Title: Particle Physics Lecture - 230303

Speakers: Asimina Arvanitaki

Collection: Particle Physics (2022/2023)

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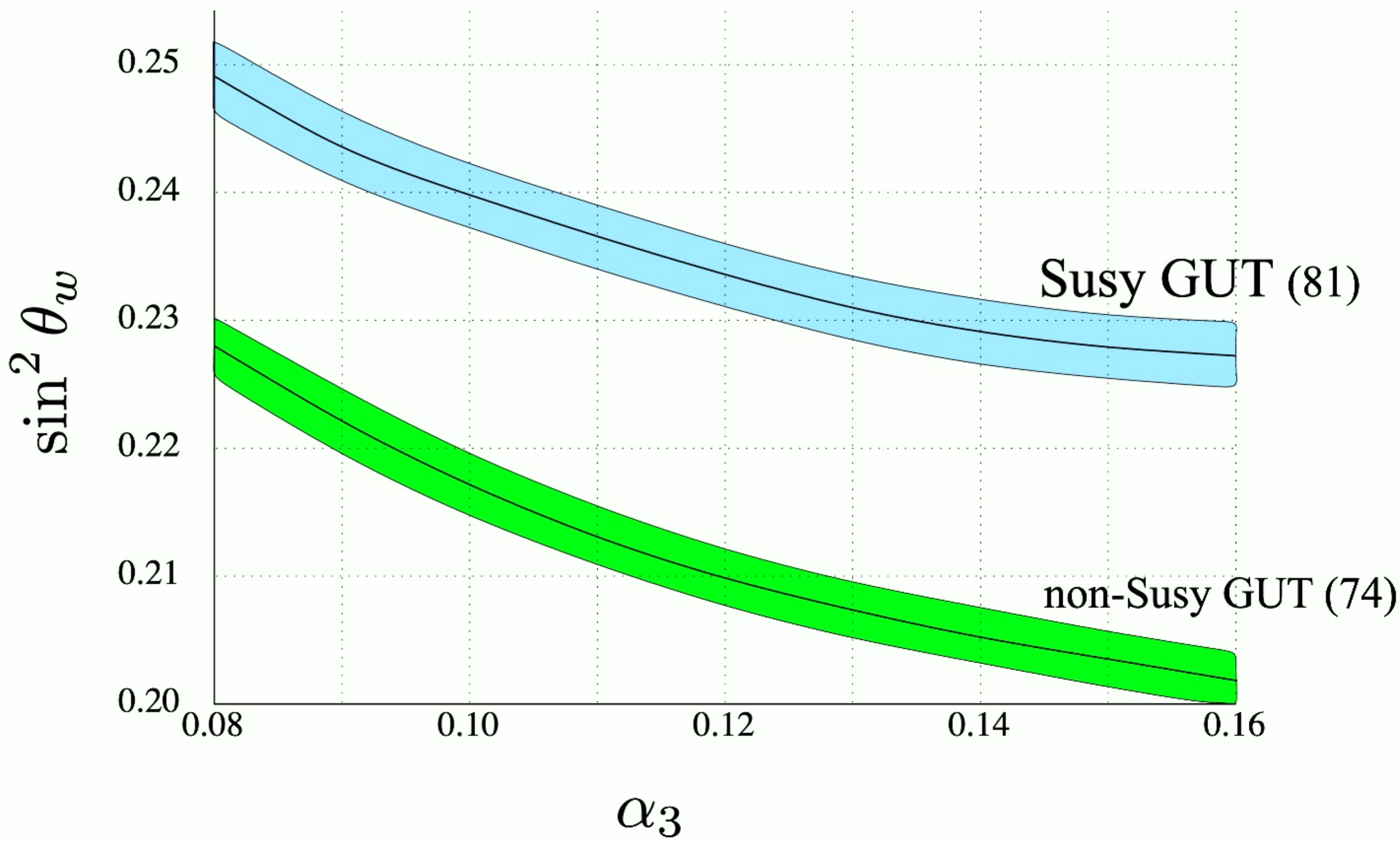
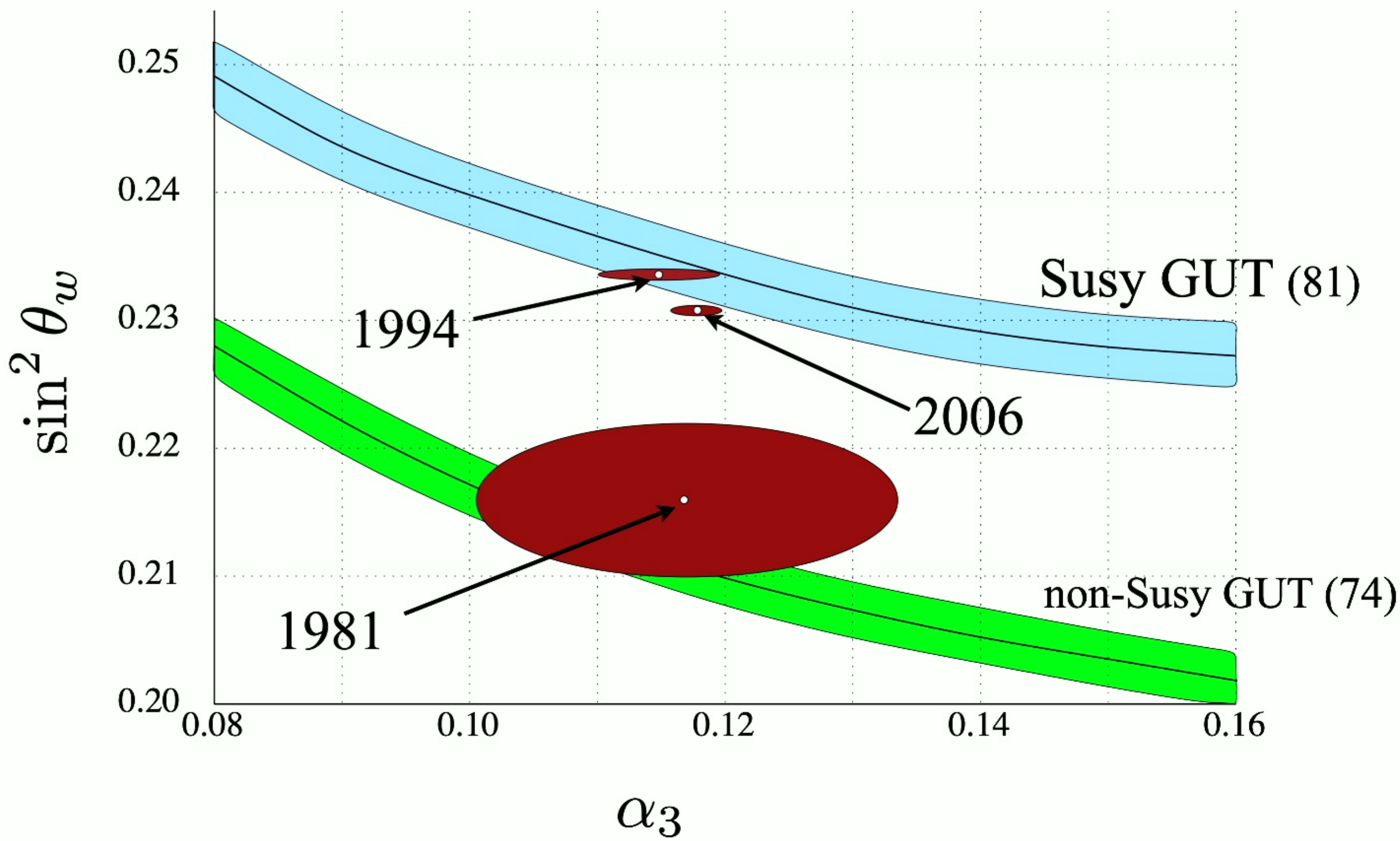
Unification



Unification



Georgi & Glashow 1974

$$SU(3)_C \times SU(2)_L \times U(1)_Y \subset SU(5)$$

$$SU(5) : N^2 - 1 = 24$$

$$\begin{pmatrix} SU(3) & \\ X, Y & SU(2) \end{pmatrix}$$

$$\underset{\text{color}}{(8,1,0)} + \underset{W,Z}{(1,3,1)} + (1,1,0) + \underset{X}{(3,2,-\tfrac{5}{6})} + \underset{Y}{(\bar{3},2,\tfrac{5}{6})}$$

$$\bar{5}_i : (\bar{3}, 1, \tfrac{1}{3}) + (1, 2, -\tfrac{1}{2}) \qquad i = 1,2,3$$

$$\quad D_i \qquad\qquad\qquad L_i$$

$$10_i : (3, 2, \tfrac{1}{6}) + (\bar{3}, 1, -\tfrac{2}{3}) + (1, 1, 1)$$

$$\quad Q_i \qquad\qquad\qquad U_i \qquad\qquad\qquad E_i$$

$$5 : (1, 2, \tfrac{1}{2}) + (3, 1, \tfrac{1}{3})$$

higgs   triplet Higgs

$$\mathcal{U}(1)_Y : \sqrt{\frac{3}{5}} \begin{pmatrix} 1/3 & & & & \\ & 1/3 & & & \\ & & 1/3 & & \\ & & & -1/2 & \\ & & & & -1/2 \end{pmatrix}$$

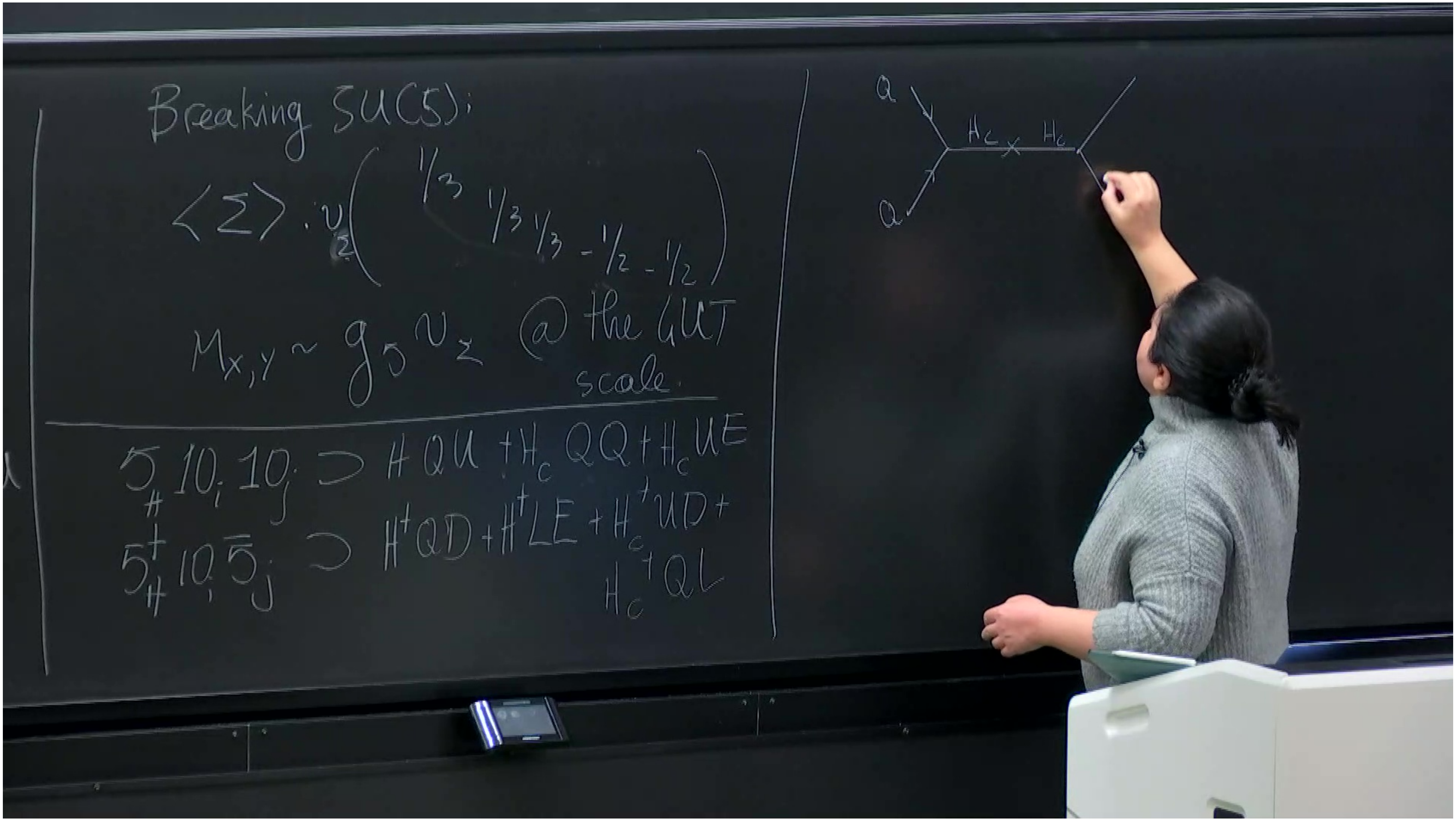
$$\psi^\dagger \left(\partial_\mu - igqA_\mu\right)\bar{\sigma}^\mu \psi$$

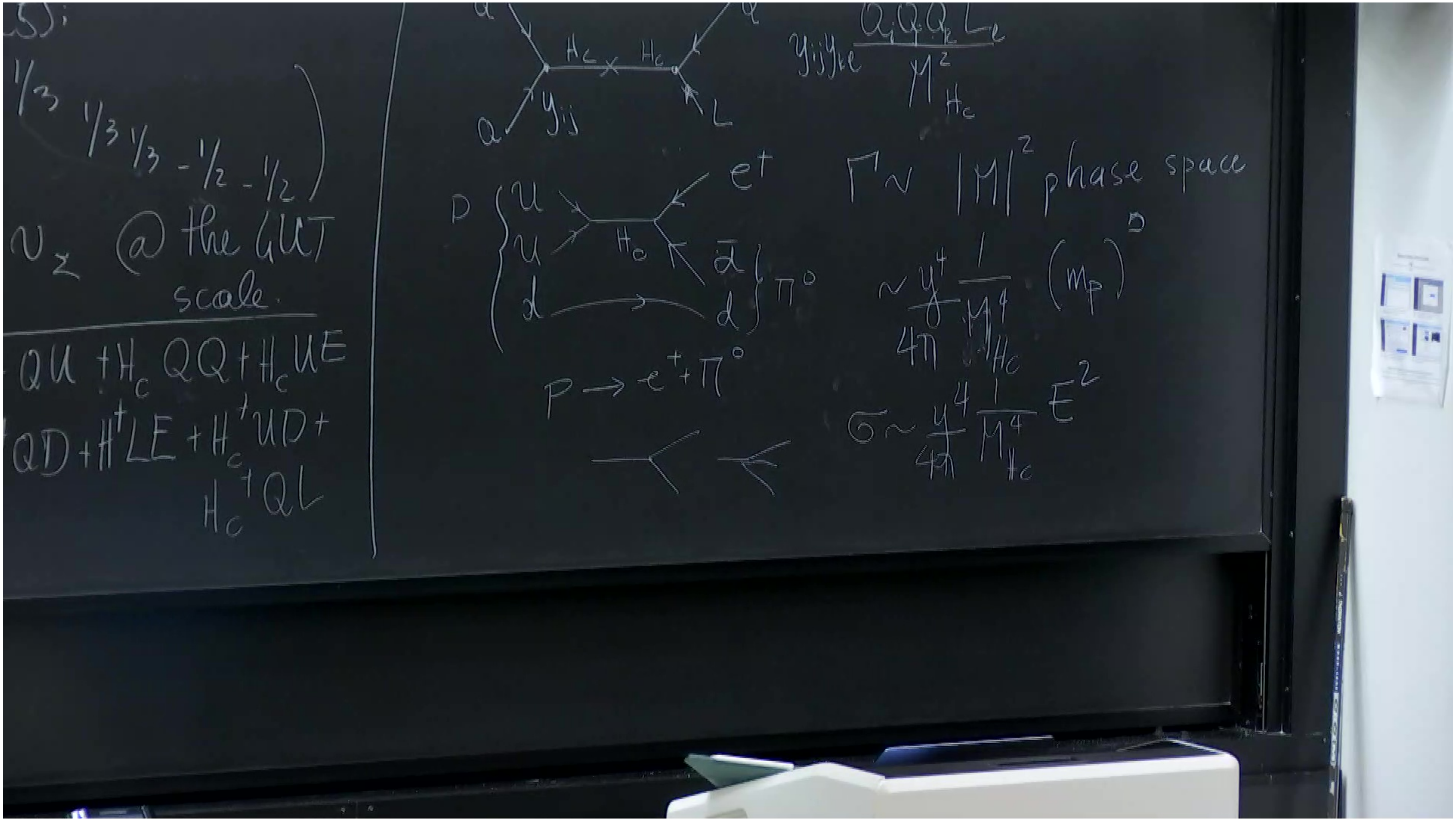
Charge quantization explained in GUTs

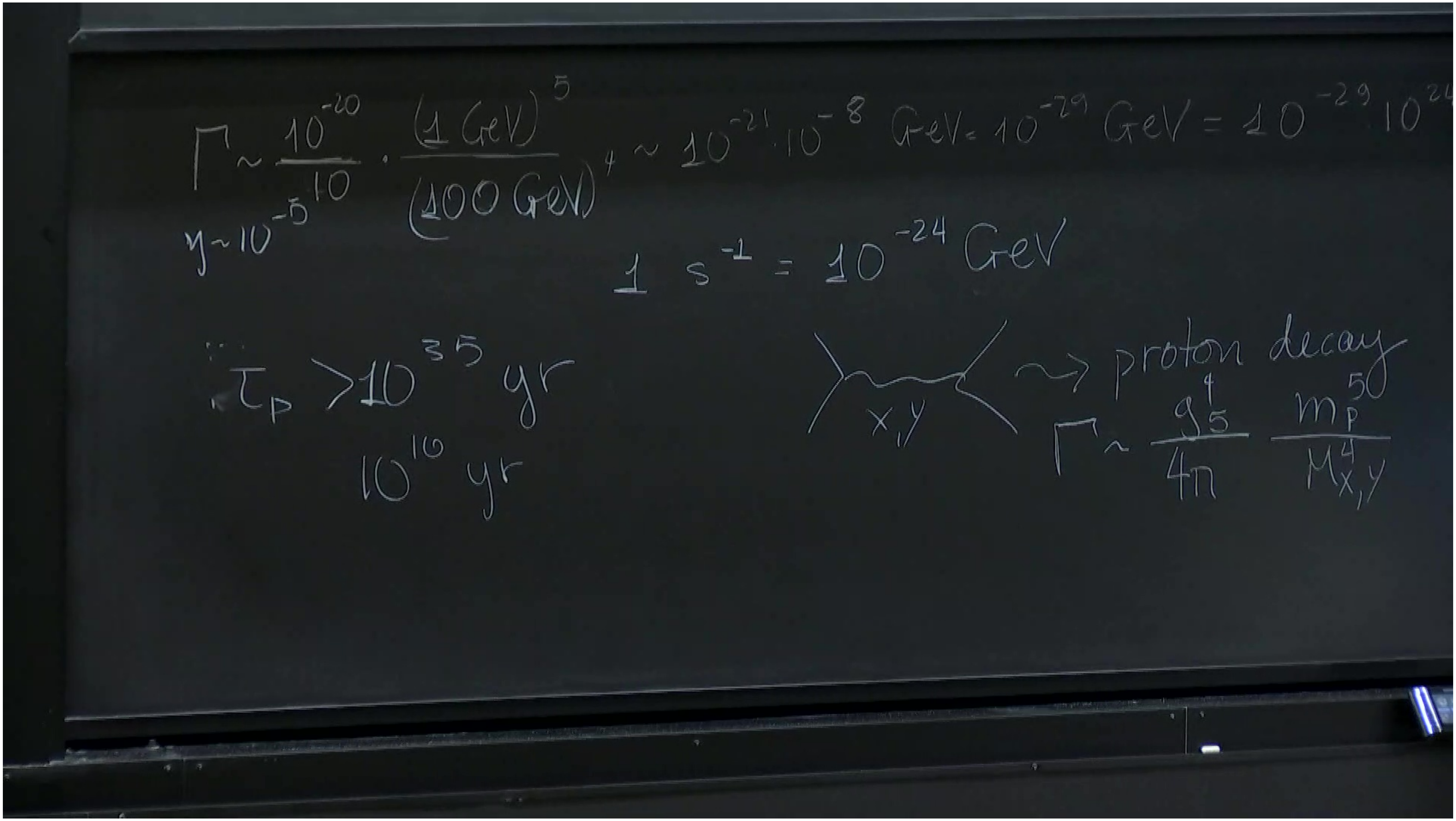
Breaking SU(5):

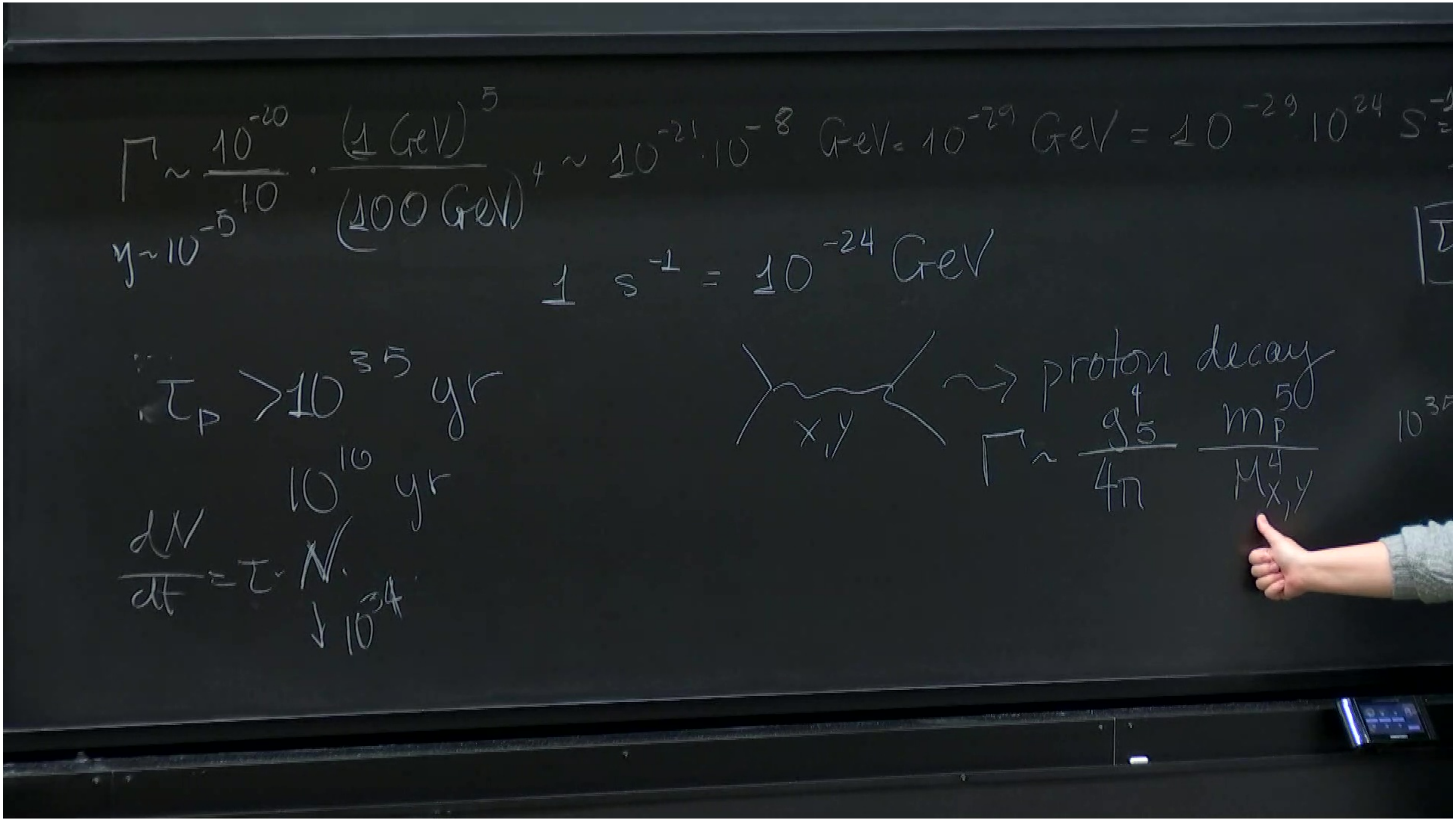
$$\langle \Sigma \rangle \cdot \frac{v}{2} \begin{pmatrix} 1/3 & & & & \\ & 1/3 & & & \\ & & 1/3 & & \\ & & & -1/2 & \\ & & & & -1/2 \end{pmatrix}$$

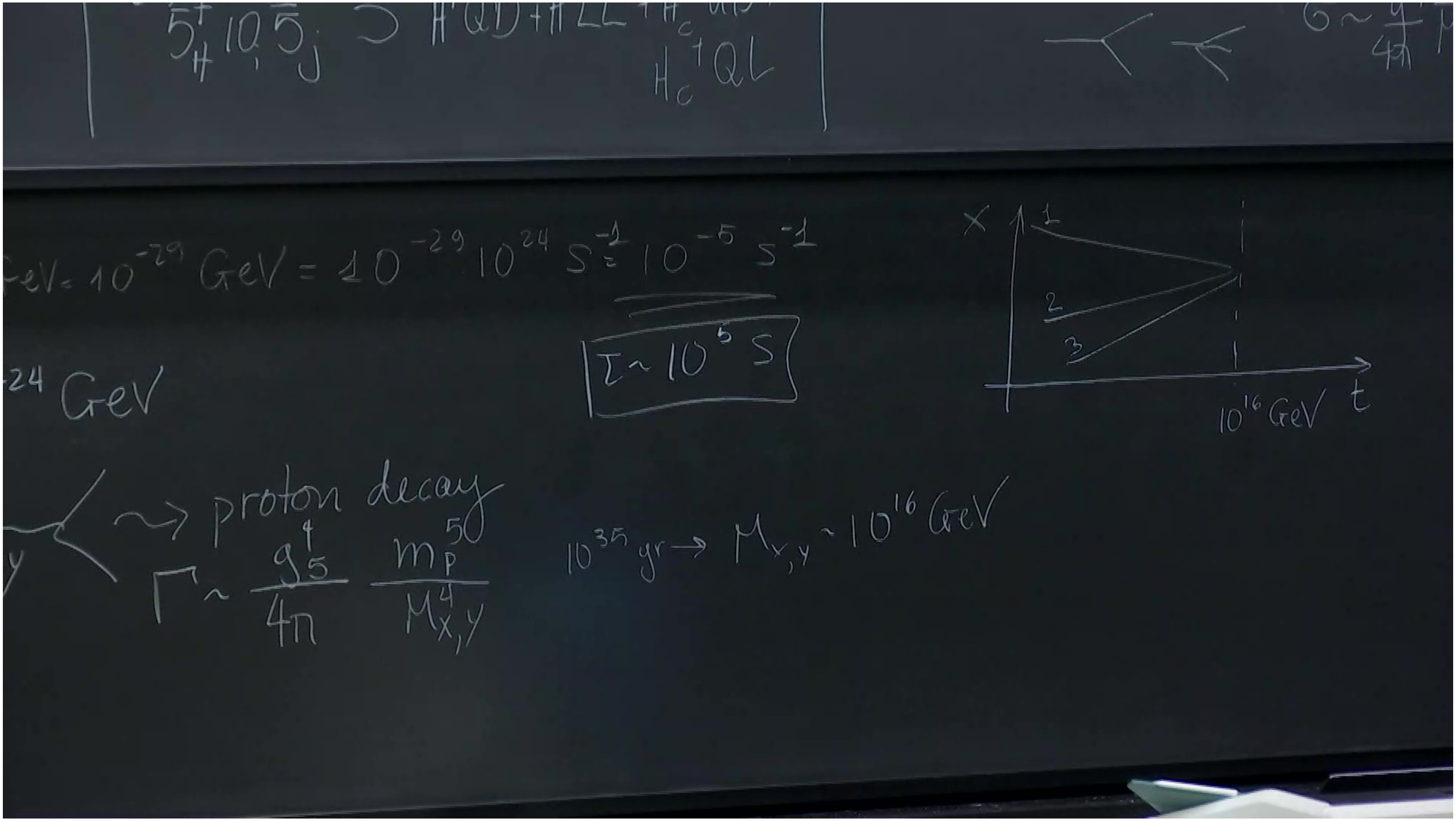
$M_{X,Y} \sim g_5 v_\Sigma$ @ the GUT scale.

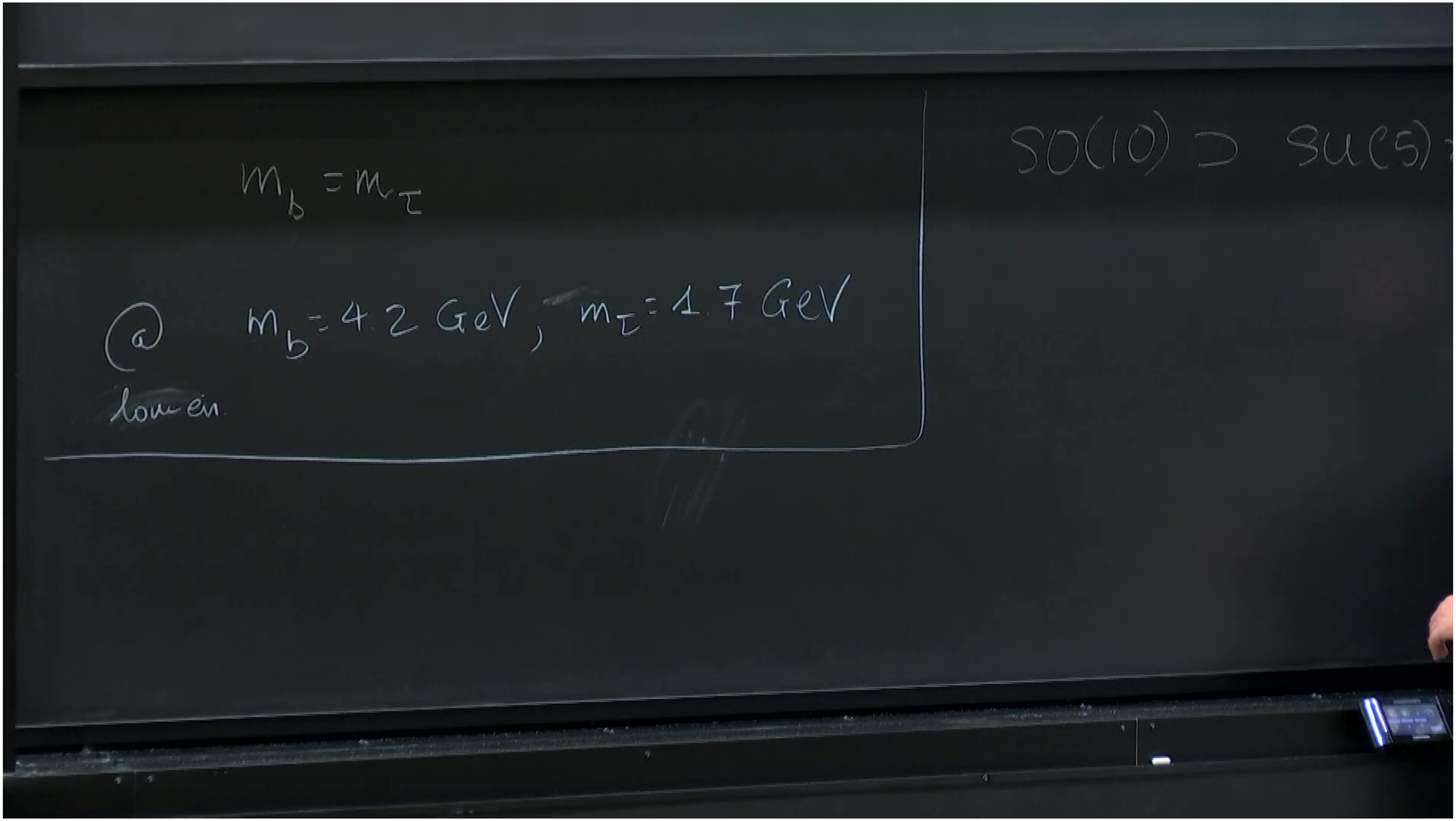

Breaking SU(5):
$\langle \Sigma \rangle = \frac{v}{2} \begin{pmatrix} 1/3 & & & & \\ & 1/3 & & & \\ & & 1/3 & & \\ & & & -1/2 & \\ & & & & -1/2 \end{pmatrix}$
$M_{X,Y} \sim g_5 v_\Sigma$ @ the GUT scale.
$5_H 10_i 10_j \supset H Q U + H_c Q Q + H_c U E$
$5_H^\dagger 10_i \bar{5}_j \supset H^\dagger Q D + H^\dagger L E + H_c^\dagger U D + H_c^\dagger Q L$
Q
Q
H_c
H_c


1/3 1/3 1/3 1/3 -1/2 -1/2
@ the GUT scale
QU + Hc QQ + Hc UE
QD + H†LE + Hc† UD +
Hc† QL
Hc Hc
yij
yij ykl Qi Qj Qk Ll / M²Hc
e+
p u u d
Hc
d̄ d π0
p → e+ + π0
Γ ~ |M|² phase space
~ y⁴/4π 1/M⁴Hc (mp)⁵
σ ~ y⁴/4π 1/M⁴Hc E²

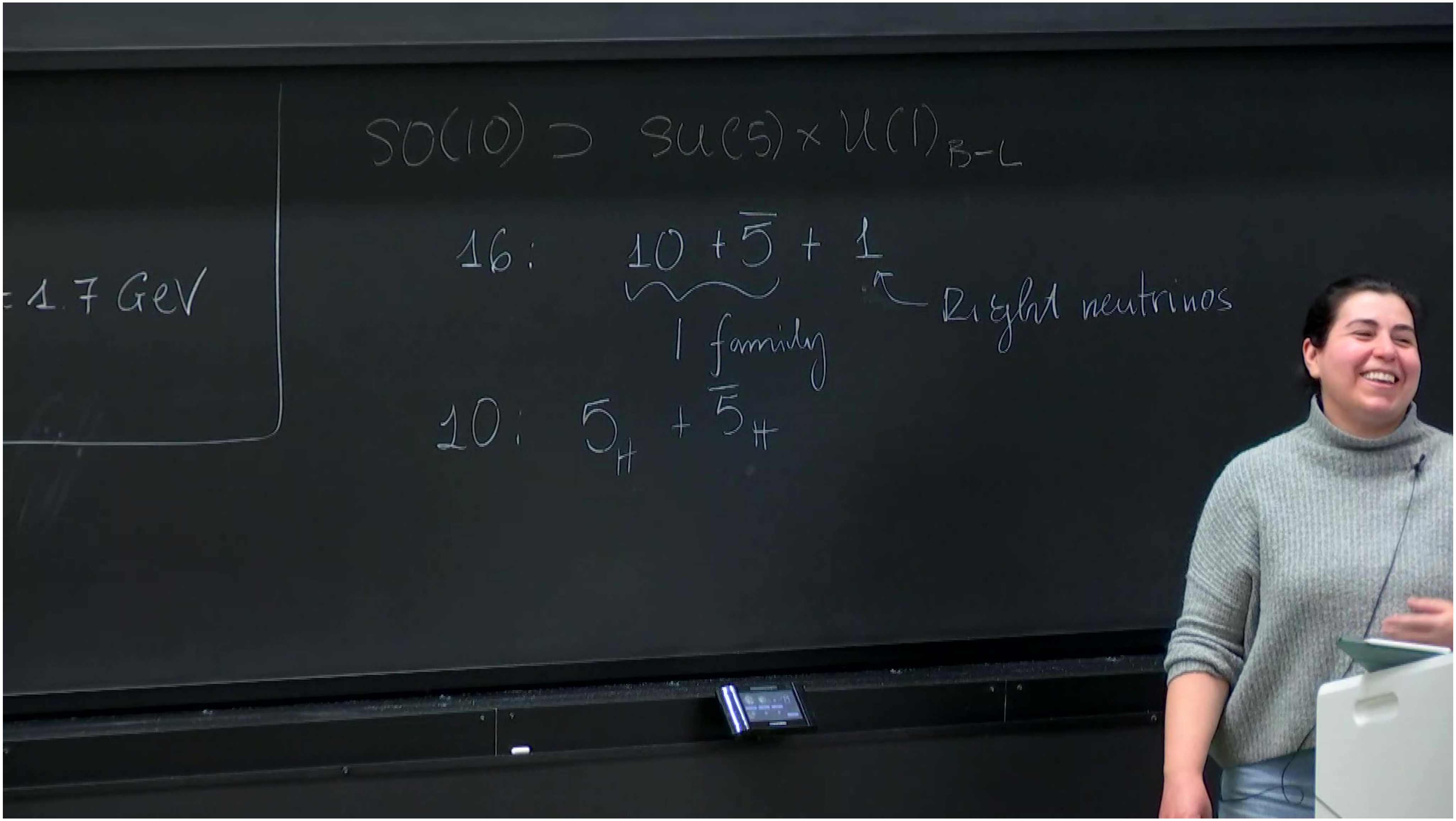

$\Gamma \sim \frac{10^{-20}}{10^{10}} \cdot \frac{(1\,\mathrm{GeV})^5}{(100\,\mathrm{GeV})^4} \sim 10^{-21} \cdot 10^{-8}\,\mathrm{GeV} = 10^{-29}\,\mathrm{GeV} = 10^{-29} \cdot 10^{24}$
$y \sim 10^{-5}$
$1\,s^{-1} = 10^{-24}\,\mathrm{GeV}$
$\tau_p > 10^{35}\,\mathrm{yr}$
$10^{10}\,\mathrm{yr}$
X, Y
$\rightsquigarrow$ proton decay
$\Gamma \sim \frac{g_5^4}{4\pi} \frac{m_p^5}{M_{X,Y}^4}$


Γ ~ 10^-20 / 10^10 · (1 GeV)^5 / (100 GeV)^4 ~ 10^-21 · 10^-8 GeV = 10^-29 GeV = 10^-29 10^24 s^-1
y ~ 10^-5
1 s^-1 = 10^-24 GeV
τ_p > 10^35 yr
10^10 yr
dN/dt = τ · N
10^34
X, Y
proton decay
Γ ~ g_5^4 / 4π · m_p^5 / M_{X,Y}^4
10^35


$\bar{5}_H\ 10_i\ \bar{5}_j \supset H\,QD + H\,LL + H_c$
$H_c\,QL$
eV = 10^{-29} GeV = $10^{-29} \cdot 10^{24}\ s^{-1} = 10^{-5}\ s^{-1}$
$\tau \sim 10^{5}\ s$
^{24} GeV
proton decay
$\Gamma \sim \frac{g_5^4}{4\pi} \frac{m_p^5}{M_{X,Y}^4}$
10^{35} yr $\rightarrow M_{X,Y} \sim 10^{16}$ GeV
x
1
2
3
10^{16} GeV
t



$m_b = m_\tau$
@ low en. $m_b = 4.2$ GeV, $m_\tau = 1.7$ GeV
$SO(10) \supset SU(5)$



1.7 GeV
SO(10) ⊃ SU(5) × U(1)_{B-L}
16: 10 + 5̄ + 1
1 family
Right neutrinos
10: 5_H + 5̄_H