Explaining *B* anomalies with Planck-safe *Z'*

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based on 2109.06201
in collaboration with

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Asymptotic Safety meets Particle Physics & Friends
17.12.2021

Various hints of new physics in b → sμμ decays

$$R_{K^{(*)}} = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\mathcal{B}(B\to K^{(*)}\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\mathcal{B}(B\to K^{(*)}e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2}$$

Obs.	Region of q^2 /	Pull_{SM}
R_{K^*}	$[0.045,\ 1.1]$	$2.5\,\sigma$
	$[1.1,\ 6.0]$	$2.5\,\sigma$
R_K	$[1.1,\ 6]$	$3.1\,\sigma$

[LHCb collaboration: 1705.05802, 2103.11769]

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» described model-independent NP Wilson coefficients

[Bause, Gisbert, Golz, Hiller: 2109.01675]

$$C_9^\mu \sim (\bar{s}_L\gamma_\nu b_L)\,(\bar{\mu}\gamma^\nu\mu)$$

$$C_{10}^\mu \sim (\bar{s}_L\gamma_\nu b_L)\,(\bar{\mu}\gamma^\nu\gamma^5\mu)$$

Dim.	Fit	C_9^μ	C_{10}^μ	Pull$_{\mathrm{SM}}$
1d	C_9^μ	-0.83 ± 0.14	0	$6.0\,\sigma$
1d	$C_{10}^\mu = -C_9^\mu$	-0.41 ± 0.07	$-C_9^\mu$	$6.0\,\sigma$
2d	$C_{9,10}^\mu$	-0.71 ± 0.17	0.20 ± 0.13	$5.9\,\sigma$

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$$C_9'^\mu \sim (\bar{s}_R\gamma_\nu b_R)\,(\bar{\mu}\gamma^\nu\mu)$$

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consistent with zero [Bause, Gisbert, Golz, Hiller: 2109.01675]

$C_9^\mu = -1.07\pm0.17$ $C_9'^\mu = 0.27\pm0.32$

$C_{10}^\mu = 0.18\pm0.15$ $C_{10}'^\mu = -0.28\pm0.19$

can generate $R_{K^*}\neq R_K$

» How to generate the NP Wilson coefficients?

$$C_9^\mu \sim (\bar{s}_L \gamma_\nu b_L)(\bar{\mu}\gamma^\nu \mu) \qquad C_{10}^\mu \sim (\bar{s}_L \gamma_\nu b_L)\left(\bar{\mu}\gamma^\nu \gamma^5 \mu\right)$$

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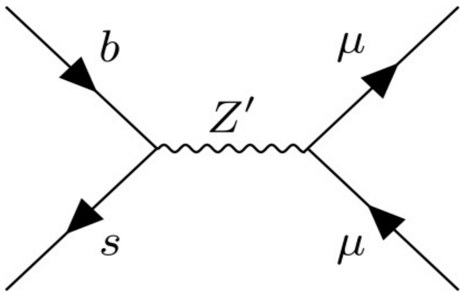

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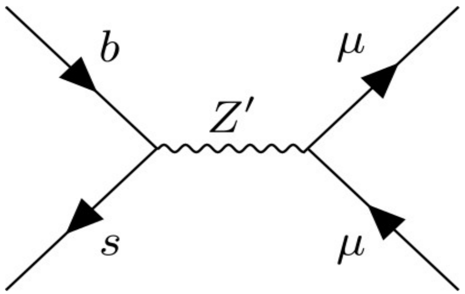
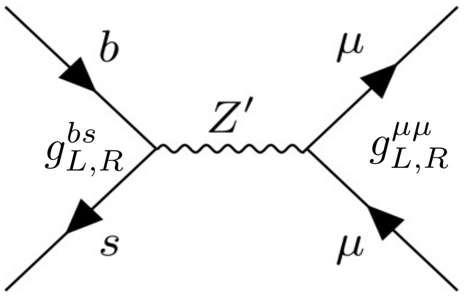


» consistent QFT: $U(1)'$ extension of SM gauge group

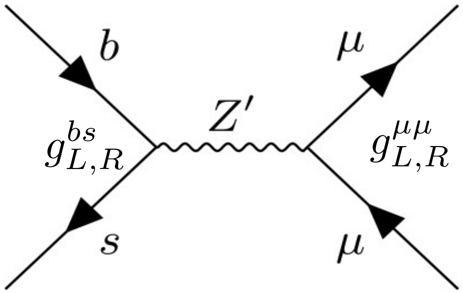
» fermions have **generation-dependent charges**



$$C^{\mu}_{9,10} \sim \frac{g^{bs}_L\,[g^{\mu\mu}_R \pm g^{\mu\mu}_L]}{M^2_{Z'}}$$

» Direct coupling to quarks: *Z'* is heavy

$M_{Z'} \gtrsim 5$ TeV first generation quarks [CMS collaboration: 2103.02708]



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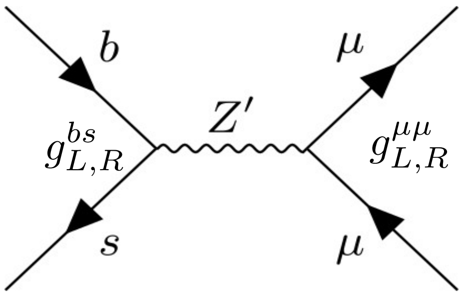
» Sizable *Z'* couplings required to account for $C^{\mu}_{9,10}$

$$g^{\mu\mu}_L = g_4\,F_{L_2} \qquad g^{\mu\mu}_R = g_4\,F_{E_2} \qquad g^{bs}_L = g_4\,V_{tb}V^*_{ts}\,(F_{Q_3} - F_{Q_2})$$



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⟶ Landau poles of g_4 before the Planck scale

» e.g. *minimal* model

$$M_{Z'} \gtrsim 5 \text{ TeV}$$

left muon and b-quark have $U(1)'$ charge + gauge anomaly cancellation

Landau pole $\mu_L \lesssim 10^{10}$ TeV

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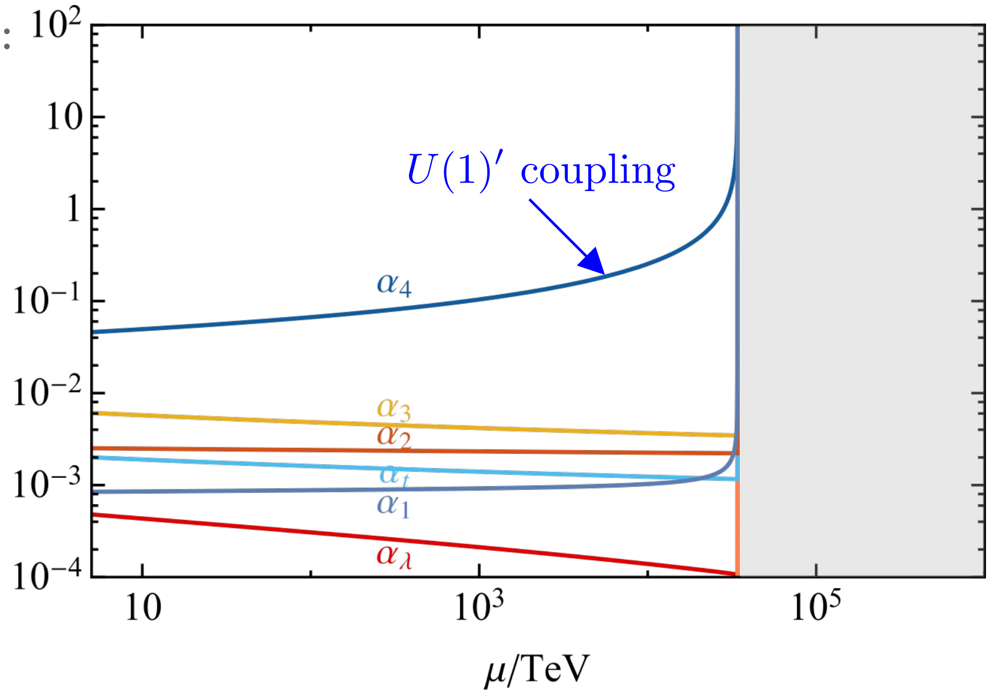
» in practice:



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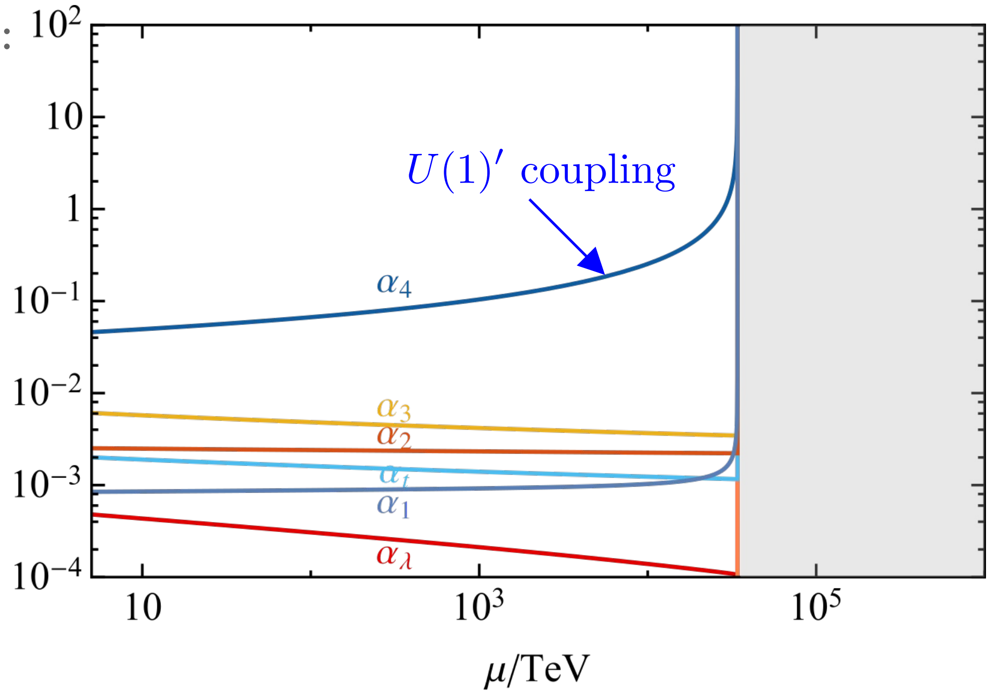

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Landau pole has to be (re)moved!

→ **Planck safety**

What is Planck Safety?

Between EW and Planck scale:

» no Landau poles, couplings remain finite
» parameters remain physical
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$\longrightarrow$ consistent, predictive until M_{Pl}

“Asymptotic Safety until the Planck scale”

$\longrightarrow$ provides additional theory constraints

How to achieve Planck Safety (in Practice)

» SM is **not** Planck-safe – Higgs metastability !

$\longrightarrow$ remove Landau poles and restore Higgs stability

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ψ_i	N_f vector-like fermions (charged) – "quark"
S_{ij}	$N_f \times N_f$ matrix-like scalars (uncharged) – "meson"

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» tame Landau poles by Yukawa interaction

$$-\mathcal{L}_y = y\,\left(\overline{\psi}_{Li}\,S_{ij}\,\psi_{Rj} + \text{h.c.}\right)$$

unbroken flavor symmetry

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- $N_f,\, N_c \to \infty$ exact UV fixed point (asymptotic safety)
- $N_f = 3$, embed in gauge group $\longrightarrow$ potentially enables Planck safety

How to achieve Planck Safety (in Practice) II

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» enhances physics predictivity:

$\longrightarrow$ previous work with BSM vector-like leptons [Hiller, Hormigos-Feliu, Litim, TS: Phys.Rev.D 102 (2020) 9]

$\longrightarrow$ simultaneous explanation for $(g-2)_{\mu,e}$ [Hiller, Hormigos-Feliu, Litim, TS: Phys.Rev.D 102 (2020) 7]

Putting it all together

» extended gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)'$

» SM matter fields $Q_i,\, U_i,\, D_i,\, L_i,\, E_i$ and Higgs H

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- » $U(1)'$ breaking, charged scalar ϕ
- » Planck-Safety sector:
  - vector-like BSM fermion ψ_i
  - uncharged 3 x 3 BSM scalar S_{ij}
- » scalar portals between H, ϕ, S_{ij}

Assigning *U(1)'* charges

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» condition for each component of SM Yukawa matrices

- diagonal quark Yukawas Y^u_{ii}, Y^d_{ii} compatible with $U(1)'$
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  $\longrightarrow$ some models allow diagonal lepton and RHN Yukawas Y^e_{ii}, Y^ν_{ii}

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» small gauge-kinetic at the electroweak scale mixing between $U(1)_Y \times U(1)'$

U(1)' charges and benchmark models

Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
$\mathbf{BM_1}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
$\mathbf{BM_2}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
$\mathbf{BM_3}$	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
$\mathbf{BM_4}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

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» no Kaon mixing

U(1)' charges and benchmark models

Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
BM$_1$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
BM$_2$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
BM$_3$	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
BM$_4$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

» pass 6 gauge anomaly cancellation conditions

» allow at least diagonal quark Yukawas

» no *Z'* – electron couplings

» no Kaon mixing

» B_s mixing bound

U(1)' charges and benchmark models

Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
BM$_1$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
BM$_2$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
BM$_3$	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
BM$_4$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

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Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
BM₁	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
BM₂	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
BM₃	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
BM₄	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

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U(1)’ charges and benchmark models

Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
BM$_1$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
BM$_2$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
BM$_3$	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
BM$_4$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

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U(1)' charges and benchmark models

Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
BM₁	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
BM₂	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
BM₃	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
BM₄	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

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» *U(1)'* breaking, no additional Yukawas

» EWSB without *U(1)'* sector

$C_9^\mu \neq 0,\ C_{10}^\mu = 0$ → **BM₁**, **BM₄**

$C_9^\mu = -C_{10}^\mu$ → **BM₂**

$C_{9,10}^\mu \neq 0$ → **BM₃**

U(1)' charges and benchmark models

Model	F_{Q_i}			F_{U_i}			F_{D_i}			F_{L_i}			F_{E_i}			F_{ν_i}			F_H	F_ψ	F_ϕ
BM$_1$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$-\frac{1}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	$-\frac{9}{10}$	$\frac{9}{10}$	0	0	0	0	1	$\frac{1}{5}$
BM$_2$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{6}$	0	1	0	0	0	1	$\frac{1}{12}$	$-\frac{1}{12}$	1	0	$\frac{11}{12}$	$\frac{1}{9}$
BM$_3$	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	$-\frac{1}{8}$	$-\frac{1}{8}$	0	0	$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	1	$\frac{1}{8}$
BM$_4$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	0	$\frac{1}{9}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{2}{3}$	0	1	$\frac{1}{6}$

- » pass 6 gauge anomaly cancellation conditions
- » allow at least diagonal quark Yukawas
- » no *Z'* – electron couplings
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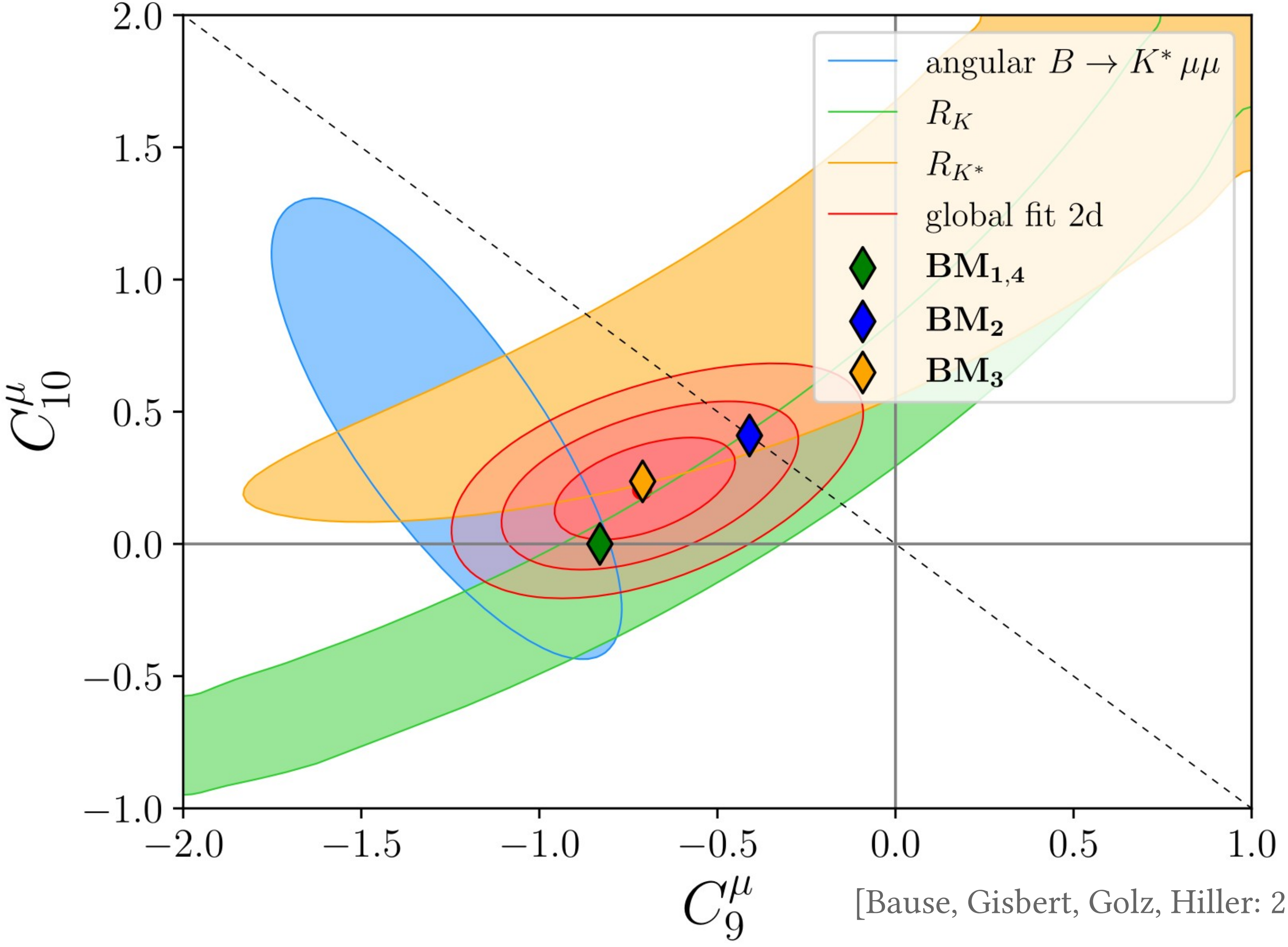
- » B_s mixing bound
- » tame Landau pole
- » *U(1)'* breaking, no additional Yukawas
- » EWSB without *U(1)'* sector

$C_9^\mu \neq 0,\ C_{10}^\mu = 0$ → **BM$_1$** no right-handed neutrinos
→ **BM$_4$** lighter *Z'*

$C_9^\mu = -C_{10}^\mu$ → **BM$_2$**

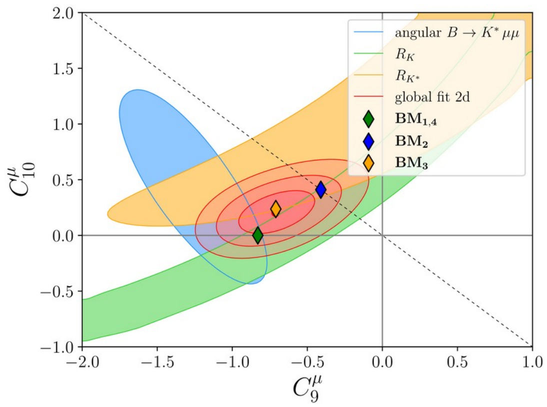
$C_{9,10}^\mu \neq 0$ → **BM$_3$**

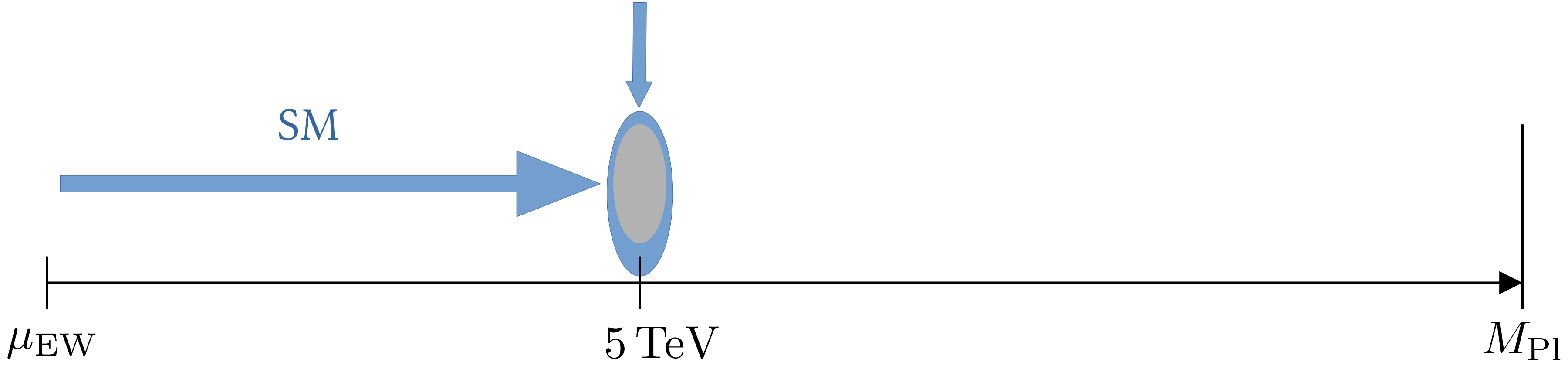


[Bauze, Gisbert, Golz, Hiller: 2109.01675]

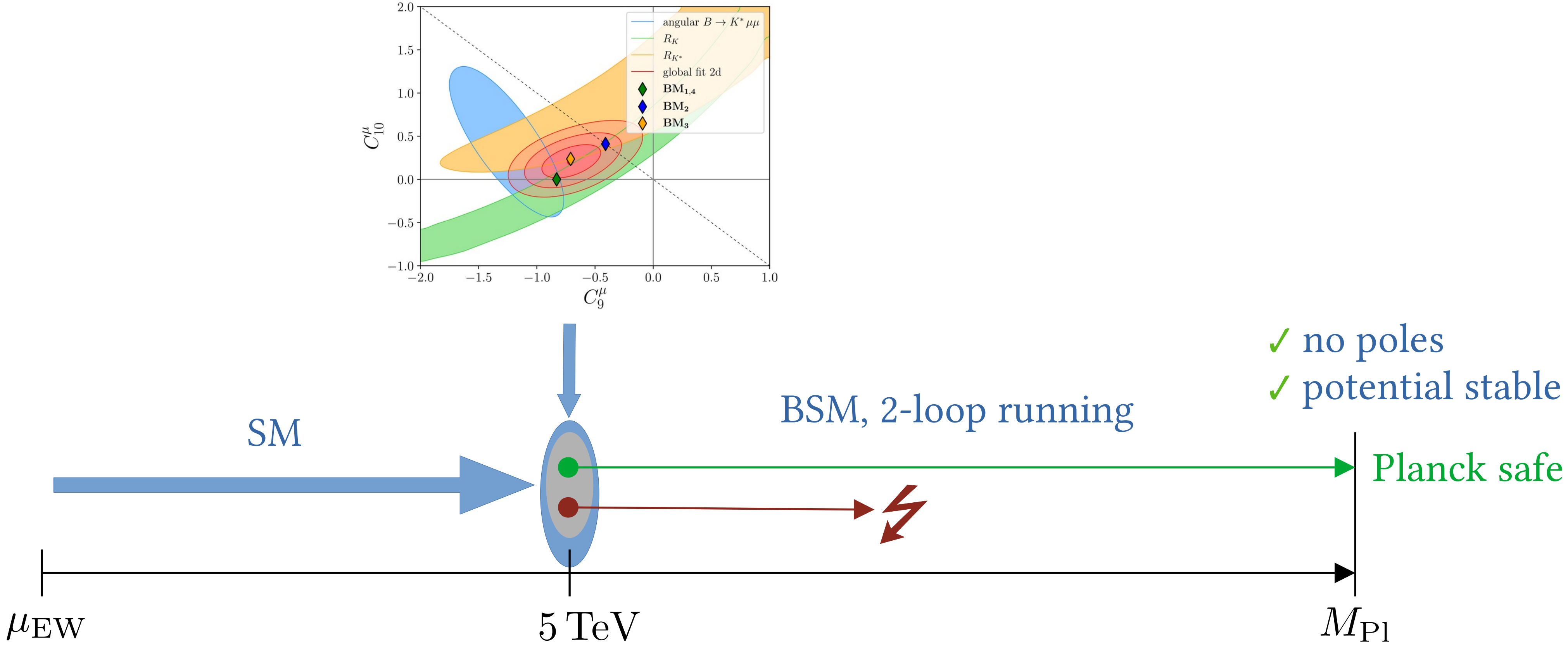
How to check for Planck-Safety

How to check for Planck-Safety

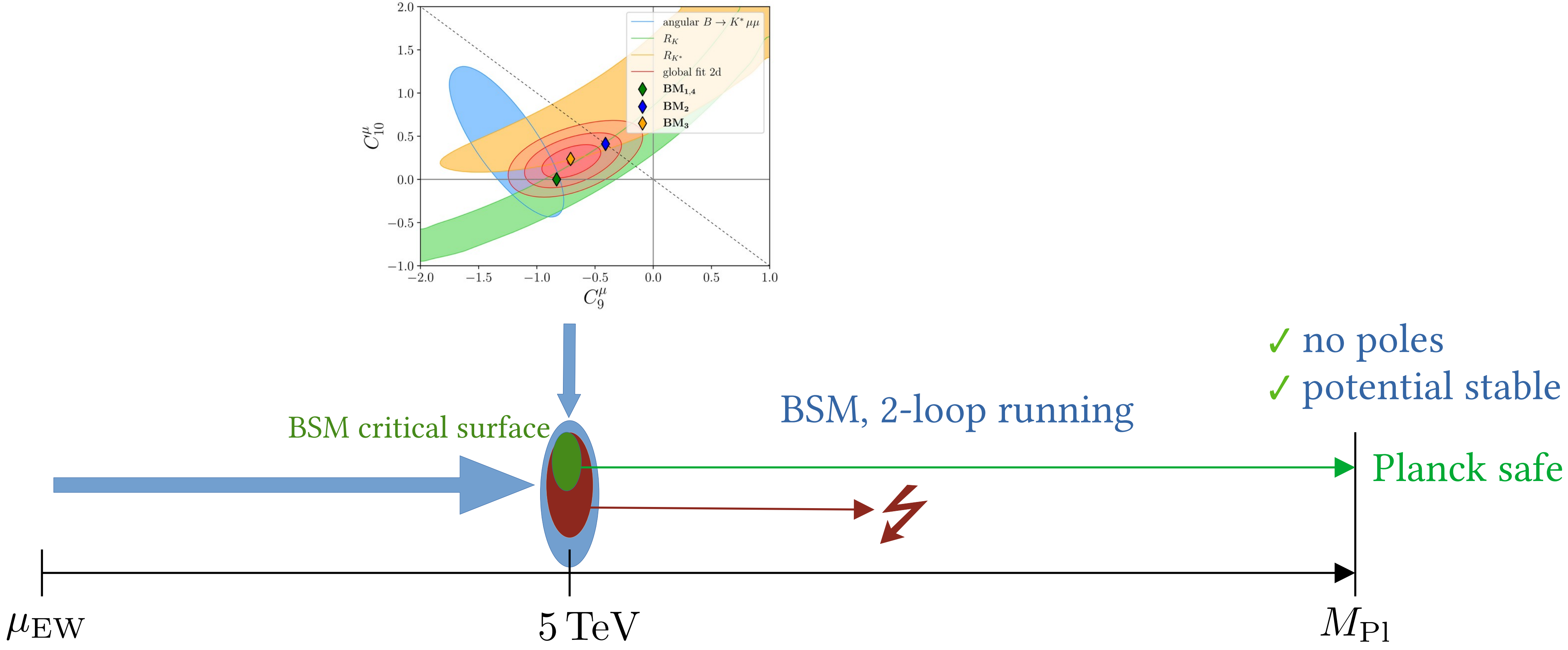




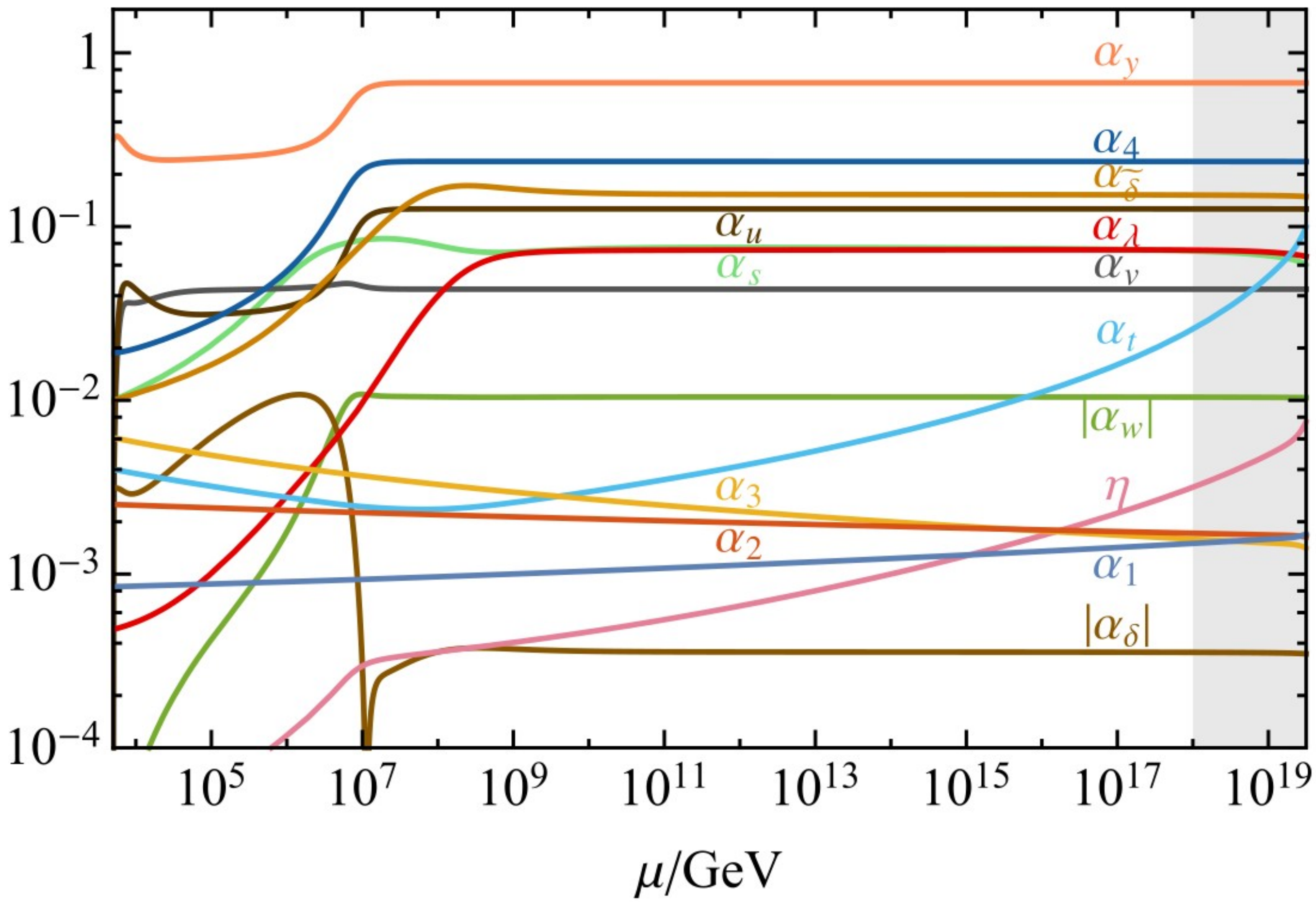
How to check for Planck-Safety



How to check for Planck-Safety

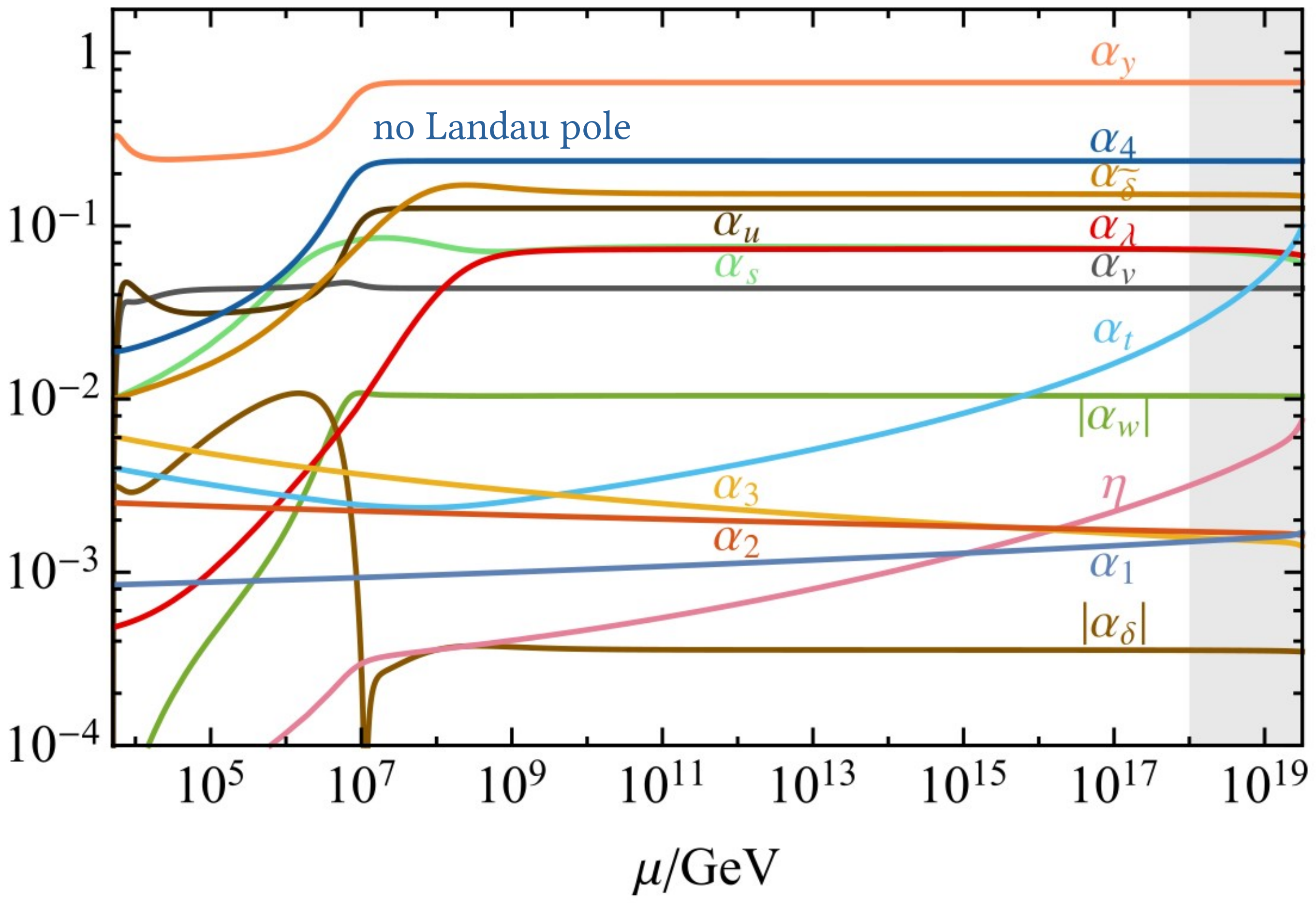


RG running



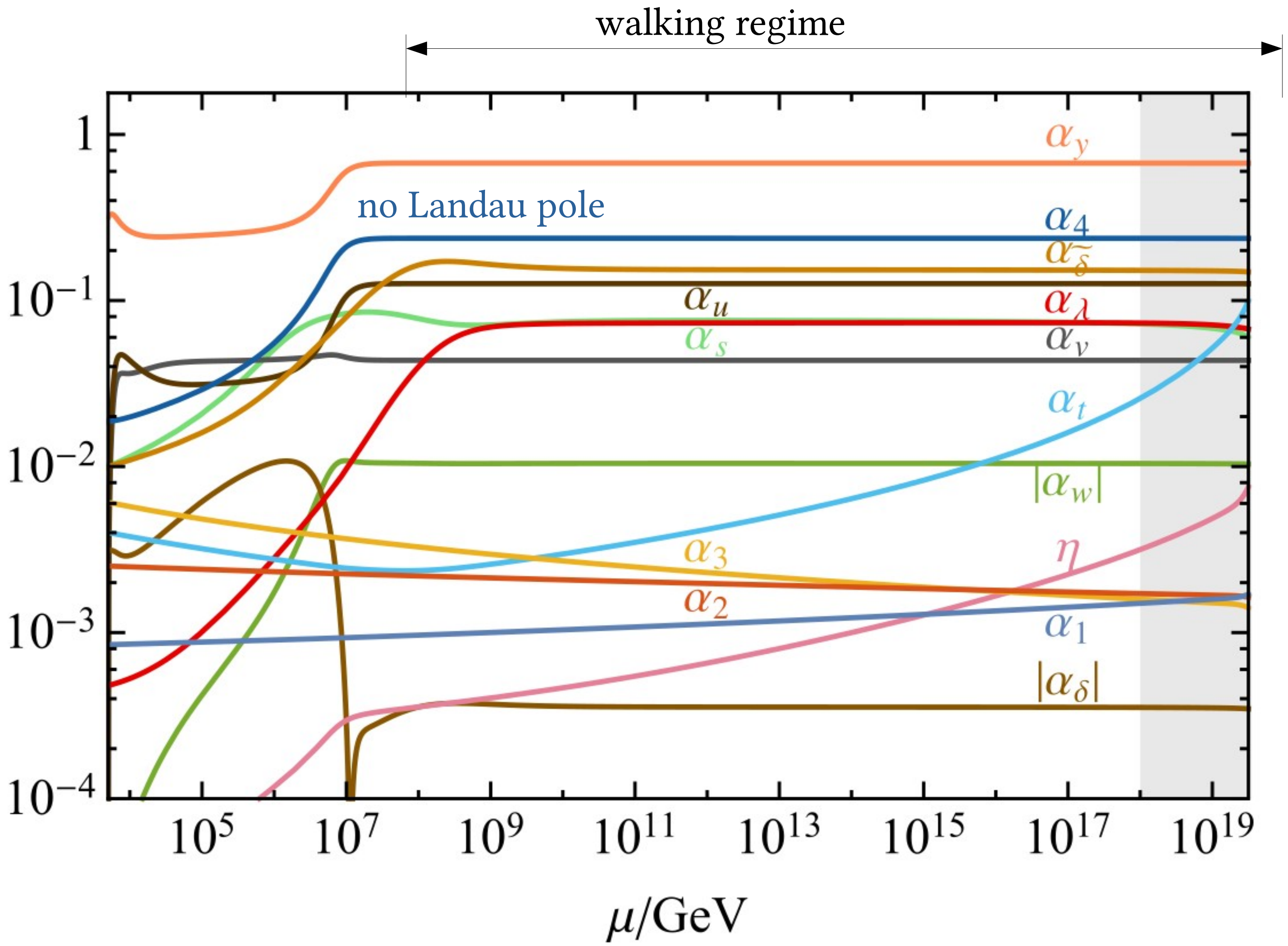
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{5}
10^{7}
10^{9}
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
μ/GeV
α_y
α_4
$\alpha_{\tilde{\delta}}$
α_u
α_λ
α_s
α_v
α_t
$|\alpha_w|$
η
α_3
α_2
α_1
$|\alpha_\delta|$

RG running



α_y
no Landau pole
α_4
$\alpha_{\tilde{\delta}}$
α_u
α_λ
α_s
α_v
α_t
$|\alpha_w|$
α_3
η
α_2
α_1
$|\alpha_\delta|$
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^5
10^7
10^9
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
μ/GeV

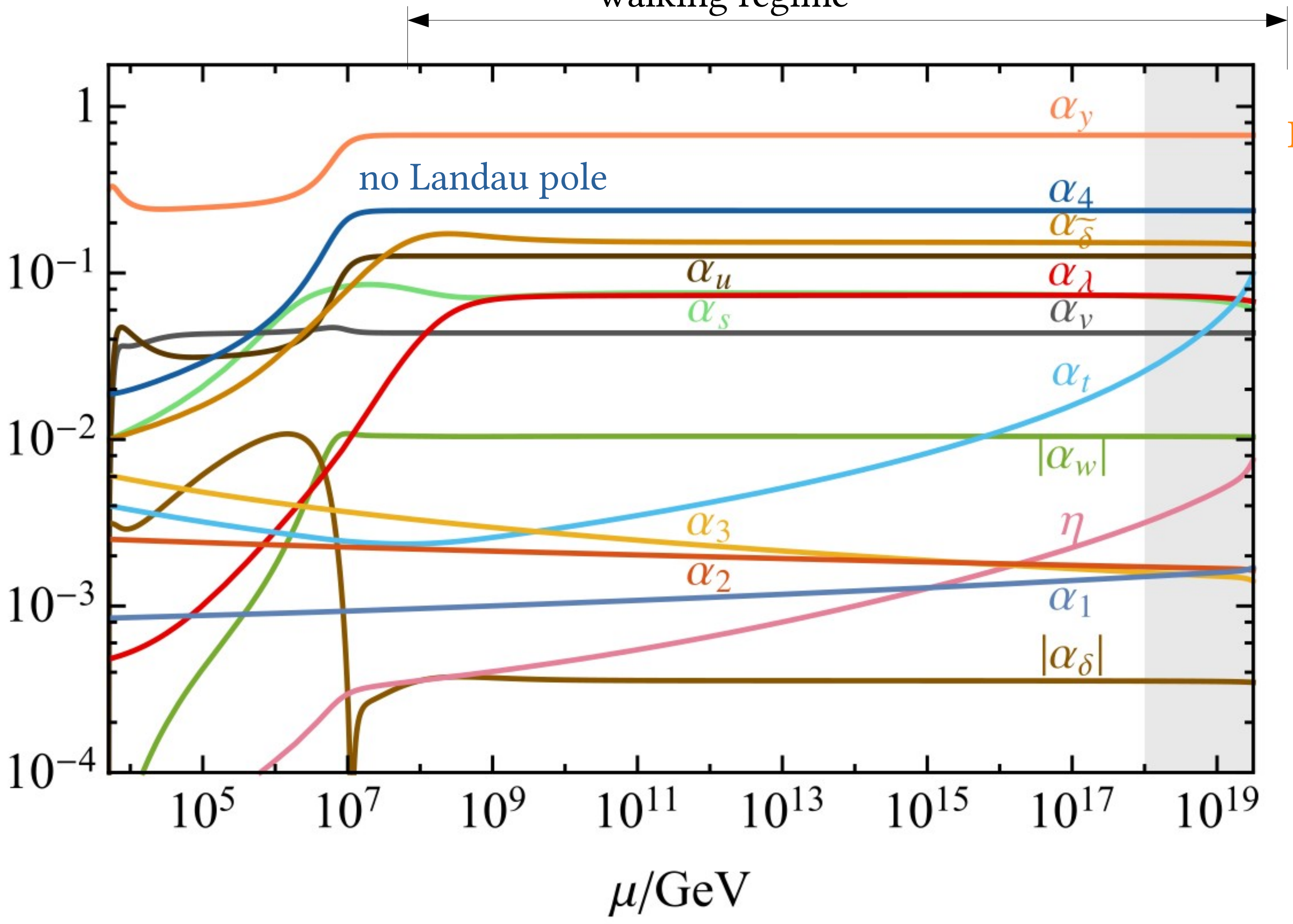
RG running



walking regime
no Landau pole
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^5
10^7
10^9
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
μ/GeV
α_y
α_4
$\alpha_{\tilde{\delta}}$
α_u
α_λ
α_s
α_v
α_t
$|\alpha_w|$
η
α_3
α_2
α_1
$|\alpha_\delta|$

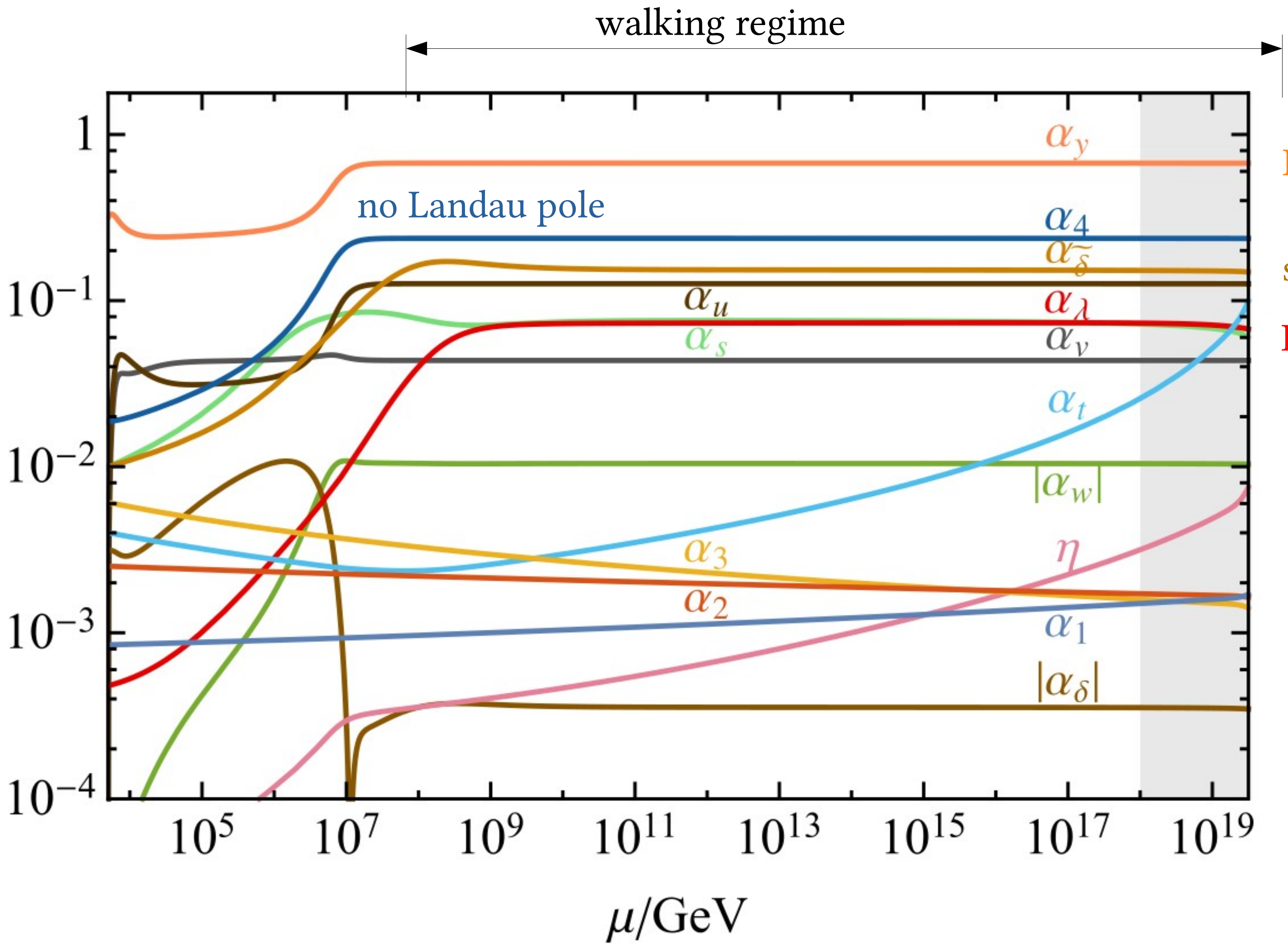
RG running

walking regime



BSM Yukawa brakes Landau pole

RG running

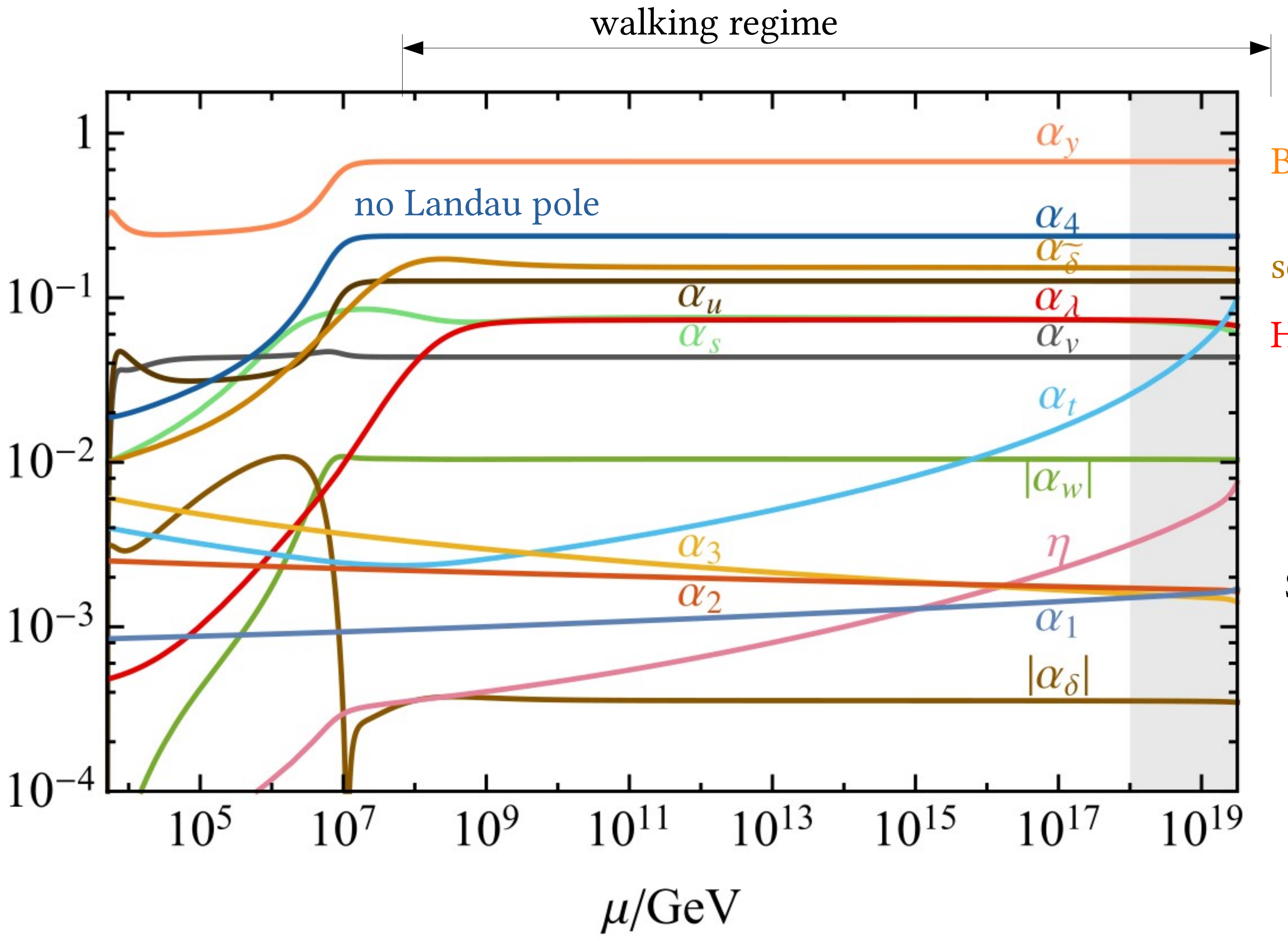


BSM Yukawa brakes Landau pole

scalar portal coupling stabilizes

Higgs potential is stable

RG running



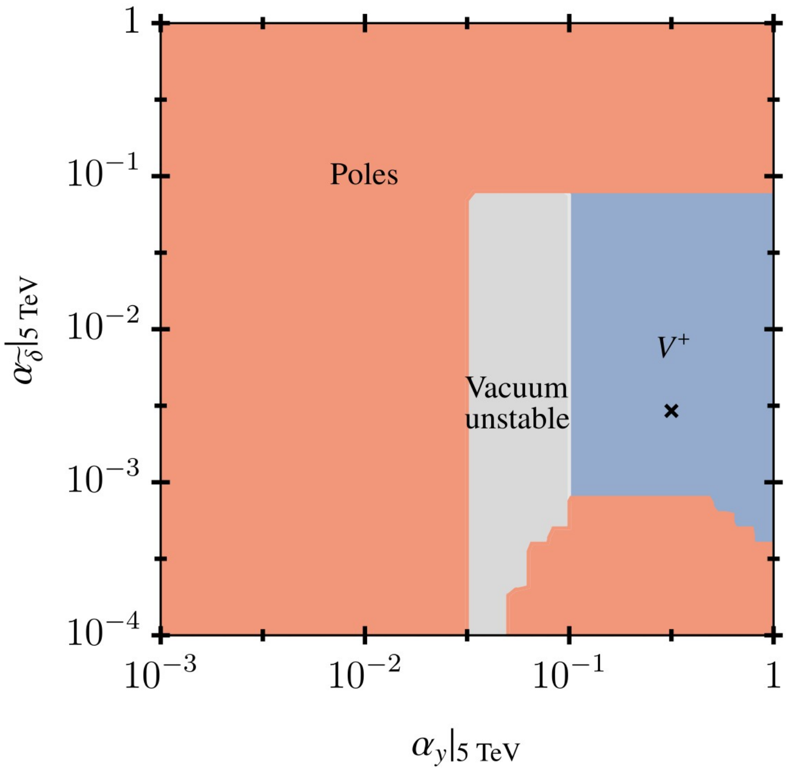
BSM Yukawa brakes Landau pole

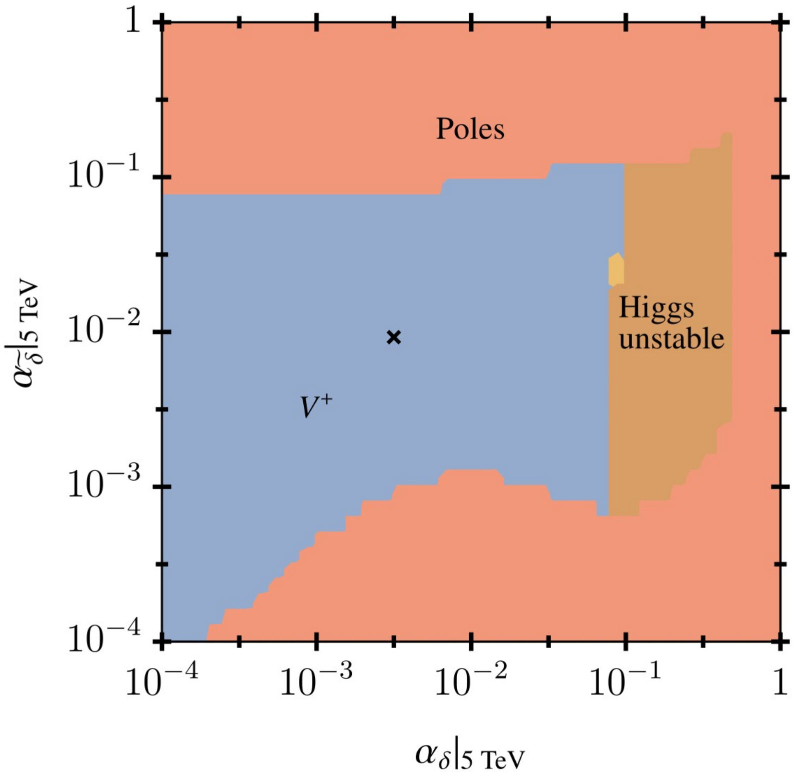
scalar portal coupling stabilizes

Higgs potential is stable

SM gauge couplings not trapped

BSM critical surface

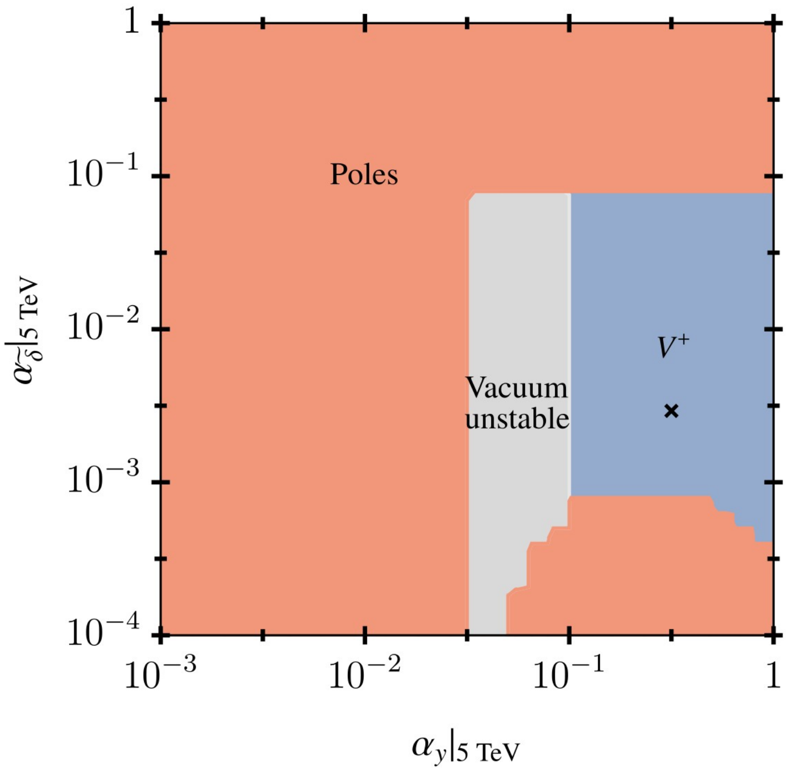


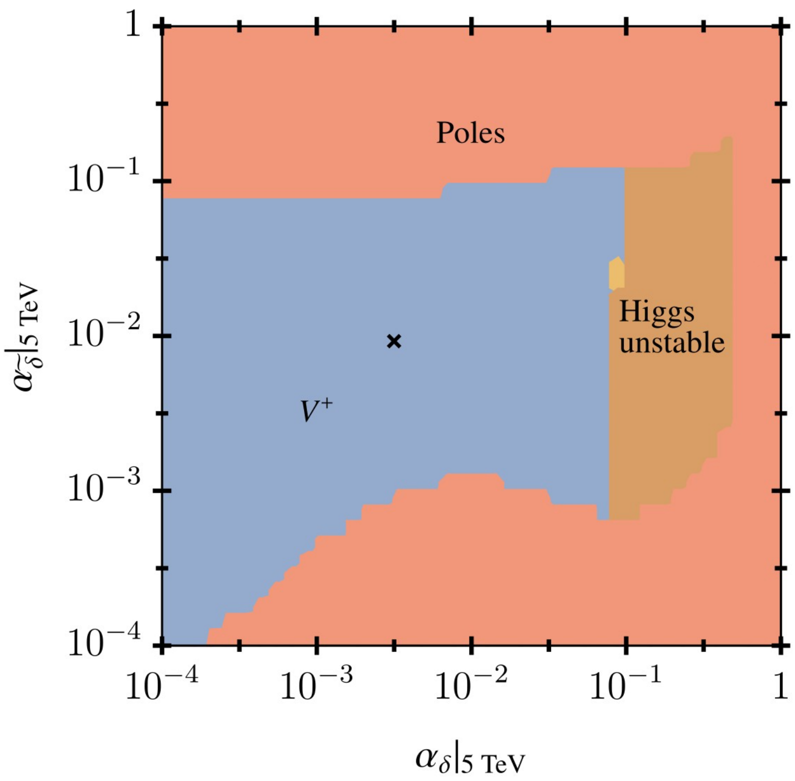


$$-\mathcal{L}_y = y\left(\overline{\psi}_{Li}\, S_{ij}\, \psi_{Rj} + \text{h.c.}\right)$$

$$-\mathcal{L}_{\text{portal}} = \delta\, \mathrm{Tr}\left[S^\dagger S\right](H^\dagger H) + \tilde{\delta}\,(\phi^\dagger\phi)(H^\dagger H)$$

BSM critical surface





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$\alpha_y(\mu_0) \gtrsim 10^{-1.25}\ldots 10^{-1}$

bounds on α_δ, $\alpha_{\tilde\delta}$ vary among BMs

Phenomenology

» broad decay of Z' to invisibles $Z' \to \bar{\psi}\psi,\ \bar{\nu}\nu$ with 65 .. 85% BR

Model	jets	b	t	e	μ	τ	$\nu_{e,\mu,\tau}$	h	$\psi_{1,2,3}$	ϕ
$\mathbf{BM_1}$	0.5	0.5	0.5	0	15	15	15	0	54	0.2
$\mathbf{BM_2}$	14	1.5	1.5	0	9	9	18	0	46	0.1
$\mathbf{BM_3}$	5	0	0	0	4	4	8	0	79	0.1
$\mathbf{BM_4}$	0	0.9	0.9	0	3	11	14	0	72	0.2

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» can be probed & models distinguished at μμ collider:

$$\sigma(\mu^+\mu^- \to Z' \to \bar{\psi}\psi, \bar{\nu}\nu) \approx (10^2..10^3)\, \sigma(\mu^+\mu^- \to Z \to \bar{\nu}\nu)^{\text{SM}}$$

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» only mildly enhanced $B \to K^{(*)}\bar{\nu}\nu$, consistent with SM expectation

Phenomenology

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» only mildly enhanced $B \to K^{(*)}\bar{\nu}\nu$, consistent with SM expectation

» benchmarks are consistent with LHC search [CMS collaboration: 2103.02708]

Summary

Model	μ_0	$\alpha_4(\mu_0)$	C_9^μ	C_{10}^μ	$Y_{ii}^{u,d}$	Y_{ii}^e	Y_{ii}^ν	r_{B_s}	$\mathcal{B}(Z' \to \text{inv.})$	ν_R
$\mathbf{BM_1}$	5 TeV	$1.87 \cdot 10^{-2}$	-0.83	0	✓	✓	X	0.35	73%	X
$\mathbf{BM_2}$	5 TeV	$5.97 \cdot 10^{-3}$	-0.41	$-C_9^\mu$	✓	X	X	0.86	64%	✓
$\mathbf{BM_3}$	5 TeV	$4.60 \cdot 10^{-2}$	-0.71	$+0.24$	✓	X	X	0.60	87%	✓
$\mathbf{BM_4}$	3 TeV	$2.46 \cdot 10^{-2}$	-0.83	0	✓	✓	✓	0.70	86%	✓

Summary

Model	μ_0	$\alpha_4(\mu_0)$	C_9^μ	C_{10}^μ	$Y_{ii}^{u,d}$	Y_{ii}^e	Y_{ii}^ν	r_{B_s}	$\mathcal{B}(Z' \to \text{inv.})$	ν_R
$\mathbf{BM_1}$	5 TeV	$1.87 \cdot 10^{-2}$	-0.83	0	✓	✓	X	0.35	73%	X
$\mathbf{BM_2}$	5 TeV	$5.97 \cdot 10^{-3}$	-0.41	$-C_9^\mu$	✓	X	X	0.86	64%	✓
$\mathbf{BM_3}$	5 TeV	$4.60 \cdot 10^{-2}$	-0.71	$+0.24$	✓	X	X	0.60	87%	✓
$\mathbf{BM_4}$	3 TeV	$2.46 \cdot 10^{-2}$	-0.83	0	✓	✓	✓	0.70	86%	✓

heavy Z' models that

- » explain B-anomalies in several interesting NP scenarios
- » compliant with anomaly cancellation, quark Yukawas, precision measurements
- » are predictive until M_{Pl} $\longrightarrow$ no Landau poles
- » stabilize the Higgs potential
- » can be probed at colliders
- » decay mostly to invisibles