Comparing AdS/QCD and Sum Rules predictions for $B \to K^* \nu \bar{\nu}$

Mount Allison University

Mohammad Ahmady[a], Alexandre Leger[a], Zoe McIntyre[b], Alexander Morrison[a], Ruben Sandapen[a,b]

[a] Mount Allison University [b] Acadia University

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Introduction

The flavor changing neutral current (FCNC) $b \to s$ transition has been at the focus of extensive experimental and theoretical investigations. The rare decay $B \to K^* \nu \bar{\nu}$ has not yet been measured experimentally and it is challenging to do so, as both leptons are detector eluding neutrinos. Only the upper bounds on the branching ratio (BR) are known and the most ones are set by the Belle Colaboration [1]:

$$\mathcal{BR}(B^+ \to K^{*+} \nu \bar{\nu}) < 4.0 \times 10^{-5} \quad (90\% \text{ CL})$$

$$\mathcal{BR}(B^0 \to K^{*0} \nu \bar{\nu}) < 5.5 \times 10^{-5} \quad (90\% \text{ CL})$$

With the advent of Super-B facilities, the prospects of measuring these branching ratios in the near future are good. The Belle-II experiment, with an integrated luminosity 50 ab^{-1} that is expected to be collected by 2023, a measurement of the SM BRs with 30% precision is expected [2]. Theoretically, the presence of only one operator in the effective Hamiltonian for the $b \to s \nu \bar{\nu}$ transition makes $B \to K^* \nu \bar{\nu}$ much less susceptible to hadronic uncertainty due to sensitivity to a minimal number of form factors. Moreover, this decay process does not suffer from additional uncertainties beyond the form factors, such as those that plague the $b \to s \ell \bar{\ell}$ transitions due to the breaking of factorization caused by photon exchange.

A remarkable feature of the AdS/QCD correspondence is referred to as light-front holography [3]. In light-front QCD, the holographic meson wavefunctions is:

$$\Psi_\lambda(x,\zeta) = \mathcal{N}_\lambda \sqrt{x(1-x)} \exp\left[-\frac{\kappa^2 \zeta^2}{2}\right] \exp\left[-\frac{(1-x)m_s^2 + x m_{\bar{q}}^2}{2\kappa^2 x(1-x)}\right]$$

The variable $\zeta = \sqrt{x(1-x)} r$ where r is the transverse distance between the quark and antiquark forming the meson and x is the fraction of the meson's momentum carried by the quark. κ is the fundamental confinement scale that emerges in light-front holography. Spectroscopic data indicate that $\kappa = 0.55$ GeV for light vector mesons. we shall fix the quark masses $m_{\bar{q}/s}$ in order to fit the experimentally measured decay constant f_{K^*}[4, 5].

$$f_{K^*} = \sqrt{\frac{N_c}{\pi}} \int_0^1 \mathrm{d}x \left[1 + \frac{m_{\bar{q}} m_s - \nabla_b^2}{x(1-x) M_{K^*}^2}\right] \Psi_L(\zeta, x)|_{\zeta=0}$$

$m_{\bar{q}} = (195 \pm 55)$ MeV and $m_s = (300 \pm 20)$ MeV lead to $f_{K^*} \sim 200$ MeV compared to the experimental value 205 ± 6 MeV from $\Gamma(\tau^- \to K^{*-} \nu_\tau)$.

Distribution Amplitudes

The Distribution Amplitudes (DAs) of the meson are related to its light-front wavefunction. The two twist-2 DAs are predicted as:

$$f_{K^*} \phi_{K^*}^{\parallel}(x,\mu) = \sqrt{\frac{N_c}{\pi}} \int \mathrm{d}b \mu J_1(\mu b) \left[1 + \frac{m_{\bar{q}} m_s - \nabla_b^2}{M_{K^*}^2 x(1-x)}\right] \frac{\Psi_L(x,\zeta)}{x(1-x)}$$

$$f_{K^*}^{\perp}(\mu) \phi_{K^*}^{\perp}(x,\mu) = \sqrt{\frac{N_c}{2\pi}} \int \mathrm{d}b \mu J_1(\mu b) [m_s - x(m_s - m_{\bar{q}})] \frac{\Psi_T(x,\zeta)}{x(1-x)}$$

The Sum Rule DAs are reconstructed as a Gegenbauer expansion

$$\phi_{K^*}^{\parallel,\perp}(x,\mu) = 6x\bar{x} \left\{1 + \sum_{j=1}^{2} a_j^{\parallel,\perp}(\mu) C_j^{3/2}(2x-1)\right\}$$

The Gegenbauer coefficients are $a_1^{\parallel} = 0.06 \pm 0.04$, $a_2^{\parallel} = 0.16 \pm 0.09$ for $\phi_{K^*}^{\parallel}(x, \ \mu = 1 \text{ GeV})$ and $a_1^{\perp} = 0.04 \pm 0.03$, $a_2^{\perp} = 0.10 \pm 0.08$ for $\phi_{K^*}^{\perp}(x, \ \mu = 1 \text{ GeV})$[6].

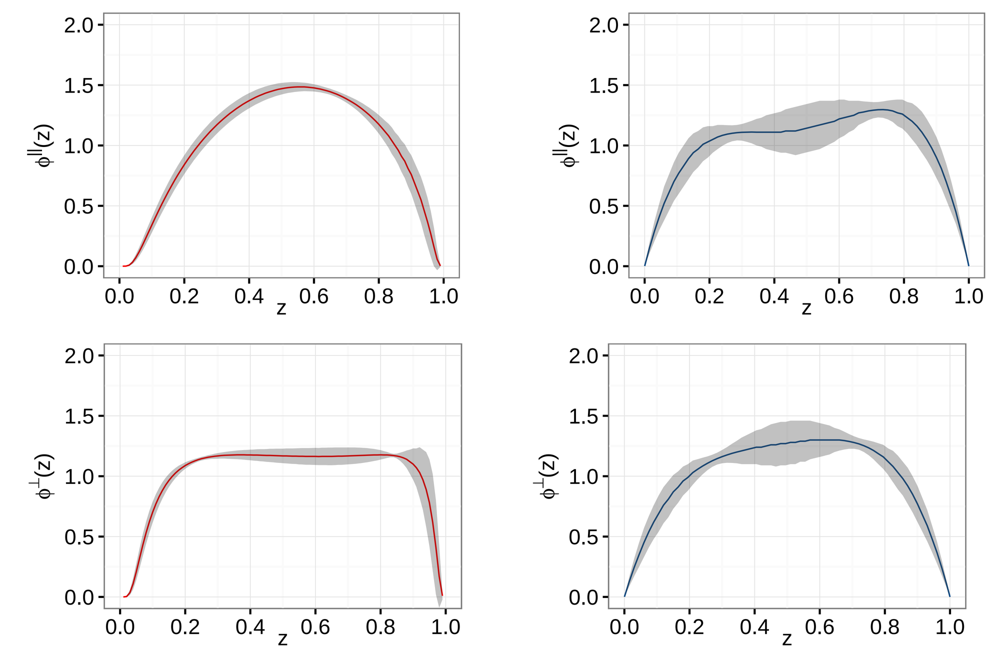

Figure 1: Twist-2 DAs predicted by AdS/QCD (graphs on the left) and SR (graphs on the right). The uncertainty band is due to the variation of the quark masses for AdS/QCD and the error bar on Gegenbauer coefficients for SR.

The form factors, computed via light cone sum rules (LCSR), are valid at low to intermediate q^2. The extrapolation to high q^2 is performed via a two-parameter fit of the following form[7, 8, 9]

$$F(q^2) = \frac{F(0)}{1 - a(q^2/m_B^2) + b(q^4/m_B^4)}$$

to the LCSR predictions as well as form factor values obtained by the lattice QCD [10] which are available at high q^2.

	F(0) (AdS/QCD)	F(0) (SR)	a (AdS/QCD)	a (SR)	b (AdS/QCD)	b (SR)
V	$0.38^{+0.01}_{-0.03}$	0.43 ± 0.03	$1.53^{+0.09}_{-0.05}$	$1.67^{+0.11}_{-0.10}$	$0.62^{+0.14}_{-0.12}$	$0.90^{+0.13}_{-0.11}$
A_1	$0.29^{+0.01}_{-0.02}$	0.34 ± 0.02	$0.24^{+0.11}_{-0.06}$	0.36 ± 0.17	$-0.68^{+0.18}_{-0.16}$	-0.37 ± 0.17
A_{12}	0.21 ± 0.01	0.25 ± 0.01	$0.33^{+0.08}_{-0.07}$	$0.11^{+0.15}_{-0.14}$	$-0.56^{+0.16}_{-0.15}$	-0.61 ± 0.12

Table 1: AdS+ lattice prediction for the form factors. Lattice data is taken from [10]. The error bars are due to the variation of the quark masses as explained in the text.

Results

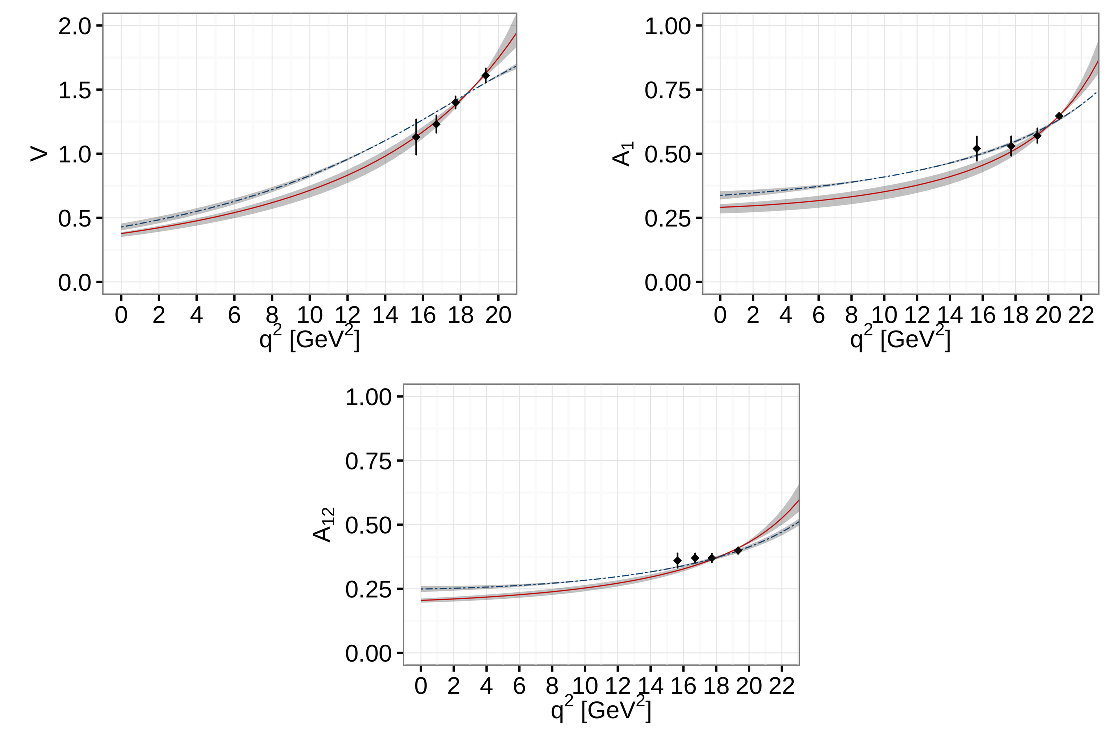

Figure 2: AdS/QCD predictions for the form factors V, A_1 and A_{12}. The two-parameter fits with the available lattice data (red) are shown and compared with the predictions of QCD SM (dashed blue). The shaded band represents the uncertainty in the predicted form factors due to uncertainty bands in DAs and variation in quark masses.

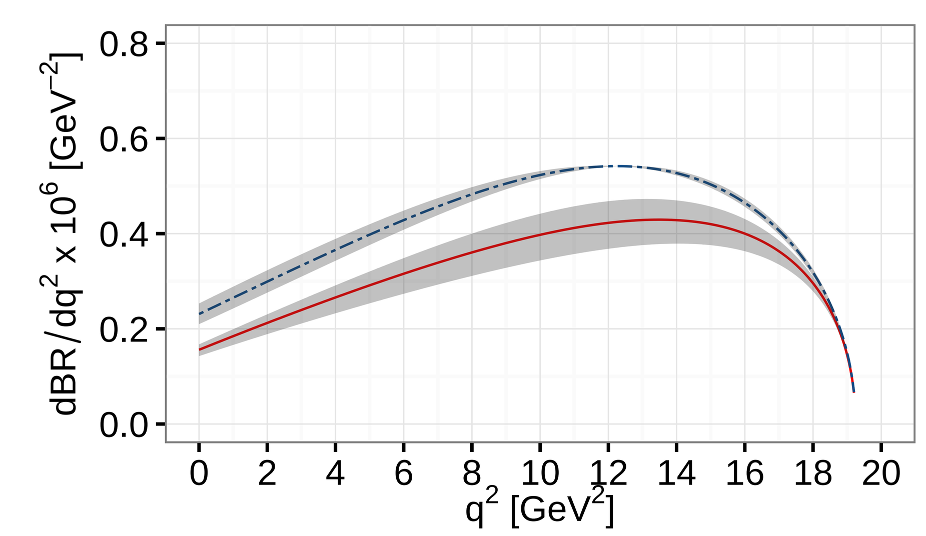

Figure 3: The AdS/QCD (Solid line) and SR (Dashed line) predictions for the differential Branching Ratio for $B \to K^* \nu \bar{\nu}$. The shaded band represents the uncertainty coming from the form factors.

The K^* longitudinal polarization fraction F_L is another observable associated with $B \to K^* \nu \bar{\nu}$ decay.

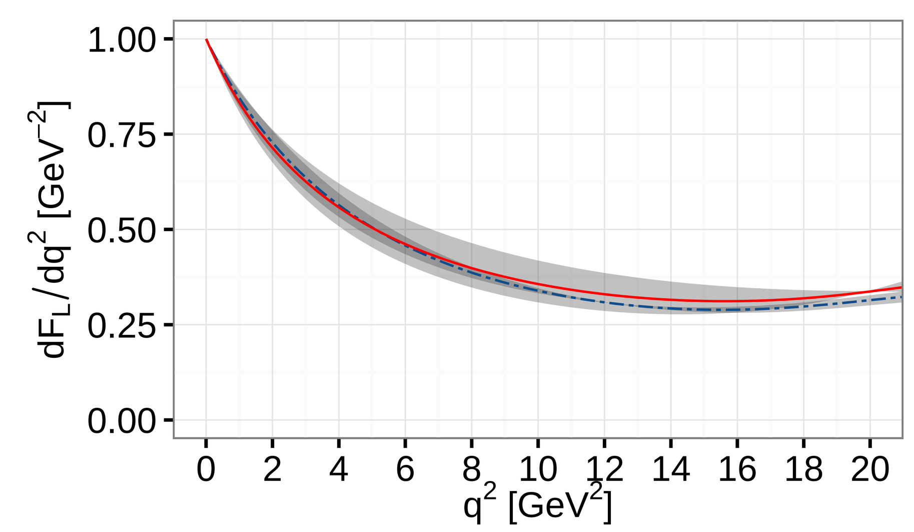

Figure 4: The AdS/QCD (Solid line) and SR (Dashed line) predictions for the polarization fraction distribution for $B \to K^* \nu \bar{\nu}$.

$$\mathcal{BR}(\ B \to K^* \nu \bar{\nu}\ )_{\text{AdS/QCD}} = (6.36^{+0.59}_{-0.74}) \times 10^{-6}$$

$$F_L(\ B \to K^* \nu \bar{\nu}\ )_{\text{SM}}^{\text{AdS/QCD}} = 0.40^{+0.02}_{-0.01}$$

$$\mathcal{BR}(\ B \to K^* \nu \bar{\nu}\ )_{\text{SR}} = (8.14^{+0.16}_{-0.17}) \times 10^{-6}.$$

$$F_L(\ B \to K^* \nu \bar{\nu}\ )_{\text{SM}}^{\text{SR}} = 0.41 \pm 0.01$$

Conclusion

Experimental observation of $B \to K^* \nu \bar{\nu}$ can provide an excellent test for the theoretical computation of the $B \to K^*$ transition form factors. The differential branching ratio for this decay shows the largest sensitivity to the form factors for low-to-intermediate values of the momentum transfer.

Ongoing and Future Research

- AdS/QCD prediction for $B \to \phi \mu^+ \mu^-$.
- Direct computation of the form factors using holographic meson wavefunctions.

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