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Theory Group of the Laboratory for Particle Physics

New Physics in the Flavour Observables

La Thuile, 08.03.2017

Outline

- Introduction:

  New Physics and Flavour anomalies

  - $b \to s\mu\mu$
  - $b \to c\tau\nu$
  - $h \to \tau\mu$
  - a_μ
- NP explanations for the anomalies
- Some Z' models
- Conclusions

Finding NP in Flavour Observables

- At colliders one produces many (up to 10^{14}) heavy quarks or leptons and measures their decays into light flavours

Experiment

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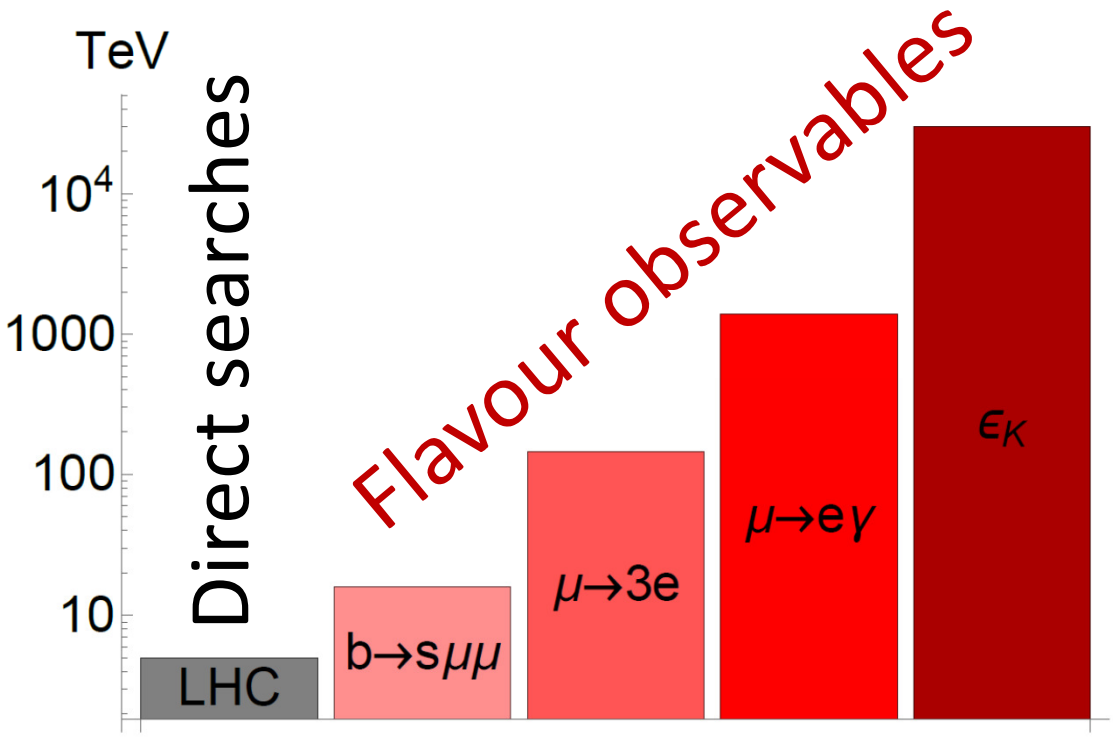
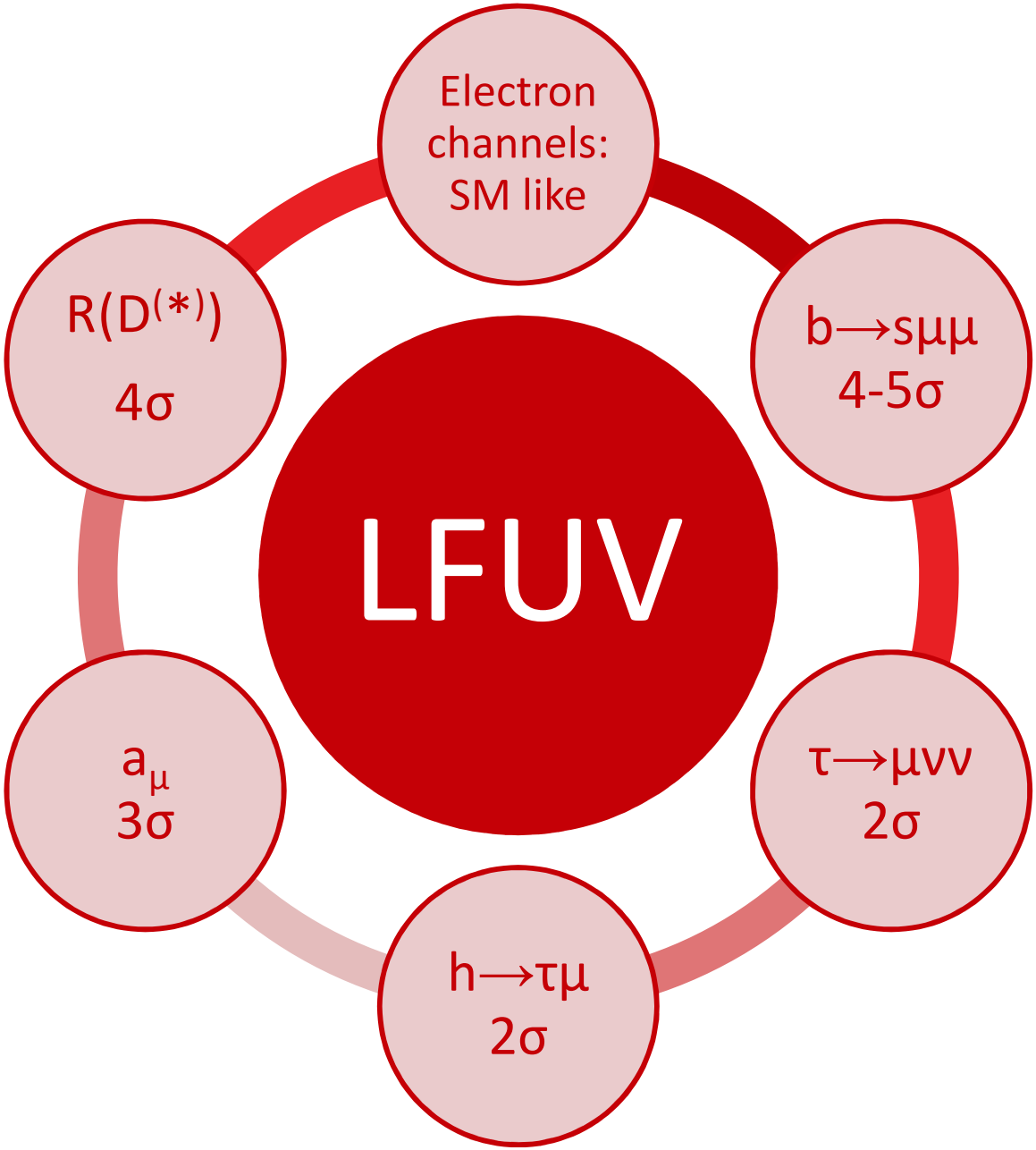
Standard Model

New Physics



Flavour observables are sensitive to higher energy scales than collider searches

Hints for LFUV



Lepton Flavour Universality Violation (LFUV)

a_μ explanations

- MSSM e.g. D. Stockinger, hep-ph/0609168
  - tan(ß) enhanced slepton loops
- Scalars e.g. A. Broggio et at. arXiv:1409.3199
  A.C. et al. arXiv:1507.07567
  - Light Higgses with enhanced muon couplings
- Z' e.g. W. Altmannshofer, C. Chen, P.S.B. Dev, A. Soni, arXiv:1607.06832
  - Very light with τμ couplings (m_τ enhancement)
- Leptoquarks e.g. A. Djouadi, T. Kohler, M. Spira, J. Tutas, Z.Phys. C46 (1990)
  - m_t enhaned effects E. Leskow, A.C., G. D'Ambrosio, D. Müller arXiv:1612.06858

Chiral enhancement or very light particles

h→τμ explanation

- Can be explained in the effective field theory approach by

$$Q_{e\phi}^{fi} = \ell_f \phi e_i \phi^\dagger \phi$$

R. Harnik, J. Kopp, and J. Zupan, 1209.1397.
G. Blankenburg, J. Ellis, and G. Isidori, 1202.5704.
S. Davidson and P. Verdier, 1211.1248.

- No dominant contribution from vector-like fermions

A. Falkowski, D. M. Straub, and A. Vicente, 1312.5329

Extended Higgs sector

J. Heeck et al. 1412.3671
A. Greljo et al. arXiv:1502.07784
A. C. et al. arXiv:1501.00993
.....
.....

R(D) & R(D*) explanations

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- Charged Higgs
  - Problems with angular distributions
- W'
  - UV complete model difficult
  - Strong constraints from direct LHC searches
- Leptoquark
  - Strong signals in $qq \to \tau\tau$ searches

See talk of Admir on Friday

Explanation difficult

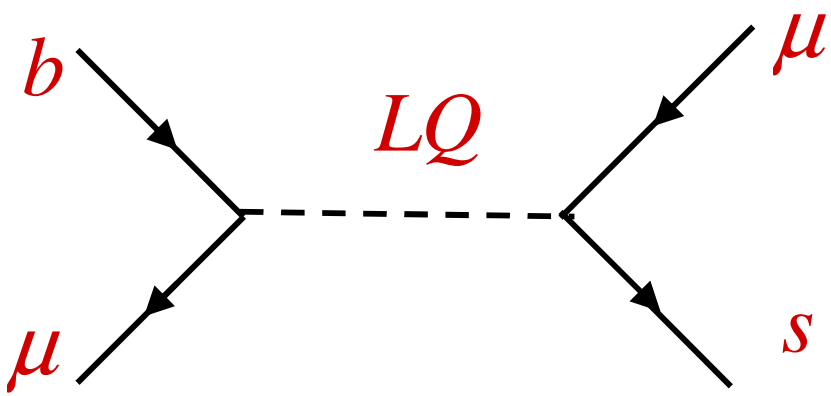
b→sμμ explanations

- Z'

U. Haisch et al. 1308.1959, Buras et al. 1311.6729
W. Altmannshofer et al. 1403.1269, AC. et al. 1501.00993, ...

- Leptoquarks

Gudrun Hiller, Martin Schmaltz.
arXiv:1411.4773
B. Gripaios, M. Nardecchia, S.A. Renner.
arXiv:1412.1791
D. Bečirević, N. Košnik, O. Sumensari,
R. Zukanovich Funchal.
arXiv:1608.07583
…

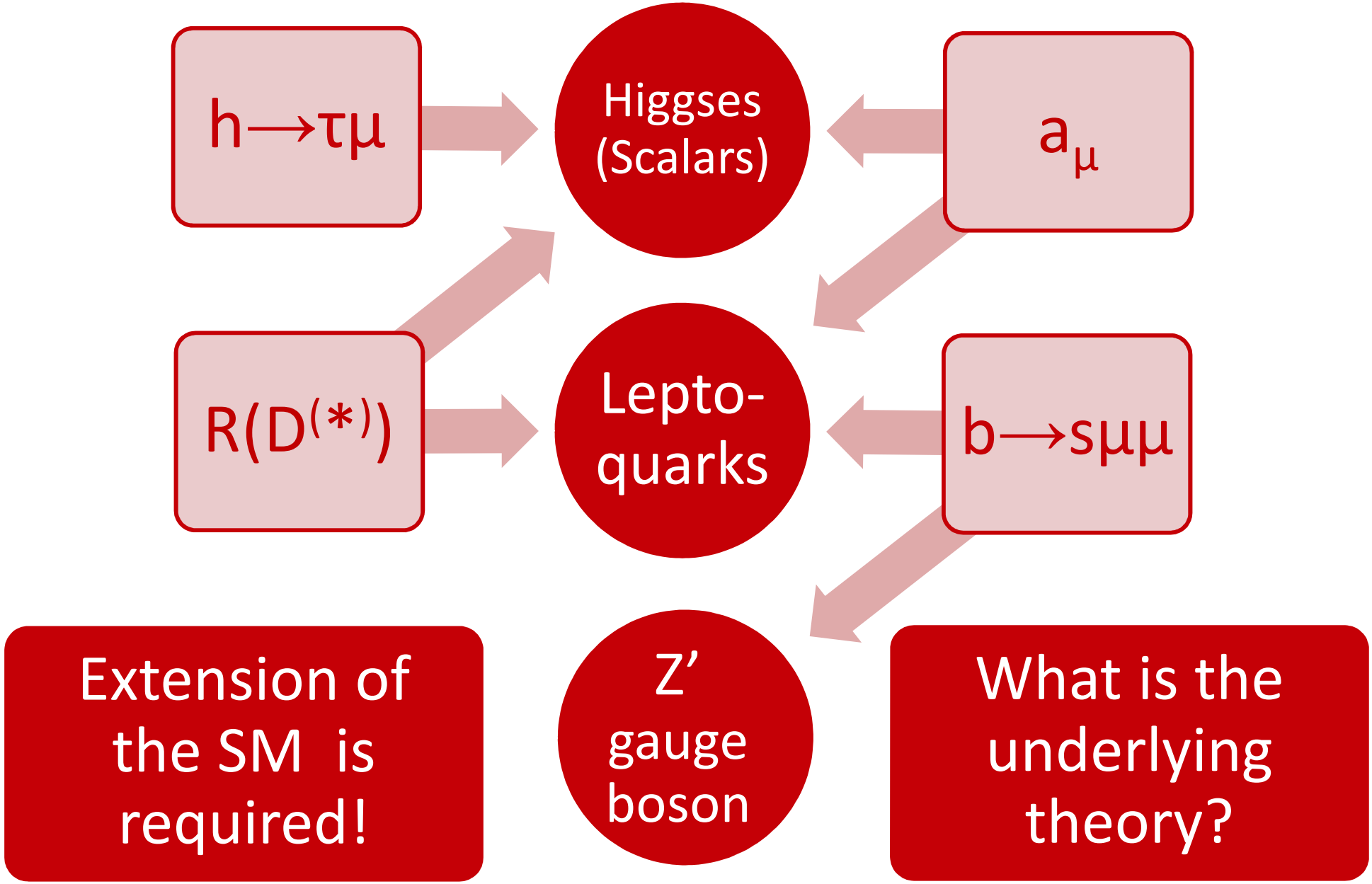


- Loop effects

B. Gripaios, M. Nardecchia, S. Renner, arXiv:1509.05020

Even high scale NP explanations possible

Implications for New Particles



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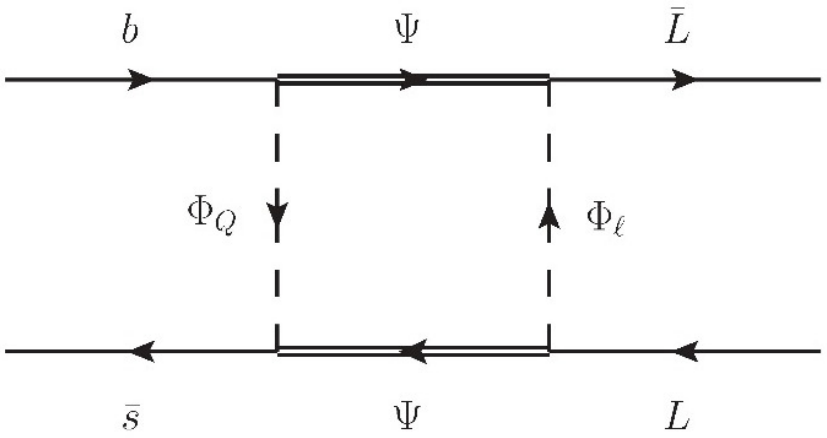
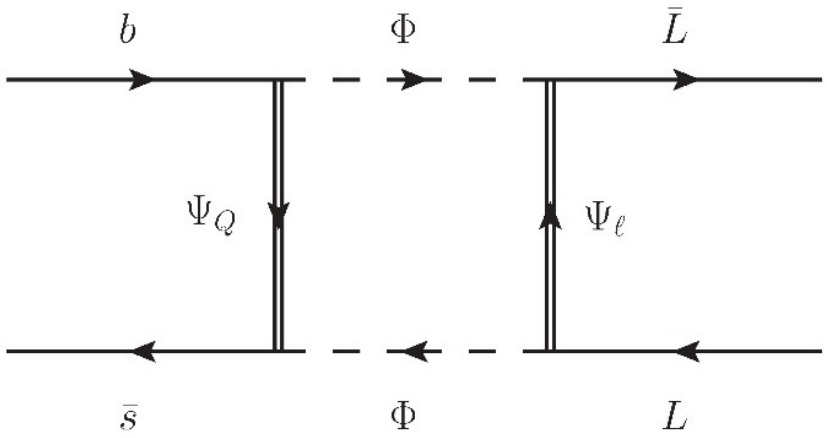
Heavy new sclars and fermions In $b \to s\mu\mu$

New Scalars and Fermions in b→sμμ





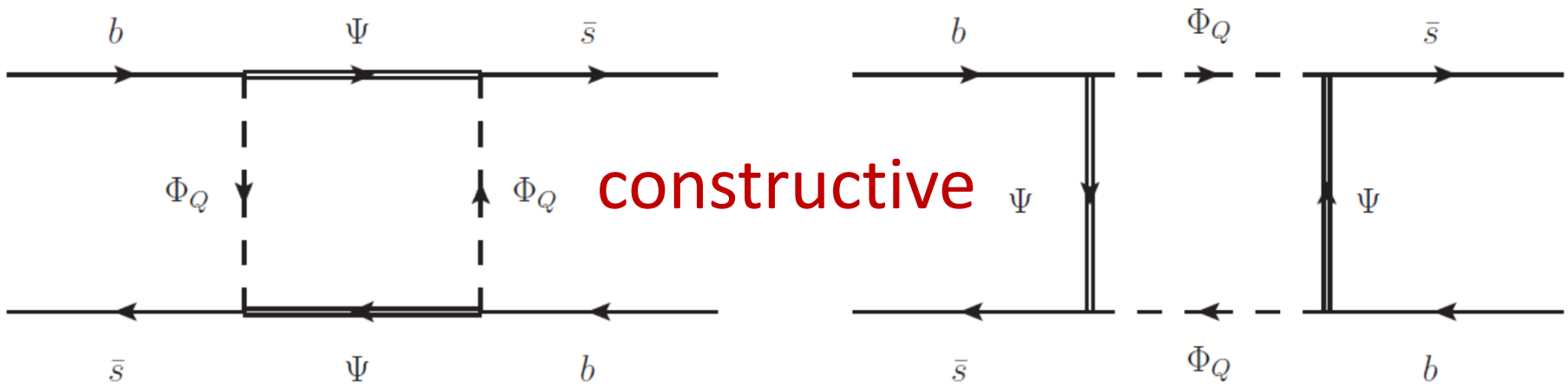
- Possible representations

$SU(2)$	Φ_Q, Ψ_Q	Φ_ℓ, Ψ_ℓ	Ψ, Φ
I	2	2	1
II	1	1	2
III	3	3	2
IV	2	2	3
V	3	1	2
VI	1	3	2

$SU(3)$	Φ_Q, Ψ_Q	Φ_ℓ, Ψ_ℓ	Ψ, Φ
A	3	1	1
B	1	$\bar{3}$	3
C	3	8	8
D	8	$\bar{3}$	3

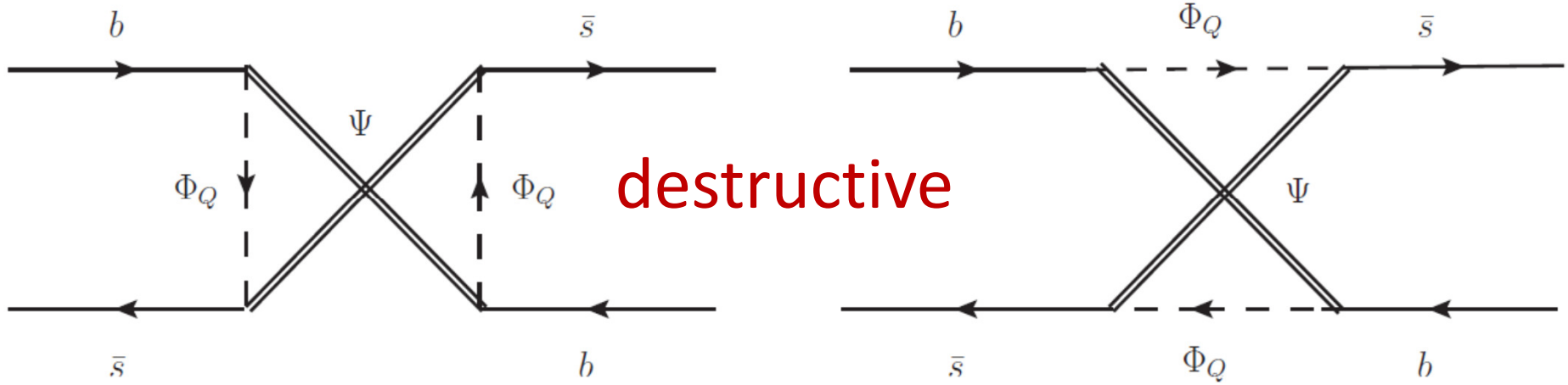
2x6x4 possibilities

Constraints from B_s mixing



Lattice results prefers destructive interference MILC, 1602.03560

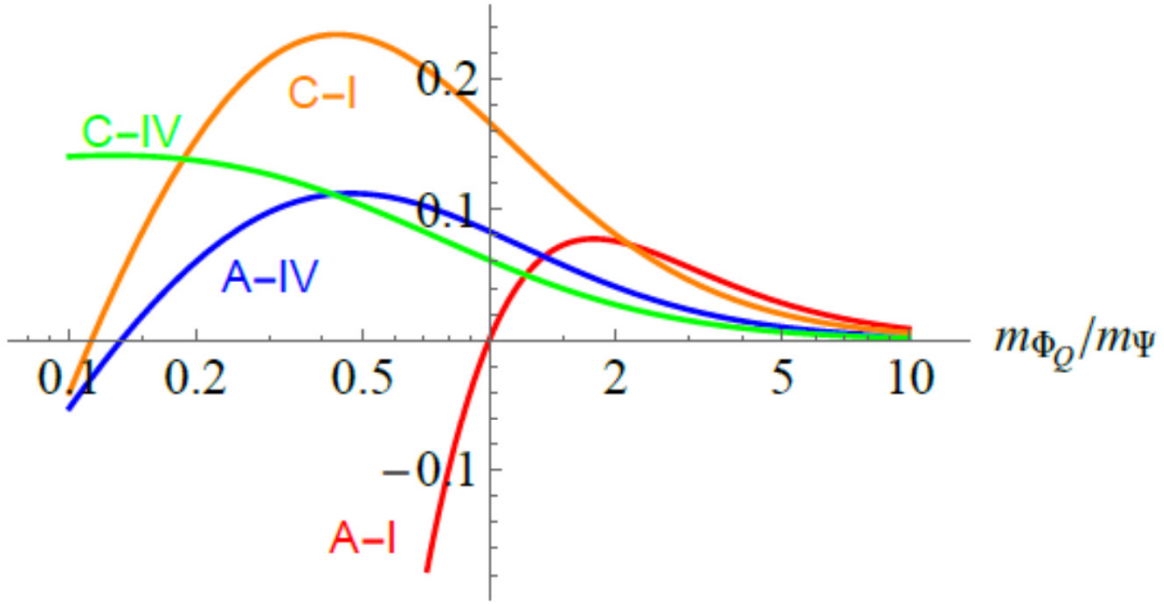
- Majorana representations



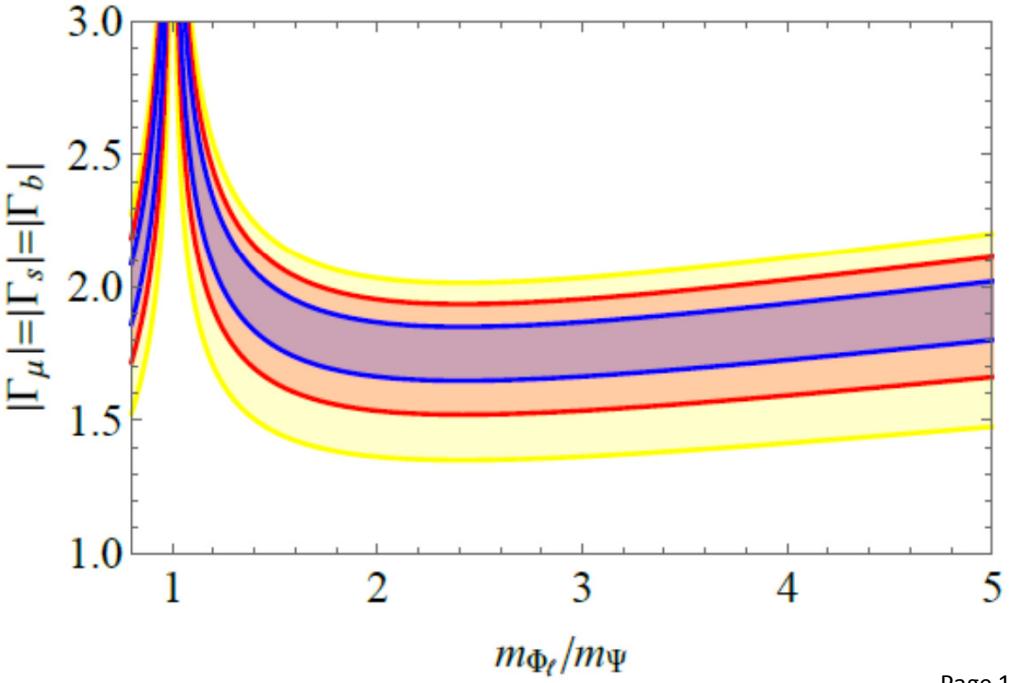
Destructive interference with Majorana fermions

$b \to s\mu\mu$ and B_s mixing

Relative effect in B_s mixing



$b \to s\mu\mu$ 3σ 1σ 2σ



Explanation with O(1) couplings

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Z' models for $b \to s\mu\mu$

Z' solution for b→sμμ with VLQ

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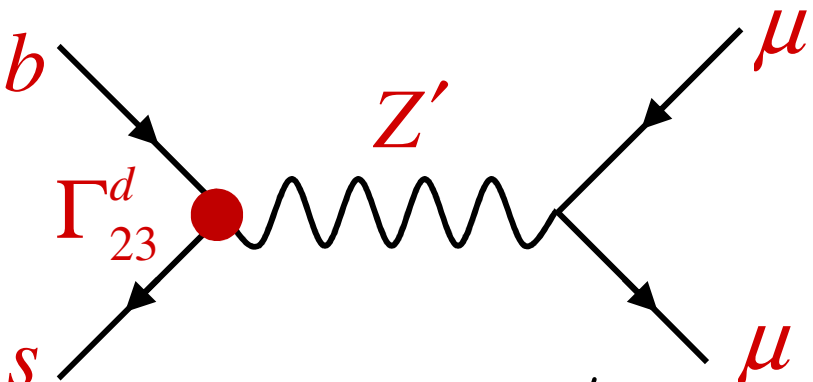
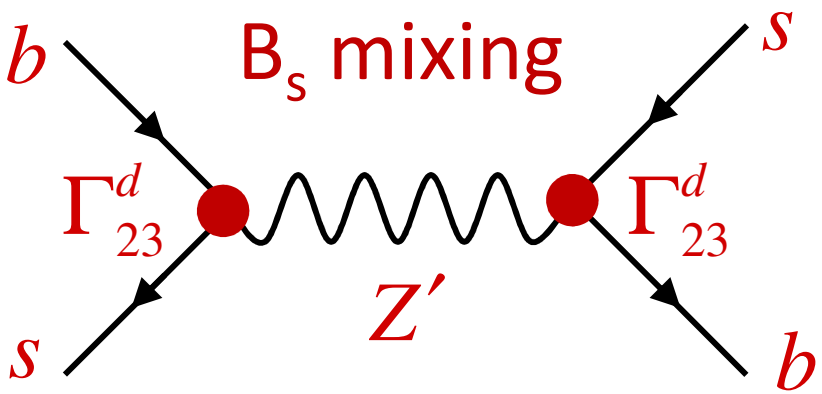
b→sμμ

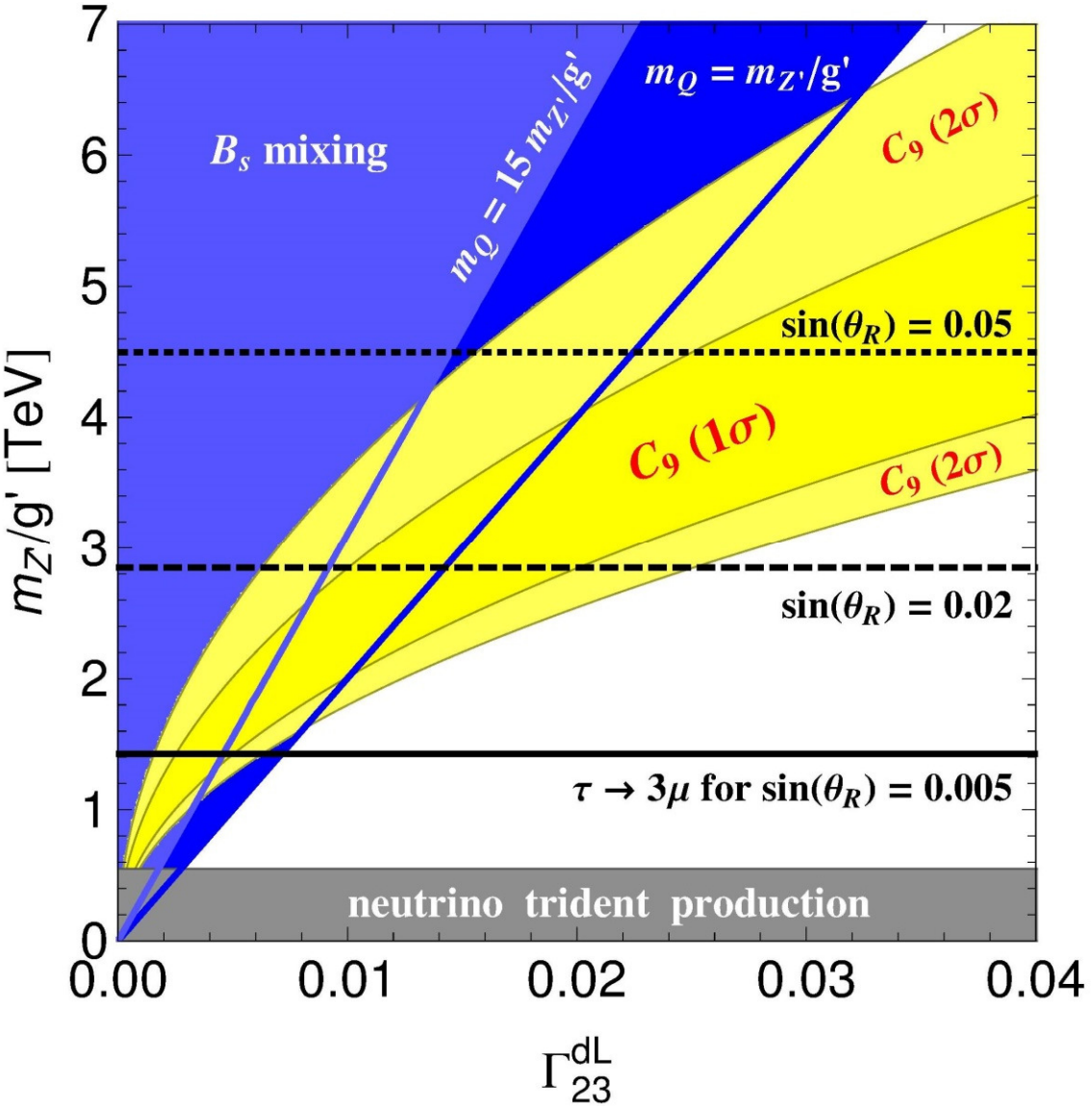


$$C_9^{\mu\mu} \propto \Gamma_{23}^{dL}\, g'^2 / m_{Z'}^2$$

B$_s$ mixing



$$\frac{\Delta M_{12}}{M_{12}^{\mathrm{SM}}} \propto \left(\Gamma_{23}^{dL}\right)^2 g'^2 / m_{Z'}^2$$



allowed regions

Solution with horizontal U(1) charges

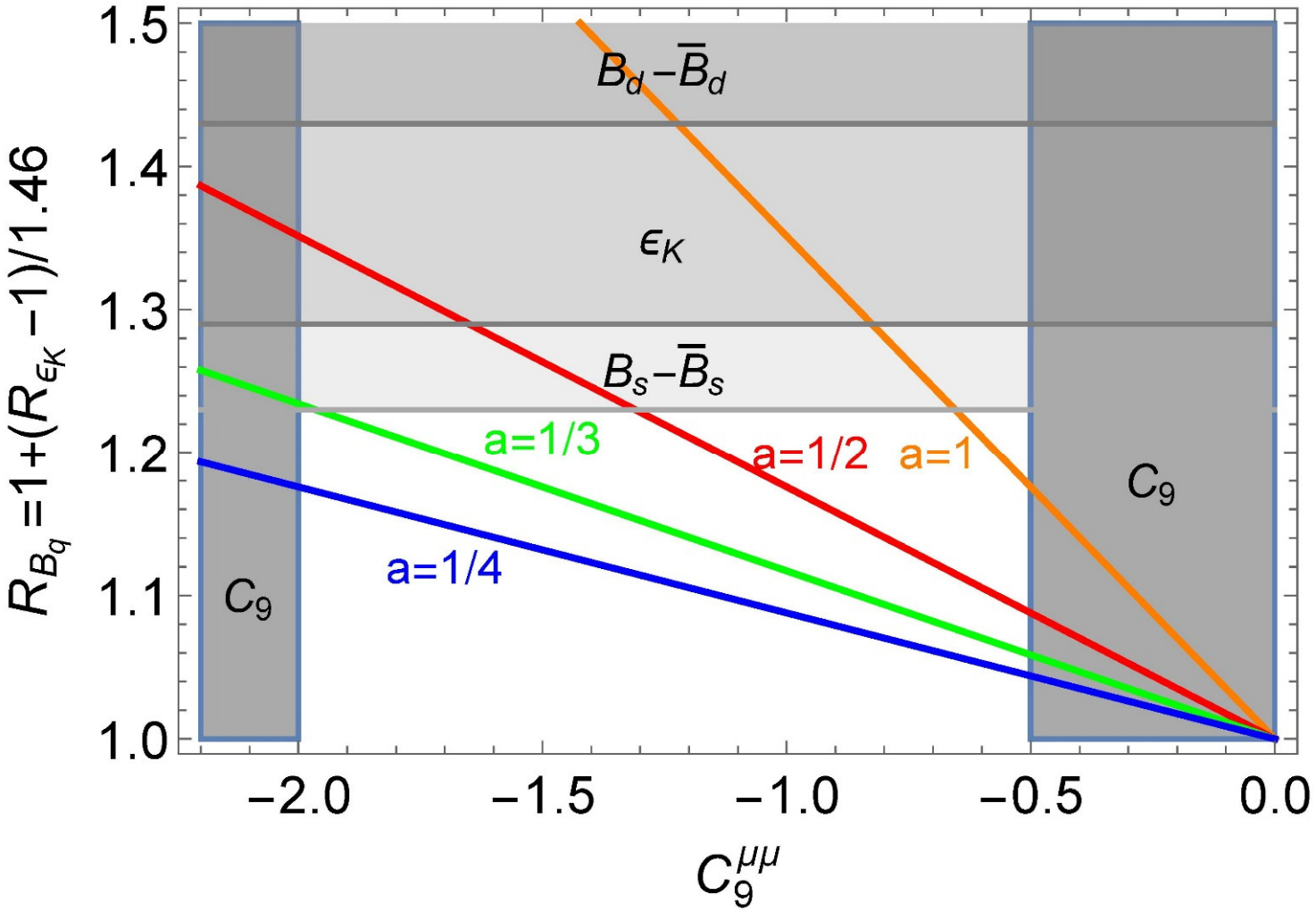
- Avoid vector-like quarks by assigning charges to baryons as well
  - Same mechanism in the quark and lepton sector
- L_μ-L_τ in lepton sector
  - Good symmetry for the PMNS matrix
  - Effect in $C_9^{\mu\mu}$ but not C_9^{ee}
- First two quark generations must have the same charges because the large Cabibbo angle would lead to huge effect in Kaon mixing
- Anomaly freedom

Q(L)=(0,1,-1) Q(B)=(a,a,-2a)

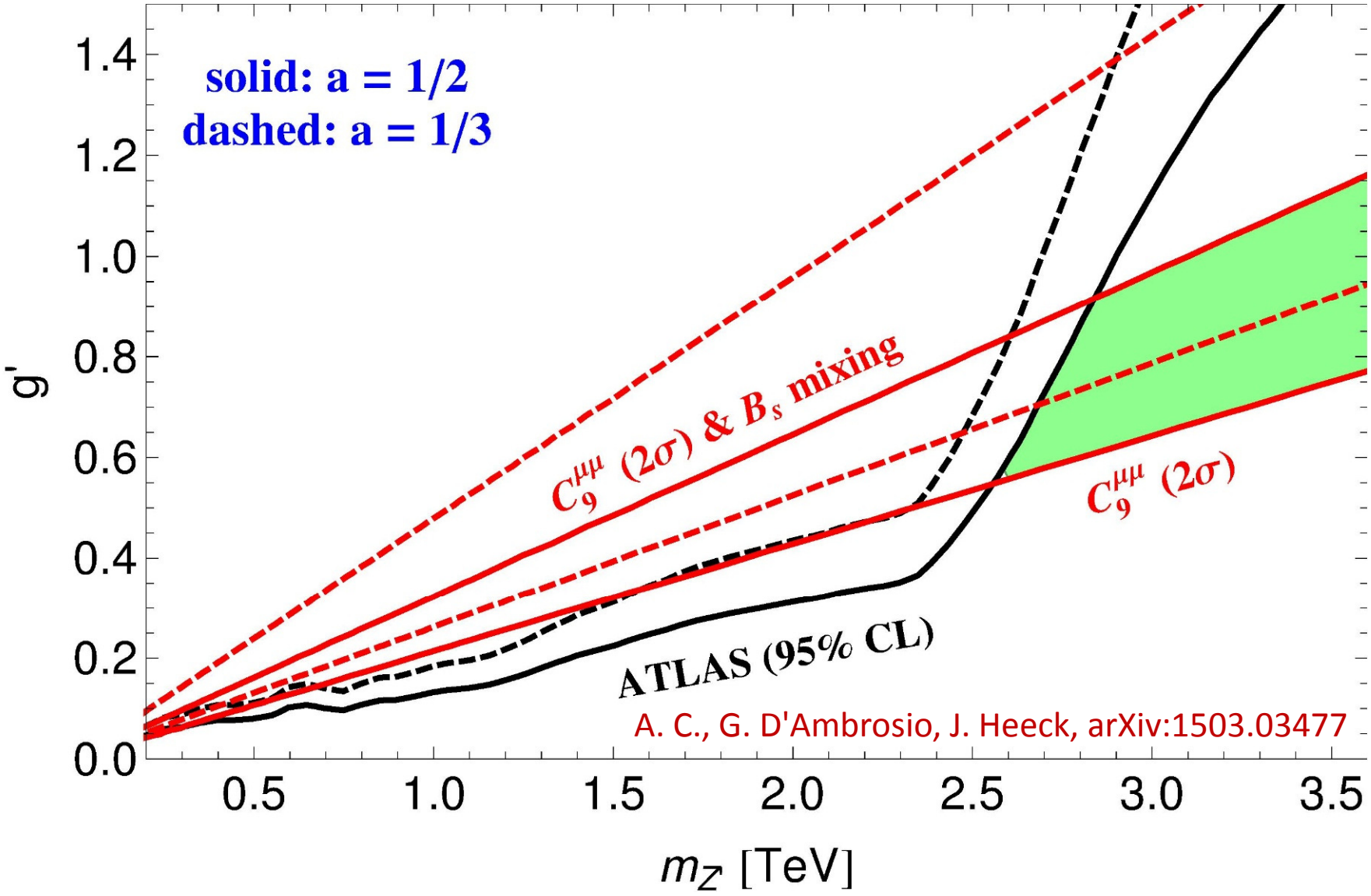
ΔF=2: Z' contribution

$$R_{B_q} = \frac{\Delta m_{B_q}}{\Delta m_{B_q}^{SM}}$$

$$R_{\varepsilon_K} = \frac{\varepsilon_K}{\varepsilon_K^{SM}}$$



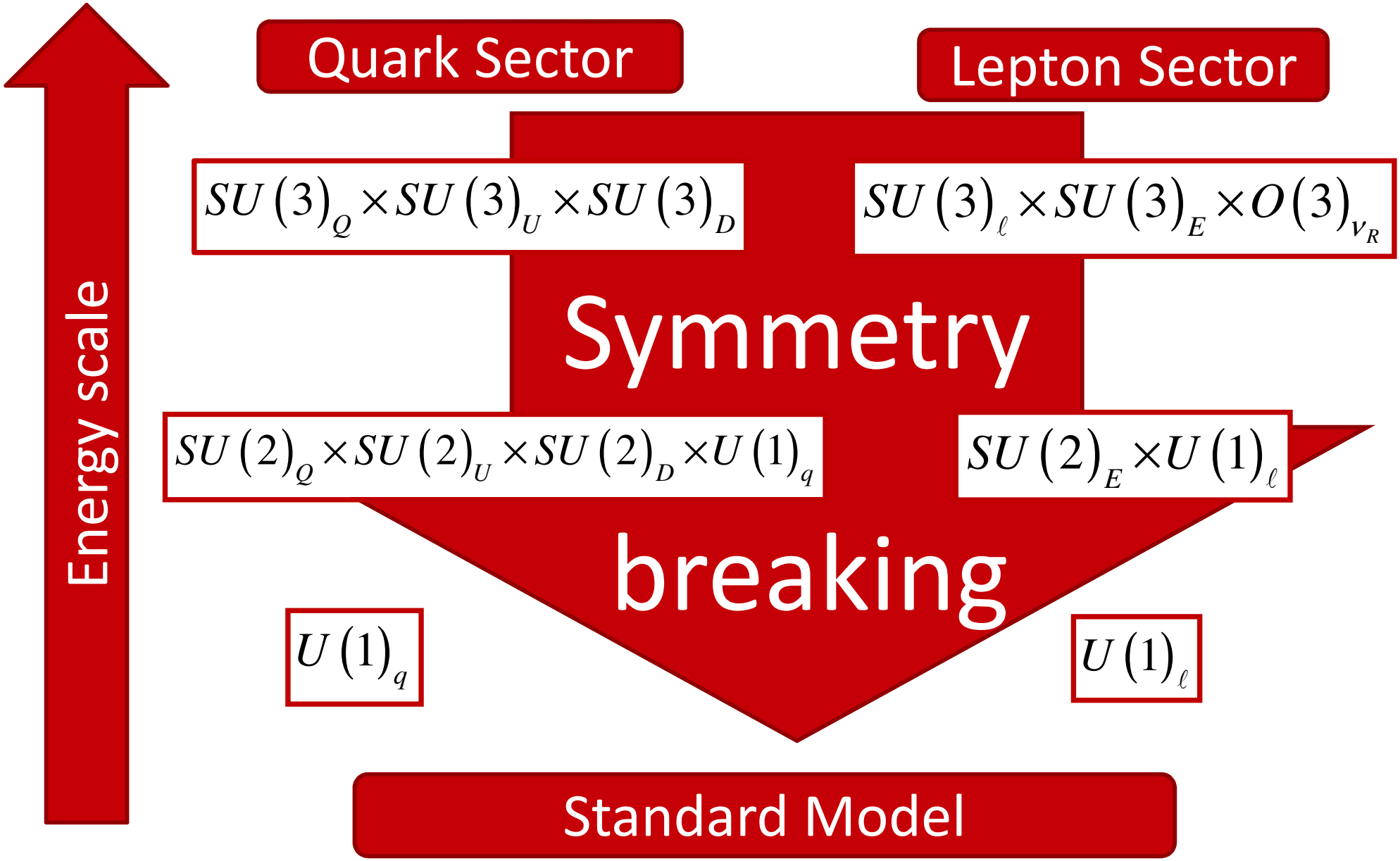
Horizontal charges: LHC limits



ATLAS $C_9^{\mu\mu}$ & $B_s - \overline{B}_s$ $a = 1/2$ allowed

Dynamical explanation of the charges

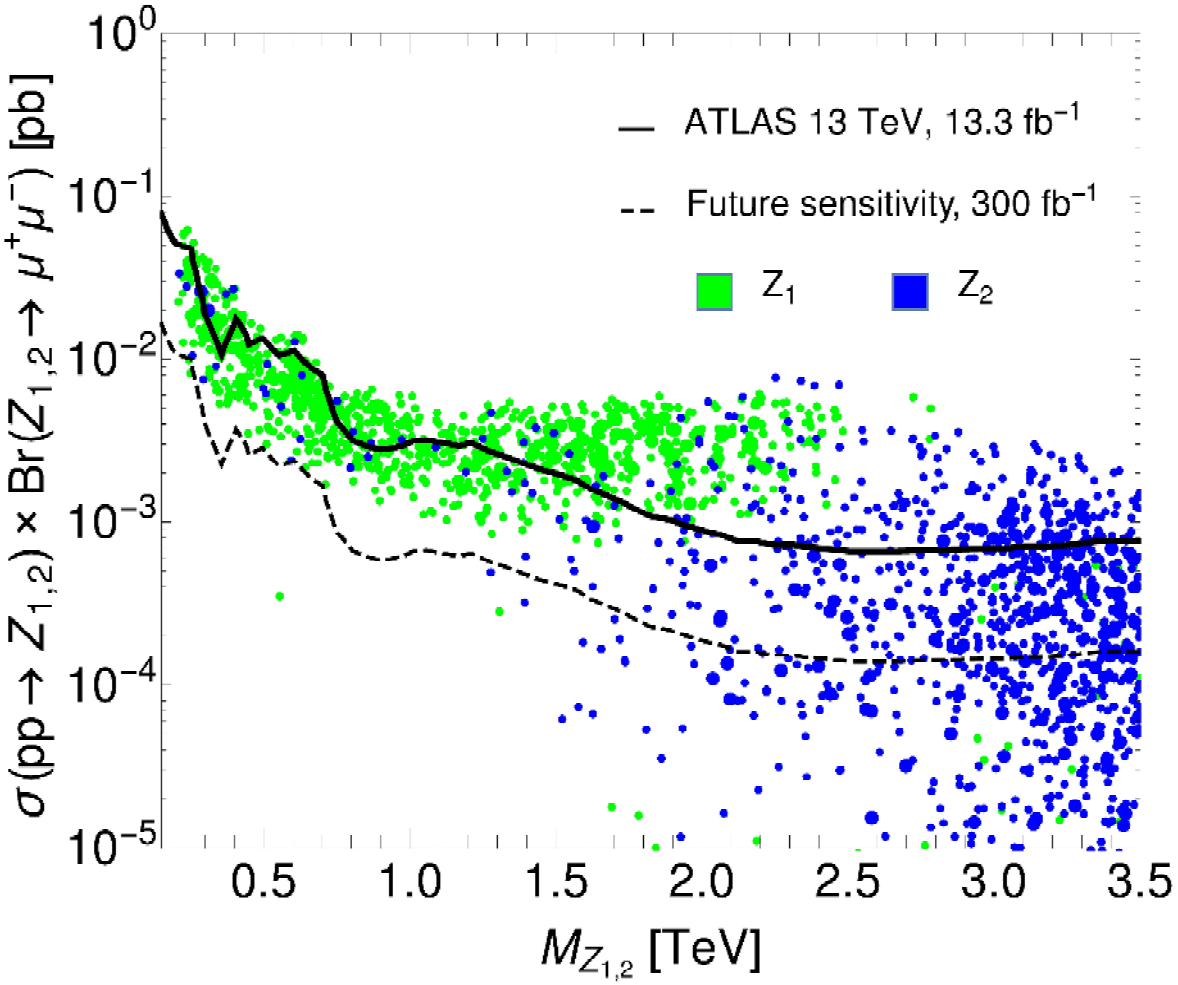
A.C., J. Fuentes-Martin, A. Greljo and G. Isidori arXiv:1611.02703



Solution with two Z's

- 2 Z' bosons
  - Z_1 coupling mainly to leptons
  - Z_2 coupling mainly to quarks

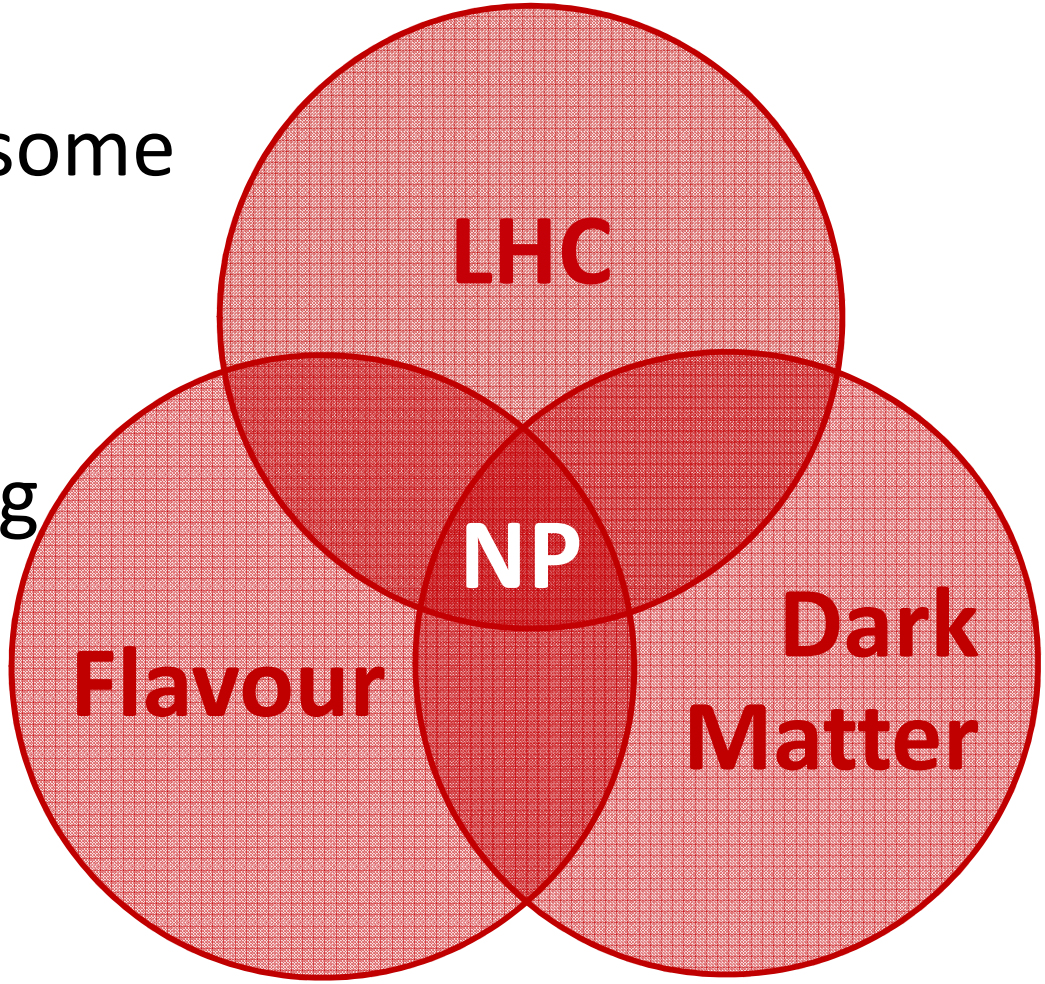
Low energy phenonenology unchanged



Different collider signatures

Conclusions

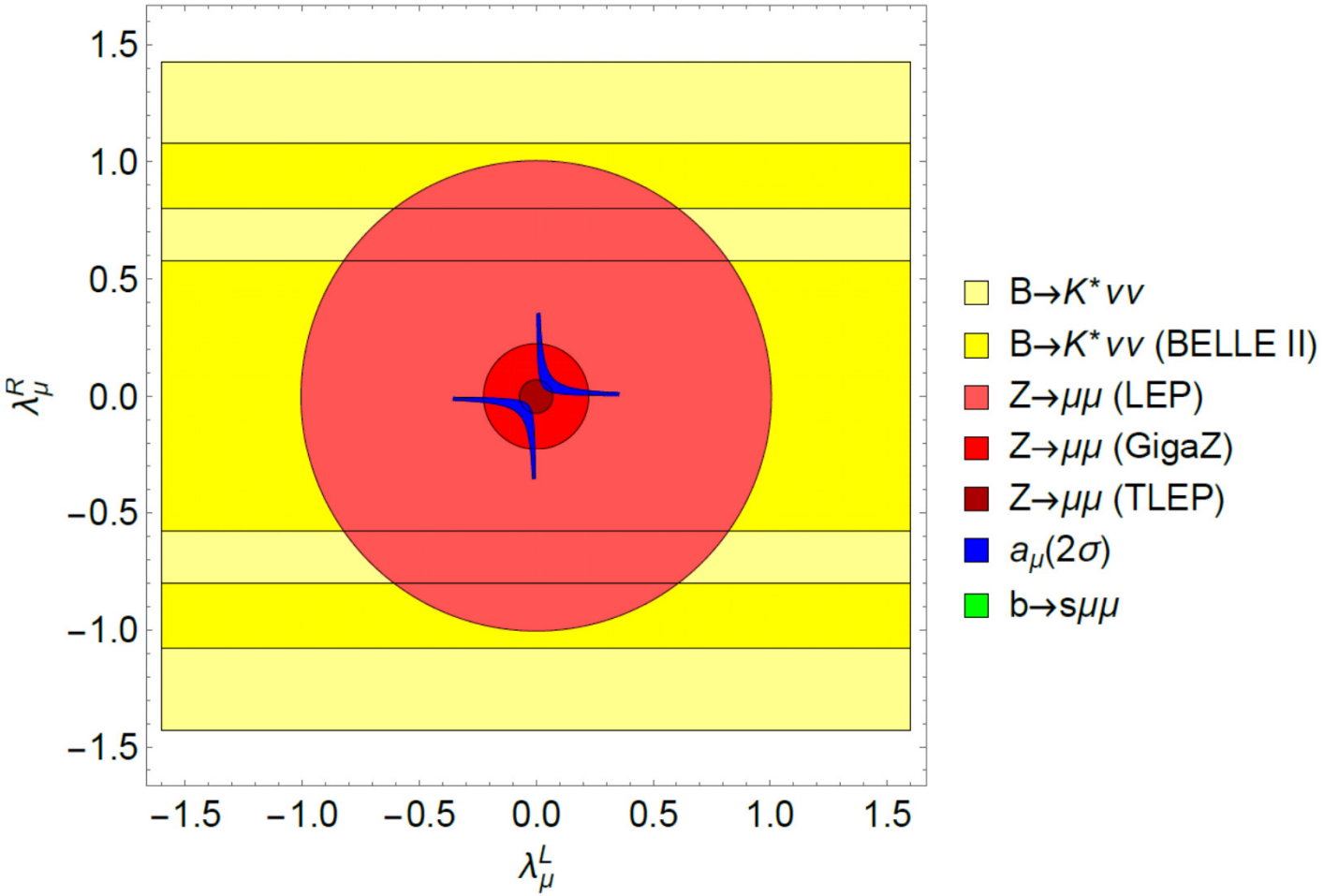
- Intriguing hints for Lepton Flavour Universality violating New Physics
- NP models can explain some of the anomalies simultaneously
- Confirming or disproving the anomalies makes a model selection
- Predictions for flavor and LHC observables



Exiting times in flavour physics are ahead of us!

Scalar Leptoquarks in a_μ

- Chirally enhanced effects via top-loops



$\lambda_\mu^{L,R}$

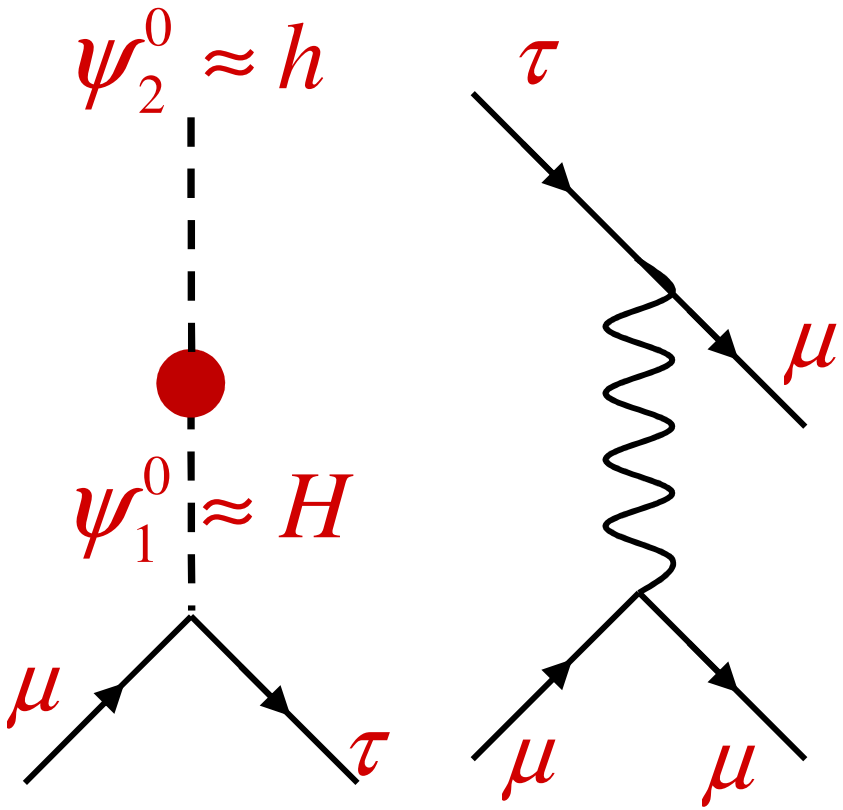
Left-, right-handed muons-top coupling

E. Leskow, A.C., G. D'Ambrosio, D. Müller
arXiv:1612.06858

Z→μμ at future colliders

h→μτ vs τ→μμμ

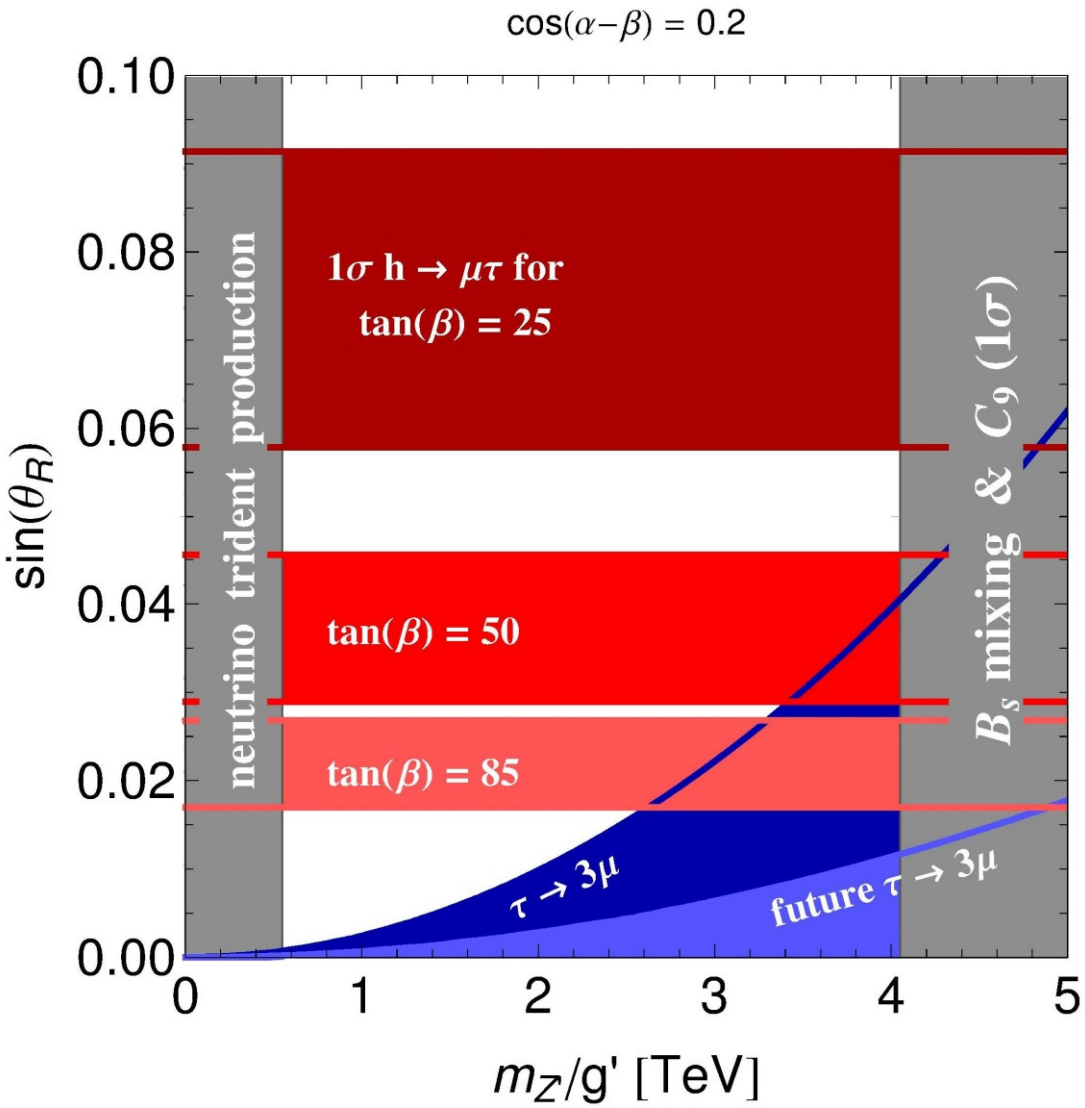
A.C., G. D'Ambrosio and J. Heeck arXiv:1501.00993



excluded

allowed by h → τμ

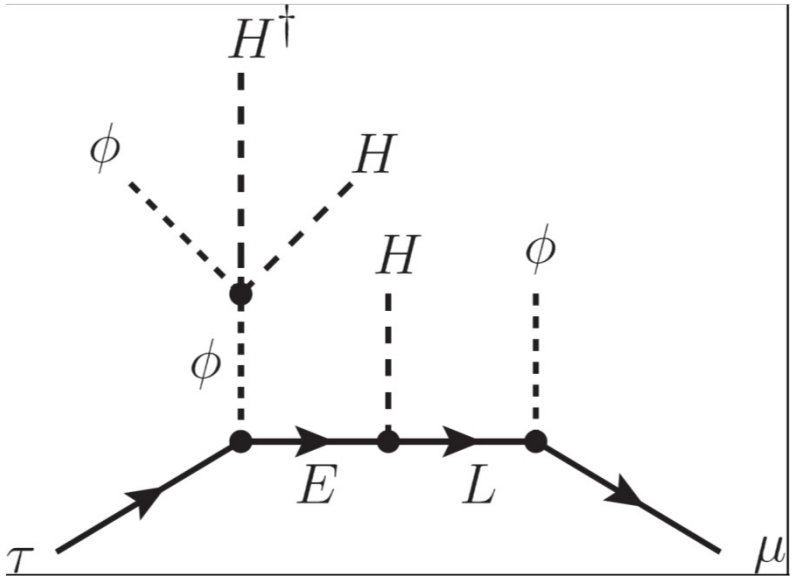
allowed by τ → μμμ

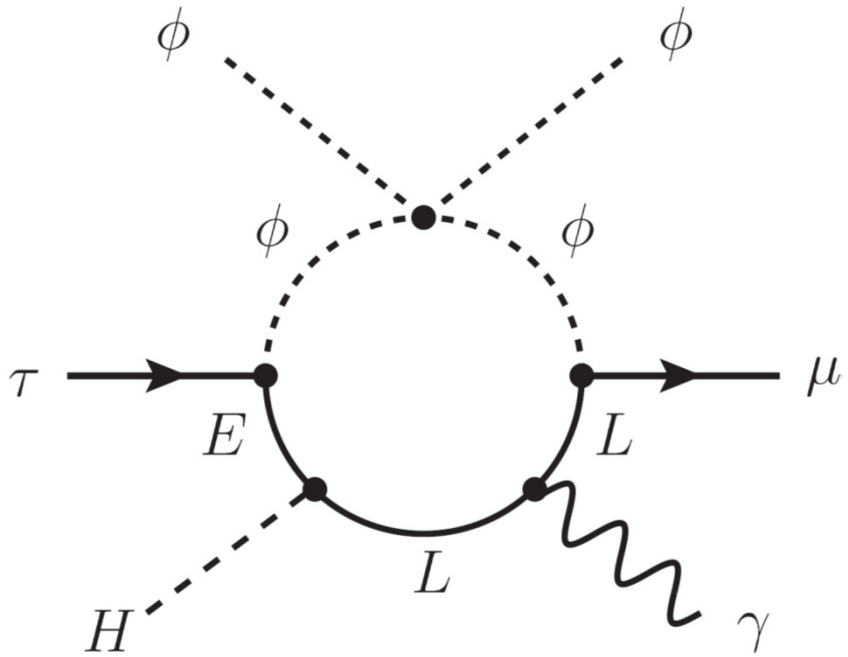


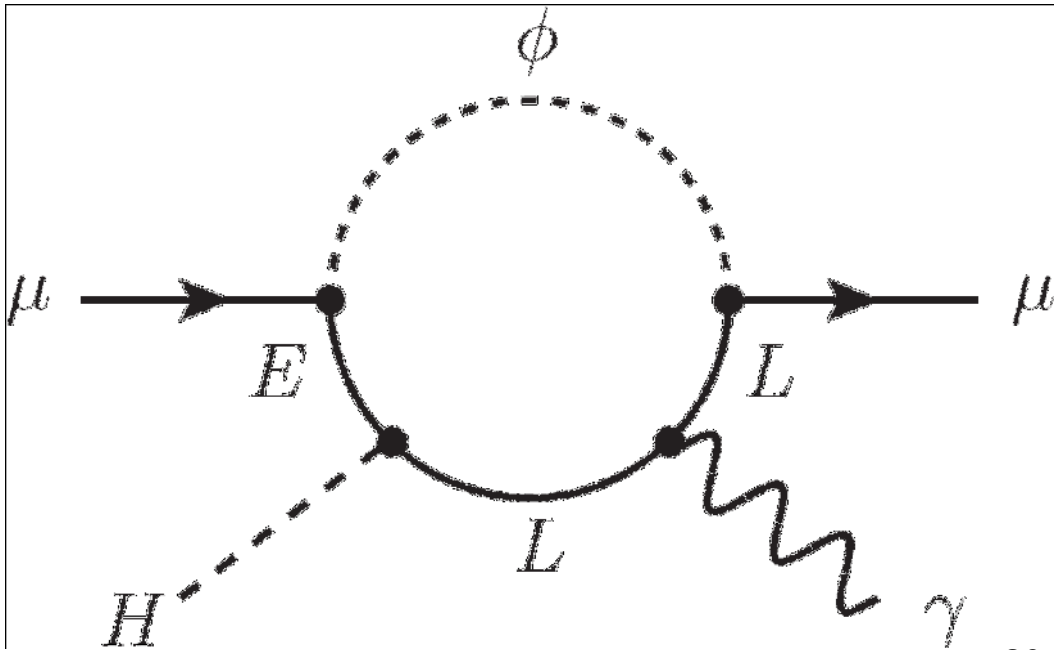
L_μ-L_τ model for a_μ and $h\to\tau\mu$

W. Altmannshofer, M. Carena, AC, 1604.08221

- L_μ-L_τ flavour symmetry
- Flavon mixes with the Higgs
- $\tau \to \mu\gamma$ is protected
- a_μ is not protected
- Effects in $h \to \mu\mu$

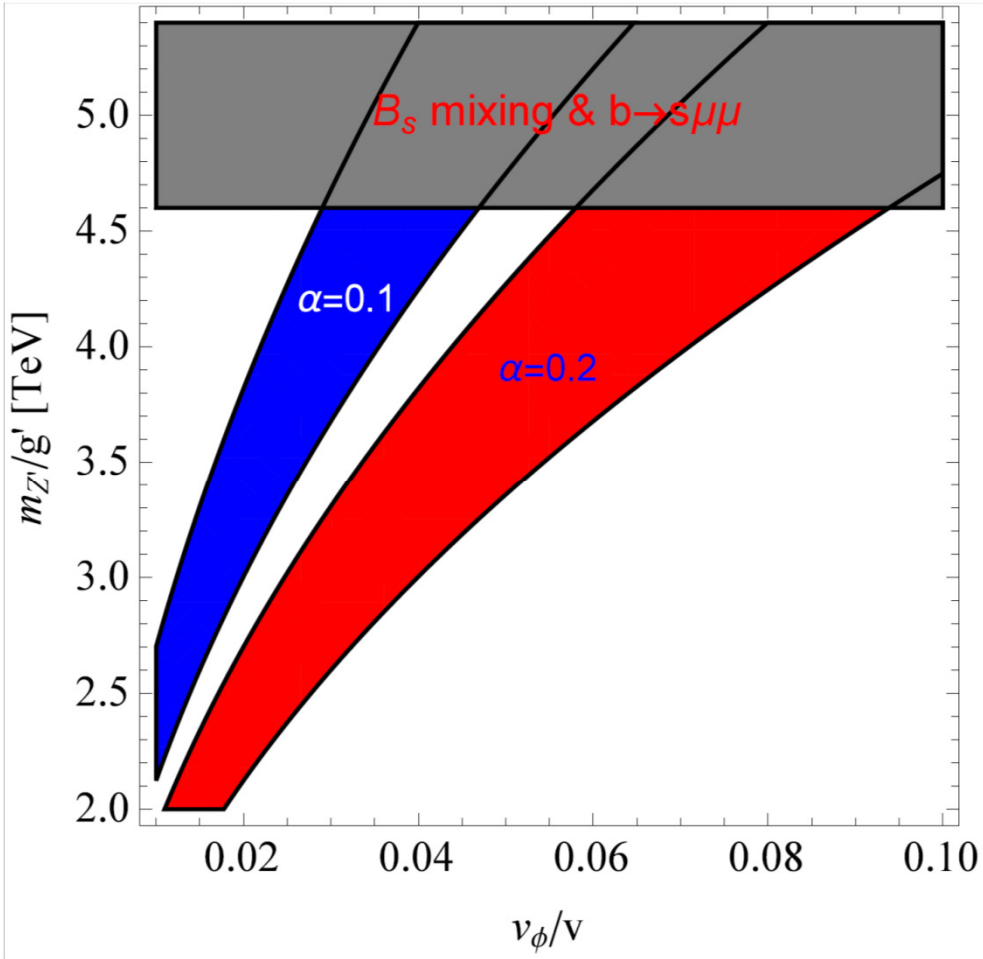




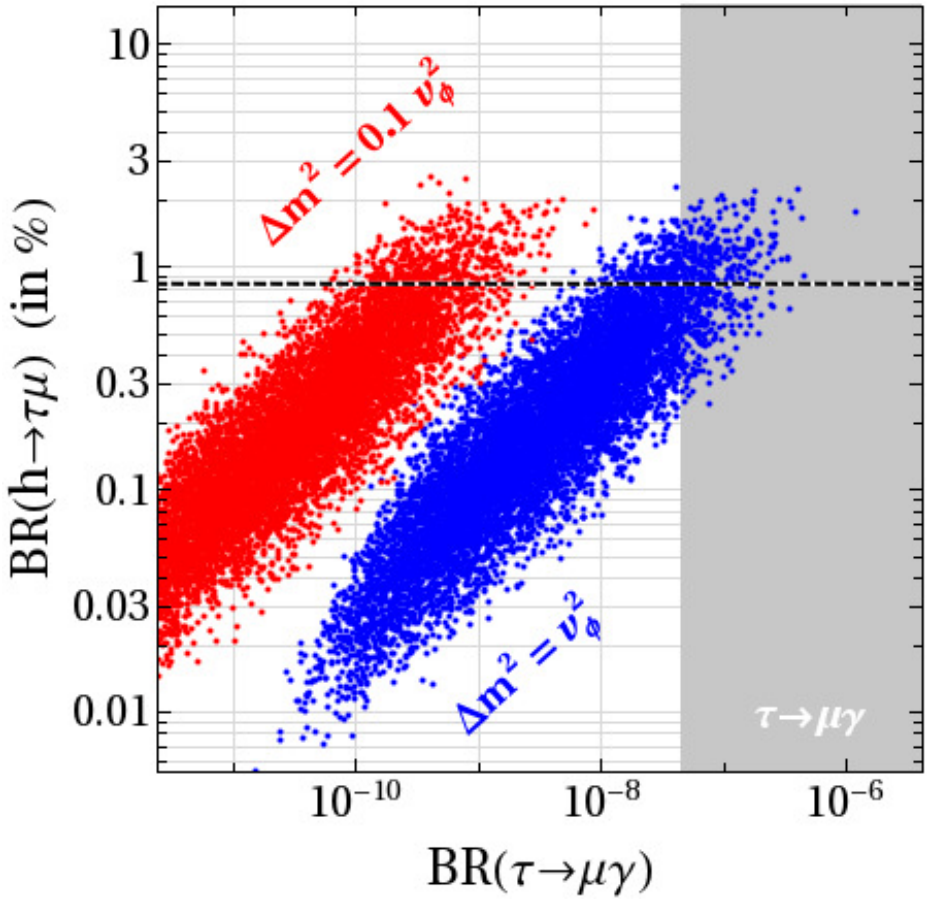


L_μ-L_τ model for a_μ and h→τμ

α : mixing among CP even Higgses



$$\Delta m^2 = m_a^2 - m_\phi^2$$



Can explain a_μ & h→μτ without violating τ→μγ bounds