FLAVOR CONSTRAINTS ON NEW PHYSICS

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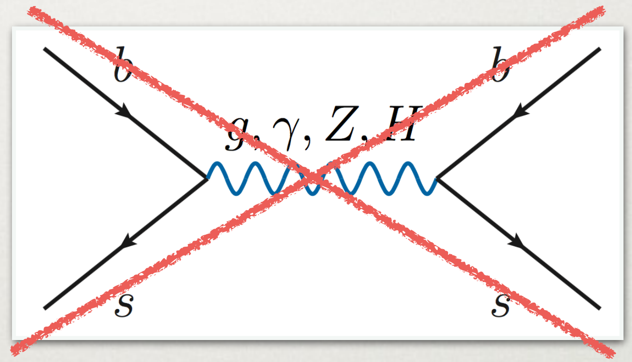
Lepton Photon, Guangzhou, Aug 8 2017

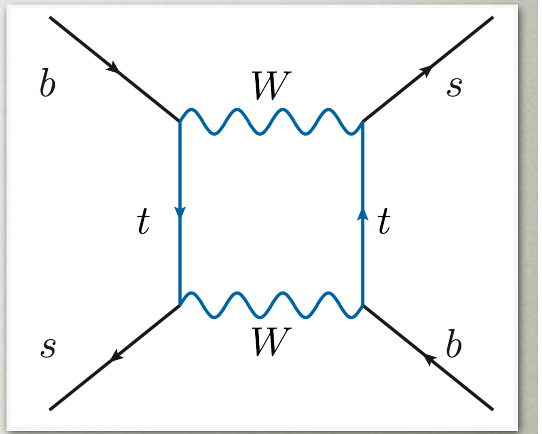
SENSITIVITY TO NEW PHYSICS

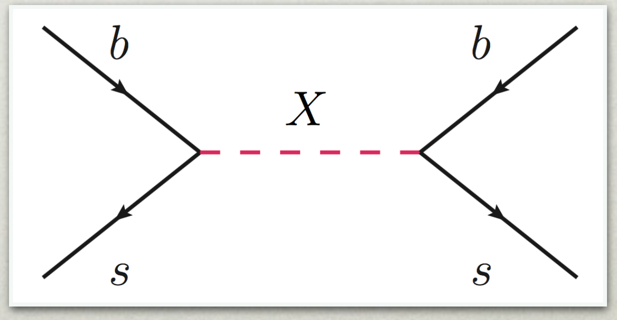
- SM@tree level: no Flavor Changing Neutral Currents
  - all FCNC processes loop suppressed
  - e.g., meson mixing
- can be modified by NP
- NP contribs. scale as

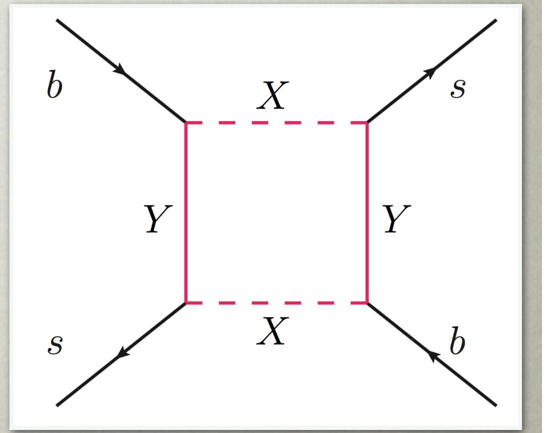
$$\delta C^{\rm NP} \propto \frac{\sin\theta_i \sin\theta_j}{M_{\rm NP}^2}$$

- depends on mix. angles and NP masses





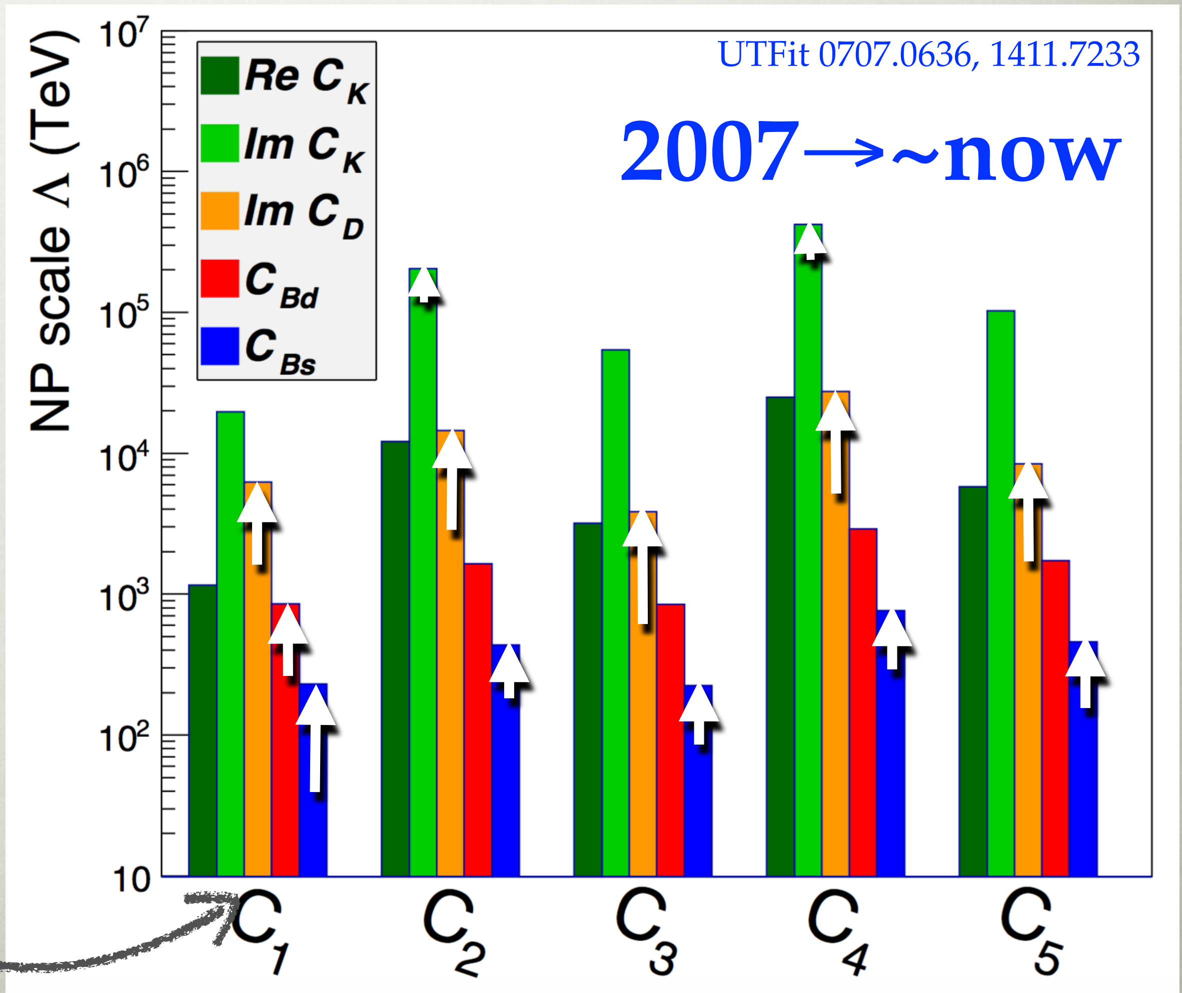




LOW ENERGY PRECISION BOUNDS

UTFit 0707.0636, 1411.7233
for latest charm see also Bazavov et al, 1706.04622

- an impressive progress on flavor bounds in last 10 years
- in D, B_s mixing
- also from ε_K



$$\frac{1}{\Lambda^2}(\bar{b}_L\gamma^\mu d_L)(\bar{b}_L\gamma_\mu d_L)$$

PRESENT EXPERIMENTAL SITUATION

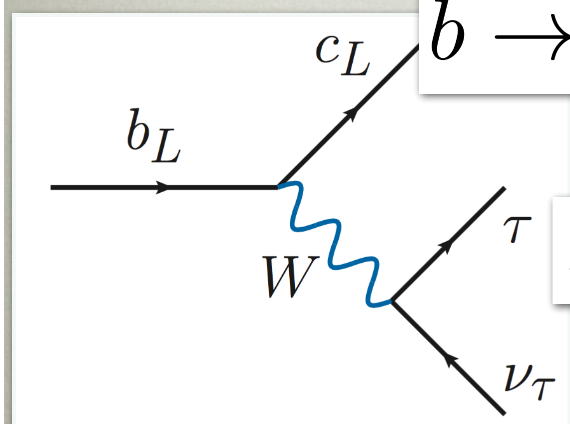
- many different transitions measured

see also talks by Greig Cowan; Monica Pepe Altarelli

- two quark level transitions show ~4σ deviations from the SM*

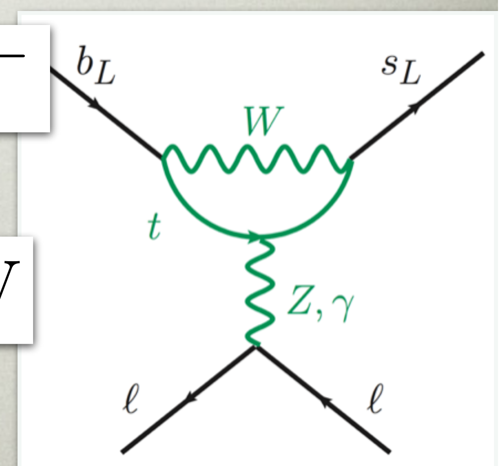
$$\mathcal{L}_{\text{SMEFT}} \supset \frac{1}{\Lambda^2_{Q_{ij}L_{kl}}} \left(\overline{Q}_i \gamma^\mu \sigma^A Q_j\right) \left(\overline{L}_k \gamma_\mu \sigma^A L_l\right)$$

$b \to c\tau\nu$



$\Lambda_{\text{NP}} \sim 3$ TeV

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



$\Lambda_{\text{NP}} \sim 30$ TeV

* there are other interesting deviations, e.g., ~3σ deviation in ε'/ε, see, e.g., Buras et al, 1507.06345; RBC-UKQCD, 1502.00263

$b \rightarrow s\mu\mu$

UPSHOT

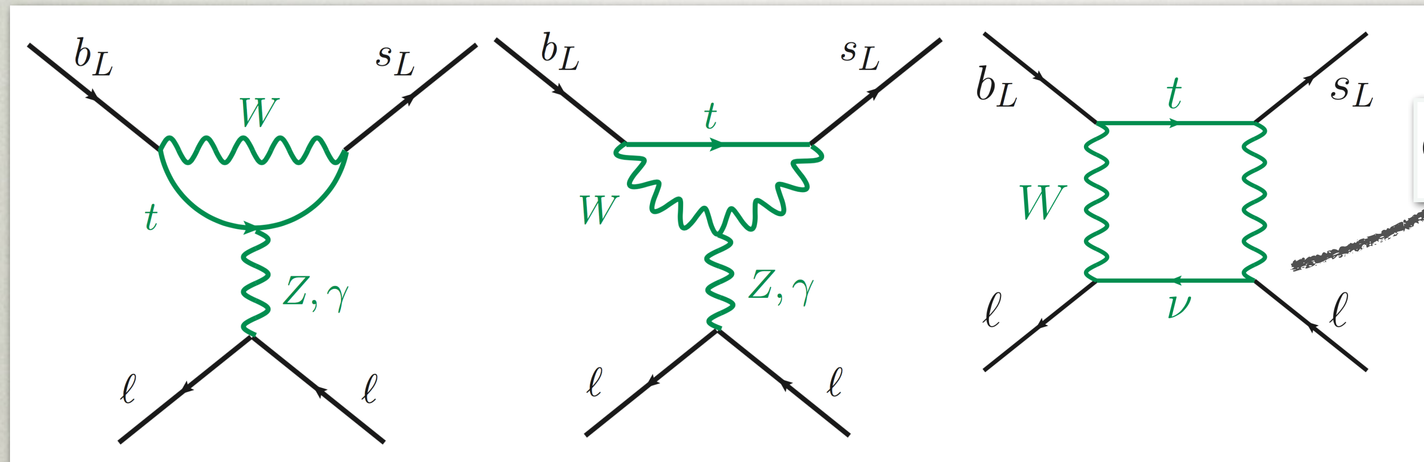
- $b \to sll$ flavor anomaly
  - theoretically clean, ~4σ excess
  - does it make sense from NP perspective?
    - reasonable scale for NP models*

*mostly face the I. I. Rabi's muon question: "Who ordered that?"

EXPERIMENTAL SITUATION

- $b \to sll$: generated at 1-loop in the SM

$$G_F V_{tb} V_{ts}^* \frac{\alpha}{4\pi} C_{9(10)} \bar{s}_L \gamma^\mu b_L \; \bar{\ell} \gamma_\mu (\gamma_5) \ell$$



$$C_9^{\mathrm{SM}} \approx -C_{10}^{\mathrm{SM}}$$

- in the SM $b \to see$ the same as $b \to s\mu\mu$
  - Lepton Flavor Universality in the SM

$b \to sll$: EXPERIMENT

- three clean observables: R_K and R_{K^*}

two bins

$$R_K = \left.\frac{Br(B \to K\mu\mu)}{Br(B \to Kee)}\right|_{[1,6]\mathrm{GeV}^2}$$

$$R_{K^*} = \frac{\mathrm{BR}(B \to K^*\mu^+\mu^-)}{\mathrm{BR}(B \to K^*e^+e^-)}$$

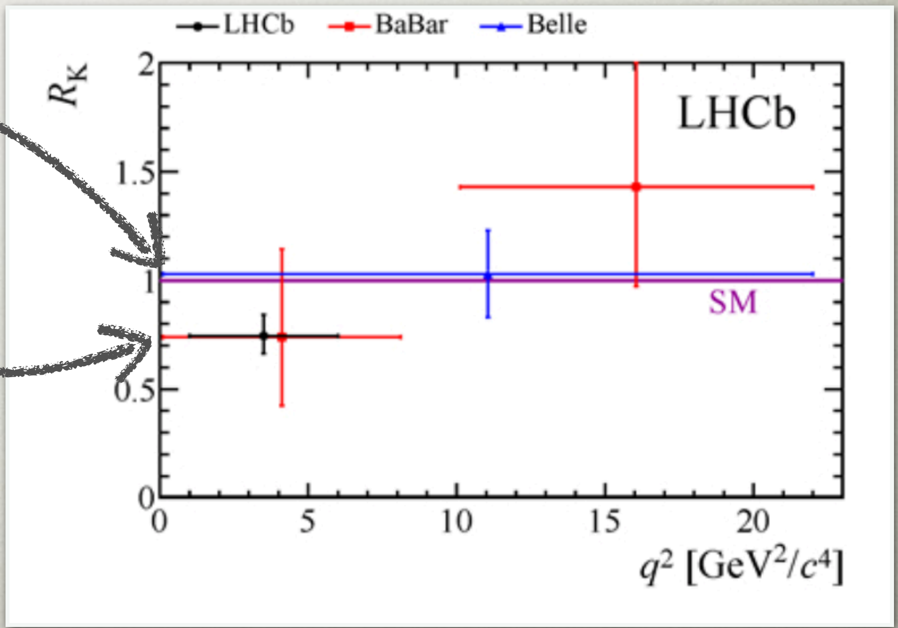
- 2.6σ anomaly in R_K

Bordone, Isidori, Pattori, 1605.07633

SM: $R_K = 1.00 \pm 0.01$

exp: $R_K = 0.745 \pm 0.082$

LHCb,1406.6482 (3.0 fb[-1] @7+8TeV)

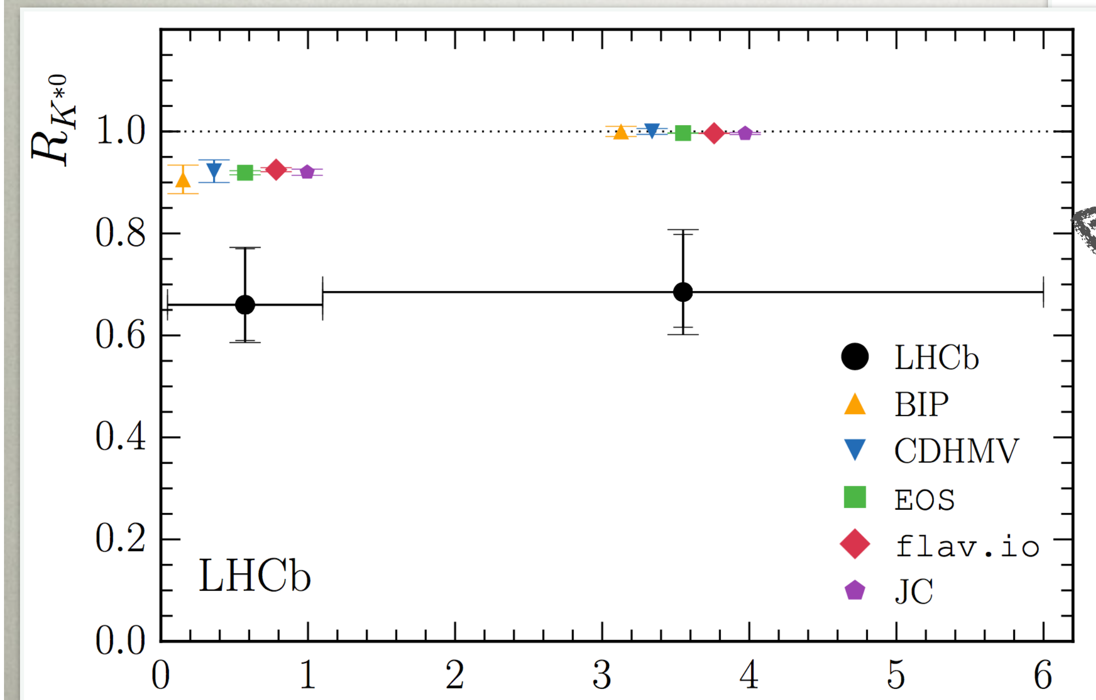


$b \to sll$: EXPERIMENT

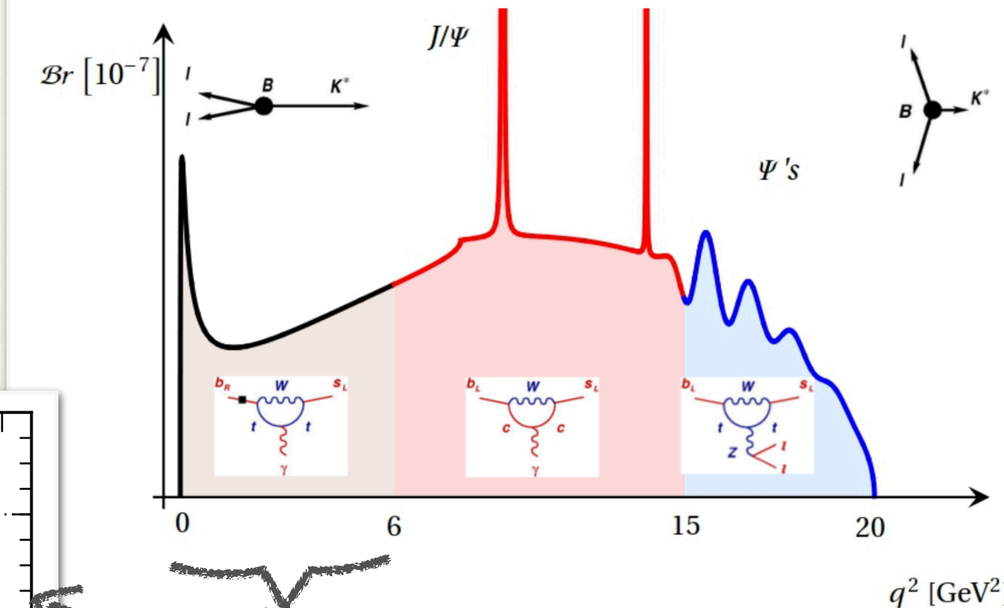
- 2 bins in R_{K^*}

$$R_{K^*} = \frac{\mathrm{BR}(B \to K^* \mu^+ \mu^-)}{\mathrm{BR}(B \to K^* e^+ e^-)}$$

- 2.2-2.5σ deviation in each



LHCb, 1705.05802



experiment: LHCb, 1705.05802 (3.0 fb^{-1} @7+8TeV)

$$R_{K^*[0.045,\ 1.1]\ \mathrm{GeV}^2} = 0.660^{+0.110}_{-0.070} \pm 0.024,$$

$$R_{K^*[1.1,\ 6]\ \mathrm{GeV}^2} = 0.685^{+0.113}_{-0.069} \pm 0.047,$$

WHAT DO WE LEARN?

see, e.g., Alonso, Grinstein, Martin Camalich, 1407.7044

- R_K can only be explained by NP in

$$\mathcal{O}_9^{(\prime)\ell} = \frac{\alpha_{\rm em}}{4\pi}(\bar{s}\gamma^\mu P_{L(R)}b)\,(\bar{\ell}\gamma_\mu\ell), \qquad \mathcal{O}_{10}^{(\prime)\ell} = \frac{\alpha_{\rm em}}{4\pi}(\bar{s}\gamma^\mu P_{L(R)}b)\,(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

  - scalar currents constrained by $B_s \to ll$

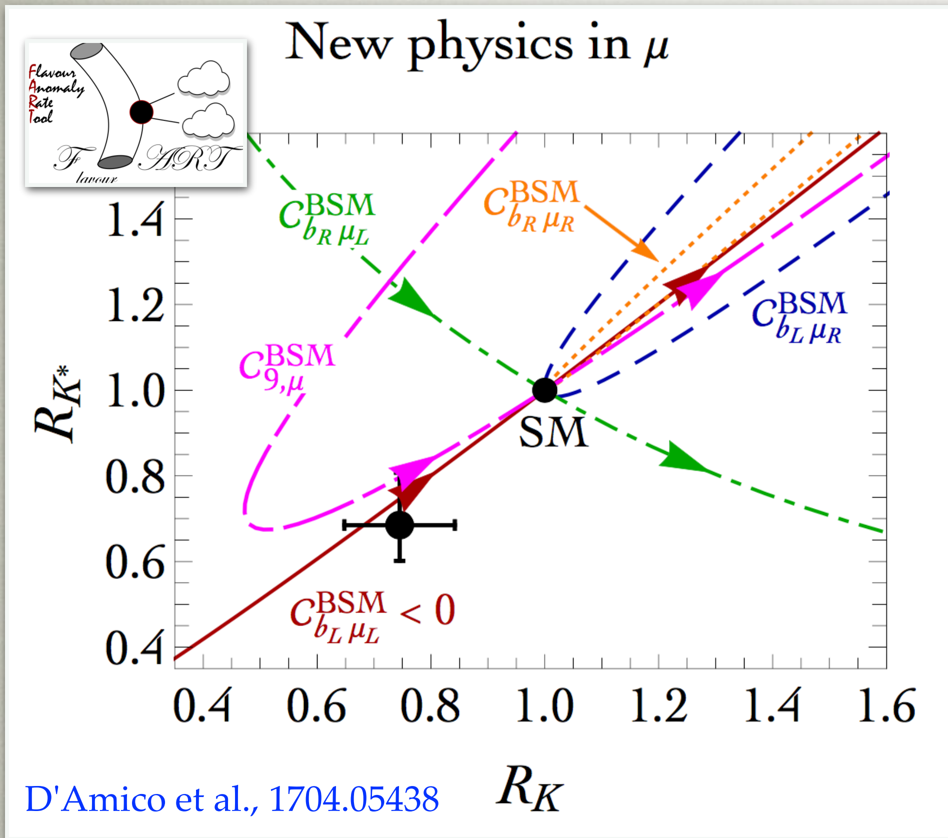
- R_K and R_{K^*} different parity, complementary info, e.g. for central bin

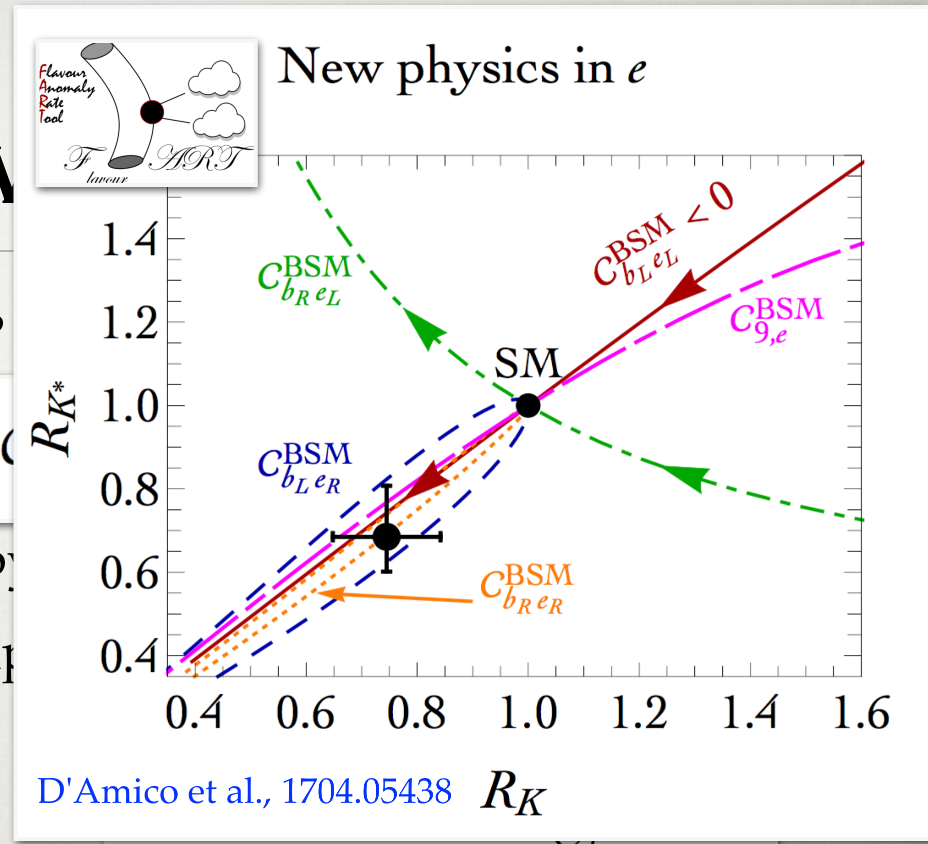
$$R_K \simeq 1 + 2\frac{\mathrm{Re}\, C^{\rm BSM}_{b_{L+R}(\mu-e)_L}}{C^{\rm SM}_{b_L\mu_L}} \qquad R_{K^*} \simeq R_K - 4p\frac{\mathrm{Re}\, C^{\rm BSM}_{b_R(\mu-e)_L}}{C^{\rm SM}_{b_L\mu_L}}$$

see, e.g., D'Amico et al., 1704.05438

- NP can be either in muons or electrons
  - in both cases $(\bar{s}b)_L$ ok
  - for electrons also $(\bar{s}b)_R(\bar{e}e)_R$ possible (from quadratic dep.)
- combined signif. from "clean" observables $>4\sigma$

Altmannshofer, Stangl, Straub, 1704.05435; D'Amico, Nardecchia, Panci, Sannino, Strumia, Torre, Urbano, 1704.05438; Capdevila, Crivellin, Descotes-Genon, Matias, Virto, 1704.05340; Hiller, Nisandzic, 1704.05444; Geng, Grinstein, Jager, Martin Camalich, Ren, Shi, 1704.05446; Chobanova, Hurth, Mahmoudi, Neshatpour, Santos, 1705.10730





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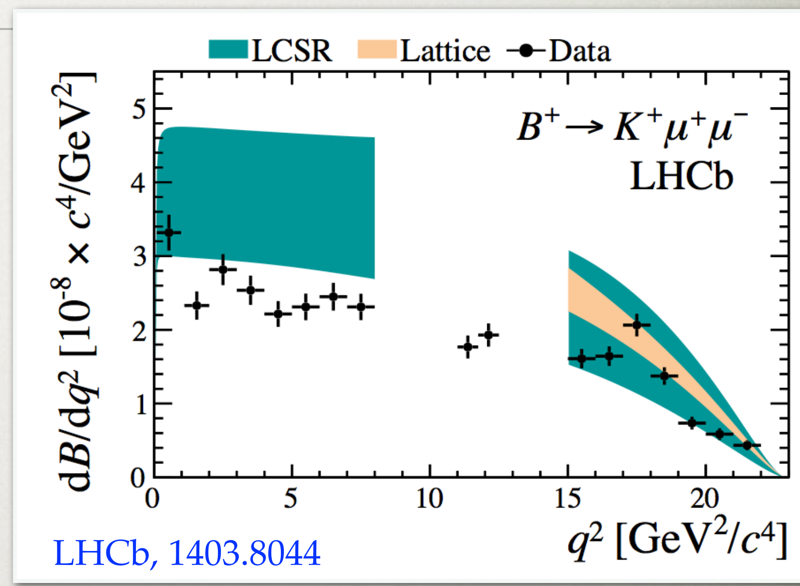
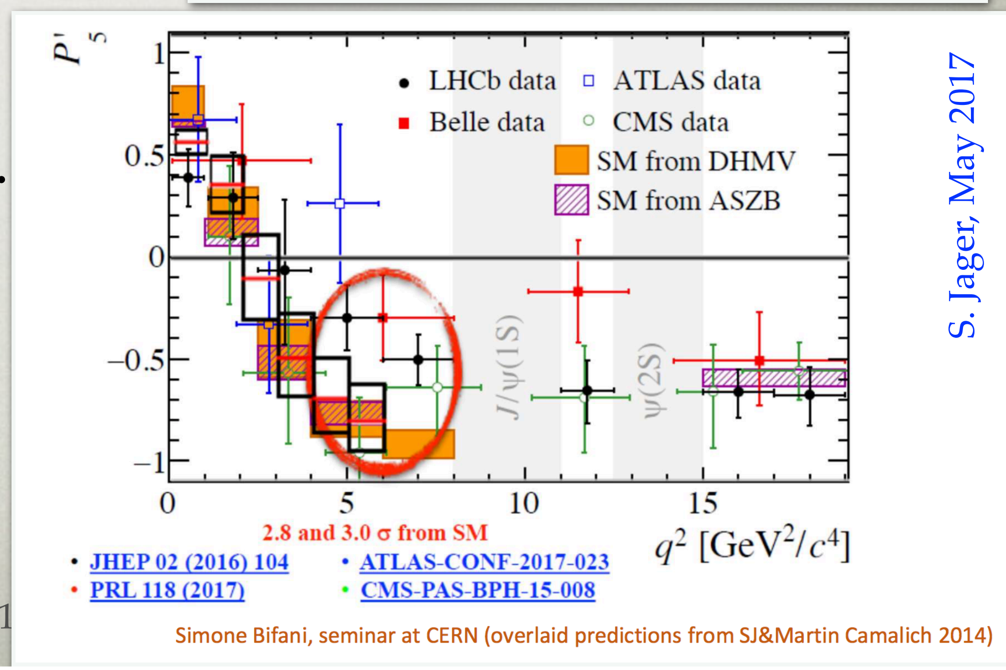
GLOBAL FITS

- in principle much more info
  - $Br(B \to K^{(*)}\mu\mu)$, $Br(B_s \to \phi\mu\mu)$, $Br(B \to X_s\mu\mu)$
  - angular obs. in $B^0 \to K^{*0}\mu\mu$, $B_s \to \phi\mu\mu$
- sensitive to hadronic inputs
  - require form factors predict. (QCD sum rules), charm loops, nonfactor. contribs.
- prefer NP in muons





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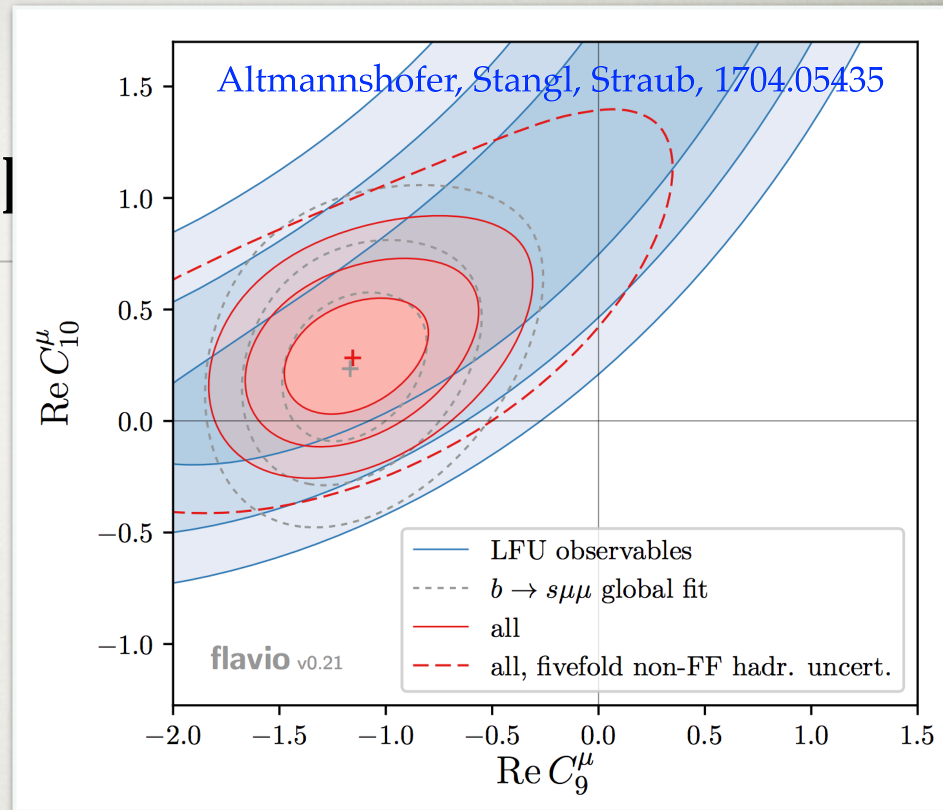
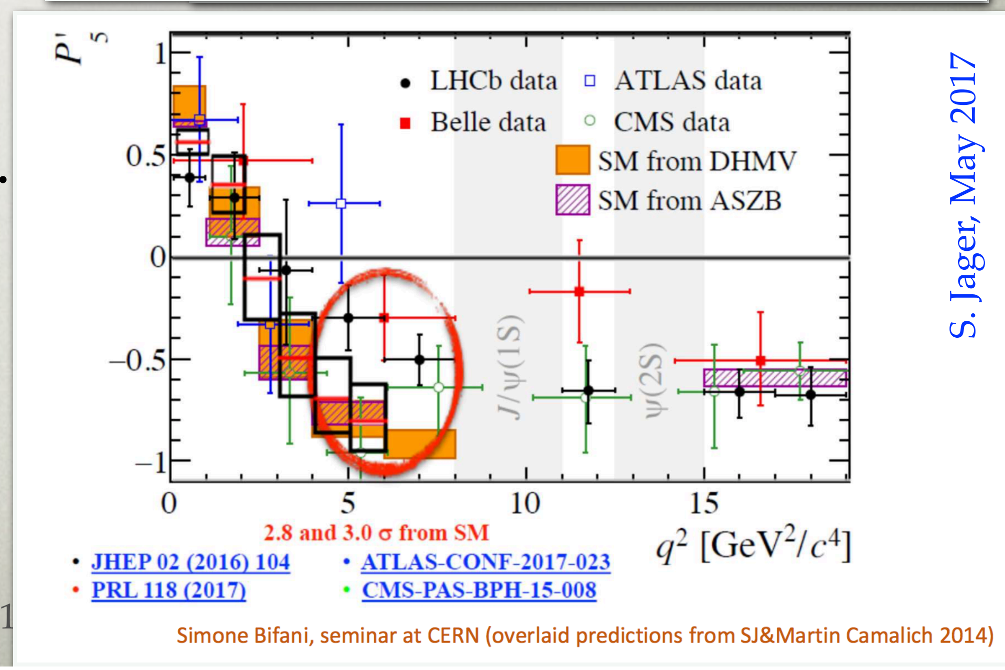




WHAT KIND OF NP?

- from now on will assume that NP in $b \to s\mu\mu$
- what is the NP scale?
  - the Wilson coeffs. in previous slides

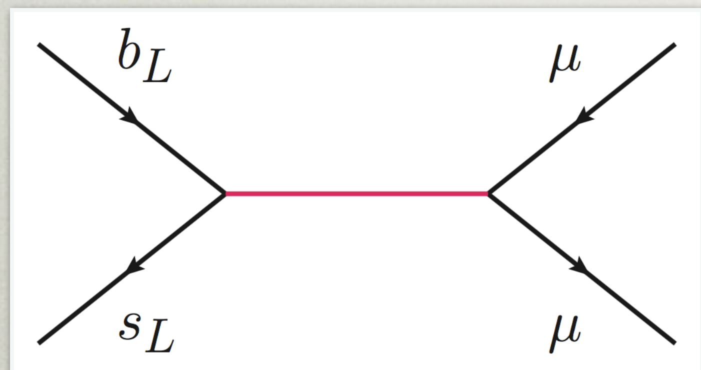
$$V_{tb}V_{ts}^* \frac{\alpha_{\rm em}}{4\pi v^2} C_I = \frac{C_I}{(36\,\text{TeV})^2}$$

$C_I^{NP} \sim O(1)$

- types of NP
  - tree level (heavy or light)
  - loop level

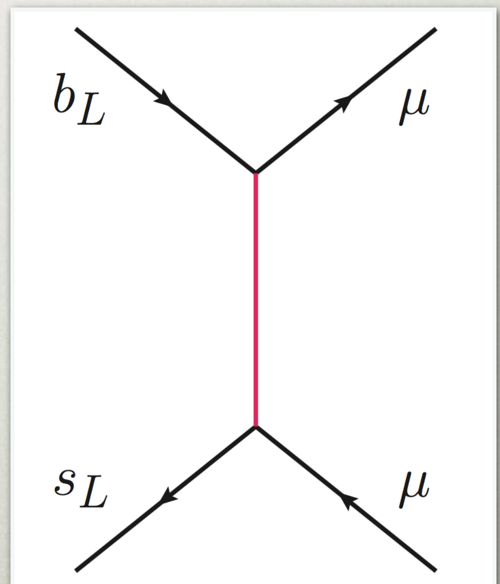
TREE LEVEL

- two distinct types:
- mediated by a Z'
  - $SU(2)_L$ singlet or triplet



Altmannshofer, Straub, 1308.1501;
Altmannshofer, Gori, Pospelov, Yavin, 1403.1269;
Greljo, Isidori, Marzocca, 1506.01705;
+many refs.

- leptoquark
  - spin 0 or 1



see, e.g., Hiller, Nisandzic, 1704.05444;
Hiller, Schmaltz, 1411.4773; +many refs

LEPTOQUARKS

Hiller, Nisandzic, 1704.05444

- 3 options if a single LQ dominates

$SU(3)_c \times SU(2)_L \times U(1)_Y$

Scalar LQ

label	representation	Wilson coefficient	Relation	$R_{K^{(*)}}$
$\tilde{S}_2$	$(3, 2, 1/6)$	C_{RL}	$C_9' = -C_{10}'$	$R_K < 1,\ R_{K^*} > 1$
S_3	$(\bar{3}, 3, 1/3)$	C_{LL}^{NP}	$C_9 = -C_{10}$	$R_K \simeq R_{K^*} < 1.$
S_2	$(3, 2, 7/6)$	C_{LR}	$C_9 = C_{10}$	$R_K \simeq R_{K^*} \simeq 1$
$\tilde{S}_1$	$(\bar{3}, 1, 4/3)$	C_{RR}	$C_9' = C_{10}'$	$R_K \simeq R_{K^*} \simeq 1$

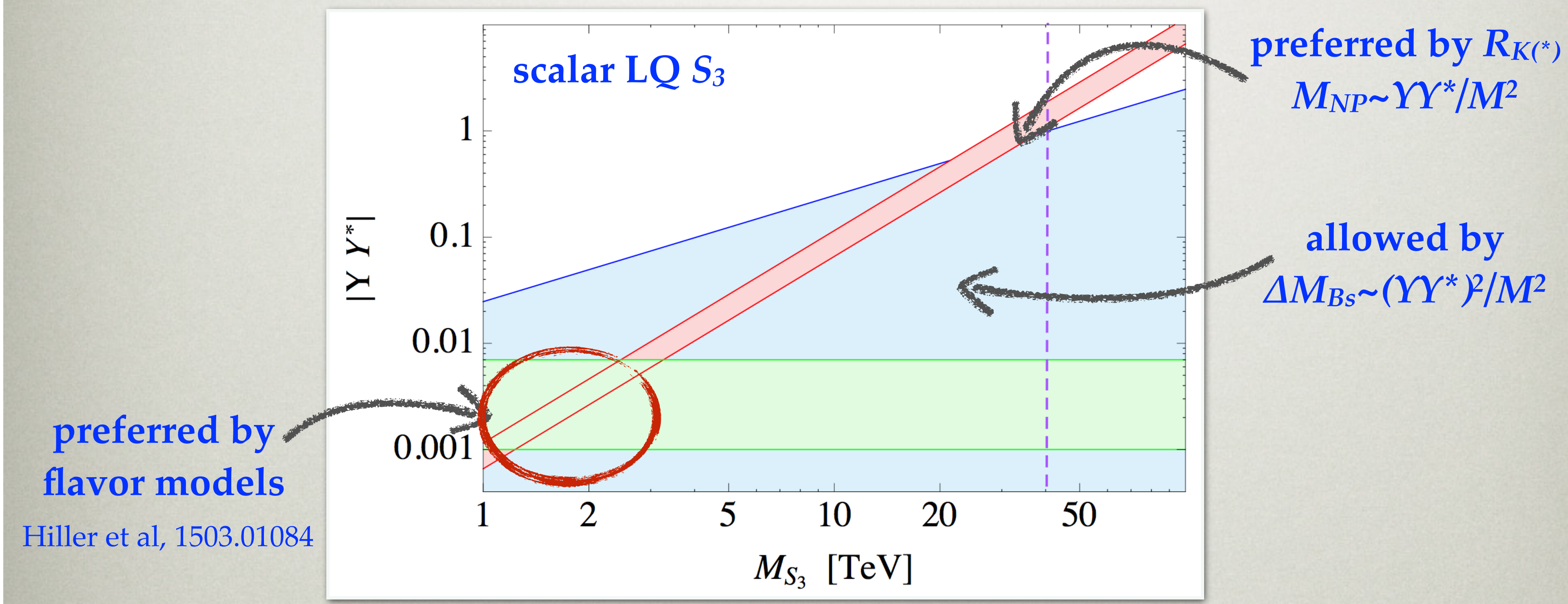
Vector LQ

label	representation	Wilson coefficient	Relation	$R_{K^{(*)}}$
V_1	$(3, 1, 2/3)$	C_{LL}^{NP}	$C_9 = -C_{10}$	$R_K \simeq R_{K^*} < 1$
		C_{LR}	$C_9 = +C_{10}$	$R_K \simeq R_{K^*} \simeq 1$
V_2	$(3, 2, -5/6)$	C_{RL}	$C_9' = -C_{10}'$	$R_K < 1,\ R_{K^*} > 1$
		C_{RR}	$C_9' = +C_{10}'$	$R_K \simeq R_{K^*} \simeq 1$
V_3	$(3, 3, -2/3)$	C_{LL}^{NP}	$C_9 = -C_{10}$	$R_K \simeq R_{K^*} < 1$

LEPTOQUARKS

Hiller, Nisandzic, 1704.05444

- at 1-loop constraints from B_s-$\bar{B}_s$ mixing



- implies upper bound on LQ mass

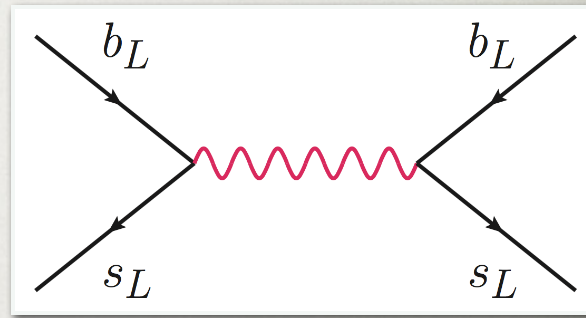
$$M \lesssim 40\,\text{TeV}\,, 45\,\text{TeV}\,, 20\,\text{TeV} \qquad \text{for } S_3, V_1, V_3$$

- UV model building often in terms of strong dynamics

Gripaios, Nardecchia, Renner, 1412.1791; Gripaios, 0910.1789; Alonso et al, 1505.05164; Barbieri et al, 1512.01560, 1611.04930

GENERAL CONSIDERTATIONS ABOUT Z'

Altmannshofer, Straub, 1308.1501; 1411.3161

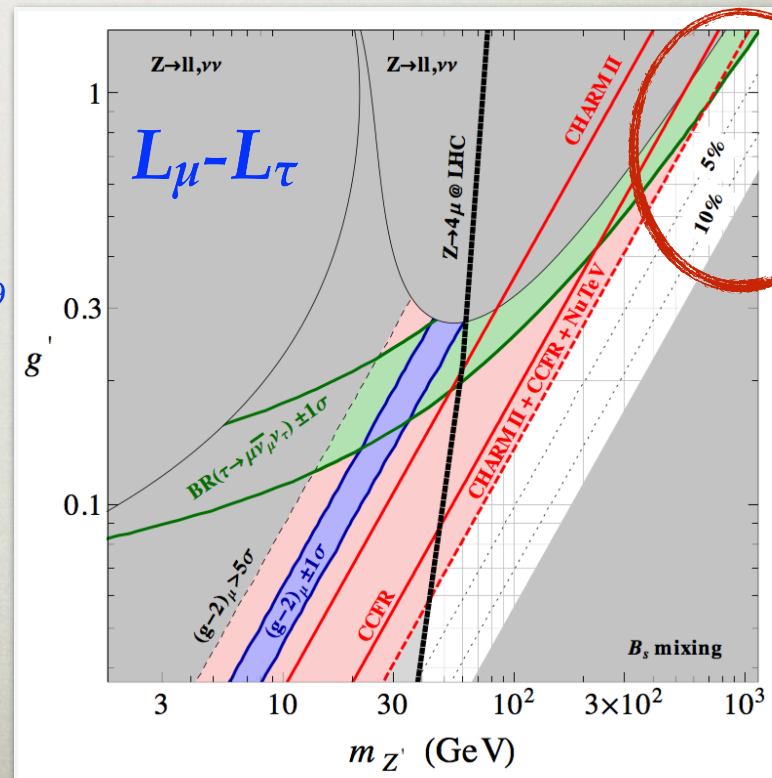


- nontrivial constraint from B_s mixing

$$\frac{g_{bsZ'}}{m_{Z'}} \lesssim \frac{0.01}{2.5\ \mathrm{TeV}}$$

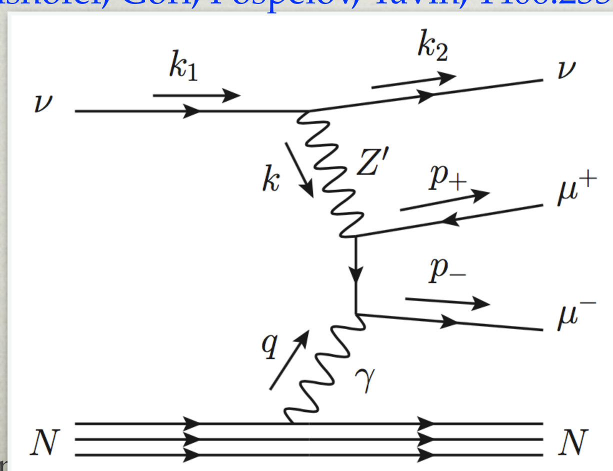
compare: $V_{ts} \simeq 0.04$

- if coupling to μ_L then a related signal in $b \to s\nu\nu$



- constraints from neutrino trident production

Altmannshofer, Gori, Pospelov, Yavin, 1406.2332; 1403.1269

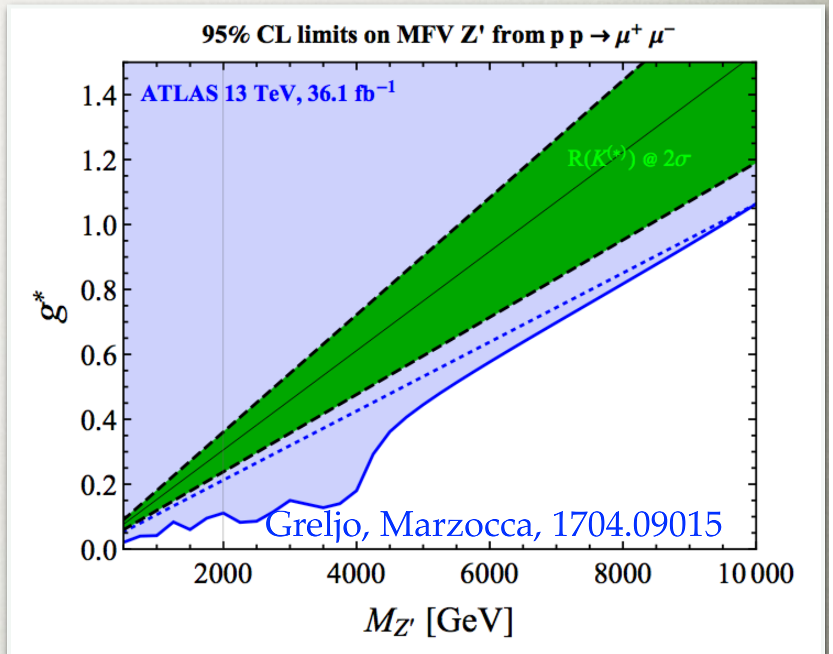


THE Z' MODELS

- bounds from ATLAS, CMS from $pp \to Z' \to \mu\mu$
  Greljo, Marzocca, 1704.09015
  - e.g., for MFV ansatz

$$c^{(3,1)}_{Q_{ij}L_{22}} \sim \left(\mathbf{1} + \alpha Y_u Y_u^\dagger + \beta Y_d Y_d^\dagger\right)_{ij}$$

$$J_\mu = g_Q^{(1),ij}(\bar{Q}_i \gamma_\mu Q_j) + g_L^{(1),kl}(\bar{L}_k \gamma^\mu L_l)$$

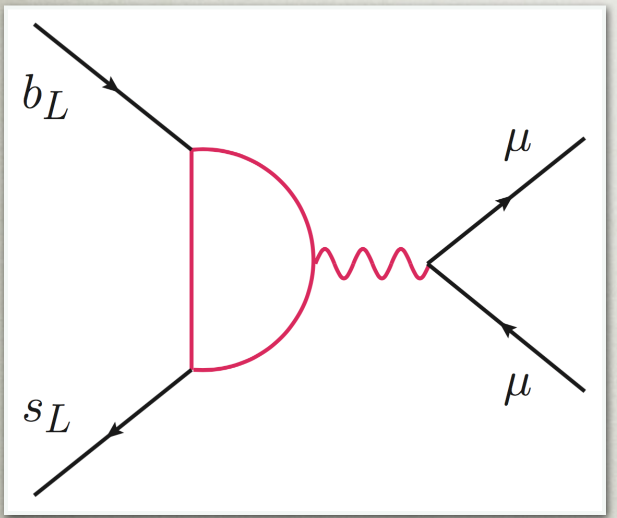


- "LHC safe" models
  Altmannshofer et al, 1403.1269
  - $U(1)_{\mu-\tau}$ models with vector-like quarks
  - models with more than one mediator (mixing suppression), e.g. $U(1)_q x U(1)_{\mu-\tau}$ Crivellin, Fuentes, Greljo, Isidori, 1611.02703
  - composite ρ exchanges Carmona, Goertz, 1510.07658; Megías et al, 1608.02362 , 1705.04822;
  - fully horizontal Z' models with third-family charges only, e.g., $U(1)_{B3-\tau}$,$U(1)_{B3-3\mu}$ Alonso, Cox, Han, Yanagida, 1705.03858; Bonilla, Modak, Srivastava, Valle, 1705.00915
    - interesting textures in the neutrino mass matrix
      Bhatia, Chakraborty, Dighe, 1701.05825

LOOP LEVEL

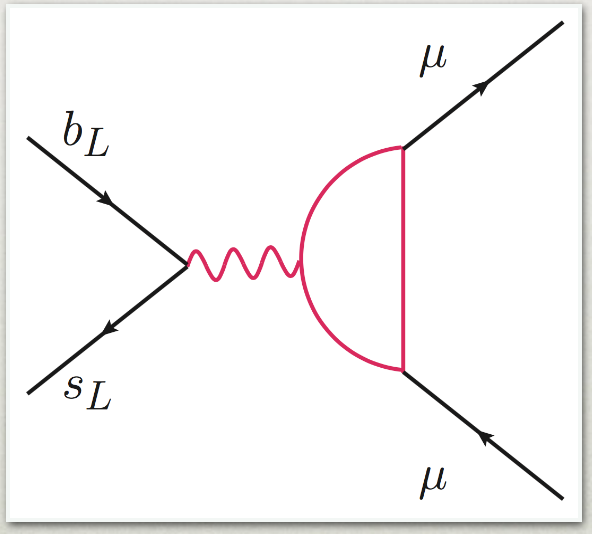
- three distinct options

- Z' w/ loop to bs



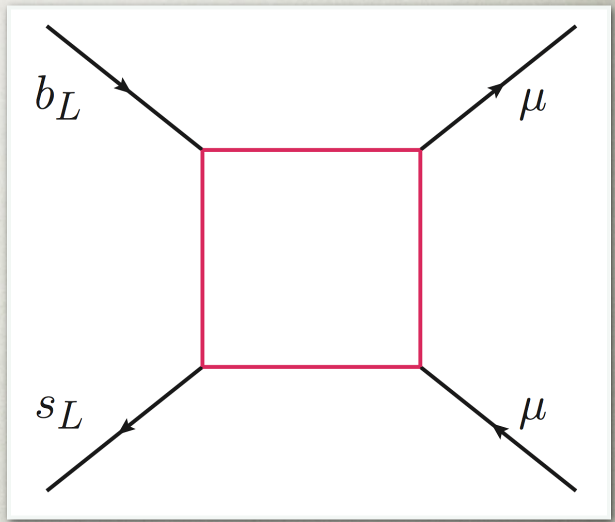
Kamenik, Soreq, JZ, 1704.06005

- Z' w/ loop to $\mu\mu$



Bélanger, Delaunay, 1603.03333

- box w/ NP fields



Gripaios, Nardecchia, Renner, 1509.05020;
Bauer, Neubert, 1511.01900;
Becirevic, Sumensari, 1704.05835

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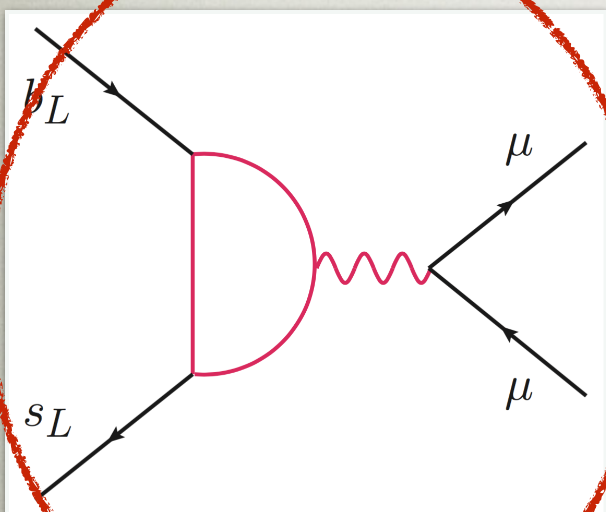

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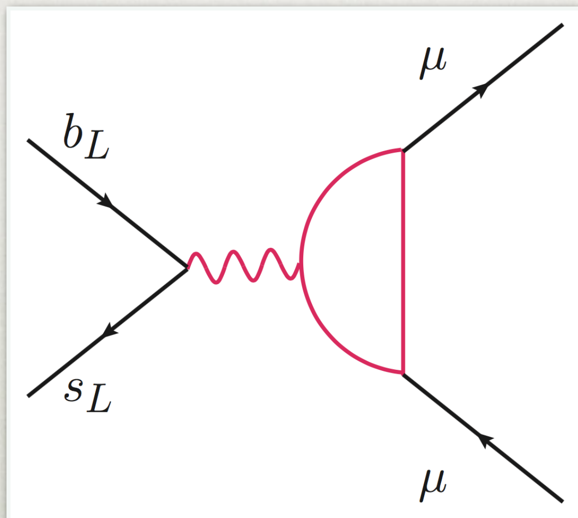

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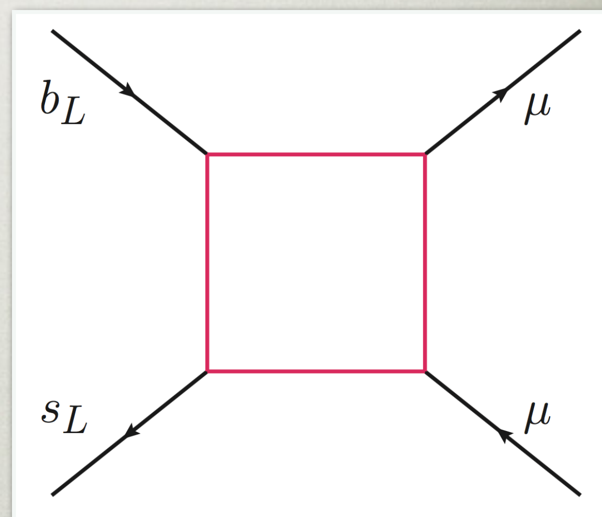

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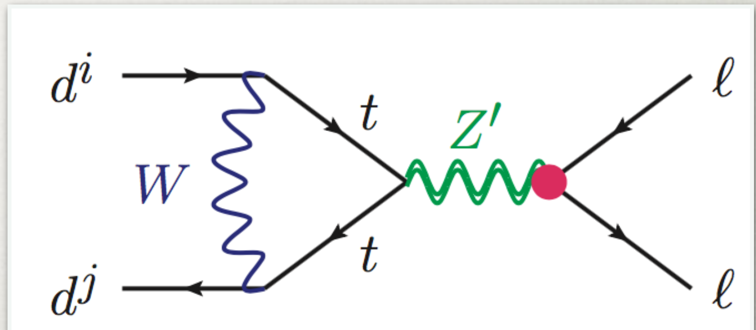
TOP-PHILIC Z'

Kamenik, Soreq, JZ, 1704.06005

- where is the flavor structure coming from?
- why the $(\bar{s}b)_{V\text{-}A}$ chiral structure?
- automatic for top-philic Z'
  - $b \to s$ due to SM W in the loop
  - avoids contraints from dimuon resonance searches
  - MFV structure: all FV due to CKM
    - there is a correlated signal in $K \to \pi\nu\nu$



$$c^{(3,1)}_{Q_{ij}L_{22}} \sim \left(\cancel{1} + \alpha Y_u Y_u^\dagger + \beta Y_d Y_d^\dagger\right)_{ij}$$

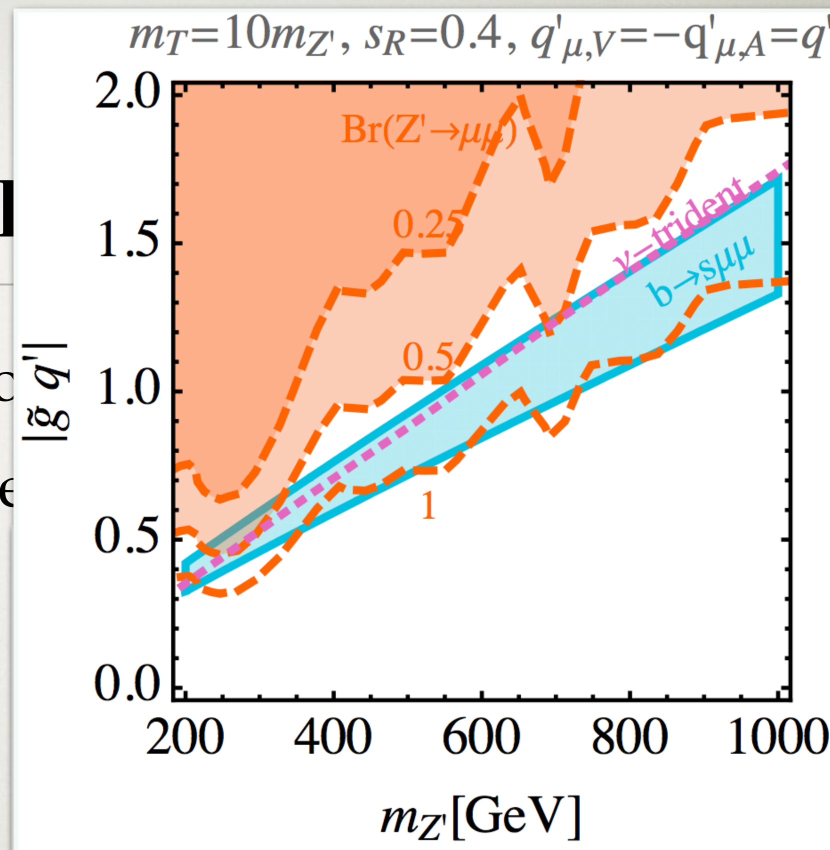
cf. NA62 reach: 10% of the SM

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) \simeq (8.4 \pm 1.0) \times 10^{-11} \times \frac{1}{3} \sum_\ell \left|1 + 0.11(C_9^{\ell,\mathrm{NP}} - C_{10}^{\ell,\mathrm{NP}})\right|^2$$

SM value

see also Bordone, Buttazzo, Isidori, Monnard, 1705.10729

TOP-PHI



4.06005

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SM value

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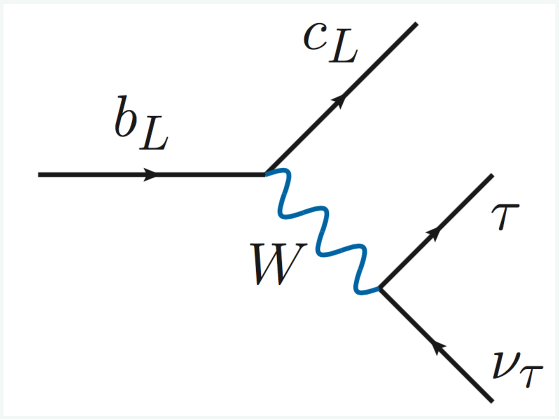
$b \to c\tau\nu$

UPSHOT

- $b \to c\tau\upsilon$ flavor anomaly
  - theoretically clean, ~4σ excess
  - NP effect large: *O(20%)* of SM tree level
    - NP interpr. often in conflict with other constraints

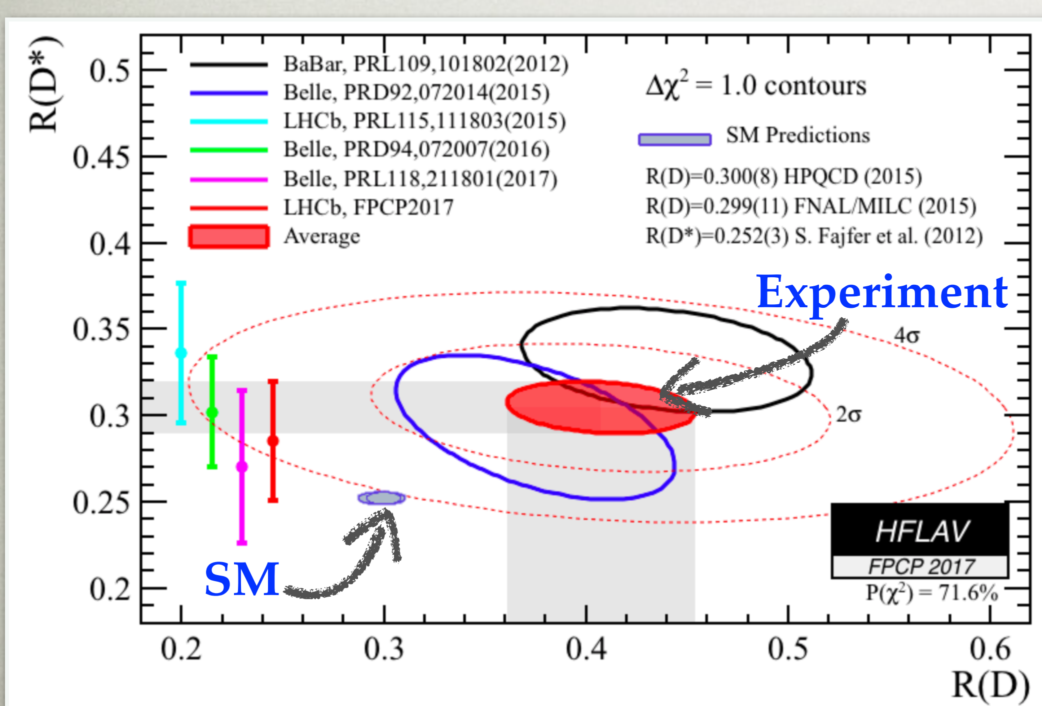


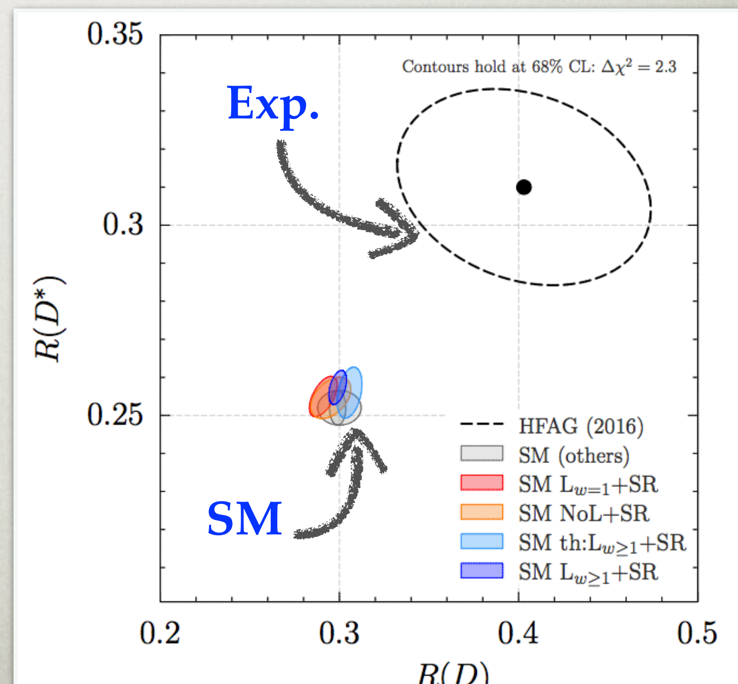
EXPERIMENTAL SITUATION

- seen in several experiments
- theory well under control

for theory predictions see, e.g.,
Fajfer, Kamenik, Nisandzic, 1203.2654
Bailey et al, 1206.4992
Becirevic, Kosnik, Tayduganov, 1206.4977
Bernlochner, Ligeti, Papucci, Robinson, 1703.05330
Bigi, Gambino, Schacht, 1707.09509

$$R(D^{(*)}) = \frac{\Gamma(\overline{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\overline{B} \to D^{(*)}l\bar{\nu})}\,, \qquad l = \mu,\, e$$

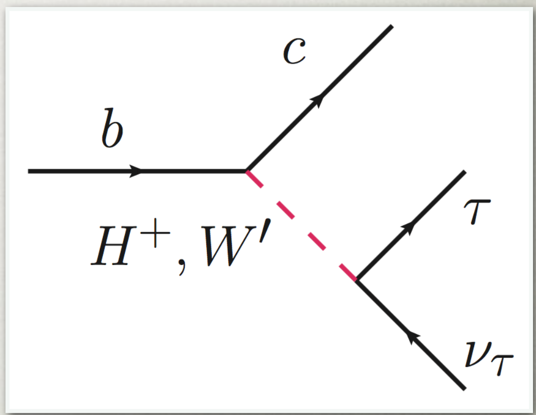


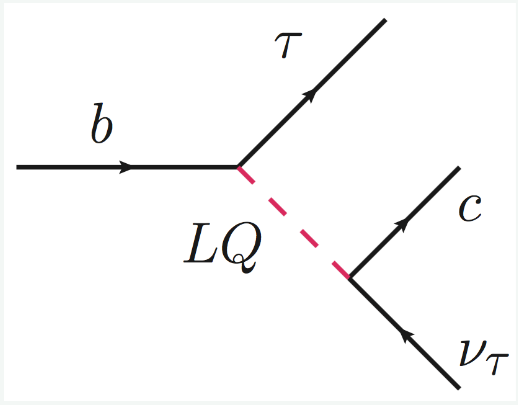


Bernlochner et al, 1703.05330

NEW PHYSICS INTERPRETATIONS

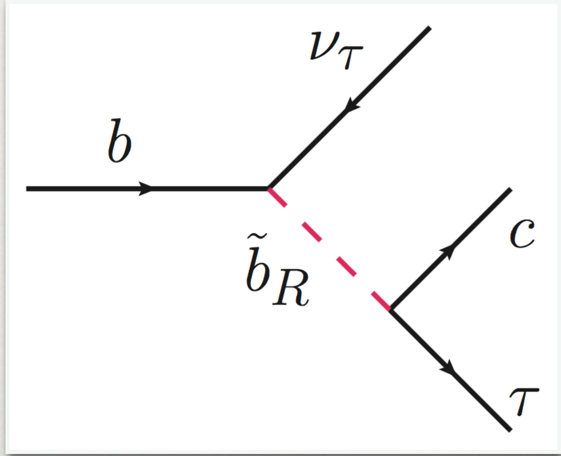
- the most obvious candidates ruled out
  - charged Higgs: total B_c lifetime, $b \to c\tau\upsilon$ q^2 distributions, searches in $pp \to \tau\tau$
  - W': related Z' ruled out from $pp \to \tau\tau$
- left with leptoquarks, will show two
  - RPV sbottom: explains $b \to c\tau\upsilon$, not ~~$b \to s\mu\mu$~~
  - vector leptoquark: explains $b \to c\tau\upsilon$ & $b \to s\mu\mu$
    - also possible if more than one scalar leptoquark   Crivellin, Muller, Ota, 1703.09226





RPV $\tilde{b}_{R,L}$

Altmannshofer, Dev, Soni, 1704.06659

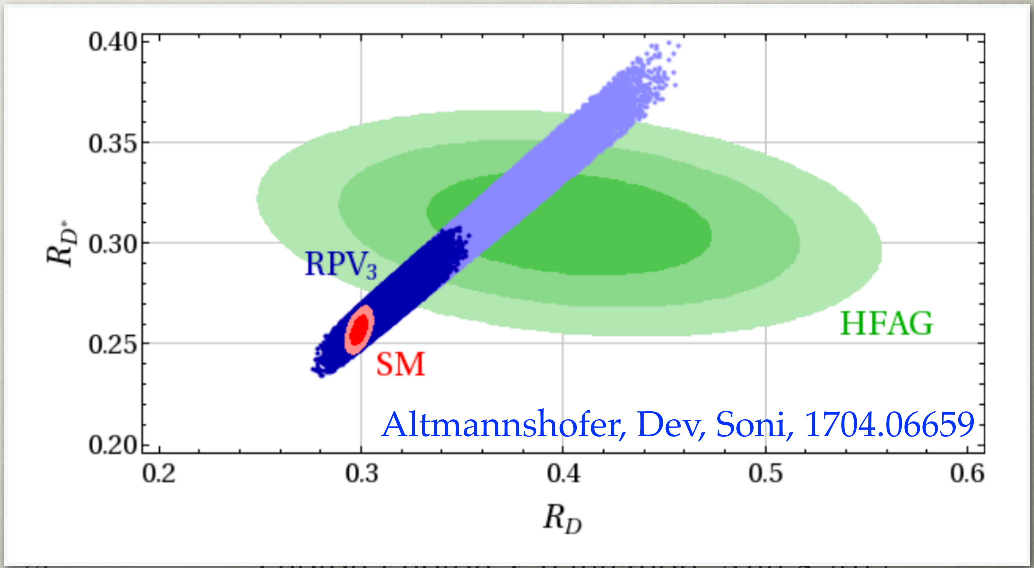


- leptoquarks: $\tilde{b}_{R,L}$ with RPV interactions

$$\lambda'_{ijk} L_i Q_j D^c_k$$

- to avoid proton decay constraints: 1st, 2nd gen. squarks taken heavy
- direct searches $pp \to tt\tau\tau$: $m(\tilde{b}_R) > 650$GeV
- unification still possible
- cannot explain $b \to s\mu\mu$

Deshpande, He, 1608.04817; Becirevic et al. 1608.07583



LEPTOQUARK FOR BOTH $b \to c\tau\nu$ AND $b \to s\mu\mu$

Buttazzo, Greljo, Isidori, Marzocca, 1706.07808

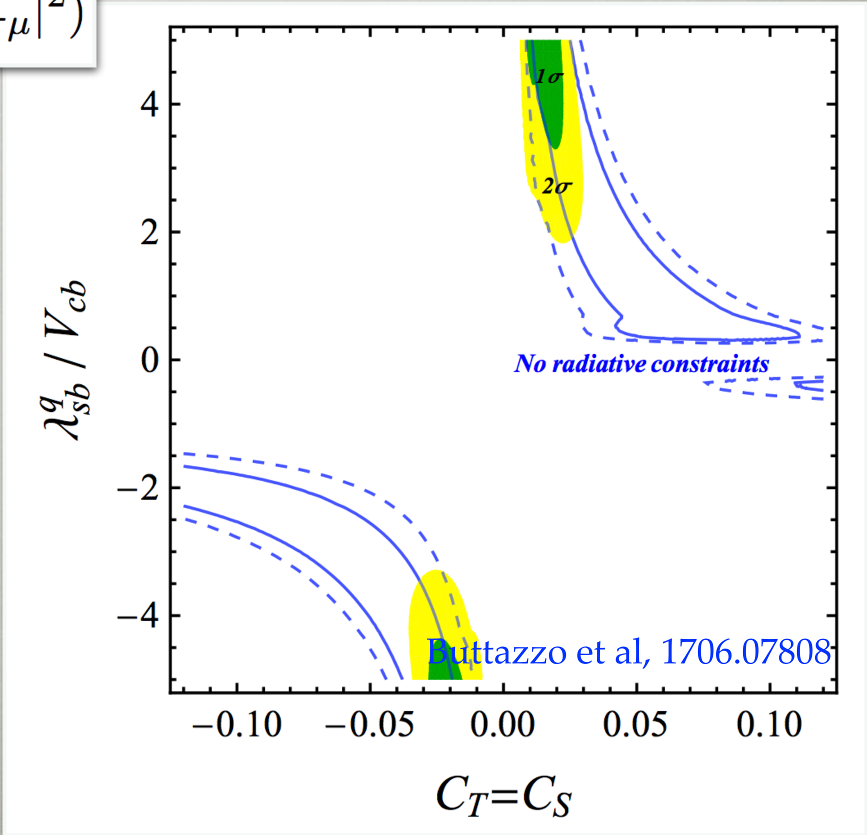
- in EFT possible to explain all anomalies

$$\frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\left[C_T\ (\bar{Q}^i_L\gamma_\mu\sigma^a Q^j_L)(\bar{L}^\alpha_L\gamma^\mu\sigma^a L^\beta_L) + C_S\ (\bar{Q}^i_L\gamma_\mu Q^j_L)(\bar{L}^\alpha_L\gamma^\mu L^\beta_L)\right]$$

$$\lambda^q_{sb} = \mathcal{O}(|V_{cb}|)\ , \quad \lambda^\ell_{\tau\mu} = \mathcal{O}(|V_{\tau\mu}|)\ , \quad \lambda^\ell_{\mu\mu} = \mathcal{O}(|V_{\tau\mu}|^2)$$

  - with MFV-like flavor structure
  - predicts *Br(b→sττ)~O(100)x SM*
- if NP contribs. dominated by one field
  - only one option: vector leptoquark

$$U_1^\mu \equiv (\mathbf{3}, \mathbf{1}, 2/3)$$



LEPTOQUARK FOR BOTH $b \to c\tau\nu$ AND $b \to s\mu\mu$

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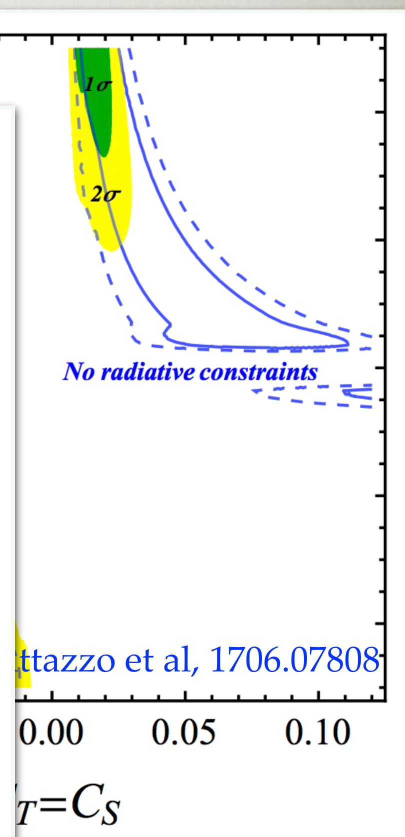
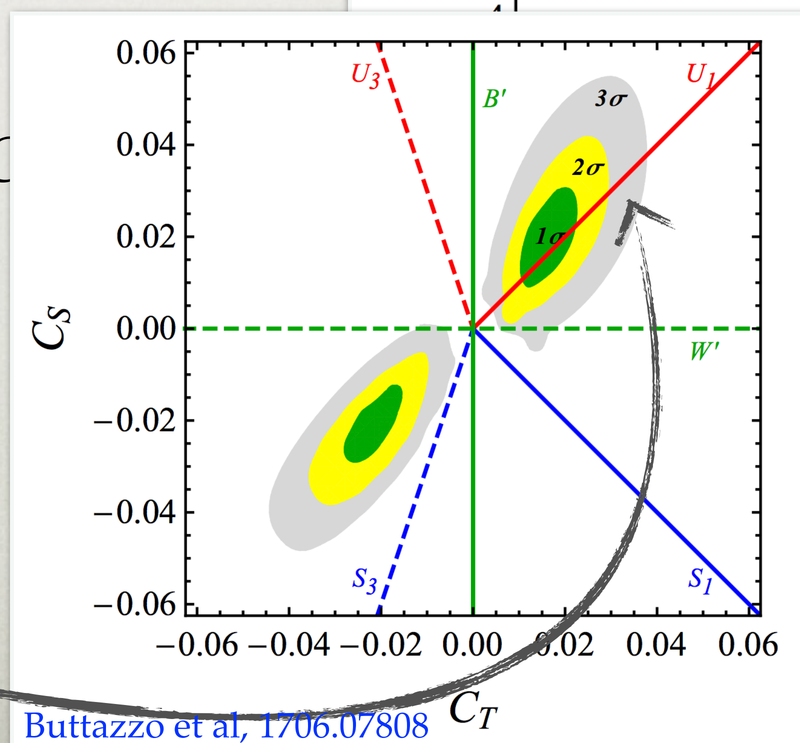
  - with MFV-like flavor
  - predicts $Br(b \to s\tau\tau) \sim \mathcal{O}$
- if NP contribs. dominated by one field
  - only one option: vector leptoquark

$$U_1^\mu \equiv (\mathbf{3}, \mathbf{1}, 2/3)$$





LEPTOQUARK FOR BOTH

$b\to c\tau\nu$ AN

Buttazzo, Greljo, Isidori, Marzocca, 1706.07808

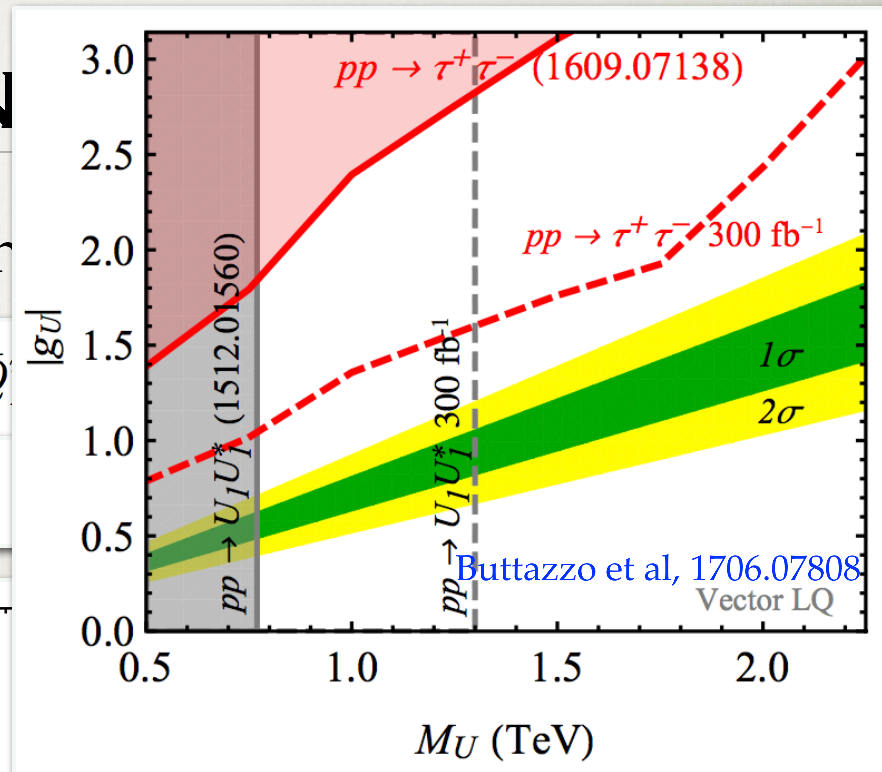
- in EFT possible to explain all ar

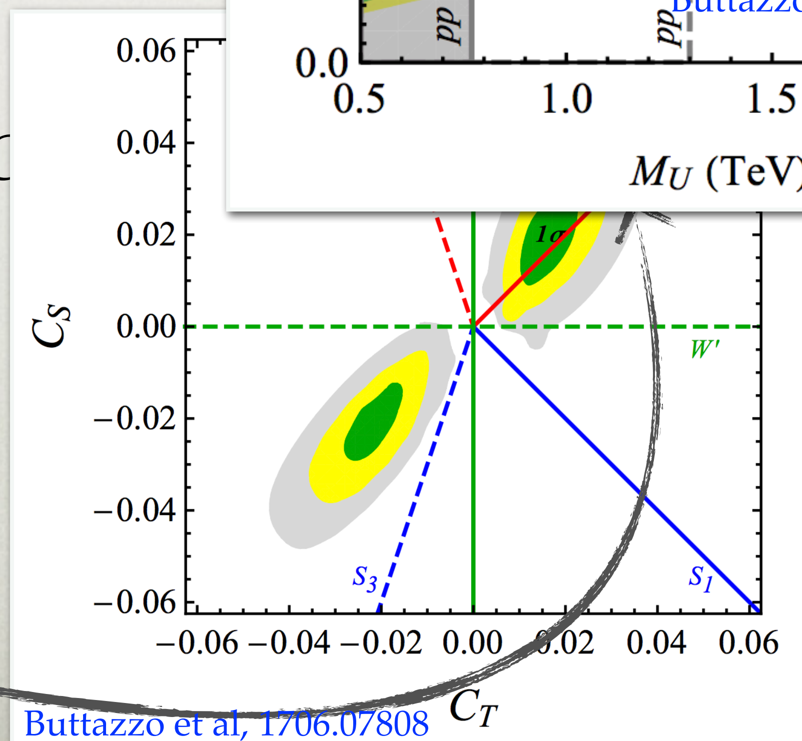
$$\frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\Big[C_T\,(\bar Q^i_L\gamma_\mu\sigma^a Q^j_L)(\bar L^\alpha_L\gamma^\mu\sigma^a L^\beta_L) + C_S\,(\bar Q$$

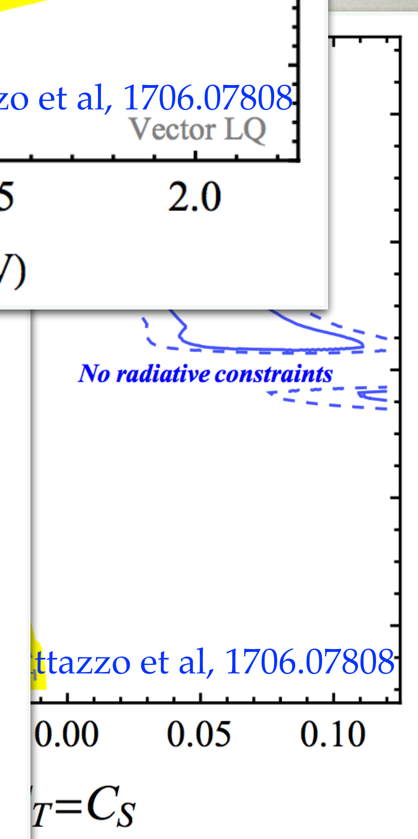
$$\lambda^q_{sb}=\mathcal{O}(|V_{cb}|)\ ,\quad \lambda^\ell_{\tau\mu}=\mathcal{O}(|V_{\tau\mu}|)\ ,\quad \lambda^\ell_{\mu\mu}=$$

  - with MFV-like flavor
  - predicts *Br(b→sττ)~C*
- if NP contribs. dominated by one field
  - only one option: vector leptoquark

$$U_1^\mu \equiv (\mathbf{3},\mathbf{1},2/3)$$







THE FUTURE

- many related modes/observables in $b \to c\tau\upsilon$ and $b \to s\mu\mu$
  - $\Lambda_b \to \Lambda_c \tau\upsilon$, $B_C \to J/\psi\tau\upsilon$, $B_S \to D_s^* \tau\upsilon$, $B_s \to \phi ll$, $b \to sll$ inclusive, LFU in angular obs., ...
- a rule of thumb: Belle 2 50x statistics of Belle

see talk by Yutaka Ushiroda

  - corresponds to ~reach in Λ_{NP} of $\sqrt[4]{50} = 2.7x$
  - like going from 13TeV LHC to 35TeV LHC
- similar for LHCb (Phase 2 Upgrade 100x stat.)

CONCLUSIONS

- the $b \to c\tau\nu$ and $b \to s\mu\mu$ anomalies clean from the theory side
- challenging but not impossible to explain both simultaneously
- imply many new signals at both high p_T (CMS, ATLAS) and in precision flavor (LHCb, Belle II, NA62, g-2,...)

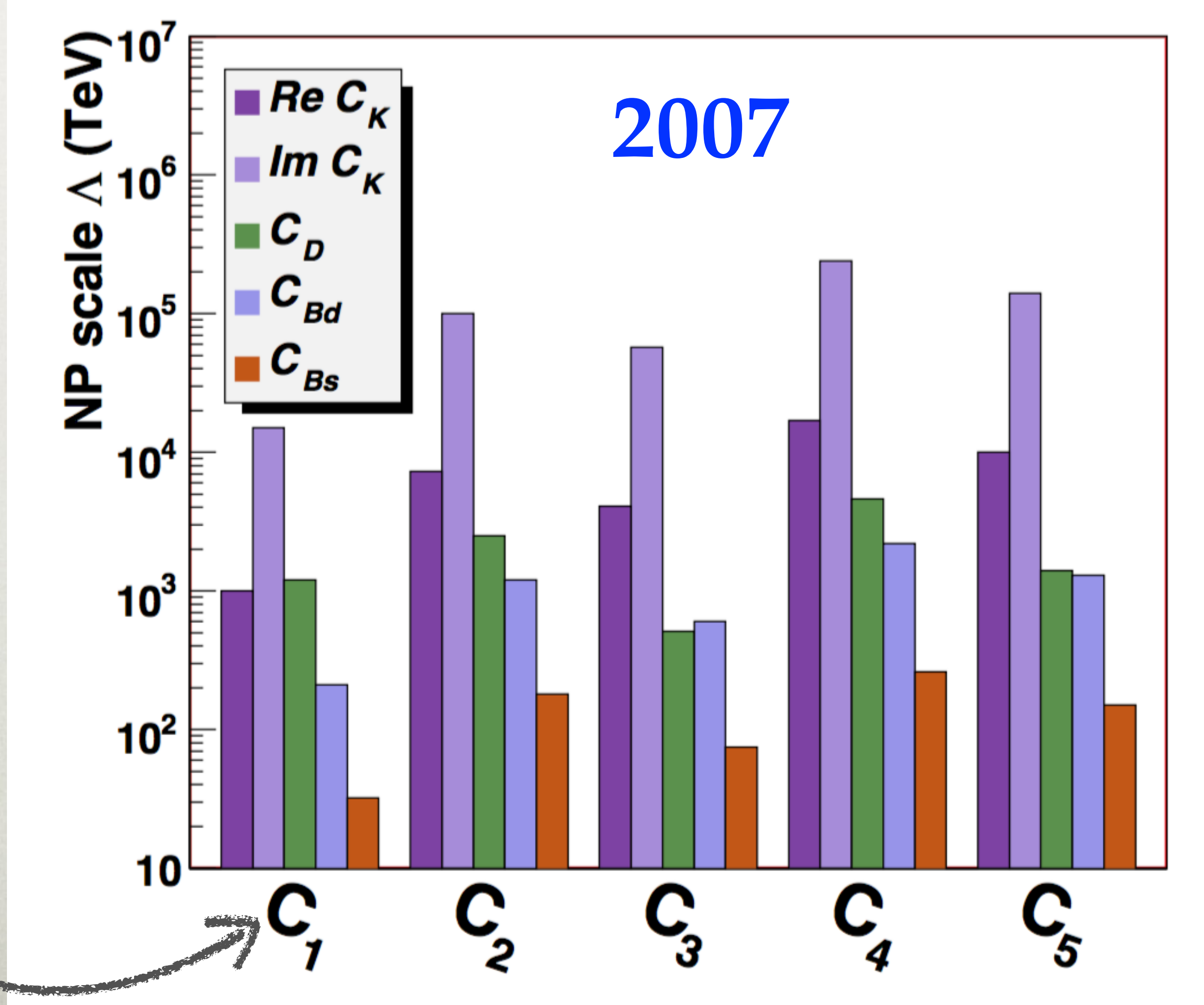
BACKUP SLIDES

LOW ENERGY PRECISION BOUNDS

UTFit 0707.0636, 1411.7233

- an impressive progress on flavor bounds in last 10 years
- in D, B_s mixing
- also from ε_K

$$\frac{1}{\Lambda^2}(\bar{b}_L\gamma^\mu d_L)(\bar{b}_L\gamma_\mu d_L)$$



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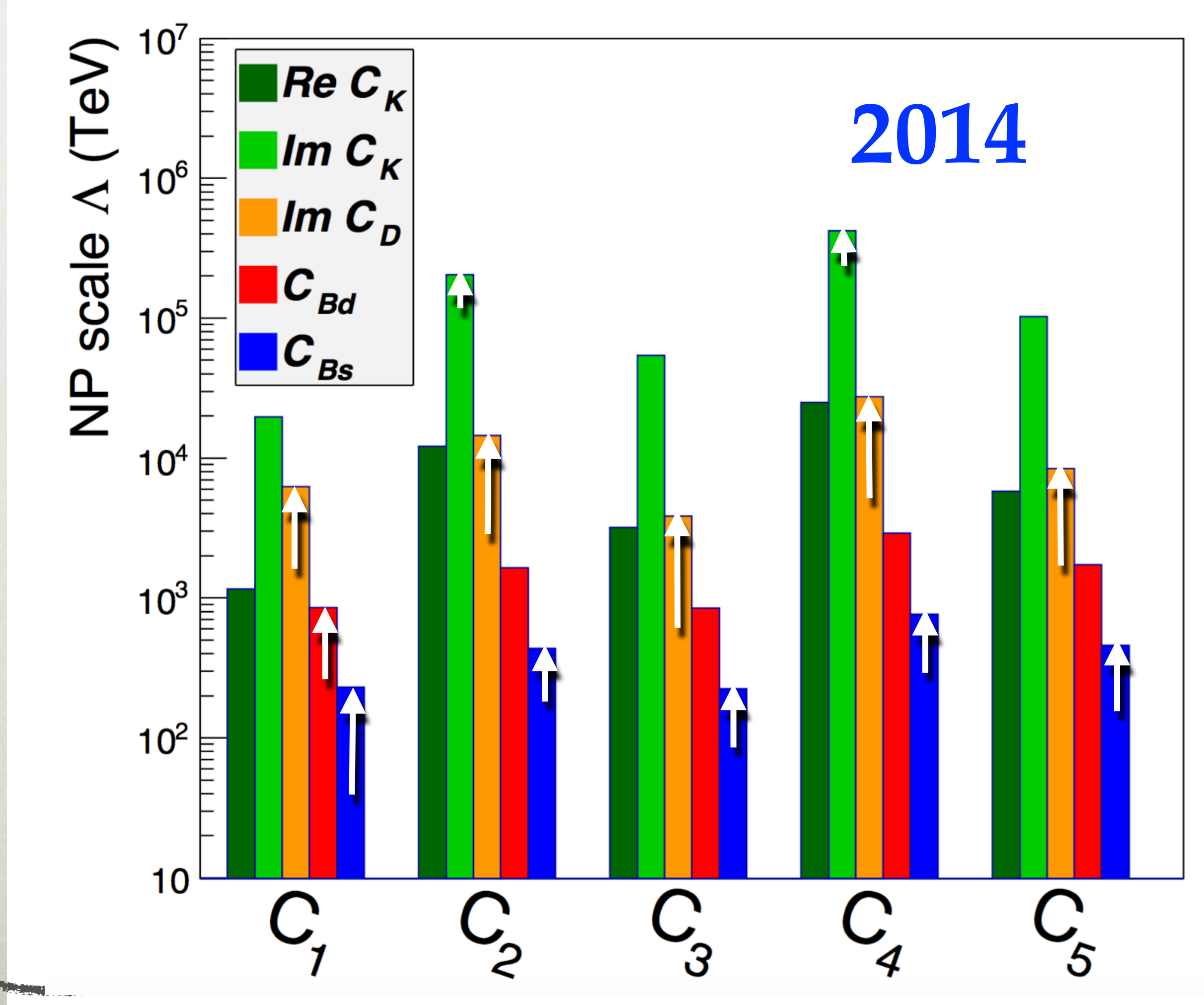


$$\frac{1}{\Lambda^2}(\bar{b}_L\gamma^\mu d_L)(\bar{b}_L\gamma_\mu d_L)$$

LEPTOQUARKS UPSHOT

L. di Luzio, 1706.01868

Simplified Model	Spin	SM irrep	c_1/c_3	$R_{D^{(*)}}$	$R_{K^{(*)}}$	No $d_i \to d_j \nu\bar{\nu}$
Z'	1	$(1,1,0)$	0	×	✓	×
V'	1	$(1,3,0)$	∞	✓	✓	×
S_1	0	$(\bar{3},1,1/3)$	-1	✓	×	×
S_3	0	$(\bar{3},3,1/3)$	3	✓	✓	×
U_1	1	$(3,1,2/3)$	1	✓	✓	✓
U_3	1	$(3,3,2/3)$	-3	✓	✓	×

Anomaly	$\mathcal{O}$	FS_Q	FS_L	Λ_A[TeV]	$\lvert\Lambda_{\mathcal{O}}\rvert$ [TeV]	Λ_U[TeV]	$M_\star$[TeV]
$b \to c\tau\bar{\nu}$	$Q_{23}L_{33}$	1	1	3.4	3.4	9.2	43
$b \to c\tau\bar{\nu}$	$Q_{33}L_{33}$	$\lvert V_{cb}\rvert$	1	3.4	0.7	1.9	8.7
$b \to s\mu\bar{\mu}$	$Q_{23}L_{22}$	1	1	31	31	84	390
$b \to s\mu\bar{\mu}$	$Q_{33}L_{22}$	$\lvert V_{ts}\rvert$	1	31	6.2	17	78
$b \to s\mu\bar{\mu}$	$Q_{33}L_{33}$	$\lvert V_{ts}\rvert$	$^{\ddagger}m_\mu/m_\tau$	31	1.5	4.1	19
$b \to s\mu\bar{\mu}$	$Q_{33}L_{33}$	$\lvert V_{ts}\rvert$	$^{*}(m_\mu/m_\tau)^2$	31	0.4	1.0	4.7

MINIMAL U(1)' MODEL

Kamenik, Soreq, JZ, 1704.06005

- new U(1)' gauge symmetry $\Phi = (\phi + \tilde{v})/\sqrt{2}$
  - scalar Φ~$(1,1,0,q')$
  - vectorlike fermion T'~$(3, 1, 2/3, q')$ ← $SU(3)xSU(2)xU(1)xU(1)'$
  - all the SM fields singlets under U(1)'
- interactions with the SM through only three terms

$$\mathcal{L}_{\rm mix} = -\lambda' |\Phi|^2 |H|^2 - \epsilon B^{\mu\nu} F'_{\mu\nu} - (y_T^i \bar{T}' \Phi u_R^i + \text{h.c.})$$

  - assume alignment with the SM up Yukawa

$$y_u^{ij} \sim \text{diag}(0, 0, y_t) \qquad y_T^i \sim (0, 0, y_T^t)$$

  - for us the interesting limit $|y_T^t| \gg \lambda', \varepsilon$

SIZE OF $b\to s\mu\mu$

- $t-$

$$\mathcal{M}_u^{t-T'} = \begin{pmatrix} y_t v/\sqrt{2} & 0 \\ y_T^t \tilde{v}/\sqrt{2} & M_T \end{pmatrix}$$

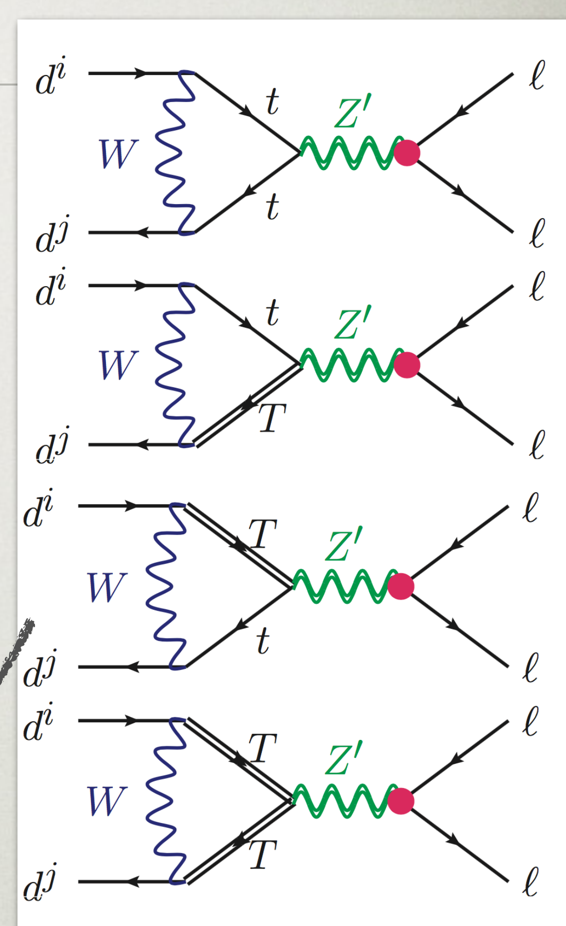
- the mixing angles for the two chiralities

$$\theta_R \sim y_T^t \tilde{v}/M_T \qquad \theta_L \sim \theta_R v/M_T$$

  - main effects due to mixing with t_R
- the induced $b\to sll$

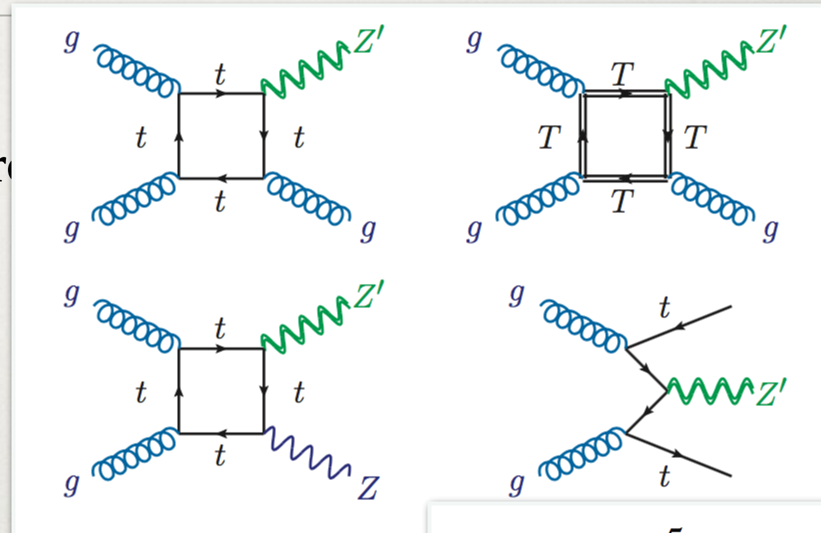
$$C_{9,10}^{\mu,\mathrm{NP}} = \frac{1}{2} q' q'_{\mu,V,A} \frac{m_t^2}{m_{Z'}^2} \frac{\tilde{g}^2}{e^2} s_R^2 \log\left(\frac{m_T^2}{m_W^2}\right) + \ldots,$$

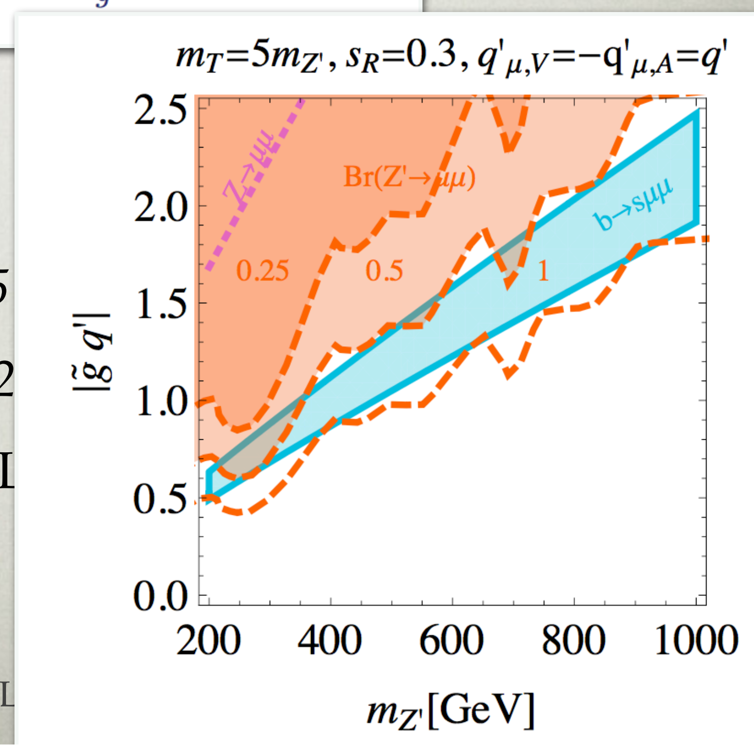
  - fits the anomaly for $m_{Z'}$~O(500 GeV), $\tilde{g}q'$~O(1)
- couplings to muons due to mixing with vectorlike leptons
  - depending on the details could explain $(g\text{-}2)_\mu$



DIRECT SEARCHES

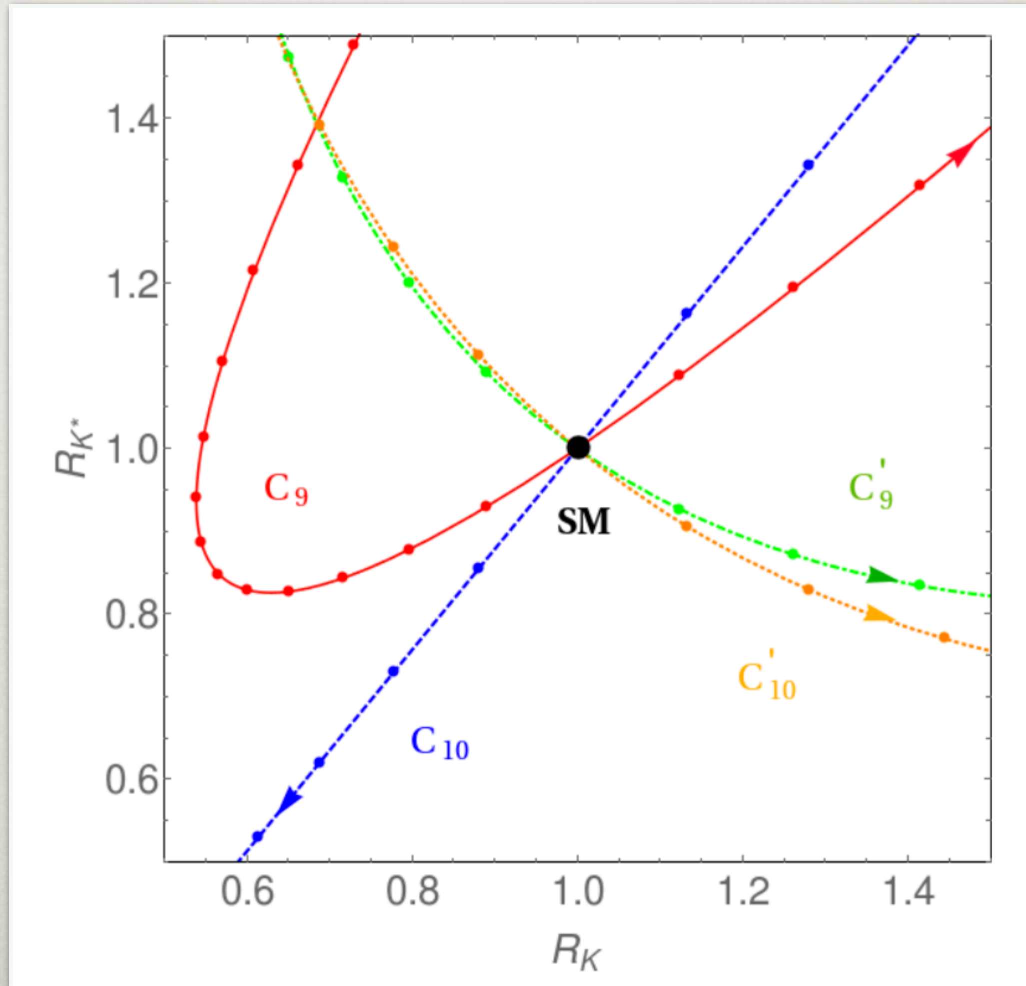
- important contraints fr
  dimuon searches
- production channels:
  - tree level $pp \to \bar{t}tZ'$,
  - 1-loop: $pp \to ZZ', jZ'$
- depends on $Br(Z' \to \mu\mu)$
  - e.g. below $\bar{t}t$ threshold:
    - coupling to μ_L $\Rightarrow Br(Z' \to \mu\mu)=0.5$
    - coupling to $\mu_L, \tau_L \Rightarrow Br(Z' \to \mu\mu)=0.2$
- interesting possible searches at CMS, ATL
  - $pp \to \bar{t}t(Z' \to \mu\mu)$, $\bar{t}t(Z' \to \tau\tau)$, $\bar{t}t(Z' \to \bar{t}t)$





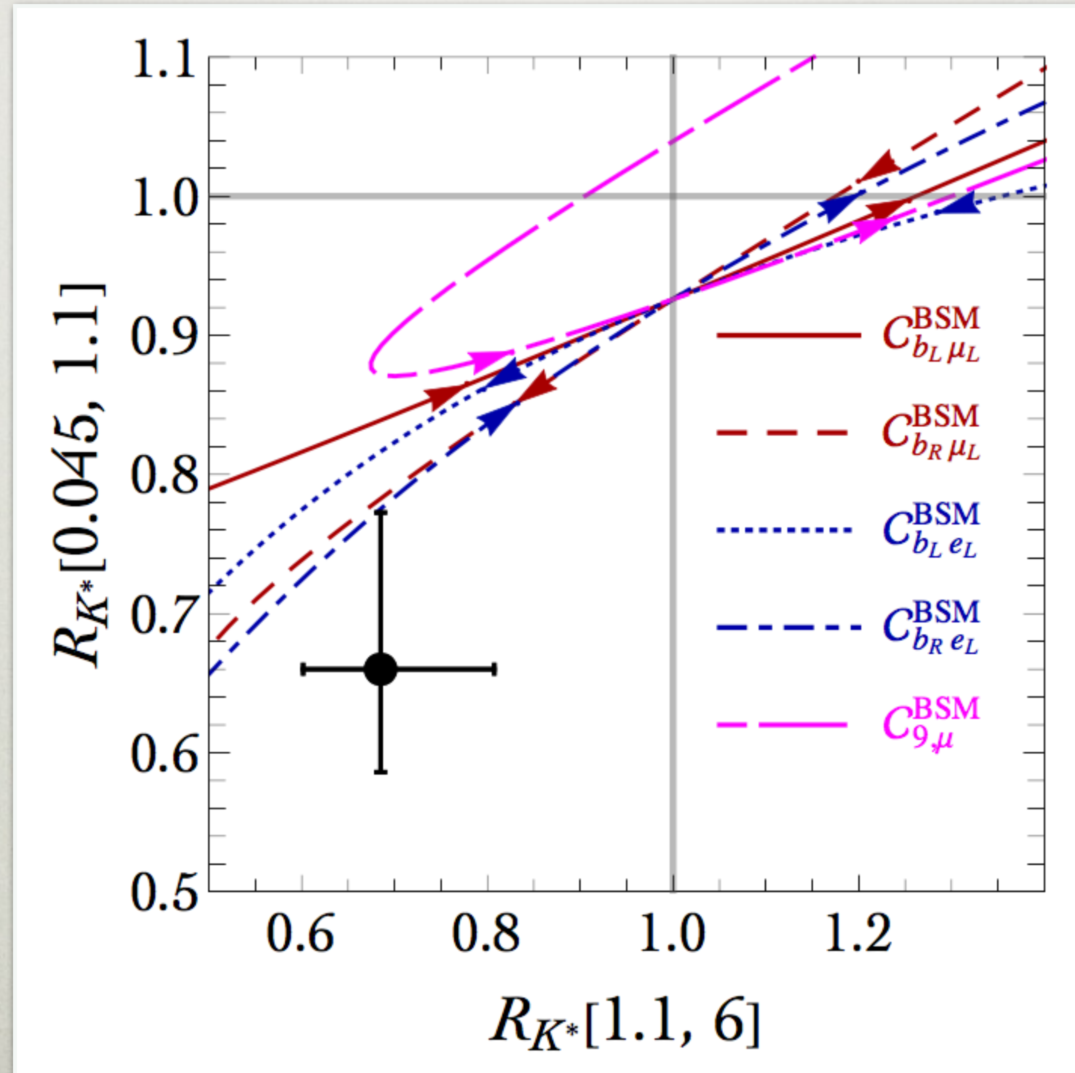
R_K vs. R_{K^*}

Geng et al, 1704.05446



LOW q^2 BIN

D'Amico et al., 1704.05438



SENSITIVITY TO NEW PHYSICS

- sensitivity to NP from virtual corrections
  - e.g. $b \to s l^+ l^-$
- NP contribs. scale as

$$\delta C^{\rm NP} \propto \frac{\sin\theta_i \sin\theta_j}{M_{\rm NP}^2}$$

- depends on mix. angles and NP masses

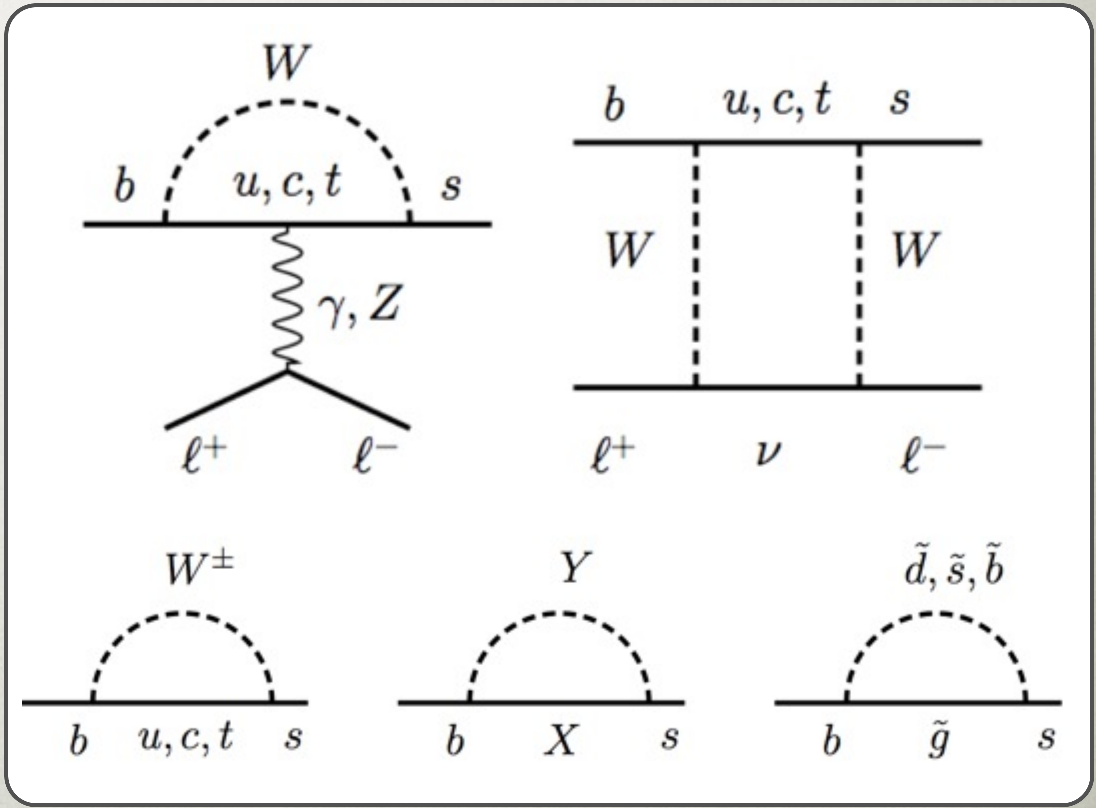
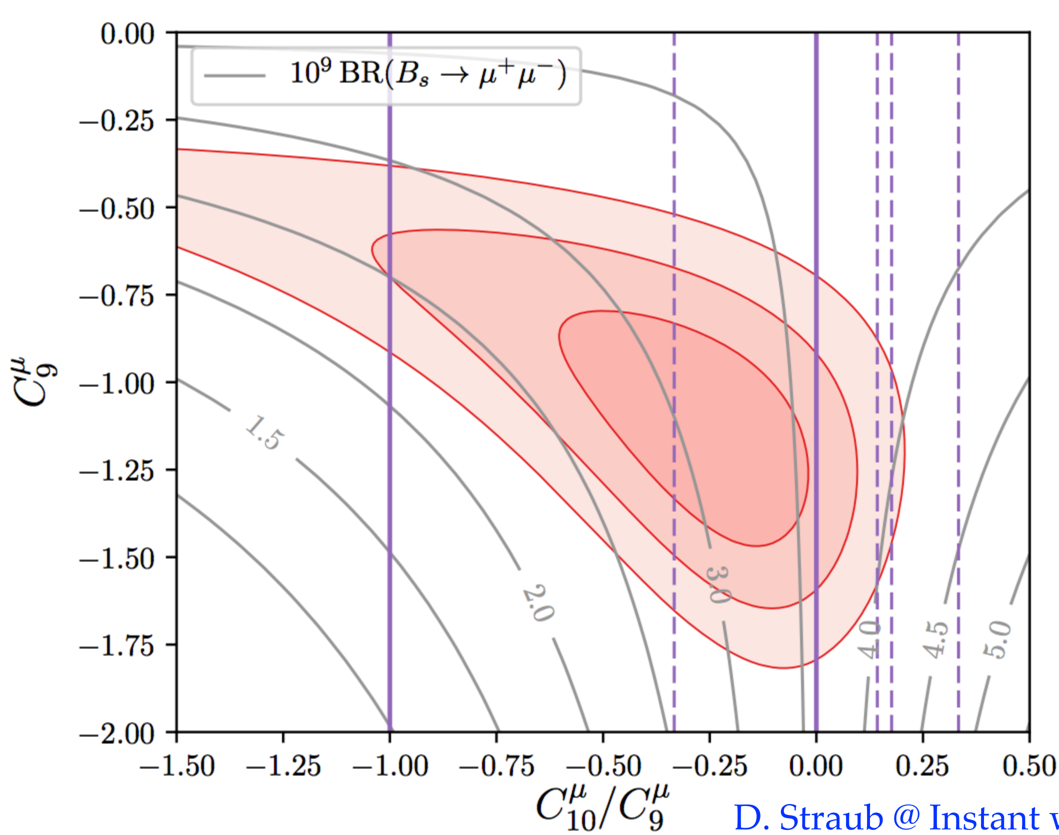


fig. from talk by G. Hiller at The First Three years of LHC, Mainz, Mar 2013

BOUNDS ON MODELS

- $B_s \to \mu\mu$ important discriminator of models



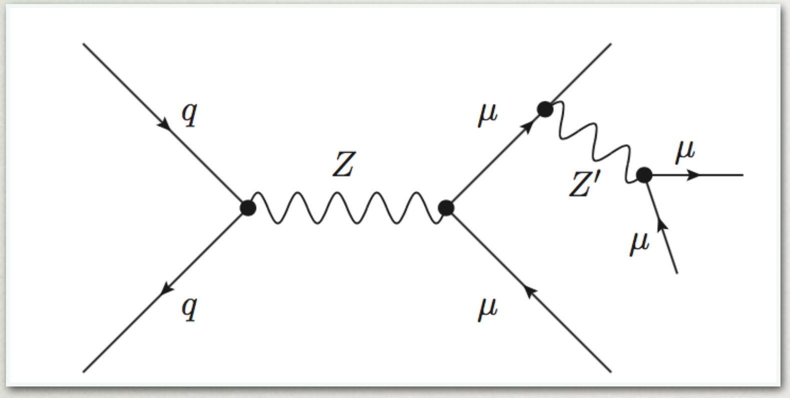
$\frac{C_{10}^\mu}{C_9^\mu}$ =: special cases

- 0: models involving L_μ
- 1: LQ models
- $\frac{3}{17}$ or $\frac{1}{3}$ Celis et al. 1505.03079
- $-\frac{1}{3}$ or $\frac{1}{7}$ Ellis et al. 1705.03447
- ...

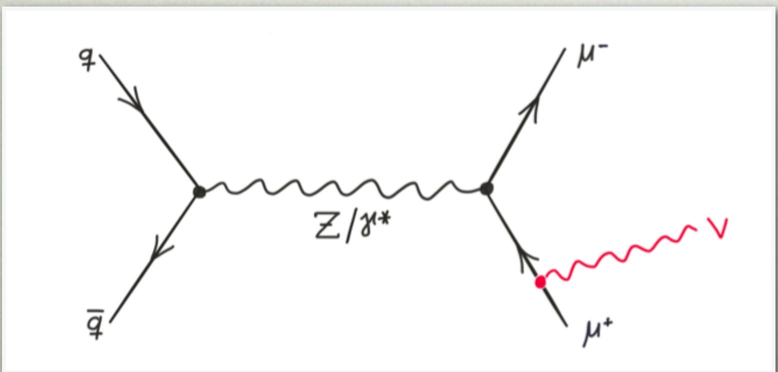
D. Straub @ Instant workshop on B anomalies, 2017

OTHER CONSTRAINTS

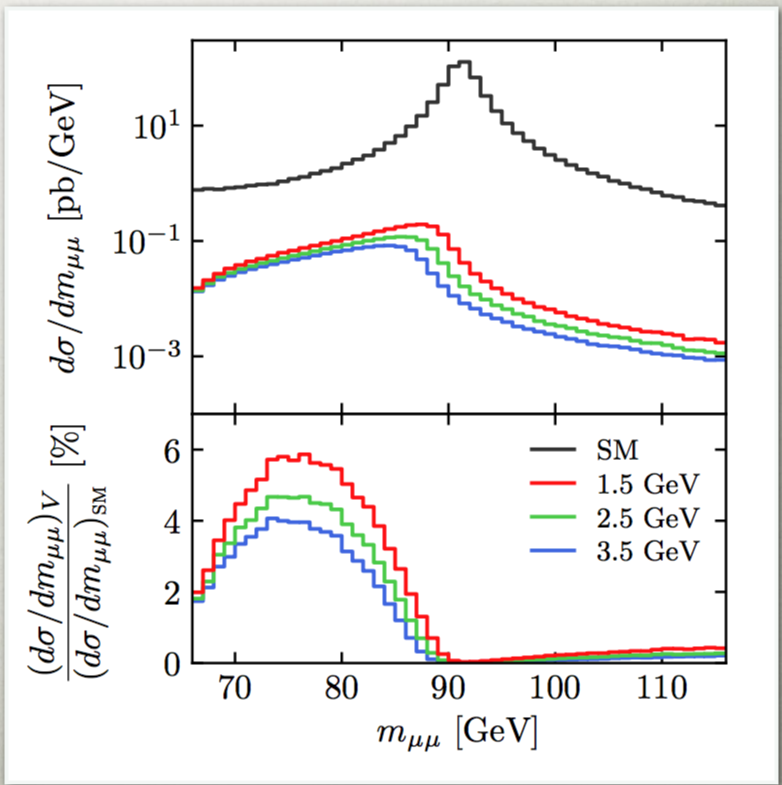
- nontrivial constraint from $Z \to 4l$



- especially for light Z' also important constraint from $\mu\mu$ p_T spectrum at the LHC



Bishara, Haisch, Monni, 1705.03465



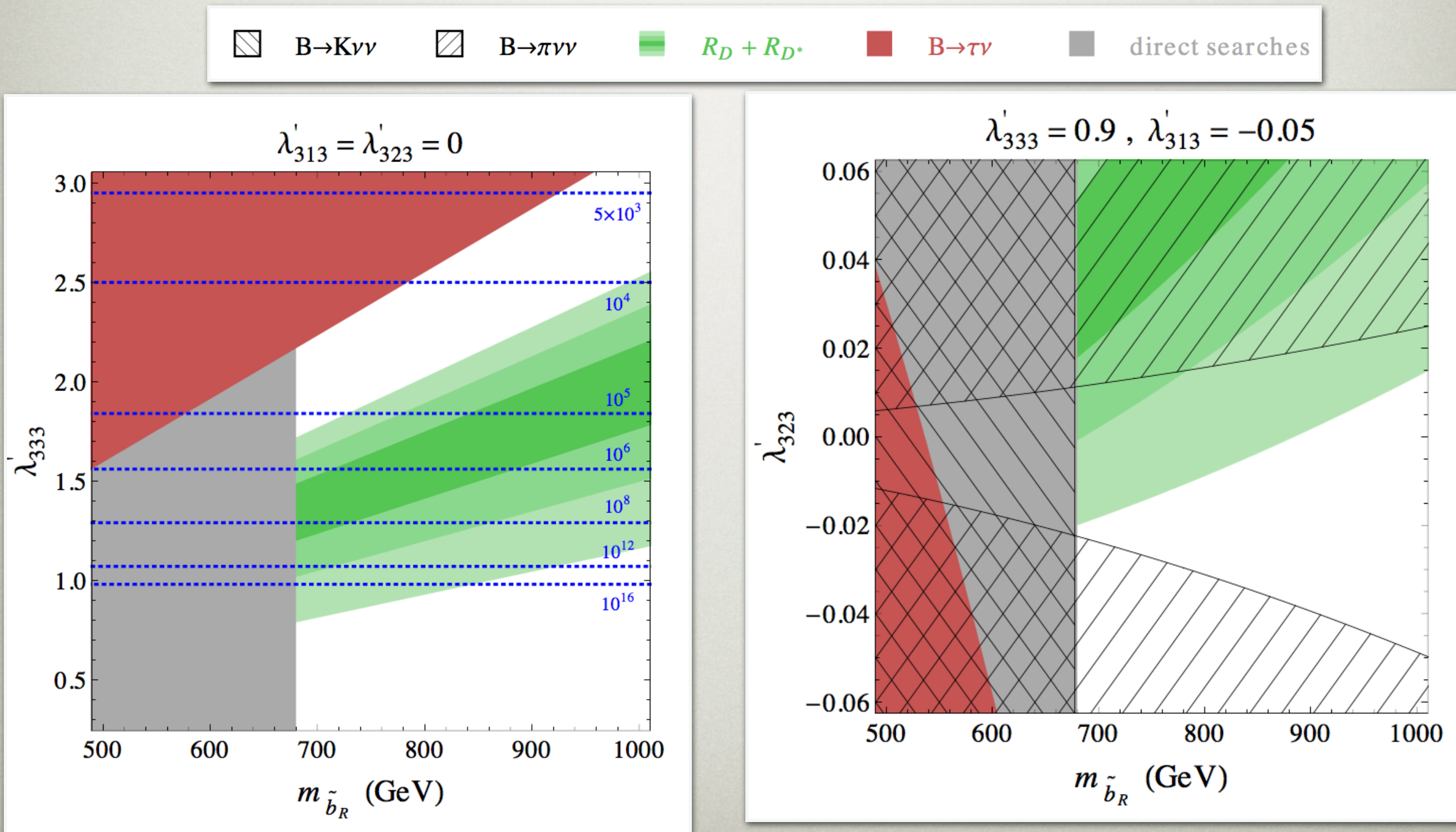
$b \to c\tau\nu$

- numerical values

	$R(D)$	$R(D^*)$
BaBar	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$
Belle	$0.375^{+0.064}_{-0.063} \pm 0.026$	$0.293^{+0.039}_{-0.037} \pm 0.015$
LHCb		$0.336 \pm 0.027 \pm 0.030$
Exp. average	0.388 ± 0.047	0.321 ± 0.021
SM expectation	0.300 ± 0.010	0.252 ± 0.005
Belle II, 50 ab^{-1}	± 0.010	± 0.005

SBOTTOM SOLUTION

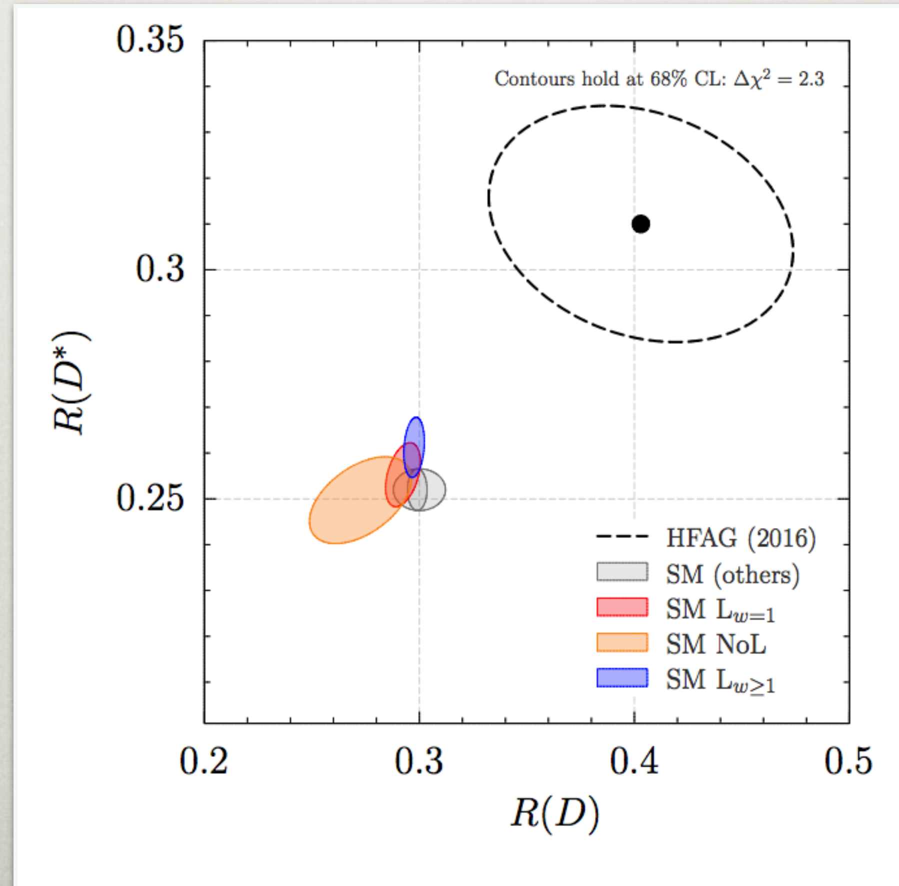
Altmannshofer, Dev, Soni, 1704.06659



R_D, R_{D^*} Predictions

Bernlochner, Ligeti, Papucci, Robinson, 1703.05330

- without light cone sum rule estimates

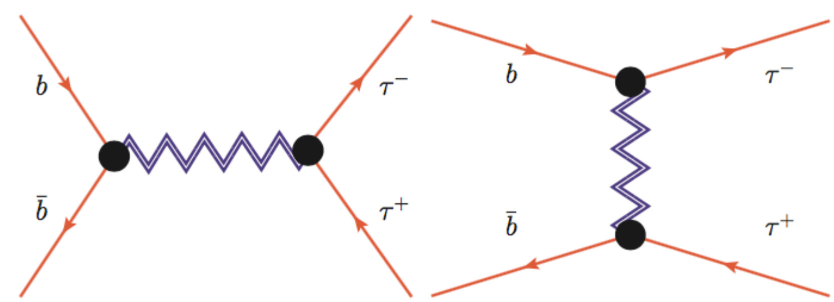


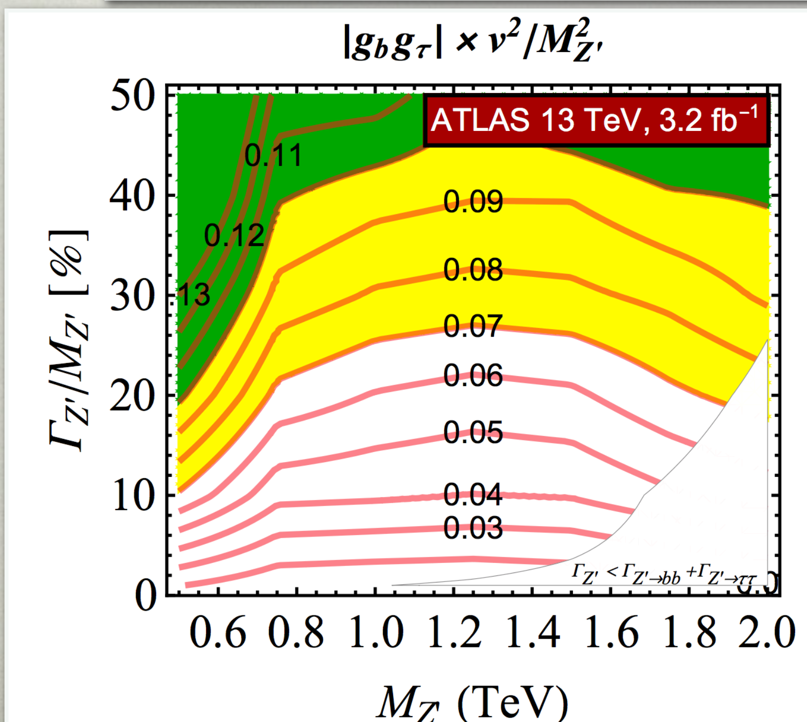
DIRECT SEARCHES IN $\tau\tau$

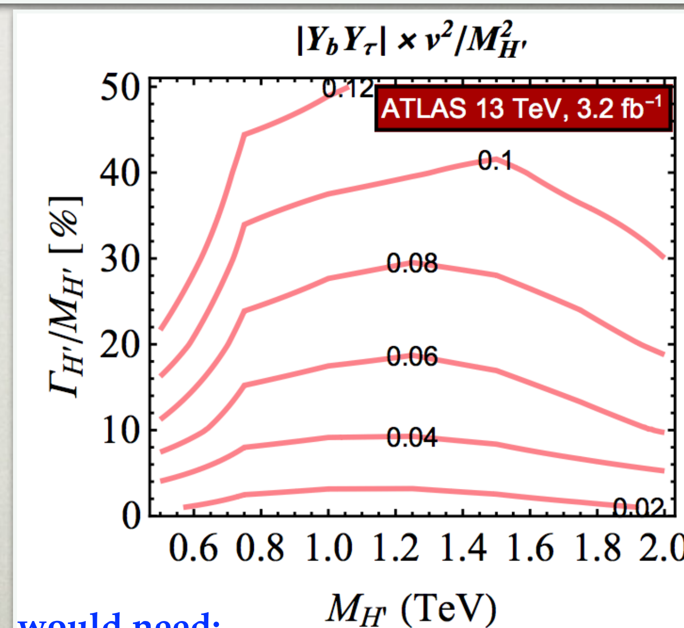
- $b \to c\tau\nu$ also implies a $1/V_{cb}$ enhanced $b\bar{b} \to \tau^+\tau^-$

	Color singlet	Color triplet
Scalar	2HDM	Scalar LQ
Vector	W'	Vector LQ

Faroughy, Greljo, Kamenik, 1609.07138







would need:

$$Y_b Y_\tau^* \times v^2/M_{H+}^2 = (2.9 \pm 0.8)$$

RADIATIVE CORRECTIONS

Feruglio, Paradisi, Pattori, 1705.00929, 1606.00524

- loop corrections important
  - modifications of the W, Z couplings to leptons
  - induced τ decays