CLEO 2018

WSi superconducting nanowire single photon detector with a temporal resolution below 5 ps

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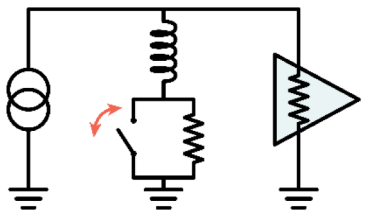
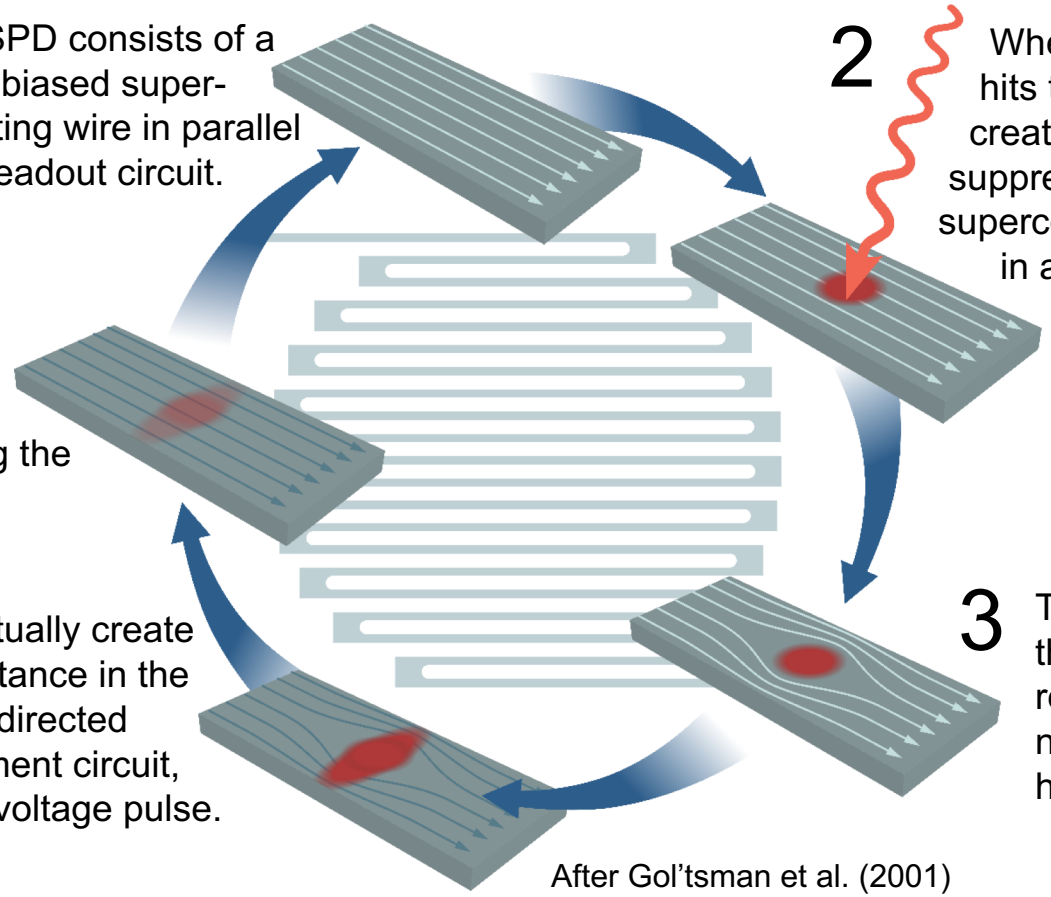
Superconducting nanowire single-photon detectors (SNSPDs)

Basic operating principle



1 An SNSPD consists of a current-biased super-conducting wire in parallel with a readout circuit.



2 When a photon hits the wire, it creates a hotspot, suppressing the superconductivity in a small region of the wire.

3 The current flowing through the resistive region heats the nanowire and the hotspot grows.

4 The hotspot can eventually create 10s of kOhms of resistance in the wire. The current is redirected through the measurement circuit, creating a detectable voltage pulse.

5 With the current through the nanowire reduced, the hotspot cools off, returning the wire to its original state.

After Gol'tsman et al. (2001)

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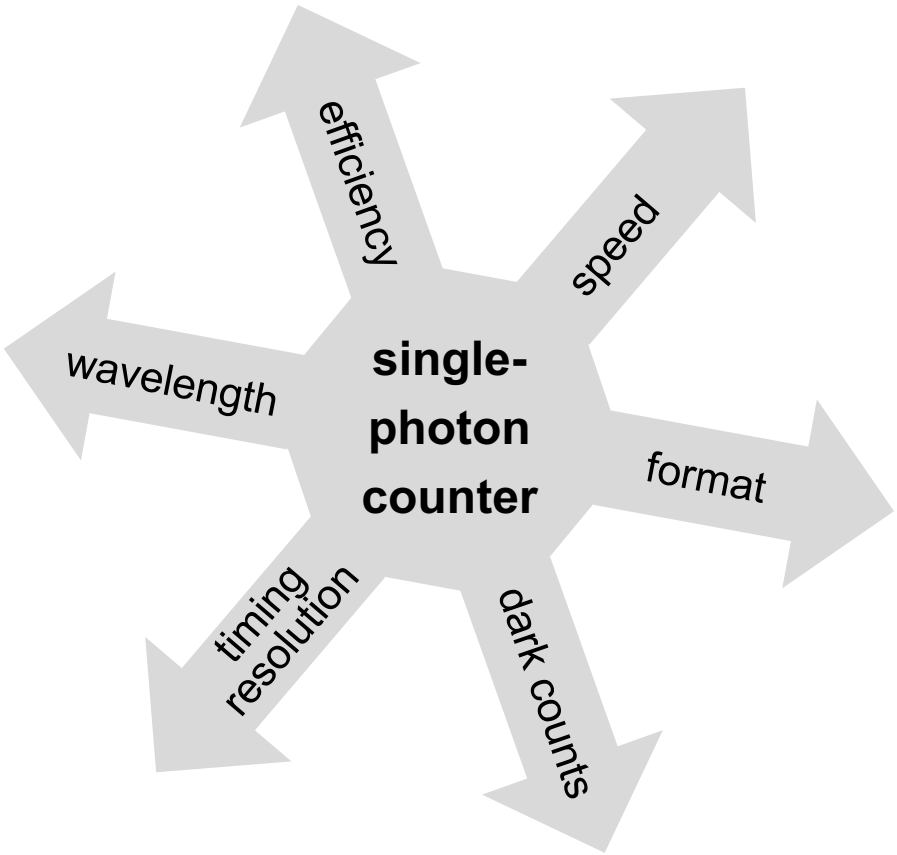
Properties of a single-photon counting detector



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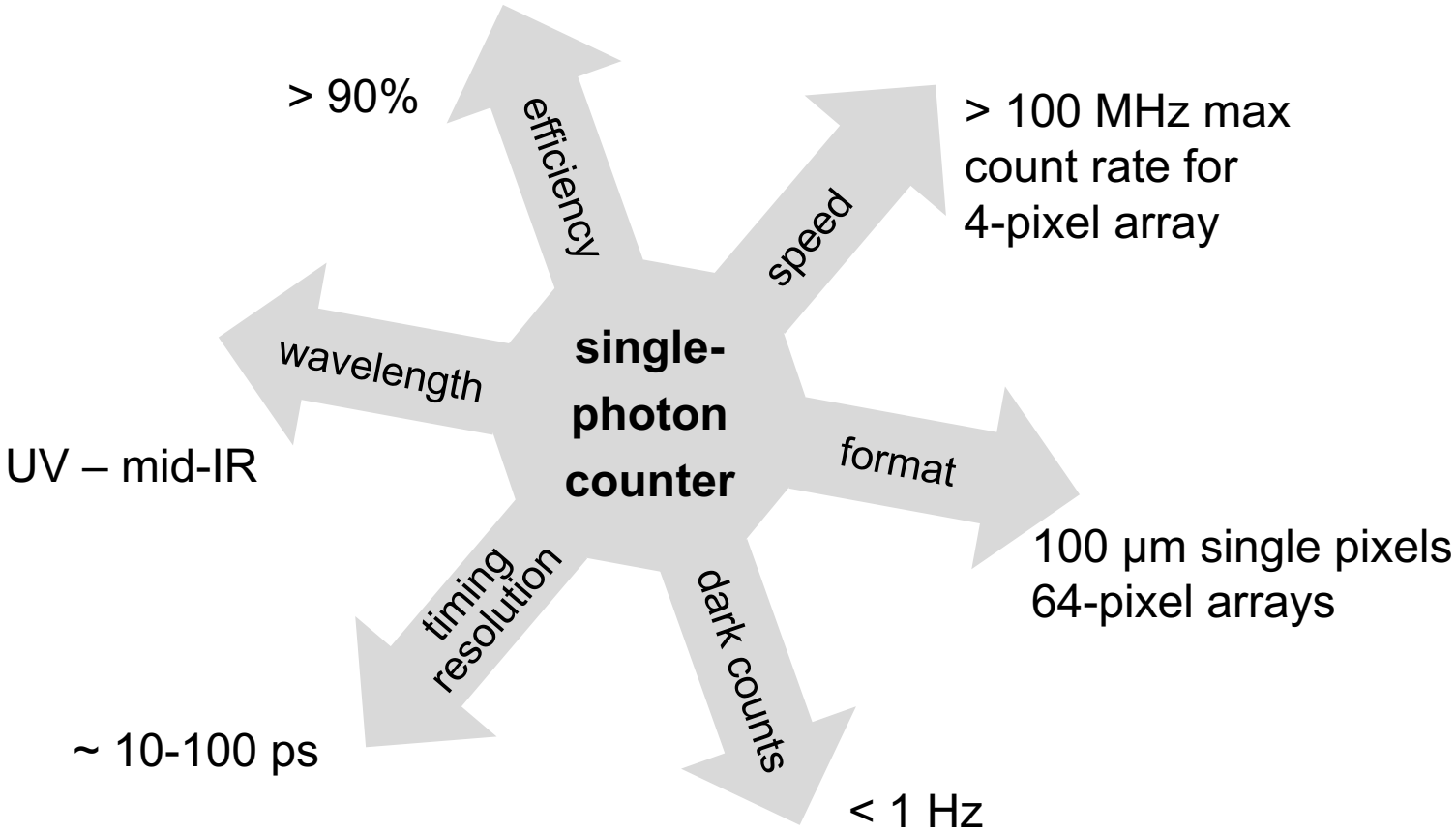
Properties of a single-photon counting detector

SNSPD performance



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Previous state of the art jitter

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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 ~10 ps has been very difficult to achieve

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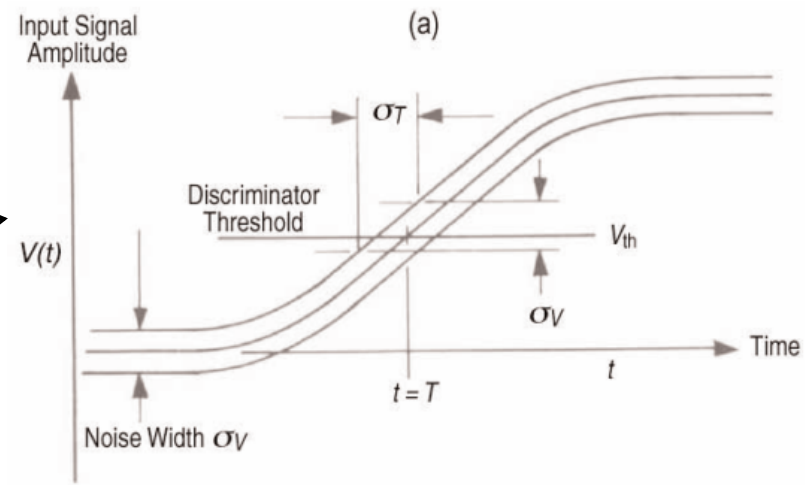
Contributions to timing jitter in SNSPDs



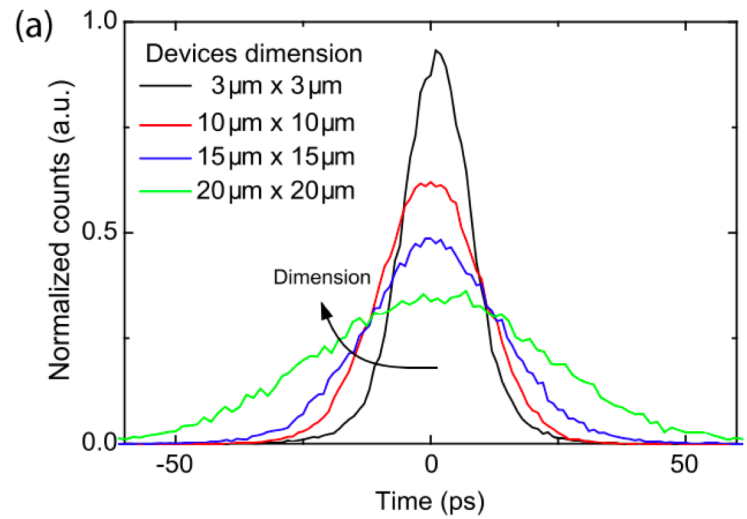
Instrumental

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

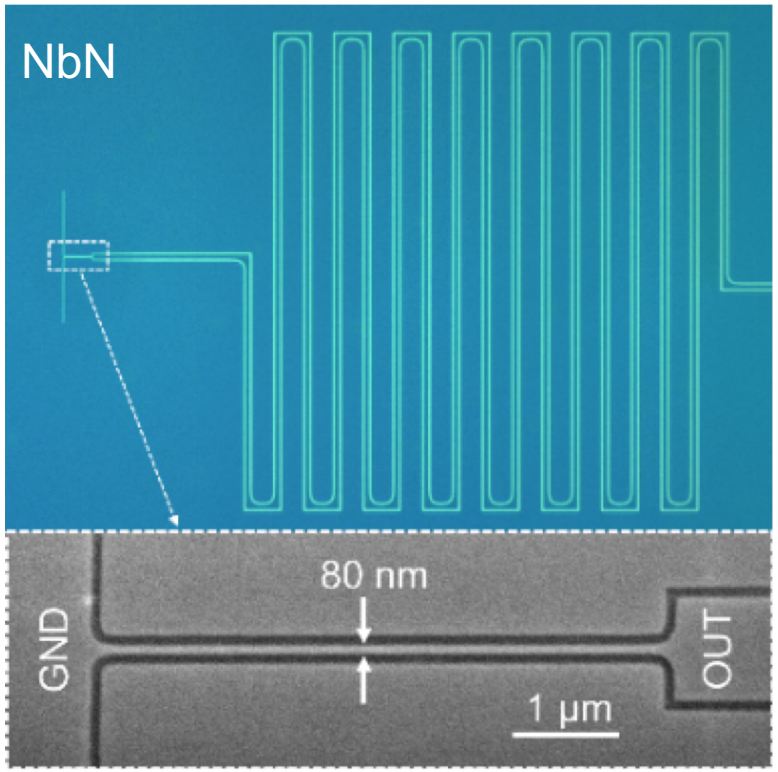
Intrinsic

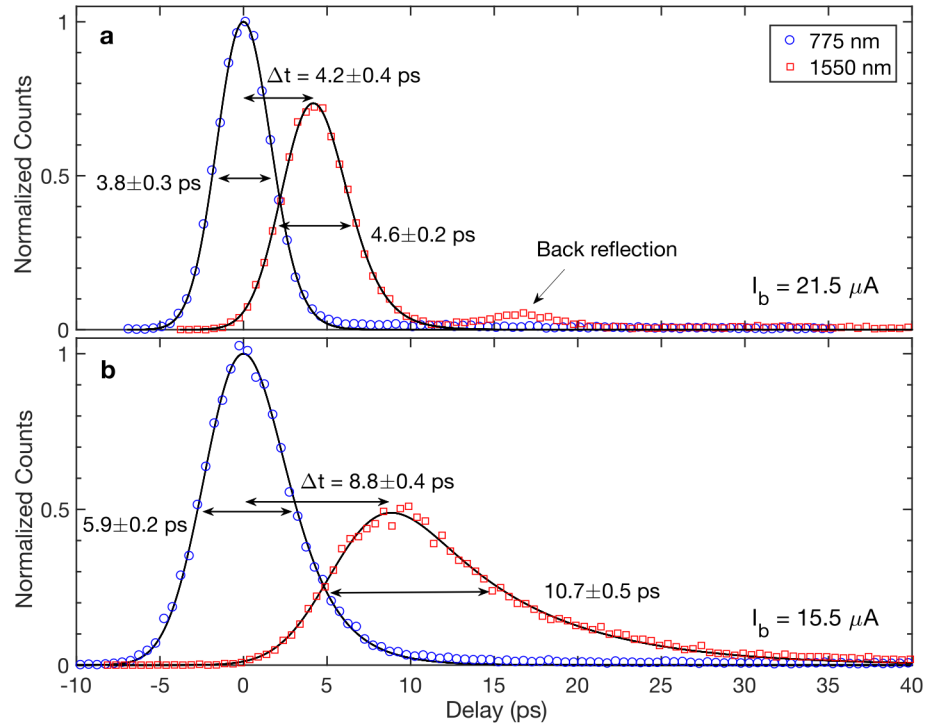
- Transverse position of photon absorption
- Fluctuations in the energy conversion from photon to cooper pair breaking
- Vortex crossing

Previously not accessible experimentally



Investigations of intrinsic jitter





- Short nano-bridge to limit the geometric contribution.
- Study of fundamental limits.

- Photon energy dependence of jitter and latency indicates presence of intrinsic effects due to detection mechanism.

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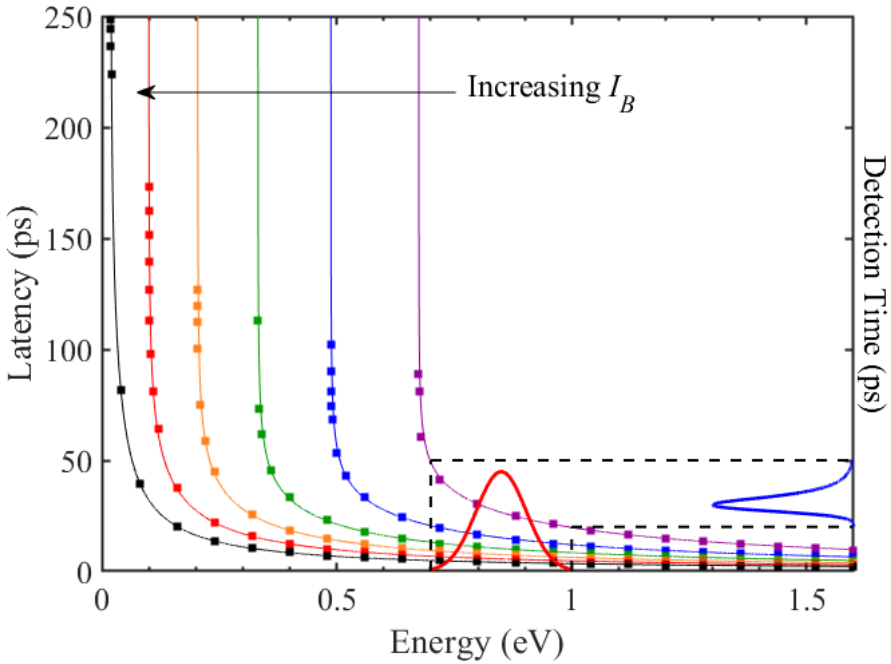
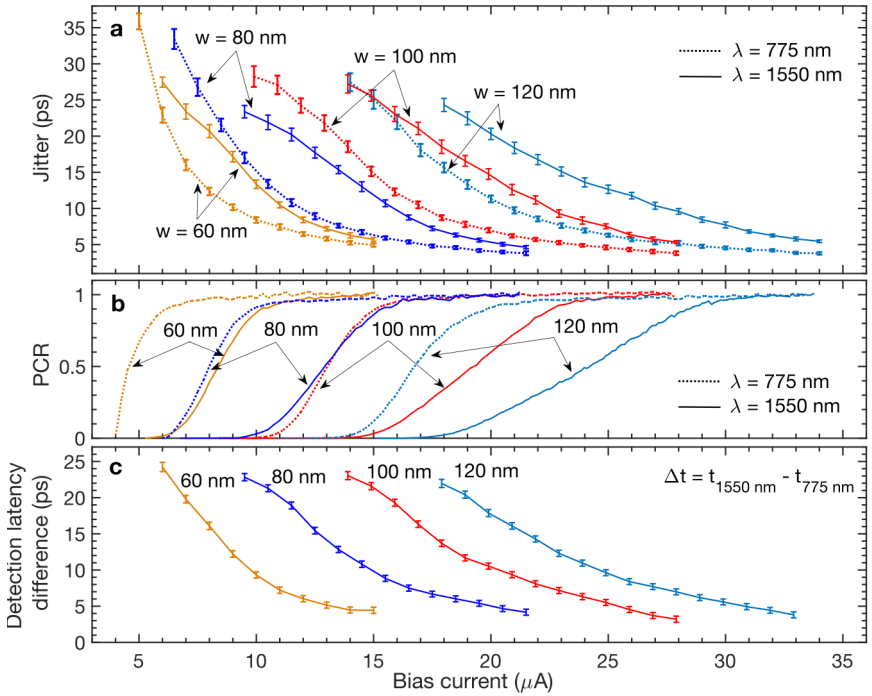
Detection latency





Allmaras et al. arXiv:1805.00130

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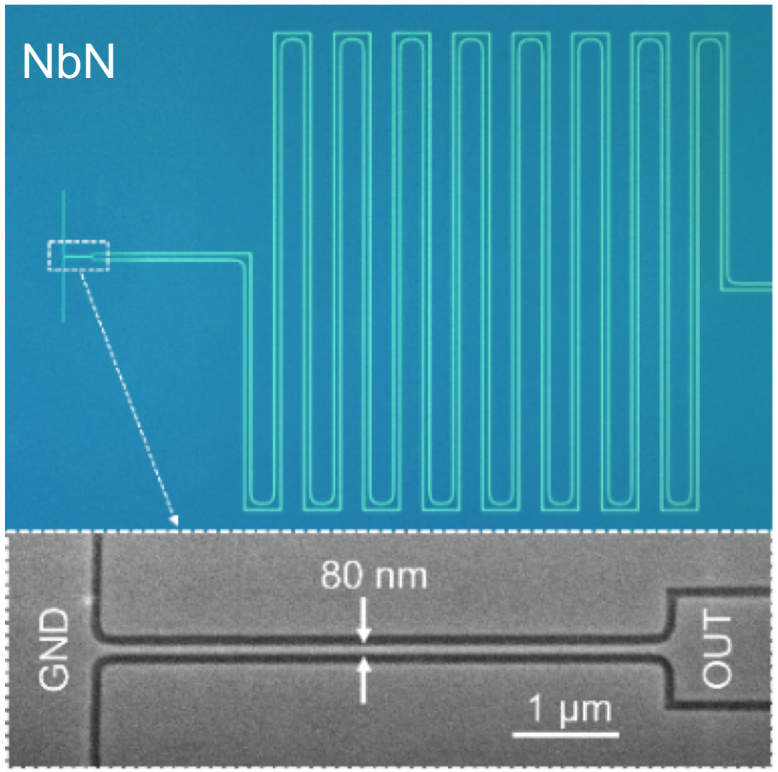
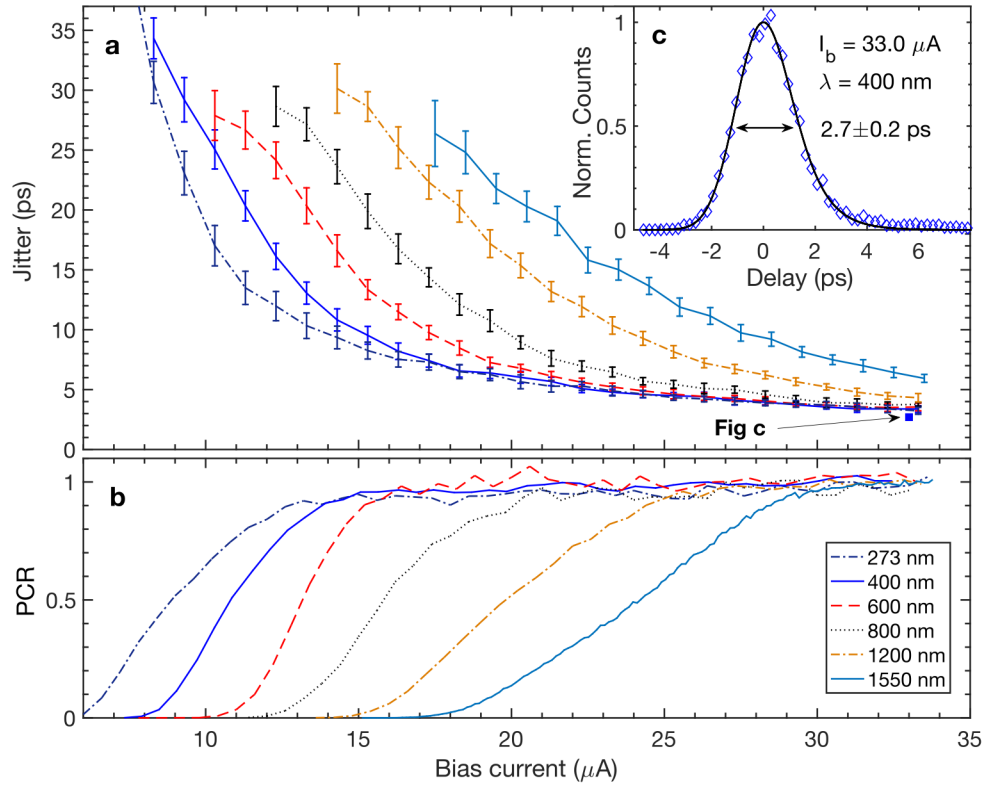
Ultra high time resolution





- Record time resolution for free-running single photon detector: 2.7 ps
- Photon energy dependence indicates presence of intrinsic effects due to detection mechanism.

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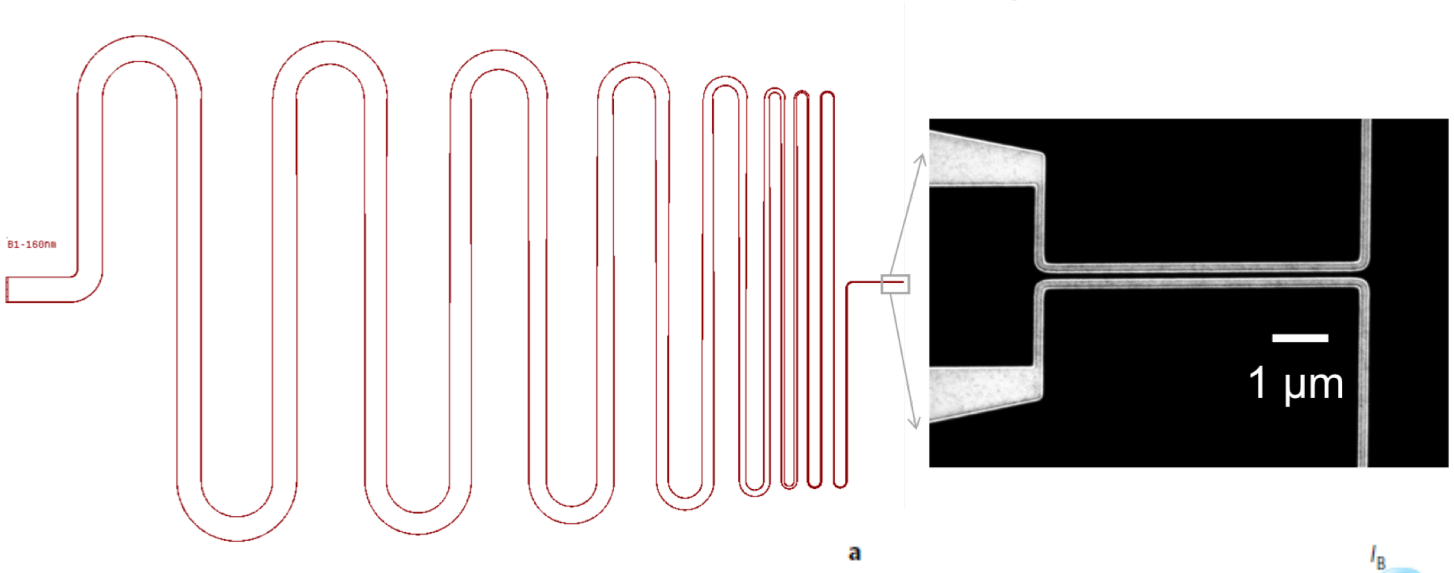
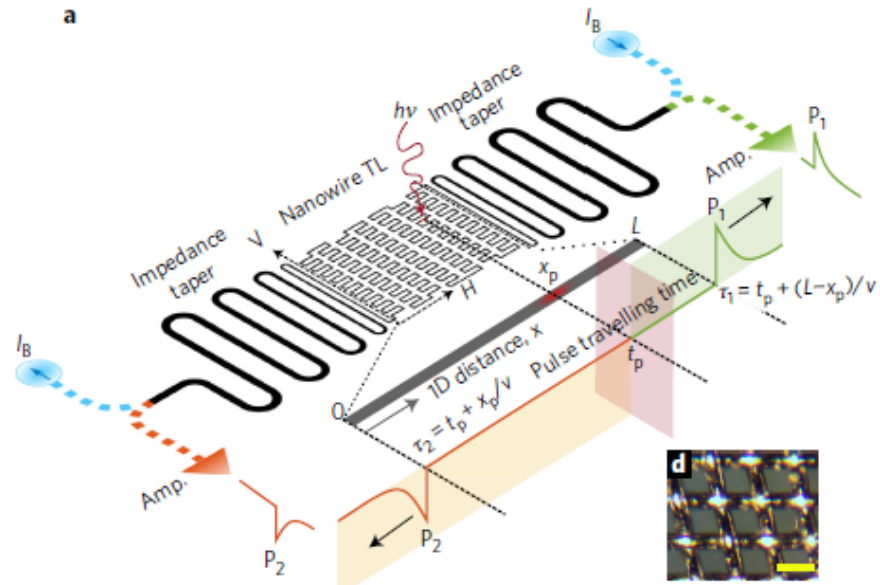
Improved impedance matching



- Large kinetic inductance of nanowires reduces the rise time.
  - Nanowire impedance is mismatched to the readout lines.
- Adiabatically tapered wire width.
  - Impedance matching.
  - Maintains a fast rise time.
  - Increases the signal.



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

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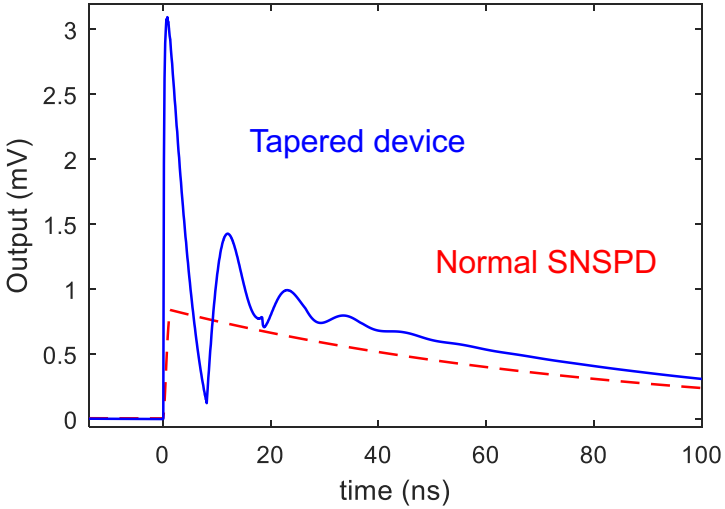
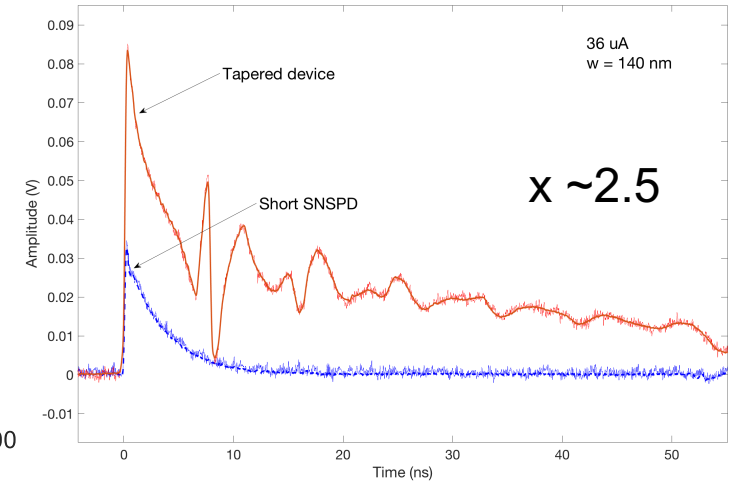
Improved impedance matching

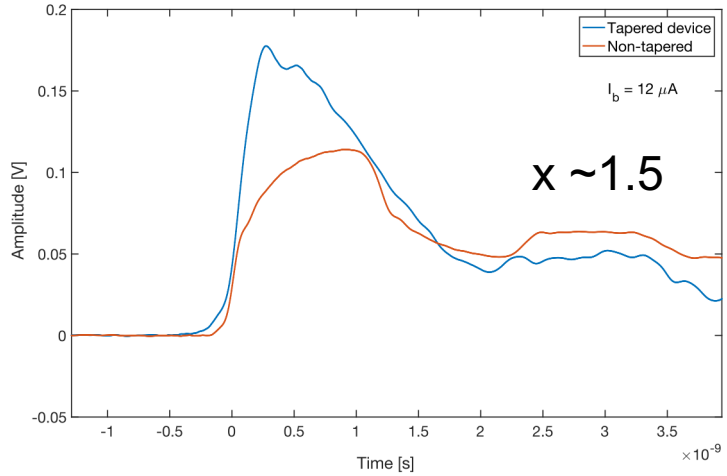
Simulation



Experiment: NbN



Experiment: WSi



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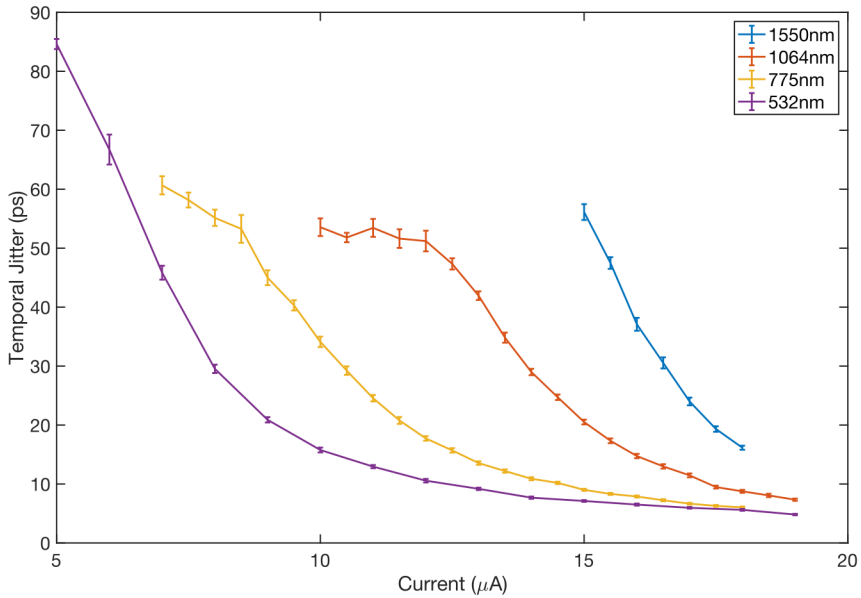
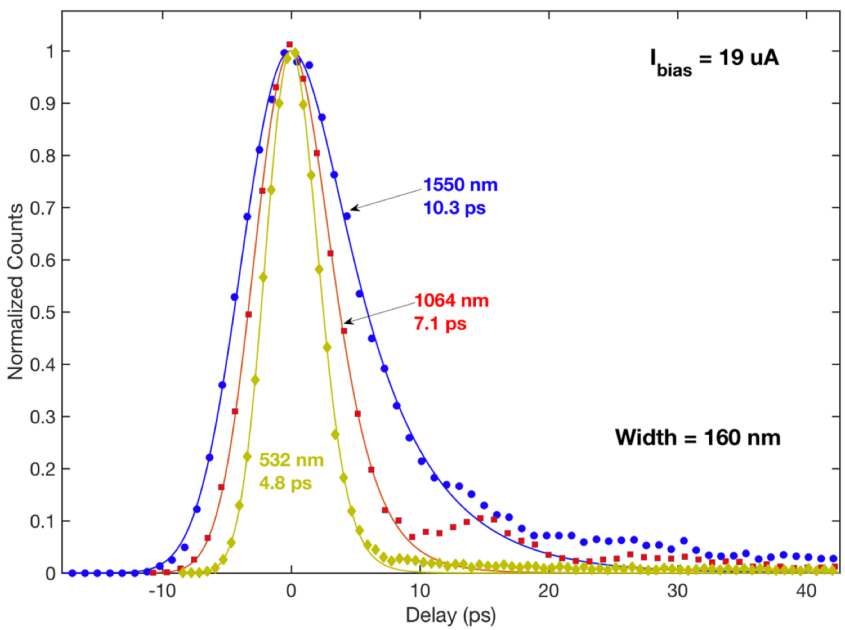
WSi jitter





- Devices fabricated at MIT with JPL WSi

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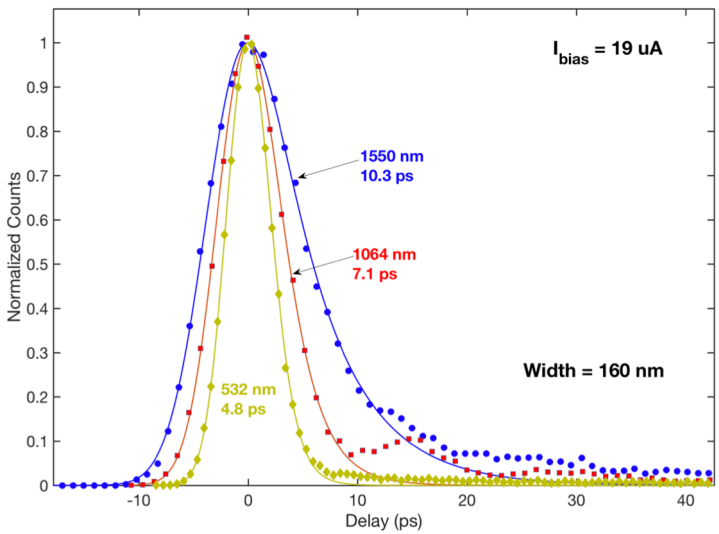
Summary

- For applications needing ultra-high time resolution, we are beginning to test the fundamental limits of SNSPD jitter
- Adiabatic tapers can improve signal to noise ratio
  - Improved noise contribution to jitter
  - Maximum count rate will be reduced due to larger kinetic inductance
  - Provides path toward large area, low jitter devices



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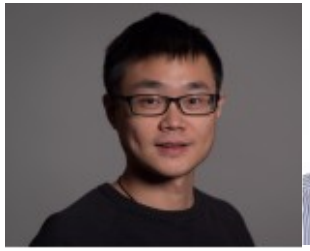
Karl K. Berggren

Marco Colangelo



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