A one-page tutorial on coherent $\nu$-N scattering

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(low-E recoils lose only 10-20% to ionization or scintillation)
- Cryogenic bolometers and other methods proposed, no successful implementation yet

- **Fundamental physics:**
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Smallish detectors... "$\nu$ technology"?

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2005: Geoneutrinos detected.
Dawn of the applied neutrino physics era?
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Nieto et al., Nuclear Science and Engineering: 149 (2005)
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- Geological prospection, planetary tomography... the list gets much wilder.
Three legged stool needed: mass, threshold, background

No “light-bulb” moment: 5 years of R&D at UC

name-of-the-game: detection of \( < 1 \) keV recoils with large (> 1 kg) detectors

(25 y and counting... must use new technologies or at least alterations)

Mass-produced 3M-UoC GEM and single-electron signals from quadruple GEM

Single-photon pulses using LN\(_2\) cooled LAAPDs (high QE)
Start with the foundations: ultra low-energy recoil calibrations at KSU reactor.
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Ti post-filter “switches off” the recoils, leaving all backgrounds unaffected

Beam characterization studies completed 2005 (submitted to Phys. Rev. C)

Ideal to explore sub-keV recoil region
Modified-electrode p-type HPGe:
A new tool in astroparticle & neutrino physics

1989 state-of-the-art in large HPGe noise:
300 eV FWHM (even with modified electrode)

The idea: we have gone a long ways in JFET technology

2005: (factor x10 improvement in JFET $C_F$ and $V_n$)
$\sim$50 eV FWHM (same as $C_D \sim 1$ pF x-ray detectors)

Developed for “Cosmion” searches.

Now a p-type (much enhanced E resolution, less sensitivity to low-E backgrounds)

Fig. 3. Structure of the shaped-field detector.

1985 (T1 2N4416) $C_F = 4.2$ pF, $V_n = 2$ nV/\sqrt{Hz}
2005 (EurifET ER105) $C_F = 0.9$ pF, $V_n = 1.6$ nV/\sqrt{Hz}
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~50 eV FWHM (same as $C_D$ ~1 pF x-ray detectors)

$\text{FWHM}_{Ge} = 40.7 \text{ eV} \cdot V_n (C_F + C_D) / \sqrt{\Delta t}$

~1985 (TI 2N4416)
$C_F = 4.2 \text{ pF}, V_n = 2 \text{nV/√Hz}$

2005 (EuroFET ER105)
$C_F = 0.9 \text{ pF}, V_n = 1.6 \text{nV/√Hz}$

The energy resolution and large mass of a HPGe plus the noise and threshold of a tiny x-ray detector???
A new tool in astroparticle & neutrino physics

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Capacitance and noise drop with size of electrode
Now a p-type (much enhanced E resolution, less sensitivity to low-E backgrounds)

~x10 less noise than conventional HPGe of same mass (475 g)
(threshold equivalent to 5 g x-ray detector)

Fig. 3. Structure of the shaped-field detector.
Delivered-To: collar@cfcp.uchicago.edu
Subject: Re: update?
From: otensch@canberra.com
To: "Juan I. Collar" <collar@uchicago.edu>
Date: Sat, 3 Dec 2005 16:41:10 -0500
X-Uchicago-Spam: Gauge=XXI, Probability=21%

Hello Juan,
We just got the first results in and they seem to be outstanding. The pulse resolution is about 160eV(FWHM) and Co-60 is well under 2.0 KV(FWHM). The detector should be shipping from France soon- in time for Christmas. It is too late now to change hardware but this might be done in future.

Best regards, Orren

Developed during 2005 by CANBERRA/EURYSYS (the one of three contacted companies up to the challenge) Funded by NNSA.
Mass and threshold in place for reactor experiment, background... almost there (anti-Compton shield & Al part replacement underway)

Expected antineutrino signal in reactor experiment with present detector. Background goal shown (scaled down from present status)

Presently 2.5 $\nu$ recoils/kg-day expected

Work on non-white noise can increase this to >30 $\nu$ recoils/kg-day (limited beyond that by state-of-the-art in JFET noise only)

Silver lining: all of the signal concentrated in small ROI
Extensive detector characterization early 2006
(submitted to Phys. Rev. C)

Series: as expected (low $C_D$ & $C_{JFET}$)
Parallel: low leakage current
Non-white: presently dominant, lossy dielectrics or mount in JFET?

Simulation of beta and gamma backgrounds

PSD of (scarce) microphonics

Shielding studies at 6 m.w.e.
(comparable to reactor site)
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This is the state-of-the-art for 1 pF detectors!
(Pentafet)
We can do better!

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Simulation of beta and gamma backgrounds

Bckg goal seems reachable

PSD of (scarce) microphonics

Shielding studies at 6 m.w.e.
(comparable to reactor site)
Some recent news: looking very good…

First KSU data: excellent agreement with simulations (rate & energy) and Lindhard’s theory (quenching factor)

KSU 24 keV beam MCNP simulations of 475g ULNHPGe (4π scattering)

Total Recoils: 11,900 c/s/MW
Recoils >600 eV: 8,600 c/s/MW
Recoils >800 eV: 7,200 c/s/MW
Recoils >1000 eV: 5,850 c/s/MW

Single Scatter endpoint ~ 1.4 keV
Multiple Scatter endpoint ~ 5 keV

another datapoint at 0.7 keV (analysis ongoing)
Some recent news: looking very good...

Relevant ROI for power reactor experiment has been explored

Mass $\sqrt{\phantom{x}}$

Threshold $\sqrt{\phantom{x}}$

Background... (on it)

J.I. Collar JMPRPPC, Oct. 06
Some recent news: looking very good...

Definitive check on DAMA soon
X50 improvement from clean Al, x10 from anti-Compton

First Physics Results expected Fall 06:
These light WIMPs remain compatible with DAMA & all other searches (accelerator bounds are model-dependent)

Next: replacement with <0.2 ppb U cryostat, develop low-bckg version of anti-Compton shield... and deploy to power reactor.

Nothing radioclean yet (need cash! 😞)
What else can you do with such a detector?

Solar-bound WIMPs: deposit ~$100$ less $E_{\text{rec}}$ than galaxy-bound, concentrate all rate in narrow spectral region (higher s/n) Sub-keV threshold a must

The neutralino is not the only supersymmetric Dark Matter candidate. Non-pointlike DM (Q-balls, Mirror matter, etc.) call for ultra-low threshold detectors

Improved sensitivity to $\nu$ magnetic moment (reactor experiment)
MAJORANA: can we avoid segmentation altogether? (cost, speed, simplicity, much lower front-end backgrounds)
Does this device have anything to offer in a $\beta\beta$ context?

Optimal E-resolution allows one to think $\beta\beta$ ...

Compare resolution with n-type 1989
(now same as coax HPGe of same mass, 1.8KeV FWHM)

Also x20 improvement in charge collection in going to p-type
How does a multiple-site interaction look in a modified-electrode HPGe?

ββ signal is single-site
Many backgrounds are multiple-site
That was then...

TOP: preamp trace
BOTTOM: 10ns int.+ diff. TFA
(follows charge arrival)

Limited ability to distinguish singles from multiples
(one bump or two?)
This is now.

Different hits get clearly stretched in time.

All this with optimal energy resolution and charge collection (and one channel)
What is happening?

standard coaxial HPGe

P-type modified electrode

radial degeneracy in multiple depositions is broken

capacitance (and noise) drops with size of p+ electrode

gradient of impurities (provides axial drift)

241Am collimated 59.5 keV gammas

amplitude of averaged preamplifier traces (a.u.)

d = 7 mm

d = 13 mm

d = 19 mm

d = 25 mm

d = 31 mm

d = 37 mm

d = 43 mm

J.I. Collar JMPRPIc, Oct. 06
Better signal acceptance / background rejection than an 8-segment clover HPGe (even before close packing!) all with a single-channel device.
Advantages of single channel p-type modified electrode vis-à-vis segmentation for MAJORANA:

- Very efficient PSA rejection of multiples. All with one channel.
- Excellent energy resolution (1.8 keV Co-60, may drop some as noise is further improved)
- Increase speed of deployment/manufacture as long as... (is gradient of impurities reproducible? How important?)
- Increase simplicity of construction and analysis (one channel)
- Decrease cost (detectors and DAQ). Improve production time (cosmogenics)
- Decrease front end-associated radioactive backgrounds, thermal load, photon path.
- Increase stability (prototype performance stable for >5 continuous mo. and counting)
- Intrinsic to p-type: ruggedness (a must when arraying) and decreased sensitivity to surface contaminations.
- Several others (e.g., rejection of ALL alphas via PIXE -studies underway-)
- CANBERRA and PHDs Co. receptive to further fabrication (and further work on noise reduction).
Disadvantages:

- Technology too new: too many unknowns in reproducibility, cost, speed of production, largest crystal size that can be produced, waste (important for \( \beta\beta \)), etc.

- Canberra’s position: We need to build 6-10 more to know (they admit “lucking out”. Hopefully this will not change).

Solution:

- This fits perfectly with planned coherent \( \nu \) program. Recent NSF/DOE proposal centered around this theme <= Help from rest of MAJORANA collaboration to maximize synergy: PNNL already funded to build more of these, ORNL seeking funding.

- Several kg of modified-electrode p-type HPGe’s built by 2007!

- GOAL: Be by early next year counting at the Columbia Generating Station (Richland, WA, 12 mi. from PNNL) and simultaneously further developing the technique (i.e., building more of these). San Onofre? (offers more depth)
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Reactor Monitoring: Right technological timing

(HPGe technology flourishing:
segmentation, encapsulation, arrays and (silent) mechanical cooling)
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(HPGe technology flourishing:
segmentation, encapsulation, arrays and (silent) mechanical cooling)

New generation of recondensing Dewars add no microphonic noise and need topping (not refilling) every ~ 1yr (can be filled from N2 gas cylinder!)
Ideal for reactor deployment.

J.I. Collar JMPRPPC, Oct. 06
11 kg, encapsulated, single cold finger (CANBERRA)

With 100 eV threshold, the equivalent of ~1 ton liquid scintillator (plus an additional ~x10 in rate beyond!)

A reality fast approaching?

SANDS Sees Reactor Turn-on in Detail
(Antineutrino Rate, Running Average)

CLUSTER array for EUROBALL
(7 encapsulated HPGe detectors)

Hexagonal tapering - diam.: 70 mm - height: 78 mm
FWHM resolution: ≤ 2.3 keV
Efficiency: ≥ 55%
Alu wall thickness: 0.7 mm
Cap-to-Ge distance: 0.7 mm.

J.I. Collar JMPRPPC, Oct. 06
Coherent neutrino detection:

I want to believe!