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Working group report: Flavor physics and model building

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Abstract. This is the report of flavor physics and model building working group at WHEPP-9. While activities in flavor physics have been mainly focused on B-physics, those in model building have been primarily devoted to neutrino physics. We present summary of working group discussions carried out during the workshop in the above fields, and also briefly review the progress made in some projects subsequently.

Keywords. Flavor physics; B-physics; CP-violation; quantum chromodynamics; neutrino masses and mixings; flavor symmetries; extra dimensions; grand unification.

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1. Introduction

The activities of this working group were divided into two subgroups. The first, flavor physics subgroup concentrated mostly on B-physics while the second, model building subgroup focused on models in neutrino physics.

The B factories have achieved unprecedented luminosities and accumulated huge data samples allowing measurement of many branching ratios and CP asymmetries. In addition, now there are other significant results from the Tevatron. The activities of the flavor physics subgroup were motivated by this experimental information as one hopes that the precision measurements in B-physics will reveal and/or tightly constrain physics beyond the Standard Model. Section 2 of this report summarizes these activities of the flavour physics subgroup.

Recent experimental data on neutrino masses and mixings have triggered considerable interest in the construction of theories beyond the Standard Model (SM) or MSSM while preserving grand unification of forces at high scales as evidenced earlier through CERN-LEP measurements. Although no general consensus has emerged so far on any particular model of particle physics, it appears that a flavor symmetry appended to the SM or its extensions works very well in explaining particle interactions along with neutrino masses and mixings through see-saw mechanism. The working group activities were focused on model building with flavor symmetries and extra dimensions with or without supersymmetry and are described in §3.

2. Flavor physics

Since the plenary talks in flavor physics were scheduled after the first discussion session, Prof. Hsiang-nan Li and Prof. Wei-Shu Hou were invited in the first meeting of the group on 5 January 2006, to give a short summary of the hot topics and possible projects that could be pursued in flavour physics. Prof. Li outlined some interesting exclusive B-meson decays which could be investigated using the PQCD approach. These included: B-meson decays into charmonia, into tensor mesons, and into baryons, and three-body B-meson decays. This short talk was complemented by that of Prof. Hou's, which emphasized using flavor physics for the study of physics beyond the Standard Model. This was followed by a general discussion and listing of the projects.

There were five plenary talks in flavor physics:

- Puzzles in B physics, recent developments in PQCD, QCDF, SCET – Hsiang-nan Li
- New physics hints in B decay and collider outlook – Wei-Shu Hou
- The future of flavor physics – David Hitlin
- CP-violation in B decays – Yoshihide Sakai
- Results from BABAR and comparison with other experiments – Franco Simonetto

Most of these talks are published in these proceedings. In addition, there were three overlapping working group talks:

- Flavor diagonal and off-diagonal fermion dipole transition in supersymmetry without R-parity – Rishikesh Vaidya
- New physics bounds on $B_s \to l^+l^-$ – Ashutosh Kumar Alok
- New physics in $b \to s\bar{s}s$ decay – Soumitra Nandi

and one working group non-overlapping talk:

- Dalitz plot analysis in the charmless B decays – Gagan Mohanty

2.1 *Lectures on PQCD*

Hsiang-nan Li

Many WG3 members expressed interest in learning details of the PQCD approach. Hence, Prof. Li gave a 1.5 h lecture on 6 January, briefly explaining the basic idea and formulation of the PQCD approach to exclusive B-meson decays. The lecture was well-received by the audience, and led to many follow-up discussions during the workshop. The content of the lecture is summarized below.

Hadronic processes involve both nonperturbative and perturbative dynamics even in the high-energy limit. It is possible to separate these two dramatically different types of dynamics, absorbing the former into hadron distribution amplitudes, and the latter into hard kernels. Such separation, i.e., factorization theorem, works to all orders in the coupling constant, and up to some inverse powers of the large energy. A simpler version of factorization theorem is collinear factorization, in which only longitudinal parton momenta are taken into account. To derive collinear factorization, nonvanishing longitudinal parton momenta are assumed. Therefore, when convoluting hard kernels with hadron distribution amplitudes, the contribution from the region with small parton longitudinal momenta should not dominate. For processes involving light hadrons, this criterion is satisfied. However, as applying collinear factorization to exclusive B-meson decays, end-point singularities from the small longitudinal parton momenta appear, indicating the failure of collinear factorization. In this case more sophisticated k_{T} factorization is more appropriate.

The PQCD approach is based on k_{T} factorization. When the region of the small longitudinal parton momenta are important, the transverse parton momenta k_{T} should be included, leading to the convolution not only in the longitudinal momenta but also in the parton transverse momenta. The aforementioned end-point singularities are then smeared into large logarithms $\ln k_{\mathrm{T}}$. To have a reliable perturbative expansion, it is necessary to resum these large logarithms into the Sudakov factor. It can be shown that the behavior of the Sudakov factor suppresses the region of small k_{T}. Hence, even when the longitudinal momenta are small, i.e., in the end-point region, k_{T} is still sufficiently large to make sense of a perturbative calculation. Using this formalism, all topological amplitudes of exclusive B-meson decays can be computed, including the factorizable, nonfactorizable, and annihilation contributions. It is not necessary to introduce arbitrary cut-offs for the end-point singularities.

The next few subsections, give a brief review of the problems pursued in flavor physics, following discussions during the workshop.

2.2 *New physics upper bounds on the branching ratios of $B_{\mathrm{s}} \to l^+l^-$ and $B_{\mathrm{s}} \to l^+l^-\gamma$*

Ashutosh Kumar Alok and S Uma Sankar

We consider the most general new physics effective Lagrangian for $b \to sl^+l^-$. We derive the upper limit on the branching ratio for the processes $B_{\mathrm{s}} \to l^+l^-$ where $l = e, \mu$, subject to the current experimental bounds on related processes, $B \to (K, K^*)l^+l^-$ [1,2]. If the new physics interactions are of vector/axial-vector form, the present measured rates for $B \to (K, K^*)l^+l^-$ constrain $B(B_{\mathrm{s}} \to l^+l^-)$ to be of the same order of magnitude as their respective Standard Model predictions. On the other hand, if the new physics interactions are of scalar/pseudoscalar form, $B \to (K, K^*)l^+l^-$ rates do not impose any useful constraint on $B(B_{\mathrm{s}} \to l^+l^-)$ and the branching ratios of these decays can be as large as the present experimental upper bounds [3]. If future experiments measure $B(B_{\mathrm{s}} \to l^+l^-)$ to be greater than 10^{-8} [4] then the new physics giving rise to these decays has to be of the scalar/pseudoscalar form [5]. The radiative decay $B_s \to l^+l^-\gamma$ is not subject to helicity suppression and hence has a larger branching ratio compared to the purely leptonic decays discussed above. We consider the effect of new physics on $B(B_s \to l^+l^-\gamma)$ subject to the present experimental constraints on $B \to (K, K^*)l^+l^-$ and $B \to K^*\gamma$. New physics in form scalar/pseudoscalar, which makes a very large contribution to $B_s \to l^+l^-$, makes *no contribution at all* to $B_s \to l^+l^-\gamma$ due to angular momentum conservation [6,7]. New physics in the form of vector/axial-vector operators is constrained by the data on $B \to (K, K^*)l^+l^-$ and new physics in the form of tensor/pseudotensor is constrained by the data on $B \to K^*\gamma$. In both cases, enhancement of $B(B_s \to l^+l^-\gamma)$ much beyond the Standard Model expectation is impossible [7]. In conclusion, present data on $B \to (K, K^*)$ transitions allow for large $B(B_s \to l^+l^-)$ (large enough to be observable at Tevatron and LHC-b) but do not allow $B(B_s \to l^+l^-\gamma)$ to be much larger than its Standard Model expectation.

2.3 k_T *factorization without light-cone singularity*

Soumitra Nandi and Hsiang-nan Li

The naive definition of a k_T-dependent B-meson wave function suffers the light-cone singularities, which result from the loop momentum parallel to the Wilson lines. Such light-cone singularities, canceling in collinear factorization, do not cause any trouble. These singularities must be removed. Otherwise, hard kernels, computed as the difference between full Feynman diagrams and effective diagrams for the B-meson wave function, will be divergent too. Therefore, the extension from collinear factorization to k_T factorization is not trivial at all. We plan to remove these singularities by introducing a denominator, which contains the same singularities as in the naive definition. We shall perform a one-loop calculation for the radiative decay $Bt \to \gamma l\nu$ to demonstrate the subtraction of the light-cone singularities. It will be the first valid derivation of the higher-order hard kernel in k_T factorization.

2.4 *Moduli contribution to the charmless nonleptonic* $B \to \Phi K_2^*$ *decay*

Prasanta Kumar Das, Basudha Misra, Jyoti Prasad Saha
and Chandradew Sharma

2.4.1 *Introduction*

Non-leptonic weak hadronic decays of B-meson in the factorization framework is a useful probe to test the Standard Model, particularly the strong interaction dynamics and has been very successful in explaining the exclusive $B \to PP$, PV, VV, PT, VT (where P, V and T stands for pseudoscalar, vector and tensor meson) decay data, reported by the CLEO, BABAR and BELLE Collaborations [8–10]. The $B \to P(V)T$ decay has been investigated in detail [11] and here we will investigate the $B \to \Phi(V)K_2^*(T)$ (with $J_{K_2^*(1430)} = 2$) decay working within the factorization framework.

Recently, the BABAR Collaboration reported [12] the angular distribution for the decay $B^0 \to \Phi K_J^{*0}(1430)$. They found 181 ± 17 events for the tensor ($J = 2$) resonance at greater than 3σ confidence level (CL). Here we will analyze this $B \to \Phi K_2^*(1430)$ decay and predict its branching ratio, CP-asymmetry ($A_{\rm CP}$) and several other observables (by making a detailed angular analysis) within the Standard Model (SM) and in the new physics (NP) context. Our ideas could be tested at LHC-b in the future.

2.4.2 *Radion in the brane world model*

The Randall–Sundrum (RS) model [13], a proposal for the hierarchy resolution, is phenomenologically quite interesting [14]. The world, according to this model, is five-dimensional where the fifth spatial dimension is S^1/Z_2 orbifold. The metric describing such a world can be written as

$$\mathrm{d}s^2 = g_{AB}\mathrm{d}x^A\mathrm{d}x^B = \mathrm{e}^{-2kR_c|\theta|}\eta_{\mu\nu}\mathrm{d}x^\mu\mathrm{d}x^\nu + \mathrm{d}y^2, \tag{1}$$

where k, the bulk curvature constant and $y(= R_c\theta)$ parametrizes the fifth dimension. R_c, the size of the extra dimension, is the expectation value of the modulus field $T(x)$ and is related to the radion by $\phi(x) = f\mathrm{e}^{-\pi kT(x)}$. Here $f = \sqrt{24M_5^3/K}$ and M_5 is the five-dimensional Planck scale. The Randall–Sundrum model with the Golberger and Wise [15] mechanism can produce a light stabilized radion by generating a potential $V(\phi(x))$ for the radion $\phi(x)$. In particular, the radion, which can be lighter than the other low-lying gravitonic degrees of freedom in the RS model, will reveal itself first either by the direct collider, indirect precision measurement or in certain B decay experiment and thus verify the notion of extra dimension(s). Studies based on the observable consequences of radion are available in the literature [16].

2.4.3 *Future plan to do*

Radion $\phi(x)$, conserving fermion flavor at the tree level, can cause the flavor changing neutral current $b \to s$ transition at the one loop and may be a useful probe in testing the new physics. The plans of our future work regarding the NP impact on this $B \to \Phi K_2^*$ decay are as follows:

- First, to make a clear estimate of the BR($B \to \Phi K_2^*$), $A_{\rm CP}(B \to \Phi K_2^*)$ and several other angular observables by making a detailed angular analysis [17], by working within the factorization framework in the Standard Model.
- Then to find the effective operator $O_{\rm NP}(b \to s\phi)$ that can cause $b \to s$ FCNC transition. Obtaining the proper branching ratio BR($\phi \to s\bar{s}$) is our next concern. These two are required to find the amplitude of the radion-mediated

partonic subprocess $b\overline{s} \to \phi \to s\overline{s}$, the subprocess which can cause the exclusive $B \to \Phi K_2^*$ decay.

- Finally, estimate the moduli(radion) contribution to the branching ratio, direct CP-asymmetry and other angular observables. Some of these observables, sensitive to new physics, are strictly equal to zero in the Standard Model. Non zero findings of these observables in the future experiment (LHC-b factory) will clearly resemble the existence of NP and thus verify the notion of warped spatial dimension.

2.5 *Angular analysis of B decaying into tensor tensor mode*

Chandradew Sharma

Angular analysis of B decaying into tensor tensor mode is being studied in a model-independent way. It will be shown how an angular analysis can be used to isolate the contributions from the different resonances and partial waves contributing to the final state $B \to T_1 T_2$. It can also be shown how to separate the contributions from the CP-even and CP-odd partial waves. For this purpose we need to study the time integrated differential decay rate.

We consider exclusive two-body decays of a B-meson into states involving the tensors resonances or their excitations. We assume that each of the resonances decays into two pseudoscalars ($T_1 \to P_1 P_2$ and $T_2 \to P_3 P_4$). This decay involving a four-body final state, can be described in terms of five variables s_1, s_2, θ_1, θ_2 and ϕ. The kinematical variables s_1 and s_2 are the invariant mass squared of the two pseudoscalar pairs respectively (it is assumed that the $P_1 P_2$ momentum is along the $+z$ axis), θ_1 is the angle of P_1 in the $P_1 P_2$ c.m. system with the z-axis, θ_2 is the angle of P_3 in the $P_3 P_4$ c.m. system with the z-axis, and ϕ is the angle between the normals to the planes defined by the momenta of $P_1 P_2$ and $P_3 P_4$, in the B rest frame. In this mode, there are five partial waves – S, P, D, F and G and five form factors. It is interesting to isolate the contributions from different partial waves contributing to the final states. We study the time-integrated differential decay rate and derive explicit solutions to both the magnitudes and the phases of the form factors contributing. We also study the forward–backward (FB) asymmetry.

3. Model building

In the inaugural talk and in a number of plenary talks in this workshop, the necessity for new models based upon flavor symmetries was pointed out in order to provide a unified explanation of particle properties and interactions including the neutrinos. In the WG3 activities a number of new investigations were suggested with emphasis on neutrino physics, leptogenesis and unification of forces.

There were three interesting working group talks given by the participants on model building:

- Neutrino oscillations and shortcuts in extra dimensions – H Pas

- Gauge coupling unification including $N = 2$ supersymmetry at an intermediate scale – B Brahmachari
- TeV scale leptogenesis in left–right symmetric models – N Sahu

In a highly stimulating discussion session led by E Ma and K S Babu the roles of tetrahedral symmetry A_4 and the permutation symmetry S_4 in explaining neutrino physics were critically examined and intimate connection of the former with the prediction of tri-bimaximal mixing pattern which appear to be strongly supported by the current measurements was discussed in detail.

K S Babu also led another interesting session on new contributions to neutrinoless double beta decay in MSSM and its extensions through vector–scalar exchanges.

The next subsections provide a brief outline of the problems suggested and persued on model building during the workshop. While investigations in some cases are complete, others are in progress.

3.1 A_4 *Symmetry and predictions of* U_{e3} *in a modified Altarelli–Feruglio model*

B Adhikary, B Brahmachari, A Ghosal, E Ma and M K Parida

The tri-bimaximal mixing ansatz [18] which has been recently realized in an extension of SM by Altarelli and Feruglio [19] with A_4 flavor symmetry matches remarkably well with the neutrino data [20]; but it predicts the CHOOZ angle (θ_{13}) to be exactly zero and $\theta_\odot = 35.3°$ whereas $(\theta_\odot)_{\rm expt.} = 33.8° \pm 1.8°$ and $(\theta_{13})_{\rm expt.} < 10°$. Possibility of nonzero θ_{13} which is of considerable theoretical and experimental investigation has been also considered by AF [19]. We modify the AF model by introducing softly broken A_4 symmetry in such a manner that while $\theta_\odot$ is brought down below the tri-bimaximal prediction to be in concordance with KamLAND and SNO, a small but nonvanishing value of $\theta_{13} \simeq 2°$–$4°$ turns out to be a natural prediction of the model [21].

(a) *The model.* We introduce three additional singlet charged scalars χ_i^+ $(i = 1, 2, 3)$ as a triplet under A_4 and consider nonsupersymmetric version of the AF model with two Higgs doublets (h_u, h_d). Denoting l as the lepton doublet of three generations that transforms also as A_4 triplet our Lagrangian is

$$\mathcal{L} = \mathcal{L}_{\rm AF} + \mathcal{L}_1 + \mathcal{L}_2, \tag{2}$$

where $\mathcal{L}_{\rm AF}$ is the same as in ref. [19],

$$\begin{aligned}\mathcal{L}_1 &= f(ll\chi_i)\\ &= f(\nu_\mu \tau \chi_1^+ + \nu_\tau e \chi_2^+ + \nu_\tau \mu \chi_3^+\\ &\quad -\nu_\tau \mu \chi_1^+ - \nu_e \tau \chi_2^+ - \nu_\mu e \chi_3^+),\end{aligned} \tag{3}$$

$$\mathcal{L}_2 = c_{12} h_u^T i\tau_2 h_d (\chi_1 + \chi_2 + \chi_3). \tag{4}$$

The term $\mathcal{L}_2$ breaks A_4 softly and in conjunction with $\mathcal{L}_1$, it gives rise to new radiative contribution known often as the Zee mechanism [22]. The following elements of the neutrino mass matrix remain the same as in the AF model: $(M_\nu)_{11} = a+2d/3$, $(M_\nu)_{22} = (M_\nu)_{33} = 2d/3$, $(M_\nu)_{12} = (M_\nu)_{21} = -d/3$.

Our new predictions are

$$(M_\nu)_{13} = (M_\nu)_{31} = -d/3 - \epsilon,$$
$$(M_\nu)_{23} = (M_\nu)_{32} = -d/3 + \epsilon \tag{5}$$

with nonvanishing value of ϵ obtained from one-loop radiative contribution [21]

$$\epsilon = f m_\tau^2 \frac{c_{12} v_u}{v_d} \frac{\ln(m_\chi^2/m_{h_d}^2)}{16\pi^2 (m_\chi^2 - m_{h_d}^2)}. \tag{6}$$

The two parameters of the model, a and d, which are in general complex are obtained in the same way as in ref. [19] through higher-dimensional operators. For our analysis and derivation of expressions for Δm^2 and $\sin\theta_{ij}$ we have considered two cases; the first with ϵ, a, and b all three real, the second with a and ϵ real but b complex.

(b) *Real parameters*. In this case it is possible to fit both $\Delta m^2_{\rm atm}$ and $\Delta m^2_\odot$ if a and b are related by $d = -\kappa a$ where $\kappa \simeq 2$ leading to

$$\Delta m^2_{\rm atm} \simeq (\kappa^2 + 2\kappa) a^2,$$
$$\Delta m^2_\odot = \frac{2-\kappa}{2+\kappa}\Delta m^2_{\rm atm} + 2\epsilon(\kappa - 1)\sqrt{\frac{\Delta m^2_{\rm atm}}{\kappa^2 + 2\kappa}}. \tag{7}$$

With $R = \Delta m^2_\odot / \Delta m^2_{\rm atm}$ the predictions for the three mixing angles are

$$\sin\theta_{13} = \frac{\kappa(\kappa+3)}{6\sqrt{2}(\kappa-1)}\left[R - \frac{2-\kappa}{2+\kappa}\right],$$
$$\sin\theta_{12} = \frac{1}{\sqrt{3}} - \frac{\sqrt{6}(\kappa+2)}{\kappa(\kappa+3)}\sin\theta_{13},$$
$$\tan^2\theta_{23} = 1 + \frac{2\sqrt{2}\kappa}{\kappa+3}\sin\theta_{13}. \tag{8}$$

It is clear that a positive value of ϵ is necessary to give θ_{12} below and θ_{23} above the tri-bimaximal limits with $\theta_{13} > 0$. The numerical predictions for $\kappa = 2$ are $\theta_{12} = 31.3°$–$33.5°$, $\theta_{13} = 3.5°$–$1.5°$, and $\theta_{23} = 45.5°$–$46°$ with $m_1 = -0.015$ eV, $m_2 = 0.017$ eV and $m_3 = -0.055$ eV.

(c) *One complex and two real parameters.* With ϵ and a real and d complex, both $\Delta m^2_{\rm atm}$ and $\Delta m^2_\odot$ can be fitted if we utilize the relation [19,23], $|d| = -2a\cos\phi$, where $\phi = \arg(d)$. In the leading approximation we obtain

$$|\sin\theta_{13}| = \frac{\sqrt{2}}{3}\left(\frac{9 + 16\cos^2\phi}{1 + 3\cos^2\phi}\right)^{1/2}\frac{\cos^2\phi}{|2\cos^2\phi - 1|}R,$$
$$\sin\theta_{12} = \frac{1}{\sqrt{3}} - \frac{2}{\sqrt{3}}\frac{\cos^2\phi}{|2\cos^2\phi - 1|}R,$$
$$\tan^2\theta_{23} = 1 + \frac{16}{3}\frac{\cos^4\phi}{|2\cos^2\phi - 1|(1 + 3\cos^2\phi)}R. \tag{9}$$

For example, our predictions for $\cos\phi = -0.575$ are $\theta_{12} = 33.5°$–$31.2°$, $\theta_{23} = 45.5°$–$46°$, and $\theta_{13} = 1.7°$–$3.7°$. The values of light neutrino masses are not likely to change significantly by radiative corrections or threshold effects [24]. While the model predictions on the CHOOZ angle θ_{13} could be verified or falsified by long baseline reactor experiments like Double CHOOZ, Triple CHOOZ, Noνa and others [25], the prediction of $\theta_\odot$ few degrees below the tri-bimaximal limit could be tested by precision solar neutrino experiments in near future.

We conclude that in both the cases our modification of the Altarelli–Feruglio model successfully explains the current data on atmospheric and solar neutrino oscillations consistent with KamLAND and SNO and at the same time it predicts nonvanishing but small CHOOZ angle up to $\theta_{13} = 4°$ [21].

3.2 *Degenerate neutrinos with the help of R-parity violating couplings*

B Allanach and R Srikanth

We impose A_4 symmetry in our model with the superfields having their respective charge assignments under A_4,

$$\begin{aligned} &L_i \sim 3, \quad E_{1\mathrm{R}} \sim 1, \quad E_{2\mathrm{R}} \sim 1', \\ &E_{3\mathrm{R}} \sim 1'', \quad N_{j\mathrm{R}} \sim 3, \quad H_u \sim 1, \\ &\Phi_k = (\phi_1, \phi_2, \phi_3) \sim 3. \end{aligned} \tag{10}$$

With R-parity violating couplings λ_i and the cube-root of unity ω the superpotential is

$$\begin{aligned} W = &\lambda_1 E_{1\mathrm{R}}(L_1L_1 + L_2L_2 + L_3L_3) \\ &+\lambda_2 E_{2\mathrm{R}}(L_1L_1 + \omega L_2L_2 + \omega^2 L_3L_3) \\ &+\lambda_3 E_{3\mathrm{R}}(L_1L_1 + \omega^2 L_2L_2 + \omega L_3L_3) \\ &+h_{ijk}L_iE_j\Phi_k + L_iN_{i\mathrm{R}}H_u + (1/2)MN_{i\mathrm{R}}N_{i\mathrm{R}}. \end{aligned} \tag{11}$$

Following the analysis of Ma and Rajasekaran [26] we can get degenerate neutrinos with maximal $\nu_\mu - \nu_\tau$ mixing. To get a realistic bi-maximal structure we have to add one-loop radiative corrections which come from R-parity violating potential. The bi-maximal mixing pattern with degenerate neutrinos at high scales is expected to emerge for some values of R-parity violating parameters in the parameter space $(\lambda_1, \lambda_2, \lambda_3)$.

3.3 *Structure of right-handed neutrino mass matrix in left–right symmetric models and implications for leptogenesis*

N Sahu

Taking the light neutrino mass formula in the Type-II see-saw,

$$m_\nu = fv_\mathrm{L} - m_D^T(fv_\mathrm{R})^{-1}m_D \tag{12}$$

we ask the following question [28]: What should be the structure of the right-handed neutrino mass matrix f without any assumption on the relative magnitudes of the Type-I (second) and Type-II (first) terms in the formula? For a single fermion generation the above formula gives two solutions (f_+, f_-) which are dual to each other. That means, the above mass formula implies another type of solution for f, i.e.

$$\hat{f} \equiv \frac{m_\nu}{v_{\rm L}} - f \tag{13}$$

provided that m_D is nonsingular. In general for n generations, the number of solutions is 2^n which, for three generations, equals to 8. We want to find out what are the possible structures of f that can give lepton asymmetry and mixings in the low-energy theory.

3.4 *Threshold corrections on neutrino masses*

B Brahmachari and E J Chun

When neutrino masses are almost degenerate, radiative corrections can lead to significant change in neutrino masses and mixing. The dominant contribution is due to the usual RG evolution from the seesaw scale $M_{\rm R}$ to the weak scale $M_{\rm W}$ arising from the flavor structure of the charged lepton Yukawa coupling, that is, from the large τ-Yukawa. Another important effect could be threshold correction due to the slepton mass spectrum in the MSSM. We recalculate the complete threshold correction in SUSY model to find a discrepancy from the previous calculations. The main purpose of this project is to look for a certain mSUGRA parameter space where the threshold correction can be larger than the RG contribution. We discuss how neutrino mixing angles and Δm^2 get changed. In particular, the impact on CP phases could be significant as the threshold correction contains stau LR mixing mass which is complex and can be large for large $\tan\beta$.

3.5 *Flavor symmetry, tri-bimaximal/bimaximal mixing and low-energy predictions*

A Ghosal, B Adhikary and M K Parida

While the tri-bimaximal prediction is remarkably close to experimental values of solar and atmospheric mixing angles, it predicts $\theta_{13} = 0$. On the other hand, a non-vanishing value of this mixing angle within the CHOOZ limit is predicted by many interesting models. Recently there have been attempts to generate small values of the angle by radiative corrections. Similarly, the bimaximal mixing of quasi-degenerate neutrinos at high scales may be modified at low energies by threshold effects and radiative corrections or through quark-lepton complementarity to be in agreement with experimental data on solar and atmospheric neutrinos consistent with SNO and the CHOOZ limit.

The purpose of this project is to examine the effects of radiative corrections on the tri-bimaximal and bimaximal neutrino mixing matrices including the Majorana and Dirac phases and also the effects of right-handed neutrinos. Both hierarchical and quasi-degeneracy in the light neutrino masses would be examined.

In particular, our analysis reveals new results for quasi-degenerate neutrinos compared to other analysis [27]. We find that even with supersymmetry, three quasi-degenerate neutrinos with opposite CP between the first and the second generation neutrinos and the tri-bimaximal mixing pattern at high seesaw scales can be easily accommodated by the current neutrino data with the prediction for a small value of $\theta_{13} \simeq 1^{\circ}$.

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