CP violation in flavour anomaly models

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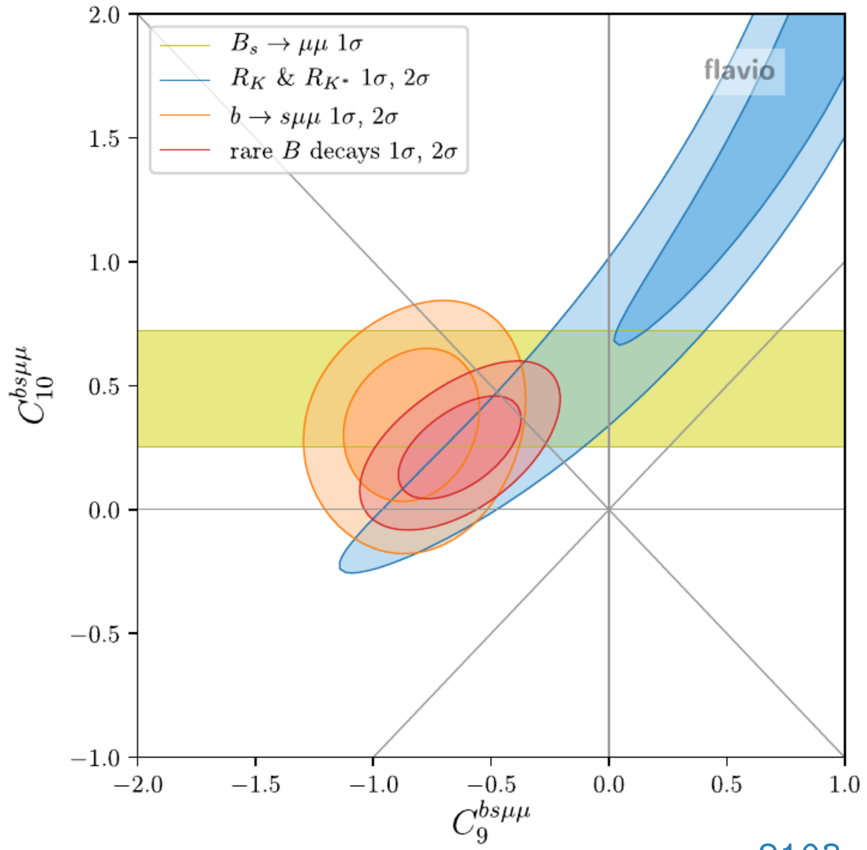
Flavour anomaly fits

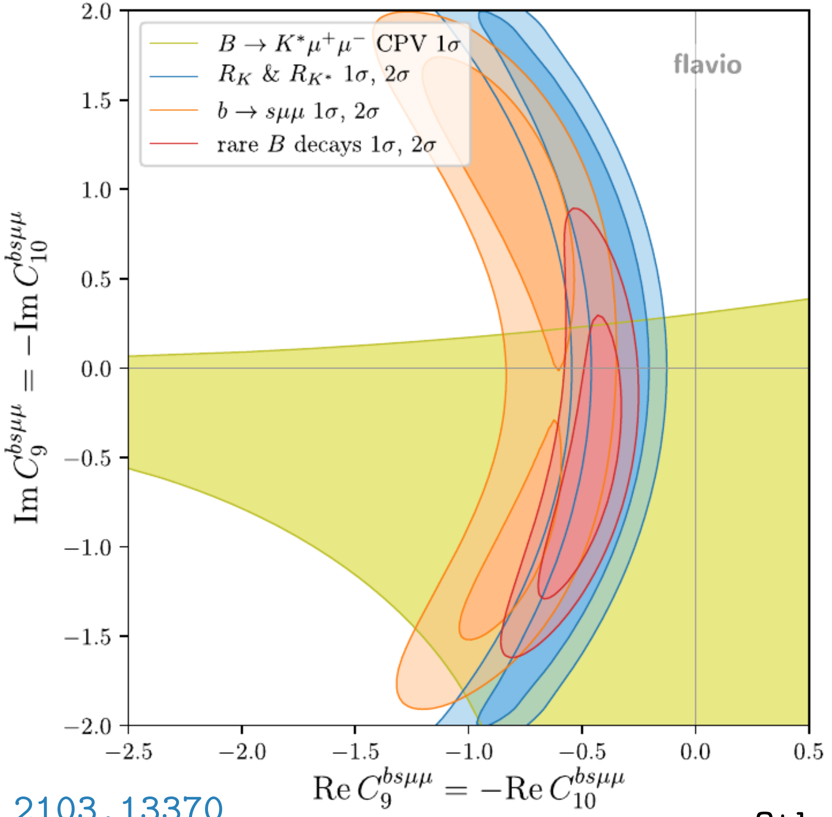


2103.13370

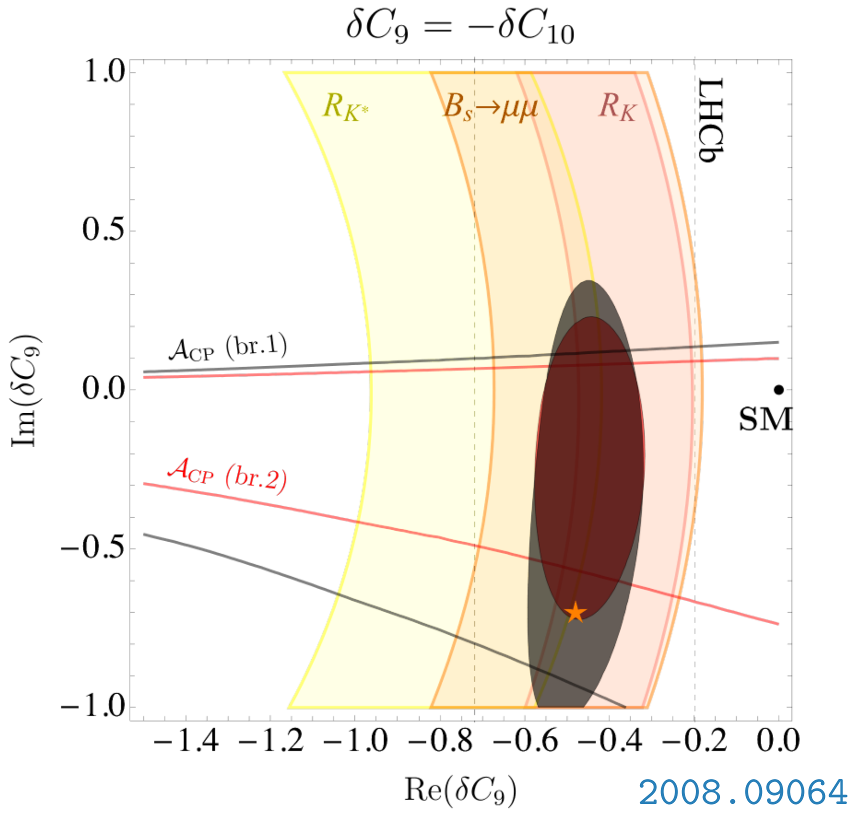
Flavour anomaly fits + CPV

- $C_9^\mu = -C_{10}^\mu \approx -0.5$
- But that assumed real couplings only
- With CPV, currently plenty of room

Flavour anomaly fits + CPV



2103.13370



2008.09064

Others available,
e.g. 2004.14687

Flavour anomaly fits + CPV

- CPV couplings could show up in various observables
- Like angular asymmetry A_7 (1703.09247), direct CP asymmetry $\mathcal{A}_{\mathrm{CP}}$ (2008.09064), or effective lifetime asymmetry $A_{\Delta\Gamma_s}^{\mu\mu\gamma}$ (2102.13390)

$$\mathcal{A}_{\mathrm{CP}}^{K^{(*)}} = \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\mu\mu) - \mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\mu\mu) + \mathcal{B}(B \to K^{(*)}\mu\mu)}$$

$$A_{\Delta\Gamma_s}^{f} = \frac{-2\int_{\mathrm{PS}} \mathrm{Re}\left(q/p\,\bar{\mathcal{A}}_f \mathcal{A}_f^*\right)}{R_H^f + R_L^f}$$

$$R_H^f + R_L^f = \int_{\mathrm{PS}} \left(|\mathcal{A}_f|^2 + |q/p|^2 |\bar{\mathcal{A}}_f|^2\right)$$

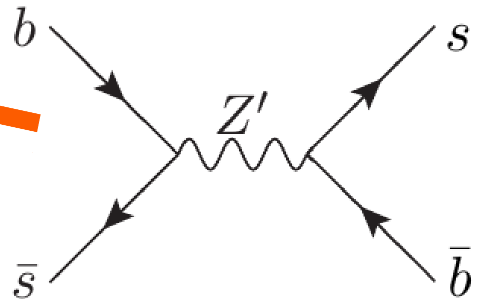
Z' explanation

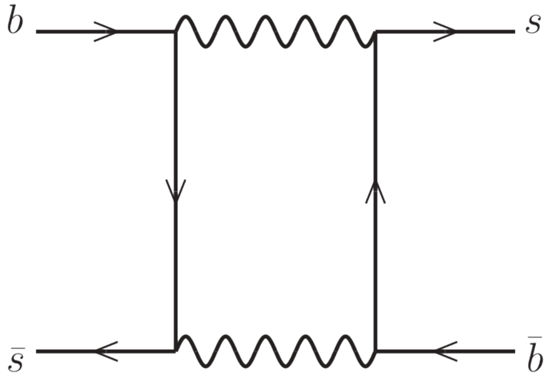
- Z' with bs and $\mu\mu$ couplings
- Easy to give bs coupling complex phase → possible CPV
- B_s mixing observables then very constraining

See 1909.11087 for more

B_s mixing observables

- $$\frac{\Delta M_s^{\text{SM+NP}}}{\Delta M_s^{\text{SM}}} = \left| 1 + \frac{C_{bsbs}^{\text{NP}}}{C_{bsbs}^{\text{SM}}} \right|$$





Z' explanation

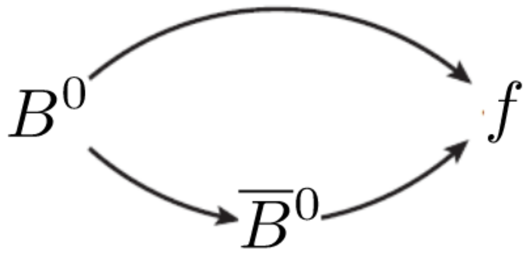
- Not just ΔM_s, but also $A_{\mathrm{CP}}^{\mathrm{mix}}$

Bs mixing observables

- $$\frac{\Delta M_s^{\mathrm{SM+NP}}}{\Delta M_s^{\mathrm{SM}}} = \left| 1 + \frac{C_{bsbs}^{\mathrm{NP}}}{C_{bsbs}^{\mathrm{SM}}} \right|$$

- $$A_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to J/\psi\phi) = \sin(\phi_\Delta - 2\beta_s)$$

$$\phi_\Delta = \arg\left(1 + \frac{C_{bsbs}^{\mathrm{NP}}}{C_{bsbs}^{\mathrm{NP}}}\right)$$

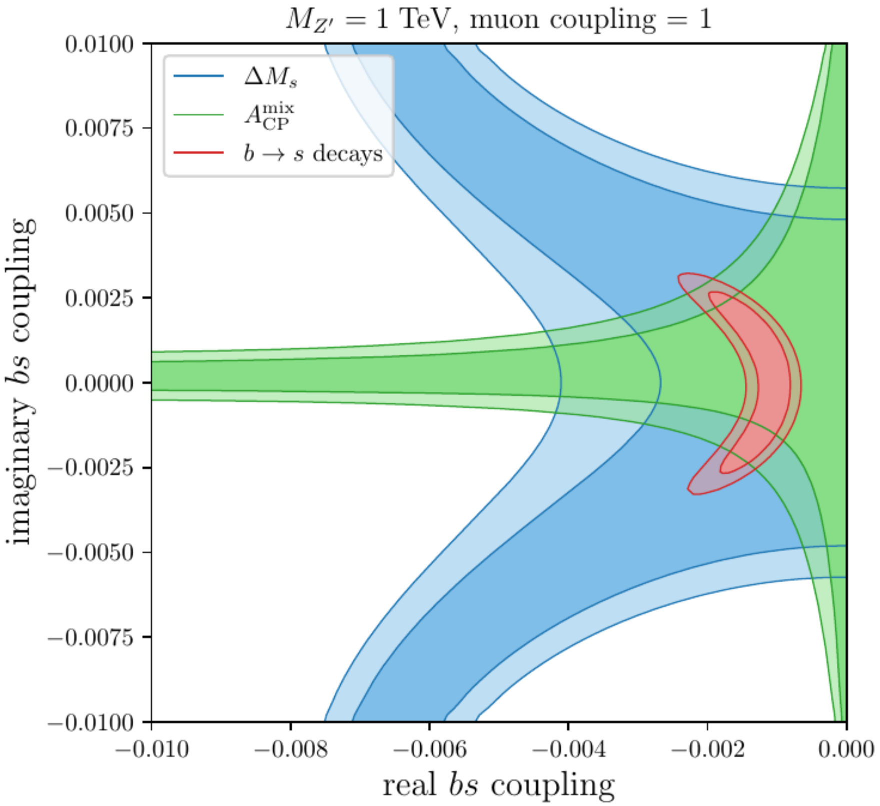


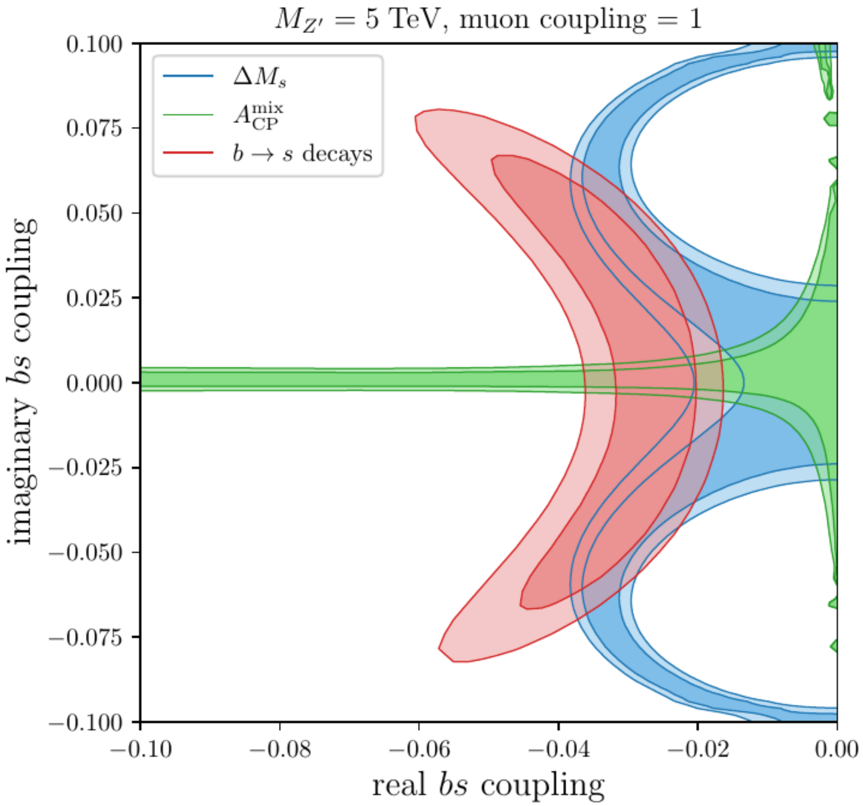
Z' explanation

- Not just ΔM_s , but also $A_{\rm CP}^{\rm mix}$
  - In principe $a_{\rm sl}^s$ would also be a constraint, but currently the experimental uncertainties are too big
- Unless Z' is very light, the CPV allowed by R_K and friends is ruled out by $A_{\rm CP}^{\rm mix}$
  - Unless some BSM penguins are present in $B_s \to J/\psi\phi$

See 1909.11087 for more

Z' explanation

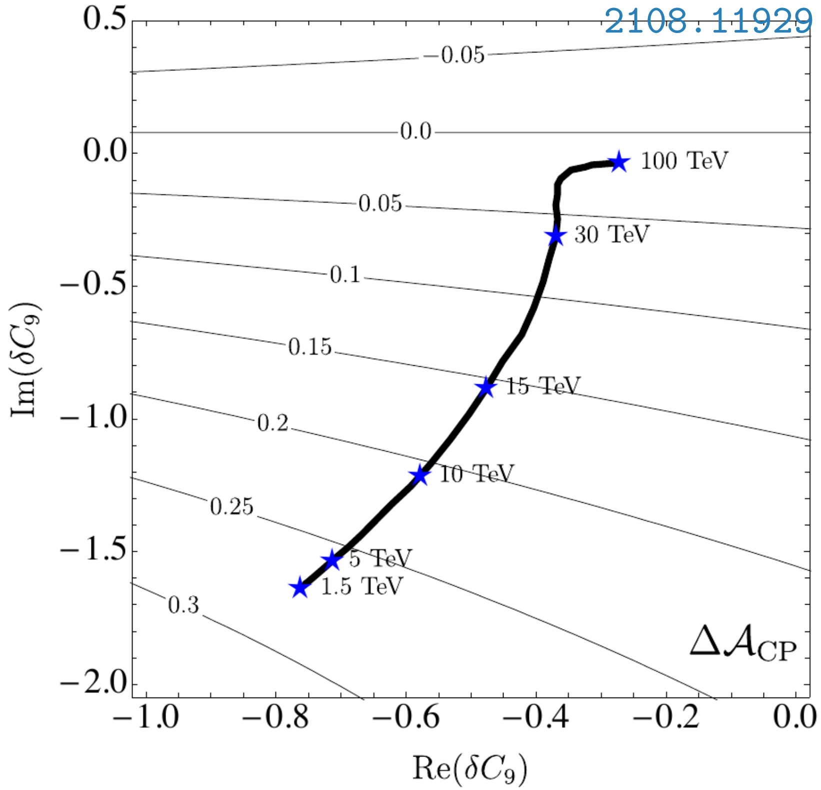




Based on 1909.11087

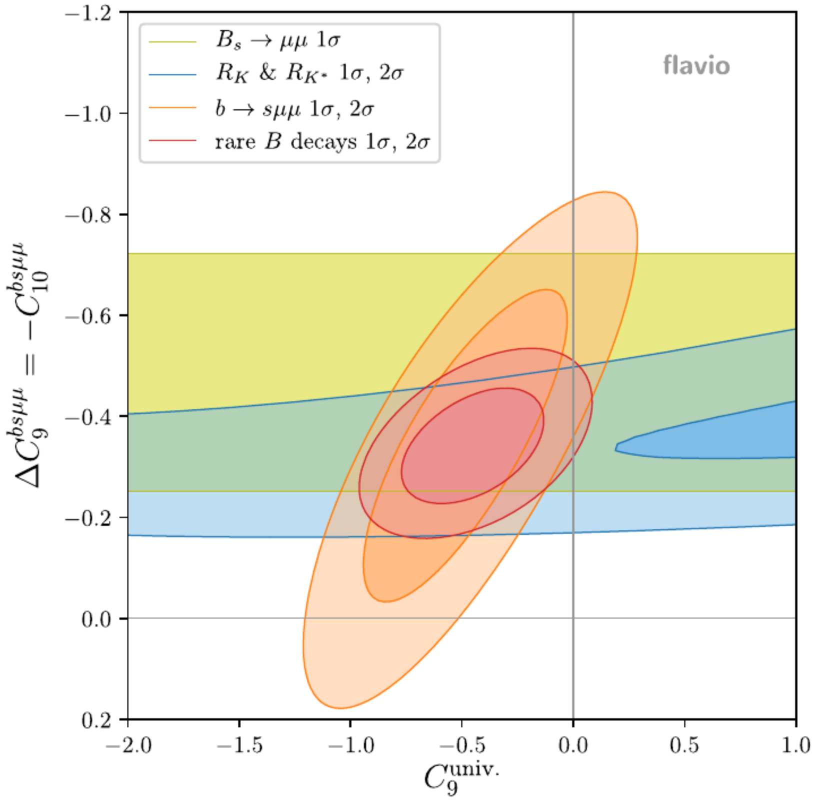
S_3 with complex WCs

- In 2108.11929, they looked at $\mathcal{A}_{\rm CP}$ enhancements in the S_3 LQ
- Similar constraints from $A_{\rm CP}^{\rm mix}$, but mass less constrained as B mixing arises at 1-loop



What about CPV in universal C_9 ?

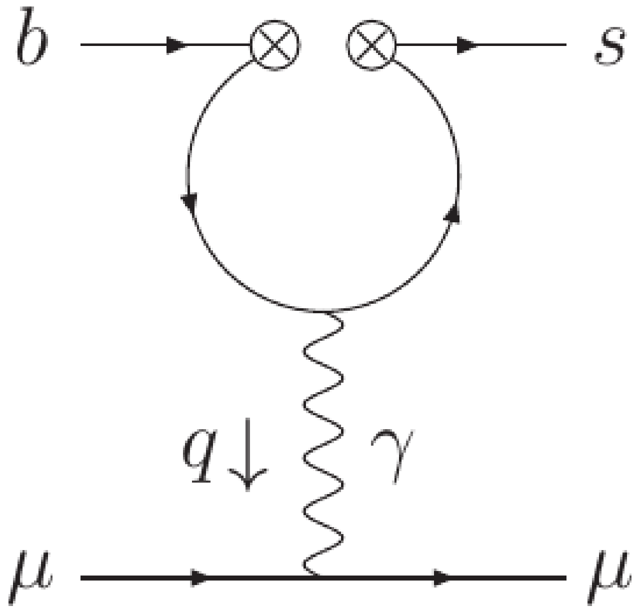
- Current data is happy with both LFUV C_9^μ and LFU $C_9^{\rm univ}$



2103.13370

What about CPV in universal C_9?

- Current data is happy with both LFUV C_9^μ and LFU C_9^{univ}
- C_9^{univ} can be generated in many ways
- E.g. 4 fermion operators – look at $(\bar{b}s)(\bar{c}c)$



Results from 1701.09183 and 1910.12924

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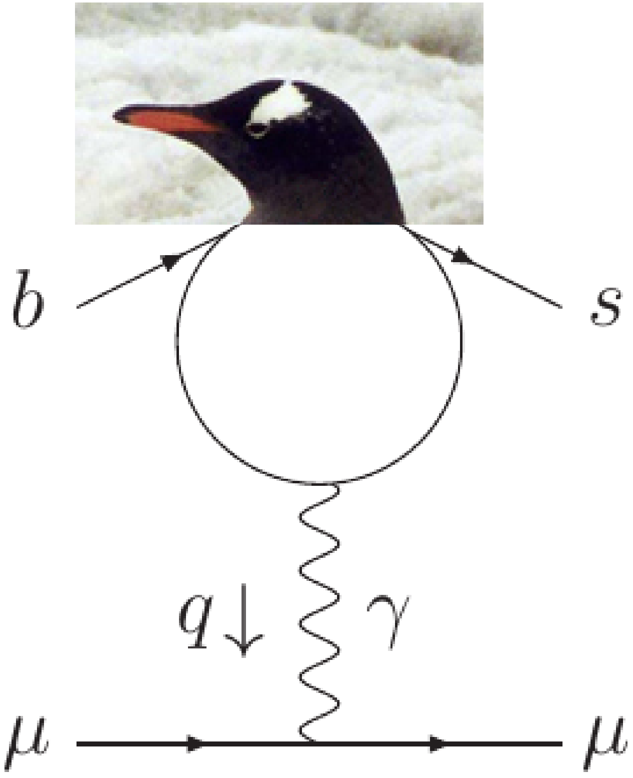


Results from 1701.09183 and 1910.12924

BSM $(\bar{b}s)(\bar{c}c)$ operators

- NP in the $C_{1,2}$ SM operators gives large effect in C_9^{univ}

$$Q_1^c = (\bar{c}_L^i \gamma_\mu b_L^j)(\bar{s}_L^j \gamma^\mu c_L^i)$$

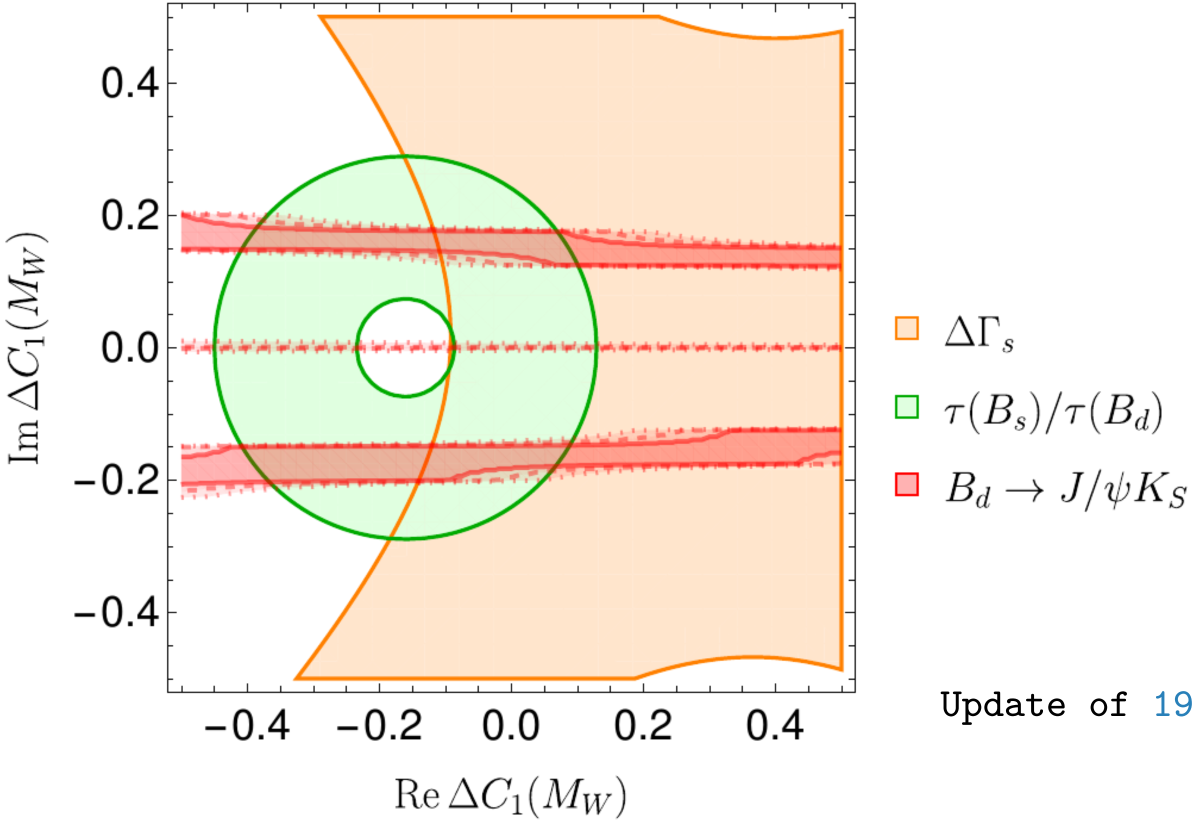
$$Q_2^c = (\bar{c}_L^i \gamma_\mu b_L^i)(\bar{s}_L^j \gamma^\mu c_L^j)$$

$$C_9^{\text{univ}}(\mu_b) = 8.5 C_1^c(\mu_{\text{EW}}) + 2.0 C_2^c(\mu_{\text{EW}})$$

BSM $(\bar{b}s)(\bar{c}c)$ operators

- NP in the $C_{1,2}$ SM operators gives large effect in C_9^{univ}
- CPV constrained by $B \to J/\psi K$
- (Interesting side note that naive factorisation agrees with data if CPV BSM is present – see 1910.12924 for discussion)

BSM $(\bar{b}s)(\bar{c}c)$ operators

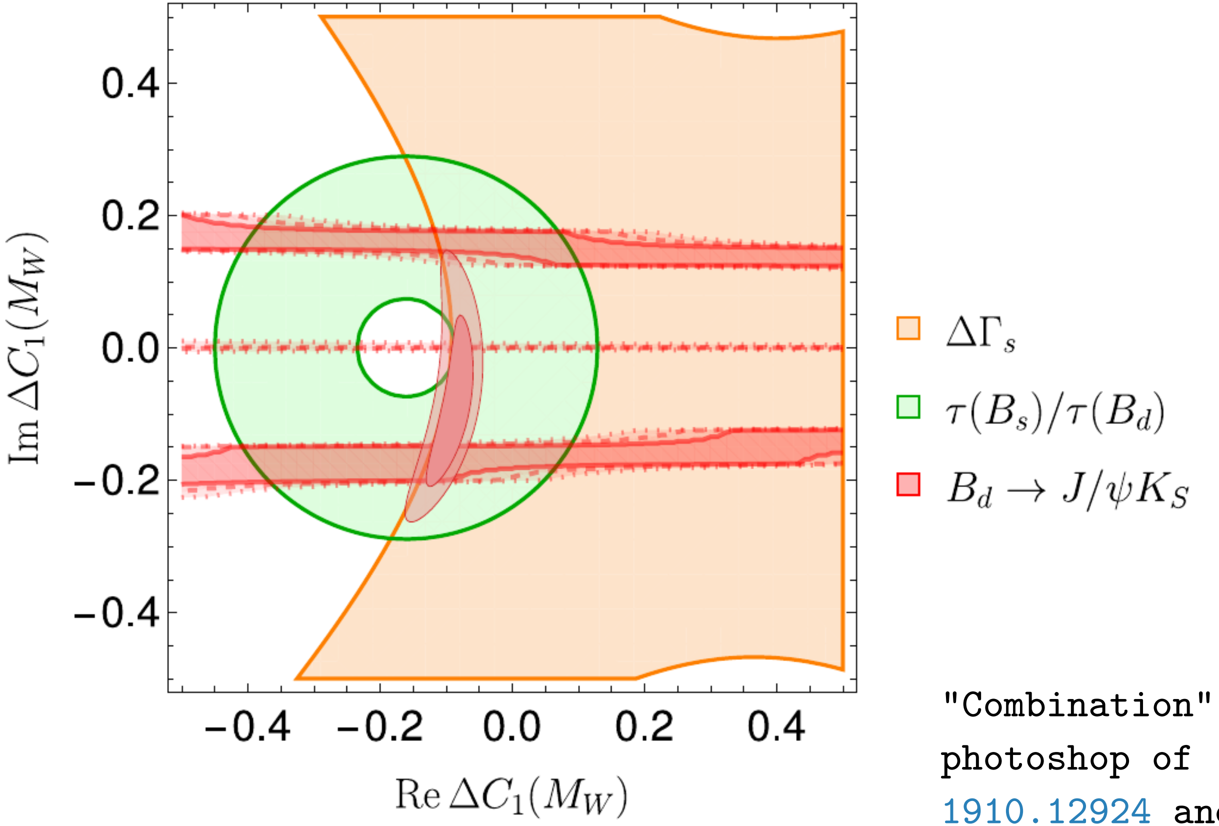


Update of 1910.12924

BSM $(\bar{b}s)(\bar{c}c)$ operators

- How does the the NP allowed by R_K and friends for a universal C_9 interact with all other constraints?

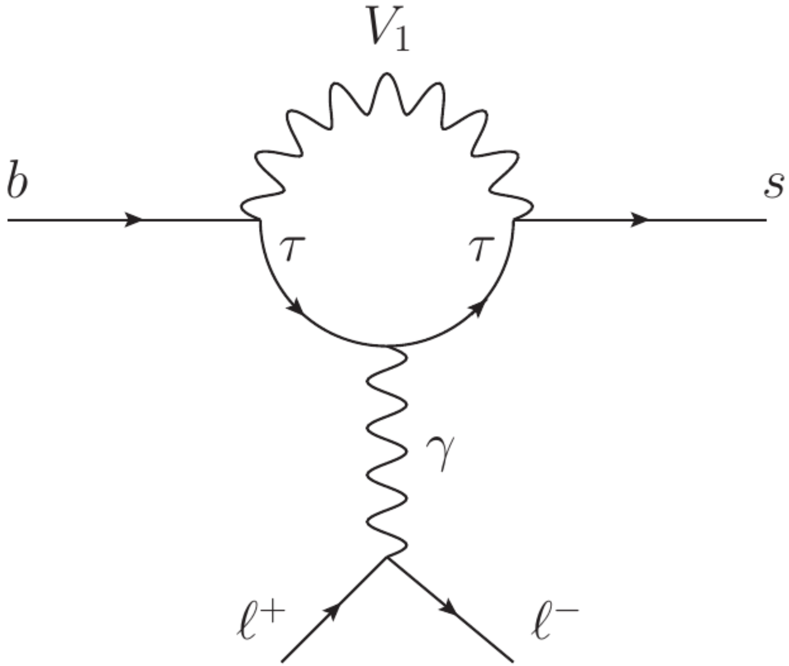
BSM $(\bar{b}s)(\bar{c}c)$ operators



"Combination" by photoshop of 1910.12924 and 2103.13370

Other 4 fermion operators

- Work has also been done on things like $(\bar{b}s)(\bar{\tau}\tau)$ operators (1109.1826, 1807.02068)
- Less hadronic constraints
- But similar mixing into C_9^{univ}



Summary

- Current data allows relatively large imaginary parts in the WCs related to the flavour anomaly
- But model dependent constraints force Z' models to be very light (less constraining for S_3 LQs)
- Complex WCs in a LFU C_9 interesting possibility though…

Summary

- Current data allows relatively large imaginary parts in the WCs related to the flavour anomaly
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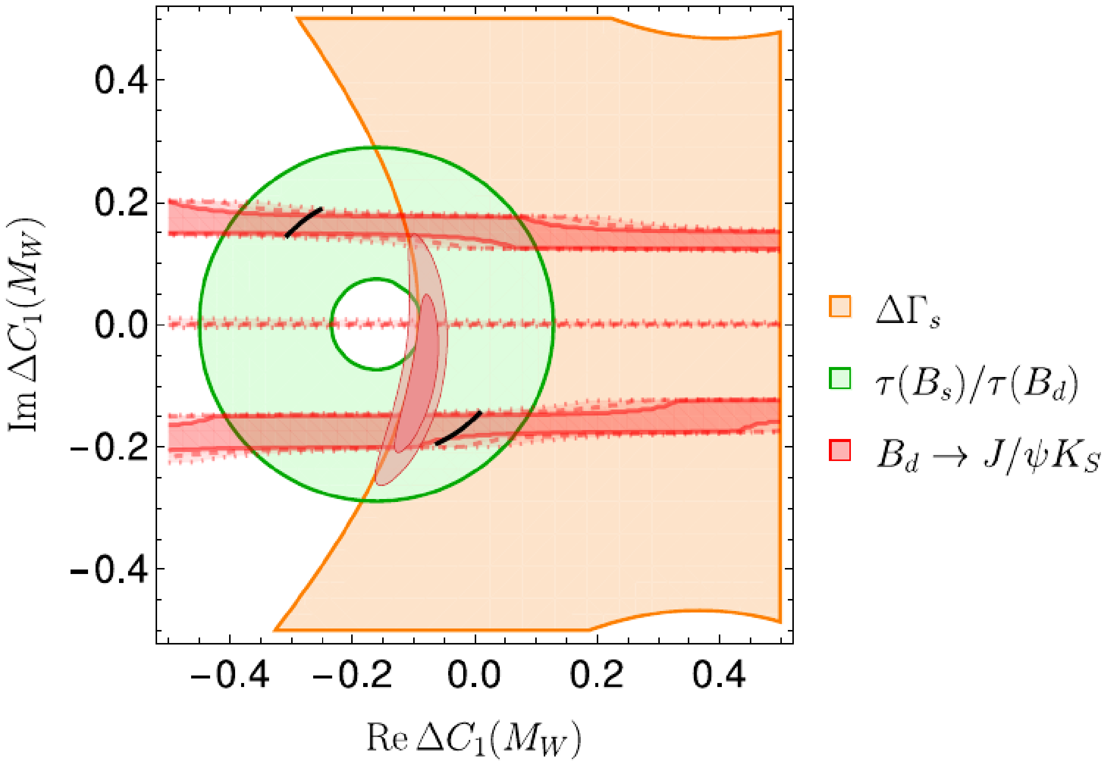
- Complex WCs in a LFU C_9 interesting possibility though…

Thanks! Questions?

Backups

NF region


0.4
0.2
0.0
−0.2
−0.4
$\mathrm{Im}\,\Delta C_1(M_W)$
−0.4
−0.2
0.0
0.2
0.4
$\mathrm{Re}\,\Delta C_1(M_W)$
$\Delta\Gamma_s$
$\tau(B_s)/\tau(B_d)$
$B_d \to J/\psi K_S$

a_sl^s

- Flavour specific asymmetry: $\bar{B} \to X\ell^{+}\nu$ is forbidden without mixing

$$a_{\rm sl} \equiv \frac{\Gamma(\bar{B}(t) \to X\ell^{+}\nu) - \Gamma(B(t) \to \overline{X}\ell^{-}\bar{\nu})}{\Gamma(\bar{B}(t) \to X\ell^{+}\nu) + \Gamma(B(t) \to \overline{X}\ell^{-}\bar{\nu})}$$

Scribbles courtesy of Alex Lenz

$$a_{sl}^{s} = \frac{\Gamma_{12}}{\Gamma_{12}} \cdot \sin(\phi_{12}^{sm} + \phi_{\Delta})$$

→ 0 How large can ϕ_{Δ} be?

Exp: $(-0.6 \pm 2.8) \cdot 10^{-3}$ $\quad$ $5 \cdot 10^{-3}$