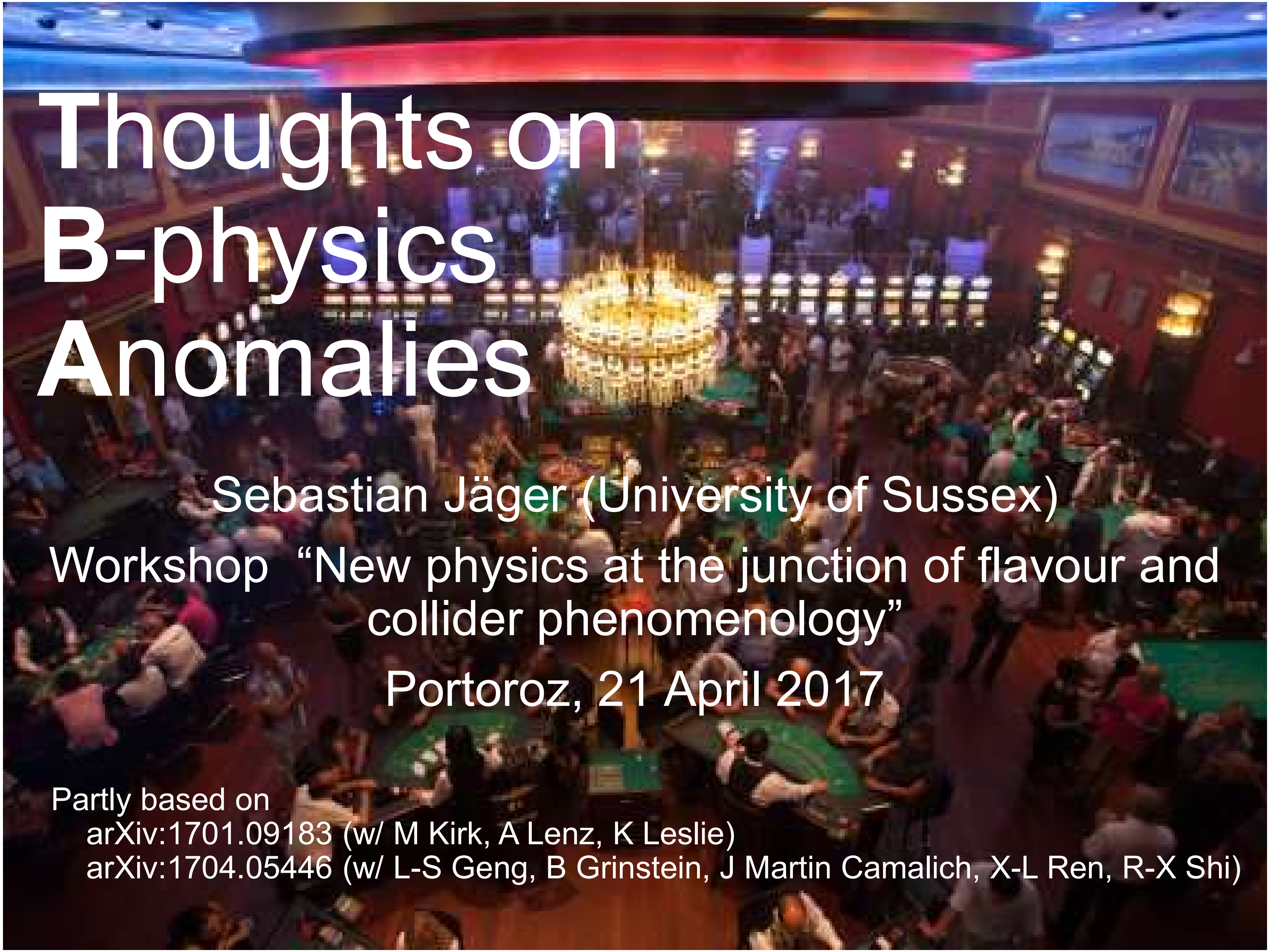


Thoughts on B-physics Anomalies

Sebastian Jäger (University of Sussex)

Workshop "New physics at the junction of flavour and collider phenomenology"

Portoroz, 21 April 2017

Partly based on

- arXiv:1701.09183 (w/ M Kirk, A Lenz, K Leslie)
- arXiv:1704.05446 (w/ L-S Geng, B Grinstein, J Martin Camalich, X-L Ren, R-X Shi)

Outline

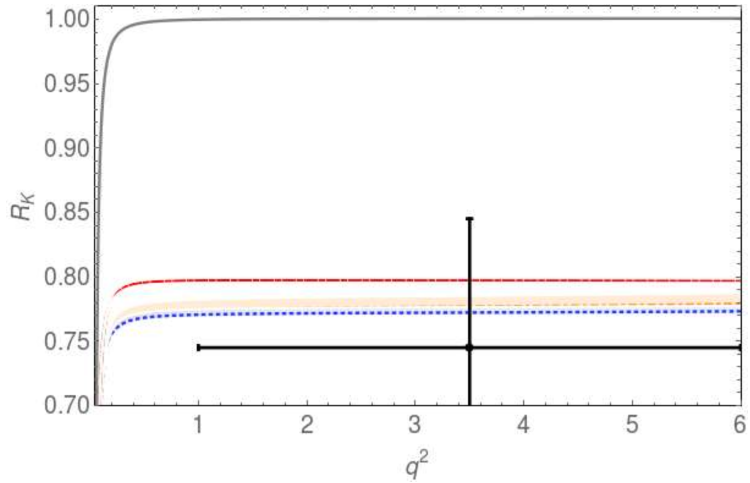
RK* measurements and lepton-universality-violation in Wilson coefficients

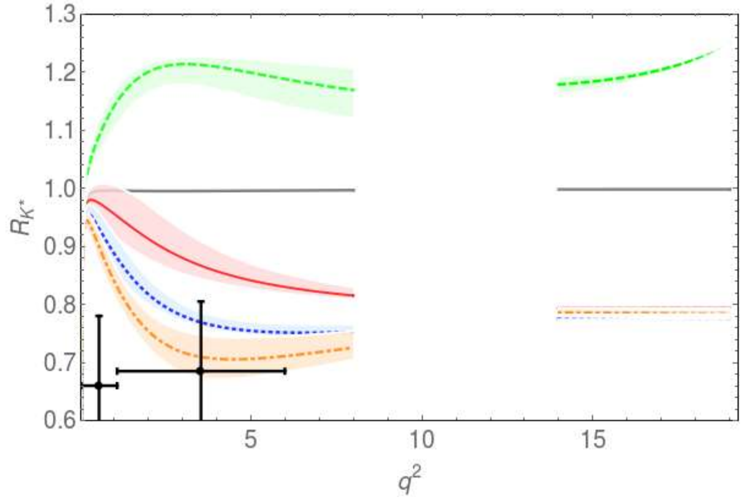
New precision probes of C10

Semi-universal BSM Wilson coefficients

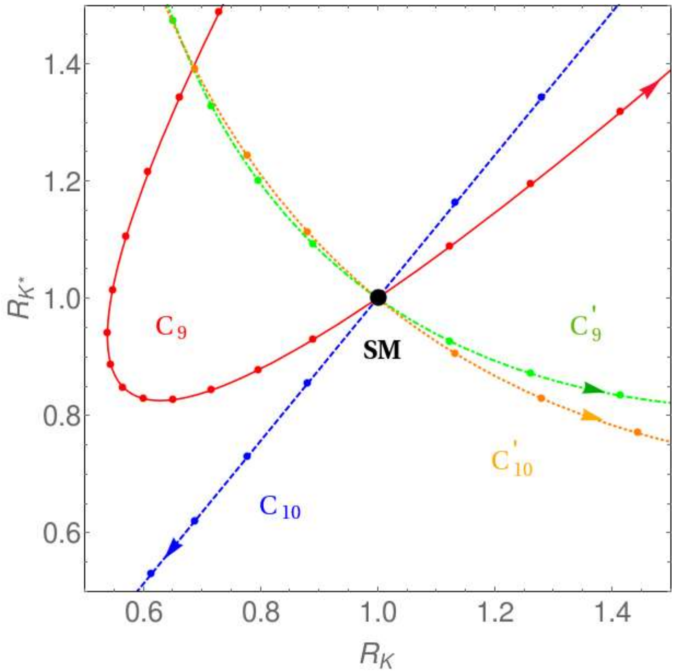
C9 from BSM $b \to c\bar{c}s$ vertex, and connection with radiative decays and lifetime observables

LUV measurements





Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446



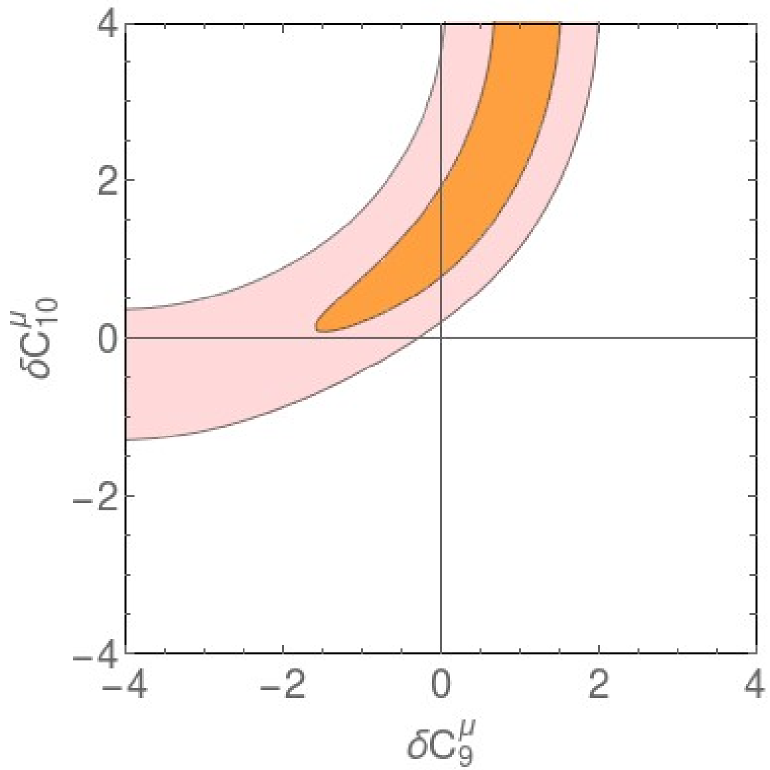
p(SM) = 2.1 x 10^-4 (3.7)

Suggests nonzero C10(BSM)

Pure LUV fit

Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446
Also Capdevila et al, Ciuchini et al, Altmannshofer et al, D'Amico et al, Hiller & Nisandzic

Obs.	Expt.	SM	$\delta C_L^\mu = -0.5$	$\delta C_9^\mu = -1$	$\delta C_{10}^\mu = 1$	$\delta C_9'^\mu = -1$
R_K [1, 6] GeV^2	0.745 ± 0.090	$1.0004^{+0.0008}_{-0.0007}$	$0.773^{+0.003}_{-0.003}$	$0.797^{+0.002}_{-0.002}$	$0.778^{+0.007}_{-0.007}$	$0.796^{+0.002}_{-0.002}$
R_{K^*} [0.045, 1.1] GeV^2	0.66 ± 0.12	$0.920^{+0.007}_{-0.006}$	$0.88^{+0.01}_{-0.02}$	$0.91^{+0.01}_{-0.02}$	$0.862^{+0.016}_{-0.011}$	$0.98^{+0.03}_{-0.03}$
R_{K^*} [1.1, 6] GeV^2	0.685 ± 0.120	$0.996^{+0.002}_{-0.002}$	$0.78^{+0.02}_{-0.01}$	$0.87^{+0.04}_{-0.03}$	$0.73^{+0.03}_{-0.04}$	$1.20^{+0.02}_{-0.03}$
R_{K^*} [15, 19] GeV^2	–	$0.998^{+0.001}_{-0.001}$	$0.776^{+0.002}_{-0.002}$	$0.793^{+0.001}_{-0.001}$	$0.787^{+0.004}_{-0.004}$	$1.204^{+0.007}_{-0.008}$



Theory uncertainties negligible.

1sigma and 3sigma confidence regions

C10(BSM)>0 favoured

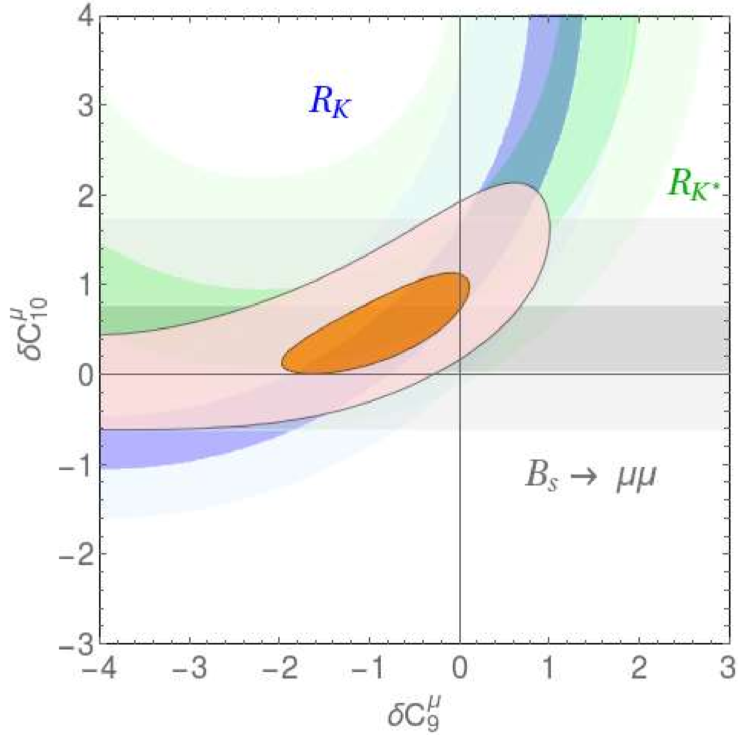
p = 0.158

SM pull 3.78 sigma

Considerable degeneracy (flat direction in chi2)

Adding Bs->mu mu

Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446



Selective probe of C10 (and C10')

Theory error negligible relative to exp (will hold till the end of HL-LHC !)

Considerably narrows the allowed fit region

p = 0.191

SM pull 3.76 sigma

Fit prefers nonzero CL = (C9-C10)/2

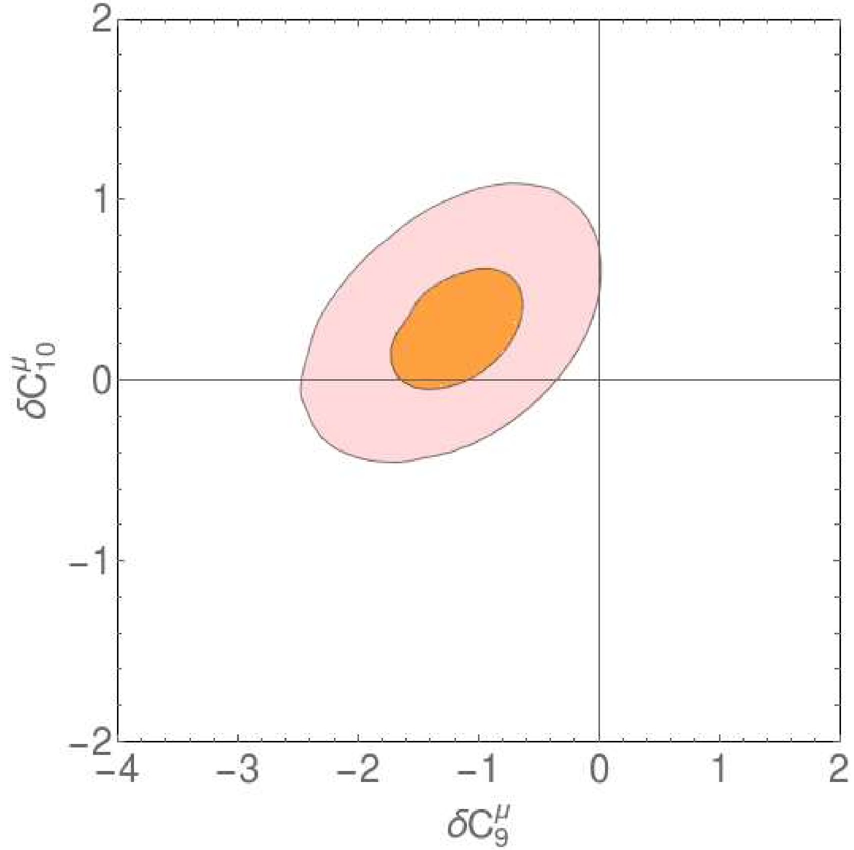
CR = (C9+C10)/2 not well constrained and consistent with zero

1-parameter CL fit: besf fit -0.61. 1sigma [-0.78, -0.41], p = 0.339

SM point (origin) excluded at 4.16 sigma

Adding B->K*mu mu angular

Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446



Serves to determine best-fit region even better.

SM pull 4.17 sigma

p = 0.572

(but p(SM) now up to to 0.086)

Wilson coefficient value CL=0 again excluded at high confidence.

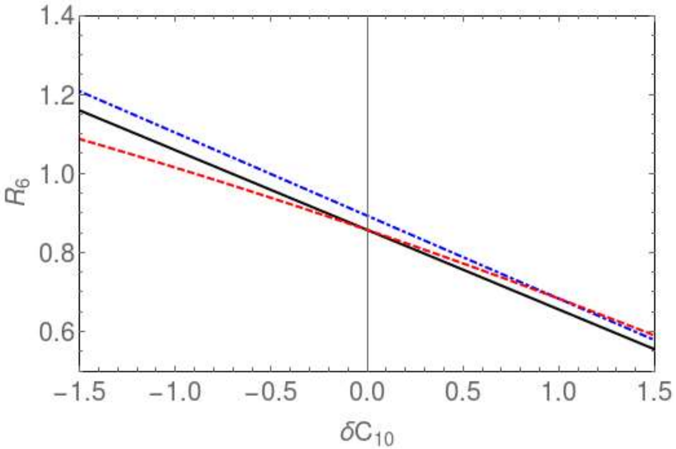
Determining CR (break C9/C10 degeneracy)

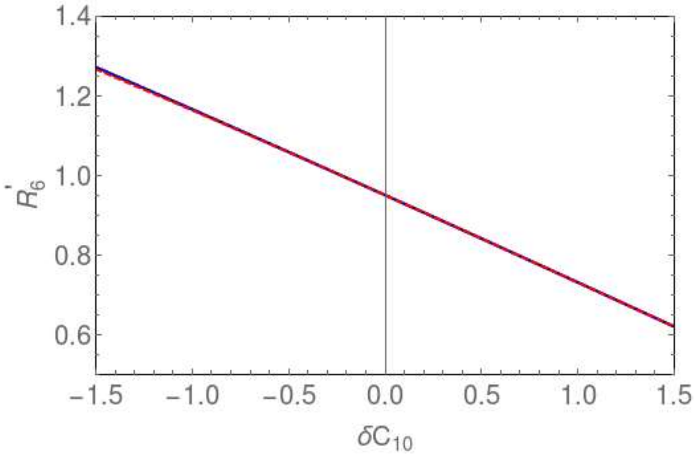
Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446

Propose to measure observable

$$R_6[a,b] = \frac{\int_a^b \Sigma_6^\mu dq^2}{\int_a^b \Sigma_6^e dq^2} \approx \frac{C_{10}^\mu}{C_{10}^e} \times \frac{\int_a^b |\vec{k}| q^2 \beta_\mu^2 \,\mathrm{Re}[H_{V-}^{(\mu)}(q^2)] V_-(q^2)}{\int_a^b |\vec{k}| q^2 \,\mathrm{Re}[H_{V-}^{(e)}(q^2)] V_-(q^2)}$$

and/or $R_6' = \langle P_2^{(\mu)} \rangle / \langle P_2^{(e)} \rangle$



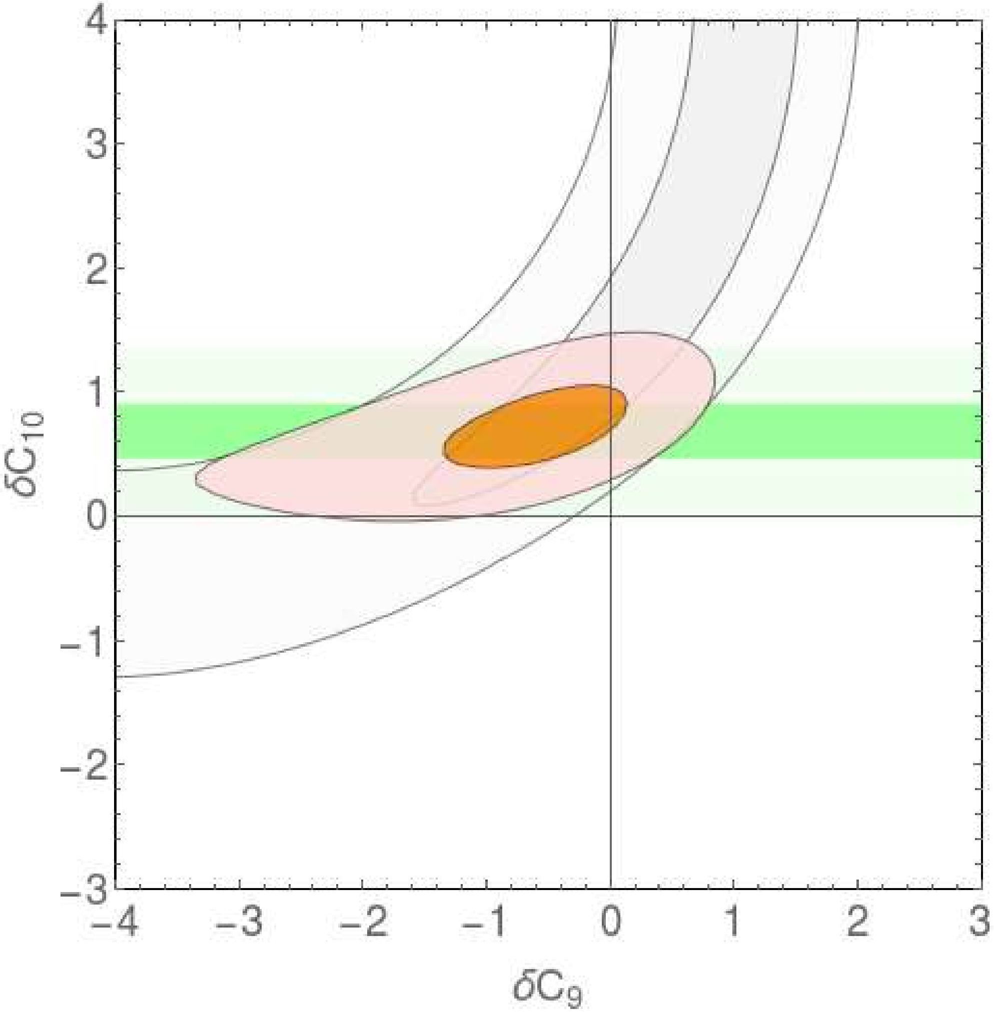


Remains very clean in presence of new physics.
Probes a LUV C10 precisely, irrespective of values of C9e, C9mu

Prospective fit with LUV obs. only

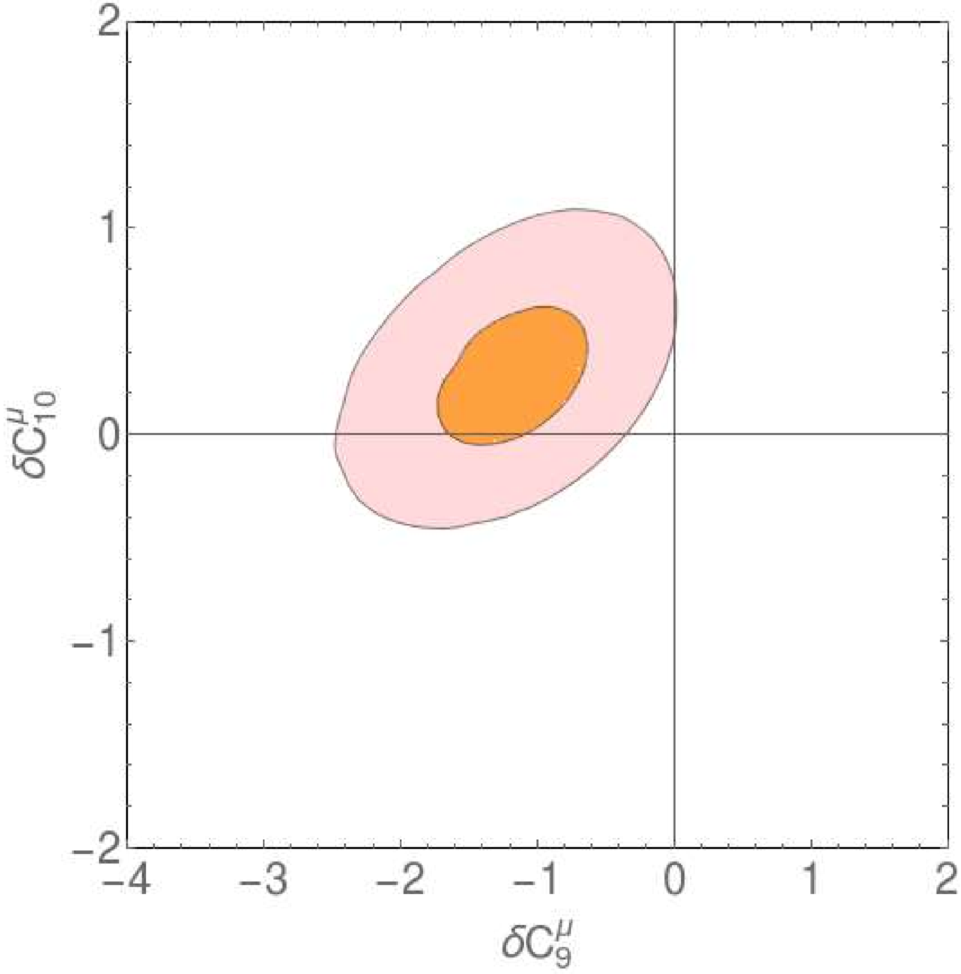
Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446

Consider a hypothetical experimental result R6' = 0.80(5)



Must C9 show LUV ?

Geng, Grinstein, SJ, Martin Camalich, Ren, Shi arxiv:1704.05446



Modified C10 needed to suppress RK* (both bins)

Preference for modified C9 (over C10) is due to angular observables in B->K* mu mu

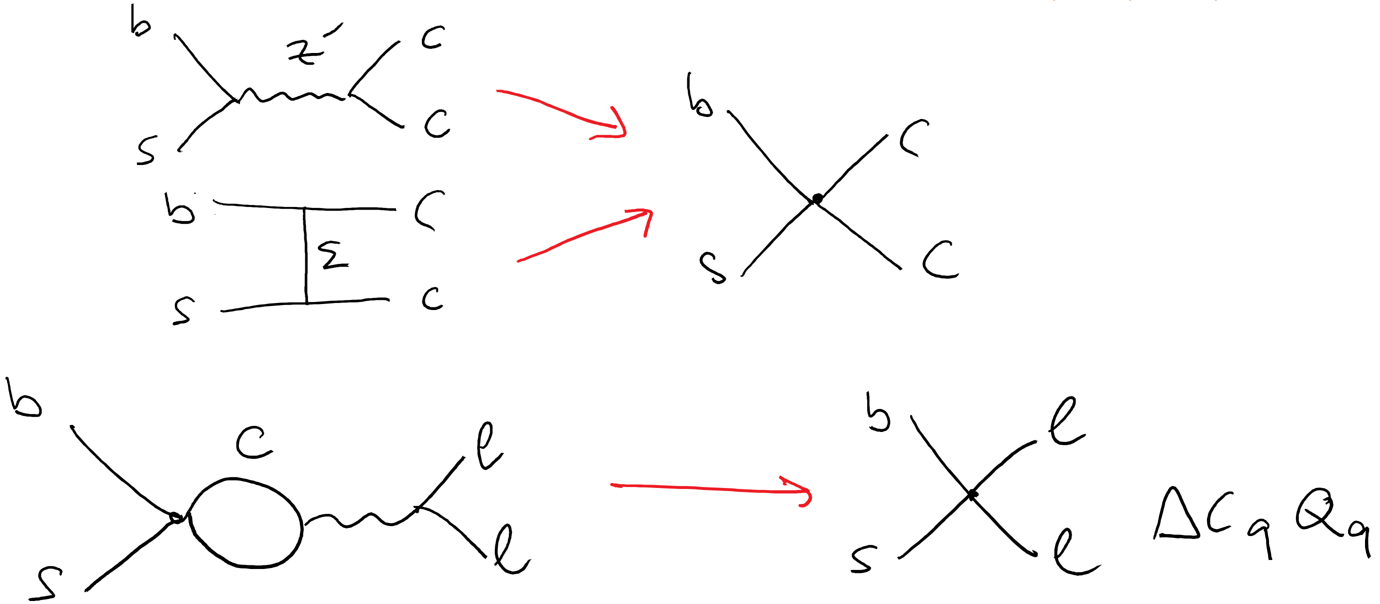
This means a model with (for example) nonzero CLmu and in addition an ordinary, **lepton-flavour-universal, C9**, can describe the data similarly well or better

[plot in progress]

Can generate from 4-quark operators

SJ, Kirk, Lenz, Leslie arxiv:1701.09183

e.g.



efficient way to generate C9(NP) = O(1)

“Charming BSM scenario”

I have (...) heard on good authority that I was dead. (…) The report of my death was an exaggeration.

As we just saw, LUV does allow such a scenario, and may even favour it. We will see that it remains alive in light of othe data.

Charming BSM scenario

SJ, Kirk, Lenz, Leslie arxiv:1701.09183

As long as NP mass scale M is >(>) mb, **model-independently** captured by an effective Hamiltonian with 20 operators/Wilson coefficients (including C1, C2 of SM)

$$
\begin{aligned}
Q_1^c &= (\bar{c}_L^i \gamma_\mu b_L^j)(\bar{s}_L^j \gamma^\mu c_L^i), & Q_2^c &= (\bar{c}_L^i \gamma_\mu b_L^i)(\bar{s}_L^j \gamma^\mu c_L^j), \\
Q_3^c &= (\bar{c}_R^i b_L^j)(\bar{s}_L^j c_R^i), & Q_4^c &= (\bar{c}_R^i b_L^i)(\bar{s}_L^j c_R^j), \\
Q_5^c &= (\bar{c}_R^i \gamma_\mu b_R^j)(\bar{s}_L^j \gamma^\mu c_L^i), & Q_6^c &= (\bar{c}_R^i \gamma_\mu b_R^i)(\bar{s}_L^j \gamma^\mu c_L^j), \\
Q_7^c &= (\bar{c}_L^i b_R^j)(\bar{s}_L^j c_R^i), & Q_8^c &= (\bar{c}_L^i b_R^i)(\bar{s}_L^j c_R^j), \\
Q_9^c &= (\bar{c}_L^i \sigma_{\mu\nu} b_R^j)(\bar{s}_L^j \sigma^{\mu\nu} c_R^i), & Q_{10}^c &= (\bar{c}_L^i \sigma_{\mu\nu} b_R^i)(\bar{s}_L^j \sigma^{\mu\nu} c_R^j),
\end{aligned}
$$

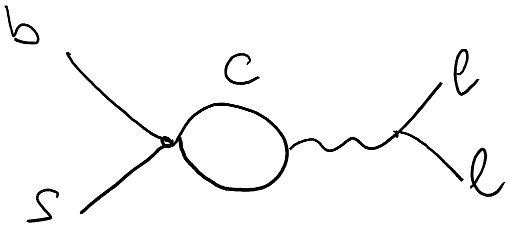
+ parity conjugates

virtual-charm BSM previously considered by

He, Tandean, Valencia (2009) (in a model; did not consider semilept/radiative decays)
Lyon&Zwicky (2014) (as a possible origin of the observed resonance structure in the open-charm region in B->Kmumu)

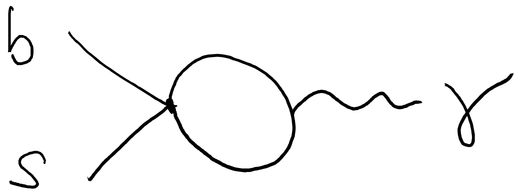
Observables

SJ, Kirk, Lenz, Leslie arxiv:1701.09183



$$\Delta C_9^{\rm eff}(q^2) = \left(C_{1,2}^c - \frac{C_{3,4}^c}{2} \right) h(q^2, m_c, \mu) - \frac{2}{9} C_{3,4}^c$$

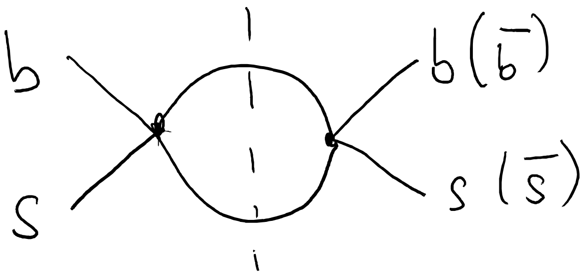
$$C_{x,y}^c = 3\Delta C_x + \Delta C_y$$



$$\Delta C_7^{\rm eff}(q^2) = \frac{m_c}{m_b} \left[(4 C_{9,10}^c - C_{7,8}^c) y(q^2, m_c, \mu) + \frac{4\, C_{5,6}^c - C_{7,8}^c}{6} \right]$$

note that h and y are q2-dependent

At one loop, radiative decay constrains C5..C10, but not C1..C4.
Focus on the latter. Then consider lifetime (mixing) observables

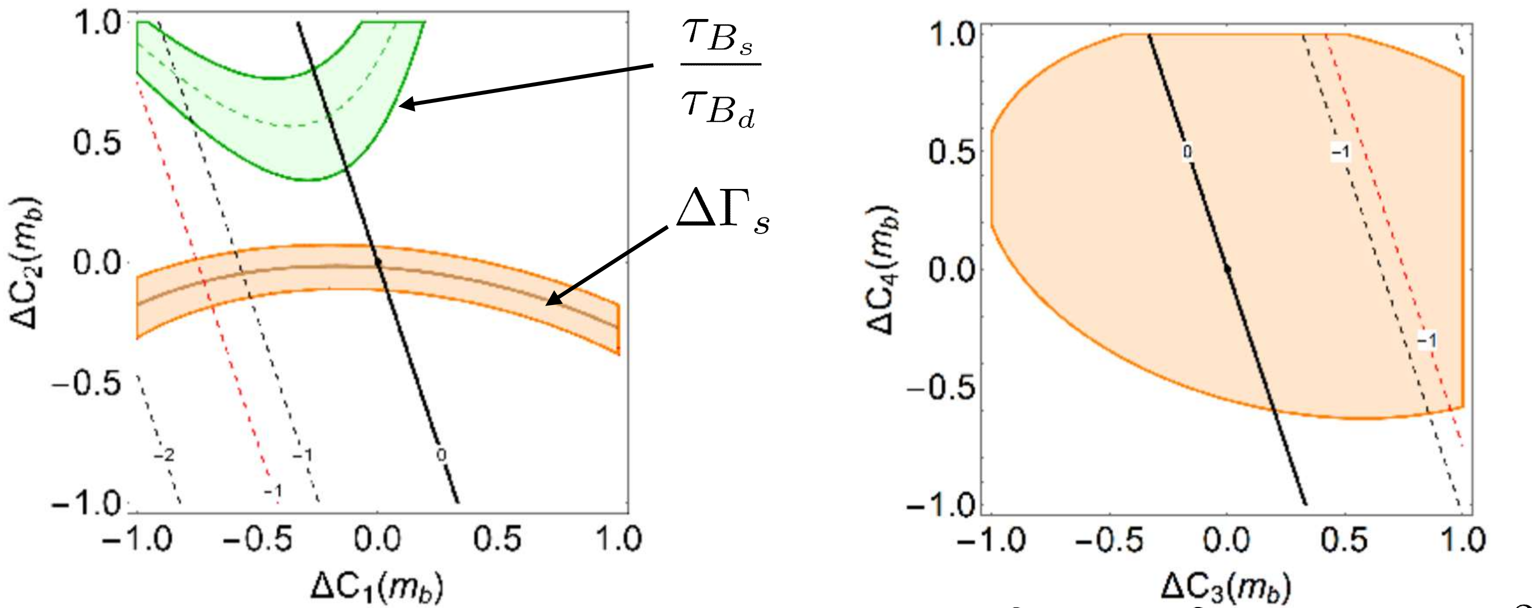


$\Delta\Gamma_s$ and τ_{B_s}/τ_{B_d} calculable in OPE
for general C1 .. C4

Phenomenology – low NP scale

SJ, Kirk, Lenz, Leslie arxiv:1701.09183

If ln(M/m_B) not large, higher-order corrections (including RGE effects) small. Can set $\mu \sim m_B, m_b$ (we choose mu = 4.6 GeV).



Straight lines: $\Delta C_9(q^2)$ contours. Red dotted: q^2=2 GeV^2, black: 5 GeV^2.

Can easily accommodate P5' anomaly while satisfying width difference.

Note that the lifetime ratio is not well consistent with the SM. Could reconcile with CBSM physics, but never consistent with width difference.

High new physics scale

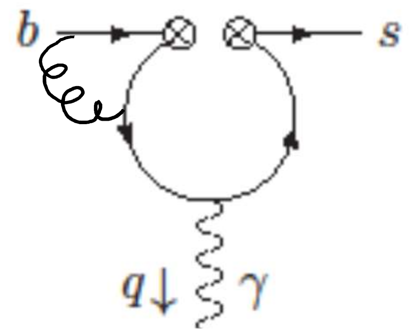
SJ, Kirk, Lenz, Leslie arxiv:1701.09183

If ln(M/m_B) >> 1 then should resum to all orders.

Technically, RG-evolve the Wilson coefficients from μ ~M to μ~ m_B
q2 dependence now a *subleading* (NLL) effect.

For C1 .. C4, leading order is
2-loop for b->s gamma (C7eff)

Technically nontrivial
(spurious IR divergences, scheme dependence of diagrams, spurious gauge-noninvariant terms, etc).



Follow method of Chetyrkin, Misiak, Muenz NPB 518 (1998) 473, hep-ph/9711266

End result gauge- and scheme-independent if expressed in terms of the scheme-independent coefficient $C_7^{\rm eff}$ (which enters observables).

RGE evolution - numerical

SJ, Kirk, Lenz, Leslie arxiv:1701.09183

For evolution from MW to 4.6 GeV: (l.h.s. at 4.6 GeV, r.h.s. at MW)

$$\Delta C_7^{\rm eff} = 0.02\Delta C_1 - 0.19\Delta C_2 - 0.01\Delta C_3 - 0.13\Delta C_4$$
$$\Delta C_9^{\rm eff} = 8.48\Delta C_1 + 1.96\Delta C_2 - 4.24\Delta C_3 - 1.91\Delta C_4$$

Setting Delta C2 to 1 and rest to zero, reproduce the (large) SM charm contribution to C9(4.6 GeV).

But C1 and C3 are even (much) more effective in generating C9!

C2 and C4 feed strongly into C7eff, hence $B \to X_s\gamma$.

But C1 and C3 are practically irrelevant for radiative decay!

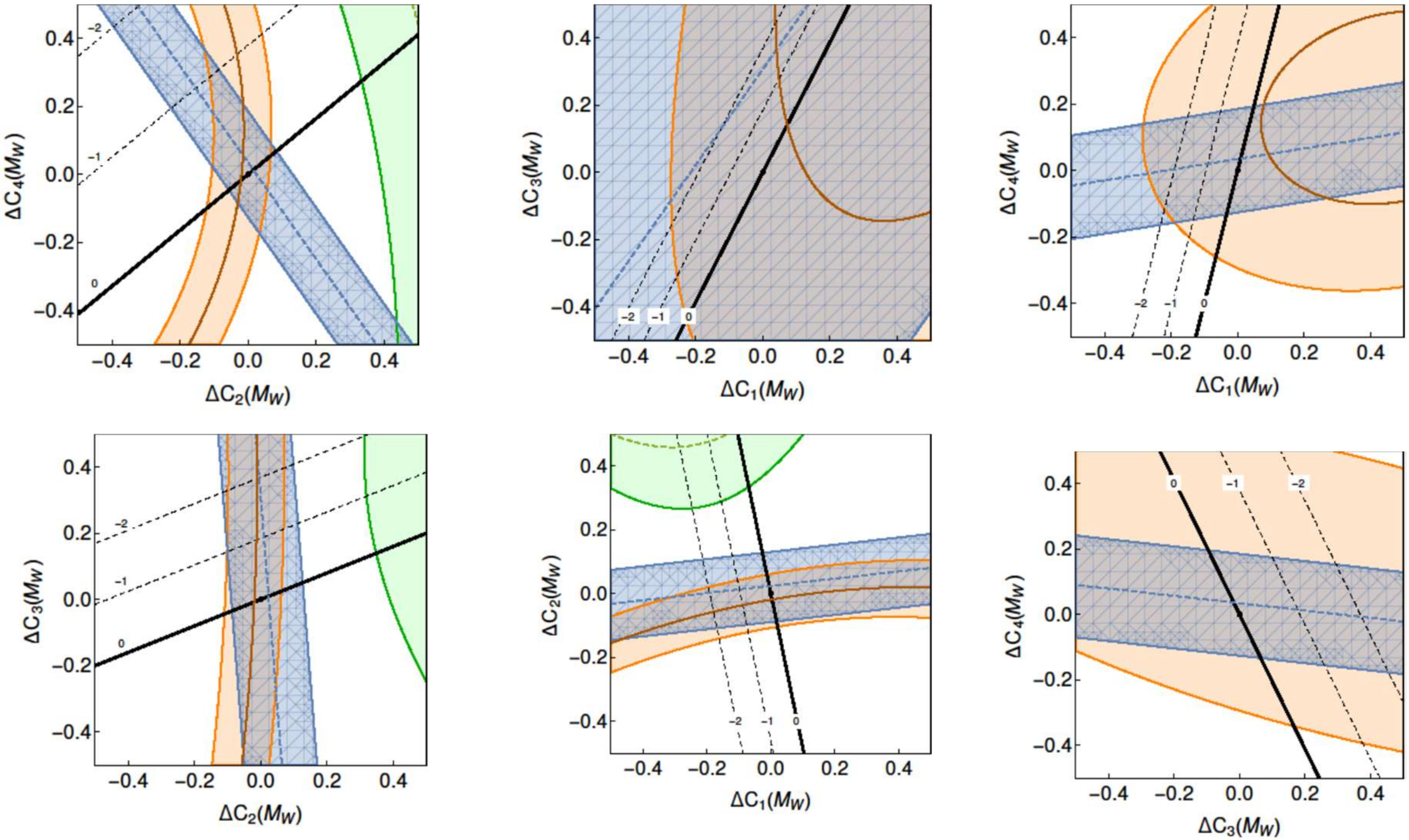
One can also have a ‘pure C2-C4’ scenario, where both contributions to C7eff cancel.

The four-quark Wilson coefficients also evolve, but comparatively mildly (see paper).

High NP scale – global analysis

SJ, Kirk, Lenz, Leslie arxiv:1701.09183

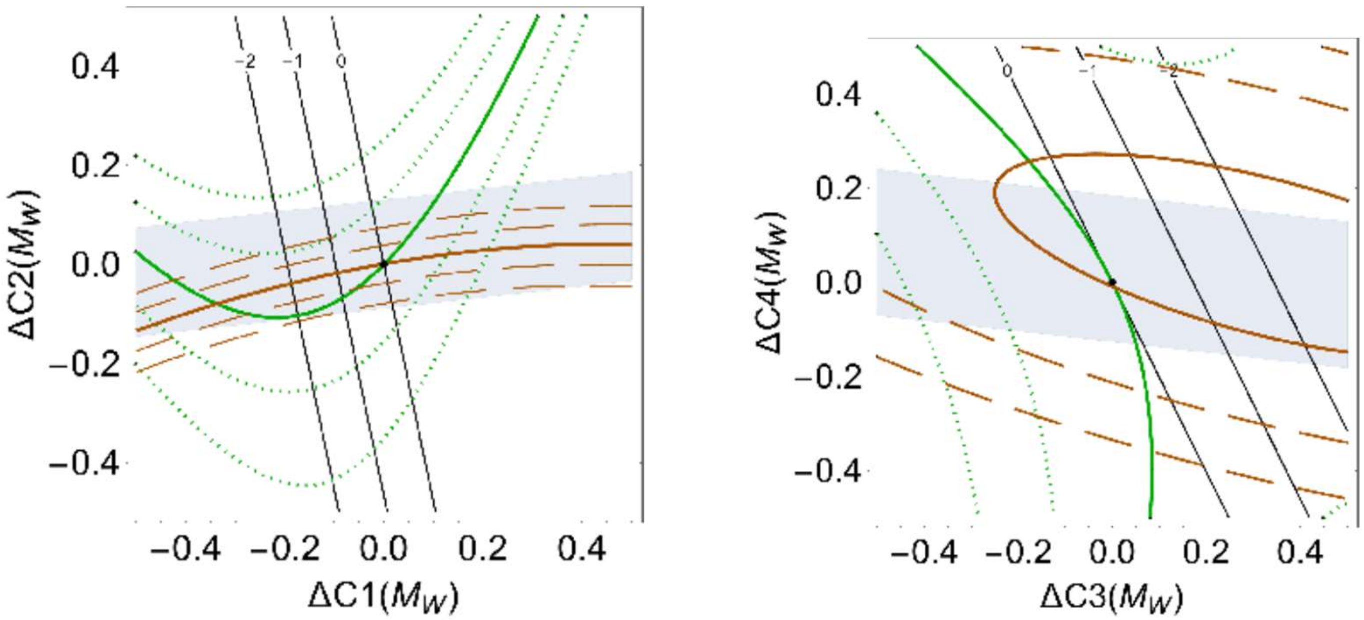
Blue – $B \to X_s\gamma$ experiment



Prospects

SJ, Kirk, Lenz, Leslie arxiv:1701.09183

Width difference, lifetime ratio, and $B \to X_s\gamma$ will all be measured with increased precision at LHCb and Belle2.
May allow to pin down allowed region in CBSM parameter space quite precisely:



Bands between width difference/lifetime contours = projected furture 1-sigma experimental error. According theory progress required.

Conclusions

Several LUV measurements in rare semileptonic decays deviate from SM prediction. (No cherry picking – there are only 3 published measurements so far.

Explaining RK* suggests BSM in C10 which is lepton-flavour-specific. CL = (C9-C10)/2 zero exluded at >4 sigma.
Will be important to pin down effect (C10 versus C9); discussed new LUV measurement with very specific C10 sensitivity

Global fit prefers negative shift of C9 (beyond CL), but this does not need to be LUV. Can be generated through BSM charm penguins.

Interesting interplay with radiative decay and lifetime observables. Viable scenarios exist and could lead to signals in lifetime measurements not normally considered together with rare decays.