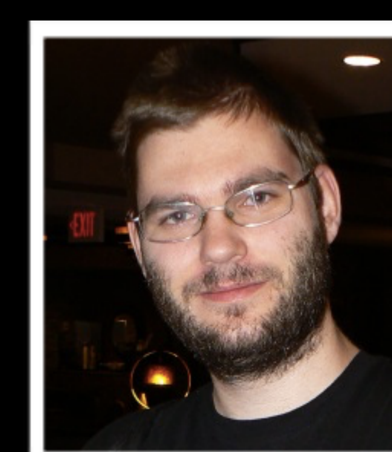
SUSY'21, August 25 2021

Perturbativity aspects of the minimal SO(10) Higgs model

Michal Malinský

IPNP, Charles University in Prague



in collaboration with
K. Jarkovská, T. Mede, V. Susić

to appear soon on ArXiv

The minimal SO(10) Higgs model

SO(10) broken by 45 + …

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The minimal SO(10) Higgs model

SO(10) broken by 45 + …

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The 45 breaking is really special:

$$\mathcal{L} \ni \frac{\kappa}{\Lambda} F^{\mu\nu} \langle 45 \rangle F_{\mu\nu} = 0$$

$$(45 \otimes 45)_{sym} = 54 \oplus 210 \oplus 770$$

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The minimal SO(10) Higgs model

$$SO(10)$$

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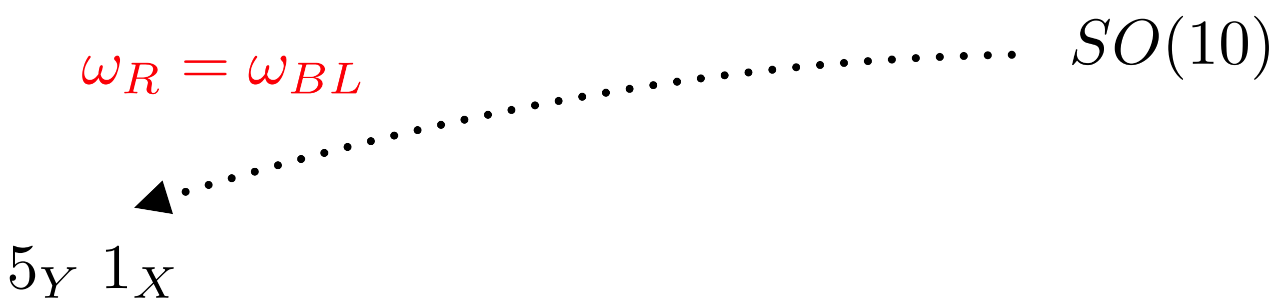
The minimal SO(10) Higgs model



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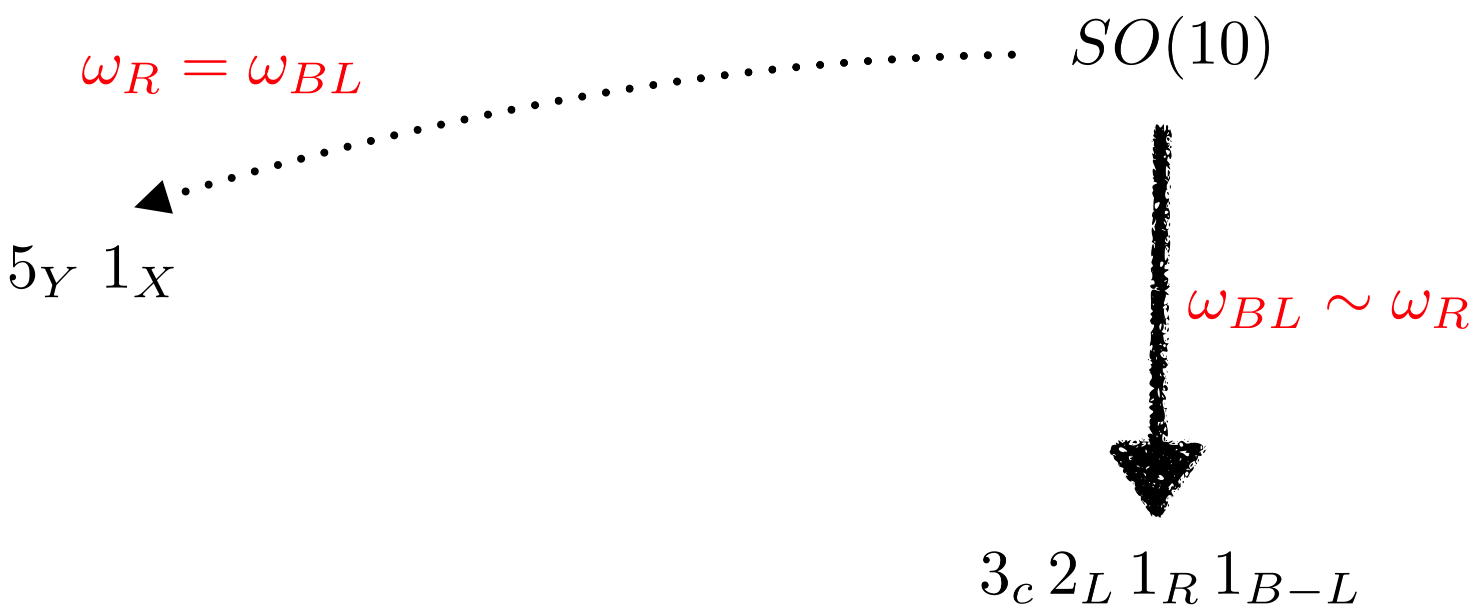

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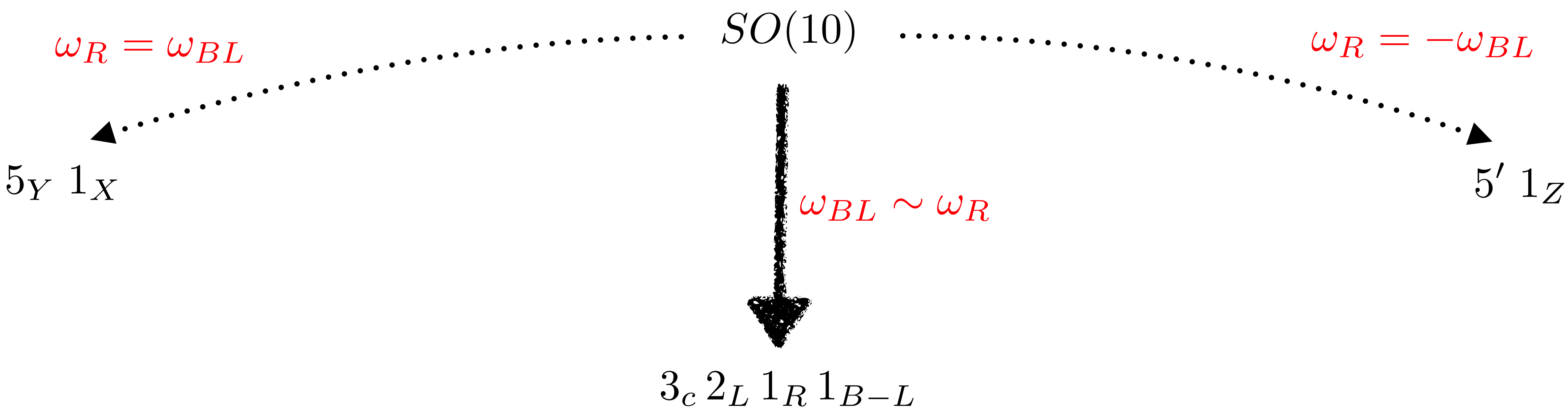

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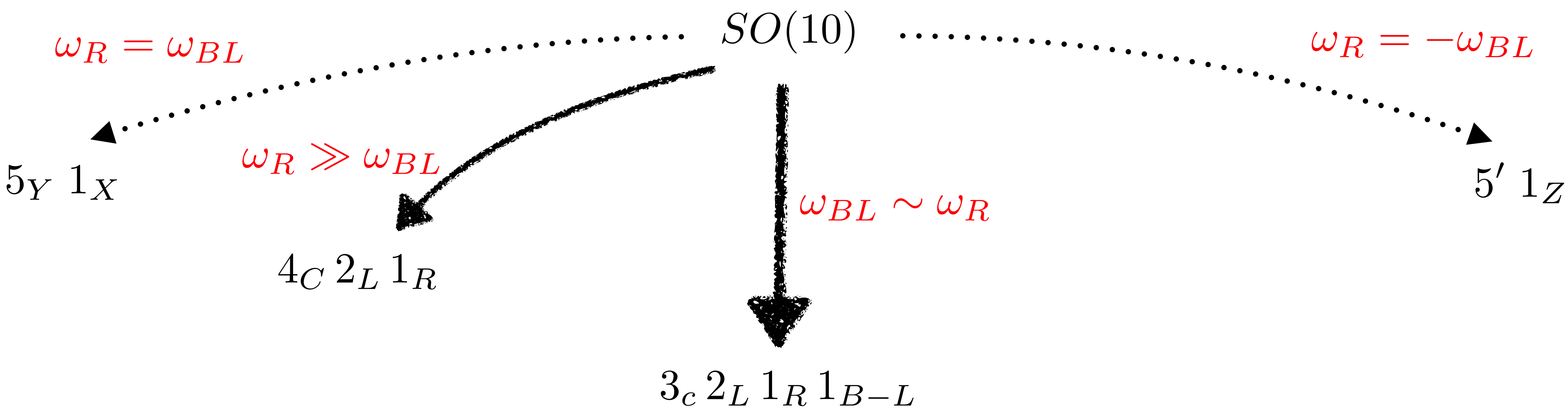

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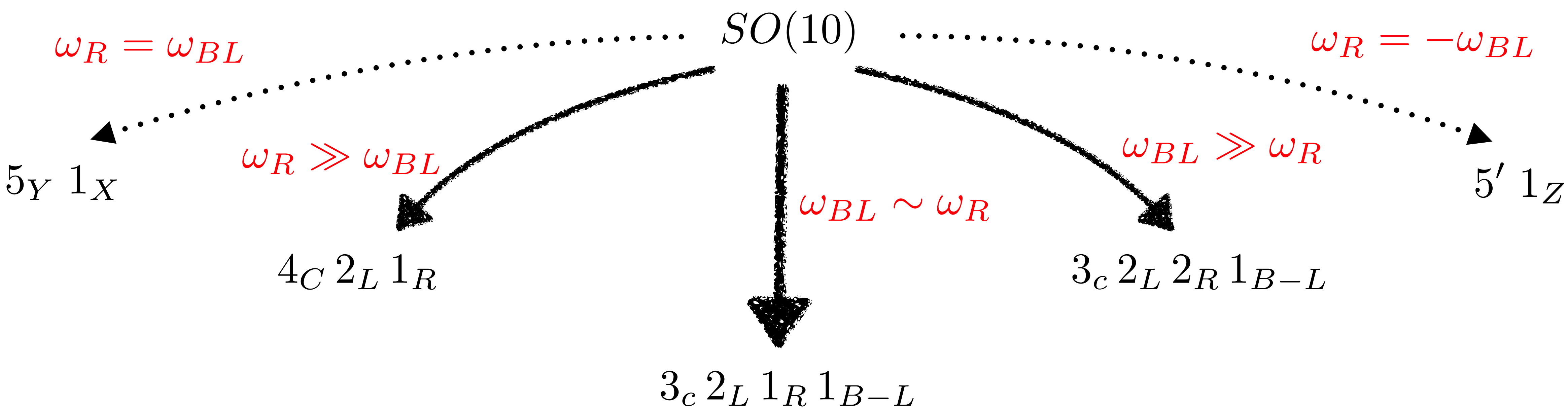

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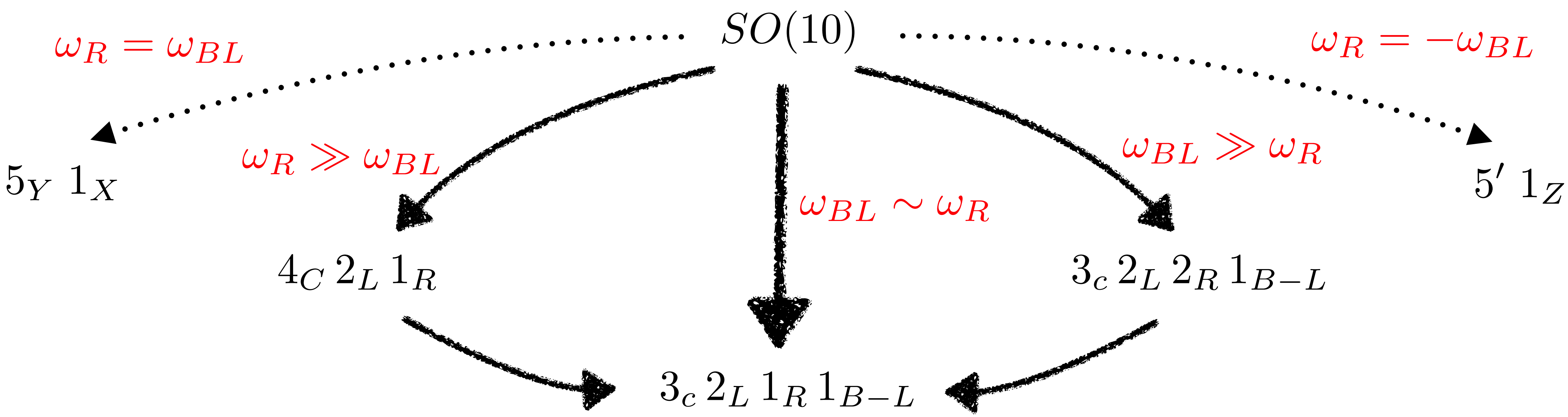

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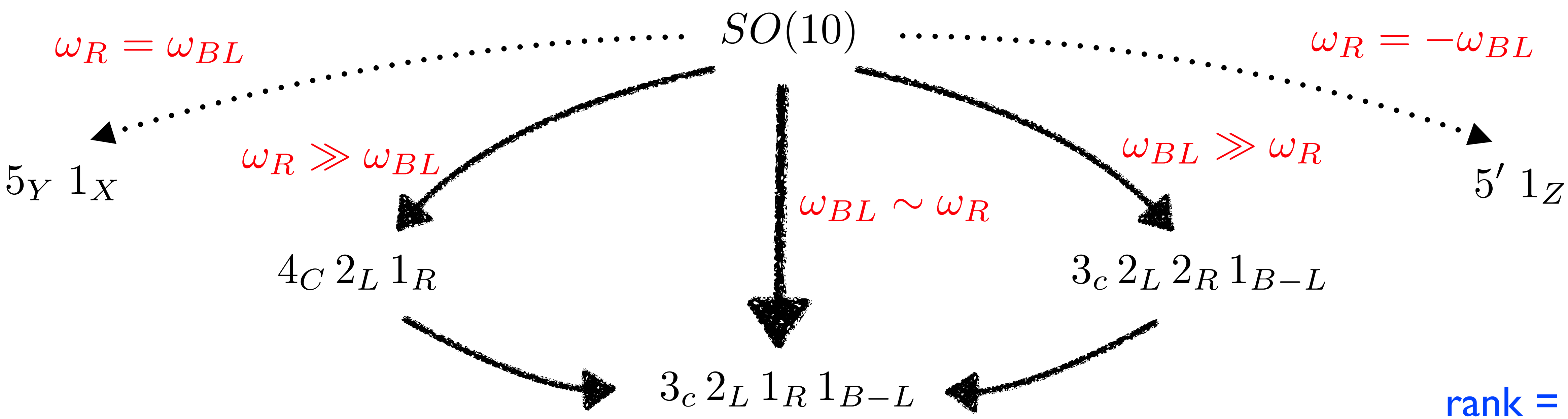

rank = 5

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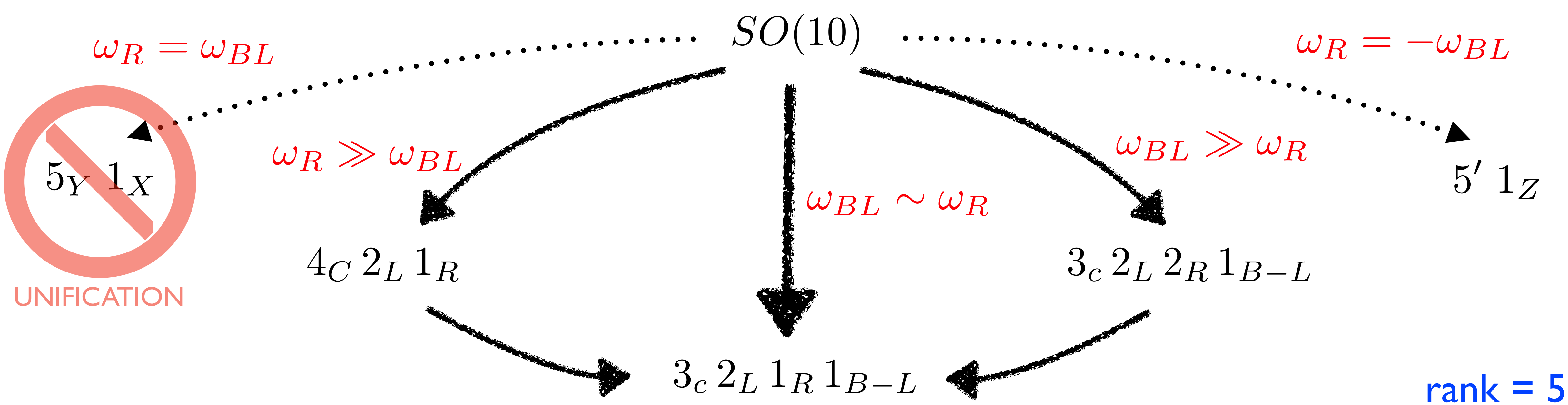

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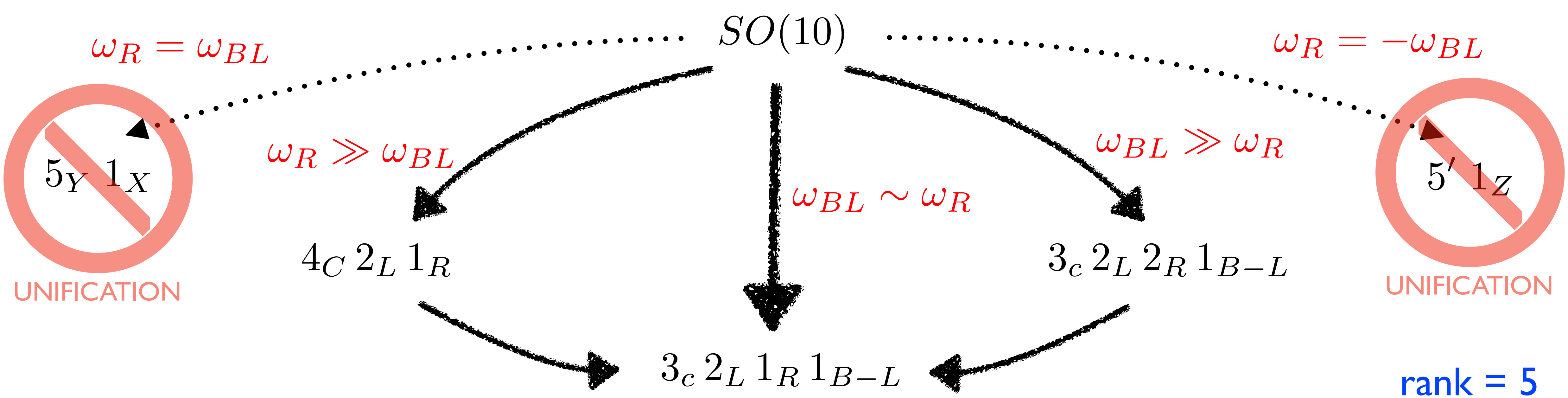

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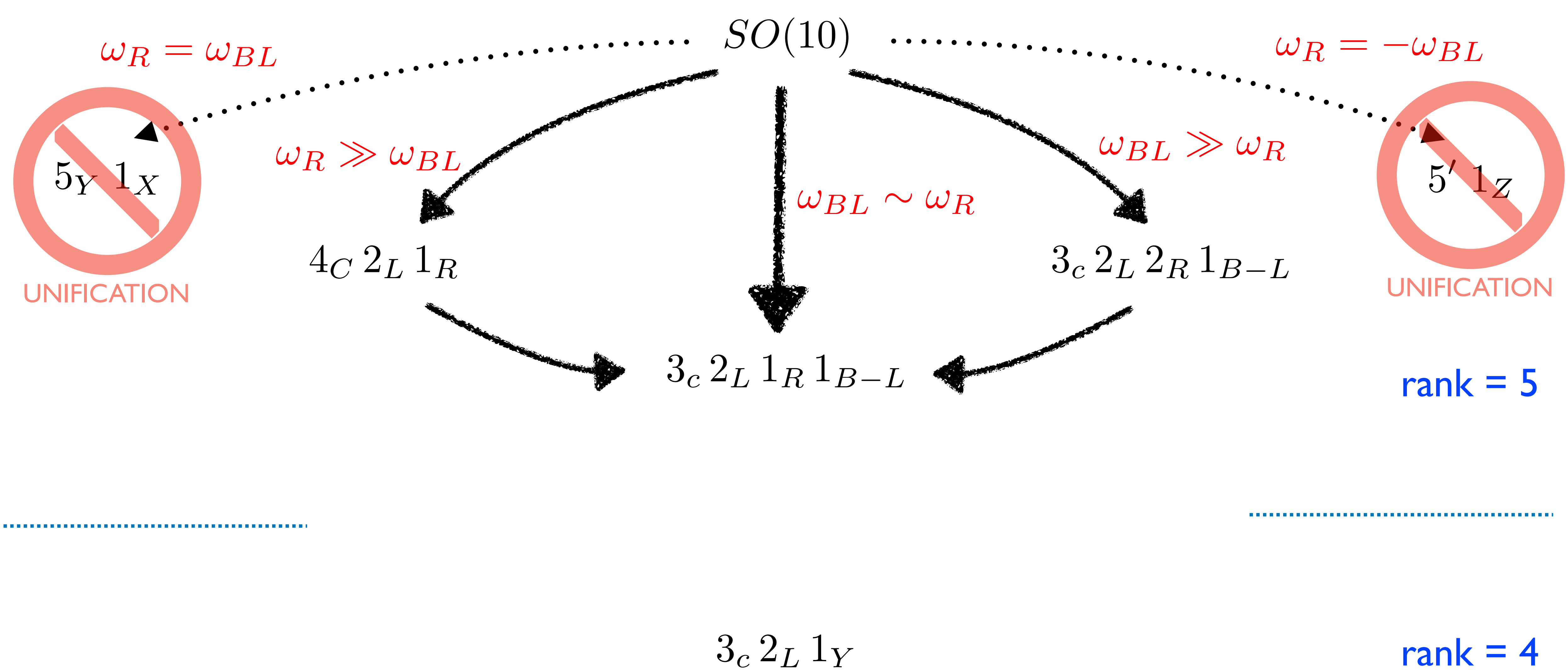

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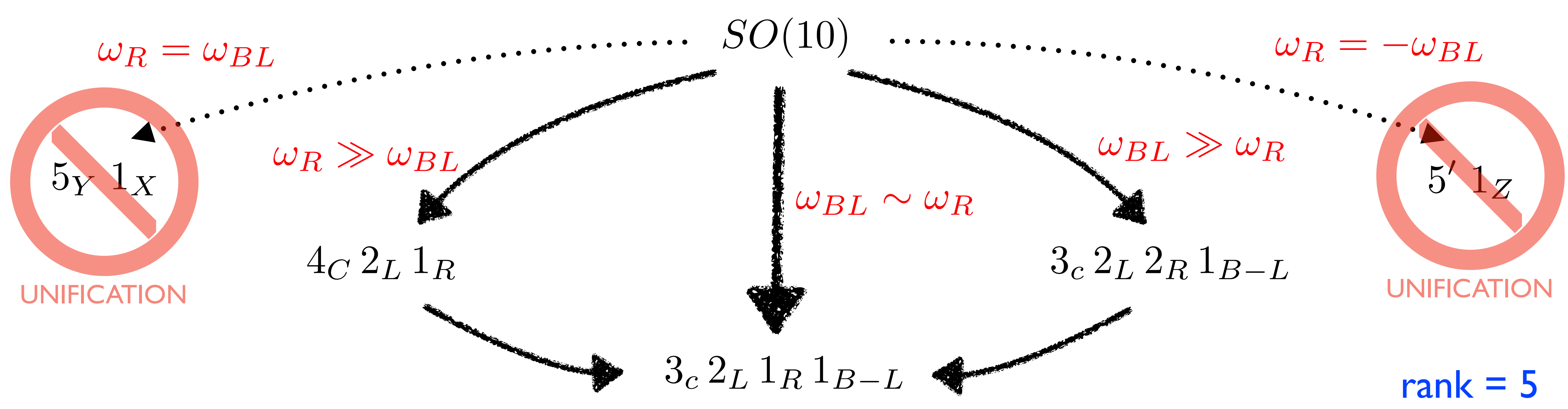

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Rank reduction: 16, 126,…

$3_c\, 2_L\, 1_Y$

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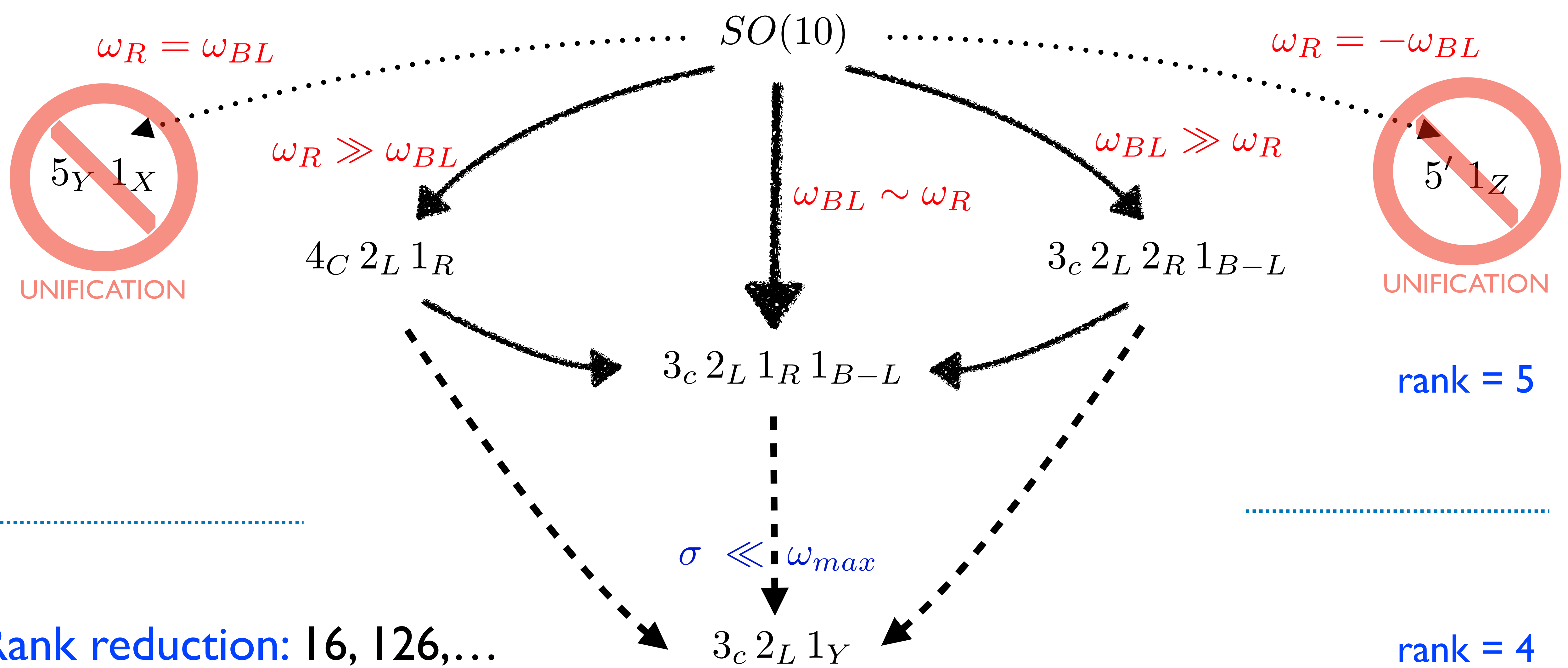
The minimal SO(10) Higgs model



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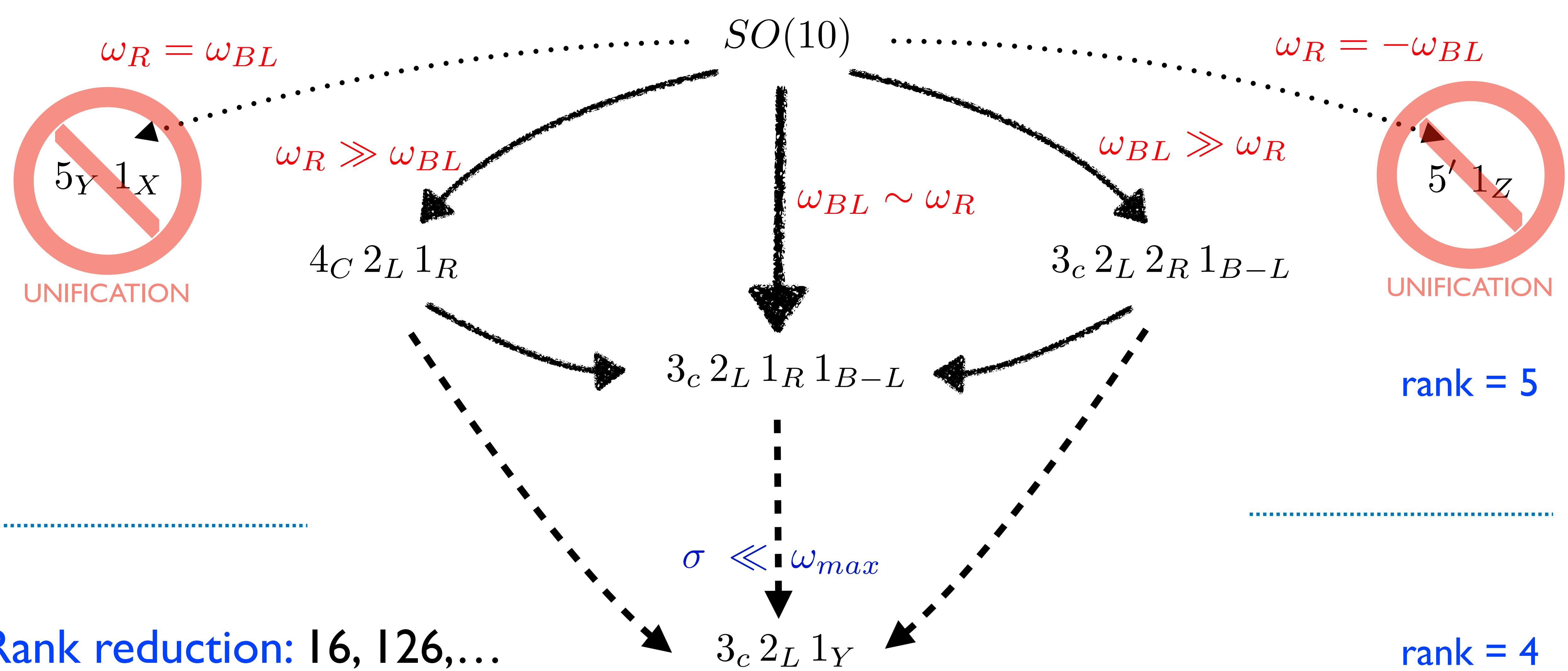

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Advantages of 126: renormalizable Yukawas & seesaw, at the right ballpark

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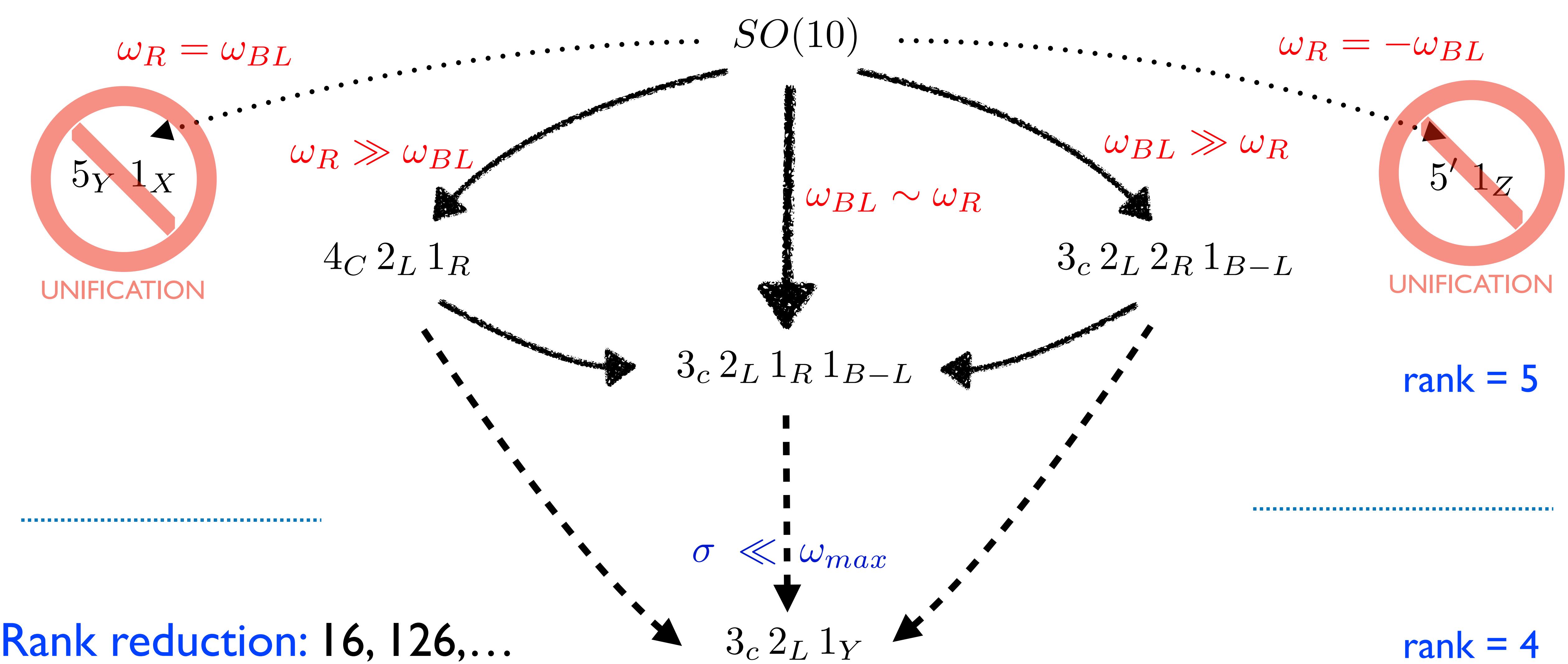

Rank reduction: 16, 126,…

Advantages of 126: renormalizable Yukawas & seesaw, at the right ballpark

Also disadvantages: tough

The minimal SO(10) Higgs model

Scalar potential: $V = V_{45} + V_{126} + V_{\rm mix}$

$$V_{45} = -\frac{\mu^2}{2}(\phi\phi)_0 + \frac{a_0}{4}(\phi\phi)_0(\phi\phi)_0 + \frac{a_2}{4}(\phi\phi)_2(\phi\phi)_2\,,$$

$$\begin{aligned} V_{126} = & -\frac{\nu^2}{5!}(\Sigma\Sigma^*)_0 \\ & + \frac{\lambda_0}{(5!)^2}(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0 + \frac{\lambda_2}{(4!)^2}(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2 \\ & + \frac{\lambda_4}{(3!)^2(2!)^2}(\Sigma\Sigma^*)_4(\Sigma\Sigma^*)_4 + \frac{\lambda_4'}{(3!)^2}(\Sigma\Sigma^*)_{4'}(\Sigma\Sigma^*)_{4'} \\ & + \frac{\eta_2}{(4!)^2}(\Sigma\Sigma)_2(\Sigma\Sigma)_2 + \frac{\eta_2^*}{(4!)^2}(\Sigma^*\Sigma^*)_2(\Sigma^*\Sigma^*)_2\,, \end{aligned}$$

$$\begin{aligned} V_{\rm mix} = & \frac{i\tau}{4!}(\phi)_2(\Sigma\Sigma^*)_2 + \frac{\alpha}{2\cdot 5!}(\phi\phi)_0(\Sigma\Sigma^*)_0 \\ & + \frac{\beta_4}{4\cdot 3!}(\phi\phi)_4(\Sigma\Sigma^*)_4 + \frac{\beta_4'}{3!}(\phi\phi)_{4'}(\Sigma\Sigma^*)_{4'} \\ & + \frac{\gamma_2}{4!}(\phi\phi)_2(\Sigma\Sigma)_2 + \frac{\gamma_2^*}{4!}(\phi\phi)_2(\Sigma^*\Sigma^*)_2\,. \end{aligned}$$

$$(\phi\phi)_0(\phi\phi)_0 \equiv \phi_{ij}\phi_{ij}\phi_{kl}\phi_{kl}$$

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$$(\phi\phi)_0 \equiv \phi_{ij}\phi_{ij}\,, \quad (\Sigma\Sigma^*)_0 \equiv \Sigma_{ijklm}\Sigma^*_{ijklm}$$

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Tree-level scalar spectrum contains tachyons…

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m^2_{(1,3,0)} &= 2a_2(\omega_Y - \omega_R)(\omega_Y + 2\omega_R)
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Yasuè 1981, Anastaze, Derendinger, Buccella 1983, Babu, Ma 1985

flipped SU(5) -like vacua only!

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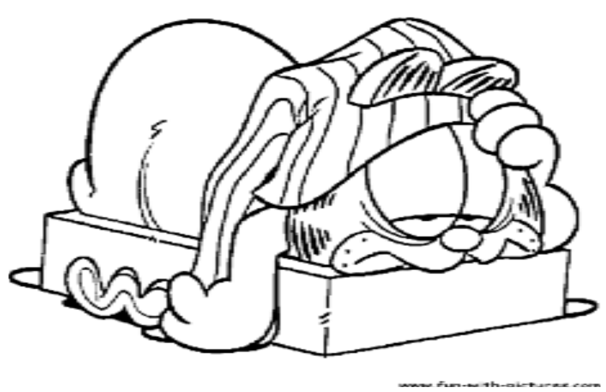

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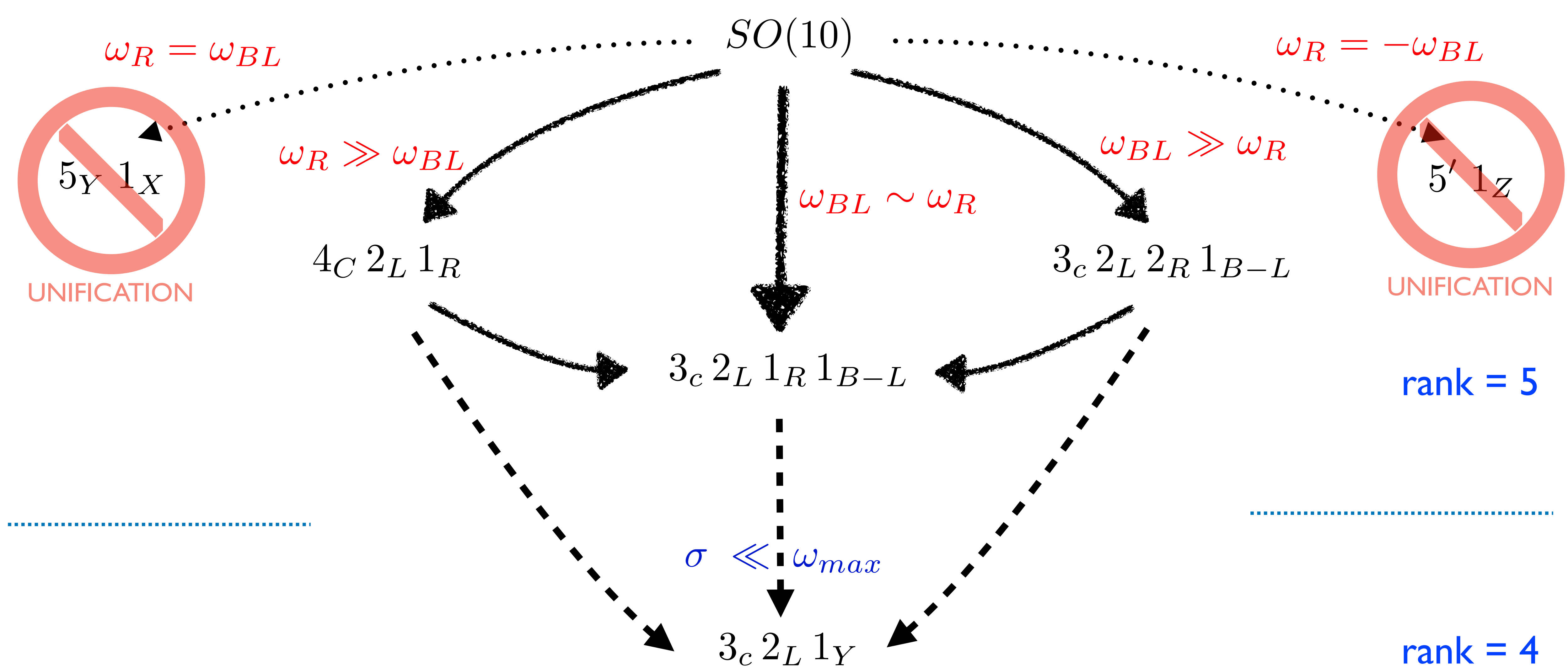

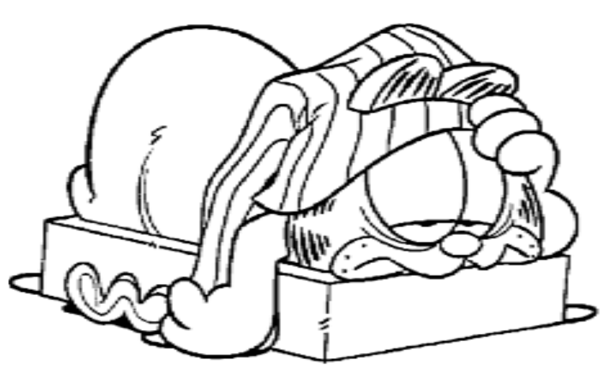

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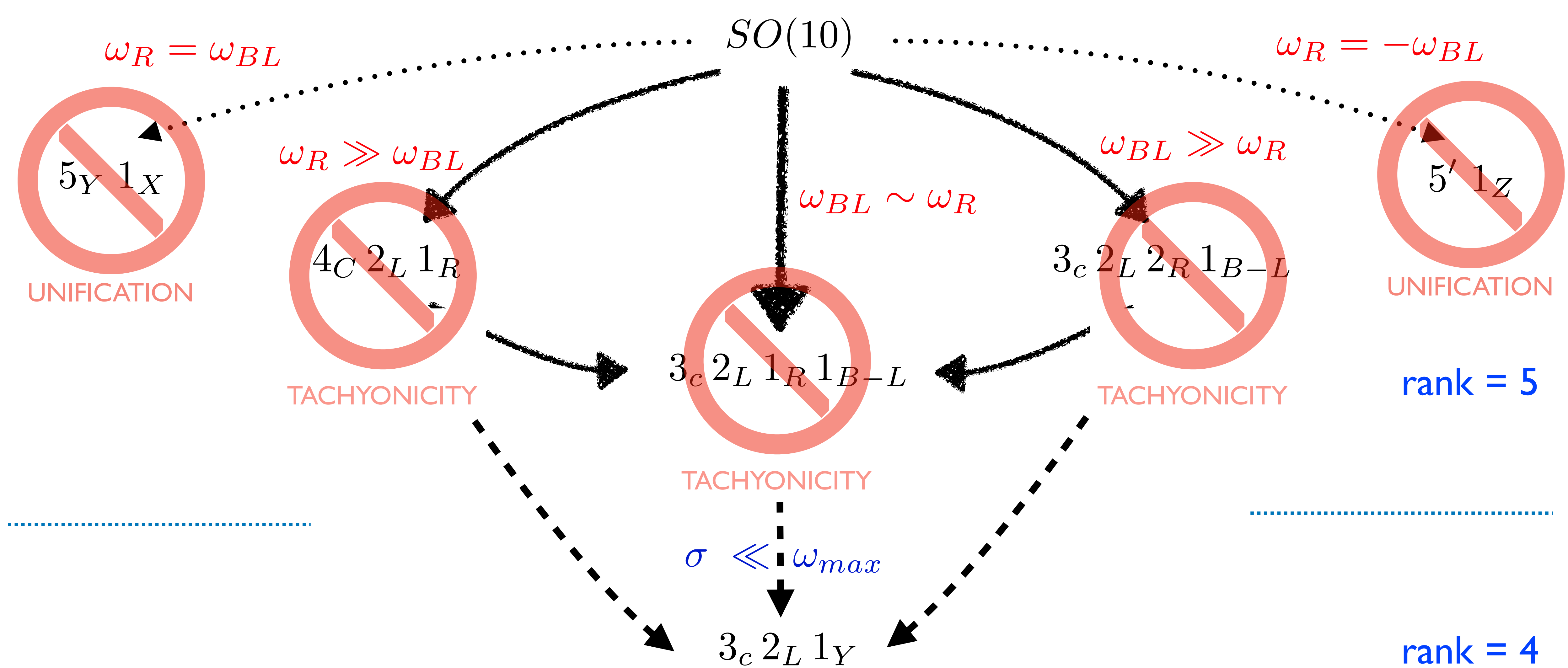

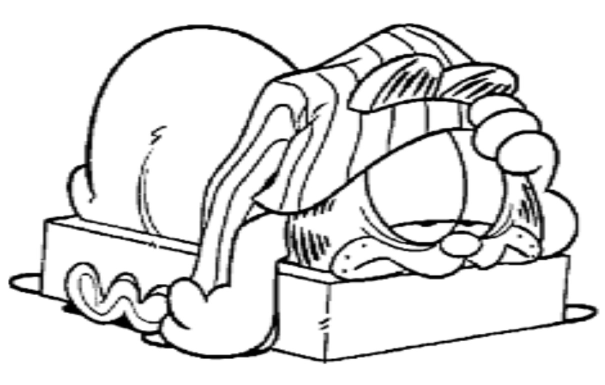

“Never trust arguments based on the lowest order of perturbative expansion!”

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The minimal quantum SO(10) Higgs ~~model~~ nightmare

Radiative corrections can change the situation completely!

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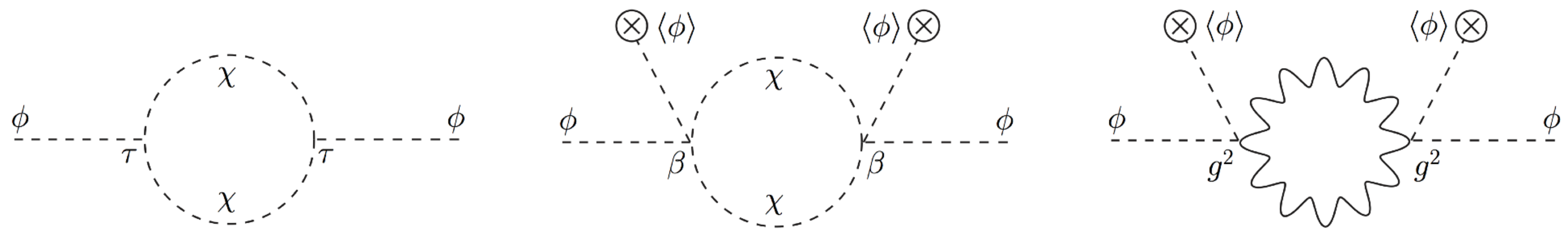

$$\Delta m^2_{(1,3,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(2\omega_R^2 - \omega_R\omega_Y + 2\omega_Y^2) + g^4\left(16\omega_R^2 + \omega_Y\omega_R + 19\omega_Y^2\right)\right] + \text{logs}\,,$$

$$\Delta m^2_{(8,1,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(\omega_R^2 - \omega_R\omega_Y + 3\omega_Y^2) + g^4\left(13\omega_R^2 + \omega_Y\omega_R + 22\omega_Y^2\right)\right] + \text{logs}\,,$$

S. Bertolini, L. Di Luzio, MM, PRD 81, 035015 (2010) - simplified initial study (scalar 16, incomplete by far)

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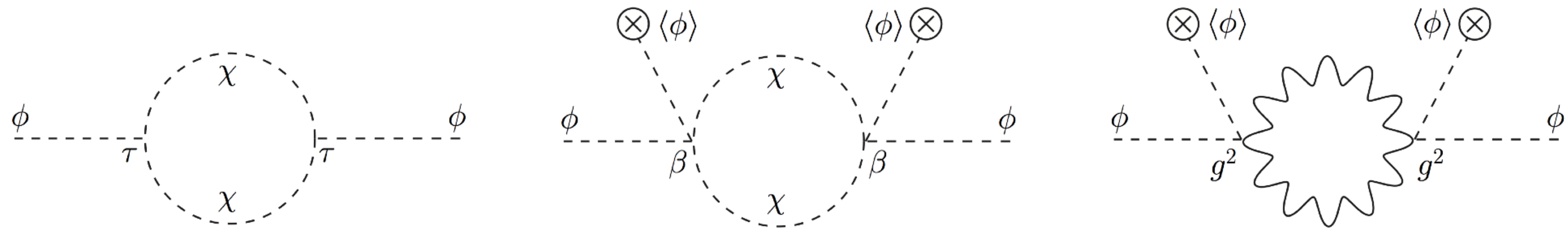

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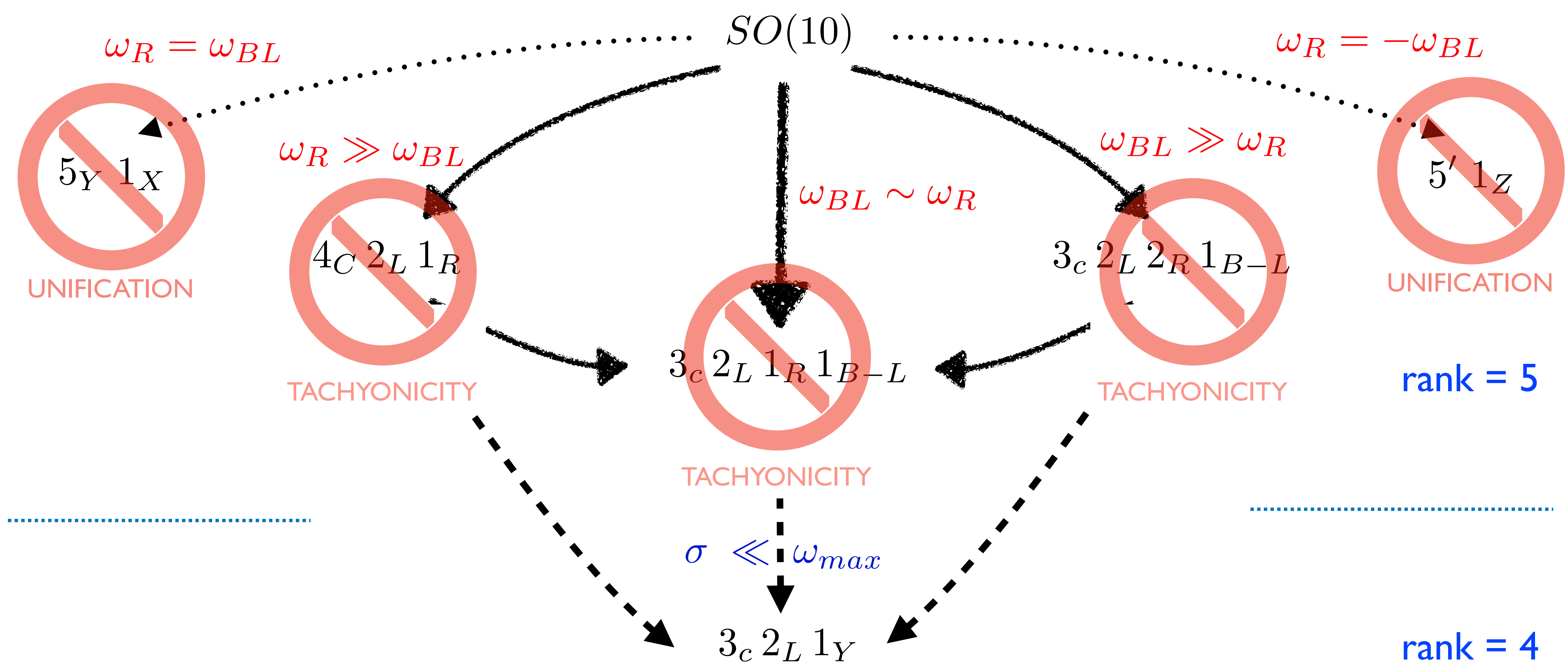
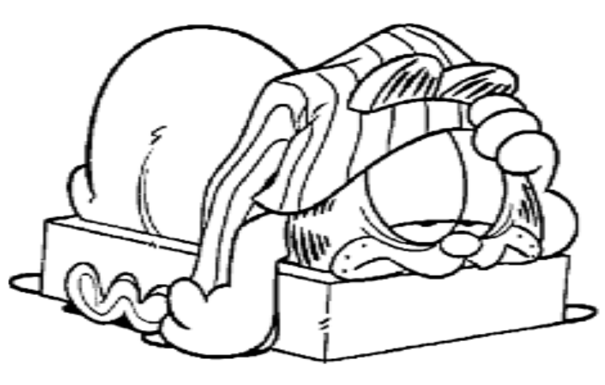
L. Gráf, H. Kolešová, MM, T. Mede, V. Susic PRD 95, 075007 (2017) - complete account of pseudo-Goldstones in the 126 scenario

The minimal quantum SO(10) Higgs model breaking landscape





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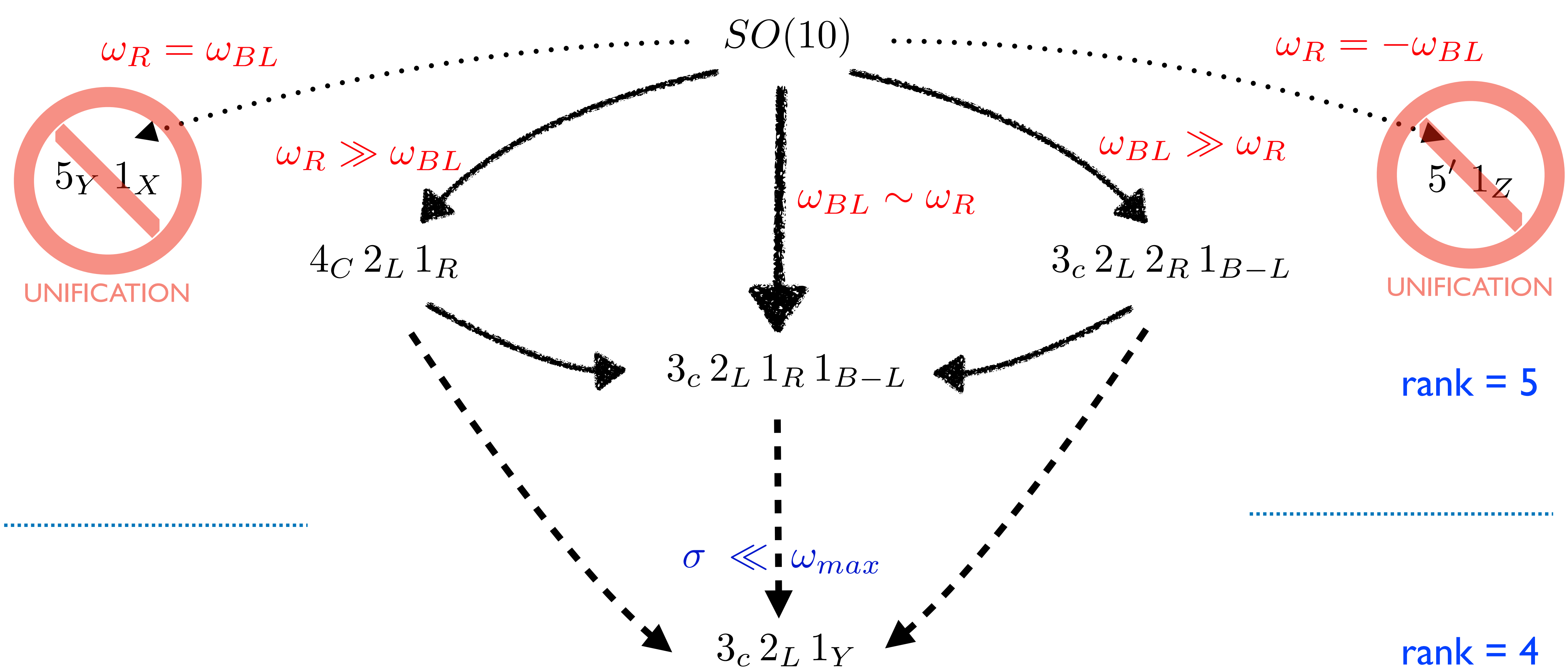

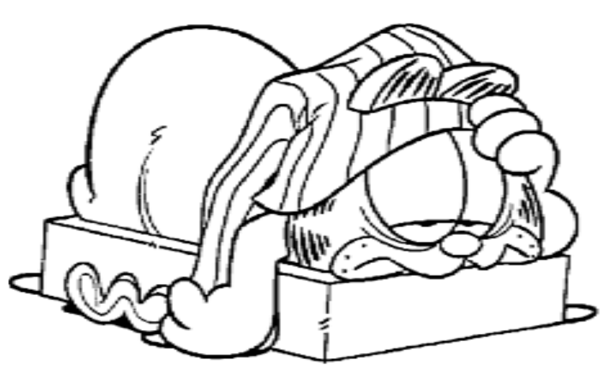

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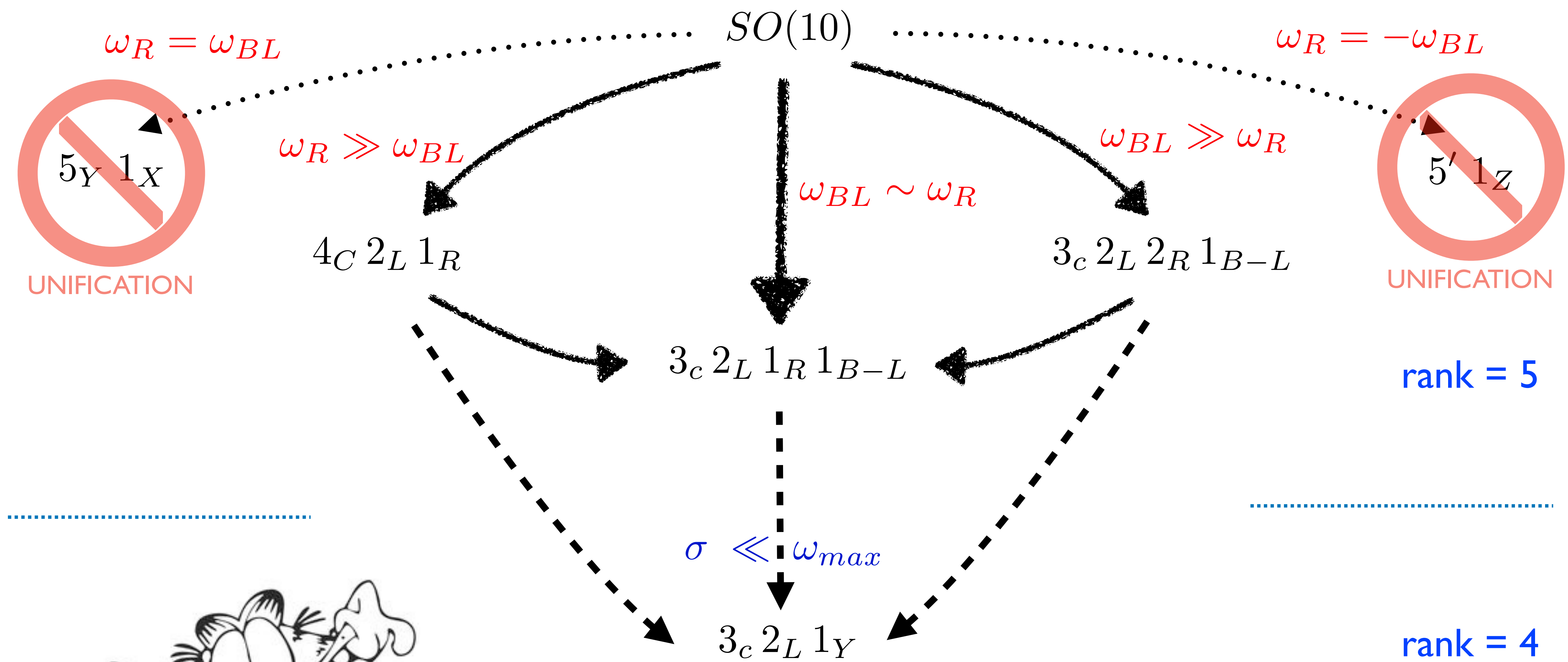

Consistency of the minimal SO(10) Higgs model at 1 loop

K. Jarkovská, MM, T. Mede, V. Susic, to appear very soon

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- Goal: a complete numerical consistency analysis concerning:

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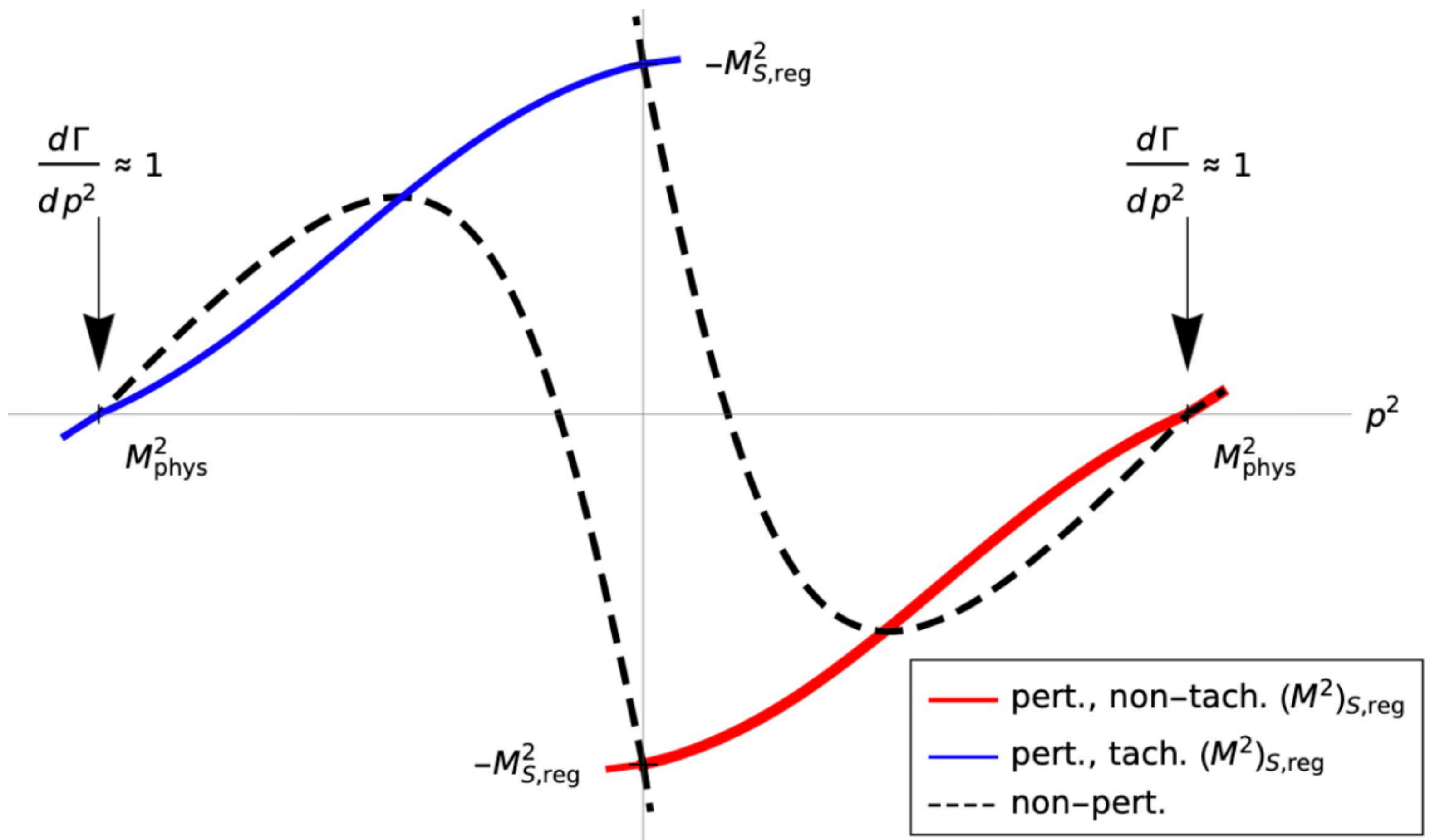


Consistency of the minimal SO(10) Higgs model at 1 loop

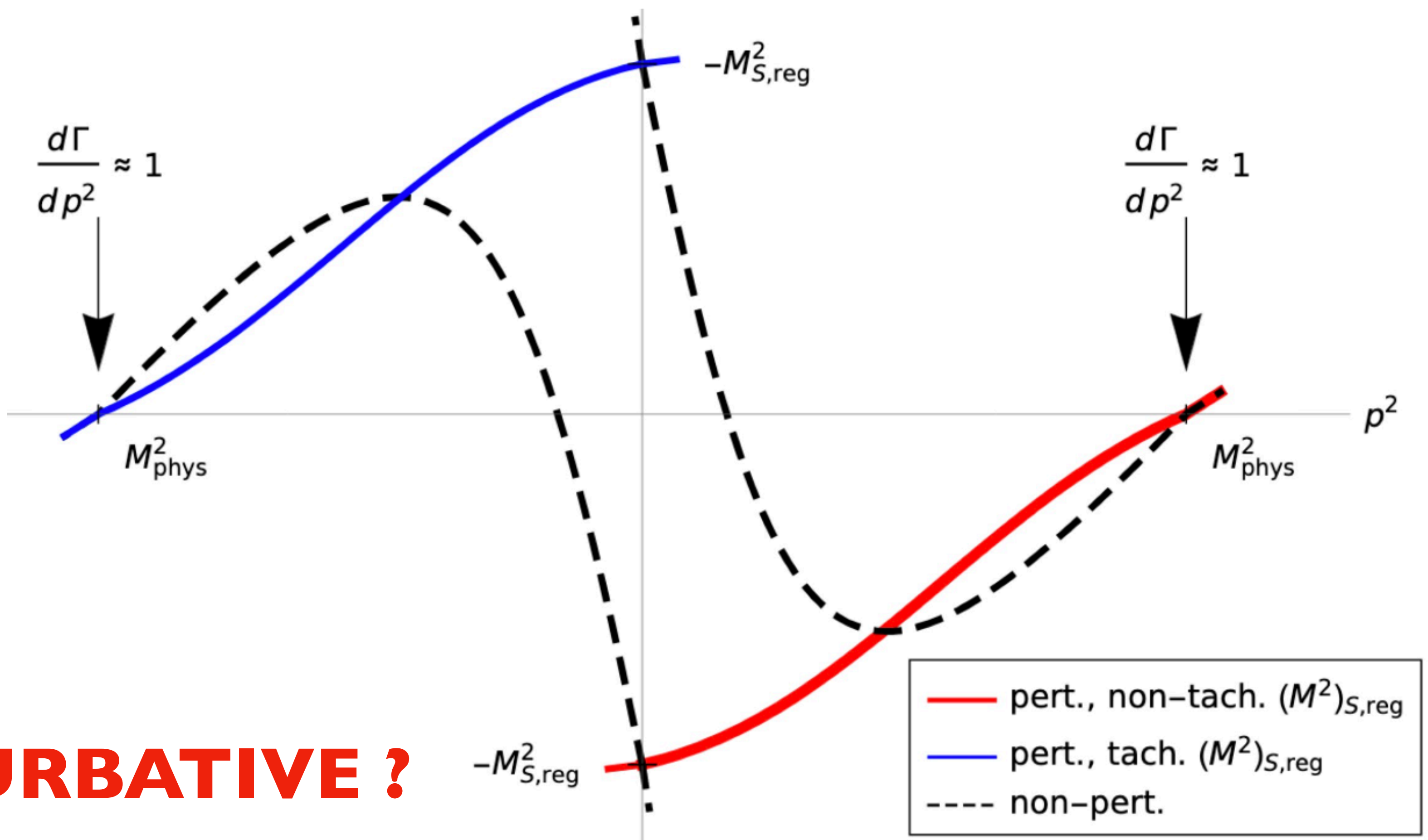
K. Jarkovská, MM, T. Mede, V. Susic, to appear very soon

- Effective potential methods used to calculate 1-loop corrections to all scalar masses

- Goal: a complete numerical consistency analysis concerning:

  1) Stability (local) of the 1-loop vacuum (non-tachyonicity of the scalar spectrum)
  2) 1-loop gauge unification constraints (going beyond was not the scope here)

- EP masses are not (RG invariant) physical masses !



IS THE SCHEME PERTURBATIVE ?

K. Jarkovská, MM, T. Mede, V. Susic, to appear very soon

Perturbative VEVs' hierarchies

Perturbativity concerns

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NB Unification suggests that the seesaw scale σ should be subleading …

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\begin{aligned}
\mu^2 = & \quad (12a_0 + 2a_2)\omega_{BL}^2 + (8a_0 + 2a_2)\omega_R^2 + 2a_2\omega_{BL}\omega_R + 4(\alpha + \beta_4')|\sigma|^2, \\
\nu^2 = & \quad 3(\alpha + 4\beta_4')\omega_{BL}^2 + 2(\alpha + 3\beta_4')\omega_R^2 + 12\beta_4'\omega_{BL}\omega_R + 4\lambda_0|\sigma|^2 + \\
& + a_2\frac{\omega_{BL}\omega_R}{|\sigma|^2}(\omega_{BL} + \omega_R)(3\omega_{BL} + 2\omega_R), \\
\tau = & \quad 2\beta_4'(3\omega_{BL} + 2\omega_R) + a_2\frac{\omega_{BL}\omega_R}{|\sigma|^2}(\omega_{BL} + \omega_R).
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Tree level: comparable ω_{BL}, ω_R look OK as far as a_2 is small (which is desired indeed!)

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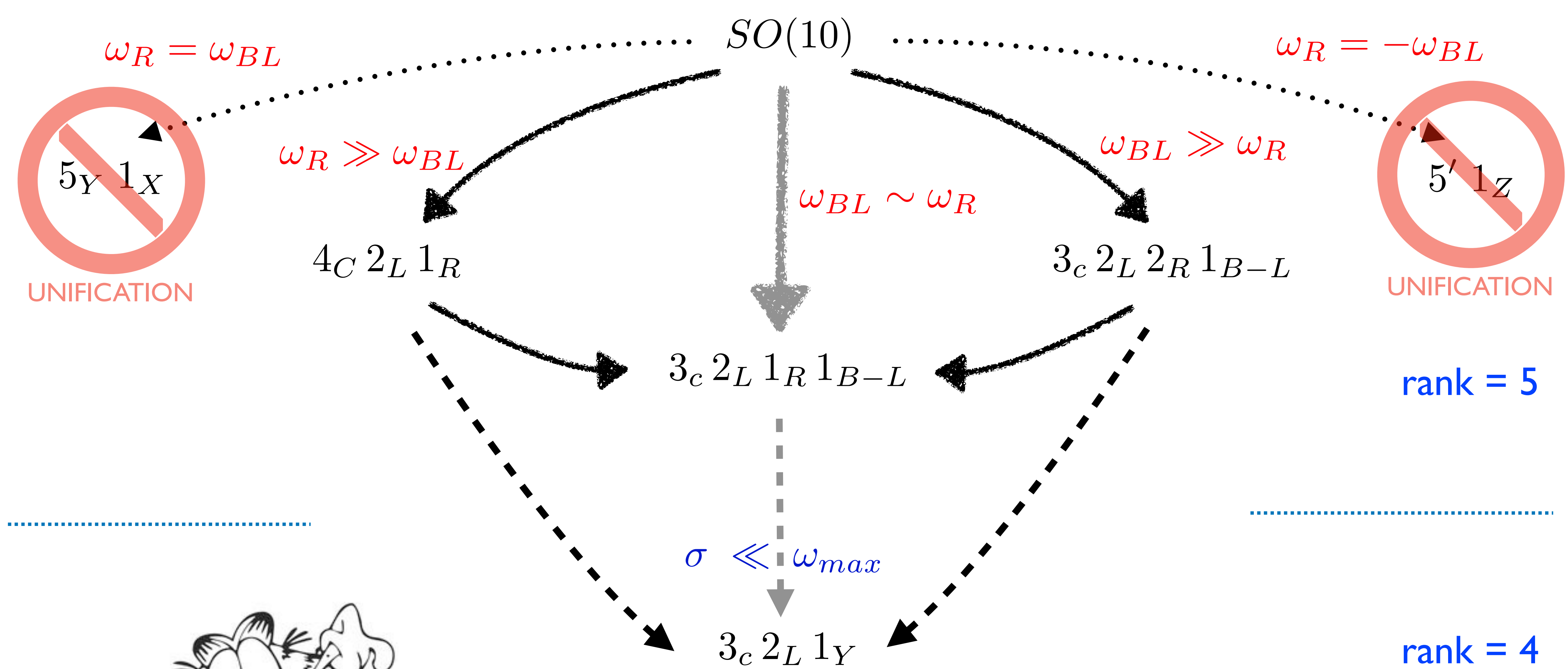
Tree level: comparable ω_{BL}, ω_R look OK as far as a_2 is small (which is desired indeed!)

Loop level: no way to suppress other potentially significant corrections (e.g. gauge)

ω_{BL}, ω_R must be strongly hierarchical !

The minimal quantum SO(10) Higgs model breaking landscape



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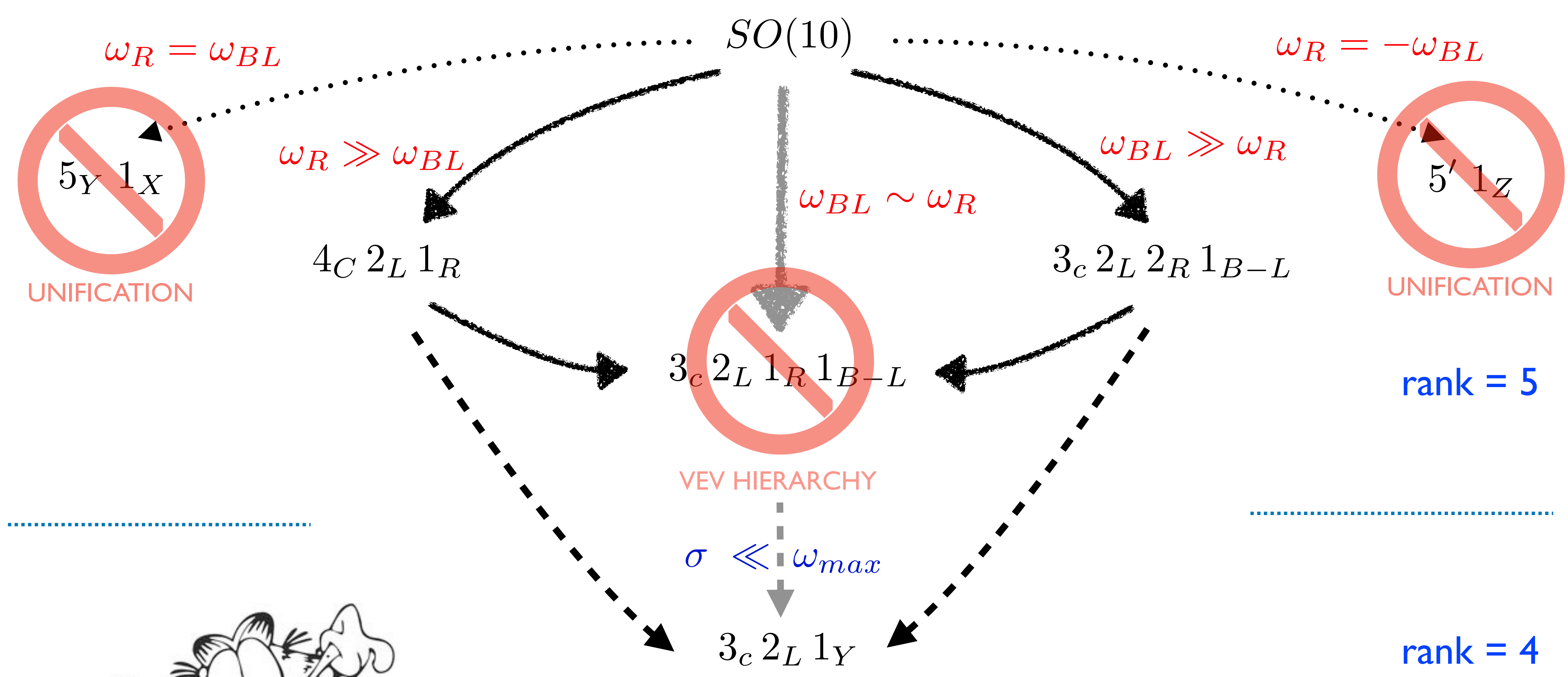

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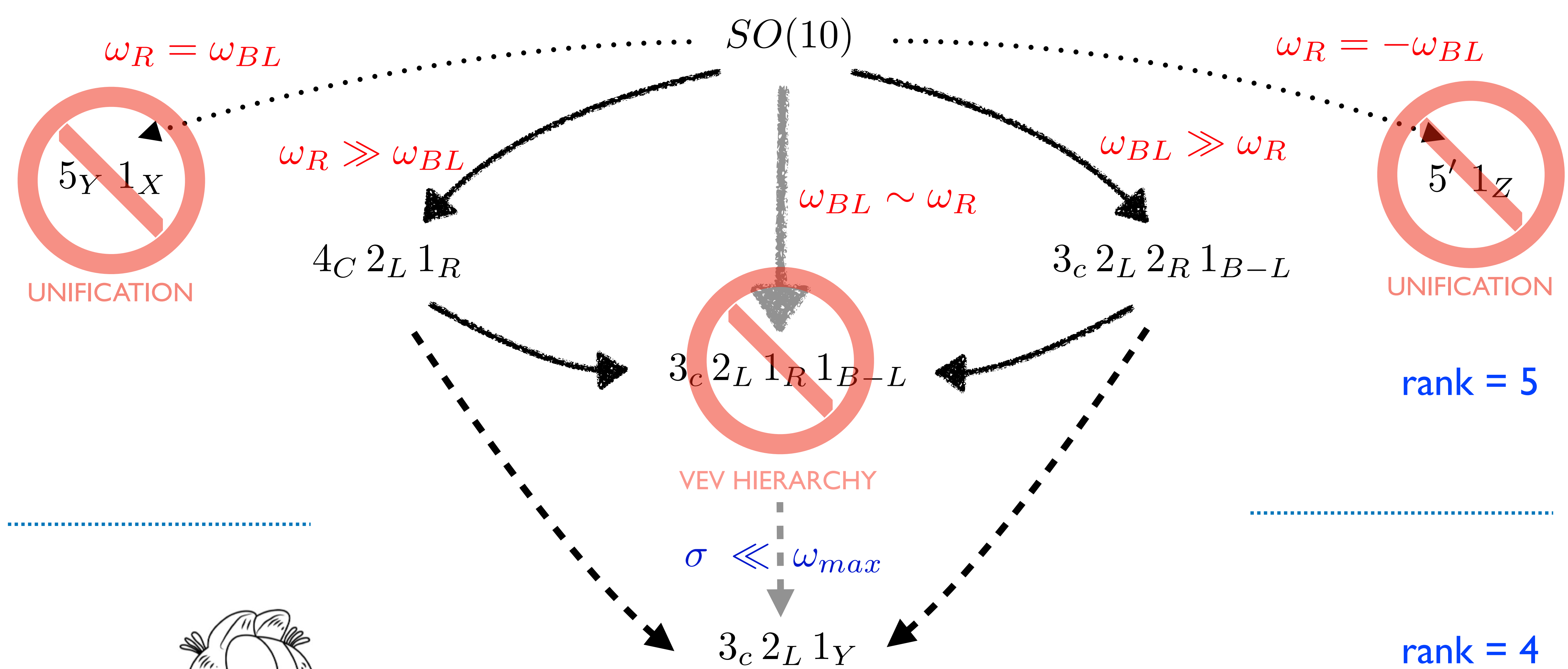

Perturbativity domains

K. Jarkovská, MM, T. Mede, V. Susic, to appear very soon

3) Look at the residual renormalization scale dependence of the scalar spectrum

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\begin{aligned}
16\pi^2 \beta_{\beta_4'} = \;& 16\alpha\beta_4' + 16a_0\beta_4' + 2a_2\beta_4 - 4a_2\beta_4' - \beta_4^2 - 28\beta_4\beta_4' + 2\beta_4\lambda_2 + 6\beta_4\lambda_4 \\
& + 80\beta_4\lambda_4' - 124\beta_4'^2 + 4\beta_4'\lambda_0 - 12\beta_4'\lambda_2 + 20\beta_4'\lambda_4 - 144\beta_4'\lambda_4' + 16\left|\gamma_2\right|^2 \\
& - 3g^4 - 123\beta_4' g^2,
\end{aligned}
$$

$$
\begin{aligned}
16\pi^2 \beta_{\alpha} = \;& 8\alpha^2 + 508\alpha\lambda_0 + 1220\alpha\lambda_2 + 1340\alpha\lambda_4 + 2480\alpha\lambda_4' + 376\alpha a_0 + 80a_0\beta_4 \\
& + 160a_0\beta_4' + 76\alpha a_2 + 16a_2\beta_4 + 32a_2\beta_4' + 4\beta_4^2 + 16\beta_4\beta_4' + 112\beta_4\lambda_0 \\
& + 272\beta_4\lambda_2 + 288\beta_4\lambda_4 + 512\beta_4\lambda_4' + 144\beta_4'^2 + 224\beta_4'\lambda_0 + 544\beta_4'\lambda_2 + 576\beta_4'\lambda_4 \\
& + 1024\beta_4'\lambda_4' + 64|\gamma_2|^2 + 12g^4 - 123\alpha g^2,
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16\pi^2 \beta_{\lambda_0} = \;& 90\alpha^2 + 40\alpha\beta_4 + 80\alpha\beta_4' + 10\beta_4^2 + 80\beta_4'^2 + 520\lambda_0^2 + 2440\lambda_0\lambda_2 + 2680\lambda_0\lambda_4 \\
& + 4960\lambda_0\lambda_4' + 3460\lambda_2^2 + 7880\lambda_2\lambda_4 + 12320\lambda_2\lambda_4' + 4660\lambda_4^2 + 13280\lambda_4\lambda_4' \\
& + 16960\lambda_4'^2 + \frac{135g^4}{2} - 150g^2\lambda_0,
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$$

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16\pi^2 \beta_{a_0} = \;& 126\alpha^2 + 56\alpha\beta_4 + 112\alpha\beta_4' + 424a_0^2 + 152a_0a_2 + 12a_2^2 + \frac{33\beta_4^2}{2} + 26\beta_4\beta_4' \\
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3) Look at the residual renormalization scale dependence of the scalar spectrum

$$V_{45} = -\frac{\mu^2}{2}(\phi\phi)_0 + \frac{a_0}{4}(\phi\phi)_0(\phi\phi)_0 + \frac{a_2}{4}(\phi\phi)_2(\phi\phi)_2\,;$$

$$\begin{aligned} V_{126} = &-\frac{\nu^2}{5!}(\Sigma\Sigma^*)_0 \\ &+ \frac{\lambda_0}{(5!)^2}(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0 + \frac{\lambda_2}{(4!)^2}(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2 \\ &+ \frac{\lambda_4}{(3!)^2(2!)^2}(\Sigma\Sigma^*)_4(\Sigma\Sigma^*)_4 + \frac{\lambda_4'}{(3!)^2}(\Sigma\Sigma^*)_{4'}(\Sigma\Sigma^*)_{4'} \\ &+ \frac{\eta_2}{(4!)^2}(\Sigma\Sigma)_2(\Sigma\Sigma)_2 + \frac{\eta_2^*}{(4!)^2}(\Sigma^*\Sigma^*)_2(\Sigma^*\Sigma^*)_2\,, \end{aligned}$$

$$\begin{aligned} V_{\rm mix} = &\frac{i\tau}{4!}(\phi)_2(\Sigma\Sigma^*)_2 + \frac{\alpha}{2\cdot 5!}(\phi\phi)_0(\Sigma\Sigma^*)_0 \\ &+ \frac{\beta_4}{4\cdot 3!}(\phi\phi)_4(\Sigma\Sigma^*)_4 + \frac{\beta_4'}{3!}(\phi\phi)_{4'}(\Sigma\Sigma^*)_{4'} \\ &+ \frac{\gamma_2}{4!}(\phi\phi)_2(\Sigma\Sigma)_2 + \frac{\gamma_2^*}{4!}(\phi\phi)_2(\Sigma^*\Sigma^*)_2\,. \end{aligned}$$

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$$16\pi^2\beta_{\lambda_2} = -4\beta_4^2 - 32\beta_4'^2 + 24\lambda_0\lambda_2 - 180\lambda_2^2 - 584\lambda_2\lambda_4 - 160\lambda_2\lambda_4' - 656\lambda_4^2 - 800\lambda_4\lambda_4' - 2560\lambda_4'^2 - 1264|\eta_2|^2 - 24g^4 - 150g^2\lambda_2,$$

$$16\pi^2\beta_{\lambda_4} = 2\beta_4^2 + 16\beta_4'^2 + 24\lambda_0\lambda_4 + 16\lambda_2^2 + 112\lambda_2\lambda_4 + 128\lambda_2\lambda_4' + 268\lambda_4^2 + 640\lambda_4\lambda_4' + 1408\lambda_4'^2 + 1328|\eta_2|^2 + 12g^4 - 150g^2\lambda_4,$$

$$16\pi^2\beta_{\lambda_4'} = 4\beta_4\beta_4' - 4\beta_4'^2 + 24\lambda_0\lambda_4' - 4\lambda_2^2 - 8\lambda_2\lambda_4 - 16\lambda_2\lambda_4' + 4\lambda_4^2 + 112\lambda_4\lambda_4' - 240\lambda_4'^2 + 32|\eta_2|^2 - 3g^4 - 150g^2\lambda_4',$$

$$16\pi^2\beta_{\beta_4} = 16\alpha\beta_4 + 16a_0\beta_4 + 16a_2\beta_4' + 48\beta_4^2 + 80\beta_4\beta_4' + 4\beta_4\lambda_0 - 8\beta_4\lambda_2 + 32\beta_4\lambda_4 + 16\beta_4\lambda_4' + 16\beta_4'^2 + 16\beta_4'\lambda_2 + 48\beta_4'\lambda_4 + 640\beta_4'\lambda_4' + 64|\gamma_2|^2 + 12g^4 - 123\beta_4g^2,$$

$$16\pi^2\beta_{\gamma_2} = 8\alpha\gamma_2 + 14\beta_4\gamma_2 + 28\beta_4'\gamma_2 + 440\eta_2\gamma_2^* - 123\gamma_2g^2,$$

$$16\pi^2\beta_{\eta_2} = \frac{32\gamma_2^2}{3} + 24\eta_2\lambda_0 + 160\eta_2\lambda_2 + 600\eta_2\lambda_4 + 640\eta_2\lambda_4' - 150\eta_2g^2.$$

Perturbativity domains

$SO(10) \to 4_C 2_L 1_R \to \mathrm{SM}$

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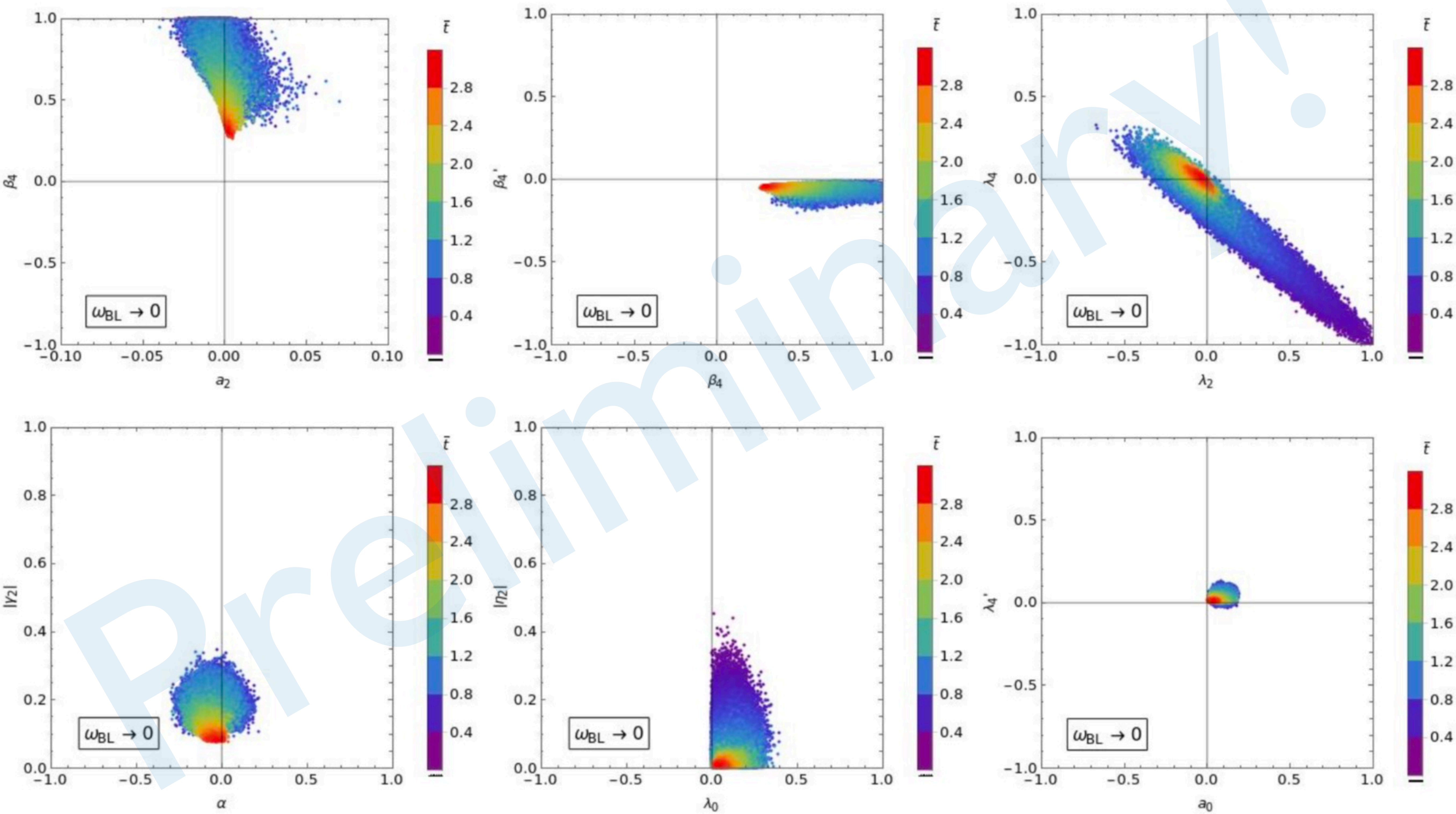

Perturbativity domains

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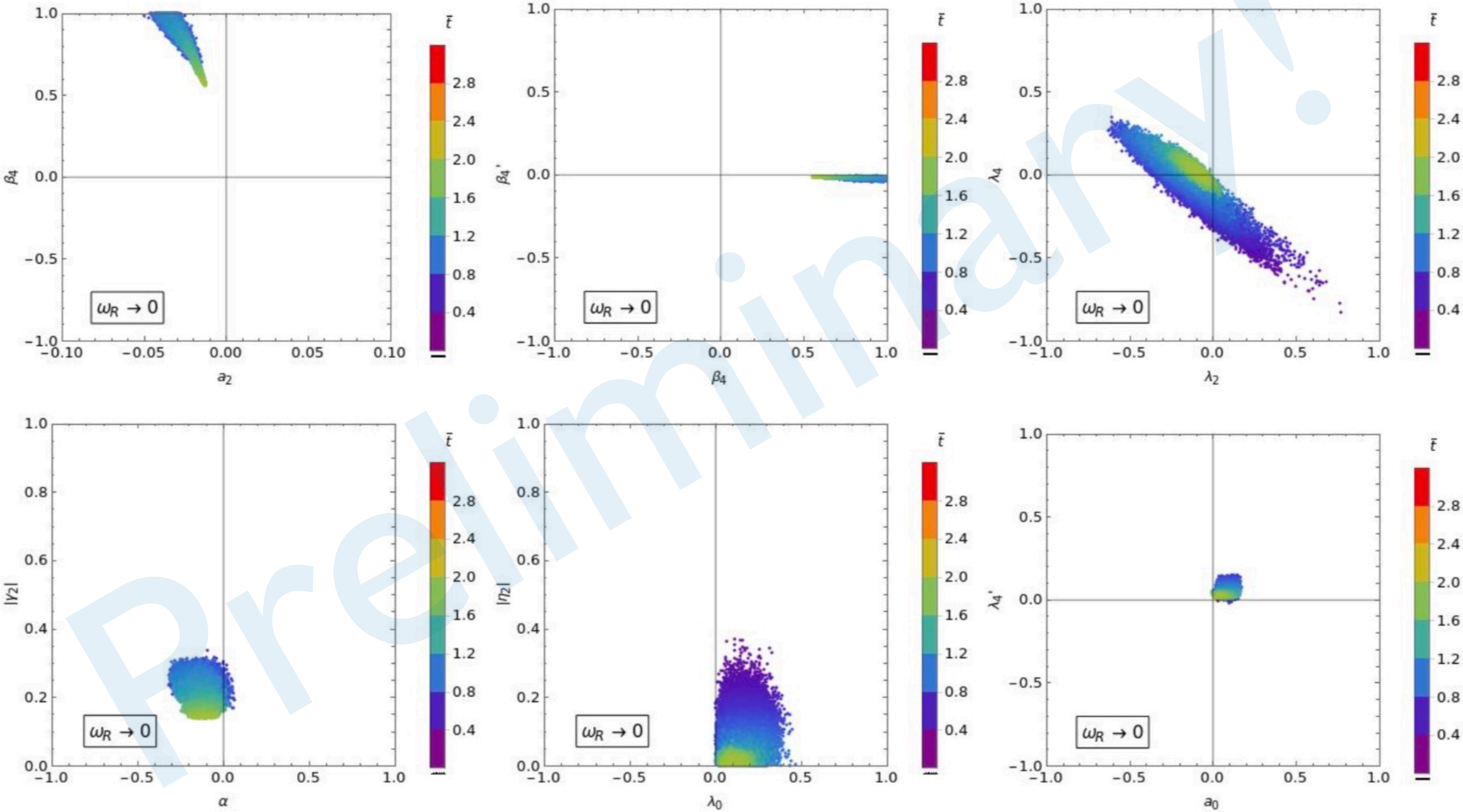
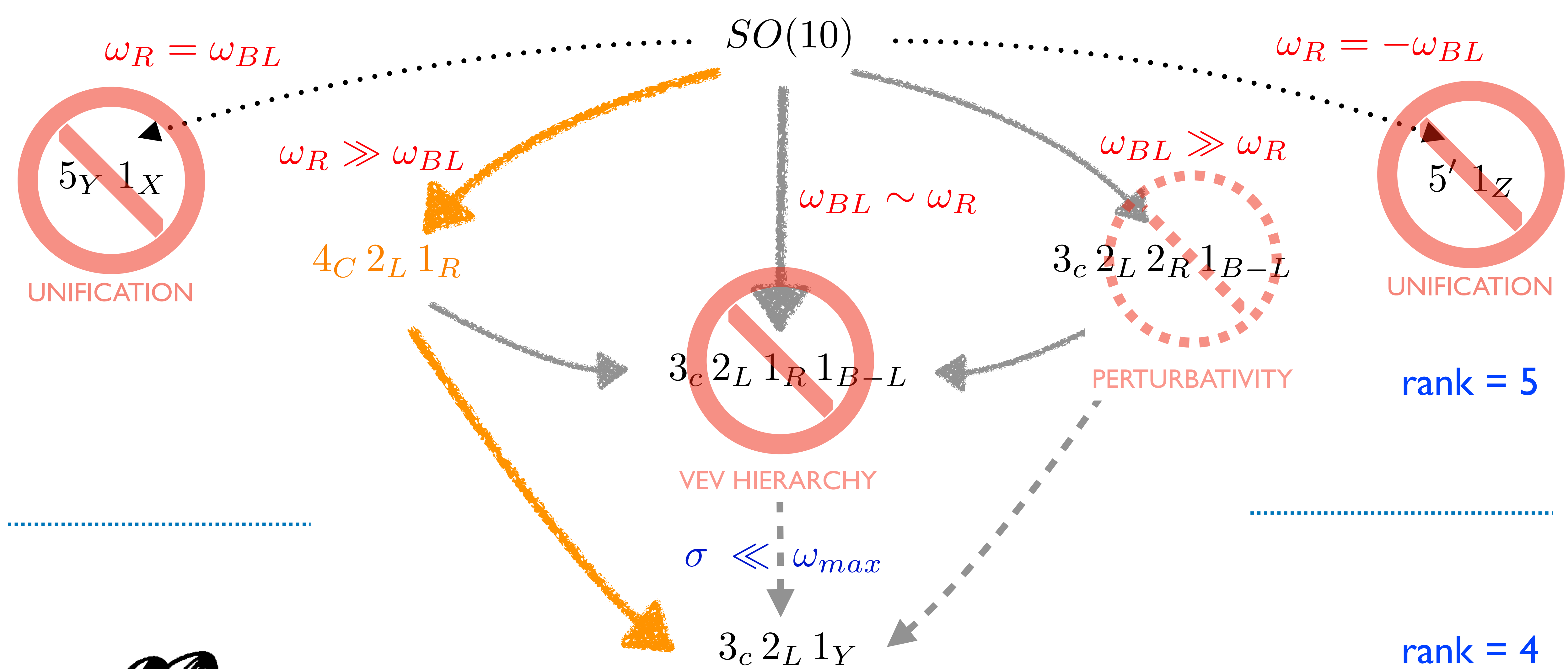
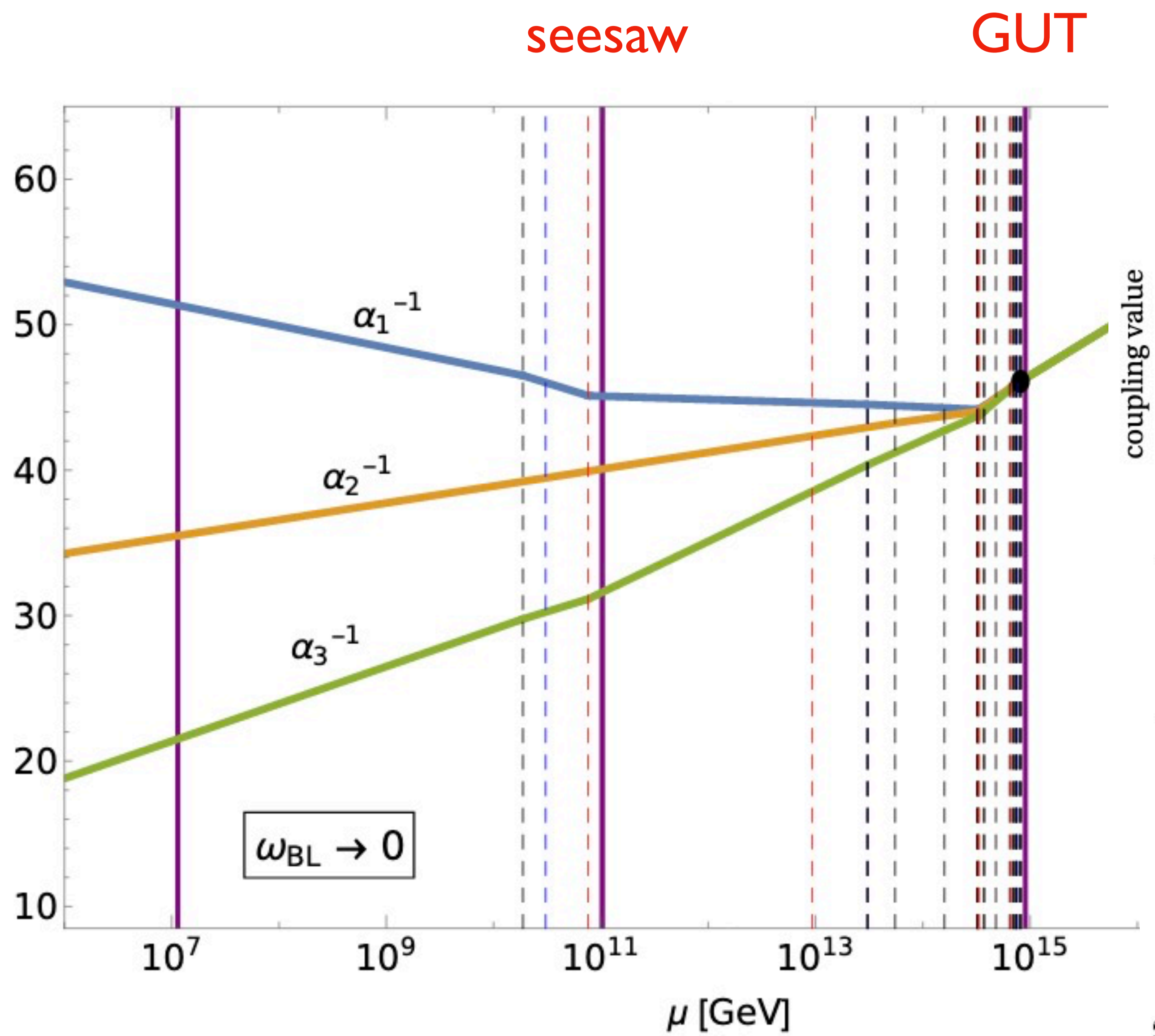


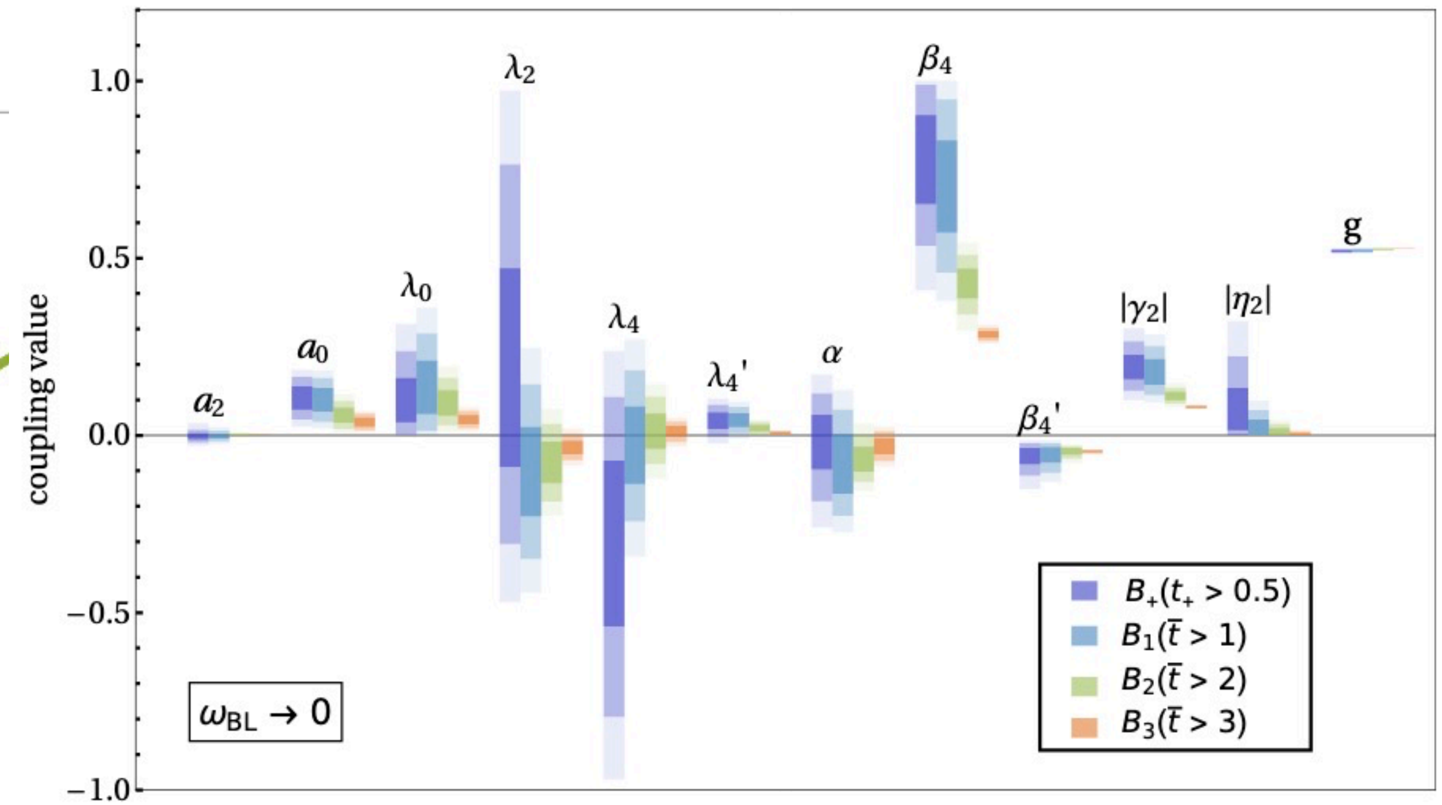
The minimal quantum SO(10) Higgs model breaking landscape
revisited

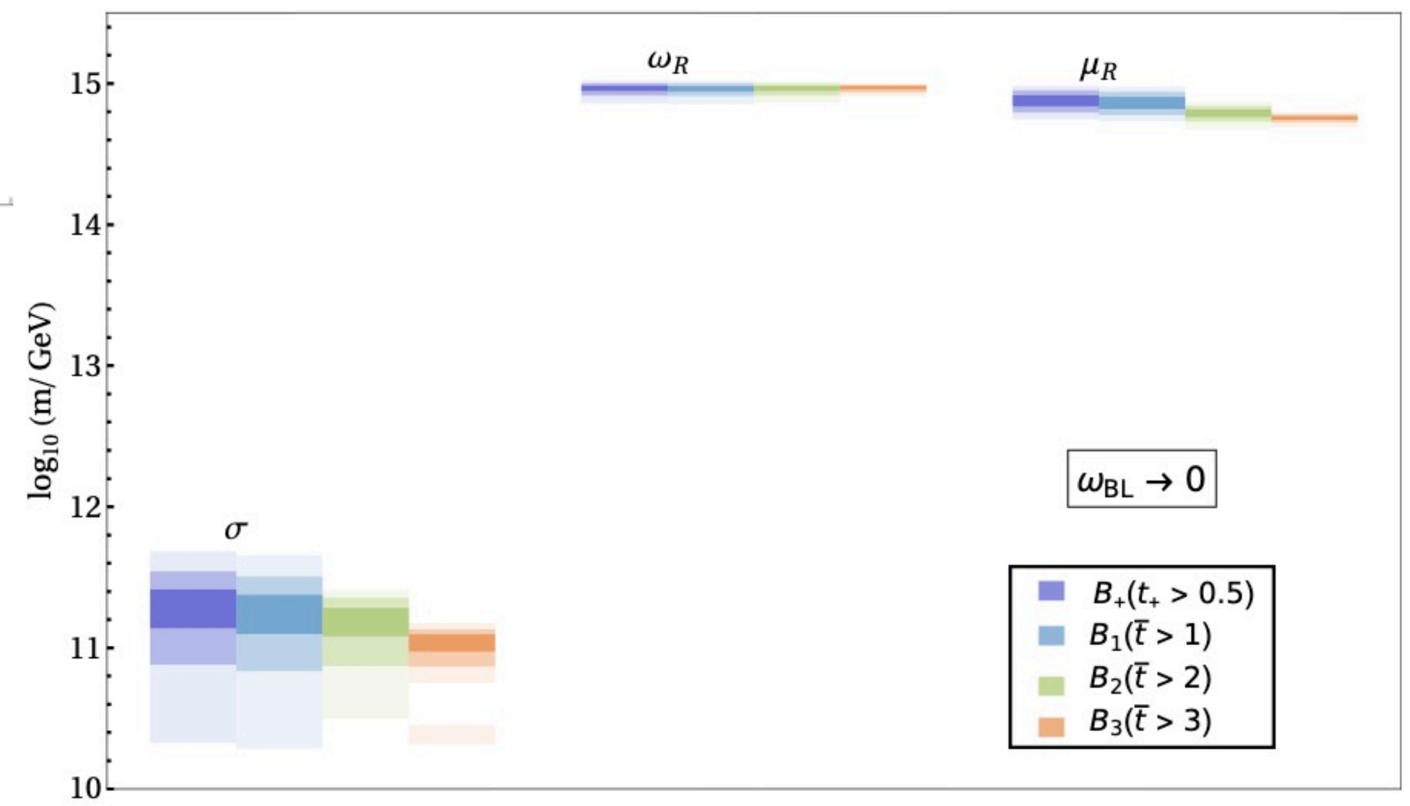


Works way better if going through the intermediate 421 stage!

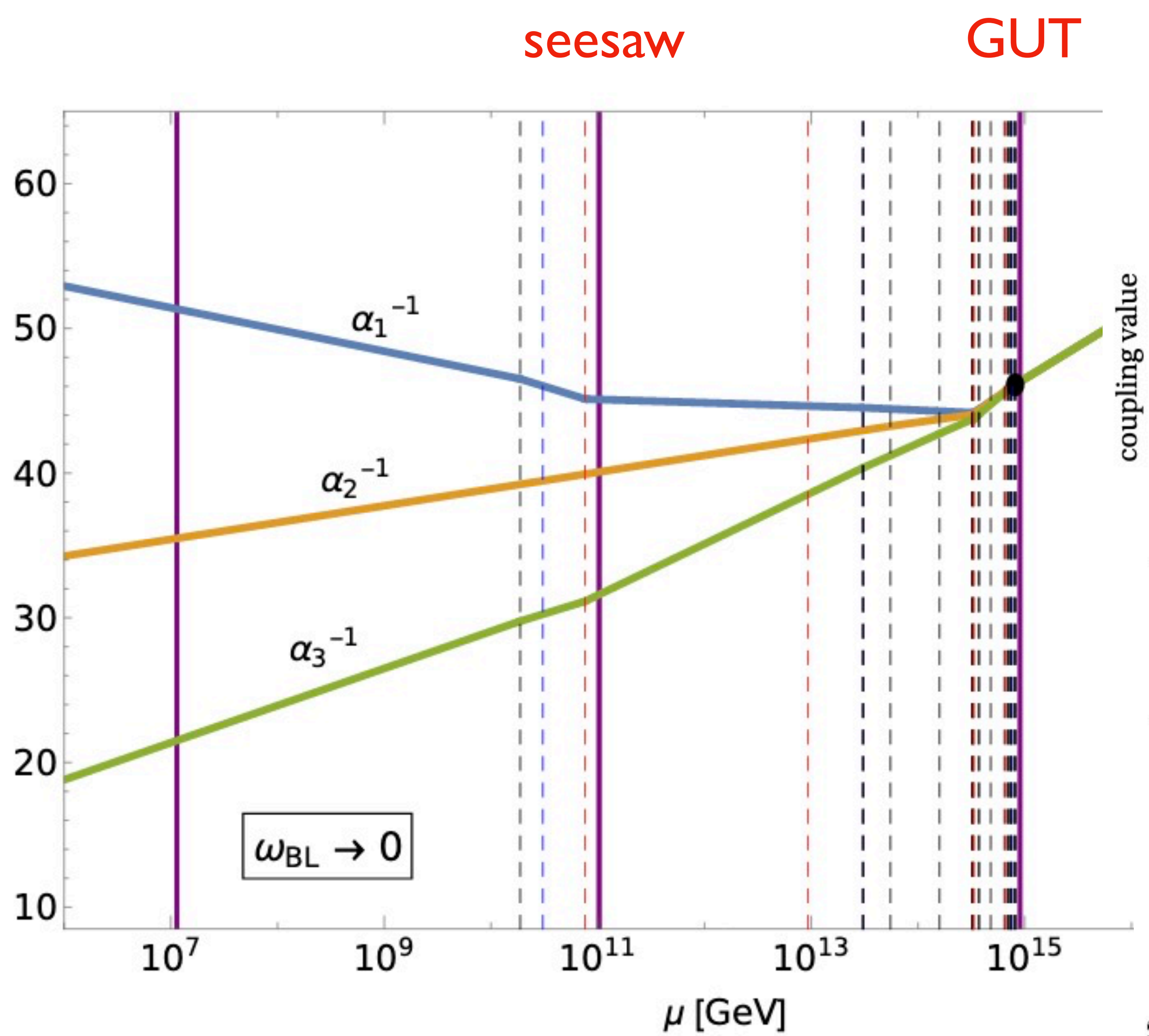
The minimal quantum SO(10) Higgs model in the 421 mode

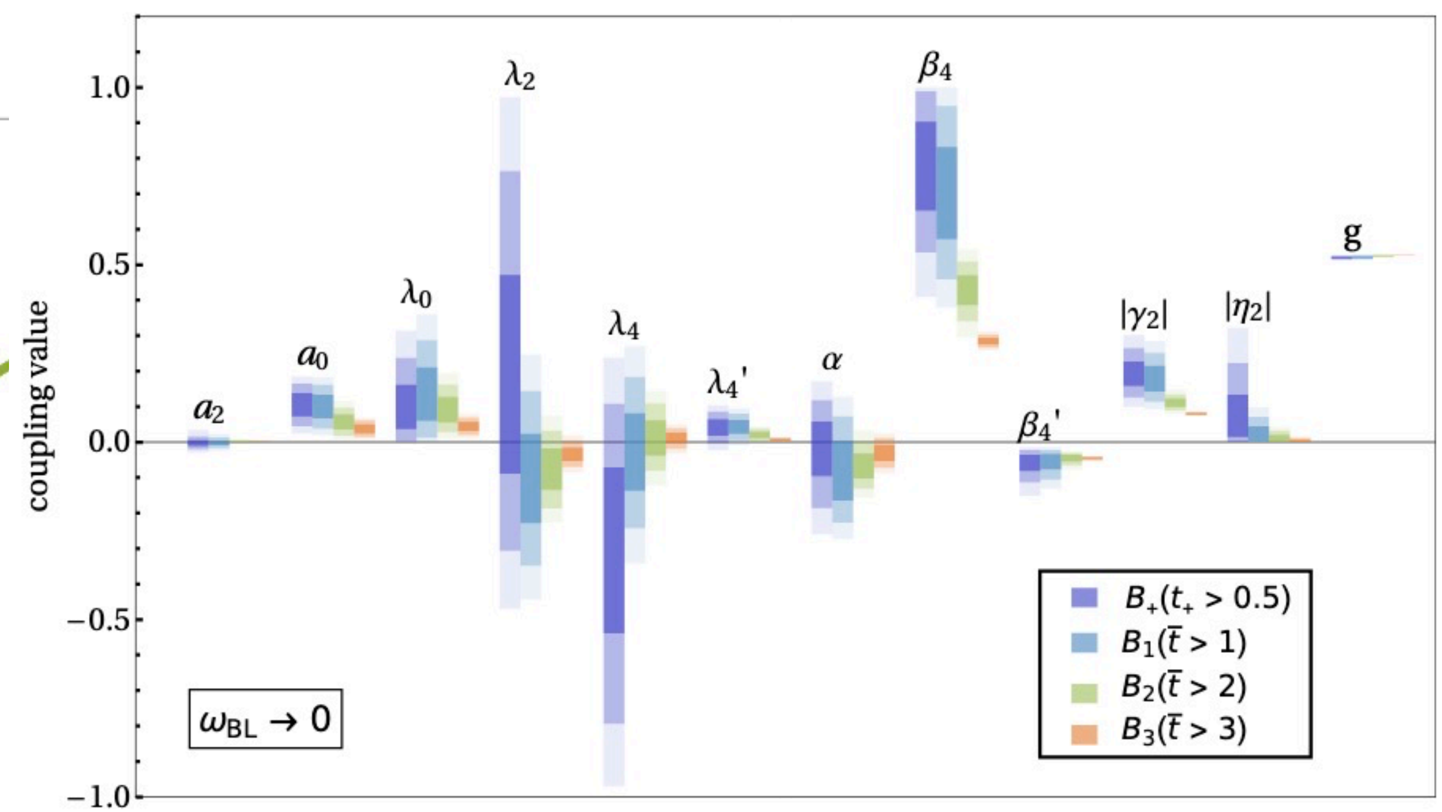


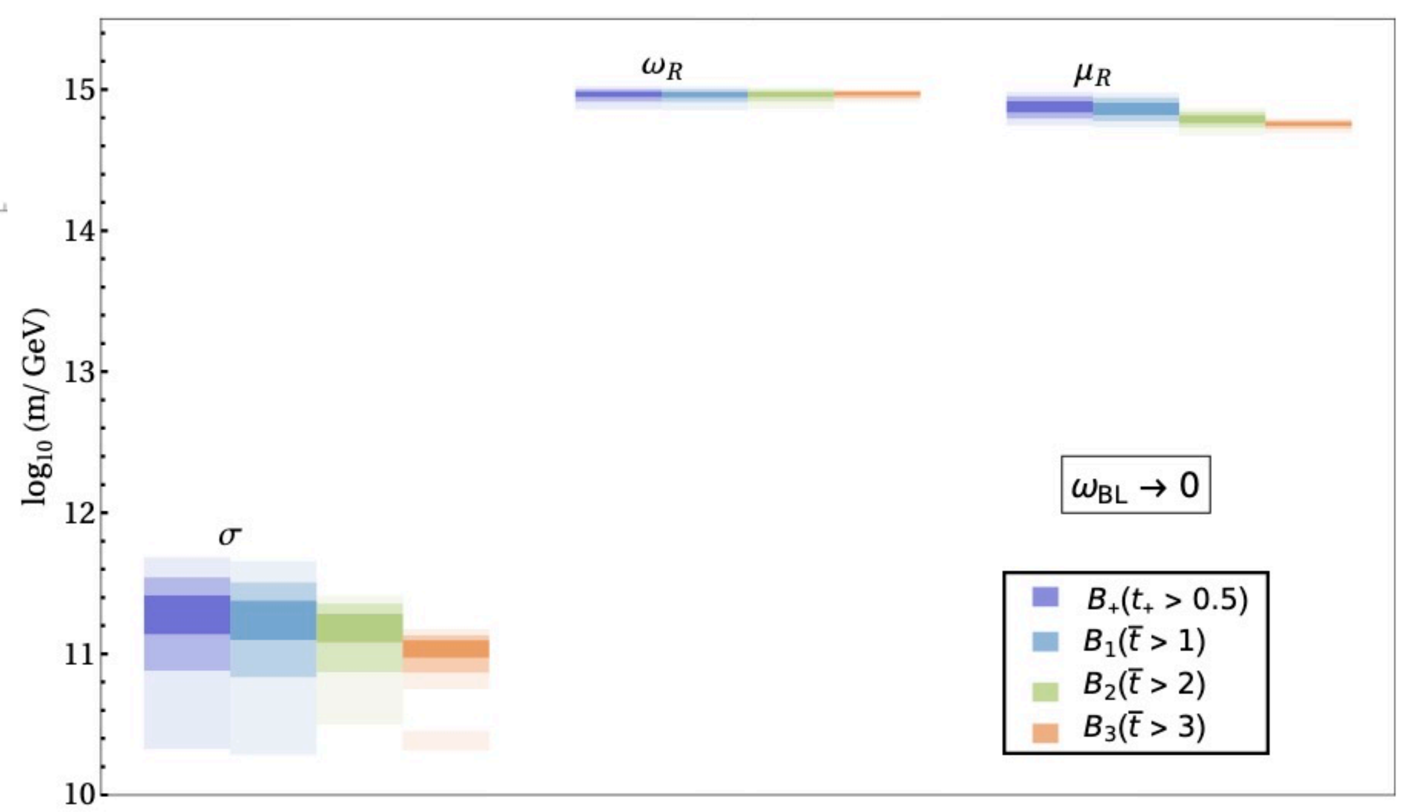




The minimal quantum SO(10) Higgs model in the 421 mode





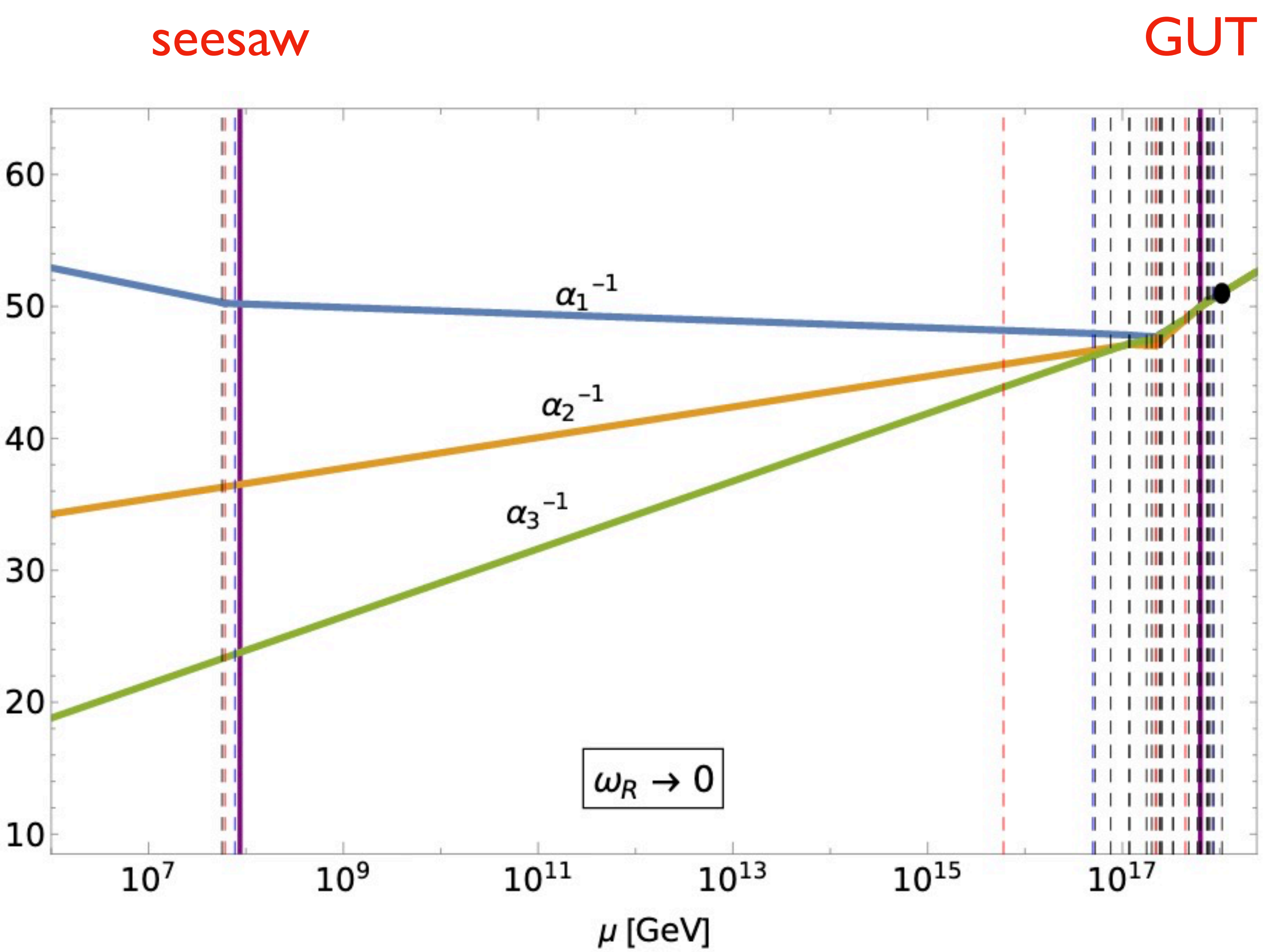


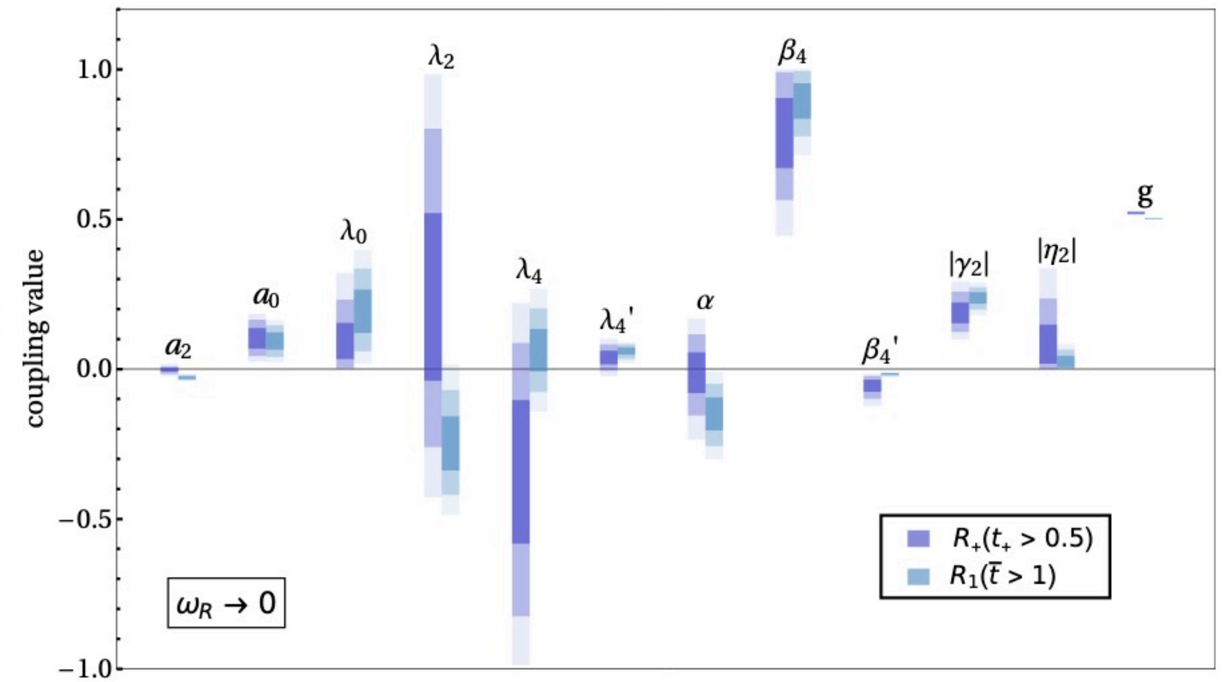
seesaw in acceptable domain, quite variable

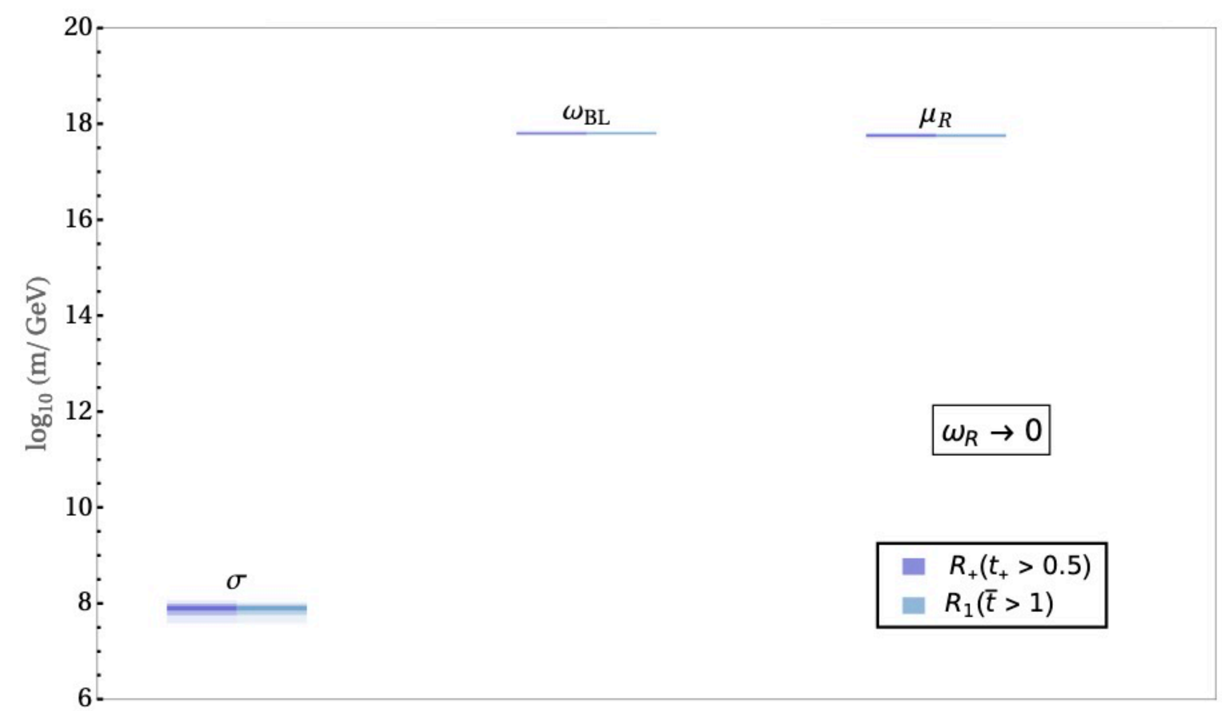
results perturbatively stable over several OOM

p-decay behind the corner (?)

The minimal quantum SO(10) Higgs model in the 3221 mode







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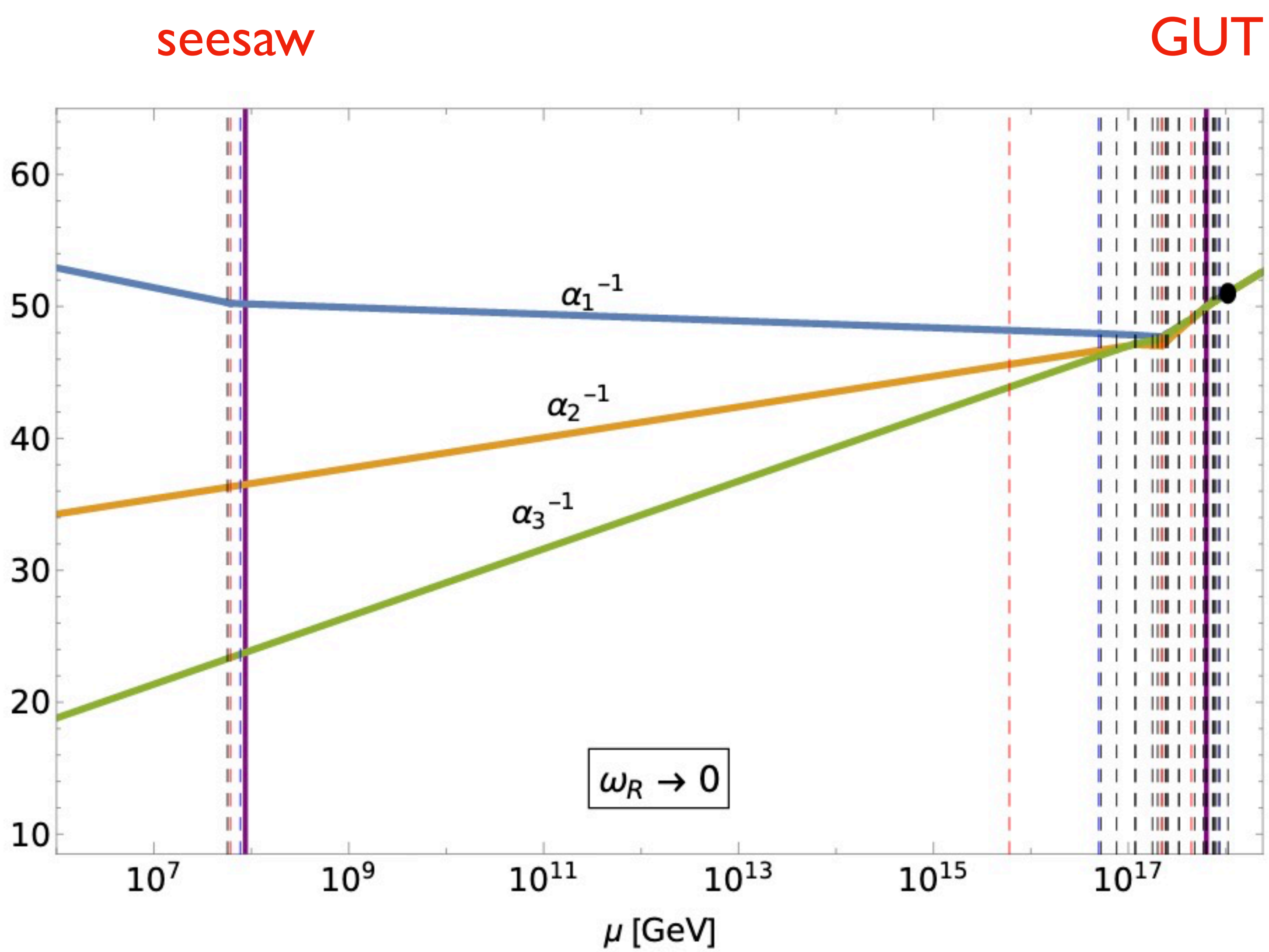
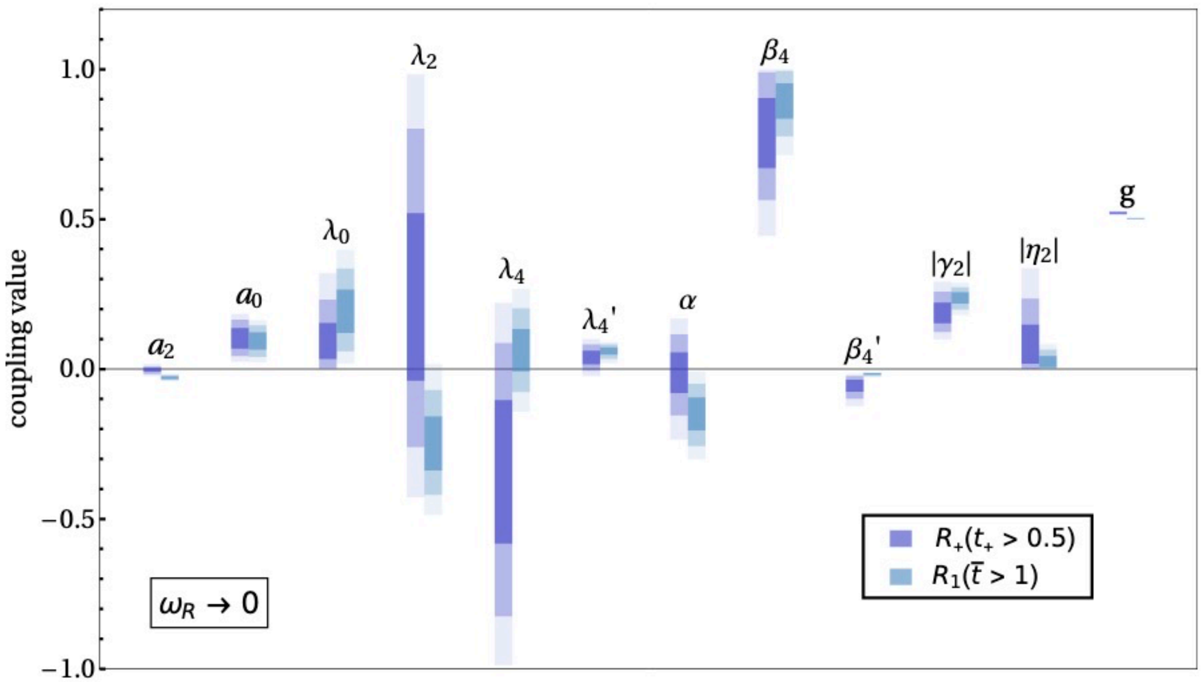
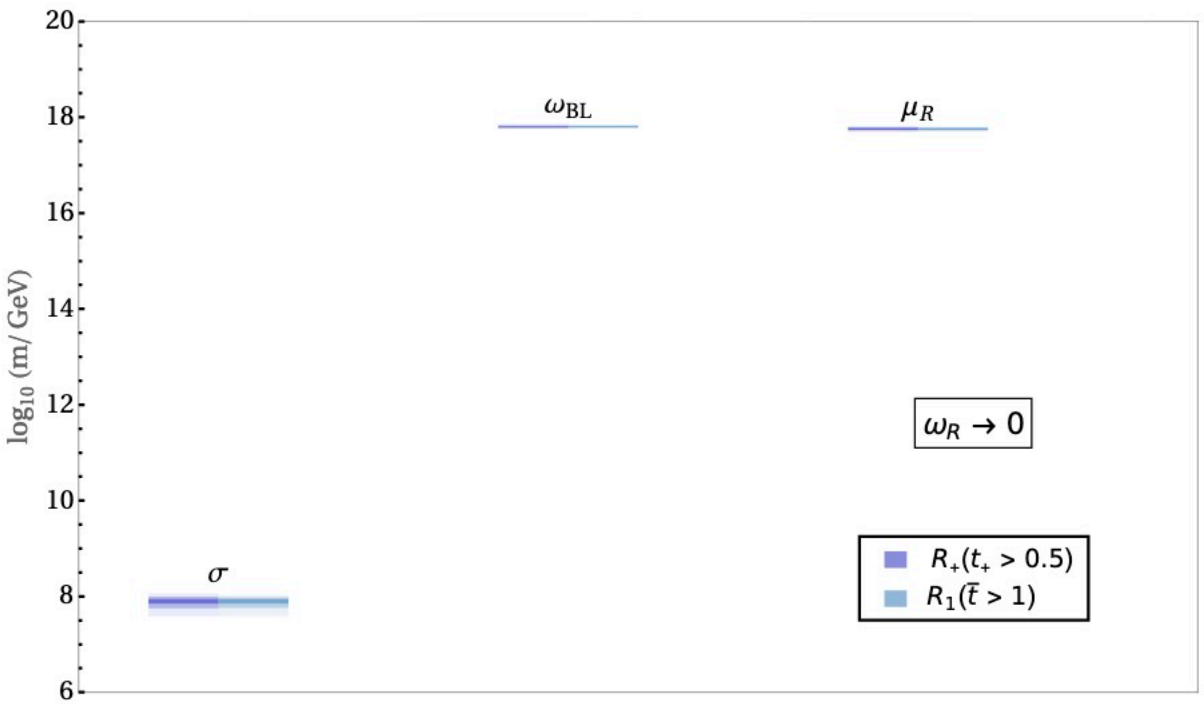




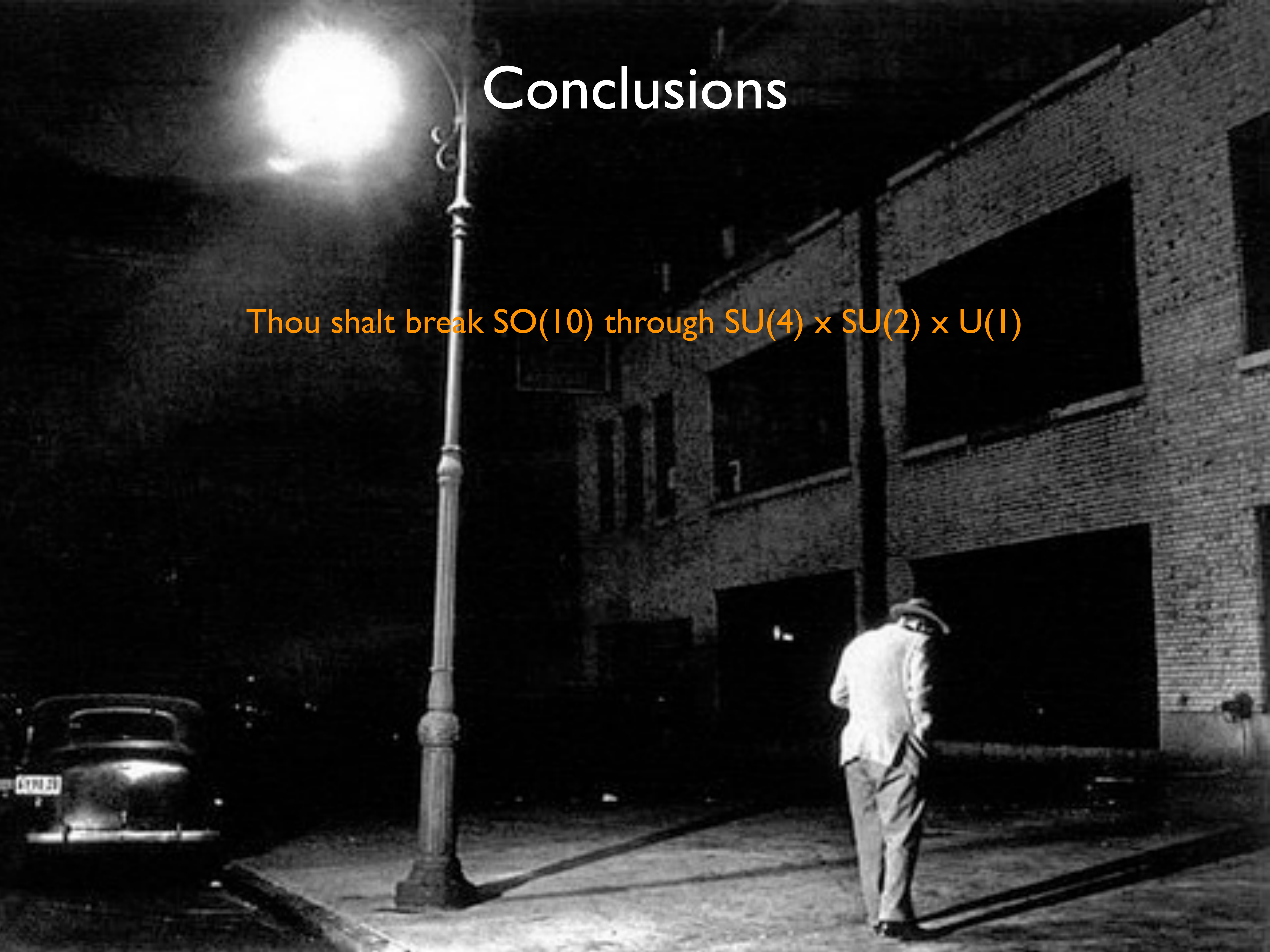


perturbativity / Planck scale proximity issues

seesaw scale very low and rigid :-(

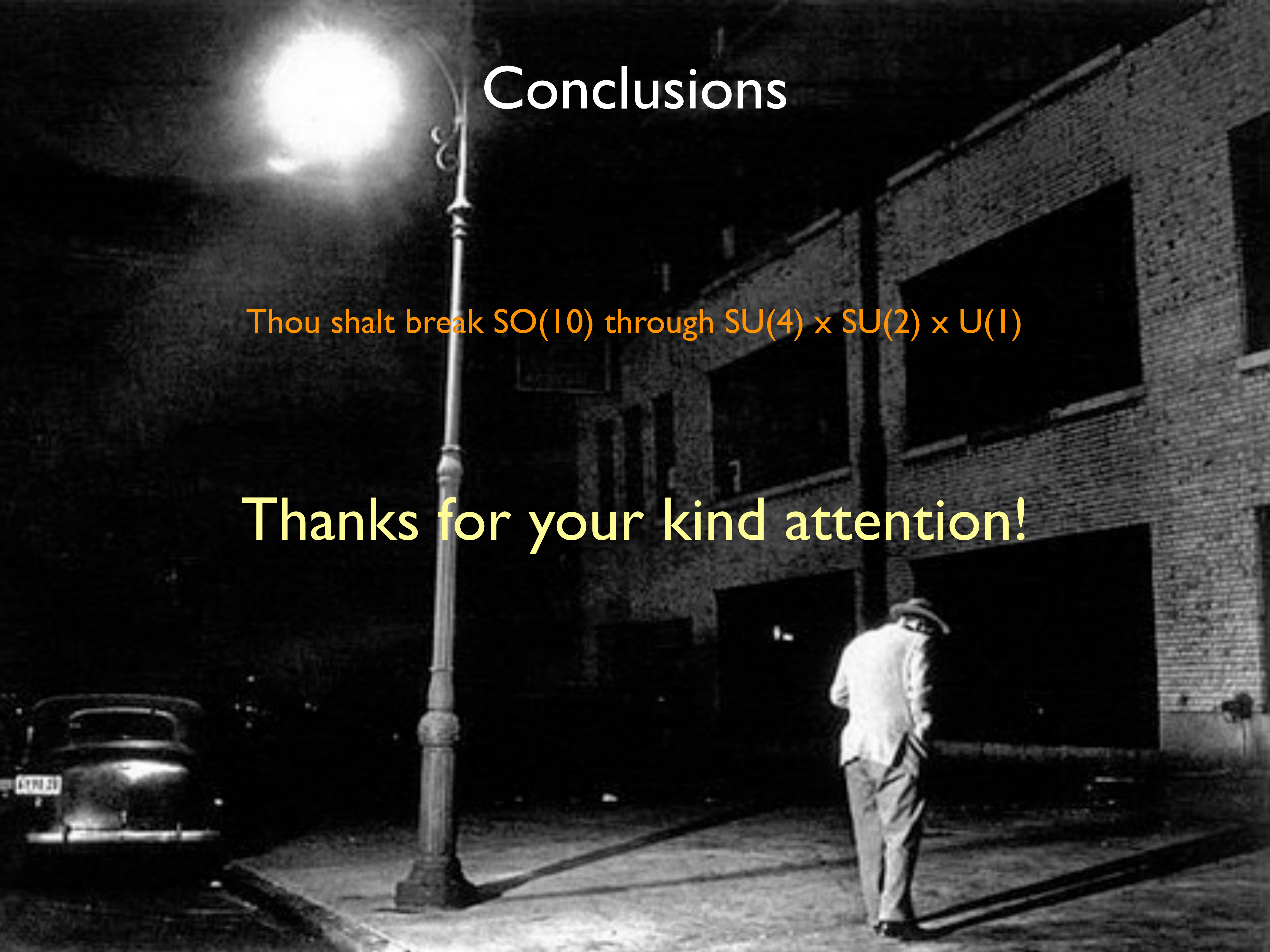
no way to see p decay

Conclusions



Thou shalt break SO(10) through SU(4) x SU(2) x U(1)

Conclusions



Thou shalt break SO(10) through SU(4) x SU(2) x U(1)

Thanks for your kind attention!