THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

Low background physics at the Kimballton Mine

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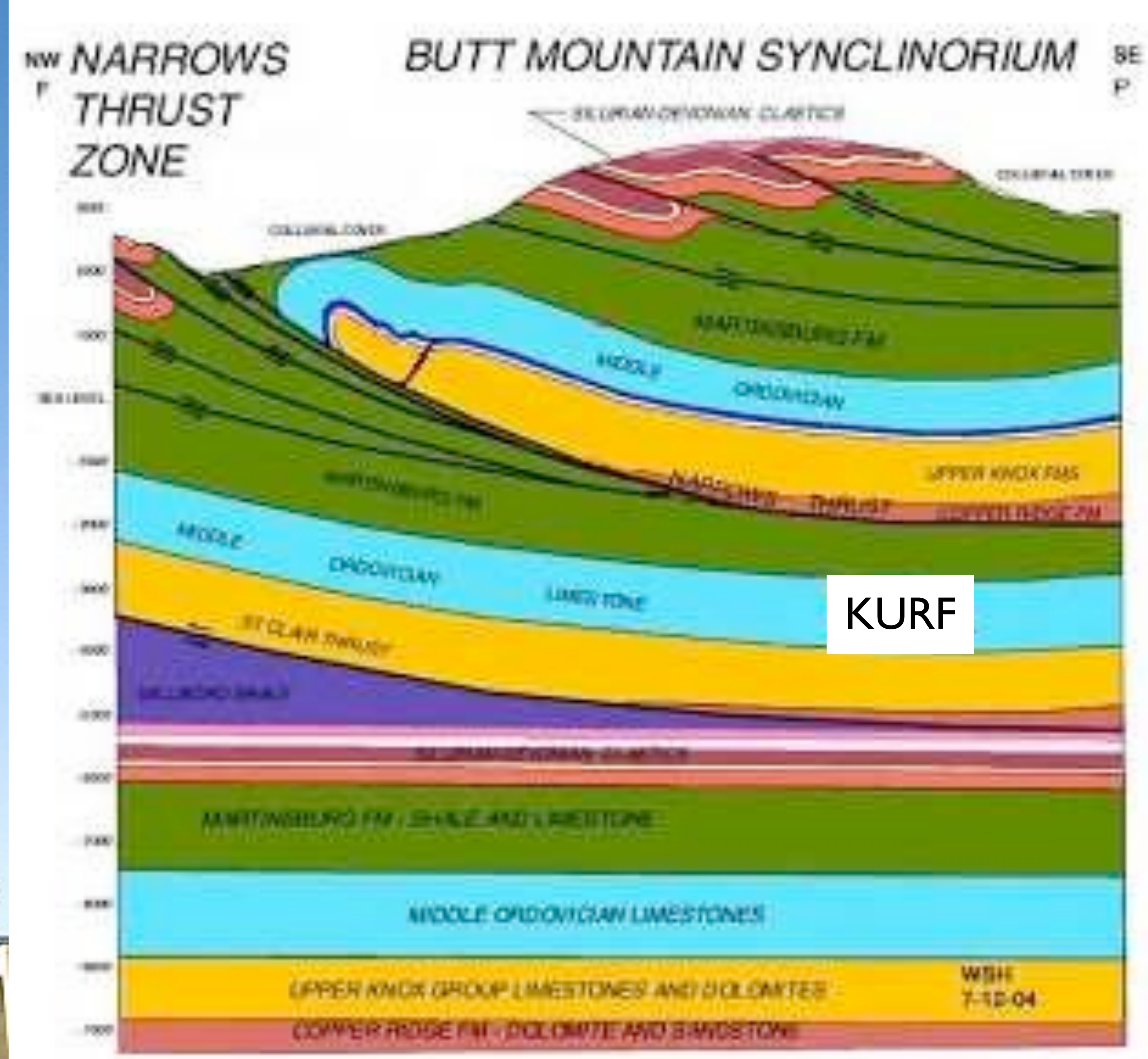
LRT
August 28, 2010

Kimballton Underground Research Facility (KURF)

- Low background counting facility (UNC/TUNL)
- Majorana Low-background BEGe at KURF (MALBEK) (UNC/TUNL)
- Double beta decay to excited states (Duke/TUNL)
- Neutron characterization (UMD/NIST)
- miniLENS (Va Tech)

KURF Basics

- Ripplemeade, Va. 30 minutes from Virginia Tech
  - Chemical Lime Co. limestone mine (700 kTon/y)
- Experimental area is on 14th level, 520 m (1450 m.w.e.)
  - Drive-in access
  - Power, water, ethernet, air filtering, mining support
  - Laboratory maintained by Virginia Tech



Gamma Assay

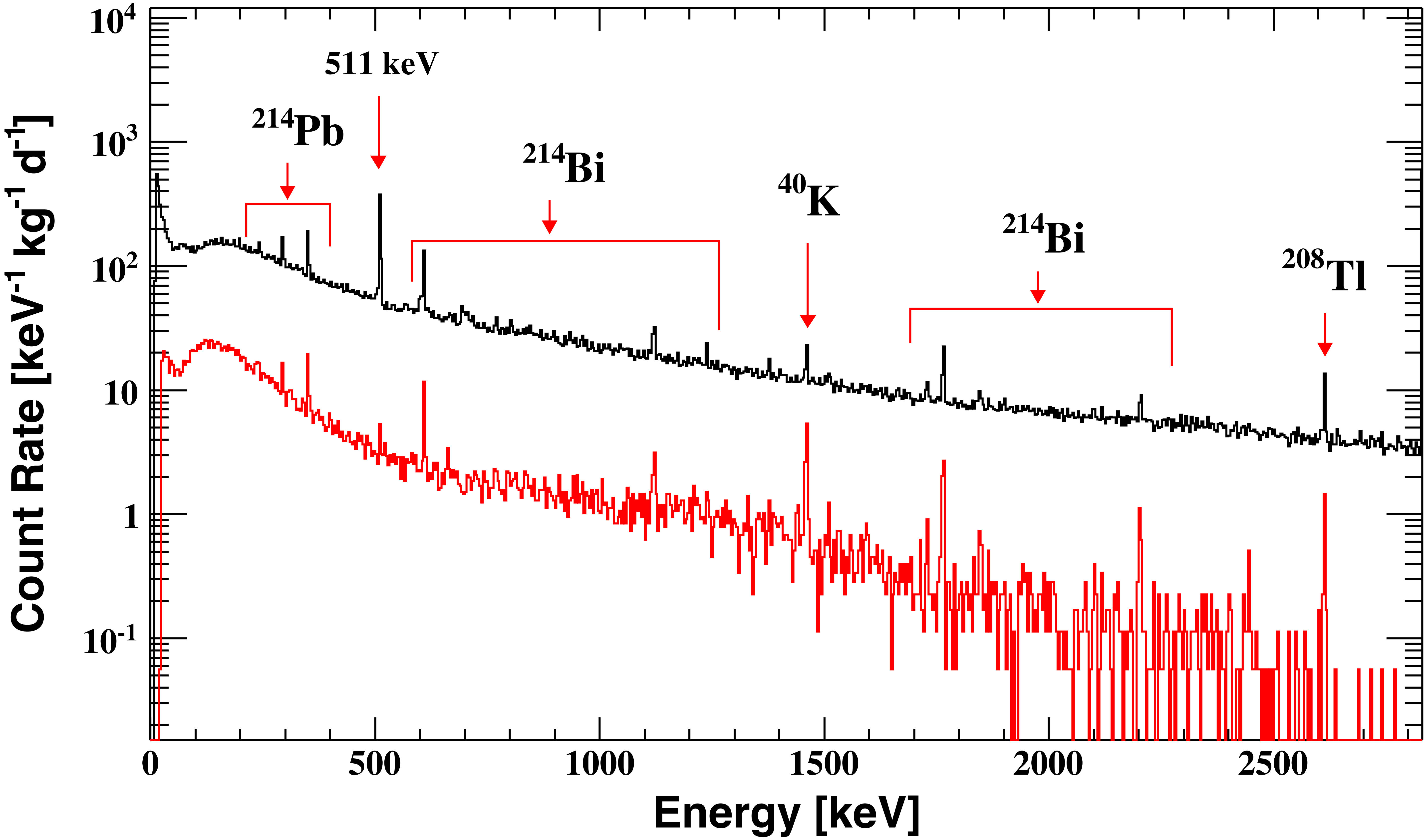
Two commercial HPGe detectors to screen for ^{238}U, ^{232}Th, ^{40}K

MELISSA

- 50% RE Canberra LB
- 1.7 keV (FWHM) at 1333 keV
- ~20 keV threshold
- 6" Doe Run lead shield
- 1" OFHC copper inner shield

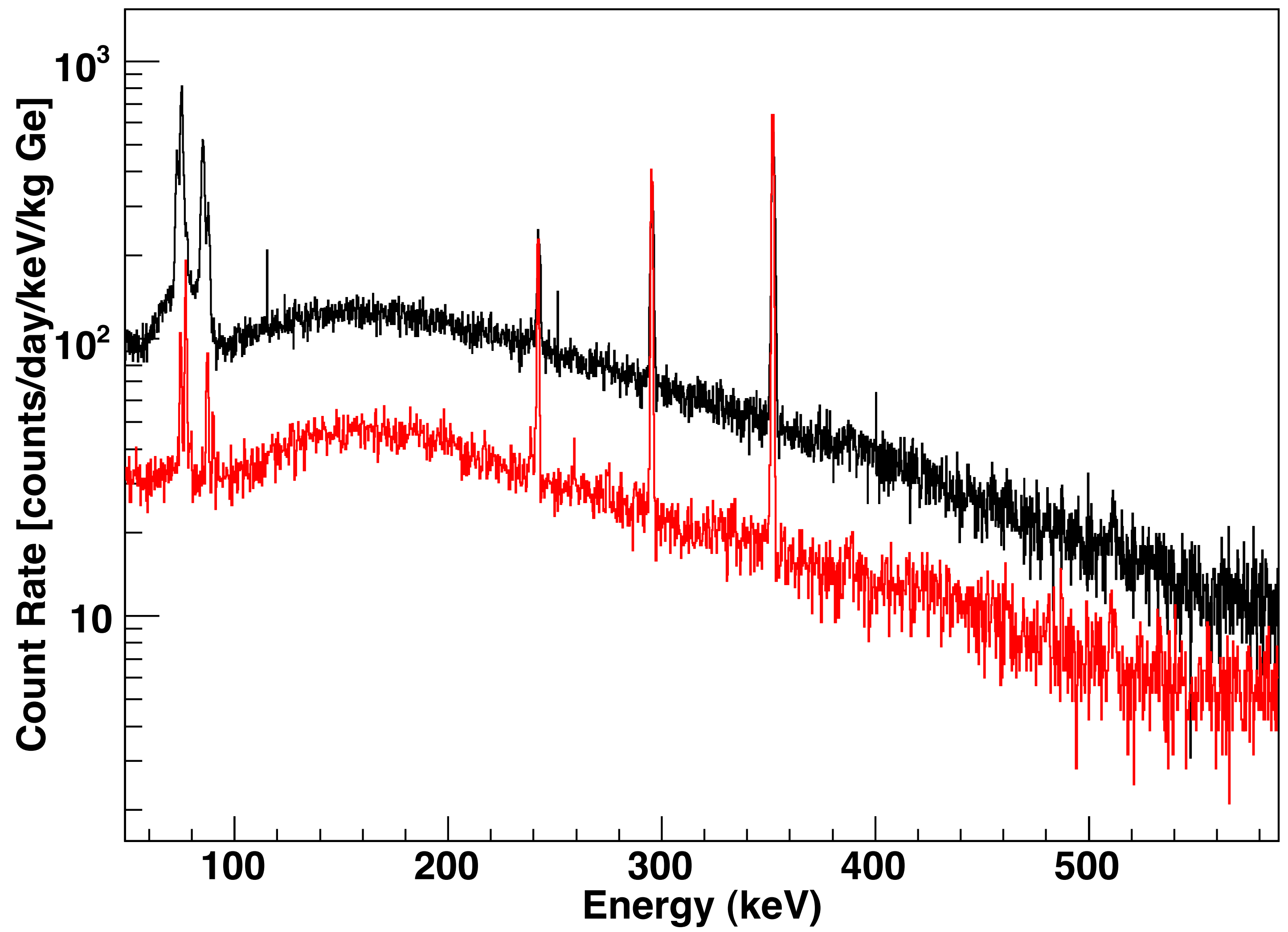
VT-1

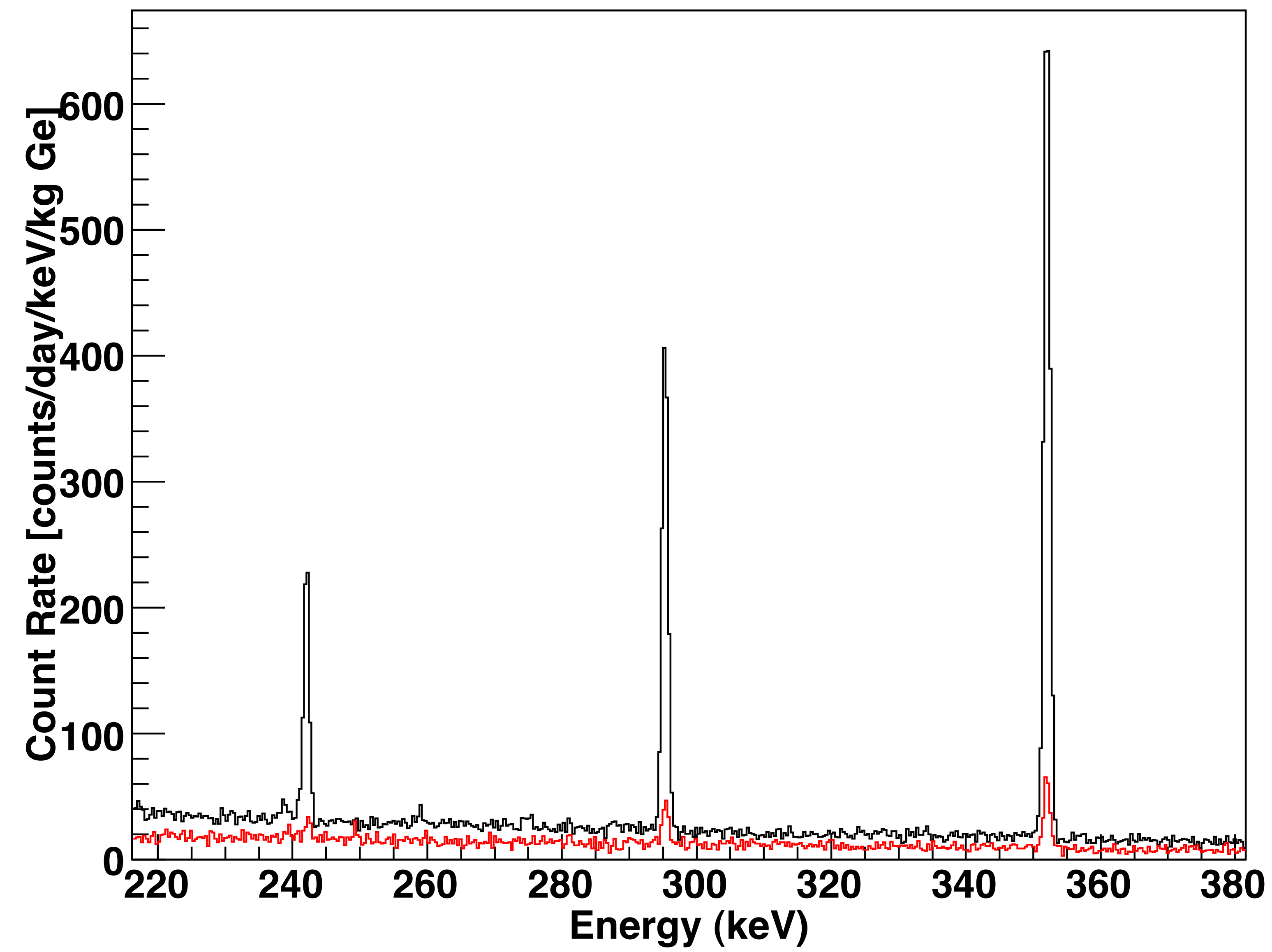
- 35% RE Ortec GEM low-background
- 1.8 keV (FWHM) at 1333 keV
- ~20 keV threshold
- 4" commercial lead shield
- 0.116" OFHC copper lining



	Melissa [cpd]	VT-1 [cpd]	VT-1 (surface) [cpd]
40-2700 keV	7.8 k	7.6 k	84 k
40-1000 keV	7.5 k	6.5 k	68 k
1000-2700 keV	270	710	16 k

Background Reduction





OFHC copper shield

- Reduces Compton continuum from ^{210}Pb
- β-decay Brehmsstrahlung
- Graded shield:
- PE absorption in Pb 75-80 keV X-ray
- Cu fluorescent X-rays are 8-9 keV

Radon mitigation

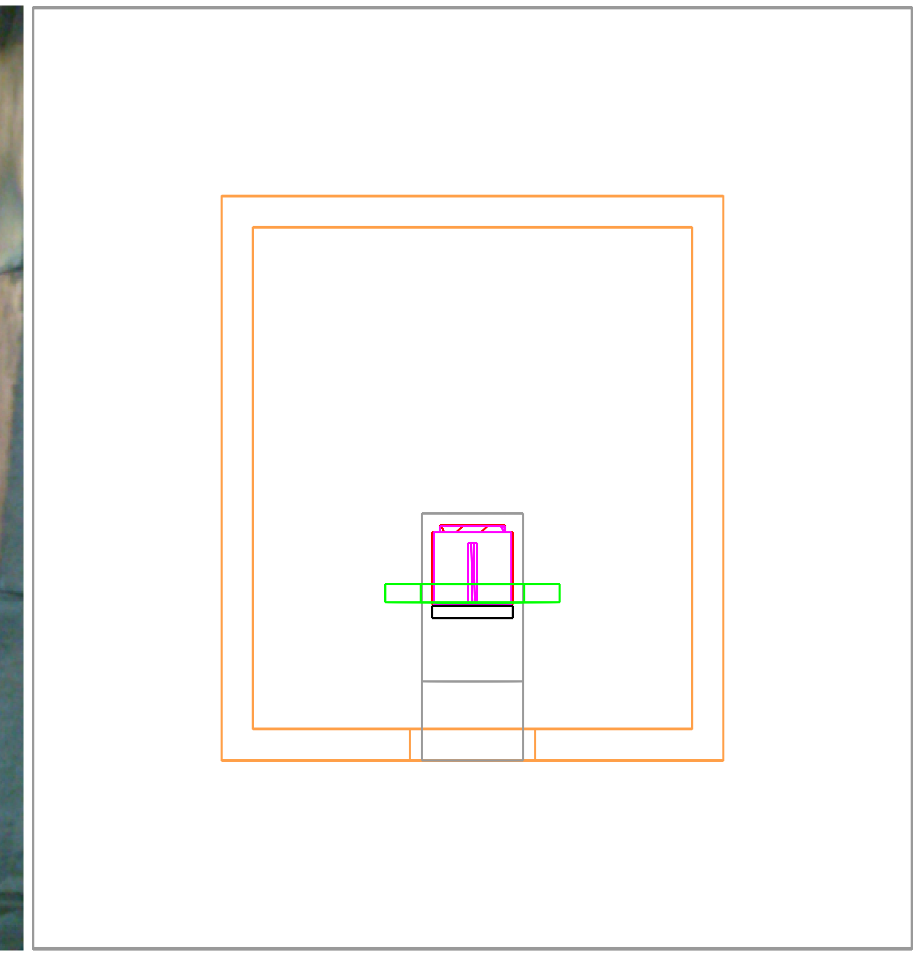
- Radon varies seasonally:
  - 3 pCi/l (summer), 0.5 pCi/l (winter)
- Dry nitrogen purge from dedicated boiloff dewar

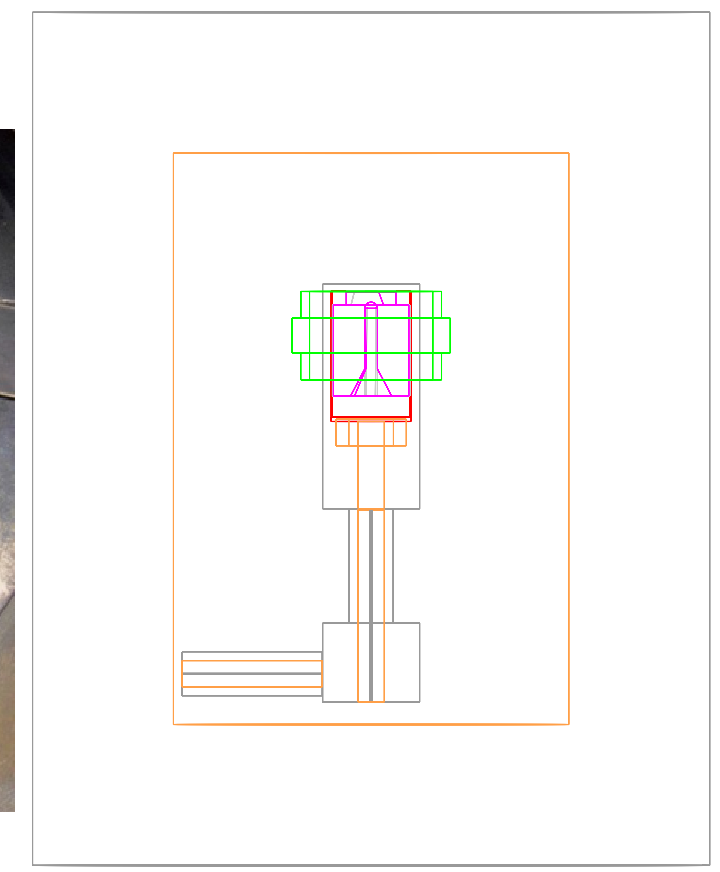
Efficiency Calculations

Efficiency depends on
- Detector (crystal size, dead layer, etc...)
- Detector and shield geometry
- Source geometry

Use MaGe/GEANT4 to simulate each sample

Monte Carlo Validation using point sources with known activity
- < 10% systematic error in efficiency

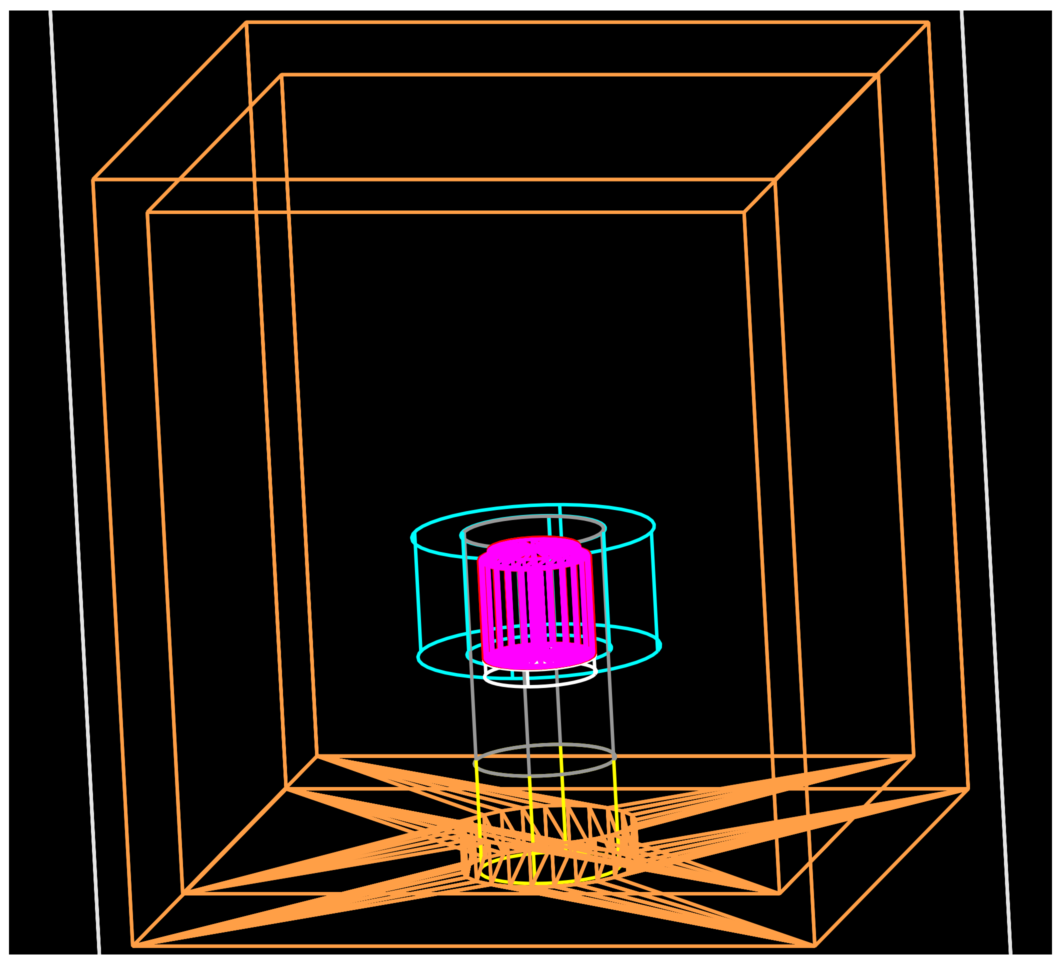


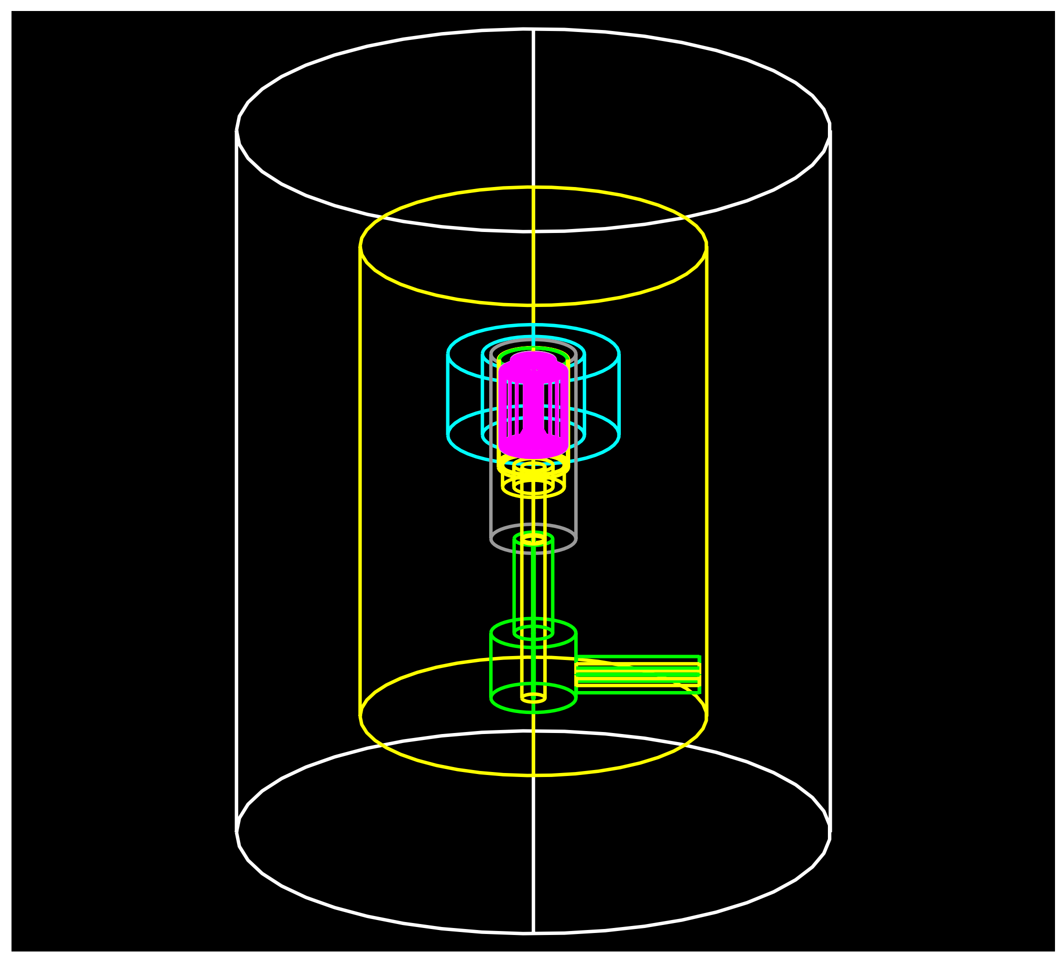


Detector Sensitivity

Sample: 1 kg Teflon in a Marinelli beaker

		Melissa		VT-1	
Energy[keV]	Isotope (Chain)	cts/day	Det. Lim. [mBq/kg]	cts/day	Det. Lim. [mBq/kg]
63	$^{234}Th(^{238}U)$	81 ± 1	80	79 ± 4	190
609	$^{214}Bi(^{238}U)$	59 ± 2	10	53 ± 3	15
238	$^{212}Pb(^{232}Th)$	133 ± 3	6	104 ± 5	10
911	$^{228}Ac(^{232}Th)$	5.7 ± 0.7	5	13 ± 2	20
1416	^{40}K	19 ± 1	30	32 ± 3	90





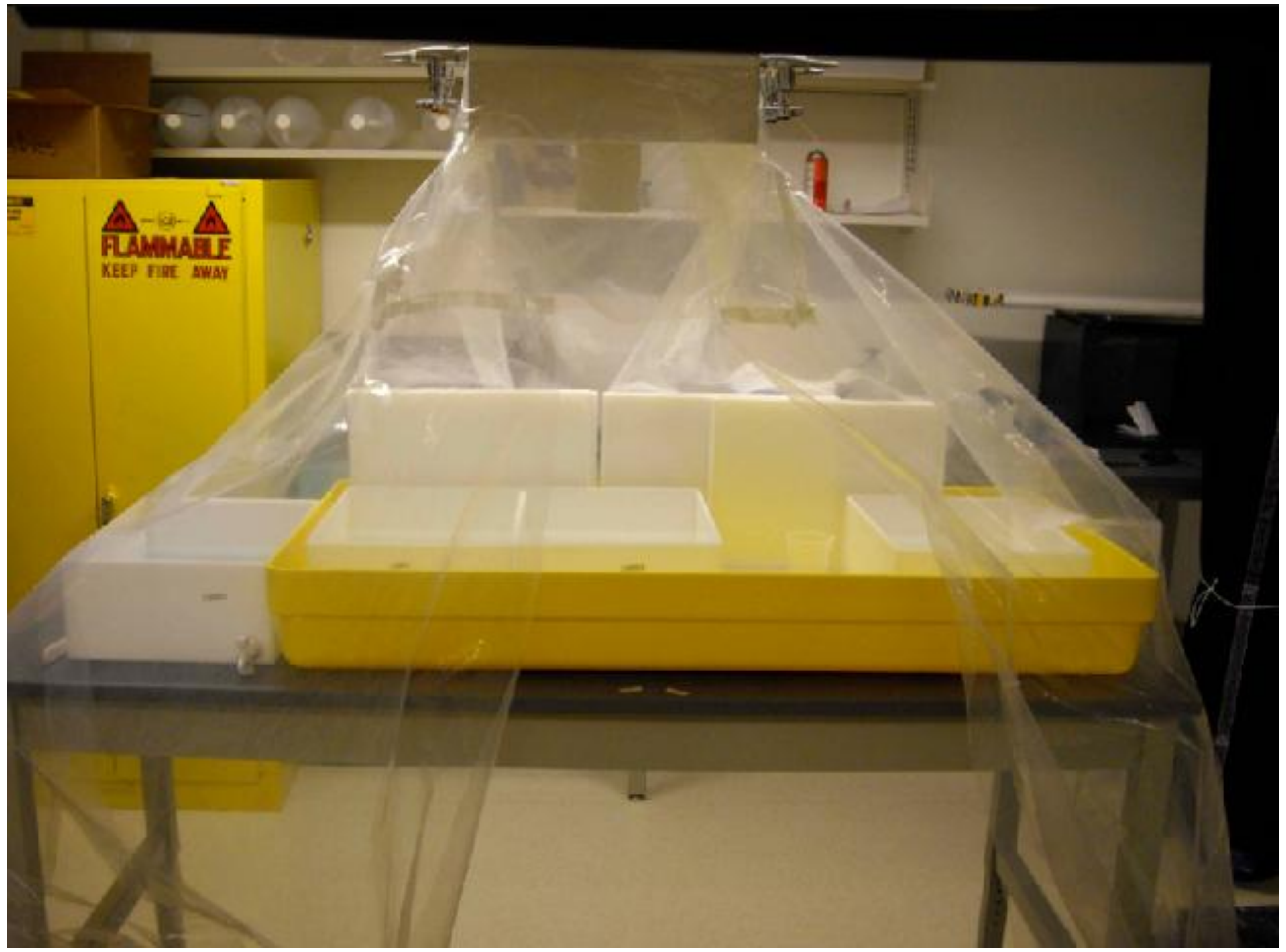
Assay Results

Sample	Detector	U(e) [Bq/kg]	U(l) [Bq/kg]	Th(e) [Bq/kg]	Th(l) [Bq/kg]	K [Bq/kg]	^{60}Co [Bq/kg]
Table Mountain rock	Melissa		100±40	100±40	270±120	790±320	
Table Mountain rock	VT-1		100±40	100±40	300±120	730±290	
Superinsulation panels	Melissa		3.0±1.2		0.09±0.03	0.9±0.4	
Aluminum stock flange coupling	Melissa	7.1±2.3	1.5±0.4	<0.1	1.5±0.4	<0.3	
PMT base electronic components	Melissa	<7	1.5±1.0	0.8±0.6	0.6±0.4	3.3±1.9	
PMT base electronic components	VT-1	<4	1.1±0.7	0.8±0.4	0.6±0.3	3.6±1.8	
Zeolite molecular seive	Melissa	5.8±1.2	8.2±0.8	9.6±0.6	10.5±0.6	4.4±0.5	
Great Stuff™ foam insulation	Melissa		<0.4		<0.3	<0.5	
Axon Picocoax®	VT-1	<1.2	<0.35	0.060±0.020	0.055±0.010	700±200	<0.018
Sullivan lead bricks	Melissa	<0.023	<0.003	<0.001	<0.0007	<0.005	
University of Washington lead bricks	Melissa	<0.026	<0.005	<0.002	<0.0007	<0.005	
PEEK plastic	VT-1	<0.40	<0.070	<0.065	<0.050	<0.260	<0.015

Sample Preparation

Clean sample prep at TUNL and UNC (class 100)

- Ultra-pure acids and solvents
- Procedures adopted from PNNL and UW



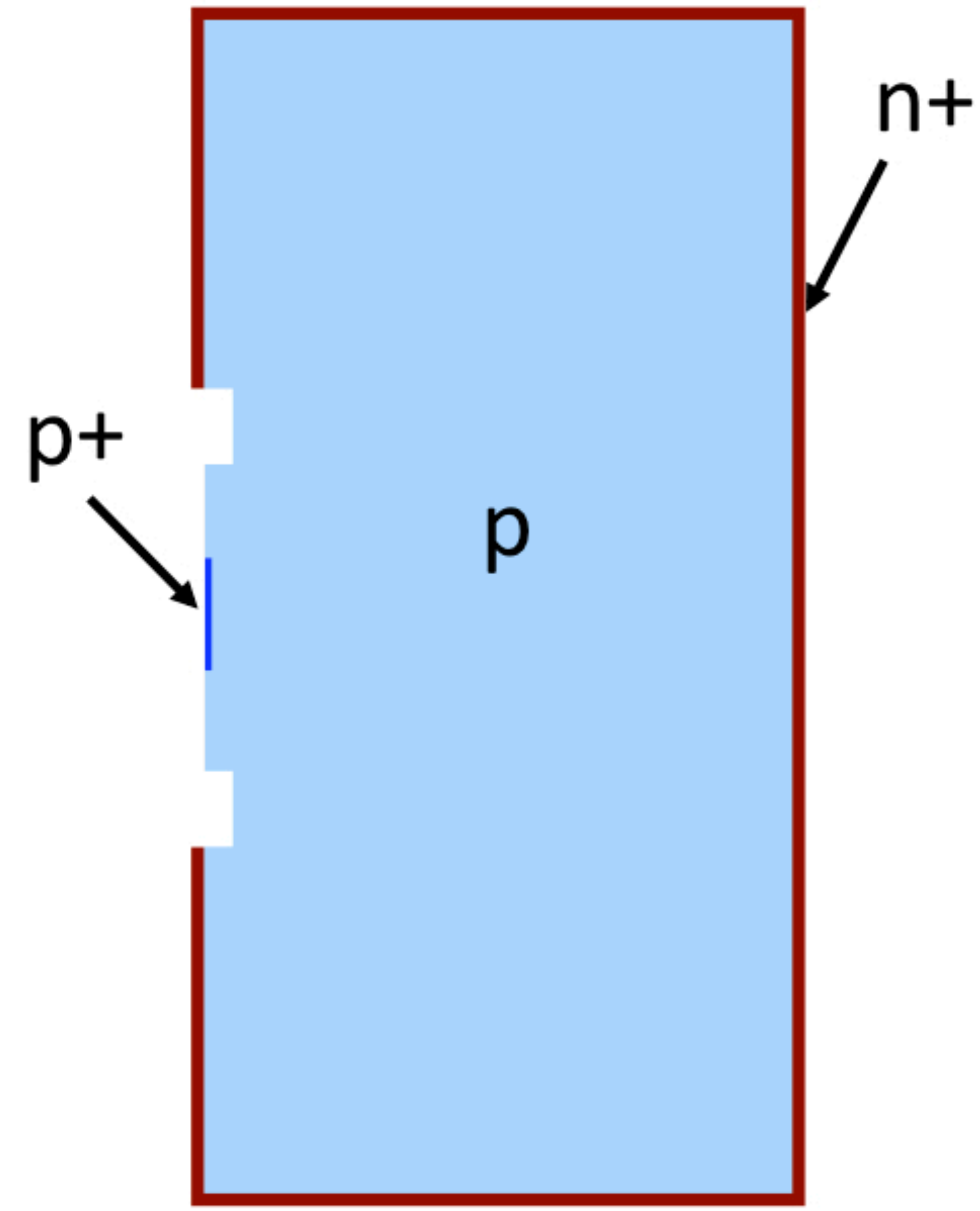
MALBEK

MAJORANA Low-Background BEGe at KURF

Broad Energy Germanium (BEGe) detectors

- Variation on PPC detector already commercially available.

MALBEK is a BEGe prototype from Canberra Industries (Meriden, CT)

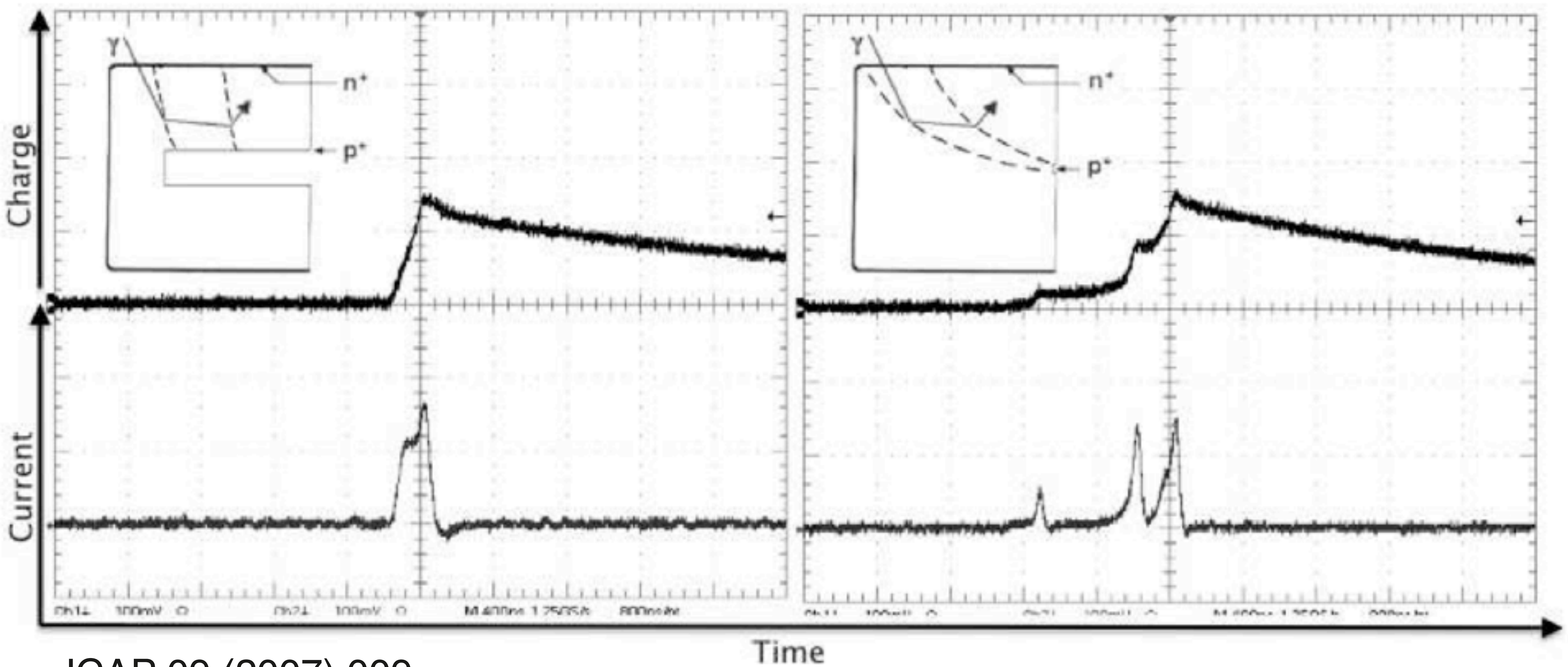


Part of the R&D process for MAJORANA

Under low-background conditions (cryostat and lab):

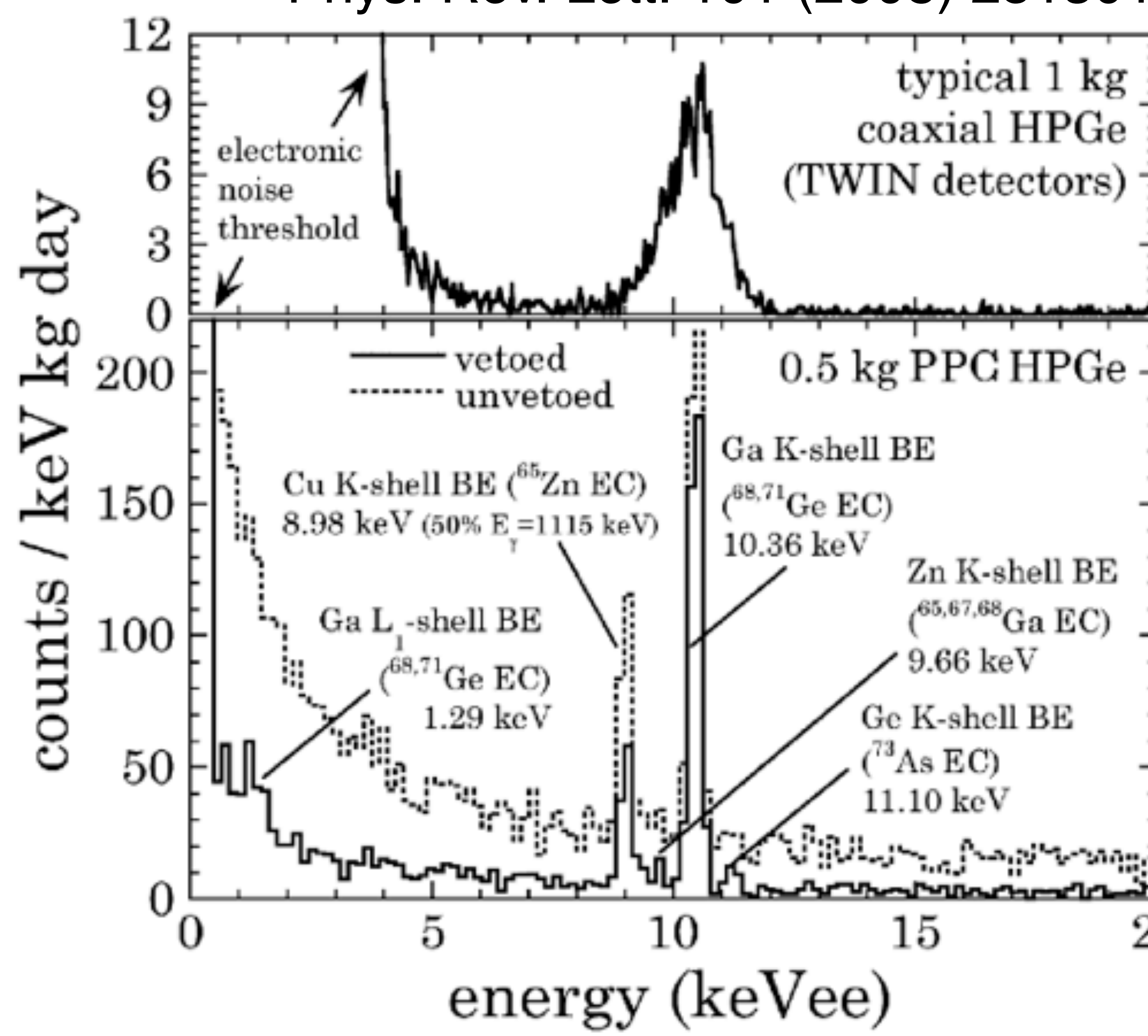
- Characterize charge pulses
- R&D for low-energy triggering
- Characterize spectrum, particularly at low energy
- Evaluate preamplifier technologies

Broad Energy Germanium (BEGe) Detectors



JCAP 09 (2007) 009

Phys. Rev. Lett. 101 (2008) 251301

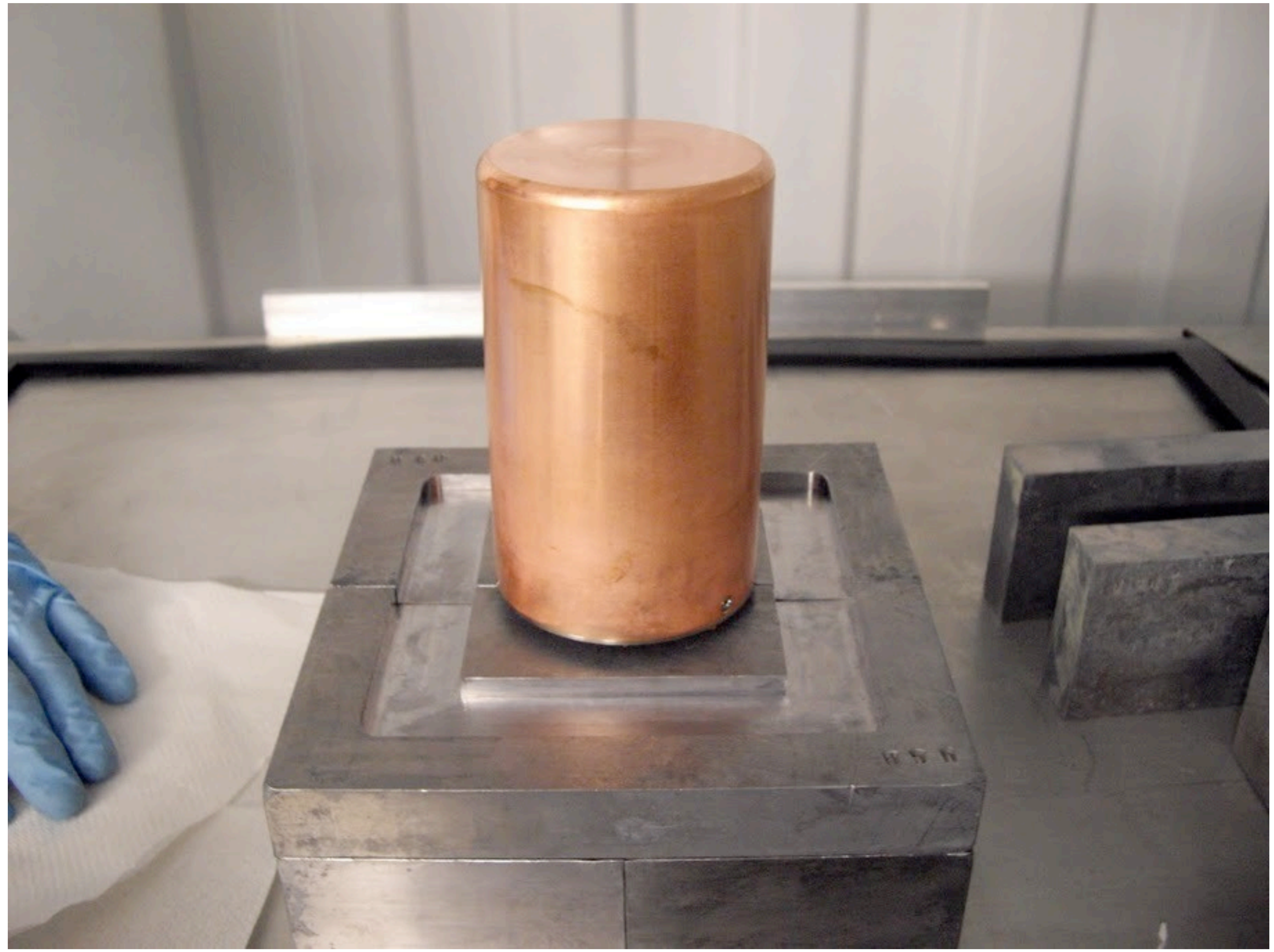


Large, short current pulses
- One for each energy deposition
- Ideal for PSA

Intrinsically low capacitance, low noise, low threshold
- Sensitive to light (<10 GeV) WIMP dark matter

Physical Characteristics

Canberra Specifications
- Mass - 450 g
- Active Diameter - 60 mm
- Length/Thickness - 30 mm
- Material - LB copper cryostat & window, 0.5 mm

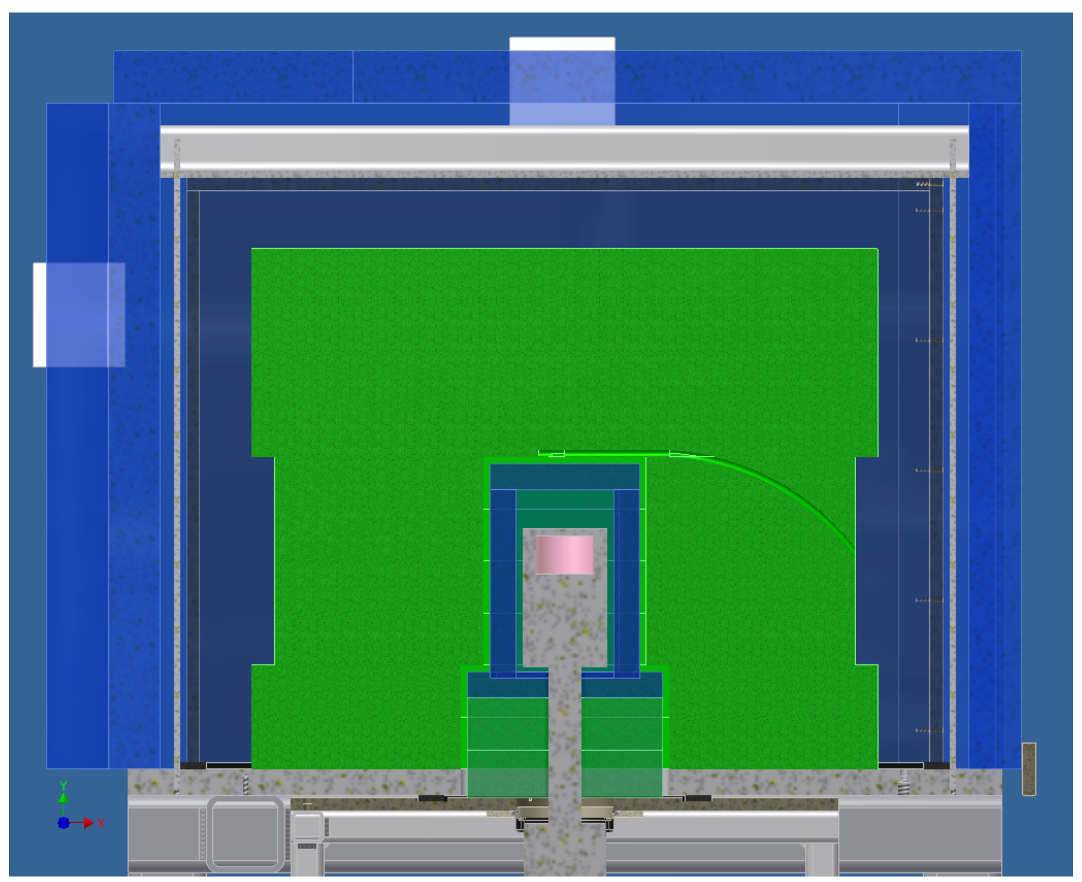


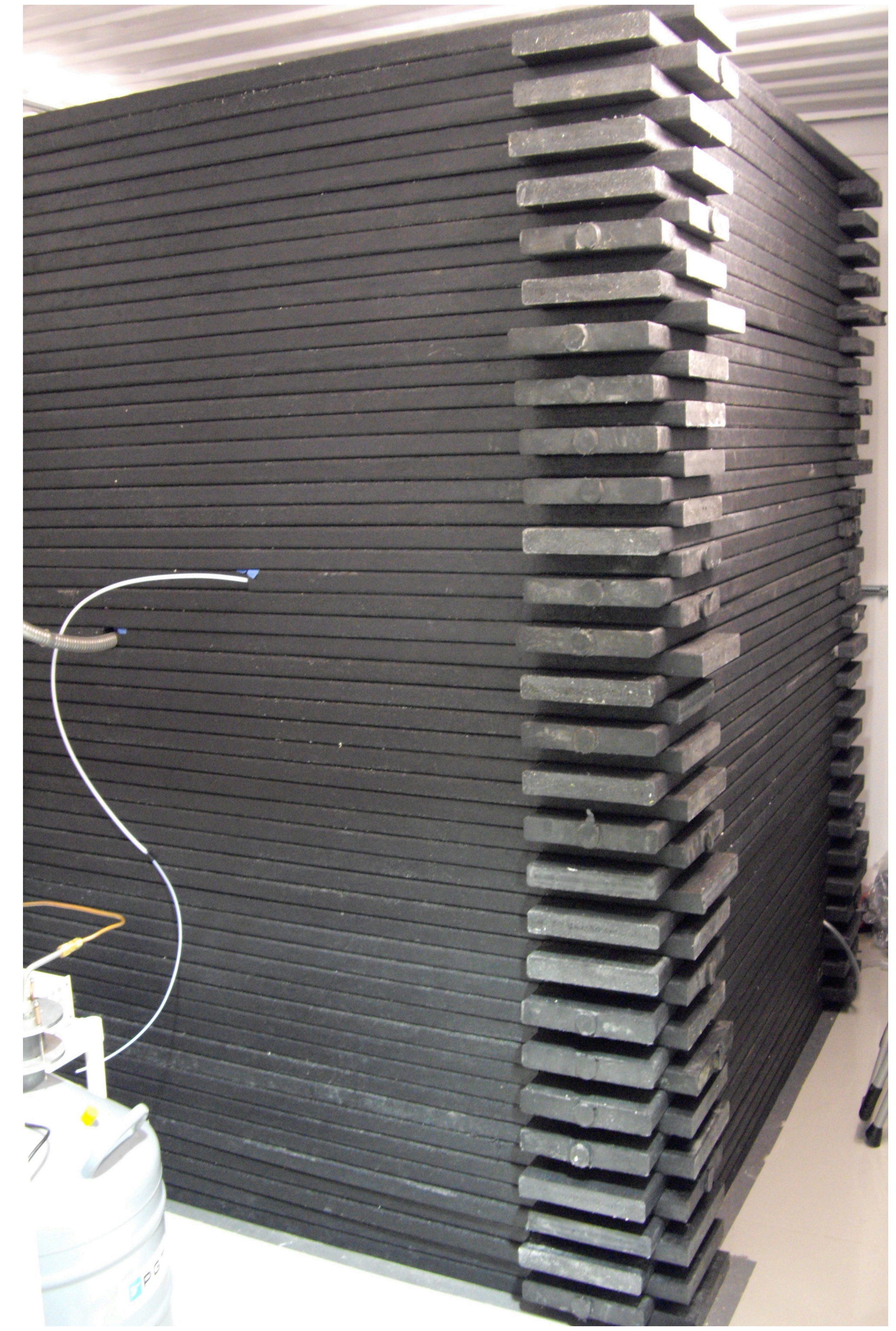
MALBEK:
- Small point contact: 3-4 mm
- Large ditch radius: 15 mm

Low-Background Shield

<u>Shielding: Inside-Out</u>

- 1” ancient lead
- 8” low-background lead
- Radon exclusion box
- 2” muon veto
- 2” borated polyethylene
- 10” polyethylene

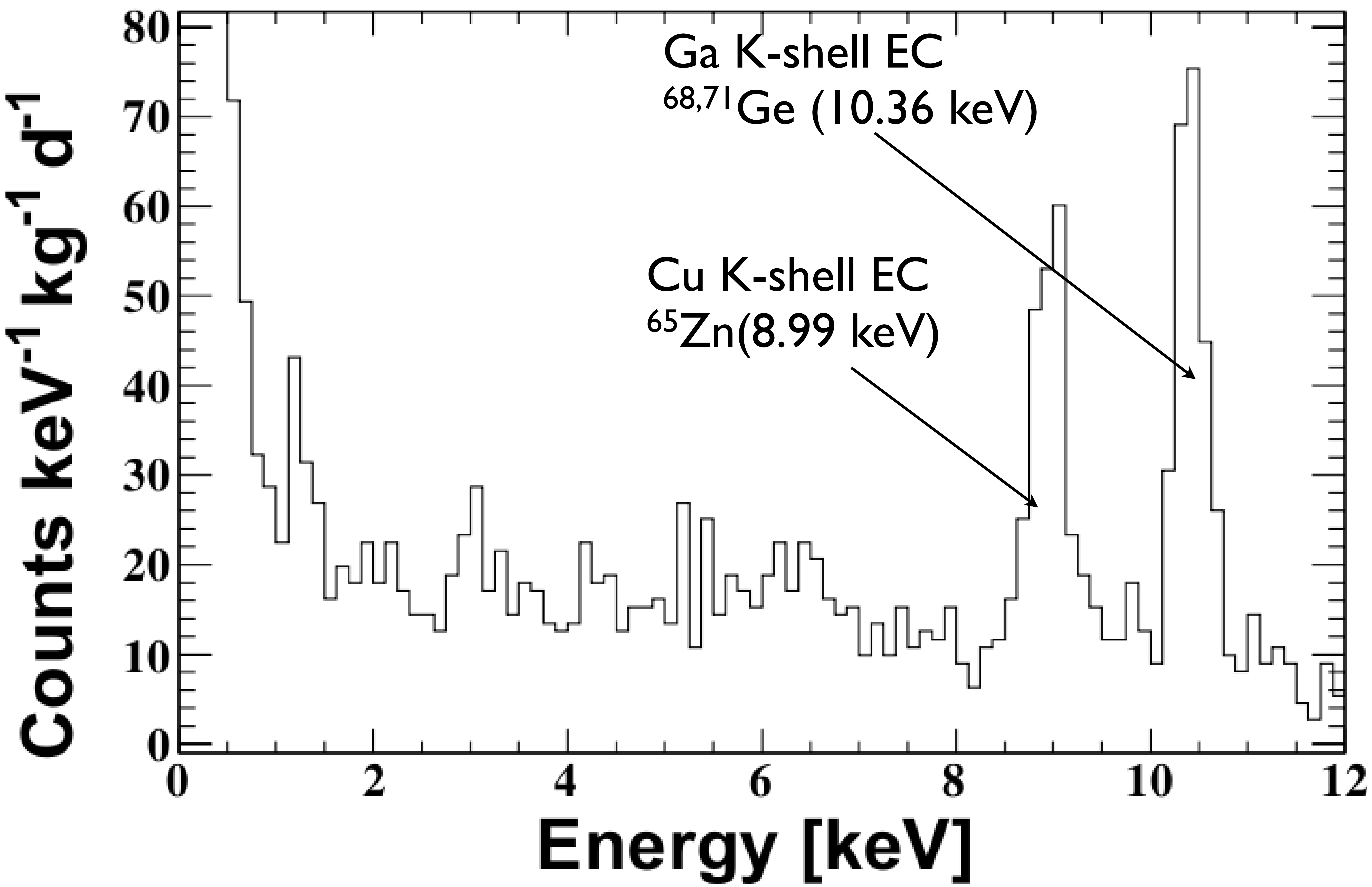




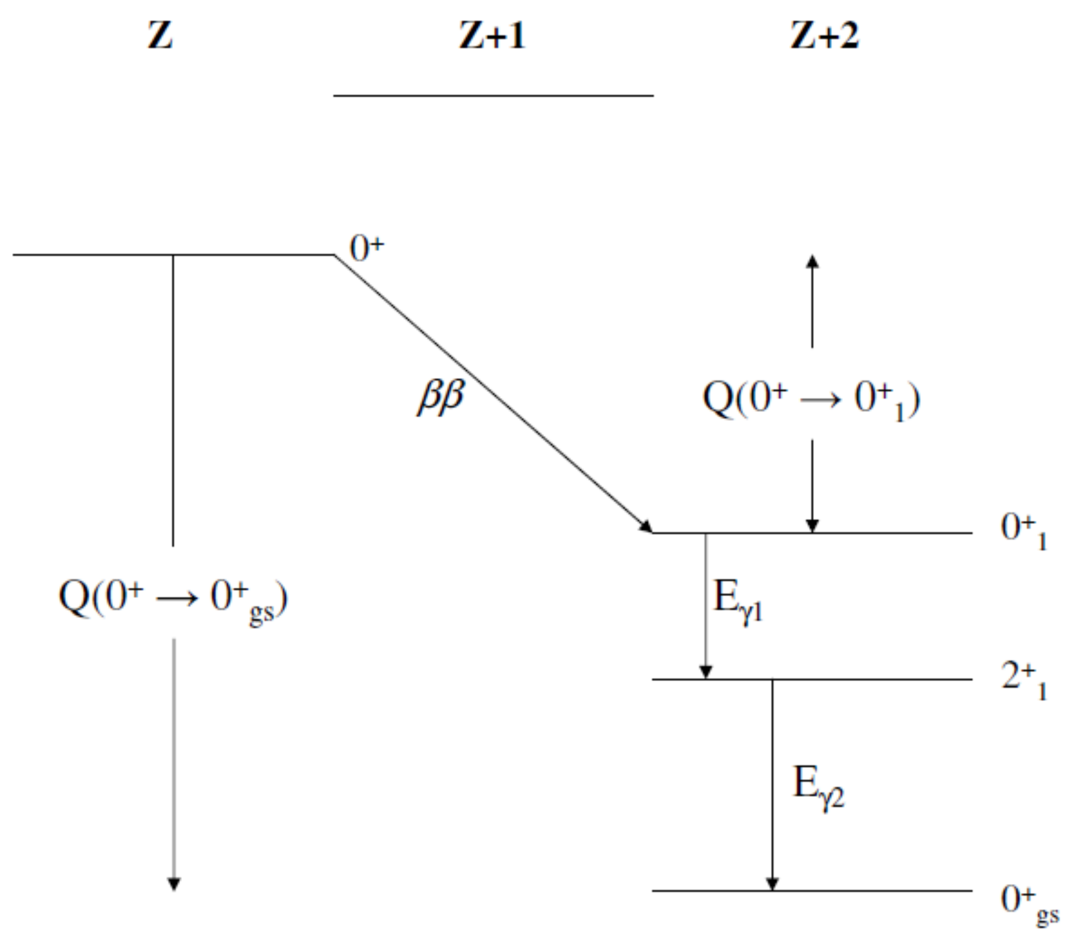
MALBEK Energy Spectrum

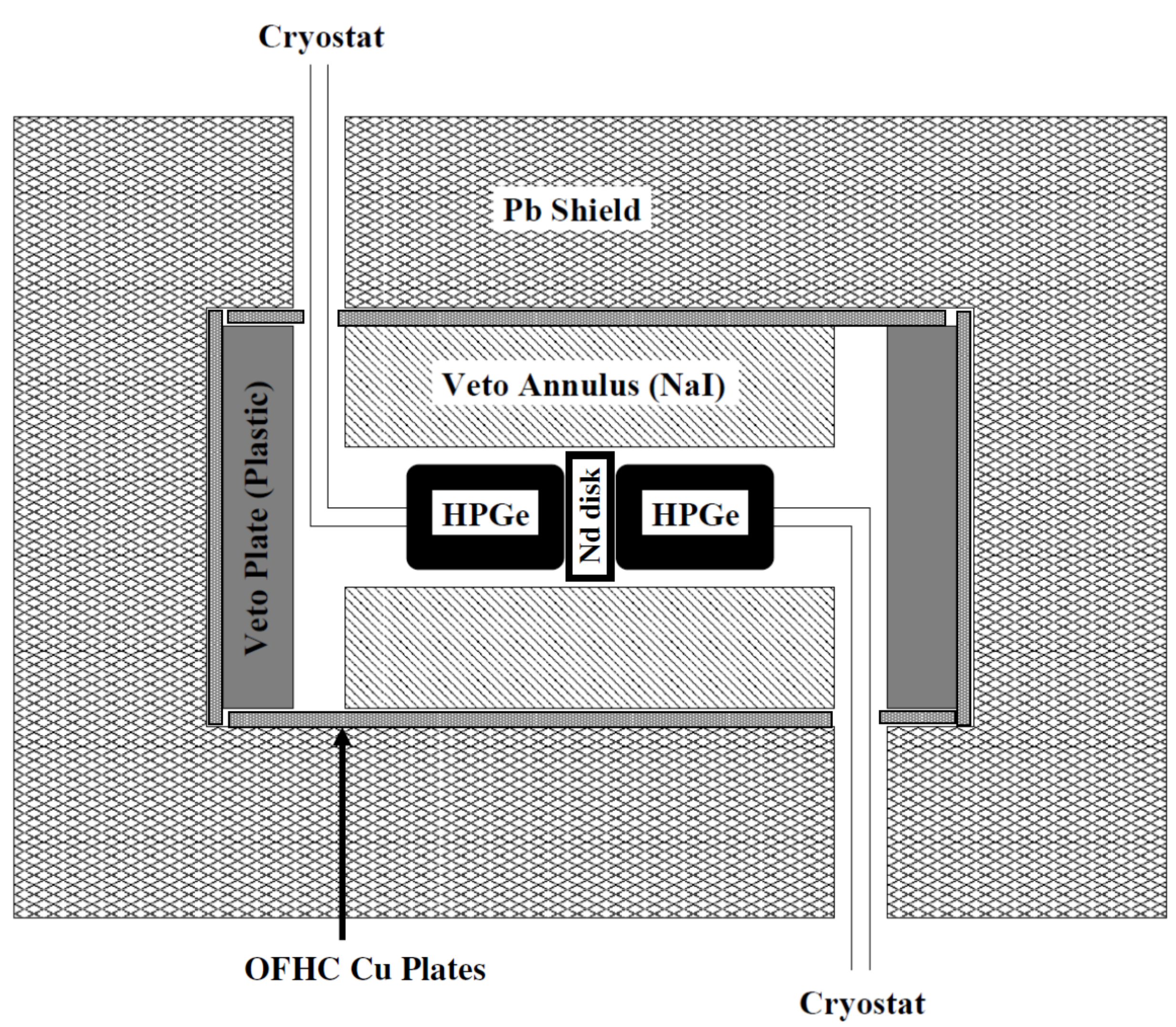
Live Time
20 days

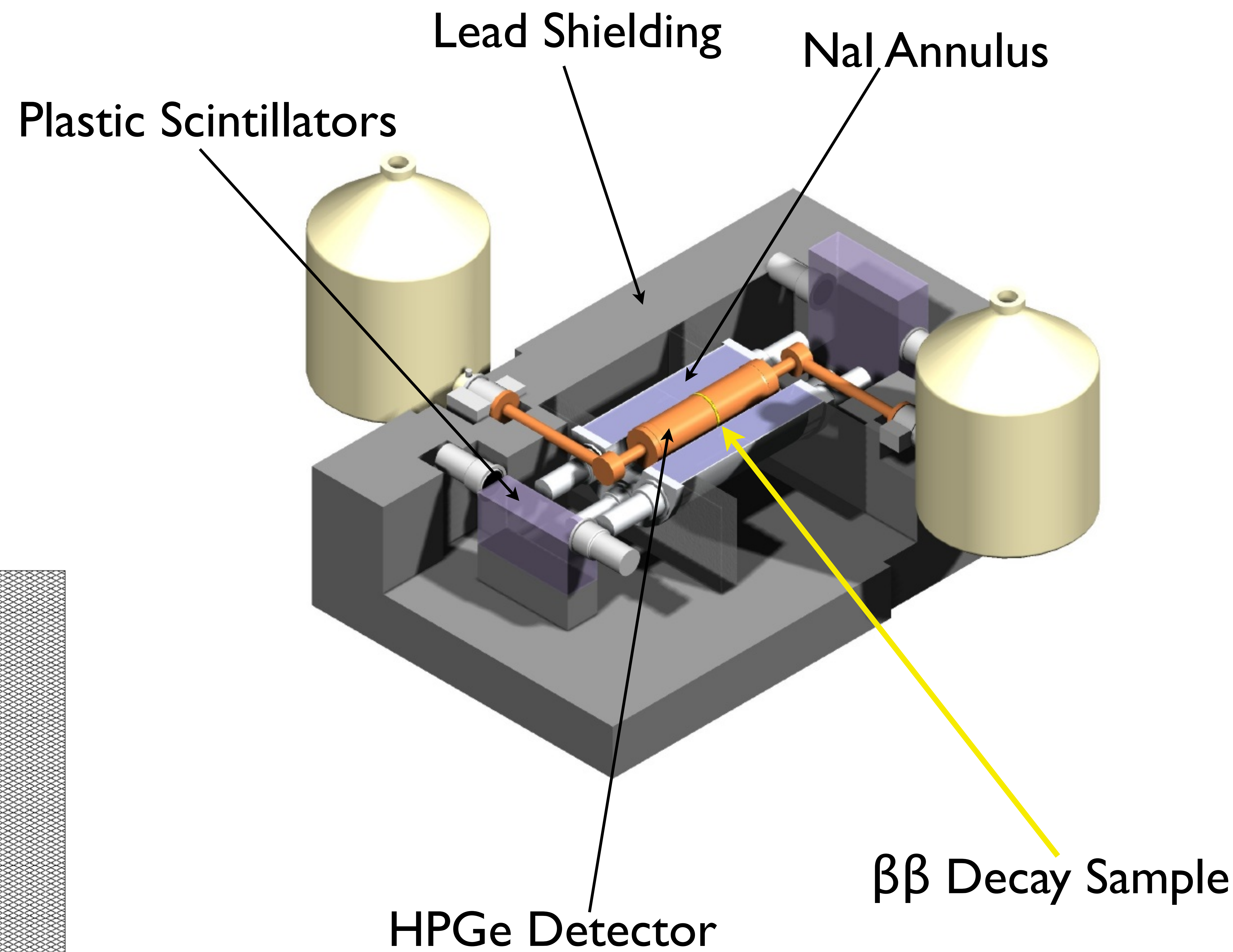
Threshold
~1 keV



TUNL ITEP ββ Setup

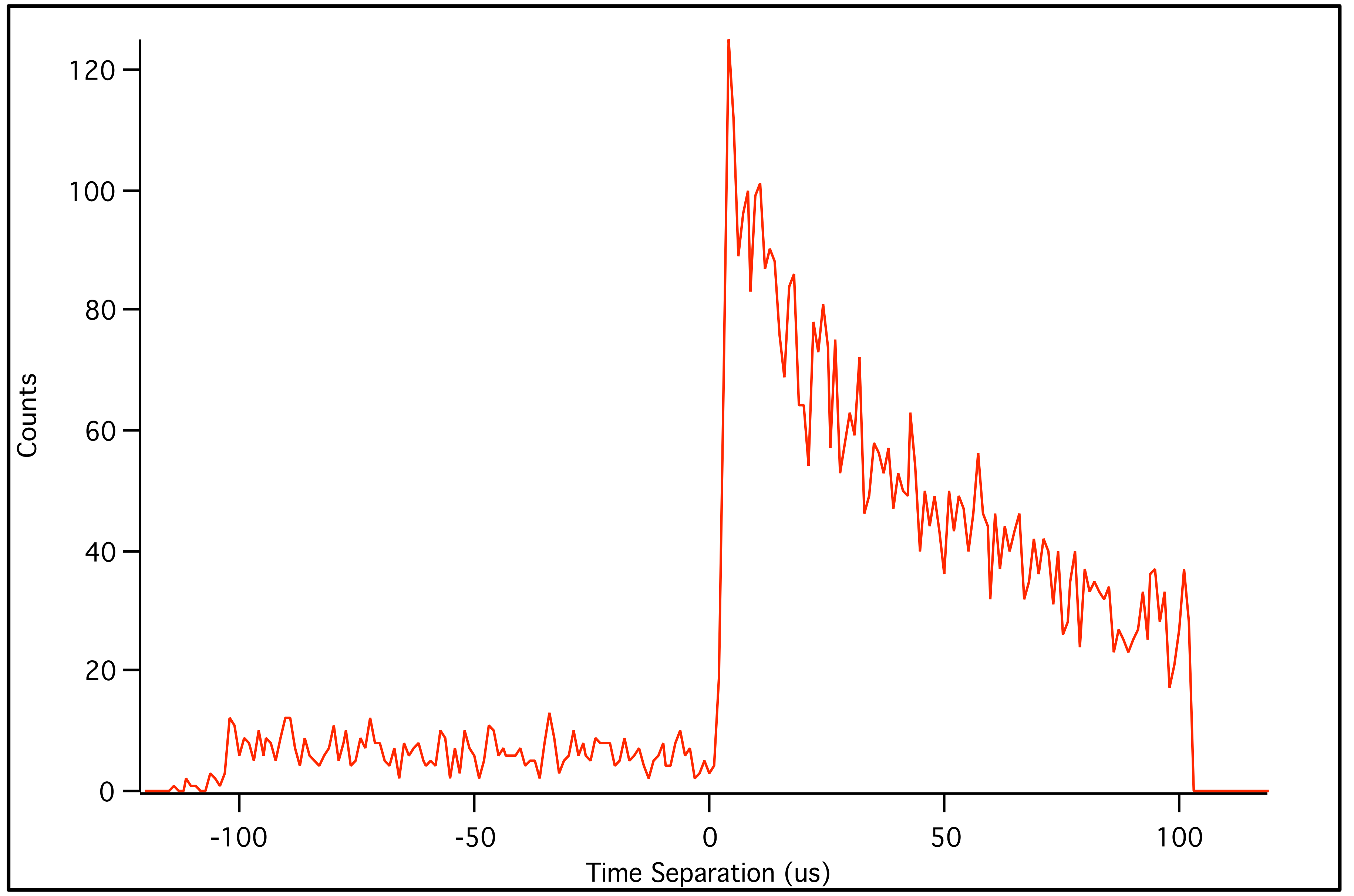


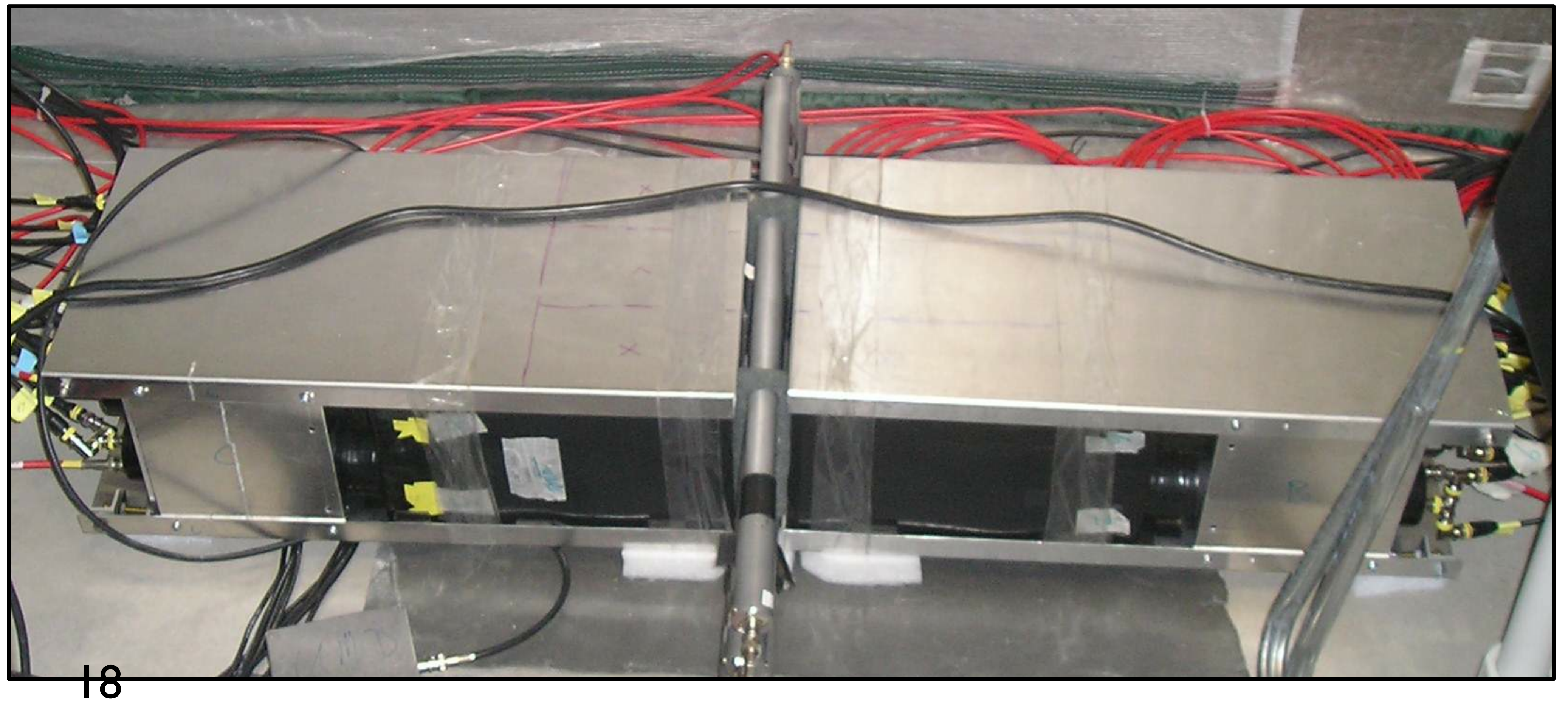




NIST/UMD Fast Neutron Spectrometer

- The fast neutron flux is a possibly irreducible background for Dark Matter and Neutrino-less double-beta decay experiments
- A direct measurement is required to test and benchmark Monte Carlo simulations of the flux
- The NIST/UMD collaboration aims to measure the neutron flux at KURF using a coincidence between segmented plastic scintillators and 3He proportional tubes





Friday, August 27, 2010

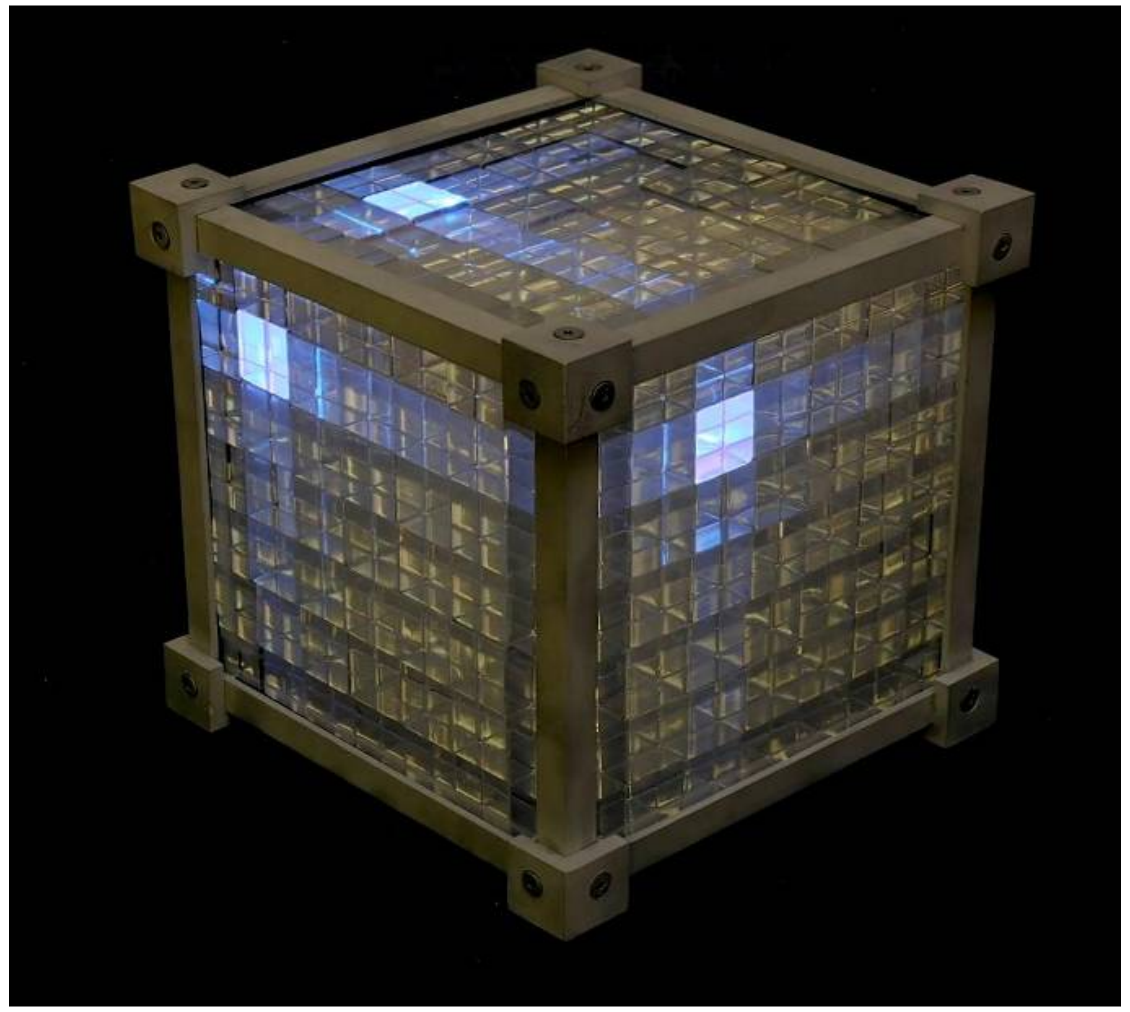
Conclusions

- Physics has been happening at KURF since 2007
- Sensitivity required to assay samples for low background physics experiments has been demonstrated with commercial HPGe detectors
  - Further descriptions at arXiv:1007.0015 (submitted to NIM A)
- MALBEK is currently taking data
  - Characterization will provide input to the MAJORANA collaboration and low background community
- Future efforts will measure the neutron, muon and gamma flux

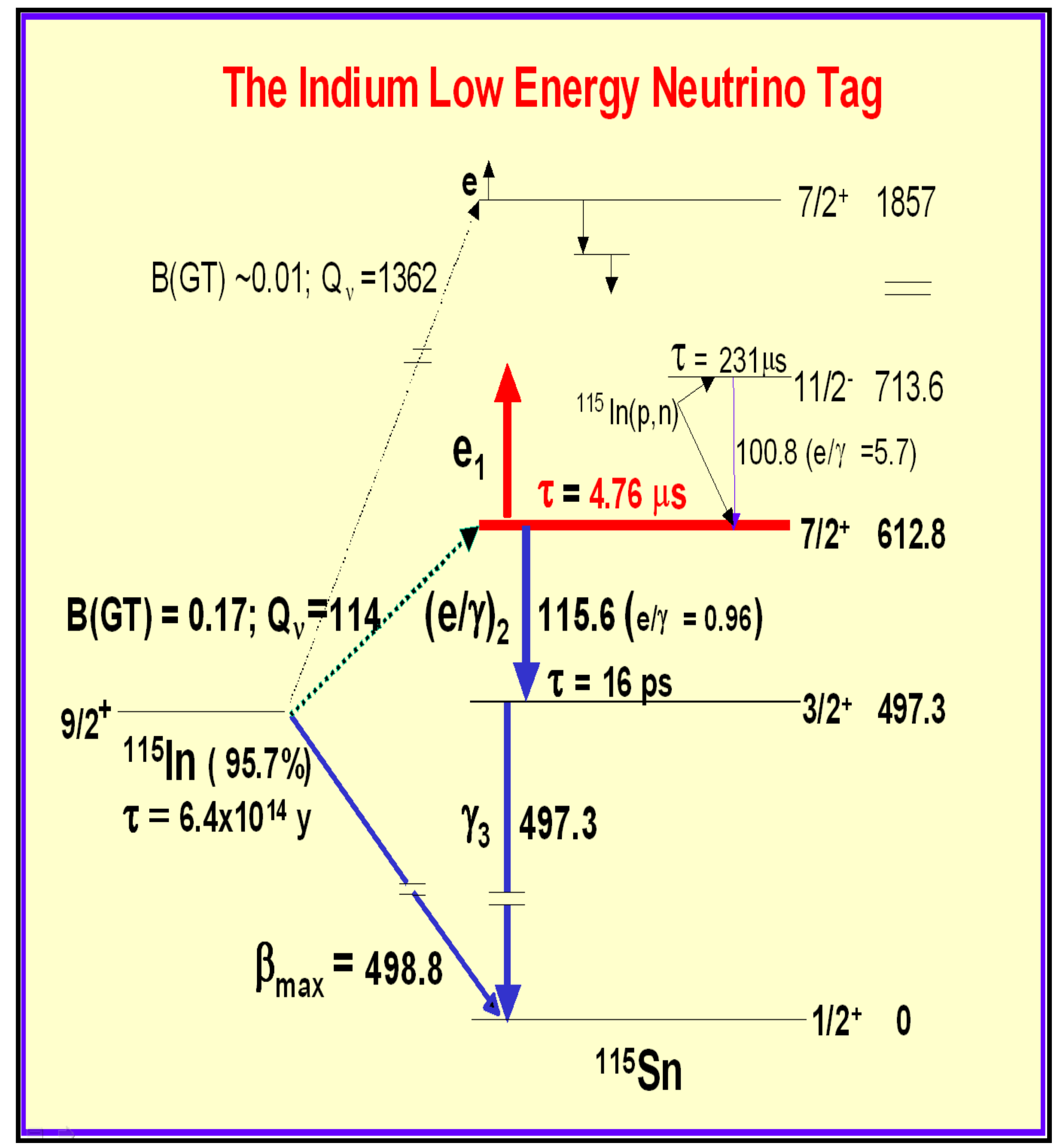
http://www.phys.vt.edu/~kimballton
http://www.physics.unc.edu/research/nuclear/particle_astro/kimballton/php
http://www.tunl.duke.edu/~tornow/below.html


Thank you!

miniLENS



$$\nu_e + {}^{115}In \rightarrow \underbrace{e^-}_{\text{solar signal}} + \underbrace{\gamma + (\gamma / e^-)}_{\text{delayed tag } (\tau = 4.76\,\mu s)} + {}^{115}Sn$$

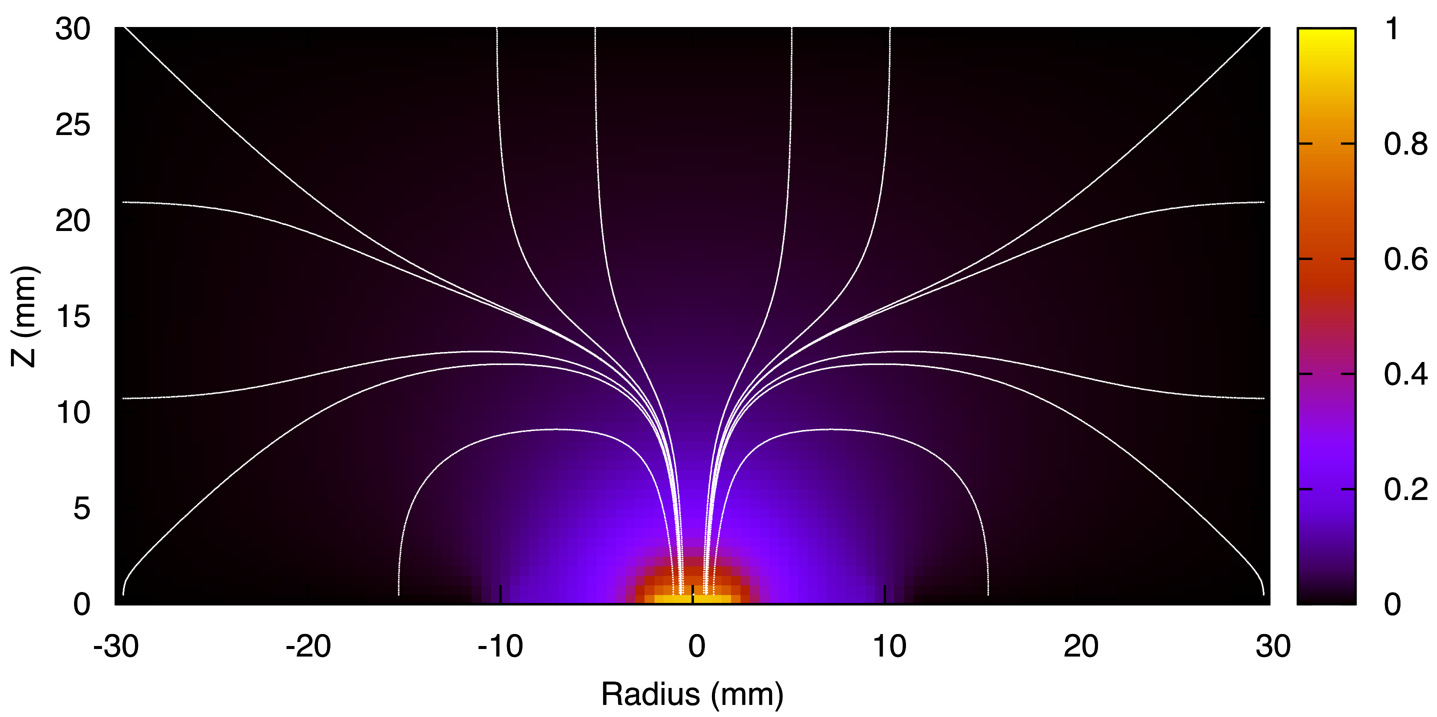


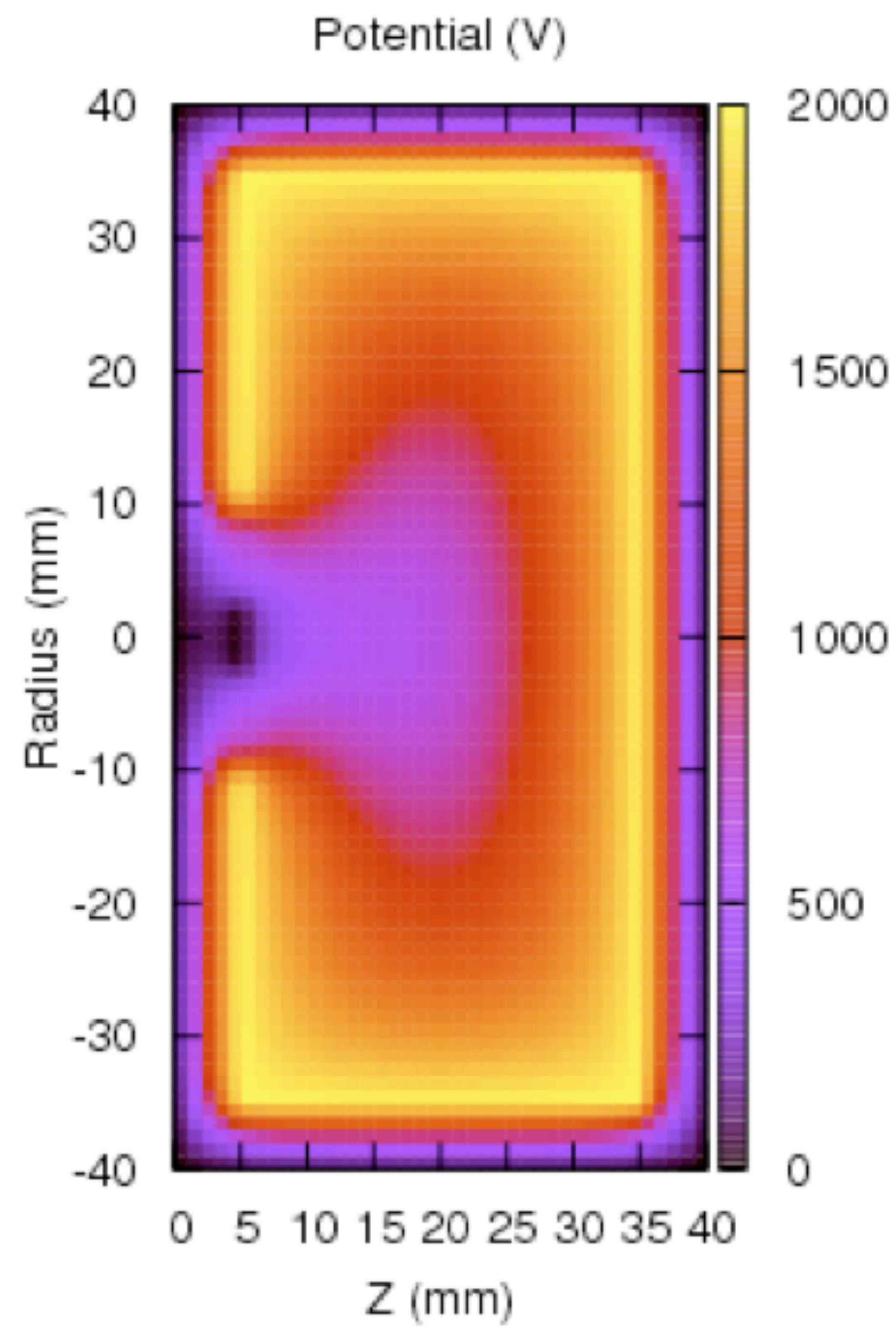
low-E neutrinos

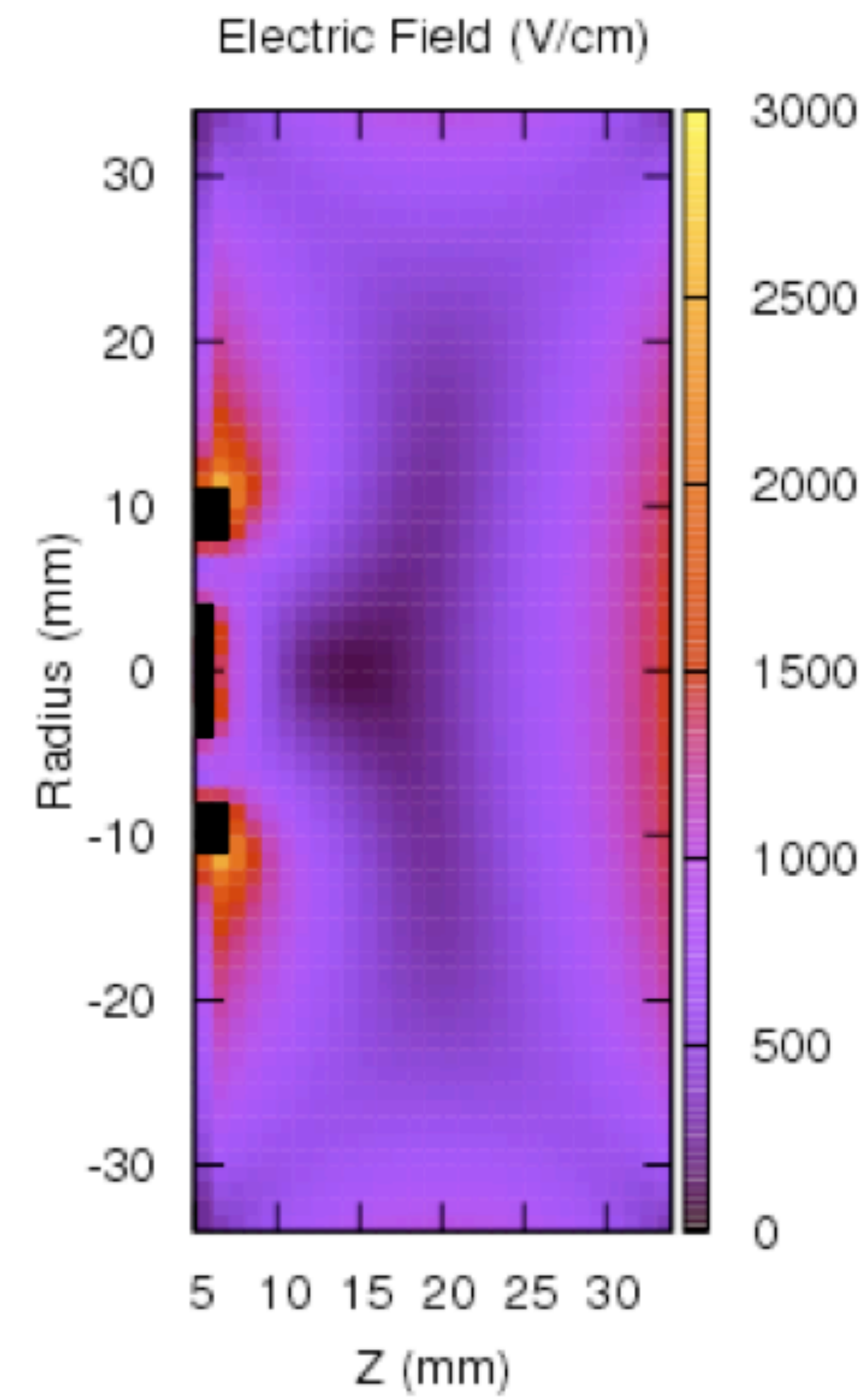
Eth = 14 keV

measure pp-ν flux

sun's primary energy generation



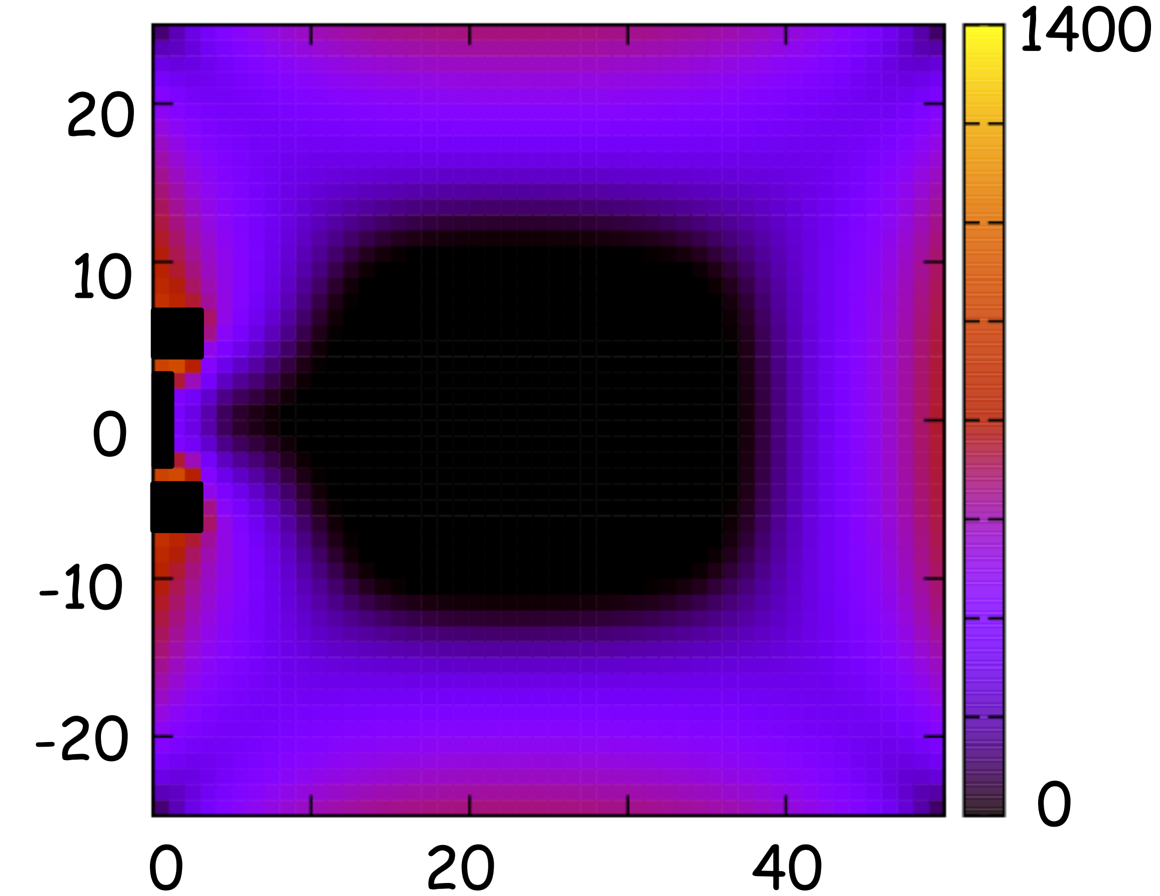




Information from R. Cooper (ORNL)

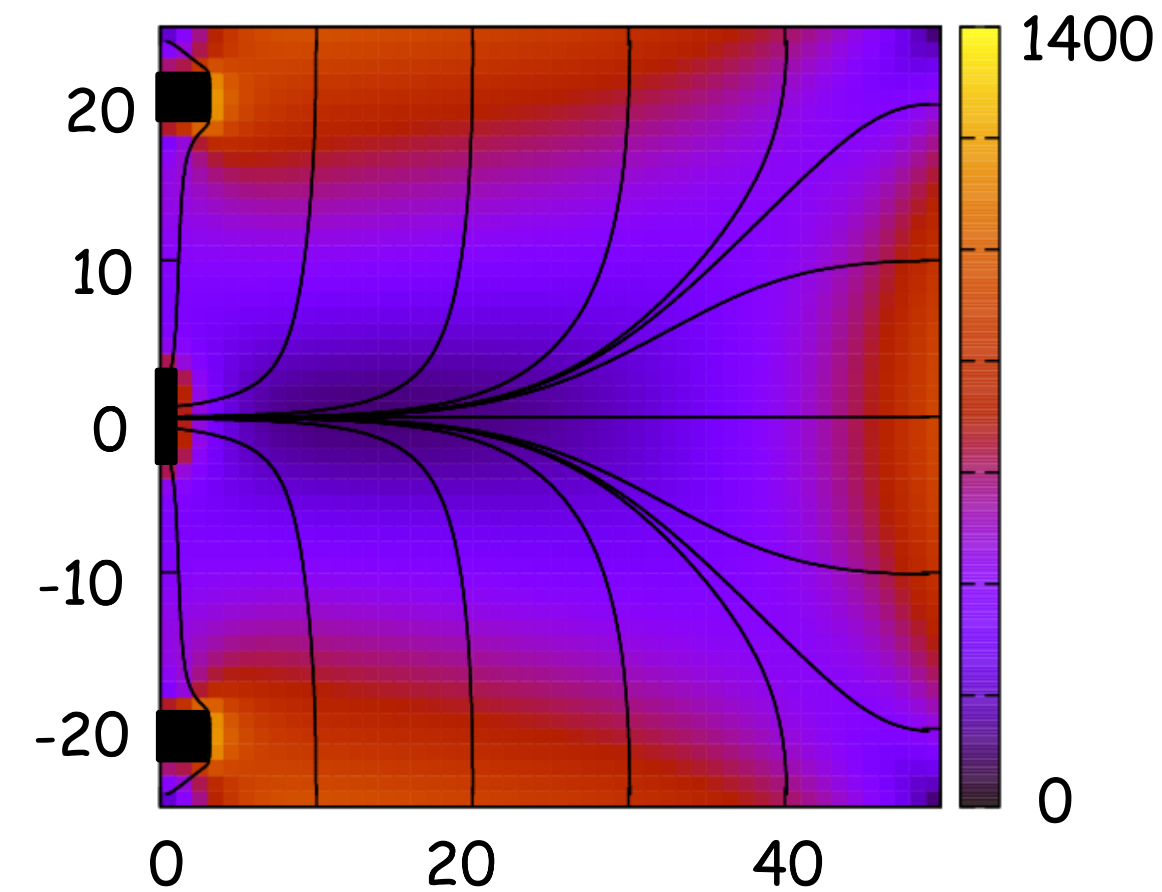
Effect of Ditch Diameter

Radial position of the isolation groove is extremely important in determining the field distribution close to the point contact surface



Too narrow: pinch-off, difficulty depleting the full volume

Too wide: loss of characteristic signal shape, poor charge collection



Information from R. Cooper (ORNL)

Effect of Point Contact Size

Smaller point contact produces shorter range weighting potential

Better PSA

Smaller point contact increases pinch-off

Creates stronger field at contact

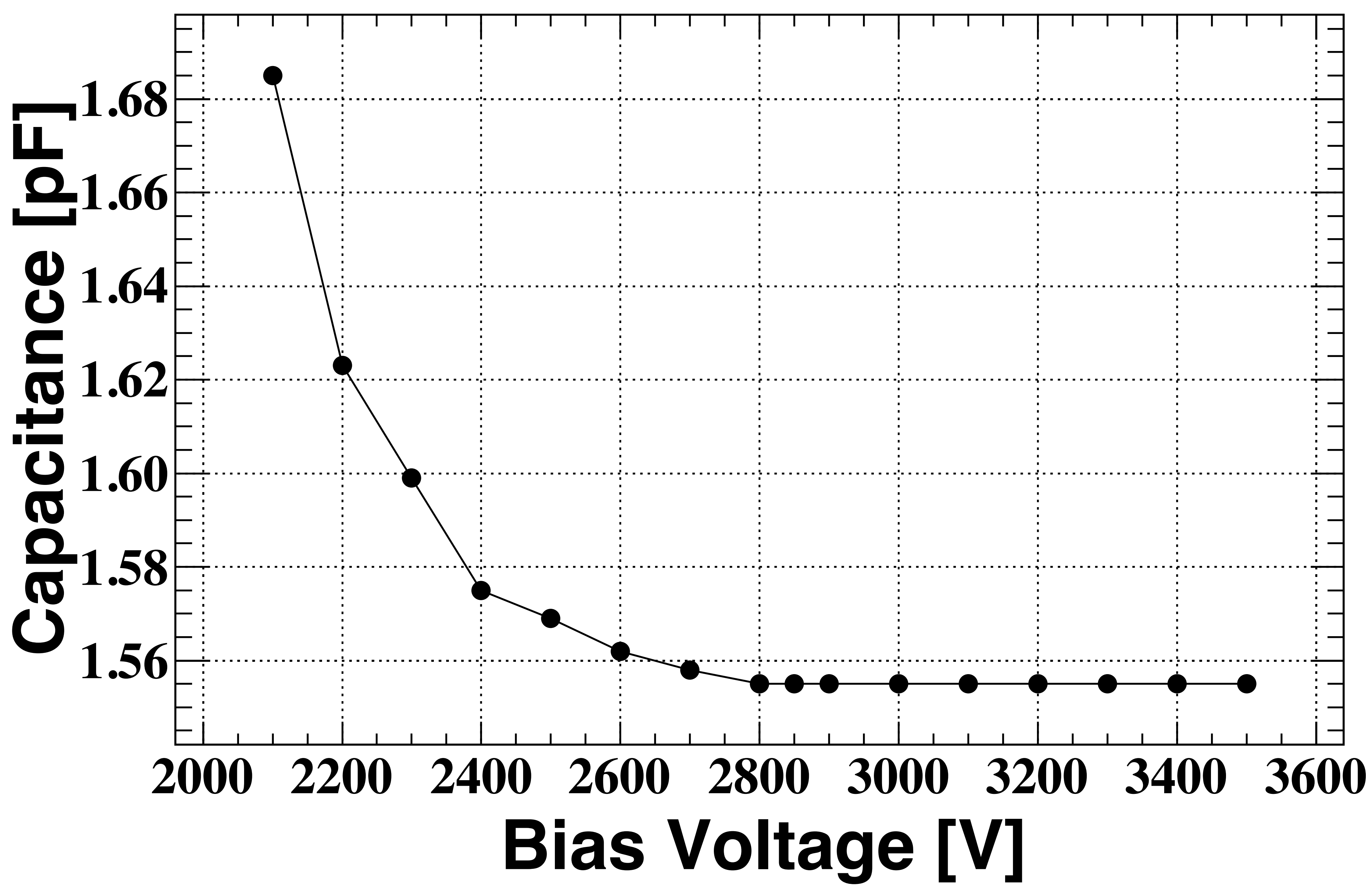
Withstands less over-bias

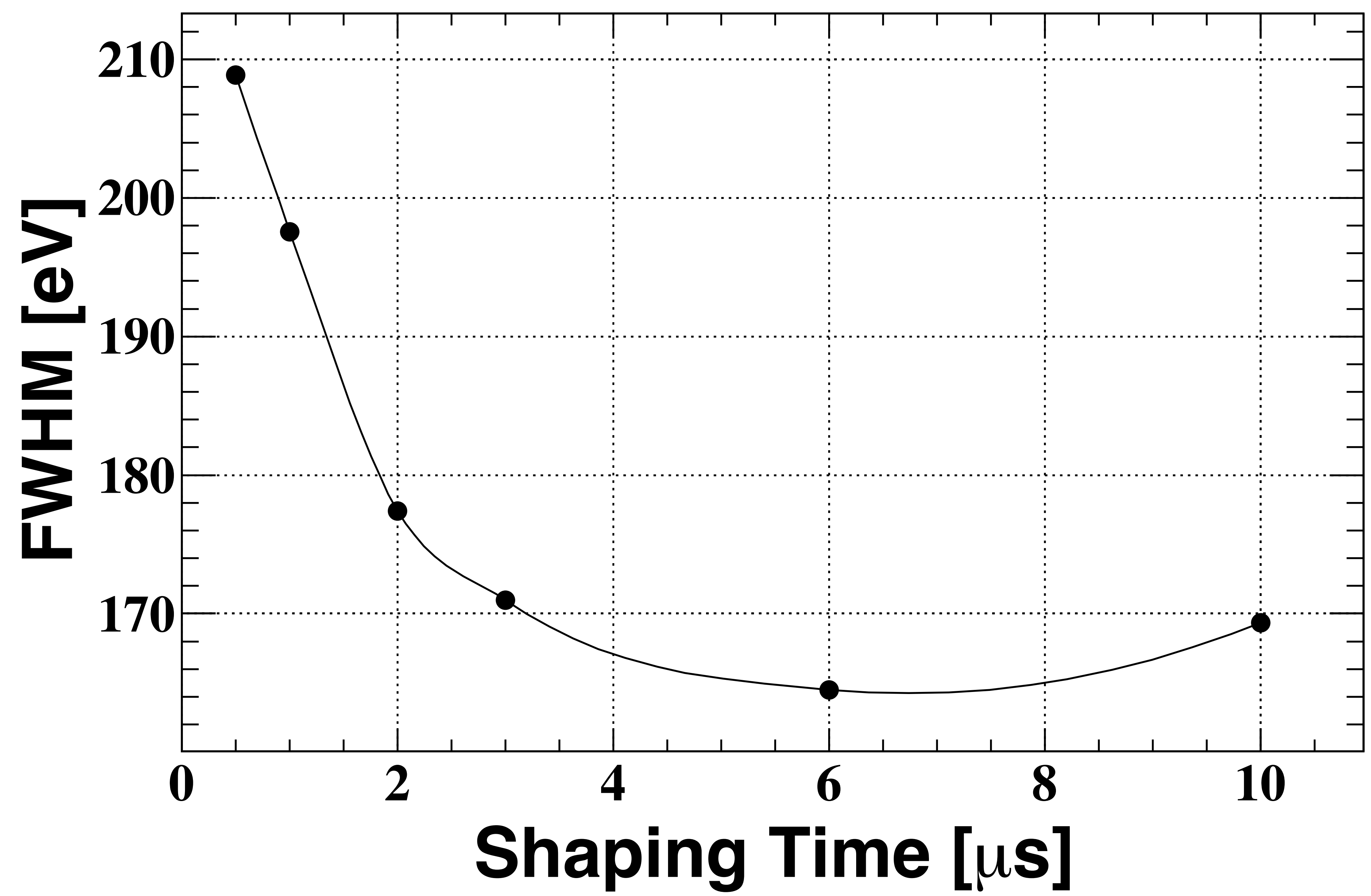
Size of point contact defines ability of over-bias to overcome pinch-off

Defines the depth into crystal that added potential extends

Large diameter means more "penetrating" potential

Information from R. Cooper (ORNL)


Capacitance [pF]
1.68
1.66
1.64
1.62
1.60
1.58
1.56
2000 2200 2400 2600 2800 3000 3200 3400 3600
Bias Voltage [V]

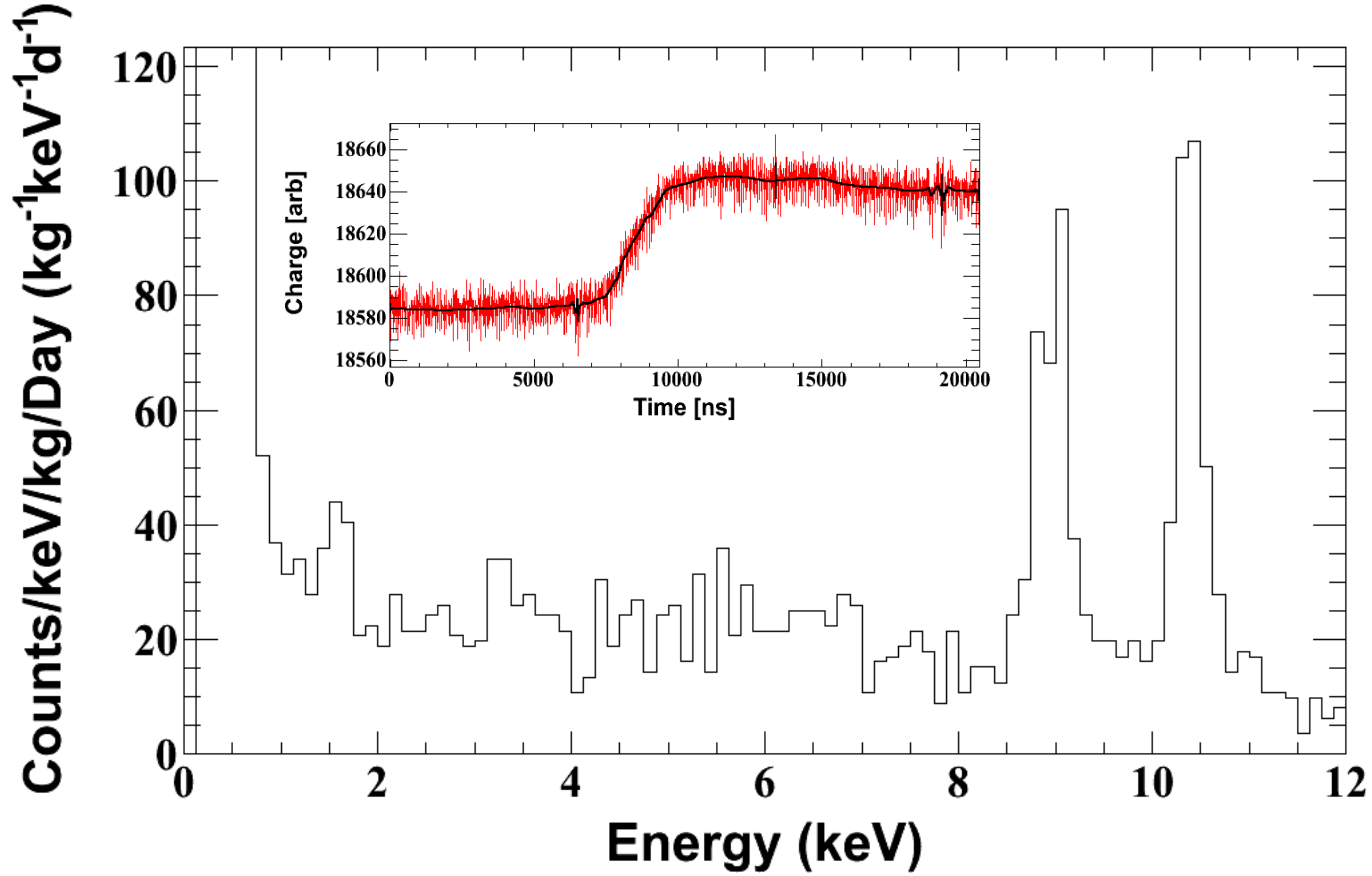

FWHM [eV]
210
200
190
180
170
0 2 4 6 8 10
Shaping Time [μs]

Data Processing

ORCA DAQ application - developed and maintained at UNC

Pulse reset preamplifier

Struck SIS3302 16 bit, 100 MHz, 8 channel digitizer



20 day MALBEK spectrum

K-shell EC ^{65}Zn(8.99 keV) and ^{68,71}Ge(10.36 keV)

Threshold ~740 eV

Inset: Wavelet de-noised waveform (black) and raw waveform (red) of a 8.31 keV event