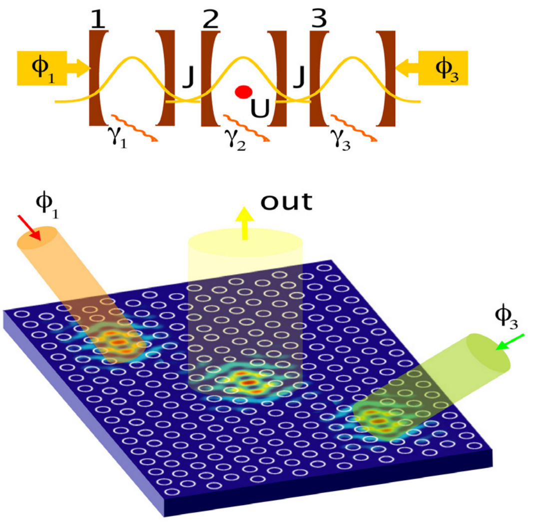
1.3.9 Quantum coherent dynamics of solid state devices

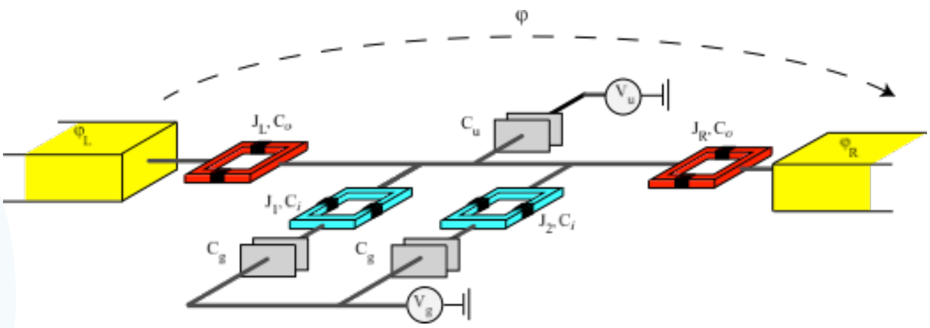
Superconducting nanostructures offer the unique opportunity to explore a wealth of different quantum effect at mesoscopic level. Coupled to mechanical moving parts these systems realize interesting quantum nano-electro-mechanical devices. Circuit-QED systems based on superconducting co-planar resonators are ideal systems to investigate the dynamics of photon blockade. Besides their interest in fundamental science, superconducting nano-circuits are among the most promising implementations of solid state quantum information processing.

Cavity quantum electrodynamics (QED) experiments in solid-state systems have lead to the observation of the photon blockade effect, where nonlinearities at the single-photon level alter the quantum statistics of light emitted by the cavity [1]. Motivated by the success of single-cavity QED experiments, the focus has recently shifted to the exploration of the rich physics promised by strongly-correlated quantum optical systems in multi-cavity and extended photonic media. The interplay between coherent tunnel coupling and on-site interactions in dissipation-free bosonic systems has lead to many spectacular observations, ranging from the demonstration of number-phase uncertainty relation to quantum phase transitions. To explore the effect of dissipation and coherent drive on tunnel coupled interacting bosonic systems, we proposed a device that is the quantum optical analog of a Josephson interferometer [2]. It is briefly sketched in the figure. It consists of two coherently driven linear optical cavities connected via a central cavity with a single-photon nonlinearity. The Josephson-like oscillations in the light emitted from the central cavity as a function of the phase difference between two pumping fields can be suppressed by increasing the strength of the nonlinear coupling. The interplay between the phase dependence of the light emitted and the strength of the non-linearities present in the system is a manifestation of the number-phase uncertainty relation Remarkably, we found that in the limit of ultra-strong interactions in the center-cavity, the coupled system maps on to an effective Jaynes-Cummings system with a nonlinearity determined by the tunnel coupling strength. In the limit of a single nonlinear cavity coupled to two linear waveguides, the degree of photon antibunching from the nonlinear cavity provides an excellent measure of the transition to the nonlinear regime where Josephson oscillations are suppressed. Photon correlation measurements for this device reveal a sharp threshold from Poissonian to sub-Poissonian statistics that is almost insensitive to the strength of the tunnel-coupling. On the other hand, in the case of a linear array of cavities coupled to a non-linear center cavity, the anti-bunching threshold is found to depend strongly on the tunnel-coupling. This observation signifies that photon correlation measurements are



very effective in revealing the interplay of coherent tunneling and on-site interactions and may contain the key to interpret and probe possible phases of extended cavity-arrays which operate under non-equilibrium conditions.

Another very interesting manifestation of quantum coherent effects in nanostructure is Cooper pair pumping. In a mesoscopic conductor a dc charge current can be obtained, in the absence of applied voltages, by cycling in time two parameters which characterize the system [3]. In the scattering approach to transport the pumped charge per cycle can be expressed in terms of derivatives



of the scattering amplitudes with respect to the pumping parameters [4]. If only superconducting leads are present and at low enough temperature, pumping is due to the adiabatic transport of Cooper pairs. Besides the dependence of the pumped charge on the cycle, in the superconducting pumps there is a dependence on the superconducting phase difference(s) (the overall process is coherent). A connection between Berry phase and pumped charge has been established also in this case thus opening the possibility to detect geometric phases in superconducting nanocircuits. We studied Cooper pair pumping in superconducting nanocircuits in the regime of Coulomb blockade. The new feature we considered was the possibility to pump in a degenerate subspace [5]. This generalization is known to have important consequences on the adiabatic evolution of quantum systems [6]. Indeed we showed that it leads to important modifications to adiabatic pumping as well. We derived an expression for the pumped charge in the presence of a degenerate spectrum and relate it to the non-Abelian connection of Wilczek and Zee. Furthermore we proposed a superconducting network (see the figure above) where this relation can be tested and discussed two clear signatures of non-abelian holonomies. First, under appropriate conditions to be discussed below, the pumped charge per cycle is quantized. Second and most important here the pumped charge depends both on the cycle and the point where the cycle starts. If tested experimentally this would be a clear proof of the non-Abelian nature of pumping.

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