Gamma-ray microcalorimeter arrays for nuclear materials analysis

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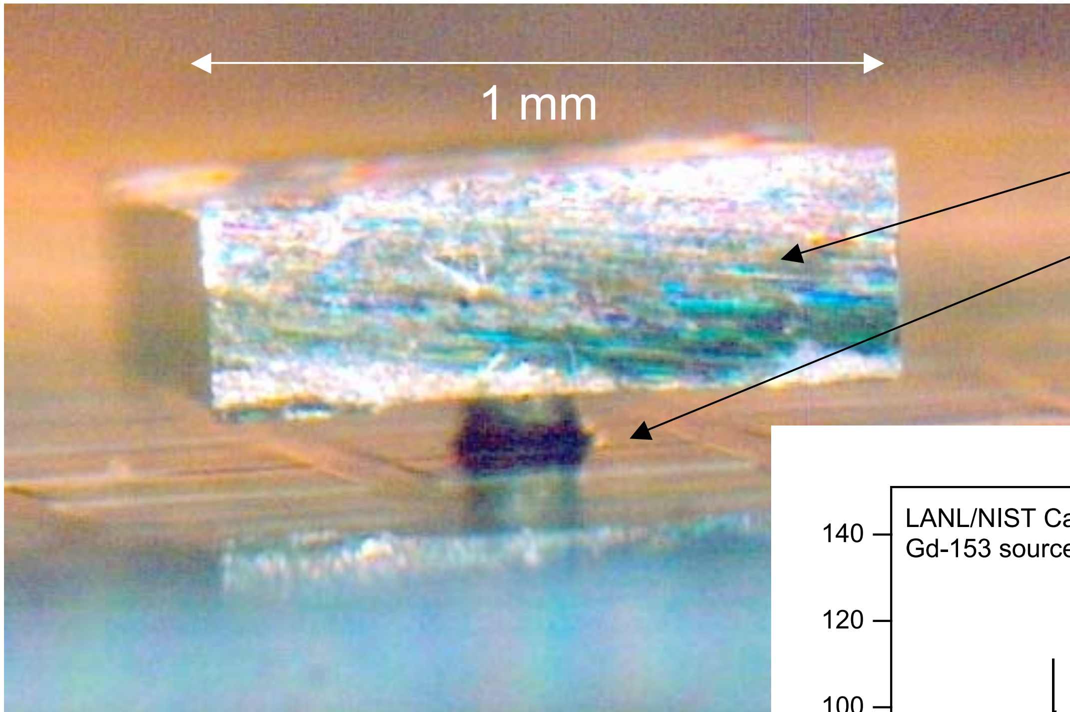
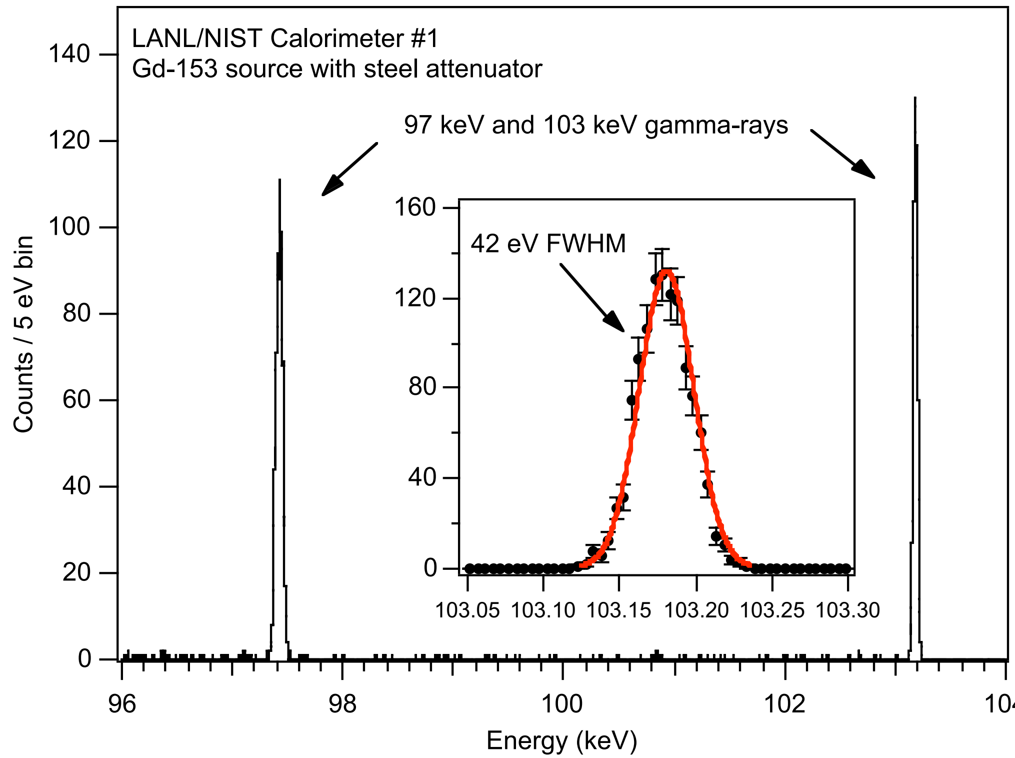
Outline

1. Early single pixel results
2. Applications
3. Scaling to arrays
4. Pixel analysis
5. Higher Z absorbers
6. Spectrometer construction

γ-ray microcalorimeters





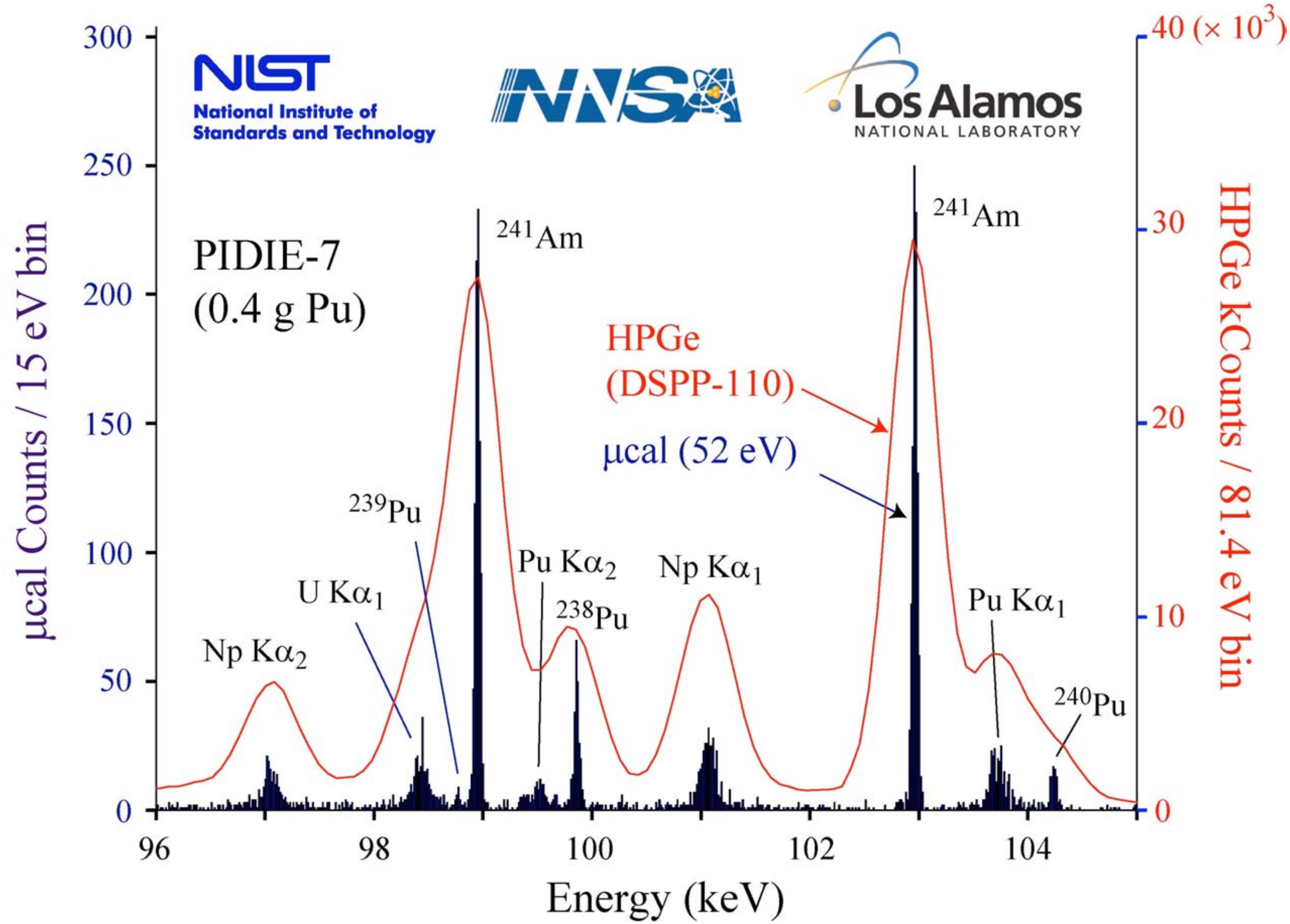
first detector: spring 2005

record result:
42 eV FWHM at 103 keV

On the road to Los Alamos …

(also Randy Doriese)

Applications: analysis of Pu isotopes



Applications: measurement of Pu in spent reactor fuel

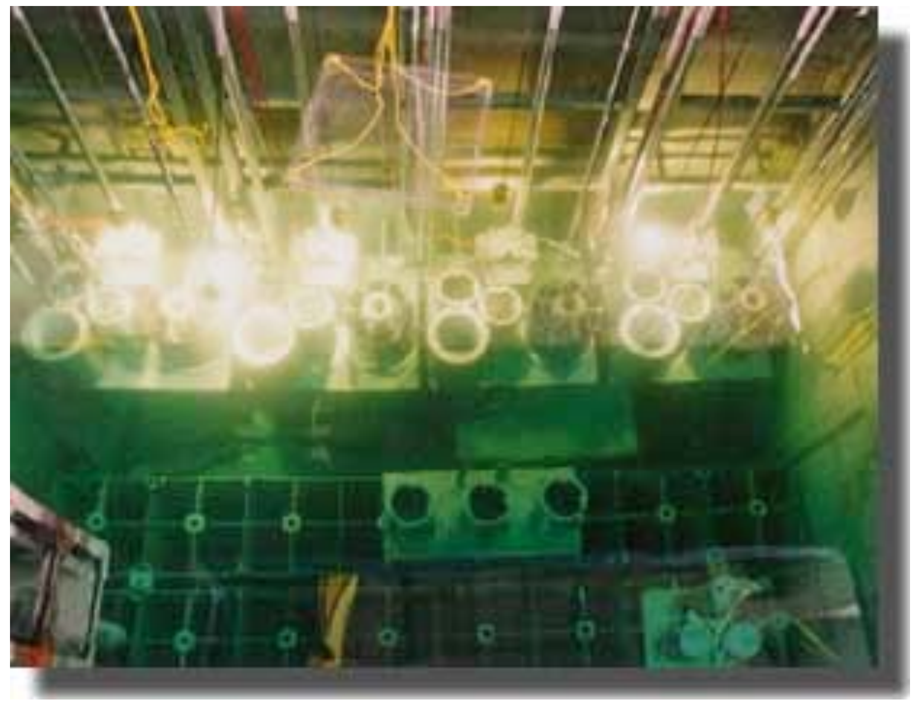
about 96 % (>600 tons) of the Pu under international safeguards is in spent fuel

Pu mass is a measure of reactor purpose: power vs weapons

current nondestructive analysis methods rely on knowledge of reactor operating history

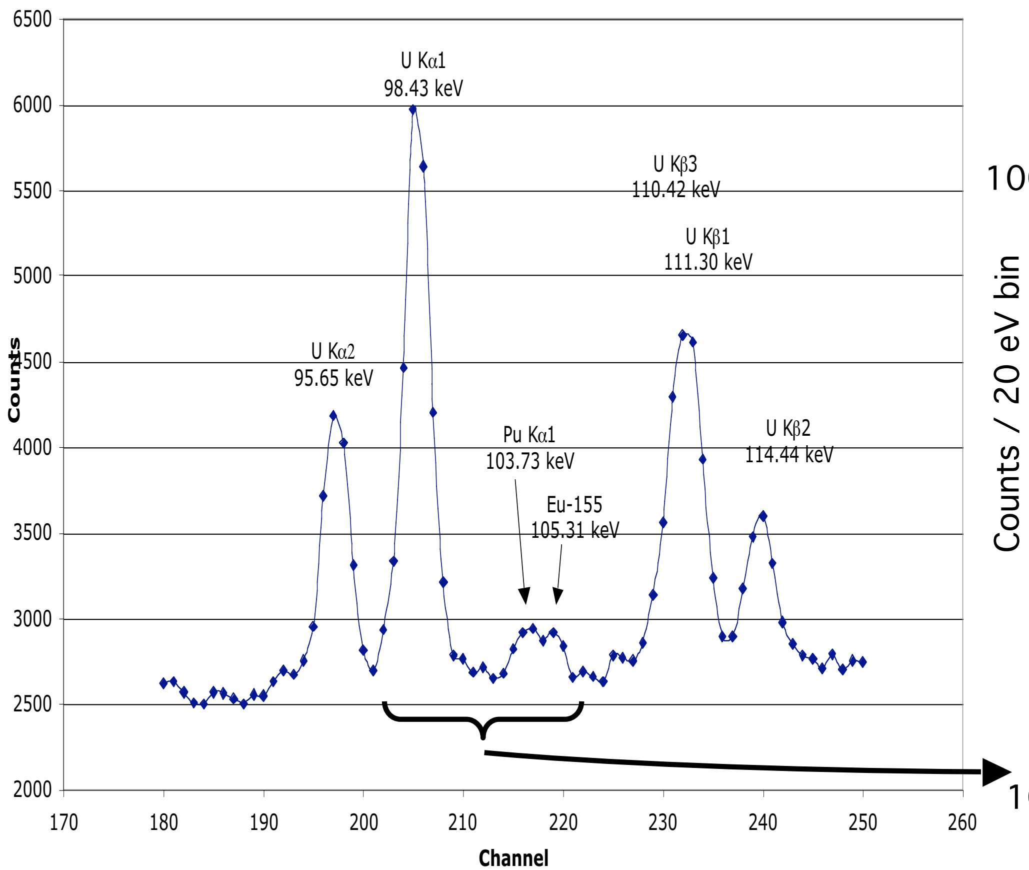
ucals may provide Pu measurement when operating history is lost or obscured

fuel in N. Korean cooling pond

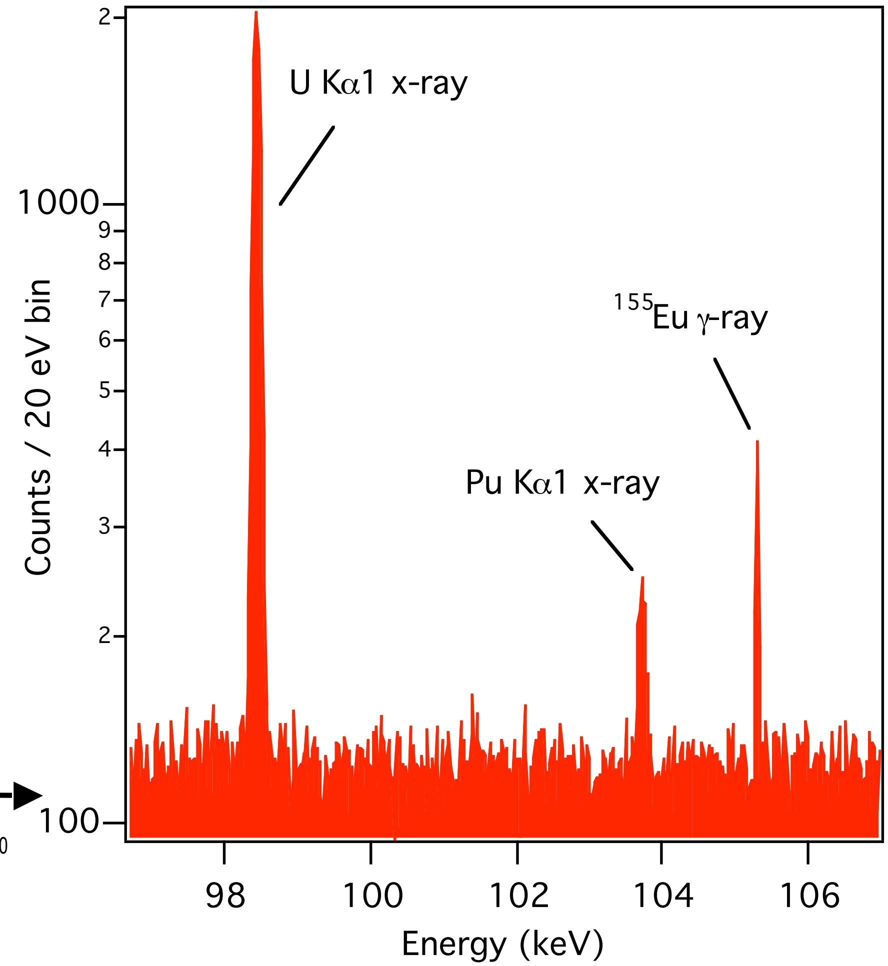


Nondestructive assay for plutonium mass in reactor fuel

HPGe spectrum of spent fuel from FSU
(courtesy LANL)

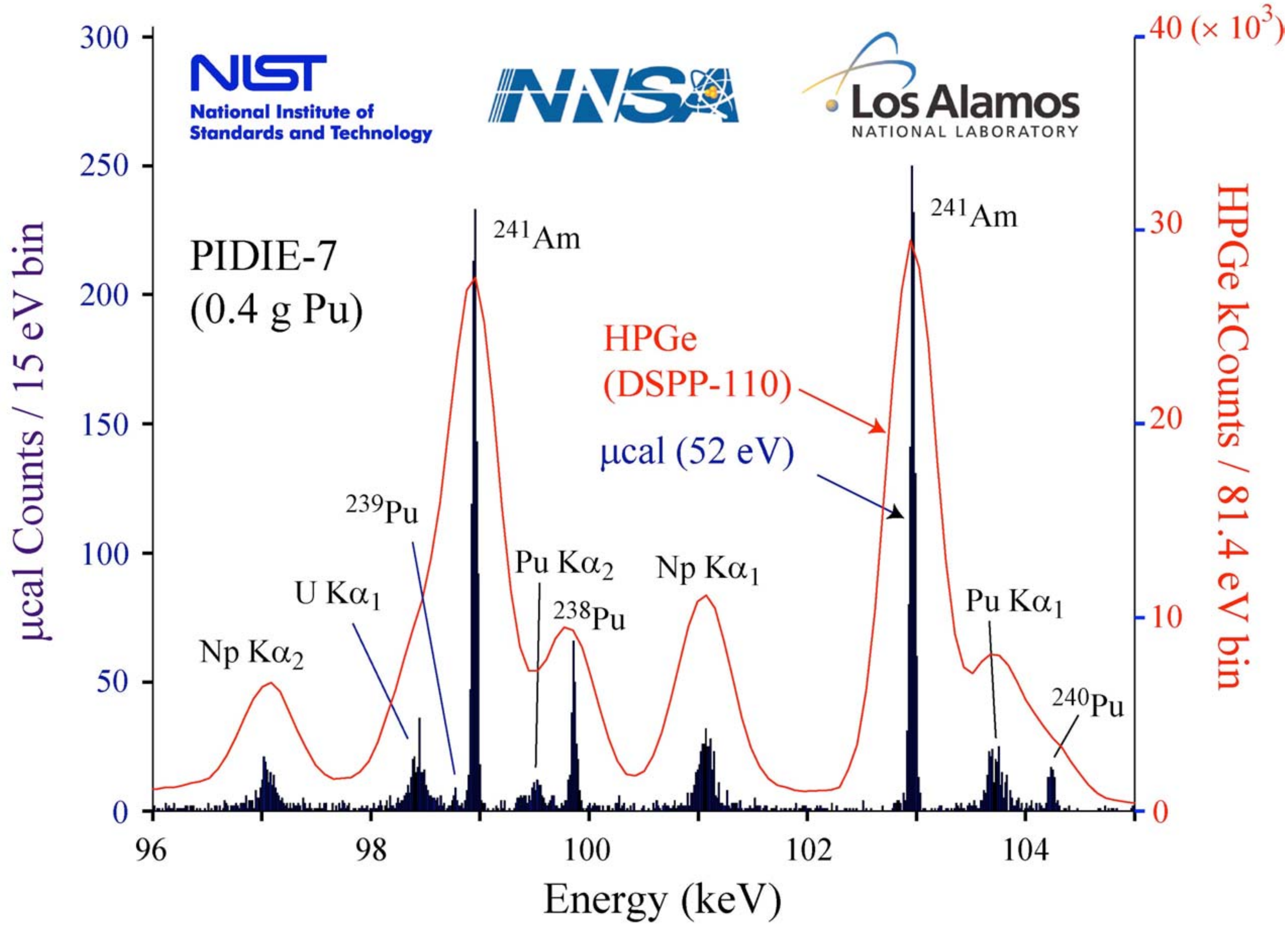


Simulation of same spectrum with µcal

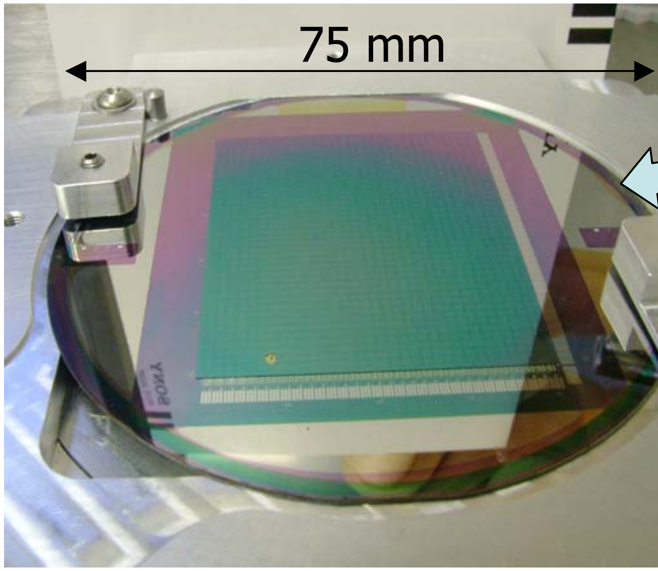


- ratio of U/Pu x-ray fluorescence ⇨ measure of Pu mass
- resolution of µcal minimizes interference from background, ^{155}Eu

Applications: analysis of Pu isotopes



A 1,000 pixel γ-ray spectrometer is feasible



existence proof: 1,280 pixel SCUBA 2 sub-array (for submm)

area

1,000 pixels $\times$ 1 mm^2/pixel ⇨

3.2 cm x 3.2 cm

count rate

1000 pixels $\times$ 100 Hz/pixel ⇨

100 kHz

energy resolution

< 42 eV at 100 keV

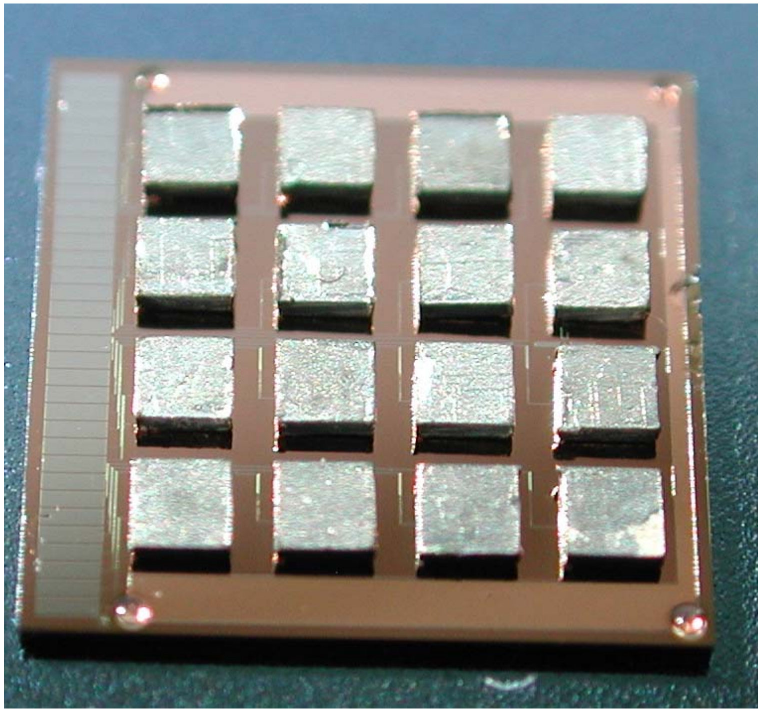
quantum efficiency

> 20% at 100 keV

NIST-LANL γ-ray arrays

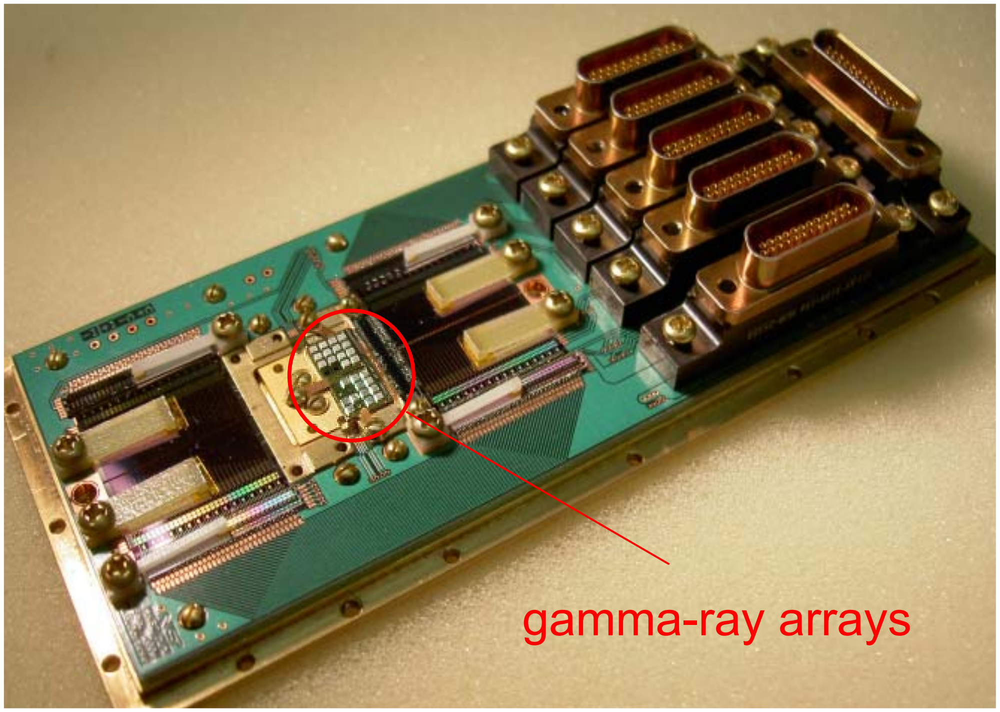
highly parallel micromachining techniques

routine fabrication of γ-ray arrays



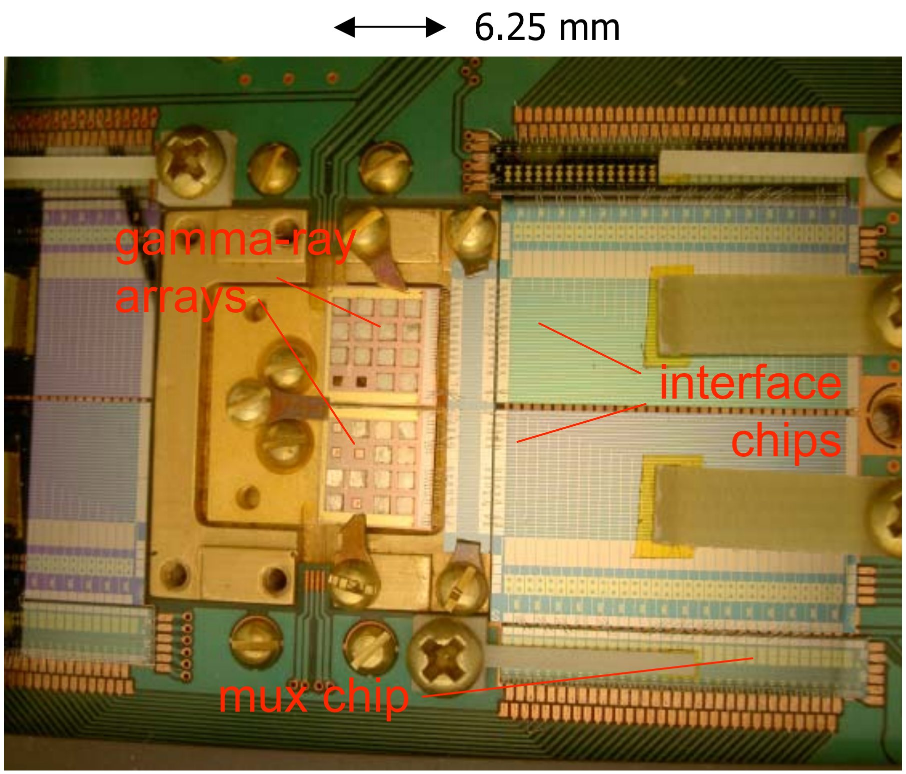
6.25 mm

testbed with all readout circuitry and wiring for 128 pixels



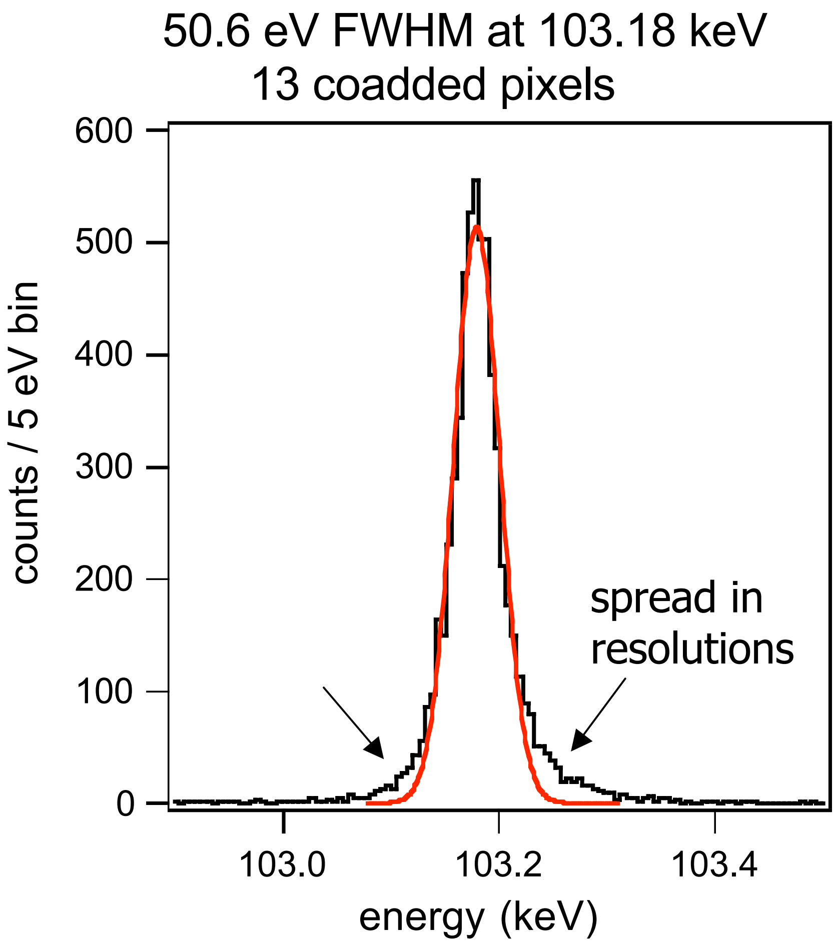
Multiplexed array testing

zoomed view of 128 pixel testbed



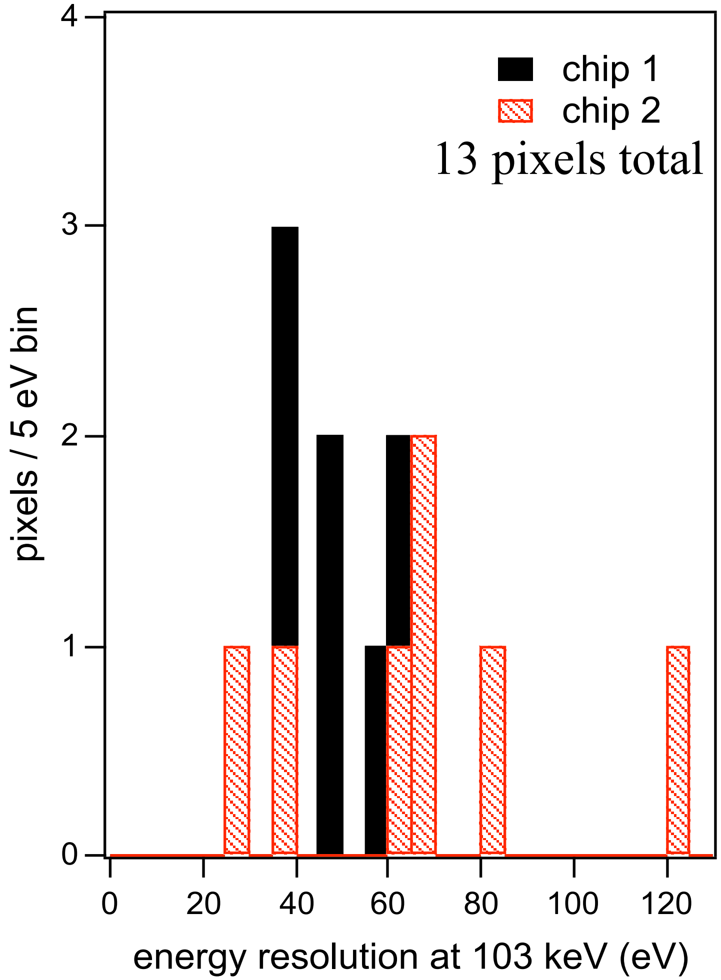
- interface chips for L/R filtering
- 4x 32:1 multiplexer chips

muxed spectrum of ^{153}Gd γ-ray source

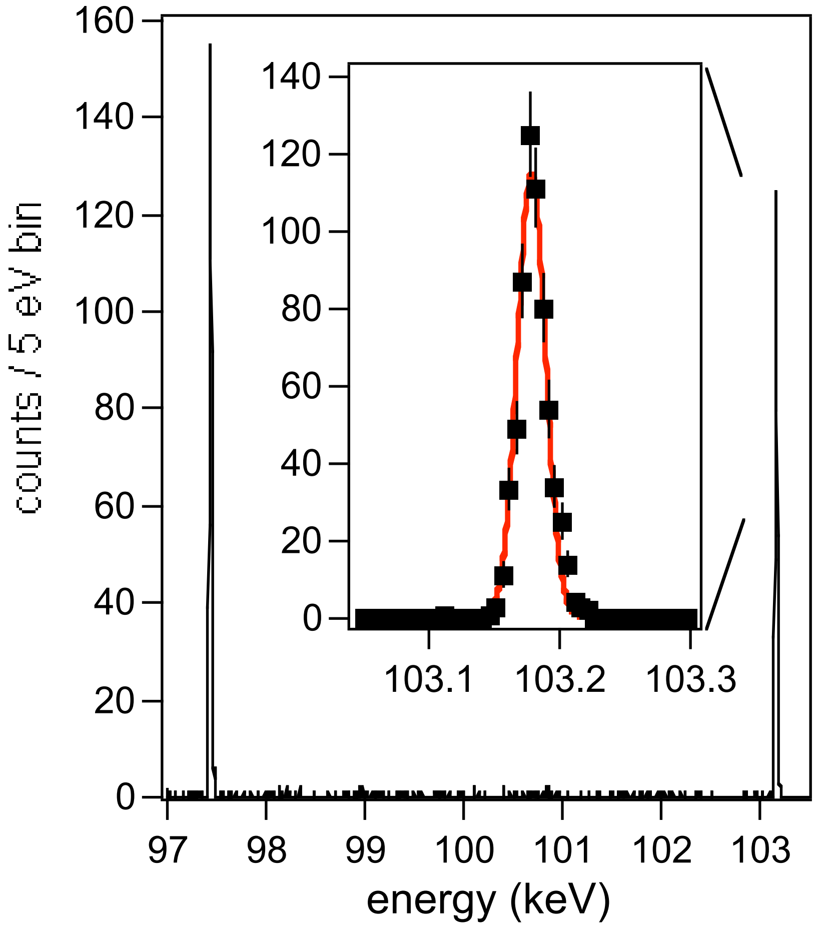


Homogeneity

energy resolution histogram

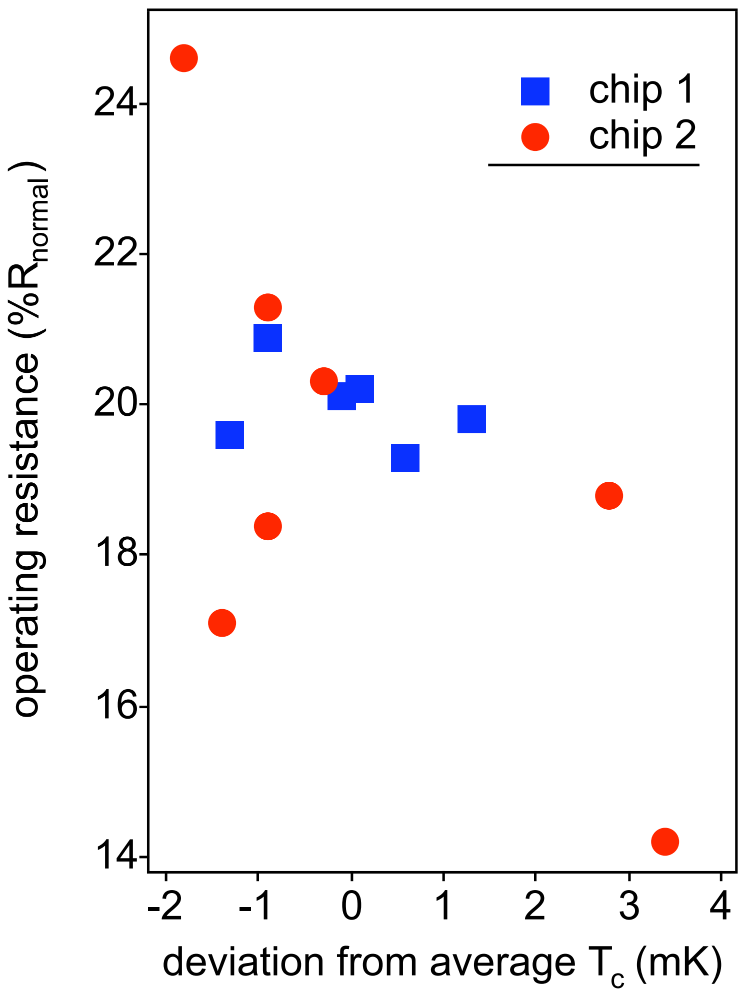


new performance record:
25 eV FWHM at 103 keV

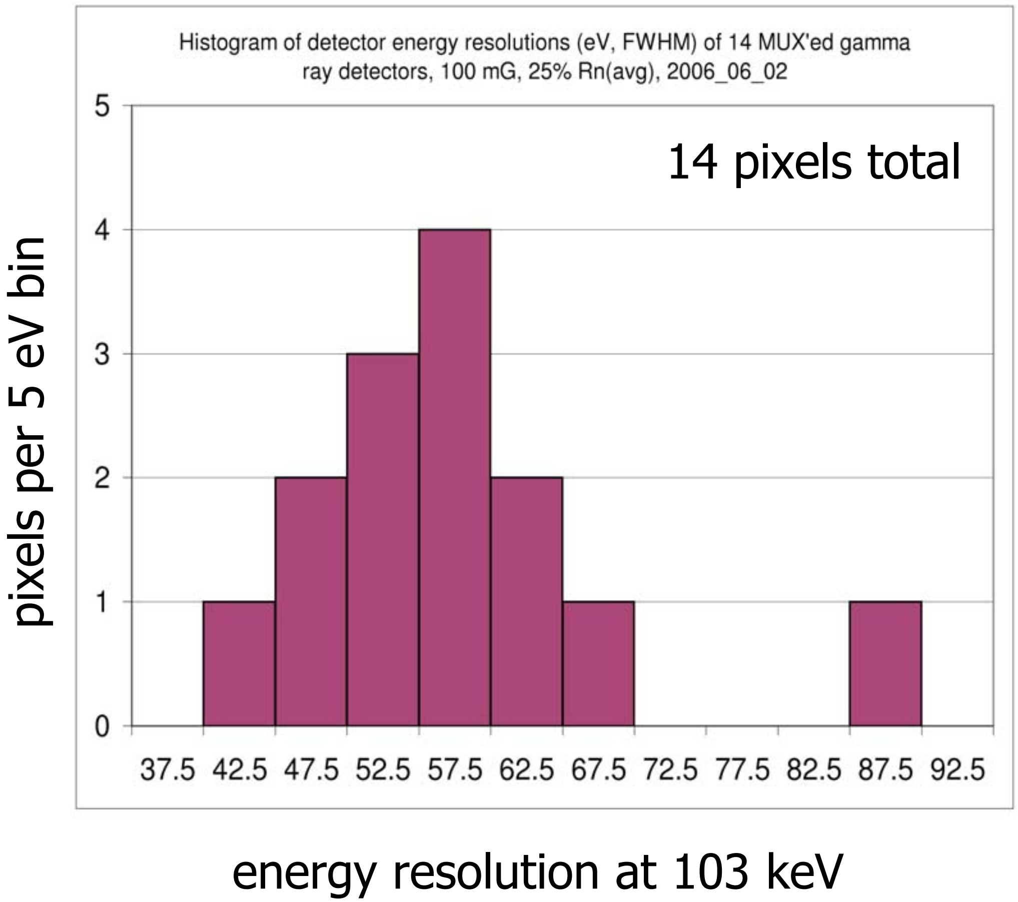


More on homogeneity

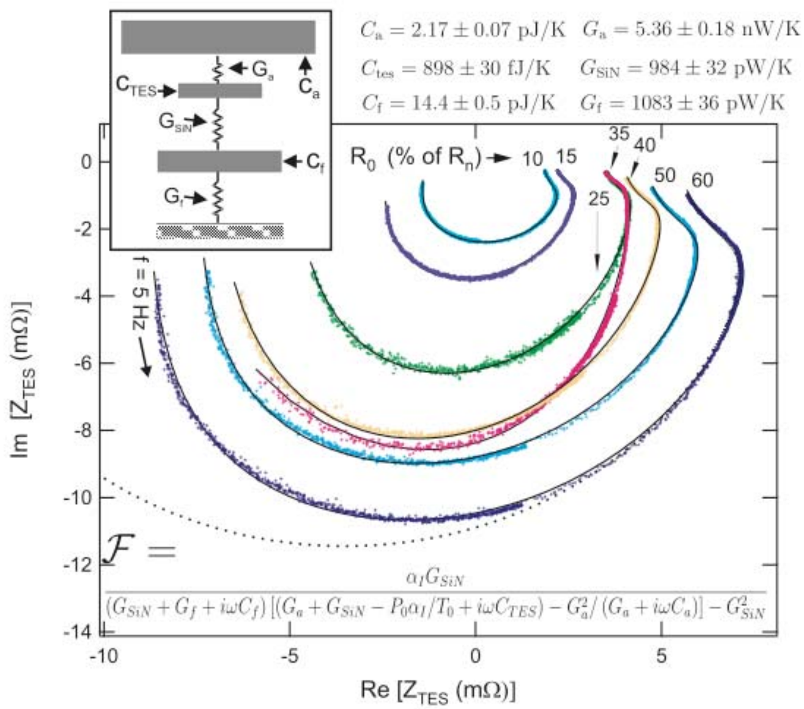
why spread in ΔE ?
common bias and spread in T_c
"   " complex transition shapes

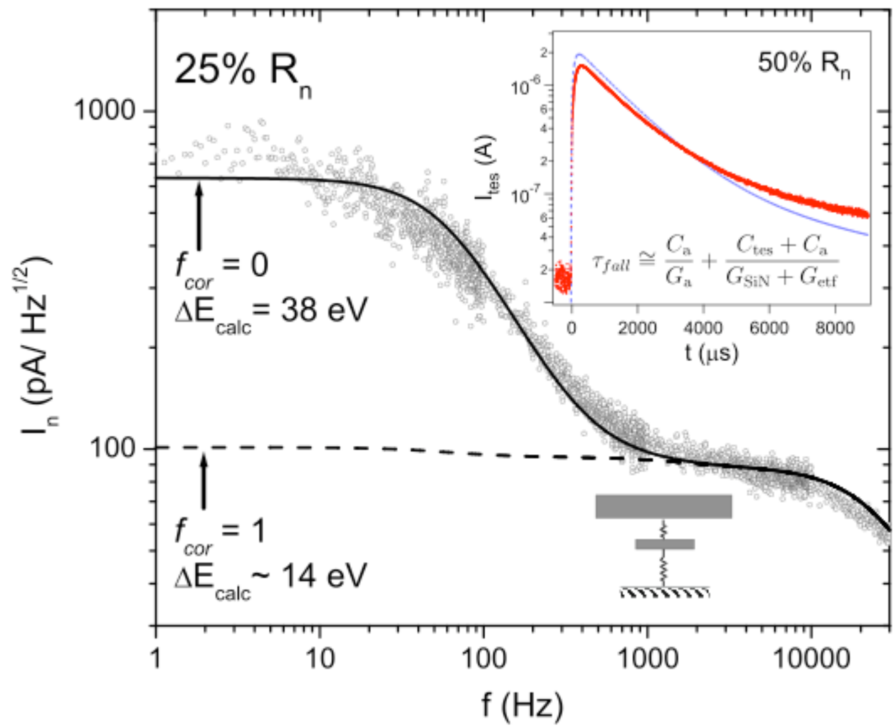


bias chosen for more homogenous ΔE



Detailed analysis of device behavior





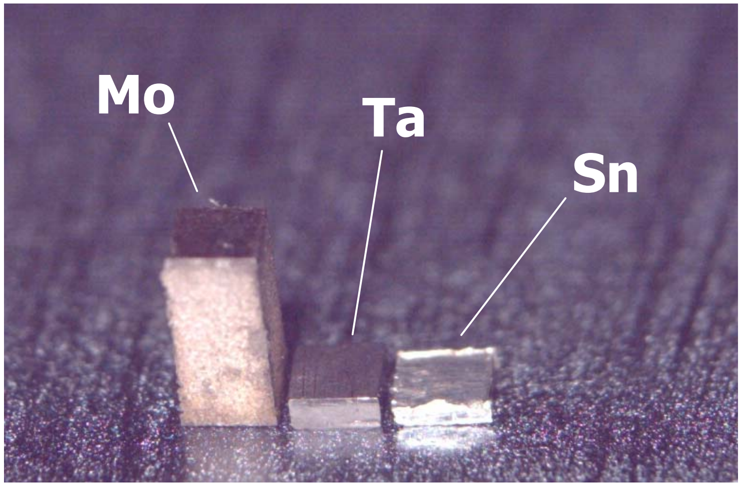
complex Z reveals absorber and (probably) frame

fitting noise requires assumption that P_N at ends of link to absorber is uncorrelated

analysis to appear in Appl. Phys. Lett. (B. Zink et al, 2006)

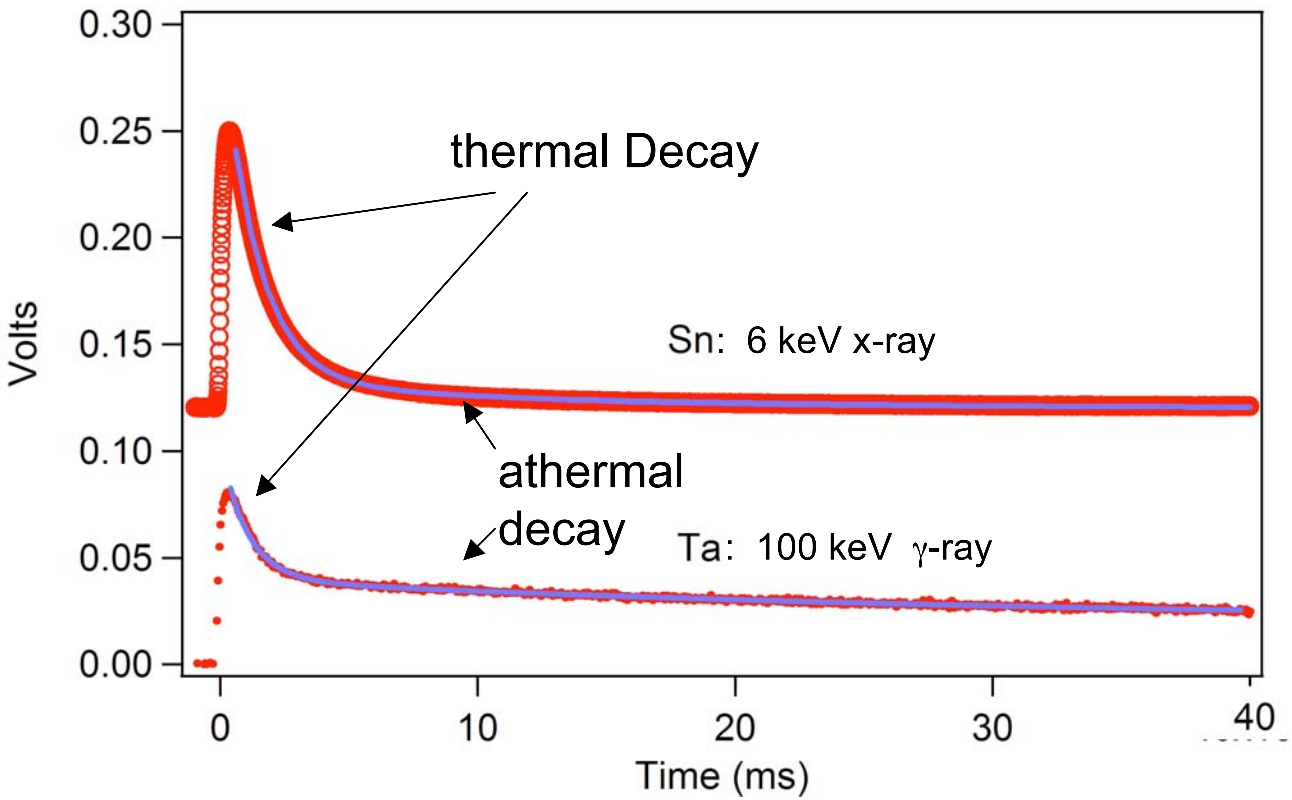
Higher efficiency possible with higher Z absorbers

Material	Z	Θ_D (K)	d (µm)	$\text{Efficiency}_{100keV}$
Sn	50	195	250	20%
Ta	73	258	387	94
Mo	42	460	1890	88
Re	75	430	1460	100
Pb	82	105	43.8	25



some insulators and semiconductors also interesting

But … complex behavior in some materials



Sn

Time Constant = 1.5 and 12.1 ms

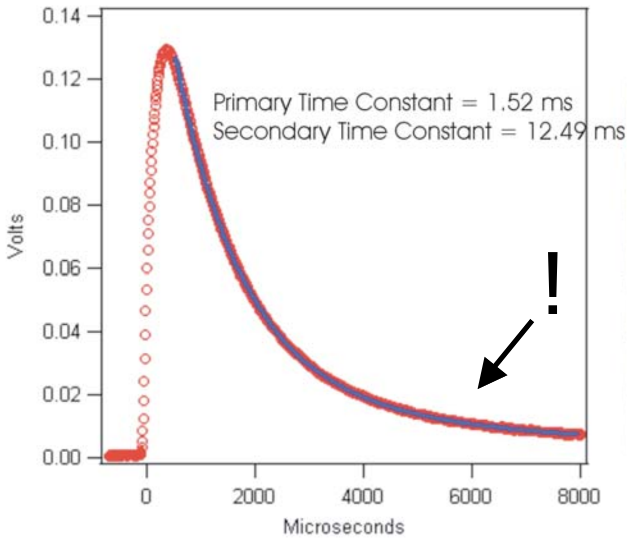
Ta

Time Constant = 1.5 and 80-100 ms

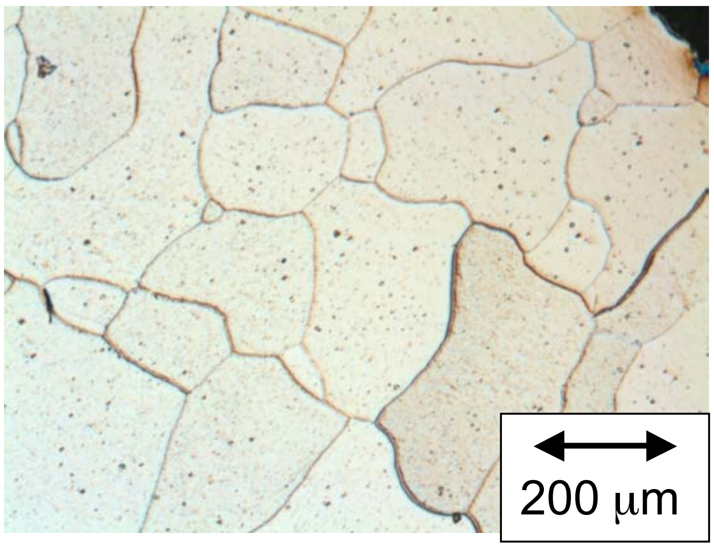
Both Sn and Ta have second, athermal decay

? Ta has anomalous high heat capacity ?

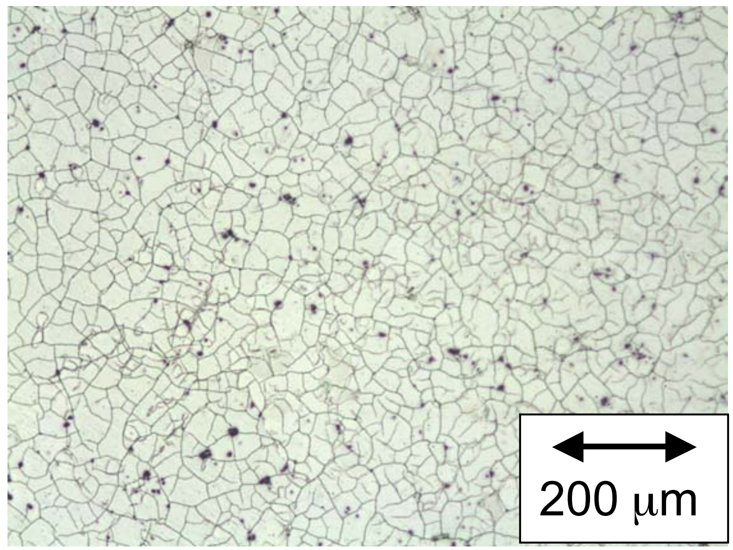
How can we eliminate athermal decay in Sn ?



- can control (and measure) Sn grain size
- will measure dependence of athermal decay on grain size
- eliminating athermal decay will allow higher count rates

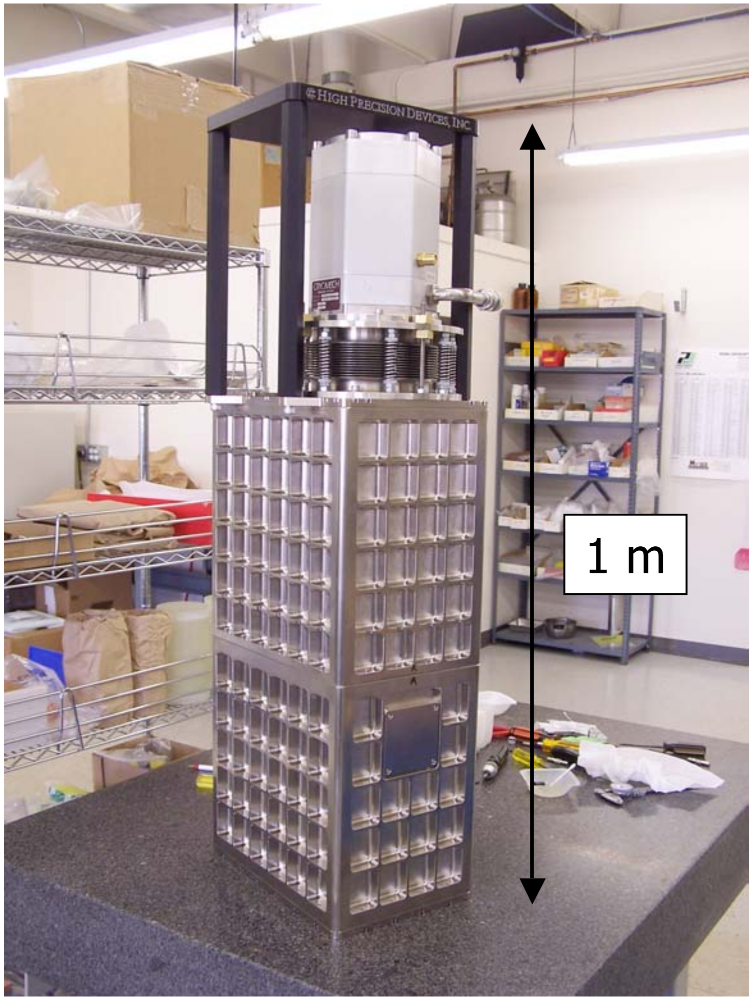


cold rolled from supplier has large grains



mechanical working leads to smaller grains

Spectrometer under construction for LANL

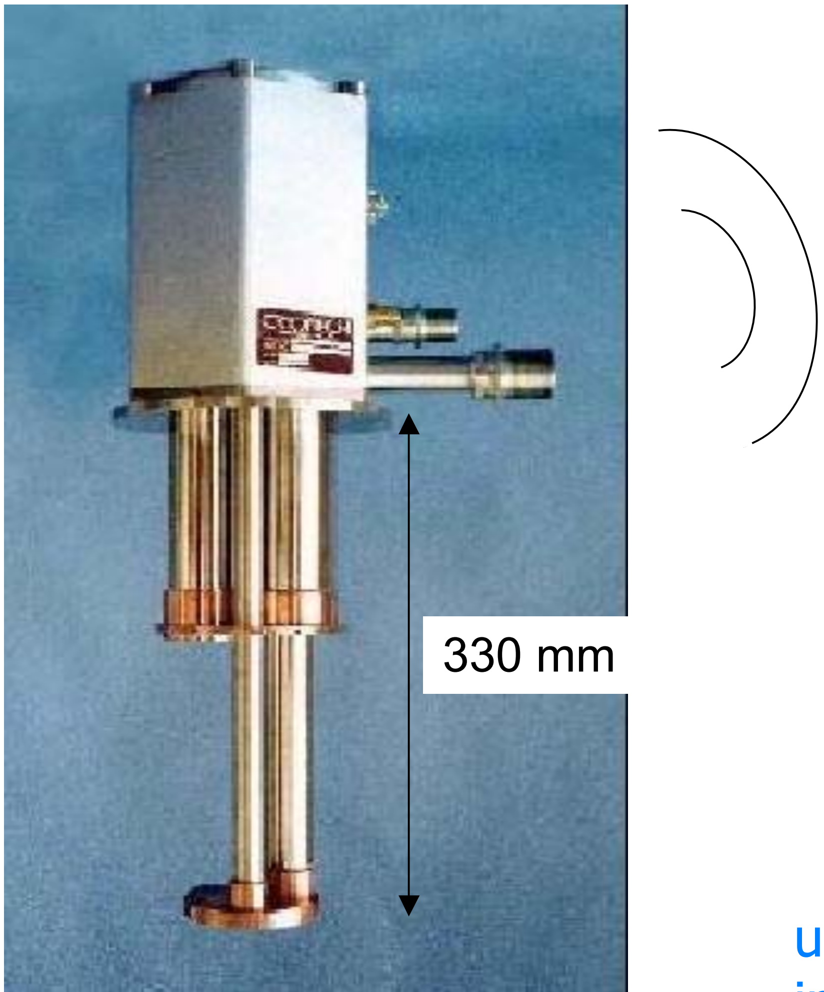


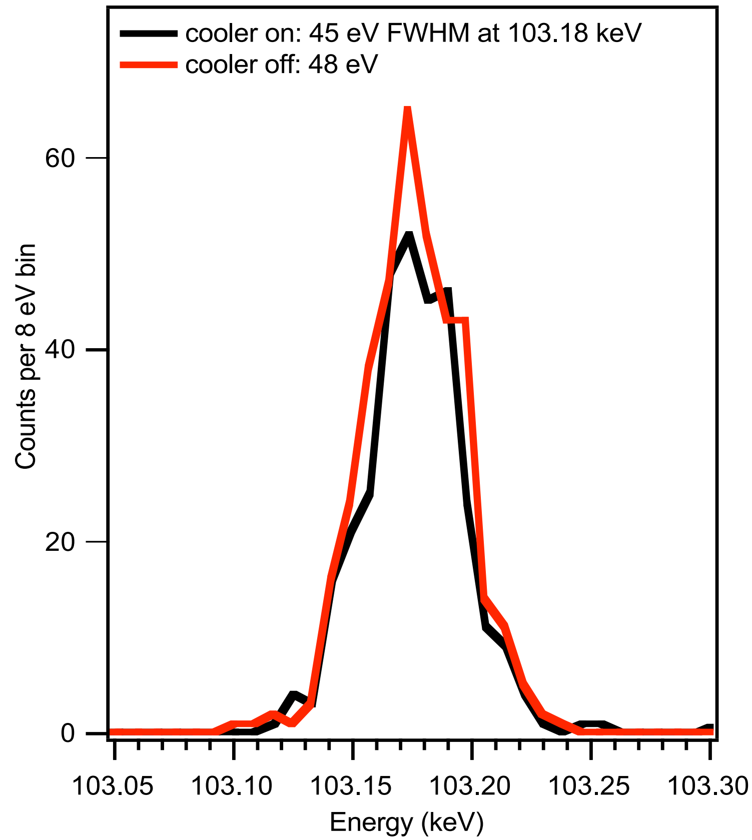
NIST-designed cryogen-free refrigerator assembled and tested

- push-button operation
- 13 hrs to cool from 300K
- 7.5 days at 100 mK
- < 1 hr to recycle

now available commercially from
High Precision Devices, Inc.

TES operation in electrical environment of cryocooler

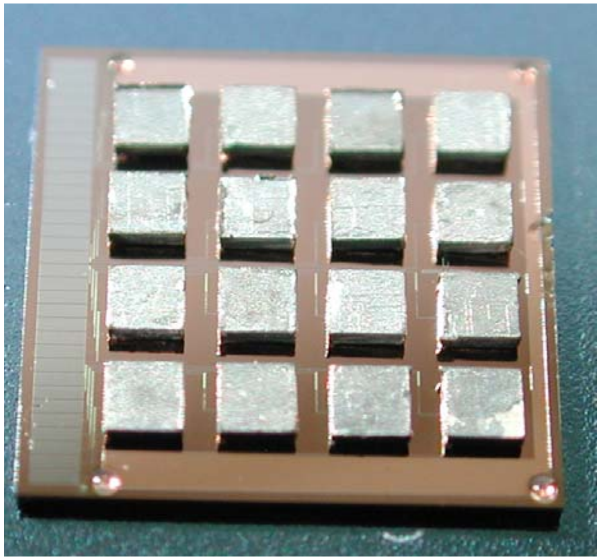




undegraded operation of gamma-ray ucal in electrical environment of pulse tube

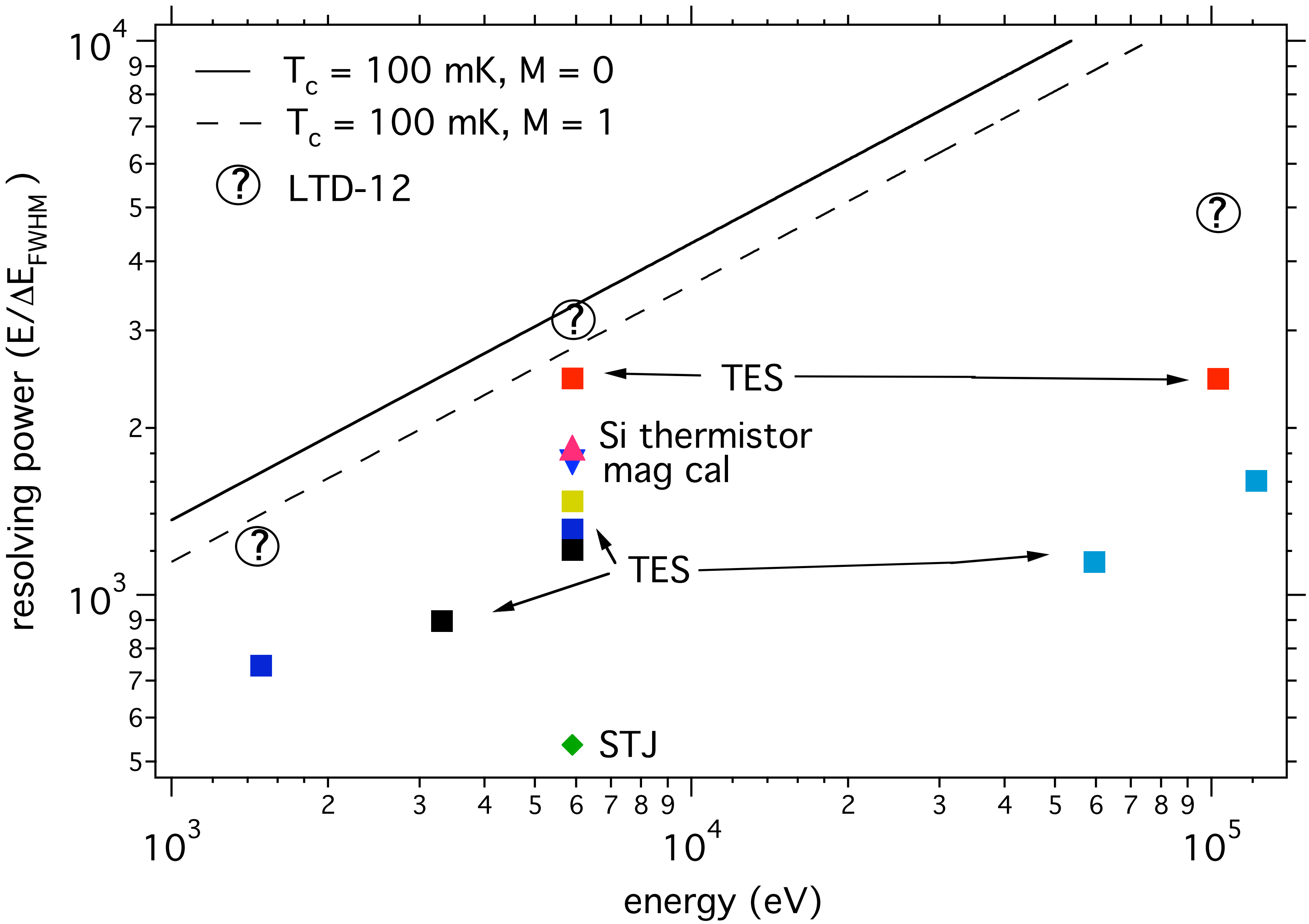
Conclusions

- there are applications for ucal arrays operating at ~100 keV
  - Pu isotopes, spent fuel, HEU, …
- we have developed array-compatible techniques for fabricating γ-ray ucals

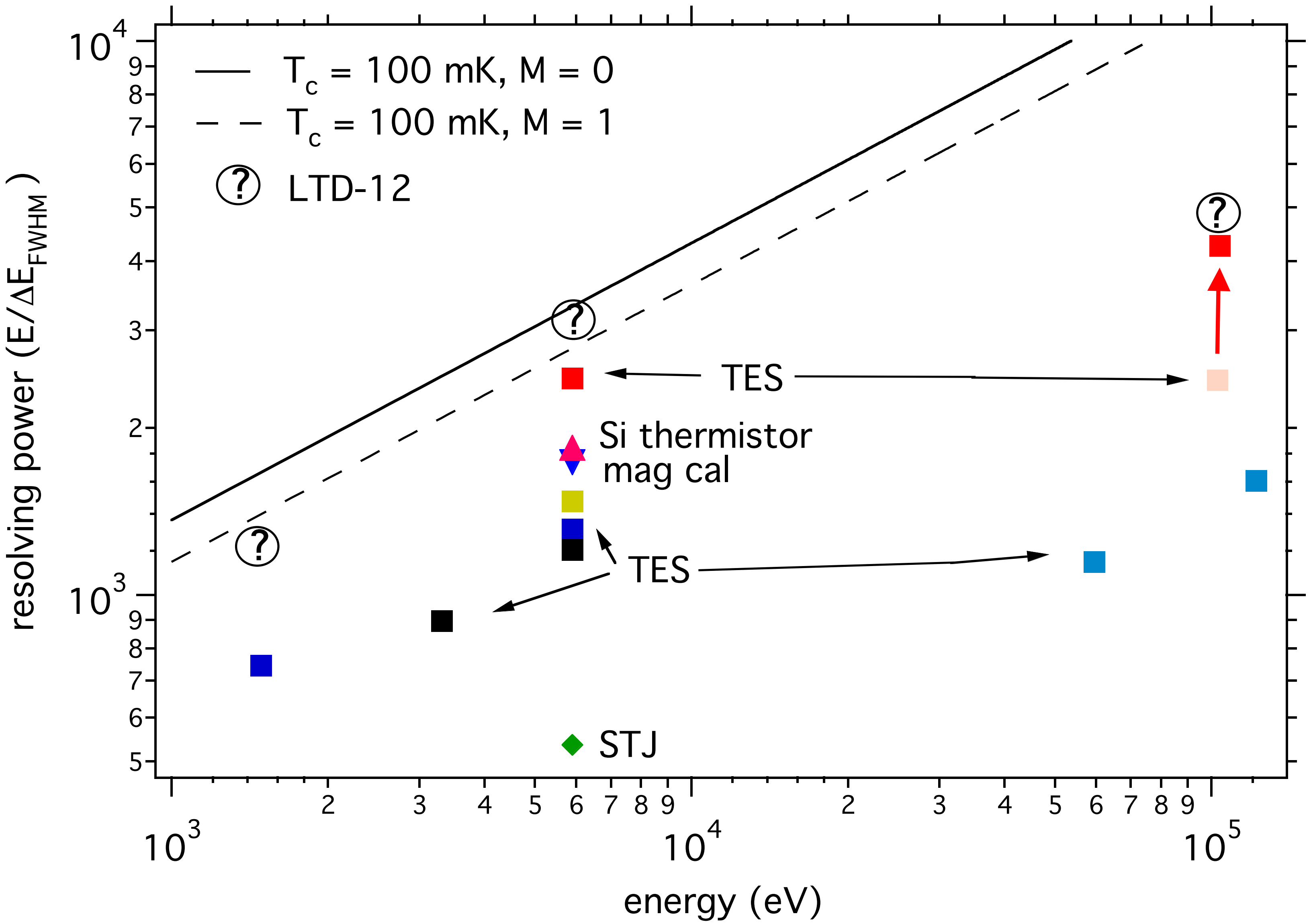


- under muxed operation
  - 50 eV at 103 keV in 13 coadded pixels
  - best pixel = 25 eV
- work to understand absorber physics underway
- full spectrometer under development with Los Alamos
  - cryogen-free dewar complete
  - undegraded ucal operation
  - testbed with wiring for 128 pixels complete

Ancient history (LTD11) : TES resolving power vs energy



TES resolving power vs energy



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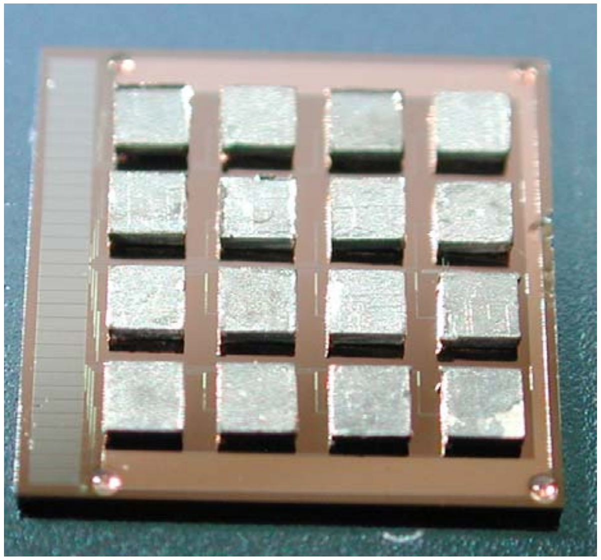

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