Review of New Physics in non-leptonic tree level B meson decays

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Status and prospects of Non-leptonic B meson decays
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Summary

- Exp. vs SM
  - Talked about what we mean by SM
- For the most part, SM agrees decently
  - But not entirely, e.g. $B \to DK$, $B \to D\pi$
  - Other places where large errors make it hard to tell

Can it be NP?

- Typically think of BSM competing with SM loop level
  - $G_F/4\pi^2 \approx 1/(2\,\mathrm{TeV})^2$
- But various places where NP can be hiding in plain sight

Topics

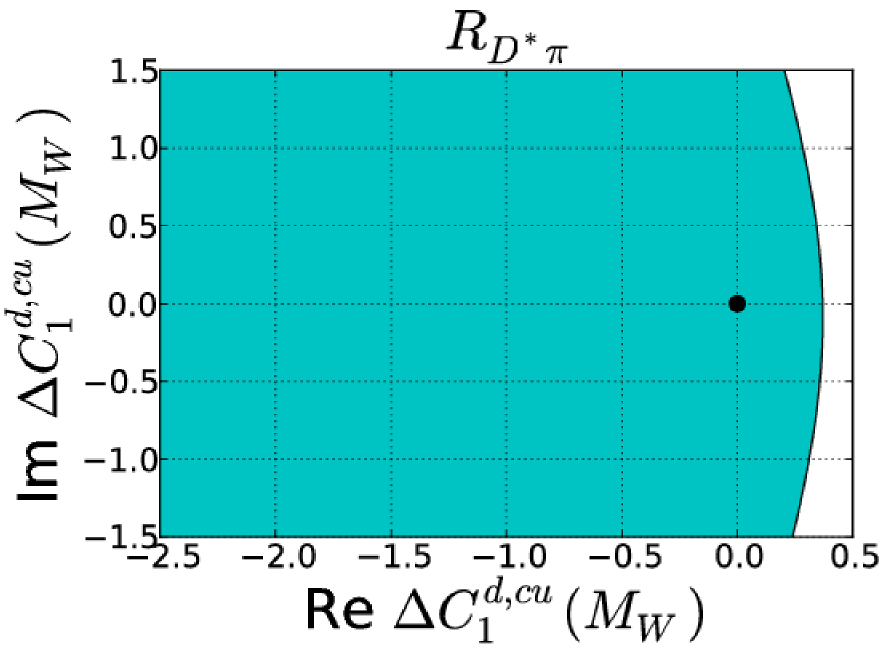
1) NP in C_1 or C_2?
    i. CKM angle γ
    ii. $\Delta\Gamma_d$
2) Complex $(\bar{b}s)(\bar{c}c)$ for C_9^{LFU} ?

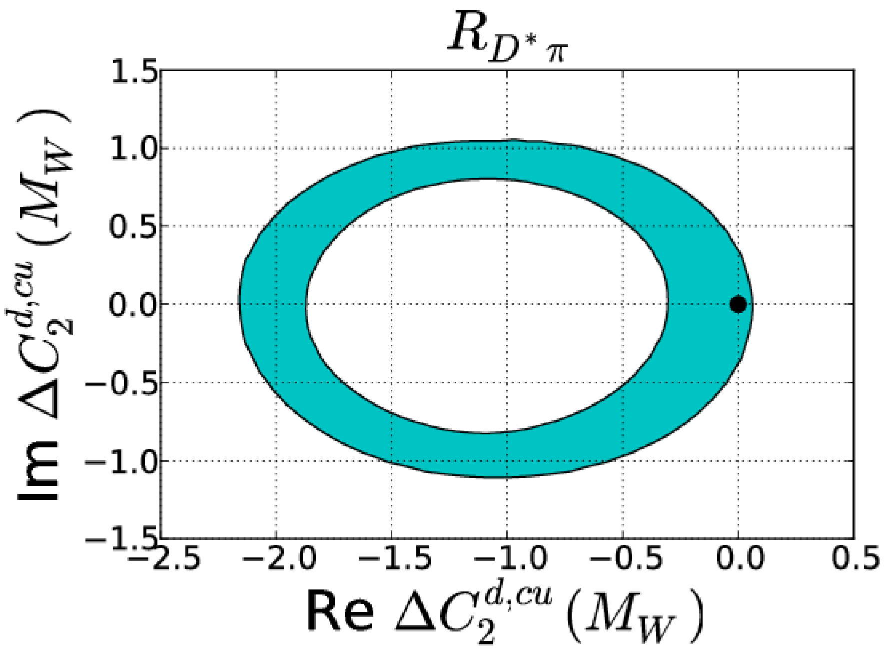
NP in C_1 or C_2?

NP in the EFT

- $Q_1^{q,pp'} = (\bar{p}_\beta \gamma^\mu (1-\gamma^5) b_\alpha)(\bar{q}_\alpha \gamma_\mu (1-\gamma^5) p'_\beta)$
- $Q_2^{q,pp'} = (\bar{p}_\alpha \gamma^\mu (1-\gamma^5) b_\alpha)(\bar{q}_\alpha \gamma_\mu (1-\gamma^5) p'_\alpha)$
- In general, C_2 is colour enhanced relative to C_1 (i.e. has factor of 3 larger coefficient)

NP in the EFT





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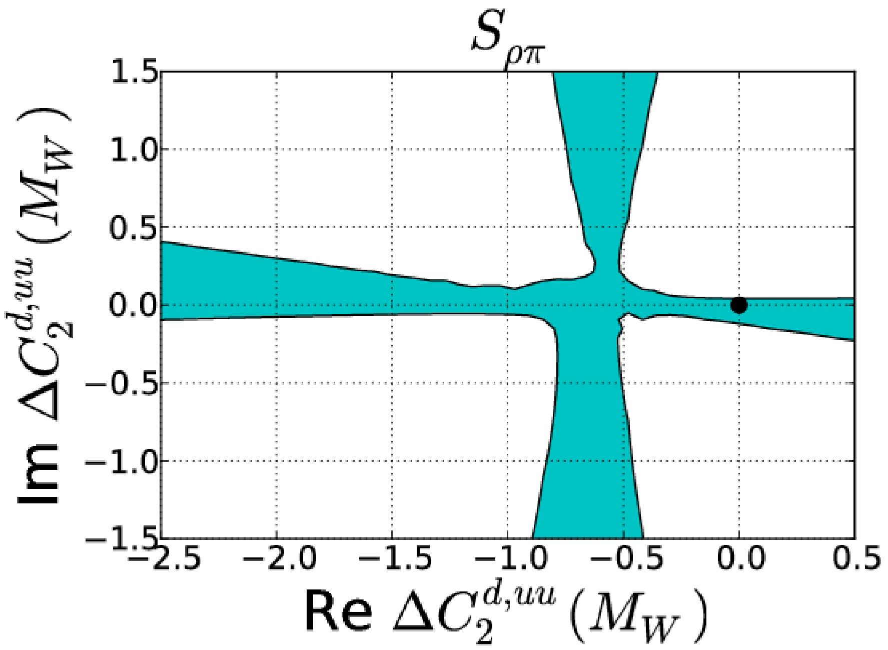
NP in the EFT



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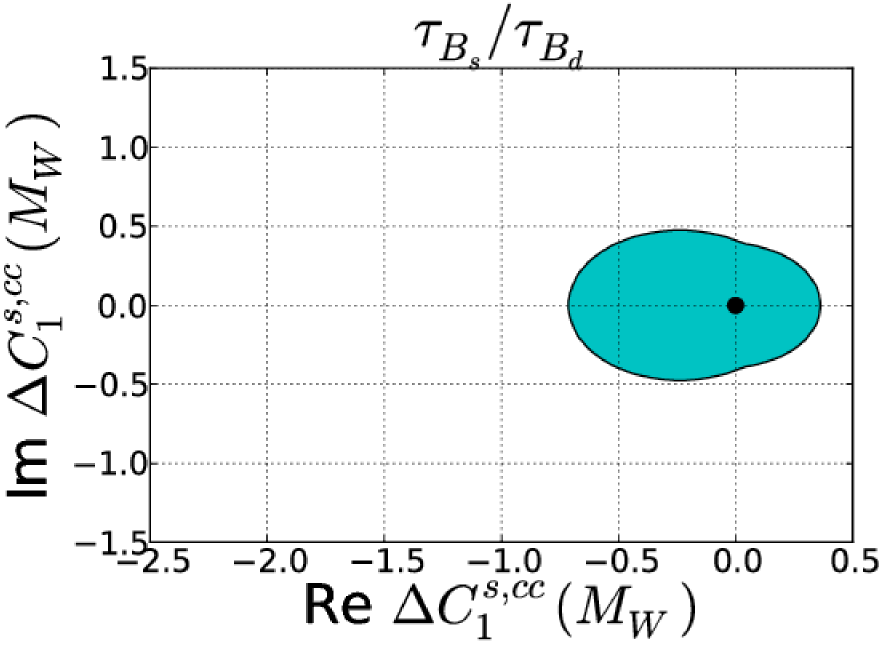

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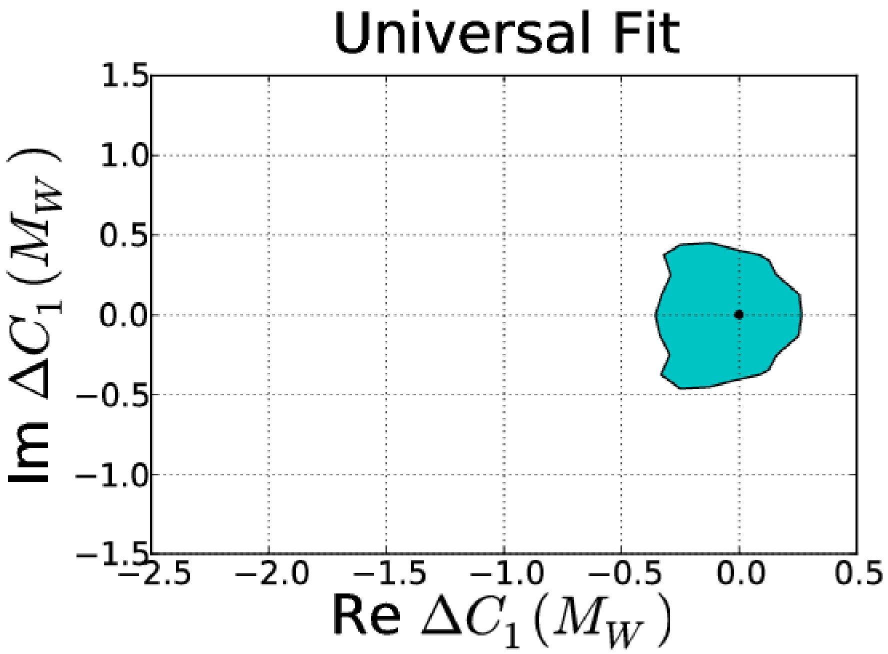
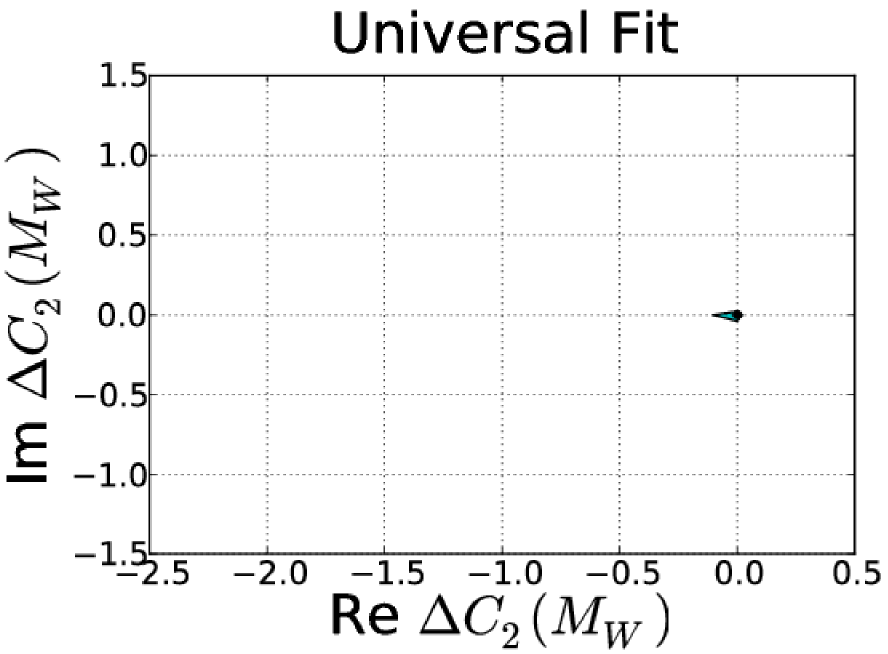
Flavour universal scenario

- All flavours turned on
- $C_i^{q,pp'} = C_i$ for all q, p, p'
- Should be most constrained scenario

NP in the EFT





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Flavour universal scenario

- All flavours turned on
- $C_i^{q,pp'} = C_i$ for all q, p, p'
- Should be most constrained scenario
- C_2 strongly constrained, but lots of room in C_1

Consequences of NP in C_1

- So if large BSM C_1 is allowed, where else would this show up?

  i. CKM angle γ

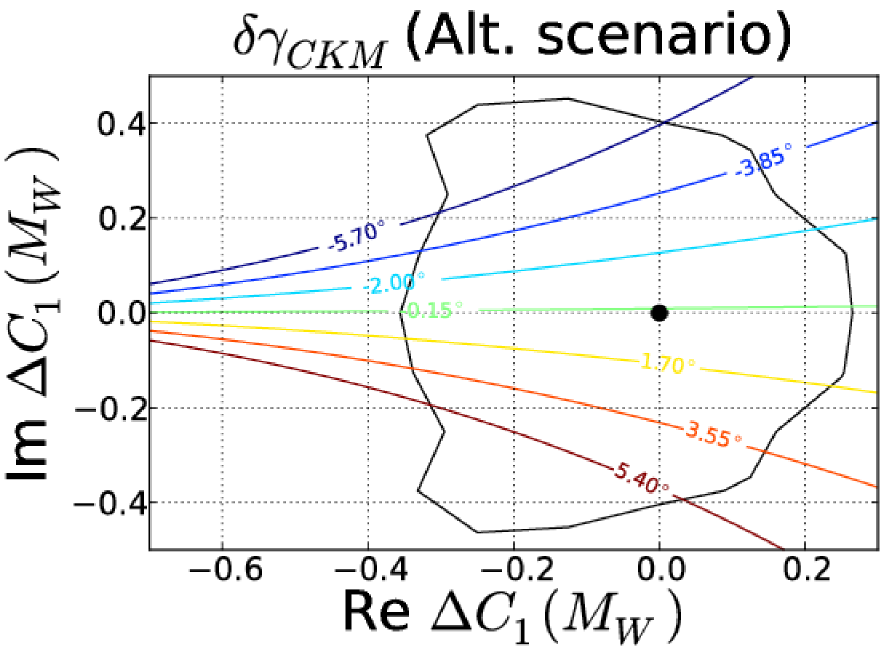
  ii. $\Delta\Gamma_d$

i. CKM angle γ

- Experimental progress impressive
  - 2014: (73 ± 7)°, 2021: (66 ± 3)°
- SM theory side under control
  - Unknown hadronic matrix elements don't affect the weak phase, 10^{-4} SM uncertainty (from new weak phases at 1-loop) 1308.5663 1412.3173

BSM in γ

- Imaginary NP in $(\bar{b}u)(\bar{c}s)$ and $(\bar{b}c)(\bar{u}s)$ can give large shift
  - (5 – 10)°, now bigger than experimental error
- Feeds into other observables



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BSM in γ

- Feeds into other observables

$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = (2.93 \pm 0.04) \times 10^{-11} \left[\frac{|V_{cb}|}{42.6 \times 10^{-3}}\right]^4 \left[\frac{\sin\gamma}{\sin(64.6^\circ)}\right]^2 \left[\frac{\sin\beta}{\sin(22.2^\circ)}\right]^2,$$

$$\mathcal{B}(B_d \to \mu^+\mu^-)_{\rm SM} = (1.02 \pm 0.02) \times 10^{-10} \left[\frac{F_{B_d}}{190.0\rm MeV}\right]^2 \left|\frac{V_{td}}{8.67 \times 10^{-3}}\right|^2 \bar{R}_d$$

$$|V_{td}| = \lambda |V_{cb}| \sin\gamma$$

$$\Delta M_d = 0.5065/\rm ps \left[\frac{\sqrt{\hat{B}_{B_d}} F_{B_d}}{210.6\rm MeV}\right]^2 \left[\frac{S_0(x_t)}{2.307}\right] \left[\frac{|V_{td}|}{8.67 \times 10^{-3}}\right]^2 \left[\frac{\eta_B}{0.5521}\right]$$

2204.10337

ii. $\Delta\Gamma_d$ enhancement

- $\Delta\Gamma_d$ hard to measure
  - $\Delta\Gamma_d/\Gamma_d$ has 1000% error (compare with $\Delta\Gamma_s/\Gamma_s$ error of 6%)
- Using B_d lifetime, get $\Delta\Gamma_d = (-1.3 \pm 6.6) \times 10^{-3}$
- Consistent with SM: $(2.4 \pm 0.4) \times 10^{-3}$

$\Delta\Gamma_d$ enhancement

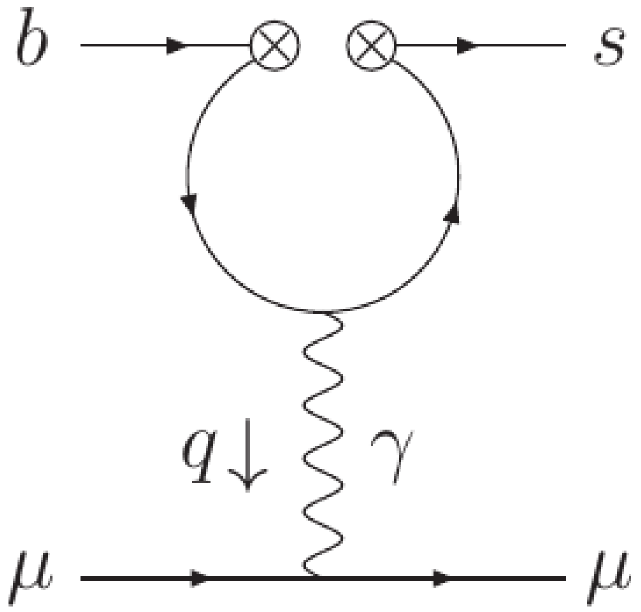
- Using B_d lifetime, get $\Delta\Gamma_d = (-1.3 \pm 6.6) \times 10^{-3}$
- Consistent with SM: $(2.4 \pm 0.4) \times 10^{-3}$
- Large effects in C_1 can give 20% change to SM prediction
- Not enough to be clearly visible as a BSM signal

Complex $(\bar{b}s)(\bar{c}c)$ for C_9^{LFU}?

$(\bar{b}s)(\bar{c}c)$ for $C_9^{\rm LFU}$

- NP in $(\bar{b}s)(\bar{c}c)$ can generate $C_9^{\rm LFU}$
- Large RG enhancement:

$$C_9(m_b) = 8.5 C_1(M_W) + 2 C_2(M_W)$$



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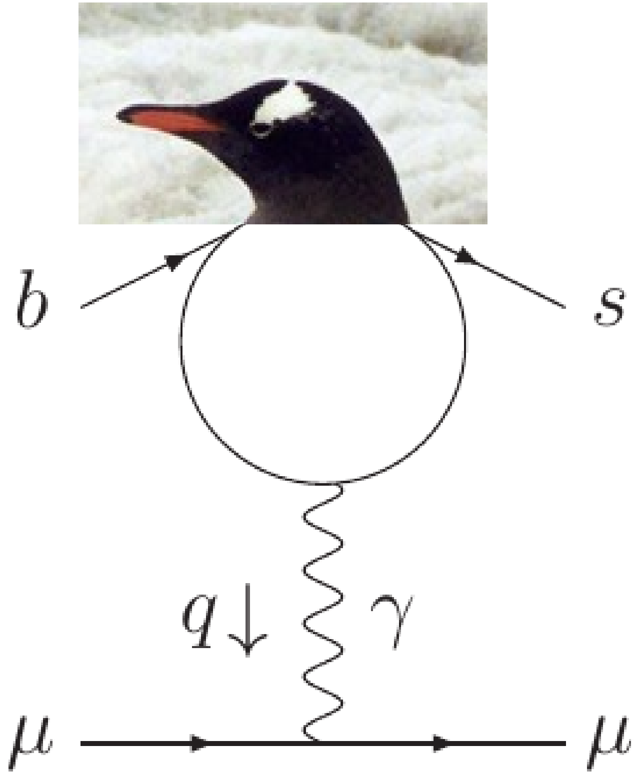
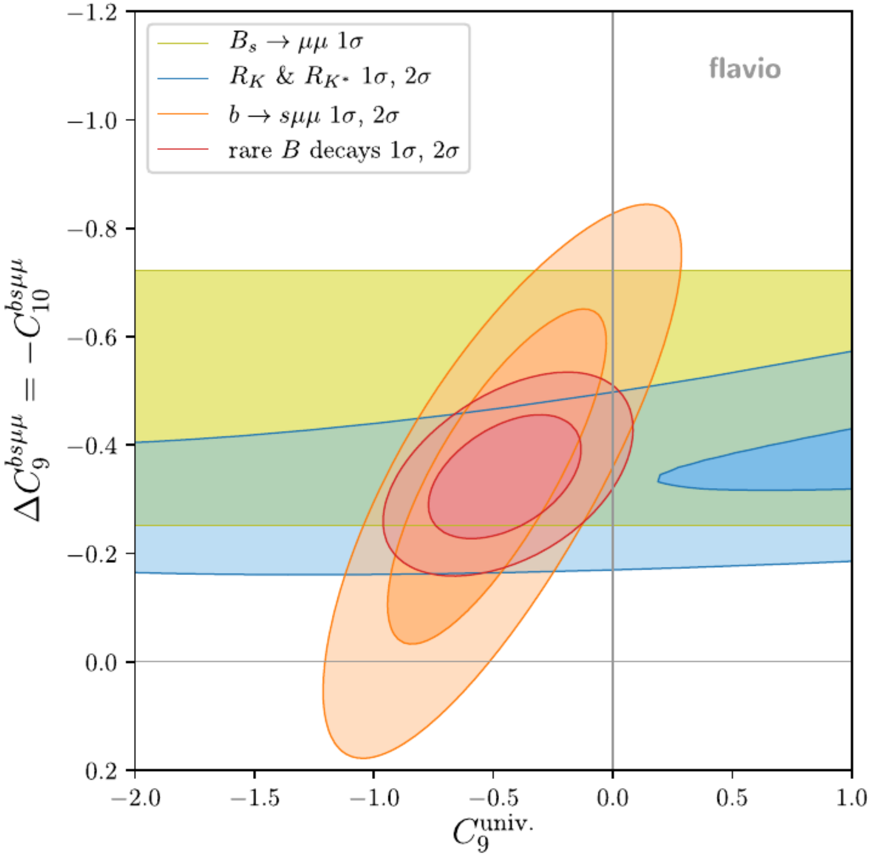


$(\bar{b}s)(\bar{c}c)$ for C_9^{LFU}

- Real C_9^{LFU} + C_9^{μ} consistent with data



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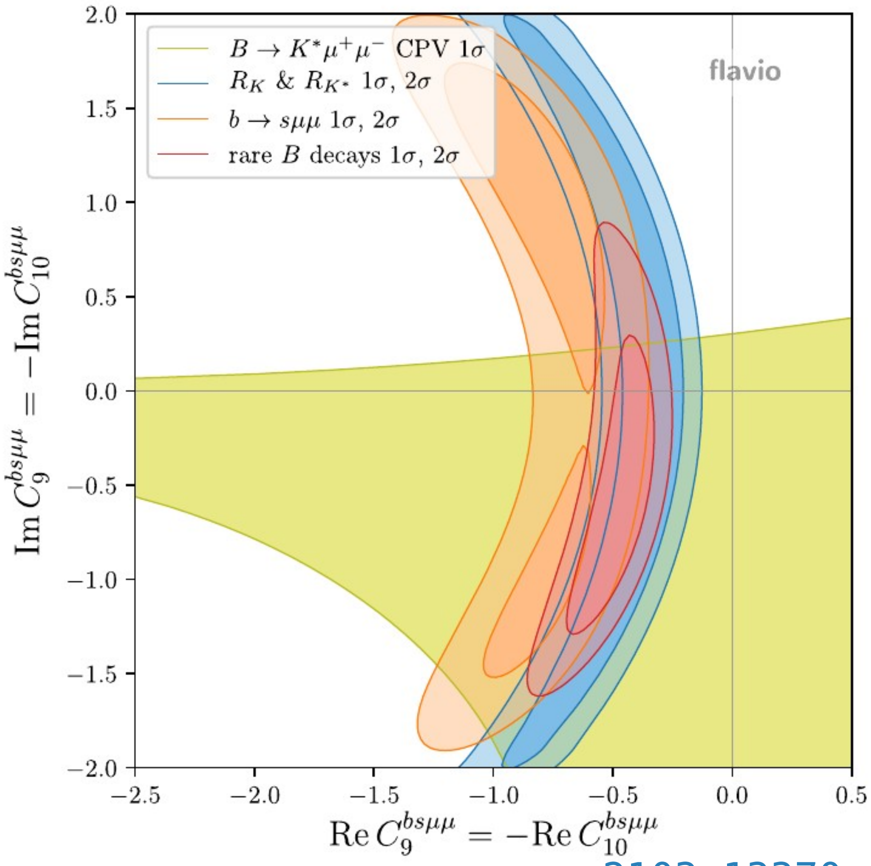
Complex $(\bar{b}s)(\bar{c}c)$ for C_9^μ

- Real C_9^{LFU} + C_9^μ consistent with data
- Complex C_9^μ consistent with data



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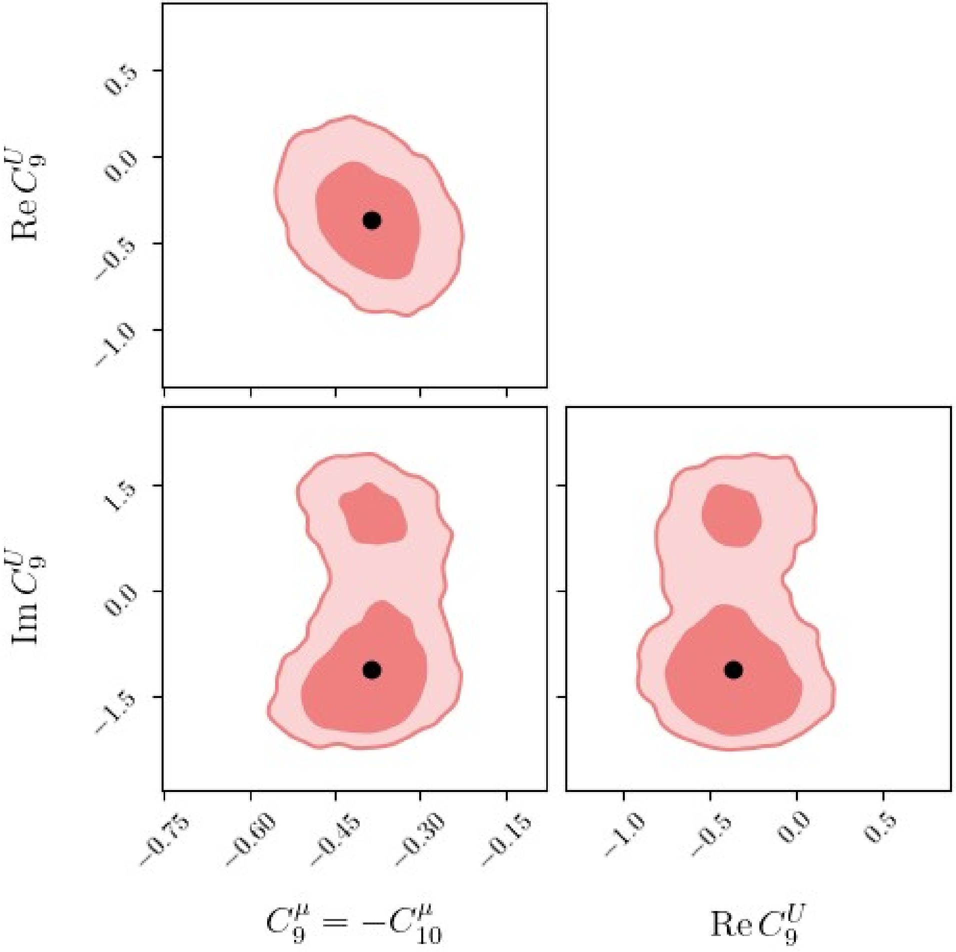
Complex $(\bar{b}s)(\bar{c}c)$ for $C_9^{\rm LFU}$?

- NP in $(\bar{b}s)(\bar{c}c)$ can generate $C_9^{\rm LFU}$
- Real $C_9^{\rm LFU}$+ C_9^{μ} consistent with data
- Complex C_9^{μ} consistent with data
- Does the $b \to s\ell\ell$ data agree with real C_9^{μ} + complex $C_9^{\rm LFU}$?

Complex $(\bar{b}s)(\bar{c}c)$ for C_9^{LFU} !

- NP in $(\bar{b}s$
- Real C_9^{L} a
- Complex
- Does the eal C_9^{μ}+ complex



Complex $(\bar{b}s)(\bar{c}c)$ for C_9^{LFU}

- NP in $C_{1,2}$ SM coefficients gives large effect in C_9
- CPV constrained by $B \to J/\psi K$

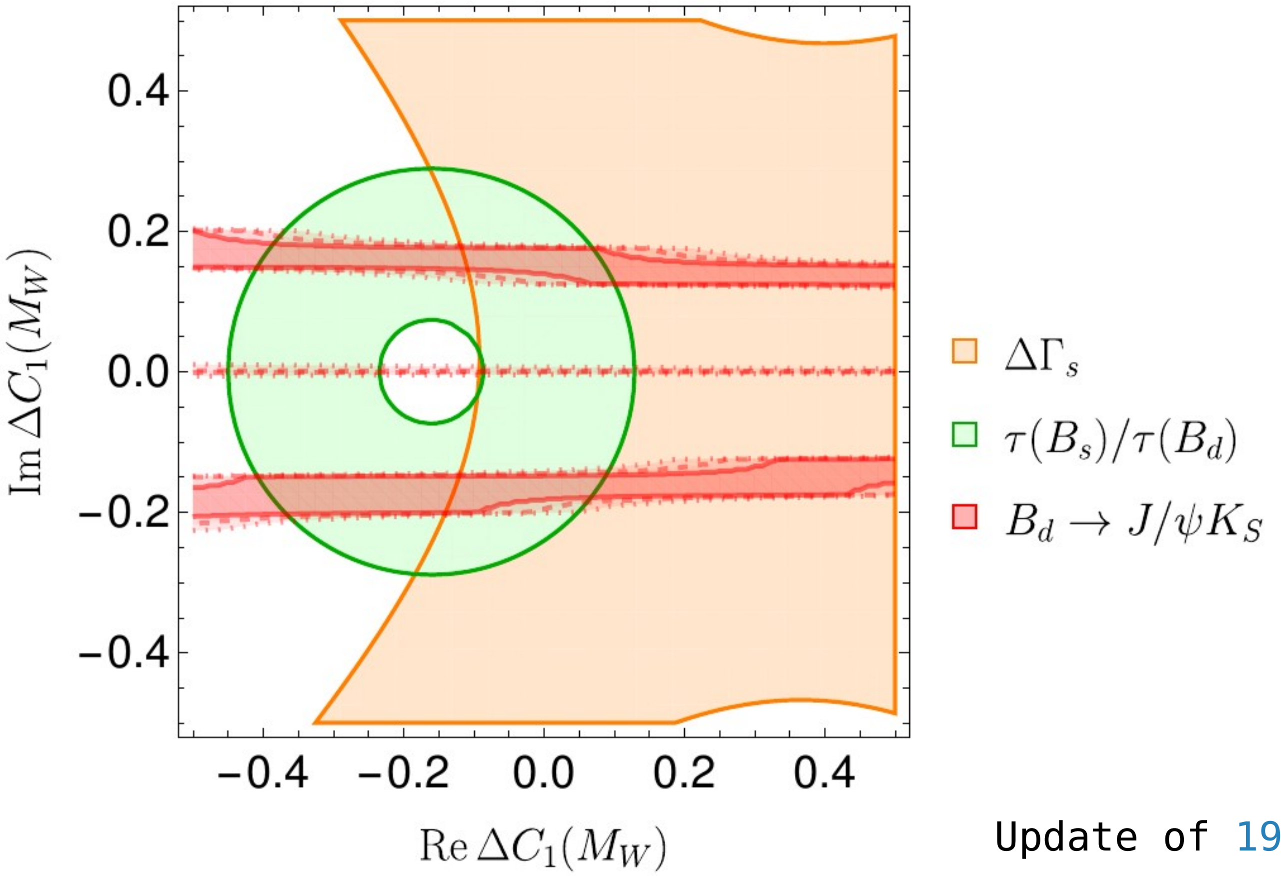
CPV constrained by $B \to J/\psi K$

- 3 main $B \to J/\psi K$ observables:
  - Br, $S_{J/\psi K}$ ($A_{\rm CP}^{\rm mix}$), $C_{J/\psi K}$ ($A_{\rm CP}^{\rm dir}$)
- BSM theoretical prediction needs 3 hadronic inputs
  - $|\langle O_1 \rangle|, \mathrm{Re}(r_{21}), \mathrm{Im}(r_{21})$ ($r_{i1} = \langle O_i \rangle / \langle O_1 \rangle$)
- Can fit to data and still constrain $C_{1,2}$

CPV constrained by $B \to J/\psi K$

- $|\langle O_1 \rangle| = (1.23 \pm 0.18)\,\mathrm{GeV}^3$ (includes $1/N_c^2$ corrections)
- $\mathrm{Re}(r_{21})$: O(1) corrections to NF
- $\mathrm{Im}(r_{21})$: O(1) corrections to NF

CPV constrained by $B \to J/\psi K$

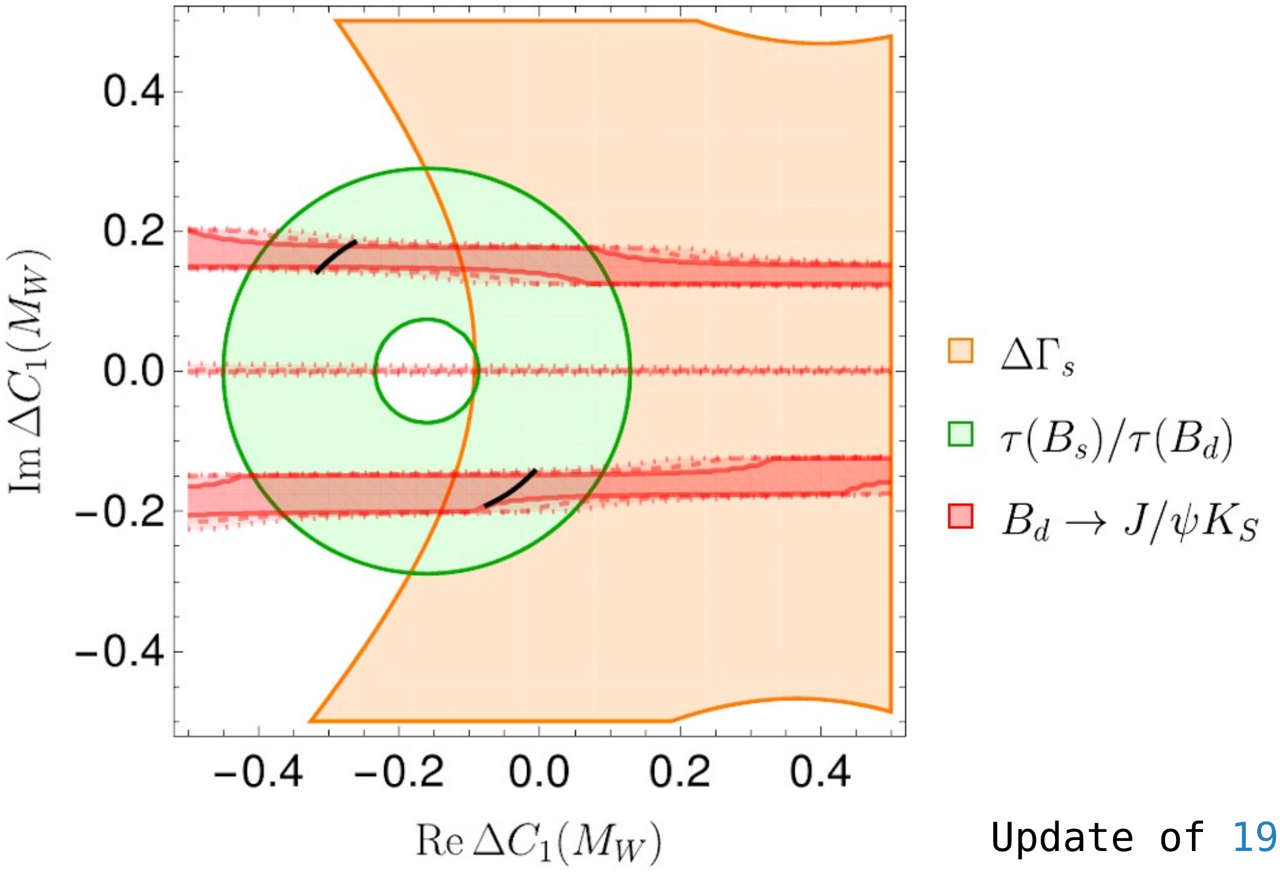


Update of 1910.12924

CPV constrained by $B \to J/\psi K$

- $|\langle O_1 \rangle| = (1.23 \pm 0.18)\,\mathrm{GeV}^3$
- $\mathrm{Re}(r_{21}) \approx 1/3$
- $\mathrm{Im}(r_{21}) \approx 0$

CPV constrained by $B \to J/\psi K$



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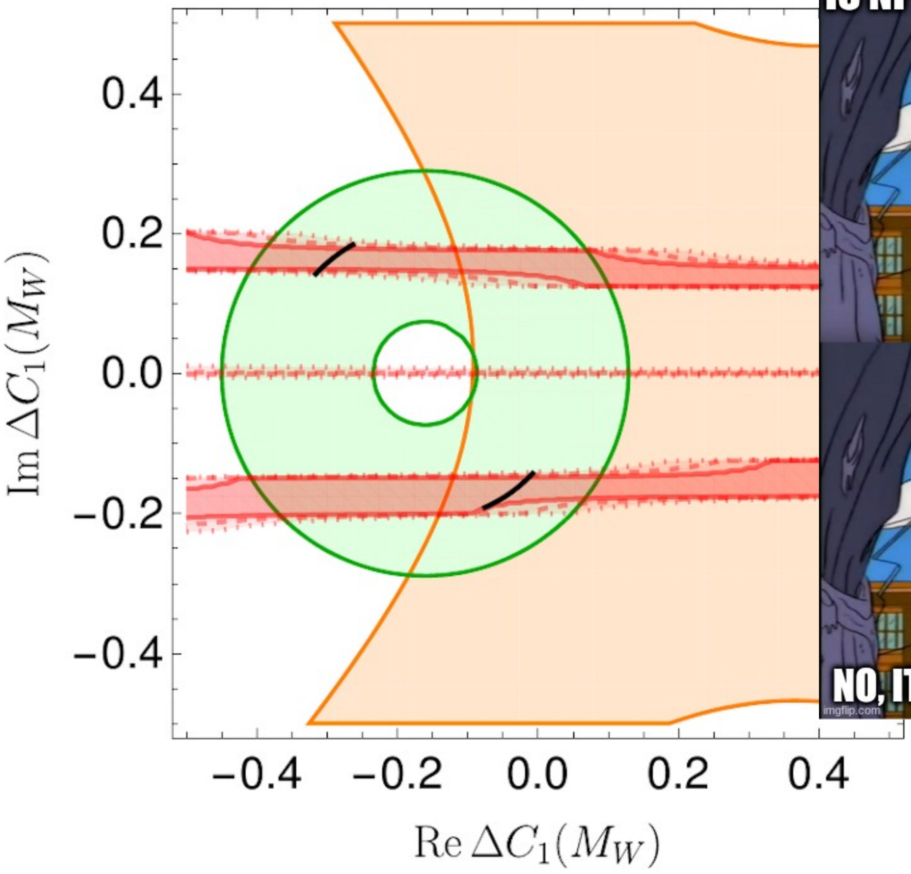
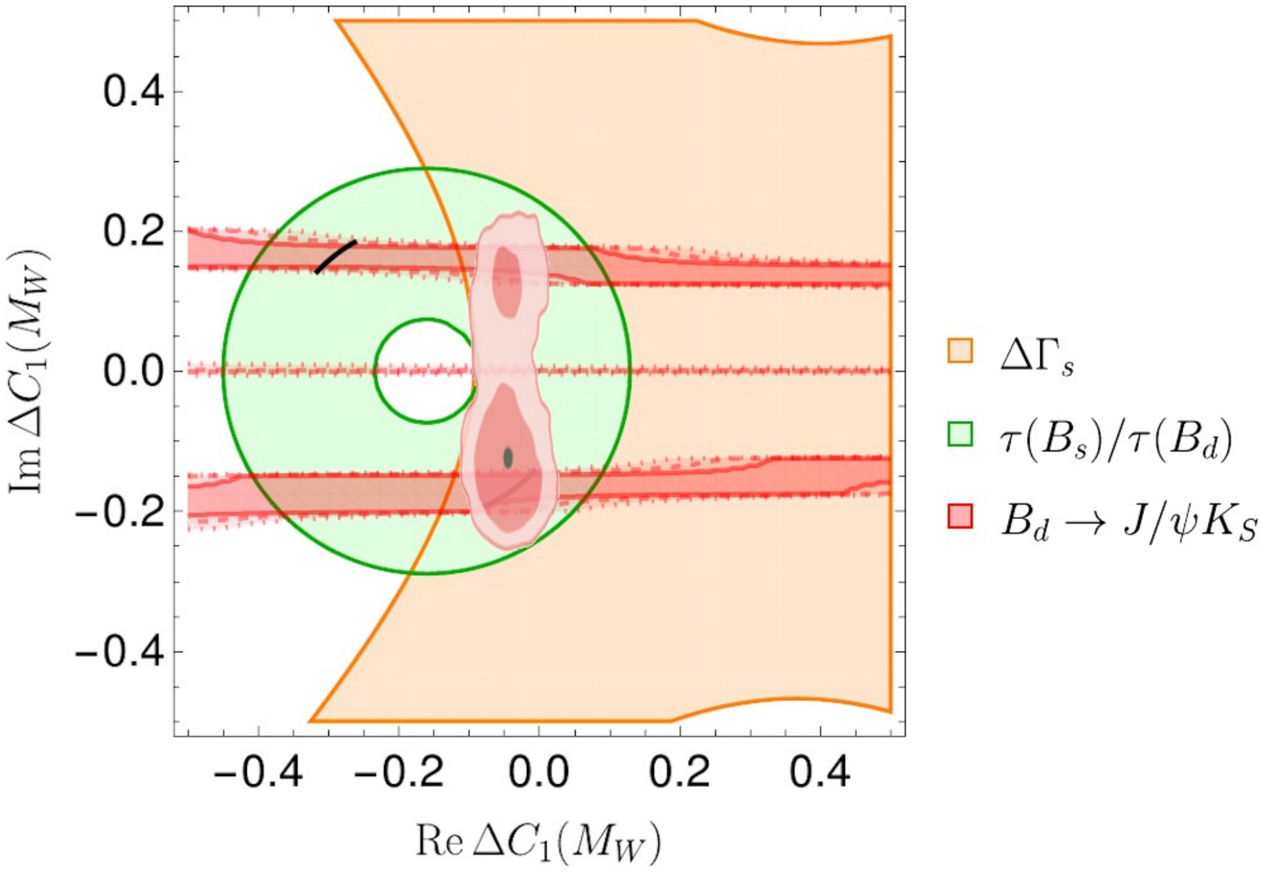


Complex $(\bar{b}s)(\bar{c}c)$ for $C_9^{\rm LFU}$

- CPV in C_1 can match $B \to J/\psi K$ data
- NP in C_1 coefficient gives large effect in $C_9^{\rm LFU}$
- The $b \to s\ell\ell$ data agrees with real C_9^μ + complex $C_9^{\rm LFU}$

Complex $(\bar{b}s)(\bar{c}c)$ for C_9^{LFU}



Conclusions

- Large room for (CPV) NP in C_1 even in the most constrained (flavour universal) case
  - CPV in $C_1^{s,cc}$ can generate a LFU C_9 and make NF work for $B \to J/\psi K$
  - Potentially large effects (5°+) in CKM γ extraction from $B \to DK$