

Sensitivity Enhancement for the Searches of Neutrino Magnetic Moments through Atomic Ionization

[arXiv:hep-ex/1001.2074, PRL in press]

OUTLINE

- Neutrino Magnetic Moment
- Atomic Ionization
- Results
- Prospects
- Measurement on $\bar{\nu}_e e^-$ Scattering with CsI.

H. T. Wong, H. B. Li and S. T. Lin

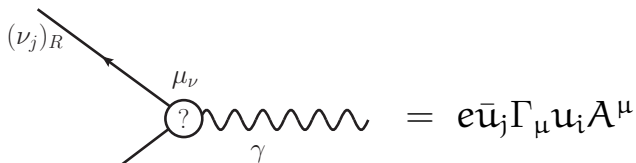
Institute of Physics, Academia Sinica, Taiwan

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ICHEP 2010, Paris



Neutrino Magnetic Moment - Vertex



$$\Gamma_\mu = (q^2 \gamma_\mu - q_\mu \not{q}) (R(q^2) + r(q^2) \gamma_5) + (D_\mu(q^2) + i D_E(q^2) \gamma_5) \sigma_{\mu\nu} q^\nu$$

D_μ : Magnetic dipole moment.

D_E : Electric dipole moment.

3×3 matrix: $\mu_{ij}^2 \equiv |D_{\mu ij} - D_{E ij}|^2$

for Majorana ν , diagonal $\mu_{ii} = 0$

Effectively :

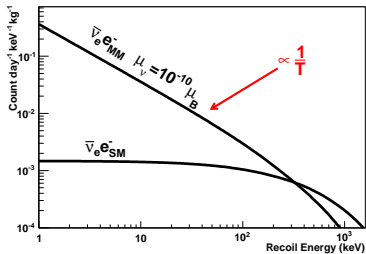
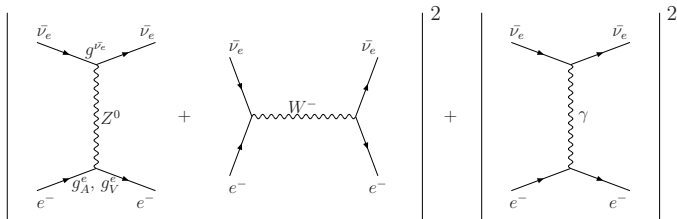
$$\mu_{\nu_e}^2 = \sum_j \left| \sum_i U_{ei} e^{-i E_\nu L} \mu_{ij} \right|^2$$

If $\mu_\nu > 10^{-14} \mu_B \rightarrow$ Majorana ν

SM + ν_{Dirac} with mass : $\mu_\nu \sim 3 \times 10^{-19} \frac{m_\nu}{1 \text{ eV}} \mu_B$



$\bar{\nu}$ Magnetic Moment - Interaction with Free Electron



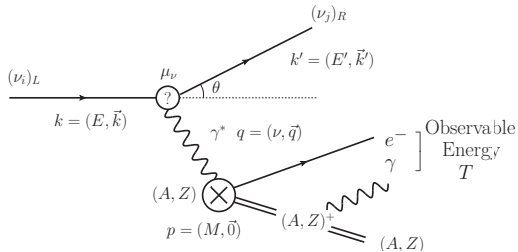
- $(\frac{d\sigma}{dT})_{SM} \sim \text{const.}$
at small T.
- $(\frac{d\sigma}{dT})_{MM} = \frac{\pi\alpha^2\mu_{\nu}^2}{m_e^2} (\frac{1}{T} - \frac{1}{E_{\nu}})$

- **Reactor $\bar{\nu}_e e^-$ scattering**
 - TEXONO : $\mu_\nu < 7.4 \times 10^{-11} \mu_B$
 - GEMMA : $\mu_\nu < 3.2 \times 10^{-11} \mu_B$ (unpublished)
- **Solar νe^- scattering** (Background Assumption Necessary)
 - Borexino : $\mu_\nu < 5.4 \times 10^{-11} \mu_B$
 - Solar ν spectrum shape(SK): $\mu_\nu < 1.1 \times 10^{-10} \mu_B$
- **Astrophysics Bound**
 - $\nu_L \rightarrow \nu_R$ in SN1987A, ${}^4\text{He}$ Abundance,
 $\gamma \rightarrow \nu \bar{\nu}$ Cooling of Helium star, absence of $\bar{\nu}$ from Sun.
 - Bound : $10^{-10} - 10^{-12} \mu_B$
 - depend on neutrino properties/interaction & stellar model



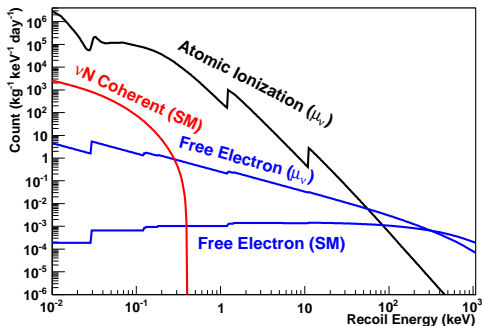
Atomic Ionization

When transfer Energy \sim binding Energy of Atom.



- $\nu + (A, Z) \rightarrow \nu + (A, Z)^+ + e^-$
 $(A, Z)^+ \rightarrow (A, Z) + \gamma$'s
- $\frac{d\sigma}{dT} \propto L^{\mu\nu} W_{\mu\nu}$
- Leptonic Current $L^{\mu\nu} = \bar{u}_L \left[\frac{\mu_\nu}{2m_e} \sigma^{\mu\lambda} q_\lambda \right] u'_R \times \text{C.C.}$
- Hadronic Current $W_{\mu\nu}$: general form with $q^\mu W_{\mu\nu} = 0$

Atomic Ionization



- As $T \ll E_\nu$
- Method of Equivalent Photons \rightarrow virtual- γ as real, $q^2 \rightarrow 0$.
- $W_{\mu\nu}(T, q^2 \rightarrow 0) \rightarrow \sigma_\gamma(E_\gamma = T)$ real photon cross-section.
-

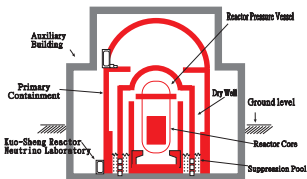
$$\Rightarrow \frac{d\sigma}{dT} = \mu_\nu^2 \frac{\alpha}{\pi} \left(\frac{E_\nu}{m_e}\right)^2 \frac{\sigma_\gamma(T)}{T}, \quad \sigma_\gamma : \text{Photoelectric Cross-section}$$

- σ_γ include Atomic effects and final state effects.

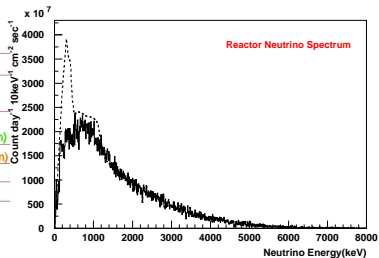
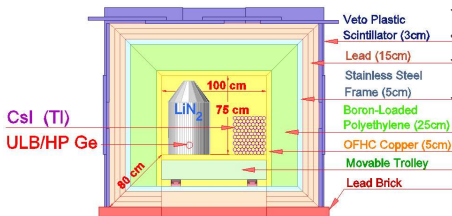
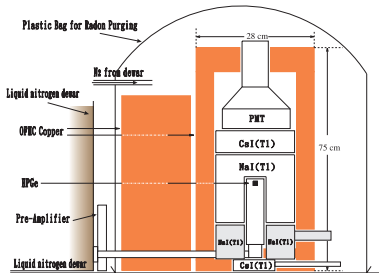


Kuo-Sheng Neutrino Lab.

Kuo-Sheng Nuclear Power Station : Reactor Building



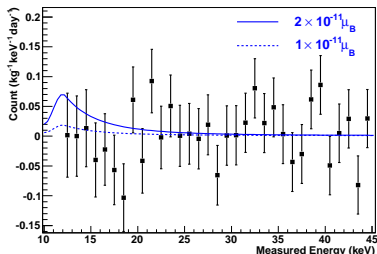
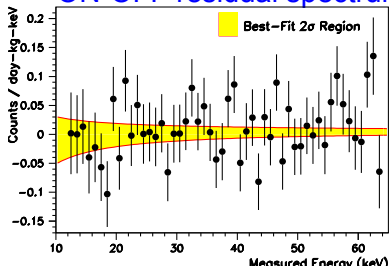
- $\phi_{\nu} = 6.4 \times 10^{12} \text{cm}^{-2} \text{s}^{-1}$
- Lab : 28 m from core,
- 30 mwe overburden.



Results: 1 kg HPGe detector

- 1 kg HPGe detector at reactor 571/128 days ON/OFF data.
- Background level ~ 1 cpkkd.
- Analysis threshold : 12 keV.

ON-OFF residual spectrum



- **Free Electron:**

$$\mu_\nu < 7.4 \times 10^{-11} \mu_B$$

(90% C. L.)

ref : [PRD 75 2007]

- **Atomic Ionization:**

$$\mu_\nu < 1.9 \times 10^{-11} \mu_B$$

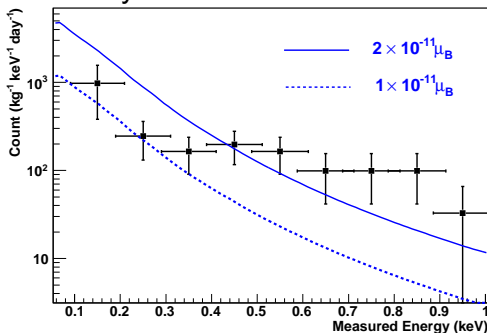
(90% C. L.)

ref : [PRL in press]



Results: 4×5 g ULE-Ge detector

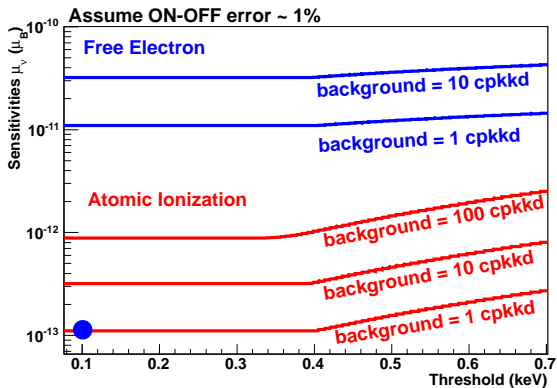
Reactor-ON data Only



- Dark Matter Search : [S. T. Lin's Talk](#)(Dark Matter Session)
[PRD 79, 061101\(R\) 2009](#)
- Data: 0.34 kg-day, Reactor-ON data only.
- Threshold(50% eff.) = 220 eV.
- NO background assumption \rightarrow signals cannot be bigger than the observed count rates
- **Binned Poisson Method:** $\mu_\nu < 1.3 \times 10^{-11} \mu_B$
ref : [PRL in press]



Projected Sensitivities



- Limited by ambient γ/n background + SM(free electron) + $\bar{\nu}_e N$.
- Threshold ~ 100 eV, bkg ~ 1 cpkkd, \rightarrow projected sensitivity $\sim 10^{-13} \mu_B$ (•)

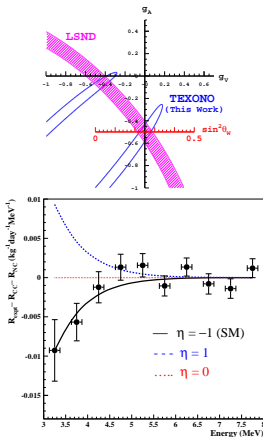
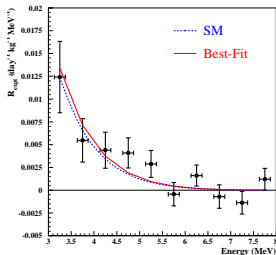
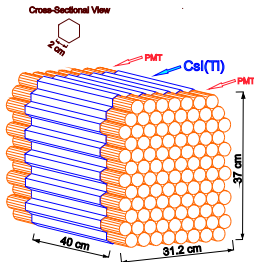


- Advances in sub-keV detectors provide ideal means to study μ_ν -induced Atomic Ionization.
- "Smoking gun" Signature: K/L/M Peaks at Atomic Binding Energies at ratio of $\sim \sigma_\gamma(T)/T$ in ON-OFF Residual Spectra.
- $\sim E_\nu^2$ dependence of cross-section boost sensitivities for higher energy low flux accelerator neutrinos.
- Atomic Ionization enhancement also applies to WIMP searches by their electromagnetic couplings via magnetic moments or milli-charge
- Further data taking at Kuo-Sheng Neutrino Lab.



$\bar{\nu}_e e^-$ Scattering at MeV

M. Deniz, et. al., PRD 81, 072001 2010



- Data (CsI) : ~ 30000 kg-day ON,
 ~ 7400 kg-day OFF
- DAQ Threshold : 500 keV :
Analysis Threshold : 3 MeV
- $\sigma_{\text{measured}}/\sigma_{\bar{\nu}_e e^-} = 1.08 \pm 0.21(\text{stat}) \pm 0.16(\text{sys})$
- $\sin^2 \theta_W = 0.251 \pm 0.031(\text{stat}) \pm 0.024(\text{sys})$
- Verify NC+CC destructive interference.
- $\mu_\nu < 2.2 \times 10^{-10} \mu_B$

