Discussion Session 1: Holographic light-front QCD (HLFQCD)

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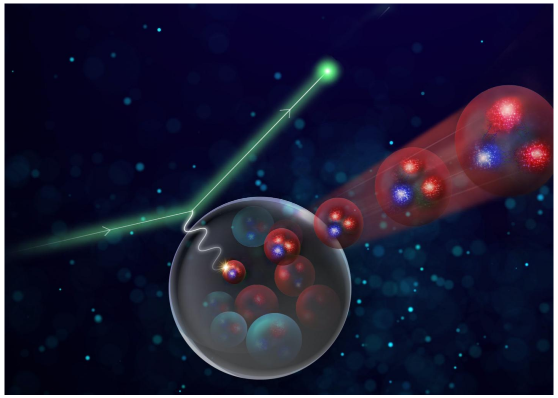
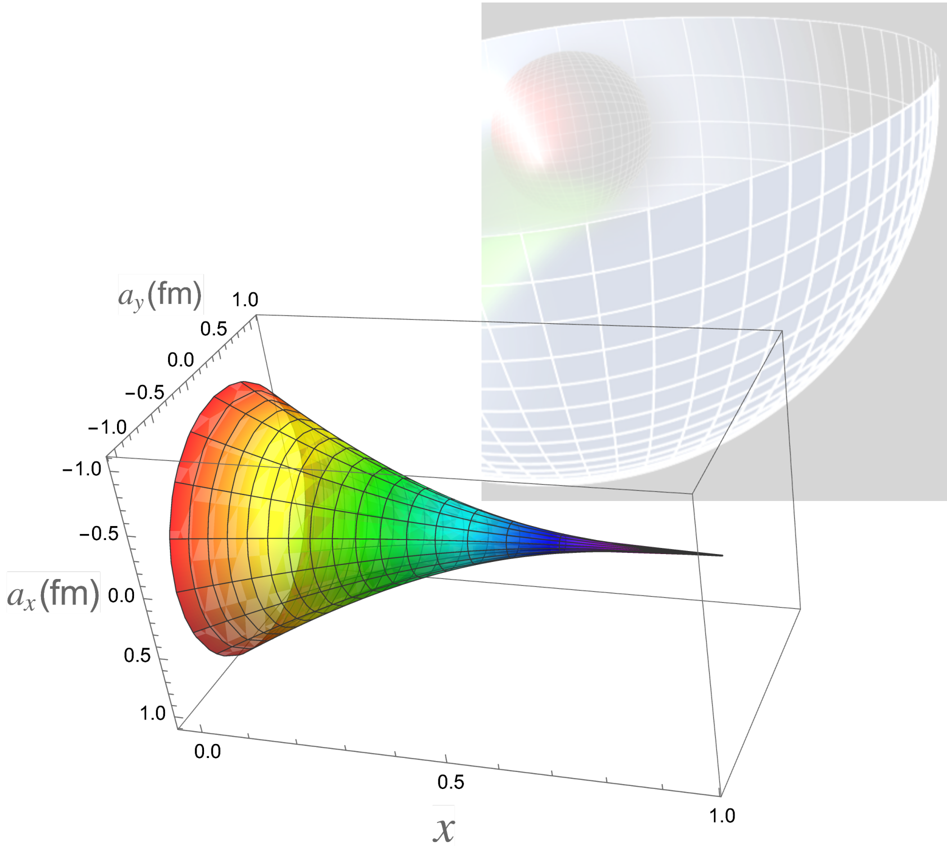
UCR

The Future of Color Transparency

and Hadronization Studies

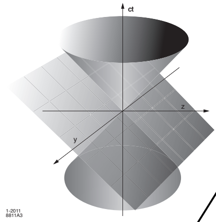
JLab, 7-8 June 2021

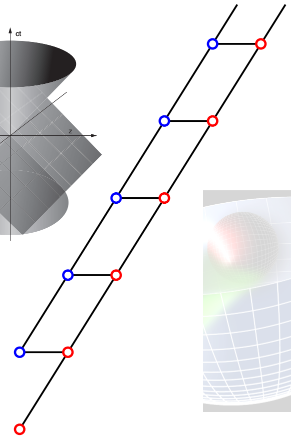




Recent overview: S. J. Brodsky, GdT and H. G. Dosch [arXiv:2004.07756 [hep-ph]].

- Threefold combined approach from (a) gauge/gravity correspondence, (b) light-front quantization and (c) superconformal algebra leads to semiclassical wave equations which incorporates essential elements which are not obvious from the QCD Lagrangian, such as confinement, chiral symmetry breaking and the connection between mesons and baryons





- It leads to the baryon bound-state equations [GdT, H.G. Dosch and S. J. Brodsky, PRD **91**, 045040 (2015)]

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + \lambda^2\zeta^2 + 2\lambda(L+S+1)\right)\psi_+ = M^2\psi_+$$

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4(L+1)^2}{4\zeta^2} + \lambda^2\zeta^2 + 2\lambda(L+S)\right)\psi_- = M^2\psi_-$$

- Eigenvalues

$$M^2 = 4\lambda(n+L+1) + 2\lambda S$$

- Eigenfunctions

$$\psi_+(\zeta) \sim \zeta^{\frac{1}{2}+L} e^{-\lambda\zeta^2/2} L_n^L(\lambda\zeta^2), \quad \psi_-(\zeta) \sim \zeta^{\frac{3}{2}+L} e^{-\lambda\zeta^2/2} L_n^{L+1}(\lambda\zeta^2)$$

Note: $\zeta^2 = x(1-x)b_\perp^2$, $z = \zeta$ holographic variable, and $S = 0, 1$,

- HLFQCD also leads to LF bound-state equations for mesons and baryons

  [H.G. Dosch, GdT, and S. J. Brodsky, PRD **91**, 085016 (2015)]

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L_M^2}{4\zeta^2} + \lambda_M^2\,\zeta^2 + 2\lambda_M(L_M + S - 1)\right)\phi_M = M^2\phi_M$$

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L_B^2}{4\zeta^2} + \lambda_B^2\,\zeta^2 + 2\lambda_B(L_B + S + 1)\right)\phi_B = M^2\phi_B$$

with $\lambda = \lambda_M = \lambda_B$ (equality of Regge slopes) and $\boxed{L_M = L_B + 1}$

- Eigenvalues

$$M_M^2 = 4\lambda\,(n + L_M) + 2\lambda S$$

$$M_B^2 = 4\lambda\,(n + L_B + 1) + 2\lambda S$$

- Longitudinal LF wave equation

$$\left(-\,\sigma^2\partial_x\,(x(1-x)\,\partial_x) + \frac{m_q^2}{x} + \frac{m_{\overline{q}}^2}{1-x}\right)\chi(x) = \Delta M^2\,\chi(x)$$

- CSB Y. Li and J. P. Vary [arXiv:2103.09993 [hep-ph]], S. J. Brodsky and GdT arXiv:2103.10950 [hep-ph]

$$M_\pi^2 = \Delta M^2 = \sigma(m_q + m_{\overline{q}}) + \mathcal{O}\big((m_q + m_{\overline{q}})^2\big)$$

- Form factors and parton distributions from phenomenological extension of LF holographic framework to arbitrary Regge trajectories incorporating the analytic structure of Veneziano amplitudes

  HLFHS Collaboration, PRL **120**, 182001 (2018); PRL **124**, 082003 (2020)

- Form factor in terms of its GPD at zero skewness $\rho_q(x,t) \equiv H^q(x, \xi = 0, t)$

$$F_q(t) = \int_0^1 dx \, \rho_q(x,t) = \int_0^1 dx \, q(x) \exp\left[t\sigma(x)\right]$$

  expressed in HLFQCD in terms of Euler's Beta function for twist-τ, the number of components,

$$F(t)_\tau = \frac{1}{N_\tau} B\left(1-\tau, 1-\alpha(t)\right)$$

$$= \frac{1}{N_\tau} \int_0^1 dx \, w'(x) w(x)^{-\alpha(t)} \left[1 - w(x)\right]^{\tau-2}$$

  where $\alpha(t) = \alpha(0) + \alpha' t, \;\; \alpha' = 1/4\lambda,$ and $w(0) = 0, \; w(1) = 1$ with $w'(x) \geq 0$

- The profile function $\sigma(x)$ and the PDF $q_\tau(x)$ are determined by the reparametrization function $w(x)$

$$\sigma(x) = \frac{1}{4\lambda} \log\left(\frac{1}{w(x)}\right), \qquad q_\tau(x) = \frac{1}{N_\tau} w'(x) w(x)^{-\alpha(0)} [1 - w(x)]^{\tau-2}$$

- Physical boundary conditions from Regge behavior at $x \to 0$, $w(x) \sim x$, and the inclusive-exclusive connection at $x \to 1$, $q_\tau(x) \sim (1-x)^{2\tau-3}$, fixes $w'(1) = 0$ and determine approximately $w(x)$

Onset of color transparency in HLFQCD

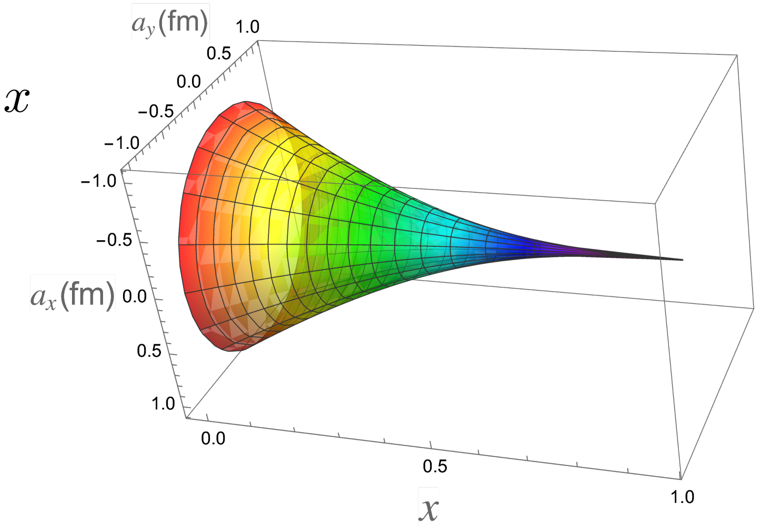
With Stan Brodsky (in progress)

- Transverse-impact GPD [Soper (1976), Burkardt (2000)]

$$q(x, \mathbf{a}_\perp) = \int \frac{d^2\mathbf{q}_\perp}{(2\pi)^2}\, e^{-i\mathbf{a}_\perp\cdot\mathbf{q}_\perp} \rho\,(x, \mathbf{q}_\perp)$$
$$= \frac{1}{4\pi}\frac{q(x)}{\sigma(x)} \exp\Big(-\frac{\mathbf{a}_\perp^2}{4\sigma(x)}\Big).$$

- Effective transverse-impact-surface dependence on x

$$\langle \mathbf{a}_\perp^2(x)\rangle = \frac{\int d^2\mathbf{a}_\perp \mathbf{a}_\perp^2\, q(x, \mathbf{a}_\perp)}{\int d^2\mathbf{a}_\perp\, q(x, \mathbf{a}_\perp)}$$
$$= -\frac{1}{\rho\,(x,t)} \nabla_{\mathbf{Q}}^2\, \rho\,(x,t)\Big|_{t=0}$$
$$= 4\,\sigma(x),$$



uniquely determined by the hadron's profile function $\sigma(x)$ which is universal in HLFQCD

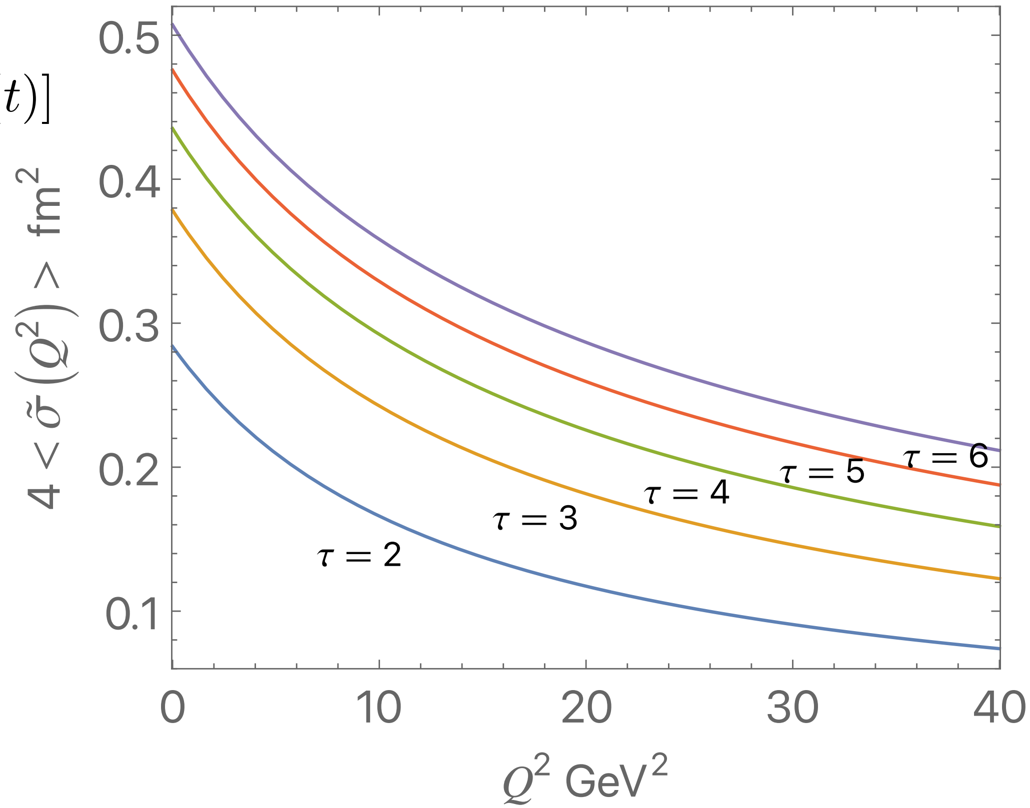
- Behavior is at the origin of color transparency in nuclei but no information on the onset of CT

- Effective transverse-impact surface dependence on $t = -Q^2$ from expectation value of PF $\sigma(x)$

  See also: L. Frankfurt, G. A. Miller and M. Strikman, NPA **555**, 752 (1993)

$$\langle \tilde\sigma(t) \rangle_\tau = \frac{\int dx\, \sigma(x) \rho_\tau(x,t)}{\int dx \rho_\tau(x,t)} = \frac{1}{F_\tau(t)} \frac{d}{dt} F_\tau(t) = \frac{1}{4\lambda} \left[\psi\left(\tau - \alpha(t)\right) - \psi(1 - \alpha(t)\right]$$

with ψ the digamma function



- For integer twist $\tau = N$

$$\langle \tilde\sigma(t) \rangle_\tau = \frac{1}{4\lambda} \sum_{j=1}^{\tau-1} \frac{1}{j - \alpha(t)}$$

- At large values $t = -Q^2$

$$\langle \tilde\sigma(t) \rangle_\tau \to \frac{(\tau - 1)}{Q^2}$$

- The Q^2 required to contract all of the valence constituents of to a color-singlet domain of given transverse size grows as the number of spectators and depends also on the properties of the quark current