SUPERCONDUCTING NANOWIRES

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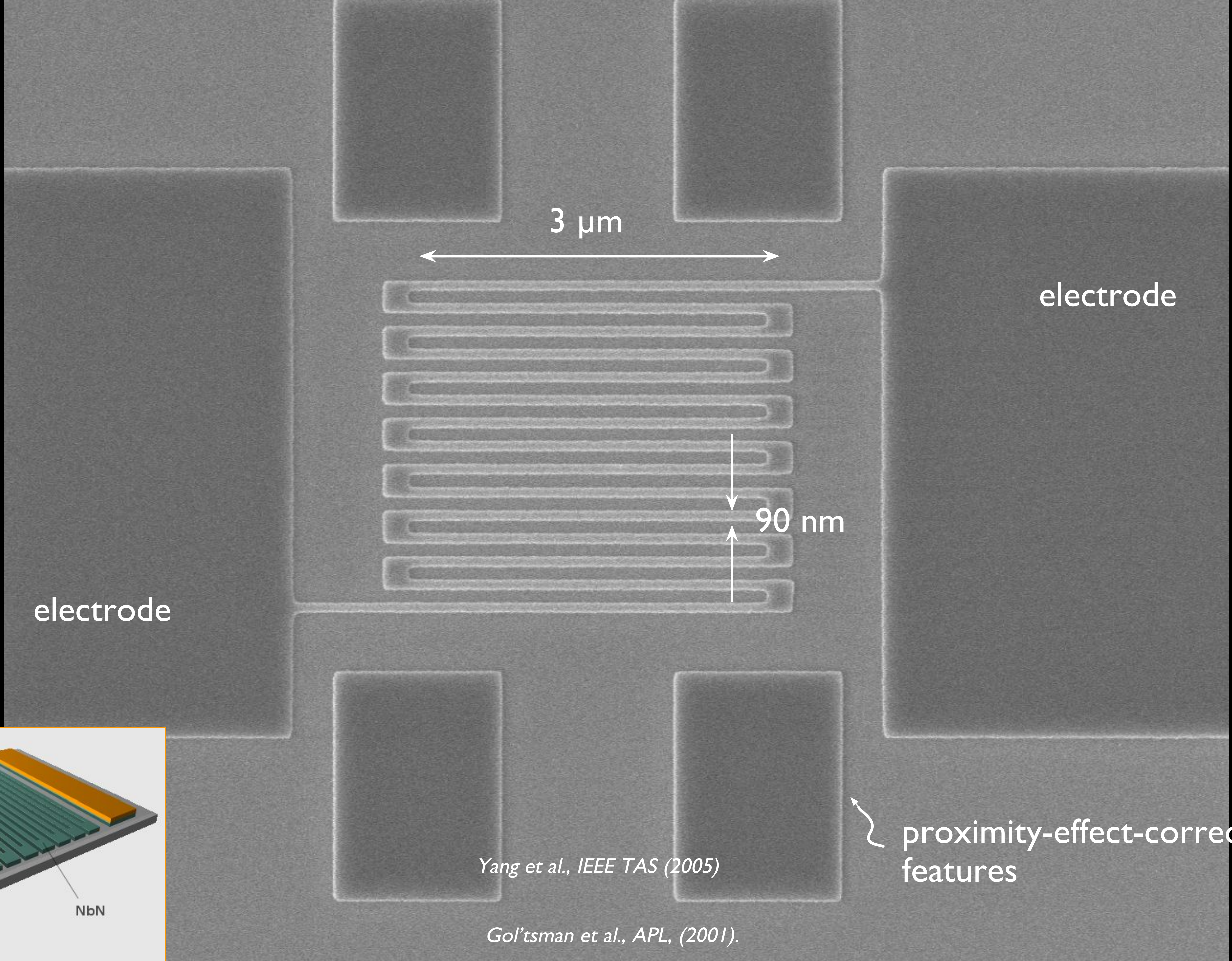
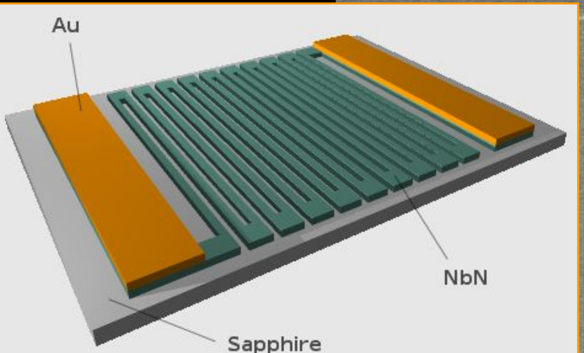
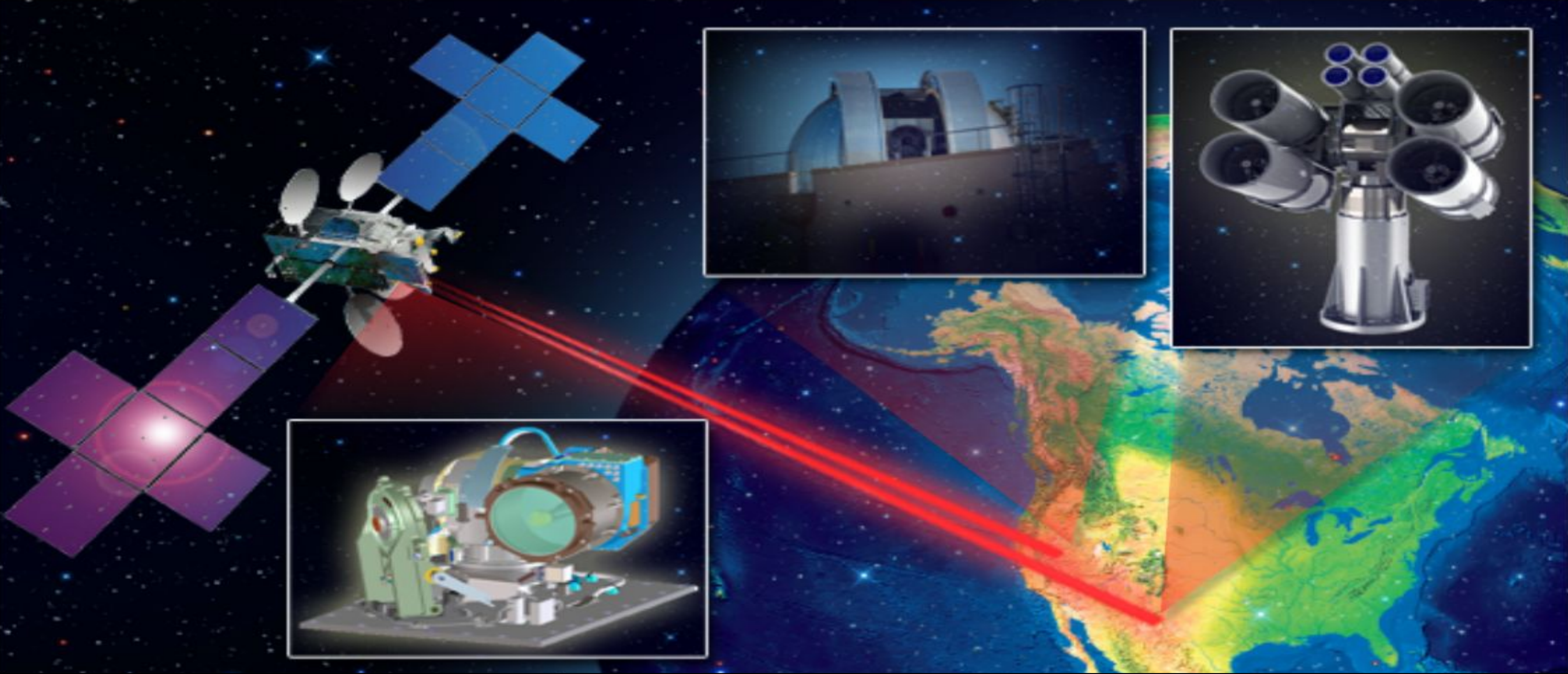


Yang et al., IEEE TAS (2005)



Gol'tsman et al., APL, (2001).



“LLCD will be the first high-rate space laser communications system that can be operated over a range ten times larger than the near-Earth ranges that have been demonstrated to date.” from http://esc.gsfc.nasa.gov/267/271.html, enabled by nanowire detectors developed at MIT Lincoln Laboratory in collaboration with MIT campus.

VLSI Circuit Evaluation

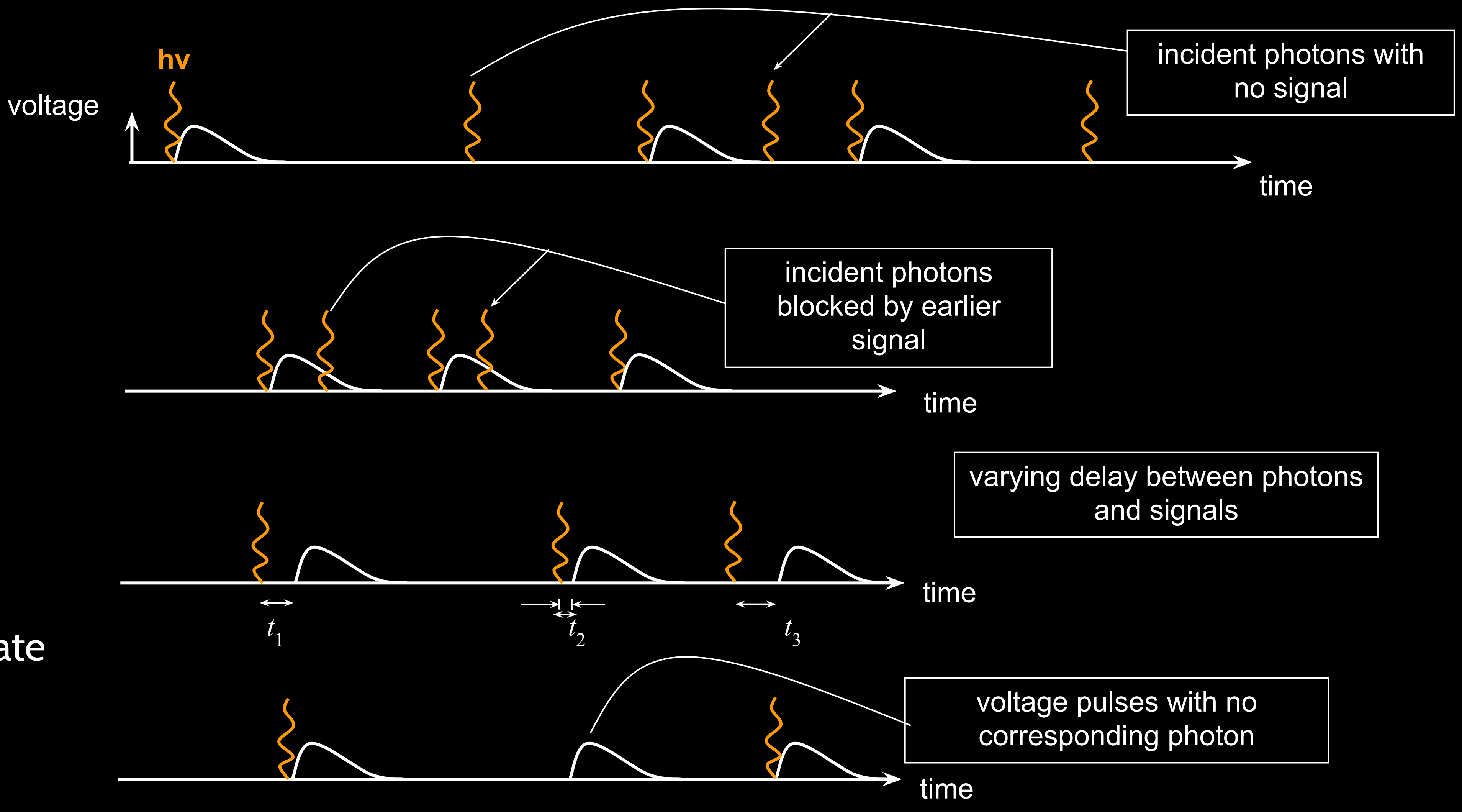
- VLSI circuit imaging and debugging
- SNSPD enables performance advances

Image courtesy of DCG Systems

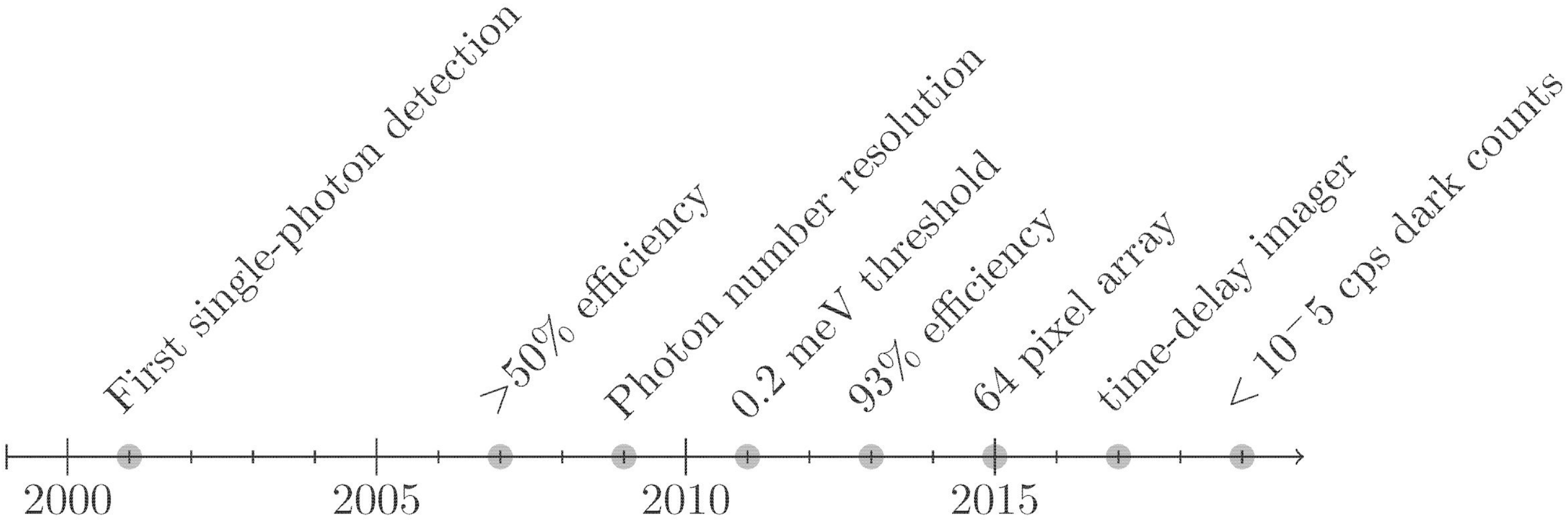
Collaboration between BU, DCG Systems, IBM, Photonspot, funded by IARPA

Characteristics of Photon Detectors

- Efficiency
- Reset time
- Jitter
- Dark count rate



SNSPD Timeline

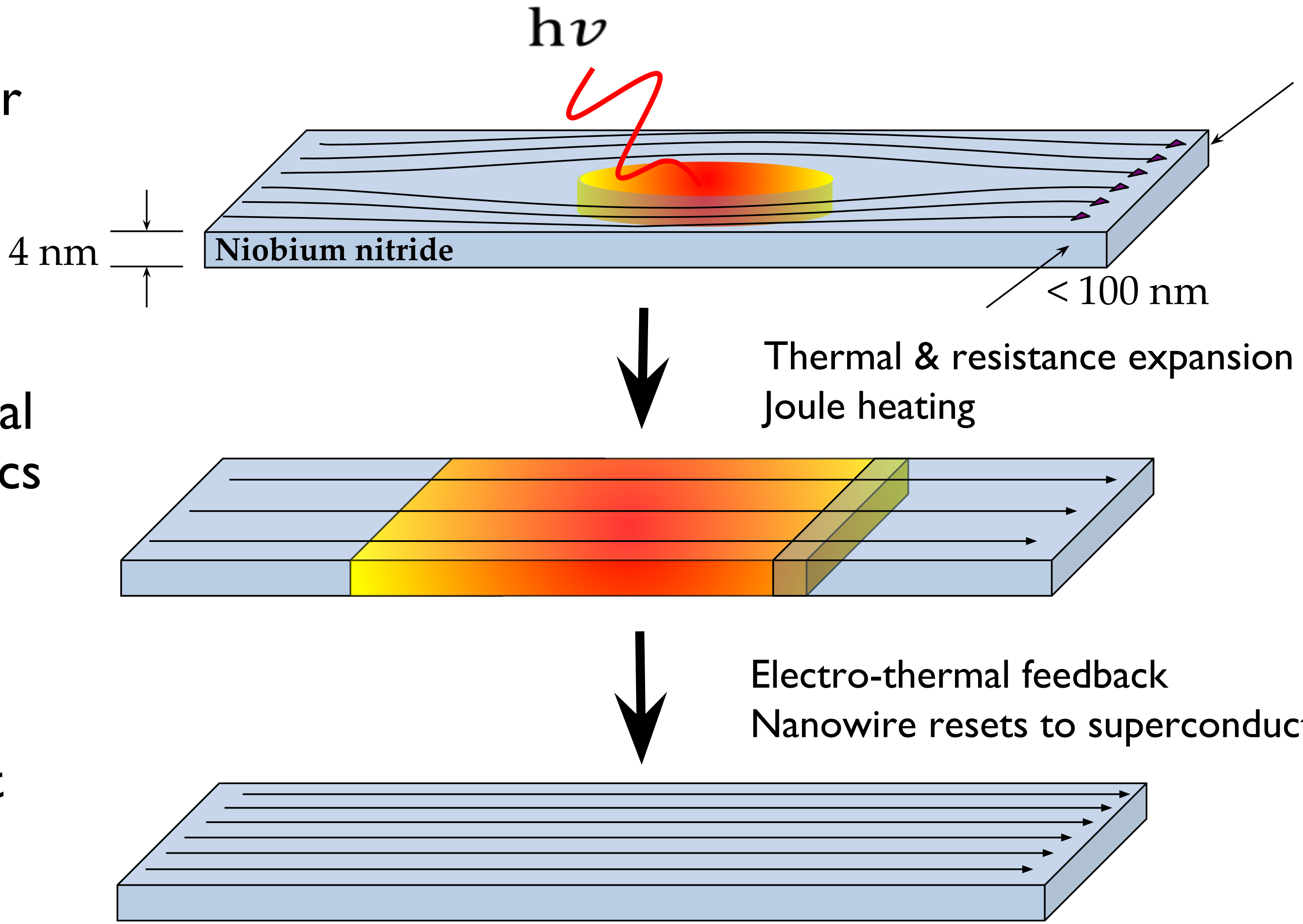


Detection mechanism

Trigger

Thermal dynamics

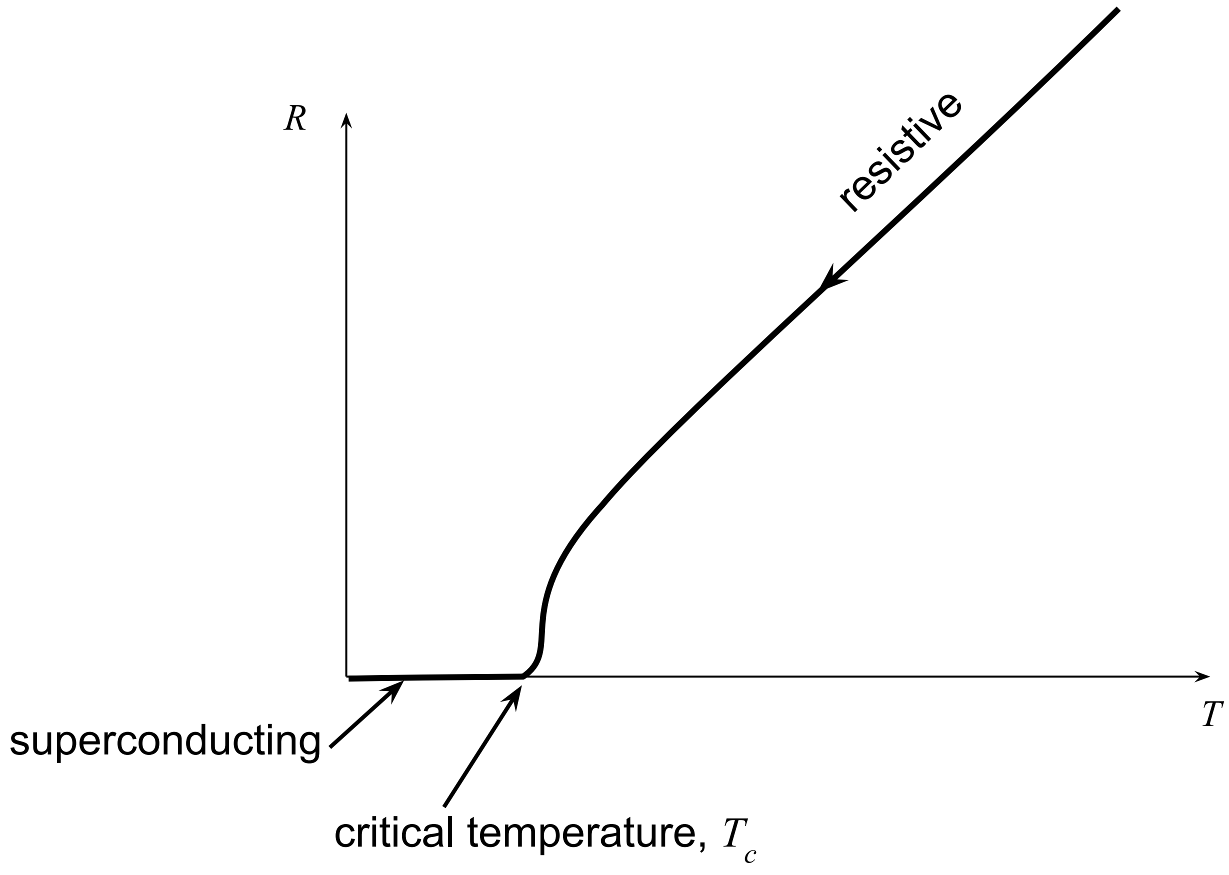
Reset



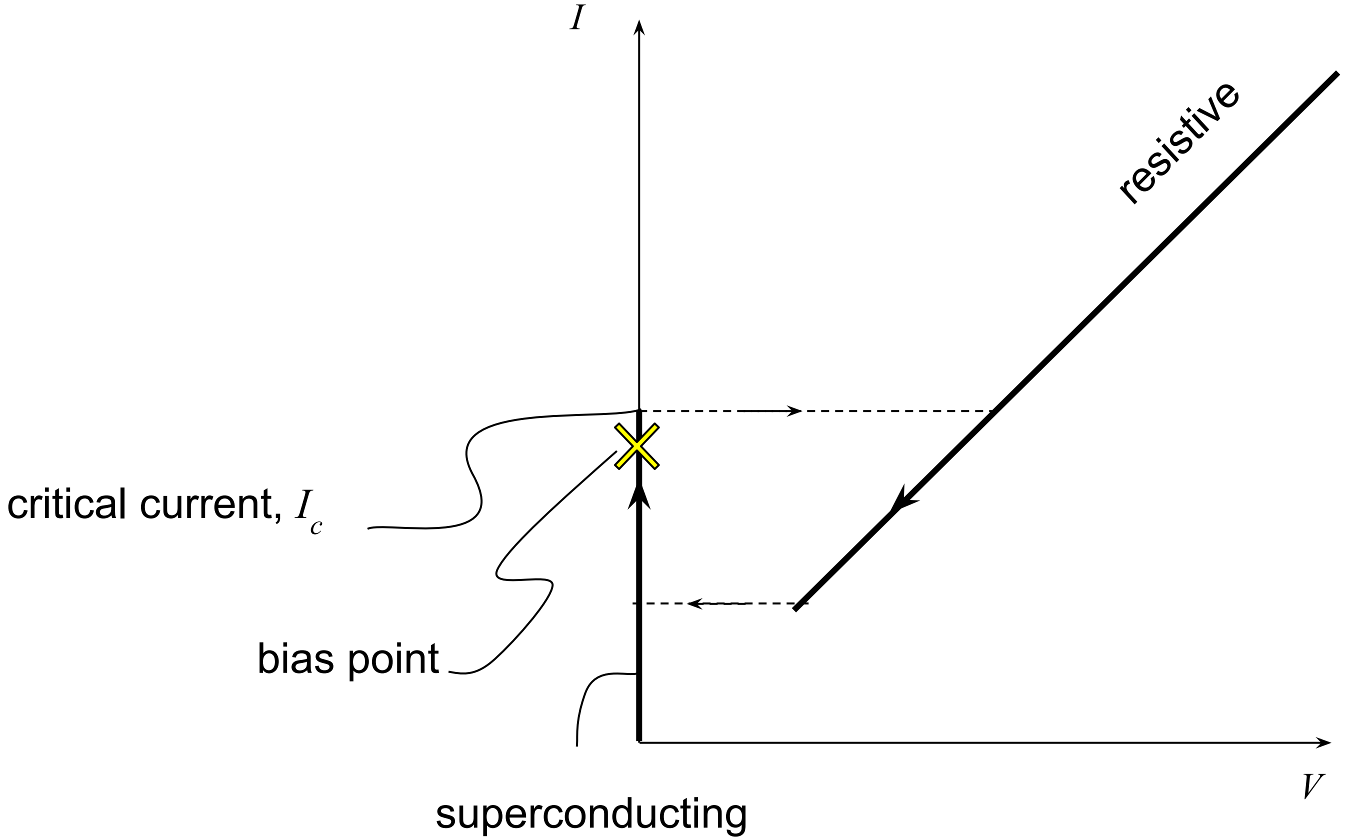
Thermal & resistance expansion assisted by Joule heating

Electro-thermal feedback
Nanowire resets to superconducting

Analog Amplifiers (e.g. Transition-Edge Sensors)



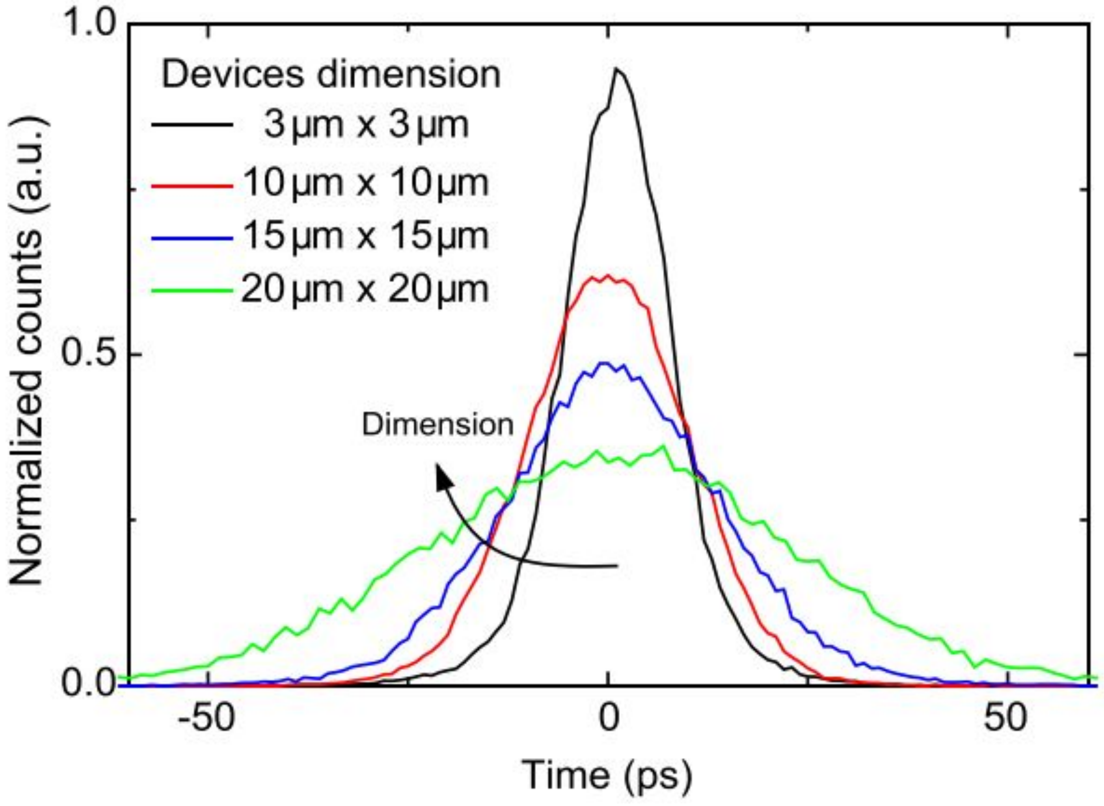
Superconductive Nanowire Operation



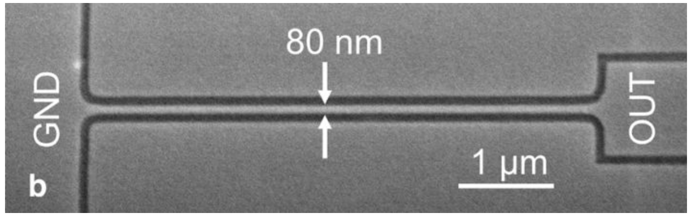
Why are Superconductors Interesting?

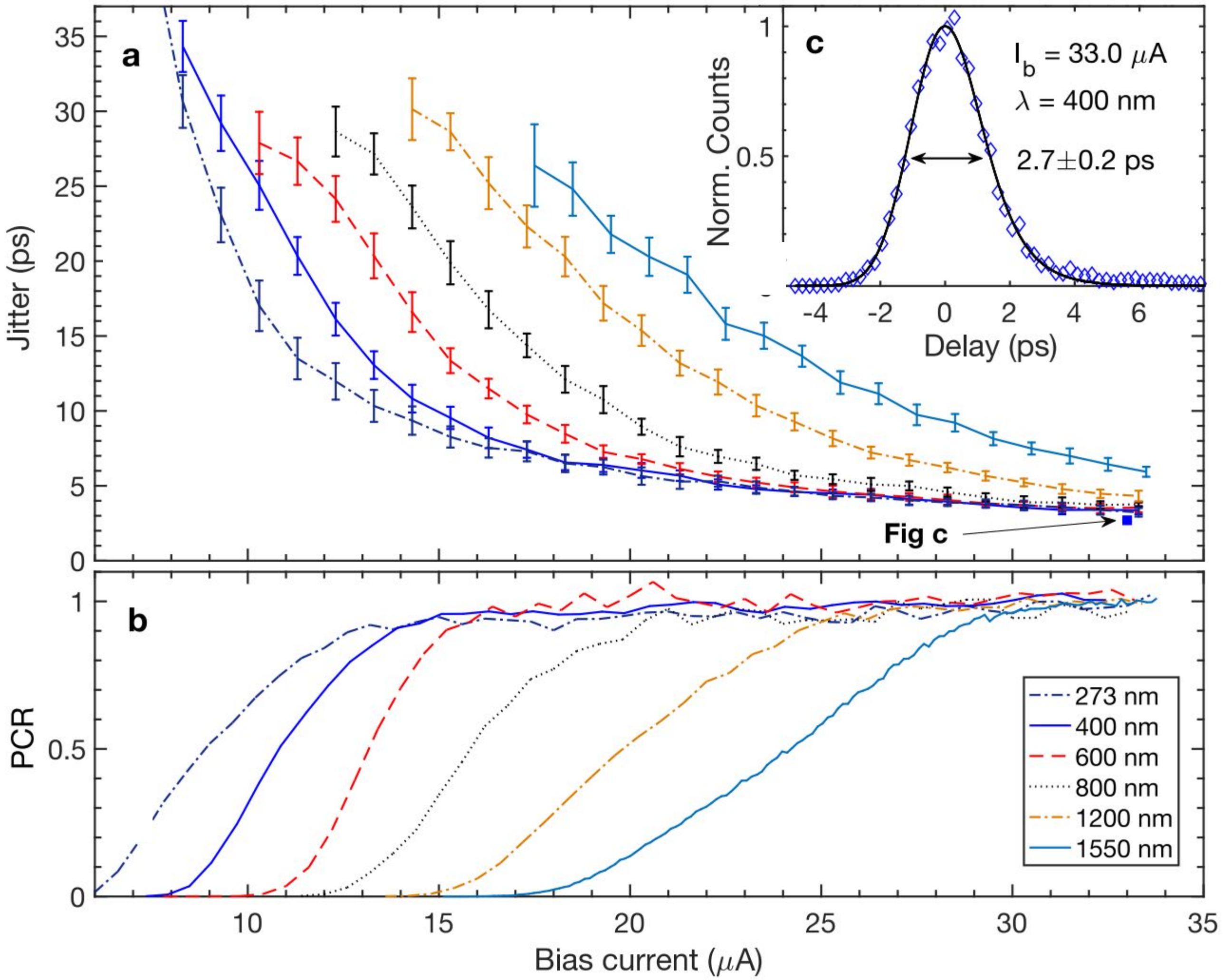
- Zero resistance
- Exclusion of magnetic field
- Strong nonlinearity

Timing jitter limited by detector geometry



Calandri et al., *Appl. Phys. Lett.*, 109 (15) 152601(2016).

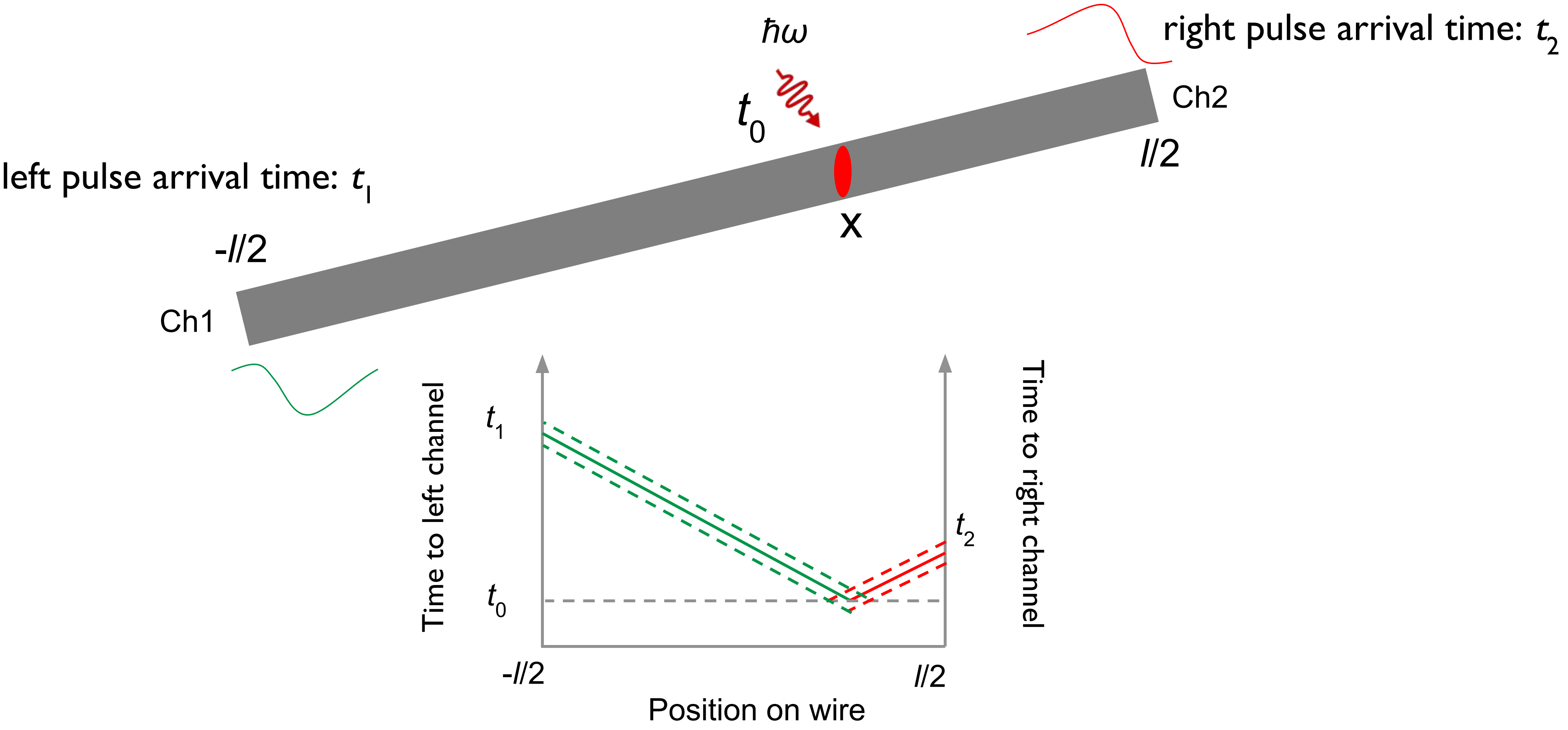




Korzh *et al.*, 1804.06839

With JPL and NIST

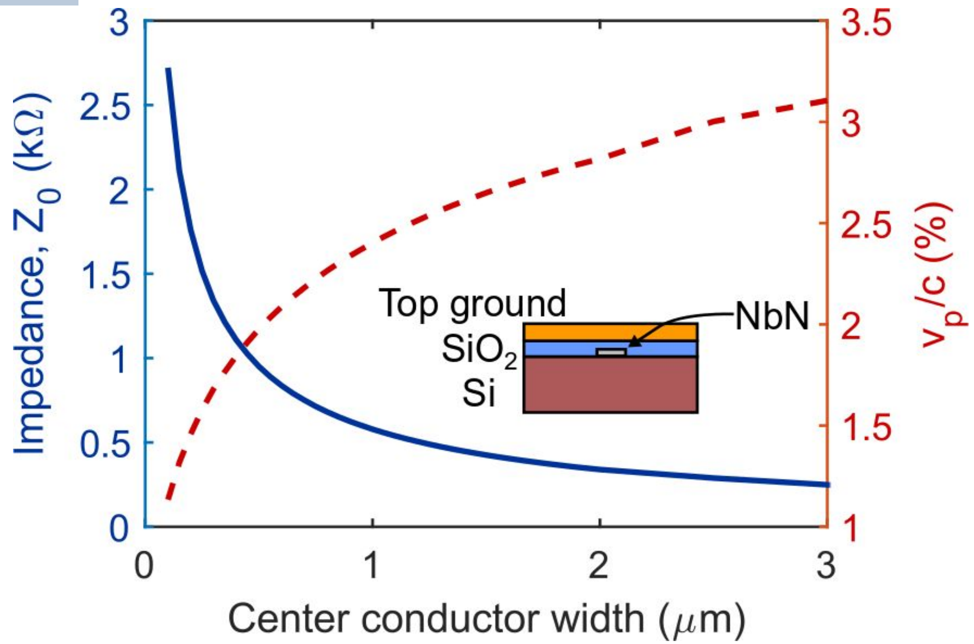
Spatial and temporal resolution in a wire

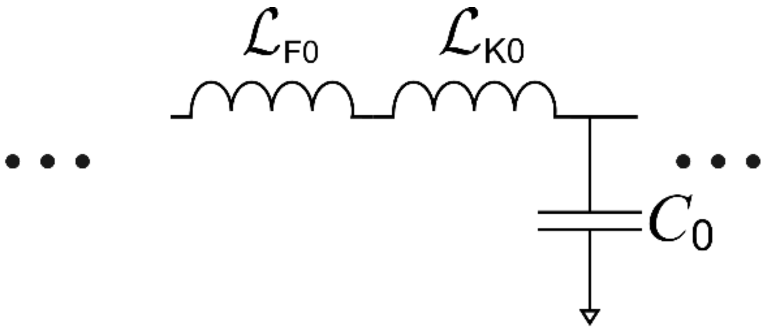


spatial resolution = timing jitter × speed of light

Slow-wave transmission line

A typical nanowire transmission line

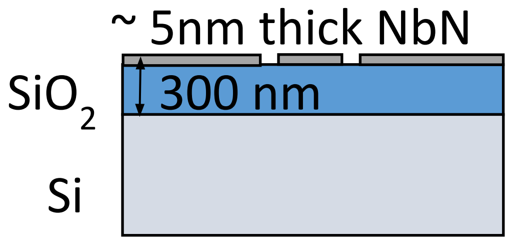




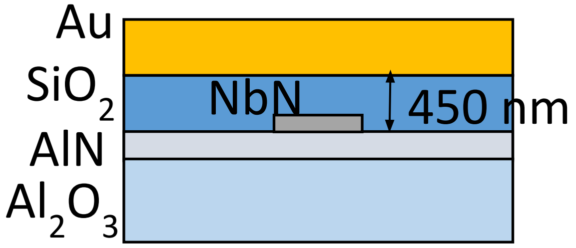
For a ~ 5 nm thick 300 nm wide NbN microstrip,

$\mathcal{L}_{K0} \approx 212\mu_0 \quad \mathcal{L}_{F0} \approx 0.3\mu_0 \quad C_0 \approx 21\epsilon_0$

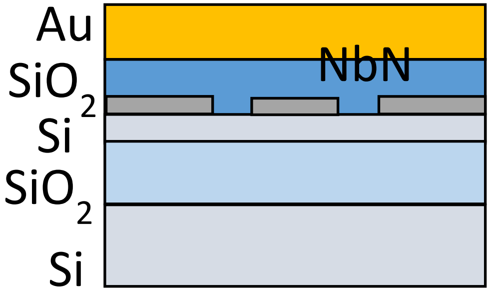
- Measured group velocities to date



CPW, 300 nm center conductor width, 3μm gap, SiO2 on Si substrate
Signal speed ~2%*c*
Zhao et al. Nat. Photonics 11, 247 (2017)



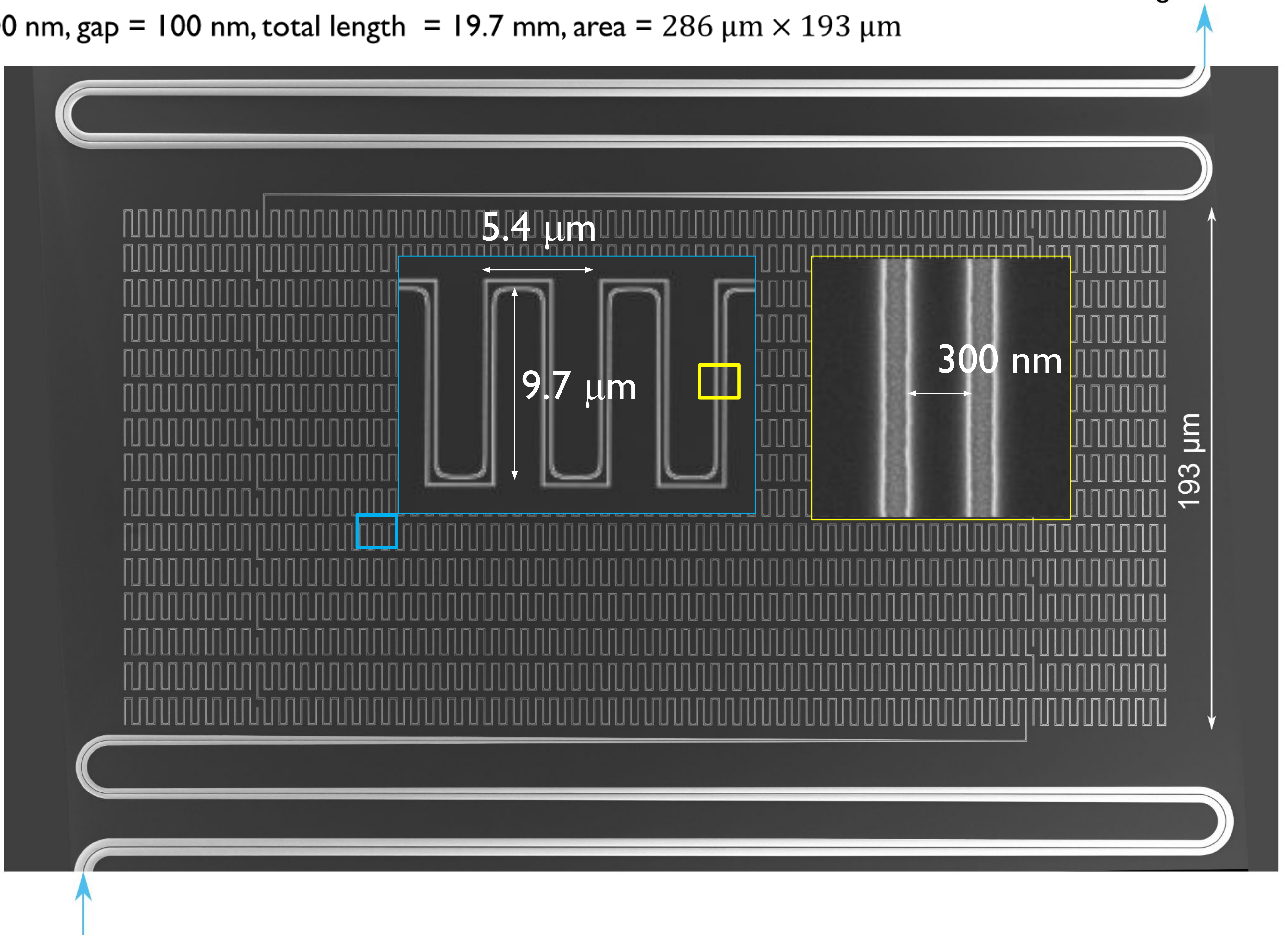
Microstrip, 300 nm width
AlN on Al_2O_3 substrate
Signal speed 1.6%*c*
Zhu et al. Nat. Nanotech. 13, 596 (2018)



CPW with top ground, 200 nm width, 1μm gap, 450 nm spacer, SOI substrate Signal speed 0.87%*c*
Zhu et al. (2018), unpublished

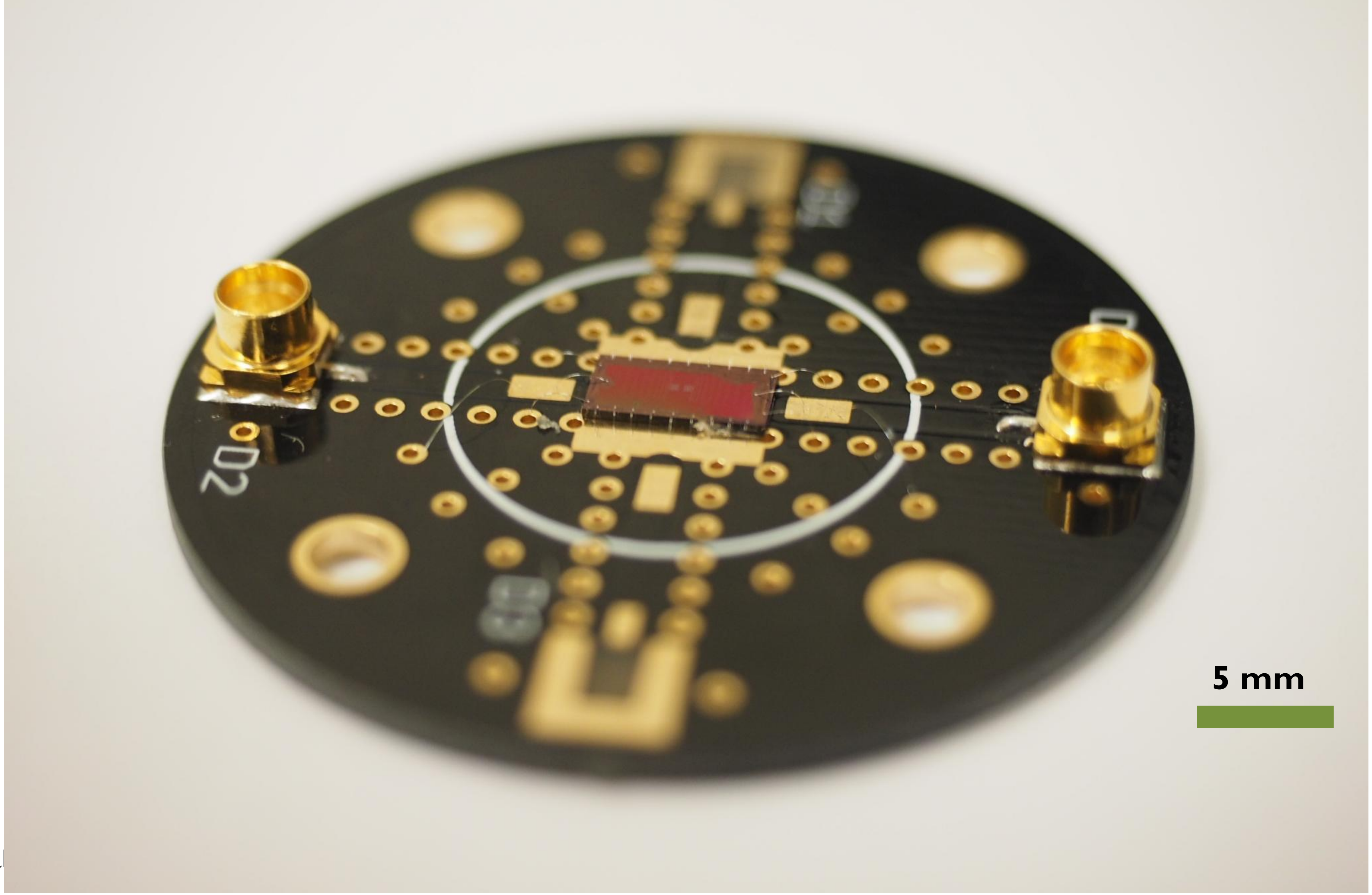
The group velocity can be further reduced by using high-index dielectric materials

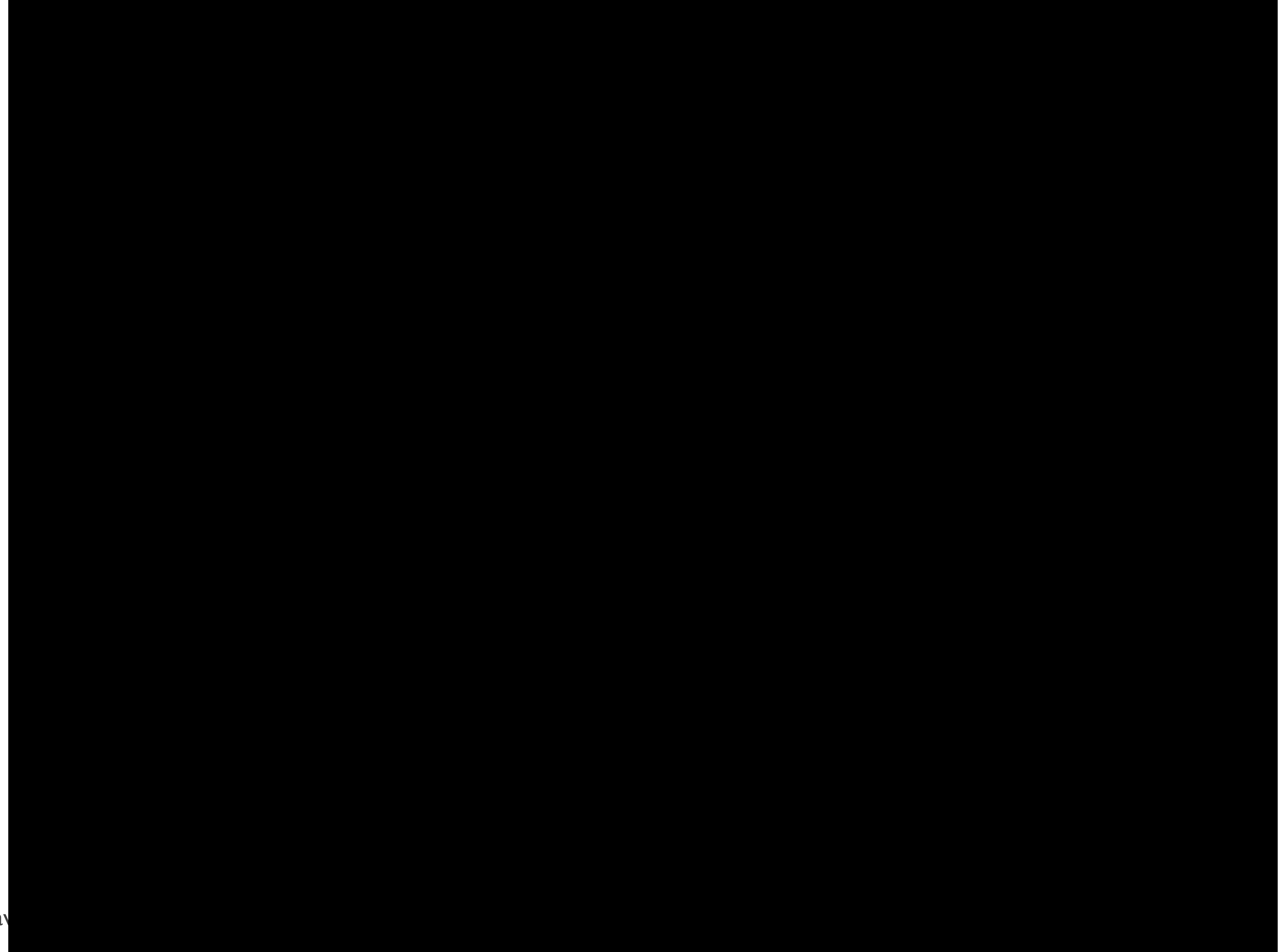
In collaboration with ***Daniel Santavicca (UNF)*** width = 300 nm, gap = 100 nm, total length = 19.7 mm, area = 286 µm × 193 µm



2019-05-10-san jc

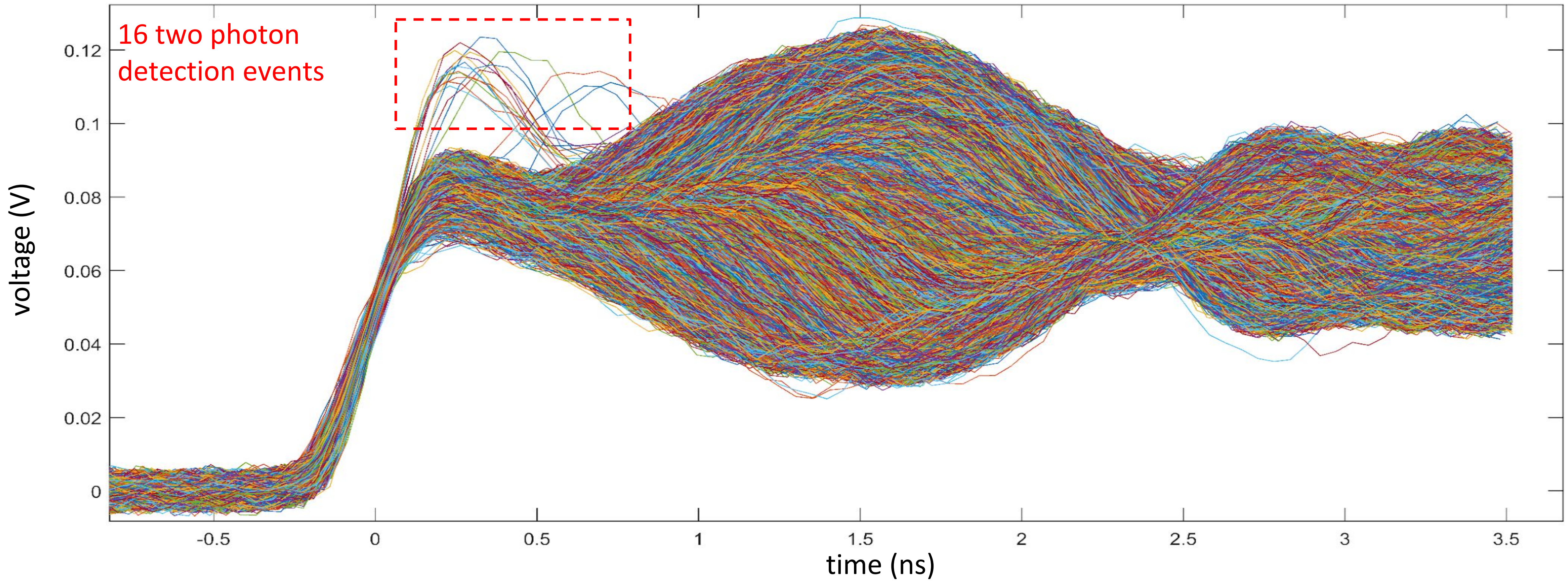
Two connectors for one imager (>500 pixels)

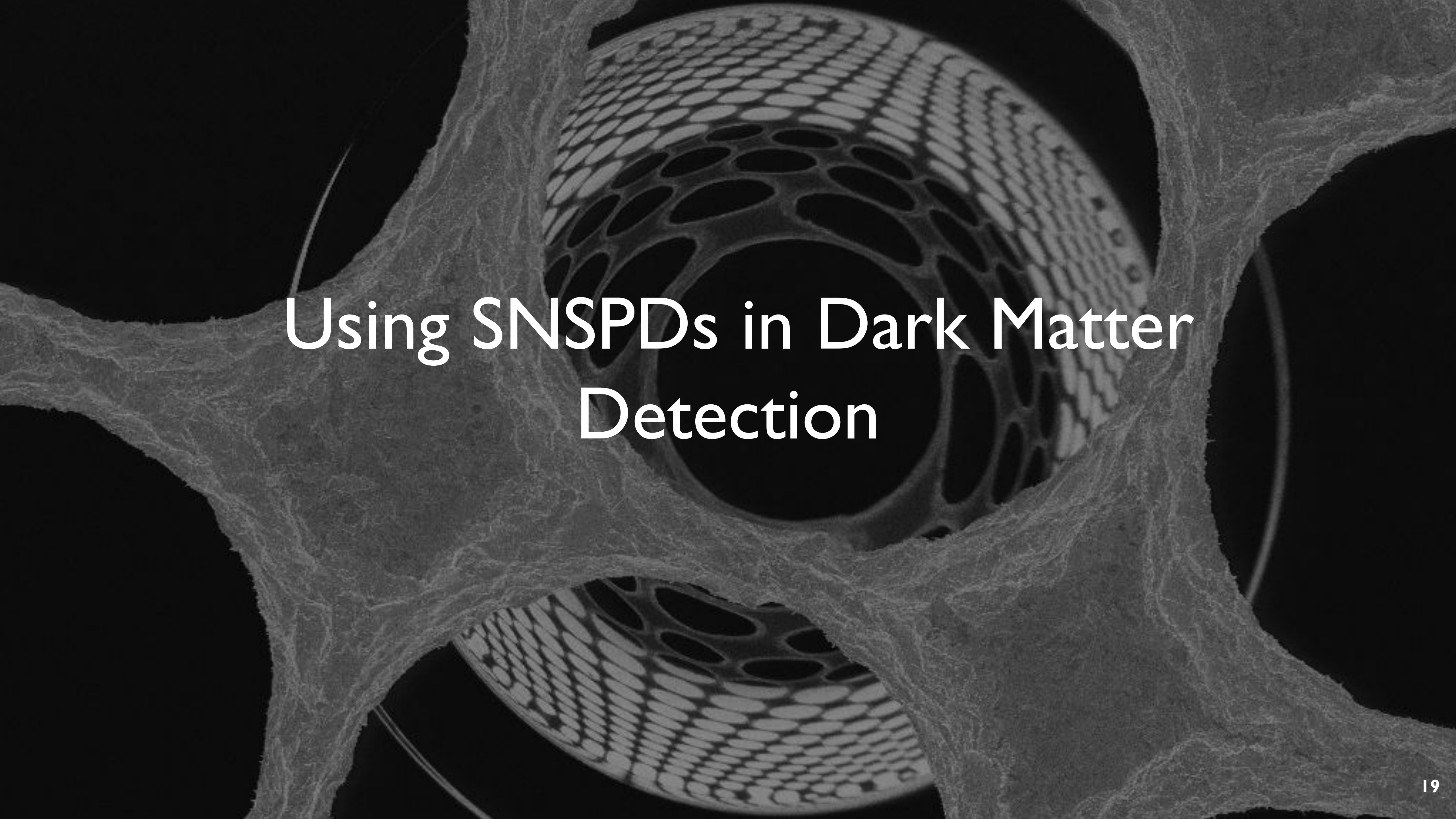




Detecting two-photon-firing events

16 two-photon firing events among 50,000 photon detection events
(flood illumination over the entire area)





Using SNSPDs in Dark Matter Detection

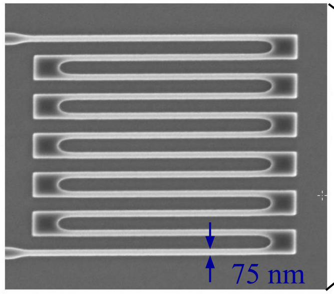
Nanowire Detection of Photons from the Dark Side

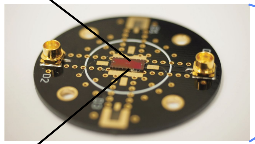
Karl K. Berggren (co-PI, MIT), Sae Woo Nam (co-PI, NIST), Asimina Arvanitaki (Perimeter), Ilya Charaev (MIT), Jeffrey Chiles (NIST), Andrew E. Dane (MIT), Ken Van Tilburg (NYU/IAS), Masha Baryakhtar (Perimeter), Robert Lasenby (Stanford University), Junwu Huang (Perimeter)

Collaboration of fundamental physics theorists, device designers, and system integrators and engineers:

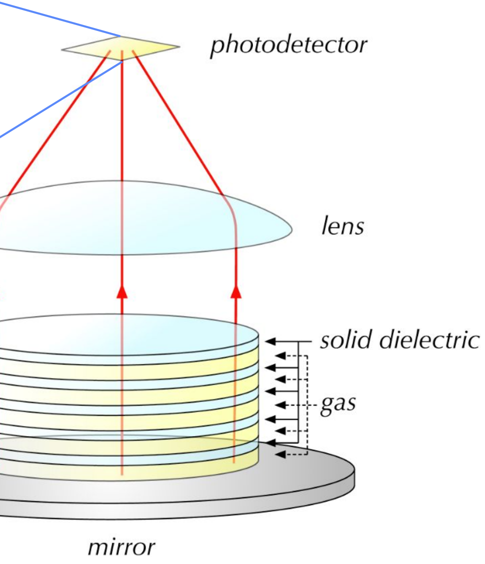
(1) Use quantum interference of dark matter to build up population in a single-photon state;
(2) Use detector technology perfected for quantum-optics to sense photon.

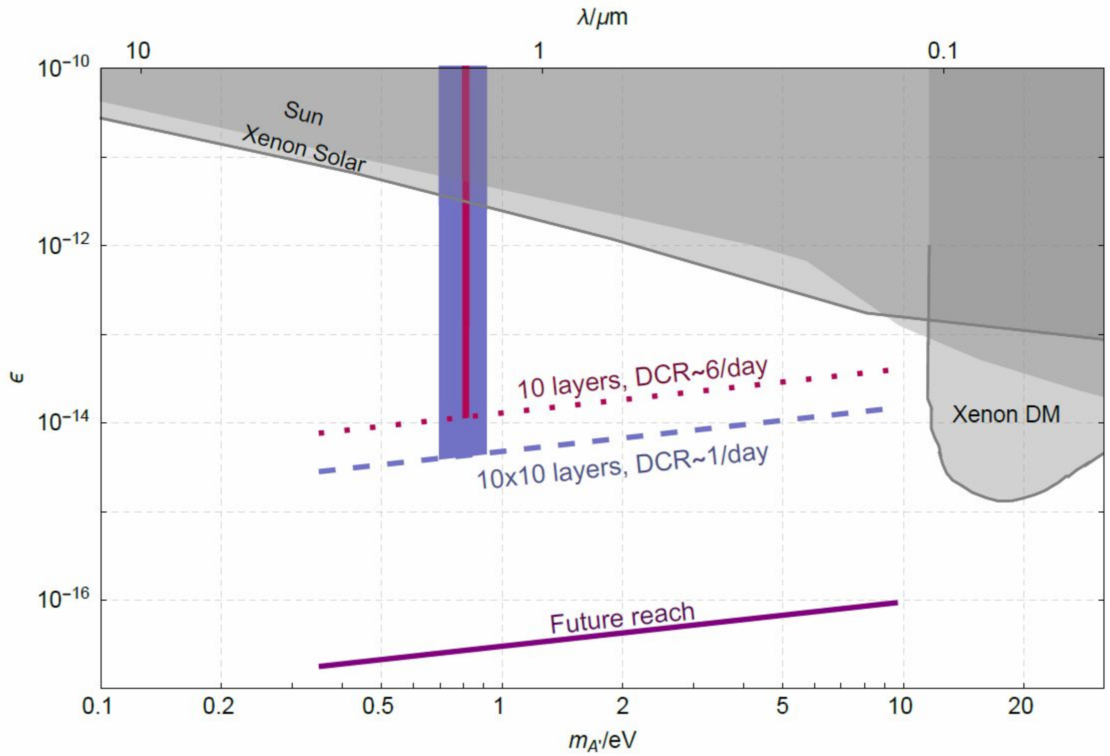
superconducting





Dark-Matter Detector Concept





Key advantage of these detectors is low Dark Count Rate (DCR) and low-energy threshold. Depending on number of layers in target, and achievable DCR, reach of experiment could extend well beyond what is possible today

Could the Detector Itself be a DM Target?

Nanowires-Only Approach

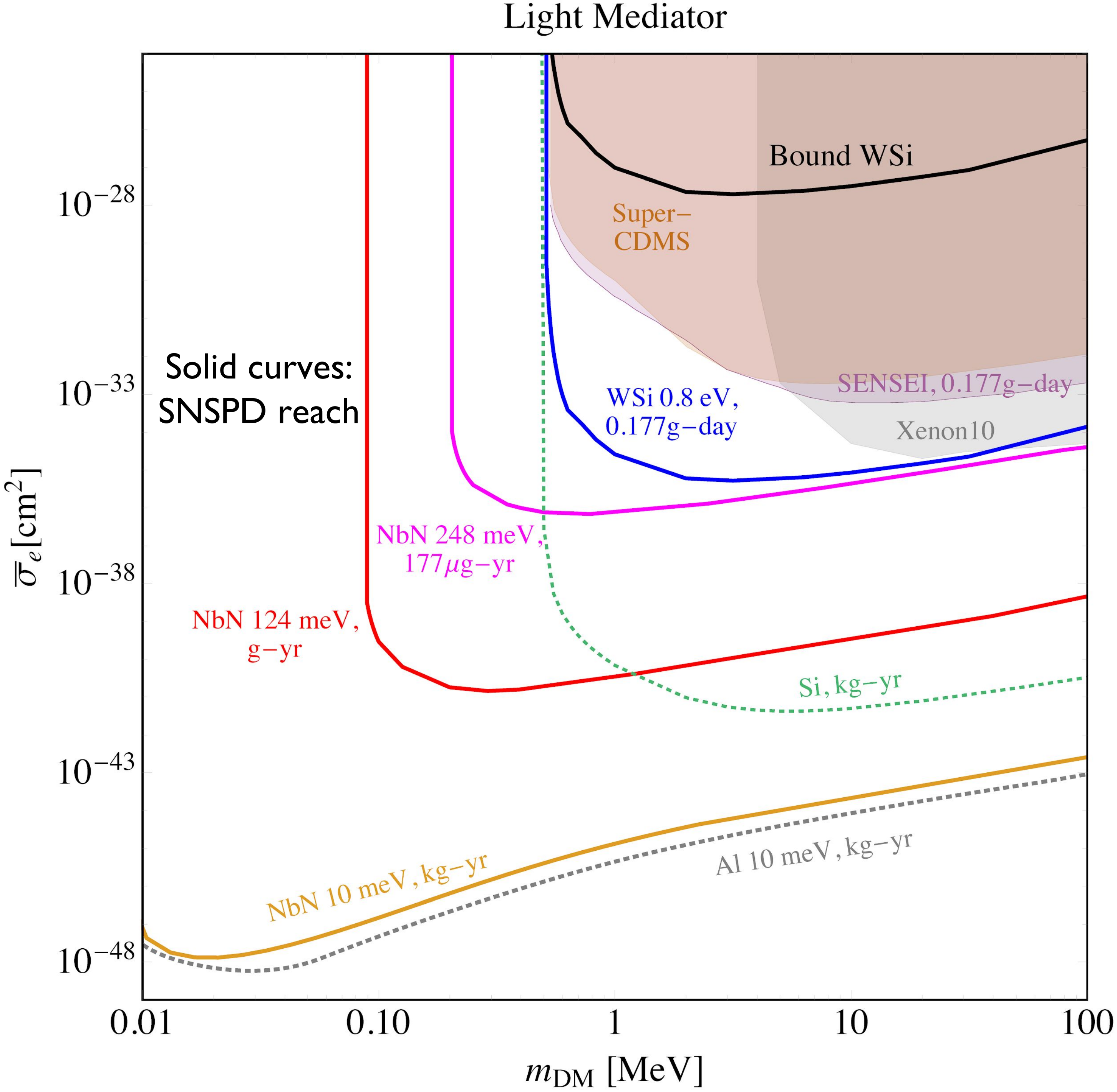
- Use SNSPDs as both target and sensitive sensor for dark matter detection in the lab
- Can detect scattering and absorption processes
- Single/rare event sensitivity
- Low dark counts major advantage
- Low thresholds ⟹ sensitive to low dark matter masses
- Small devices already play meaningful role

Inspired by related proposals, as well as preceding work:
[Hochberg et al, 2017], [Hochberg, Zhao, Zurek, + w/ Pyle, + w/ Lin, 2015]

*[Hochberg, Charaev, Nam, Verma, Colangolo, **KKB**, 1903.05101, submitted to PRL]*

SNSPDs as target + sensor

Dark matter scattering off electrons

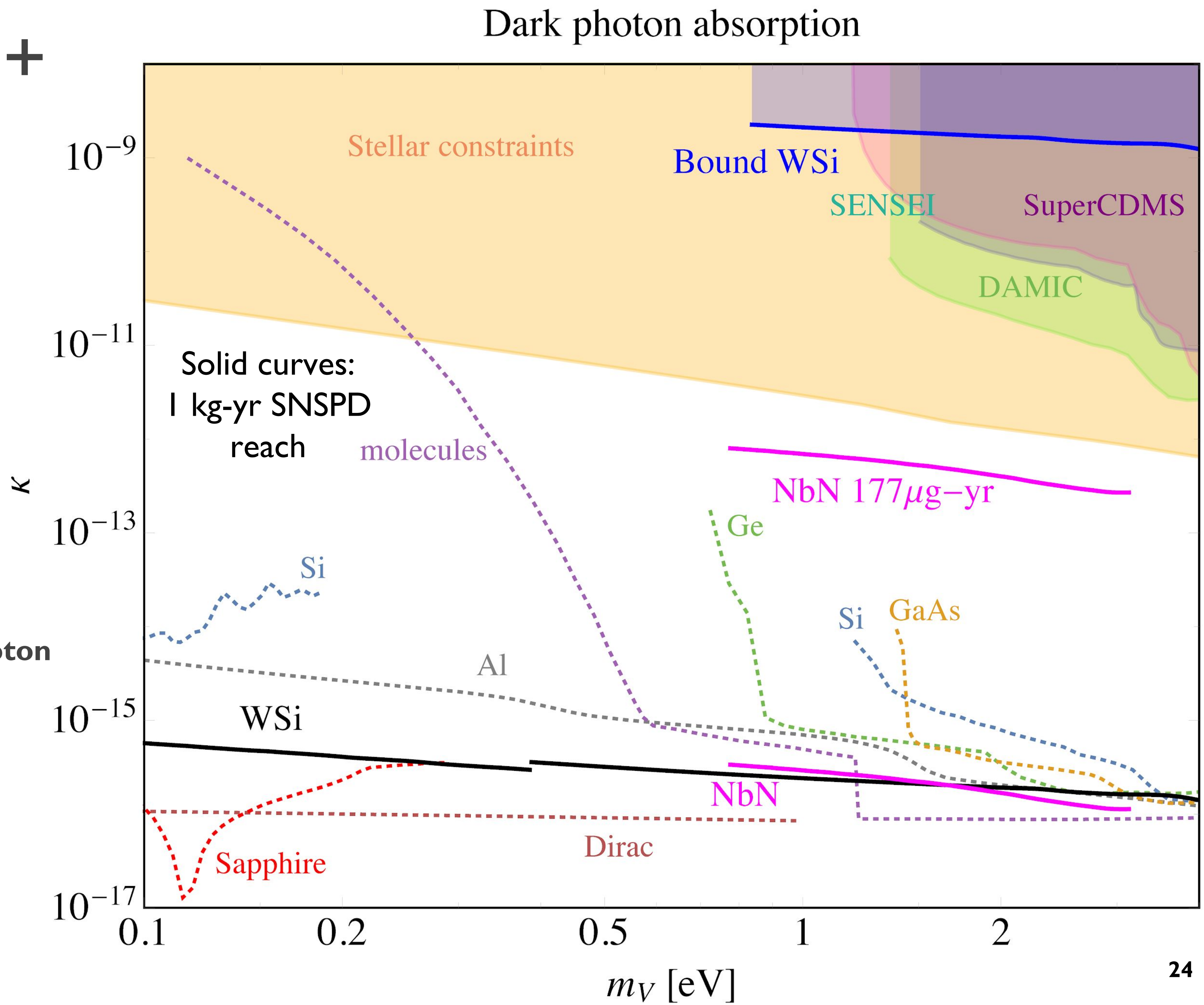


[Hochberg, Charaev, Nam, Verma, Colangolo, KKB, 1903.05101]

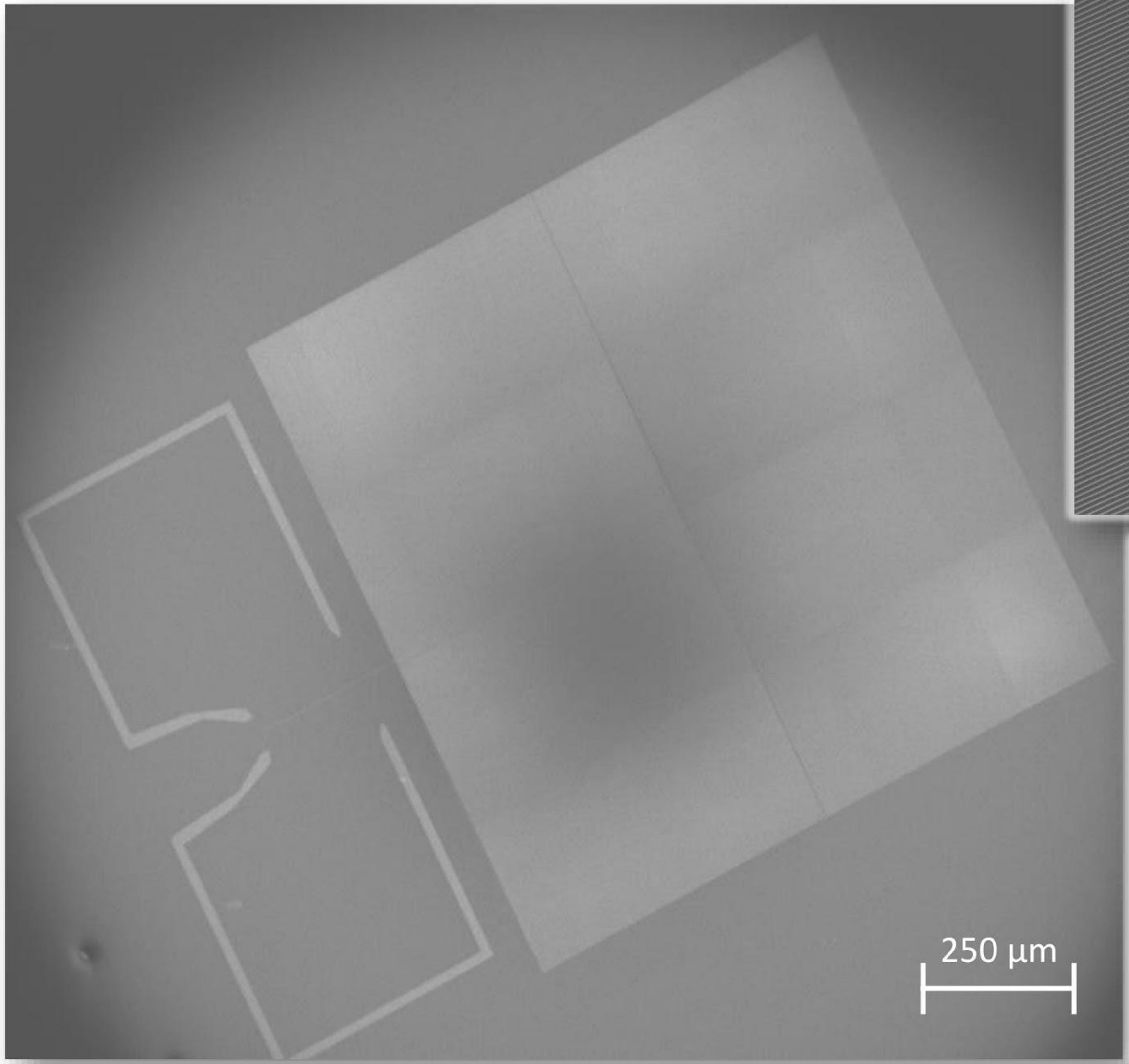
SNSPDs as target + sensor

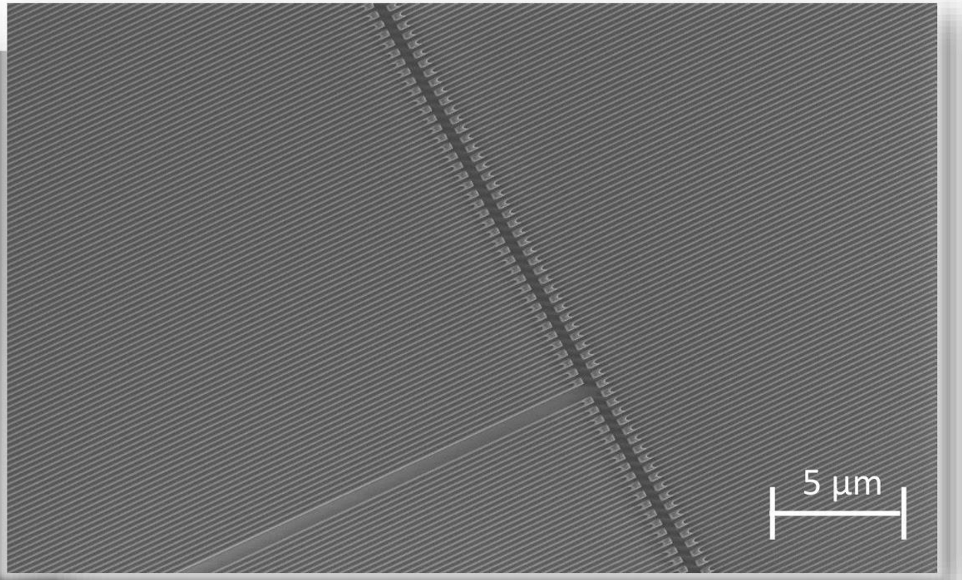
[Hochberg, Charaev, Nam, Verma, Colangolo, KKB, 1903.05101]

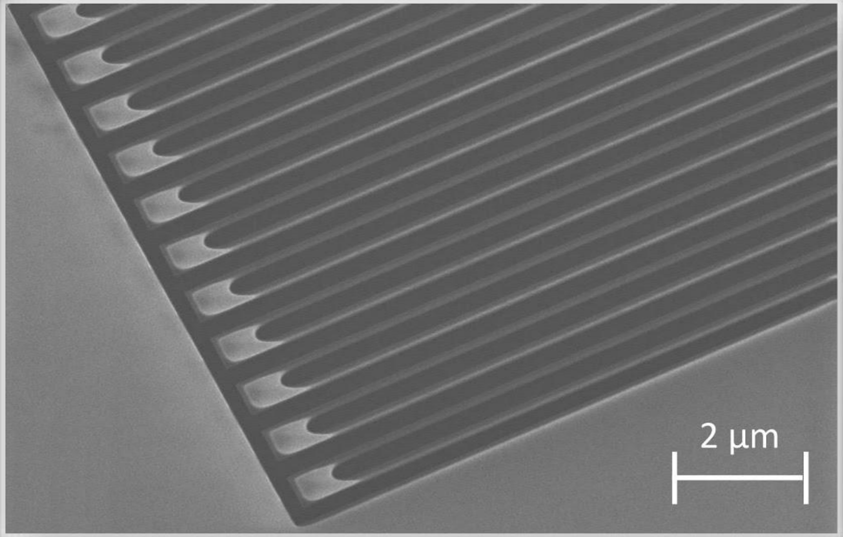
Absorption of kinetically mixed dark photon



Large-area WSi SNSPD







What Are We Excited About?

1. Relatively easy apparatus to set deep and broad limits at low energies

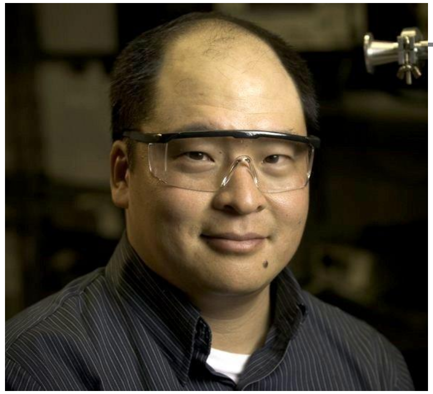
What Are We Worried About?

1. When will we start to see background? What will it look like? What will we do about it?

FINANCIAL SUPPORT

- Dept. of Energy
- U.S. Air force Office of Scientific Research
- U.S. Office of Naval Research
- DARPA DETECT program
- IARPA
- NASA
- NSF
- Skoltech
- Many U.S. and international fellowships

Dark-Matter Collaborators



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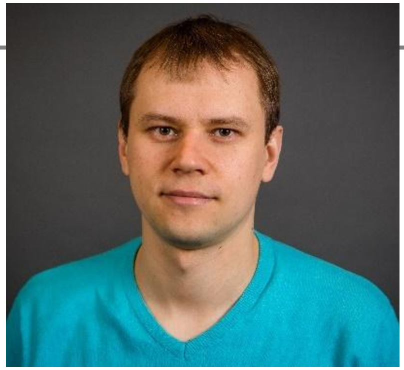
Yonit Hochberg

THE HEBREW UNIVERSITY OF JERUSALEM



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Massachusetts Institute of Technology

Jeff Chiles

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Masha Baryakhtar

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Ken van Tilburg

NYU IAS INSTITUTE FOR ADVANCED STUDY

Robert Lasenby
Stanford

Junwu Huang

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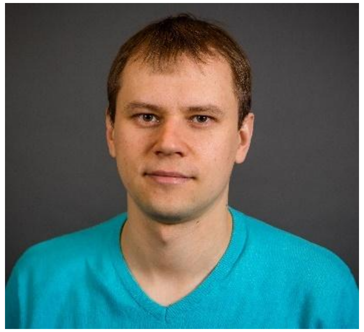
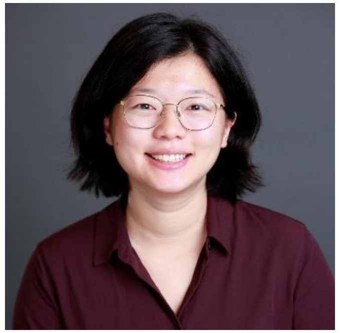
Superconductivity Team in QNN Group


Andrew Dane
(NASA Fellow)

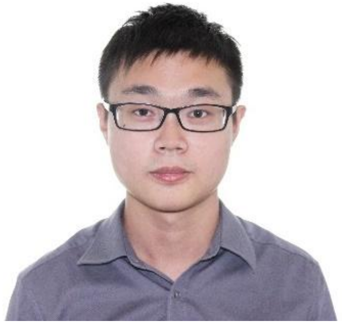

Reza Baghdadi
(Post-Doc)


Emily Toomey
(NSF Fellow)


Ilya Charaev
(Post-Doc)


Ashley Qu
(Grad Student)


Marco Colangelo
(Research Fellow)


Di Zhu
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Brenden Butters
(Grad Student)


Murat Onen
(Grad Student)

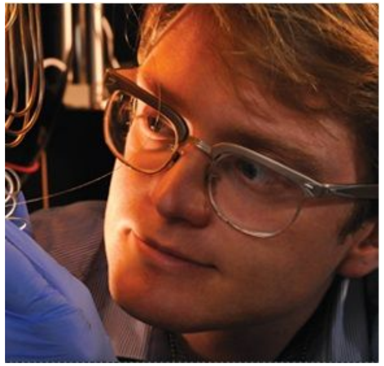
<u>Graduated/Former</u>

Nathan Abebe
Lucy Archer
Francesco Bellei
Ignacio Estay Forno
Niccolo Calandri
Yachin Ivry
Adam McCaughan
Faraz Najafi
Kristen Sunter
Hao-Zhu Wang
Qing-Yuan Zhao

<u>Not Pictured:</u> Glenn Martinez & Owen Medeiros (Undergraduates)

Collaborators

Boris Korzh
(JPL)



Matthew Shaw
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- Angle Velasco (JPL)
- Andrew Beyer (JPL)
- Jason Allmaras (JPL)
- Edward Ramirez (JPL)

- Brian Noble (UNF)
- William Strickland (UNF)

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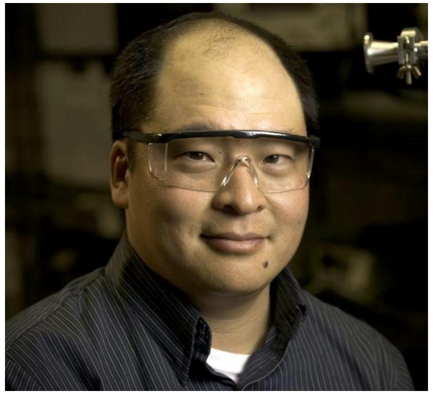

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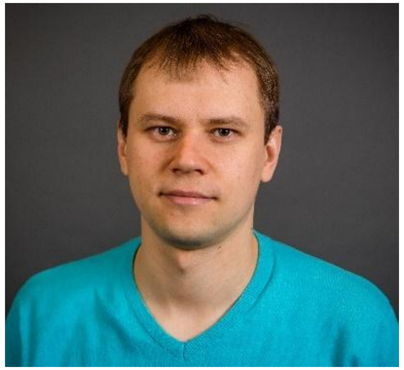
Institute for Advanced Studies



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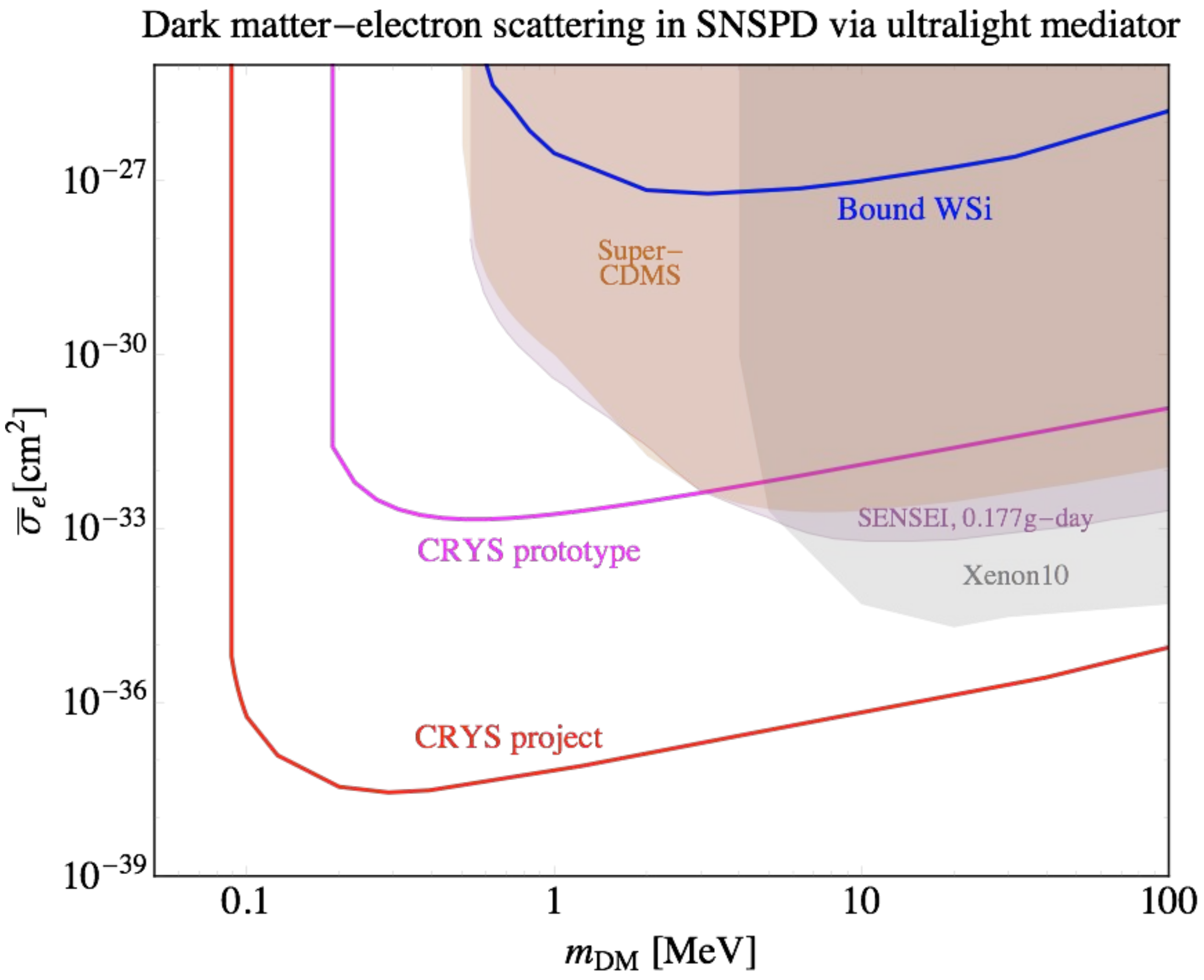
Masha Baryakhtar
New York University

Junwu Huang
Perimeter Institute for Theoretical Physics

END OF PRESENTATION

Backup

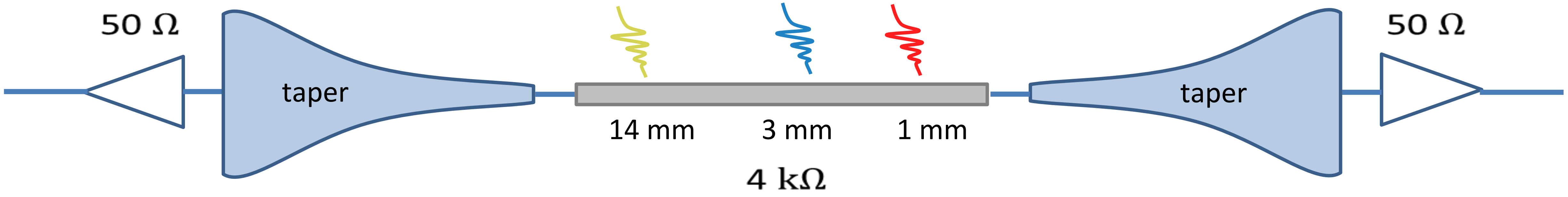


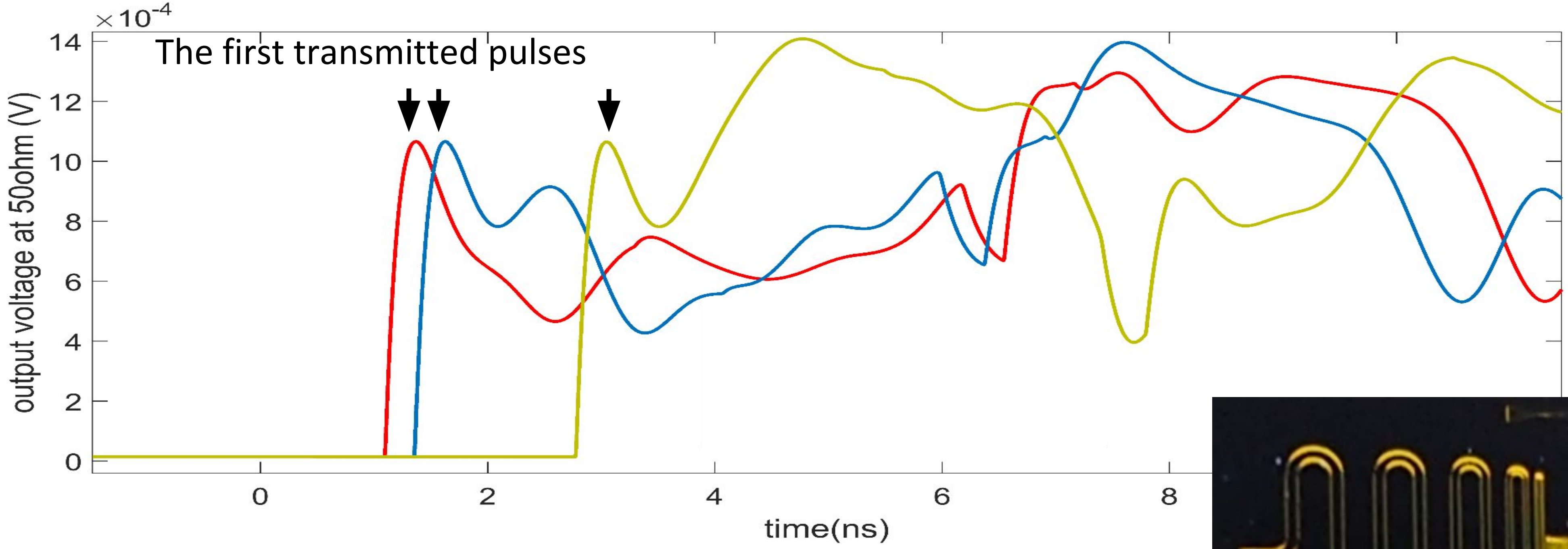
Solid curves: SNSPD reach

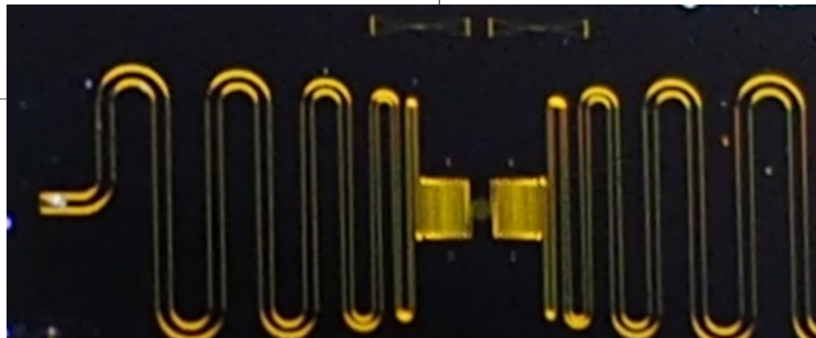
Prototype:
1cm^2,
1e-3 Hz/cm^2 background
1 year

Project::
(100cm)^2,
1e-6 Hz/cm^2 background
1 year

Read out the propagation delay without reflections

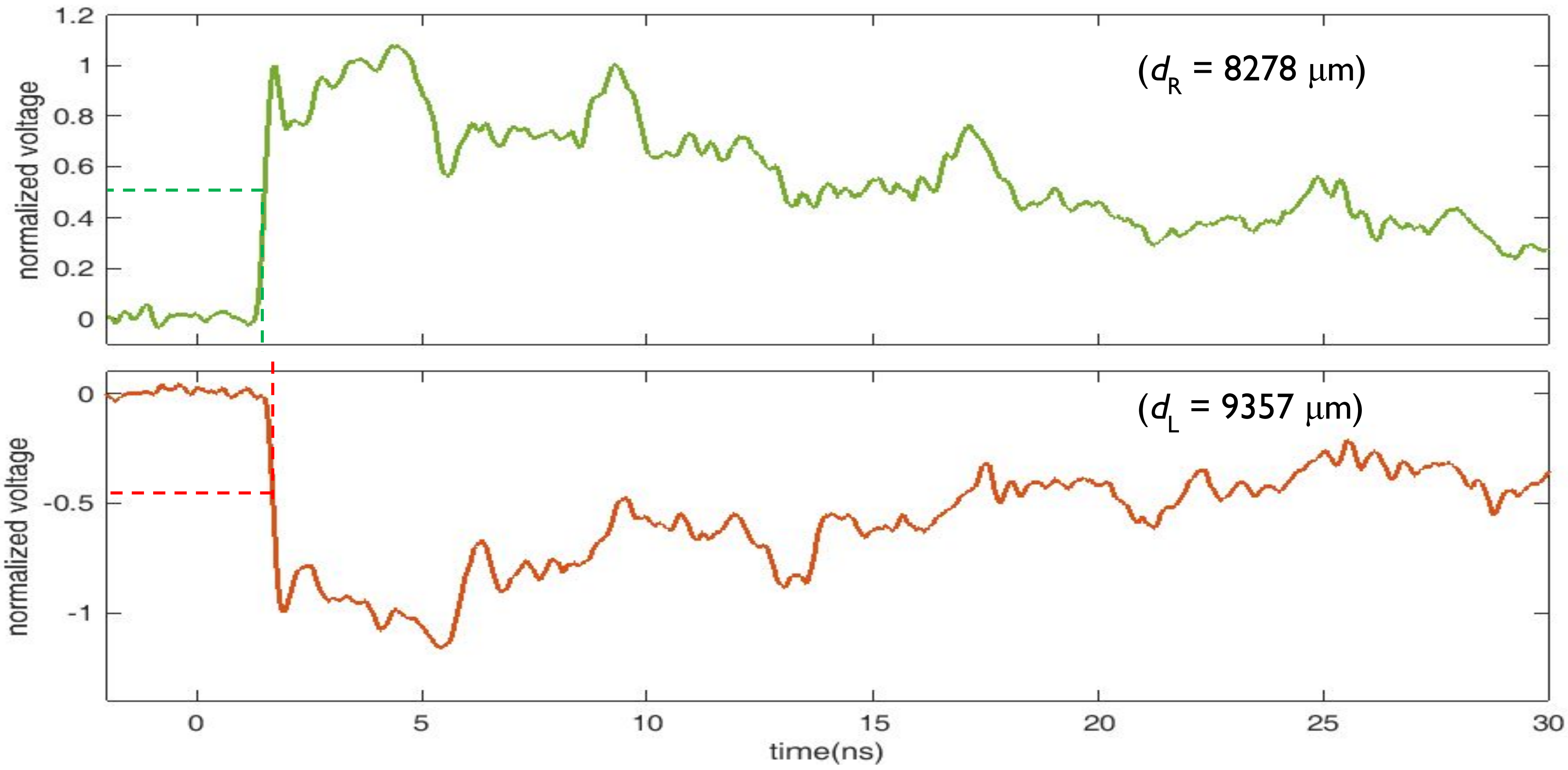






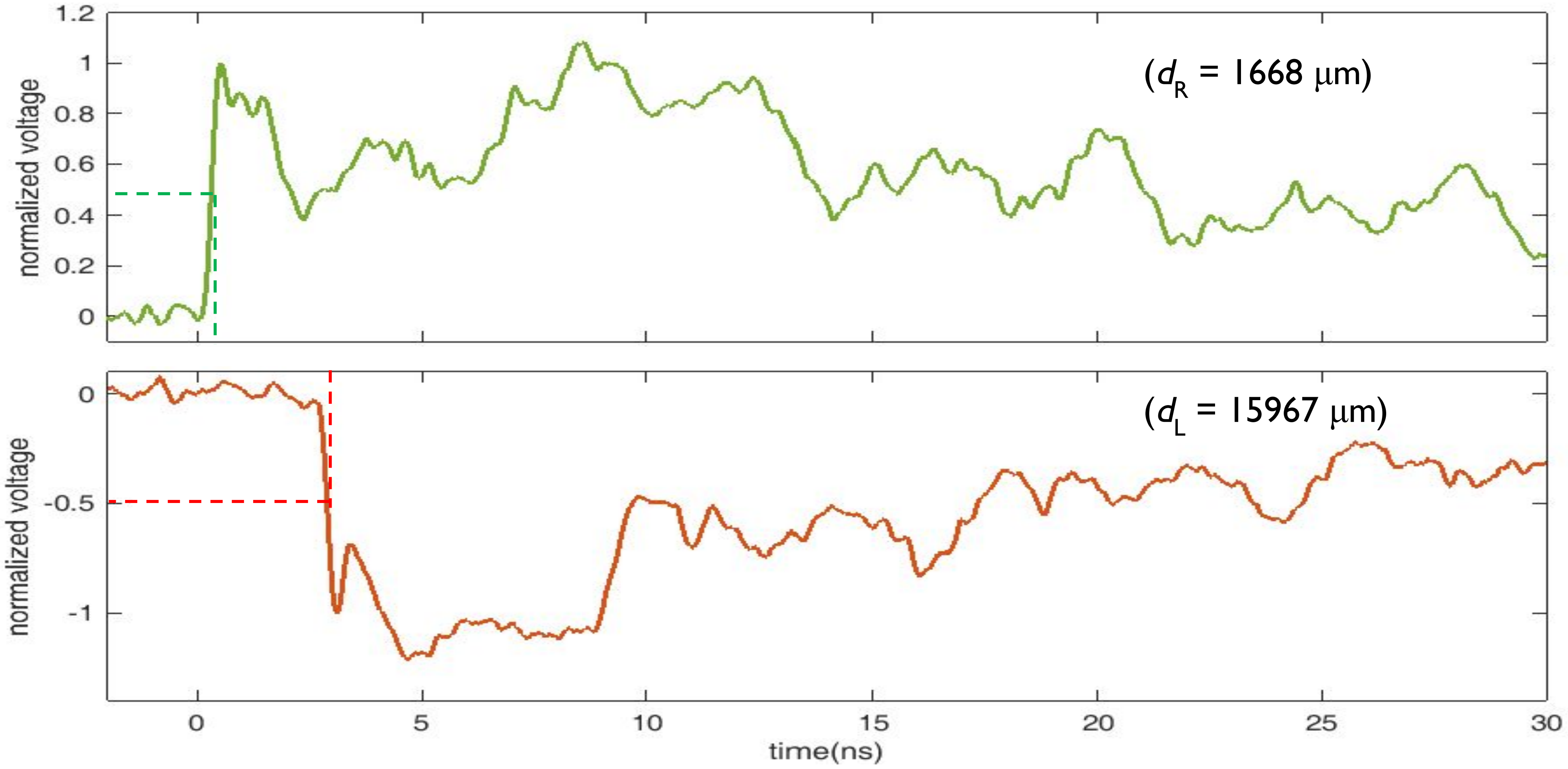
Output pulses from the SNSPI

Photon lands near the middle



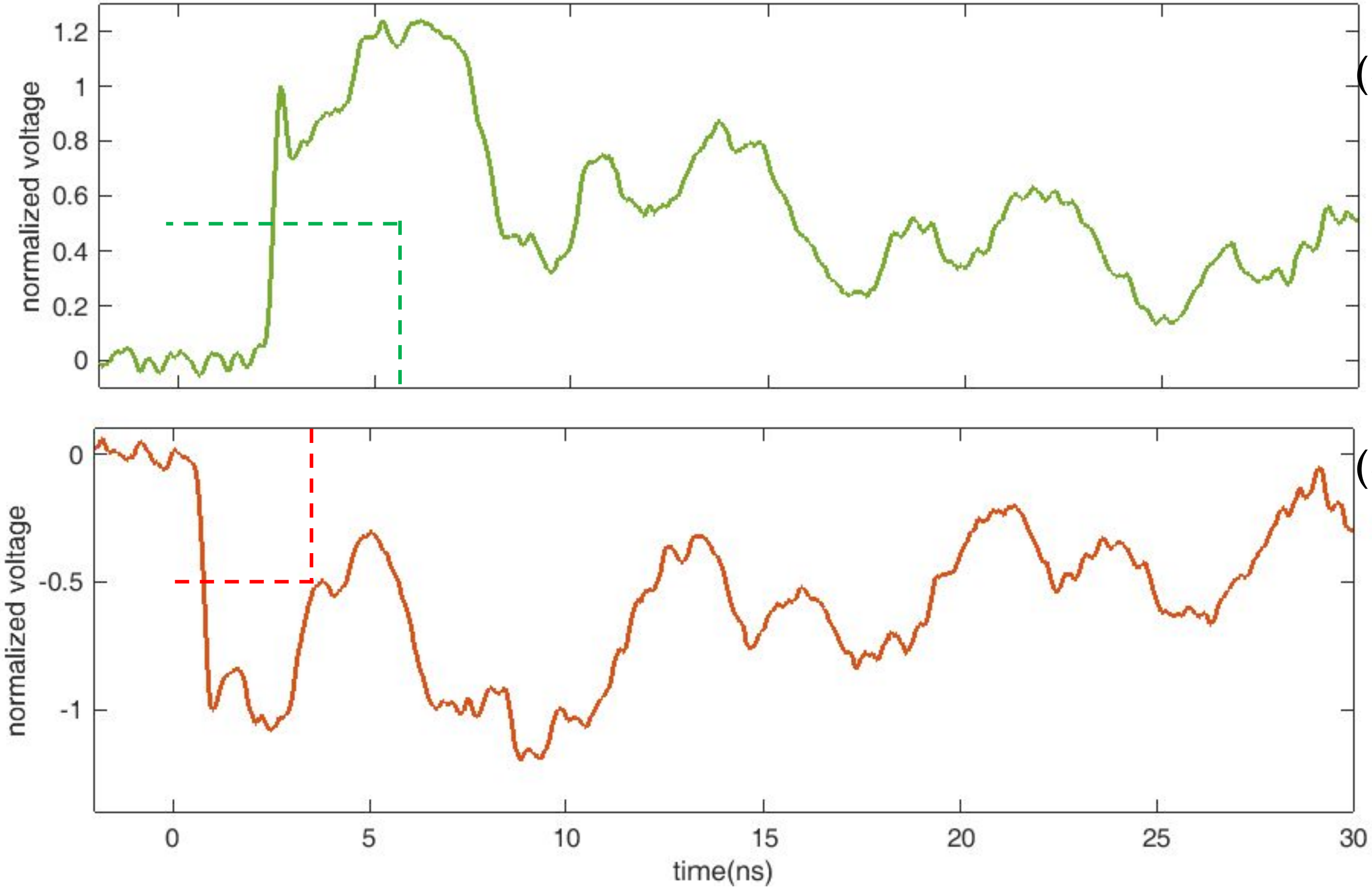
Output pulses from the SNSPI

Photon lands near the right end



Output pulses from the SNSPI

Photon lands near the left end



(d_R = 13317 μm)

(d_L = 4318 μm)