MA 18: Transport: Quantum Coherence and Quantum Information Systems - Theory (jointly with MA, HL)

Time: Tuesday 9:30–13:15 Location: HSZ 103

MA 18.1 Tue 9:30 HSZ 103

Adiabatic Quantum Simulations with Superconducting Qubits — •Nikolaj Moll, Panagiotis Barkoutsos, Daniel Egger, Stefan Filipp, Andreas Fuhrer, Marc Ganzhorn, Andreas Kuhlmann, Peter Müller, Marco Roth, Peter Staar, and Ivano Tavernelli — IBM Research – Zurich, Säumerstrasse 4, CH-8803 Rüschlikon, Switzerland

Quantum computing technology is improving fast and quantum computers with approximately 100 qubits appear feasible in the not so distant future. The quest for systems which profit of exponential speed-up and cannot be calculated on classical computers has recently triggered a lot of attention. Fermionic quantum systems, such as quantum chemistry or the Fermi-Hubbard model, are among the best candidates for exploiting the exponential speed-up. Such a quantum system can be implemented on a quantum computer based on superconducting qubits. However, the controlled realization of different types of interactions between qubits without compromising their coherence is essential. A coupling method between fixed-frequency transmon qubits can be achieved with the frequency modulation of an auxiliary capacitively coupled quantum bus. An adiabatic protocol for the Hydrogen molecule can be implemented on such a coupled qubit system.

MA 18.2 Tue 9:45 HSZ 103

Tunable, Flexible and Efficient Optimization of Control Pulses for Superconducting Qubits, part I - Theory — •Shai Machnes[1,2], Elie Assémat[1], David Tannor[2], and Frank Wilhelm[1] — [1]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Weizmann Institute of Science, 76100 Rehovot

Quantum computation places very stringent demands on gate fidelities, and experimental implementations require both the controls and the resultant dynamics to conform to hardware-specific ansatzes and constraints. Superconducting qubits present the additional requirement that pulses have simple parametrizations, so they can be further calibrated in the experiment, to compensate for uncertainties in system characterization. We present a novel, conceptually simple and easy-to-implement gradient-based optimal control algorithm, GOAT [1], which satisfies all the above requirements.

In part II we shall demonstrate the algorithm's capabilities, by using GOAT to optimize fast high-accuracy pulses for two leading superconducting qubits architectures - Xmons and IBM's flux-tunable couplers.
[1] S. Machnes, D.J. Tannor, F.K. Wilhelm and E. Assémat, ArXiv 1507.04261 (2015)

MA 18.3 Tue 10:00 HSZ 103

Tunable, Flexible and Efficient Optimization of Control Pulses for Superconducting Qubits, part II: Applications — Shai Machnes[1,2], •Elie Assemat[1], David Tannor[2], and Frank Wilhelm[1] — [1]Saarland University, Saarbrücken, Germany — [2]Weizmann Institute of Science, Rehovot, Israel

In part I, we presented the theoretic foundations of the GOAT algorithm [1] for the optimal control of quantum systems. Here in part II, we focus on several applications of GOAT to superconducting qubits architecture. First, we consider a control-Z gate on Xmons [2] qubits with an Erf parametrization of the optimal pulse. We show that a fast and accurate gate can be obtained with only 16 parameters, as compared to hundreds of parameters required in other algorithms. We present numerical evidences that such parametrization should allow an efficient in-situ calibration of the pulse. Next, we consider the flux-tunable coupler by IBM [3]. We show optimization can be carried out in a more realistic model of the system than was employed in the original study, which is expected to further simplify the calibration process. Moreover, GOAT reduced the complexity of the optimal pulse to only 6 Fourier components, composed with analytic wrappers.
[1] S. Machnes et al., ArXiv 1507.04261v1 (2015)
[2] R. Barends et al., Phys. Rev. Lett. 100, 080502 (2013)
[3] D. C. McKay et al., ArXiv 1604.0307v2 (2016)

MA 18.4 Tue 10:15 HSZ 103

Symmetry Benchmarking of Quantum Algorithms — •Tobias Chasseur Chasseur[1], Felix Motzoi[1,2], Michael Kaicher[1], Pierre-Luc Dallaire-Demers[1], and Frank Wilhelm[1] — [1]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark

Scalable and robust benchmarking of quantum gates is essential on the path to a useful quantum computer, as current candidates such as superconducting qubit systems are set to leave the few qubit regime in the near future. Randomized Benchmarking and related approaches provide solutions for specific gates such as the Clifford group or a limited number of qubits; however a tool for benchmarking arbitrary gates without exponential scaling in the number of qubits seems prohibited by the inherent power of quantum computation. In this work we present a symmetry benchmarking protocol to estimate the implementation fidelity of specific algorithms with polynomial scaling. The proposed protocol relies on unitary 1-designs on the eigenspaces of algorithm-specific preserved quantities, as well as sequence structures similar to Randomized Benchmarking. It benchmarks the symmetry preservation of the implementation as an indicator for the overall fidelity. We demonstrate the protocol for the specific example of algorithms consisting of number preserving gates.

MA 18.5 Tue 10:30 HSZ 103

Implementation of Quantum Stochastic Walks — •Peter Schuhmacher[1], Luke Govia[2], Bruno Taketani[1], and Frank Wilhelm[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Department of Physics, McGill University, Montreal, Quebec, Canada

Quantum walks are one of the most prominent frameworks in which to design and think about quantum algorithms. Both the continuous- and discrete-time versions have been shown to provide speed-up over classical information processing tasks, and can be regarded as universal quantum computers. Classical (probabilistic) and quantum unitary random walks yield different distributions due to interference effects. Combining the two, stochastic quantum walks (QSW) can be defined in an axiomatic manner to include unitary and non-unitary effects, and include both classical and quantum walks as limiting cases. While a general purpose quantum computer is still far over the horizon, intermediary technologies have been emerging with the promise to breach classical limitations. Within these, artificial intelligence is one exciting field where the use of quantum physics can lead to important improvements. Here, we focus on the physical realizability of both kinds of quantum stochastic walks (continuous-time and discrete-time).

MA 18.6 Tue 10:45 HSZ 103

Normal metal traps for superconducting qubits — •Roman-Pascal Riwar[1,2], Amin Hosseinkhani[1,3], Luke D. Burkart[2], Yvonne Y. Gao[2], Robert J. Schoelkopf[2], Leonid I. Glazman[2], and Gianluigi Catelani[1] — [1]Forschungszentrum Jülich, Germany — [2]Yale University, USA — [3]RWTH Aachen University, Germany

The coherence time of superconducting qubits is intrinsically limited by the presence of quasiparticles. While it is difficult to prevent the generation of quasiparticles, keeping them away from active elements of the qubit provides a viable way of improving the device performance. We develop theoretically and validate experimentally a model for the effect of a single small trap on the dynamics of the excess quasiparticles injected in a transmon-type qubit. By means of this model, we show that for small traps, increasing the size shortens the evacuation time of quasiparticles from the transmon. We further identify a characteristic trap size above which the evacuation time saturates to the diffusion time of the quasiparticles. In the diffusion limit, the geometry of the qubit and the trap become relevant. We compute the optimal trap number and placement for several realistic geometries. Finally, our estimates show that the dissipation introduced by the presence of normal metal traps is well below the losses observed in the transmon.

MA 18.7 Tue 11:00 HSZ 103

Proximity Effect in Normal-Metal Quasiparticle Traps — •Amin Hosseinkhani[1,2] and Ginaluigi Catelani[1] — [1]Peter Grunberg Institut (PGI-2), Forschungszentrum Jülich, Jülich, Germany — [2]JARA-Institute for Quantum Information, RWTH Aachen University, Aachen, Germany

In many superconducting devices, including qubits, quasiparticle excitations are detrimental. A normal metal (N) in contact with a su-

perconductor (S) can trap these excitations. However, the contact between N and S modifies the properties of both materials, a phenomenon known as proximity effect which has drawn attention since the '60s. Despite this long history, we find new analytical results for the density of states, which shows a square root threshold behavior at the minigap energy. In superconducting qubits, the trap must be placed far enough from a Josephson junction in order not to harm the qubit coherence. To estimate the minimum trap-junction separation, we study how the density of states in the superconductor depends on the distance from the trap. For high interface resistance between N and S, a separation of several (5-7) coherence lengths is sufficient.

15 min. break.

MA 18.8 Tue 11:30 HSZ 103

Generating Entangled Quantum Microwaves in a Josephson-Photonics Device — •Simon Dambach, Björn Kubala, and Joachim Ankerhold — Institute for Complex Quantum Systems, Ulm University, Ulm, Germany

The realization of efficient sources for entangled microwave photons is of paramount importance for many promising applications of quantum technology. In this talk, we demonstrate that Josephson-photonics devices are logical candidates for this task since they allow to create a broad range of different bi- and multipartite entangled states in a surprisingly simple way [1].

In a Josephson-photonics device, a Cooper pair tunneling across a dc voltage-biased Josephson junction simultaneously creates photons in several series-connected microwave cavities. The interplay of this multiphoton creation process and subsequent individual photon leakage from the cavities leads to a stationary state with complex entanglement properties. Sophisticated pulse-shaping schemes as required in conventional circuit-QED architectures are thus not necessary here. Varying experimental parameters in situ or by construction then allows to access the rich wealth of entangled states differing, e.g., in the number of entangled parties or the dimension of state space. Such devices, besides their promising potential to act as a highly versatile source of entangled quantum microwaves, may be also an excellent playground for the abstract branch of quantum information theory to test entanglement criteria on naturally existing quantum states.

[1] S. Dambach, B. Kubala, and J. Ankerhold, arXiv:1609.08990

MA 18.9 Tue 11:45 HSZ 103

Theory of mode locking in pulsed semiconductor quantum dots — •Wouter Beugeling, Götz S. Uhrig, and Frithjof B. Anders — Lehrstuhl für Theoretische Physik 1/2, TU Dortmund, Dortmund, Germany

Electron spins in semiconductor quantum dots appear unsuitable for quantum computing at first sight, due to their fast decoherence caused by hyperfine interactions to the nuclear spins in the substrate. However, the coherence time is dramatically increased by periodic optical pulsing. The underlying mechanism is known as mode locking: Oscillation frequencies incommensurate with the pulse repetition rate are suppressed, and only resonant contributions remain. Because the resonant frequencies are set by the pulse repetition rate only, the system becomes effectively immune to perturbations induced by the hyperfine interactions and by variations between the individual quantum dots in an ensemble.

In this presentation, we explore the mechanism of mode locking with a combination of analytical and numerical methods. Exploiting the fact that the hyperfine interaction is small compared to the external magnetic field, we calculate the dynamics perturbatively. The resulting frequency distributions show clear signs of mode locking. We study the positions of the resonant frequencies and the rate at which mode locking sets in, and compare the results to other theoretical and experimental studies. We also discuss the influence of the hyperfine coupling strength, of the Zeeman effect of the nuclear spins, and of the pulse shape and detuning.

MA 18.10 Tue 12:00 HSZ 103

Higher Order Spin Correlation in Semi-Conductor Quantum Dots — •Nina Fröhling and Frithjof Anders — Technische Universität Dortmund, Deutschland

We study higher order auto-correlation functions of electron spin decay in an isolated semi-conductor quantum dot described by the central spin model. The electronic central spin is coupled to a bath of nuclear spins via hyperfine interaction, which dominates the short time regime. Via quantum measurement theory we show that the experiment by Bechtold et al. (Phys. Rev. Lett. 117. 027402, 2016) can be described as a fourth order auto-correlation function. We compare our results obtained from a semiclassical approach, exact diagonalization and a Lanczos algorithm to the experimental results. In order to explain the observed long time dynamics in the forth order autocorrelation the nuclear Zeeman splitting and the strain induced anisotropic quadrupolar moment of the nuclei must be included.

MA 18.11 Tue 12:15 HSZ 103

Non-equilibrium nuclear spin distributions in a periodically pulsed quantum dot — •Natalie Jäschke and Frithjof Anders — Technische Universität Dortmund, Lehrstuhl für Theoretische Physik II, 44227 Dortmund

In pump-probe experiments single electron charged semiconductor quantum dots are subjected to periodic optical excitations. This mechanism generates electron and nuclear spin polarization. In the short time regime the decoherence of the electron spin polarization is governed by the hyperfine interaction with the nuclear spins. We aim for a theory that combines the effect of the periodic laser pump pulses and the nuclear spin bath on the electron spin polarization. Since the laser pulses occur on the shortest time scale of the system, and the electronic decay times are small compared to those of the nuclear spin bath, we treat the laser pumping quantum-mechanically using a Lindblad approach and keep the nuclear spins as frozen during that time. Then a classical simulation of the Overhauser field bridges the time until the next laser pulse. On the one hand we analyze the time dependence of the electron spin dynamics and on the other hand present data for the non-equilibrium steady state spectral distributions of the Overhauser field for the long time limit. For the electron spin dynamics a revival effect right before the next pulse is observed. The Overhauser field shows mode locking effects in the component parallel to the external magnetic field.

MA 18.12 Tue 12:30 HSZ 103

Detection of coherent oscillations in proximitized quantum dot spin valves — Philipp Stegmann, Jürgen König, and •Stephan Weiss — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

Spin coherent oscillations in a proximitized quantum dot spin valve are resolved by means of full counting statistics of electrons [1]. Especially, generalized factorial cumulants [2,3] of the electronic distribution function are suitable for the detection of the transition between different spin states in the system. We furthermore study the influence of a tunnel coupled superconductor. Due to the presence of Andreev reflections, coherent oscillations between different spin states are modified, the Larmor frequency is renormalized. We explore that general factorial cumulants are able to distinguish different fundamental transport processes of the model [1].

[1] Ph. Stegmann, J. König, S. Weiss, submitted (2016)
[2] Ph. Stegmann, J. König, Phys. Rev. B **92**, 155413 (2015)
[3] Ph. Stegmann, J. König, Phys. Rev. B **94**, 125433 (2016)

MA 18.13 Tue 12:45 HSZ 103

Apparent pairing and subperiods in integer quantum Hall interferometers — •Giovanni Andrea Frigeri[1,3], Daniel Scherer[2], and Bernd Rosenow[3] — [1]Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany — [2]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [3]Institut für Theoretische Physik, Universität Leipzig, Leipzig, Germany

We analyze the magnetic field and gate voltage dependence of the conductance in an integer quantum Hall Fabry-Pérot interferometer, taking into account the interactions between an interfering edge mode, a non-interfering edge mode and the bulk. For weak bulk-edge coupling and sufficiently strong inter-edge interaction, we observe that the interferometer operates in the Aharonov-Bohm regime with a flux periodicity halved respect to the usual expectation. Even in the regime of strong bulk-edge coupling, this behavior can be observed as a subperiodicity of the interference signal in the Coulomb dominated regime. We do not find evidence for a connection between a reduced flux period and electron pairing, though. Our results can reproduce recent experimental findings.

MA 18.14 Tue 13:00 HSZ 103

Interplay of Hamiltonian control and and decoherence: a caveat, some hope and a new simulation strategy — •Jürgen Stockburger — Institute for Complex Quantum Systems, Ulm University

Hamiltonian control and decoherence are intricately intertwined in low-temperature quantum systems. For controls which act on timescales shorter than the thermal time $\hbar\beta$, Markovianity can no longer be assumed (RWA breakdown) [1]. When open-system dynamics is mapped on a stochastic propagation, this case can be treated exactly, and standard optimal control techniques can be used to explore synergy effects between control and reservoir interaction. Quantum states can thus be purified [2] and systems entangled [3] by the combined effect of local control and dissipation.

This stochastic mapping can now be combined with non-perturbative projection techniques, requiring only moderate computational resources [4].

[1] Alicki, R., Lidar, D. A. and Zanardi, P., Phys. Rev. A **73**, 052311 (2006)
[2] Schmidt, R. *et al.*, Phys. Rev. Lett. **107**, 130404 (2011)
[3] Schmidt, R., Stockburger, J. T. and Ankerhold, J., Phys. Rev. A **88**, 052321 (2013)
[4] Stockburger, J. T., EPL (Europhysics Letters) **115**, 40010 (2016)