Nonlinear Response of Single-Photon Detectors

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The efficient detection and counting of single photons provide a quantum advantage regime, enhancing measurement sensitivity crucial for cutting-edge technologies. However, photon-counting measurement precision is significantly affected by the nontrivial response of detectors, which stems from the strong inherent nonlinear nature of single-photon detection and detector-specific phenomena. This can be particularly harmful in comparative measurements with count rates varying over a large dynamic range, as arising in quantum state tomography, correlated photon-pair spectroscopy or experimental tests of quantum physics. We extensively investigated the detection nonlinearity and contributed to the ultraprecise identification and mitigation of nonlinear effects in single-photon detectors, paving the way to significantly improve detector performance and advance measurement accuracy.

We designed and experimentally realized a direct measurement of single-photon detection nonlinearity using incoherent-beam superposition, enabling stable, error-free, self-contained operation without calibrated references. We characterize nonlinearity with unprecedented accuracy across seven orders of magnitude of incident illumination. We investigate SPADs and SNSPDs and report anomalous saturation counteracting effect (supralinearity) in both. For SPADs, this is new and unexplained by current models; for SNSPDs, we observe for the first time supralinearity under faint continuous illumination at very low detection rates, empirically describable by two-photon detection events [2]. By uncovering previously unexplained nonlinear behavior, this work paves the way for a new level of precision and reliability in single-photon measurements.

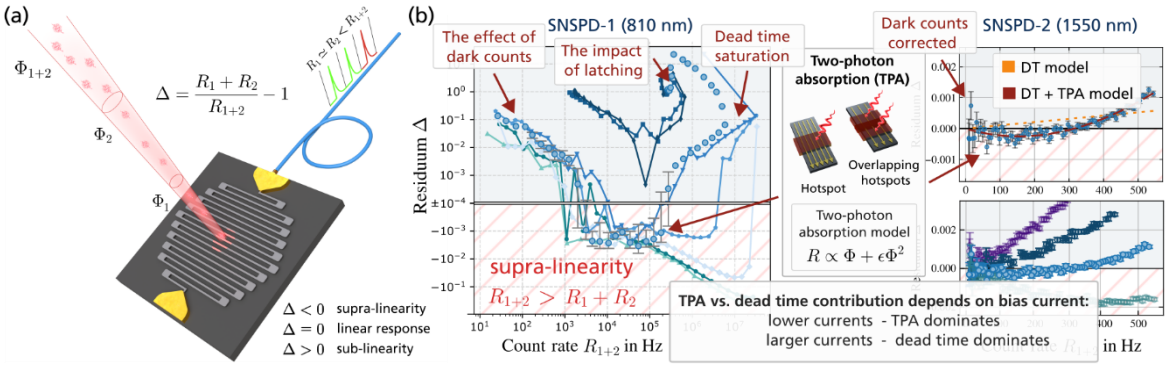

Fig. 1: *(a) Illustration of detector nonlinearity and its (b) measured behavior in SNSPDs.*

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References

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