Saving protons (and SUSY) with flavor symmetry

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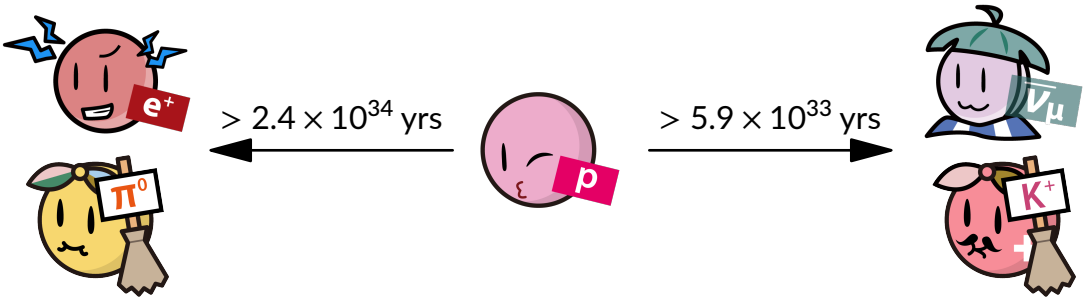
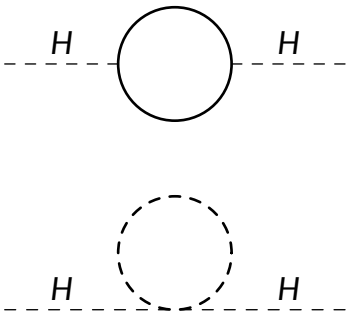
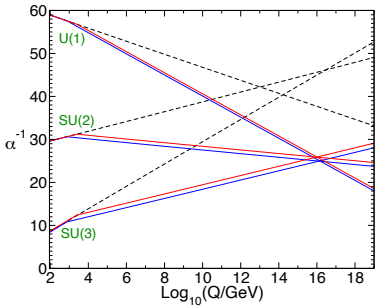
SUSY and proton decay

Proton decay



Supersymmetry





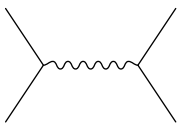
[S. Martin; 1998]

PeV-scale mini-split SUSY

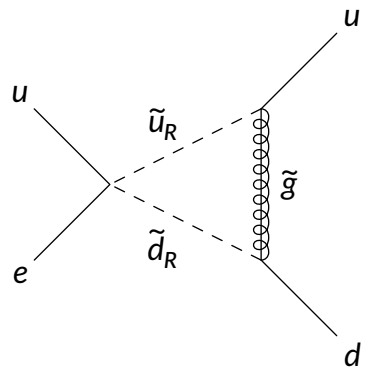
- Focus on:
  - Anomaly mediation [Randall, Sundrum; 1999][Giudice, Luty, Murayama; 1998]
  - $m_0 \sim m_{3/2} \sim$ PeV
  - $m_{1/2} \sim$ TeV
- Consistent with LHC results (incl. m_H)
- Better handle on SUSY flavor/CP problems

Proton decay in MSSM

- $W \supset \frac{1}{\Lambda} QQQL + \frac{1}{\Lambda} \bar{u}\bar{e}\bar{u}\bar{d}$
- Decay rate $\propto \Lambda^{-2}$
  - cf. $\propto M_{\mathrm{GUT}}^{-4}$ for X exchange in GUT

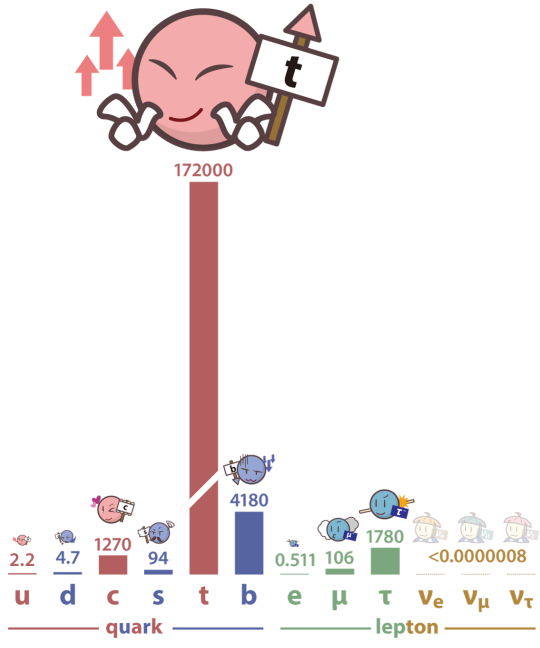


  - Lifetime $< 10^{30}$ yrs even for $\Lambda = M_{\mathrm{Pl}}$
    - Violates Super-K bound

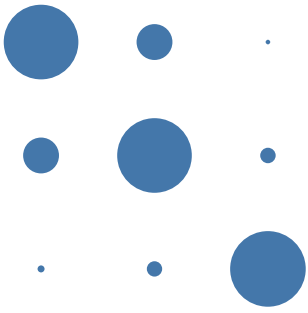


Q1: How to extend proton lifetime?

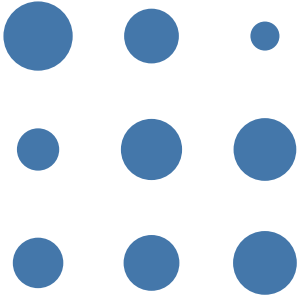
Flavor puzzle


t
172000
4180
2.2
4.7
1270
94
0.511
106
1780
<0.0000008
u
d
c
s
t
b
e
μ
τ
νe
νμ
ντ
quark
lepton

$\left|V^{ij}_{\text{CKM}}\right|$



$\left|U^{ij}_{\text{PMNS}}\right|$



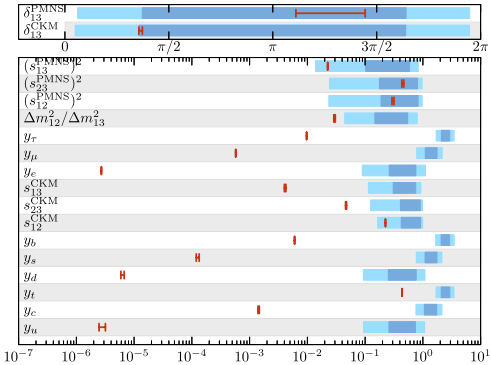
Flavor symmetry

Example: Froggatt-Nielsen mechanism

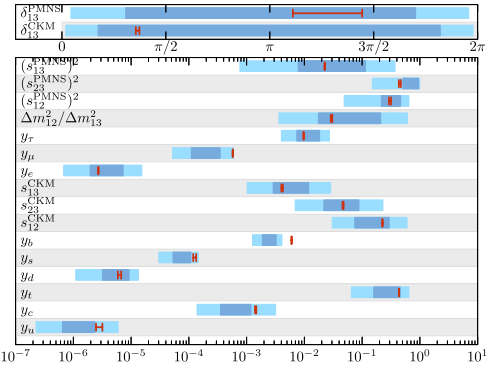
- Idea: suppress unwanted operators with global $U(1)_{FN}$ symmetry
- Break it with $\langle\Phi\rangle$ w/ $q_\Phi = 1$

$$\mathcal{L} \supset \mathcal{O}(1) \times \left(\frac{\Phi^{(\dagger)}}{M_{\text{Pl}}}\right)^{|q_{q_i}+q_{\bar{u}_j}|} q_i H \bar{u}_j + \cdots$$

  - $\epsilon := \dfrac{\langle\Phi\rangle}{M_{\text{Pl}}} = \mathcal{O}(0.1)$
- With SUSY, chiral fields $\Phi_\pm$ with $q = \pm 1$ needed
  - $|\langle\Phi_+\rangle| = |\langle\Phi_-\rangle|$ for simplicity



all charges = 0



$q_{\bar{u}} = (8, 4, 1)$, $q_{\bar{d}} = (6, 6, 6)$, $q_q = (5, 3, 0)$

$q_L = (2, 0, -1)$, $q_{\bar{e}} = (10, 8, 5)$, $q_N = (0, 0, 0)$

Too many possibilities

[Ibe, Shirai, Watanabe; 2025]

$\bar{u}$	$\bar{d}$	q	L	$\bar{e}$
8, 4, 1	6, 6, 6	5, 3, 0	7, 3, 0	5, 5, 4
6, 3, 1	4, 5, 4	3, 2, 0	2, 2, 0	3, 3, −10
7, 3, 1	5, 6, 5	4, 3, 0	10, 6, 4	1, 0, 0
4, 2, 0	3, 3, 3	3, 2, 0	3, −1, −5	−7, 8, 7
4, 2, 0	3, 3, 3	3, 2, 0	1, −6, −6	2, 1, −5
6, 3, 1	4, 5, 4	4, 2, 0	5, 2, 0	4, 4, 3
4, 2, 0	3, 4, 3	4, 3, 0	7, 5, 3	1, 0, 0
6, 3, 1	4, 5, 4	3, 2, 0	2, 1, −4	8, 7, −7
8, 4, 1	6, 6, 6	5, 3, 0	−2, −2, −4	−10, 9, 9
7, 3, 1	5, 6, 5	4, 3, 0	−9, −7, −4	−2, 0, 1
7, 3, 1	5, 6, 5	5, 3, 0	6, 2, 0	5, 5, 4
4, 2, 0	3, 3, 3	3, 2, 0	9, 1, −3	6, 5, −5
7, 3, 1	5, 6, 5	5, 3, 0	10, 6, 4	1, 1, 0
4, 2, −1	3, −10, 4	4, 4, 0	2, 2, −6	3, 3, −10
7, 4, 1	7, 5, 5	5, 3, 0	10, 7, 5	2, 0, −1
4, 2, 0	3, 4, 3	4, 3, 0	2, 2, −6	3, 3, −10
7, 3, 1	5, 6, 5	5, 3, 0	1, 3, 5	10, −9, −9
4, 2, 0	3, 3, 3	3, 2, 0	10, 0, −2	5, 4, −4
4, 2, 0	3, 4, 3	4, 3, 0	7, 5, 3	1, 0, 0
7, 3, 1	5, 6, 5	5, 3, 0	6, 2, 0	5, 5, 4
		⋮		

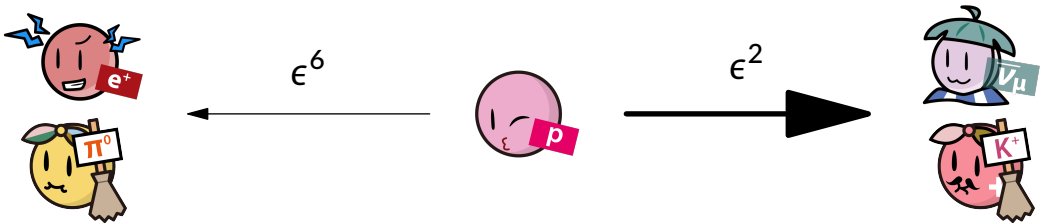
Q2: How to probe them?

Proton decay and Froggatt-Nielsen

- Flavor symmetry can also suppress proton decay:

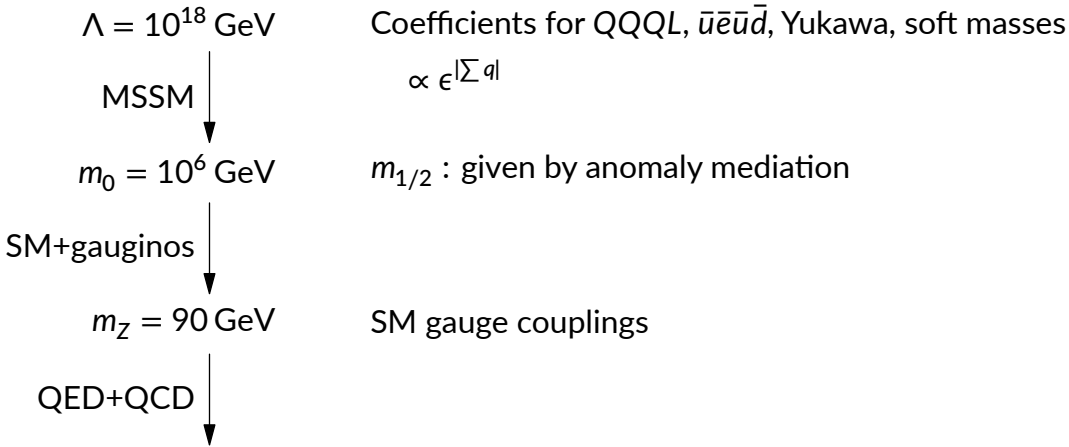
$$W_{\text{eff}} = \frac{\mathcal{O}(1)}{\Lambda}\epsilon^{|q_{Q_i}+q_{Q_j}+q_{Q_k}+q_{L_l}|}Q_iQ_jQ_kL_l + \frac{\mathcal{O}(1)}{\Lambda}\epsilon^{|q_{\bar{u}_i}+q_{\bar{e}_j}+q_{\bar{u}_k}+q_{\bar{d}_l}|}\bar{u}_i\bar{e}_j\bar{u}_k\bar{d}_l$$

- A1?: $U(1)_{FN}$ helps evade SK bound
- A2?: Decay mode(s) reflect the charge assignment



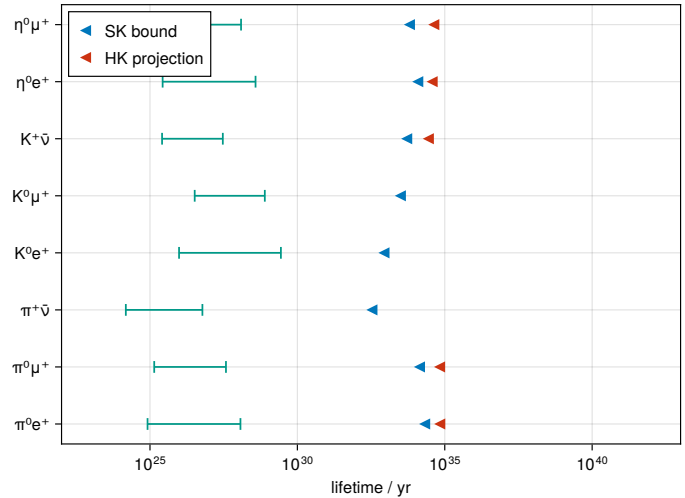
Proton lifetime in MSSM with $U(1)_{FN}$

Calculation of lifetime

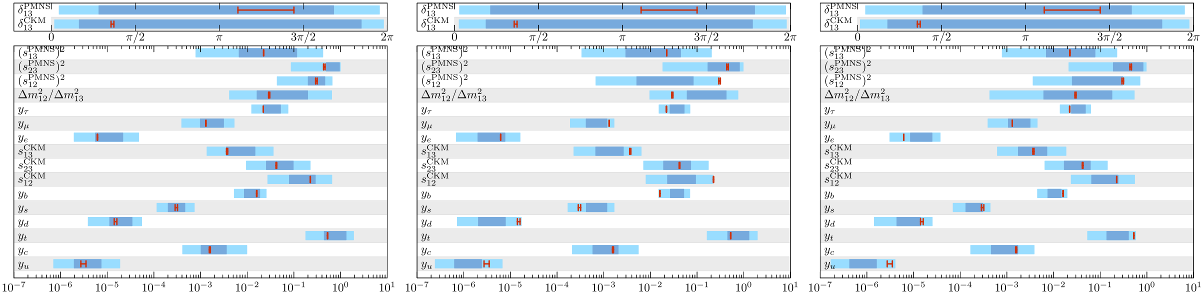


Results (Preliminary)

No charges

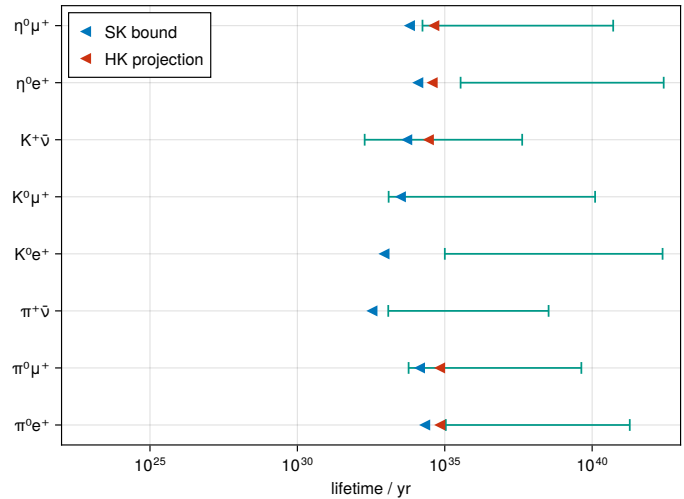

SK bound
HK projection
$\eta^0\mu^+$
η^0e^+
$K^+\bar{\nu}$
$K^0\mu^+$
K^0e^+
$\pi^+\bar{\nu}$
$\pi^0\mu^+$
π^0e^+
10^{25}
10^{30}
10^{35}
10^{40}
lifetime / yr

Examples: flavor structure



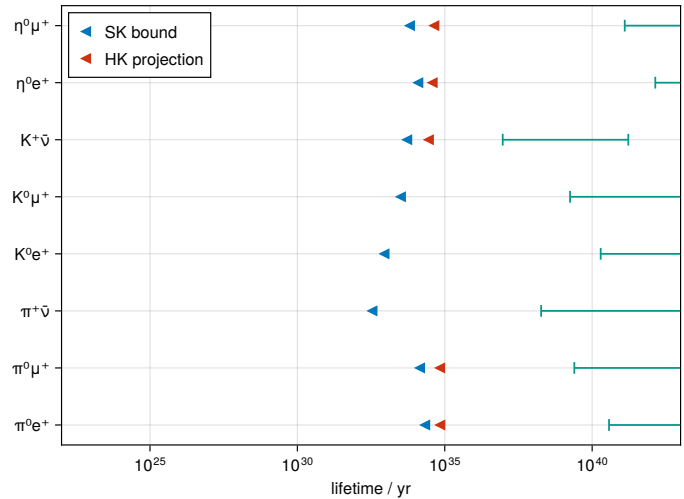
Example 1

$$q_{\bar{u}} = (7, 3, 0), q_{\bar{d}} = (5, 5, 4), q_Q = (5, 3, 0)$$
$$q_L = (2, 0, -1), q_{\bar{e}} = (9, 6, 4)$$



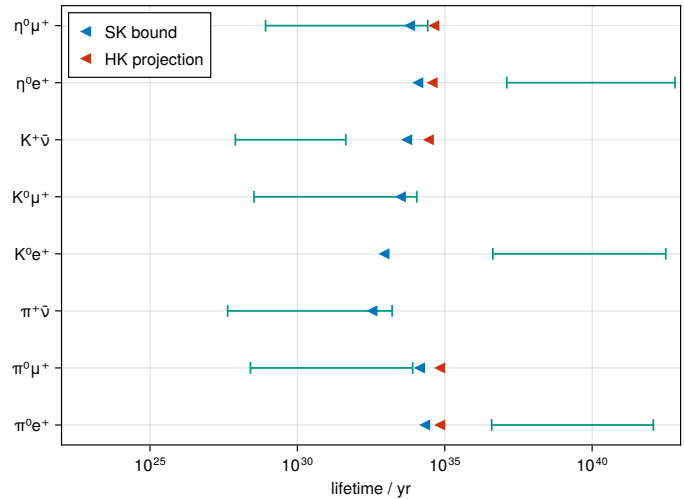
Example 2

$$q_{\bar{u}} = (6,3,0), q_{\bar{d}} = (5,3,3), q_Q = (6,3,0)$$
$$q_L = (5,3,3), q_{\bar{e}} = (6,3,0)$$



Example 3

$$q_{\bar{u}} = (7, 3, 1), q_{\bar{d}} = (4, 5, 4), q_Q = (5, 3, 0)$$
$$q_L = (10, -9, -9), q_{\bar{e}} = (-1, 4, 6)$$



Summary

- (PeV-scale) SUSY is an attractive framework
  - Issue: rapid proton decay
- $U(1)_{FN}$ flavor symmetry can explain the flavor structure of (MS)SM
  - Issue: too many possible charge assignments
- Flavor symmetry may extend proton lifetime and save MSSM
- Proton decay can be a probe for the $U(1)_{FN}$ charges

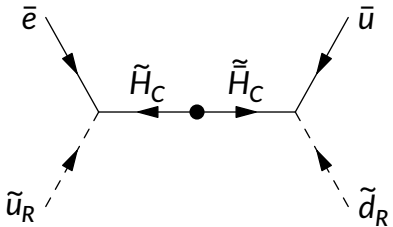
Thank you!

Backup

Proton decay in SUSY SU(5)

Q: If SUSY catalyzes proton decay,
why is SUSY SU(5) OK (when non-SUSY SU(5) is not)?

A: The dimension-5 operator is generated by colored Higgsino exchange e.g.



whose coupling is suppressed by Yukawas and / or CKM mixing angles.