Neutrino dipole moments and Solar experiments

Marco Picariello

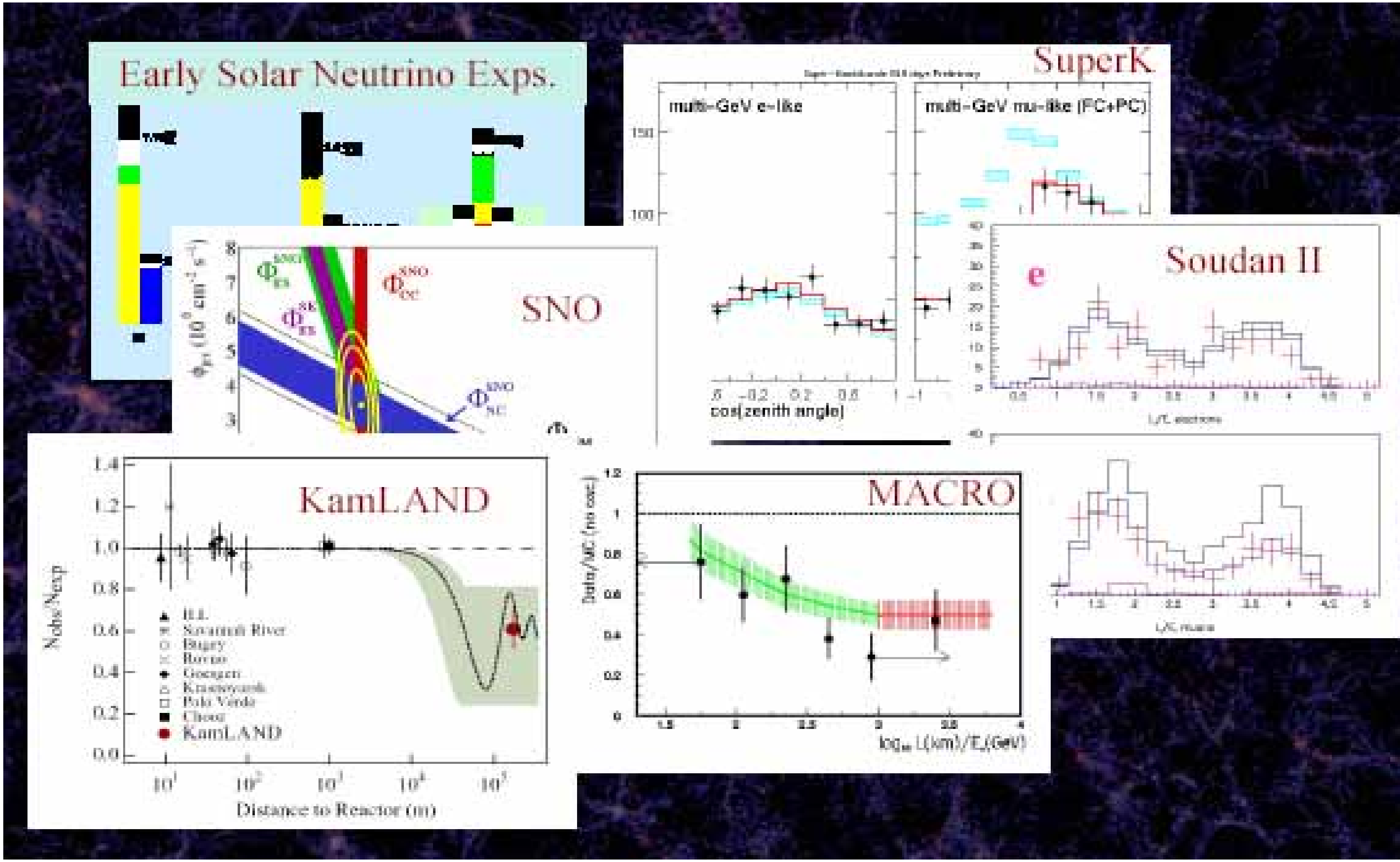
INFN Istituto Nazionale di Fisica Nucleare Sezione di Lecce

Università degli Studi di Lecce

Torrente-Lujan, Fernandez-Melgarejo (Murcia), Pulido, Das, Chauhan (Lisboa), Montanino (Lecce)

- *Light sterile neutrinos, spin flavour precession and the solar neutrino experiments* 0902.1310
- PRD D77:093011, 2008;
- Eur.Phys.J.C57:13-182, 2008, Report of Working Group 3 of the CERN Workshop ”Flavour in the era of the LHC”;
- JHEP 0711 (2007) 055;
- J. Phys. G: Nucl. Part. Phys. 34 (2007) 18031812;
- Phys.Rev.D69:013005,2004;
- JHEP 0302 (2003) 025;
- Nuclear Physics B634 (2002) 393-409.

Neutrino precision tests



What is known, what is unknown

- **Neutrino flavour oscillations**

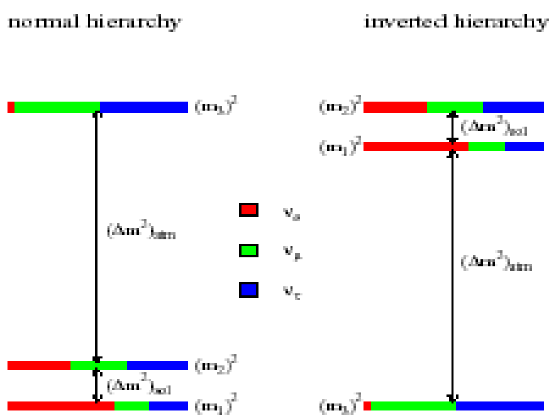
$\Delta m^2_{21}=7.67\ 10^{-5}\ eV^2$ $\sin\Theta_{12}=0.559$

$\Delta m^2_{23}=2.39\ 10^{-3}\ eV^2$ $\sin\Theta_{23}=0.683$

$\theta_{13} < 10^o$ δ ?

- **Absolute neutrino masses ?** → ^3H beta decay, Cosmology

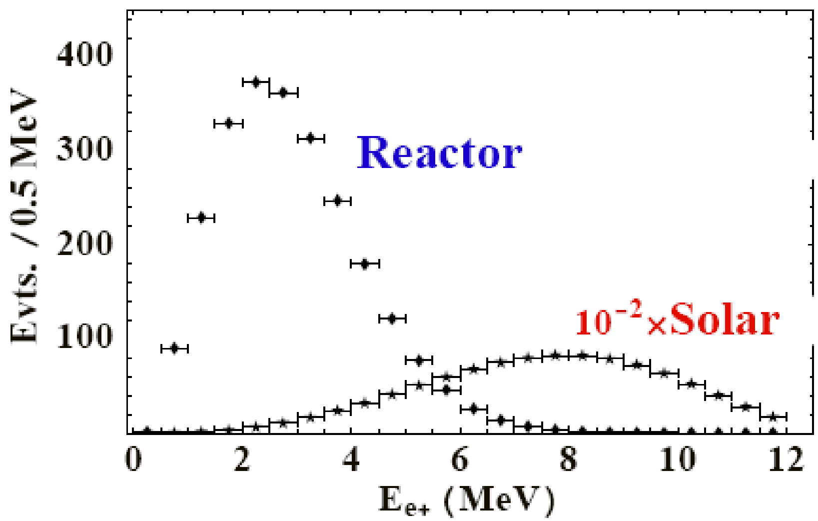
- **Form of the mass spectrum**



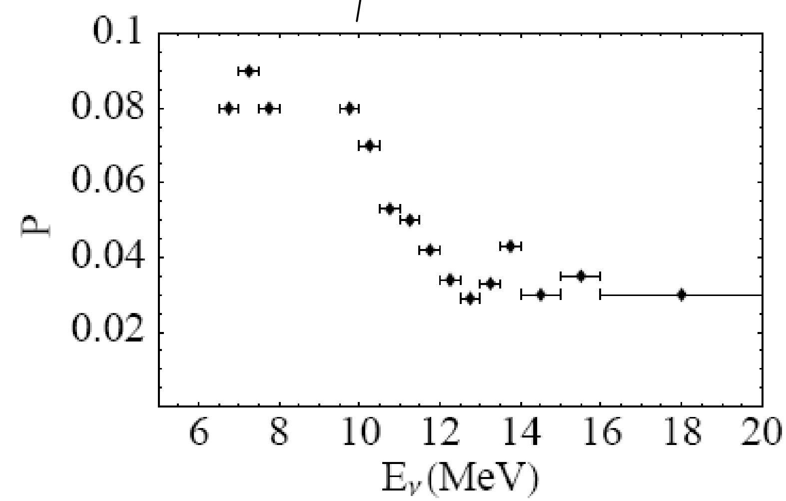
→ Matter effect in neutrino propagation

- **Majorana neutrinos** ? → $0\nu\beta\beta$: masses and phases

KamLAND, solar antineutrinos and their magnetic moment



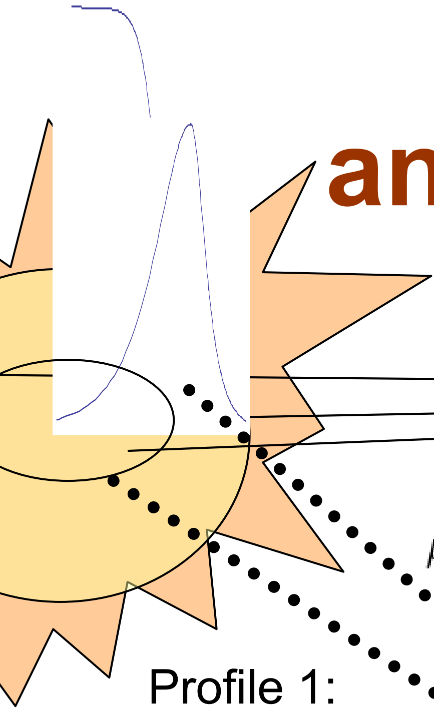
$$\cos^2\alpha = 0.08^{+0.20}_{-0.40}$$

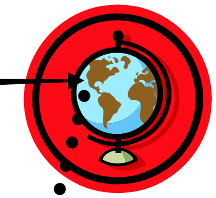


3 neutrinos: Limit from Borexino $|\mu_\nu| < 0.84 \times 10^{-10}\ \mu_B$

- Better than the limits obtained for SK-I global analysis ($|\mu_\nu| < 3.6 \times 10^{-10}\ \mu_B$ Liu 2004), and the combined analysis of the Kamiokande-Clorine experiments ($|\mu_\nu| < 5.4 \times 10^{-10}\ \mu_B$ Mourao 1992);
- Comparable with the combined analysis from other solar neutrino experiments ($|\mu_\nu| < 1.5 \times 10^{-10}\ \mu_B$ at 90% CL Beacom 1999) (SSM-GS98);
- Comparable with the Super Kamiokande total rate analysis ($|\mu_\nu| < 2.1 \times 10^{-10}\ \mu_B$ at 90% CL (SSM-AGS05);
- Competitive with respect to the direct limits from reactors (i.e. $|\mu_\nu| < 1.0 \times 10^{-10}\ \mu_B$ at 90% CL in MuNu Daraktchieva 2003, $|\mu_\nu| < 0.58 \times 10^{-10}\ \mu_B$ at 90% CL in GEMMA experiment Beda 2007);
- Independent on the solar standard model: $|\mu_{\nu_\mu}| < 1.5 \times 10^{-10}\ \mu_B$ ($< 6.8 \times 10^{-10}\ \mu_B$), $|\mu_{\nu_\tau}| < 1.9 \times 10^{-10}\ \mu_B$ ($< 3900 \times 10^{-10}\ \mu_B$).

Light sterile neutrinos and spin flavour precession





$\mu_\nu = 10^{-12}\mu_B$

Profile 1:

Δm^2_{01}=1.25 10^{-7} eV^2,

B_0=0-280 kGuss,

@ convection zone

Profile 2:

Δm^2_{01}=2.7 10^{-6} eV^2,

B_0=1.5 MGauss

@ center (Wood-Saxon type)

$$N_{T_e^{in}}^{T_e^{fin}} = \sum_{\phi=\nu\ Fluxes} Q_0 N_{\Phi^\phi} \int_{E_\nu=E_\nu^{min}}^{E_\nu^{max}} dE_\nu\, \Phi^\phi(E_\nu) \int_{E_e=E_e^{min}}^{E_e^{max}} dE_e\, \tilde{R}(E_e, T_e^{in}, T_e^{fin}, \sigma)$$

$$\sum_{\nu_x=\nu_e,\nu_\mu,\nu_\tau} \left\{ P(E_\nu)_{\nu_e\to\nu_x} \frac{d\sigma^{\nu_x}(E_e,E_\nu)}{dE_e} \right\}$$

Two gallium data sets, spin flavour precession and KamLAND

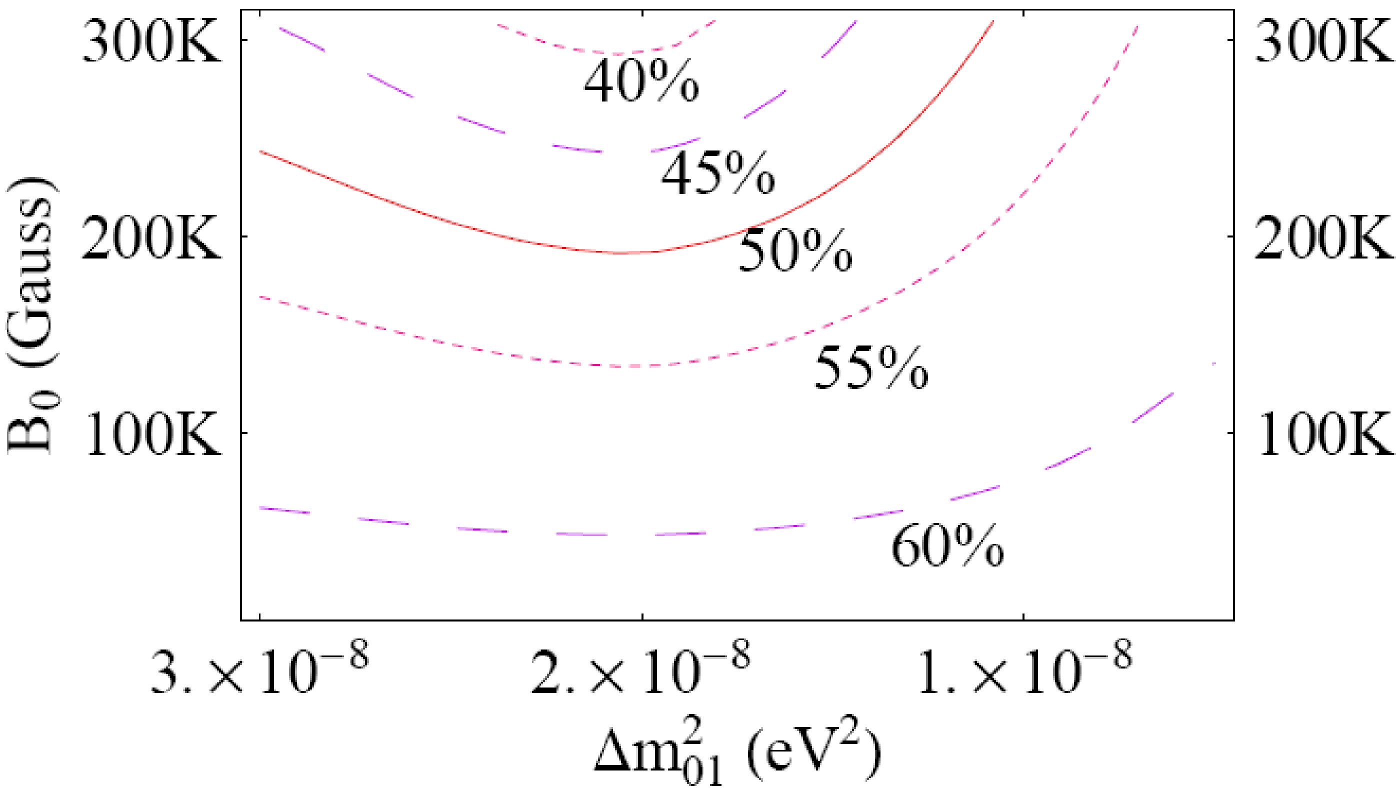
Period	1991–1997 (I)	1998–2003 (II)
SAGE + Ga/GNO	77.8 ± 5.0	63.3 ± 3.6
Ga/GNO only	77.5 ± 7.7	62.9 ± 6.0
SAGE only	79.2 ± 8.6	63.9 ± 5.0

Best fits to data sets (1991–1997 and 1998–2003), and LMA best fit. For data set (1991–1997) only Ga, Cl and Kamiokande data were available and for set (1998–2003) all SuperKamiokande and SNO data were available but not Cl. In set (1998–2003) only the Ga rate contributes to χ^2 rates. Units are SNU for Ga and Cl and 10^6 cm^{-2} s^{-1} for SK and SNO. Here $\Delta m^2_{01}=0.65\ 10^{-7}$ eV^2

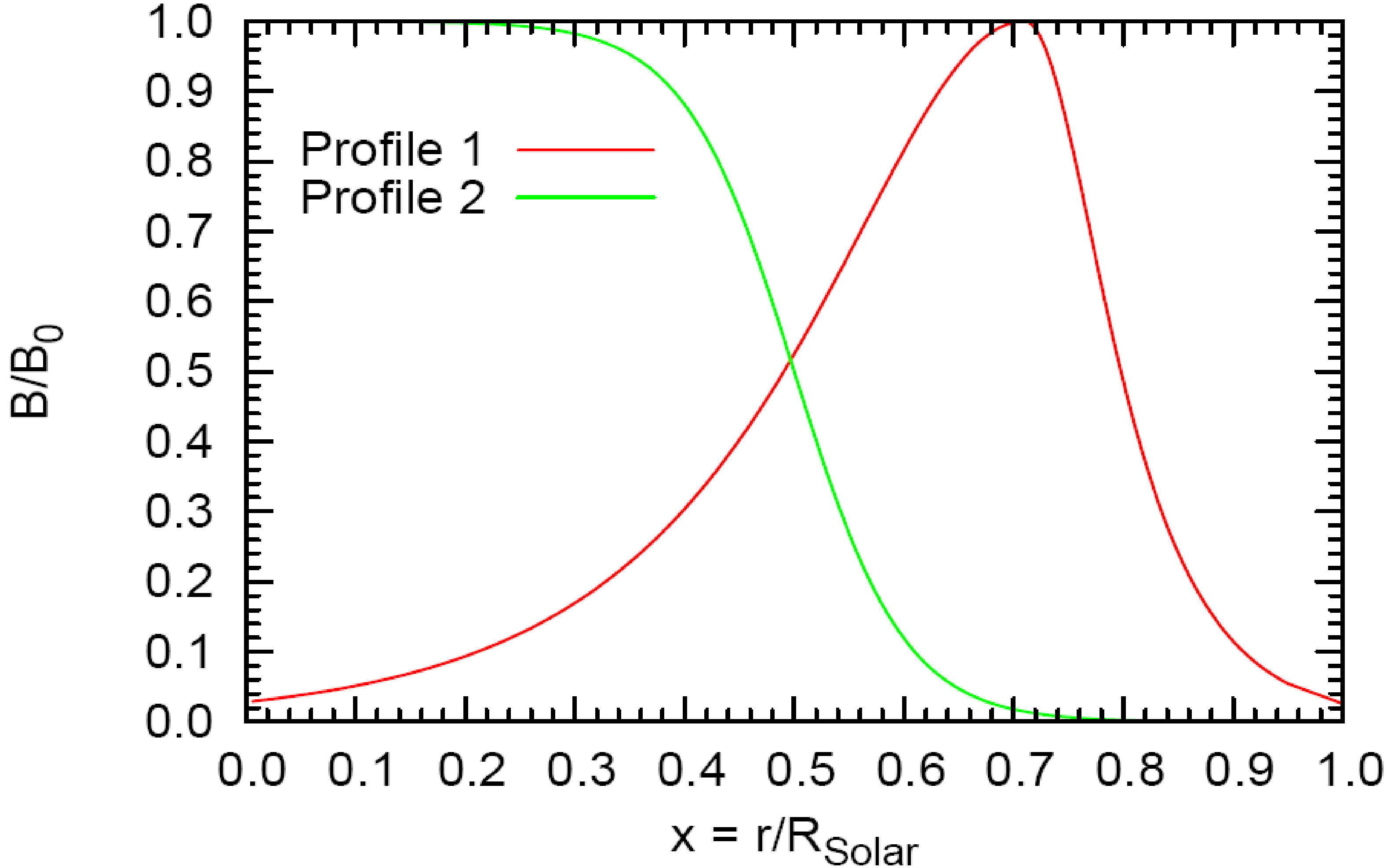
	Ga	Cl	K (SK)	SNO_{NC}	SNO_{CC}	SNO_{ES}	χ^2_{rates}	$\chi^2_{SK_{sp}}$	$\chi^2_{SNO_{gl}}$	χ^2_{KL}
Set (I)	71.7	2.66	2.29				3.09			15.3
Set (II)	69.6		2.18	5.53	1.54	2.16	2.28	44.6	45.8	15.3
LMA	64.8	2.74	2.30	5.10	1.75	2.28	0.95	45.7	43.1	14.5

SNO+: predictions from SSM and resonant spin flavour precession

The expected rate reduction for the pep flux with respect to the non-oscillation case, as a function of the peak value B_0 of the solar magnetic field (profile 1) and Δm^2_{01}.



Magnetic field profiles



Magnetic field @ convention zone (Profile 1)

$B_0(kG)$	$\sin\theta_{13}$	Ga	Cl	SK	SNO_{NC}	SNO_{CC}	SNO_{ES}	χ^2_{rates}	$\chi^2_{SK_{sp}}$	χ^2_{SNO}	χ^2_{gl}
	0	67.2	2.99	2.51	5.62	1.90	2.49	0.07	42.7	57.2	99.9
0	0.1	66.0	2.94	2.49	5.62	1.87	2.46	0.30	42.1	55.2	97.6
	0.13	65.0	2.90	2.46	5.62	1.84	2.44	0.62	41.7	53.7	96.0
	0	66.4	2.82	2.32	5.37	1.76	2.31	0.20	37.6	46.0	83.8
140	0.1	65.3	2.77	2.29	5.37	1.73	2.28	0.53	37.9	44.9	83.3
	0.13	64.3	2.72	2.27	5.37	1.70	2.25	0.95	38.4	44.1	83.4

Table I - Peak field values (profile 1), $\sin\theta_{13}$, *total rates (in SNU for Ga and Cl experiments, in* $10^6 cm^{-2}s^{-1}$ *for SK and SNO), and the corresponding* χ^2*'s. The total number of degrees of freedom is 82 = 84 experiments (Ga + Cl + 44 SK + 38 SNO data points) - 2 parameters, (see ref. [15]). It is seen that for a sizable field* ($B_0 = 140$ *kG) all fits improve.*

Magnetic field @ center (Profile 2)

$B_0(MG)$	$\sin\theta_{13}$	Ga	Cl	SK	SNO_{NC}	SNO_{CC}	SNO_{ES}	χ^2_{rates}	$\chi^2_{SK_{sp}}$	χ^2_{SNO}	χ^2_{gl}
	0	64.7	2.75	2.32	5.38	1.76	2.32	0.76	38.0	46.1	84.8
0.75	0.1	63.6	2.70	2.30	5.38	1.73	2.29	1.32	38.4	45.0	84.7
	0.13	62.6	2.66	2.28	5.38	1.70	2.26	1.92	38.8	44.2	84.9

Table II - Same as table I for profile 2 where the vanishing field case is ommited. As for profile 1, with a sizable field ($B_0 = 0.75$ MG) all fits improve with relation to the vanishing field (compare with table I).

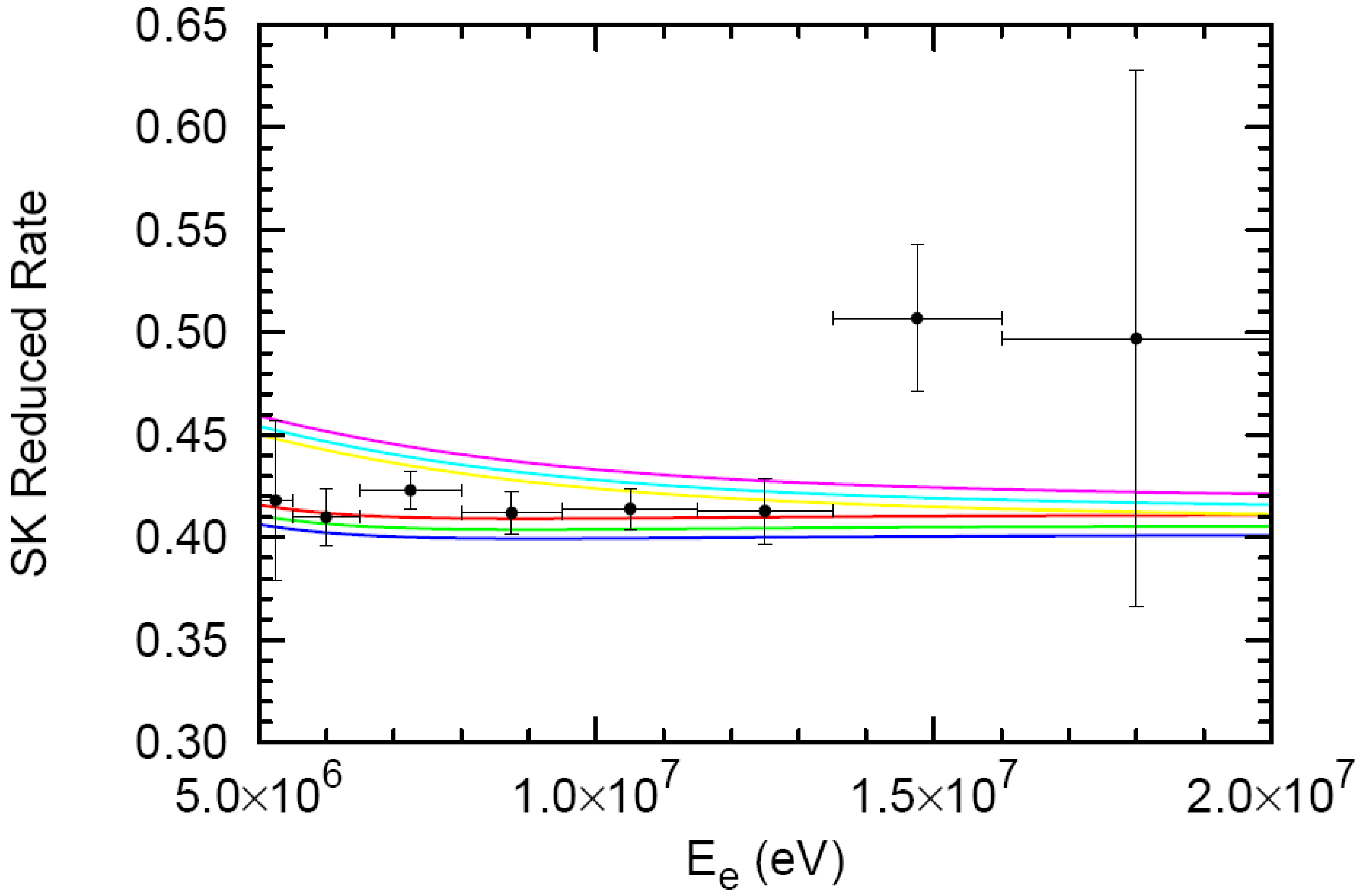
Magnetic field & solar neutrinos

Varying field	^8B flux	Others
Profile 1 (CZ)	Yes	No
Profile 2 (WS)	Yes	Yes

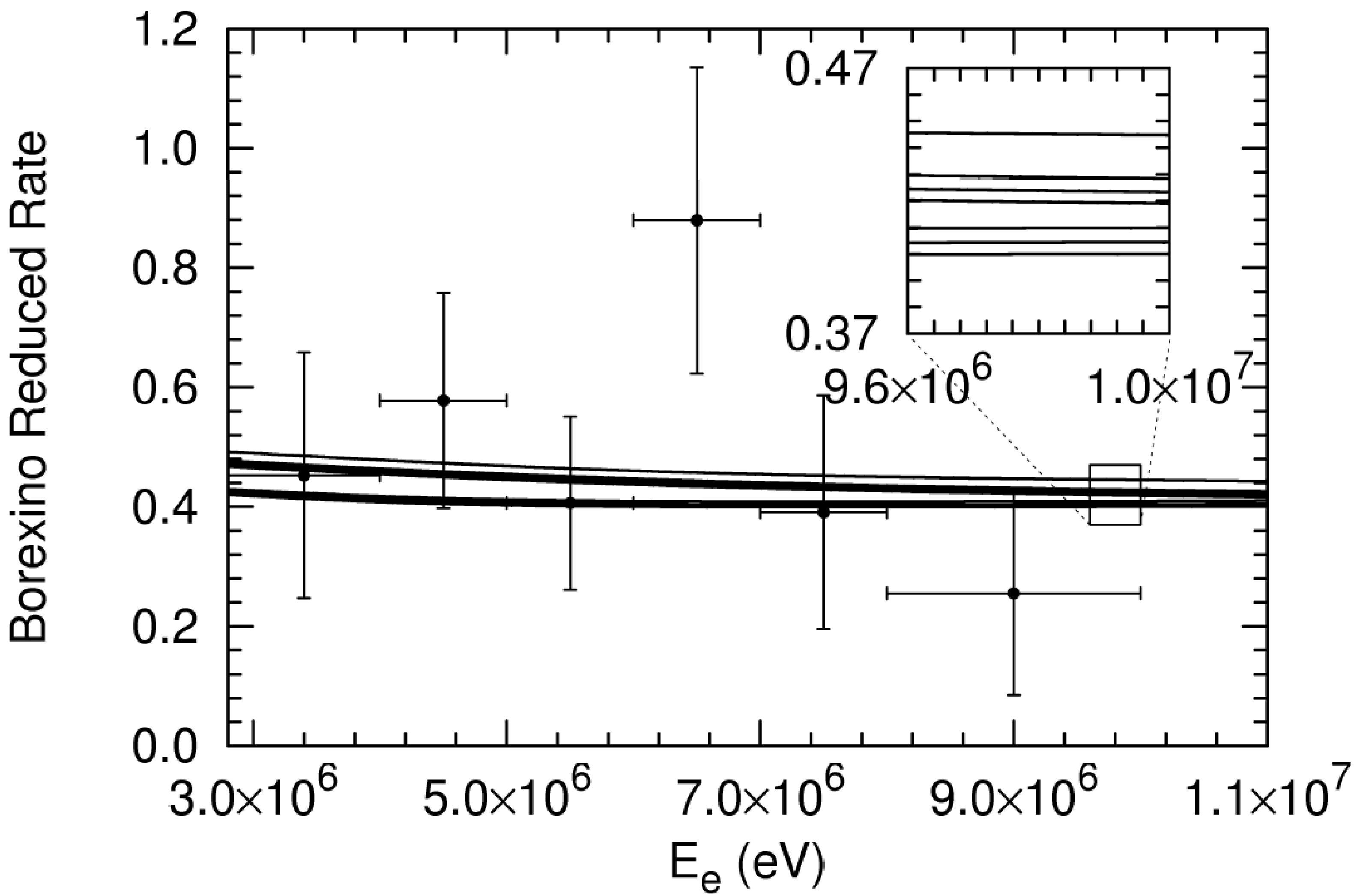
Table III - The possibility for detecting through solar neutrino experiments the magnetic fields concentrated either in the convection zone (profile 1) or in the core and radiation zone (profile 2).

The SuperKamiokande spectrum:

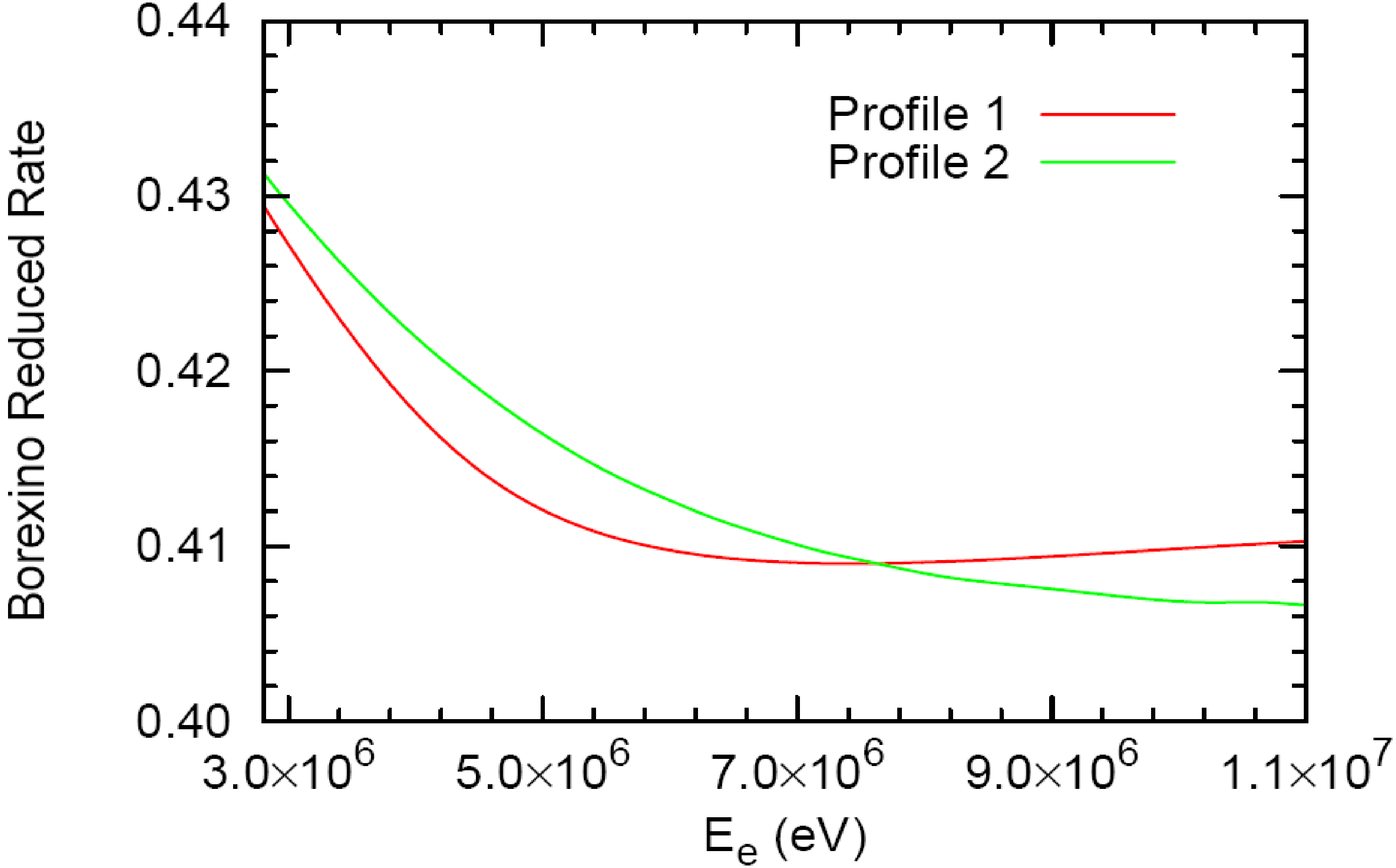
the top three curves refer to sin Θ_{13} = 0, 0.1, 0.13 *from top to bottom in the case of zero magnetic field, and the lower three curves refer to the same values of* sin Θ_{13} *for a sizable field (profile 1), with* B = 140 *kG at the peak.*



Borexino Reduced Rate

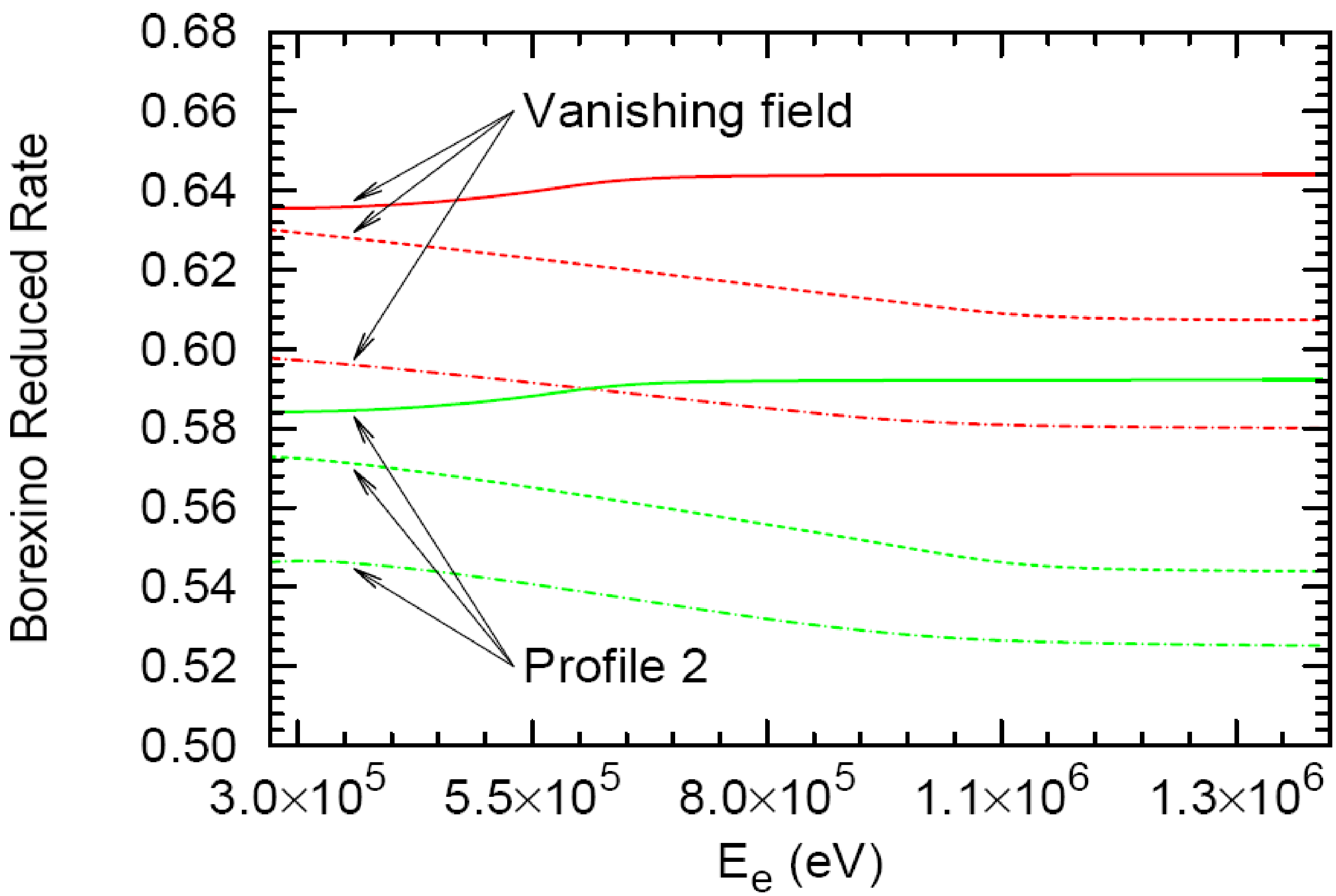


Borexino spectra for ^{8}**B** ***neutrinos*** *evaluated for profiles 1 and 2 at the best fit with* $\Theta_{13} = 0$. *The spectrum for profile 1 exhibits a shallow minimum while for profile 2 it is monotonically and smoothly decreasing with the energy.*



Borexino spectra for ^{7}Be ν (full lines), ^{15}O (dashed) and ^{13}N (dot-dashed)

evaluated for vanishing field and profile 2 at the best fit with Θ_{13} = 0.



Conclusions

- We studied the **R**esonant **S**pin **F**lavour **P**recession of Solar ν to **light sterile** ν, a mechanism which is added to the well known LMA one, in a 4 ν scenario.
- The transition magnetic moments from the ν_μ and ν_τ to ν_s play the dominant role in fixing the amount of active flavour suppression.
- The data from all solar neutrino experiments except Borexino exhibit a clear preference for a sizable magnetic field either in the convection zone or in the core and radiation zone.
- We argue that the solar neutrino experiments are capable of tracing the possible modulation of the solar magnetic field.
  - Those monitoring the high energy neutrinos, namely the ^{8}B flux, appear to be sensitive to a field modulation either in the convection zone or in the core and radiation zone.
  - Those monitoring the low energy fluxes will be sensitive to the second type of solar field profiles only.

  In this way Borexino alone may play an essential role, since it examines both energy sectors, although experimental redundance from other experiments will be most important.