A holographic light-front wavefunction for the ρ meson

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Work done in collaboration with
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Aim

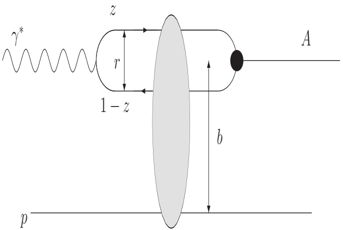
Compute rates for diffractive ρ production using an AdS/QCD holographic meson wavefunction with no free parameters and compare with current HERA data

Some previous work on diffractive ρ production :
J. R. Forshaw and R. Sandapen, JHEP 1110 :093, 2011
J. R. Forshaw and R. Sandapen, JHEP 1011 :037,2010
H. Kowalski, L. Motyka and G. Watt, PRD 74 (2006) 074016
J. R. Forshaw, R. Sandapen and G. Shaw, PRD 69 (2004) 094013

AdS/QCD correspondence and light-front holography :
G. F. de Téramond and S. J. Brodsky (2012), 1203.4025.

Brodsky and de Téramond, PRL 102 (2009) 081601

Diffractive ρ production in the dipole model



- $A = \rho$
- r : transverse dipole size
- $z = k^+/P^+$: fraction of photon's light-front momentum carried by quark

At high energy ($s \gg t, Q^2, M_\rho^2$), amplitude factorises

$$\Im\text{m}\mathcal{A}_\lambda(s,t;Q^2) = \sum_{h,\bar{h}} \int \mathrm{d}^2\mathbf{r}\mathrm{d}z \Psi^{\gamma^*,\lambda}_{h,\bar{h}} \Psi^{\rho,\lambda *}_{h,\bar{h}} e^{-iz\mathbf{r}.\mathbf{\Delta}} \mathcal{N}(x,\mathbf{r},\mathbf{\Delta})$$

Universal dipole cross-section

$$\hat{\sigma}(x,\mathbf{r}) = \mathcal{N}(x,\mathbf{r},\mathbf{0})/s$$

$\hat{\sigma}$ is well constrained by very precise F_2 HERA data

Dipole models

Color Glass Condensate (CGC)

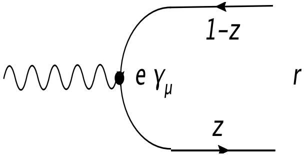
G. Soyez, Phys. Lett. B655 (2007) 32

$$
\begin{aligned}
\mathcal{N}(rQ_s, x, 0) &= \mathcal{N}_0 \left(\frac{rQ_s}{2}\right)^{2\left[\gamma_s + \frac{\ln(2/rQ_s)}{\kappa\lambda\ln(1/x)}\right]} && \text{for} \quad rQ_s \leq 2 \\
&= \{1 - \exp[-a\ln^2(brQ_s)]\} && \text{for} \quad rQ_s > 2
\end{aligned}
$$

Saturation scale $Q_s = (x_0/x)^{\lambda/2}$

- CGC[0.74] : anomalous dimension $\gamma_s = 0.74$ (fitted)
- Other dipole models which fit F_2 give similar results

Light-front wavefunctions



Photon γ^μ

Light-front QED

$x^+ = x^0 + x^3$: LF time

Spinor × Scalar

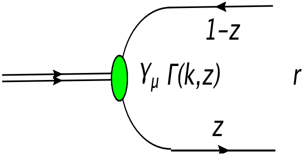
$$\Psi^{\gamma\{\lambda\}}_{h,\bar{h}}(\mathbf{k}, z; Q^2) \propto S^{\gamma,\lambda}_{h,\bar{h}}(\mathbf{k}, z) \times \phi_\gamma(\mathbf{k}, z; Q^2)$$

$$S^{\gamma,\lambda}_{h,\bar{h}}(\mathbf{k}, z) = \frac{\bar{u}_h(\mathbf{k})}{\sqrt{z}} \gamma^\mu \cdot \varepsilon^\lambda_\mu \frac{v_{\bar{h}}(-\mathbf{k})}{\sqrt{1-z}}$$

▷ Sensitive to phenomenological quark mass m_f as $Q^2 \to 0$

▷ Here $m_f = 0.14$ GeV as fixed in the fits to extract dipole cross-section from F_2

Light-front wavefunctions



Meson $\gamma^{\mu}\Gamma(\mathbf{k}, z)$

Light-front QCD

$x^{+} = x^{0} + x^{3}$: LF time

Spinor $\times$ Scalar

$$\Psi^{\rho\{\lambda\}}_{h,\bar{h}}(\mathbf{k}, z) \propto S^{\rho,\lambda}_{h,\bar{h}}(\mathbf{k}, z) \times \phi(\mathbf{k}, z)$$

$$S^{\rho,\lambda}_{h,\bar{h}}(\mathbf{k}, z) = \frac{\bar{u}_h(\mathbf{k})}{\sqrt{z}} \gamma^{\mu} \cdot e^{\lambda}_{\mu} \frac{v_{\bar{h}}(-\mathbf{k})}{\sqrt{1-z}}$$

Scalar part is unknown for meson

Light-front wavefunction

Brodsky and de Téramond (PRL 102 (2009) 081601)

Factorized form

$$\phi(z,\zeta,\varphi) = \frac{\Phi(\zeta)}{\sqrt{2\pi\zeta}} f(z) \mathrm{e}^{iL\varphi}$$

Impact variable : transverse separation at equal light-front time

$$\zeta = \sqrt{z(1-z)}r$$

Light-front Schrödinger equation for transverse modes

$$\left(-\frac{\mathrm{d}^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta,L,S)\right)\Phi(\zeta) = M^2\Phi(\zeta)$$

$U(\zeta,L,S)$ is the confining potential at equal light-front time

Light-front holography

Impact variable ζ maps onto the fifth dimension z_5 in AdS space

$$\zeta \Leftrightarrow z_5$$

$U(\zeta, L, S) = 0$

Light-front Schrödinger equation

$$\Updownarrow$$

EOM for spin-J string mode in AdS space

Light-front holography

Impact variable ζ maps onto the fifth dimension z_5 in AdS space

$$\zeta \Leftrightarrow z_5$$

$U(\zeta, L, S) \neq 0$

Light-front Schrödinger equation with confining potential

$$\Updownarrow$$

EOM for spin-J string mode in AdS space with dilaton background

Light-front holography

Impact variable ζ maps onto the fifth dimension z_5 in AdS space

$$\zeta \Leftrightarrow z_5$$

Soft wall dilaton correctly reproduces Regge-like mass spectrum

A. Karch et al. (2006)

$$U(z_5) = \kappa^4 z_5^2 + 2\kappa^2 (L + S - 1) \qquad M^2 = 4\kappa^2 (n + L + S/2)$$

For vector mesons, $\kappa = 0.55$ GeV (best fit value)

AdS/QCD holographic ρ wavefunction

ρ meson : $n = L = 0$, $S = 1$

$$M_\rho^2 = 2\kappa^2 \qquad \Phi(\zeta) = \kappa\sqrt{2\zeta}\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)$$

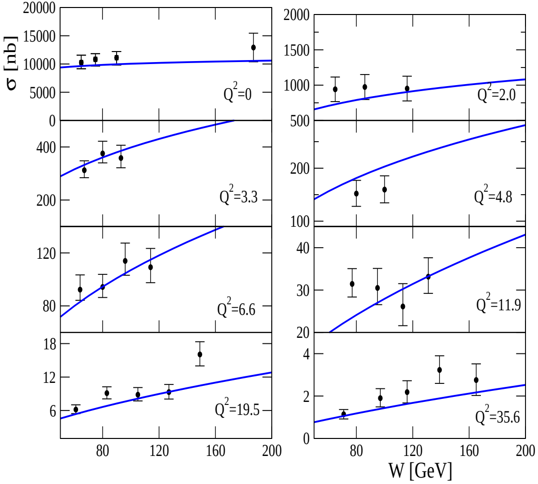
Compare pion form factor in LCQCD and in AdS space

$$f(z) = \mathcal{N}\sqrt{z(1-z)}$$

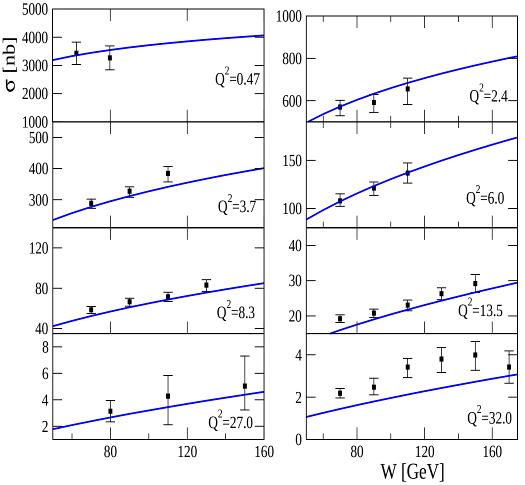
Final form of the holographic wavefunction

$$\phi(z,\zeta) = \mathcal{N}\sqrt{z(1-z)}\exp\left(-\frac{m_f^2}{2\kappa^2 z(1-z)}\right)\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)$$

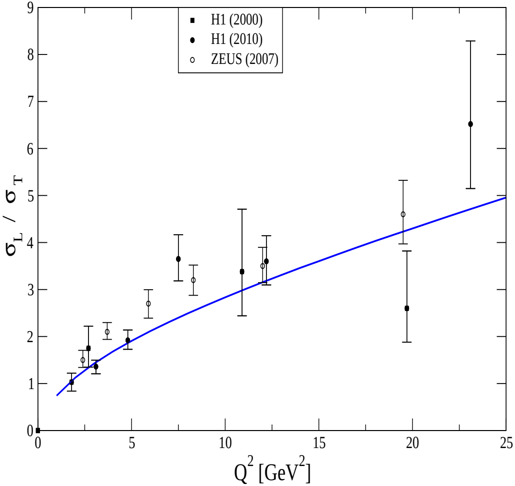
Predictions with the AdS/QCD holographic wavefunction



- Total cross-section
- H1 data
- No free parameters
- Expect to undershoot at high Q^2



- Total cross-section
- ZEUS data
- No free parameters
- Expect to undershoot at high Q^2



- Ratio σ_L/σ_T
- H1 and ZEUS data
- No free parameters

Leptonic decay width

Decay constant related to AdS/QCD wavefunction at origin

$$f_\rho = \frac{1}{2}\left(\frac{N_c}{\pi}\right)^{1/2} \int_0^1 \mathrm{d}z \left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2 z(1-z)}\right) \phi(z, \zeta = 0)$$

Decay width

$$f_\rho = \left(\frac{3\Gamma_{e^+e^-} M_\rho}{4\pi\alpha_{\mathrm{em}}^2}\right)^{1/2}$$

AdS/QCD : $\Gamma_{e^+e^-} = 6.66$ keV PDG : $\Gamma_{e^+e^-} = 7.04 \pm 0.06$ keV

AdS/QCD predictions and fits

AdS/QCD holographic wavefunction

$$\phi(z,\zeta) = \mathcal{N}\sqrt{z(1-z)}\exp\left(-\frac{m_f^2}{2\kappa^2 z(1-z)}\right)\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)$$

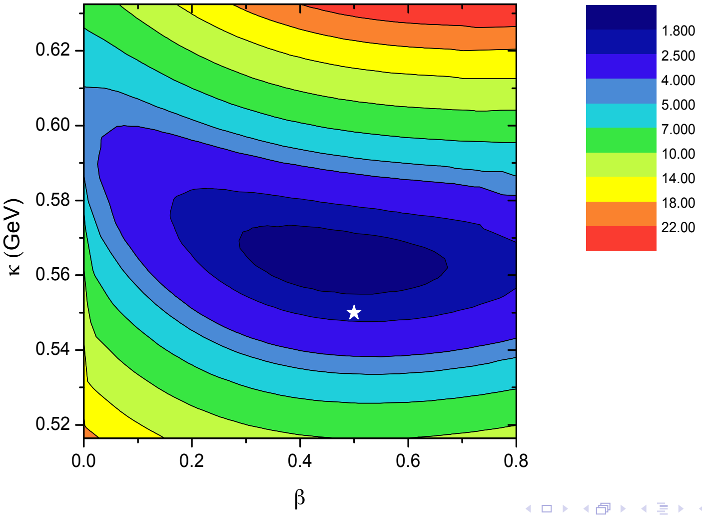
Ansatz with 2 free parameters

$$\phi(z,\zeta) = \mathcal{N}[z(1-z)]^{\beta}\exp\left(-\frac{m_f^2}{2\kappa^2 z(1-z)}\right)\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)$$

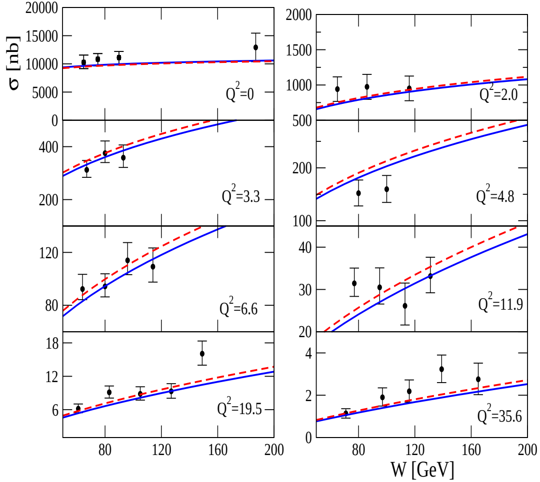
Fit to HERA and decay width data : $\beta = 0.47$ and $\kappa = 0.56$ GeV

χ^2 distribution in (β, κ) parameter space

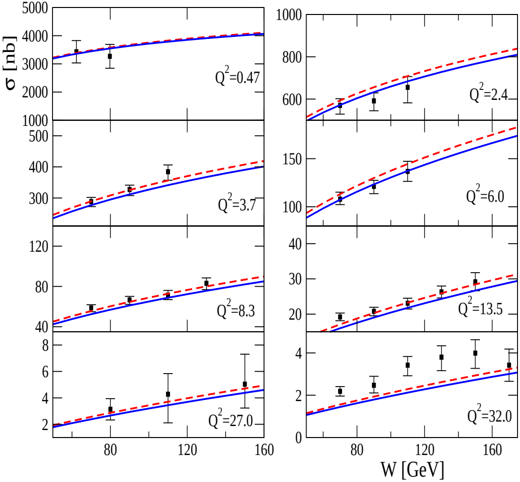
White star is the AdS/QCD prediction



Predictions and fits

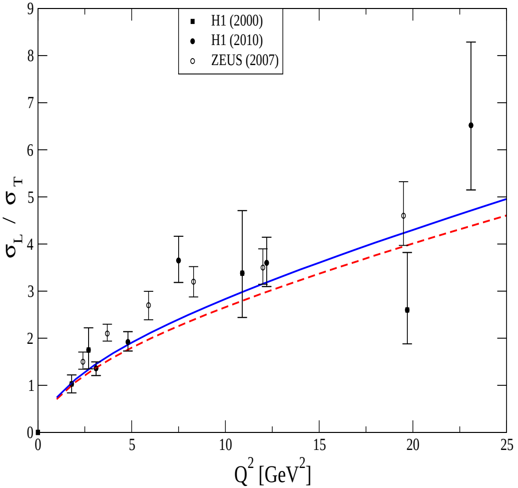


- H1 data
- Blue : AdS/QCD
- Red : Fit



- ZEUS data
- Blue : AdS/QCD
- Red : Fit

Predictions and fits



- H1 and ZEUS data
- Blue : AdS/QCD
- Red : Fit

Distribution Amplitude

DA is related to LFWF : J. R. Forshaw and RS (JHEP 2010, 2011)

Twist-2 DA

$$\varphi(z,\mu) = \left(\frac{N_c}{\pi}\right)^{1/2} \frac{1}{2f_\rho} \int \mathrm{d}r\ \mu J_1(\mu r) \left(1 + \frac{m_f^2 - \nabla^2}{z(1-z)M_\rho^2}\right) \phi(z,\zeta)$$

Lowest moment

$$\langle \xi^2 \rangle_\mu = \int_0^1 \mathrm{d}z \xi^2 \varphi(z,\mu) \qquad \xi = 2z - 1$$

Moment of the twist-2 DA

Approach	Scale μ	$\langle \xi^2 \rangle_\mu$
AdS/QCD	$\sim$ 1 GeV	0.228
Sum Rules	3 GeV	0.24 ± 0.02
Lattice	2 GeV	0.24 ± 0.04

Sum Rules : Ball, Braun and Lenz (2007)
Lattice : RBC Collaboration, P. A. Boyle et al. (2008)

Conclusions & Outlook

- Parameter-free AdS/LFQCD predictions agree well with HERA data
- Agreement with QCD Sum Rules and lattice predictions for corresponding twist-2 DA
- AdS/QCD DAs relevant for radiative B decays to vector mesons (work in progress)
- Extend analysis to ρ' and ρ'' (work in progress)