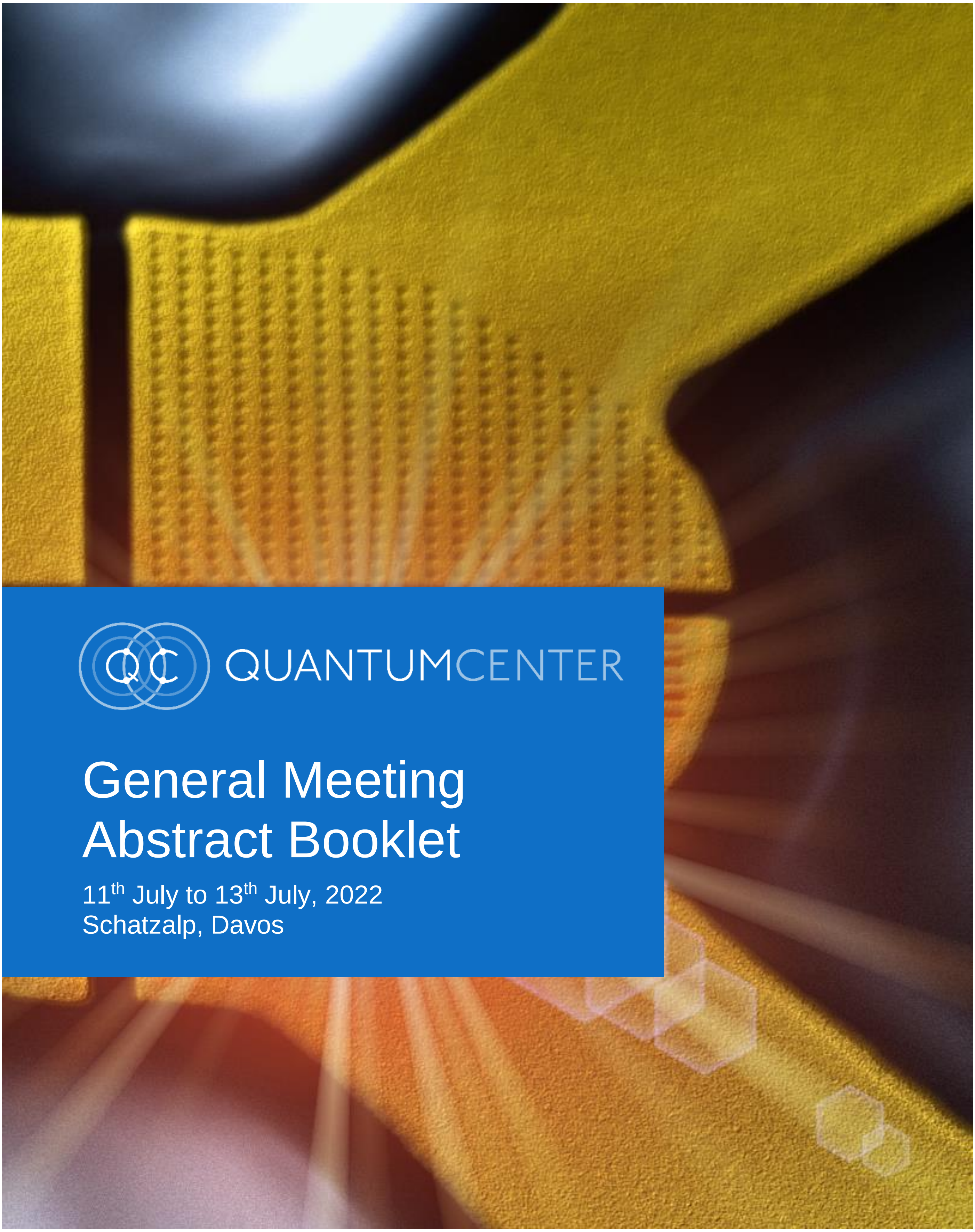
ETH zürich



QUANTUMCENTER

# General Meeting Abstract Booklet

11th July to 13th July, 2022
Schatzalp, Davos

# Welcome to the General Meeting of the Quantum Center

We are delighted to welcome the members of the Quantum Center and their groups to join us for three days of talks, posters, discussions, and networking in Davos. The program is full of exciting science talks from various fields across the areas of activity of the Quantum Center member groups, a poster session with apéro, an input talk from the CEO of a Swiss start-up company in quantum sensing followed by a panel discussion, and time to socialize with fellow researchers.

It is great to have you here in Davos at Schatzalp and we are looking forward to spending thrilling days with you.

With best wishes,

Andreas Wallraff, Philipp Kammerlander & Francesca Bay

Photo on the front page: Markus Parzefall

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# Program

## Schedule

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| 09:30 | | W. Huang | M. Drimmer | 09:30 |
| 10:00 | | C. Carisch | S. Gerber | 10:00 |
| 10:30 | | Coffee Break | Coffee Break | 10:30 |
| 11:00 | | J.-C. Besse | W. Legrand | 11:00 |
| 11:30 | | R. Wolf | B. MacDonald-de Neeve | 11:30 |
| 12:00 | Arrival / Light Lunch / Posters up | S. Stepanov | Concluding Remarks | 12:00 |
| 12:30 | | Lunch | Lunch / Departure | |
| 14:00 | Welcome and Introduction | M. Huang | | 14:00 |
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| 19:00 | Dinner (Schatzalp) | Conference Dinner (Strela Alp) | | 19:00 |
| 21:00 | Input by G. Puebla Hellmann (QZabre) followed by a Panel Discussion | | | |

# Detailed Program and Abstracts

## Monday, 11 July 2022

| | |
|---|---|
| **12:00 - 14:00** | **Arrival, Light Lunch and Posters up** |
| **14:00 - 14:30** | **Welcome**<br>**Introduction to the Executive Office and Student Board** |
| | *Chair: Philipp Kammerlander* |
| **14:30 - 15:15** | **Invited Talk: Kenny Paterson, Applied Cryptography Group, D-INFK**<br>Post-Quantum Cryptography: Why, How, and When? |
| **15:15 - 15:45** | **Mischa Woods, Quantum Information Theory Group, D-PHYS**<br>Quantum clocks and how to realise them |
| **15:45 - 16:15** | **Alexander Grimm, Laboratory for X-ray Nanoscience and Technologies (LNX), PSI**<br>Quantum information processing with Schrödinger-cat qubits |
| **16:15 - 16:45** | **Poster Flash** |
| **16:45 - 18:45** | **Poster Session with Welcome Apéro** |

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|---|---|
| **19:00 - 21:00** | **Dinner** |
| **21:00 - 22:00** | **Input Talk by Gabriel Puebla Hellmann (QZabre) followed by a Panel Discussion on Academia and Industry** |

14:30 - 15:15

**Kenny Paterson**

### POST-QUANTUM CRYPTOGRAPHY: WHY, HOW, AND WHEN?

In this talk, I'll give a brief overview of what has been happening in the field of Post-Quantum Cryptography (PQC), that is, the study of cryptographic algorithms that resist attack by quantum computers. I'll focus on explaining why we need PQC, how we will get PQC, and when the transition to PQC will begin. The talk will not assume any specialist knowledge about cryptography.

15:15 - 15:45

**Mischa Woods**

### QUANTUM CLOCKS AND HOW TO REALISE THEM

Quantum clocks (also referred to as "ticking clocks" by some authors) are quantum analogues of classical clocks, i.e. devices which autonomously emit ticks at approximately regular intervals. Unlike for classical clocks, where both the register (i.e. the clockface) and the clockwork are classical, in a quantum clock only the register is classical. A clock is very accurate if its ticks are uniformly distributed over time. An important task is to characterize how accurate a clock can be as a function of relevant parameters such as dimension or energy and answer questions such as is there a quantum advantage to timekeeping? It was recently proven that there is a quadratic advantage from a dimension perspective (see [2] below). However, since the proof was an existence proof and not constructive, it was completely unknown how it could be realised. In particular, what environment was necessary and whether or not it was physical. In this talk I would review these results and talk about new research showing how the optimal quantum clock could be realised using an optical cavity and flux loops.

A selected subset of references are

[1] Autonomous quantum clocks: does thermodynamics limit our ability to measure time? https://doi.org/10.1103/PhysRevX.7.031022, (editor's suggestion)

[2] Quantum clocks are more precise than classical ones https://doi.org/10.1103/PRXQuantum.3.010319

[3] The thermodynamics of clocks https://doi.org/10.1080/00107514.2020.1837471

[4] Autonomous quantum machines and the finite sized Quasi-Ideal clock https://doi.org/10.1007/s00023-018-0736-9

15:45 - 16:15

### Alexander Grimm

#### QUANTUM INFORMATION PROCESSING WITH SCHRÖDINGER-CAT QUBITS

Quantum two-level systems are routinely used to encode qubits but tend to be inherently fragile, leading to errors in the encoded information. Quantum error correction (QEC) addresses this challenge by encoding effective qubits into more complex quantum systems. Unfortunately, the hardware overhead associated with QEC can quickly become very large.

In contrast, a qubit that is intrinsically protected against a subset of quantum errors can be encoded into superpositions of two opposite-phase oscillations in a resonator, so-called Schrödinger-cat states. This “Schrödinger-cat qubit” has the potential to significantly reduce the complexity of QEC. In a recent experiment, we have demonstrated the stabilization and operation of such a qubit through the interplay between Kerr nonlinearity and single-mode squeezing in a superconducting microwave resonator.

In this talk, I will review some key concepts of QEC and situate our approach within the field. I will give an overview of the cat qubit, followed by an outlook on different applied and fundamental research directions it enables.

16:15 - 16:45

### Poster Flash

Everyone who brings a poster gets the chance to flash the content of it on one slide in one minute time. This is to give everyone an overview for the poster session afterwards.

21:00 - 22:00

### Input Talk and Panel Discussion on the Interplay between Academia and Industry

An important aspect of the vision currently being established for the Quantum Center at ETH Zurich is to be an ETH-wide contact and entry point for third parties interested in quantum science and technology. As part of this, the Quantum Center will put effort in acquiring industry contacts and establishing partnerships with companies from the private sector.

In this 60-minute session we will engage in a discussion about the opportunities, chances, and risks of such an endeavor and touch upon questions like:

What can the Quantum Center at ETH Zurich offer to partners from industry, and vice versa?

How should the Quantum Center approach potential partners?

What would an optimal environment for mutually beneficial collaborative efforts look like?

What roles could initiatives from the public sector play in this respect?

**Program:**

- Input Talk by Gabriel Puebla-Hellmann, CEO of QZabre (https://qzabre.com/). Gabriel will present his views on fruitful interactions and successful collaborations between academia and industry, in particular with respect to his own experiences made as the CEO of the Swiss start-up company QZabre.
- Following Gabriel's input talk we will engage in a panel discussion moderated by Philipp Kammerlander.

**Panelists:**
Dr. Gabriel Puebla-Hellmann, CEO QZabre

Dr. Cornelius Hempel, External Partnerships Officer at the Quantum Center & Group Head Trapped Ions at the ETHZ-PSI Quantum Computing Hub

PD Dr. Martin Frimmer, Program Manager Quantum Engineering MSc & Senior Scientist in the Photonics Laboratory

Kristina Kirova, Quantum Center Student Board

Questions and inputs from the audience during the panel discussion are highly welcome.

# Tuesday, 12 July 2022

| | |
|---|---|
| | *Chair: Cornelius Hempel* |
| **08:45 - 09:30** | **Invited Talk: Yiwen Chu, Hybrid Quantum Systems Group, D-PHYS**<br>Cirquit QAD and quantum optomechanics with bulk acoustic wave resonators |
| **09:30 - 10:00** | **Wister Huang, The Ensslin Nanophysics Group, D-PHYS**<br>Quantum information processing with graphene quantum dots |
| **10:00 - 10:30** | **Christian Carisch, Quantum Engineered Systems, D-PHYS**<br>Is the measurement-induced entanglement phase transition classical? |
| **10:30 - 11:00** | **Coffee break** |
| | *Chair: Simon Gerber* |
| **11:00 - 11:30** | **Jean-Claude Besse, Quantum Device Lab, D-PHYS**<br>Deterministic Generation and Manipulation of Entangled Microwave Photonic Qubits |
| **11:30 - 12:00** | **Ramona Wolf, Quantum Information Theory Group, D-PHYS**<br>True randomness from quantum physics |
| **12:00 - 12:30** | **Sebastian Stepanov, Magnetism and Interface Physics Group, D-MATL**<br>Exploring the magnetism of single spins on surfaces |
| **12:30 - 14:00** | **Lunch** |
| | *Chair: Ramona Wolf* |
| **14:00 - 14:30** | **Mengzi Huang, Quantum Optics Group, D-PHYS**<br>Superfluid transport through a lossy channel |
| **14:30 - 15:00** | **Andrei Militaru, Photonics Laboratory, D-ITET**<br>Ponderomotive squeezing of light by a levitated nanoparticle in free space |
| **15:00 - 15:30** | **Joao Pinto Barros, Institute for Theoretical Physics, D-PHYS**<br>Analog Quantum Simulation of Gauge Theories in the Particle Representation |
| **15:30 - 16:15** | **Coffee break** |
| | *Chair: Martin Frimmer* |
| **16:15 - 16:45** | **Alexa Herter, Quantum Optoelectronics Group, D-PHYS**<br>Probing vacuum fields in causally disconnected space-time regions |
| **16:45 - 17:15** | **Hua Wang, Integrated Systems Laboratory, D-ITET**<br>Example cryo-CMOS radio-frequency integrated circuit building blocks |
| **17:15 - 19:00** | **Free time / hike to Strela Alp** |
| **19:00 - 21:00** | **Conference Dinner at Strela Alp (**https://strelaalp.com/**)** |

08:45 - 9:30

## Yiwen Chu

### CIRCUIT QAD AND QUANTUM OPTOMECHANICS WITH BULK ACOUSTIC WAVE RESONATORS

Bulk acoustic wave (BAW) resonators are mechanical oscillators that confine sound waves in a solid-state material. Due to their use in a wide range of classical devices, they have been engineered to exhibit high quality factors, and their interactions with electromagnetic fields have been extensively studied. Recently, BAW resonators have also rapidly developed into a promising platform for new quantum devices. In this talk, I will give an overview of our work on interfacing them with microwave frequency superconducting circuits and infrared frequency optics. I will present our demonstrations of the strong dispersive regime in a circuit quantum acousto-dynamics device and Brillouin cavity optomechanics at cryogenic temperatures.

09:30 - 10:00

## Wister Huang

Wister Wei Huang[1], Chuyao Tong[1], Lisa Maria Gächter[1], Rebekka Garreis[1], Annika Kurzmann[1], Jonas Daniel Gerber[1], Max Josef Ruckriegel[1], Benedikt Kratochwil[1], Folkert Kornelis de Vries[1], Kenji Watanabe[2], Takashi Taniguchi[2], Thomas Ihn[1], Klaus Ensslin[1]

[1]Solid State Physics Laboratory, ETH Zurich, CH-8093 Zurich, Switzerland; [2]National Institute for Material Science, 1-1 Namiki, Tsukuba 305-0044, Japan

### QUANTUM INFORMATION PROCESSING WITH GRAPHENE QUANTUM DOTS

Spin qubits in semiconductors have the advantage that the operation and fabrication of gate electrodes are similar to classical transistors. High-quality qubits have been demonstrated on multiple semiconductor platforms including traditional bulk MOSFETs as well as on III-V, silicon- and germanium-based heterostructures.

Graphene offers several advantages as a host material for spin qubits, namely naturally low nuclear spin concentrations and weak spin-orbit interactions, similar to silicon. In addition, the 2D nature of graphene allows for much smaller and more strongly coupled quantum devices. Furthermore, bilayer graphene quantum dots offer the flexibility of bipolar operation.

Here we demonstrate recent advancements toward quantum information processing; we study the excited state spectrum for one- and two-electron states in single and double quantum dots and demonstrate that the spin and valley states can be manipulated by both electric and magnetic fields [1-2]. The high-tunability allows us to switch controllably between Pauli spin-blockade and valley-blockade physics [3], which are the crucial underlying mechanisms for qubit readout and two-qubit operations. We then perform an Elzerman style [4] single-shot readout of the spin state with a signal-to-noise ratio of about 7 and find relaxation times up to 50ms, with a strong magnetic field dependence, promising even higher values for smaller magnetic fields [5]. The spin relaxation time is a few orders of magnitude longer than typical spin qubit operation times and competes very well with other group IV elements, like silicon.

[1] A. Kurzmann *et al.*, *Phys. Rev. Lett.* **123**, 026803 (2019)

[2] C. Tong *et al.*, *Nano Letters* **21**, 1068 (2021)

[3] C. Tong *et al.*, *Phys. Rev. Lett.* **128**, 067702 (2022)

[4] J. M. Elzerman *et al.*, *Nature* **430**, 431–435 (2004)

[5] L. M. Gächter, R. Garreis *et al.*, *PRX Quantum **3**, 020343* (2022)

10:00 - 10:30

## Christian Carisch

Christian Carisch[1], Alessandro Romito[2], Oded Zilberberg[3]

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[2]alessandro.romito@lancaster.ac.uk
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### IS THE MEASUREMENT-INDUCED ENTANGLEMENT PHASE TRANSITION CLASSICAL?

The long-time behavior of open quantum systems involves their non-equilibrium steady state (NESS). In general, the NESS is a mixed state describing an ensemble of pure quantum states. In recent years, a novel type of phase transition in this ensemble attracts much attention. The rate of projective measurements of the quantum system seems to drive the NESS from an ensemble of extensively entangled states to an ensemble of near-product states. This transition is called entanglement phase transition because the entanglement of the ensemble states serves as an order parameter. However, similar observations in classical systems raise doubts about the quantumness of this entanglement phase transition. In this talk, we discuss whether the transition can be observed on the level of the mixed state itself rather than its ensemble constituents. For the analysis, we deploy our recently developed entanglement measure for mixed states. Our preliminary results help to shed light into the physics behind the entanglement phase transition.

11:00 - 11:30

## Jean-Claude Besse

Jean-Claude Besse, Kevin Reuer, Michele C Collodo, Lucien Wernli, Adrian Copetudo, Daniel Malz, Paul Magnard, Philipp Kurpiers, Abdulkadir Akin, Mihai Gabureac, Graham J. Norris, J. Ignacio Cirac, Andreas Wallraff and Christopher Eichler

### DETERMINISTIC GENERATION AND MANIPULATION OF ENTANGLED MICROWAVE PHOTONIC QUBITS

Sources of entangled electromagnetic radiation, and photon-photon gates, are key components for distributed quantum information processing. Both processes remain challenging to perform deterministically, without relying on post-selection. Here, we demonstrate a unique superconducting device able to deterministically generate a wide family of entangled states of microwave radiation such as cluster, GHZ, and W states [1], and mediate photon-photon interactions [2].

We tomographically reconstruct all sequentially emitted quantum many-body states entirely for up to $N = 4$ photonic modes and characterize states for larger $N$ by considering the repetitive nature of the sequential emission process. We estimate that localizable entanglement persists over a distance of approximately ten photonic qubits.

We also realize a universal gate set by combining the controlled absorption and re-emission of photonic qubits with single qubit gates and qubit-photon controlled-phase gates. We measure external quantum process fidelities in excess of 50% for all gates, limited mainly by radiation loss and decoherence.

The demonstrated platform has a wide range of potential applications in local area superconducting quantum networks.

[1] Besse et al., *Realizing a deterministic source of multipartite-entangled photonic qubits.* Nature Communications **11**, 4877 (2020).

[2] Reuer, Besse et al., *Realization of a Universal Quantum Gate Set for Itinerant Microwave Photons.* Phys. Rev. X **12**, 011008 (2022).

11:30 - 12:00

**Ramona Wolf**

### TRUE RANDOMNESS FROM QUANTUM PHYSICS

Randomness is a regular part of our (more or less) daily lives: from drawing lottery numbers to running computer simulations and the security of cryptographic schemes, various applications rely on random numbers. But does true randomness actually exist? If so, can we create truly random numbers in our labs? This task proposes many challenges, already on a fundamental theoretical level. In this talk, I will discuss what is necessary to realize quantum random number generators, starting with how to properly define randomness (which is a surprisingly nontrivial task!) up to explaining the different kinds of protocols that fall under the name ''quantum random number generation'' and how far we have come in experimental realizations.

12:00 - 12:30

**Sebastian Stepanow**

S. Kovarik, R. Schlitz, A. Vishwakarma, T. S. Seifert, P. Gambardella and S. Stepanow

Department of Materials, Magnetism and Interface Physics, ETH Zürich, Switzerland

### EXPLORING THE MAGNETISM OF SINGLE SPINS ON SURFACES

Magnetic atoms on surfaces are emerging as a new class of systems with exceptionally long spin relaxation times, which allows for reading and writing magnetic bits on the atomic scale. The magnetic properties of the single-ion magnets depend crucially on their atomic environment and enhancing their spin dynamics may lead to the development of single-atom qubits. The discovery of unusually high magnetic anisotropy and long spin life times in transition metal atoms on the thin insulating platforms has culminated in the observation of magnetic remanence in individual Ho atoms adsorbed on ultrathin MgO(100) layers on Ag(100).[1] Despite detailed descriptions of these systems, there are open questions on the manipulation and addressability of the surface spins as well as their quantum coherence properties.

A great leap towards the determination spin coherence in single spin systems was made with the demonstration of electron paramagnetic resonance (EPR) spectroscopy using the tip of a scanning tunneling microscope (STM).[2] This technique uses an electrical method both to drive and read the spin, permitting sub-atomic resolution magnetic resonance imaging in combination with the precise measurements of g-factors and spin decoherence times of single spins on surfaces. In our work, we explore the mechanism[3] behind EPR-STM and apply the technique to novel adsorbate systems[4]. The recent progress in this emerging field highlights the general applicability of the technique providing unprecedented insights into the charge and spin states of adsorbate systems.

References:

[1] F. Donati, S. Rusponi, S. Stepanow, C. Wäckerlin, A. Singha, L. Persichetti, R. Baltic, K. Diller et al., Science **352**, 318 (2016).

[2] S. Baumann, W. Paul, T. Choi, C. P. Lutz, A. Ardavan, and A. J. Heinrich, Science 2015, 350, 417; K. Yang, W. Paul, S.-H. Phark, P. Willke, Y. Bae, T. Choi, T. Esat, A. Ardavan, A. J.Heinrich, C. P. Lutz, Science **366**, 509 (2019).

[3] T. S. Seifert, S. Kovarik, D. M. Juraschek, N. A. Spaldin, P. Gambardella, and S. Stepanow, Science Advances **6**, eabc5511 (2020).

[4] S. Kovarik, R. Robles, R. Schlitz, T. S. Seifert, N. Lorente, P. Gambardella, and S. Stepanow, Nano Letters **22**, 4176 (2022).

14:00 - 14:30

**Mengzi Huang**

M.-Z. Huang[1], Ph. Fabritius[1], J. Mohan[1], A.-M. Visuri[2], M. Talebi[1], S. Wili[1], S. Uchino[3], T. Giamarchi[4] & T. Esslinger[1]

[1]Institute for Quantum Electronics, ETH Zurich, Switzerland; [2]Physikalisches Institut, University of Bonn, Germany; [3]Advanced Science Research Center, Japan Atomic Energy Agency, Japan; [4]Department of Quantum Matter Physics, University of Geneva, Switzerland

### SUPERFLUID TRANSPORT THROUGH A LOSSY CHANNEL

Quantum simulation with ultracold atoms can provide new insights on strongly correlated matter under exotic conditions. For example, superconductivity is expected to be fragile to pair-breaking particle loss, which is difficult to realize in solid-state systems. But in a quantum gas experiment, direct observations of this scenario are possible. In this talk, I will present our recent results in a model system consisting of a narrow channel connecting two reservoirs of strongly interacting fermionic lithium atoms. We engineer a local spin-dependent particle loss inside the channel with a focused laser beam, and observe its impact on the superfluid flow between the reservoirs. The superfluid current is typically characterized by a non-Ohmic current-bias relation which can be understood with multiple Andreev reflections. We observe that this high-order coherent process does not vanish sharply as dissipation increases, as predicted qualitatively by a mean-field model using the Keldysh formalism. On the other hand, the microscopic loss process, which is not captured by the minimal model, would reveal pairing properties in the strongly correlated system. Our current efforts amount to understanding the loss effect in different transport scenarios such as spin and heat transport. Our work opens up perspectives in dissipative engineering of superfluid transport.

14:30 - 15:00

**Andrei Militaru**

Andrei Militaru,[1,*] Massimiliano Rossi,[1,*] Felix Tebbenjohanns,[1,†] Oriol Romero-Isart,[2,3] Martin Frimmer,[1] and Lukas Novotny[1,4]

[1]Photonics Laboratory, ETH Zürich, CH-8093 Zurich, Switzerland; [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020, Innsbruck, Austria; [3]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria; [4]Quantum Center, ETH Zürich, CH-8093 Zürich, Switzerland

### PONDEROMOTIVE SQUEEZING OF LIGHT BY A LEVITATED NANOPARTICLE IN FREE SPACE

The interaction between optical fields and mechanical systems lies at the heart of the field of optomechanics. An emerging optomechanical platform is represented by a dielectric nanoparticle trapped in a strongly focused, propagating beam. This represents an example of free-space optomechanics, where no optical resonator is used to boost the light-particle interaction.

In order to exert quantum control of the trapped nanoparticle, two key ingredients are necessary. In first place, the mechanical motion must be predominantly driven by the vacuum fluctuations of the light field. In second place, the information radiated about the nanoparticle's position must be suitably detected. In two recent studies [1,2], quantum control has been demonstrated by using a measurement-based feedback force to cool the center-of-mass motion of the nanoparticle to its quantum ground state.

Together with ground-state-cooling of the center-of-mass motion, there is a second, complementary phenomenon enabled by the quantum measurement regime. Because the amplitude quadrature of the the interacting light field drives the motion while the phase quadrature probes it, the optomechanical interaction gives rise to correlations between amplitude and phase of this interacting field. When strong enough, these correlations translate into squeezing of the optical fluctuations below the vacuum level for a specific quadrature—a phenomenon known as ponderomotive squeezing. In this work, we demonstrate ponderomotive squeezing in free space by identifying the light modes responsible for the optomechanical interaction and observing a reduction of their fluctuations up to 25% below vacuum noise [3].

[*] These authors contributed equally to this work.
[†] Present address: Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

[1] L. Magrini, P. Rosenzweig, C. Bach, A. Deutschmann-Olek, S. G. Hofer, S. Hong, N. Kiesel, A. Kugi, and M. Aspelmeyer, Nature **595**, 373 (2021).

[2] F. Tebbenjohanns, M. L. Mattana, M. Rossi, M. Frimmer, and L. Novotny, Nature **595**, 378 (2021).

[3] A. Militaru, M. Rossi, F. Tebbenjohanns, O. Romero-Isart, M. Frimmer, and L. Novotny, "Ponderomotive squeezing of light by a levitated nanoparticle in free space," (2022), arXiv:2202.09063 [quant-ph].

15:00 – 15:30

**Joao C. Pinto Barros**

### ANALOG QUANTUM SIMULATION OF GAUGE THEORIES IN THE PARTICLE REPRESENTATION

Gauge theories are physical theories that exhibit a “large” number of symmetries, gauge symmetries, which should be regarded as redundancies in the description of the system. They play a role in a wide range of fields, from quantum computation (e.g. toric code) to particle physics (e.g. quantum chromodynamics). When these theories are in a strongly correlated phase, analytical approaches are usually lacking. Numerical (classical) simulations can fill in this role, but further problems may arise making certain calculations impossible. These could be solved, in principle, with a quantum computer, either universal or single-purpose (analog). Both would simulate the desired system directly in the quantum realm, surpassing the fundamental drawbacks of classical simulations.

In this talk, I will introduce lattice gauge theories and the existing challenges regarding their (quantum) simulations. I will argue how the description of the gauge degrees of freedom in the particle representation offers a unique route to the realization of some gauge theories using ultracold atoms, though the approach can be extended to other platforms

16:15 - 16:45

**Alexa Herter**

### PROBING VACUUM FIELDS IN CAUSALLY DISCONNECTED SPACE-TIME REGIONS

With the discovery of quantum mechanics, the picture of causality has changed. Now the effect of entanglement allows the correlation also between space-time points outside the light cone. For the theoretical description of such effects physicists working in quantum field theory often follow the example of Feynman by using the picture of atoms described by a two-level system interacting with the quantum state of light. Thereby, already the ground state of light – well known as vacuum fluctuations – can create non-causal connections between two atoms, since the vacuum fluctuation being a pure quantum state is naturally entangled. For the discussion of causality, a precisely defined starting time for the interaction of the atoms with each other as well as with the vacuum starts is crucial. Consequently, an experimental realization failed at the permanent presence of the vacuum fluctuations and the impossibility to switch off the interaction of atoms with the surrounding electromagnetic fields. At the same time, optical signals do not interact with the vacuum field in general, but interaction can be achieved by overlapping the contributing fields inside a non-linear crystal. Within the spectral range of THz up to mid-infrared, electro-optic sampling allows mapping the electric field of a signal onto the polarization state of near-infrared laser pulses by the use of second-order nonlinear interaction. In this manner, the statistics of vacuum fluctuations and their first-order temporal field correlation within a single spatial point have been analysed in the past. Now we expand the latter investigation by separating the near-infrared probing pulses also in the spatial dimension. For a distance of 50 µm – corresponding to a time-of-flight of 470 fs – we demonstrate a non-vanishing vacuum-induced correlation between two 195 fs pulses. The theoretical description in a Greens-formalism using the identical parameters as in the experiment verifies non-causal contributions dominating our signal. In conclusion, we build an experimental analogy to the theoretical two-atom picture paving the way to novel insights into quantum field theory.

16:45 - 17:15

**Hua Wang**

### EXAMPLE CRYO-CMOS RADIO-FREQUENCY INTEGRATED CIRCUIT BUILDING BLOCKS

The recent developments in quantum computing and sensing have created a growing demand for integrated cryogenic interface electronics. CMOS technologies provide a promising solution for large-scale qubits cryogenic systems due to their low-cost and unparalleled large-scale integration as well as their potential compatibility with semiconductor qubits fabrication. In this talk, I will present two cryo-CMOS RF circuit examples in Globalfoundries CMOS SOI technologies from my ETH IDEAS group. The first block is a compact broadband cryogenic low noise amplifier (LNA) with simultaneous noise and power matching with transformer-based feedback. At 16K, the LNA achieves 31.4dB–34.7dB gain over 4.2-9.2 GHz with a minimum noise Figure (NF) of 0.065dB and NF < 0.3dB, as the best cryo-CMOS radio-frequency LNA NF reported so far. The second example is a noise circulating and multi-mode wideband voltage controlled oscillator (VCO) over 4-8GHz. The VCO achieves the best reported close-in phase noise and a very competitive figure-of-merit (FoM) among reported designs.

## Wednesday, 13 July 2022

| | |
|---|---|
| | *Chair: Sebastian Stepanov* |
| **08:45 - 09:30** | **Invited Talk: Marina Marinkovic, High-Performance Computational Physics, D-PHYS**<br>NISQ computing as a training ground for simulations in particle and atomic physics |
| **09:30 - 10:00** | **Maxwell Drimmer, Hybrid Quantum Systems Group, D-PHYS**<br>Quantum Wavelength Conversion with Bulk Acoustic Waves |
| **10:00 - 10:30** | **Simon Gerber, Quantum Photon Science Group, PSI**<br>Time-domain interferometry and quantum optics exploiting X-ray free-electron lasers |
| **10:30 - 11:00** | **Coffee Break** |
| | *Chair: Jean-Claude Besse* |
| **11:00 - 11:30** | **William Legrand, Magnetism and Interface Physics, D-MATL**<br>Toward magnet-based and magnonic hybrid quantum systems |
| **11:30 - 12:00** | **Brennan de Neeve, Trapped Ion Quantum Information Group, D-PHYS**<br>Error correction of a logical grid state qubit by dissipative pumping |
| **12:00 - 12:15** | **Concluding Remarks** |
| **12:30 - 14:00** | **Lunch / Departure** |

08:45 - 09:30

**Marina Marinkovic**

### NISQ COMPUTING AS A TRAINING GROUND FOR SIMULATIONS IN PARTICLE AND ATOMIC PHYSICS

The rapid progress of quantum technologies and AI over the past few years has the potential to impact many areas of physics where analytical solutions are not feasible and classical simulation techniques fail. The talk starts with a review of a quantum machine learning procedure to address condensed matter and particle physics systems hampered by the sign problem. I then move to atomic physics and show recent results on a quantum circuit mapping of the Tavis-Cummings open system dynamics in the single-excitation regime, suitable for execution on NISQ devices.

09:30 - 10:00

**Maxwell Drimmer**

### QUANTUM WAVELENGTH CONVERSION WITH BULK ACOUSTIC WAVES

A low-noise, efficient, bi-directional microwave-to-optical transducer could connect superconducting circuits in distant dilution refrigerators, offering a promising route towards powerful, large-scale quantum computers and networks. We present our advances in developing a device in which a Bulk Acoustic Wave (BAW) resonator mediates interactions between the microwave field of a transmon qubit and a telecom-frequency mode of a Fabry-Perot cavity. We discuss the design challenges of building the cryogenic optomechanical cavity, in particular thermal misalignment and isolation against dilution refrigerator vibrations, and present our first observation of optomechanical coupling and mode thermometry. We also detail our strategy for minimizing the amount of stray optical radiation that impinges on the superconductor. We show results from an experiment that studies quasiparticle generation due to laser light and its detrimental effects on our microwave circuitry.

10:00 - 10:30

**Simon Gerber**

### TIME-DOMAIN INTERFEROMETRY AND QUANTUM OPTICS EXPLOITING X-RAY FREE-ELECTRON LASERS

X-ray free-electron lasers (FELs) deliver ultrabright X-ray pulses, but not the sequences of phase-coherent pulses required for time-domain interferometry and control of quantum states. For conventional, so-called split-and-delay schemes to produce such sequences, the challenge stems from extreme stability requirements when splitting Ångstrom wavelength beams, where the tiniest path-length differences introduce phase jitter. I will present an FEL mode based on selective electron-bunch degradation and transverse beam shaping in the accelerator, combined with a self-seeded photon emission scheme. Instead of splitting the photon pulses after their generation by the FEL, we split the electron bunch in the accelerator, prior to photon generation, to obtain phase-locked X-ray pulses with subfemtosecond duration. Time-domain interferometry becomes possible, enabling the concomitant program of classical and quantum optics experiments with X-rays. The scheme leads to scientific benefits of cutting-edge FELs with attosecond and/or high-repetition rate capabilities, ranging from the X-ray analog of Fourier transform infrared spectroscopy to damage-free measurements.

11:00 - 11:30

**William Legrand**

### TOWARD MAGNET-BASED AND MAGNONIC HYBRID QUANTUM SYSTEMS

We will cover in this presentation several on-going works involving magnetically ordered, condensed matter systems of use in hybrid quantum devices.

Spin qubits hosted in double quantum dots can be operated by interaction with a microwave superconducting resonator, in a scheme called electric-dipole spin resonance, where the spin character of a level transition is mixed with a dipole character. This allows for a much stronger coupling to the electric component of a photon mode than what can be achieved to the magnetic component. It is usually realized by integrating the quantum dots inside an inhomogeneous magnetic field, obtained from nearby nanoscale ferromagnetic electrodes. While the strength of this inhomogeneous magnetic field directly determines the coupling rates, only few corresponding magnet geometries and materials have been explored [1-3]. We have investigated how to improve the inhomogeneous stray fields, and reverted to the fundamentals of nanomagnetism to design elements as close as possible to ideal field gradient sources.

When the size of the magnetic element is increased to fill a macroscopic electromagnetic cavity, it can become a sensitive detector of electromagnetic field anomalies, in particular terms of the form $\mathbf{E}\cdot\mathbf{B}$ [4]. We will present our work within the increasingly popular field of axion dark matter candidate detection, involving a hybrid magnon–photon system.

It remains however unsatisfying that sizeable direct coupling between the magnetic component of microwave fields and magnons can only be achieved for macroscale ensembles, of the order of $10^{12}$ spins [5,6] and $10^{18}$ spins [7] for lithographed and macroscopic resonators, respectively. We aim to pursue several material-based strategies to improve the direct coupling rates in magnon–photon devices, in order to enable experiments closer to the quantum regime.

[1] Pioro-Ladrière, M. et al. Electrically driven single-electron spin resonance in a slanting Zeeman field. Nat. Phys. 4, 776–779 (2008).

[2] McNeil, R. P. G. et al. Localized Magnetic Fields in Arbitrary Directions Using Patterned Nanomagnets. Nano Lett. 10, 1549–1553 (2010).

[3] Mi, X. et al. A coherent spin–photon interface in silicon. Nature 555, 599–603 (2018).

[4] Sikivie, P. Invisible axion search methods. Rev. Mod. Phys. 93, 15004 (2021).

[5] Hou, J. T. & Liu, L. Strong Coupling between Microwave Photons and Nanomagnet Magnons. Phys. Rev. Lett. 123, 107702 (2019).

[6] Li, Y. et al. Strong Coupling between Magnons and Microwave Photons in On-Chip Ferromagnet-Superconductor Thin-Film Devices. Phys. Rev. Lett. 123, 107701 (2019).

[7] Tabuchi, Y. et al. Coherent coupling between a ferromagnetic magnon and a superconducting qubit. Science 349, 405–408 (2015).

11:30 - 12:00

**Brennan de Neeve**

Brennan de Neeve, Thanh-Long Nguyen, Tanja Behrle, Jonathan P. Home

Institute for Quantum Electronics, ETH Zürich, Zürich, Switzerland; Quantum Center, ETH Zürich, Zürich, Switzerland.

### ERROR CORRECTION OF A LOGICAL GRID STATE QUBIT BY DISSIPATIVE PUMPING

Stabilization of encoded logical qubits using quantum error correction is key to the realization of reliable quantum computers. While qubit codes require many physical systems to be controlled, oscillator codes offer the possibility to perform error correction on a single physical entity. One powerful encoding for oscillators is the grid state or GKP encoding [1-3], which allows small displacement errors to be corrected. Here we introduce and implement a dissipative map designed for physically realistic finite GKP codes which performs quantum error correction of a logical qubit implemented in the motion of a single trapped ion. The correction cycle involves two rounds, which correct small displacements in position and momentum respectively. Each consists of first mapping the finite GKP code stabilizer information onto an internal electronic state ancilla qubit, and then applying coherent feedback and ancilla repumping. We demonstrate the extension of logical coherence using both square and hexagonal GKP codes, achieving an increase in logical lifetime of a factor of three. The simple dissipative map used for the correction can be viewed as a type of reservoir engineering, which pumps into the highly non-classical GKP qubit manifold. These techniques open new possibilities for quantum state control and sensing alongside their application to scaling quantum computing.

[1] Gottesman, D., Kitaev, A. & Preskill, J. Encoding a qubit in an oscillator. Phys. Rev. A **64**, 012310 (2001).

[2] Flühmann, C. et al. Encoding a qubit in a trapped-ion mechanical oscillator. Nature **566**, 513–517 (2019).

[3] Campagne-Ibarcq, P. et al. Quantum error correction of a qubit encoded in grid states of an oscillator. Nature **584**, 368–372 (2020).

[4] de Neeve B. et al. Error correction of a logical grid state qubit by dissipative pumping. Nat. Phys. **18**, 296–300 (2022).

# Posters

| No. | Authors | Title | Group |
|---|---|---|---|
| P1 | **Elías Portolés**, S.Iwakiri, G. Zheng, P. Rickhaus, T. Taniguchi, K. Watanabe, T. Ihn, K. Ensslin, and F. K. de Vries | A Tunable Monolithic SQUID in Twisted Bilayer Graphene | The Ensslin Nanophysics Group, D-PHYS |
| P2 | **Qian Ding**, I. Bouquet, D. Casati, A. Schenk, and M. Luisier | TCAD Simulation Framework for Silicon FinFET Spin Qubit Devices | Nano-TCAD group, D-ITET |
| P3 | Colin Scarato, C. Hellings, J. Herrmann, S. M. Llima, A. Remm, P. Zapletal, N. A. McMahon, F. Swiadek, C. K. Andersen, S. Krinner, N. Lacroix, S. Lazar, M. Kerschbaum, D. C. Zanuz, G. J. Norris, M. J. Hartmann, A. Wallraff, C. Eichler | Towards Training of a Quantum Convolutional Neural Network on a Superconducting Processor | Quantum Device Lab, D-PHYS |
| P4 | **Jan Kosata**, A. Leuch, T. Kästli, and O. Zilberberg | Fixing the rotating-wave approximation for strongly-detuned quantum oscillators | ETH Zurich, Universität Konstanz |
| P5 | **Jeffrey Mohan**, P. Fabritius, A.-M. Visuri, M. Talebi, S. Wili, S. Uchino, T. Giamarchi, M.-Z. Huang, and T. Esslinger | Superfluid transport through a lossy channel | Quantum Optics Group, D-PHYS |
| P6 | **K. Kirova**, E. Zapusek, Z. Lenarçiç, and F. Reiter | Variational preparation of generalized Gibbs ensembles | Trapped Ion Quantum Information Group, D-PHYS |
| P7 | **Wojciech Adamczyk**, S.Koch, H. Passagem, C.Fisher, and J.Home | Towards Optical trapping of Calcium Rydberg atoms | Trapped Ion Quantum Information Group, D-PHYS |
| P8 | **Petar Tomic**, F. Schupp, L. Ostertag, M. Mergenthaler, G. Salis, A. Fuhrer, T. Ihn, and K. Ensslin | Silicon MOS Gate Stack Optimization for Fin-FET Quantum Dots | The Ensslin Nanophysics Group, D-PHYS; IBM Zurich - Semiconductor Qubit Technologies Group |
| P9 | **Guy Matmon**, **Manuel Grimm**, T. Shen, M. Müller, S. Gerber,and G. Aeppli | Implementation of a QIP scheme using electro-nuclear states in rare-earth doped insulators | Laboratory for Solid State Physics, D-PHYS, Quantum Photon Science Group, Photon Science Division, PSI |
| P10 | **Stepan Kovarik**, R. Schlitz, A. Vishwakarma, P. Gambardella, and S. Stepanow | Probing magnetic resonance of individual adsorbates using EPR in STM | Intermag, D-MATL |
| P11 | **Nicola Carlon Zambon**, J. Vijayan, Carlos Gonzalez-Ballestero, H. Imboden, R. | Probing the acoustic modes of a levitated nanoparticle | Photonics Laboratory, D-ITET |

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| | Reimann, M. Frimmer, O. Romero-Isart, and L. Novotny | | |
| P12 | **Louisiane Devaud**<br>E. Bonvin, L. Bobzien, M. Frimmer, and L. Novotny | Hybrid traps for coherent expansion and levitated spectroscopy | Photonics Laboratory, D-ITET |
| P13 | **Luca I. Huber**, J. Flannery, R. Matt, R. Oswald, K. Wang, C. Decaroli, C. Axline, and J. Home | Low-crosstalk individual addressing for cryogenic ion trapping | Trapped Ion Quantum Information Group, D-PHYS |
| P14 | **Giulia Zheng**, E. Portolés, F. K. de Vries, J. Zhu, P. Tomic, A. H. MacDonald, T. Ihn, K. Ensslin, and P. Rickhaus | Fabry-Pérot Cavities Using Different Dispersions in Twisted Double Bilayer Graphene | Solid State Physics Laboratory, D-PHYS, University of Texas at Austin |
| P15 | **Joanna Zielinska**, F. van der Laan, and L. Novotny | Rotational Optomechanics | Photonics Laboratory, D-ITET |
| P16 | **Javier del Pino**, J. J. Slim, E. Verhagen, J. Košata, T. L.Heugel, and O. Zilberberg | From chiral squeezing to nonlinear topology in optomechanics | Electronic and photonic quantum engineered systems, D-PHYS |
| P17 | P. Leindecker, **Edgar Brucke**, M. Marinelli, J. Ang’ong’a, F. Timpu, O. Hefti, J. Home, and C. Hempel | Towards large scale quantum computing – a many qubit ion trap at room temperature | Trapped Ion Quantum Information Group, D-PHYS |
| P18 | **Rodrigo Benevides**, M. Drimmer, G. Bisson, F. Adinolfi, U. v. Lüpke, H. Doeleman, and Y. Chu | Bogoliubov quasiparticles in phonon-mediated quantum transducers | Hybrid Quantum Systems Group, D-PHYS |
| P19 | **Christian Carisch**, and O. Zilberberg | Mixed state entanglement by efficient separation of quantum from classical correlations | Quantum engineered systems, D-PHYS |
| P20 | **Fons van der Laan**, F. Tebbenjohanns, R. Reimann, J. Vijayan, J. Zielinska, and L. Novotny, and M. Frimmer | Towards quantum rotational levitodynamics | Photonics Laboratory, D-ITET |
| P21 | J. Andberger, **Lorenzo Graziotto,** M. Beck, G. Scalari, and J. Faist | Characterization and analysis of a symmetry-breaking THz chiral metamaterial | Quantum Optoelectronics Group, D-PHYS |
| P22 | **Dante C. Zanuz**, J-C. Besse, Q. Ficheux, A. Orekhov, L. Michaud, K. Hanke, A. Remm, A. Flasby, C. Hellings, M. Kerschbaum, N. Lacroix, S. Lazar, G. J. Norris, M. B. Panah, F. Swiadek, C. Eichler, and A. Wallraff | Mitigating Losses at the Josephson Junctions of Superconducting Qubits | Quantum Device Lab, D-PHYS |
| P23 | **Alban Morelle**, P. Tomic, S.P. Ramanandan, A. Fontcuberta i Morral, T. Ihn, and K. Ensslin | Quantum coherent hole transport in selective area grown Ge nanowires | The Ensslin Nanophysics Group, D-PHYS; Laboratory of Semiconductor Materials, EPFL |
| P24 | **Matteo D'Anna** | Schwinger Model: a digital quantum simulation with optimized number of gates | HPCP Lab, D-PHYS |

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| P25 | **Venkatesh Vilasini**, and R. Renner | Embedding cyclic causal structures in acyclic spacetimes: no-go results for process matrices | Quantum Information Theory Group, D-PHYS |
| P26 | J. Cao, G. Gandus, T. Agarwal, M. Luisier, and **Youseung Lee** | Dynamics of charge qubit in 2D bilayer materials: Ab-initio quantum transport and qubit measurement | Nano-TCAD Group, D-ITET |
| P27 | **Thea Budde**, J. Pinto Barros, and M. Marinkovic | Overcoming the Fermion Sign Problem for Lattice Gauge Theories | High Performance Computational Physics, D-PHYS |
| P28 | N. Lacroix, S. Krinner, A. Remm, A. Di Paolo, E. Genois, C. Leroux, **Christoph Hellings**, S. Lazar, F. Swiadek, J. Herrmann, G. J. Norris, C. K. Andersen, M. Müller, A. Blais, C. Eichler, and A. Wallraff | Repeated Quantum Error Correction in a Distance-3 Surface Code | Quantum Device Lab, D-PHYS |
| P29 | **Victor Gitton** | Converging Outer Approximations of Classical Network Correlations | Quantum Information Theory Group, D-PHYS |
| P30 | **Arianne Brooks**, H. Doeleman, A. Riedhauser, and Y. Chu | Bonding LiNbO3 thin films on CaF2 | Hybrid Quantum Systems Group, D-PHYS |
| P31 | **Alessandro Bruno**, M. Bild, Y. Yang, M. Fadel, U. von Lüpke, and Y. Chu | Parameter estimation for creating Schrödinger cat states in an electromechanical system | Hybrid Quantum Systems Group, D-PHYS |
| P32 | **Jonas D. Gerber**, M. Masseroni, R. Garreis, C. Tong, L. M. Gächter, M. J. Ruckriegel, C. Adam, B. Kratochwil, H. Duprez, W. W. Huang, T. Ihn, and K. Ensslin | Spin-orbit qubits in graphene/transition-metal dichalcogenide heterostructures | The Ensslin Nanophysics Group, D-PHYS |
| P33 | **Max J. Ruckriegel**, D. Kealhofer, L. M. Gächter, R. Garreis, C. Tong, B. Kratochwil, M. B. Panah, A. Wallraff, T. Ihn, K. Ensslin, and W. W. Huang | Progress on Hybrid Circuit QED with Graphene Quantum Dots | The Ensslin Nanophysics Group, D-PHYS |
| P34 | **Christoph Adam**, H. Duprez, M. Röösli, G. Nicoli, A. Hofmann, C. Reichl, T. Ihn, W. Wegscheider, and K. Ensslin | Measuring Entropy in Mesoscopic Systems | The Ensslin Nanophysics Group, D-PHYS |
| P35 | **Lidia Stocker**, S. H. Sack, M. S. Ferguson, and O. Zilberberg | Kondo physics in structured mesoscopic impurities | Quantum engineered systems group, D-PHYS |

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**Publisher:** Quantum Center, ETH Zurich
**Editorial:** Francesca Bay, Philipp Kammerlander
**Picture:** Markus Parzefall