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Diffractive vector meson production at HERA using holographic AdS/QCD wavefunctions

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We demonstrate another success of the AdS/QCD correspondence by showing [1, 2] that an AdS/QCD holographic light-front wavefunction for the ρ meson generates predictions for the cross-sections of diffractive ρ production that are in agreement with data collected at the HERA electron-proton collider [3, 4].

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1. Introduction

The AdS/QCD correspondence [5, 6, 7, 8] refers to the connection between QCD in physical spacetime and string theory in a higher dimensional anti-de Sitter (AdS) space. The precise nature of this connection has not yet been elucidated but there is growing evidence, to which we add here, that there exists such a connection. One particular realization of this connection is light-front holography [9] proposed by Brodsky and de Téramond. In light-front holography, the confining QCD potential at equal light-front time between a quark and antiquark in a meson is determined by the profile of the dilaton field which breaks conformal invariance of the higher dimensional AdS space in which strings propagate.

In a semi-classical approximation to light-front QCD, Brodsky and de Téramond derived a Schroedinger-like equation for mesons:

$$\left(-\frac{\mathrm{d}^2}{\mathrm{d}\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta)\right)\Phi(\zeta) = M^2\Phi(\zeta)\,, \tag{1.1}$$

where $\zeta = \sqrt{x(1-x)}r$ is the transverse separation between the quark and antiquark at equal light-front time [1], L is the orbital quantum number, M is the mass of the meson and $\Phi(\zeta)$ is the transverse mode of the light-front wavefunction which is itself given by

$$\phi(x,\zeta,\varphi) = \frac{\Phi(\zeta)}{\sqrt{2\pi\zeta}} f(x) \mathrm{e}^{iL\varphi}\,. \tag{1.2}$$

It remains a challenge to derive the confining potential $U(\zeta)$ from first-principles QCD but after identifying ζ with the co-ordinate in the fifth dimension and angular momentum with the fifth dimensional mass[2], equation (1.1) describes the propagation of spin-J string modes, in which case $U(\zeta)$ is determined by the choice for the dilaton field. Remarkably, it can be shown [10] that the dilaton profile is constrained to be quadratic so that the resulting confining potential is given by

$$U(\zeta) = \kappa^4\zeta^2 + 2\kappa^2(J-1)\,. \tag{1.3}$$

Solving equation (1.1) with this confining potential yields the eigenfunctions

$$\Phi_{nL}(\zeta) = \kappa^{1+L}\sqrt{\frac{2n}{(n+L)}}\,\zeta^{1/2+L}\exp\left(-\kappa^2\zeta^2/2\right) L_n^L(\kappa^2\zeta^2) \tag{1.4}$$

with the corresponding eigenvalues

$$M^2_{nL,S} = 4\kappa^2\left(n+L+\frac{S}{2}\right)\,. \tag{1.5}$$

[1] x is the fraction of light-front momentum carried by the quark and r is the transverse separation between the quark and the antiquark at equal ordinary time

[2] $(m_5R)^2 = -(2-J)^2 + L^2$ where R is the radius of curvature in AdS space.

2. The ρ meson wavefunction

For the ρ meson, $n = 1$, $L = 0$ and $J = 1$ so that $\kappa = M_\rho/\sqrt{2} = 0.54$ GeV. In equation (1.2), $f(x)$ is fixed by comparing the expressions for the pion EM form factor in light-front QCD and in AdS space. This yields $f(x) = \sqrt{x(1-x)}$ so that the resulting AdS/QCD for the ρ is then given by

$$\phi(x,\zeta) \propto \sqrt{x(1-x)}\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)\exp\left(-\frac{m_f^2}{2\kappa^2 x(1-x)}\right) \tag{2.1}$$

where the dependence on the quark mass has been introduced according to the prescription by Brodsky and de Téramond [11]. Here we use a light quark mass $m_f = 0,14$ GeV [1].

An earlier procedure to obtain the meson wavefunction is by boosting a non relativistic gaussian Schroedinger wavefunction [12, 13] which results in the so-called Boosted Gaussian (BG):

$$\phi^{\mathrm{BG}}(x,\zeta) \propto x(1-x)\ \exp\left(\frac{m_f^2 R^2}{2}\right)\exp\left(-\frac{m_f^2 R^2}{8x(1-x)}\right)\ \exp\left(-\frac{2\zeta^2}{R^2}\right)\ . \tag{2.2}$$

If $R^2 = 4/\kappa^2$ then the two wavefunctions differ only by a factor of $\sqrt{x(1-x)}$, which is not surprising given that in both cases confinement is modelled by a harmonic oscillator [1]. In what follows we shall consider a parameterization that accommodates both the AdS/QCD and the BG wavefunctions:

$$\phi(x,\zeta) \propto [x(1-x)]^\beta \exp\left(-\frac{\kappa^2\zeta^2}{2}\right)\exp\left(-\frac{m_f^2}{2\kappa^2 x(1-x)}\right)\ . \tag{2.3}$$

The AdS/QCD wavefunction is obtained by fixing $\beta = 0.5$ and $\kappa = 0.55$ GeV where as the BG wavefunction is obtained by fixing $\beta = 1$ and treating κ as a free parameter.

3. Results and conclusions

To compute the rate for diffractive ρ production, we use the dipole model of high-energy scattering [14, 15, 16, 17] in which the scattering amplitude for diffractive ρ meson production is a convolution of the photon and vector meson $q\bar{q}$ light-front wavefunctions with the total cross-section to scatter a $q\bar{q}$ dipole off a proton. QED is used to determine the photon wavefunction and the dipole cross-section can be extracted from the precise data on the deep-inelastic structure function F_2 [18, 19]. This formalism can then be used to predict rates for vector meson production and diffractive DIS [13, 20] or to to extract information on the ρ meson wavefunction using the HERA data on diffractive ρ production [21, 22]. Here we use it to test whether the HERA data prefer the AdS/QCD wavefunction given by equation (2.1). To do so, we compute the χ^2 per data point in the (β,κ) parameter space using the parametrization (2.3) for the ρ wavefunction.[3]

Figure 1 confirms that the AdS/QCD prediction lies impressively close to the minimum in χ^2. The best fit has a χ^2 per data point equal to 114/76 and is achieved with $\kappa = 0.56$ GeV and $\beta = 0.47$ which should be compared with the AdS/QCD prediction: $\kappa = 0.54$ and $\beta = 0.5$ shown

[3] We include the electroproduction data and decay width datum in the fit.

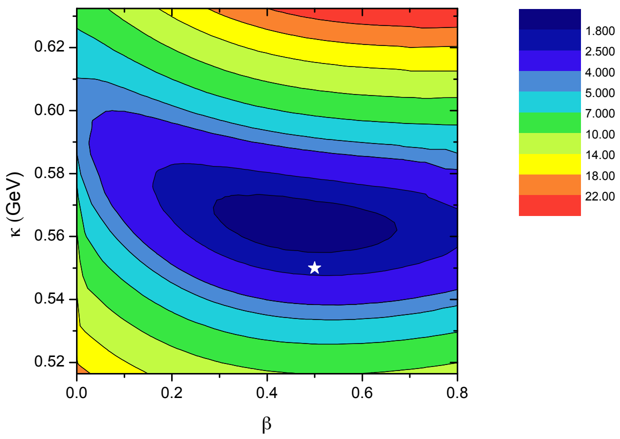

Figure 1: The χ^2 distribution in the (β, κ) parameter space. The AdS/QCD prediction is the white star.

as the white star on figure 1. Note that the BG prediction i.e. $\beta = 1, \forall\kappa$, is clearly further away from the minimum in χ^2.

Finally, we note that these results are produced using a particular Color Glass Condensate dipole model [18] but that similar results are obtained by using other forward dipole models [19] that fit the F_2 structure function data. It remains to be seen how the χ^2 distribution changes if a more sophisticated dipole model, such as the recent impact parameter saturation model [23] which fits the combined HERA F_2 data, is used.

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