Model Independent bounds on NP in Tree Level (constraints from flavour observables)

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Based on:

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Operator Basis

$$\hat{\mathcal{H}}_{eff}^{|\Delta B|=1} = \frac{G_F}{\sqrt{2}} \Bigg\{ \sum_{p,p'=u,c} \lambda_{pp'}^{(q)} \sum_{i=1,2} C_i^{q,\,pp'}(\mu) \hat{Q}_i^{q,\,pp'} + \sum_{p=u,c} \lambda_p^{(q)} \left[\sum_{i=3}^{10} C_i^q(\mu) \hat{Q}_i^q + C_{7\gamma}^q \hat{Q}_{7\gamma}^q + C_{8g}^q \hat{Q}_{8g}^q \right] \Bigg\} + h.$$

$$\lambda_p^{(q)} = V_{pb} V_{pq}^* \,, \qquad \lambda_{pp'}^{(q)} = V_{pb} V_{p'q}^* \,.$$

$$\hat{Q}_1^{q,\,pp'} = \left(\bar{\hat{p}}_\beta \hat{b}_\alpha\right)_{V-A} \left(\bar{\hat{q}}_\alpha \hat{p}'_\beta\right)_{V-A}, \qquad \hat{Q}_2^{q,\,pp'} = \left(\bar{\hat{p}} \hat{b}\right)_{V-A} \left(\bar{\hat{q}} \hat{p}'\right)_{V-A},$$

$$\hat{Q}_3^q = \left(\bar{\hat{q}} \hat{b}\right)_{V-A} \sum_k \left(\bar{\hat{k}} \hat{k}\right)_{V-A}, \qquad \hat{Q}_4^q = \left(\bar{\hat{q}}_\alpha \hat{b}_\beta\right)_{V-A} \sum_k \left(\bar{\hat{k}}_\beta \hat{k}_\alpha\right)_{V-A},$$

$$\hat{Q}_5^q = \left(\bar{\hat{q}} \hat{b}\right)_{V-A} \sum_k \left(\bar{\hat{k}} \hat{k}\right)_{V+A}, \qquad \hat{Q}_6^q = \left(\bar{\hat{q}}_\alpha \hat{b}_\beta\right)_{V-A} \sum_k \left(\bar{\hat{k}}_\beta \hat{k}_\alpha\right)_{V+A},$$

$$\hat{Q}_7^q = \left(\bar{\hat{q}} \hat{b}\right)_{V-A} \sum_k \frac{3}{2} e_k \left(\bar{\hat{k}} \hat{k}\right)_{V+A}, \qquad \hat{Q}_8^q = \left(\bar{\hat{q}}_\alpha \hat{b}_\beta\right)_{V-A} \sum_k \frac{3}{2} e_k \left(\bar{\hat{k}}_\beta \hat{k}_\alpha\right)_{V+A},$$

$$\hat{Q}_9^q = \left(\bar{\hat{q}} \hat{b}\right)_{V-A} \sum_k \frac{3}{2} e_k \left(\bar{\hat{k}} \hat{k}\right)_{V-A}, \qquad \hat{Q}_{10}^q = \left(\bar{\hat{q}}_\alpha \hat{b}_\beta\right)_{V-A} \sum_k \frac{3}{2} e_k \left(\bar{\hat{k}}_\beta \hat{k}_\alpha\right)_{V-A},$$

$$\hat{Q}_{7\gamma}^q = \frac{e}{8\pi^2} m_b \bar{\hat{q}} \sigma_{\mu\nu} \left(1+\gamma_5\right) \hat{F}^{\mu\nu} \hat{b}\,, \qquad \hat{Q}_{8g}^q = \frac{g_s}{8\pi^2} m_b \bar{\hat{q}} \sigma_{\mu\nu} \left(1+\gamma_5\right) \hat{G}^{\mu\nu} \hat{b}\,.$$

New Physics at Tree Level

Strategy:

$$C_1(M_W) := C_1^{\mathrm{SM}}(M_W) + \Delta C_1(M_W),$$
$$C_2(M_W) := C_2^{\mathrm{SM}}(M_W) + \Delta C_2(M_W),$$

$$\vec{C}(\mu) = \boldsymbol{U}(\mu, M_W, \alpha)\vec{C}(M_W)\,,$$

Evolution matrix

$\mu = m_b$

$$\boldsymbol{U}(\mu, M_W, \alpha) = \Big[\boldsymbol{U}_0 + \frac{\alpha_s(\mu)}{4\pi}\boldsymbol{J}\boldsymbol{U}_0 - \frac{\alpha_s(M_W)}{4\pi}\boldsymbol{U}_0\boldsymbol{J} + \frac{\alpha}{4\pi}\Big(\frac{4\pi}{\alpha_s(\mu)}\boldsymbol{R}_0 + \boldsymbol{R}_1\Big)\Big],$$

$C_1^{SM}(m_b) \simeq -0.30$ $\qquad$ $C_2^{SM}(m_b) \simeq 1.0$

Chi^2 Fit

$$\chi^2(\vec{\omega}) = \sum_i \left(\frac{\tilde{O}_{i,\mathrm{exp}} - \tilde{O}_{i,\mathrm{theo}}(\vec{\omega})}{\sigma_{i,\mathrm{exp}}} \right)^2,$$

parameters to be fitted

$$\vec{\omega} = \left(\Delta C_1(M_W), \Delta C_2(M_W), \vec{\lambda} \right).$$

nuisance parameters

decay constants, form factors, masses, other QCD quantities, etc.

Use a likelihood ratio test.

Observables

$b \to u \bar{u} d$

$$R_{\pi\pi} = \frac{\Gamma(B^+ \to \pi^+\pi^0)}{d\Gamma(\bar{B}_d^0 \to \pi^+\ell^-\bar{\nu}_\ell)/dq^2|_{q^2=0}}$$

$\bar{B}_d^0 \to \pi^+\pi^-$

$B_d^0 \to \pi^+\pi^-$

$$S_{\pi\pi} = \frac{2\,\mathrm{Im}\left(\lambda^{\mathrm{d}}_{\pi\pi}\right)}{1+|\lambda^d_{\pi\pi}|^2}, \qquad \lambda^d_{\pi\pi} = \left[\frac{V_{td}V_{tb}^*}{|V_{td}V_{tb}^*|}\right]^2 \frac{\bar{\mathcal{A}}_{\pi^+\pi^-}}{\mathcal{A}_{\pi^+\pi^-}}.$$

$\bar{B}_d^0 \to \pi^+\rho^-$

$\bar{B}_d^0 \to \rho^+\pi^-$

$$\tilde{S}_{\pi\rho} = \frac{2\,\mathrm{Im}\left(\lambda^{\mathrm{d}}_{\pi\rho}\right)}{1+|\lambda^d_{\pi\rho}|^2}, \quad \tilde{S}_{\rho\pi} = \frac{2\,\mathrm{Im}\left(\lambda^{\mathrm{d}}_{\rho\pi}\right)}{1+|\lambda^d_{\rho\pi}|^2},$$

$$R_{\rho\rho} = \frac{\mathcal{B}r\left(B^- \to \rho_L^-\rho_L^0\right)}{\mathcal{B}r\left(\bar{B}_d^0 \to \rho_L^+\rho_L^-\right)} = \frac{\left|\mathcal{A}_{\rho^-\rho^0}\right|^2}{\left|\mathcal{A}_{\rho^+\rho^-}\right|^2},$$

Observables

$$b \rightarrow c\,\bar{u}\,d$$

$$R_{D^*\pi} = \frac{\Gamma(\bar{B}^0 \to D^{*+}\pi^-)}{d\Gamma(\bar{B}^0 \to D^{*+}l^-\bar{\nu}_l)/dq^2|_{q^2=m_\pi^2}}$$

$$b \rightarrow c\,\bar{c}\,s$$

$$\mathcal{B}r(\bar{B} \to X_s\gamma)$$

$$S_{J/\psi\phi} = \frac{2\,\mathcal{I}m\left(\lambda^s_{J/\psi\phi}\right)}{1+\left|\lambda^s_{J/\psi\phi}\right|^2}$$

$$\Delta\Gamma_s$$

$$\frac{\tau_{B_s}}{\tau_{B_d}}$$

Observables

$$b \rightarrow c\,\bar{c}\,d$$

M_{12}^{d} ⇨ $\sin(2\beta_d)$ $\mathcal{B}_r\ (\bar{B} \to X_d\gamma)$

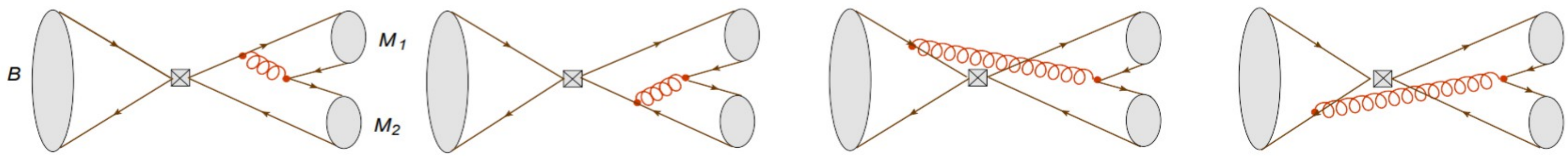
Multi-channel Observables

a_{sl}^{s} a_{sl}^{d} $\Delta\Gamma_s$

Useful for obtaining extra constraints in each transition channel and to determine maximal constraints

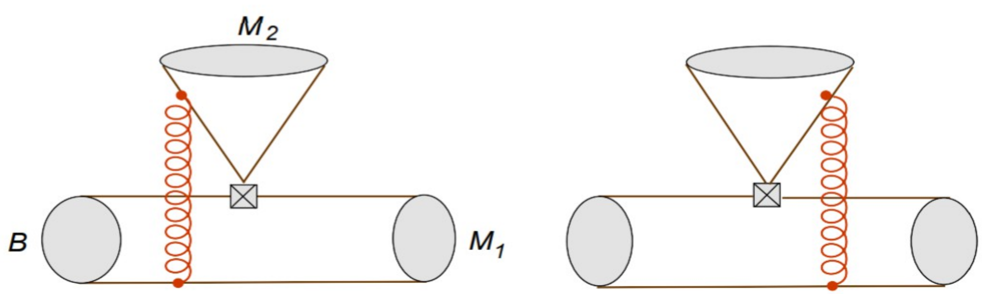
Important uncertainties in QCD-factorization

Annihilation: end-point singularities



$$X_A = \left(1 + \rho_A e^{i\phi_A}\right) \ln \frac{m_B}{\Lambda_h} \qquad 0 < \rho_A < 2\,, \quad 0 < \phi_A < 2\pi$$

Spectator-scattering: end-point singularities



$$X_H = \left(1 + \rho_H e^{i\phi_H}\right) \ln \frac{m_B}{\Lambda_h} \qquad 0 < \rho_H < 2, \qquad 0 < \phi_H < 2\pi$$

Important uncertainties in QCD-factorization

$$\bar{A}_{\pi^+\rho^-} = A_{\pi\rho}\Big(\lambda_u^{(d)}\alpha_2^{\pi\rho} + \sum_{p=u,c}\lambda_p^{(d)}\Big[\tilde{\alpha}_4^{p,\pi\rho} + \tilde{\alpha}_{4,EW}^{p,\pi\rho} + \beta_3^{p,\pi\rho} + \beta_4^{p,\pi\rho} - \frac{1}{2}\beta_{3,EW}^{p,\pi\rho} - \frac{1}{2}\beta_{4,EW}^{p,\pi\rho}\Big]\Big) + A_{\rho\pi}\Big(\lambda_u^{(d)}\beta_1^{\rho\pi} + \sum_{p=u,c}\lambda_p^{(d)}\Big[\beta_4^{p,\rho\pi} + \beta_{4,EW}^{p,\rho\pi}\Big]\Big),$$

Individual annihilation topological amplitudes are of O(5%)

The total effect in the uncertainty of the observables can be Important if the Amplitudes depend on several of them.

Example: $R_{\rho\rho}$

$$R_{\rho\rho} = \frac{\mathcal{B}r\left(B^- \to \rho_L^- \rho_L^0\right)}{\mathcal{B}r\left(\bar{B}_d^0 \to \rho_L^+ \rho_L^-\right)}$$

$$\mathcal{A}_{\rho^-\rho^0} = \frac{A_{\rho\rho}}{\sqrt{2}}\left[\lambda_u^{(d)}\left(\alpha_1^{\rho\rho} + \alpha_2^{\rho\rho}\right) + \frac{3}{2}\sum_{p=u,c}\lambda_p^{(d)}\left(\alpha_7^{p,\rho\rho} + \alpha_9^{p,\rho\rho} + \alpha_{10}^{p,\rho\rho}\right)\right],$$

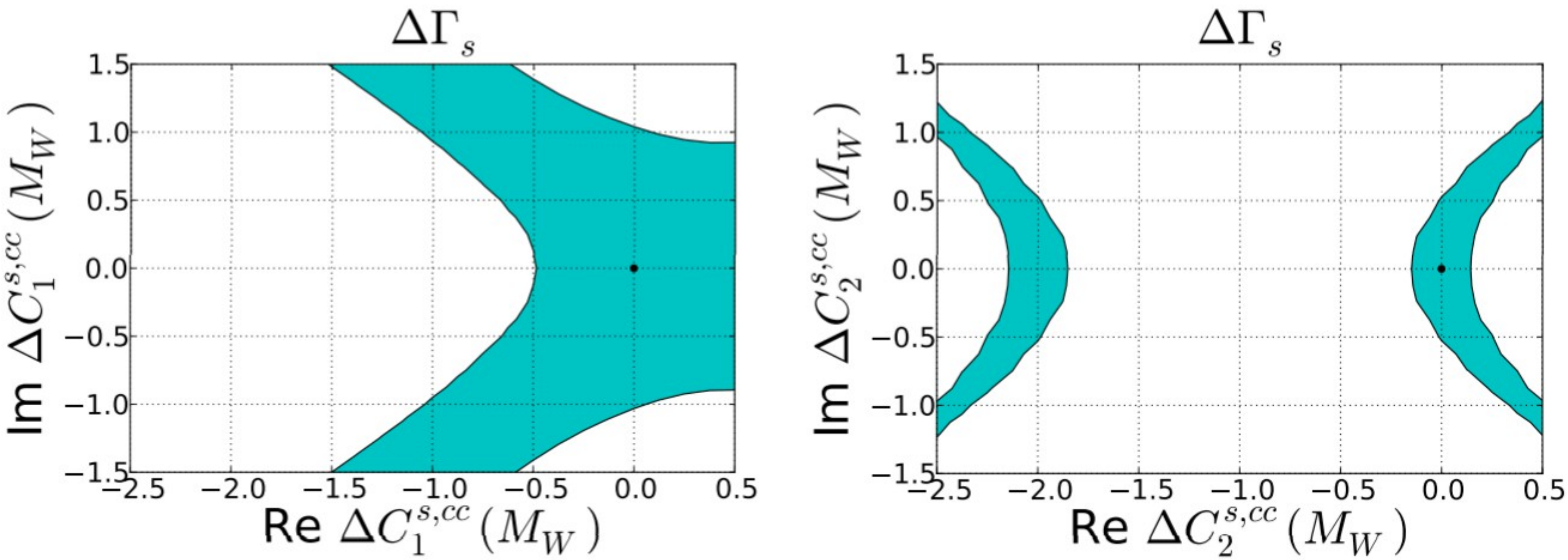
$$\mathcal{A}_{\rho^+\rho^-} = A_{\rho\rho}\left[\lambda_u^{(d)}\left(\alpha_2^{\rho\rho} + \beta_2^{\rho\rho}\right) + \sum_{p=u,c}\lambda_p^{(d)}\left(\alpha_4^{p,\rho\rho} + \alpha_{10}^{p,\rho\rho} + \beta_3^{p,\rho\rho} + 2\beta_4^{p,\rho\rho} - \frac{1}{2}\beta_{3,EW}^{p,\rho\rho} + \frac{1}{2}\beta_{4,EW}^{p,\rho\rho}\right)\right].$$

Parameter	Relative Error
X_A	26.40%
X_H	23.33%
λ_B	12.32%
μ	6.78%
$A_0^{B\to\rho}$	2.54%
a_2^ρ	2.24%
f_ρ	0.46%
Λ_5^{QCD}	0.45%
γ	0.38%
m_b	0.27%
f_B	0.15%
$f_\rho^\perp$	0.15%
m_c	0.12%
Total	38.09%

$$R_{\rho\rho}^{\mathrm{SM}} = \left(67.5 \pm 25.7\right)\cdot 10^{-2}$$

$$R_{\rho\rho}^{\mathrm{Exp}} = \left(83.14 \pm 8.98\right)\cdot 10^{-2}$$

Determination of the allowed NP regions per observable

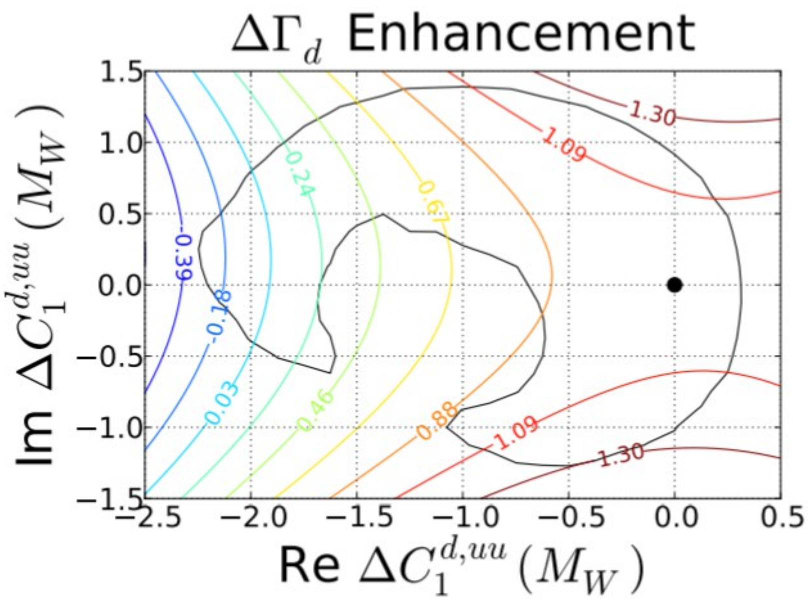


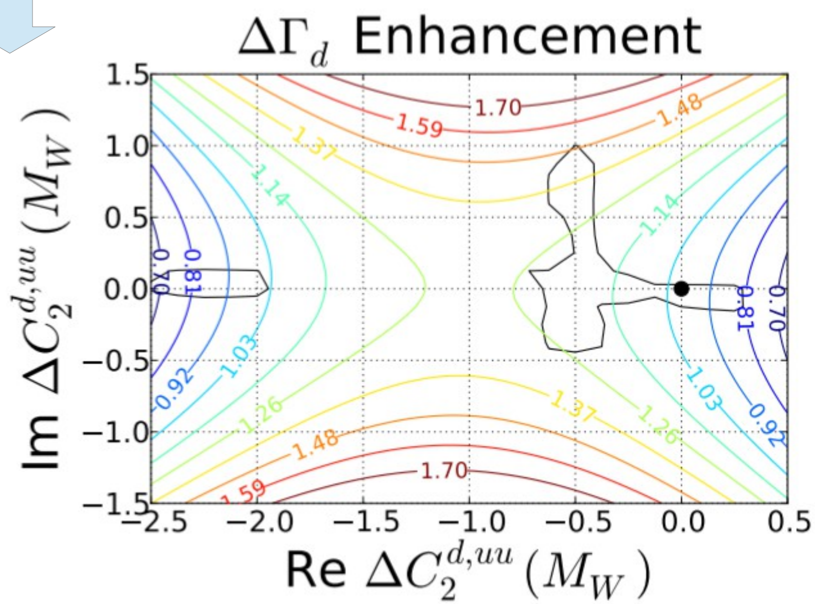
Turn on one coefficient at a time.

Assume complex NP contribution to the tree-level Wilson coefficients.

Perform the fit per b quark level transition

b--> u $\bar{u}$ d





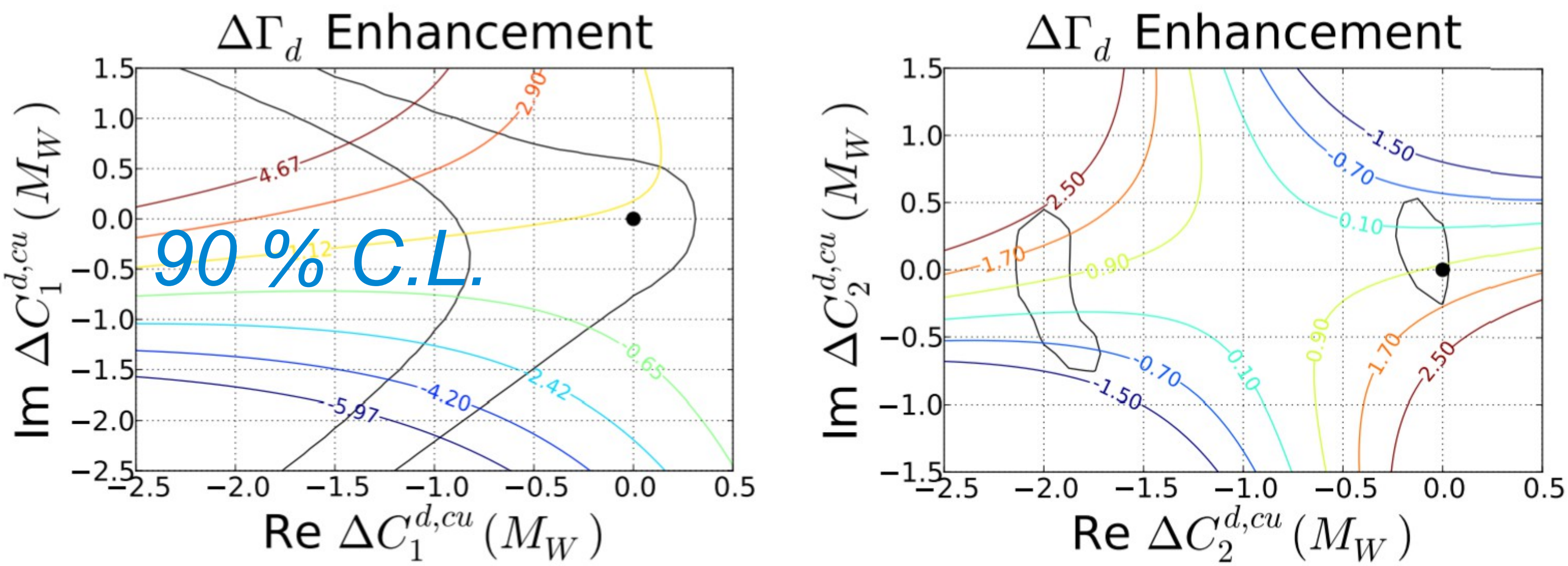
In general we find variations of O(1) in the NP contributions per quark level transition

Implications in mixing

$$\Delta\Gamma_d^{\rm Exp} = \left(-1.3 \pm 6.6\right)\cdot 10^{-3}\ {\rm ps}^{-1} \qquad \Delta\Gamma_d^{\rm SM} = \left(2.6 \pm 0.4\right)\cdot 10^{-3}\ {\rm ps}^{-1}$$

HFLAV: 1612.07233

NP in Tree-Level can lead to enhancements in $\Delta\Gamma_d$



$$\text{for } \Delta C_1^{d,cu}(M_W): \quad -5.97 < \Delta\Gamma_d/\Delta\Gamma_d^{\rm SM} < 4.67,$$
$$\text{for } \Delta C_2^{d,cu}(M_W): \quad -1.5 < \Delta\Gamma_d/\Delta\Gamma_d^{\rm SM} < 2.50.$$

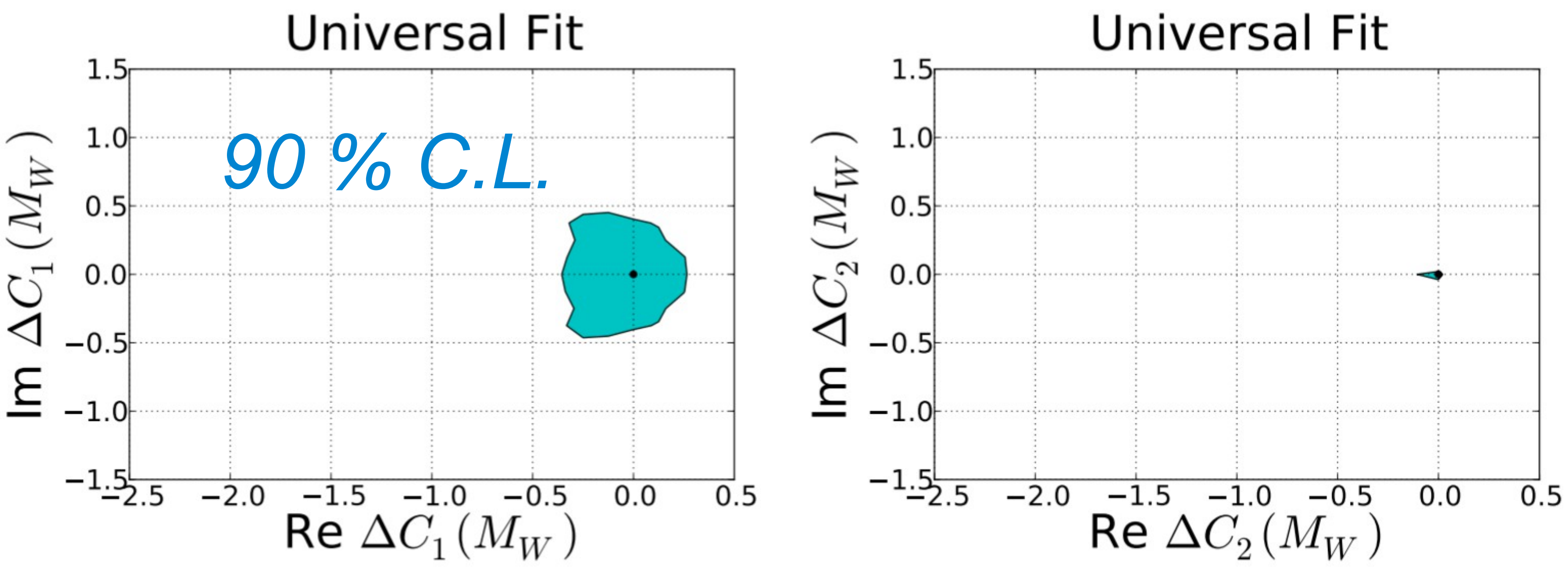
Saturates bounds ,
Use it to constrain NP in Tree

Universal Fit

Obtain maximal NP constraints by taking

$$\Delta C_1^{s,ab}(M_W) = \Delta C_1^{d,ab}(M_W) = \Delta C_1(M_W)$$
$$\Delta C_2^{s,ab}(M_W) = \Delta C_2^{d,ab}(M_W) = \Delta C_2(M_W)$$

for $a = u, c$ and $b = u, c$



Universal Fit

90 % C.L. Regions

$$\mathrm{Re}\left[\Delta C_1(M_W)\right]\Big|_{\min} = -0.36, \quad \mathrm{Im}\left[\Delta C_1(M_W)\right]\Big|_{\min} = -0.47,$$

$$\mathrm{Re}\left[\Delta C_1(M_W)\right]\Big|_{\max} = 0.26, \quad \mathrm{Im}\left[\Delta C_1(M_W)\right]\Big|_{\max} = 0.45,$$

$$\mathrm{Re}\left[\Delta C_2(M_W)\right]\Big|_{\min} = -0.11, \quad \mathrm{Im}\left[\Delta C_2(M_W)\right]\Big|_{\min} = -0.04,$$

$$\mathrm{Re}\left[\Delta C_2(M_W)\right]\Big|_{\max} = 0.02, \quad \mathrm{Im}\left[\Delta C_2(M_W)\right]\Big|_{\max} = 0.02.$$

Impact on the CKM angle γ

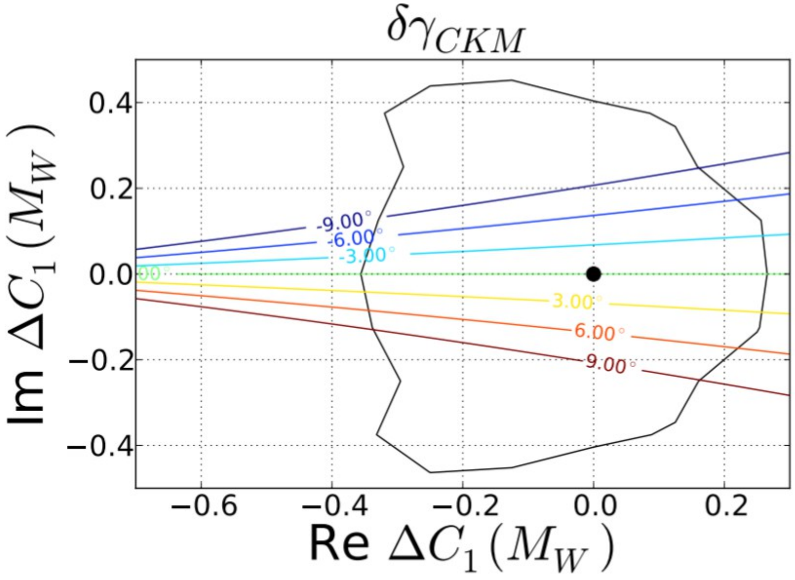
Sensibility to NP in Tree-Level

$$\delta\gamma = (r_A - r_{A'}) \frac{\mathrm{Im}\,[\Delta \mathrm{C}_1]}{C_2}$$

Large uncertainties in the ratios

$$r_{A'} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{u}cs} | B^- \rangle}{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle},$$

$$r_A = \frac{\langle D^0 K^- | Q_1^{\bar{c}us} | B^- \rangle}{\langle D^0 K^- | Q_2^{\bar{c}us} | B^- \rangle}$$

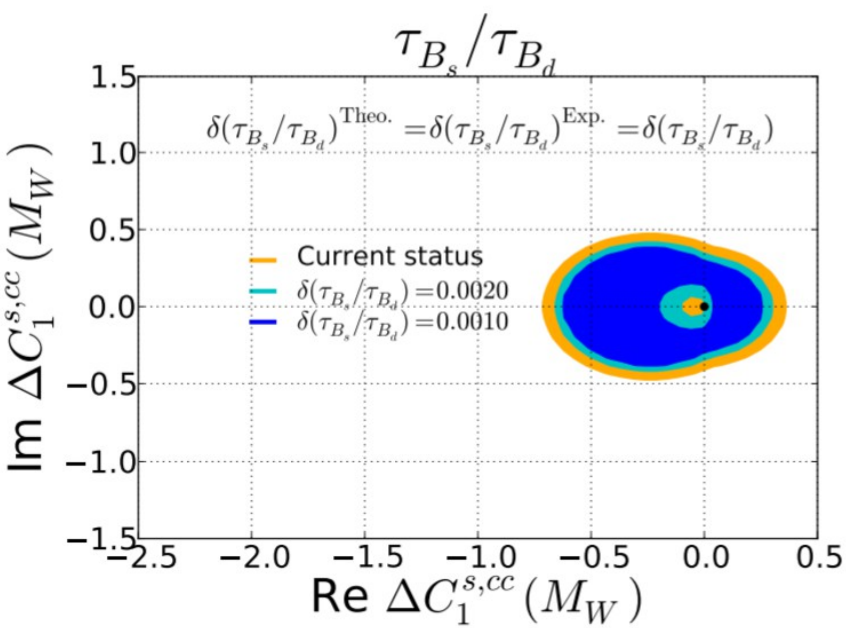


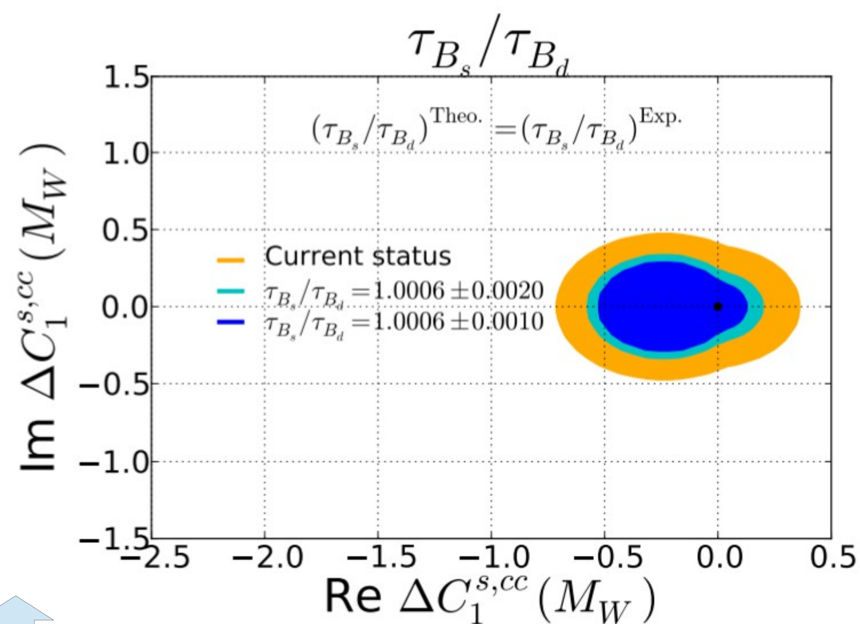
Reduce $\mathrm{Im}\,[\Delta \mathrm{C}_1]$ *to minimize potential effects in* γ

Effect of the Life-time ratio

$$\left(\frac{\tau_{B_s}}{\tau_{B_d}}\right)^{\text{Exp}} = 0.994 \pm 0.004 \qquad \left(\frac{\tau_{B_s}}{\tau_{B_d}}\right)^{\text{SM}} = 1.0006 \pm 0.0020$$

HFLAV: 1612.07233 *Kirk, Lenz and Rauh: 1711.02100*

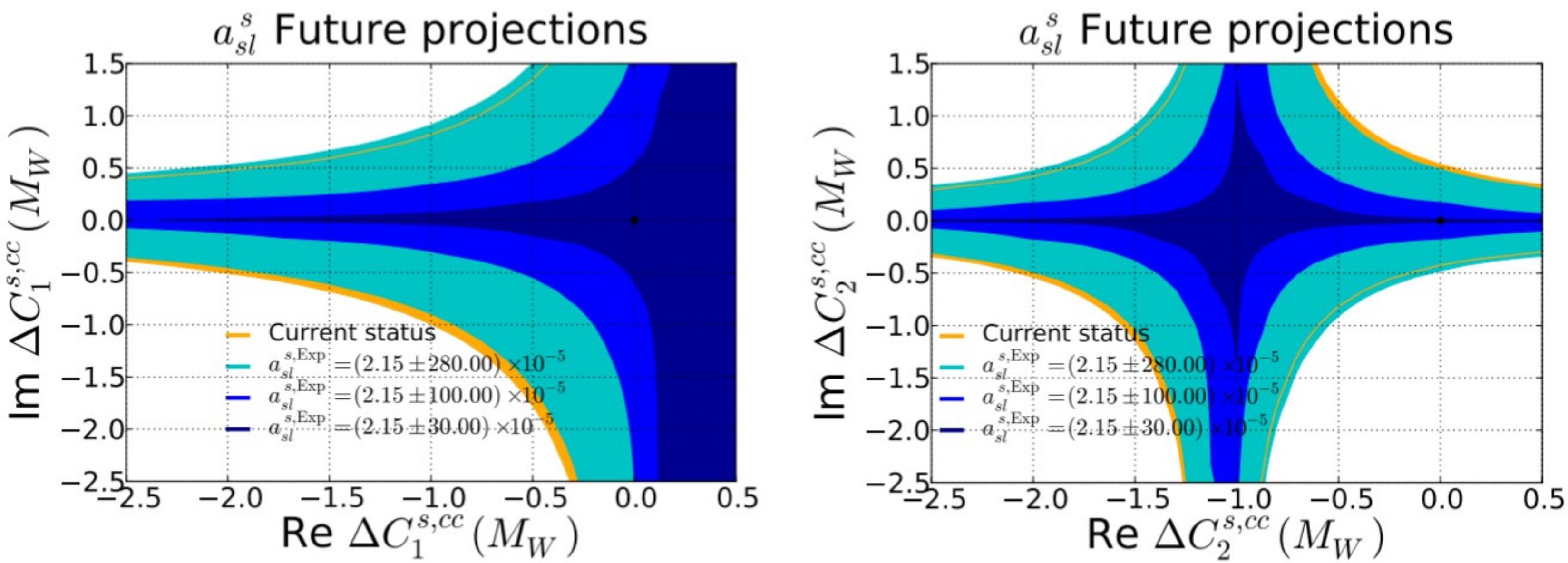




Impact of the uncertainty

To be updated soon....

Semileptonic Asymmetries



$a_{sl}^{s,\mathrm{SM}} = \left(2.06 \pm 0.18\right) \cdot 10^{-5}$ $a_{sl}^{s,\mathrm{Exp}} = \left(60 \pm 280\right) \cdot 10^{-5}$ *HFLAV: 1612.07233*

projections for the uncertainty

$$\delta\left(a_{sl}^s\right) = 1 \cdot 10^{-3} \qquad \text{LHCb 2025}$$

$$\delta\left(a_{sl}^s\right) = 3 \cdot 10^{-4} \qquad \text{Upgrade II}$$

Closing Remarks

- *Deviations with respect to the SM on the tree-level Wilson coefficients C_1 and C_2 are allowed by* current theoretical and experimental results in *flavour observables.*

- The deviations on *C_1 can be as sizeable as 40%.*

- *Potential enhancements in the observable* $\Delta\Gamma_d$

- Potential sizeable effects on the uncertainty of CKM γ .

- *Updates on mixing observables and the neutral B meson life-time ratio play a central role in reducing the size of the deviations on C_1 and C_2.*