Solar and atmospheric neutrinos with non-standard interactions in dark matter detectors

Shu Liao

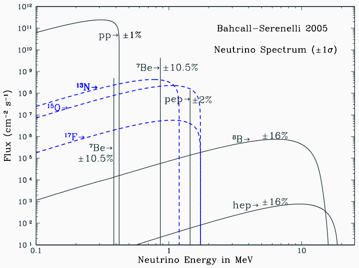
based on: 1705.00661(B. Dutta, L. Strigari, J. Walker) and on-going paper

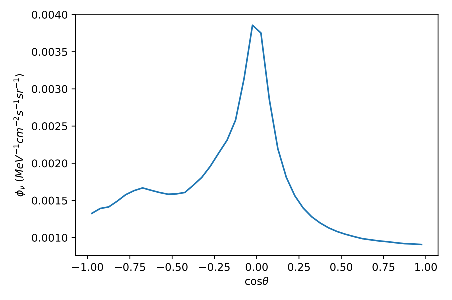
Texas A&M University

Outline

Motivation

Solar and atmopheric neutrino

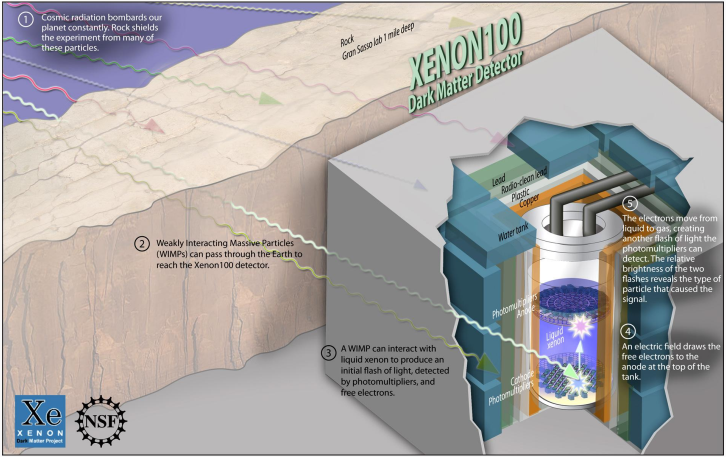




Solar and atmospheric neutrino spectrum*

*left: Bahcall, ApJ, 621, L85 (2005), right: G. Battistoni et al. Phys. 19, 269 (2003)

Xenon dark matter detector



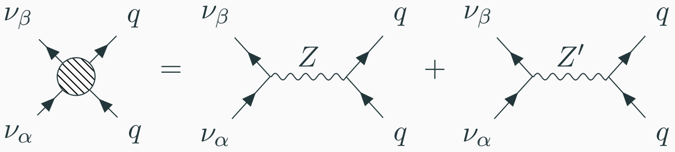
Xenon dark matter detector†

†http://xenon.astro.columbia.edu/XENON100_Experiment/

Non-Standard interactions (NSI) of neutrino

General four fermion interaction:

$$\mathcal{L}_{\text{int}} = 2\sqrt{2}G_F \bar{\nu}_{\alpha L}\gamma^{\mu}\nu_{\beta L}\left(\epsilon^{qL}_{\alpha\beta}\bar{q}_L\gamma_{\mu}q_L + \epsilon^{qR}_{\alpha\beta}\bar{q}_R\gamma_{\mu}q_R\right)$$



The NSI couplings:

$$\epsilon = \frac{1}{2\sqrt{2}G_F}\frac{g_\nu g_q}{q^2 + m^2_{Z'}}$$

Differential cross section

Differential cross section of $\nu_\beta + N \to \nu_\alpha + N$ as a function of recoil energy E_r:

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 Q_V^2}{2\pi} m_N \left(1 - \left(\frac{m_N E_R}{E_\nu^2}\right) + \left(1 - \frac{E_R}{E_\nu}\right)^2\right) F(q^2)$$

$$Q_V^2 = \left[Z(\frac{1}{2} - 2\sin^2\theta_w + 2\epsilon_{\alpha\alpha}^{uV} + \epsilon_{\alpha\alpha}^{dV}) + N(-\frac{1}{2} + \epsilon_{\alpha\alpha}^{uV} + 2\epsilon_{\alpha\alpha}^{dV})\right]^2 + \frac{1}{2}\left|Z(2\epsilon_{\alpha\beta}^{uV} + \epsilon_{\alpha\beta}^{dV}) + N(\epsilon_{\alpha\beta}^{uV} + 2\epsilon_{\alpha\beta}^{dV})\right|^2$$

Neutrino oscillation in matter

The propagation of neutrino is described by:

$$\mathcal{H}_{\beta\alpha} = \left[U \mathrm{diag}\left(0, \frac{\Delta m_{21}^2}{2E}, \frac{\Delta m_{31}^2}{2E}\right) U^\dagger \right]_{\beta\alpha} + \sqrt{2} G_F \sum_f n_f \left(\delta^{ef} \delta_{e\alpha} + \epsilon^f_{\beta\alpha} \right)$$

U: mixing matrix, n_f: number density of fermion f.

Diagonalize $\mathcal{H}$ into $\tilde{U} diag \tilde{U}^\dagger$

If matter density changes slowly, neutrino propagates through matter adiabatically:

$$P_{\alpha\to\beta} = \sum_{i,j} \tilde{U}_{\beta i} \tilde{U}^*_{\alpha i} \tilde{U}^*_{\beta j} \tilde{U}_{\alpha j} e^{-i(m_i - m_j)L}$$

Current constrains

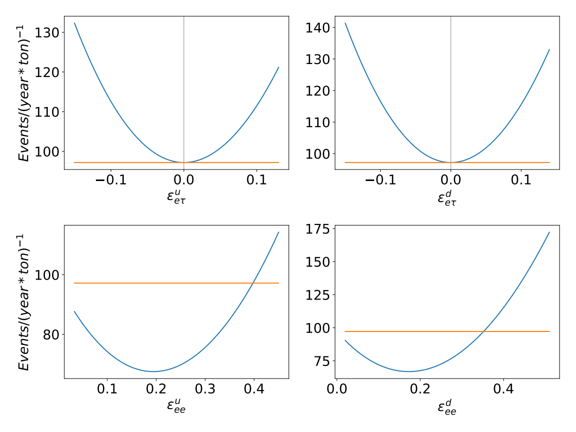
PRESENT (OSC+CHARM+NuTeV)	
$\epsilon_{ee}^{u,V}$	$[-0.97, -0.83] \oplus [0.033, 0.450]$
$\epsilon_{\mu\mu}^{u,V}$	$[-0.008, 0.005]$
$\epsilon_{\tau\tau}^{u,V}$	$[-0.015, 0.04]$
$\epsilon_{e\mu}^{u,V}$	$[-0.05, 0.03]$
$\epsilon_{e\tau}^{u,V}$	$[-0.15, 0.13]$
$\epsilon_{\mu\tau}^{u,V}$	$[-0.006, 0.005]$
$\epsilon_{ee}^{d,V}$	$[0.02, 0.51]$
$\epsilon_{\mu\mu}^{d,V}$	$[-0.003, 0.009]$
$\epsilon_{\tau\tau}^{d,V}$	$[-0.001, 0.05]$
$\epsilon_{e\mu}^{d,V}$	$[-0.05, 0.03]$
$\epsilon_{e\tau}^{d,V}$	$[-0.15, 0.14]$
$\epsilon_{\mu\tau}^{d,V}$	$[-0.007, 0.007]$

Current constraints[‡]

[‡]P. Coloma, P. B. Denton, M. C. Gonzalez-Garcia, M. Maltoni and T. Schwetz, arXiv:1701.04828 [hep-ph]

Solar neutrino

Solar neutrino



Number of events above a nuclear recoil energy threshold of 1 keV as each ϵ varies over its allowable range (blue curves). Orange curve: SM contribution.

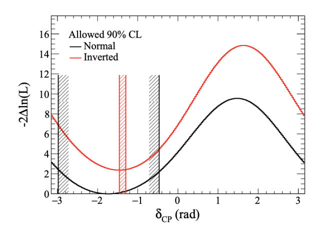
MSW vs. noMSW

	$\epsilon_{ee}^{eL} = 0.052$	$\epsilon_{ee}^{eR} = 0.08$	$\epsilon_{e\tau}^{eR} = 0.19$	$\epsilon_{\tau\tau}^{eL} = -0.16$	$\epsilon_{ee}^{u} = 0.2$	$\epsilon_{e\tau}^{d} = -0.15$	$\epsilon_{ee}^{d} = 0.26$
$\frac{N_{MSW}}{N_{SM}}$	1.10	1.07	1.05	1.14	0.69	1.45	0.69
$\frac{N_{noMSW}}{N_{SM}}$	1.69	1.51	1.55	1.47	4×10^{-5}	19.07	5×10^{-3}

Ratio to only SM. Rows 1: MSW turned on, Row2: MSW turned off

Atmospheric neutrino

CP phase



log-likelihood as a function of δ_{CP} for the normal (black) and inverted (red) mass ordering[§]

CP phase in off diagnal term of NSI parameters:

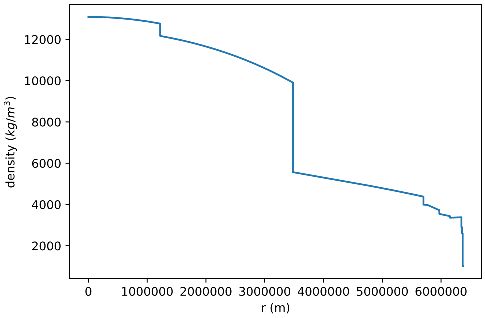
$$\epsilon = \begin{pmatrix} \epsilon_{ee} & \epsilon_{e\mu}e^{-i\phi_{e\mu}} & \epsilon_{e\tau}^{-i\phi_{e\tau}} \\ \epsilon_{e\mu}e^{i\phi_{e\mu}} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau}e^{-i\phi_{\mu\tau}} \\ \epsilon_{e\tau}^{i\phi_{e\tau}} & \epsilon_{\mu\tau}e^{i\phi_{\mu\tau}} & \epsilon_{\tau\tau} \end{pmatrix}$$

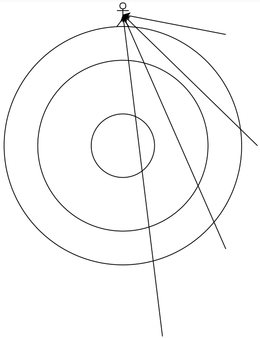
If NSI CP phase is present, it can degenerate with δ_{CP} in the oscillation parameters.[¶]

[¶] PDG, Phys. Rev. D 98, 030001 (2018)

[¶] Liao, J., Marfatia, D., & Whisnant, K. JHEP 2017(1), 71.

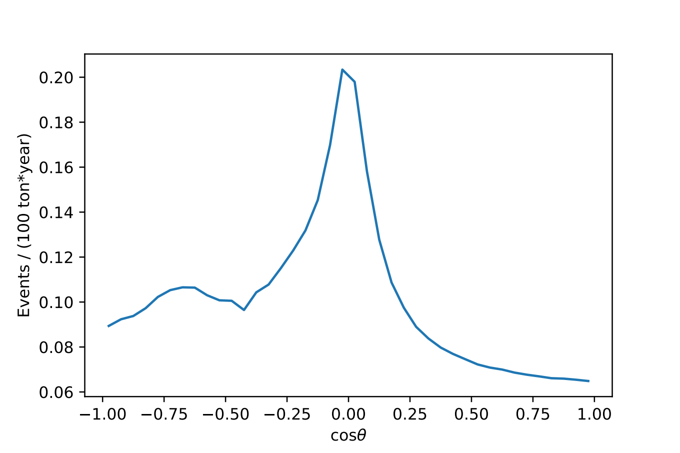
Neutrino oscillation in earth matter





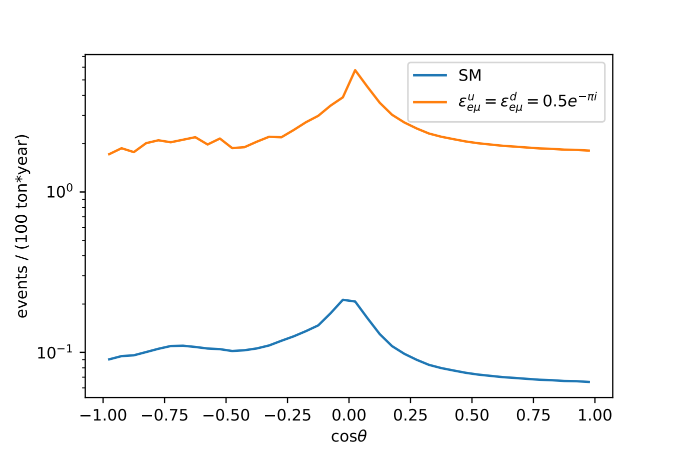
Neutrinos that propagates through earth matter

Number of events at each angle



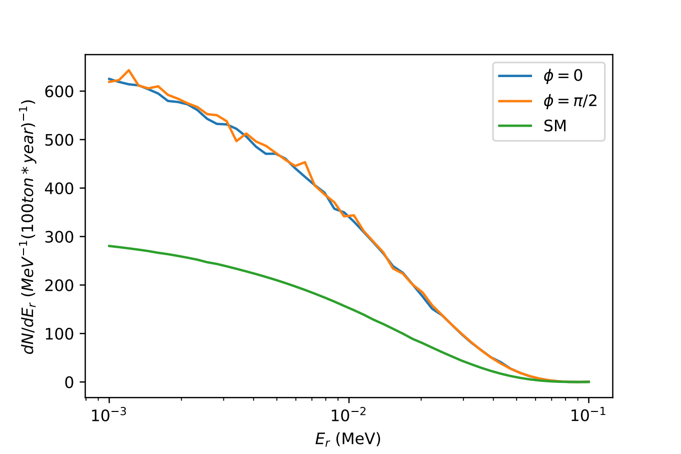
Number of events at Xe detector assuming no non-standard interations

Atmospheric neutrino



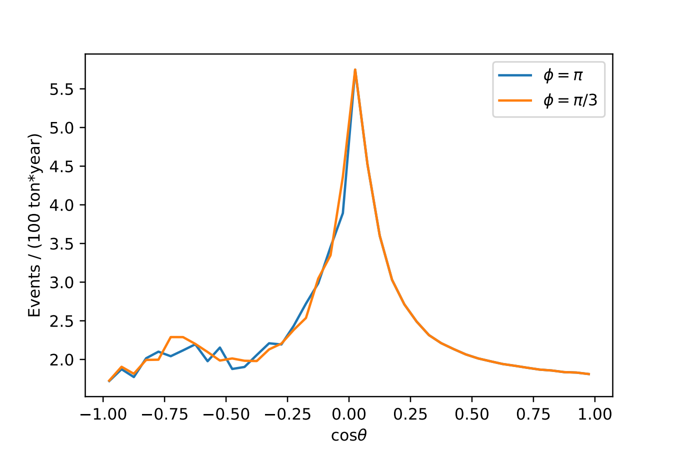
Zenith angle dependent comparison with SM

Oscillating spectrum



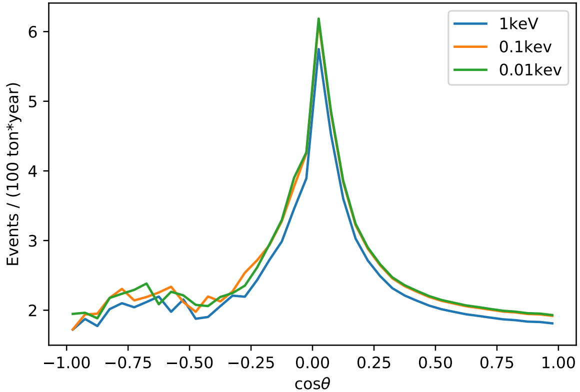
Oscillating spectrum, with $\epsilon^u_{e\tau} = \epsilon^d_{e\tau} = -0.15e^{-\phi i}$ (integrated over zenith angle)

Degeneracies breaking



$\epsilon_{e\mu}^{u} = \epsilon_{e\mu}^{d} = 0.5e^{-\phi i}$ with different ϕ

Threshold dependence



Number of events on different threshold at Xe detector,
NSI parameters: $\epsilon^u_{e\mu} = \epsilon^d_{e\mu} = 0.5e^{-\pi i}$

Conclusion

Conclusion

- Direct dark matter searches are able to probe NSI parameter space that cannot be probed by current neutrino experiments.
- NSI parameters plus neutrino oscillation can play important role in detecting the neutrino events.
    - it will change the events rate on the detector side
    - it will produce observable oscillations which do not exist in Standard model
- Atmospheric neutrino detection on dark matter detector may help resolve degeneracies on the CP phase when NSI parameters are introduced.