Leaflet

MVQC

MONTE VERITÀ QUANTUM CODES

April 19 - 24, 2024

Organized by

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This is the version of the booklet for print use. Some of its information can be found in the electronic version at https://mvqc.ethz.ch/

This booklet has been created using an open-source LaTeX template that is available at https://github.com/maximelucas/AMCOS_booklet

Contents

About

Monte Verità Quantum Codes 2026 Conference

The conference will bring together leading researchers in quantum error correction, spanning theory and experiment, and working across a wide range of platforms—from superconducting qubits and trapped ions to photonic and atomic systems. The goal is to foster exchange between communities that, while operating in distinct physical regimes and frameworks such as discrete and continuous variable codes, share common goals in building robust, fault-tolerant quantum technologies. By covering a broad spectrum of approaches, the conference aims to provide an interdisciplinary platform to explore synergies, confront shared challenges, and chart new directions in the pursuit of scalable quantum computing.

About this document

This document serves as participants' companion during the conference. It includes a detailed schedule, information about accommodation, conference dinner and excursion, as well as the abstracts of the submitted posters. It is a preliminary booklet which will be completed progressively until a few weeks away from the beginning of MVQC 2026.

Partner Institution and Sponsors

The MVQC 2026 conference is part of the ETH Zürich "Organize a meeting" project, funded by Congressi Stefano Franscini and ETH Zürich. Additional financial support was provided by the Swiss National Science Foundation (SNSF grant No. IZSEZ0_241496), Alice & Bob, ZuriQ, QC Design, Nord Quantique, Quantinuum, and IBM Quantum. The organizing committee gratefully acknowledges the support of all these contributors.

Congressi Stefano Franscini

monte verità

ETH zürich

Swiss National Science Foundation

⟨S|Q|I⟩ Swiss Quantum Initiative

ALICE & BOB

ZuriQ

QCDESIGN

Nord Quantique™

QUANTINUUM

IBM Quantum

QM QUANTUM MACHINES

Venue Information

MVQC 2026 will be taking place at the Congressi Stefano Franscini (ETH Zürich) in Monte Verità, Ascona, Switzerland. Bellow you will find practical information on how to get there, details about accommodation as well as organizational aspects during the conference.

Coming to Monte Verità

Source: `https://csf.ethz.ch/monte-verita.html`

Several options exist for arriving to Monte Verità from abroad. We recommend the following one: (1) arrive to Zürich or Milan by flight or train, (2) take a train to Locarno, (3) reach Ascona using organized shuttles, public bus or taxi. Below we provide further details about each step.

From Zürich Airport and Zürich main station

Take a train from Zürich Flughafen (aiport) to Locarno which often requires changing trains in Zürich HB (main station) and in Bellinzona. We recommend this trip as it is generally the fastest route and is a scenary train ride through the alps.

Timetable and tickets:
Swiss national railway SBB, https://www.sbb.ch/fr/home.html

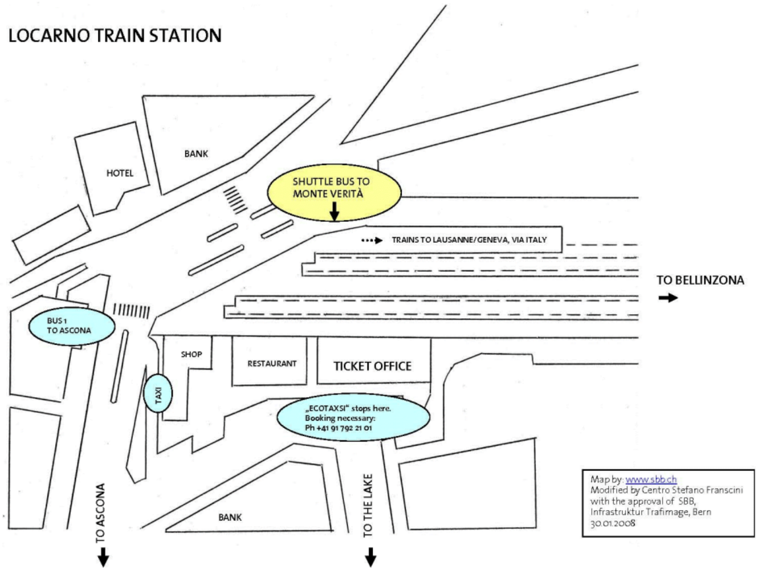
From Airport Malpensa and Milano Centrale

Take a train from Airport Malpensa or Milano Centrale (main station) which often requires changing trains in Lugano (Switzerland) for Swiss railway system.

Timetable and tickets:
From Malpesa, https://www.milanomalpensa-airport.com/en/from-to/by-train
From Centrale, https://www.raileurope.com/en-us/destinations/stations/milano-centrale

From Locarno by shuttle

A shuttle bus (8-seater) to Monte Verità will be available on the arrival day of MVQC between 13:30 and 17:30. If you arrive outside this time range, or wish to go to a different hotel first, please organize your own transport (see below). The shuttle bus stops next to the end of platform 4 (close to where public transport is leaving, see map). Look for the white bus with the Monte Verità logo.



From Locarno by public bus

Take bus no. 1 from Locarno railway station to the bus stop “Ascona Centro" (duration: 15 - 20 minutes). Refer to the time table in https://fartiamo.ch/en/line-1/ for the bus schedule. Note that the schedule is different for Monday - Saturday (Lunedì - Sabato e feriali) and for Sundays and holidays (Domenica e festivi).

From the bus stop “Ascona Centro" you can also reach Monte Verità in 25 - 30 minutes on foot (follow the "Strada Collina") or by taxi located next to the Autosilo Ascona.

From Locarno by taxi

Various taxis are available at Locarno railway station. The company "EcoTaxsi" usually has a slightly lower price, reservation required: +41 91 792 21 01 or 0800 321 321 (free call from Swiss numbers). The ride takes about 15 minutes and costs about CHF 40.00.

Accommodation

Most of the participants will be staying at the Hotel La Perla (Strada Collina 14, 6612 Ascona, Ticino) which is 15min walk from the conference venue. Every room is furnished with twin beds and will accommodate one to two people according to the participant's preferences indicated during the application. For practical reasons, we organized only single gender rooms. If the participants would like to arrange their own accommodation, please inform the organizers.

The hotel cost **is not included** in the registration fee and must be paid directly to the hotel. To arrange payment, please contact the hotel directly at hotel@laperla.ch. As your room is already reserved, **please do not book through the hotel website**.

Welcome drink and dinner + 1st day of MVQC

On Sunday, April 19, all participants are invited to **a welcome drink** (apéro) **at 18:00** at the conference venue. This will be the perfect occasion to meet the rest of the participants. It will be followed by a dinner starting at 19:00.

Every day the scientific program will start at 8:40. On the 1st day there will be an introductory presentation by us and the Fondazione Monte Verità.

Breakfasts, coffee breaks, lunch meals and dinners

Breakfasts at each hotel (Monte Verità and La Perla) are included in the accommodation cost. There will be **no breakfast** at the conference venue.

Throughout the conference, the participants will have the opportunity to discuss research with their peers over a cup of coffee and snacks. Lunch breaks and dinners will take place at the conference venue, except **on Friday**, where **lunch boxes will be distributed** for participants to take on the road. These expenses **are included** in the registration fee.

Excursion to the botanical garden of the Brissago Islands

On Wednesday 22nd, in the afternoon, all participants are invited to an excursion to the botanical garden of the Brissago Islands on the Lake Maggiore.

The Brissago Islands date back to the Roman time (vestiges of that time have been found on the islands) but became particularly famous thanks to the fascinating Russian Baroness Antoinette de Saint Léger who owned the Islands (1885-1927) and launched an intense cultural activity. At the same time, she started what has be- come a unique botanical garden in Switzerland (today the property of the Canton Ticino), with 1500 plant species both indigenous and from sub-tropical zones. It takes one hour to visit the botanical garden.

Program *(times are subject to slight changes depending on the boat timetable and on the group size)*

3.00 pm	Departure on foot from Monte Verità
3.25 pm	Arrival at the port in Ascona
3.40 pm	Departure by boat
4.00 pm	Arrival at Brissago Islands and guided visit of the botanical garden
5.10 pm	Free time at your disposal
6.30 pm	Dinner at Ristorante Isole di Brissago
9.00 pm	Departure from the Islands by private boat
9.15 pm	Arrival at Crodolo-Porto Ronco
9.20 pm	Transfer to Monte Verità by minibus
9.30 pm	Arrival at Monte Verità

Both the excursion and the dinner **are included** in the registration fee.

Registration fees

The registration fees are 350.- CHF. These fees have to be paid in Swiss francs (CHF) directly through the online platform provided by the Congressi Stefano Franscini. The URL has been sent by email directly to the participants.

Export control

The MVQC conference organizers kindly request all attendees to comply with the export control regulations of their respective home institutions and countries. As a reminder, please note that exchanging and discussing unpublished know-how might fall under such regulations.

Schedule

Schedule by themes

	Sunday 19th	Monday 20th	Tuesday 21st	Wednesday 22nd	Thursday 23th	Friday 24th
07:00		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
08:40		**Introduction** Theory of DV QEC	Experimental DV QEC	Theory of CV QEC	Experimental FT	Experimental FT
10:00		Coffee break	Coffee break	Coffee break	Coffee break	Coffee break
10:30		Experimental DV QEC	Theory of DV QEC	Experimental CV QEC **Nord Quantique**	Theory of CV QEC	Theory of FT
12:30		Lunch	Lunch	**Quantinuum**	Lunch	Lunch (Take-away)
14:00	Participants' arrival	Free time	Free time	Lunch	Free time	Participants' departure
16:00		Theory of CV QEC	Experimental CV QEC **Alice & Bob** **QC Design**	Excursion & Conference dinner	Theory of DV QEC	
17:20	18:00 Welcome drink	Coffee break	Coffee break		Coffee break	
17:40	&	Experimental CV QEC	Theory of FT		Experimental DV QEC	
19:30	19:00 Welcome dinner	Dinner	Dinner		Dinner	
20:30		Posters and apéro	Posters and apéro		Posters and apéro	

The conference is organized around six broad topics: theoretical quantum error correction (QEC) with discrete (DV) and continuous variable (CV) systems, experimental QEC with DV and CV platforms, theoretical and experimental approaches to fault tolerance (FT). It is interleaved with long breaks in order for the participants to discuss these various research topics and exchange ideas across communities. Below is an non-exhaustive list of concepts that are included in each of the topics.

Broad topics	Example subtopics
Theory of DV QEC	Basics of QEC (Stabilizer codes, ...) Decoders QLDPC
Theory of CV QEC	Basics of CV QEC Translation sym codes (GKP) Rotation sym codes (Cats,...)
Theory of FT	Basics of FT (transversality, flag q., gate teleporation) Lattice surgery + Code switching New FT techniques (Magic state cultivation, ...)
Experimental DV QEC	Superconducting qubits Trapped ions Neutral atoms
Experimental CV QEC	Circuit QED Trapped ions Photonic
Experimental FT	Superconducting qubits Trapped ions Neutral atoms

Schedule by speakers

	Sunday 19th	Monday 20th	Tuesday 21st	Wednesday 22nd	Thursday 23th	Friday 24th
07:00		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
08:40		**Introduction** Nikolas Breuckmann	Seigo Tarucha Yiheng Lin	Élie Gouzien Liang Jiang	Marcel Meyer Ian Hesner & Ilya Besedin	Harry Putterman Alexandra Geim
10:00		Coffee break	Coffee break	Ting Rei Tan Ingrid Strandberg	Coffee break	Coffee break
10:30		Jeff Thompson Wes Campbell Ohad Lib	Ken Brown Benjamin Brown Charles ChunJun Cao	Vlad Sivak **Nord Quantique**	Steve Flammia Julio Magdalena Eleanor Crane & Alex Schucker	Dominik Hangleiter Christophe Vuillot Simon Burton
12:30		Lunch	Lunch	**Quantinuum**	Lunch	Lunch (Take-away)
14:00	Participants' arrival	Free time	Free time	Lunch	Free time	Participants' departure
16:00		Barbara Terhal Victor Albert	Francesco Adinolfi **Alice & Bob** **QC Design**	Excursion & Conference dinner	Friederike Butt Anqi Gong	
17:20	18:00 Welcome drink &	Coffee break	Coffee break		Coffee break	
17:40		Philippe Campagne-Ibarcq Matteo Simoni	Nicolas Delfosse Earl Campbell		Tim Taminiau Nicola Meggiato	
19:30	19:00	Dinner	Dinner		Dinner	
20:30	Welcome dinner	Posters and apéro	Posters and apéro		Posters and apéro	

The figure above shows the MVQC 2026 conference schedule by speaker; the title of each presentation appears below.

- **Fault-Tolerant Quantum Computation with Adversarial Errors**
  Nikolas Breuckmann, *University of Bristol*
- **Fast, efficient QEC with neutral atom qubits**
  Jeff Thompson, *Princeton University*
- **Single-atom QEC in angular-momentum eigenstates**
  Wes Campbell, *UCLA Physics & Astronomy*
- **Velocity-Enabled Quantum Computing with Neutral Atoms**
  Ohad Lib, *Max Planck Institute of Quantum Optics*
- **Decoding across transversal logical gates in the surface code**
  Barbara Terhal, *QuTech*
- **"Qudit GKP" — quantum codes in the Lee metric**
  Victor V. Albert, *University of Maryland and NIST*
- **Engineering dissipation in high impedance superconducting circuits to stabilize advanced bosonic codes**
  Philippe Campagne-Ibarcq, *Inria - ENS Paris*
- **Nonlinear reservoir engineering and control of a trapped-ion oscillator**
  Matteo Simoni, *ETH Zurich*
- **Noise impact in quantum gate fidelity and error correction**
  Seigo Tarucha, *RIKEN*
- **Autonomous Error Correction with Trapped Ions**

Yiheng Lin, *University of Science and Technology of China*

- **Tools for Quantum Error Correction**
  Kenneth Brown, *Duke University*
- **Quantum computing with anyons is fault tolerant**
  Ben Brown, *IBM Quantum*
- **Quantum Lego Power-up: building addressable transversal gates with tensor networks**
  Charles Cao, *Virginia Tech*
- **Enhancing Kerr-Cat Qubit Coherence with Controlled Dissipation**
  Francesco Adinolfi, *Paul Scherrer Institute*
- **Quantum error correction for trapped ions**
  Nicolas Delfosse, *IonQ*
- **Unlocking early fault-tolerant quantum computing with mitigated magic dilution**
  Earl Campbell, *Riverlane*
- **Fiber Bundle Fault Tolerance of GKP Codes**
  Steven Flammia, *Virginia Tech*
- **High-threshold decoding of non-Pauli codes for 2D universality**
  Julio Magdalena de la Fuente, *Freie Universität Berlin*
- **Bosonic Quantum Signal Processing with Qubit-Oscillator System in a Trapped Ion**
  Ting Rei Tan, *Sydney Nanoscience Hub*
- **Frequency-bin dual-rail encoded microwave photons for loss-detectable quantum links**
  Ingrid Strandberg, *Chalmers University of Technology*
- **Reinforcement learning control of quantum error correction**
  Volodymyr Sivak, *Google Quantum AI*
- **Quantum Error Correction with Trapped Ions**
  Marcel Meyer, *University of Innsbruck*
- **Lattice surgery realized on two distance-three repetition codes with superconducting qubits**
  Ian Hesner & Ilya Besedin, *ETH Zurich*
- **Simultaneous lattice surgery for fast two-level factories with biased-noise qubits**
  Élie Gouzien, *Alice & Bob*
- **GKP Code for Pure-Loss and Amplification Channels**
  Liang Jiang, *University of Chicago*
- **Qubit-Fermion-Boson Quantum Computing**

Eleanor Crane & Alexander Schuckert, *King's College London & ENS Paris and CNRS*

- **Measurement-free Quantum Computing**
  Friederike Butt, *RWTH Aachen, IQI*
- **Magic state distillation via codes over binary extension fields**
  Anqi Gong, *ETH Zurich*
- **Towards distributed quantum computation with color centers**
  Tim Hugo Taminiau, *QuTech - Delt University of Technology*
- **Weight-four parity checks with silicon spin qubits**
  Nicola Meggiato, *QuTech*
- **Hardware-efficient quantum error correction using concatenated bosonic qubits**
  Harry Putterman, *AWS Center for Quantum Computing*
- **A fault-tolerant neutral-atom architecture for universal quantum computation**
  Alexandra Geim, *Harvard University*
- **In-situ benchmarking of fault-tolerant quantum circuits**
  Dominik Hangleiter, *ETH Zurich and Berkeley*
- **Computing with biased-noise qubits**
  Christophe Vuillot, *Alice & Bob*
- **Breaking even with magic**
  Simon Burton, *Quantinuum*

Tuesday and Wednesday will host two industry sessions with the following talks

- **Access to quantinuum hardware**
  Simon Burton, *Quantinuum*
- **Nord Quantique - the Logical Qubit Company**
  Florian Hopfmüller, *Nord Quantique*
- **A cat qubit architecture with tunable dissipation**
  Ronan Gautier, *Alice & Bob*
- **Unified framework for obtaining fault-tolerance thresholds of arbitrary hardware imperfections**
  Ish Dhand, *QC Design*

List of Participants

The table below lists all conference participants and their affiliations. The first column shows the day of the poster session **(1 = Monday, 2 = Tuesday, 3 = Thursday)** when each participant will present their work.

1	Alessandro Ciani	*Forschungszentrum Jülich*
1	Aneesh Anand Kamat	*Forschungszentrum Jülich*
1	Gabriele Johannes Giuli	*ETH Zürich*
1	Giacomo Fregona	*University of Copenhagen*
1	Kyrylo Gerashchenko	*Inria, LPENS*
1	Lev-Arcady Sellem	*Université de Sherbrooke, Institut Quantique*
1	Amaya Calvo-Sánchez	*Imperial College London*
1	Argyrios Giannisis Manes	*University of Chicago*
1	Aristomenis Zazanis	*University of Edinburgh*
1	Cesar Benito	*Institute for Theoretical Physics UAM-CSIC*
1	Daniel Haxell	*Paul Scherrer Institute*
1	Daniel Malz	*University of Basel*
1	Edoardo Carnio	*neQxt GmbH*
1	Evangelia Takou	*Duke University*
1	Ha Nguyen	*Forschungszentrum Jülich*
1	Jan Apolín	*ETH Zürich*
1	Jeremy Metzner	*ETH Zürich*
1	Jin Ming Koh	*Harvard University*
2	Jimmy Hung	*AWS CQC*
2	Kiara Hansenne	*IPhT, CEA Paris-Saclay*
2	Konstantin Tiurev	*ParityQC*
2	Lina Vandré	*neQxt GmbH*
2	Mackenzie Shaw	*TU Delft, QuTech*
2	Christopher Erickson	*Riverlane*
2	Mahadevan Subramanian	*University of Chicago*
2	Manuel Guatto	*Forschungszentrum Jülich*
2	Marc Serra Peralta	*TU Delft, QuTech*
2	Maryam Khanahmadi	*Chalmers University of Technology*
2	May Chee Loke	*Centre for Quantum Technologies, National University of Singapore*
2	Minh Pham	*TU Delft, QuTech*
2	Perrine Vantalon	*EPFL*
2	Preeti Pandey	*Paul Scherrer Institute*

2	Rémi Rousseau	*ETH Zürich*
2	Shana Winston	*Imperial College London*
2	Shi Jie Samuel Tan	*University of Maryland*
2	Stuart Nicholls	*University of Sydney*
2	Susan Chen	*University of Bristol, University of Copenhagen*
2	Tomasz Andrzejewski	*TU Wien, Atominstitut*
2	Will Staples	*Princeton University*
2	Winston Fu	*Princeton University*
3	Aliki Capatos	*University of Copenhagen, NQCP*
3	Xanda Kolesnikow	*University of Sydney*
3	Xanthe Croot	*University of Sydney*
3	Yi Li	*University of Science and Technology of China*
3	Dmitry Grinko	*University of Amsterdam*
3	Ronan Gautier	*Alice & Bob*
3	Kshitij Kapoor	*QC Design and University of Ulm*
3	Trinidad Lantaño	*QC Design*
3	Ahmet Alperen Tekin	*EPFL, TUM*
3	Guo Zheng	*University of Chicago*
3	Pierce Wickenden	*Virginia Tech*
3	Qingyuan Mei	*University of Science and Technology of China*
3	Romain Moyard	*ZuriQ*
3	Bright Ye	*AWS Center for Quantum Computing*
3	Yanting Teng	*EPFL*
3	Seyma Bodur	*neQxt GmbH*
3	Ilya Besedin	*ETH Zürich*
3	Arthur Morris	*University of Copenhagen*
3	Jose Ricardo Mejía	*Universidad de los Andes*
3	Zhanchuan Zhang	*ETH Zürich*
3	Matteo Bellino	*ETH Zürich*

List of Posters

The list below presents the titles and abstracts of the poster that the participants will present during the poster sessions of the MVQC 2026 conference.

Probabilistic error cancellation for Gottesman-Kitaev-Preskill codes

Alessandro Ciani, *Forschungszentrum Jülich*

In order to solve practical problems on a quantum computer, it is necessary to use fault-tolerant quantum error correction schemes to overcome noise: the errors arising from imperfections in physical components. The Gottesman-Kitaev-Preskill (GKP) code achieves this by encoding a finite dimensional logical space within the continuous variables Hilbert space of one or more bosonic modes. This offers a promising pathway towards scalable, fault-tolerant quantum computing. In this work we study the combination of an error mitigation method known as probabilistic error cancellation (PEC) with GKP error correction. We compare Steane-type and teleportation-based GKP error correction, and calculate sampling overheads for square and hexagonal GKP codes. The (quasi)probabilities of sampling basis operations for PEC and their corresponding overheads are derived using the stabilizer subsystem decomposition for GKP codes. Considering noise from finite squeezing of the data and the two ancilla modes, as well as other noise contributions, such as photon loss, we examine the relationship between the overhead and the noise. Our results are calculated for single- and two-GKP-qubit Clifford gates and one round of error correction. Our analysis suggests that teleportation-based GKP error correction outperforms Steane-type error correction, when combined with error mitigation techniques, in terms of sampling overhead. Finally, we show that, unlike the simple qubit case, when we combine multiple noisy channels the sampling overhead is not given simply by the product of the individual ones, but the leftover error from one channel influences the sampling overhead of following ones.

Mitigating Leakage in Accelerated CZ Gates on Tunable Fluxonium Architecture for Scalable Quantum Error Correction

Aneesh Anand Kamat, *Forschungszentrum Jülich*

The path to fault-tolerant quantum computing requires entangling gates that are not only fast but also minimize leakage into non-computational states, a critical failure mode that can significantly degrade QEC code performance. The Fluxonium qubit is a premier candidate for large-scale fault tolerance due to its superior coherence and high anharmonicity, the latter of which provides a natural defense against leakage. However, the Fluxonium's inherent protection often complicates high-speed entangling operations. To realize the high-threshold gates required for surface or LDPC codes, we utilize the Fluxonium-Transmon-Fluxonium (FTF) architecture. By leveraging a flux-tunable Transmon coupler, we enable the strong effective couplings necessary for accelerated CZ gates while preserving the long coherence of the Fluxonium manifold. We characterize the dominant leakage channels in experimentally realized FTF systems during flux-controlled operations. By employing quantum optimal control, we develop pulse-shaping strategies that drastically reduce both state leakage and gate infidelity. Our results provide a detailed error budget for flux-tunable architectures, offering a clear pathway to reaching the demanding error thresholds necessary for scalable quantum error correction.

Cryogenic Apparatus for Dual-Isotope Trapped-Ion Crystal Experiments

Gabriele Johannes Giuli, *ETH Zürich*

We present a cryogenic experimental apparatus for trapped-ion experiments on dual-isotope long crystals of calcium. Dual isotope operation makes this system ideal for quantum error correction protocols, as isotope shifts provide spectral separation between data and ancilla qubits. In addition, this setup has been used to probe beyond-standard-model effects by measuring isotope shifts via correlation spectroscopy. The experimental setup features passive Mu-metal shielding and active trapping potential stabilization for extended coherence times in both the motional and spin degrees of freedoms. Ions can be individually addressed with an optical fiber array whose output is focused and aligned with the ion crystal. Future revisions of the addressing system will feature a 3D laser-written waveguide array for improved crosstalk suppression. Parallel ion state detection is performed with a low-latency EMCCD imaging system integrated with a custom FPGA-based control system.

Numerical Analysis of Rare Events in Bivariate Bicycle Codes with BP-OSD

Giacomo Fregona, *University of Copenhagen*

Quantum LDPC codes are promising error-correcting codes that combine high encoding rates with large code distances. However, their full error correction potential can only be realized when coupled with effective decoders. Belief-propagation (BP) decoders are popular for classical LDPC codes, but they do not handle the degeneracy of quantum codes very well, potentially leading to error floors, especially at low physical error rates. We used the Splitting method to explore this low-error regime, more specifically isolating the most likely faulty configurations in the rare events setting and assessing their impact on the error correcting performance. In particular, we analyzed an error floor that arises when combining Bivariate Bicycle codes with the BP-OSD algorithm at code capacity, considering both the product-sum, min-sum, and custom variants of BP. Together with degeneracy in error configurations in quantum codes, we identified that numerical stability of belief propagation is a significant issue that can lead the decoder to fail with relatively low weight errors (« d/2). As a side finding, we determined a setting in which the Markov chain underlying the Splitting method is not ergodic, leading to incorrect failure rate estimates. Overall, our results provide insights into the application of BP on Bivariate Bicycle codes, and highlight potential issues when applying the Splitting method.

Probing the quantum motion of a macroscopic mechanical oscillator with a radio-frequency superconducting qubit

Kyrylo Gerashchenko, *Inria, LPENS*

Long-lived mechanical resonators like drums oscillating at MHz frequencies and operating in the quantum regime offer a powerful platform for quantum technologies and tests of fundamental physics. Yet, quantum control of such systems remains challenging, particularly owing to their low energy scale and the difficulty of achieving efficient coupling to other well-controlled quantum devices. Here, we demonstrate repeated, and high-fidelity interactions between a 4 MHz suspended silicon nitride membrane and a resonant superconducting heavy-fluxonium qubit. The qubit is initialized at an effective temperature of 27 μK and read out in a single-shot with 77% fidelity. During the membrane's 6 ms lifetime, the two systems swap excitations more than 300 times. After each interaction, a state-selective detection is performed, implementing a stroboscopic series of weak measurements that provide information about the mechanical state. The accumulated records reconstruct the membrane's position noise-spectrum, revealing both its thermal occupation nth=47 at 10 mK and the qubit-induced back-action. By preparing the qubit either in its ground or excited state before each interaction, we observe an imbalance between the emission and absorption spectra, proportional to nth and nth+1, respectively-a hallmark of the non-commutation of phonon creation and annihilation operators. Since the predicted Diósi-Penrose gravitational collapse time is comparable to the measured mechanical decoherence time, our architecture enters a regime where gravity-induced decoherence could be tested directly.

Fast and local conditional displacements with a tunable fluxonium ancilla

Lev-Arcady Sellem, *Université de Sherbrooke, Institut Quantique*

Bosonic quantum error correction offers a hardware-efficient route to fault-tolerant quantum computing. Gottesman-Kitaev-Preskill (GKP) qubits, in particular, have achieved break-even performance in 3D microwave cavities using transmon ancillas, where their preparation and stabilization rely on ancilla-mediated conditional displacements. We propose storing a GKP qubit in a 2D resonator to enhance scalability, and replacing the transmon ancilla by a protected qubit to reduce ancilla-induced errors. We show that modulating the Josephson energy of a tunable fluxonium at the storage frequency can activate a parametric conditional displacement using only weak drives and small phase-space excursions, thereby reducing sensitivity to storage-mode nonlinearities. The weak storage-ancilla coupling further suppresses unwanted nonlinear effects. Simulations show that the displacements required for GKP stabilization can be achieved in approximately 220 ns with this technique, faster than current realizations.

Toward Mechanical Gottesman-Kitaev-Preskill States with Weak Nonlinearities

Amaya Calvo-Sánchez, *Imperial College London*

Gottesman-Kitaev-Preskill (GKP) codes provide a scalable route for encoding qubits and error correction in continuous variable systems. The code states have a grid-like structure in phase space which is also particularly apt for sensing. Much progress has been made toward their implementation, however, state generation remains challenging owing to weak nonlinearities in current experimental approaches. Utilizing pulsed optomechanics, we propose a state preparation and error correction protocol for mechanical GKP states with attainable experimental parameters, by enhancing the nonlinearities of the radiation pressure interaction through a geometric phase realised via a sequence of linear interactions. This geometric phase can additionally be harnessed to implement generalized controlled gates in order to achieve a universal set of operations. To demonstrate the feasibility of our scheme, we analyse the scale of unwanted effects including optical loss, pump noise, and contributions beyond the linearized regime. Our framework opens a new avenue for such encoding in mechanical degrees of freedom and can be readily employed in solid state and cold atom-based systems.

Optimal dual-mode spin codes for photon loss

Argyrios Giannisis Manes, *University of Chicago*

Photon loss is the dominant source of noise in bosonic systems and a fundamental limitation in optical and superconducting qubits. We identify numerically optimal codes in the fixed total-photon-number subspace of two oscillators that maximize entanglement fidelity under pure-loss noise. Constraining to a fixed total photon number supports experimentally feasible error detection via photon-number-resolving measurements and yields a compact, number-conserving generalization of dual-rail encodings to higher photon numbers. Surprisingly, some optimal solutions align with representation-theoretic spin-code constructions, with numerical evidence for symmetry-based selection rules that can force many error-correction matrix elements to vanish. This points to a design principle that bridges numerical code discovery with analytic constructions and may enable scalable families at larger photon numbers. We will present the numerical landscape, the emerging symmetry connection, and initial directions toward hardware-compatible implementations.

Contextuality as a code invariant of CSS codes

Aristomenis Zazanis, *University of Edinburgh*

Quantum contextuality is a fundamental resource for quantum computational speedups and a powerful diagnostic of nonclassicality in many-body quantum states. We investigate the contextuality of Calderbank–Shor–Steane (CSS) quantum error-correcting codes through their performance in nonlocal XOR games. Building on the recent framework of Hart et al. "Many-body contextuality and self-testing quantum matter via nonlocal games", we interpret the optimal classical success probability of these games as an operational measure of the "quantumness" of a CSS codeword. This measure is determined by the nonlinearity of a code-dependent Boolean function and is invariant under local Clifford transformations. We evaluate this quantity for several CSS constructions, including the repetition (GHZ) code, one-dimensional cluster states, and the two-dimensional toric code. We further extend the analysis to probe contextuality density in qLDPC codes and color codes, using the hypergraph-state mapping to efficiently bound classical strategies. Finally, we use CSS submeasurement games as a translation-invariant "fingerprint" to certify these states via self-testing, and discuss how this perspective applies across different CSS code families. Our results demonstrate how nonlocal games furnish a unifying and operational benchmark for assessing the resource potential of quantum error-correcting codes.

Surface code error correction on IBM heavy-hex devices

Cesar Benito, *Institute for Theoretical Physics UAM-CSIC*

Demonstrating subthreshold scaling of a surface-code quantum memory on hardware whose native connectivity does not match the code remains a central challenge. We address this on IBM heavy-hex superconducting processors by co-designing the code embedding and control: a depth-minimizing SWAP-based fold-unfold embedding that uses bridge ancillas, together with robust, gap-aware dynamical decoupling (DD). On Heron-generation devices we perform anisotropic scaling from a uniform distance 3 code to anisotropic distance (dx,dz) = (3,5) and (5,3) codes. We find that increasing dz (dx) improves the protection of Z-basis (X-basis) logical states across multiple quantum error correction cycles. Even if global subthreshold code scaling for arbitrary logical initial states is not yet achieved, we argue that it is within reach with minor hardware improvements. We show that DD plays a major role, suppressing coherent ZZ crosstalk and non-Markovian dephasing that accumulate during idle gaps on heavy-hex layouts. To quantify performance, we derive an entanglement fidelity metric that is computed directly from X- and Z-basis logical-error data and provides per-cycle, SPAM-aware bounds.

The entanglement fidelity metric reveals that widely used single-parameter fits used to compute suppression factors can mischaracterize or obscure code performance when their assumptions are violated; we identify the strong assumptions of stationarity, unitality, and negligible logical SPAM required for those fits to be valid and show that they do not hold for our data. Our results establish a concrete path to robust tests of subthreshold surface-code scaling under biased, non-Markovian noise by integrating QEC with optimized DD on non-native architectures.

One-order-of-magnitude relaxation-time enhancement in a transmon with engineered dissipation

Daniel Haxell, *Paul Scherrer Institute*

Quantum error correction (QEC) protocols typically encode information redundantly across many physical qubits, resulting in increased hardware overhead. Qubits with strong engineered noise bias offer a way to reduce this overhead. However, they typically require complex circuit designs and often involve significant trade-offs between noise bias and operational fidelity. In this work, we enhance the relaxation time of a standard superconducting transmon qubit coupled to a readout cavity by using engineered dissipation. We activate this dissipation with a single pump tone, effectively converting cavity decay into a stabilizing process for the new qubit excited state. Due to its simplicity, our approach is compatible with common experimental setups. As compared to the standard encoding based on Fock states 0 and 1, we extend the relaxation time by more than an order of magnitude. Crucially, this improvement is achieved while maintaining fast, high-fidelity gate operations.

Complexity of contracting injective tensor networks from fault tolerance

Daniel Malz, *University of Basel*

Projected entangled pair states (PEPS) are an important variational family that is frequently used both analytically and numerically to represent ground states. PEPS are by design memory efficient, but need not be computationally efficient. We give a construction based on a fault-tolerant postselected quantum computation that shows that contracting constant-injective PEPS is as hard as simulating a postselected quantum computer. This extends a previous result by Anshu, Breuckmann, Nguyen that contracting injective PEPS is BQP-hard. I'll also present an earlier analogous result, where we show that injective isoTNS (a supposedly more nicely behaved class composed of isometric tensors) are in a sense BQP-complete.

Protection of QEC code states against collective dephasing

Edoardo Carnio, *neQxt GmbH*

The application of quantum error correction (QEC) theory provides a viable path of systematically correcting Pauli errors occurring locally on one or at most few qubits. In contrast to this assumption, dephasing caused by global external fields is a prevalent source of errors in quantum hardware based on trapped ions. In particular, when qubits interact with a common noise source, they can experience collective dephasing. Under such a noise channel, we show families of multipartite states whose entanglement properties are preserved at all times, even if the state itself is not. Such properties might be advantageous for equipping QEC codes with additional passive protection beyond decoherence-free subspaces. Constant-excitation codes are naturally resilient against amplitude damping: we investigate how to translate this advantage to the case of collective dephasing.

Estimating noise in QEC using detector error models

Evangelia Takou, *Duke University*

Precise knowledge of the noise of quantum devices enables the design of less resource-intensive QEC codes and boosts the logical error suppression via noise-aware decoding. Typical characterization methods such as tomography are limited to small systems due to the prohibitive computational and experimental overhead. I will describe an efficient top-down approach for noise estimation, which utilizes only the syndrome history of QEC experiments. This method can be used to learn both stochastic and coherent noise, as well as capture noise drifts. I will showcase the method through simulations of memory QEC experiments such as repetition, surface, and color code memories, and show how one can build accurate noise models to benefit decoders.

Preparing Multi-Mode GKP States with Half the Stabilizer Measurements

Ha Nguyen, *Forschungszentrum Jülich*

Recent advances in quantum engineering have enabled the realization of high-quality bosonic qubits. Among these approaches, Gottesman–Kitaev–Preskill (GKP) codes are particularly promising, having enabled the first experimental demonstration of quantum error correction beyond the break-even point. GKP codes are notably resilient against small displacement errors in phase space, which approximate many physically relevant noise channels. However, this robustness relies on the ability to prepare high-quality GKP states. Moreover, correcting larger displacement errors typically requires moving beyond single-mode GKP codes to multi-mode constructions. Efficient preparation of multi-mode GKP states is therefore critical for practical GKP-based quantum error correction. We introduce a new method for preparing general multi-mode GKP states, which requires only half of the stabilizer measurements compared to existing schemes. Our approach begins with a carefully designed multi-mode Gaussian ansatz state, which is subsequently projected into the GKP code space via stabilizer measurements. A key ingredient is the judicious choice of the generator matrix defining the high-dimensional lattice structure of the multi-mode GKP code. The protocol offers two main advantages: it starts from a Gaussian ansatz state whose preparation is experimentally simple and relies only on standard Gaussian operations, and it provides a flexible framework for optimizing GKP state preparation under imperfections such as finite squeezing.

Universal gate set for the dual-rail encoding in Penning micro-traps

Jan Apolín, *ETH Zürich*

Achieving large-scale quantum information processing requires encoding logical information in a way that is resistant to the physical system's dominant errors. Trapped ion systems typically suffer from electric field noise, which limits the fidelity of their logical operations. Penning micro-traps are a promising platform for scalable computation and present new opportunities for qubit encoding. I will present work in which we exploit the symmetric dependence of the radial mode frequencies on the electric field to realize protected bosonic qubits. Due to the symmetry, each ion can host a two-mode decoherence-free subspace insensitive to electric fields. The insensitivity also makes it challenging to perform logical operations on the codespace. We discuss the noise robustness of the scheme and provide a universal gate set based on coupling of the motional modes to an ancilla spin. Combining the scalability of Penning micro-traps with a noise-robust encoded qubit represents a step towards logical quantum computation and long-lived quantum memories.

Generation and Error correction of GKP logical Bell state

Jeremy Metzner, *ETH Zürich*

Recent experimental advances using GKP codes include the demonstration of error correction beyond break-even as well as of a universal two-qubit quantum gate set, which involve the use of an ancillary qubit. Errors in the ancillary qubit that happen during a gate can propagate into the bosonic mode causing uncorrectable errors. We demonstrate the ability to couple GKP states in two different modes directly via a beam splitter interaction, which provides an essential element for performing an error correctable 2-qubit gate. We use the beam splitter to generate entangled GKP qubits in a two mode Bell state by inputting two qunaught states, which show the periodic features of GKP qubits but cannot encode logical information. To characterize the correlations, we measure points in the two-mode characteristic function, which contain logical information, using measurement techniques designed for finite energy GKP states. Our measurement results show clear signatures of entanglement between the modes upon reconstruction of the logical density matrix. In addition to characterization of the entanglement, we perform error correction on the individual modes to demonstrate the ability to extend the lifetime of the logical Bell state.

Phantom codes: Logical entanglement without physical gates

Jin Ming Koh, *Harvard University*

Logical entangling operations are essential for scalable fault-tolerant quantum computing, but are costly due to the error rates and overheads of physical two-qubit gates and stabilizer measurements. Phantom codes realize the absolute minimum of this cost—all in-block logical CNOTs are implemented by qubit permutations that are compiled away as qubit relabellings, yielding zero-depth, zero-error logical entanglement. We develop the first systematic study of such codes. Through an exhaustive enumeration of all 27 billion inequivalent CSS codes for $n \leq 14$, we identify every phantom code at this scale and extend the search to $n \leq 21$ using SAT-based automated code discovery. We further construct infinite phantom code families, including higher-distance generalizations of the hypercube and Carbon codes, and determine the additional fault-tolerant logical Clifford and non-Clifford gate sets supported across both enumerated and constructed examples. We benchmark a representative high-distance phantom code against the surface-code across multiple tasks, using end-to-end simulations that include fault-tolerant state preparation, repeated QEC cycles, and realistic physical error models. In an eight-body Hamiltonian simulation task on 64 logical qubits at current error rates, the phantom code achieves a 207x advantage in logical fidelity while using fewer qubits, a drastically shorter-depth circuit, and a 22% preselection rate. This large performance gap persists across different system sizes, and improves with reductions in physical error rate. These results establish phantom codes as a structurally constrained yet promising approach to fault-tolerant quantum computation, with scalable benefits for circuits featuring dense entangling structures.

High Fidelity Erasure Detection of Transmon Dual-Rail Qubits Using Symmetrically Coupled Readout

Jimmy Hung, *AWS CQC*

Erasure qubits have been proposed as a platform for implementing hardware-efficient quantum error correction. These are qubits for which nearly all errors are detectable erasure errors, and which therefore can facilitate QEC with favorable thresholds. A key ingredient in the operation of such an erasure encoded qubit is high-fidelity mid-circuit erasure detection which we implement using a single resonator dispersively and symmetrically coupled to both transmons. This approach enables fast erasure detection with simple and compact circuit components, minimizing footprint overhead compared to standard transmon architectures. We experimentally demonstrate sub-kHz chi-mismatch enabling us to accomplish high fidelity erasure check with residual error per check below 0.1%.

Benchmarking Decoder Accuracy against Optimal Mixed-MPS Decoding

Kiara Hansenne, *IPhT, CEA Paris-Saclay*

The development of practical quantum computers is currently a major research topic, with quantum error correction playing a crucial role in achieving fault-tolerant quantum computing. Researchers are working towards qubits with physical noise rates below the error correction code threshold, a critical metric for evaluating an error correction code. This threshold is highly influenced by the noise model and by the decoding techniques used. In this work, we propose to compare the performances of different decoding strategies (such as belief-propagation or minimum-weight perfect matching) against optimal decoding under circuit-level noise. Whereas such analysis is usually done by error sampling, our approach follows the density matrix throughout the circuit, representing it by a mixed matrix product state. Although this limits the exploration to small code distances, it allows us to reach arbitrarily small error rates such that our results provide essential benchmarks for current decoders and estimate code thresholds with high accuracy.

Resource-efficient magic factories for arbitrary levels of the Clifford hierarchy

Konstantin Tiurev, *ParityQC*

Universal fault-tolerance can be achieved by supplementing Clifford operations with magic state distillation, with magic T state being the most popular choice. We introduce magic factories for efficient distillation of gates from kth level of the Clifford hierarchy using 2^{k+2} physical qubits. We provide constructive schemes for composing such magic factories for an arbitrary level of the Clifford hierarchy. Our benchmarks demonstrate advantage of higher-level gate distillation over the (Clifford + T) gate set both in terms of logical gate fidelities and space-time resource cost in experimentally relevant regimes. The proposed scheme hence offers a promising building block for fault-tolerant architectures where small-angle rotations are produced directly rather than approximated using a (Clifford + T) set.

Graphical Framework for Non-Gaussian Quantum States

Lina Vandré, *neQxt GmbH*

Multipartite entangled states are used as a resource in quantum technologies. For instance, in quantum cryptography, entanglement is used to generate a key. The exponentially increasing dimension of the Hilbert space with the number of particles is a challenging factor when analysing multipartite entanglement. Graph and hypergraph states, initially defined for qubits, form families of multipartite quantum states that can be described by a graphical formalism. Notably, graph states are stabiliser states. Their applications include gate- or measurement-based quantum computing and quantum error correction. Beyond qubits, there exist quantum systems with higher dimensions. Finite dimensional systems, such as qudit systems, are referred to as discrete variable (DV) systems, whereas those with infinite dimensions are called continuous variable (CV) systems. Examples of CV states include Gaussian and non-Gaussian states. The graphical formalism of graph- and hypergraph states has been extended to CV systems. Remarkably, CV graph states are Gaussian while general hypergraph states are non-Gaussian. Preparation of non-Gaussian states is experimentally more demanding than that of Gaussian states, yet they are necessary for achieving quantum universality.Nonetheless, there is very little exploration of CV hypergraph states. In my contribution, I present a novel graphical method to describe and analyse non-Gaussian quantum states using a hypergraph framework. The framework encapsulates transformation rules for a series of typical Gaussian unitary operations and local quadrature measurement, offering a visually intuitive tool for manipulating such states through experimentally feasible pathways. In particular, I will demonstrate how to generate complex hypergraph states with more or higher-order hyperedges from simple structures through Gaussian operations only, facilitated by the graphical rules.

Optimising QEC Codes using Morphing Circuits

Mackenzie Shaw, *TU Delft, QuTech*

Quantum error correction codes are traditionally defined and searched for without specifying the manner in which its syndrome extraction circuits are executed fault-tolerantly using elementary gates and measurement. We show how the use of (dynamic) morphing circuits provides a way of optimizing syndrome extraction circuits and codes directly in terms of connectivity, choice of two-qubit gate and number of qubits, using existing codes. In addition to providing an overview of morphing circuits and how to construct them, in this poster we focus on one particular application of morphing circuits: the 2D hexagonal-lattice colour code. The advantage of using morphing circuits to implement the colour code is that they use a purely degree-3 qubit connectivity, unlike the current state-of-the-art superdense circuits that require ancilla qubits to be degree-4. However, until now, the number of physical qubits required to achieve a given circuit-level distance is larger for morphing circuits than for superdense circuits. We present multiple novel morphing circuits for the colour code and we show how to optimise the colour code boundary conditions to maximise the circuit-level distance of the resulting code. With the standard triangular boundaries, the morphing circuit optimisation reduces the number of physical qubits required to achieve a given distance but remains higher than that of the superdense circuits. The optimisation is more effective for rectangular boundaries - matching the qubit efficiency of the superdense circuits - but because the rectangular boundaries encode two logical qubits the resulting code no longer can implement all Clifford gates transversally. We benchmark the resulting optimised colour code morphing circuits numerically under a circuit-level noise model using a minimum weight decoder and found that the performance of both morphing circuits is comparable to the superdense colour code circuits while using a lower qubit connectivity.

Pauli + Kraus simulation; sampling analogue magic state preparation in linear time.

Christopher Erickson, *Riverlane*

Pauli frame simulators are essential tools for validating and benchmarking decoders for quantum error correction circuits. Notably, Pauli frame simulators sample noise in Clifford circuits in linear time. By contrast, stabilizer tableau methods have quadratic complexity. We introduce a framework that extends Pauli frame sampling to quantum error correction circuits containing non-Clifford gates, such as cultivation, by sampling the logical Kraus operators given the syndrome. After compilation this hybrid approach enables linear time simulation of some relevant non-Clifford state preparation circuits. We apply this technique to analogue rotation based magic state preparation, find further examples of possible simulation targets, and characterize properties of non-Clifford QEC circuits that remain tractable within this framework.

Achievable Rates for Concatenated Square Gottesman-Kitaev-Preskill Codes

Mahadevan Subramanian, *University of Chicago*

The Gottesman-Kitaev-Preskill (GKP) codes are known to achieve optimal rates under displacement noise and pure-loss channels, which establishes theoretical foundations for its optimality. However, such optimal rates are only known to be achieved at a discrete set of noise strengths with the current self-dual symplectic lattice construction. In this work, we develop a new coding strategy using concatenated continuous variable-discrete variable encodings to go beyond past results and establish GKP's optimal rate over all noise strengths. In particular, for displacement noise, the rate is obtained through a constructive approach by concatenating GKP codes with a quantum polar code and analog decoding. For a pure-loss channel, we prove the existence of capacity-achieving GKP codes through a random coding approach. These results highlight the capability of concatenation-based GKP codes and provides new methods for constructing good GKP lattices.

Real-time adaptive quantum error correction by model-free multi-agent learning

Manuel Guatto, *Forschungszentrum Jülich*

The quest for building large-scale quantum computers requires optimal strategies to encode logical states, detect errors, and correct them—tasks that rely on enlarged Hilbert space encodings, which are challenging due to the exponential growth of the Hilbert space, and time-dependent nature of the noise. While earlier codes assume static errors, we present a two-level framework based on Reinforcement Learning (RL) that learns from scratch a general code which can correct even time-dependent errors and non-stationary noise. At the first level, we employ model-free Multi-Agent RL (MARL) to autonomously discover the full QEC cycle—logical state encoding, stabilizer measurements, and recovery—without prior system knowledge. Leveraging the stabilizer formalism, we show that MARL can uncover novel QEC codes tailored to multi-level quantum architectures. At the second level, we introduce a variational algorithm, termed BRAVE, which adaptively tunes the MARL policies on the fly by adjusting the physical basis of the error. This protocol allows the QEC code to remain effective under time-varying noise while reducing computational overhead and minimizing retraining steps. By combining MARL and BRAVE to design adaptive QEC cycles tailored for realistic noise environments, we obtain over an order-of-magnitude gain in logical fidelity, demonstrating a powerful framework for boosting the performance and reliability of real quantum hardware.

Improved error correction with leakage reduction units built into qubit measurement in a superconducting quantum processor

Marc Serra Peralta, *TU Delft, QuTech*

Leakage to non-computational states is a source of correlated errors in both time and space that limits the effectiveness of quantum error correction (QEC) with superconducting circuits. We present and experimentally demonstrate a high-fidelity, leakage reduction unit (LRU) operating concurrently with transmon measurement without incurring time overhead. Adapted from double-drive reset of population (DDROP), the protocol utilizes simultaneous drives on the transmon and its readout resonator, leveraging the dispersive shift to create a directional process that returns the transmon to the computational subspace. The LRU achieves a 98.4% leakage removal fraction without compromising the computational-state assignment fidelity (99.2%). We combine LRU-enhanced measurement and neural-network decoding to successfully suppress logical error rates in both memory and stability QEC experiments without any post-selection.

Environment-Assisted Generation of Non-Gaussian Wavepacket Quantum States

Maryam Khanahmadi, *Chalmers University of Technology*

Generating non-Gaussian states and converting them into traveling wavepackets is crucial yet challenging for scalable, fault-tolerant quantum computing. We present a hardware-efficient approach that simultaneously achieves both tasks by combining an engineered nonlinear dissipation with a linear transmission loss from a superconducting circuit to a waveguide. This combination of dissipative channels leverages low-order interactions to induce a high-order nonlinearity, enabling deterministic emission of a wide range of non-Gaussian, error-correctable states, such as Schr¨odinger cat states, GKP states, and pair-cat states. We identify experimental superconducting circuit platforms and realistic parameter regimes for our proposal.

W Cat: Entanglement at Quantum-Classical Boundary

May Chee Loke, *Centre for Quantum Technologies, National University of Singapore*

Multimode entanglement is a valuable resource for various quantum information tasks. In this work, we realize a tripartite entanglement in the form of a macroscopic W-state using a bosonic cQED architecture. Our system consists of three tantalum planar resonators as high-Q storage modes, collectively coupled to a single ancillary transmon. We develop an extension to the ECD (Echo Conditional Displacement) gate that leverages the higher ancilla levels to effectively create the W-state. Finally, we characterise the resulting state by probing 64 distinct points of the three-mode characteristic function. This implementation lays the groundwork for further exploration of W-states in quantum networking, quantum teleportation, and entanglement at the quantum-classical boundary.

Fault-Tolerant Non-Clifford GKP Gates using Polynomial Phase Gates and On-Demand Noise Biasing

Minh Pham, *TU Delft, QuTech*

The Gottesman-Kitaev-Preskill (GKP) error correcting code uses a bosonic mode to encode a logical qubit, and has the attractive property that its logical Clifford gates can be implemented using Gaussian unitary gates. In contrast, a direct unitary implementation of the T gate using the cubic phase gate has been shown to have logical error floor unless the GKP codestate has a biased noise profile. In this work, we propose a method for on-demand noise biasing based on a standard GKP error correction circuit. This on-demand biasing circuit can be used to bias the GKP codestate before a T gate and return it to a non-biased state afterwards. With the on-demand biasing circuit, we prove that the logical error rate of the T gate can be made arbitrarily small as the quality of the GKP codestates increases. We complement our proof with a numerical investigation of the cubic phase gate subject to a phenomenological noise model, showing that the T gate can achieve average gate fidelities above 99% with 12 dB of GKP squeezing without the use of postselection. Moreover, we develop a formalism for finding optimal unitary representations of logical diagonal gates in higher levels of the Clifford hierarchy

that is based on a framework of "polynomial phase stabilizers" whose exponents are polynomial functions of one of the quadrature operators. This formalism naturally extends to multi-qubit logical gates and even to number-phase bosonic codes, providing a powerful algebraic tool for analyzing non-Clifford gates in bosonic quantum codes.

A statistical mechanical approach to circuit depth of low energy states of a class of local Hamiltonians

Perrine Vantalon, *EPFL*

We consider a class of n-qubit local quantum Hamiltonians, on a d dimensional lattice, whose ground state is a purification of the Ising model Gibbs distribution on the d dimensional torus. We prove that $d \geq 2$, the ground state is complex in the sense that the circuit representation with 1- and 2-qubit gates necessarily involves a depth of at least log(n). Our proof is based on the computation of reduced density matrices and directly connects the long range order of the Ising model in $d \geq 2$ at low temperature with the non trivial separability decomposition of the reduced density matrices involving at least two terms. The argument is extended to a class of low energy states violating a sub-linear number of local terms in the Hamiltonian. The model and results are a low dimensional version of the combinatorial NLTS construction. The proof analysis is completely different and based on classical tools of statistical mechanics.

Impact of leakage population on a Kerr-cat qubit

Preeti Pandey, *Paul Scherrer Institute*

Bosonic codes offer a hardware-efficient platform for quantum error correction, by redundantly encoding information in the large Hilbert space of a quantum harmonic oscillator rather than in physical two-level systems. An example is the Schrödinger cat qubit, comprising opposite-phase coherent states and their quantum superpositions, the Schrödinger cat states. A superconducting Kerr-nonlinear resonator subject to a two-photon drive stabilizes such states via Hamiltonian confinement, defining the Kerr-cat qubit (KCQ). The KCQ Bloch sphere has one protected axis due to the intrinsic robustness of the coherent states against noise. This property positions the KCQ as a promising candidate for reducing the hardware overhead of quantum-error-correction codes. However, recent experiments have found that this error protection is significantly below theoretical expectation, and this reduction is mainly attributed to leakage outside of the KCQ manifold. While the coherent-state lifetime is shown to improve with reduced leakage population, a systematic study of this leakage and its effect on the coherent state lifetime is missing. Here we present a method to reliably identify leakage to excited states in a KCQ under operation. We then use this approach to investigate the leakage population and study its impact on the coherent-state lifetime.

Enhancing dissipative cat qubit protection by squeezing

Rémi Rousseau, *ETH Zürich*

Bosonic qubits implement error correction by harnessing the high-dimensional Hilbert space of a harmonic oscillator to redundantly encode logical quantum information. Squeezing of quantum states—a cornerstone of precision metrology—redistributes uncertainty between conjugate quadratures to enhance sensitivity in one variable at the expense of the other. In bosonic codes, decoherence can be seen as the environment performing an unwanted measurement on a noise-sensitive quadrature, collapsing superpositions and inducing errors. By redistributing uncertainty to that quadrature, squeezing can be leveraged to reduce the environment's measurement strength, thereby prolonging coherence. Here, we exploit this insight to implement a squeezing deformation of the simplest bosonic code—the cat qubit—extending the bit-flip time with minimal impact on the phase-flip rate. We observe a dramatic reduction in bit-flip errors, achieving a 160-fold improvement over standard cat qubits and bringing multi-cat architectures closer to fault-tolerant quantum computation.

Error-mitigated Gaussian Boson Sampling

Shana Winston, *Imperial College London*

Gaussian Boson Sampling (GBS) is a near-term photonic quantum computational model which can be implemented using only linear operations. It involves measuring the output photon distribution from a linear interferometer with Gaussian state inputs. Many applications of GBS arise from its relationship with graph problems, where the output photon distribution determines graph encodings. Applications of the GBS protocol are threatened by the presence of noise within the interferometer, which leads to an erroneous output photon distribution from a noisy unitary. We present a quantum error mitigation technique, unitary averaging, which can be applied to GBS to correct these errors. Unitary averaging uses central limit theorem to approximate a target unitary from multiple noisy copies. We demonstrate improved fidelity within the GBS device through simulations of a variety of interferometer sizes and unitary averaging depths, comparing the photon distribution of ideal GBS devices, noisy GBS devices, and noisy unitary averaged GBS devices. Finally, we present work towards an experimental implementation of unitary averaged GBS on a fully programmable 10x10 silicon nitride photonic integrated chip. We add phase noise to the chip, before using unitary averaging to decrease the distance between the ideal and noisy output photon distributions.

Single-Shot Universality in Quantum LDPC Codes via Code-Switching

Shi Jie Samuel Tan, *University of Maryland*

Code-switching is a powerful technique in quantum error correction that allows one to leverage the complementary strengths of different codes to achieve fault-tolerant universal quantum computation. However, existing code-switching protocols that encapsulate recent generalized lattice surgery approaches often either require many rounds of measurements to ensure fault-tolerance or suffer from low code rates. We present a single-shot, universal protocol that uses code-switching between high-rate quantum codes to perform fault-tolerant quantum computation. To our best knowledge, our work contains the first universal fault-tolerant quantum computation protocol that achieves what we term single-shot universality on high-rate codes that is characterized by (i) single-shot error correction, (ii) single-shot state preparation, as well as (iii) universal logical gates and logical measurements with constant depth circuits. We achieve this feat with single-shot code-switching between constant-rate 2D hypergraph product (HGP) codes and high-rate 3D HGP codes that can be viewed as a generalization of Bombin's dimensional jump for color codes. In addition, we prove the fault-tolerance of our protocol under both the adversarial and local-stochastic noise models. We introduce a vastly simpler recipe to construct high-rate 3D HGP codes with transversal CCZ gates that grants immense flexibility in the choice of expander graphs and local codes, allowing us to expand the search space for codes with good parameters and interesting logical gates. Our work opens an alternative path towards universal fault-tolerant quantum computation with low space-time overhead by circumventing the need for magic state distillation.

Tensor product code concatenation in measurement based quantum computing

Stuart Nicholls, *University of Sydney*

The chain complex formalism has recently proven useful to describe foliation of CSS codes in MBQC. However, a chain complex description of syndrome extraction for CSS subsystem codes in MBQC has not been formalized. In this paper we formalize such a subsystem fault complex, a total complex which is generalization of a fault complex to a foliated subsystem code. Expanding upon a result that a concatenated code can be viewed as a gauge-fixing of a subsystem tensor (homological) product code, we show how the subsystem fault complex can be used to generate resource states for a concatenated code syndrome extraction protocol, which has low (additive in the weight of checks of constituent codes) detector weight, and low node degree. Low spacetime overhead implementation of concatenated codes has been of recent theoretical interest. We prove that the fault distance of this protocol is the minimum of the time-like distance (number of measurement rounds), and the spacelike distance, which we show is the distance of the 'half-concatenated code'. The distance of the half-concatenated code is closely related to but distinct from the distance of the full tensor product code, which is an important unproven conjecture in the literature. Compared to Litinski's recent blocklets construction, this protocol has a better distance for one level of concatenation, and does not require swap gates, at the cost of larger vertex degree of the resource state (by a linear factor).

Fusion-based implementation of qLDPC codes with quantum emitters

Susan Chen, *University of Bristol, University of Copenhagen*

Quantum low-density parity check (qLDPC) codes offer higher encoding rate than topological codes, e.g. surface codes, making them favourable for practical, fault-tolerant quantum computing with low overhead. These codes are particularly well-suited for fusion-based photonic implementations as this platform readily supports non-local connections. We propose an architecture specifically tailored to quantum emitters which implements any Calderbank–Shor–Steane (CSS) qLDPC code, where the photonic resource states produced are deterministically available through the platform and a conditional repeat-until-success strategy is incorporated to achieve boosted photon loss tolerance. We simulate small exemplary Bivariate Bicycle qLDPC codes and analyse the performance of our constructions under relevant physical noise mechanisms, including erasures due to fusion failure or photon loss, as well as Pauli errors. We obtain performances comparable with topological architectures though with significantly higher encoding rates.

Towards fault tolerant quantum computation through code teleportation

Tomasz Andrzejewski, *TU Wien, Atominstitut*

QEC codes have different capabilities: qLDPC codes have a high encoding rate but are not particularly useful for processing while topological codes have poor encoding rate but high thresholds and allow for fault-tolerant quantum computation through code switching or magic state injection. These differences may be exploited by storing information in a dedicated quantum memory while performing computation on a quantum processor. The ideal memory code should be noise resistant (high distance, bias-tailored), such that quantum information can be stored for a long time, while having a high encoding rate to maintain resource efficiency. Processor codes should be small and allow for (easily implementable and resource-efficient) fault-tolerant gates. Ideally, the memory-processor combination should enable universal fault-tolerant quantum computation. In this talk we consider experiments demonstrating code teleportation as a tool for fault- tolerant quantum computation in ion trap quantum computers. We employ surface codes as hybrid memory-processor codes to enable universal fault- tolerant Clifford computation while fault-tolerantly using lattice surgery to teleport information into a [[8, 3, 2]] 3D color code whenever non-Clifford operations are required. 3D color code is interesting as it has a transversal CZ and CCZ gates and it was implemented in ion traps. We therefore use lattice surgery to teleport information from three minimal [[4, 1, 2]] surface codes to a 3D color code and perform a transversal CCZ gate between the teleported qubits. We discuss applications of CCZ vased gadget such as arbitrary rotation of a state. The experiments proposed here demonstrate the use and feasibility of a fault tolerant quantum computer based on code teleportation

Modular Post-selection for Surface Codes

Will Staples, *Princeton University*

The surface code is one of the most promising codes for practical realization owing to its 2-local connectivity requirements and high threshold. However, its major weakness in comparison to alternative scheme is the significant overhead required to reach algorithmically relevant logical error rates. We aim to reduce this overhead by leveraging the naturally available soft information form the Minimum Weight Perfect Matching decoder. In this poster, we will propose a technique of slicing quantum algorithms into a series of small resource states which can be independently filtered for low confidence events. We show this technique allows for distance reduction of the surface code without compromising logical error rate at realistic noise levels.

Modular Post-selection for the Surface Code

Winston Fu, *Princeton University*

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Fault Tolerance at Speed in a T-Center Photonic Surface Code

Aliki Capatos, *University of Copenhagen, NQCP*

Scalable quantum computing will require error-correcting architectures that can tolerate imperfect hardware primitives while still running fast enough to be practical. Photonic systems in particular offer many promising benefits, but suffer from photon loss and non-deterministic local operations. We propose a T-center based surface code architecture in which two-qubit interactions are realized through a teleported CNOT gate implemented by a choice of three novel photonic entanglement protocols, leveraging the fast, optically addressable electron spins before swapping the resulting state onto the longer-lived nuclear spins for storage and computation. Combined with repeat-until-success entanglement attempts and a smart scheduler that adaptively orders CNOT operations in the code to minimize computational time and idle errors, we estimate fault-tolerance thresholds for both square-lattice and hexagonal connectivity layouts. We further extend the analysis to an ancilla-free measurement paradigm and report the corresponding thresholds under the same physical error model. Across protocols and layouts, we benchmark tradeoffs among photon loss tolerance, hardware-native errors, and effective logical clock speed. Our results identify operating regimes where each protocol is preferable and quantify how connectivity and scheduling choices translate hardware-level parameters into logical performance. Our work provides the first concrete guidance on designing readily scalable and fault-tolerant T-center-based quantum computing architectures.

Protected phase gate for the 0-pi qubit using its internal modes

Xanda Kolesnikow, *University of Sydney*

Realising fault-tolerant quantum computers hinges on being able to bring physical error rates substantially below the threshold for quantum error correction. Being far below threshold ensures algorithmically relevant error rates are reached without unrealistically large numbers of qubits. Protected superconducting qubits, such as the 0-pi qubit, promise to achieve this by reducing susceptibility to errors at the hardware level. However, a key challenge is designing gates for these qubits that do not compromise their protection, or become infeasibly slow as the protection of the qubit is improved. In this work we propose a protected phase gate that is compatible with the protected regime of the 0-pi qubit, and does not suffer from spurious coupling to additional circuit modes. Our scheme utilises an internal bosonic mode of the circuit as an ancilla and makes use of GKP encodings to ensure fault tolerance. Through numerical simulations, we study how the gate error scales with the circuit parameters of the 0-pi qubit, finding that a protected gate is possible with near-term circuit parameters. Our work opens up the possibility of performing protected gates on protected superconducting qubits, which may significantly reduce hardware overheads for quantum computation.

An Erasure Qubit in Integer Fluxonium

Xanthe Croot, *University of Sydney*

Resource efficiency in quantum error correction can be significantly improved by engineering the underlying noise bias of physical qubits. In superconducting circuits, dual-rail architectures have been used to encode qubits dominated by erasure errors, which have favourable thresholds for quantum error correction. In this work, we propose an erasure qubit encoded in a single fluxonium circuit at integer flux, and undertake qubit characterisation, readout, gate implementation and error analysis in initial devices.

Experimental realization and synchronization of a quantum van der Pol oscillator

Yi Li, *University of Science and Technology of China*

Self-sustained oscillators, that generate periodic motion without periodic external forcing, are ubiquitous in science and technology. The realization of a quantum driven-dissipative system that exhibits self-oscillations has been a long-standing goal in quantum physics. We here present the experimental implementation of a quantum van der Pol (vdP) oscillator using a single trapped ion. We demonstrate the existence of a quantum limit cycle in phase space in the absence of a drive and the occurrence of quantum synchronization when the nonlinear oscillator is externally driven. We additionally show that synchronization can be enhanced with the help of squeezing perpendicular to the direction of the drive and, counterintuitively, linear dissipation. We also observe the bifurcation to a bistable phase-space distribution for large squeezing. Our results pave the way for the exploration of autonomous quantum oscillators and their application to quantum technology.

Dynamiqs: an open-source Python library for GPU-accelerated and differentiable simulations of quantum systems

Ronan Gautier, *Alice & Bob*

We present an open-source Python library for solving the dynamics of closed and open quantum systems, designed for large-scale simulations on GPUs and with end-to-end differentiable solvers. Built with JAX and leveraging solvers from Diffrax and custom positivity-preserving solvers, Dynamiqs supports integration of the Schrödinger equation, the Lindblad master equation, and stochastic master equations. Key features include high-performance simulations on both CPUs and GPUs, concurrent execution of multiple simulations via batching, dense and sparse matrix support, and gradient computation for arbitrary system parameters. It features a QuTiP-like API while also being fully compatible with the entire JAX ecosystem. Dynamiqs addresses the critical need for an accessible tool facilitating gradient-based parameter estimation and quantum optimal control, particularly for large quantum systems. Its design targets large-scale problems while maintaining efficiency for smaller CPU-based tasks. By filling the gap in the availability of such tools, dynamiqs aims to accelerate quantum technology development through reliable and fast simulations. This poster discusses the architecture, features, and potential applications of dynamiqs, highlighting its role in the quantum computing community. Documentation is available at dynamiqs.org, and the library is open-sourced at github.com/dynamiqs/dynamiqs.

Unified framework for obtaining fault-tolerance thresholds of arbitrary hardware imperfections

Kshitij Kapoor, *QC Design and University of Ulm*

We present a comprehensive framework to assess the impact of arbitrary hardware imperfections on fault-tolerant quantum computing performance. Our approach bridges detailed physical modeling and scalable simulations of fault-tolerance circuits, enabling determination of error correction thresholds for realistic, previously unmanageable noise processes. Our framework has two components: physics-based simulations of quantum gate operations and fault-tolerant quantum circuit simulations. The first uses detailed physics simulations incorporating hardware imperfections to construct precise error models as error objects. These models, described using Kraus operators or propagators, are efficiently simulated by decomposition into linear combinations of Clifford gates or via suitable, possibly generalized, twirling techniques. The second component enables simulation of these exact or approximate error models using specialized simulators tailored to different scenarios. Full-state simulators provide exact sampling for circuits with few qubits, while linear combinations of Clifford circuits enable efficient sampling of near-Clifford circuits. Generalized Pauli twirling allows scalable simulation of leakage or vibrational-mode-induced errors within extended Clifford simulators, and standard Pauli twirling enables efficient simulation via Clifford-only simulations. We implemented this framework in the high-performance fault-tolerance design tool Plaquette, which is 10–100 times faster than values reported in literature, enabling thresholds for previously intractable imperfections, including: intermediate state scattering (neutral atoms); leakage (transmons); coherent over-/under-rotation (superconducting and trapped ions); vibrational heating (trapped ions); and finite lifetime in quantum dots for photonic resource-state generation. These hardware-native thresholds apply to surface code variants, color codes, and qLDPC codes (including hypergraph product, bivariate bicycle, generalized bicycle, and lifted product codes) as well as user-defined codes, and generalize to MBQC and FBQC via foliation. This work provides, for the first time, a single systematic approach to quantify fault-tolerance performance under realistic hardware imperfections, enabling design and optimization of scalable fault-tolerant quantum architectures.

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Trinidad Lantaño, *QC Design*

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Design and Characterization of Longitudinal Readout Architectures for Superconducting Qubits

Ahmet Alperen Tekin, *EPFL, TUM*

High-fidelity and quantum non-demolition (QND) readout is a critical challenge for scaling superconducting quantum processors. Unlike standard transversal readout, longitudinal coupling offers a pathway to faster measurement rates without inducing Purcell decay, enabling more robust scalable architectures. This poster presents my ongoing work at EPFL's Hybrid Quantum Circuits Laboratory on the design, simulation, and cryogenic characterization of longitudinal readout circuits. The research focuses on engineering the Hamiltonian parameters to optimize signal-to-noise ratio (SNR) and minimize backaction. I discuss the end-to-end implementation challenges, from microwave resonator design and fabrication to the optimization of the cryogenic RF signal chain. Furthermore, I analyze the requirements for room-temperature and cryogenic control electronics needed to support these novel readout schemes, highlighting the intersection between quantum device physics and mixed-signal hardware constraints. . .

High-Rate Surgery: towards constant-overhead logical operations

Guo Zheng, *University of Chicago*

Scalable quantum computation requires not only quantum codes with low memory overhead but also encoded operations with low space–time overhead. High-rate quantum low-density parity-check (qLDPC) codes address the former by achieving a high information-encoding rate, yet existing methods for implementing logical operations often suffer from a low information-processing rate, leading to substantial space–time costs. Here, we introduce high-rate surgery, a general scheme that can perform extensive, addressable logical Pauli-product measurements in parallel on arbitrary qLDPC codes using a shared ancilla system, attaining nearly constant space–time overhead. We develop both algebraic and randomized ancilla constructions and demonstrate, using the [[144, 12, 12]] Gross code and new instances of qLDPC codes (e.g., [[1125, 245,<=10]]) with encoding rate up to 25%, that up to hundreds of randomly sampled logical measurements can be executed simultaneously with a total space-time overhead within a factor of two of that of memory experiments. Our results address a major bottleneck for performing complex, addressable logical operations on qLDPC codes in practice, advancing the prospect of scalable, constant-overhead fault-tolerant quantum computation.

Statistical Mechanics Mapping of Quantum Weight Enumerator Polynomials

Pierce Wickenden, *Virginia Tech*

Quantum weight enumerator polynomials provide important algebraic insight into the structure of quantum error-correcting codes (QECCs), yet they are generally difficult to compute. To date, there are only a few instances of states or codes for which the exact analytic form of the enumerators are known. In this work, we use the quantum Lego (QL) and tensor-weight-enumerator framework to develop a general analytical approach to compute these polynomials. To achieve this, we introduce a new and highly flexible statistical mechanics mapping that connects the QL formulation of QECCs to a classical spin model. In the latter, the problem of computing the quantum weight enumerator polynomial is equivalent to evaluating a classical partition function. Hence, this mapping provides a unifying bridge between the stabilizer formalism, tensor-networks, and statistical mechanics in an effective and transparent manner. Using this technique, we produce new analytical expressions of enumerators including those of cluster states and surface/toric codes. Beyond demonstrating a general and systematic approach for analytic computation, our formulation reveals an interesting physical connection which relates the 1d cluster state enumerator to a 1d Z2 lattice gauge theory. We also uncover hidden dualities between classical spin Hamiltonians by leveraging the MacWilliams Identities in coding theory, offering new insight into QECCs and classical statistical mechanics models.

Beating the break-even point with autonomous quantum error correction

Qingyuan Mei, *University of Science and Technology of China*

Quantum error correction (QEC) is essential for practical quantum computing, as it protects fragile quantum information from errors by encoding it in high-dimensional Hilbert spaces. Conventional QEC protocols typically require repeated syndrome measurements, real-time feedback or post-selection, and the use of multiple physical qubits for encoding.

Such implementations pose significant technical complexities, particularly for trapped-ion systems, with high demands on precision and scalability. Here, we realize autonomous QEC with a logical qubit encoded in multiple internal spin states of a single trapped ion, surpassing the break-even point for qubit lifetime. Our approach leverages engineered spin-motion couplings to transfer error-induced entropy into motional modes, which are subsequently dissipated through sympathetic cooling with an ancilla ion, fully eliminating the need for measurement and feedback. By repetitively applying this autonomous QEC protocol, we observe lifetime extension under both ambient and controlled noise conditions. Under ambient laboratory conditions, the logical qubit lifetime is improved from 24.7ms to 42.7ms through QEC protection, showing an enhancement factor of $\Lambda = 1.45 \pm 0.33$ compared with the physical qubit (29.4ms), thereby beating the break-even point with autonomous protection of quantum information with out measurement or post-selection. Under injected low-frequency magnetic noise designed to emulate challenging environment conditions, we achieve an enhancement factor $\Lambda = 11.9 \pm 0.8$, with a protected logical qubit lifetime of 11.7ms substantially outperforming those for both the physical qubit (0.98ms) and the uncorrected logical qubit (0.83 ms). This work presents an efficient approach to fault-tolerant quantum computing that harnesses the intrinsic multi-level structure of trapped ions, providing a distinctive path toward scalable architectures and robust quantum memories with reduced overhead.

Coherent CNOT gate between dissipative cat qubits with strong bias-preservation

Bright Ye, *AWS Center for Quantum Computing*

Dissipative cat qubits can exhibit strong noise bias due to their exponentially enhanced bit-flip times and only polynomially reduced phase-flip times with photon number, which makes them attractive candidates for hardware-efficient quantum error correction. However, it is difficult to maintain this strong noise bias in logical operations such as CNOT gates between cats. Here, we propose a coherent CNOT gate scheme between two dissipative cats that strongly preserves noise-bias. The proposed gate relies only on unitary operations, which avoids the non-idealities associated with many existing gate schemes that rely on engineered dissipations. Assuming good component lifetimes and a cat size of 10 photons, the proposed gate can enable logical memory in the megaquop regime (logical error rates $< 1e\text{-}6$) with a repetition code of only a dozen cats.

Symmetries in quantum simulations

Yanting Teng, *EPFL*

Classical simulation tools are essential for characterizing quantum devices and for the development of fault-tolerant quantum hardware. We present a symmetry-adapted framework for simulating quantum dynamics based on Pauli propagation (PP), motivated by the observation that many circuits of interest—particularly in quantum error correction—exhibit stabilizer symmetries. When a quantum circuit respects a symmetry, large families of Pauli strings evolve redundantly under the action of the corresponding symmetry group. We exploit this redundancy by identifying and merging Pauli strings related by symmetry transformations, and propagating only a minimal set of orbit representatives. We formalize this approach as symmetry-adapted Pauli propagation. For circuits and initial states that respect the symmetry, we prove that symmetry-adapted PP yields exactly the same expectation values as standard PP. Analytically, we show that symmetry merging reduces the space complexity by a factor set by the size of the symmetry orbits, with explicit results for translational and permutation symmetries. We benchmark the method on all-to-all interacting Heisenberg dynamics on periodic two-dimensional lattices, where symmetry adaptation improves numerical stability, particularly in the presence of truncation and noise. Our results suggest interesting direction to incorporating stabilizer-group symmetries into Pauli-based simulation methods for non-Clifford dynamics. We provide code and data in the open-source PauliPropagation.jl library.

Constructing CSS-T Quantum Codes Using the Schur Product of Evaluation Codes

Seyma Bodur, *neQxt GmbH*

CSS-T quantum codes are a family of Calderbank–Shor–Steane (CSS) codes. They enable the transversal implementation of the non-Clifford T gate. Therefore, these codes play a central role in fault-tolerant quantum computation. We study the Schur product (also known as the componentwise or Hadamard product) of monomial–Cartesian codes by exploiting its correspondence with the Minkowski sum of their defining exponent sets. We show that J-affine variety codes are well-suited for such products, thereby generalizing earlier results for cyclic, Reed–Muller, hyperbolic, and toric codes. Building on this structure, we construct CSS-T quantum codes from weighted Reed–Muller codes and binary subfield-subcodes of J-affine variety codes, leading to codes with better parameters than previously known. This is a joint work with Fernando Hernando, Edgar Martínez-Moro, and Diego Ruano.

Constraints on phantom codes from automorphism group bounds

Arthur Morris, *University of Copenhagen*

Executing a logical quantum circuit fault-tolerantly incurs a large spacetime (qubit and time) overhead. Recent work has proposed and investigated phantom codes, defined by the property that every logical CNOT circuit can be implemented with a physical permutation. Since permutations can be compiled as relabeling and so may incur essentially zero gate cost, phantom codes provide a pathway for reducing quantum gate overheads, especially in platforms with non-local connectivity. Empirical studies of phantom codes have suggested, however, that phantom codes can encode at most logarithmically many qubits. We provide a firm basis for this observation by proving that a tight bound $k \leq \log_2(n+1)$ holds for all binary phantom codes with $k \geq 2$ distance $d \geq 2$, where $k \neq 4$. We further show that, within the class of nontrivial CSS phantom codes with $k \neq 4$, there is a unique family of codes saturating this bound, while for $k = 4$ we explicitly construct a nonstabiliser $((8, 2^4, 2))$ phantom code that violates the bound and has a transversal non-Clifford gate. In addition, we prove that this logarithmic ceiling cannot be circumvented by permitting additional local unitary gates, or by making use of subsystem codes: any subspace or subsystem code admitting a SWAP-transversal implementation of every logical CNOT circuit is constrained to satisfy the same bound. These bounds follow from a general theorem relating the length of a quantum code to the structure of its automorphism group, a result which may find applications beyond phantom codes.

Noise as a Resource in Photonic Quantum Protocols: From Decoherence-Assisted QKD to Spatial Interference Recovery

Jose Ricardo Mejía, *Universidad de los Andes*

We present two optical experiments that share a common principle: the transverse spatial degree of freedom of light acts as a tunable, structured environment for photonic quantum protocols. In the first experiment, we demonstrate a decoherence-assisted BB84 quantum key distribution scheme in which a non-Markovian dephasing channel — implemented by coupling polarization and spatial modes via a polarizing tunable beam displacer — reduces the Rényi information accessible to an eavesdropper under the entangling probe attack, while allowing Alice and Bob to recover a low quantum bit error rate by coordinating their decoherence parameters. In the second experiment, we show that two-photon quantum interference can be recovered even when photons are strongly distinguishable in transverse momentum, provided detection is performed in the conjugate near-field position basis — an optical realization of the Alford-Gold effect in the spatial domain. Both results challenge the view that noise is purely detrimental: in the first case, dephasing suppresses eavesdropping; in the second, spatial distinguishability hides rather than destroys quantum correlations.

Dual-type dual-element atom arrays for quantum information processing

Zhanchuan Zhang, *ETH Zürich*

Neutral-atom arrays are a leading platform for quantum technologies, offering a promising route toward large-scale, fault-tolerant quantum computing. However, several challenges remain in this platform, including low experimental repetition rate, reconfigurable individual addressability and rapid, non-demolition, site-selective readout. To address these

limitations, we are developing a novel quantum processing architecture based on dual-type, dual-element Yb-Rb atom arrays, where individually trapped Yb atoms serve as data qubits, and small Rb atomic ensembles enable ancillary operations. By leveraging the selective initialization, coherent control, and collective optical response of atomic ensembles, we have designed ensemble-assisted quantum operations that enable reconfigurable, fast control of individual data qubits and rapid mid-circuit readout, including both projective single-qubit and joint multi-qubit measurements. Moreover, we will implement continuous reloading atoms from 3D magneto-optical trap to optical tweezer arrays to address atom loss during quantum processing, which will reduce the experimental cycle time. These capabilities open new pathways toward scalable, fault-tolerant quantum computation, enabling repetitive error syndrome detection and efficient generation of long-range entangled many-body states, thereby expanding the quantum information toolbox beyond existing platforms.