

# Saving protons (and SUSY) with flavor symmetry

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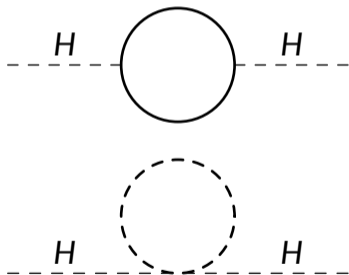
# Supersymmetry

# Supersymmetry

- bosons  $\leftrightarrow$  fermions
  - e.g. lepton  $\leftrightarrow$  slepton, gluon  $\leftrightarrow$  gluino ...
- broken at scale  $m_0$ 
  - $\rightarrow$  mass scale of superpartners of SM fermions

# Motivations

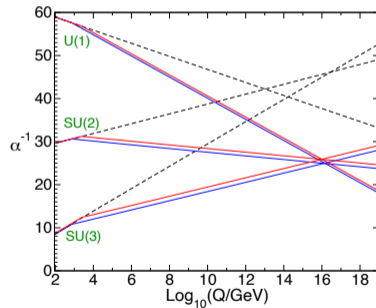
Hierarchy problem:  $m_H \ll M_{\text{Pl}}$



Dark matter



Coupling unification



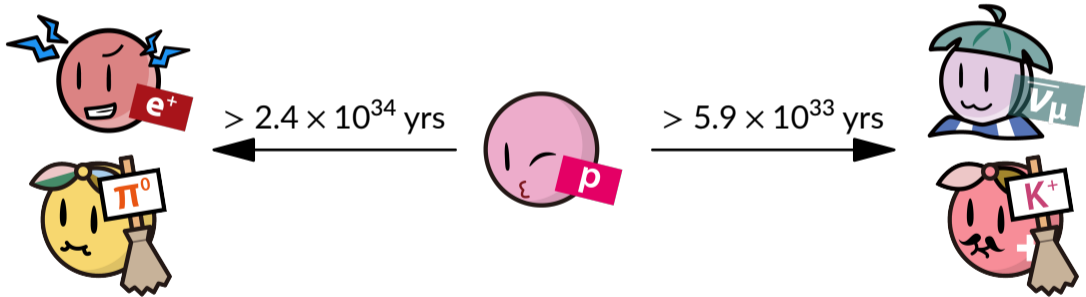
[S. Martin; 1998]

# PeV-scale mini-split SUSY

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

Proton decay

# Proton decay



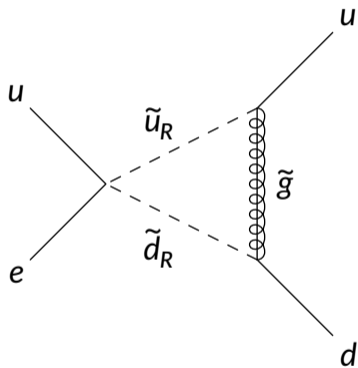
# $B$ - and $L$ -violation

- $B, L$ : accidental symmetries of SM
  - No renormalizable operators violating them
- Violated by  $\mathcal{L} \supset \frac{1}{\Lambda^2} \bar{u} \bar{e} \bar{u} \bar{d}$  etc.
  - $\Lambda$ : scale of new physics
  - Sensitive up to GUT scale!

SUSY and proton decay

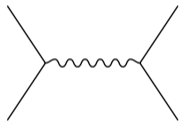
# Proton decay in MSSM [Dine, Draper, Shepherd; 2013]

- $W \supset \frac{1}{\Lambda} QQQ L + \frac{1}{\Lambda} \bar{u} \bar{e} \bar{u} \bar{d}$
- $\rightarrow \mathcal{L}_{\text{MSSM}} \supset \frac{1}{\Lambda} \bar{u} \bar{e} \tilde{u}_R \tilde{d}_R$  etc.
- Mediated to SM via sparticles
- $\rightarrow \mathcal{L}_{\text{SM}} \supset \frac{m_{1/2}}{m_0^2 \Lambda} \bar{u} \bar{e} \tilde{u}_R \tilde{d}_R$  etc.



# Proton decay in MSSM [Dine, Draper, Shepherd; 2013]

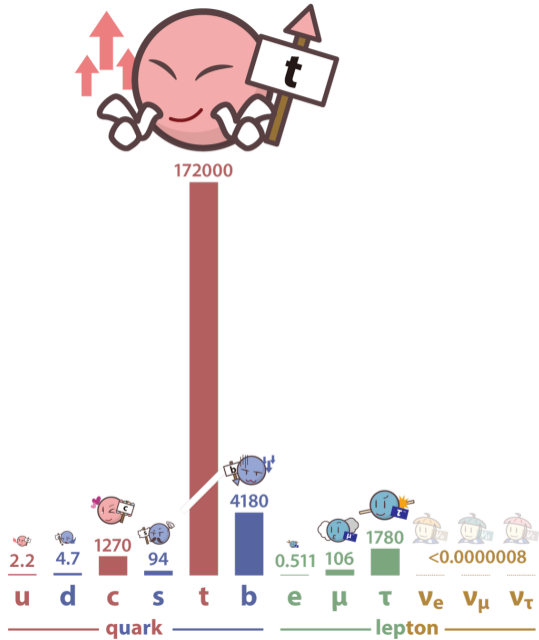
- Decay rate  $\propto \Lambda^{-2}$ 
  - cf.  $\propto M_{\text{GUT}}^{-4}$  for  $X$  exchange in GUT

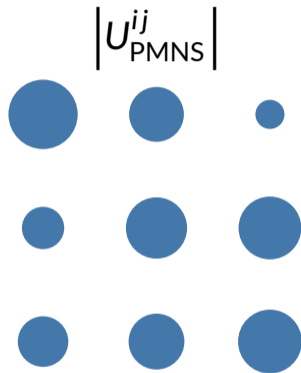
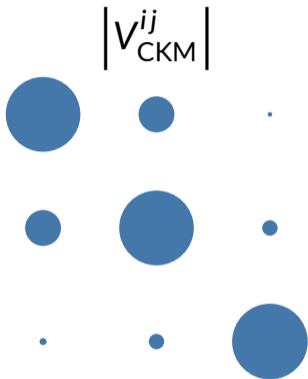


- Lifetime  $< 10^{30}$  yrs even for  $\Lambda = M_{\text{Pl}}$ 
  - Violates Super-K bound

Q1: (How) can we extend proton lifetime?

Flavor puzzle





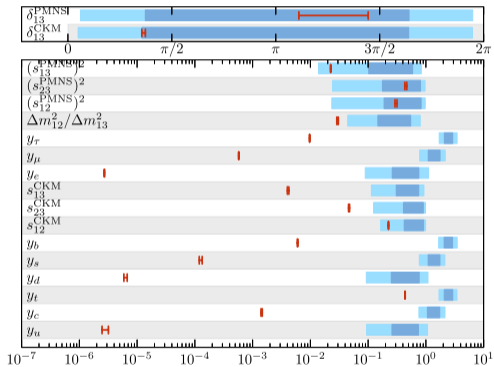
# Flavor symmetry

## Example: Froggatt-Nielsen mechanism

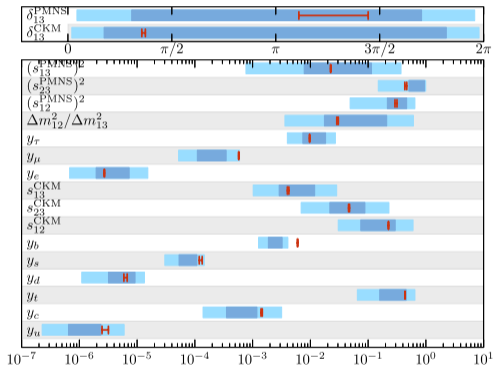
- Idea: suppress unwanted operators with global  $U(1)_{\text{FN}}$  symmetry
- Break it with  $\langle \Phi \rangle$  w/  $q_\Phi = 1$

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

- $\epsilon := \frac{\langle \Phi \rangle}{M_{\text{Pl}}} = \mathcal{O}(0.1)$
- 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
		⋮		

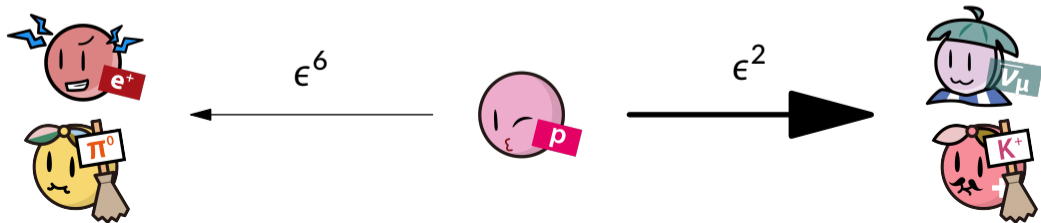
Q2: How to probe them?

# Proton decay and Froggatt-Nielsen

- Flavor symmetry can also suppress proton decay:

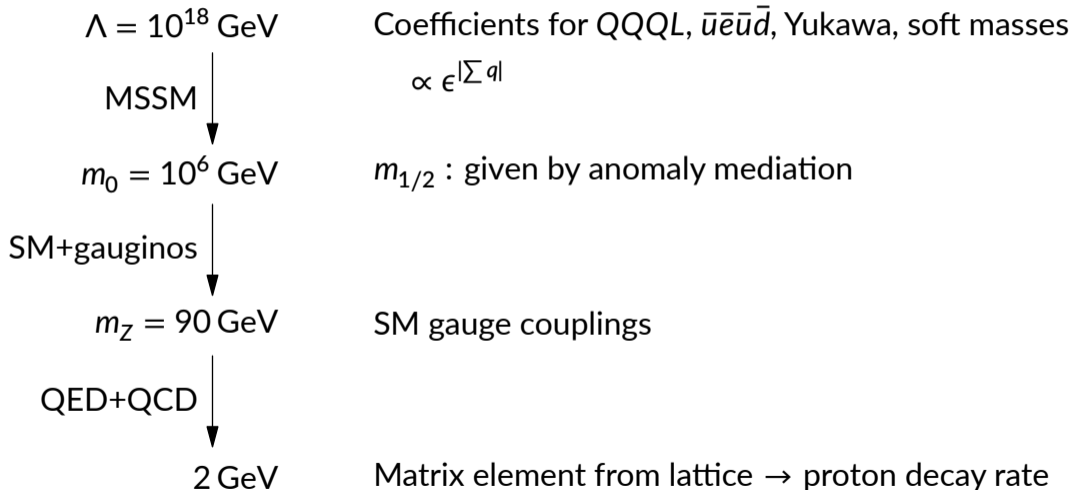
$$W_{\text{eff}} = \frac{\mathcal{O}(1)}{\Lambda} \epsilon^{|q_{Q_i} + q_{Q_j} + q_{Q_k} + q_{L_l}|} Q_i Q_j Q_k L_l + \frac{\mathcal{O}(1)}{\Lambda} \epsilon^{|q_{\bar{u}_i} + q_{\bar{e}_j} + q_{\bar{u}_k} + q_{\bar{d}_l}|} \bar{u}_i \bar{e}_j \bar{u}_k \bar{d}_l$$

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



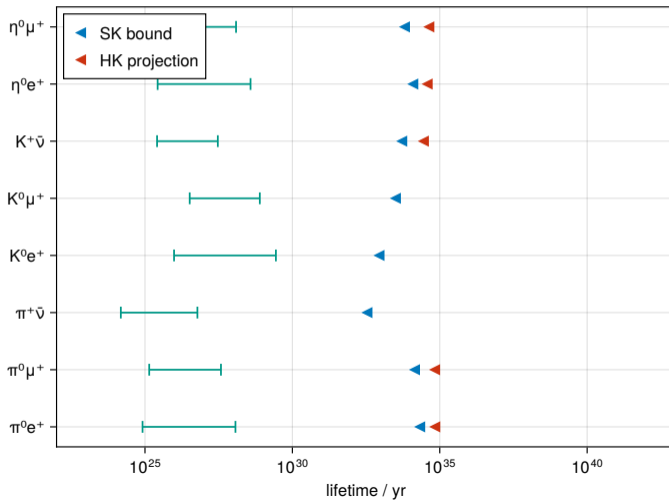
Proton lifetime in MSSM with  $U(1)_{FN}$

# Calculation of lifetime

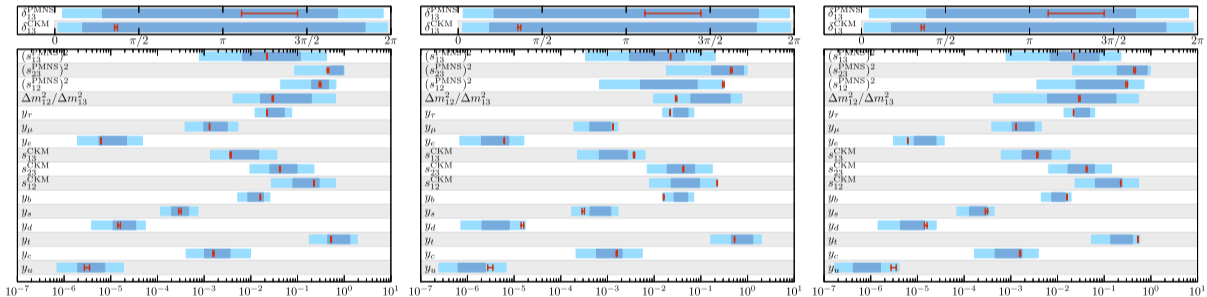


## Results (Preliminary)

# No charges

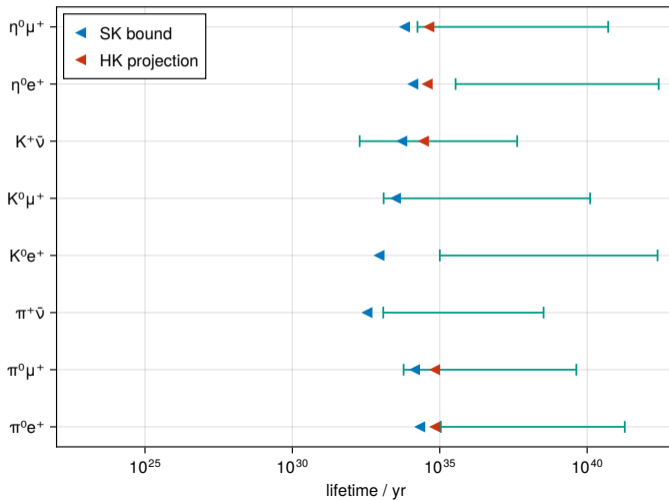


# Examples: flavor structure



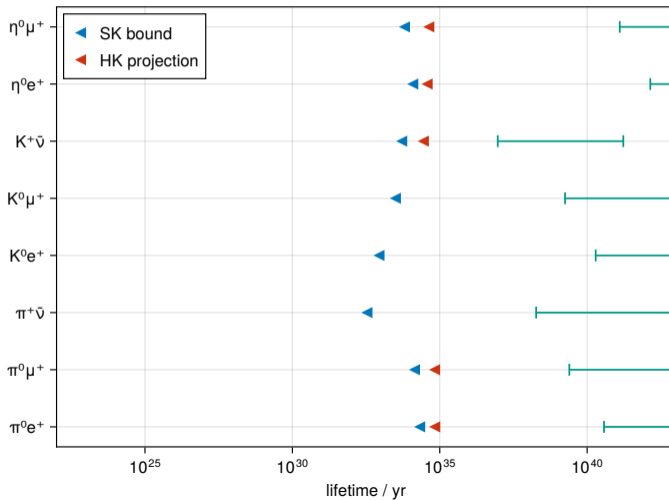
# Example 1

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



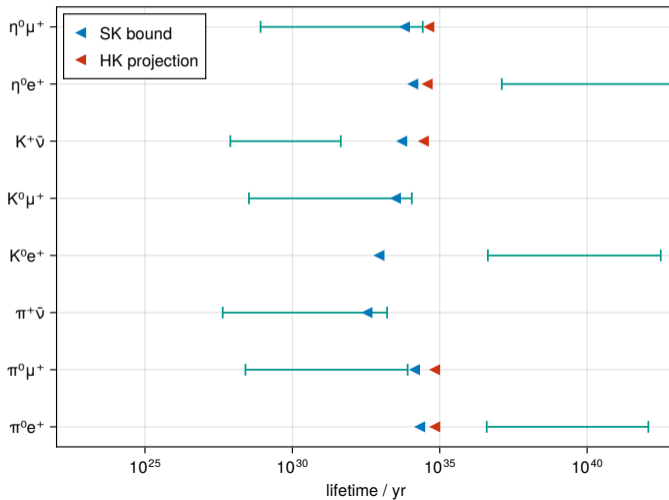
# Example 2

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



# 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

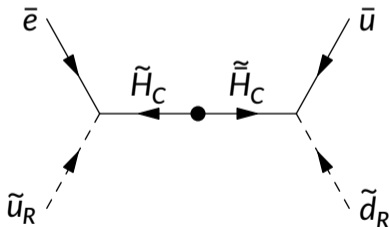
Thank you!

Backup

# Proton decay in SUSY SU(5)

Q: If SUSY catalyzes proton decay,  
why is SUSY SU(5) viable (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.

# Flavor constraint : $K^0 - \bar{K}^0$

