Constraining non standard neutrino-electron interactions

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Outline

- Introduction and motivation
- Solar ν analysis NSI with d quark and e
- Laboratory constraints NSI with e
- future perspectives
- Based on:
  1. F. J. Escrihuela, OGM, M.A. Tortola, J.W.F. Valle
  2. A. Bolaños, OGM, A. Palazzo, M. A. Tortola, J. W. F. Valle PRD **79** 073011 (2009)
  3. J. Barranco, OGM, T.I. Rashba JHEP 0512:021 PRD **76** 073008 (2007)
  4. J. Barranco, OGM, C. A. Moura, J. W. F. Valle PRD **73** 113001 (2006), PRD **77** 093014 (2008)

Motivation

Massive neutrinos are a strong motivation for physics beyond the Standard Model.

$$\begin{bmatrix} M_L & D \\ D^T & M_R \end{bmatrix}$$

Minkowski; Gell-mann, Ramond, Slansky; Yanagida; Mohapatra, Senjanovic; Schechter, Valle

$$M_{\nu\,\mathrm{eff}} = M_L - DM_R^{-1}D^T$$

$$K = (K_L, K_H)$$

Motivation

$$\begin{bmatrix} 0 & D & 0 \\ D^T & 0 & M \\ 0 & M^T & \mu \end{bmatrix}$$

Mohapatra, Valle, PRD **34** 1642 (1986)

$$M_L = D M^{-1} \mu {M^T}^{-1} D^T \,. \tag{1}$$

$$\mathcal{L} = \frac{ig'}{2\sin\theta_W} Z_\mu \bar{\nu_L} \gamma_\mu K^\dagger K \nu_L \,.$$

$\not{R}_p$ parity violating SUSY

Non-standard neutrino-electron and neutrino quark interactions:

$$\mathcal{L} = \lambda_{ijk} \tilde{e}_R^{k*} (\bar{\nu}_L^i)^c e_L^j + \lambda'_{ijk} \tilde{d}_L^j \bar{d}_R^k \nu_L^i + \ldots$$

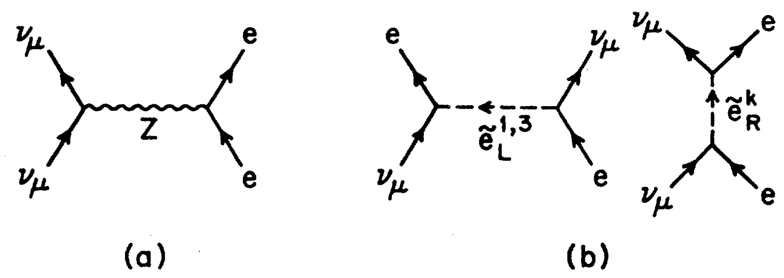
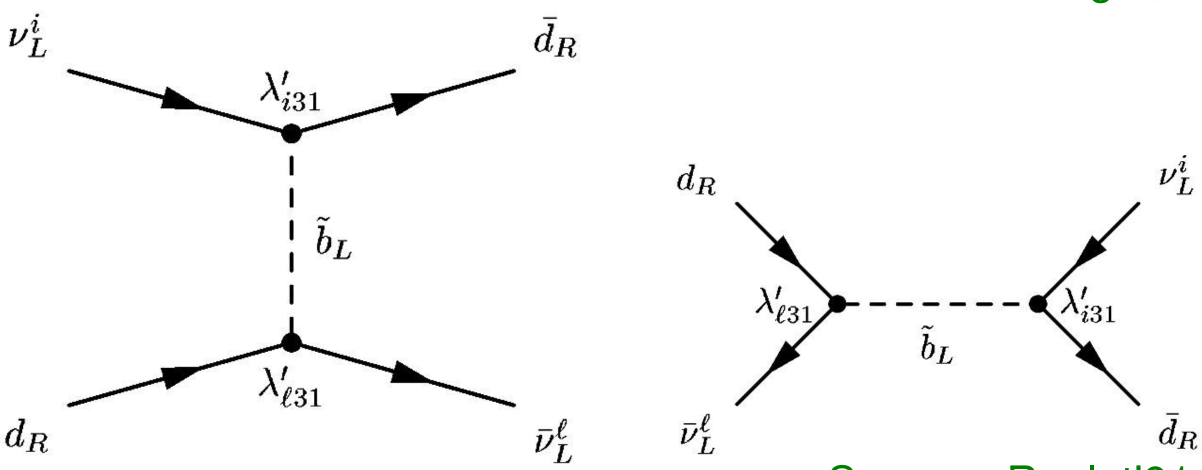


FIG. 2. Feynman diagrams for $\nu_\mu e$ scattering from (a) the standard model, and (b) the R-breaking interactions.

Barger, Giudice & Han'89



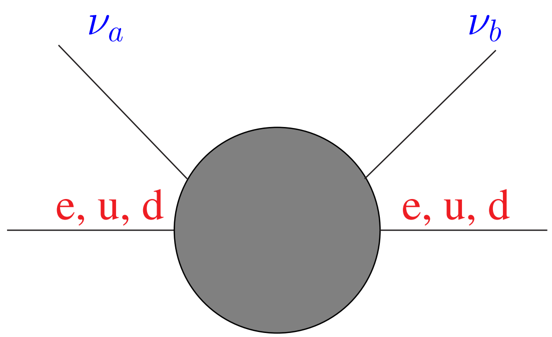
See e.g. Roulet'91, Amanik et al'05

Non Standard Interactions (NSI)

Most extensions of the SM predict neutral current non-standard interactions (NSI) of neutrinos which can be either flavor preserving (FD or NU) or flavor-changing (FC).

NSI effective Lagragian form:

$$\mathcal{L}_{eff}^{NSI} = -\sum_{\alpha\beta f P} \varepsilon_{\alpha\beta}^{fP} 2\sqrt{2} G_F (\bar{\nu}_\alpha \gamma_\rho L \nu_\beta)(\bar{f}\gamma^\rho P f)$$



Here $\alpha, \beta = e, \mu, \tau; \quad f = e, u, d; \quad P = L, R; \quad L = (1-\gamma_5)/2; \quad R = (1+\gamma_5)/2$

Solar neutrino data

- Solar neutrinos could be sensitive to NSI
- NSI could affect the propagation for d quark and e
- NSI Could also affect detection, especially in SuperKamiokande

$$\sigma(\nu_e e \to \nu e) = \frac{2G_F^2 m_e E_\nu}{\pi} \left[(1 + g_L^e + \varepsilon_{ee}^{eL})^2 + \sum_{\alpha \neq e} |\varepsilon_{\alpha e}^{eL}|^2 + \frac{1}{3}(g_R^e + \varepsilon_{ee}^{eR})^2 + \frac{1}{3} \sum_{\alpha \neq e} |\varepsilon_{\alpha e}^{eR}|^2 \right]$$

Oscillations in matter

Wolfenstein 1978

- Neutral currents (NC): exchange of Z_0
- Charge currents (CC): exchange of $W_\pm$

$$V_e = \sqrt{2}\, G_F \left(N_e - \frac{N_n}{2} \right) , \qquad V_\mu = V_\tau = \sqrt{2}\, G_F \left(-\frac{N_n}{2} \right) .$$

Evolution equation

$$i \frac{d}{dt} \begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} -\frac{\Delta m^2}{4E} \cos 2\theta + \sqrt{2}\, G_F N_e & \frac{\Delta m^2}{4E} \sin 2\theta \\ \frac{\Delta m^2}{4E} \sin 2\theta & \frac{\Delta m^2}{4E} \cos 2\theta \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} .$$

Constant density case

Conversion probabilitiy $\nu_e \leftrightarrow \nu_\mu$:

$$P(\nu_e \to \nu_\mu;\ L) = \sin^2 2\theta_m \ \sin^2\left(\pi \frac{L}{l_m}\right) ,$$

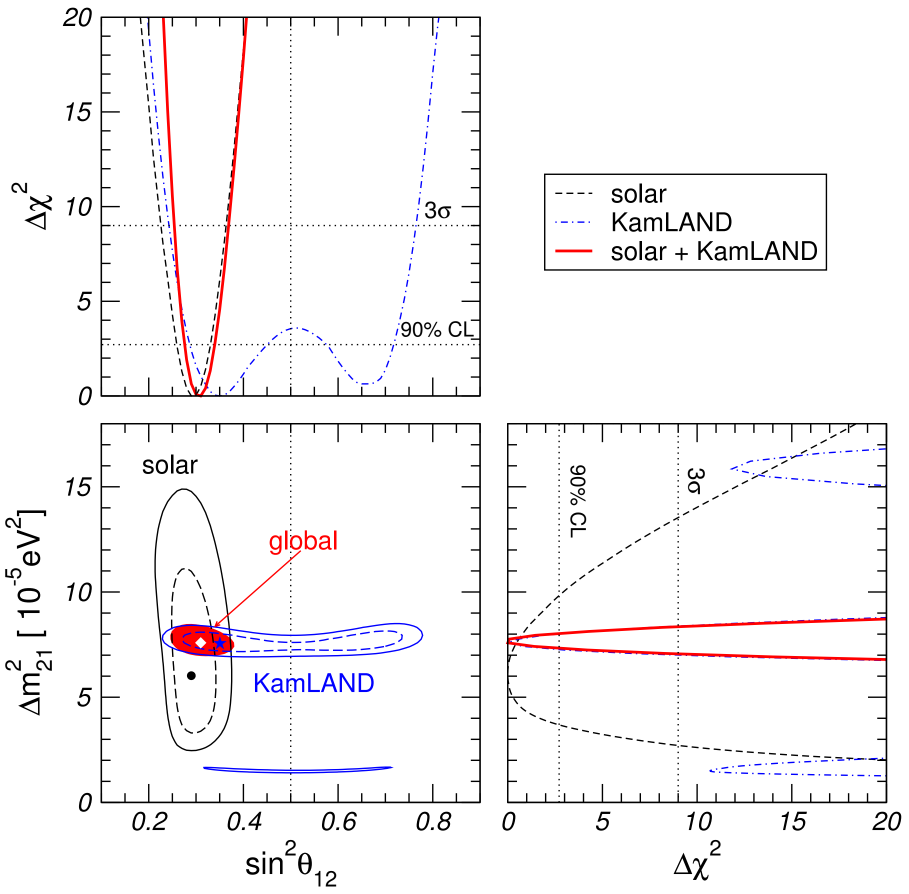
Mixing angle in matter

$$\sin^2 2\theta_m = \frac{\left(\frac{\Delta m^2}{2E}\right)^2 \sin^2 2\theta}{\left(\frac{\Delta m^2}{2E}\cos 2\theta - \sqrt{2}\, G_F\, N_e\right)^2 + \left(\frac{\Delta m^2}{2E}\right)^2 \sin^2 2\theta}$$

Resonance $\sqrt{2}\, G_F\, N_e = \frac{\Delta m^2}{2E}\cos 2\theta$

Wolfenstein 1978, Mikheev & Smirnov 1985

Δm^2_{21} and $\sin^2\theta_{12}$



$\sin^2\theta_{12} = 0.304^{+0.022}_{-0.016}$, $\quad \Delta m^2_{21} = 7.65^{+0.23}_{-0.20} \times 10^{-5}$ eV ^{2}

Schwetz, Tortola, Valle New J. Phys. **10** 113011,2008

Solar ν Oscillations and NSI with quarks

$$H_{\rm NSI} = \sqrt{2} G_F N_f \left(\begin{array}{cc} 0 & \varepsilon \\ \varepsilon & \varepsilon' \end{array} \right) .$$

with

$$\varepsilon = -\sin\theta_{23}\, \varepsilon^{fV}_{e\tau} \qquad \varepsilon' = \sin^2\theta_{23}\, \varepsilon^{fV}_{\tau\tau} - \varepsilon^{fV}_{ee}$$

and

$$\varepsilon^{fV}_{\tau\tau} = \varepsilon^{fL}_{\tau\tau} + \varepsilon^{fR}_{\tau\tau}$$

Non Standard Interactions

$$H_{\text{NSI}} = \sqrt{2} G_F N_f \begin{pmatrix} 0 & \varepsilon \\ \varepsilon & \varepsilon' \end{pmatrix} .$$

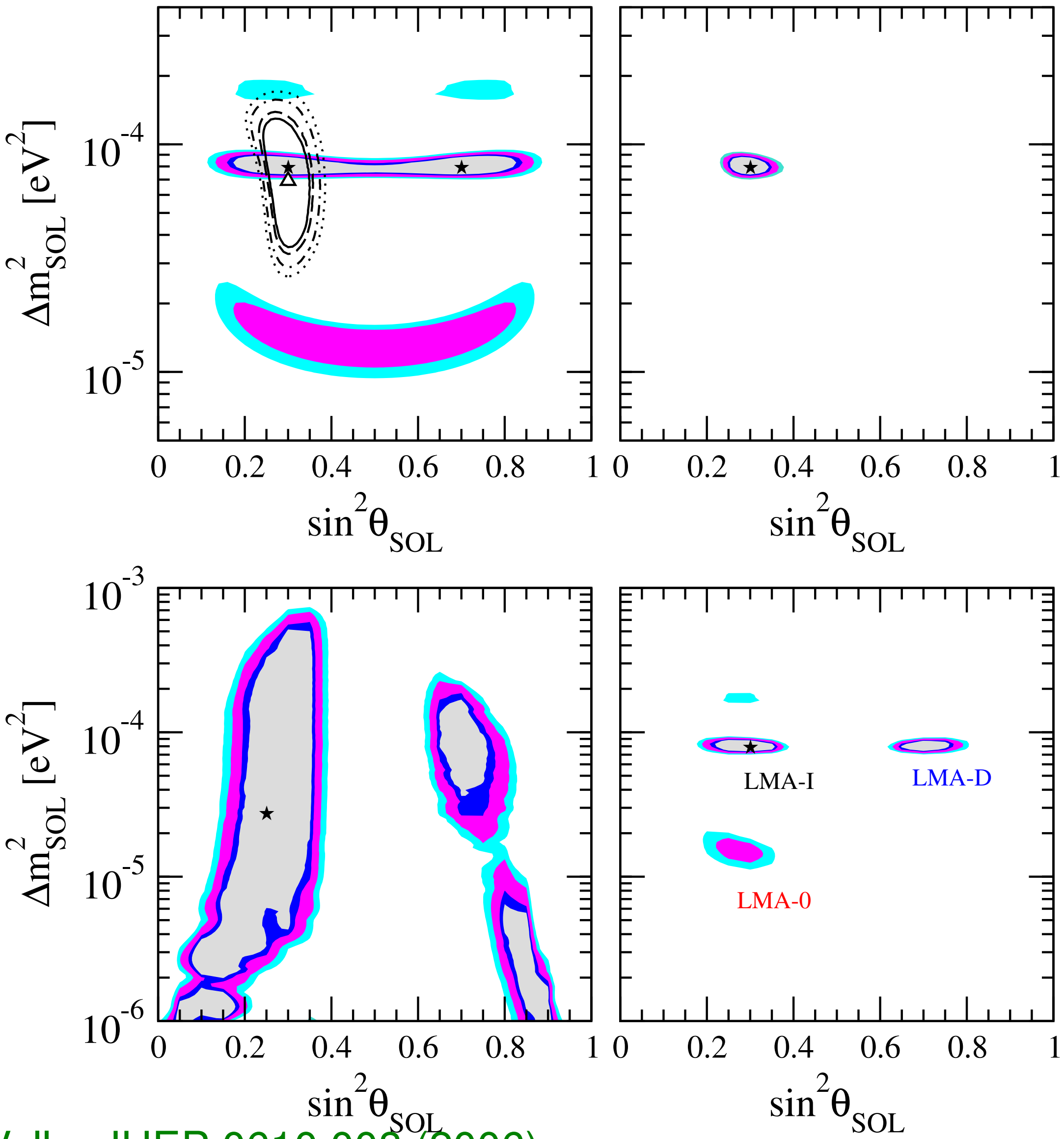
Mixing angle in matter + NSI

$$\tan 2\theta_m = \frac{\left(\frac{\Delta m^2}{2E}\right) \sin 2\theta + 2\sqrt{2} G_F \varepsilon N_d}{\frac{\Delta m^2}{2E} \cos 2\theta - \sqrt{2}\, G_F\, N_e + \sqrt{2}\, G_F \varepsilon'\, N_d} .$$

Resonance $\quad \dfrac{\Delta m^2}{2E} \cos 2\theta - \sqrt{2}\, G_F\, N_e + \sqrt{2}\, G_F\, \varepsilon'\, N_d = 0\, .$

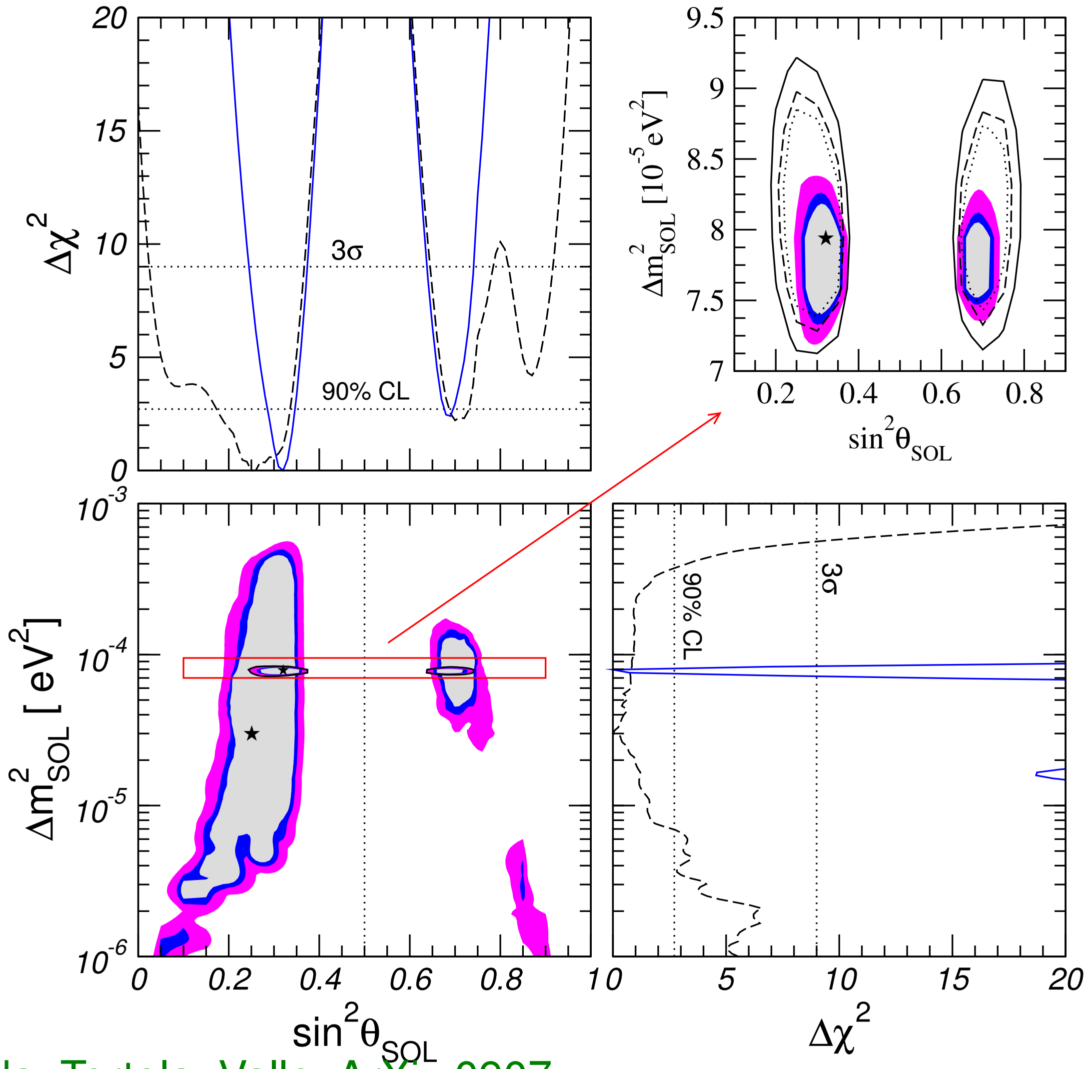
$$\varepsilon' > \frac{N_e}{N_d}$$

Solar + KamLAND without and with NSI - d



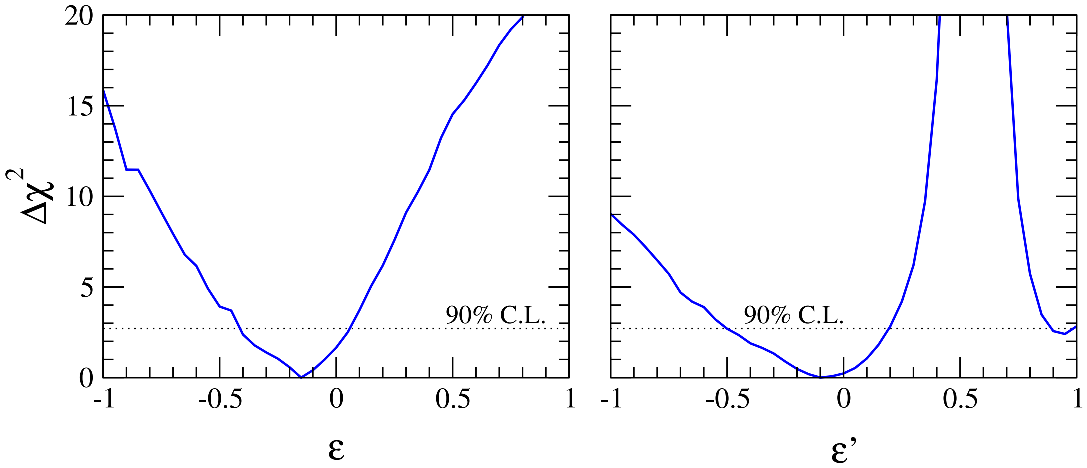
Miranda, Tortola, Valle, JHEP 0610:008 (2006)

Solar + KamLAND without and with NSI - d

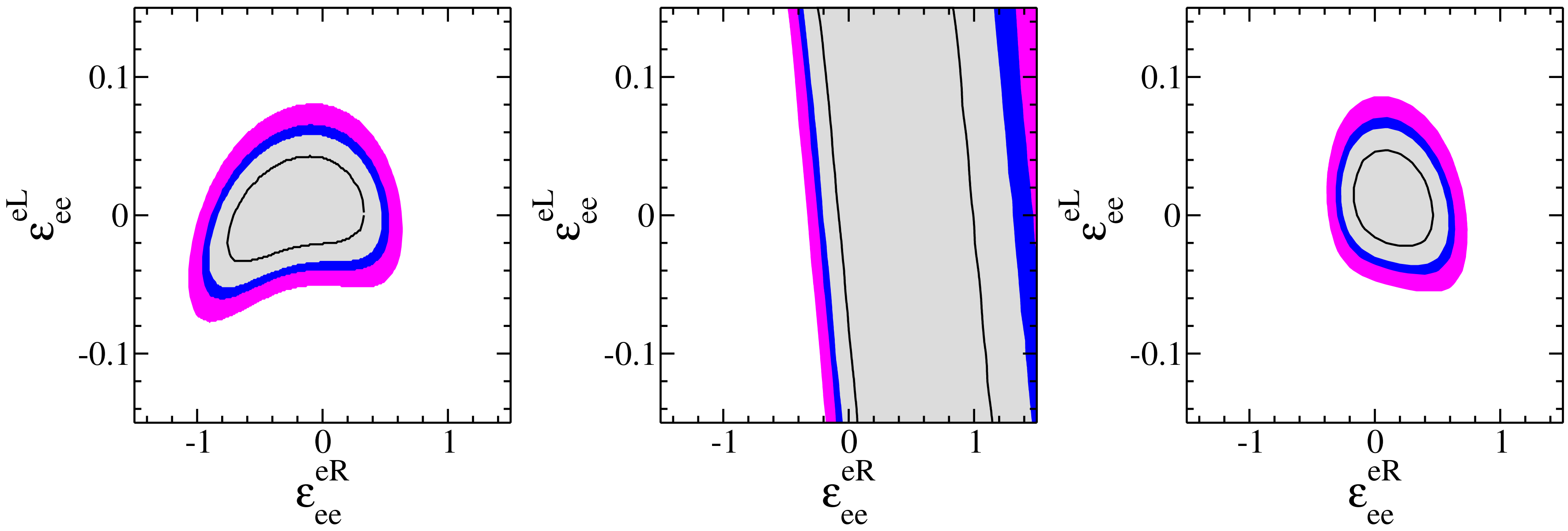


Escrihuela, Miranda, Tortola, Valle, ArXiv:0907.xxxx

NSI-d constraints from Solar + Kamland

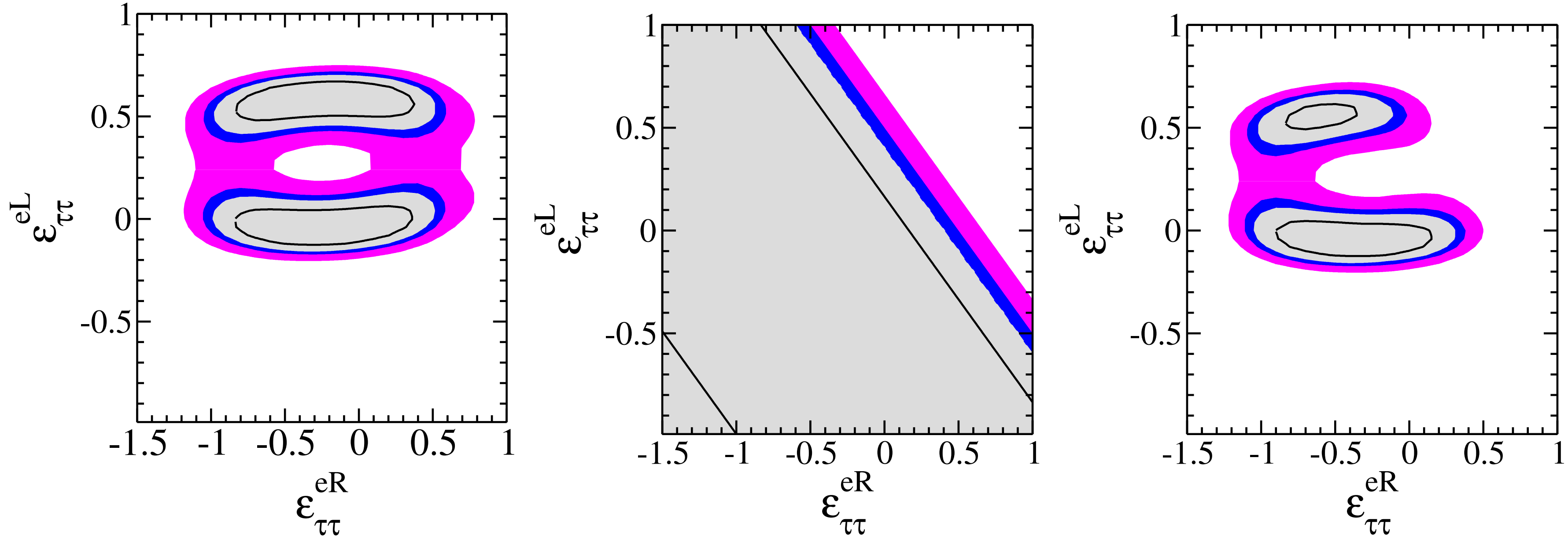


Solar neutrino data and NSI-e



Bolaños, Miranda, Palazzo, Tortola, Valle PRD **79** 113012 2009

Solar neutrino data and NSI-e

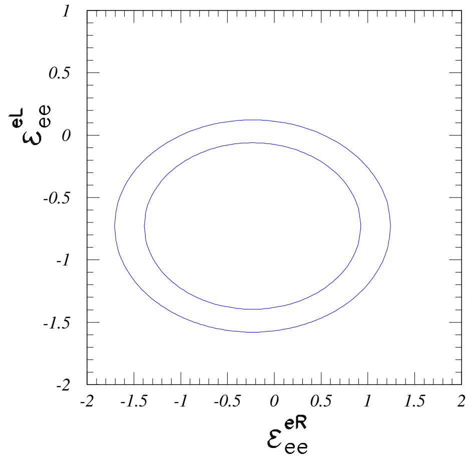


Bolaños, Miranda, Palazzo, Tortola, Valle PRD **79** 113012 2009

NSI-e Laboratory constraints

- Laboratory experiments:
  1. Reactor neutrinos
  2. LEP data ($e^+e^- \rightarrow \nu\bar{\nu}gamma$)
  3. CHARM

The $\nu_e e$ interaction

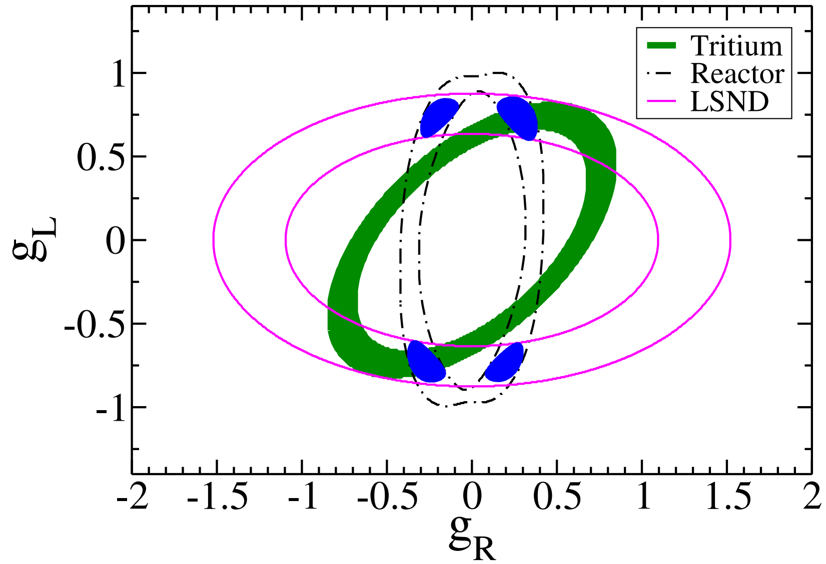


$$\sigma(\nu_e e \to \nu e) = \frac{2G_F^2 m_e E_\nu}{\pi}\left[(1+g_L^e+\varepsilon_{ee}^{eL})^2+\sum_{\alpha\neq e}|\varepsilon_{\alpha e}^{eL}|^2+\frac{1}{3}(g_R^e+\varepsilon_{ee}^{eR})^2+\frac{1}{3}\sum_{\alpha\neq e}|\varepsilon_{\alpha e}^{eR}|^2\right]$$

- Davidson, Peña-Garay,Rius,Santamaria JHEP 0303:011 (2003) hep-ph/0302093:
  $-0.07 < \varepsilon_{ee}^{eL} < 0.1 \qquad -1.0 < \varepsilon_{ee}^{eR} < 0.50$ at 90 % C L
- Berezhiani, Raghavan, Rossi PLB **535** 207 (2002) hep-ph/0111138:
  $-0.15 < \varepsilon_{ee}^{eL} < 0.17 \qquad -0.95 < \varepsilon_{ee}^{eR} < 0.50$ at 99 % C L

The $\nu_e e$ interaction

Experiment	Energy (MeV)	events	measurement
LSND $\nu_e e$	10-50	191	$\sigma = [10.1 \pm 1.5] \times E_{\nu_e}(\mathrm{MeV}) \times 10^{-45}\mathrm{cm}^2$
Irvine $\bar{\nu}_e - e$	1.5 - 3.0	381	$\sigma = [0.86 \pm 0.25] \times \sigma_{V-A}$
Irvine $\bar{\nu}_e - e$	3.0 - 4.5	77	$\sigma = [1.7 \pm 0.44] \times \sigma_{V-A}$
Rovno $\bar{\nu}_e - e$	0.6 - 2.0	41	$\sigma = (1.26 \pm 0.62) \times 10^{-44}\mathrm{cm}^2/\mathrm{fission}$
MUNU $\bar{\nu}_e - e$	0.7 - 2.0	68	1.07 ± 0.34 events day $^{-1}$



The $e^+e^- \to \nu\bar{\nu}\gamma$ interaction

$$\sigma^{\rm theo}_{\rm LEP}(s) = \int {\rm d}x \int {\rm d}c_\gamma \; H(x, s_\gamma; s) \; \sigma^{\rm theo}_0(\hat{s}) \,,$$

$$H(x, s_\gamma; s) = \frac{2\alpha}{\pi x s_\gamma} \left[\left(1 - \frac{x}{2}\right)^2 + \frac{x^2 c_\gamma^2}{4} \right] \,,$$

$$\begin{aligned}
\sigma^{\rm SM}_0 \quad (s) &= \frac{N_\nu G_F^2}{6\pi} M_Z^4 (g_R^2 + g_L^2) \frac{s}{[(s - M_Z^2)^2 + (M_Z \Gamma_Z)^2]} \\
+ \quad & \frac{G_F^2}{\pi} M_W^2 \left\{ \frac{s + 2M_W^2}{2s} - \frac{M_W^2}{s} \left(\frac{s + M_W^2}{s} \right) \log \left(\frac{s + M_W^2}{M_W^2} \right) \right. \\
- \quad & \left. \frac{g_L M_Z^2 (s - M_Z^2)}{(s - M_Z^2)^2 + (M_Z \Gamma_Z)^2} \left[\frac{(s + M_W^2)^2}{s^2} \log \left(\frac{s + M_W^2}{M_W^2} \right) - \frac{M_W^2}{s} - \frac{3}{2} \right] \right\},
\end{aligned}$$

The $e^+e^- \to \nu\bar{\nu}\gamma$ interaction

$$\sigma_0^{\rm NU}(s) = \sum_{\alpha=e,\mu,\tau} \frac{G_F^2}{6\pi} s \left[(\varepsilon_{\alpha\alpha}^L)^2 + (\varepsilon_{\alpha\alpha}^R)^2 - 2(g_L \varepsilon_{\alpha\alpha}^L + g_R \varepsilon_{\alpha\alpha}^R) \frac{M_Z^2(s - M_Z^2)}{(s - M_Z^2)^2 + (M_Z \Gamma_Z)^2} \right]$$

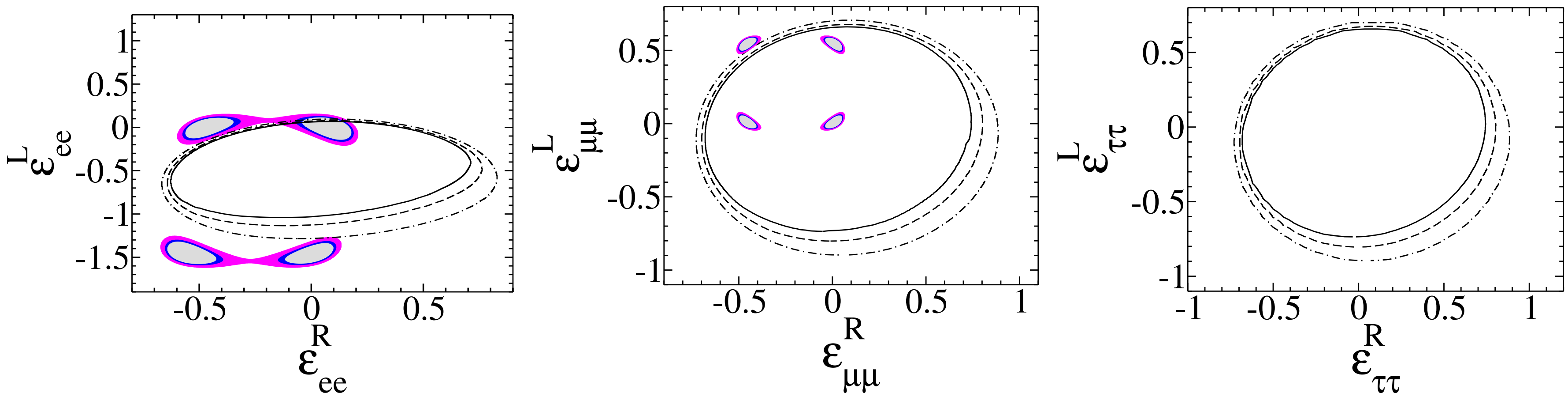
$$+ \frac{G_F^2}{\pi} \varepsilon_{ee}^L M_W^2 \left[\frac{(s + M_W^2)^2}{s^2} \log\left(\frac{s + M_W^2}{M_W^2} \right) - \frac{M_W^2}{s} - \frac{3}{2} \right],$$

$$\sigma_0^{\rm FC}(s) = \sum_{\alpha\neq\beta=e,\mu,\tau} \frac{G_F^2}{6\pi} s \left[(\varepsilon_{\alpha\beta}^L)^2 + (\varepsilon_{\alpha\beta}^R)^2 \right].$$

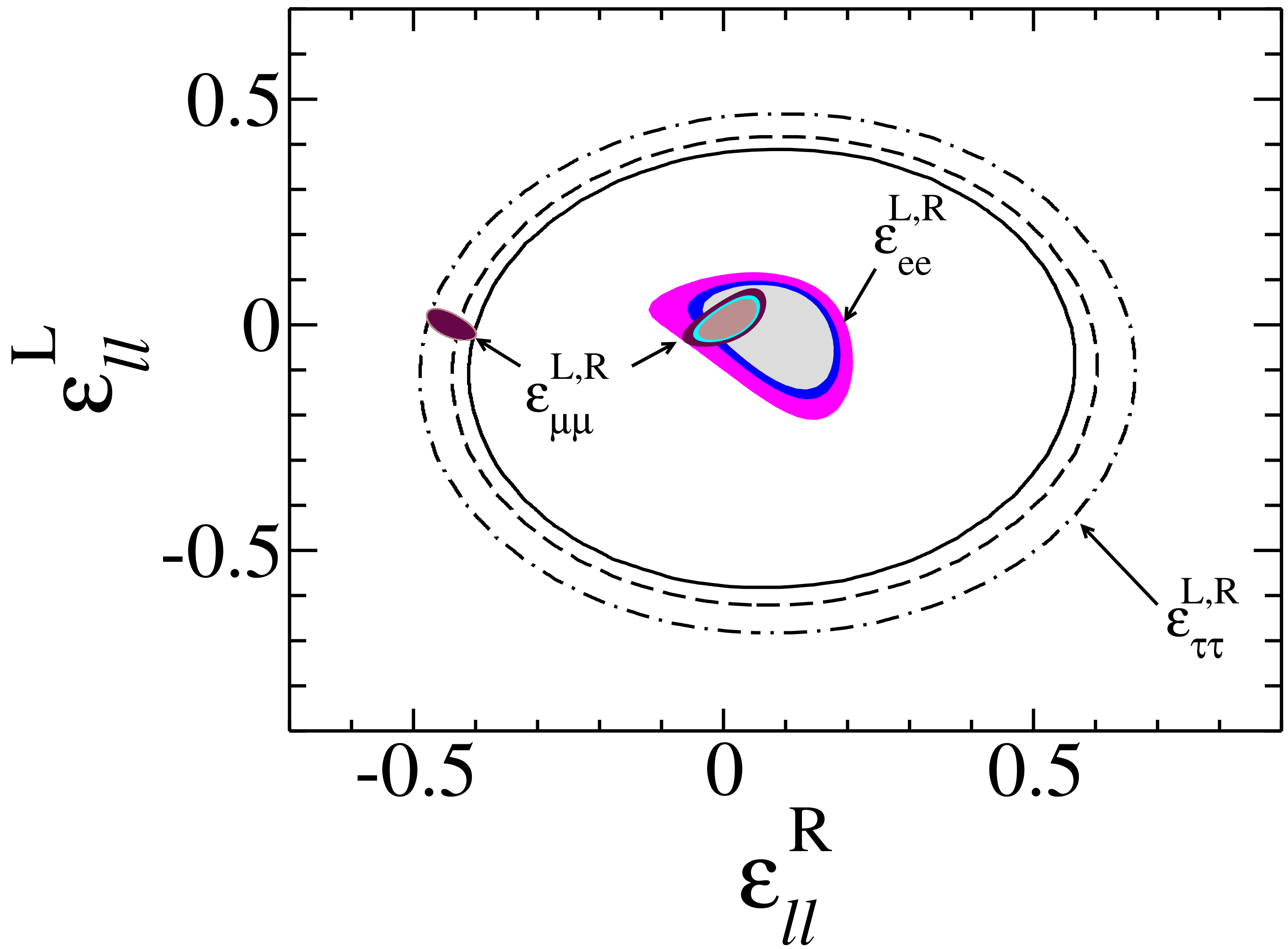
The $\nu_\mu e \to \nu_\mu e$ interaction

$$\frac{\mathrm{d}\sigma^{\mathrm{theo}}_{\mathrm{CHARM}}}{\mathrm{d}y} = \frac{2G_F^2 m_e}{\pi} E_\nu \left[\left(\tilde{g}_L^2 + \sum_{\alpha \neq \mu} |\varepsilon^L_{\alpha\mu}|^2 \right) + \left(\tilde{g}_R^2 + \sum_{\alpha \neq \mu} |\varepsilon^R_{\alpha\mu}|^2 \right) (1-y)^2 \right]$$

Laboratory constraints



Laboratory constraints



NSI-e constraints

	Solar analysis	Laboratory analysis	Previous limits
ε_{ee}^{L}	$-0.036 < \varepsilon_{ee}^{L} < 0.063$	$-0.14 < \varepsilon_{ee}^{L} < 0.09$	$-0.05 < \varepsilon_{ee}^{L} < 0.1$
ε_{ee}^{R}	$-0.27 < \varepsilon_{ee}^{R} < 0.59$	$-0.03 < \varepsilon_{ee}^{R} < 0.18$	$0.04 < \varepsilon_{ee}^{R} < 0.14$
$\varepsilon_{\mu\mu}^{L}$		$-0.033 < \varepsilon_{\mu\mu}^{L} < 0.055$	$\lvert\varepsilon_{\mu\mu}^{L}\rvert < 0.03$
$\varepsilon_{\mu\mu}^{R}$		$-0.040 < \varepsilon_{\mu\mu}^{R} < 0.053$	$\lvert\varepsilon_{\mu\mu}^{R}\rvert < 0.03$
$\varepsilon_{\tau\tau}^{L}$	$-0.16 < \varepsilon_{\tau\tau}^{L} < 0.11$	$-0.6 < \varepsilon_{\tau\tau}^{L} < 0.4$	$\lvert\varepsilon_{\tau\tau}^{L}\rvert < 0.5$
$\varepsilon_{\tau\tau}^{R}$	$-1.05 < \varepsilon_{\tau\tau}^{R} < 0.31$	$-0.4 < \varepsilon_{\tau\tau}^{R} < 0.6$	$\lvert\varepsilon_{\tau\tau}^{R}\rvert < 0.5$

Bolaños, Miranda, Palazzo, Tortola, Valle PRD **79** 113012 2009

Barranco, Miranda, Moura, Valle PRD **77** 093014 '08

Davidson, Peña-Garay,Rius,Santamaria JHEP 0303:011 (2003) hep-ph/0302093

NSI-e constraints

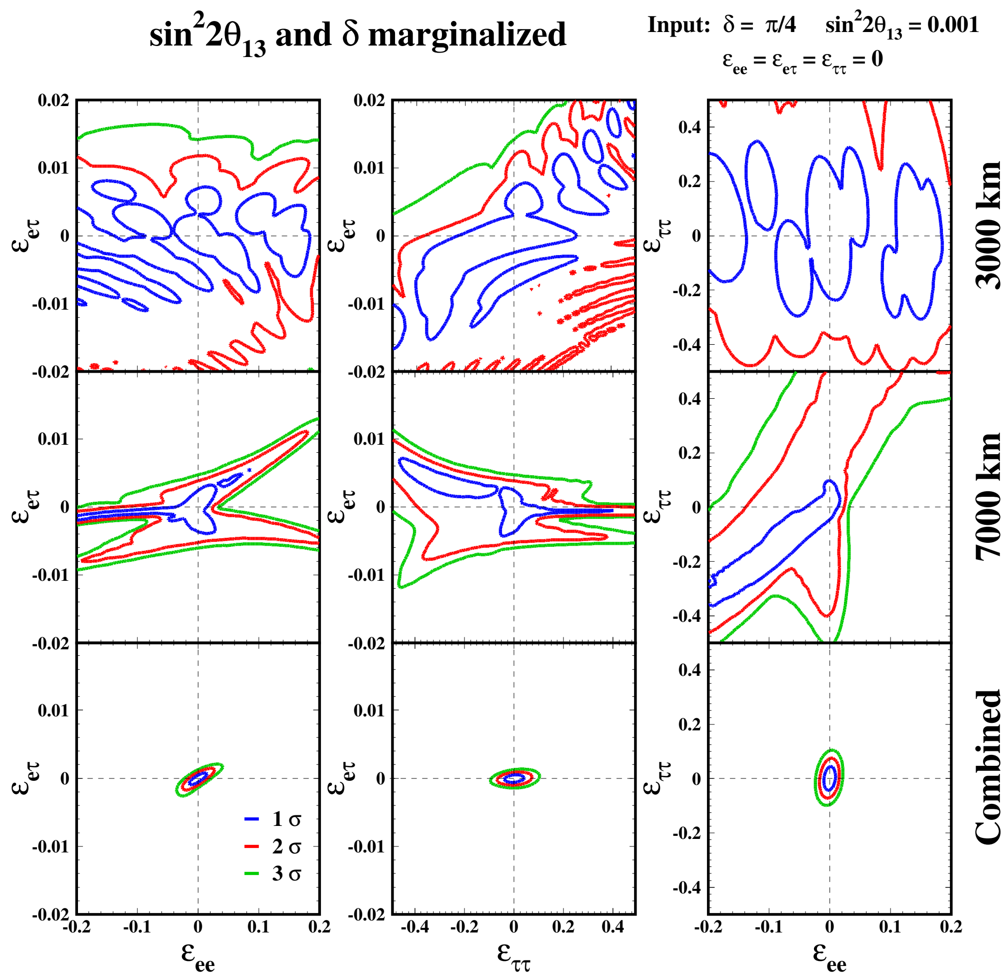
	Laboratory analysis
$\varepsilon_{e\mu}^{L}$	$\|\varepsilon_{e\mu}^{L}\| < 0.13$
$\varepsilon_{e\mu}^{R}$	$\|\varepsilon_{e\mu}^{R}\| < 0.13$
$\varepsilon_{e\tau}^{L}$	$\|\varepsilon_{e\tau}^{L}\| < 0.4$
$\varepsilon_{e\tau}^{R}$	$\|\varepsilon_{e\tau}^{R}\| < 0.27$
$\varepsilon_{\mu\tau}^{L}$	$\|\varepsilon_{\mu\tau}^{L}\| < 0.1$
$\varepsilon_{\mu\tau}^{R}$	$\|\varepsilon_{\mu\tau}^{R}\| < 0.1$

Barranco, Miranda, Moura, Valle PRD **77** 093014 ’08

Davidson, Peña-Garay,Rius,Santamaria JHEP 0303:011 (2003) hep-ph/0302093

Future perspectives

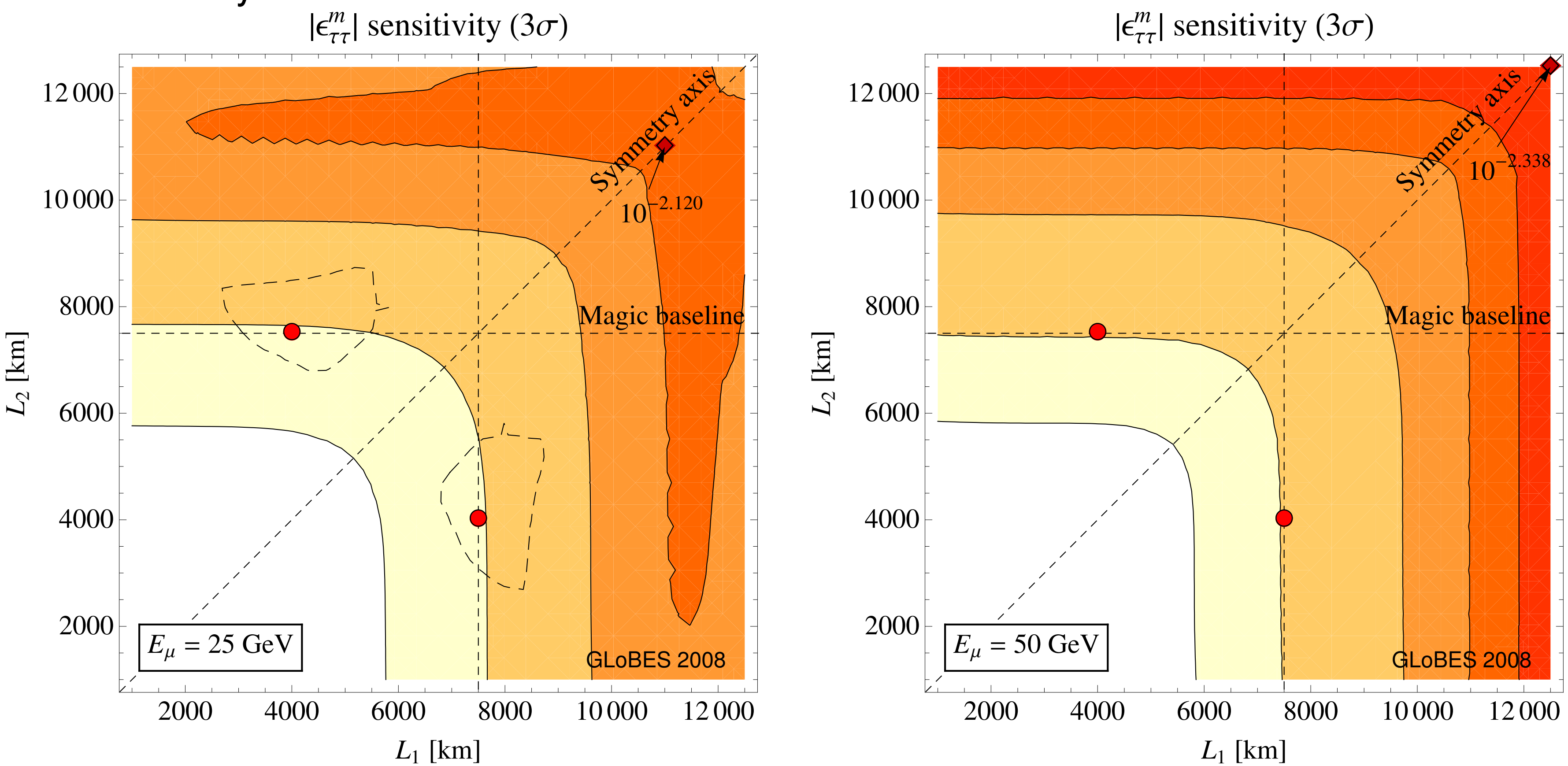
Neutrino factory + two different neutrino detectors



Ribeiro, Minakata, Nunokawa, S. Uchinami , R. Zukanovich-Funchal JHEP 0712:002,2007.

Future Perspectives

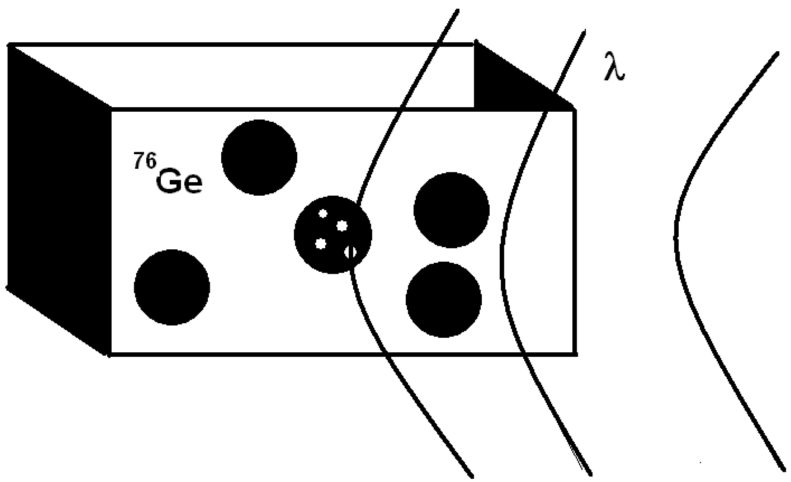
Neutrino factory + two different neutrino detectors



Kopp, Ota, Winter, PRD **78** 053007 ’08

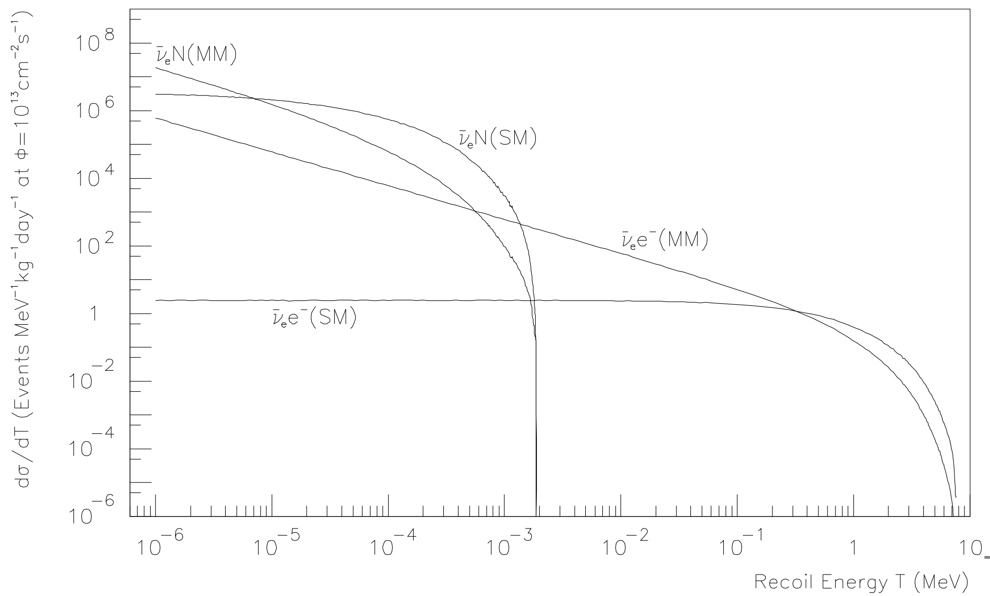
NSI with d, u quark, Coherent $\nu - N$ scattering

- Coherent scattering if the momentum transfer, Q, is small, $QR < 1$ (R is radius of nucleus): $\Longrightarrow$ ν-s doesn't "see" structure of nucleus!
- For most of nuclei: $1/R \sim 25 - 150$ MeV
- Planned experiments to measure coherent ν-N scattering: NOSTOS, TEXONO . . . and many proposals
- Experimentally difficult: very low energy threshold
- Good statistics due to quadratic coherent enhancement
- Sensitivity to ν-quark couplings



Proposed experiments to measure coherent ν-N scattering

- TEXONO: 1kg of germanium, reactor neutrinos J. Phys. Conf. Ser. **39** 266 (2006) hep-ex/0511001
- Large-Mass Ultra-Low Noise Germanium Detectors P.S. Barbeau, J. I. Collar, O. Tench JCAP 0709:009 (2007)
- NOSTOS: spherical TPC detector, 10 ton of Xenon Phys. Atom. Nucl. **70** 140 (2007) astro-ph/0511470
- Stopped-pion neutrino beam and kg-to-ton mass detector K. Scholberg, Phys. Rev. D **73** (2006) 033005



ν-N coherent scattering

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left\{(G_V+G_A)^2+(G_V-G_A)^2\left(1-\frac{T}{E_\nu}\right)^2-(G_V^2-G_A^2)\frac{MT}{E_\nu^2}\right\}$$

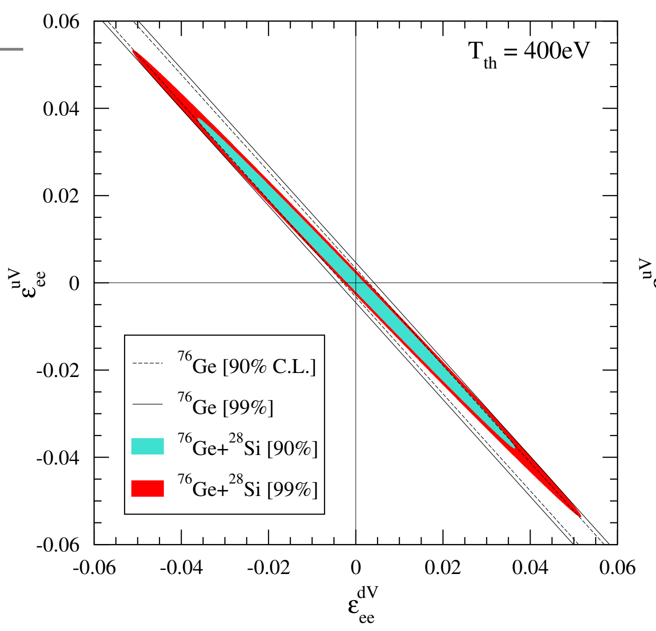
$$G_V = \left[\left(g_V^p+2\varepsilon_{ee}^{uV}+\varepsilon_{ee}^{dV}\right)Z+\left(g_V^n+\varepsilon_{ee}^{uV}+2\varepsilon_{ee}^{dV}\right)N\right]F_{nucl}^V(Q^2)$$

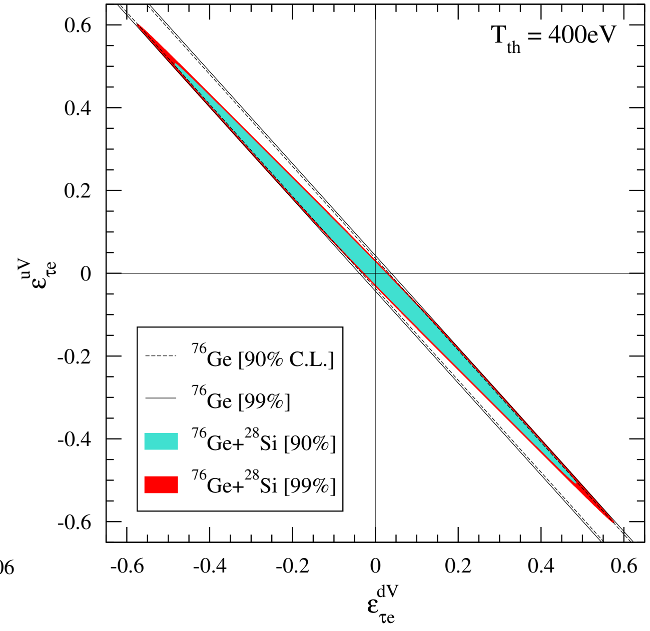
$$G_A = \left[\left(g_A^p+2\varepsilon_{ee}^{uA}+\varepsilon_{ee}^{dA}\right)(Z_+-Z_-)+\left(g_A^n+\varepsilon_{ee}^{uA}+2\varepsilon_{ee}^{dA}\right)(N_+-N_-)\right]F_{nucl}^A(Q^2)$$

$$\begin{aligned}\frac{d\sigma}{dT}(E_\nu,T) &= \frac{G_F^2 M}{\pi}\left(1-\frac{MT}{2E_\nu^2}\right)\times\\ &\times\left\{\left[Z(g_V^p+2\varepsilon_{ee}^{uV}+\varepsilon_{ee}^{dV})+N(g_V^n+\varepsilon_{ee}^{uV}+2\varepsilon_{ee}^{dV})\right]^2+\right.\\ &+\left.\sum_{\alpha=\mu,\tau}\left[Z(2\varepsilon_{\alpha e}^{uV}+\varepsilon_{\alpha e}^{dV})+N(\varepsilon_{\alpha e}^{uV}+2\varepsilon_{\alpha e}^{dV})\right]^2\right\}\end{aligned}$$

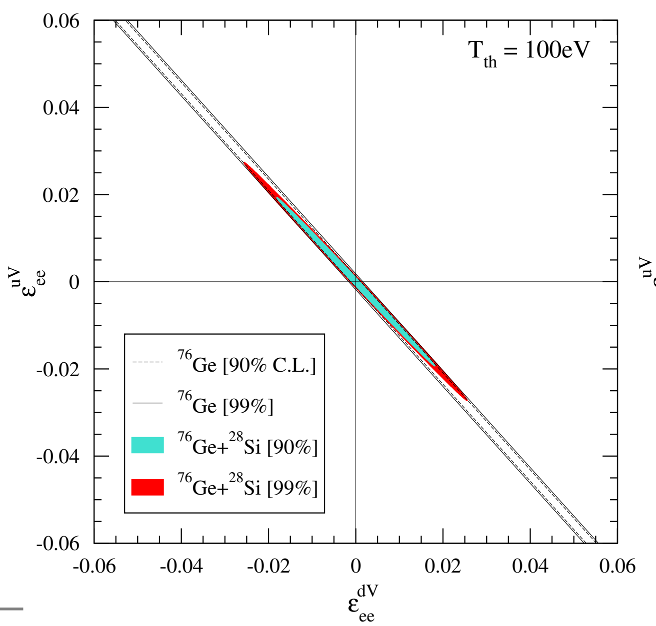
- Axial couplings contribution is zero or can be neglected
- Coherent enhancement of cross section
- Degeneracy in determination of NSI parameters

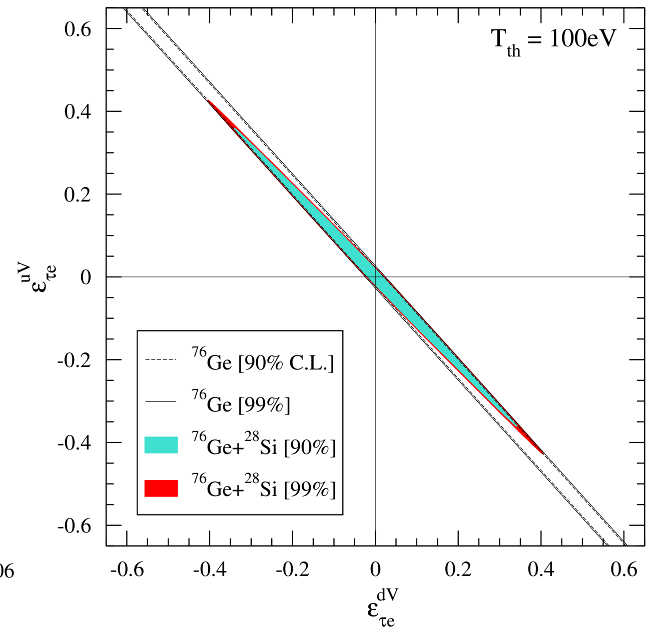
Estimated bounds on NSI from TEXONO-like experiment (Ge+Si)





^{76}Ge+^{28}Si $T_{th}=400eV$
$\|\epsilon^{dV}_{ee}\| < 0.036$
$\|\epsilon^{uV}_{ee}\| < 0.038$
$\|\epsilon^{dV}_{\tau e}\| < 0.48$
$\|\epsilon^{uV}_{\tau e}\| < 0.50$





^{76}Ge+^{28}Si $T_{th}=100eV$
$\|\epsilon^{dV}_{ee}\| < 0.018$
$\|\epsilon^{uV}_{ee}\| < 0.019$
$\|\epsilon^{dV}_{\tau e}\| < 0.34$
$\|\epsilon^{uV}_{\tau e}\| < 0.37$

Present and future bounds on NSI

One parameter analysis to compare coherent scattering sensitivity with present bounds and νFactory sensitivity (taken from Davidson et al'03)

	Present Limits	ν Factory	^{76}Ge $_{T_{th}=400eV}$ (^{76}Ge $_{T_{th}=100eV}$)	^{76}Ge+^{28}Si $_{T_{th}=400eV}$ (^{76}Ge+^{28}Si $_{T_{th}=100eV}$)
ϵ_{ee}^{dV}	$-0.5 < \epsilon_{ee}^{dV} < 1.2$	$\|\epsilon_{ee}^{dV}\| < 0.002$	$\|\epsilon_{ee}^{dV}\| < 0.003$ ($\|\epsilon_{ee}^{dV}\| < 0.001$)	$\|\epsilon_{ee}^{dV}\| < 0.002$ ($\|\epsilon_{ee}^{dV}\| < 0.001$)
$\epsilon_{\tau e}^{dV}$	$\|\epsilon_{\tau e}^{dV}\| < 0.78$	$\|\epsilon_{\tau e}^{dV}\| < 0.06$	$\|\epsilon_{\tau e}^{dV}\| < 0.032$ ($\|\epsilon_{\tau e}^{dV}\| < 0.020$)	$\|\epsilon_{\tau e}^{dV}\| < 0.024$ ($\|\epsilon_{\tau e}^{dV}\| < 0.017$)
ϵ_{ee}^{uV}	$-1.0 < \epsilon_{ee}^{uV} < 0.61$	$\|\epsilon_{ee}^{uV}\| < 0.002$	$\|\epsilon_{ee}^{uV}\| < 0.003$ ($\|\epsilon_{ee}^{uV}\| < 0.001$)	$\|\epsilon_{ee}^{uV}\| < 0.002$ ($\|\epsilon_{ee}^{uV}\| < 0.001$)
$\epsilon_{\tau e}^{uV}$	$\|\epsilon_{\tau e}^{uV}\| < 0.78$	$\|\epsilon_{\tau e}^{uV}\| < 0.06$	$\|\epsilon_{\tau e}^{uV}\| < 0.036$ ($\|\epsilon_{\tau e}^{uV}\| < 0.023$)	$\|\epsilon_{\tau e}^{uV}\| < 0.023$ ($\|\epsilon_{\tau e}^{uV}\| < 0.018$)

Conclusions

- NSI arise naturally in many models of physics beyond the SM and may be important in oscillation experiments.
- For big values of NSI the solar neutrino oscillation parameters can change drastically.
- Current and future neutrino experiments will be able to give stronger constraints on these parameters and perhaps could give a hint on the physics underlying neutrino masses.