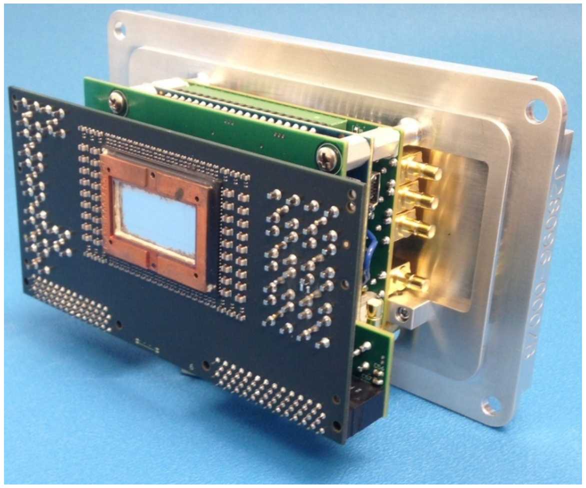
Sandia National Laboratories

October 6, 2015

First Use of Hybrid CMOS Cameras on Z and NIF



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Collaborators

- **Sandia**
  - **Photodiodes:** Doug Trotter, Rex Kay, and Quinn Looker
  - **ASIC:** Liam Claus, Gideon Robertson, Marcos Sanchez
  - **Packaging:** Lu Fang
  - **Semiconductor fabrication:** MESA Fab team and Zipptronix
  - **Characterization & Z integration:** John Stahoviak, Mark Kimmel, Joel Long, and Larry Ruggles

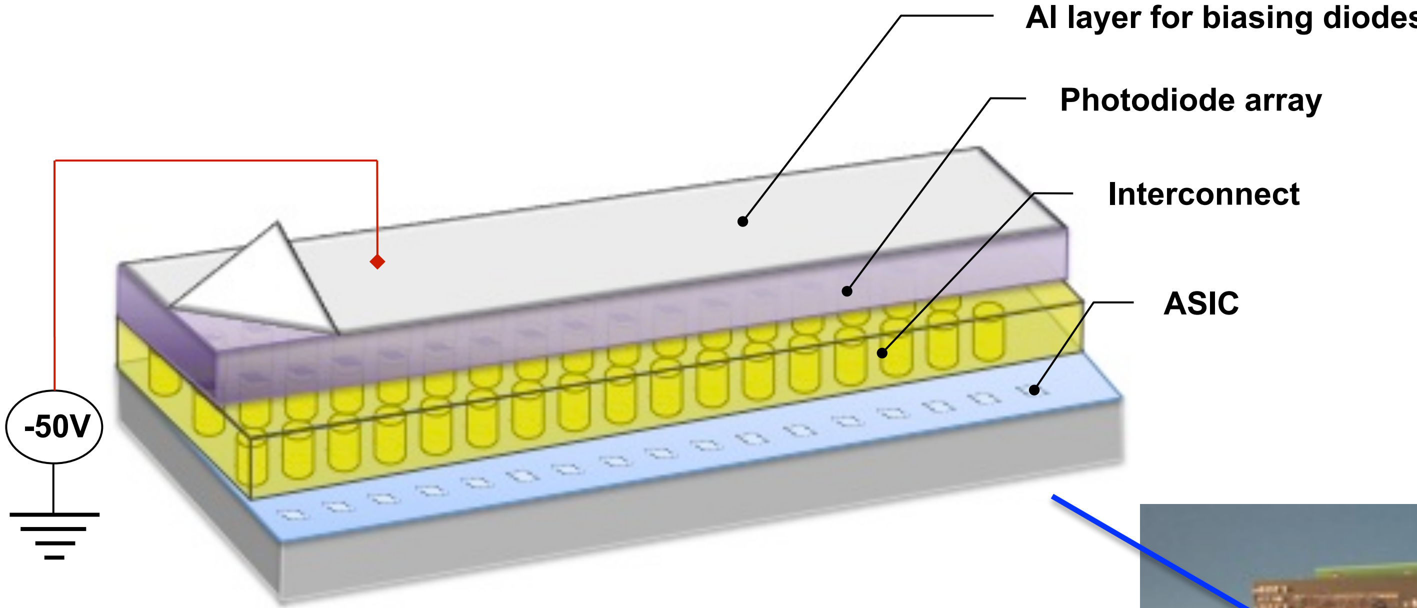
- **LLNL**
  - **NIF integration:** Hui Chen, Nathan Palmer, Jarom Nelson, Sukhdeep Heerey, and Perry Bell

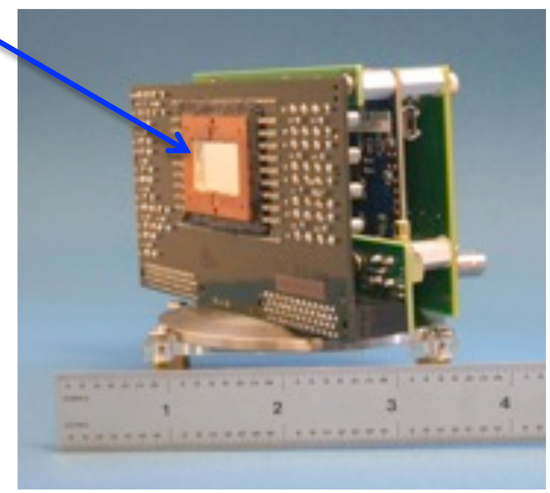
- **GA**
  - **NIF integration:** Terry Hilsabeck and Joe Kilkenny

Outline

- **Hybrid CMOS camera overview**
- **Characterization of “Furi” camera performance**
- **Images from Z & NIF**
- **Future plans and conclusion**

A hybrid CMOS detector enables independent optimization of the radiation sensor and Integrated Circuit





Advantages of hCMOS architecture

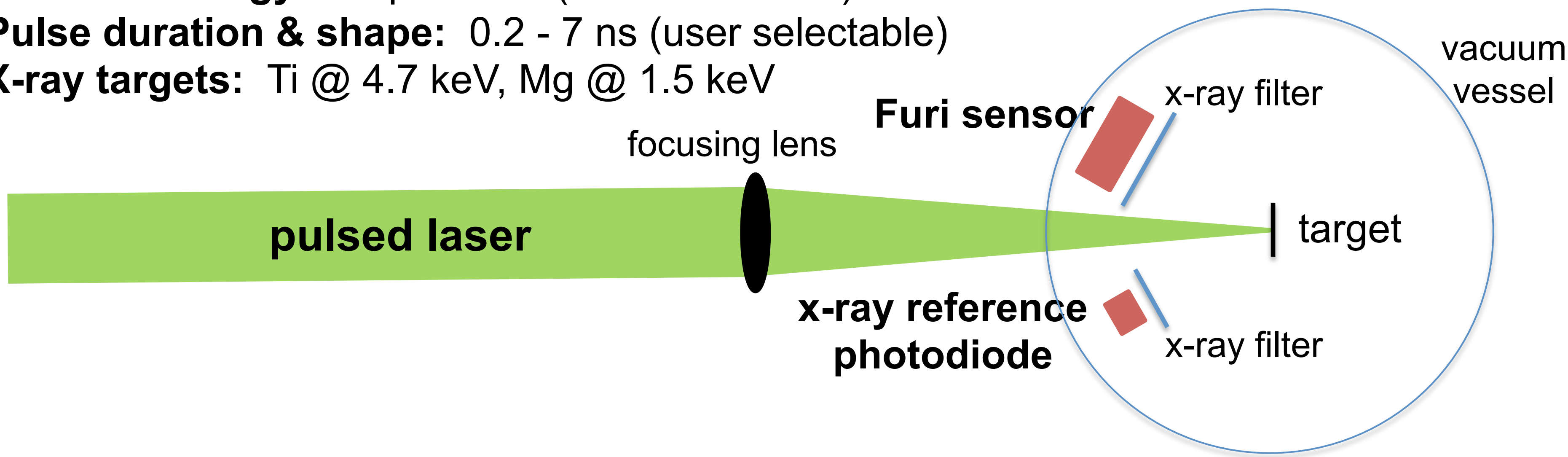
- Photodiode array can be optimized for sensitivity to visible light, x-rays, electrons, protons, or neutrons
- ASIC can be optimized for exposure level, speed, pixel size, number of frames, and radiation tolerance
- Optimized cameras can be created by interconnecting different combinations of ASICs and photodiode arrays

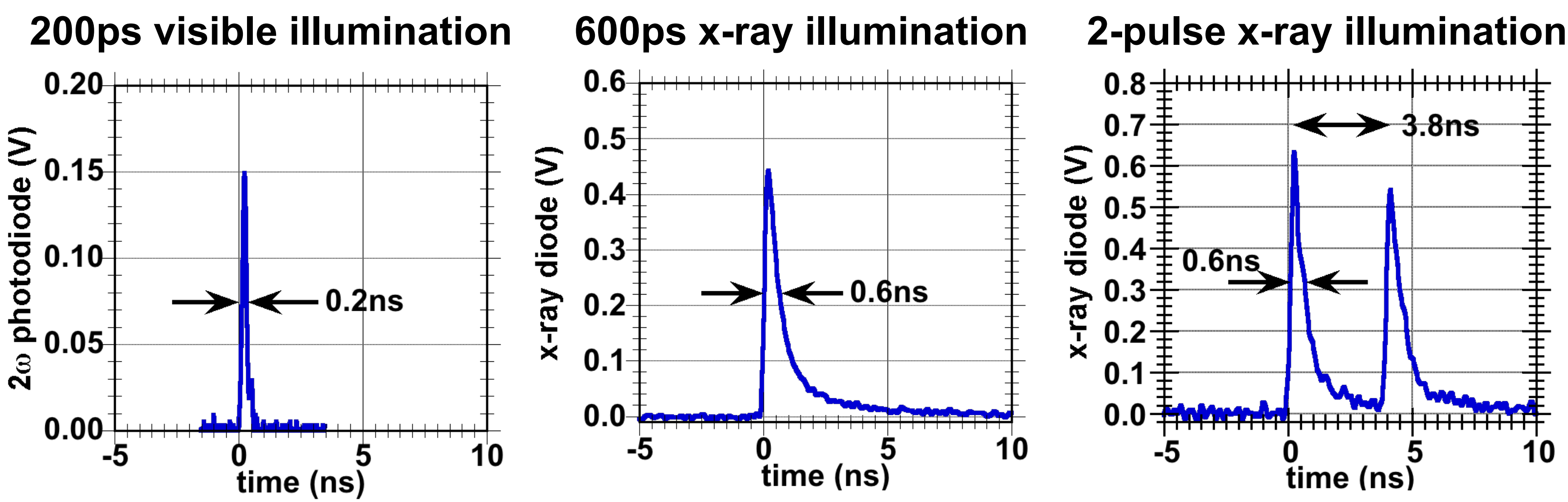
Evolution of Sandia's hCMOS camera designs

	Griffin	**Furi**	Hippogriff	Icarus	Acca
Year	2012	**2013**	2014	2015	2016
Pixel pitch	25µm	**25µm**	25µm	25µm	25µm
Min. gate time	1.5ns	**1.5ns**	2ns	1.5ns (TBD)	1ns
Pixels	15 x 128	**448 x 1024**	448 x 1024	512 x 1024	512 x 512
Frames/pixel	4	**2**	2 ,4, or 8 (interlaced)	4	8
Sensor types	500-900 nm, 0.7-6 keV	**500-900 nm, 0.7-6 keV**	500-900 nm, 0.7-9 keV	400-900 nm, 0.3-9 keV 4keV electrons	350-900 nm, 0.2-9 keV 2keV electrons
Dynamic range	1000x, 1500-1.5x10^6 e$^-$	**1000x, 1500-1.5x10^6 e$^-$**	1000x, 1500-1.5x10^6 e$^-$	1000x, 500-5x10^5 e$^-$	1000x, 500-5x10^5 e$^-$
Tiling option	No	**No**	No	No	Yes
CMOS process	350nm	**350nm**	350nm	350nm	130nm
Status	completed	**completed**	completed	in packaging	in design

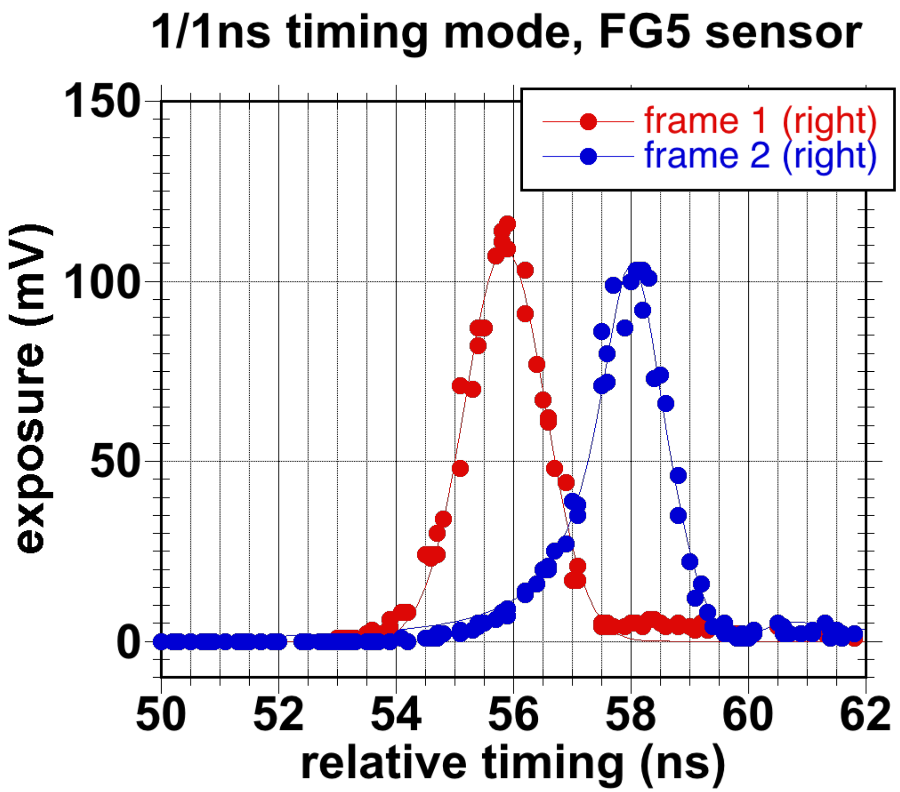
We use a pulsed laser to characterize camera response to either x-rays or visible illumination

Laser wavelength: 532 nm (frequency doubled)
Laser 2ω energy: 0.1 μJ - 15 J (user selectable)
Pulse duration & shape: 0.2 - 7 ns (user selectable)
X-ray targets: Ti @ 4.7 keV, Mg @ 1.5 keV

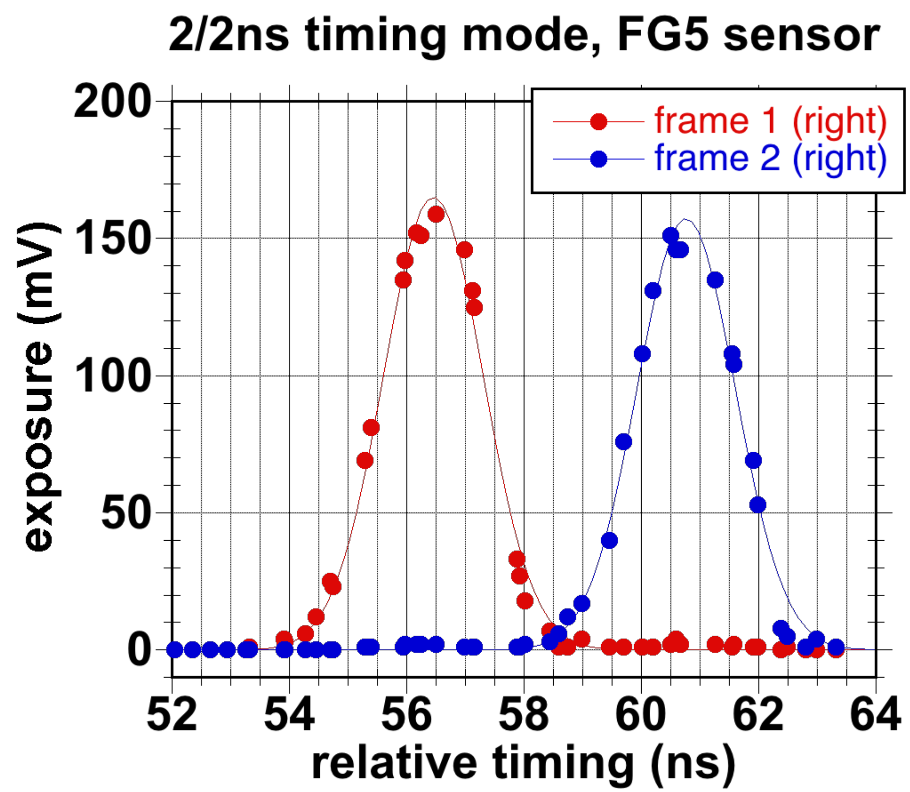




Example of Furi time-response measurements using 200ps pulsed visible illumination



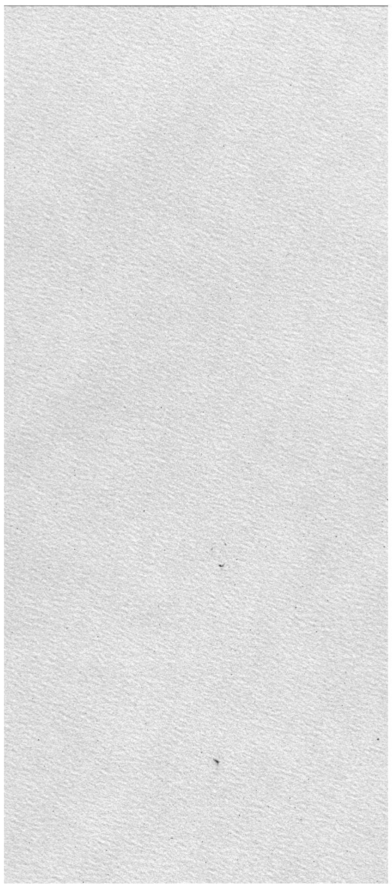
	FWHM (ns)	Frame Δt (ns)	left/right Δt (ns)
frame 1	1.6		0.9
frame 2	1.6	2.1	0.8



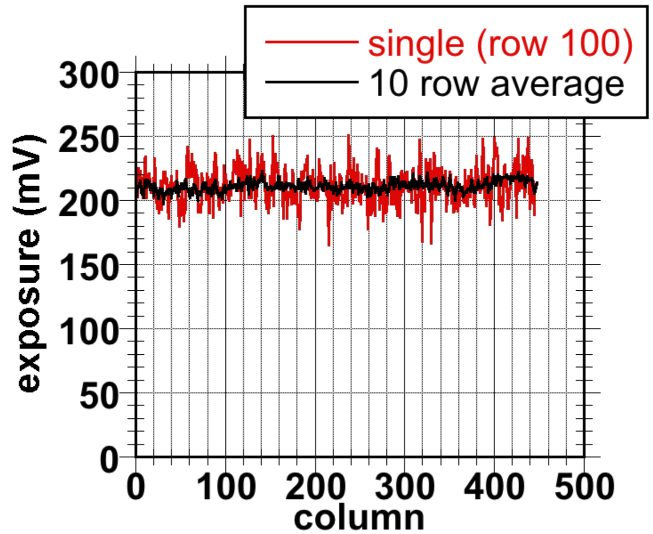
	FWHM (ns)	Frame Δt (ns)	left/right Δt (ns)
frame 1	2.0		0.9
frame 2	2.0	4.3	0.8

Example of Furi flat-field measurement using 600ps pulsed x-ray illumination

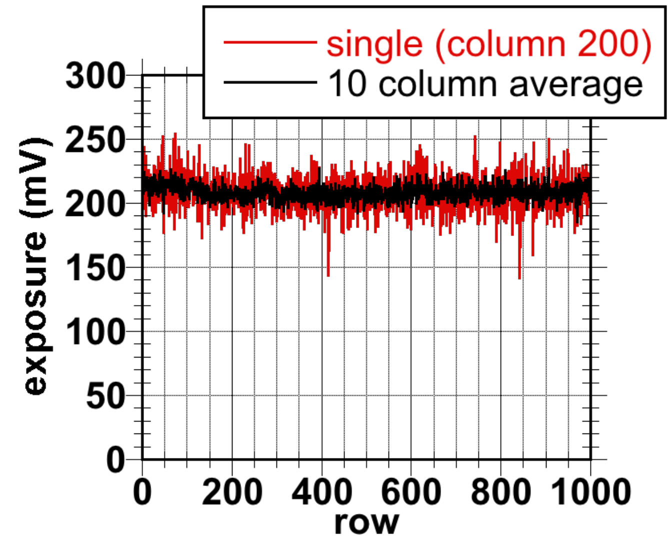
Frame 2, F1X8 sensor
10/10ns timing mode



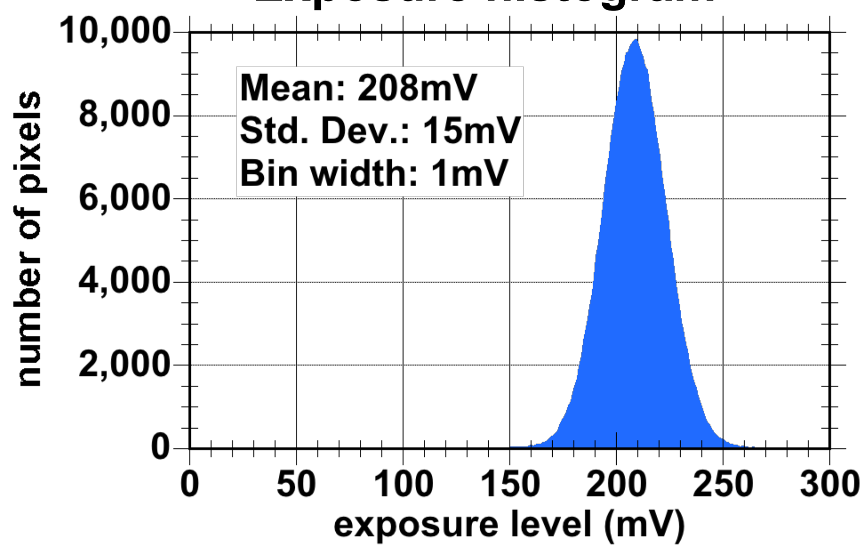
Row lineout



Column lineout

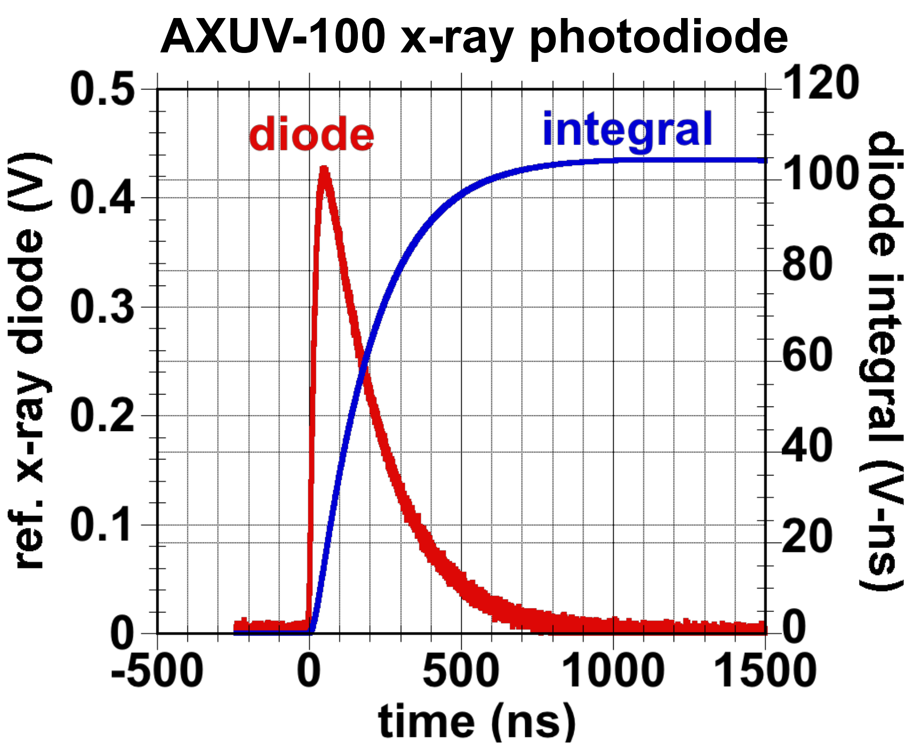


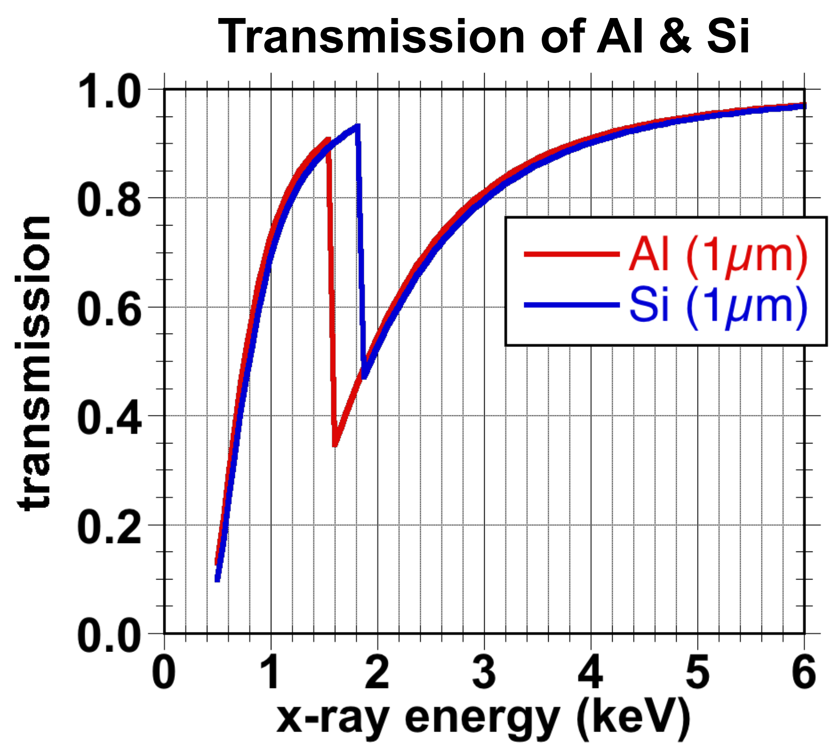
Exposure histogram



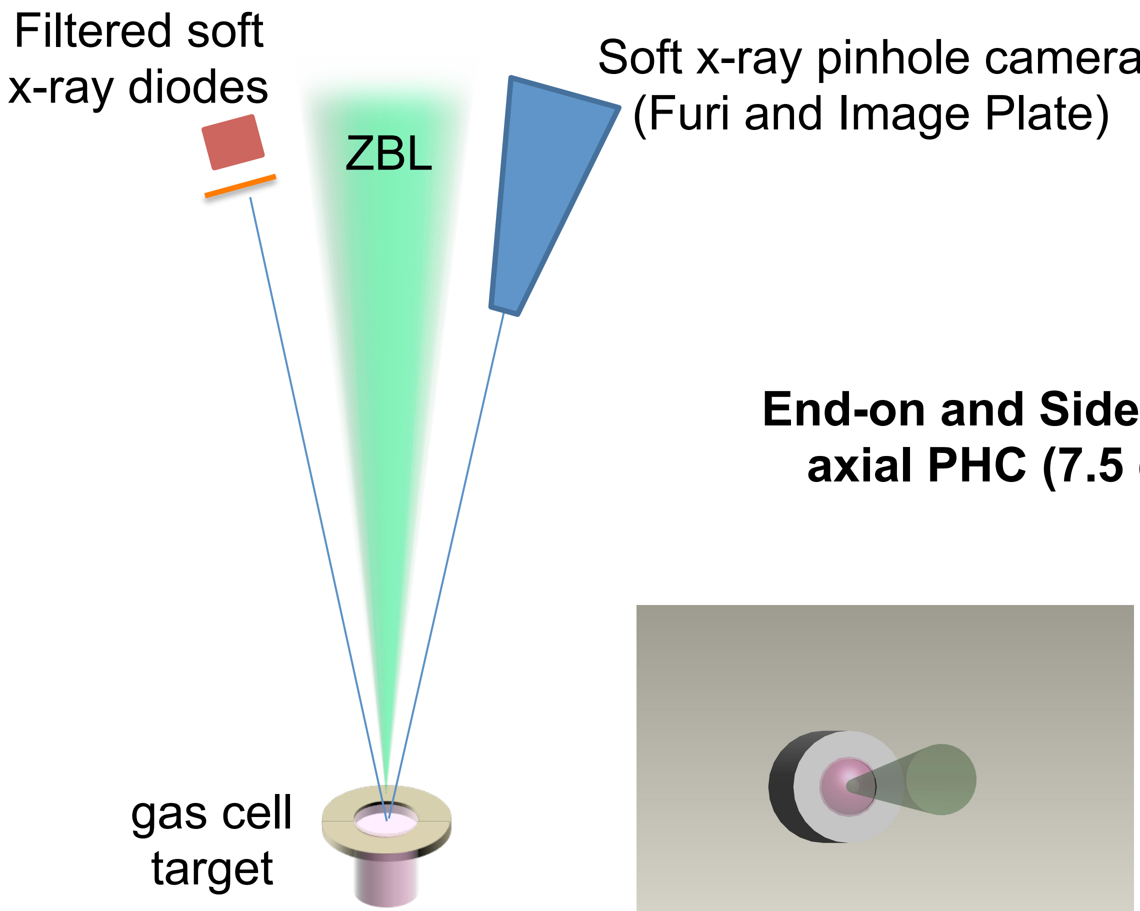
Cross calibration of x-ray sensitivity using AXUV-100 Si photodiode

Ref. diode model:	IRD AXUV-100	**Ref. diode integral into 50Ω:**	105 V-ns
Ref. diode thickness:	40-50μm	**Ref. diode collected charge:**	1.3 x 10^{10} e^-
Ref. diode aperture:	5 mm dia.	**Ref. diode absorbed energy:**	4.7 x 10^{10} eV
Ref. diode sensitivity:	3.62 eV/e-h pair	**X-ray flux incident on Furi:**	3.2 x 10^6 eV/pixel
Target/diode distance:	77 cm	**Furi average exposure level:**	208 mV
Target/F1X8 distance:	52 cm	**Furi sensitivity @ 1.5 keV:**	1.5 x 10^4 eV/mV
X-ray filter:	12.5μm Al	**Furi design sensitivity for 100% absorption:**	6 x 10^3 eV/mV
X-ray target material:	Mg (1.5 keV x-rays)		

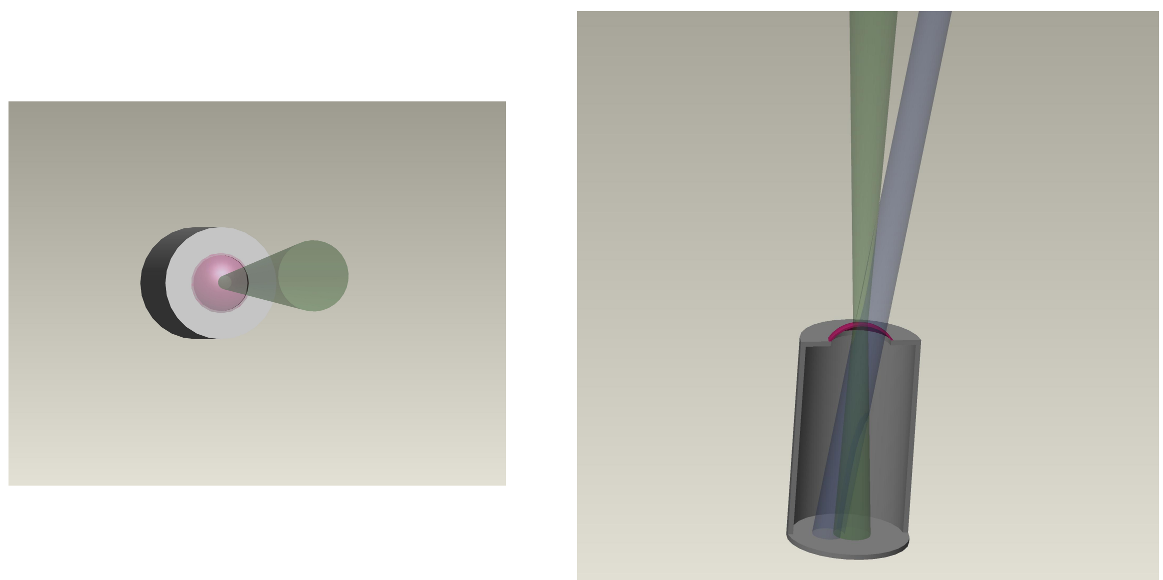




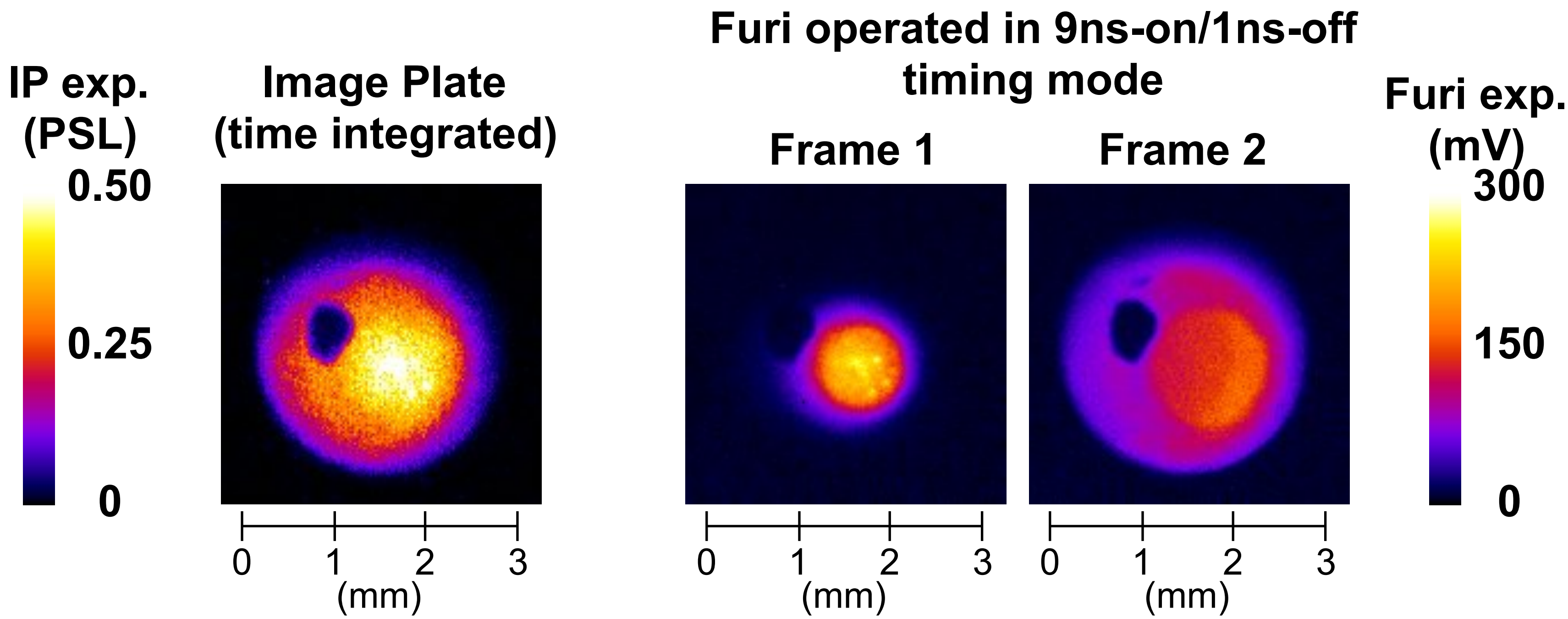
Experimental setup for axial soft x-ray imaging on Z of Magnitized Liner Inertial Fusion (MagLIF) target



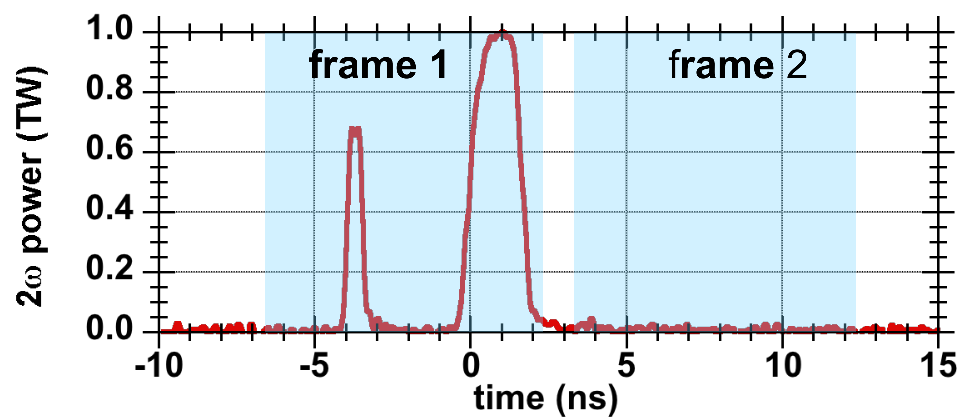
End-on and Side-on views of target from axial PHC (7.5 degree viewing angle)



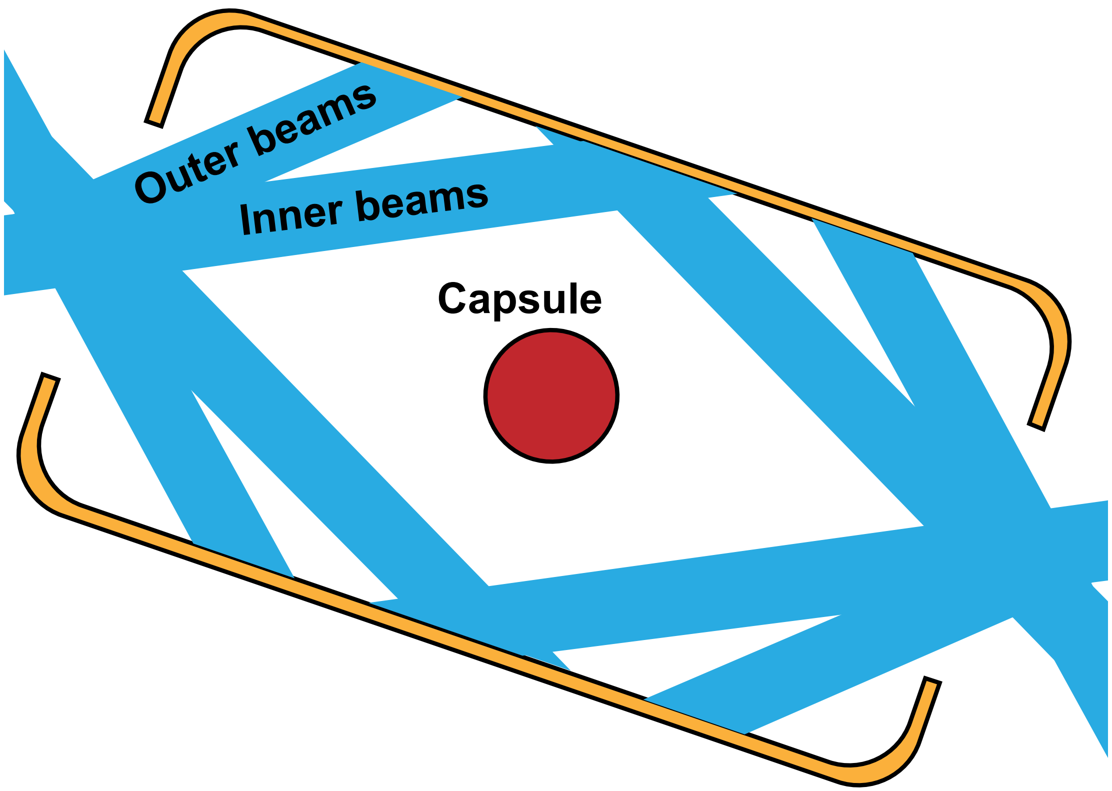
Axial pinhole camera images on Z shot H33 (6/15/2015)



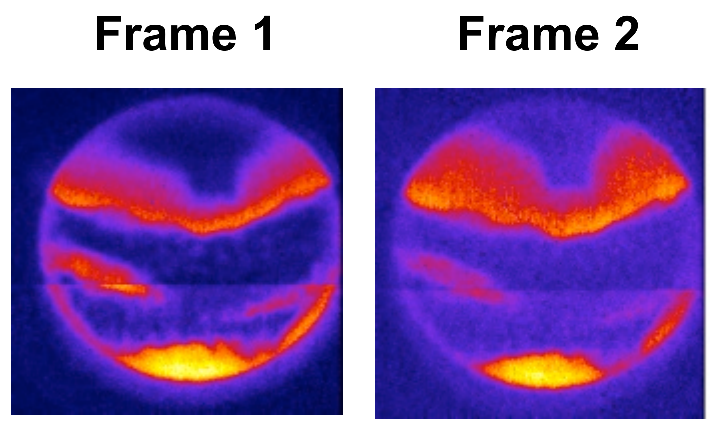
Furi timing relative to ZBL laser-heating pulse



A Furi camera is being fielded on NIF on the lower SXI diagnostic in place of one of the x-ray CCDs



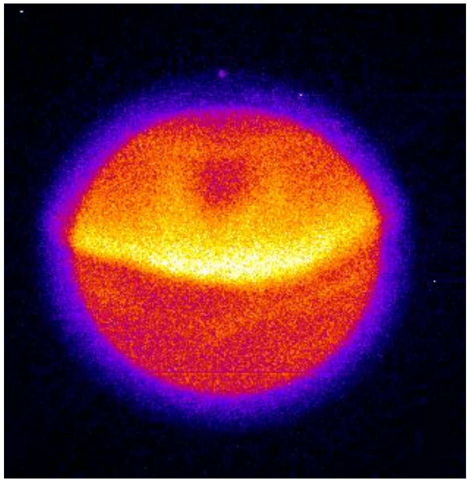
Furi operated in 1ns-on/1ns-off timing mode



Data courtesy H. Chen and N. Palmer (LLNL)

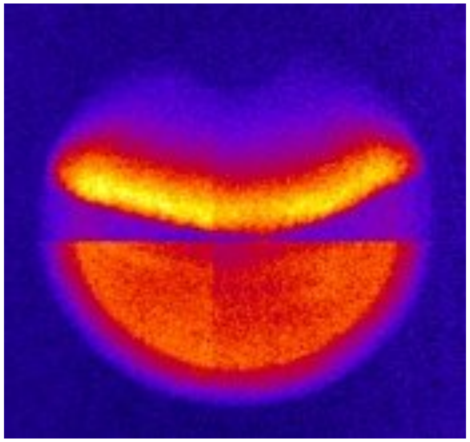
Comparison of Furi and CCD images on NIF shot N150901-002-999

CCD

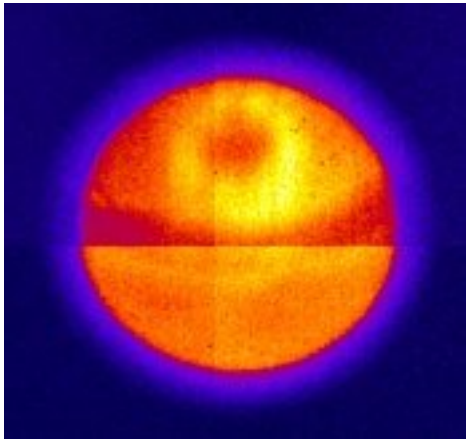


Furi operated in 2ns-on/2ns-off timing mode

Frame 1



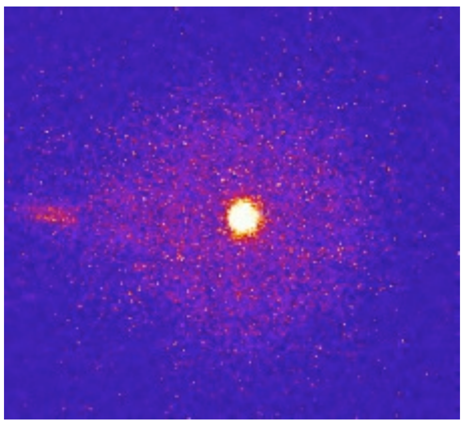
Frame 2



Data courtesy H. Chen and N. Palmer (LLNL)

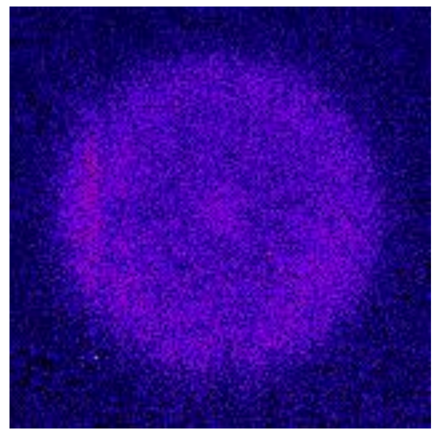
Furi images from recent NIF exploding pusher experiment

CCD image from a similar shot

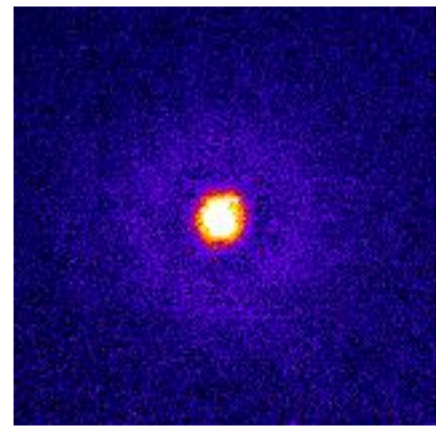


Furi operated in 1ns-on/1ns-off timing mode

Frame 1



Frame 2



Data courtesy H. Chen and N. Palmer (LLNL)

Next Steps

- **Characterize & begin fielding next-generation cameras**
  - Hippogriff
  - Icarus
  - Small Outline Package
- **Integrate cameras into new diagnostics**
  - Multi-frame x-ray backlighting
  - Pulse-dilation framing camera
  - X-ray spectrometers
  - Visible shadowgraphy
  - Neutron detection
- **Correct limitations in present Furi/Hippogriff design**
  - Improve exposure uniformity
  - Reduce integration time
  - Option for using diodes optimized for higher- or lower-energy detection
  - Option for "tiling" to increase effective sensor size