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Hint of family gauge bosons with an inverted mass hierarchy from the observed tau decays

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based on ArXiv:1209.1694

Abstract

The present data

$$B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) = (17.41 \pm 0.04)\%$$
$$B(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = (17.83 \pm 0.04)\%$$

(PDG 2012)

show a deviation from the e-μ universality

$$\varepsilon \equiv \varepsilon_\mu - \varepsilon_e = 0.0020 \pm 0.0016$$

which suggests existence of family gauge bosons with an inverted mass hierarchy.

The present data suggest that the lightest family gauge boson has a mass

$$M_{33} = 0.87^{+1.07}_{-0.22}\ \text{TeV}$$

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1. Phenomenological motivation:

-- What does the observed deviation from e-μ universality suggest?

From the branching ratios (PDG2012)

$$Br(\tau^- \to \mu^- \bar{\nu}_\tau \nu_\tau) = (17.41 \pm 0.04)\%$$
$$Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = (17.83 \pm 0.04)\% \qquad (1)$$

we obtain

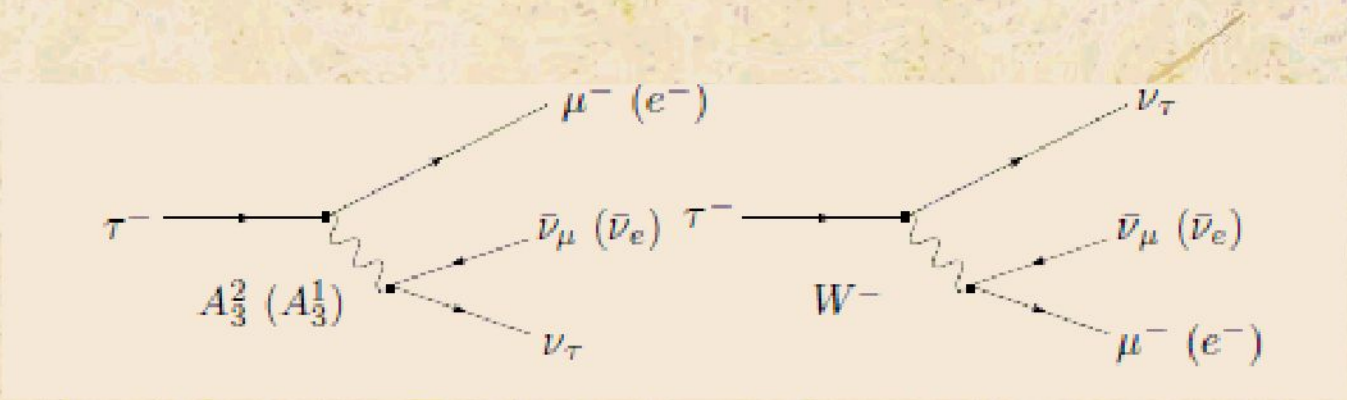
$$R_{amp} \equiv \frac{1+\varepsilon_\mu}{1+\varepsilon_e} = \sqrt{\frac{Br(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \frac{f(m_e/m_\tau)}{f(m_\mu/m_\tau)}} = 1.0020 \pm 0.0016. \qquad (2)$$

where $f(x) = 1 - 8x^2 + 8x^6 - x^8 - 12x^4 \log x^2$

Therefore, we obtain

$$\varepsilon \equiv \varepsilon_\mu - \varepsilon_e = 0.0020 \pm 0.0016 \qquad (3)$$

What means ε > 0 ?



Since we suppose

$$\varepsilon_i^0 = \frac{g_F^2/M_{3i}^2}{g_W^2/8M_W^2} \qquad (4)$$

the observed value $\varepsilon > 0$ (i.e. $\varepsilon_\mu > \varepsilon_e$) suggests $M_{23} < M_{13}$,

In other words, it suggests existence of family gauge bosons with an inverted mass hierarchy.

(Of course, the data, at present, have too large errors to obtain a conclusive result.)

Such a family gauge symmetry model with an inverted mass hierarchy has recently proposed by YK and T.Yamashita

YK and T. Yamashita, PLB 711, 384 (2012)

In the model, masses M_{ij} of the gauge bosons A_i^j are given by

$$M_{ij}^2 \equiv m^2(A_i^j) = k\left(\frac{1}{m_{ei}} + \frac{1}{m_{ej}}\right) \tag{5}$$

where m_{ei} are charged lepton masses.

2. Theoretical Motivation

-- Why we need family gauge bosons?

Sumino mechanism: Y. Sumino, PLB 671, 477 (2009)

Sumino has seriously taken why the mass formula

$$K \equiv \frac{m_e + m_\mu + m_\tau}{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2} = \frac{2}{3} \qquad \textbf{(6)}$$

is so remarkably satisfied with the pole masses:

$$K^{pole} = (2/3) \times (0.999989 \pm 0.000014) \qquad \textbf{(7)}$$

while if we take the running masses, the ratio becomes

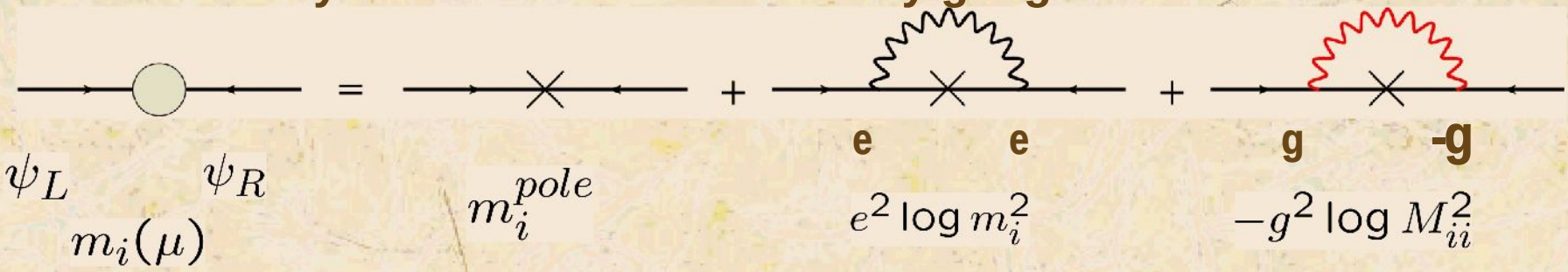
$$K(\mu) = (2/3) \times (1.00189 \pm 0.000002) \quad \text{e.g.} \quad \mu = m_Z \qquad \textbf{(8)}$$

The deviation comes from the QED radiative correction

$$\delta m_i = -\frac{\alpha(\mu)}{\pi} m_i \left(1 + \frac{3}{4} \log \frac{\mu^2}{m_i^2}\right) \qquad \textbf{(9)}$$

Note that if we can make $\varepsilon_i = 0$ **in** $m_i \to m_i(1 + \varepsilon_o + \varepsilon_i)$ **,**
K can be invariant under this transformation.

Therefore, Sumino has proposed an idea that the $e^2 \log m_i^2$ term is canceled by a contribution from family gauge bosons



Sumino model

(i) $(\psi_L, \psi_R) = (\mathbf{3}, \mathbf{3}^*)$ **of the U(3) family symmetry**

(ii) Masses of the gauge bosons : $M_{ij}^2 \equiv m^2(A_i^j) = k(m_{ei} + m_{ej})$

Thus, the term $\log m_i^2$ due to the photon is canceled by

$-\log M_{ii}^2 = -\frac{1}{2}\log m_{ei}^2 - \log k$ due to the family gauge bosons

Problems of Sumino model

(i) Sumino model is not anomaly free

(ii) Effective current-current interactions with Δ N_f =2 appear

(iii) The vertex type diagram does not work in a SUSY model.

Why "inverted mass hierarchy"?

-- An alternative model of the Sumino mechanism

YK and T. Yamashita, PLB 711, 384 (2012)

We assign $(\psi_L, \psi_R) = (\mathbf{3}, \mathbf{3})$ of U(3) family symmetry and we assume that the family gauge bosons have an inverted mass hierarchy

$$M_{ij}^2 \equiv m^2(A_i^j) = k\left(\frac{1}{m_{ei}} + \frac{1}{m_{ej}}\right)$$

Thus, the term $\log m_i^2$ **due to the photon is cancelled by** $+\log M_{ii}^2 = -\frac{1}{2}\log m_{ei}^2 + \log k$ **due to the family gauge bosons**

Characteristics of the new model

(i) The model is anomaly free.

(ii) Family-number violating interactions appear only through quark family mixing.

(iii) The mode is applicable to a SUSY model, too.

(iv) The lightest gauge boson is A_3^3 which interacts only with the third generation particles.

3. What value of M_{33} is suggested from the data?

The effective four Fermi interaction for $\tau^- \to \mu^- \nu_\mu \nu_\tau$

is given by

$$H^{eff} = \frac{G_F}{\sqrt{2}} \left\{ [\bar{\mu}\gamma_\rho(1-\gamma_5)\nu_\mu)][\bar{\nu}_\tau \gamma^\rho (1-\gamma_5)\tau] + \varepsilon_\mu^0 (\bar{\nu}_{L\tau}\gamma_\rho \nu_{L\mu})(\bar{\mu}\gamma^\rho \tau) \right\}$$

$$= 4\frac{G_F}{\sqrt{2}} \left\{ \left(1 + \frac{1}{4}\varepsilon_\mu^0\right)(\bar{\mu}_L \gamma_\rho \nu_{L\mu})(\bar{\nu}_{L\tau}\gamma^\rho \tau_L) - \frac{1}{2}\varepsilon_\mu^0 (\bar{\mu}_R \nu_{L\mu})(\bar{\nu}_{L\tau}\tau_R) \right\} \quad (10)$$

Therefore, we obtain

$$\varepsilon_\mu = \frac{1}{2}\left(1 - 2x_\mu \frac{g(x_\mu)}{f(x_\mu)}\right)\varepsilon_\mu^0 \quad (11)$$

where $g(x) = 1 + 9x^2 - 9x^4 - x^6 + 6x^2(1+x^2)\log x^2$

$x_\mu = m_\mu / m_\tau$ and

$$\varepsilon_\mu^0 = \frac{g_F^2 / M_{32}^2}{g_W^2 / 8M_W^2} \quad (12)$$

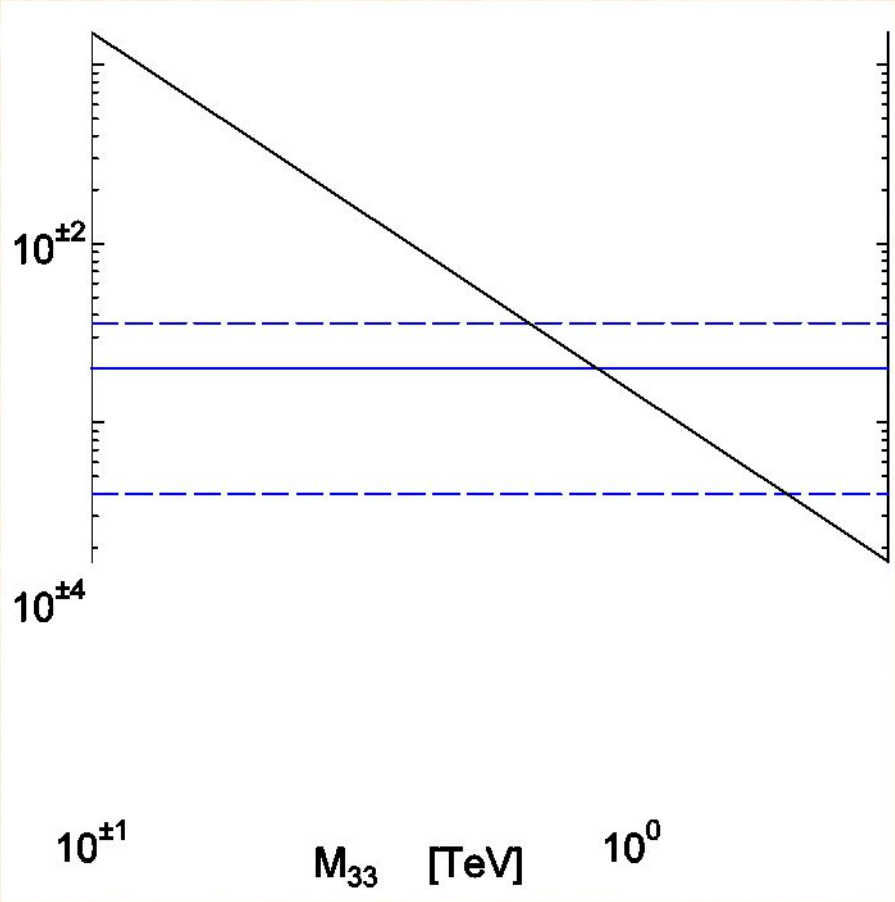
By using the family gauge boson mass relation (5) and the relation for the gauge coupling constants

$$g_F^2 = \frac{3}{2}\zeta\ e^2 = \frac{3}{2}\zeta\ g_W^2 \sin^2\theta_W \quad (13)$$

we can estimate the value of ε_μ vs M_{33}.

The horizontal lines denote

$$\varepsilon^{obs} = 0.0020 \pm 0.0016 \quad (14)$$



ε_μ vs M_{33}

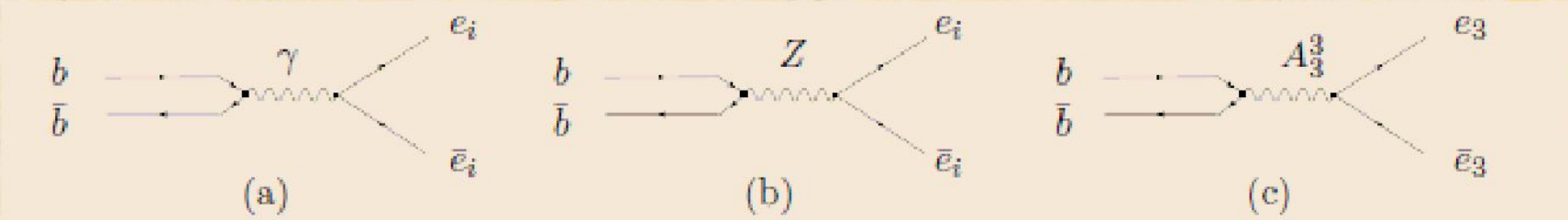
The observed value suggests that the lightest family gauge boson mass is

$$M_{33} = 0.87^{+1.07}_{-0.22}\ \text{TeV} \quad (15)$$

The numerical result should not be taken rigidly, because the error is too large at present.

How about deviations from the e-μ-τ universality in Υ decays

We consider that the deviation from the e-μ-τ universality in the Υ decays is caused by the family gauge boson exchange terms



Under an approximation of neglecting family mixing in the quark sector, the b quark interacts only with A_3^3 boson, so that the deviation parameter is given by

$$\varepsilon_\tau = \frac{g_F^2}{e^2/3}\frac{M_\Upsilon^2}{M_{33}^2} \qquad (16)$$

The observed value

$$R_{Br} \equiv \frac{Br(\Upsilon \to \tau^+\tau^-)}{Br(\Upsilon \to \mu^+\mu^-)} = 1.048 \pm 0.046 \quad (17)$$

gives

$$R_{amp} = 1 + \varepsilon_\tau = 1.028 \pm 0.022 \quad (18)$$

where

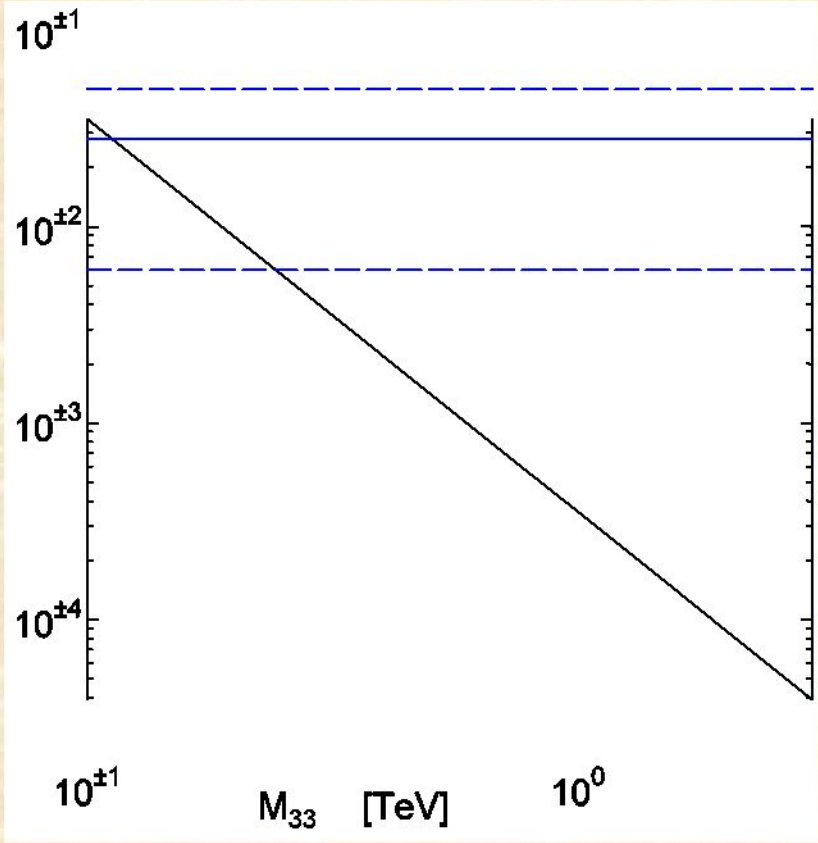
$$R_{amp} \equiv \sqrt{R_{Br} R_{kine}} \quad (19)$$

and

$$R_{kine} = \frac{1 + 2\frac{m_\tau^2}{M^2}}{1 + 2\frac{m_\mu^2}{M^2}} \sqrt{\frac{1 - 4\frac{m_\tau^2}{M^2}}{1 - 4\frac{m_\mu^2}{M^2}}} \quad (20)$$

The data suggest

$$M_{33} = 112^{+130}_{-26} \text{ GeV} \quad (21)$$



ε_τ vs M33

4. Can we accept a family gauge boson with such a lower mass?

Usually, one considers that it is impossible to observe such gauge boson effects at a low energy scale, because we know

(a) a severe constraint $\Lambda \geq 10^6$ GeV from the observed K^0-$\bar{K}^0$ mixing;

(b) No observation of $A_1^1 \to e^+e^-$ at Tevatron and LHC.

Nevertheless, we has speculated $M_{33} \sim 1$ TeV.

Is that OK?

Recall that our family gauge bosons have an inverted mass hierarchy

$$m^2(A_i^j) \equiv M_{ij}^2 = k\left(\frac{1}{m_{ei}} + \frac{1}{m_{ei}}\right) \quad (22)$$

(a) The lightest gauge boson A_3^3 interacts only with the third generation particles, i.e. $\tau^-\tau^+$, $b\bar{b}$ and $t\bar{t}$

Therefore, search for the lightest gauge boson has to be done for

$$pp \to A_3^3 + X \to (\tau^+\tau^-) + X \quad (23)$$

A constraint from the Z' search at Tevatron (PRL95, (2005)) is dependent on the production rate.

The production rate of A_3^3 is considerably small compared with that of Z', so that the constraint is not apply to our case.

(b) Constraint from K^0-$\bar{K}^0$ mixing becomes mild because of $M_{33}^2 << M_{22}^2 << M_{11}^2$.

Besides, family number violating processes appear only through the quark family mixings:

5. Family-number non-conservation induced by quark mixing

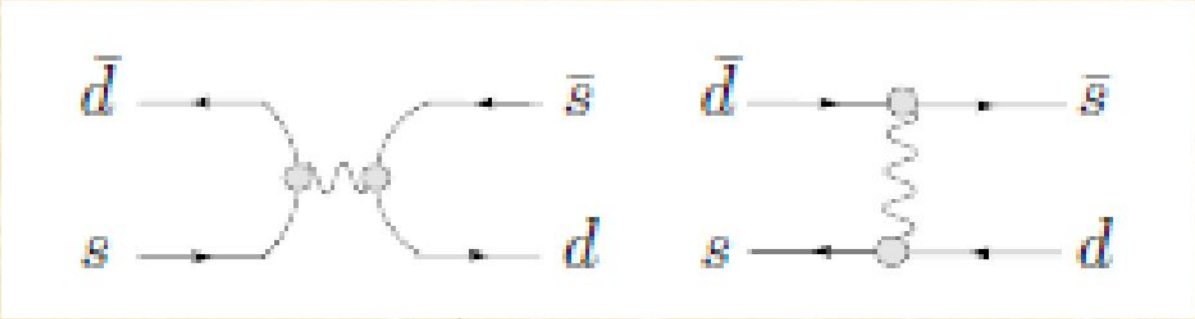
In the present model, the family number is defined by a flavor basis in which the charged lepton mass matrix M_e is diagonal, while, in general, quark mass matrices M_u and M_d are not diagonal in this basis.

In the charged lepton sector, there are no family violating interactions at tree level, while in the quark sectors, family violating interactions appear only via quark family mixings:

$$H_{fam} = g_F \sum_{q=u,d} (\bar{q^0}^i \gamma_\mu q_j^0)(A_i^j)^\mu$$

$$= g_F \sum_{q=u,d} (A_i^j)_\mu \left[(U_L^{q*})_{ik} (U_L^q)_{jl} (\bar{q}_{Lk} \gamma^\mu q_{Ll}) + (L \to R) \right] \quad \textbf{(24)}$$

★ K^0-$\bar{K}^0$ Mixing



$$H^{eff} = g_R^2 \left[\frac{1}{M_{33}^2}(U_{31}^{d*}U_{32}^d)^2 + \frac{1}{M_{22}^2}(U_{21}^{d*}U_{22}^d)^2 + \frac{1}{M_{11}^2}(U_{11}^{d*}U_{12}^d)^2 \right] (\bar{s}\gamma_\mu d)(\bar{s}\gamma^\mu d) + h.c. \quad (25)$$

$$\Delta m_K^{fam} = \left[(U_{31}^{d*}U_{32}^d)^2 + (U_{21}^{d*}U_{22}^d)^2 \times 5.95 \times 10^{-2} + (U_{11}^{d*}U_{12}^d)^2 \times 2.88 \times 10^{-4} \right] \times \frac{1.291 \times 10^{-11}}{M_{33}^2} \text{ TeV} \quad (26)$$

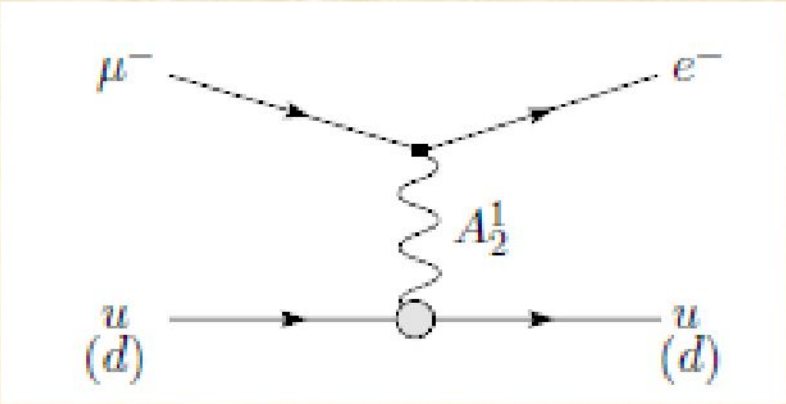
c.f

Observed value: $\Delta m_K^{obs} = (4.484 \pm 0.006) \times 10^{-18}$ TeV

SM value: $\Delta m_K^{SM} \sim 2 \times 10^{-18}$ TeV

(27)

★ μ-e conversion



$$H^{eff}_{\mu\to e} = \frac{g_F^2}{M_{21}^2}\left[(U^{u*}_{21}U^{u}_{11})(\bar{u}\gamma_\rho u) + (U^{d*}_{21}U^{d}_{11})(\bar{d}\gamma_\rho d)\right](\bar{e}\gamma^\rho\mu)$$

(28)

$$\left(\frac{g_F^2/M_{21}^2}{g_W^2/8M_W^2}\right)^2 |U^{q*}_{21}U^{q}_{11}|^2 = |U^{q*}_{21}U^{q}_{11}|^2 \times \frac{3.00\times 10^{-10}}{(M_{33}[\mathrm{TeV}])^4}$$

(29)

6. Summary

The present data in the tau decays show a deviation from the e-μ universality $\varepsilon \equiv \varepsilon_\mu - \varepsilon_e = 0.0020 \pm 0.0016$ **which suggests existence of family gauge bosons with an inverted mass hierarchy. The data suggest that the lightest family gauge boson has a mass** $M_{33} = 0.87^{+1.07}_{-0.22}$ TeV

When we consider that the lightest family gauge boson has a mass $M_{33} \sim 1$ TeV, the current whole data do not reject this possibility.

However, at present, the numerical result should not be taken rigidly, because the data have large errors.

We are eager for more accurate data.

Those are now within our reach.