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

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Based on:

A. Lenz, GTX : 1912.07621 / JHEP07(2020)177

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Operator Basis

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

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

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

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

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

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

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

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

New Physics at Tree Level

Strategy

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

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

$\mu = m_b$

Evolution matrix

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

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

Chi^2 Fit

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

parameters to be fitted

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

nuisance parameters

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

Use a likelihood ratio test assuming the validity of Wilks theorem.

Observables

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

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

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

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

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

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

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

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

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

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

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

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

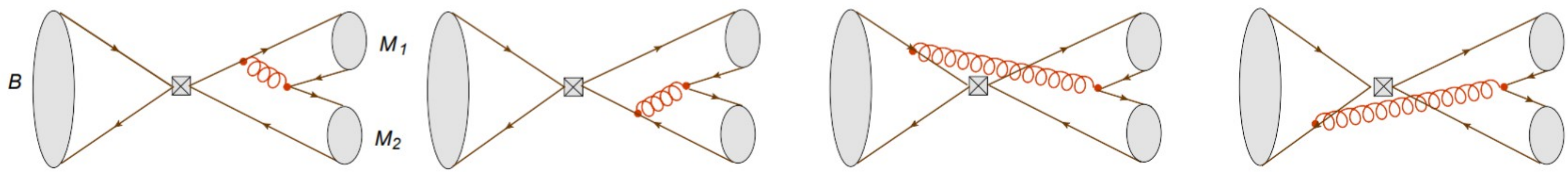
Multi-channel Observables

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

Useful for obtaining maximal constraints

Important uncertainties in QCD-factorization

Annihilation end-point singularities



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

Can play an important role in the determination of the uncertainties of some of our observables.

Important uncertainties in QCD-factorization

$$\bar{A}_{\pi^+\rho^-} = A_{\pi\rho}\Big(\lambda_u^{(d)}\alpha_2^{\pi\rho} + \sum_{p=u,c}\lambda_p^{(d)}\Big[\tilde{\alpha}_4^{p,\pi\rho} + \tilde{\alpha}_{4,EW}^{p,\pi\rho}$$

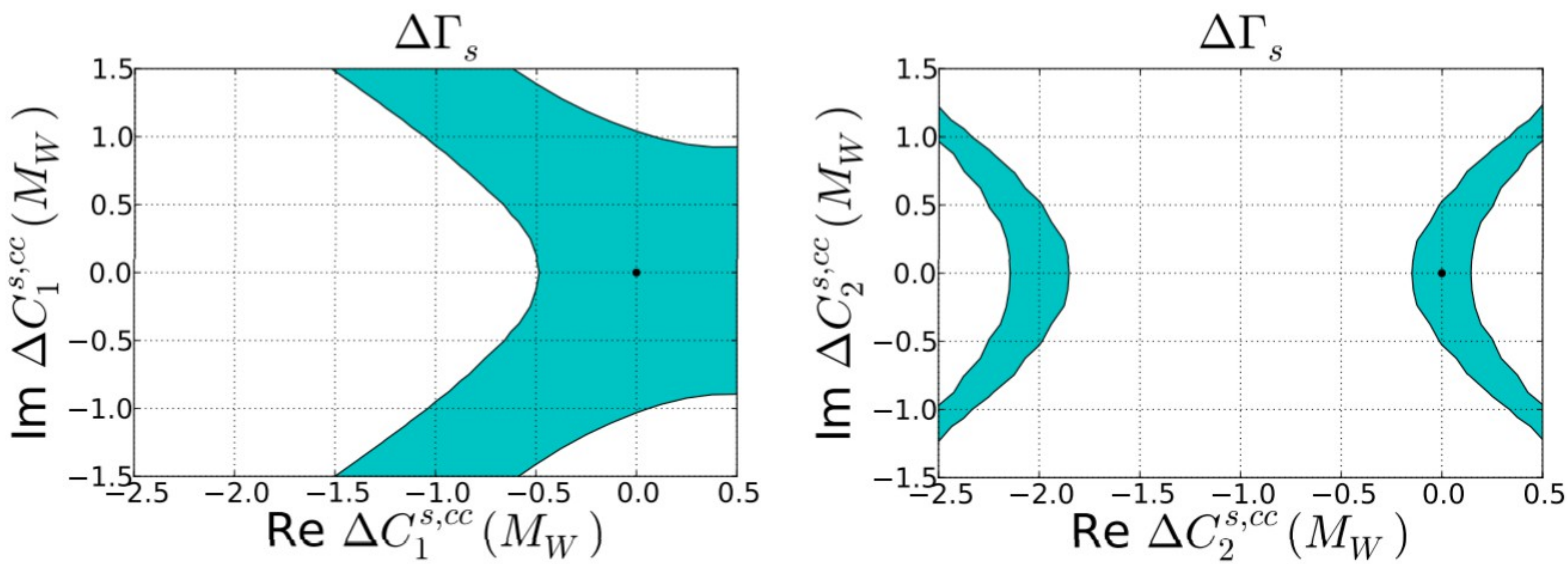
$$+ \beta_3^{p,\pi\rho} + \beta_4^{p,\pi\rho} - \frac{1}{2}\beta_{3,EW}^{p,\pi\rho} - \frac{1}{2}\beta_{4,EW}^{p,\pi\rho}\Big]\Big)$$

$$+ A_{\rho\pi}\Big(\lambda_u^{(d)}\beta_1^{\rho\pi} + \sum_{p=u,c}\lambda_p^{(d)}\Big[\beta_4^{p,\rho\pi} + \beta_{4,EW}^{p,\rho\pi}\Big]\Big),$$

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.

Determination of the allowed NP regions per observable

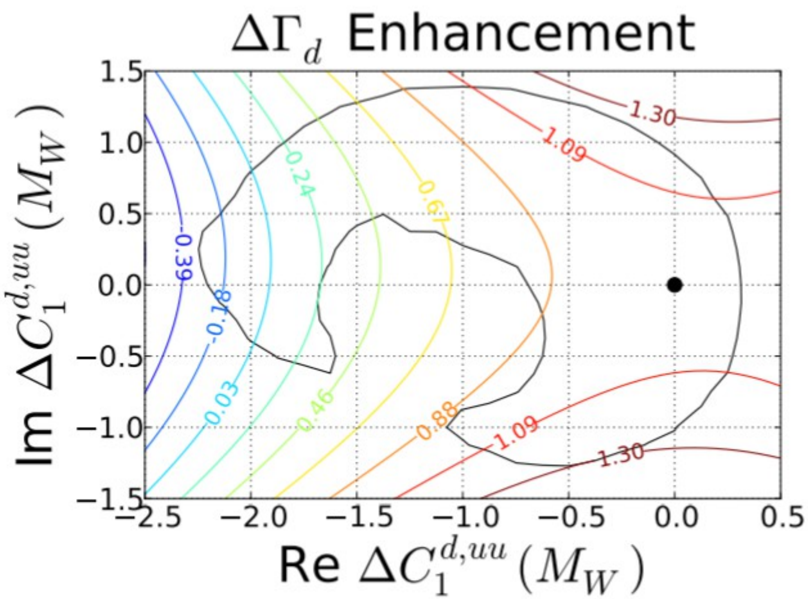


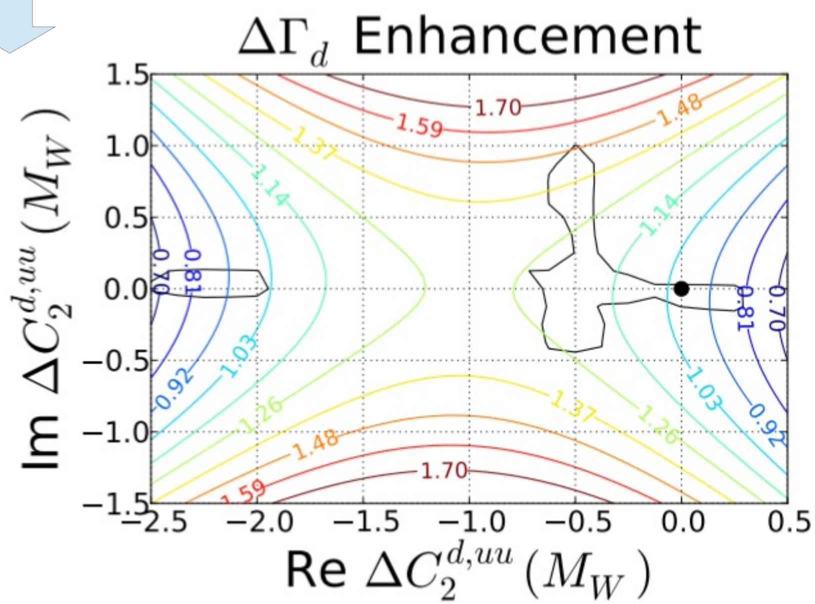
Turn on one coefficient at a time.

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

Perform the fit per b quark level transition

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





variations of O(1) in the NP contributions

$$-5.97 < \Delta\Gamma_d/\Delta\Gamma_d^{\rm SM} < 4.67,$$

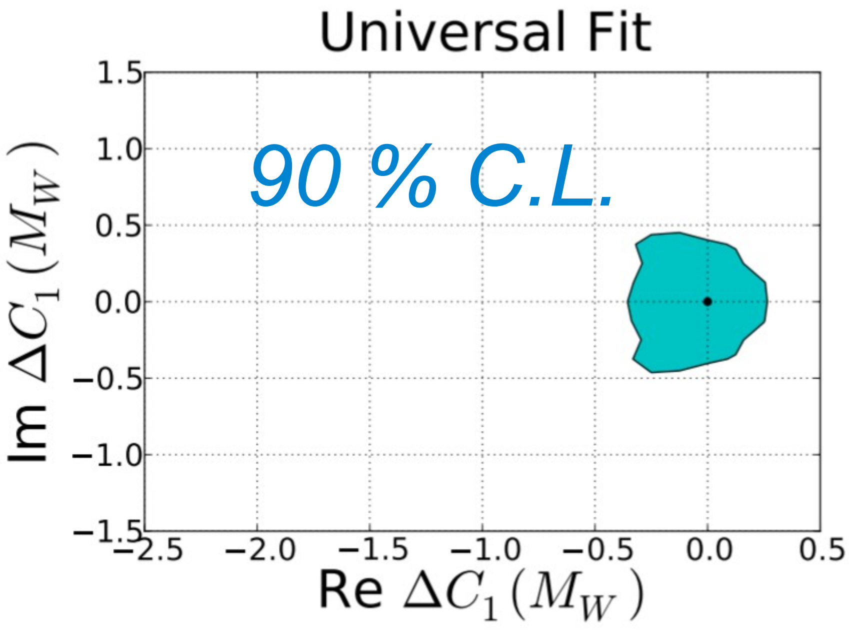
b--> c $\bar{u}$ d

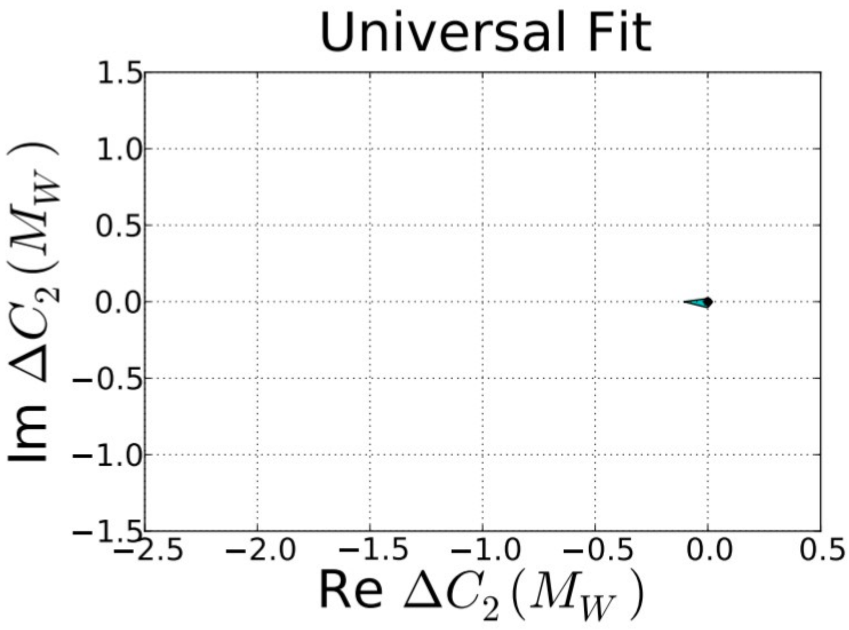
Universal Fit

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

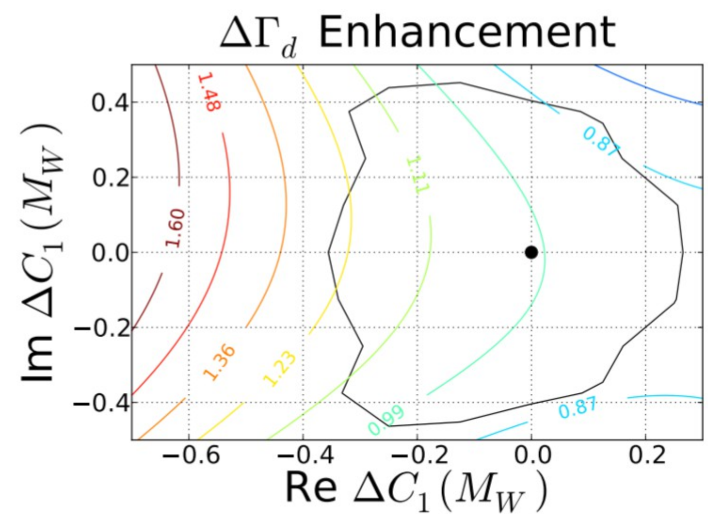
90 % C.L. Regions

$$\mathrm{Re}\left[\Delta C_1(M_W)\right]\Big|_{\min} = -0.36,\quad \mathrm{Im}\left[\Delta C_1(M_W)\right]\Big|_{\min} = -0.47,$$
$$\mathrm{Re}\left[\Delta C_1(M_W)\right]\Big|_{\max} = \ \ 0.26,\quad \mathrm{Im}\left[\Delta C_1(M_W)\right]\Big|_{\max} = \ \ 0.45,$$

$$\mathrm{Re}\left[\Delta C_2(M_W)\right]\Big|_{\min} = -0.11,\quad \mathrm{Im}\left[\Delta C_2(M_W)\right]\Big|_{\min} = -0.04,$$
$$\mathrm{Re}\left[\Delta C_2(M_W)\right]\Big|_{\max} = \ \ 0.02,\quad \mathrm{Im}\left[\Delta C_2(M_W)\right]\Big|_{\max} = 0.02.$$

Impact on other Observables

$\Delta\Gamma_d$

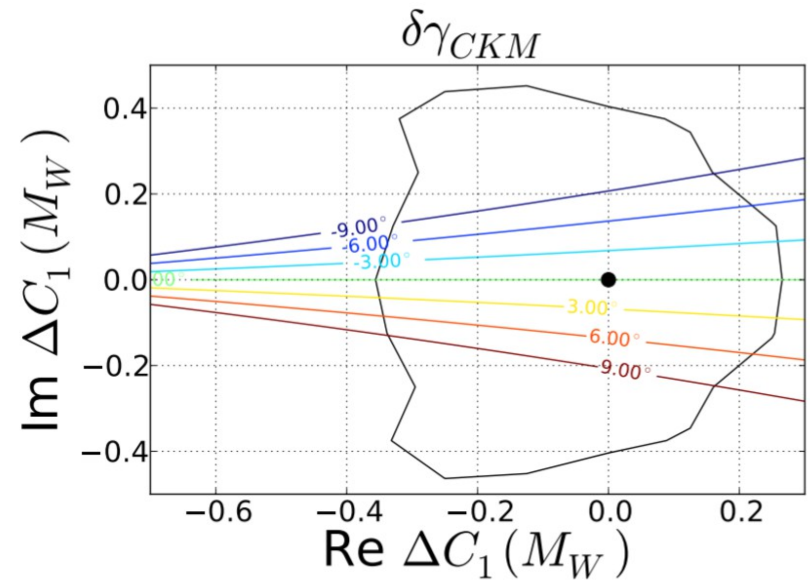


CKM angle γ

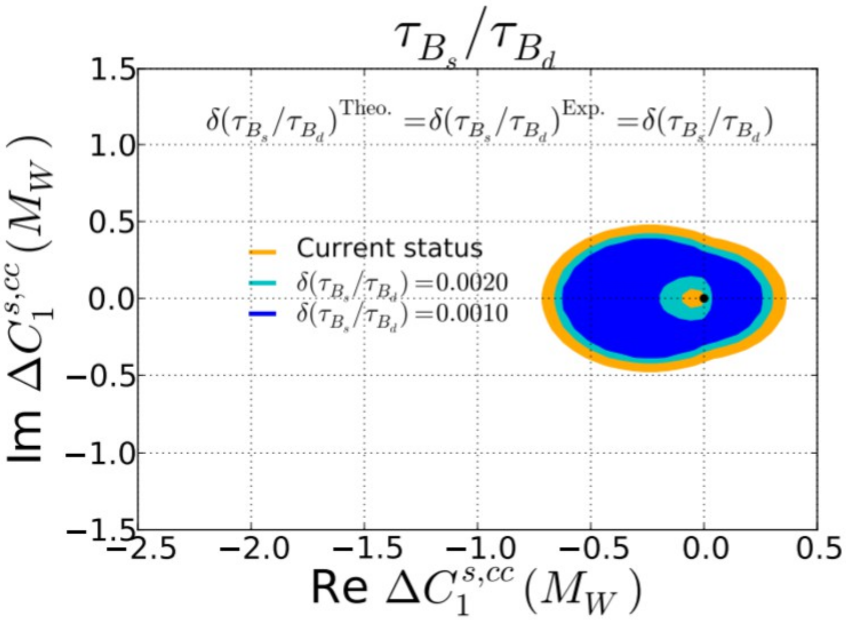
$$r_{A'} = \frac{\langle \bar{D}^0 K^- | Q_1^{\bar{u}cs} | B^- \rangle}{\langle \bar{D}^0 K^- | Q_2^{\bar{u}cs} | B^- \rangle},$$

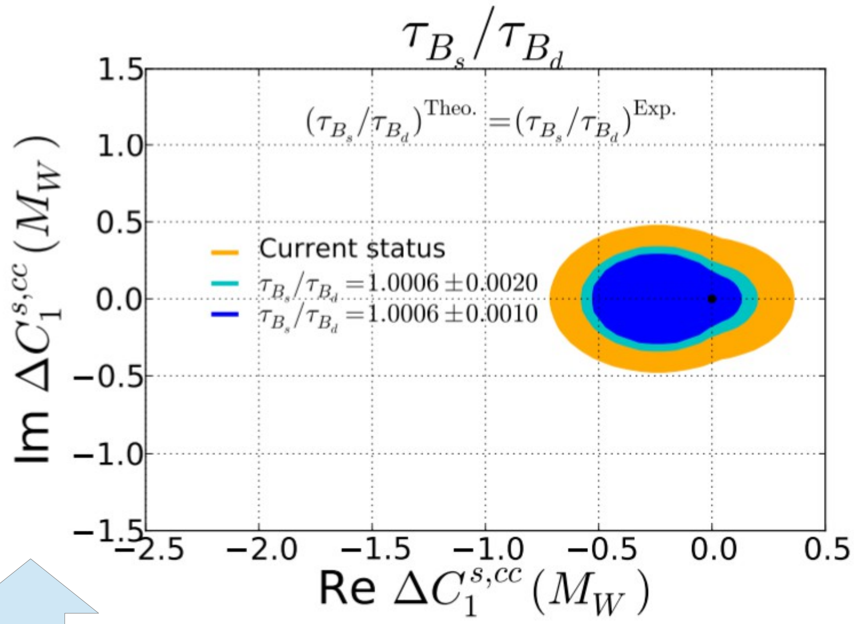
$$r_A = \frac{\langle D^0 K^- | Q_1^{\bar{c}us} | B^- \rangle}{\langle D^0 K^- | Q_2^{\bar{c}us} | B^- \rangle}$$

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



Effect of the Life-time ratio

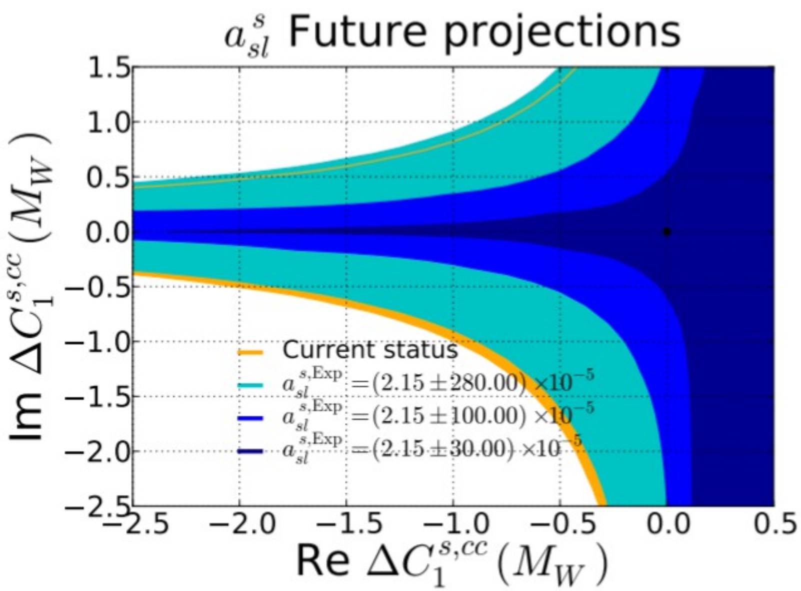


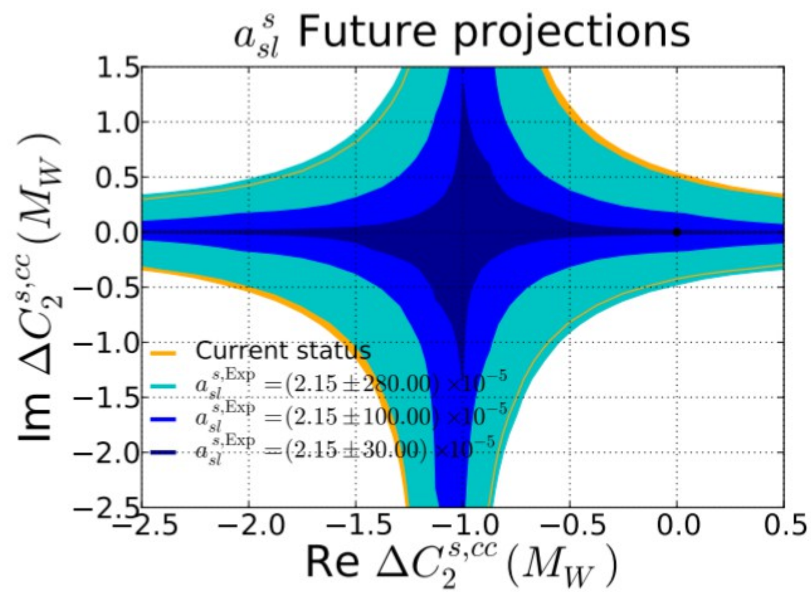


Impact of the uncertainty

To be updated soon....

Semileptonic Asymmetries





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 the CKM angle gamma. .

- *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.*