# probing asymptotic safety beyond the Standard Model

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**based on**
**AD Bond, G Hiller, K Kowalska, DF Litim, 1702.01727**

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**CERN LHC LLP Workshop**

# asymptotic safety

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**new model building idea**

Steven Weinberg (originally for quantum gravity)

running couplings achieve **interacting** UV fixed point

**generic features**

**new particles** charged under the SM

often in **higher-dim reps**

**new Yukawa** interactions

**proof** of existence in SU(N) **DF Litim, F Sannino, 1406.2337**

**theorems** for SM-like theories **AD Bond, DF Litim, 1608.00519**

# asymptotic safety beyond the SM

**minimal framework:** AD Bond, G Hiller, K Kowalska, DF Litim, 1702.01727

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 coupling

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# UV fixed point search

## possible fixed points
(two gauge plus BSM Yukawa couplings)

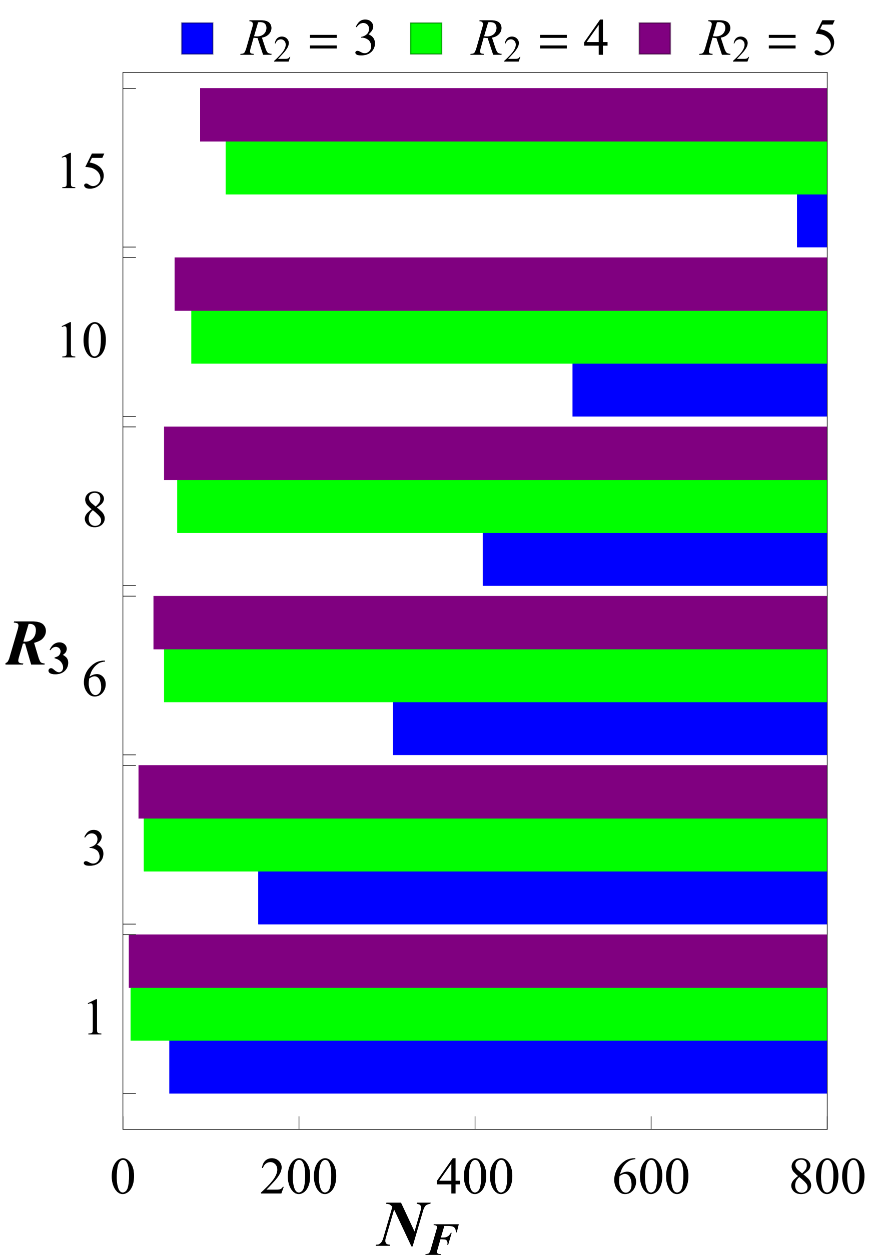
| # | gauge couplings | | BSM Yukawa | type & info | |
|---|---|---|---|---|---|
| **FP$_1$** | $\alpha_3^* = 0$ | $\alpha_2^* = 0$ | $\alpha_y^* = 0$ | $\mathbf{G \cdot G}$ | non-interacting |
| **FP$_2$** | $\alpha_3^* = 0$ | $\alpha_2^* > 0$ | $\alpha_y^* > 0$ | $\mathbf{G \cdot GY}$ | partially interacting |
| **FP$_3$** | $\alpha_3^* > 0$ | $\alpha_2^* = 0$ | $\alpha_y^* > 0$ | $\mathbf{GY \cdot G}$ | partially interacting |
| **FP$_4$** | $\alpha_3^* > 0$ | $\alpha_2^* > 0$ | $\alpha_y^* > 0$ | $\mathbf{GY \cdot GY}$ | fully interacting |

**we want partially or fully interacting FPs**

# results: BSM fixed points

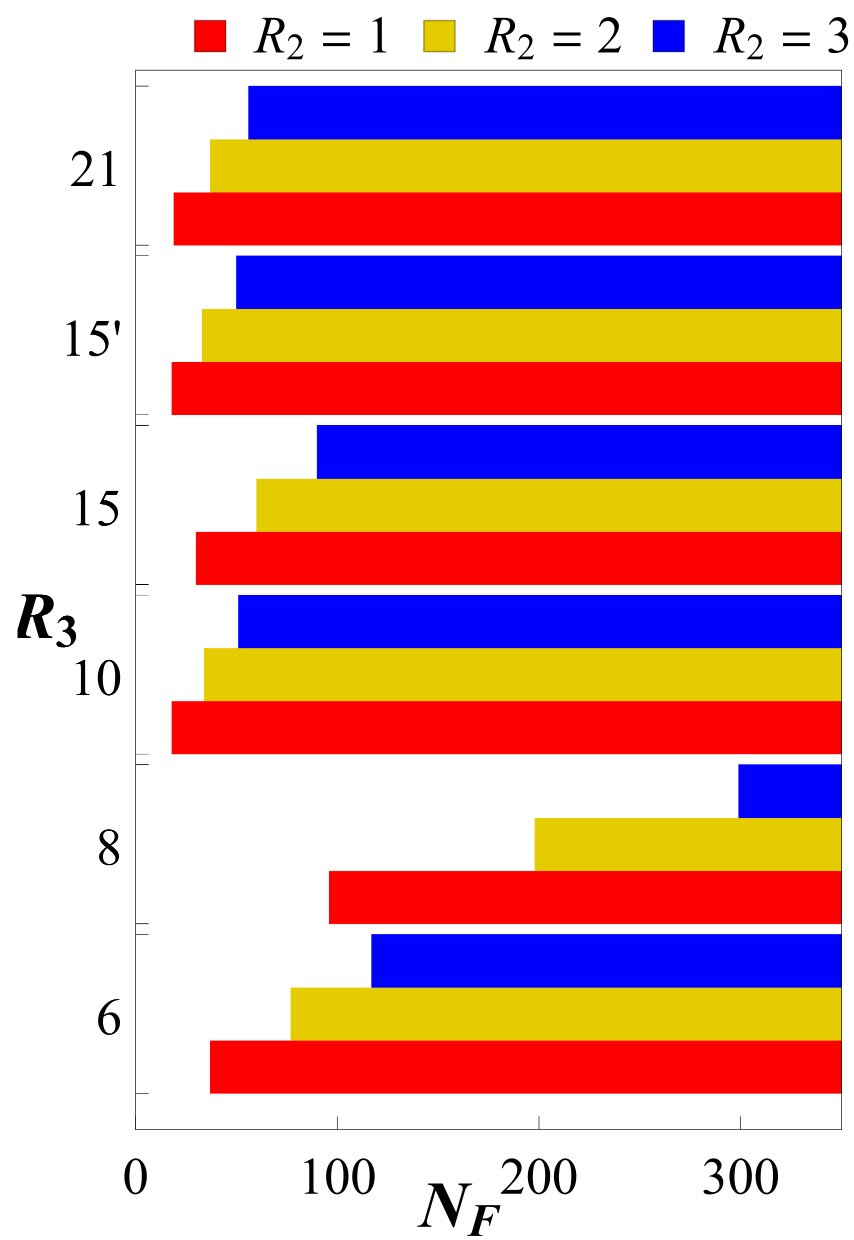
## $\mathbf{FP_2}$

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



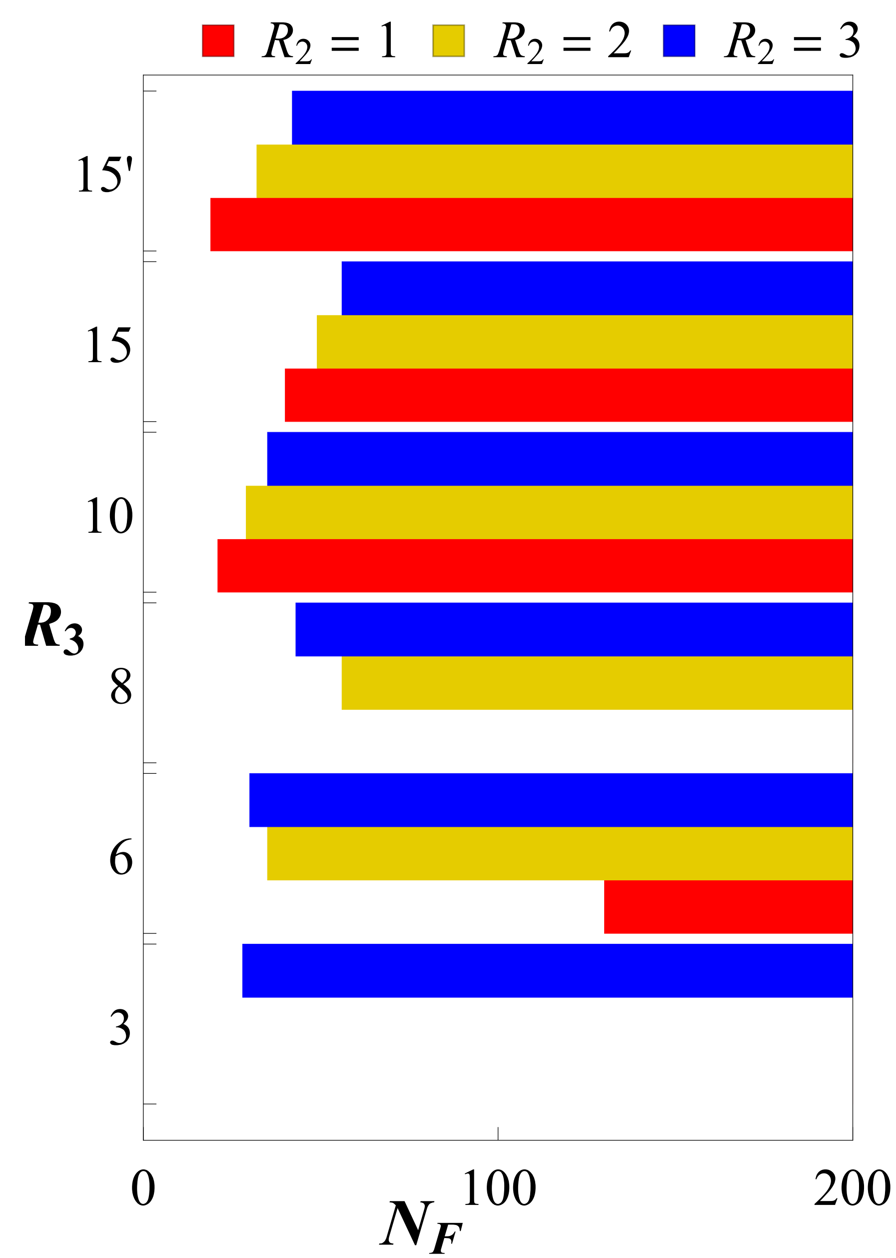

## $\mathbf{FP_3}$

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




## $\mathbf{FP_4}$

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



# benchmark models

| model | parameter $(R_3, R_2, N_F)$ | UV fixed points $\alpha_3^*$ | $\alpha_2^*$ | $\alpha_y^*$ | 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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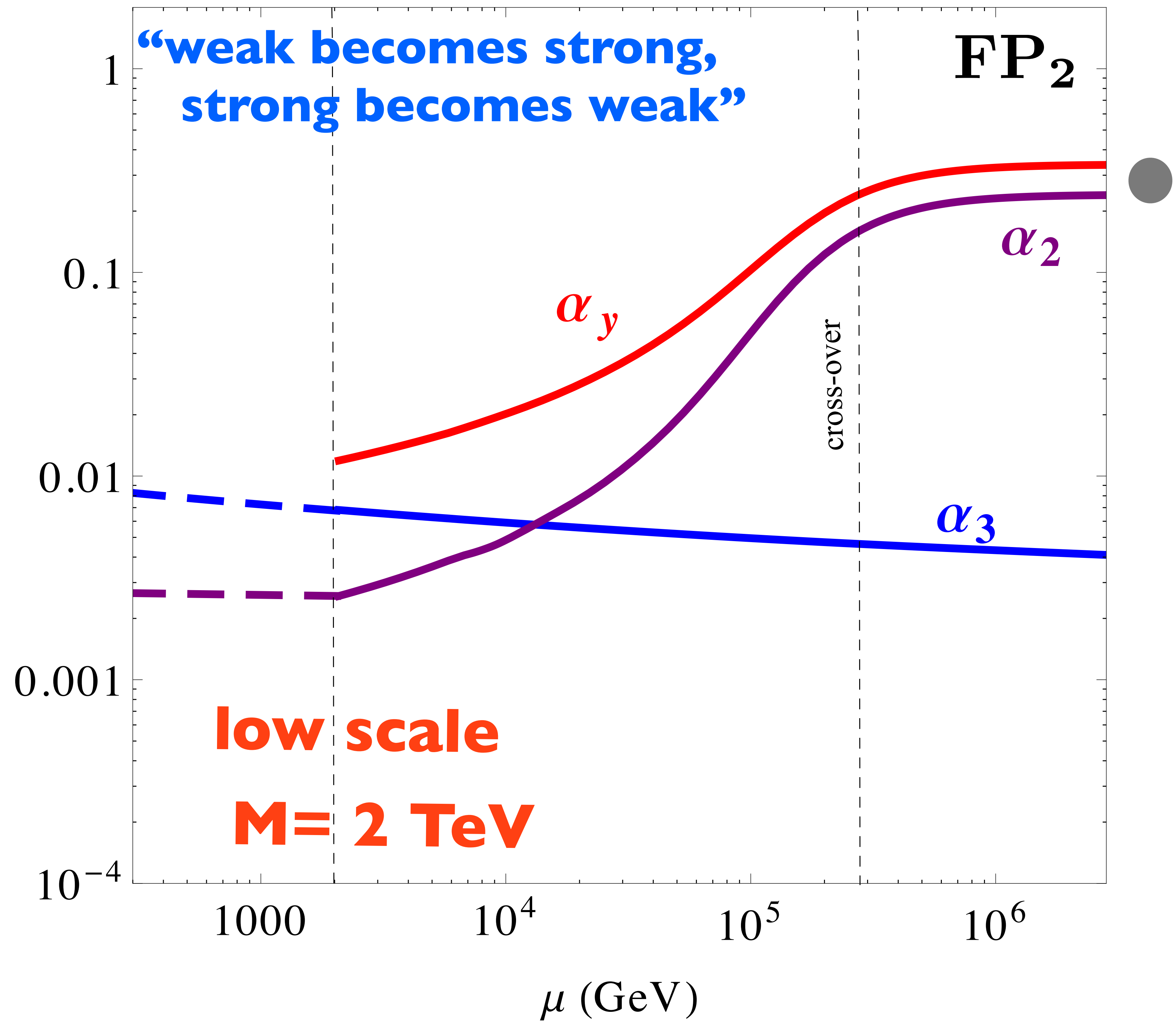
# benchmark models

## model A

$(R_3, R_2, N_F) =$ (**1**,**4**,12)



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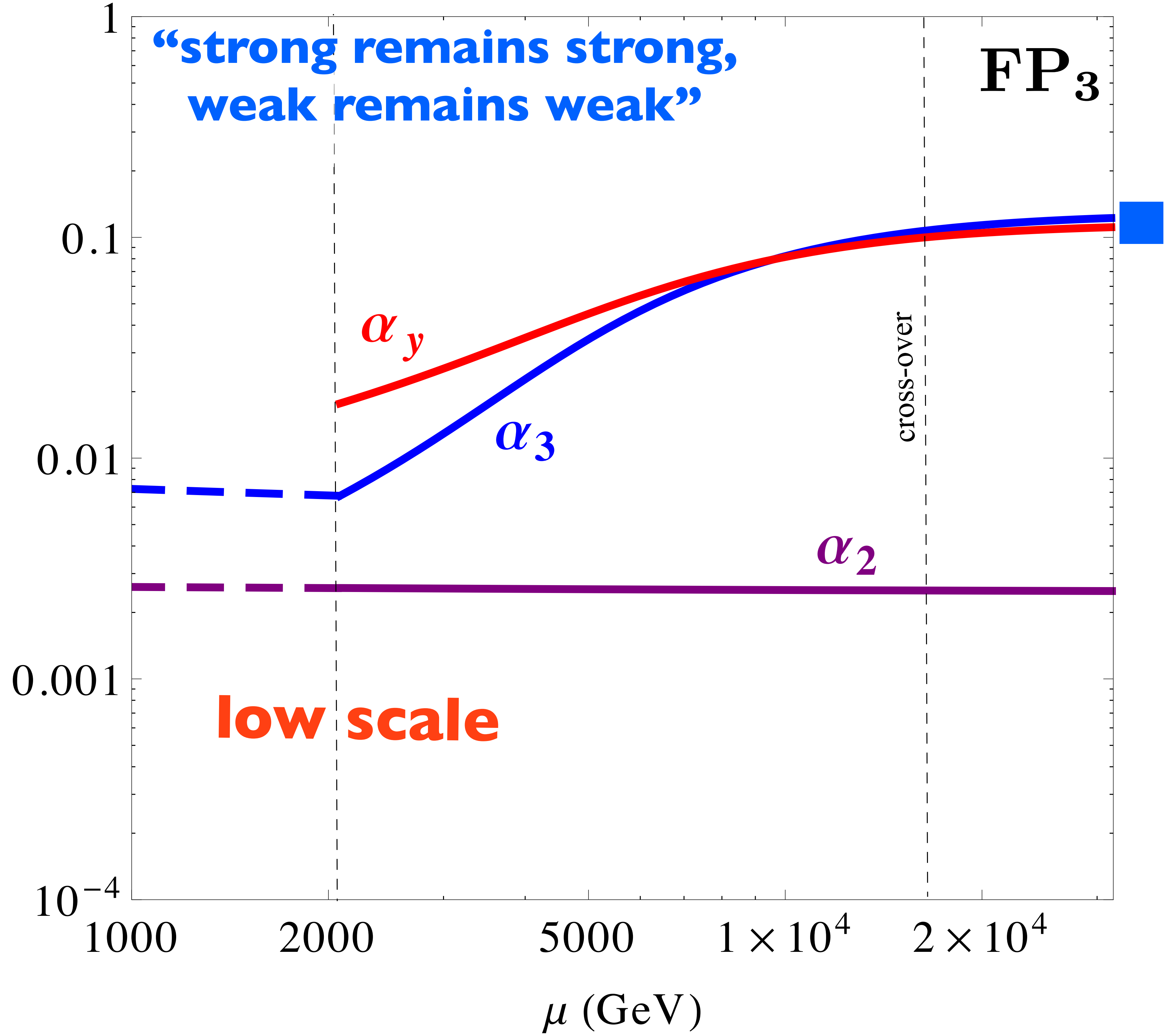
# benchmark models

## model B

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



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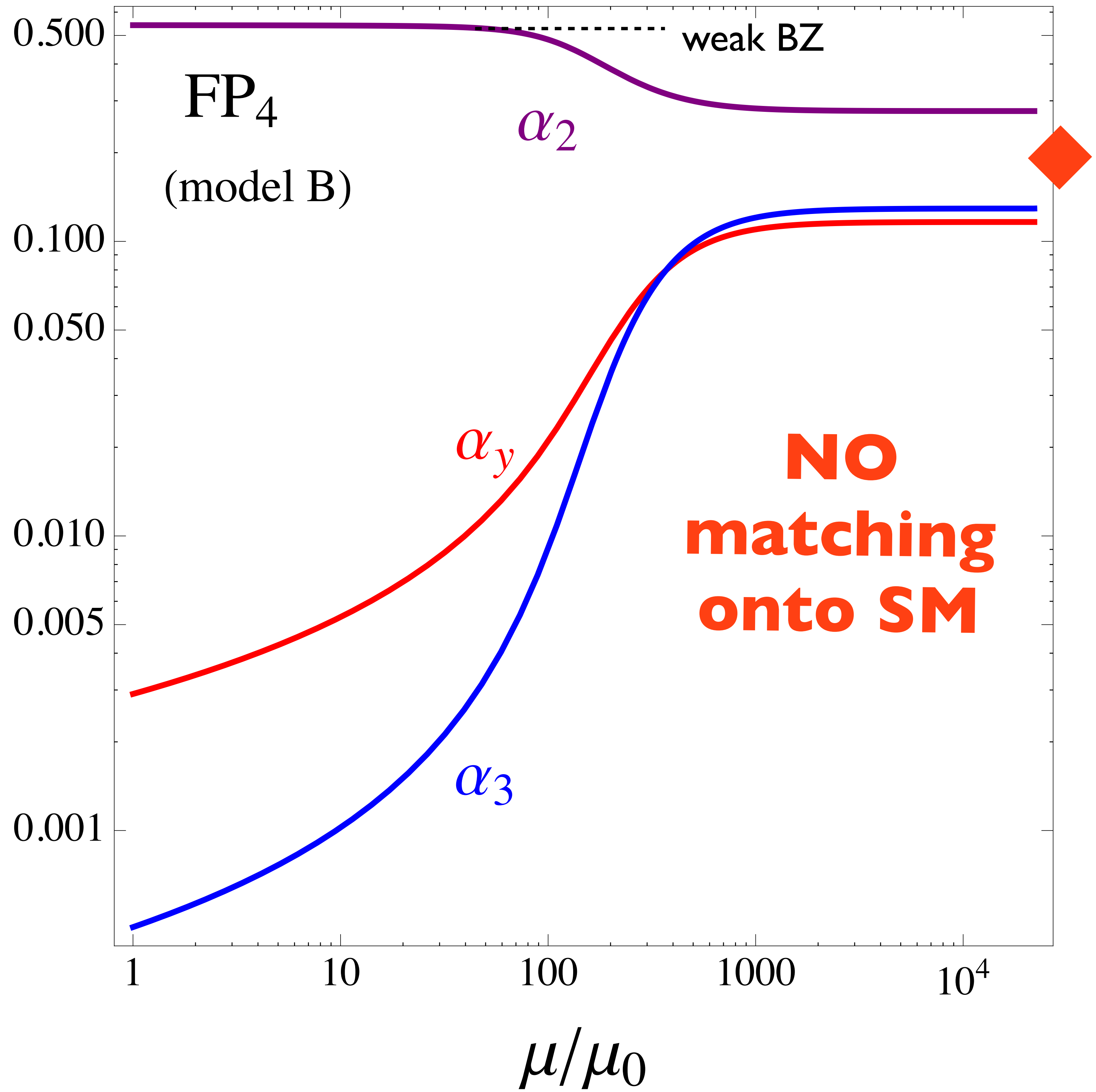
# benchmark models

## model B

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



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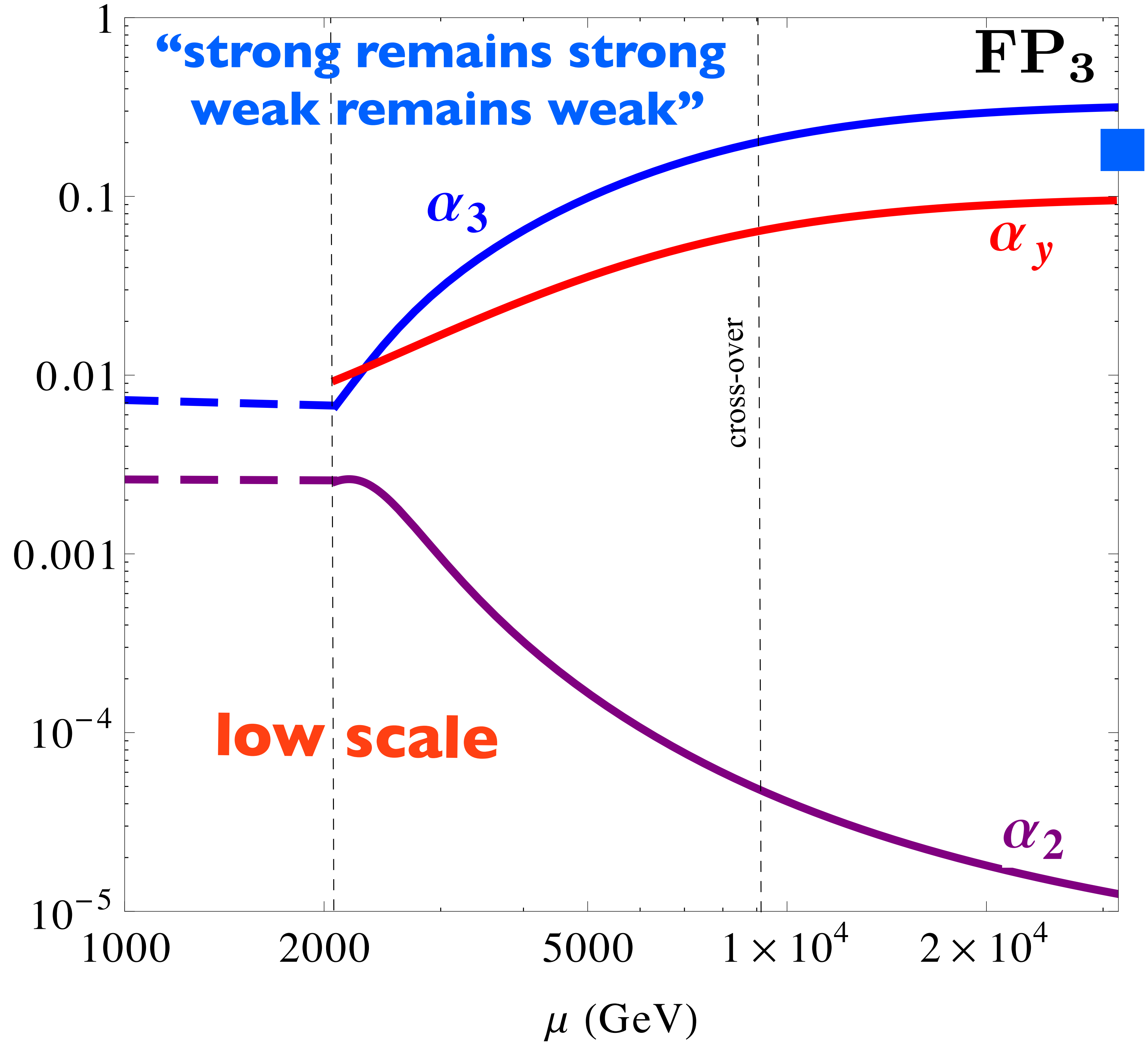
# benchmark models

## model C

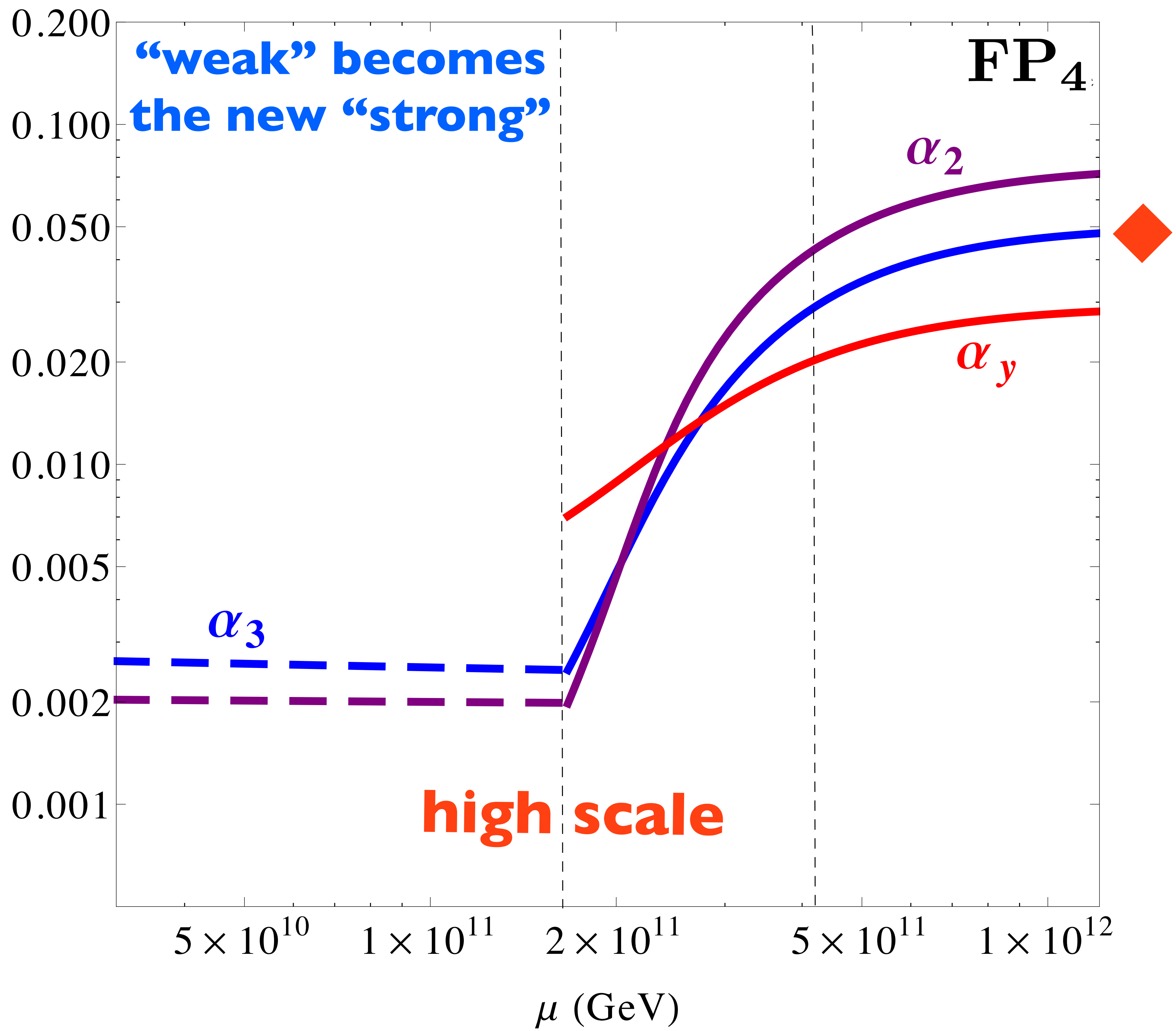
$(R_3, R_2, N_F) = \ (\mathbf{10}, \mathbf{4}, 80)$



# benchmark models

## model C

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



# benchmark models

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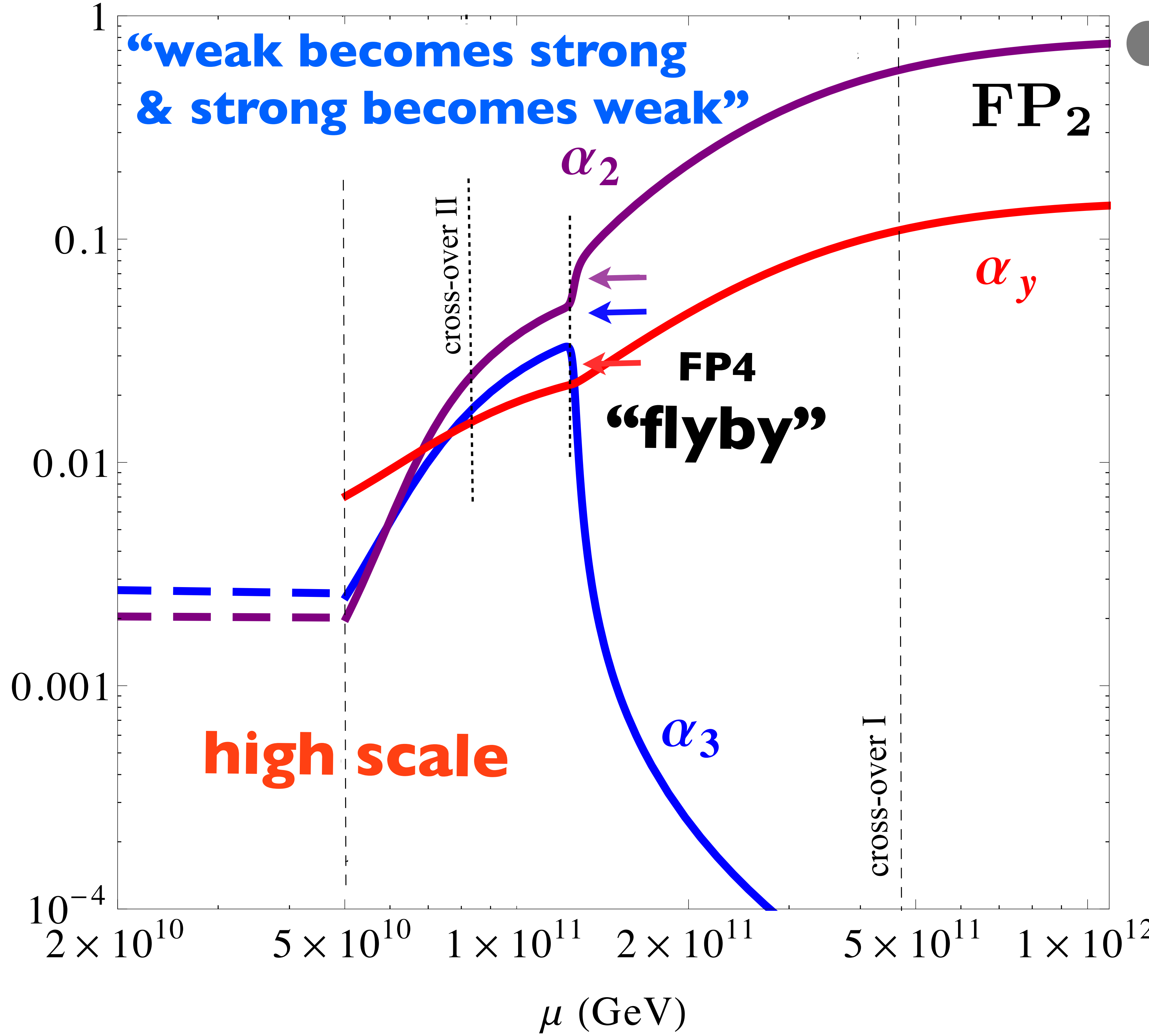
## model C

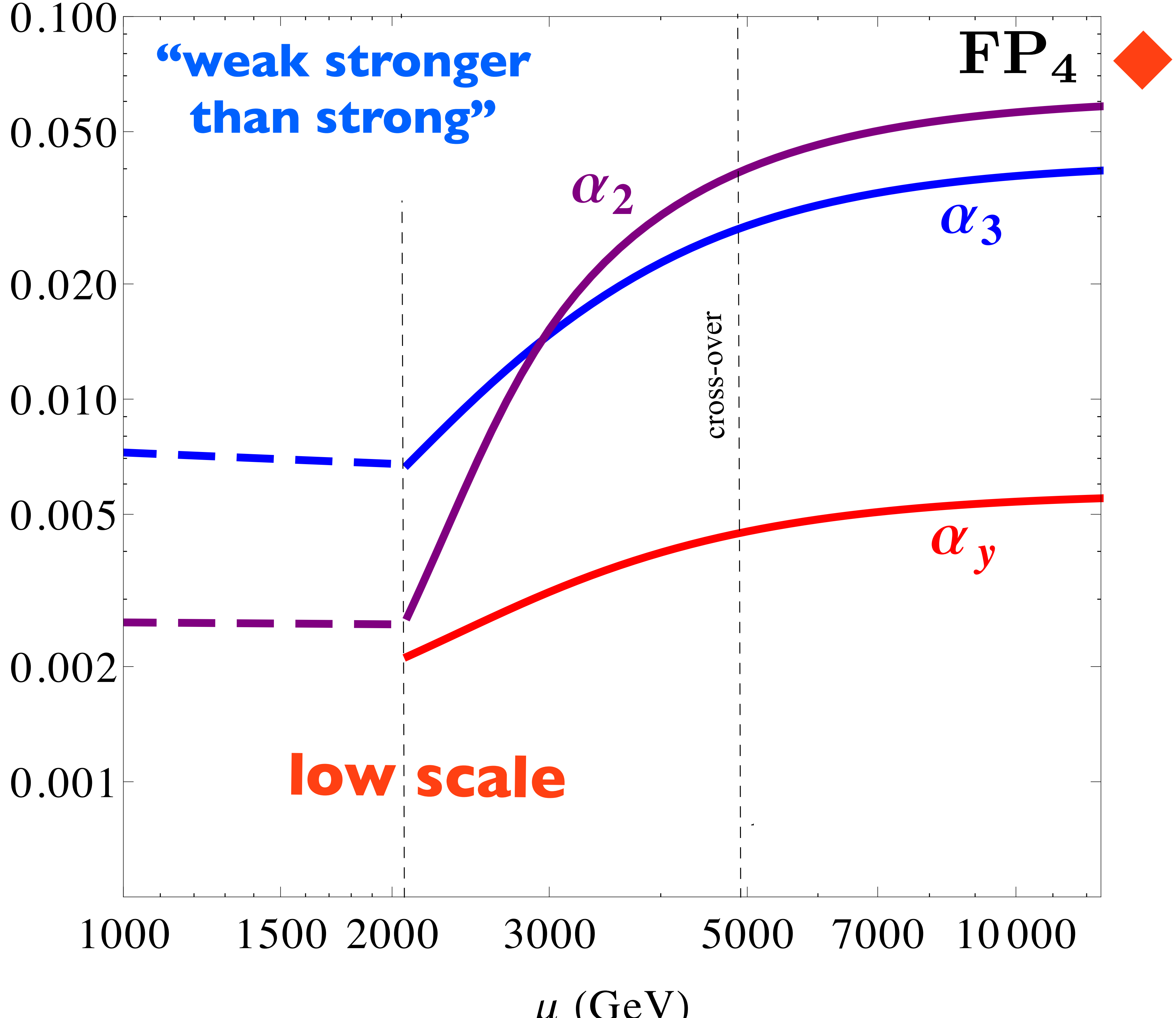
$(R_3, R_2, N_F) = $ (**10**,**4**,80)



# benchmark models

## model D

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



# asymptotic safety

## collider signatures

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# collider signatures

**assume low scale matching**
some BSM masses within **TeV** energy range

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

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

**search modes** include
- running couplings
- the weak sector
- long-lived QCD bound states (R hadrons)
- di-boson spectra
- Psi-onia resonances

**Y Kats, MJ Strassler, 1204.1119, 1602.08819**

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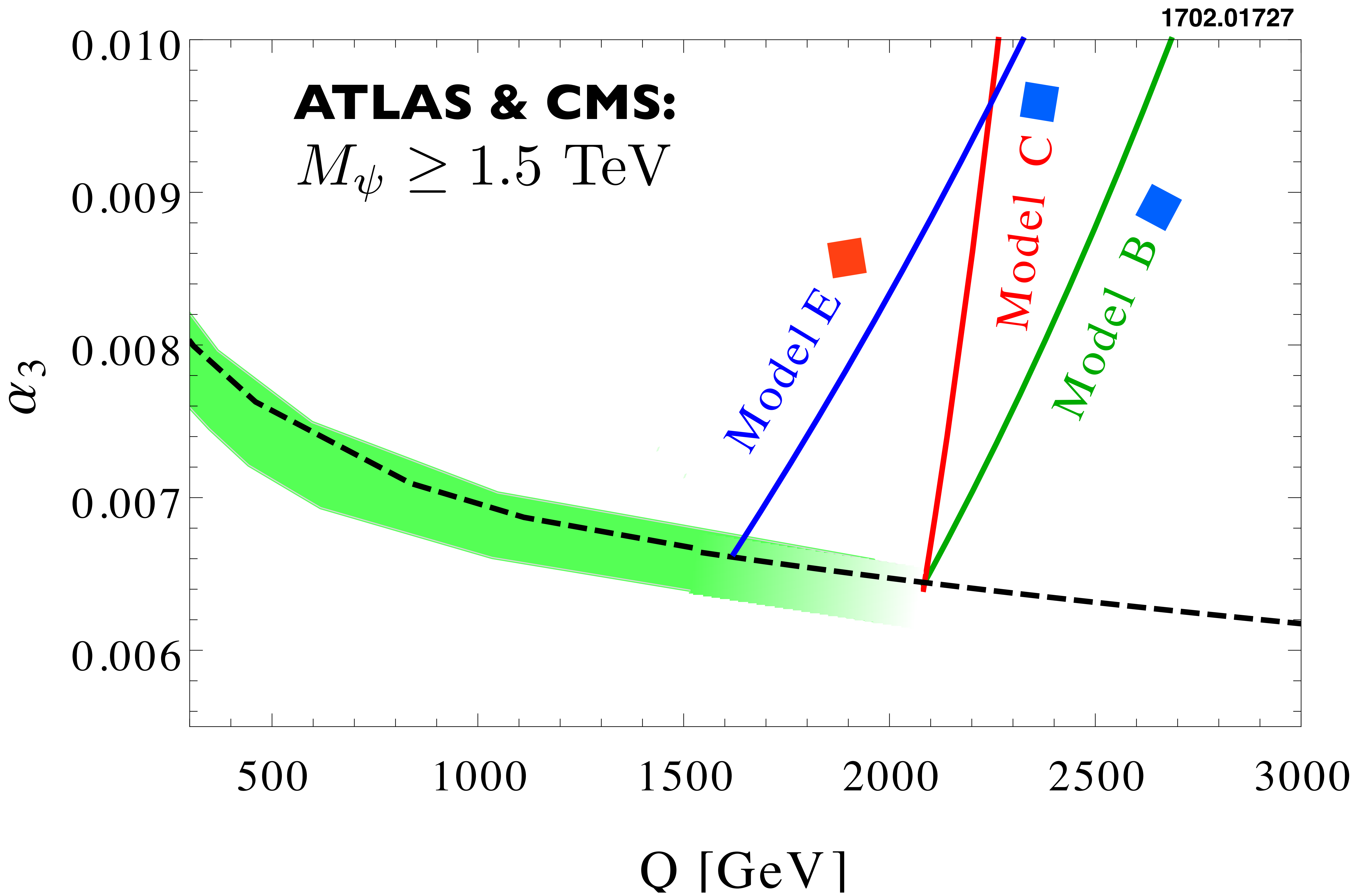
# SU(3) BSM running



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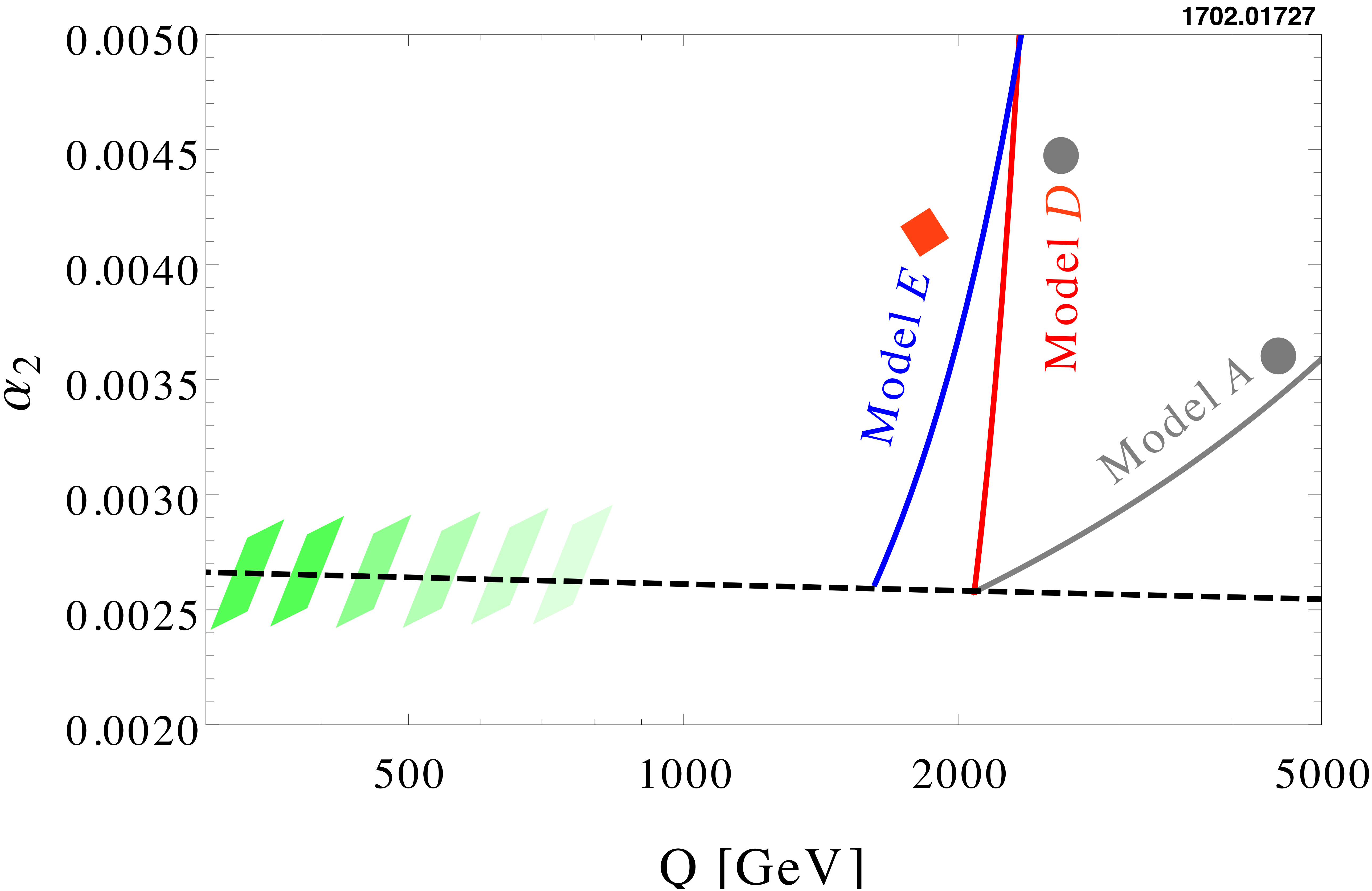
# SU(2) BSM running



# di-boson spectra and resonances

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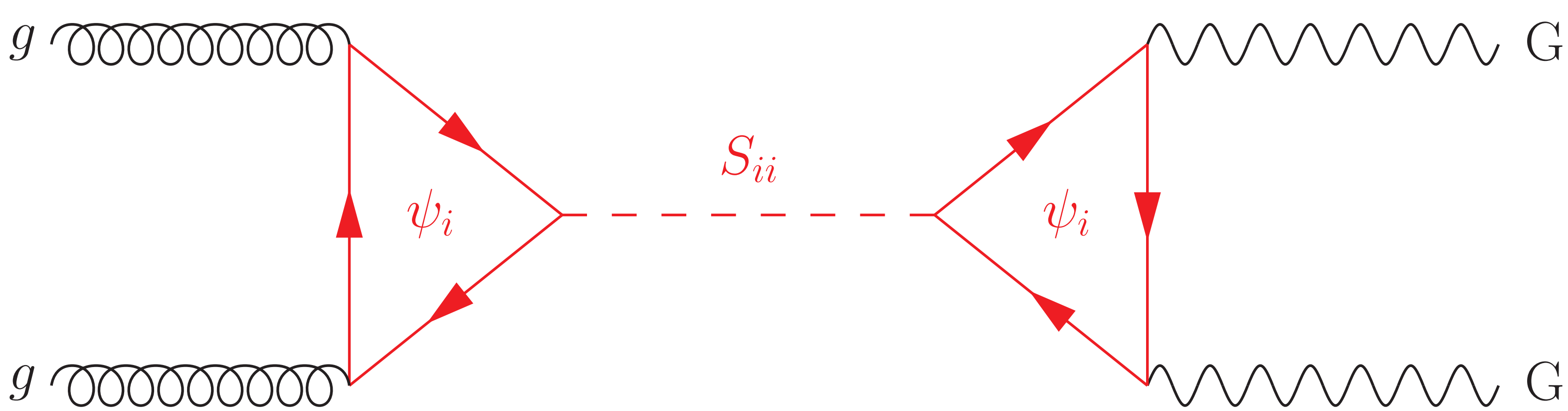
assume **resonant production** of BSM scalars

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

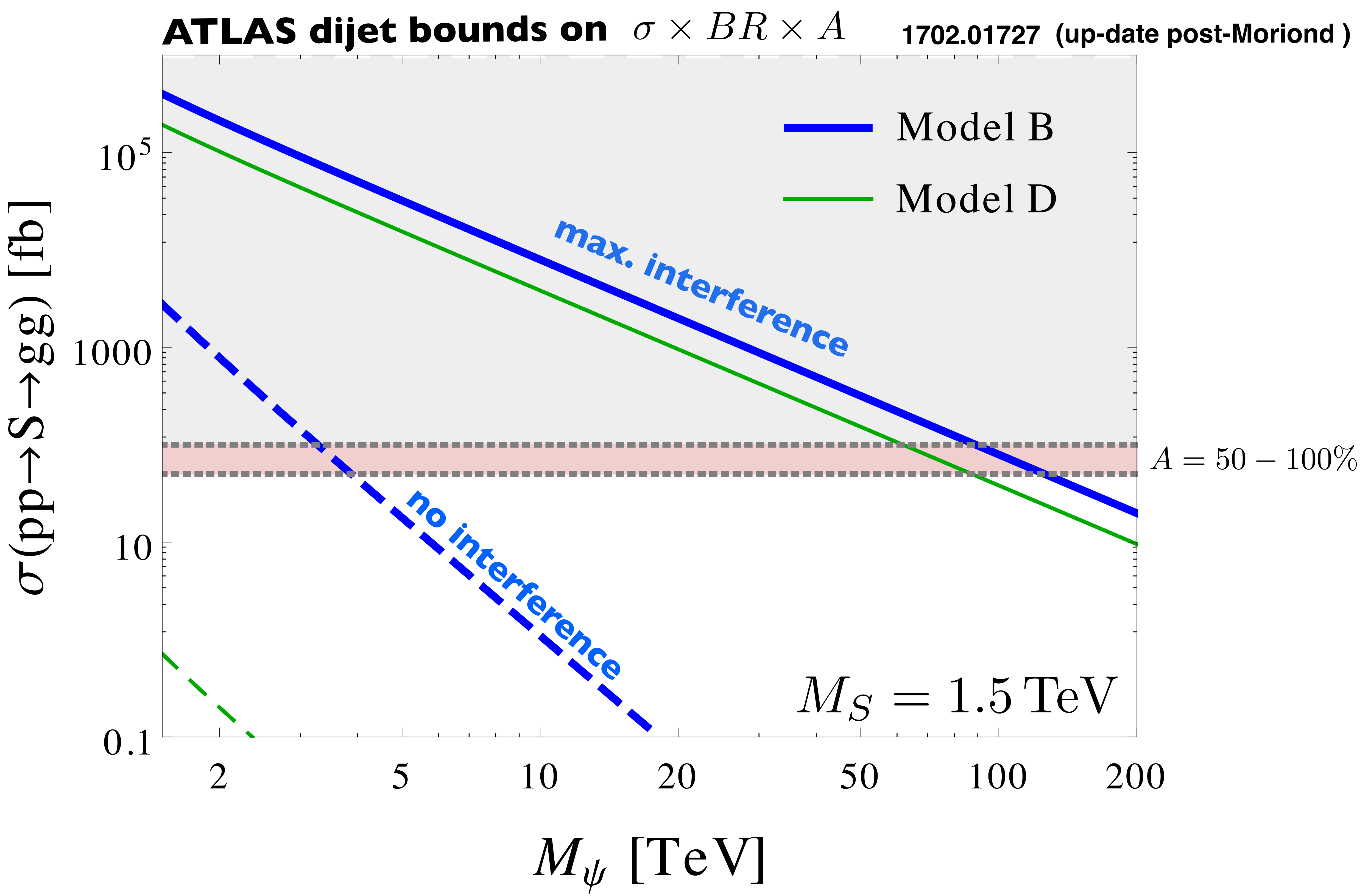
**"low Ms"** $M_S \lesssim M_\psi$ $\qquad$ **"high Ms"** $M_\psi \lesssim M_S < 2M_\psi$

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




interference effects

# dijet cross section



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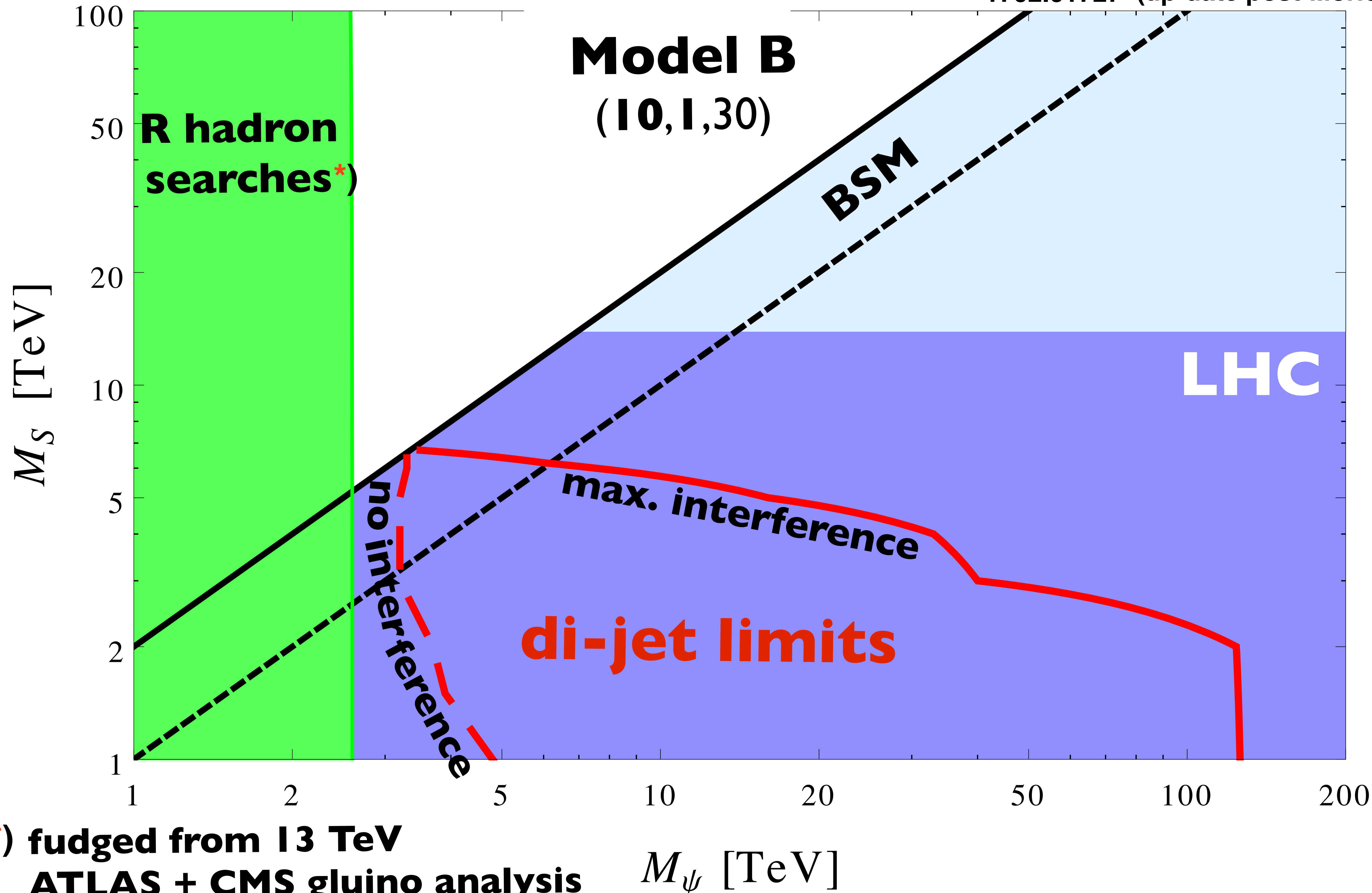
# mass exclusion limits

1702.01727 (up-date post-Moriond )




*) fudged from 13 TeV ATLAS + CMS gluino analysis

# conclusions

asymptotic safety provides

**directions** for model building

can be tested at colliders

stay tuned...

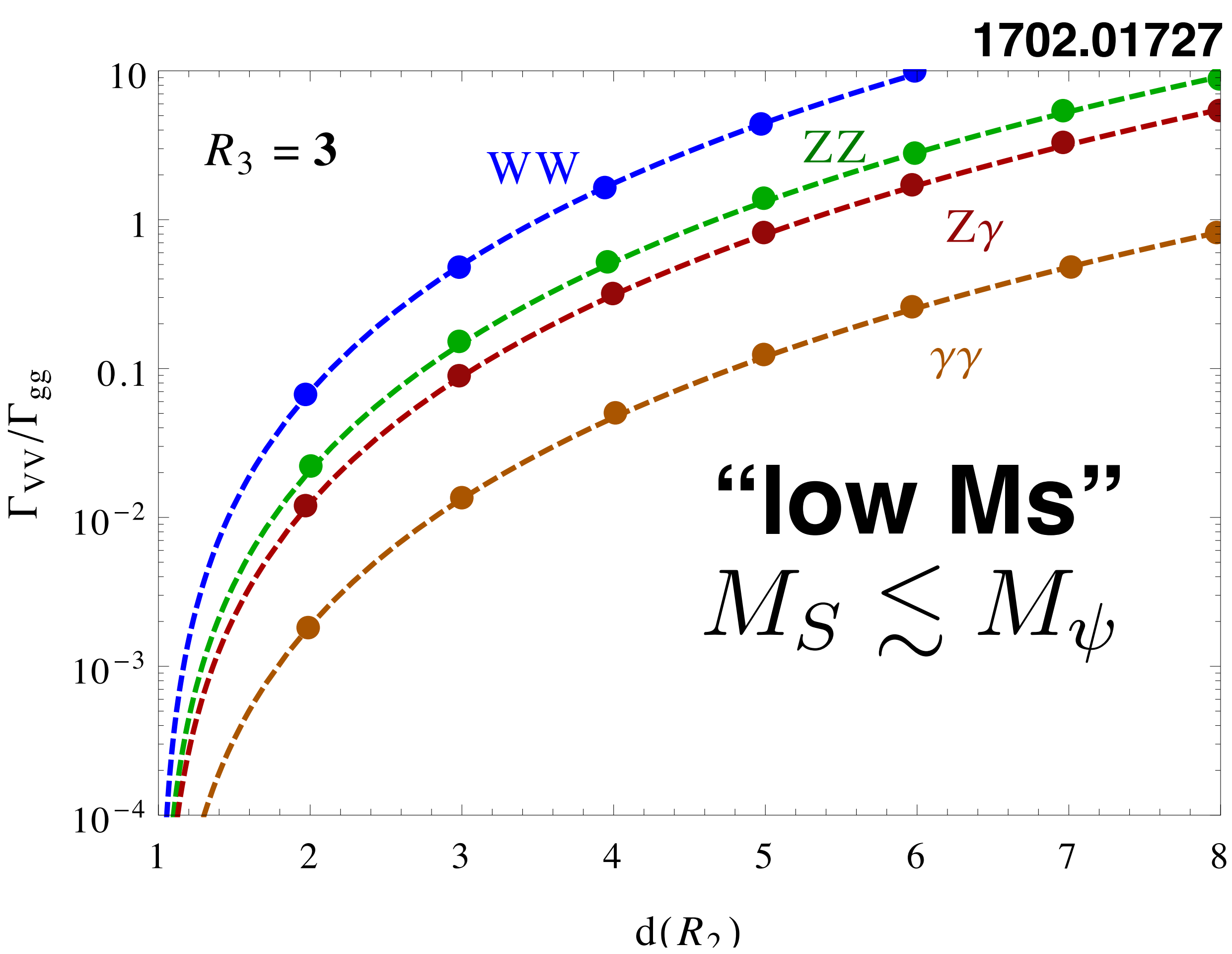
# extra material

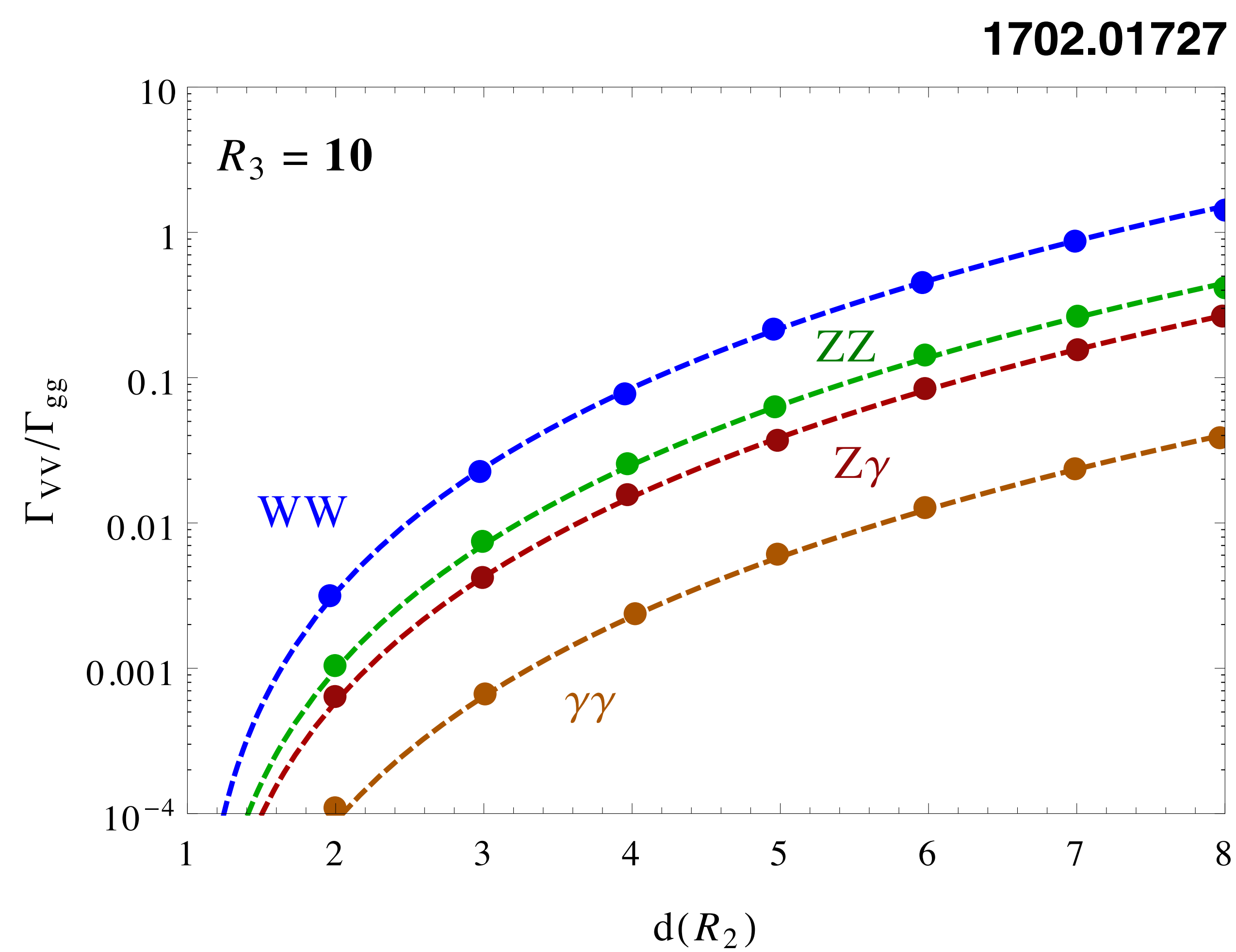
# decays into electroweak gauge bosons

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

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

growth with dim(R2)



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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

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

## modifications for **"high Ms"**:

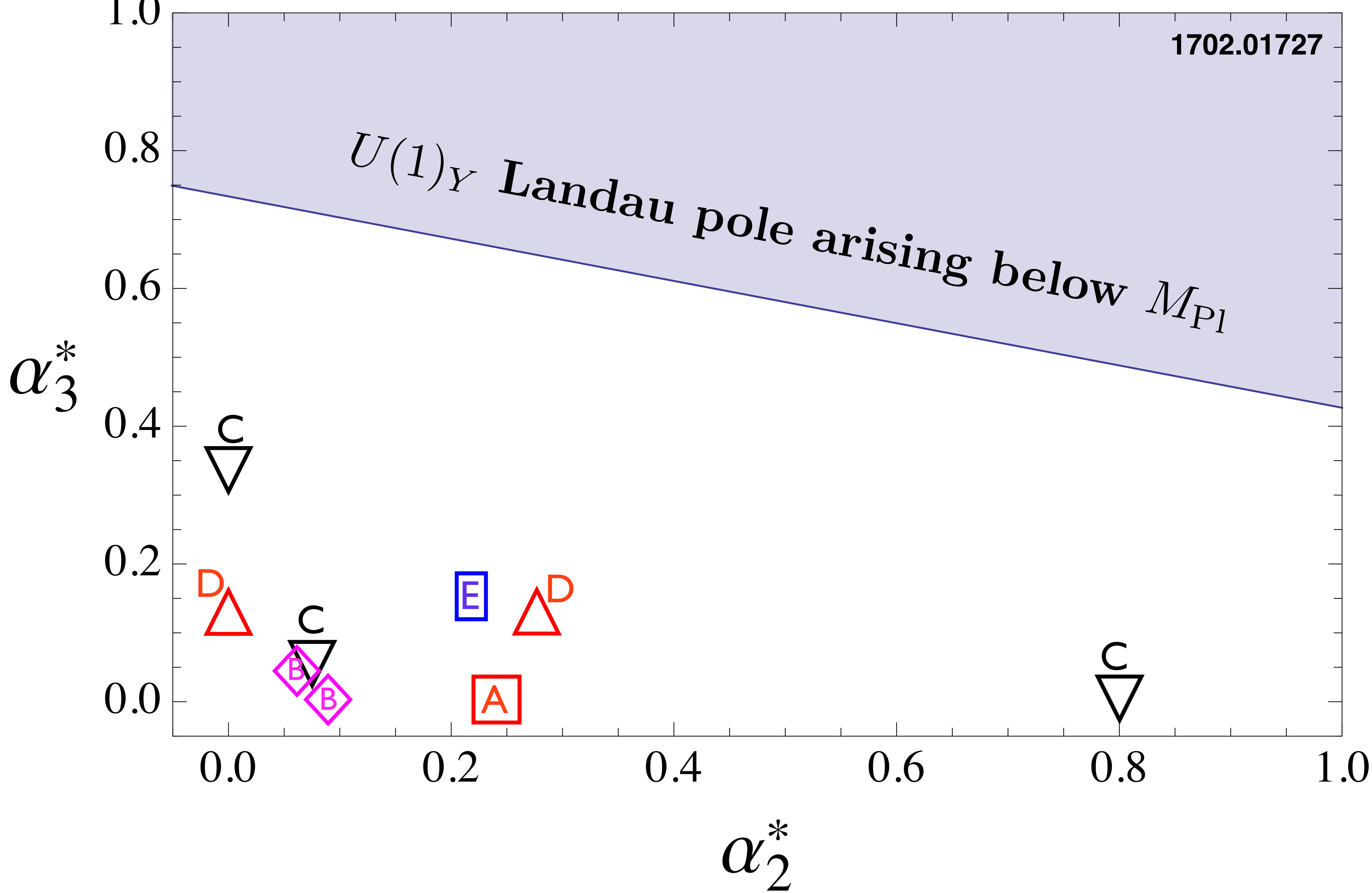
**FP$_2$** $\bar{\Gamma}_{WW}, \bar{\Gamma}_{ZZ}, \bar{\Gamma}_{Z\gamma}$ ↗ $\bar{\Gamma}_{\gamma\gamma}$ ?

**FP$_3$** $\bar{\Gamma}_{WW}, \bar{\Gamma}_{ZZ}, \bar{\Gamma}_{Z\gamma}, \bar{\Gamma}_{\gamma\gamma}$ ↘

**FP$_4$** $\bar{\Gamma}_{WW}, \bar{\Gamma}_{ZZ}$ ↗ $\bar{\Gamma}_{\gamma\gamma}$ ↘ $\bar{\Gamma}_{Z\gamma}$ ?

# U(1)Y BSM

## BSM matter uncharged under U(1)Y



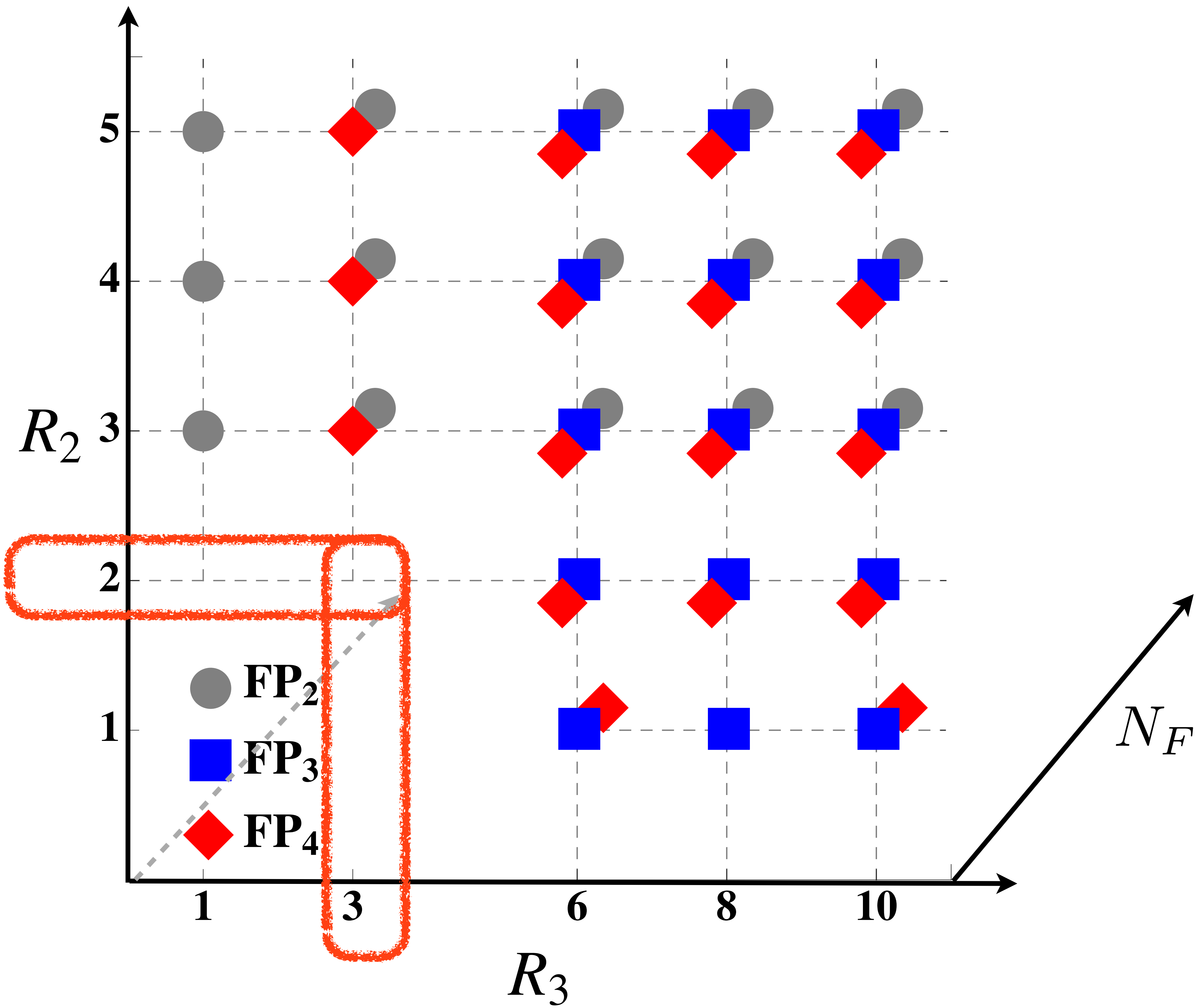
# U(1)Y BSM

## BSM matter charged under U(1)Y (to appear)

| model | parameter $(R_3, R_2, N_F)$ | UV fixed points $\alpha_3^*$ | $\alpha_2^*$ | $\alpha_y^*$ | 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**

# summary of fixed points



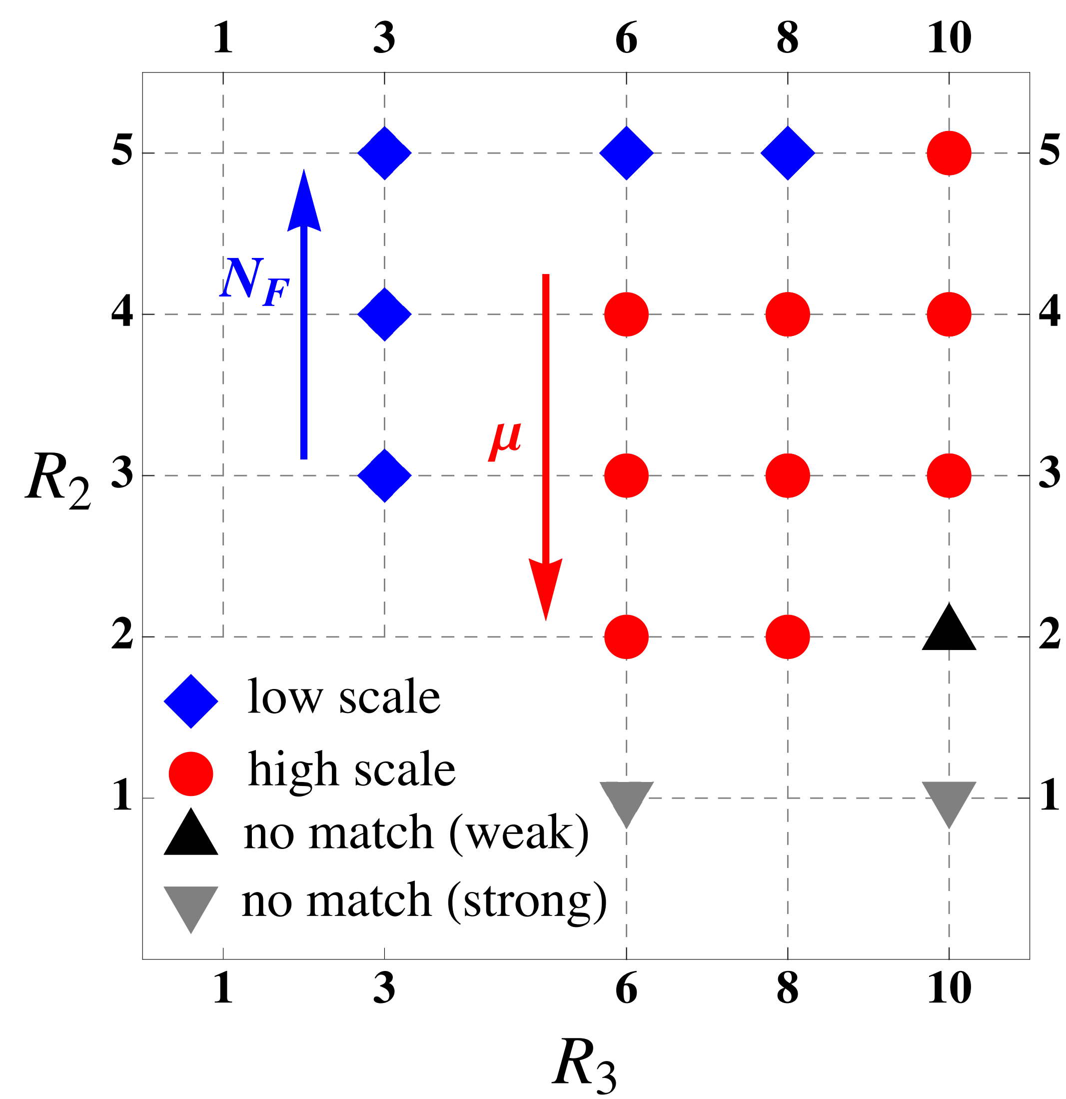
# summary of SM matching: when it works

**partially interacting FP (one safe, one free)**

genuinely, except in very special circumstances

**fully interacting FP (both safe)**

for most reps - see plot



# why asymptotic safety?

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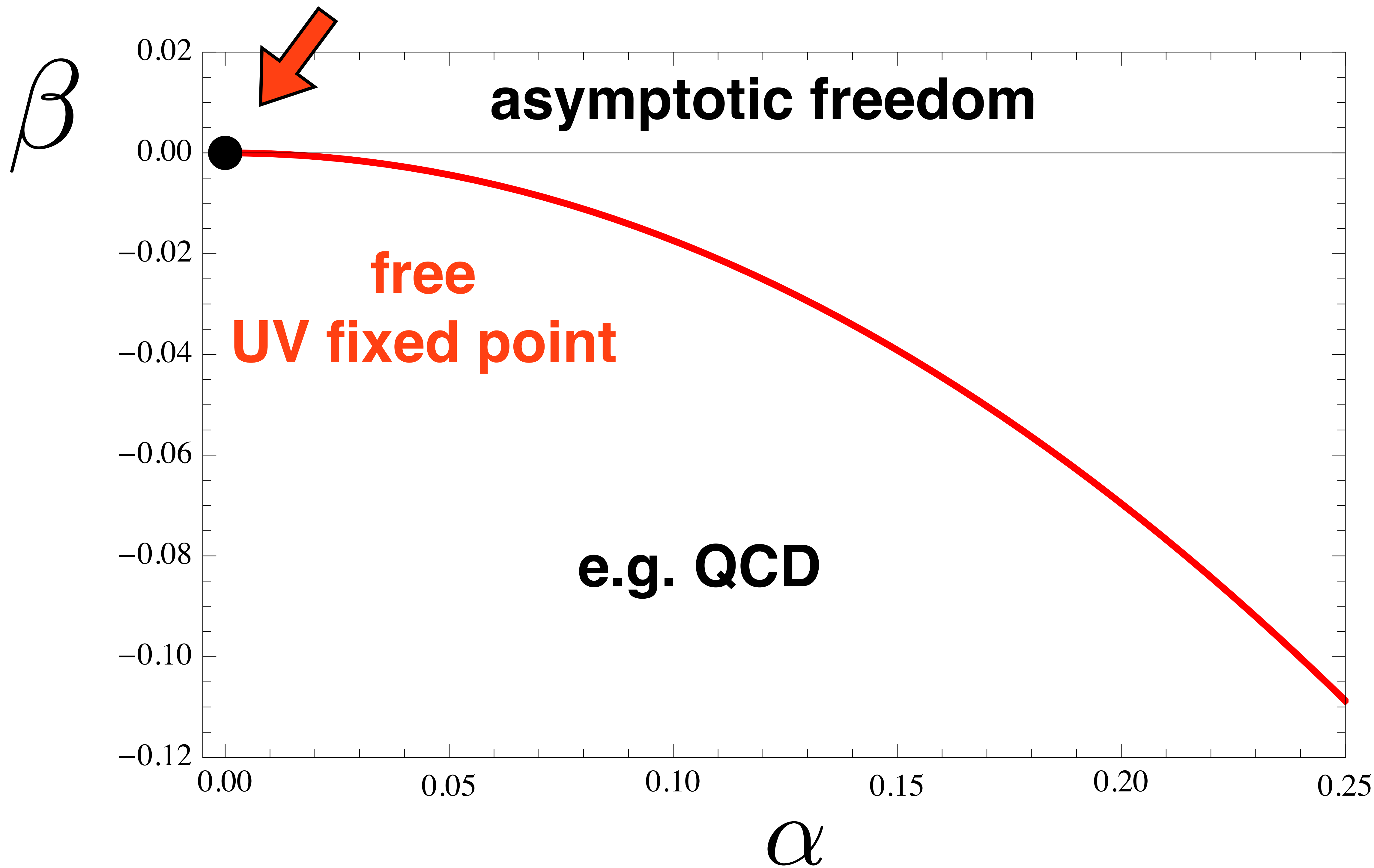

# why asymptotic safety?

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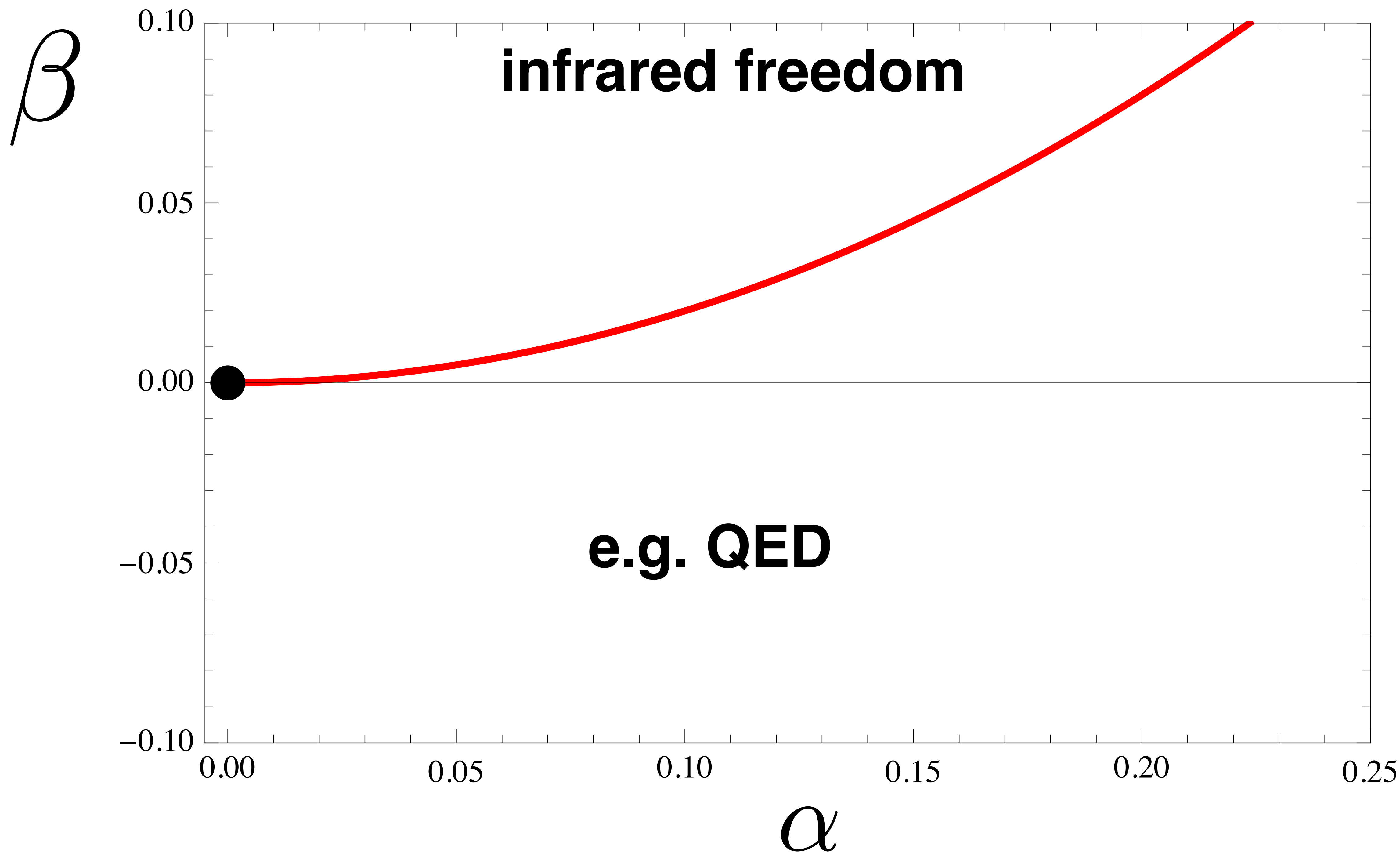

# why asymptotic safety?

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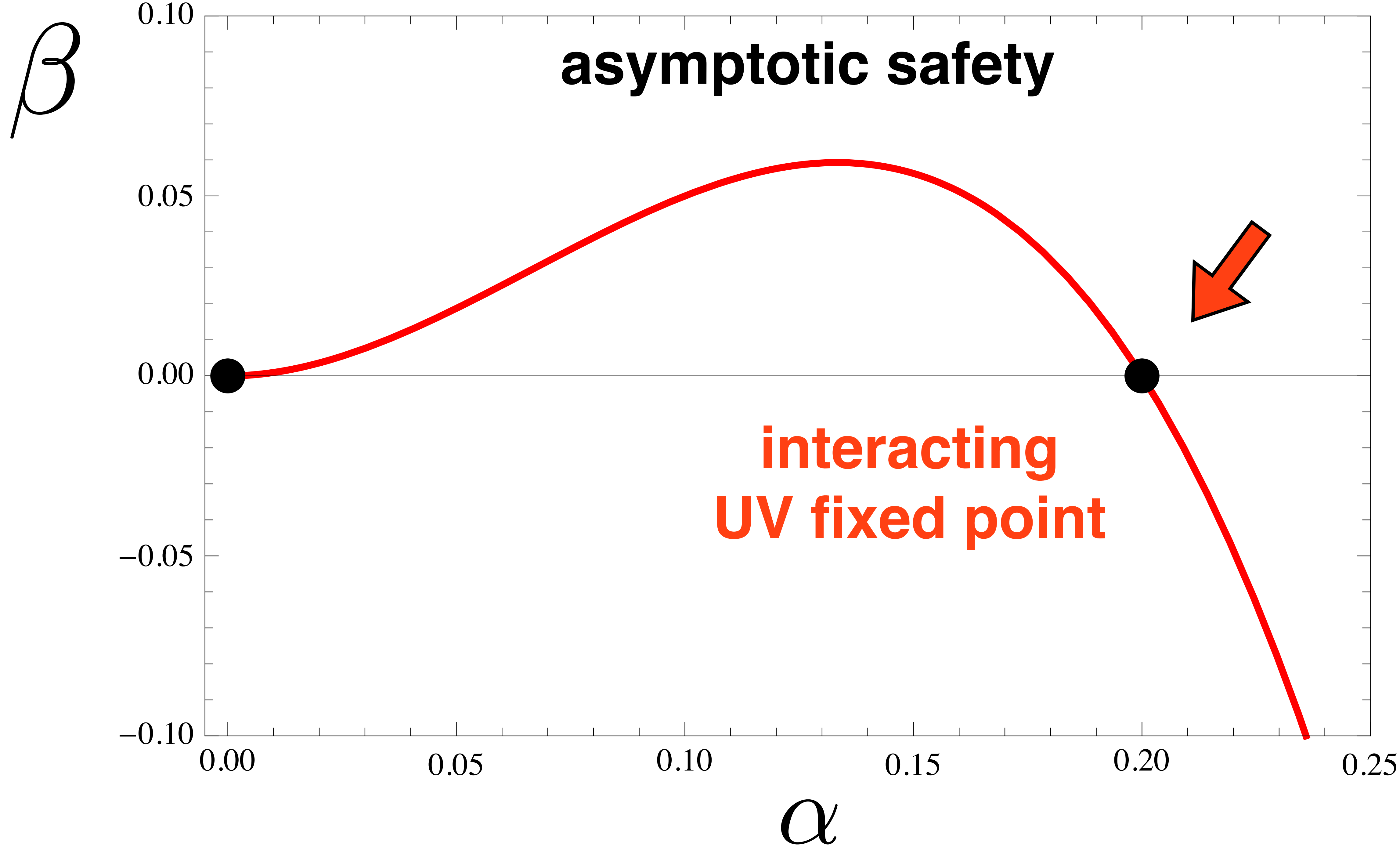

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# theorems for asymptotic safety

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