100 eV – 400 eV Neutron Capture: Calibrations and Backgrounds

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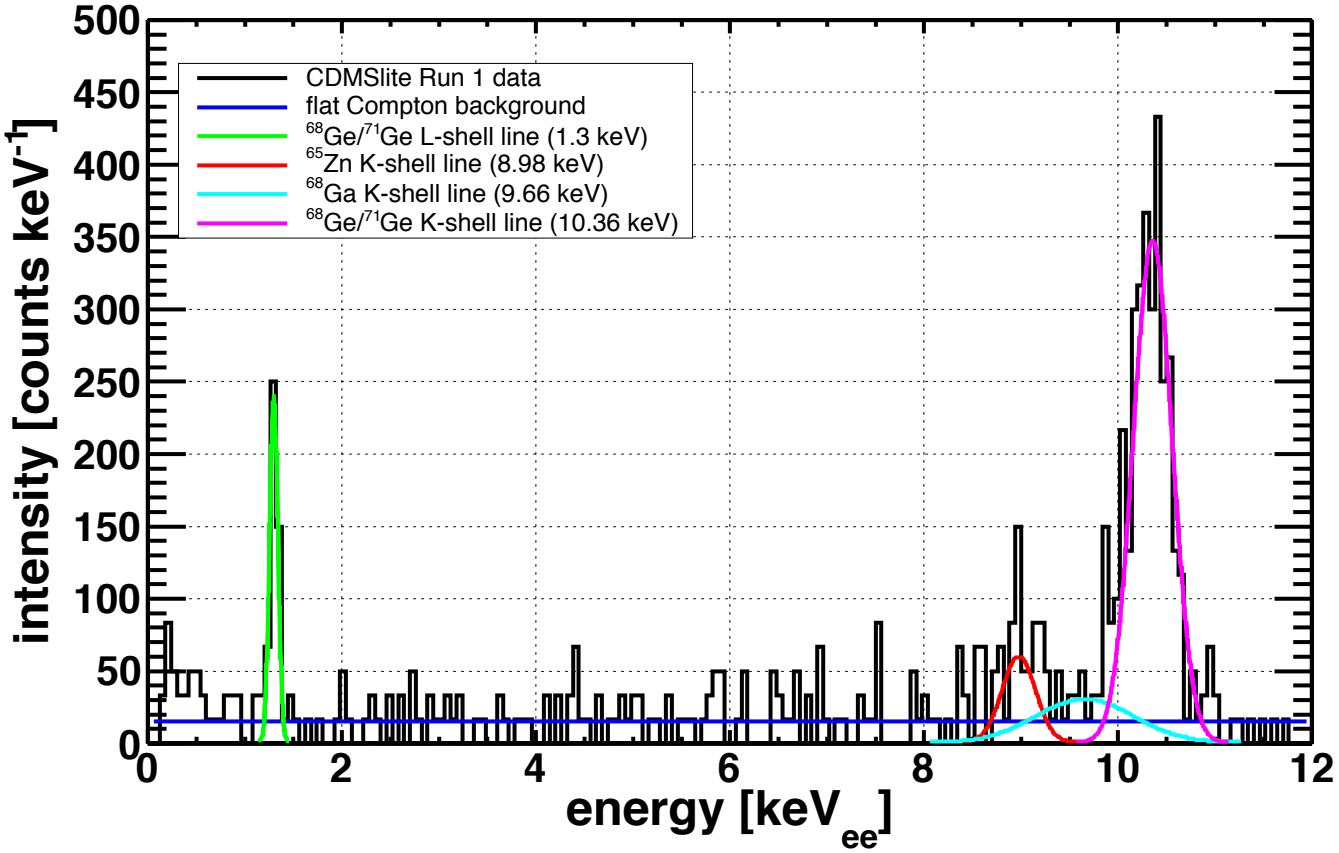
Motivation

- Many new detectors talked about, they need calibrations, this is often challenging (see next slide for germanium)
- For many searches the signal may be specifically NRs which have a hard-to-access energy calibration
- Neutron capture can provide a versatile calibration for many detector materials with prompt tags for events in the 100 eV – 400 eV energy range
- Some detectors may need to think about mitigation of background for this process

An Example: Germanium

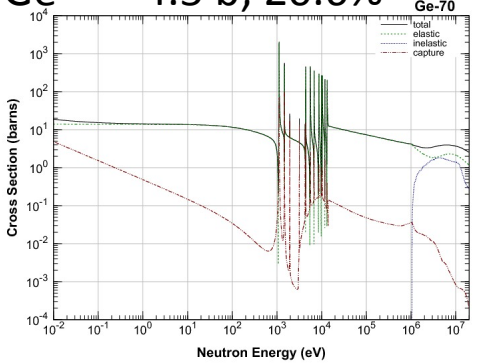


1. Have internal activation lines—seems like we're awash in energy anchors
2. → **But** for light DM we need things below 1 keVee and we would need to know NR energy scale separately if we want to use nuclear scattering
3. silicon doesn't have any natural activation lines so no clear energy standards

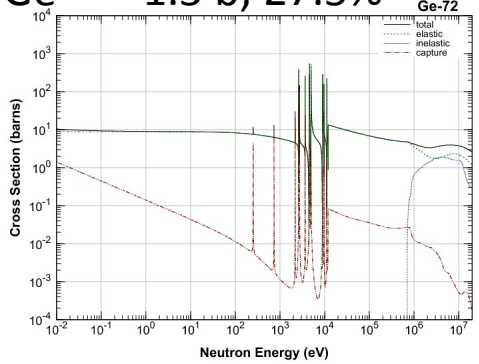
n Capture Gives Nuclear Recoils

1. **Thermal neutrons capture on nuclei of detector (Ge for example)** JENDL 4.0

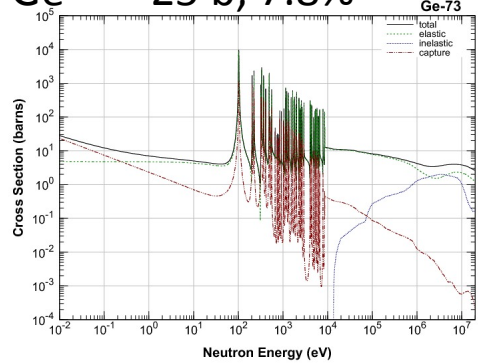
^{70}Ge -- ~ 4.5 b; 20.6%



^{72}Ge -- ~ 1.5 b; 27.5%

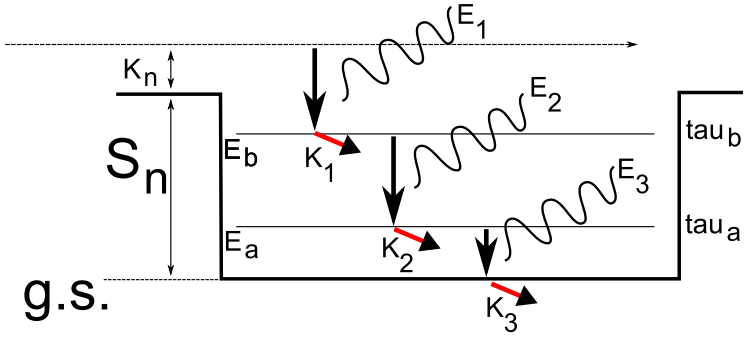


^{73}Ge -- ~ 25 b; 7.8%

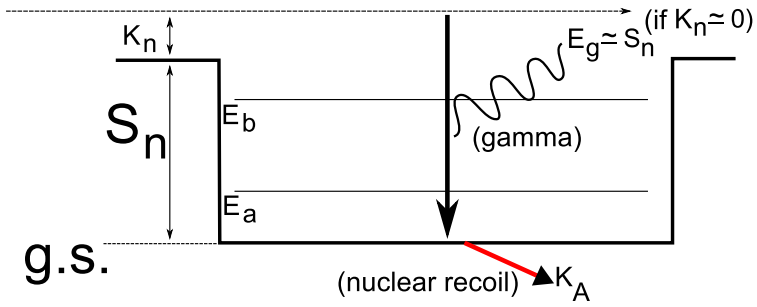


2. **Cascades result in low-energy pure nuclear recoils if gammas escape**

Cascade



Direct to Ground

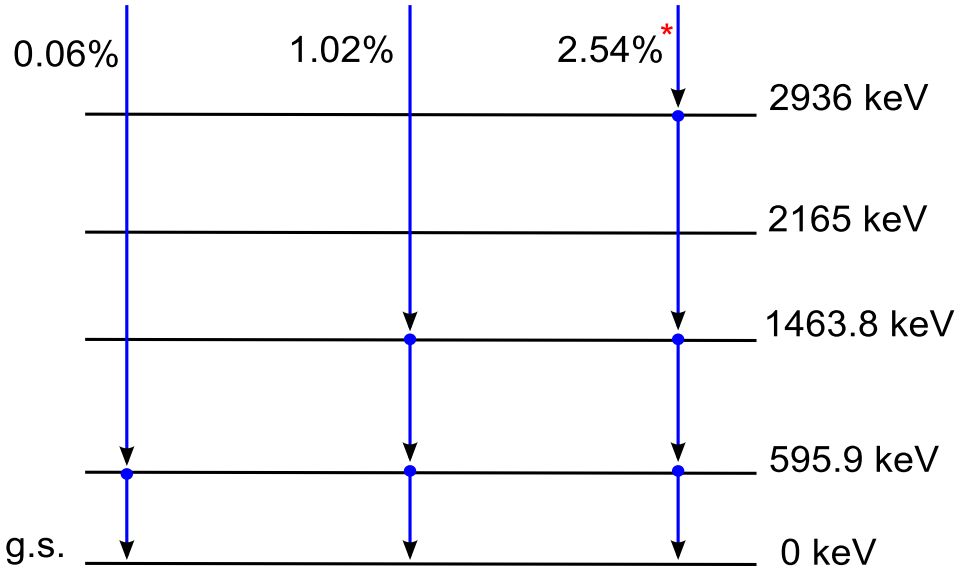


Cascade Details

^{73}Ge capture as:

$$n + {}^{73}Ge \longrightarrow {}^{74}Ge + \text{cascade}$$

some relevant nuclear levels are ^{74}Ge:



* There are other branches to this cascade

Cascade info from:
Islam et al., PRC **43**, 1086 (1991)

^{73}Ge has good capture cross section but cascade into the ^{74}Ge ground state is very complex:

1. Some examples of specific cascades are shown at the left with the total percentages of captures that are channeled through this cascade
2. Jones, et al. have computed that nuclear recoil stopping may take times < 10's of femtoseconds;
3. For many of these intermediate states, lifetimes are ~ 1-10 ps
4. So for these particular cascades we get approx. 672, 562, and 407 eV total recoil energies (left to right)
5. So the large peak on the last slide is turned into **many** smaller peaks

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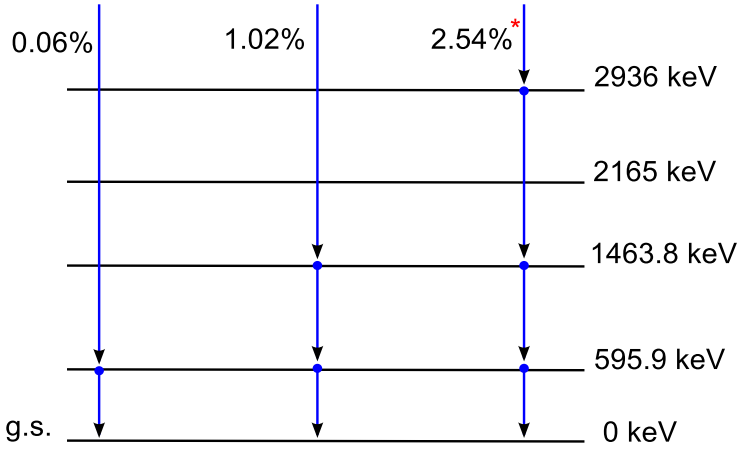
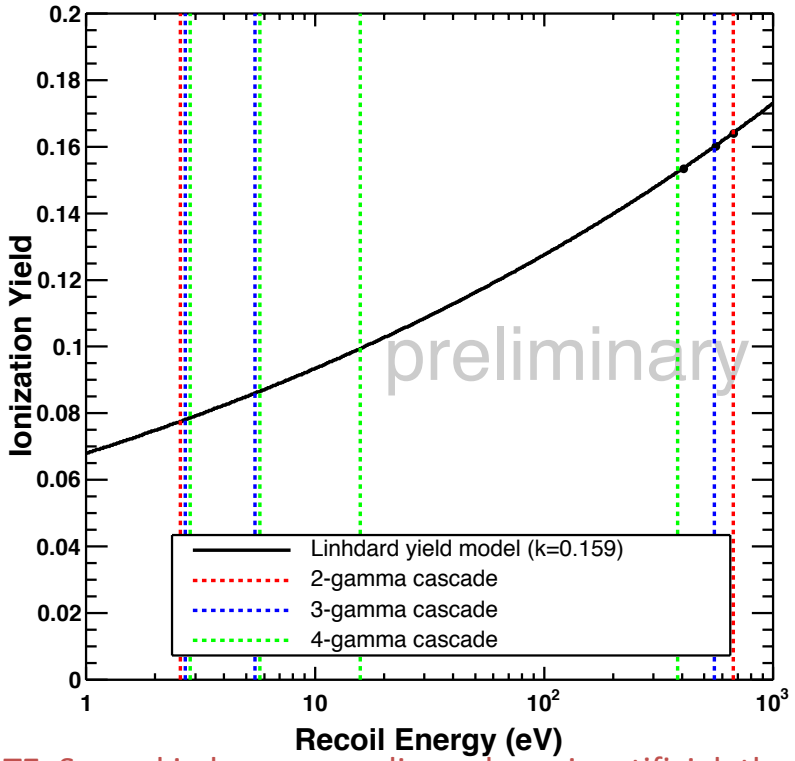


* There are other branches to this cascade

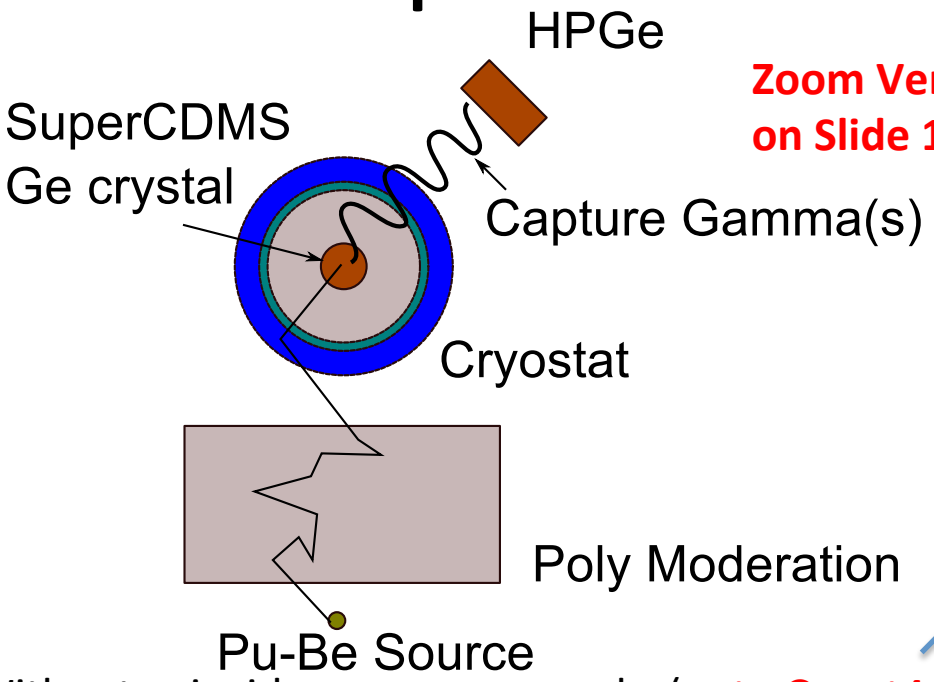
$$E_r \simeq \frac{E_\gamma^2}{2M_{nuc}}$$

The cascades shown at the left probe the yield function not at the total recoil energies (black points below) but at a range of energies across the curve

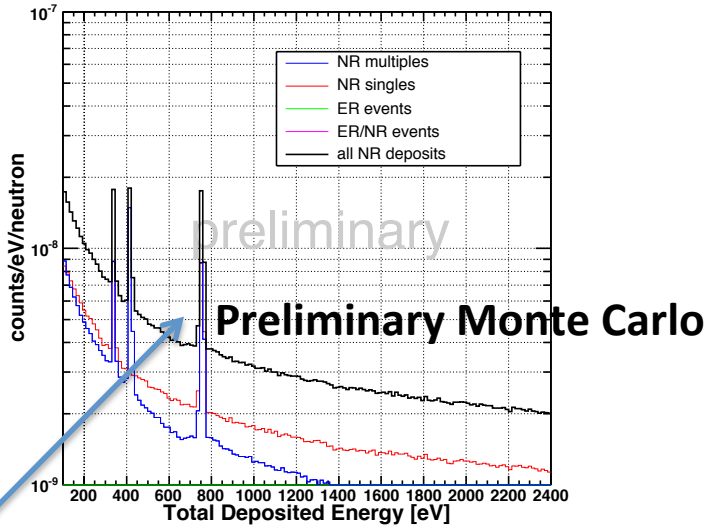


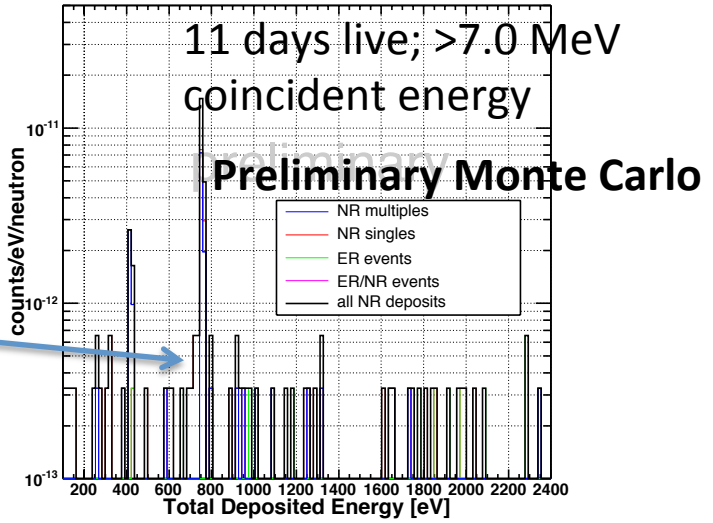
NOTE: Spread in low-energy lines above is artificial, they are really degenerate; **Zoom versions on slide 20**

A Capture Calibration Test



Zoom Versions on Slide 19

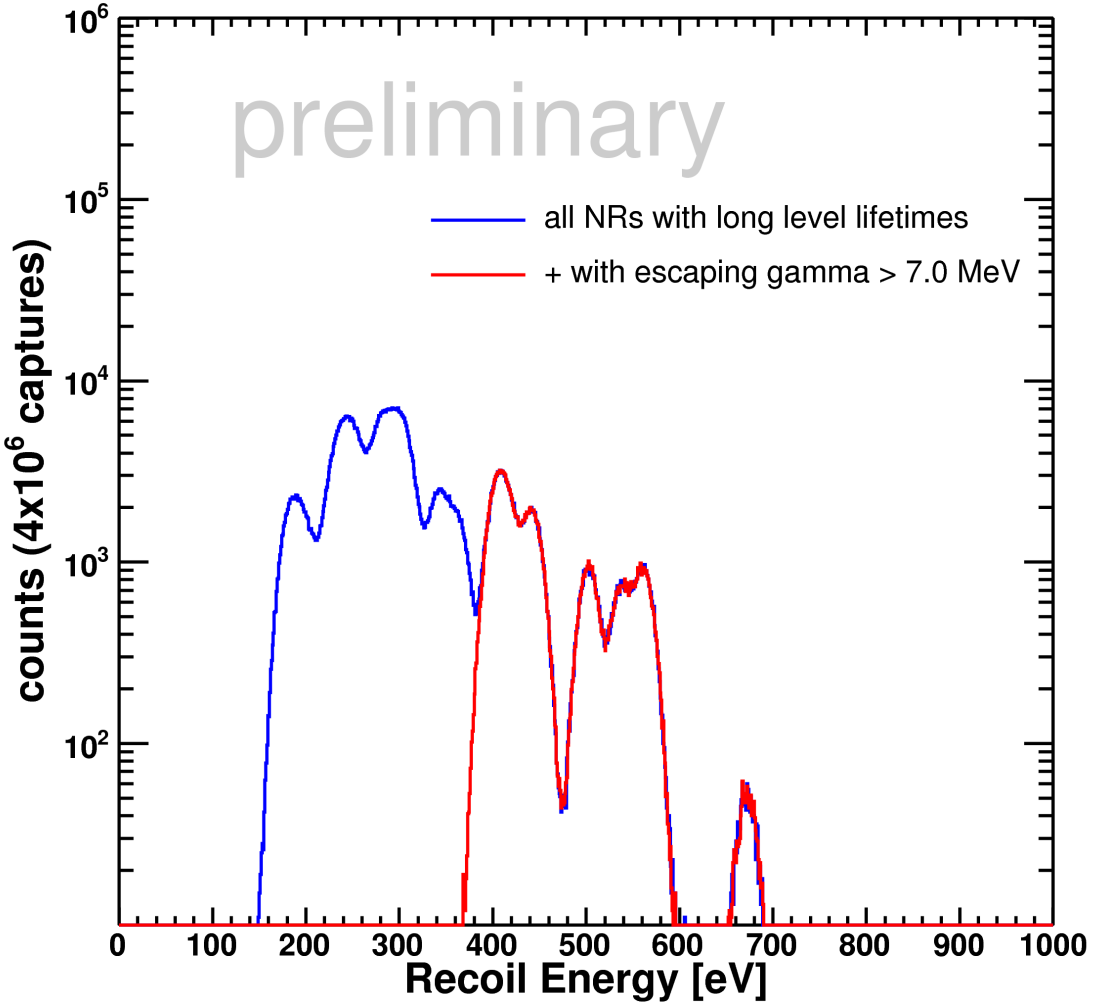




1. Without coincidence can see peaks (note Geant4 **is not** producing the correct NR de-excitation, so take it as a qualitative energy-range) but we have high direct-NR contribution
2. By requiring a 7 MeV coincidence energy deposit in HPGe, can enhance the peak
3. Live time is about 11 days for a PuBe source that emits ~ 1×10^6 n/s (we have this)

Long-Lifetime Spectra for Ge and Si

- Germanium nuclear recoils promptly following neutron capture
- Many cascades modeled: assumed dominant branching to largest energy gamma at each step
- Prompt tag on escaping gamma can select energies
- 10 eV assumed resolution– those humps are actually bunches of lines



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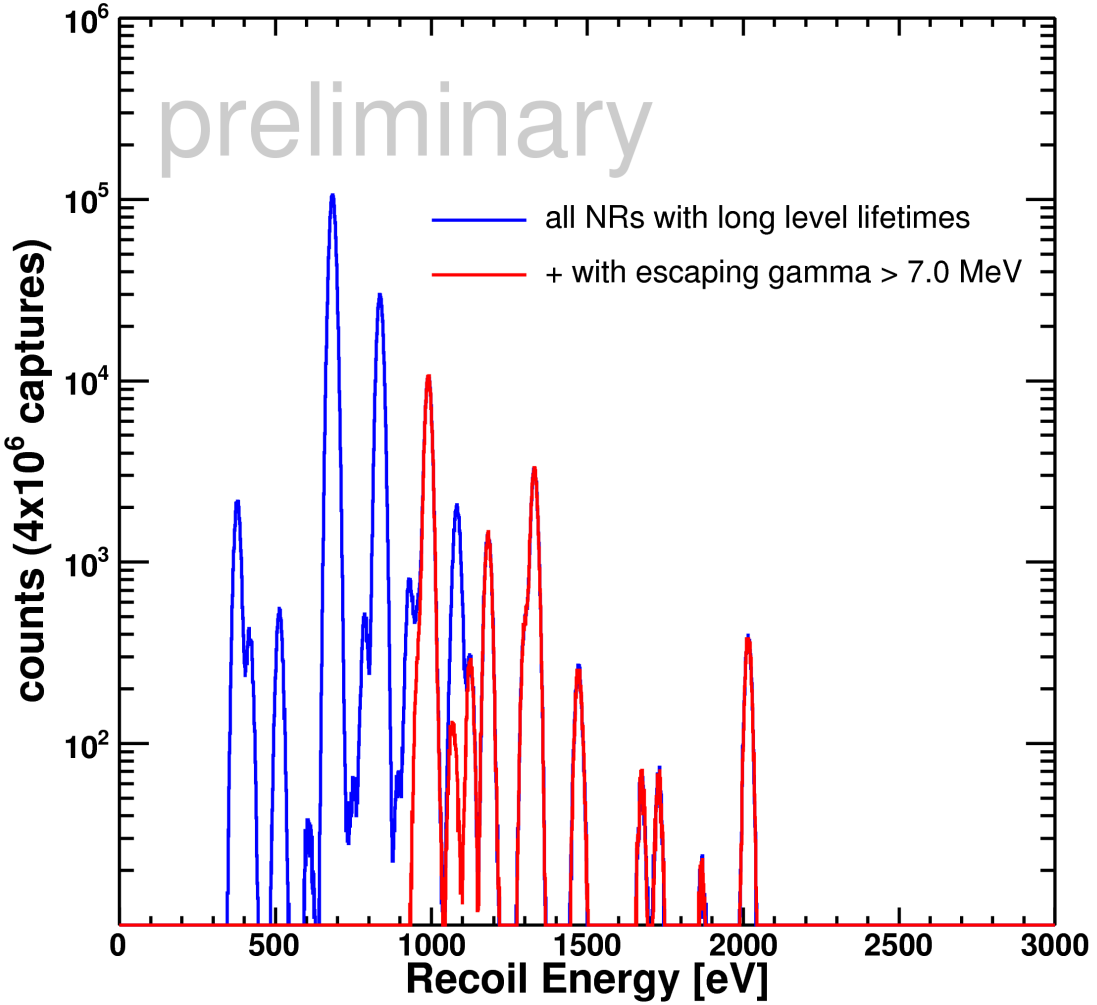
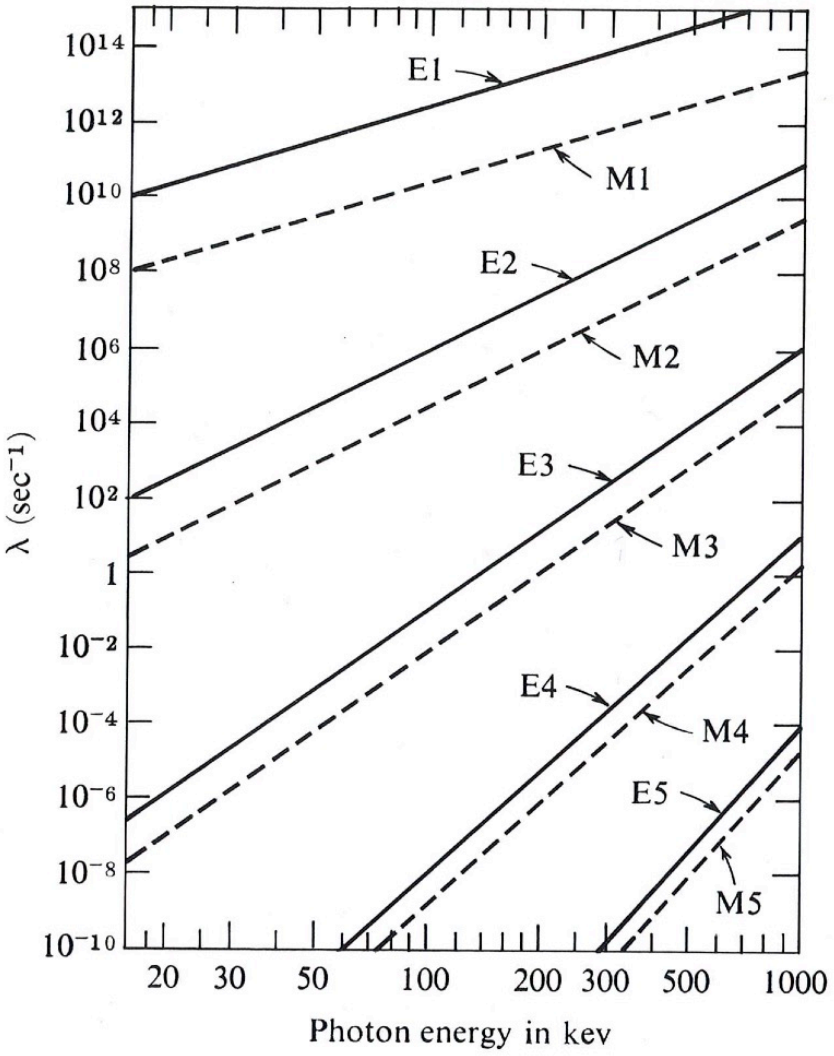


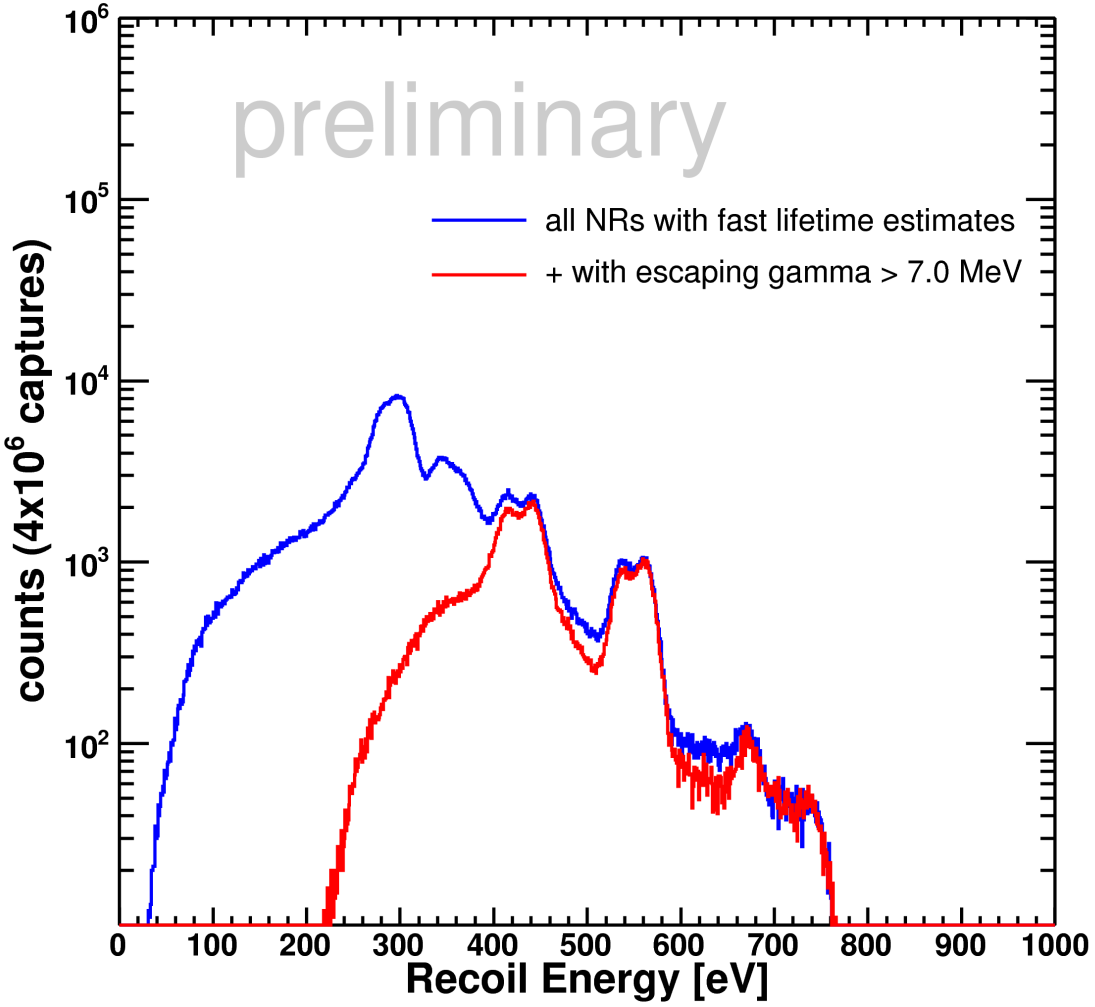
Weisskopf Estimates for Lifetimes

- Level lifetimes can be fast enough for intermediate nuclei to decay in flight
- So, even if we get all the cascades, lifetimes of states can govern the spread of energies from a given cascade
- Some lifetimes are known, but others we may only be able to estimate (see Weisskopf estimates)
- The Weisskopf estimates give the trends but can be off by large factors (sometimes 10^4)



Fast Estimate Spectra for Ge and Si

- Germanium nuclear recoils promptly following neutron capture
- Assumptions:
  - Constant nuclear stopping power
  - Only largest-energy gamma branch cascades
  - Unknown lifetimes get fastest Weisskopf estimates



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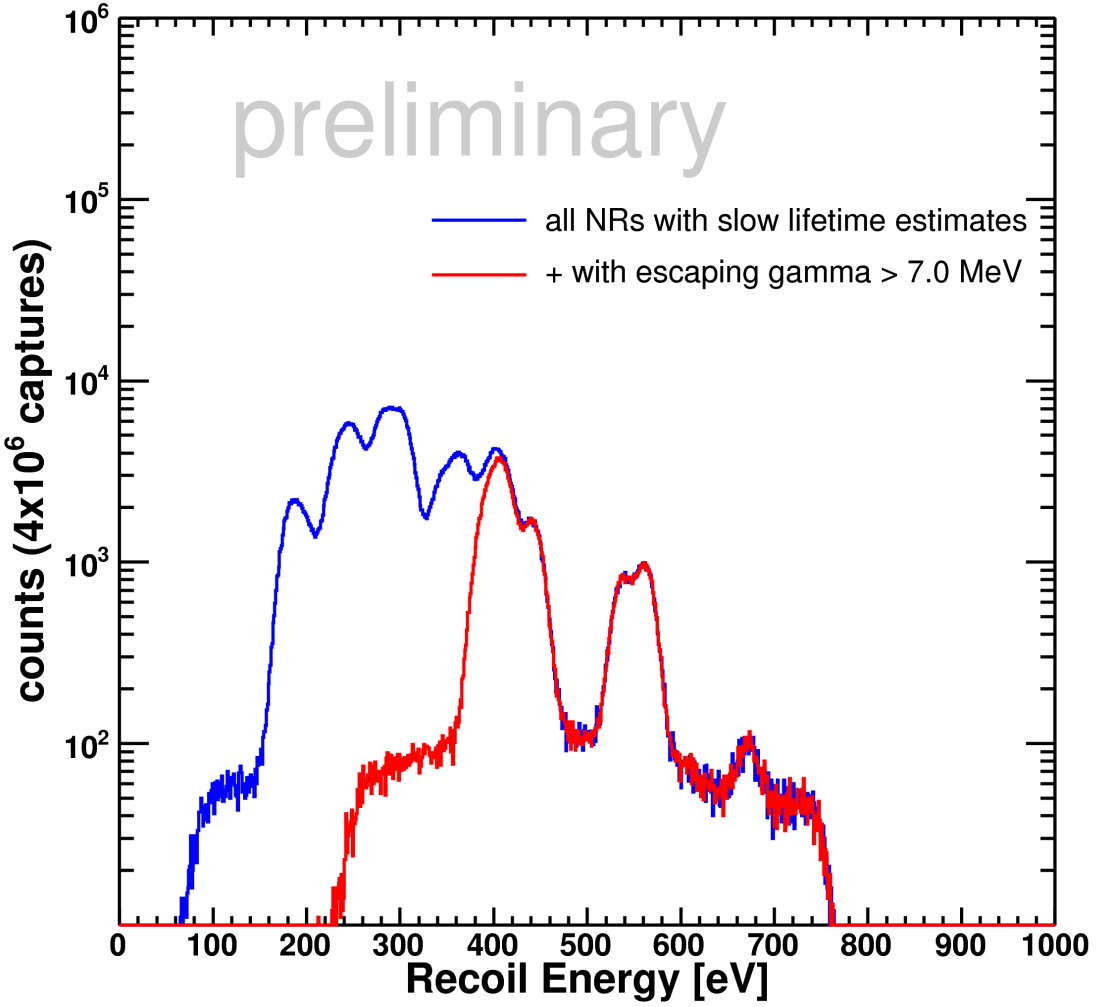

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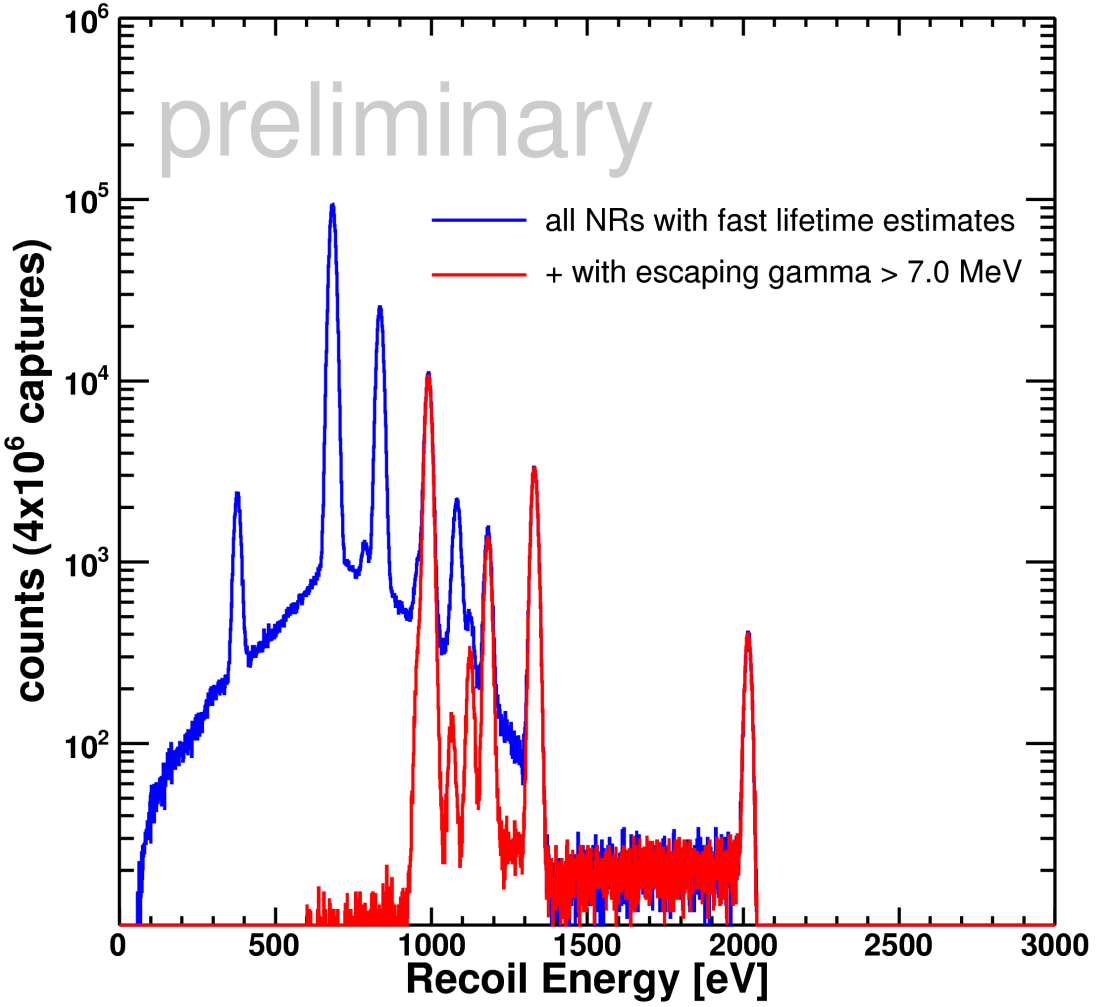

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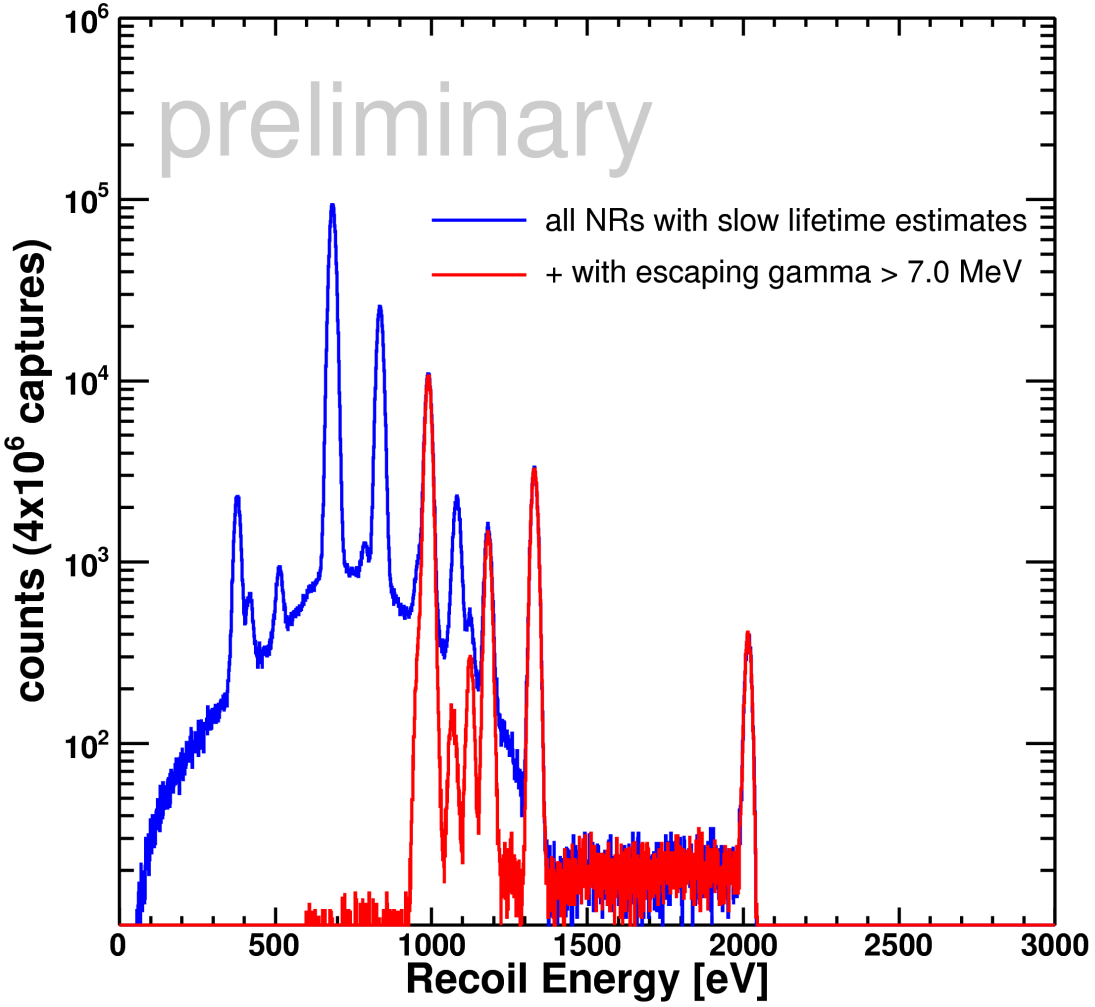
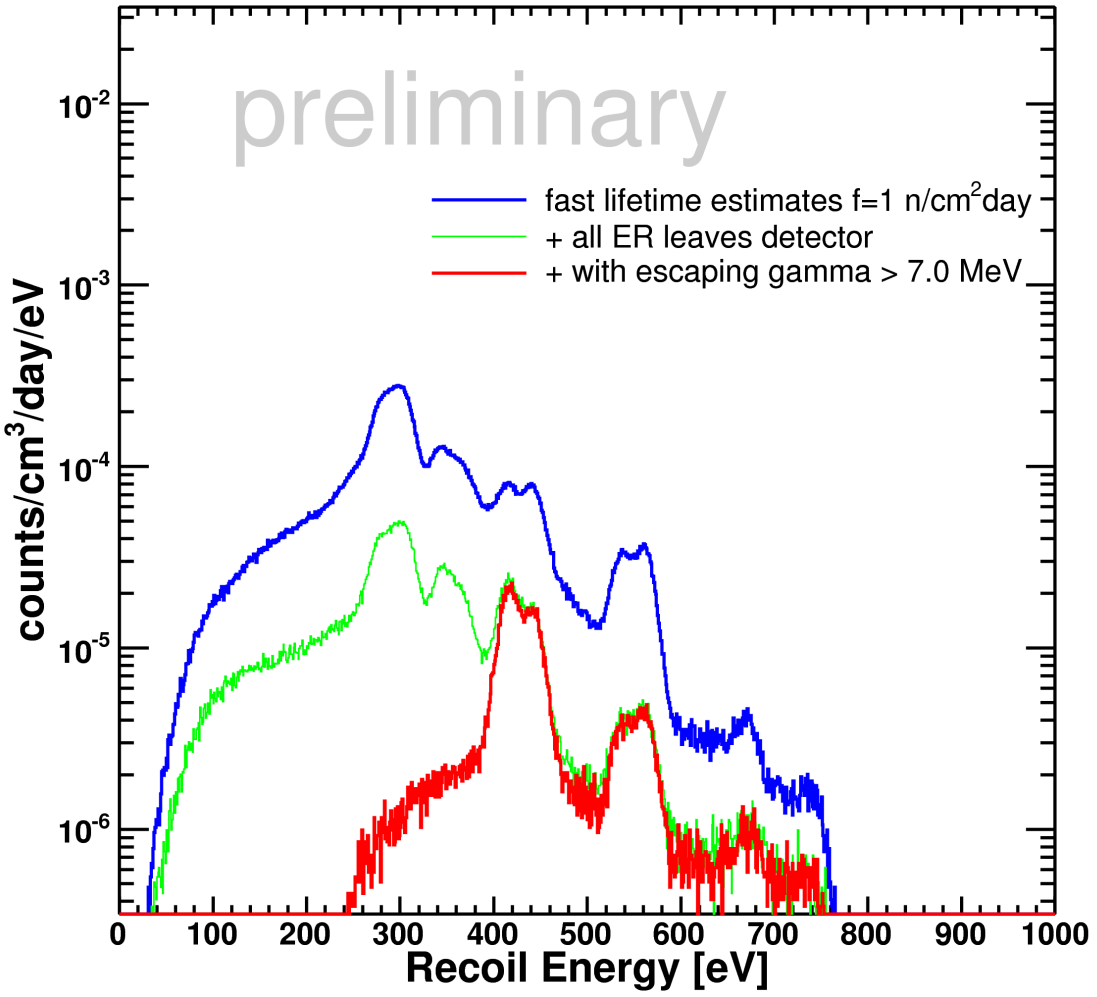


Ge γ Escape and Backgrounds

- Assume a thermal flux of 1 n/cm^{2}day
- A little uncertain what the thermal neutron flux in low counting environments is
- We usually measure only "visible" recoils from neutrons which would have energies >> eV, so the standard flux measurements need to be amended
- Sampling this spectrum sparsely → spectra similar to signal events?



Si γ Escape and Backgrounds

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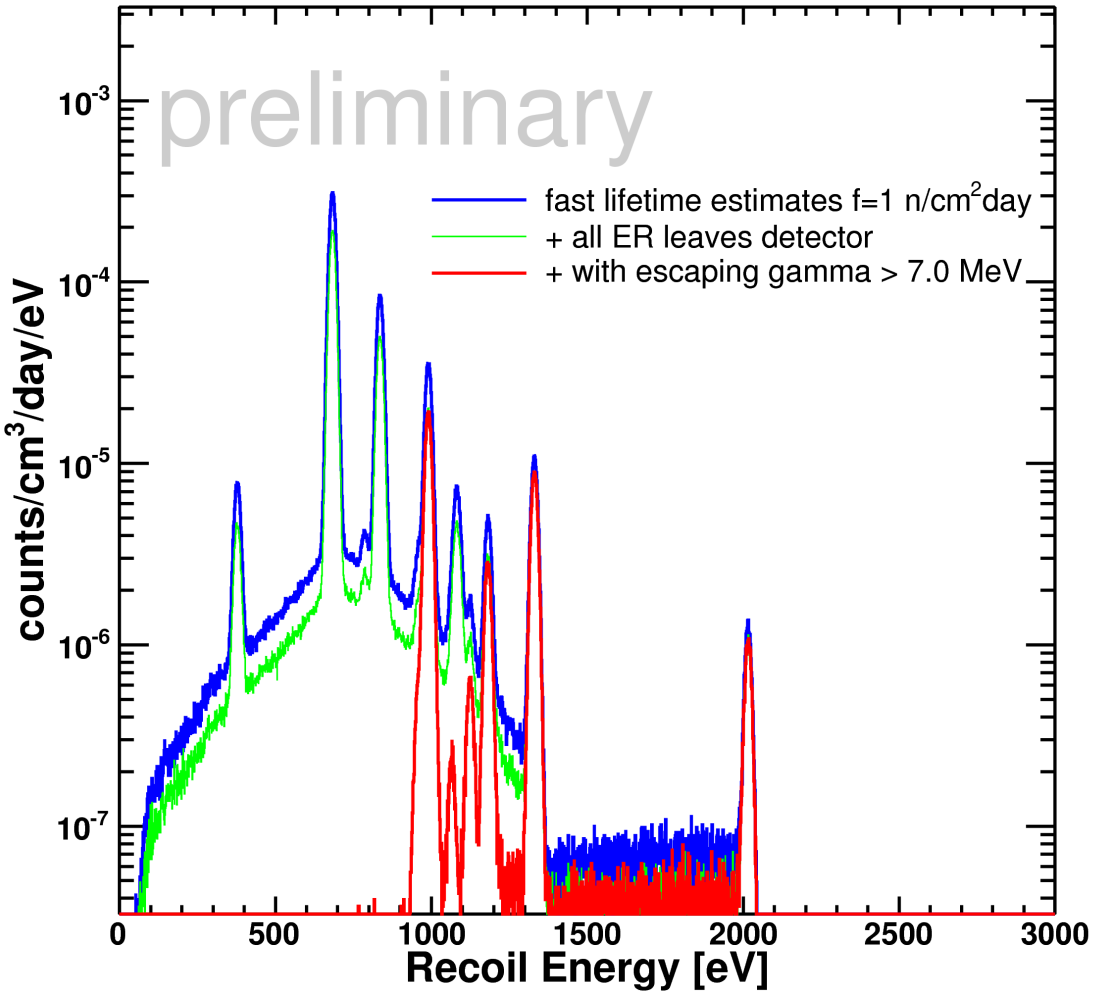


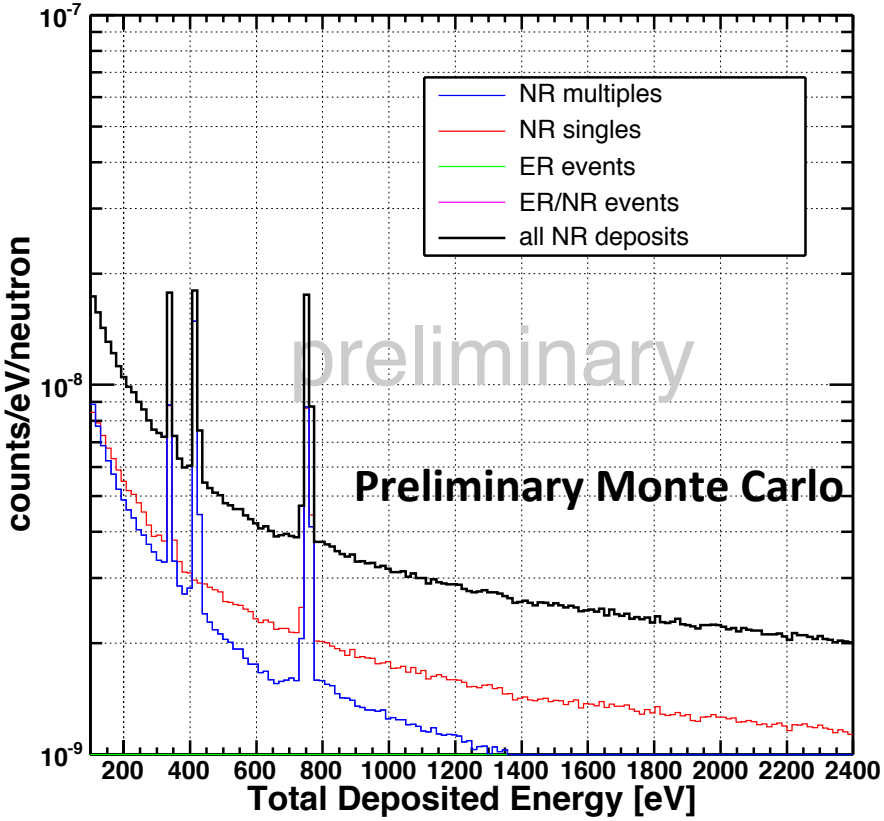
Summary

- Neutron capture can provide a valid calibration process and under some circumstances an important background for small detectors looking for light DM.
- Of course, since the purpose of this meeting is to expand our technologies, there may be many such niche calibrations
- How can this be stated in a white paper?
- Does it need to be? Critical for operating detectors and the science case in my opinion.

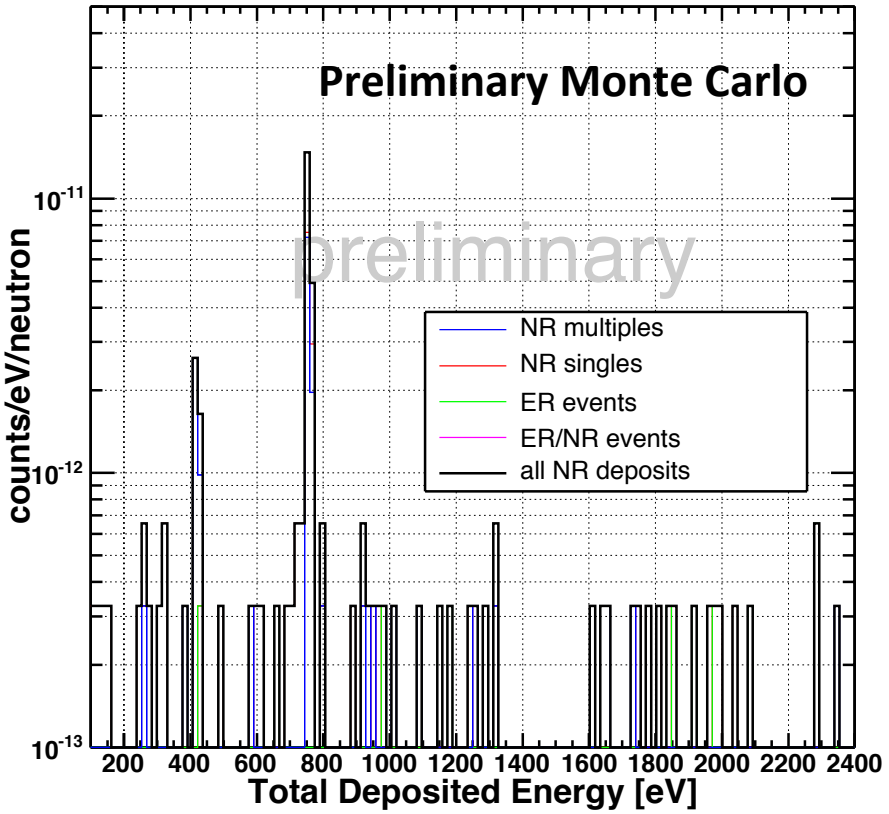
Extra Slides

A Capture Calibration Test

No Coincidence



Coincidence data:
11 days live; >7.0 MeV
coincident energy



Cascade Details