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COHERENT NEUTRINO-NUCLEAR SCATTERING WITH GERMANIUM

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Sandia National Laboratories

Coherent Neutrino-Nucleus Scattering (CNNS)

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Coherent effects of a weak neutral current

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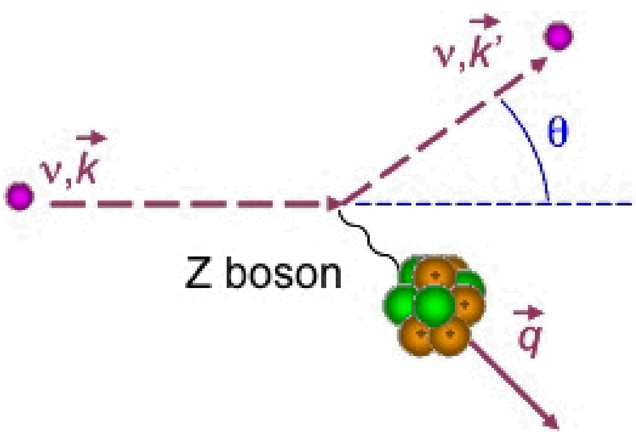
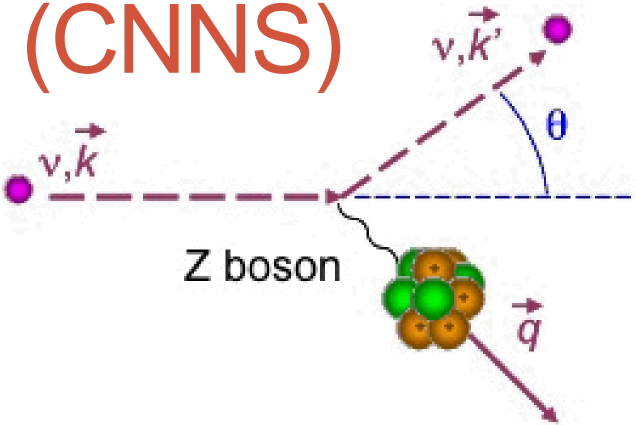
(Received 15 October 1973; revised manuscript received 19 November 1973)



. . . The idea is very simple: If there is a weak neutral current, elastic neutrino-nucleus scattering should exhibit a sharp coherent forward peak characteristic of the size of the target just as electron-nucleus elastic scattering does. . .

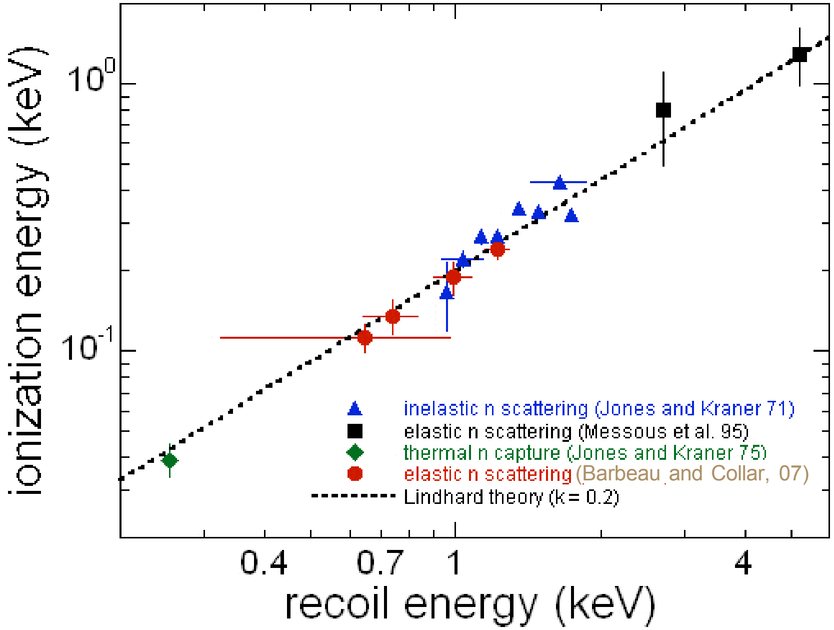
- It has never been observed!

Coherent Neutrino-Nucleus Scattering (CNNS)

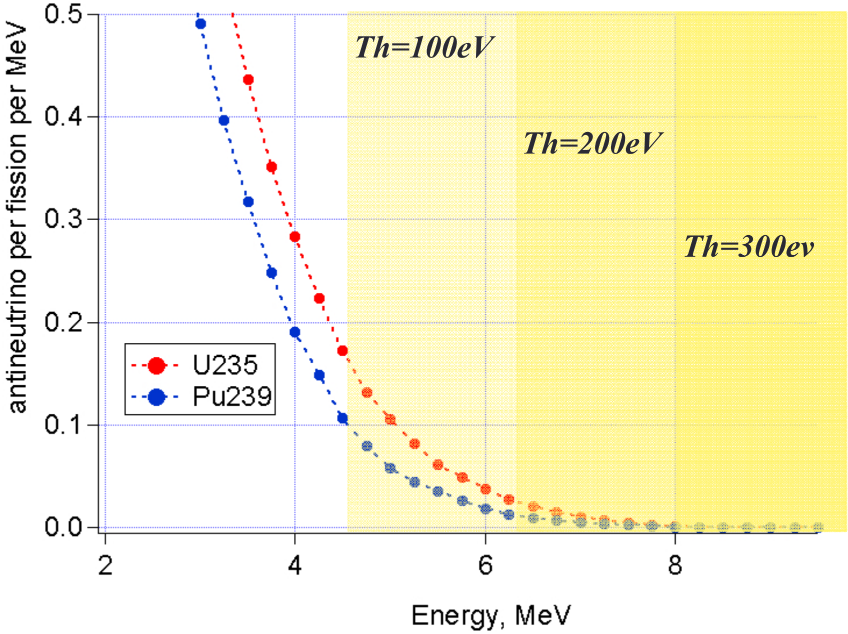


- Cross section enhanced by N^2
- Detection of nucleus recoil with transfer momentum $\boldsymbol{q}$ << 1/(nucleus radius) ~ tens of MeV (condition of coherence)
- Recoil energy $\leq \frac{2}{A}\left[\frac{E_\nu}{1\text{MeV}}\right]^2 \text{keV}$

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

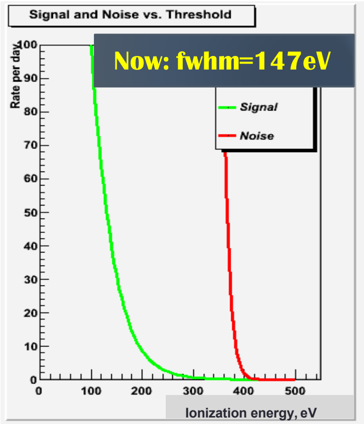


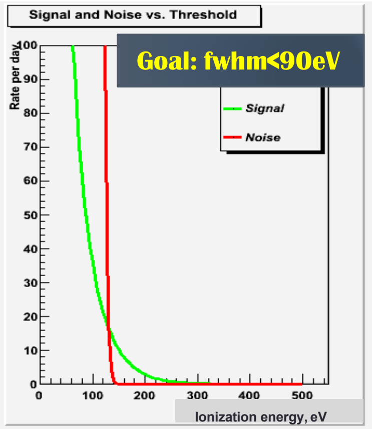
Antineutrino signal vs. HPGe threshold



Ge detector Threshold (eV)	CNNS counts / day kg at 25m from core
300	~0.4
200	~3
100	~20

- Detector threshold imposes a kinematic constraint on accessible reactor antineutrino energies

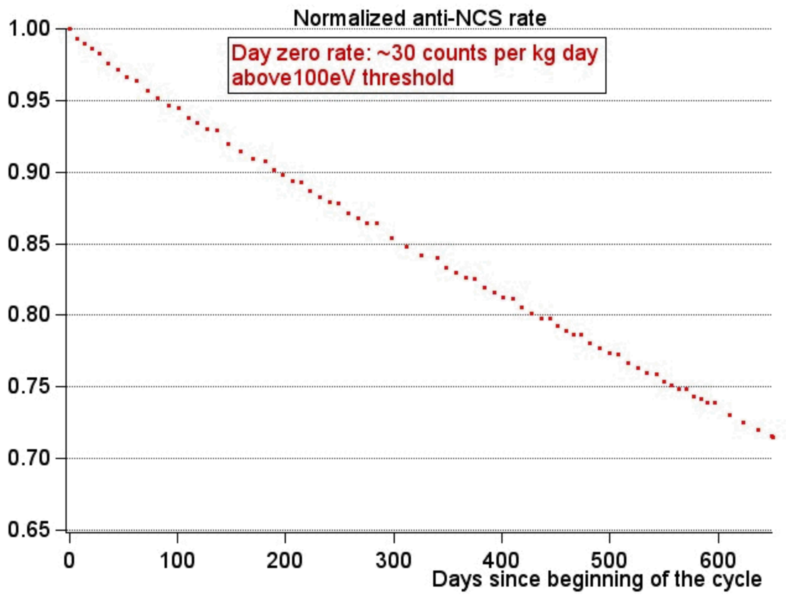




FWHM = 2.35 σ
Threshold ~ 5 σ

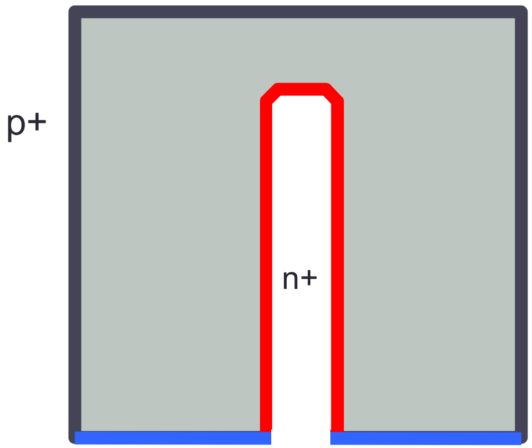
- The noise pedestal recedes faster than the signal with decreasing noise

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

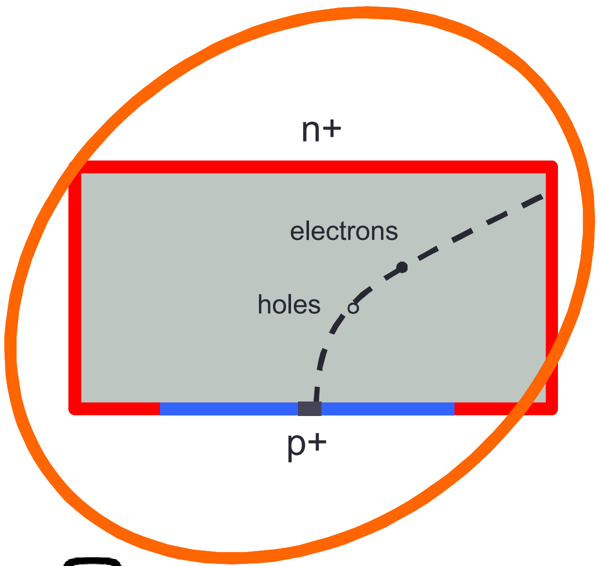


- About 25% variation in total
- C(anti)NNS events during NPP fuel cycle
- Higher sensitivity to fuel composition than inverse beta (10% variation)

Point-Contact HPGe detector

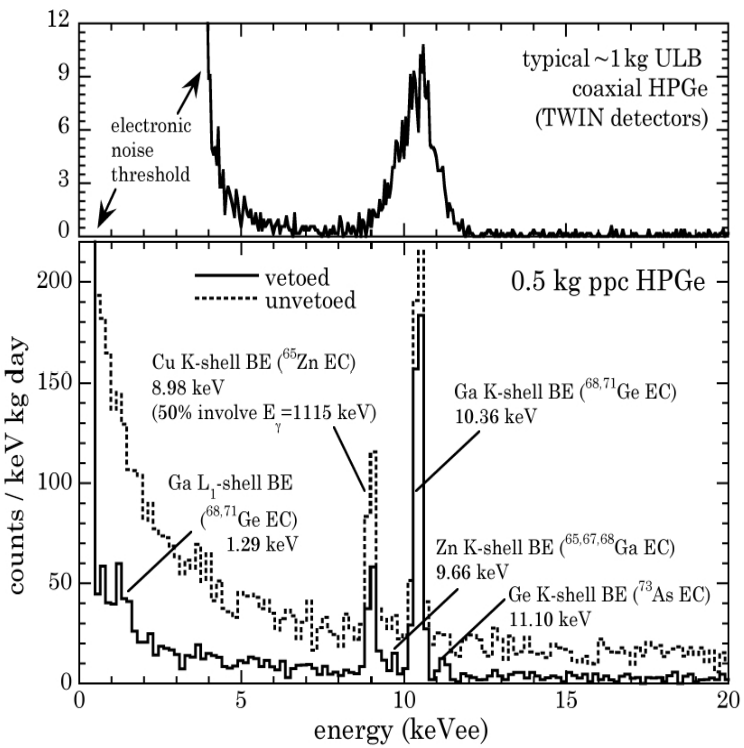


- Coaxial C~20pF
- ~1kg
- Typical FWHM ~1.8keV



- Point-contact C~1pF
- ~0.5kg
- FWHM~163eV in this Fig.

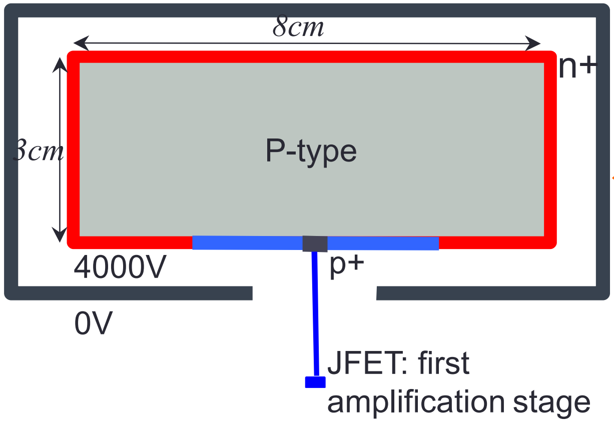
Decrease capacitance to lower noise threshold and improve resolution



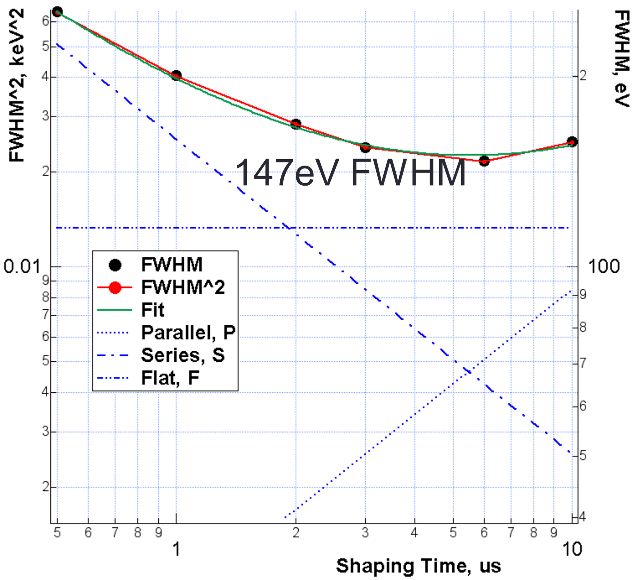
Aalseth *et al.* PRL 101, 251301 (2008)

BEGe: P-type ‘Point’ Contact

- Modified **Broad Energy Ge** detector by Canberra INC
- Large mass 0.82kg
- Point contact ~5mm,
- Low capacitance ~1.5pF



- 147eV FWHM still too large
- Negligible contribution from other circuits (preamp and High Voltage) according to SPICE analysis
- Most of noise from detector element and Front-End electronics (HPGe crystal + JFET assembly)

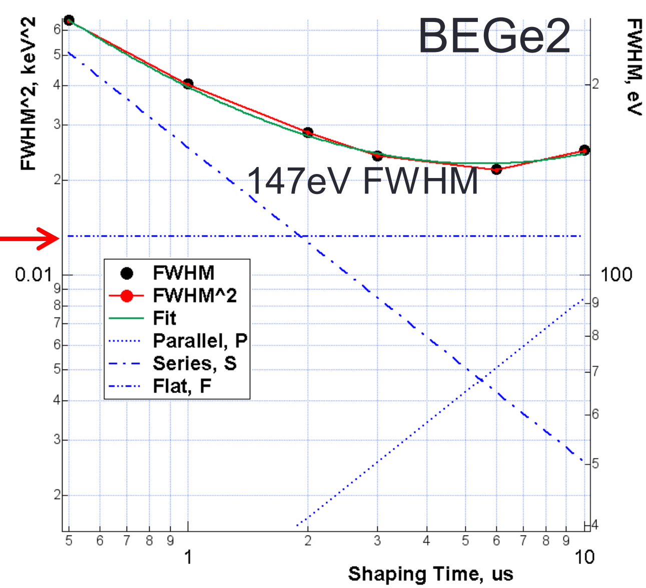


Sources of electronic noise in the Front-End

- ***S*** ~ $C_{detector}$ + $C_{feedback}$ + C_{JFET} + C_{stray}
- $C_{detector}$ reduced with a smaller point contact
- ***P*** ~ $I_{leakage}$, depends on crystal fabrication and operating temperature
- ***F*** is the main noise contribution in BEGe2
- ***F*** ~ $C_{detector}$ + $C_{feedback}$ + C_{JFET} + C_{stray}
- In JFETs, ***F*** noise is negligible
- ***F*** can have another component due to lossy dielectric in contact with JFET input

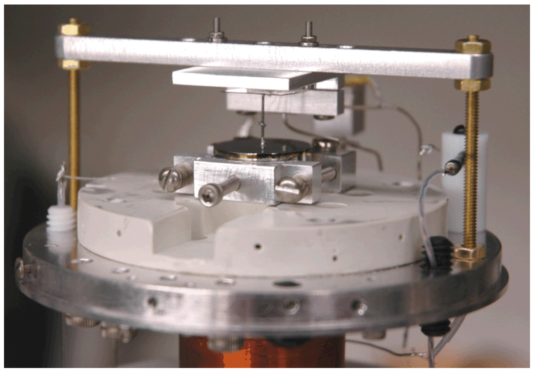
$$FWHM^2 = \frac{S}{\tau} + F + P\tau$$

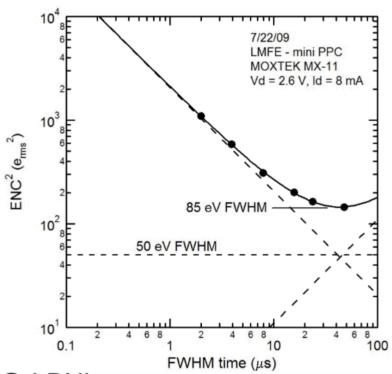
/ = shaping time



BEGe in LBNL Front-End

LBNL mini-PPC-20g

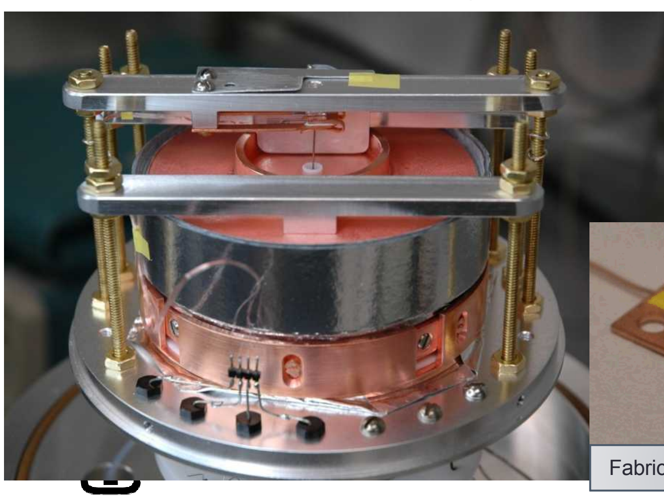




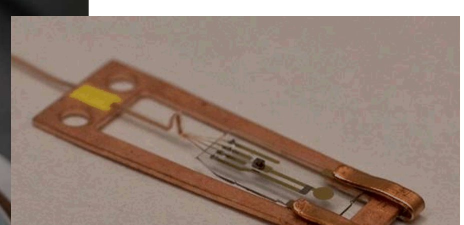
Fabricated by Paul Luke @ LBNL

- FWHM = 85eV, threshold ~ 185eV
- Low-Mass Front-End: JFET in thin silica substrate to reduce stray capacitance, radio purity
- Achieved as low as 55eV FWHM without detector.
- Adapted to test larger BEGe detector to investigate ***F*** noise source

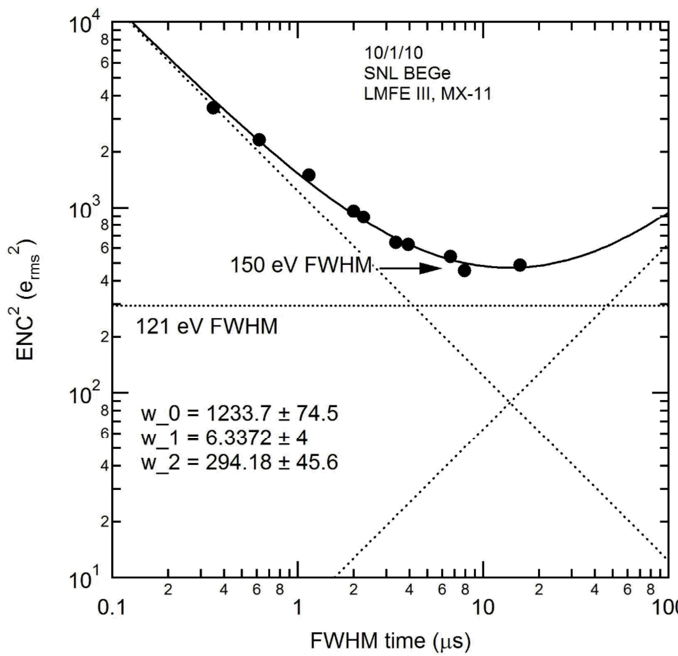
Canberra BEGe 820g



Results w/ BEGe: 150eV FW
identical to in Canberra Fron
End

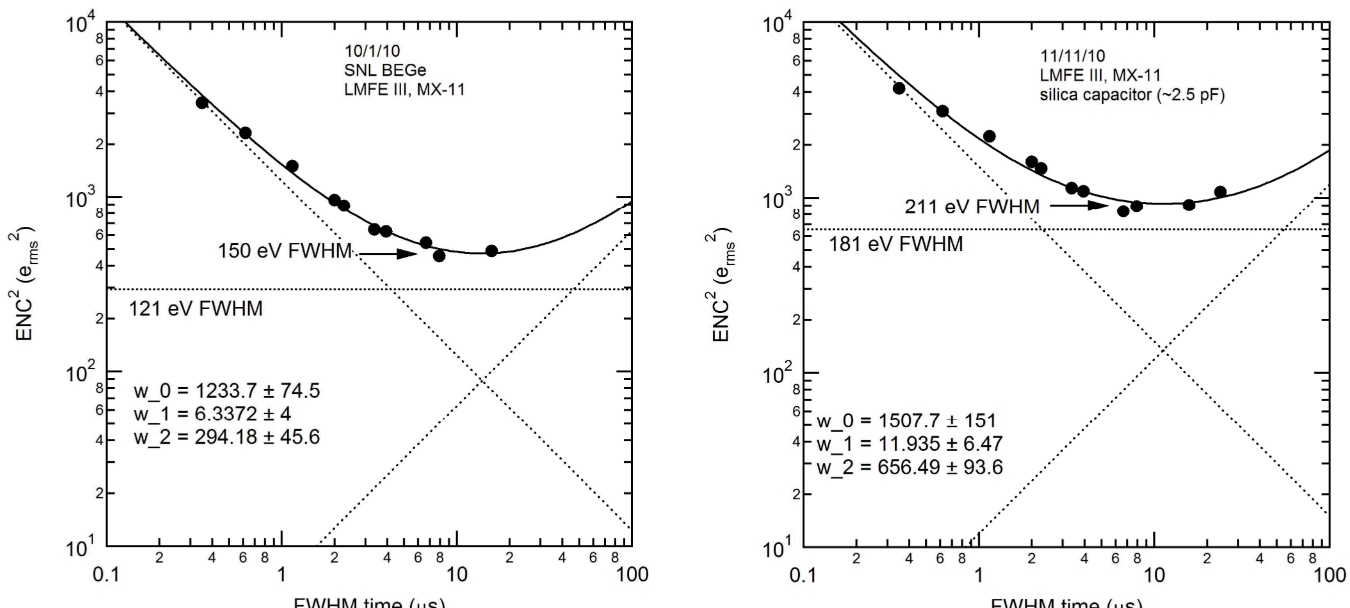


Fabricated @ LBNL



BEGe in LBNL Front-End

BEGe ~ 1.5pF | **Capacitor ~ 2.5pF**



Results by Paul Luke @ LBNL

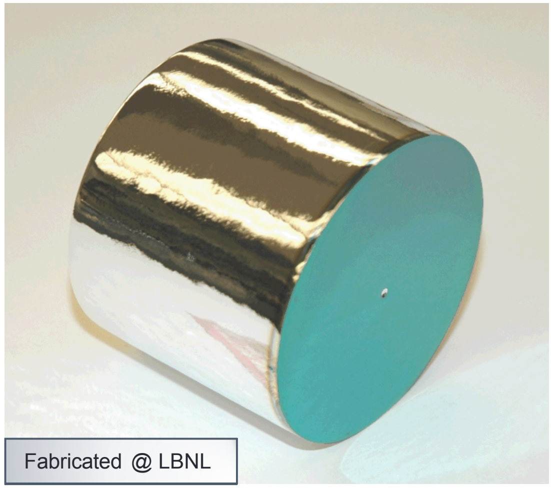
- Replacing detector with a larger capacitor suggest (though not conclusive) that the flat noise is capacitance-induced

- Next: reduce detector capacitance by reducing the point contact size

1-kg PPC in LBNL Front-End

- LBNL currently fabricating 1kg-detector: different surface and contact preparation, 1.5 mm pc diameter
- First iteration: C~0.9pF, $I_{leakage}$~1mA
- Problems with incomplete charge collection, but useful for electronic noise testing
- Modifying readout to 4-terminal JFET (Mx20)
- SNL fabricating cryostat to hold crystal and Front-End board

Goal: First time building a 1-kg Ge detector with ~50-80eVFWHM of electronic noise



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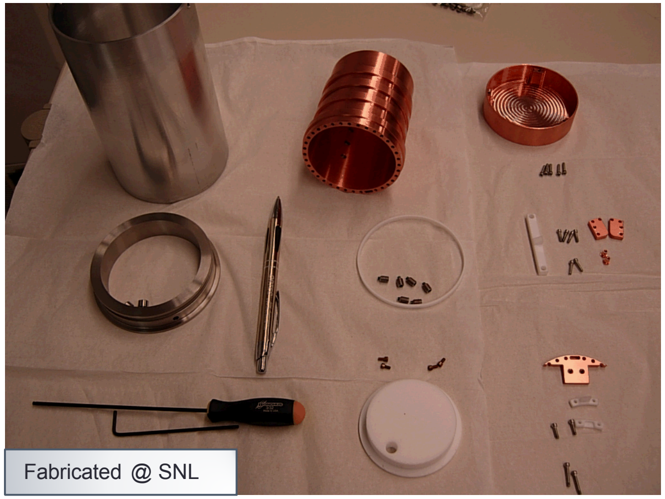


Fabricated @ SNL

Deployable system at a reactor site

1- Requires stringent control of background:

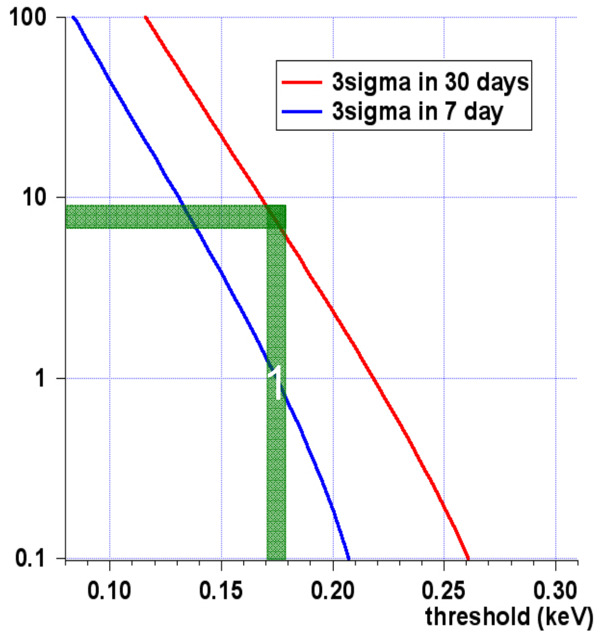
- Shielding of cosmic background: any overburden, tight muon veto, polyethylene neutron moderator and borated thermal neutron absorber
- Reduction of radioactive background: ultra-low background Lead, anticoincidence Compton and neutron veto, radio clean detector materials
- Control and rejection of cosmogenic activation

2- With background of ~8kg^{-1} day^{-1} in range <1keV :

- 175eV threshold (~82eVFWHM) ➔ observation of reactor ON/OFF transition with **3σ in 30days**
- 210eV threshold (~94eVFWHM) ➔ observation of reactor ON/OFF transition with **1.64σ in 30days**

3- CoGeNT deployment at SONGS2009 and Dark Matter experiment CoGeNT2010 showed it could be done

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



Deployable system at a reactor site

- **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.**

Conclusions

- Electronic noise threshold still the main barrier for CNNS observation with PPC HPGe: SNL-LBNL collaboration working on this.
- “Measured” background allow possible observation of CNNS (reactor ON/OFF) at ~210eV of electronic threshold

Backup slides

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 ?		

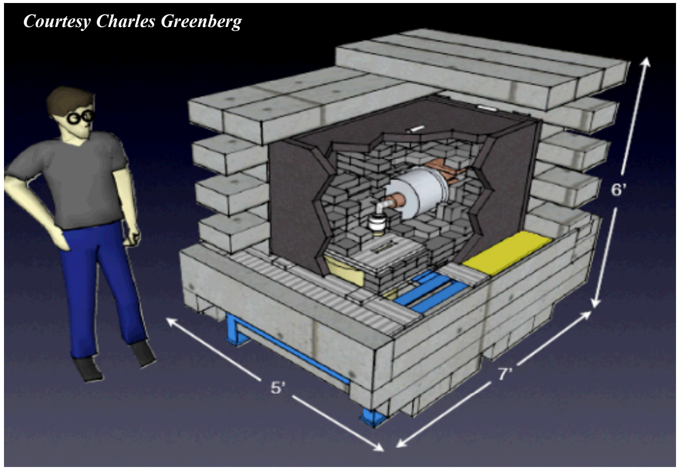
Shielding background particles

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

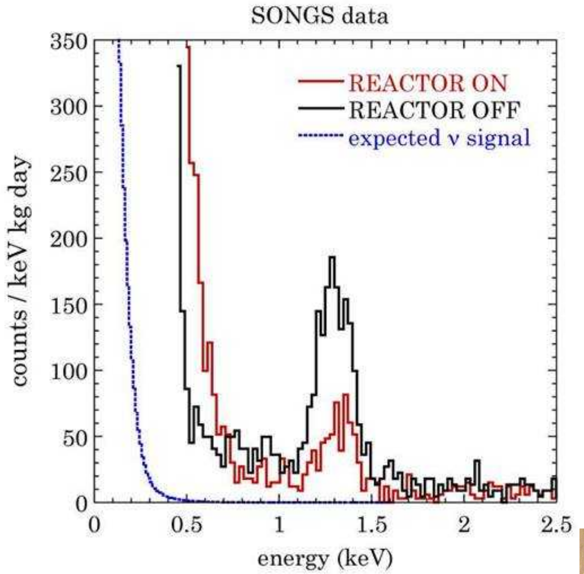


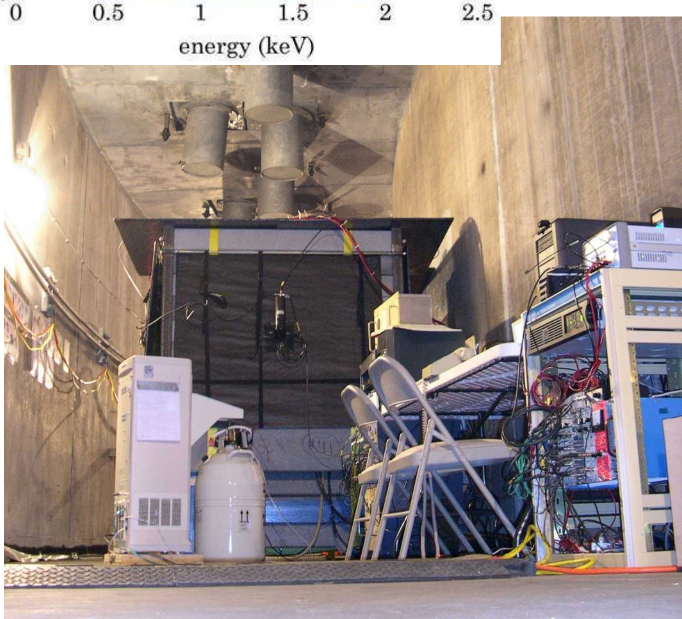
Shielding for SONGS deployment

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).

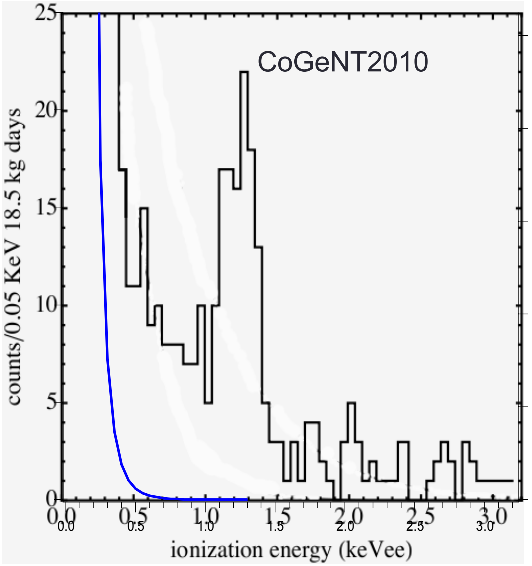




Measured backgrounds from other experiments: underground mine

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

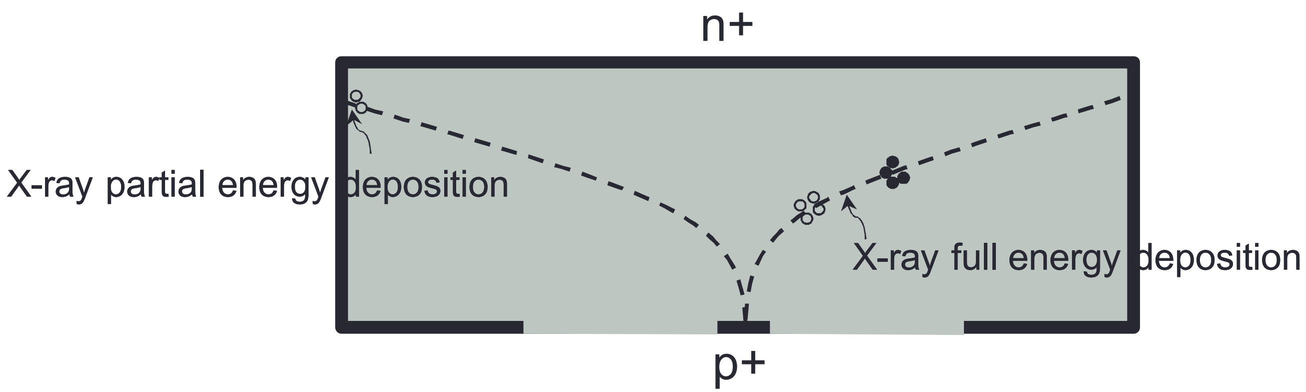
- CANBERA BEGe, 440g, 163eV FWHM
- After 3 months underground, and “microphonics” and “risetime” cuts
- Background counts: **~2keV^{-1}kg^{-1} d^{-1}**
- Near-threshold counts: **~8keV^{-1}kg^{-1} d^{-1}**



- **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**

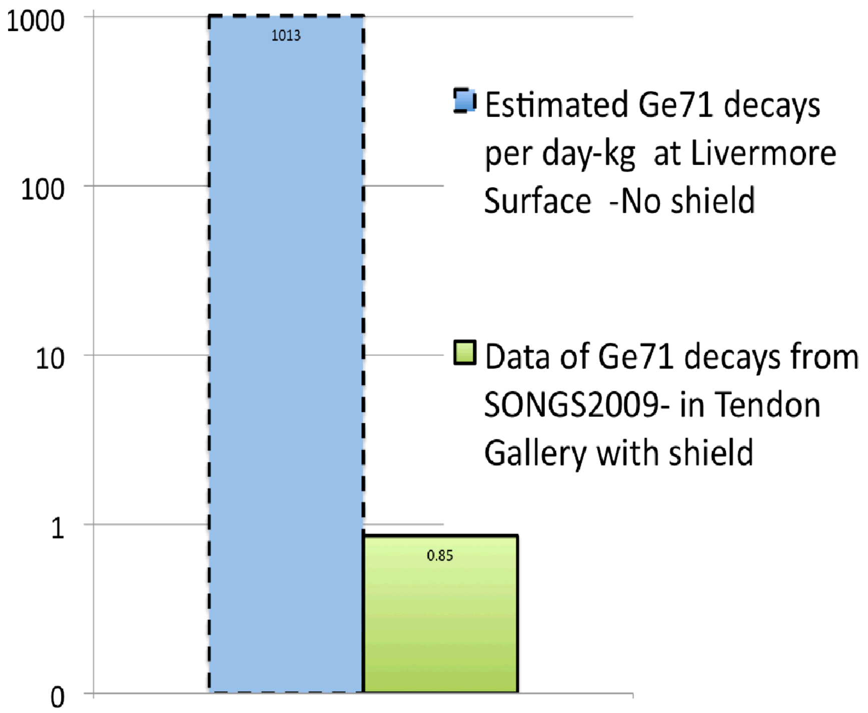
How “Risetime” cuts work

- 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



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)



Deployable system

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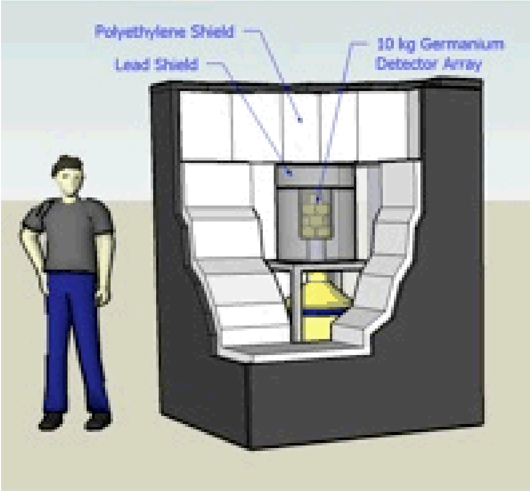
- Little or no safety concerns from the facility operators.
- In addition, the ability to shrink the active detector from 1 ton of scintillator material to something on the order of 10 kg of germanium would allow for much more flexibility in finding locations suitable for detector installation.
- A smaller detector will also present a smaller area for interaction with cosmic backgrounds.

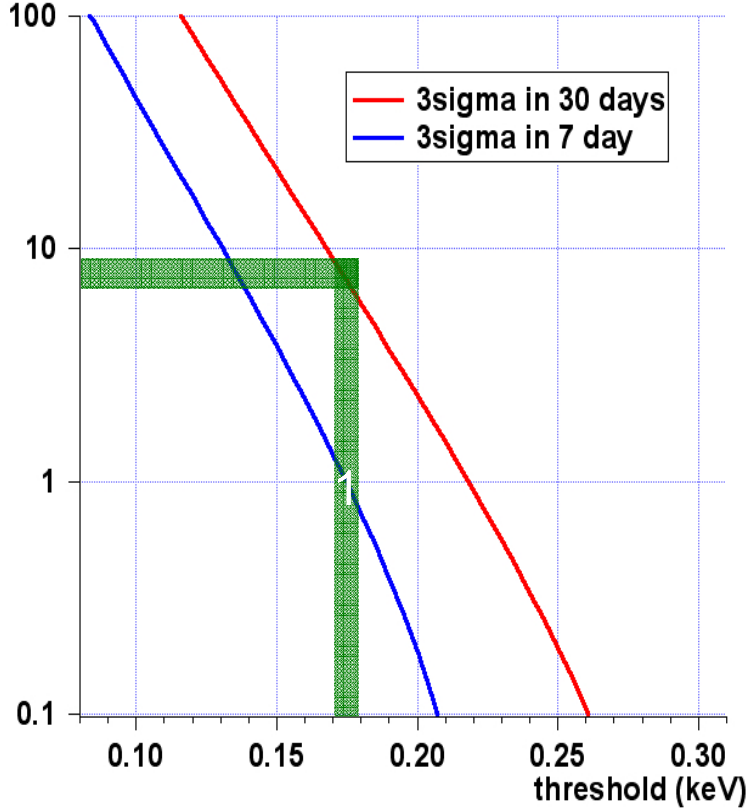


Signal vs. Background

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



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%*?

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