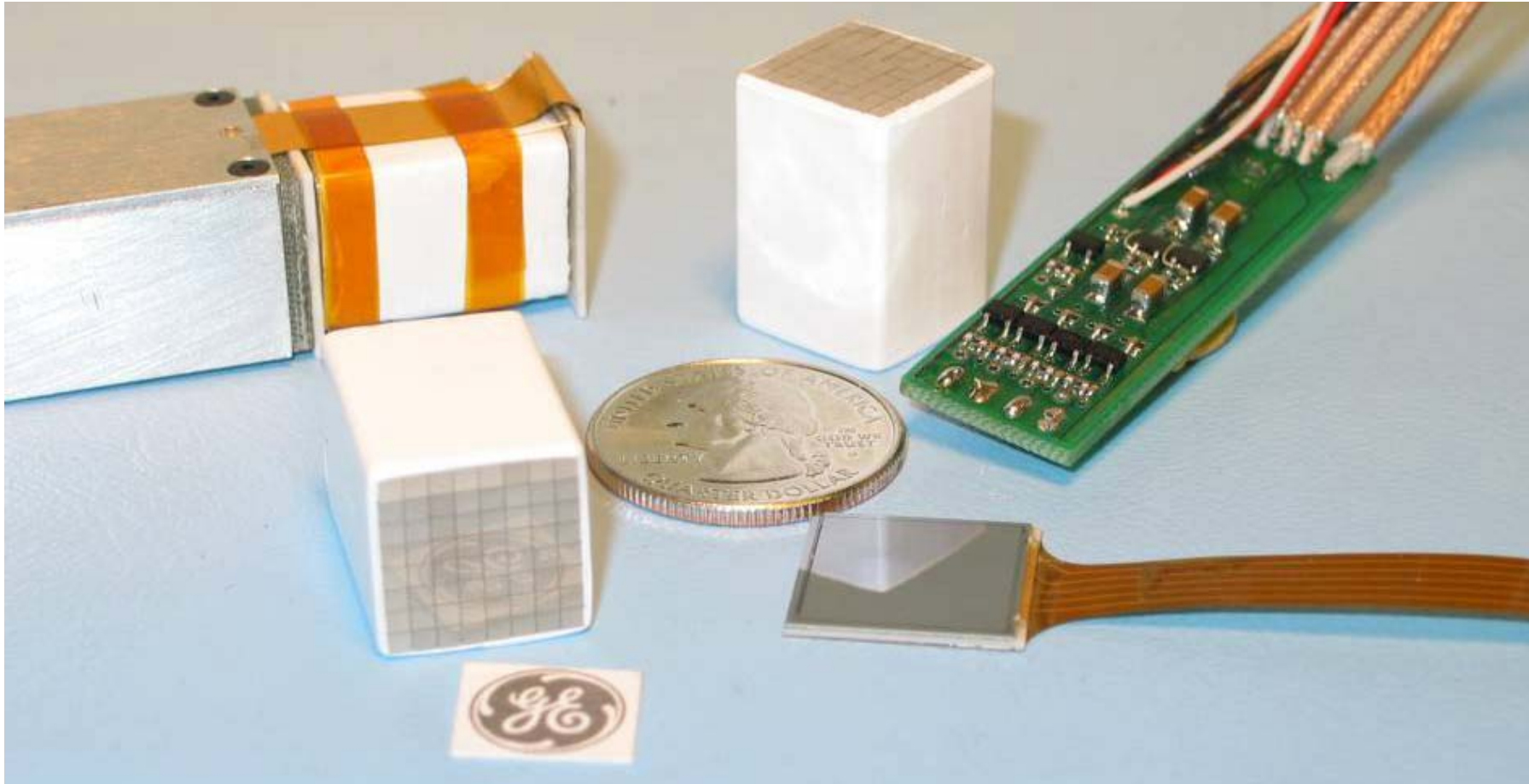
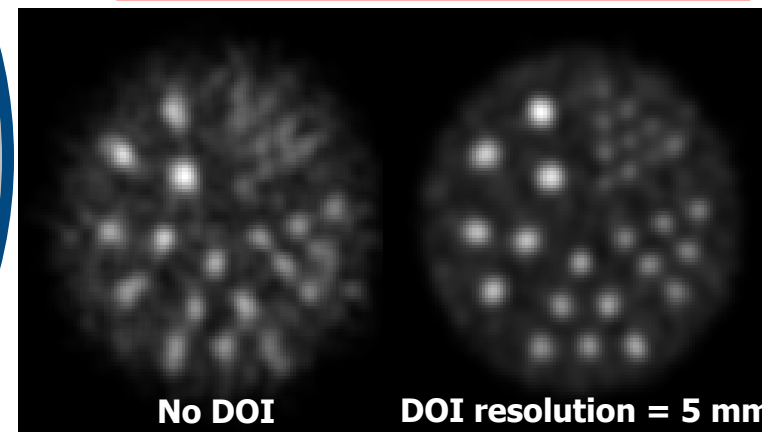
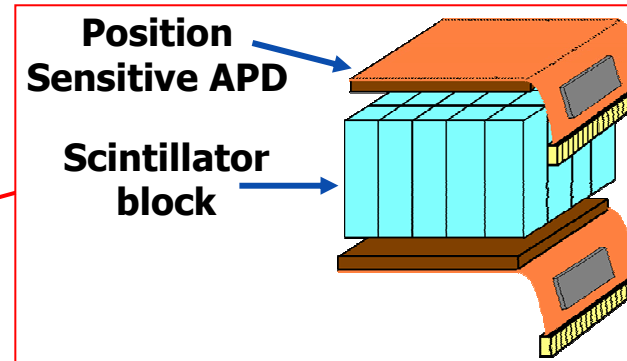
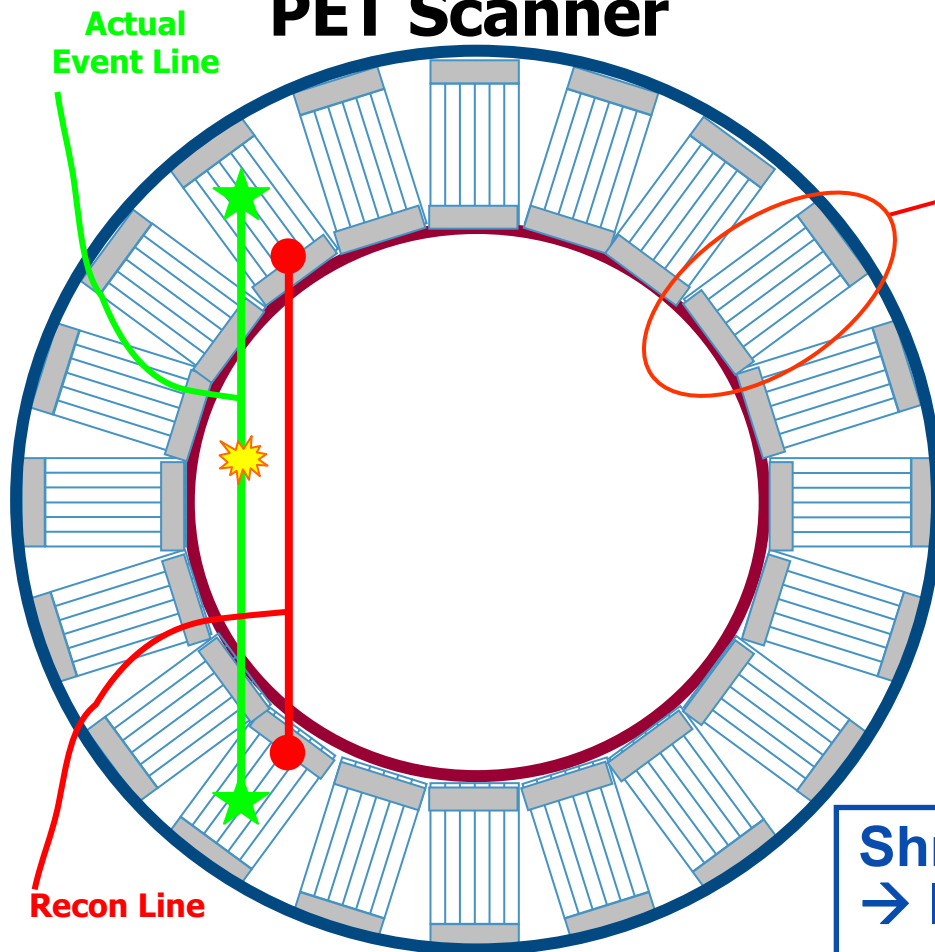


Design of Scintillator Arrays for Dual-End Depth-of-Interaction Encoding Small-Animal PET Detectors



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Detector Technology Lab, GE Research

Challenges in Small-Animal PET PET Scanner

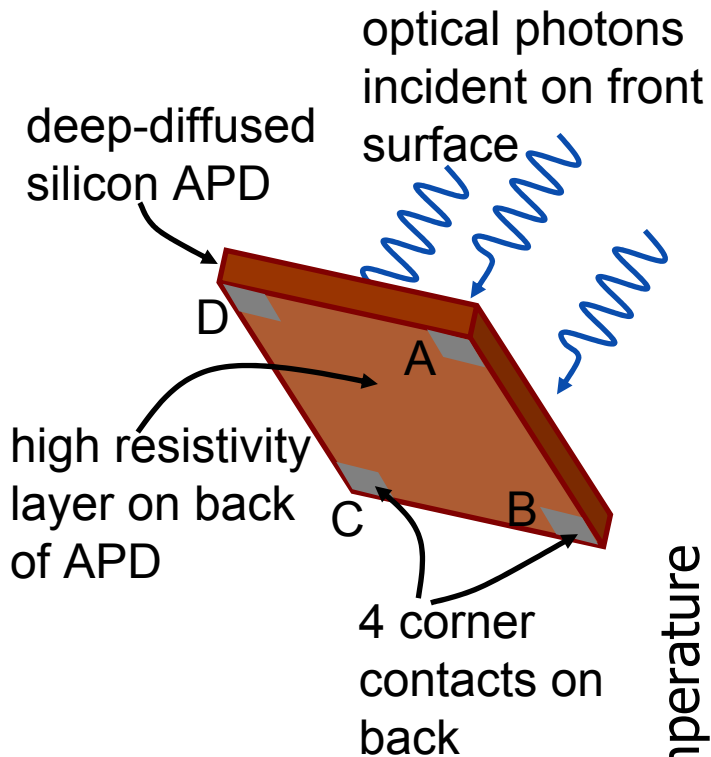


Shrink the bore and use long crystals
→ Increase sensitivity
but ...
Parallax error → Lose resolution

***3D Position Information Breaks Inverse Relationship
between Sensitivity and Resolution***

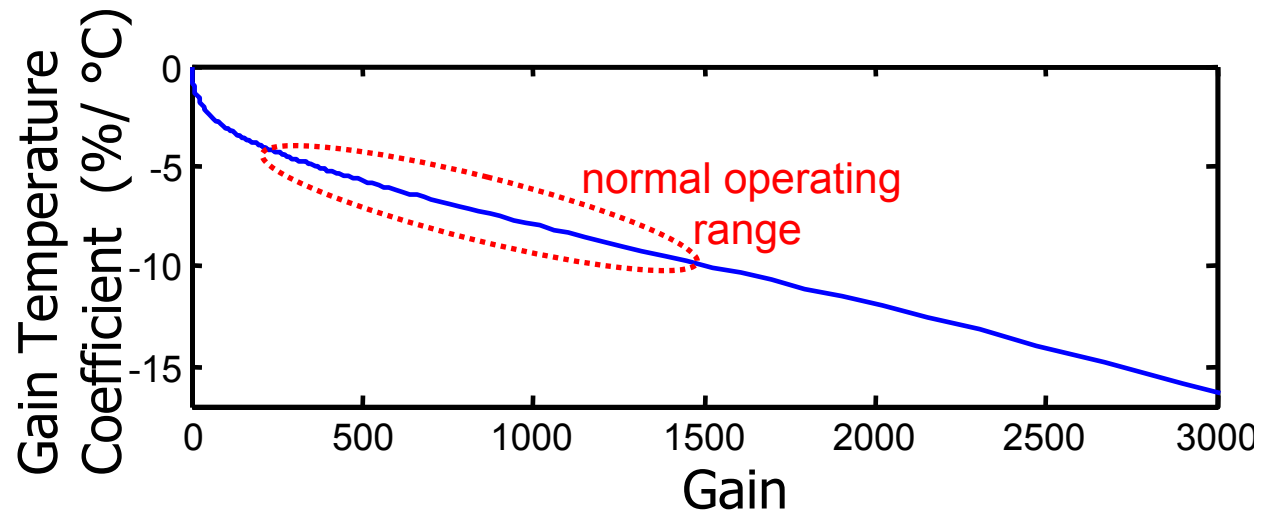
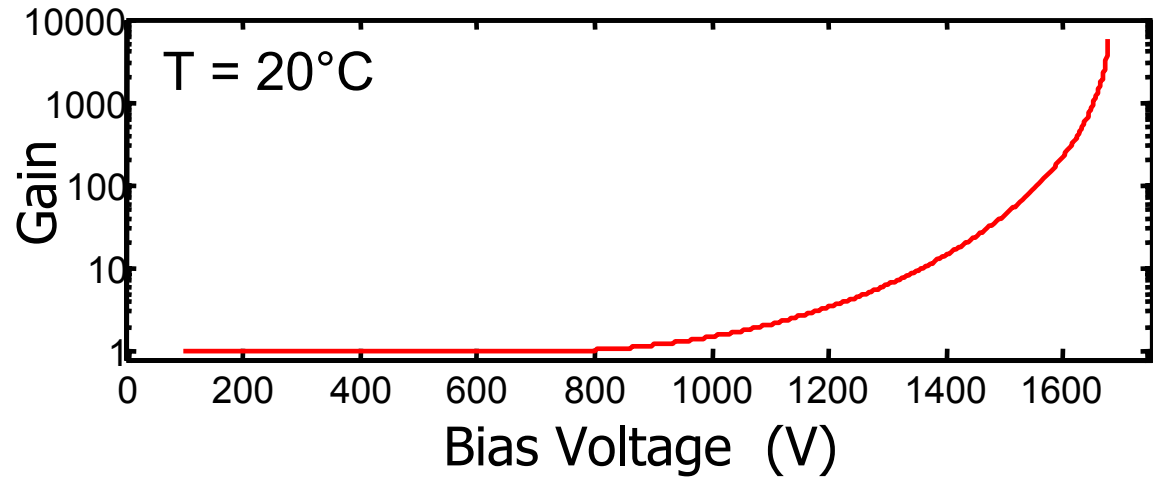
*animated

Position Sensitive APD* introduction



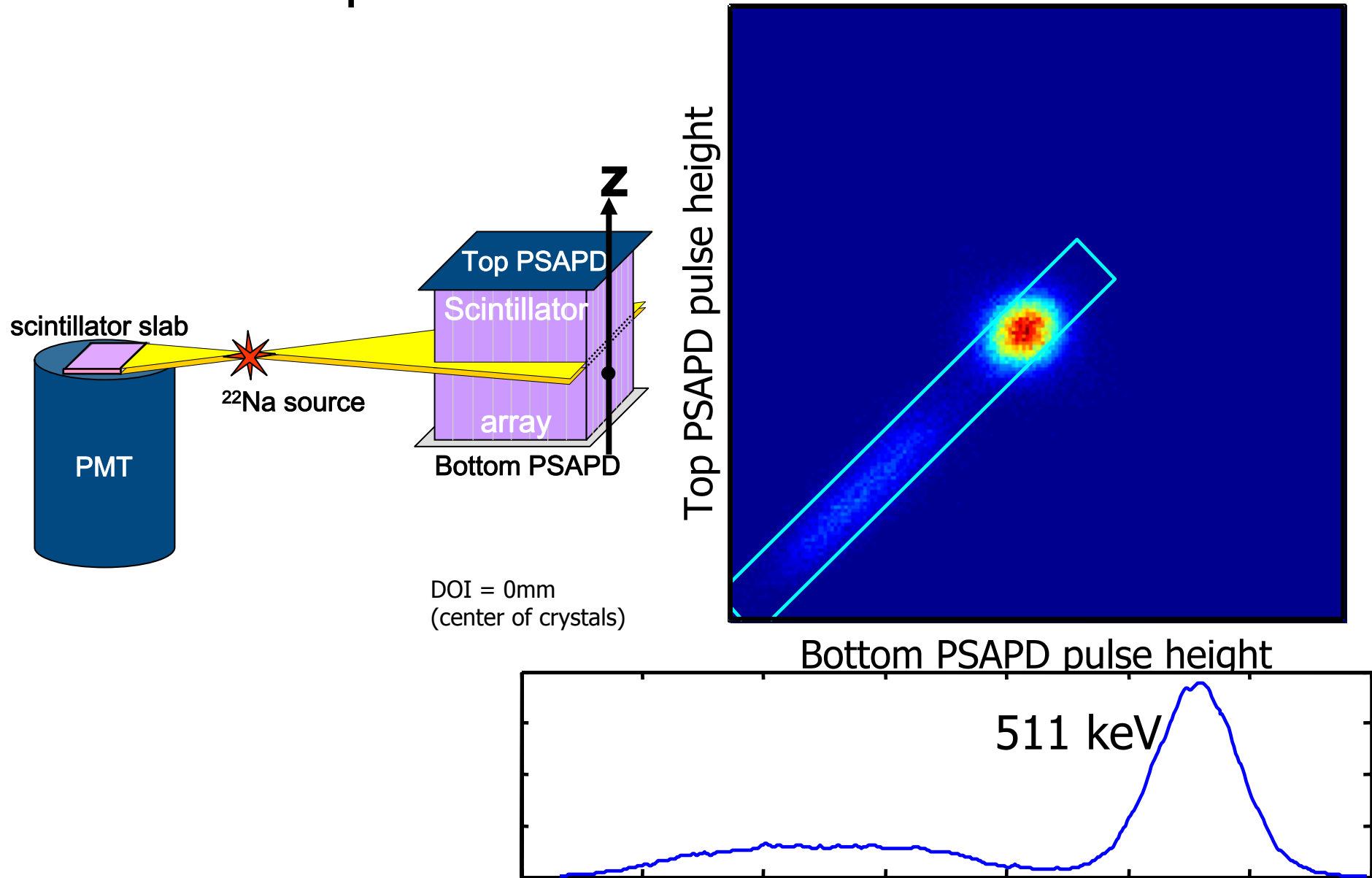
$$x = \frac{(A+B)-(C+D)}{(A+B+C+D)}$$

$$y = \frac{(A+D)-(B+C)}{(A+B+C+D)}$$



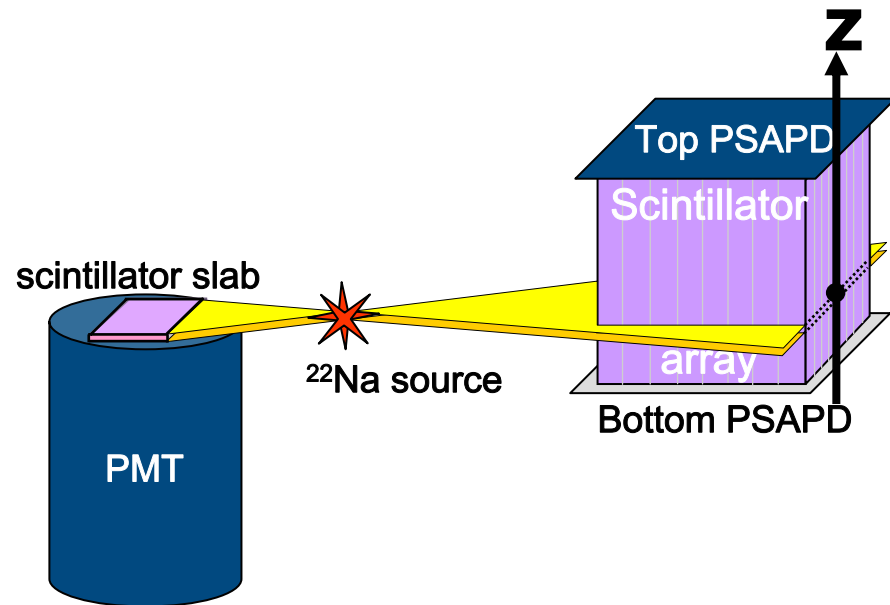
*PSAPDs manufactured by Radiation Monitoring Devices, Inc., Watertown, MA, USA.

Depth-of-Interaction Illustration

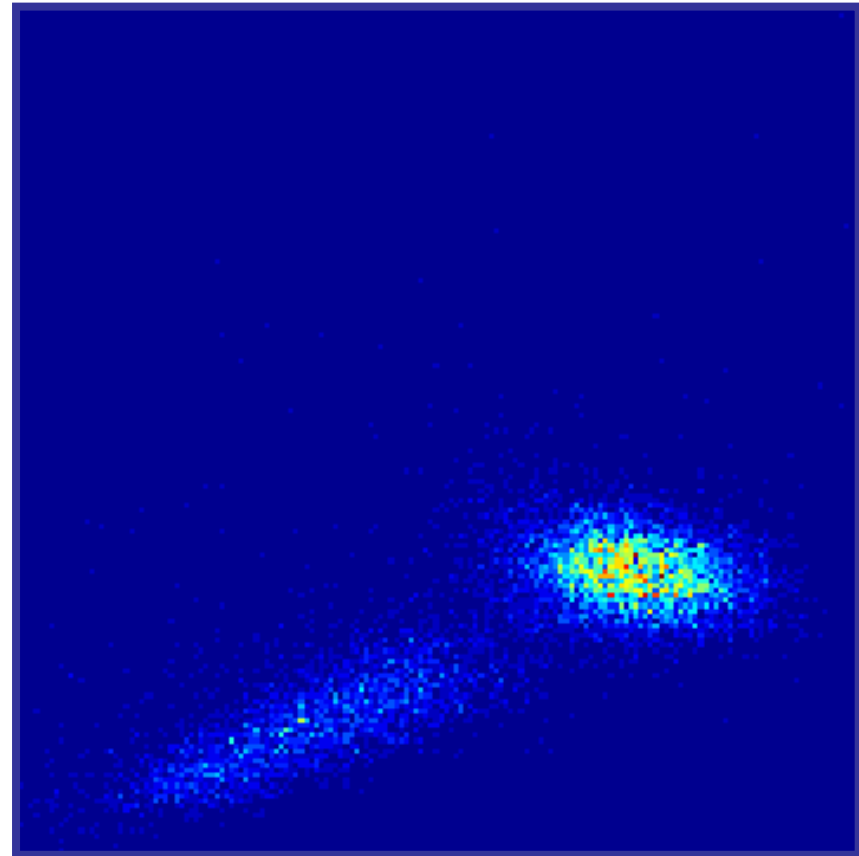


*animated

Depth-of-Interaction Illustration



Top PSAPD pulse height



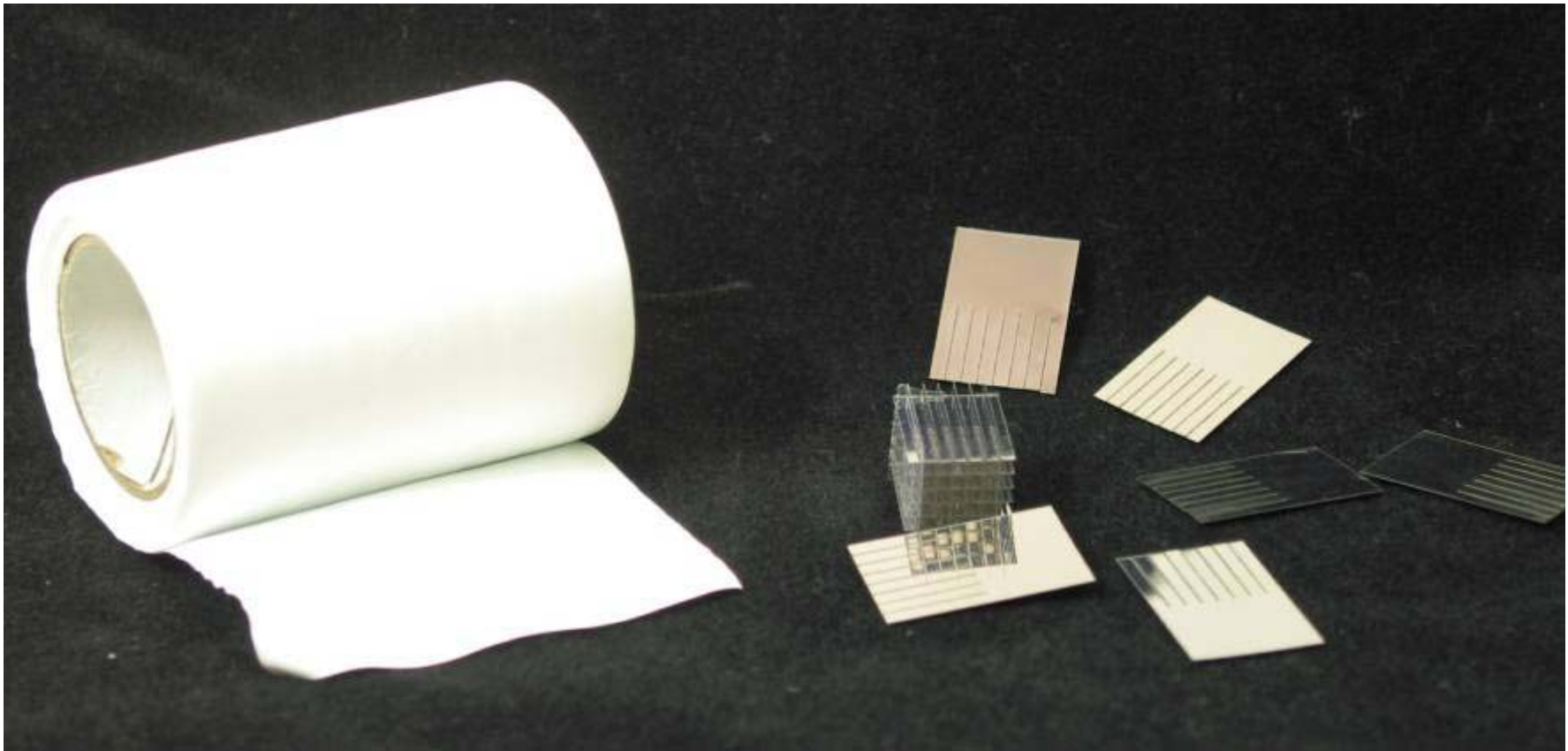
Bottom PSAPD pulse height

*animated

Scintillator Array Design

scintillator array attribute	selection	reason
scintillator material	<i>mixed lutetium silicate</i> , MLS	high light output, high density & Z, fast decay
array size, crystal dimensions	8x8 array, 1.65mm x 1.65mm x 22mm	PSAPD size, resolution, sensitivity, crystal cutting capabilities
reflector material	<ul style="list-style-type: none"> • Teflon tape • VM2000 (3M Corp.) 	experimental
crystal side surface roughness	<ul style="list-style-type: none"> • P (polished, 7nm <i>rms</i>) • M5 (lapped with 5μm grit, 16nm <i>rms</i>) • M10 (lapped with 10μm grit, 700nm <i>rms</i>) • M20 (lapped with 20μm grit, 1000nm <i>rms</i>) 	experimental

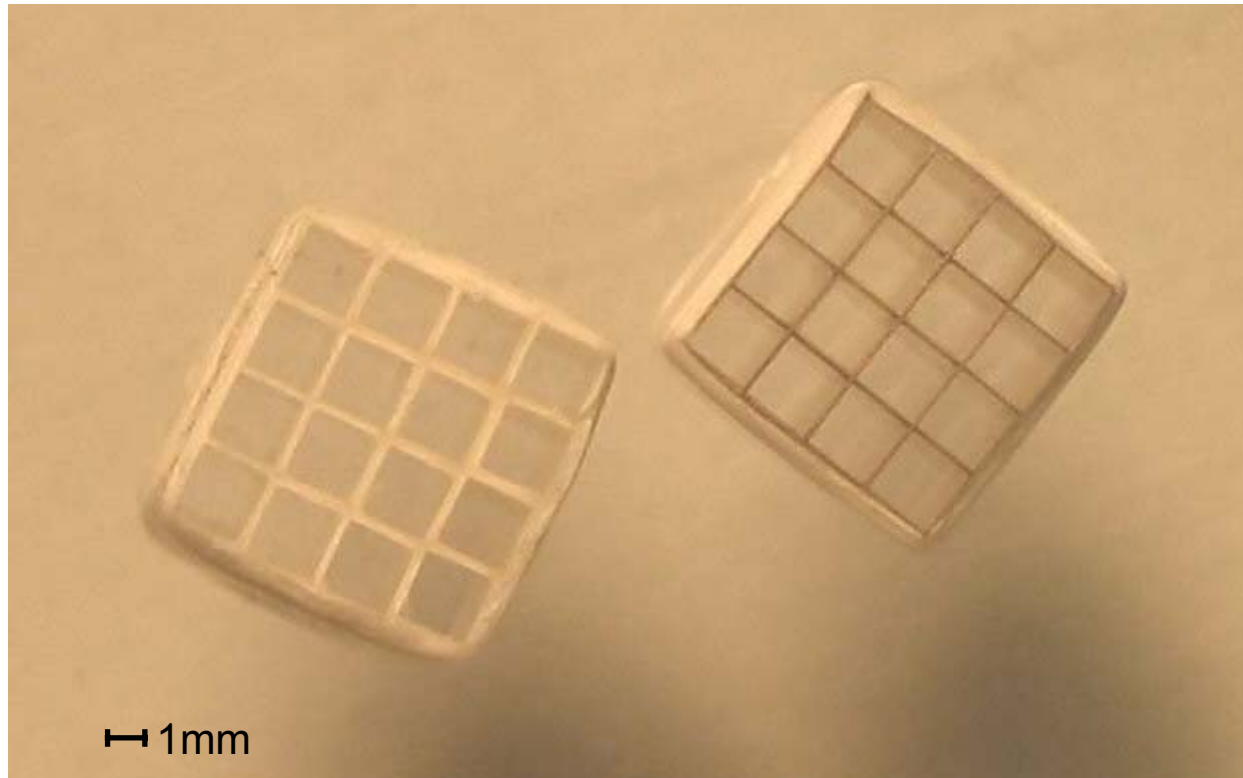
reflector material



Teflon

VM2000

reflector material



Teflon

- best light collection
- time-consuming to assemble
- well-known problems with reproducibility, shrinkage, wicking, etc.

VM2000

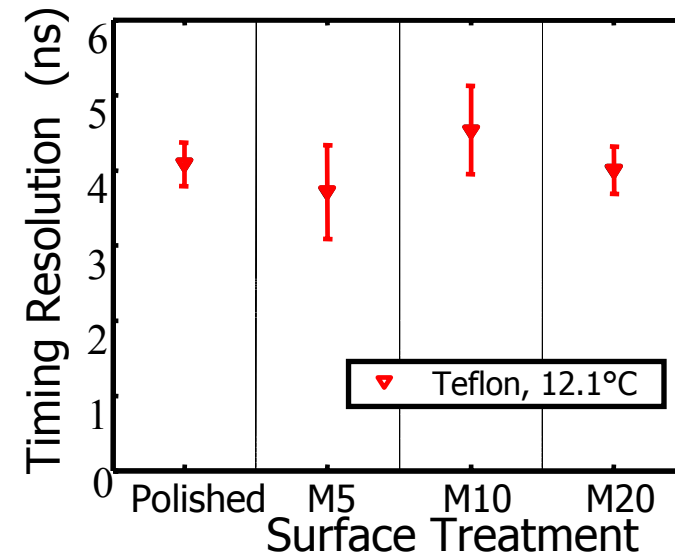
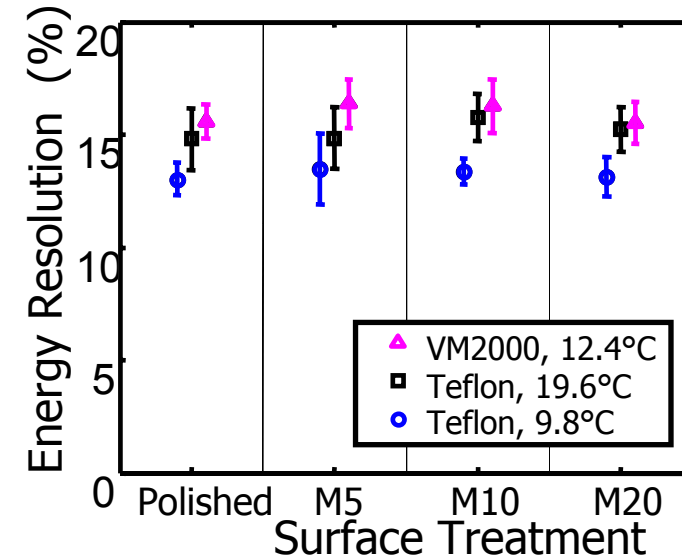
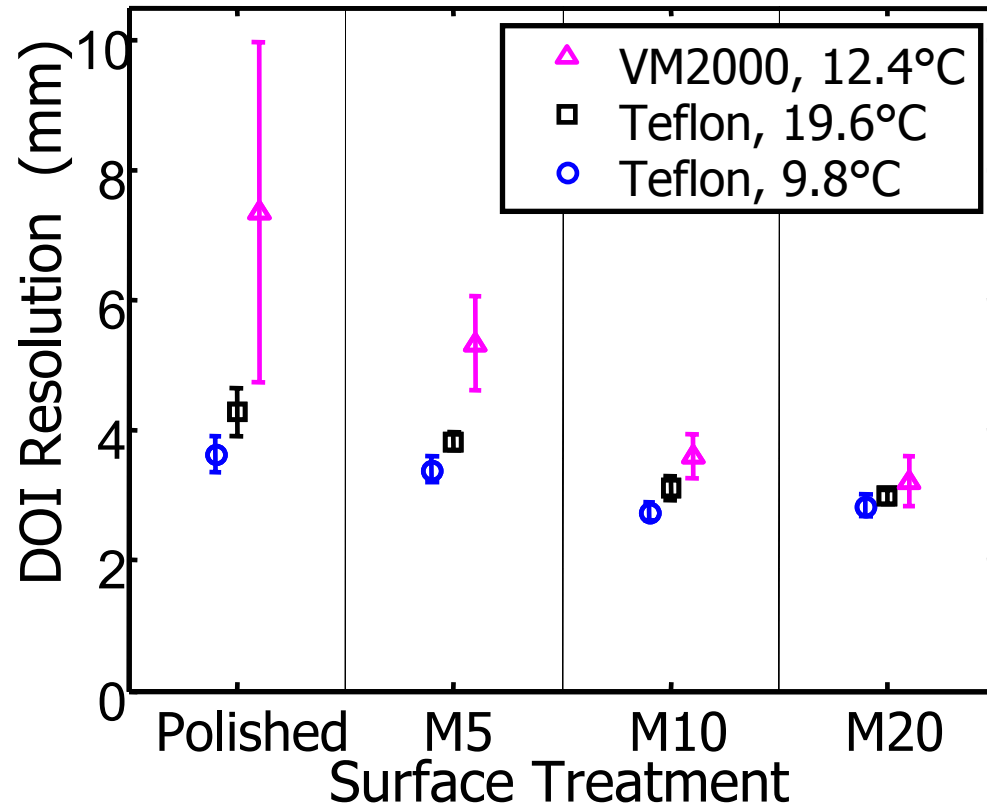
- laser cut film
- much faster assembly
- improved reproducibility
- reduced dead-space
- somewhat reduced light collection efficiency (~75% of Teflon)

Scintillator Array Experiments

- 4 different surfaces (P, M5, M10, M20)
- 2 reflector materials (Teflon, VM2000)
- 5x5 array of crystals (parallel data acquisition under identical conditions)
- 1.9mm x 1.9mm x 20mm MLS crystals
- 14mm x14mm PSAPD
- arrangement chosen so that:
 - each row and column have at least one of each crystal type
 - central 3x3 of array has at least two crystals of each type
 - "black" crystal used for unambiguous identification of crystals
 - each corner crystal has different surface
 - each 2x2 in corner has one crystal of each type, except for corner that has "black" crystal

P	Black	M20	M10	M5
M10	M20	M5	P	M20
M5	P	M20	M10	M5
P	M5	M10	M20	P
M20	M10	P	M5	M10

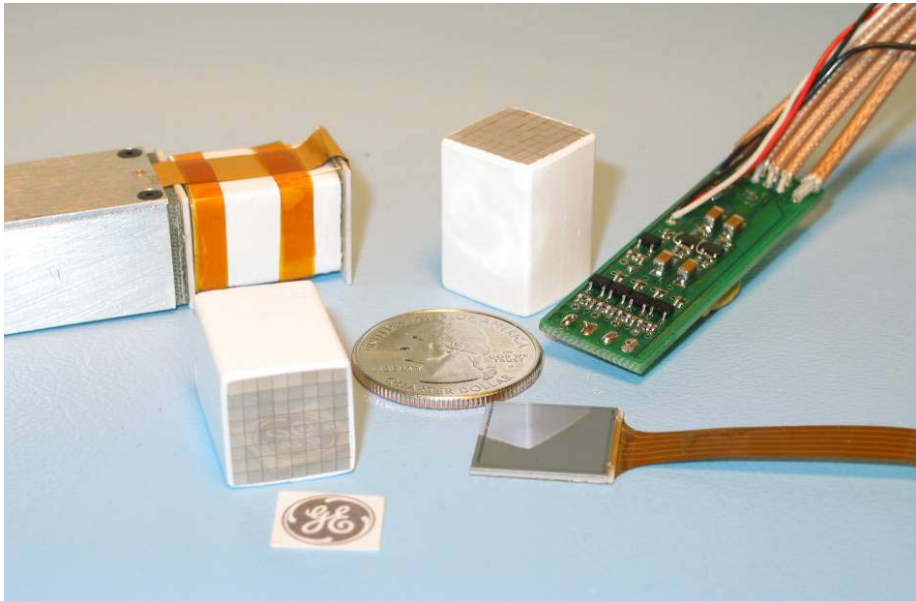
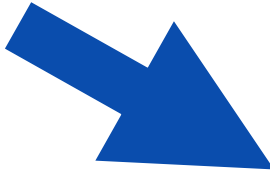
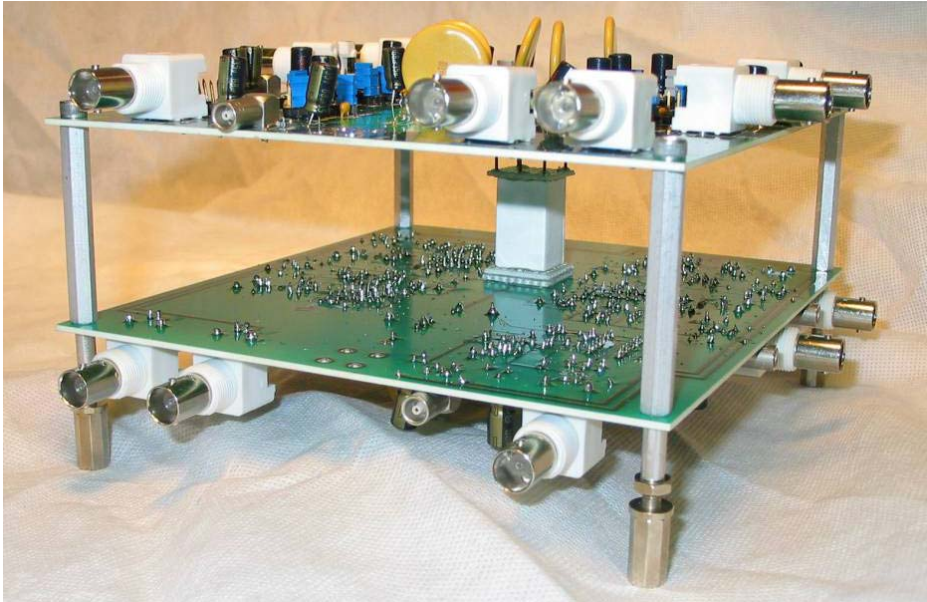
Scintillator Array Experiments: Results



Roughening the surface improves DOI ...

... without degrading energy resolution and timing resolution.

Detector Evolution



*animated

Detector Specifications

PSAPD

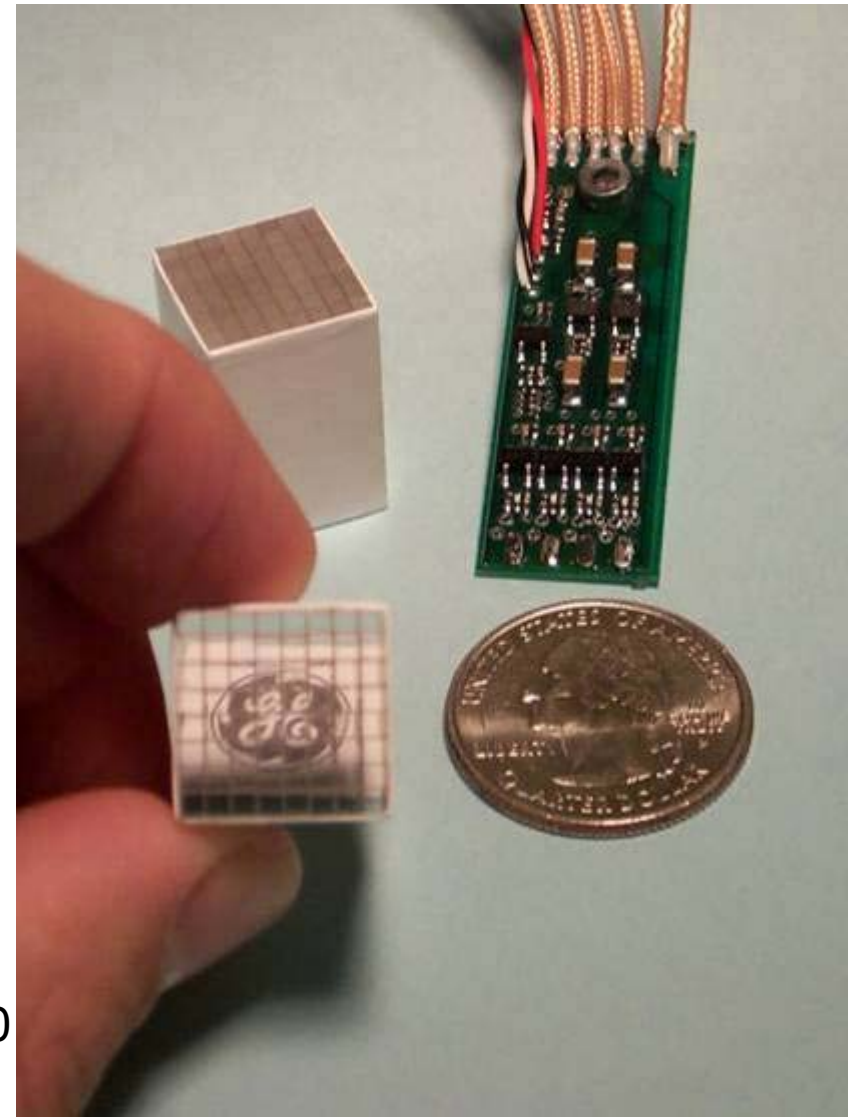
- 14 mm x 14 mm active area
- operated at 10°C and -1630V
- gain ~950
- leakage current ~1 μ A

Scintillator array

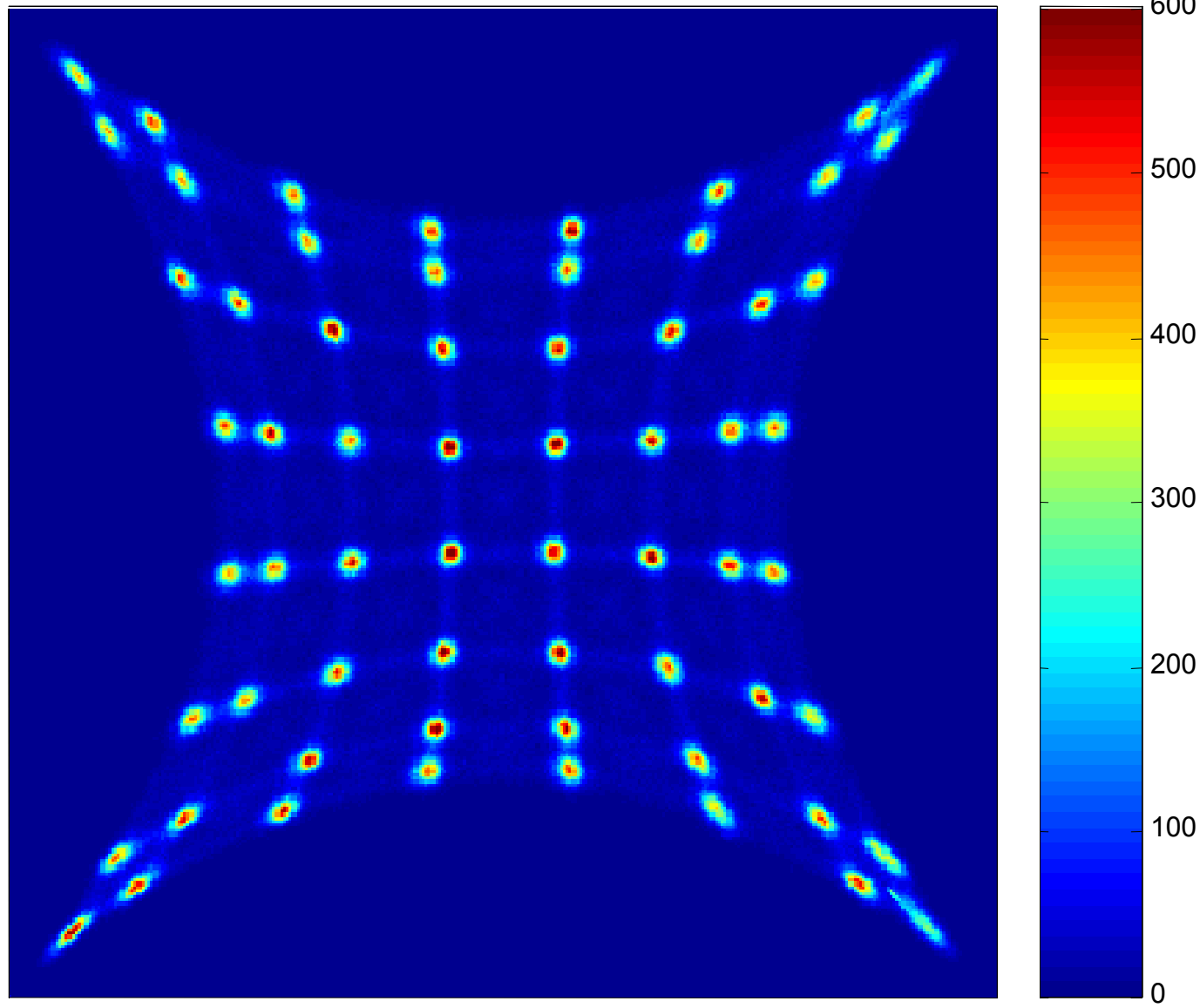
- 8x8 MLS
- 1.65 mm x 1.65 mm x 22.00 mm
- 1.75 mm pitch
- 3M VM2000 reflective film
- rough side surfaces, polished ends
- coupled to PSAPD using Cargille Meltmount

Electronics

- corner contacts: low noise JFET input wide bandwidth transimpedance amplifier with a 100 kohm transimpedance gain
- trigger and energy signal from analog sum of corner contacts

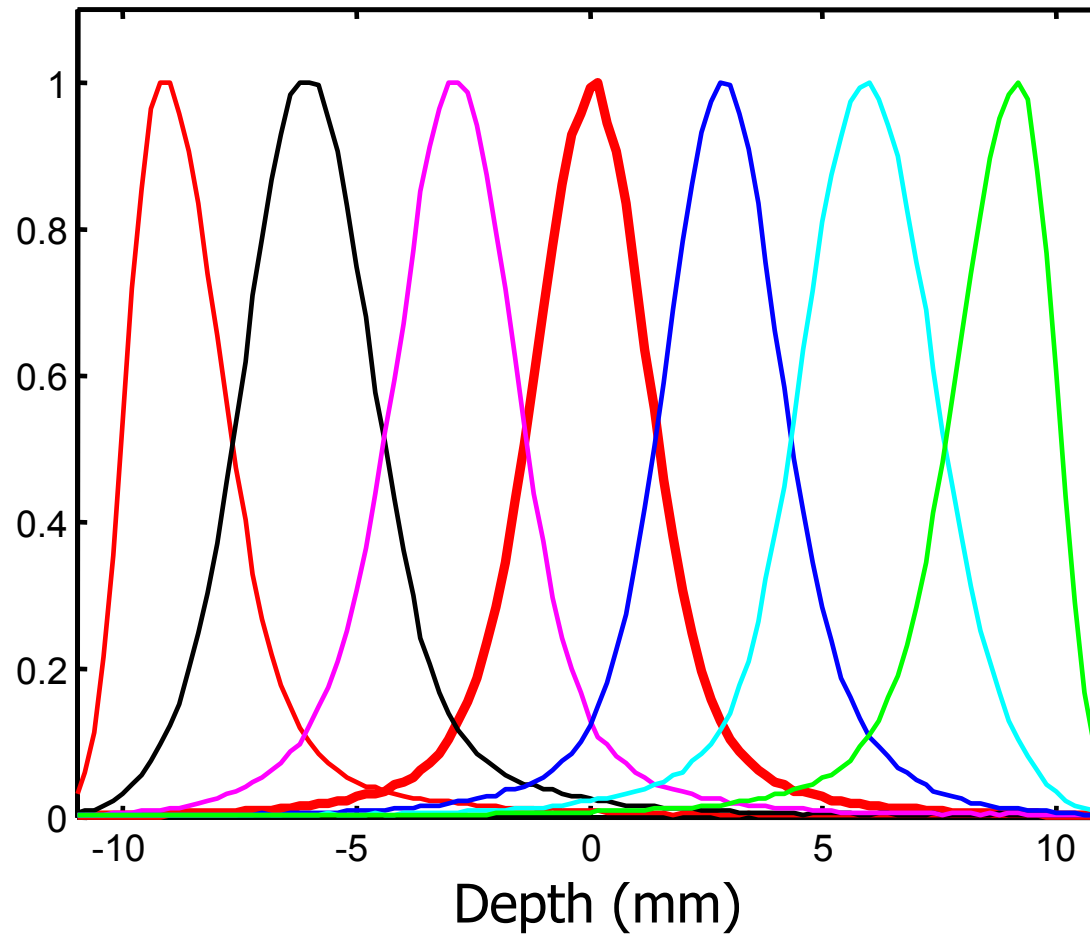


Flood Histogram – ^{22}Na



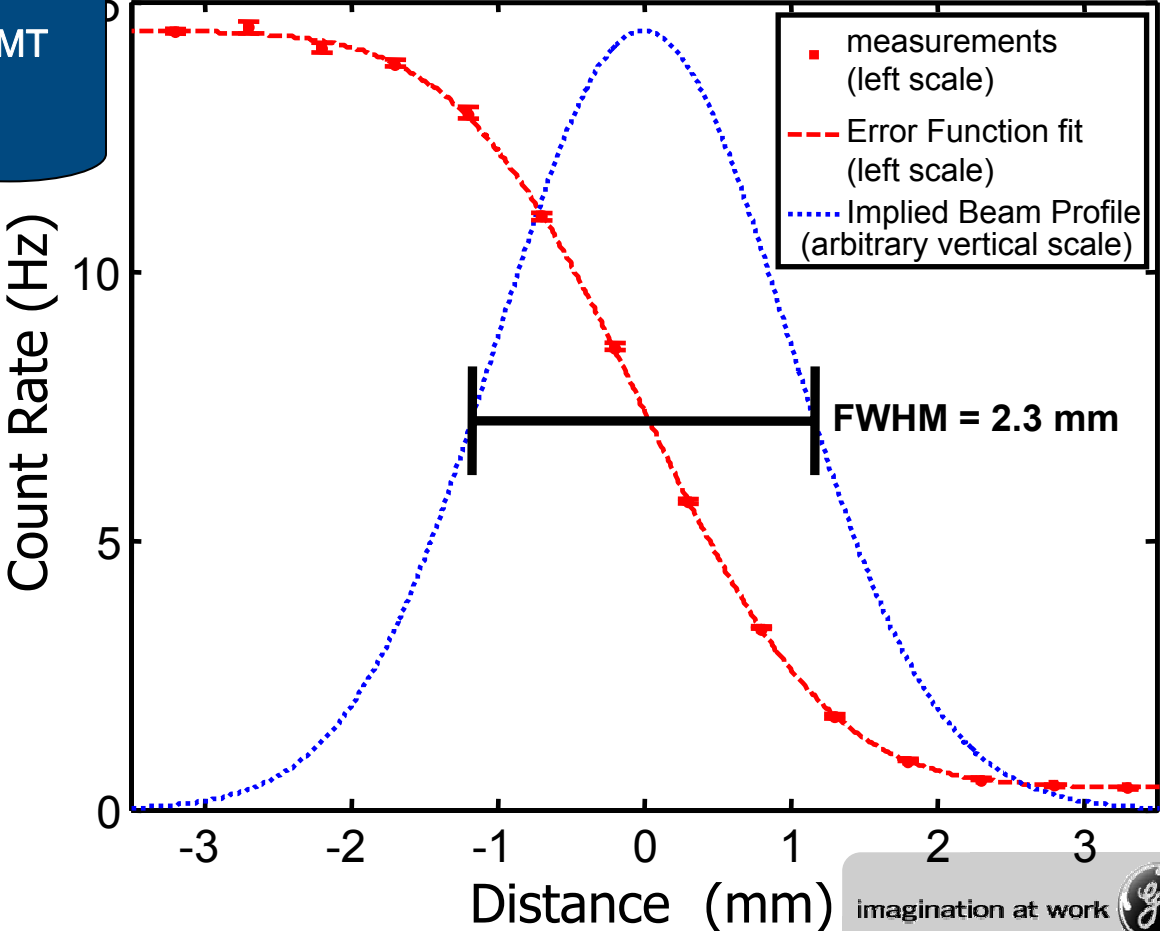
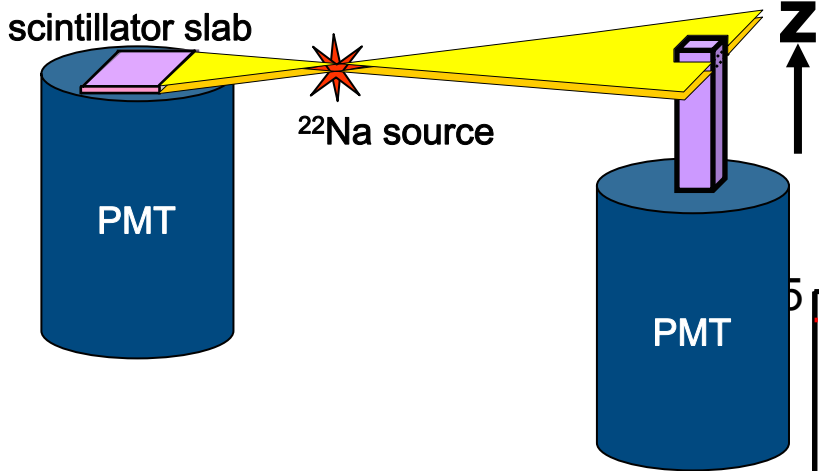
Energy Window: 250-650 keV

DOI Resolution

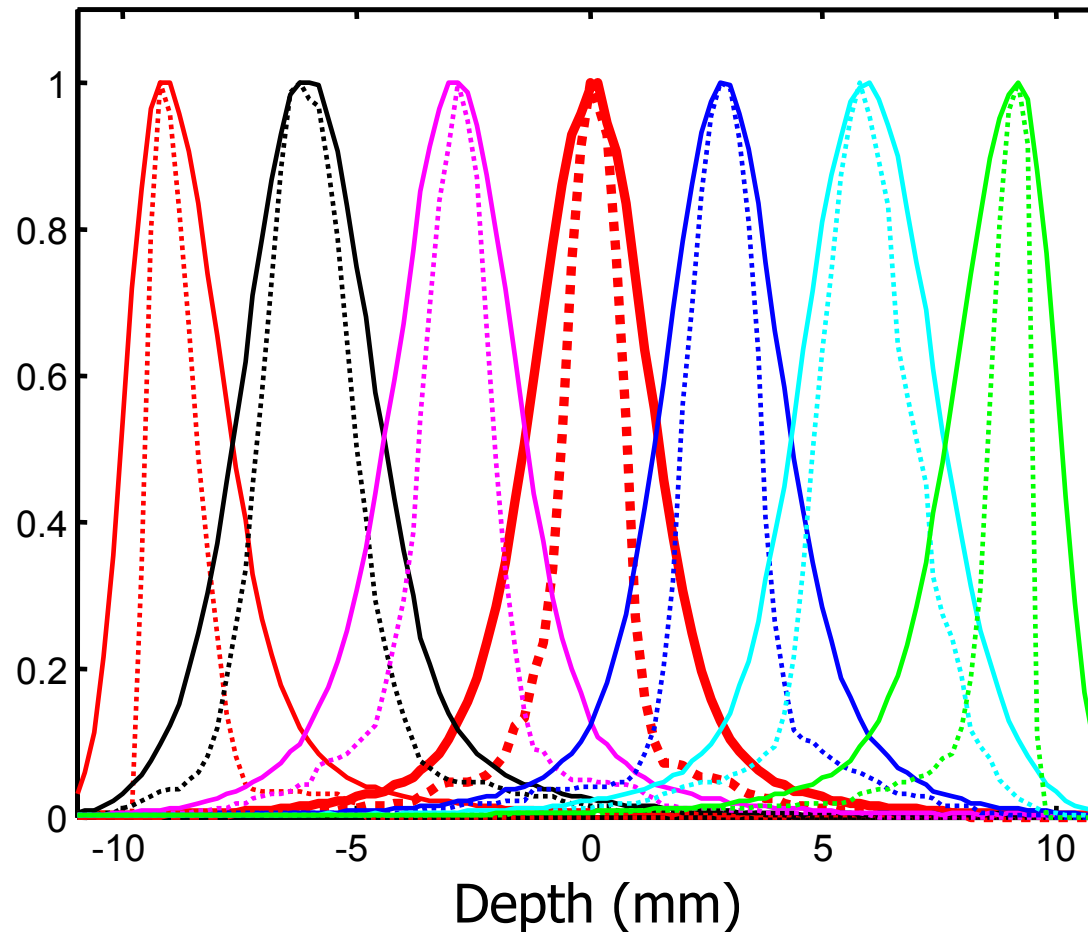


Energy Window: 250-650 keV
Integrated counts from all crystals.

Width of Electronically Collimated Beam

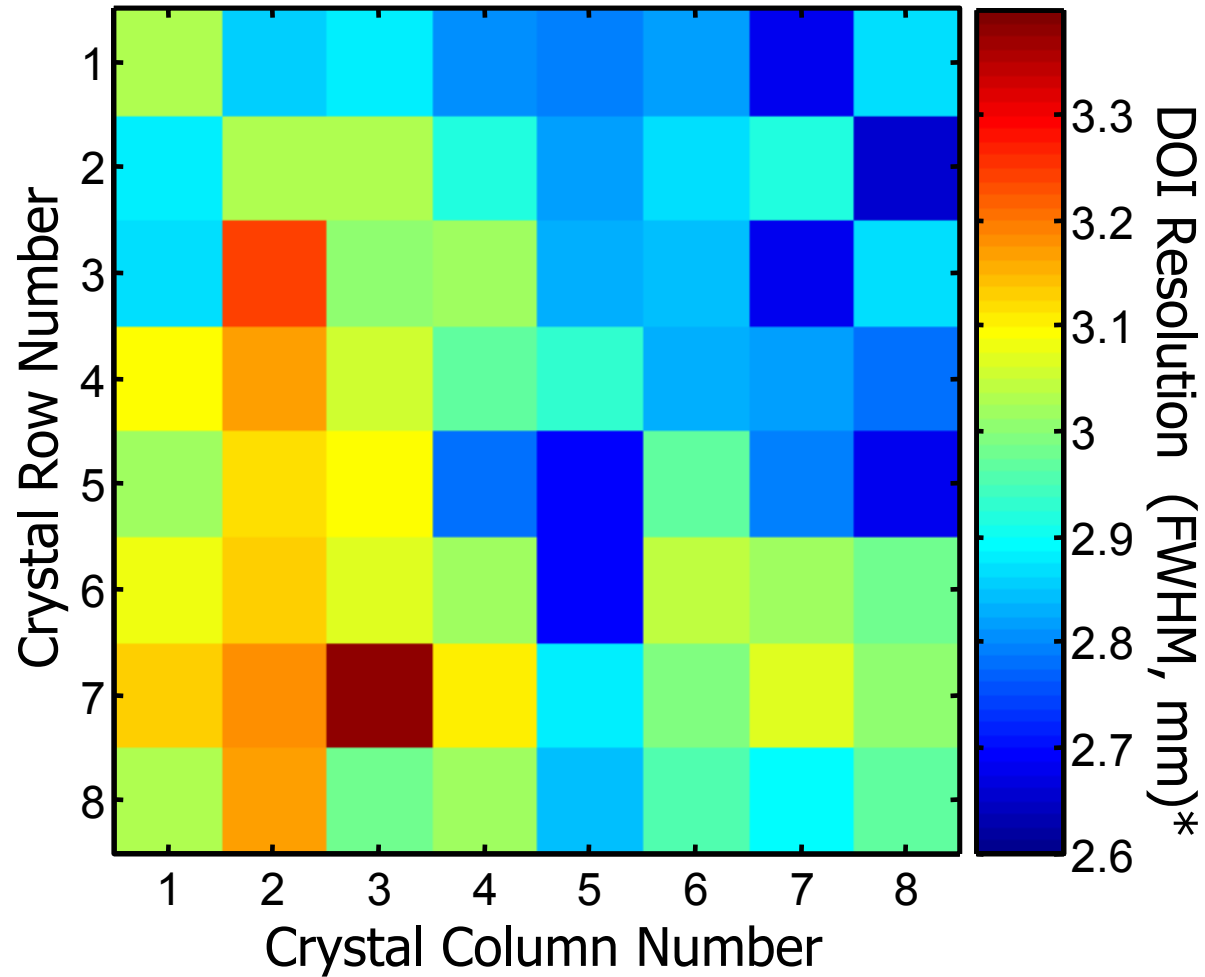


DOI Resolution (deconvolved)



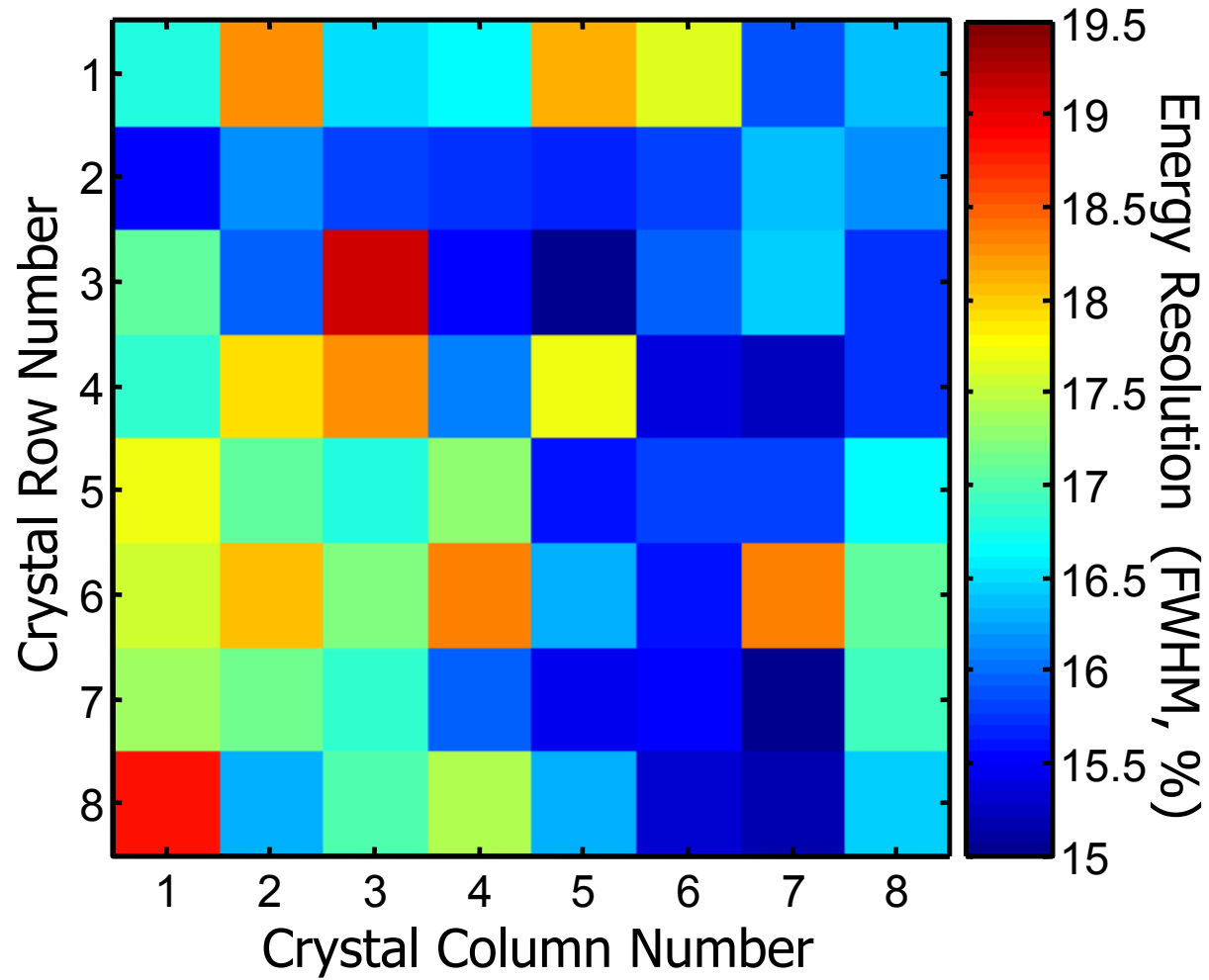
Energy Window: 250-650 keV
Integrated counts from all crystals.

DOI Resolution Map*

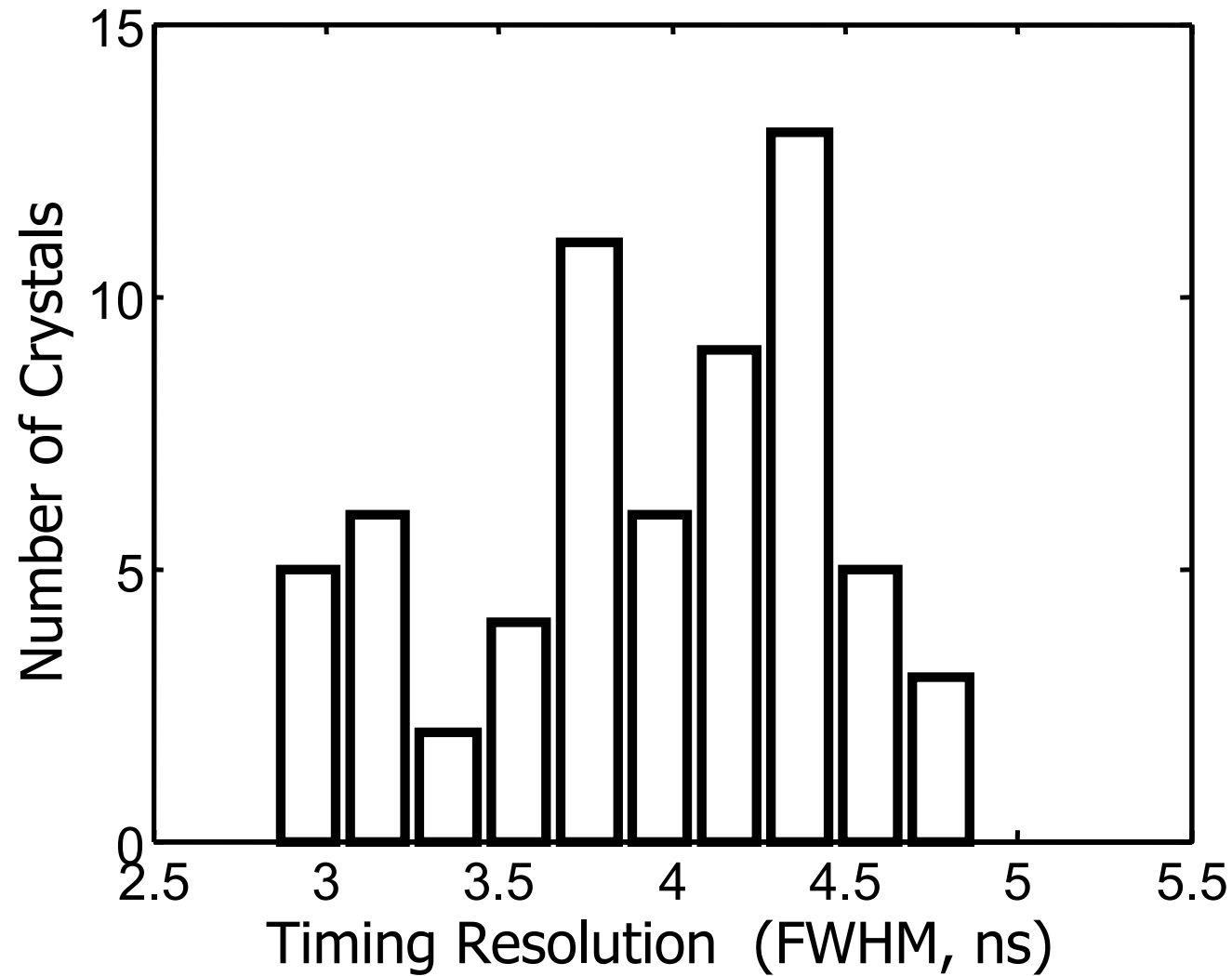


*without deconvolution of beam width

Energy Resolution Map

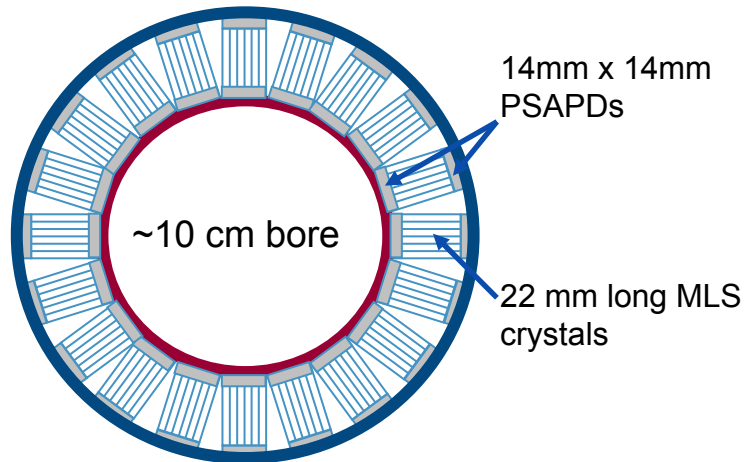


Timing Resolution Distribution

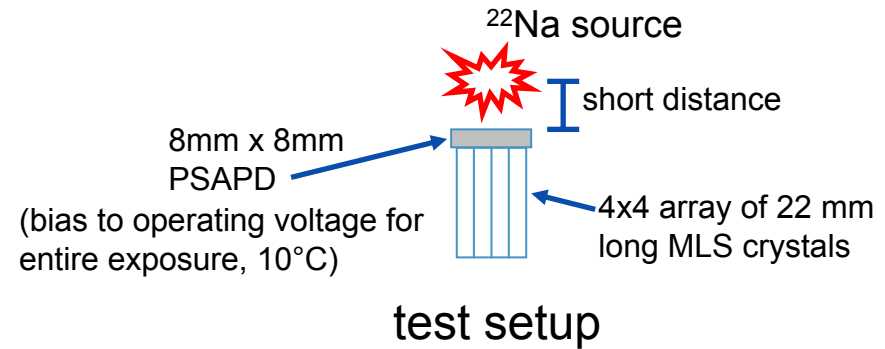


Radiation Damage? (preliminary measurements)

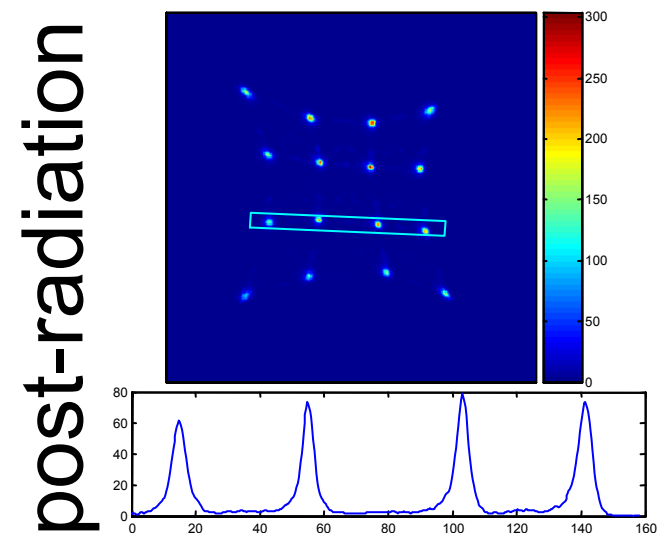
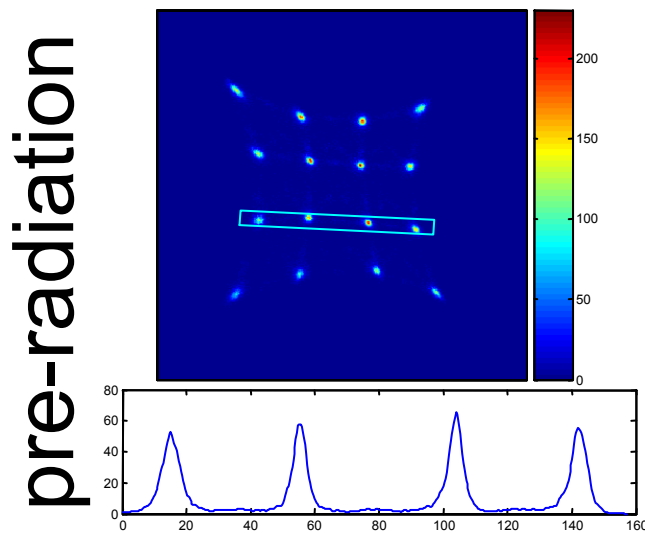
Small-animal PET is not a “high radiation” environment.



small-animal scanner



Exposed PSAPD to 2 - 10 years*
equivalent accumulated 511 keV flux



No Negative Impact on Performance Observed

*depending on scanner utilization assumptions

Conclusion

Demonstrated High-Res DOI PET detector with:

- 8x8 array of 1.65 mm x 1.65 mm x 22.00 mm crystals, with surface treatments chosen to optimize DOI resolution
- Minimal dead-space within array
- Compact front-end electronics
- No radiation damage effects observed
- Tileable design
- Excellent performance
 - DOI resolution of <3 mm FWHM
 - Energy resolution of $\sim 16\%$ FWHM
 - Timing resolution of ~ 4 ns FWHM (vs. plastic)



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