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Theory Group of the Laboratory for Particle Physics

New Physics in the Flavour Sector

Warsaw, 26.05.2017

Outline

- Introduction:

  New Physics and Flavour anomalies

  – $b \to s\mu\mu$

  – $b \to c\tau\nu$

  – a_μ

  – Z’ explanations for $b \to s\mu\mu$

- Simultaneous explanations with LQs
- Conclusions

ε'/ ε see talk of Andrzej

Finding NP in Flavour Observables

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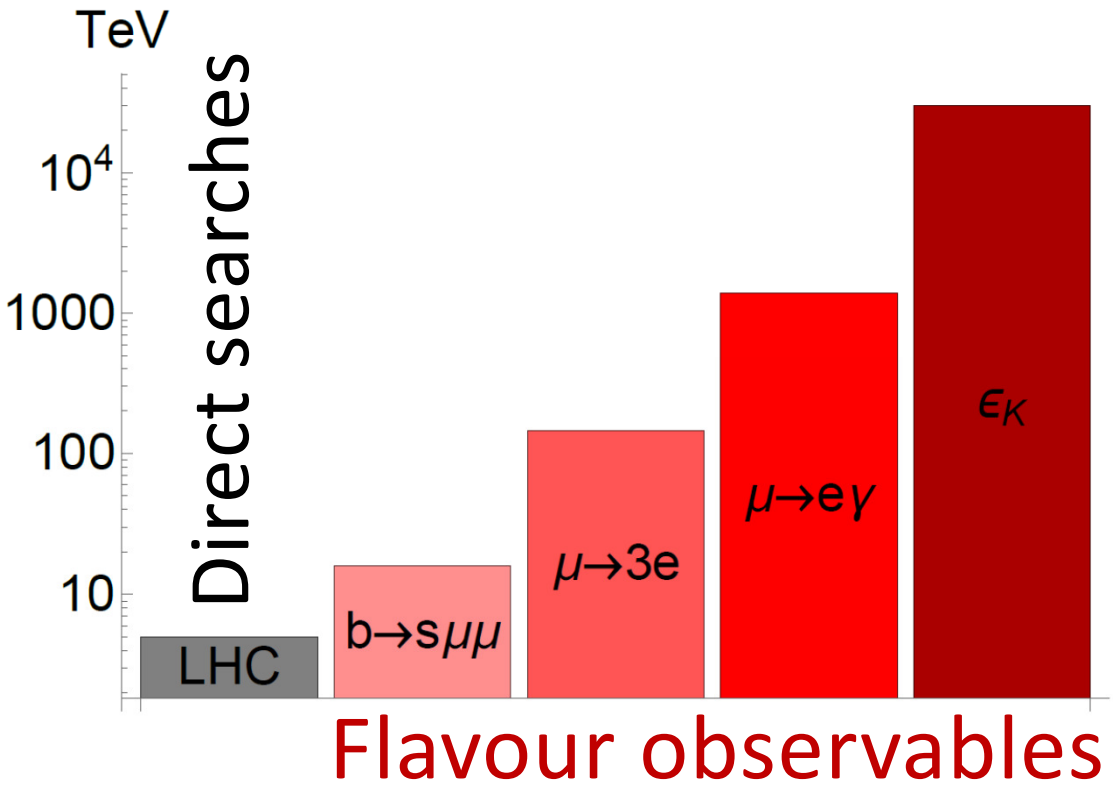
- At colliders one produces many (up to 10^{14}) heavy quarks or leptons and measures their decays into light flavours

Experiment

≠

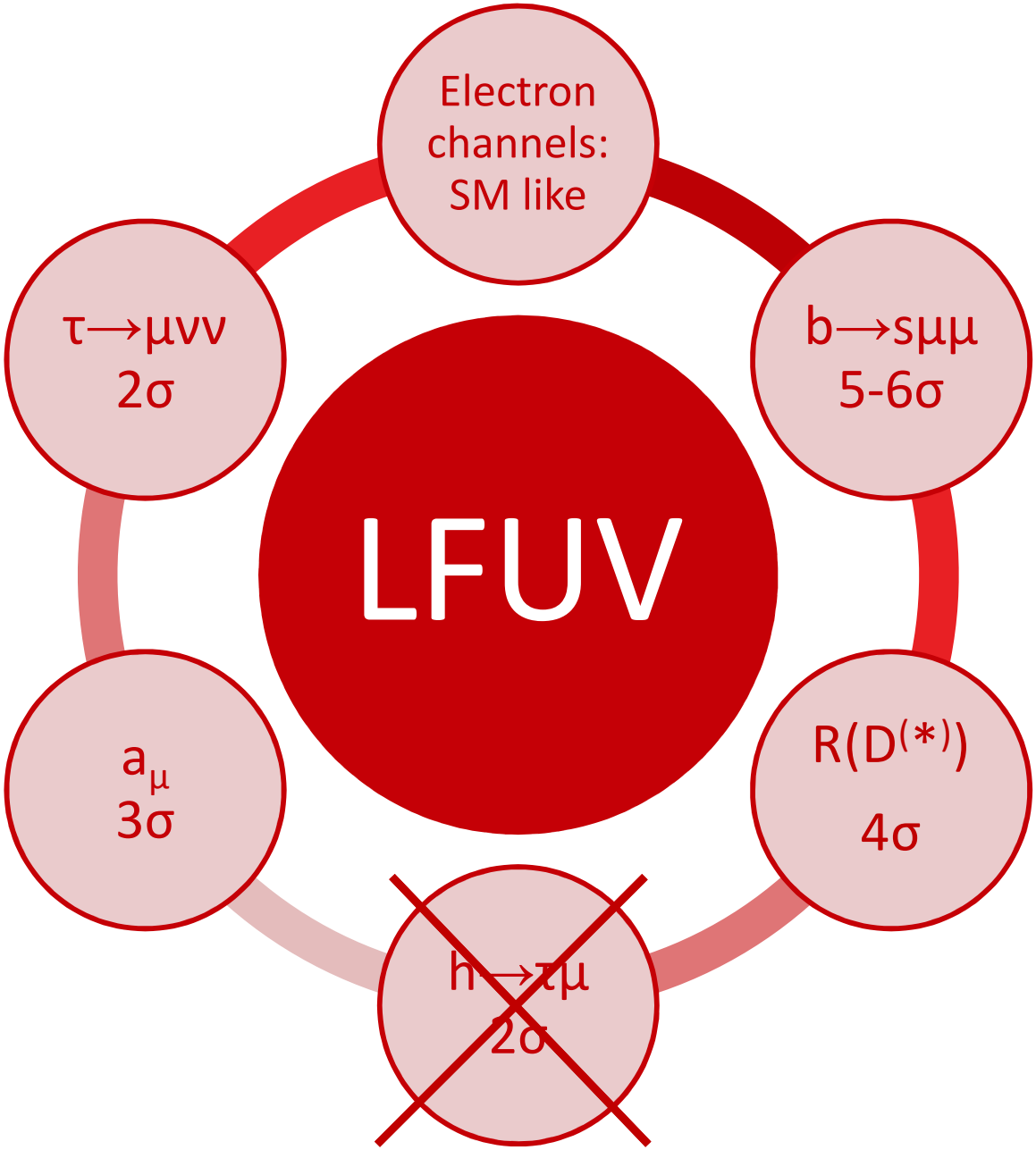
Standard Model

New Physics



Flavour observables are sensitive to higher energy scales than collider searches

Hints for LFUV



Lepton Flavour Universality Violation (LFUV)

a_μ explanations

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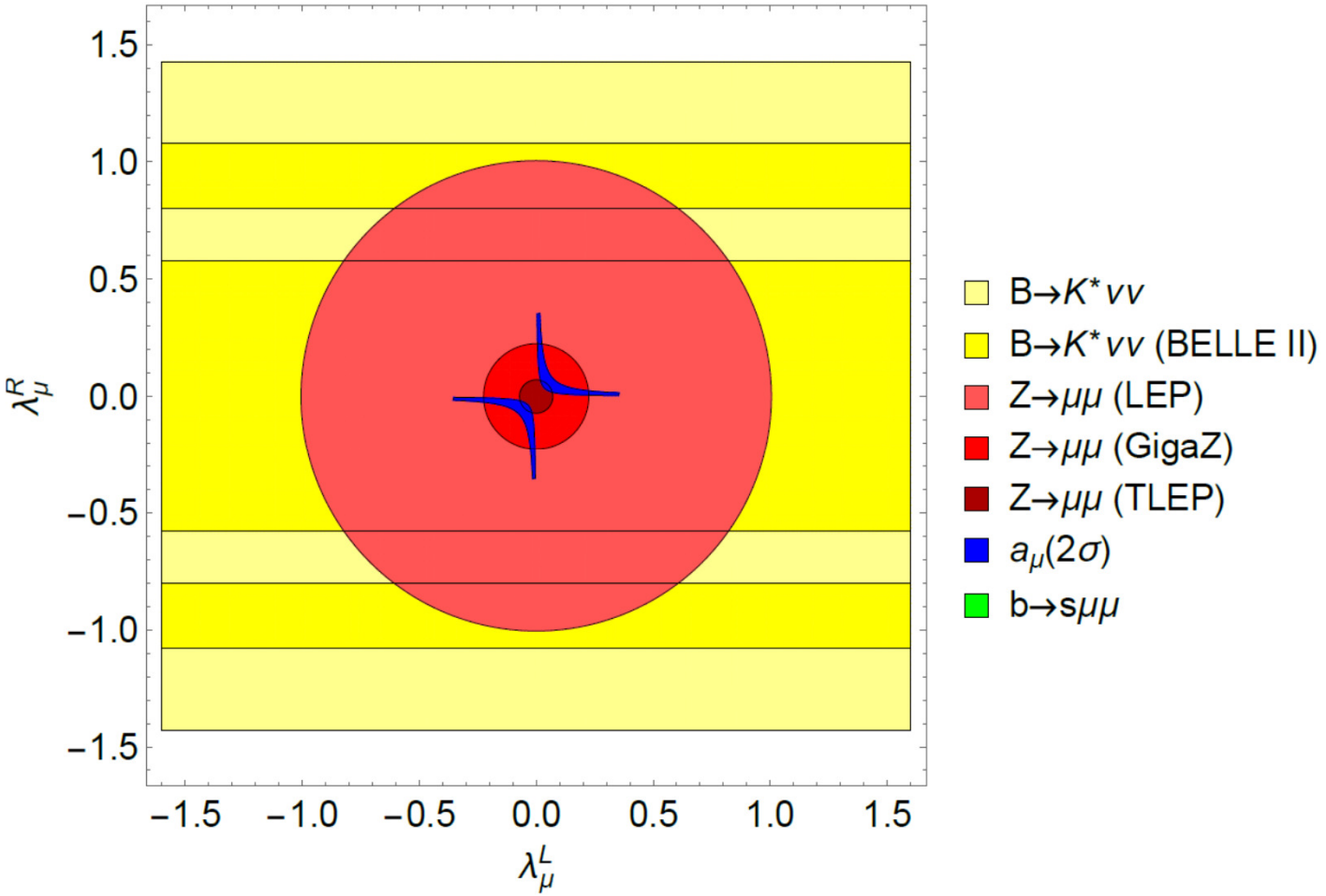
- MSSM e.g. D. Stockinger, hep-ph/0609168
  - tan(ß) enhanced slepton loops
- Scalars e.g. A. Broggio et at. arXiv:1409.3199
  A.C. et al. arXiv:1507.07567
  - Light scalars with enhanced muon couplings
- Z' e.g. W. Altmannshofer, C. Chen, P.S.B. Dev, A. Soni, arXiv:1607.06832, …
  - Very light with 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

Scalar Leptoquarks in a_μ

- Chirally enhanced effects via top-loops



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

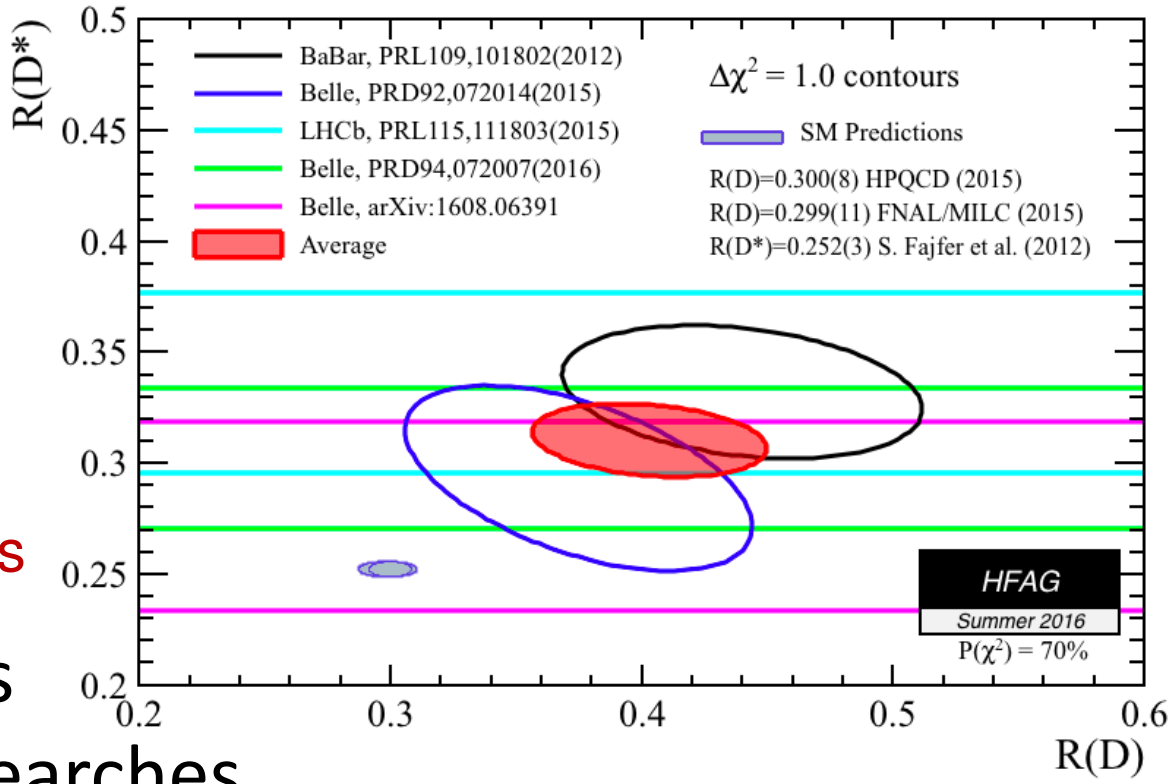
Left-, right-handed muons-top coupling

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

Z→μμ at future colliders

R(D) & R(D*)

- Charged scalars
  - Problems with q2 distributions and B_c lifetime
- W' Talk of Mariano Quiros
  - Strong constraints from direct LHC searches
- Leptoquark
  - Strong signals in qq→ττ searches

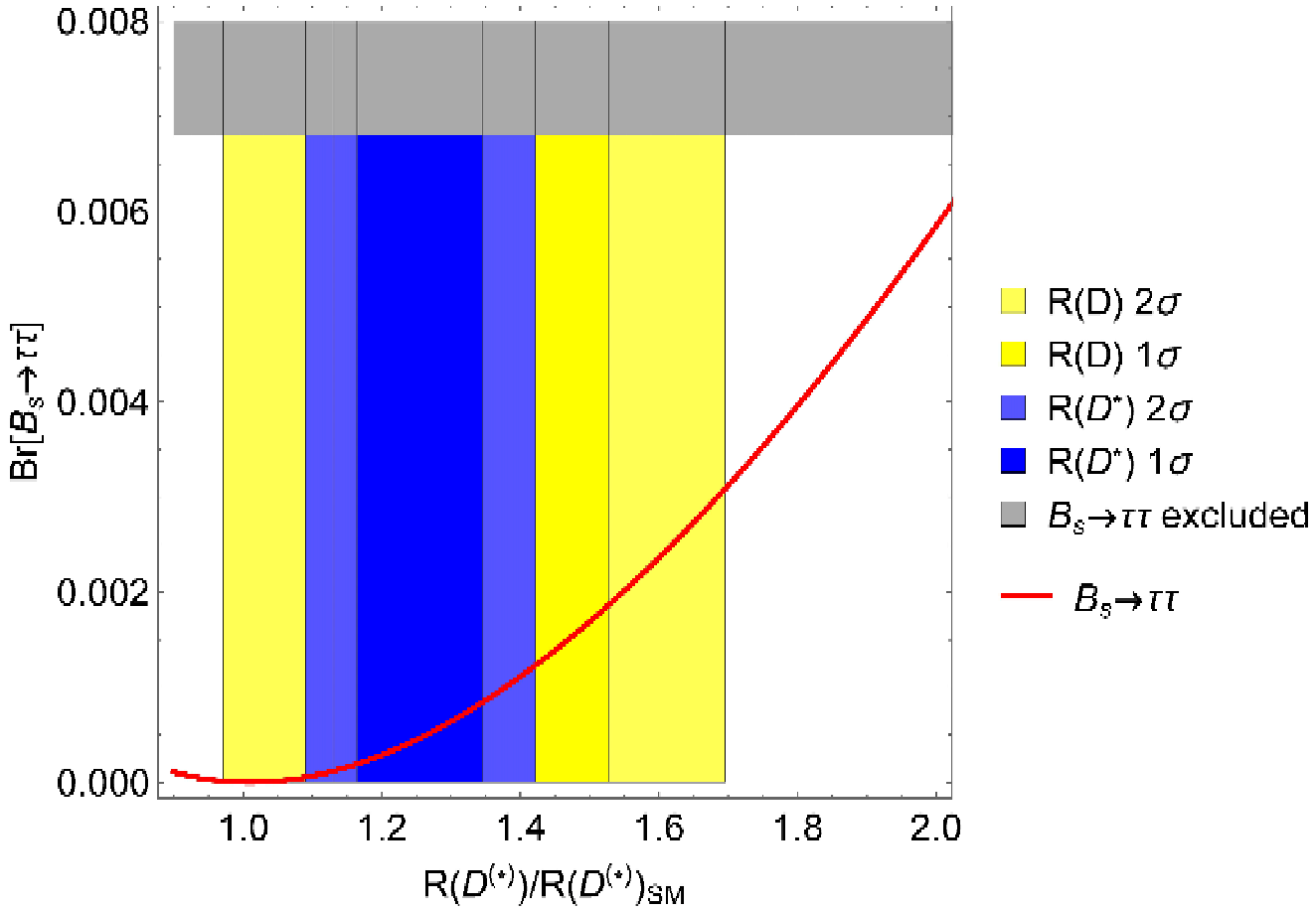


Faroughy et al. arXiv:1609.07138

Explanation difficult

$R(D^{(*)})$ and $b \to s\tau\tau$ (model-independent)

- Large couplings to the second generation needed in order avoid collider bounds
- Cancelation in $b \to s\nu\nu$ needed: $C^{(1)}=C^{(3)}$



$B_s \to \tau\tau$ very strongly enhanced

b→sμμ model-independent analysis

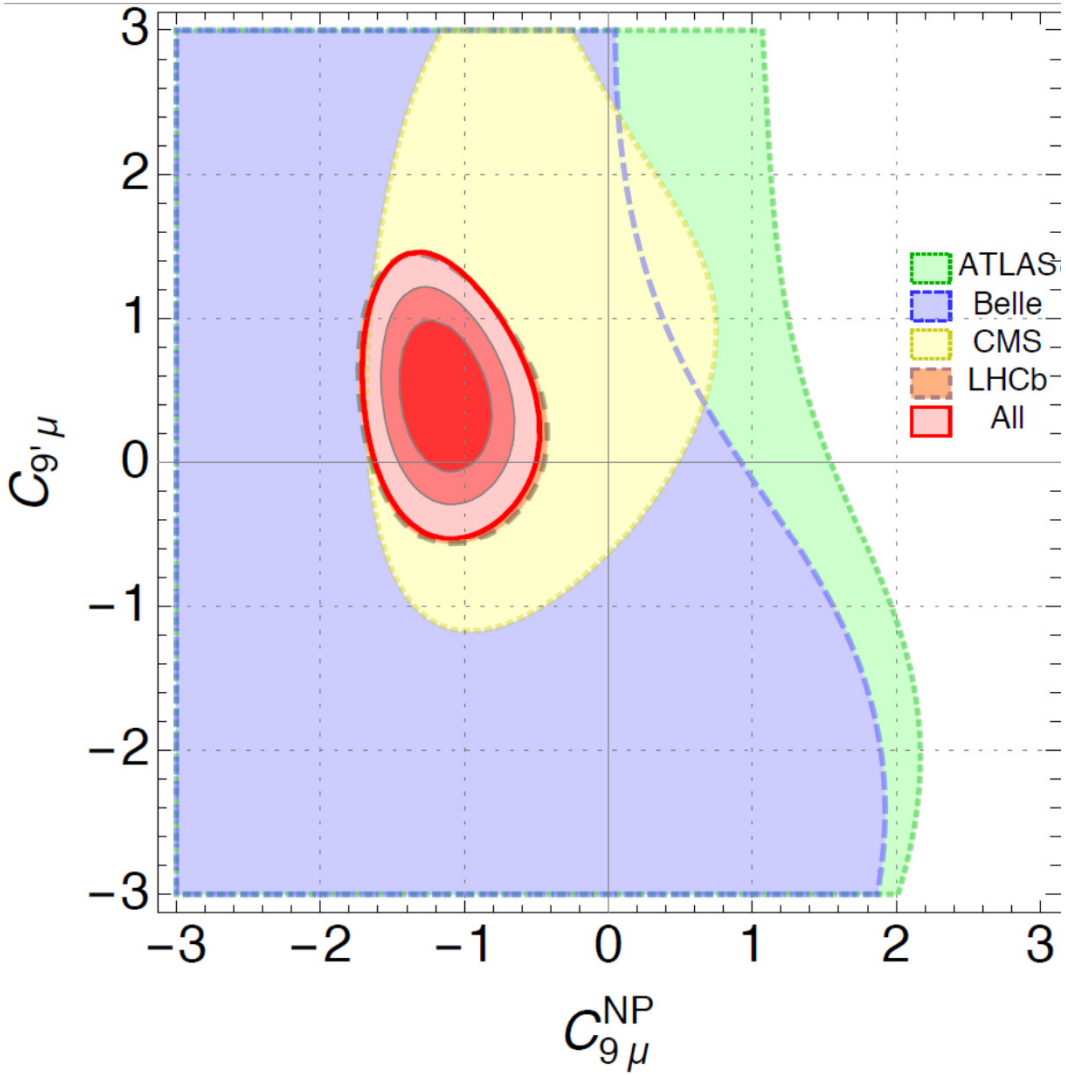
- Several 2-3σ deviations in more than 130 observables
  - P5'
  - R(K)
  - R(K*)
  - $B_s \to \phi\mu\mu$

More in Gino's talk

- 6 NP operators

$$O_{9\mu}^{(')} = \bar{s}\gamma^{\mu} P_L b \bar{\mu}\gamma_{\mu}\left(\gamma^5\right)\mu$$

Model independent fit 5-6 σ better than SM



B. Capdevila, AC, S. Descotes-Genon, J. Matias and J. Virto, arXiv:1704.05340 [hep-ph].

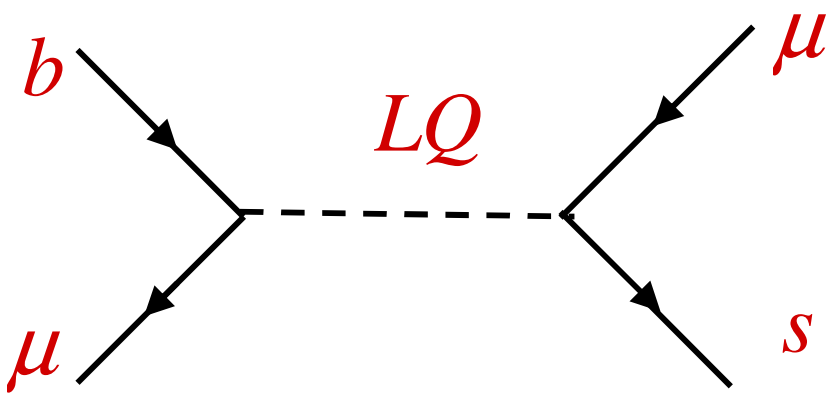
b→sμμ explanations

- 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
L. Calibbi, AC. T. Ota, PRL 2015
...

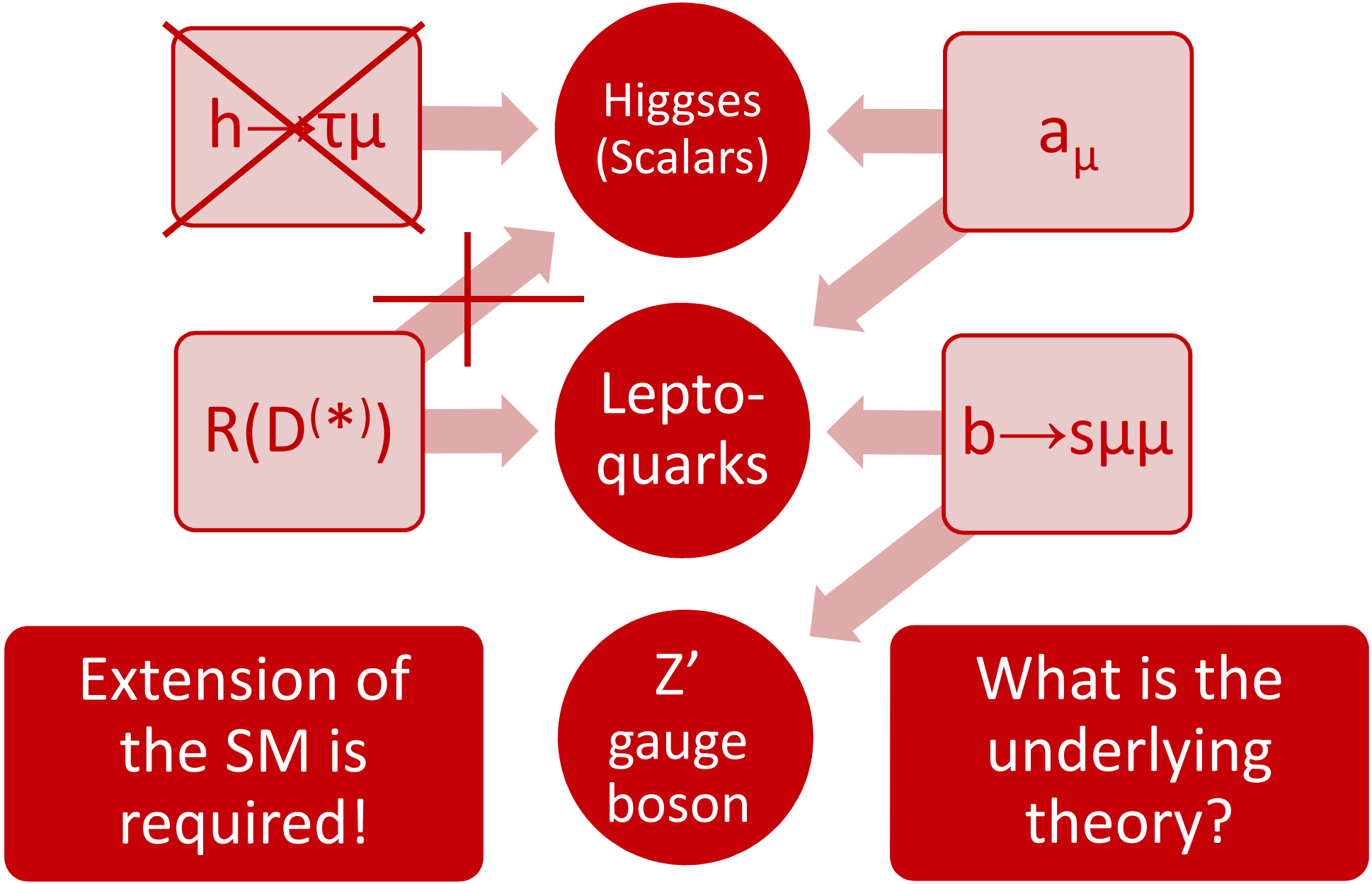


- Loop effects

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

Even high scale NP explanations possible

Implications for New Particles



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Z’ bososns in b→sμμ

Z' solution for b→sμμ with VLQ

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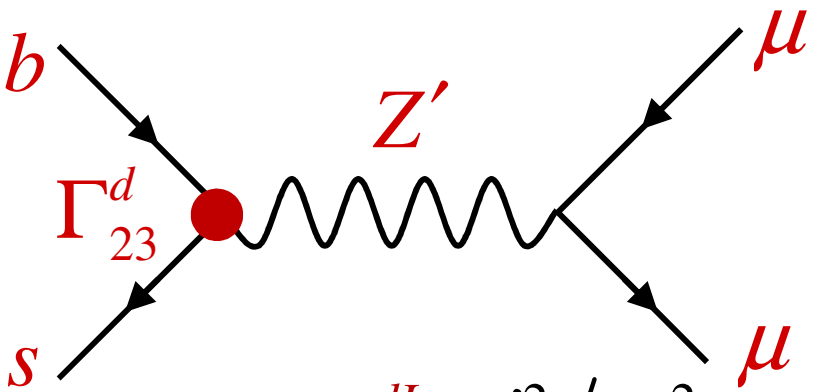
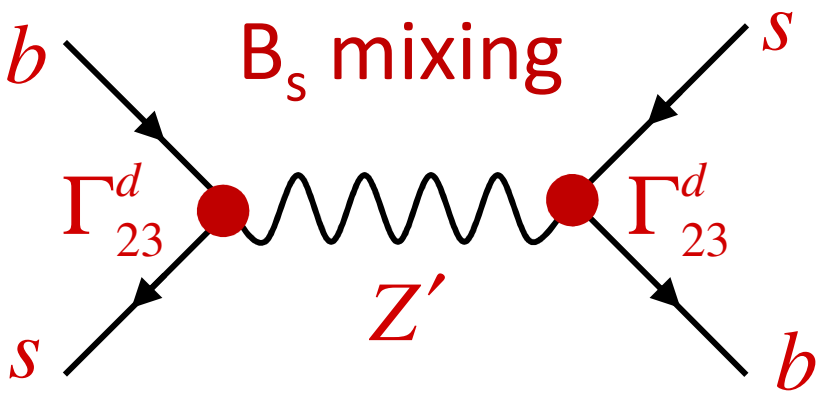
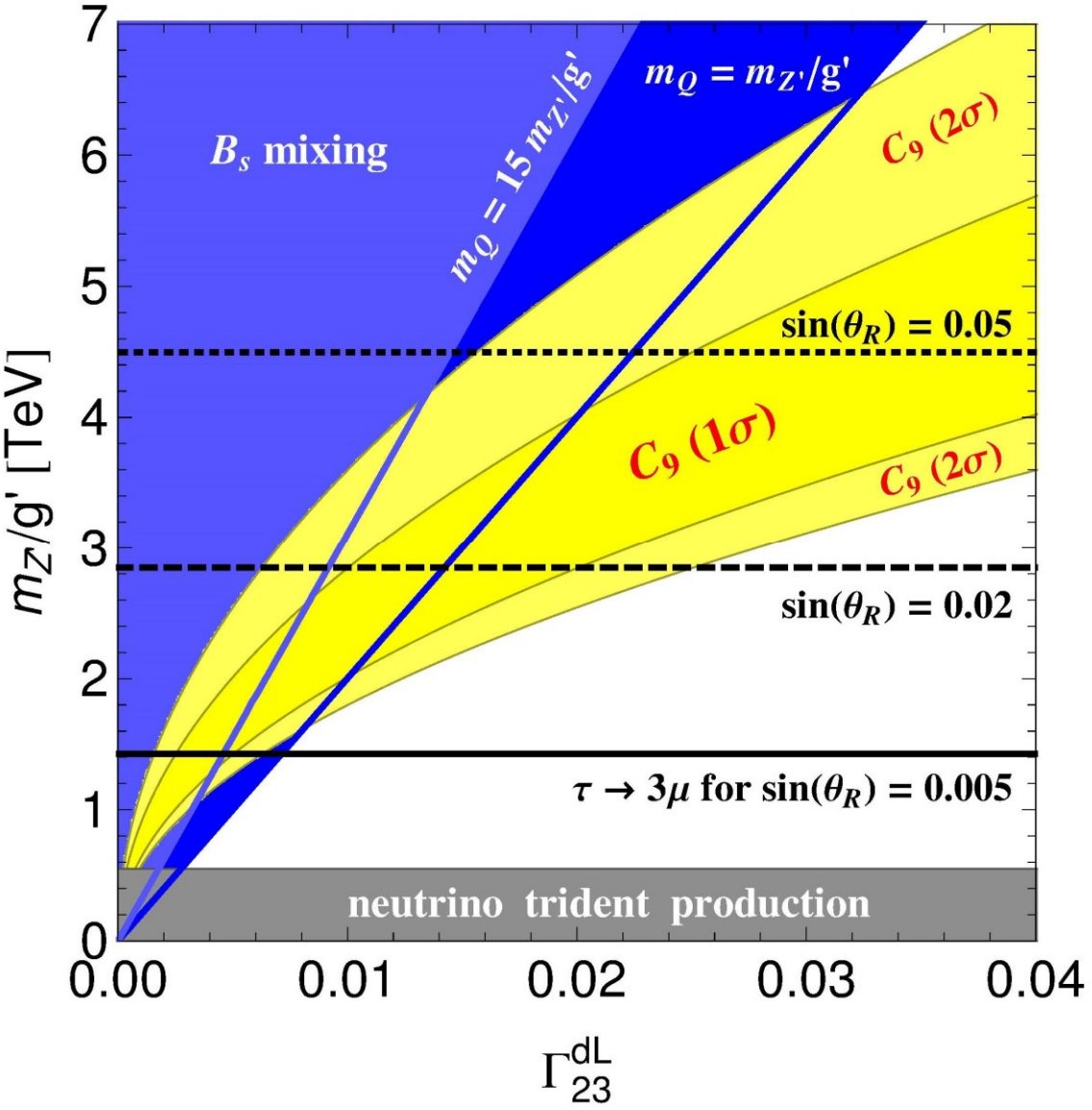
b→sμμ



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



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



allowed regions

Solution with horizontal U(1) charges

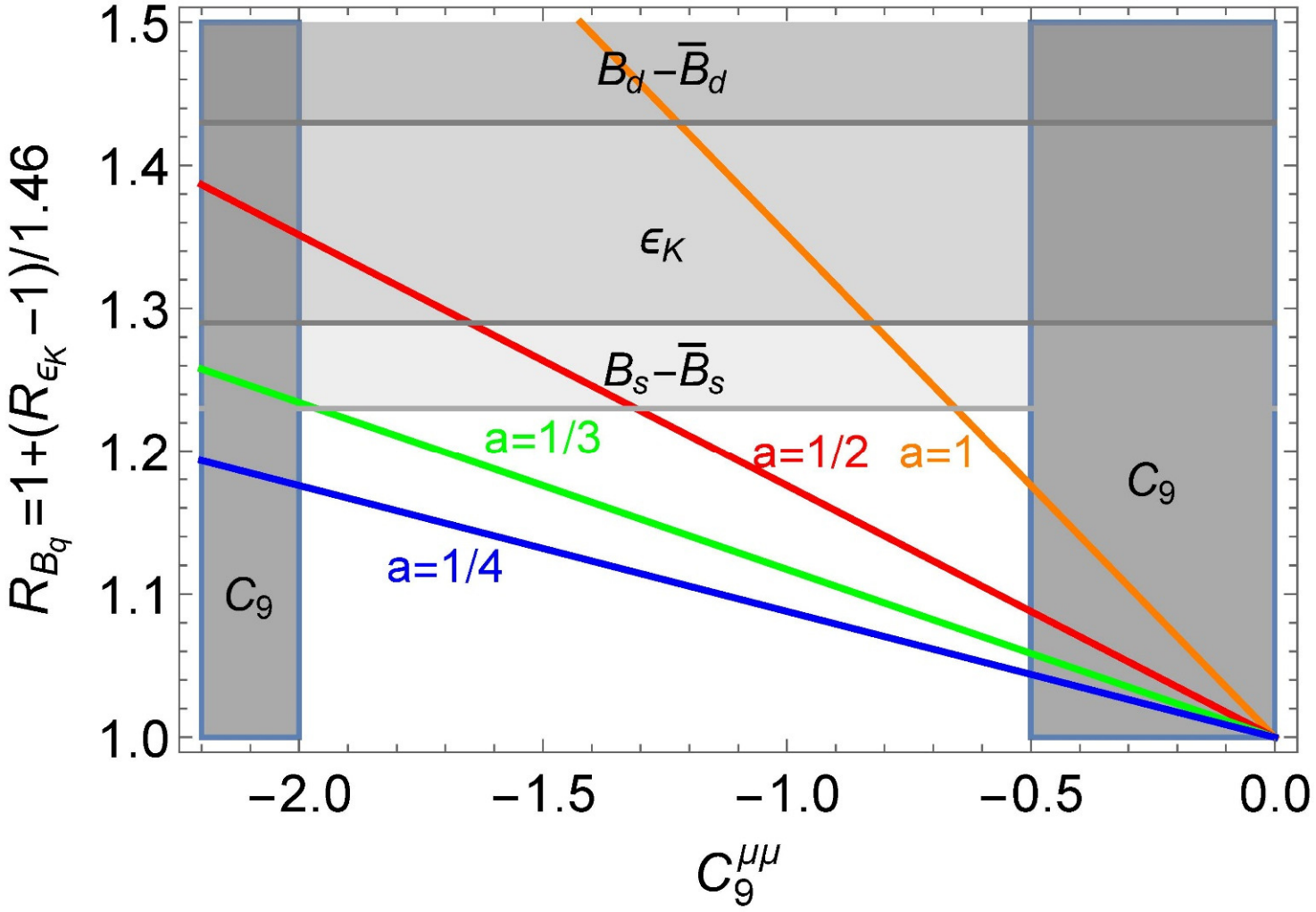
- Avoid vector-like quarks by assigning charges to baryons as well
  - Same mechanism in the quark and lepton sector
- L_μ-L_τ in lepton sector
  - Good symmetry for the PMNS matrix
  - Effect in $C_9^{\mu\mu}$ but not C_9^{ee}
- First two quark generations must have the same charges because the large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

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

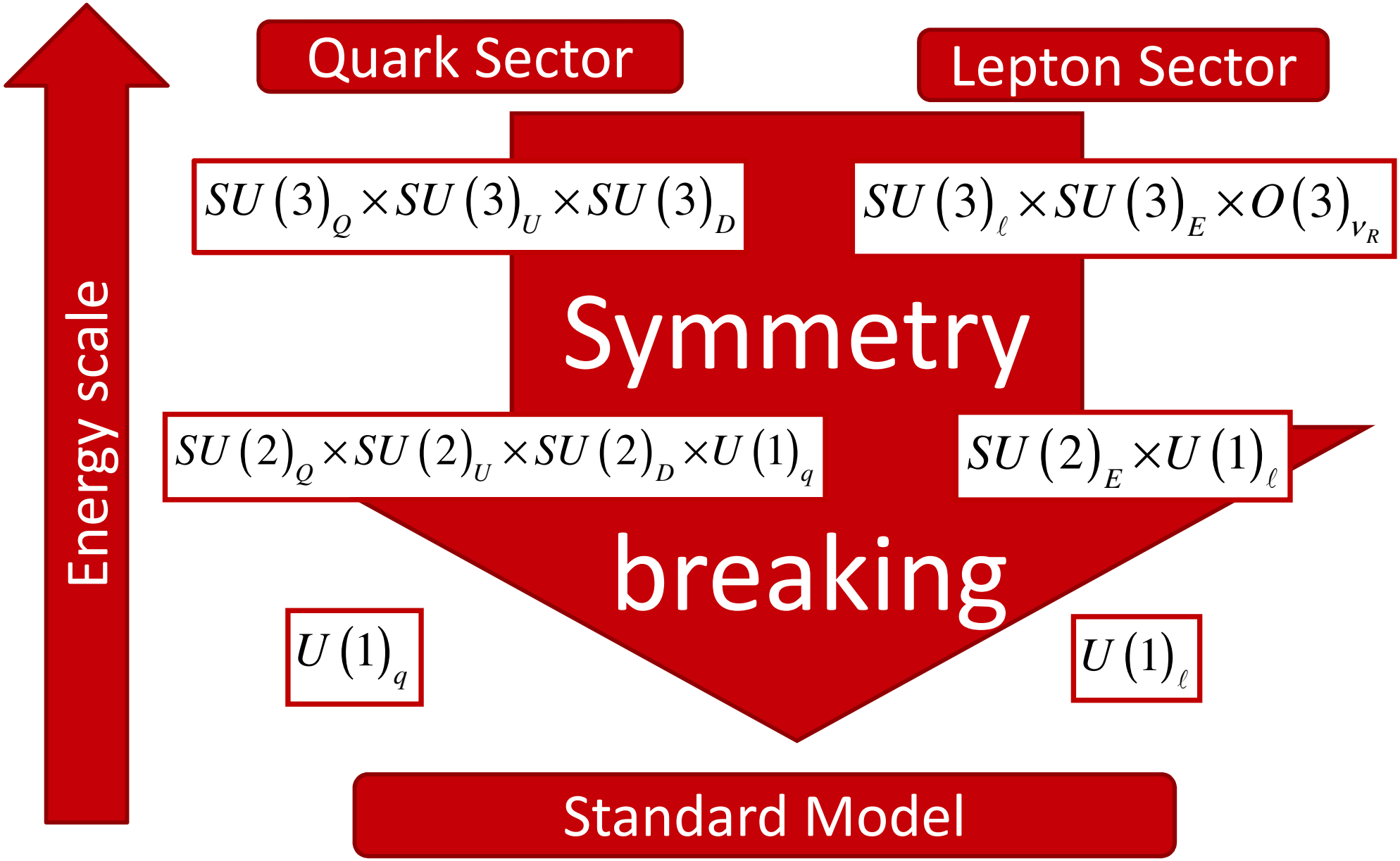
$$R_{\varepsilon_K} = \frac{\varepsilon_K}{\varepsilon_K^{SM}}$$



Necessarily constructive, but Higgs effects and be destructive.

Dynamical explanation of the charges

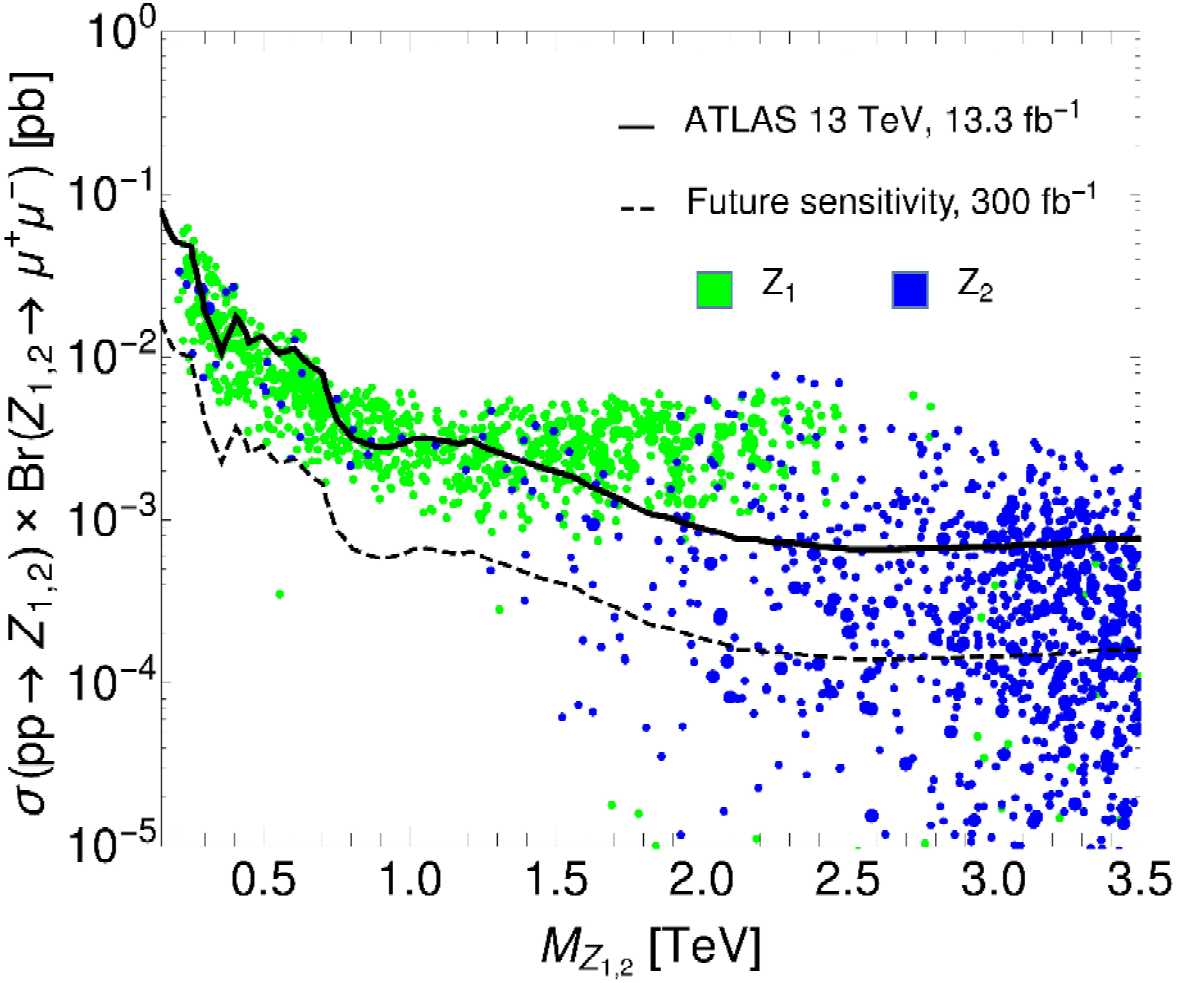
A.C., J. Fuentes-Martin, A. Greljo and G. Isidori arXiv:1611.02703



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

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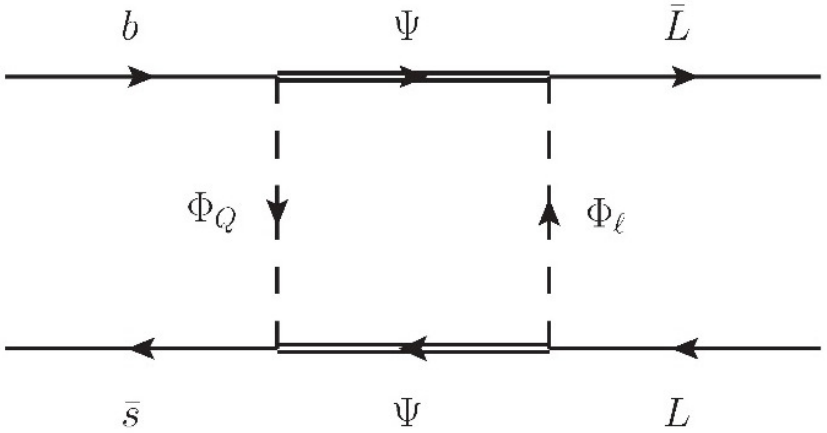
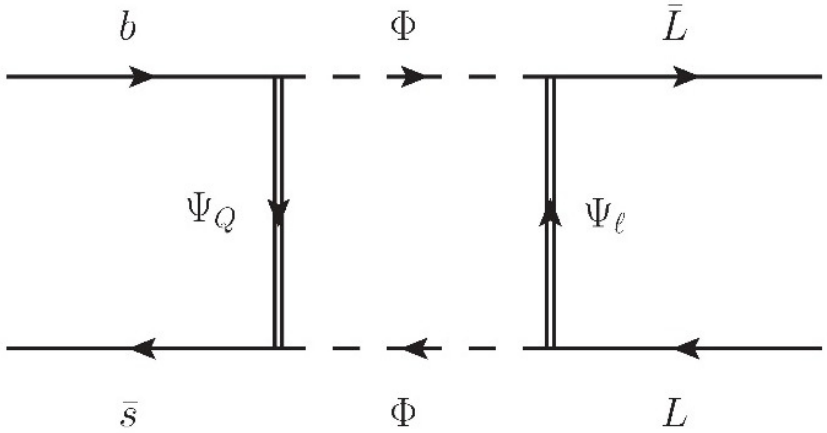
Heavy new sclars and fermions In $b \to s\mu\mu$

Pere Arnan, A.C., Lars Hofer and Federico Mescia, arXiv:1608.07832

New Scalars and Fermions in b→sμμ





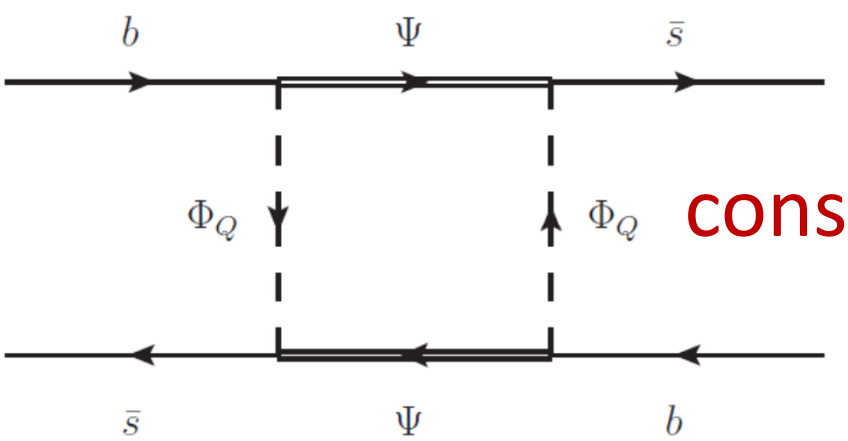
- Possible representations

$SU(2)$	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

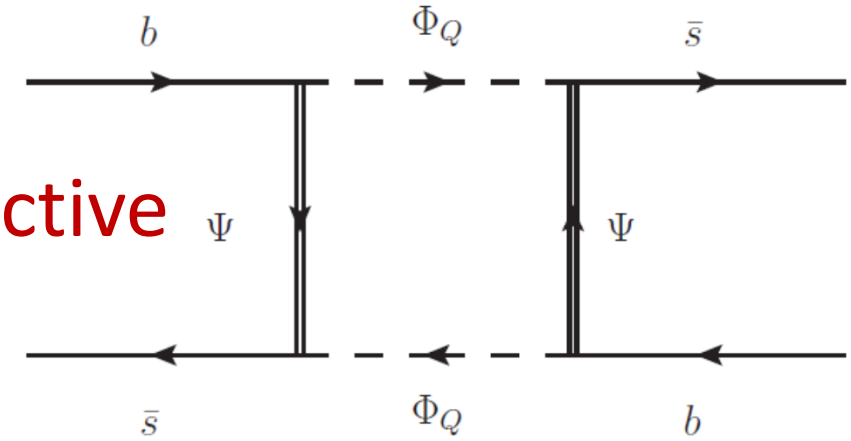
$SU(3)$	Φ_Q, Ψ_Q	Φ_ℓ, Ψ_ℓ	Ψ, Φ
A	3	1	1
B	1	$\bar{3}$	3
C	3	8	8
D	8	$\bar{3}$	3

2x6x4 possibilities

Constraints from B_s mixing

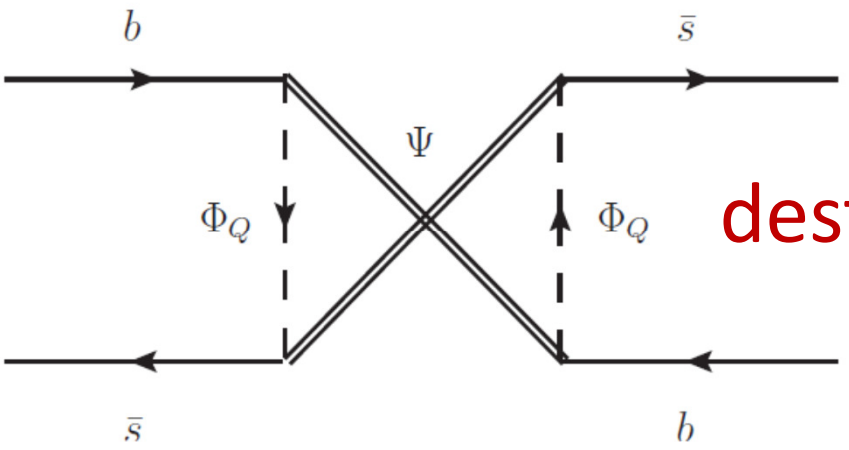


constructive

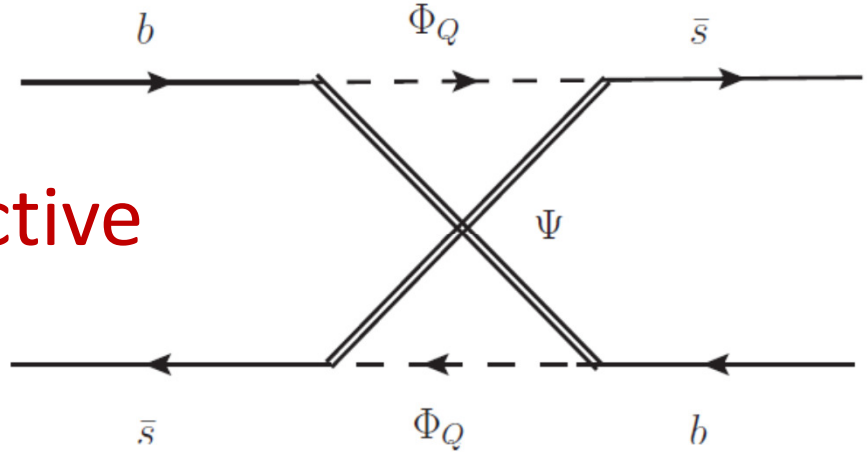


Lattice results prefers destructive interference MILC, 1602.03560

- Majorana representations



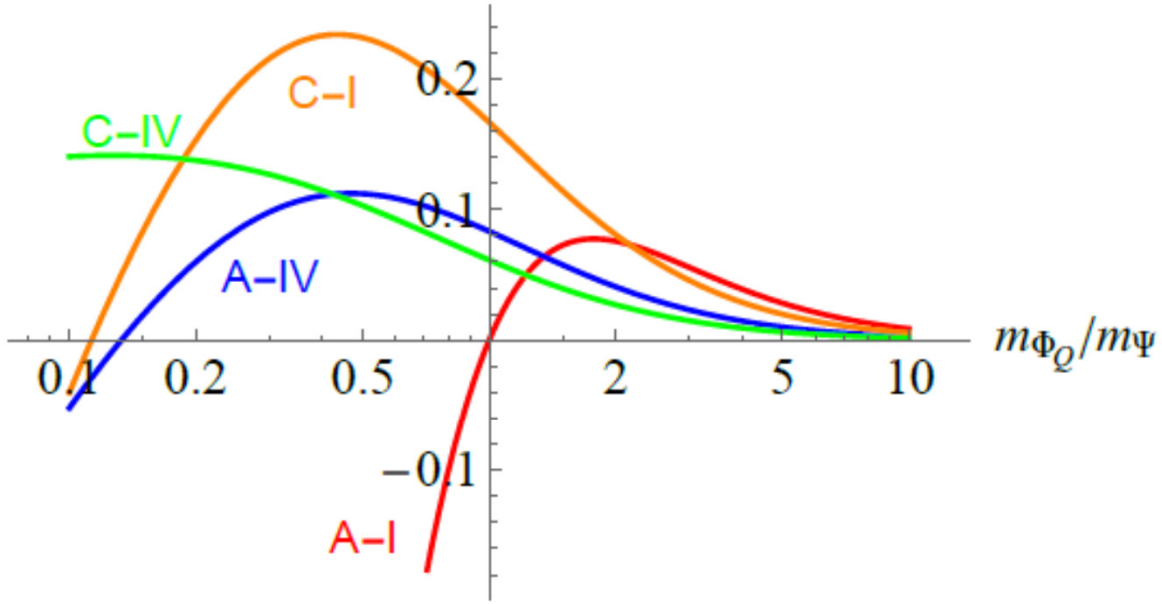
destructive



Destructive interference with Majorana fermions

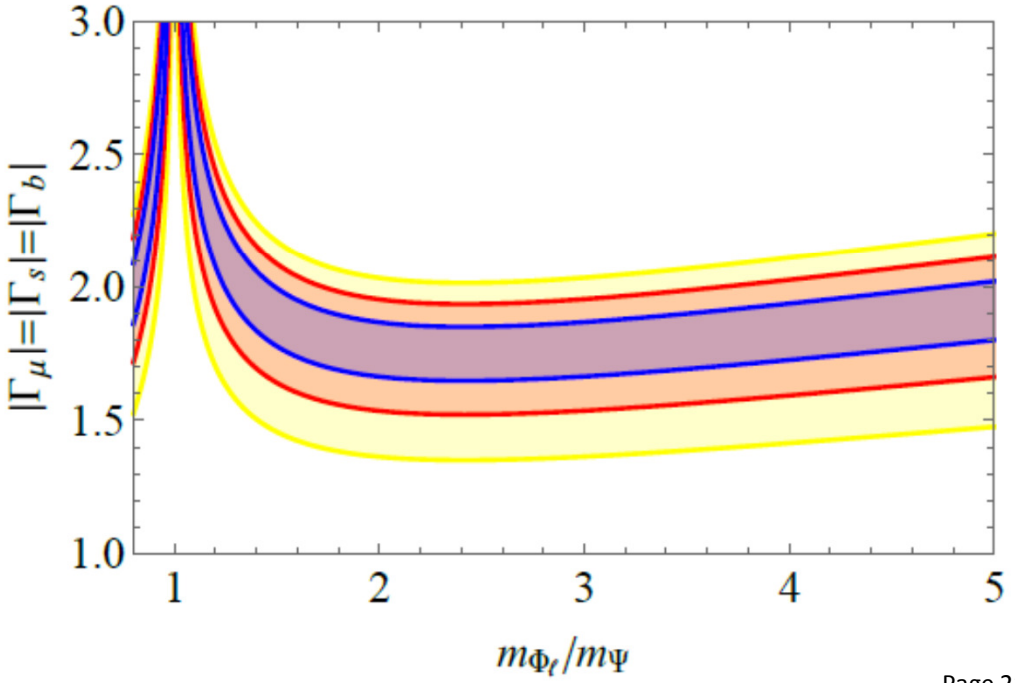
$b \to s\mu\mu$ and B_s mixing

Relative effect in B_s mixing



$b \to s\mu\mu$ 3σ 1σ 2σ

Explanation with O(1) couplings



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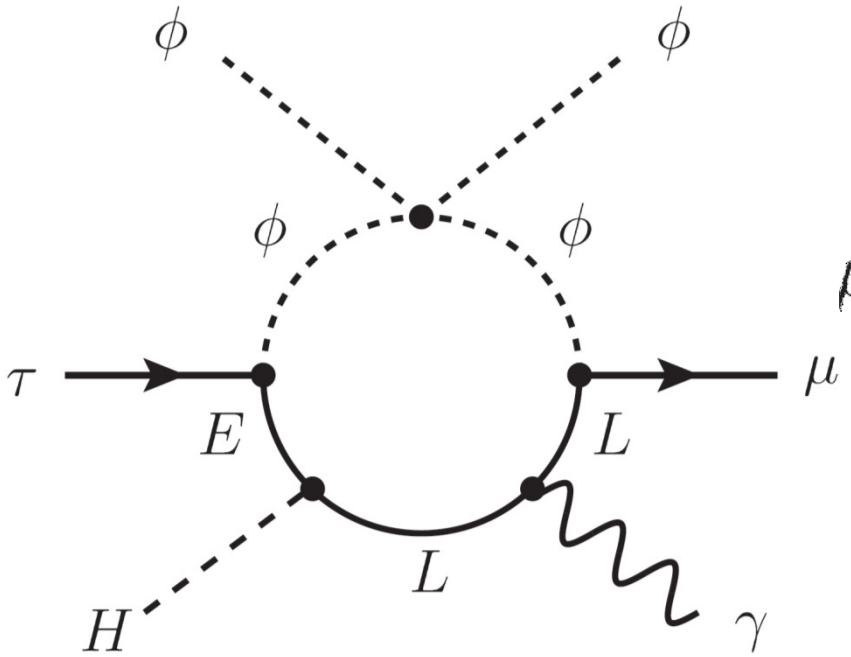
Simultaneous Explanation of R(D), R(D*), a_μ and $b \to s\mu\mu$

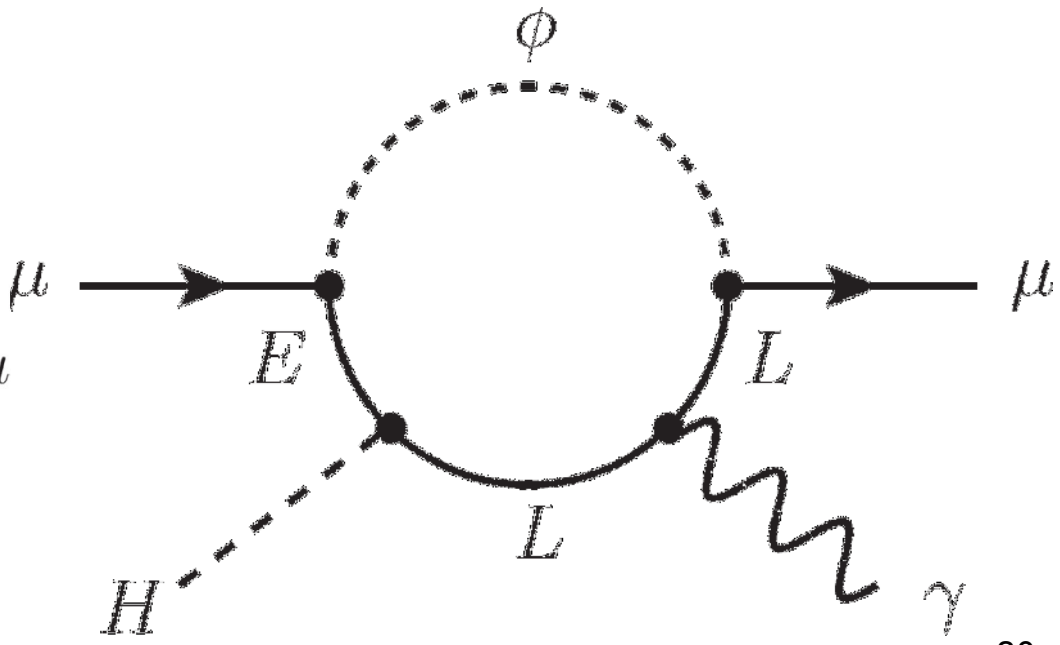
L_μ-L_τ model for a_μ

W. Altmannshofer, M. Carena, AC, 1604.08221

- L_μ-L_τ flavour symmetry
- Flavon couples to μ and τ
- $\tau \to \mu\gamma$ is protected
- a_μ is not protected
- Effects in $h \to \mu\mu$

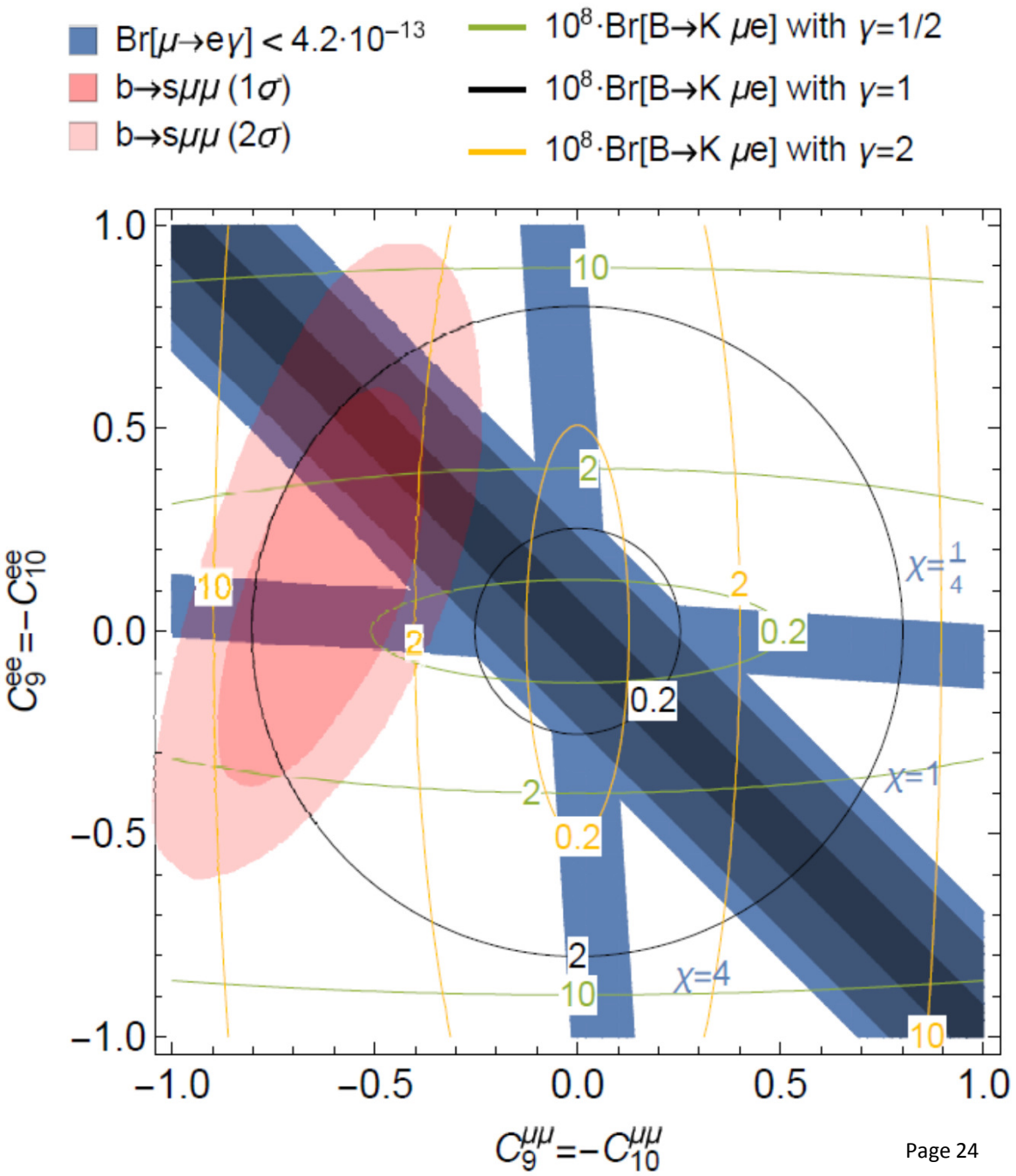
Explanation of a_μ and b→sμμ





R(K), R(K*) and μ→eγ with LQs

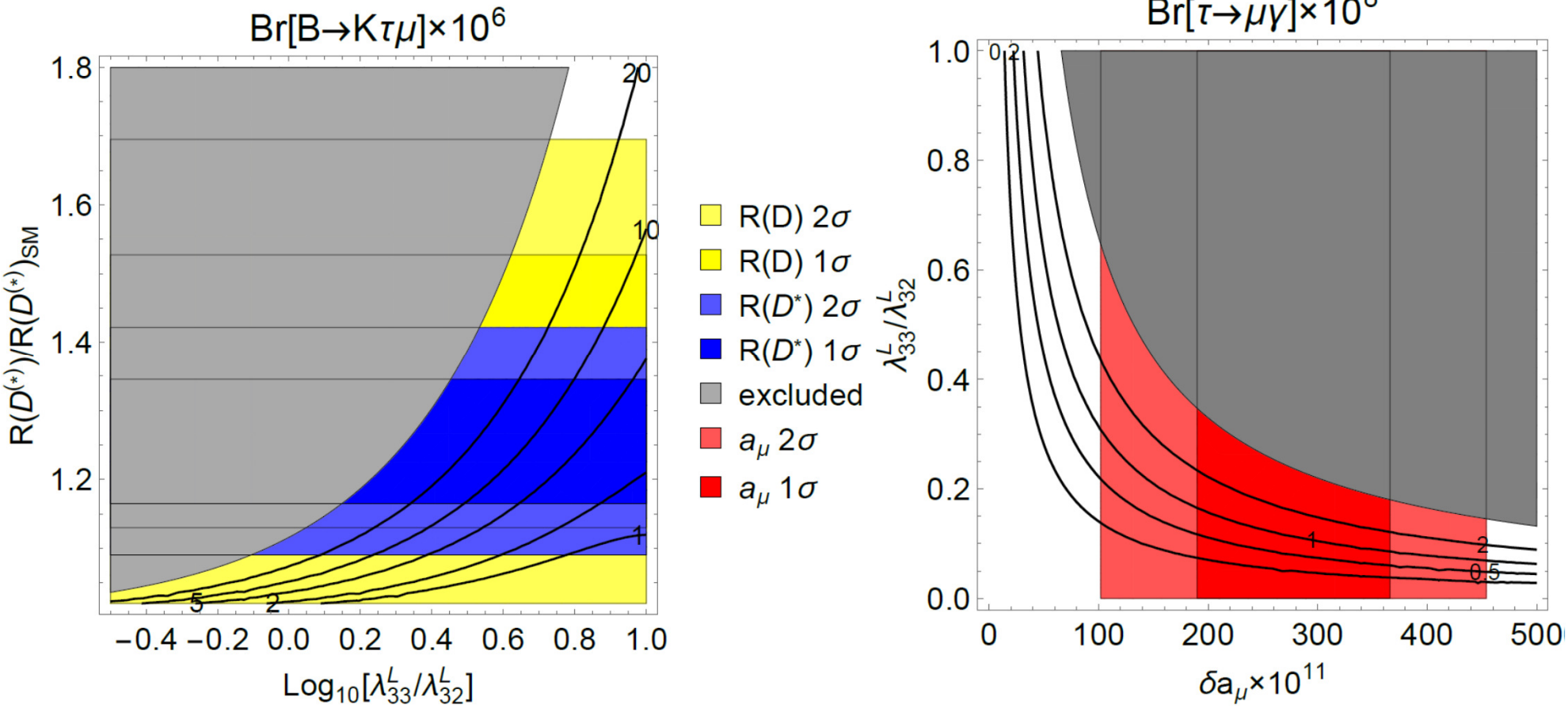
- Three LQs give a good fit
  - Scalar triplet
  - Vector singlet
  - Vector triplet
- Simultaneous effect in b→sμμ and b→see generate μ→eγ



AC, D. Mueller, A. Signer, Y. Ulrich, arXiv:1505.xxxx

$R(D^{(*)})$, $b\to s\mu\mu$ and a_μ with LQs

- Scalar leptoquark singlet + triplet with Y=-2/3
- Cancelation in $b\to s\nu\nu$ imposed

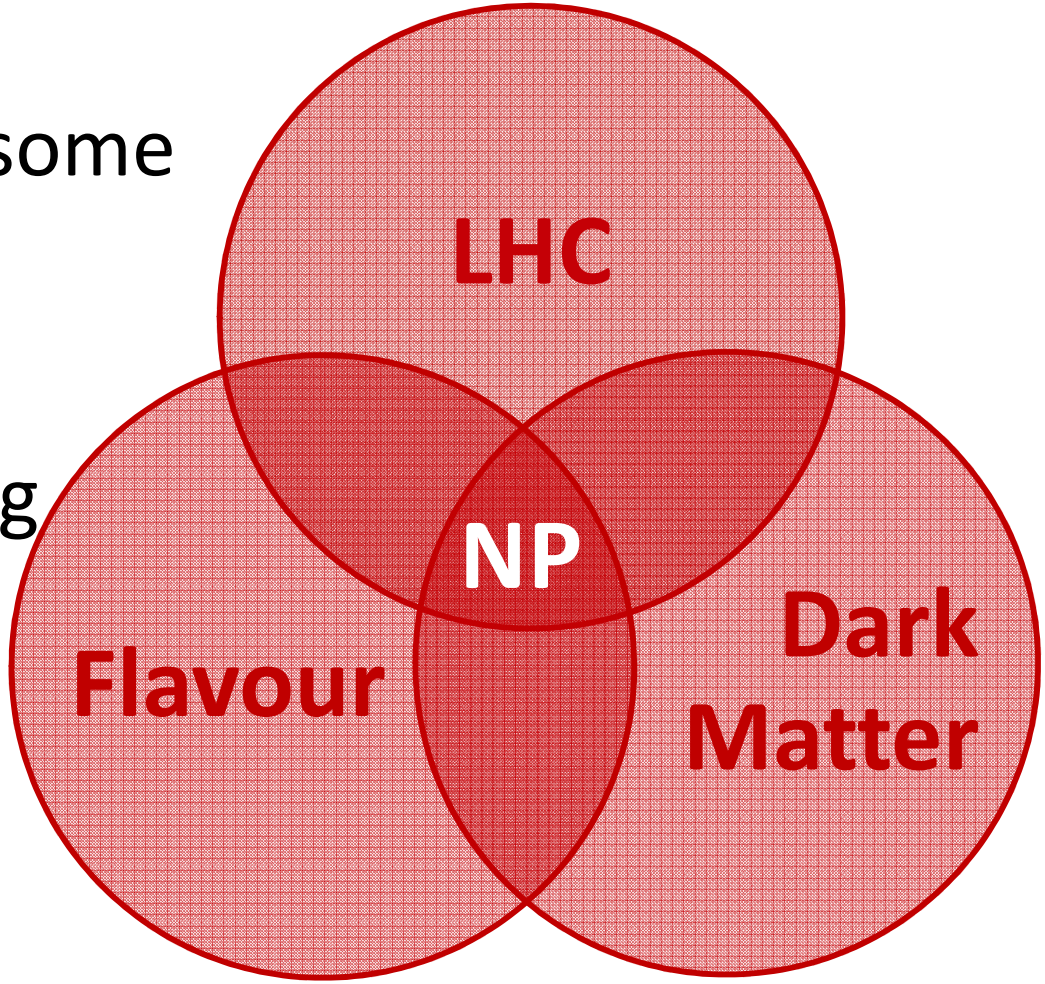


AC, D. Mueller, T. Ota arxiv:1703.09226

2 out of 3 can be explained

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!