Resonance Spin Flavour Precession and Solar Neutrino

International Workshop and Seminar/School on

Coherent Evolution in Noisy Environments

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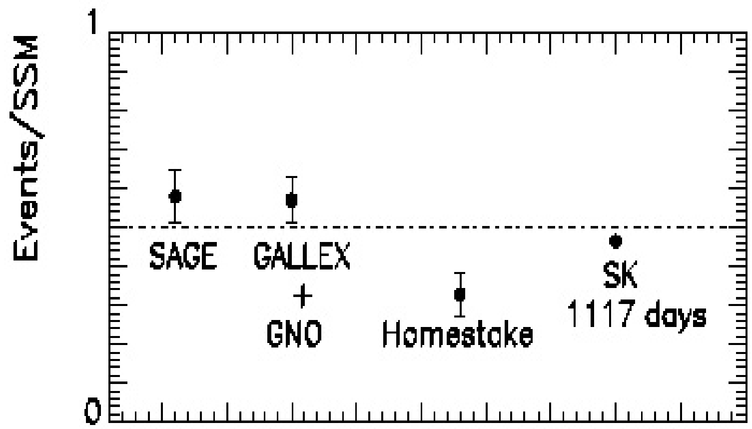
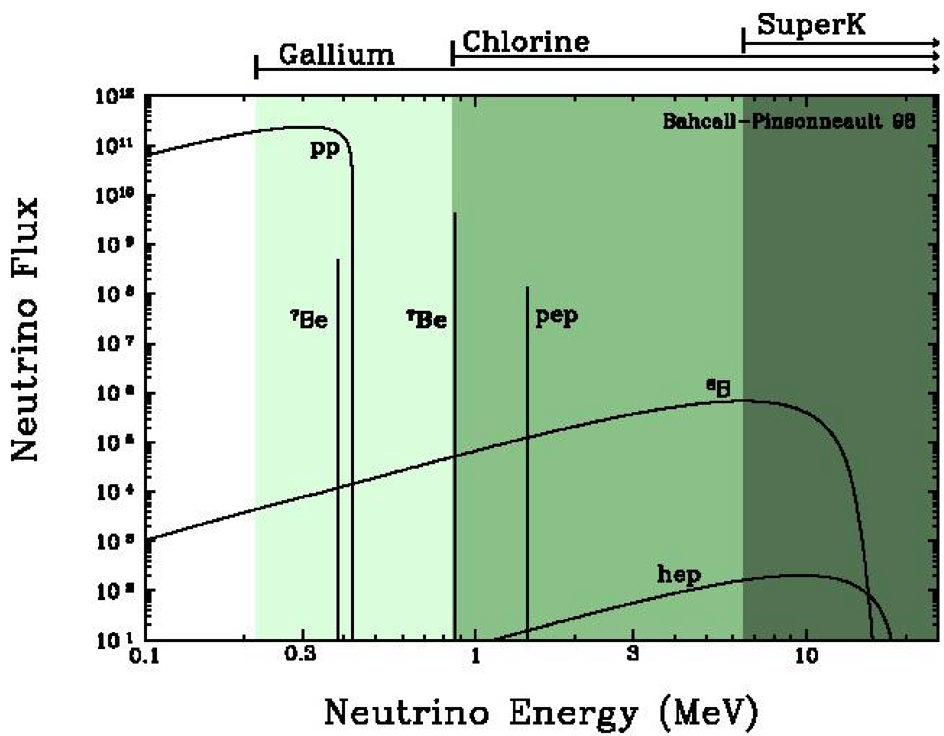
Experimental Status

Measured solar neutrino events rates





Solar neutrino energy spectrum

Experimental Status

Solar neutrino Rates:

Experiment	BP2000	Measured	Measured/SSM
Chlorine	$7.7^{+1.3}_{-1.1}$	2.56 ± 0.23	0.33 ± 0.06
GALLEX + GNO	129^{+9}_{-7}	$74.1^{+6.7}_{-7.8}$	0.57 ± 0.07
SAGE	129^{+9}_{-7}	$75.4^{+7.8}_{-7.4}$	0.58 ± 0.07
Kamiokande	$5.15[1^{+0.20}_{-0.10}]$	$2.8[1 \pm 0.14]$	0.54 ± 0.13
S-Kamiokande	$5.15[1^{+0.20}_{-0.10}]$	$2.4[1^{+0.04}_{-0.03}]$	0.47 ± 0.09

Experimental Status

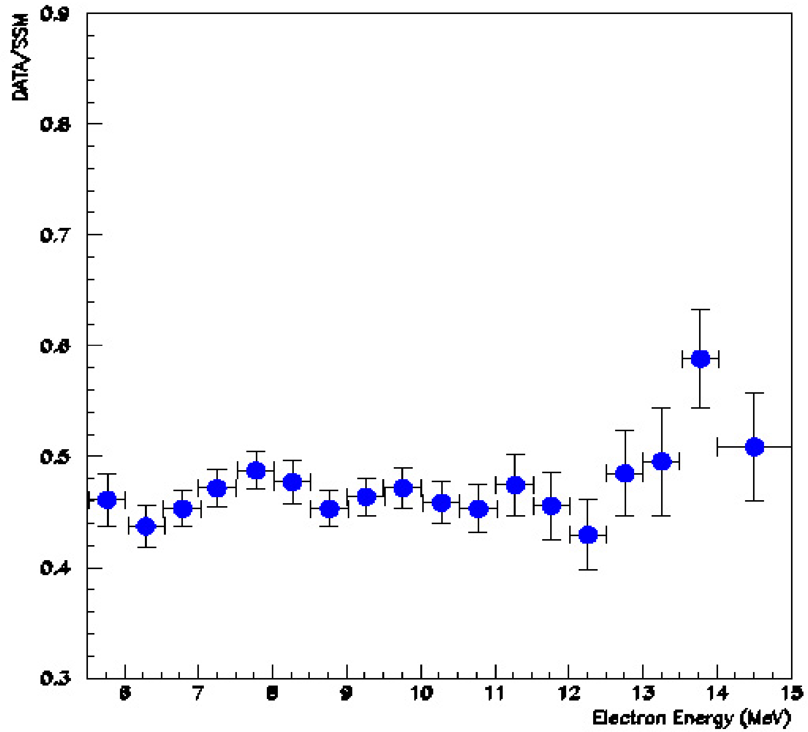
SuperKamaiokande:

•Recoil electron energy spectrum:

Data: 1117 days

$$\chi^2_{flat} = 13.7/(17dof)$$

Consistent to be flat.



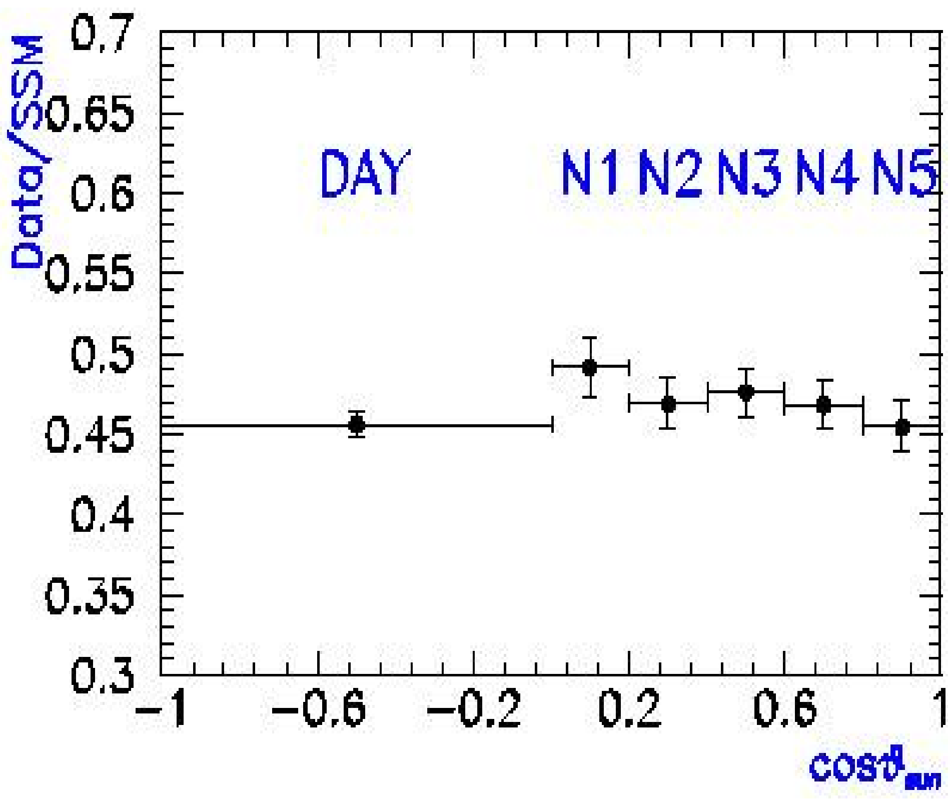
Experimental Status

•Zenith Angle Distribution

Day/Night Effect

$$\frac{D-N}{(D+N)/2} = -0.034 \pm 0.024$$

Only 1.3σ level



Neutrino Oscillation

$$\nu_e = \cos\vartheta\,\nu_1 + \sin\vartheta\,\nu_2$$

$$\nu_\mu = -\sin\vartheta\,\nu_1 + \cos\vartheta\,\nu_2$$

The evolution of neutrino is gouverned by:

$$H = \begin{pmatrix} E_1 & 0 \\ 0 & E_2 \end{pmatrix}_{\nu_{1,2}}$$

Transition probability:

$$\boxed{P_{\nu_e \to \nu_\mu}(L) = \sin^2(2\vartheta)\sin^2(\pi L / L_\nu)}$$

$$L_\nu = 4\pi E / \Delta m^2$$

Neutrino Oscillation

MSW medium-effects:

$$\begin{pmatrix} E_1 - GN_e \cos^2\vartheta & -GN_e \sin\vartheta\cos\vartheta \\ -GN_e \sin\vartheta\cos\vartheta & E_2 - GN_e \sin^2\vartheta \end{pmatrix}$$

$$\boxed{P_{\nu_e \to \nu_\mu} = \frac{1}{2}\sin^2(2\vartheta)\left(\frac{L_m}{L_\nu}\right)^2\left[1-\cos(2\pi L / L_m)\right]}$$

$$L_m = L_\nu\left[1+\left(\frac{L_\nu}{L_0}\right)^2 - 2\cos(2\vartheta)\left(\frac{L_\nu}{L_0}\right)\right]^{-\frac{1}{2}}$$

$$L_0 = 2\pi / GN_e$$

Environment Influence on Neutrino Oscillation

The Schrodinger equation:

$$i\frac{d}{dt}\rho = [H,\rho]$$

Reznik generalization

$$i\frac{d}{dt}\hat{\rho} = [H,\hat{\rho}] + L\hat{\rho} + \hat{\rho}R + g_{ij}K_i\hat{\rho}K'_j$$

$$\hat{\rho}\hat{\rho}^+ \equiv \rho$$

$$i\frac{d}{dt}\hat{\rho} = [\tilde{H},\hat{\rho}] + K\hat{\rho}K'$$

Environment Influence on Neutrino Oscillation

Extension term:

$$K\rho K' = (a\sigma_1 + b\sigma_3)\hat{\rho}\lambda\sigma_3$$

$$P = \frac{1}{2}\sin^2(2\vartheta)(\frac{L_m}{L_\nu})^2[1 - \cos(2\pi L / L_m)\cos(2\pi L\lambda / L_m)$$
$$+ \cos(2\vartheta)\sin(2\pi L / L_m)\sin(2\pi\lambda L / L_m)]$$

Resonant Spin-Flavor Precession

Time evolution of the solar neutrino

Majorana Neutrino

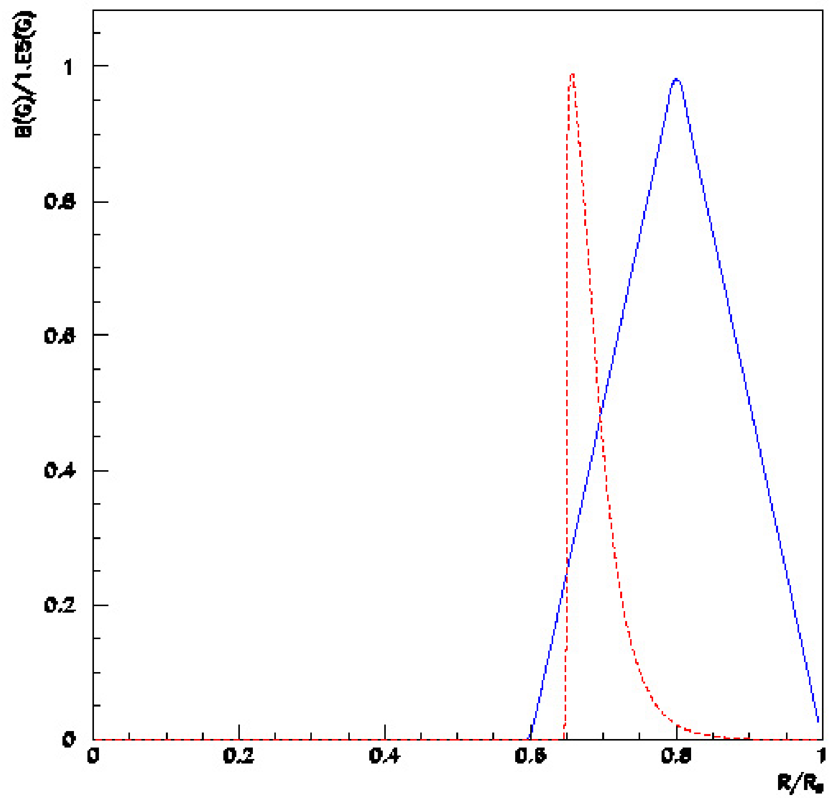
- Static field:

$$i\frac{d}{dt}\begin{pmatrix}\nu_e \\ \bar{\nu}_\mu\end{pmatrix} = \begin{bmatrix}\frac{5G_F n_e}{3\sqrt{2}} & \mu B \\ \mu B & \frac{\Delta m^2}{2E}\end{bmatrix}\begin{pmatrix}\nu_e \\ \bar{\nu}_\mu\end{pmatrix}$$

Resonant Spin-Flavor Precession

Solar magnetic field:
Very little is known.

Sudden sharp rise in the bottom of the convective zone.



Total event rates

Linear distribution:

$$\Delta m^2 = 1.77\ 10^{-8} eV^2$$

$$\mu = 5.53\ 10^{-11} \mu_B$$

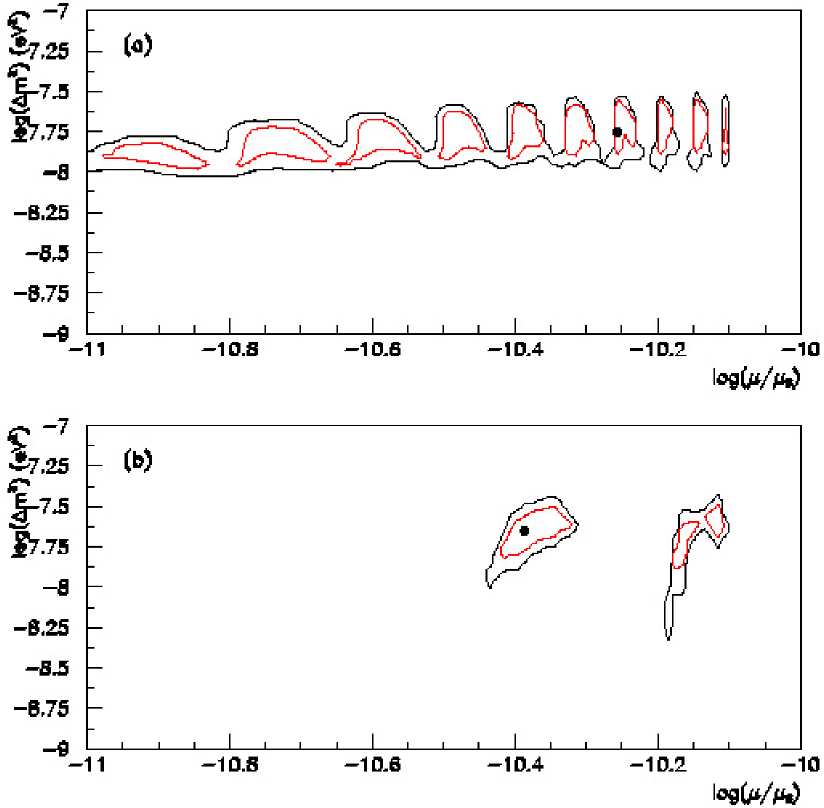
$$\chi^2 = 0.05$$

•Hyperbolic distribution:

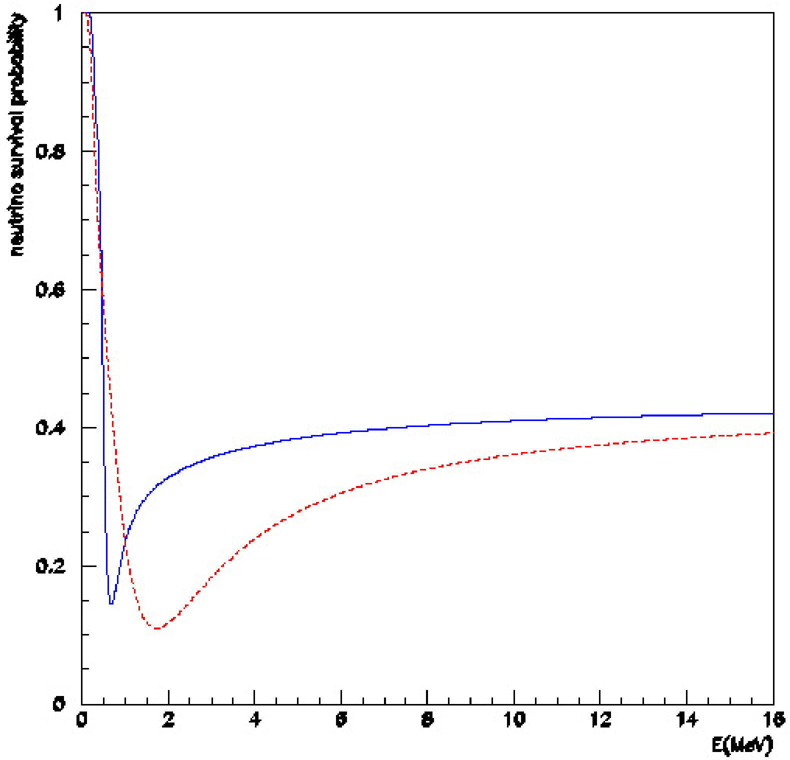
$$\Delta m^2 = 2.23\ 10^{-8} eV^2$$

$$\mu = 4.10\ 10^{-11} \mu_B$$

$$\chi^2 = 0.05$$



Total event rates



Very good fit:

- •PP neutrinos are not so suppressed
- •Be7 neutrinos are strongly suppressed
- •B8 neutrinos are moderately suppressed

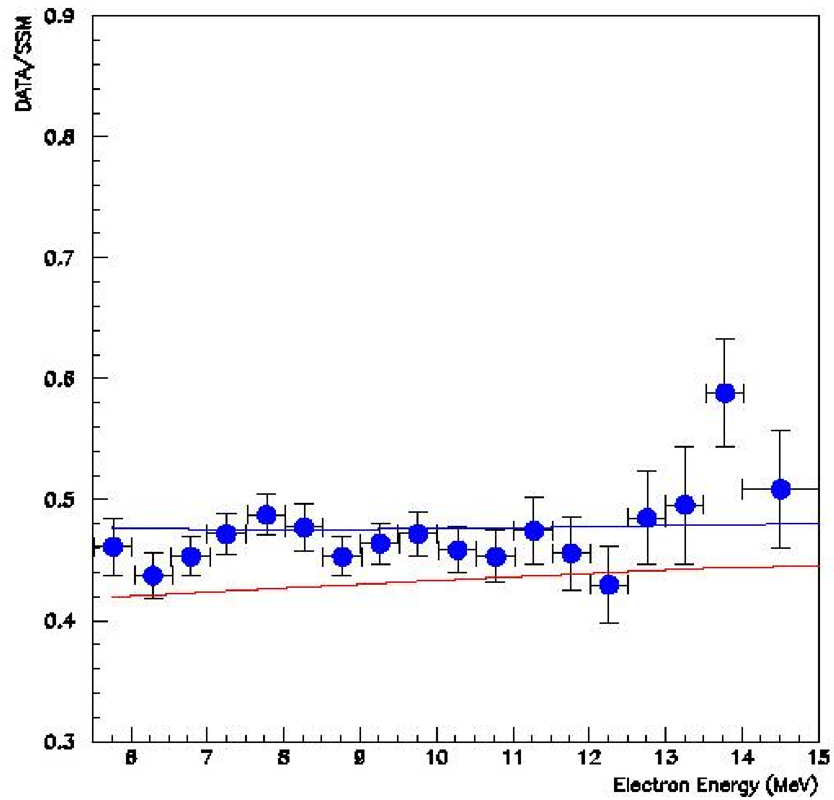
Recoil electron energy spectrum

- Linear distribution:

$$\chi^2 = 21.18/16\, d.o.f$$

- Hyperbolic distribution:

$$\chi^2 = 63.46/16\, d.o.f$$



Twisting magnetic field

- Twisting magnetic field

$$i\frac{d}{dt}\begin{pmatrix}\nu_e \\ \bar{\nu}_\mu\end{pmatrix} = \begin{bmatrix} \frac{5G_F n_e}{3\sqrt{2}} + \dot{\phi} & \mu B \\ \mu B & \frac{\Delta m^2}{2E} \end{bmatrix} \begin{pmatrix}\nu_e \\ \bar{\nu}_\mu\end{pmatrix}$$

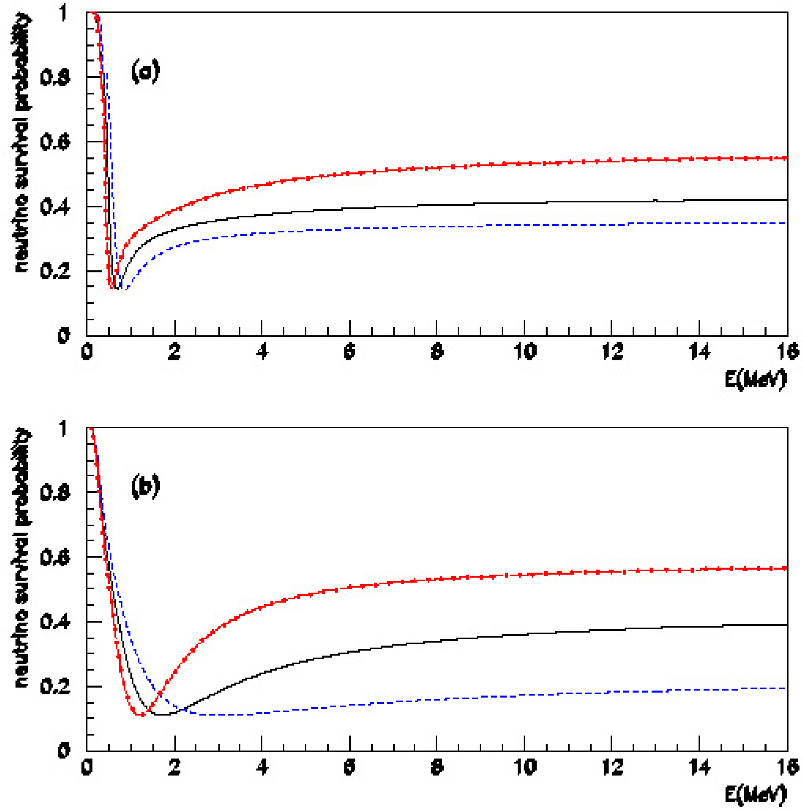
$$\dot{\phi} \approx \frac{1}{r_0} \approx 0.1 R_s$$

$$k = \frac{R_s}{r_0} = \pm 10$$

Twisting magnetic field

RSFP:

- is amplified when k =-10
- Is suppressed for k=+10



Total event rates

K = -10

$$\Delta m^2 = 1.41\,10^{-8}\,eV^2$$

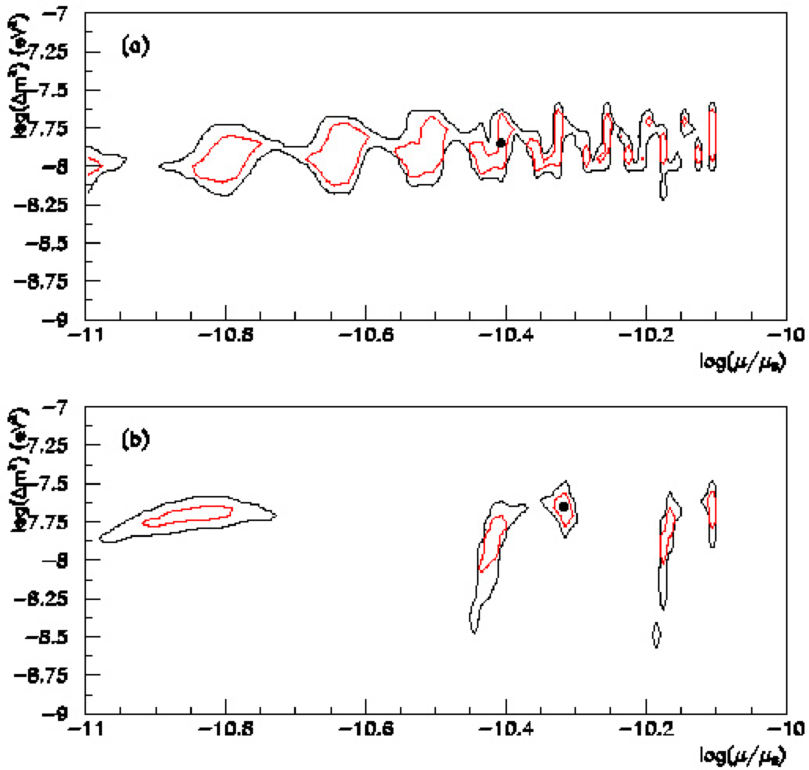
$$\mu = 3.91\,10^{-11}\,\mu_B$$

$$\chi^2 = 0.03$$

$$\Delta m^2 = 2.23\,10^{-8}\,eV^2$$

$$\mu = 4.82\,10^{-11}\,\mu_B$$

$$\chi^2 = 0.01$$



Total event rates

K = +10

$$\Delta m^2 = 2.23\,10^{-8}\,eV^2$$

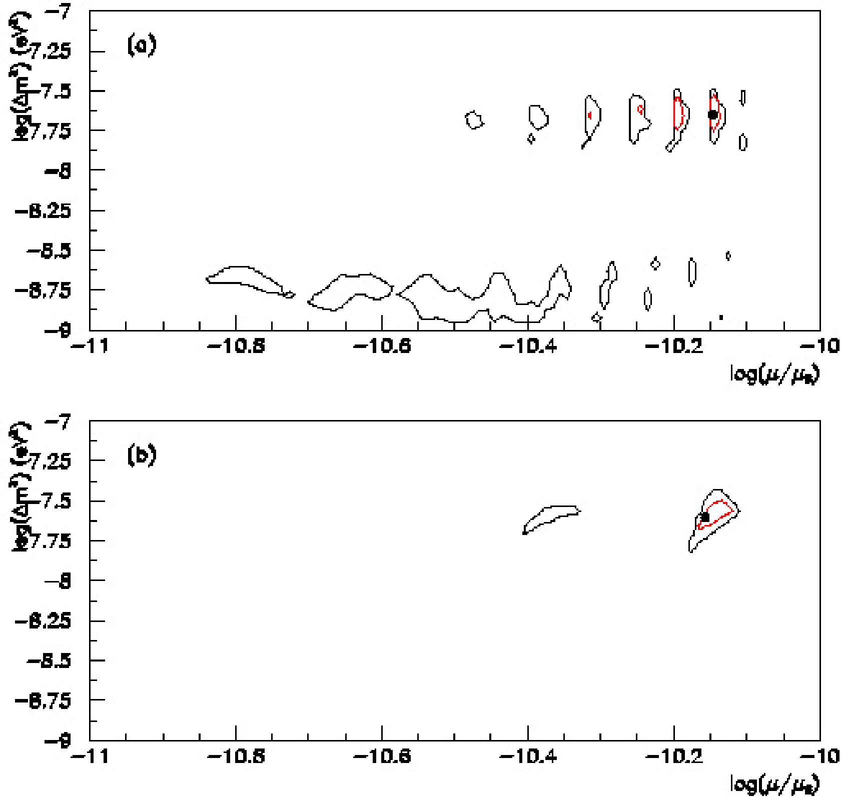
$$\mu = 7.13\,10^{-11}\,\mu_B$$

$$\chi^2 = 0.08$$

$$\Delta m^2 = 2.51\,10^{-8}\,eV^2$$

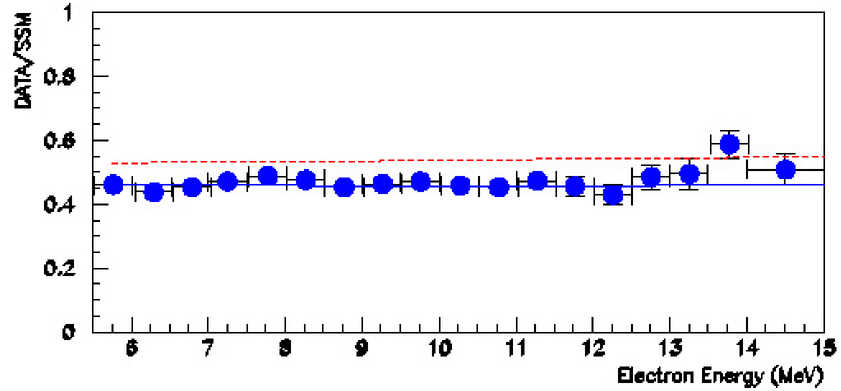
$$\mu = 6.96\,10^{-11}\,\mu_B$$

$$\chi^2 = 0.06$$

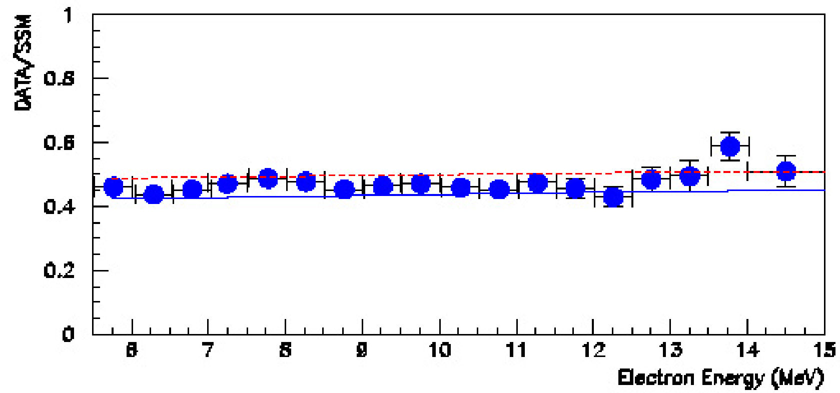


Recoil electron energy spectrum

$$\Delta m^2 = 1.41\,10^{-8} eV^2$$
$$\mu = 3.91\,10^{-11} \mu_B$$
$$\chi^2 = 18.04 / 16 dof$$



$$\Delta m^2 = 2.23\,10^{-8} eV^2$$
$$\mu = 4.82\,10^{-11} \mu_B$$
$$\chi^2 = 51.82 / 16 dof$$



Charged and neutral currents at SNO

- CC. reaction (Q =1.44MeV)

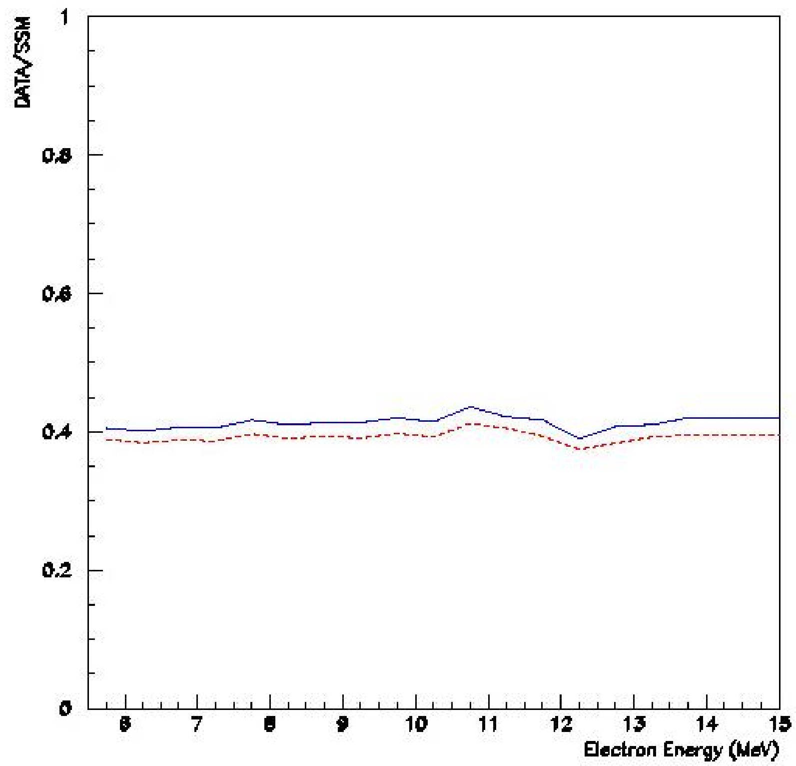
$$\nu_e + d \rightarrow p + p + e$$

- NC. reaction

$$\nu_x + d \rightarrow n + p + \nu_x$$

Es = 5MeV

$$\frac{\frac{R_{NC}}{R^0_{NC}}}{\frac{R_{CC}}{R^0_{CC}}} \approx 2.38$$



Conclusion

- environmental influence may be experimentaly accessible.
- RSFP mechanism can still provide a good solution to the solar neutrino problem.
- Solar twisting field with positive k seems to be disfavored.
- It is crucial to have a good enough knowledge of the sun magnetic field.
- What is the most likely solution? (possible time variation)