An AdS/QCD holographic wavefunction for the ρ meson

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We use an AdS/QCD holographic wavefunction to generate predictions for the rate of diffractive ρ-meson electroproduction that are in reasonable agreement with data collected at the HERA electron-proton collider.

1 Introduction

In the dipole model of high-energy scattering [1, 2, 3, 4], 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 [5, 6]. This formalism can then be used to predict rates for vector meson production and diffractive DIS [7, 8] or to to extract information on the ρ meson wavefunction using the HERA data on diffractive ρ production [9, 10]. Here we use it to predict the cross-sections for diffractive ρ production using an AdS/QCD holographic wavefunction proposed by Brodsky and de Téramond [11]. We also compute the second moment of the twist-2 distribution amplitude and find it to be in agreement with Sum Rules and lattice predictions.

2 The AdS/QCD holographic wavefunction

In a semiclassical approximation to light-front QCD the meson wavefunction can be written in the following factorized form [11]

$$\phi(x,\zeta,\varphi) = \frac{\Phi(\zeta)}{\sqrt{2\pi\zeta}} f(x) \mathrm{e}^{iL\varphi} \tag{1}$$

where L is the orbital quantum number and $\zeta = \sqrt{x(1-x)}b$ (x is the light-front longitudinal momentum fraction of the quark and b the quark-antiquark transverse separation). The function $\Phi(\zeta)$ satisfies a Schrödinger-like wave equation

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

where $U(\zeta)$ is the confining potential defined at equal light-front time. After identifying ζ with the co-ordinate in the fifth dimension in AdS space, Eq. (2) describes the propagation of spin-J string modes, in which case $U(\zeta)$ is determined by the choice for the dilaton field. We use here the soft-wall model [12], in which

$$U(\zeta) = \kappa^4 \zeta^2 + 2\kappa^2 (J-1) \ . \tag{3}$$

The eigenvalues of Eq. (2) are then given as

$$M^2 = 4\kappa^2 (n + J/2 + L/2) \ , \tag{4}$$

so that the parameter κ can then be fixed as the best fit value to the Regge slope for vector mesons. Here we use $\kappa = 0.55$ GeV. After solving Eq. (2) with $L = 0$ and $S = 1$ to obtain $\Phi(\zeta)$, it remains to specify the function $f(x)$ in equation (1). This is done by comparing the expressions for the pion EM form factor obtained in the light-front formalism and in AdS space [13]. After accounting for non zero quark masses [14], the final form of the AdS/QCD wavefunction is [15]

$$\phi(x,\zeta) = N \frac{\kappa}{\sqrt{\pi}} \sqrt{x(1-x)} \exp\left(-\frac{\kappa^2 \zeta^2}{2}\right) \exp\left(-\frac{m_f^2}{2\kappa^2 x(1-x)}\right) \ , \tag{5}$$

where N is fixed so that

$$\int \mathrm{d}^2\mathbf{b} \, \mathrm{d}x \, |\phi(x,\zeta)|^2 = 1 \ . \tag{6}$$

The meson's light-front wavefunctions can be written in terms of the AdS/QCD wavefunction $\phi(x,\zeta)$ [10]. For longitudinally polarized mesons:

$$\Psi^L_{h,\bar{h}}(b,x) = \frac{1}{2\sqrt{2}} \delta_{h,-\bar{h}} \left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2 \, x(1-x)}\right) \phi(x,\zeta) \ , \tag{7}$$

where $\nabla^2 \equiv \frac{1}{b}\partial_b + \partial_b^2$ and h $(\bar{h})$ are the helicities of the quark (anti-quark). The imposition of current conservation implies that this can be replaced by

$$\Psi^L_{h,\bar{h}}(b,x) = \frac{1}{\sqrt{2}} \delta_{h,-\bar{h}} \ \phi(x,\zeta) \ . \tag{8}$$

We choose to normalize $\phi(x,\zeta)$ using

$$\sum_{h,\bar{h}} \int \mathrm{d}^2\mathbf{b} \, \mathrm{d}x \, |\Psi^L_{h,\bar{h}}(b,x)|^2 = 1 \tag{9}$$

using either Eq. (7) or Eq. (8) and refering to them as Method B or Method A respectively. Note that Method A implies that Eq. (6) is satisfied exactly whereas Method B is equivalent to assuming that the integral in Eq. (6) is a little larger than unity.

For transversely polarized mesons:

$$\Psi^{T=\pm}_{h,\bar{h}}(b,x) = \pm[i e^{\pm i\theta} (x \delta_{h\pm,\bar{h}\mp} - (1-x)\delta_{h\mp,\bar{h}\pm})\partial_b + m_f \delta_{h\pm,\bar{h}\pm}] \frac{\phi(x,\zeta)}{2x(1-x)} \ , \tag{10}$$

where $be^{i\theta}$ is the complex form of the transverse separation, $\mathbf{b}$.

3 Comparing to data, sum rules and the lattice

Our predictions for the total cross-section and the ratio of longitudinal to transverse cross-section are compared to the HERA data in Fig. 1. As can be seen, the agreement is quite good given that our predictions do not contain any free parameters. The disagreement at high Q^2 is expected since this is the region where perturbative evolution of the wavefunction will be relevant and the AdS/QCD wavefunction we use is clearly not able to describe that.

We also compute the second moment of the corresponding twist-2 Distribution Amplitude and find our predictions to be in agreement with those made using Sum Rules and lattice QCD. We obtain a value of 0.217 for Method A and 0.228 for Method B, which is to be compared with the Sum Rule result of 0.24 ± 0.02 at $\mu = 3$ GeV [16] and the lattice result of 0.24 ± 0.04 at $\mu = 2$ GeV [17]. The AdS/QCD wavefunction neglects the perturbatively known evolution with the scale μ and should be viewed as a parametrization of the DA at some low scale $\mu \sim 1$ GeV. Viewed as such, the agreement is good.

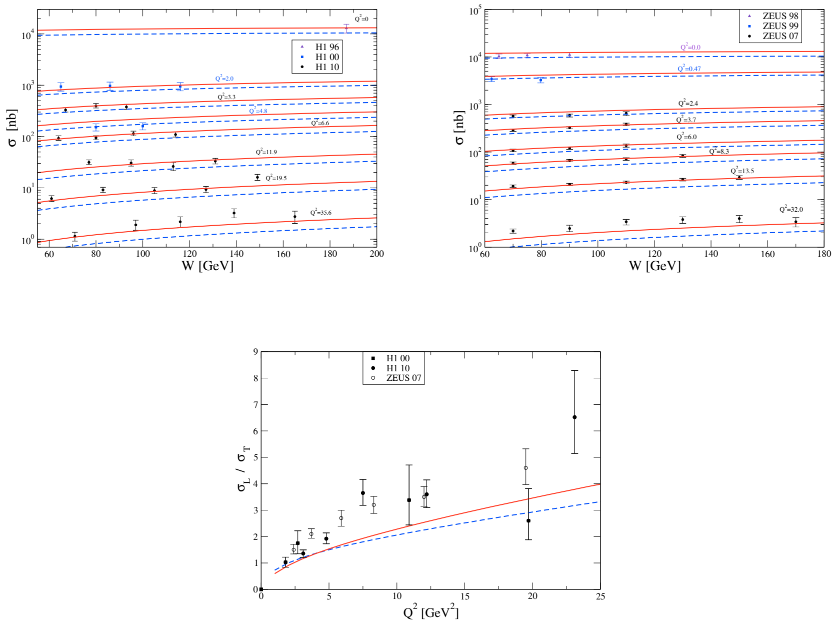

Figure 1: Comparison to the HERA data [18, 19]. Solid red curve is for Method B and the dashed blue curve is for Method A.

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