Photonic simulation in quantum thermodynamics, quantum computing, and communication

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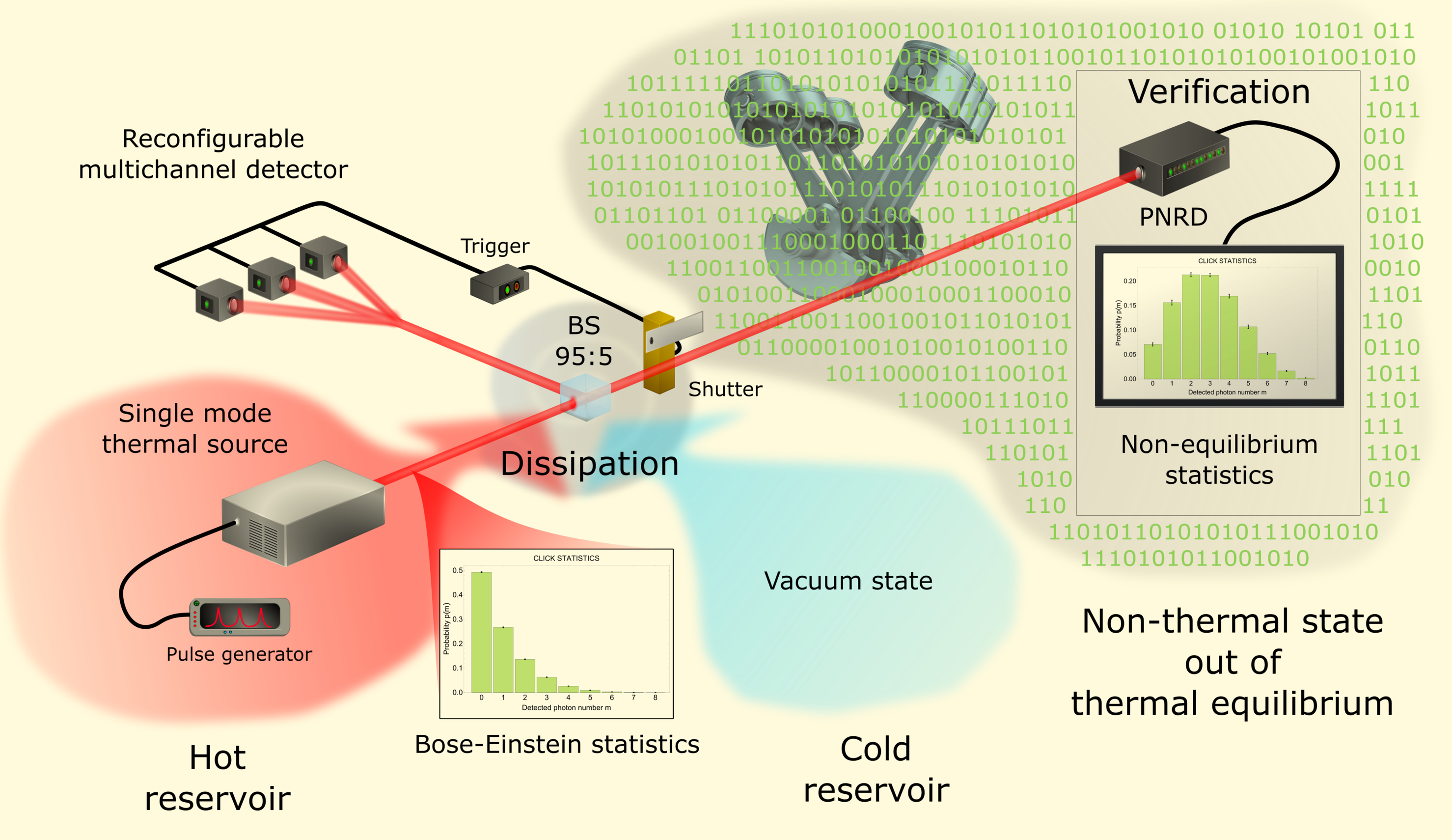
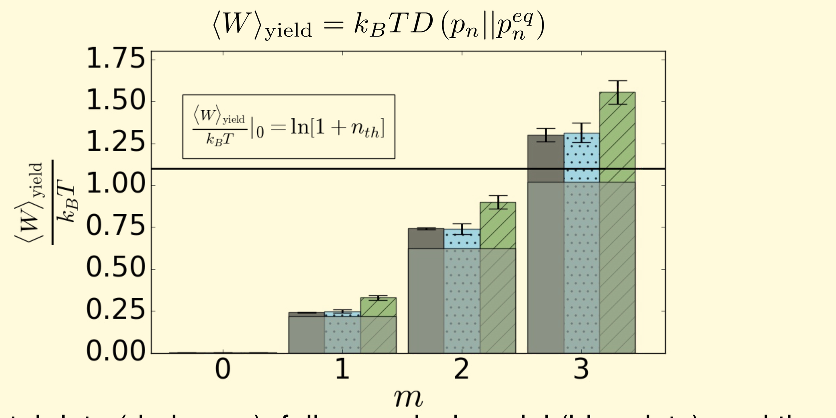
Work and information from thermal states after subtraction of energy quanta - towards quantum Maxwell's daemon

Out-of-equilibrium states generated via multiple-photon subtraction. Thermal light governed by Bose-Einstein statistics dissipates at an unbalanced beam splitter to the vacuum reservoir modes. A fraction of light in the reservoir modes is detected by a multichannel detector formed by m on-off detectors. Coincidence detection events trigger the non-equilibrium output verified by a photon-number-resolving detector.

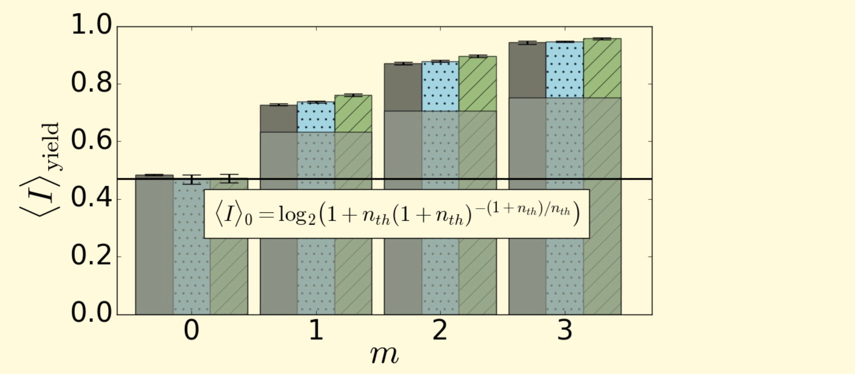


J. Hloušek, et al., Sci. Rep. 7, 13046 (2017).

The normalized available work as a function of subtracted photon number m. The horizontal threshold (solid black line) corresponds to the work available by a cooling of the oscillator mode to the ground state.

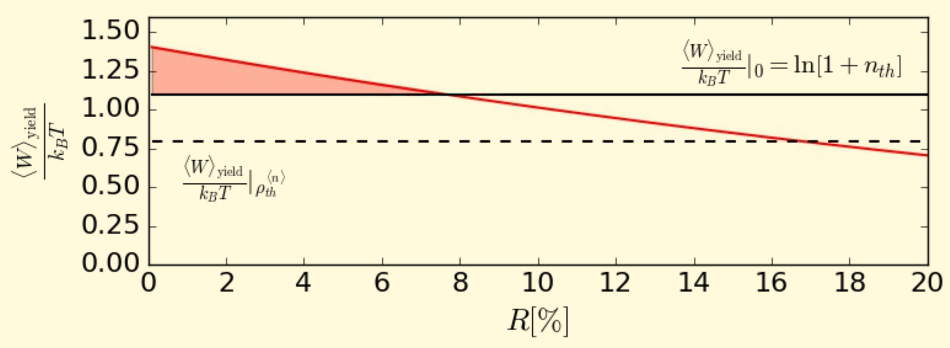


The maximum mutual information against a number of subtracted photons m. Solid black line represents a threshold of maximum mutual information available when encoding `1' using the initial thermal state.

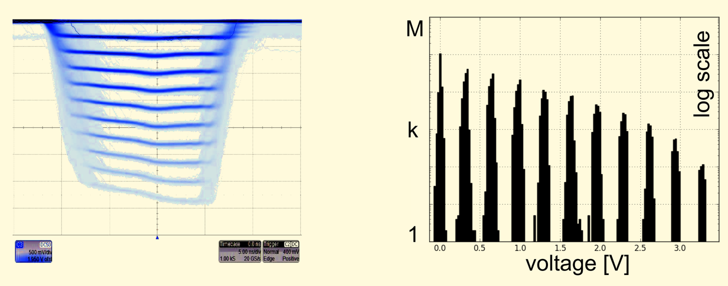


Experimental data (dark gray), full numerical model (blue dots), and the simplified model (green tiles). The horizontal threshold (solid black line) corresponds to the work available by a cooling of the oscillator mode to the ground state. Light gray areas represent lower bounds derived for thermal state heated with the same mean number of photons as the corresponding m-photon subtracted states.

Experimental stability and accuracy. The available work vs. the beam-splitter reflectivity for three-photon-subtracted thermal state.



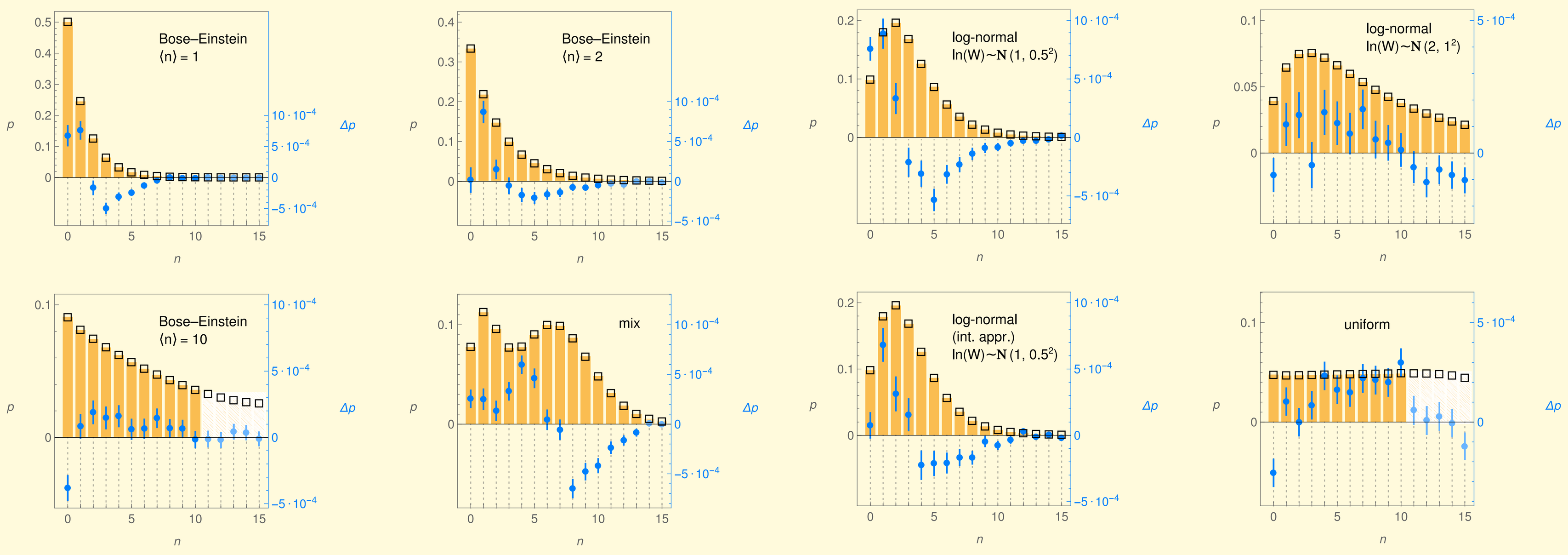
Photon-number-resolving detector free of systematic errors. Fast and accurate photon statistics reconstruction algorithm (EME).



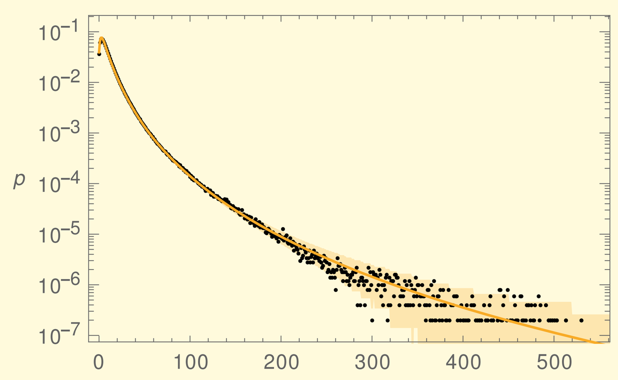
J. Hloušek, et al., in preparation (2018).

Generator of arbitrary classical photon statistics - probing quantum processes and simulating rare phenomena

Generation of light with arbitrary classical photon-number distribution with given parameters including Poissonian, super-Poissonian, thermal, and heavy-tailed distributions like log-normal. Extremely high precision <0.001 can be reached for lower photon numbers, and faithful tail behavior can be reached for very high photon numbers.



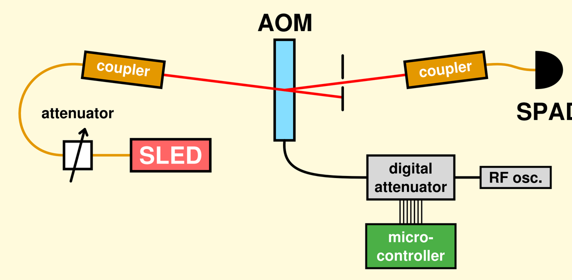
Arbitrary statistics generation for **up to 500 photons.** Actually limited by a measurement duration and a detector calibration - SPAD model accurate in the order of 10^{-4}.



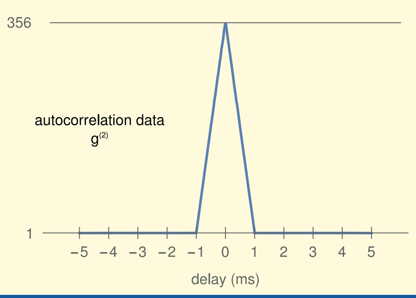
Simulation of Lévy flights, rogue waves, and other rare events. Simulation of communication channels, e.g. turbulent atmosphere. Detection and characterization of heavy-tailed distributions in finite time.

I. Straka, et al., arXiv: 1801.03063, accepted in Opt.Express (2018).

Programmable acousto-optical modulation with dynamic range of more than 30 dB and inter-level transitions faster than 500 ns. 40 dB and several hundred MHz shoud be possible with a single modulator; several modulators can be cascaded.



The maximum measured autocorrelation value $g^{(2)}(0)>350$.

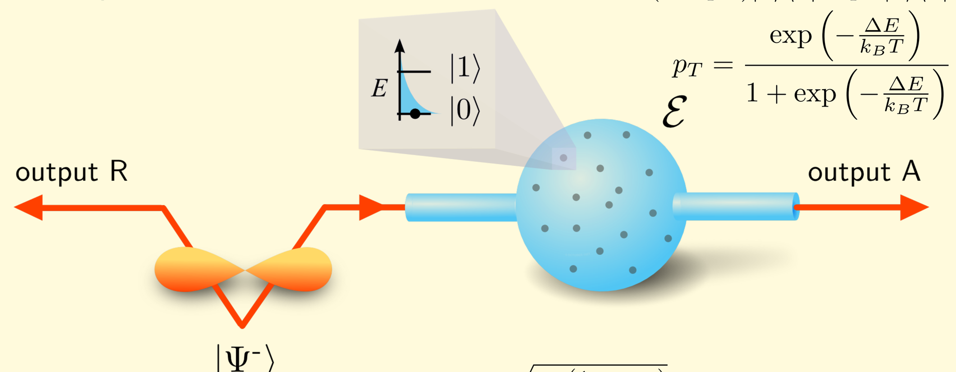


Cooling limits for quantum channel going through incoherent environment

Entanglement transfer through multi-qubit incoherent environment with temperature T.

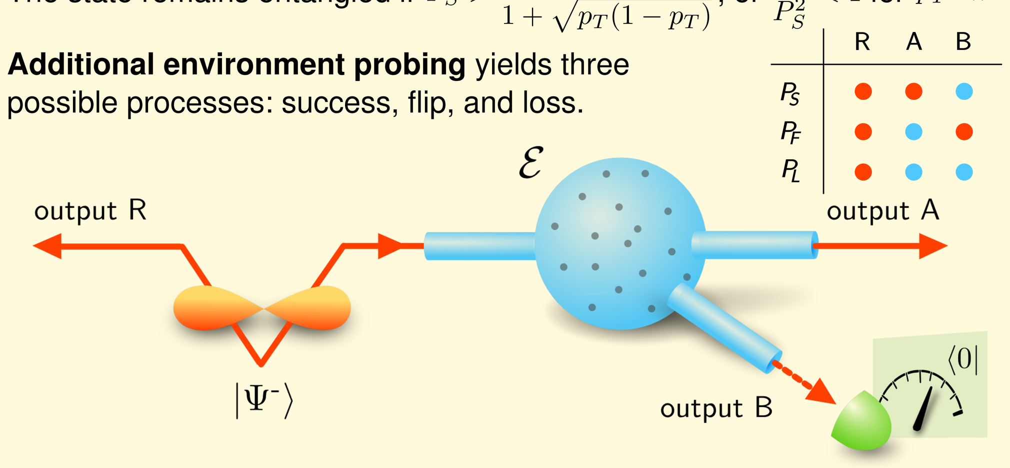
$$\mathcal{E} = (1-p_T)|0\rangle\langle 0| + p_T|1\rangle\langle 1|$$

$$p_T = \frac{\exp\left(-\frac{\Delta E}{k_B T}\right)}{1+\exp\left(-\frac{\Delta E}{k_B T}\right)}$$



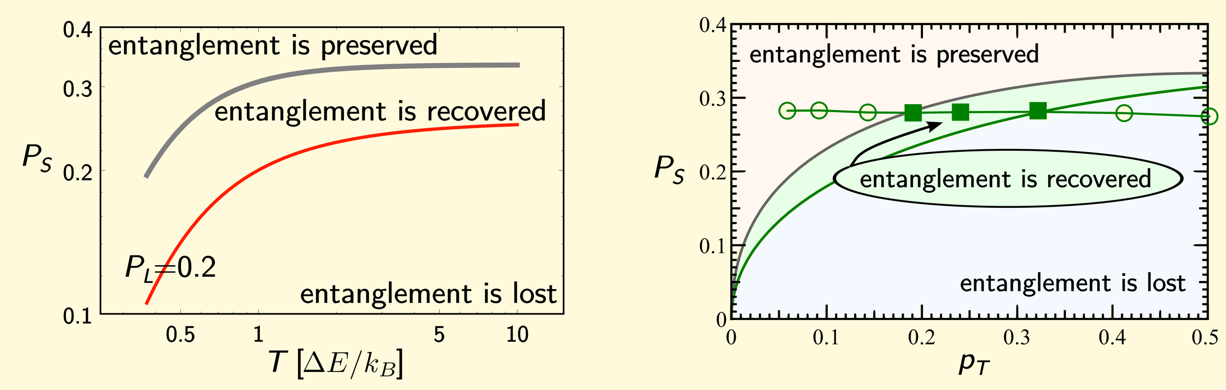
The state remains entangled if $P_S > \frac{\sqrt{p_T(1-p_T)}}{1+\sqrt{p_T(1-p_T)}}$, or $\frac{p_T}{P_S^2} < 1$ for $p_T \ll 1$

Additional environment probing yields three possible processes: success, flip, and loss.

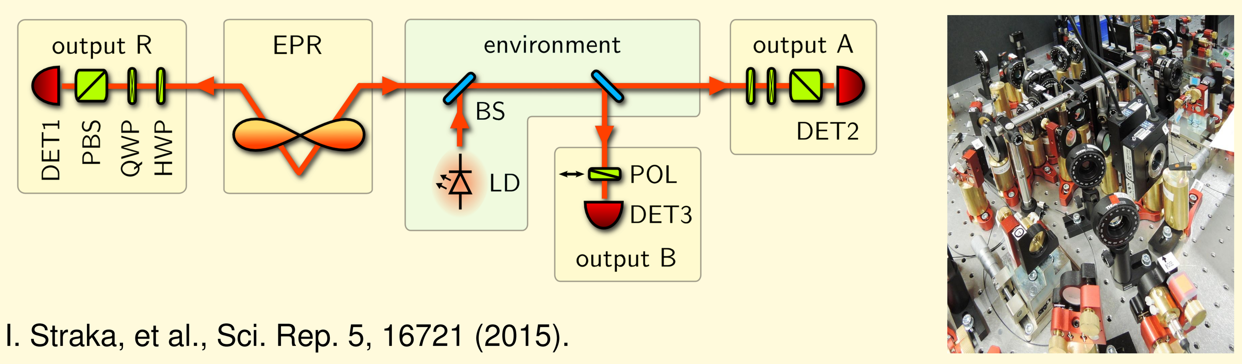


Auxiliary channel B is **projected to ground state** of the environment.

The RA state remains entangled if $P_S > \frac{1}{2}\left(\sqrt{p_T P_L(4-3p_T P_L)} - p_T P_L\right)$ or $\frac{p_T P_L}{P_S^2} < 1$ for $p_T \ll 1$

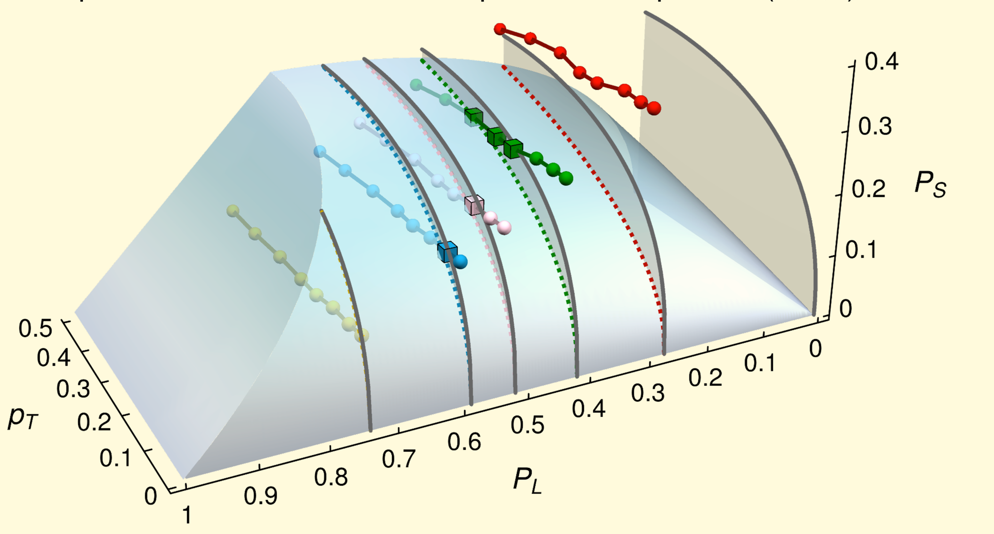


Photonic simulator - full quantum tomography with 3-fold coincidences of independent continuous-wave sources, tunable coincidence window, tunable noise depolarization.

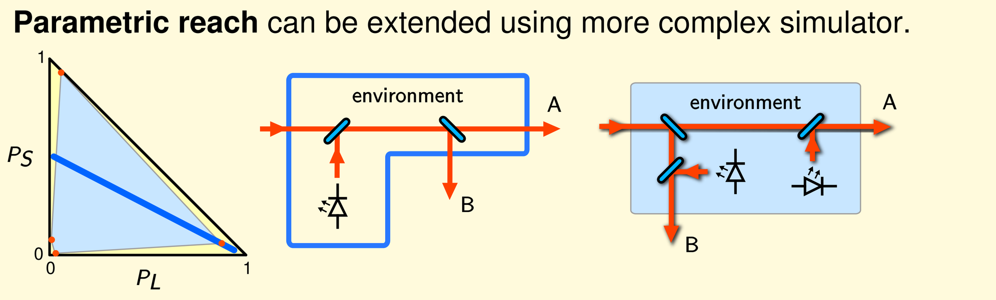


I. Straka, et al., Sci. Rep. 5, 16721 (2015).

Two-parameter simulator covers a plane in 3D space of (T,S,L).

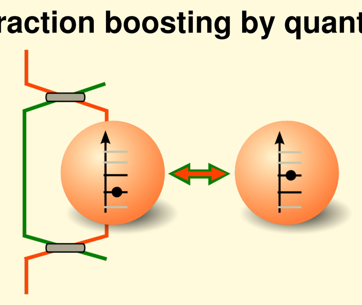


Parametric reach can be extended using more complex simulator.

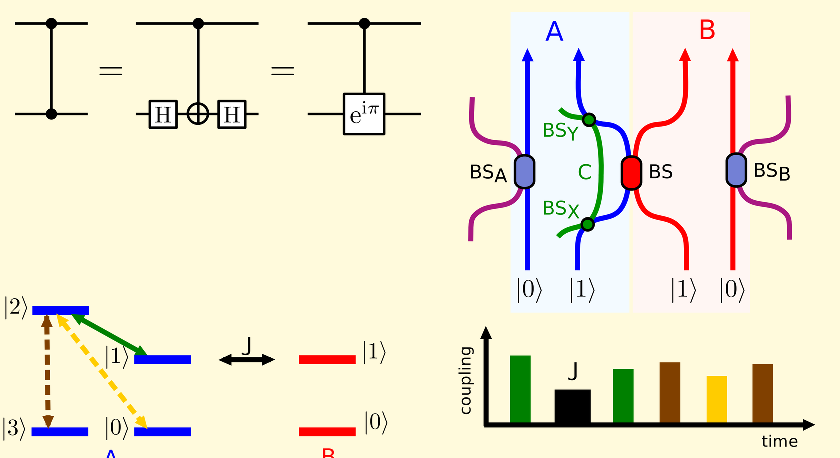


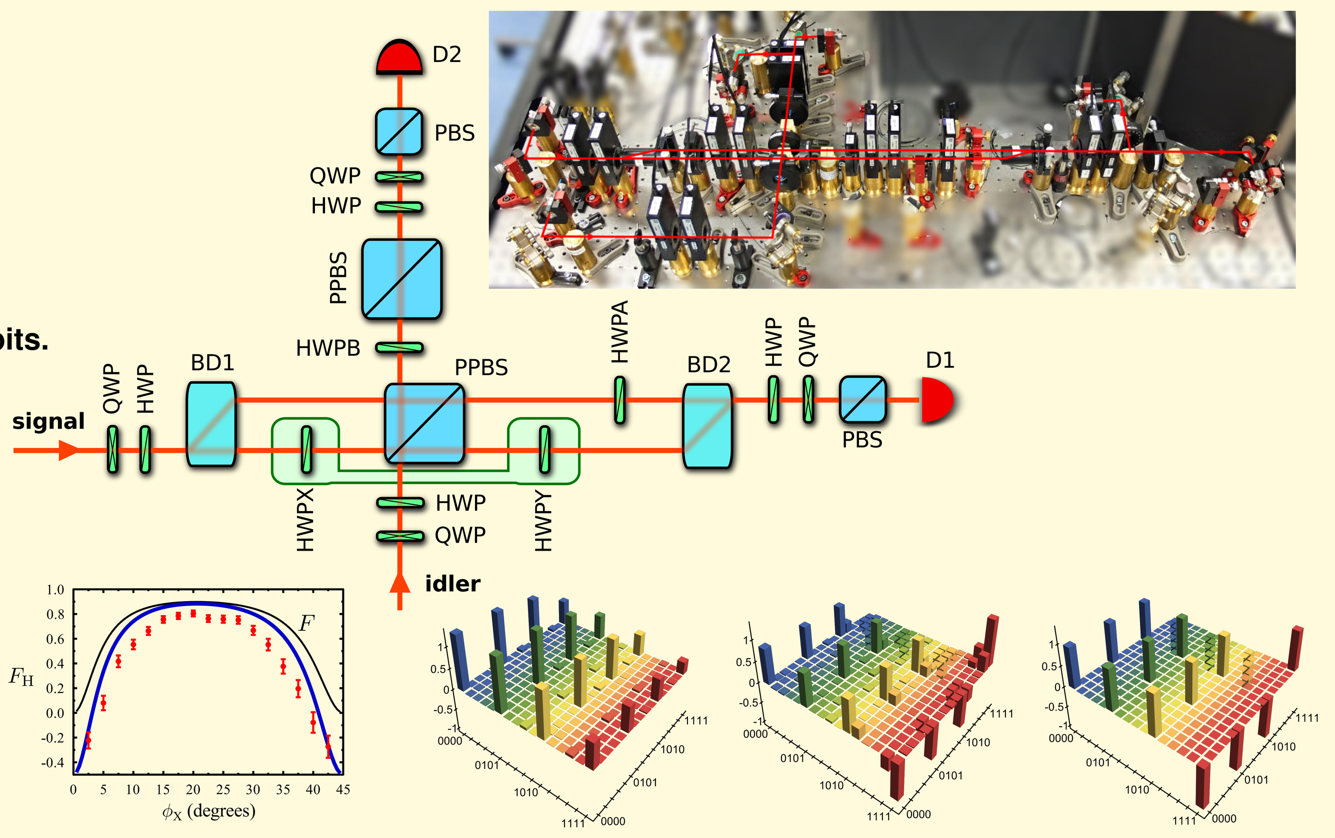
Computing with weakly interacting qubits - simulation and conditional enhancement the interaction strength

Conditional interaction boosting by quantum interference.



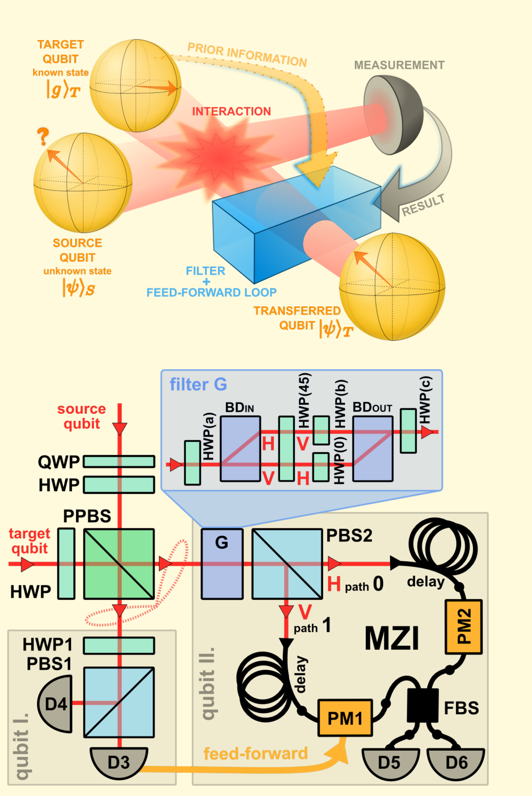
Quantum controlled-Z/NOT gate for weakly interacting qubits.

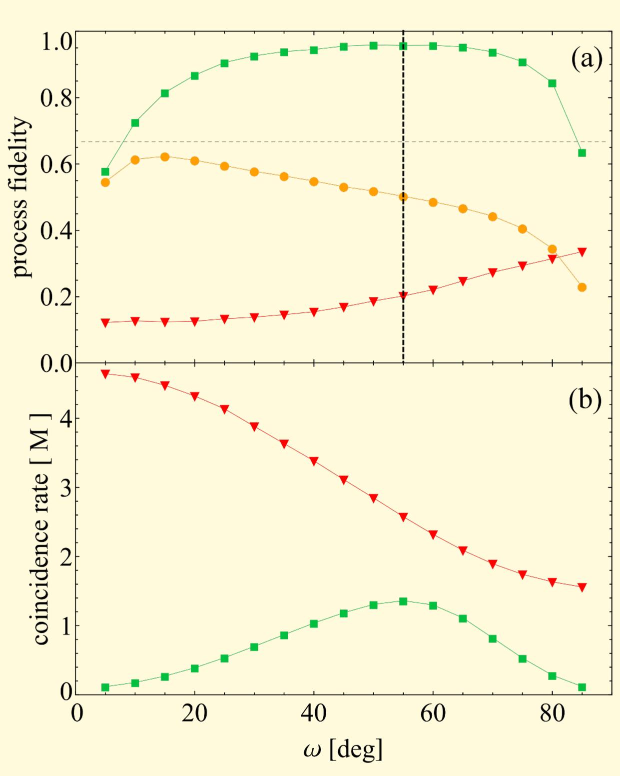




Mičuda, et al., PRA 92, 022341 (2015); Stárek, et al., PRA 93, 042321 (2016).

Quantum state transfer between weakly coupled qubits.





Miková et al., Sci. Rep 6, 32125 (2016).

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