QCSC workshop 2025

Report of Contributions

Contribution ID: **13** Type: **Keynote**

Neutral-atom quantum computing in the Munich Quantum Valley

Tuesday 9 December 2025 14:00 (50 minutes)

Analog quantum simulators based on ultracold atoms trapped in optical lattices can be used to study condensed matter systems with single-site resolution. The quest for more control over individual atoms in such systems has culminated in a new generation of experiments based on atom arrays assembled with optical tweezers. These atom arrays can be created rapidly in arbitrary two- and three-dimensional geometries, and atoms in these arrays can be entangled using long-range Rydberg interactions.

Based on these developments, atom arrays have emerged as one of the most promising platforms to build digital quantum computers, because (1) atoms can realize qubits with many seconds of coherence time; (2) they have no manufacturing variations; and (3) it is easy to scale up to arrays with thousands of qubits. Here, I report on the digital quantum computer demonstrators developed in the academic projects within the Munich Quantum Valley and the commercial quantum computers developed at our spin-off, planqc.

Presenter: BLATT, Sebastian (planqc & MPQ Munich)

Session Classification: Sebastian Blatt: Neutral-atom quantum computing in the Munich Quantum Valley

Contribution ID: **14** Type: **Invited**

Quatum computational downsampling and optical classification

Tuesday 9 December 2025 14:50 (30 minutes)

Visual information can be manipulated in terms of images, usually captured and then processed through a sequence of computational operations. Alternatively, optical systems can perform such operations directly, reducing computational overhead at the cost of stricter design requirements. We discuss this workflow in the context of quantum technologies. First, we introduce a quantum algorithm that uses the quantum Fourier transform to discard the high spatial-frequency qubits of an image, downsampling it to a lower resolution. Our method allows us to capture, compress, and communicate visual information even with limited resources [1,2]. Then, we present a quantum optical pattern recognition method for binary classification tasks. Our method classifies patterns without reconstructing their images, encoding the spatial information of the object in the spectrum of a single photon, providing a superexponential speedup over classical methods [3,4].

References

[1] Simone Roncallo, Lorenzo Maccone and Chiara Macchiavello, Quantum JPEG, AVS Quantum Sci. 5, 043803 (2023)

[2] Emanuele Tumbiolo, Simone Roncallo, Chiara Macchiavello and Lorenzo Maccone, Quantum frequency resampling, npj Quantum Inf. 11, 123 (2025)

[3] Simone Roncallo, Angela Rosy Morgillo, Chiara Macchiavello, Lorenzo Maccone and Seth Lloyd, Quantum optical classifier with superexponential speedup, Commun. Phys. 8 147 (2025)

[4] Simone Roncallo, Angela Rosy Morgillo, Seth Lloyd, Chiara Macchiavello and Lorenzo Maccone, Quantum optical shallow networks, arXiv.2507.21036

Presenter: RONCALLO, Simone (University of Pavia)

Session Classification: Simone Roncallo: Quatum computational downsampling and optical classification

Contribution ID: **15** Type: **Contributed**

Quantum variational photonic solver for the travelling salesman problem

Tuesday 9 December 2025 15:20 (20 minutes)

In our work, we formulate a novel variational quantum approach to solve the travelling salesman problem (TSP), and we demonstrate it through a silicon photonic circuit (Si-PIC). The TSP [1] is a well-known combinatorial classical problem which is NP-hard. The aim consists of finding the shortest route among N cities, passing through each city once and ending at the initial city. Today, there is no classical algorithm able to solve this problem without an exponential growth of resources and time instances. For this reason, researchers are investigating the possibility of achieving a better behaviour with hybrid-quantum- classical architectures and associated variational quantum algorithms (VQAs) [2, 3]. The most famous formulation is given by the quadratic unconstrained binary optimization with Ising-like Hamiltonians, implemented on superconducting platforms [4].
Our variational approach outmatches the known methods in terms of the number of qubits and two-qubit gates. In particular, the first feature scales logarithmically and the latter quadratically with respect to N. The procedure is based on the preparation of trial states in the form of two maximally entangled quantum registers, one for the departing cities and one for the arriving ones. Then, the cost function of the problem is calculated by utilizing the correlation matrix between the two quantum registers and the values of distances among the different city pairs. As in any VQA, the classical hardware updates the preparation set- ting of the trial states through a classical minimization routine for the cost function until the convergence to an extremal value is reached. On the same Si-PIC used to solve a quantum chemistry problem and factorization tasks [5], we implemented the proposed VQA for the generic TSP with four cities. The circuit allows for the generation of entangled photon pairs, whose spatial modes encode the two quantum registers for the desired TSP. The solution can be read directly from the twin-photon cor- relation matrix after the classical optimization convergence. Contrary to other variational approaches, the solution is not written in the state itself but in one of its observables: thus, no state tomography is needed. Our method shows how future entanglement-based specific-purpose quantum hardware could reach quantum utility even in the noisy intermediate quantum era [6].
References
[1] Beardwood,J.,et al.”Theshortestpaththroughmanypoints.”Mathematical proceedings of the Cambridge philosophical society. (1959).
[2] Peruzzo, A.,et al. ”A variational eigenvalue solver on a photonic quantum processor.”Nature Comm.5.1(2014).
[3] Cerezo,M.,etal.”Variational quantum algorithms.”Nature Reviews Physics 3.9 (2021).
[4] McGeoch, C. C., et al. “Experimental evaluation of an adiabiatic quantum system for combinatorial optimization.”Proceedings of the ACM International Conference on Computing Frontiers (2013).
[5] Baldazzi, A., et al. ”Four-qubit variational algorithms in silicon photonics with integrated entangled photon sources.”npj Quantum Information 11.1 (2025): 107..
[6] Moody,G.,etal.”2022 Roadmap on integrated quantum photonics.”Journal of Physics: Photonics 4.1 (2022).

Presenter: BALDAZZI, Alessio (University of Trento)

Session Classification: Alessio Baldazzi: Quantum variational photonic solver for the travelling salesman problem

Contribution ID: **16** Type: **Invited**

Discrete local dynamics in globally driven dual-species Rydberg atom arrays

Tuesday 9 December 2025 16:10 (30 minutes)

Abstract TBA

Presenter: PIROLI, Lorenzo (University of Bologna)

Session Classification: Lorenzo Piroli: Discrete local dynamics in globally driven dual-species Rydberg atom arrays

Contribution ID: **17** Type: **Contributed**

Efficient quantum state preparation with Bucket Brigade QRAM

Tuesday 9 December 2025 16:40 (20 minutes)

The preparation of data in quantum states is a critical component in the design of quantum algorithms. The cost of this step can significantly limit the realization of quantum advantage in domains such as machine learning, finance, and chemistry. One of the main approaches to achieve efficient state preparation is through the use of Quantum Random Access Memory (QRAM), a theoretical device for coherent data access with several proposed physical implementations. In this work, we present a framework that integrates the physical model of the Bucket Brigade QRAM (BBQRAM) with the classical data structure of the Segment Tree to achieve efficient state preparation. We introduce a memory layout that embeds a segment tree within BBQRAM memory cells by preserving the segment tree's hierarchy and supporting data retrieval in logarithmic time via specialized access primitives. We demonstrate that, under the proposed memory layout, our method encodes a matrix $A \in \mathbb{R}^{M \times N}$ in a quantum register of $\Theta(\log_2(MN))$ qubits in $\mathcal{O}(\log_2^2(MN))$ time using constant ancillary qubits under a fixed-precision assumption. This framework provides theoretical support for quantum algorithms that assume negligible data loading overhead and establishes a foundation for designing classical-to-quantum encoding algorithms that are aware of the underlying physical QRAM architecture.

Presenter: GHISONI, Francesco (University of Pavia)

Session Classification: Francesco Ghisoni: Efficient quantum state preparation with Bucket Brigade QRAM

Contribution ID: **18** Type: **Contributed**

New solutions to the maximum independent set via probabilistic and quantum cellular automata

Tuesday 9 December 2025 17:00 (20 minutes)

We introduce a novel framework that connects probabilistic cellular automata (PCA) with quantum cellular automata (QCA) to tackle graph optimization problems, focusing on the Maximum Independent Set (MIS) task. Starting from a new class of classical PCA rules acting locally on graphs with bounded degree, we show how to construct a corresponding QCA whose dissipative dynamics drives the system toward configurations close to the optimal solution. Remarkably, this quantum extension allows the automaton to explore the solution space more efficiently, approaching the optimal MIS with high probability in polynomial time. This approach highlights how QCA dynamics can serve as a unifying language bridging classical stochastic computation and quantum optimization.

Presenter: DELL'ANNA, Federico (University of Bologna)

Session Classification: Federico Dell'Anna: New solutions to the maximum independent set via probabilistic and quantum cellular automata

Contribution ID: **19** Type: **Keynote**

Utilizing and controlling collective states in superconducting waveguide QED

Wednesday 10 December 2025 09:00 (50 minutes)

Propagating microwave photons in waveguides couple well to superconducting qubits and mediate long-range interactions between distant qubits causing the emergence of collective states. Of particular interest are dark or subradiant states, which are protected from decoherence as they decouple from the waveguide environment.

However, the protection from decoherence comes with a caveat that the control of such states is challenging. Recently, we probed a collective dark state formed by two transmon pairs, each pair also exhibiting a local dark state, exploiting local control.

Here, I will present the experimental characterisation of such a four qubit system with an optimised set of parameters for the implementation of a two-qubit gate operation between two local dark states in the waveguide separated by several centimetres. I will show results where we extend the system to larger arrays of transmon qubits in a planar implementation to explore higher excitation states.

Furthermore, I will show how we can use collective states of two qubits in the waveguide to build a primary thermometer which can distinguish the influence of a local bath from the temperature of the mode it
should measure.

Presenter: KIRCHMAIR, Gerhard (UIBK & IQOQI, Innsbruck)

Session Classification: Gerhard Kirchmair: Utilizing and controlling collective states in superconducting waveguide QED

Contribution ID: **20** Type: **Invited**

Quantum Computing @ CINECA

Wednesday 10 December 2025 09:50 (30 minutes)

Abstract TBA

Presenter: OTTAVIANI, Daniele (CINECA)

Session Classification: Daniele Ottaviani: Quantum Computing @ CINECA

Contribution ID: **21** Type: **Invited**

The superconducting quantum computing center "Partenope": progresses and quantum algorithm

Wednesday 10 December 2025 10:50 (30 minutes)

The engineerable quantum macroscopic and artificial nature of superconducting quantum platforms [1], also recognized by the recent Nobel prize to Clarke, Martinis and Devoret, has favored noticeable advancements towards both quantum utility in the Noisy and Intermediate Scale Quantum (NISQ) era and quantum error correction for fault-tolerant quantum computing [2-5]. Nevertheless, the incredibly fast development of superconducting quantum computers prevents their use as "black boxes"to unlock their full potential in the NISQ era.

In this work, we discuss the strategy pursued to build the first superconducting quantum computing center in Italy, "Partenope", funded by the National Center for High-Performance, Big Data and Quantum Computing (ICSC) [6,7]. We will first report on the Quantum Characterization, Validation and Verification (QCVV) of a Quantum Processing Unit (QPU) made of 25 transmon qubits, and then delve into the future evolutions of the infrastructure towards a multi-node platform.

Specifically, we will focus on the study of its computational resources, e.g. the well-known superposition and entanglement, but also the more advanced magic, a computational resource that quantifies how much a quantum state deviates from being a stabilizer state [8]. Stabilizer operations give access to entanglement, but no magic; local operations to magic, but no entanglement. The onset of quantum advantage then resides in the interplay between entanglement and magic. Non-local magic is recognized as the quantity that measures the interplay between them [9], although not commonly investigated experimentally, and notably depends on the level of errors in the hardware at hand. The direct access to our QPU's characteristics unlocked the first demonstration of non-local magic in a superconducting platform [10], further motivating the strong request for a full knowledge of the hardware at hand as a tool to advance knowledge.

These results have been pivotal also for the implementation of proof-of-concepts algorithms applied to Quantum Finance [11]. In collaboration with G2Q Computing and Intesa SanPaolo, we applied Quantum Amplitude Estimation (QAE) methods for Credit Risk Analysis, i.e. the Gaussian Conditional-Independence (GCI) model [12]. Here, a key role is played by the generation of Gaussian distributions encoded in a qubits register. We demonstrate that hardware- aware quantum circuit transpilation based on a variational-like approach directly at the machine level allows to overcome the limited connectivity and gate errors in our NISQ QPU, with reasonable outcome for such use-case.

[1] M. Devoret et al., Phys. Rev. Lett. 53, 1260 (1984).

[2] Arute, F., et al., Nature 574, 505–510 (2019)

[3] Kim, Y., et al., Nature 618, 500–505 (2023)

[4] Google Quantum AI and Collaborators. Nature 638, 920–926 (2025).

[5] Google Quantum AI and Collaborators. Nature 646, 825–830 (2025).

[6] Ahmad H.G., et al., Adv Quantum Technol. 2024, 2300400

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[10] Ahmad H.G., et al., manuscript in submission.

[11] Ahmad H.G., et al., manuscript in preparation.

[12] M. Rutkowski, et al., International Journal of Theoretical and Applied Finance 18, 1550034 (2015)

Presenter: AHMAD, Halima Giovanna (University of Napoli ”Federico II”)

Session Classification: Halima Giovanna Ahmad: The superconducting quantum computing center “Partenope”: progresses and quantum algorithm

Contribution ID: **22** Type: **Contributed**

Ferromagnetic Josephson junctions for pulsed-tunable coupling in superconducting qubits

Wednesday 10 December 2025 11:20 (20 minutes)

Superconducting circuits are recognized as one of the most promising platforms for scalable quantum information processing, demonstrating both quantum advantage and rapid progress in multi-qubit control [1,2]; this maturity is further emphasized by the 2025 Nobel Prize in Physics awarded to J. Clarke, M. H. Devoret, and J. M. Martinis for their pioneering contributions to superconducting quantum circuits. On Partenope, our 25-qubit transmon platform, we have built and optimized the full control stack required for reproducible, high-fidelity CZ-gate operation, establishing a baseline for algorithmic execution. Yet, scalability remains challenged by flux-line distortions, inter-channel flux crosstalk, and the requirement of persistent DC flux bias. Recently, we have demonstrated that ferromagnetic Josephson junctions can offer a novel pathway to tunability for transmon qubit by exploiting the intrinsic magnetic properties of the ferromagnetic layer within the junction [3].

In this work, we introduce the concept of a ferromagnetic tunable coupler, where the inter-qubit coupling is set by the magnetization state of a ferromagnetic Josephson junction. Unlike dc-SQUID couplers that rely on continuous flux biasing and suffer from low-frequency flux noise, this scheme exploits an intrinsic magnetic degree of freedom to realize flux-free tunability. The magnetization-dependent Josephson energy acts as an effective mutual inductance between neighboring transmons, providing programmable coupling without the need for DC-bias offsets. Operating at zero static flux reduces sensitivity to flux noise and simplifies large-scale integration.

Preliminary simulations indicate a coupling range spanning more than two orders of magnitude and a tunability compatible with high-fidelity gate operation, while preserving minimal added decoherence. This magnetization-controlled coupling paradigm provides a pulse-programmable, flux-bias-free route toward scalable superconducting processors, naturally compatible with superconducting control electronics such as SFQ-based drivers. The device concept and related patent submission [4] mark a step toward large-scale, pulsed programmable qubit architectures.

[1] Arute, F., et al., Nature 574, 505–510 (2019).
[2] Google Quantum AI, Nature 646, 825–830 (2025).
[3] H. G. Ahmad et al., Phys. Rev. B 105, 224508 (2022).
[4] European Patent Application No. 24425069.2 (submitted)

Presenter: COSENZA, Carlo (University of Napoli ”Federico II”)

Session Classification: Carlo Cosenza: Ferromagnetic Josephson junctions for pulsed-tunable coupling in superconducting qubits

Contribution ID: **23** Type: **Contributed**

Circuit quantum electrodynamics with semiconductor quantum dots

Wednesday 10 December 2025 11:40 (20 minutes)

Circuit quantum electrodynamics (circuit QED) advanced thanks to the development of the field of quantum circuit which find applications not only as quantum bits for quantum information processing but also in the linear and nonlinear manipulation of quantum microwave fields. Circuit QED with quantum dots (QDs) is a platform where quantum dots act as artificial atoms that interact with microwave photons in superconducting circuits, enabling the study of light-matter interaction at the quantum level.

After providing an overview of the field, I will present theoretical proposals for generating entangled photons and detecting single microwave photons by utilizing coherent nanoconductors as quantum sources and detectors, harnessing the unique properties of superconducting and semiconducting nanostructures in combination with microwave quantum devices.

In a first work [1], we explore a proposal to transfer entanglement from a many-body quantum condensate—specifically, a BCS superconductor—to microwave photons propagating in transmission lines. We demonstrate the potential to generate pairs of frequency-entangled photons from electrons emitted by a superconducting nanoscale quantum device known as a "Cooper pair splitter." In a second work [2], we study quantum dots dispersively coupled to a microwave resonant cavity, enabling Quantum Non-Demolition (QND) detection of individual itinerant microwave photons.

[1] M. Governale, C. Schönenberger, P. Scarlino, and G. Rastelli,
"Entangled Photon-Pair Emission in Waveguide Circuit QED from a Cooper Pair Splitter"PRX Quantum 6, 020339 (2025)
https://physics.aps.org/articles/v18/s70 (Physics Magazine)
[2] S. Matern, A. Biella, P. Scarlino, I. Carusotto, G. Rastelli,
"Quantum nondemolition detection of single microwave photons with quantum dots" (to be submitted)

Presenter: RASTELLI, Gianluca (Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Trento)

Session Classification: Gianluca Rastelli: Circuit quantum electrodynamics with semiconductor quantum dots

Contribution ID: **24** Type: **Invited**

Quantum computing in computational chemistry

Wednesday 10 December 2025 14:00 (30 minutes)

Abstract TBA

Presenter: GUIDONI, Leonardo (University of L'Aquila)

Session Classification: Leonardo Guidoni: Quantum computing in computational chemistry

Contribution ID: **25** Type: **Contributed**

Exploring quantum correlations in non-covalent bonded dimers: A mutual information approach using extended VQE simulations with MPS-emulator

Wednesday 10 December 2025 14:30 (20 minutes)

Non-covalent interactions (i.e. dispersions, hydrogen-bonding, polarization) are fundamental molecular interactions with key implications for the fields of chemistry, biology, and materials science. A precise understanding of these forces requires an accurate treatment of electron correlation effects, which remains a challenge for classical computational methods. Quantum computing offers a promising alternative, yet current noisy intermediate-scale quantum (NISQ) devices and algorithms face significant limitations.

In this study, we employ a highly parallelizable Matrix Product State (MPS)-based quantum computer emulator (QuantumMatchaTea[1]) to systematically investigate quantum correlations in Non-Covalent bonded dimers (e.g., He2, (H2)2, (H_2O)2 and (HF)2). Our approach extends the capabilities of the Adaptive Variational Quantum Eigensolver 2 algorithm, enabling an on-the-run characterization of the quantum correlations in the simulated molecular systems. By computing the evolution of orbital entanglement and mutual information during the VQE optimization, we introduce a modified adaptive scheme. This strategy dynamically identifies the most relevant excitations and optimizes their parameters while accounting for the quantum correlations they generate. We then quantify how these correlations are encoded and distributed within the quantum circuit and relate them to the orbital representation of the Non-Covalent bonded molecules.

To contextualize our findings, we compare the Mutual Information extracted from our VQE simulations with similar results from high-level classical methods (e.g., CASSCF). This allows for a direct comparison between the two theoretical descriptions of the of Non-Covalent interactions and let us evaluate the different contributions that distinguish quantum from classical algorithms.

Our study provides one of the first systematic analyses of noncovalent interactions using NISQ-era quantum algorithms. By relating entanglement and mutual information to molecular interactions, we shed new light on the role of quantum correlations in noncovalent binding and extend the reach of quantum computing in electronic structure theory.

[1] Ballarin, Marco. "Quantum Computer Simulation via Tensor Networks." Mater Thesis. (2021).
[2] Grimsley, H. R., Economou, S. E., Barnes, E., & Mayhall, N. J. (2019). Nature communications, 10(1), 3007

Presenter: POLI, Emiliano (University of Padova)

Session Classification: Emiliano Poli: Exploring quantum correlations in non-covalent bonded dimers: A mutual information approach using extended VQE simulations with MPS-emulator

Contribution ID: **26** Type: **Contributed**

Tackling photodynamic therapy oriented photosensitizes with quantum computers: AEGISS method for selecting chemically meaningful active-spaces

Wednesday 10 December 2025 14:50 (20 minutes)

Photochemistry involves light-induced chemical processes that lead to changes in the (excited-state) molecular structures and drive chemical transformations. When molecules absorb light, they can transition to excited states, leading to ensuing processes like internal conversion, Inter–System Crossing (ISC), or radiative emission (fluorescence and phosphorescence) to dissipate the excess energy.

In Photodynamic Therapy [1,2], a light-triggered targeted anticancer therapy, photons activates a Photosensitizer (PS), initiating an ISC and energy transfer to oxygen, with the ultimategoal to generate Reactive Oxygen Species (ROS) that are capable of introducing apoptosis in cancer cells. Here, a small energy gap between singlet and triplet states (ΔS1-T1) enhances ISC and reverse ISC (RISC) rates, that can lead to improved ROS production and therefore an increase in therapy eNiciency [3]. DiNerent criteria must be met to define whether a candidate molecule is a good PS: Lack of dark toxicity; Solubility in aqueous vehicle; Chemically pur;, easy to synthesize; High absorption in PDT window for deep light penetration, i.e. 700-900 nm; preferential accumulation in tumor; rapid elimination from the body; and also been able to generate suNicient singlet oxygen, even under hypoxic conditions. Some PS contains transition metals and biradicals which demand multi-configurational or strongly correlated approaches. In such cases, active space selection is vital, as it determines which orbitals are included in the description of electronic states, ensuring accurate modeling of complex structures and interactions while also controlling the computational cost. The selection of a balanced active space is therefore a critical step in multi-reference quantum chemistry calculations, particularly for systems with strong electron correlation

In this work, we present a novel approach inspired by both the AVAS [4] (Atomic Valence Active Space) and AutoCAS [5] methods. Atomic-Orbital and Entropy Guided Inference for Space Selection (AEGISS) [6] unifies orbital entropy analysis with atomic orbital projections to guide the construction of chemically and physically meaningful active spaces. This integrated scheme enables a more consistent and flexible selection of active orbitals while retaining automation and scalability. We validate our approach on a set of molecular systems relevant to photodynamic therapy, in particular a set of Ru(II)-complexes [7,8,9,10], selected to span increasing levels of electron correlation and structural complexity. These molecules serve as challenging test cases due to the presence of strong static correlation and the need for highly accurate electronic structure descriptions. Our results demonstrate that the method can reliably identify compact, chemically intuitive active spaces that capture the essential physics,making it suitable for both classical and quantum computational frameworks.

[1] 10.3390/pharmaceutics13091332
[2] 10.1063/5.0170949
[3] 10.1021/acs.chemrev.8b00211
[4] 10.1021/acs.jctc.7b00128
[5] 10.1021/acs.jctc.6b00156
[6] 10.48550/arXiv.2508.10671
[7] 10.1021/ct200640q
[8] 10.1021/acs.jctc.7b00379
[9] 10.1021/acs.chemrev.8b00211

[10] 10.1021/acs.inorgchem.6b01782

Presenter: TAROCCO, Fabio (University of L'Aquila)

Session Classification: Fabio Tarocco: Tackling photodynamic therapy oriented photosensitizes with quantum computers: AEGISS method for selecting chemically meaningful active-spaces

Contribution ID: **27** Type: **Invited**

Tensor networks @UniPd: simulating quantum many-body systems and beyond

Wednesday 10 December 2025 15:10 (30 minutes)

Recent breakthroughs in quantum simulation and computation are fostering new insights into exotic phenomena in quantum many-body systems, as well as motivating extensive research to develop novel experimental protocols to speed up the solution of classical optimization problems. On the one hand, these advances call for state-of-the-art numerical techniques to test new protocols and benchmark experimental results. On the other, they have driven the development of classical, quantum-inspired techniques and new optimization algorithms for solving use-case problems.

In our group, we investigate quantum simulation and computation protocols that can be implemented on state-of-the-art experimental platforms, as well as quantum-inspired algorithms to solve optimization problems. We extensively develop and use algorithms based on tensor-network techniques, an extremely versatile tool to efficiently compress, store, and manipulate the information contained in quantum many-body states. In particular, our algorithms are based on Tree-Tensor-Networks (TTNs), an Ansatz suited for the study of high-dimensional systems.

In my talk, I will present results obtained with TTNs, ranging from quantum simulation and computation protocols for quantum-many-body systems to algorithms for the solution of optimization problems.

Presenter: NOTARNICOLA, Simone (University of Padova)

Session Classification: Simone Notarnicola: Tensor networks @UniPd: simulating quantum many-body systems and beyond

Contribution ID: **28** Type: **Keynote**

Mari Carmen Bañuls

Thursday 11 December 2025 09:00 (50 minutes)

TBA

Presenter: BAÑULS, Mari Carmen (MPQ Munich)

Session Classification: Mari Carmen Bañuls

Contribution ID: **29** Type: **Invited**

Quantum computing activities at INFN

Thursday 11 December 2025 09:50 (30 minutes)

In this talk, an overview of the quantum computing activities carried out at the Istituto Nazionale di Fisica Nucleare (INFN) will be presented, with a particular focus on their applications to particle and astroparticle physics. Examples include the use of quantum computing techniques in Large Hadron Collider data analysis, neutrino experiments, and theoretical calculations. It will be shown how quantum algorithms—such as classification methods based on quantum machine learning, quantum simulations, and quantum-assisted reconstruction techniques—can compete with traditional approaches in these research domains. Finally, prospects for future applications of quantum computing in high-energy physics will be discussed.

Presenter: SESTINI, Lorenzo (INFN Firenze)

Session Classification: Lorenzo Sestini: Quantum computing activities at INFN

Contribution ID: **30** Type: **Invited**

Role of nonstabilizerness in quantum optimization

Thursday 11 December 2025 10:50 (30 minutes)

Quantum optimization has emerged as a promising approach for tackling complicated classical optimization problems using quantum devices. However, the extent to which such algorithms harness genuine quantum resources and the role of these resources in their success remain open questions.

In this work, we investigate the resource requirements of the Quantum Approximate Optimization Algorithm (QAOA) through the lens of the resource theory of nonstabilizerness. We demonstrate that the nonstabilizerness in QAOA increases with circuit depth before it reaches a maximum, to fall again during the approach to the final solution state—creating a barrier that limits the algorithm's capability for shallow circuits. We find curves corresponding to different depths to collapse under a simple rescaling, and we reveal a nontrivial relationship between the final nonstabilizerness and the success probability.

Finally, we identify a similar nonstabilizerness barrier also in adiabatic quantum annealing. Our results provide deeper insights into how quantum resources influence quantum optimization.

Presenter: CAPECCI, Chiara (UniTN - Pitaevskii BEC Center & INFN-TIFPA)

Session Classification: Chiara Capecci: Role of nonstabilizerness in quantum optimization

Contribution ID: **31** Type: **Contributed**

Krylov spaces and algebras for efficient simulation of quantum dynamics

Thursday 11 December 2025 11:20 (20 minutes)

When we aim to accurately simulate the behaviour of complex dynamical
systems, the problem of finding simpler representations for the model of interest becomes critical. We focus on completely-positive (CP) dynamics, which can be used to describe a wide variety of physically-relevant systems for quantum and classical information, including quantum walks and open quantum systems. For these models, a reduction approach based on Krylov subspaces is derived, by leveraging information on initial conditions and observables of interests. The reduced models obtained by the procedure are provably the smallest linear models that exactly reproduce the target evolution. These can be extended in order to retain a physically admissible evolution, if desired. In doing this, we highlight the minimal memory resources needed to perfectly simulate a given process and thus probe its "quantum-ness". The algebraic tools developed in the process can be used in a variety of settings, including model reduction of quantum trajectories and also approximate model reduction, e.g. by restricting the dynamics onto the slowest evolving modes.

Relevant publications:
[1] Exact Model Reduction for Continuous-Time Open Quantum Dynamics Tommaso Grigoletto, Yukuan Tao, Francesco Ticozzi, Lorenza Viola, Quantum 9, 1814 (2025) [online][arxiv]
[2] Model Reduction for Quantum Systems: Discrete-time Quantum Walks and Open Markov Dynamics, Tommaso Grigoletto, Francesco Ticozzi, IEEE Transactions on Information Theory,2025 [online][arxiv]

Presenter: GRIGOLETTO, Tommaso (University of Padova)

Session Classification: Tommaso Grigoletto: Krylov spaces and algebras for efficient simulation of quantum dynamics

Contribution ID: **32** Type: **Contributed**

Superdiffusion and non-KPZ fluctuations in chiral SU(2) systems

Thursday 11 December 2025 11:40 (20 minutes)

Symmetries play a crucial role in shaping transport in quantum many-body systems, often leading to departures from conventional diffusion. In this talk, I will discuss transport at infinite temperature in chiral integrable systems with global SU(2) symmetry. We study both Hamiltonian and Floquet (circuit) realizations, finding the dynamics exhibit a dynamical exponent z=3/2, consistent with superdiffusion in the Kardar–Parisi–Zhang (KPZ) universality class. However, as in the isotropic XXX model, an analysis of higher-order fluctuations – specifically the excess kurtosis – reveals clear deviations from KPZ scaling, signaling anomalous behavior beyond this universality.

Presenter: BHAKUNI, Devendra Singh (Abdus Salam International Centre for Theoretical Physics (ICTP))

Session Classification: Devendra Singh Bhakuni: Superdiffusion and non-KPZ fluctuations in chiral SU(2) systems

Contribution ID: **33** Type: **Keynote**

Two-dimensional Coulomb crystals: from structural transitions to quantum interfacesTBA

Thursday 11 December 2025 14:00 (50 minutes)

The self-organization of strongly interacting particles in confined geometries gives rise to a variety of structural phenomena that are relevant both to fundamental physics and to the advancement of controllable quantum systems. Two-dimensional Coulomb crystals of trapped ions provide an ideal platform to explore these effects and represent one of the most promising routes toward scalable ion-based quantum processors.

We report on two structural phenomena in such crystals that highlight the complex interplay between trapping geometry and interactions. First, we investigate orientational melting, a transition specific to mesoscopic two-dimensional systems in which ions lose angular order while remaining radially localized [1]. Second, we explore structural bistability and demonstrate how configuration changes can emulate molecular isomerization [2]. Using Monte Carlo simulations, we map the potential energy surface of a six-ion crystal and identify a double-well structure supporting two coexisting metastable isomers. Experimentally, we resolve the occupation dynamics between these isomers with sub-millisecond resolution.

Finally, I will discuss the perspective of integrating two-dimensional Coulomb crystals into a bow-tie optical cavity. In contrast to conventional Fabry–Perot resonators, the bow-tie geometry provides uniform coupling between the entire ion crystal and the optical mode, offering a promising route toward distributed quantum computing architectures. Moreover, this configuration enables the generation of deep optical potentials for micromotion-free optical trapping of two-dimensional crystals [3], with the prospect of reaching lower temperatures and exploring the role of quantum fluctuations in structural transitions.

[1] N. Mizukami et al. arXiv2508.05902
[2] L. Duca et al. Phys. Rev. Lett. 131, 083602 (2023)
[3] E. Perego et al. Appl. Sci. 10, 2222 (2020)

Presenter: SIAS, Carlo (Istituto Nazionale di Ricerca Metrologica)

Session Classification: Carlo Sias: Two-dimensional Coulomb crystals: from structural transitions to quantum interfaces

Contribution ID: **34** Type: **Invited**

Quantum spin glass state of the Heisenberg model in two dimensions

Thursday 11 December 2025 14:50 (30 minutes)

By means of a Neural Network Variational Wave Function numerical
method, we study the Quantum Spin Glass phase of a disordered Heisenberg model in two spatial dimensions. As the fraction of antiferromagnetic bonds is increased, we find that the model has a QSG phase clearly distinct from the ferro- and antiferro-magnetic order. We further investigate this phase using a semiclassical approximation, and characterize the Bogoljubov spin waves as localized excitations on top of the classical ground state. We posit that the reason for the stability of the QSG phase as opposed to the instability of the SG phase in the corresponding classical model is to be addressed to the localization of such excitations.

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