New physics analysis of some $b-$baryon decays

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Abstract

We analyse the semileptonic decays $\Sigma_b \to \Sigma_c^{(*)}\tau^-\overline{\nu}_\tau$ which are mediated by $b \to c\tau^-\overline{\nu}_\tau$ transitions. Using a general effective Hamiltonian which includes both standard model (SM) and new physics (NP) contributions, we investigate the effects of the new contributions on the semileptonic q^2 spectra, such as the differential decay rate, ratio of branching fractions and forward-backward asymmetry of the charged lepton in various new physics scenarios.

Motivation

- The SM gauge interactions are lepton flavor universal.
- Measurements in the $b \to c\tau^-\overline{\nu}_\tau$ transitions suggest violation of lepton flavor universality.
- Deviations observed in the ratios defined as:

$$R_{D^{(*)}(J/\psi)} = \frac{BR(\overline{B} \to D^{(*)}(J/\psi)\tau^-\overline{\nu}_\tau)}{BR(\overline{B} \to D^{(*)}(J/\psi)l^-\overline{\nu}_l)}$$

$$\begin{aligned}
R_D^{Expt} &= 0.340 \pm 0.027 \pm 0.013, \quad R_D^{SM} = 0.299 \pm 0.003,\\
R_{D^*}^{Expt} &= 0.295 \pm 0.011 \pm 0.008, \quad R_{D^*}^{SM} = 0.258 \pm 0.005,\\
R_{J/\psi}^{Expt} &= 0.71 \pm 0.17 \pm 0.18, \quad R_{J/\psi}^{SM} = 0.289 \pm 0.01
\end{aligned}$$

Effective Hamiltonian Framework

The most general effective Hamiltonian describing $b \to cl\nu_l$ transitions is given by:

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}}V_{cb}[(1 + C_{V_L})O_{V_L} + C_{V_R}O_{V_R} + C_{S_R}O_{S_R} + C_{S_L}O_{S_L} + C_T O_T] + h.c$$

The fermionic operators are:

$$\begin{aligned}
O_{V_{L,R}} &= (\bar{c}\gamma^\mu b_{L,R})(\bar{l}_L\gamma_\mu\nu_{lL})\\
O_{S_{L,R}} &= (\bar{c}b_{L,R})(\bar{l}_R\nu_{lL})\\
O_T &= (\bar{c}\sigma^{\mu\nu}b_L)(\bar{l}_R\sigma_{\mu\nu}\nu_{lL})
\end{aligned}$$

and $C_{V_{L,R}}, C_{S_{L,R}}, C_T$ are the vector, scalar and tensor type NP couplings.

Observables

- Differential decay rate of $B_b \to B_c l\overline{\nu}_l$ decay including NP contributions is given by

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{cb}|^2 q^2|\mathbf{p}_{B_2}|}{192\pi^3 m_{B_1}^2}\left(1 - \frac{m_l^2}{q^2}\right)^2\left[B_1^{SM} + \frac{m_l^2}{2q^2}B_2^{SM} + \frac{3}{2}B_3^{NP} + \frac{3m_l}{\sqrt{q^2}}B_4^{Int}\right]$$

- Ratio of branching fractions

$$R(q^2) = \frac{\frac{d\Gamma}{dq^2}(B_b \to B_c\tau\overline{\nu}_\tau)}{\frac{d\Gamma}{dq^2}(B_b \to B_c l\overline{\nu}_l)}$$

- Forward-backward asymmetry of the charged lepton

$$A_{FB}^l(q^2) = \frac{\frac{d\Gamma}{dq^2}(forward) - \frac{d\Gamma}{dq^2}(backward)}{\frac{d\Gamma}{dq^2}}$$

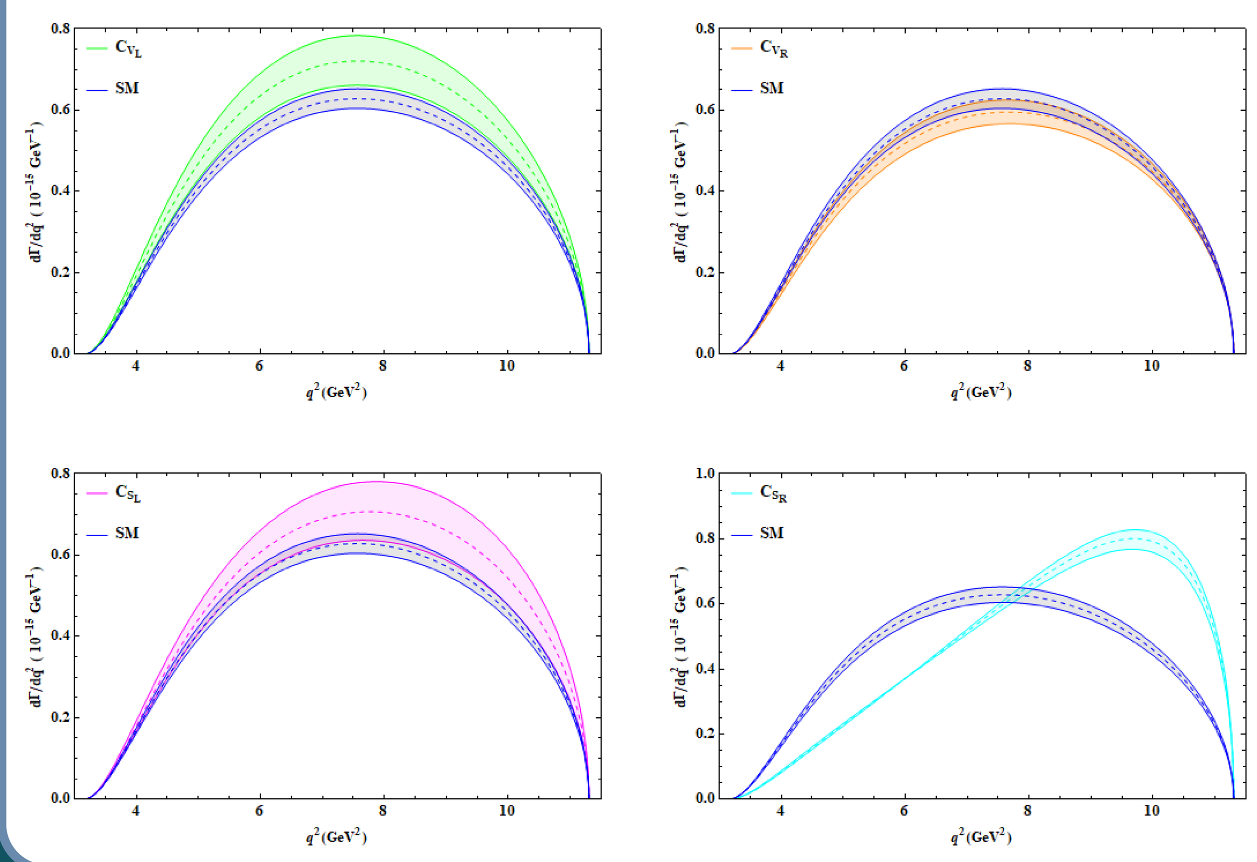
Constraints on New Couplings

- In this work, we consider only vector and scalar new couplings.
- NP couplings are assumed to be real.
- We consider one coupling at a time.
- The new couplings are constrained using experimental measurements of $R_{D^{(*)}}$, $R_{J/\psi}$ and $BR(B_c^+ \to \tau^+\nu_\tau)$.
- χ^2 fitting is performed to obtain the best-fit values.

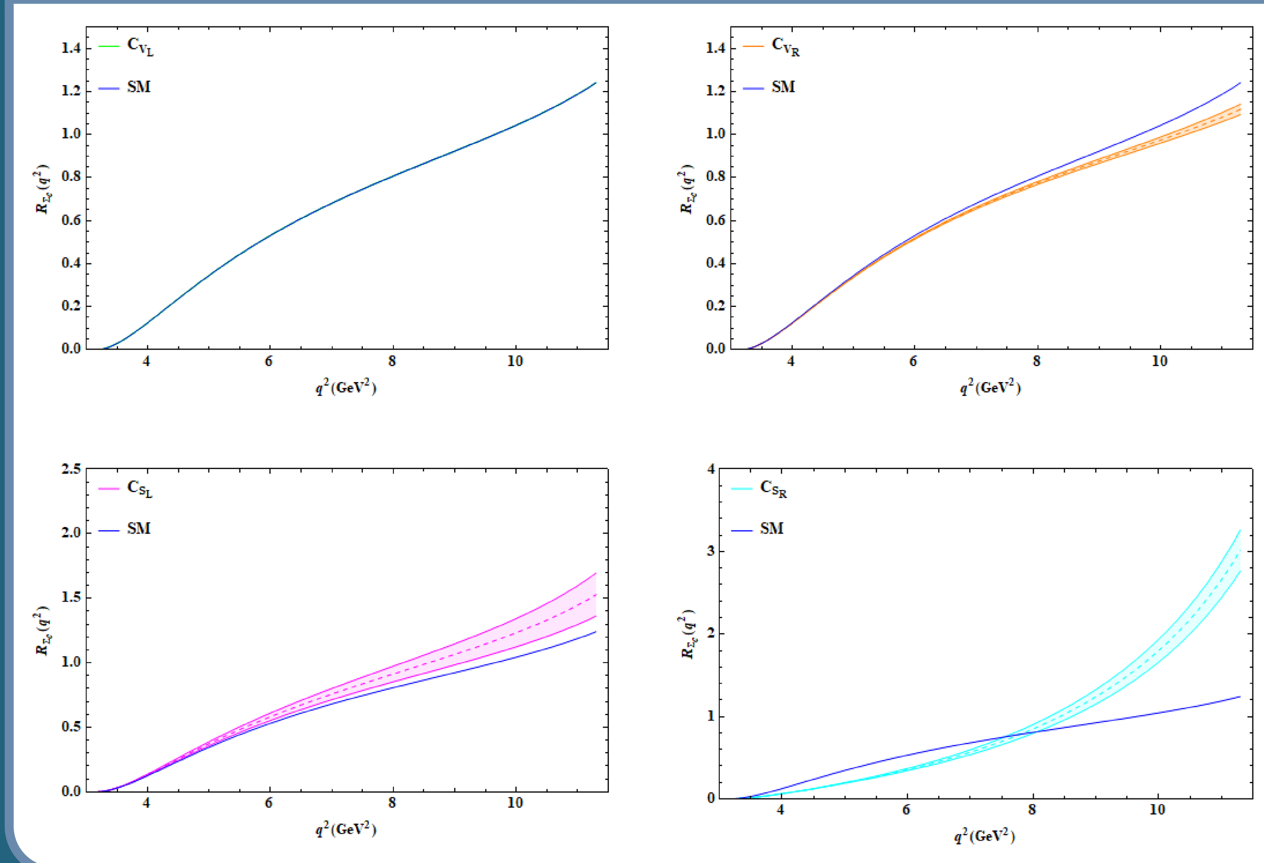
$$\chi^2 = \sum_i \frac{(y_i^{exp} - y_i^{th})^2}{(\Delta y_i)^2}$$

NP coupling	Best-fit value	1σ range
C_{V_L}	0.0714	[0.0460, 0.0961]
C_{V_R}	-0.053	[-0.0648, -0.0417]
C_{S_L}	0.0915	[0.0407, 0.1388]
C_{S_R}	-1.3409	[-1.3846, -1.2938]

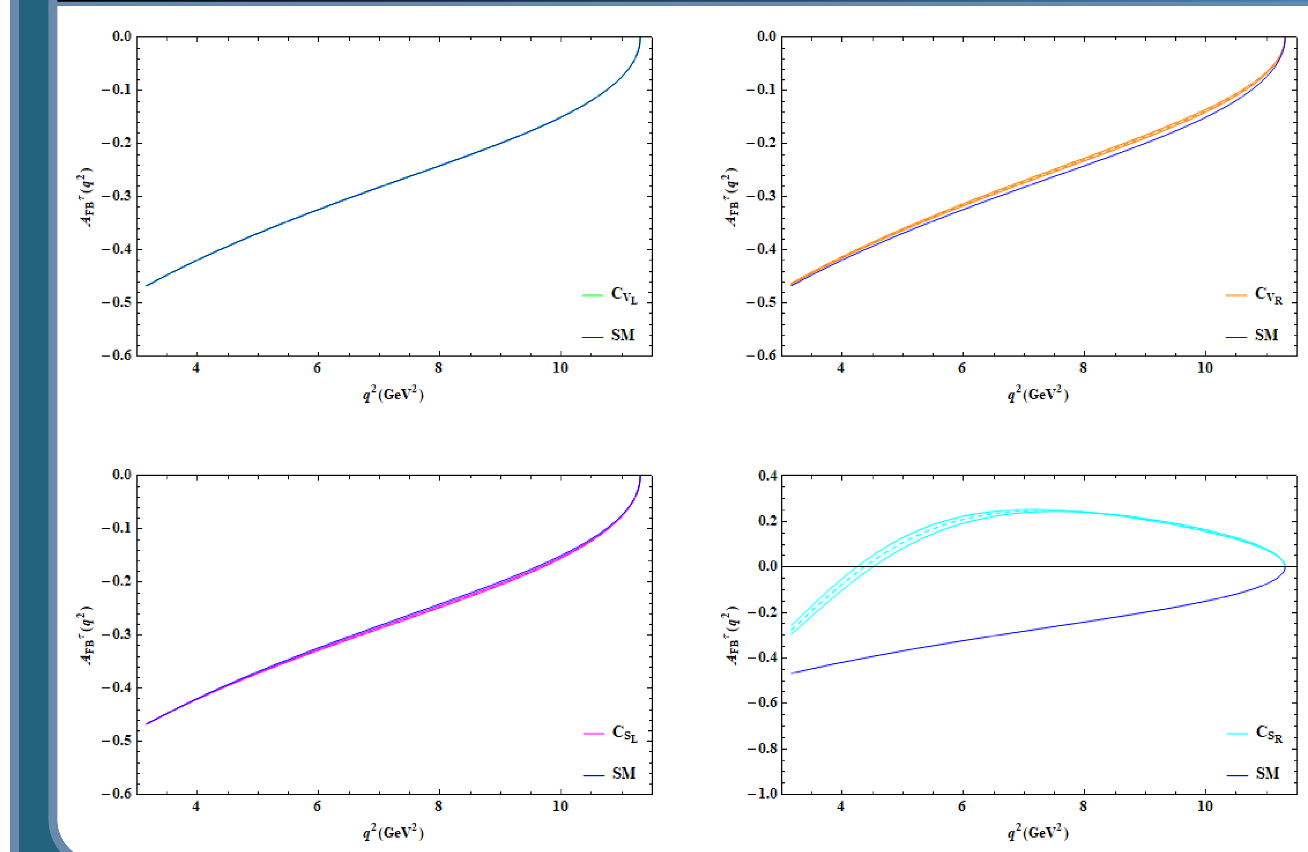
$d\Gamma/dq^2$ for $\Sigma_b \to \Sigma_c\tau^-\overline{\nu}_\tau$



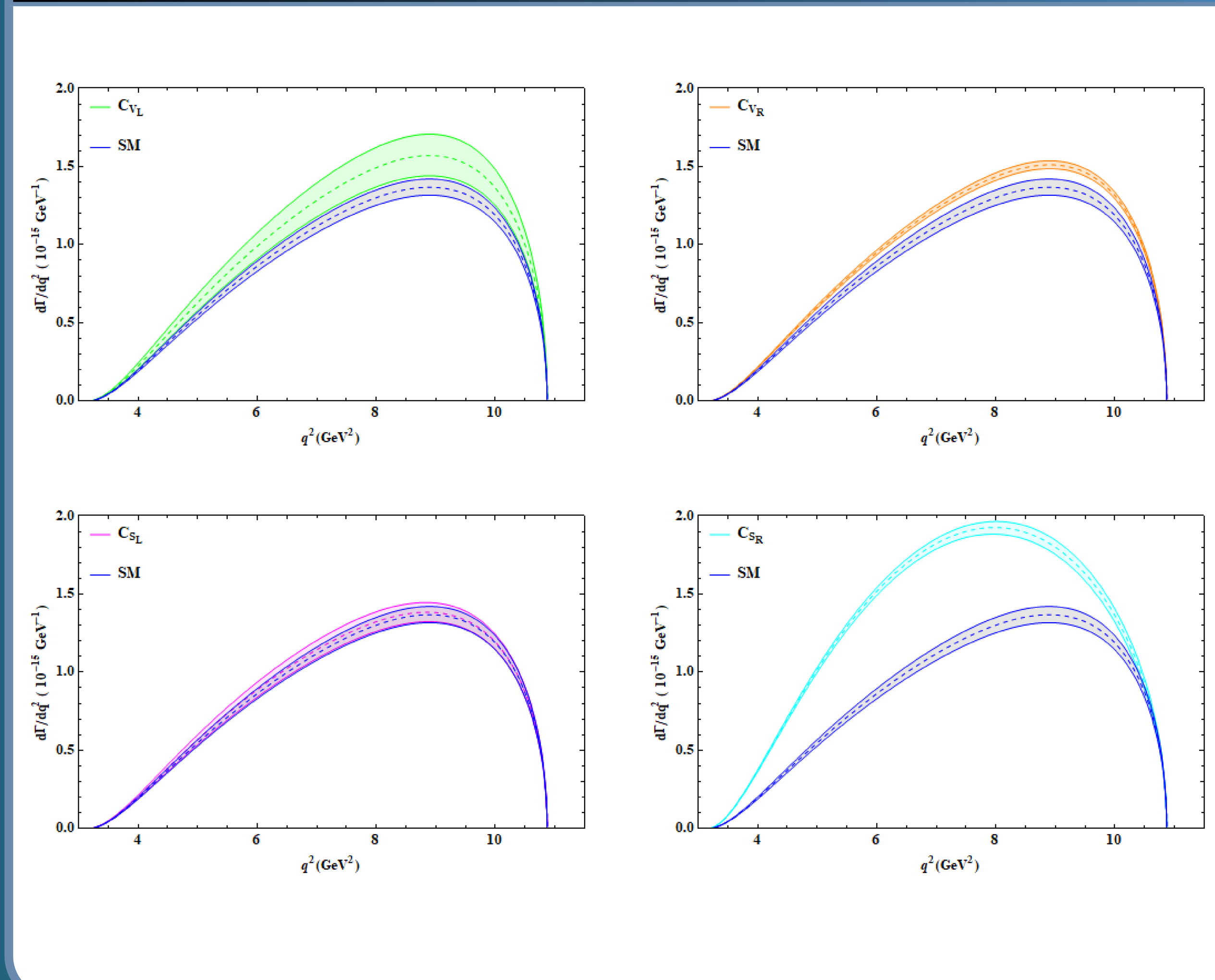
$R_{\Sigma_c}(q^2)$ for $\Sigma_b \to \Sigma_c\tau^-\overline{\nu}_\tau$



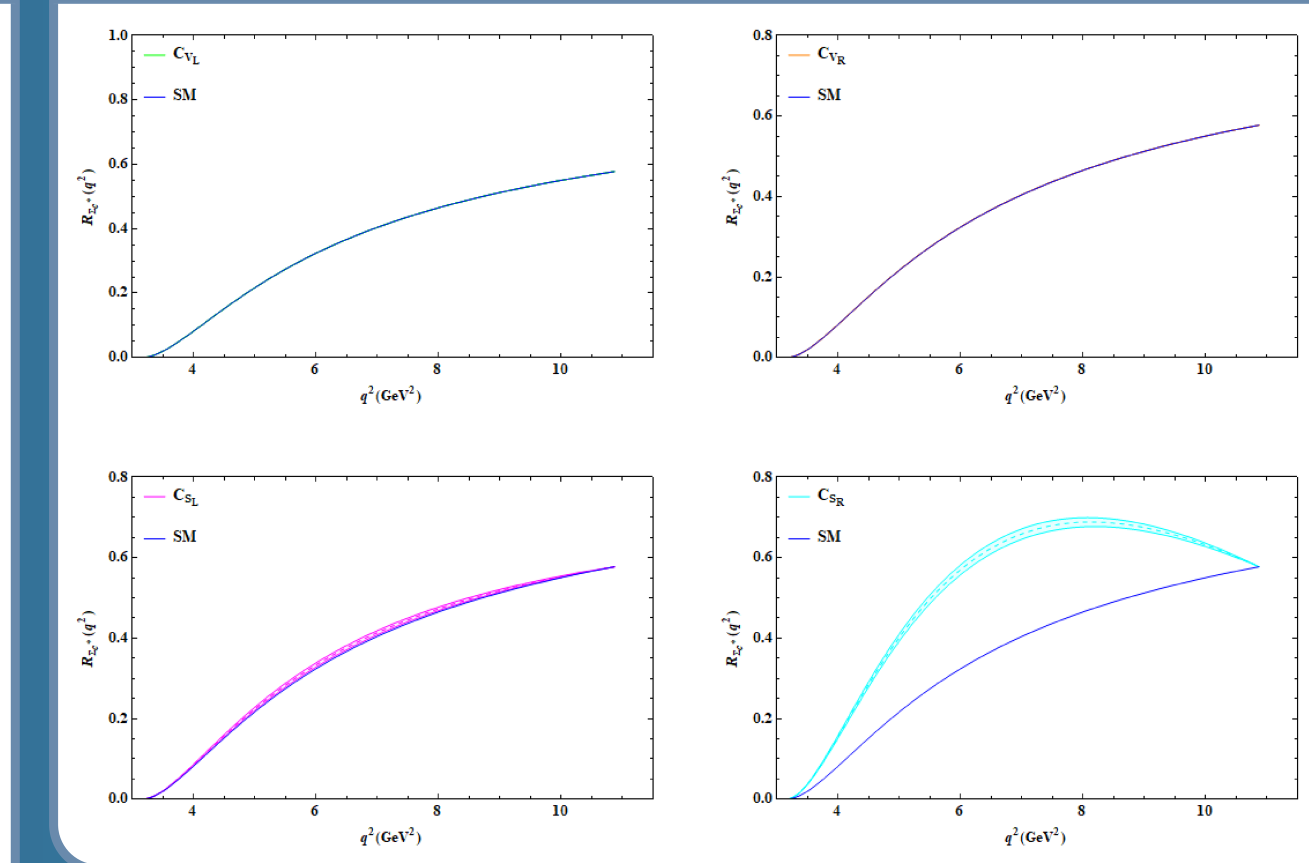
$A_{FB}^\tau(q^2)$ for $\Sigma_b \to \Sigma_c\tau^-\overline{\nu}_\tau$



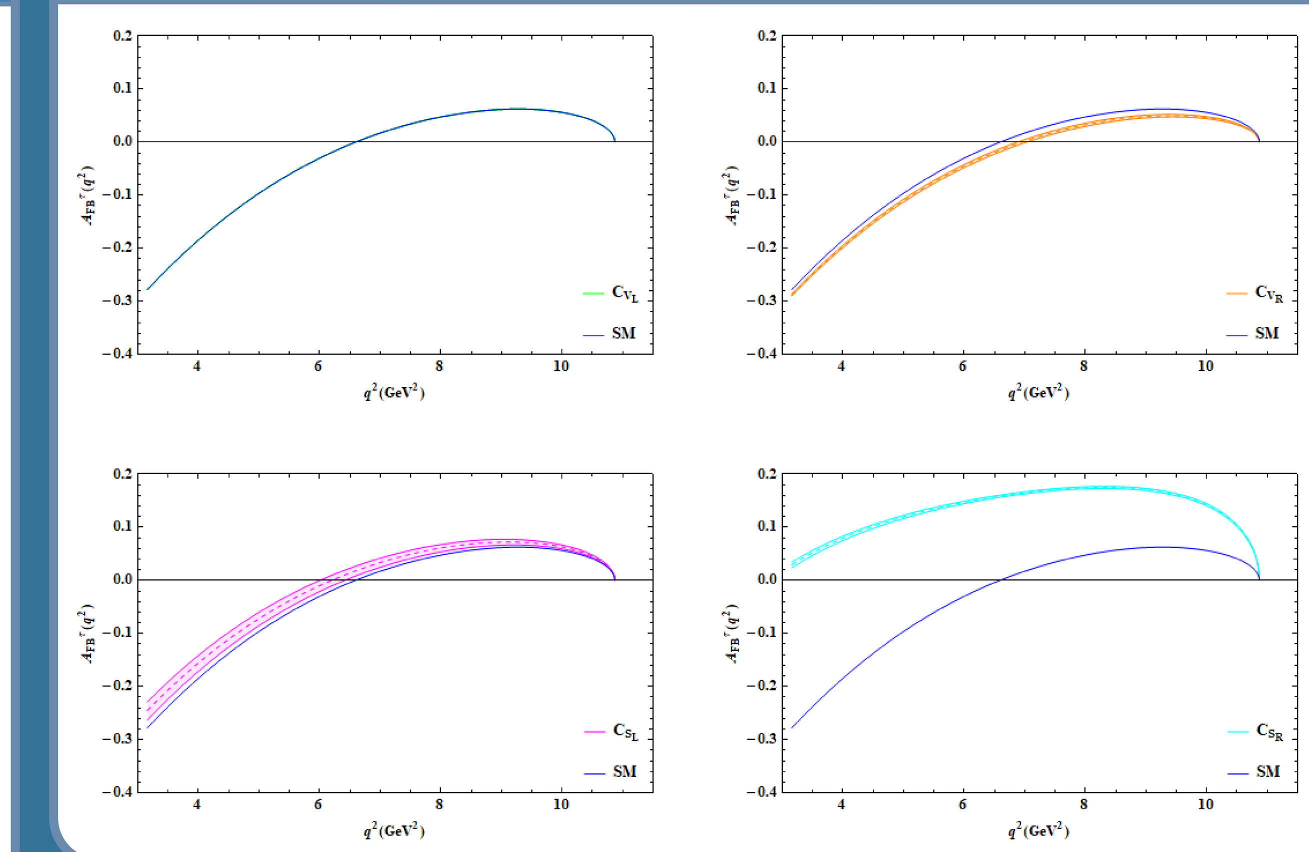
$d\Gamma/dq^2$ for $\Sigma_b \to \Sigma_c^*\tau^-\overline{\nu}_\tau$



$R_{\Sigma_c^*}(q^2)$ for $\Sigma_b \to \Sigma_c^*\tau^-\overline{\nu}_\tau$



$A_{FB}^\tau(q^2)$ for $\Sigma_b \to \Sigma_c^*\tau^-\overline{\nu}_\tau$



Conclusions

- Semileptonic decays $\Sigma_b \to \Sigma_c\tau^-\overline{\nu}_\tau$ and $\Sigma_b \to \Sigma_c^*\tau^-\overline{\nu}_\tau$ are analyzed within the SM and beyond.
- Predictions for various q^2-dependent observables are presented in the SM and in various NP scenarios.
- The observables are sensitive to NP effects. Deviations from the SM prediction are more conspicuous in the case of the C_{S_R} coupling than that of other new couplings.
- For modes mediated by $b \to cl\nu_l$ transitions, $b-$baryon decays can act as complementary channels to $b-$meson decays with respect to NP search.

References

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