New Physics in $\Delta\Gamma_d$

Gilberto Tetlalmatzi,
Ben Pecjak, Alexander Lenz,
Christoph Bobeth,Ulrich Haisch

IPPP Durham University

gilberto.tetlalmatzi-xolocotz@durham.ac.uk

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$C_{d,s}$: Production-detection coefficients.

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$\Gamma(B_d \to f) \neq \Gamma(\bar{B}_d \to f)$

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- Some theoretical studies claim up to 10 orders of magnitude deficit of the CP violation provided by the SM
- New sources of CP violation are required to explain the matter dominance

A bit about mixing

$$i\frac{d}{dt}\begin{pmatrix}|B_d\rangle\\|\bar{B}_d\rangle\end{pmatrix} = \Sigma^d\begin{pmatrix}|B_d\rangle\\|\bar{B}_d\rangle\end{pmatrix}$$

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In the diagonal case

$$\Sigma = \begin{pmatrix} M_{11} - \frac{i}{2}\Gamma_{11} & 0 \\ 0 & M_{22} - \frac{i}{2}\Gamma_{22}\end{pmatrix}$$

$$|B_d\rangle \quad = \quad e^{-i(M_{11}-\frac{i}{2}\Gamma_{11})t}\,|B_d\rangle$$

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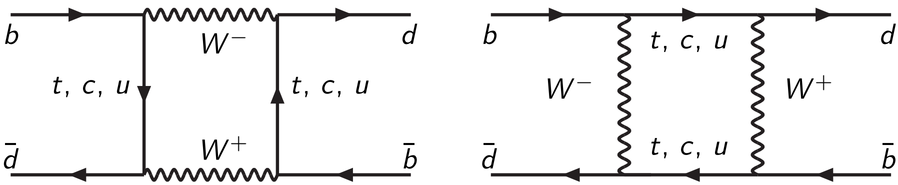

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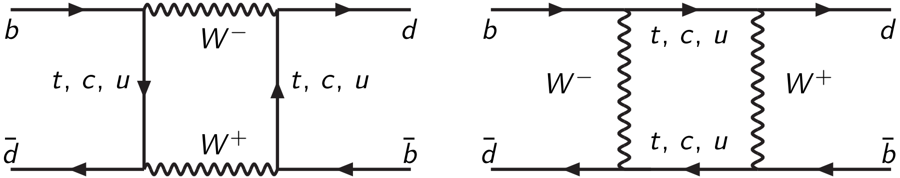

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Eigenvalues of Σ

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$$\begin{aligned} |B_{L,H}(t)\rangle &= e^{-i(M_{H,L} - i\frac{\Gamma_{H,L}}{2})t}\,|B_{L,H}\rangle \\ |B^0(t)\rangle &= g_+(t)\,|B^0\rangle + \frac{q}{p}g_-(t)\,|\bar{B}^0\rangle \\ |\bar{B}^0(t)\rangle &= \frac{p}{q}g_-(t)\,|B^0\rangle + g_+(t)\,|\bar{B}^0\rangle \end{aligned}$$

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g_+(t) &= e^{-imt} e^{-\frac{\Gamma}{2}t} \left[cosh\frac{\Delta\Gamma t}{4} cos\frac{\Delta mt}{2} - i \times sinh\frac{\Delta\Gamma t}{4} sin\frac{\Delta mt}{2} \right] \\
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$$\begin{aligned} \Delta M &\approx 2|M_{12}| \\ \phi &\equiv arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \\ \Delta\Gamma &\approx 2|\Gamma_{12}| cos(\phi) \end{aligned}$$

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Theory Vs Experiment $\Delta\Gamma_s$:

$$\begin{aligned} (\Delta\Gamma_s)_{SM} &= (0.087 \pm 0.021)\text{ps}^{-1}. \\ (\Delta\Gamma_s)_{exp} &= (0.081 \pm 0.011)\text{ps}^{-1}\ . \end{aligned}$$

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(\frac{\Delta\Gamma_d}{\Gamma_d})_{SM} &= (0.42 \pm 0.08)\% , \\
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Main Goal: To calculate how big the enhancement in $\Delta\Gamma_d$ can be without violate other experimental constraints.

$\Delta\Gamma_d$ vs $\Delta\Gamma_s$

New Physics (NP) effects in $\Delta\Gamma_s$ are strongly constrained in comparison with $\Delta\Gamma_d$ because:

$$\begin{aligned} \Delta\Gamma_d & \quad \text{triggered by } b \to c\bar{c}d \\ \Delta\Gamma_s & \quad \text{triggered by } b \to c\bar{c}s \\ Br(b \to c\bar{c}d) &= (1.31 \pm 0.07)\% \\ Br(b \to c\bar{c}s) &= (23.7 \pm 1.3)\% \end{aligned}$$

$\Longrightarrow$ 100% enhancement on $\Gamma(b \to c\bar{c}s)$ leads to sizable effect on Γ_{tot}

$\Longrightarrow$ 100% enhancement on $\Gamma(b \to c\bar{c}d)$ can be hidden within the hadronic uncertainties.

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$\Longrightarrow$ enhancement by a factor of 4 in $\Delta\Gamma_d$

$\Longrightarrow$ enhancement by a factor of 1.4 in $\Delta\Gamma_s$.

Current-Current Operators

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An effective approach is followed

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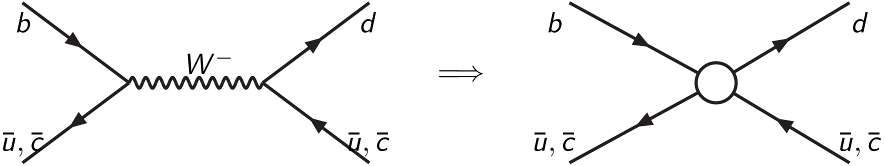

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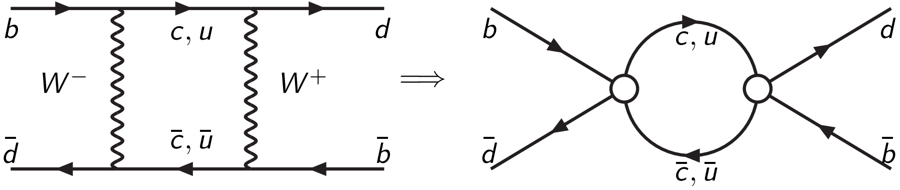
Calculation of Γ_{12}



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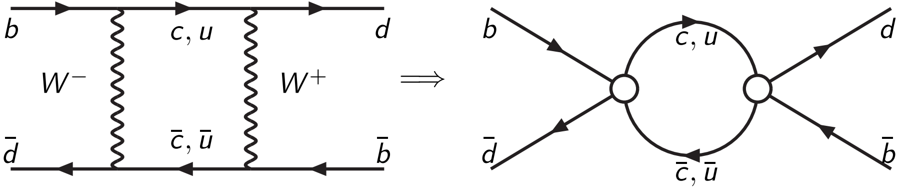

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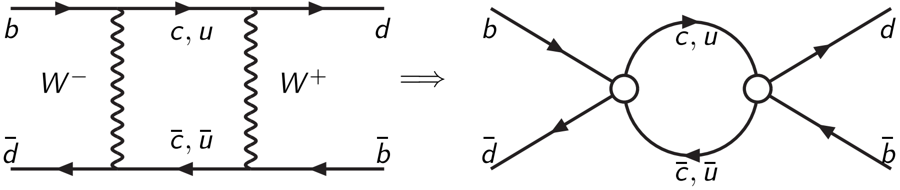

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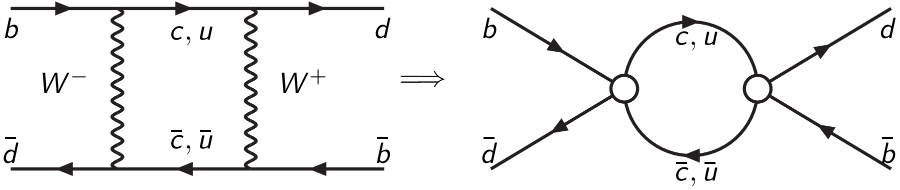

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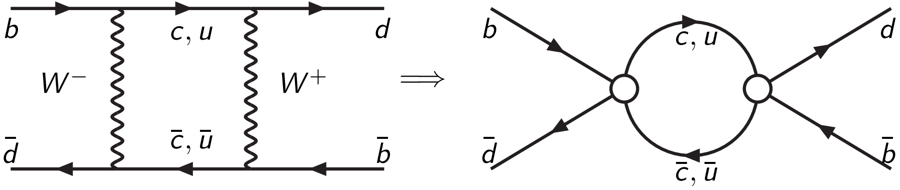

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& \left. - 0.26\Delta C_1^{cc} + 0.77\left(\Delta C_1^{cc}\right)^2\right] \\
& + (0.21 - 0.052i)\left[(\Delta C_2^{uu})^2 + 0.35\Delta C_1^{uu}\Delta C_2^{uu} + 2.0\Delta C_2^{uu}\right. \\
& \left. - 0.16\Delta C_1^{uu} + 1.3\left(\Delta C_1^{uu}\right)^2\right] \\
& + (0.53 + 0.79i)\left[\Delta C_2^{cu}\Delta C_2^{uc} + 1.05\Delta C_1^{cu}\Delta C_1^{uc}\right. \\
& + 0.11(\Delta C_1^{uc}\Delta C_2^{cu} + \Delta C_1^{cu}\Delta C_2^{uc}) \\
& \left. + 1.0(\Delta C_2^{cu} + \Delta C_2^{uc}) - 0.10(\Delta C_1^{cu} + \Delta C_1^{uc})\right]
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$$S_{\pi^+\pi^-} \simeq (-44 \pm 20) \left[\frac{3.8\,\mathrm{Im}\, r_{\pi^+\pi^-} + 1.9\,\mathrm{Re}\, r_{\pi^+\pi^-}}{1 + 0.88\left| r_{\pi^+\pi^-} \right|^2} \right] \%$$

$C_{\pi^+\pi^-}$ is suppressed by powers of $1/\alpha_s$ or $1/m_b$ in QCD so it is difficult to predict quantitatively.

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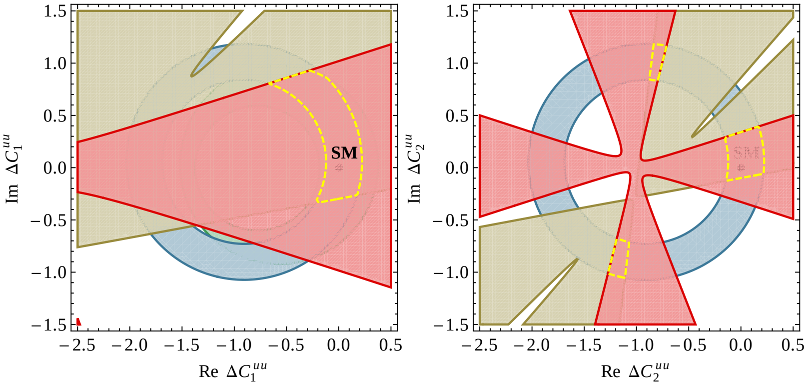
Bounds from $\Gamma_{12}^{uu,d}$

Constrictions for ΔC_1 and ΔC_2



Bounds from $\Gamma_{12}^{uu,d}$

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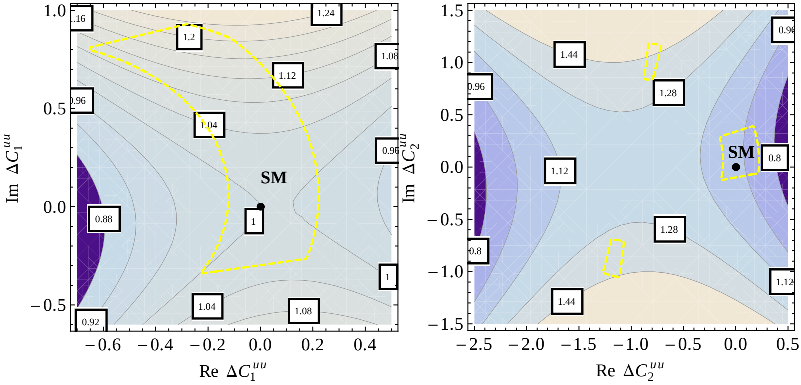

$\Gamma_{12}/\Gamma_{12}^{SM} < 1.44$

Bounds from $\Gamma_{12}^{uc,d}$

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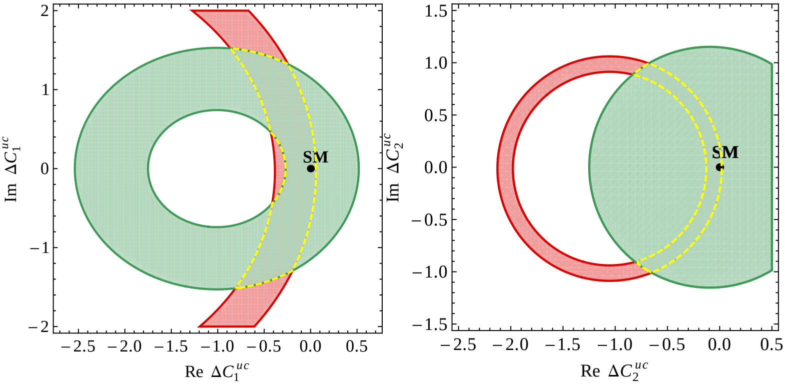

Channels taken into account: $\bar{B}^0 \to D^{*+}\pi^-$ and τ_{B_d}

Bounds from $\Gamma_{12}^{uc,d}$

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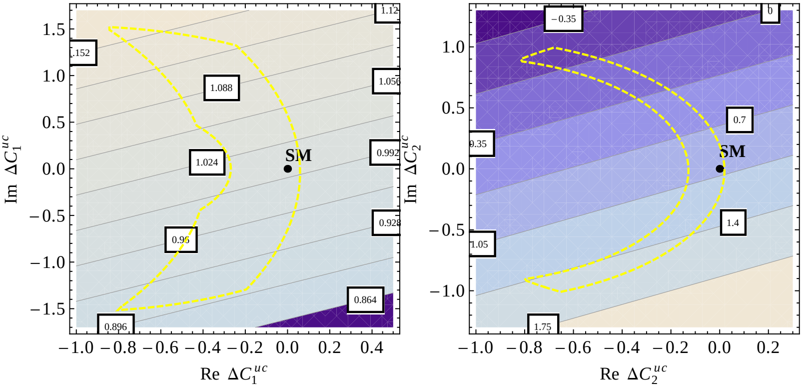
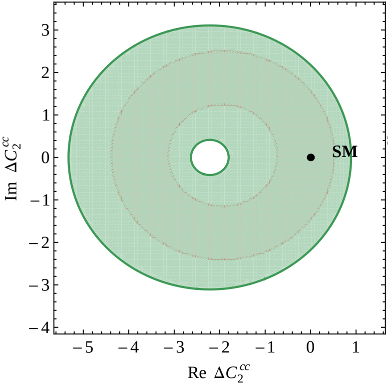
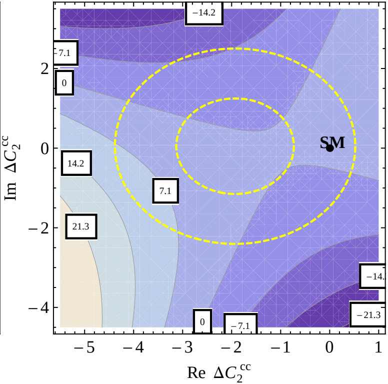


$\Gamma_{12}/\Gamma_{12}^{SM} < 1.5$

Bounds from $\Gamma_{12}^{cc,d}$

Constrictions and enhancement for $\Gamma_{12}^{cc,d}$





Channel taken into account: $B_d \to X_d\gamma$.

$$\Gamma_{12}/\Gamma_{12}^{SM} < 7.0$$

$(b\bar{d})\,(\bar{\tau}\tau)$ Operators

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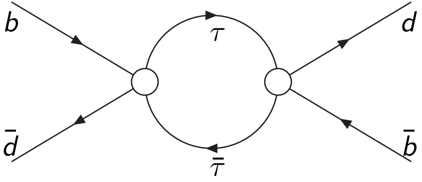

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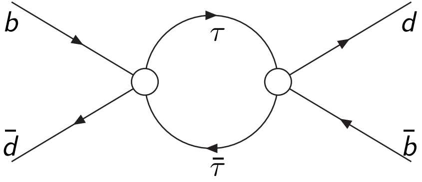

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Including all possible Dirac structures, one has the following set

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The effective Lagrangian involving these operators is written as

$$H_{\mathrm{eff}} = \sum_i \frac{4 G_F}{\sqrt{2}} V_{td}^{*} V_{tb} C_i(\mu) Q_i$$

Bounds on the operators $(b\bar{d})(\bar{\tau}\tau)$

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Setting $\Gamma_s^{NP} = 0$ gives an upper bound on (also invisible) new physics contributions to B_d decays

$$Br(B_d \to X) < 0.0\% + x \cdot 0.9\% = \begin{cases} 0.9\% & 1\sigma \\ 1.8\% & 2\sigma \\ 2.7\% & 3\sigma \end{cases}$$

$(b\bar{d})\,(\bar{\tau}\tau)$ Operators

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$$|\tilde{\Delta}_d| = \frac{\Delta\Gamma_d \;\; cos(\phi_d)^{SM}}{\Delta\Gamma_d^{SM} cos(\phi_d)}.$$

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Dependence of $\tilde{\Delta}_d$ on the Wilson coefficients

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|\tilde{\Delta}_d|_{S,AB} &< 1 + (0.4 \pm 0.1)|C_{S,AB}(m_b)|^2 \\
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The problem is reduced to the calculation of bounds for the Wilson Coefficients $C_{S,AB}(m_b)$, $C_{V,AB}(m_b)$ and $C_{T,A}(m_b)$ depending on different experimental constraints.

Direct bounds over the Wilson Coefficients

Process	$\lvert C_S(m_b)\rvert$	$\lvert C_V(m_b)\rvert$	$\lvert C_T(m_b)\rvert$
$B_d \to \tau^+\tau^-$	1.04	2.12	
$B \to X_d\tau^+\tau^-$	8.12 $(Br = 0.9\%)$ 11.49 $(Br = 1.8\%)$ 14.07 $(Br = 2.7\%)$	4.06 $(Br = 0.9\%)$ 5.74 $(Br = 1.8\%)$ 7.03 $(Br = 1.8\%)$	1.17 $(Br = 0.9\%)$ 1.66 $(Br = 1.8\%)$ 2.03 $(Br = 2.7\%)$
$B \to \pi^+\tau^+\tau^-$	4.51 $(Br = 0.9\%)$ 6.38 $(Br = 1.8\%)$ 7.81 $(Br = 2.7\%)$	4.50 $(Br = 0.9\%)$ 6.36 $(Br = 1.8\%)$ 7.79 $(Br = 2.7\%)$	2.0 $(Br = 0.9\%)$ 2.8 $(Br = 1.8\%)$ 3.5 $(Br = 2.7\%)$

The most important constraints for the scalar and vector cases come from the channel $B_d \to \tau^+\tau^-$

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$$\begin{aligned} B_d &\to \gamma\gamma \implies b \to d\ell^+\ell^- \\ B^+ &\to \pi^+\mu^+\mu^- \implies b \to d\ell^+\ell^- \\ B_d &\to X_d\gamma \implies b \to d\gamma \end{aligned}$$

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The operators associated with the transitions $b \to d\gamma$ and $b \to d\ell^+\ell^-$ are

$$Q_{7,A} = \frac{e}{g_s^2}\, m_\tau\, (\bar{d}\,\sigma^{\mu\nu} P_A\, b) F_{\mu\nu}\,, \qquad Q_{9,A} = \frac{e^2}{g_s^2}\, (\bar{d}\,\gamma^\mu P_A\, b)(\bar{\ell}\,\gamma_\mu\,\ell)$$

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$$C_{7,A}(m_b) = \eta_6^{4/21} \left(0.6 - \eta_6^{-1}\right) C_{T,A}(\Lambda),$$
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with $\eta_6 = \frac{\alpha_s(\Lambda)}{\alpha_s(m_b)}$.

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$$Br(B_d \to X_d\gamma)^{exp} < (1.41 \pm 0.57) \times 10^{-5}$$

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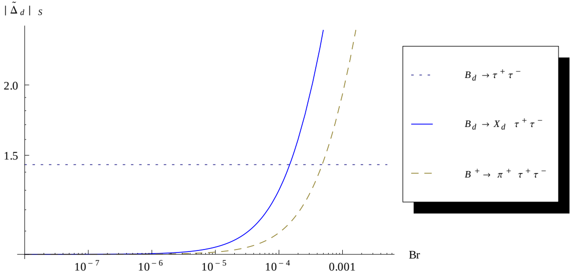
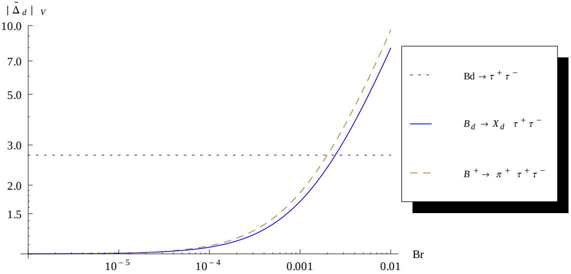
Scalar contribution



$$|\tilde{\Delta}_d| = 1.4$$

$|\tilde{\Delta}_d|$ vs Br

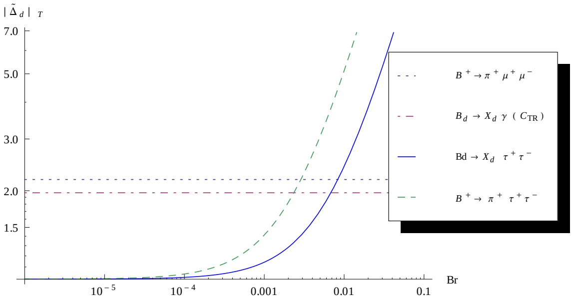
Vector contribution



$$|\tilde{\Delta}_d| = 2.8$$

$|\tilde{\Delta}_d|$ vs Br

Tensor contribution



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- The next step is to study new effects over $\Delta\Gamma_d$ within a specific beyond SM scenario.