

Constraints on neutrino magnetic moments
from Super-K, SNO and reactor
experiments

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Neutrino magnetic moments

$$\mu_{ij} \bar{\nu}_i \sigma_{ab} \nu_j F^{ab}$$

- Neutrino magnetic moments can be directly measured in terrestrial experiments using the neutrino beam from the sun as in Super-K or SNO.
- with neutrinos from nuclear reactors as in the MUNU and in the Texono experiments.
- These experiments have put upper bounds of the order of $10^{-10} \mu_B$ on the effective neutrino magnetic moment.

The effective neutrino magnetic moment μ_{eff}

- In scattering event $\nu_i + e^- \rightarrow \nu_j + e^-$, cross section proportional to $|\mu_{eff}|^2$.
- μ_{eff} is proportional to the incoherent sum of outgoing neutrino states ν_j as :

$$|\mu_{eff}|^2 = \sum_j \left| \sum_i A_i(L) \mu_{ij} \right|^2$$

- $A_i(L)$ is the probability amplitude of a neutrino produced as a flavor eigenstate (lets say ν_e or $\bar{\nu}_e$) to be in the i' th mass eigenstate on propagating over distance L .

- For vacuum oscillations $A_i(L) = U_{ei} \exp(-iE_i L)$ and effective magnetic moment is

$$|\mu_{eff}|_{VO}^2 = c_{12}^2 (\mu_{11}^2 + \mu_{12}^2 + \mu_{13}^2) + s_{12}^2 (\mu_{21}^2 + \mu_{22}^2 + \mu_{23}^2) + 2c_{12} s_{12} (\mu_{11}\mu_{21} + \mu_{12}\mu_{22} + \mu_{13}\mu_{23}) \cos\left(\frac{\Delta m_{12}^2 L}{2E_\nu}\right)$$

(assuming that U_{e3} is negligible small and the atmospheric mixing angle is maximal).

MUNU (Z. Paraktchieva et al (2003)) and Texono (H.B.Li et al (2003)) detect $\bar{\nu}_e$ from nuclear reactors by the elastic scattering with e^- .

- The source-detector distance is small ($L = 18m$ in MUNU and $L = 28m$ in TEXONO) compared to the $\nu_1 - \nu_2$ oscillation length so that the Cosine term in $|\mu_{eff}|_{VO}$ is unity.
- The magnetic moment matrix μ_{ij} is symmetric for Dirac neutrinos and anti-symmetric if the neutrinos are Majorana.
- Experimental upper bounds on $|\mu_{eff}|_{VO}$ is $1.0 \times 10^{-10} \mu_B$ (MUNU) and $1.3 \times 10^{-10} \mu_B$ (Texono) (both at 90% C.L).

Bound from Super-K (solar neutrinos)

Extra events in elastic scattering $\nu_i + e^- \rightarrow \nu_j + e^-$.

- For the solar neutrinos the expression for $|\mu_{eff}|^2$ reduces to a sum of two positive definite quantities

$$|\mu_{eff}|_{MSW}^2 = P_1 (\mu_{11}^2 + \mu_{12}^2 + \mu_{13}^2) + P_2 (\mu_{21}^2 + \mu_{22}^2 + \mu_{23}^2)$$

- $P_1 = |A_{e1}(L)|^2$ and $P_2 = |A_{e2}(L)|^2$ are the probabilities of the solar neutrinos to be in the mass eigenstate ν_1 and ν_2 respectively at the earth. No interference term.

The 8B neutrinos which are detected by electron scattering at Super-K are predominantly ν_2 state.

- Recent upper bound $|\mu_{eff}|_{MSW} < 1.1 \times 10^{-10} \mu_B$ at 90% *C.L* established by Super-Kamiokande (2004).
- The Super-K bound on $|\mu_{eff}|_{MSW}$ implies $|\mu_{12}| < 1.1 \times 10^{-10} \mu_B$; $|\mu_{22}|, |\mu_{23}| < 1.13 \times 10^{-10} \mu_B$ and $|\mu_{11}|, |\mu_{13}| < 4.49 \times 10^{-10} \mu_B$
(J.F. Beacom and P.Vogel, Phys Rev Lett, **83**,5222 (1999);
A.S.Joshi pura and S.M, Phys. Rev. **D 66**, 012003 (2002)
W.Grimus et al , Nucl Phys **B 648**, 376 (2003) and others).
- Super-K elastic scattering bound depends upon neutrino parameters since

$$\sigma_{\nu\mu} \sim \frac{1}{6} \sigma_{\nu e}.$$

Bounds on neutrino magnetic moment from SN0-NC

A.J.Grifols, E.Masso and S.M, arXiv:hep-ph/0401144 To appear in Phys Lett B 2004.

- Neutrinos with non-zero magnetic moments can dissociate deuterium in addition to the weak neutral currents.
- Cross section by equivalent photon approximation

$$\sigma_{mag} = \mu_{eff}^2 \frac{\alpha}{\pi} \left(\frac{E_\nu}{m_e} \right)^2 \int_{\epsilon_b/E_\nu}^1 dx \frac{(1-x)^2}{x} \sigma_\gamma(E_\gamma = xE_\nu) \quad (1)$$

Where σ_γ the deuterium photo-dissociation cross section.

The experimental "NC" flux reported by SNO can be related to the magnetic moment cross section as

$$\Phi_{NC}^{SNO} = \Phi_{SSM} \left(1 + \frac{\int dE_\nu \xi \sigma_{mag}}{\int dE_\nu \xi \sigma_{NC}} \right)$$

$\Phi_{SSM} = (5.82 \pm 1.34) \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$ is the 8B neutrino flux and ξ is the spectral shape of the 8B neutrino flux.

From SNO-NC (salt phase) we have

$$\Phi_{NC}^{SNO} = (4.90 \pm 0.37) \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$$

Using SNO-NC data we find that $|\mu_{eff}|^2$ is

$$|\mu_{eff}|^2 = (-2.61 \pm 3.35) \times 10^{-16}$$

This can be interpreted as an upper bound on $|\mu_{eff}|$ at 95% C.L. (1.96σ) given by

$$|\mu_{eff}| < 1.99 \times 10^{-8} \mu_B \quad (95\% C.L.)$$

The bound on μ_{eff} established from SNO-NC data does not depend upon the oscillation parameters unlike in the case of Super-K.