Exploring new physics with $B_c^+ \to \tau^+ \nu_\tau$

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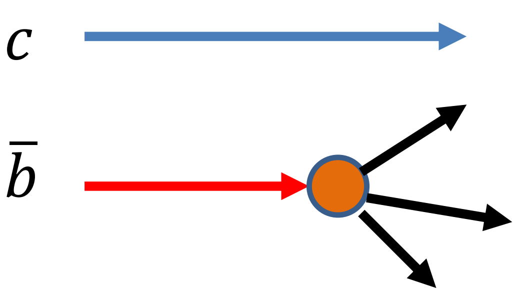
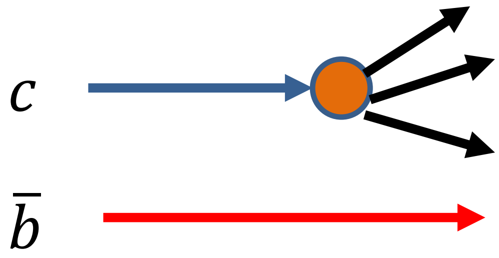
Introduction

- The B_c meson is the heaviest weakly decaying meson.
- Made two heavy quarks: $b\bar{c}$ or $c\bar{b}$.
- Compared to other B mesons, it has heavier mass and low production cross section at Z pole
- Only a handful of its properties have been measured. In terms of decay, it has three decay categories:

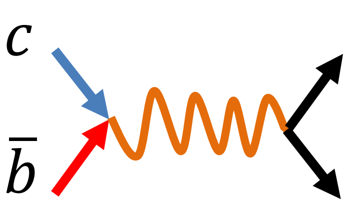
b quark decay



c quark decay



Annihilation



e.g. $B_c \to \tau\nu$

$B_c \to \tau\nu$ decay within SM

- $B_c \to \tau\nu$ decay width in SM:

$$\Gamma_{SM}(B_c^+ \to l^+ \nu_l) = \frac{G_F^2}{8\pi} |V_{cb}|^2 f_{B_c}^2 m_{B_c} m_l^2 \left(1 - \frac{m_l^2}{m_{B_c}^2}\right)^2$$

- Some of the interests within SM:

- The channel is sensitive to both decay constant f_{B_c} and the CKM matrix element $|V_{cb}|$
- The quark dynamics of B_c is very hard to calculate
- Improve $|V_{cb}|$ measurement. So far it is measured using inclusive simileptonic $b \to c$ transitions or exclusive channel of $\bar{B} \to D^* l \bar{\nu}_l$

Interest beyond SM (BSM)

In recent years, a few discrepancies with SM has been found in the bottom sector, especially the tauonic decay modes of B meson (mostly $B \to D^{(*)}\tau\nu$) (arXiv:1205.5442; 1904.08794; 1708.08856) gave hints for lepton flavor universality violation.

While these decay modes are sensitive to the vector/axial-vector type interactions, the (pseudo)scalar type interactions which can be induced in many popular NP models (such as 2HDM and leptoquark) are less constrained by them.

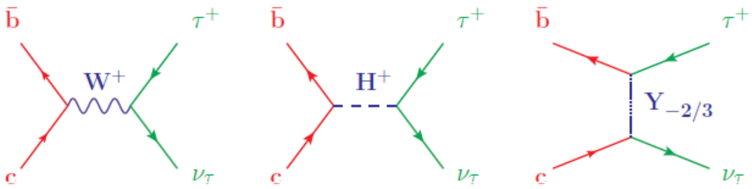


Fig. 1: Feynman diagrams for tauonic B_c decays in the SM, 2HDM and LQ models.

Due to helicity suppression from V-A interactions in $B_c \to \tau\nu$, this channel has a better sensitivity to the (pseudo)scalar NP interactions (arXiv: 1605.09308; 1611.06676)

Theoretical approach to BSM analysis

Effective Hamiltonian of $b \to c\tau\nu$ can be written as:

$$H_{eff} = \frac{4G_F}{\sqrt{2}} V_{cb}\left[(1 + C_{V_1})O_{V_1} + C_{V_2}O_{V_2} + C_{S_1}O_{S_1} + C_{S_2}O_{S_2}\right] + \text{h.c.},$$

Where O_i are four-fermion operators and C_i are corresponding Wilson coefficients.

- O_{V_1} is the only operator present in the SM
- 2HDM can contribute to O_{S_1}
- Leptoquarks can have more versatile contributions depending on their spin and chirality in couplings

Current status of Wilson coefficients

Γ_{eff} and Γ_{SM} denote the width of the $B_c \to \tau\nu$ decay with and without new physics contributions, respectively.

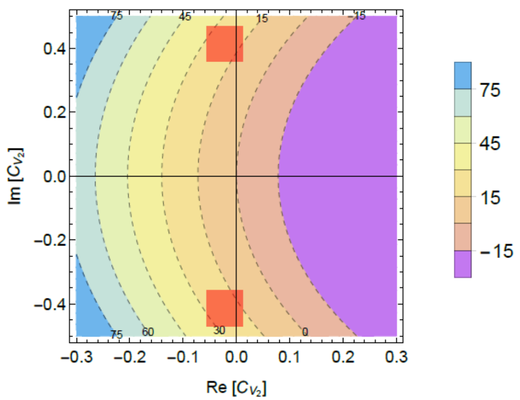


Fig. 2: Sensitivities of $(\Gamma_{\rm eff} - \Gamma_{\rm SM})/\Gamma_{\rm SM}(\%)$ to C_{V_2}. The SM lies at the origin with $\mathrm{Re}[C_{V_2}] = \mathrm{Im}[C_{V_2}] = 0$. Labels (in units of %) on contours denote the modification of branching ratios (decay widths) with respect to the SM values. The red shaded area corresponds to the global fitted results of available data on $b \to c\tau\nu$ decays, as shown in Eq. (9). These areas deviate from the SM predictions by about a few σ.

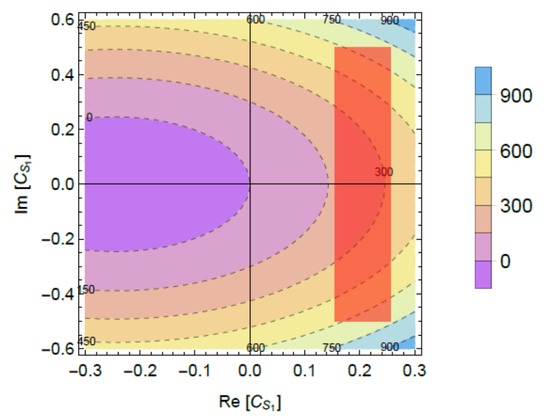


Fig. 3: Sensitivities of $(\Gamma_{\rm eff} - \Gamma_{\rm SM})/\Gamma_{\rm SM}(\%)$ to C_{S_1}. The SM lies at the origin with $\mathrm{Re}[C_{S_1}] = \mathrm{Im}[C_{S_1}] = 0$. Labels (in units of %) on contours denote the modification of branching ratios (decay widths) with respect to the SM values. The red shaded area corresponds to the global fitted results of available data on $b \to c\tau\nu$ decays, as shown in Eq. (10).

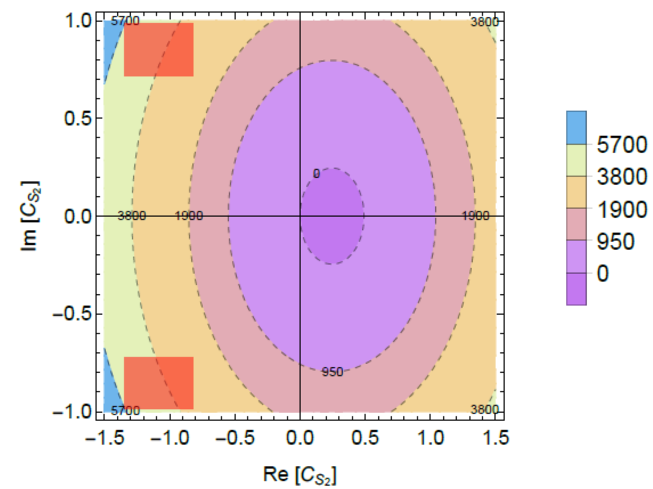
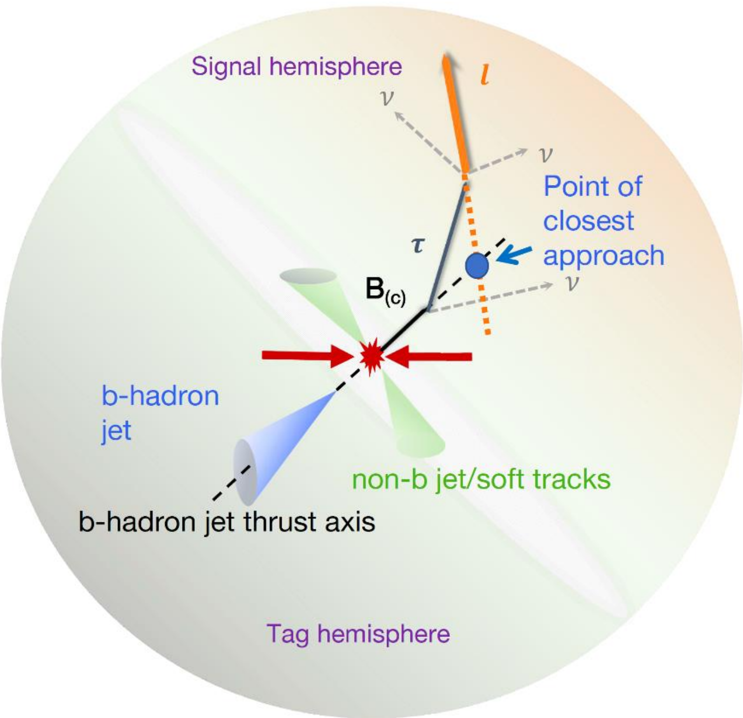


Fig. 4: Similar to Fig. 3 with red shaded area as parameter space of C_{S_2} given in Eq. (11).

Studying $B_c \to \tau\nu$ at CEPC

Lepton colliders operating at Z pole energy will provide a good opportunity for the study of $B_c \to \tau\nu$. The CEPC will produce up to 1 trillion Z bosons (Tera-Z). Which could lead to $\mathrm{O}(10^6) \sim \mathrm{O}(10^7)$ $B_c \to \tau\nu$ decays.



$B_{(c)} \to \tau\nu, \tau \to e/\mu\nu\nu$ in $Z \to b\bar{b}$. The most critical background for $B_c^+ \to \tau\nu$ is $\mathrm{B}^+ \to \tau\nu$, which share similar event topology.

Studying $B_c \to \tau\nu$ at CEPC

Result of the sensitivity study for $B_c \to \tau\nu, \tau \to e/\mu\nu\nu$ at CEPC (arXiv: 2007.08234, done by me and others, not yet finalized, needs revision)

- Signal strength accuracy could reach around ~1% at Tera-Z
- $B_c \to \tau\nu$ could be discovered with ~10^8 Z bosons
- $|V_{cb}|$ could be determined up to $O(1\%)$ under certain conditions
- Constraints on the C_{V_2}
- Similar constraints could be applied to C_{S_1} and C_{S_2}, but they will change the $\Gamma(B_c \to \tau\nu)$ so much that they will likely be verified or ruled out much earlier.

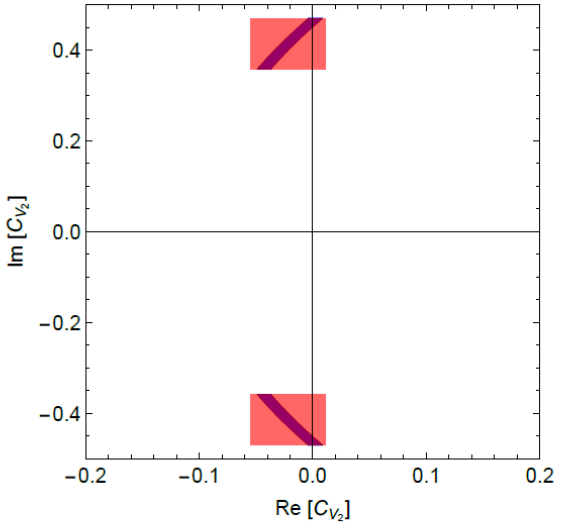
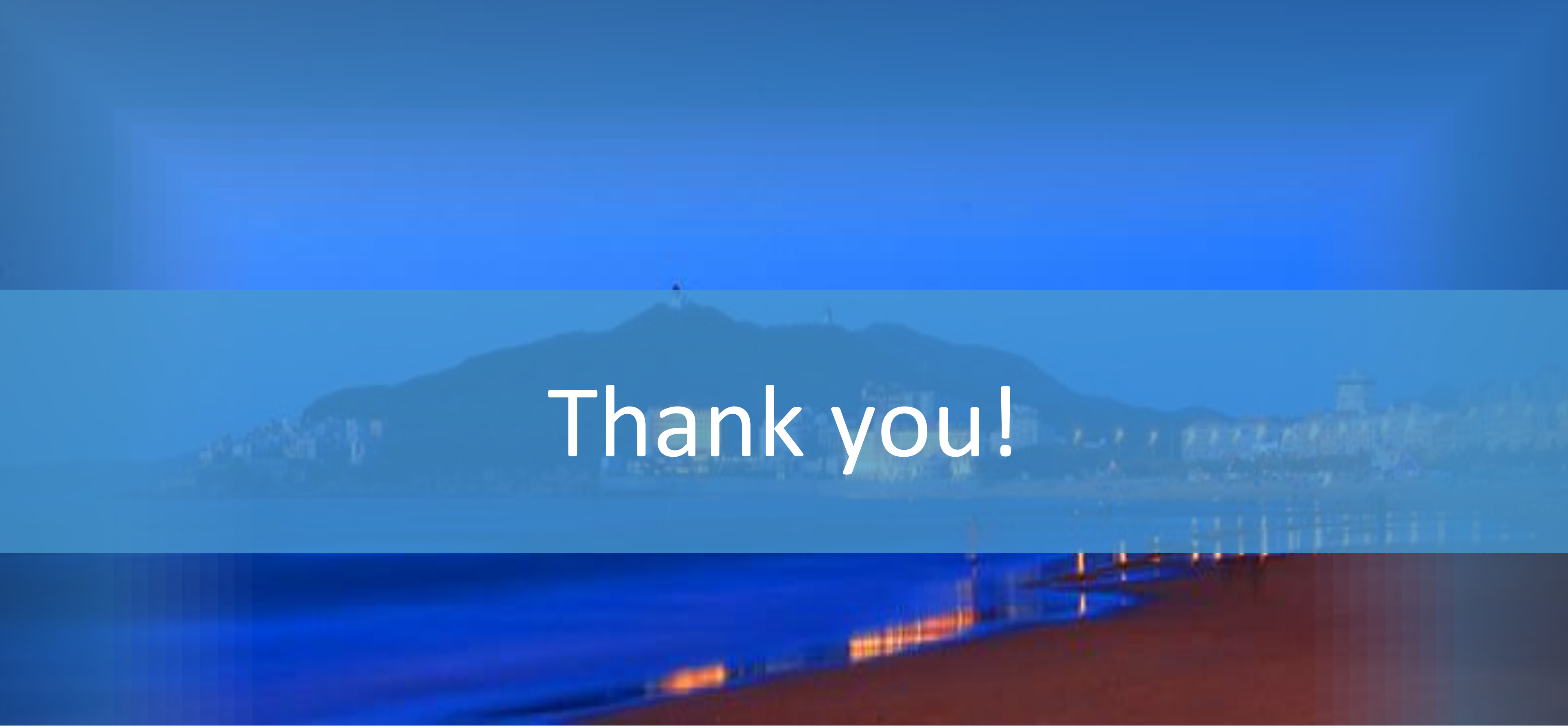


Fig. 11: Constraints on the real and imaginary parts of C_{V_2}. The red shaded area corresponds to the current constraints using available data on $b \to c\tau\nu$ decays. If the central values in Eq. (9) remain while the uncertainty in $\Gamma(B_c^+ \to \tau^+\nu_\tau)$ is reduced to 1%, the allowed region for C_{V_2} shrinks to the dark-blue region.



Thank you!