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Prospects of Coherent neutrino-nuclear scattering for reactor monitoring

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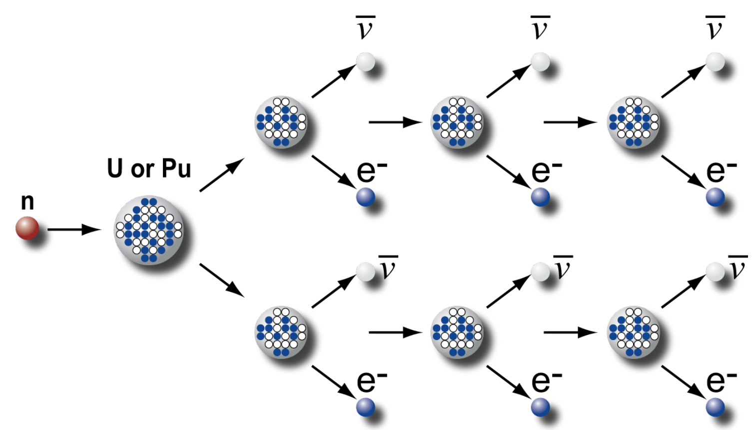
Sandia National Laboratories

Outline

- Reactor antineutrino spectra
- Fuel isotope composition monitored by neutrino coherent scattering (NCS) signal
- Detector threshold: collaboration with LBNL
- Background: CoGeNT2010 data
- A deployable system: shielding, cooling

Reactors emit huge number of antineutrinos

- 6 antineutrinos per fission from beta decay of daughters
- 10^{21} fissions per second in a 3,000-MWt reactor
- About 10^{22} antineutrinos are emitted per second from a typical PWR unattenuated and in all directions



Antineutrinos for reactor monitoring

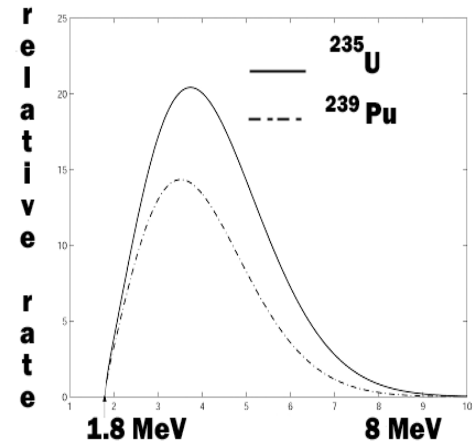
- Different antineutrino spectra from ^{235}U and ^{239}Pu

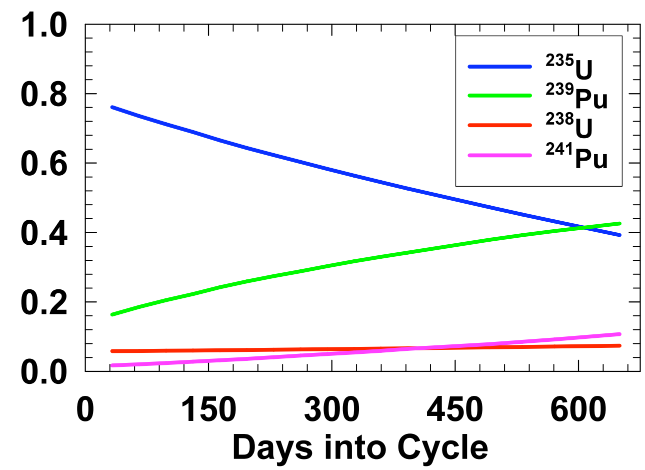
- The isotope fuel composition changes during the reactor fuel cycle: ^{235}U is consumed and ^{239}Pu is produced

- Measured antineutrino rate is sensitive to the isotopic composition of the core

$$N_{\bar{\nu}} = \gamma(1+k)P_{th}$$

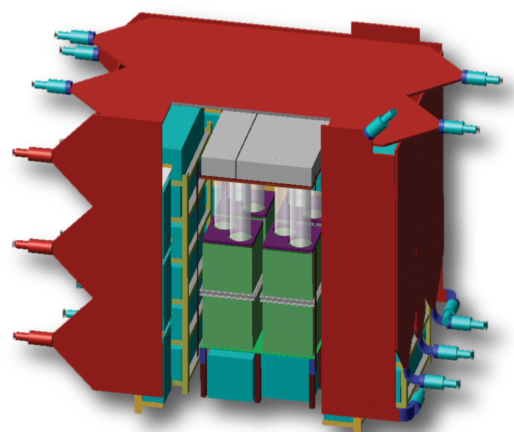
Burnup: depends on fuel composition





Antineutrino detectors are useful for Reactor Monitoring and Safeguards because:

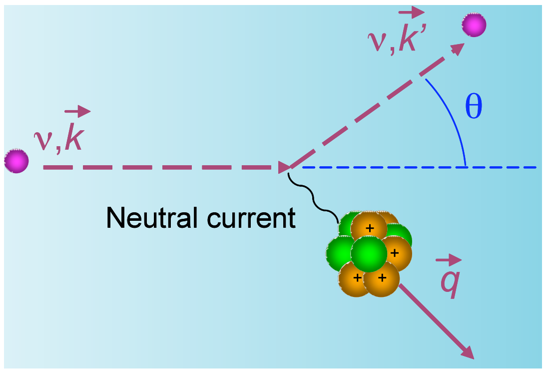
- Provide real-time quantitative information about core power and isotopic composition while reactor online
- Report reactor status independent of operator declarations
- Continuous, non-intrusive, remote, unattended monitoring



SONGS1: 0.64 tons of Gadolinium-doped liquid scintillator, monitored fuel composition through inverse β-decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Neutrino coherent scattering



- Cross section enhanced by N^2
- Detection of nucleus recoil with transfer momentum

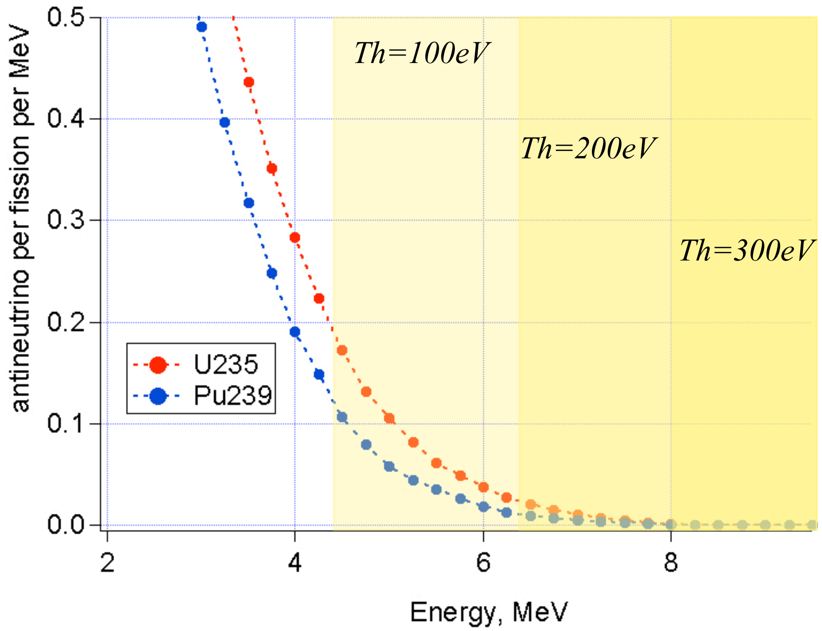
  q << 1/(nucleus radius) ~ tens of MeV

  (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 → detection of ionization signal <~600eV

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



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

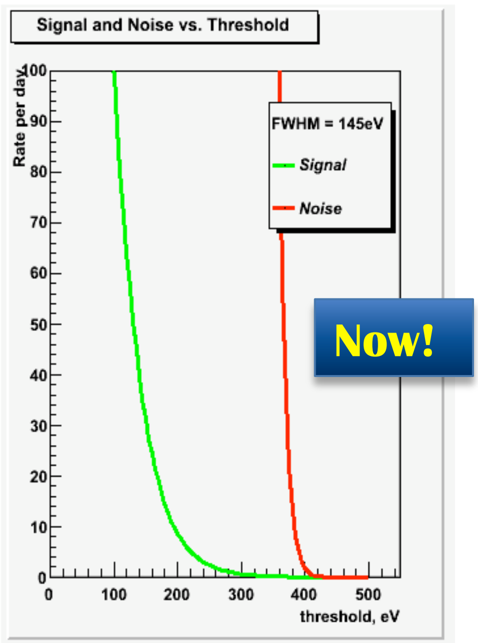
  but …there are fewer reactor neutrinos at higher energies

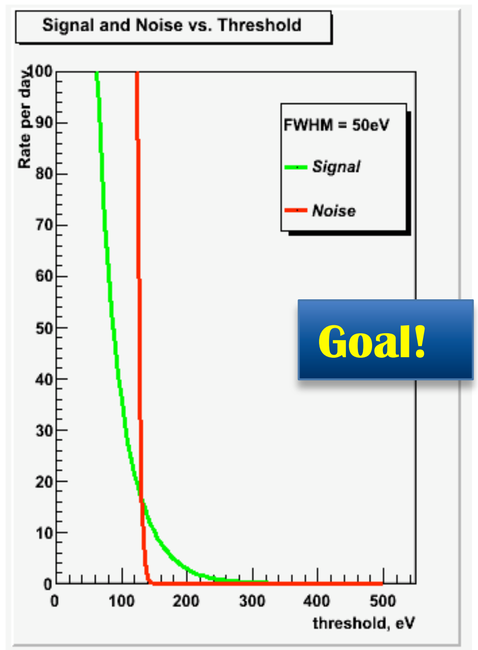
- Detector threshold imposes a kinematic constraint on accessible reactor antineutrino energies: to produce a recoil with energy E_R, the minimum neutrino energy is

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

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

Reactor anti-ν signal *vs.* electronic noise

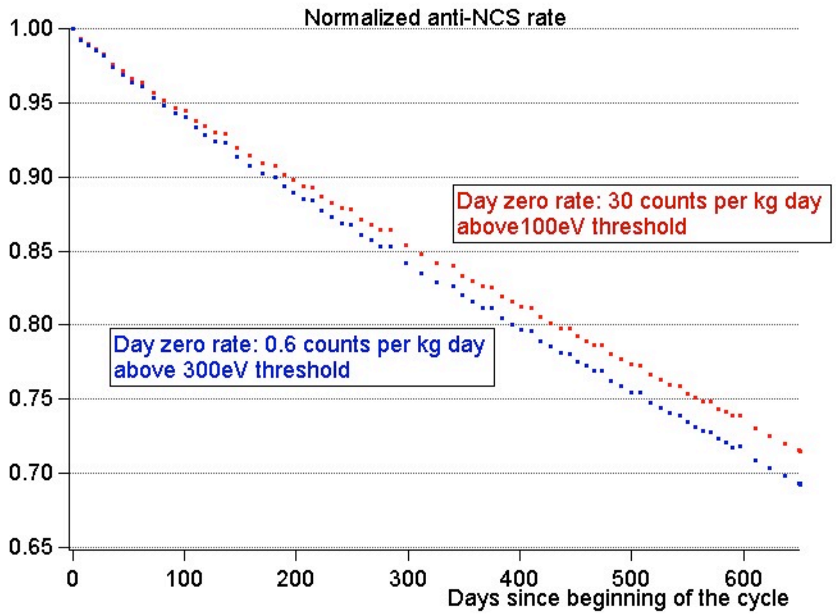




- The noise pedestal recedes faster than the signal with decreasing noise FWHM
- Goal → electronic noise threshold ~100eV (corresponds to FWHM~50eV)

Ge detector Threshold (eV)	Signal counts / day kg at 20m from reactor core
300 (now)	**2.6**
200	**8.3**
100 (goal)	**35.9**

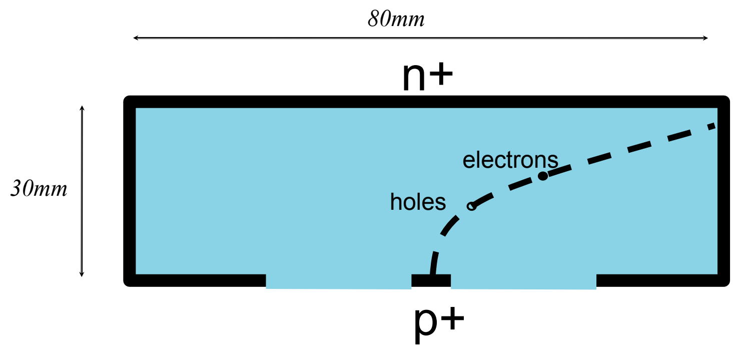
Reactor anti-ν signal rate *vs.* burnup

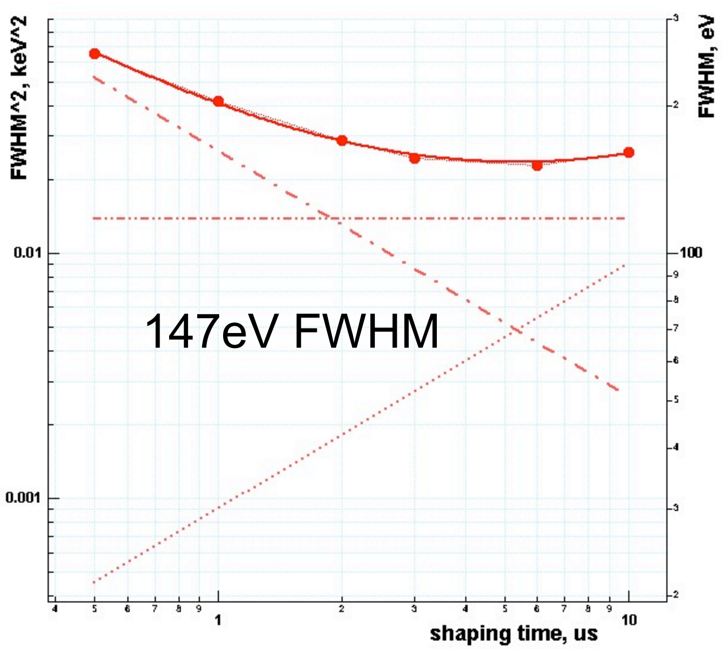


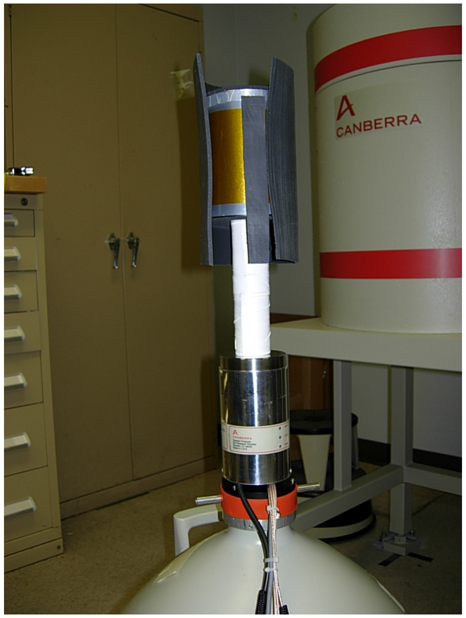
- About 25% variation in total events during NPP cycle
- anti-NCS has better sensitivity to fuel composition than inverse beta
- Percentage variation reduced with threshold but overall signal increases significantly

Our HPGe detector

- CANBERRA BEGe
- p-type, 800g
- FWHM 147eV: mainly 1/f

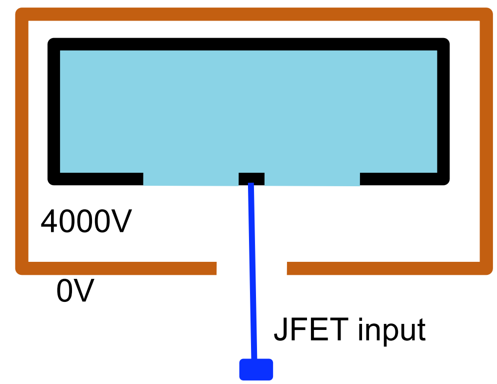






SNL-LBNL collaboration

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

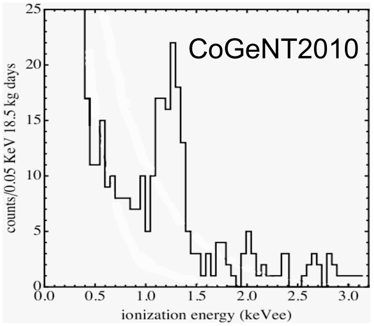


Measured backgrounds from other experiments

- CANBERA BEGe, 450g, 163eV FWHM

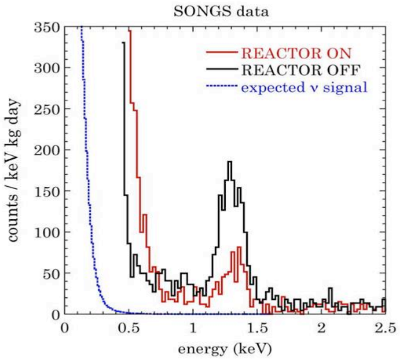
CoGeNT2010 data: in Soudan mine at 2,100m.w.e.

- **Background counts: ~2keV^{-1}kg^{-1} d^{-1}**
- **Near-threshold counts: ~8keV^{-1}kg^{-1} d^{-1}**
- **After 3 months underground. After "michrophonic" and "risetime" cuts**



SONGS2009 data: in SONGS at 30m.w.e.

- **Background counts: ~10keV^{-1}kg^{-1} d^{-1} .**
- **Near-threshold counts: ~22keV^{-1}kg^{-1} d^{-1}**
- **No "risetime cuts" because no raw preamplifier traces were recorded, but x2-3 reduction expected.**
- **No evidence of increase neutron background due to less overburden**



Signal to background relation

- Success: unambiguous observation of a reactor ON/OFF transition

Required backgrounds

Conclusions

- Collaboration with LBNL to isolate and mitigate sources of electronic noise in BEGe2. Consider to use their cryostat and crystal instead.
- Origin of near-threshold background events