Single Photon Workshop 2017

Single photon detection with a system temporal resolution below 10 ps

Boris Korzh[1], Qing-Yuan Zhao[2], Simone Frasca[1], Emma Wollman[1], Marco Colangelo[2], Andrew E. Dane[2], Peter Day[1], Karl K. Berggren[2] and Matthew Shaw[1]

[1]*Jet Propulsion Laboratory*

[2]*Massachusetts Institute of Technology*

Jet Propulsion Laboratory
California Institute of Technology

Previous State of the art

- Until now, timing jitter in SNSPDs has been limited by instrumental mechanisms
- Time resolution below ~15 ps has been very difficult to achieve
- Physics of intrinsic SNSPD jitter mechanism has not been accessible

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	–	14.8	Single Quantum 2016

Copyright 2017. All rights reserved.

Contributions to timing jitter in SNSPDs

Instrumental

- Amplifier Noise
- Geometric jitter (longitudinal position of photon absorption)
- Input pulse width, chromatic and modal dispersion
- Residual uncertainty in timing electronics

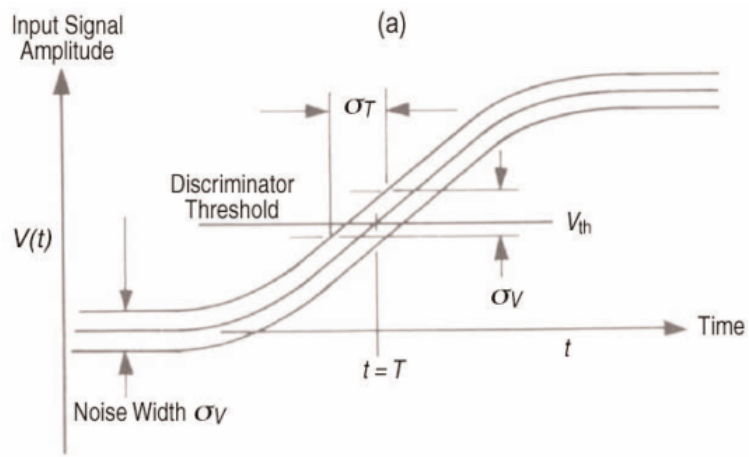
Intrinsic

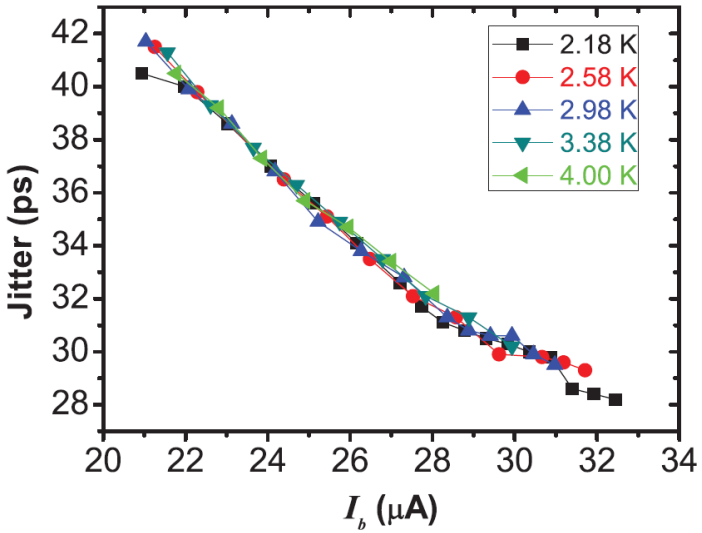
- Transverse position of photon absorption
- Fluctuations in the energy down-conversion process
- Fluctuations and energy dependence in gap suppression time
- Spatial variation in energy gap along nanowire

Copyright 2017. All rights reserved.

Electrical noise contribution

When limited by amplifier noise, jitter scales linearly and is independent of temperature

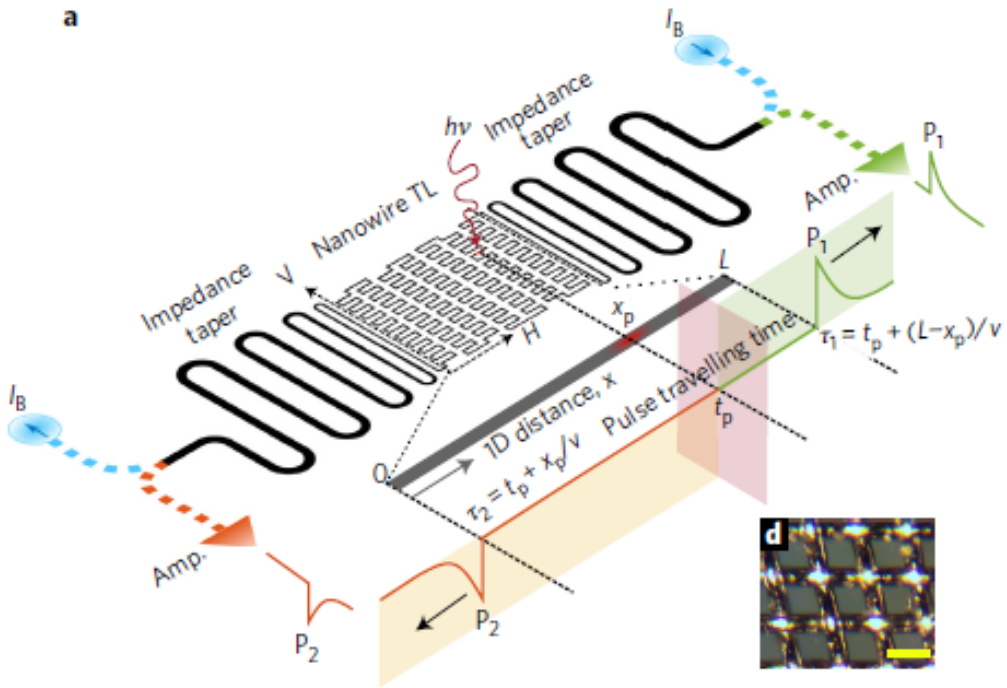




L.X. You et al (2013)

Copyright 2017. All rights reserved.

Geometric contribution

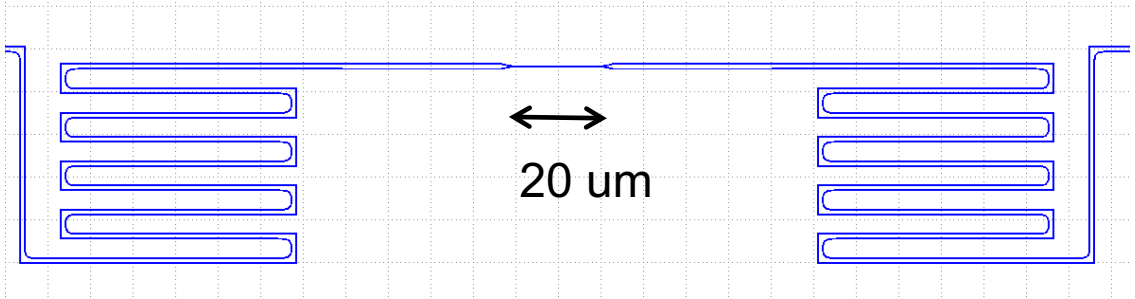


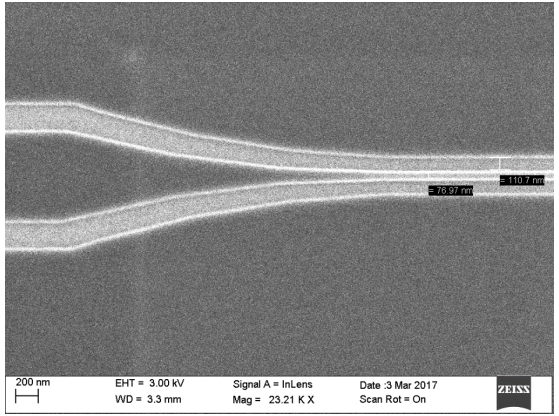
N. Calandri et al, Appl. Phys. Lett. **109**, 152601 (2016).
Q-Y. Zhao et al, Nat. Photonics **11**, 247 (2017).

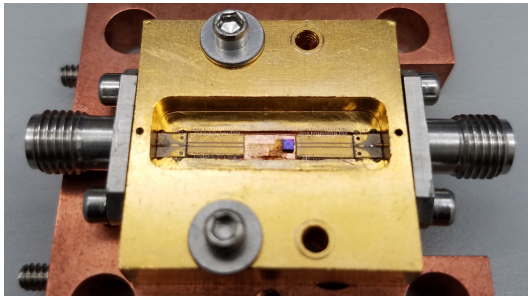
- SNSPD acts as a high impedance transmission line up to mm in length
- Speed of light can be ~0.02c (6 μm / ps) along meander
- Longitudinal position of photon arrival is relevant contribution to jitter
- By using a differential readout, we can circumvent this tradeoff between active area and timing jitter

Copyright 2017. All rights reserved.

Low jitter device



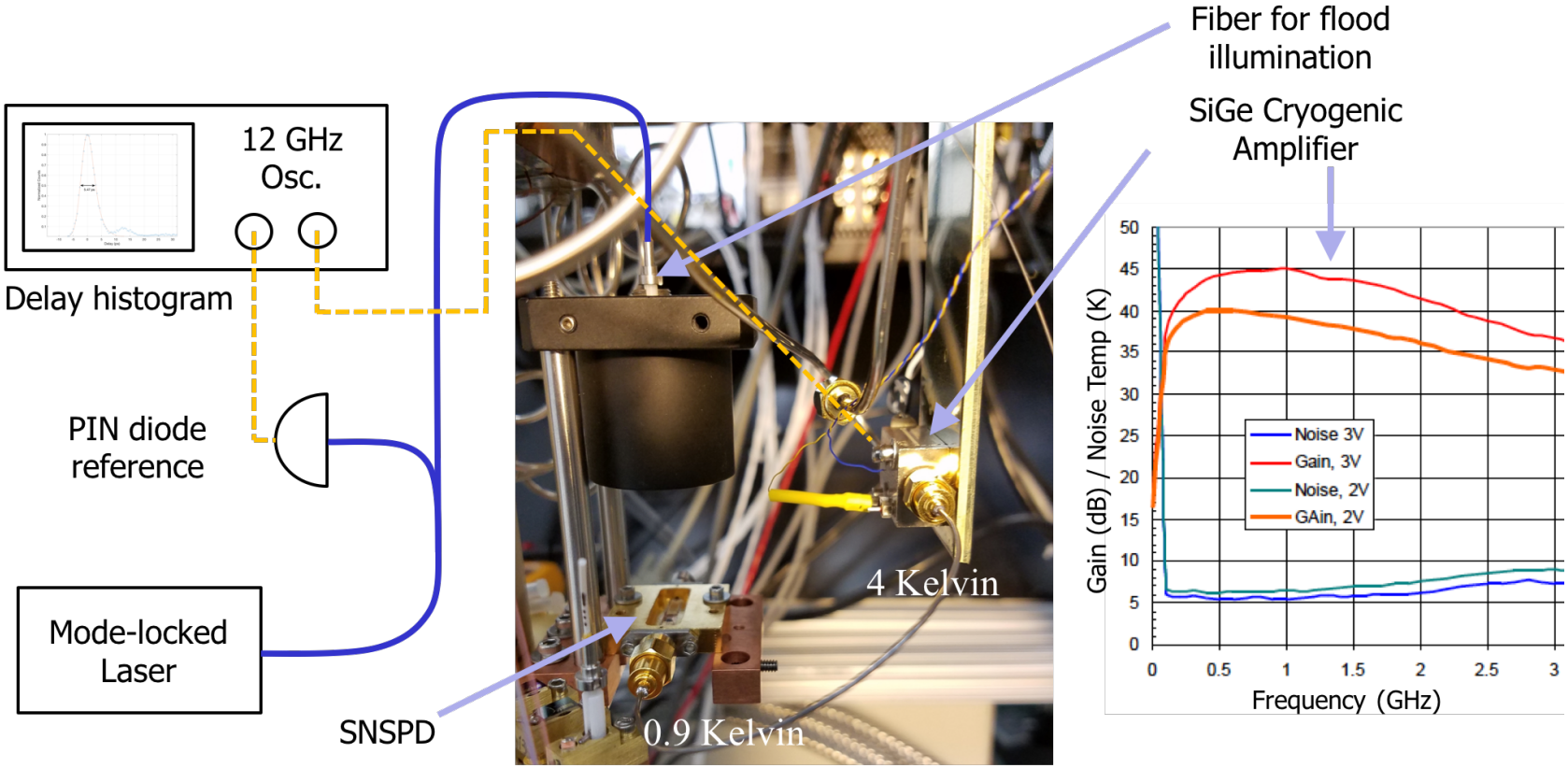




- Short structure to reduce geometric jitter (~3 ps)
- NbN material for high switching current
- Ultra-low jitter nanowire fabricated at MIT and tested at JPL

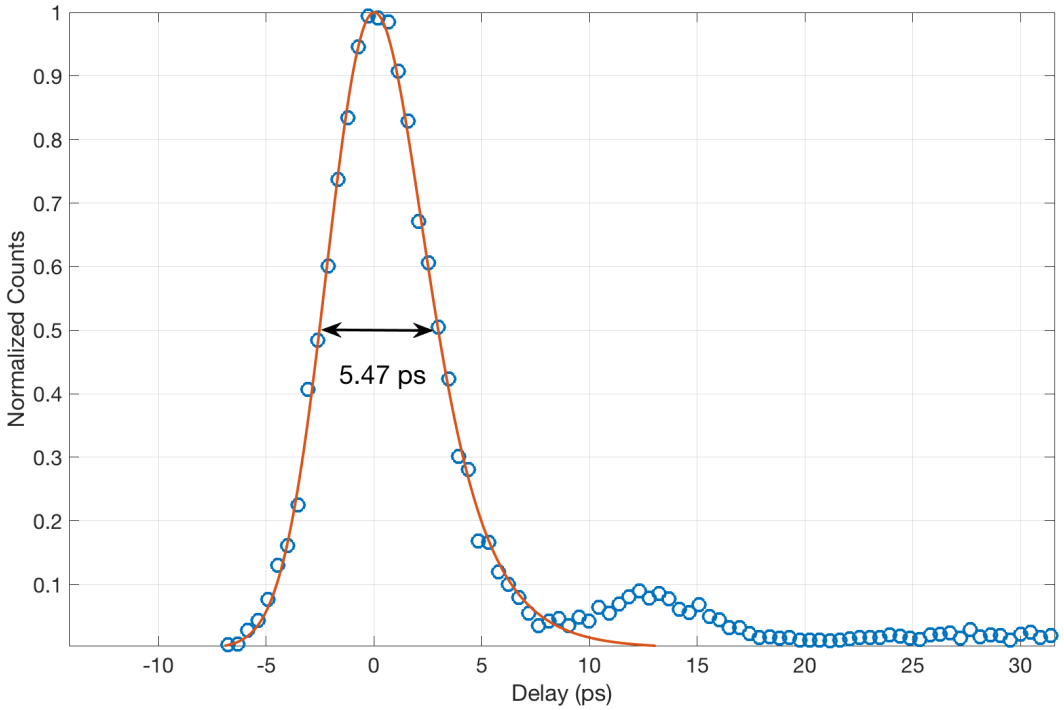
Copyright 2017. All rights reserved.

Measurement setup



Copyright 2017. All rights reserved.

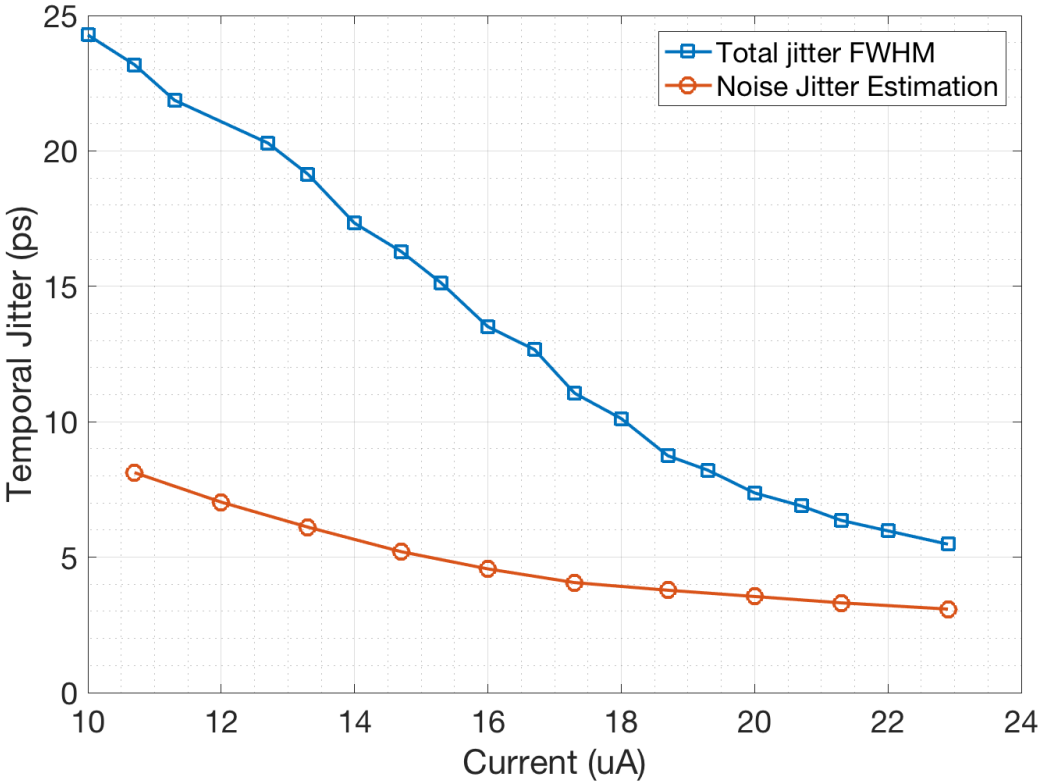
5 ps system temporal jitter



- 1550 nm characterization wavelength
- Reduction by a factor of 3 over previous record

Copyright 2017. All rights reserved.

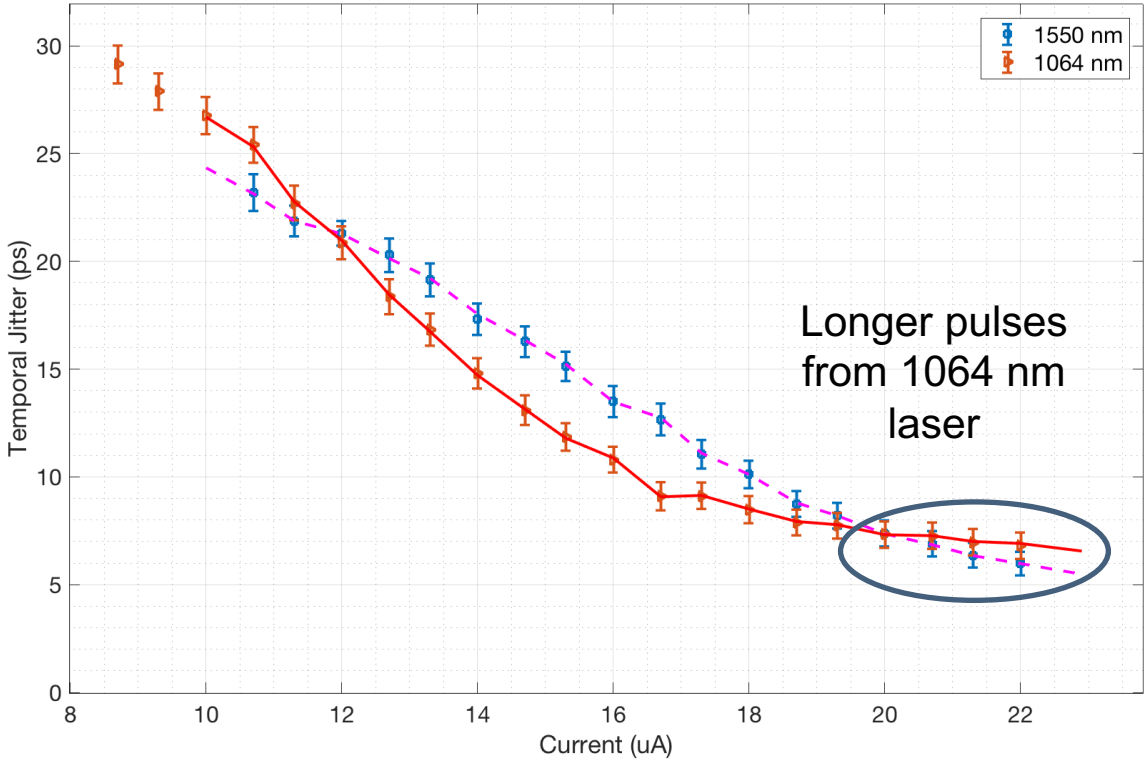
Jitter not limited by noise



- Approaching limits due to amplifier noise, geometric jitter, and pulse dispersion
- Lowest jitter likely not limited by intrinsic mechanisms

Copyright 2017. All rights reserved.

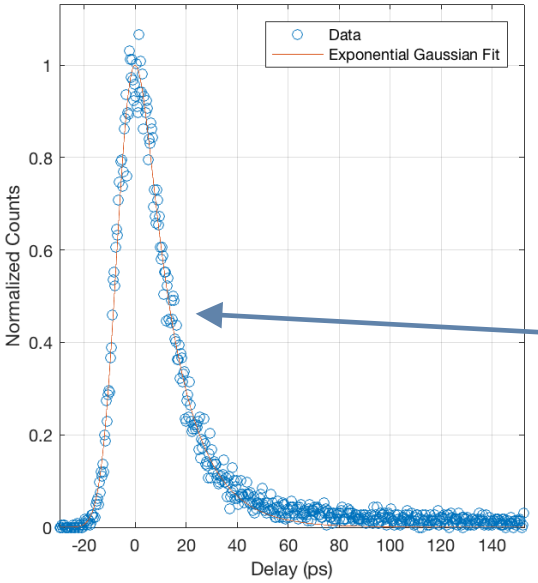
Evidence of energy dependence

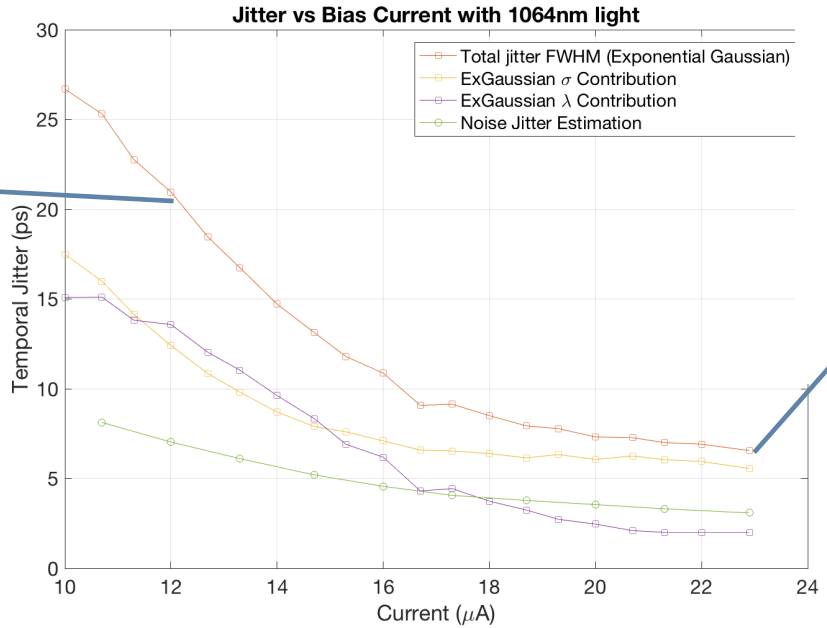


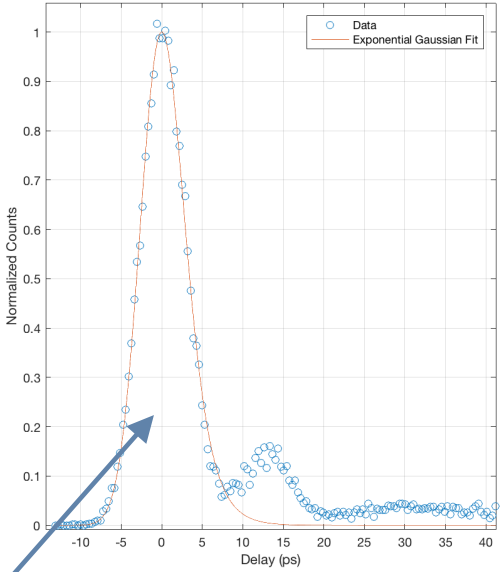
- Preliminary energy dependence suggests emergence of intrinsic jitter mechanisms

Copyright 2017. All rights reserved.

Variation in detection distributions

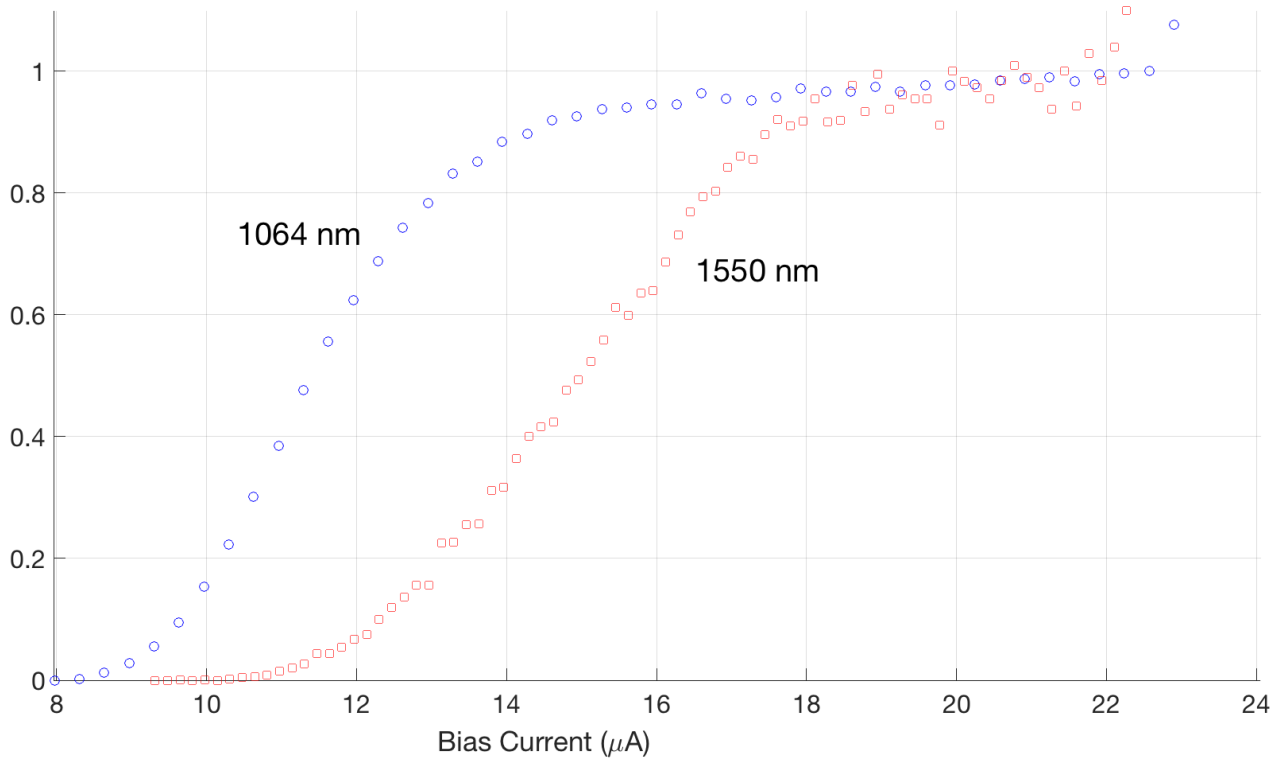






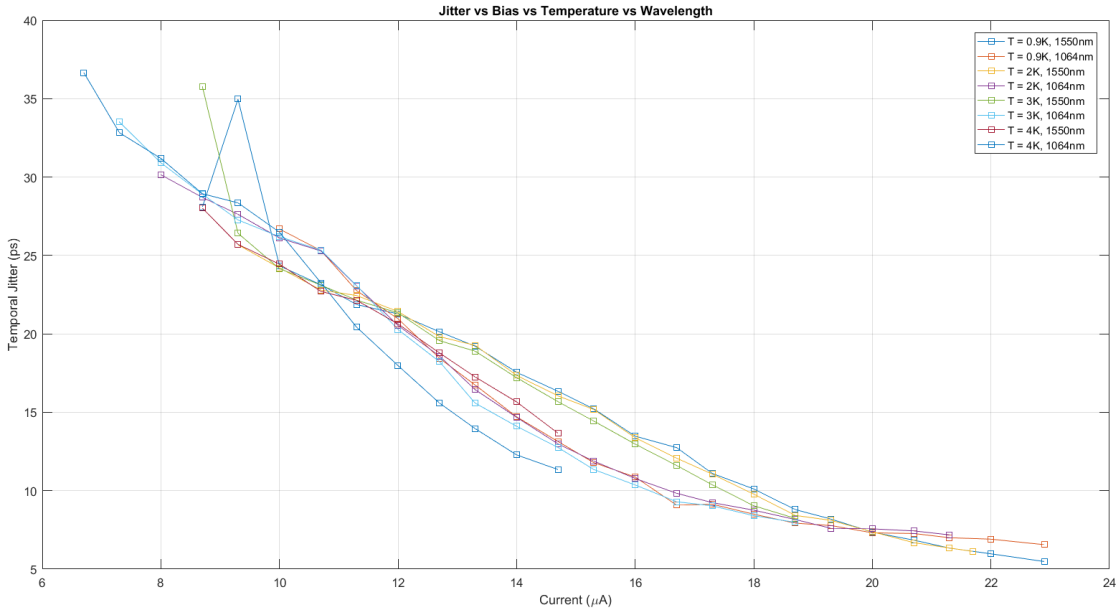
Copyright 2017. All rights reserved.

Photo response



Copyright 2017. All rights reserved.

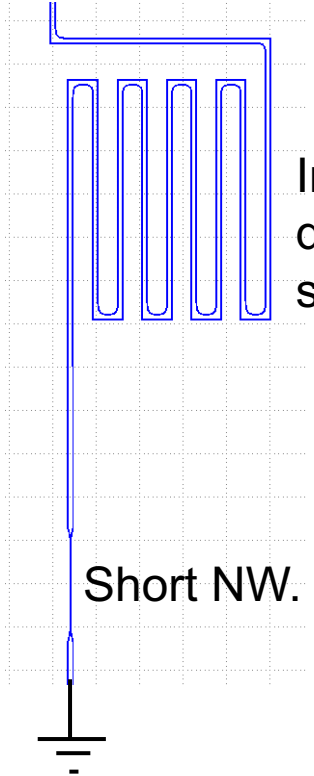
Temperature dependence of the jitter

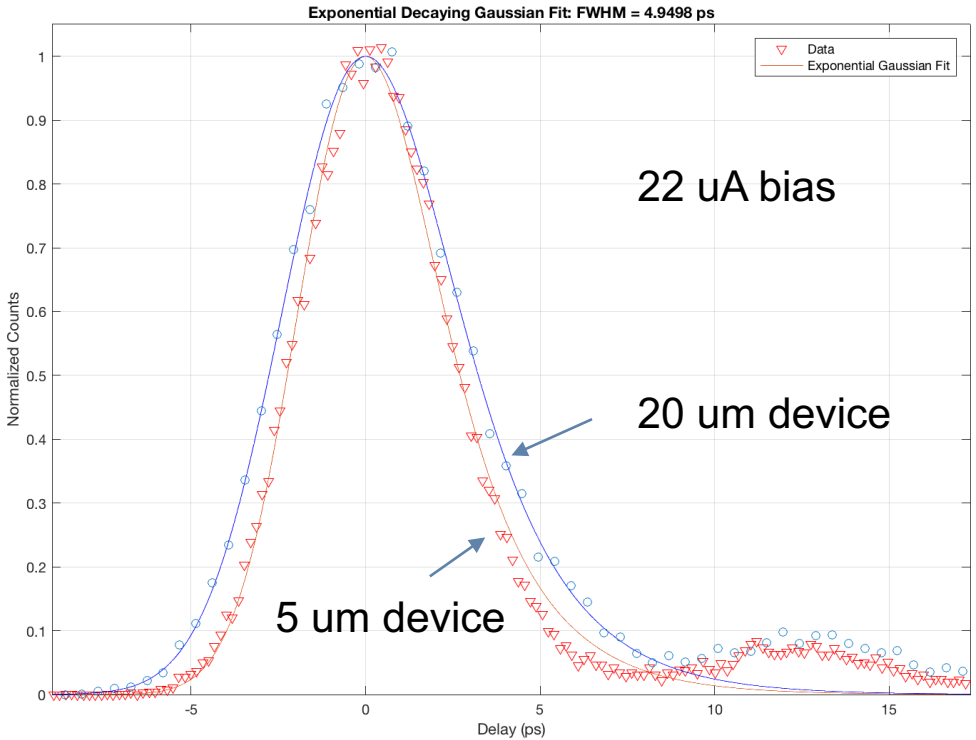


- Jitter reduction for a given bias current at 4 K

Copyright 2017. All rights reserved.

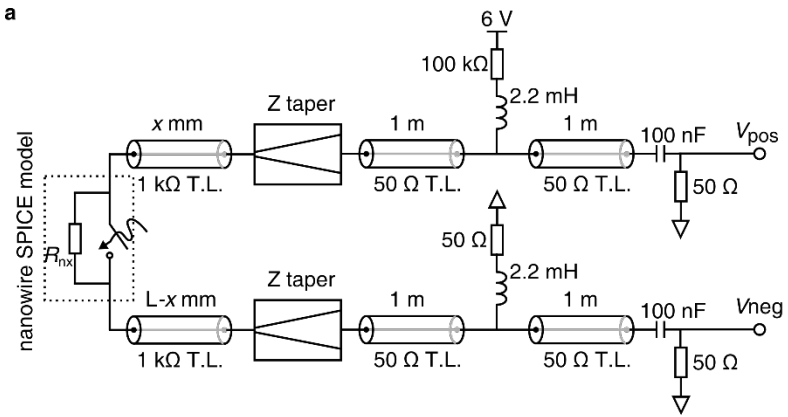
Reducing the geometric jitter further

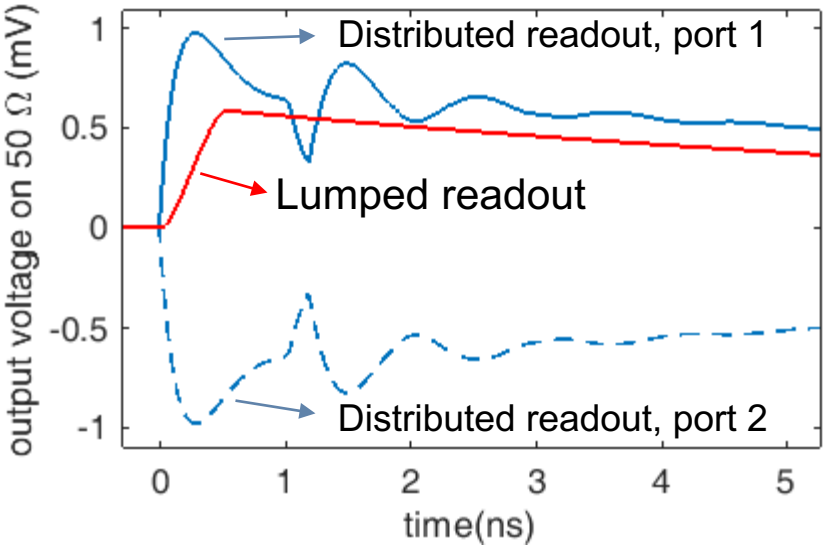




Copyright 2017. All rights reserved.

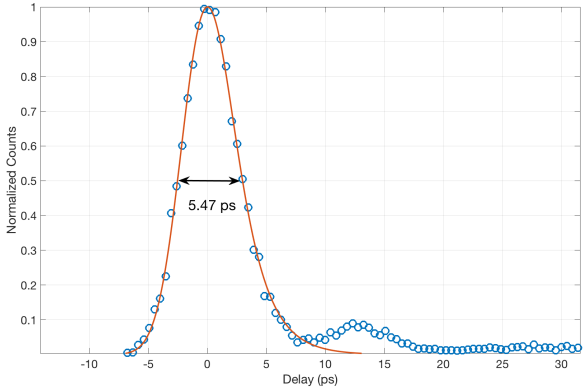
Large area devices with low jitter

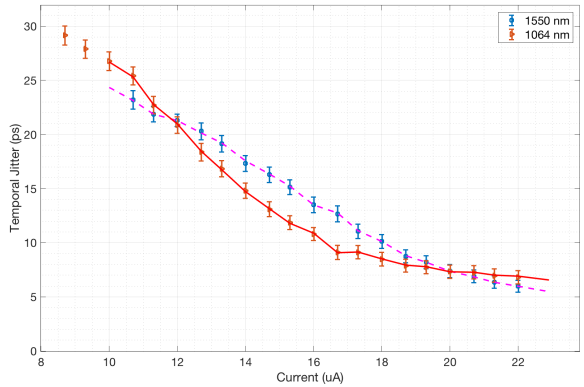




Copyright 2017. All rights reserved.

Summary





- Minimized noise through use of cryogenic amplifier
- Reduced geometric jitter with short nanowires
- Reduction by a factor of 3 over previous record
- First evidence of intrinsic jitter
  - Energy dependence
  - Temperature dependence
- Important insights for understanding detection mechanism
- Significant step towards sup-ps jitter

Copyright 2017. All rights reserved.

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov