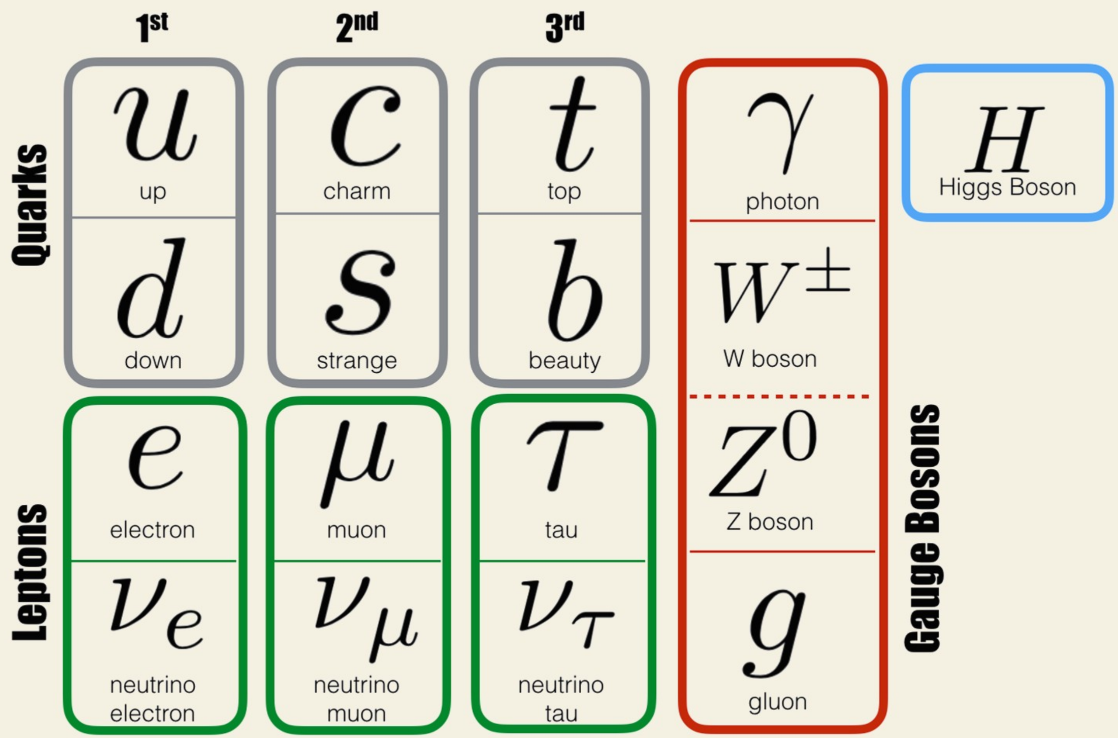
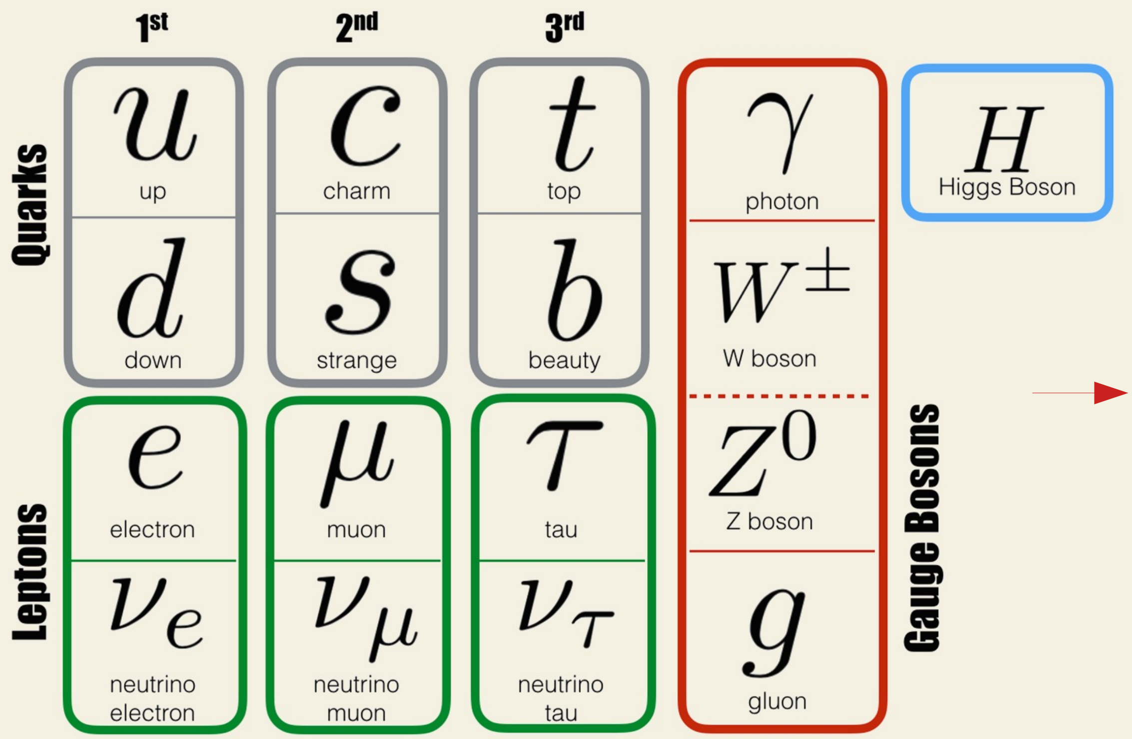
Quantum aspects
of the minimal potentially realistic
SO(10) Higgs model

Katerina Jarkovska
IPNP, UNCE seminar 2021

Standard model

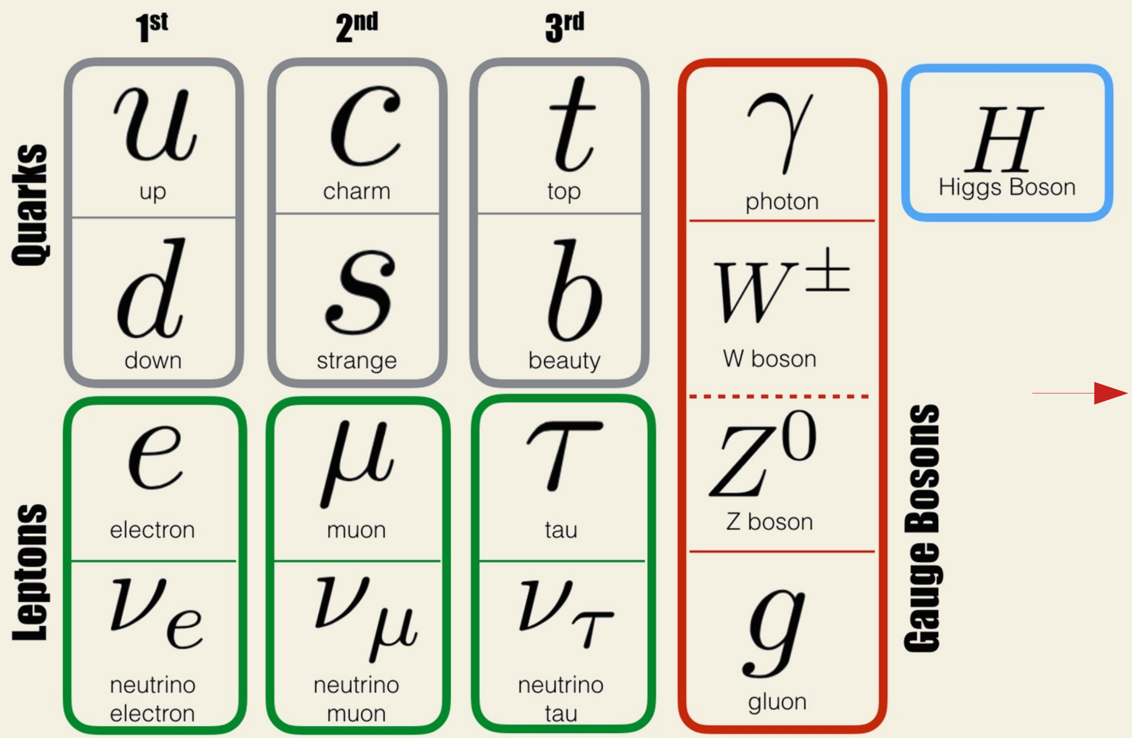


Standard model



Neutrino masses?

Standard model



→ **Neutrino masses?**

$$SU(3)_c \times SU(2)_L \times U(1)_Y \longrightarrow SO(10)$$

- See-saw mechanism
- Charge quantization
- BLNV (proton decay)

The minimal renormalizable non-SUSY SO(10)

SO(10)

- All fermion fields from one generation + right-handed neutrino N_R

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

SO(10)

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- SM gauge fields + leptoquarks, diquarks (carry colour & flavour)

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

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- Additional scalar fields in the minimal realistic setting:

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

$45_S \rightarrow \omega_{BL},\ \omega_R$

$126_S \rightarrow \sigma$

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

SO(10)

Inherently quantum model

Tree-level scalar masses contain pseudo-Goldstone bosons if not near the flipped $SU(5)\times U(1)'$ breaking chain

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

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

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

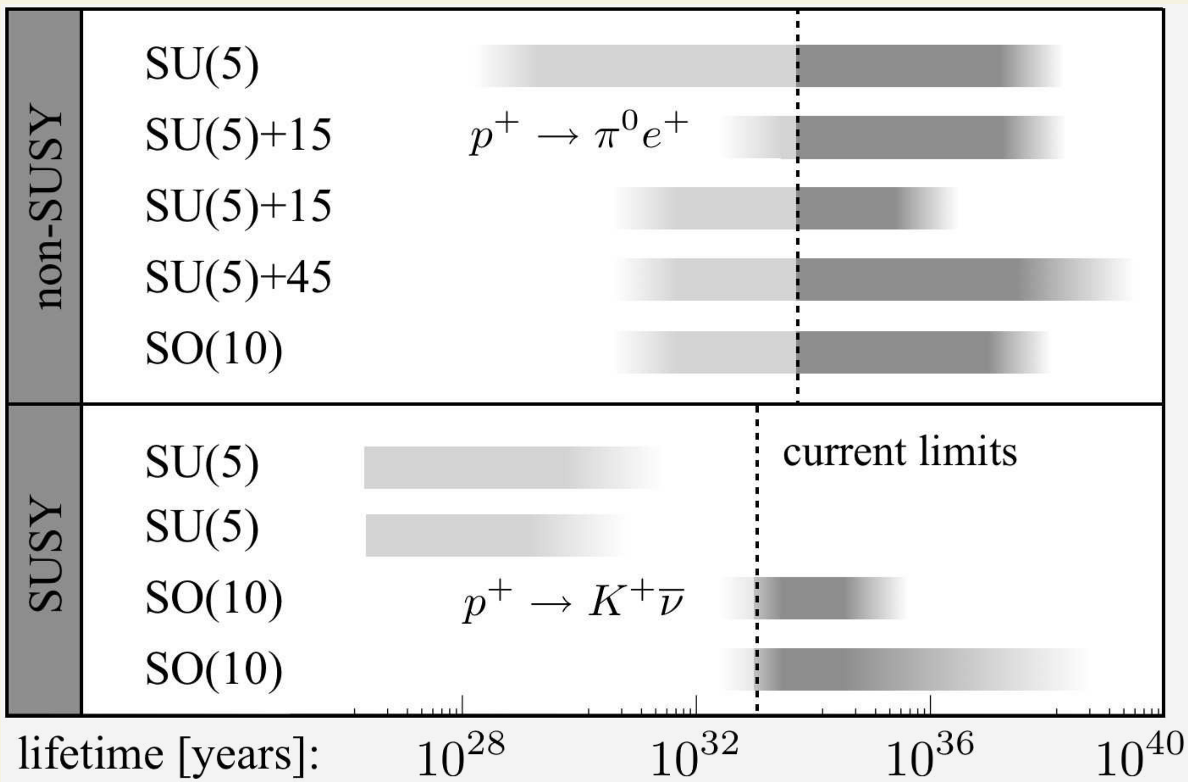
If $a_2 \ll 1$, one-loop corrections dominate.

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

SO(10)

Allows BLNV processes

The most prominent BLNV process is proton decay.



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

→ Theoretical uncertainties can be made smaller

Thorough theory investigation → “precise” proton decay prediction

Proton lifetime calculation

Parameter space

$$a_0,\ a_2,\ \lambda_0,\ \lambda_2,\ \lambda_4,\ \lambda_4',\ \alpha,\ \beta_4,\ \beta_4',\ |\gamma_2|,\ |\eta_2|$$
$$\omega_{BL},\ \omega_R,\ \sigma$$
$$g$$

↓

Parameter space analysis

- Theoretical contraints
- Phenomenological constraints

↓

Extract GUT scale, gauge coupling, proton decay mediator mass → **Proton decay width**

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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)

↓

Complete calculation of full one-loop effective scalar mass corrections

Parameter space analysis
Theoretical constraints

Tachyonicity

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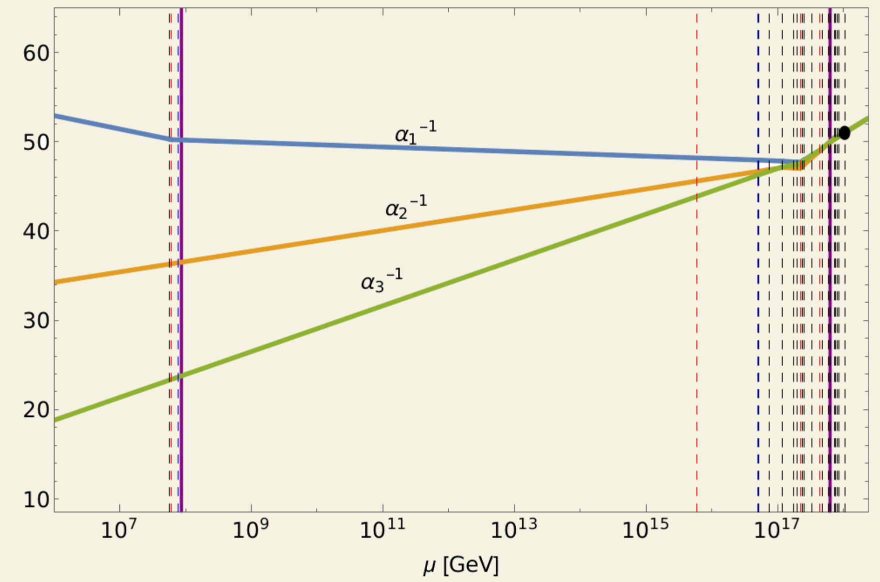
Complete calculation of full one-loop effective scalar mass corrections

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

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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

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There are only four distinct possible breaking chains

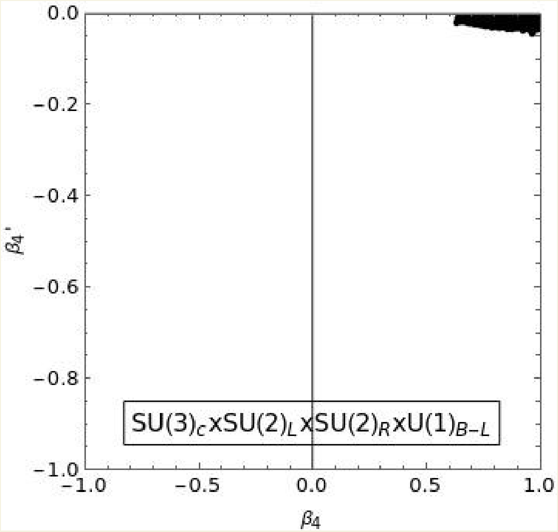
1) One step breaking

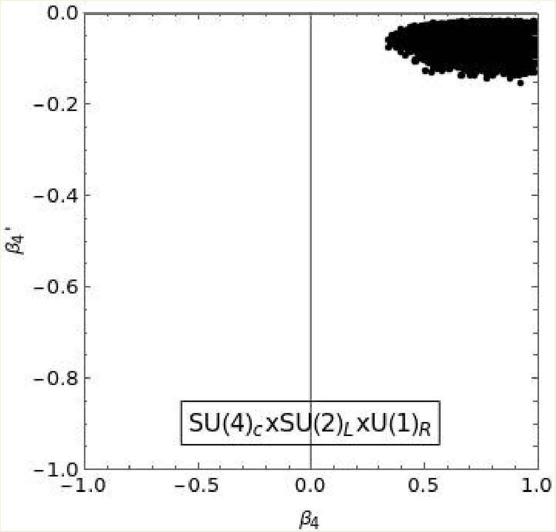
2) (Flipped) SU(5) inter. stage

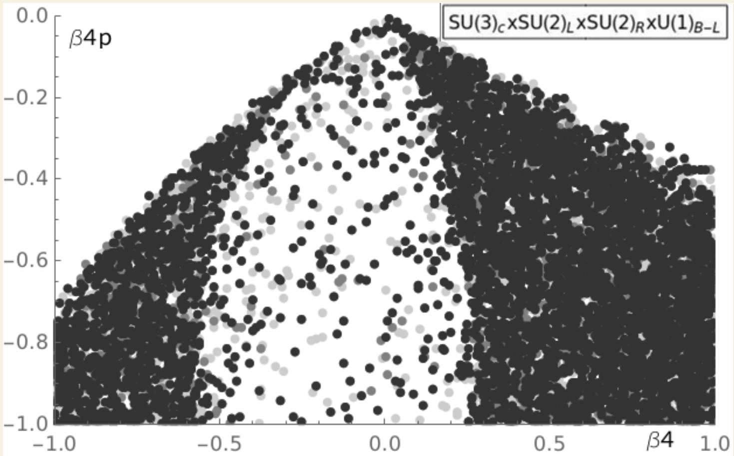
3) $SU(4)_c x SU(2)_L x U(1)_R$ inter. stage

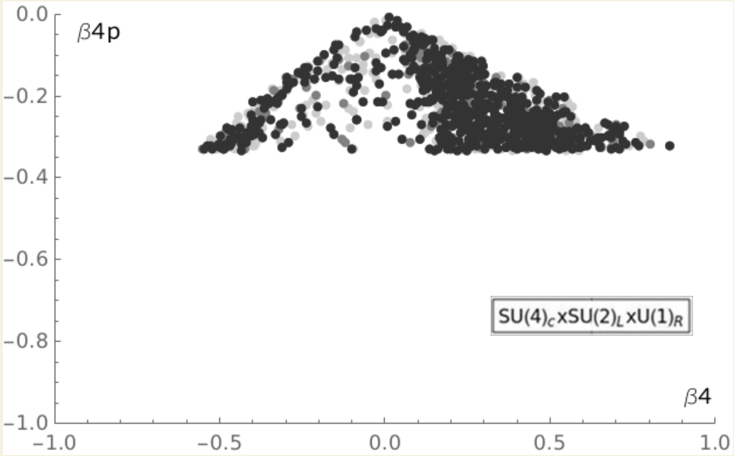
4) $SU(3)_c x SU(2)_L x SU(2)_R x U(1)_{B-L}$ inter. stage

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]

Summary & Outlook

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

- Inherently quantum model
- Proton lifetime estimate is robust with respect to the theoretical uncertainties

The proton lifetime calculation has to involve thorough parameter space analysis. The following constraints were implemented:

- Tachyonicity
- Gauge coupling unification
- Perturbativity

Paper in Peer Review Process

Phenomenological constraints still need to be implemented. These involve mainly proton decay width experimental limits and constraints on the see-saw scale. Gauge coupling unification has to be considered on two-loops level.