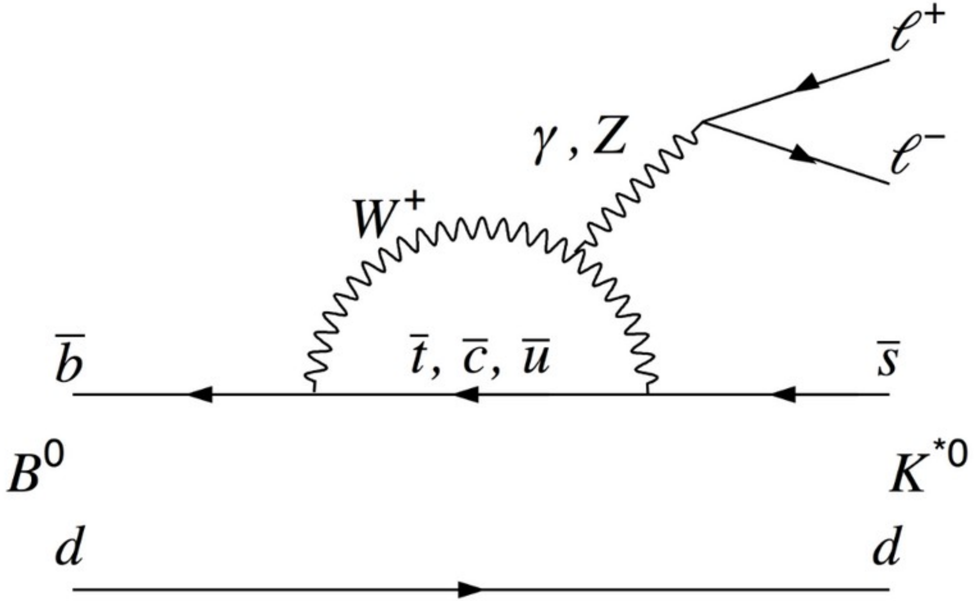
Leptoquarks without leptons for $bs\ell\ell$

Matthew Kirk

Siegen University - 4 Dec 2023
(based on 2309.07205 with Andreas Crivellin)

$b \to s\ell\ell$ decays

- $b \to s\ell\ell$ decay processes are very rare in the SM



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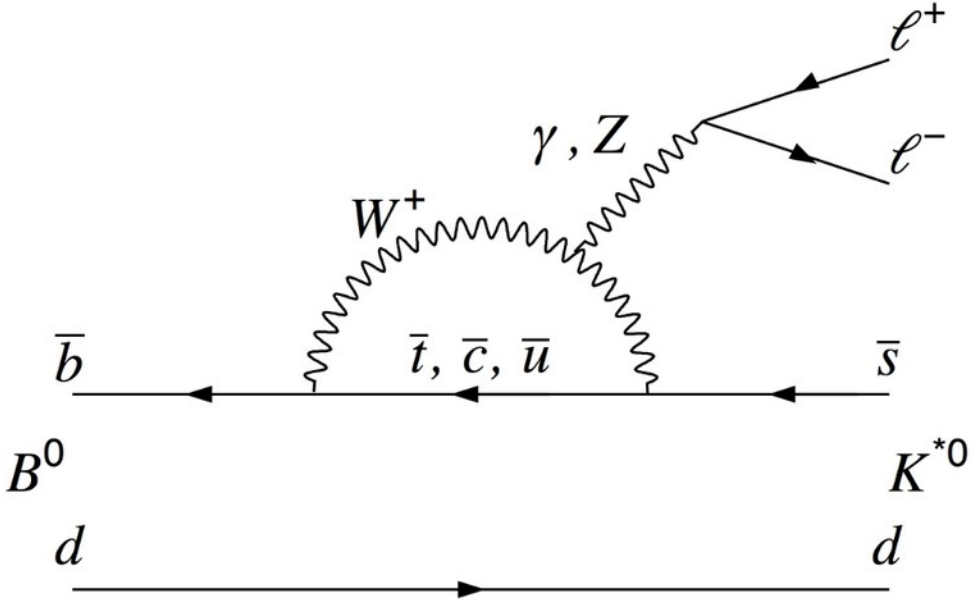
  - Why?



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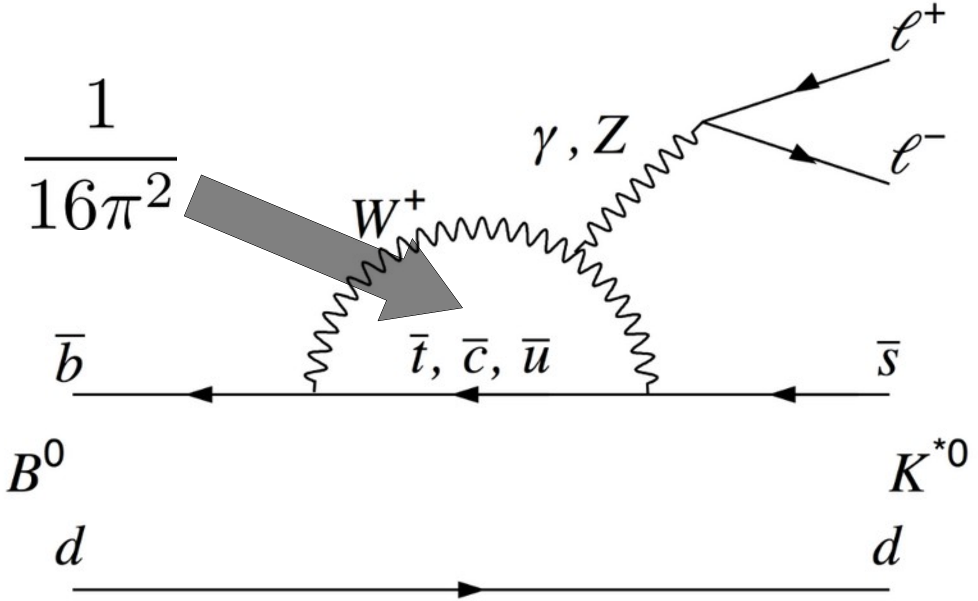

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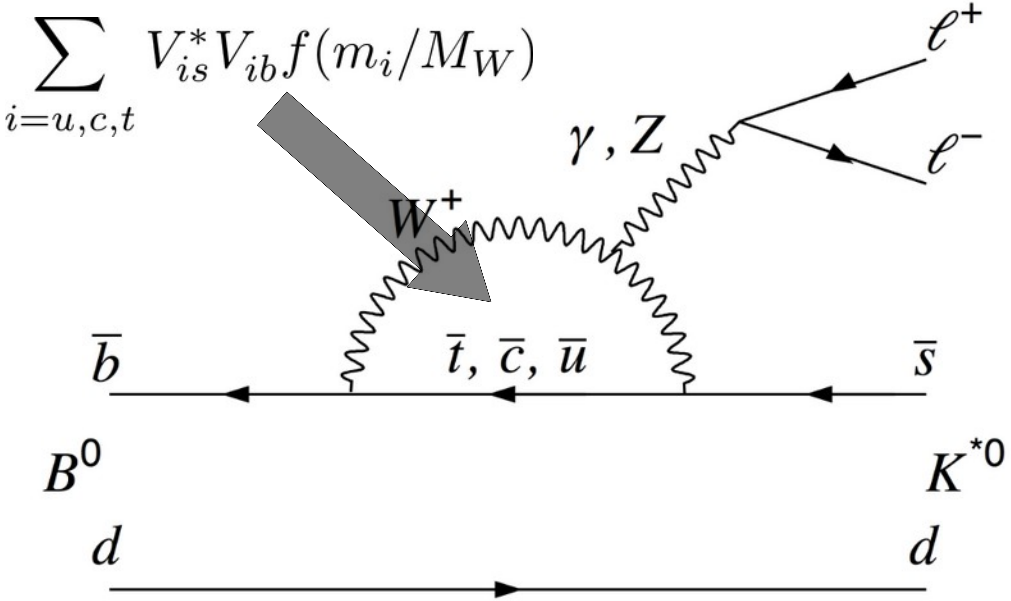

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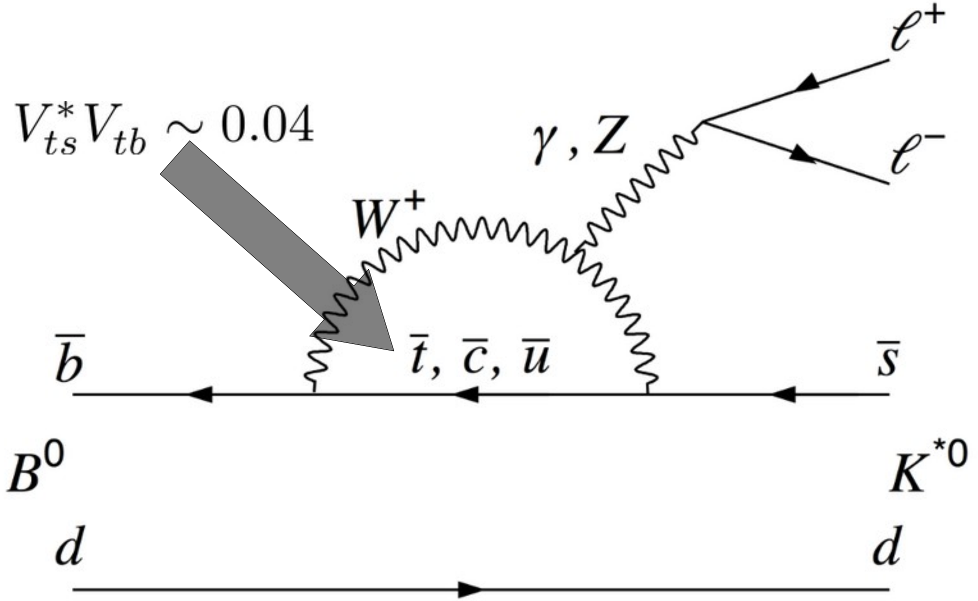

$b \to s\ell\ell$ decays

- $b \to s\ell\ell$ decay processes are very rare in the SM
  - Why?
    - FCNC – only occurs at loop level
    - GIM – would vanish if $m_t = m_c = m_u$
    - CKM – since $m_t \gg m_c, m_u$, final result ~ $V_{tb}V_{ts}$
  - Overall: Br ~ 10^{-7}

Enhancing $b \to s\ell\ell$ decays

- Great place to look for new physics effects, since if NP is not suppressed by any (or all) of loop/GIM/CKM, we would expect a much larger signal

Enhancing $b \to s\ell\ell$ decays

- Do we expect NP to be suppressed like the SM?
  - No!

Enhancing $b \to s\ell\ell$ decays

- Do we expect NP to be suppressed like the SM?
- FCNC – accidentally forbidden at tree level in SM due to gauge structure
- GIM – accidental due to observed masses
- CKM – accidental due to observed CKM structure

Enhancing $b \to s\ell\ell$ decays

- Great place to look for new physics effects, since if NP is not suppressed by any (or all) of loop/GIM/CKM, we would expect a much larger signal
- Naive example: tree level mediator ~ 1 TeV, O(1) couplings => BR ~ 10^{-5} - 10^{-6}

Do we see anything?

- Maybe

(Aside on EFTs

EFT for $b \to s\ell\ell$

- We use an effective field theory to describe the $b \to s\ell\ell$ transitions
  - (Why? $\alpha_s \log(M_W/m_b)$ is large, can't do QCD expansion)

EFT for $b \to s\ell\ell$

- Effective Lagrangian looks like:

$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{eff}}^{\text{SM}} - \frac{4G_F}{\sqrt{2}} \frac{e^2}{16\pi^2} \sum_{q=s,d} \sum_{\ell=e,\mu} \sum_{i=9,10,S,P} V_{tb} V_{tq}^* (C_i^{bq\ell\ell} O_i^{bq\ell\ell} + C_i'^{bq\ell\ell} O_i'^{bq\ell\ell}) + \text{h.c.}\,.$$

The semileptonic operators of interest are defined as

$$\begin{aligned}
O_9^{bq\ell\ell} &= (\bar{q}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, & O_9'^{bq\ell\ell} &= (\bar{q}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,, \\
O_{10}^{bq\ell\ell} &= (\bar{q}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, & O_{10}'^{bq\ell\ell} &= (\bar{q}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \\
O_S^{bq\ell\ell} &= m_b(\bar{q} P_R b)(\bar{\ell}\ell)\,, & O_S'^{bq\ell\ell} &= m_b(\bar{q} P_L b)(\bar{\ell}\ell)\,, \\
O_P^{bq\ell\ell} &= m_b(\bar{q} P_R b)(\bar{\ell}\gamma_5 \ell)\,, & O_P'^{bq\ell\ell} &= m_b(\bar{q} P_L b)(\bar{\ell}\gamma_5 \ell)\,.
\end{aligned}$$

EFT for $b \to s\ell\ell$

- Effective Lagrangian looks like:
- In the SM, only the coefficients C_9 and C_{10} are non-zero
  - $C_9^{\rm SM} \approx -C_{10}^{\rm SM} \approx 4$

)

$bs\ell\ell$ anomalies

- Since 2013 there have been deviations in $b \to s\mu\mu$ decays

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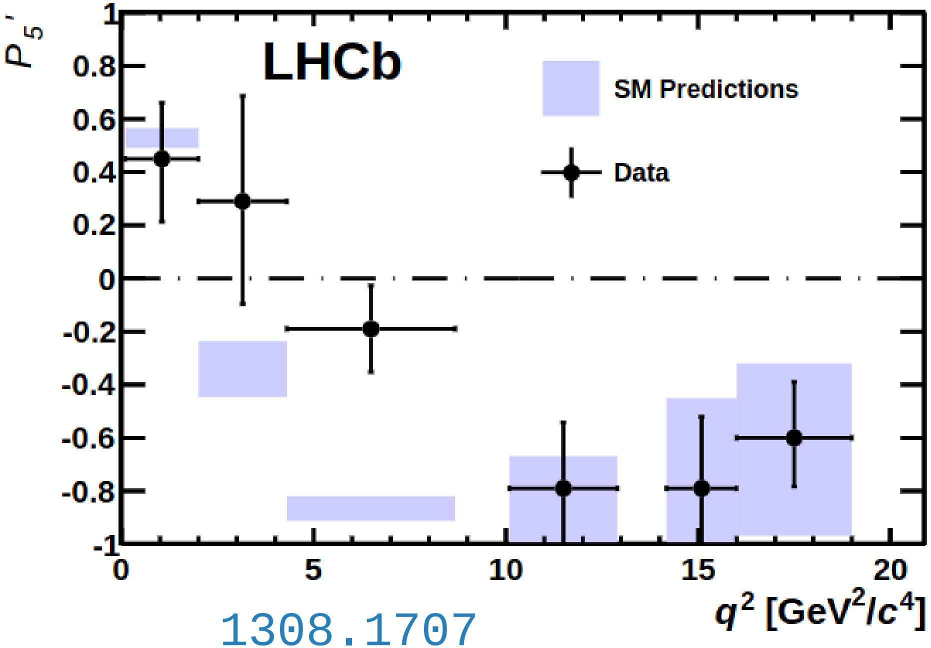


1308.1707

Optimizing the basis of $B \to K^*\ell^+\ell^-$ observables in the full kinematic range

Sébastien Descotes-Genon[a], Tobias Hurth[b], Joaquim Matias[c] and Javier Virto[c]

1303.5794

$bs\ell\ell$ anomalies

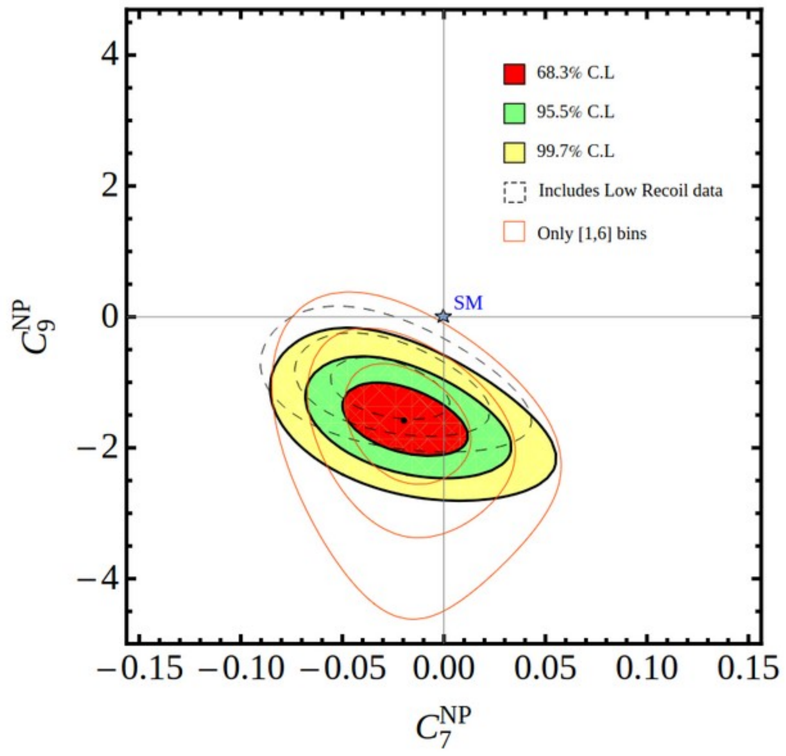
- Since 2013 there have been deviations in $b \to s\mu\mu$ decays

Understanding the $B \to K^*\mu^+\mu^-$ Anomaly

Sébastien Descotes-Genon[a], Joaquim Matias[b] and Javier Virto[b]

1307.5683

Observable	Experiment	SM prediction	Pull
$\langle P_1\rangle_{[0.1,2]}$	$-0.19^{+0.40}_{-0.35}$	$0.007^{+0.043}_{-0.044}$	-0.5
$\langle P_1\rangle_{[2,4.3]}$	$-0.29^{+0.65}_{-0.46}$	$-0.051^{+0.046}_{-0.046}$	-0.4
$\langle P_1\rangle_{[4.3,8.68]}$	$0.36^{+0.30}_{-0.31}$	$-0.117^{+0.056}_{-0.052}$	$+1.5$
$\langle P_1\rangle_{[1,6]}$	$0.15^{+0.39}_{-0.41}$	$-0.055^{+0.041}_{-0.043}$	$+0.5$
$\langle P_2\rangle_{[0.1,2]}$	$0.03^{+0.14}_{-0.15}$	$0.172^{+0.020}_{-0.021}$	-1.0
$\langle P_2\rangle_{[2,4.3]}$	$0.50^{+0.00}_{-0.07}$	$0.234^{+0.060}_{-0.086}$	$+2.9$
$\langle P_2\rangle_{[4.3,8.68]}$	$-0.25^{+0.07}_{-0.08}$	$-0.407^{+0.049}_{-0.037}$	$+1.7$
$\langle P_2\rangle_{[1,6]}$	$0.33^{+0.11}_{-0.12}$	$0.084^{+0.060}_{-0.078}$	$+1.8$
$\langle P_4'\rangle_{[0.1,2]}$	$0.00^{+0.52}_{-0.52}$	$-0.342^{+0.031}_{-0.026}$	$+0.7$
$\langle P_4'\rangle_{[2,4.3]}$	$0.74^{+0.54}_{-0.60}$	$0.569^{+0.073}_{-0.063}$	$+0.3$
$\langle P_4'\rangle_{[4.3,8.68]}$	$1.18^{+0.26}_{-0.32}$	$1.003^{+0.028}_{-0.032}$	$+0.6$
$\langle P_4'\rangle_{[1,6]}$	$0.58^{+0.32}_{-0.36}$	$0.555^{+0.067}_{-0.058}$	$+0.1$
$\langle P_5'\rangle_{[0.1,2]}$	$0.45^{+0.21}_{-0.24}$	$0.533^{+0.033}_{-0.041}$	-0.4
$\langle P_5'\rangle_{[2,4.3]}$	$0.29^{+0.40}_{-0.39}$	$-0.334^{+0.097}_{-0.113}$	$+1.6$
$\langle P_5'\rangle_{[4.3,8.68]}$	$-0.19^{+0.16}_{-0.16}$	$-0.872^{+0.053}_{-0.041}$	$+4.0$
$\langle P_5'\rangle_{[1,6]}$	$0.21^{+0.20}_{-0.21}$	$-0.349^{+0.088}_{-0.100}$	$+2.5$
$\langle P_6'\rangle_{[0.1,2]}$	$0.24^{+0.23}_{-0.20}$	$-0.084^{+0.034}_{-0.044}$	$+1.6$
$\langle P_6'\rangle_{[2,4.3]}$	$-0.15^{+0.38}_{-0.36}$	$-0.098^{+0.043}_{-0.056}$	-0.1
$\langle P_6'\rangle_{[4.3,8.68]}$	$0.04^{+0.16}_{-0.16}$	$-0.027^{+0.060}_{-0.063}$	$+0.4$
$\langle P_6'\rangle_{[1,6]}$	$0.18^{+0.21}_{-0.21}$	$-0.089^{+0.042}_{-0.052}$	$+1.3$
$\langle P_8'\rangle_{[0.1,2]}$	$-0.12^{+0.56}_{-0.56}$	$0.037^{+0.037}_{-0.030}$	-0.3
$\langle P_8'\rangle_{[2,4.3]}$	$-0.30^{+0.60}_{-0.58}$	$0.070^{+0.045}_{-0.034}$	-0.6
$\langle P_8'\rangle_{[4.3,8.68]}$	$0.58^{+0.34}_{-0.38}$	$0.020^{+0.054}_{-0.055}$	$+1.5$
$\langle P_8'\rangle_{[1,6]}$	$0.46^{+0.36}_{-0.38}$	$0.063^{+0.042}_{-0.033}$	$+1.0$
$\langle A_{FB}\rangle_{[0.1,2]}$	$-0.02^{+0.13}_{-0.13}$	$-0.136^{+0.051}_{-0.048}$	$+0.8$
$\langle A_{FB}\rangle_{[2,4.3]}$	$-0.20^{+0.08}_{-0.08}$	$-0.081^{+0.055}_{-0.069}$	-1.1
$\langle A_{FB}\rangle_{[4.3,8.68]}$	$0.16^{+0.06}_{-0.05}$	$0.220^{+0.138}_{-0.113}$	-0.5
$\langle A_{FB}\rangle_{[1,6]}$	$-0.17^{+0.06}_{-0.06}$	$-0.035^{+0.037}_{-0.034}$	-2.0
$\langle P_1\rangle_{[14.18,16]}$	$0.07^{+0.26}_{-0.28}$	$-0.352^{+0.697}_{-0.468}$	$+0.6$
$\langle P_1\rangle_{[16,19]}$	$-0.71^{+0.36}_{-0.26}$	$-0.603^{+0.589}_{-0.315}$	-0.2
$\langle P_2\rangle_{[14.18,16]}$	$-0.50^{+0.03}_{-0.00}$	$-0.449^{+0.136}_{-0.041}$	-1.1
$\langle P_2\rangle_{[16,19]}$	$-0.32^{+0.08}_{-0.08}$	$-0.374^{+0.151}_{-0.126}$	$+0.3$
$\langle P_4'\rangle_{[14.18,16]}$	$-0.18^{+0.54}_{-0.70}$	$1.161^{+0.190}_{-0.332}$	-2.1
$\langle P_4'\rangle_{[16,19]}$	$0.70^{+0.44}_{-0.52}$	$1.263^{+0.119}_{-0.248}$	-1.1
$\langle P_5'\rangle_{[14.18,16]}$	$-0.79^{+0.27}_{-0.22}$	$-0.779^{+0.328}_{-0.363}$	$+0.0$
$\langle P_5'\rangle_{[16,19]}$	$-0.60^{+0.21}_{-0.18}$	$-0.601^{+0.282}_{-0.367}$	$+0.0$
$\langle P_6'\rangle_{[14.18,16]}$	$0.18^{+0.24}_{-0.25}$	$0.000^{+0.000}_{-0.000}$	$+0.7$
$\langle P_6'\rangle_{[16,19]}$	$-0.31^{+0.38}_{-0.39}$	$0.000^{+0.000}_{-0.000}$	-0.8
$\langle P_8'\rangle_{[14.18,16]}$	$-0.40^{+0.60}_{-0.50}$	$-0.015^{+0.009}_{-0.013}$	-0.6
$\langle P_8'\rangle_{[16,19]}$	$0.12^{+0.52}_{-0.54}$	$-0.008^{+0.005}_{-0.007}$	$+0.2$
$\langle A_{FB}\rangle_{[14.18,16]}$	$0.51^{+0.07}_{-0.05}$	$0.404^{+0.199}_{-0.191}$	$+0.5$
$\langle A_{FB}\rangle_{[16,19]}$	$0.30^{+0.08}_{-0.08}$	$0.360^{+0.205}_{-0.172}$	-0.3
$10^4\,\mathcal{B}_{B\to X_s\gamma}$	3.43 ± 0.22	3.15 ± 0.23	$+0.9$
$10^6\,\mathcal{B}_{B\to X_s\mu^+\mu^-}$	1.60 ± 0.50	1.59 ± 0.11	$+0.0$
$10^9\,\mathcal{B}_{B_s\to\mu^+\mu^-}$	2.9 ± 0.8	3.56 ± 0.18	-0.8
$A_I(B \to K^*\gamma)$	0.052 ± 0.026	0.041 ± 0.025	$+0.3$
$S_{K^*\gamma}$	-0.16 ± 0.22	-0.03 ± 0.01	-0.6



$bs\ell\ell$ anomalies

- Since 2013 there have been deviations in $b \to s\mu\mu$ decays
- For a while we thought these were muon specific

Different leptons in $bs\ell\ell$

- Look at the ratio $$R_K = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{{\rm d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{{\rm d}q^2}{\rm d}q^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{{\rm d}\Gamma[B^+ \to K^+e^+e^-]}{{\rm d}q^2}{\rm d}q^2} ,$$

- In the SM, leptons only differ by mass, so expect this ratio to by close to 1
  - Call this lepton flavour universality (LFU)

Different leptons in $bs\ell\ell$

- In 2014: $R_{K^+} = 0.745 \pm 0.090$

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- By Spring 2022: $R_{K^+} \to 0.846 \pm 0.042$

$$R_{K^{*+}} = 0.70 \pm 0.15$$

$$R_{K^0_S} = 0.66 \pm 0.17$$

$$R_{pK} = 0.86 \pm 0.12$$

Different leptons in $bs\ell\ell$

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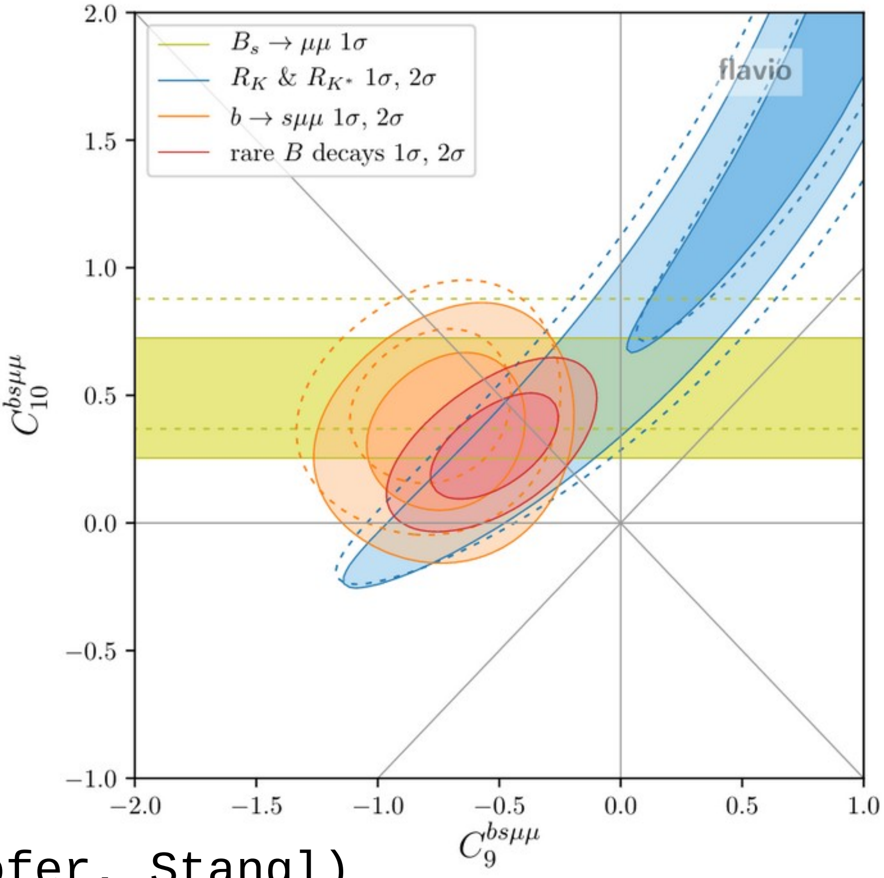
- In 2017: $R_{K^{*0}} = 0.67 \pm 0.10$
- By Spring 2022: $R_{K^+} \to 0.846 \pm 0.042$
- Lepton flavour universality violation (LFUV)!

$$R_{K^{*+}} = 0.70 \pm 0.15$$

$$R_{K^0_S} = 0.66 \pm 0.17$$

$$R_{pK} = 0.86 \pm 0.12$$

Global fit Spring 2021



2103.13370
(Altmannshofer, Stangl)

Global fit Spring 2022

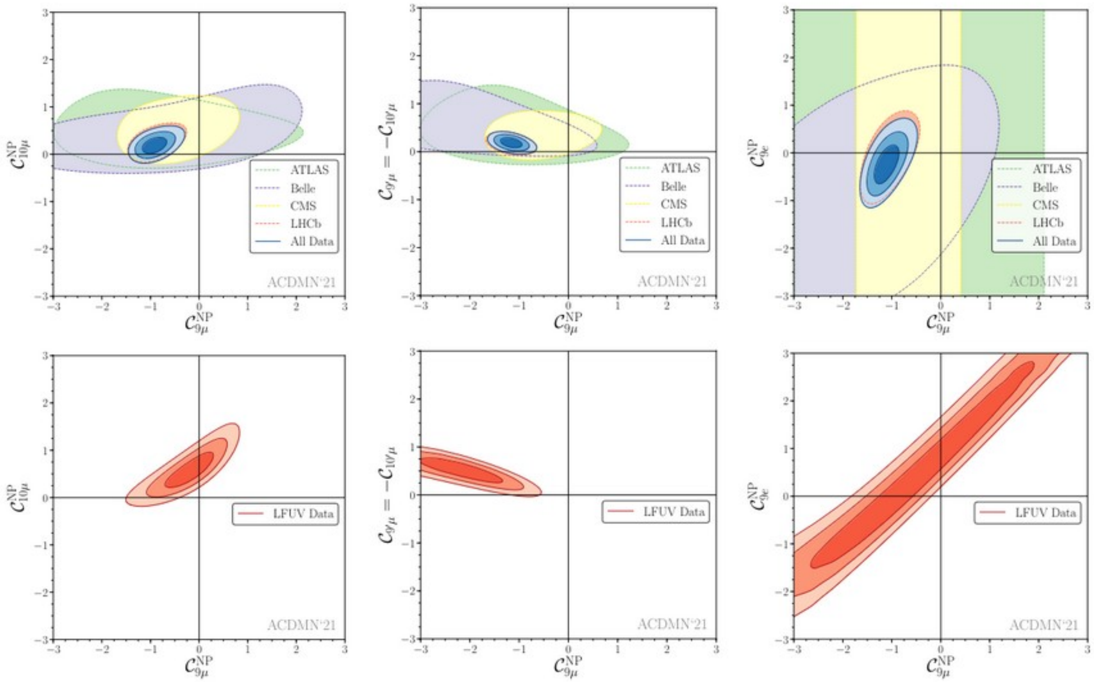


Figure 1: From left to right: Allowed regions in the $(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{10\mu}^{NP})$, $(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{9'\mu} = -\mathcal{C}_{10'\mu})$ and $(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{9e}^{NP})$ planes for

	All			LFUV		
2D Hyp.	Best fit	Pull_{SM}	p-value	Best fit	Pull_{SM}	p-value
$(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{10\mu}^{NP})$	$(-0.92, +0.17)$	6.8	25.6 %	$(-0.16, +0.55)$	4.7	71.2 %
$(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{7'})$	$(-1.02, +0.01)$	6.7	22.8 %	$(-0.88, -0.04)$	4.1	37.5 %
$(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{9'\mu})$	$(-1.12, +0.36)$	6.9	27.4 %	$(-1.82, +1.09)$	4.5	60.2 %
$(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{10'\mu})$	$(-1.15, -0.26)$	7.1	31.8 %	$(-1.88, -0.59)$	5.0	88.1 %
$(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{9e}^{NP})$	$(-1.11, -0.26)$	6.7	23.8 %	$(-0.52, +0.34)$	4.0	35.3 %
Hyp. 1	$(-1.01, +0.31)$	6.7	24.0 %	$(-1.60, +0.32)$	4.5	62.5 %
Hyp. 2	$(-0.89, +0.06)$	5.4	8.0 %	$(-1.95, +0.25)$	3.6	20.4 %
Hyp. 3	$(-0.45, +0.04)$	6.2	15.9 %	$(-0.39, -0.14)$	4.7	70.2 %
Hyp. 4	$(-0.47, +0.07)$	6.3	16.8 %	$(-0.48, +0.15)$	4.8	79.6 %
Hyp. 5	$(-1.15, +0.17)$	7.1	31.1 %	$(-2.13, +0.50)$	5.0	89.4 %

Table 2: Most prominent 2D patterns of NP in $b \to s\mu\mu$. The last five rows correspond to Hypothesis 1: $(\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{NP} = \mathcal{C}_{10'\mu})$, 2: $(\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{NP} = -\mathcal{C}_{10'\mu})$, 3: $(\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{10\mu}^{NP}, \mathcal{C}_{9'\mu} = \mathcal{C}_{10'\mu})$, 4: $(\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{10\mu}^{NP}, \mathcal{C}_{9'\mu} = -\mathcal{C}_{10'\mu})$ and 5: $(\mathcal{C}_{9\mu}^{NP}, \mathcal{C}_{9'\mu} = -\mathcal{C}_{10'\mu})$.

2104.08921v4
(Algueró, Capdevila, Descotes-Genon, Matias, Novoa-Brunet)

LFUV in $bs\ell\ell$?

- But in Dec 2022:

EPFL

LHCb

Measurements of R_K and R_{K^*} with the full LHCb Run 1 and 2 data

Renato Quagliani

École Polytechnique Fédérale de Lausanne (EPFL)

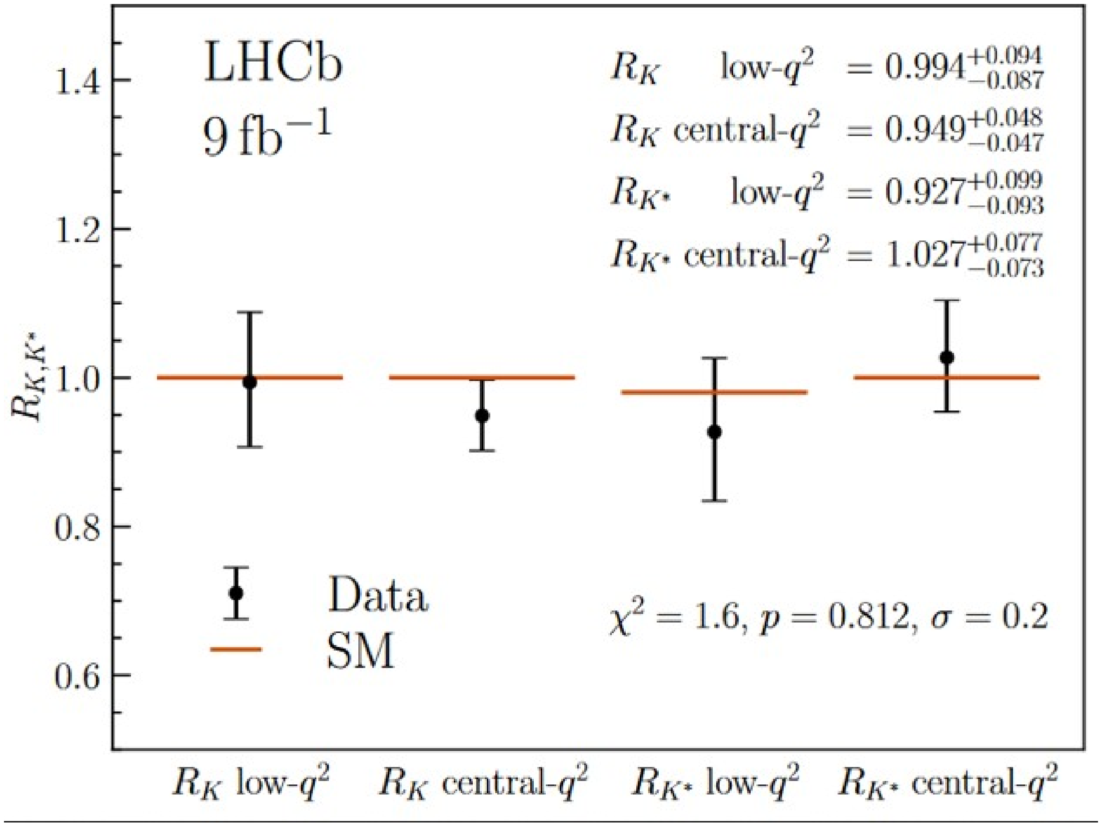
On behalf of the LHCb collaboration

LHCb-PAPER-2022-045
LHCb-PAPER-2022-046

Renato Quagliani LHC Seminar, CERN 20/12/2022

LFUV in $bs\ell\ell$? No!

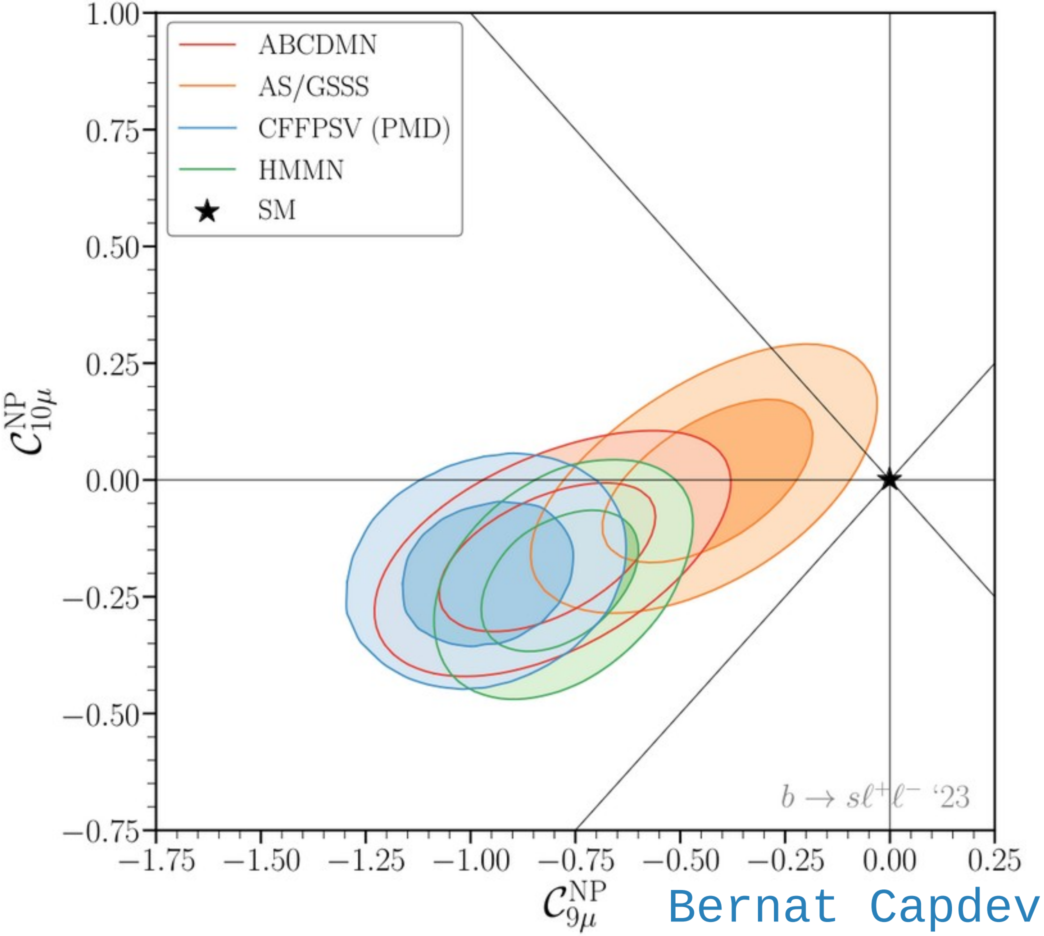
- But in Dec 2022:

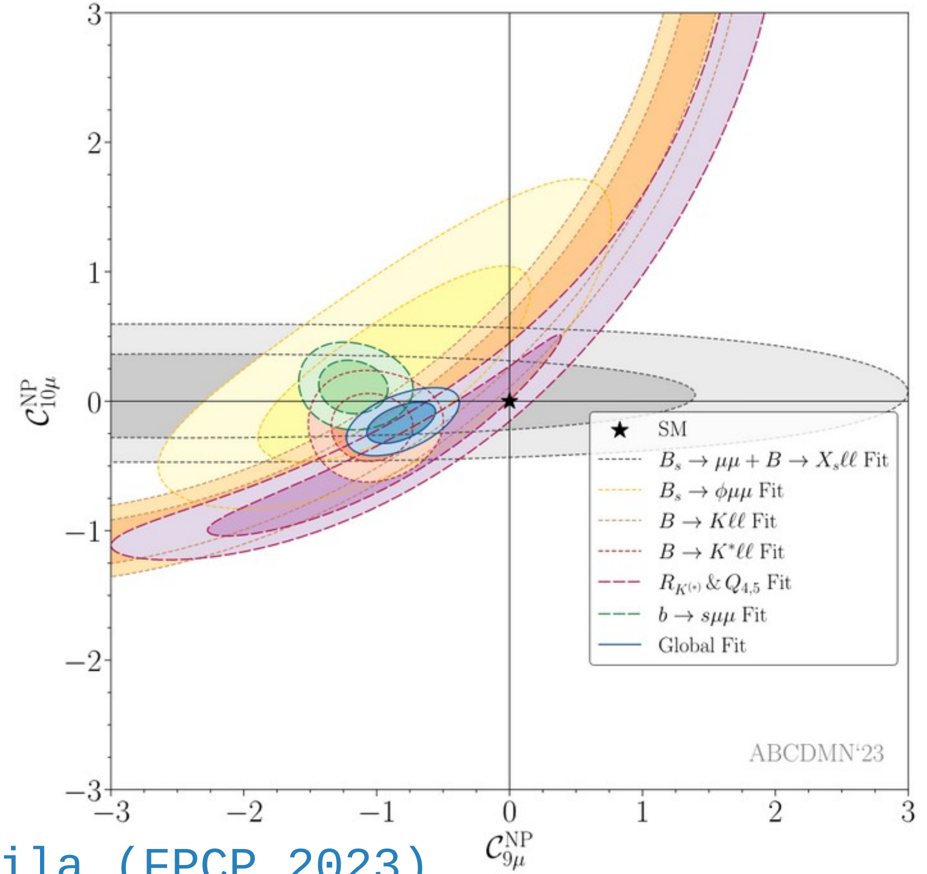


$bs\ell\ell$ anomalies

- So what is the current status?
- Is there anything?
- Hopefully!

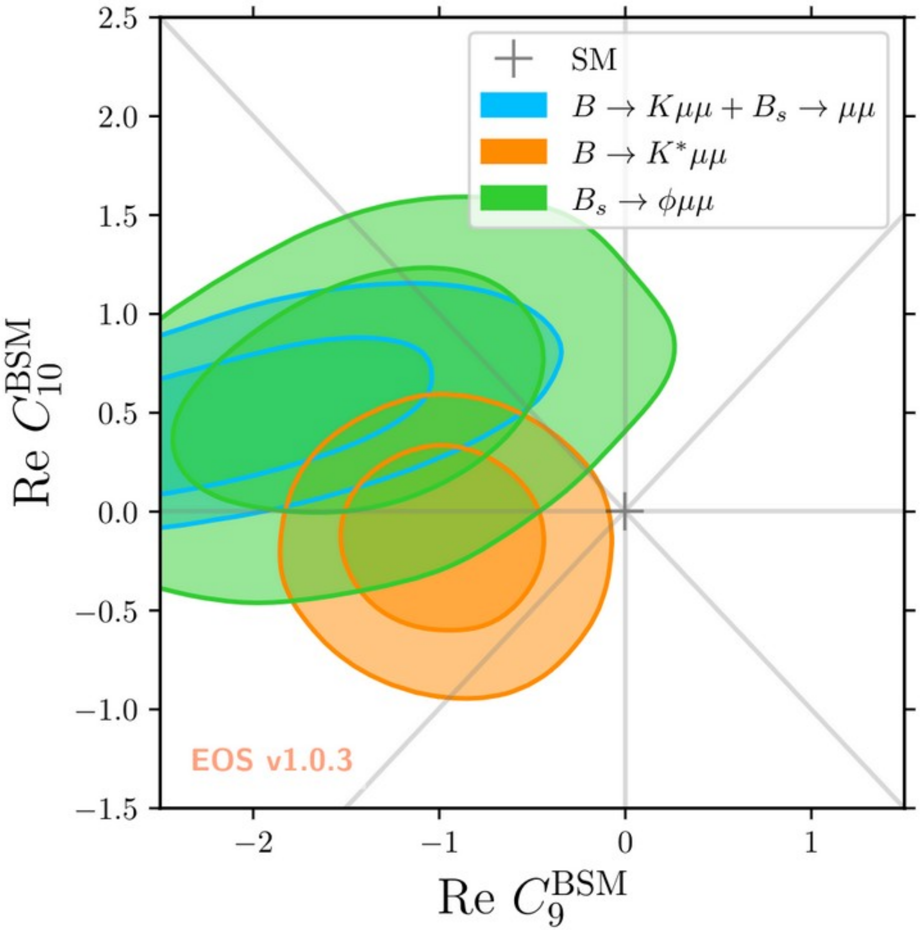
Global fit in 2023





Bernat Capdevila (FPCP 2023)

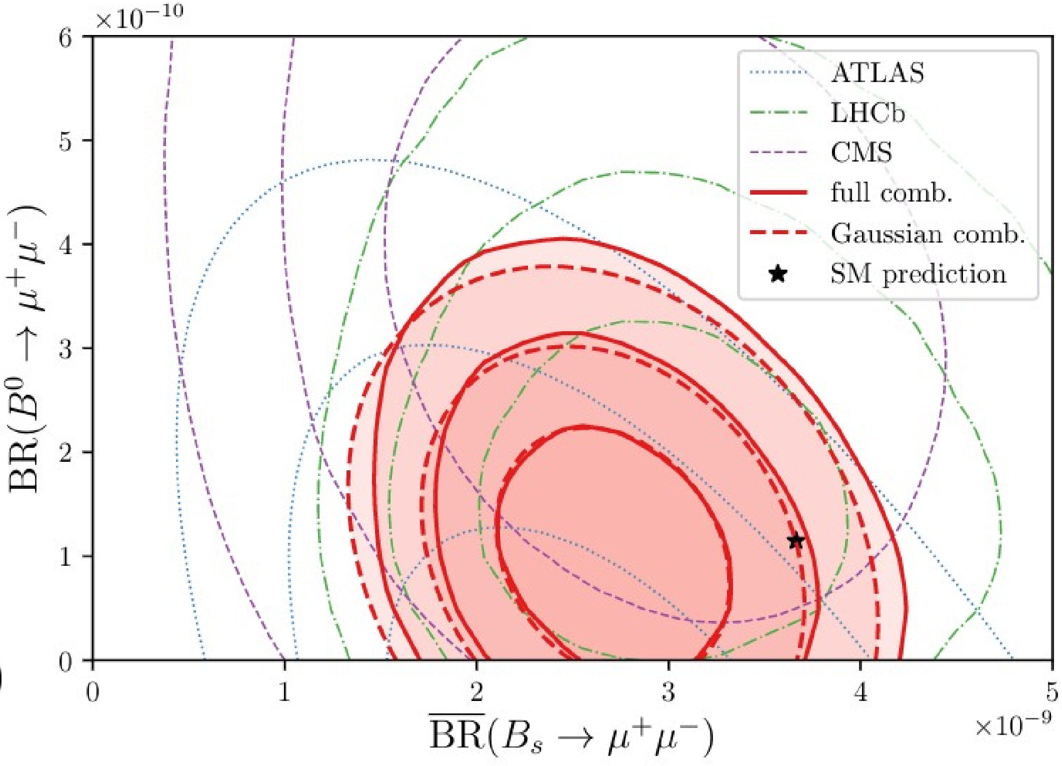
$bs\ell\ell$ anomalies



Gubernari, Reboud, van Dyk, Virto (2206.03797)

$bs\ell\ell$ anomalies

- $B_s \to \mu\mu$
  - Seemed to be below SM
- Favoured positive C_{10}^{NP}
  - And hence $C_9 = -C_{10}$



1903.10434 (Aebischer, Altmannshofer, Guadagnoli, Reboud, Stangl, Straub)

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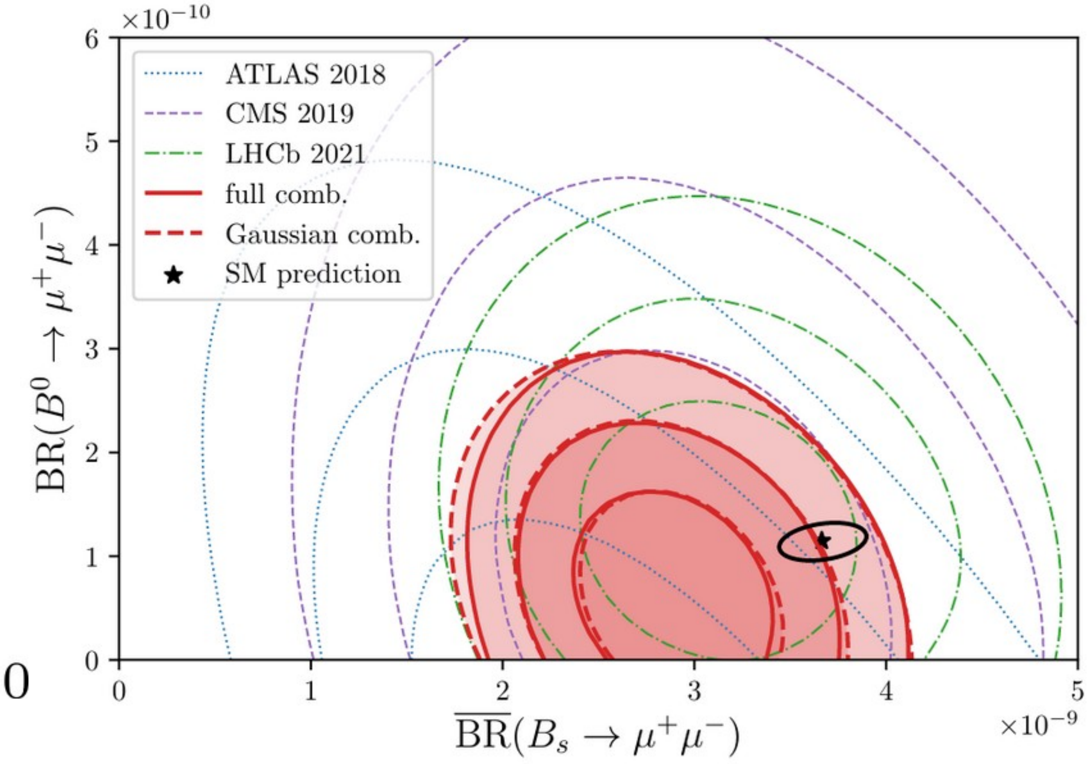
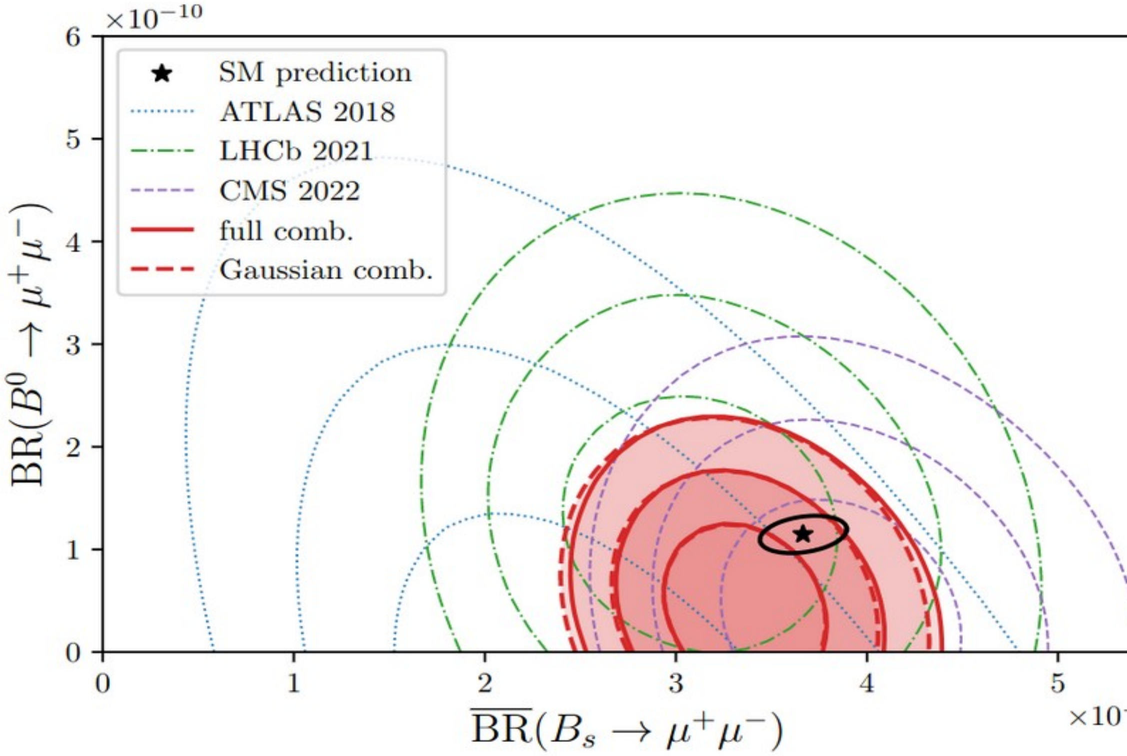


2103.13370 (Altmannshofer, Stangl)

$bs\ell\ell$ anomalies

- $B_s \to \mu\mu$
  - CMS 2022 was above the SM
- C_9 a better fit than $C_9 = -C_{10}$ now



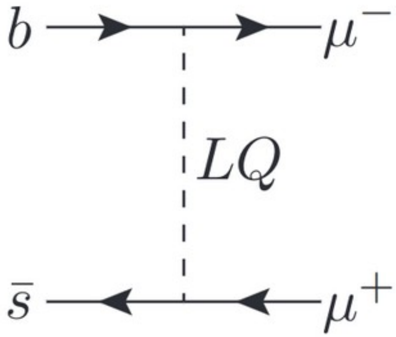
2212.10497 (Greljo, Salko, Smolkovič, Stangl)

$bs\ell\ell$ anomalies

- So what is the current status?
- Is there anything?
- Hopefully!
  - But it has to treat leptons the same

LQs for $bs\ell\ell$

- LQs are natural models for $bs\ell\ell$
- 10-25% deviation in $bs\ell\ell$



Diagrams from Luca di Luzio @ CKM 2018

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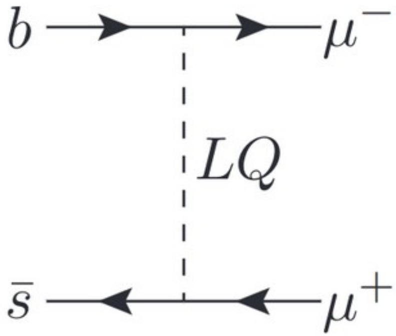
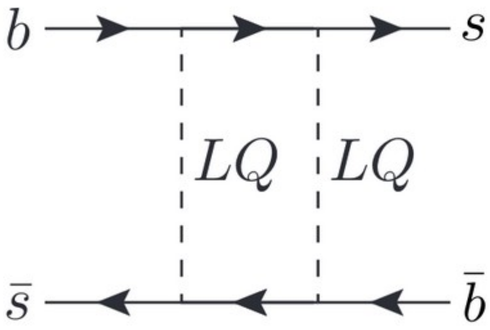


Diagrams from Luca di Luzio @ CKM 2018

- But <5-10% deviation allowed in ΔM_s



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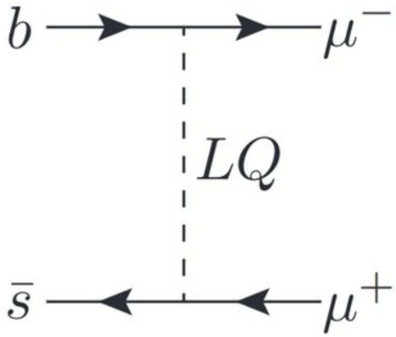
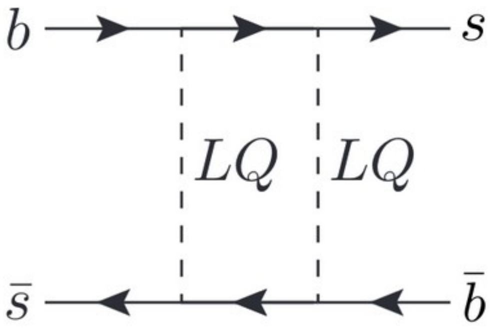
- LQs are natural models for $bs\ell\ell$
- 10-25% deviation in $bs\ell\ell$



Diagrams from Luca di Luzio @ CKM 2018

- But <5-10% deviation allowed in ΔM_s



- And they turn up in many BSM models

LQs for $bs\ell\ell$

- LQs are natural models for $bs\ell\ell$
  - But a LQ coupling to multiple lepton generations generally leads to lepton flavour violation (LFV)

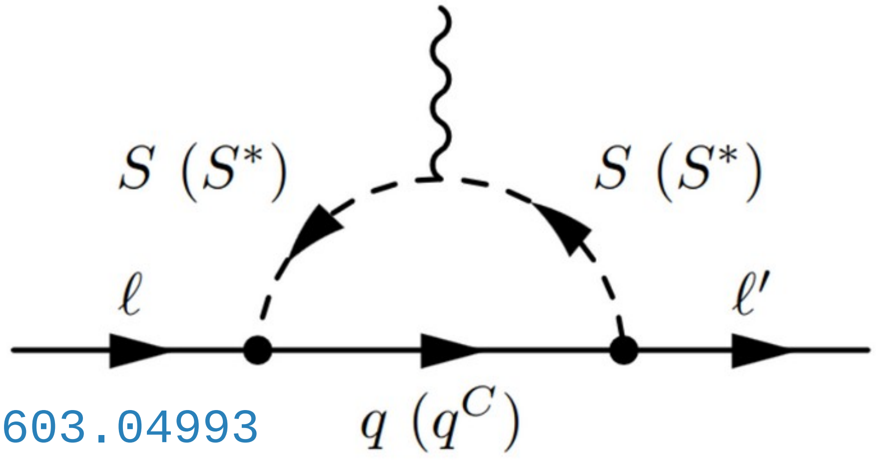
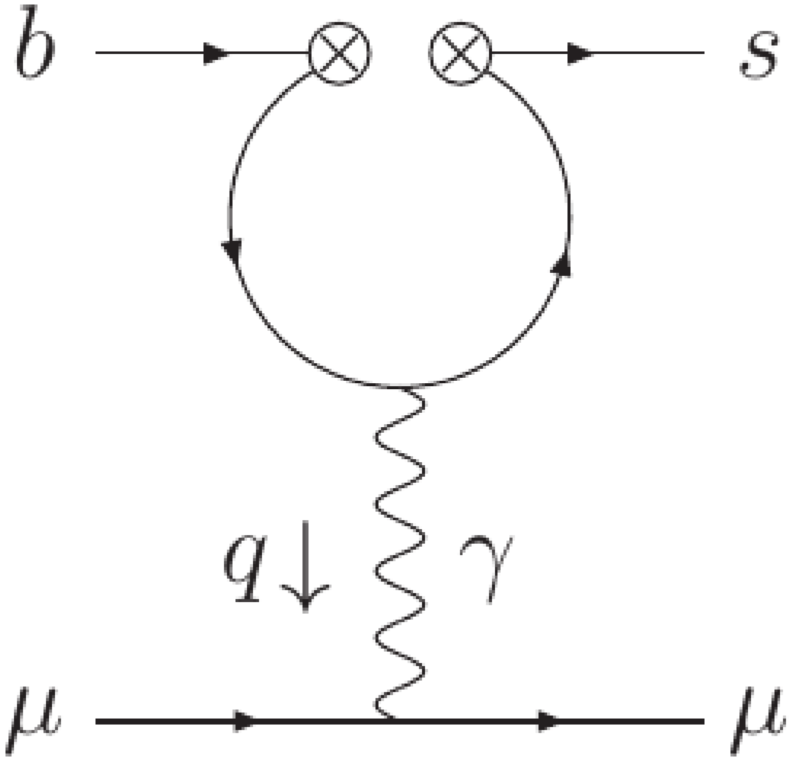


Diagram from 1603.04993

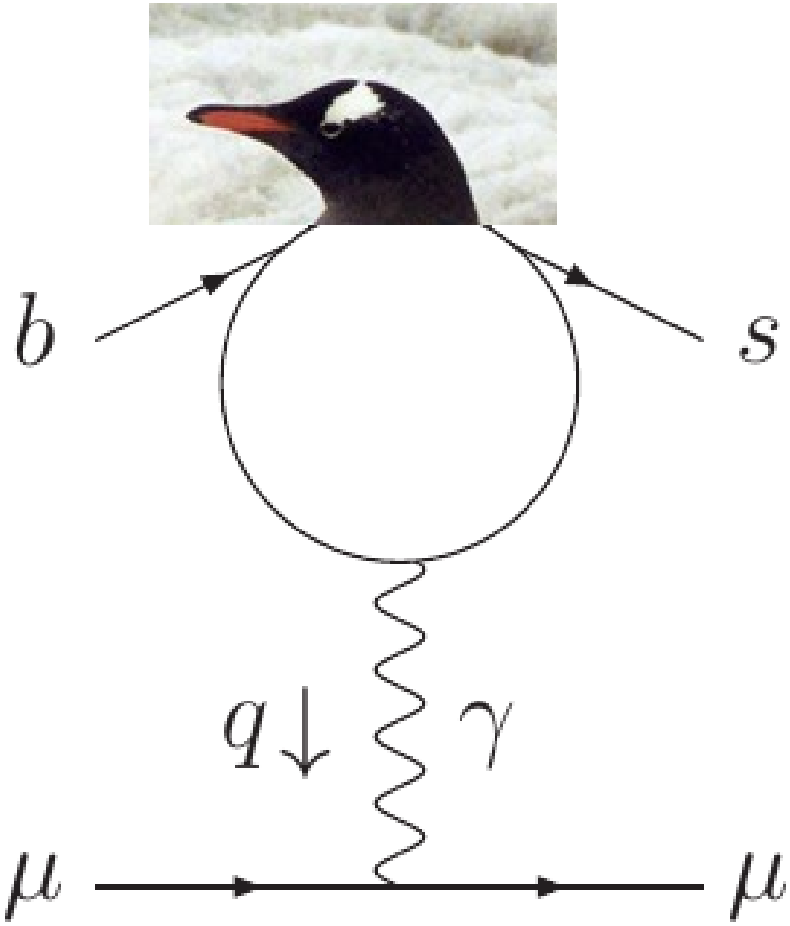
$bscc \to bs\ell\ell$

- Old idea: NP in $bscc$?
- In the SM, about half of the C_9 coefficient generated through charm loops

$$bscc \to bs\ell\ell$$



$bscc \to bs\ell\ell$



$bscc \to bs\ell\ell$

- In the SM, about half of the C_9 coefficient generated through charm loops
- What if some NP modified $bscc$ operators?

Charming new physics in rare B-decays and mixing?

Sebastian Jäger and Kirsten Leslie
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(Dated: January, 2018)

1701.09183 & 1910.12924

Charming New B-Physics

Sebastian Jäger, [a] Matthew Kirk,[b] Alexander Lenz[c] and Kirsten Leslie[a]
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$bscc \to bs\ell\ell$

- In the SM, about half of the C_9 coefficient generated through charm loops
- What if some NP modified $bscc$ operators?
- Potential for large $bs\ell\ell$ effects, plus correlated effects in various precise B meson observables

$bscc \to bs\ell\ell$

- Correlated effects in various B meson observables
  - Width difference in B_s meson mixing ($\Delta\Gamma_s$, ~15% precision)
  - B meson lifetimes ($\tau(B_s)/\tau(B_d)$, ~1%)
  - Radiative B decay ($B \to X_s\gamma$, ~5%)

UV $\to bscc$

- What kind of NP can generate $bscc$ after being integrated out?
  - Size of anomaly suggests tree level effect
- If tree level b and s interactions, need to avoid tree level B_s mixing
  - Big problem for Z's, or heavy gluon type field

UV $\to bscc$

- Charged Higgs is one option
- Has been re-examined recently

Kumar 2212.07233
& Iguro 2302.08935

- But parameter space is quite constrained ($M_{H^+} \leq 200 - 250\,\mathrm{GeV}$)

S_1

- Consider the $S_1 : (\mathbf{3}, \mathbf{1}, -1/3)$
- In addition to lepton-quark interactions, can write down quark-quark interactions
- Only get $u - d - S_1$ terms, not $d - d - S_1$ or $u - u - S_1$, so safe from meson mixing

S_1 LQ without leptons

- In general, having both lepton-quark and quark-quark couplings leads to tree level proton decay
- So often people drop the diquark term
- But instead we drop the lepton-quark term

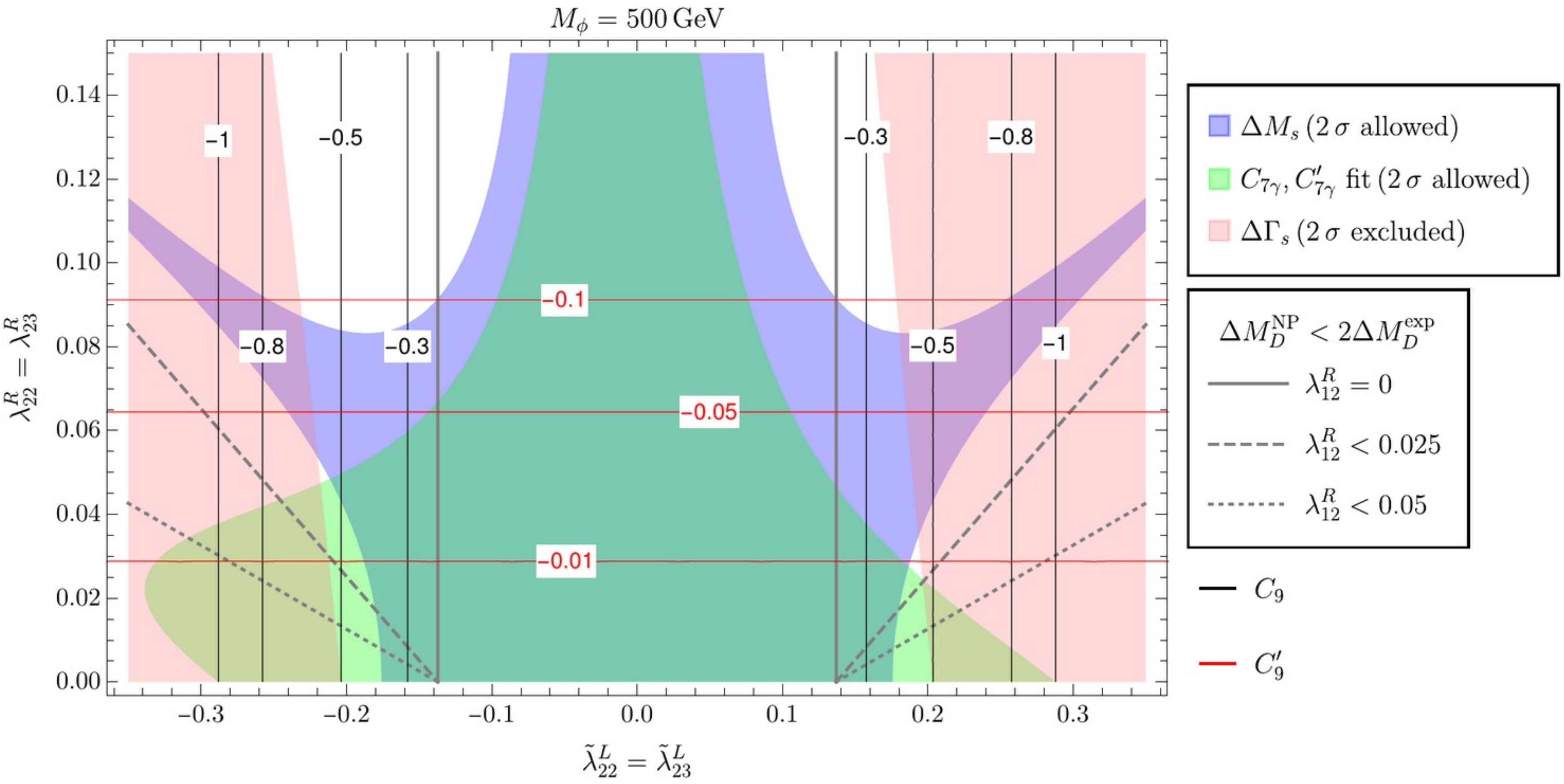
S_1 diquark

- $(\lambda_L \bar{Q}^c Q + \lambda_R \bar{u}^c d) S_1$
- $\rightarrow \bar{u}^c (\lambda_L P_L + \lambda_R P_R) d \, S_1$

S_1 diquark

- It will turn out that we need the S_1 to be quite light – $M_{S_1} \sim 500\,\mathrm{GeV}$
- Integrate it out along with top/Z/W
- Loop calculations give (extra) constraints from B_s mixing, $B \to X_s\gamma$, D mixing

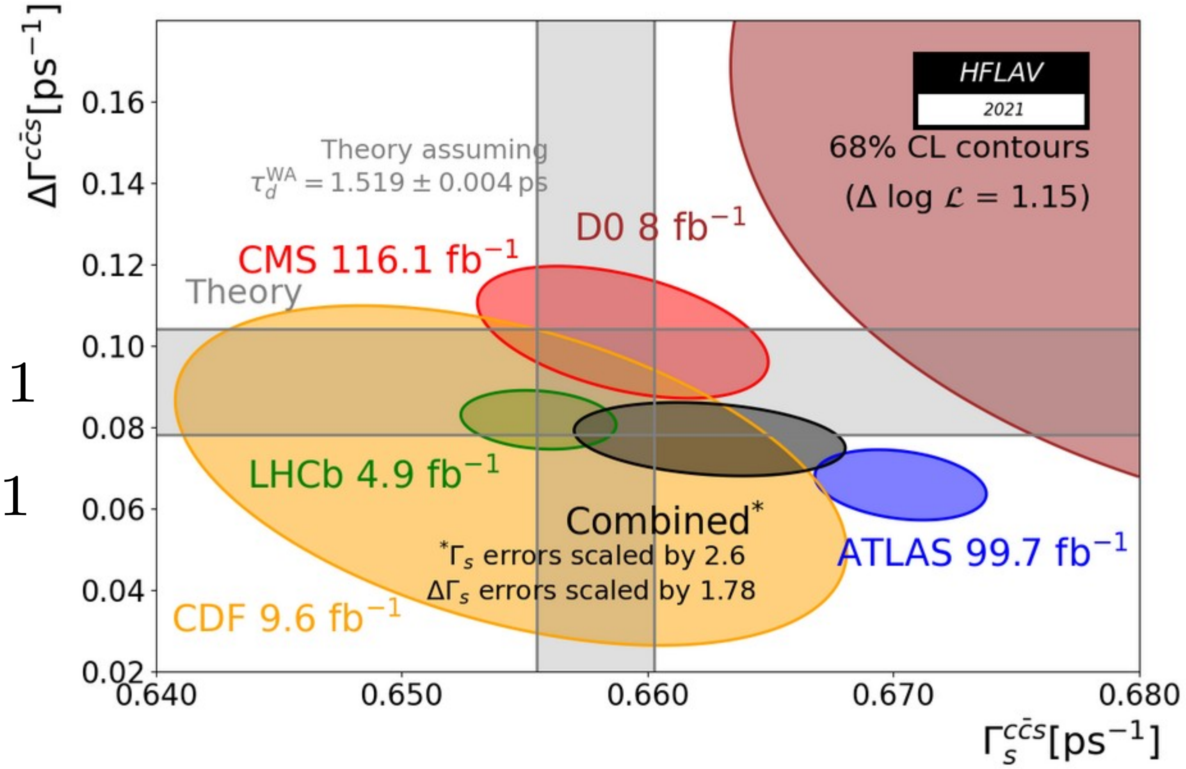
Results



$M_\phi = 500\,\mathrm{GeV}$
$\lambda^R_{22} = \lambda^R_{23}$
$\tilde{\lambda}^L_{22} = \tilde{\lambda}^L_{23}$
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
−1
−0.5
−0.3
−0.8
−0.8
−0.3
−0.5
−1
−0.1
−0.05
−0.01
ΔM_s (2 σ allowed)
$C_{7\gamma}, C'_{7\gamma}$ fit (2 σ allowed)
$\Delta\Gamma_s$ (2 σ excluded)
$\Delta M_D^{\mathrm{NP}} < 2\Delta M_D^{\mathrm{exp}}$
$\lambda^R_{12} = 0$
$\lambda^R_{12} < 0.025$
$\lambda^R_{12} < 0.05$
C_9
C'_9

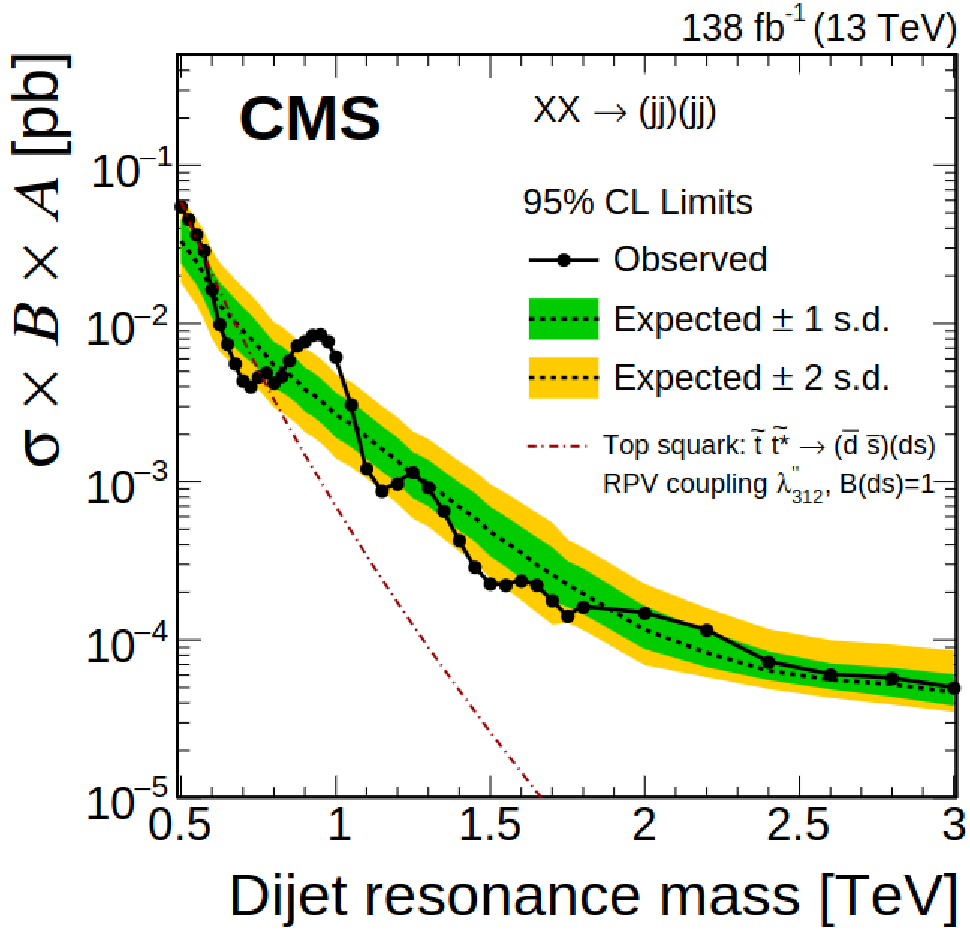
Results

- Interestingly, we predict an increase to $\Delta\Gamma_s$
- From $90 \times 10^{-3}\,\mathrm{ps}^{-1}$ $\rightarrow 110 \times 10^{-3}\,\mathrm{ps}^{-1}$



Results

- CMS di-di-jet analysis (2206.09997)
  - Hints for 500 GeV scalar?



Results

- Missing charm puzzle?
  - Inclusive $b \to c\bar{c}s$ rate

hep-ph/0011258

Some comments on the missing charm puzzle

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Abstract. In this talk we summarize the status of theoretical predictions for the average number of charm quarks in a B-hadron decay.

New physics in inclusive decays? II

Motivation for a re-analysis of inclusive decays:

- Old analyses at least 15 years old - input parameters ($m_b, m_c, V_{CKM}, ...$) are now much better known
  Missing charm puzzle; semileptonic branching fraction, e.g.
  Bigi et al '94; Bagan et al. '94; Falk, Wise, Dunietz '95, Buchalla et al '95; Neubert '97; Kagan '97,'98,... A.L. ,hep-ph/0011258
- Theory is now much more reliable! e.g. $b \to c\bar{c}s$
- Many rare decays were neglected, e.g. $b \to sg, b \to u\bar{u}s, ...$
- Some NLO-QCD contributions are still missing
- Experimental improvements - latest number from BaBar; hep-ex/0606026
- This gives model and even decay channel independent bounds

Thanks!

BACKUP

Explicit GIM suppression

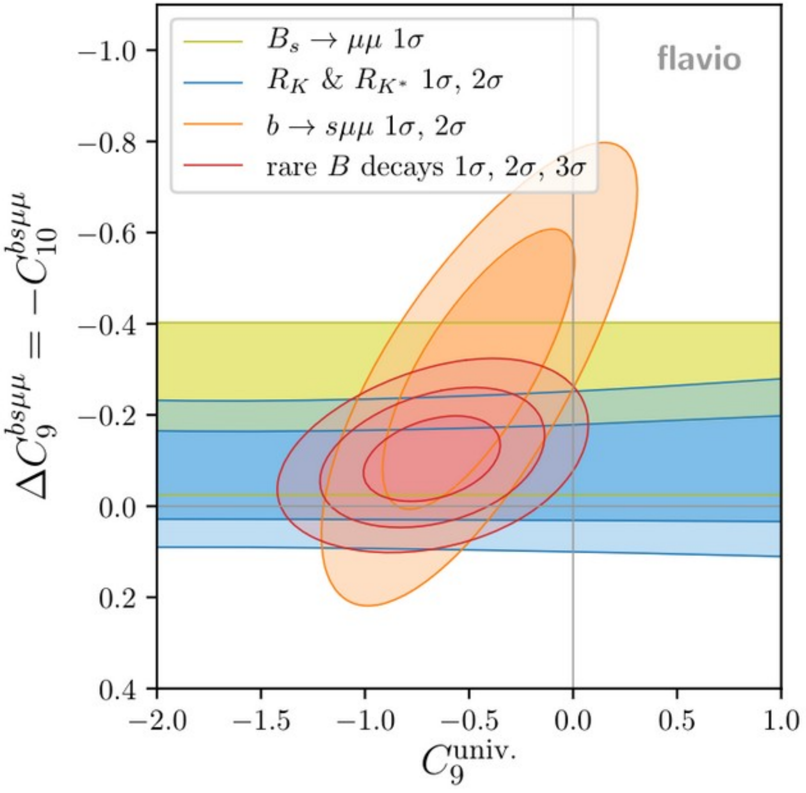
$$\mathcal{A} \sim \sum_{i=u,c,t} \lambda_i f(m_i/M_W)\,, \lambda_i = V_{ib}V_{is}^*$$

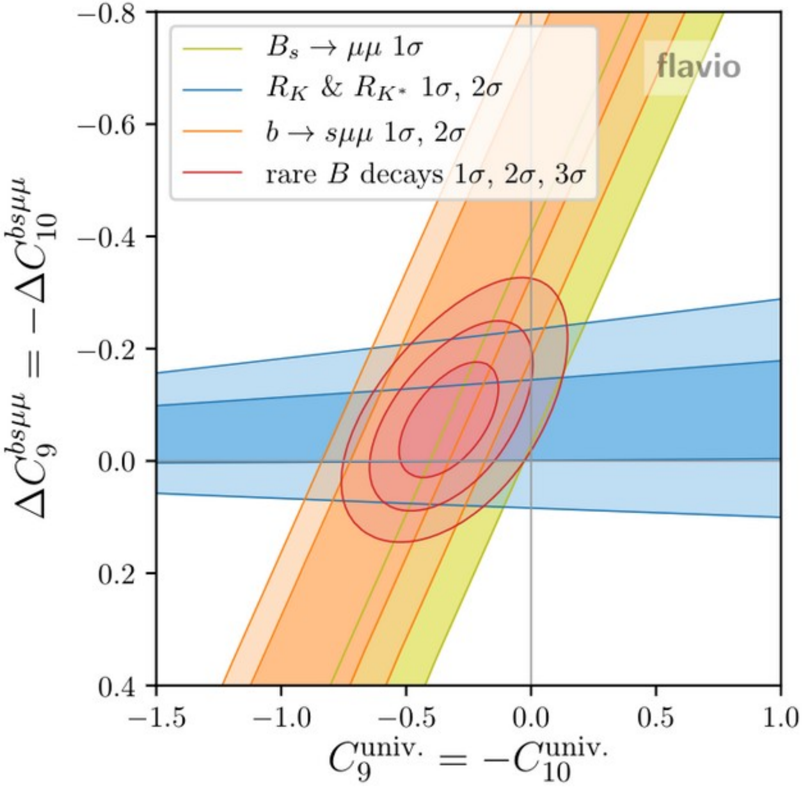
$$\sim \lambda_t[f(m_t/M_W) - f(m_u/M_W)]$$

$$+ \lambda_c[f(m_c/M_W) - f(m_u/M_W)]$$

$$\sim \lambda_t[f(m_t/M_W) - f(0)]$$

More bsll global fits





2212.10497 (Greljo, Salko, Smolkovič, Stangl)

ATLAS di-jet

- 1804.03496