Impact of statistics of entangled photon sources on quantum key distribution: parametric generators and quantum dots

R. Hošák[1], I. Straka[1], A. Predojević[2], R. Filip[1], M. Ježek[1]

Abstract: The effect of photon-pair generation rate on quantum entanglement is analyzed. Two techniques of producing polarization entanglement are compared in terms of quantum key distribution performance: spontaneous parametric down-conversion and a self-assembled quantum dot. We find that the secure key rate of down-converted photon pairs is limited by multiphoton contributions that are fundamentally unavoidable. The secure key rate of quantum dots is limited only technically by photon collection efficiency.

Related Publications: R. Hošák et al., (2020, in preparation)

Palacký University Olomouc

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[1] Department of Optics, Palacký University, 17. listopadu 12, 77146 Olomouc, Czech Republic
[2] AlbaNova University Center, Stockholm University, Department of Physics, SE – 106 91, Stockholm, Sweden

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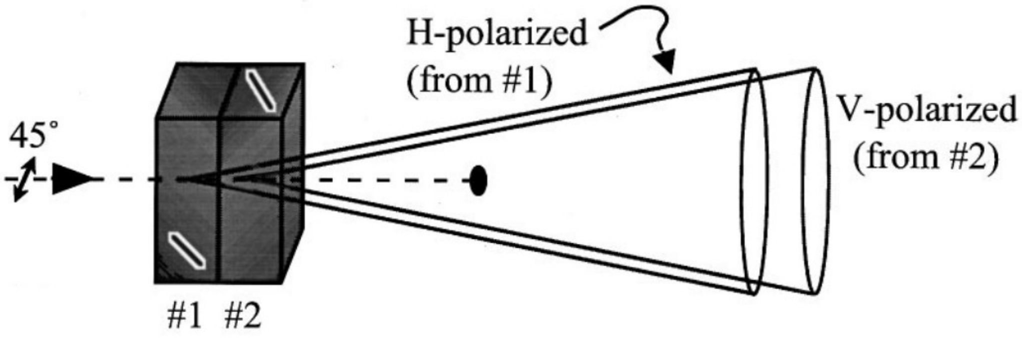
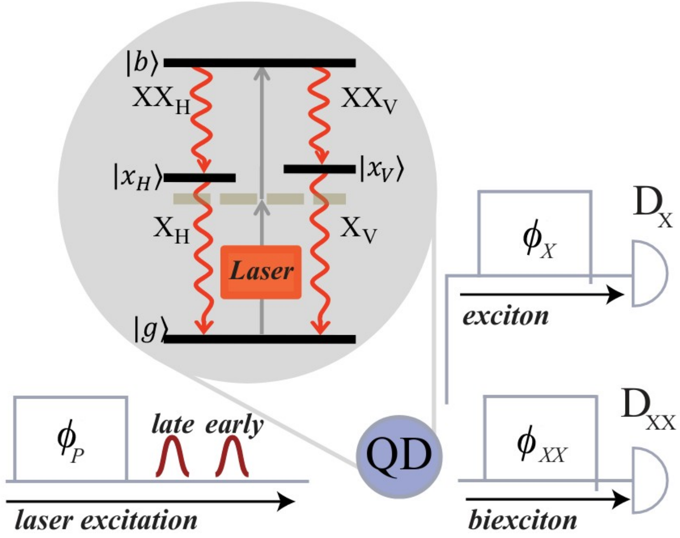
Evaluating the performance of entanglement sources in quantum protocols

Motivated by application: Device independent QKD protocols relies on entanglement as a security guarantee.





Analysis and comparison: SPDC (left) and quantum dots (right) both produce entangled states. However, they differ in photon number *statistics.*

How viable are these entanglement sources in applications? How to compare them across multiple different implementations with different statistics?

We choose to study the effect of statistics on performance in a QKD protocol. We focus especially on the secure key rate lower bound (r_{DW})

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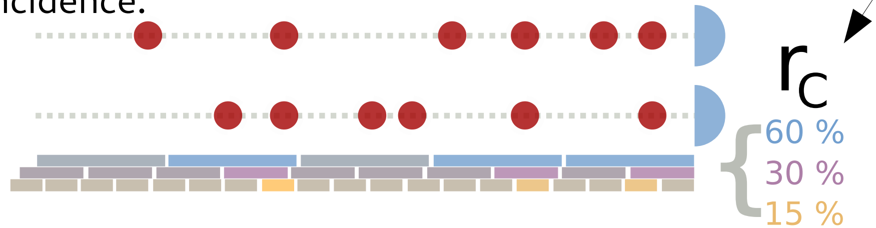
Parametric down conversion based sources

Starting point: A low-gain SPDC process produces states close to a perfect Bell state. Higher-gain SPDC yields better r_C, at the cost of deteriorated entanglement.

Emulation of higher-gain SPDC is possible by lengthening the coincidence window to allow photons from *independent* low-gain SPDC processes to be registered as a coincidence.

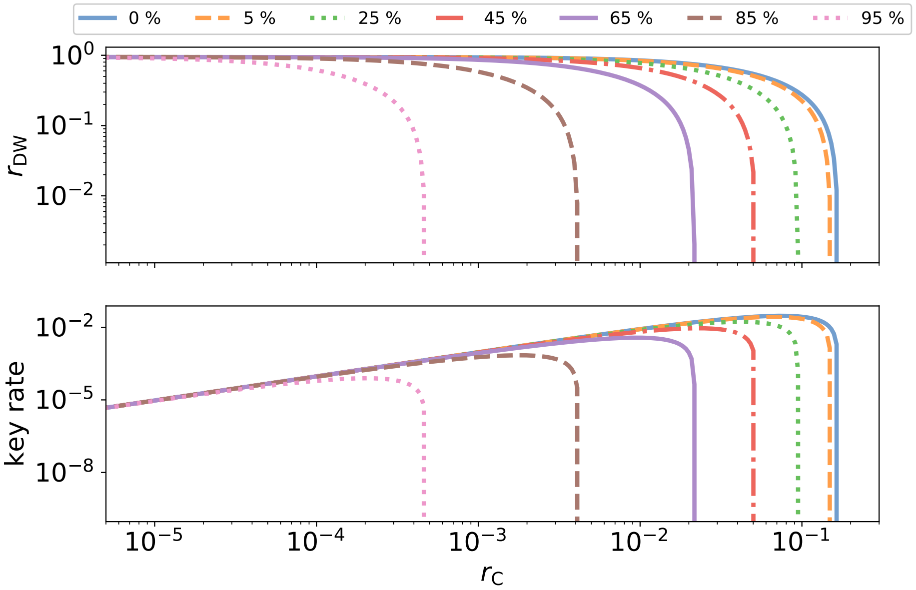


This allows us to study the effect of multi-pair statistics in high-gain SPDC states on performance in the QKD protocol

From coincidences to characterization: We calculate/measure coincidence counts for tomographic projections. From there we reconstruct an effective multi-photon entangled quantum state, and we calculate the secure key rate lower bound (r_{DW}) along with the absolute key rate (in bits per pulse, or bits per coincidence window – depending on pump regime).

Coincidence rate (r_C): The probability of registering a coincidence during a coincidence window. Alternatively the probability of coincidence per excitation pulse.

The multi-photon nature of SPDC states results in **progressively deteriorating performance** in the QKD protocol. Shown for different amounts of overall loss in the system.

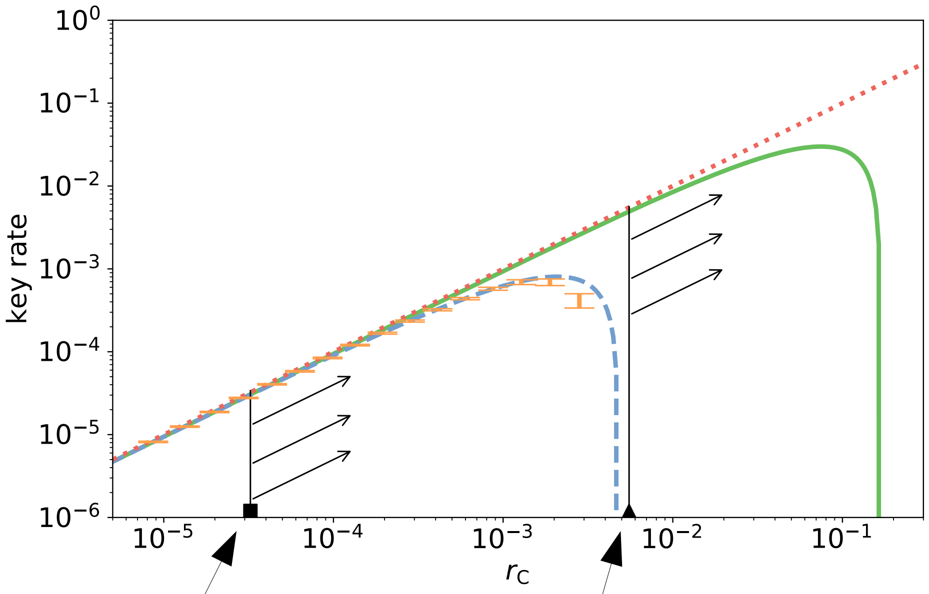


Comparison of SPDC and quantum dots

Resonantly excited quantum dots can produce strictly one-pair entangled states. Thus increase in the coincidence rate r_C leads to no deterioration of the secure key rate r_{DW}.

Orange points: experimental data (CW SPDC source, increasing coincidence window length to emulate high-gain multi-photon SPDC states).
Blue dashed line: CW SPDC model with 84 % loss (to match 16 % coupling efficiency of our setup).
Green line: CW SPDC model, no loss. The ultimate bound on key rate for SPDC in this protocol.
Red dotted line: Quantum dot prediction, no loss.
Black lines: Predictions for quantum dot key rate scaling with improvements in r_C.

Principal factor governing r_C of quantum dots:
Signal collection efficiency.



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For more information, follow
Radim Hošák **@baxthepigeon**, Miroslav Ježek **@QuantumHedgehog**
Quantum Optics Lab Olomouc (QOLO) **@OpticsOlomouc**

Paper in preparation!

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