while that of the 2nd one is $A^{2/3}$. The comparison with the experimental data in the Figure shows a good agreement. A more critical verification requires hydrogen target data and a better accuracy.

An analogous A-dependence should take place at high energies, but this is non-trivial only for slow $\bar{p}$'s with momenta about 1 GeV/c. The relevant measurements [7] have been done at E = 70 GeV/c and an A-dependence with an exponent $\alpha \approx 0.6$ has been observed for the slow $\bar{p}$ production*.

4. The relative distance between the created N and $\bar{N}$ with close momenta can be measured in hadron-hadron collisions** by means of the interference method [9,10]. It is interesting to

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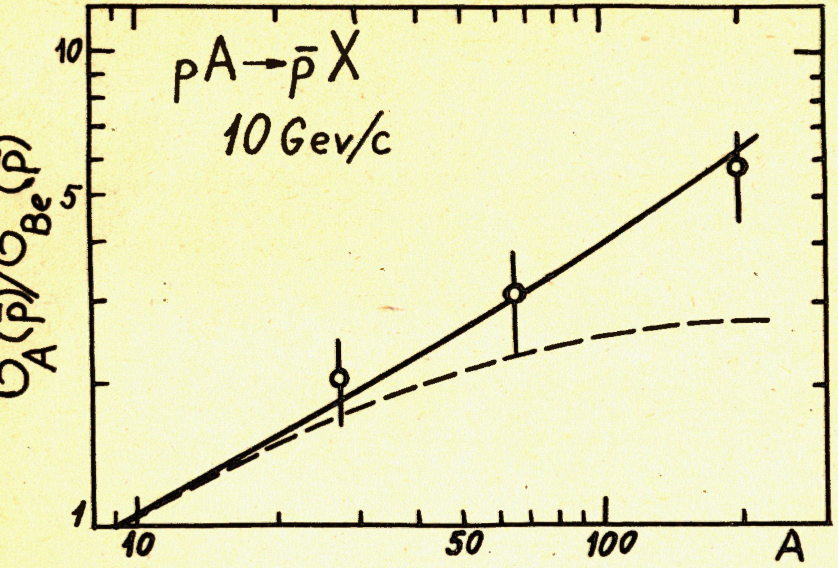
* This contradicts the explanation in ref. [8] of data [5] based on nearness of the threshold.

** The authors are grateful to D.Hazins for colling their attention to this fact.



$\bar{p}$ *production cross section on various nuclei divided by production cross section on beryllium. - - - - result of calculation [5] corresponding to "normal" absorption, ——— - our calculation.*

note that for light particles close momenta in the multiperipheral model mean small relative distances, which is usually obtained by analyzing the experimental data. For a pair of heavy particles, as pointed out above, the distance is large even at close momenta.

5. The effect of weaker absorption under the barrier, noticed above, is interesting itself and is worth studying experimentally. This quantum-mechanical effect may appear in different areas where tunnelling takes place (the Josephson effect; a beam of light passing through a gap at total inner reflection, etc.).

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REFERENCES

1. Kogut J., Susskind P. Phys.Rev., 1974, D10, p.732.
2. Casher A., Neuberger H., Nussinov S. Phys.Rev., 1979, D20, p.179.
3. Gurvich E.G. Phys.Lett., 1979, 87B, p.386.

4. Andersson B., Gustafson G., Sjöstrand T. Baryon Production in Jet Fragmentation. LU TP 84-9, Lund, 1984.
5. Veisenberg A.O. et al. JETP Lett., 1979, 29, p.1719.
6. Barabash L.Z. et al. ITEP Preprint-48, Moscow, 1980.
7. Barkov L.M. et al. IHEP Preprint, 82-107, Serpukhov, 1981.
8. Frankfurt L.L., Strikman M.I. LNPI Preprint, 838, Leningrad, 1983.
9. Kopylov G.I., Podgoretsky M.I. Yad.Fiz., 1971, 13, p.1116; Lednicky R., Lyuboshitz V.L. Yad.Fiz., 1982, 35, p.1316.
10. Cocconi G. Phys.Lett., 1974, 49B, p.459.

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Копелиович Б.З., Нидермайер Ф. E2-84-644
Поглощение частиц ядерной средой при туннелировании из вакуума

"Мягкий" механизм адронизации цветных струн приводит к тому, что тяжелые $q\bar{q}$ пары или $N\bar{N}$ рождаются из вакуума не в точке, а на относительном расстоянии ~1 Фм в их с.ц.и. Показано, что при рождении пары в ядерной среде частицы в процессе туннелирования из вакуума не поглощаются. Эти два эффекта объясняют аномально крутую A-зависимость образования медленных $\bar{p}$ на ядрах.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Kopeliovich B.Z., Niedermayer F. E2-84-644
Absorption of Particles in Nuclear Matter during Tunnelling from Vacuum

Due to "soft" hadronization of colour strings heavy $q\bar{q}$ or $N\bar{N}$ pairs are created from vacuum at a relative distance $\gtrsim$ 1 fm in their c.m.s. It is shown that during tunnelling from vacuum in the nuclear matter they are not absorbed. These two effects may explain the anomalously steep A-dependence of slow $\bar{p}$'s produced on nuclei.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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