SAND2012-9862C

Development of a Germanium Detector for Reactor Monitoring

David Reyna

Belkis Cabrera-Palmer

Sandia National Laboratories, CA

In Collaboration with

P. Barton, M. Amman, P. Luke, K. Vetter

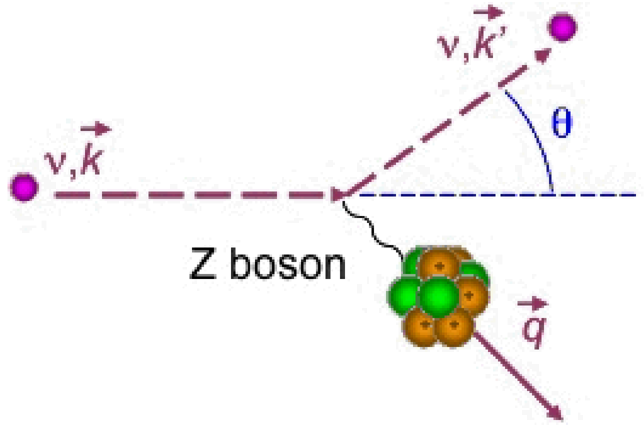
Lawrence Berkeley National Laboratory

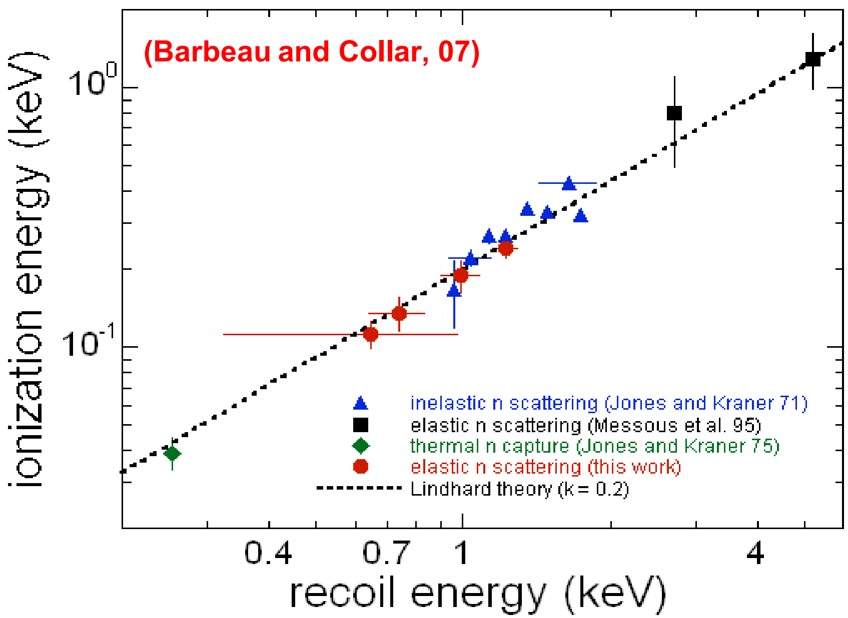
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Coherent Neutrino-Nucleus Scattering (CNNS)

- Cross section enhanced by N^2
- Product is a recoiling Ge nucleus
- Condition for coherence: transfer momentum q << 1/(Ge nucleus radius)

~ tens of MeV





- Reactor antineutrinos produce Ge recoils of <~3keV
- Only ~20% of the Ge recoil energy is converted into ionization
- Measure Signal of <~600eV

Why Germanium?

Recoil energy $E_r = \dfrac{E_\nu^2(1-\cos\theta)}{MA}$ **, where M = nucleon mass[1]**

Average recoil energy $\langle E_r \rangle = 716\ \text{eV}\ \dfrac{(E_\nu/\text{MeV})^2}{\boxed{A}}$

Lower A (and N) is better

If the maximum recoil energy is below threshold, we won't see any recoils at all. The optimized target isotope depends on detector performance.

With Germanium, ~3eV / electron, we drift 100's of electrons.

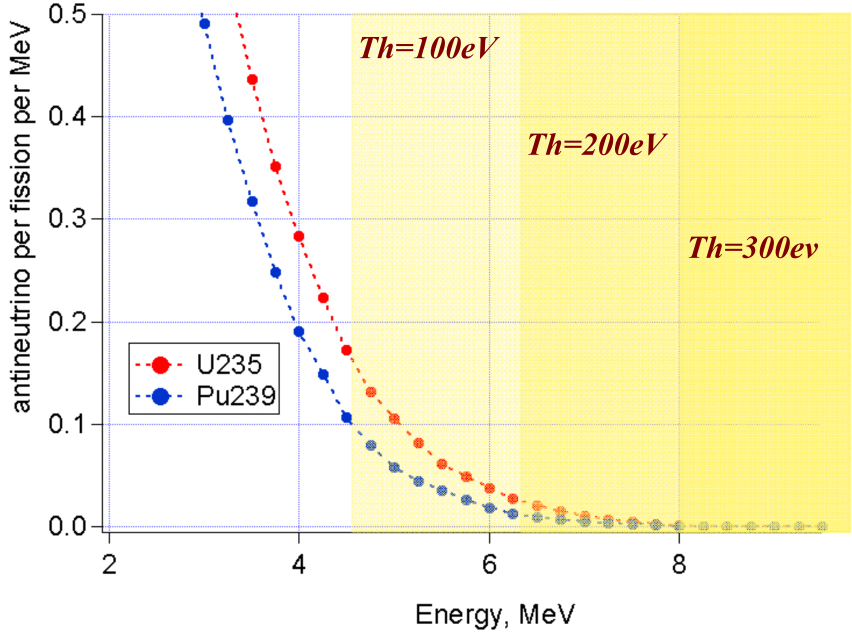
Challenge is to surpass electronic readout noise.

Ionization table

# of e^-	Ar (%)	Xe (%)
0	71.0	98.9
1	15.1	1.1
2	6.7	small
3	3.2	
4	1.7	
5	0.9	

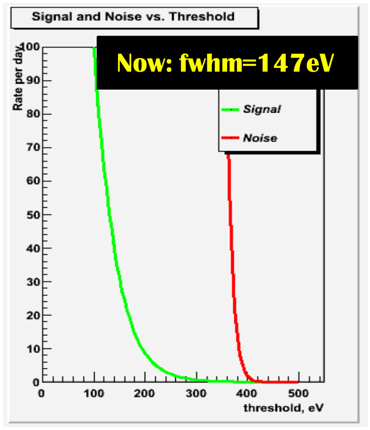
[1] **Drukier & Stodolsky, *PRD* 30(11), 1984.**

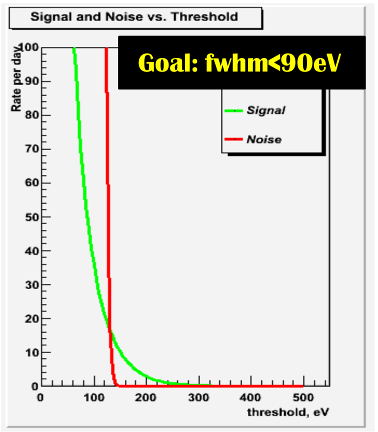
Antineutrino signal vs. HPGe threshold



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**



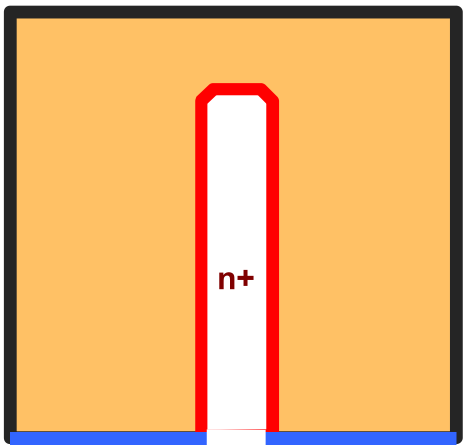


FWHM = 2.35 σ

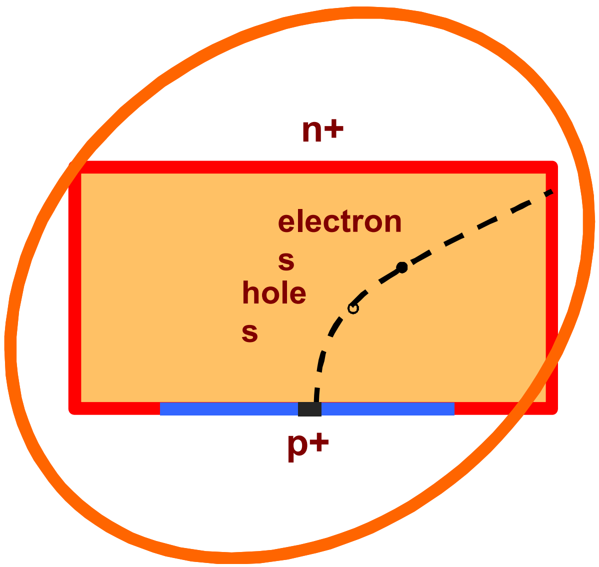
Threshold ~ 5 σ

The noise pedestal recedes faster than the signal with decreasing noise

Point-Contact HPGe detector

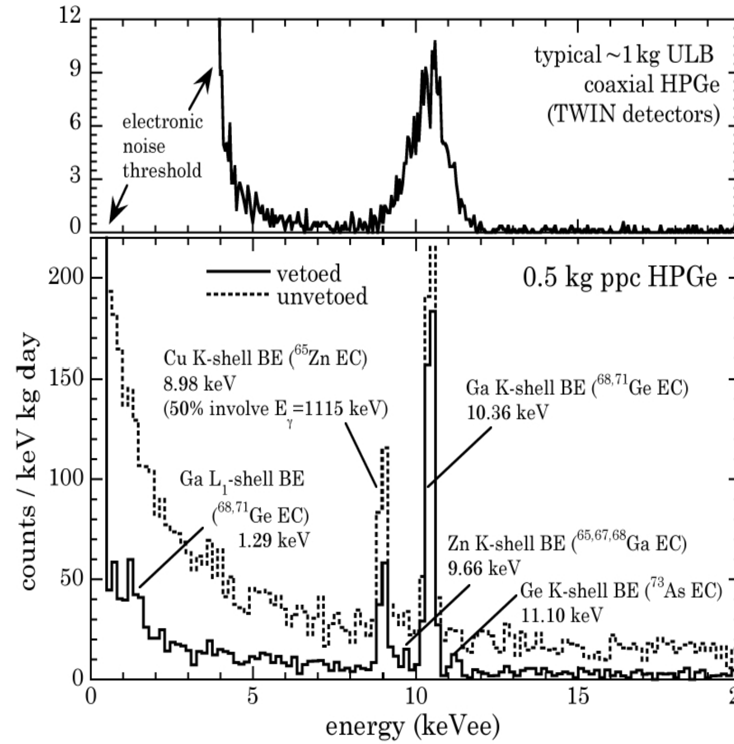


- Coaxial C~20pF
- ~1kg
- Typical FWHM ~1.8keV



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

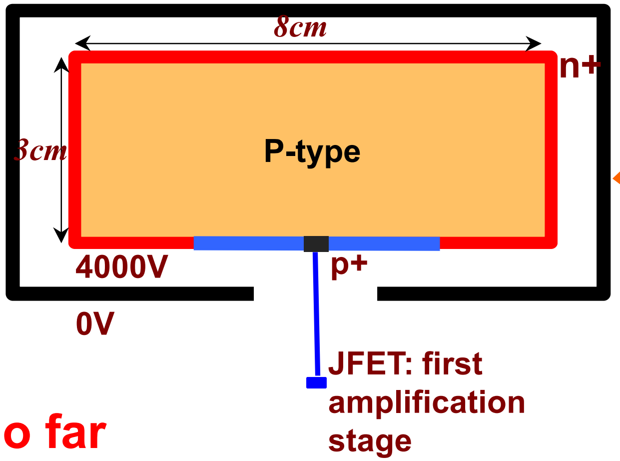
Decrease capacitance to lower noise threshold and improve resolution



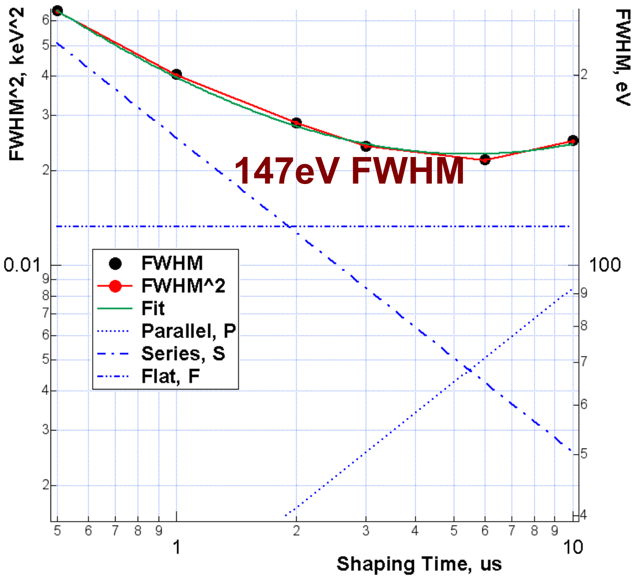
Aalseth *et al.* PRL 101, 251301 (2008)

BEGe2: a P-type 'Point' Contact

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



147eV FWHM is the lowest value **so far for a large mass Germanium detector, but** still too high



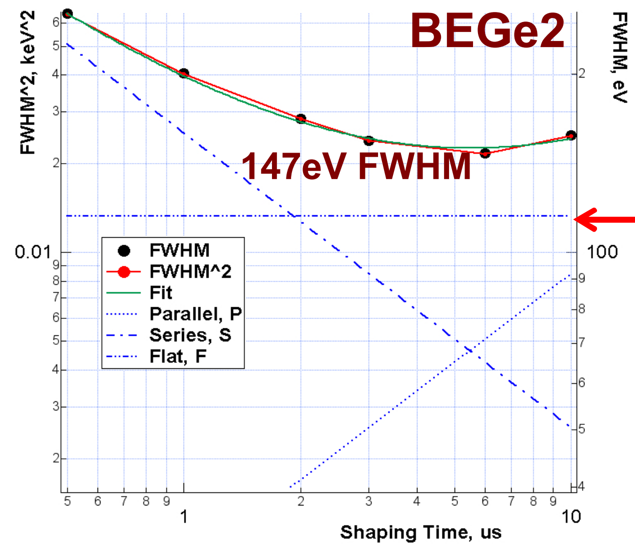
Negligible contribution from other circuits (preamp and High Voltage) according to SPICE analysis

Most of noise from detector element and Front-End (FE) electronics (HPGe crystal + JFET assembly)

Sources of electronic noise in the Front-End

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

τ = shaping time



Usually, the smaller the input capacitance is at the first amplification stage of the signal, the lower the electronic noise at the output.

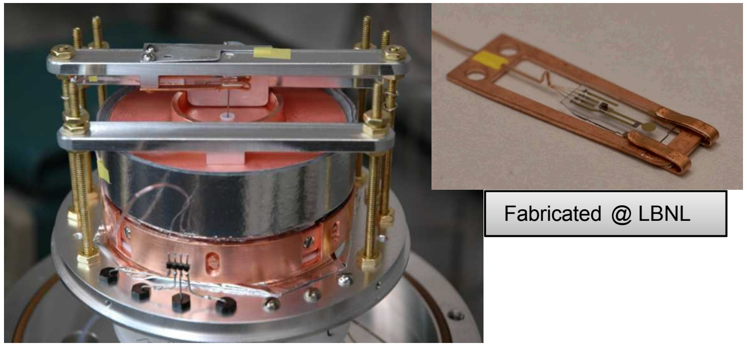
- $S \sim C_{detector} + C_{feedback} + C_{JFET} + C_{stray}$
- $F \sim C_{detector} + C_{feedback} + C_{JFET} + C_{stray}$
- $C_{detector} \propto$ A(contact diame

$P \sim I_{leakage}$, **depends on crystal fabrication and operating temperature**

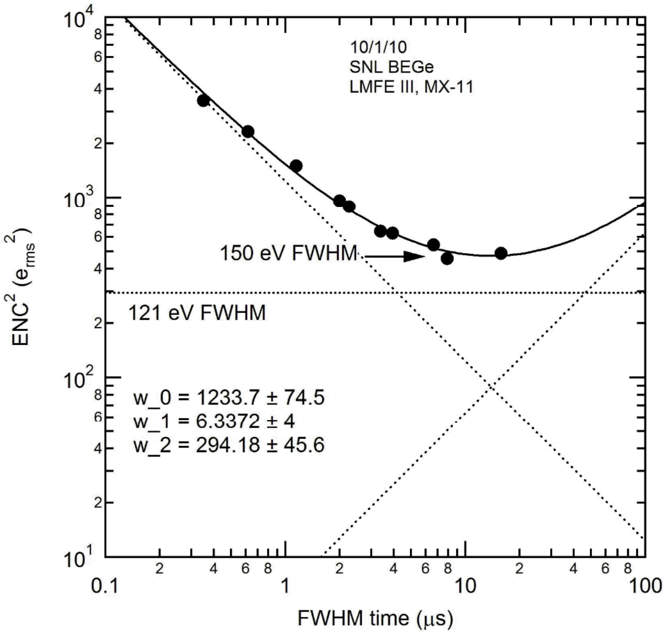
- ***F* is the main noise component in BEGe2**
- **In JFETs, *F* noise is negligible**
- ***F* can also originate from lossy dielectric in contact with JFET input**

BEGe2 with LBNL Front-End

- LBNL Front-End proven performance with 20g mini PPC: 85eV FWHM
- Achieved as low as 55eV FWHM without detector
- JFET on thin silica substrate to reduce stray capacitance



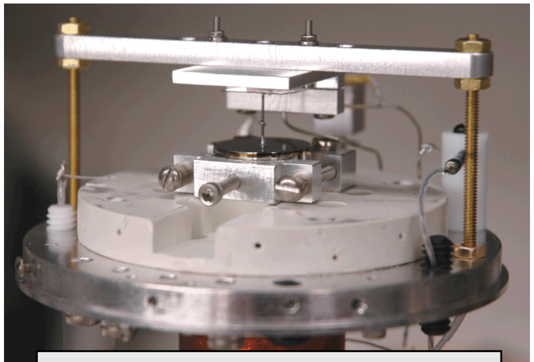
Fabricated @ LBNL



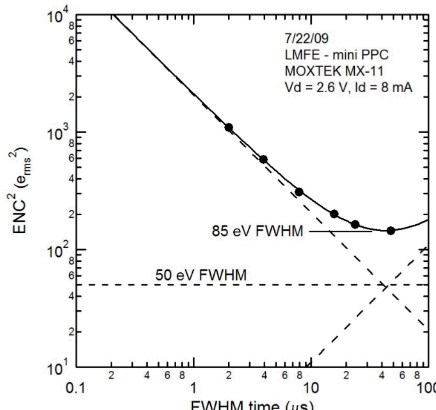
- All noise components are identical in two very different FE assemblies (Canberra FE with 4-terminal Mx20 JFET vs. LBNL FE with 3-terminal Mx11 JFET)
- Therefore, noise originates from the detector element

Testing in LBNL Front-End

LBNL mini-PPC-20g



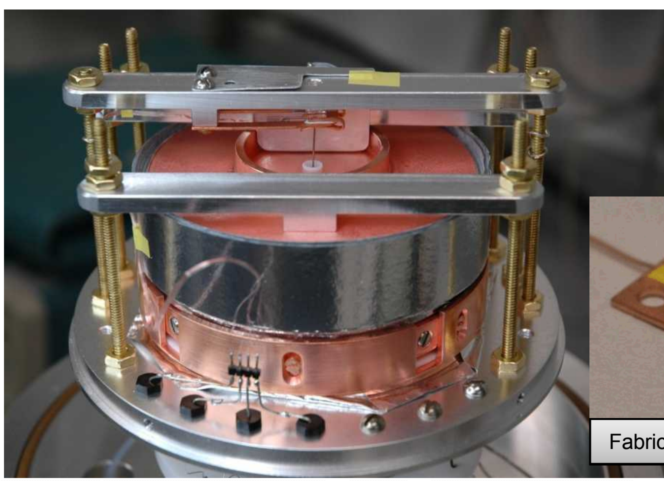
Fabricated by Paul Luke @ LBNL



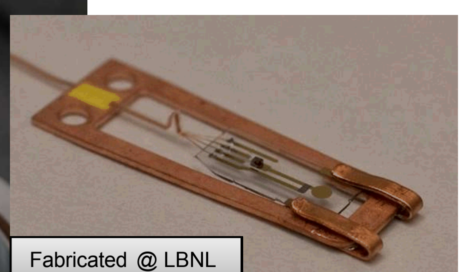
Results by Paul Luke @ LBNL

- **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**

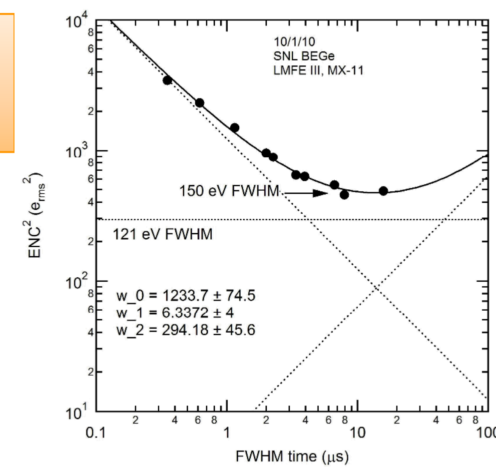
Canberra BEGe 800g



Results w/ BEGe: 150eV FWHM, same as in Canberra Front-End

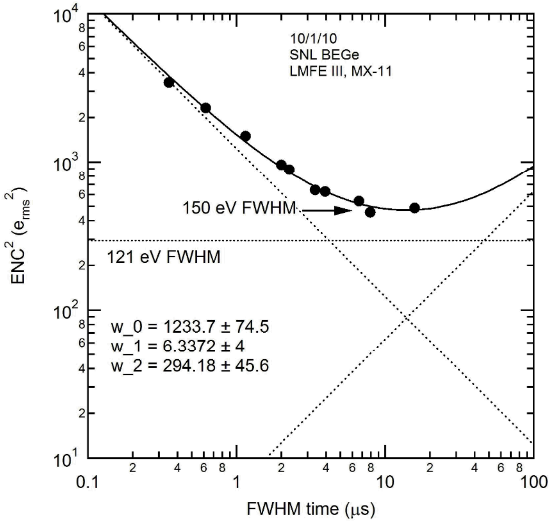


Fabricated @ LBNL



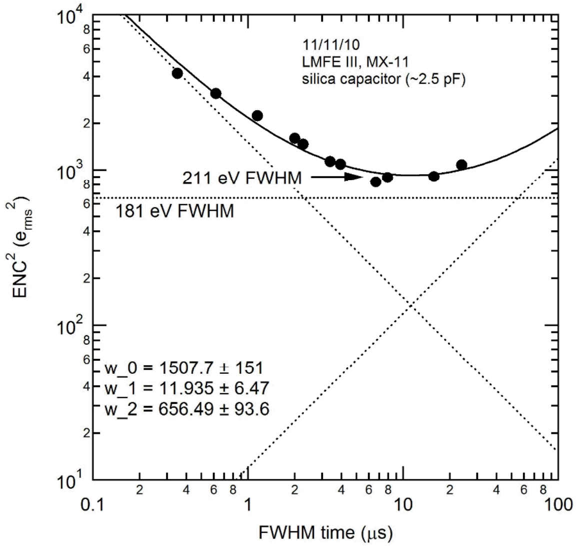
Testing in LBNL Front-End

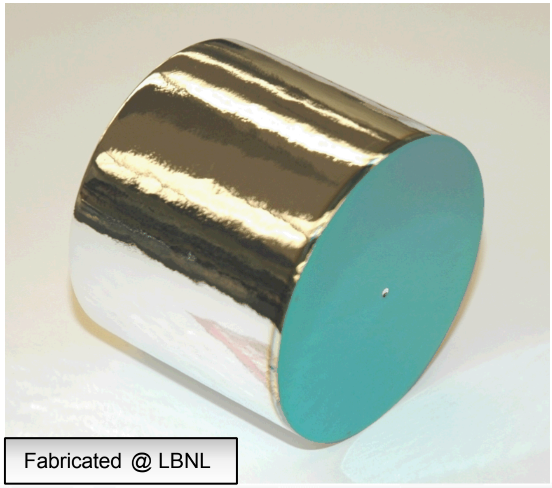
BEGe ~ 1.5pF



- Replacing detector with a larger capacitor suggest that the flat noise is capacitance-induced
- Next: reduce detector capacitance with a smaller point contact!

Capacitor ~ 2.5pF





Fabricated @ LBNL

LBNL currently fabricating 1kg-detector: different surface and contact preparation, 1.5 mm pc diameter

First iteration: C~0.9pF, $I_{leakage}$~1mA

Adapting LMFE cryostat to different aspect ratio **crystal**

Modifying readout to 4-terminal JFET (Mx20)

Problems with incomplete charge collection

Can we achieve (~50-80eV FWHM) with a 1-kg large crystal?

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 v	Scattering off Ge nucleus	Ge-nucleus recoils
WIMP ?		

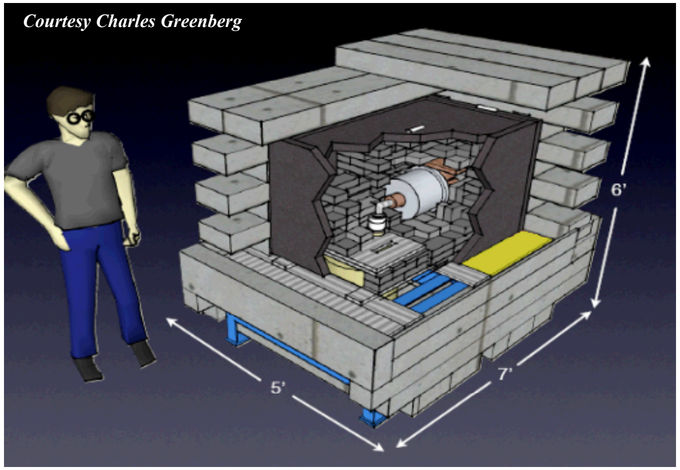
Shielding background particles

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

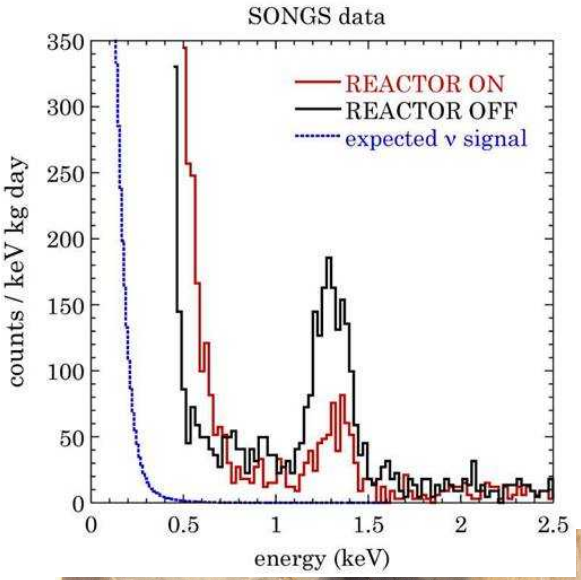


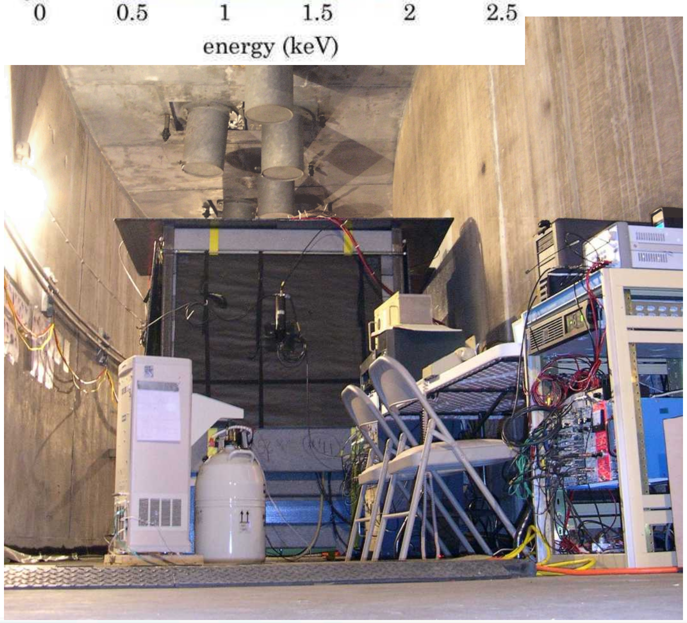
Shielding for SONGS deployment

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).**

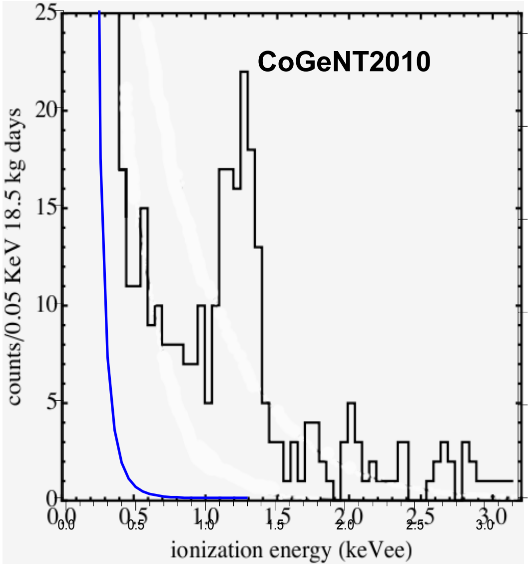




Measured backgrounds from other experiments: underground mine

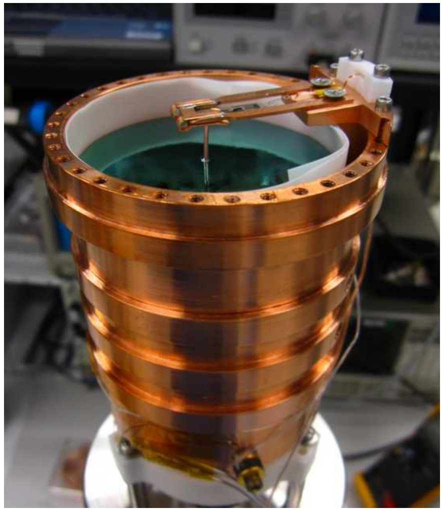
CoGeNT2010 data: in Soudan mine at 2,100m.w.e.

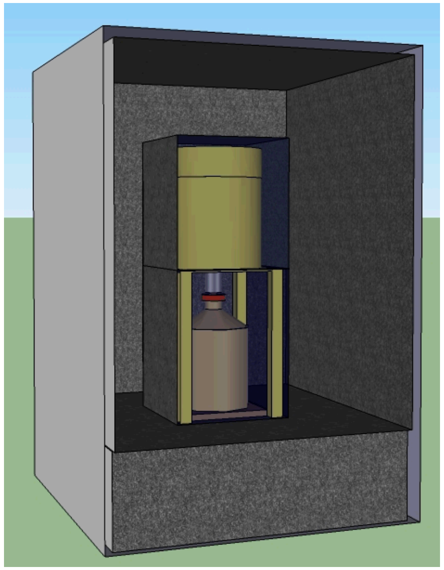
- **CANBERA BEGe, 440g, 163eV FWHM**
- **After 3 months underground, and "microphonics" and "risetime" cuts**
- **Background counts: ~2keV^{-1}kg^{-1} d^{-1}**
- **Near-threshold counts: ~8keV^{-1}kg^{-1} d^{-1}**



- **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**

Conclusions





- Electronic noise threshold is the main barrier for CNNS observation with PPC HPGe detectors
- Our tests indicate that the path to lower noise is smaller capacitance: reducing detector and stray capacitance
- LBNL-SNL working on development of 1-kg detector with small point contact diameter and optimized low-threshold FE
- "Measured" background (CoGeNT2010, SONGS2009) allow possible observation of CNNS (reactor ON/OFF) at ~210eV electronic threshold