Vectorlike Fermions as Portals into Higgs Stability

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based on arXiv:2207.07737
Phys.Rev.D 106 (2022) 11, 115004

in collaboration with
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PIKIMO – April 29th 2023

Problem?

- Higgs potential in the SM is metastable [Degrassi, Di Vita, Miro, Espinosa, Giudice, Isidori, Strumia '12]
  [Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia '13]

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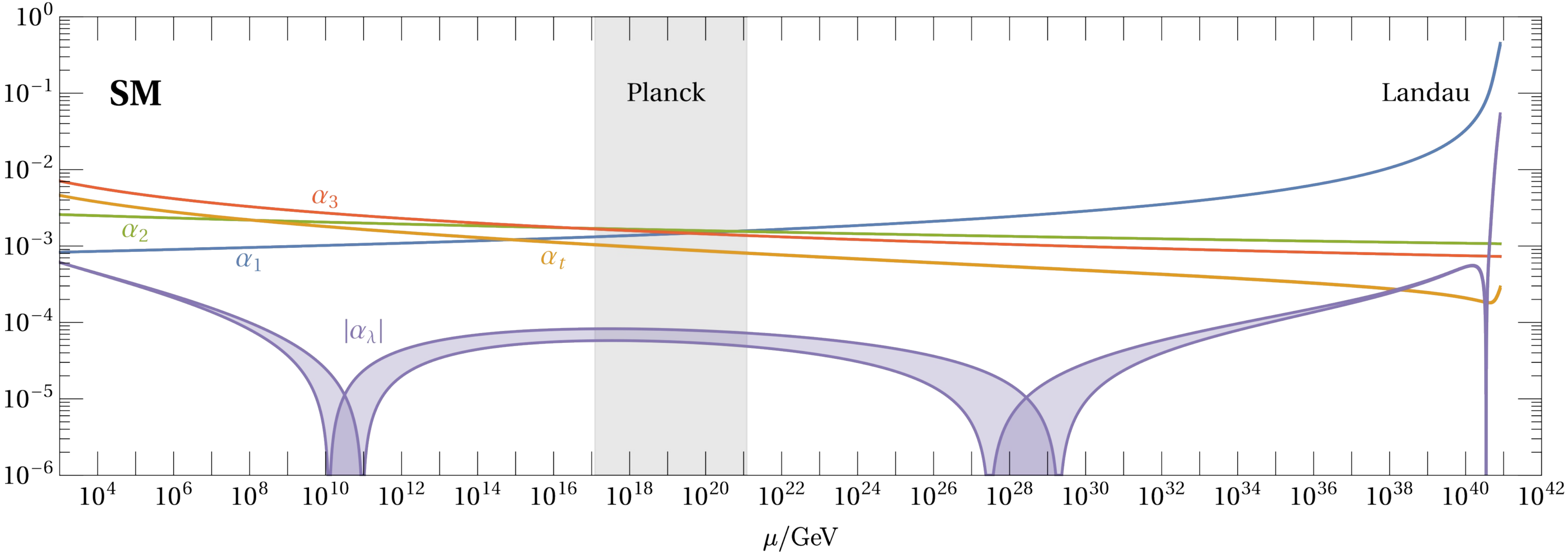

» metastability: $\lambda < 0$ around 10^{10} GeV

» Landau pole around 10^{41} GeV

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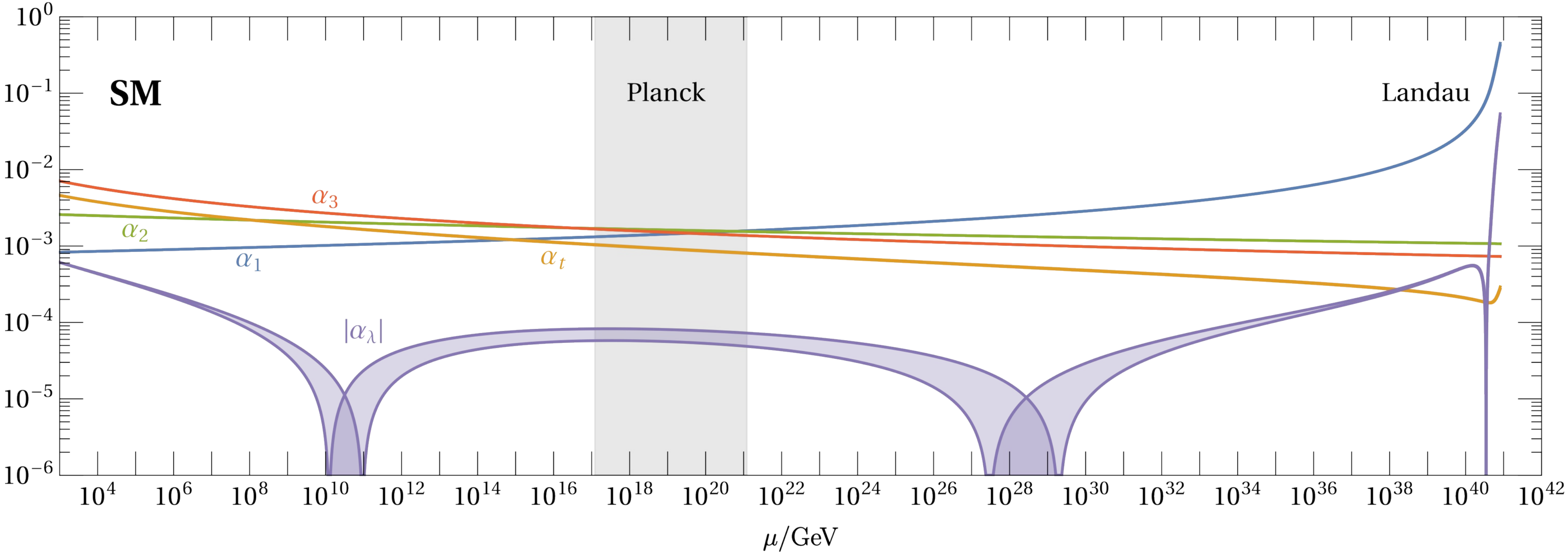

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What is the easiest way to cure metastability?

Can the SM metastability be cured?

» common approach: BSM scalar fields S

$\longrightarrow$ scalar portal coupling $\propto \delta\,(H^\dagger H)(S^\dagger S)$

$\longrightarrow$ uplift of the Higgs coupling $\propto \lambda\,(H^\dagger H)^2$ $\quad \beta_\lambda = \beta_\lambda^{\mathrm{SM}} + c\,\delta^2$

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» Our Models:

$\longrightarrow$ N_F vector-like fermions

$\longrightarrow$ mass M_F can be TeV-ish or higher

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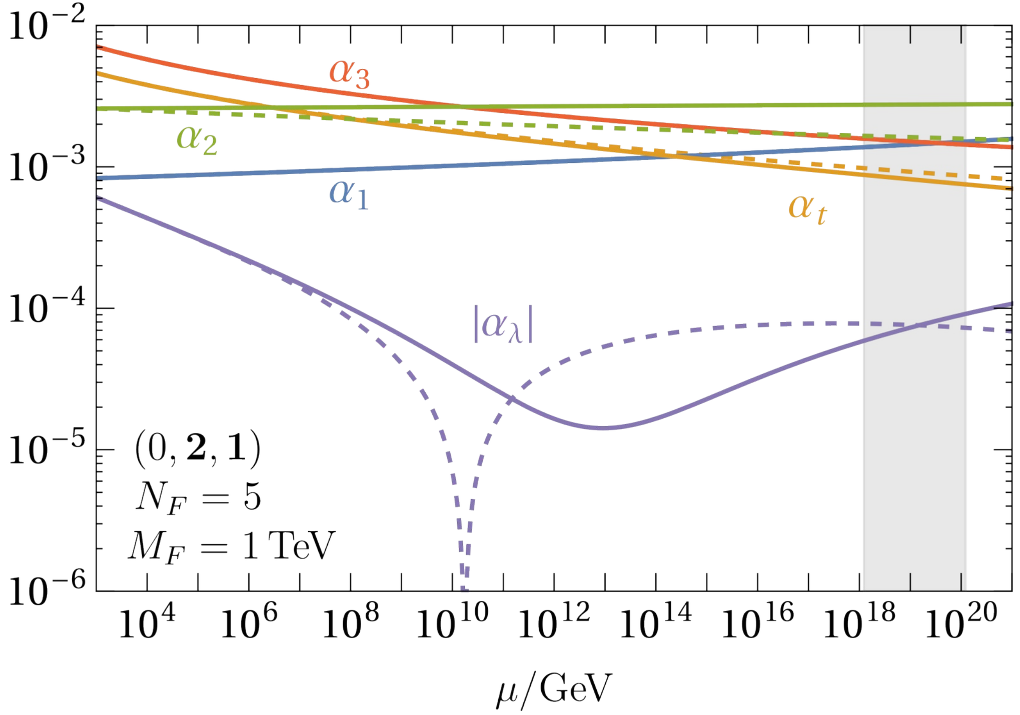
Example: Isospin portal $(0, \mathbf{2}, \mathbf{1})$



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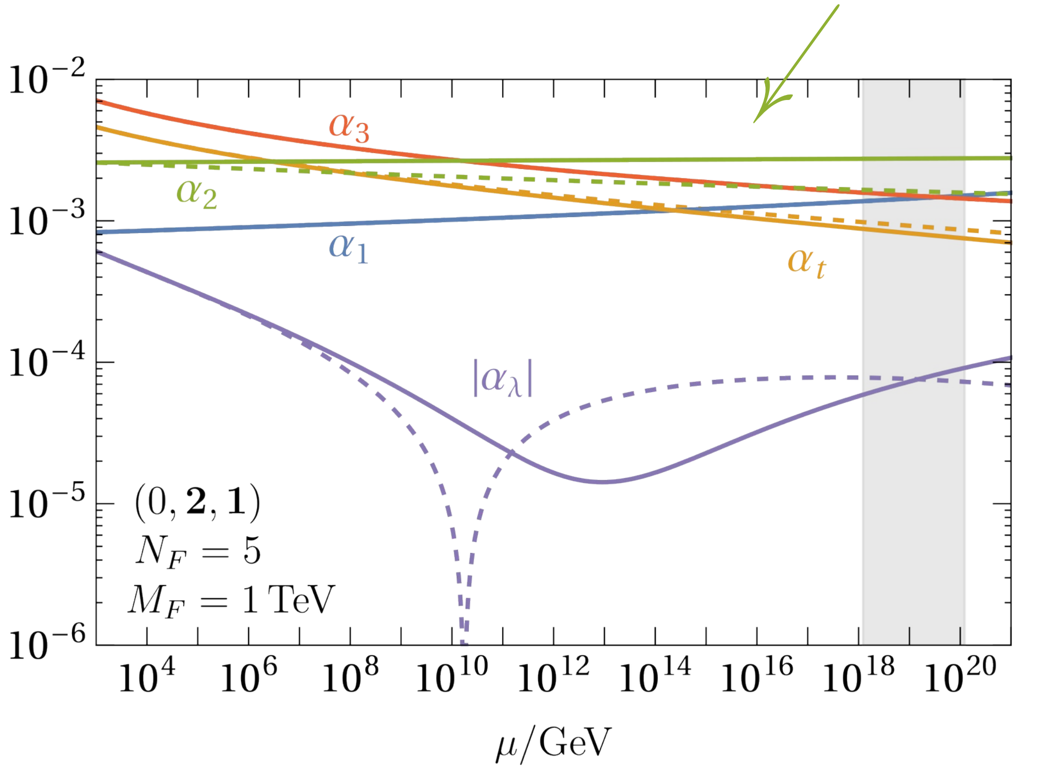
$$\beta_2 = \left(-\tfrac{19}{3} + \# N_F\right)\alpha_2^2 \quad \rightarrow \quad \alpha_2 > \alpha_2^{\rm SM}$$



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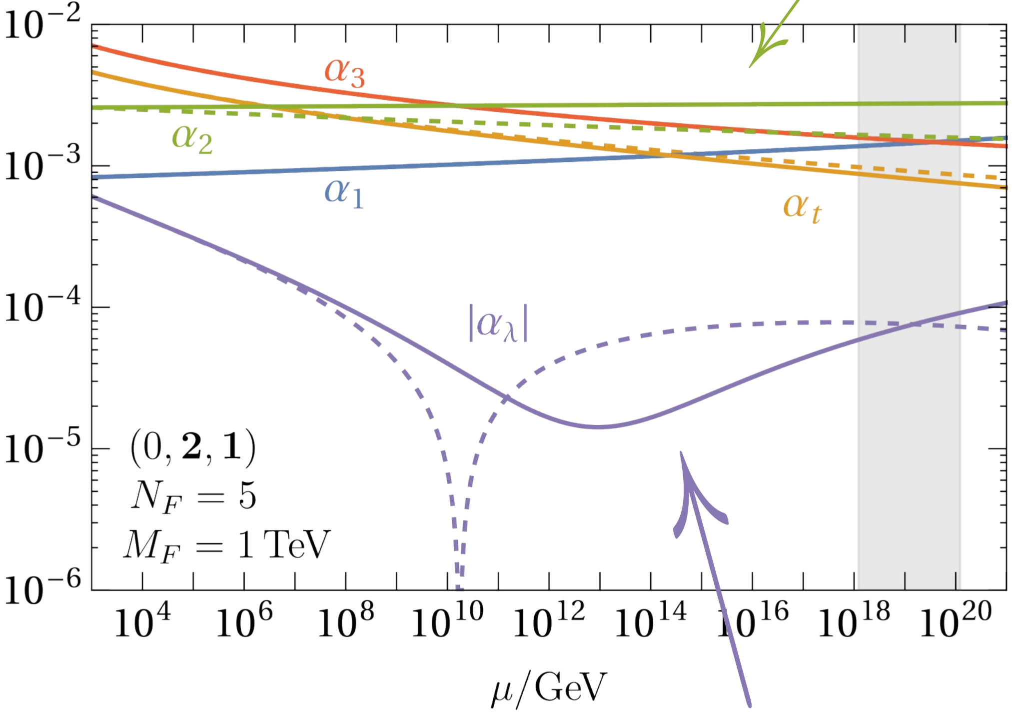

$$\beta_\lambda \approx \tfrac{3}{8}\left[\alpha_1^2 + 2\,\alpha_1\alpha_2 + 3\,\alpha_2^2\right] - 6\,\alpha_t^2$$

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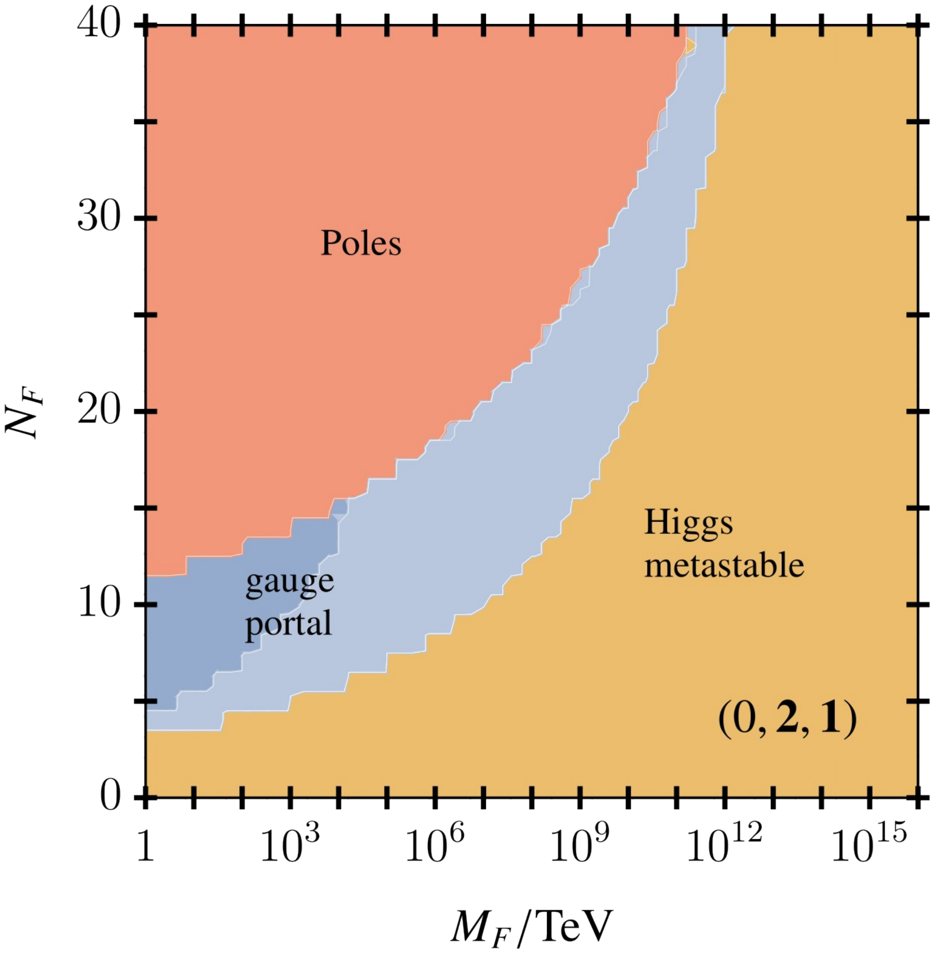

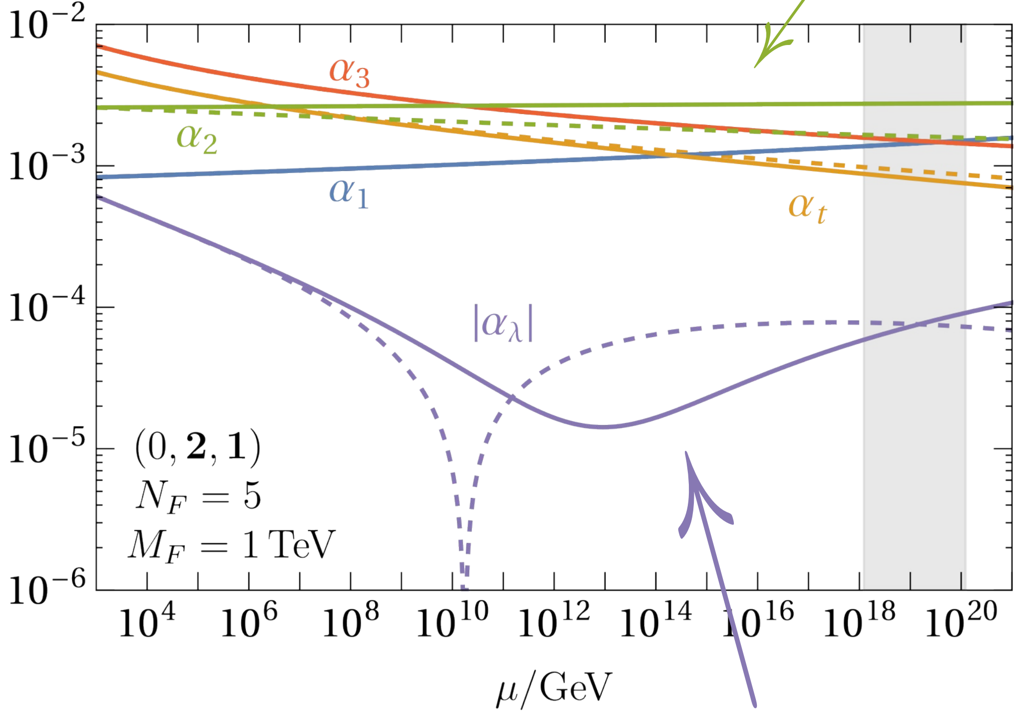

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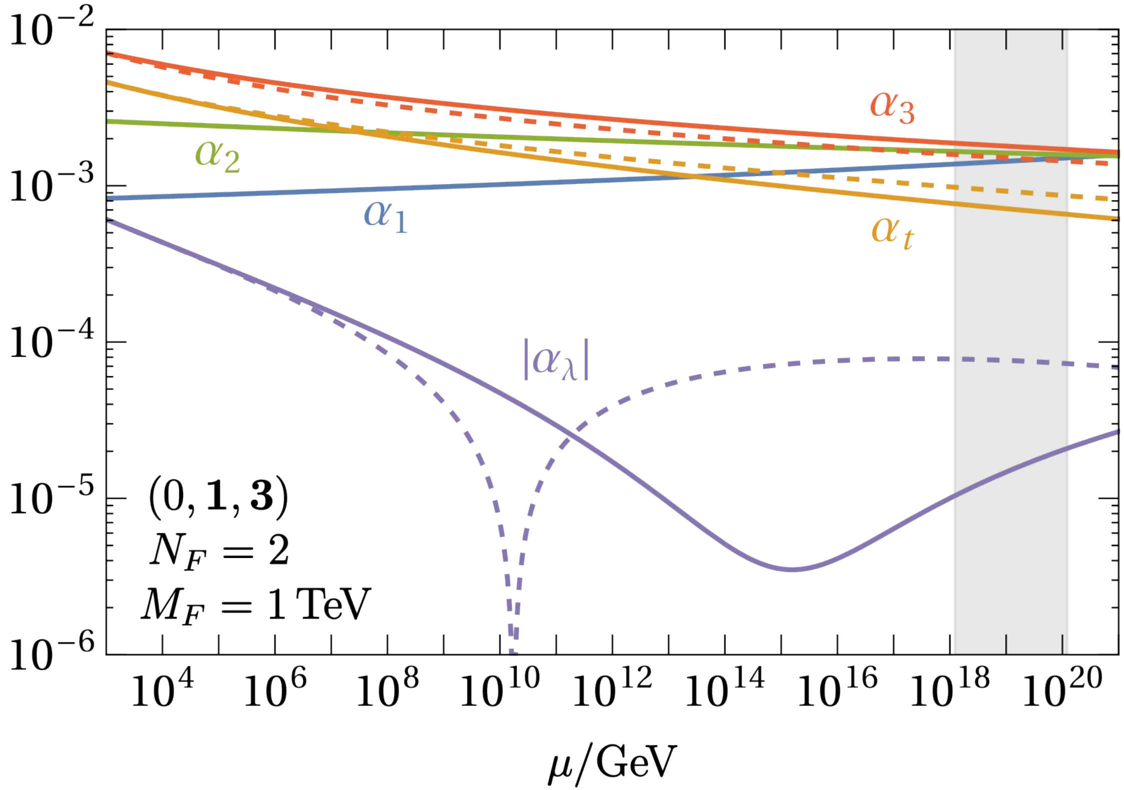

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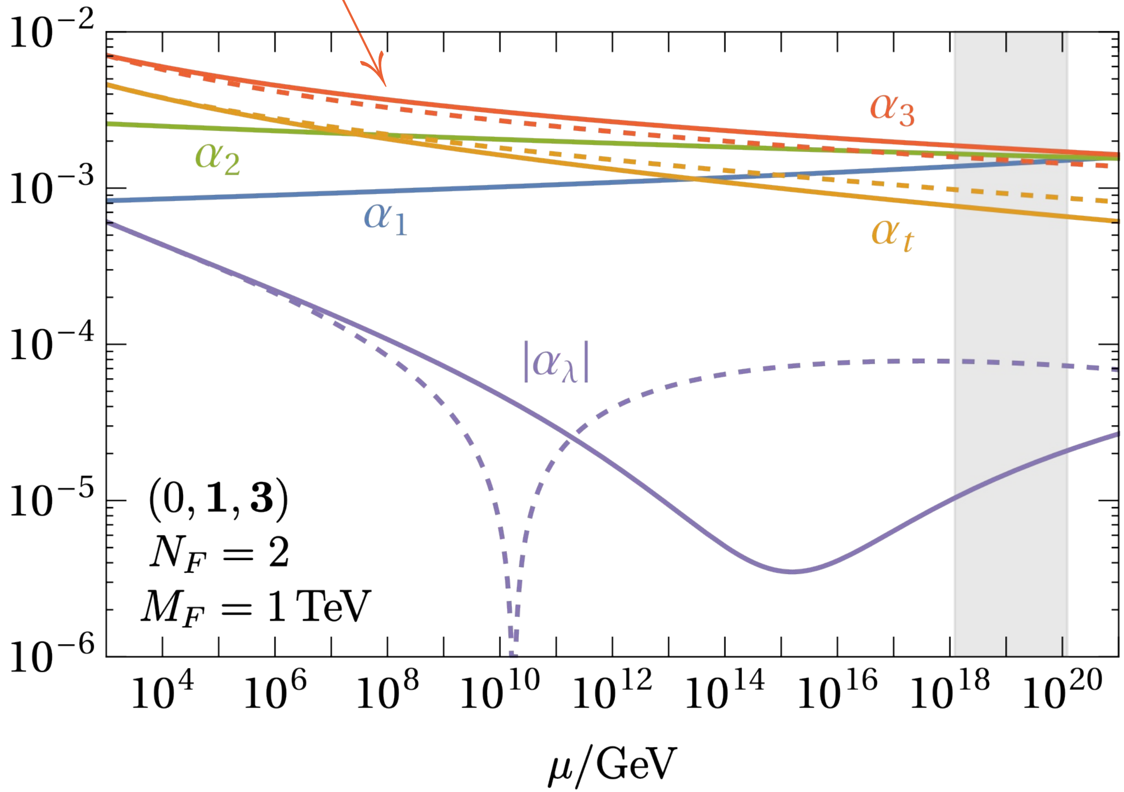

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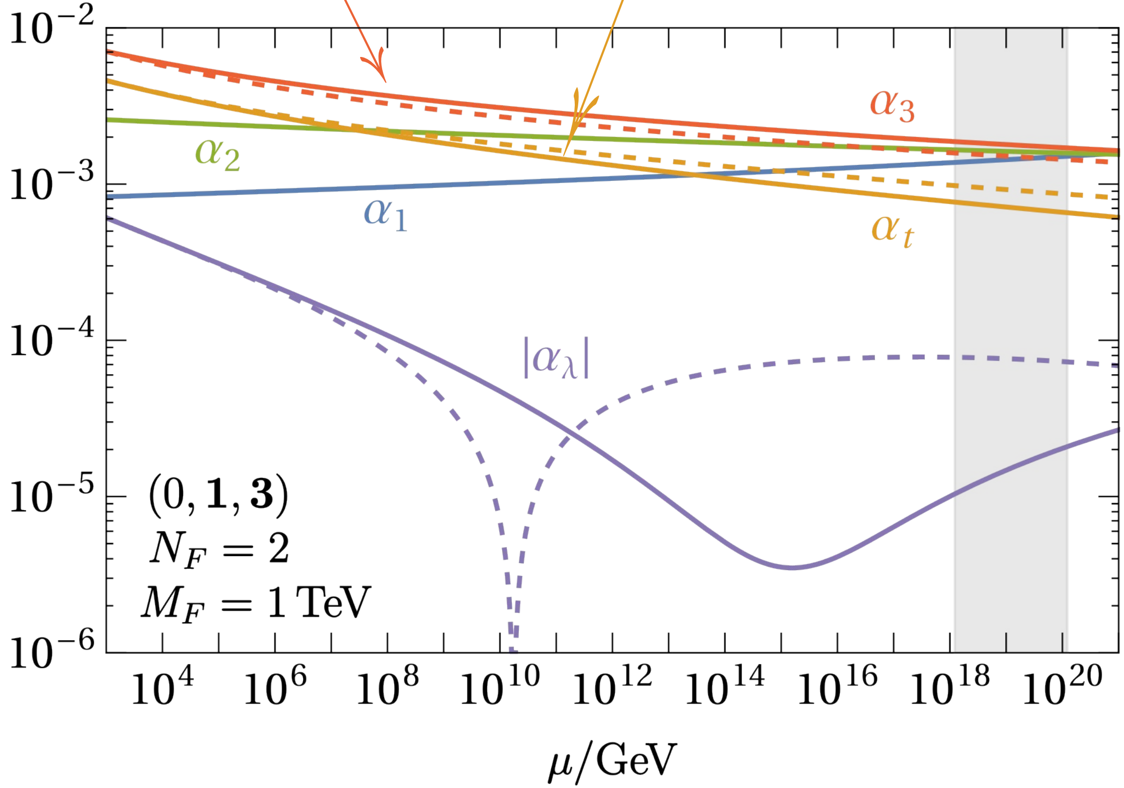

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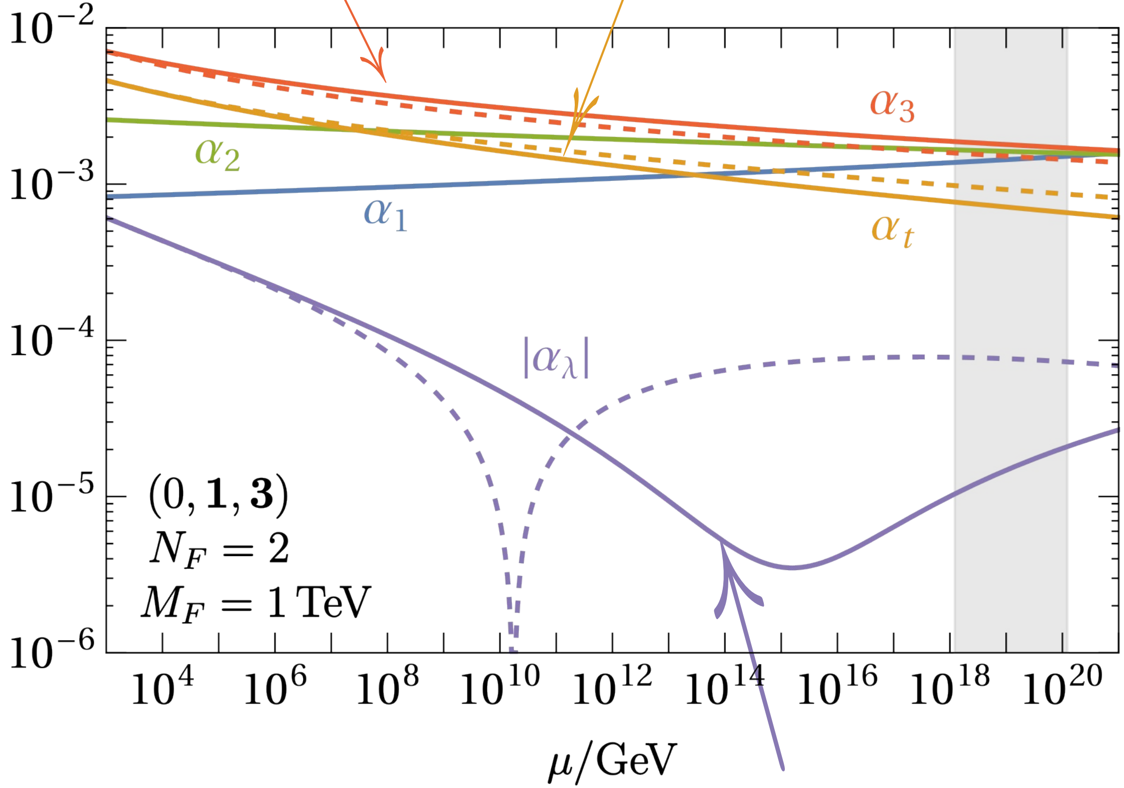

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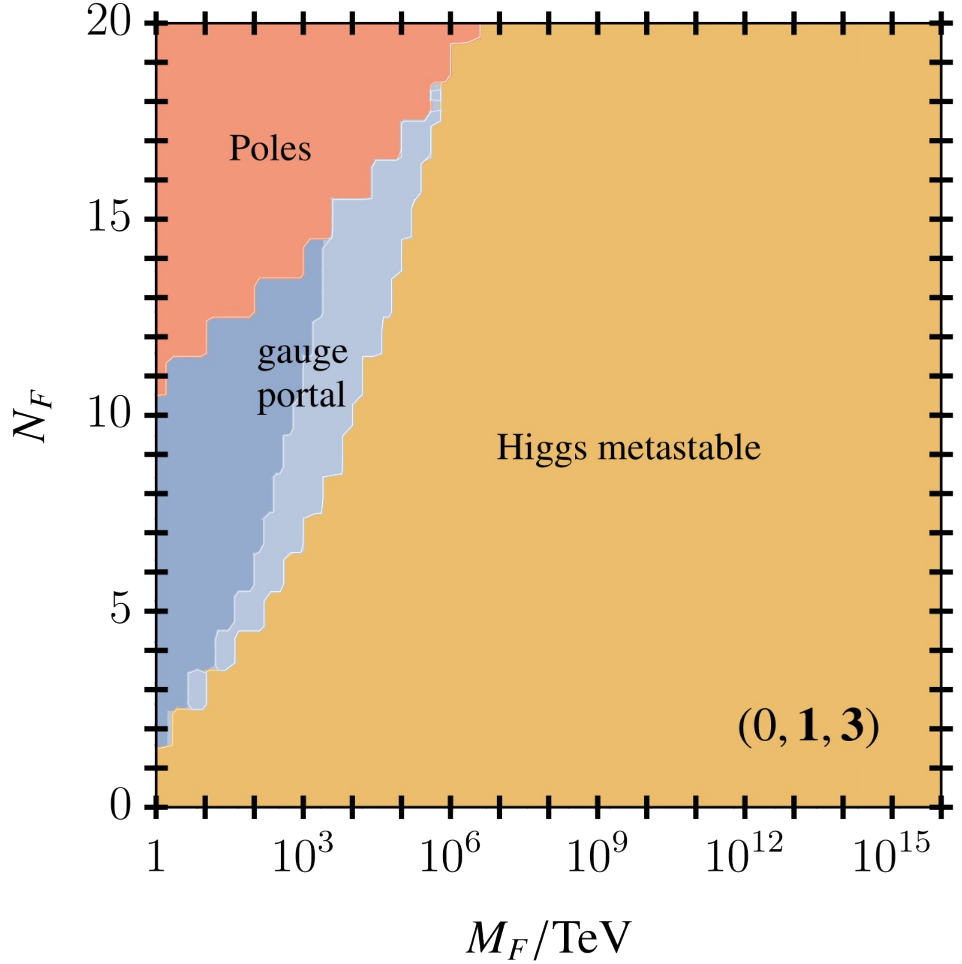

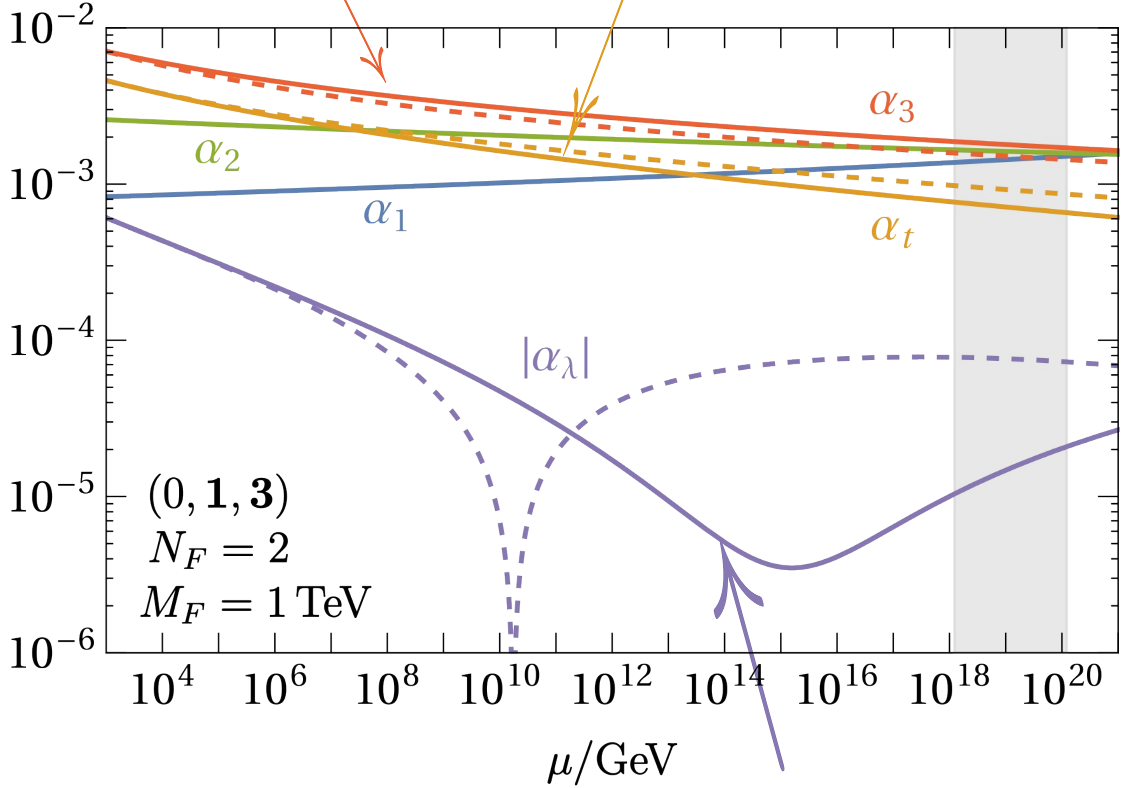

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- » but: some reps. allow for SM-BSM interaction with Higgs

Model	(Y_F, d_2, d_3)	Poles N_F^{pole}	α^{pole}	Stability $\alpha_\lambda\|_{M_{\text{Pl}}} \geq 0$	$\alpha_\lambda \geq 0$
A	$(-1, \mathbf{1}, \mathbf{1})$	7	α_1	$N_F = 6$	X
B	$(-1, \mathbf{3}, \mathbf{1})$	3	α_1	$1 \leq N_F \leq 2$	$1 \leq N_F \leq 2$
C	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1})$	12	α_2	$3 \leq N_F \leq 11$	$5 \leq N_F \leq 11$
D	$(-\frac{3}{2}, \mathbf{2}, \mathbf{1})$	2	α_1	$N_F = 1$	X
E	$(0, \mathbf{1}, \mathbf{1})$	n.a.		X	X
F	$(0, \mathbf{3}, \mathbf{1})$	3	α_2	$1 \leq N_F \leq \frac{5}{2}$	$\frac{3}{2} \leq N_F \leq \frac{5}{2}$
G	$(-\frac{1}{3}, \mathbf{1}, \mathbf{3})$	11	α_3	$2 \leq N_F \leq 10$	$2 \leq N_F \leq 10$
H	$(+\frac{2}{3}, \mathbf{1}, \mathbf{3})$	6	α_1	$2 \leq N_F \leq 5$	$2 \leq N_F \leq 5$
I	$(-\frac{1}{3}, \mathbf{3}, \mathbf{3})$	1	α_2	X	X
J	$(+\frac{2}{3}, \mathbf{3}, \mathbf{3})$	1	α_2	X	X
K	$(+\frac{1}{6}, \mathbf{2}, \mathbf{3})$	4	α_2	$1 \leq N_F \leq 3$	$1 \leq N_F \leq 3$
L	$(+\frac{7}{6}, \mathbf{2}, \mathbf{3})$	1	α_1	X	X
M	$(-\frac{5}{6}, \mathbf{2}, \mathbf{3})$	2	α_1	$N_F = 1$	$N_F = 1$

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Model	(Y_F, d_2, d_3)	Poles $N_F^{\rm pole}$	$\alpha^{\rm pole}$	Stability $\alpha_\lambda\vert_{M_{\rm Pl}} \geq 0$	$\alpha_\lambda \geq 0$	Yukawa
A	$(-1, \mathbf{1}, \mathbf{1})$	7	α_1	$N_F = 6$	X	$\kappa_{ij}\,\overline{L}_i H \psi_{Rj}$
B	$(-1, \mathbf{3}, \mathbf{1})$	3	α_1	$1 \leq N_F \leq 2$	$1 \leq N_F \leq 2$	$\kappa_{ij}\,\overline{L}_i \psi_{Rj} H$
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D	$(-\frac{3}{2}, \mathbf{2}, \mathbf{1})$	2	α_1	$N_F = 1$	X	$\kappa_{ij}\,\overline{\psi}_{Li} H^c E_j$
E	$(0, \mathbf{1}, \mathbf{1})$	n.a.		X	X	$\kappa_{ij}\,\overline{L}_i H^c \psi_{Rj}$
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K	$(+\frac{1}{6}, \mathbf{2}, \mathbf{3})$	4	α_2	$1 \leq N_F \leq 3$	$1 \leq N_F \leq 3$	$\kappa^u_{ij}\,\overline{\psi}_{Li} H^c U_j + \kappa^d_{ij}\,\overline{\psi}_{Li} H D_j$
L	$(+\frac{7}{6}, \mathbf{2}, \mathbf{3})$	1	α_1	X	X	$\kappa_{ij}\,\overline{\psi}_{Li} H U_j$
M	$(-\frac{5}{6}, \mathbf{2}, \mathbf{3})$	2	α_1	$N_F = 1$	$N_F = 1$	$\kappa_{ij}\,\overline{\psi}_{Li} H^c D_j$

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- coupling α_κ moves gauge Landau poles to higher scales

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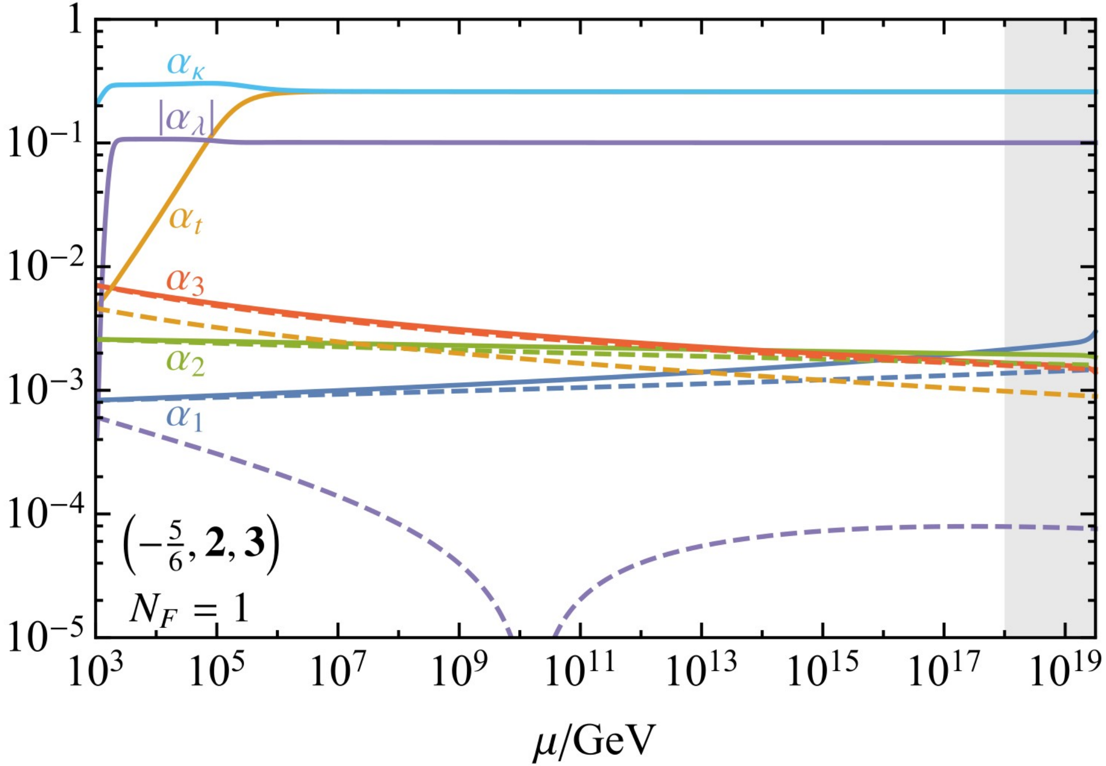

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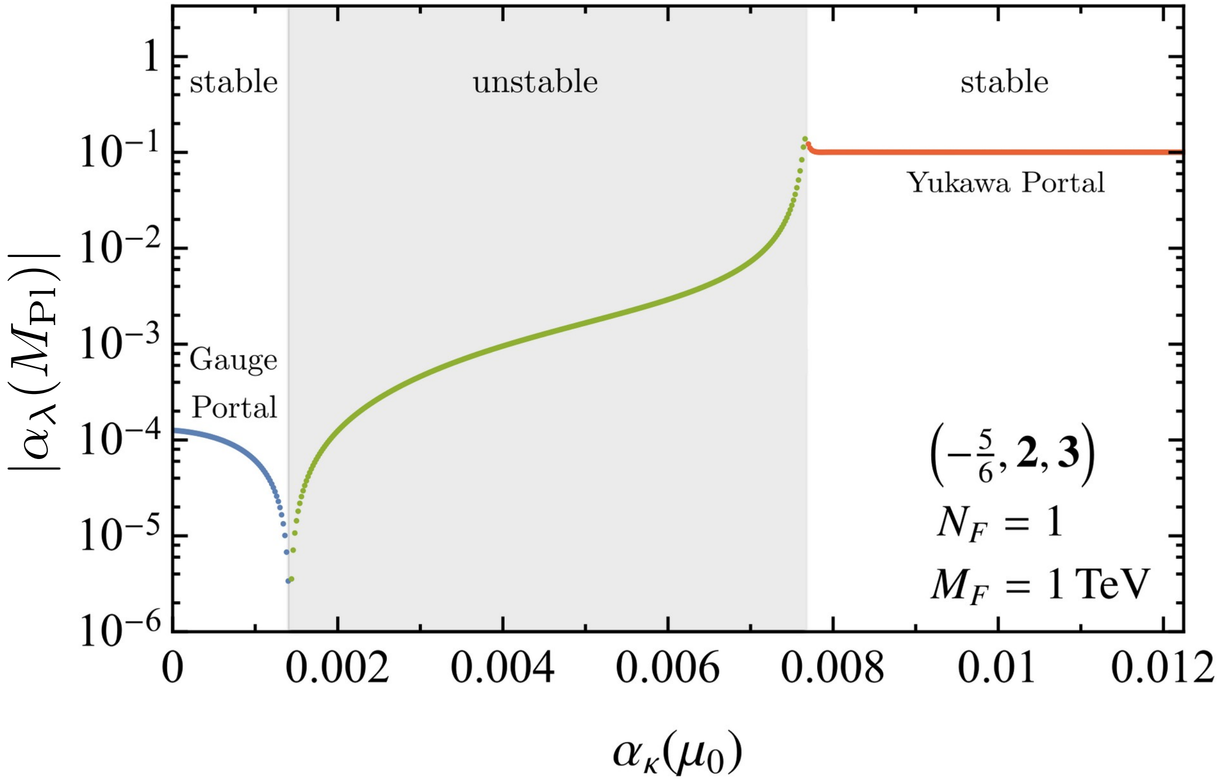
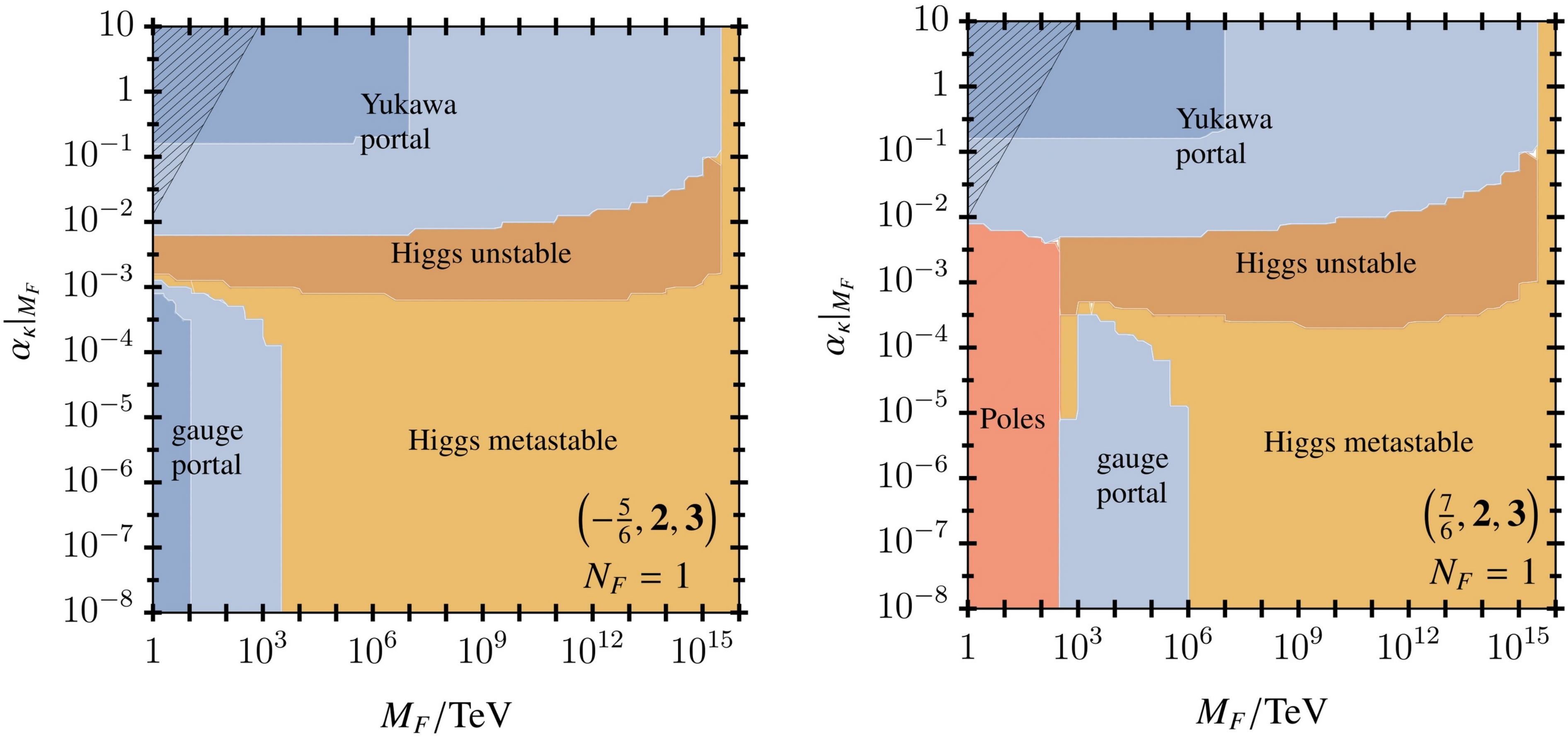


Yukawa portal

Model	(Y_F, d_2, d_3)	Interactions	Gauge Portal	Yukawa Portal
A	$(-1, \mathbf{1}, \mathbf{1})$	$\kappa\, \overline{L}_3 H \psi_R$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(6\cdot 10^{-3})$
B	$(-1, \mathbf{3}, \mathbf{1})$	$\kappa\, \overline{L}_3 \psi_R H$	$\alpha_\kappa\vert_{1\text{ TeV}} \lesssim 2\cdot 10^{-4}\,(1.6\cdot 10^{-3})$	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.4\,(1.6\cdot 10^{-2})$
C	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1})$	$\kappa\, \overline{\psi}_L H E_3$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(6\cdot 10^{-3})$
D	$(-\frac{3}{2}, \mathbf{2}, \mathbf{1})$	$\kappa\, \overline{\psi}_L H^c E_3$	$(\alpha_\kappa\vert_{1\text{ TeV}} \lesssim 3\cdot 10^{-5})$	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(8\cdot 10^{-3})$
E	$(\,0,\ \mathbf{1}, \mathbf{1})$	$\kappa\, \overline{L}_3 H^c \psi_R$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(5\cdot 10^{-3})$
F	$(\,0,\ \mathbf{3}, \mathbf{1})$	$\kappa\, \overline{L}_3 \psi_R H^c$	$(\alpha_\kappa\vert_{1\text{ TeV}} \lesssim 10^{-3})$	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.4\,(1.6\cdot 10^{-2})$
G	$(-\frac{1}{3}, \mathbf{1}, \mathbf{3})$	$\kappa\, \overline{Q}_3 H \psi_R$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(1\cdot 10^{-2})$
H	$(+\frac{2}{3}, \mathbf{1}, \mathbf{3})$	$\kappa\, \overline{Q}_3 H^c \psi_R$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(6\cdot 10^{-3})$
I	$(-\frac{1}{3}, \mathbf{3}, \mathbf{3})$	$\kappa\, \overline{Q}_3 \psi_R H$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.6\,(0.3)$
J	$(+\frac{2}{3}, \mathbf{3}, \mathbf{3})$	$\kappa\, \overline{Q}_3 \psi_R H^c$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.6\,(0.3)$
K	$(+\frac{1}{6}, \mathbf{2}, \mathbf{3})$	$\kappa_t\, \overline{\psi}_L H^c U_3 + \kappa_b\, \overline{\psi}_L H D_3$	$\alpha_{\kappa_t,\kappa_b(\kappa_t)}\vert_{1\text{ TeV}} \lesssim 10^{-5}\,(10^{-4})$	$\alpha_{\kappa_t,\kappa_b}\vert_{1\text{ TeV}} \gtrsim 0.25\,(0.13)$
L	$(+\frac{7}{6}, \mathbf{2}, \mathbf{3})$	$\kappa\, \overline{\psi}_L H U_3$	X	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.20\,(10^{-2})$
M	$(-\frac{5}{6}, \mathbf{2}, \mathbf{3})$	$\kappa\, \overline{\psi}_L H^c D_3$	$\alpha_\kappa\vert_{1\text{ TeV}} \lesssim 8\cdot 10^{-4}\,(1.4\cdot 10^{-3})$	$\alpha_\kappa\vert_{1\text{ TeV}} \gtrsim 0.2\,(8\cdot 10^{-3})$

$$N_F = 1\,,\ \ M_F = 1\ \text{TeV}$$

Yukawa portal



Conclusion

» *stable great desert*: Theory is well defined, predictive until Planck scale with stabilized Higgs potential

» no BSM scalars required

» opportunities to connect with flavor physics

» gauge portal: weakly coupled mechanism!

$\longrightarrow$ charged/colored long-lived particles, diboson resonances, R-hadrons

» Yukawa portal

$\longrightarrow$ prompt decay to SM particles already for feeble values $\alpha_\kappa M_F \gtrsim 10^{-14}$ TeV

$\longrightarrow$ global SMEFT fits, FCNC bounds