Limits On the Neutrino Magnetic Moment Using Super-Kamiokande-I Solar Neutrino Data

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(Super-Kamiokande Collaboration)

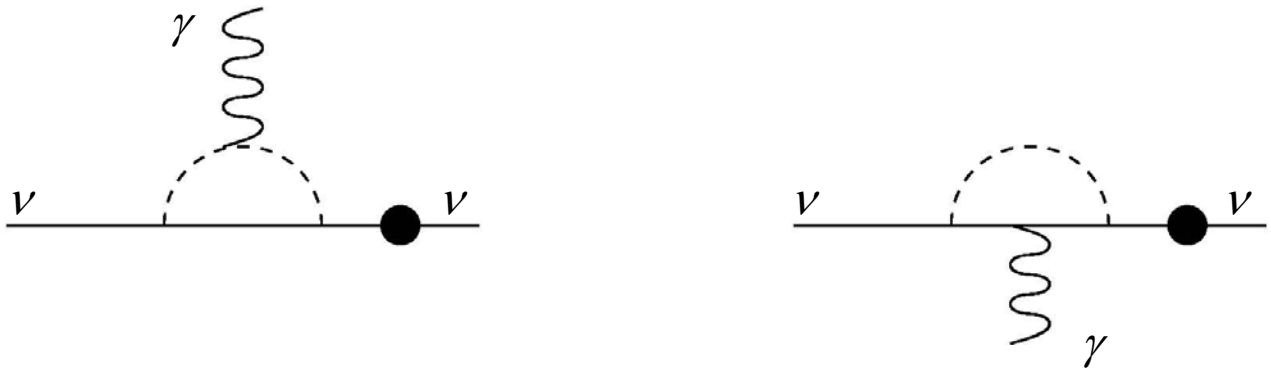
Introduction

- Pauli:Neutrino bound in nuclei by EM force through neutrino magnetic moment
- Magnetic moment is defined as a coefficient of the coupling

$$\overline{\nu_L}\sigma_{\alpha\beta}q^{\beta}\nu_R A^{\alpha} + \overline{\nu_R}\sigma_{\alpha\beta}q^{\beta}\nu_L A^{\alpha}$$

- In SM, $\mu_\nu = 0$

- Neutrinos Oscillate $\Rightarrow \; m_\nu \neq 0$



- Dirac neutrinos can have a loop induced magnetic moments

$$\mu_\nu = \frac{3 G_F e m_\nu}{8\sqrt{2}\pi^2} \approx 3.2 \times 10^{-19} \left(\frac{m_\nu}{1eV} \right) \mu_B$$

Experiment Search of μ_ν

- Reactor anti-neutrino experiments

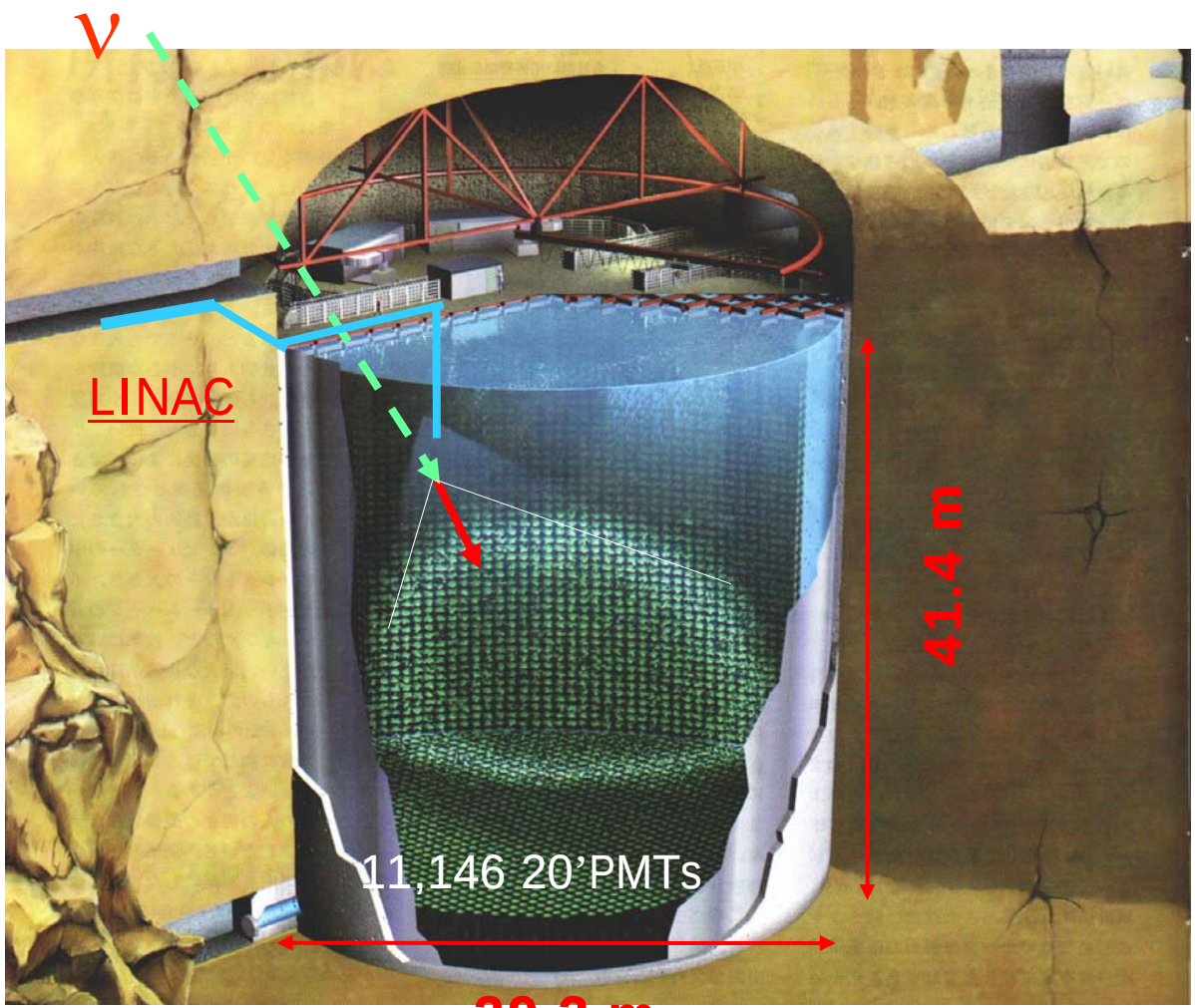
$$(1-4)\times 10^{-10}\,\mu_B$$

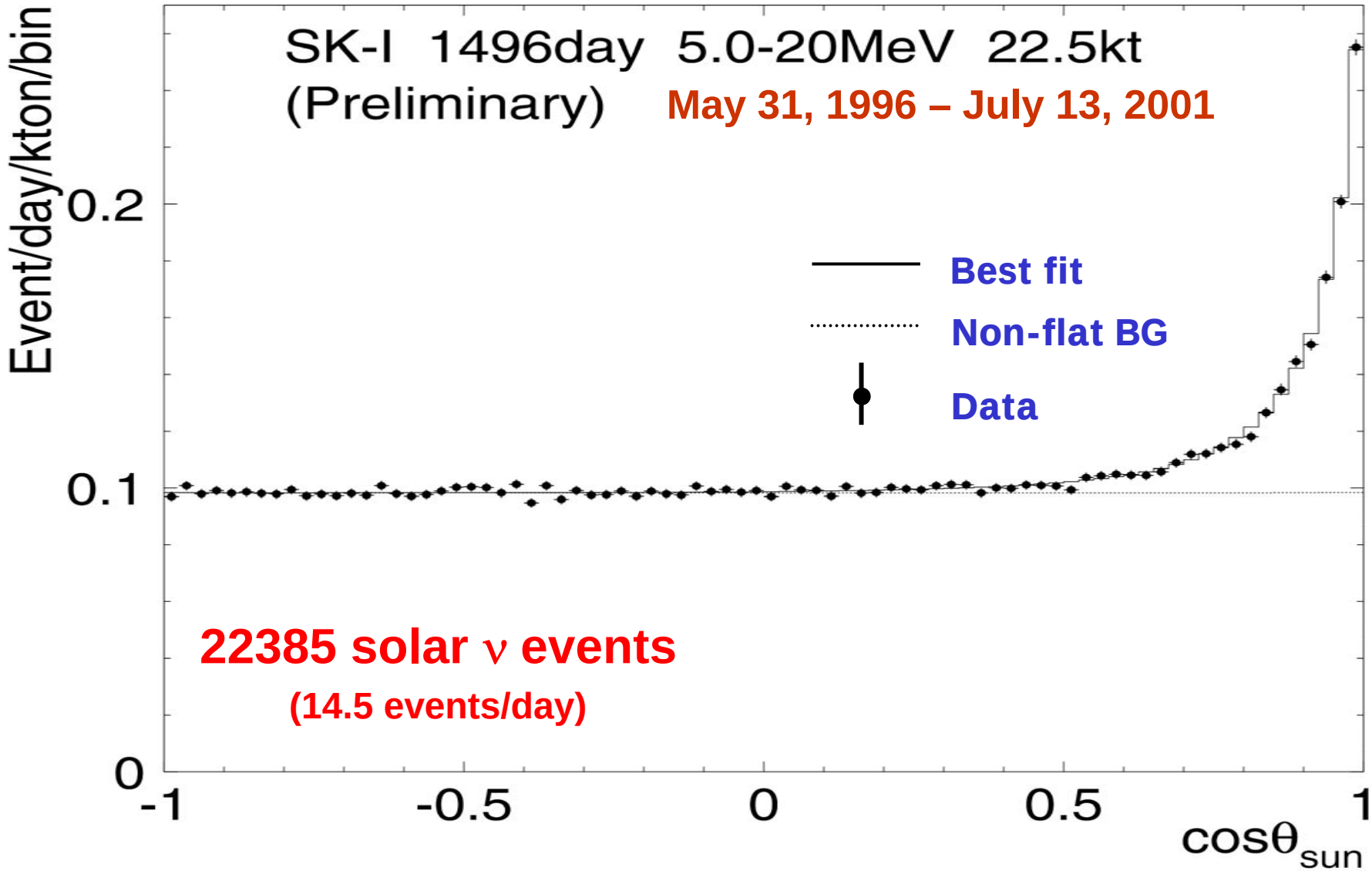
- Astrophysical Limits

$$10^{-12}-4\times 10^{-10}\,\mu_B$$

- Positive observation → New Physics
- SK high statistics solar neutrino data

Super-Kamiokande




SK-I 1496day 5.0-20MeV 22.5kt
(Preliminary)
May 31, 1996 – July 13, 2001
Best fit
Non-flat BG
Data
22385 solar ν events
(14.5 events/day)
Event/day/kton/bin
0.2
0.1
0
-1
-0.5
0
0.5
1
cosθsun

Neutrino-Electron Scattering

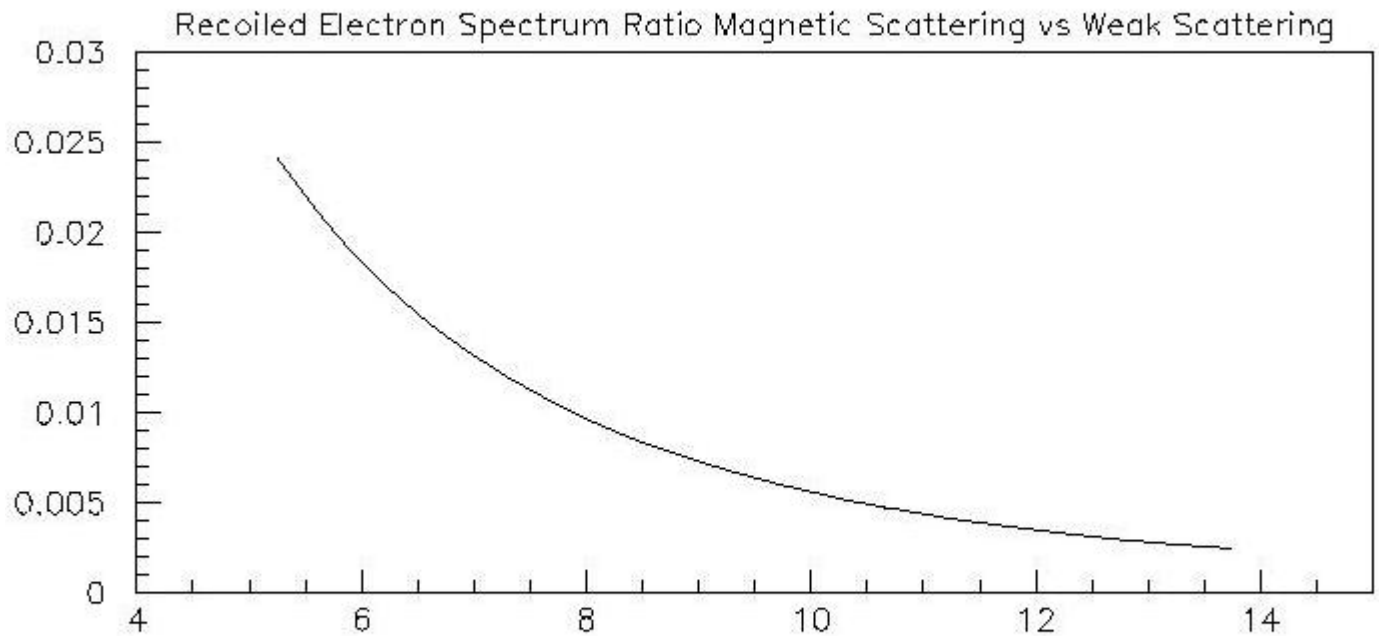
- Beacom & Vogel (PRL83,5222(99)) spectrum distortion
- Weak Scattering

$$\left(\frac{d\sigma}{dT}\right)=\frac{2G_F^2 m_e}{\pi}\left[g_L^2+g_R^2\left(1-\frac{T}{E_\nu}\right)^2-g_L g_R\frac{m_e T}{E_\nu^2}\right]$$

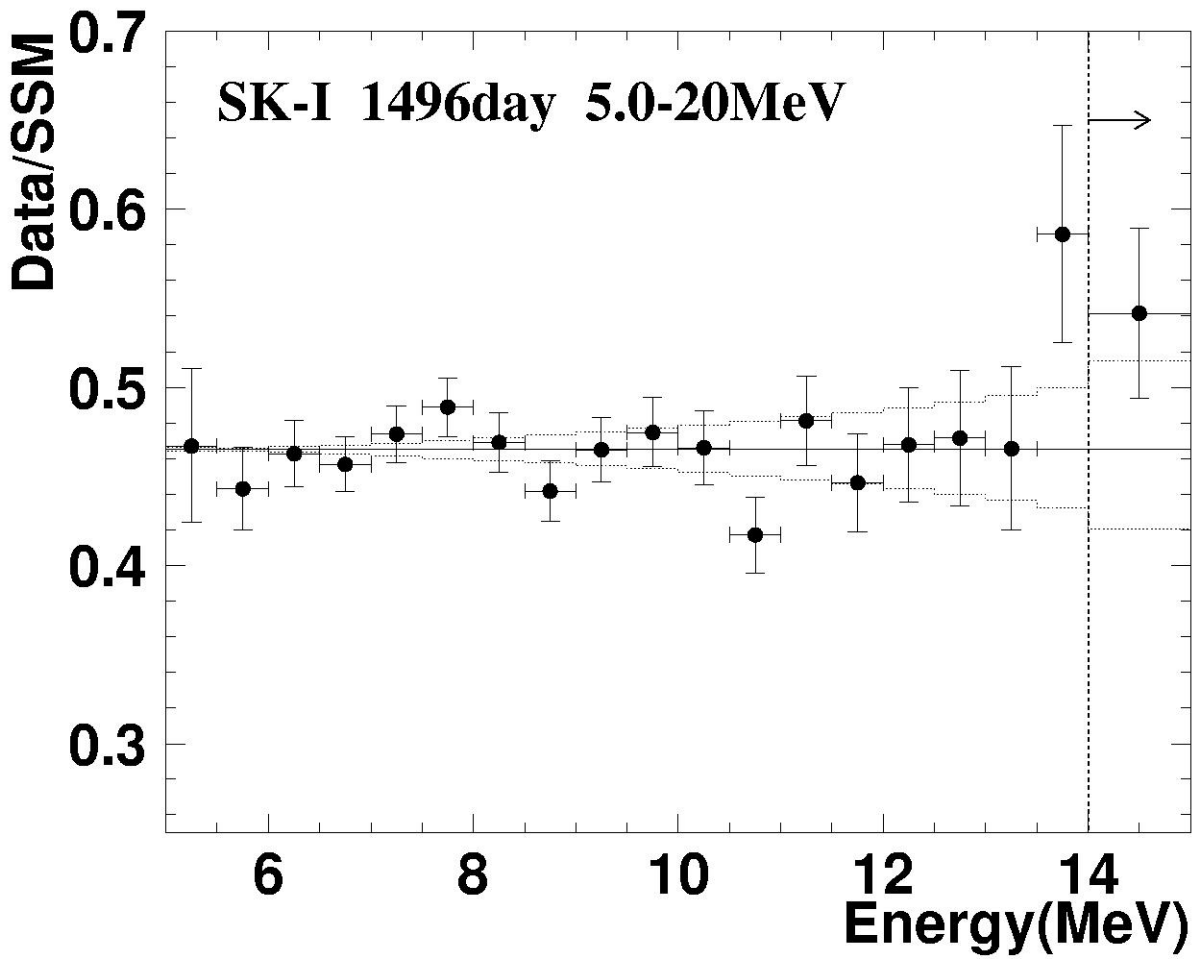
- Magnetic Scattering

$$\left(\frac{d\sigma}{dT}\right)=\mu_\nu^2\frac{\pi\alpha^2}{m_e^2}\left(\frac{1}{T}-\frac{1}{E_\nu}\right)$$

Magnetic Scattering vs Weak Scattering

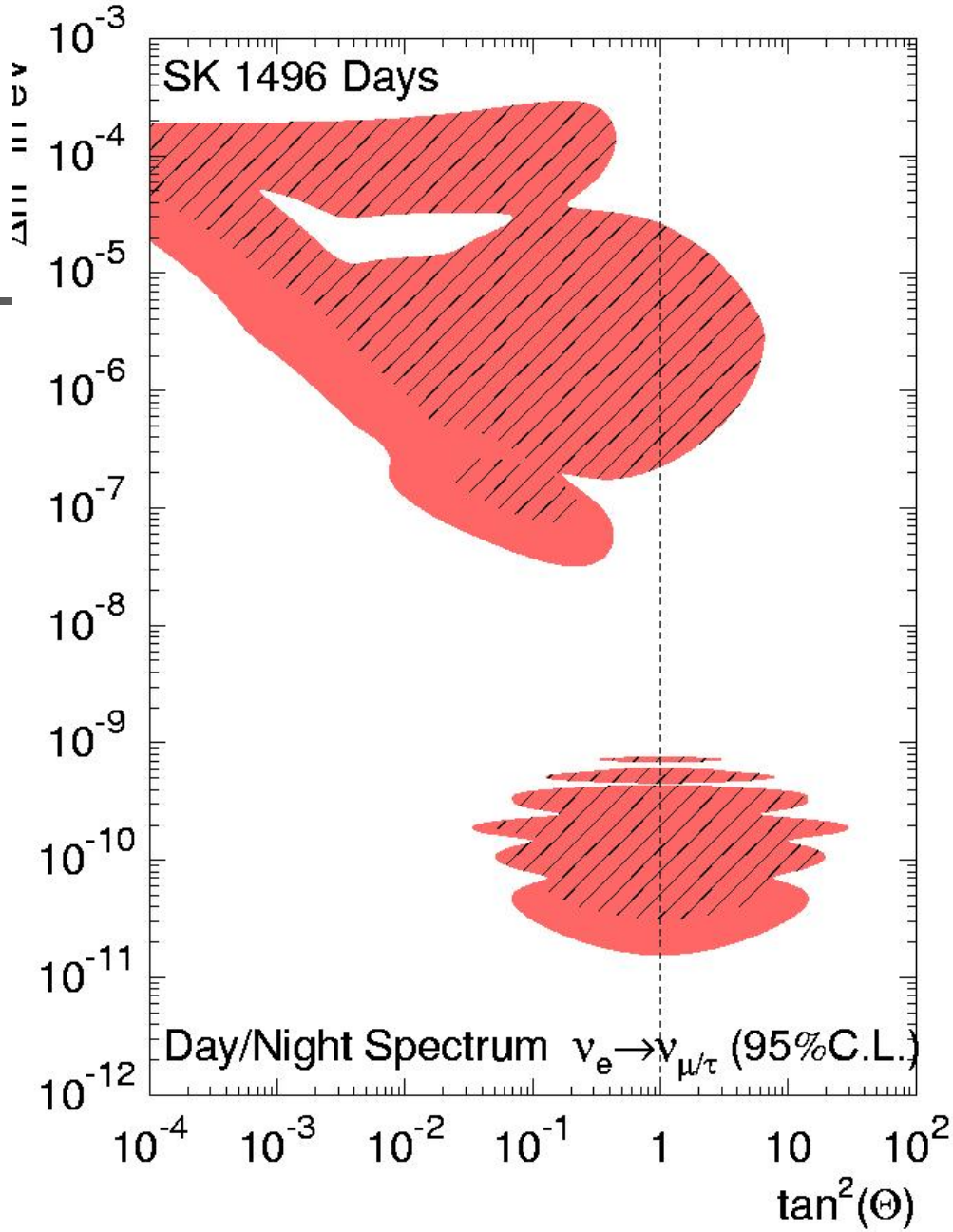


SK Recoil Electron Energy Spectrum

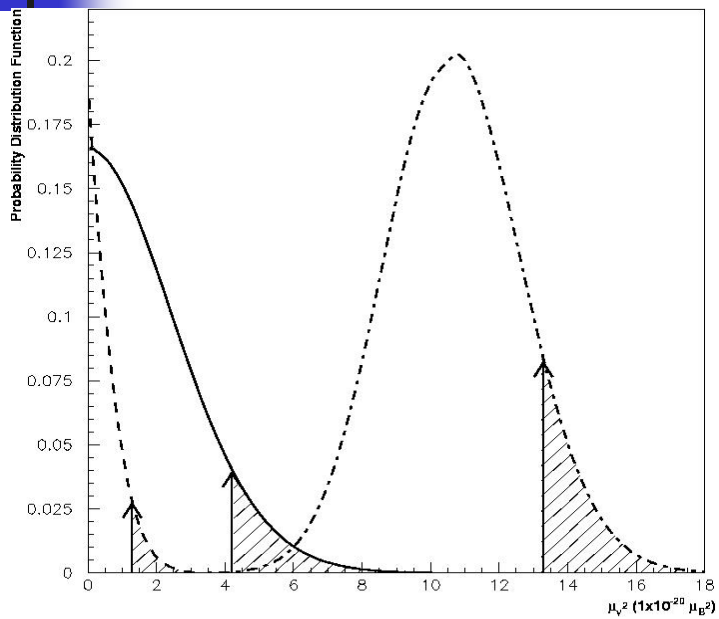


- Oscillation could distort the spectrum
- The measured energy spectrum is examined in the oscillation parameter space

$$\chi^2 = \sum_{a=d,n} \sum_{i=1}^{18} \left[\frac{\frac{\alpha}{1+\beta\delta_i}\left(W_i^a + \mu_\nu^2 M_i\right) - D_i^a}{\sigma_i^a} \right]^2 + \beta^2$$


SK 1496 Days
Day/Night Spectrum $\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
$\tan^2(\Theta)$

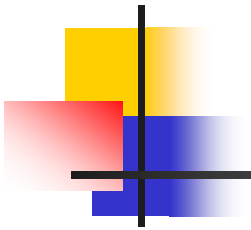
Limit on the neutrino magnetic moment



$$\Pr\left[\Delta\chi^2\left(\mu^2 \geq \mu_0^2\right)\right] = 0.1 \times \Pr\left[\Delta\chi^2\left(\mu^2 \geq 0\right)\right]$$

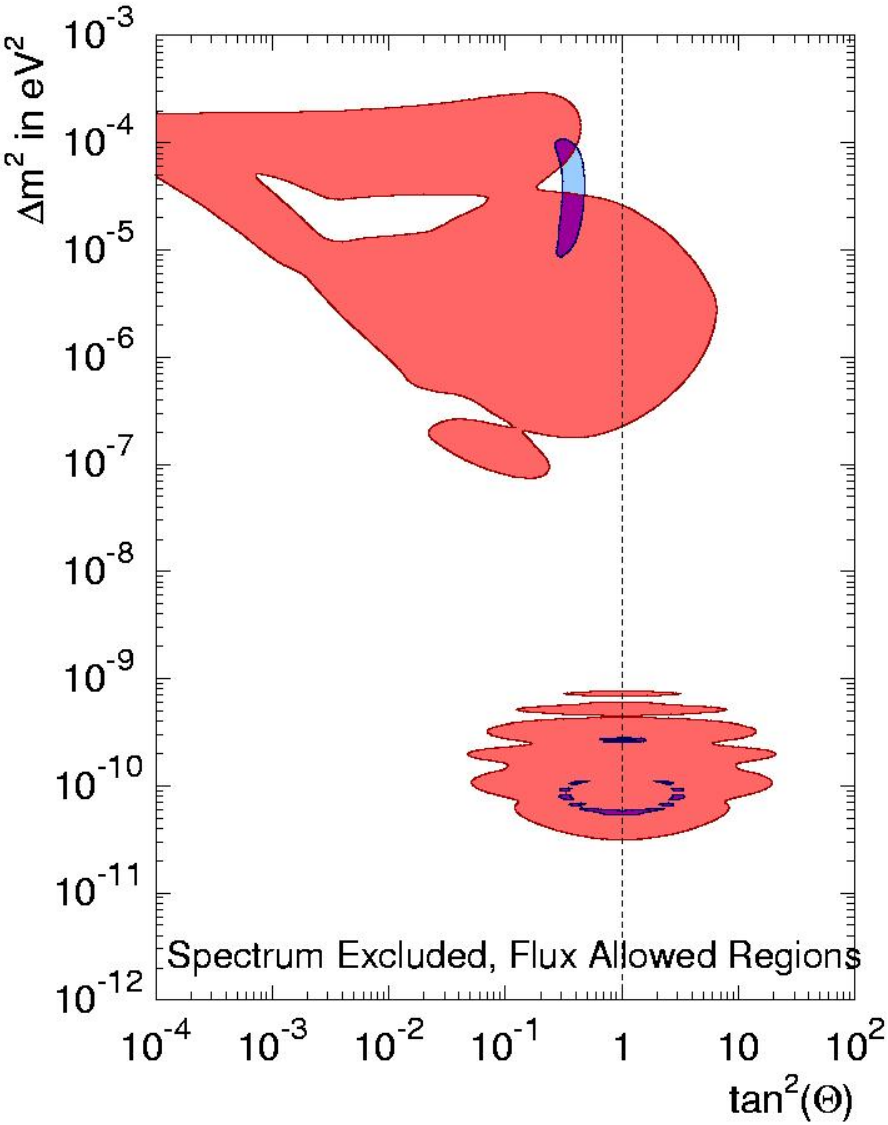
$$\mu_\nu \leq 3.6 \times 10^{-10}\,\mu_B$$

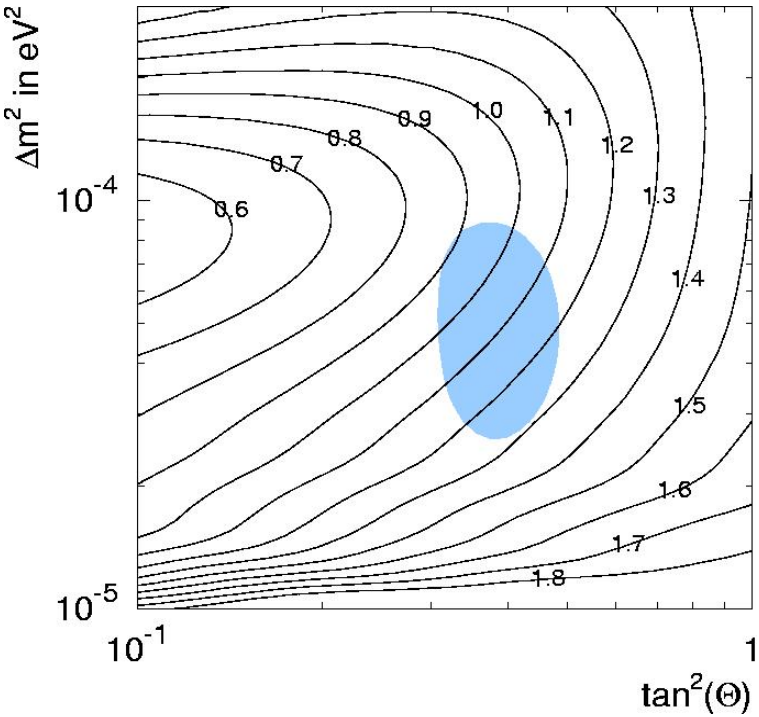
$$\Delta m^2 = 3.13 \times 10^{-11} eV^2, tg^2\theta = 0.91$$



Solar Neutrino Experiments

- Radiochemical experiments Homestake, SAGE and Gallex/GNO detect solar neutrinos via charged current interactions
- SNO using directional distributions of different interactions to extract CC, NC and elastic rates.
- The presence of neutrino magnetic moment would not change the rates measured by the aforementioned experiments





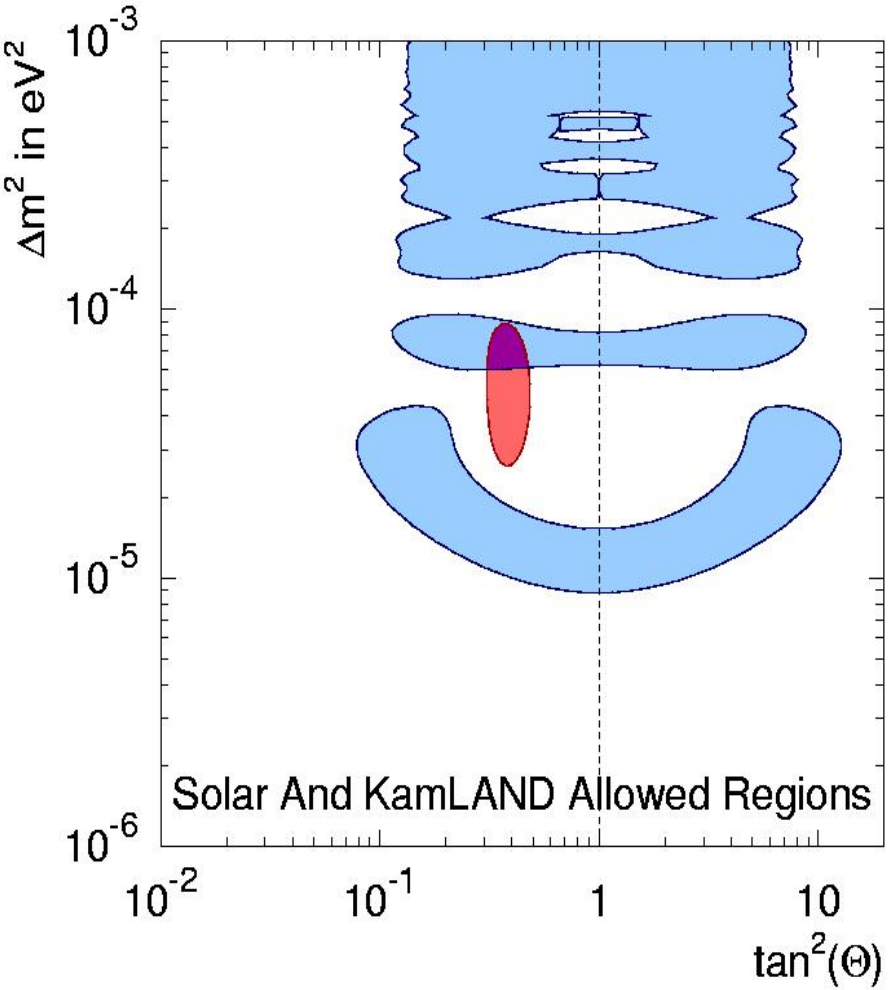
$$\mu_\nu \leq 1.3 \times 10^{-10}\, \mu_B$$

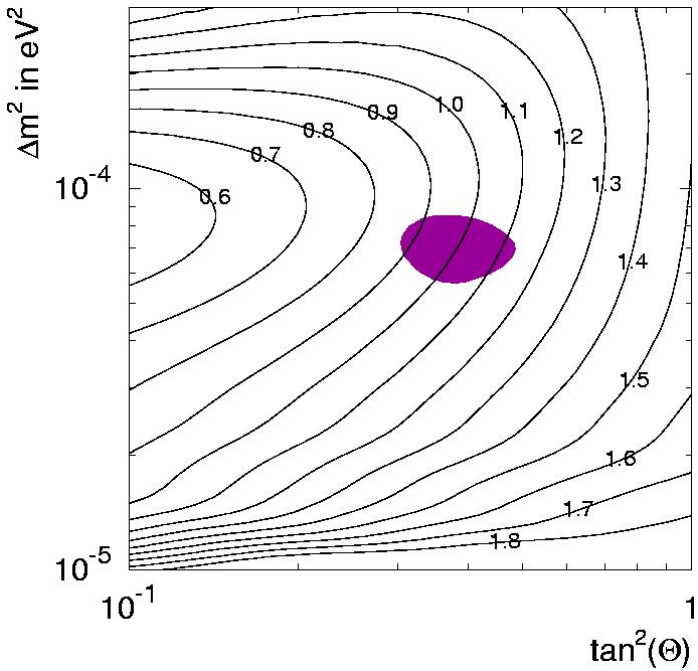
$$\Delta m^2 = 2.75 \times 10^{-5}\, eV^2$$

$$tg^2\theta = 0.42$$

KamLAND Experiment

- KamLAND uses inverse β decay interaction to detect.
- KamLAND results would not be affected by a non-zero neutrino magnetic moment
- Assuming CPT invariance

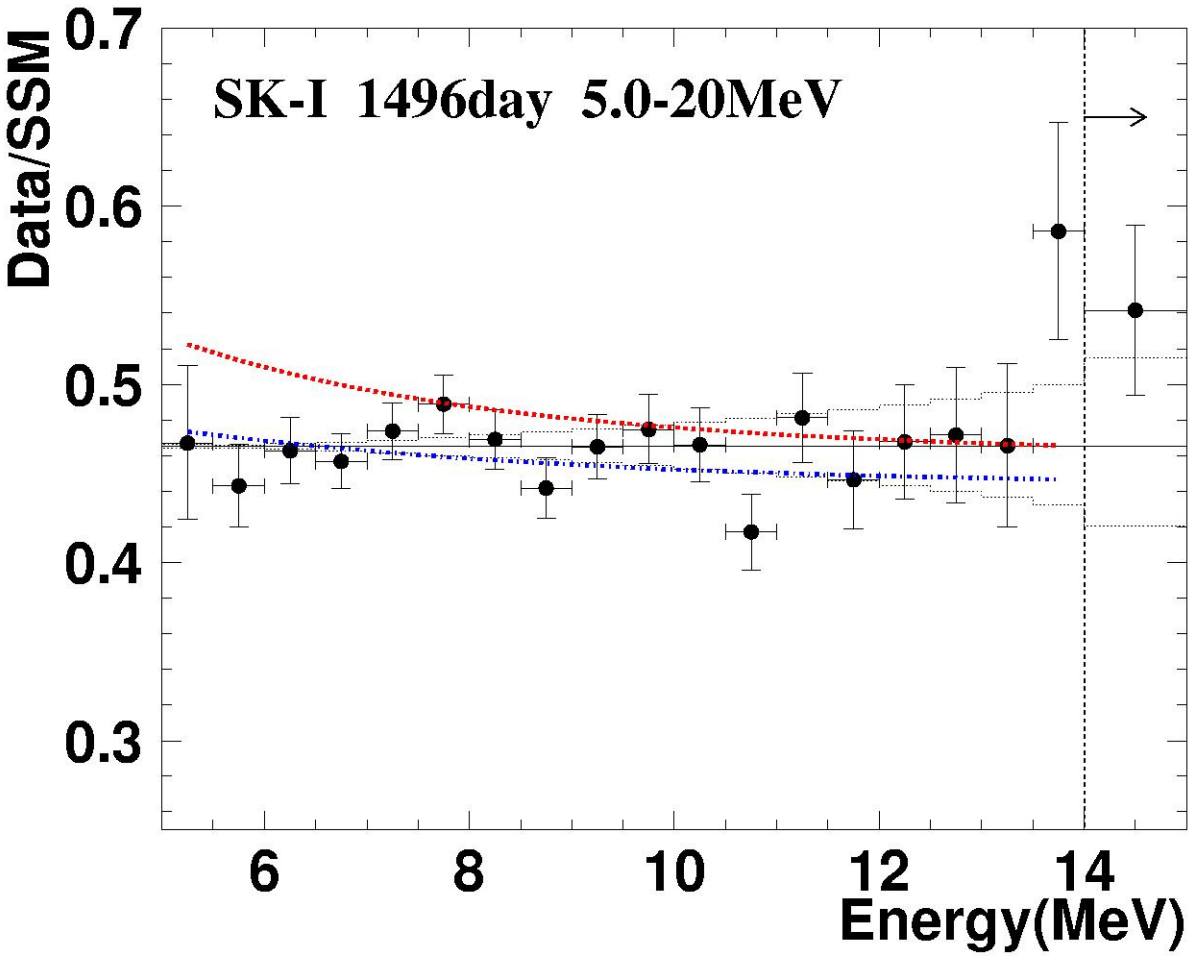




$$\mu_\nu \leq 1.1\times 10^{-10}\,\mu_B$$

$$\Delta m^2 = 6.61\times 10^{-5} eV^2$$

$$tg^2\theta = 0.48$$


SK-I 1496day 5.0-20MeV
Data/SSM
0.7
0.6
0.5
0.4
0.3
6
8
10
12
14
Energy(MeV)

Limits on the Neutrino Magnetic Moment

- A limit $1.1\times10^{-10}\,\mu_B$ on the neutrino magnetic moment using the 1496 days of SK solar neutrino data has been obtained (PRL93,021802(04))
- Comparable to most recent reactor neutrino results (MUNU) $1.0\times10^{-10}\,\mu_B$, (TEXONO) $1.3\times10^{-10}\,\mu_B$