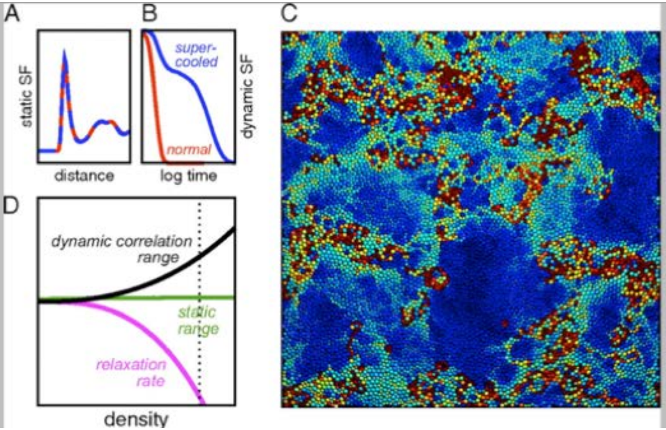
APRIL 12, 2018

PROGRESS ON FAST DETECTORS FOR XPCS AT APS AND APS-U



Juan P. Garrahan PNAS **108**, 4701 (2011)

ALEC SANDY

APS-U Forum

ACKNOWLEDGEMENTS

Detector specific

- APS
  - Eric Dufresne
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  - Pete Siddons
- FNAL
  - Grzegorz Deptuch
- AGH University, Poland
  - Anna Koziol
  - Piotr Maj
  - Piotr Kmon
  - Robert Szczygiel
  - Pawel Grybos
- LDRD program for facilitating UFXC collaboration and science applications

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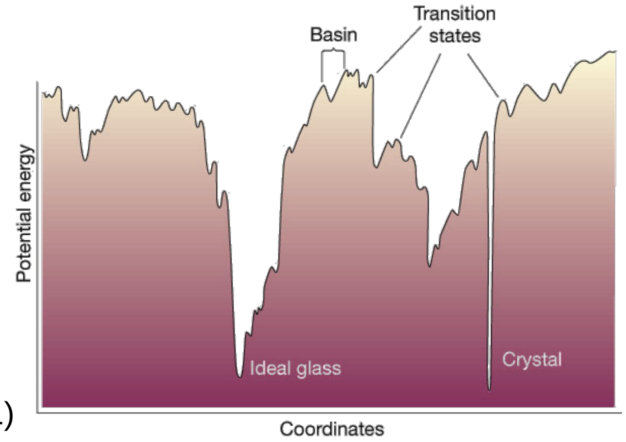
OUTLINE

- APS-U XPCS beamline
  - General motivation and considerations
- Detectors
  - Requirements
  - Landscape
  - R&D efforts
    - Ultrafast x-ray camera (UFXC)
    - Vertically integrated photon imaging chip (VIPIC)
- Conclusions

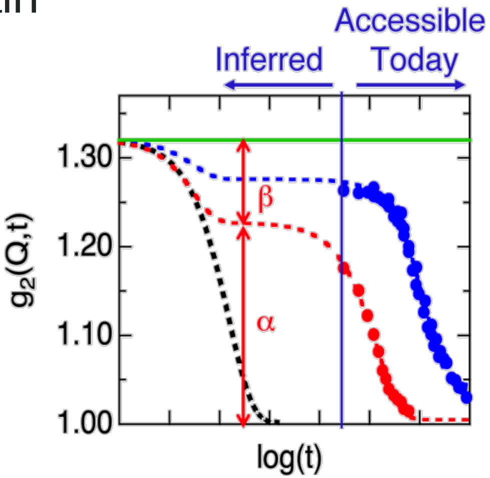
APS-U XPCS BEAMLINE

X-ray photon correlation spectroscopy (XPCS)

- Tool for measuring the nano- and meso-scale dynamic properties of materials via correlations within a time-evolving x-ray speckle pattern
  - Measurements performed in the time domain



P. G. Debenedetti,
F. H. Stillinger,
Nature **410**, 259 (2001)



  - Lack of coherent flux and appropriate detectors limit sensitivity to motion in time and space

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APS-U XPCS BEAMLINE

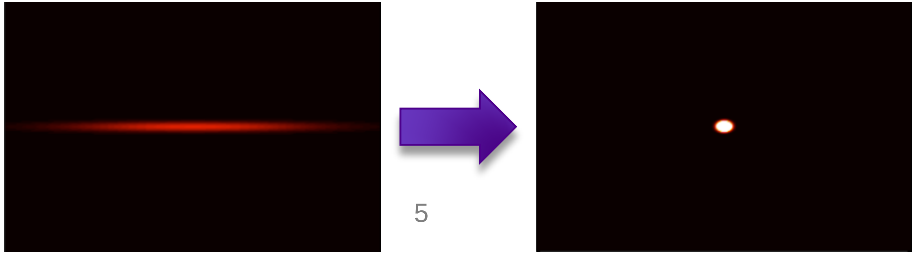
Mission and supported techniques

- Mission
  - Application of hard (~ 8–25 keV) coherent x-rays to measure dynamics in complex materials at the nano and mesoscale
- Supported Techniques:
  - X-ray photon correlation spectroscopy at small and large scattering angles
- Why APS-U?

Coherent flux (Intensity) = Brightness × $\lambda^2/4$

SNR = Contrast × Intensity × $(T\tau N)^{1/2}$

Accessible delay times (τ) $\propto$ 1/Brilliance^2



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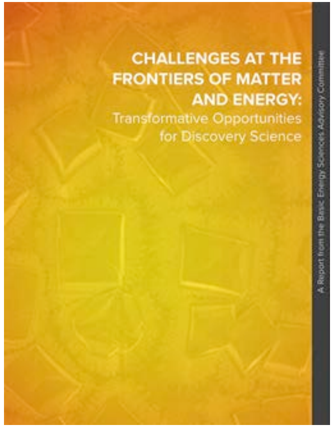
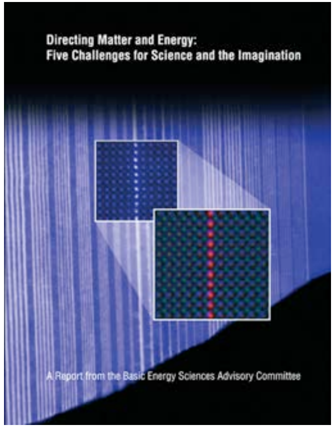
APS-U XPCS BEAMLINE

Why?



2015

2012



2007

“Many real materials are inherently heterogeneous across spatial and temporal scales, as evidenced by their compositional, spatial/structural, and temporal fluctuations and disorder. …. Yet we often have considered materials in idealized, ‘frozen’ states or as represented by their spatially or temporally averaged structures. These overly simplistic models do not capture the nuances of structure and dynamics that often drive desired functional behavior.”

Challenges at the Frontiers of Matter and Energy, BESAC (2015)

APS-U XPCS BEAMLINE

Requirements

- Maximize brightness ➜ Maximum coherent flux
- Energy range
  - 8–25 keV, continuous tunability and scanning not required
- Variable bandpass ($\Delta E/E$) radiation
  - ~ 1% for near USAXS (pinhole) XPCS to 0.005% for WA-XPCS
- Variable sample spot sizes (zoom focusing)
  - Tunable sensitivity to fluctuation length scales and efficient speckle sampling
- Dedicated small-angle and wide-angle experiment stations
- Dynamic range
  - Up to 10 orders of magnitude in delay time: 100 ns – 1,000 s

DETECTOR REQUIREMENTS

Item	Requirement	Comment
Form factor	2-D	≥ 10^6 pixels
Pixel size	≤ 100 μm	
Efficiency	~ 100%	≤ 25 keV
Type	Integrating preferred	Counting almost always works especially w/ multiple gates
Dynamic range	Small	Can be ≤ 2 bits
Frame rate	≈ 1–10 MHz	76 ns spacing in 48-bunch mode
Readout	Sparse	
Timing	Synch with ext. signals	
Other	Rolling buffer	Intermittent event capture

DETECTOR LANDSCAPE

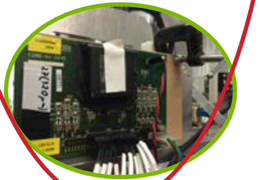
Commercial detectors (PADs): APS-U Scope

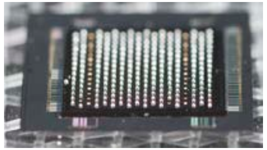
Parameter	Lambda		Eiger	
Pixel Size (µm)	55	✔☐	75	✔☐
Size (Mpix)	0.75	✔☐	0.5	✗
Frame Rate (MHz)	0.002	✗	0.009	✗
Sparsified readout	Sorta	✗	Sorta	✗
Dynamic range (bits)	12	✔☐	4 (@9 kHz)	✔☐
Time resn (1/frame rate) (µs)	500	✗	110	✗

DETECTOR LANDSCAPE

Commercial and R&D PADs

Parameter	Lambda	Eiger	UFXC	VIPIC-L
Pixel Size (μm)	55	75	75	65
Size (Mpix)	0.75	0.5	0.03	1
Frame Rate (MHz)	0.002	0.009		
Sparsified readout	Sorta	Sorta	No	Yes
Dynamic range (bits)	12	4 (@9 kHz)	2	2, 5, 7
Time resn (1/frame rate) (μs)	500	110		

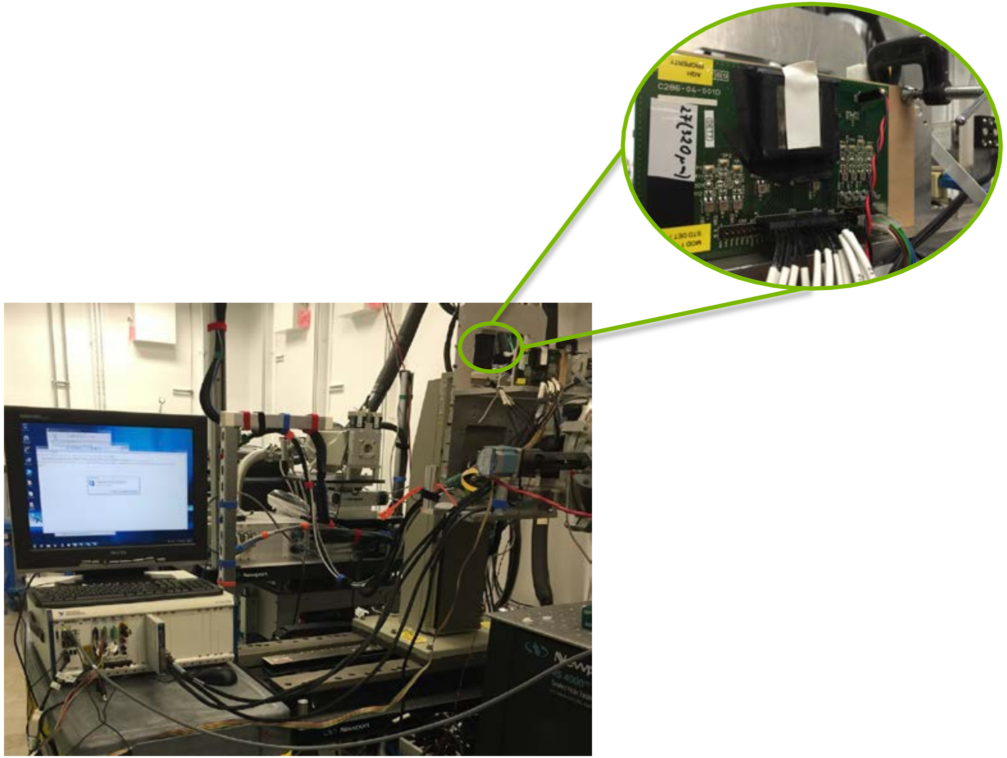




DETECTORS

UFXC pixel array detector

- Collaboration with AGH University
  - 128 × 256 75-µm pixels
  - 300-µm-thick Si sensor
  - 2 × 14-bit counters per pixel
    - 2-bit-depth for fast XPCS
  - World-record continuous XPCS frame rates of 50 kHz
    - 0.05 MHz



Q. Zhang *et al.*, Phys. Rev. Lett. **109**, 178006 (2017)

P. Grybos *et al.*, IEEE Trans. Nucl. Sci. **63**, 1155 (2016)

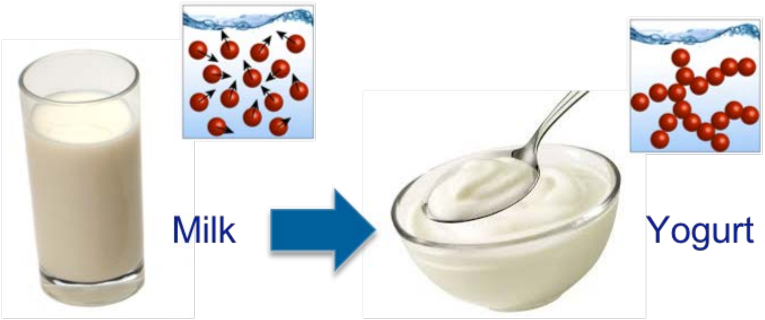
Q. Zhang *et al.*, J. Synch. Rad., accepted (2018)

DETECTORS

UFXC pixel array detector

- Science application:

Dynamic scaling in colloid gel formation

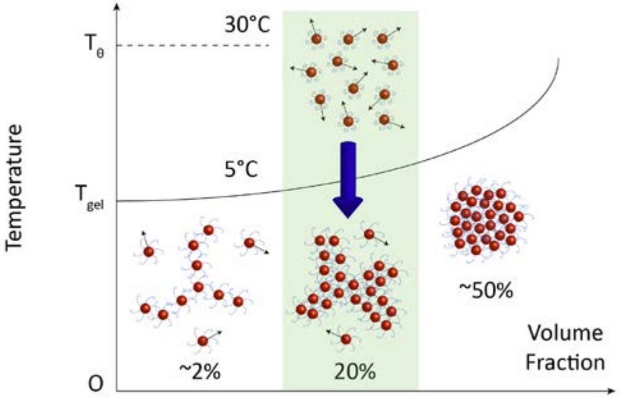


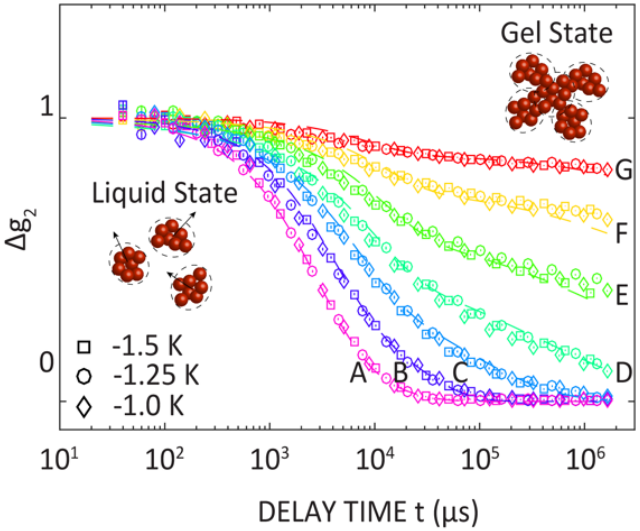
Dramatic changes in viscoelasticity,
structure and dynamics

Q. Zhang *et al.*, Phys. Rev. Lett. **109**, 178006 (2017)

P. Grybos *et al.*, IEEE Trans. Nucl. Sci. **63**, 1155 (2016)

Q. Zhang *et al.*, J. Synch. Rad., accepted (2018)

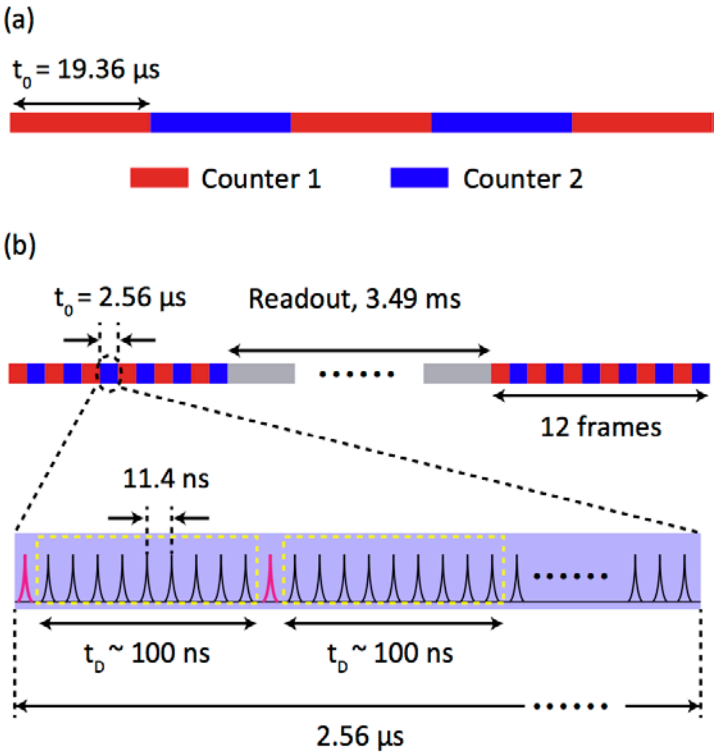




DETECTORS

UFXC pixel array detector

- Still higher frame rates achieved by acquiring a small number of frames in a “burst”
  - 2 × 14-bit counters per pixel reconfigured to rapidly acquire 12 × 2-bit signals (then a relatively slow readout)



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Q. Zhang *et al.*, J. Synch. Rad., accepted (2018)

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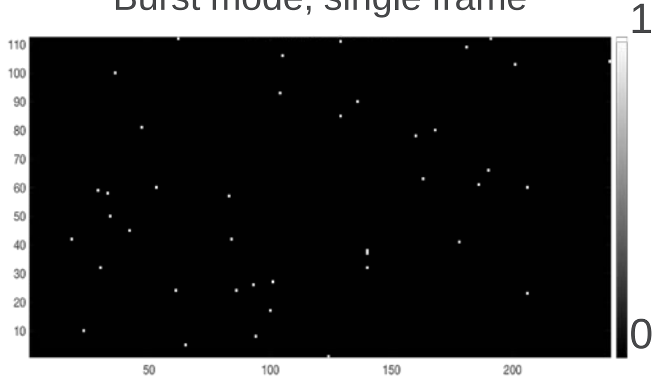
DETECTORS

UFXC pixel array detector

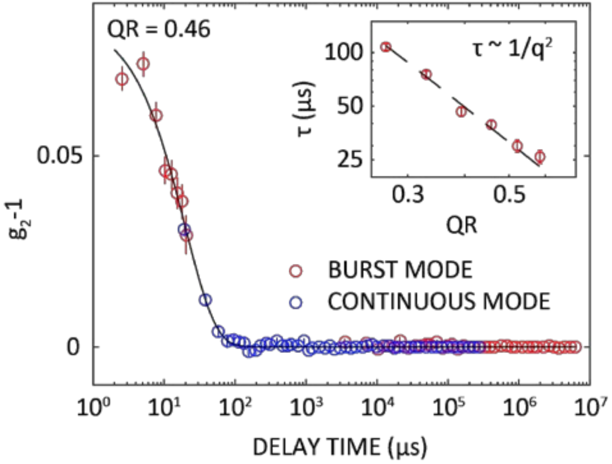
- Still higher frame rates achieved by acquiring a small number of frames in a "burst"
  - Stitch 2.6 µs results with 20 µs continuous frames

- Correlation decays measured over 7 decades in delay time

Burst mode, single frame



Dynamics of R=10 nm colloids in water



Q. Zhang *et al.*, Phys. Rev. Lett. **109**, 178006 (2017)

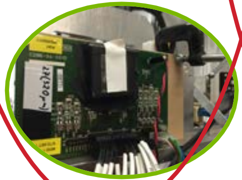
P. Grybos *et al.*, IEEE Trans. Nucl. Sci. **63**, 1155 (2016)

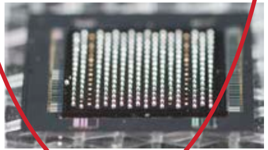
Q. Zhang *et al.*, J. Synch. Rad., accepted (2018)

DETECTOR LANDSCAPE

Commercial and R&D PADs

Parameter	Lambda	Eiger	UFXC	VIPIC-L
Pixel Size (µm)	55	75	75	65
Size (Mpix)	0.75	0.5	0.03	1
Frame Rate (MHz)	0.002	0.009	0.4	
Sparsified readout	Sorta	Sorta	No	Yes
Dynamic range (bits)	12	4	2	2, 5, 7
Time resn (1/frame rate) (µs)	500	110	2.56	

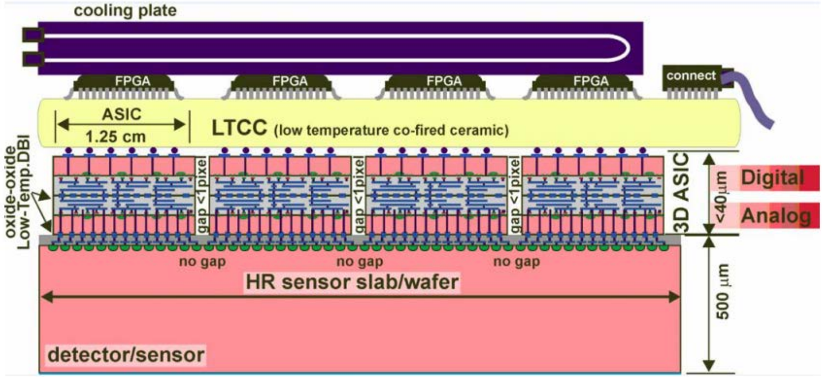




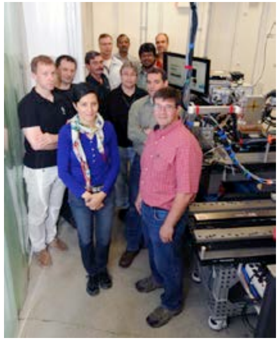
DETECTORS

VIPIC pixel array detector

- Collaboration of FNAL, ANL and BNL to build an XPCS-optimized detector
  - < 2014: prototype, ≥ 2014: 2× 1 Mpix detectors (NSLS-II and APS-U)
- 3-D detector structure enables parallel time-tagging of arriving photons with precision < 150 ns
  - Sparse and “image” readout modes



VIPIC prototype commissioning team



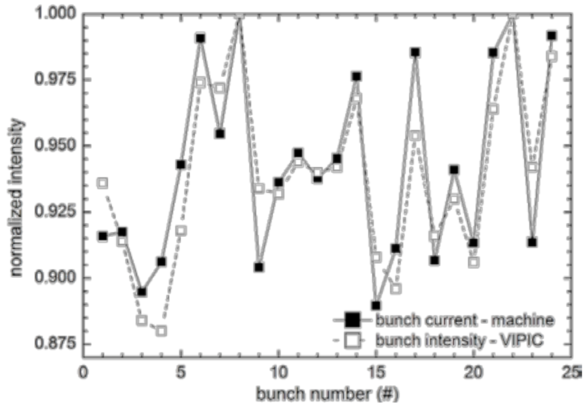
G. Deptuch *et al.*, IEEE Trans. Elect. Dev. **63**, 205 (2016)

DETECTORS

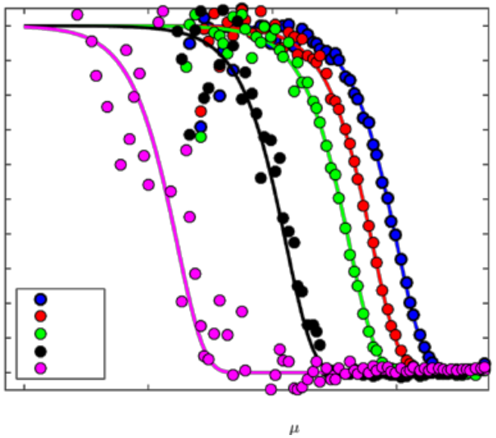
VIPIC pixel array detector

- Results from the 64 X 64 pixels VIPIC prototype detector:
  - Programmatic funding to ANL, BNL, and FNAL to develop a full-sized version of this detector
  - Prototype no longer functioning but VIPIC-L development proceeding

A. Rumaiz *et al.*, J. Synch. Rad. **23**, 404 (2016)



Direct beam logging



Fast colloid dynamics

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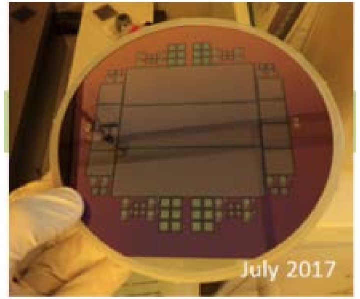
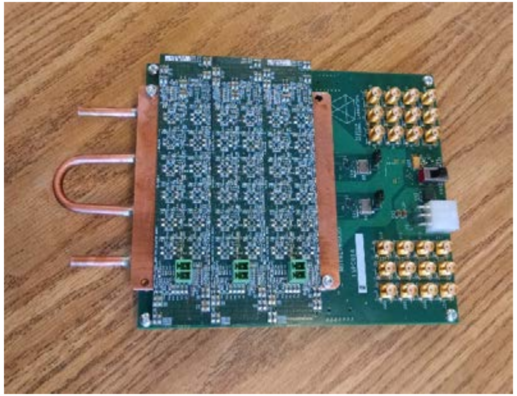
DETECTORS

VIPIC pixel array detector

- VIPIC-L status

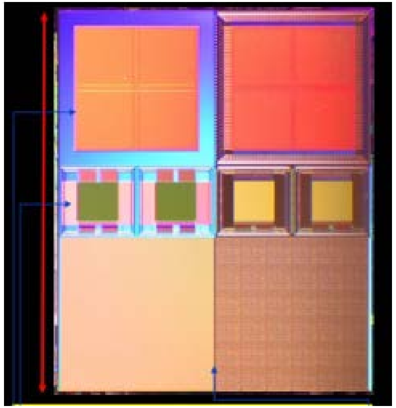


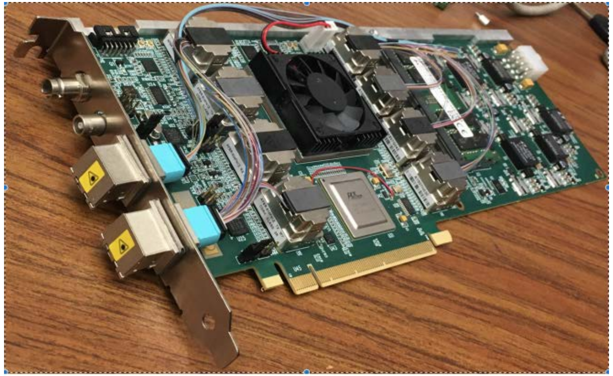
Sensor designed and fabricated



ASIC has been designed, but needs to be validated

Completed and tested prototypes of all detector electronics



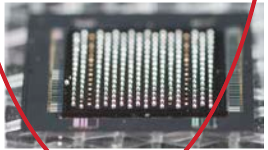


FELIX data acquisition card

DETECTOR LANDSCAPE

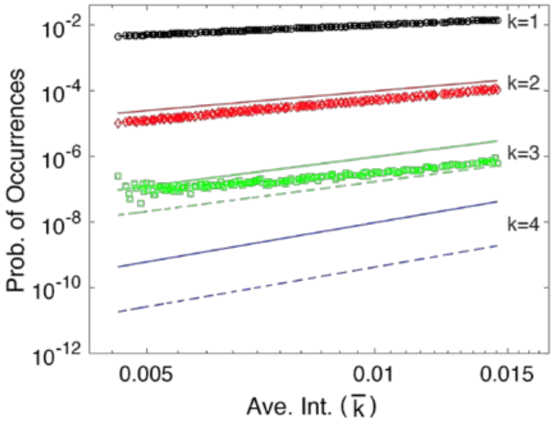
Commercial and R&D PADs

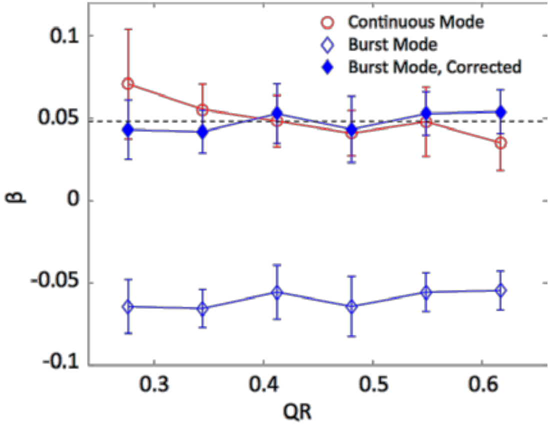
Parameter	Lambda	Eiger	UFXC	VIPIC-L
Pixel Size (μm)	55	75	75	65
Size (Mpix)	0.75	0.5	0.03	1
Frame Rate (MHz)	0.002	0.009	0.4	0.08
Sparsified readout	Sorta	Sorta	No	Yes
Dynamic range (bits)	12	4 (@9 kHz)	2	2, 5, 7
Time resn (1/frame rate) (μs)	500	110	2.56	*0.02 × Hits*



TO-DO AND CONCLUSIONS

- Technical:
  - Small numbers of photon events reveal subtle problems:
    - Speckle contrast (β)
      $\beta \approx 2\times[P(2)/P(1)^2]\times[1-P(1)] - 1$
      - Pixel-response dead-time of ~130 ns changes β from ~ 0.05 to ~ -0.07
- Many issues remain but 1–10 MHz frame rates for APS-U XPCS detectors do not seem completely crazy





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THANK YOU