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Color Transparency and the Proton Form Factor-Evidence For The Feynman Mechanism

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A recent experiment [**Phys. Rev. Lett. 126,082301 (2021)**] used the $(e, e'p)$ reaction on ^{12}C to search for the effects of color transparency (the absence of final state interactions). Color transparency was said to be ruled out. Observing the effects of color transparency depends on the ability of a putative point-like-configuration (PLC), formed in a high-momentum transfer coherent reaction, to escape the nucleus without expanding its size. We study the expansion aspect of color transparency using superconformal baryon-meson symmetry and light-front holographic QCD. A new formalism is obtained and used to analyze the recent experiment. The resulting conclusion is that effects of expansion would not be sufficiently significant in causing final state interactions to occur. Therefore we conclude that a PLC was not formed. This means that the Feynman mechanism involving virtual photon absorption on a single high momentum quark is responsible for high momentum electromagnetic form factor of the proton.

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I. INTRODUCTION

The recent striking experimental finding [1], that color transparency does not occur in reactions with momentum transfer up to 14.2 GeV^2 demands an interpretation and assessment of the consequences. This paper aims to provide such, beginning with a brief discussion of color transparency.

Strong interactions are strong: when hadrons hit nuclei they generally break up the nucleus or themselves. Indeed, a well-known semi-classical formula states that the intensity of a beam of hadrons falls exponentially with the penetration distance through nuclei. This effect is known as absorption. It is remarkable that QCD admits the possibility that, under specific conditions, the strong interactions can be turned off and hadronic systems can move freely through a nuclear medium.

How can this occur? Consider elastic scattering of a small color-singlet $q\bar{q}$ system by a nucleon. At sufficiently high energy, the separation b of the quarks (in a direction transverse to the momentum) does not change. The lowest-order perturbative contribution is given by two-gluon exchange [2–4] and the remarkable feature is that, as b approaches 0, the cross section vanishes because color-singlet point particles do not exchange colored gluons. Thus as $\lim_{b\to 0}\sigma(b^2) \propto b^2$. This reduced interaction, caused by interference between emission by quarks of different colors in coherent processes, is the basic widely-used, un-questioned ingredient behind QCD factorization proofs [5].

It is natural to suppose that small-sized color-singlet objects stand out in processes involving coherent high momentum transfer reactions. Early perturbative QCD calculations [6–11], see Fig. 1a, of the pion elastic electromagnetic form factor were interpreted [12] as follows: A high-momentum, Q, photon hits one of the partons that greatly increases the relative momentum to Q. The system can only stay together only by exchanging a gluon carrying that momentum. That gluon has a range of only $1/Q$ so that the partons must be close together, making a small-sized system or point-like configuration (PLC). As time goes by the point-like configuration evolves to a physical wave function of the pion. Many consequences of the PLC idea were spelled out by Frankfurt & Strikman [13]. A clear analysis of the proton in perturbative QCD was presented in [14].

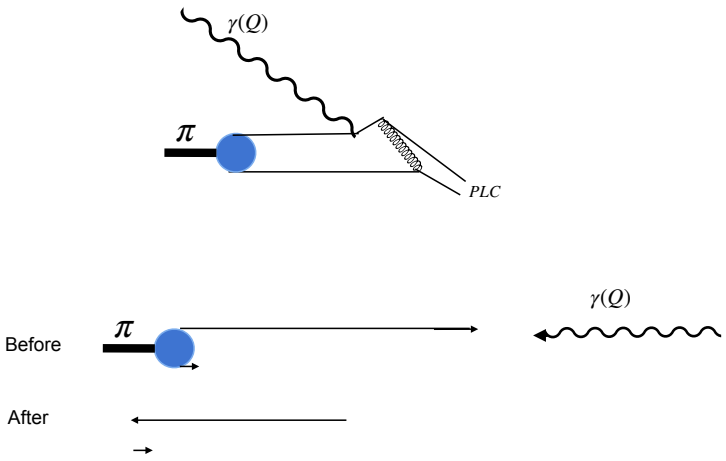


FIG. 1. High momentum transfer reaction mechanisms. Top picture: a pQCD mechanism. Middle picture: Initial state in the Feynman mechanism. Bottom pictire: final state in the Feynman mechanism. The final state overlaps well with the turned around version of the initial state.

Thus, if a high-momentum transfer reaction that is coherent on the hadronic level occurs in a nucleus, the initial and final state reactions that normally occur are suppressed. This is color transparency. However, it is important that the putative PLC not expand to a system of ordinary hadronic size when it is in the nucleus. The expansion time in the rest frame of the ejected proton is of the order of the inverse of an excitation energy. Time dilation increases this time as the proton momentum increases. For this reason, the very high-momentum transfer experiment [1] is of vital importance.

Although it is natural to suppose that PLCs dominate coherent high-momentum transfer processes, it is far from

obvious that this is the case [10, 11, 15]. The doubts are especially relevant for baryons. Indeed, Feynman [15] remarked that "if a system is made of 3 particles, the large Q^2 behavior depends not on the singularity when just two come together, but rather when all three are on top of one another". Furthermore, "such pictures are too simple and inadequate".

Another mechanism competes with PLC dominance (Fig. 1b). In this idea, first published by Drell & Yan [16] (known as the Feynman mechanism [15]) the process occurs when a single quark, carrying a large fraction of the nucleon's momentum, is turned around by the incident virtual photon. The spectator system is not required to shrink to a small size and color transparency effects involving protons would not be expected to occur. In this picture, a reasonably valid relation between elastic and deep inelastic scattering is obtained. See also [17]. A more recent example favoring the Feynman mechanism is [18].

Models of Generalized Parton Distributions (GPDS) [19] access both the longitudinal and transverse structure of nucleons so that measurements can distinguish the different mechanisms. It has been said [20] that GPDs parameterize soft dynamics akin to the Feynman mechanism. Specific models of GPDs, for example [21] also favor the Feynman mechanism. More generally, a review of the history teaches us [22] that there are only two proposals for the mechanism responsible for high momentum elastic reactions.

To summarize [23]: the magical disappearance of a strong scattering amplitude arises in three steps: (a) A coherent high-momentum transfer reaction creates a color-singlet PLC (b) the PLC doesn't interact (a well-defined aspect of QCD) (c) If the PLC escapes the nucleus before expanding, then no re-interactions occur and effects of color transparency are to be observed.

The non-interaction of a PLC is a given, as is the necessity of expansion. The interesting aspect of color transparency is whether or not PLC's are created in high-momentum transfer coherent reactions. However, evaluating the effects of expansion creates significant uncertainty in making conclusions. This paper is devoted to providing a better estimate of expansion, based on new findings using holographic techniques to represent the effects of confinement, see the review [24].

The considerable efforts to observe color transparency, along with a spectacular success [25], has been reviewed several times [26–29]. Here we focus on color transparency studies involving incident high-energy pions at FermiLab [25], electro-production of pions at JLab [30], electro-production of rho mesons at JLab [31], and the $(e, e'p)$ reaction culminating with [1]. The FermiLab experiment involved pions of 500 GeV. The $(e, e'\pi)$ experiment [30] involved space-like squares of virtual photon four-momentum Q^2 between 1.10 and 4.69. GeV^2, with outgoing pions of momentum between 2.79 and 4.4 GeV. The $(e, e'\rho)$ experiment involved Q^2 between 1 and 3 GeV^2, with virtual photon energy around 3 GeV, to avoid the effect of changing the coherence length. The outgoing momentum of the ρ-meson was about 5 GeV for all kinematic conditions.

The signature of color transparency in the FermiLab experiment was a spectacular dependence of the cross section for di-jet production by incident pions on the nuclear atomic number of about $A^{5/3}$, for high relative transverse momentum between the two jets, in accord with theoretical predictions [32, 33]. The electron scattering experiments measure the transparency, T, which is the ratio of the measured experimental yield to the expected yield in the absence of final interactions. The signature of the onset of color transparency is a rise in the value of T with respect to an increase with Q^2. A significant rise occurs only by effects of color transparency.

We evaluate the effects of expansion using relativistic light-front wave functions obtained from light front holographic QCD [24], that provides a relativistic treatment of confined systems. Light-front quantization is a relativistic, frame-independent approach to describing the constituent structure of hadrons. The simple structure of the light-front (LF) vacuum allows an unambiguous definition of the partonic content of a hadron in QCD [34]. The spectrum and light-front wave functions of relativistic bound states are obtained in principle from the eigenvalue equation $H_{LF}|\psi\rangle = M^2|\psi\rangle$, an infinite set of coupled integral equations. This provides a quantum-mechanical, probabilistic interpretation of the structure of hadrons in terms of their constituents at the same light-front time $x^+ = x^0 + x^3$, the time marked by the front of a light wave [35]. The matrix diagonalization [34] of the frame-independent LF Hamiltonian eigenvalue equation has not been achieved, so other methods and approximations [24] are needed to understand the relativistic bound states of QCD.

To a first semiclassical approximation, where quantum loops and quark masses are not included, the relativistic bound-state equation for light hadrons can be reduced to an effective LF Schrödinger equation. The technique is to

identify the invariant mass of the constituents as a key dynamical variable, ζ, measuring the separation of the partons within the hadron at equal light-front time [36]. Thus, the multi-parton problem in QCD is reduced, to an effective one-dimensional quantum field theory in which the complexities of the strong interaction dynamics are hidden in an effective potential U.

In the semiclassical approximation described above, the light-front Hamiltonian has a structure which matches exactly the eigenvalue equations in AdS space [24]. This offers the possibility to explicitly connect the AdS wave function $\Phi(z)$ to the internal constituent structure of hadrons. In fact, one can obtain the AdS wave equations by starting from the semiclassical approximation to light-front QCD in physical space-time. This connection yields a relation between the coordinate z of AdS space with the impact LF variable ζ [36], thus giving the holographic variable z a precise definition and intuitive meaning in light-front QCD.

Light-front holographic methods were originally introduced [37, 38] by matching the electromagnetic current matrix elements in AdS space [39] with the corresponding expression derived from light-front quantization in physical space-time [16, 17]. It was also shown that one obtains identical holographic mapping using the matrix elements of the energy-momentum tensor [40] by perturbing the AdS metric around its static solution [41], thus establishing a precise relation between wave functions in AdS space and the light-front wave functions describing the internal structure of hadrons.

The light front wave functions that arise out of this light front holographic approach provide a new way to study old problems that require the use of relativistic-confining quark models. The study of the expansion of a PLC is an excellent example of such a problem.

The starting point for the present calculations is the relativistic light-front wave equation for hadronic light front wave function $\phi(\zeta)$. Consider a hadronic bound state of two constituents, each of vanishing mass. The wave equation is:

$$\Big(-\frac{d^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta, J)\Big)\phi(\zeta) = M^2\phi(\zeta) \tag{1}$$

The eigenmodes of this equation determine the hadronic mass spectrum and represent the probability amplitude to find the partons at transverse impact separation ζ. The connection between ϕ and wave functions Φ in a higher-dimensional space asymptotic to anti-de-Sitter space is explained in Ref. [24]. In the soft-wall model [42] the potential is harmonic and holographically related to a unique dilaton profile the follows from the requirements of conformal invariance. The effective potential is given [24] by

$$U(\zeta, J) = \kappa^4\zeta^2 + 2\kappa^2(J-1) \tag{2}$$

where κ is the strength of the confinement, and J is the total angular momentum. This form was used in [43–45], to obtain relations between the baryon and meson spectrum [45], with a universal value of $\kappa = 0.53$ GeV. The results are specified here to: $U(\zeta) = \kappa^4\zeta^2 + C_H$, with $C_\pi = -2\kappa^2$, $C_\rho = 0$, $C_N = 2\kappa^2$. We shall see that these different values have profound effects on the ability to observe color transparency. The eigenvalues are : $M^2_{nL} = 4\kappa^2(n + \frac{J+L_M}{2})$ for mesons, and for baryons $M^2_{nL} = 4\kappa^2(n + L_B + 1)$ with $L_M = L_B + 1$.

We next convert Eq. (2) to a light front 3-dimensional wave equation in coordinate space. This is done by using $\phi(\zeta) \to \sqrt{\zeta}\psi(x, \mathbf{b}) = \sqrt{z}e^{iL\phi}\psi_L(x, b)$ with the replacement $\zeta \to b\sqrt{x(1-x)}$, so the equation for a meson is given by:

$$\Big(-\frac{1}{x(1-x)}\nabla_b^2 + U(b^2(x(1-x), J)\Big)\psi(x, \mathbf{b}) = M^2\psi(x, \mathbf{b}) \tag{3}$$

The equation for the nucleon is of the same form, but there are two components, denoted $\psi_\pm$. The smaller-sized of these two components is ψ_+ and $\psi_-(x, 0) = 0$. Therefore ψ_+ is the relevant one whose time development is studied here. A good description of electromagnetic form factors and parton distributions is obtained [46].

The Hamiltonian contains no operator that changes the value of x. The longitudinal degree of freedom is fixed in this model. However, the known meson and baryon spectra are well reproduced, which is the central necessity for obtaining a reasonable treatment of the expansion of the PLC wave packet. The light-front wave functions obtained by solving Eq. (3) are given by:

$$\psi_{nL_z}(\mathbf{b}, x) = \sqrt{2}\sqrt{\frac{n!}{(n+L)!}}\frac{e^{iL_z\varphi}}{\sqrt{2\pi}}e^{-\kappa^2b^2x(1-x)/2}(\sqrt{x(1-x)}b)^L L_n^L(\kappa^2b^2x(1-x)), \tag{4}$$

where b is the transverse separation, φ is the transverse angle, and x is the plus-momentum ratio of one of the quarks.

The average value of b^2 in the ground state is given by $\bar{b}^2 \equiv \langle\Psi_{00}|b^2|\Psi_{00}\rangle = \frac{1}{\kappa^2 x(1-x)}$. This quantity can be very large if x approaches 0 or 1. However, the x-dependent wave function that vanishes at those endpoints would remove this feature. Here we are concerned with studying how a small-sized wave packet, or PLC expands as a function of time. This means that cases with x near 0 or 1 are not under consideration. Moreover, if x is near the endpoints, the Feynman mechanism is the dominant contributor to the form factor, so that the conclusion of this paper would be reached immediately.

It is necessary to obtain the time-development operator for a system that is moving in the z direction with a given large value of P^+. This is done using the Feynman path integral technique [47]. First step we regard the right-hand-side of Eq. (2) as an operator P^-P^+, to obtain the LF Schroedinger equation

$$2i\frac{\partial}{\partial\tau}\Psi = P^-\Psi = \frac{1}{P^+}\left(-\frac{1}{x(1-x)}\boldsymbol{\nabla}_b^2 + U(b^2(x(1-x),J)\right)\Psi, \tag{5}$$

with the light-front time variable: $\tau \equiv x^+$. The factor of 2 arises from the definition: $x^\pm = x^0 \pm x^3$, so that $P\cdot x = 1/2(P^-x^+ + P^+x^-) - \mathbf{P}\cdot\mathbf{x}$. The vectors written in bold face are two-dimensional vectors.

The time development of a PLC that moves at high speed is studied. The longitudinal momentum fraction, x, is fixed in the present model. This is a good approximation because interactions proportional to b^2 do not change the value of x [5, 48].

One could construct the time-development operator, K, using the stated wave functions of Eq. (4). Instead, it is much more efficient to use the Feynman path integral formalism [47], in which K is the path integral of the exponential of i times the classical action. The necessary Lagrangian is expressed in terms of velocities, defined as partial derivatives of the Hamiltonian with respect to momenta. The entire formalism is based on a Hamiltonian operator that is i times the partial derivative with respect to time. For this purpose, it is useful to define a time $t \equiv \tau/2$. For a system moving in the laboratory with speed close to that of light, $x^3 \approx x^0$, so that t is approximately the laboratory time.

Next we identify a Lagrangian that corresponds to the Hamiltonian of Eq. (5). The operator $\mathbf{p} = -i\boldsymbol{\nabla}_b$ so that by Hamilton's equations $\frac{\partial}{\partial t}\mathbf{b} = \mathbf{v} = \frac{\partial H}{\partial \mathbf{p}} = 2\mathbf{p}/(P^+x(1-x))$. Then:

$$L = \frac{P^+}{4}x(1-x)\mathbf{v}^2 - \frac{1}{P^+}U(\zeta,J) \tag{6}$$

The formalism is tested by taking the limit of a free particle, $U(\zeta,J)\to 0$, using the well-known expression for the time development of a plane wave, starting at $t=0$. At later times, the initial plane wave acquires time-dependence of $e^{-iP^-t} = e^{-iP^-\tau/2}$, which is the correct form.

Having specified the Lagrangian, the known result [47] for harmonic oscillator potentials yields the time development operator K for times between 0 and t:

$$\langle\mathbf{b},t|K|\mathbf{b}',0\rangle = \left[\frac{x(1-x)\kappa^2}{2\pi i\sin\frac{2\kappa^2 t}{P^+}}\right]\exp\left[i\Big(\frac{x(1-x)\kappa^2}{2\sin\frac{2\kappa^2 t}{P^+}}\Big)((b^2+b'^2)\cos\frac{2\kappa^2 t}{P^+} - 2\mathbf{b}\cdot\mathbf{b}')\right]\exp\left(-i\frac{C_H}{P^+}t\right). \tag{7}$$

The term C_H accounts for the constant term in U, and $C_\pi = -2\kappa^2$, $C_\rho = 0, C_N = 2\kappa^2$. One may check that the above expression becomes $\delta(\mathbf{b}-\mathbf{b}')$ in the limit that $t\to 0$. The same limit is achieved if $P^+\to\infty$ in which the separation between partons in the PLC is unchanged as it moves through the nucleus. This fixed transverse separation configuration is said to be frozen. Note that the presence of the term C_H shows that the expansion process depends on the hadron that is involved. This non-universality of the expansion process arising from a unified treatment of meson and baryon spectra is the first new result presented here. See also Ref. [49].

Given the time-development operator of Eq. (7), we may study the time development of a PLC, potentially formed in a high momentum transfer (hard) reaction. A measure of expansion was introduced in Ref. [50]. The idea is that a PLC is originated via a hard interaction involving nucleons initially bound in a nucleus. The soft interactions between the PLC and the surrounding medium is proportional to the square of the transverse separation distance [2–4]. We wish to compare the relative effects of escaping with an interaction to that of escaping without an interaction. This

is given by a ratio defined as $b^2(t)$. This effective size is given by the ratio of matrix elements:

$$b^2(t) \equiv \frac{\langle \Psi_{00}|b^2 K(t)|\mathrm{PLC}\rangle}{\langle \Psi_{00}|\mathrm{PLC}\rangle}, \tag{8}$$

where Ψ_{00} is the ground state wave function of Eq. (4), and $K(t)$ is from Eq. (7). This expression is first-order in final-state interactions. A multiple scattering series was presented in [51]. The term $i\sigma\frac{b^2(t)}{\langle b^2\rangle}$ has also been thought of as scattering amplitude that varies along the path length, ℓ, of an outgoing PLC, with $t = \ell$ [13, 23].

Evaluations of $b^2(t)$ proceed by taking a simple form for the PLC: $\langle \mathbf{b}|\mathrm{PLC}\rangle = \mathrm{e}^{-\gamma \mathrm{b}^2}$, so that the evaluation of Eq. (8) is straightforward with the result:

$$b_H^2(t) = \frac{2}{\kappa^2}\frac{i}{x(1-x)}\sin\left(\frac{2\kappa^2}{P^+}t\right)\exp\left[-i\left(\frac{4\kappa^2}{P^+}+\frac{C_H}{P^+}\right)t\right] + \frac{2}{\kappa^2 x(1-x)+2\gamma}\exp\left[-i\left(\frac{6\kappa^2}{P^+}+\frac{C_H}{P^+}\right)t\right]. \tag{9}$$

The time dependence is independent of the value of x, and the results are periodic with an angular frequency of $\omega \equiv 2\kappa^2/P^+$. Therefore, the second term vanishes smoothly for all values of t as γ approaches infinity, the point-like limit. In that case, the first term of Eq. (9) accurately describes the time development and is independent of the detailed form of $\langle \mathbf{b}|\mathrm{PLC}\rangle$, provided the size parameter of the PLC is sufficiently small.

The expression for $b_H^2(t)$ is complex-valued (as has been known for a long time [23]), but only the real part contributes to the absorption of the propagating ejectile. Therefore, we take the limit $\gamma \to \infty$ and use the real part of b_H^2. This, with the stated values of C_H, yields:

$$\frac{b_\pi^2}{2b^2} = \sin^2\left(\tfrac{2\kappa^2}{P^+}t\right) \tag{10}$$

$$\frac{b_\rho^2}{2b^2} = \sin\left(\tfrac{2\kappa^2}{P^+}t\right)\sin\left(\tfrac{4\kappa^2}{P^+}t\right) \tag{11}$$

$$\frac{b_N^2}{2b^2} = \sin\left(\tfrac{2\kappa^2}{P^+}t\right)\sin\left(\tfrac{6\kappa^2}{P^+}t\right). \tag{12}$$

These expressions contain the result that the effects of confinement cause the expansion time to be very different for pions, rho mesons and nucleons. The oscillations inherent above are of no consequence. Once the first maximum is hit, the system is strongly absorbed and the formulae are no longer relevant.

The results of evaluations are shown in Figs. 2-4. The pionic results of Fig 2 are presented for the upper and lower values of P_π^+ of Ref. [30] along with 100 GeV/c. It is useful to define the expansion time, t_H as the *lowest* time for which b_H^2 hits its maximum value. For the pion this is $t_\pi = 1.57\frac{P^+}{2\kappa^2} = 0.552\frac{P^+}{\mathrm{GeV}}\mathrm{fm}$. This time increases from about 2 fm to 6 fm in the kinematic range of Ref. [30] . This increase is large enough so that the observed increase in the measured transparency can reasonably be ascribed to the effects of color transparency. The FermiLab experiment was done at 500 GeV, but the results shown here are for 100 GeV. This is done only to allow a non-zero value to be shown. It is very clear that, in the FermiLab experiment, the PLC goes through an entire nucleus without expanding.

The results for the expansion of a ρ PLC are presented in Fig. 3. For the experiment of [31] $t_\rho = .955\frac{P^+}{2\kappa^2} = 0.335\frac{P^+}{\mathrm{GeV}}\mathrm{fm}$ is only about 2 fm for all of its kinematic variables. This indicates that the observed rise in the transparency, while consistent with theoretical predictions, may not be due to color transparency. However, a new experiment that doubles the value of P^+ could lead to observation of the effects of color transparency.

The key results here are for the proton as shown in Fig. 4. The proton expansion time is given by $t_p = 0.659\frac{P^+}{2\kappa^2} = 0.231\frac{P^+}{\mathrm{GeV}}\mathrm{fm}$. In the $(e, e'p)$ experiment on a ^{12}C target [1], the value of Q^2 ranges between 8 and 14.2 GeV^2. The photon energy $\nu = Q^2/(2M)$, and $P_p^+ \approx 2\nu$. Thus P^+ ranges from about 8 to 14 GeV. As shown in Fig. 3, t_p ranges between about 2 to about 3 fm. This is large enough to observe the effects of color transparency because the radius of ^{12}C is only about 2.4 fm. If a PLC had been formed, it would have made it out of the nucleus without being absorbed. Thus we are led to the inevitable conclusion that a PLC was not formed. This means that all of the quarks are not on top of each other during the high-momentum transfer process, so that the Feynman mechanism is the only one left standing. for $(e, e'p)$.

The conclusion that the Feynman mechanism is responsible for the proton electromagnetic form factor raises a number of interesting questions. The first is whether this Feynman dominance occurs for all hadrons, in particular the pion. The pion electromagnetic form factor has been studied extensively via perturbative and non-perturbative means, including lattice QCD calculations. In the analytic examples, both the perturbative QCD and light front

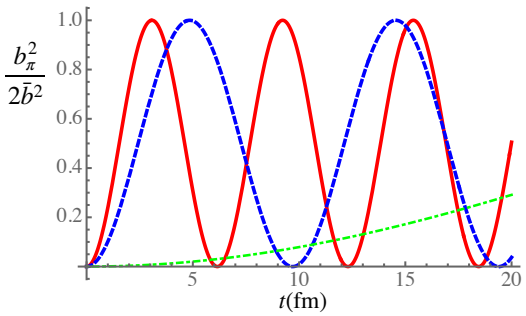


FIG. 2. $\frac{b_\pi^2}{2\bar{b}^2}$. Solid (red) $P_\pi^+ = 5.5$ GeV, Dashed (blue) $P_\pi^+ = 8.8$ GeV, Dot-dashed (green) $P_\pi^+ = 100$ GeV. t is in units of fm

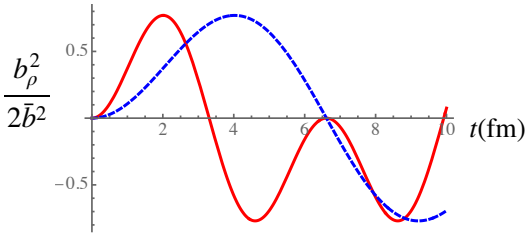


FIG. 3. $\frac{b_\rho^2}{2\bar{b}^2}$. Solid (red) $P_\rho^+ = 6$ GeV, Dashed (blue) $P_\rho^+ = 12$ GeV. t is in units of fm

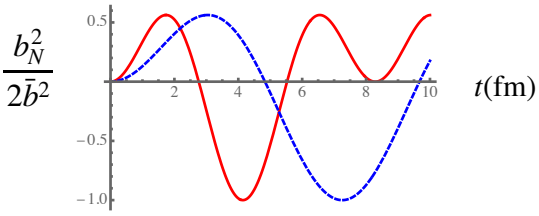


FIG. 4. $\frac{b_N^2}{2\bar{b}^2}$ Solid (red) $P_N^+ = 8$ GeV, Dashed (blue) $P_N+ = 14$ GeV. t is in units of fm.

holography calculations lead to an asymptotic form factor $\sim 1/Q^2$. The PLC is part of the former calculations. The Feynman mechanism does dominate in the latter calculations at infinite momentum [52]. However, values of x near 1/2 dominate the light front wave function [38] for the relative momenta involved in the FermiLab experiment. Thus the result that the astounding A-dependence observed is due to color transparency is not challenged.

Another point concerns the relation with the EMC effect, the nuclear suppression of high quark structure function at large values of Bjorken x. Frankfurt & Strikman suggested [13, 53] that this suppression is due to the reduction of the nucleon's PLC component caused by the attractive nature between the nucleon's non-PLC component and the residual nucleus. This idea has been followed up in many papers, including [54–57], and an excellent interpretation along with a qualitative description of nuclear structure functions in the valence region has been obtained. The question arises: does the lack of PLC dominance of the electromagnetic form factor cast doubt on the basic idea that the different nuclear interactions of different-sized components of the nucleon wave function is responsible for the EMC effect. The answer is no, because the having a dominant PLC is not necessary. The only necessity is that different sized components of the nucleon wave function interact differently with the nucleus. A first application of this idea using a light front holographic treatment [21] of the nucleon wave function was presented in [57]. The two different components are configurations of three and four partons. Further development is proceeding.

The results of Figs. 2-4 arise from using a specific model, based on a semi-classical approximation, in which quantum loops and quark masses are not included. For example, situations in which the starting configuration includes gluonic components are not included. In that case, the high-momentum transfer process proceeds via a mechanism that is not the Feynman mechanism. This would correspond to a new, unpublished mechanism that is neither perturbative QCD nor the Feynman mechanism.

The present results provide a new way to compute the effects of the spatial expansion of a putative PLC. The formalism of the light front holographic model and the resulting expansion effects, combined with the experimental result [1] that color transparency does not occur in reactions with momentum transfer up to 14.2 GeV^2, leads to an answer to a decades old question: the Feynman mechanism dominates the high-momentum transfer values of the proton electromagnetic form factor.

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