Measuring Low Energy Nuclear Recoil Ionization Yield with Thermal Neutron Capture

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5 Dec 2018

Acknowledgements: M. Fritts, A.N. Villano

Overview

- Low energy NR ionization yield in Ge and Si
  - Who needs it?
  - Current measurements
- n-capture technique
- Experiment
  - CDMS SNOLAB HV detector
  - n-capture experiment design
  - Theoretical n-capture recoil signal
- n-flux measurement with Ge activation
- HV noise in Ge detector
- Preliminary results in Si
- Future plans

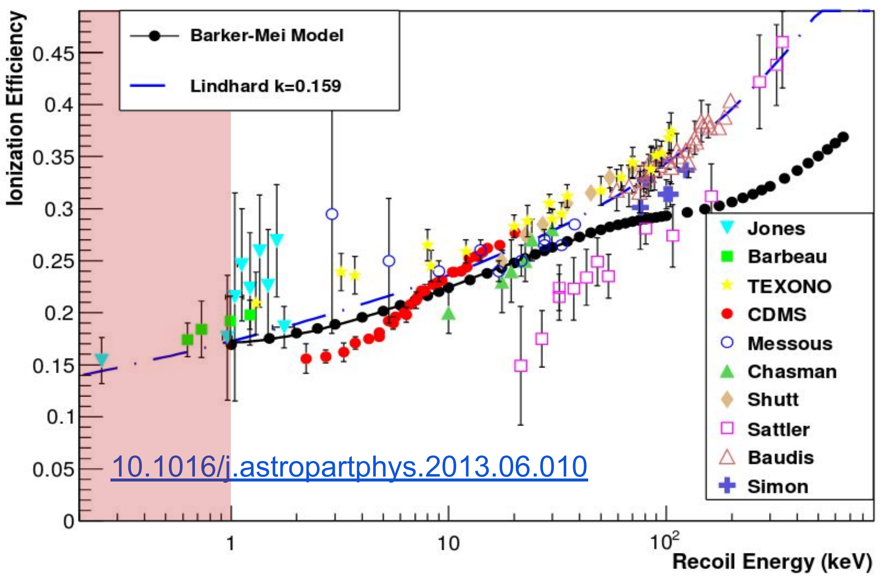
Experiments using NR in Ge/Si

Who relies on nuclear recoils (NR) in Ge/Si at E $\lesssim$ 1 keV?

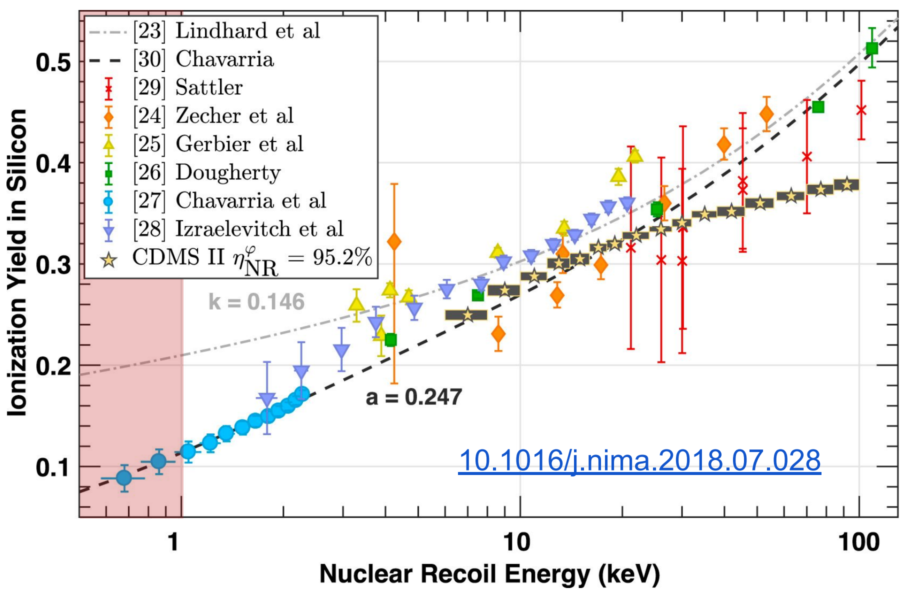
- Dark Matter (DM)
  - CDMS (Ge,Si)
  - DAMIC (Si)
  - Edelweiss (Ge)
  - CDEX (Ge)
  - ...
- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)
  - MIνER (Ge,Si)
  - CONUS (Ge)
  - CONNIe (Si)
  - TEXONO (Ge)
  - νGeN (Ge)
  - Ricochet at Chooz (Ge)
  - ...

Low Energy NR Yield

Ge

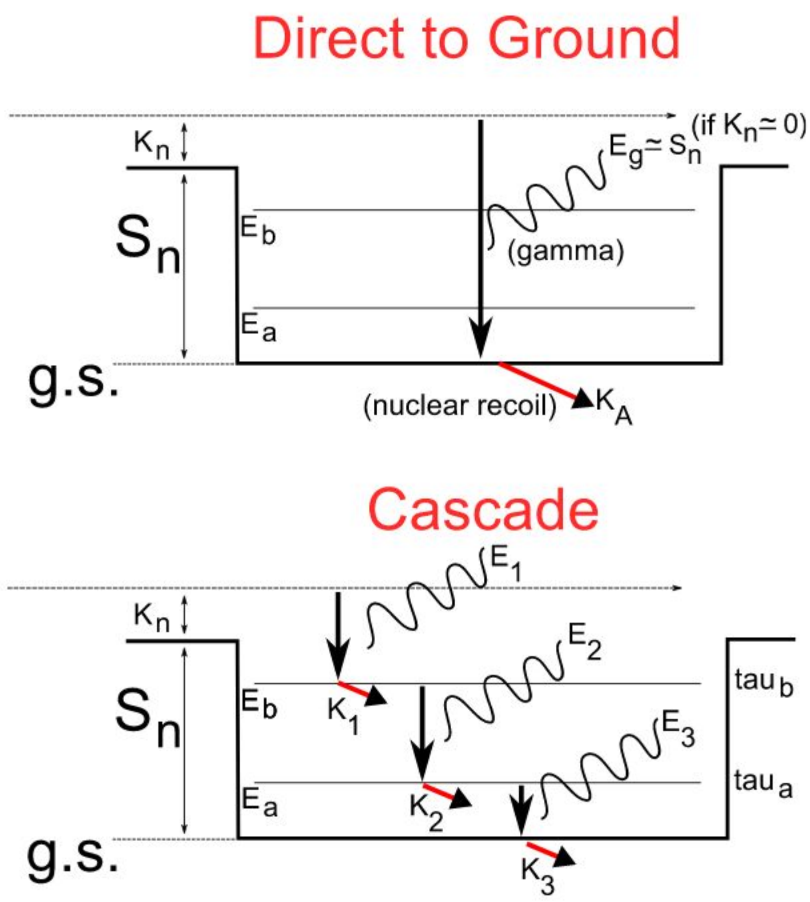


Si



- NR produces less ionization for a given recoil energy, E_R
  - Ionization Yield, $Y = N_{NR}/N_{ER}$
  - Often use 2 different energy scales: E_{ee} and E_{nr}
- NR Yield is energy- and material-dependent
- **Not well known** at low energies (<1 keV)

n,γ NR Calibration Technique



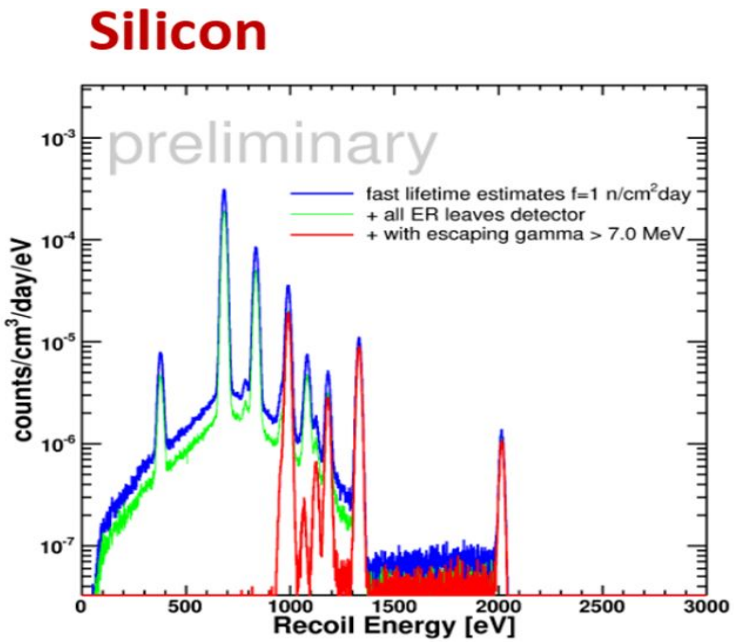
- Capture thermal neutrons on detector nuclei
- Decays result in **pure NR** (if gamma escapes)
- Cascade paths are quite complex (multiple gammas, lifetimes)

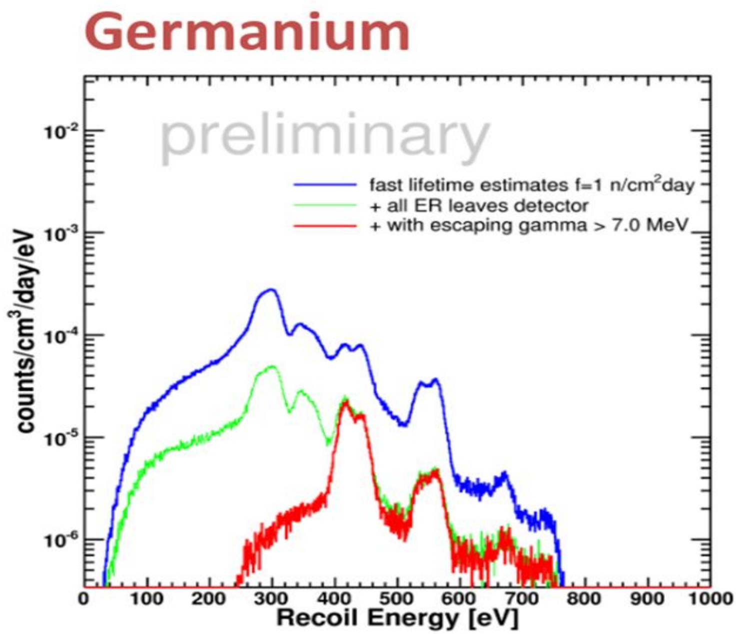
$$n + {}^{73}Ge \rightarrow {}^{74}Ge + \gamma + (\gamma + \ldots)$$

[A. Villano, Cosmic Visions 2017]

Theoretical NR Spectra

$$E_{Recoil} \simeq \frac{E_\gamma^2}{2M_N}$$



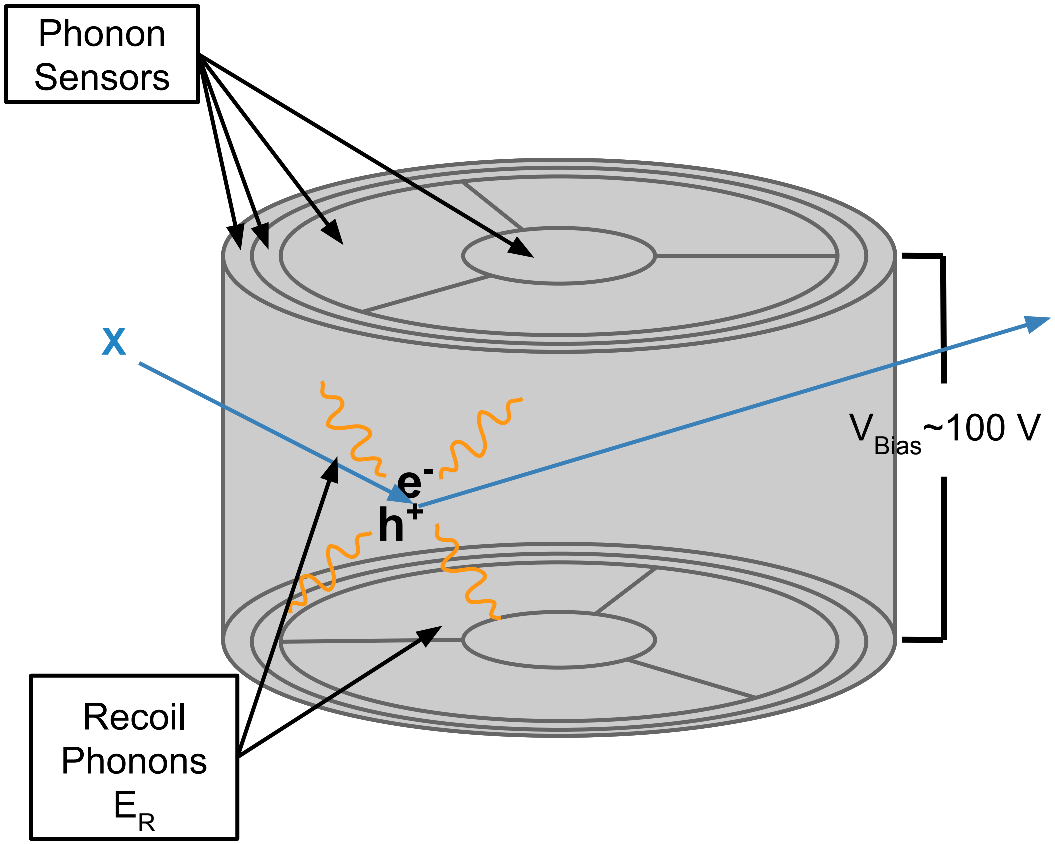


All energy scales are NR, 60 eVnr resolution applied

- Measure this spectrum in E_{ee} to get ionization yield
- Detailed structure depends on nuclear levels, lifetimes, Fano factor, detector resolution

A. Villano, Cosmic Visions 2017

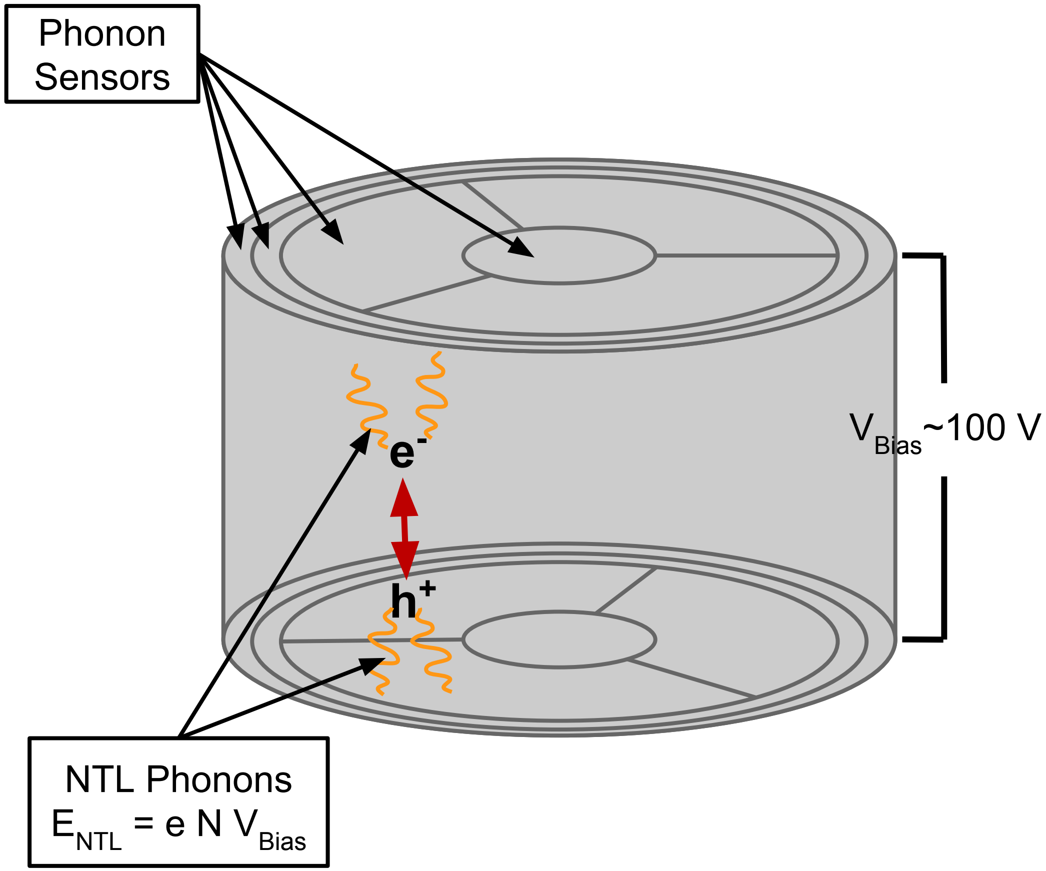
CDMS HV Detector



- Prototype Ge and Si detectors for CDMS SNOLAB
- TES-based phonon sensors
  - Operated at ~35 mK
- NTL Effect used to amplify charge signal
- Small energy resolution to see low mass DM

Measured Phonon Signal: $E_{Tot} = E_R + \ ...$

CDMS HV Detector



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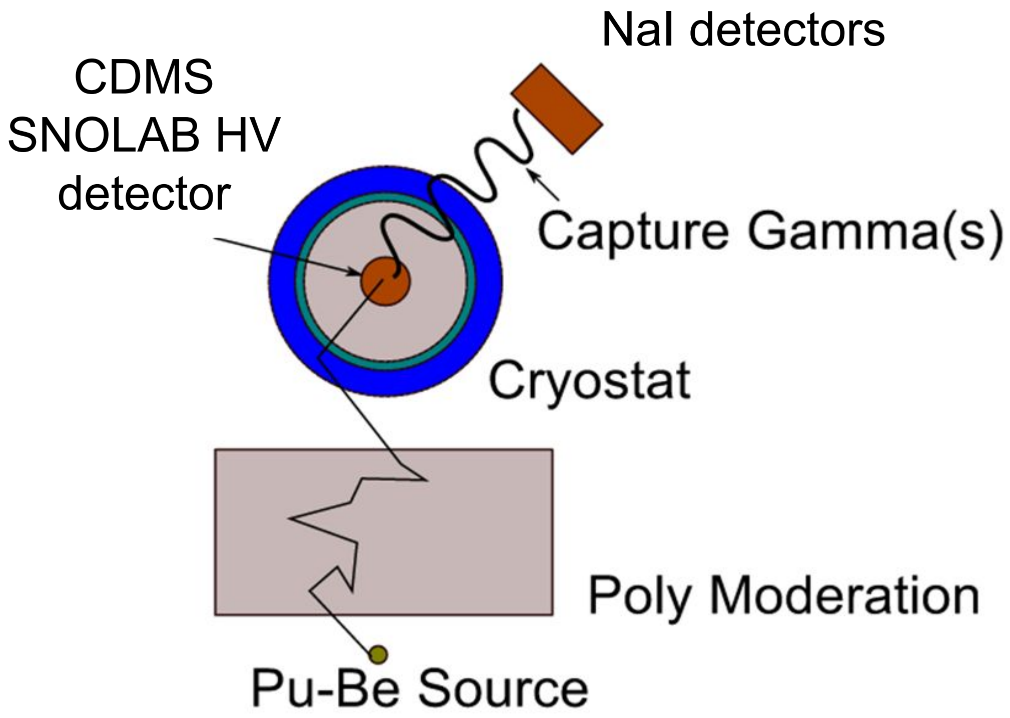
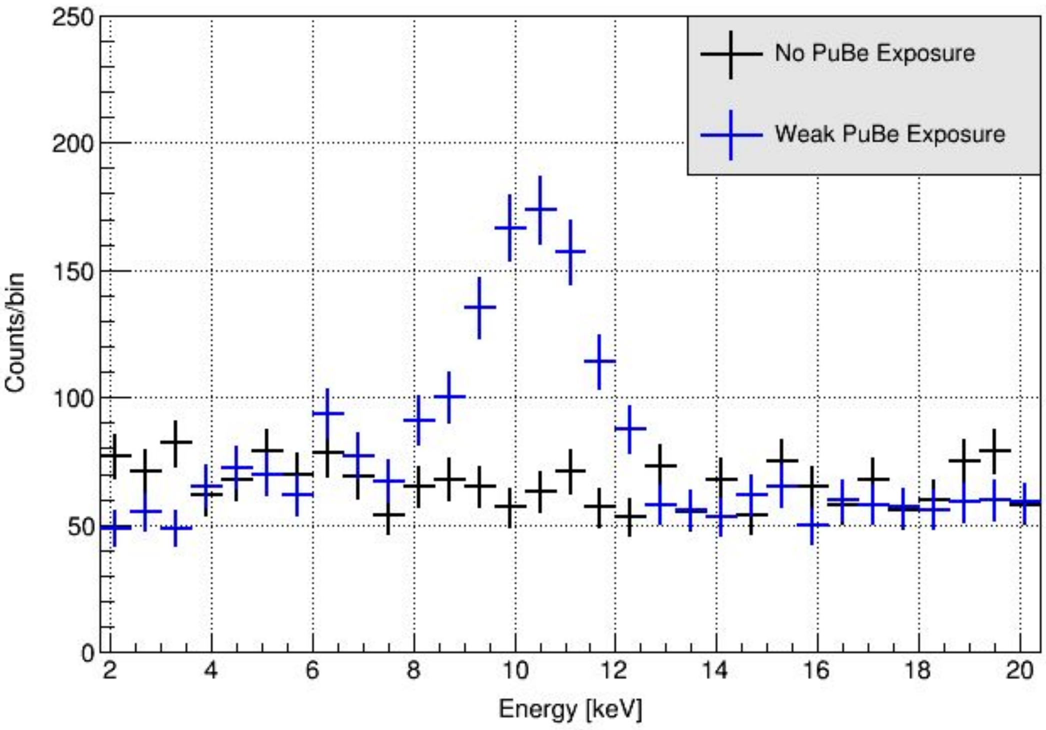
Measured Phonon Signal: $E_{Tot} = E_R + e N V_{Bias} \approx e N V_{Bias}$

Experimental Setup



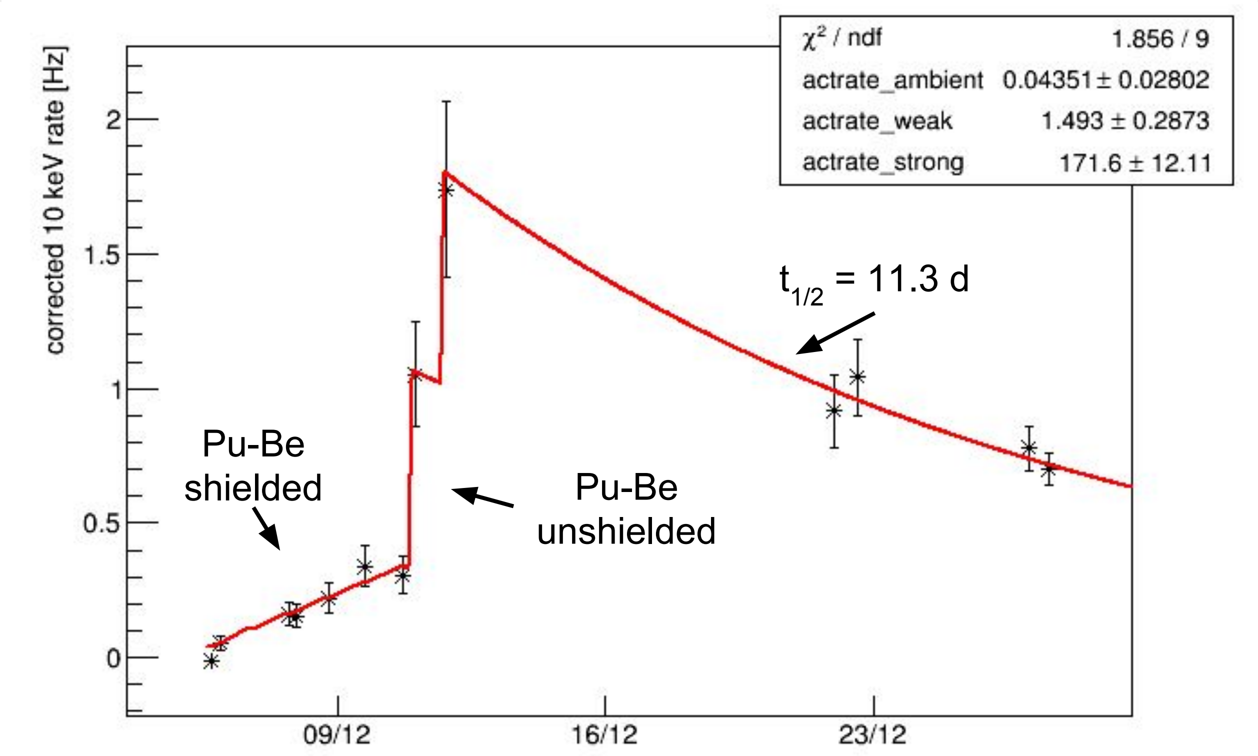
- 1Ci Pu-Be source provides ~1x10^6 n/s
- ~1 m polyethylene for neutron moderation
- 30 cm of Pb (not pictured) for source gamma attenuation
- NaI detectors for ~MeV gamma coincidence

n-flux measurement with Ge activation



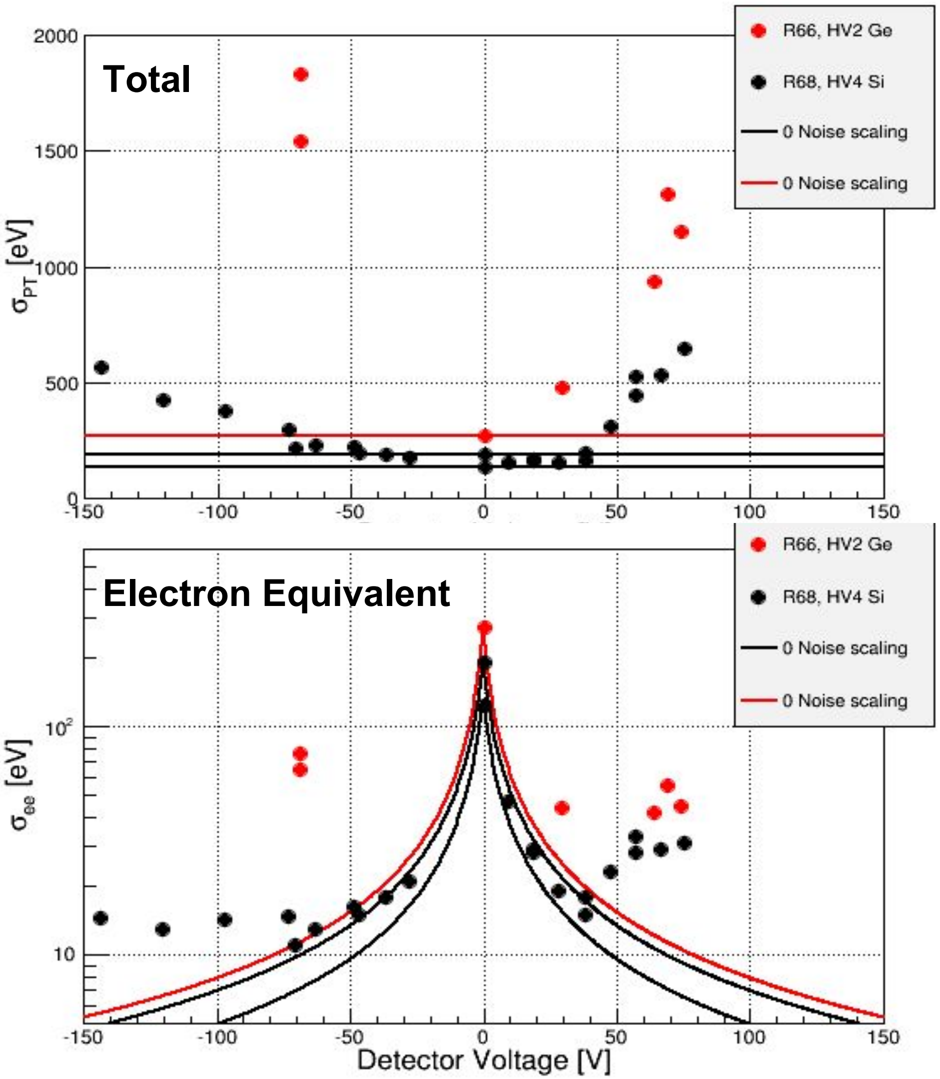
- n-capture on ^{70}Ge results in ER activation lines (10, 1, 0.1 keV_{ee})
- Activation rate depends on n capture cross section (~known), ^{71}Ge half life (known), n flux

n-flux measurement with Ge activation



- Activation rate gives n-flux (Assuming σ = 3.71 bn)
- Measured thermal n fluxes from 0.2 - 20 n/cm^2/s with different source positions
  - Optimize source configuration
  - Benchmark simulations

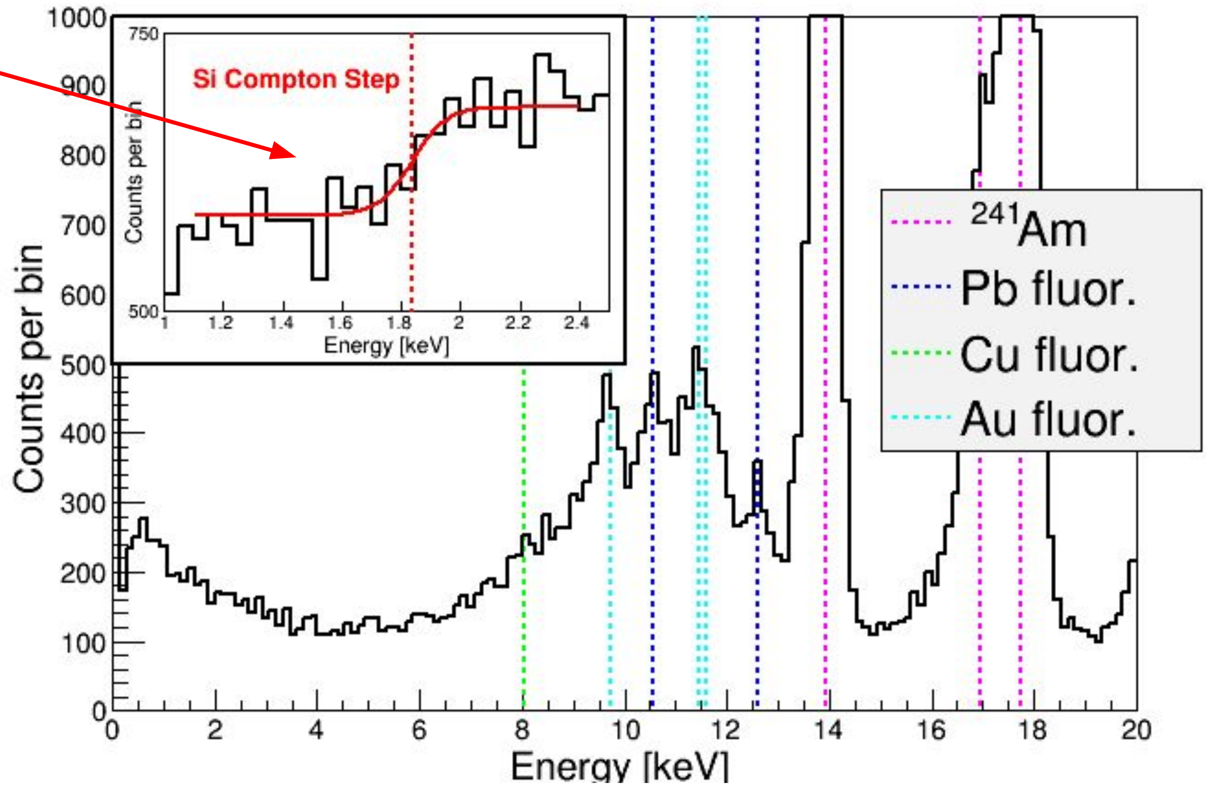
HV Noise



- Phonon signal ∝ V_{Bias}
- HV related noise limits these detectors
  - Polarity dependent
  - Bulk detrapping vs. surface leakage?
  - Being studied in single-e/h sensitive chips
  - May be improved with IR shielding, contact-free electrode
- Observed lowest noise with Si CDMS HV detector at -125 V

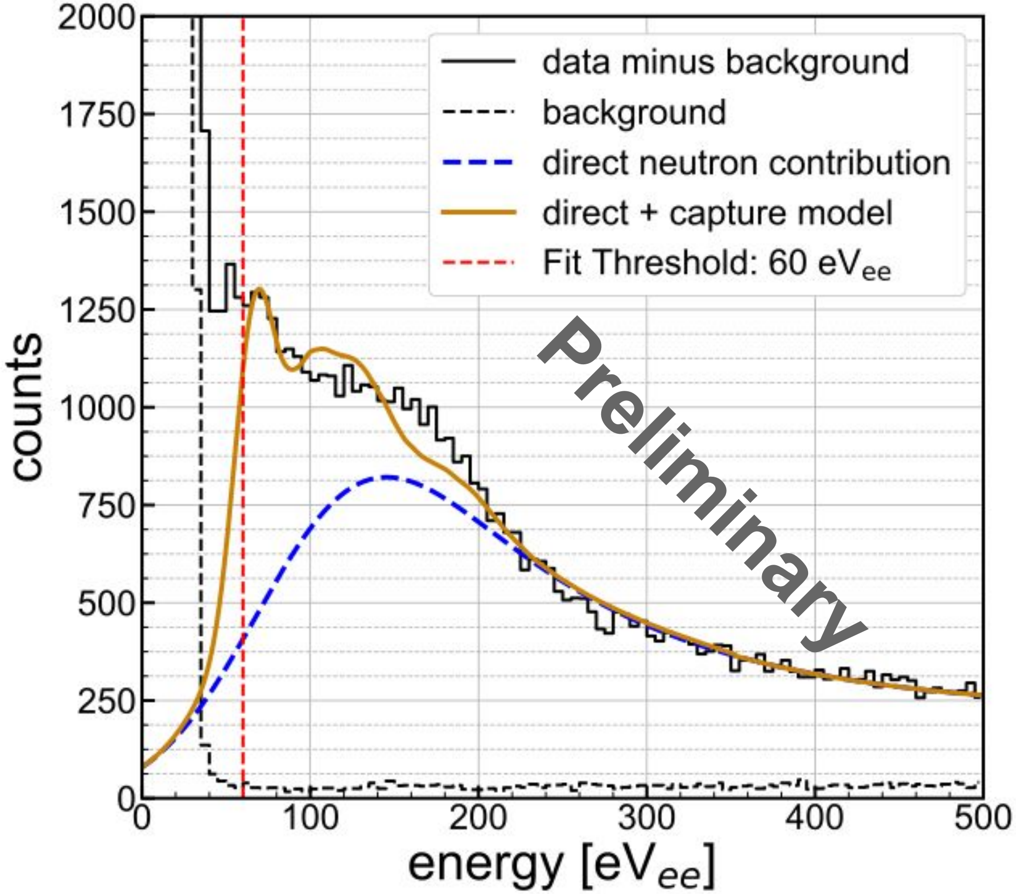
Calibration in Si

w/ ^{22}Na source



- Calibrate using ^{241}Am, fluorescence lines, Compton edge, and Compton step

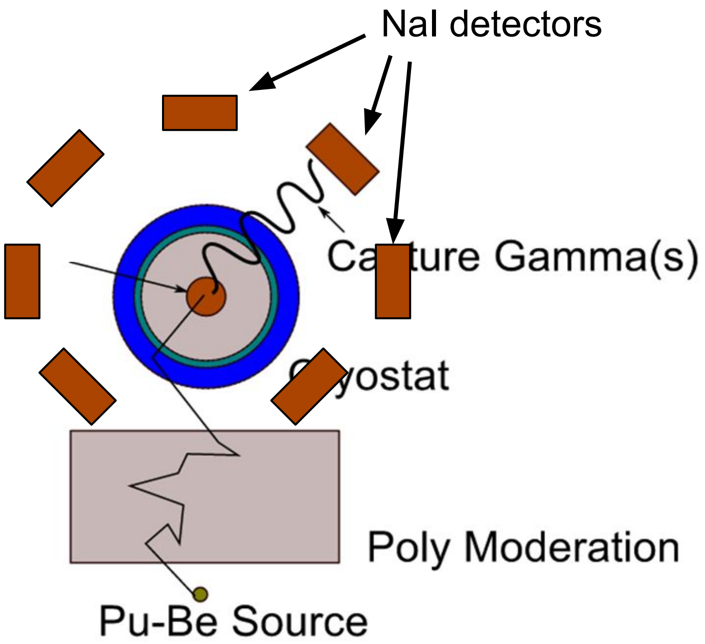
Encouraging Evidence in Si

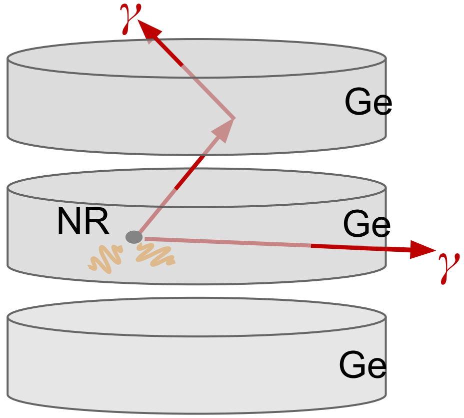


- ~100 hrs of weak Pu-Be exposure
- V_{Bias} = -125 V (×30 phonon amplification)
- Signal consistent with known estimates of NR yield and flux
- Working to understand trigger/cut efficiencies, energy calibration, other systematics

Plans for Future Measurement

- Repeat with Ge
  - Contact-free electrode
  - Improved IR shielding
- Improve coincidence tagging
  - Higher NaI coverage
  - Detector stack?



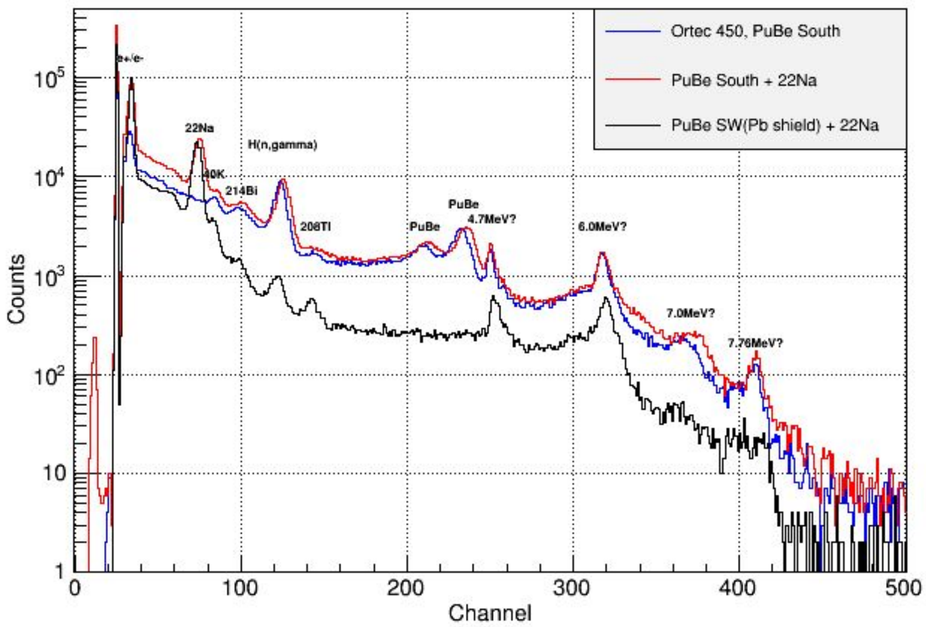


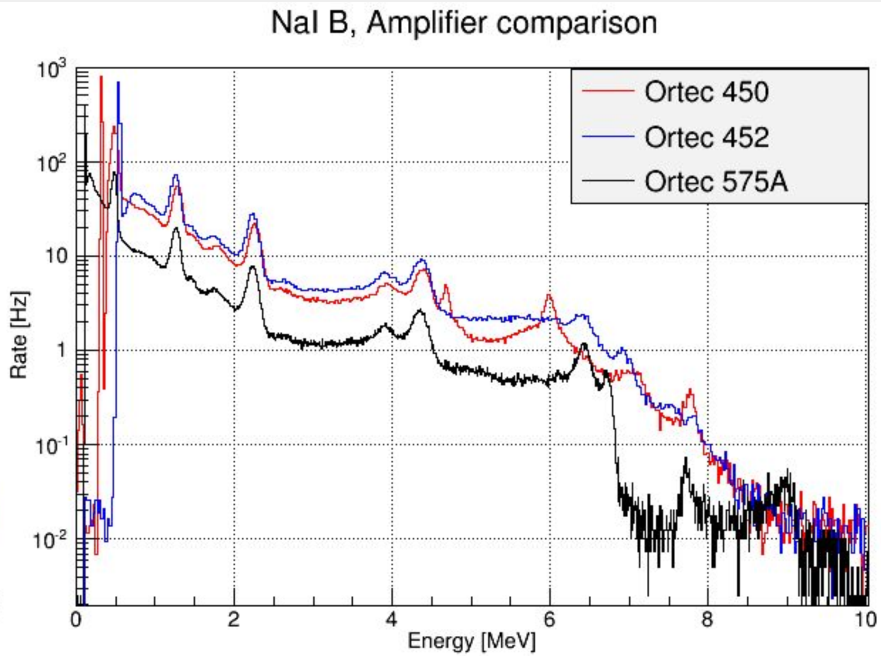
Summary

- Low energy NR ionization yield in Ge and Si needs to be understood
- Cryogenic phonon-based detectors are a good platform to make such a measurement
- n-capture technique provides rich spectral features
    - Low energy NRs
    - n-flux measurement with long lived states
- Preliminary evidence in Si
- Working toward improved measurements in Ge and Si

Backup Slides

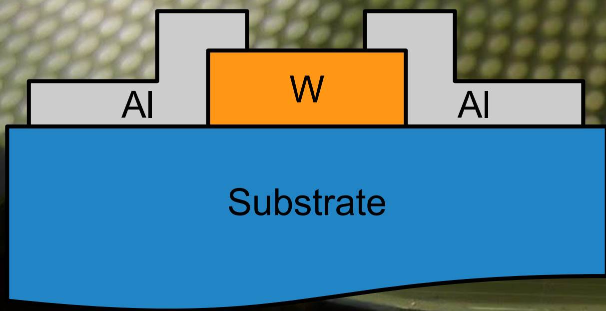
NaI detectors



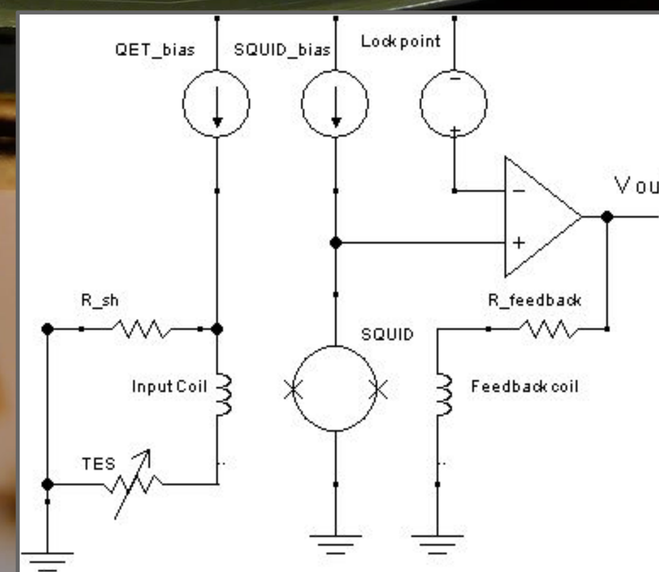


- Early results showed surprisingly little coincidence
- Spectra w/ funny amplifier resonances
- Amplifier saturation effects
- Need good ~10 MeV calibration features

Phonon Sensors



- TES current change tracks absorbed phonon power
- Measure with SQUID-based amplifier



CDMS phonon circuit

- TES in ETF mode
- Voltage biased
- $P=V^2$ / R(T) ⇒ stable at W's TC

$$c_V \frac{dT}{dt} = P_{in} - \kappa (T^n - T^n_{crystal})$$