

# Limiting NP in tree level non leptonic decays

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# Why new Physics at Tree Level?

- Based on the data available there is plenty of room for SM deviations.
- NP effects in semileptonic tree level transitions  $b \rightarrow c\ell\nu$ :

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\nu)}{\mathcal{B}(B \rightarrow D^{(*)}\ell\nu)}$$

BABAR + LHCb + Belle combination 3.9  $\sigma$  deviation with respect to the SM.

*Amhis et al. (2016), arXiv:1612.07233 [hep-ex]*

- NP effects in non leptonic  $b$  decays to:

Address the 2010 [D0 dimuon asymmetry](#)

*Bauer and Dunn, Phys. Lett. B 696 (2011) 362, arXiv:106.1629 [hep-ph]*

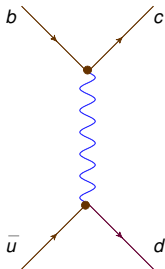
Evaluate enhancements in  [\$\Delta\Gamma\_d\$](#)

*Bobeth, Haisch, Lenz, Pecjak and T-X, JHEP 1406 (2014) 040, arXiv: 1404.2534 [hep-ph]*

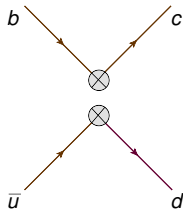
Determine the impact on the determination of the [CKM angle  \$\gamma\$](#)

*Brod, Lenz, T-X, Wiebusch, Phys. Rev. D.92 (2015) no. 3, 033002, arXiv: 1412.1446 [hep-ph]*

# Effective field theory formalism



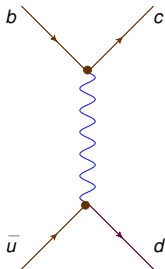
$$\hat{Q}_1 = (\bar{c}_\alpha b_\beta)_{V-A} (\bar{d}_\beta u_\alpha)_{V-A}$$



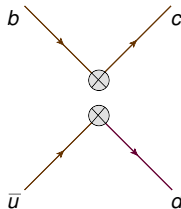
$$\hat{Q}_2 = (\bar{c}_\alpha b_\alpha)_{V-A} (\bar{d}_\beta u_\beta)_{V-A}$$

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \left( \sum_{p,p'=u,c} \lambda_{pp'}^s \sum_{i=1,2} C_i^{pp'}(\mu) \hat{Q}_i^{pp'} \right)$$

# Effective field theory formalism



$$\hat{Q}_1 = (\bar{c}_\alpha b_\beta)_{V-A} (\bar{d}_\beta u_\alpha)_{V-A}$$



$$\hat{Q}_2 = (\bar{c}_\alpha b_\alpha)_{V-A} (\bar{d}_\beta u_\beta)_{V-A}$$

$$\begin{aligned} \mathcal{H}_{\text{eff}} = & \frac{G_F}{\sqrt{2}} \left( \sum_{p,p'=u,c} \lambda_{pp'}^s \sum_{i=1,2} C_i^{pp'}(\mu) \hat{Q}_i^{pp'} \right. \\ & \left. + \sum_{p=u,c} \lambda_p^s \sum_{i=3}^{10} C_i(\mu) \hat{Q}_i + C_{7\gamma} \hat{Q}_{7\gamma} + C_{8g} \hat{Q}_{8g} \right) + h.c., \end{aligned}$$

$$\lambda_p^s = V_{pb} V_{ps}^* \quad \lambda_{pp'}^s = V_{pb} V_{p's}^*$$

# New Physics effects

$$C_{1,2}^{SM} \rightarrow C_{1,2}^{SM} + \Delta C_{1,2}.$$

New Physics effects are propagated to the other coefficients through the R.G.E

$$\mu \frac{d\vec{C}}{d\mu} = \hat{\gamma}^T \vec{C}. \quad \vec{C}(\mu) = \hat{U}(\mu, \mu_W, \alpha) \vec{C}(M_W)$$

To assess the size of  $\Delta C_{1,2}$  we perform a  $\chi$ -squared fit using MyFitter  
*M. Wiebusch, Comput. Phys. Commun. 184 (2013) 2438.*

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

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

$\vec{\lambda}$ : CKM parameters,  $\mu, f_\pi, \dots \Rightarrow$  nuisance parameters.

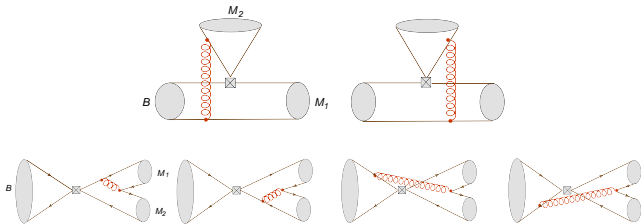
# Power corrections

Different observables associated with the decays:  $B \rightarrow \pi\pi, \rho\pi, \rho\rho, D^*\pi, J/\psi K_{S,L}$   
 Introduce the amplitudes obtained using QCD factorization

$$\langle M_1 M_2 | \hat{Q}_i | B \rangle = \sum_j F_j^{B \rightarrow M_1}(0) \int_0^1 du T_{ij}^I(u) \Phi_{M_2}(u) + (M_1 \leftrightarrow M_2) \\
 + \int_0^1 d\xi du dv T_i^{II}(\xi, u, v) \Phi_B(\xi) \Phi_{M_1}(v) \Phi_{M_2}(u) + \mathcal{O}\left(\frac{\Lambda_{QCD}}{m_b}\right).$$

Important source of uncertainties from non-factorizable contributions: Hard spectator scattering and Annihilation topologies

$$X_H = \left(1 + \rho_H e^{i\phi_H}\right) \ln \frac{m_B}{\Lambda_h} \quad X_A = \left(1 + \rho_A e^{i\phi_A}\right) \ln \frac{m_B}{\Lambda_h} \quad \int_0^1 d\xi \frac{\Phi_B(\xi)}{\xi} \equiv \frac{m_B}{\lambda_B}$$



# Power corrections

Parameter	Standard analysis
$\delta(\mu)$	3.87%
$\delta(A_5)$	1.10%
$\delta(m_t(m_t))$	0.01%
$\delta(m_c)$	0.06%
$\delta(m_s)$	1.45%
$\delta(m_b)$	0.58%
$\delta( V_{us} )$	0.47%
$\delta( V_{cb} )$	0.01%
$\delta( V_{ub}/V_{cb} )$	10.22%
$\delta(\gamma)$	44.67%
$\delta(f_B)$	0.24%
$\delta(f_\pi)$	0.02%
$\delta(\alpha_{2\pi})$	0.12%
$\delta(F_0^{B \rightarrow \pi})$	1.97%
$\delta(\lambda_B)_\pm$	1.55%
$\delta(X_H)^{max}$	2.67%
$\delta(X_A)^{max}$	62.96%
$(\sum \delta)_1$	46.10%
$\sum \delta$	78.08%

$$S_{\pi\pi} = \frac{2\text{Im} \left( e^{-2i\beta} \frac{\bar{A}_{\pi^+\pi^-}}{A_{\pi^+\pi^-}} \right)}{1 + \left| \frac{\bar{A}_{\pi^+\pi^-}}{A_{\pi^+\pi^-}} \right|^2}$$

# Decay transitions

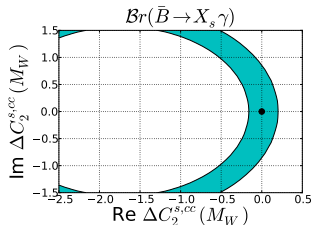
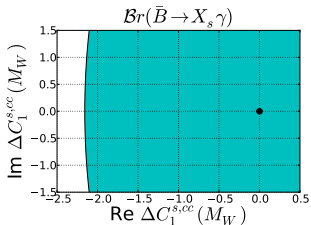
$$b \rightarrow u\bar{u}d : B \rightarrow \pi\pi, B \rightarrow \pi\rho, B \rightarrow \rho\rho$$

$$b \rightarrow c\bar{u}d : B \rightarrow D^*\pi, B \rightarrow D^*\eta, B \rightarrow D^*\omega$$

$$b \rightarrow c\bar{c}d : B \rightarrow X_d\gamma$$

$$b \rightarrow c\bar{c}s : B \rightarrow X_s\gamma, B \rightarrow J/\psi K$$

Probe for New weak phases by allowing  $\Delta C_1$  and  $\Delta C_2$  to be complex





## Multiple channel constraints

$$i \frac{d}{dt} \begin{pmatrix} |B^0(t)\rangle \\ |\bar{B}^0(t)\rangle \end{pmatrix} = \hat{\mathcal{H}} \begin{pmatrix} |B^0(t)\rangle \\ |\bar{B}^0(t)\rangle \end{pmatrix} \quad \begin{aligned} \Delta M &= M_H - M_L, \\ \Delta \Gamma &= \Gamma_L - \Gamma_H. \end{aligned}$$

$$\hat{\mathcal{H}} = \begin{pmatrix} M_{11} - \frac{i}{2}\Gamma_{11} & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* - \frac{i}{2}\Gamma_{12}^* & M_{11} - \frac{i}{2}\Gamma_{11} \end{pmatrix},$$

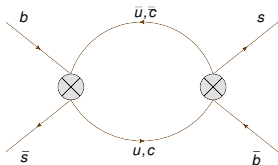
$$i \frac{d}{dt} \begin{pmatrix} |B_H(t)\rangle \\ |B_L(t)\rangle \end{pmatrix} = \begin{pmatrix} \lambda_H & 0 \\ 0 & \lambda_L \end{pmatrix} \begin{pmatrix} |B_H(t)\rangle \\ |B_L(t)\rangle \end{pmatrix}.$$

$$\lambda_H = M_H - \frac{i}{2}\Gamma_H,$$

$$\Delta M = M_H - M_L,$$

$$\lambda_L = M_L - \frac{i}{2}\Gamma_L,$$

$$\Delta \Gamma = \Gamma_L - \Gamma_H.$$



$$a_s^{sl} = |\Gamma_{12}| / |M_{12}| \sin \phi_{12}, \quad \Delta \Gamma_s: b \rightarrow u\bar{u}s, b \rightarrow u\bar{c}s, b \rightarrow c\bar{c}s$$

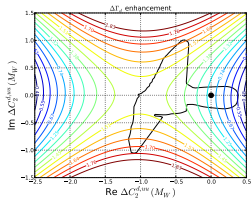
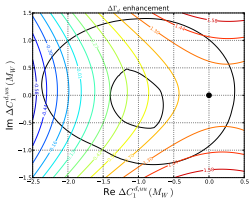
$$a_d^{sl}: b \rightarrow u\bar{u}d, b \rightarrow u\bar{c}d, b \rightarrow c\bar{c}d$$

# Implications on $\Delta\Gamma_d$

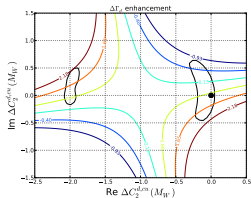
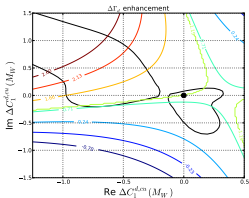
$$-3.91 < \Delta\Gamma_{d;exp}/\Delta\Gamma_{d;SM} < 2.60$$

$(\Delta\Gamma_d/\Gamma_d)_{exp}$  from HFAG, online update 2017

$$b \rightarrow u\bar{u}d: 0 < \Delta\Gamma_d/\Delta\Gamma_{d;SM} < 1.76$$

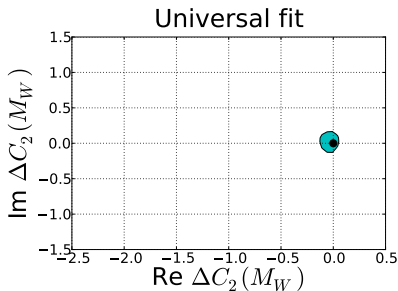
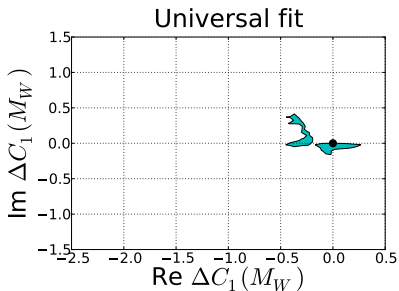


$$b \rightarrow c\bar{u}d: -0.93 < \Delta\Gamma_d/\Delta\Gamma_{d;SM} < 2.60$$



# Universal Tree level bounds

$$\text{Assume } \Delta C_{1,2} = \Delta C_{1,2}^{uu} = \Delta C_{1,2}^{cu} = \Delta C_{1,2}^{cc}$$



# Effects on CKM $\gamma$

The CKM angle  $\gamma$  can be extracted from

$$r_B e^{i(\delta_B - \gamma)} = \frac{A(B^- \rightarrow \bar{D}^0 K^-)}{A(B^- \rightarrow D^0 K^-)}$$

New physics effects in  $C_1$  and  $C_2$  modify  $r_B e^{i(\delta_B - \gamma)}$  as

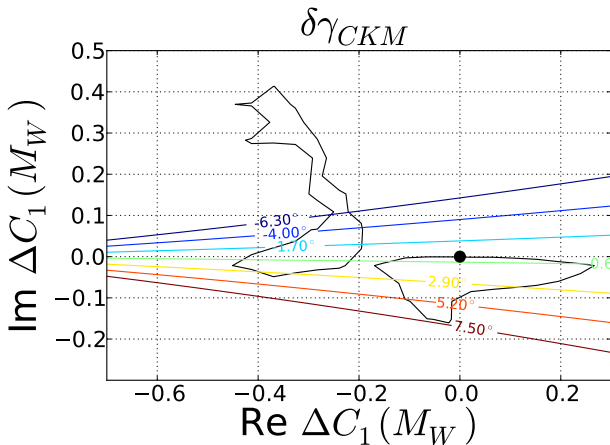
$$r_B e^{i(\delta_B - \gamma)} \rightarrow r_B e^{i(\delta_B - \gamma)} \cdot \left[ \frac{C_2 + \Delta C_2 + r_{A'}(C_1 + \Delta C_1)}{C_2 + r_{A'} C_1} \frac{C_2 + r_A C_1}{C_2 + \Delta C_2 + r_A(C_1 + \Delta C_1)} \right].$$

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

$$r_B e^{i(\delta_B - \gamma)} \rightarrow r_B e^{i(\delta_B - \gamma)} \cdot \left[ 1 + (r_{A'} - r_A) \frac{\Delta C_1}{C_2} \right]$$

$$\delta\gamma = (r_A - r_{A'}) \frac{\text{Im}\Delta C_1}{C_2}$$

# Effects on CKM $\gamma$



$$\gamma = 72.1^\circ \pm \delta\gamma \quad -5.8^\circ < \delta\gamma < 5.4^\circ$$

CKMfitter online update 2018

Use CKM  $\gamma$  to bound  $\Delta C_1$

# Conclusions and outlook

- New Physics in tree level non leptonic can be sizeable.
- Colour suppressed  $\Delta C_1$ :  $Re \Delta C_1 \approx 0.20$ ,  $Im \Delta C_1 \approx 0.40$
- $\Delta \Gamma_d$  can be enhanced by a factor of 2.6 with respect to the SM
- $\Delta C_1, \Delta C_2$  affected by: power corrections, renormalization scale, CKM parameters,...
- CKM  $\gamma$  is sensitive to  $Im \Delta C_1$
- Reduce the size of  $Im \Delta C_1$  using  $\sin 2\beta$ :  $A_{B \rightarrow J/\psi K_S}$  ?