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

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Abstract

The present data show a deviation from the e-m universality $\varepsilon \equiv \varepsilon_\mu - \varepsilon_e = 0.0020 \pm 0.0016$. If we consider that the deviation originates in a mass difference between family gauge bosons A_3^2 and A_3^1, the sign of the observed deviation suggests $\varepsilon_\mu > \varepsilon_e$, i.e. mass relation $M(A_3^2) < M(A_3^1)$. A possibility of a family gauge boson model with an inverted mass hierarchy is discussed. It is concluded that, contrary to a conventional expectation, it is possible to take a considerably lower mass $M(A_3^3) \sim 1$ TeV, even the constraint from K^0-$\bar{K}^0$ mixing is taken into consideration.

Keywords: flavor symmetry, family gauge bosons

1. What does the observed deviation from e-μ universality suggest to us? From the present observed branching ratios [1] $Br(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) = (17.41 \pm 0.04)\%$ and $Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = (17.83 \pm 0.04)\%$, we obtain a ratio $R_{Br} \equiv Br(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)/Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = 0.97644 \pm 0.00314$. We define parameters δ_μ and δ_e from the ratio R_{amp} of the decay amplitudes:

$$R_{amp} \equiv \frac{1+\delta_\mu}{1+\delta_e} = \sqrt{R_{Br} \frac{f(m_e/m_\tau)}{f(m_\mu/m_\tau)}} = 1.0020 \pm 0.0016, \quad (1)$$

where $f(x)$ is known as the phase space function and it is given by $f(x) = 1 - 8x^2 + 8x^6 - x^8 - 12x^4 \log x^2$. Then, the result (1) gives

$$\delta_{\mu/e} \equiv \delta_\mu - \delta_e = 0.0020 \pm 0.0016. \quad (2)$$

Of course, from this value (2), we cannot conclude that we found a significant difference of the deviation from the e-μ universality.

Here, we notice the sign of the deviation (2), not the magnitude. The sign seems to give us a hint of family gauge bosons. When we consider that the deviation in the tau decays originates in exchange of gauge bosons A_3^2 and A_3^1 which interact as $\tau \to A_3^2 + \mu$ and $\tau \to A_3^1 + e$, respectively as shown in Fig.1. The observed ratio (1) shows $R_{amp} > 1$, i.e. $\delta_\mu > \delta_e$. Since the deviations are considered as $\delta_i \propto g_F^2/M_{3i}^2$ $(i = 1, 2)$, this suggests that a mass of A_3^1 is larger than that of A_3^2, i.e. $M_{32}^2 < M_{31}^2$, where $M_{ij} \equiv m(A_i^j)$. This suggests that the deviation (2) is caused by family gauge bosons with an inverted mass hierarchy.

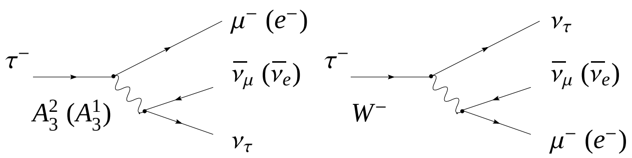

Figure 1: Deviation from e-μ universality in tau decays

The idea that family gauge bosons have an inverted mass hierarchy has some advantages in the phenomenological aspect: (i) A sizable deviation from μ-τ universality in the upsilon decays will be observed because the the lightest gauge boson is A_3^3. (ii) A family gauge boson with the highest mass is A_1^1, so that it plays a role

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in reducinig of the severe constraint from the observed K^0-$\bar{K}^0$ mixing. (iii) The lightest family gauge boson A_3^3 interacts with only quarks and leptons of the third generation, so that the lightest gauge boson search has to be done by $X \to \tau^+\tau^-$, not by $X \to e^+e^-$.

Such a family gauge symmetry model with an inverted mass hierarchy has recently proposed by Yamashita and the author [2]. In this model, masses M_{ij} of the gauge bosons A_i^j are given as follows:

$$m^2(A_i^j) \equiv M_{ij}^2 = k\left(\frac{1}{m_{ei}} + \frac{1}{m_{ej}}\right), \tag{3}$$

where m_{ei} are charged lepton masses. This model was proposed, stimulated by the Sumino mechanism [3]. The model has the following characteristics: (i) Since we assume U(3) family symmetry (not SU(3)), there are 9 family gauge bosons. (ii) The free parameter is only the lightest family gauge boson mass M_{33}. The mass ratios among the family gauge bosons are fixed by the relation (3), and the gauge coupling constant g_F is related to the electric gauge coupling constant e by a relation $g_F^2 = (3/2)\zeta e^2$ ($\zeta \simeq 7/4$). (iii) The violation of the family number is caused only via quark mixing.

2. Can the lightest gauge boson mass be an order of TeV? First, on the basis of the model with the gauge boson masses (3), we investigate a possible deviation from the e-μ universality in the tau decays. Since our family currents are pure vector, the observed deviation parameter $\delta_{\mu/e}$ is related to the theoretical deviation parameter $\delta_i^0 = g_F^2/M_{3i}^2/g_W^2/8M_W^2$ with some correction factor. (For the details, see Ref.[4].) The observed value (2) gives the family gauge boson mass $M_{23} = 2.6^{+3.2}_{-0.7}$ TeV, which corresponds to the lightest family gauge boson mass

$$M_{33} = 0.87^{+1.07}_{-0.22} \text{ TeV}, \tag{4}$$

from the relation (3). Of course, we should not take these numerical results rigidly.

Also, the deviations from the e-μ-τ universality in the upsilon decays $\Upsilon(1S) \to \ell^+\ell^-$ ($\ell = e, \mu, \tau$) have been reported. (Also see, Ref.[4].)

Note that 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. Therefore, in the charged lepton sector, there are no family violating interactions at tree level, while in the quark sectors, family violating interactions appear via quark family mixings:

$$H_{fam} = g_F \sum_{q=u,d} (A_\mu)_i^j (U^{q*})_{ik} (U^q)_{jl} (\bar{q}_k \gamma^\mu q_l), \tag{5}$$

where, for simplicity, we have taken $U_L^d = U_R^d$. For example, in the present model, the $b \to s + \gamma$ is allowed, but $\tau \to \mu + \gamma$ is highly suppressed. Also, we can expect a sizable μ-e conversion. The details are see Ref.[4].

The greatest interest to us is whether we can take a lower value of M_{33} without contradicting the constraint from the observed K^0-$\bar{K}^0$ mixing. The K^0-$\bar{K}^0$ mixing is caused by A_1^1, A_2^2 and A_3^3 exchanges only when the down-quark mixing $U_{L/R}^d \neq \mathbf{1}$ exists. If we assume the vacuum-insertion approximation, we obtain

$$\Delta m_K^{fam} = \Big[(U_{31}^{d*}U_{32}^d)^2 + (U_{21}^{d*}U_{22}^d)^2 \times 5.95 \times 10^{-2}$$

$$+ (U_{11}^{d*}U_{12}^d)^2 \times 2.88 \times 10^{-4}\Big] \times \frac{1.291 \times 10^{-11}}{M_{33}^2} \text{ TeV}, \tag{6}$$

where the value of M_{33} is taken in a unit of TeV. On the other hand, the observed value is $\Delta m_K = (4.484 \pm 0.006) \times 10^{-18}$ TeV [1], and the standard model has a share of $\Delta m_K \sim 2 \times 10^{-18}$ TeV. If we take $U^d = V_{CKM}$ on trial, we obtain $[4.3287 \times 10^{-19} + 2.8337 \times 10^{-14} + 1.37722 \times 10^{-16}]/M_{33}^2$, as the value of Δm_K^{fam}. The dominant term is the second term which is due to the exchange of A_2^2 boson. Therefore, if we suppose $U^d \simeq V_{CKM}$, we must consider (i) M_{33} must be $M_{33} \geq 10^2$ TeV; or (ii) if we want a lower M_{33}, we must take $U^d = \mathbf{1}$, especially, $|U_{21}^d| < 10^{-2}$; (iii) for the case $U^d = \mathbf{1}$, we must also check the D^0-$\bar{D}^0$ mixing for the case $U^d \simeq V_{CKM}$, so that a similar problem occurs.

However, we can show [4] that it is possible to take $M_{33} \sim 1$ TeV as far as we adopt a special quark mass matrix model with $|U_{21}^u| < 10^{-2}$ and $|U_{21}^d| < 10^{-2}$ but with $|U_{12}^u| \simeq |U_{12}^d| \simeq |V_{us}|$.

3. Conclusion In conclusion, the sign of the deviation from the e-μ universality in the tau decays is in favor of the family gauge boson model with an inverted mass hierarchy. Present data are consistent with a model with the lightest family gauge boson with the mass $M_{33} \sim 1$ TeV. We are eager for more accurate data on the deviations from the e-μ-τ universality, because those are now within our reach. Also, we expect a direct search for A_3^3, for example, at the LHC. For the details of the direct search for the lightest family gauge boson A_3^3 at the LHC, we shall report elsewhere.

References

[1] J. Beringer *et al.* Particle Data Group, Phys. Rev. D **86**. 0100001, (2012).
[2] Y. Koide and T. Yamashita, Phys. Lett. B **711**, 384 (2012).
[3] Y. Sumino, Phys. Lett. B **671**, 477 (2009).
[4] Y. Koide, arXiv.1209.1694 [hep-ph].