Charged Lepton Corrections to Neutrino Mixing Angles and CP Phases Revisited

S. Antusch¹, S. F. King²

School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, U.K.

Abstract

We re-analyze charged lepton corrections to neutrino mixing angles and CP phases, carefully including CP phases from the charged lepton sector. We present simple analytical formulae for including the charged lepton corrections and derive compact new results for small neutrino and charged lepton mixings $\theta_{13}^\nu$ and $\theta_{13}^e$. We find a generic relation $\theta_{12} + \frac{1}{\sqrt{2}} \theta_{12}^e \cos(\delta - \pi) \approx \theta_{12}^\nu$, which relates the prediction from the neutrino sector $\theta_{12}^\nu$ to the charged lepton mixing $\theta_{12}^e$ and to the MNS neutrino oscillation phase $\delta$. We apply our formula to the examples of bimaximal or tri-bimaximal neutrino mixing. One implication is that the so-called quark-lepton complementarity relation $\theta_{12} + \theta_C = 45^\circ$ can only hold for $\delta = \pi$ and it gets modified in the presence of leptonic CP violation. On the other hand, the lepton mixing $\theta_{13}^e$ generated from the charged lepton correction $\theta_{12}^e$ is independent of CP phases and given by $\theta_{13} = \frac{\sqrt{2}}{2} \theta_{12}^e$. Combining these results leads to a model-independent sum rule: $\theta_{12} + \theta_{13}^e \cos(\delta - \pi) \approx \theta_{12}^\nu$ where $\theta_{12}^e = (35.26^\circ)$ $45^\circ$ in the case of (tri-)bimaximal neutrino mixing, for example.

¹E-mail: santusch@hep.phys.soton.ac.uk
²E-mail: sfk@hep.phys.soton.ac.uk
# Introduction

Recently, there has been some interest in relations between the lepton mixing angle $\theta_{12}$ and the Cabibbo angle $\theta_C$ \cite{1}, often referred to as quark-lepton complementarity (QLC). It was initiated from the observation that current best fit values (see e.g. \cite{2}) are compatible with an intriguing relation $\theta_{12} + \theta_C = 45^\circ$. One conclusion was that if a relation between the Cabibbo angle and $\theta_{12}$ were found, this could point towards quark-lepton unification. In addition, further relations between the lepton mixings $\theta_{13}$ and $\theta_{23}$ and quark mixings have been proposed. The general idea is that specific predictions from the neutrino sector, i.e. for the solar angle, get modified by the charged lepton mixings \cite{3} such as $\theta_{e12}$, and that these corrections from the charged lepton sector can be be related to quark mixings in quark-lepton unified theories. While the above relation, where $\theta_{12}$ and $\theta_C$ add up to $45^\circ$, was based on bimaximal neutrino mixing, another interesting complementarity emerges if the neutrino sector predicts tri-bimaximal mixing \cite{4}, which can naturally be realized with non-Abelian flavour symmetry SO(3) \cite{5} or SU(3) \cite{6}.

Motivated by this recent interest in charged lepton corrections to neutrino mixings, we re-analyze this issue in this note. We shall first present simple formulae for including the charged lepton corrections, which allow to discuss the effects analytically. Since the two types of complementarity scenarios involve small 1-3 mixing $\theta_{13}^\nu$ from the neutrino sector, we then mainly focus on this case and find some interesting results: For small neutrino and charged lepton mixings $\theta_{13}^\nu$ and $\theta_{13}^e$, we find for instance the new relation

$$\theta_{12} + \frac{1}{\sqrt{2}} \theta_{12}^e \cos(\delta - \pi) \approx \theta_{12}^\nu,$$

(1)

which connects the prediction $\theta_{12}^\nu$ for the solar mixing from the neutrino sector to the charged lepton mixing $\theta_{12}^e$ and to the MNS CP phase relevant for neutrino oscillations $\delta$. Compared to previous works which consider charged lepton contributions \cite{3}, the general relation of Eq. (1) holds model-independently as long as the neutrino and charged lepton mixings $\theta_{13}^\nu$ and $\theta_{13}^e$ are small. It is surprisingly compact and shows that under the above conditions, measuring the MNS CP phase $\delta$ is essential for testing any model predictions for the neutrino mixing $\theta_{12}^\nu$ modified by charged lepton corrections.

The compact formula in Eq. (1) may be used as a basis for studying quark-lepton complementarity, if the charged lepton mixing angle $\theta_{12}^e$ is related to the Cabibbo angle $\theta_C$. The exact type of complementarity depends on the prediction for the neutrino mixing angle $\theta_{12}^\nu$, specifically either $\theta_{12}^\nu \approx 45^\circ$ in the case of bi-maximal complementarity, or $\theta_{12}^\nu \approx 35.26^\circ$ in the case of tri-bimaximal complementarity. In both cases, Eq. (1) shows that the presence of the leptonic CP phase $\delta$ plays a crucial role in any complementarity relation. Indeed bimaximal...
complementarity in its simple form is seen to be disfavored in the presence of leptonic CP violation (i.e. \( \delta \neq \pi \)). Tri-bimaximal complementarity gives testable predictions, which however require a measurement of \( \delta \) in addition to a more precise measurement of \( \theta_{12} \). In the context of tri-bimaximal complementarity [5], the relation of Eq. (1) with the specific prediction for \( \theta_{12}^\nu \approx 35.26^\circ \) has been found in a specific model. Discussions of charged lepton contributions to neutrino mixings in other specific scenarios, such as for instance bi-maximal neutrino mixing, can be found in Refs. [3]. However, as we will show, the general relation of Eq. (1) holds model-independently, as long as \( \theta_{13}^\nu \) and \( \theta_{e13}^e \) are small.

For small \( \theta_{13}^\nu \) and \( \theta_{e13}^e \), the total lepton mixing \( \theta_{13} \) is induced from the charged lepton correction \( \theta_{12}^e \), which leads to the relation

\[
\theta_{13} = \frac{1}{\sqrt{2}} \theta_{12}^e ;
\]

independent of CP phases. This means that if the charged lepton mixing \( \theta_{12}^e \) is related to the Cabibbo angle \( \theta_C \) in any form, this would show up more directly in \( \theta_{13} \) than in the solar angle \( \theta_{12} \).

Combining these results leads to a model-independent sum rule:

\[
\theta_{12} + \theta_{13} \cos(\delta - \pi) \approx \theta_{12}^\nu
\]

where \( \theta_{12}^\nu = 45^\circ \) in the case of bimaximal neutrino mixing, or \( \theta_{12}^\nu = 35.26^\circ \) in the case of tri-bimaximal neutrino mixing, for example. It is worth emphasizing that under the generic assumption of small \( \theta_{13}^\nu \) and \( \theta_{e13}^e \) the combined measurement of the lepton mixings \( \theta_{12}, \theta_{13} \) and of the MNS CP phase \( \delta \) in future precision experiments on neutrino oscillations has the potential to reveal if there are any symmetries determining the neutrino mixing \( \theta_{12}^\nu \).

In the most general case, if we relax the condition of small \( \theta_{13}^\nu \) and \( \theta_{e13}^e \), charged lepton CP phases still modify the charged lepton corrections to the solar mixing angle, however the relevant CP phase is then not related to the low energy CP phase \( \delta \) observable (in principle) in future neutrino oscillation experiments. Then the situation is similar to the charged lepton correction to \( \theta_{23} \): Since it depends on charged lepton CP phases which are not related to \( \delta \) and just marginally contribute to one of the Majorana CP phases, we conclude that it is not realistic to expect any generic complementarity relation for \( \theta_{23} \). The maximal charged lepton correction to \( \theta_{23} \) is \( |\Delta \theta_{23}| \lesssim \theta_{23}^e \), which is nevertheless interesting with respect to future precision neutrino experiments.

2 Preliminaries on the Mixing Formalism

Before we discuss charged lepton corrections, it is necessary to specify the definition of lepton mixings and our conventions for the charged lepton and neutrino mass
matrices: The Dirac mass matrices of the charged leptons is given by

$$m_{\text{LR}}^e = Y_{\text{LR}}^e v_d$$

(4)

where $v_d = \langle h_0^0 \rangle$ and the Lagrangian is of the form

$$\mathcal{L} = -Y_{\text{LR}}^e \bar{e}_L \ell R + \text{H.c.}$$

(5)

We will focus on three light Majorana neutrinos in the following, with the neutrino mass being defined by the Lagrangian

$$\mathcal{L} = -\frac{1}{2} \bar{\nu}_L m_{\nu L}^\nu \nu_L + \text{H.c.}$$

(6)

The change from flavour basis to mass eigenbasis can be performed with the unitary diagonalization matrices $V_{\text{el}}, V_{\text{er}}$ and $V_{\nu L}$ by

$$V_{\text{el}} m_{\text{LR}}^e V_{\text{er}}^\dagger = \begin{pmatrix} m_e & 0 & 0 \\ 0 & m_\mu & 0 \\ 0 & 0 & m_\tau \end{pmatrix}, \quad V_{\nu L} m_{\nu LL}^\nu V_{\nu L}^T = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}.$$  

(7)

The MNS matrix, the mixing matrix in the lepton sector, is then given by

$$U_{\text{MNS}} = V_{\text{el}} V_{\nu L}^\dagger.$$  

(8)

After eliminating so-called unphysical phases as usual, by charged lepton phase rotations, the MNS matrix can be parameterized as

$$U_{\text{MNS}} = R_{23} U_{13} R_{12} P_0$$  

(9)

using the matrices $R_{23}, U_{13}, R_{12}$ and $P_0$ defined by

$$R_{12} := \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad U_{13} := \begin{pmatrix} c_{13} & 0 & s_{13} e^{-i \delta} \\ 0 & 1 & 0 \\ -s_{13} e^{i \delta} & 0 & c_{13} \end{pmatrix},$$

$$R_{23} := \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}, \quad P_0 := \begin{pmatrix} e^{i \beta_1} & 0 & 0 \\ 0 & e^{i \beta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$  

(10)

and where $s_{ij}$ and $c_{ij}$ stand for $\sin(\theta_{ij})$ and $\cos(\theta_{ij})$, respectively. The matrix $P_0$ contains the Majorana phases $\beta_1$ and $\beta_2$. $\delta$ is the Dirac CP phase relevant for neutrino oscillations.

Another useful parameterization, in particular for including charged lepton corrections, is

$$U_{\text{MNS}} = U_{23} U_{13} U_{12}.$$  

(11)
with matrices $U_{23}, U_{13}, U_{12}$ being defined as

$$
U_{12} := \begin{pmatrix} 
  c_{12} & s_{12} e^{-i\delta_{12}} & 0 \\
  -s_{12} e^{i\delta_{12}} & c_{12} & 0 \\
  0 & 0 & 1 
\end{pmatrix}, \quad U_{13} := \begin{pmatrix} 
  c_{13} & 0 & s_{13} e^{-i\delta_{13}} \\
  0 & 1 & 0 \\
  -s_{13} e^{i\delta_{13}} & 0 & c_{13} 
\end{pmatrix},
$$

$$
U_{23} := \begin{pmatrix} 
  1 & 0 & 0 \\
  0 & c_{23} & s_{23} e^{-i\delta_{23}} \\
  0 & -s_{23} e^{i\delta_{23}} & c_{23} 
\end{pmatrix}. \tag{12}
$$

One can easily switch between these two conventions using the identities \[7\]

$$
\delta_{23} = \beta_2 \tag{13a} \\
\delta_{13} = \delta + \beta_1 \tag{13b} \\
\delta_{12} = \beta_1 - \beta_2. \tag{13c}
$$

and the fact that $\theta_{ij}$ remains the same in both notations. We will use the latter convention in the following and introduce the more common phase convention $\delta, \beta_1, \beta_2$ if appropriate, in particular for making the connection to the Dirac CP phase $\delta$ observable in neutrino oscillations.

### 3 Simple Formulae for Including Charged Lepton Corrections

We will now consider the situation that bi-large neutrino mixing stems mainly from the neutrino sector, and that the mixing angles induced by the charged leptons can be considered as corrections. In this approximation, we will derive formulae which allow to include corrections to neutrino mixing angles and CP phases conveniently. We will see that special care has to be taken when dealing with complex phases from the charged lepton sector.

Parameterizing the neutrino and charged lepton diagonalization matrices in $V_{eL}^\dagger$ and $V_{\nu L}^\dagger$ an analogous way to Eq. (12), we can write $U_{\text{MNS}}$ as \[7\]

$$
U_{\text{MNS}} = U_{12} U_{13} U_{23} U_{eL}^\dagger U_{\nu L}^\dagger U_{\nu L} U_{\nu L}^\dagger. \tag{14}
$$

The additional unphysical phases have been shifted to the left and then absorbed, as usual, by charged lepton phase rotations. The procedure for extracting the charged lepton and neutrino angles and phases is given in great detail in the Appendix of Ref. \[7\].

In this parameterization, the MNS matrix can be conveniently expanded in terms of neutrino and charged lepton mixing angles and phases to leading order.
in small quantities, i.e. in the charged lepton mixing angles and in $\theta_{13}$: \(^1\)

\[
\begin{align*}
\sin \theta_{23} e^{-i\delta_{23}} &\approx \sin \nu_{23} e^{-i\delta_{23}} - \theta^\nu_{23} c_{23} \nu_{23} e^{-i\delta_{23}} \\
\theta_{13} e^{-i\delta_{13}} &\approx \theta^\nu_{13} e^{-i\delta_{13}} - \theta^e_{13} c_{23} \nu_{23} e^{-i\delta_{23}} - \theta^\nu_{12} c_{23} e^{i(-\delta_{23} - \delta_{13})} \\
\sin \theta_{12} e^{-i\delta_{12}} &\approx \sin \nu_{12} e^{-i\delta_{12}} + \theta^e_{13} c_{12} \nu_{23} e^{i\delta_{23} - \delta_{13}} - \theta^\nu_{12} c_{23} e^{-i\delta_{12}}
\end{align*}
\] (15a) (15b) (15c)

Using Eq. (13) it is simple to express the phases on the left-hand side in terms of the phases $\beta_1, \beta_2$ and $\delta$, if desired. Before we turn to applications, let us remark that since we have assumed that the two large lepton mixing angles $\theta_{23}$ and $\theta_{12}$ stem mainly from the neutrino sector, the phases $\delta_{23}, \delta_{12}$ and thus also $\beta_1, \beta_2$ are mainly determined from the neutrino sector, with only small corrections from the charged lepton sector.

With this respect, $\theta_{13}$ and the Dirac CP phase $\delta$ are very different: Since we only know that the total lepton mixing $\theta_{13}$ is rather small and without making further assumptions, it can stem from the neutrino mixing $\theta^\nu_{13}$ or it can alternatively be mainly induced from the charged lepton mixings $\theta^e_{13}$ and/or $\theta^e_{12}$. In the latter case, the charged lepton corrections also mainly determine the Dirac CP phase $\delta$, observable in neutrino oscillations.

Let us finally note that lepton mixing angles are subject to renormalization group (RG) running between high energy, where models typically predict the flavour structure, and low energy, where experiments are performed. A numerical calculation of the RG corrections can be performed with the software packages REAP/MPT introduced in [10].

\section{3.1 Charged Lepton Corrections with Small $\theta^\nu_{13}$}

As discussed in the introduction, one interesting special case is that $\theta^\nu_{13}$ as well as $\theta^e_{13}$ are rather small, i.e. $\ll \theta^e_{12}$. From Eq. (15b) and using the leading order relations $\delta_{23}^\nu \approx \beta_2$ and Eq. (13b), we obtain

\[
\theta_{13} e^{-i\delta} \approx \theta^e_{12} c_{23} e^{-i(\beta_2 - \beta_1) - i\delta_{12}},
\] (16)

and it follows that

\[
\delta \approx \beta_2 - \beta_1 + \pi + \delta_{12}.
\] (17)

Let us note that for instance in scenarios with an inverted neutrino mass hierarchy and a Majorana parity between $m_1$ and $m_2$, we have $\beta_2 - \beta_1 = \pi$ and the Dirac CP phase $\delta$ is simply given by the charged lepton phase $\delta_{12}^e$. In addition, we obtain

\[
\theta_{13} = \theta^e_{13} c_{23}.
\] (18)

\(^1\)These results differ somewhat from those in [1], in particular the sign of the last term in Eq. (15c) has been corrected.
The charged lepton 1-2 mixing generates $\theta_{13}$ independent of charged lepton CP phases. From Eq. (15c), the solar mixing angle $\theta_{12}$ is given by

$$s_{12} \approx s_{12}^{\nu} + \theta_{12}^{\nu} c_{23}^\nu c_{12}^\nu \cos(\beta_2 - \beta_1 + \pi + \delta_{12}^\nu) \approx s_{12}^{\nu} + \theta_{12}^{\nu} c_{23}^\nu c_{12}^\nu \cos(\delta) ,$$  

(19)

where we have used the result of Eq. (17) and $\delta_{12} \approx \delta_{12}^\nu$. In terms of mixing angles, approximating $\theta_{23}^\nu \approx 45^\circ$, we obtain:

$$\theta_{12} + \frac{1}{\sqrt{2}} \theta_{12}^{\nu} \cos(\delta - \pi) \approx \theta_{12}^\nu .$$  

(20)

The relation of Eq. (20) was first found in a model of tri-bimaximal neutrino mixing based on SO(3) flavour symmetry [5] where $\theta_{13}^\nu = 0$ and $\theta_{12}^\nu = 35.26^\circ$. We have shown here that such a result holds quite generally, not just for any model of tri-bimaximal neutrino mixing, but also for any model of bimaximal neutrino mixing, or indeed any model of neutrino mixing in which $\theta_{13}^\nu$ and $\theta_{13}^\nu$ are small compared to $\theta_{12}^\nu$. We emphasize that under these assumptions, the corrections to $\theta_{12}$ from the charged lepton sector depend on the charged lepton 1-2 mixing and on the Dirac CP phase $\delta$, a fact which is often overlooked in studies of complementarity, as we now briefly discuss.

4 Applications

4.1 Consequences for Quark-Lepton Complementarity

The general idea of quark-lepton complementarity [1] is that the solar mixing predicted from the neutrino sector is corrected by charged lepton contributions, which are in turn related to quark mixing angles. For example in the case of bimaximal complementarity, the starting point is a maximal solar neutrino angle $\theta_{12}^\nu = 45^\circ$, and a relation like $\theta_{12} + \theta_C = 45^\circ$, compatible with present best-fit values, could in principle emerge. For example in [8] it has been shown how a charged lepton mixing $\theta_{12}^e = \frac{3}{2} \theta_C$, which could nearly realize the QLC relation, can arise in quark-lepton unified theories, and leads to a prediction for $\theta_{13} = \theta_C$ which also holds in the presence of CP violating phases. As has been pointed out by many authors, an inverted neutrino mass hierarchy with a Majorana parity between $m_1$ and $m_2$ is a good starting point for QLC. For $\theta_{12}^\nu = 45^\circ$ and $\theta_{12}^e = \frac{3}{2} \theta_C$, under the assumptions of Sec. 3.1 which are in general satisfied in approaches to QLC via inverted neutrino mass hierarchy, Eq. (20) reads

$$\theta_{12} + \theta_C \cos(\delta - \pi) \approx 45^\circ .$$  

(21)
In general, we would therefore not expect a relation such as \( \theta_{12} + \theta_C = 45^\circ \), where the Cabibbo angle enters directly, unless CP is conserved (i.e. \( \delta = \pi \)). All quark-lepton complementarity relations are modified for non-zero \( \delta \) and a measurement of the leptonic Dirac CP phase is required for testing Cabibbo-like corrections to neutrino mixing.

An interesting application of our general results in the presence of CP violation is to tri-bimaximal neutrino mixing, where \( \theta_{13} = 0 \) and \( \theta_{12} = 35.26^\circ \). For example, for a charged lepton mixing \( \theta_{12} = \theta_C / 3 \) corresponding to the Georgi-Jarlskog relation [9] which arises in many quark-lepton unified theories, Eq. (20) leads to a tri-bimaximal complementarity relation [5]

\[
\theta_{12} + \frac{\theta_C}{3\sqrt{2}} \cos(\delta - \pi) \approx 35.26^\circ ,
\]

which is consistent with current data for a wide range of CP phases \( \delta \). This also leads to the prediction \( \theta_{13} \approx \theta_C / (3\sqrt{2}) \).

### 4.2 Consequences for Leptogenesis – MNS Links

It is well known that in general, there is no relation between the CP phase \( \delta \) observable in neutrino oscillations and the cosmological CP phase which appears in the leptogenesis mechanism [11], where the baryon asymmetry of our universe arises via out-of-equilibrium decay of the right-handed neutrinos involved in the see-saw mechanism. However, for specific classes of flavour models with symmetries or specific assumptions such as texture zeros or sequential dominance conditions, links between these CP violating phases emerge from predictions for the decay asymmetries \( \epsilon_1 \) of the lightest right-handed neutrino. Since \( \epsilon_1 \) depends only on the product \( Y_{\nu}^\dagger Y_{\nu} \) [12] in the mass basis of the right-handed neutrinos, it is not affected by charged lepton mixings and phases at all. Therefore, Eq. (15b) immediately shows that links between the MNS CP phase \( \delta \) and cosmological CP violation relevant for leptogenesis can only hold if \( \theta_{12}^\nu, \theta_{13}^\nu \ll \theta_{13}^\nu \), i.e. if \( \theta_{13} \) stems mainly from the neutrino sector. Otherwise, there are large contributions to \( \delta \) from the charged lepton sector which are completely decoupled from leptogenesis. If \( \theta_{12}^\nu \) or \( \theta_{13}^\nu \) are much larger than \( \theta_{13}^\nu \), the lepton mixing \( \theta_{13} \) and thus also \( \delta \) stem dominantly from charged lepton corrections and any leptogenesis-MNS link is lost.

### 5 Summary and Conclusions

In this note, we have revisited charged lepton corrections to neutrino mixing and CP phases, carefully including CP phases from the charged lepton sector. We have therefore presented simple analytical formulae for including the charged lepton
corrections. Based on these formulae, we have derived interesting new results for small neutrino and charged lepton mixings $\theta_{13}^\nu$ and $\theta_{13}^e$: For instance, we have found the relation

$$\theta_{12} + \frac{1}{\sqrt{2}} \theta_{12}^e \cos(\delta - \pi) \approx \theta_{12}^\nu$$

which connects the prediction from the neutrino sector $\theta_{12}^\nu$ to the charged lepton mixing $\theta_{12}^e$ and to the Dirac CP phase $\delta$. We have then applied our formula to the examples of bimaximal or tri-bimaximal neutrino mixing. One implication was that the so-called quark-lepton complementarity relation $\theta_{12} + \theta_C = 45^\circ$ can only hold for $\delta = \pi$ and it gets modified in the presence of leptonic CP violation. We have also found that the lepton mixing $\theta_{13}$ generated from the charged lepton correction $\theta_{12}^e$ is independent of CP phases and given by

$$\theta_{13} = \frac{1}{\sqrt{2}} \theta_{12}^e$$

Combining these results leads to a model-independent sum rule:

$$\theta_{12} + \theta_{13} \cos(\delta - \pi) \approx \theta_{12}^\nu$$

where $\theta_{12}^\nu = 45^\circ$ in the case of bimaximal neutrino mixing, or $\theta_{12}^\nu = 35.26^\circ$ in the case of tri-bimaximal neutrino mixing, for example. It is worth emphasizing that under the generic assumption of small $\theta_{13}^\nu$ and $\theta_{13}^e$ the combined measurement of the lepton mixings $\theta_{12}$, $\theta_{13}$ and of the MNS CP phase $\delta$ in future precision experiments on neutrino oscillations has the potential to reveal if there are any symmetries determining the neutrino mixing $\theta_{12}^\nu$.

In the most general case, if we relax the condition of small $\theta_{13}^\nu$ and $\theta_{13}^e$, charged lepton CP phases still modify the charged lepton corrections to the solar mixing angle, however the relevant CP phase is then not related to the low energy CP phase $\delta$ observable (in principle) in future neutrino oscillation experiments. Then the situation is similar to the charged lepton correction to $\theta_{23}$. The latter depends on charged lepton CP phases which are not related to $\delta$ and just marginally contribute to one of the Majorana CP phases, and we conclude that it is not realistic to expect any generic complementarity relation for $\theta_{23}$. The maximal charged lepton correction to $\theta_{23}$ is $|\Delta \theta_{23}| \lesssim \theta_{23}^e$, which is nevertheless interesting with respect to future precision neutrino experiments.

We have furthermore argued that any link between the MNS CP phase $\delta$ and cosmological CP violation relevant for leptogenesis is generically lost if $\theta_{13}^\nu$ is small compared to $\theta_{13}^e$ and/or $\theta_{13}^e$. Then $\delta$ stems dominantly from charged lepton corrections which are completely decoupled from the decay asymmetry for leptogenesis.
Acknowledgements

We acknowledge support from the PPARC grant PPA/G/O/2002/00468.

References

[1] M. Raidal, Phys. Rev. Lett. 93 (2004) 161801, hep-ph/0404046. H. Minakata and A. Y. Smirnov, Phys. Rev. D 70, 073009 (2004), hep-ph/0405088. J. Ferrandis and S. Pakvasa, Phys. Rev. D 71 (2005) 033004, hep-ph/0412038. S. K. Kang, C. S. Kim and J. Lee, Phys. Lett. B 619, 129 (2005), hep-ph/0501029. N. Li and B. Q. Ma, Phys. Rev. D 71, 097301 (2005), hep-ph/0501226. K. Cheung, S. K. Kang, C. S. Kim and J. Lee, Phys. Rev. D 72, 036003 (2005), hep-ph/0503122. D. Falcone, hep-ph/0503197. Z. z. Xing, Phys. Lett. B 618 (2005) 141, hep-ph/0503200. A. Datta, L. Everett and P. Ramond, Phys. Lett. B 620 (2005) 42, hep-ph/0503222. S. Antusch, S. F. King and R. N. Mohapatra, Phys. Lett. B 618 (2005) 150, hep-ph/0504007. M. Lindner, M. A. Schmidt and A. Y. Smirnov, JHEP 0507, 048 (2005), hep-ph/0505067. H. Minakata, hep-ph/0505262. T. Ohlsson, Phys. Lett. B 622, 159 (2005), hep-ph/0506094.

[2] M. Maltoni, T. Schwetz, M. A. Tortola and J. W. F. Valle, New J. Phys. 6 (2004) 122, hep-ph/0405172v4.

[3] Charged lepton contributions to neutrino mixings have been considered, e.g., in: P. H. Frampton, S. T. Petcov and W. Rodejohann, Nucl. Phys. B 687 (2004) 31, hep-ph/0401206; G. Altarelli, F. Feruglio and I. Masina, Nucl. Phys. B 689 (2004) 157, hep-ph/0402155; S. Antusch and S. F. King, Phys. Lett. B 591 (2004) 104, hep-ph/0403053; F. Feruglio, Nucl. Phys. Proc. Suppl. 143 (2005) 184 [Nucl. Phys. Proc. Suppl. 145 (2005) 225], hep-ph/0410131; R. N. Mohapatra and W. Rodejohann, hep-ph/0507312.

[4] P. F. Harrison, D. H. Perkins and W. G. Scott, Phys. Lett. B 530 (2002) 167, hep-ph/0202074; P. F. Harrison and W. G. Scott, Phys. Lett. B 535 (2002) 163, hep-ph/0203209; P. F. Harrison and W. G. Scott, Phys. Lett. B 557 (2003) 76, hep-ph/0302025; C.I. Low and R.R. Volkas, hep-ph/0305243; F. Plentinger and W. Rodejohann, hep-ph/0507143.

[5] S. F. King, hep-ph/0506297.

[6] I. de Medeiros Varzielas and G. G. Ross, hep-ph/0507176.

[7] S. F. King, JHEP 0209 (2002) 011, hep-ph/0204360.
[8] S. Antusch, S. F. King and R. N. Mohapatra, Phys. Lett. B 618 (2005) 150, hep-ph/0504007.

[9] H. Georgi and C. Jarlskog, Phys. Lett. B 86 (1979) 297.

[10] S. Antusch, J. Kersten, M. Lindner, M. Ratz and M. A. Schmidt, JHEP 0503, 024 (2005), hep-ph/0501272.

[11] M. Fukugita and T. Yanagida, Phys. Lett. 174B (1986), 45.

[12] L. Covi, E. Roulet, and F. Vissani, Phys. Lett. B384 (1996), 169–174, hep-ph/9605319.