$R(D^{(*)})$ and $B_c \to \tau\,\nu$ in a generic 2HDM

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In collaborations with

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&

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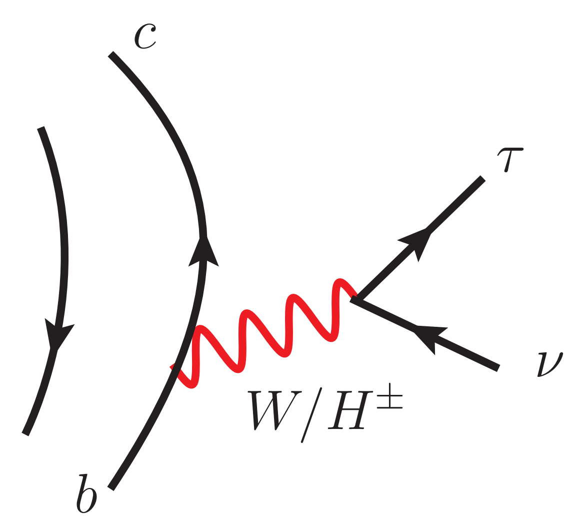


Introduction

- A challenge to lepton universality is reported in B decays, such as the excesses in the measured ratios $R(D^{(*)}) = \frac{B(B\to D^{(*)}\tau\nu)}{B(B\to D^{(*)}\ell\nu)}$

TABLE II: Average from the heavy flavor averaging group (HFLAV).

Exp	$R(D^*)$	$R(D)$	remarks
BaBar	$0.332 \pm 0.024 \pm 0.018$	$0.440 \pm 0.058 \pm 0.042$	PRL109(12);PRD88(13)
Belle	$0.293 \pm 0.038 \pm 0.015$	$0.375 \pm 0.064 \pm 0.026$	PRD92(15)
Belle	$0.302 \pm 0.030 \pm 0.011$	–	PRD94(16)
LHCb	$0.336 \pm 0.027 \pm 0.030$	–	PRL115(15)
Belle	$0.270 \pm 0.035^{+0.028}_{-0.025}$	–	PRL118(17)
LHCb	$0.285 \pm 0.019 \pm 0.029$	–	FPCP2017
Avg	$0.304 \pm 0.013 \pm 0.007$	$0.407 \pm 0.039 \pm 0.024$	
SM	0.252 ± 0.003	$0.299 \pm 0.011/0.300 \pm 0.008$	PRD85(12); PRD92(15)
	3.4σ	2.3σ	

- Considering the R(D)-R(D*) correlation, 4.1σ deviation from the SM

- If the excesses hint at new physics, what effects causes the excesses? We investigate the charged Higgs ($H^{\pm}$) effect in a two-Higgs-doublet model (2HDM)
  - $H^{\pm}$ couplings to the quarks and leptons depend on the taken schemes

$$tan\beta = \frac{v_2}{v_1}$$

α: h − H mixing angle

	Type I	Type II	Lepton-specific	Flipped
ξ_h^u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
ξ_h^d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
ξ_h^ℓ	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$
ξ_H^u	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
ξ_H^d	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
ξ_H^ℓ	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$
ξ_A^u	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
ξ_A^d	$-\cot\beta$	$\tan\beta$	$-\cot\beta$	$\tan\beta$
ξ_A^ℓ	$-\cot\beta$	$\tan\beta$	$\tan\beta$	$-\cot\beta$

Branco etal Phys.Rept. 516 (12)

  - What we focus on is the generic 2HDM, where we do not impose extra symmetry to suppress the FCNCs at tree level

➢ $H^{\pm}$ Yukawa couplings to the quarks and leptons:

$$
\begin{aligned}
-\mathcal{L}_Y &= \bar{Q}_L Y_1^d D_R H_1 + \bar{Q}_L Y_2^d D_R H_2 \\
&\quad + \bar{Q}_L Y_1^u U_R \tilde{H}_1 + \bar{Q}_L Y_2^u U_R \tilde{H}_2 \\
&\quad + \bar{L} Y_1^\ell \ell_R H_1 + \bar{L} Y_2^\ell \ell_R H_2 + H.c.\,,
\end{aligned}
$$

$$
H_i = \begin{pmatrix} \phi_i^+ \\ (v_i + \phi_i + i\eta_i)/\sqrt{2} \end{pmatrix}
$$

h couplings:

$$
\begin{aligned}
-\mathcal{L}_Y^h &= \bar{u}_L \left[\frac{c_\alpha}{v s_\beta} \mathbf{m_u} - \frac{c_{\beta\alpha}}{s_\beta} \mathbf{X}^u \right] u_R h + \bar{d}_L \left[-\frac{s_\alpha}{v c_\beta} \mathbf{m_d} + \frac{c_{\beta\alpha}}{c_\beta} \mathbf{X}^d \right] d_R h \\
&+ \bar{\ell}_L \left[-\frac{s_\alpha}{v c_\beta} \mathbf{m}_\ell + \frac{c_{\beta\alpha}}{c_\beta} \mathbf{X}^\ell \right] \ell_R h + h.c.\,,
\end{aligned}
$$

$$
\mathbf{X^u} = V_L^u \frac{Y_1^u}{\sqrt{2}} V_R^{u\dagger}
$$

$$
\mathbf{X^d} = V_L^d \frac{Y_2^d}{\sqrt{2}} V_R^{d\dagger} \quad \mathbf{X}^\ell = V_L^\ell \frac{Y_2^\ell}{\sqrt{2}} V_R^{\ell\dagger}
$$

H,A couplings:

$$
\begin{aligned}
-\mathcal{L}_Y^{H,A} &= \bar{u}_L \left[\frac{s_\alpha}{v s_\beta} \mathbf{m_u} + \frac{s_{\beta\alpha}}{s_\beta} \mathbf{X}^u \right] u_R H + \bar{d}_L \left[\frac{c_\alpha}{v c_\beta} \mathbf{m_d} - \frac{s_{\beta\alpha}}{c_\beta} \mathbf{X}^d \right] d_R H \\
&+ \bar{\ell}_L \left[\frac{c_\alpha}{v c_\beta} \mathbf{m}_\ell - \frac{s_{\beta\alpha}}{c_\beta} \mathbf{X}^\ell \right] \ell_R H + i\bar{u}_L \left[-\frac{\cot\beta}{v} \mathbf{m_u} + \frac{\mathbf{X}^u}{s_\beta} \right] u_R A \\
&+ i\bar{d}_L \left[-\frac{\tan\beta}{v} \mathbf{m_d} + \frac{\mathbf{X}^d}{c_\beta} \right] d_R A + i\bar{\ell}_L \left[-\frac{\tan\beta}{v} \mathbf{m}_\ell + \frac{\mathbf{X}^\ell}{c_\beta} \right] \ell_R A + h.c.
\end{aligned}
$$

$X^{\mathrm{u,d},\ell}$ lead to tree FCNCs, $Xs = 0$, the expressions return to the type-II 2HDM

$$
\begin{aligned}
-\mathcal{L}_Y^{H^\pm} &= \sqrt{2}\bar{d}_L V_{CKM}^\dagger \left[-\frac{\cot\beta}{v} \mathbf{m_u} + \frac{\mathbf{X}^u}{s_\beta} \right] u_R H^- \\
&+ \sqrt{2}\bar{u}_L V_{\rm CKM} \left[-\frac{\tan\beta}{v} \mathbf{m_d} + \frac{\mathbf{X}^d}{c_\beta} \right] d_R H^+ \\
&+ \sqrt{2}\bar{\nu}_L V_{\rm PMNS} \left[-\frac{\tan\beta}{v} \mathbf{m}_\ell + \frac{\mathbf{X}^\ell}{c_\beta} \right] \ell_R H^+ + h.c.\,,
\end{aligned}
$$

$s_\beta = sin\beta; c_\beta = \cos\beta\,;\ c_{\beta\alpha} = \cos(\beta - \alpha)$

$s_{\beta\alpha} = \sin(\beta - \alpha)$

A & $H^{\pm}$ have similar couplings

➢ To suppress the tree FCNCs, we take Cheng-Sher ansatz,

Cheng&Sher PRD35(87)

$$X_{ij}^f = \frac{\sqrt{m_i^f m_j^f}}{v}\chi_{ij}^f,$$ χ_{ij}^f are free parameters

$$\begin{aligned} -\mathcal{L}_Y^{H^\pm} &= \sqrt{2}\bar{d}_L V_{CKM}^\dagger \left[-\frac{\cot\beta}{v}\mathbf{m_u} + \frac{\mathbf{X}^u}{s_\beta}\right] u_R H^- \\ &+ \sqrt{2}\bar{u}_L V_{\rm CKM}\left[-\frac{\tan\beta}{v}\mathbf{m_d} + \frac{\mathbf{X}^d}{c_\beta}\right] d_R H^+ \\ &+ \sqrt{2}\bar{\nu}_L V_{\rm PMNS}\left[-\frac{\tan\beta}{v}\mathbf{m}_\ell + \frac{\mathbf{X}^\ell}{c_\beta}\right]\ell_R H^+ + h.c.\,, \end{aligned}$$

➢ Enhancement factor of $H^\pm$ coupling:

- Lepton current in $b \to c\,\ell\nu$: $tan\beta \sim \frac{m_t}{m_b}$, $\chi_{\tau\tau}^\ell \sim O(1-10)$

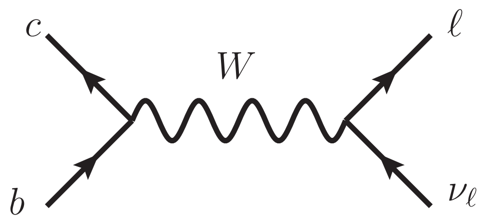
- Quark current: for simplicity we take $\chi_{ij}^d \ll 1$, the interesting enhancement factor:

$$\begin{aligned} (\mathbf{V}^\dagger \mathbf{X}^\mathbf{u})_{bc} &= V_{ub}^* X_{uc}^u + V_{cb}^* X_{cc}^u + V_{tb}^* X_{tc}^u\,, \\ &\approx \frac{\sqrt{m_t m_c}}{v}\chi_{tc}^u\,, \qquad V_{ub}, V_{cb} \ll V_{tb} \approx 1 \end{aligned}$$

Numerically, $\frac{\sqrt{m_c m_t}}{v} \approx 0.06 \sim V_{cb} \approx 0.04$, if $\chi_{tc}^u \sim O(1) \longrightarrow$ an enhancement factor

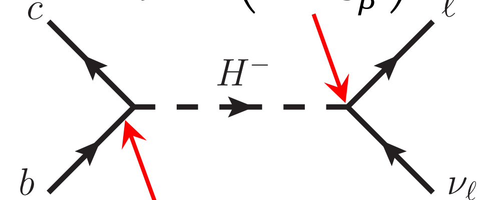
Phenomenological analysis of $B \to D^{(*)}\ell\nu$

- The SM W + $H^{\pm}$-mediated effects



$H \supset \frac{G_F}{\sqrt{2}} V_{cb} (\bar{c}b)_{V-A} (\bar{\ell}\nu_\ell)_{V-A}$

$$\frac{tan\beta\ m_\ell}{v}\left(1 - \frac{\chi^\ell_{\ell\ell}}{s_\beta}\right)\mathrm{P_L}$$



$$\frac{tan\beta\ m_b}{v} P_R +$$

$$\frac{cot\beta\ m_c}{v}\left(1 - \sqrt{\frac{m_t}{m_c}}\frac{\chi^u_{ct}}{c_\beta\ V_{cb}}\right)\mathrm{P_L}$$

- The effective Hamiltonian

$$H_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{cb} \left[(\bar{c}b)_{V-A} (\bar{\ell}\nu)_{V-A} + C^\ell_L (\bar{c}b)_{S-P} (\bar{\ell}\nu)_{S-P} + C^\ell_R (\bar{c}b)_{S+P} (\bar{\ell}\nu)_{S-P} \right]$$

$$C^\ell_L \approx -\frac{m_c m_\ell}{m^2_{H^\pm}} \left(1 - \frac{\chi^\ell_{\ell\ell}}{s_\beta}\right) \left(1 - \sqrt{\frac{m_t}{m_c}} \frac{\chi^u_{ct}}{c_\beta V_{cb}}\right),$$

$$C^\ell_R \approx -\frac{m_b m_\ell \tan^2\beta}{m^2_{H^\pm}} \left(1 - \frac{\chi^\ell_{\ell\ell}}{s_\beta}\right).$$

➢ Decay amplitudes of $B \to D^{(*)}\ell\bar{\nu}_\ell$

$$A_D = \frac{G_F}{\sqrt{2}} V_{cb} \left[F_1 \left(P^\mu - \frac{P \cdot q}{q^2} q^\mu \right) (\bar{\ell}\nu)_{V-A} \right.$$
$$\left. + \left(m_\ell F_0 \frac{P \cdot q}{q^2} + \boxed{(C_R^\ell + C_L^\ell)} (m_B + m_D) F_S \right) (\bar{\ell}\nu)_{S-P} \right]$$

$$A_{D^*}^L = -i \frac{G_F}{\sqrt{2}} V_{cb} \left\{ \epsilon^* \cdot q \left(\boxed{(C_R^\ell - C_L^\ell)} F_P + 2A_0 \frac{m_{D^*} m_\ell}{q^2} \right) (\bar{\ell}\nu)_{S-P} \right.$$
$$\left. + \left[(m_B + m_{D^*}) A_1 \left(\epsilon_\mu^*(L) - \frac{\epsilon^* \cdot q}{q^2} q_\mu \right) - \frac{A_2 \epsilon^* \cdot q}{m_B + m_D} \left(P_\mu - \frac{P \cdot q}{q^2} q_\mu \right) \right] (\bar{\ell}\nu)_{V-A} \right. ,$$
$$A_{D^*}^T = \frac{G_F}{\sqrt{2}} V_{cb} \left[\frac{V}{m_B + m_{D^*}} \varepsilon_{\mu\nu\rho\sigma} \epsilon_\nu^*(T) P^\rho q^\sigma - i(m_B + m_{D^*}) A_1 \epsilon_\mu^*(T) \right] (\bar{\ell}\nu)_{V-A} ,$$

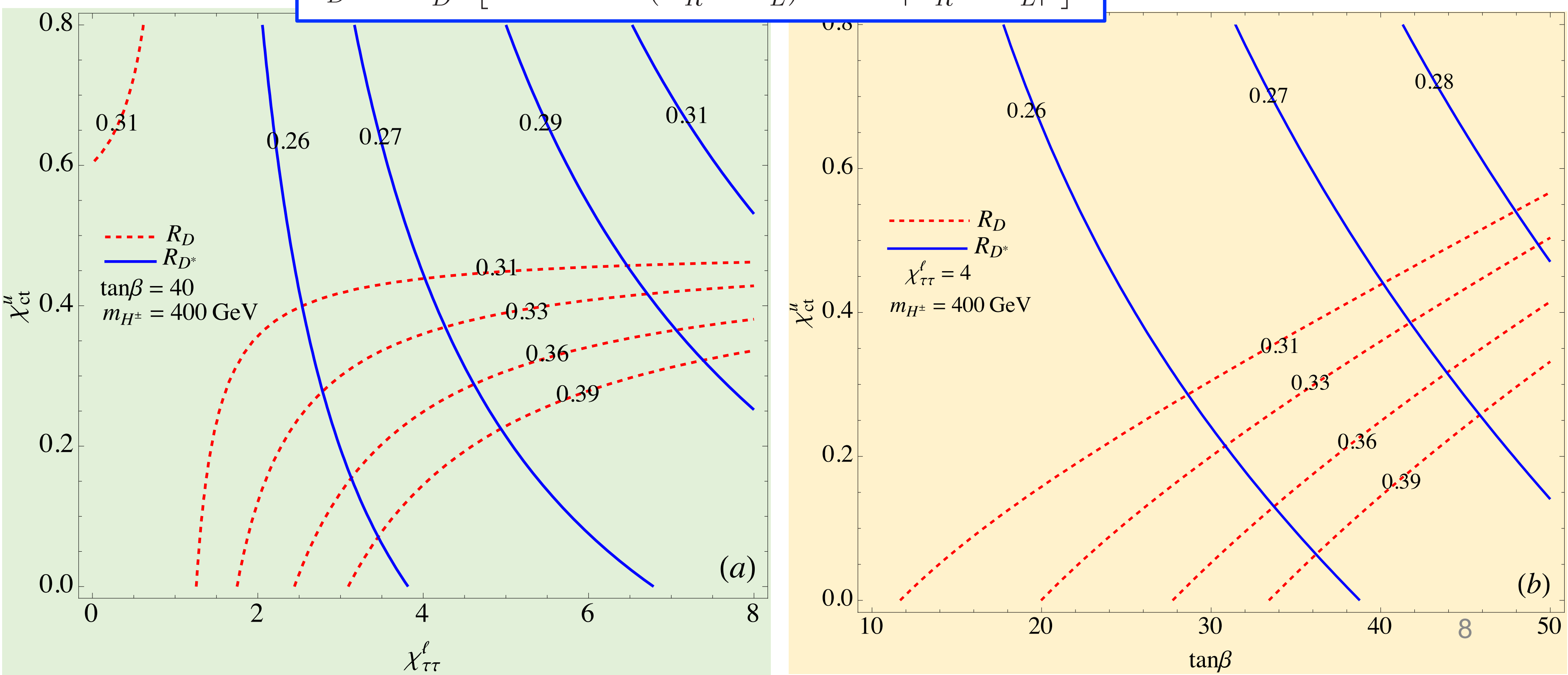
- $C_{R,L}^\mu \propto m_\mu$, influence could be small, we drop them with $\chi_{22}^\ell \ll 1$
- $|C_L^\tau| < |C_R^\tau|$, $C_R^\tau < 0$ in type-II 2HDM, destructive contribution
- To obtain constructive interference with the SM, we need $C_R^\tau \pm C_L^\tau > 0$, $C_R^\tau > 0 > C_L^\tau$

- Generic 2HDM, we need $\chi^{\ell}_{\tau\tau}$ to change the sign of C^{τ}_{R}; we also need χ^{u}_{ct} so that $C^{\tau}_{L} < 0$; that is, we need two parameters to enhance R(D) and R(D*)

$$C^{\ell}_{L} \approx -\frac{m_c m_\ell}{m^2_{H^\pm}}\left(1-\frac{\chi^{\ell}_{\ell\ell}}{s_\beta}\right)\left(1-\sqrt{\frac{m_t}{m_c}}\frac{\chi^{u}_{ct}}{c_\beta V_{cb}}\right),$$
$$C^{\ell}_{R} \approx -\frac{m_b m_\ell \tan^2\beta}{m^2_{H^\pm}}\left(1-\frac{\chi^{\ell}_{\ell\ell}}{s_\beta}\right).$$

- Ratios of the BR of $D^{(*)}\tau$ to $D^{(*)}\ell$ modes Fajfer etal, PRD85(12)

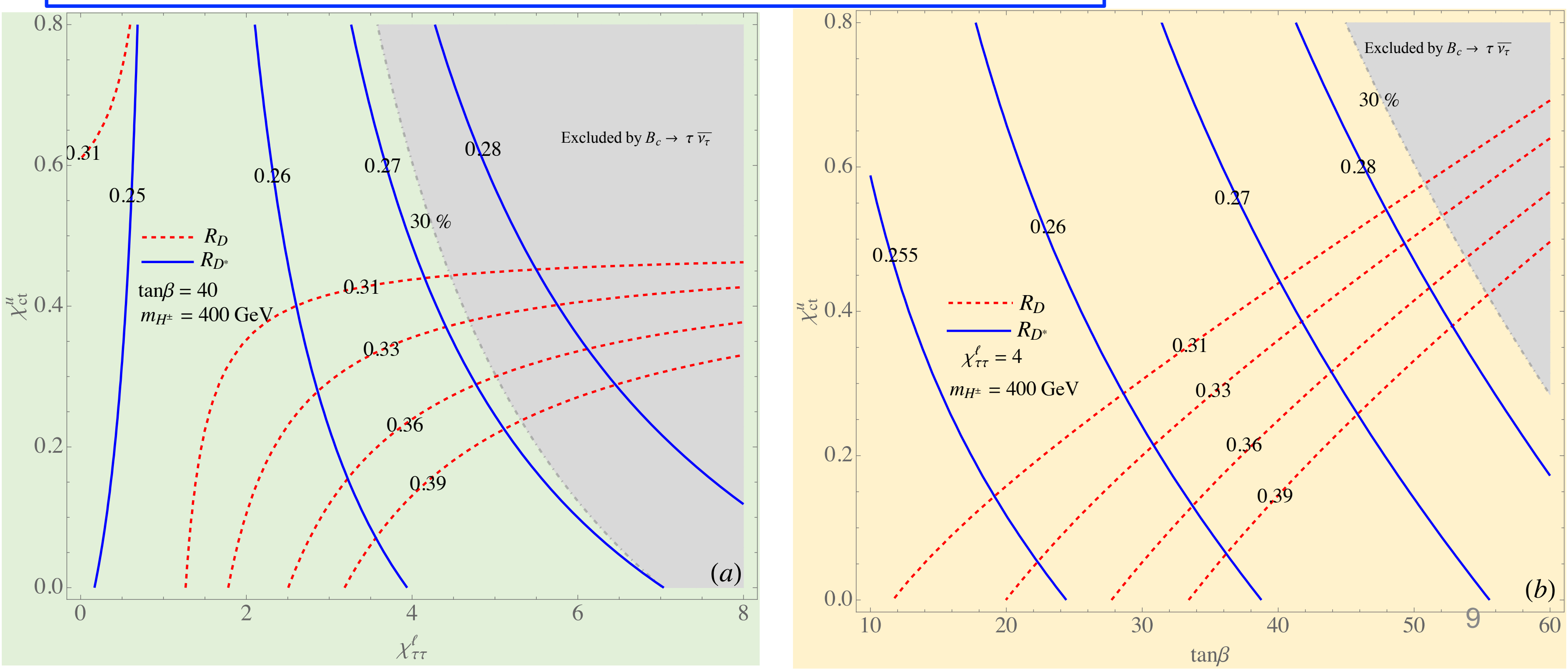
$$R_D \approx R_D^{\rm SM}\left[1+1.5Re(C^\tau_R+C^\tau_L)+1.0|C^\tau_R+C^\tau_L|^2\right],$$
$$R_{D^*} \approx R_{D^*}^{\rm SM}\left[1+0.12Re(C^\tau_R-C^\tau_L)+0.05|C^\tau_R-C^\tau_L|^2\right].$$



- Unfortunately, the charged-Higgs effects also enhance the BR for the $B_c \to \tau\ \nu$ decay, which has not yet observed. **$BR(B_c \to \tau\nu)^{SM} \approx 2.2\%$**
  - constraint from $BR(B_c \to \tau\nu) \le 1$ **Li etal JHEP1608(16)**
  - Based on the inconsistency in B_c lifetime between experimental data and theoretical estimation, it is found that $BR(B_c \to \tau\nu) \lesssim 30\%$ **Alonso etal PRL118(17)**

$$BR(B_c \to \tau\bar{\nu}_\tau) = \tau_{B_c} \frac{m_{B_c} m_\tau^2 f_{B_c}^2 G_F^2 |V_{cb}|^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_{B_c}^2}\right)^2 \left|1 + \frac{m_{B_c}^2}{m_\tau (m_b + m_c)} \epsilon_P\right|^2$$

$$\epsilon_P = C_R^\tau - C_L^\tau$$



Limit on the BR($B_c \to \tau\nu$) $from\ LEP1$

- Although the result of $BR(B_c \to \tau\nu) \lesssim 30\%$ limits R(D*) < 0.29, the deviation from the SM of R(D*)=0.25 is still significant.
- Can we further bound the BR of $B_c \to \tau\nu$?
  - B_c contributing to $B \to \tau\nu$ was investigated

The contribution of B_c mesons to the search for $B^+ \to \tau^+\ \nu_\tau$ decays at LEP

Michelangelo L. Mangano [a, 1], S.R. Slabospitsky [b] **PLB410(97)**

N_P: # $of\ \tau\nu\ from\ P \to \tau\nu$

$$\frac{N_{B_c}}{N_{B_u}} = \frac{f(b \to B_c)}{f(b \to B_u)} \left|\frac{V_{cb}}{V_{ub}}\right|^2 \left(\frac{f_{B_c}}{f_{B_u}}\right)^2 \frac{m_{B_c}}{m_{B_u}} \frac{\tau_{B_c}}{\tau_{B_u}} \frac{(1-\frac{m_\tau^2}{m_{B_c}^2})^2}{(1-\frac{m_\tau^2}{m_{B_u}^2})^2},$$

$f(b \to P)$:probability that a b-quark hadronizes into a P

although $f(b \to B_u) \gg f(b \to B_c)$, $V_{ub} \ll V_{cb}$

$$\boxed{\frac{N_{B_c}}{N_{B_u}} = 1.2 \left[\frac{f(b \to B_c)}{10^{-3}}\right]}$$

$$\mathrm{Br}(B_u \to \tau\nu) < 5.7 \times 10^{-4} \quad (90\%\ CL).$$

LEP(L3) PLB396(97)

Need to take the contamination from Bc

- Following MS approach, we updated the N_{B_c}/N_{B_u} with more accurate f_B and CKM matrix elements in **Akeroyd etal PRD77(08);** a specific limit on $BR(B_c \to \tau\nu)$ did not explicitly show
- Can the bound of the $\mathrm{BR}(B_c \to \tau\nu)$ from the LEP be more strict?
  - We reexamine the LEP (L3) bound with updated CDF run II data and LHC results
  - The effective BR for $b \to \tau\nu$ can be expressed as:

$$\mathrm{BR}_{\mathrm{eff}} = \mathrm{BR}(B_u^- \to \tau\bar{\nu})\left(1 + \frac{N_c}{N_u}\right) \qquad \frac{N_c}{N_u} = \frac{f_c}{f_u}\frac{\mathrm{BR}(B_c^- \to \tau\bar{\nu})}{\mathrm{BR}(B_u^- \to \tau\bar{\nu})}$$

model-independent

$$\mathrm{BR}(B_c^- \to \tau\bar{\nu}) = \frac{f_u}{f_c}\left[\mathrm{BR}_{\mathrm{eff}} - \mathrm{BR}(B_u^- \to \tau\bar{\nu})\right]$$

$$BR_{\mathrm{eff}} < 5.7\times10^{-4}\ (L3);\ BR(B_u \to \tau\nu)^{exp} = (1.06 \pm 0.09)\times10^{-4}$$

If we can determine f_u/f_c, then we can give an upper limit on $B_c \to \tau\nu$

- Using $f_u = 0.404 \pm 0.006$ (HFLAV) and $\mathrm{f_c} \sim 10^{-3}$, $BR(B_c \to \tau\nu) \sim 18.7\%$
- f_c/f_u from CDF Run II and LHC data:
  - CDF measured the ratio:

theoretical input

$$\mathcal{R}_\ell = \frac{\sigma(B_c)\cdot \mathrm{BR}(B_c^- \to J/\psi \ell \bar{\nu})}{\sigma(B_u)\cdot \mathrm{BR}(B_u^- \to J/\psi K^-)}$$

from B factory

$$\frac{f_c}{f_u} = \frac{f(b \to B_c)}{f(b \to B_u)} = \frac{\sigma(B_c)}{\sigma(B_u)}$$

	Tevatron Run I	Tevatron Run II	Average I+II	LHC
$\mathcal{R}_\ell$	0.13 ± 0.06	0.211 ± 0.024	0.171 ± 0.032	0.143 ± 0.017

PRD58(98) **PRD93(16)**

  - LHC does not directly show the observation of R_ℓ; but the measurements are shown:

$$R_{\pi/K} = \frac{\sigma(B_c)}{\sigma(B_u)} \frac{BR(B_c \to J/\psi\pi^-)}{BR(B_u \to J/\psi K^-)} = (6.72 \pm 0.19)\times 10^{-3},$$

$$R_{\pi/\mu} = \frac{BR(B_c \to J/\psi\pi^-)}{BR(B_c \to J/\psi\mu\nu)} = 0.0469 \pm 0.0054$$

$$\boxed{\mathcal{R}_\ell = \frac{\mathcal{R}_{\pi/K}}{\mathcal{R}_{\pi/\mu}} = 0.143 \pm 0.017}$$

- The theoretical estimations of $BR(B_c \to J/\psi\, \ell\nu)$ are diverse

TABLE XX. Branching-fraction predictions for the decay $B_c^+ \to J/\psi\, \mu^+\nu$.

Branching-fraction predictions in %													
Reference	[5]	[39]	[40]	[41]	[6]	[42]	[43]	[44]	[45]	[46]	[47]	[48]	[49]
Prediction	1.9	2.37	1.44	1.21	2.07	2.35	1.5	1.2	1.49	1.15	1.47	2.01	6.7

CDF PRD93(16)

- HPQCD lattice results can help to judge: $B_c \to J/\psi$ form factors at $q^2 = [0, \text{max}]$ are given as $A_1 = [0.49, 0.79]$ and $V = [0.77, none]$

arXiv:1611.01987

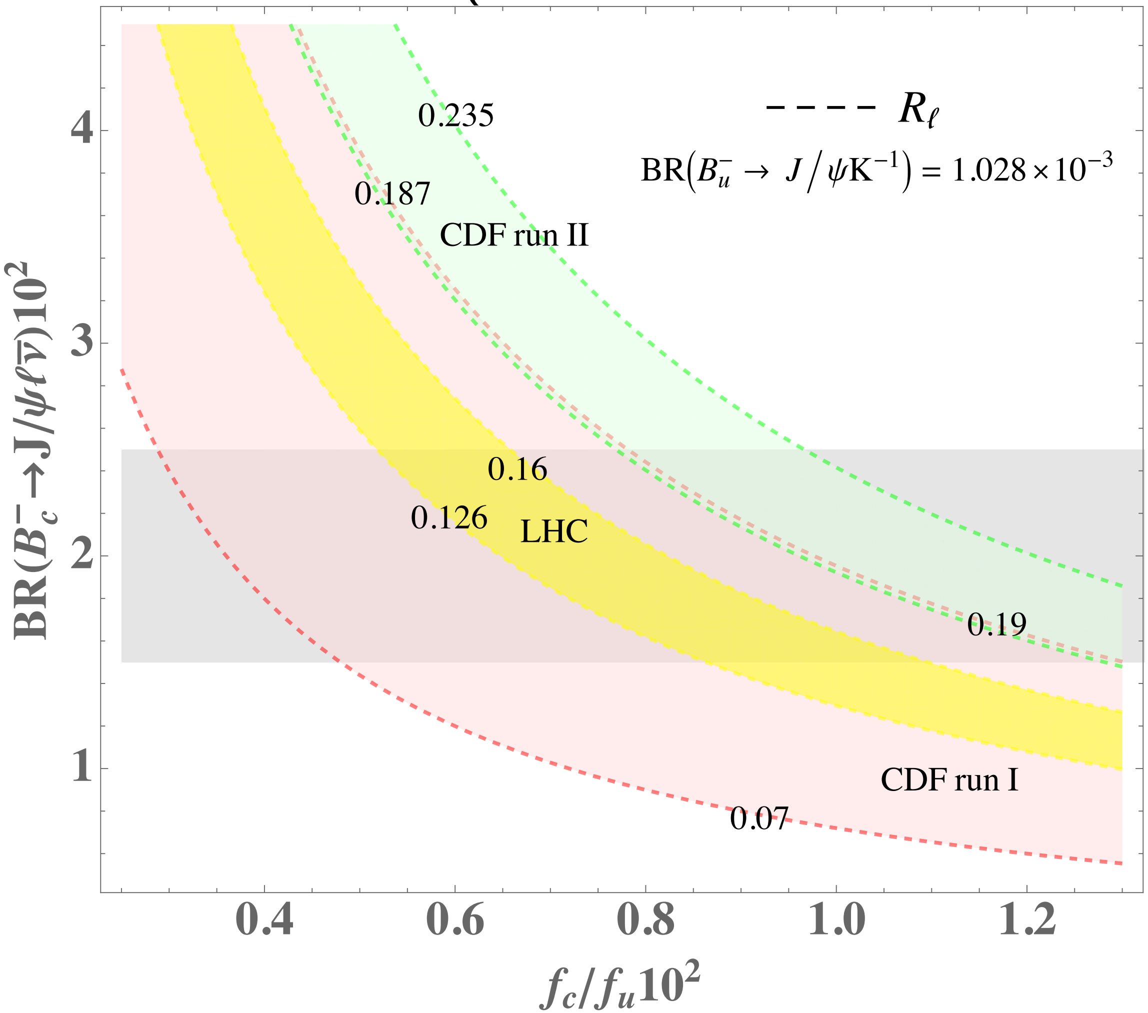
- $BR(B_c \to J/\psi\, \ell\nu) = (1.5 - 2.5)\%$ by the QCD models, which the obtained form factors can match HPQCD results within 15%,

TABLE III: Form factors for $B_c^- \to J/\psi$ at $q^2 = 0$ and q^2_{max}.

	$(F(0), F(q^2_{max}))$	A_1	V	$\mathrm{BR}(B_c \to J/\Psi \ell \bar{\nu})$
	HPQCD[34]	(0.49, 0.79)	(0.77, None)	None
Rel. quark-meson model	NW[26]	$(0.53, 0.76^a)$	$(0.73, 1.29^a)$	1.47%
Rel. quark model	IKS[28]	(0.55, 0.85)	(0.83, 1.53)	2.17%
Light-Front QCD	WSL[31]	(0.50, 0.80)	(0.74, 1.45)	1.49%

$$\frac{f_c}{f_u} = \frac{10^{-4}}{\mathrm{BR}(B_c^- \to J/\psi \ell \bar{\nu})} \begin{cases} 1.758 \pm 0.336 & (\text{Tevatron data}), \\ 1.470 \pm 0.184 & (\text{LHC data}). \end{cases}$$

$$\mathcal{R}_\ell = \frac{\sigma(B_c) \cdot \mathrm{BR}(B_c^- \to J/\psi \ell \bar{\nu})}{\sigma(B_u) \cdot \mathrm{BR}(B_u^- \to J/\psi K^-)}$$

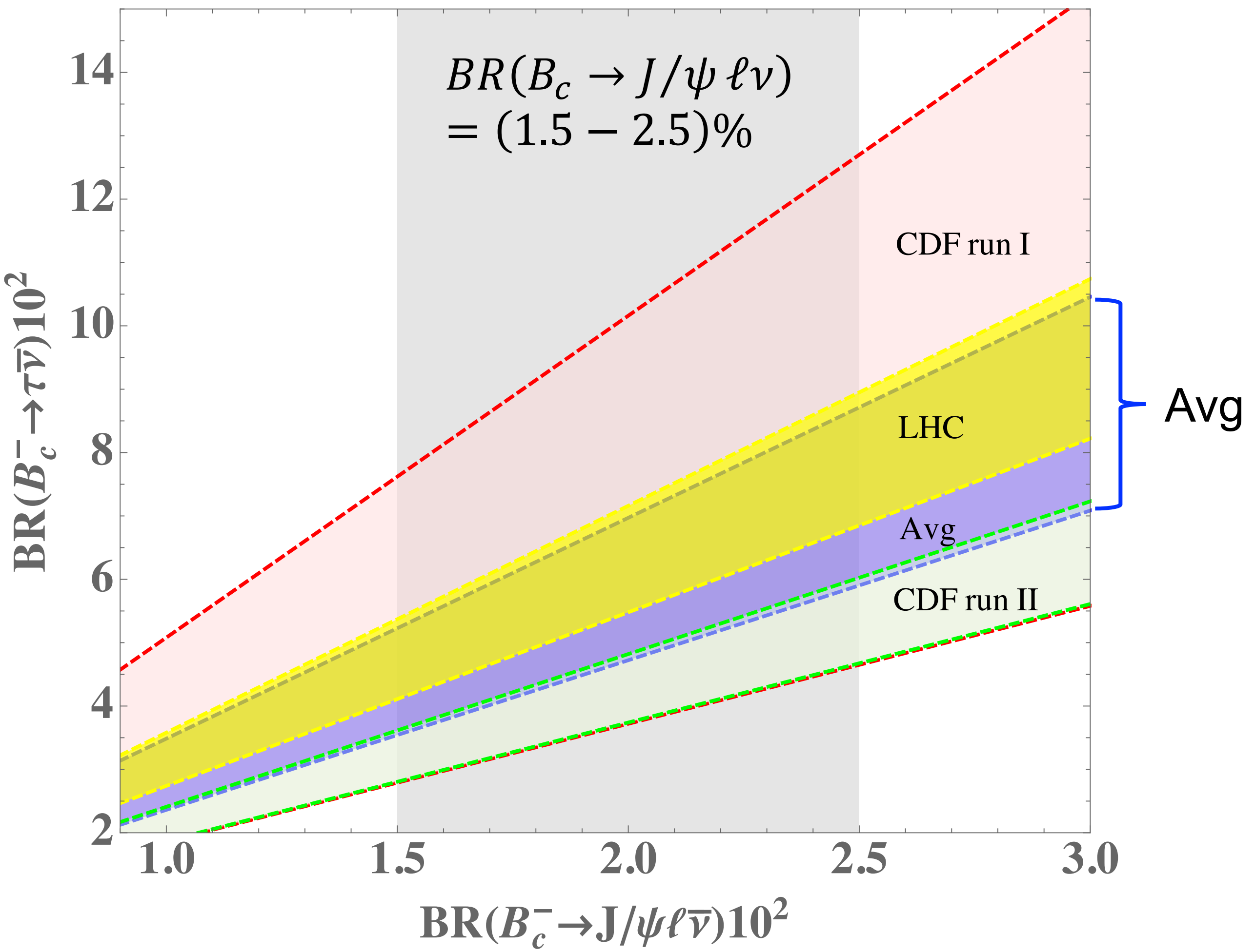


Contours for R_ℓ as a function of $BR(B_c \to J/\psi\, \ell\nu)$ and f_c/f_u

$BR(B_c \to J/\psi\, \ell\nu) = (1.5 - 2.5)\%$

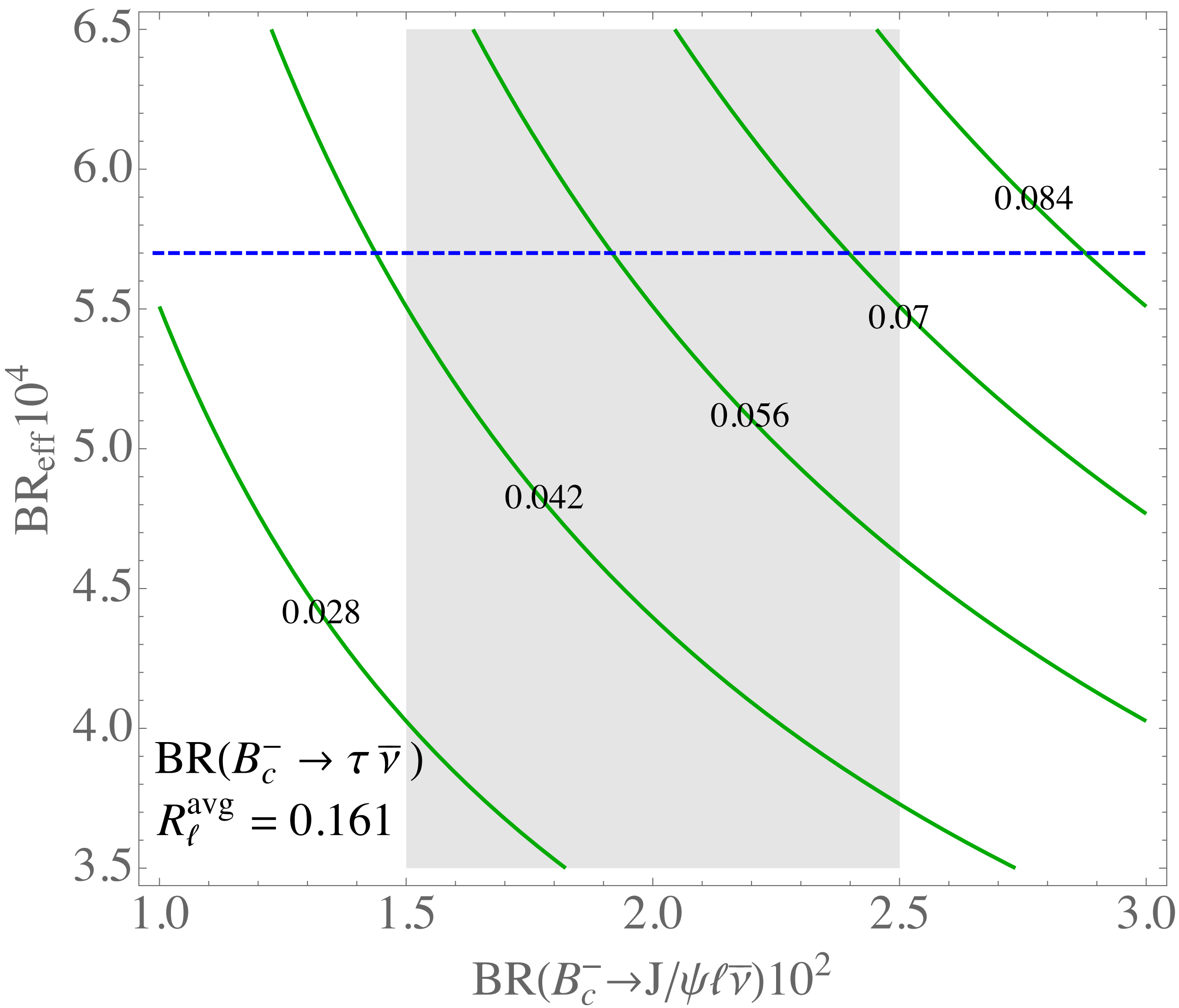
	Tevatron Run I	Tevatron Run II	Average I+II	LHC
$\mathcal{R}_\ell$	0.13 ± 0.06	0.211 ± 0.024	0.171 ± 0.032	0.143 ± 0.017

$$\mathrm{BR}(B_c^- \to \tau\bar{\nu}) = \mathrm{BR}(B_c^- \to J/\psi\ell\bar{\nu})\frac{1}{\mathcal{R}_\ell}\frac{\mathrm{BR}_{\mathrm{eff}} - B_u^{exp}}{\mathrm{BR}(B_u^- \to J/\psi K^-)_{exp}}$$



- Using LEP, Tevatron, and LHC data, we obtain $BR(B_c \to \tau\nu) \lesssim 10\%$

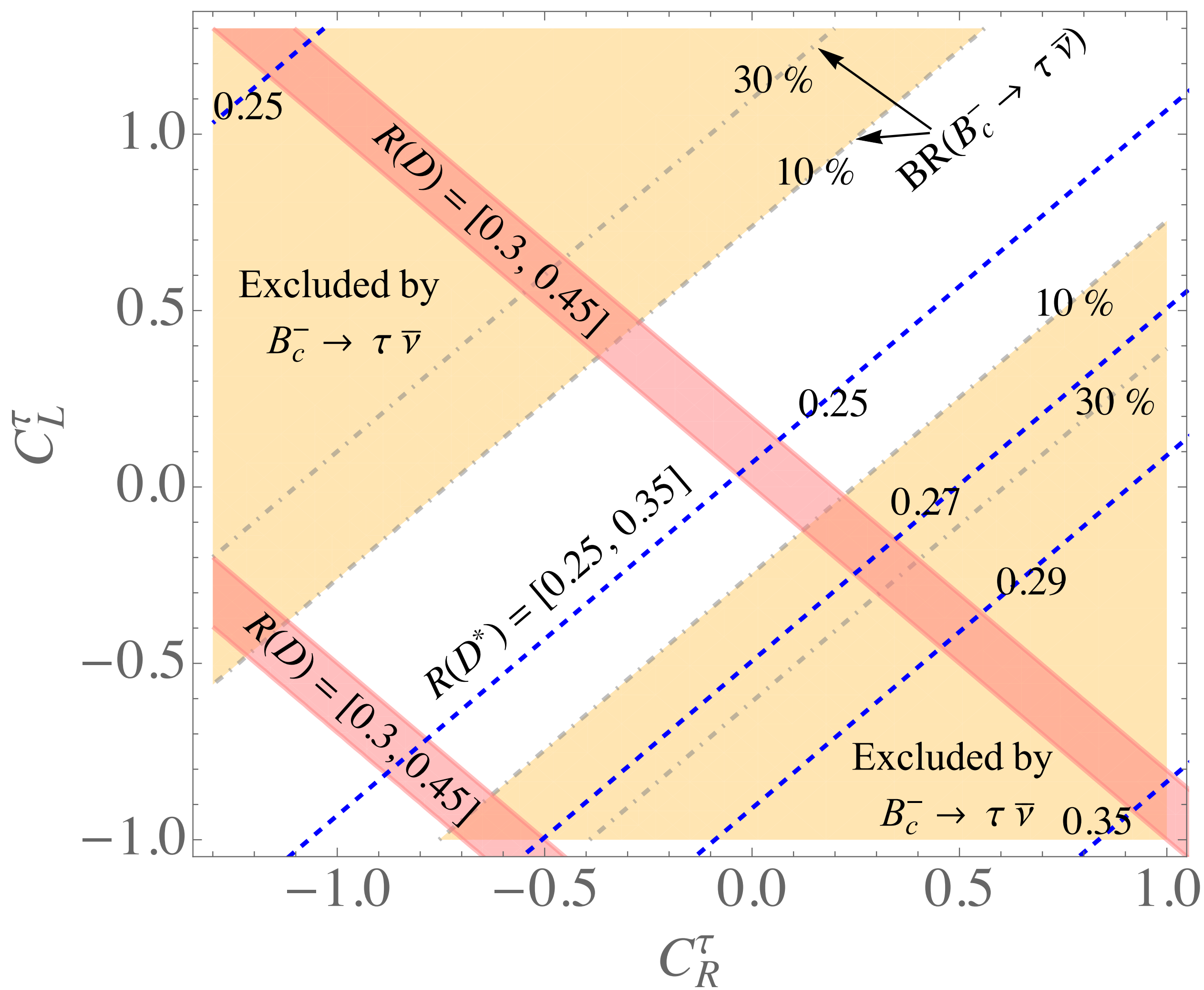
Indeed, L3 just used 40% of available data; with full data sample, $BR_{\mathrm{eff}} \sim 4\times10^{-4}$ is expected, then $BR(B_c \to \tau\nu) < 5\%$



$$\mathrm{BR}(B_c^- \to \tau\bar{\nu}) = \mathrm{BR}(B_c^- \to J/\psi\ell\bar{\nu})\frac{1}{\mathcal{R}_\ell}\frac{\mathrm{BR_{eff}} - B_u^{exp}}{\mathrm{BR}(B_u^- \to J/\psi K^-)_{exp}}$$

❑ Revisit R(D) and R(D*) by $H^{\pm}$ effects

$$\mathcal{H}_{\rm eff} = \frac{G_F V_{cb}}{\sqrt{2}} \left[(\bar{c}b)_{V-A}(\bar{\tau}\nu_\tau)_{V-A} + \left(C_R^\tau(\bar{c}b)_{S+P} + C_L^\tau(\bar{c}b)_{S-P}\right)(\bar{\tau}\nu_\tau)_{S-P} \right]$$



$R(D)$ can still be as large as 0.4; but, $R(D*) \lesssim 0.26$ when $BR(B_c \to \tau\nu) \lesssim 10\%$ is taken into account

Summary:

- Charged-Higgs in the generic 2HDM can enhance R(D) and R(D^*)

- R(D^*) can be limited to be less than 0.29 by the constraint of $BR(B_c \to \tau\nu) < 30\%$, which is obtained from the B_c lifetime difference between theoretical estimation and data

- We find that $BR(B_c \to \tau\nu) < 10\%$ can be achieved by LEP data, R(D) can reach 0.4, but R(D^*) $\lesssim$ 0.26

- Belle & LHCb with hadronic tau decays show R(D^*) is lower than leptonic decays, 0.270(Belle) & 0.285(LHCb); If the excess just occurs in R(D), not in R(D^*), the charged-Higgs effects could be the potential candidate