Non-Markovian dynamics of BIC generation via single-photon scattering

Giuseppe Magnifico[1,2], **Maria Maffei**[1,2], **Domenico Pomarico**[1,2], **Debmalaya Das**[1,2], **Paolo Facchi**[1,2], **Saverio Pascazio**[1,2], **Francesco Pepe**[1,2]

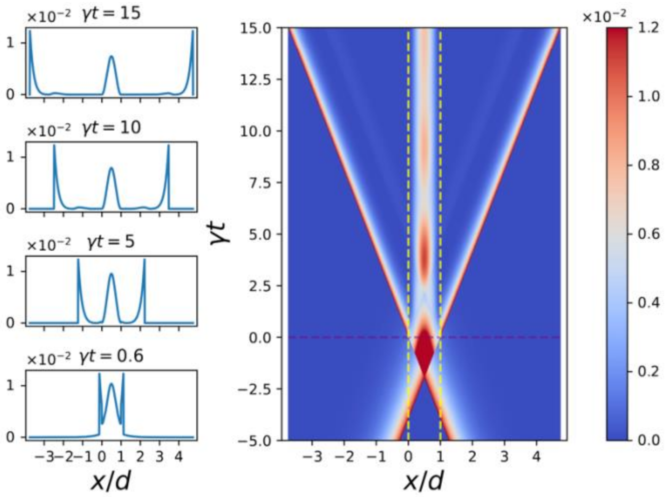
1 Dipartimento di Fisica, Università di Bari, I-70126 Bari, Italy

2 INFN, Sezione di Bari, I-70125 Bari, Italy

Abstract: Using Tensor Networks simulations of the dynamics, we prove that single-photon scattering and properly engineered time variation of the qubits detuning can excite the BIC of two distant qubits in a parity-invariant waveguide (non-Markovian dynamics).

Waveguide Quantum Electrodynamics represents one of the most promising platforms for quantum technology implementations and for theoretical investigation of light-matter interactions [1]. Interesting effects already emerge for a pair of two-level emitters (qubits), coupled to one parity-invariant waveguide. When the qubits distance is an integer multiple of their half-wavelength, i.e. d = (λ/2)n, the system spectrum features a bound state in the continuum (BIC) [2]. The qubits reduced state in the BIC is, with a good approximation, a Bell state, respectively $|\Phi_{\pm}\rangle = (|e, g\rangle \pm |g, e\rangle)/\sqrt{2}$, for n being odd or even, while the photonic part of the BIC is a standing wave between the emitters.

In Ref. [3], we propose a method to excite the BIC via single-photon scattering: it consists in preparing the single-photon input in a superposition of right- and left-propagating modes with same symmetry of the BIC to populate (resp. $|\xi_{\pm}\rangle = (|1_R\rangle \pm |1_L\rangle)/\sqrt{2}$) and screening the qubits from the interaction until the photon entered the region between them. This switch is attained by changing the qubits frequency instantaneously with respect to the evolution, which is feasible in CircuitQED implementations [4].



Time evolution of the average photon number along the one-dimensional WG (x axis). The first qubit is placed in x=0 and the second in x=d. The qubits start in their ground states and the incoming photon is prepared in $|\xi_+\rangle$ (see the text). The light-matter coupling is switched on when the right-propagating wavefront is in the position of the second qubit (x = d) and the left-propagating one is in the position of the first qubit (x = 0). The insets show the average photon number in every point of the WG at different times during system's evolution. As expected, in the long-time limit, t = 15 γ^{-1}, part of the field has remained trapped in the BIC standing wave between the emitters. All the data are obtained by MPS numerical simulation with truncation error equal to 10^{-4}.
Find a video of the real-time evolution here

We consider a qubits distance such that the time-of-flight of the photon between them is bigger than the life-time of the excited states (γ^{-1}). In this regime, feedback effects, due to the field propagating between the emitters, make their dynamics non-Markovian and hence impossible to solve with standard open quantum system methods. We solved the dynamics with a Matrix Product States (MPS) simulation of the joint qubits-field evolution, as first proposed in [5]. Using the MPS numerical solutions we demonstrated that the proposed method is more effective in populating the BIC than previously proposed ones [6,7].

References

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