Low-energy neutrino-electron scattering as a standard model probe: The potential of LENA as case study

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Phys. Rev. D 85, 073006 (2012)

Outline

- Introduction.
- LENA with ^{51}Cr (E=747keV) neutrino source:

(a) the possible determination of the electroweak mixing angle

(b) sensitivity to new physics such as nonstandard neutrino

- LENA with ^{7}Be (E=862keV) solar neutrinos.

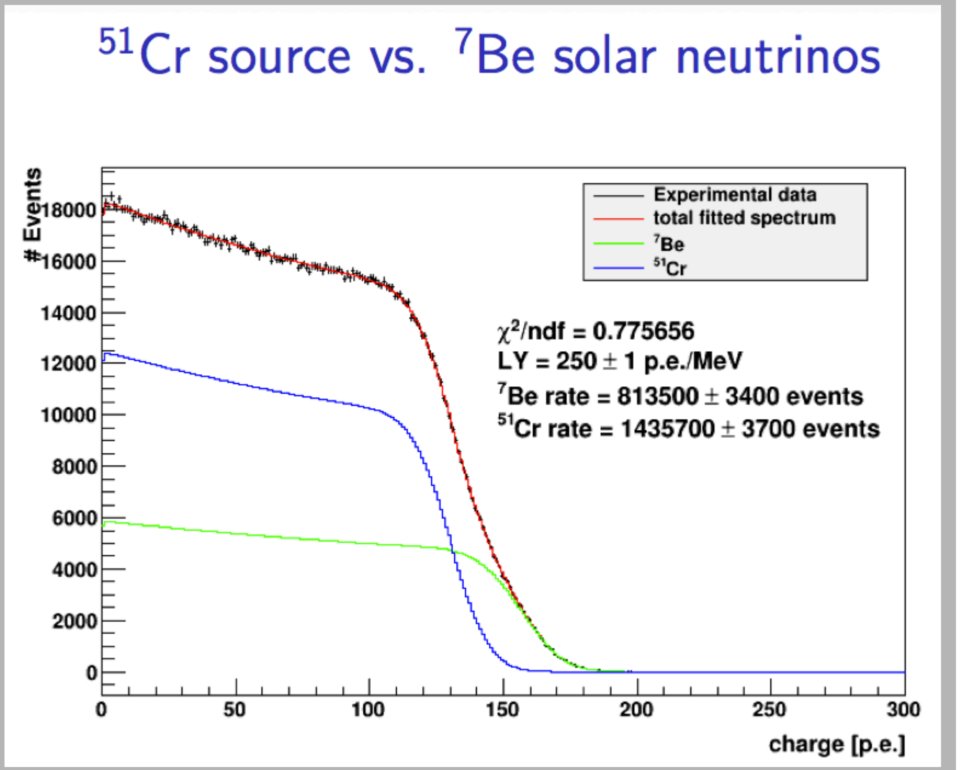
Introduction

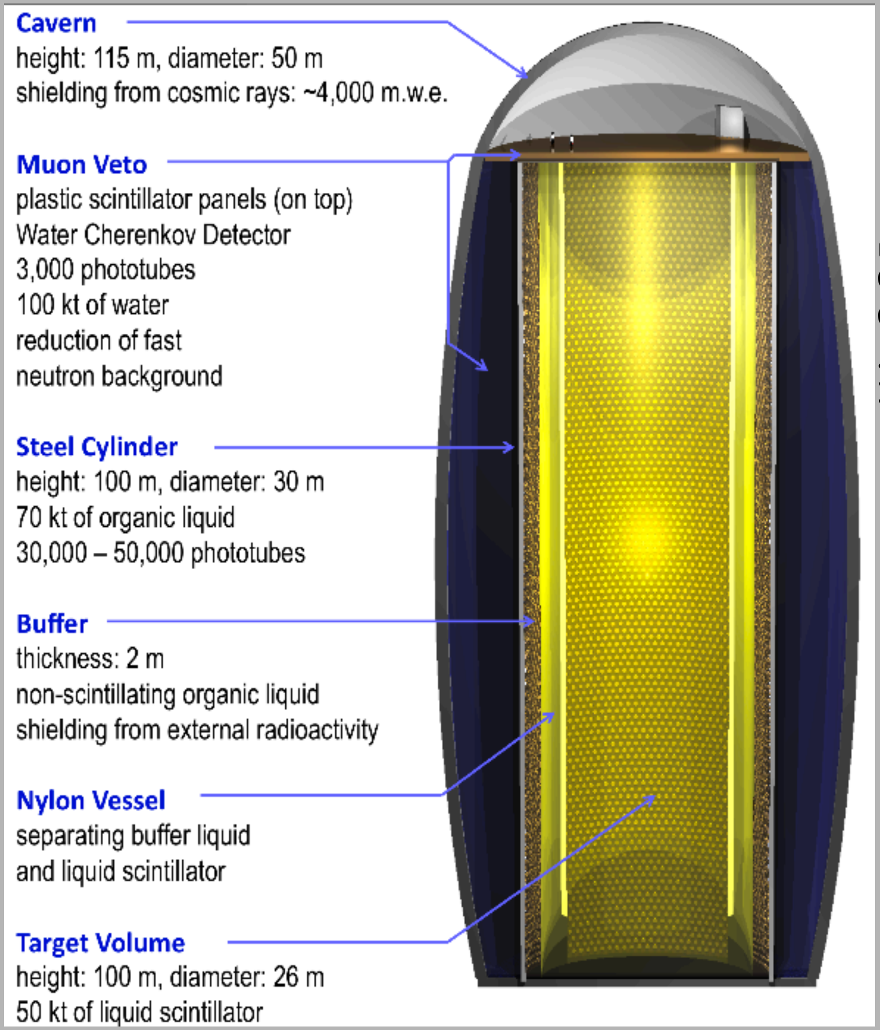
- A new generation of proposed large neutrino experiments is currently under the R&D phase. Multipurpose exp. to improve the knowledge of neutrino oscillations and to test physics bSM.

- Low-energy neutrino experiments provide a clean way to probe the weak mixing angle (reactor and water Cerenkov detectors), with an expected sensitivity in the range of few percent or less.

- It is also of interest to investigate the potential sensitivity of low energy ν-e scattering experiments to new physics, such as NSI, potentially associated to the mechanism of neutrino mass generation and/or new gauge bosons.

LENA: Low Energy Neutrino Astrophysics





100 m

M. Wurm et al. (LENA Collaboration), arXiv:1104.5620.

L.S. 50kT.

Neutrino electron scattering (ES)

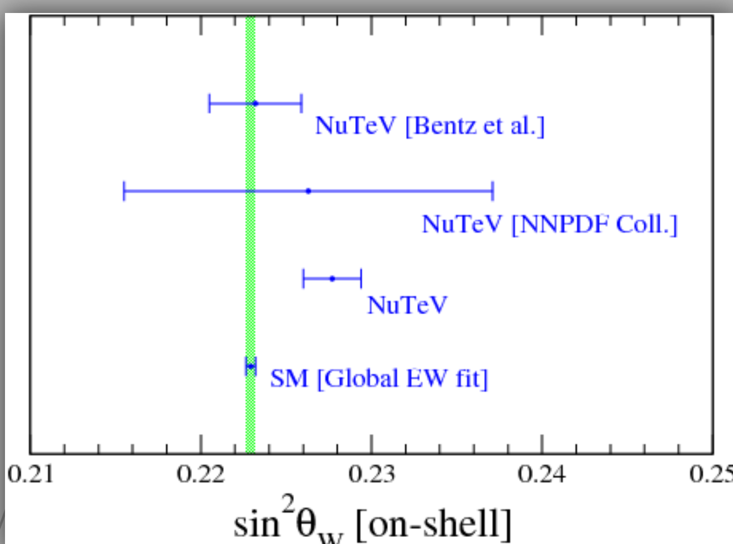
At tree level, the nu-e scattering cross section is given as:

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

$$g_L = \frac{1}{2} + \sin^2\theta_W$$
$$g_R = \sin^2\theta_W.$$

NuTeV(ν-N) $\sin^2\theta_W$(1–5% error), reestimation of syst. errors.

(ν-e) scattering, the current accuracy in is about 10–20% (TEXONO&LSND).
$\sin^2\theta_W = 0.251 \pm 0.031(\text{stat}) \pm 0.024(\text{sys})$ (Deniz et. Al 2010).



W. Bentz et. al. Phys. Lett. B693, 462-466 (2010).

R. D. Ball et al. [The NNPDF Collaboration], Nucl. Phys. B823, 195-233 (2009)

$$N_i = n_e \phi_{Cr} \Delta t \int_{T_i}^{T_{i+1}} \int \frac{d\sigma}{dT} R(T,T') dT' dT,$$

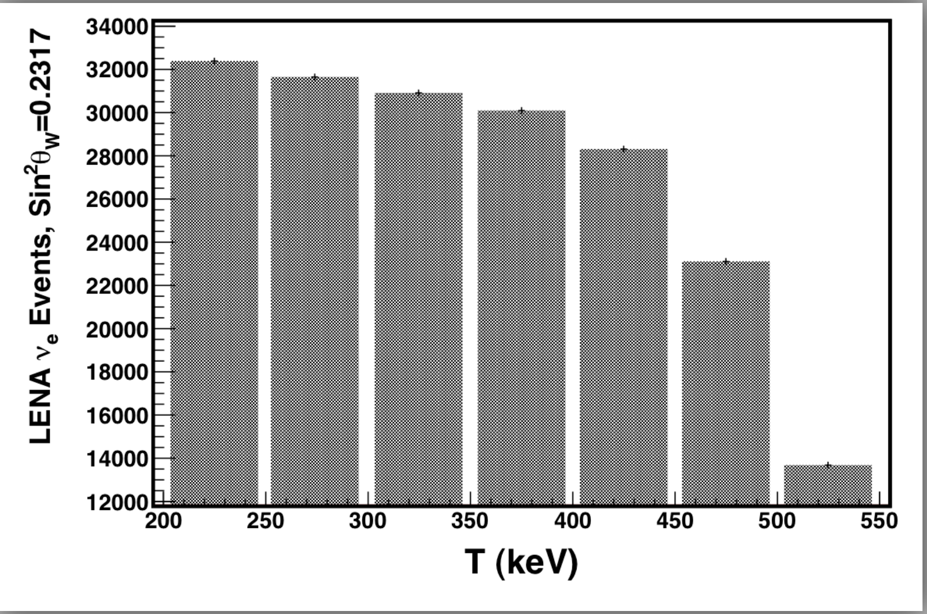
T(250-550keV)

51Cr (5 Mci) 747 keV

$$R(T,T') = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(T-T')^2}{(2\sigma^2)}],$$

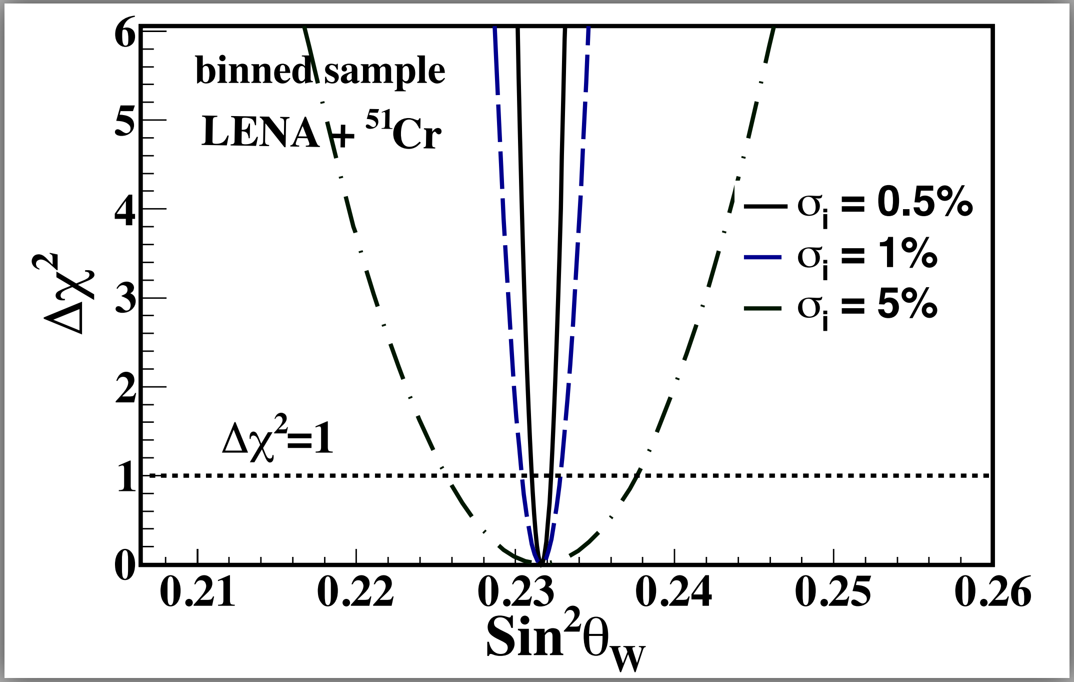
$$\sigma = 0.075\sqrt{T/MeV}.$$

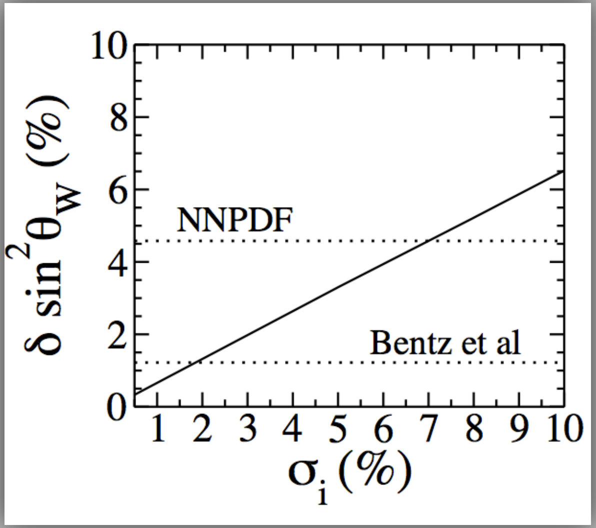
T1/2(28 days) 1.9x10^5 neutrino events



$$\chi^2 = \sum_i \frac{(N_i^{\rm theo} - N_i^{\rm exp})^2}{\sigma_i^2},$$

Sensitivity obtained to the weak mixing angle





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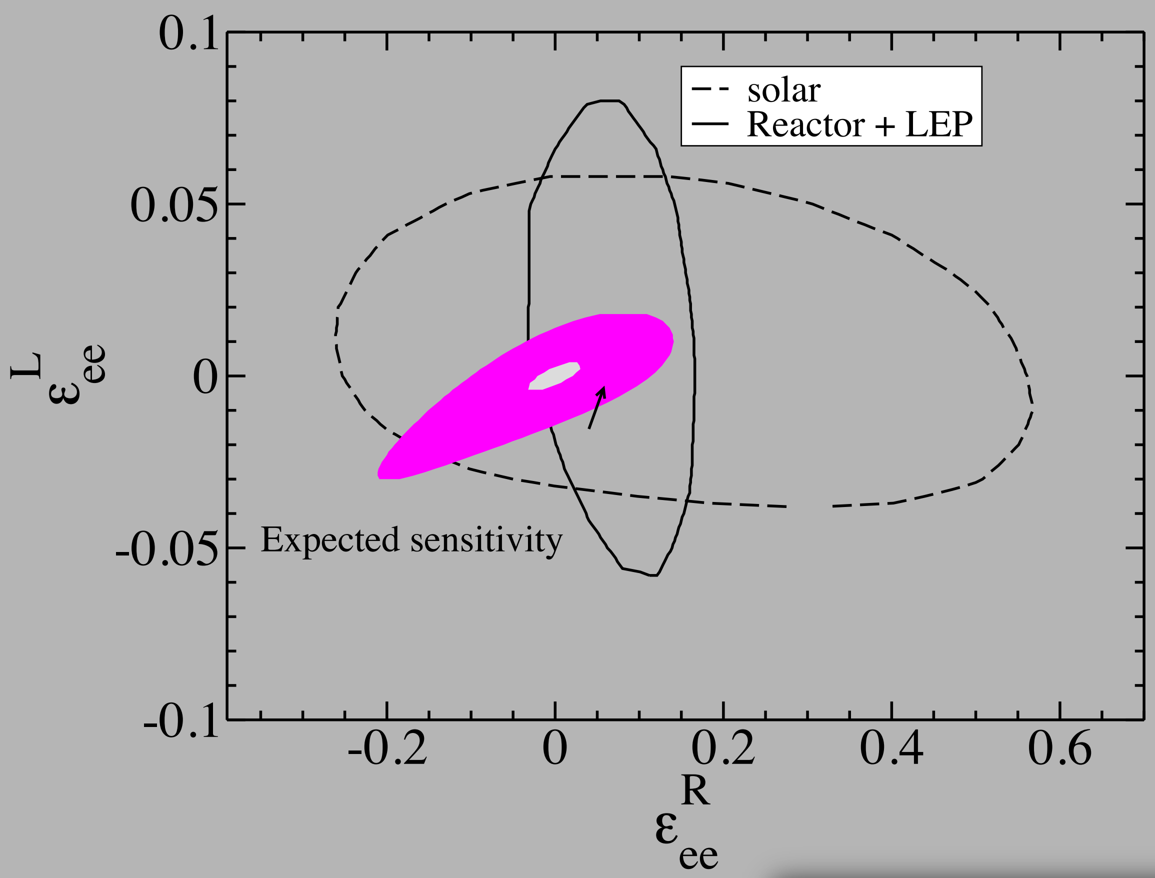
Probing Non-Standard-Interactions NSI- NU

- NSI parameters are associated to the generation of neutrino mass through a low-scale seesaw mechanism or through scalar-boson mediation. A generic effective four-fermion NSI Lagrangian

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

GF is the Fermi constant and εfP parameterize the strength of the NSI. This term must be added to the SM Lagrangian. f is a first-generation SM fermion (e, u, or d). The chiral projectors P=L,R = ½(1+/-γ5), α and β denote the three neutrino flavors: e, μ, and τ .

Lena, NSI-NU



90%CL (1%, 5% error)

$$g_R \longrightarrow g_R + \varepsilon^R_{ee}; \qquad g_L \longrightarrow g_L + \varepsilon^L_{ee},$$

Bolaños, et. al Phys.Rev. D79, 113012 (2009), 0812.4417 [hep-ph]
Barranco et al., Phys. Rev. D 77, 093014 (2008).

Specific theories bSM

One can also apply these results to the case of specific theories bSM involving an additional relatively light neutral gauge boson Z', which may arise in a variety of scenarios, such as the E6 gauge group (J. W. F. Valle, Phys. Lett. B 196, 157 (1987)).

$$\varepsilon^L = 2\gamma \sin^2\theta_W \rho_{\nu e}^{NC} \left(\frac{3c_\beta}{2\sqrt{6}} + \frac{s_\beta}{3}\sqrt{\frac{5}{8}}\right)^2$$

$$\varepsilon^R = 2\gamma \sin^2\theta_W \rho_{\nu e}^{NC} \left(\frac{c_\beta}{2\sqrt{6}} - \frac{s_\beta}{3}\sqrt{\frac{5}{8}}\right)\left(\frac{3c_\beta}{\sqrt{24}} + \frac{s_\beta}{3}\sqrt{\frac{5}{8}}\right)$$

$$\gamma = \frac{{M_{Z'}}^2}{{M_Z}^2}$$

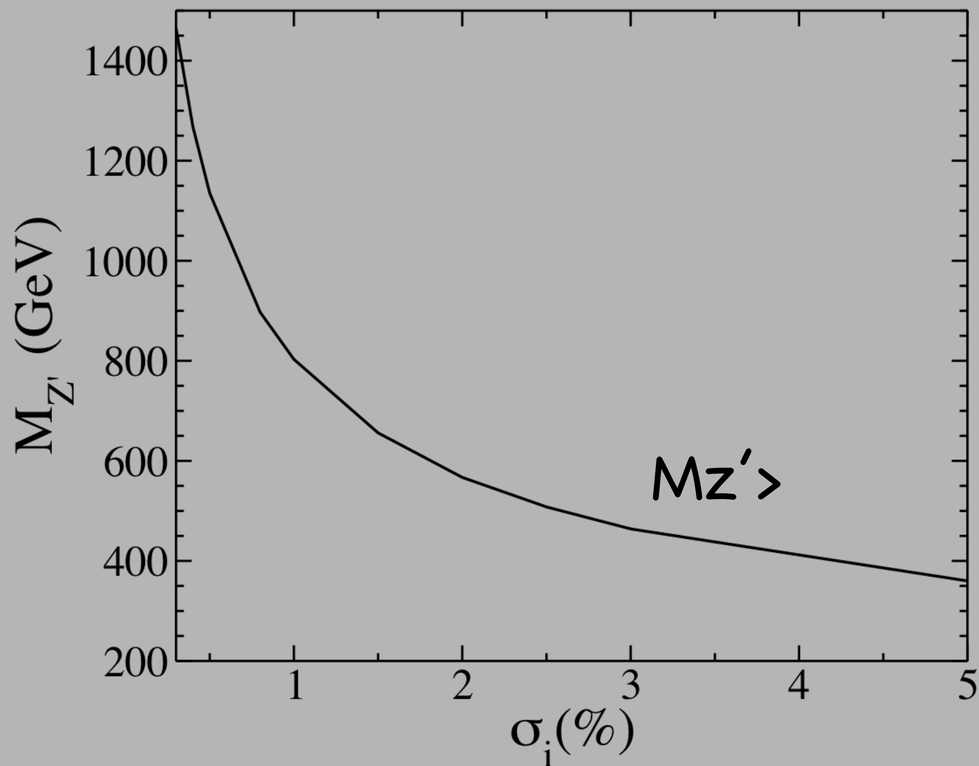
$\cos\beta = 1$ (χ model)

$\cos\beta = 0$ ψ model)

$\cos\beta = \frac{\sqrt{3}}{\sqrt{8}}$, $\sin\beta = -\frac{\sqrt{5}}{\sqrt{8}}$ (η model)

Limits to the extra neutral boson (Z') mass Complementary to those from LHC.

90%CL



A constraint in the range from 360 GeV to 1.1 TeV would be attainable depending on the statistics (the assumed error in the detectedevent number varying from 0.5% to 5%).

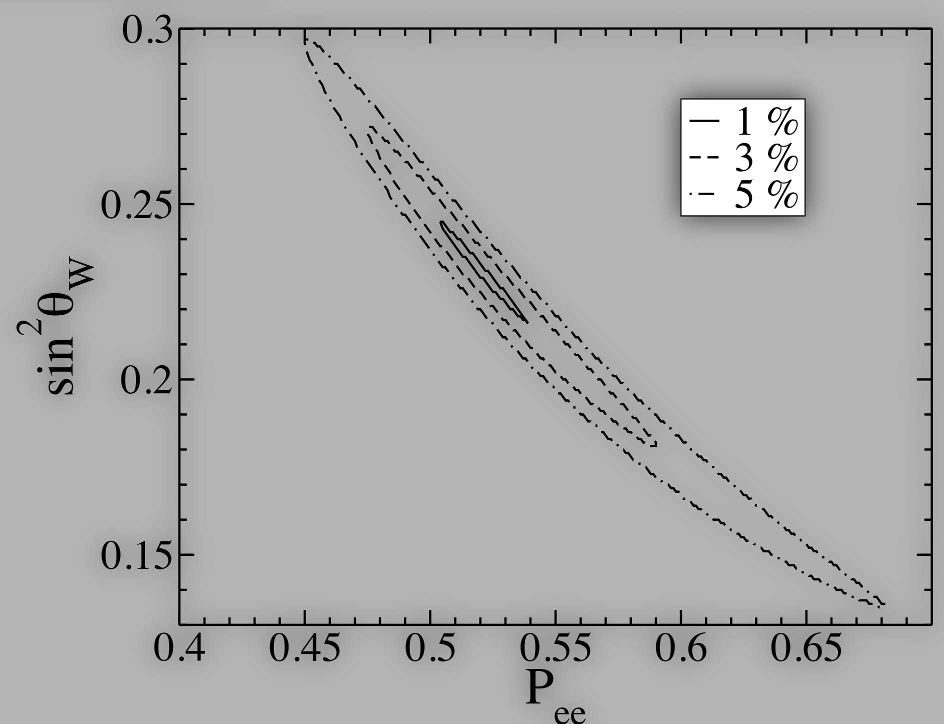
(B) LENA + Solar Neutrinos

- 7Be(0.862 MeV), in T(50keV) bins. χ2

$$N_i = n_e \phi_{\mathrm{Be}} \Delta t \int_{T_i}^{T_{i+1}} \int \left(P_{ee} \frac{d\sigma^{\nu_e e}}{dT} + (1 - P_{ee}) \frac{d\sigma^{\nu_{\mu,\tau} e}}{dT} \right) \times R(T, T') dT' dT. \qquad (9)$$

$$g_L^{\nu_{\mu,\tau}} = -\tfrac{1}{2} + \sin^2\theta_W,$$

$$g_R^{\nu_{\mu,\tau}} = \sin^2\theta_W.$$



For an error of 1%, despite the correlation with the survival probability, there would be a sensitivity to $\sin^2\theta_W$ of the order ~6%.

Conclusions

- The LENA proposal in combination with a Cr neutrino source could provide a precise measurement of the electroweak mixing angle.
- LENA could also be used to probe physics bSM, such as NSI, and the possible existence of new electroweak neutral gauge bosons.
- We also discussed the potential of the LENA detector for the solar beryllium signal. It would be worthwhile to perform a more realistic simulation by taking advantage of Borexino spectral results.