# Q 4: Quantum Computing and Simulation I

Time: Monday 11:45–13:00 Location: P 10

Q 4.1 Mon 11:45 P 10

**Mølmer-Sørensen Gates Robust to AC Shifts** — •Erin Feldkemper[1], Victor Martinez Lahuerta[1], Christian Ospelkaus[1], Naceur Gaaloul[1], and Klemens Hammerer[2,3,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Theoretische Physik, Universität Innsbruck — [3]Institut für Theoretische Physik, Leibniz Universität Hannover — [4]IQOQI Österreichische Akademie der Wissenschaft

Fast and high-fidelity quantum gates are essential for scaling trapped-ion quantum computing, and their optimization has become increasingly important. One of the key challenges is mitigating the AC shift, which can arise in both laser-driven and microwave-driven gates, introducing errors that degrade the performance. In this theory work, we focus on microwave-driven Mølmer-Sørensen gates and specifically the impact of the AC Zeeman shift on the gate performance. To this end, we derived an effective Hamiltonian including leading-order AC corrections. In order to reduce the noise, we focus on two methods. The first consists in using spin echoes, which exploits the fact that the shift is linear with the $S_z$ spin component. The other method is to time-dependently control the parameters of the gate and optimize them using optimal control theory. To evaluate the fidelity of the protocols, we use Kraus operators as a figure of merit for a good quantum channel. Both of these methods are exploited, compared to each other, and would ultimately be combined to improve the gate precision.

Q 4.2 Mon 12:00 P 10

**Tailoring spin–spin coupling of trapped ions by electrode shape optimization** — •Kais Rejaibi, Patrick H. Huber, and Christof Wunderlich — Universität Siegen, Walter-Flex-Straße 3, 57072 Siegen

Trapped ions are a leading physical platform for quantum information processing. When scaling up such quantum processors, it is advantageous to control the qubit's coherent dynamics by directly using electronic signals in the (quasi-)direct current (DC) and radio frequency (RF) regime, without conversion of these signals into the optical domain. $N$-qubit gates ($N \geq 2$) controlled by electronic signals are possible when applying a static or RF magnetic gradient field in a Paul trap. The matrix characterizing the interaction between $N$ qubits can be tailored, for instance, by modifying the trapping potential confining the ions. We developed a numerical method to design and optimize electrode shapes that determine the trapping potential in 2D ion traps. From this we obtain the ion positions, mode structure, and effective interaction matrix. These results enter a cost function that measures how well a given design reproduces the desired interaction pattern under constraints such as maximum voltage and trap depth. By minimizing this cost function we obtain electrode geometries that favour the chosen interaction with low control-voltage requirements. While we focus on linear trap segments, the same approach can also be applied to more elements such as junctions in scalable ion-trap chips.

Q 4.3 Mon 12:15 P 10

**Scaling-up a trapped-ion quantum computer using MAGIC** — •Saptarshi Biswas[1], Ivan Boldin[1], Benjamin Bürger[1], Friederike J. Giebel[3,4], Radhika Goyal[2], Patrick H. Huber[1], Eike Iseke[3,4], Lukas Kilzer[2], Nila Krishnakumar[3,4], Rodolfo M. Rodriguez[1], Tobias Pootz[2], Kais Rejaibi[1], David Stuhrmann[2], Nora D. Stahr[2,4], Jacob Stupp[2,4], Konstantin Thronberens[3,4], Celeste Torkzaban[2], Pedram Yaghoubi[1], Christian Ospelkaus[2,3,4], and Christof Wunderlich[1] — [1]Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Laboratory of Nano and Quantum-Engineering, Hannover, Germany

We present the status of a cryogenic (4K) experimental set-up for quantum computing with radio frequency (RF)-controlled trapped ions. It incorporates a novel micro-structured planar Paul trap with integrated micromagnets, and we report on the characterization of such a trap. Also, progress in developing laser cooling techniques for mixed $Yb^+$-$Ba^+$ crystals is reported.

Q 4.4 Mon 12:30 P 10

**Towards a cryogenic trapped ion quantum processor with cryogenic control electronic** — •Dorna Niroomand[1], Daniel Busch[1], Eike Iseke[2,3], Nila Krishnakumar[2,3], Max Glantschnig[5], Leon Dixius[4], Alexander Meyer[6], Garima Saraswat[7], Matthias Brandl[4], Friederike J. Giebel[2,3], Vadim Issakov[6], Michael Johanning[7], and Christof Wunderlich[1] for the ATIQ SIEGEN-Collaboration — [1]Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Laboratory of Nano and Quantum-Engineering, Hannover, Germany — [4]Infineon Technologies AG, Neubiberg, Germany — [5]Infineon Technologies Austria AG, Villach, Austria — [6]Institut für CMOS Design,TU Braunschweig, Braunschweig, Germany — [7]eleQtron GmbH, Siegen, Germany

Trapped ion quantum computing platforms in cryogenic vacuum have the advantage of providing extreme high vacuum (XHV) allowing for long ion storage times, even in the relatively shallow trapping potential of surface-electrode Paul traps. Furthermore, anomalous heating of trapped ions is strongly suppressed. Here, we will discuss the progress towards building and operating a cryogenic quantum demonstrator that includes low-noise cryogenic electronics to precisely control trapping potentials and enable shuttling of ions. En route towards scalable trapped ion quantum processors, multiple generations of microfabricated surface-electrode traps with integrated magnets and cryogenic control electronics are investigated in this platform.

Q 4.5 Mon 12:45 P 10

**Experimental characterization of all-to-all-coupled trapped-ion quantum registers** — •Markus Nünnerich, Patrick H. Huber, Dorna Niroomand, and Christof Wunderlich — Dept. of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany

For quantum computing and -simulation, high connectivity between qubits mediated by long-range interactions can be beneficial to speed up running times of algorithms and to enable efficient error correction. Here, we experimentally characterize computational quantum registers of varying size with all-to-all interaction between qubits. The qubits are encoded into hyperfine states of laser-cooled trapped $^{171}Yb^+$ ions. The ions interact via magnetic gradient induced coupling (MAGIC) and all coherent operations on qubits are performed using RF radiation. We carry out measurements on individual addressing of interacting qubits within a computational register (crosstalk), qubit read-out, and the all-to-all interaction between qubits. Furthermore, we entangle subsets of the qubit register using bare-state qubits or dressed-state qubits. In addition, we describe how fluctuations of the trapping potential affect the interaction between qubits.