Coherent Neutrino-Nucleus Scattering at the SONGS Reactor with PPC Germanium Detectors

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Coherent neutrino-nucleus scattering

- Standard Model process: Large enhancement in neutral current cross-section ($\sigma \propto N^2$)

- Fundamental Physics applications
  - Largest $\sigma_\nu$ in supernova dynamics, should be measured to validate models
  - A large detector can measure total $E$ and $T$ of SN $\nu_\mu, \nu_\tau \Rightarrow$ determination of $\nu$ oscillation pattern and mass of star
  - Coherent $\sigma$ is flavor independent. Possible $\nu_{\text{sterile}}$ search
  - Sensitive probe of weak nuclear charge
  - Non-standard neutrino interactions
  - $\sigma$ is critically dependent on $\mu_\nu$

- Reactor Monitoring (see Belkis’ talk)

Signature is a Sub-keV nuclear recoil for ~few MeV reactor anti-neutrinos
PPC detectors (hello again)


- improvements after ~20 year wait
  - P-Type detector with proper charge collection and less sensitivity to Low-E backgrounds
  - Modern FET technology = lower noise (160 eV FWHM Pulser)

- Energy resolution and mass of a conventional HPGe with the noise and threshold of a tiny x-ray detector.

![Image of PPC detector structure](image)

**Fig. 3.** Structure of the shaped-field detector.
Quenching Factor measurement

- Quenching factor: the fraction of the nuclear recoil energy that goes into ionization.
  - ~20% in HPGe semiconductor detectors
  - has been previously measured only indirectly or at higher energies.
  - with PPC: measured QF for low energy nuclear recoils using 24 keV neutron beam we developed at KSU TRIGA research reactor
SONGS deployment

CoGeNT 330 m.w.e. (internal contamination)
CDMS 2100 m.w.e. (arXiv:0902.4693)
CoGeNT @ SONGS 30 m.w.e.

counts keV$^{-1}$ kg$^{-1}$ d$^{-1}$

energy (keV)

“Tendons” 30 mwe
San Onofre core ~20 m that way

20cm Pb Bricks
25 meters
25 meters

HDPE Lumber
Muon Veto
Ge Detector Inside AC Veto

LN2 generation
Status of coherent neutrino-nucleus scattering measurement

12.5 kg-days of low background and low threshold data

$^{68, 71}$Ge L-Shell

We are just around the corner…
Also: Neutrino Magnetic Moment

- sensitivity benefits from 1/T spectral shape
- \( \mu_\nu < 4 \times 10^{-10} \, \mu_B \) without Rx-off subtraction
- 6.5 yr projection (5 cycles) \( \mu_\nu < 6.5 \times 10^{-11} \, \mu_B \)

\[ \mu_\nu \propto \frac{1}{\sqrt{N_\nu}} \left( \frac{B}{M t} \right)^{1/4} \]

plot credit: TEXONO collaboration
(and) Neutrino Magnetic Moment: Atomic Ionization enhancement

- Enhancement when $T \sim E_b$ for bound electrons
- $\mu_\nu < 9.1 \times 10^{-12} \mu_B$ without Rx-off subtraction
- 6.5 yr projection (5 cycles) $\mu_\nu < 1.4 \times 10^{-12} \mu_B$ projected

\[
\left( \frac{d\sigma}{dT} \right)_{AI} \simeq \mu_\nu^2 \frac{\alpha_{em}}{\pi} \left( \frac{E_\nu}{m_e} \right)^2 \frac{1}{T} \sigma_{\gamma A}(E_\gamma = T)
\]

The team:

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UW: Hamish Robertson, Tim Van Wechel, Mike Marino, Mike Miller
UNC: John Wilkerson

(+ much help from MAJORANA collaborators)

and those that I may have forgotten
Neutron Backgrounds at SONGS (30 m.w.e.)

Cosmic secondary neutrons

Muon induced neutrons (shielding)
Sub-keV recoil calibrations at the KSU TRIGA reactor

![Graph showing cross-section vs. neutron energy](image1)

- 24 keV n's mimic reactor ν's
- Fe-Al filter + Ti post-filter

![Graph showing recoils vs. recoil energy](image2)

- MCNP4b simulation
  - 2.6E4 n/(cm² s MW) under 24 keV peak (98.9% beam purity)
  - 80 n/(cm² s MW) off beam
  - 1.2E3 γ/(cm² s MW) on beam (<E> = 2.2 MeV)
  - 10 γ/(cm² s MW) off beam (<E> = 1.5 MeV)
Sub-keV recoil calibrations at the KSU TRIGA reactor

Ti post-filter “switches off” the recoils, leaving all backgrounds unaffected

Beam characterization studies completed 2005
(nucl-ex/0701011)
Cosmogenic backgrounds

$^{71}\text{Ge}$ production from $n\alpha$ capture
1.48 ± 4.71 cpd (K-shell) in equilibrium

$^{71}\text{Ge}$ $t_{1/2} = 10.9 \pm 0.8$ days

$^{68}\text{Ge}$ (K-shell)

~38.3±1.2 cpd

$^{100}\text{Mo}$ (10.56 keV)

$^{65}\text{Zn}$ 8.08 keV
$^{31}\text{P}$ 1.29 keV

$^{59}\text{Fe}$ 11.10 keV

$^{99m}\text{Tc}$ 144 keV

$^{51}\text{Cr}$ 5.48 keV
$^{64}\text{Cu}$ 9.67 keV

$^{60}\text{Co}$ 1.26 keV
$^{62}\text{Zn}$ 8.48 keV

Ga L-Shell

V K-Shell

Ga K-Shell

Ge K-Shell

10.36 keV peak

1.29 keV peak

2.5-7.5 keV

20-80 keV

counts keV⁻¹ kg⁻¹ d⁻¹

rate in plateau 3-4% of 10.3 keV peak also decaying with $t_{1/2} = 11.4$ d

$^{71}\text{Ge}$ $n\alpha$ activation
Ga K-Shell (10.36 keV)