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

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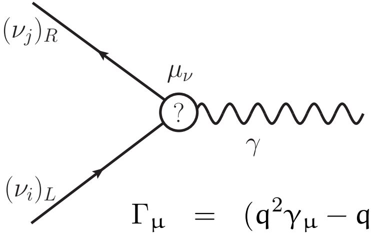
Neutrino Magnetic Moment - Vertex



$$= e\bar{u}_j \Gamma_\mu u_i A^\mu$$

$$\Gamma_\mu = (q^2\gamma_\mu - q_\mu q.\gamma)(R(q^2) + r(q^2)\gamma_5) + (D_\mu(q^2) + iD_E(q^2)\gamma_5)\sigma_{\mu\nu}q^\nu$$

D_μ: Magnetic dipole moment.

D_E: Electric dipole moment.

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

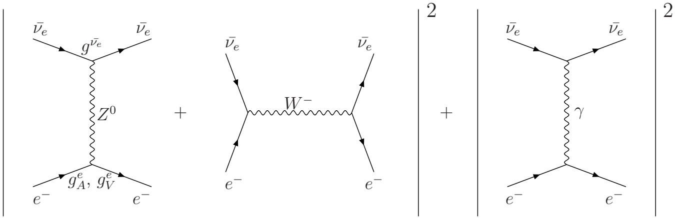
for Majorana ν, diagonal $\mu_{ii} = 0$

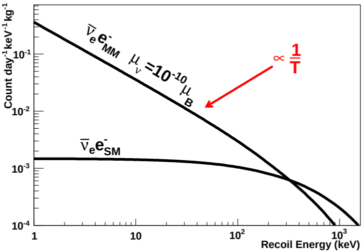
Effectively : $\mu_{\nu_e}^2 = \sum_j |\sum_i U_{ei} e^{-iE_\nu L} \mu_{ij}|^2$

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

SM+ν_{Dirac} with mass : $\mu_\nu \sim 3\times10^{-19} \frac{m_\nu}{1\text{ ev}} \mu_B$

ν Magnetic Moment - Interaction with Free Electron





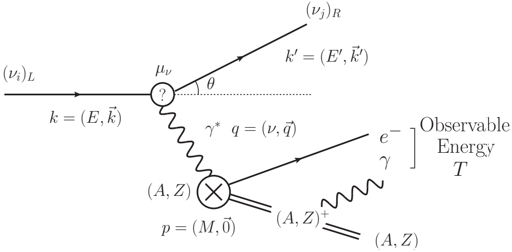
- $\left(\frac{d\sigma}{dT}\right)_{SM} \sim const.$
  at small T.
- $\left(\frac{d\sigma}{dT}\right)_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left(\frac{1}{T} - \frac{1}{E_\nu}\right)$

Present Limits

- Reactor $\bar{\nu}_e e^-$ scattering
  - TEXONO : $\mu_\nu < 7.4\times10^{-11}\mu_B$
  - GEMMA : $\mu_\nu < 3.2\times10^{-11}\mu_B$
- 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
  - $\nu_L \to \nu_R$ in SN1987A, ^{4}He Abundance,
    $\gamma \to \nu\bar{\nu}$ Cooling of Helium star, absense of $\bar{\nu}$ from Sun.
  - Bound : $10^{-10} - 10^{-12}\mu_B$
  - depend on neutrino properties/interaction & stellar model

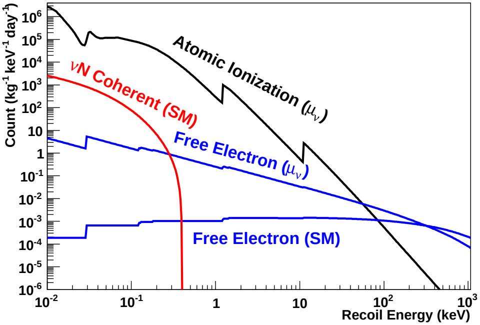
Atomic Ionization

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 $L^{\mu\nu} = \bar{u_L} [\frac{\mu_\nu}{2m_e} \sigma^{\mu\lambda} q_\lambda] u'_R \times$ C.C.
- Hadronic Current $W_{\mu\nu}$: general form with $q^\mu W_{\mu\nu} = 0$

Atomic Ionization

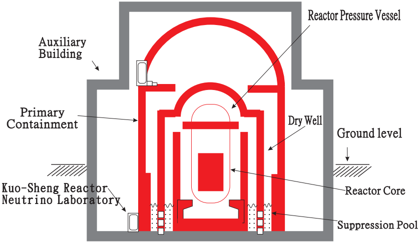


- As $T << E_\nu$
- Method of Equivalent Photons $\rightarrow$ virtual-γ as real, $q^2 \rightarrow 0$.
  $\rightarrow$ proven in charged fermion case.
- $W_{\mu\nu}(T, q^2 \rightarrow 0) \rightarrow \sigma_\gamma(E_\gamma = T)$ real photon cross-section.
-

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

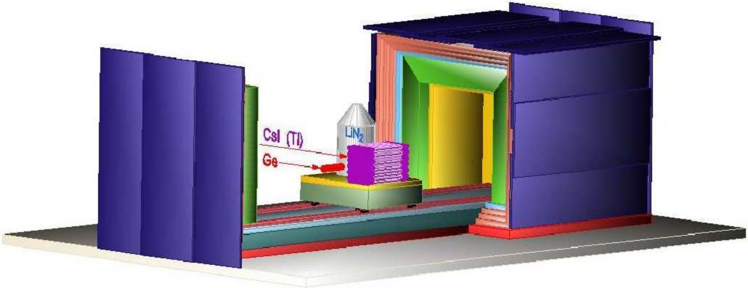
Kuo-Sheng Power Plant

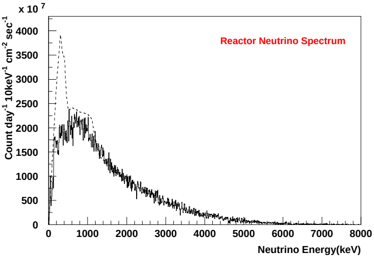
Kuo-Sheng Nuclear Power Station : Reactor Building

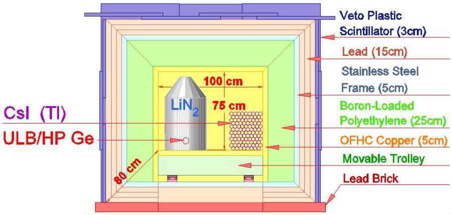


- $\phi_{\nu} = 6.4 \times 10^{12} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
- Lab : 28 m from near core,
- 30 mwe overburden.

Kuo-Sheng Neutrino Lab.



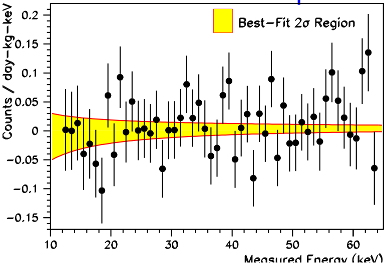


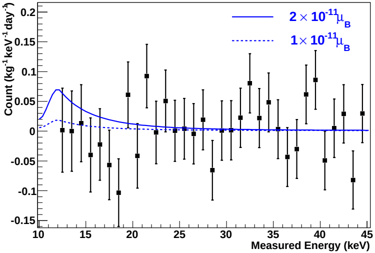


Results: 1 kg HPGe detector

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

ON-OFF residual spectrum

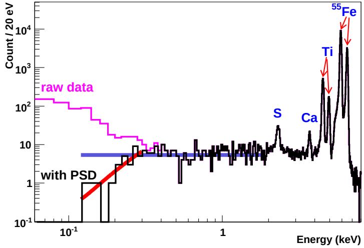


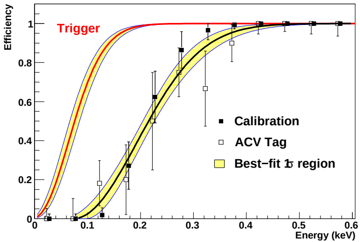


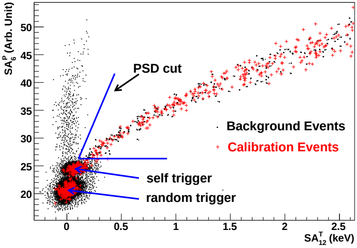
- Free Electron:
  $\mu_\nu < 7.4 \times 10^{-11} \mu_B$
  (90% C. L.)
  ref : [PRD 75 2007]

- 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 : PSD efficiencies



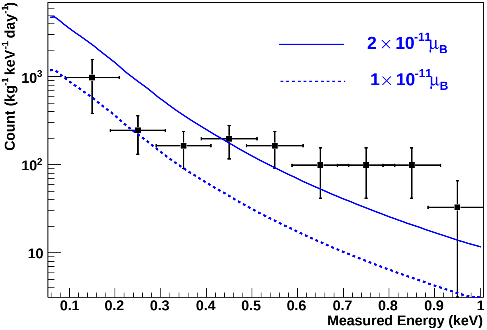




- ACV tag method & spectrum-edge fitting method consistent.
- Trigger(50% eff.) ~ 100 eV.
- PSD(50% eff.) ~ 220 eV.

Results: 4×5 g ULE-Ge detector : results

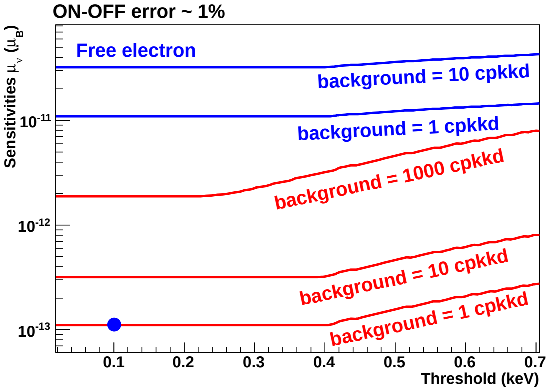
Reactor-ON data Only



- Dark Matter Search : S. T. Lin's Talk(Dark Matter)
  PRD 79, 061101(R) 2009
- Data: 0.34 kg-day, Reactot-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$\sim$100 eV, bkg$\sim$1 cpkkd, $\rightarrow$ projected sensitivity $\sim 10^{-13}\mu_B$ (●)

Prospects

- 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.
- $\sim E^2{}_\nu$ 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.
  $\rightarrow$ threshold $\sim$ 500 eV, $few \times 10^{-12} \mu_B$.

Merci.