Beta Cage

A Screener of Ultra-Low-Level Radioactive Surface Contamination

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In collaboration with
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(and with work from others who have moved on)
Original Motivation: CDMS

• CDMS experiment limited by beta contaminants (especially $^{210}\text{Pb}$ from radon) on surface or in thin films of detectors
  ♦ Projected 150 kg SuperCDMS experiment could be background free if beta contamination kept < 6 m$^{-2}$ day$^{-1}$ in WIMP energy region

![Diagram of W trap, Bias rail, W TES, and Trilayers for Phonon sensors and Ionization grid.]

- Trilayer for Phonon sensors:
  - 35 nm of W
  - 300 nm of Al
  - 40 nm of amorphous Si

- Si or Ge substrate (1 cm thick NOT TO SCALE)

- Trilayer for Ionization grid:
  - 40 nm of amorphous Si
  - 20 nm of Al
  - 20 nm of W
Additional Motivation

- **EDELWEISS** similarly sensitive to beta contamination on surfaces
- **Alphas on surfaces**
  - Generic problem for experiments with liquid targets (DEAP/CLEAN, WARP,...)
  - Dominant background is recoiling nuclei from alpha emission (especially $^{210}$Po from radon) on surface
  - Same source reduces livetime in COUPP

- **Carbon or tritium dating, etc.**
Need for Alpha/Beta Screening Facility

- Better sensitivity to some $\alpha$-emitting or $\beta$-emitting isotopes than Ge $\gamma$ detectors or other techniques such as ICP-MS
- Some beta-emitting isotopes can be probed only by their beta or alpha emission

<table>
<thead>
<tr>
<th>Method</th>
<th>Detectable Long-lived Beta-emitting Isotopes</th>
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</thead>
<tbody>
<tr>
<td>ICP-MS (1 ppb)</td>
<td>$^{40}\text{K} \quad ^{48}\text{Ca} \quad ^{50}\text{V} \quad ^{87}\text{Rb} \quad ^{92}\text{Nb} \quad ^{98}\text{Tc} \quad ^{113}\text{Cd} \quad ^{115}\text{In} \quad ^{123}\text{Te}$  \n</td>
</tr>
<tr>
<td>ICP-MS (1 ppt)</td>
<td>$^{10}\text{Be} \quad ^{36}\text{Cl} \quad ^{60}\text{Fe} \quad ^{79}\text{Se} \quad ^{93}\text{Zr} \quad ^{94}\text{Nb} \quad ^{97}\text{Tc} \quad ^{99}\text{Tc} \quad ^{107}\text{Pd} \quad ^{126}\text{Sn}$  \n</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$^{40}\text{K} \quad ^{50}\text{V} \quad ^{60}\text{Fe} \quad ^{60}\text{Co} \quad ^{93}\text{Zr} \quad ^{92}\text{Nb} \quad ^{94}\text{Nb} \quad ^{93}\text{Mo} \quad ^{98}\text{Tc} \quad ^{99}\text{Tc} \quad ^{101}\text{Rh} \quad ^{101m}\text{Rh}$  \n</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>$^{210}\text{Pb} \quad ^{208}\text{Po} \quad ^{209}\text{Po} \quad ^{228}\text{Ra} \quad ^{227}\text{Ac} \quad ^{232}\text{Th}$  \n</td>
</tr>
<tr>
<td>$\beta$ only</td>
<td>$^{3}\text{H} \quad ^{14}\text{C} \quad ^{32}\text{Si} \quad ^{63}\text{Ni} \quad ^{90}\text{Sr} \quad ^{106}\text{Ru} \quad ^{113m}\text{Cd} \quad ^{147}\text{Pm} \quad ^{151}\text{Sm} \quad ^{171}\text{Tm} \quad ^{194}\text{Os}$  \n</td>
</tr>
</tbody>
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H. Nelson, UCSB
Basic Design Principles

• Deploy sample in detector (don’t use window)
• Backgrounds are proportional to mass of detector
  ◆ Ultraclean materials to minimize internal contamination
  ◆ Underground, shielded apparatus to minimize external backgrounds
• Deploy minimum material needed to stop $\beta$s.
  ◆ Gas is best method to achieve this low mass
  ◆ 150 keV $e^-$ $\approx$ 30 cm Ne (1 atm)
  ◆ Can identify betas with <200 keV endpoint with 40 cm height
  ◆ Could Use Xe (1 atm) for higher-energy betas (range $\sim$7x less)
  ◆ 10 MeV alpha range is only 20 cm in Ne
• Maximize counting statistics
  ◆ Large surface area (horizontal dimension) $\sim$1 m$^2$
• Guard region to reject events emitted from outside chamber
• Expect $\sim$100x more sensitive than existing instruments
BetaCage

• Multiwire proportional counter
• Wires provide minimum surface area for emissions
  – 25 μm Ø, 1/2 cm spacing - 0.5% coverage
• Crossed grids could yield ~mm xy position information
  – Identify source position of contamination
• Reject background interactions in bulk of gas by creating narrow (5 mm) “trigger region” near samples
  - Most gamma interactions in gas don’t cause trigger
  - Reduces backgrounds in gas to 15% of unrejectable total due to gamma interactions in sample that eject electrons into trigger region (these look exactly like beta emission)
Results of Monte Carlo Simulation

- Reject most gamma interactions in gas

Survey Substrates

40 cm

5 mm

L. DeViveiros & R. Gaitskell, Brown U.
Backgrounds

• Dominated by external gammas (3 x 10^{-5} \text{ keV}^{-1} \text{ cm}^{-2} \text{ day}^{-1})
  - Backgrounds of 1 event/ (kg keV day) straightforward with simple lead shield (including ultraclean copper or ancient lead liner)
  - 10x improvement possible with better shield (e.g. clean water)

• Other:
  - $^{14}\text{C}$ in quench gas (5 x 10^{-6} \text{ keV}^{-1} \text{ cm}^{-2} \text{ day}^{-1})
    - 5% methane, 10^{-16} \text{ g/g } ^{14}\text{C}/^{12}\text{C}
    - Evaluating impact & alternatives (pure gas), may ultimately limit
  - Wires
    - Bulk: negligible (10^{-13} \text{ keV}^{-1} \text{ cm}^{-2} \text{ day}^{-1})
    - Surface: at 25 \text{ µm} \Ø, 0.5 \text{ cm} spacing -> 200x smaller than sample
      — May have to clean wires (expect 10^{-8} \text{ keV}^{-1} \text{ cm}^{-2} \text{ day}^{-1})
  - Additional Construction: Plastics / Cu (negligible gammas), minimize number of resistors inside chamber (10^{-6} \text{ keV}^{-1} \text{ cm}^{-2} \text{ day}^{-1})
    - Don’t need vacuum chamber for neon gas since it can be vented (rather than recovered) after counting
Sensitivity (with background subtraction)

- Sensitivity (with background subtraction) in counts per keV day cm^-2.
- Worst-case scenario indicated.
- SuperCDMS 150 kg projected requirement for zero-background.
- Current aim:
  - Easy scenario.
  - Eventually (e.g. large water shield).

Graph showing 3 sigma limit vs. linear dimension of sample (cm) for different Ge dru equivalents.
Sensitivity (with background subtraction)

30 days counting, 200 keV bin, trigger depth = 0.5 cm, gas $A = 2$

\begin{align*}
3 \sigma \text{ limit (counts keV}^{-1} \text{ cm}^{-2} \text{ day}^{-1})
\end{align*}

- Ge dru equivalent = 0.1 cnts/kg/keV/day
- Ge dru equivalent = 1 cnts/kg/keV/day
- Ge dru equivalent = 10 cnts/kg/keV/day

SuperCDMS 150 kg projected requirement for zero-background easy

Eventually (e.g. large water shield) current aim

Linear dimension of sample (cm)
Sensitivity (with background subtraction)

3 days counting, 200 keV bin, trigger depth = 0.5 cm, gas A = 20

- **SuperCDMS 150 kg projected**
- **requirement for zero-background**
- **current aim**
- **Eventually** (e.g. large water shield)
- **easy**
BetaCage Prototype

- Purpose: demonstrate functionality at low cost
  - Basic MWPC construction and gas details
  - Beta identification via endpoint energy
  - Alpha identification
  - Some vetoing of gamma-induced events
- Cut costs by not being radiopure, using simplified DAQ, smaller size
  (40 cm x 40 cm x 20 cm)
  - Aluminum vacuum chamber
  - Start with P10 (argon/methane) not neon
    - Less expensive, simple gas handling
    - Also allows prototype to be half size of final instrument (since electron ranges in Ar are half that in Ne)
  - Use few channels (trigger, bulk, and veto regions
BetaCage Prototype Status

• Bulk of work done by Caltech grad student (Z. Ahmed) and Case undergrad (K. Poinar)
• Mechanical design done
• Electromagnetic simulations done
  ◆ Wiring pad system and wires in hand. Improved frames and field shapers should arrive soon.
  ◆ Test assembly this month at Caltech
• Vacuum chamber made and tested
• HV and gas handling systems done
  ◆ Operation demonstrated using Dahl/Shutt 10-cm prototype-prototype
• DAQ was done (under repair)
• Full assembly at Case Western this summer
(Funded) BetaCage Proposal

- Funded NSF/DOE DUSEL R&D proposal (to start this year)
- Switch to neon from argon, switch to all radiopure materials
  - Switch to neon requires doubling detector size, mix our own gas
  - Plastic chamber
    - Since not vacuum chamber, using Xe would be too expensive
- DAQ
  - Intending to gang together wires as non-redundant mask to reduce channel readout without sacrificing x-y position information
- Shield (1 dru) to be provided by Soudan Low-Background Counting Facility
  - Saves $55k
    - Uses ultra-low-radioactivity Cu as an alternative to ancient Pb
- Possible Upgrades
  - Improved shielding to improve sensitivity
Conclusions

• Funded BetaCage: Large, clean, shielded, underground drift chamber could be world’s most sensitive screener for all non-penetrating radiation

• Broad applications in the Hunt for Dark Matter (etc.)
  ♦ Needed for screening CDMS detectors’ thin films for beta contaminants
  ♦ Expect virtually no background for alphas
  ♦ Excellent sensitivity for carbon or tritium dating

• Prototype screener to demonstrate operation, energy reconstruction, some background rejection in 2007

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I am starting at Syracuse this fall with significant resources and opening for a post-doc