SO(10) unification at next-to-leading order

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Joint work with Michal Malinský (IPNP), Stefano Bertolini (SISSA) and Luca Di Luzio (Universita di Genova)
Proton decay: theoretical uncertainties vs experiment
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- grand unified theories (GUTs) predict baryon number violation
- non-SUSY GUTs: “golden” channel for proton decay: $p \rightarrow \pi^0 e^+$
- recent experimental limit
  [Super-Kamiokande, S.Mine talk]
  $\tau(p \rightarrow \pi^0 e^+) \geq 1.4 \times 10^{34}$ y
- new experiments planned to reach up to $\tau(p \rightarrow \pi^0 e^+) \geq 1 \times 10^{35}$ y
  [Hyper-Kamiokande, S.Mine talk]

What about the theory side?
Proton decay: theoretical uncertainties vs experiment

Toy model:
SM model running with 1-loop \( \beta \) function

Effect of 2-loop uncertainties (zoomed in)

One-loop result with "typical" errors due to neglecting 2-loop effects

Log_10 \( \tau(p\rightarrow\pi^0e^+)\)[y]

HK (10 years): \( \tau_p > 1 \times 10^{35} \) y

Recent SK limit: \( \tau_p > 1.4 \times 10^{34} \) y

\( \tau_p \sim M_G^4 \)
Proton decay: theoretical uncertainties vs experiment

Toy model:
SM model running with 2-loop $\beta$ function

$\alpha_S^{-1}$, $\alpha_L^{-1}$

log$_{10}\mu$ [GeV]

Effect of 3 loops negligible w.r.t. uncertainties in $\alpha_S$ (EW)

One-loop result with "typical" errors due to neglecting 2-loop effects

Two-loop result with error due to uncertainty in $\alpha_S$

Recent SK limit: $\tau_p > 1.4 \times 10^{34}$ y

HK (10 years): $\tau_p > 1 \times 10^{35}$ y

Log$_{10}\tau(p\to\pi^0e^+)[y]$

$\tau_p \sim M_G^4$
Proton decay: theoretical uncertainties vs experiment

Still other sources of uncertainties!

- threshold effects ($\sim$ size of 2-loop corrections) $\Rightarrow$ knowledge of the heavy spectrum needed
- SUSY GUTs: $m_{\text{SUSY}}$ uncertainty
- Planck induced effective operators


$$\frac{c}{M_{\text{pl}}} \text{Tr} (G_{\mu\nu} G^{\mu\nu} H)$$

$$\langle H \rangle = M_G \Rightarrow \text{redefinition of gauge couplings} \Rightarrow \alpha_i \text{ measured} \times \text{unification condition:}$$

$$(1 + k_i \varepsilon)\alpha_i(M_G) = (1 + k_j \varepsilon)\alpha_j(M_G)$$

$$\varepsilon \sim M_G / M_{\text{pl}}, \, k_i \sim \mathcal{O}(1)$$

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$\tau_p \sim M_G^4$
Proton decay: theoretical uncertainties vs experiment

Toy model: SM model running with 1-loop β function

"Typical" uncertainty due to Planck-suppressed operators (zoomed in)

One-loop result with "typical" errors due to neglecting 2-loop effects
Two-loop result with error due to uncertainty in $\alpha_S$

One-loop result with "typical" error due to Planck-suppressed operators

Log$_{10}$τ($p \rightarrow \pi^0 e^+$)[y]

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$\tau_p \sim M_G^4$
Non-SUSY SO(10) broken by $\langle 45_H \rangle$

- $\text{SO}(10) \xrightarrow{\langle (1,1,1,0)_{45_H} \rangle} SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ or
  $\text{SO}(10) \xrightarrow{\langle (1,1,3,0)_{45_H} \rangle} SU(4)_C \times SU(2)_L \times U(1)_R$

Abandoned due to tachyonic instabilities, however, cured @ quantum level!


Exact unification and correct seesaw scale ($\langle 126_H \rangle \equiv \sigma \sim 10^{13}$ GeV) ensured by making either $(8, 2, +1/2)$ or $(6, 3, 1/3)$ scalar field light


(8, 2, +1/2) within the reach of LHC if proton lifetime above HK limits
Non-SUSY SO(10) broken by $\langle 45_H \rangle$

- $\text{SO}(10) \overset{\langle (1,1,0)_{45_H} \rangle \equiv \omega_{BL}}{\longrightarrow} \text{SU}(3)_c \times \text{SU}(2)_L \times \text{SU}(2)_R \times \text{U}(1)_{B-L}$ or
- $\text{SO}(10) \overset{\langle (1,3,0)_{45_H} \rangle \equiv \omega_{R}}{\longrightarrow} \text{SU}(4)_C \times \text{SU}(2)_L \times \text{U}(1)_{R}$

- Abandoned due to tachyonic instabilities, however, cured @ quantum level!

- $\text{Tr} (G_{\mu\nu} 45_H G^{\mu\nu}) = 0 \Rightarrow$ LO “gravity smearing” effects absent
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- Studied @ 2 loop level, heavy spectrum computed

Non-SUSY SO(10) broken by $\langle 45_H \rangle$

- SO(10) $\langle (1,1,1,0)_{45_H} \rangle \equiv \omega_{BL} \rightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ or
  - SO(10) $\langle (1,1,3,0)_{45_H} \rangle \equiv \omega_R \rightarrow SU(4)_C \times SU(2)_L \times U(1)_R$

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Helena Kolešová: SO(10) @ NLO
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Thank you for attention!