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High-efficiency superconducting single-photon detectors

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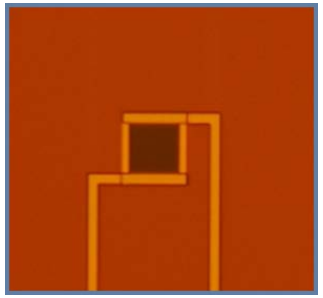
Applications:

- Exo-planet detection : Low light level sensing, low dark counts
- Asteroid Detection : Imaging, IR sensitivity
- LIDAR : Time-of-flight
- Spectroscopy : Calorimetric Measurements
- Quantum Information : High Efficiency

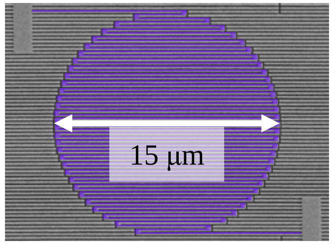
Superconducting detectors

- Extremely low to no dark counts
- Very high detection efficiency

- Transition Edge Sensors (TESs)
  - Photon-number resolving
  - Shown Sensitivity: 400 nm – 2500 nm*



- Superconducting Nanowire Single Photon Detectors (SNSPDs)
  - Fast Gaussian response, extremely low jitter
  - Shown Sensitivity: 300 nm – 7000 nm



SUPERCONDUCTING NANOWIRE SINGLE PHOTON DETECTOR (SNSPD)

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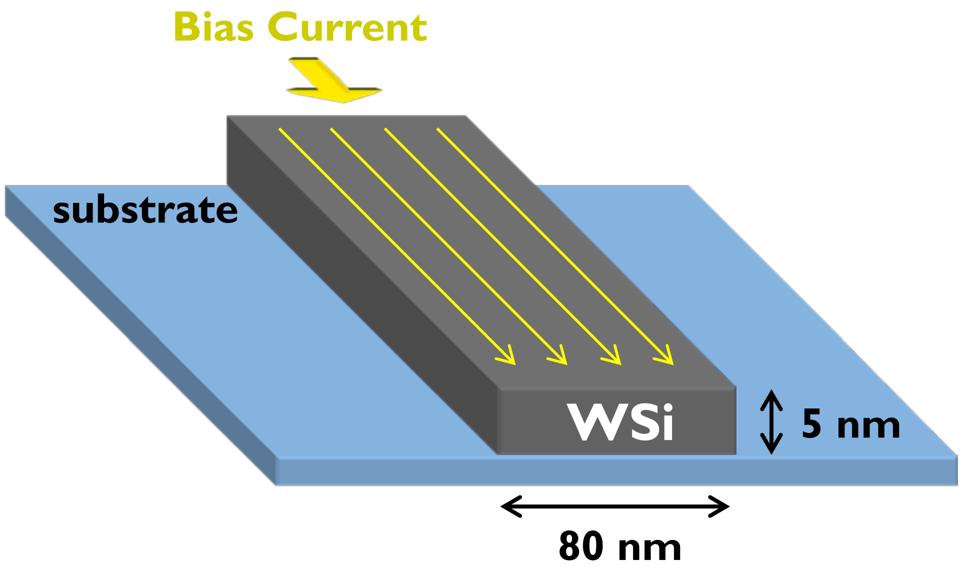

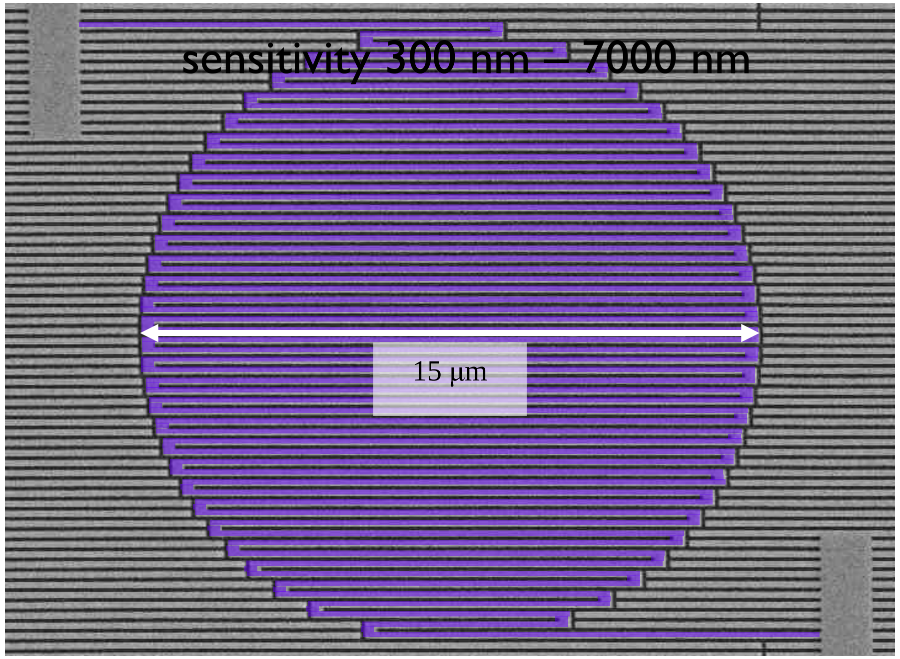

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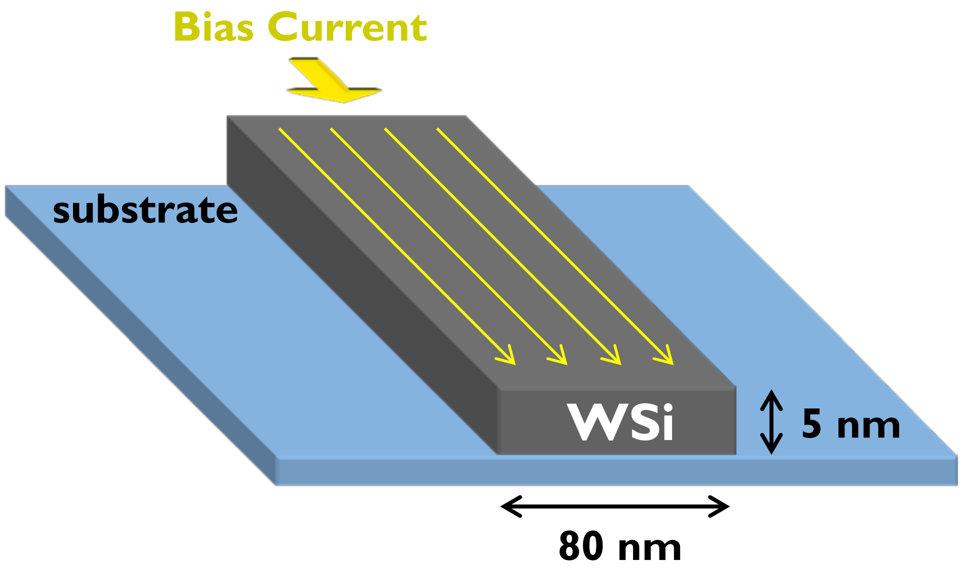
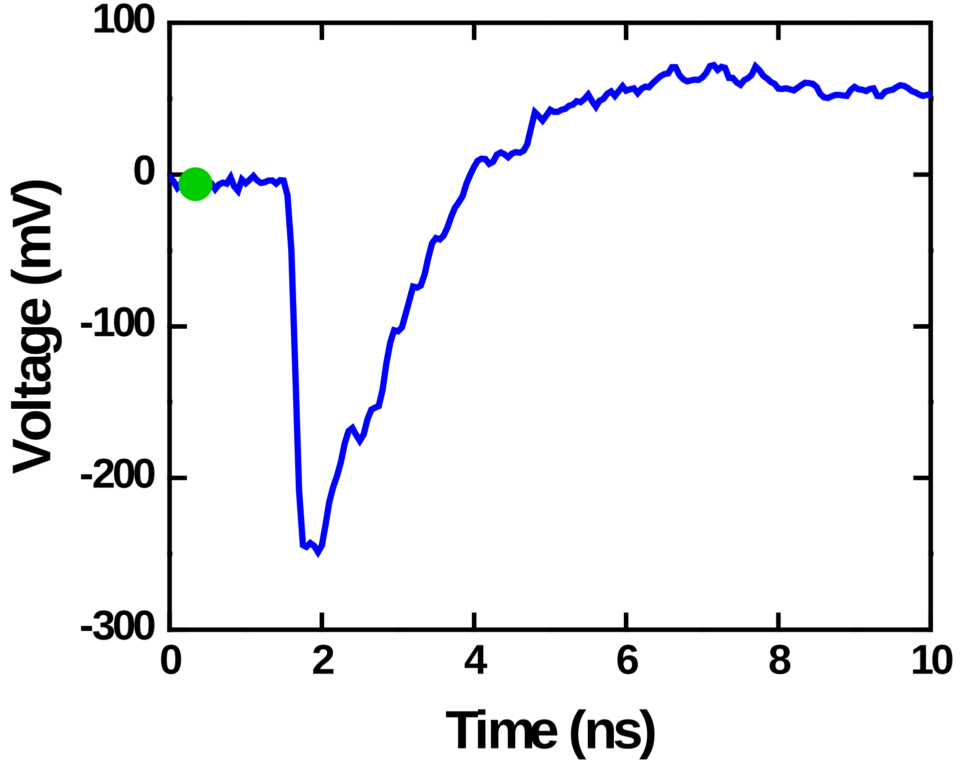
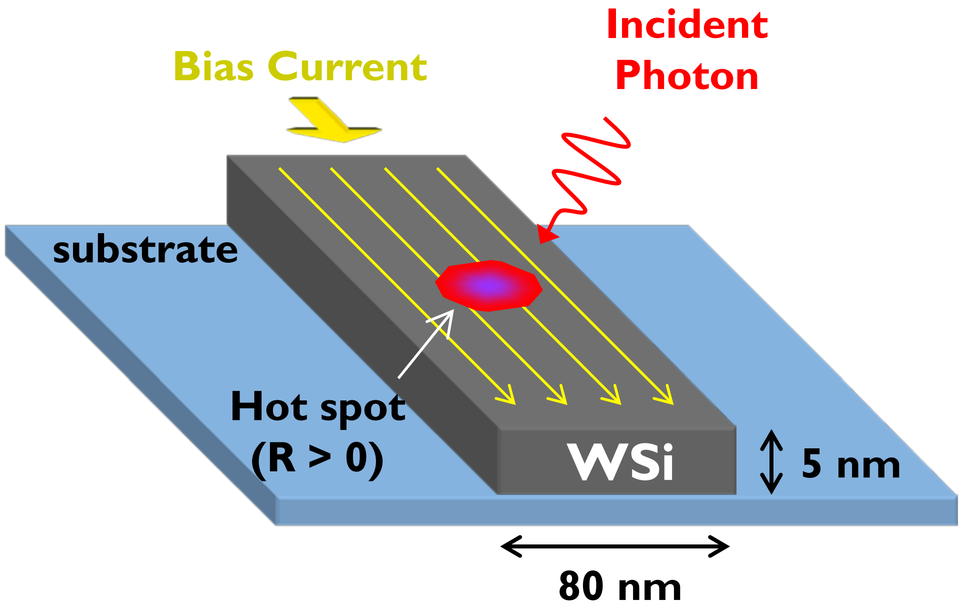
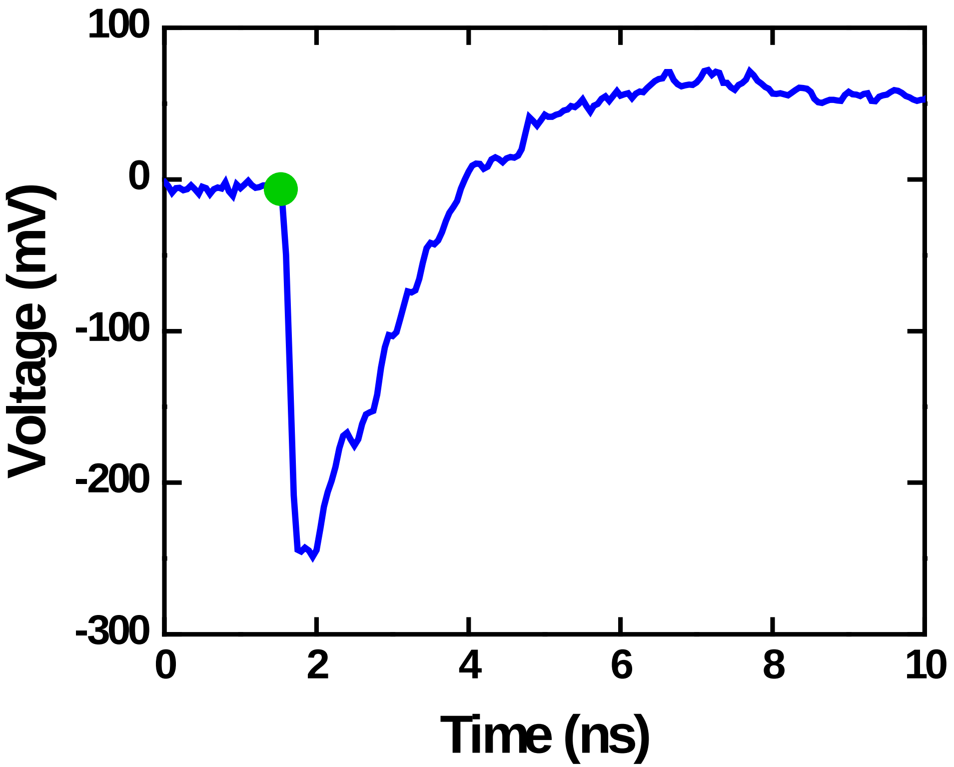


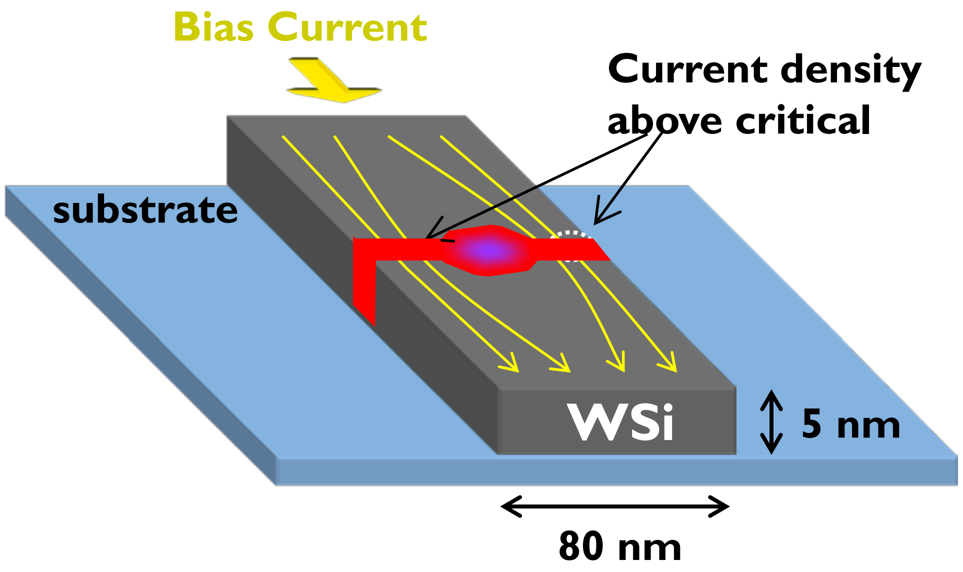


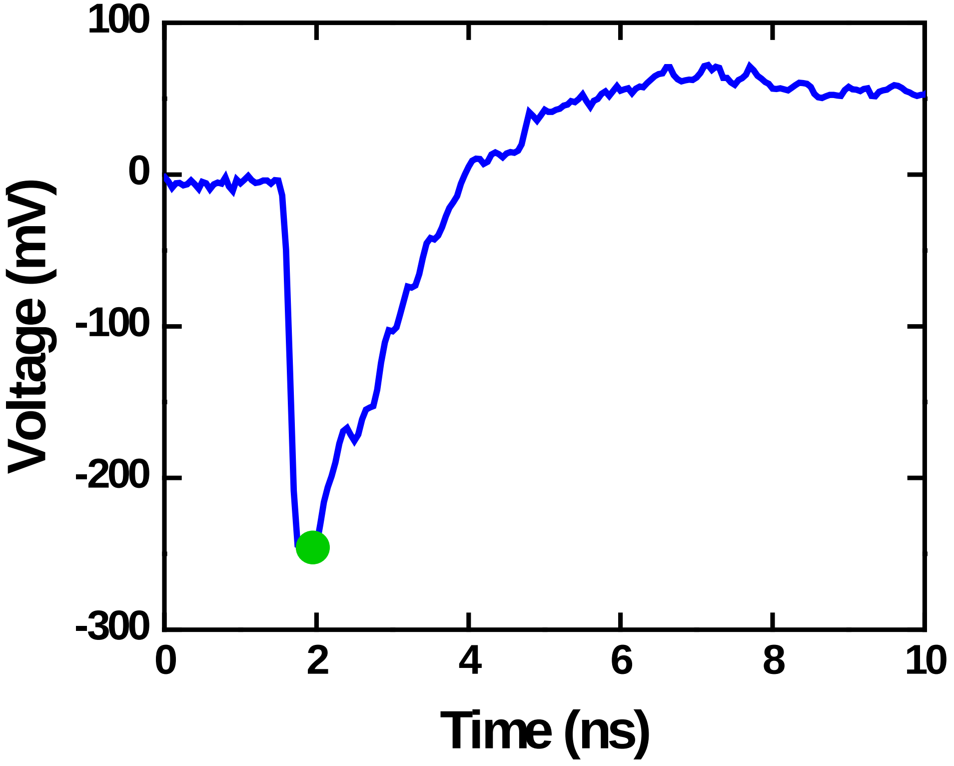
Superconducting Nanowire Single Photon Detector (SNSPD)



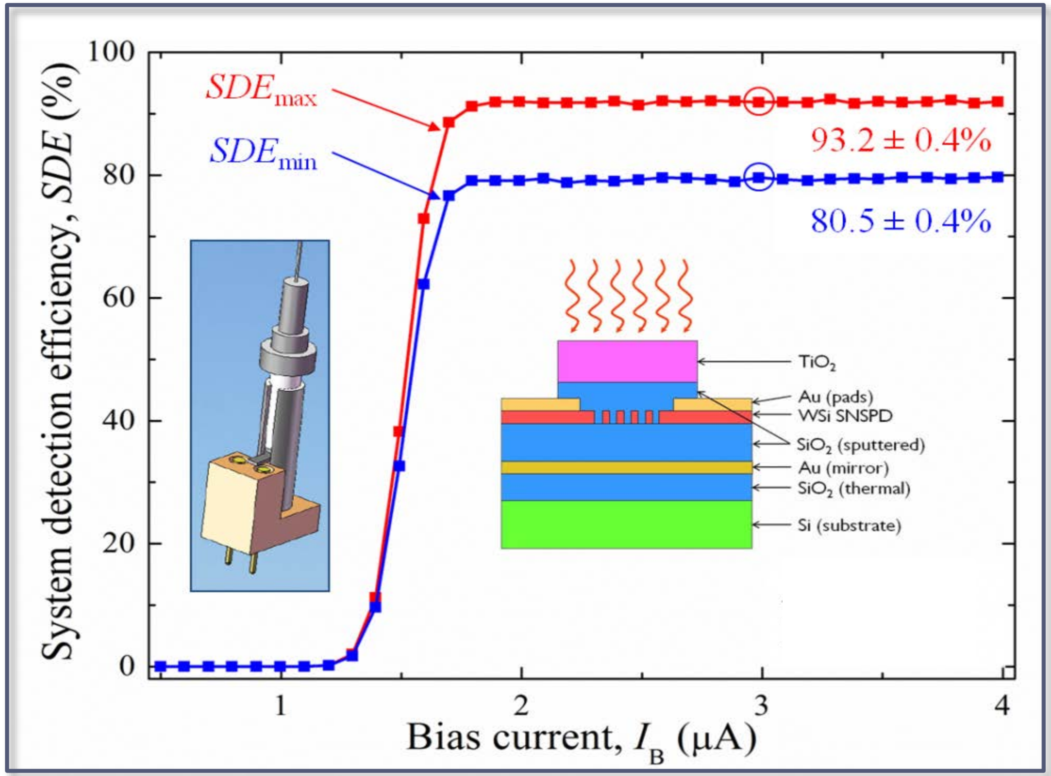


Superconducting Nanowire Single Photon Detector (SNSPD)

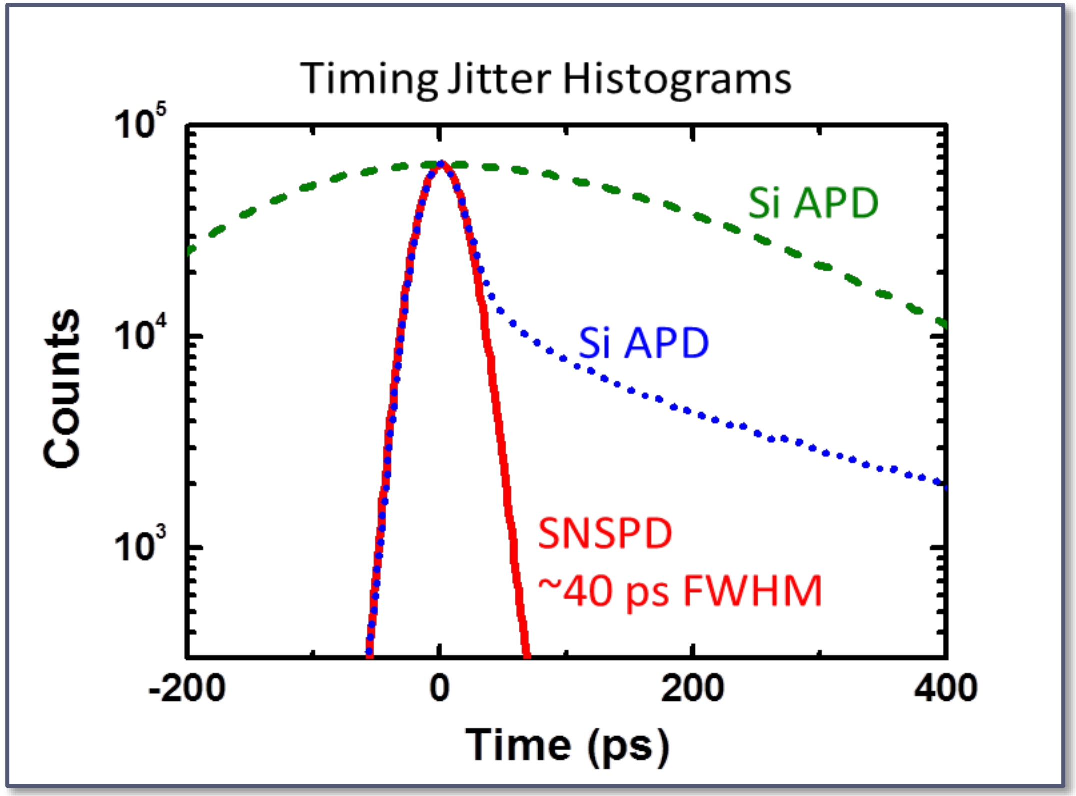




SNSPD EFFICIENCY AND TIMING JITTER PERFORMANCE



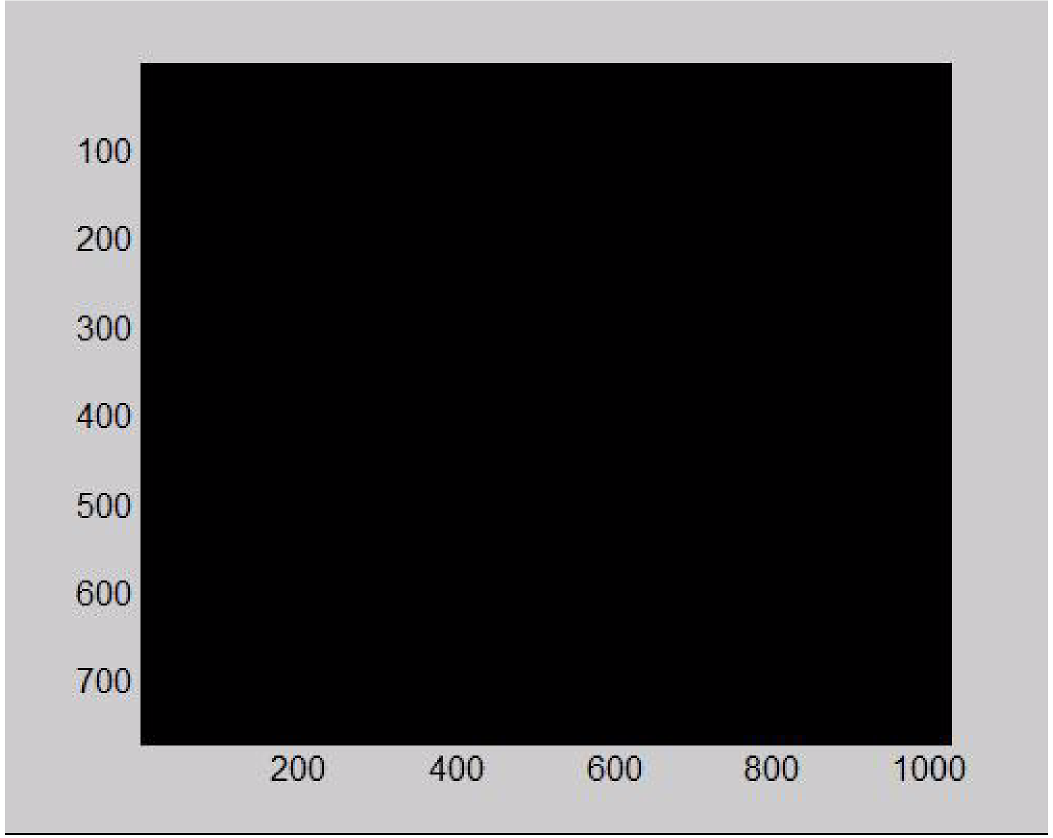
Marsili et al, *Nat. Photon* **7,** 210 (2013)

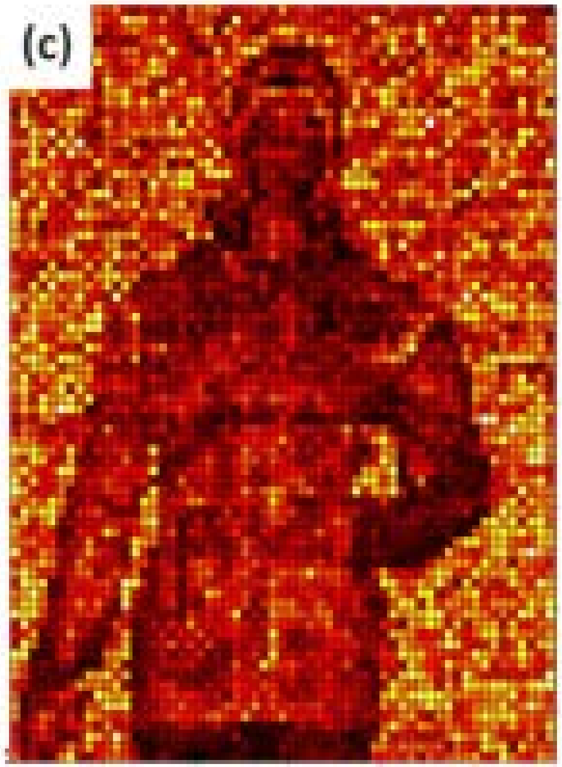


Overview

- Superconducting Nanowire Single Photon Detectors
- Compressive Imaging using SNSPDs
- Transition Edge Sensors
- Single photon detector calibration efforts at NIST

Time-of-flight measurements



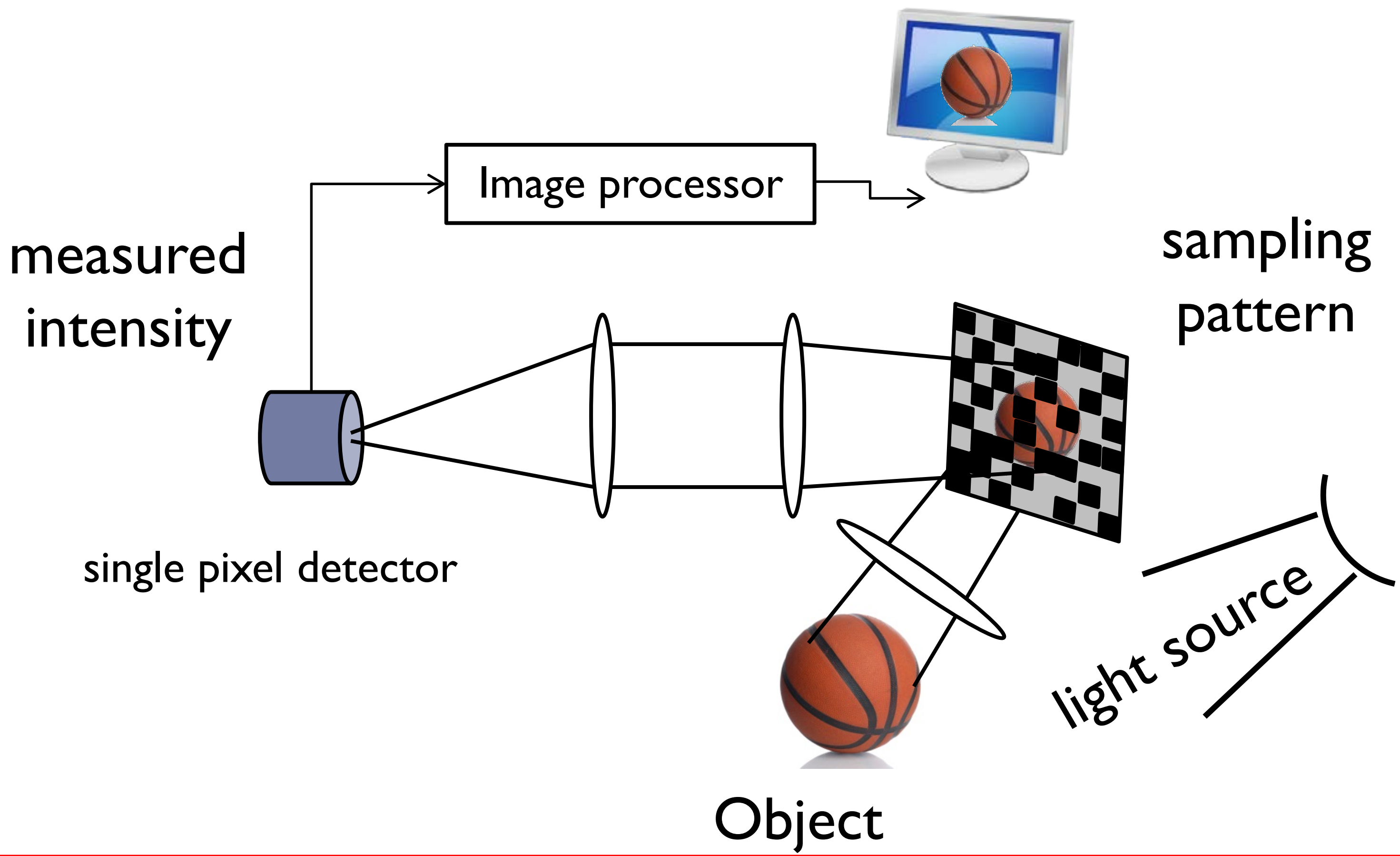


McCarthy et al. *Opt. Expr.* **21**, 8904 (2013)

Direct measurement of the scene. However, long integration times required

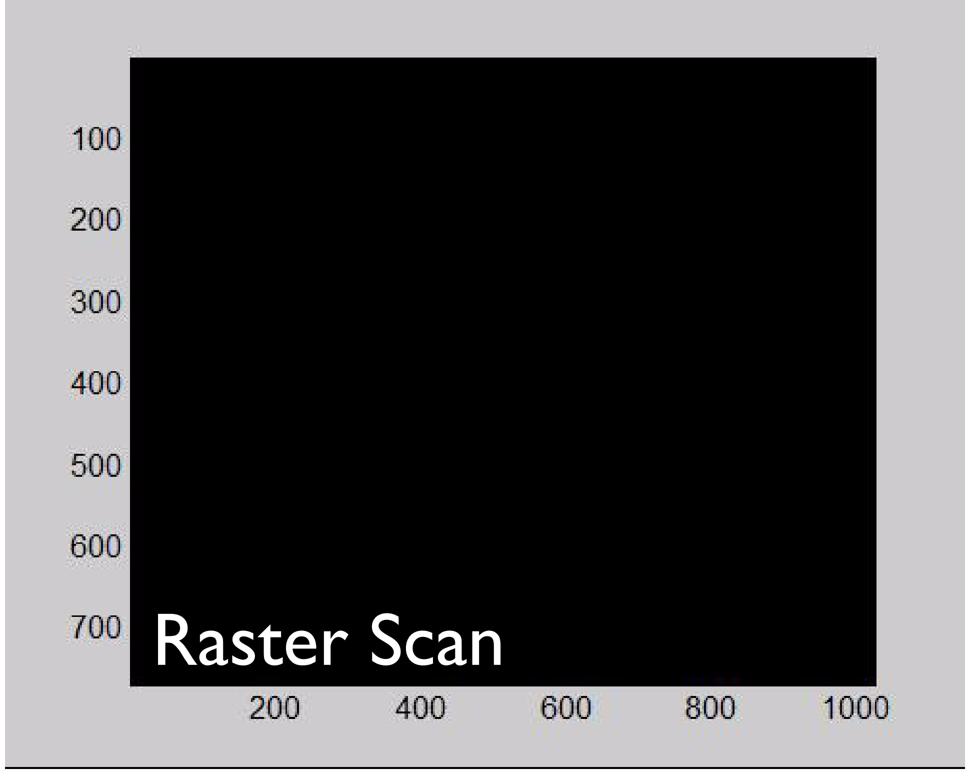
SINGLE PIXEL CAMERA

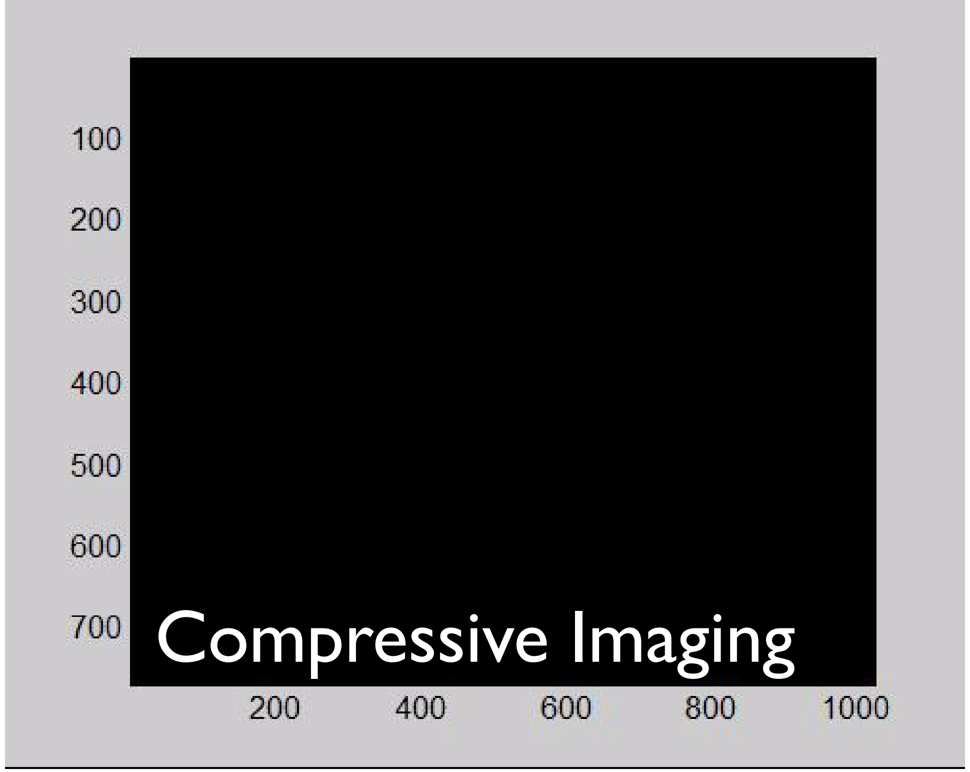
(VIA COMPRESSIVE IMAGING)



System receives a series of measurements with changing known sampling patterns

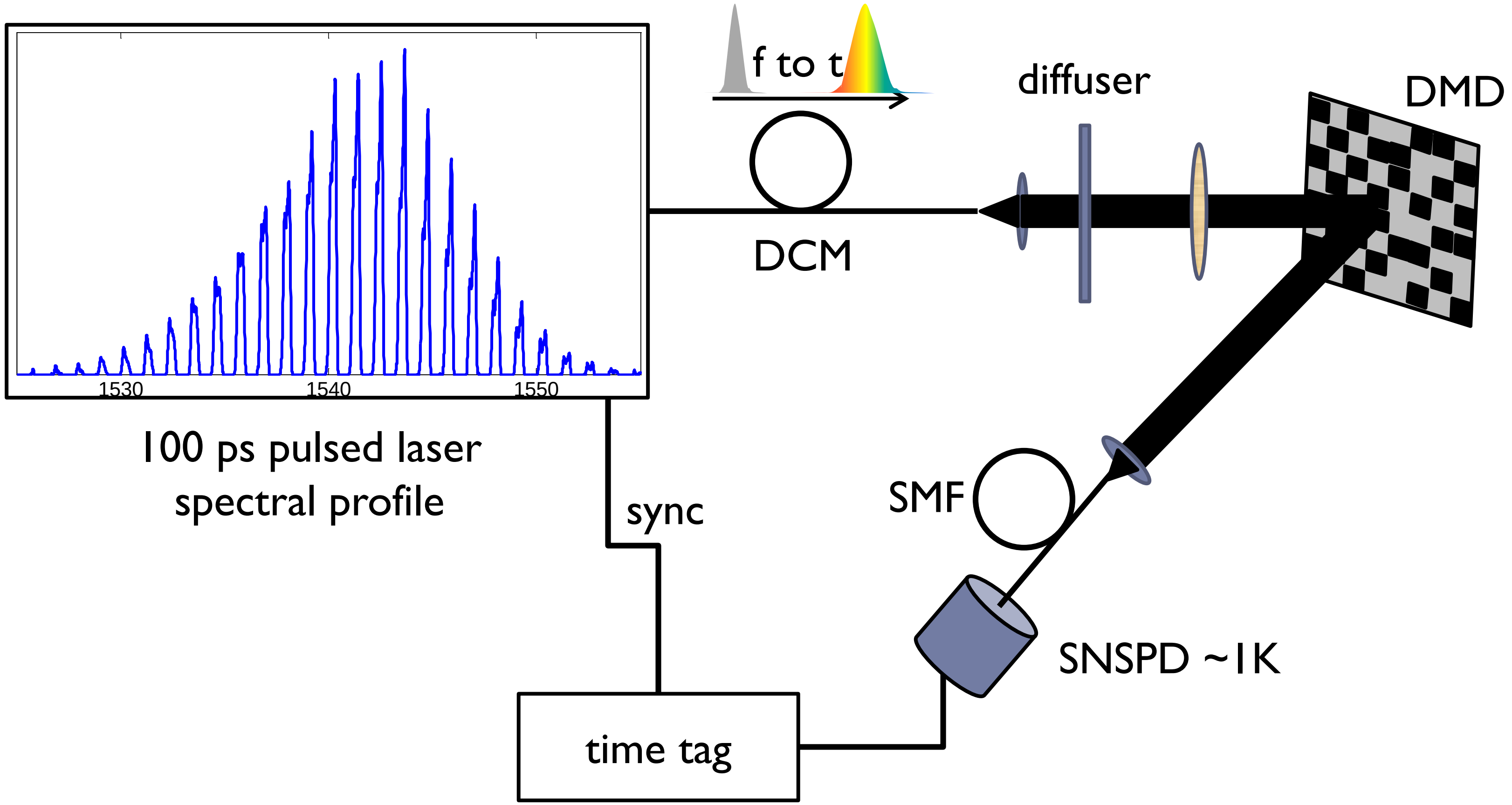
Raster Scan vs. Compressive Imaging





Compressive Imaging requires less measurements (M) compared to Raster Scanning, typically less than 10 percent.

SUB-NANOSECOND, TIME-RESOLVED IMAGING



Gerrits et al. *Opt. Expr.*, **26**, 15519 (2018)

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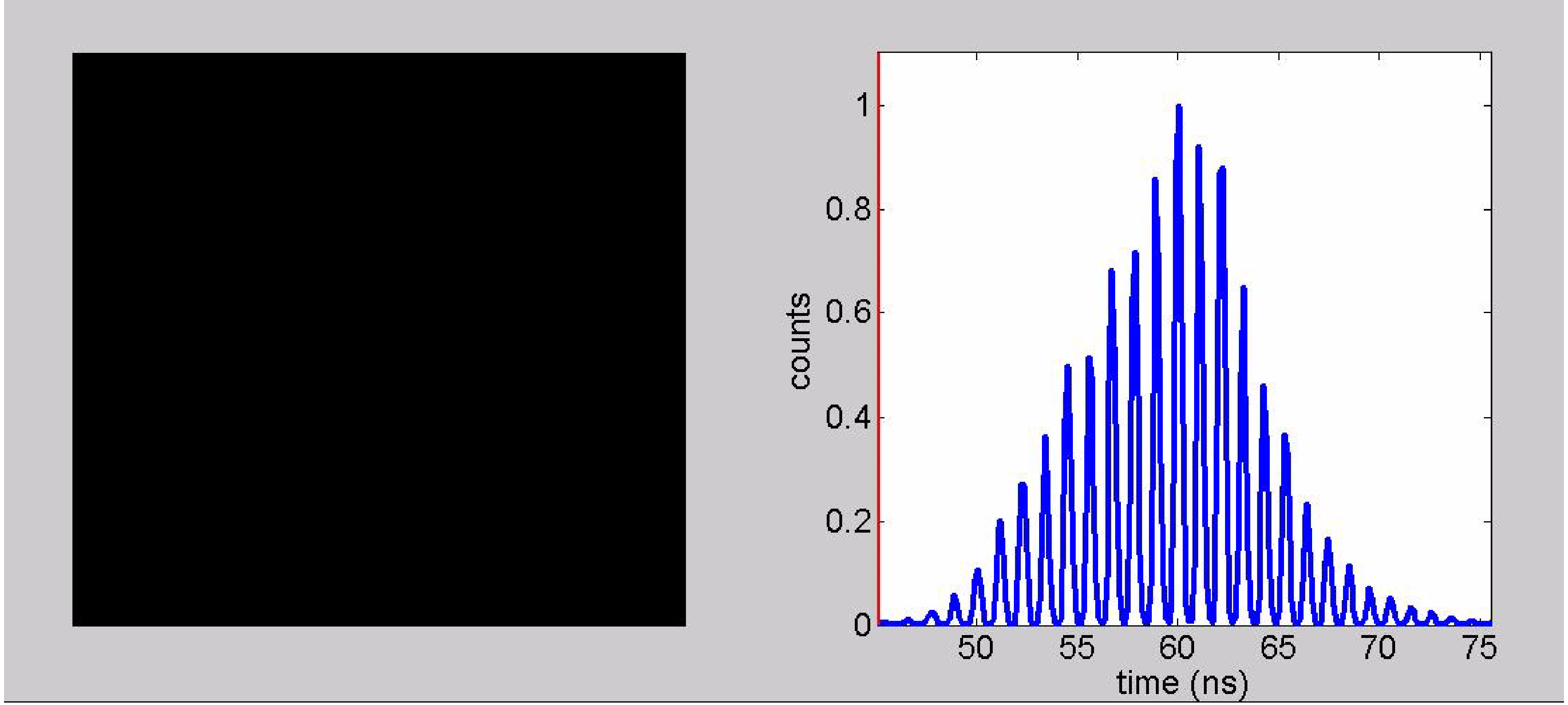
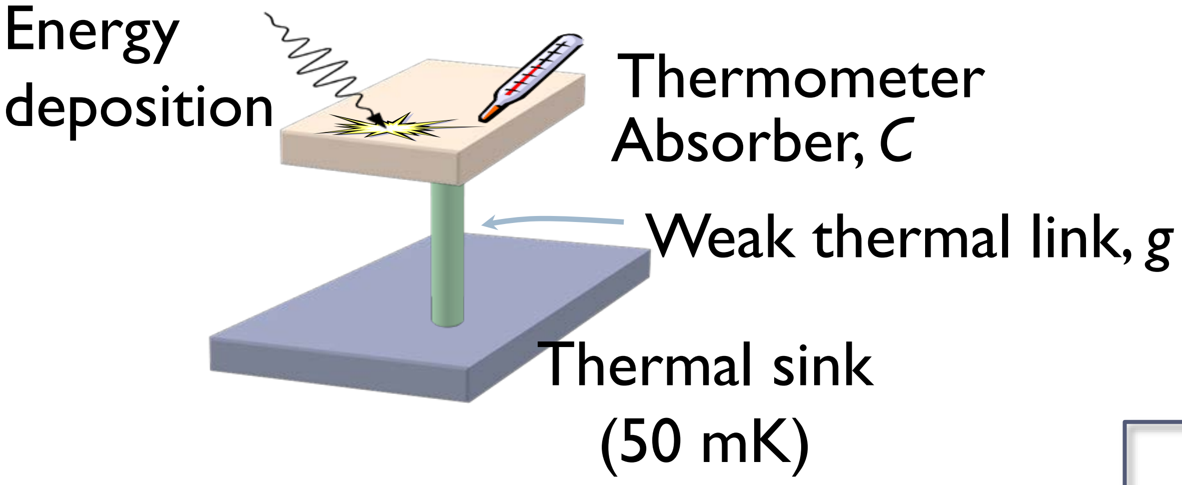


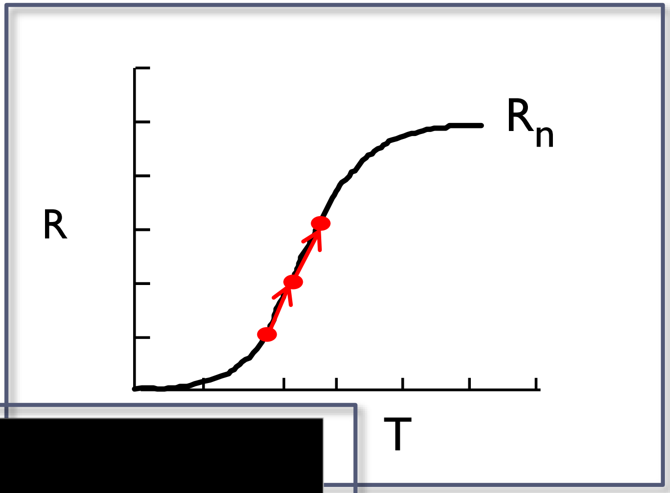
Gerrits et al. *Opt. Expr.*, **26**, 15519 (2018)

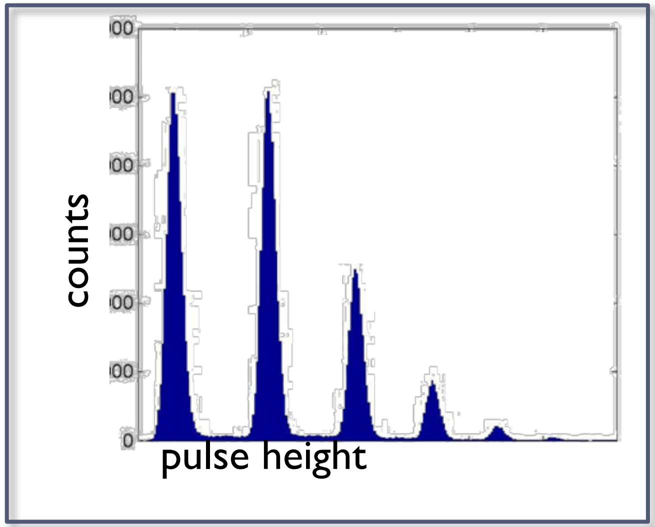
OVERVIEW

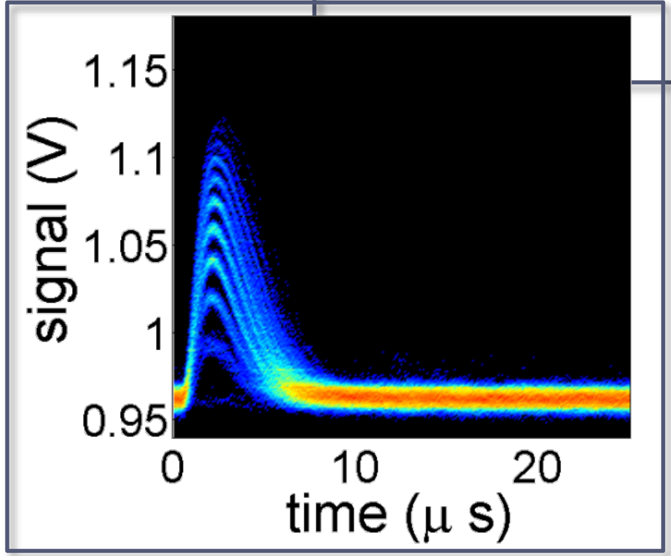
- Superconducting Nanowire Single Photon Detectors
- Compressive Imaging using SNSPDs
- Transition Edge Sensors
- Single photon detector calibration efforts at NIST

TRANSITION EDGE SENSOR









LARGE PHOTON NUMBER COUNTING

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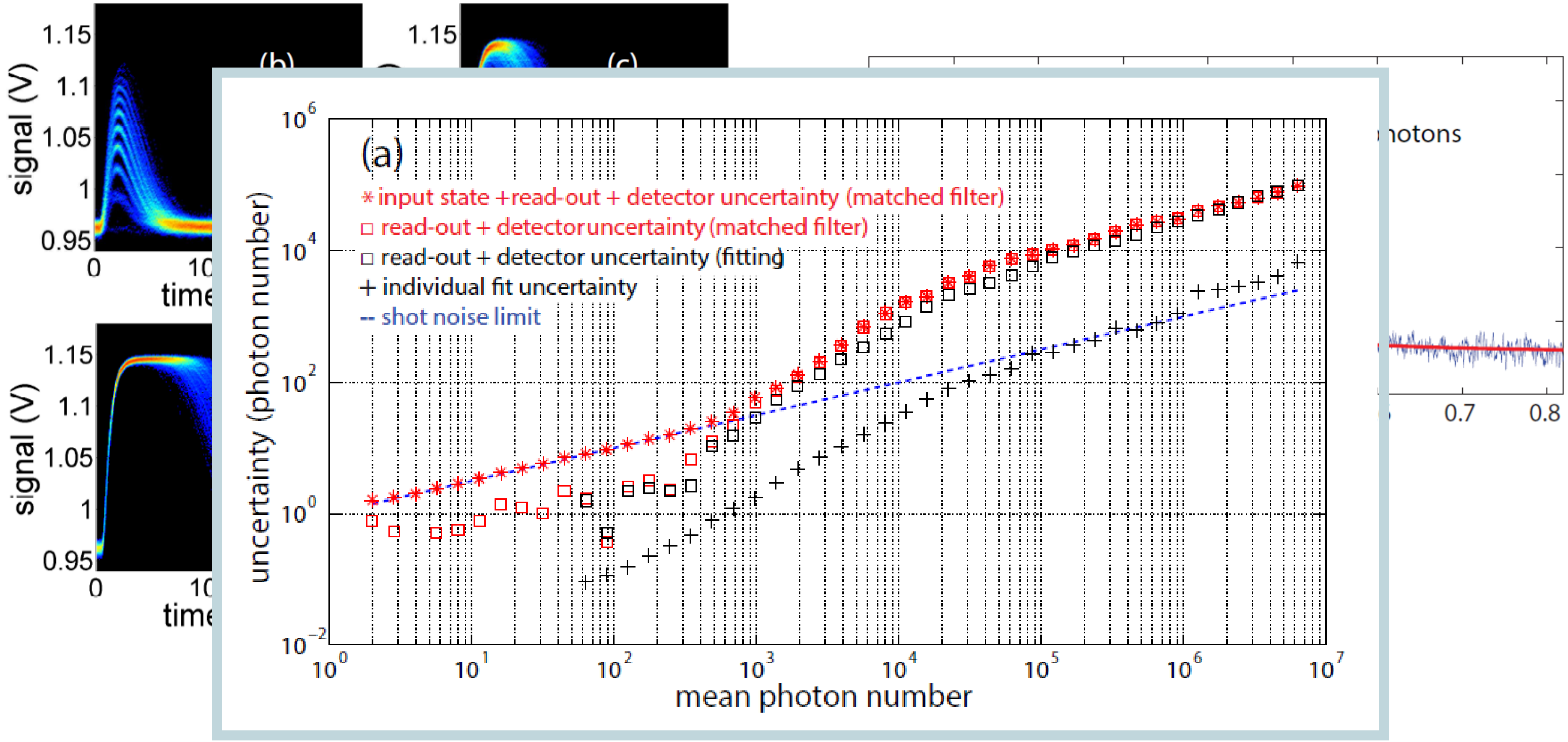
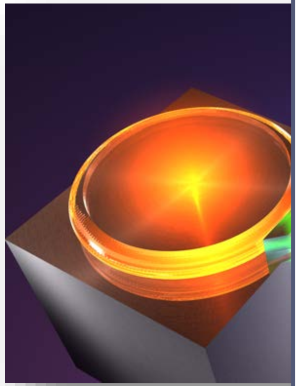
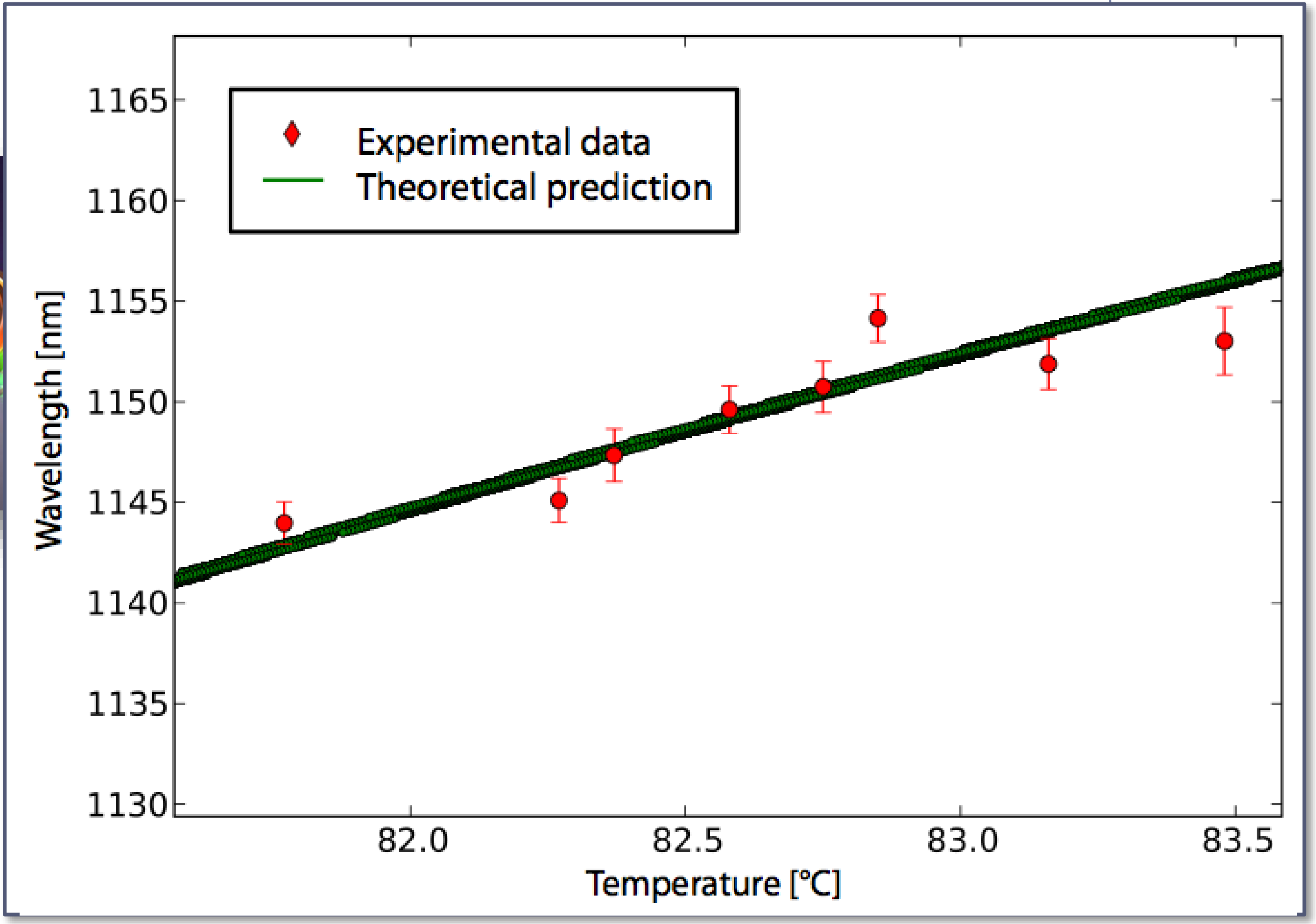


Gerrits et al., *Opt. Expr.* **20**, 23798 (2012)

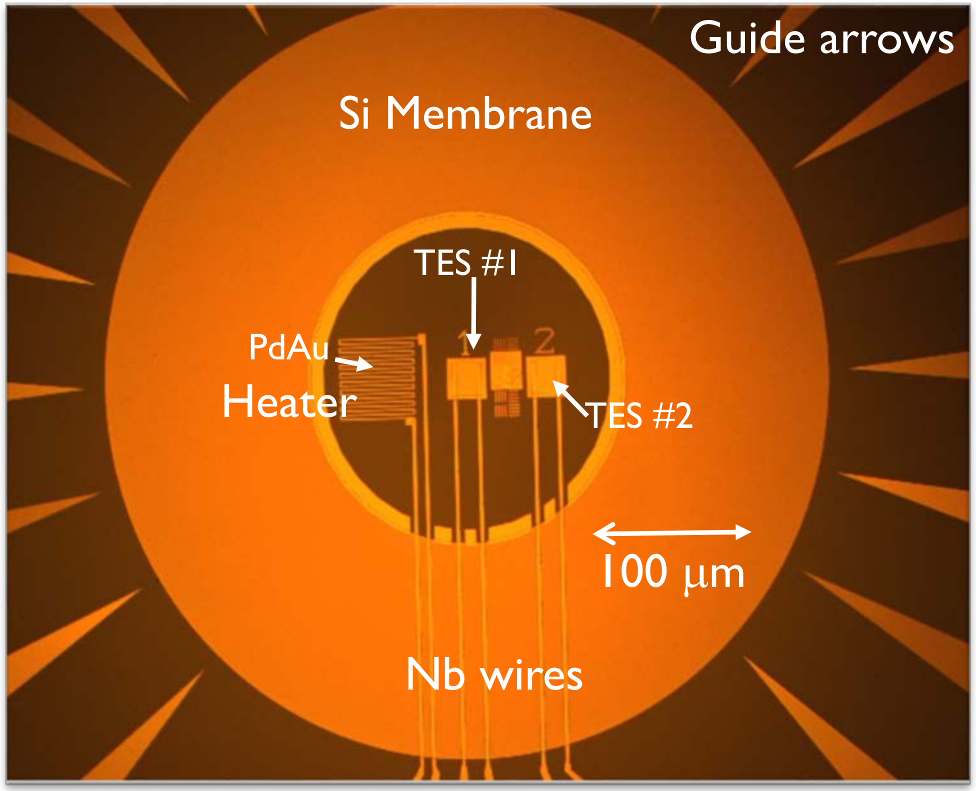
TES SPECTROMETER AND WGM RESONATORS

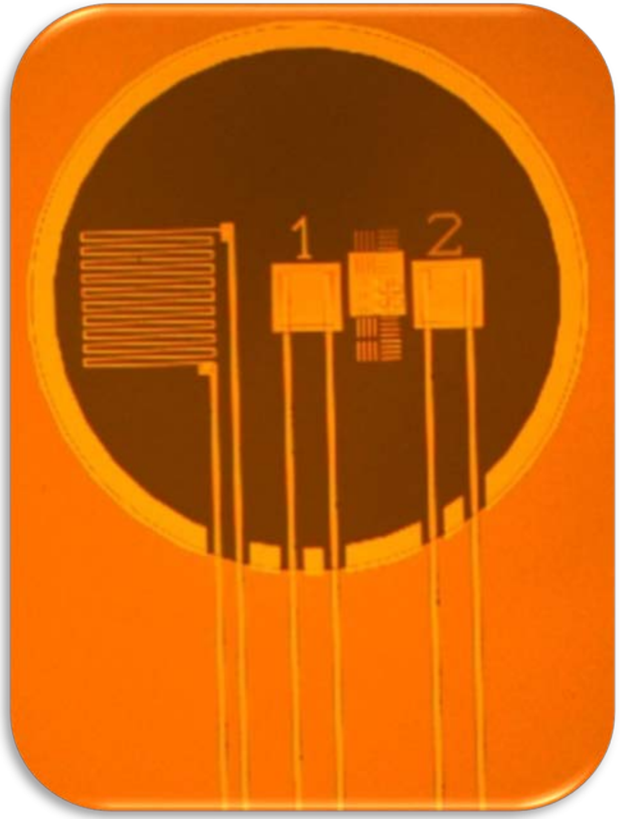




Förtsch, M. et al. J. Opt. ***17****, 065501 (2015)*

Electrical Substitution TES





Electrical substitution of up to 5 pW of optical power

Overview

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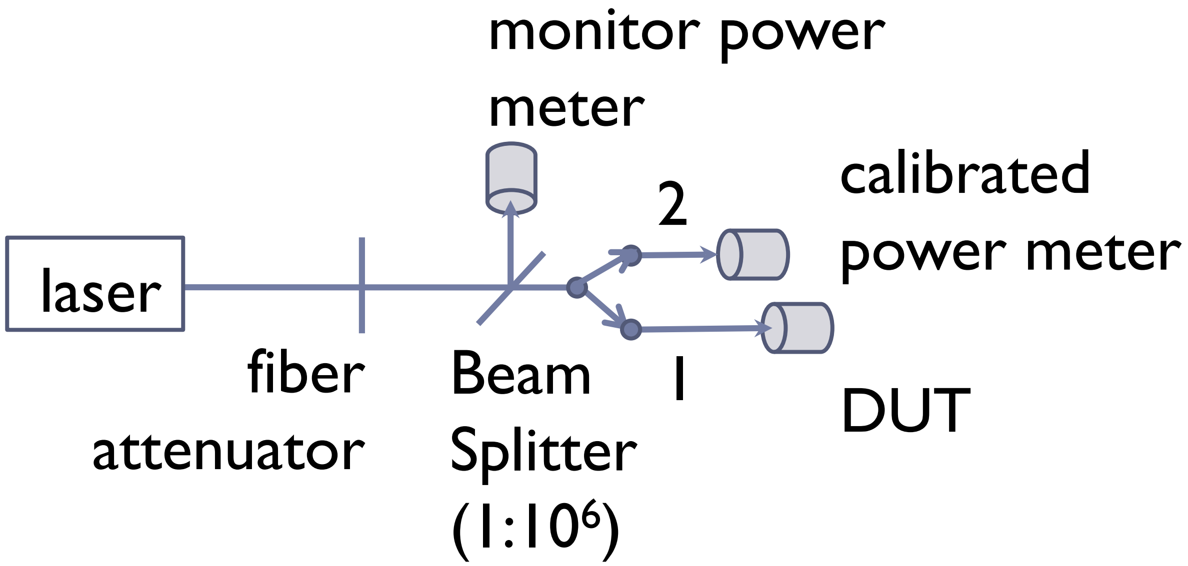
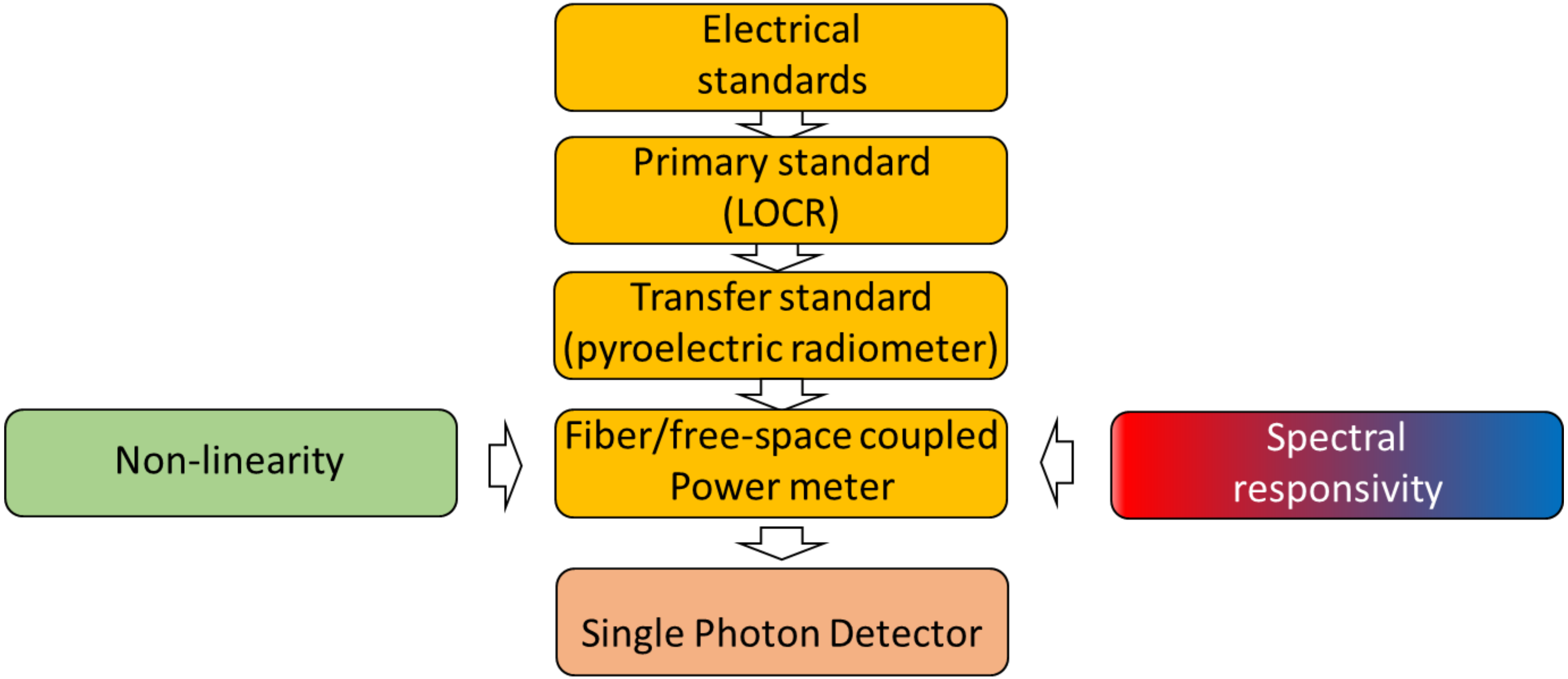
Beamsplitter calibration method



Free-space and fiber coupled at 850 nm and 1533 nm

NIST Single Photon Detector Calibration Chain



RESULTS

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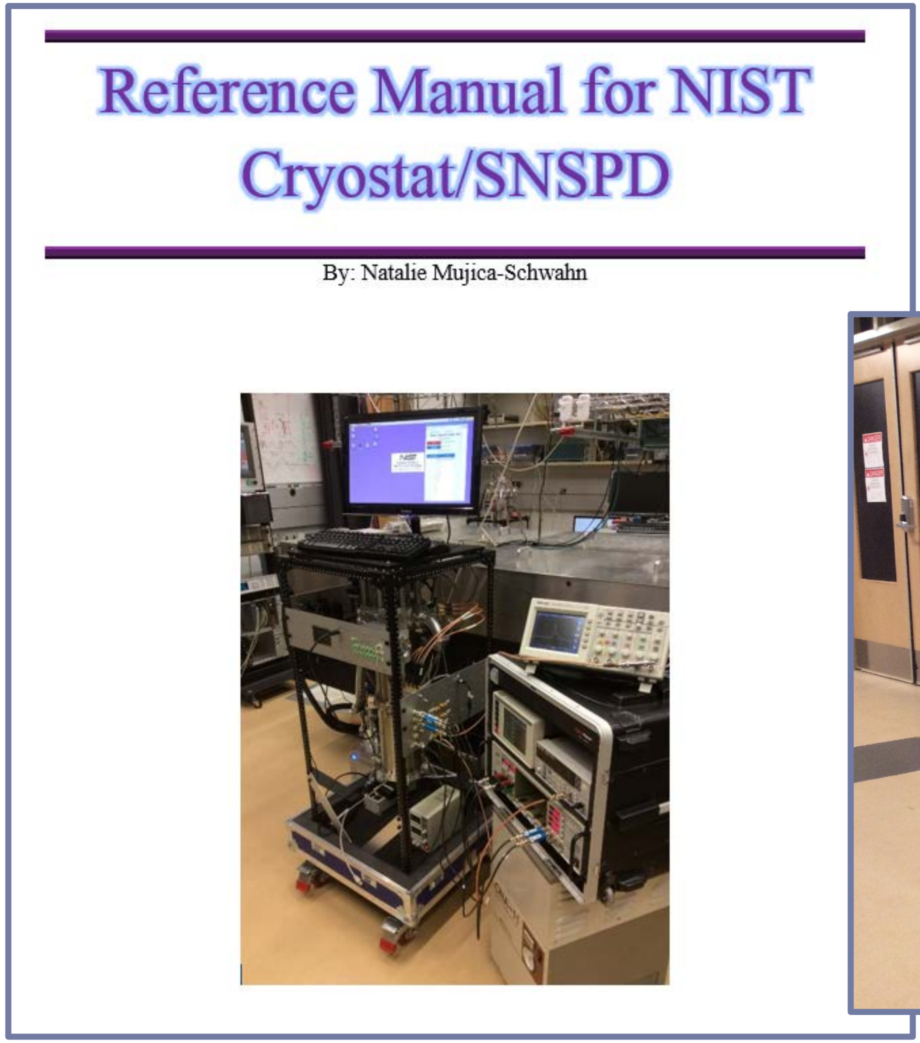
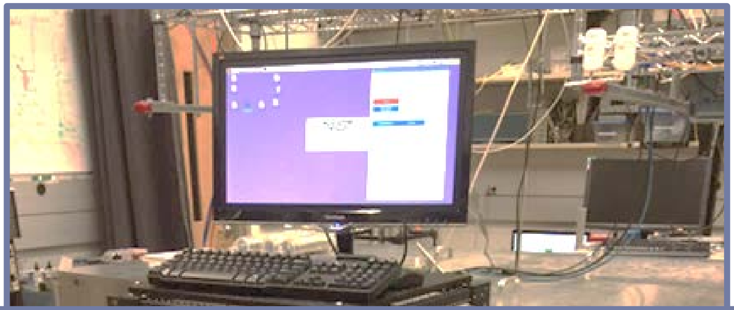
	Laser			Fiber-coupled							
detector	CW	Ti:Sa	Free-space	Direct fiber	connectorized	spliced	Wavelength (nm)	Measure-ments	DE at 10^5 cps	rel. standard type A unc.	rel. expanded combined unc.
NIST8103		x	x				850.76	5	0.5567	0.05 %	1.22 %
NIST8103	x		x				851.73	5	0.5547	0.27 %	1.33 %
V23172	x			x			851.73	4	0.6081	0.17 %	0.76 %
V23173	x			x			851.78	3	0.6036	0.26 %	0.82 %
PD9D	x					x	851.76	3	0.9176	0.19 %	0.78 %
NS233	x				x		1533.63	3	0.8921	0.13 %	0.52 %
NS233	x					x	1533.63	3	0.9237	0.12 %	0.50 %

Dedicated reference superconducting nanowire single photon detector system



Reference Manual for NIST Cryostat/SNSPD

By: Natalie Mujica-Schwahn



CONCLUSIONS

- Transition Edge Sensors are energy-resolving detectors with timing (spatial) resolution of ~100 ns (~30 m) and no dark counts
- Superconducting nanowire single photon detectors provide exquisite timing resolution, low dark count rate and high efficiency
- Imaging of sparse scenes with a single detector – potential for 3d, hyper- and multispectral imaging
- Calibration service establishment efforts underway at NIST for customers – free-space, fiber-coupled, afterpulsing, dark counts, blocking loss, etc