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Progress in Few-Photon Metrology at NRC

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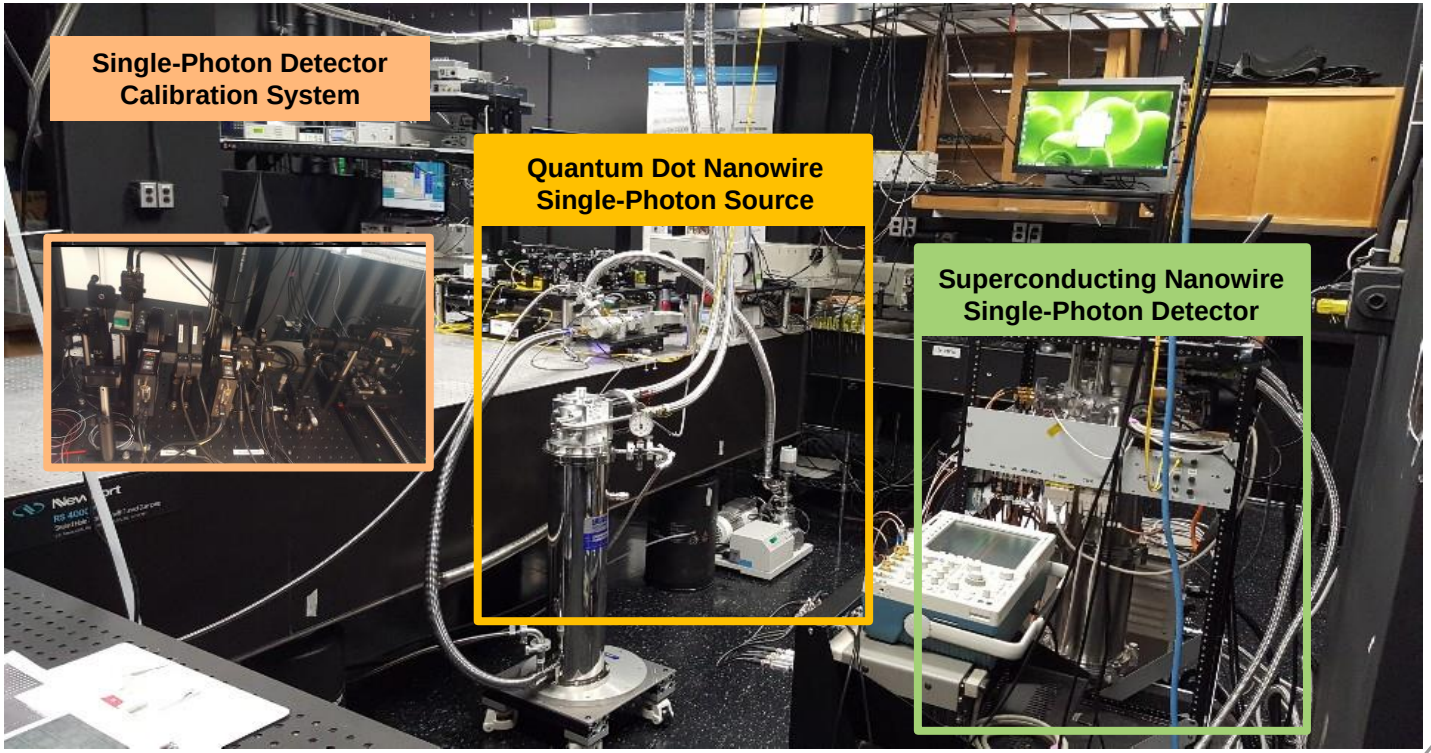
CORM2019

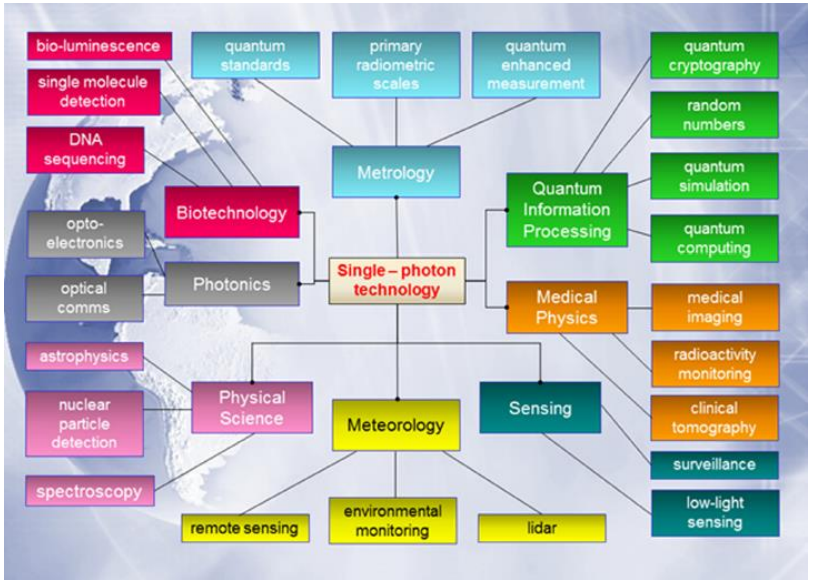
Outline

1. Few-photon metrology for single-photon detectors and sources
2. Single-photon detection efficiency calibration system
3. Single-photon detectors
4. Single-photon sources

Few-photon metrology laboratory



Few-photon metrology for quantum photonics



C. J. Chunnilall *et al.*, *Optical Engineering* **53**, 081910 (2014)

SI-traceable detection-efficiency calibration

NRC Absolute Cryogenic Radiometer

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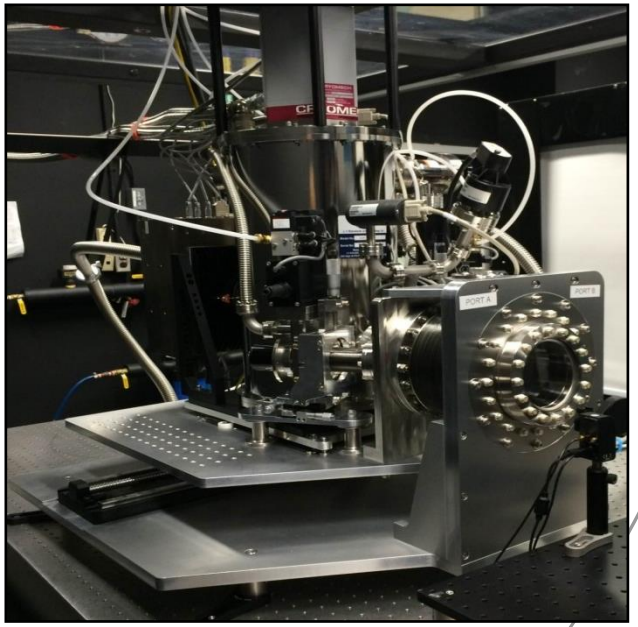
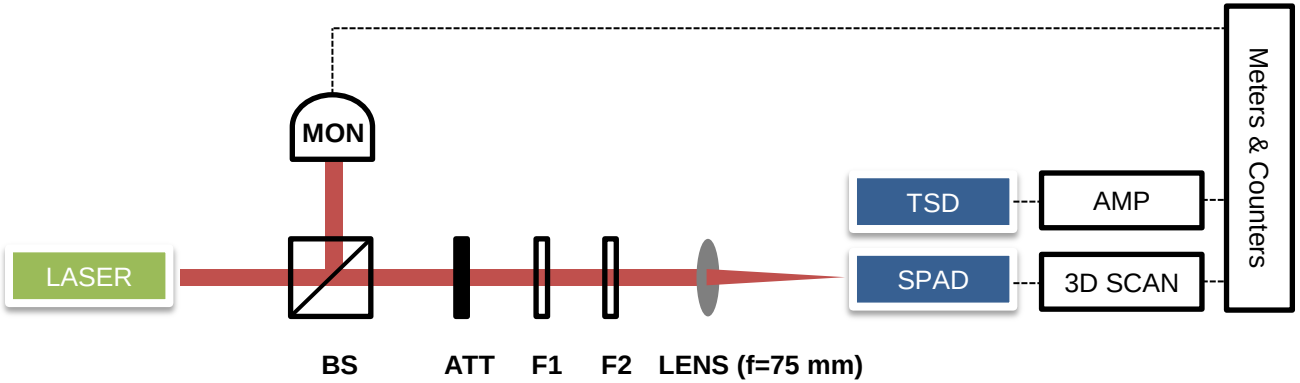
Transfer Standard Radiometer

↓

Single-Photon Detector



Detection efficiency characterization[1]

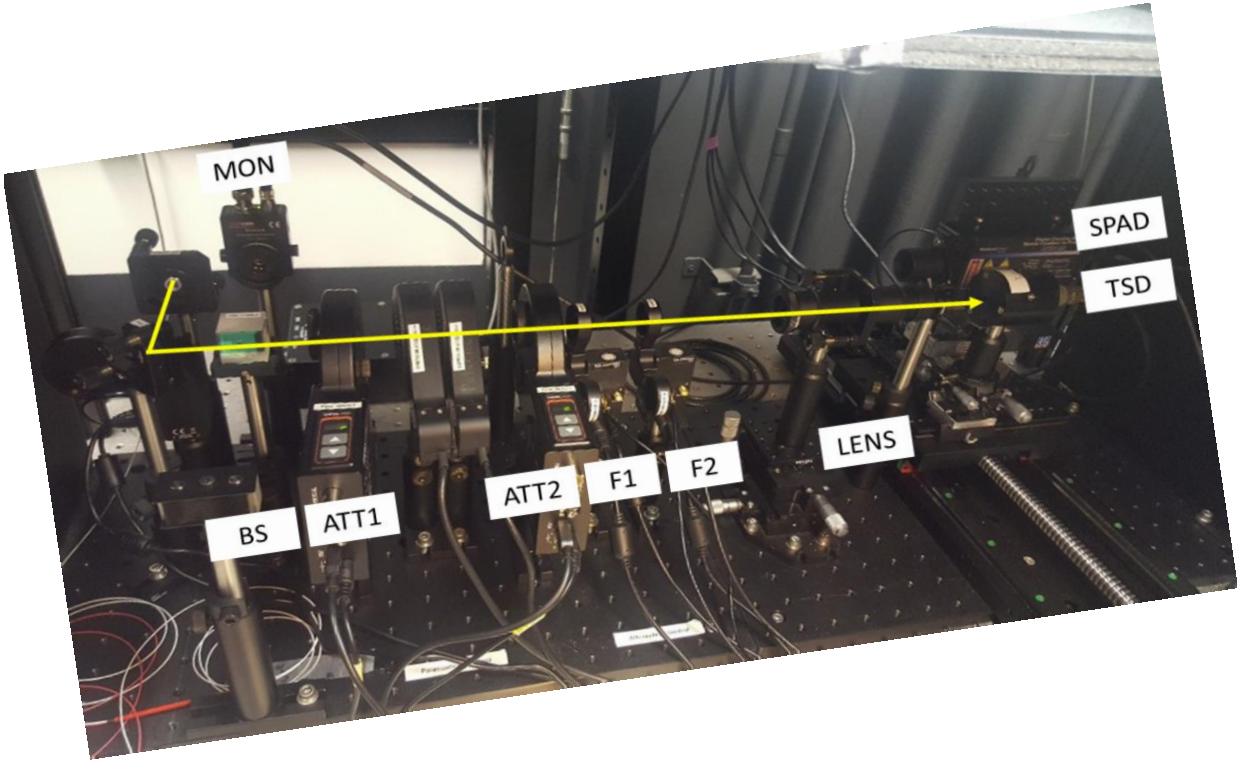


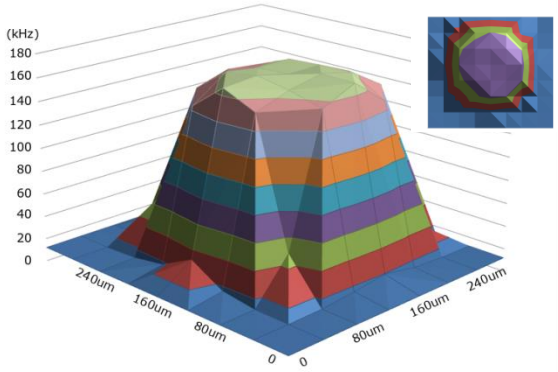
$$\eta_{eff} = \frac{E_{det}}{E_{in}} = \frac{\frac{hc}{\lambda} \times N_{SPAD}}{E_0 \times \prod_{i=1}^{2} T_i} = \frac{hc}{\lambda} \times As \times \frac{Q_0 \times Q_{SPAD}}{Q_1 \times Q_2}$$

h: Planck constant
c: speed of light
λ : wavelength
N_{SPAD}: number of photons detected by SPAD
$T_i (i = 1,2)$: filter transmission
s: TSD spectral responsivity
A: amplification
$Q_i (i = 0,1,2)$: ratio $V_i/V_{i,mon}$
Q_{SPAD} : ratio $N_{SPAD}/V_{SPAD,mon}$

[1] M. López *et al*., *J. Mod. Opt.* **62**, S21 (2015)

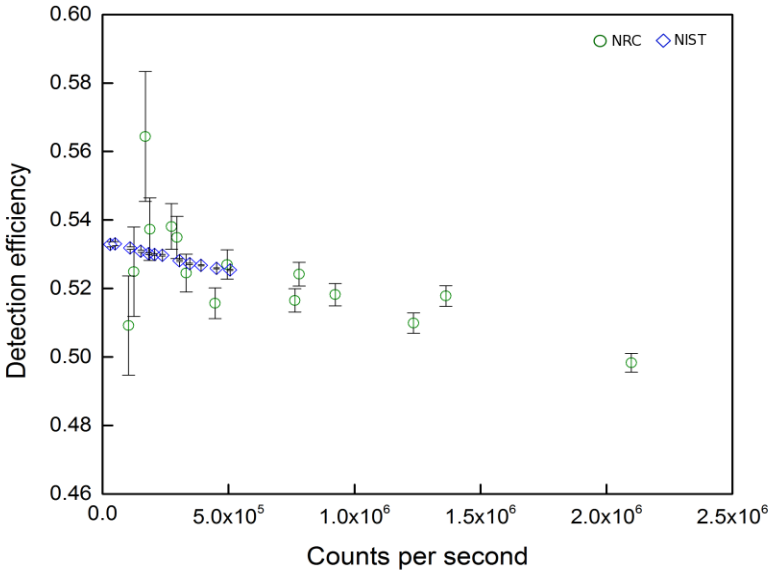
Measurement apparatus

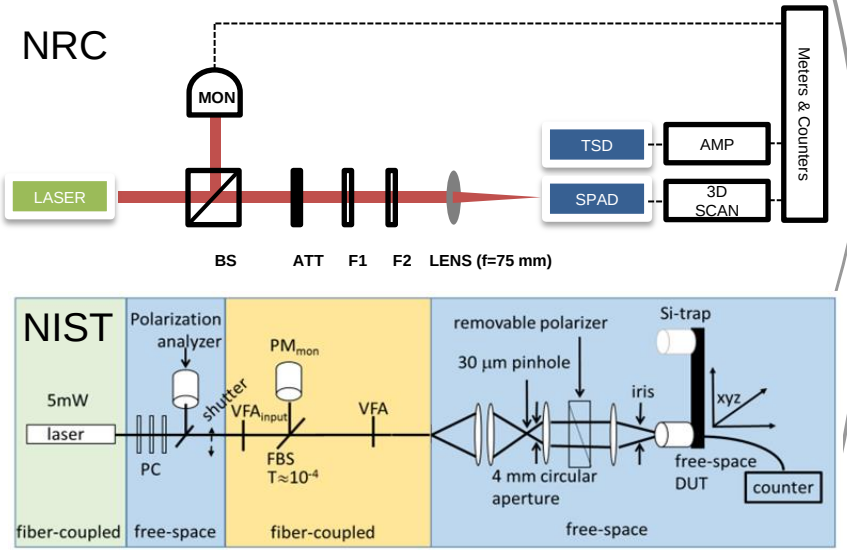




Active area of SPAD

Measurement results





Single-photon detector at NRC
in collaboration with NIST

Type: superconducting nanowire

Material: Tungsten silicide

Operating temperature: 0.7 K

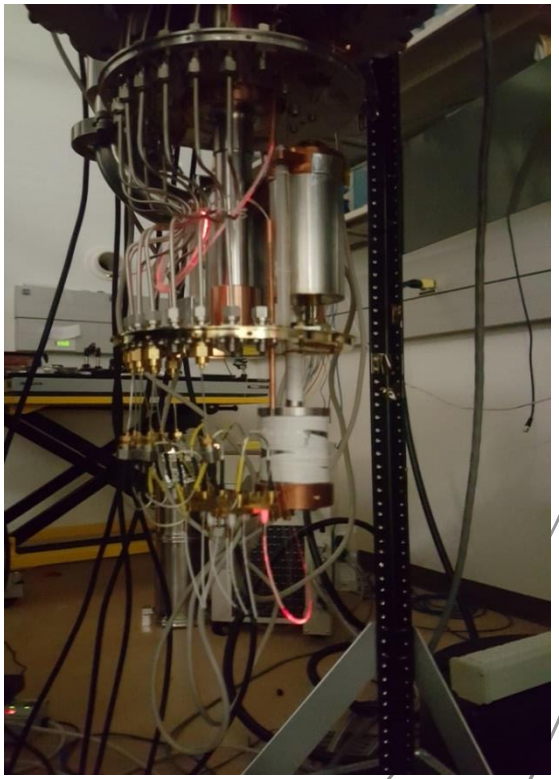
Wavelengths: 800, 1064, and 1550 nm

Efficiencies: > 90 %

Timing resolution: 80 ps

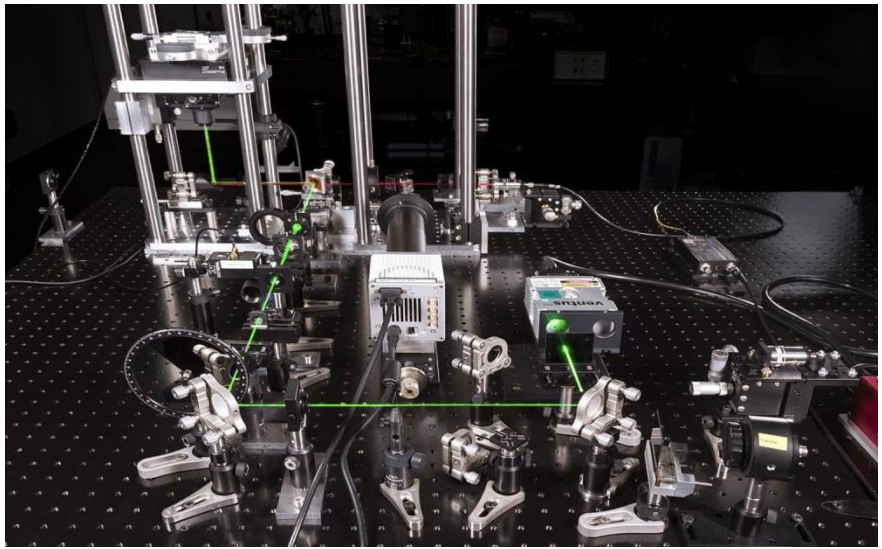
Dark counts: < 1Hz

Recovery time: 30 ns

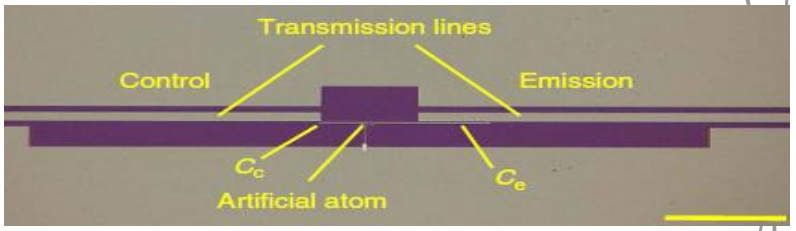


Single-photon source towards quantum candela

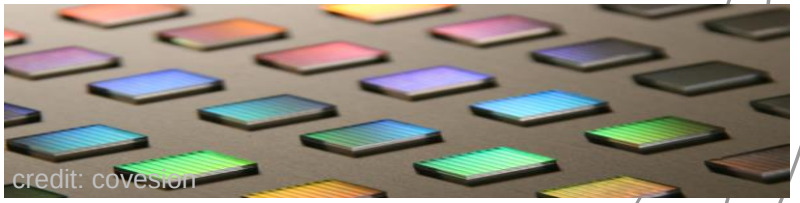
PTB: NV-centered diamond[1]



NPL: artificial atom[2]



INRIM: PP-lithium niobate crystal[3]



[1] B. Rodiek *et al*., *Optica.* **4**, 71 (2017)
[2] Z. H. Peng *et al*., *Nature Communications.* **7**, 12588 (2016)
[3] E. Rebufello *et al*., *Metrologia.* **56**, 025004 (2019)

Single-photon source at NRC

in collaboration with NRC Advanced Electronics and Photonics & Security and DisruptiveTechnology

Type: semiconductor quantum dot nanowire

Material: InAs-InP

Operating temperature: <10 K

Wavelength: 930 nm

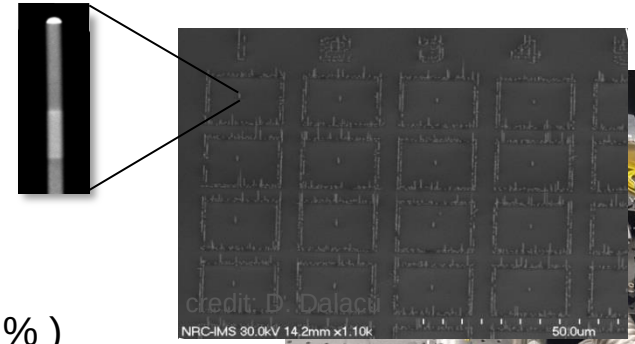
Lifetime[1]: 1.6 ns

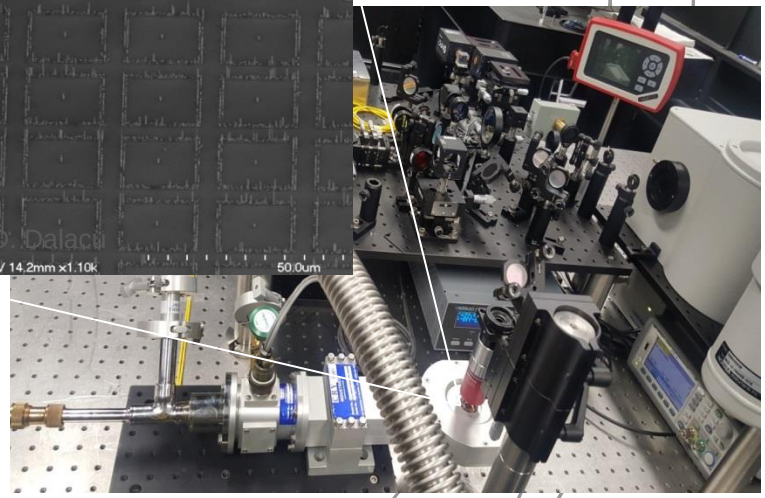
Bandwidth[1]: 4 μeV

Efficiency[1]: 43 % (di-directional -> total 86 %)

Single-photon purity[1]: 0.002 (0 for a true single photon)

Tapered waveguide





[1] D. Dalacu *et al*., *Nanotechnology* **30**, 232001 (2019)

Towards single-photon metrology