Prospects of Coherent neutrino-nuclear scattering for reactor monitoring

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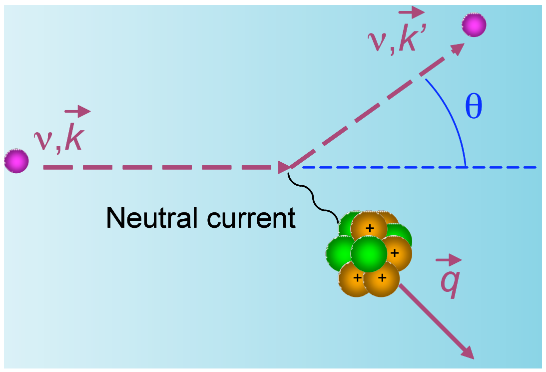
Outline

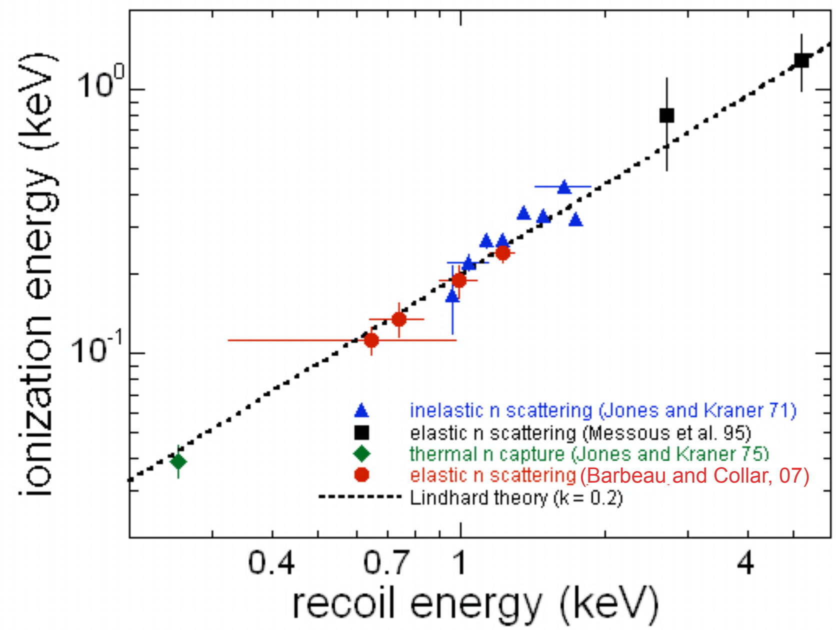
- Neutrino coherent scattering (NCS) physics
- Fuel isotope composition monitored by NCS
- Ge detector electronic threshold
- Background
- Deployable system

Neutrino coherent scattering

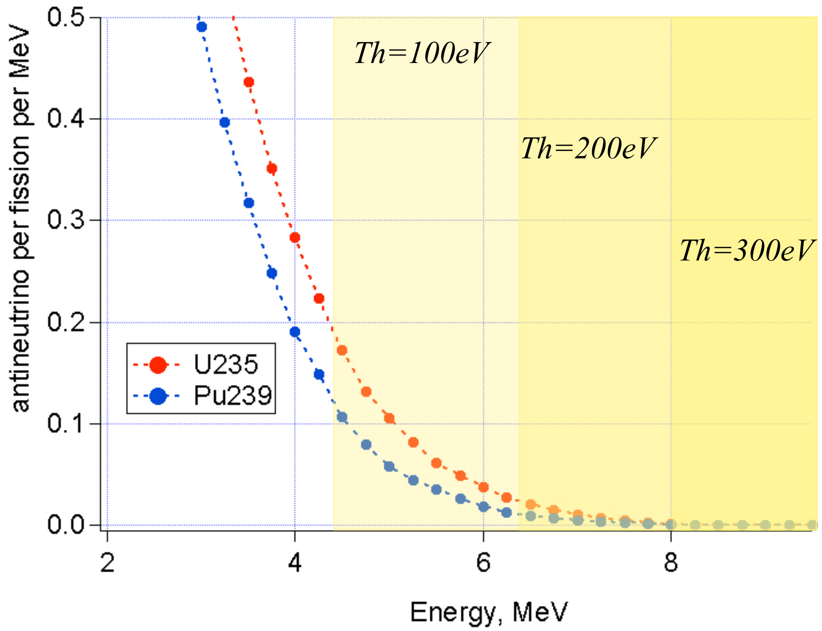


- Cross section enhanced by N^2
- Detection of nucleus recoil with transfer momentum $\boldsymbol{q} << 1/(\text{nucleus radius}) \sim$ tens of MeV (condition of coherence)
- Recoil energy $\leq \frac{2}{A}\left[\frac{E_\nu}{1\text{MeV}}\right]^2 \text{keV}$

- Reactor antineutrinos produce Ge recoils of <~3keV
- Quenching to ~20% of the recoil energy
- → detection of ionization signal <~600eV



Reactor anti-ν signal rate *vs.* detection threshold



- Cross-section increases with neutrino energy: $\dfrac{d\sigma}{d\cos\theta} \sim E_\nu^{\,2}$

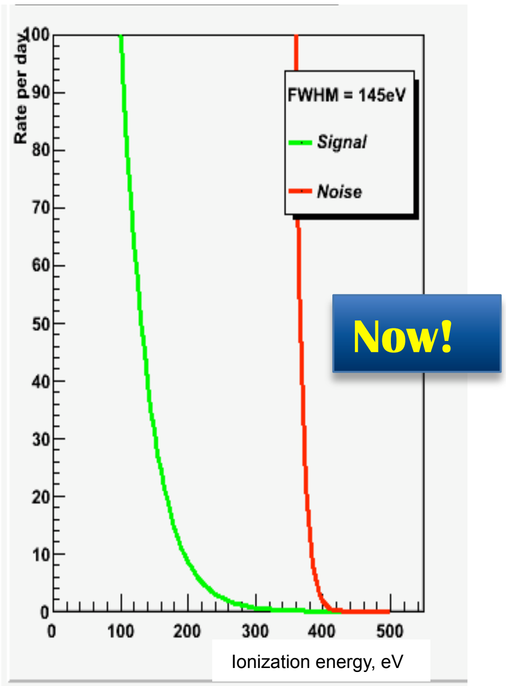
  but …there are fewer reactor neutrinos at higher energies

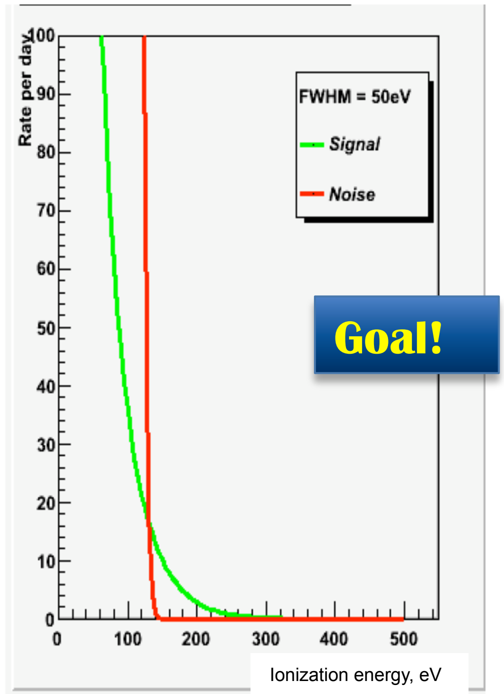
- Detector threshold imposes a kinematic constraint on accessible reactor antineutrino energies: to produce a recoil with energy E_R, the minimum neutrino energy is

  $$E_\nu^{\min} = \sqrt{\frac{ME_R}{2}}$$

- Thus, the lower the threshold, the higher the anti-ν signal rate

Reactor anti-ν signal *vs.* electronic noise

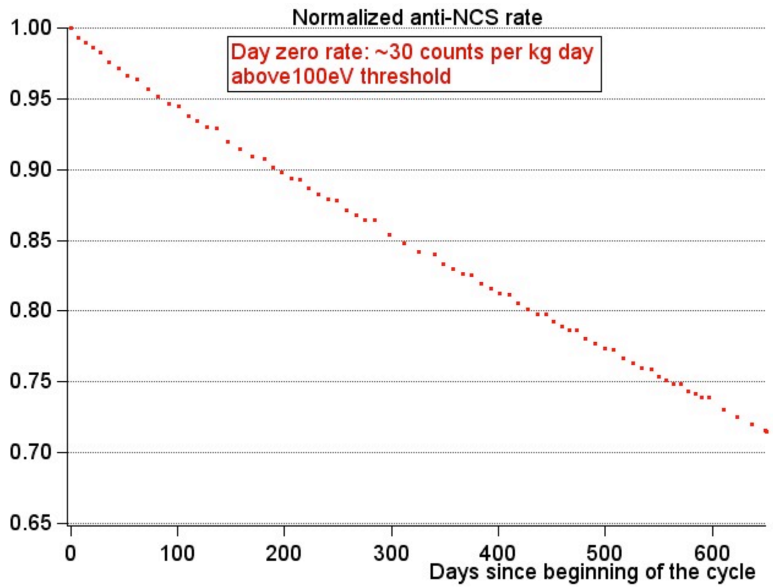




- The noise pedestal recedes faster than the signal with decreasing noise FWHM
- Goal → electronic noise threshold $5\sigma_n$~100eV (corresponds to FWHM~50eV)

Ge detector Threshold (eV)	Signal counts / day kg at 25m from reactor core
300 (now)	**0.4**
200	**3**
100 (goal)	**22**

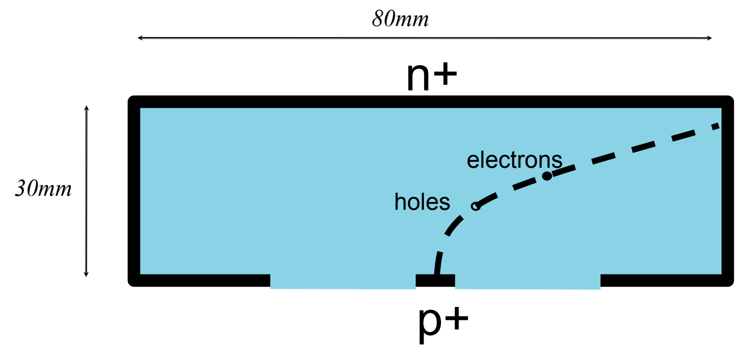
Reactor anti-ν signal rate *vs.* fuel cycle burnup

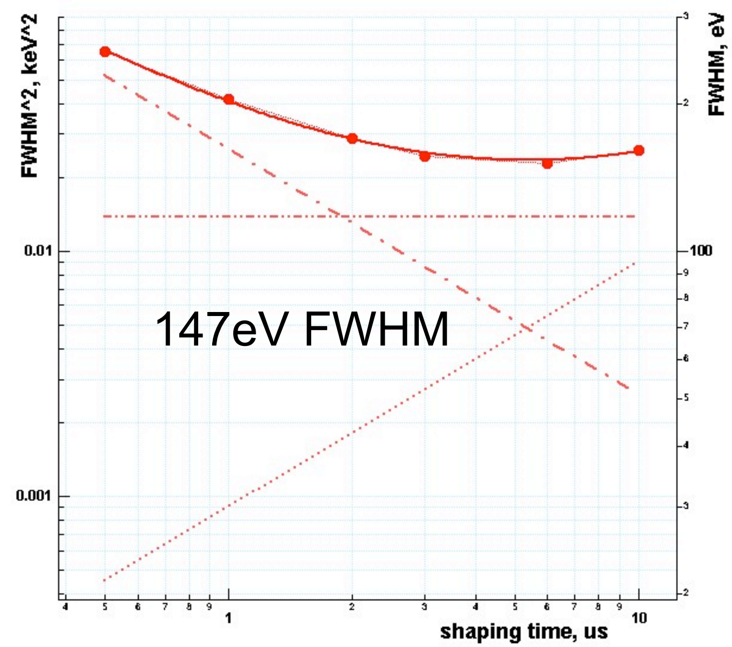


- About 25% variation in total anti-NCS events during NPP fuel cycle
- Higher sensitivity to fuel composition than inverse beta (10% variation)

Our HPGe detector

- CANBERRA BEGe
- p-type, 820g
- FWHM 147eV: mainly 1/f





SNL-LBNL collaboration

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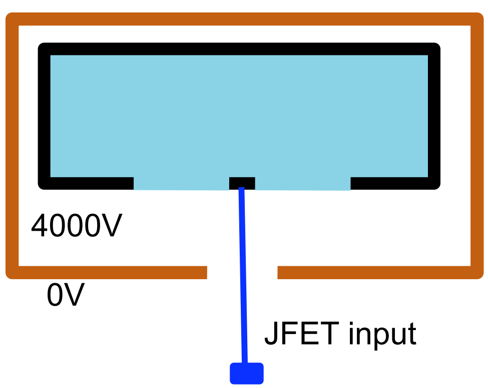
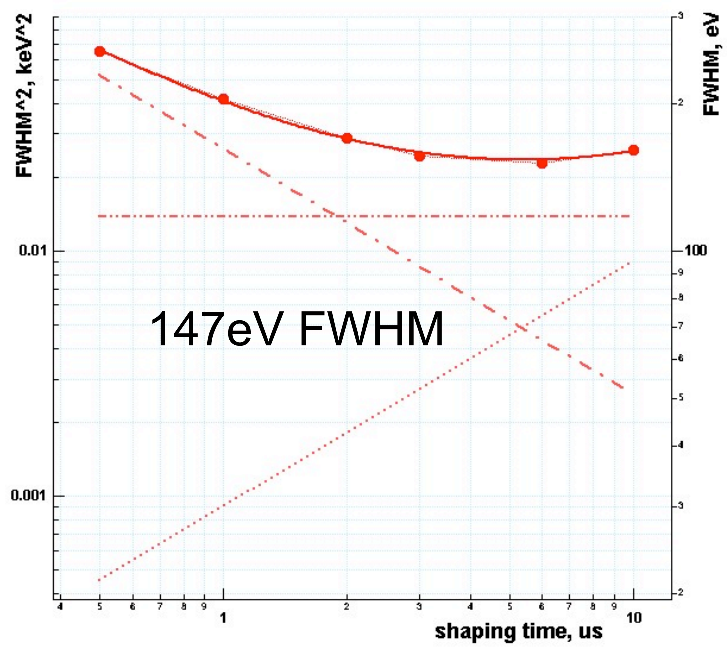
Ernest Orlando Lawrence Berkeley National Laboratory

- BEGe series noise is optimal
- Currently investigating 1/f noise by testing BEGe crystal in LBNL low-mass front-end
- Parallel noise will need crystal reprocessing





Background signals < 3keV

Primary particle	Process	Background signal
Cosmic secondary n and μ–induced n	Scattering off Ge nucleus	Ge–nucleus recoils
Cosmic secondary n and μ–induced n	Nuclei activation: ^{71}Ge, ^{68}Ga,^{65}Zn	Partial energy depositions from X–rays and Auger e–, internal to germanium
Cosmic primary p at sea level	Nuclei activation: ^{73}As, ^{68}Ge	
Thermal n	^{71}Ge activation	
γ	Natural radioactivity from detector materials	Forward–peaked Compton scattering
Solar and Geo ν	Scattering off Ge nucleus	Ge–nucleus recoils
WIMP ?		

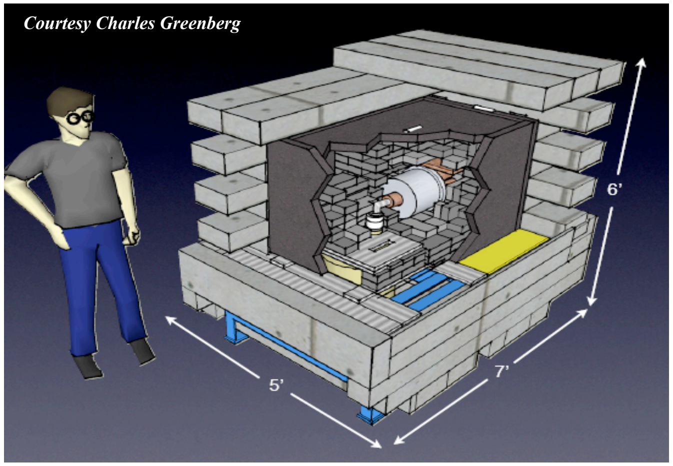
Shielding background particles

The usual,

- Any existing overburden
- Tight muon veto
- Polyethylene neutron moderator and borated thermal neutron absorber

But also,

- Ultra-low background Lead
- Anticoincidence Compton veto
- Radioclean shield and detector materials
- Lithium-drifted n+ contact covering most Ge surface
- Shield during transportation

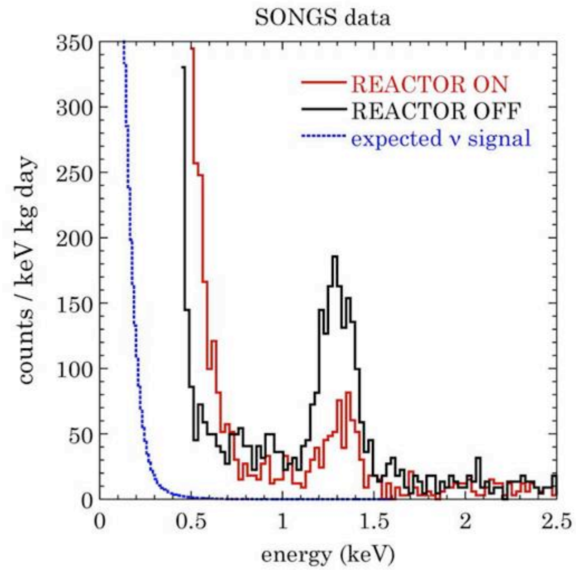


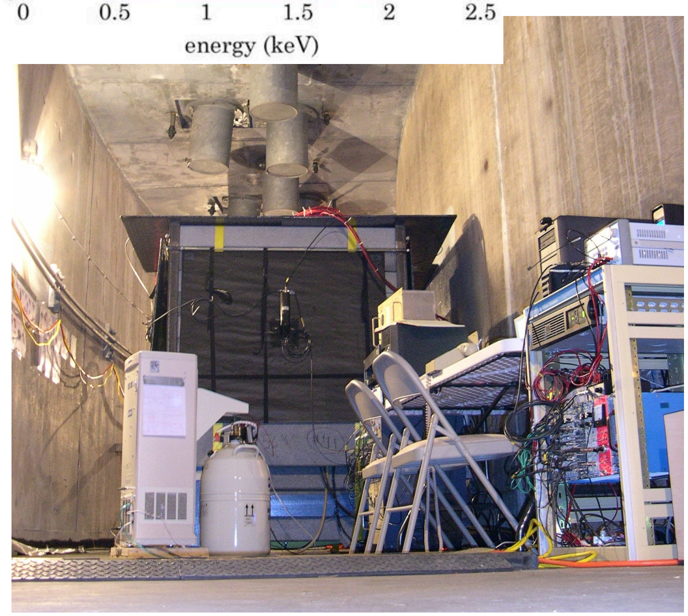
Shielding for SONGS deployment

Measured backgrounds from other experiments: SONGS Tendon Gallery

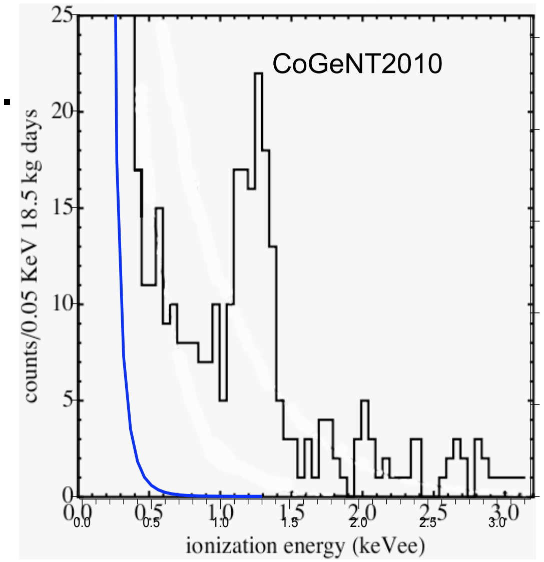
SONGS2009: CANBERA BEGe, 440g, 163eV_FWHM, at 30m.w.e.

- Background counts: ~10keV^{-1}kg^{-1} d^{-1} .
- Near-threshold counts: ~22keV^{-1}kg^{-1} d^{-1} .
- No evidence of significant increase in neutron background at this overburden with proper shielding.
- Signal processing to reduced cosmogenic background not applied because no raw preamplifier trace were recorded, but x2-3 reduction expected (see next slide).





Measured backgrounds from other experiments: underground mine



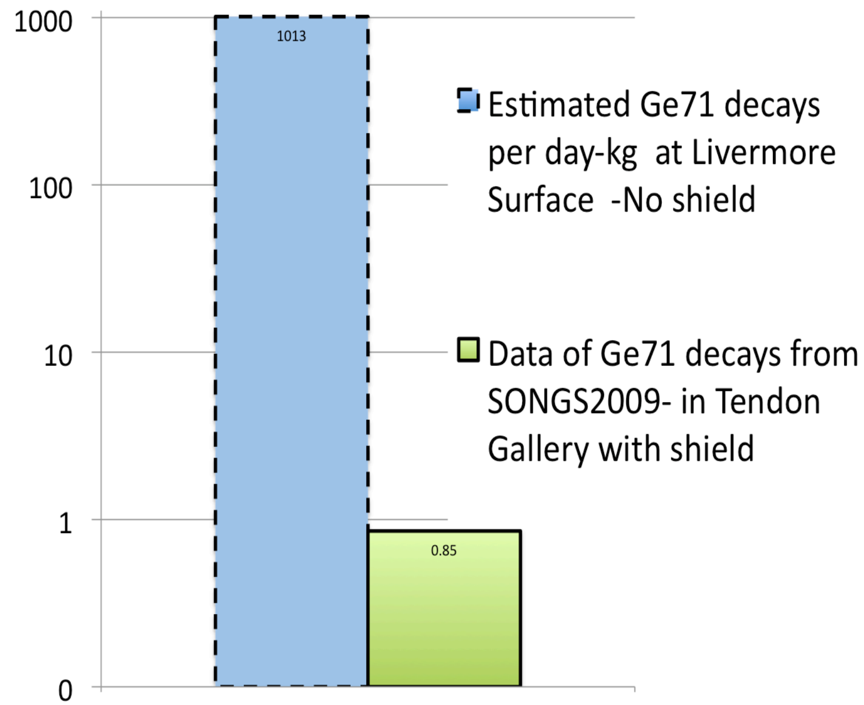
CoGeNT2010 data: in Soudan mine at 2,100m.w.e.

- CANBERA BEGe, 440g, 163eV FWHM
- After 3 months underground, and "microphonics" and "risetime" cuts
- Background counts: ~2keV^{-1}kg^{-1} d^{-1}
- Near-threshold counts: ~8keV^{-1}kg^{-1} d^{-1}

- **Confirmed that decays from cosmogenic activation internal to Ge populate the region <3keV.** (Use cosmogenic peaks for calibration.)
- **Partial energy deposition events (from nuclei decays) are a significant near threshold but can be efficiently rejected by "risetime" cuts.**
- **Natural radioactivity from materials is estimated to be negligible**

Thermal-Neutron activation

- Roughly estimate the Ge^{71} decay rate from measured thermal neutron background
- A shield with a thermal-neutron reduction ~100 times, would bring the aboveground rate of Ge^{71} decays to 10 counts per day-kg.
- ➔Aboveground monitoring might not be possible (Simulations are underway)

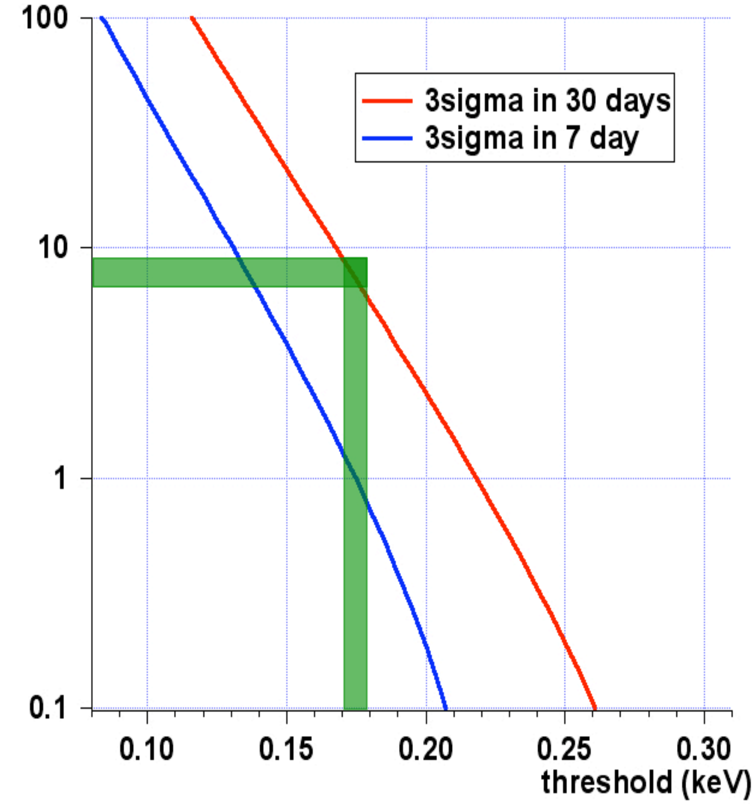


Signal vs. Background

For a given measurement time (7days or 30days) and background rate, the 3σ-confidence level sets the required electronic threshold.

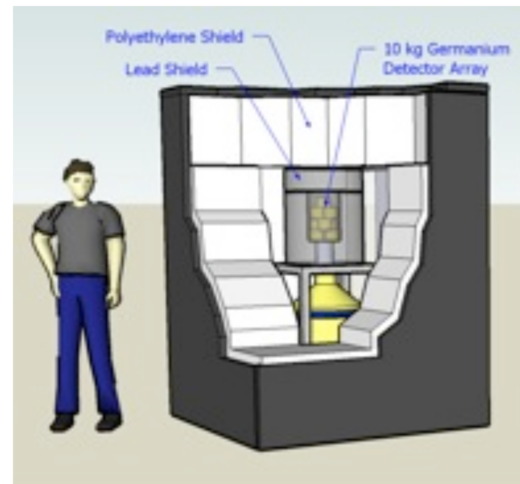
- Extrapolate background below 400eV to be same as in CoGeNT2010: ~**$8kg^{-1}$ day^{-1}** in range <1keV
- Then, observation of reactor ON/OFF transition at 3σ in 30days ➔ 175eV threshold (~82eVFWHM)
- At 1.64σ in 30days ➔ 210eV (~94eVFWHM)

Maximum background events/(kg day) *vs*. electronic threshold



Deployable system

- Cryogenic germanium detectors are already well known and are frequently used at nuclear reactor facilities around the world.
- Little or no safety concerns from the facility operators.
- In addition, the ability to shrink the active detector from 1 ton of scintillator material to something on the order of 10 kg of germanium would allow for much more flexibility in finding locations suitable for detector installation.
- A smaller detector will also present a smaller area for interaction with cosmic backgrounds.



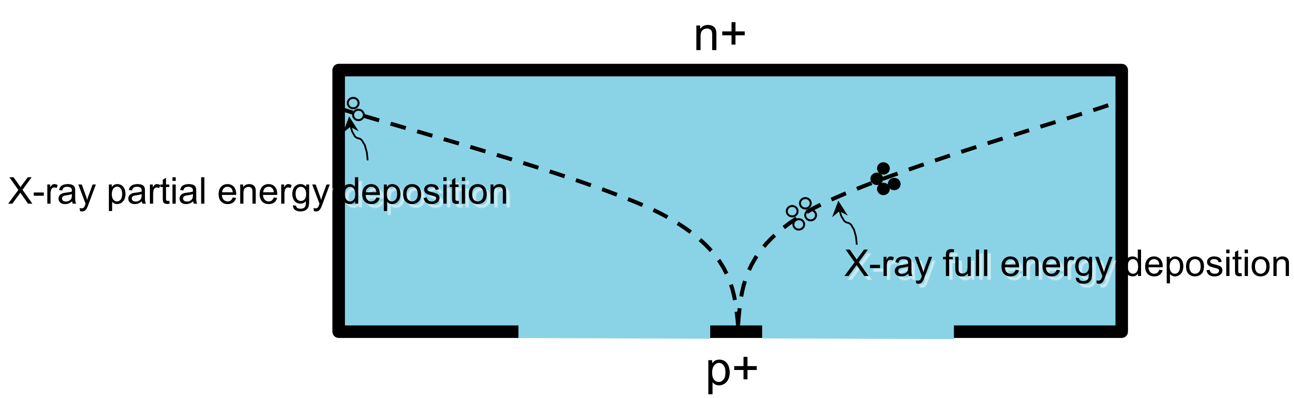
Conclusions

- Electronic noise threshold still the main barrier for NCS observation with BEGe: SNL–LBNL collaboration working on this.
- "Measured" background allow possible observation of NCS (reactor ON/OFF) at ~210eV of electronic threshold
- Lower threshold (~135eV) required for 3σ–CL and more timely observation (7days) of reactor ON/OFF

Backup slides

How "Risetime" cuts work

- Events near the dead region will only deposit part of the energy
- But also, the induced charge in the electrodes will rise slowly because near the dead layer the electric field is weak



Signal vs. Background

Safeguards problem: timely and unambiguous observation of a reactor ON/OFF transition, that could signify a fuel diversion situation

- With reactor OFF, background measurement sets the signal trigger level $$L_T = 3\sigma_{OFF}$$
- With reactor ON, how large must the detectable signal N_D be so that the false negative are less that *0.15%*?

$$N_D \geq L_T + 3\sigma_{ON}$$