Dual Threshold X-Ray Photon Counter

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Dual Threshold X-Ray Photon Counter (DT-XPC)

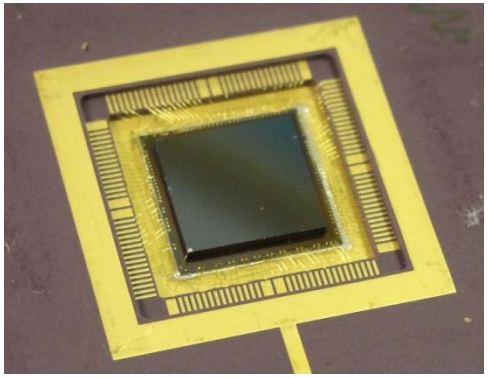
Advanced Photon Source (APS)

24-bunch mode: 80ps (FWHM)

153ns spacing

324-bunch mode: 50ps (FWHM)

11.4ns spacing



To utilize the full potential offered by APS

- Fast pulse pair resolution (10ns and 150 ns)
- Single photon counting (5k~20keV)
- Dual threshold counters (energy windowing)
- High dynamic range (1G counts/pixel)
- Gated counter operation (pump and probe)

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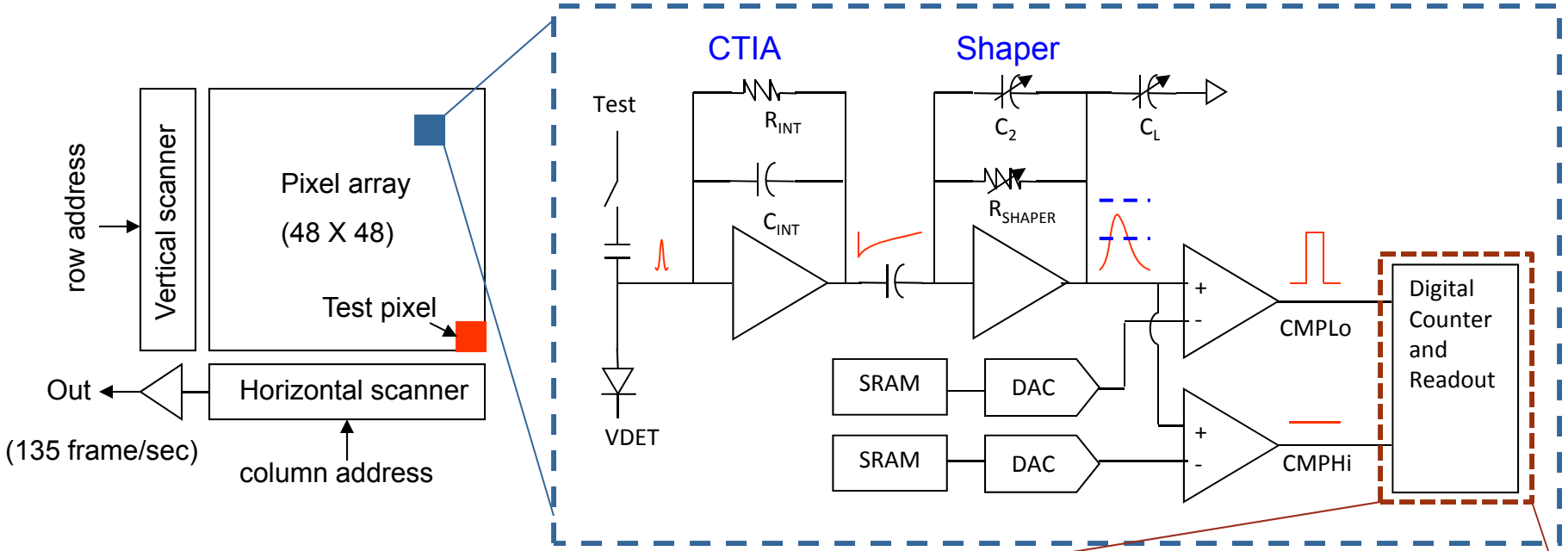
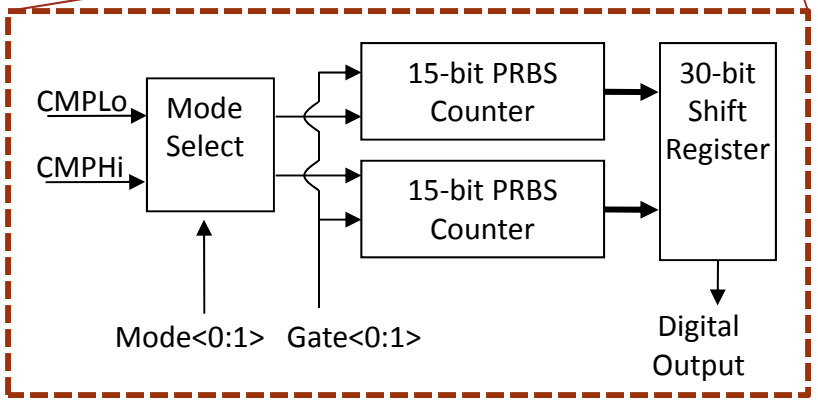
DT-XPC Sensor Functionality



- By changing R_{shaper}, C_2, and C_L, the width and amplitude of the shaper output pulse could be controlled and optimized for 10ns or 150ns bunch mode.
- With combination of comparator threshold, mode and gate signals, the device can support dual 15-bit counting, single 30 bit counting, energy windowing, and pump and probe testing.
- A 30-bit shift register allows the device to operate in integrate-while-read mode, resulting in minimum dead time of 3us.



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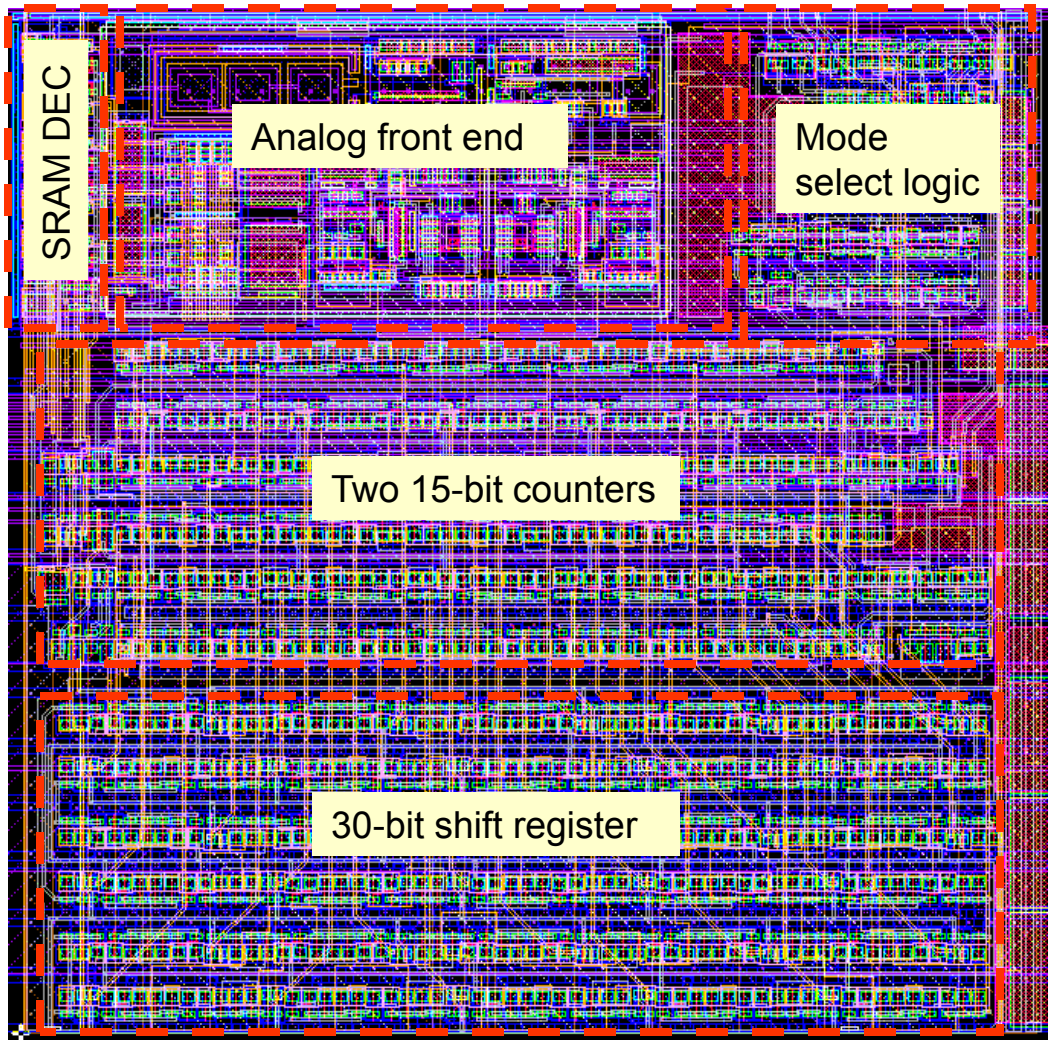
Pixel Layout



- TSMC 0.25 µm CMOS
- 130 µm by 130 µm
- 20% analog, 80% digital

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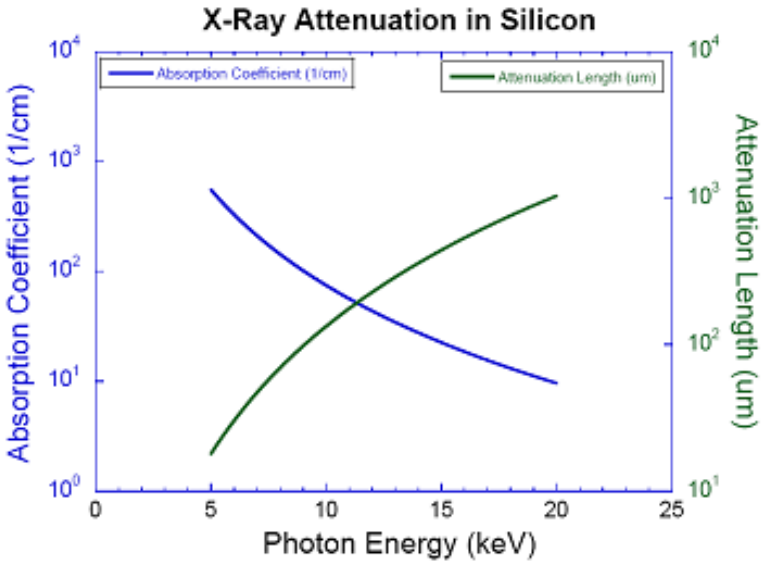
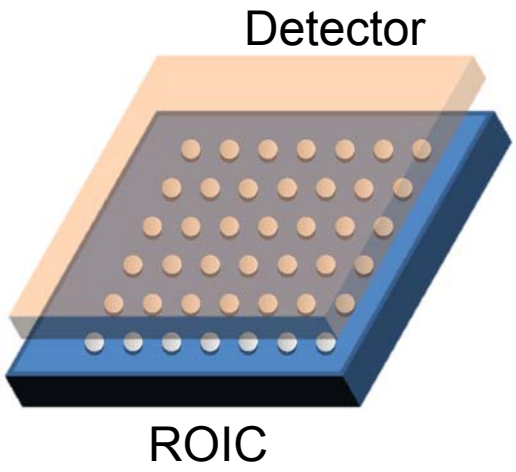
Thick Silicon Detector Development





Working with the Advanced Photon Source at Argonne National Lab and Northern Illinois University, 520 µm thick, backside-illuminated silicon photodiode arrays were fabricated aiming for detection of X-rays in the range of 5keV to 20keV.

520 µm fully depleted silicon detector:
- Quantum efficiency: ~ 90% for 5keV and ~40% for 20keV X-rays.
- Response time: ~ 20 ns (too slow for 10 ns bunch mode)
- ***Germanium detector under development for 10 ns bunch mode***

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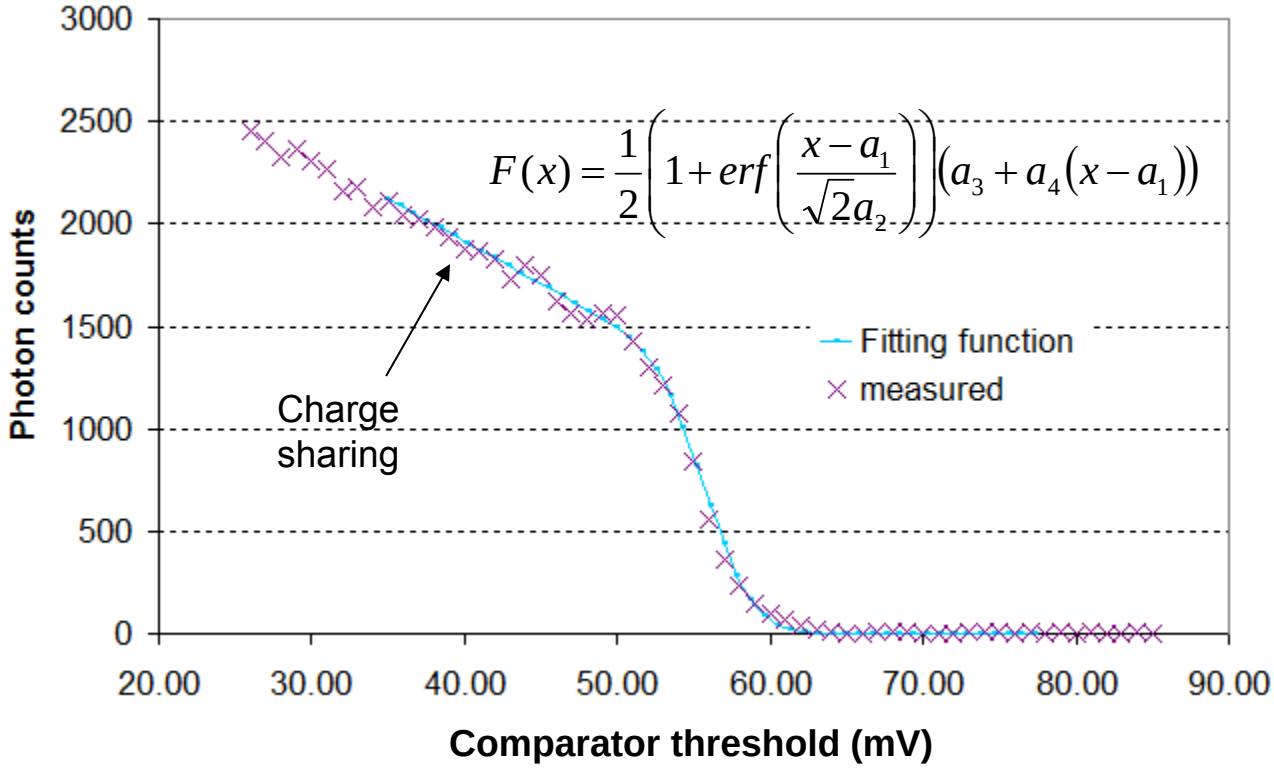
Threshold Scan with Iron-55

X-ray Source:
Fe55 (5.9keV)



Conversion gain and noise numbers have been calculated from this threshold scan measurement. In 150ns bunch mode conversion gain is 32 µV/e- and the noise (detector + pixel circuitry + x-ray source) is 77.5 e- or 283eV (RMS).

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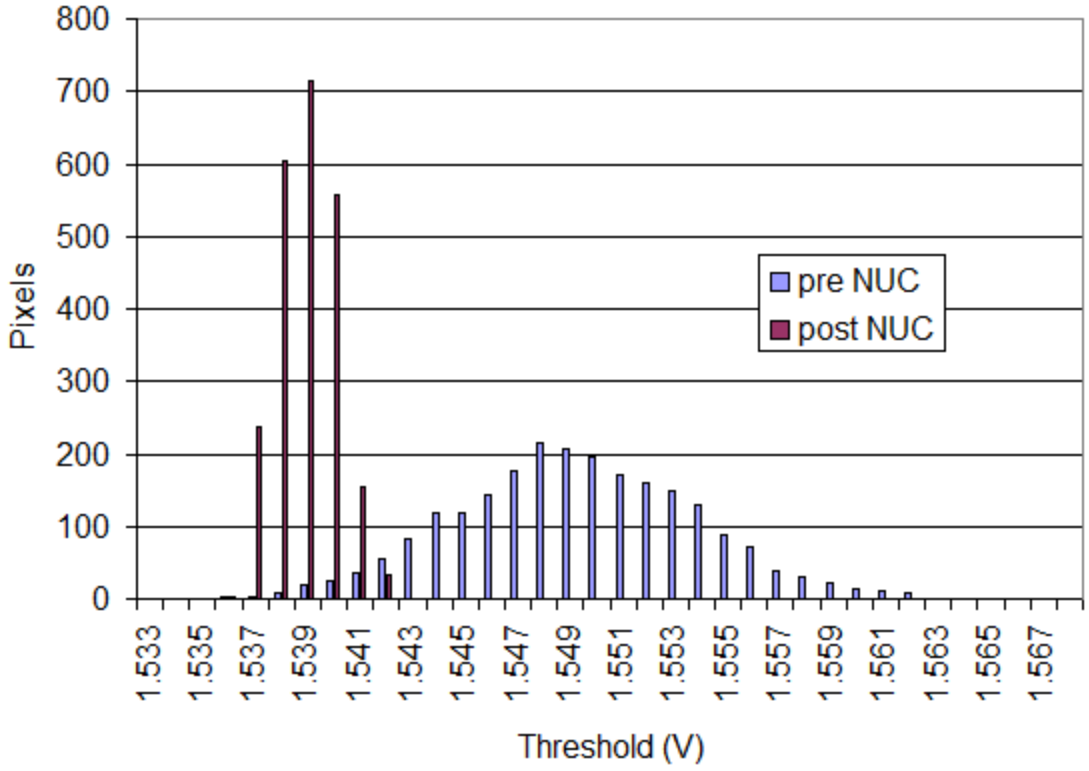
Non-Uniformity Correction



- Threshold distribution across the array when 5.9keV equivalent test charge is injected to each pixel.
- Distribution of threshold without NUC is 4.54 mV or 502 eV. Using the 3-bit in-pixel calibration of the comparator threshold, the non-uniformity is reduced to 1.15 mV or 127 eV.

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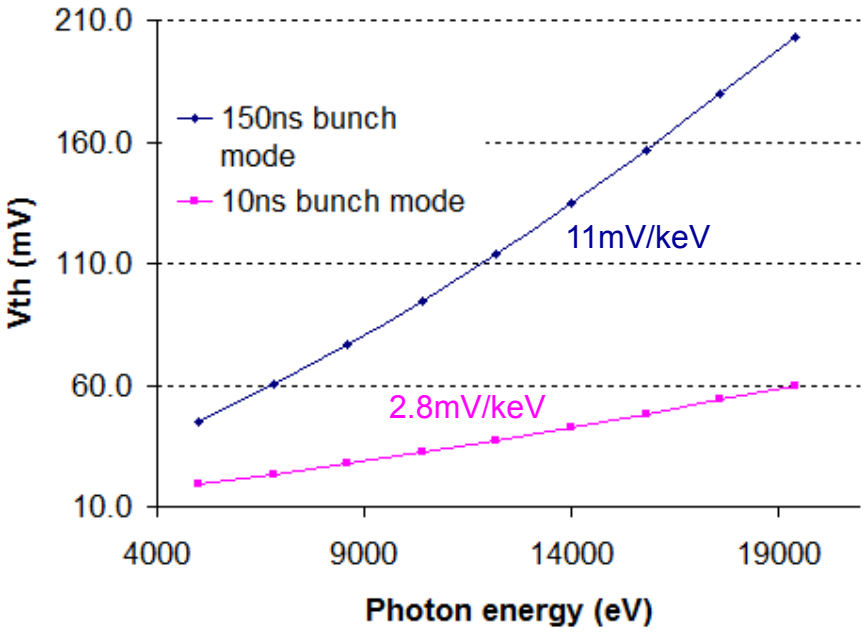
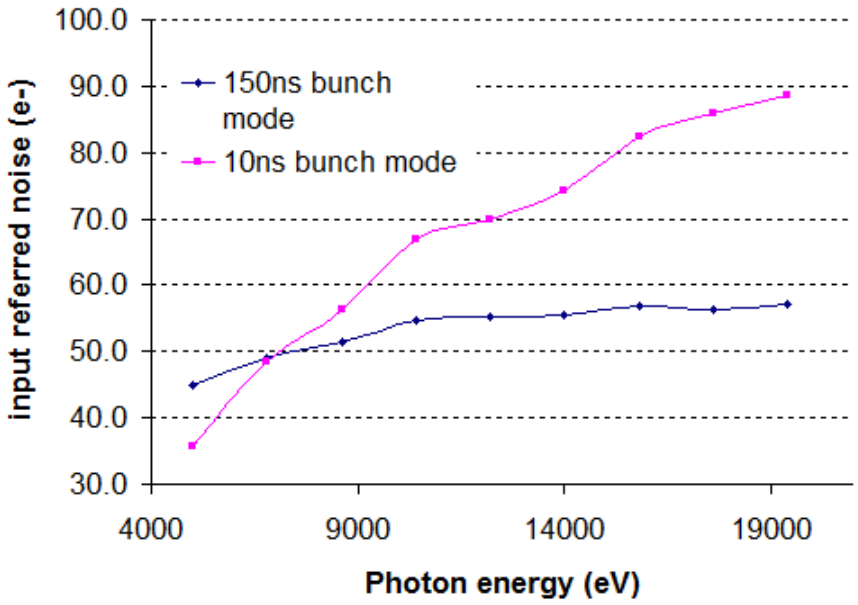
Energy response





- Test pulse charge is injected to a pixel through in pixel charge injection circuitry
  - 150 ns bunch mode: charge pulse with 22 ns pulse width and 1 MHz repetition rate.
  - 10 ns bunch mode: charge pulse with 5 ns pulse width and 1 MHz repetition rate.
- 6.5% and 5.6% non-linearity on 150 ns and 10 ns bunch mode respectively across 5k~20keV.
- Input referred noise increases with photon energy especially for 10 ns bunch mode.

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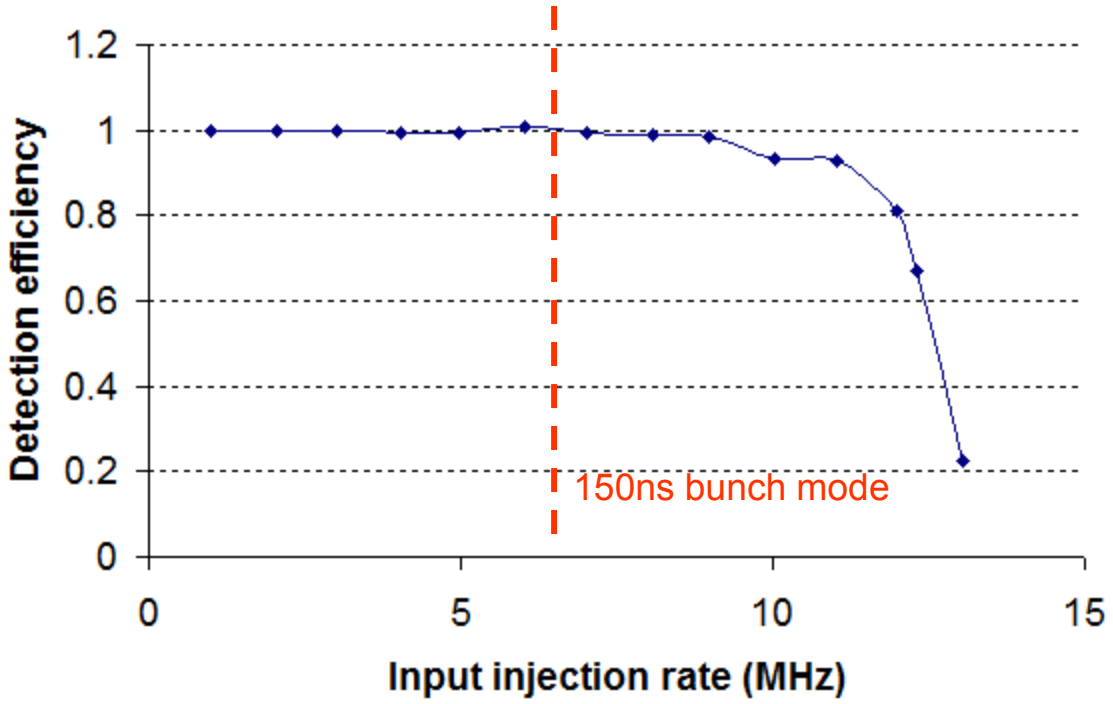
Detection Efficiency vs. Input Injection Rate



- 1060nm laser pulse with equivalent to 5.9 keV energy used for input source
- Almost no detection efficiency drop found up to 9 MHz

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DT-XPC Sensor Summary and Future Developments

Sensor Parameter	Units	Specification (150ns bunch mode)
Array size	pixels	48 x 48
Active area	mm	6.24 x 6.24
Pixel pitch	µm	130
X-ray energy	keV	5 – 20
Detector thickness (Si)	µm	520
Dynamic range	bits	2 x 15 or 30
Conversion gain	uV / e-	31
Read noise (RMS)	e- / eV	46.7 / 170.5
Threshold dispersion	e- / eV	34.8 / 127.2
Minimum Bunch spacing @ >1% loss	ns	110
Power consumption	uW / pixel	300

In Development

Beamline Camera

- DT-XPC sensor characterization testing is limited to Voxtel's labs.
- **Planned:** Will move testing to Advanced Photon Source when beam-line camera is complete.

2nd Generation ROIC Design

- **Planned:** Will increase sensor active area to ~ 20 mm x 20 mm on reduced pixel pitch.

Germanium detector

- **Planned**: Will provide high stopping power and fast response time.

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Thank you

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