asymptotic safety BSM

Daniel F Litim

University of Sussex

52nd Moriond EW, 21 Mar 2017

AD Bond, G Hiller, K Kowalska, DF Litim, 1702.01727
AD Bond, DF Litim, 1608.00519
DF Litim, F Sannino, 1406.2337

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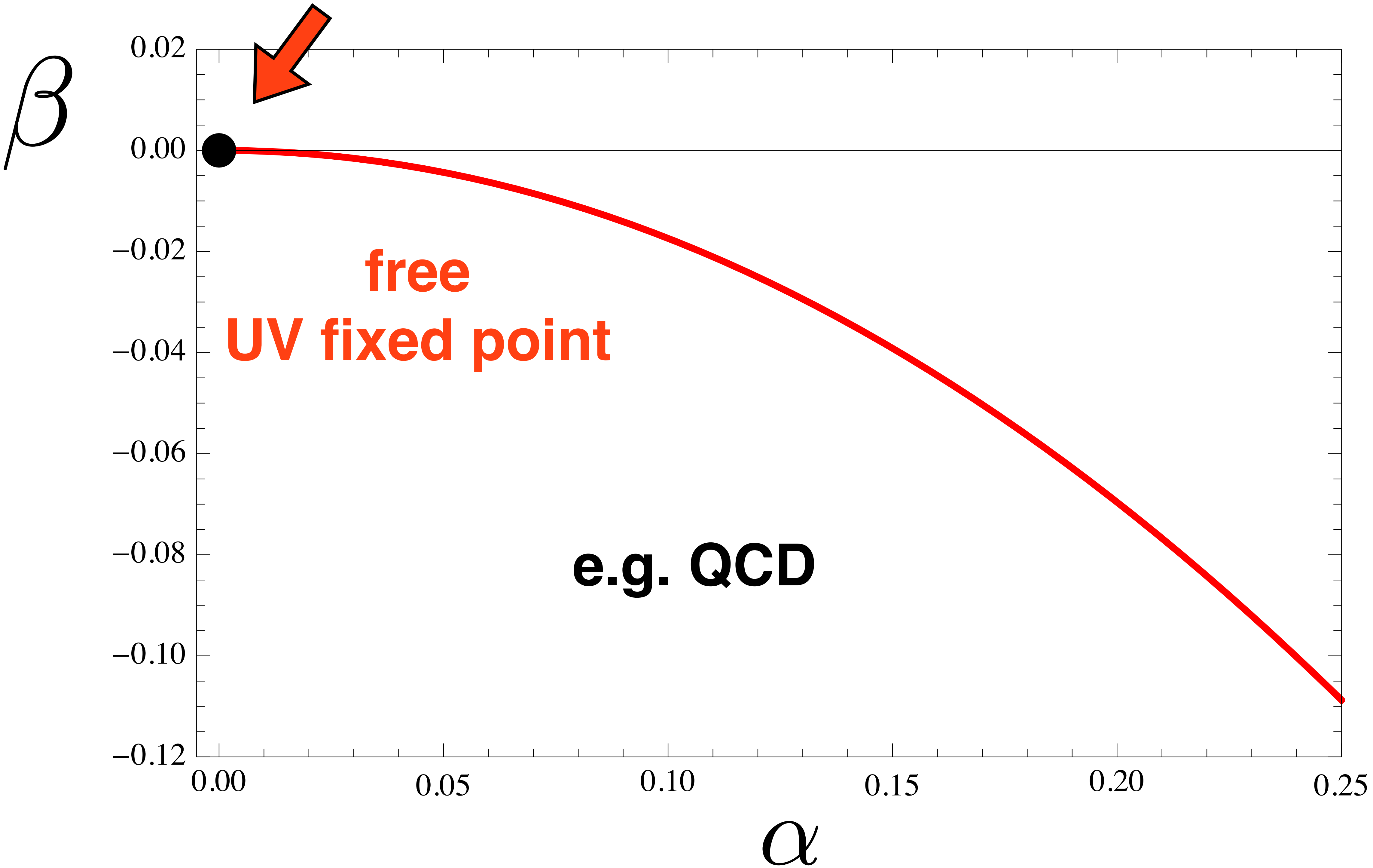
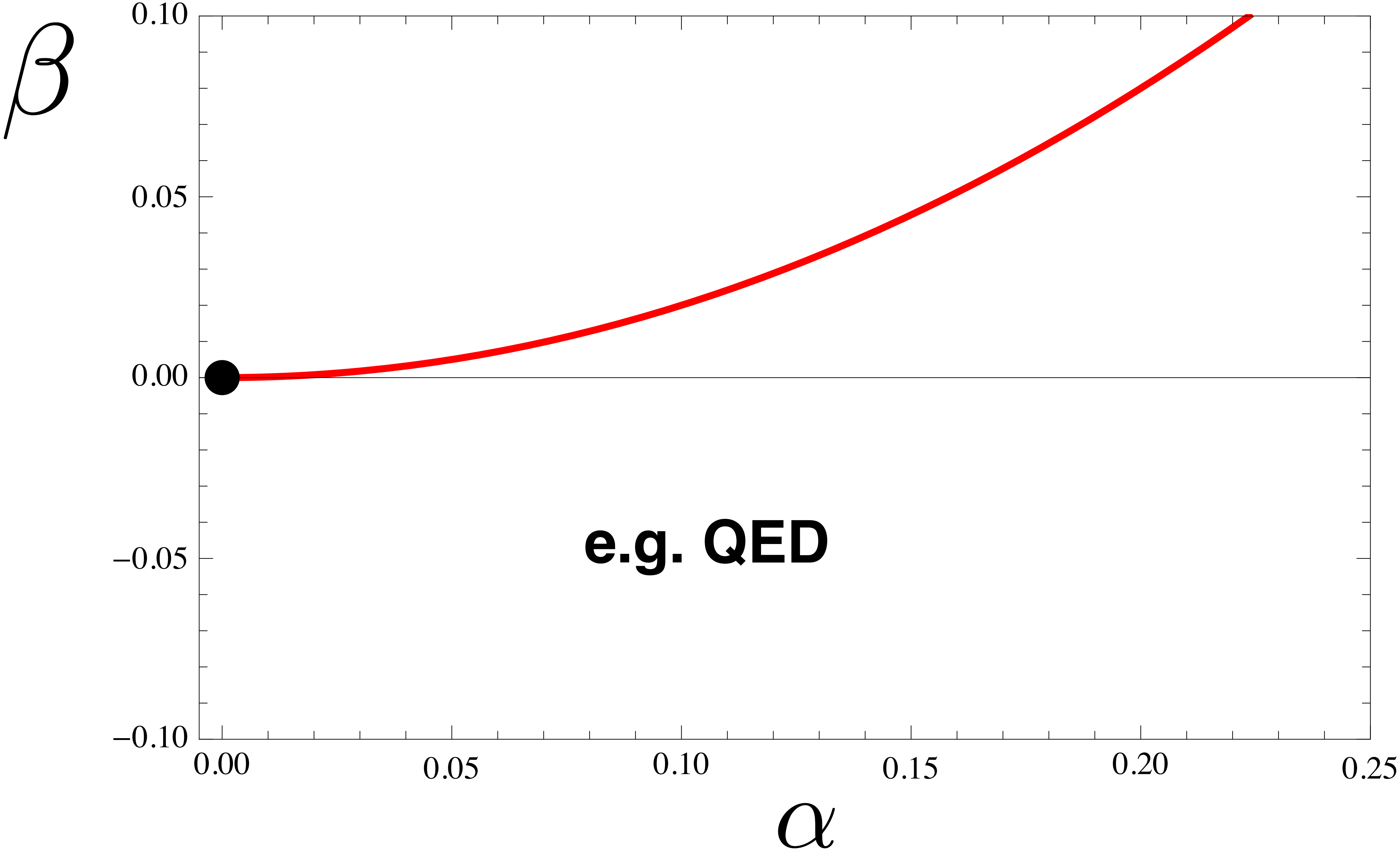
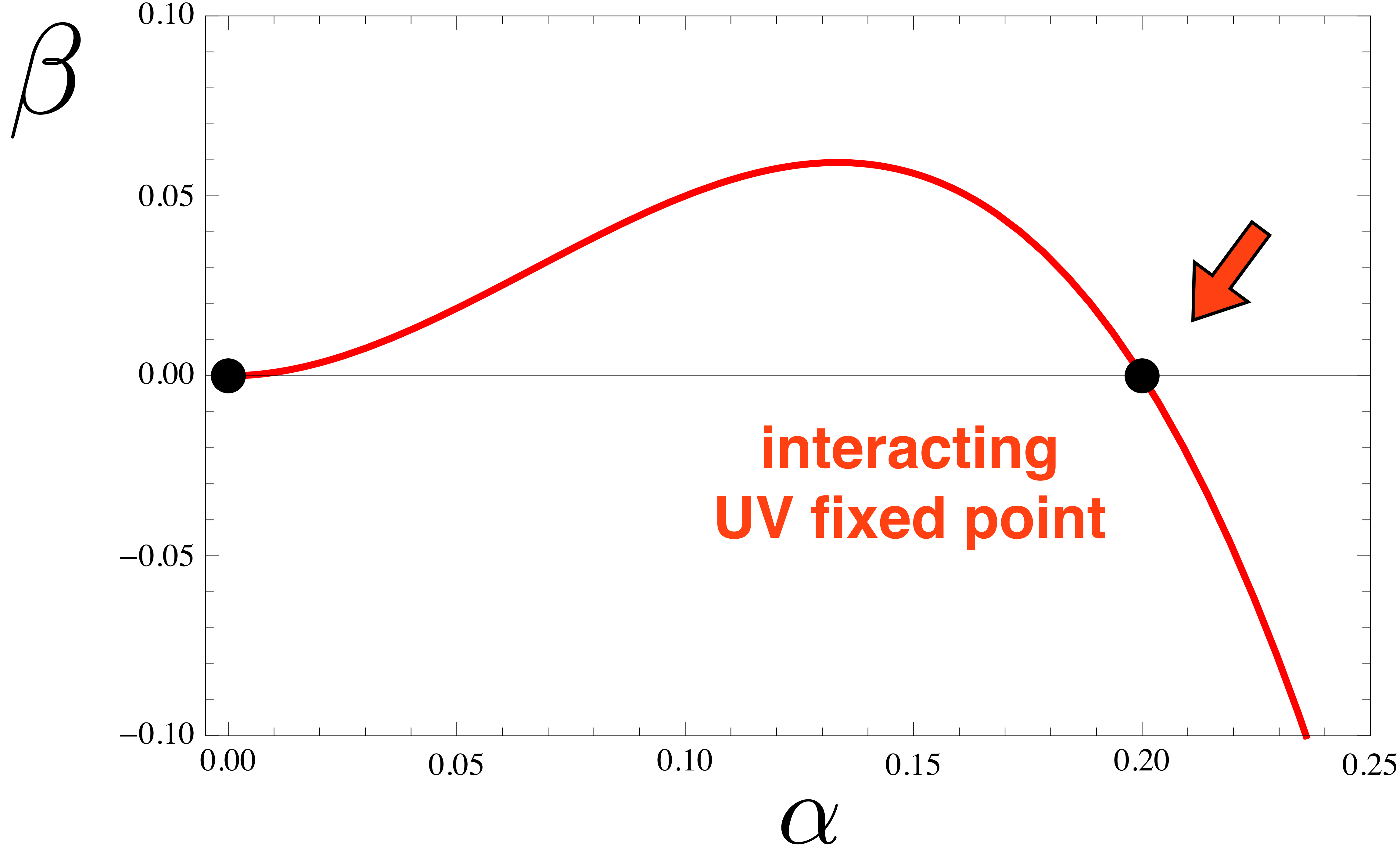
asymptotic freedom



infrared freedom



asymptotic safety



conditions for asymptotic safety

Bond, Litim 1608.00519

case	gauge group	matter	Yukawa	asymptotic safety
a)	simple	fermions in irreps	No	No
b)	simple or abelian	fermions, any rep	No	No
		scalars, any rep	No	No
		fermions and scalars, any rep	No	No
c)	semi-simple, with or without abelian factors	fermions, any rep	No	No
		scalars, any rep	No	No
		fermions and scalars, any rep	No	No
d)	simple or abelian	fermions and scalars, any rep	Yes	Yes *)
e)	semi-simple, with or without abelian factors	fermions and scalars, any rep	Yes	Yes *)

*) provided certain auxiliary conditions hold true

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basics of asymptotic safety

gauge theory

$$\partial_t \alpha_g = -B\,\alpha_g^2 + C\,\alpha_g^3 \overset{!}{=} 0$$

$t = \ln \mu/\Lambda$

$\alpha_* \ll 1$

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basics of asymptotic safety

gauge Yukawa theory

$$\partial_t \alpha_g = -B\,\alpha_g^2 + C\,\alpha_g^3 - D\,\alpha_g^2\,\alpha_y \overset{!}{=} 0 \qquad t = \ln \mu/\Lambda$$

$$\partial_t \alpha_y = E\,\alpha_y^2 - F\,\alpha_g\,\alpha_y \overset{!}{=} 0 \qquad \alpha_* \ll 1$$

loop coefficients $D, E, F > 0$ **in any QFT**

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basics of asymptotic safety

gauge Yukawa theory

$$\partial_t \alpha_g = -B\,\alpha_g^2 + C\,\alpha_g^3 - D\,\alpha_g^2\,\alpha_y \qquad t = \ln \mu/\Lambda$$

$$\partial_t \alpha_y = E\,\alpha_y^2 - F\,\alpha_g\,\alpha_y \qquad \alpha_* \ll 1$$

→ **interacting UV fixed point** provided that

$$D\,F - C\,E > 0$$

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basics of asymptotic safety

gauge Yukawa theory

$$\partial_t \alpha_g = -B\,\alpha_g^2 + C\,\alpha_g^3 - D\,\alpha_g^2\,\alpha_y \qquad t = \ln \mu/\Lambda$$

$$\partial_t \alpha_y = E\,\alpha_y^2 - F\,\alpha_g\,\alpha_y \qquad \alpha_* \ll 1$$

exact proofs of existence (Veneziano limit)

SU(N) + scalars + fermions

DF Litim, F Sannino, 1406.2337

SU(N) x SU(M) + scalars + fermions

AD Bond, DF Litim, @ERG2016 (to appear)

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asymptotic safety beyond the SM

AD Bond, G Hiller, K Kowalska, DF Litim, 1702.01727

minimal framework:

SM gauge symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y$

N_F flavors of BSM fermions $\psi_i(R_3, R_2, Y)$

BSM singlet scalars S_{ij}

features: vector-like fermions

global flavor symmetry $U(N_F) \times U(N_F)$

single BSM Yukawa couplings

UV fixed points

possible fixed points

(two gauge plus BSM Yukawa couplings)

#	gauge couplings		BSM Yukawa	type & info	
FP₁	$\alpha_3^* = 0$	$\alpha_2^* = 0$	$\alpha_y^* = 0$	$\mathbf{G \cdot G}$	non-interacting
FP₂	$\alpha_3^* = 0$	$\alpha_2^* > 0$	$\alpha_y^* > 0$	$\mathbf{G \cdot GY}$	partially interacting
FP₃	$\alpha_3^* > 0$	$\alpha_2^* = 0$	$\alpha_y^* > 0$	$\mathbf{GY \cdot G}$	partially interacting
FP₄	$\alpha_3^* > 0$	$\alpha_2^* > 0$	$\alpha_y^* > 0$	$\mathbf{GY \cdot GY}$	fully interacting

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running couplings

gauge couplings

BSM Yukawa

$$\alpha_2 = \frac{g_2^2}{(4\pi)^2}\,, \qquad \alpha_3 = \frac{g_3^2}{(4\pi)^2}\,, \qquad \alpha_y = \frac{y^2}{(4\pi)^2}$$

BSM RG beta functions

$$\frac{d\alpha_3}{d\ln\mu} = (-B_3 + C_3\,\alpha_3 + G_3\,\alpha_2 - D_3\,\alpha_y)\,\alpha_3^2$$

$$\frac{d\alpha_2}{d\ln\mu} = (-B_2 + C_2\alpha_2 + G_2\,\alpha_3 - D_2\,\alpha_y)\,\alpha_2^2$$

$$\frac{d\alpha_y}{d\ln\mu} = (E\,\alpha_y - F_2\,\alpha_2 - F_3\,\alpha_3)\,\alpha_y$$

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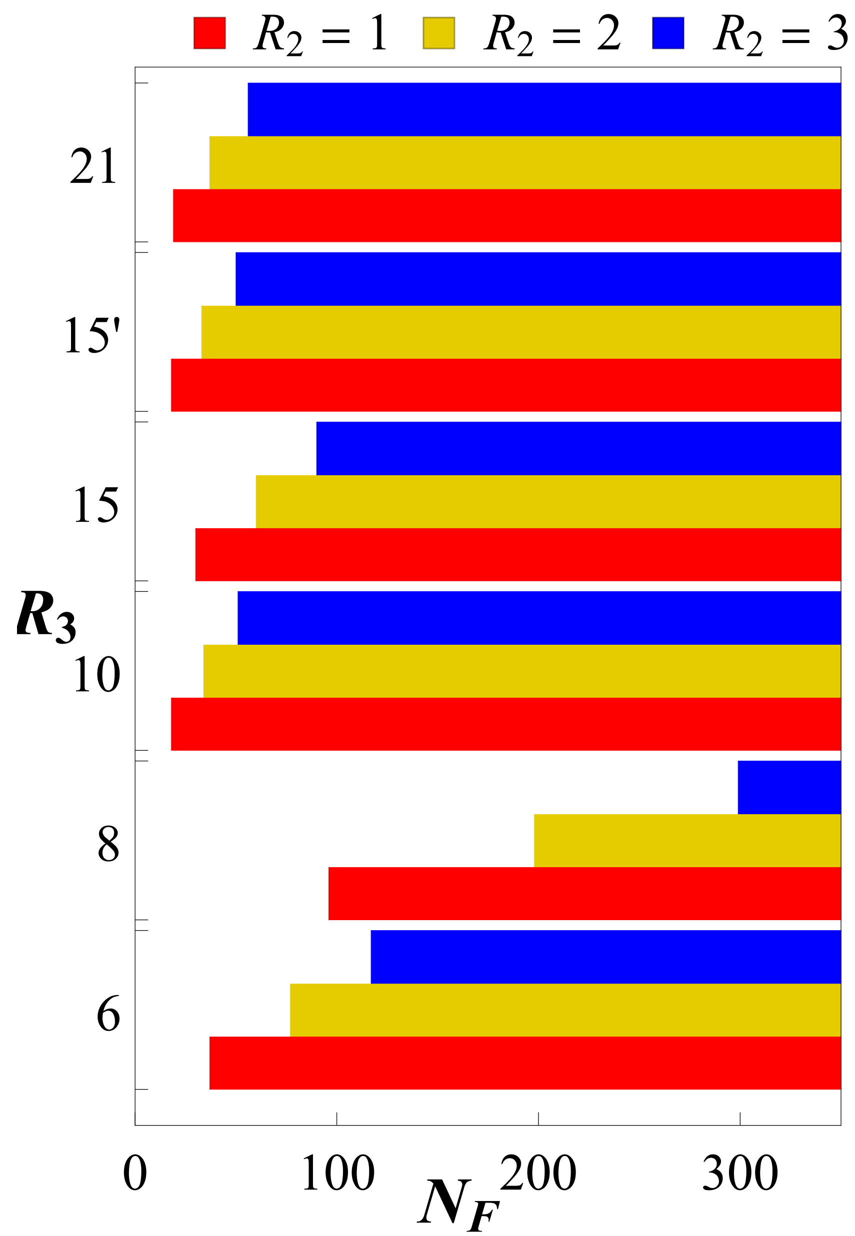
BSM fixed points

$\mathbf{FP_3}$

$\alpha_3^* > 0$

$\alpha_2^* = 0$



BSM fixed points

FP$_2$

$\alpha_2^* > 0$

$\alpha_3^* = 0$

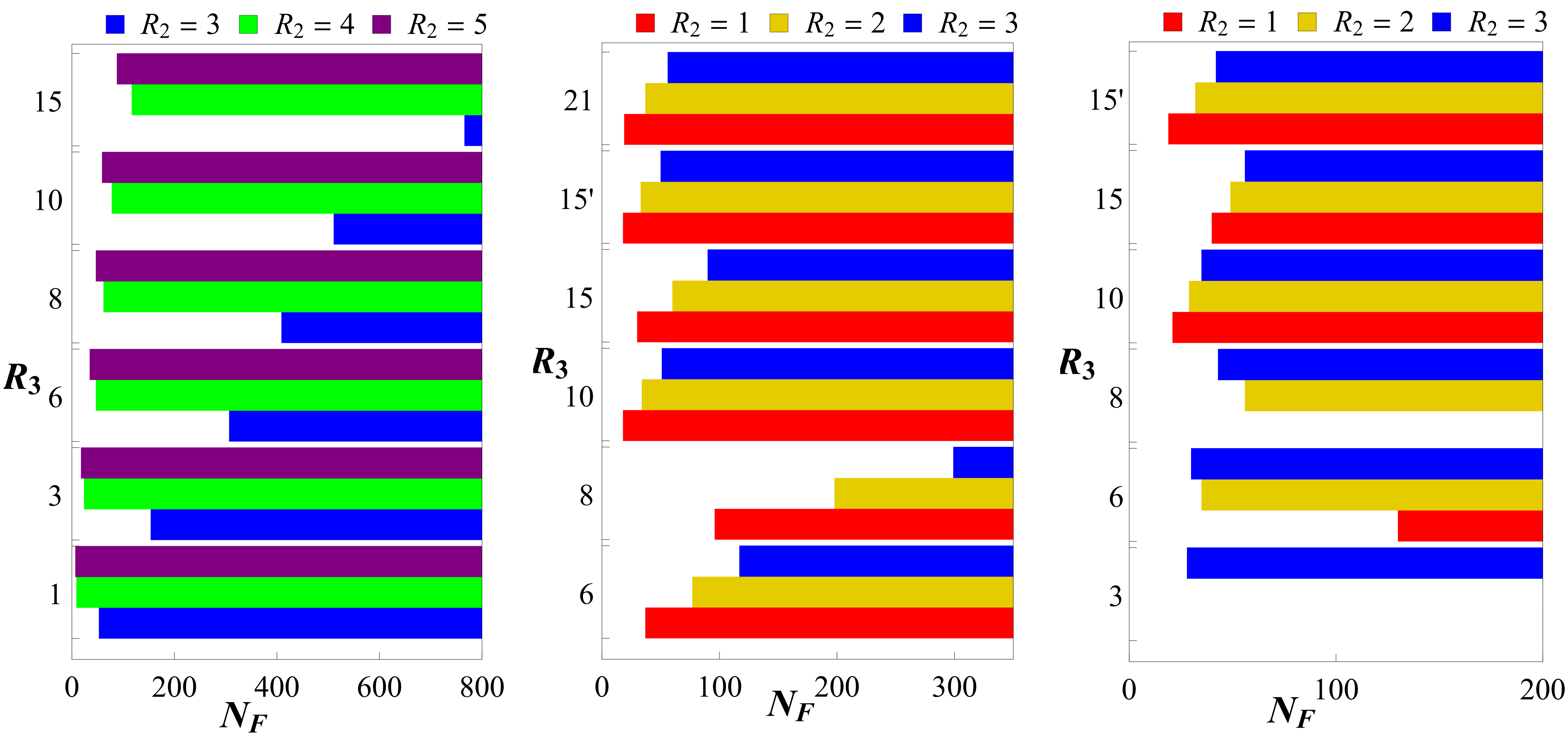
FP$_3$

$\alpha_3^* > 0$

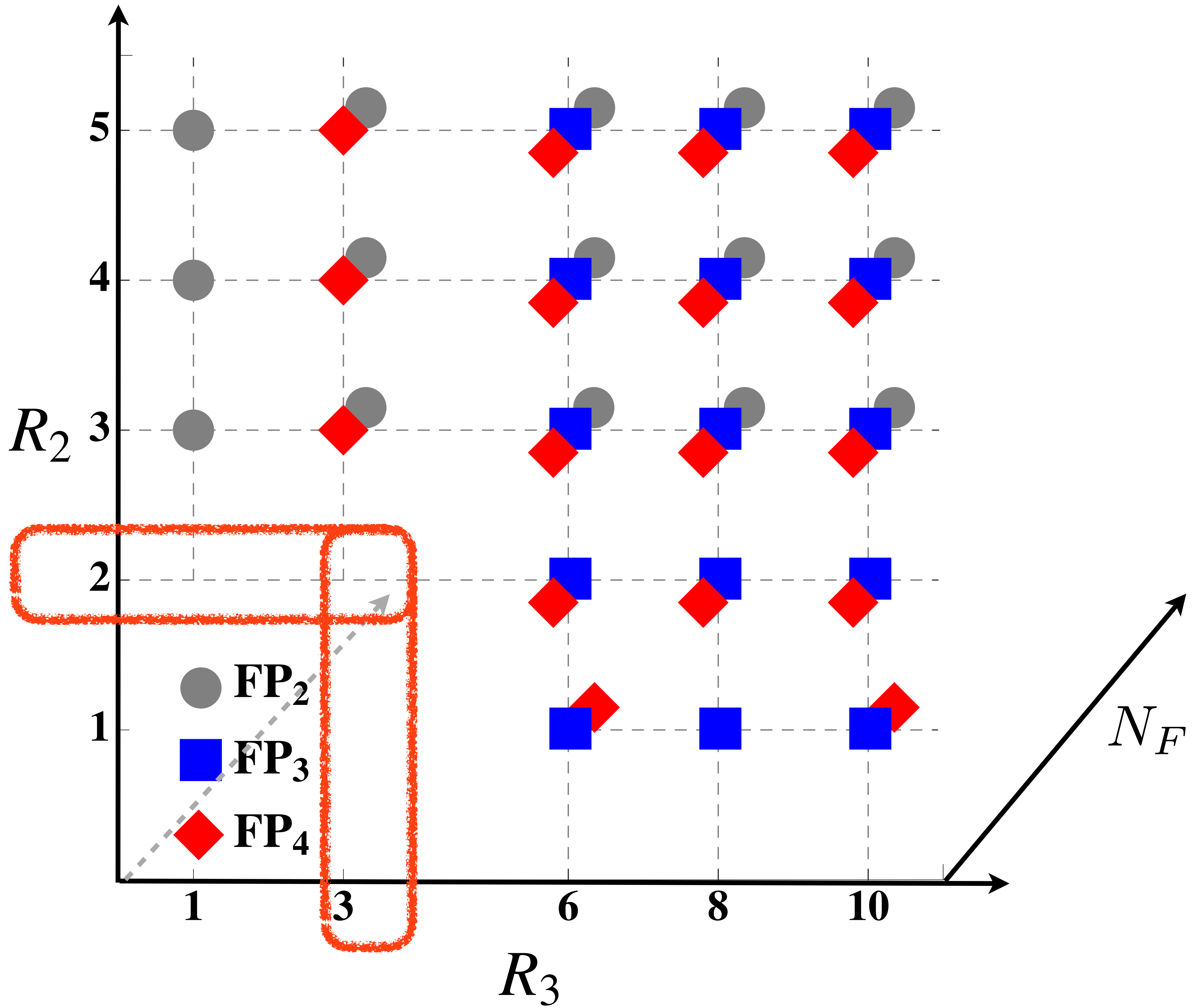
$\alpha_2^* = 0$

FP$_4$

$\alpha_2^*, \alpha_3^* > 0$



summary of fixed points



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benchmark models

model	parameter (R_3, R_2, N_F)	UV fixed points α_3^*	α_2^*	α_y^*	type
A	$(\mathbf{1}, \mathbf{4}, 12)$	0	0.2407	0.3385	$\mathbf{FP_2}$ ●
B	$(\mathbf{10}, \mathbf{1}, 30)$	0.1287	0	0.1158	$\mathbf{FP_3}$ ■
		0.1292	0.2769	0.1163	$\mathbf{FP_4}$ ◆
C	$(\mathbf{10}, \mathbf{4}, 80)$	0.3317	0	0.0995	$\mathbf{FP_3}$ ■
		0.0503	0.0752	0.0292	$\mathbf{FP_4}$ ◆
		0	0.8002	0.1500	$\mathbf{FP_2}$ ●
D	$(\mathbf{3}, \mathbf{4}, 290)$	0	0.0895	0.0066	$\mathbf{FP_2}$ ●
		0.0416	0.0615	0.0056	$\mathbf{FP_4}$ ◆
E	$(\mathbf{3}, \mathbf{3}, 72)$	0.1499	0.2181	0.0471	$\mathbf{FP_4}$ ◆

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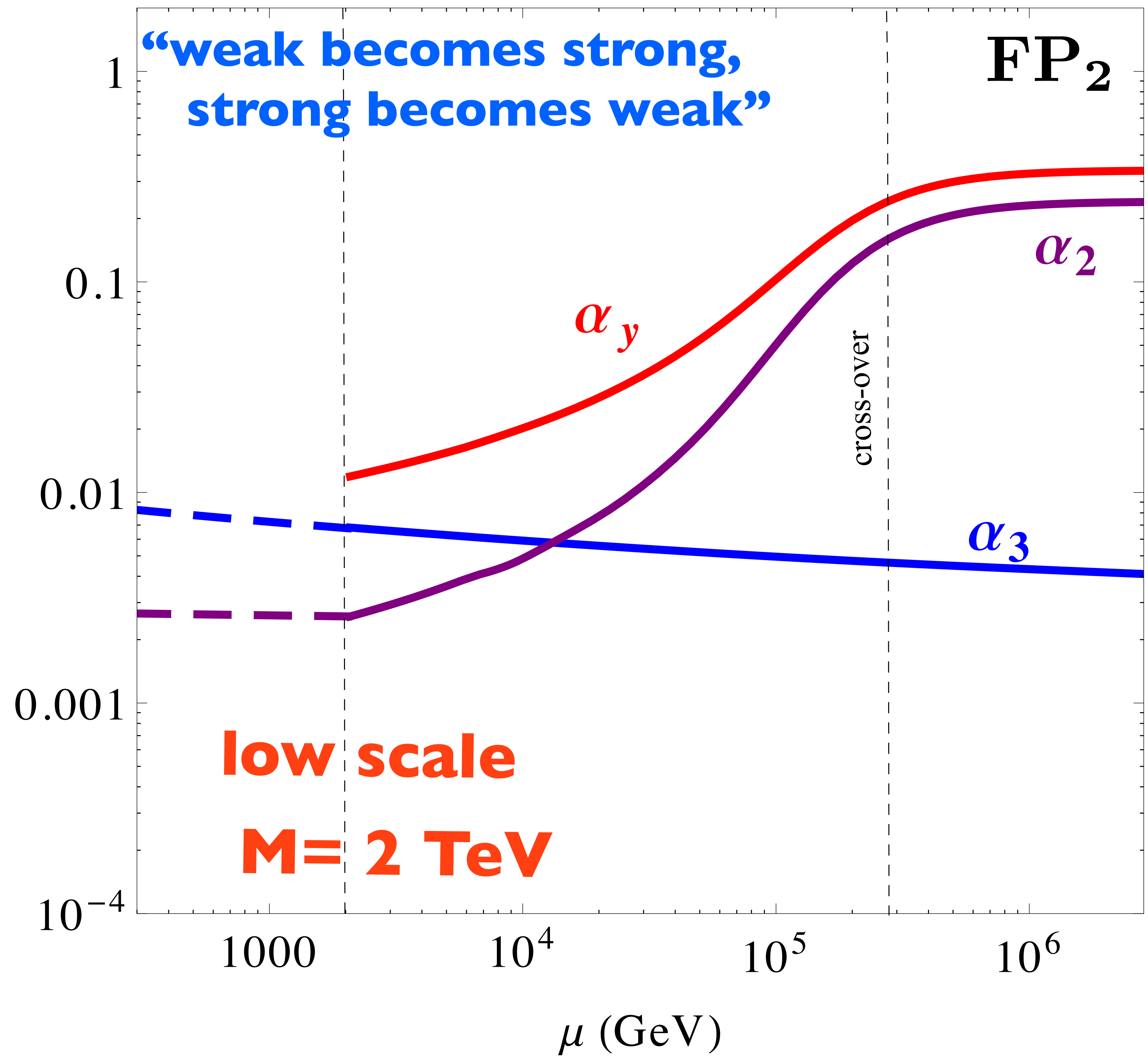
benchmark models

model A

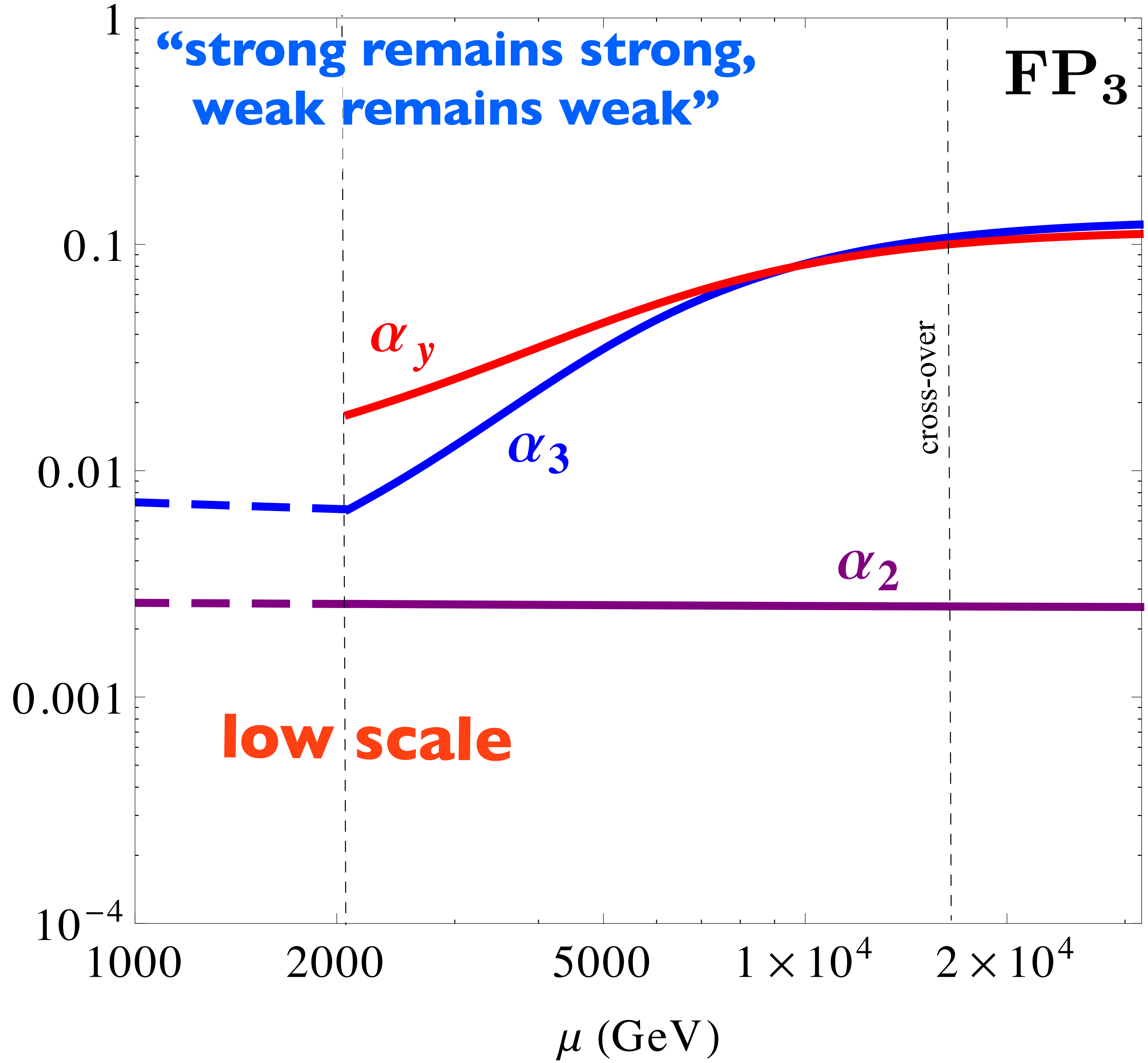
$(R_3, R_2, N_F) = \; (\mathbf{1},\mathbf{4},12)$



benchmark models

model B

$(R_3, R_2, N_F) = $ **(10,1,30)**



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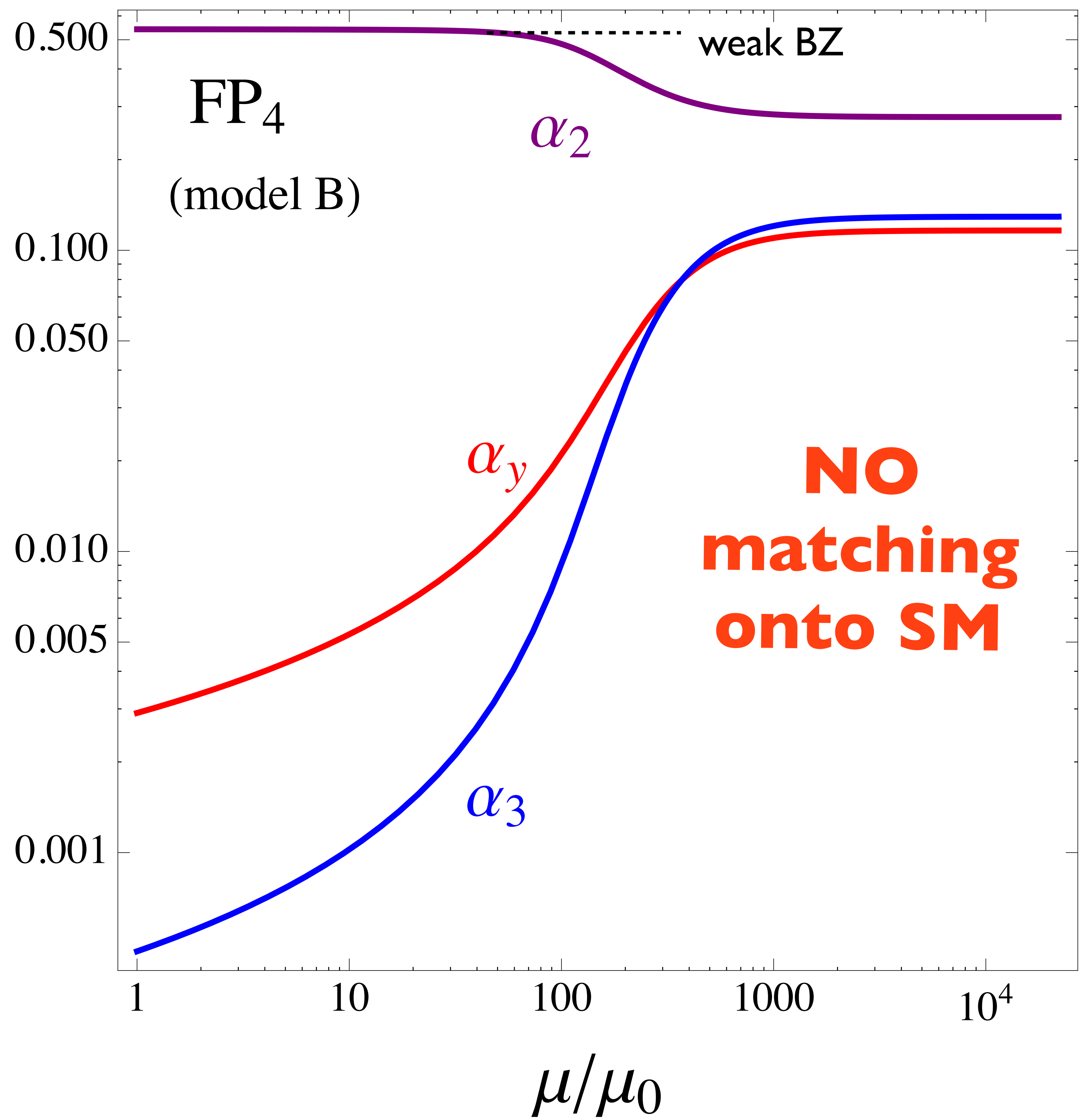
benchmark models

model B

$(R_3, R_2, N_F) =$ **(10,1,30)**



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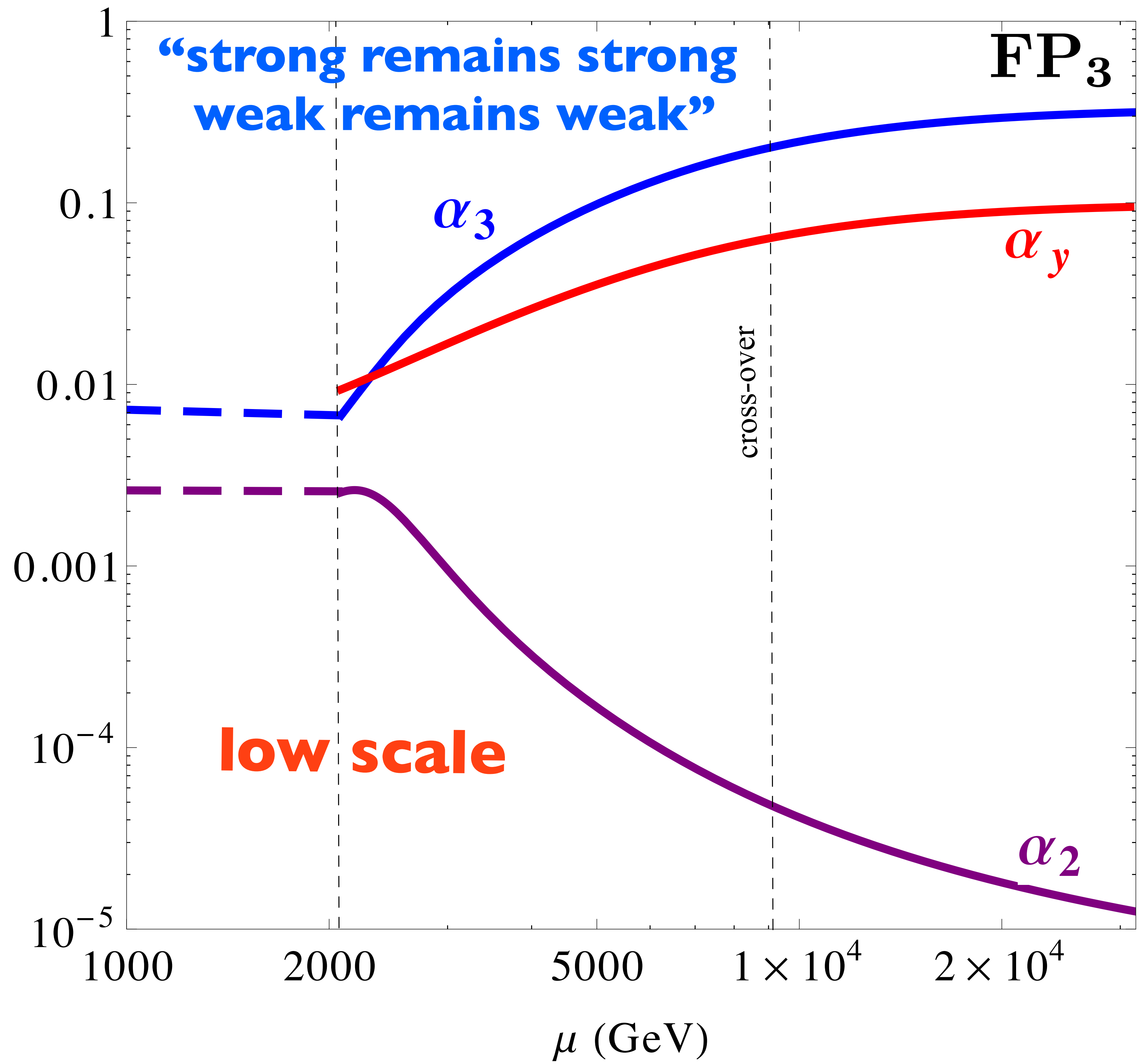
benchmark models

model C

$$(R_3, R_2, N_F) = \quad (\mathbf{10}, \mathbf{4}, 80)$$



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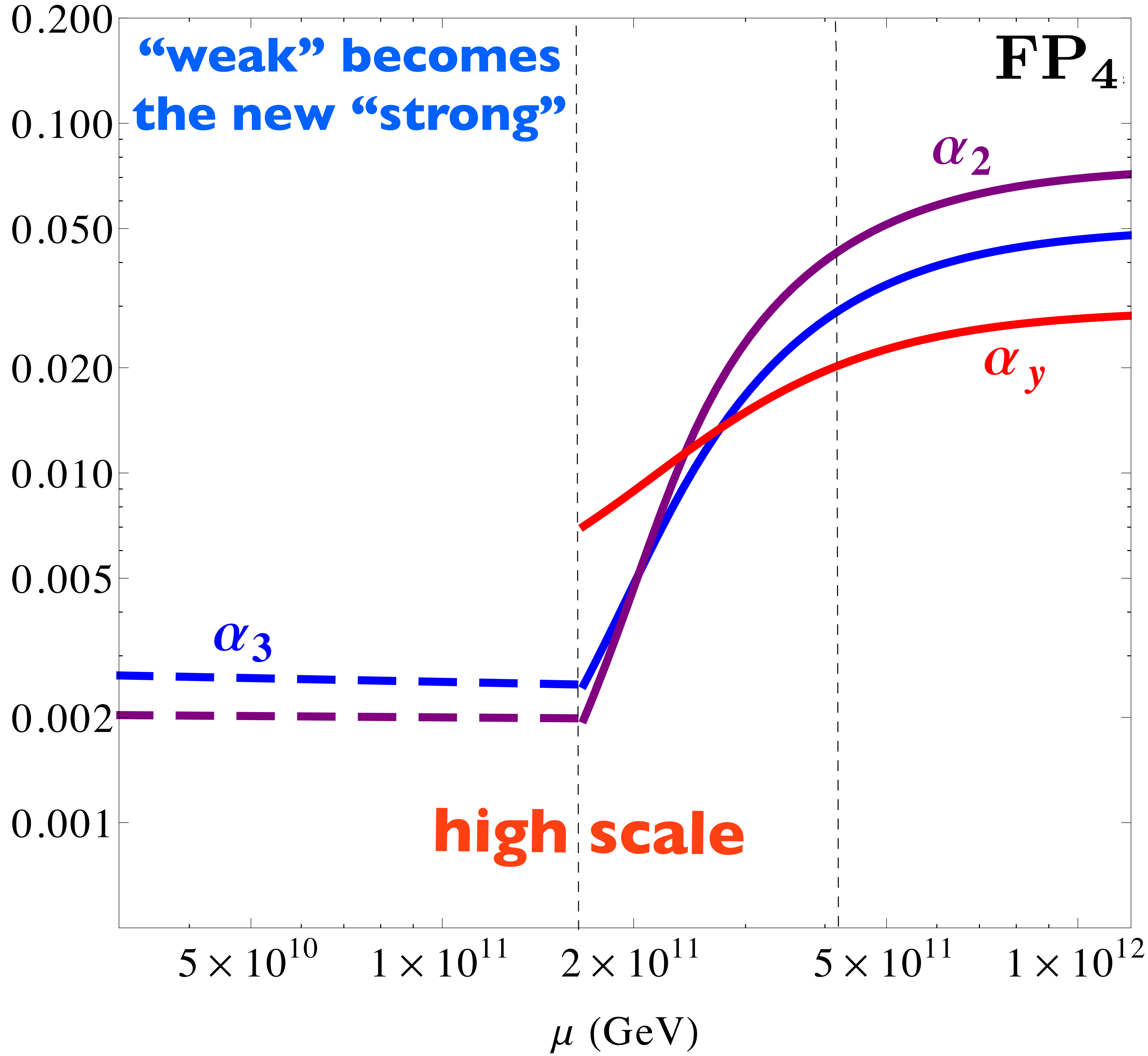
benchmark models

model C

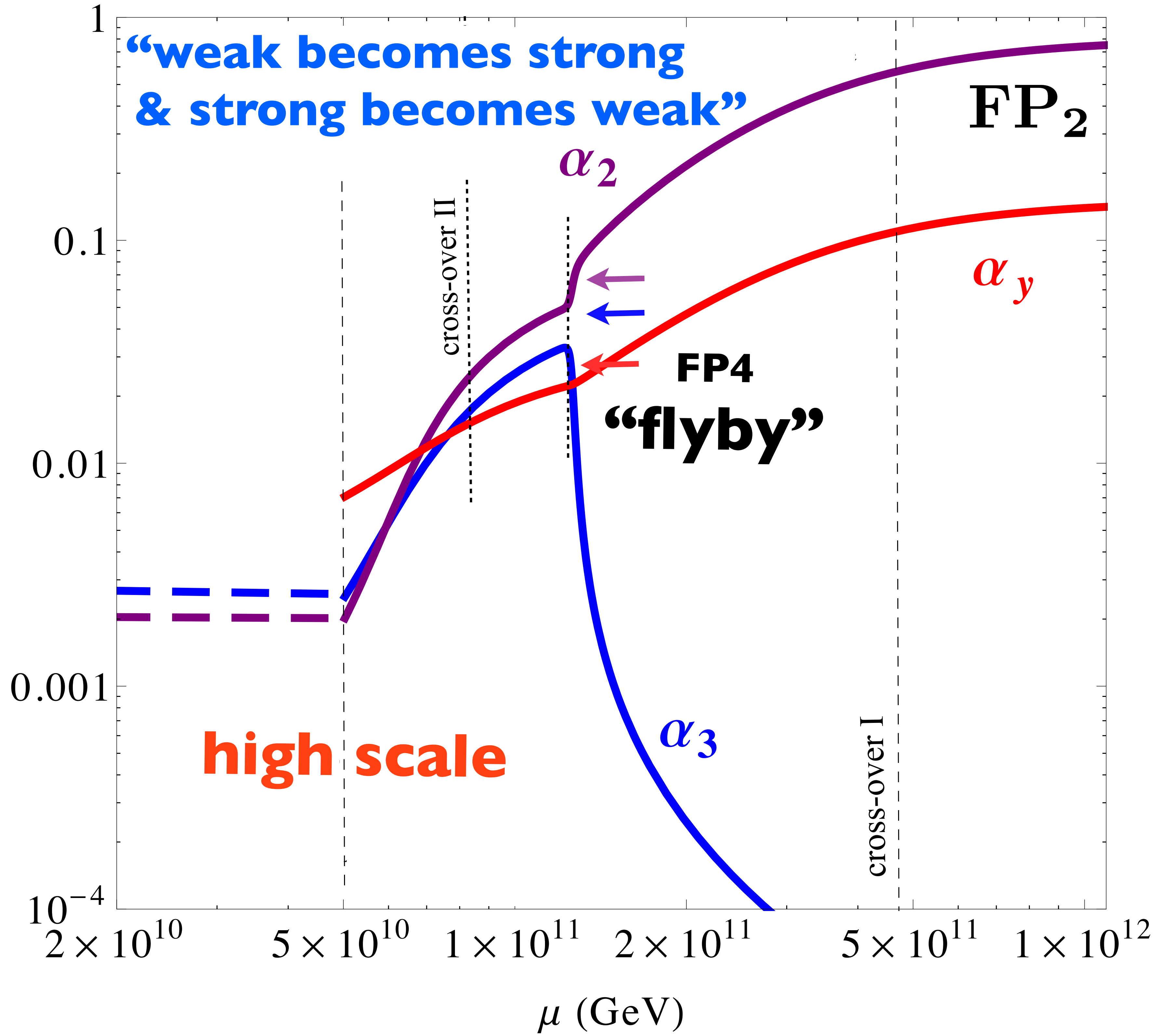
$(R_3, R_2, N_F) =$ (**10**,**4**,80)



benchmark models

model C

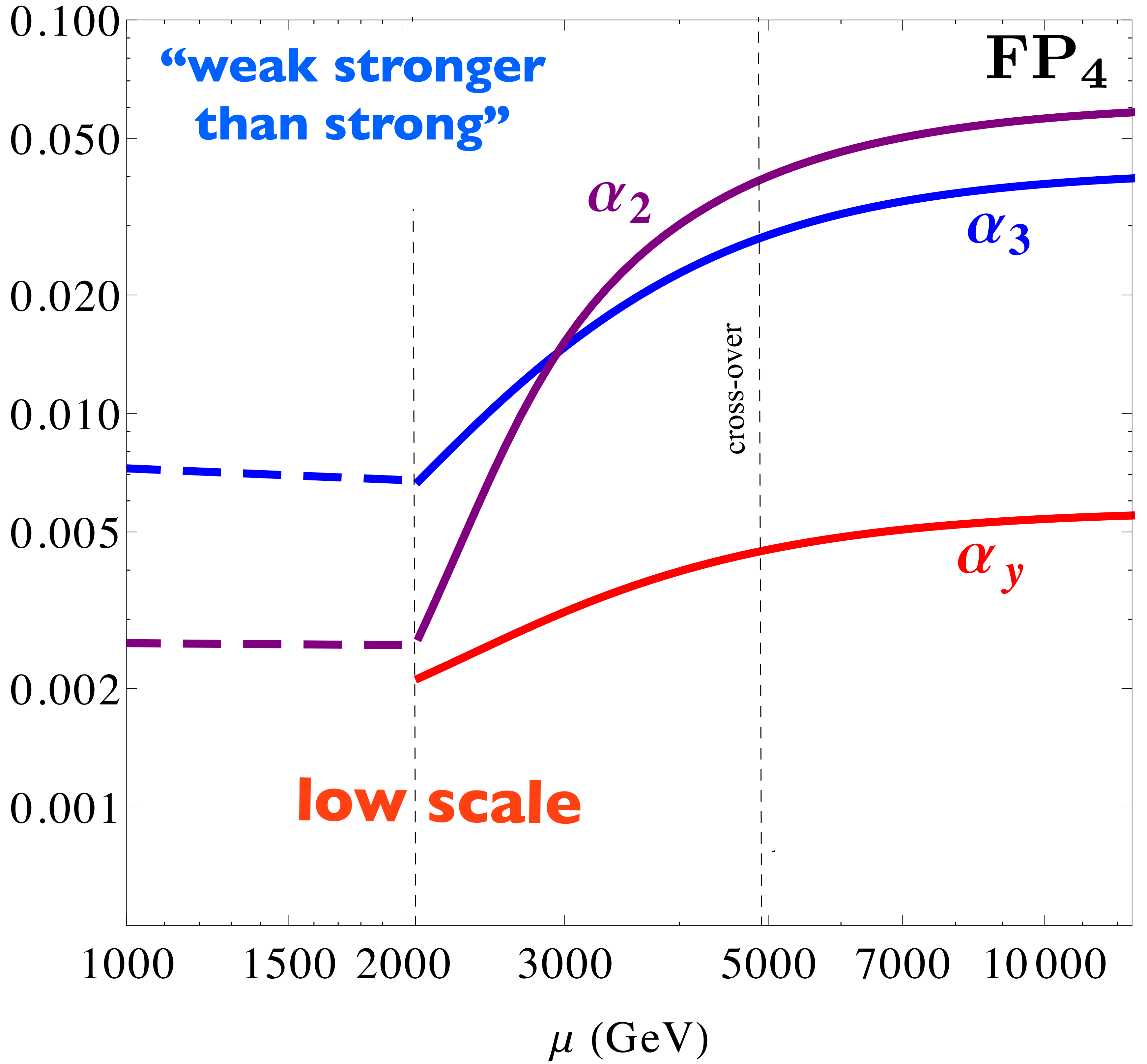
$(R_3, R_2, N_F) = \ (\mathbf{10},\mathbf{4},80)$



benchmark models

model D

$(R_3, R_2, N_F) =$ (**3**,**4**,290)



summary of SM matching: when it works

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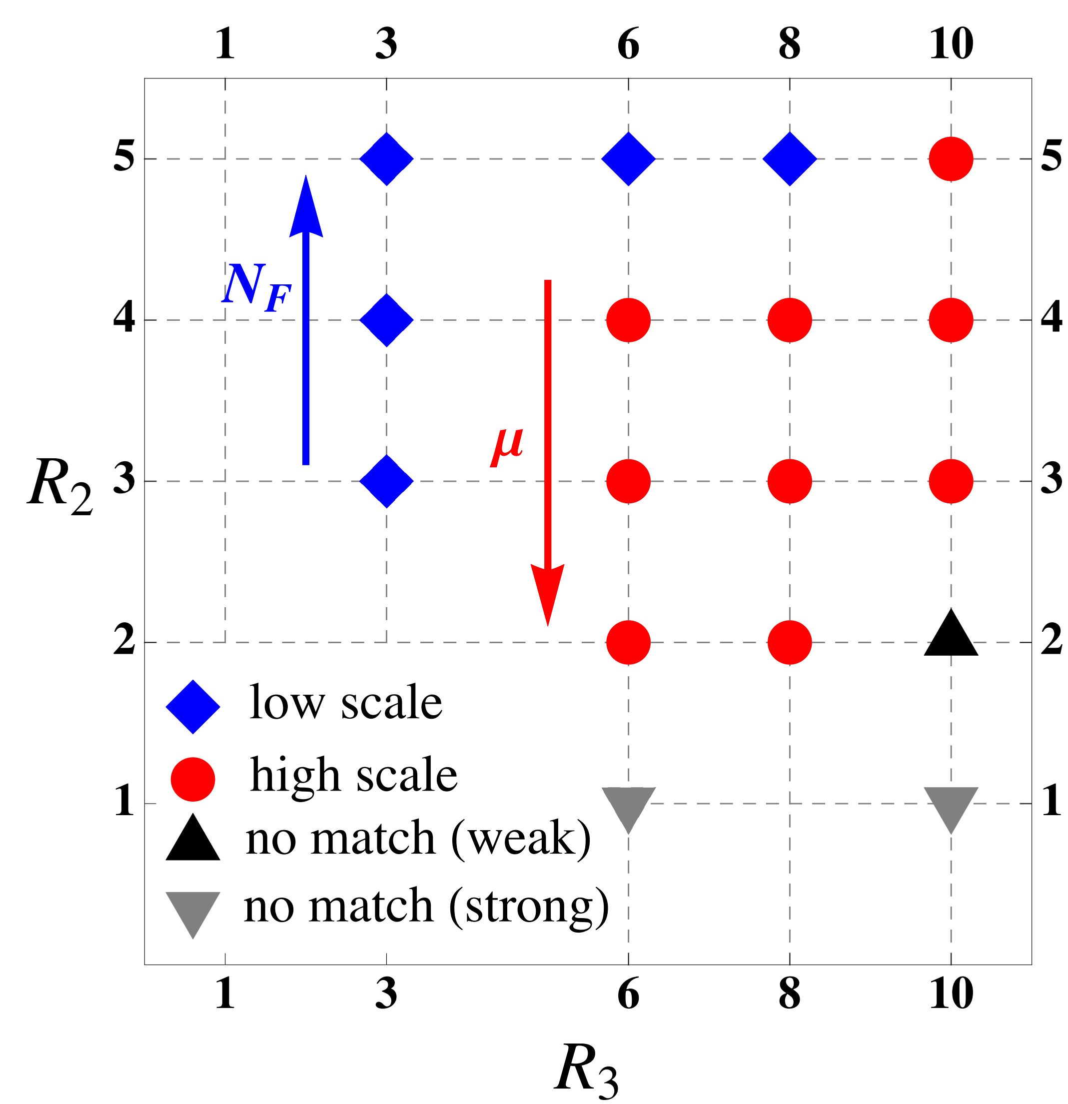
partially interacting FP (one safe, one free)

genuinely, except in very special circumstances

fully interacting FP (both safe)

for most reps - see plot



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asymptotic safety

collider phenomenology

phenomenology

assume low scale matching
some BSM masses within TeV energy range

assume $R_3 \neq 1$ for LHC
($R_3 = 1$ can be tested at future e^+e^- colliders)

flavor symmetry: stable BSM fermions
broken flavor symmetry: lightest BSM fermion stable

constraints from
- running couplings
- the weak sector
- long-lived QCD bound states (R hadrons)
- di-boson searches

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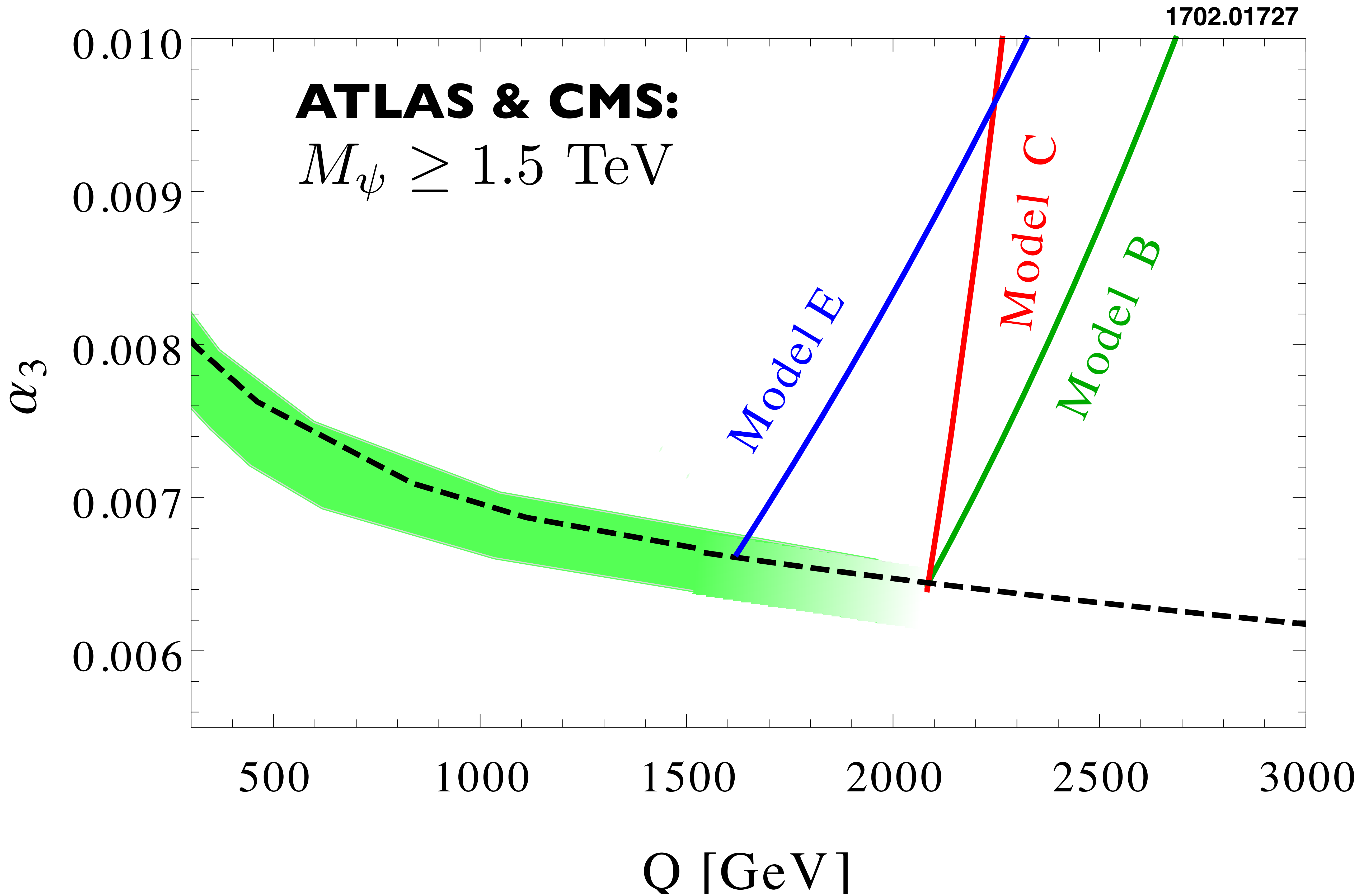
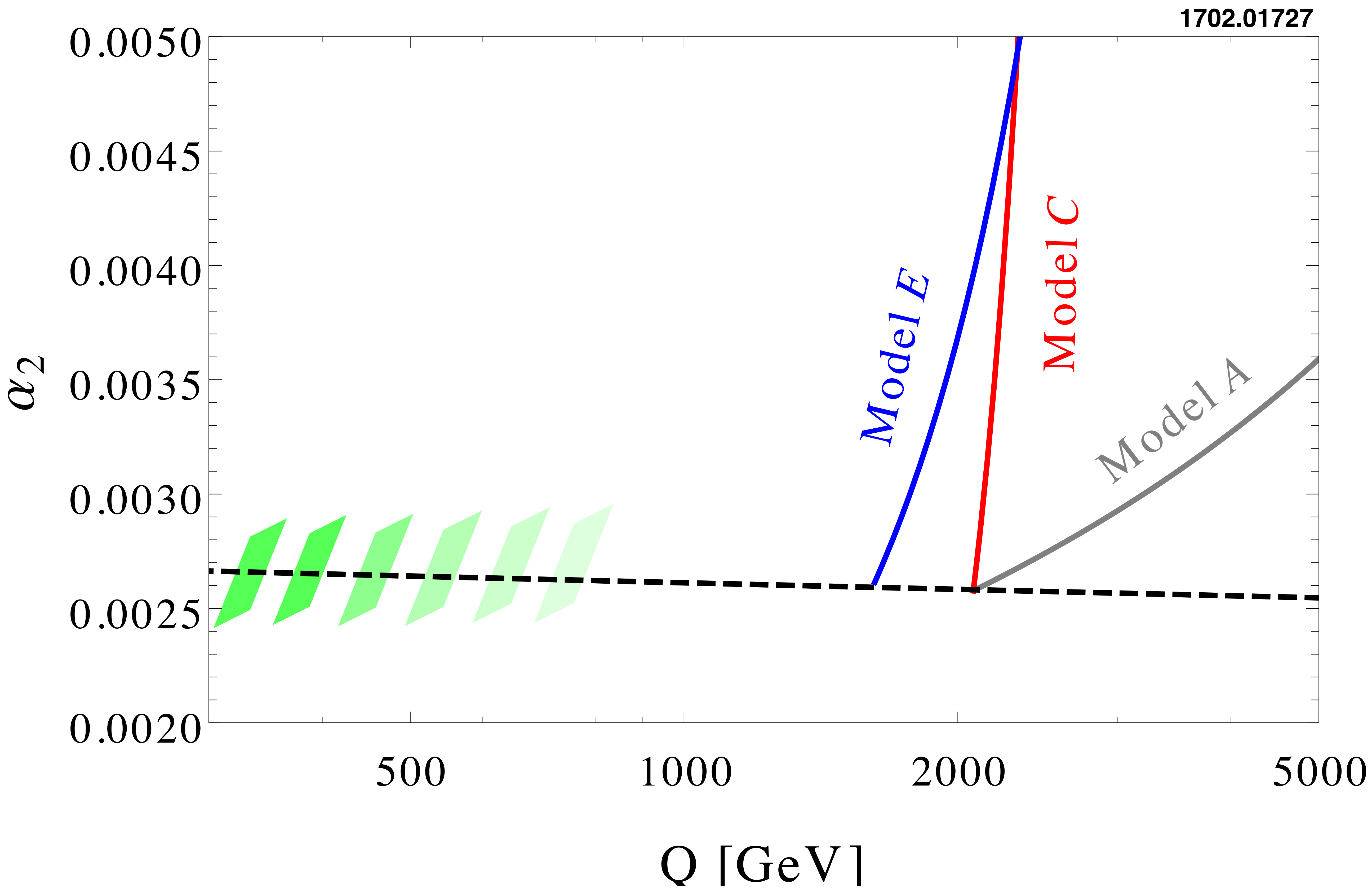
SU(3) BSM running



SU(2) BSM running



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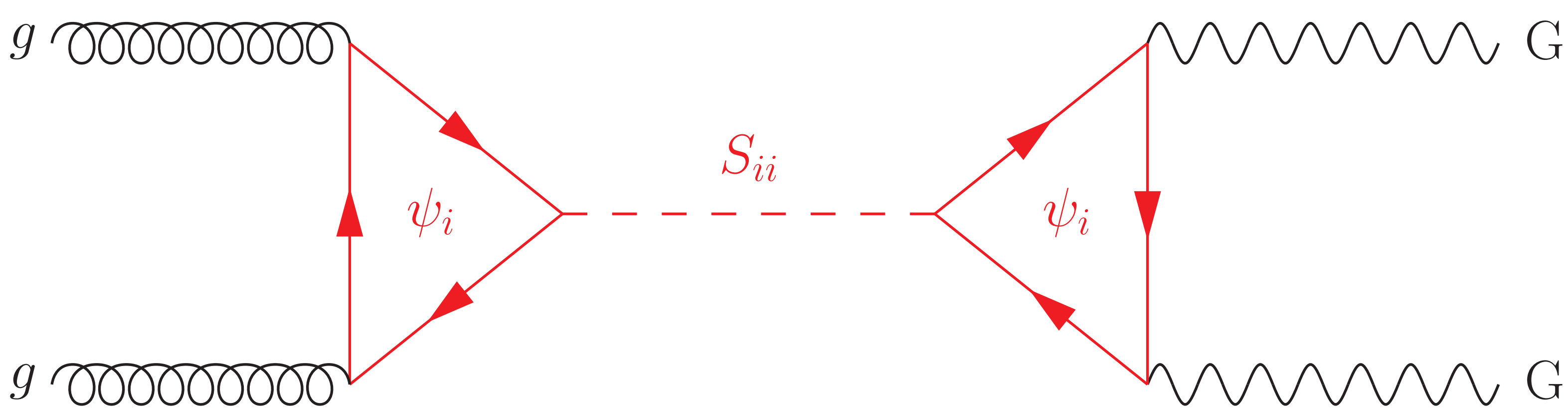
di-boson spectra and resonances

assume **resonant production** of BSM scalars

$M_S < \sqrt{s}$ $M_S < 2M_\psi$

"low Ms" $M_S \lesssim M_\psi$ **"high Ms"** $M_\psi \lesssim M_S < 2M_\psi$

loop-mediated decay into $GG = gg,\ \gamma\gamma,\ ZZ,\ Z\gamma,\ \text{or}\ WW$



interference effects

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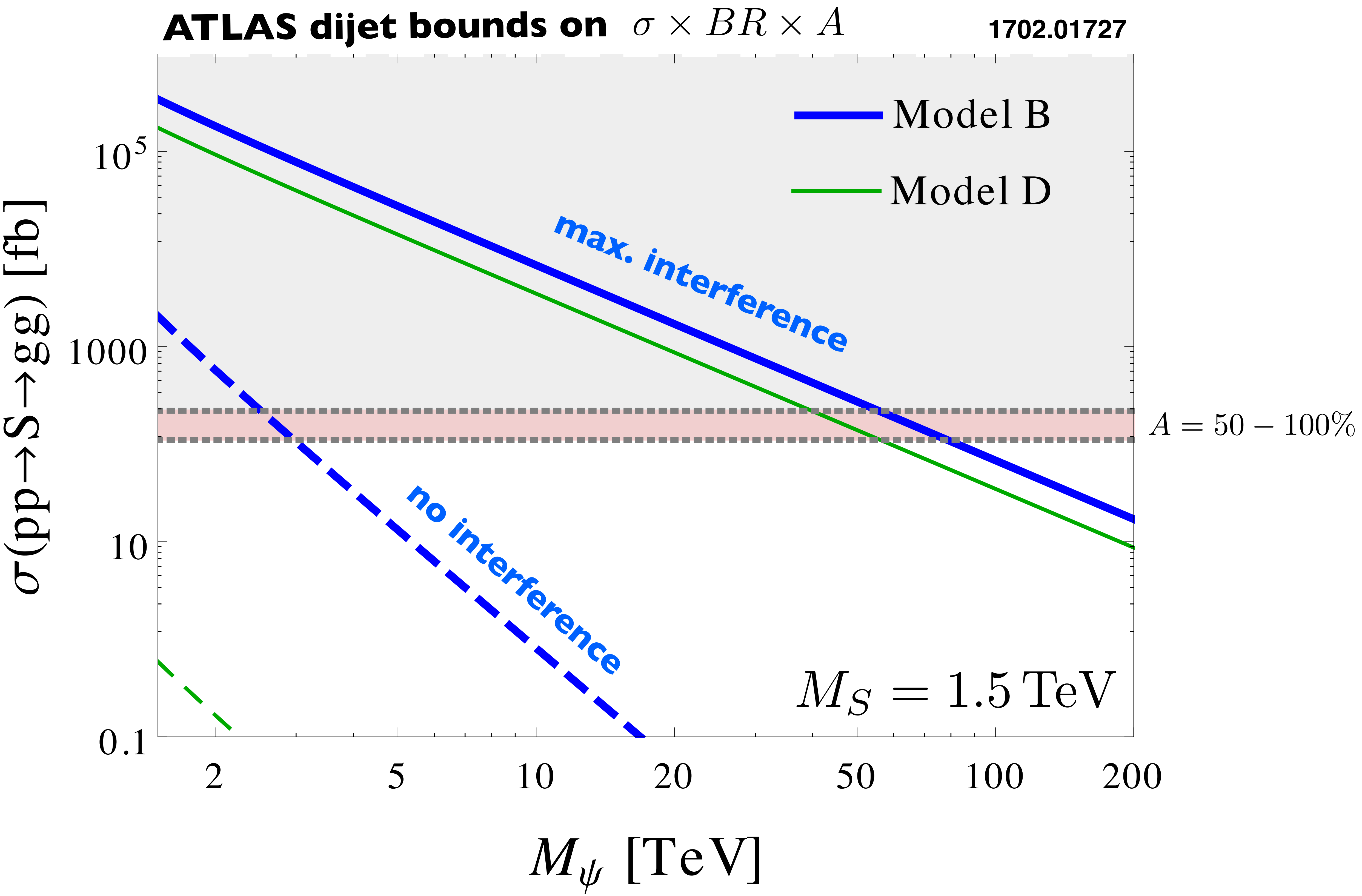
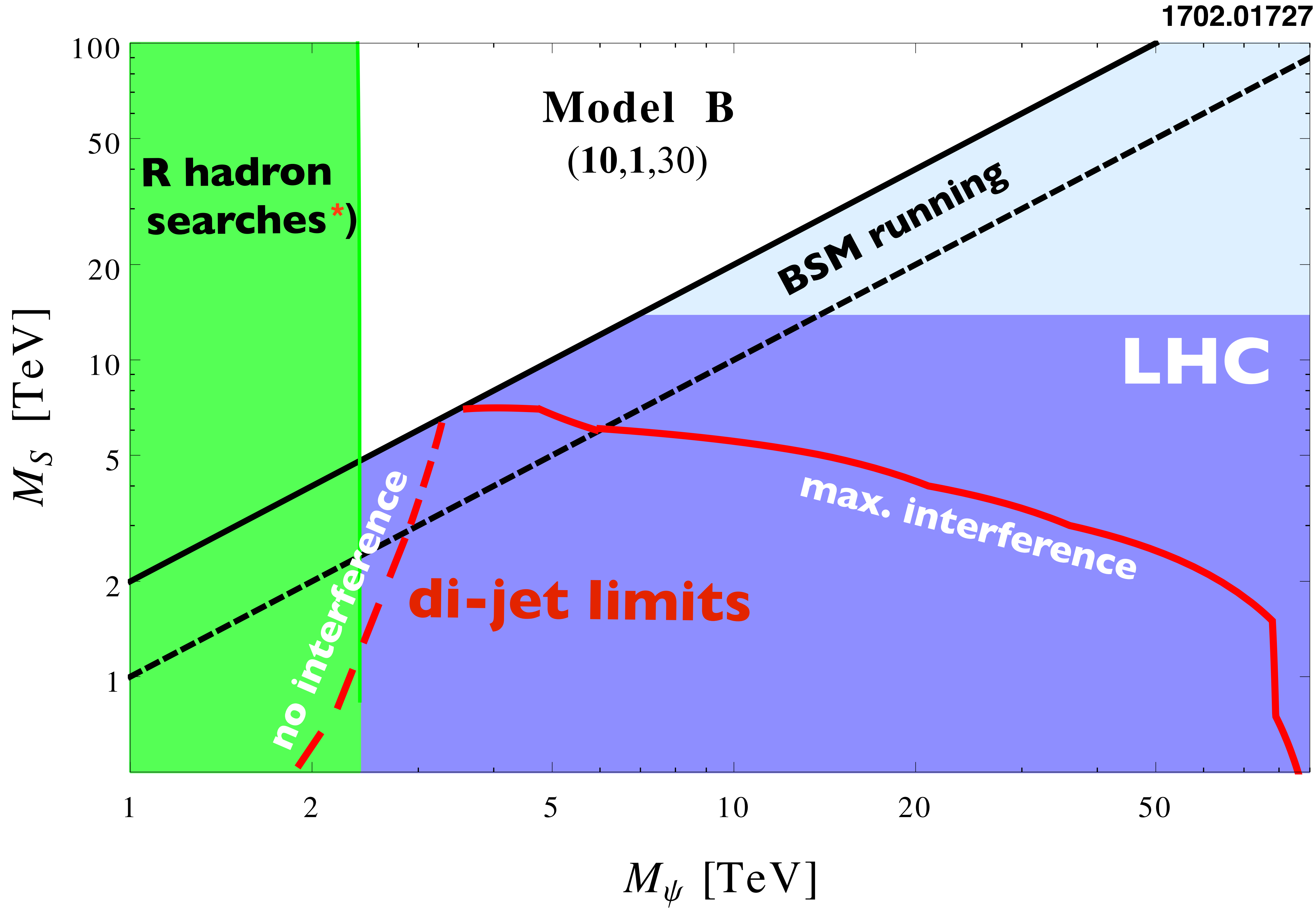
dijet cross section



mass exclusion limits



*) fudged from 13 TeV
ATLAS + CMS gluino analysis

conclusions

asymptotic safety provides

directions for model building

can be tested at colliders

stay tuned...

extra material

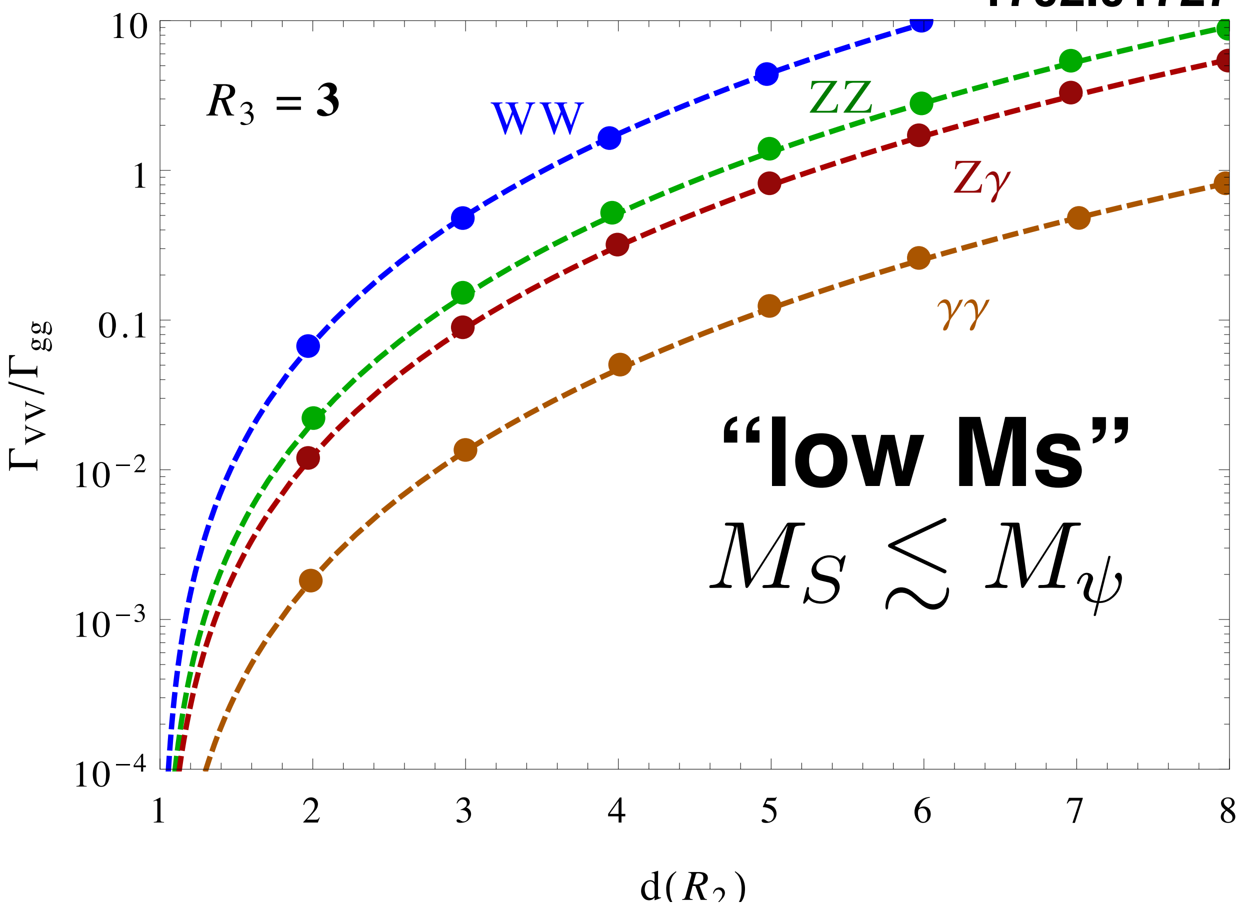
decays into electroweak gauge bosons

further signatures if $d(R_2) \neq 1$

general scalar resonance decaying into $WW, ZZ, Z\gamma, \gamma\gamma$

growth with dim(R2)

1702.01727



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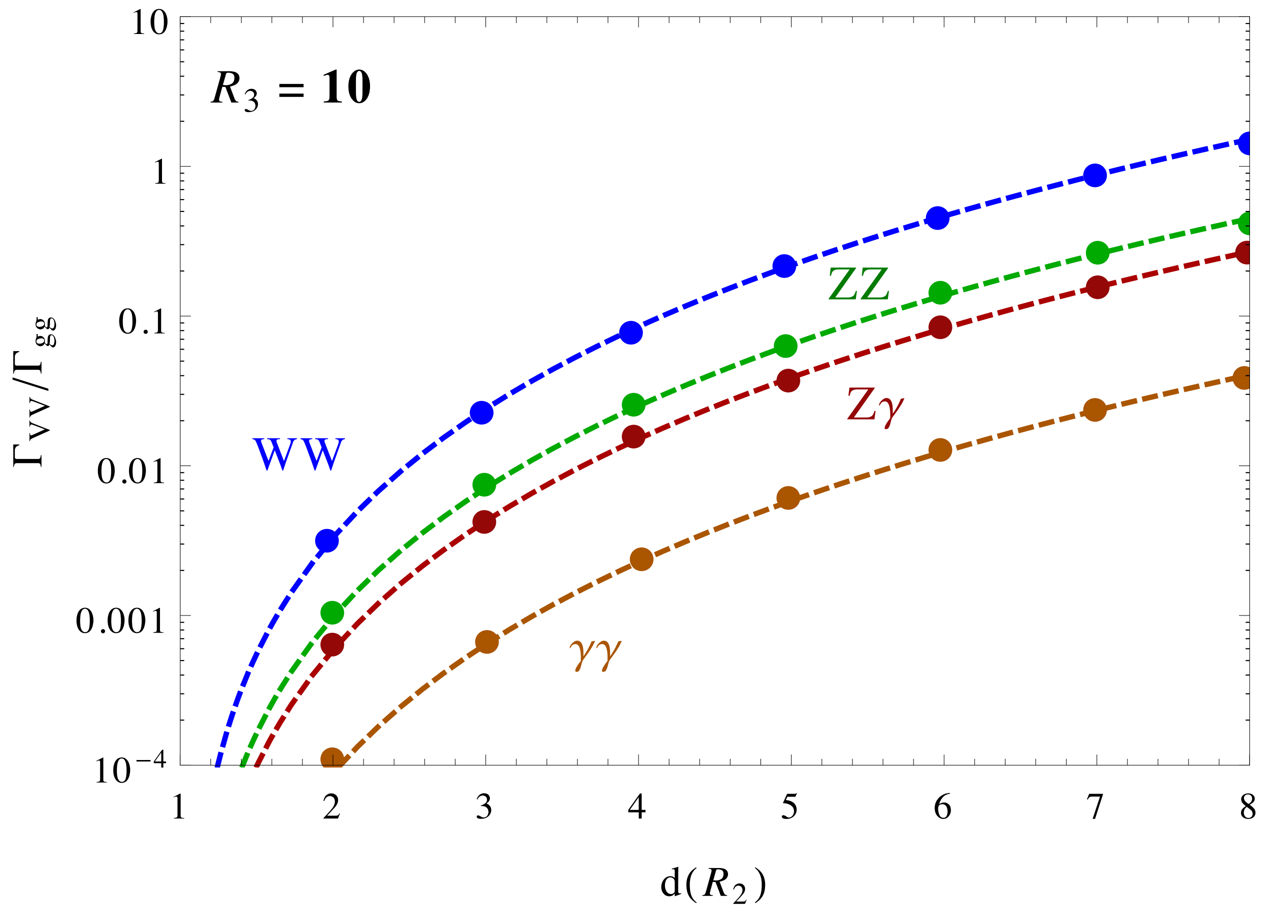

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decays into electroweak gauge bosons

"reduced" decay widths

$$\bar\Gamma_{VV} = \frac{1}{F}\,\frac{\Gamma_{VV}}{\Gamma_{gg}}\,, \quad \text{with} \quad F = \left(\frac{4}{3}\,\frac{C_2(R_2)}{C_2(R_3)}\right)^2$$

for small hypercharge coupling

$$\bar\Gamma_{WW} = \frac{\alpha_2^2}{\alpha_3^2}\,, \quad \bar\Gamma_{ZZ} \approx \frac{1}{2}\,\frac{\alpha_2^2}{\alpha_3^2}\,, \quad \bar\Gamma_{Z\gamma} \approx \frac{\alpha_1}{\alpha_3}\,\frac{\alpha_2}{\alpha_3}\,, \quad \bar\Gamma_{\gamma\gamma} \approx \frac{1}{2}\,\frac{\alpha_1^2}{\alpha_3^2}$$

modification of widths for "high Ms"

FP$_4$ $\quad \bar\Gamma_{WW}, \bar\Gamma_{ZZ}$ ↗ $\quad \bar\Gamma_{\gamma\gamma}$ ↘ $\quad \bar\Gamma_{Z\gamma}$?

FP$_2$ $\quad \bar\Gamma_{WW}, \bar\Gamma_{ZZ}, \bar\Gamma_{Z\gamma}, \bar\Gamma_{\gamma\gamma}$ ↗

FP$_3$ $\quad \bar\Gamma_{WW}, \bar\Gamma_{ZZ}, \bar\Gamma_{Z\gamma}, \bar\Gamma_{\gamma\gamma}$ ↘

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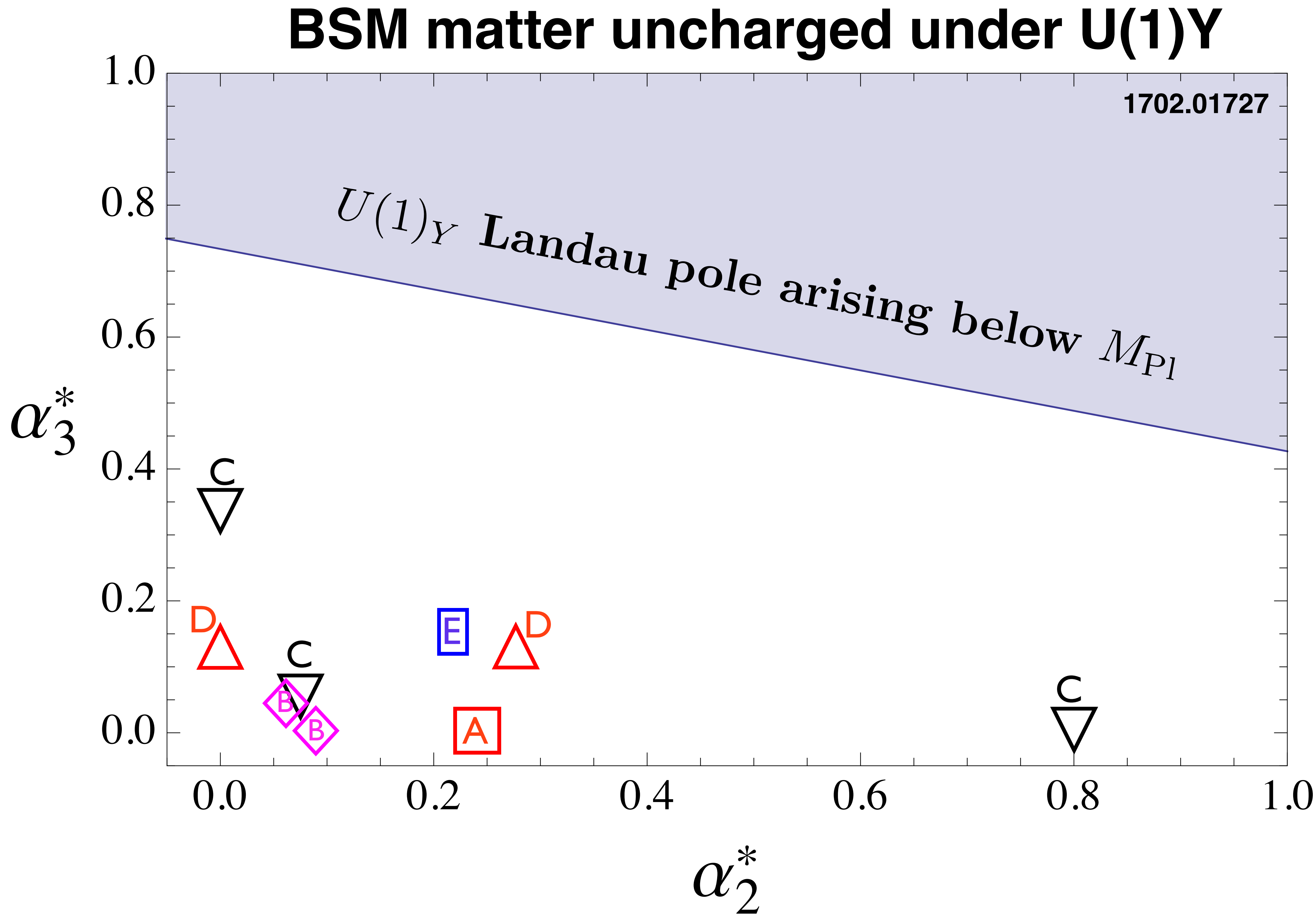
U(1)Y BSM



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U(1)Y BSM

BSM matter charged under U(1)Y

(to appear)

model	parameter (R_3, R_2, N_F)	UV fixed points α_3^*	α_2^*	α_y^*	AF for $U(1)_Y$	info
A	$(\mathbf{1}, \mathbf{4}, 12)$	0	0.2407	0.3385	$Y > 0.228$	$\mathbf{FP_2}$ ●
B	$(\mathbf{10}, \mathbf{1}, 30)$	0.1287	0	0.1158	$Y > 0.107$	$\mathbf{FP_3}$ ■
		0.1292	0.2769	0.1163	$Y > 0.114$	$\mathbf{FP_4}$ ♦
C	$(\mathbf{10}, \mathbf{4}, 80)$	0.3317	0	0.0995	$Y > 0.024$	$\mathbf{FP_3}$ ■
		0.0503	0.0752	0.0292	$Y > 0.050$	$\mathbf{FP_4}$ ♦
		0	0.8002	0.1500	$Y > 0.018$	$\mathbf{FP_2}$ ●
D	$(\mathbf{3}, \mathbf{4}, 290)$	0	0.0895	0.0066	$Y > 0.042$	$\mathbf{FP_2}$ ●
		0.0416	0.0615	0.0056	$Y > 0.052$	$\mathbf{FP_4}$ ♦
E	$(\mathbf{3}, \mathbf{3}, 72)$	0.1499	0.2181	0.0471	$Y > 0.073$	$\mathbf{FP_4}$ ♦

lower bounds
on hypercharge