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Strong Interactions in B Physics

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Introduction

Semileptonic B decays like $B \to \rho\ell\nu$ and $B \to K^*\mu^+\mu^-$ are very useful for precision tests of the Standard Model and for probing New Physics (NP). To fully understand such decays, it is essential to model the strong interaction between the quark and antiquark forming the final light meson. This is a challenging non-perturbative problem which we address here using a relatively new tool named the anti-de Sitter/Quantum Chromodynamics (AdS/QCD) correspondence.

A remarkable feature of the AdS/QCD correspondence recently discovered by Stan Brodsky (SLAC) and Guy de Téramond (Costa Rica U.) is referred to as light-front holography [1]. In light-front QCD, with massless quarks, the meson wavefunction can be written in the following factorized form:

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

with $\Phi(\zeta)$ satisfying the so-called holographic light-front Schroedinger equation (hLFSE)

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

In the above equations, L is the orbital angular momentum quantum number and M is the mass of the meson. The variable $\zeta = \sqrt{z(1-z)}r$ where r is the transverse distance between the quark and antiquark forming the meson and z is the fraction of the meson's momentum carried by the quark. Remarkably, the hLFSE maps onto the wave equation for strings propagating in AdS space if ζ is identified with the fifth dimension in AdS. The confining potential $U(\zeta)$ in physical spacetime is then determined by the perturbed geometry of AdS space. In particular, a quadratic dilaton field breaking the conformal invariance of AdS space yields a harmonic oscillator potential in ordinary spacetime, i.e.

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

where $J = L + S$. The holographic light-front wavefunction for a vector meson ($L = 0, S = 1$) then becomes

$$\phi_\lambda(z,\zeta) \propto \sqrt{z(1-z)} \exp\left(-\frac{\kappa^2\zeta^2}{2}\right) \exp\left\{-\left[\frac{m_q^2 - z(m_q^2 - m_{\bar{q}}^2)}{2\kappa^2 z(1-z)}\right]\right\}$$

with $\kappa = M_V/\sqrt{2}$ and where the dependence on quark masses has been introduced using a prescription by Brodsky and de Téramond. This holographic wavefunction has been used to successfully predict diffractive ρ-meson electroproduction[2].

Distribution Amplitudes

The Distribution Amplitudes (DAs) of the meson are related to its light-front wavefunction which in turn can be obtained using AdS/QCD. For vector mesons such as ρ or K^*, there are two such DAs at twist-2 accuracy. The DAs are important because they are inputs in the light-cone sum rules computations of $B \to \rho$ and $B \to K^*$ transition form factors. These form factors are in turn required to compute the decay rates of $B \to \rho\ell\nu$ and $B \to K^*\mu^+\mu^-$. The leading twist-2 DAs for vector mesons are related to the meson light-front wavefunction as follows [3, 4]:

$$\phi_V^{\parallel}(z,\mu) \propto \int \mathrm{d}r\ \mu J_1(\mu r)[M_V^2 z(1-z) + m_q m_{\bar{q}} - \nabla_r^2]\frac{\phi_L(r,z)}{z(1-z)}$$

$$\phi_V^{\perp}(z,\mu) \propto \int \mathrm{d}r\ \mu J_1(\mu r)[(1-z)m_q + z m_{\bar{q}}]\frac{\phi_T(r,z)}{z(1-z)}$$

The form factors are then obtained from the DAs using the light cone sum rules as explained in reference [5]. For example, our predictions for the tensor form factors $T_1^{B\to V}$, as a function of the momentum transfer squared, are shown in figures 1 and 2.

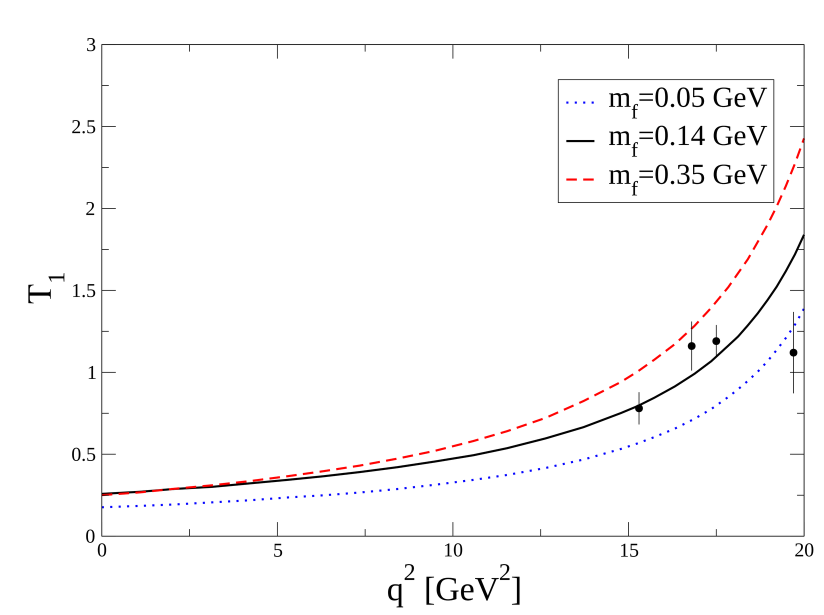


Figure 1: Our predictions for the form factor $T_1^{B\to\rho}$[6] compared to the lattice data [7].

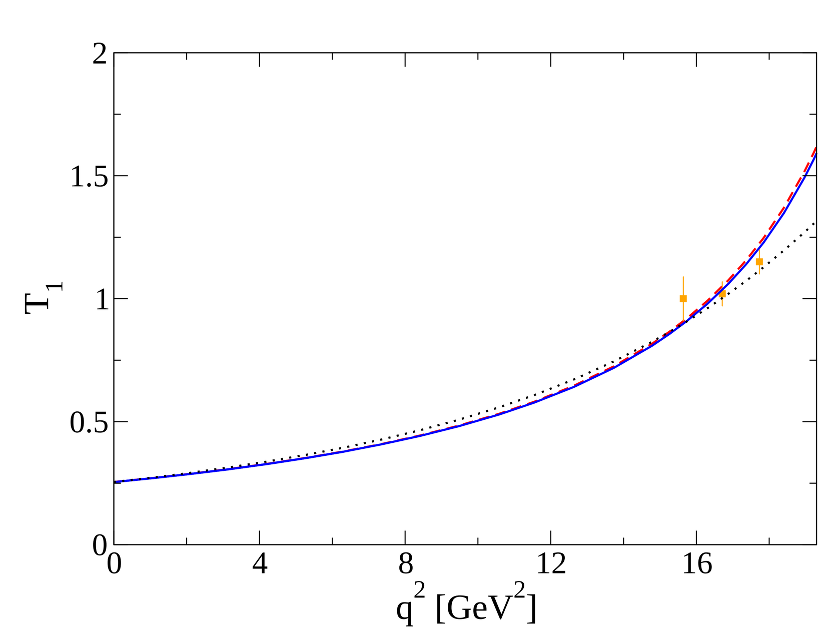
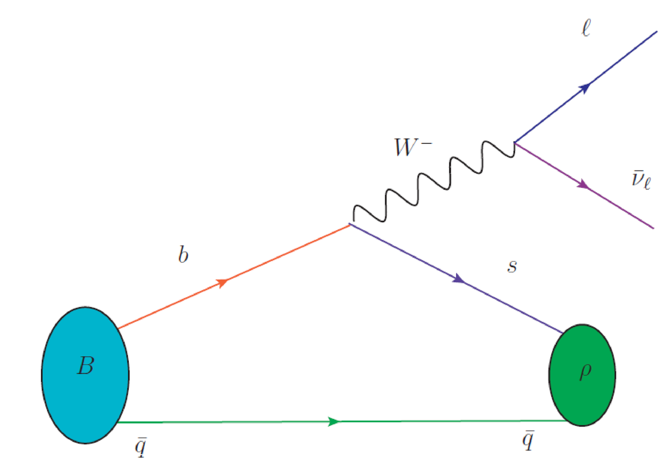


Figure 2: Our predictions for the form factor $T_1^{B\to K^*}$[8] and the lattice data [9].

Results

1) $B \to \rho\ell\nu$



The BaBar collaboration has measured partial decay widths in q^2 bins[10]:

$\Delta\Gamma_{\rm low} = \int_0^8 \frac{d\Gamma}{dq^2}dq^2$	$\Delta\Gamma_{\rm mid} = \int_8^{16} \frac{d\Gamma}{dq^2}dq^2$	$\Delta\Gamma_{\rm high} = \int_{16}^{20.3} \frac{d\Gamma}{dq^2}dq^2$
$(0.564\pm0.166)\cdot10^{-4}$	$(0.912\pm0.147)\cdot10^{-4}$	$(0.268\pm0.062)\cdot10^{-4}$

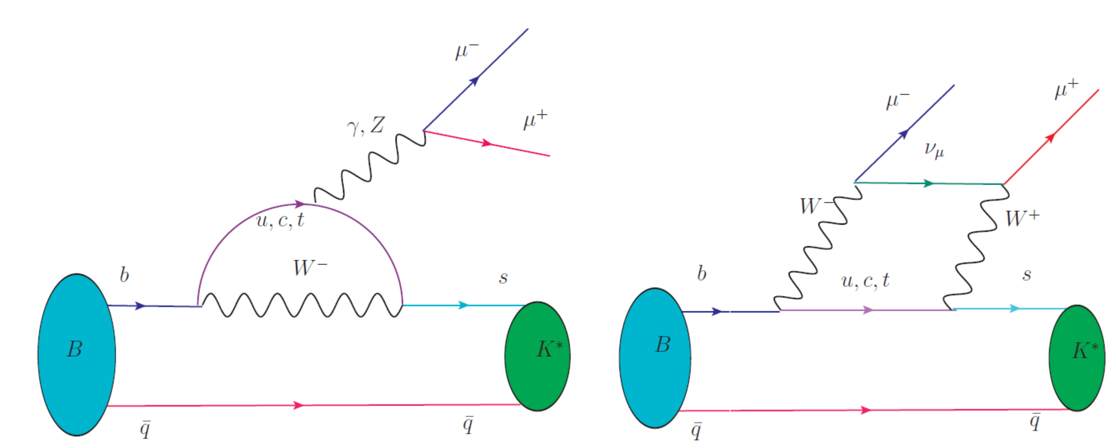
so that

$$R_{\rm low} = \frac{\Gamma_{\rm low}}{\Gamma_{\rm mid}} = 0.618 \pm 0.207 \qquad R_{\rm high} = \frac{\Gamma_{\rm high}}{\Gamma_{\rm mid}} = 0.294 \pm 0.083$$

Our predictions for $m_f = 0.14, 0.35$:

$$R_{\rm low} = 0.580, 0.424 \qquad R_{\rm high} = 0.427, 0.503$$

2) $B \to K^*\mu^+\mu^-$



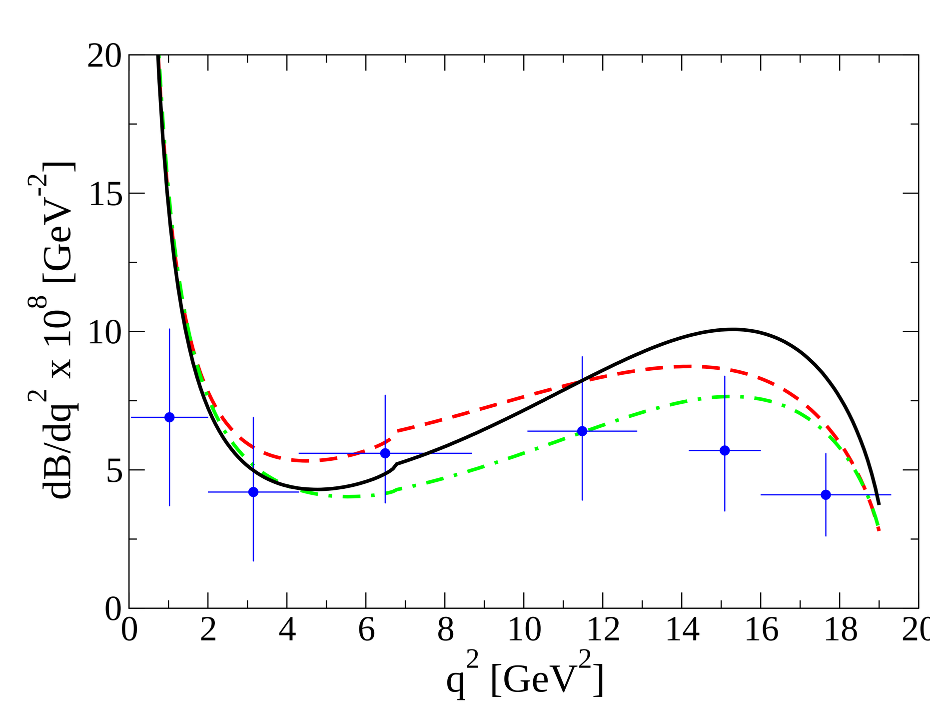


Figure 3: Differential branching ratio: Dashed-red AdS/QCD, solid-black AdS+lattice, green AdS+lattice and new physics. The data from LHCb[11].

By integrating over q^2 and excluding the regions of the narrow charmonium resonances, we obtain a total branching fraction of 1.56×10^{-6}(1.55×10^{-6}) when we are including (excluding) the lattice data compared to the LHCb measurement $(1.16\pm0.19) \times 10^{-6}$. In both cases, we overestimate the total branching fraction. With a new physics contribution to C_9, we obtain a total branching fraction of 1.35×10^{-6} in agreement with the LHCb data.

Conclusion

Light-front holography is a new remarkable feature of the AdS/QCD correspondence. We have used it here to compute the non-perturbative Distribution Amplitudes for the vector mesons ρ and K^* which we then use as inputs to light-cone sum rules to predict $B \to V$ transition form factors. Agreement with data is good especially for low to moderate momentum transfer.

Ongoing and Future Research

- Calculation of the isospin and forward-backward asymmetry in $B \to K^*\mu^+\mu^-$.
- Computing observables related to B decay to psuedoscalar and scalar mesons.

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