Theorist's perspective: BSM & flavour

Sebastian Jäger (University of Sussex)

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Precision frontier: beyond QED

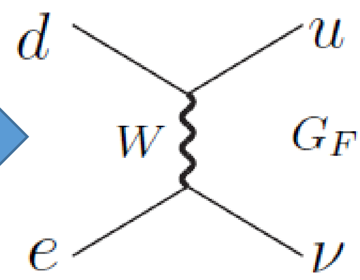
Some past indirect discoveries

- parity violation — Lee, Yang 1956; Wu et al, Goldhaber et al 1957
- V-A structure of weak interactions — Feynman, Gell-Mann 1957; Shudarshan, Marshak 1957
- universality of weak decays — Gell-Mann, Levy 1960
- CP violation — Christenson et al 1964
- electroweak symmetry breaking — BEHGHK, Glashow, Salam, Weinberg 1960-67
- charm to explain $K_L \to \mu\mu$ suppression — Glashow, Iliopoulos, Maiani 1970
- third generation to explain CPV — Kobayashi, Maskawa 1972

Neutral currents (‘73), charm(‘74), 3rd gen. (‘75), W,Z (’83), Higgs (‘12) later discovered.

$$H_W \sim G_F \left(\bar{p}\gamma^\mu n\right)\left(\bar{e}\gamma_\mu \nu\right)$$

(Fermi 1934)



$$G_F = \frac{g^2}{4\sqrt{2}M_W^2}$$

post-GSW

The Standard Model

spin 1

electromagnetism U(1)
weak interactions SU(2)
strong interactions SU(3)

universal couplings — 3 generations

spin 1/2

$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	u_R d_R	$\begin{pmatrix} c_L \\ s_L \end{pmatrix}$	c_R s_R	$\begin{pmatrix} t_L \\ b_L \end{pmatrix}$	t_R b_R	$Q = +2/3$ $Q = -1/3$
$\begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}$	$-$ e_R	$\begin{pmatrix} \nu_{\mu L} \\ \mu_L \end{pmatrix}$	$-$ μ_R	$\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}$	$-$ τ_R	$Q = 0$ $Q = -1$

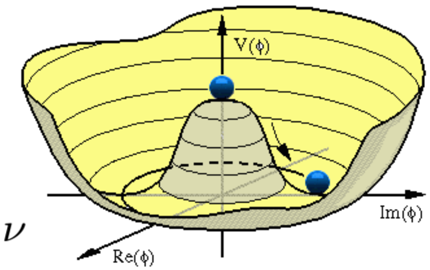
spin 0

Higgs - sets mass scale of entire Standard Model

Origin of masses? Flavour mixings? What determines the weak scale?

Dynamics

At length scales above an attometre we have approximately (up to gravity)



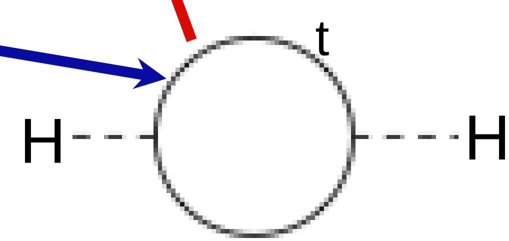
EW scale setting

$SU(3)^5$ flavour symmetric kinetic/gauge terms

$$\mathcal{L}_{\rm SM} = \sum_f \bar{\psi}_f \gamma^\mu D_\mu \psi_f - \frac{1}{4} \sum i, a \frac{g_i}{4} F^{ia}_{\mu\nu} F^{ia\mu\nu}$$

$$-\bar{u}_R Y^U \phi^{c\dagger} q_L - \bar{d}_R Y^D \phi^\dagger q_L - \bar{e}_R Y^E \phi^\dagger l_L - \mu^2 \phi^\dagger \phi - \frac{\lambda}{2} \left(\phi^\dagger \phi\right)^2$$

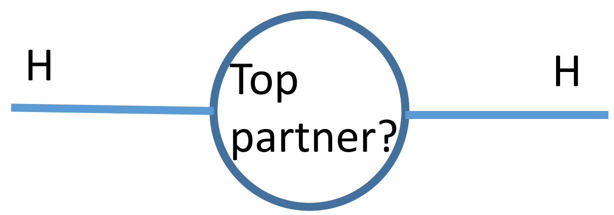
flavour-breaking fermion masses
and Higgs couplings



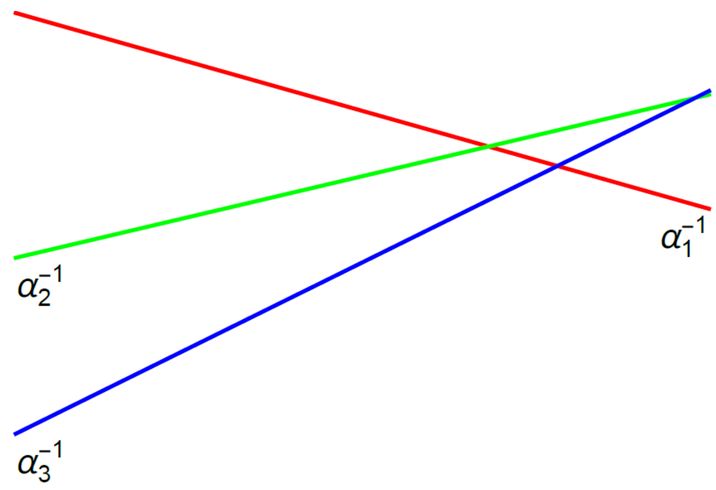
$\propto y_t^2 M^2$

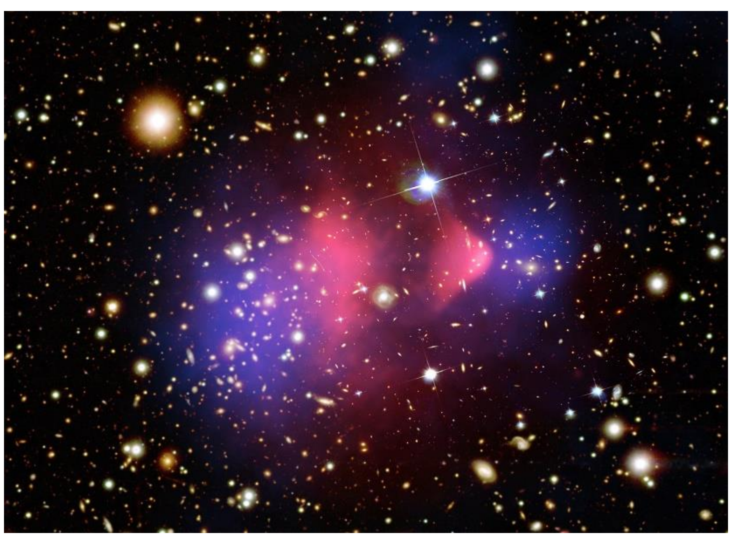
Quadratic divergence from flavour-breaking sources -> any cure likely to be flavour-breaking (happens in SUSY, composite Higgs, …)

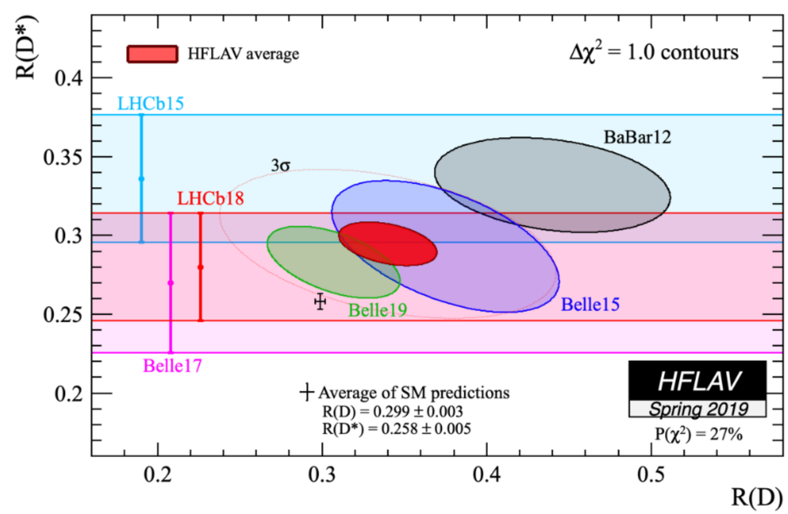
Beyond the SM



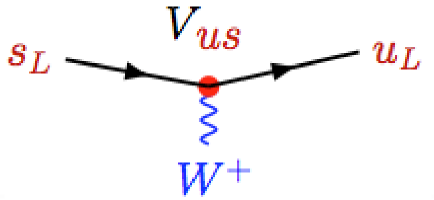
$$\Delta m_H^2 \propto y_t^2 \Lambda_{\rm UV}^2$$



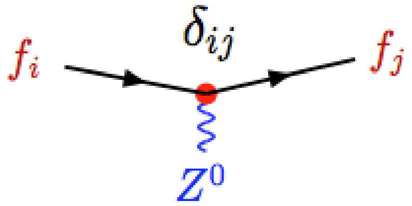




Flavour physics & rare decays



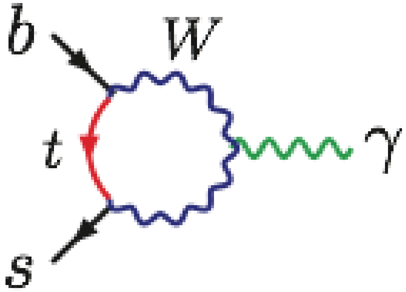
all flavour violation in charged weak current



(tree level) neutral current conserves flavor

strong & electromagnetic preserve flavour

Loop and CKM/GIM suppression of flavour-changing neutral current processes



-> enhanced BSM sensitivity

Flavour: the dogs that did not bark

From AC Doyle, "The Adventure of Silver Blaze" [with thanks to J Ellis]

> Gregory (Scotland Yard detective): "Is there any other point to which you would wish to draw my attention?"
> Holmes: "To the curious incident of the dog in the night-time."
> Gregory: "The dog did nothing in the night-time
> Holmes: "That was the curious incident."

Quote and S Paget's illustration via Wikipedia

Absence of an effect in a BSM-sensitive observable can be as important a clue as an anomaly.

Eg Meson-antimeson mixing → constrain NP scales up to 10^5 TeV (for maximally flavor-violating BP)

Where to look

Observables with suppressed and/or controlled SM contribution

- flavour-changing neutral currents, eg

  Meson-antimeson mixing (B_s, B_d, D , K)

  $b \to s\mu^+\mu^-$ and $b \to s\gamma$

  $B \to K^{(*)} \mu^+\mu^-$, $B \to K^{(*)} e^+e^-$, $B_s \to \phi\mu^+\mu^-$
  $B \to K^{(*)} \gamma$ — Babar, Belle; LHCb, ATLAS, CMS; Belle2

  $B \to X_s \mu^+\mu^-$, $B \to X_s \gamma$ — Babar, Belle, Belle2

  $s \to d\nu\nu$

  $K^+ \to \pi^+ \nu \nu$ — NA62 (CERN)

- lepton-flavour ratios, eg

  $BR(B \to K^{(*)} \mu^+\mu^-)/BR(B \to K^{(*)} e^+e^-) - 1$ — Babar, Belle, LHCb; Belle2

  $BR(B \to D^{(*)} \tau\nu)/BR(B \to D^{(*)} l\nu) - (SM)$

- CP violation, eg

  $K_L \to \pi\,\pi$ (ε_K, ε'_K) — …, NA48, KTeV

  $K_L \to \pi^0 \nu\,\nu$ — KOTO

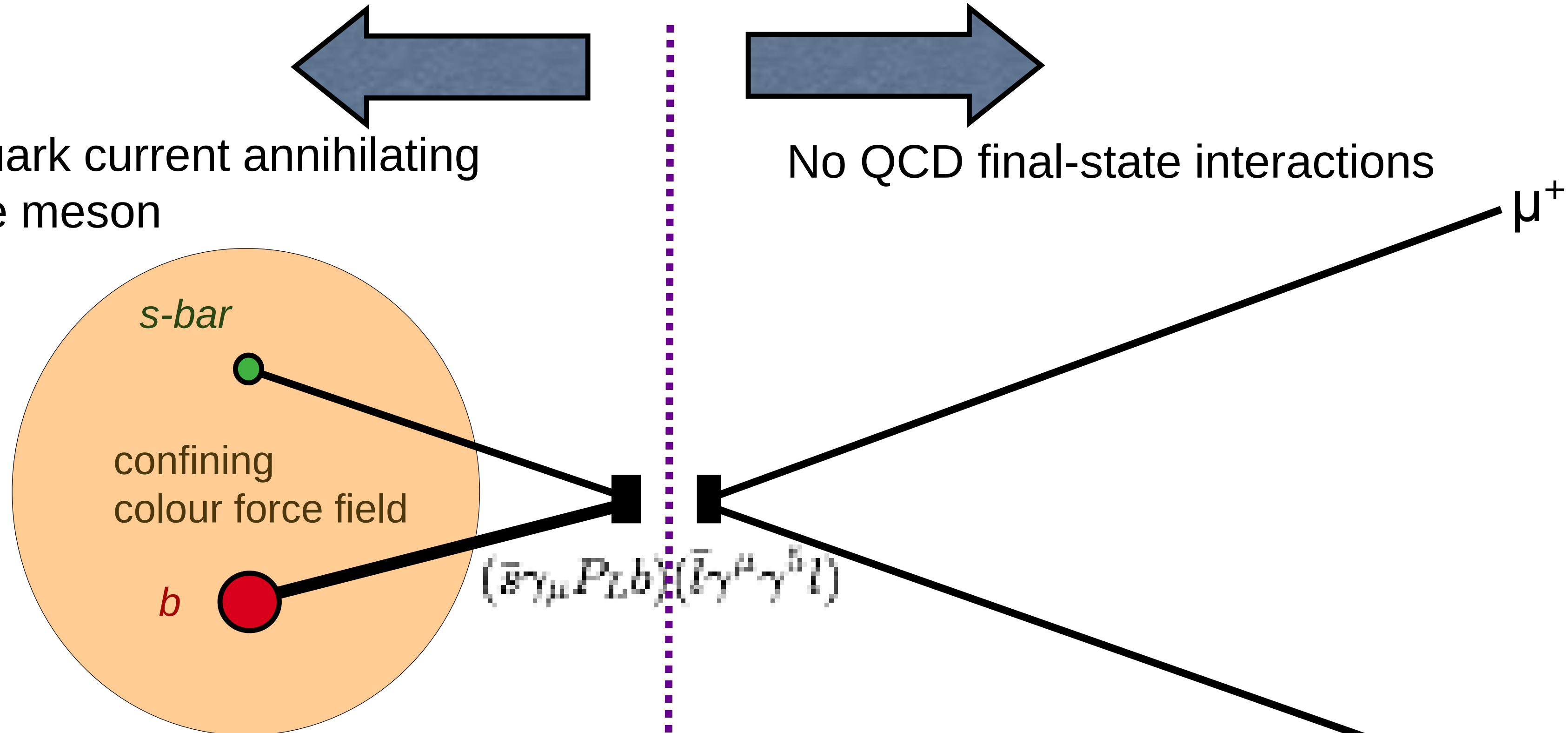
ATLAS analyses

Analysis	Expected/plausible BSM scale	theory	current BSM significance
B(s,d) -> mu mu	(few) TeV (nat'lness)	excellent	2-3 σ
RK(*)	(few) TeV (nat'lness)	excellent	3-4 σ
B->K*mu mu (ee?) angular	(few) TeV (nat'lness)	good (P5') to excellent (rh current)	unclear
Tau->3 mu	GUT scale or below	excellent	none
B->J/psi phi etc	(few) TeV	depends	none
B lifetimes	(few) TeV	depends	none
4 muons searches			
Bc/Bc(2S)	} Outside scope of what I can discuss in this talk		
Pentaquark/Zc			
CPV in b from ttbar			

A “clean” observable: Leptonic decay

Quark current annihilating the meson

No QCD final-state interactions



parameterised by a decay constant
not calculable in perturbation theory

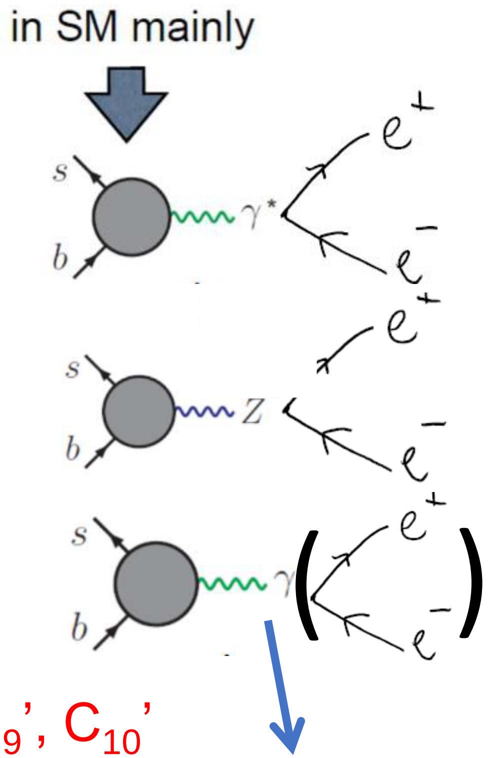
quantum electrodynamics only
very well controlled theoretically

Very small long-distance QED corrections Beneke, Bobeth, Szafron 2019

leading theory uncertainty are CKM parameters & decay constant

Rare B-decay: short-distance (theory)

BSM (and SM weak interactions) enter flavour physics through effective contact interactions (SMEFT/H_{weak})



C_9: dilepton from vector current

$$(\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l)$$

C_{10}: dilepton from axial current

$$(\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma^5 l)$$

C_7: dilepton from dipole

$$(\bar{s}\sigma^{\mu\nu} P_R b)F_{\mu\nu}$$

+parity conjugate "right-handed currents" - C_7', C_9', C_{10}' suppressed by m_s/m_b in SM

Can also have real photon

Alternative basis with chiral leptons l_L, l_R

$$C_L = (C_9 - C_{10})/2 \qquad C_R = (C_9 + C_{10})/2$$

Also “clean”: Lepton-flavour ratios

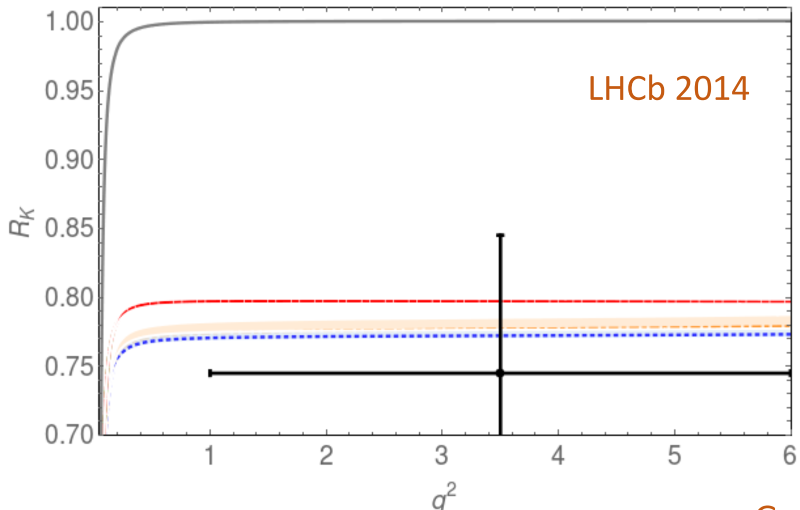
$$R_{K^{(*)}}[a,b] = \frac{\int_a^b \frac{d\Gamma}{dq^2}(B \to K^{(*)}\mu^+\mu^-)dq^2}{\int_a^b \frac{d\Gamma}{dq^2}(B \to K^{(*)}e^+e^-)dq^2}$$

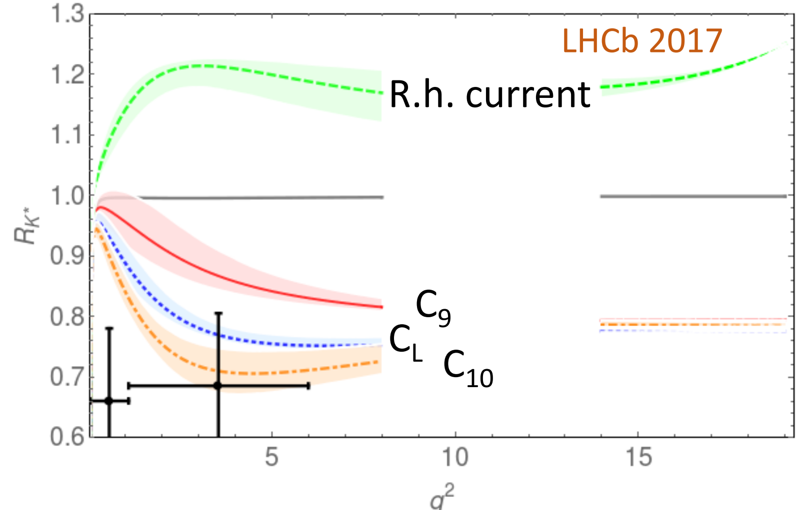
Theory uncertainties largely cancel out, negligible relative to experiment.

leading is QED: net effect <1% after experimental corrections

Bordone, Isidori, Pattori 2016; Isidori, Nabeebaccus, Zwicky 2020

Situation in 2017 (first RK* measurement):





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

Rare B-decay anomalies – fit to data

Observables in the fit

Basic idea: use only observables which are sensitive to b->s l l but independent of hadronic form factors, long-distance charm etc.

I.e. $R_{K(*)}$ and B_s -> mu mu.

This is a well-defined set of observables, first employed in 2017, with several data updates since then. No "look-elsewhere effect" to take into account.

In the following I describe the fit in arXiv:2103.12738 (Geng, Grinstein, SJ, Li, Martin Camalich, Shi); see also work by Altmannshofer & Stangl and a few others

A note on the $B_s \to \mu\mu$ input

Together with the R_{K^*} update, LHCb presented a significant update to $BR(B_s \to \mu\mu)$

ATLAS and CMS have also measured this

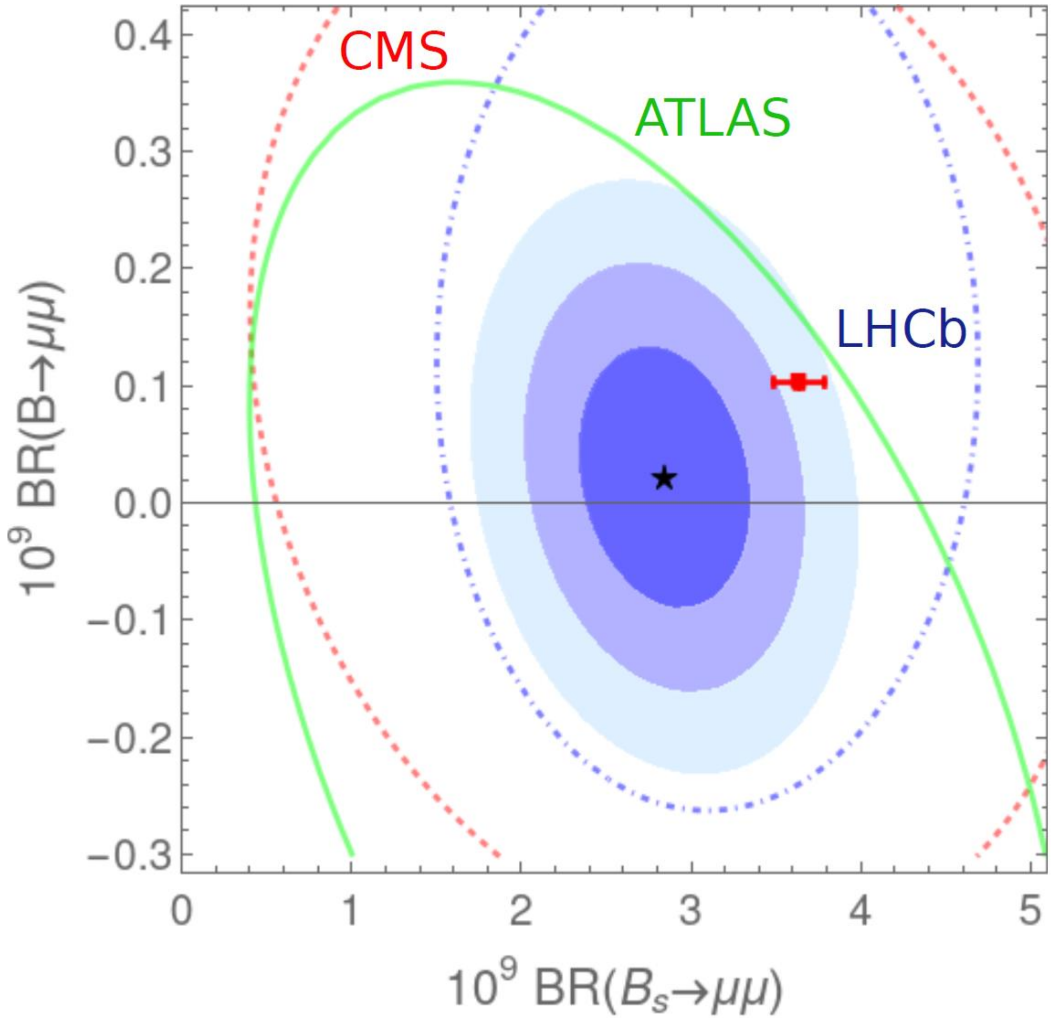
Measurements show non-negligible correlations with $BR(B_d \to \mu\mu)$ (biggest in ATLAS).

Hence to obtain a $BR(B_s \to \mu\mu)$ average first combine the 3x2 measurements.

Then profile over $BR(B_d \to \mu\mu)$.

$B_q \to \mu\mu$ world combination

Geng, Grinstein, SJ, Li, Martin Camalich, Shi arXiv:2103.12738



From this:

$BR(B_s \to \mu\mu) = (2.8 \pm 0.3) 10^{-9}$

$\chi^2_{min} = 3.75$ (5 d.o.f.)

Input data

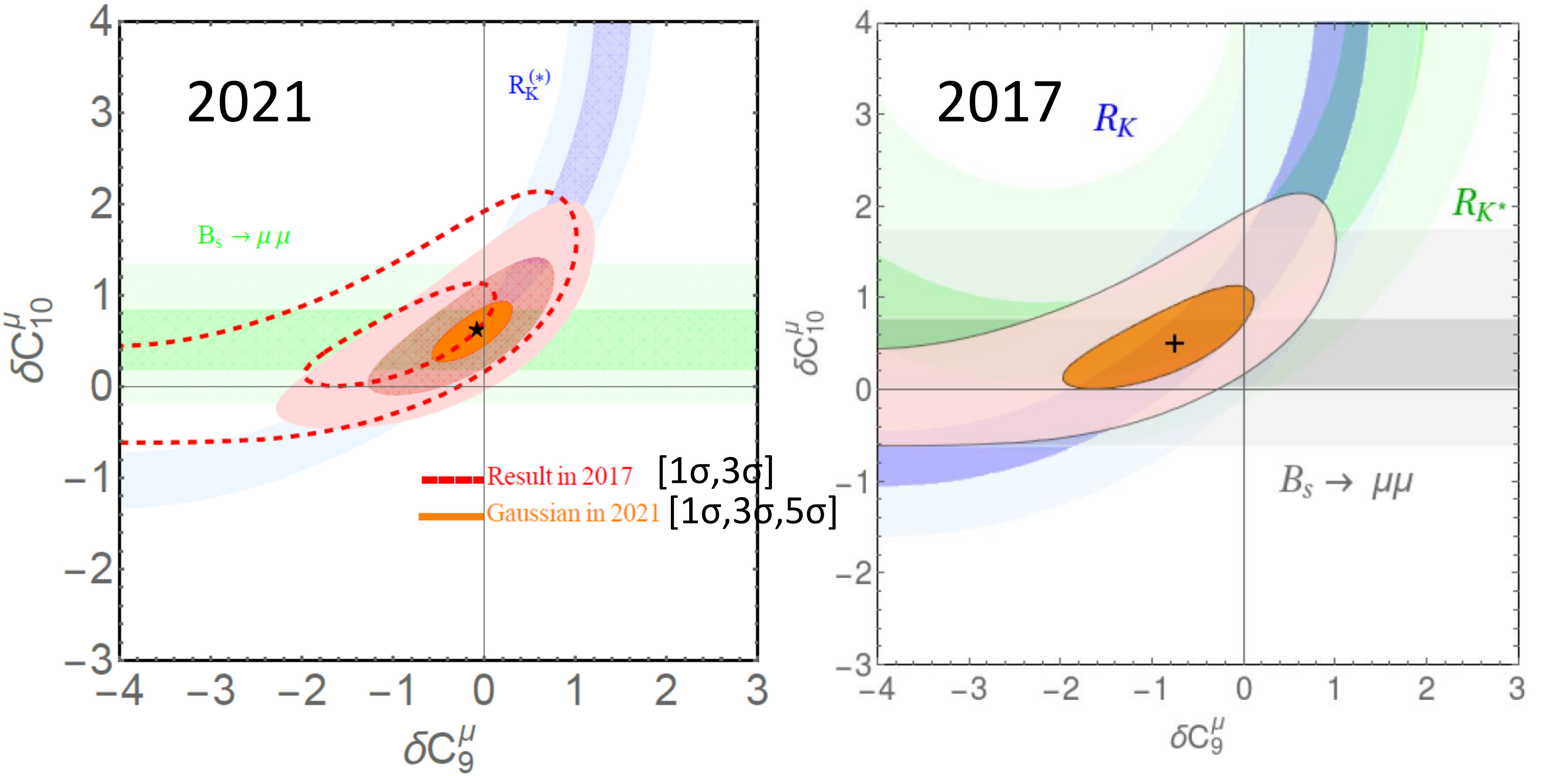
Observable	Value	Source	Reference
$BR(B_s \to \mu^+\mu^-)$	$(2.8^{+0.8}_{-0.7}) \times 10^{-9}$	ATLAS	[11]
	$(2.9 \pm 0.7 \pm 0.2) \times 10^{-9}$	CMS	[12]
	$(3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$	LHCb update	[10]
	$(2.842 \pm 0.333) \times 10^{-9}$	our average	this work
	$(3.63 \pm 0.13) \times 10^{-9}$	SM prediction	[13]
$R_K[1.1, 6]$	0.846 ± 0.044	LHCb	[6]
$R_K[1, 6]$	1.03 ± 0.28	Belle	[14]
$R_{K^*}[0.045, 1.1]$	0.660 ± 0.113	LHCb	[15]
$R_{K^*}[1.1, 6]$	0.685 ± 0.122	LHCb	[15]
$R_{K^*}[0.045, 1.1]$	0.52 ± 0.365	Belle	[16]
$R_{K^*}[1.1, 6]$	0.96 ± 0.463	Belle	[16]

Self-consistency of dataset: χ^2_{min}= 4.61 (8 d.o.f.) / p = 0.80 (counting 6 BR($B_q \to \mu\mu$) measurements)

SM p-value is 5.4 x 10^{-5} (4.0σ) [counting BR($B_s \to \mu\mu$) average] reduces to 3.5σ when counting the 6 BR($B_q \to \mu\mu$) measurements separately

Clean fit: results: 2-parameter BSM fit

Geng, Grinstein, SJ, Li, Martin Camalich, Shi   arXiv:2103.12738



Clean fits: numerical results

Geng, Grinstein, SJ, Li, Martin Camalich, Shi arXiv:2103.12738

Fit three 1-parameter scenario (vectorial, axial, left-handed coupling to muons)

TABLE II. Best fit values, $\chi^2_{\rm min}$, p-value, Pull$_{\rm SM}$ and confidence intervals of the Wilson coefficients in the fits of the R_K, R_{K^*}, $B_s \to \mu\mu$ da only using Gaussian form $\chi^2_{\rm th}$. For the cases of single Wilson-coefficient fits, we show the 1σ and 3σ confidence intervals. In the $(\delta C_9^\mu, \delta C_1$ case, the 1σ interval of each Wilson coefficient is obtained by profiling over the other one to take into account their correlation.

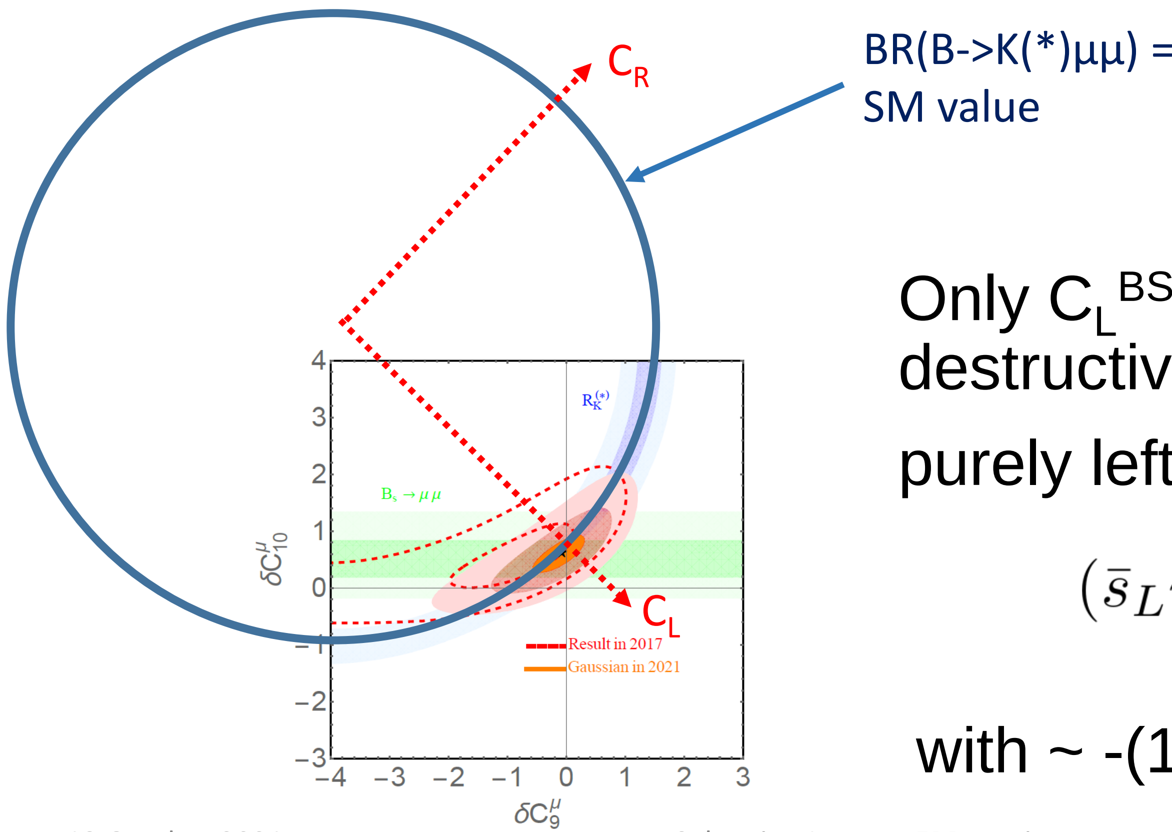
Coeff.	best fit	$\chi^2_{\rm min}$	p-value	Pull$_{\rm SM}$	1σ range	3σ range	ρ
δC_9^μ	-0.82	14.70 [6 dof]	0.02	4.08	$[-1.06, -0.60]$	$[-1.60, -0.20]$	–
δC_{10}^μ	0.65	6.52 [6 dof]	0.37	4.98	$[0.52, 0.80]$	$[0.25, 1.11]$	–
δC_L^μ	-0.40	7.36 [6 dof]	0.29	4.89	$[-0.48, -0.31]$	$[-0.66, -0.15]$	–
$(\delta C_9^\mu, \delta C_{10}^\mu)$	$(-0.11, 0.59)$	6.38 [5 dof]	0.27	4.62	$\delta C_9^\mu \in [-0.41, 0.17]$	$\delta C_{10}^\mu \in [0.38, 0.81]$	0.762
$(\delta C_L^\mu, \delta C_R^\mu)$	$(-0.35, 0.25)$				$\delta C_L^\mu \in [-0.45, -0.26]$	$\delta C_R^\mu \in [0.00, 0.48]$	0.406

Note that C_L is well-determined in both the left-handed and the two-parameter scenario, with consistent values. Not true for C_9. Pure C_9 model also much worse fit (p=1/50).

$R_K^{(*)}$ and C_L

Assume here that the BSM effect is in the muonic mode, and no right-handed currents.

Because in the SM, $|C_R|$, $|C_7| << |C_L|$,
BR ≈ const $|C_L^{SM} + C_L^{BSM}|^2$ + … ≈ const $|4 + C_L^{BSM}|^2$ +positive



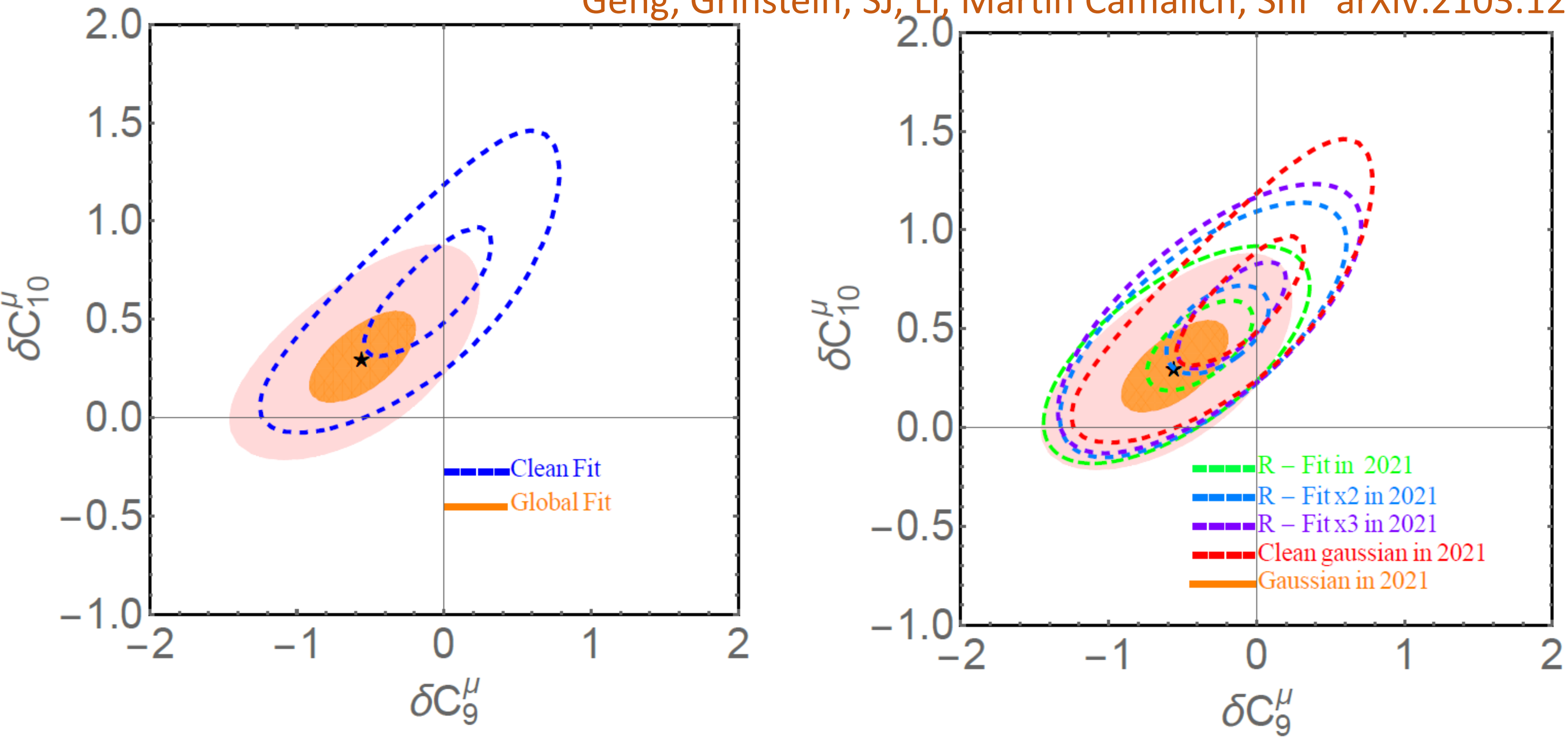
Only C_L^{BSM} can interfere destructively: $R_K^{(*)}$ point to purely left-handed coupling

$$(\bar{s}_L \gamma^\mu b_L)\,(\bar{\mu}_L \gamma_\mu \mu_L)$$

with ~ -(10-15)% of SM value

Adding B→K*μμ angular data

Geng, Grinstein, SJ, Li, Martin Camalich, Shi arXiv:2103.12738



Left plot: extra data pulls fit approx. along the C_R direction.
C_L=0 remains excluded at high confidence.
p(SM) up at 0.02
Right plot: effect of increasing hadronic uncertainties

Minimal contact interaction

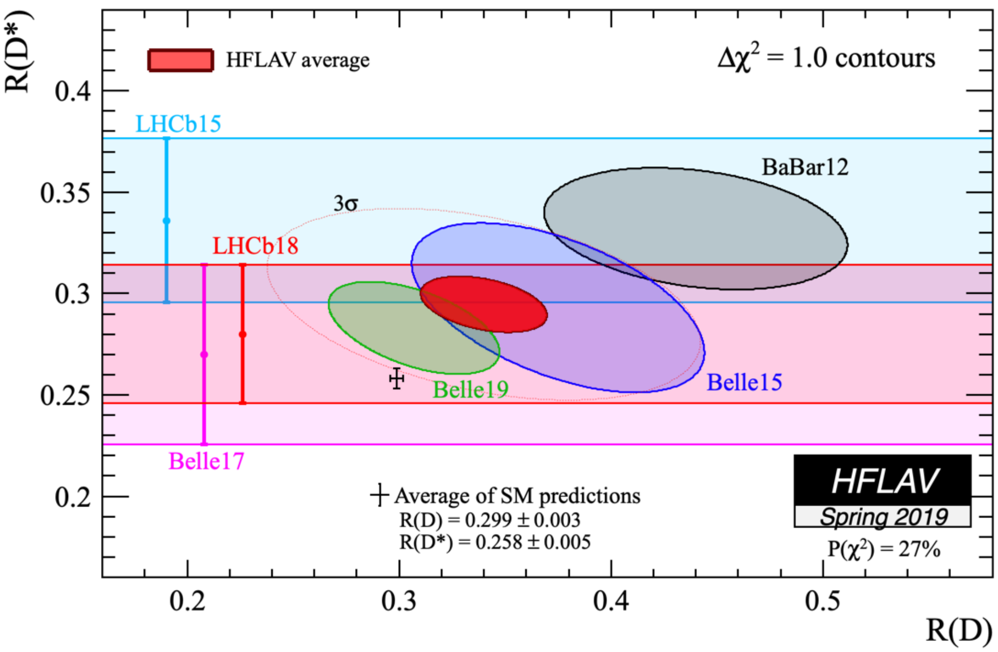
In summary, the B-decay anomalies suggest at a minimum the interaction

$$\frac{1}{\Lambda^2}\left(\bar{s}_L \gamma^\mu b_L\right)\left(\bar{\mu}_L \gamma_\mu \mu_L\right)$$

numerically Λ ~ 40 TeV

Small enough to be a loop effect even BSM (as it is in SM!)

Non-rare semileptonic decays



$$R(D^{(*)}) = \frac{BR(B \to D^{(*)}\tau\nu_\tau)}{BR(B \to D^{(*)}\ell\nu_\ell)}$$

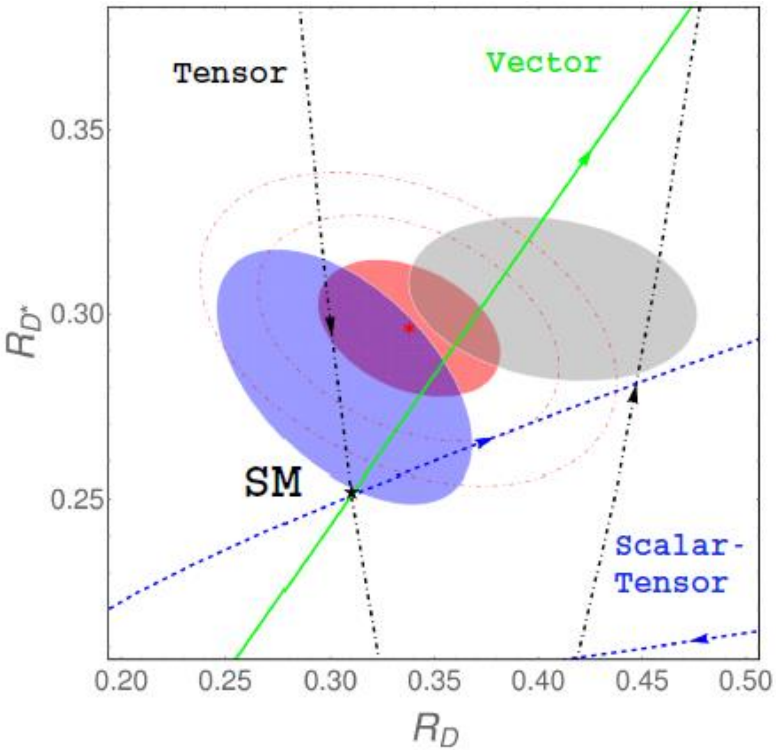
SM **tree-level**

large effect; theory error still (almost) negligible

Possible BSM

ε_R^l flavour-universal by SU(2) x U(1) invariance (no dim-6 SMEFT operator)

$$\mathcal{L}_{\rm eff}^{\rm LE} \supset -\frac{4G_F V_{cb}}{\sqrt{2}}[(1+\epsilon_L^\tau)(\bar\tau\gamma_\mu p_L\nu_\tau)(\bar c\gamma^\mu P_L b) + \epsilon_R^\tau(\bar\tau\gamma_\mu P_L\nu_\tau)(\bar c\gamma^\mu P_L b)$$
$$+\epsilon_{S_L}^\tau(\bar\tau P_L\nu_\tau)(\bar c P_L b) + \epsilon_{S_R}^\tau(\bar\tau P_L\nu_\tau)(\bar c P_R b) + \epsilon_T^\tau(\bar\tau\sigma_{\mu\nu}P_L\nu_\tau)(\bar c\sigma^{\mu\nu}P_L b)] + \text{H.c.},$$



Best fit value moved **substantially** closer to SM with Belle 2019 update

Different BSM operators imply different correlations between shifts to RD, RD*

BSM implications of B-anomalies (qualitative)

Scale of new physics

Di Luzio, Nardecchia 2017

B-decay anomalies point to (at least) the interactions

$$\frac{1}{\Lambda^2}\left(\bar{c}_L\gamma^\mu b_L\right)\left(\bar{\nu}_\tau\gamma_\mu\tau_L\right) \qquad \frac{1}{\Lambda^2}\left(\bar{s}_L\gamma^\mu b_L\right)\left(\bar{\mu}_L\gamma_\mu\mu_L\right)$$

numerically $\Lambda \sim 4$ TeV and $\Lambda \sim 40$ TeV.

For a tree-level mediator,

$$\Lambda^{-2} = (g_{NP}\, M_{NP})^{-2} \quad \rightarrow \quad M_{NP} = g_{NP}\, \Lambda \leq 4\pi\, \Lambda \sim (30,\ 300\ \text{TeV})$$

Stronger constraint from partial-wave unitarity: maximal NP scale of below 10 (100) TeV.

If the NP is less than maximally flavour-violating, or the NP is weakly coupled, the scale will be 1-2 orders of magnitudes lower.

While the bounds are (so far) high, the fact that there are any at all should be encouraging, further refinements may be possible.

Tree-level mediators: leptoquarks

Scalar or vector leptoquarks can generate interactions

Eg Gripaios, Nardecchia, Renner, …
(Hiller, Nisandzic 2017)

$$\frac{1}{\Lambda^2}(\bar{c}_L\gamma^\mu b_L)(\bar{\nu}_\tau\gamma_\mu\tau_L)$$

$$\frac{1}{\Lambda^2}(\bar{s}_L\gamma^\mu b_L)(\bar{\mu}_L\gamma_\mu\mu_L)$$

$(3,1,-1/3)$ or $(3,3,2/3)$

$(3,3,-1/3)$

$(3,1,2/3)$ or $(3,3,2/3)$

$(3,1,2/3)$ or $(3,3,2/3)$

(more possibilities at loop level Eg Bauer,Neubert; Becirevic et al)

Tree-level mediators: W', Z'

$$\frac{1}{\Lambda^2}\left(\bar{c}_L\gamma^\mu b_L\right)\left(\bar{\nu}_\tau\gamma_\mu\tau_L\right)$$

$$\frac{1}{\Lambda^2}\left(\bar{s}_L\gamma^\mu b_L\right)\left(\bar{\mu}_L\gamma_\mu\mu_L\right)$$

$(0,3,0)$

$(0,3,0)$ or $(0,1,0)$

- appear as resonances in composite models (KK excitations in RS, vectors coupling to symmetry currents in 4D composite models)

- Z' exchange contributes to B_s mixing at tree-level. Leptoquarks do not!

Isidori et al, Quiros et al, Ligeti et al, Becirevic et al, Crivellin et al, …

Summary & outlook

Flavour provides a plethora of observables sensitive to new physics

Stringent constraints on new physics, not only from meson-antimeson mixing

Significant progress in lattice calculations for flavour phenomenology, (much) more to come

B-anomalies – independent verification by upcoming Belle2 experiment. Near-discovery level significance already with theoretically clean measurements

BACKUP

A Z' model for $R_{K(*)}$

Accommodating *all* b->s l l anomalies *requires* a muon-specific C_L –type interaction

$$\frac{1}{\Lambda^2}\left(\bar{s}_L \gamma^\mu b_L\right)\left(\bar{\mu}_L \gamma_\mu \mu_L\right)$$

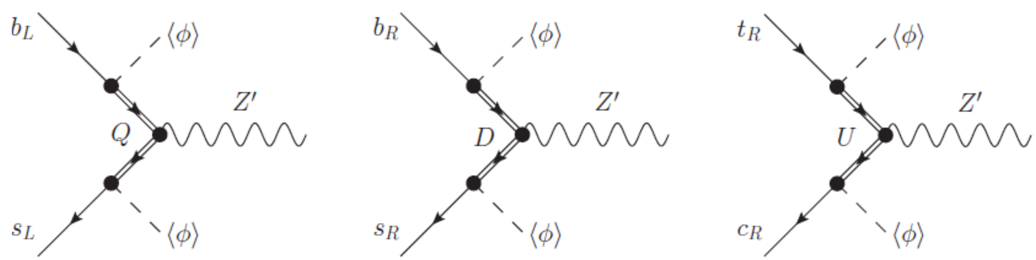
with $\Lambda \sim 30$ TeV

However, C_R is weakly constrained and can also be present.

Anomaly-free Z' model with gauged L_μ - L_τ , nonminimal (dim-6) coupling to quarks, can eg come from heavy vectorlike quarks:

Altmannshofer et al 2014

Also Crivellin et al, …



The small coupling to quarks suppresses contributions to Bs mixing

Importance of virtual charm

Also **purely hadronic** operators enter, in SM primarily:

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

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

RG mixes these into C_9 and C_7

+ dipole

$$C_7^{\rm eff}(4.6{\rm GeV}) = 0.02\, C_1(M_W) - 0.19\, C_2(M_W)$$

$$C_9(4.6{\rm GeV}) = 8.48\, C_1(M_W) + 1.96\, C_2(M_W)$$

SM: O(50%) of total in both cases!

At μ=m_b: C_7^{eff} ~ -0.3 , C_L ~ 4 , $C_R \approx 0$

- SM: accidentally almost left-chiral muon interactions
- Long-distance virtual charm important theory uncertainty

C_9 from BSM $(\bar{s}b)(\bar{\tau}\tau)$ operators

Bobeth, Haisch arXiv:1109.1826
Crivellin et al arXiv:1807.02068

Similarly strong RG mixing into C_9 as in charming BSM case

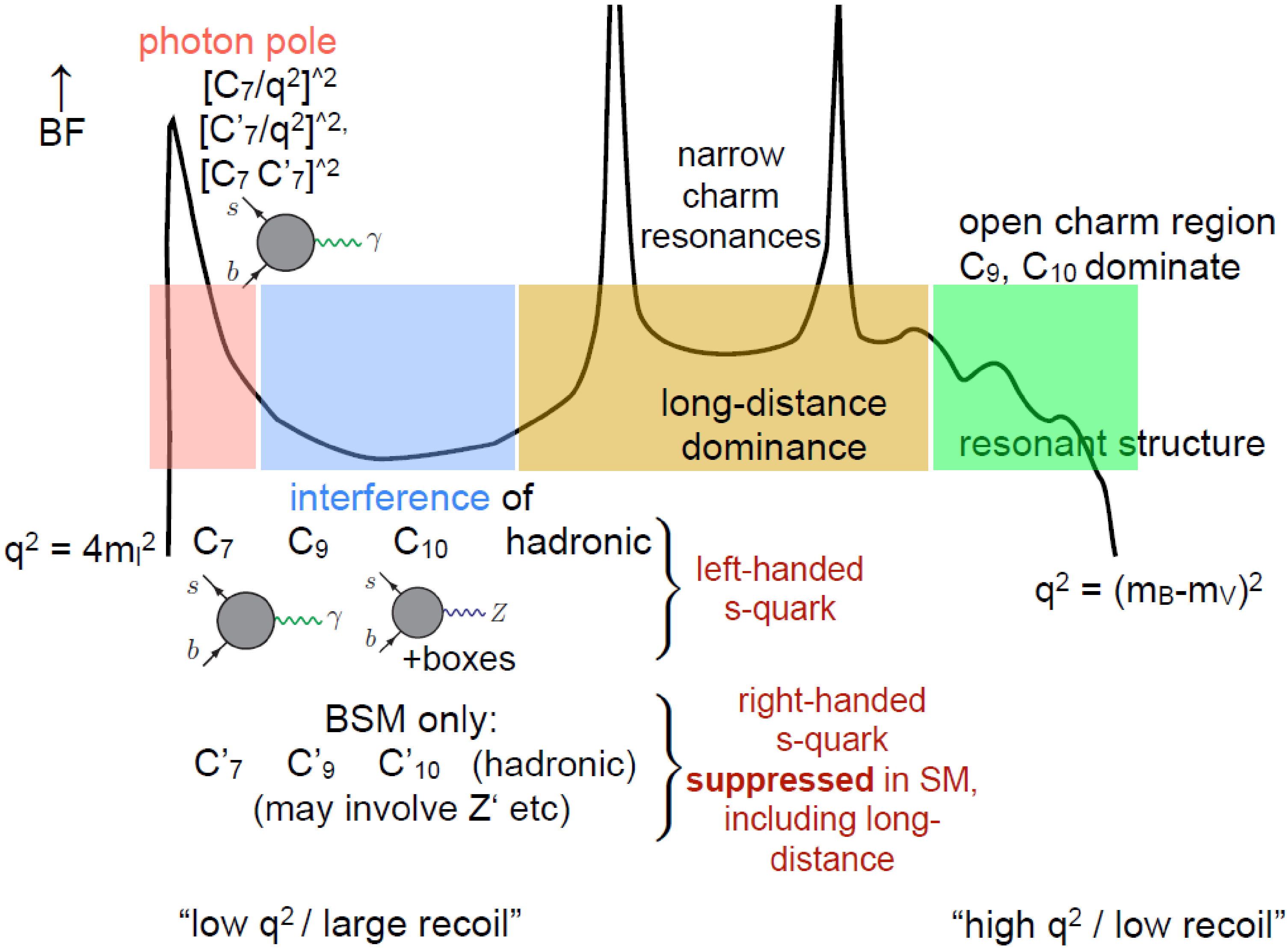
- This operator is automatically present for "left-handed" $R_{D(*)}$ explanations via $(\bar{c}_L \gamma^\mu b_L)(\bar{\nu}_\tau \gamma_\mu \tau_L)$

    This is a consequence of $SU(2)_W$ symmetry and the experimental bound on $B \to K^*\nu\nu$ Buras et al arXiv:1409.4557

- Radiatively generated C_9 is again O(1) and negative (and lepton-universal)

τ

B->V l l: rate (schematic)



Rare decay null tests of the SM

2 clean null tests of SM from (mainly) B → K*γ and B→ K*μμ

$$P_1 \equiv \frac{I_3 + \bar{I}_3}{2(I_{2s} + \bar{I}_{2s})} = \frac{-2\,\mathrm{Re}(H_V^+ H_V^{-*} + H_A^+ H_A^{-*})}{|H_V^+|^2 + |H_V^-|^2 + |H_A^+|^2 + |H_A^-|^2} \approx 0$$

$$P_3^{CP} \equiv -\frac{I_9 - \bar{I}_9}{4(I_{2s} + \bar{I}_{2s})} = -\frac{\mathrm{Im}(H_V^+ H_V^{-*} + H_A^+ H_A^{-*})}{|H_V^+|^2 + |H_V^-|^2 + |H_A^+|^2 + |H_A^-|^2} \approx 0$$

(Melikhov 1998)
Krueger, Matias 2002
Lunghi, Matias 2006
Becirevic, Schneider 2011
Becirevic, Kou, et al 2012
SJ, Martin Camalich 2012

Vey suppressed in the absence of right-handed currents. No effect seen in data.

'Pseudo-observables:' Wilson coefficients from global fit

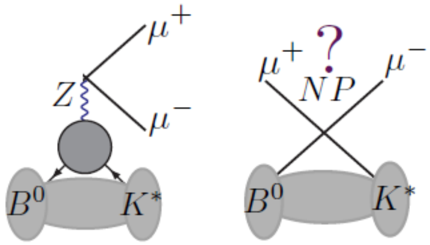
$$C'_{7\gamma} = 0.018 \pm 0.037$$ Aebischer et al arXiv:1903.10434

$$C'_{9V} = 0.09 \pm 0.15$$ Paul & Straub arXiv:1608.02556

Decay amplitude structure

Two mechanisms to produce dilepton in & beyond SM

- via axial lepton current (in SM: Z, boxes) C10

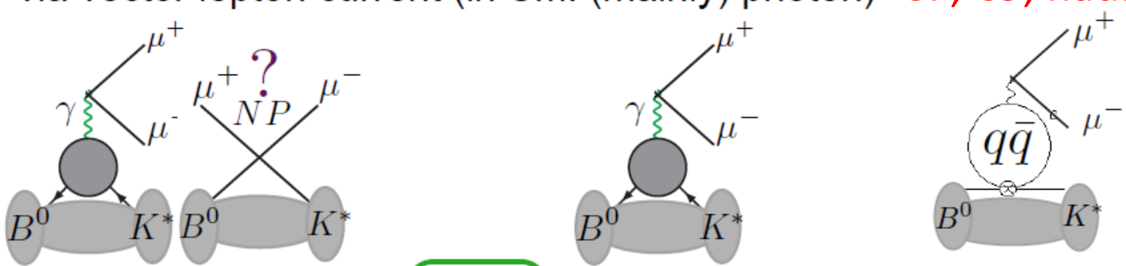


K* helicity

$$H_A(\lambda) \propto \tilde{V}_\lambda(q^2) C_{10} - V_{-\lambda}(q^2) C'_{10}$$

one form factor (nonperturbative) per helicity
amplitudes factorize naively
[nb - one more amplitude if not neglecting lepton mass]

- via vector lepton current (in SM: (mainly) photon) C7, C9, hadronic hamiltonian



$$H_V(\lambda) \propto \tilde{V}_\lambda(q^2) C_9 - V_{-\lambda}(q^2) C'_9 + \frac{2\, m_b m_B}{q^2}\left(\tilde{T}_\lambda(q^2) C_7 - \tilde{T}_{-\lambda}(q^2) C'_7\right) - \frac{16\,\pi^2 m_B^2}{q^2} h_\lambda(q^2)$$

photon pole at q^2=0

two form factors interfere for each helicity

nonlocal "quark loops"
do **not** factorize naively

Natural, systematic discussion in terms of helicity amplitudes SJ, Martin Camalich 2012, 2014

Photon pole absent for helicity-0 (form factor rescaling)

Rare B-decay: observables

Branching ratios

leptonic (differential in dilepton mass)

$B_s \to \mu\mu$, $B_d \to \mu\mu$,

Nonperturbative QCD fully controlled (decay constant from lattice)

semileptonic (differential in dilepton mass)

$B \to K^{(*)}\mu\mu$, $B \to K^{(*)}ee$, $B_s \to \phi\mu\mu$

Lepton universality ratios

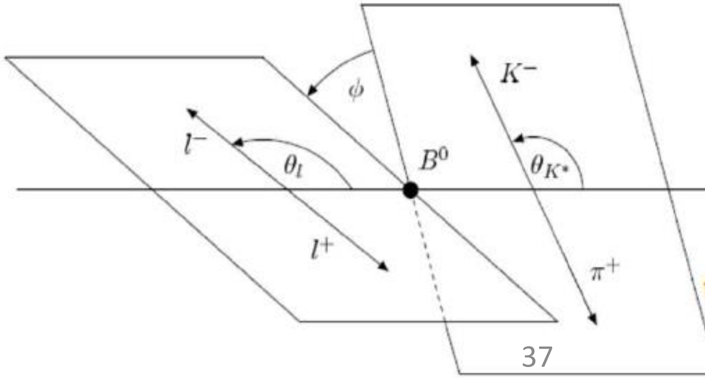
$$R_{K^{(*)}}[a,b] = \frac{\int_a^b \frac{d\Gamma}{dq^2}(B \to K^{(*)}\mu^+\mu^-)dq^2}{\int_a^b \frac{d\Gamma}{dq^2}(B \to K^{(*)}e^+e^-)dq^2}$$

Form factors, 4-quark operator contributions, QED radiation cancel out to ~% level (relative to LHCb treatment)

eg Bordone,Isidori,Pattori arXiv:1605.07633

differential angular distribution for B->Vll

3 angles, dilepton mass q^2



7 angular differential observables:

(A_{FB}, P_5’, etc)