Low-energy hints of physics beyond the Standard Model

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- Introduction
- On the recent B-physics anomalies
- Speculations on the breaking of Lepton Flavor Universality
- Conclusions

Introduction (Where do we stand in the search for NP?)

The 1st run of the LHC has tested the validity of the SM in an un-explored range of energies, finding no significant deviations. The key results of the 1st LHC run can be summarized as follows:

- The Higgs boson (= last missing ingredient of the SM) has been found
- The Higgs boson is "light" ($m_h \sim 125$ GeV → not the heaviest SM particle)
- There is a "mass-gap" above the SM spectrum (i.e. no unambiguous sign of NP up to ~ 1 TeV)

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- There is a "mass-gap" above the SM spectrum

This is perfectly consistent with the (pre-LHC) indications coming from indirect NP searches (EWPO + flavor → light Higgs + mass gap above SM spectrum).

But all the problems of the SM (hierarchy problem, flavor pattern, dark-matter, U(1) charges,…) are still unsolved → the motivation for NP are still there (*somehow even stronger than before*)

The key questions are (*as in the "pre LHC era"*):

- How large is the "mass gap"?
- Can we expect a non-minimal flavor pattern?

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- Direct bounds on NP exceed ~ 1-2 TeV only for new states colored and/or strongly coupled to 1^{st} & 2^{nd} generation of quarks
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The 2 questions may well be connected !!

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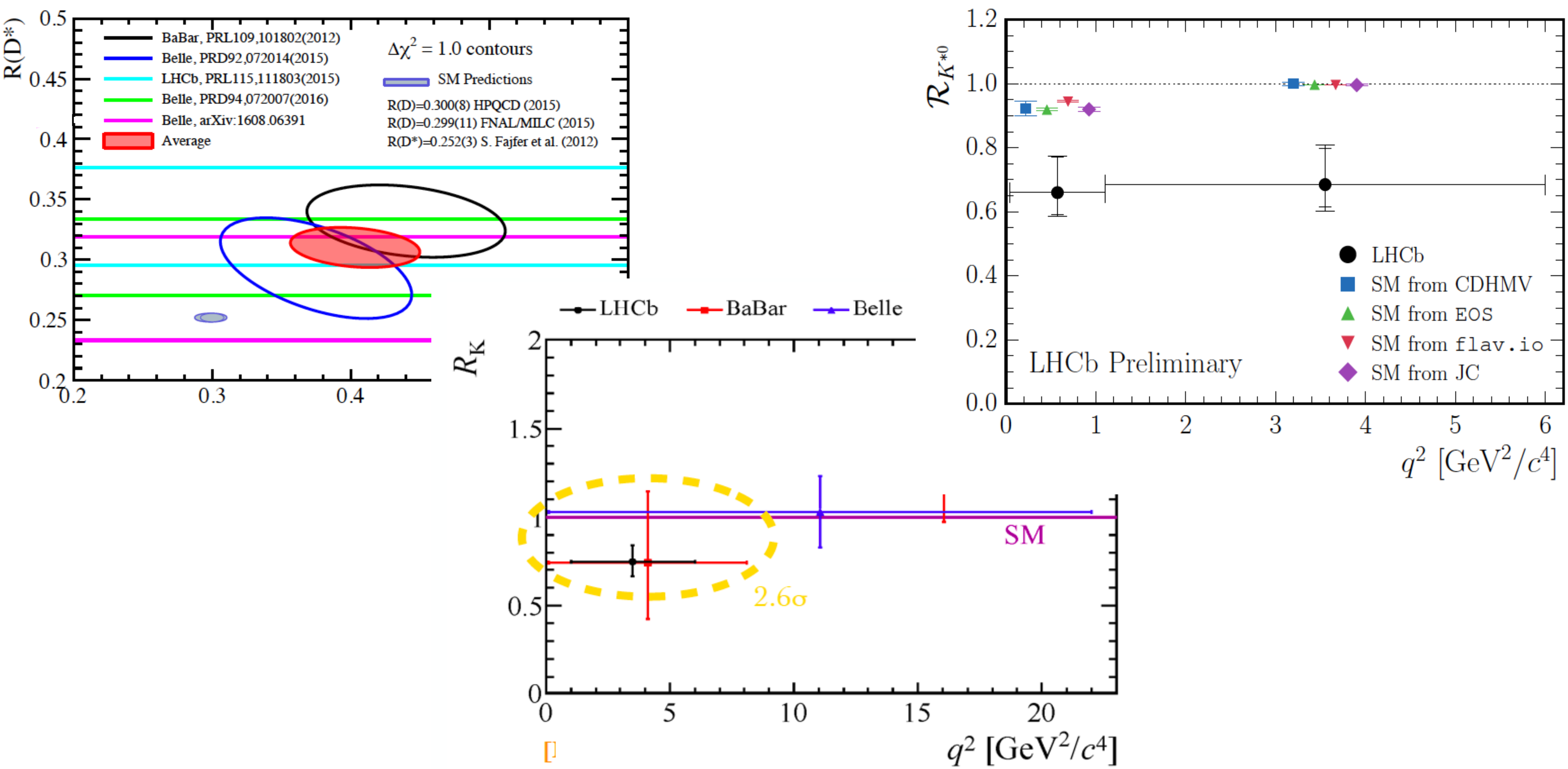
⇓

NP models with (relatively) light NP and where 3^{rd} generation of quarks & leptons have a special role are (still) very well-motivated
The interplay of flavor-physics and high-pT physics extremely important

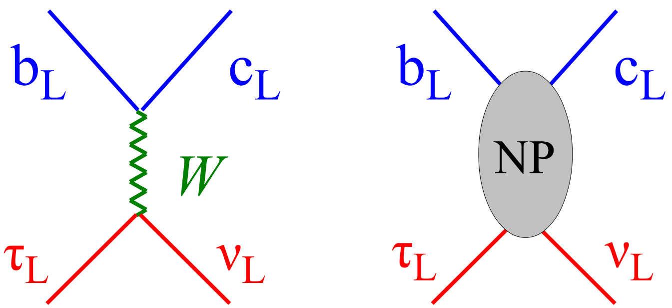
On the recent B-physics anomalies

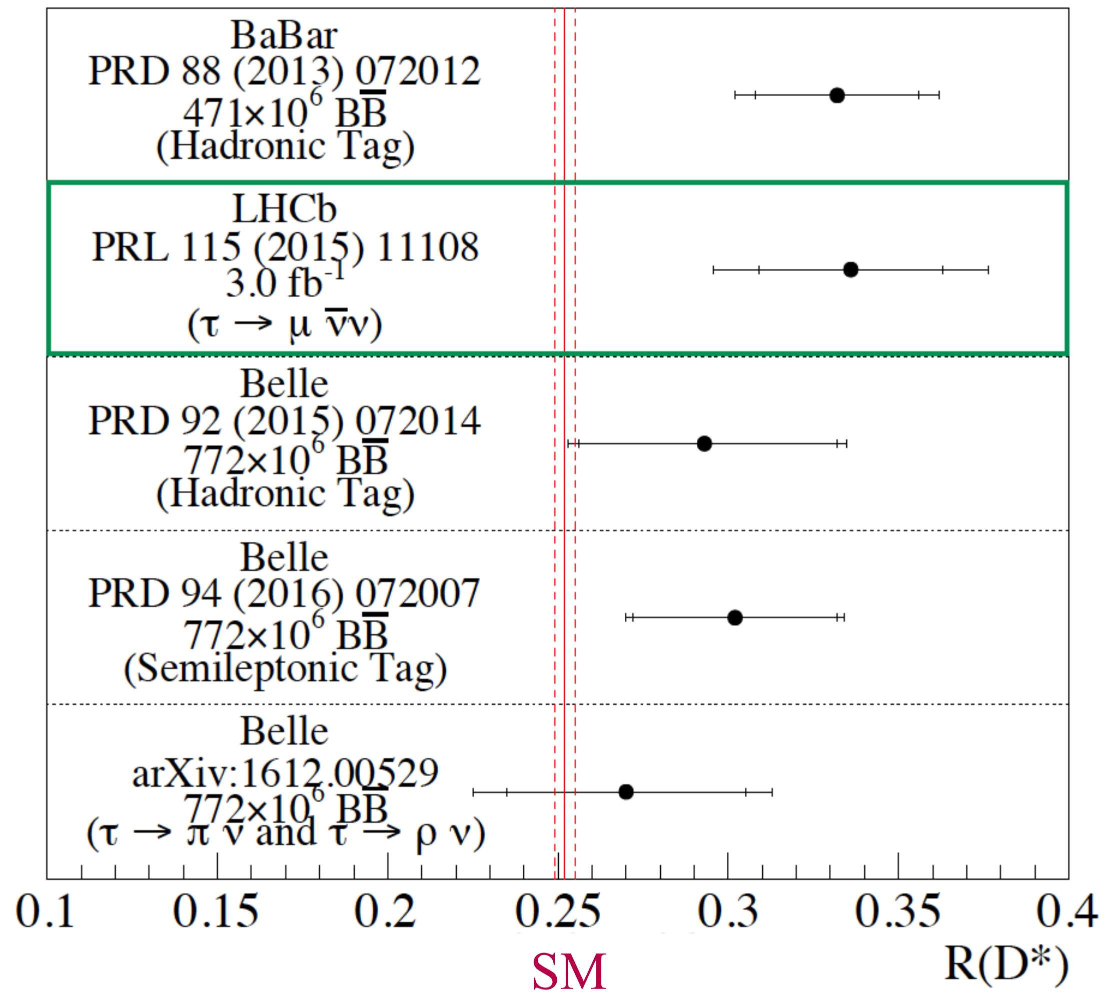


I. $B \to D^{(*)} \tau\nu$ [LHCb, Belle]

Test of LFU in charged currents [τ vs. light leptons (μ, e)]:

$$R(X) = \frac{\Gamma(B \to X\tau\bar{\nu})}{\Gamma(B \to X\ell\bar{\nu})}$$





- SM prediction quite solid: f.f. uncertainty cancel (*to a good extent...*) in the ratio
- Consistent exp. results by 3 (very) different experiments

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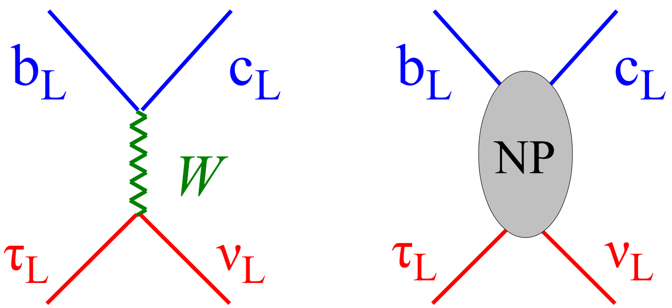

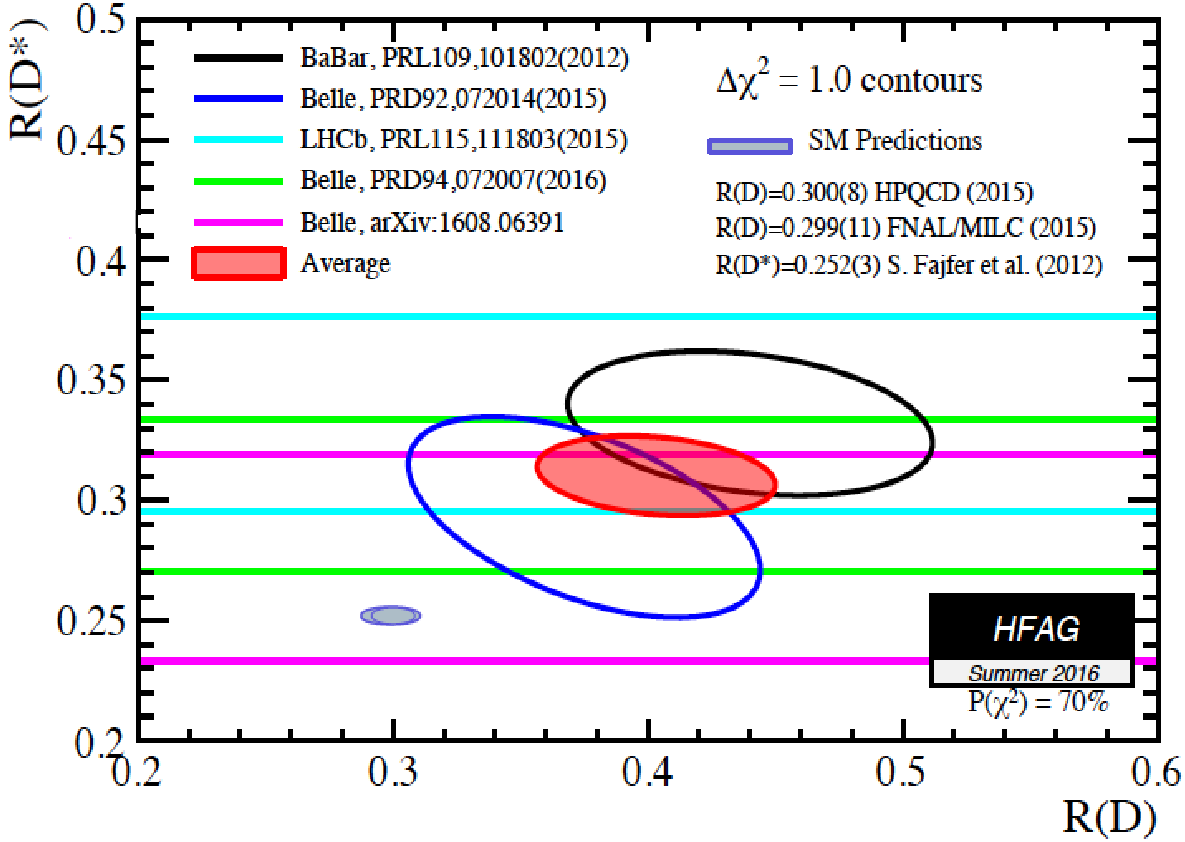

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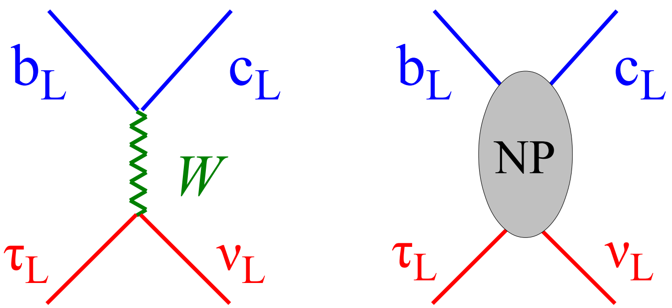

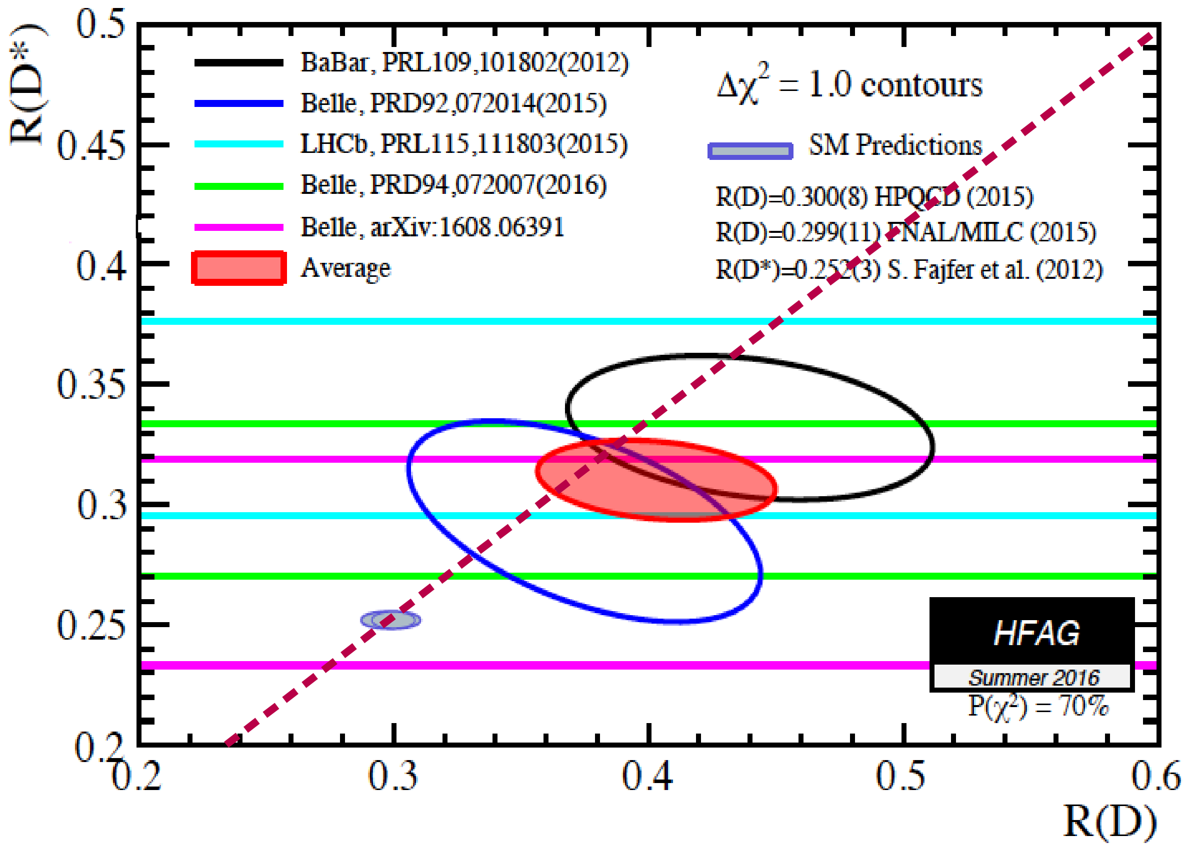

- SM prediction quite solid: f.f. uncertainty cancel (*to a good extent...*) in the ratio
- Consistent exp. results by 3 (very) different experiments
  - 4σ excess over SM (if D and D* combined)
  - The two channels are well consistent with a universal enhancement (~30%) of the SM $b_L \to c_L\ \tau_L\ \nu_L$ amplitude (*RH or scalar amplitudes disfavored*)

II. Anomalies in $B \to K^{(*)}\mu\mu$ / ee [LHCb]

The largest anomaly is the one [*obs. in 2013 and confirmed with higher stat. in 2015*] in the P_5' [$B \to K^{*}\mu\mu$] angular distribution.

Less significant correlated anomalies present also in other $B \to K^{*}\mu\mu$ observables and also in other $b \to s\mu\mu$ channels [overall smallness of all BR($B \to$ Hadron + $\mu\mu$)]

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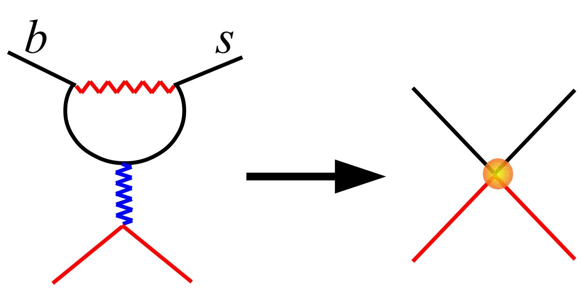
$B \to K^{(*)} ll$ are FCNC amplitudes ("natural" probes of physics beyond the SM):

- No SM tree-level contribution
- Strong suppression within the SM because of CKM hierarchy

Key point to be addressed: th. control of QCD effects

Three-step procedure to deal with the various scales of the problem:

A. Construction of a local eff. Hamiltonian at the electroweak scale



$$H_{\rm eff} = \Sigma_i\, C_i(M_W)\, Q_i$$

- Heavy NP encoded in the $C_i(M_W)$
- No difference among all $b \to s\, ll$ decays

B. Evolution of $H_{\rm eff}$ down to low scales using RGE

FCNC operators (E.W. penguins)

$$Q_9 = Q_f (b\,s)_{V-A} (l\,l)_V$$
$$Q_{10} = Q_f (b\,s)_{V-A} (l\,l)_A$$
$$\vdots$$

$$H_{\rm eff} = \Sigma_i\, C_i(M_W)\, Q_i$$

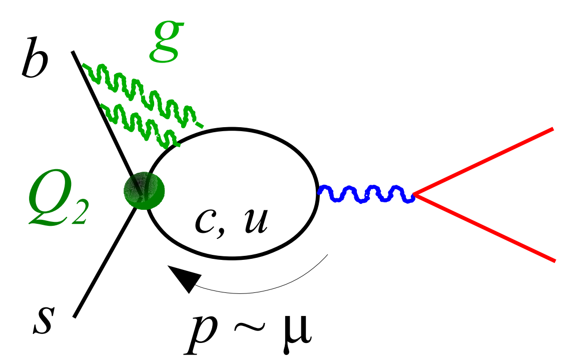
↓

$$H_{\rm eff} = \Sigma_i\, C_i(\mu \sim m_b)\, Q_i$$

Four-quark (tree-level) ops.:

$$Q_1 = (b\,s)_{V-A} (c\,c)_{V-A}$$
$$Q_2 = (b\,c)_{V-A} (c\,s)_{V-A}$$
$$\vdots$$

Mixing of the four-quark Q_i into the FCNC Q_i
["dilution" of the potentially interesting NP]:



Negligible for Q_{10} [$B_{s,d} \to ll$ & $B \to K^{(*)}ll$]

Large for "photon penguins" Q_9 [$B \to K^{(*)}ll$ only]

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C. Evaluation of the hadronic matrix elements

$$A(B \to f) = \Sigma_{\rm i}\, C_i(\mu)\ \langle f |\, Q_i\, | B \rangle\, (\mu)$$

- sensitivity to long-distances (*cc* threshold...)
- distinction between different modes

non-perturbative effects...

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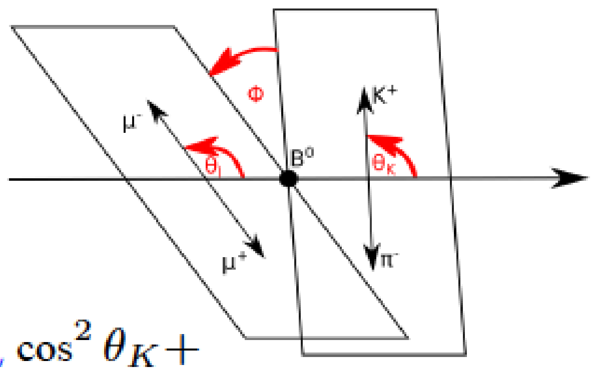
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$



$$\frac{d^4(\Gamma+\bar\Gamma)}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

$$P'_{4,5} = \frac{S_{4,5}}{\sqrt{F_L(1-F_L)}}$$

observables designed to cancel f.f. dependence in the HQ limit

Descotes-Genon, Matias, Ramon, Virto '12

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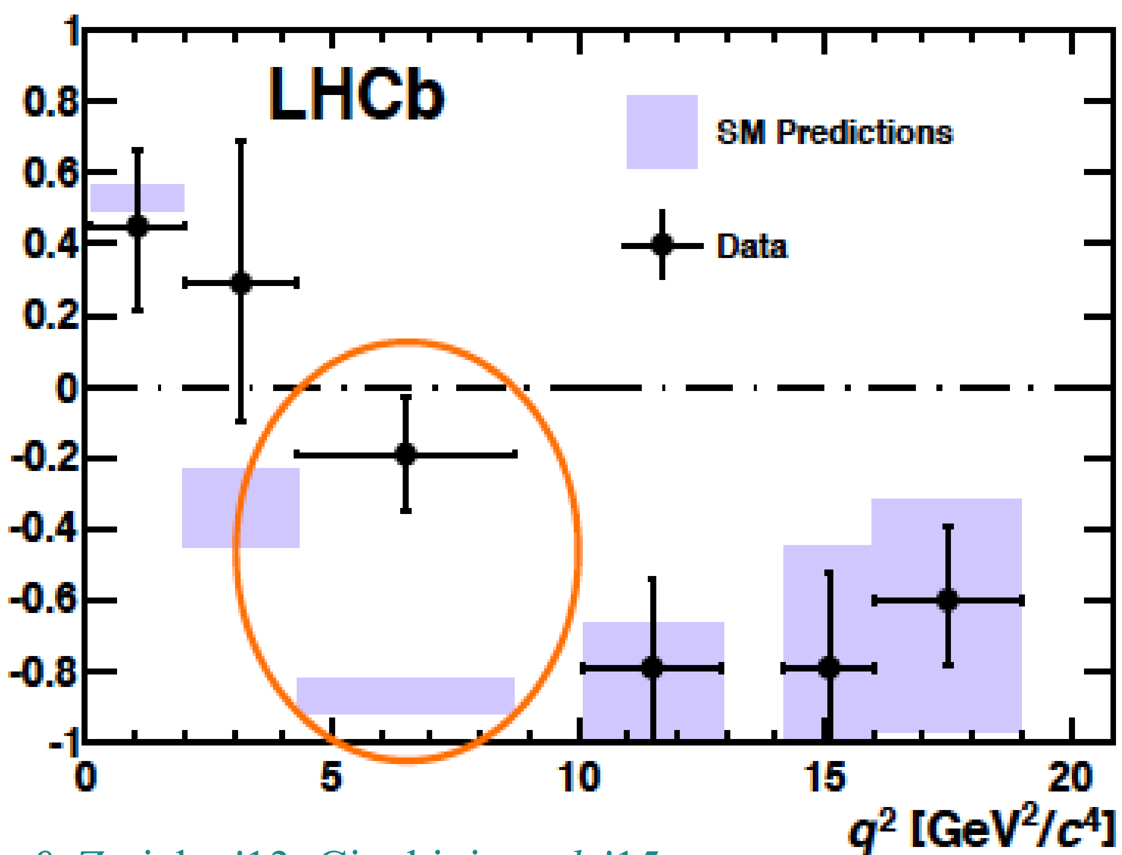
Pro NP:

- Reduced tension in all the observables with a unique fit of non-standard $C_i(M_W)$

Against NP:

- Main effect in P_5' not far from cc threshold
- "NP" mainly in C_9 ($\leftrightarrow$ *charm*)
- Significance reduced with conservative estimates of non-factorizable corrections



Jaeger *et al.* '12, Hambrock *et al.* '13, Hiller & Zwicky '13, Ciuchini *at al.* '15, ...

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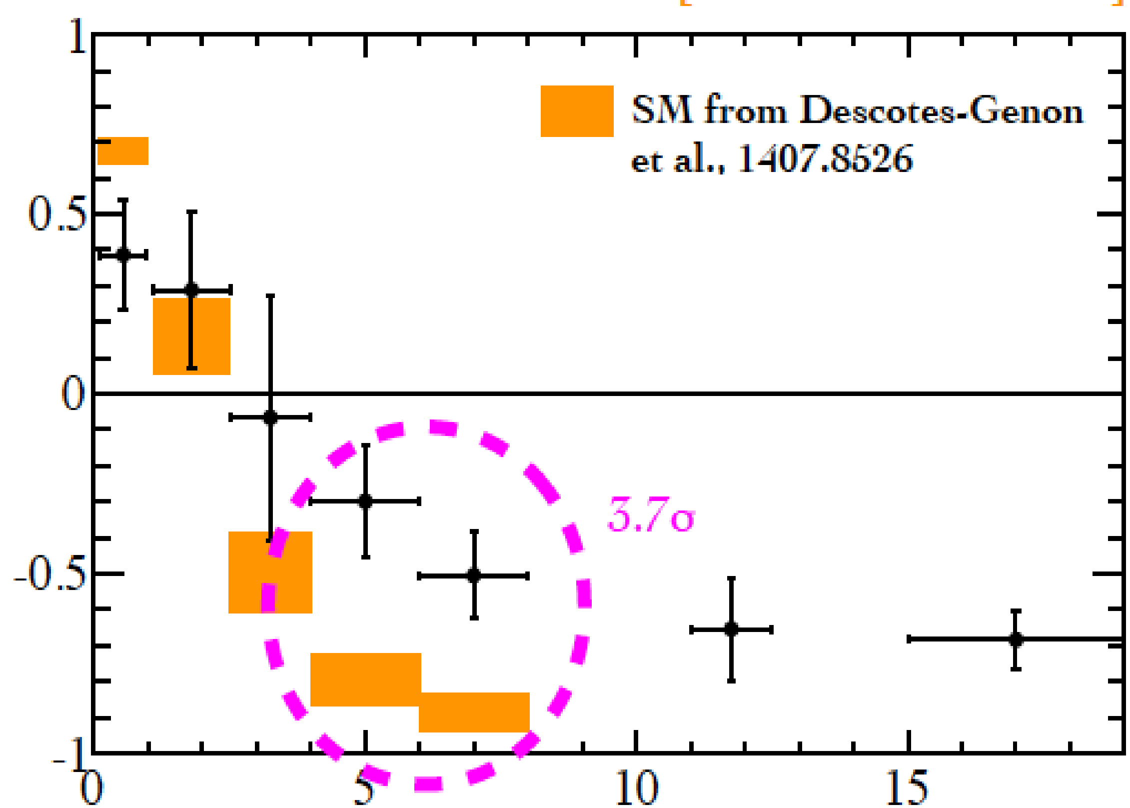
[LHCb-CONF-2015-002]



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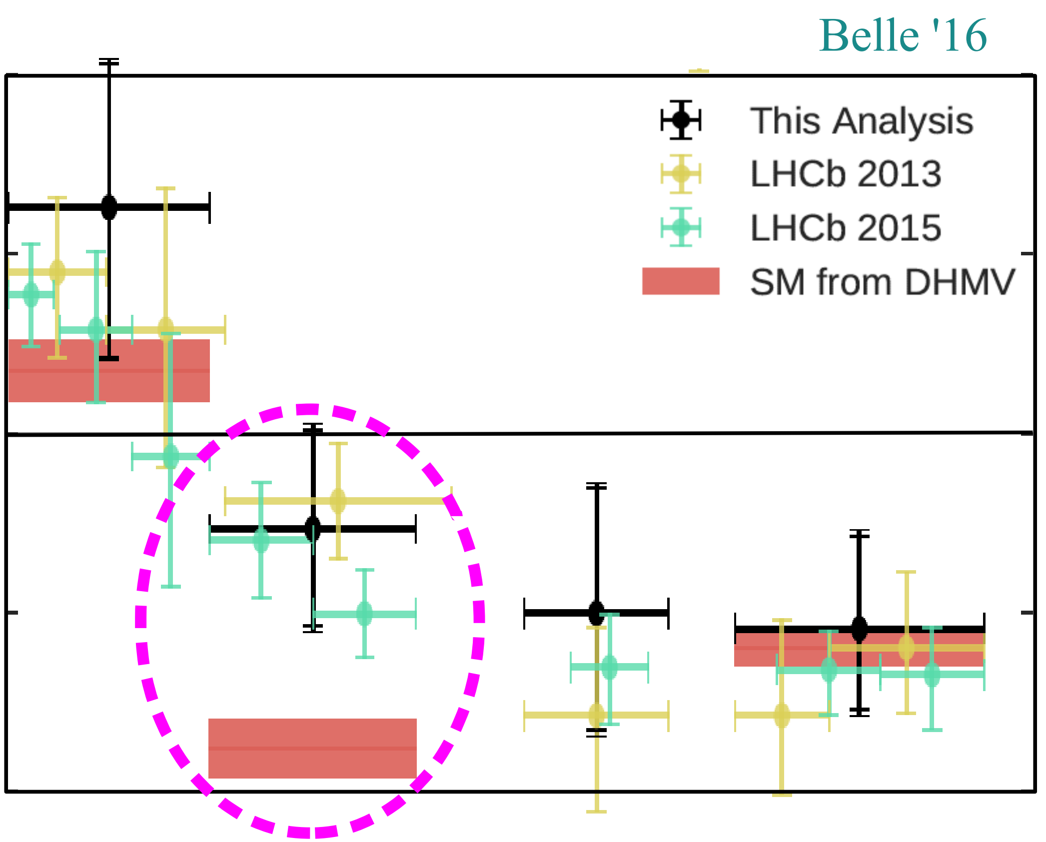

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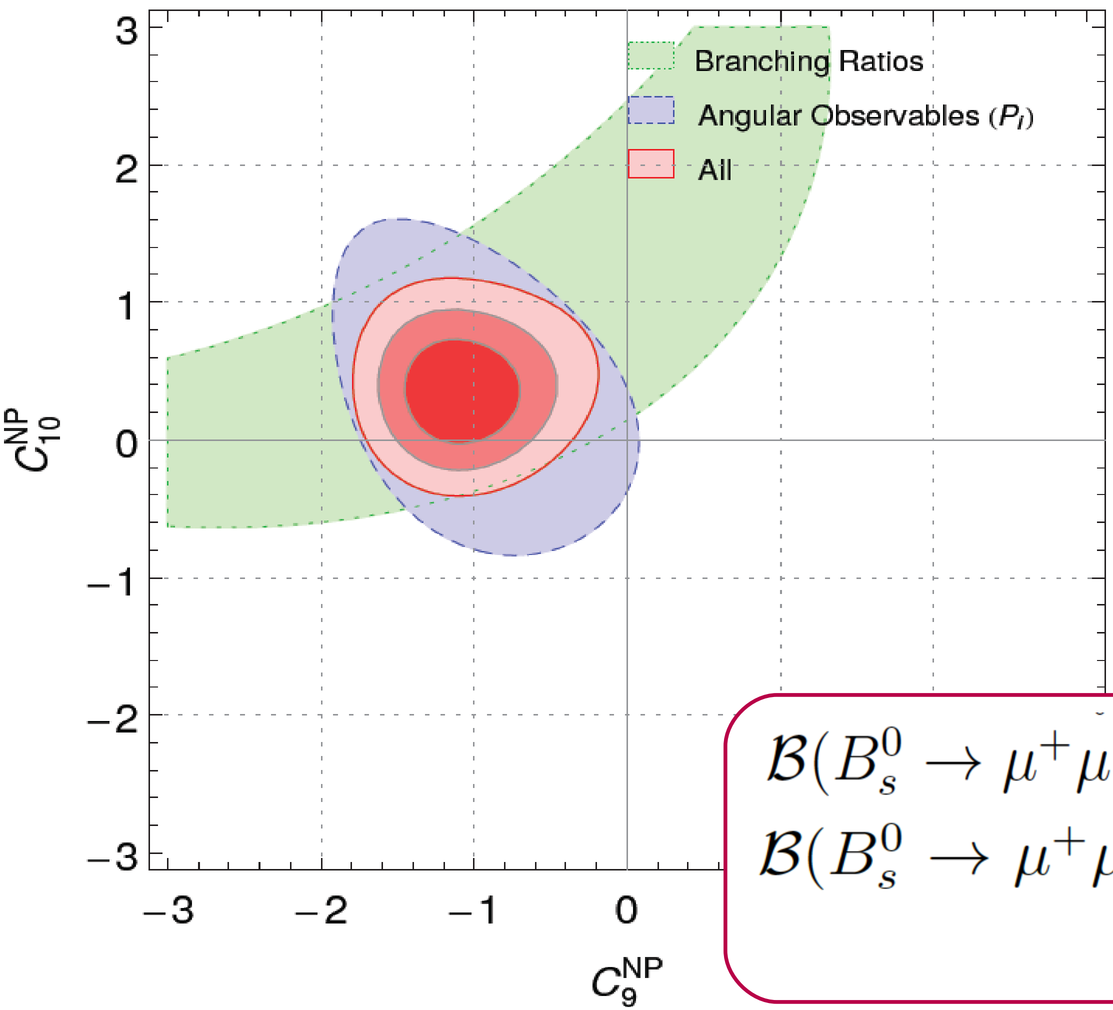
II. Anomalies in $B \to K^{(*)} \mu\mu$ / ee [LHCb]

Pro NP:

- Reduced tension in all the observables with a unique fit of non-standard short-distance Wilson coefficients

Descotes-Genon, Matias, Virto '13, '15
Altmannshofer & Straub '13, '15
Beaujean, Bobeth, van Dyk '13
Horgan *et al.* '13



$$\mathcal{O}_9 = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$$

$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

Consistency with smallness of $BR(B_s \to \mu\mu)$ for $C_9 = - C_{10}$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\rm SM} = (3.66 \pm 0.23) \times 10^{-9}$$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.8\,^{+0.7}_{-0.6}) \times 10^{-9}$$

LHCb + CMS

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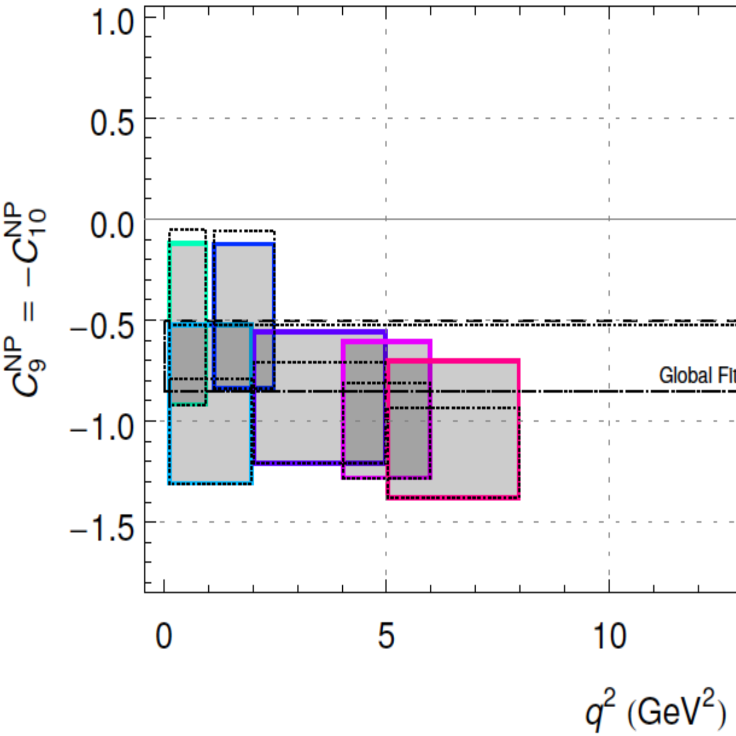
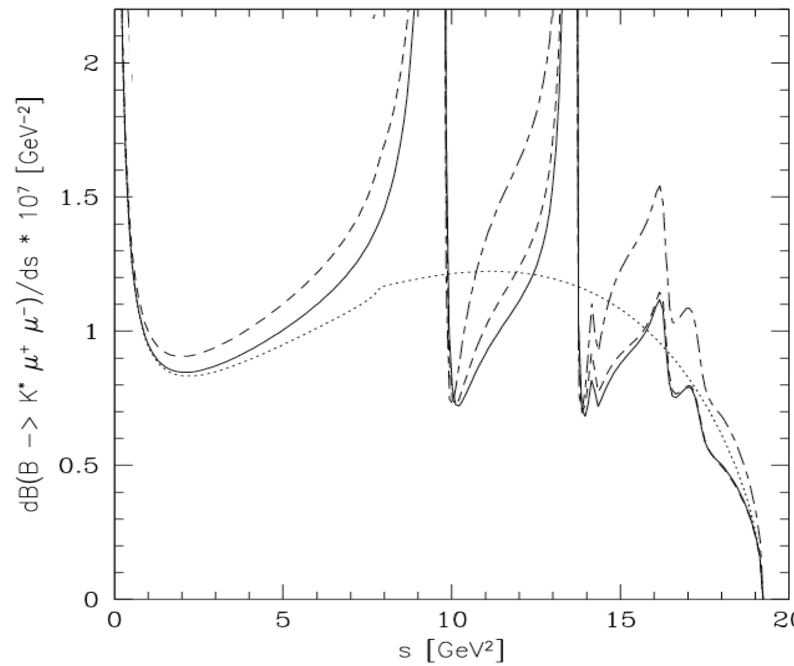




More precise data on the $q^2 = m_{\mu\mu}$ distribution can help to distinguish NP vs. SM

Descotes-Genon, Matias, Virto '15

II. Anomalies in $B \to K^{(*)} \mu\mu$ / ee [LHCb]

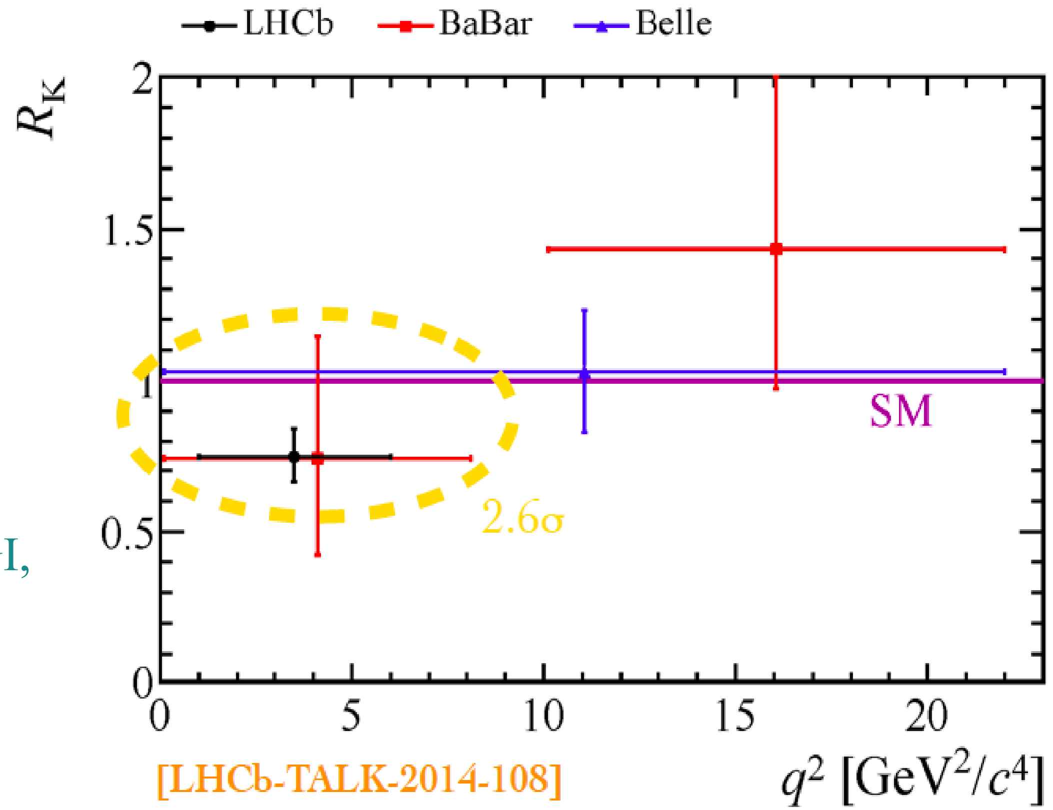
But the most interesting effects in $b \to s\ell\ell$ transitions are deviations from μ/e universality in appropriate "clean" ratios:

1)
$$R_K = \frac{\int d\Gamma(B^+ \to K^+\mu\mu)}{\int d\Gamma(B^+ \to K^+ ee)}$$
[1-6] GeV^2

- Negligible th. error → clean test of LFU (in neutral currents)

$R_K^{(SM)} = 1.00 \pm 0.01$ Bordone, GI, Patttori '16

$R_K^{(exp)} = 0.75 \pm 0.09$ LHCb, '14



[LHCb-TALK-2014-108]

- This anomaly is perfectly described assuming NP only in $b \to s\mu\mu$ [*and not in* $b \to see$] consistently with P_5' & the other $b \to s\mu\mu$ anomalies

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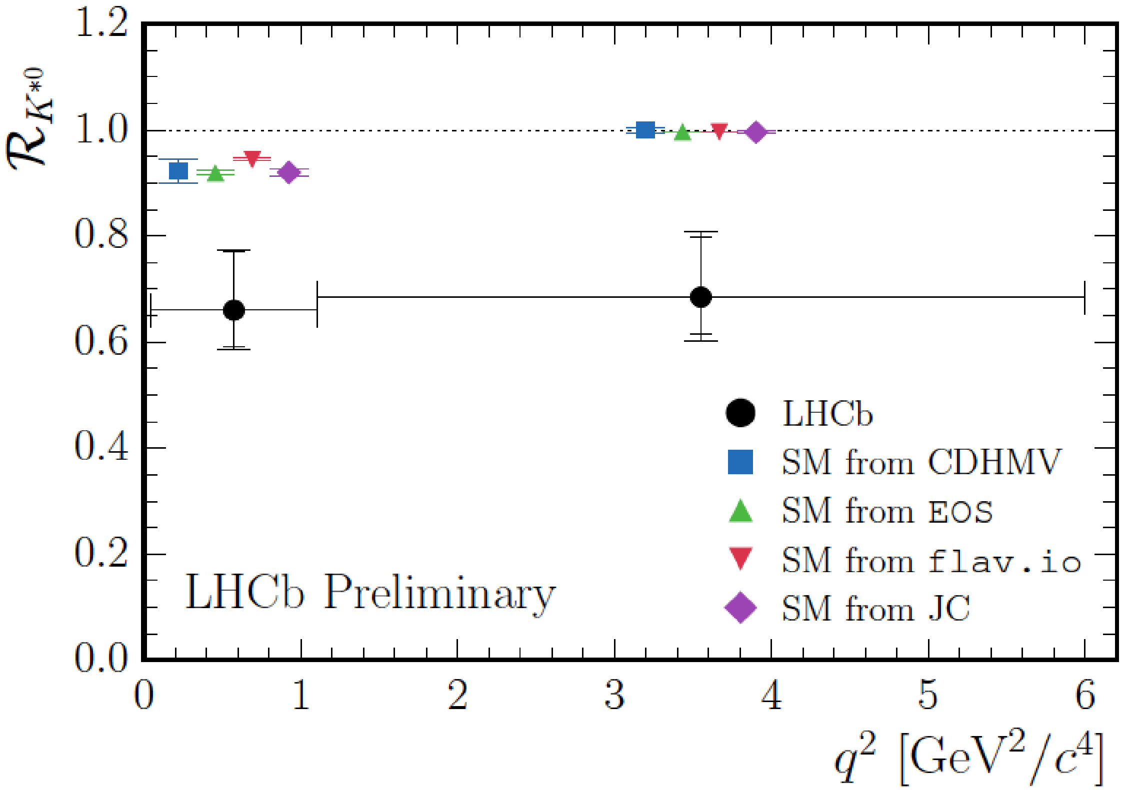
2)
$$R_{K^*} = \frac{\int d\Gamma(B^0 \to K^* \mu\mu)}{\int d\Gamma(B^0 \to K^* ee)}$$

"Breaking News" (*18 April 2017, CERN*):
Very similar effect observed also in R_{K^*}



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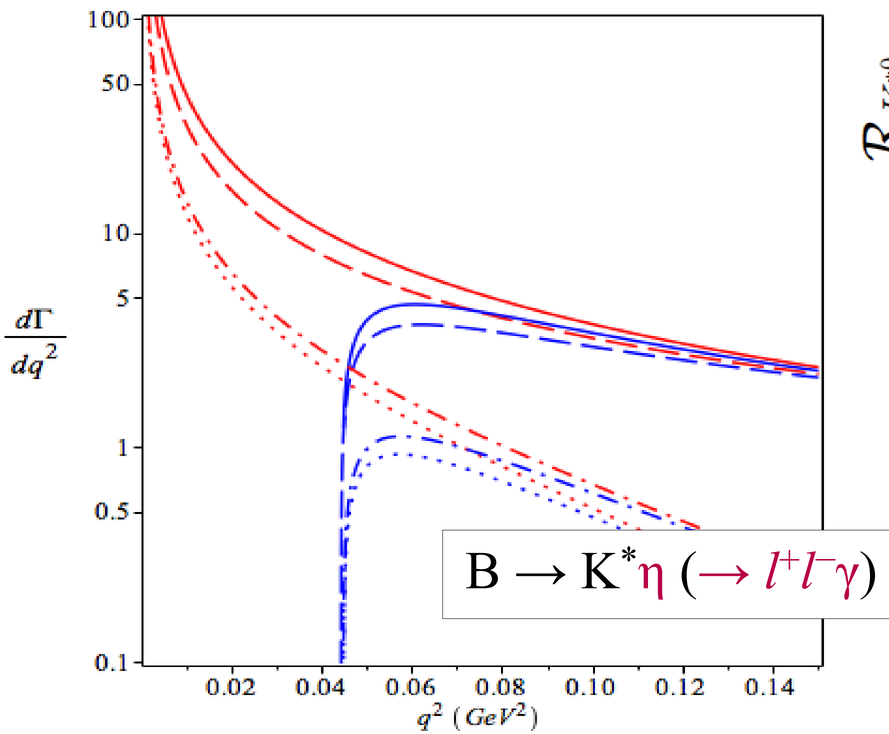

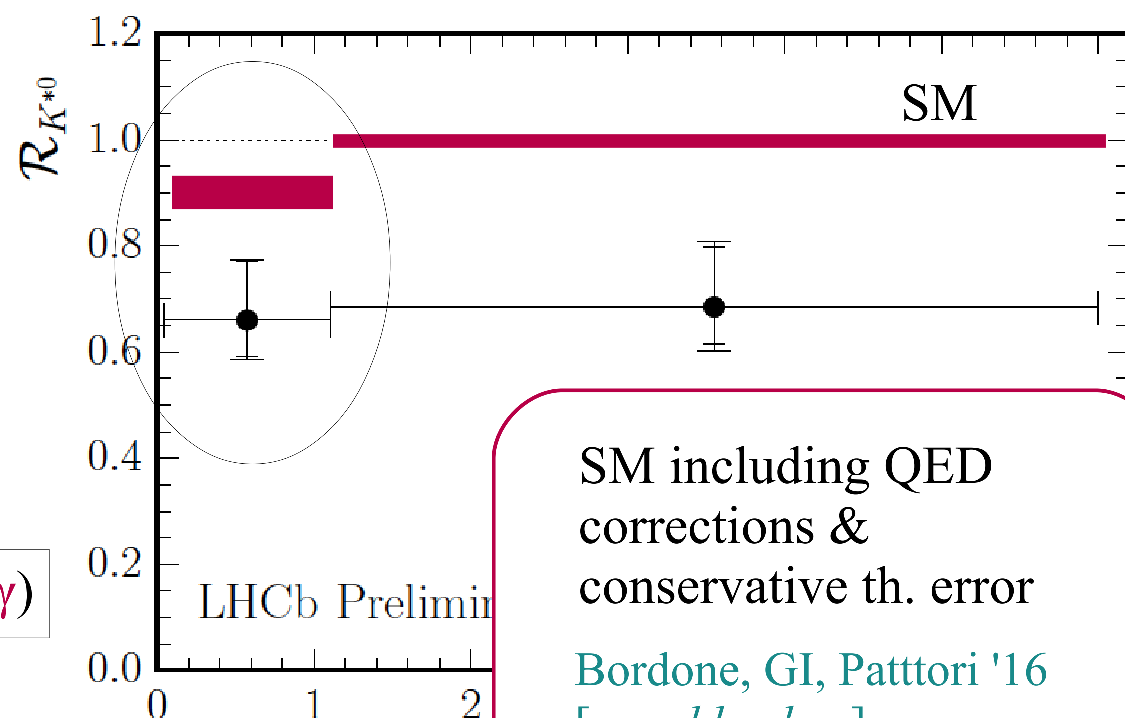

SM including QED corrections & conservative th. error

Bordone, GI, Patttori '16 [→ *addendum*]

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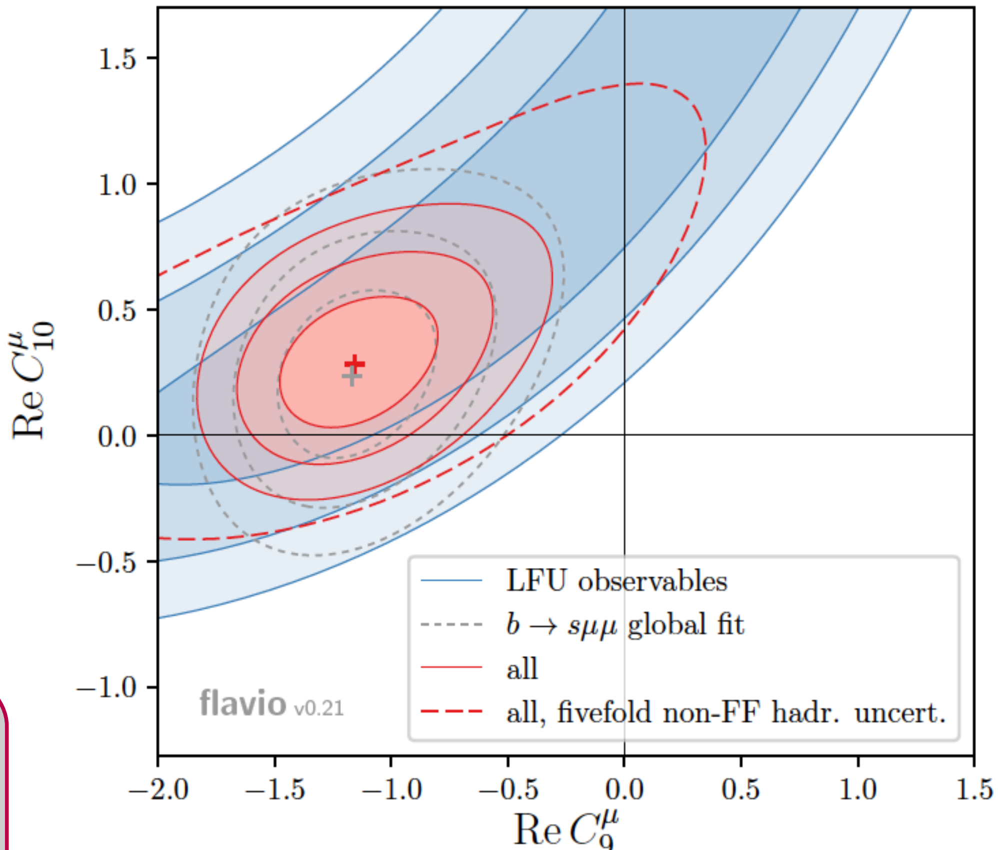
But the most interesting effects in $b \to s\ell\ell$ transitions are deviations from μ/e universality in the "clean" ratios R_K & R_{K*} (combined effect exceeding 3σ) :

Various "*instant papers*" have updated the fit to $b \to s\ell\ell$ Wilson coeff.

Main messages:

- Low-q^2 bin a bit too low (*the central value cannot be explained by NP – but there the theory error is larger...*)
- All the rest perfectly consistent with what we already knew:



Altmannshofer, Stangl, Straub '17

- All anomalies are well described assuming NP only in $b \to s\mu\mu$
- Stronger indication in favor of V-A interaction

Speculations on the breaking of Lepton Flavor Universality

Speculations on the breaking of LFU

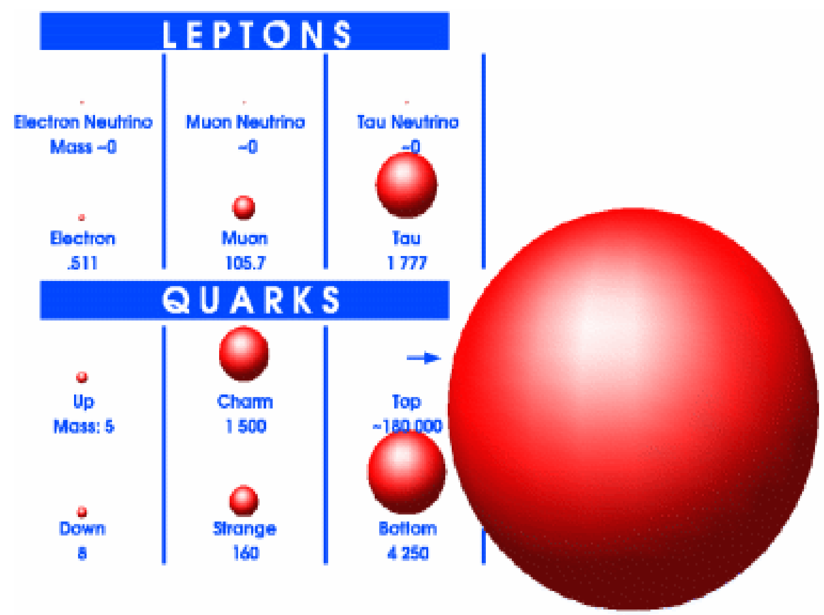
These recent results have stimulated a lot of theoretical activity

- *Hints* of LFU violations in $b \to c$ charged currents: τ vs. light leptons (μ, e)
- *Hints* of LFU violations in $b \to s$ neutral currents: μ vs. e

IF taken together... this is probably the largest "coherent" set of NP effects in present data...

A few general messages:

- LFU is not a fundamental symmetry of the SM Lagrangian (*global symmetry of the gauge sector only, broken by Yukawas*)
- LFU tests at the Z peak are not too stringent ($\to$ gauge sector)
- Most stringent tests of LFU involve only 1st-2nd gen. quarks & leptons



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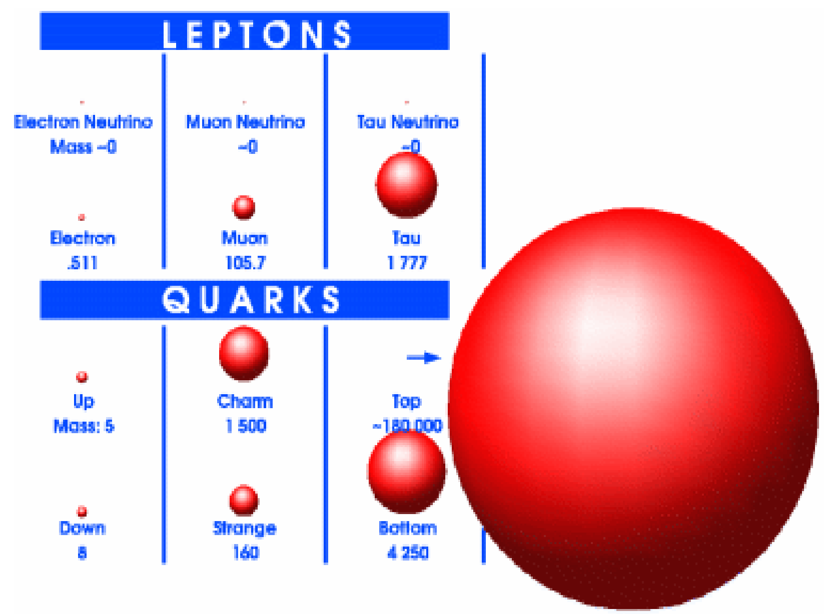

Natural to conceive NP models where LFU is violated more in processes involving 3^{rd} gen. quarks & leptons (↔ *hierarchy in Yukawa coupl.*)

Speculations on the breaking of LFU

These recent results have stimulated a lot of theoretical activity
(*not particularly instructive to discuss all NP proposals*...)

What I will discuss next is a bottom-up approach made of three main steps:

Generic EFT approach
↓
Simplified Dynamical Models
↓
High-energy behavior and UV completion

The main guide will be the attempt to describe both LFU effects within the same framework and, while "going up" in energies (and assumptions), check the consistency with

- other low-energy data
- high-pT physics

EFT-type considerations

- Anomalies are seen only in semi-leptonic (quark×lepton) operators
- RR and scalar currents disfavored → LL current-current operators
- Necessity of at least one $SU(2)_L$-triplet effective operator (*as in the Fermi theory*):

$$\frac{g_q g_\ell}{\Lambda^2}\lambda^q_{ij}\lambda^\ell_{kl}(\bar{Q}^i_L T^a \gamma_\mu Q^j_L)(\bar{L}^k_L T^a \gamma^\mu L^l_L)$$

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- Large coupling (competing with SM tree-level) in bc ($=33_{CKM}$) → $l_3\,\nu_3$
- Small non-vanishing coupling (competing with SM FCNC) in bs → $l_2\,l_2$

Glashow, Guadagnoli, Lane '14
Bhattacharya *et al.* '14
Alonso, Grinstein, Camalich '15
Greljo, GI, Marzocca '15
Bordone *et al.* '17

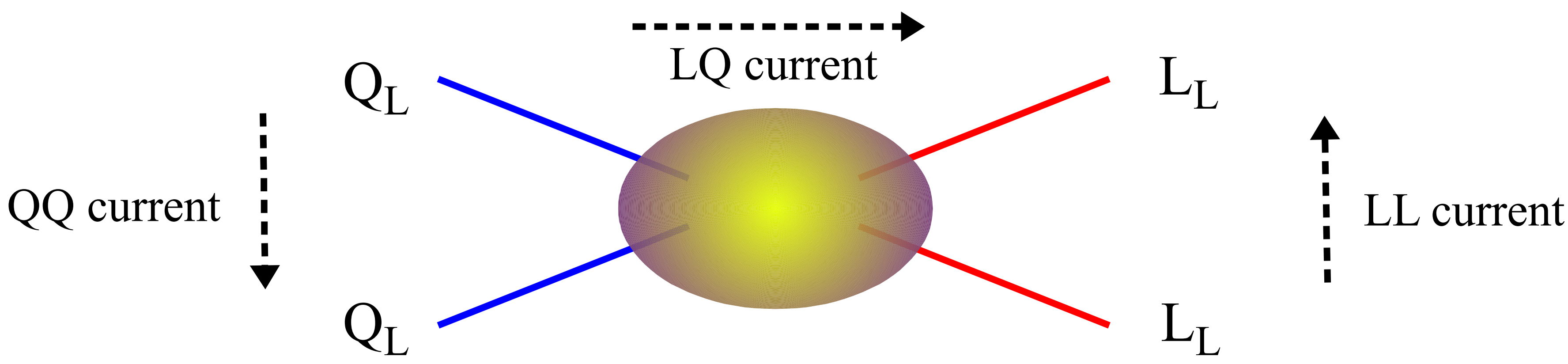
⬇

$$\lambda^{q,\ell}_{ij} = \delta_{i3}\delta_{3j}$$ + small corrections for 2^{nd} (& 1^{st}) generations

EFT-type considerations

- Anomalies are seen only in semi-leptonic (quark×lepton) operators
- RR and scalar currents disfavored → LL current-current operators
- Necessity of at least one $SU(2)_L$-triplet effective operator (*as in the Fermi theory*):

$$\frac{g_q g_\ell}{\Lambda^2}\lambda^q_{ij}\lambda^\ell_{kl}(\bar{Q}^i_L T^a \gamma_\mu Q^j_L)(\bar{L}^k_L T^a \gamma^\mu L^l_L)$$



- Two natural classes of mediators, giving rise to different correlations among quark×lepton, (evidence) and quark×quark + lepton×lepton (bounds)

- *EFT-type considerations* [general consequences in charged currents]

$$\frac{\mathcal{A}(b \to c\, \ell^i \bar{\nu}^i)_{\rm SM+NP}}{\mathcal{A}(b \to c\, \ell^i \bar{\nu}^i)_{\rm SM}} = 1 + \boxed{R_0} \lambda^\ell_{ii} \qquad R_0 \equiv \frac{g_\ell g_q}{g^2} \frac{m_W^2}{\Lambda^2}$$

I. From R(D*) & R(D) data [Γ(b → cτν)/Γ(b → cμν)] → $\boxed{R_0 = 0.14 \pm 0.04}$

▸ *EFT-type considerations* [general consequences in charged currents]

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II. In principle, it should be possible to get a strong bound on the sub-leading leptonic coupling ($\lambda_{\mu\mu}$) from $\Gamma(b \to c\mu\nu)/\Gamma(b \to ce\nu)$, but surprisingly it is not so stringent ($|\lambda_{\mu\mu}| \lesssim 0.1$) $\to$ *no dedicated studies @ B-facotries !*

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III. This breaking of LFU in c.c. decrease the tension (*although only in part...*) between exclusive & inclusive determinations of $|V_{ub}|$ & $|V_{cb}|$:

$B \to X_{c,u}\, \tau\, \nu$

↳ $\mu\nu\nu$

Irreducible bkg. for the inclusive meas. subtracted (at present) assuming SM-like $\Gamma(B \to X_{c,u}\tau\nu)$ →

if $\Gamma(B \to X_{c,u}\tau\nu)$ is enhanced over the SM → $|V_{c(u)b}|_{\rm incl.}$ are overestimated

▸ *A simplified dynamical model* (I)

Greljo, GI, Marzocca '15

Main assumptions:

- We assume the effective triplet operator is the result of integrating-out a heavy triplet of vector bosons (W', Z') coupled to a single current:

$$J^a_\mu = g_q \lambda^q_{ij} \left(\bar{Q}^i_L \gamma_\mu T^a Q^j_L\right) + g_\ell \lambda^\ell_{ij} \left(\bar{L}^i_L \gamma_\mu T^a L^j_L\right) \longrightarrow \frac{1}{2m_V^2} J^a_\mu J^a_\mu$$

- Non-Universal flavor structure of the currents → mainly 3rd generations

→ Coupling to 3rd generations not suppressed

→ Coupling to light generations controlled by small $U(2)_q \times U(2)_l$ breaking terms related to sub-leading terms in the Yukawa couplings (*link to models explaining CKM hierarchy*)

A simplified dynamical model (I)

A brief detour: U(2)^n flavor symmetries

Barbieri, G.I., Jones-Perez, Lodone, Straub, '11

- 3rd generations fermions are singlets
- 1st and 2nd generation fermions are doublets

→ Efficient protection of FCNCs (~MFV like)

→ The exact symmetry limit is good starting point for the SM spectrum ($m_u=m_d=m_s=m_c=0$, $V_{CKM}=1$) → small breaking terms needed

$$Y_u = y_t \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \rightarrow \begin{bmatrix} \Delta & V \\ 0 & 1 \end{bmatrix}$$

unbroken symmetry $|V| \sim 0.04$ $|\Delta| \sim 0.006$

Possible "natural solution" of models with "dynamical Yukawas"

Alonso, Gavela, G.I., Maiani '13

Coming back to the heavy-triplet model, the flavor symmetry implies:

$$\lambda_{bd} << \lambda_{bs} << \lambda_{bb} = 1 \qquad \lambda_{ss} \sim \lambda_{bs}^2 \sim |V_{ts}|^2$$

A simplified dynamical model (I)

Five free parameters: $\epsilon_{\ell,q} \equiv \frac{g_{\ell,q}\, m_W}{g\, m_V} \approx g_{\ell,q} \frac{122\ \mathrm{GeV}}{m_V}$ + $\lambda^q_{bs},\ \lambda^\ell_{\mu\mu},\ \lambda^\ell_{\tau\mu}$

Several constraints:

- $R(D^*)$ & $R(D)$
- R_K & P_5'

- $B(B \to K\nu\nu)$
- ΔM_{Bs} , ΔM_{Bd}
- CPV(D-D)
- $\Gamma(B \to X\mu\nu)/\Gamma(B \to Xe\nu)$
- $\tau \to 3\mu$
- $\Gamma(\tau \to \mu\nu\nu)/\Gamma(\tau \to e\nu\nu)$

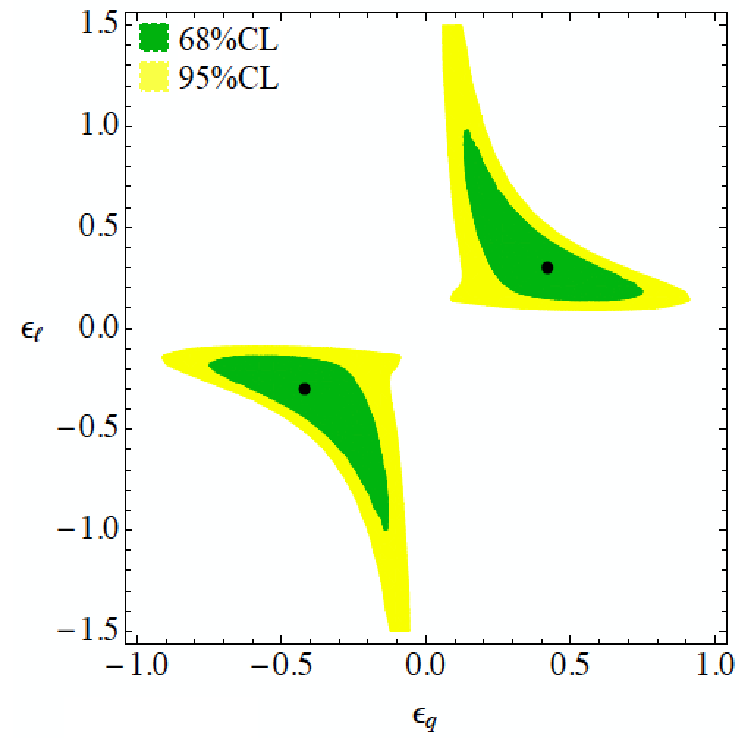
Overall good fit of low-energy data

(*non-trivial given tight constraints from ΔF=2 & LFV*)

Best fit point: $\epsilon_\ell \approx 0.37$, $\epsilon_q \approx 0.38$

$p(\mathrm{SM}) = 0.002$

Heavy vector mass: 200 GeV (weak coupl.) ⟷ 2 TeV (strong coup.)



▸ *A simplified dynamical model* (I)

Five free parameters:

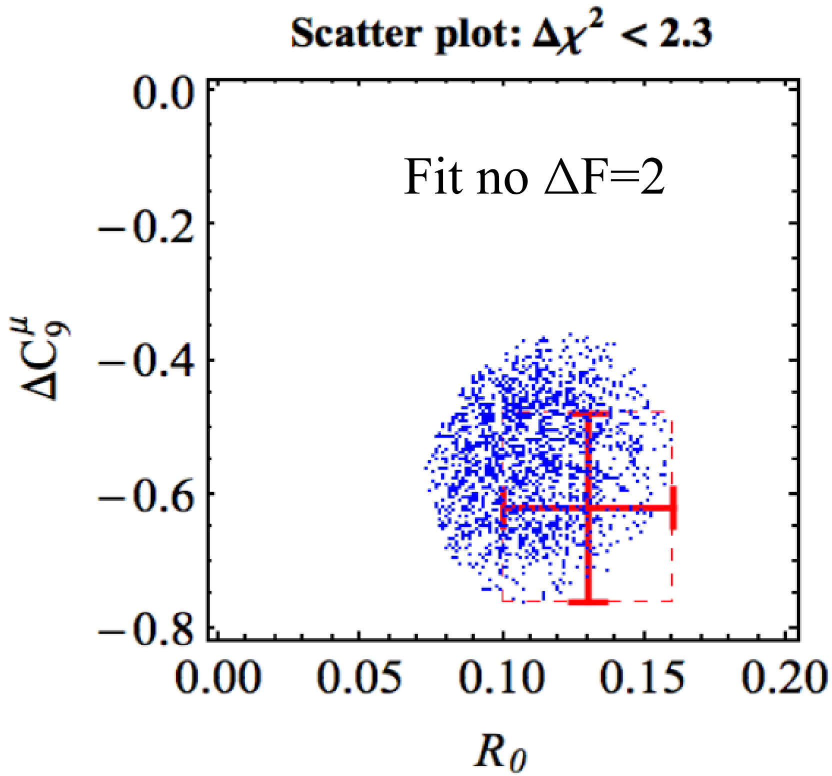
$$\epsilon_{\ell,q} \equiv \frac{g_{\ell,q}\, m_W}{g\, m_V} + \lambda^q_{bs},\ \lambda^\ell_{\mu\mu},\ \lambda^\ell_{\tau\mu}$$

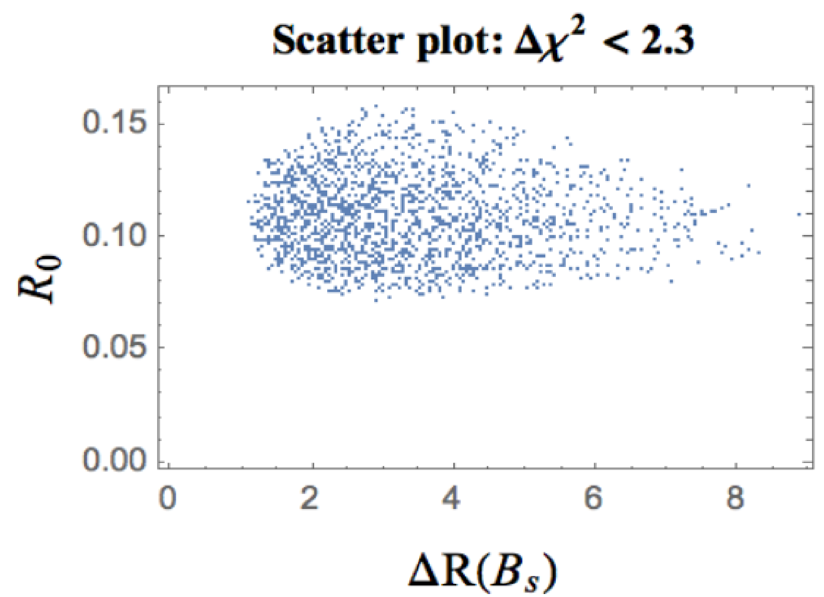
Several low-energy constraints

⬇

Overall good fit of low-energy data

Some residual tension
[ΔF=2 vs. LFU tests in tau decays]
which can be ameliorated including extra contributions
(e.g. $SU(2)_L$ singlets Z' or color-octet)





A simplified dynamical model (I)

$$\mathscr{L}_{\rm eff} = -\frac{1}{2m_V^2} J_\mu^a J_\mu^a$$

works well...

..and give rise to a rich low-energy phenomenology:

- $b \to c(u)\, l\nu$

$BR(B \to D^* \tau\nu)/BR_{SM} = BR(B \to D\tau\nu)/BR_{SM} = BR(\Lambda_b \to \Lambda_c \tau\nu)/BR_{SM}$

$= \ldots = BR(B_u \to \tau\nu)/BR_{SM}$

$R^{\mu/e}(X) \sim 10\%\ R^{\tau/\mu}(X)$

- universal 20-30% enhancement of C.C. semi-leptonic decays into tau leptons
- 1-2 % (universal) breaking of universality between muons & electrons (in leading CC modes)

A simplified dynamical model (I)

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- $b \to s\,\mu\mu$ — $\Delta C_9^\mu = -\Delta C_{10}^\mu$
- $b \to s\,\tau\tau$ — $|NP| \sim |SM| \to$ large enhanc. (up to 10×SM !) or strong suppr.
- $b \to s\,\nu\nu$ — $\sim \pm$ 50% deviation from SM in the rate

N.B: the deviations should be seen universally in all the hadronic modes: $B \to K^*\tau\tau$, $B \to K\tau\tau$, $\Lambda_b \to \Lambda\tau\tau$,...

A simplified dynamical model (I)

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- Meson mixing — $\sim 10\%$ deviations from SM both in ΔM_{Bs} & ΔM_{Bd}
- τ decays — $\tau \to 3\mu$ not far from present exp. Bound ($BR \sim 10^{-9}$)

A simplified dynamical model (II)

Main assumptions:

Barbieri, GI, Pattori, Senia '15

- We assume the effective triplet operator is the result of integrating-out Lepto-Quark (LQ) fields
- Non-Universal flavor structure of the current, based again on approximate $U(2)_q \times U(2)_l$ flavor symmetry
- Both Vector and Scalar LQ tried → Vector LQ produce a very good fit to data (*essentially as good as in model I*)

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Peculiar prediction of the LQ set-up: sizable modification of $\Gamma(K \to \pi\nu\nu)$

$$\Gamma(K \to \pi\nu\nu) = \Gamma(K \to \pi\nu_e\bar{\nu}_e) + \Gamma(K \to \pi\nu_\mu\bar{\nu}_\mu) + \Gamma(K \to \pi\nu_\tau\bar{\nu}_\tau)$$

SM like

few % deviation as in $b\to s\mu\mu$

possible O(1) deviation from SM expected also in $b\to s\tau\tau$

A simplified dynamical model (II)

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- Non-Universal flavor structure of the current, based again on approximate $U(2)_q \times U(2)_l$ flavor symmetry
- Both Vector and Scalar LQ tried → Vector LQ produce a very good fit to data (*essentially as good as in model I*)

⬇

Vector-mediator mass: 200 GeV (weak coupl.) ⟷ 2 TeV (strong coup.)

UV completions and high-energy bounds

In both cases (heavy vector triplets & vector LQ) we should address two basic questions:

- *Are these models compatible with high-energy (direct) searches?*
- *Can we find meaningful UV completions?*

UV completions and high-energy bounds

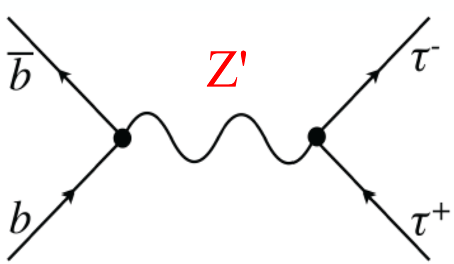
In both cases (heavy vector triplets & vector LQ) we should address two basic questions:

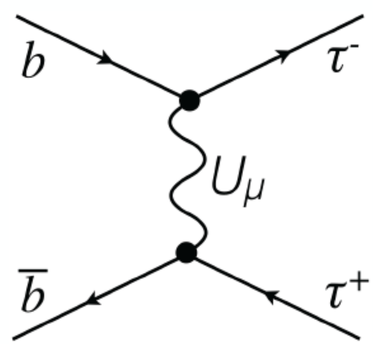
- *Are these models compatible with high-energy (direct) searches?* Yes, but...

  In both cases no real problem provided we are in a regime of strong-coupling [large couplings → heavy masses & large widths].

  E.g.: the heavy vectors could have a mass ~ 1-2 TeV
  (*not easily detectable due to small coupling to light quarks & large width*)

In both cases there is a model-independent expectation of sizable (broad) excess in pp → ττ & pp → bb, tt that should be accessible in Run-II

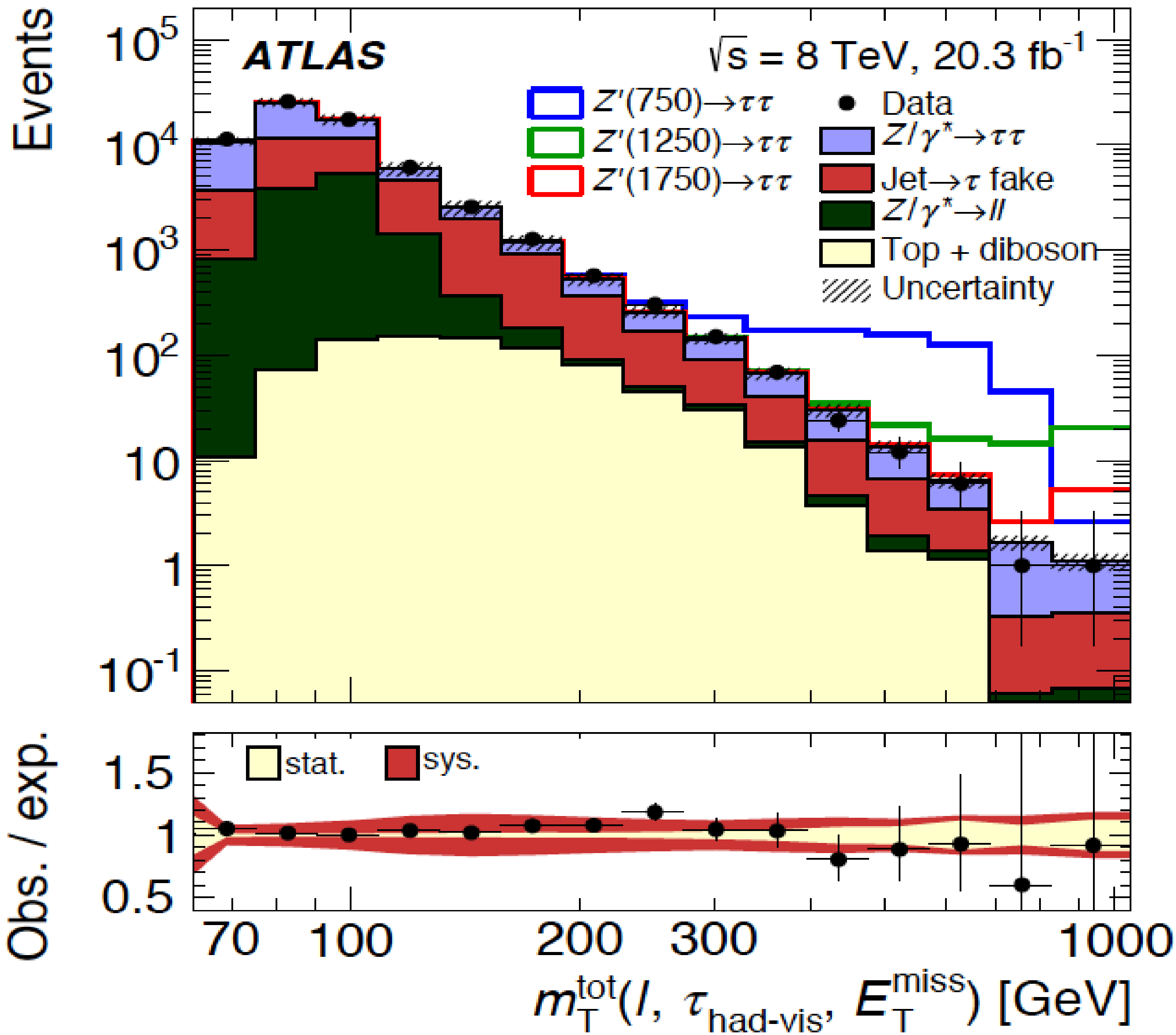




→

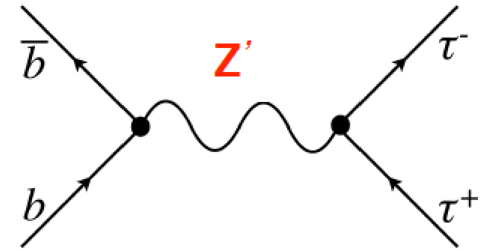
- *Already some tension with ATLAS & CMS.*
- *Deviations from SM around the corner...*

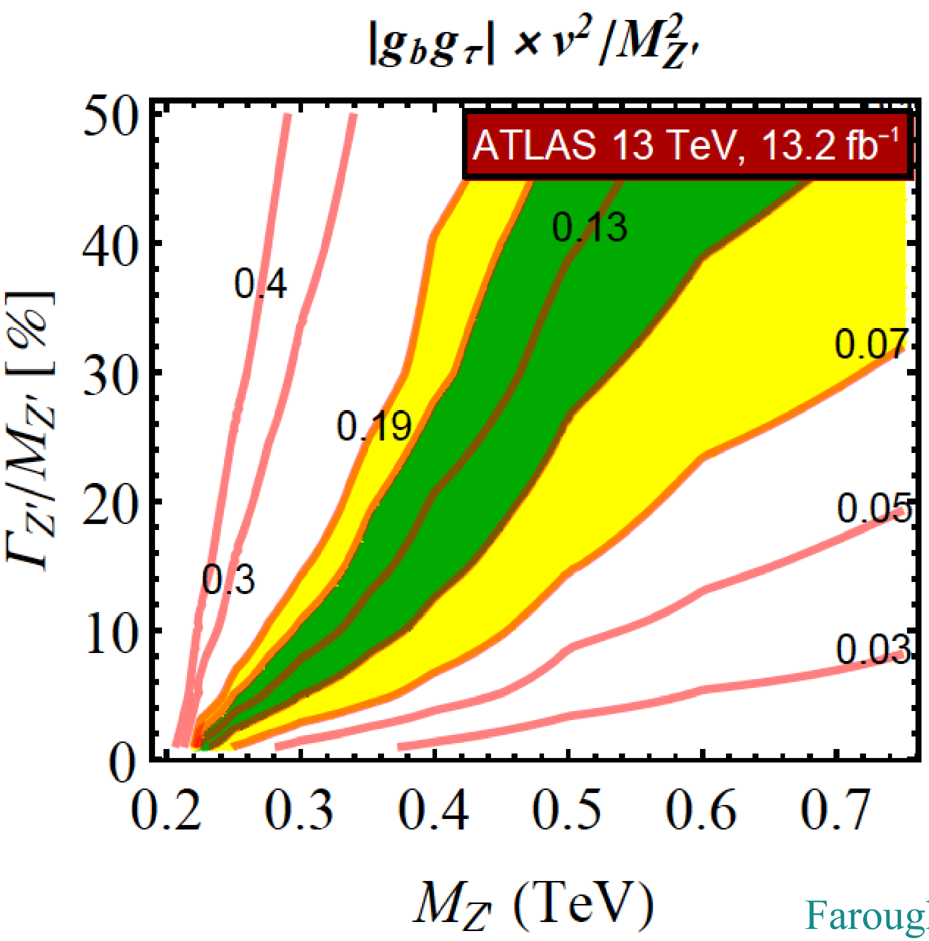
UV completions and high-energy bounds

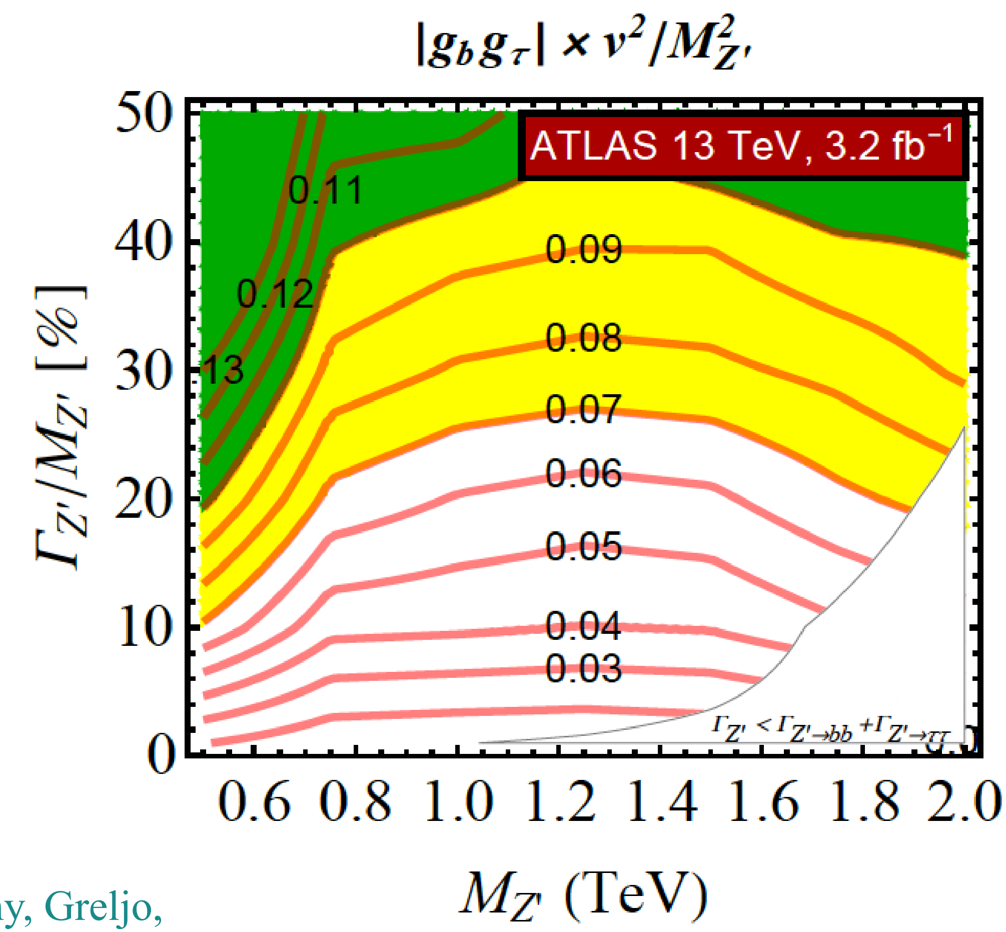


▸ UV completions and high-energy bounds

Recast of recent ATLAS searches of $Z' \to \tau\tau$



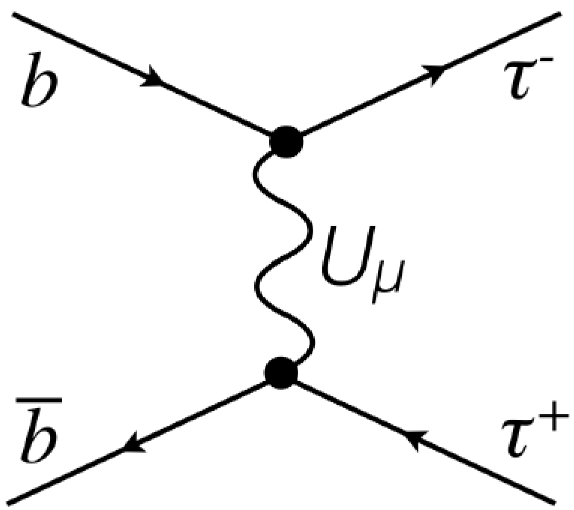


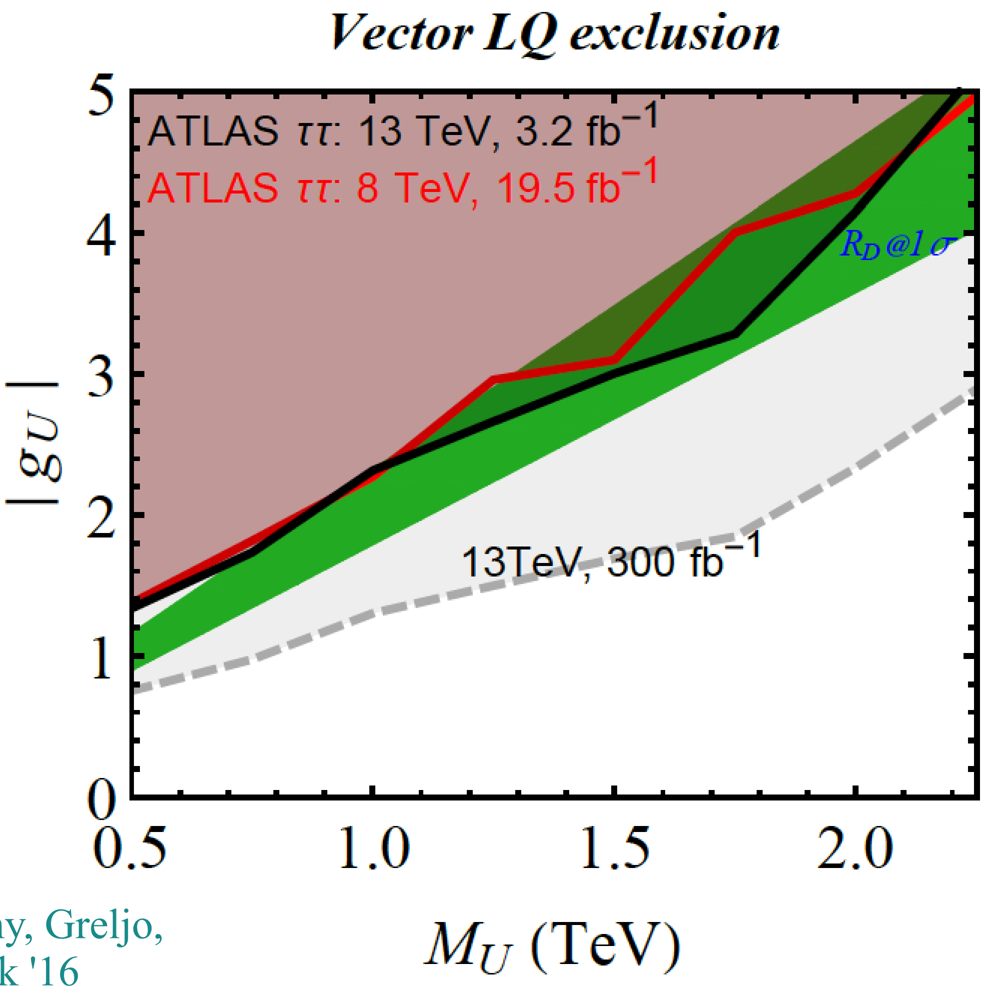


Faroughy, Greljo, Kamenik '16

UV completions and high-energy bounds

Recast of recent ATLAS searches of $Z' \to \tau\tau$ interpreted in the vector LQ model





Faroughy, Greljo, Kamenik '16

UV completions and high-energy bounds

In both cases (heavy vector triplets & vector LQ) we should address two basic questions:

- *Are these models compatible with high-energy (direct) searches?* Yes, but...
- *Can we find meaningful UV completions?* Maybe...

An attractive possibility is to consider these heavy (spin-1) mediators as composite state of some new strong dynamics [Buttazo, Greljo, GI, Marzocca, '16]

UV completions and high-energy bounds

SM

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

$f_i^{\rm SM,chiral}$

New sector

$SU(N_{TC})_{TC}$

$\Psi_{L,R}$ [different SM charges]

$SU(N_F)_L\times SU(N_F)_R\times U(1)_V$

↓

$SU(N_F)_{L+R}\times U(1)_V$

Global "flavor symmetry"
Spontaneously broken as in QCD
at a scale $\Lambda_{TC}\sim$ TeV

The basic construction is based on the idea of "*Vector-like confinement*"

- Very similar to the old idea of technicolor
- Key difference is that the SSB of the new sector preserves the SM gauge symmetry, that is broken in a 2nd step by an appropriate Higgs field

UV completions and high-energy bounds

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Lowest-lying spectrum of resonances:

pseudo-GB
π, η, ...

Heavy vectors
ρ, ω, φ, …

(+ possibly LQ)

UV completions and high-energy bounds

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SM gauge

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→ Higgs

(SM-like *partially-composite* H)

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ρ, ω, φ, …

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► *UV completions and high-energy bounds*

SM

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

$f_i^{SM,chiral}$

SM gauge

$f_3^{SM} - B(\Psi_{L,R})$

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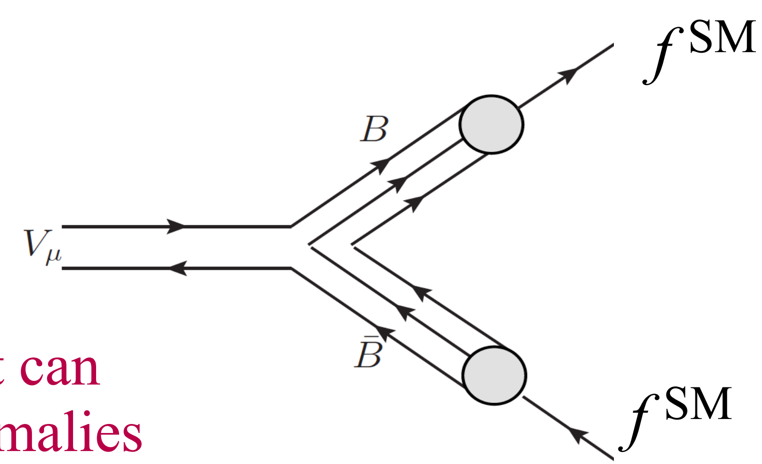
Heavy vectors

ρ, ω, φ, …

4f operators that can "solve" flavor anomalies



Conclusions

- Very interesting hints of LF non Universality in recent semi-leptonic B-physics data

- The overall picture is still far form being clear, but the patter of anomalies is apparently coherent → more data can help to clarify the situation

- Main messages in view of future data:
  - (re)analyze B physics data without assuming LFU
  - conceive more low-energy tests of LFU (especially in B decays)
  - the search for LFV in charged leptons is extremely well motivated
  - the bounds on NP coupled mainly to 3^{rd} generation are still relatively weak
  - the interplay of low- and high-energy searches is essential