Quantum structure of the minimal calculable unified model

*work in progress**

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Can we improve the theoretical predictions for the *proton lifetime*?

Introduction

Problems of **SM** :

neutrino oscillations, DM, charge quantization, hierarchy problem, parity violation, ...

$\downarrow$

BSM

GUT*s* :

experimental signature $\longrightarrow$ **proton decay**

large *uncertainties* in τ_p estimates !!!

Motivation

Experiment :

Future proton decay searches (DUNE, Hyper-K, . . .)

$\downarrow$

$\mathcal{O}(10)$ increase in $\tau_p(p^+ \to \pi^0 e^+, K^+\bar{\nu})$ sensitivity

Theory :

matching experiment: first ever *NLO* calculation

$\downarrow$

requires reducing the large uncertainties in predicted τ_p

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Outline

Theoretical uncertainties

Main sources of uncertainties in τ_p estimates in GUTs:

- **hadronic matrix elements** :
  $\langle \pi^{+,0}, K^{+,0}, \eta | \ldots | p^+ \rangle$
  lattice $\longrightarrow$ $\Delta \sim \mathcal{O}(20 - 40\%)$

Theoretical uncertainties

Main sources of uncertainties in τ_p estimates in GUTs:

- **unification scale** *determination* :

  M_{GUT} = effective mediator mass $\longrightarrow$ $\tau_p \propto M_{GUT}^4$
  (in non-SUSY predominantly *heavy gauge bosons*:
  $(3, 2, -5/6)_{45}$ or $(3, 2, 1/6)_{45}$)

  @ NLO:

  * running of λ_i **@ 2-loop** ($\Delta\alpha_i^{exp}(m_Z)$)
  * *threshold effects* **@ 1-loop** (scalar spectrum @ tree level/1-loop)
  * *Planck scale effects* : gauge kinetic form operators

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

$\longrightarrow$ uncontrolled & inhomogeneous *shifts in matching*
$\Delta\alpha_i^{-1}(M_{GUT}) \sim \mathcal{O}(1)$
$\longrightarrow$ orders of magnitude uncertainty in M_{GUT}
$\longrightarrow$ tame them or no sense in NLO

Theoretical uncertainties

Main sources of uncertainties in τ_p estimates in GUTs:

- **flavour structure** *of the BLV currents* :
  - $*$ partial widths $\Gamma(p^+ \rightarrow \mathrm{final\ state})$ in general depend on *rotation matrices* $\longrightarrow$ some channels are more *robust* to *perturbations of the mass matrices*

    $\Gamma(p^+ \rightarrow K^+\bar{\nu}, \pi^+\bar{\nu})$ independent of rotation matrices for symmetric quark-sector mass matrices $\longrightarrow$ governed only by mediator masses
  - $*$ *Planck scale effects :* scalar & fermionic kinetic form, higher-order Yukawa operators $\longrightarrow$ *shifts in* $d = 4$ *matching*

$$\mathcal{L} \ni \frac{\rho}{\Lambda}(D_\mu\phi)^\dagger\langle\Phi\rangle(D^\mu\phi)$$

$$\mathcal{L} \ni \frac{1}{\Lambda} i\bar{\psi}_{R_i}\not{D}_{R_i} Y' \psi_{R_i}\langle\Phi\rangle$$

$$\mathcal{L} \ni \frac{1}{\Lambda}\psi_{R_1} Y'' \psi_{R_2}\phi\langle\Phi\rangle$$

  - $*$ Yukawa sector fits inaccurate to $\langle\Phi\rangle/\Lambda \sim 1\%$ due to shifted matching $\longrightarrow$ potentially large changes in the *mixing angles* and *BLV currents* !

The minimal renormalizable non-SUSY SO(10) model

SO(10) *GUT spontaneously broken by* **45** :

leading Planck-scale effects in gauge matching *absent* (group theory argument)

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

Higgs sector :

- SO(10) broken by $\omega_Y \equiv (15,1,1)_{PS}$, $\omega_R \equiv (1,3,1)_{PS} \subset \langle \mathbf{45} \rangle$

$$SO(10) \xrightarrow{\omega_Y} 3_C \times 2_L \times 2_R \times 1_{B-L} \xrightarrow{\omega_R} 3_C \times 2_L \times 1_R \times 1_{B-L}$$

or

$$SO(10) \xrightarrow{\omega_R} 4_C \times 2_L \times 1_R \xrightarrow{\omega_Y} 3_C \times 2_L \times 1_R \times 1_{B-L}$$

- **rank** reduced by $(1\overline{0},3,1)_{PS} \subset \langle \mathbf{126} \rangle$

$$3_C \times 2_L \times 1_R \times 1_{B-L} \xrightarrow{\langle 126 \rangle} 3_C \times 2_L \times 1_Y$$

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

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Is the *minimal renormalizable non-SUSY SO(10)* really ruled out?

Spectrum computation

@ tree level :

Yasue '81
Anastaze et al. '83
Babu, Ma '85

either **tachyonic** *spectrum* or **flipped SU(5)** *vacuum*

$$\left.\begin{array}{l} m^2_{(8,1,0)_{45}} \propto (\omega_Y - \omega_R)(\omega_R + 2\omega_Y) \\ m^2_{(1,3,0)_{45}} \propto (\omega_R - \omega_Y)(\omega_Y + 2\omega_R) \end{array}\right\} \longrightarrow -2 < \frac{\omega_Y}{\omega_R} < -\frac{1}{2}$$

@ 1-loop :

large corrections $\longrightarrow$ *quantum salvation* *Bertolini, Di Luzio, Malinský '10*

$$\Delta m^2_{(8,1,0)_{45}} = \frac{1}{(4\pi^2)}\left[\tau^2 + \beta^2(\omega_R^2 - \omega_R\omega_Y + 3\omega_Y^2) + g^4(13\omega_R^2 + \omega_R\omega_Y + 22\omega_Y^2)\right] + logs$$

$$\Delta m^2_{(1,3,0)_{45}} = \frac{1}{(4\pi^2)}\left[\tau^2 + \beta^2(2\omega_R^2 - \omega_R\omega_Y + 2\omega_Y^2) + g^4(16\omega_R^2 + \omega_R\omega_Y + 19\omega_Y^2)\right] + logs$$

RGE running with realistic *see-saw scale* $\longrightarrow$ some "light" scalars in the desert: $(8,2,1/2)_{126}$ or $(6,3,1/3)_{126}$

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Summary & outlook

τ_p calculation accuracy :

not enough to *rule out* any particular GUT model

$\downarrow$

i) the *mediator mass* at best *@ LO*

or

ii) *flavour structure* of BLV currents not robust

||

too sensitive to generic $\mathcal{O}(1)$ *Planck-scale effects*

Summary & outlook

$\ast\ast\ast$ *minimal realistic GUT @ NLO* :

renormalizable non-SUSY SO(10) model with a $\mathbf{126} \oplus \mathbf{45}$

▷▷▷ the only *perturbative* unified theory, with at least some classes of Planck scale operators (*gauge kinetic form operators*) under control

$\downarrow$

can compute *radiative corrections* to *masses* and τ_p

▷▷▷ genuinely *quantum* theory $=$ no available *tree level* description (*tachyons*)

$\downarrow$

1-loop

▷▷▷ *robustness* in the ν *channel* $=$ prerequisite for *proton decay upper limit*

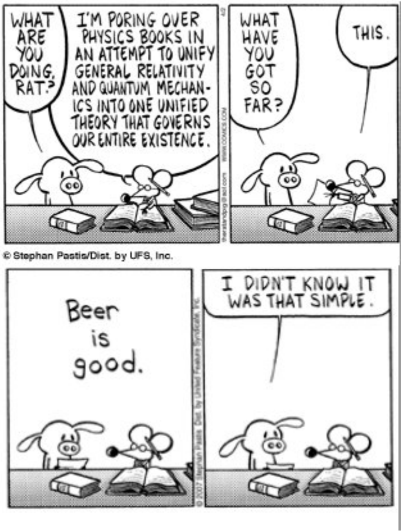
$\downarrow$

DUNE sensitive to "*flavour robust*" final states

Summary & outlook

TO DO :

- compute the whole **spectrum** (V_{eff} approach)
- show it's **realistic** & check **vacuum state** longevity
- provide the first ever **NLO computation** of corresponding $\tau_{\mathbf{p}}$



Thank you for your attention!