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Monte-Carlo-Markov-Chain Detector Tomography of Nanobridge SNSPDs with 56% quantum efficiency

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Superconducting Nanowire Single Photon Detectors (SNSPDs) are a leading technology for quantum optics and information, offering fast recovery, low timing jitter, high detection efficiency, and intrinsic photon number resolution, making them ideal for future quantum applications [1]. We introduce a Monte-Carlo-Markov-Chain (MCMC) approach to Detector Tomography for nanobridge NbTiN devices, separating internal and external quantum efficiencies. This is key to understanding SNSPD detection mechanisms and performance trade-offs.

We perform MCMC Detector Tomography on a 120 nm × 120 nm nanobridge SNSPD made from a 13 nm NbTiN thin film connected to a ∼ 700 nH on-chip inductor to prevent latching. The detector is cooled to 4.2 K and illuminated with an 850 nm, picosecond pulsed laser at 5 MHz repetition rate. The optical power is monitored by a power meter to correct fluctuation while the power is varied from 5 nW to 7 µW. Count events are recorded using a 5 GS s^{-1} digitizer and dark counts are discarded by selecting only counts that arrive within a 10 ns window from the laser pulse. This filtered data allows precise determination of the click probability per pulse P_{click}.

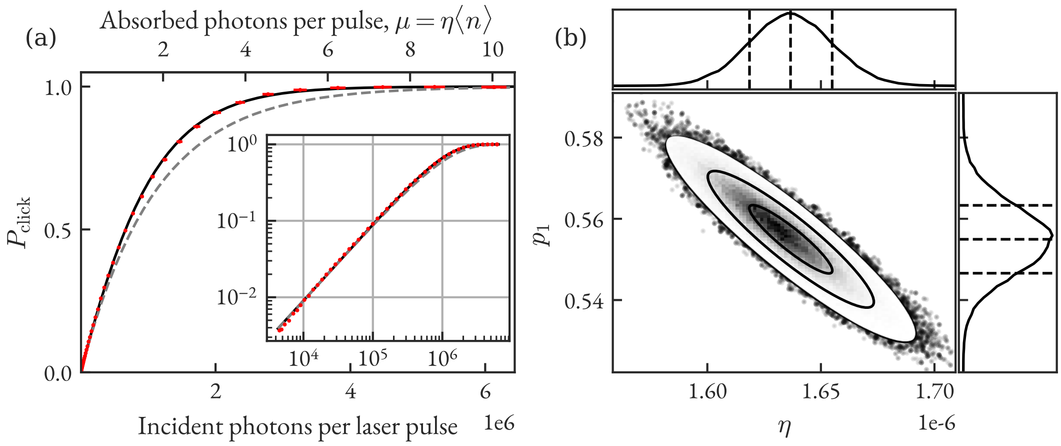

Fig. 1 MCMC detector tomography. **(a)** Measured click probability vs. incident photons per pulse. Data (red symbols) are fitted to the model ($\eta = (1.64 \pm 0.02) \times 10^{-6}$, $p_1 = 0.56 \pm 0.01$) and compared to a curve for an ideal single-photon threshold detector (dashed line). **(b)** Result of the MCMC analysis showing the covariance between fit parameters.

Figure 1 shows the measured detection probability as a function of the average photons per pulse for the 120 nm-wide nanobridge. The detector shows clear saturation at $P_{\text{click}} = 1$ as well as clear single photon detection at low powers as is evident from the linear dependence at low powers (see inset of Fig. 1).

The click probability for pulsed laser illuminated detectors is given by [2]

$$P_{\text{click}} = 1 - \exp\left(-\eta \langle n\rangle\right) \sum_{i=0}^{N_{\max}} (1 - p_i) \frac{(\eta \langle n\rangle)^i}{i!}, \tag{1}$$

where η is the external quantum efficiency (absorption), p_i is the internal quantum efficiency for an i-photon event and $\langle n\rangle$ is the average number of photons per pulse. The MCMC method yields an internal detection efficiency of 56%, which we explain by the relatively inefficient tapered connection parts of the nanobridge.

We will present a detailed analysis of photon detection in nanobridge detectors, including data on detection efficiency at higher laser repetition rates, revealing a surprisingly lower maximum rate for accurate detector tomography than expected from the inverse reset time. Our Monte-Carlo-Markov-Chain results enable comparisons across various device geometries. For the first time, modified tomography can be applied to detectors with external quantum efficiencies from 10^{-6} to near 100%, offering a robust method to explore SNSPD limitations and performance trade-offs.

References

[1] I.E. Zadeh, J. Chang, J.W.N. Los, S.Gyger, A.W. Elshaari, S. Steinhauer, S. N. Dorenbos and V. Zwiller, "Superconducting nanowire single-photon detectors: A perspective on evolution, state-of-the-art, future developments, and applications" Appl. Phys. Lett. **118** (2021).
[2] J.J. Renema, G. Frucci, Z. Zhou, F. Mattioli, A. Gaggero, R. Leoni, M.J.A. de Dood, A. Fiore, and M.P. van Exter, "Modified detector tomography technique applied to a superconducting multiphoton nanodetector," Opt. Express **20**, 2806 (2012).

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