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Development of a High-Speed Multi-frame Hybrid CMOS Sensor

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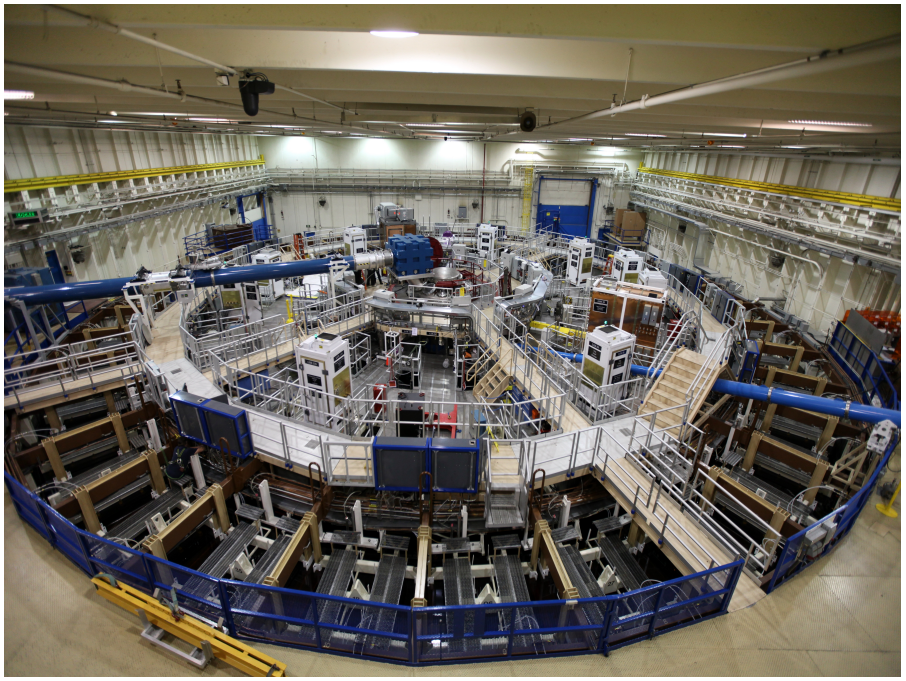
Project team

- **ASIC**
  - Liam Claus and Gideon Robertson
- **Photodiode array**
  - Rex Kay, Doug Trotter, and Andy Pomerene
- **Systems electronics and integration**
  - Marcos Sanchez and John Stahoviak
- **Packaging**
  - Lu Fang
- **Fabrication**
  - MESA-fab team
- **X-ray testing**
  - Mark Kimmel

Motivation



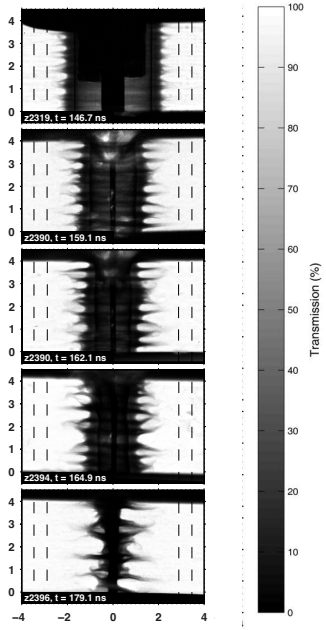
t = 147 ns

t = 159 ns

t = 162 ns

t = 165 ns

t = 179 ns

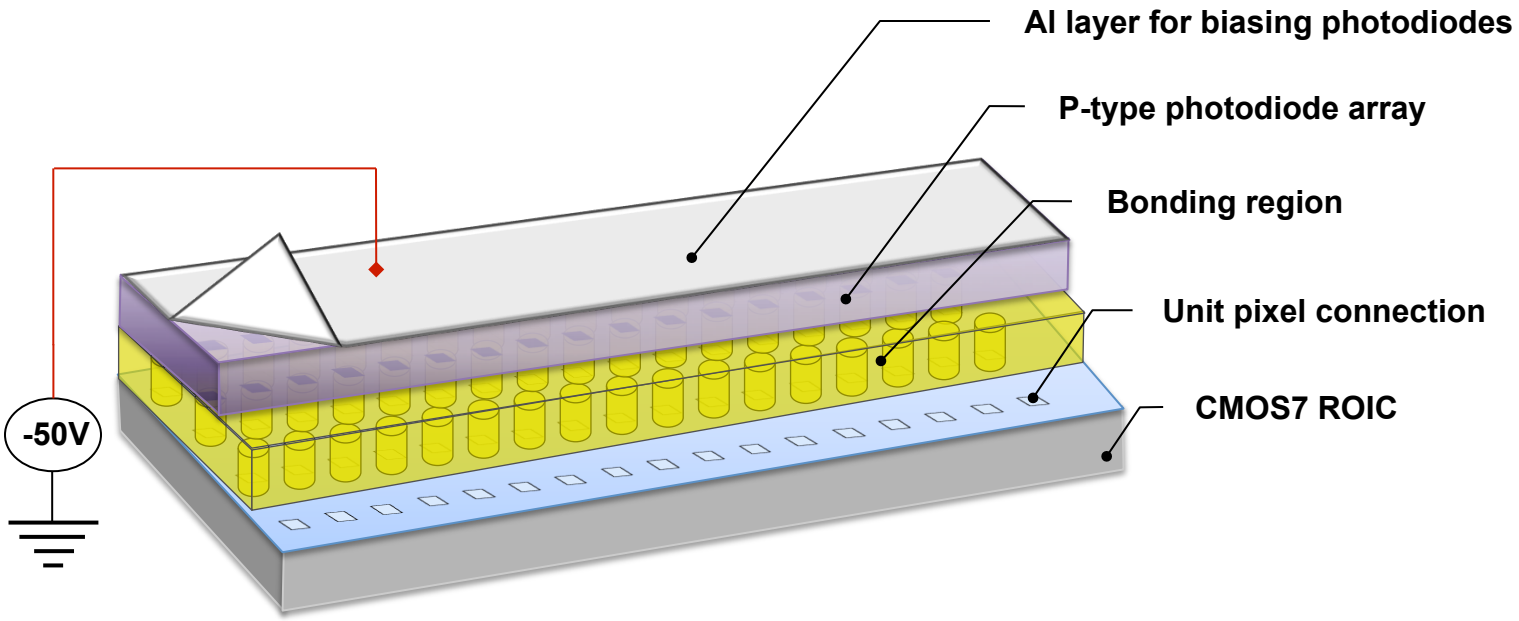


R. D. McBride, et. al., Physics of Plasmas, 20, 056309 **(2013)**

X-ray sensor performance goals

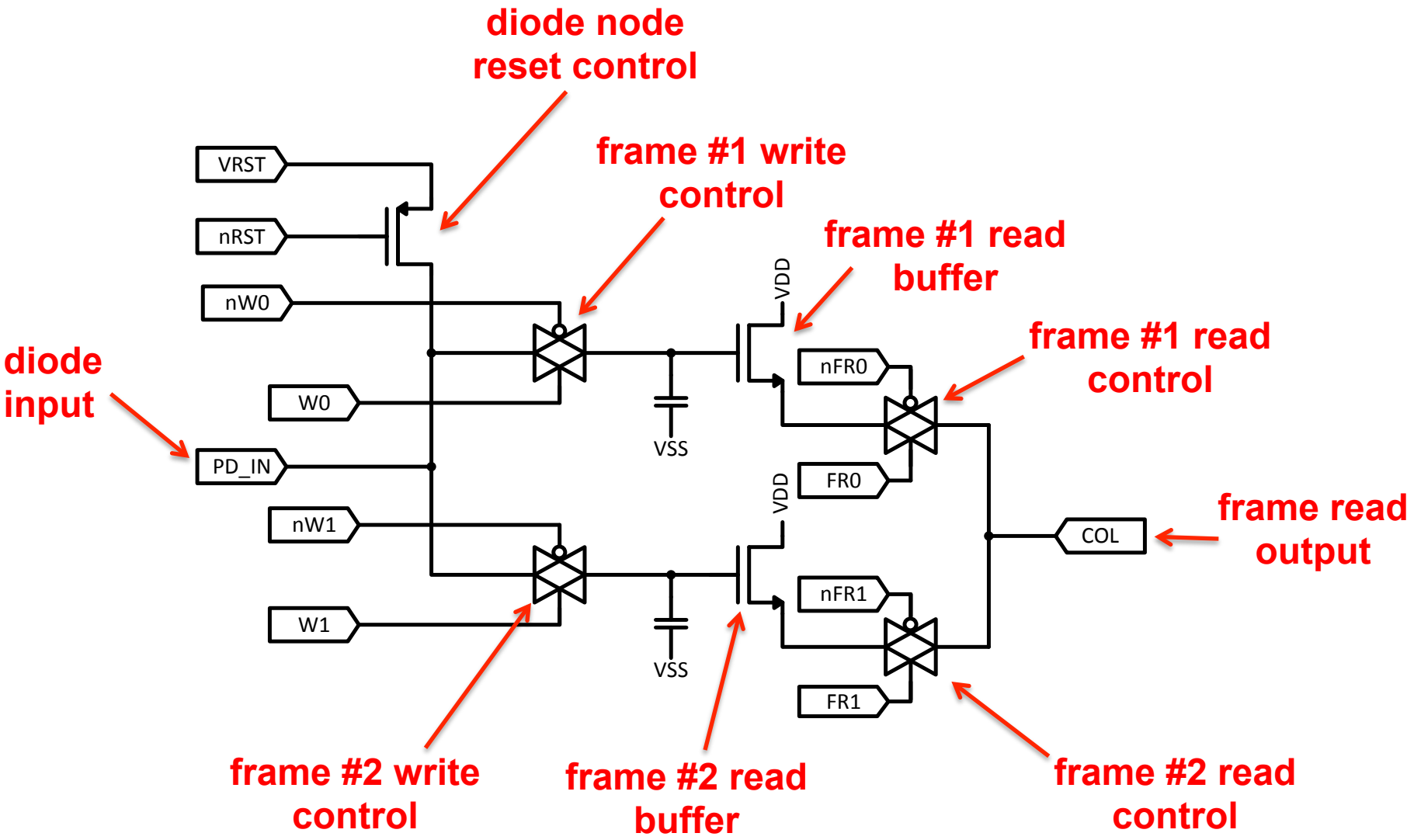
- **25 µm x 25 µm pixel size**
  - 100% diode fill factor
- **2-4 frames per pixel**
  - limited by size of transistors and capacitors in Sandia's 0.35 µm CMOS process
- **1 nsec min. integration time (limited by speed of Sandia's 0.35 µm process)**
  - asynchronous frame capture time
  - maximum integration time of order 500 msec without cooling (determined by time scale for capacitor charge leakage)
- **1 nsec min. time interval between frames**
- **50% Q.E. for 6 keV x-rays**
- **11-bit effective dynamic range**
  - minimum detected charge of 1,500e^-
  - maximum detected charge of 3,000,000e^-
  - 100A maximum peak diode current
- **1024 x 448 array (25.6 mm x 11.2 mm) giving 459k pixels**
  - 25.6 mm limited by size of mask tool (reticle) at Sandia's CMOS Fab
  - 11.2 mm limited by distortion of 1 nsec gate signals (timing skew across array)
- **Operational in Z vacuum chamber within 0.5 meters of z-pinch**

Hybrid sensor concept

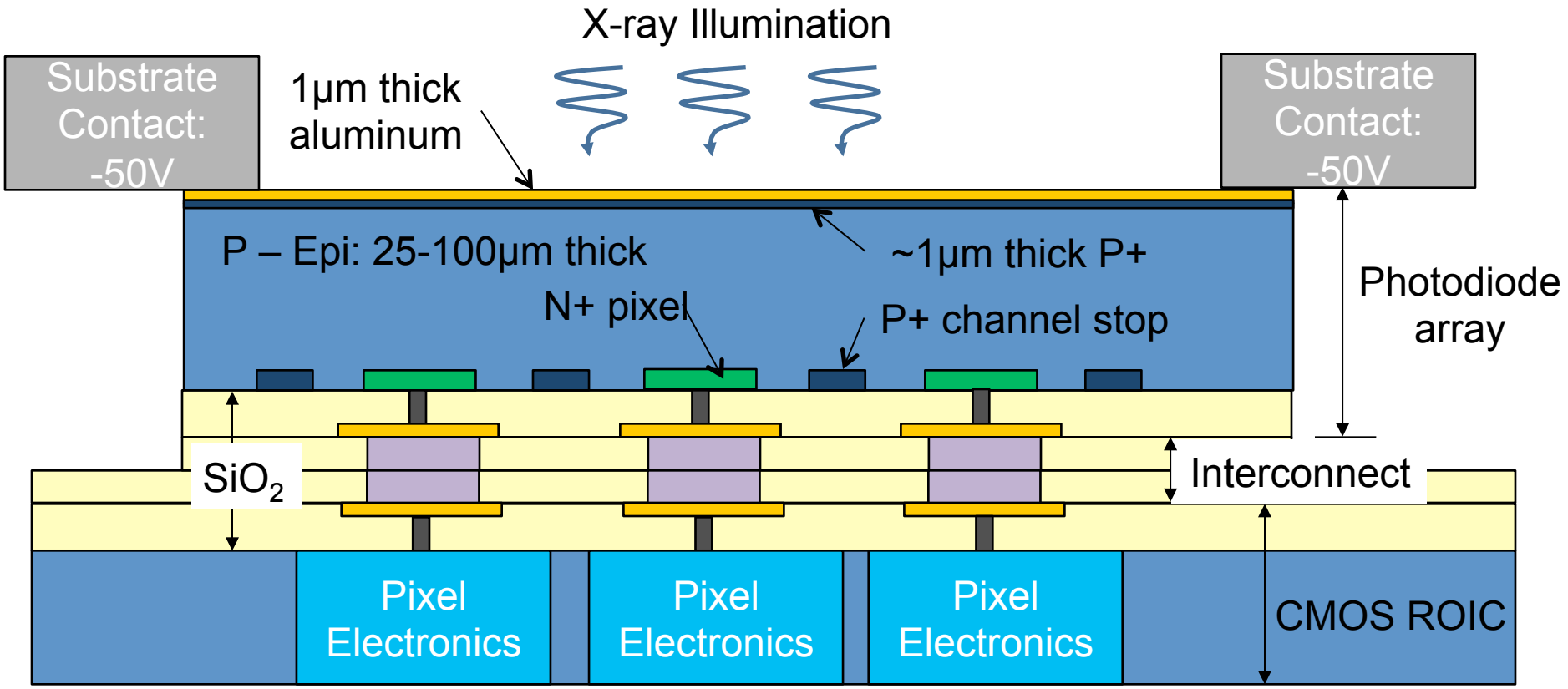


- Photodiode array converts incident radiation into electron-hole pairs
- CMOS integrated circuit stores charge from each photodiode on a 250 fF capacitor for each of 2-4 selected integration times. Integration time can be as short as 1 nsec.
- Photodiode array is connected to CMOS integrated circuit by wafer-to-wafer bonding

Pixel schematic

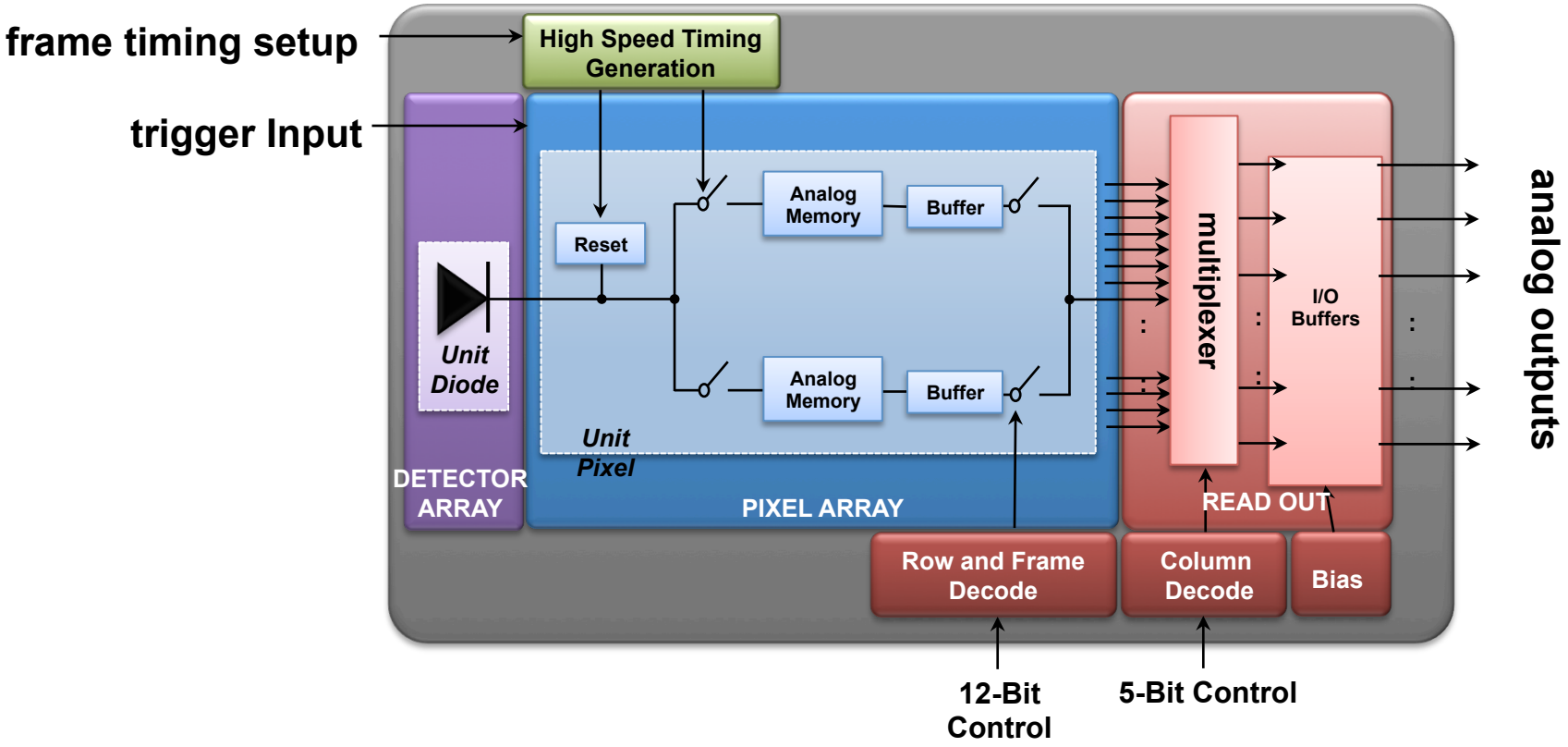


Hybrid sensor composition



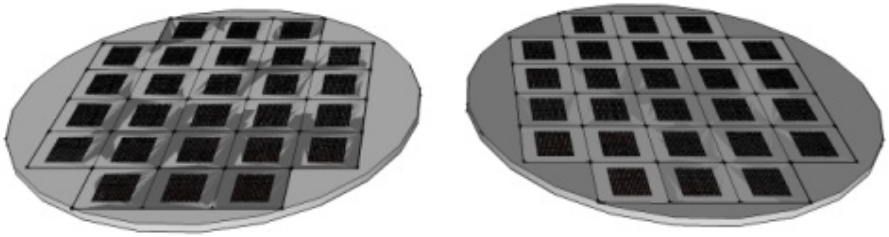
Sensor block diagram

- Inputs
  - Power, trigger, high speed timing setup and decode signals
- Outputs
  - 16 pixel array columns (analog voltage)



Hybrid sensor fabrication process

6” ROIC wafer fabricated with Sandia 0.35 µm CMOS7 process



6” photodiode wafer fabricated at Sandia

photodiode wafer flipped and bonded to ROIC wafer by Ziptronix, Inc.

photodiode handle wafer removed, Al electrode applied, ROIC bond pads exposed to enable packaging

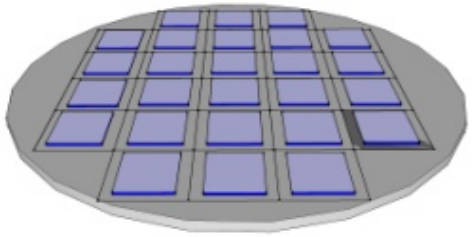
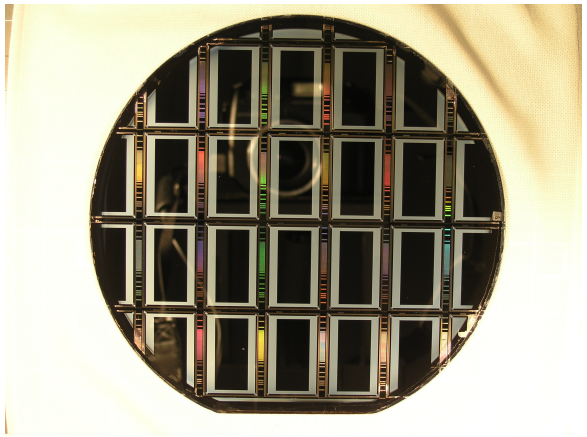
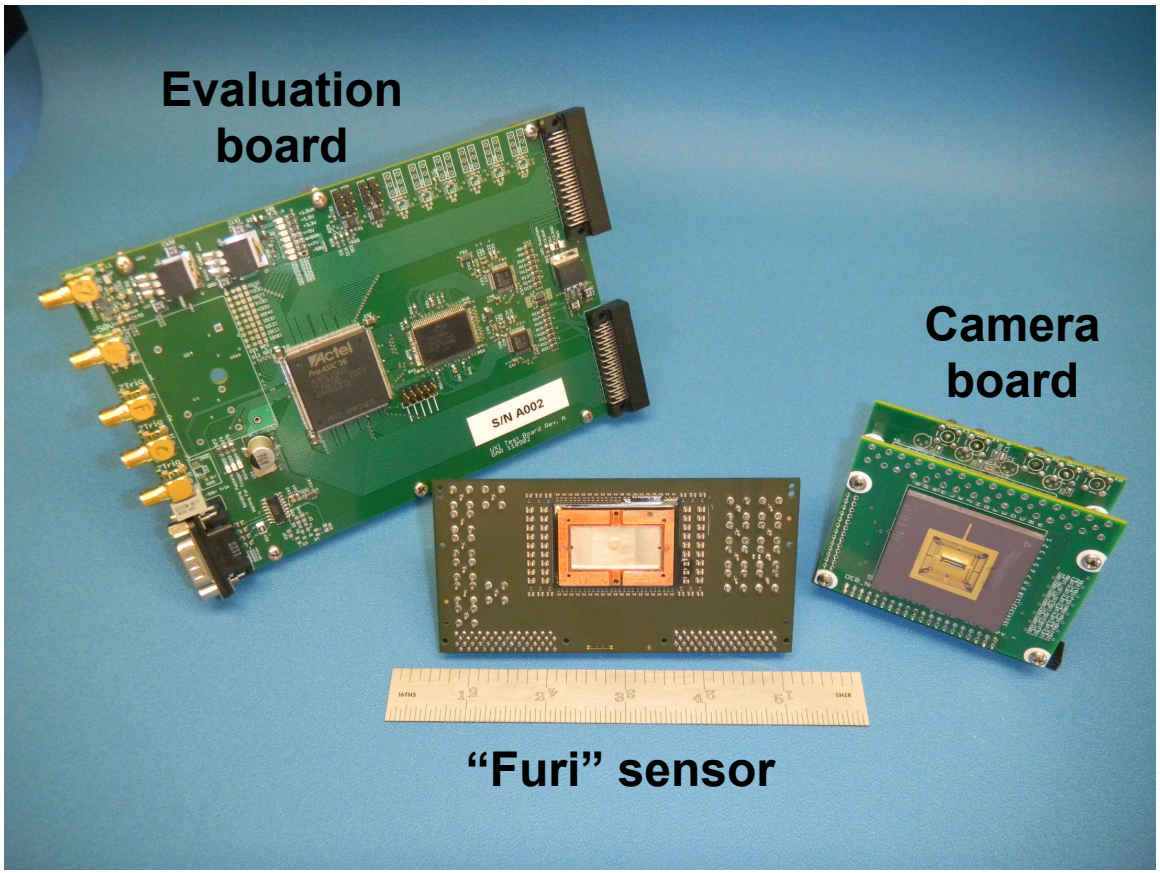


Photo of hybridized sensor after die sawing



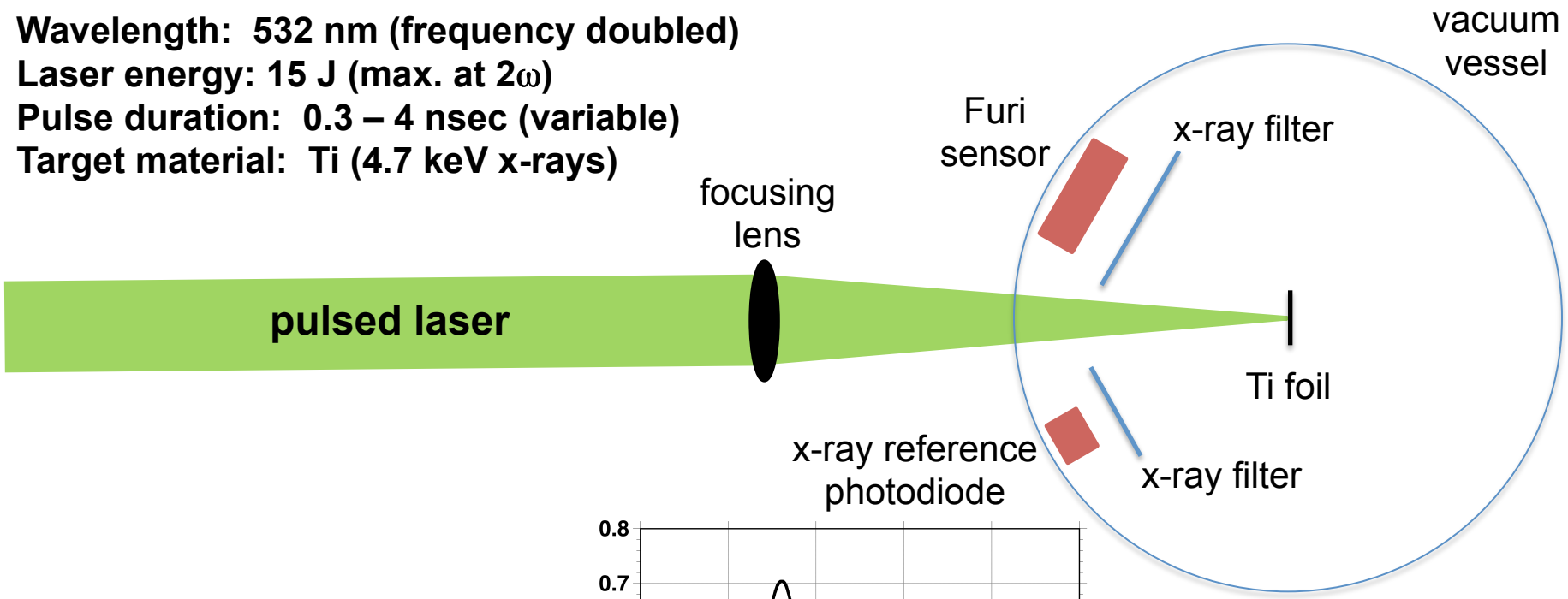
Sensor and system electronics

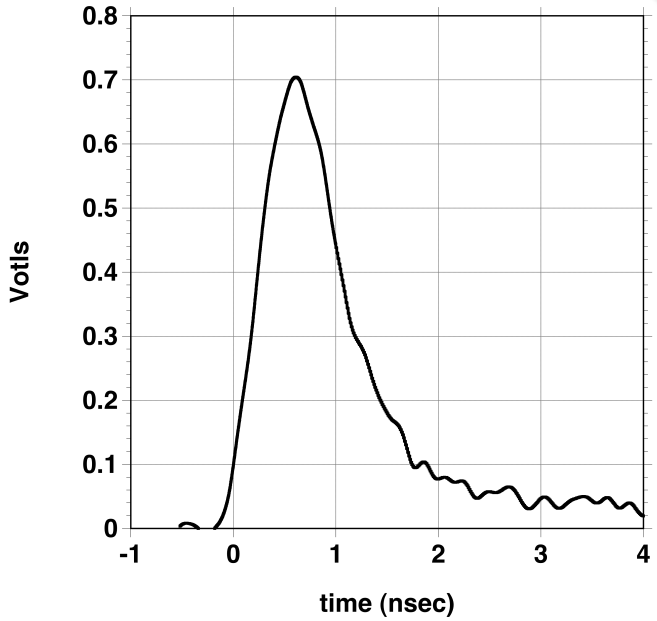
- **Inputs: 7V power, -50V diode bias, trigger**
- **Outputs: clock monitor, Frame 0 and Frame 1 monitors, serial communication computer interface**



x-ray characterization setup

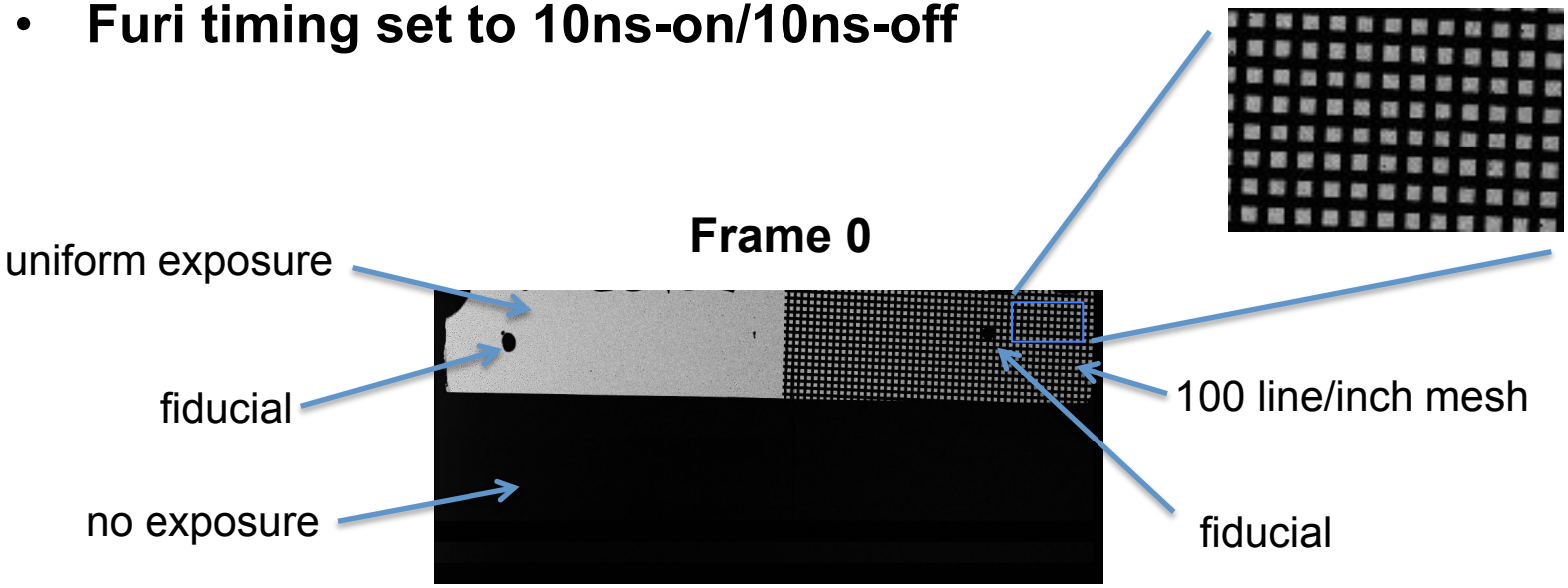
Wavelength: 532 nm (frequency doubled)
Laser energy: 15 J (max. at 2ω)
Pulse duration: 0.3 – 4 nsec (variable)
Target material: Ti (4.7 keV x-rays)





X-ray measurements

- **1ns x-ray pulse centered on Frame 0**
- **Furi timing set to 10ns-on/10ns-off**



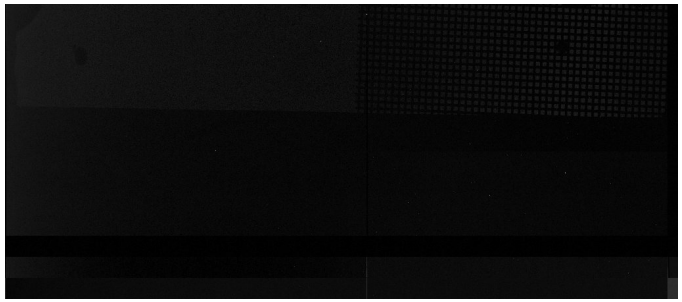
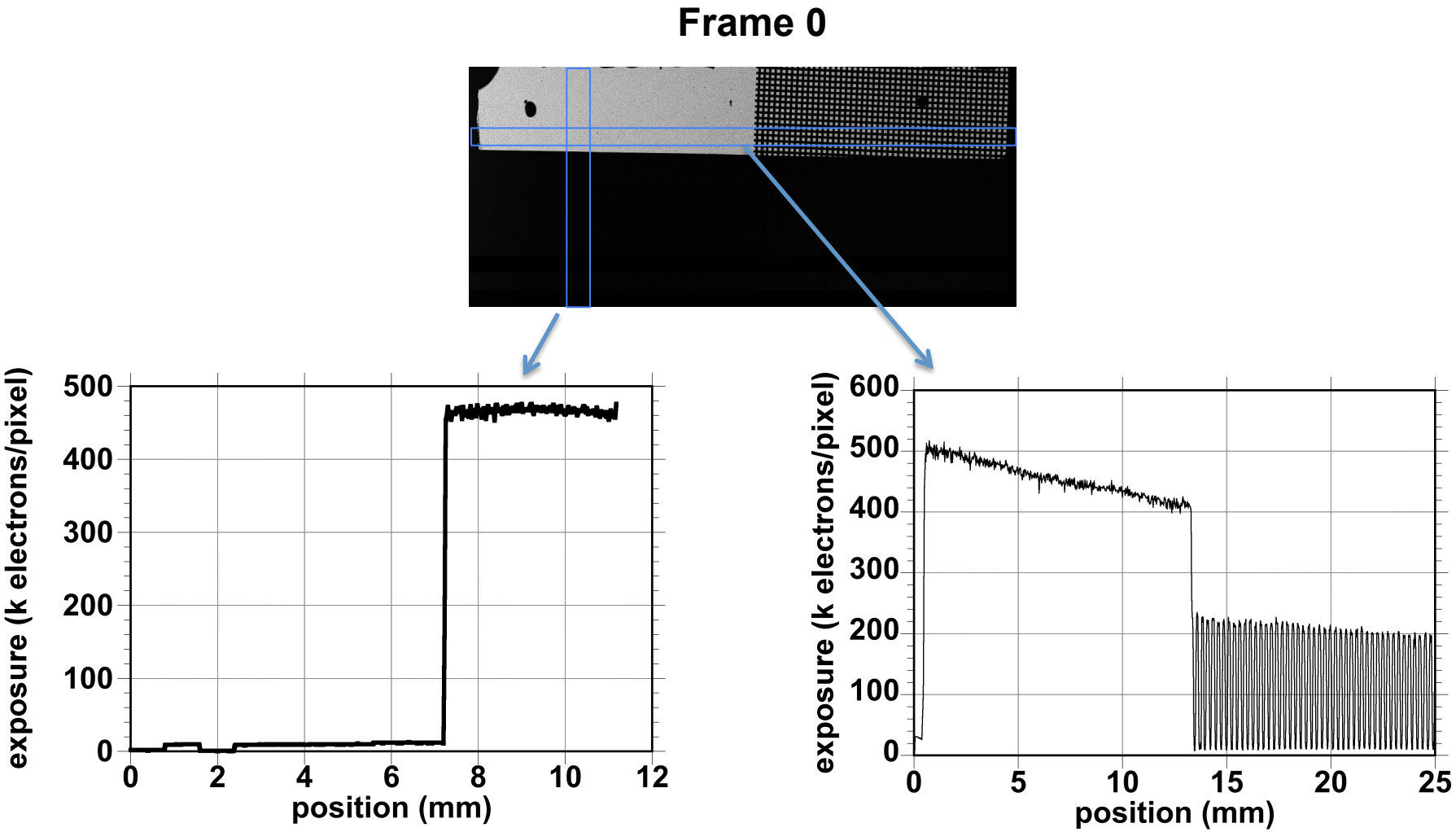
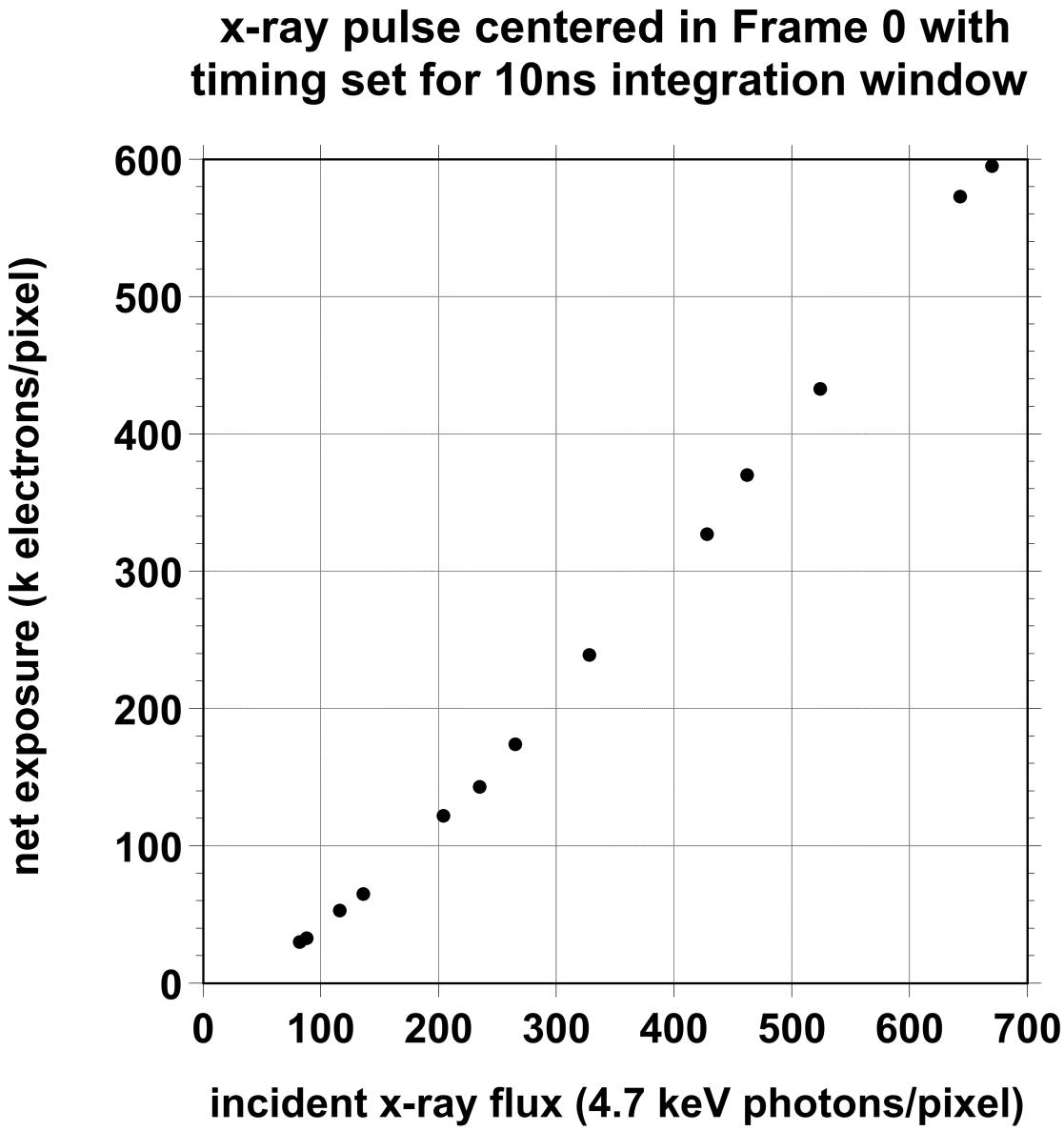


Image lineouts

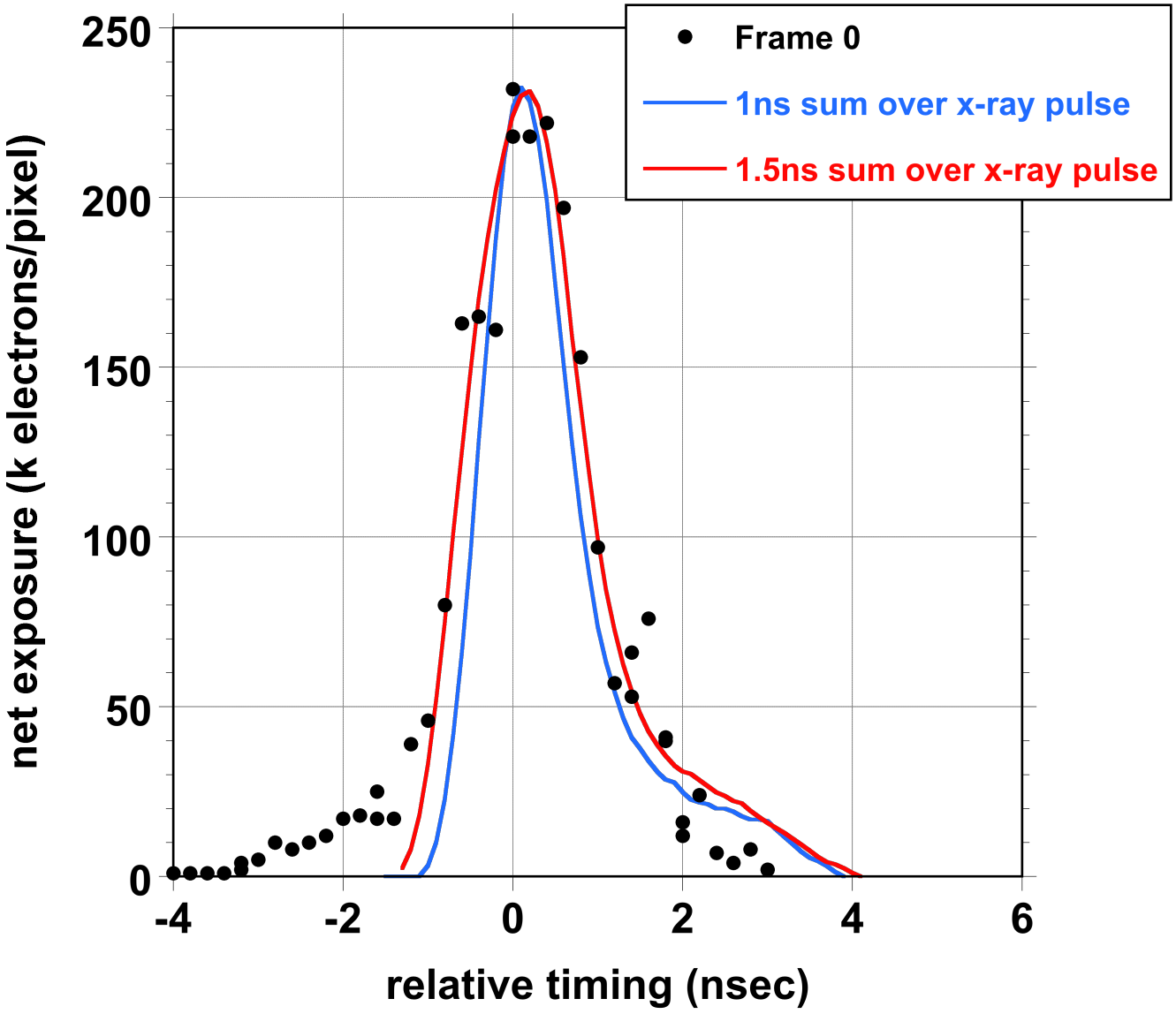
- 1ns x-ray pulse centered on Frame 0
- Furi timing set to 10ns-on/10ns-off



x-ray sensitivity



Time response compared to x-ray pulse



Near term plans

- **"Furi"**
  - Continued characterization
  - Refinement of modeling and simulation
  - Move to more compact and robust systems electronics
  - Integrate into Z experiments

- **Interlaced 8-frame, 1024 x 448 pixel x-ray sensor- "Hippogriff"**
  - Options of 2 frames with 1024x448 active pixels, 4 frames with 512x448 active pixels, or 8 frames with 256x448 active pixels
  - Improved frame-to-frame isolation
  - In Fabrication with packaged cameras available for initial use by February 2014

- **4-frame, 512 x 512 pixel sensor with optimized sensitivity for electrons (down to 1 keV), soft x-rays (down to 100 eV), and blue light (350 nm) - "Icarus"**
  - Change polarity of diode and CMOS pixel
  - Characterization of prototype diodes underway
  - Interlaced 8-frame capability
  - Designed for close packing of 2-4 die to create 1024x512 or 1024x1024 pixel sensors
  - Signal capture range per pixel modified to match lower energy electrons and x-rays ($250e^-$ to $500{,}000e^-$)
  - Fabrication planned to begin in November with packaged camera available in June 2014