Quantum analysis
of the minimal potentially realistic
SO(10) model

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SO(10)
(The minimal renormalizable non-SUSY)

- All fermion fields from one generation + right-handed neutrino in 16_F.

$$16_F = L_L \oplus \overline{d}_L \oplus Q_L \oplus \overline{u}_L \oplus \overline{e}_L \oplus \boxed{N_L^c}$$

- Gauge fields in 45_G, accommodates SM gauge fields + leptoquarks, diquarks (carry colour & flavour) with masses ~ heavy symmetry breaking scale

$$45_G = G_\mu^b \oplus A_\mu^a \oplus B_\mu, Y_\mu \oplus (3,1,\tfrac{2}{3}) \oplus \boxed{(3,2,-\tfrac{5}{6})}$$
$$\boxed{\oplus (3,2,\tfrac{1}{6})} \oplus (1,1,1) + h.c.$$

Mediate proton decay

SO(10)
(The minimal renormalizable non-SUSY)

- The minimal realistic scalar sector contains following scalar fields:

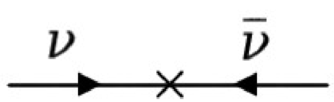
$$45_S \oplus 126_S\,(\oplus 10_S)$$

$\omega_{BL},\ \omega_R$ (SO(10) breaking)

σ (Intermediate symmetry breaking)

$|\sigma| \ll \max[|\omega_{BL}|, |\omega_R|]$

Neutrino masses – type I (N_R) and type II (triplet in 126_S) seesaw



Inherently quantum model

Tree-level scalar spectrum contains tachyonic scalars if not near the flipped $SU(5) \times U(1)'$ breaking chain

$$\mathrm{M}_S^2[(8,1,0)] = 2a_2(\omega_{BL} - \omega_R)(\omega_R + 2\omega_{BL}),$$

$$\mathrm{M}_S^2[(1,3,0)] = 2a_2(\omega_R - \omega_{BL})(2\omega_R + \omega_{BL}),$$

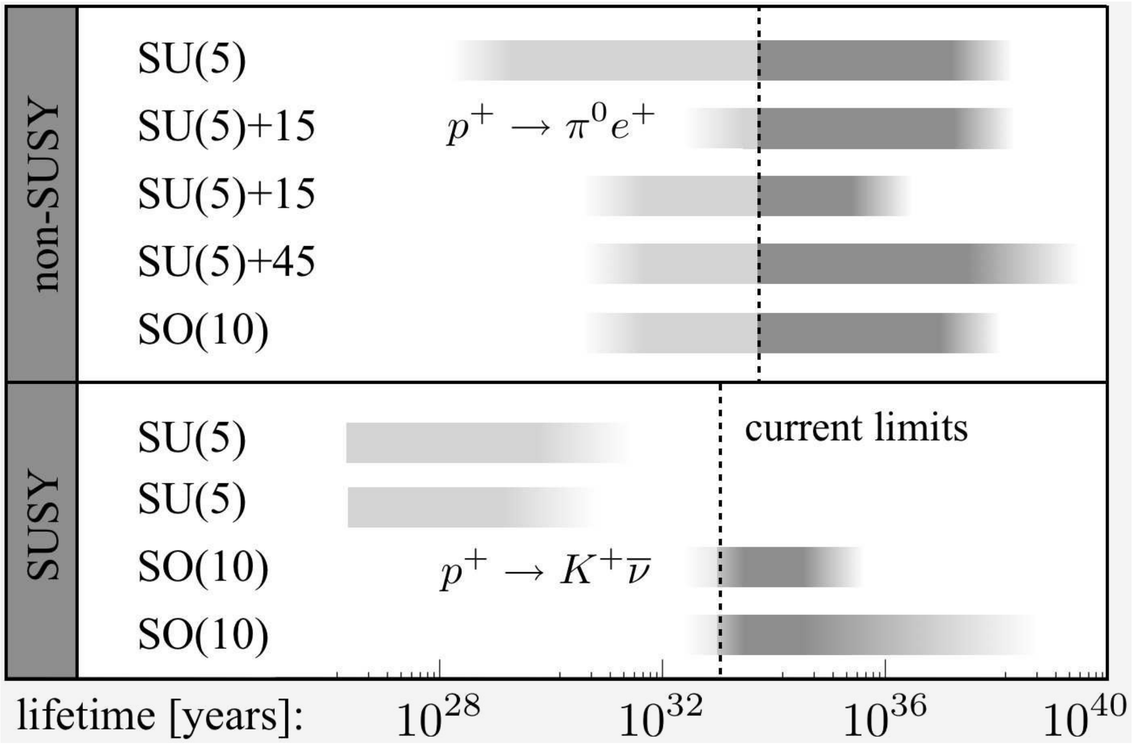
$$M^2[(1,1,0)] = a_2 \left(-\frac{45\omega_{BL}^4}{3\omega_{BL}^2 + 2\omega_R^2} + 13\omega_{BL}^2 - 2\omega_{BL}\omega_R - 2\omega_R^2 \right) + O\left(a_2^2\right) + O\left(\frac{\sigma^2}{\omega_{max}^2}\right)$$

If $a_2 \ll 1$, one-loop corrections dominate → pseudo-Goldstone bosons of the broken O(45) global symmetry

[S.Bertolini, L. Di Luzio, M. Malinsky, Phys.Rev.D 81 (2010), 035015]

Allows BLNV processes

Gauge & scalar leptoquarks lead to baryon and/or lepton number violation. The most prominent BNV process is proton decay. Proton lifetime prediction in the non-SUSY minimal renormalizable SO(10) is robust with respect to the theoretical uncertainties.

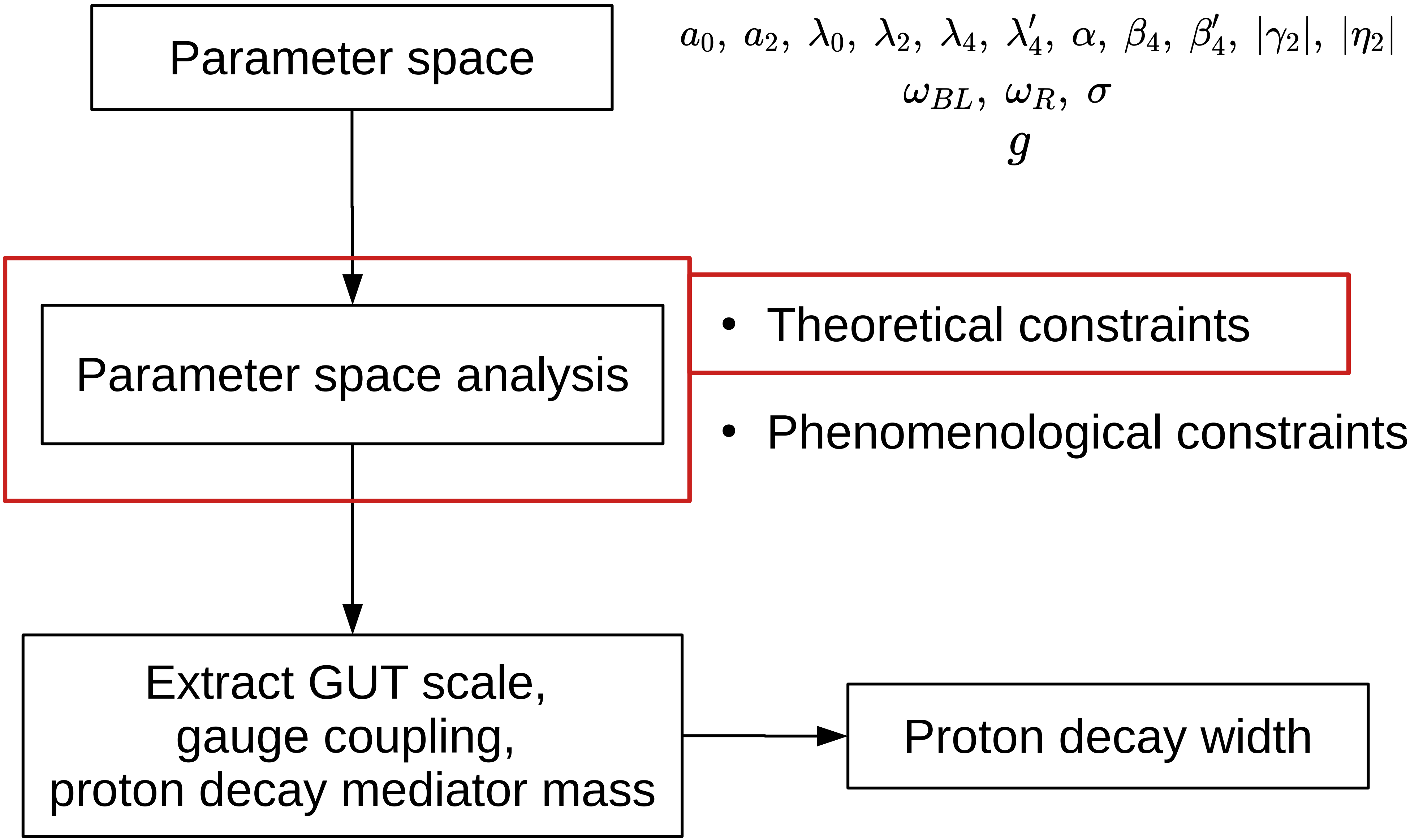


"Precise" proton decay prediction

Thorough theory investigation

[H. Kolesova, M. Malinsky: Proceedings ICHEP 2014]

Proton lifetime calculation



Parameter space analysis
Theoretical constraints

Tachyonicity

- Non-tachyonicity of the mass spectrum is essential requirement
- Accidentally light pseudo-Goldstone bosons (need to go beyond tree-level, inherently quantum model)

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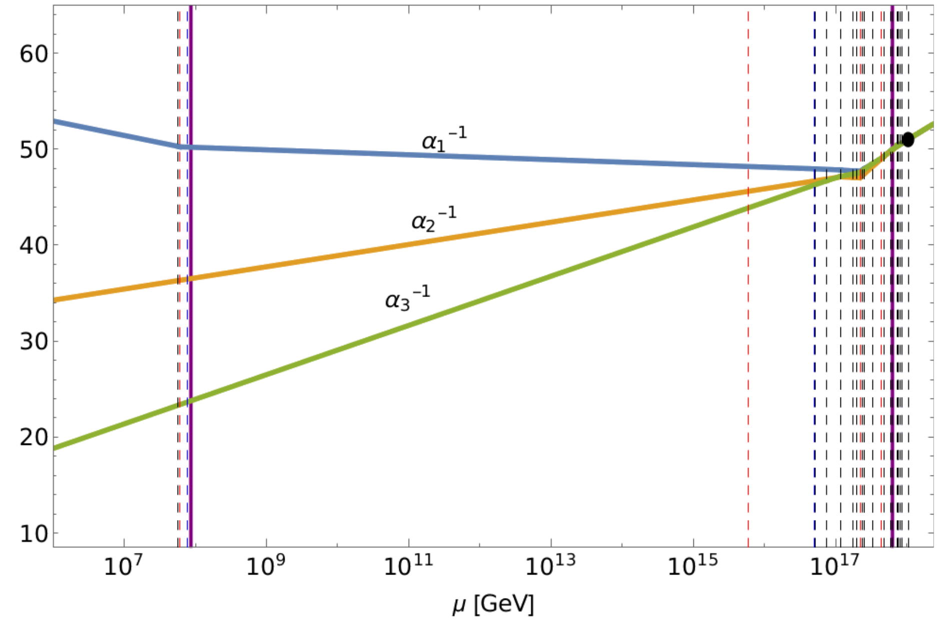
Complete calculation of full one-loop effective scalar mass corrections

Gauge coupling unification

- All three gauge couplings have to unify when run to the high energy scales
- Multi-stage symmetry breaking



Parameter space analysis
Theoretical constraints

Perturbativity

- Global mass perturbativity – the relative size of the one-loop mass corrections is restricted with respect to the tree-level masses ⟵ one-loop corrections to the effective scalar masses

- Stability under RG running – one-loop effective scalar masses possess residual renormalization scale dependence which is controlled by RG running restrictions

↓

Complete system of one-loop beta functions of all dimensionless couplings

Parameter space analysis
Theoretical constraints

Perturbativity

- Vacuum position stability – one-loop vacuum is not too far from the tree-level vacuum in the VEV space

$$\tau = P(\sigma, \omega_{BL}, \omega_R, \lambda) + Q(\lambda)\frac{\omega_{BL}\omega_R(\omega_{BL}+\omega_R)}{|\sigma|^2}$$

↓

There are only four distinct possible breaking chains

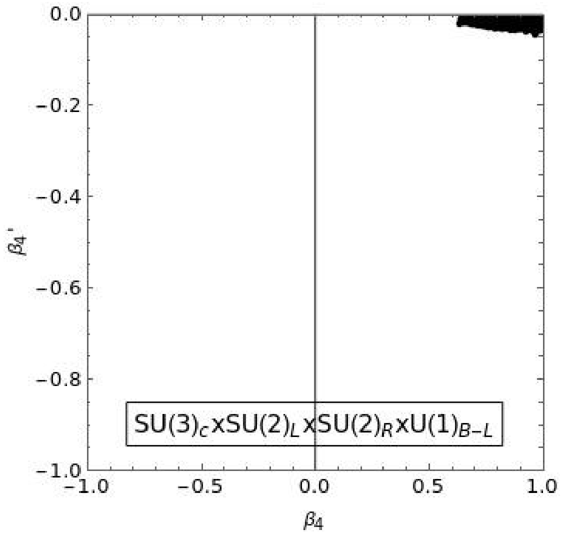
1) One step breaking

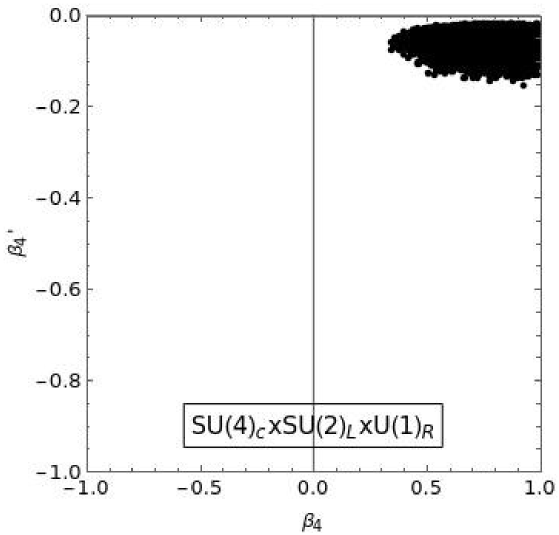
2) (Flipped) SU(5) inter. stage

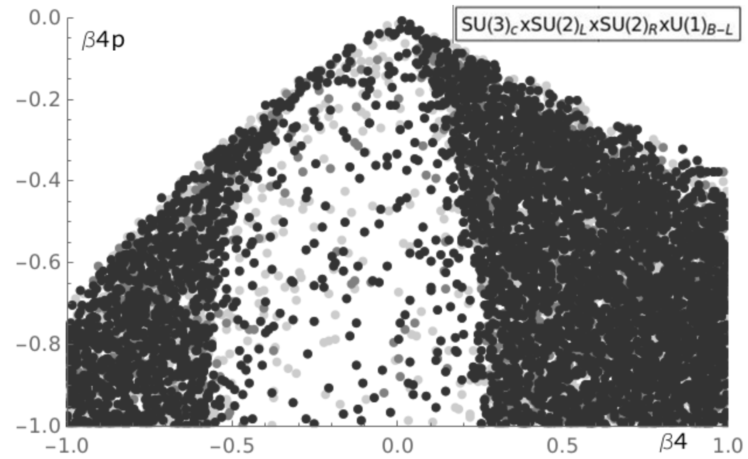
3) $SU(4)_c xSU(2)_L xU(1)_R$ inter. stage

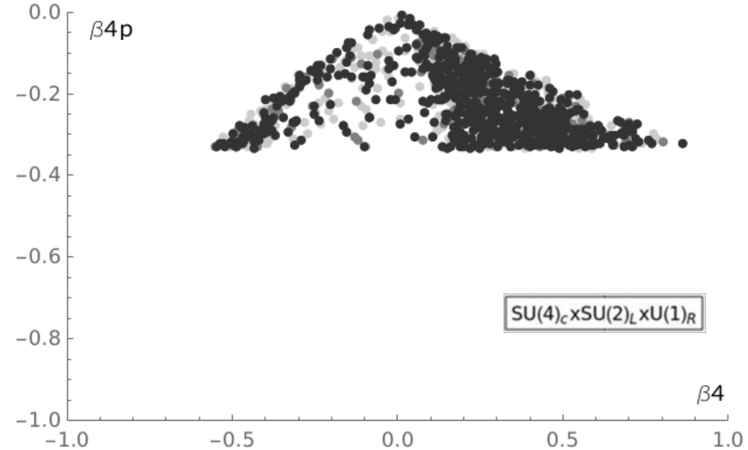
4) $SU(3)_c xSU(2)_L xSU(2)_R xU(1)_{B-L}$ inter. stage

Parameter space analysis
Theoretical constraints







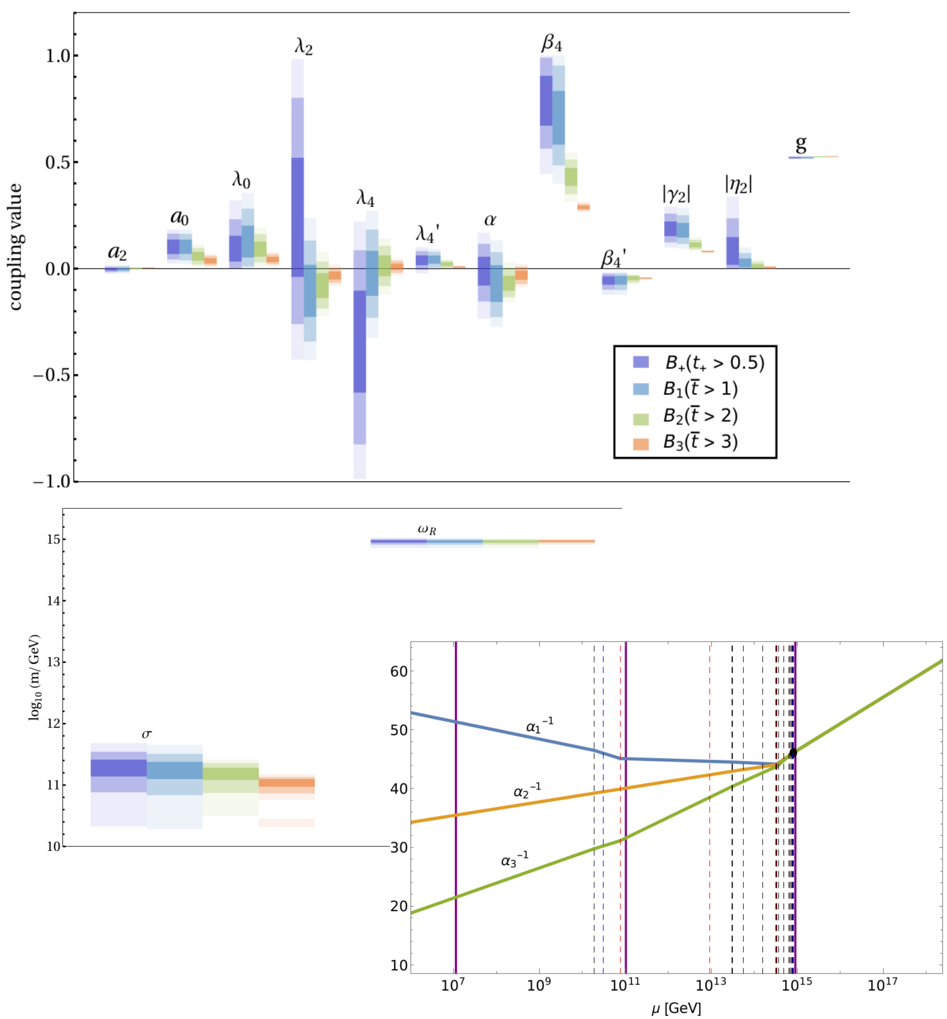


[S.Bertolini, L. Di Luzio, M. Malinsky, Phys.Rev.D 87 (2013) 8, 085020]
[H. Kolesova, M. Malinsky, : Phys.Rev.D 90 (2014) 11, 115001]

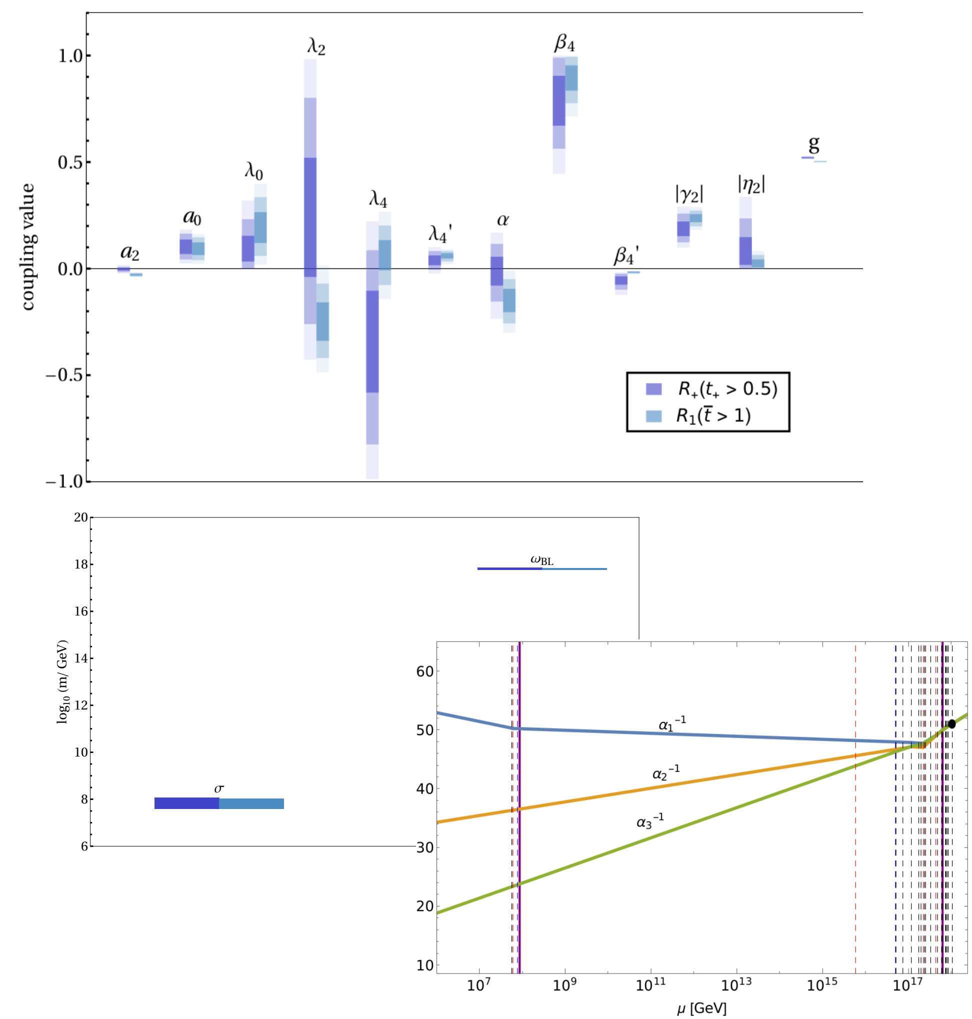
Parameter space analysis

Results

$SU(4)_c \times SU(2)_L \times U(1)_R$



$SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$



Summary & Outlook

Minimal renormalizable non-SUSY **SO(10)**:

- Gauge bosons in 45_S, one-generation of fermions (+ N_R) in 16_F, scalars in 45_S, 126_S (+ 10_S)
- Inherently quantum model
- Proton lifetime estimate is robust with respect to the theoretical uncertainties

Phys.Rev.D 105 (2022) 9, 095003

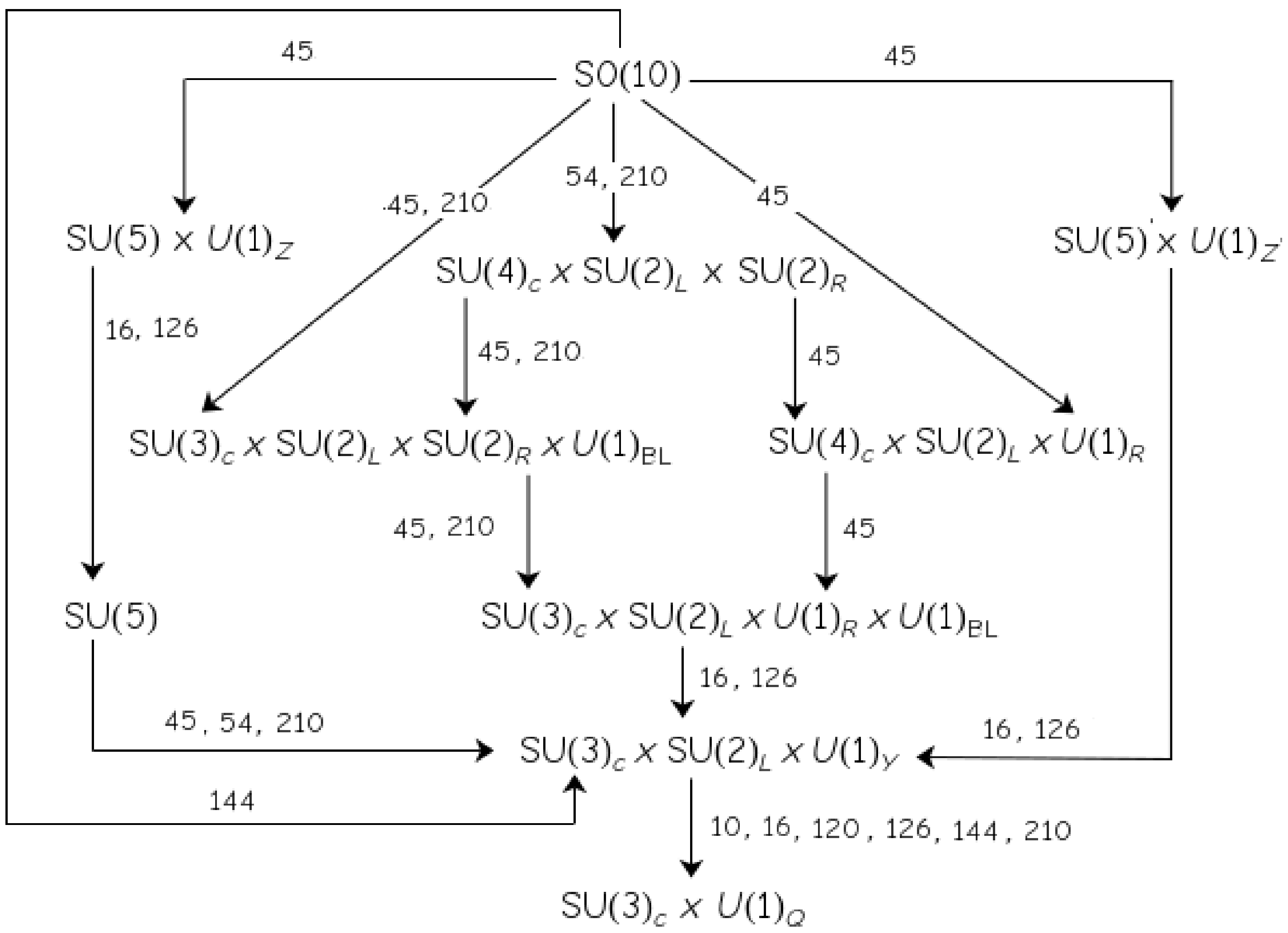
The proton lifetime calculation has to involve thorough parameter space analysis involving constraints:

- Tachyonicity (one-loop effective masses)
- Gauge coupling unification
- Improved Perturbativity

Phenomenological constraints still need to be implemented (see-saw scale constraints, Yukawa sector). Gauge coupling unification has to be considered on two-loops level.

Additional slides

SO(10) breaking chanes
(non-SUSY minimal renormalizable)



Theoretical uncertainties

$$\Gamma(p \to \pi^0 e^+) \propto |\langle \text{hadr.} \rangle|^2 \times \frac{\alpha_G^2}{M_X^4} \times$$
$$\text{flavour} \times \text{eff. operator running}$$

Irreducible:

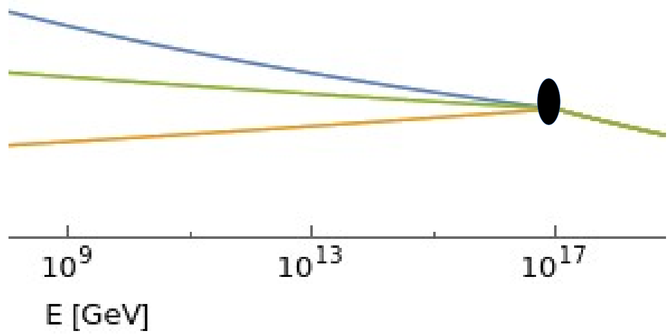
- Hadronic matric elements
- Planck scale physics (dim 5 operators)

Reducible:

- Finite order in perturbation theory

$$\frac{c}{M_{Pl}} F^{\mu\nu} \Phi F_{\mu\nu} \to c \frac{M_{GUT}}{M_{Pl}} F^{\mu\nu} F_{\mu\nu}$$

SO(10)



$$\frac{c}{M_{Pl}} f_i f_j H \Phi \to c \frac{M_{GUT}}{M_{Pl}} f_i f_j H$$

Suppressed in SO(10)

[Kolesova, Malinsky: Phys.Rev.D 99 (2019)]

[Kolesova, Malinsky,Mede: AIP Conf.Proc. 1743 (2016)]