FCNC SOLUTIONS TO THE SOLAR NEUTRINO PROBLEM

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We present the status of FCNC solutions to the solar neutrino problem. Our analysis shows that the FCNC solutions with massless neutrinos provide a good fit to the latest solar neutrino data. Predictions for future experiments are formulated which will permit further tests of these solutions.

1 Introduction

In his seminal paper, Lincoln Wolfenstein considered flavor changing neutral current (FCNC) effects on neutrino oscillations. He noticed that if the neutrino current in the effective four-fermion interaction Lagrangian has a flavor non-symmetric part it can significantly affect neutrino oscillations by changing the neutrino indices of refraction in matter. Furthermore, if the neutrinos are massless, flavor diagonal neutral currents (FDNC), the couplings of which are not flavor symmetric, are also needed for strong transitions to take place.

In supersymmetric theories without R-parity, both FCNCs and FDNCs occur at tree level. The FCNCs in these theories can enhance neutrino oscillations in matter even for vanishingly small mixing angles in vacuum. In the minimal standard supersymmetric model (MSSM) without R-parity the possibility exists of solving the solar neutrino problems (SNP) even with massless neutrinos by the interplay of both FCNCs and FDNCs. The first definitive confrontation with data, as well as the thorough investigation of all possibilities done in ref. showed that this is indeed so.

Since 1991, when the FCNC solution was first considered, new solar neutrino data has become available. In particular, reliable new data from both gallium detectors, GALLEX and SAGE, now exists. The solar models have been also significantly improved. The latest solar models include diffusion of helium and heavy elements, which is important for the excellent agreement with helioseismology. These developments justify a new data analysis in order to determine the status of the FCNC solution to the SNP.

2 FCNC mechanism

In the MSSM without R-parity $\nu_\tau$ can scatter off $d$-quark via exchange of a $b$-squark and either remain $\nu_\tau$ or emerge as a $\nu_e$. This tree level process leads to neutrino mixing in matter even if the neutrinos are massless or the vacuum mixing is zero. In order for a resonant conversion between the neutrino flavors
to take place both FCNC and flavor diagonal but flavor non-symmetric contributions to the neutrino indices of refraction need to be present. The relevant transitions can only take place between the first and third generations because the data from rare decays, atomic parity violation, deep-inelastic scattering etc. impose strong constraints on the values of the flavor-changing Yukawa couplings in the superpotential required for the mixing between the first two generations in matter. In general there might be two types of solutions depending on the type of quark, $u$ or $d$, which facilitates the flavor changing transition. In the case of the MSSM without R-parity, the parameters entering the evolution equations are functions of the Yukawa couplings, $\lambda_{ijk}$, in the superpotential and the mass of the $b$-squark:

$$\epsilon_d = \frac{\lambda'_{331} \lambda'_{131}}{4\sqrt{2} G_F m_b^2}.$$  

$$\epsilon'_d = \frac{|\lambda'_{331}|^2 - |\lambda'_{131}|^2}{4\sqrt{2} G_F m_b^2}.$$  

The evolution equation for neutrino oscillations in matter does not depend on the energy of the neutrinos. The resonance condition is:

$$\epsilon'_d = \frac{1}{1 + 2 N_n/N_e},$$

where $N_n$ and $N_e$ are respectively the neutron and electron number densities. Unlike the MSW effect, both neutrinos and anti-neutrinos can undergo simultaneously resonant transitions. Since the transitions do not depend on the energy of the neutrinos, but only on the ratio of the neutron to electron number densities, this poses a problem for solving the SNP. As shown in ref.7 any energy independent suppression mechanism is ruled out by the current solar neutrino data (assuming current solar models do not underestimate the uncertainties in the solar neutrino fluxes) at 99.96 % C.L. The solution of this problem was pointed out in 3. Since the different solar neutrinos ($pp$, $^7$Be, $^8$B etc.) have different production regions in the sun, by properly choosing the parameter $\epsilon'_d$ the fluxes of these neutrinos can be depleted with different suppression factors depending on the position of the resonance in the sun.

3 Present Status of the FCNC Solutions

In our analysis we use the latest solar neutrino data presented at the NEUTRINO '96 conference. We compute the average survival probabilities for $pp$,

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Figure 1: Regions in parameter space allowed at 95 % C.L. (shaded area) from the latest (NEUTRINO ’96) solar neutrino data. The regions allowed by each solar neutrino experiment at 95 % C.L. are also shown.

8B, 7Be, pep and CNO neutrinos to remain electron neutrinos at the surface of the sun by averaging over their respective production regions as given in the standard solar model (SSM). Using the computed survival probabilities, the solar neutrino fluxes from the SSM, and published detection cross-sections, we calculate the expected event rates in the operating detectors. By a standard procedure, we calculate the $\chi^2$ and determine the 95 % C.L. allowed regions. The latter are shown in Fig.1 for both the $d$- and $u$-quark solutions.

4 Predictions for Future Experiments

After obtaining the allowed at 95 % C.L. regions in parameter space we proceed with calculations of the event rates in future detectors. The results of this calculation are summarized in Fig.2. The ranges of the ratios of event rates reduced by FCNC transitions in SuperKamiokande, SNO, BOREXINO, ICARUS and HELLAZ/HERON to the corresponding event rates predicted with the neutrino fluxes from the standard solar model by Bahcall and Pinsonneault are shown. In each case we have varied the parameters $\epsilon$ and $\epsilon'$ within the 95 % C.L. region and for each point within this region we have computed the predicted event rate in each of the five detectors. An interesting prediction of the FCNC solutions is that the signals in SNO and ICARUS
Figure 2: Predicted ratios of event rates after FCNC ($\nu_e \to \nu_\tau$) transitions to the corresponding expected rates without transitions in: 1-SuperK, 2-SNO and ICARUS, 3-BOREXINO, 4-HELLAZ/HERON. The ranges in the event rates correspond to the uncertainty in the parameters $\epsilon' - \epsilon$ which were varied within the 95 \% C.L. allowed regions in Fig. 1.

should be suppressed by one and the same factor even though the reactions in which solar neutrinos will be detected in these two detectors are completely different.

Experiments that are being developed to test neutrino physics solutions of the solar neutrino problem in a solar model independent way will hopefully be able to distinguish also between different neutrino physics solutions, e.g. between the MSW and FCNC mechanisms. The combination of the three “smoking gun” effects, namely distortion of the spectrum of recoil electrons in neutrino-electron scattering experiments, the double ratio of CC/NC events in SNO and the earth regeneration effect should look differently in these two cases. The FCNC mechanism predicts no distortion of the electron spectrum, whereas in the small mixing angle (SMA) MSW solution this spectrum is expected to be distorted. The FCNC solutions also predict an energy-independent CC/NC ratio, similar to the large mixing angle (LMA) MSW solution but unlike the SMA solution where this ratio is expected to be energy dependent. Finally, the night-day asymmetry due to the earth regeneration effect is generally expected to be energy dependent for the MSW solution, whereas the FCNC solutions predict a strictly energy independent asymmetry.
5 Conclusions

The FCNC solutions with massless neutrinos arising from theories with broken R-parity fit well the present solar neutrino data. However they require unnatural choice of Yukawa couplings. Fine tuning is needed in order to keep the neutrino masses and/or mixing angles negligibly small. Scenarios in which neutrinos have masses and FCNCs and/or FDNCs contribute to the neutrino transitions in matter are difficult to test experimentally since they usually introduce more parameters and predict smaller deviations from either the vacuum oscillations or the MSW mechanism. The latter currently provides the best fit to the data among a variety of neutrino physics solutions of the SNP without the necessity of any additional modifications of the standard electroweak theory besides neutrino masses.

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