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Limits on the Neutrino Magnetic Moment Using Super-Kamiokande Solar Neutrino Data

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Existence of non-zero neutrino magnetic moment would mean new physics beyond the standard model. A search for the neutrino magnetic moment has been conducted using the high statistic solar neutrino data from Super-Kamiokande-I. This is done by looking for the distortion to the observed energy spectrum of recoil electrons. A non-zero neutrino magnetic moment would cause an increase of event rates at lower energies. The search found no clear signal of neutrino magnetic moment. A limit on the neutrino magnetic moment has been obtained at $3.6 \times 10^{-10}\mu_B$ at 90% C.L. by fitting to the Super-Kamiokande day-night spectra. The effects of neutrino oscillation have been included in the analysis. Including results from other neutrino experiments limiting the oscillation region, a limit of $1.1 \times 10^{-10}\mu_B$ at 90% C.L. was obtained.

Keywords: Neutrino; Magnetic Moment; Oscillation.

1. Introduction

When Pauli proposed the existence of neutrinos to solve the nuclear β decay problem, he suggested that neutrinos had magnetic moments and thus being bound in the nuclei by the electromagnetic forces [1]. We know this is not true. In the standard model, neutrinos are massless and have no magnetic moments. Recent experiments show that neutrinos have tiny masses, consequently neutrinos can acquire magnetic moments from the coupling of the left-hand and the right-hand currents through the mass term, $\mu_\nu \approx 3.2 \times 10^{-19}(\frac{m_\nu}{1eV})\mu_B$, which is several order of magnitude smaller than the current limits on the neutrino magnetic moments. Therefore an observation of neutrino magnetic moment larger could imply new physics beyond the standard model.

A search for neutrino magnetic moments has been conducted using the high statistic 1496 live-days solar neutrino data from Super-Kamiokande-I [2]. The idea behind this search is that if neutrinos have non-zero magnetic moments, in addition

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to the usual weak contribution to the neutrino-electron elastic scattering, there is an additional incoherent contribution from the magnetic scattering [3]:

$$\left(\frac{d\sigma}{dT}\right)_{EM} = \mu_\nu^2 \, \frac{\pi\alpha_{em}^2}{m_e^2} \, \left(\frac{1}{T} - \frac{1}{E_\nu}\right) \tag{1}$$

where μ_ν is in units of μ_B, E_ν is the neutrino energy, $T = E_e - m_e$, and $T(E_e)$ is the kinetic (total) energy of the recoil electrons. While the weak contribution is relatively flat with respect to the energy, the magnetic contribution increases at lower energies. So the signature of non-zero neutrino magnetic moments would be excess of event rates at lower energies.

2. Super-K Results

Super-Kamiokande (SK) is a water Cherenkov detector, with a fiducial volume of 22.5 kton, located in the Kamioka mine in Gifu, Japan. SK detects solar neutrinos via the elastic scattering of neutrinos off electrons in the water. During 1496 live days, about 22385 solar neutrino events have been observed. The recoil electron spectrum have been measured with high precision.

Since both neutrino oscillation and magnetic scattering could distort the SK recoil electron energy spectrum, a χ^2 method is utilized to investigate the distortions taking into account of both effects. As with the standard oscillation analysis, SK energy spectrum could exclude certain regions in the oscillation parameter space. The excluded regions at 95% C.L. are smaller than that without considering magnetic scattering. The reason is that we have one more parameter, μ_ν^2, to minimize the χ^2. Since there is no obvious increase of event rates at lower energies, a Bayesian method is used to get the limit (μ_0) on the neutrino magnetic moment at 90% C.L. for each point in the non-excluded oscillation parameter space regions:

$$\text{Probability}(\Delta\chi^2(\mu^2 \geq \mu_0^2)) = 0.1 \times \text{Probability}(\Delta\chi^2(\mu^2 \geq 0)) \tag{2}$$

The overall limit on the neutrino magnetic moment is the maximum of the aforementioned limits. A limit of $3.6 \times 10^{-10}\mu_B$ is thus obtained.

Results from other neutrino experiments could further limit the oscillation allowed regions. But we first need to check the effects of non-zero neutrino magnetic moments on their results.

- Radiochemical experiments, Homestake, SAGE and Gallex/GNO, detect solar neutrinos via charged current interactions with nucleons. Non-zero neutrino magnetic moments would not affect their measurements.
- SNO measure the charged current, neutral current and elastic scattering rates by utilizing their distinctive angular distributions. Charged current rates would not be affected. The effects of non-zero magnetic moment on the SNO neutral current interaction have been estimated to be very small [4]. A magnetic moment could change the elastic scattering rates but would not change the angular distribution of the elastic scattering events. Therefore, SNO's charged current and

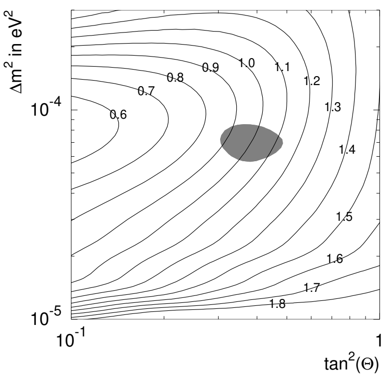

Fig. 1. The 90% C.L. μ_ν limit contours (in units of $10^{-10}\mu_B$) and neutrino oscillation allowed region. The shaded area shows the allowed region for solar experiments plus KamLAND.

neutral current rates will be essentially unaffected by non-zero neutrino magnetic moments.

- KamLAND's detection of reactor $\bar{\nu}_e$s using inverse β-decay interactions should not be affected by non-zero neutrino magnetic moments.

Therefore assuming CPT invariance, the combination of KamLAND results with radiochemical results, SNO neutral current result and SK spectrum further constrains the neutrino oscillation solutions to a small area in the LMA region as shown in Figure 1). Limiting the search for neutrino magnetic moment in this region gives a limit on the neutrino magnetic moment at 90% C.L. of 1.1×10^{-10} μ_B. This result is comparable to the most recent neutrio magnetic moment limits from reactor neutrino experiments of 1.3×10^{-10} μ_B (TEXONO) [5] and 1.0×10^{-10} μ_B (MUNU) [6], albeit for neutrinos and not anti-neutrinos.

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