A universal holographic wavefunction for light hadrons

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A virtual tribute to Quark Confinement and the Hadron Spectrum

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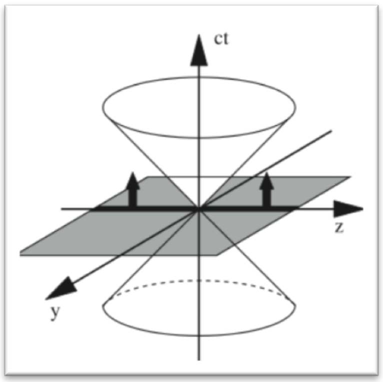
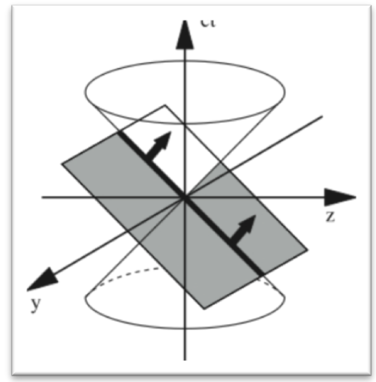
August 6th, 2021

Based on work done with M. Ahmady, D. Chakraborti, S. Kaur, and C. Mondal

Light-front QCD

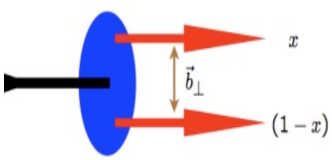


Ordinary time



Light-front time

$$x^{+} = x^{0} + x^{3}$$



LF Schrodinger-like Equation in the conformal limit

$$\left(-\frac{\mathrm{d}^2}{\mathrm{d}\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U_{\mathrm{eff}}(\zeta)\right)\phi(\zeta) = M^2\phi(\zeta)$$

$$\zeta = \sqrt{\frac{x}{(1-x)}}\left|\sum_{j=1}^{N-1} x_j \mathbf{b}_{\perp,j}\right|$$

$$x = \frac{k^{+}}{P^{+}}$$

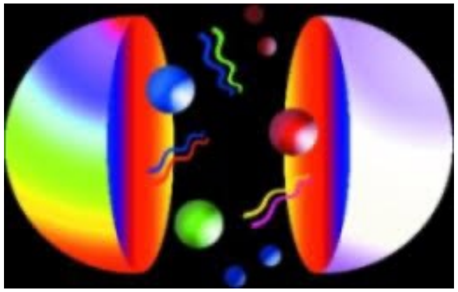
Holographic dictionary

Light front transverse distance maps onto 5th dimension of AdS

$$\zeta \leftrightarrow z_5$$

(Orbital angular momentum)^2 maps onto (AdS mass parameter x radius)^2 and spin

$$L^2 = (\mu R)^2 + (2 - J)^2$$



Unique confinement potential

Confinement in physical spacetime⟺ dilaton field in AdS

$$U(\zeta) = \frac{1}{2}\varphi''(\zeta) + \frac{1}{4}\varphi'(\zeta)^2 + \frac{2J-3}{2\zeta}\varphi'(\zeta)$$

$$\varphi = \kappa^2 z_5^2$$

$$U(\zeta) = \kappa^4\zeta^2 + 2\kappa^2(J-1)$$

κ : emerging mass scale !

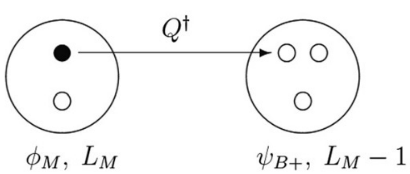
Quadratic dilaton/potential is required by underlying conformal symmetry

Supersymmetric light-front holography

Brodsky, de Teramond, Dosch, Lorce, Phys. Lett. B 759 (2016)
Dosch, de Teramond, Brodsky, Phys. Rev. D 95 034016 (2017)
Neilson, Brodsky, Phys. Rev. D 97 114001 (2018)

$$H\,|\phi\rangle = M_\perp^2\,|\phi\rangle$$

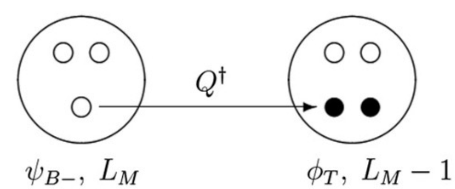
$$H = \begin{pmatrix} -\frac{d^2}{d\zeta^2} + \frac{4L_M^2-1}{4\zeta^2} + U_M(\zeta) & 0 \\ 0 & -\frac{d^2}{d\zeta^2} + \frac{4L_B^2-1}{4\zeta^2} + U_B(\zeta) \end{pmatrix} \qquad |\phi\rangle = \begin{pmatrix} \phi_M(L_M = L_B + 1) & \psi^-(L_B+1) \\ \psi^+(L_B) & \phi_T(L_T = L_B) \end{pmatrix}$$



quark-antiquark quark-diquark

$$U_M(\zeta) = \kappa^4\zeta^2 + 2\kappa^2(L_M + S_M - 1)$$

$$U_B(\zeta) = \kappa^4\zeta^2 + 2\kappa^2(L_B + S_D)$$

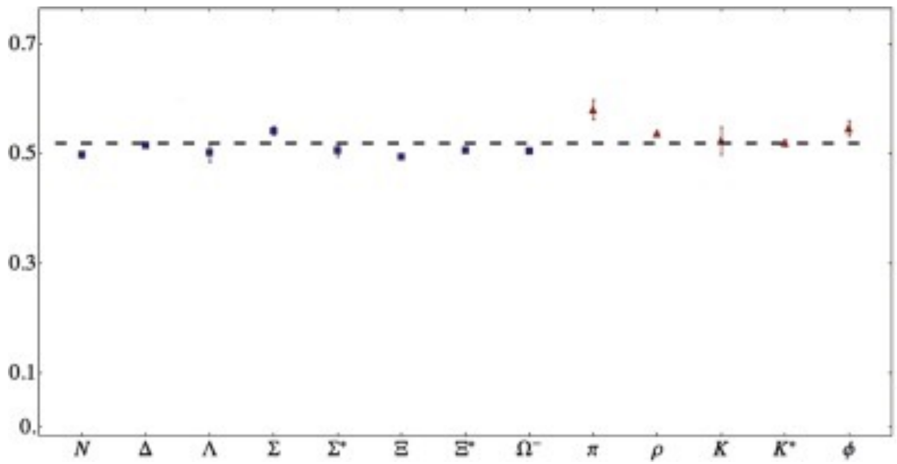


quark-diquark diquark-antidiquark

$$M^2_{\perp,M} = 4\kappa^2\left(n_\perp + L_M + \frac{S_M}{2}\right) \qquad M^2_{\perp,B} = 4\kappa^2\left(n_\perp + L_B + \frac{S_D}{2} + 1\right) \qquad M^2_{\perp,T} = 4\kappa^2\left(n_\perp + L_T + \frac{S_T}{2} + 1\right)$$

Each baryon has two supersymmetric partners: a meson and a tetraquark

A universal holographic mass scale



$$\kappa = 523 \pm 24 \text{ MeV}$$

Brodsky, de Teramond, Dosch, Lorce (2013)

Universal holographic wavefunction for ground state

$$\Psi(x, k_\perp^2) \propto \frac{1}{\sqrt{x\bar{x}}} \exp\left(-\frac{M^2}{2\kappa^2}\right) \qquad M^2 = k_\perp^2/x\bar{x}$$

Fourier conjugate to ζ

$k_\perp^2 \rightarrow k_\perp^2 + m^2$ For massive quarks

Quark masses and spins

- For a successful phenomenology, we need to account for dynamical effects of quark masses and spins

$$\Psi_{h,\bar{h}}^{\mathcal{P},\mathcal{V}}(x,\mathbf{k}) = S_{h,\bar{h}}^{\mathcal{P},\mathcal{V}}(x,\mathbf{k})\Psi(x,k_\perp^2),$$

Mesons (quark-antiquark)

$$S_{h_q h_{\bar{q}}}^{V(\lambda)}(x,\mathbf{k}) \propto \frac{\bar{v}_{h_{\bar{q}}}((1-x)P^+,-\mathbf{k})}{\sqrt{\bar{x}}}[\epsilon_V^\lambda\cdot\gamma]\frac{u_{h_q}(xP^+,\mathbf{k})}{\sqrt{x}}$$

$$S_{h_q h_{\bar{q}}}^{P}(x,\mathbf{k}) \propto \frac{\bar{v}_{h_{\bar{q}}}(\bar{x}P^+,-\mathbf{k})}{\sqrt{\bar{x}}}[\gamma^5]\frac{u_{h_q}(xP^+,\mathbf{k})}{\sqrt{x}}$$

$\boxed{B \gg 1}$

Nucleons (quark-diquark)

$$S_{h_N h_q}^{N(\lambda)}(x,\mathbf{k}) \propto \frac{\bar{u}_{h_q}(xP^+,\mathbf{k})}{\sqrt{x}}[(\epsilon_D^\lambda\cdot\gamma)\gamma^5]\frac{u_{h_N}(P^+,\mathbf{0})}{\sqrt{1}}$$

$$S_{h_N h_q}^{N}(x,\mathbf{k}) \propto \frac{\bar{u}_{h_q}(xP^+,\mathbf{k})}{\sqrt{x}}[\mathbb{1}]\frac{u_{h_N}(P^+,\mathbf{0})}{\sqrt{1}}$$

EM transition form factors

PHYSICAL REVIEW D **102,** 034021 (2020)

Light-front holographic radiative transition form factors for light mesons

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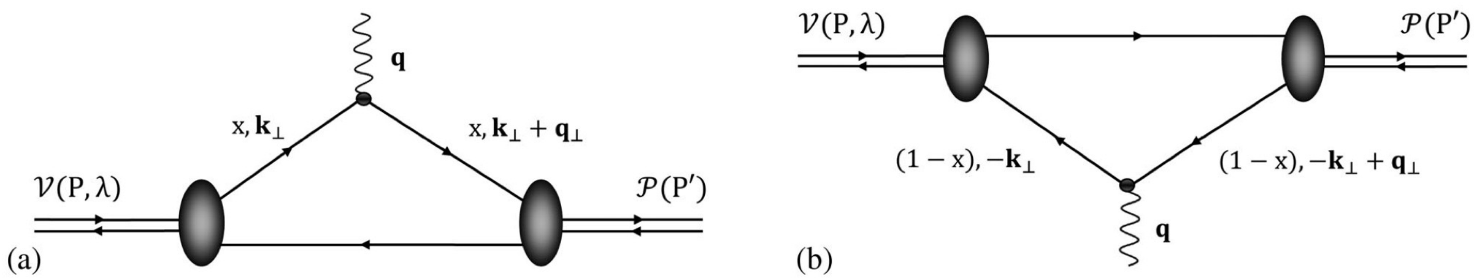
(Received 17 June 2020; accepted 22 July 2020; published 19 August 2020)

$$V \to P + \gamma^*$$



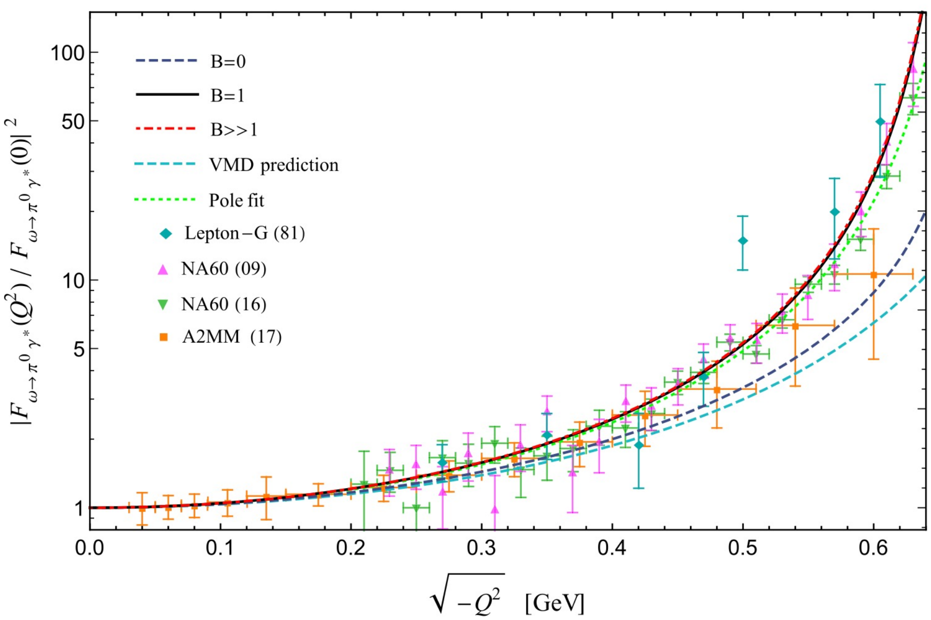
Predictions for radiative decay widths

TABLE I. Our predictions for the $(\rho, \omega, \phi) \to \pi\gamma$ decay widths, compared to the PDG averages [2].

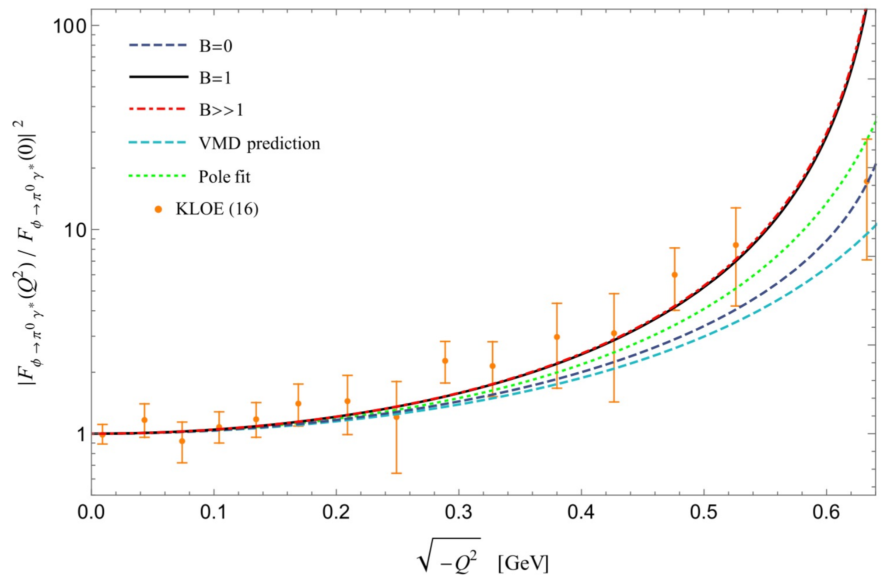
Decay widths	Spin-improved LFH [keV] B = 0	Spin-improved LFH [keV] B = 1	Spin-improved LFH [keV] B ≫ 1	PDG (2018) [keV]
$\Gamma(\rho^{\pm} \to \pi^{\pm}\gamma)$	23.46 ± 3.12	64.52 ± 6.94	66.37 ± 7.00	67.10 ± 7.82
$\Gamma(\rho^{0} \to \pi^{0}\gamma)$	23.46 ± 3.12	64.52 ± 6.94	66.37 ± 7.00	70.08 ± 9.32
$\Gamma(\omega \to \pi^{0}\gamma)$	221.03 ± 29.90	607.96 ± 65.44	625.38 ± 66.03	713.16 ± 25.40
$\Gamma(\phi \to \pi^{0}\gamma)$	1.84 ± 0.33	5.06 ± 0.80	5.21 ± 0.82	5.52 ± 0.22

Pure γ^5

Predictions for the transition form factors

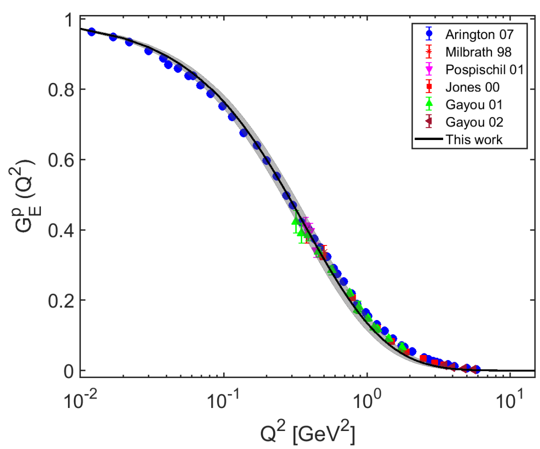


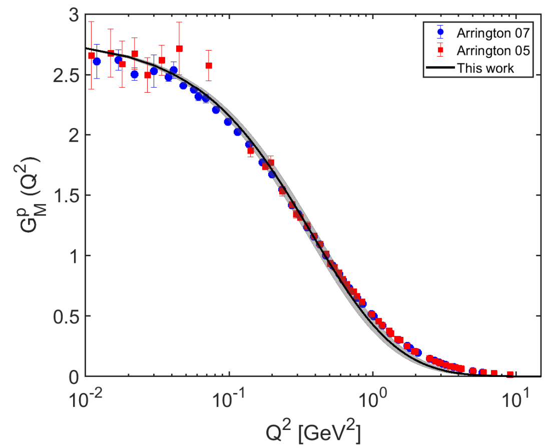
$\omega \to \pi + \gamma^*$

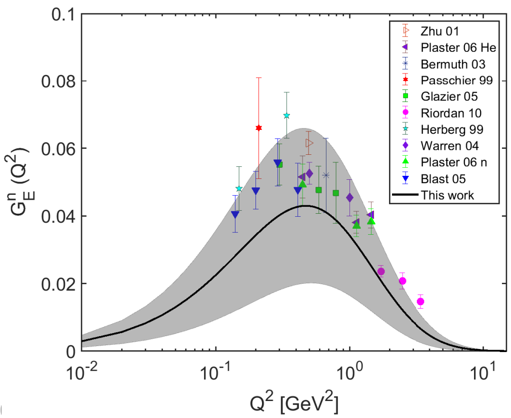


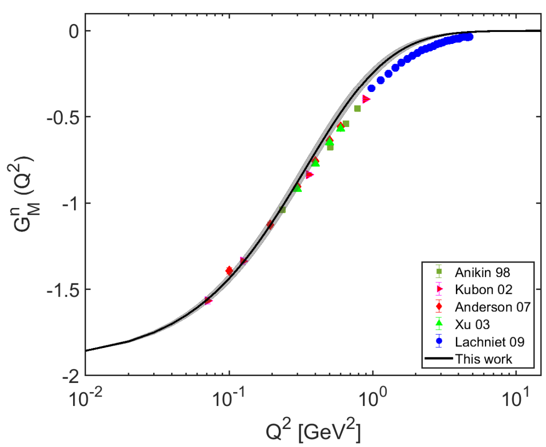
$\varphi \to \pi + \gamma^*$

Nucleon EM elastic form factors









- M. Ahmady, D. Chakraborti, C. Mondal, R. Sandapen, E-print: 2105.02213 [hep-ph]
- Excellent agreement at low momentum transfer
- Large uncertainties for neutron where LO contributions tend to cancel out

Predictions for the EM radii of nucleons

Radius	Our prediction	Experimental data
$\langle r_E \rangle_p$ fm	0.833 ± 0.010	0.833 ± 0.010 [48]; 0.831 ± 0.019 [50] ; 0.841 ± 0.084 [49]
$\langle r_M \rangle_p$ fm	0.7985 ± 0.0313	0.851 ± 0.026 [52]
$\langle r_E^2 \rangle_n$ fm^2	-0.0704 ± 0.0434	-0.1161 ± 0.0022 [52]; -0.110 ± 0.008 [53]
$\langle r_M \rangle_n$ fm	0.8388 ± 0.0288	$0.864^{+0.009}_{-0.008}$ [52]

Conclusions & Acknowledgements

- Light hadrons share a universal holographic wavefunction which is modified differently by their spin structures

- This research is supported by the Natural Sciences and Engineering Research Council of Canada