Flavor violating Z’ from SO(10) SUSY GUT in high-scale SUSY scenario

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Based on PLB744 (2015) 395 (arXiv: 1503.06156)
with J. Hisano, Y. Muramatsu, M. Yamanaka

ーDSU 2015 @ Kyotoー

Standard Model ($SU(3)_C \times SU(2)_L \times U(1)_Y$)

is very successful in particle physics

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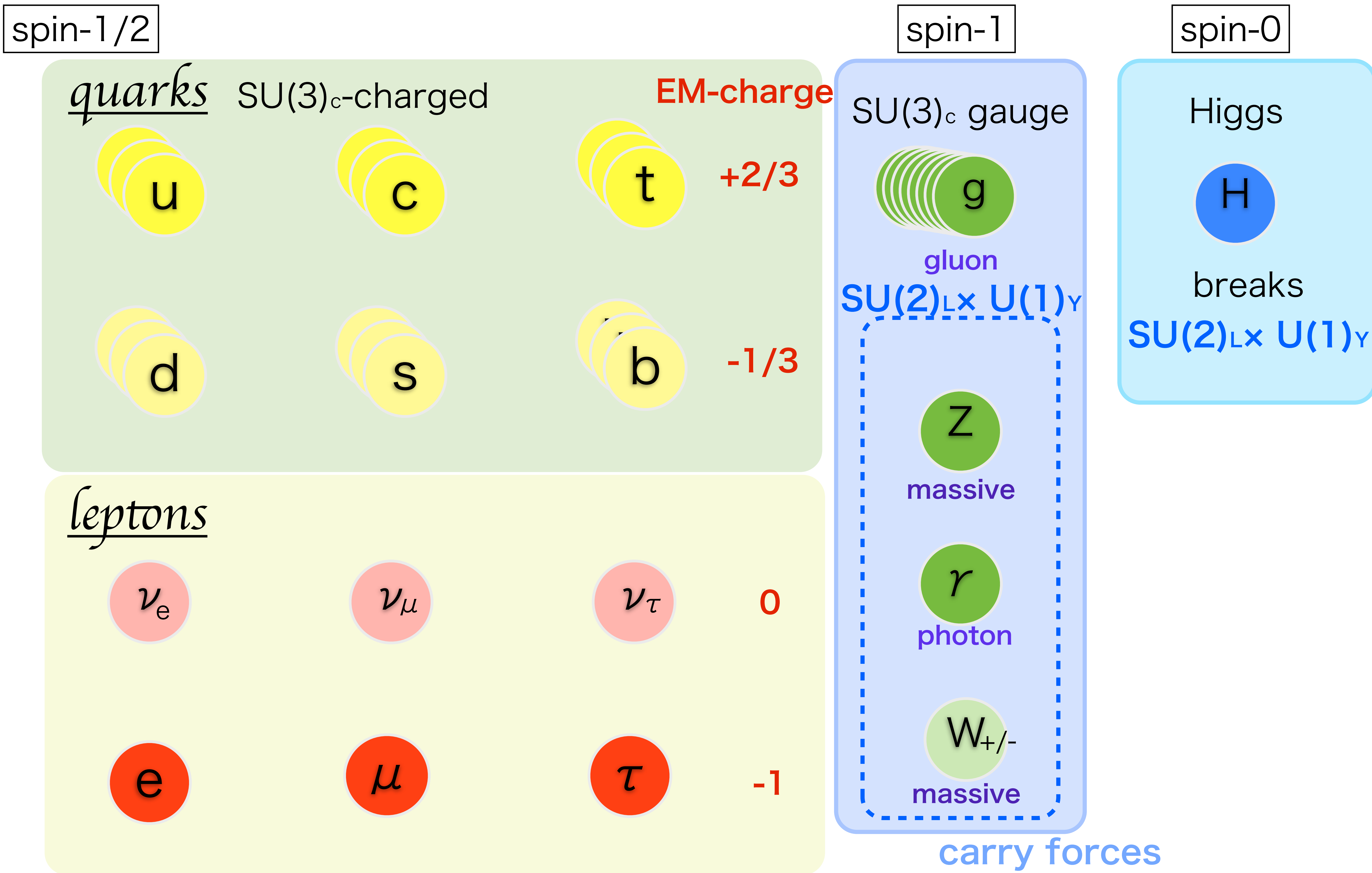
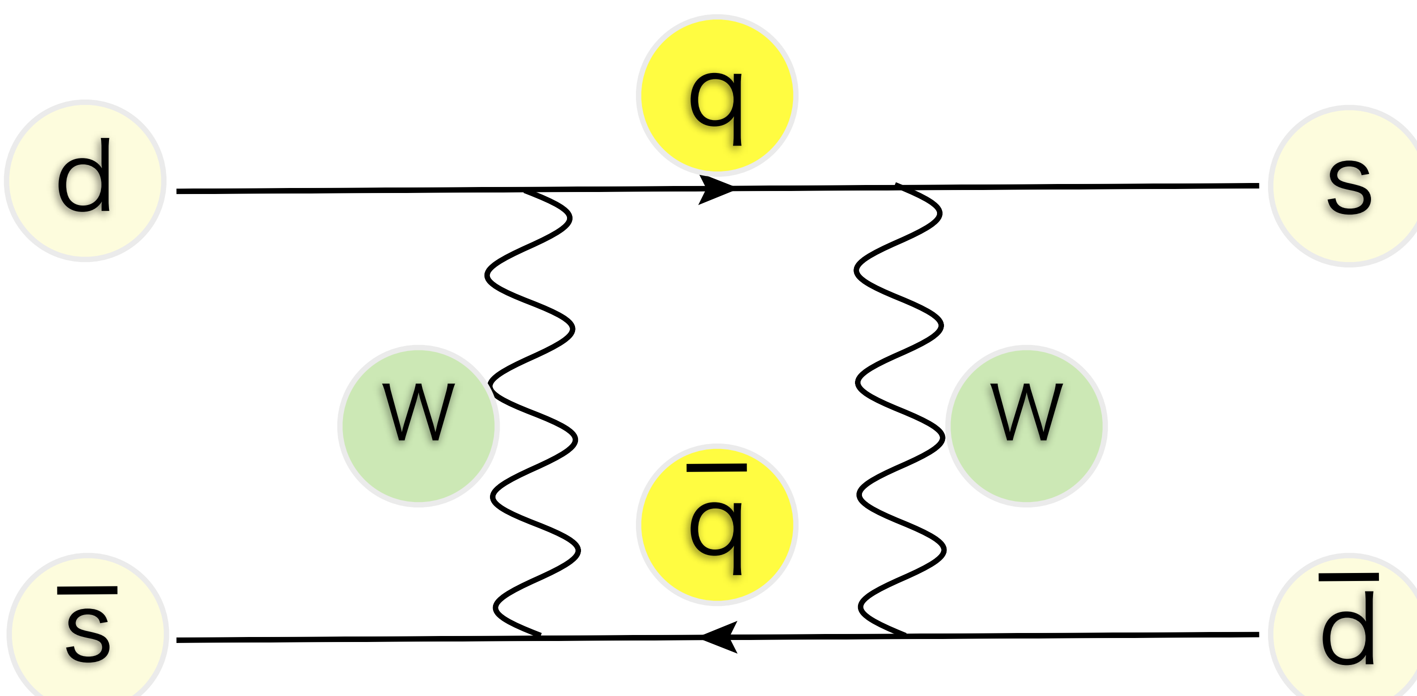


Of course, the SM is very successful in **flavor physics** as well.

- No tree-level FCNCs.
- Flavor changing processes are very suppressed by the GIM mechanism.

For instance,



K_0-$\overline{K_0}$ mixing predicted by the one-loop, and very small.

This is not the end of the story!

because of

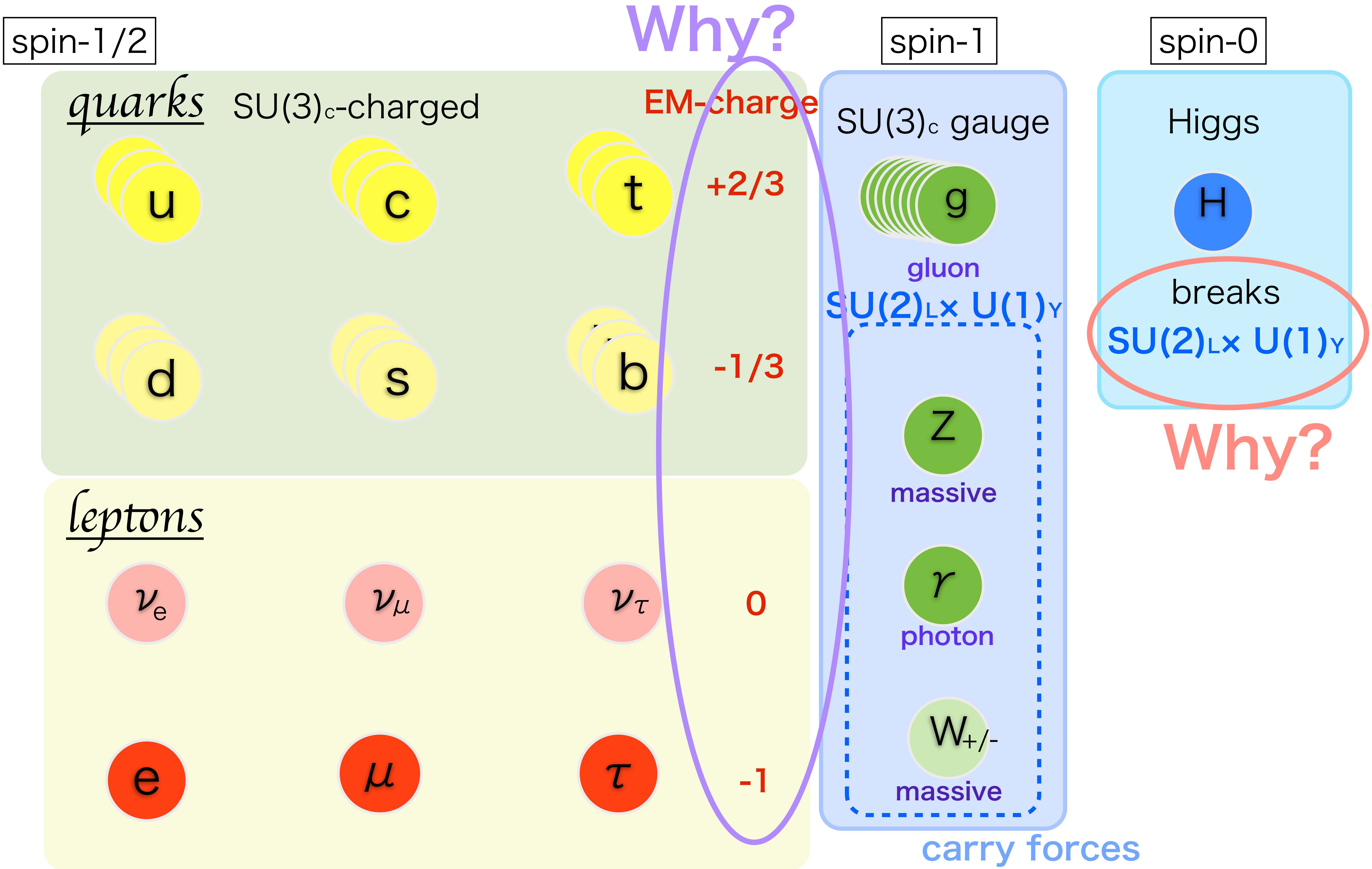
Dark matter

and

there are many “why” in the SM.

Standard Model ($SU(3)_c \times SU(2)_L \times U(1)_Y$) is very successful in particle physics

Why?

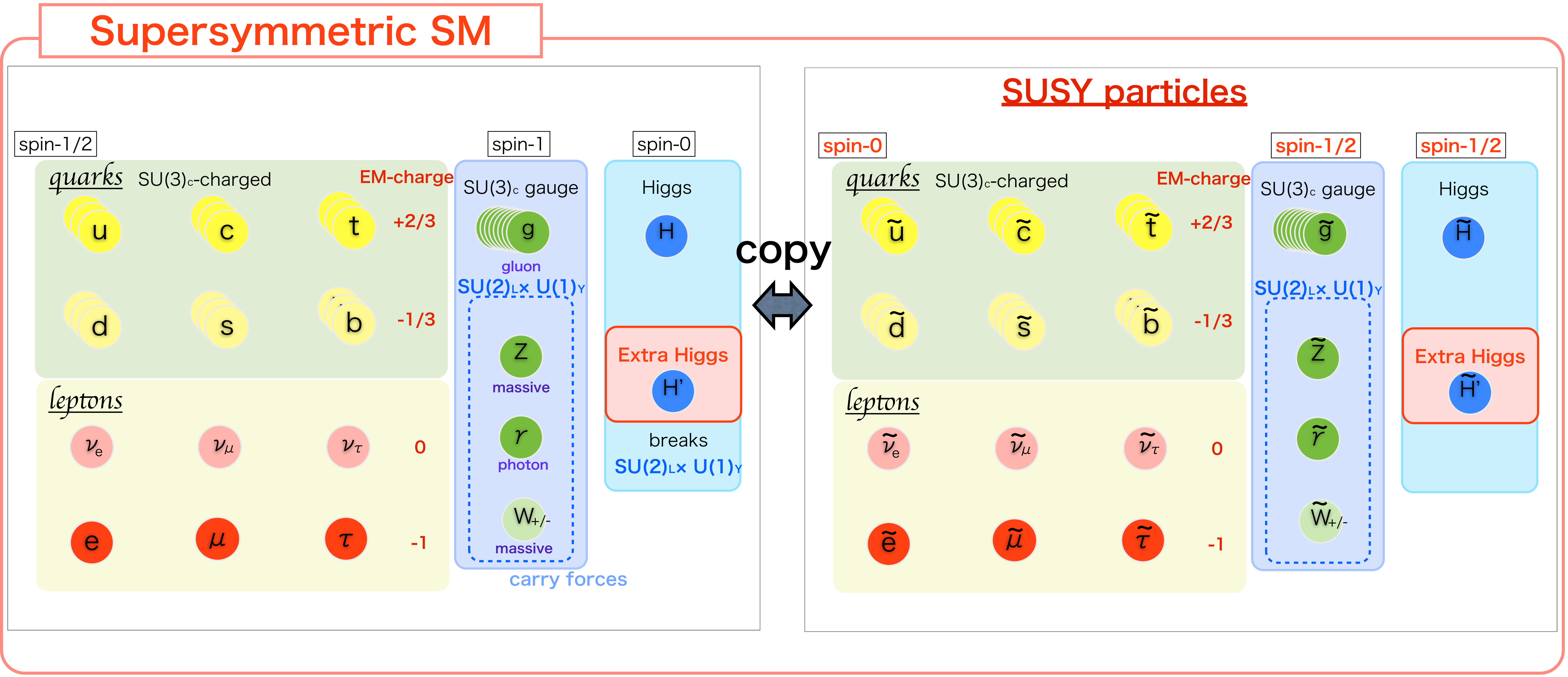


Supersymmetric

Grand Unified Theory

is very natural explanation!

SUSY can explain why $SU(2)_L \times U(1)_Y$ breaking happen around 246 GeV



no quadratic divergence

radiative $SU(2)_L \times U(1)_Y$ breaking

dark matter

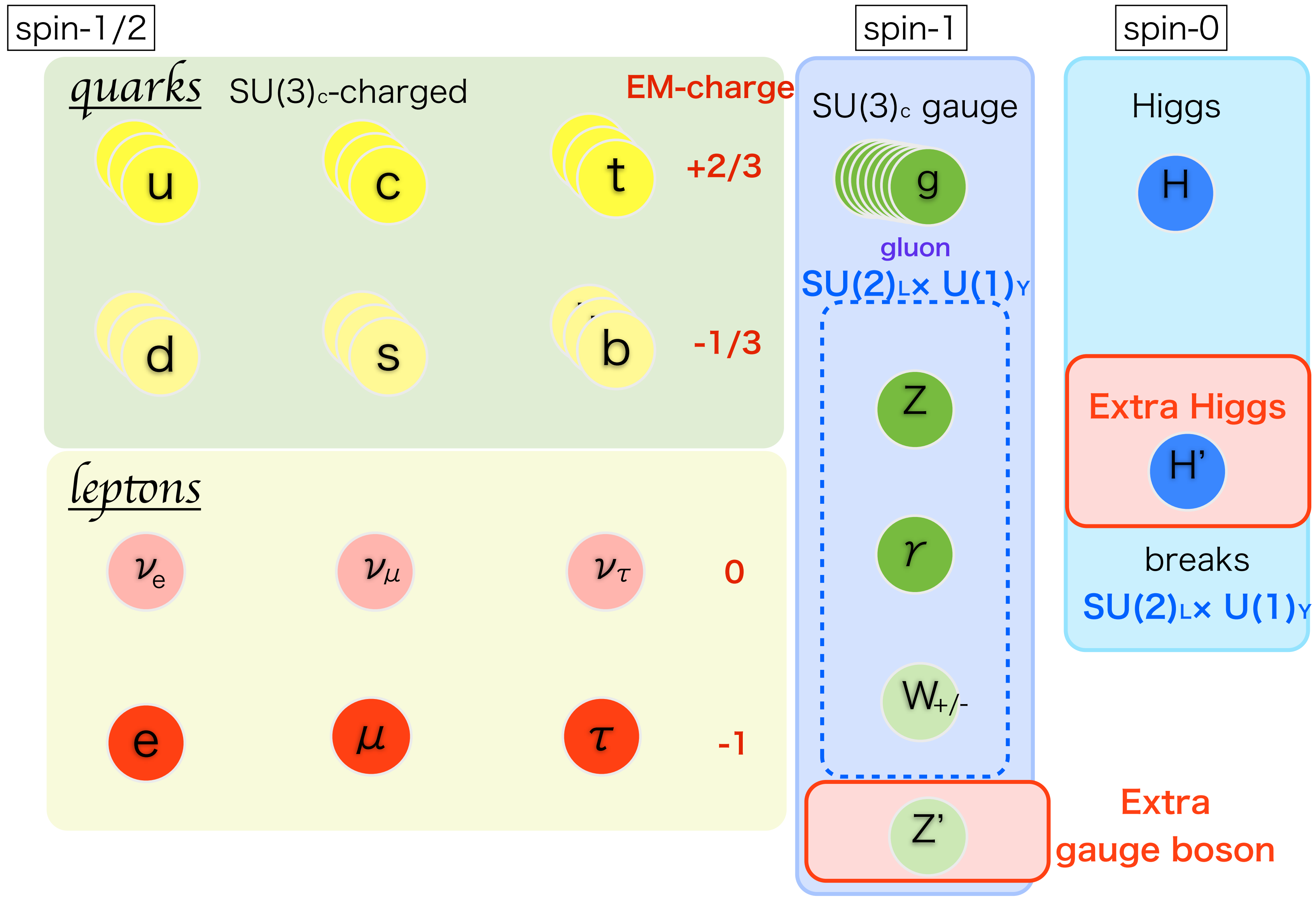
Grand Unified Theory (GUT)

is a good answer
to the origin of gauge symmetry

SM gauge groups naturally embedded into GUT

SO(10) Embedding: $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_X \rightarrow SO(10)$

slightly extended SM — extra



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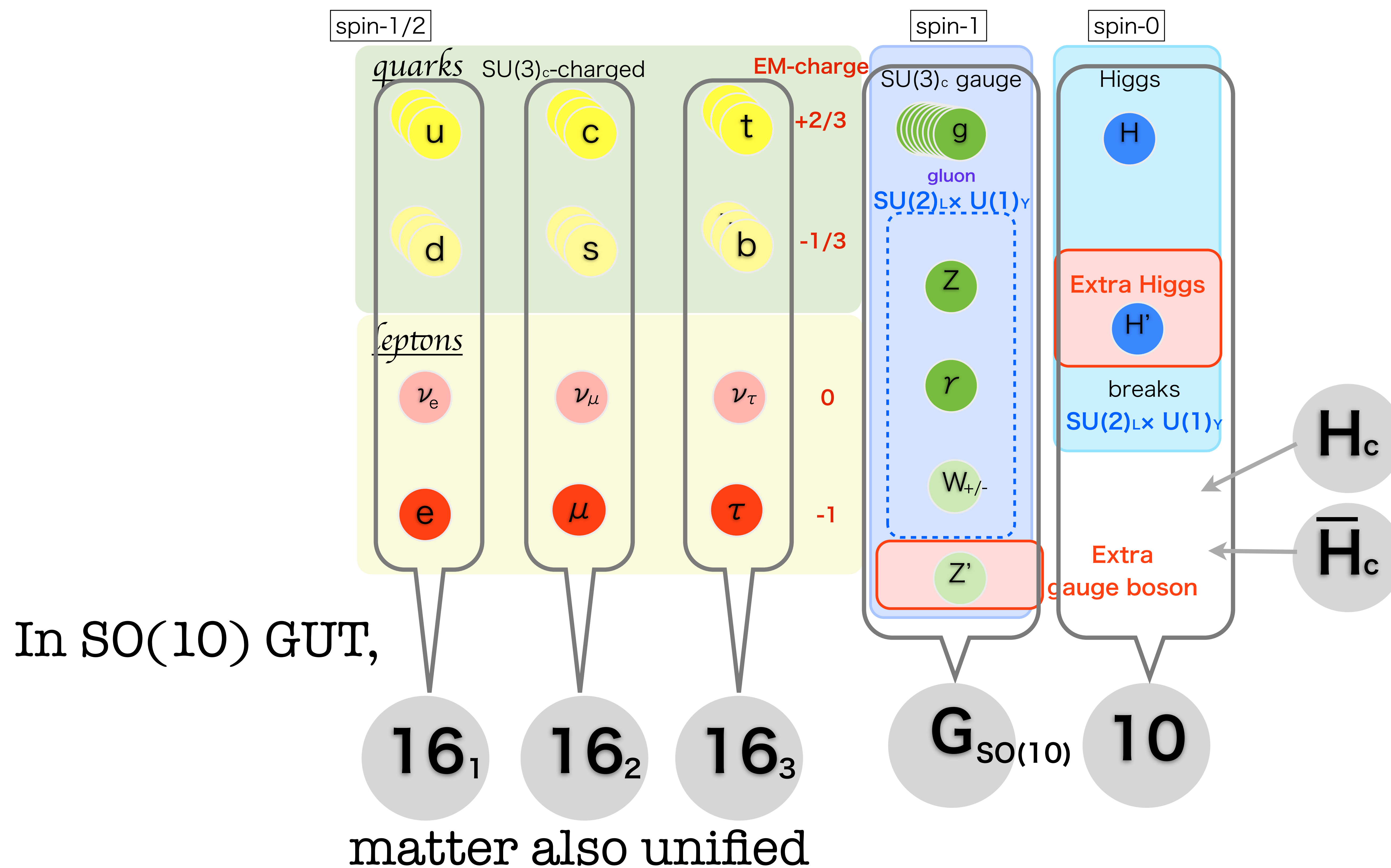

supersymmetric SO(10) GUT looks very elegant and natural

but story is not so simple…

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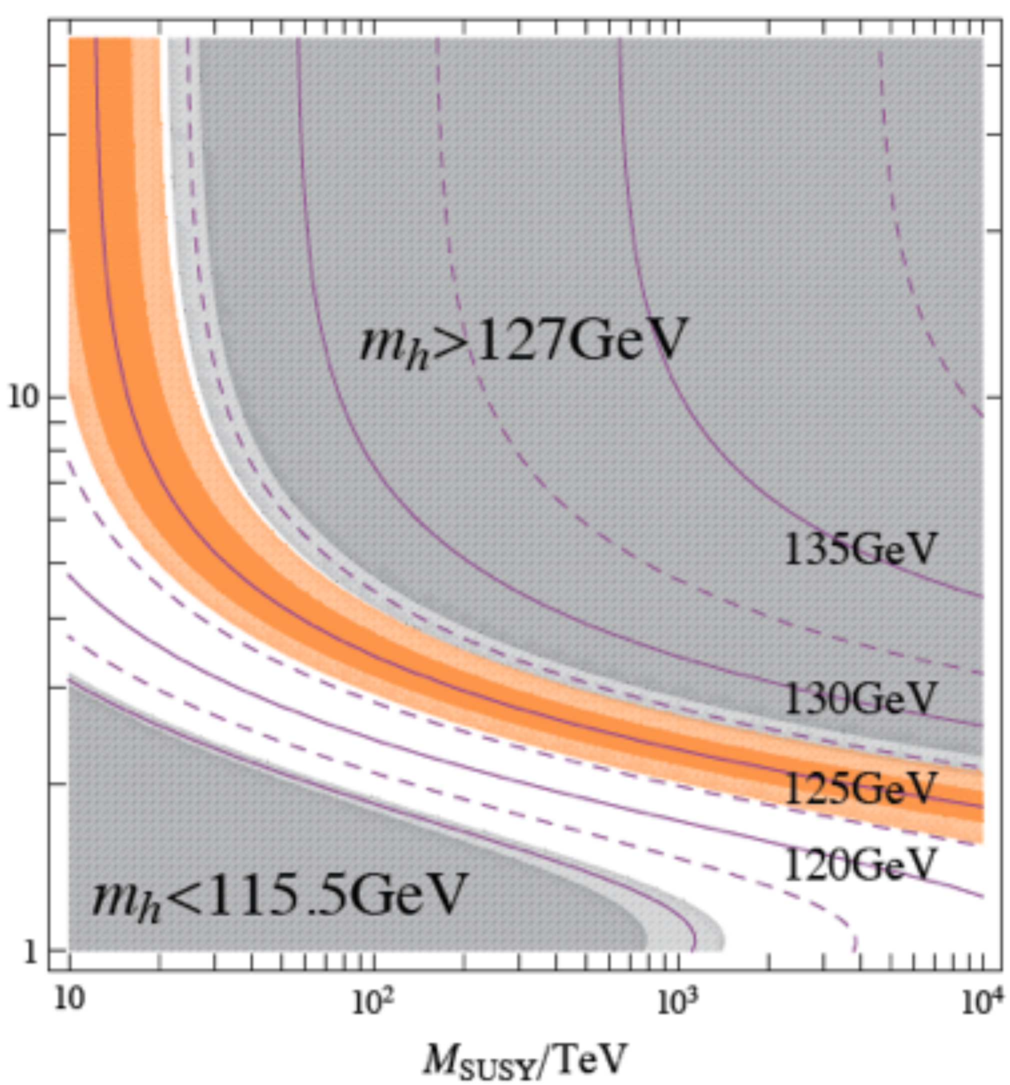
but story is not so simple...

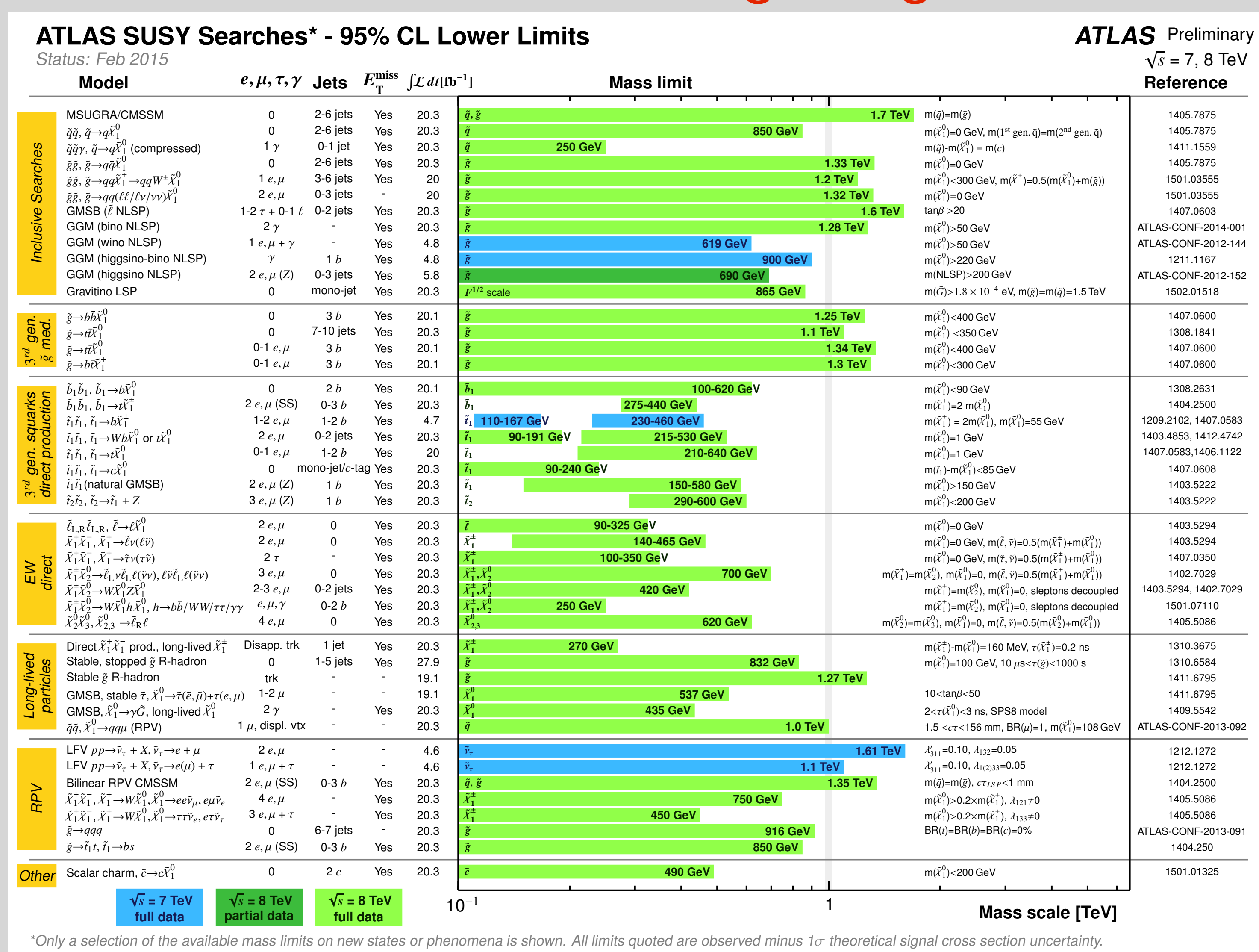
Problem 1

It is difficult to achieve 125 GeV Higgs in the MSSM.



(Ibe, Matsumoto,Yanagida, 1202.2253)

SUSY search also getting severe!



Problem 2

It is difficult to realize the realistic Yukawa couplings in the GUT.

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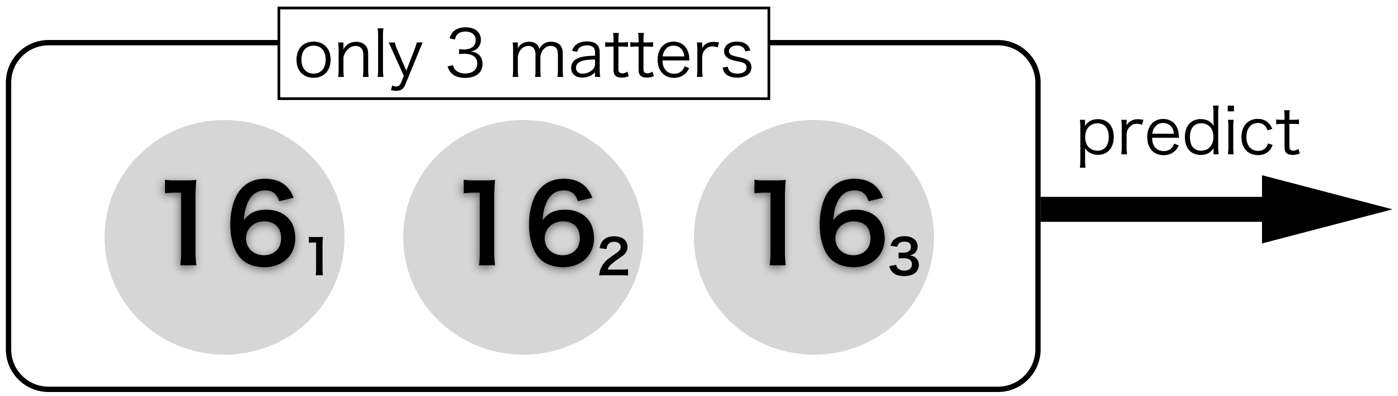
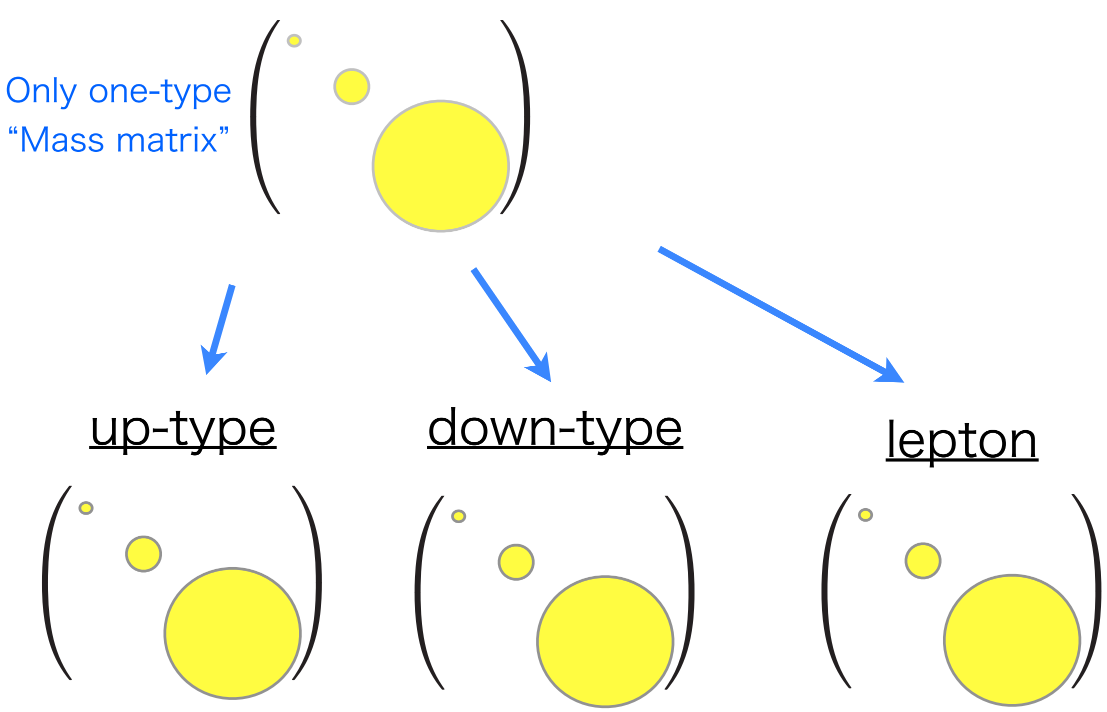


same mass matrices
of (u,c,t), (d,s,b),(e,μ,τ)

no CKM mixing

SO(10) GUT unifies quarks and leptons into **16** rep.

$W_{\rm min} = h_{ij}\mathbf{16}_i\mathbf{16}_j\mathbf{10}_H$ @ $\tan\beta = 1$



same mass spectrum

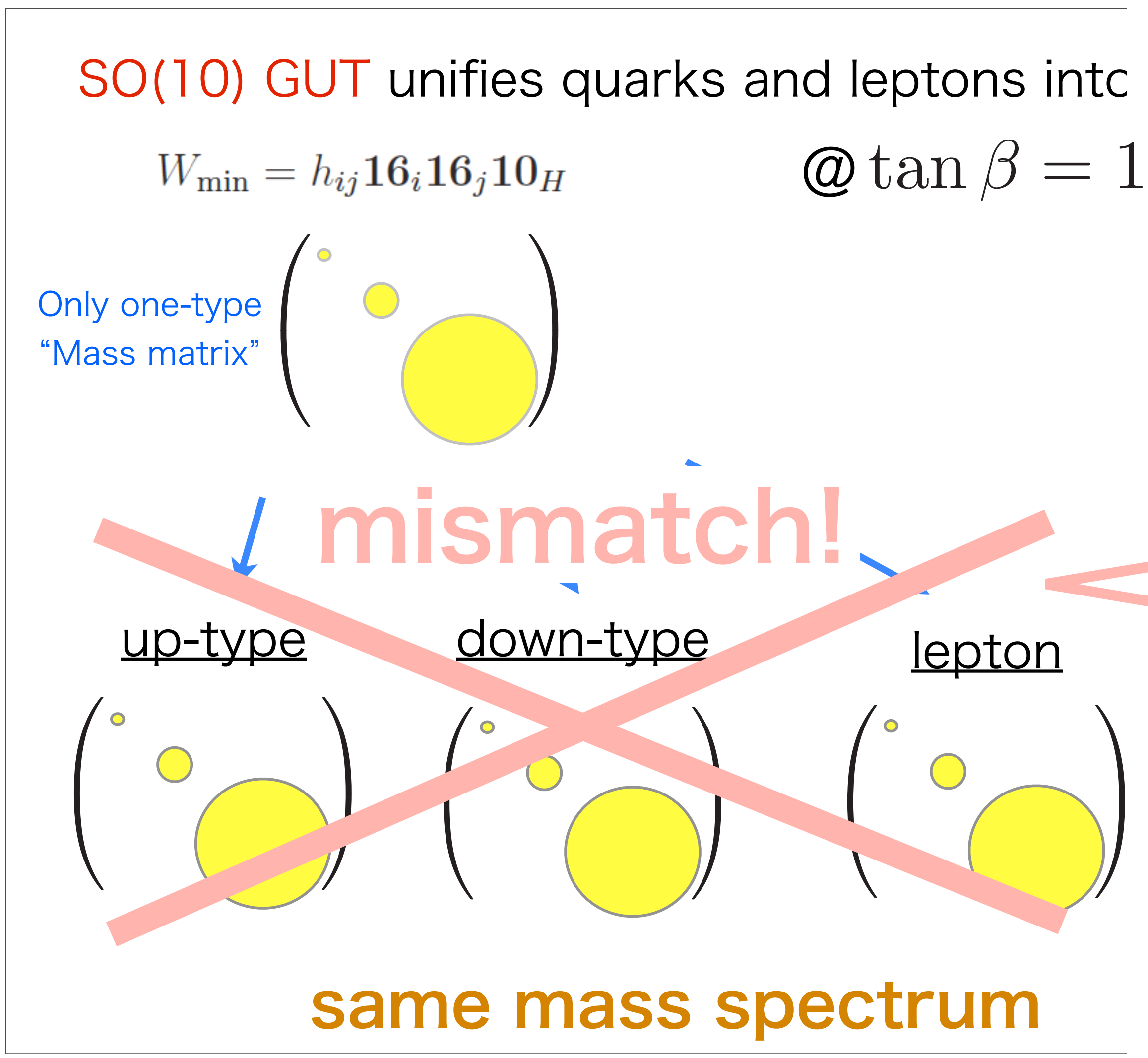
Problem 2

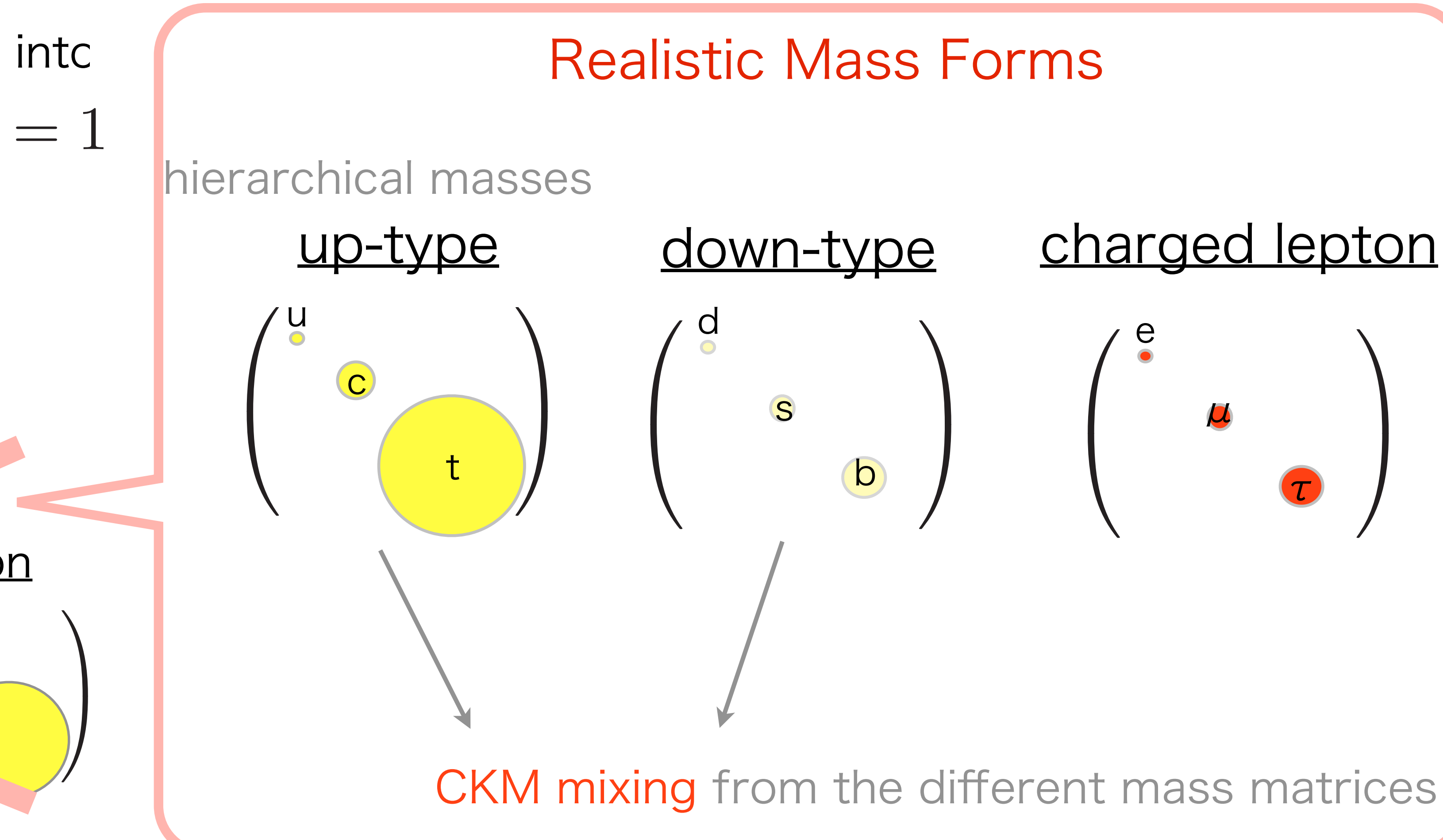
It is difficult to realize the realistic Yukawa couplings in the GUT.

only 3 matters: $\mathbf{16}_1$ $\mathbf{16}_2$ $\mathbf{16}_3$ → predict

same mass matrices of (u,c,t), (d,s,b),(e, μ , τ)

no CKM mixing

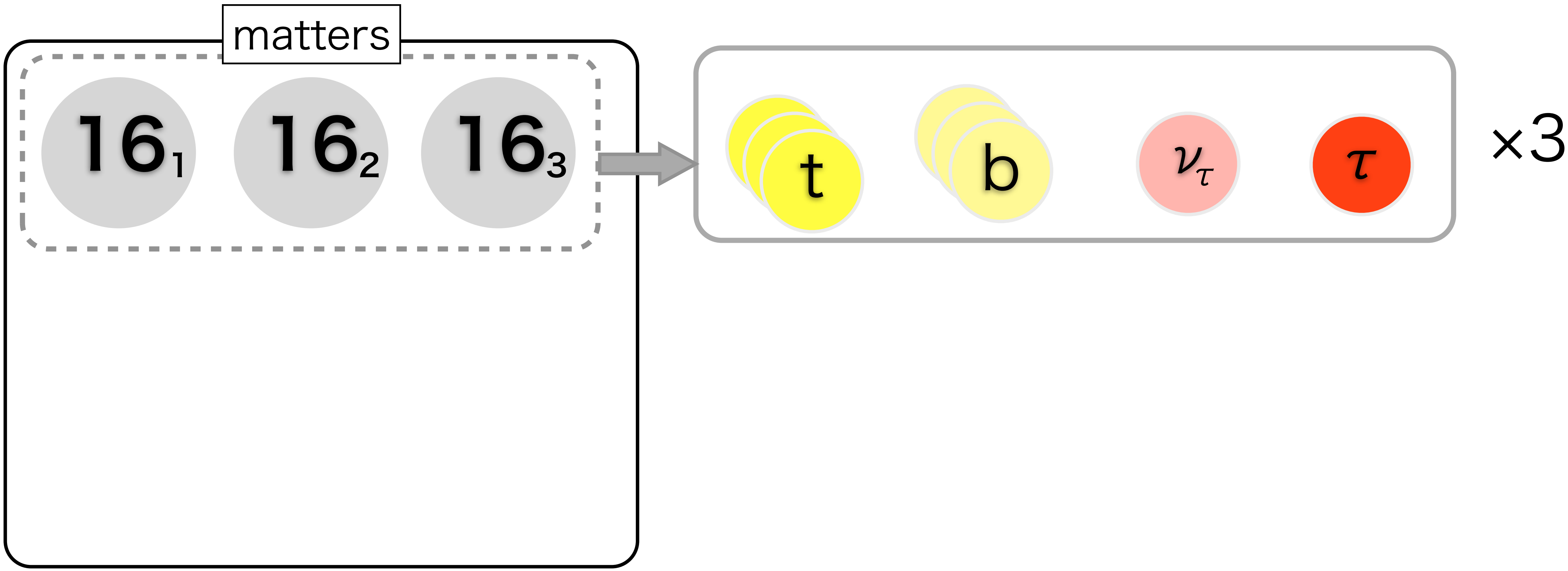




We need extra something.

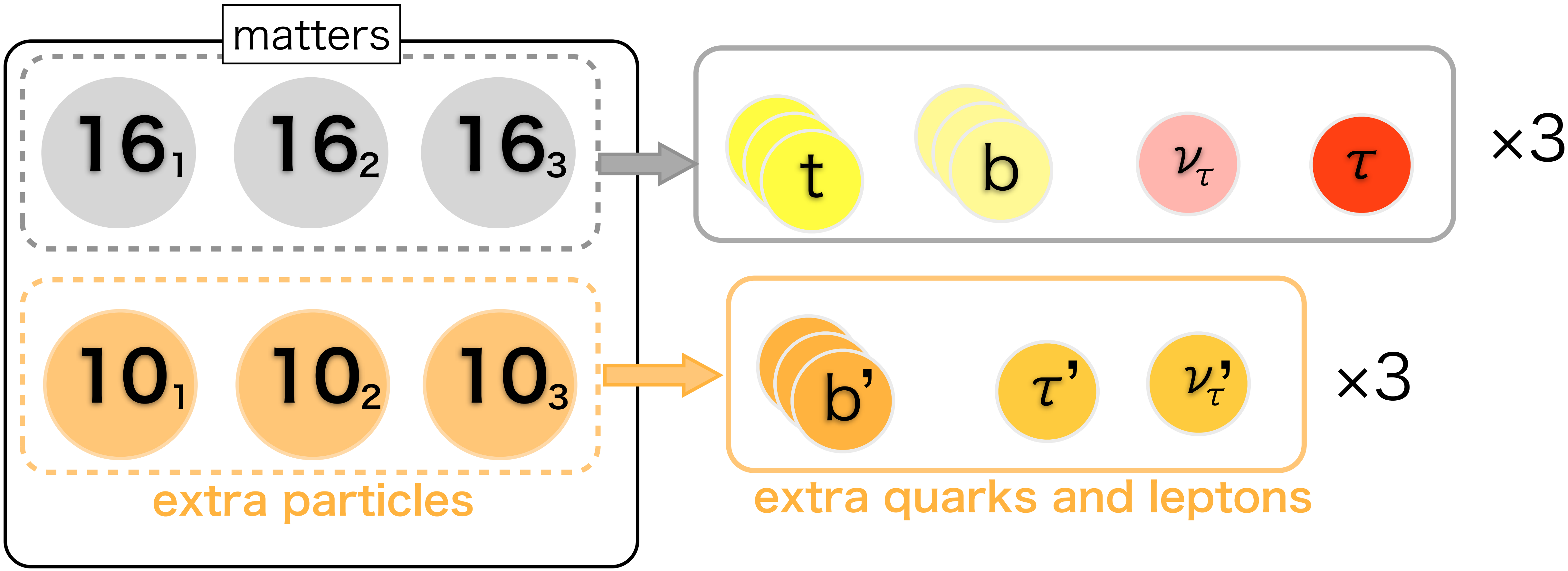
Our setup

(extension of the minimal SO(10) GUT to solve the problems) minimal setup



Let me add extra matters (**10**$_1$, **10**$_2$, **10**$_3$)

(YO, J. Hisano, Y. Muramatsu, M. Yamanaka)



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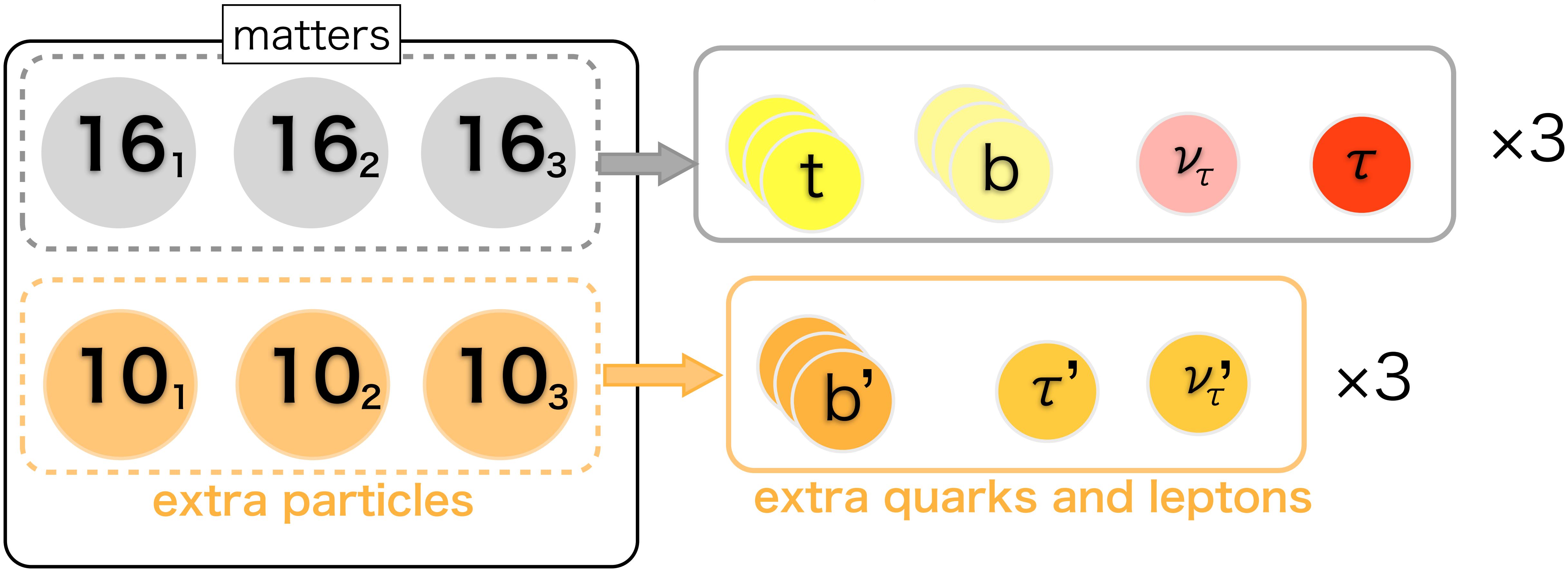

Then SM particles are given by the linear combinations:

ex)

minimal **extended**

$$|(b_R^c)_{SM}> = |b_R^c> \Rightarrow |(b_R^c)_{SM}> = (\cos\theta_b)|b_R^c> + (\sin\theta_b)|b_R'^c>$$

3rd generation

$$m_b \approx m_t \times (1/60)$$

top: $\left(m_t \right) t_L t_R^c$

bottom: $\left(m_t \right) b_L \hat{b}_R^c$

3rd generation

$m_b \approx m_t \times (1/60)$

top: $\left(m_t \right) t_L t_R^c$

from
$g^{ij} \mathbf{16}_i \mathbf{10}_j \mathbf{16}_H + \mu_{10}^{ij} 10_i 10_j$

"extra" quarks

bottom: $\left(m_t \right) b_L \hat{b}_R^c \quad + M' \overline{b'_R}^c \hat{b}_R^c + \mu_{10} \overline{b'_R}^c b_R'^c$

mass mixing

3rd generation

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"extra" quarks

bottom: $\left(m_t \right) b_L \hat{b}_R^c \; + M' \overline{b'_R}^c \hat{b}_R^c + \mu_{10} \overline{b'_R}^c b'^c_R$

mass mixing

$\to M_h \overline{b'_R}^c b''^c_R$

$\to (\;)b_R^c + (\;)b''^c_R$

bottom quark

$$m_b = \left(m_t \right) \times \left(\cos\theta_b \right)$$

bottom quark mainly from **10** rep. (b'^c_R)

The mixing between 10 and 16 can realize the hierarchy between top and bottom.

(High-scale SUSY predict small tan β)

But it is difficult for only the mixing to achieve the all elements of realistic Yukawa coupling.

$$(mixing) = \tan\beta (V_{CKM})_{ub} \frac{m_b}{m_u} > 1$$

We add Higher-dim. operators

$$(h_{u\,ij} + \epsilon_{d\,ij}) Q_{L\,i} \hat{D}^c_{R\,j} H_d + (h_{u\,ij} + \epsilon_{e\,ij}) \hat{L}_{L\,i} E^c_{R\,j} H_d$$

Next question

How prove this model?

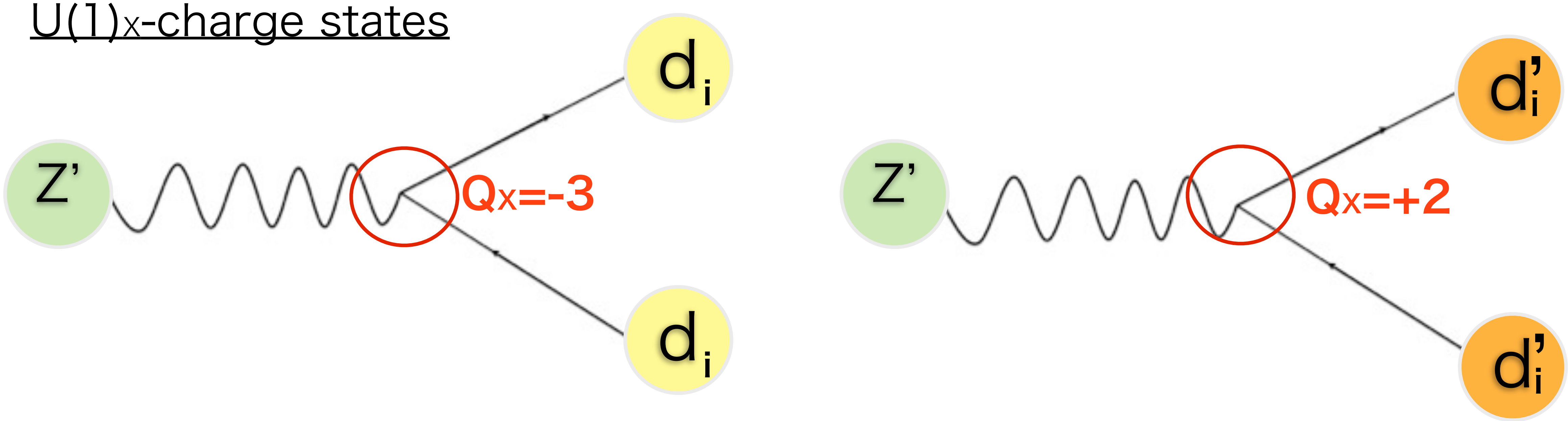
(YO, J. Hisano, Y. Muramatsu, M. Yamanaka)

Crucial point is

d_i and d'_i carry different $U(1)_X$ charges

extra

U(1)X-charge states



(YO, J. Hisano, Y. Muramatsu, M. Yamanaka)

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d_i and d'_i (extra) carry different $U(1)_X$ charges

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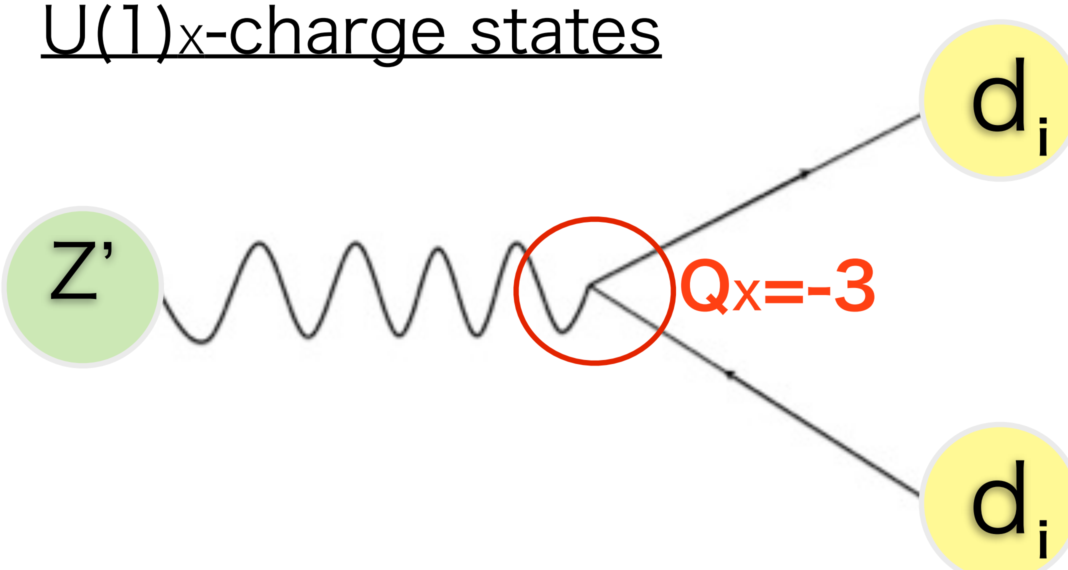
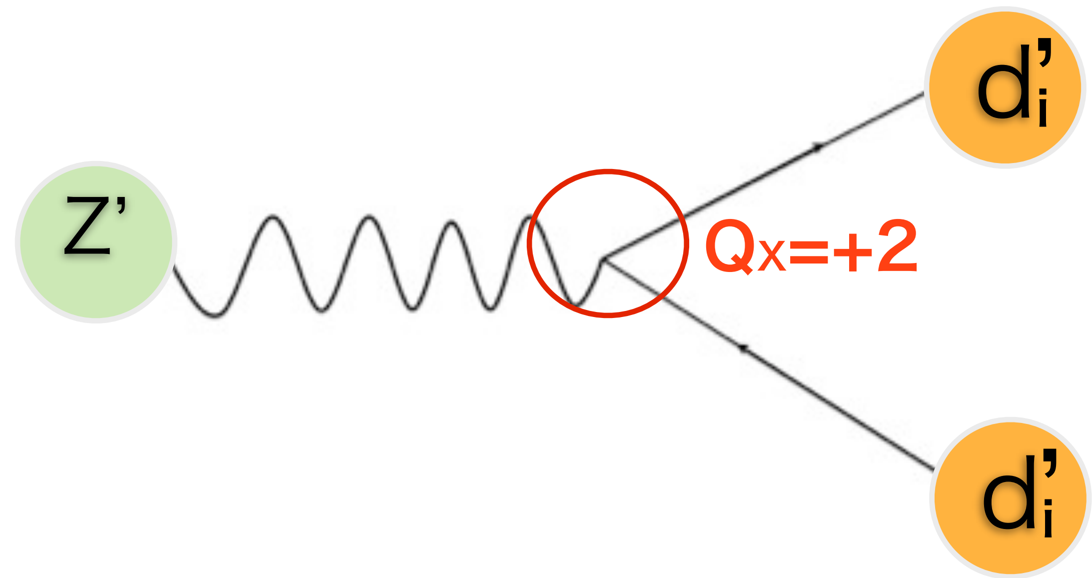
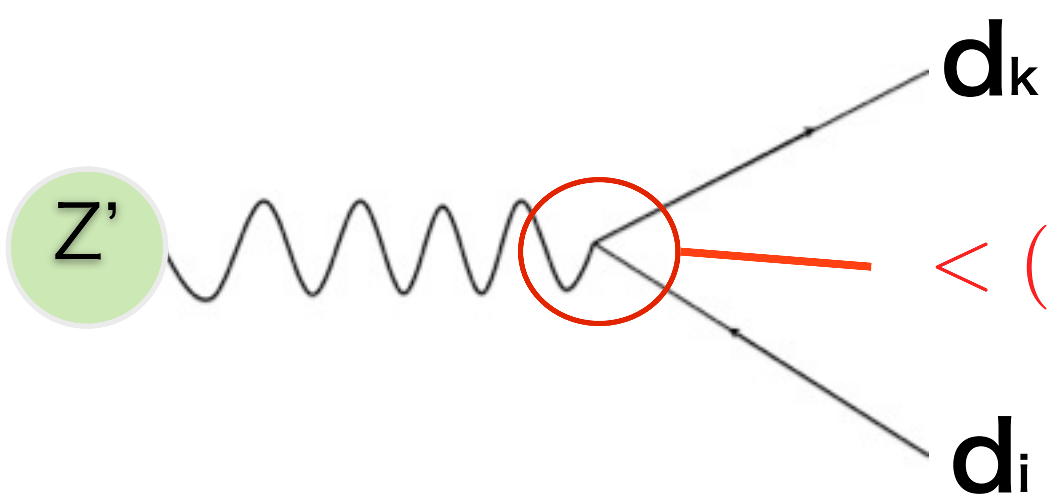




mass eigenstates

down-type quarks

$$|(d_R^i)_{SM}> = U_{ij}|d_R^j(-3)> + U'_{ij}|d_R'^j(+2)>$$

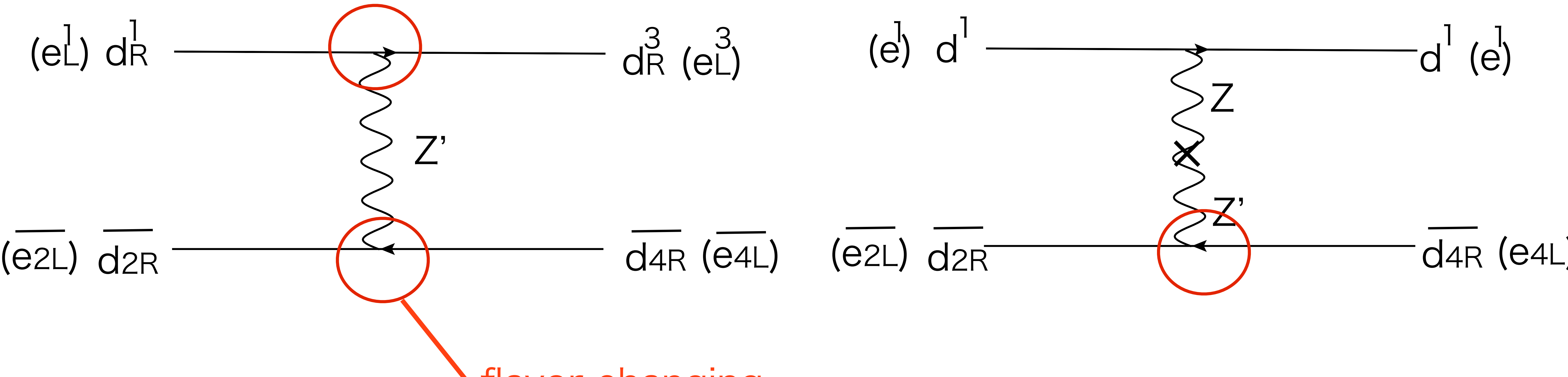


$$< (d_R^k)_{SM}|\hat{Q}_X|(d_R^i)_{SM} > \not\propto \delta_{ik}$$

Flavor violating!

Contributions to Flavor Physics

finite Z-Z' mass mixing predicted



flavor changing

almost "flavor-universally"

(d,s), (d,b), (s,b), (e,μ), (e,τ), (μ,τ), ... elements are O(1) and complex.

Very nice predictions

because it is usually difficult to prove GUTs.

Note that

1. In order to achieve the 125 GeV Higgs,

   SUSY scale is around 100TeV.

2. U(1)’ is assumed to be broken radiatively.

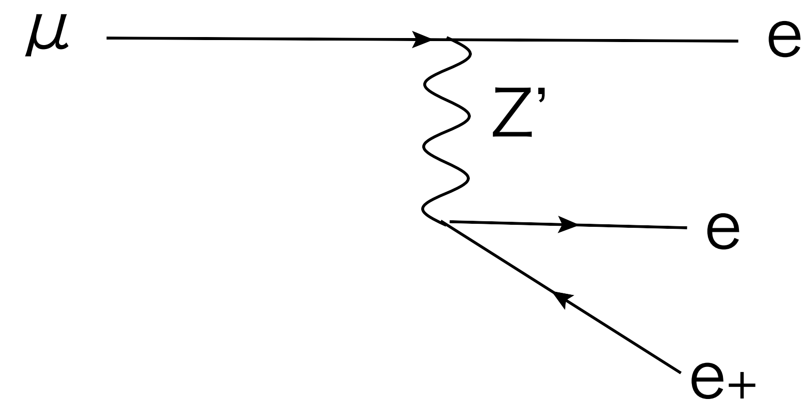
   → Z’ is also around 100 TeV.

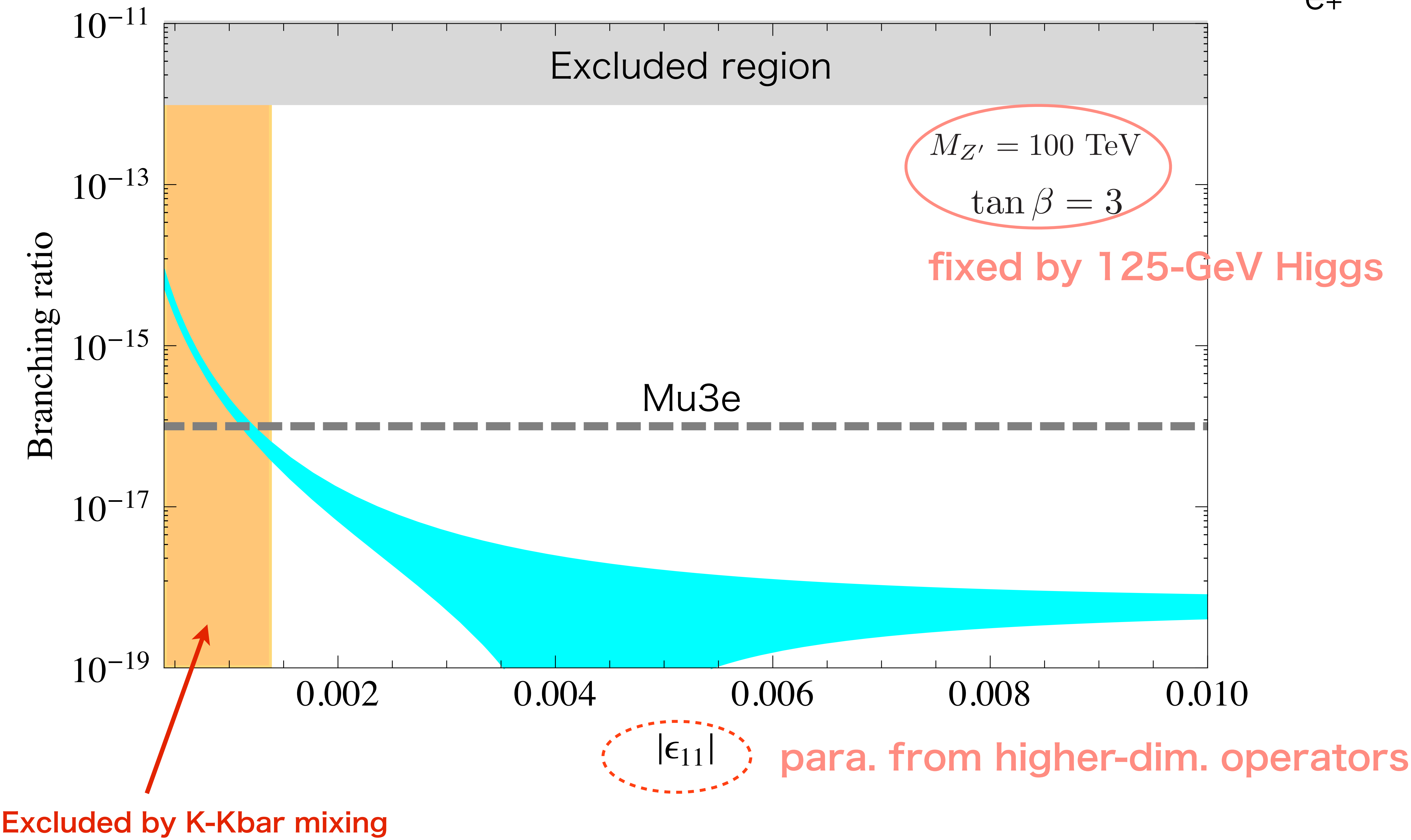
3. We have O(1) flavor changing gauge coupling of Z’ in all elements.

   → Important processes are K and μ physics

   because of the strongest constraints and the sensitivity to the New physics.

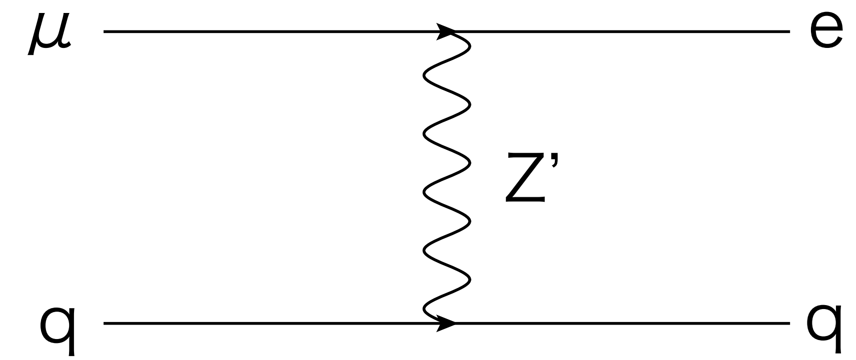
Allowed region for $\mu \to 3e$

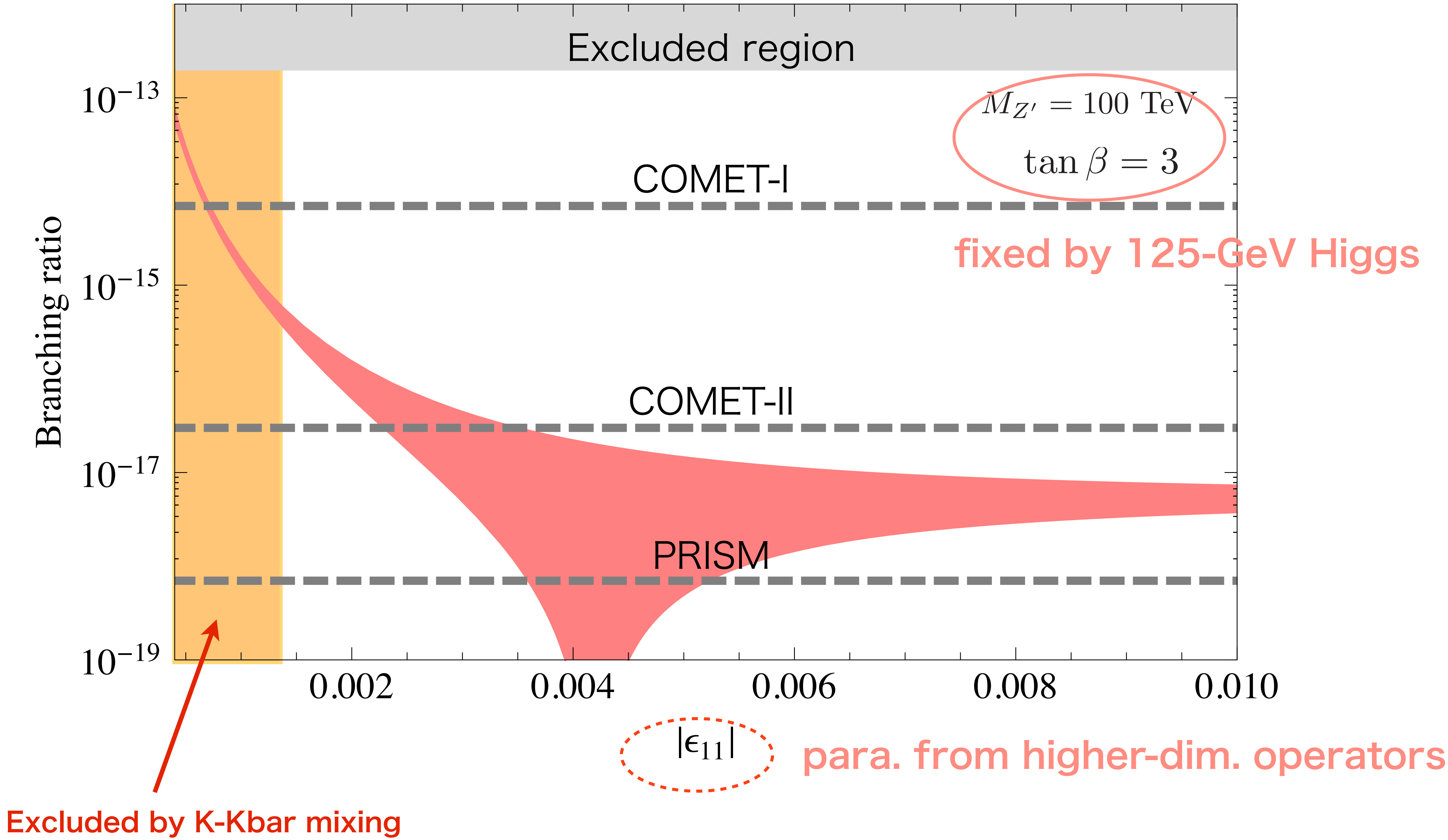




deviations of $K_L \to \mu\mu, \mu e$, $K_+ \to \pi_+ \nu\nu$ are less than O(1)%.

Allowed region for μN→e N





deviations of $K_L \to \mu\mu, \mu e$, $K_+ \to \pi_+ \nu\nu$ are less than O(1)%.

Summary

- Higgs discovered! What is next?
- We are waiting for discovery of new physics.
- Flavor violations will be very good processes to find the evidence of new physics. SM predicts tiny flavor violation.

- I discussed SUSY SO(10) GUT.

125GeV Higgs mass

realistic Yukawa

⇒ flavor violating O(100)-TeV Z'

assuming U(1)' from SO(10) is radiatively broken.

- K and μ physics are the most important.

Thank you

Backup

μ decays

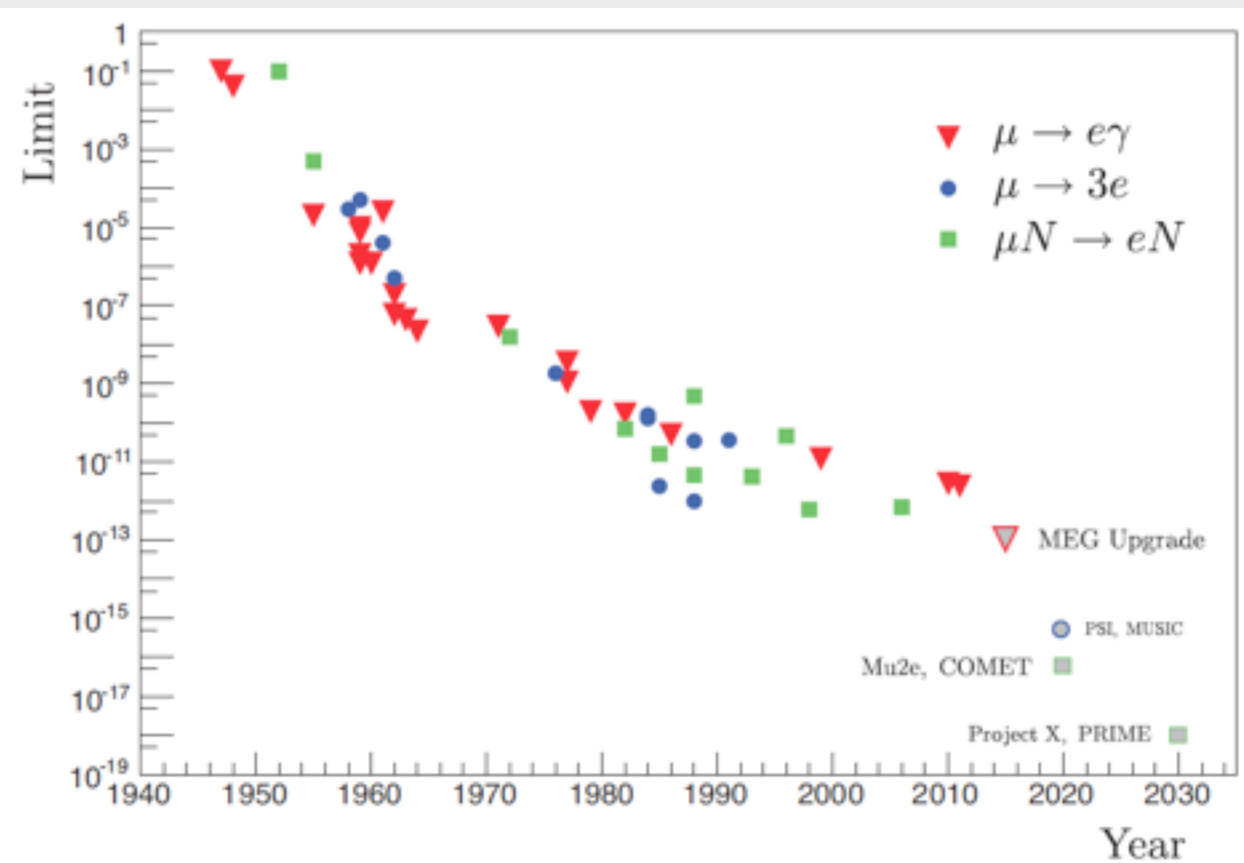
τ decay

$$\mathrm{BR}(\tau \to l_i l_j l_k) \lesssim 10^{-8}$$

$$\mathrm{BR}(\tau \to l_i \gamma) \lesssim 10^{-8}$$

(arXiv:1001.3221;0908.2381)

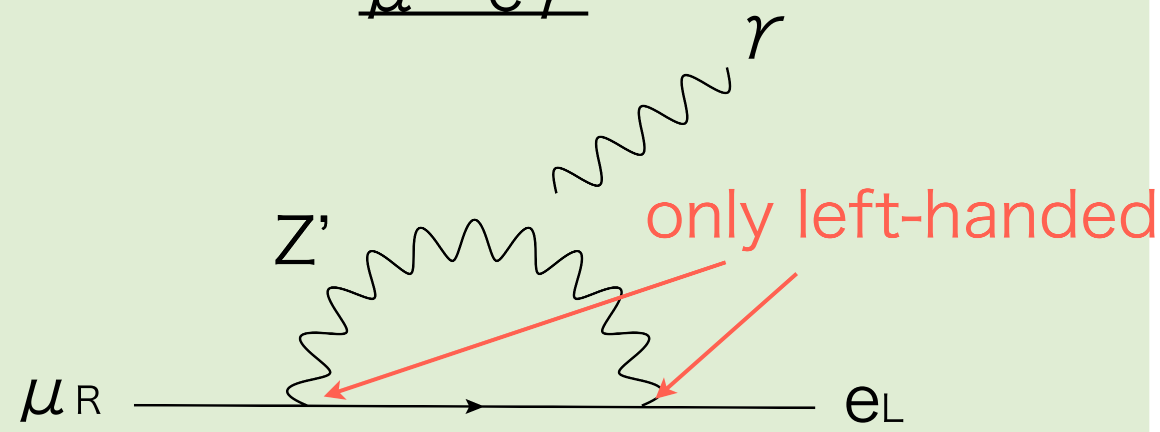
μ decay



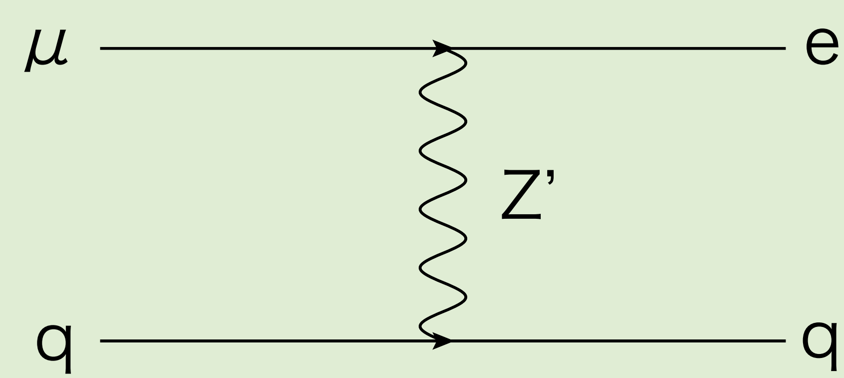
(arXiv:1307.5787)

vs

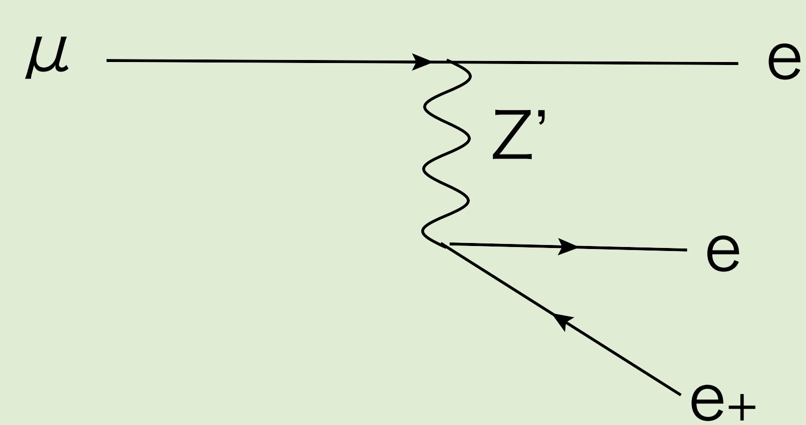
$\mu \to e\gamma$



$\mu \to$e conversion

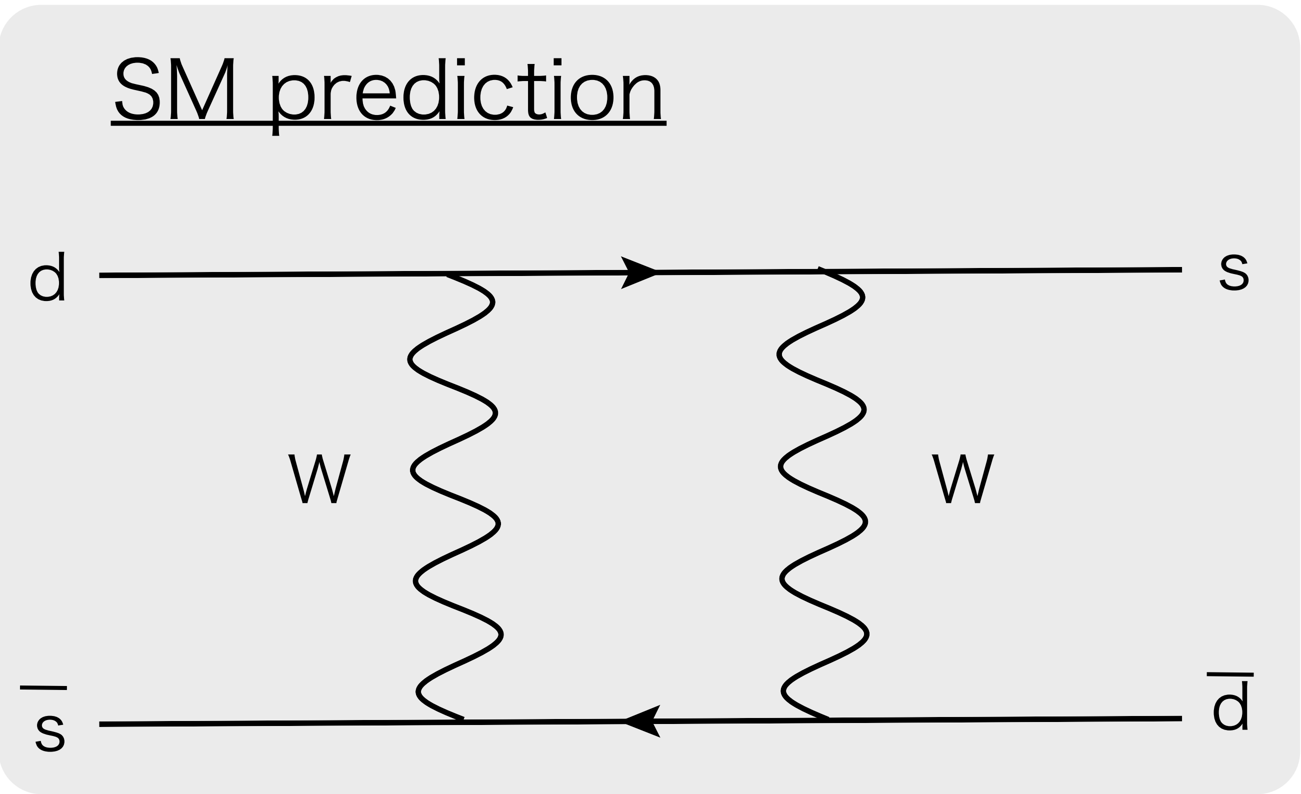


$\mu \to eee_+$

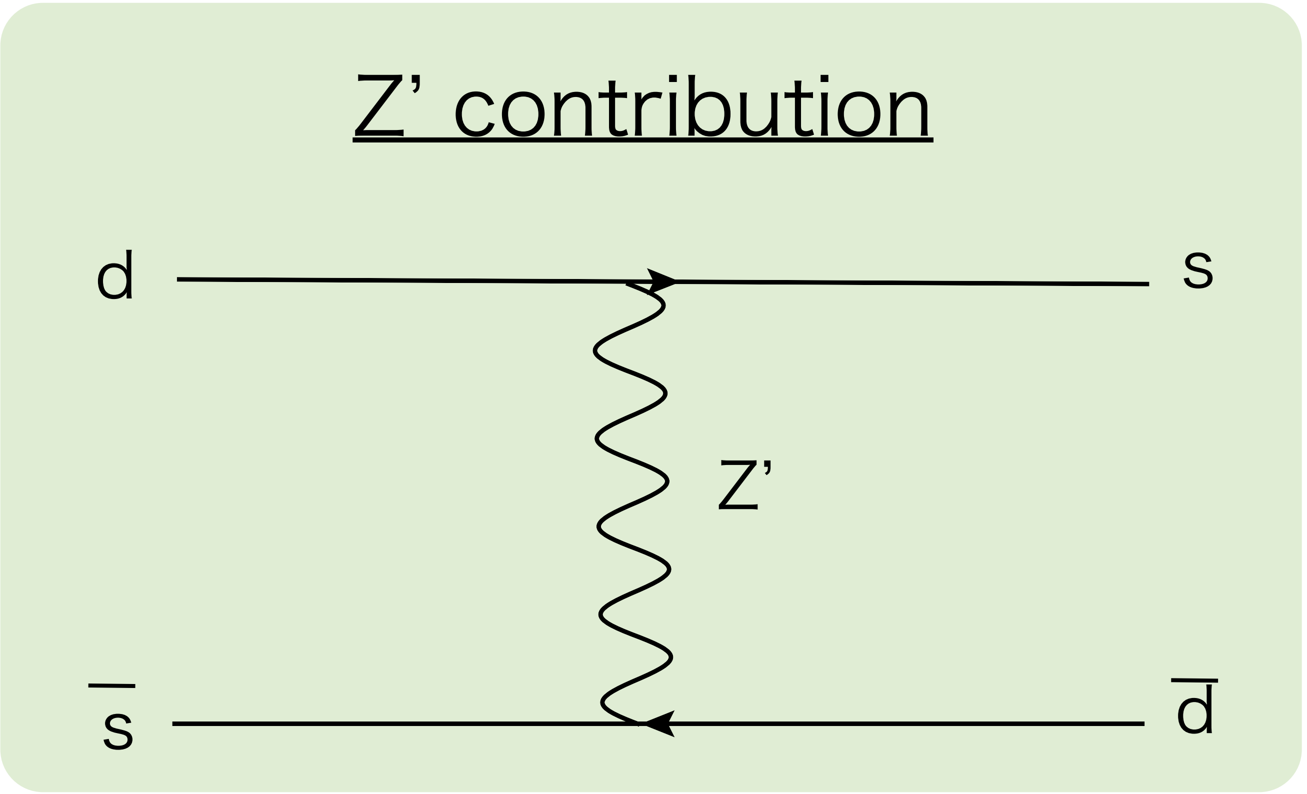


$\mu \to 3e$, μ-e conversion are most important

K physics



vs



$$\underbrace{|V_{ts}^{*}V_{td}|}_{K\text{ system}} \sim 5\cdot 10^{-4} \ll \underbrace{|V_{tb}^{*}V_{td}|}_{B_d\text{ system}} \sim 10^{-2} < \underbrace{|V_{tb}^{*}V_{ts}|}_{B_s\text{ system}} \sim 4\cdot 10^{-2}$$

K system is more sensitive to new physics