Cosmological Constraint on the Zee model

N. Haba$^{1,2}$, K. Hamaguchi$^3$, and Tomoharu Suzuki$^{2,†}$

$^1$Faculty of Engineering, Mie University, Tsu Mie 514-8507, Japan
$^2$Department of Physics, Nagoya University, Nagoya, 464-8602, Japan
$^3$Department of Physics, University of Tokyo, Tokyo, 113-0033, Japan

March 25, 2022

Abstract

It is well known that the Zee model induces small neutrino masses by radiative corrections, where the bi-maximal flavor mixing is possible. We analyze the cosmological condition in order for the baryon asymmetry generated in the early universe not to be washed out in the Zee model. Since the lepton number is violated explicitly in the Zee model, the baryon asymmetry might be washed out through the sphaleron processes together with the lepton-number violating interactions. In this letter, we will show that the baryon asymmetry is not washed out, although it has been said that the Zee model cannot preserve the baryon asymmetry generated in the early universe. This can be seen by considering an approximately conserved number, $L' \equiv L_e - L_\mu - L_\tau$. 

$^*haba@eken.phys.nagoya-u.ac.jp$

$^†hama@hep-th.phys.s.u-tokyo.ac.jp$

$^‡tomoharu@eken.phys.nagoya-u.ac.jp$
1 Introduction

Recently the evidences of neutrino oscillations are strongly supported by both of the atmospheric \cite{1, 2} and the solar neutrino experiments \cite{3, 4, 5, 6}. The former suggests an almost maximal lepton flavor mixing between the 2nd and the 3rd generations, while the favorable solution to the solar neutrino deficits is given by large mixing angle solution between the 1st and the 2nd generations (LMA, LOW or VO) \cite{7}. Neutrino oscillation experiments indicate that the neutrinos have tiny but finite masses, with two mass squared differences $\Delta m^2_\odot < \Delta m^2_{\text{atm}}$. Since the neutrino mass is much smaller than other quarks and leptons, the origin of the neutrino mass is expected to be different from that of others. The most popular mechanism to induce the small neutrino masses is the seesaw mechanism \cite{8}, which needs heavy right-handed neutrinos. However, it is important to consider also other possible scenarios which can explain the small neutrino masses, especially low-energy extensions of the standard model. The Zee model \cite{9} is such an alternative, which induces small neutrino masses by radiative corrections, where the lepton number is violated explicitly.

Generally, if there are lepton number violating interactions, care has to be taken for these interactions not to be too strong at the temperatures above the electroweak scale, since the baryon asymmetry generated in the early universe might be washed out by the “sphaleron” process \cite{10}, which violates a linear combination of baryon ($B$) and lepton ($L$) number, $B + L$. If the rate of the lepton number violating process becomes faster than the Hubble expansion rate $H$ during the epoch when the sphaleron process is in thermal equilibrium, the baryon asymmetry generated at higher temperature would be washed out, and there would be no matter anti-matter asymmetry in the present universe, which conflicts with the observation.

In this letter, we analyze the cosmological condition in order for the baryon asymmetry generated in the early universe not to be washed out in the Zee model. (We will not discuss the production mechanism of the baryon asymmetry. Instead, we just assume that the desired amount of the baryon asymmetry is generated in the early universe and discuss whether or not this baryon asymmetry can be preserved against the lepton number violating interaction in the Zee model together with the sphaleron process.) In most part of the analysis, we take the LOW solution to the solar neutrino problem. (We shall note on the cases of other solutions in the last section.) We find that the baryon asymmetry is not washed out, although it has been said that the Zee model cannot preserve the baryon asymmetry \cite{11}. This can be easily shown from the view point of a new lepton number $L' \equiv L_e - L_\mu - L_\tau$.

\footnote{In this letter we assume that the production of the baryon asymmetry took place in the early universe before the electroweak phase transition.}
2 Brief review of the Zee model

Let us give a brief overview of the Zee model \cite{12, 13, 14, 15, 16} at first. The Zee model is a simple extension of the standard model, which has two Higgs doublets \( \phi_i = (\phi_0^i, \phi_-^i)^T \) \((i = 1, 2)\) and one \(SU(2)_L\)-singlet charged Higgs field (Zee singlet) \( \omega^\pm \). The Zee model has the following interactions in addition to the standard model ones;

\[
\Delta L = f_{\alpha\beta} l_{\alpha L}^C (i\tau_2) l_{\beta L}^C \omega^+ + \mu \phi_2^T (i\tau_2) \phi_1 \omega^+ + h.c.,
\]

where \( l_{\alpha L} \) denote the left-handed lepton doublets with flavor indices \( \alpha, \beta = e, \mu, \tau \). Notice that the coupling \( f_{\alpha\beta} \) is anti-symmetric for the flavor index. For simplicity, we have omitted the Higgs potential \( V(\phi_1, \phi_2, \omega) \) which are irrelevant to the following discussion. As for the Yukawa interaction, we assume only \( \phi_1 \) couples to lepton fields as,

\[
\mathcal{L}_Y = (y_e)_{\alpha\beta} \tilde{\phi}_1^\dagger l_{\alpha L} + h.c.,
\]

where \( \tilde{\phi}_1 \equiv (i\tau_2) \phi_1^* \). As can be seen from Eqs. (1) and (2), the lepton number \( L \) is explicitly violated in the Zee model.

In the charged Higgs sector, the Zee singlet \( \omega \) is mixed with the charged Higgs boson \( \Phi^- \) through the \( \mu \phi_1 \phi_2 \omega \) interaction in Eq. (1);

\[
\Phi^- = \cos \chi S_1^- - \sin \chi S_2^-,
\]

\[
\omega^- = \sin \chi S_1^- + \cos \chi S_2^-.
\]

Here, \( \Phi^- = \cos \beta \phi_1^- - \sin \beta \phi_2^- \) is the charged Higgs boson which is orthogonal to the would-be Goldstone boson after the neutral Higgs fields acquire vacuum-expectation values (VEVs) \( \langle \phi_0^1 \rangle = v_1 \), where \( \tan \beta \equiv \langle \phi_0^1 \rangle / \langle \phi_0^2 \rangle = v_1 / v_2 \). We denote the mass eigenstates of the charged Higgs sector as \( S_{\pm1} \) and their mass \( m_{S_i} \).

In the Zee model, neutrino masses are generated by radiative corrections, as shown in Fig. 1, and hence this model could provide an explanation of the smallness of neutrino masses. The element of the mass matrix, generated by radiative correction at one loop level, is given by

\[
m_{\alpha\beta} = f_{\alpha\beta} (m_{\beta\beta}^2 - m_{\alpha\alpha}^2) \mu \cot \beta \frac{1}{16\pi^2} \frac{1}{m_{S_1}^2 - m_{S_2}^2} \ln \frac{m_{S_1}^2}{m_{S_2}^2}.
\]

Here \( m_{L\alpha} (\alpha = e, \mu, \tau) \) are the charged lepton masses. In Eq. (4), we have used \( m_{S_i} \gg m_{L\alpha} \).

Since the coupling constants \( f_{\alpha\beta} \) are antisymmetric for the indices \( \alpha, \beta \), the mass matrix Eq. (4) is traceless. The above Zee mass matrix has been analyzed \cite{12} in the light of

\(^1\)We assume that there is a mixing term between \( \phi_1 \) and \( \phi_2 \), \( m_2^2 \phi_1^\dagger \phi_2 + h.c., \) in \( V(\phi_1, \phi_2, \omega) \).

\(^2\) If we consider higher order loops, non-zero values appear in the diagonal elements. We shall neglect them, since the conclusion does not change.
Figure 1: Neutrino mass diagram in the Zee model

recent neutrino-oscillation experiments, and it was shown that it must be the following bi-maximal form to explain the experimental results:

\[
M_\nu = \begin{pmatrix} 0 & m_{e\mu} & m_{e\tau} \\ m_{e\mu} & 0 & m_{\mu\tau} \\ m_{e\tau} & m_{\mu\tau} & 0 \end{pmatrix} \simeq m_0 \begin{pmatrix} 0 & -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & 0 & \epsilon \\ 1/\sqrt{2} & \epsilon & 0 \end{pmatrix},
\]

(5)

where \(m_0^2 = m_{e\mu}^2 + m_{e\tau}^2\), \(\epsilon = m_{\mu\tau}/m_0\), \(m_{e\mu} \simeq -m_{e\tau}\) and \(\epsilon \ll 1\). The eigenvalues and the MNS matrix induced from the neutrino mass matrix Eq. (5) is given by

\[m_1 \simeq m_0(1 - 1/2\epsilon) \quad m_2 \simeq -m_0(1 + 1/2\epsilon), \quad m_3 \simeq m_0 \epsilon,\]

(6)

and

\[U_{\text{MNS}} \sim \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 0 \\ -1/2 & 1/2 & 1/\sqrt{2} \\ 1/2 & -1/2 & 1/\sqrt{2} \end{pmatrix}.
\]

(7)

The neutrino mass hierarchy is shown in Fig. 1. The mixing angle between the 1st and the 2nd generations is maximal as well as the mixing angle between the 2nd and the 3rd generations (\(\theta_{12} \sim \theta_{23} \sim 45^\circ\)). From oscillation experiments, the eigenvalues of the mass matrix have to satisfy the following relations,

\[m_1^2 - m_3^2 \simeq m_2^2 - m_3^2 \simeq m_0^2\]

\[\simeq 2m_{e\mu}^2 \simeq 2m_{e\tau}^2 \simeq \Delta m_{\text{atm}}^2,\]

(8)

\[m_2^2 - m_1^2 \simeq 2m_0^2 \epsilon \]

\[\simeq 2m_0m_{\mu\tau} \simeq \Delta m_\odot^2.\]

(9)
Then, the relations among $f_{e\mu}$, $f_{e\tau}$ and $f_{\mu\tau}$ should be

$$\left| \frac{f_{e\mu}}{f_{e\tau}} \right| \simeq \frac{m_\tau^2}{m_\mu^2} \simeq 3 \times 10^2,$$  

(10)

$$\left| \frac{f_{e\tau}}{f_{\mu\tau}} \right| \simeq \frac{\sqrt{2} \Delta m^2_{\text{atm}}}{\Delta m^2_{\odot}} \simeq 3 \times 10^4,$$  

(11)

from Eq. (4) and explicit values of $m_\mu$, $m_\tau$, $\Delta m^2_{\text{atm}}$ and $\Delta m^2_{\odot}$. Here we take the LOW solution to the solar neutrino problem [§]. These relations induce the ratio of $f_{e\mu}, f_{e\tau}$ and $f_{\mu\tau}$ as

$$|f_{e\mu}| : |f_{e\tau}| : |f_{\mu\tau}| = 1 : 3 \times 10^{-3} : 10^{-7}.$$  

(12)

The phenomenological constraints on $f_{\alpha\beta}$ from various experimental bounds [13, 17, 18] are given by

$$\frac{|f_{e\mu}|^2}{M^2} < 3 \times 10^{-3} G_F \quad \rightarrow \quad |f_{e\mu}| < 2 \times 10^{-1} \left( \frac{M}{1 \text{TeV}} \right),$$  

(13)

$$\frac{|f_{\mu\tau}|^2}{M^2} < 8.5 \times 10^{-3} G_F \quad \rightarrow \quad |f_{\mu\tau}| < 3 \times 10^{-1} \left( \frac{M}{1 \text{TeV}} \right),$$  

(14)

where $G_F$ is Fermi constant and

$$\frac{1}{M^2} \equiv \frac{\sin^2 \chi}{m_{S_1}^2} + \frac{\cos^2 \chi}{m_{S_2}^2}.$$  

(15)

§ As for the other solar neutrino solutions, we will give comments in the last section.
Equations (13) and (14) mean that \( f_{\alpha\beta} \) cannot be of \( \mathcal{O}(1) \) unless the charged Higgs boson masses are of order 10 TeV. Notice that the constraints for \( f_{\mu\tau} \) and \( f_{e\tau} \) in Eq. (14) are automatically satisfied as long as the relation in Eq. (12) and the constraint for \( f_{e\mu} \) in Eq. (13) are satisfied. Actually, the conditions Eqs. (12) and (13) give rise to the following constraint on the smallest coupling \( f_{\mu\tau} \):

\[
|f_{\mu\tau}| < 2 \times 10^{-8} \times \left( \frac{M}{1\text{TeV}} \right),
\]

which is much severer constraint than that of Eq. (14).

### 3 Cosmological Constraint on the Zee model

Now let us turn to discuss the cosmological constraint on the Zee model. A crucial point is that a linear combination of the lepton flavors, \( L' \equiv L_e - L_\mu - L_\tau \), is approximately conserved in the Zee model. This is because the \( L' \)-number is violated only through the coupling \( f_{\mu\tau} \), which is much smaller than the other couplings, as can be seen in Eq. (12).

(Here, we assign the \( L' \)-number of the Zee singlet \( \omega \) to be zero.) Notice that the sphaleron preserves not only the total \( B-L = B - (L_e + L_\mu + L_\tau) \) but each \( B/3 - L_\alpha \) (\( \alpha = e, \mu, \tau \)). Thus, the number \( B/3 + L' \) is also conserved under the sphaleron process, and is violated only by the tiny coupling \( f_{\mu\tau} \).

When the temperature \( T \) is higher than the mass of \( \omega \), \( M_\omega \), the relevant interactions which violate \( L' \) are; \( l_\mu l_\tau \leftrightarrow l_e l_\mu \), \( l_\mu l_\tau \leftrightarrow \phi_1 \phi_2 \), and \( l_\mu l_\tau \leftrightarrow \omega \). We consider the three-body process \( l_\mu l_\tau \leftrightarrow \omega \), since it gives the severest constraint on the coupling \( f_{\mu\tau} \). The rate of this process is given by

\[
\Gamma(l_\mu l_\tau \leftrightarrow \omega) \simeq \frac{1}{2\pi} |f_{\mu\tau}|^2 M_\omega \left(\frac{M_\omega}{T}\right).
\]

This \( L' \)-violating interaction is out of equilibrium if the above rates is slower than the Hubble parameter of the expanding universe, \( H \simeq (g_\ast \pi^2/90)^{1/2} T^2 / M_{\text{PL}} \). \((M_{\text{PL}} \simeq 2 \times 10^{18})\)

\footnote{If \( \mu > M_\omega \), the four-body process \( l_\mu l_\tau \leftrightarrow \phi_1 \phi_2 \) can give a severer constraint on \( f_{\mu\tau} \) than that of the above three-body process. In this case, we must take care the possibility that the condition \( \mu > M_\omega, M_\Phi \) might make the physical Higgs masses, \( m_{S_{1,2}}^2 \), be negative. If the condition \( \mu > M_\omega \) and \( m_{S_{1,2}}^2 > 0 \) is satisfied, we can analyze the out-of-equilibrium condition of this four-body process in a similar way to the three-body case. However, the following conclusion does not change, since the coupling \( f_{\mu\tau} \) is suppressed by \( (M_\omega/\mu)^2 \) for \( \mu > M_\omega \) [See Eq. (12)] and hence the out-of-equilibrium condition is satisfied more easily than the three-body case.}
GeV is the reduced Planck scale and \( g_* \simeq 100 \) is the number of relativistic degrees of freedom.) Namely, the out-of-equilibrium condition is given by

\[ |f_{\mu\tau}|^2 \lesssim 1 \times 10^{-14} \left( \frac{M_\omega}{1 \text{ TeV}} \right). \tag{18} \]

On the other hand, as discussed in the previous section, the coupling \( f_{\mu\tau} \) is very small in order to explain the neutrino oscillation experiments. Hereafter, we assume \( M_\omega \gg M_\Phi \) for simplicity. In this case, we could consider \( m_{S_2} \simeq M_\omega \gg m_{S_1} \simeq M_\Phi \). Then, from Eqs. (4), (8), and (9), the coupling \( f_{\mu\tau} \) is given by

\[ |f_{\mu\tau}|^2 \simeq 64\pi^4 \frac{M_\omega^4 (\Delta m^2_{\odot})^2}{m_\mu^2 \mu^2 \Delta m^2_{\text{atm}}} \]

\[ \simeq 10^{-19} \left( \frac{M_\omega}{1 \text{ TeV}} \right)^4 \left( \frac{100 \text{ GeV}}{\mu} \right)^2 \left( \frac{\Delta m^2_{\odot}}{10^{-7} \text{ eV}^2} \right)^2 \left( \frac{3 \times 10^{-3} \text{ eV}^2}{\Delta m^2_{\text{atm}}} \right), \tag{19} \]

where we take \( \tan \beta = O(1) \) and \( \ln(M^2_\Phi/M^2_\omega) = O(1) \).

Here we take the explicit values of \( \mu \) and \( M_\omega \), for example, as \( \mu \sim 100 \text{ GeV} \) and \( M_\omega \sim 1 \text{ TeV} \). In this case Eqs. (18) and (19) show that the \( L' \)-violating interactions are really out of equilibrium during \( T > M_\omega \). This means that the baryon asymmetry is not washed out in the case of LOW solution. This result is not changed, unless \( M_\omega \) is much heavier than \( O(10 \text{ TeV}) \) or \( \mu \) is extremely small.

At the lower temperature \( T < M_\omega \), the rate of the three-body process is reduced because the number density of the \( \omega \) particle is suppressed by a Boltzmann factor \( e^{-M_\omega/T} \), and the four-body interactions are also suppressed by a factor \( (T/M_\omega)^4 \).

As we have seen in this section, the \( L' \)-violating interactions have been out of equilibrium since the birth of our universe. This is because \( f_{\mu\tau} \) must be small in order to explain the neutrino oscillation experiments. Actually, the analysis of chemical potentials in the high-temperature phase gives the following relation between the baryon asymmetry \( B \) and the number \( B/3 + L' \);

\[ B = \frac{60}{563} (B/3 + L'). \tag{20} \]

Therefore the baryon asymmetry in our universe can be preserved, once the asymmetry of \( B/3 + L' \) is produced in the early universe.
4 Summary and Discussion

Recent neutrino experiments indicate that neutrino masses are tiny and there are two mass squared differences as $\Delta m^2_\odot < \Delta m^2_{\text{atm}}$. It is well known that the Zee model induces small neutrino masses by radiative corrections, where the lepton number is violated explicitly. If the lepton number violating interaction becomes faster than the Hubble parameter before the electroweak phase transition, the baryon asymmetry generated at higher temperature (in the early universe) would be washed out. Therefore, in order not to destroy the baryon asymmetry, the lepton number violating interaction must be out-of-equilibrium.

In this letter we have analyzed the cosmological condition in order for the baryon asymmetry generated in the early universe not to be washed out in the Zee model, taking the LOW solution to the solar neutrino problem. In this case, we find the baryon asymmetry is not washed out, although it has been said that the Zee model cannot preserve the baryon asymmetry [11]. This can be easily shown from the viewpoint of the new lepton number $L' \equiv L_e - L_\mu - L_\tau$.

The lepton number $L'$ is almost conserved quantity which is violated only by the tiny coupling $f_{\mu\tau}$. From the viewpoint of $L'$, the sphaleron process preserves $B/3 + L'$. The $L'$ violating interaction through $f_{\mu\tau}$ is out-of-equilibrium in the Zee model when the results from neutrino-oscillation experiments and natural mass scales of Higgs masses are used for the input parameters. Therefore, we can conclude that once the asymmetry of $B/3 + (L_e - L_\mu - L_\tau)$ is produced, the baryon asymmetry is preserved in our universe.

We have shown that the baryon asymmetry is preserved against the lepton-number violating interaction in the Zee model. However, it is very difficult to explain the origin of the asymmetry of $B/3 + L'$ within the Zee model. Therefore, some mechanism which can generate a $B/3 + L'$ asymmetry is necessary.

Finally, we comment on the cases of other solar neutrino solutions (LMA and VO). First, we consider the LMA case. It has been pointed out [14] that the Zee model could not explain the LMA solution, since the Zee model induces a nearly maximal mixing of solar-neutrino oscillation ($\sin^2 2\theta_\odot \simeq 1$), which is in poor agreement with the observed data [7]. If one would still apply the present analysis to the LMA solution, the out-of-equilibrium condition of $L'$ violating interaction is marginally satisfied [See Eqs. (18) and (19)], although it requires a more detailed analysis including a numerical solution of the Boltzmann equation. The second case is the VO solution. As can be seen in Eq. (19), the coupling $f_{\mu\tau}$ which violates $L'$ is proportional to the $\Delta m^2_\odot$. Therefore, in the case of the VO solution, where $\Delta m^2_\odot$ is much smaller than that of the LOW solution, the rate of the $L'$-violating interaction is also small enough, and the baryon asymmetry is preserved as discussed in previous section.
Acknowledgment

We would like to thank T. Yanagida for the suggestion of this work. We also thank T. Moroi for the collaboration in the early stage of this work, and thank M. Tanimoto, Y. Koide and S. Kanemura for useful discussions. NH is supported in part in part by the Grant-in-Aid for Science Research, Ministry of Education, Science and Culture, Japan (No. 12740146 ). The work of KH was supported by the Japanese Society for the Promotion of Science.

References

[1] Y. Fukuda et al. [Kamiokande Collaboration], Phys. Rev. Lett. 77 (1996) 1683.

[2] Y. Fukuda et al. [Kamiokande Collaboration], Phys. Lett. B 335 (1994) 237; Y. Fukuda et al. [Super-Kamiokande Collaboration], Phys. Rev. Lett. 81 (1998) 1562 [hep-ex/9807003]; T. Kajita [Super-Kamiokande Collaboration], in Neutrino Physics and Astrophysics, Proceedings of the XVIIIth International Conference on Neutrino Physics and Astrophysics (Neutrino '98), June 4-9, 1998, Takayama, Japan, edited by Y. Suzuki and Y. Totsuka, (Elsevier Science B.V., Amsterdam, 1999) page 123; Nucl. Phys. Proc. Suppl. 77, 123 (1999) [hep-ex/9810001].

[3] Y. Fukuda et al. [Super-Kamiokande Collaboration], Phys. Rev. Lett. 81 (1998) 1158 [hep-ex/9805021]; Erratum-ibid. 81 (1998) 4279; Phys. Rev. Lett. 82 (1999) 2430 [hep-ex/9812011]; Phys. Rev. Lett. 82 (1999) 1810 [hep-ex/9812009].

[4] Q. R. Ahmad et al. [SNO Collaboration], nucl-ex/0106015.

[5] K. Lande et al., Astrophys. J. 496 (1998) 505.

[6] V. N. Gavrin [SAGE Collaboration], Nucl. Phys. Proc. Suppl. 91 (2001) 36; E. Bellotti, Nucl. Phys. Proc. Suppl. 91 (2001) 44.

[7] V. Barger, D. Marfatia and K. Whisnant, hep-ph/0106207. G. L. Fogli, E. Lisi, D. Montanino and A. Palazzo, hep-ph/0106247; J. N. Bahcall, M. C. Gonzalez-Garcia and C. Pena-Garay, hep-ph/0106258; A. Bandyopadhyay, S. Choubey, S. Goswami and K. Kar, hep-ph/0106264.

[8] T. Yanagida, “Horizontal Symmetry And Masses Of Neutrinos”, Prog. Theor. Phys. 64 (1980) 1103, and in Proceedings of the “Workshop on the Unified Theory and the Baryon Number in the Universe”, Tsukuba, Japan, Feb 13-14, 1979, Eds. O. Sawada
and A. Sugamoto, KEK report KEK-79-18, p. 95; M. Gell-Mann, P. Ramond and R. Slansky, in “Supergravity” (North-Holland, Amsterdam, 1979) eds. D.Z. Freedman and P. van Nieuwenhuizen, Print-80-0576 (CERN).

[9] A. Zee, Phys. Lett. B 93 (1980) 389 [Erratum-ibid. B 95 (1980) 461]; Phys. Lett. B 161 (1985) 141.

[10] V. A. Kuzmin, V. A. Rubakov and M. E. Shaposhnikov, Phys. Lett. B 155 (1985) 36.

[11] E. Ma, M. Raidal and U. Sarkar, Phys. Lett. B 460 (1999) 359 [hep-ph/9901409]; U. Sarkar, Pramana 54 (2000) 101 [hep-ph/9906335].

[12] C. Jarlskog, M. Matsuda, S. Skadhauge and M. Tanimoto, Phys. Lett. B 449 (1999) 240 [hep-ph/9812282], [hep-ph/0005147].

[13] A. Y. Smirnov and M. Tanimoto, Phys. Rev. D 55 (1997) 1665 [hep-ph/9604370].

[14] P. H. Frampton and S. L. Glashow, Phys. Lett. B 461 (1999) 95 [hep-ph/9906375]; Y. Koide, [hep-ph/0104226].

[15] S. Kanemura, T. Kasai, G. Lin, Y. Okada, J. Tseng and C. P. Yuan, [hep-ph/0011357].

[16] D. Chang and A. Zee, Phys. Rev. D 61, 071303 (2000) [hep-ph/9912380].

[17] G. C. McLaughlin and J. N. Ng, Phys. Lett. B 455 (1999) 224 [hep-ph/9903508].

[18] E. Mituda and K. Sasaki, [hep-ph/0103202].