TT 105: Focus Session: Mesoscopic Superconductivity and Quantum Circuits

The ongoing second wave of the quantum revolution has led to significant advances in complex quantum circuits. These circuits have not only demonstrated the basic building blocks for quantum information processing, but have also led to beautiful quantum optics experiments in the microwave frequency domain and atomic physics experiments using superconducting qubits as artificial atoms. This session covers the central advances by experimentalists and theorists working in the area of superconducting quantum circuits.

Organization: Gianluigi Catelani, Forschungszentrum Jülich; Denis Vion, CEA-Saclay; Martin Weides, Karlsruhe Institute of Technology

Time: Friday 9:30–13:05 Location: H 0104

Invited Talk TT 105.1 Fri 9:30 H 0104

New Hardware Components for Scalable Quantum Computers — •David DiVincenzo — Forschungszentrum Jülich

I introduce some new constructions for the optimal scaling of superconducting quantum processors.

Invited Talk TT 105.2 Fri 10:00 H 0104

Quantum Communcation with Propagating Microwaves — •Frank Deppe — Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — Physik-Department, TU München, 85748 Garching, Germany — Nanosystems Initiative Munich (NIM), 80799 München, Germany

Due to the advent of superconducting architectures for quantum information processing, microwave frequencies have become a promising option for quantum communication and illumination. One prominent branch in the resulting line of research are continuous-variable propagating quantum microwaves. As opposed to discrete-variable (quantum-bit) based approaches, quantum information is encoded in a continuous degree of freedom such as space or momentum here. In this talk, I first introduce the fundamental concept of continuous-variable quantum systems in the context of superconducting circuits. Next,I summarize important milestones reached in the last years: generation and detection schemes, entanglement generation, displacement gate and finite-time correlations on single-mode squeezed and two-mode squeezed entangled microwave radiation. Finally, I discuss recent progress on the remote preparation of a squeezed microwave state.

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Invited Talk TT 105.3 Fri 10:30 H 0104

Dynamics of a Qubit While Simultaneously Monitoring its Relaxation and Dephasing — Quentin Ficheux[1,2], Sebastien Jezouin[2], Zaki Leghtas[2], and •Benjamin Huard[1,2] — [1]Ecole Normale Superieure de Lyon, France — [2]Ecole Normale Superieure, Paris, France

Measuring a spin-1/2 along one direction projectively maximally randomizes the outcome of a following measurement along a perpendicular direction. Here, using either projective or weak measurements, we explore the dynamics of a superconducting qubit for which we measure simultaneously the three components x, y and z of the Bloch vector.

The x and y components are obtained by measuring the two quadratures of the fluorescence field emitted by the qubit. Conversely the z component is accessed by probing an off-resonant cavity dispersively coupled to the qubit. The frequency of the cavity depends on the energy of the qubit and the strength of this last measurement can be tuned from weak to strong in situ by varying the power of the probe.

In this experiment, the tracked system state diffuses inside the Bloch sphere and performs a random walk whose steps obey specific rules revealing the backaction of incompatible quantum measurements. The associated quantum trajectories follow a variety of dynamics ranging from diffusion to Zeno blockade. Their peculiar dynamics highlight the non trivial interplay between the backaction of the two aforementioned incompatible measurements.

15 min. break.

Invited Talk TT 105.4 Fri 11:15 H 0104

Estimating the Error of an Analog Quantum Simulator by Additional Measurements — •Michael Marthaler — Theoretische Physik, Universität des Saarlandes — Institut für die Theorie der Kondensierten Materie, Karlsruher Institut für Technologie

We study an analog quantum simulator coupled to a reservoir with a known spectral density. The reservoir perturbs the quantum simulation by causing decoherence. The simulator is used to measure an operator average, which cannot be calculated using any classical means. Since we cannot predict the result, it is difficult to estimate the effect of the environment. Especially, it is difficult to resolve whether the perturbation is small or if the actual result of the simulation is in fact very different from the ideal system we intend to study. Here, we show that in specific systems a measurement of additional correlators can be used to verify the reliability of the quantum simulation. The procedure only requires additional measurements on the quantum simulator itself. We demonstrate the method theoretically in the case of a single spin connected to a bosonic environment.

Invited Talk TT 105.5 Fri 11:45 H 0104

On-demand distribution of quantum information between superconducting cavity quantum memories — •Wolfgang Pfaff — Department of Applied Physics, Yale University, USA — Microsoft Station Q, TU Delft, Netherlands

Superconducting cavities can store microwave fields for several milliseconds, naturally making them a promising system for realizing memories for superconducting circuits. In this talk, I will present our approach for using cavities for modular, distributed quantum computing.

Microwave cavities coupled to Josephson qubits can serve as long-lived quantum memories. In particular, 3D cavities made from bulk superconductors can store quantum states on millisecond time scales. Further, these systems are capable of processing and protecting quantum information encoded in complex multiphoton states stored in the cavity.

It is an ongoing challenge to scale up to large quantum computing architectures from individual cavity systems. We aim to realize a modular architecture in which individual nodes exchange quantum information through propagating photons in transmission lines. We show that we can, rapidly and on-demand, convert quantum states from a cavity memory into propagating channels. This enables us to realize deterministic quantum state transfer and entanglement between remote cavities. Our cavity system can thus serve as the backbone in a microwave quantum network. It can be used to realize error-protected distribution of quantum information and provides a route towards a modular quantum computer.

Invited Talk TT 105.6 Fri 12:15 H 0104

Quantum Simulation of Light-Matter Interaction — •Jochen Braumüller[1], Michael Marthaler[2], Andre Schneider[1], Alexander Stehli[1], Hannes Rotzinger[1], Martin Weides[1], and Alexey V. Ustinov[1,3] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

The quantum Rabi model describes the fundamental mechanism of light-matter interaction. It consists of a two-level atom or qubit coupled to a quantized harmonic oscillator mode via a transversal interaction. In the small coupling regime, it reduces to the well-known Jaynes-Cummings model by applying a rotating wave approximation (RWA). In the ultra-strong coupling (USC) regime, where the effective coupling strength is comparable to the subsystem energies, the RWA breaks down and remarkable features in the system dynamics are revealed. We demonstrate an analog quantum simulation of an effective quantum Rabi model in the ultra-strong coupling regime, achieving a relative coupling ratio of up to 0.6. The quantum hardware of the simulator is a superconducting circuit. We observe fast and periodic quantum state collapses and revivals of the initial qubit state as one of the hallmark signatures of USC dynamics. As an outlook, we demonstrate first experimental efforts in implementing the spin boson model.

[1] Braumüller *et al.*, Nat. Commun. 8, 779 (2017)

TT 105.7 Fri 12:35 H 0104

Quantum Chemistry with Superconducting Qubits — •Nikolaj Moll[1], Stefan Filipp[1], Andreas Fuhrer[1], Jay M. Gambetta[2], Antonio Mezzacapo[2], and Kristan Temme[2] — [1]IBM Research – Zurich, Säumerstrasse 4, CH-8803 Rüschlikon, Switzerland — [2]IBM T.J. Watson Research Center, Yorktown Heights, NY 10598, USA

Recent advances in the field of quantum computing have boosted the hope that one day we might be able to solve complex problems using quantum computers. Already smaller quantum processors with a couple of hundred physical qubits with no error correction will be available soon. Solving problems in quantum chemistry could benefit from such processors: Chemical systems could then be simulated and their properties, including correlation functions and reaction rates calculated. To calculate the ground states of chemical systems the quantum optimization based on the variational principle is especially suited. In this method, part of the computational load is transferred to the classical computer, while the complex trial wavefunctions are generated using entangling gates and single qubit rotations on the quantum processor. The advantage is that the calculation of the total energy can now be done efficiently using trial function of short depth and ideally run in much shorter time than the coherence time of the quantum processor.

TT 105.8 Fri 12:50 H 0104

Quantum microwaves with a DC-biased Josephson junction — •Fabien Portier, Ambroise Peugeot, Iouri Moukharski, Phillipe Joyez, Denis Vion, Daniel Estève, Patrice Roche, Carles Altimiras, Marc Westig, Max Hofheinz, and Olivier Parlavecchio — NanoElectronics and Quantronics groups, SPEC, CEA, CNRS, Université Paris-Saclay, CEA-Saclay, 91191 Gif-sur-Yvette Cedex, France

Tunneling of a Cooper pair through a dc-biased Josephson junction is possible if collective excitations (photons) are produced in the rest of the circuit to conserve the energy. The probability of tunneling and photon creation, well described by the theory of dynamical Coulomb blockade, increases with the coupling strength between the tunneling charge and the circuit mode, which scales as the mode impedance. Using very simple circuits with only one or two high impedance series resonators, we first show the equality between Cooper pair tunneling rate and photon production rate [1]. Then we demonstrate a blockade regime for which the presence of a single photon blocks the next tunneling event and the creation of a second photon. Finally, using two resonator with different frequencies, we demonstrate photon pair production [2], two-mode squeezing, and entanglement between the two modes leaking out of the resonators.

[1] M. Hofheinz et al., Phys. Rev. Lett. 106, 217005 (2011)
[2] M. Westig et al., arXiv:1703.05009 (2017)