New physics sensitivities of some $b \to c(u)\ell\nu_\ell$ decay modes

Barilang Mawlong [1], Karthik Jain

School of Physics
University of Hyderabad

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[1] Presenter

Theoretical Framework

- Decay modes considered : $B_s \to D_s^{**}\ell\nu_\ell$ ($D_s^{**} \in \{D_{s0}^*, D_{s1}^*, D_{s1}, D_{s2}^*\}$) and $B \to \eta^{(\prime)}\ell\nu_\ell$.
- Effective Lagrangian for $b \to (q = c, u)\ell\nu_\ell$ transitions including new physics (NP) contributions is [2]

$$
\begin{aligned}
\mathcal{L}_{eff} &= -\frac{4G_F}{\sqrt{2}} V_{qb} \Big[(1 + C_{V_L}^\ell) O_{V_L}^\ell + C_{V_R}^\ell O_{V_R}^\ell + C_{S_L}^\ell O_{S_L}^\ell \\
&+ C_{S_R}^\ell O_{S_R}^\ell + C_T^\ell O_T^\ell\Big] + h.c.,
\end{aligned}
$$

with fermionic operators defined as

$$
\begin{aligned}
O_{V_L}^\ell = (\bar{q}\gamma^\mu P_L b)(\bar{\nu}_\ell \gamma_\mu P_L \ell) \quad &, \quad O_{V_R}^\ell = (\bar{q}\gamma^\mu P_R b)(\bar{\nu}_\ell \gamma_\mu P_L \ell), \\
O_{S_L}^\ell = (\bar{q} P_L b)(\bar{\nu}_\ell P_R \ell) \quad &, \quad O_{S_R}^\ell = (\bar{q} P_R b)(\bar{\nu}_\ell P_R \ell), \\
O_T^\ell &= (\bar{q}\sigma^{\mu\nu} P_L b)(\bar{\nu}\ell \sigma_{\mu\nu} P_R \ell)
\end{aligned}
$$

and $C_i^\ell (i = V_L, V_R, S_L, S_R, T)$ are corresponding Wilson coefficients.

[2] Y. Sakaki et. al, Phys. Rev. D 88 9, 094012 (2013)

$B_s \to D_s^{**}\ell\nu_\ell$

- The differential decay rate for $B_s \to D_s^{**}\ell\nu$ is [3]

$$\frac{d\Gamma}{dq^2} = (1+C_{V_L})^2 \frac{G_F^2}{(2\pi)^3}|V_{cb}|^2 \frac{\sqrt{\lambda}(q^2-m_\ell^2)^2}{24 M_{B_s}^3 q^2} \times \left[HH^\dagger \left(1+\frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2}\left\{ H_t^{SM}\left(1+(C_{S_R}\pm C_{S_L})\frac{q^2}{m_\tau(m_b \mp m_c)}\right)\right\}^2 \right]$$

- The ratio of decay rates is

$$R(D_s^{**}) = \frac{\frac{d\Gamma}{dq^2}(NP)}{\frac{d\Gamma}{dq^2}(SM)}$$

- The best fit values of vector C_{V_L} and scalar $C_{S_{L(R)}}$ Wilson coefficients are obtained using a χ^2-fit method to the experimentally measured values of $R_{D^{(*)}}$, $R_{J/\psi}$, $P_\tau^{D^*}$ and $F_L^{D^*}$ [4].

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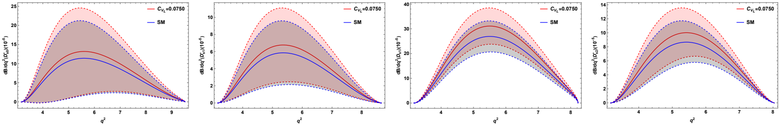
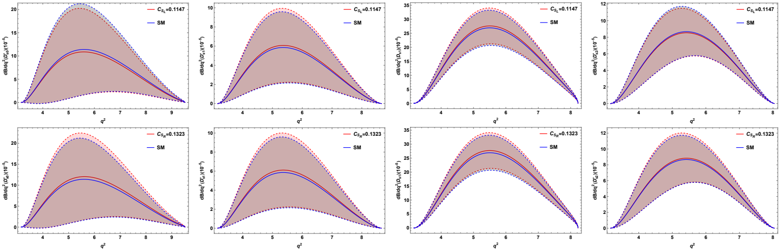
[3] F. U. Bernlochner, and Z. Ligeti, Phys. Rev. D 95, 014022 (2017)

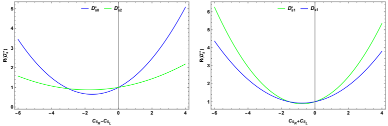
[4] C. P. Haritha, K. Jain, B. Mawlong, Eur. Phys. J. C 83:136 (2023)



q^2-dependence of differential branching fraction of $B_s \to D_s^{**}\tau\nu_\tau$ in the presence of vector coupling.



q^2-dependence of differential branching fraction of $B_s \to D_s^{**}\tau\nu_\tau$ in the presence of scalar couplings.



The behaviour of $R(D_s^{**})$ in the presence of scalar couplings.

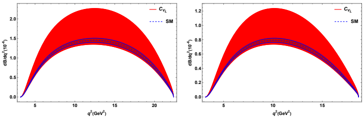
$B \to \eta^{(\prime)} \ell \nu_\ell$

- For $B \to \eta^{(\prime)} \ell \nu_\ell$, the q^2-dependent observables like $\frac{dB}{dq^2}$, P_F^ℓ, A_{FB} and C_F^ℓ [5] are analyzed by constraining NP couplings.
- The parameter space of new couplings is obtained using available experimental measurements of semileptonic and pure leptonic B meson decays. [6]
- Using isospin symmetry, the form factors of $B \to \eta^{(\prime)}$ can be obtained from those of $B \to \pi$. The $B \to \pi$ form factors are obtained from lattice QCD using the BCL z-parametrization [7]

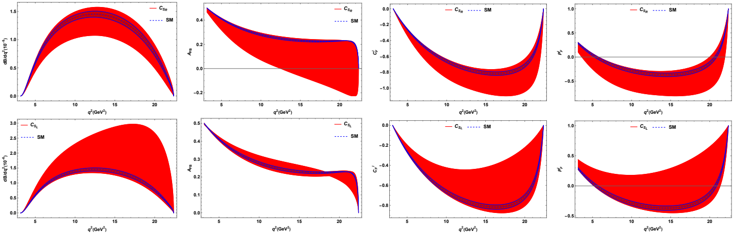
[5] D. Becirevic et. al. JHEP 05 175 (2021)

[6] R. L. Workman et. al. PTEP 2022:083C01(2022)

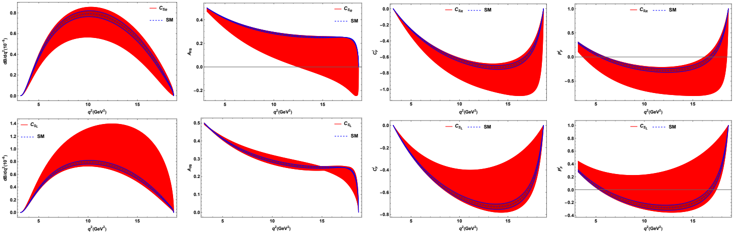
[7] J. A. Bailey et al., Phys. Rev. D. 92(1) (2015) 014024



q^2-dependence of differential branching fraction in the presence of vector coupling for $B \to \eta \tau \nu$(left) and $B \to \eta' \tau \nu_\tau$(right).



q^2-dependence of various observables in the presence of scalar couplings for $B \to \eta \tau \nu_\tau$



q^2-dependence of various observables in the presence of scalar couplings for $B \to \eta' \tau \nu_\tau$

Conclusion

- Analysis of $B_s \to D_s^{**}\ell\nu_\ell$ and $B \to \eta^{(\prime)}\ell\nu_\ell$ modes provides complementary information on the structure of new physics, particularly in distinguishing various new physics scenarios.
- The current analysis of $b \to c(u)$ transitions show good scope for exploring new physics. With the availability of more experimental results in the future, better constraints can be expected.
- Differential branching ratio (dBR) of $B_s \to D_s^{**}$ ($b \to c$) modes display more sensitivity to the new coupling C_{V_L} than the scalar couplings $C_{S_{L(R)}}$. However, better theoretical understanding of form factors is needed which will help in reducing SM uncertainties.
- For the $B \to \eta^{(\prime)}\ell\nu_\ell$ modes, most of the observables are sensitive to new interactions, except for A_{FB} with respect to the scalar C_{S_L} coupling.
- In some NP models, NP couplings of $b \to u$ transitions can be related to that of $b \to c$ transitions. The constraints on $b \to c$ Wilson coefficients can be used in analysing NP sensitivities of various $b \to u$ modes (Future work).

THANK YOU