Physics and Applications of Superconducting Nanowire Single Photon Detectors 2018

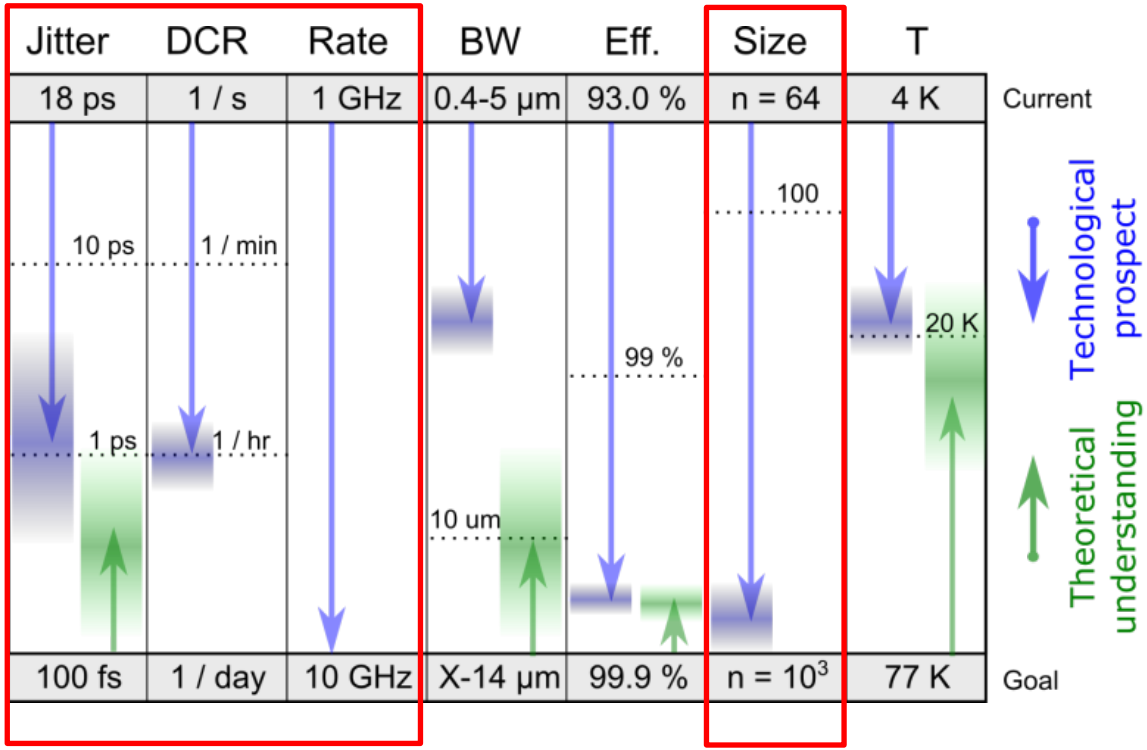
Experimental methods for studies of intrinsic jitter and latency in SNSPDs

B. A. Korzh[1], Q-Y. Zhao[2], S. Frasca[1], J. P. Allmaras[1,3], T. M. Autry[4], E. A. Bersin[1,2], M. Colangelo[2], C. Pena[3], N. Sinclair[3], S. Xie[3], G. M. Crouch[1], A. E. Dane[2], T. Gerrits[4], F. Marsili[1], G. Moody[4], E. Ramirez[1], J. D. Rezac[4], M. J. Stevens[4], E. E. Wollman[1], D. Zhu[2], P. D. Hale[4], K. L. Silverman[4], R. P. Mirin[4], M. Spiropulu[3], S. W. Nam[4], A. G. Kozorezov[5], M. D. Shaw[1] and K. K. Berggren[2]

[1]*Jet Propulsion Laboratory, California Institute of Technology, USA*
[2]*Massachusetts Institute of Technology, USA*
[3]*California Institute of Technology, USA*
[4]*National Institute of Standards and Technology, USA*
[5]*Lancaster University, UK*

Jet Propulsion Laboratory
California Institute of Technology

DETECT Project: Detector metric goals



Focused metrics in tasks

- Begin by studying individual metrics
  - Enables better understanding of fundamental limits

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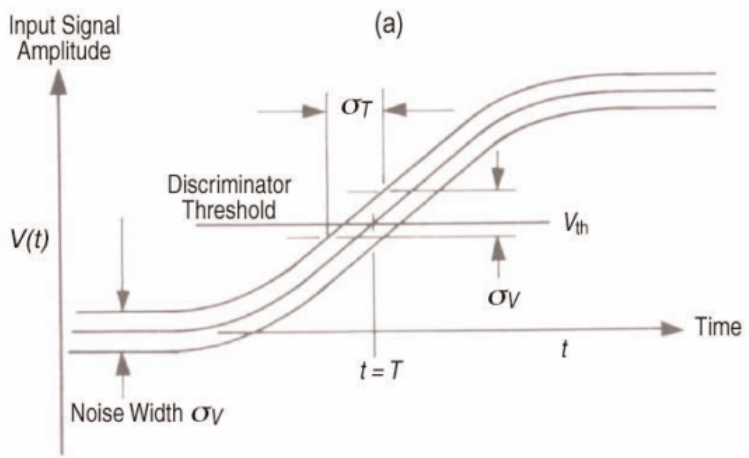
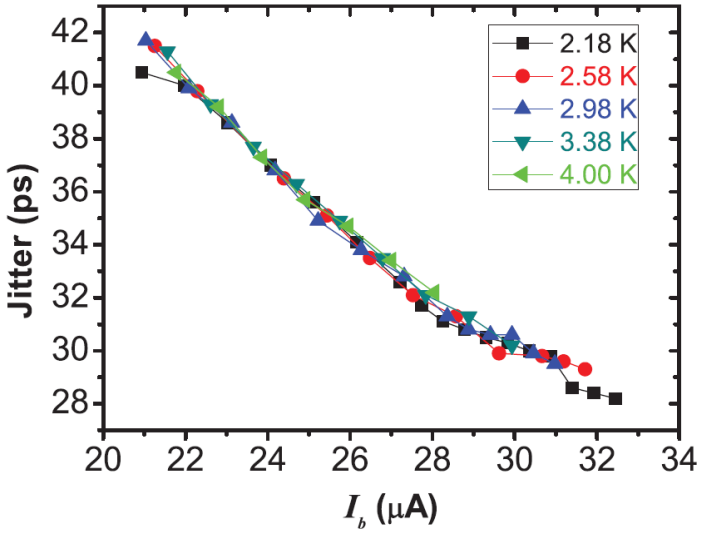
Electrical noise contribution



$$\sigma_T = \frac{\sigma_T}{Slope}$$

$$Slope \propto I_b$$



You et al, *AIP Advances* **3**, 072135 (2013)

- When limited by amplifier noise
  - Jitter is inversely proportional on current
  - Independent of temperature

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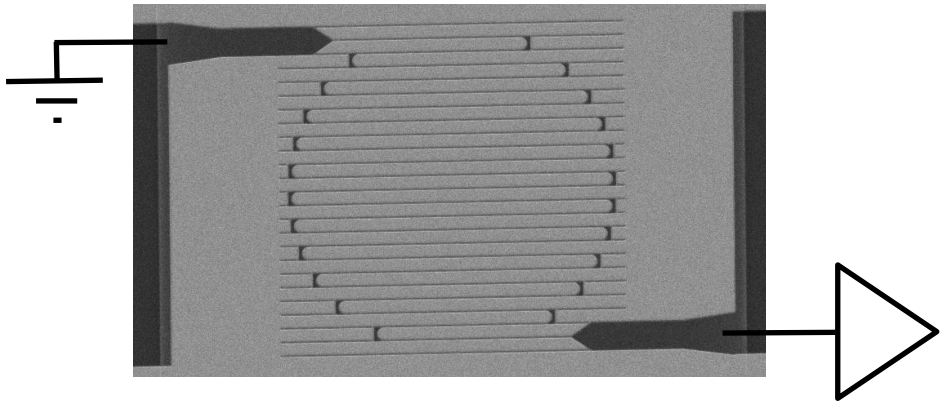
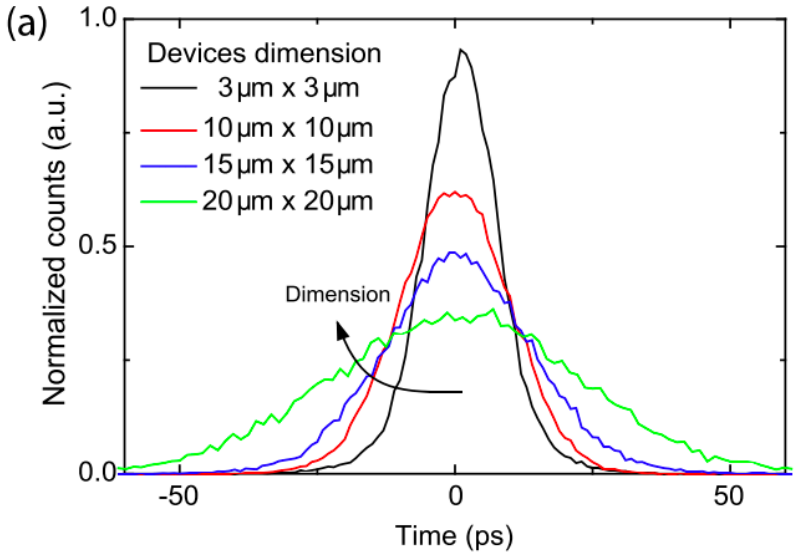
Geometric contribution





- SNSPD acts as a high impedance transmission line up to mm in length
  - Slow propagation due to high inductivity
- Longitudinal position of photon arrival is relevant contribution to jitter

Calandri et al, *Appl. Phys. Lett.* **109**, 152601 (2016).
Zhao et al, *Nat. Photonics* **11**, 247 (2017).

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Contributions to timing jitter in SNSPDs

Instrumental

- Amplifier Noise
- Geometric jitter
- Input pulse width, chromatic and modal dispersion
- Residual uncertainty in timing electronics

Intrinsic

- Transverse position of photon absorption
- Fluctuations in the energy conversion from photon to cooper pair breaking
- Vortex crossing

?

Previously not accessible experimentally

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Previous State of the art

2196 Vol. 56, No. 8 / March 10 2017 / *Applied Optics* Research Article

Table 1. Reported Device Characteristics and Jitter Measurements

Switching Current (μA)[a]	Rising Time (ps)	Optical Coupling	Amplifier	Maximum Rising Edge Slope (mV/ps)[b]	System Jitter (ps)	Reference
24–30	100	free space	40 db gain, 18 GHz, RT[c]	1.1	18	MSPU 2005
24–30	250	SMF[d]	4 GHz, RT	–	37	MSPU 2007
24–30	–	MMF[e]	4 GHz, RT	–	58	MSPU 2007
44.5	469	SMF	20 db gain, 4 GHz, RT	0.57	24.5	Nanjing 2011
17.0	514	SMF	20 db gain, 4 GHz, RT	0.15	37.6	Nanjing 2011
28	250	waveguide	Picosecond Labs 5828, RT	1.8	18.4	Yale 2012
70	700	SMF	RF Bay LNA 650, RT	1.6	18	SIMIT 2013
45	–	SMF	40 db gain, RT	–	17.8	MSPU 2016
–	–	SMF	operating at 30 K	–	14.80	Single Quantum 2016

- Time resolution below ~15 ps has been very difficult to achieve

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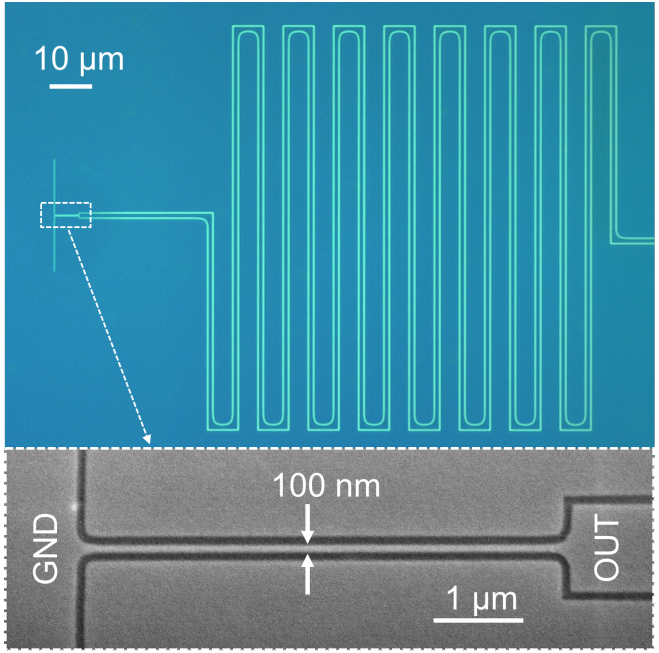
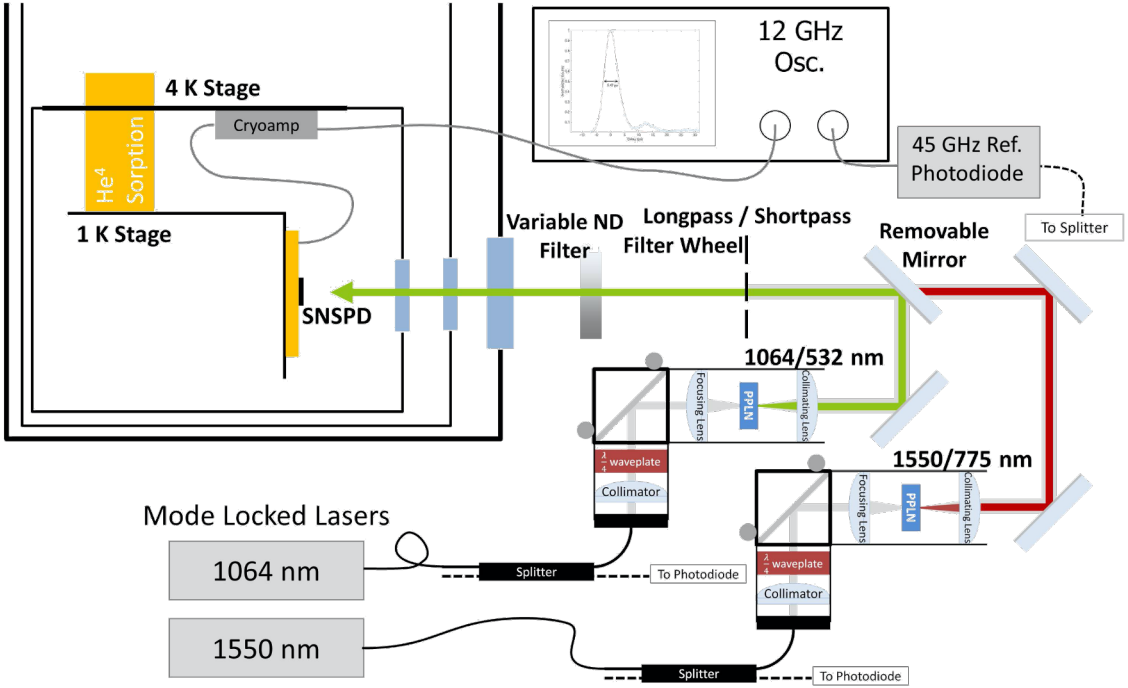
Measurement setup





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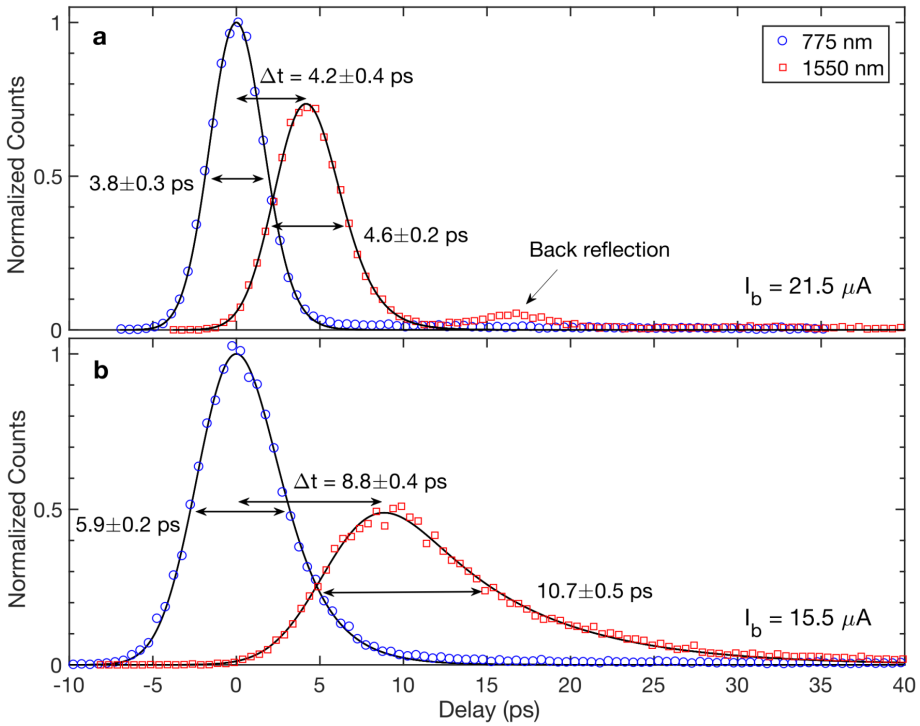
Temporal jitter and latency



Lower energy photons result in **larger detection delays**

Delay increases with lower bias current

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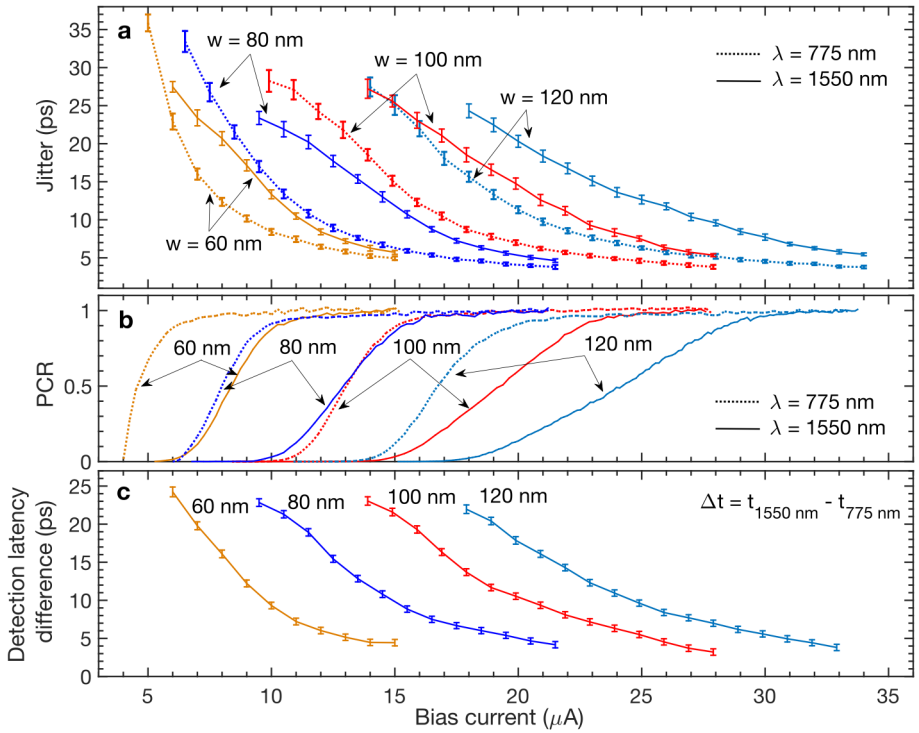
Latency difference



- Change in latency is closely related to the jitter
- **Characterization of latency is the key to understanding of jitter**

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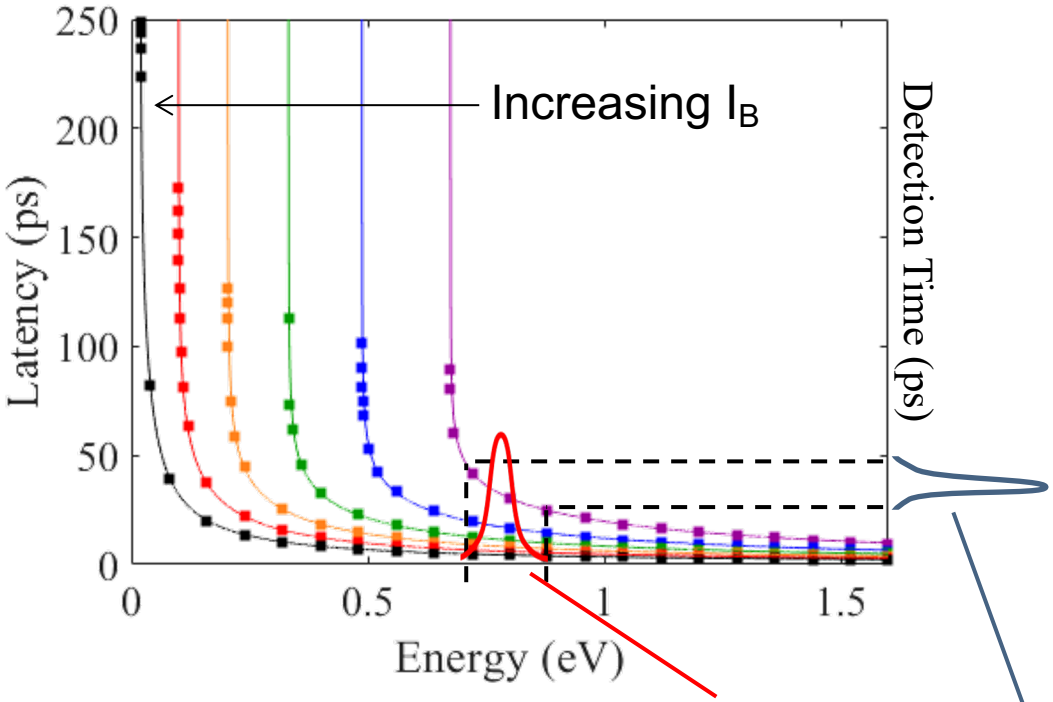
Latency linked to jitter



Fluctuations in energy lead to fluctuations in detection time (jitter)

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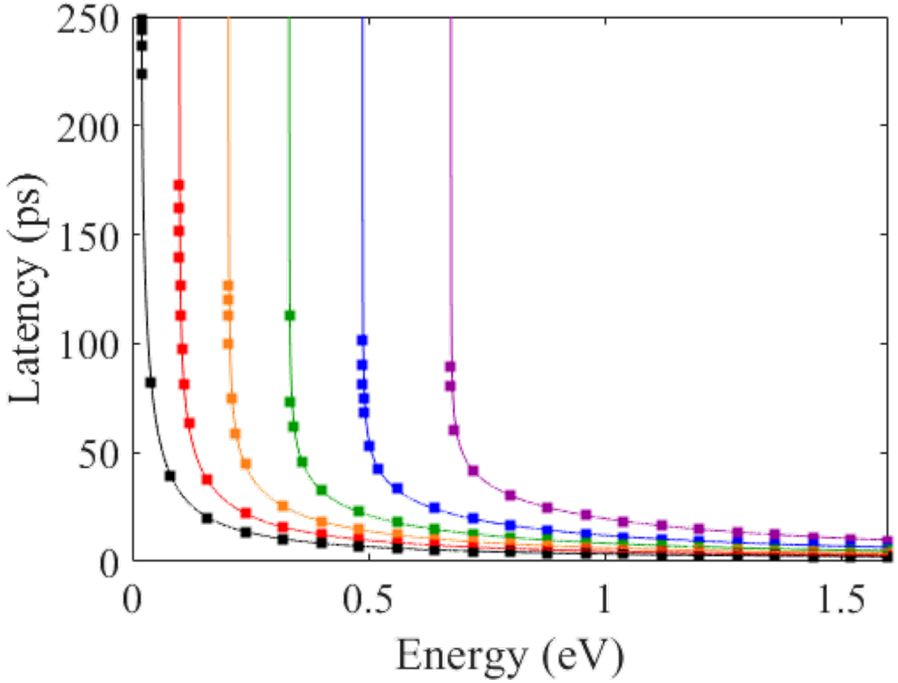
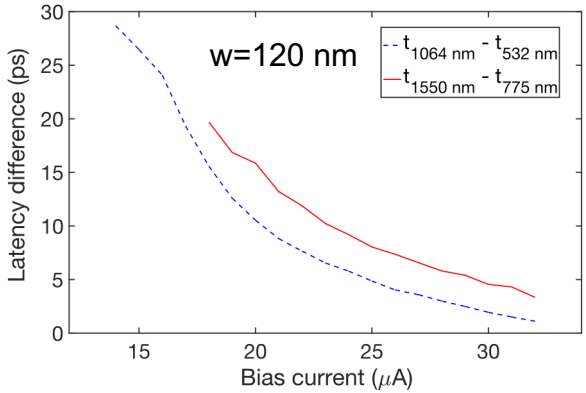
Latency functional form





- Higher photon energy photon pair
  - Lower latencies
- **Positive curvature** of latency vs. energy curve → agrees with theory

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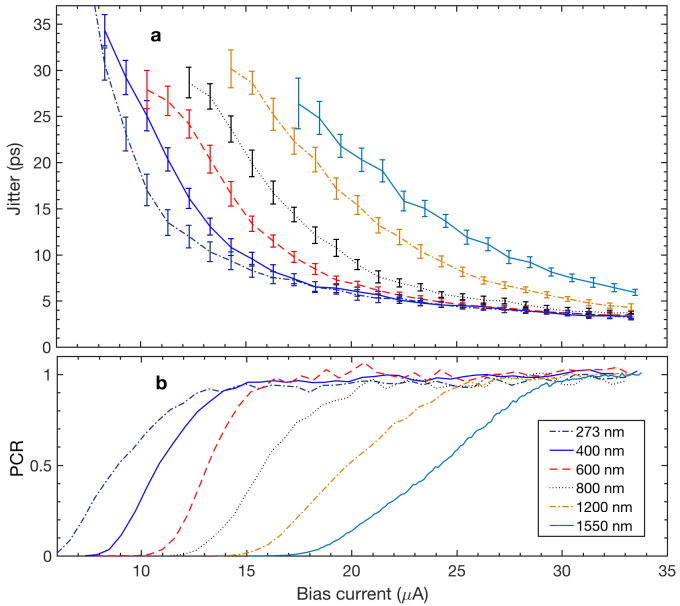
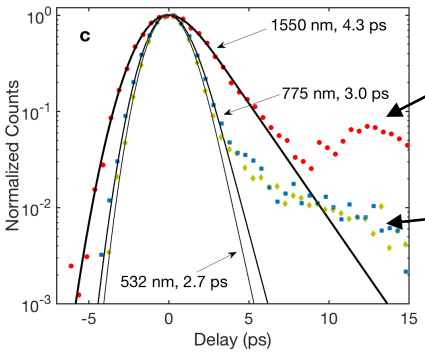
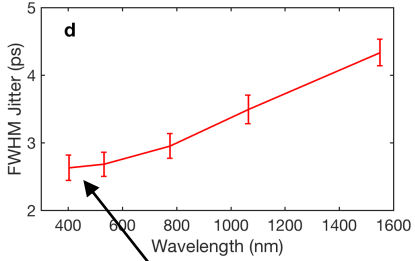
Timing jitter: towards differential architecture



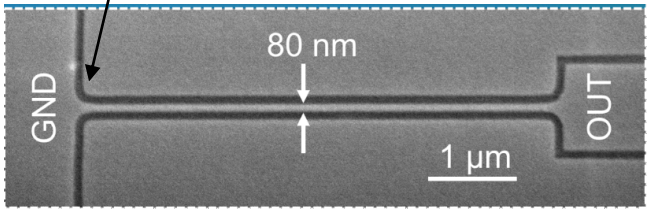




Bump due to reflection from back of wafer

Tail due to detections in wider sections

- Future designs should avoid detections in bends and tapers

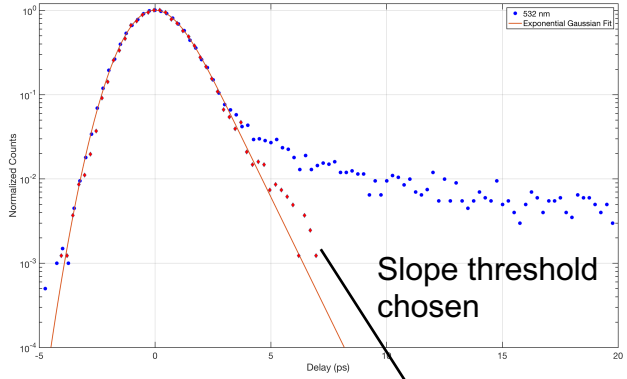


Saturation due to instrumental jitter?

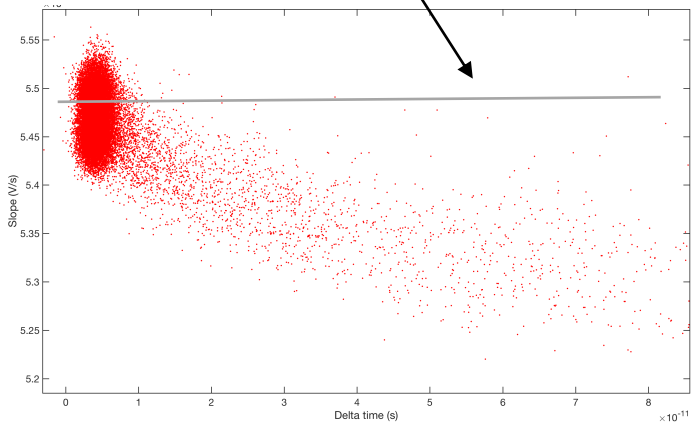
Korzh et al, arXiv:1804.06839

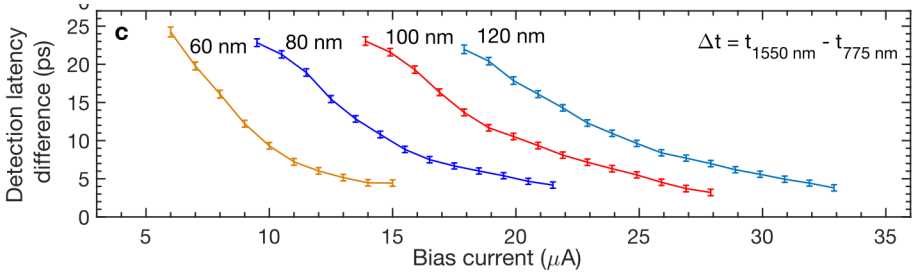
Allmaras et al. arXiv:1805.00130

Tail event removal



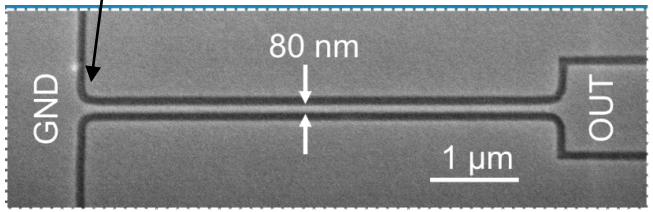
Slope threshold chosen





Wide section detections lead to a lower resistance

- Slew rate is lower
- Can be used to “postselect” detections in nanowire only



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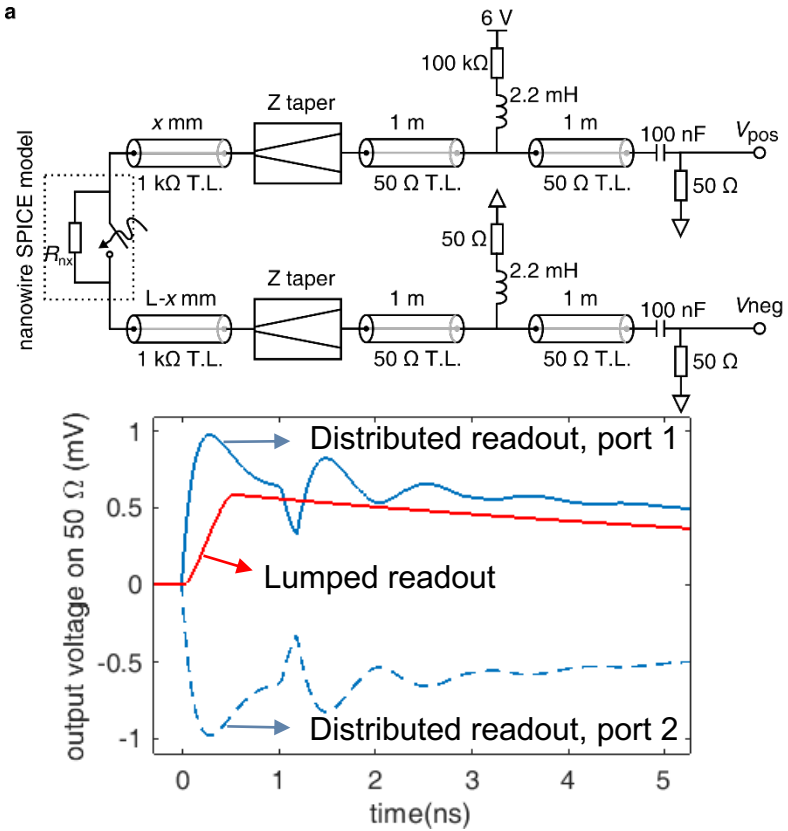
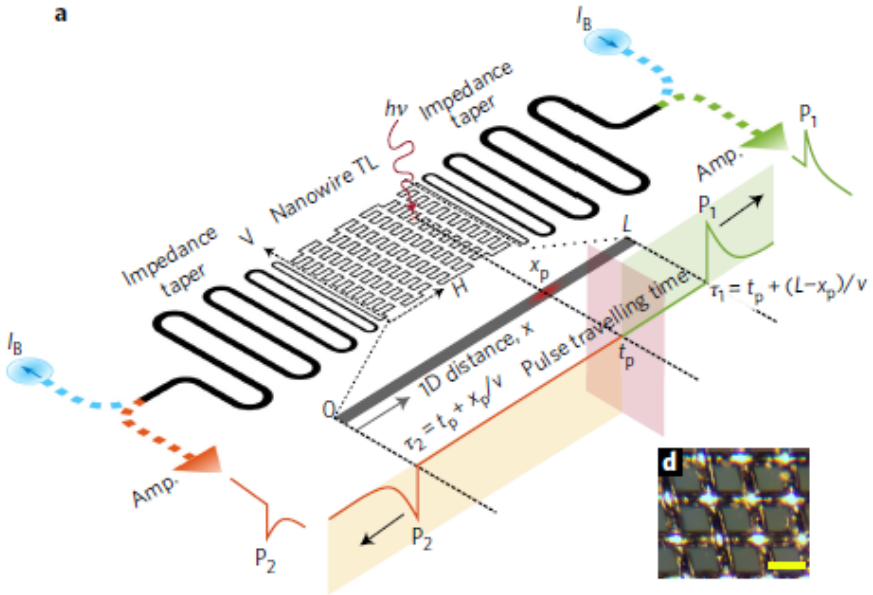
Scaling to larger areas: Differential readout





Calandri et al, *Appl. Phys. Lett.* **109**, 152601 (2016)
Zhao et al, *Nat. Photonics* **11**, 247 (2017)

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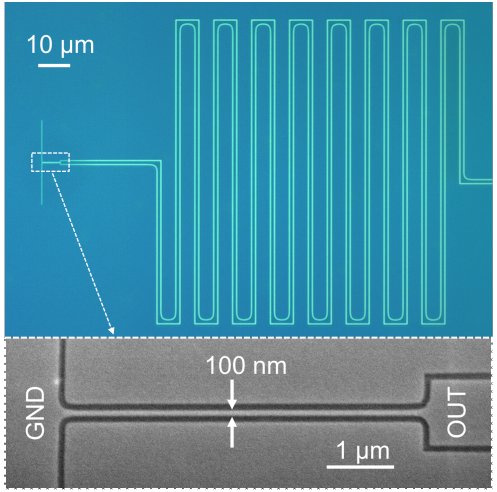
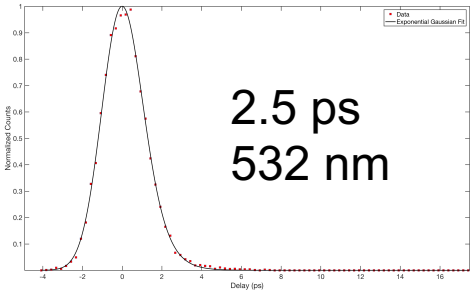
Summary





- Minimized noise through use of cryogenic amplifier (4 Kelvin)
- Reduced geometric jitter with short nanowires
- Reduction by a factor of 3 over previous record
- Evidence of intrinsic jitter and latency
- Good platform for studying detection mechanism
- Avoid detections in bends and tapering sections

Korzh et al, arXiv:1804.06839

Allmaras et al. arXiv:1805.00130

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