Comment on "Quantum Color Transparency"

Ralston and Pire [1] have proposed a factorization hypothesis regarding large-momentum-transfer quasiexclusive scattering in nuclei, but in vague terms. As applied in [1] it fails to capture the dominant effect at experimentally relevant values of Q^2 and thus it is either incomplete or only relevant at inaccessible energies. Their "quantum description of color transparency" implicitly relies on the assumption that "minihadrons" (small-size configurations of quarks) are eigenstates of the free Hamiltonian and thus "frozen" in size except for interactions with the nucleus, since they use the eikonal formalism taking the cross section for absorption to be independent of the distance from the interaction point. As we show below, the actual degree of absorption of a "minihadron" of initial transverse size $b \sim 1/Q \ll 1$ fm is much larger than their description indicates.

Consider a quantum system $\tilde{p}$ which at time $t=0$ is concentrated in a region of transverse size b and has three-momentum P. Denote its wave function by $\psi_{\tilde{p}}(x_t,P)$. For instance such a state exists for a time $\sim 1/Q$ in the quasiexclusive large-momentum-transfer reaction $eA \rightarrow e'\tilde{p}(A-1)^*$, where the state $(A-1)^*$ is an excited state of the nucleus, no additional particles are produced, $\tilde{p}$ denotes three quarks with the quantum numbers of the proton carrying three-momentum P, and Q^2 is the momentum transfer between (e,e'). According to QCD, the characteristic transverse size of the state $\tilde{p}$ will be $\sim 1/Q$ when it is produced.

In order to describe the time development of the state $\psi_{\tilde{p}}(x_t,P,t)$ for $t>0$ we must decompose it in terms of eigenstates of the Hamiltonian: physical hadrons and superpositions of hadrons with the same quantum numbers as $\tilde{p}$ [2]. Let us denote these hadron wave functions by ψ_n, with $n=1$ corresponding to the nucleon. Then

$$\psi_{\tilde{p}}(x_t,P,t)=\sum_n c_n \psi_n(x_t,P)e^{i(m_n^2+P^2)^{1/2}t}. \quad (1)$$

The coefficients c_n in this expansion depend on the transverse shape of the state $\tilde{p}$ at $t=0$. Evidently, if the momentum transfer were zero and if the approximation that nucleons in the nucleus are the same as free nucleons were justified, then $\tilde{p}$ would simply be a proton and so $c_1=1$ and all other $c_{n>1}=0$. However, since the characteristic size of the proton and higher resonances is ~ 1 fm, in general many c_n's are important for a state $\tilde{p}$ of characteristic size $b \sim 1/Q \ll 1$ fm. Without more detailed knowledge than we have at present regarding the x_t shape of a state $\tilde{p}$ produced in a collision of momentum transfer Q, and knowledge of the x_t shapes of the nucleonic resonances, we cannot predict the c_n's. However, it is clear that as $Q \rightarrow \infty$ the number of important c_n's must increase because we are requiring more and more precise localization of $\psi_{\tilde{p}}(x_t,t=0)$ around $x_t \simeq 0$ and the sizes of the hadronic excited states are all comparable, since they are determined by confinement effects.

We now return to the time development of the state $\psi_{\tilde{p}}$. To simplify the discussion we make the approximation that only the nucleon and one other state called N' dominate (1). We are interested in the case $P \gg m_{N,N'}$, so we expand the exponentials as $(P^2+m^2)^{1/2}=P+m^2/2P$. Thus as long as $t(m_{N'}^2-m_N^2)/2P \ll 1$, the loss of coherence between the ψ_N and $\psi_{N'}$ wave functions is unimportant and the state remains localized in the transverse dimension. However, when $t(m_{N'}^2-m_N^2)/2P \sim 1$, the coefficients of the N and N' wave functions have changed substantially from their values in the initial superposition, and the characteristic size of the state $\psi_{\tilde{p}}(x_t,P, t\sim 2P/(m_{N'}^2-m_N^2))$ is the same as the characteristic size of ψ_N and $\psi_{N'}$. Thus by the time the state $\tilde{p}$ has traveled a distance $\sim 2P/\Delta m^2$, its characteristic size is ~ 1 fm and it has normal hadronic cross section. In general the relevant value of Δm^2 will be greater than $m_{N^*}^2-m_N^2$ and will grow with increasing Q^2, since as $\tilde{p}$ is more and more localized, more and more resonances will be needed in (1). A qualitatively similar conclusion was reached in [3] for a harmonic-oscillator model. In that case only neighboring states are coupled, due to simplifying assumptions on the structure of the interaction.

We can estimate the importance of this "expansion" due to loss of coherence, by noting that it will be important unless $A^{1/3}$ fm [the typical nuclear distance to be transversed by the state $\psi_{\tilde{p}}(t)$] is $\ll 2P/\Delta m^2$. To illustrate, for the process $eA \rightarrow e'\tilde{p}(A-1)^*$ the final three-momentum of the $\tilde{p}$ system is $P \approx Q^2/2m$, when $Q^2 \gg m^2$. Thus loss of coherence is the dominant effect in absorption of $\tilde{p}$ unless $A^{1/3}$ fm $\ll Q^2/m\,\Delta m^2 \approx 0.36$ fm for $Q^2=2$ GeV^2 (≈ 3.6 fm for $Q^2=20$ GeV^2). Since the assumption that the minihadron is "frozen" with a size $b \sim 1/Q$ is invalid for essentially the entire range of A and Q^2 shown in Fig. 2 of Ref. [1], that calculation grossly overestimates the expected effect of color transparency in the Q^2 range under discussion and is very misleading for present experimental planning. The factorization theorem conjectured in Ref. [1], even if it could be made precise and proved to be true at asymptotically large energy, would be inapplicable at feasible energies unless it could be made to incorporate this physics.

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