Flavor theory & outlook

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Outline

Anomalies
- anomalous muon magnetic moments
- B meson anomalies $R_{D(*)}$, $R_{K(*)}$, P_5'

SM contributions to anomalous processes

New Physics explanation
- effective Lagrangian approach
- models of NP
- constraints from low-energy observables & LHC data
- NP from B to K

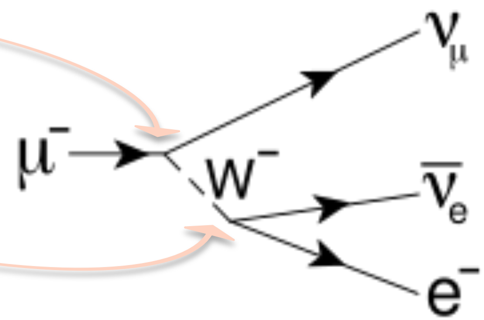
Predictions relevant for LHCb, Belle2 &LHC

UV complete theories of NP → ? → **Flavor puzzle**

Outlook

Lepton Flavour Universality (LFU)

the same coupling of lepton
and its neutrino with
W for all three lepton generations!



$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix} \quad \Gamma(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) = \Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$$

valid for quarks too!

Basic property of the SM: universal g

$$\mathcal{L}_f = \bar{f} i D_\mu \gamma^\mu f \qquad f = l_L^i,\ q_L^i,\ \ i = 1, 2, 3$$

for each of three generations in weak interactions

$$D_\mu = \partial_\mu + ig\frac{1}{2}\vec{\tau} \cdot \vec{W}_\mu + ig'\frac{1}{2} Y_W B_\mu$$

$$\mathcal{L}_{eff} = -\frac{G_F}{\sqrt{2}} J_\mu^\dagger J^\mu$$

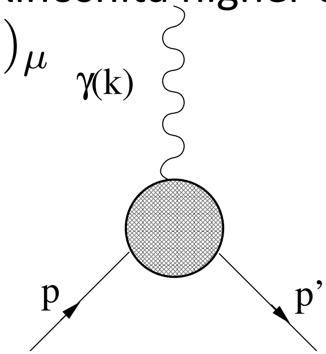
$$\frac{g^2}{8m_W^2} = \frac{G_F}{\sqrt{2}}$$

the same for all SM fermions

Muon anomalous magnetic moment

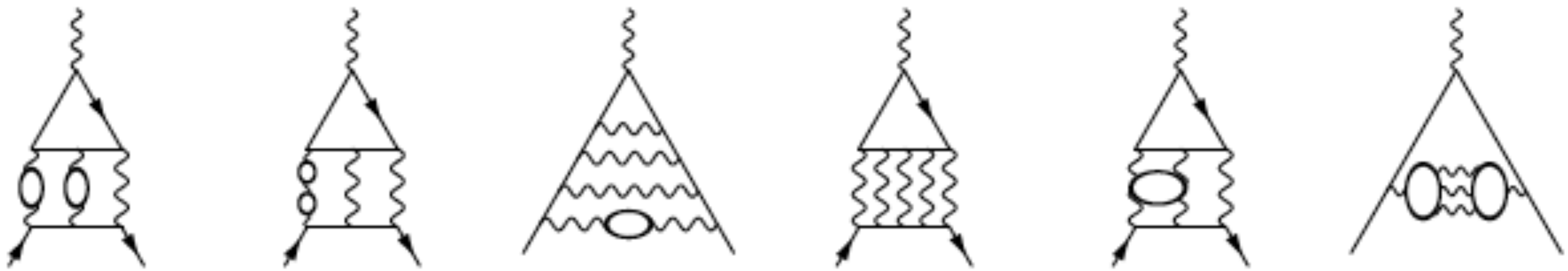
(Schwinger α/π,
Kinoshita higher orders in α)

$$ie\bar{u}_\ell(p')\left[\gamma^\mu - \frac{a_\ell}{2m_\ell} i\sigma^{\mu\nu}q_\nu\right]u_\ell(p)\epsilon^*_\mu, \qquad q_\mu = (p-p')_\mu$$



Dirac equation predicts g=2 $\quad a = (g-2)/2$

For electron a_e theory and experiment agrees!



(18) (18) (2072) (120) (18) (2)

$$a_\mu^{th} - a_\mu^{exp} = -(3.06 \pm 0.76) \times 10^{-8}$$ 4 σ

Theory: uncertainty in hadronic contributions to the muon g − 2, (Jägerlehner, 1802.08019).
Lattice QCD great progress light-by-light study (RBC & UKQCD, 1801.07224).

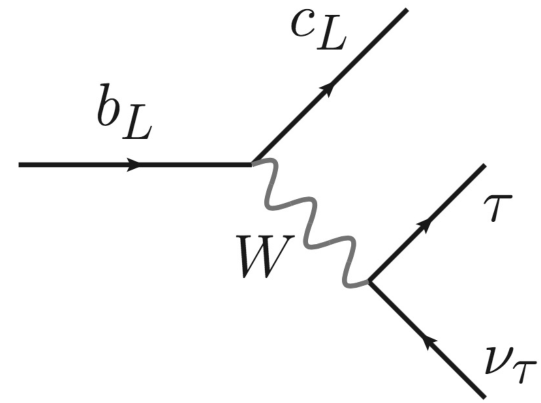
Fermilab and J-Park experiments are expected to clarify existing discrepancy!

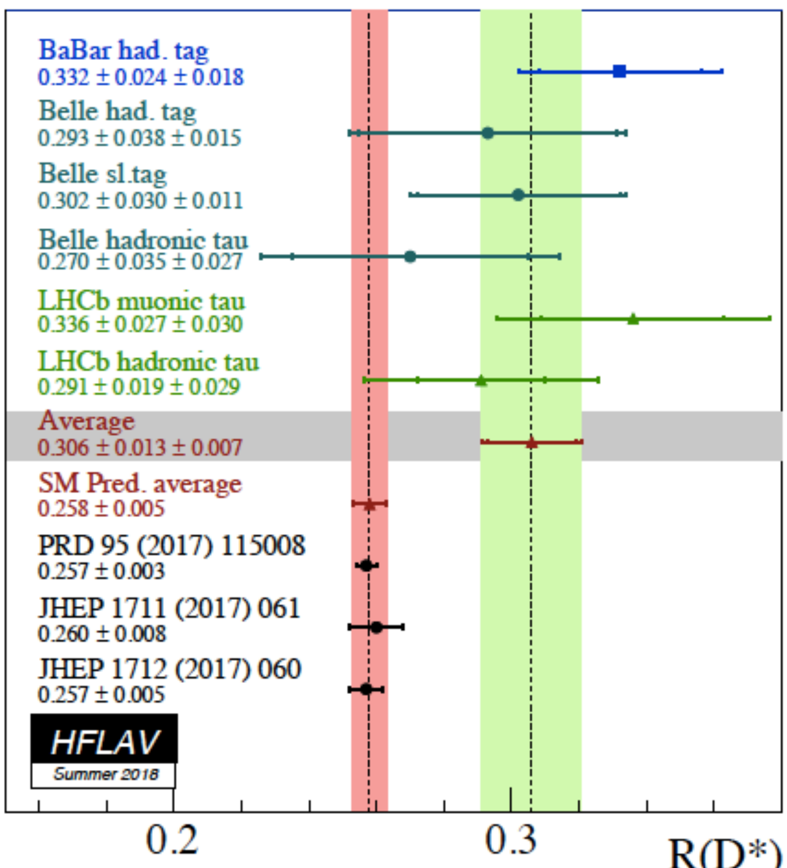
B physics anomalies: experimental results ≠ SM predictions!

charged current (SM tree level)

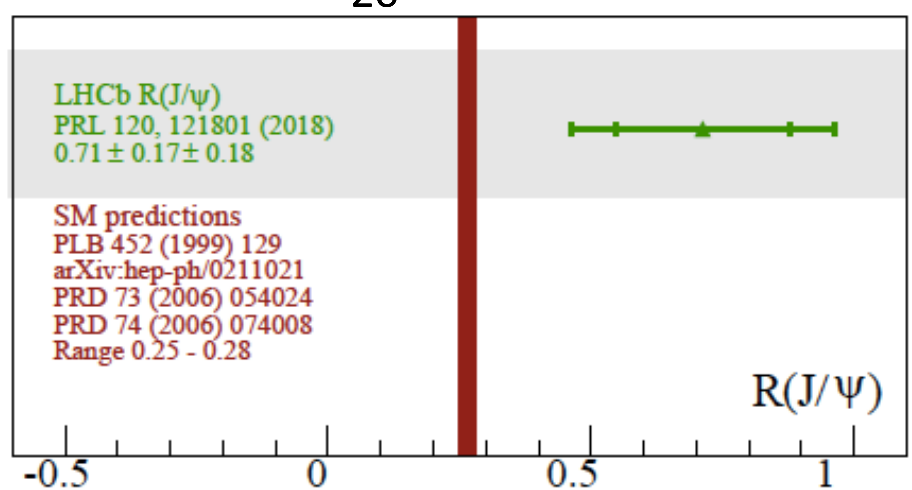
$$R_{D^{(*)}} = \frac{BR(B \to D^{(*)} \tau \nu_\tau)}{BR(B \to D^{(*)} \mu \nu_\mu)}$$

3.8σ





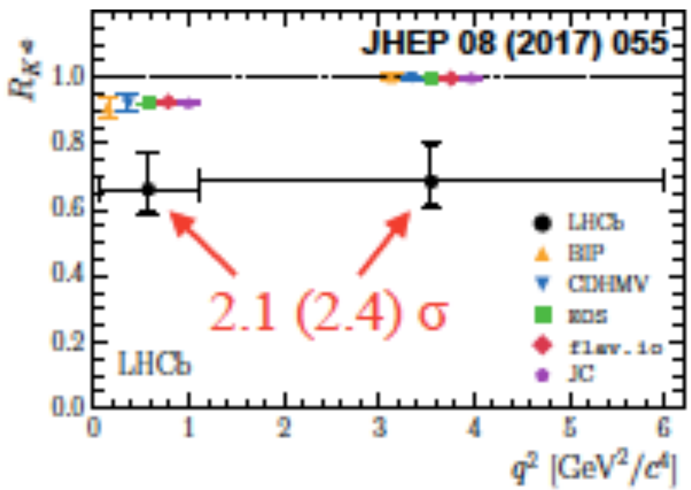
2σ

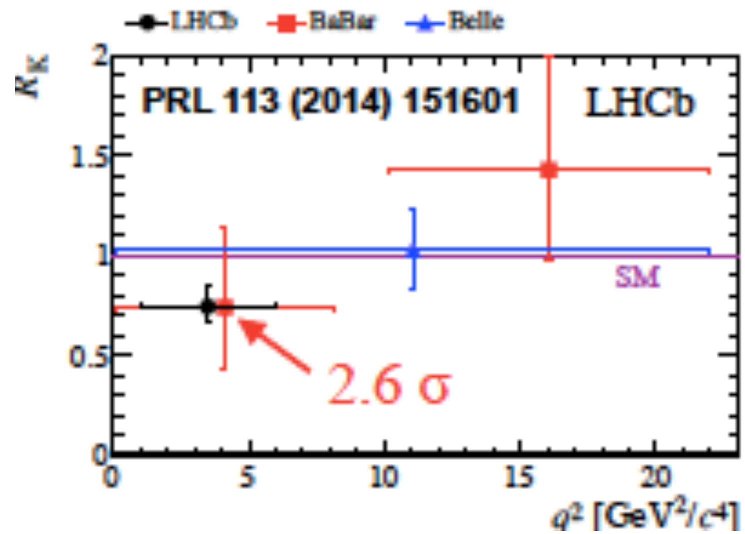


See Leroy's talk at ICHEP2018

FCNC - SM loop process: $R_{K^{(*)}}$ anomaly

$$R_{K^{(*)}} = \left. \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)} \right|_{q^2 \in [q^2_{min}, q^2_{max}]}$$



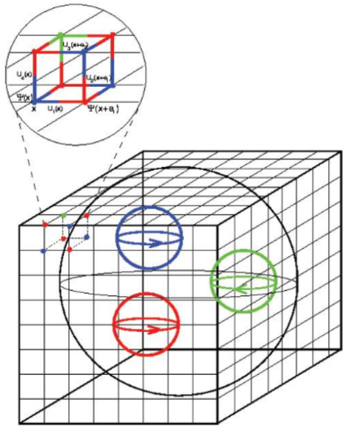


P_5' in $B \to K^* \mu^+ \mu^-$ (angular distribution functions) 3σ

LHCb: the discrepancy present in $B_s \to \phi\mu\mu$ and $\Lambda_b \to \Lambda\mu\mu$

(see Capriotti talk at ICHEP2018)

$R_{D(*)}$ in SM- hadronic uncertaintoes



$$< D|\bar{c}\gamma_\mu b|B >$$

SM: R_D =0.299±0.03

- two form factors,
- complete information comes from – lattice QCD; (Fermilab Lattice and MILC Collaborations J. A. Bailey et al. 1503.0 7237).

$$< D^*|\bar{c}\gamma_\mu(1-\gamma_5)b|B >$$

We do need lattice QCD form factors!

- one V form-factor, three axial form-factor (scalar form-factor A_0 does not play so important role in R_{D*})
- no full lattice QCD result yet!

HQET

Caprini et al.,hep-ph/9712417,
R_{D*}=0.252(3,) SF et al, 1203.2654,
Boyd et al., hep-ph/9504235,
better in explaining $|V_{cb}|$
inclusive/ exclusive difference
1702.01521

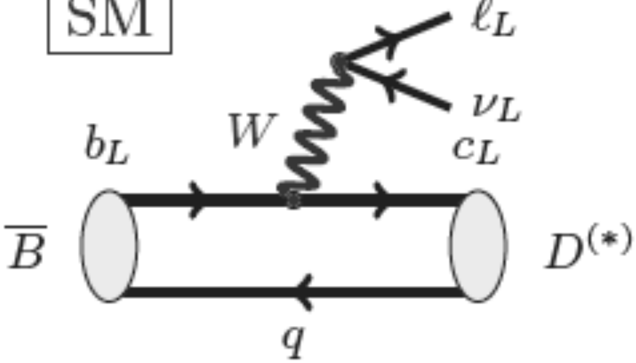
FLAV 2018

SM: R_{D*} =0.258± 0.005

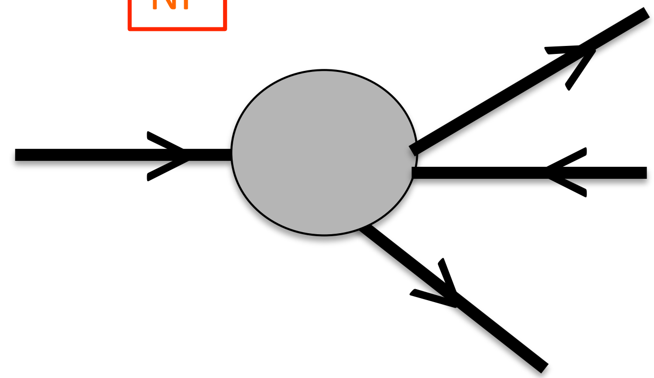
D.Bigi, et al., 1606.08030, 1707.09509,
F.Bernlochner et al., 1703.05330,
S.Jaiswal et al., 1707.09977.

Effective Lagrangian approach for $b \to c\tau\nu_\tau$ decay

SM



NP



$$\mathcal{L}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{cb}[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{l}_L\gamma^\mu\nu_L) + g_{V_R}(\bar{c}_R\gamma_\mu b_R)(\bar{l}_L\gamma^\mu\nu_L)$$

$$+g_{S_R}(\bar{c}_L b_R)(\bar{l}_R\nu_L) + g_{T_R}(\bar{c}_L\sigma_{\mu\nu}b_R)(\bar{l}_R\sigma^{\mu\nu}\nu_L)]$$

has all symmetries of the SM

e.g: many authors favorable solution

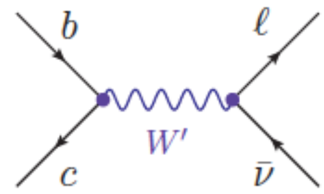
$$0.09 \leq g_{V_L} \leq 0.13$$

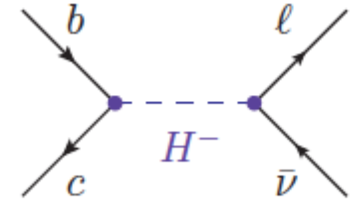
Freytsis, et al., 1506.08896, S.F. et al.,1206.1872;
Di Luzio & Nardecchia, 1706.01868,
Bernlochner et al., 1703.05330,
F. Feruglio et al., 1806.10155, 1606.00524
....

(see Grelljo et al. (1804.0462) for $\mathcal{L}_{eff}$ with ν_R!)

Assuming NP at scale Λ_{NP} (Di Luzio, Nardecchia, 1706.0!868)

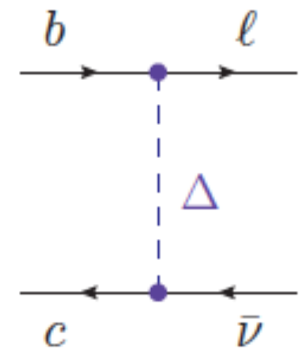
$$\frac{4G_F}{\sqrt{2}} V_{cb}\, g_V \to \frac{2}{\Lambda_{NP}^2}$$





What is the scale of New Physics?

$$\Lambda_{NP} \simeq 3\,\mathrm{TeV}$$



Perturbativity of NP

$$\mathcal{L}_{NP} \supset \frac{C_D}{\Lambda_{NP}^2} (\bar{c}_L \Gamma_\mu b_L)(\tau_L \gamma^\mu \nu_L)$$

V-A form of NP

(current)(current) operators are invariant under QCD running

$\Lambda_{NP} > 3\,\mathrm{TeV}$ C_D becomes non-perturbative!

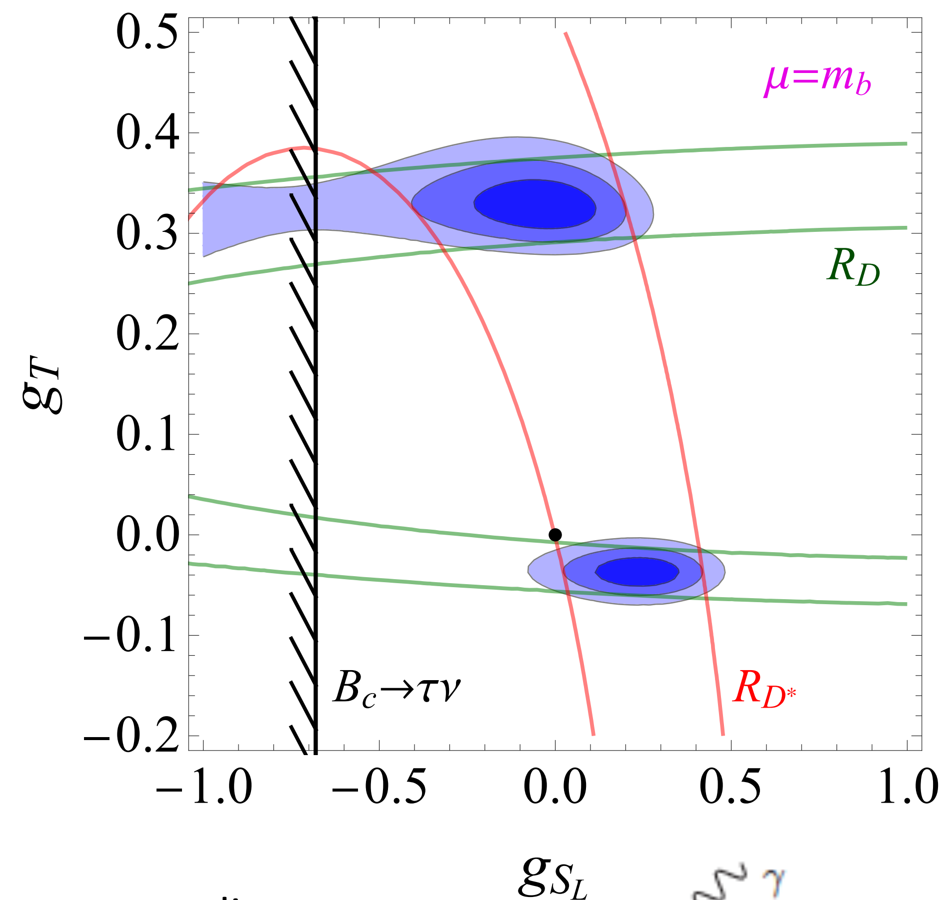
Hiller et al., 1609.08895 $R_{D(*)}$

Scalar and Tensor operators in R_{D*}

V-A is not the only one solution!

Recent:
Feruglio et al., 1806.10155 g_{SL} , g_T
Becirevic et al., 1806.05689
Hiller et al.,1609.08895

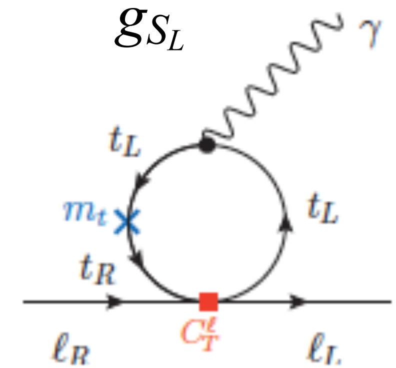
Scalar operator gets strong constraints from $\Gamma_{NP}(B_c \to \tau\nu) \simeq 30\%$
Alonso et al., 1611.06676



Feruglio et al., 1806.10155

the muon g - 2 can be explained only if the tensor couplings are hierarchical

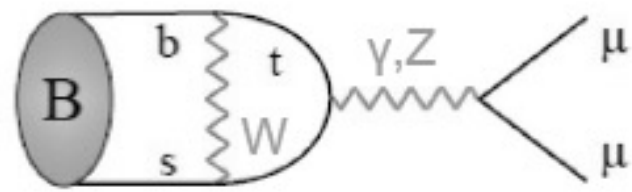
$$|C_T^\tau| \gg |C_T^\mu| \geq |C_T^e|$$



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

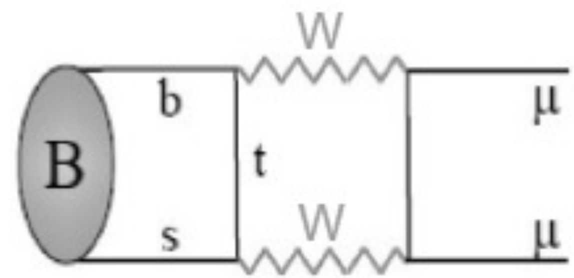
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,\dots,10} \left(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu) \right) \right]$$

$$\mathcal{O}_7 = \frac{e}{g^2} m_b \bar{s}\sigma_{\mu\nu} F_{\mu\nu} b$$



$$\mathcal{O}_9 = \frac{e^2}{g^2} \bar{s}\gamma_\mu b(1-\gamma_5) b\,\bar{l}\gamma^\mu l$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2} \bar{s}\gamma_\mu b(1-\gamma_5) b\,\bar{l}\gamma^\mu \gamma_5 l$$



$$\mu_b = 4.8\,\mathrm{GeV} \qquad C_7^{SM} = 0.29;\; C_9^{SM} = 4.1;\; C_{10}^{SM} = -4.3;$$

Buras et al.,hep-ph/9311345;
Altmannshofer et al., 0811.1214;
Bobeth et al., hep-ph/9910220

NP in R_K and R_{K^*}

Global analysis suggests NP in $C_{9,10}$

$$C_i = C_i^{SM} + C_i^{NP}$$

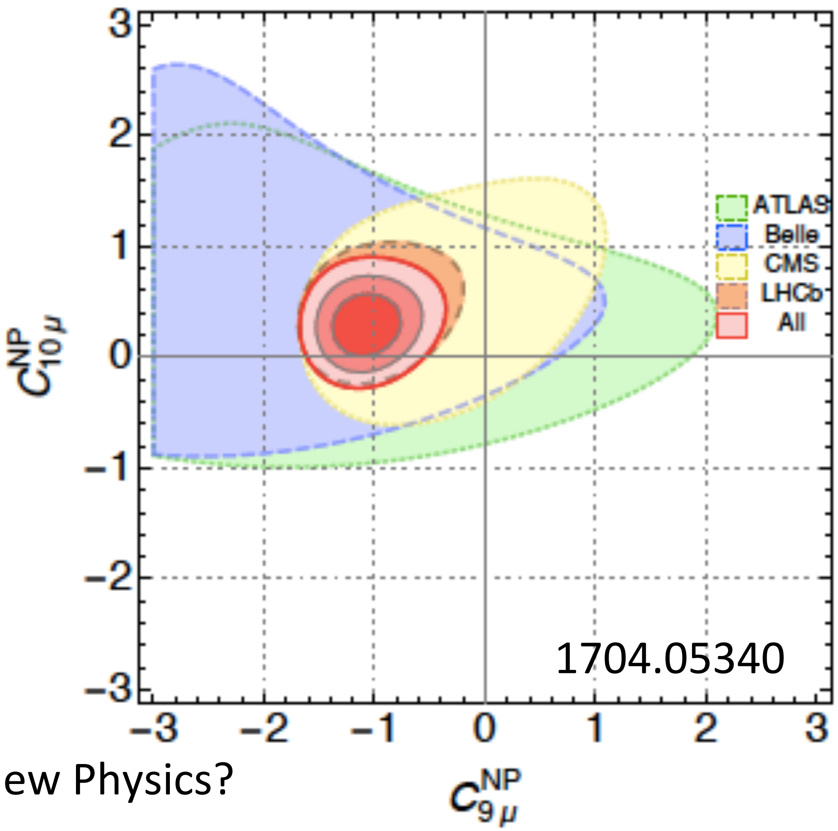
Instead of SM values for C_9 and C_{10} (for μ)

$$C_9^{NP} = -C_{10}^{NP} = -0.64$$

best fit point

$$[-0.85, -0.5]$$

Capdevila et al., 1704.05340,
Altmannshofer et al., 1704.05435,
D'Amico et al., 1704.05438.



What is the scale of New Physics?

$$\mathcal{L}_{NP} = \frac{1}{\Lambda_{NP}^2} \bar{s}_L \gamma^\alpha b_L \bar{\mu}_L \gamma_\alpha \mu_L$$

$$\Lambda_{NP} \simeq 30\,\mathrm{TeV}$$

(see Mauri's talk at ICHEP2018)

NP explaining both B anomalies

$$R_{D^{(*)}}^{exp} > R_{D^{(*)}}^{SM}$$

$$R_{K^{(*)}}^{exp} < R_{K^{(*)}}^{SM}$$

$$\mathcal{L}_{NP} = \frac{1}{(\Lambda^D)^2} 2\, \bar{c}_L \gamma_\mu b_L \bar{\tau} \gamma^\mu \nu_L$$

$$\mathcal{L}_{NP} = \frac{1}{(\Lambda^K)^2} \bar{s}_L \gamma_\mu b_L \bar{\mu}_L \gamma^\mu \mu_L$$

$$\Lambda^D \simeq 3\,\mathrm{TeV}$$

$$\Lambda^K \simeq 30\,\mathrm{TeV}$$

If the scale is the same $\Lambda^D \sim \Lambda^K$

$$\Lambda^D = \Lambda$$

NP in FCNC $B \to K^{(*)} \mu^+ \mu^-$ has to be suppressed

$$\frac{1}{(\Lambda^K)^2} = \frac{C_K}{\Lambda^2} \qquad C_K \simeq 0.01$$

suppression factor

How to achieve suppression of NP in $R_{K(*)}$?

In the case of V-A form NP couples dominantly to the third generation

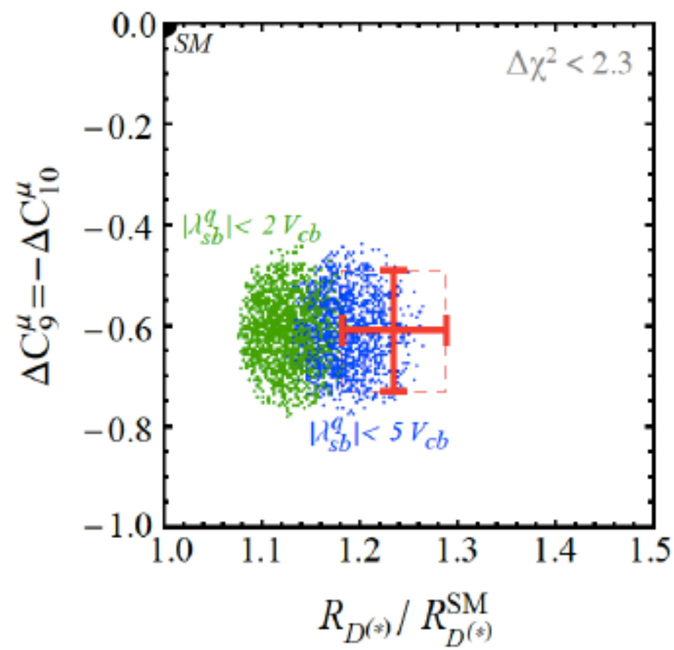
$$\mathcal{L}_{NP} = \frac{C_S}{\Lambda^2} \underbrace{\bar{q}_{3L}\gamma_\mu q_{3L}} \underbrace{\bar{l}_{3L}\gamma^\mu l_{3L}} + \frac{C_T}{\Lambda^2} \underbrace{\bar{q}_{3L}\gamma_\mu \tau_i q_{3L}} \underbrace{\bar{l}_{3L}\gamma^\mu \tau_i l_{3L}}$$

$SU(2)_L$ singlets

$SU(2)_L$ triplets

$$q_L^3 \sim \begin{bmatrix} V_{ib}^* u_L^i \\ b_L \end{bmatrix}$$

+ small correction for 2nd and 1st generations

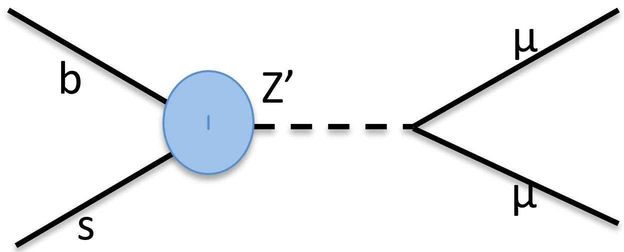


Buttazzo et al.,1706.07808,
Feruglio et al., 1606.00524; 1705.00929,
Battacharaya et al., 1412.7164; 1609.09078,
Glashow et al., 1411.0565...

Lepton flavor non-universality
Lepton flavor violation

Flavor constraints allow only ~ 10-15 % increase in $R_{D(*)}$

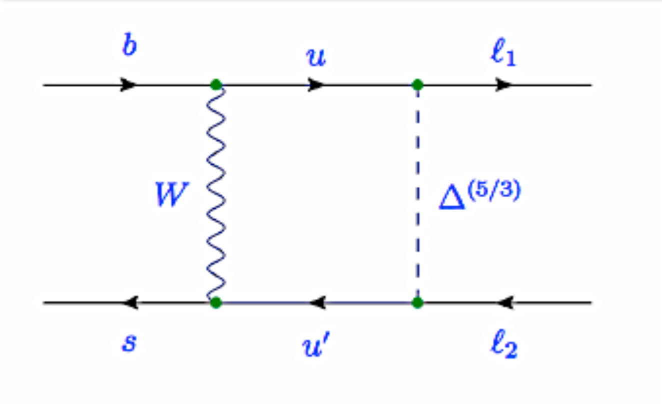
New boson Z’



- different origin of Z’, e.g. by gauging L_μ- L_τ, Altmannshofer et al, 1403.1269,
- New Z’+ new vector-like quarks (UV complete theories) Kamenik et al., 1704.06005,
- Fermiophobic Z’, couples to 4th generation of the vector-like fermions, Falkowski et al, 1803.04430...

see Tandean’s talk at ICEHEP2018!

$R_{K(*)}$ explained by NP at loop level



Bauer&Neubert, 1511.01900, + muon (g-2)
Bečirević et al, 1608.07583, strong constraints from charm, K, leptonic decays and $B \to D^{(*)} e(\mu)\nu$

If the same NP in $R_{D(*)}$ and $R_{K(*)}$ suppression factor from the loop

$$C_K \approx 1 / 16\pi^2$$

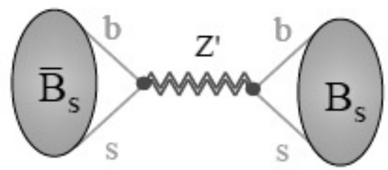
Constraints from flavor observables

$(g-2)_\mu$

$B_c \to \tau\nu \quad B \to \tau\nu$

$B \to K^{(*)}\nu\bar{\nu}$

$B_s^0 - \bar{B}_s^0$

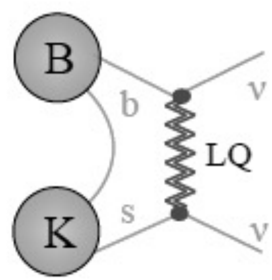


$D^0 - \bar{D}^0$

$B \to D\mu\nu_\mu$

$K \to \mu\nu_\mu$

$D_{d,s} \to \tau, \mu\nu$



$K \to \pi\mu\nu_\mu$

$W \to \tau\bar{\nu},\ \tau \to \ell\bar{\nu}\nu$

$Z \to b\bar{b} \qquad Z \to l^+l^-$

Constraints from LFV

$\tau \to \mu\gamma$

$\mu \to e\gamma$

$\tau \to K(\pi)\mu(e)$

$K \to \mu e$

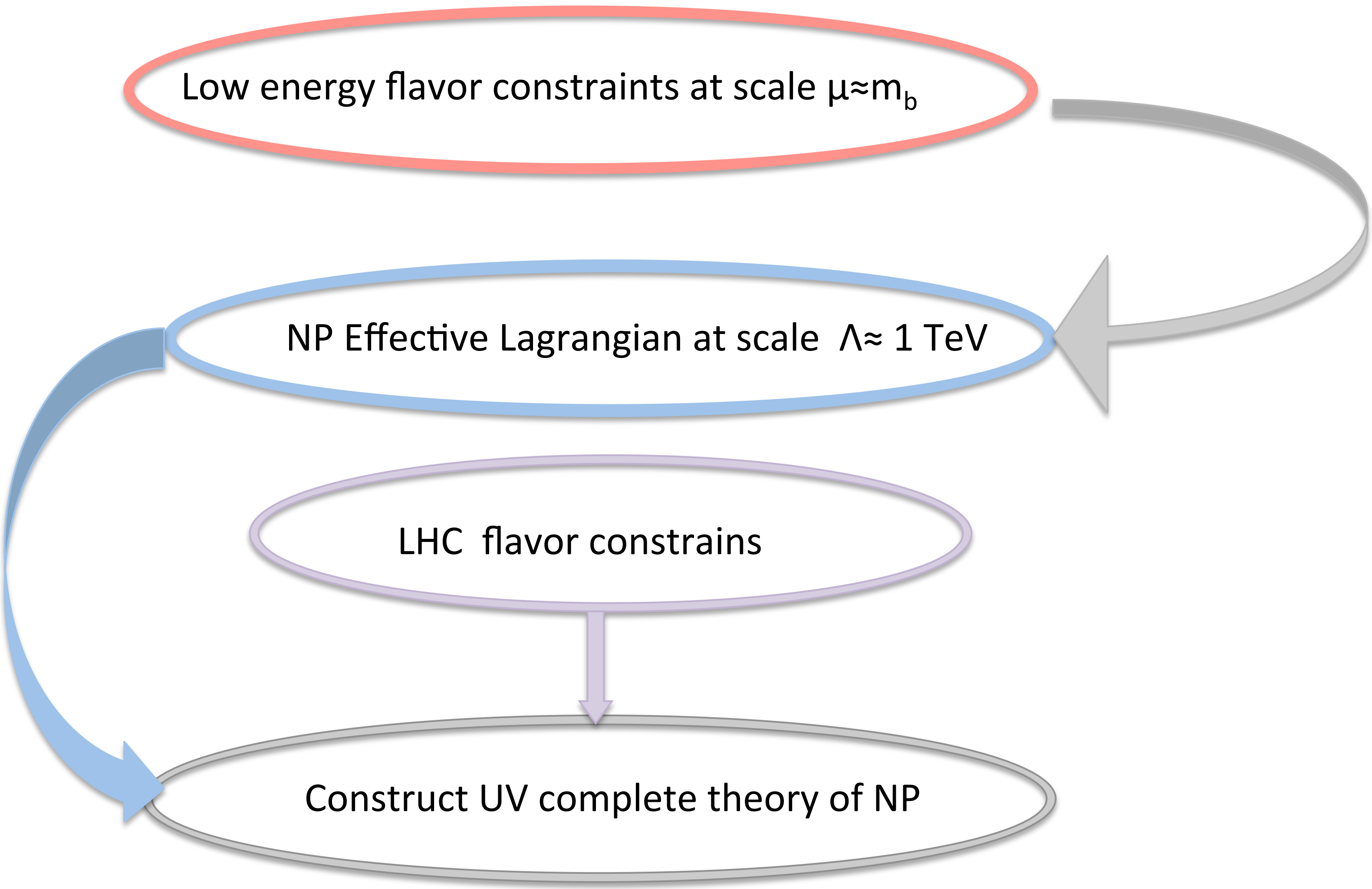
$B \to K\mu e$

$\tau \to \mu\mu\mu$

$\tau \to \phi\mu$

$t \to c\ell^+\ell'^-$

Becirevic et al., 1806.05689, 1608.07583, 1608.08501, Alonso et al., 1611.06676,…
Radiative constraints Feruglio et al.,1606.00524;



"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong. "
Richard P. Feynman

Models at TeV scale explaining both B anomalies

Scalar LQ as pseudo-Nambu-Goldstone boson

Gripaios et al, 1010.3962,
Gripaios et al., 1412.1791,
Marzocca 1803.10972…

Models with scalar LQs

Hiller & Schmaltz, 1408.1627,
Becirevic et al. 1608.08501, SF and Kosnik, 1511.06024, Becirevic et al., 1503.09024,
Dorsner et al, 1706.07779,
Cox et al., 1612.03923,
Crivellin et al.,1703.09226…

W', Z' in warped space

Megias et al.,1707.08014

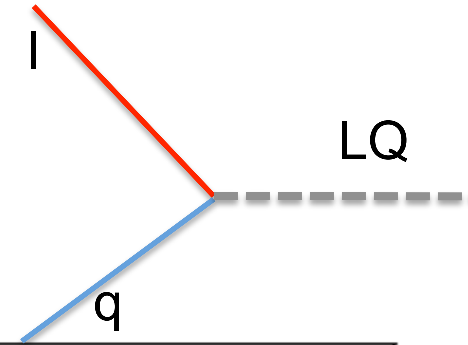
Vector resonances (from techni-fermions)

Barbieri et al.,1506.09201, Buttazzo et al. 1604.03940,
Barbieri et al., 1611.04930
Blanke & Crivellin, 1801.07256,…

Gauge bosons

Greljo et al., 1804.04642
Cline, Camalich, 1706.08510
Calibbi et al.,1709.00692
Assad et al., 1708.06350
Di Luzio et al.,1708.08450
Bordone et al.,1712.01368, 1805.09328…

Leptoquarks as a resolution of B anomalies:



$LQ=(SU(3)_c, SU(2)_L)_Y$

$Q=I_3+Y$

or $LQ=(SU(3)_c, SU(2)_L, Y)$

no proton decay at tree level

Model	$R_{D^{(*)}}$	$R_{K^{(*)}}$	$R_{D^{(*)}}$ & $R_{K^{(*)}}$	
$S_1=(\bar{3},1)_{1/3}$	✓	✗	✗	Spin 0
$R_2=(3,2)_{7/6}$	✓	✗*	✗	
$S_3=(\bar{3},3)_{1/3}$	✗	✓	✗	
$U_1=(3,1)_{2/3}$	✓	✓	✓	Spin 1
$V_2=(3,1)_{2/3}$	✗	✗	✗	
$\widetilde{V}_2=(\bar{3},2)_{-1/6}$	✗	✗	✗	
$U_3=(3,3)_{2/3}$	✗	✓	✗	

No single scalar LQ to solve simultaneously both anomalies!

Doršner, SF, Greljo, Kamenik , Košnik, 1603.04993

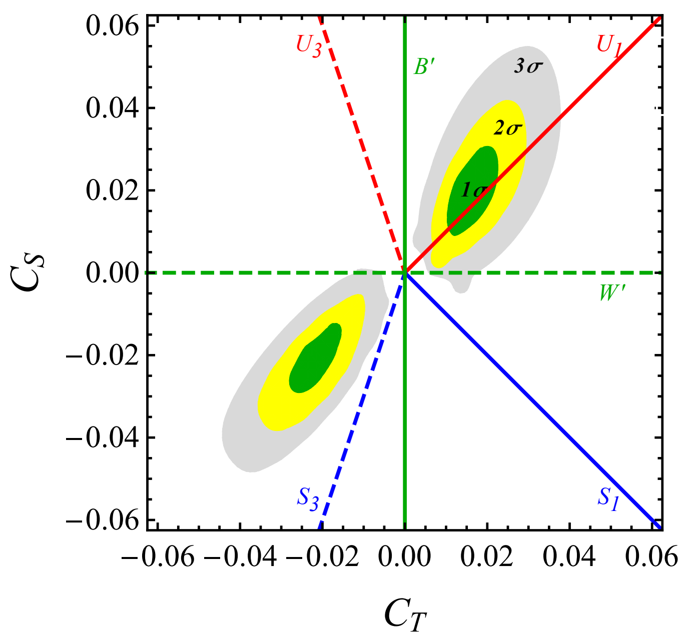
Scalar LQ → simpler UV completion;

Only R_2 and S_1 might explain $(g-2)_\mu$ (both chiralities are required with the enhancement factor m_t/m_μ) Muller 1801.0338.

Only one LQ mediator

$$\mathcal{L}_{NP} = \frac{C_S}{\Lambda_{NP}^2}\bar{q}_{3L}\gamma_\mu q_{3L}\bar{l}_{3L}\gamma^\mu l_{3L} + \frac{C_T}{\Lambda_{NP}^2}\bar{q}_{3L}\gamma_\mu \tau_i q_{3L}\bar{l}_{3L}\gamma^\mu \tau_i l_{3L}$$

Buttazzo, Greljo, Isidori, Marzocca (1706.07808)



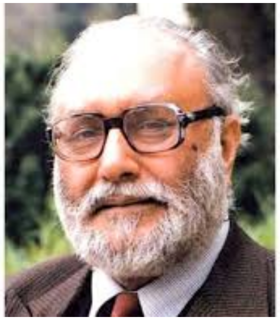
Vector leptoquark U_1(3,1,2/3) passes all tests

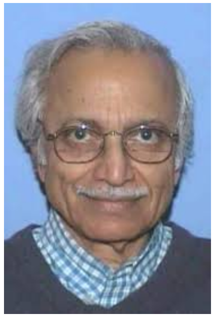
If vector LQ is not a gauge boson – difficult to handle!

(see also Alonso et al., 1505.05164,
Di Luzio et al., 1708.08450;
Bordone et al., 1712.01368;
Callibi et al., 1709.00692)

Scale of NP should be 1.5 TeV!

GUT Pati-Salam Model for $U_1(3,1,2/3)$
gauge group SU(4) x SU(3)' x $SU(2)_L$ x U(1)'
spontaneosly broken gauge theory





Di Luzio et al., 1708.08450
Calibbi et al., 1709.00692
Blanke and Crivellin, 1801.07256.

Bordone et al., 1712.01368, 1805.0932

$$[\ PS\ ]^3 = [\ SU(4)\times SU(2)_L \times SU(2)_R\ ]^3$$

SU(4) means quarks carry 3 colours and leptons have the fourth colour.

in these models $R_{D(*)}$ gets additional non V-A contributions

Leads to explanation of the masses of fundamental fermions "flavor puzzle".

Many new gauge bosond:
new colored octet, a triplet and three SM singlets; their masses ~ TeV region

$M_{Z'}$ = 1.3 TeV, M_U = 1.5 TeV, and $M_{g'}$ = 1.9 TeV.

Unification scale rather low ~10^6 GeV. No proton decays!

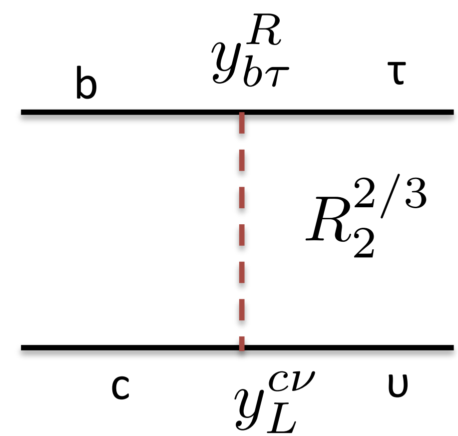
Two scalar LQs solution of $R_{D(*)}$ and $R_{K(*)}$

Why 2 LQs?

- GUT possible with 2 light scalar LQs within SU(5);
- LQ S_3 within SU(5) proton decay avoided, Doršner et al., 1706.07779;
- Neutrino masses generated with 2 light LQs (Doršner et al., 1701.08322).

(3,3,1/3) + (3,1,-1/3)
Crivellin et al., 1703.09226,
Marzocca, 1803.10972.

} V-A form

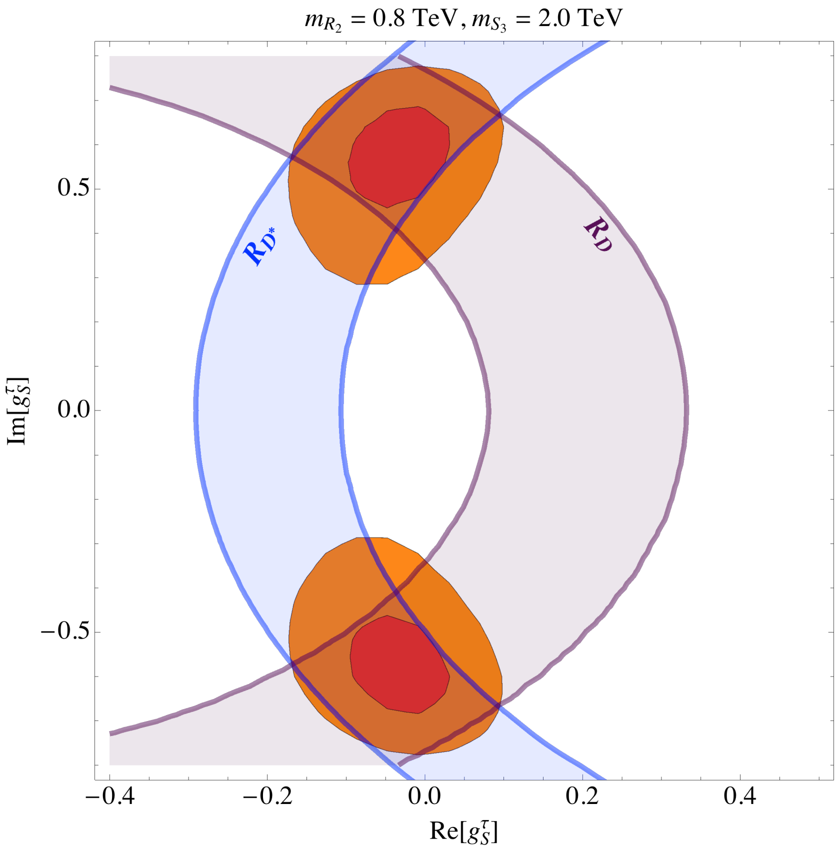


R_2(3,2,7/6) scalar and tensor in $R_{D(*)}$

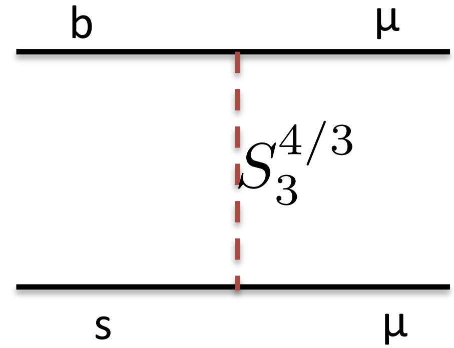
+and small contribution of S_3=(3,3,1/3)

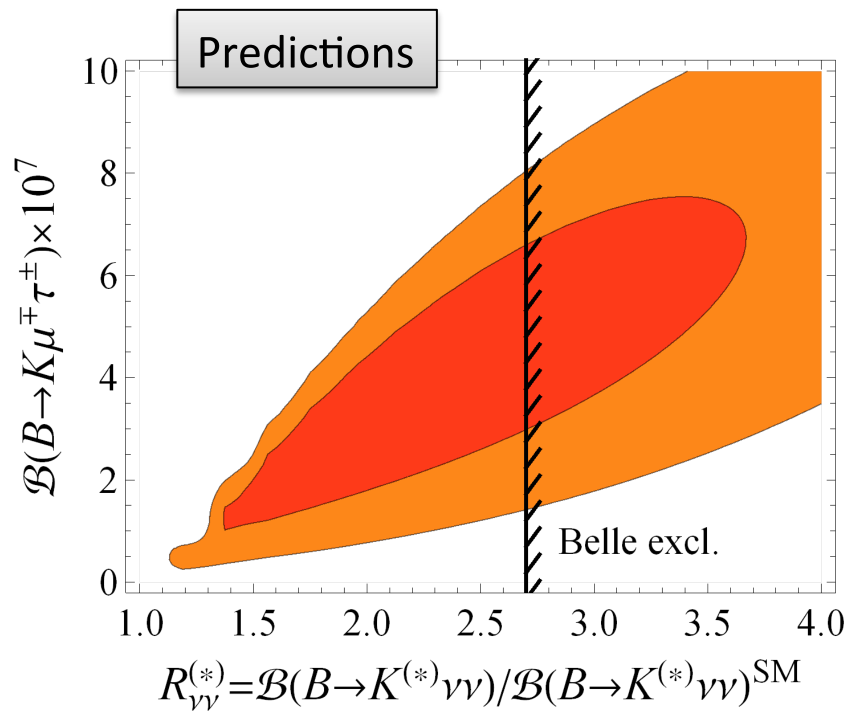
$$\mathcal{L}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{cb} \big[(1 + g_V)(\bar{u}_L \gamma_\mu d_L)(\bar{\ell}_L \gamma^\mu \nu_L) + g_S(\mu)\,(\bar{u}_R d_L)(\bar{\ell}_R \nu_L) + g_T(\mu)\,(\bar{u}_R \sigma_{\mu\nu} d_L)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L) \big] + \text{h.c.}$$

Becirevic, Dorsner, S. F, Faroughy, Kosnik and Sumensari 1806.05689,
Hiller, Loose, Schoenwald 1609.08895



$R_{K(*)}$ explained by V-A contributions of S_3 =(3,3,1/3)



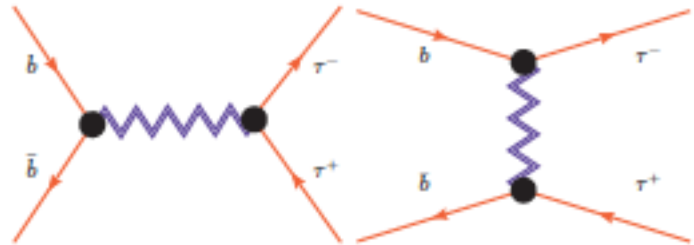


Only 4 parameters (one of them complex- $y^{b\tau}_R$) from Yukawa couplings and masses of R_2 and S_3.
R_2 and S_3 are in the same GUT representation.
Important: the largest couplings are ≤ 1

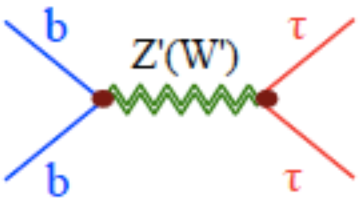
Important to improve current bounds by Belle 2 and LHCb !

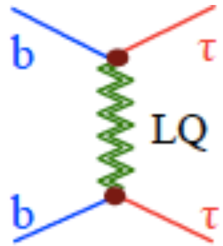
LHC constraints on NP

$pp \to \tau^+\tau^-$

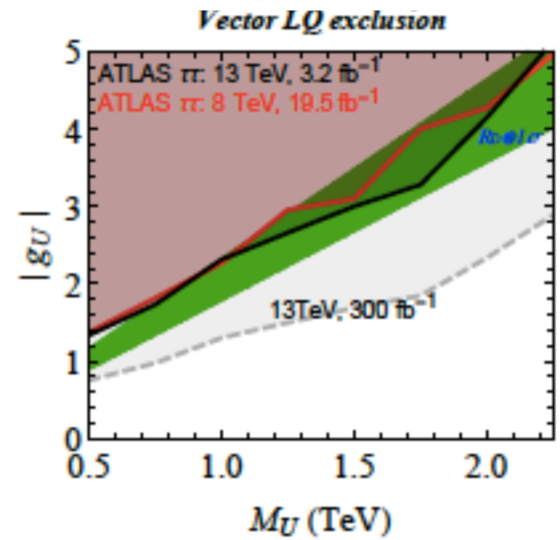


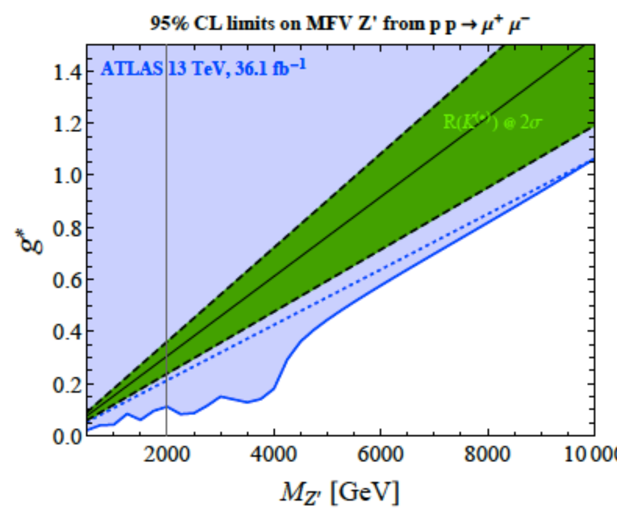
Processes in s and t-channel





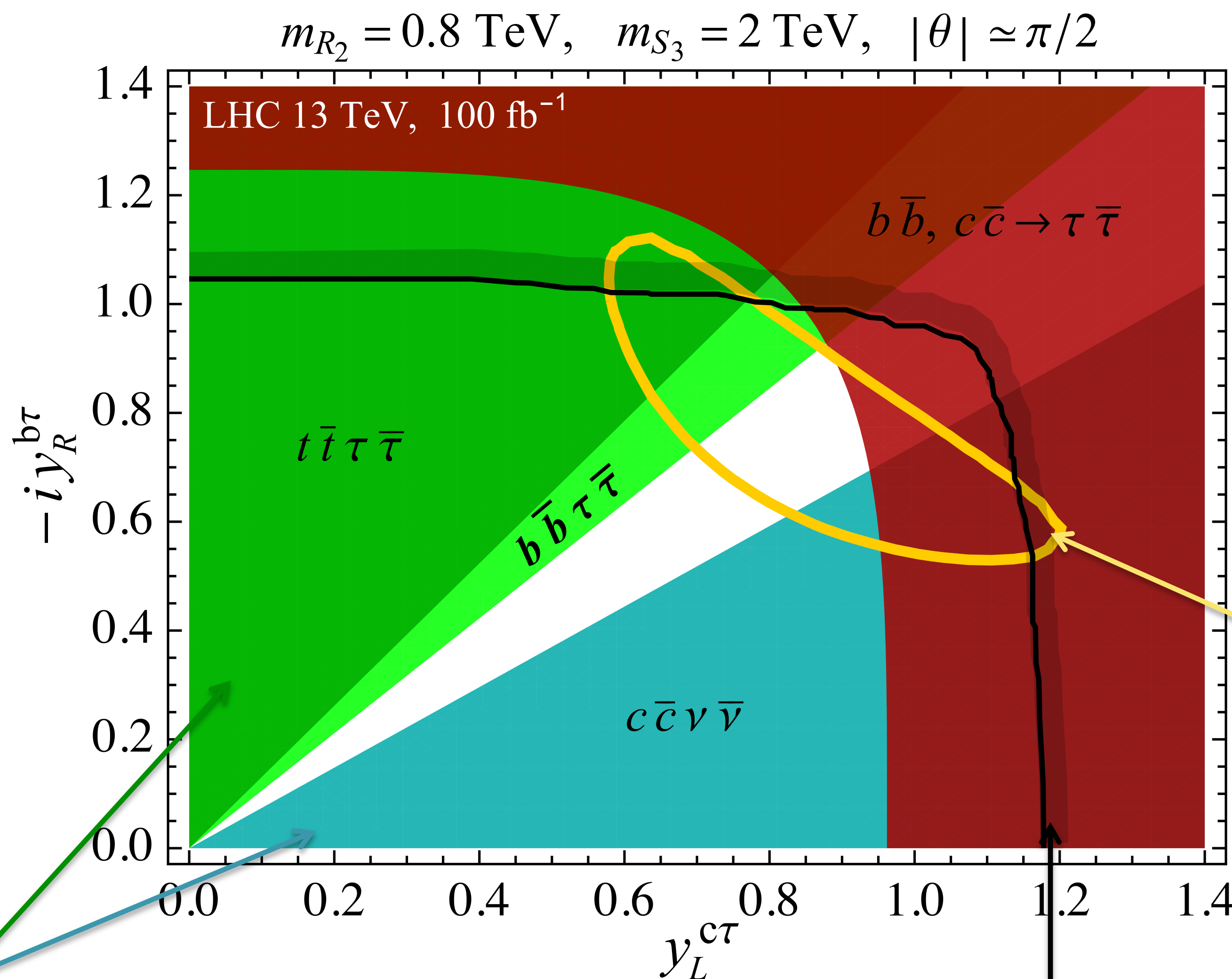
	Color singlet	Color triplet
Scalar	2HDM	Scalar LQ
Vector	W'	Vector LQ





LQs in B puzzles sτ , bτ and cτ are relatively large .
(Faroughy, Greljo and Kamenik, 1609.07138)

$R_{K(*)}$ and LHC searches
(Greljo and Marzocca, 1704.09015)



low- energy flavor constraints at 1 σ

CMS exclusion regions - LQ pair production searches

perturbativity up to GUT scale

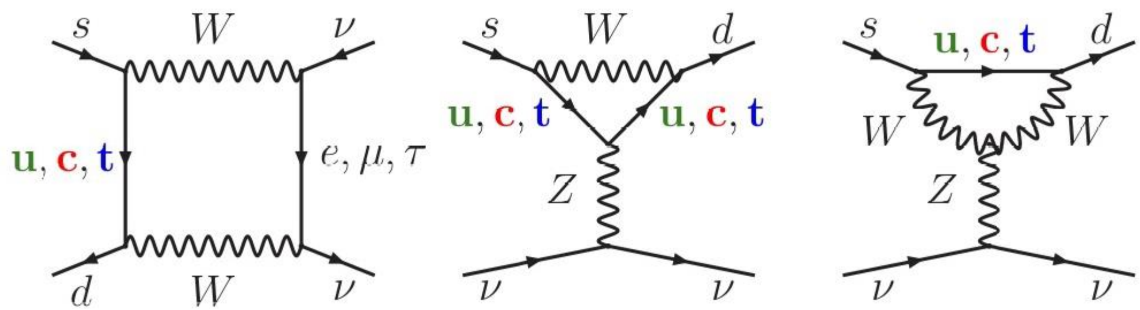
Becirevic et al., 1806.05689

$K \to \pi\nu\bar{\nu}$

The "cleanest" rare K meson decay- SM SD contribution dominates over LD

SM

Buchalla and Buras, hep-ph/9308272, Buras et al, 1503.02693.



$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\rm SM} = (8.4 \pm 1.0) \times 10^{-11}$$
$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})_{\rm SM} = (3.4 \pm 0.6) \times 10^{-11}$$

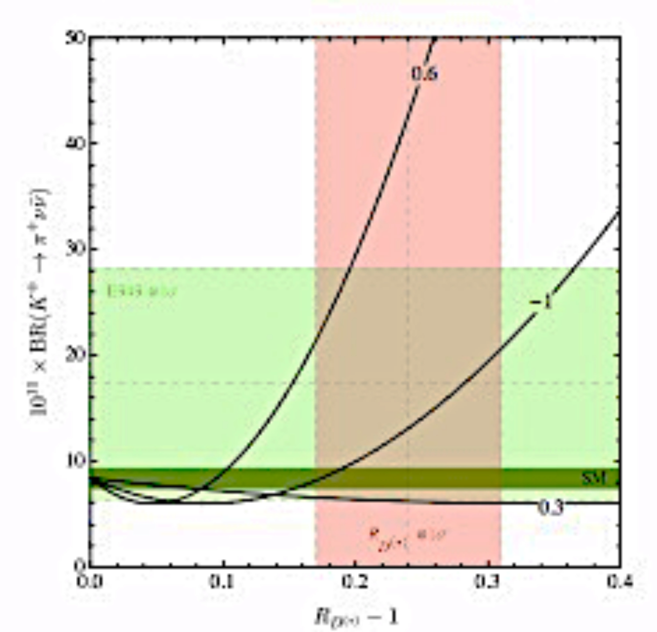
present experiments:

$K^+ \to \pi^+\nu\nu$: NA62 experiment at CERN

$K_L \to \pi^0\nu\nu$: KOTO experiment at JPARC

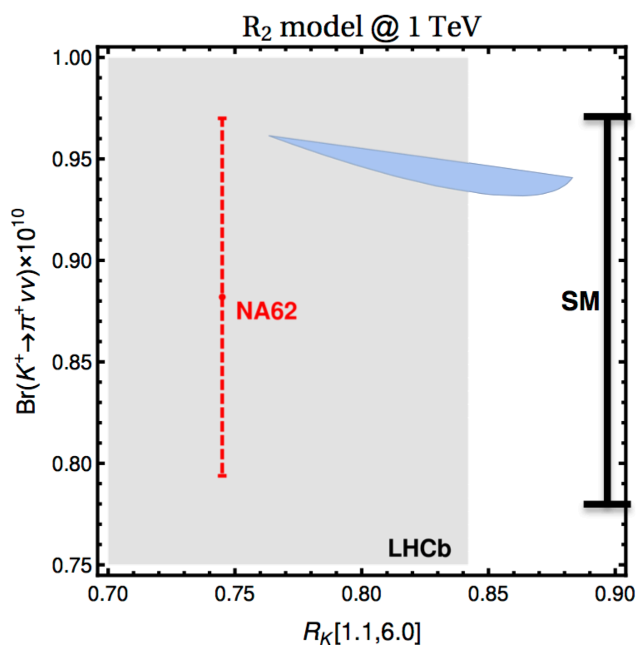
$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\rm exp} = 17.3^{+11.5}_{-10.5} \times 10^{-11},$$
$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})_{\rm exp} \le 2.6 \times 10^{-8} \qquad (90\%\ \mathrm{CL})$$

NP from $R_{D(*)}$ to $K \to \pi \nu \bar{\nu}$

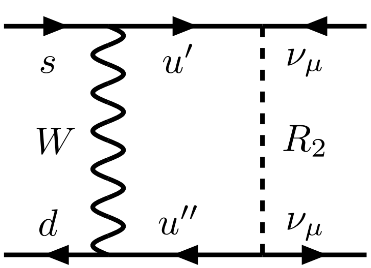


Bordone et al, , Buttazzo, Isidori, Monnard, 1705.10729,

The interference of NP with the SM amplitude leads to the suppression ~ 30%, relative the SM value.



NP from $R_{K(*)}$ to $K \to \pi \nu \bar{\nu}$

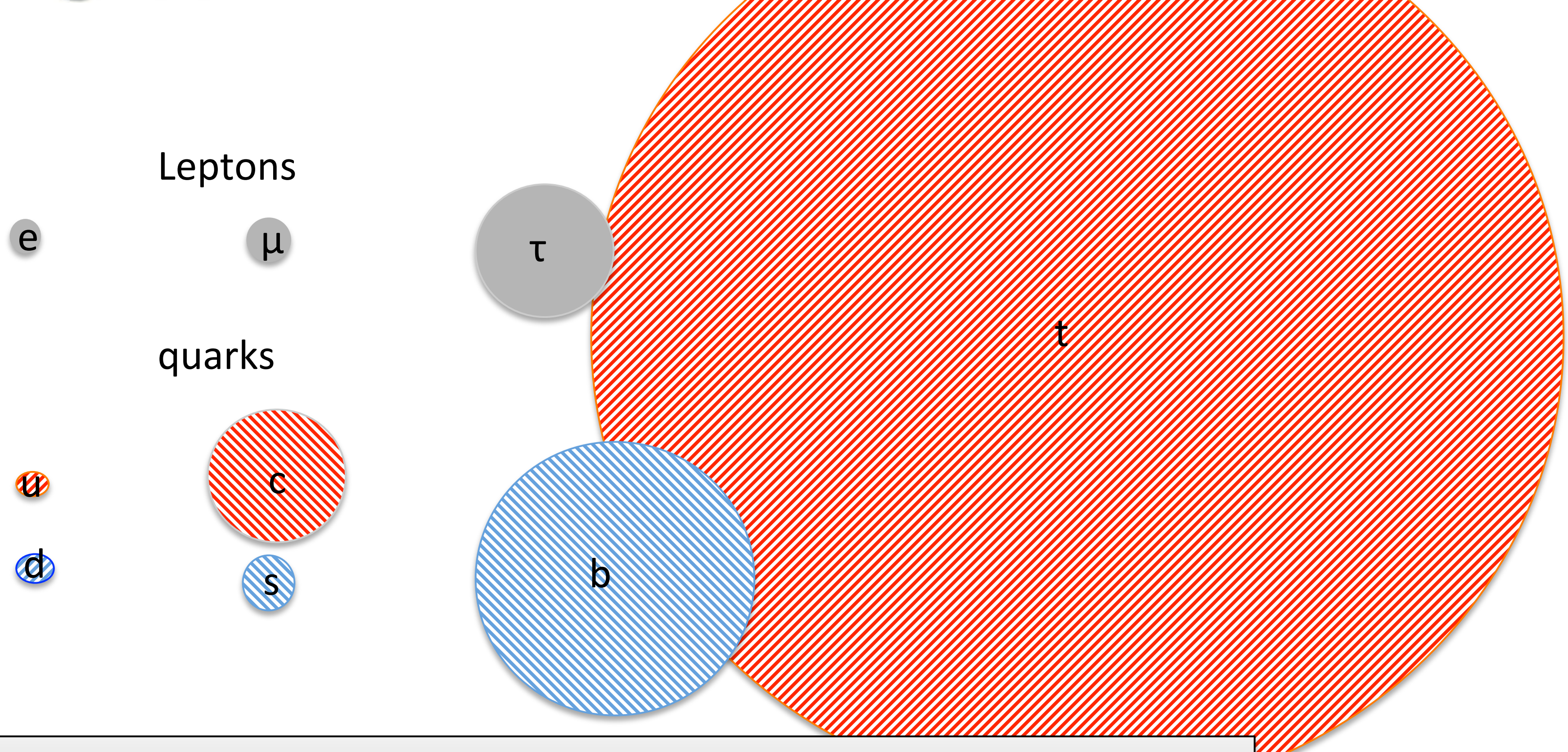


SF, Kosnik, Vale-Silva, 1802.00786, LQs from $R_{K(*)}$

max. enhancement ~15% in $K^+ \to \pi^+ \nu \bar{\nu}$ and ~ 10 % in $K^0 \to \pi^0 \nu \bar{\nu}$

Flavor puzzle

All properties are the same but masses are different!



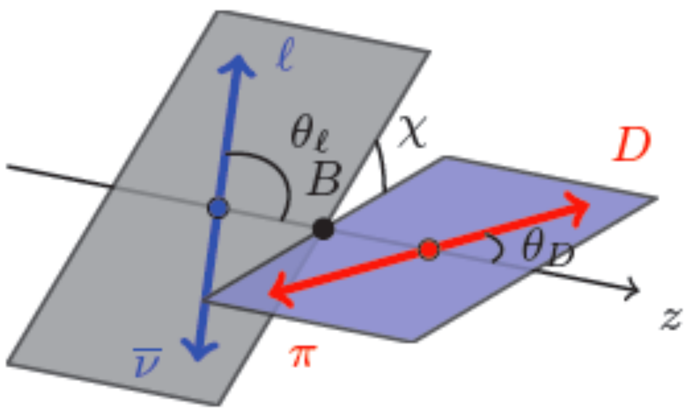
Constructing new UV complete theories based on B anomalies explanation might help in understanding SM quarks and leptons Yukawa couplings.

Barbieri et al. 1512.01560, Smith at ICHEP 2018, 1612.03825,...

Outlook

- We have to wait on Belle 2 & LHCb new results on $R_{D(*)}$ and $R_{K(*)}$ and Fermilab and J-PARC on $(g-2)_\mu$;
- Necessary Lattice QCD results on $B \longrightarrow D^*$ form factors and $Bc \longrightarrow J/\psi$;
- To measure all possible observables in angular correlations

  Differential decay distribution
  Forward-backward asymmetry
  Lepton polarization asymmetry
  Partial decay rate according to the polarization of D*;



- To test all possible observable in all $b \to s\mu\mu$ processes;

- If there is NP in $R_{D(*)}$ and $R_{K(*)}$, it have to be present in

$$B \to K^{(*)} \nu\bar{\nu}$$

$$K \to \pi\nu\bar{\nu}$$

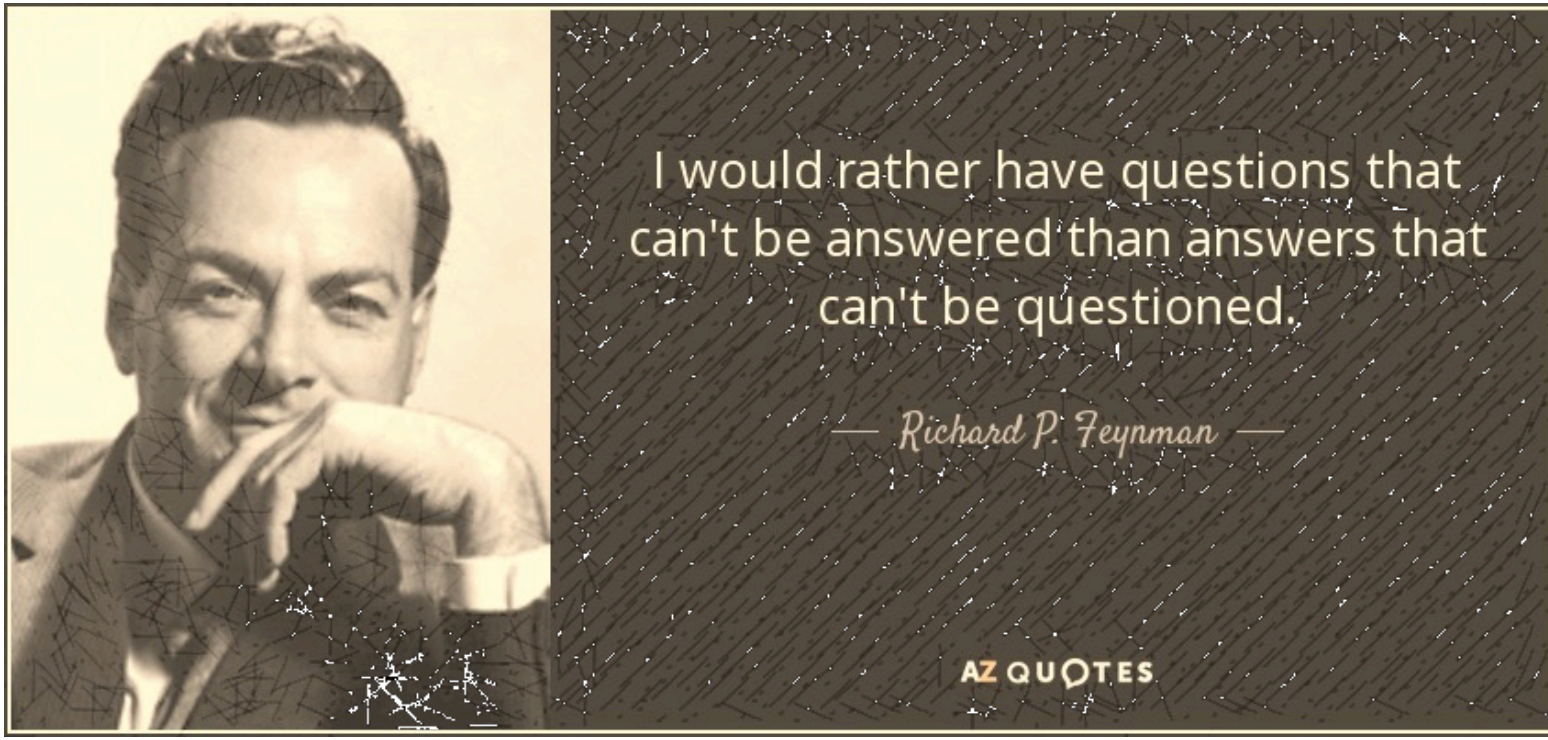
$$\tau \to \mu\gamma$$

$$\tau \to 3\mu$$

$$B \to K^{(*)} \tau\mu$$

$$B \to \tau\mu$$

- Further test of all flavor couplings at LHC;
- To check LFU in the first and second generations as precise as possible- below 1%!
- Continue to build effective Lagrangian approaches as well as NP models.


I would rather have questions that can't be answered than answers that can't be questioned.
— Richard P. Feynman —
AZ QUOTES

Thanks!

CP violation in $K \to \pi\pi$

Exp. $\frac{\epsilon'}{\epsilon} = (16.6 \pm 2.3) \times 10^{-4}$ NA48, hep-ex/0208009
KTeV, [hep-ex/0208007, 0909.2555.

SM
2.7 σ difference

$(1.1 \pm 5.1) \times 10^{-4}$ Kitahara et al., 1607.06727,

$(1.9 \pm 4.5) \times 10^{-4}$ Buras et al., 1507.06345,

$(15 \pm 7) \times 10^{-4}$ Gisbert & Pich, 1712.06147.

$$\mathrm{Re}\frac{\epsilon'}{\epsilon} = 1.38(5.15)(4.59) \times 10^{-4}$$

RBC and UKQCD Collaborations 1505.07863 .

$$\epsilon'/\epsilon = (\epsilon'/\epsilon)_{SM} + (\epsilon'/\epsilon)_{NP}$$

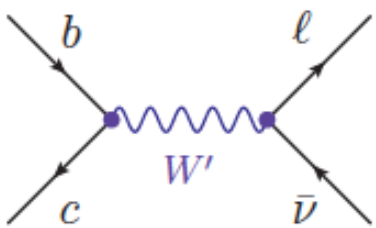
Is there any possibility to see NP?

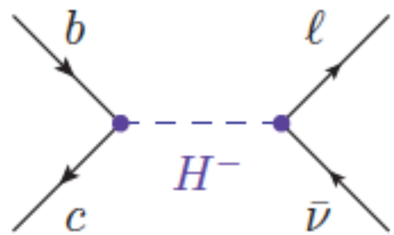
- Need non-zero couplings to first generation
- Need imaginary couplings
- Need both left-handed and right-handed couplings

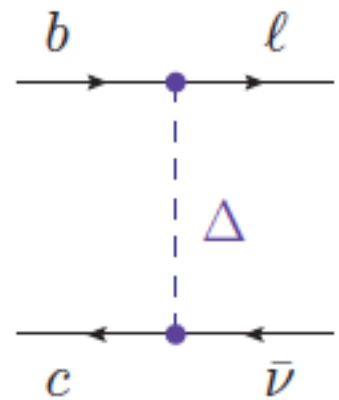
Analitic calculations of $K \to \pi\pi$ within DQCD,
Aebischer et al., general $SU(3)_c \times U(1)_{QED}$ structure, 40 operators (1807.01709) – might help in clarifying NP contributions.

Expecting future improvements by lattice QCD

Proposals of NP in $R_{D(*)}$:







A.Greljo et al, 1804.04642,
S.F. , J.F.Kamenik, NišandŽić, 1203.2654
S.F. J.F. Kamenik, I. Nišandžić, J. Zupan, 1206.1872
Körner& Schuller, ZPC 38 (1988) 511,
Kosnik, Becirevic, Tayduganov, 1206.4977
D. Becirevic, S.F. I. Nisandzic, A. Tayduganov,
1602.03030, Fretsis et al, 1506.08896,
S. Faller et al., 1105.3679,
Sakai&Tanaka, 1205.4908.
Biancofiore , Collangelo,
DeFazio 1302.1042,
R.Alonso et al, 1602.0767,Bardhan et al., 1610.03038

Di Luzio Nardecchia, 1706.0!868,
Crivellin etal, 1703.09226,
Blanke&Crivellin,1801.07256,
Biswas et al, 1801.03375,
Freytsis et al, 150608896,
Sakaki et al, 1309.0301,
Celis et al, 1612.07757,
Altmannshofer et al, 170406659

Impossible to write all references. My apology to all authors not written here

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NP in K and D physics

- strong constraints from atomic parity violation, LFU holds at 1% level for π and K − it suggest to avoid coupling of NP to the first generation;

- in K and D FCNC decays usually long distance physics overshadow short distance dynamics;

$$M_{LD} > M_{SM}$$

Any NP in B anomalies constrained by

$$\left\{ \begin{array}{ll} K^0 - \bar{K}^0 & K \to l\nu_l \\ D^0 - \bar{D}^0 & D_s \to l\nu_l \end{array} \right.$$

How large can be effects of NP explaining B anomalies in K and D charged current and FCNC rare decays having in mind existing and planned experimental precision?

$$D_s \to l\nu_l$$

In charm meson leptonic decays LQ explaining B anomalies give ~ 1-2 % modification od the decay width.