2023 IQIS

15th Italian Quantum Information Science Conference
18-22 September 2023, University of Trieste

Book of Posters

Schedule of poster sessions

Tuesday 19th September, 18:30 - 20:00

Omar Abdel Karim
Maria Gorizia Ammendola
Giuliano Angelone
Maurizio Artoni
Alessio Belfiglio
Alberto Bottarelli
Filippo Bregolin
Luca Brodoloni
Simone Cantori
Roberto Capecelatro
Isita Chatterjee
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Riccardo Cioli
Emanuele Costa
Giulio Crognaletti
Federico Dell'Anna
Pasquale Ercolano
Diego Forlivesi
Massimo Frigerio
Marco Giovanni Genoni
Farzad Ghafari
Luca Guariento
Gediminas Juska
Emre Köse
Aritra Kundu

Thursday 21st September, 18:30 - 20:00

Federico Amato
Jacopo Angeletti
Tony John George Apollaro
Edoardo Ballini
Ciro Bruscino
Chiara Capecci
Gabriele Cenedese
Francesco Cesa
Giuliano Chiriacò
Carola Ciaramelletti
Luca Colavecchi
Ricardo Costa De Almeida
Giovanni Di Fresco
Sandro Donadi
Beatrice Donelli
Lucia Duca
Rocco Duquennoy
Ramin Emadi
Davide Ferrari
Gianluca Francica
Giulia Guarda
Luca Innocenti
Emma King
Seid Koudia
Theerthagiri Lakshmanan

Anna Levochkina
Lorenzo Maccone
Stefano Martina
Pasquale Mastrovito
Daniele Morrone
Matteo Paris
Jacopo Pelini
Marcel Augusto Pinto
Leonardo Ratini
Federico Roccati
Andrea Santoni
Lukas Scarfe
Giuseppe Scriva
Xuejian Sun
Diana Tartaglia
Alex Ungar
Paolo Villoresi
Gennaro Zanfardino

Emilio Macaluso
Marco Malitesta
Francesco Marzioni
Matteo Mezzadri
Faezeh Mousavi
Dilip Paneru
Vincenzo Parisi
Marco Pinel
Niccolò Preti
Domenico Ribezzo
Paola Savarese
Carlo Schiano
Andrew Stasiuk
Alessia Suprano
Simone Tibaldi
Lorenzo Valentini
Mara Vizzuso
Danilo Zia

Abstracts of Posters

Omar Abdel Karim

University of Napoli

A new quantum simulation platform based on ytterbium atoms trapped in hybrid tweezer-lattice potentials

Abstract: Neutral atoms trapped in an array of individual optical tweezer microtraps have emerged as a promising platform for quantum science. Optical tweezer microtraps enable the manipulation, control, and detection at the single-atom level. Furthermore, the dynamic rearrangement of tweezer traps allows the generation of large-scale defect-free atom arrays in many geometry configurations. Here, we present the construction of a new ytterbium experiment capable of realizing one-dimensional (1D) and two-dimensional (2D) system of atomic arrays both in optical tweezer arrays and in optical lattices. This allows to combine the precise control provided by tweezers and the versatility provided by optical lattices in a system where it's possible to directly implant reordered arrays in optical lattice traps. Our experimental setup utilizes a high numerical aperture microscope objective, enabling both the tuning of atom trapping within the array and the high resolution imaging of atoms. This, together with the ytterbium atom's wide range of spectral lines, opens up the study of complex quantum phenomena and new avenues for exploring quantum information processing.

Federico Amato

University of Palermo

Phaseonium-Driven Dynamics and Entanglement of Cascaded Systems of Harmonic OscillatorsPhaseonium-Driven Dynamics and Entanglement of Cascaded Systems of Harmonic Oscillators

Abstract: We study the dynamics of a pair of harmonic oscillators interacting with a thermally excited beam of phaseonium atoms. The two subsystems are arranged in a cascaded configuration so that the second one interacts with phaseonium atoms, which act as ancillas, only after their interaction with the first subsystem. We present exact closed dynamics of the first subsystem for arbitrarily long interaction times. Also, we show how the second subsystem follows a non-Markovian evolution due to interactions with the "used" ancillary atoms, that enable entanglement with the first oscillator. We track the evolution of the system by measuring both the entanglement created between the subsystems and the mutual information shared by them. We finally highlight the role played by the characteristic coherence phase of phaseonium atoms in determining the steady states of the first subsystem alone as well as that of the ancillas.

Maria Gorizia Ammendola

University of Napoli

Photonic 2D quantum walk via complex polarization transformations

Abstract: Photonic simulators are controllable optical systems where light flow can be engineered so as to mimic the evolution of other physical systems, both in classical and quantum regimes. In particular, for digital quantum applications, there is a great effort to engineer reconfigurable platforms where a large number of optical modes are unitarily mixed in an accurate way, keeping at the same time losses at minimum values. This work aims to tackle some of these challenges by developing a minimal optical circuit based on spin-orbit photonics. Here we report a proof-of-concept experiment for the simulation of up to 10 steps of a synthetic 2-dimensional quantum walk dynamics, which couples one mode at the entrance of the walk with hundreds of output modes. This is achieved via periodic space-dependent polarization transformations on a light beam, or equivalently a stream of photons. Light propagation through these devices couples spatial modes of light having circular polarization and carrying a quantized amount of transverse momentum. Building on these results, we plan to leverage this technology to simulate more complex and large-scale unitary evolutions, eventually testing our platform with quantum states of light.

Jacopo Angeletti

University of Napoli

Microwave Quantum Illumination with Correlation-To-Displacement Conversion

Abstract: Entanglement is vulnerable to degradation in a noisy sensing scenario, but surprisingly, the quantum illumination protocol has demonstrated that its advantage can survive. However, designing a measurement system that realizes this advantage is challenging since the information is hidden in the weak correlation embedded in the noise at the receiver side. Recent progress in a correlation-to-displacement conversion module provides a route towards an optimal protocol for practical microwave quantum illumination. In this work, we extend the conversion module to accommodate experimental imperfections that are ubiquitous in microwave systems. To mitigate loss, we propose amplification of the return signals. In the case of ideal amplification, the entire six-decibel error-exponent advantage in target detection error can be maintained. However, in the case of noisy amplification, this advantage is reduced to three-decibel. We analyze the quantum advantage under different scenarios with a Kennedy receiver in the final measurement. In the ideal case, the performance still achieves the optimal one over a fairly large range with only on-off detection. Empowered by photon number resolving detectors, the performance is further improved and also analyzed in terms of receiver operating characteristic curves. Our findings pave the way for the development of practical microwave quantum illumination systems.

Giuliano Angelone

University of Bari

Classical echoes of quantum boundary conditions

Abstract: In this talk I will discuss the classical limit of a quantum particle in a ring with a junction, describing the behavior of the Wigner function for the eigenfunctions of the kinetic-energy operator with arbitrary self-adjoint boundary conditions. In particular, by analyzing this system in the high-energy regime, we find that the quantum boundary conditions can be divided in two classes, which we denote as regular and singular. As it turns out, while the Wigner functions for regular boundary conditions all collapse to the same classical probability distribution, the Wigner functions for singular boundary conditions show a residual dependence on the boundary conditions even in the classical limit.

Tony John George Apollaro

University of Malta

Thermal state preparation via a quantum variational algorithm

Abstract: An important task in quantum state preparation on a quantum computer is the preparation of finite-temperature thermal states of a given Hamiltonian These finite-temperature thermal states, known as Gibbs states, are relevant for a variety of tasks, from quantum simulation and quantum machine learning to quantum optimization and quantum thermodynamics. In this talk, a concise overview of the algorithms aiming at preparing Gibbs states will be presented, including joint system-environment Hamiltonian evolution, quantum imaginary time evolution, and variational quantum algorithms (VQA) adopting the Helmholtz free energy as a cost function. Belonging to the latter class, a VQA for the preparation of Gibbs states of the quantum Ising model based on the exact evaluation of the free energy will be presented [1]. We show that the proposed algorithm performs with fidelity higher than 90% for 3 qubits in a large range of temperatures on currently available quantum computers.

[1] Consiglio et al., Variational Gibbs State Preparation on NISQ devices, arXiv:2303.11276

Maurizio Artoni

University of Brescia

Synthetic Giant Atoms & Optical Waveguides

Abstract: Giant atoms are attracting interest as an emerging paradigm in the quantum optics of engineered waveguides. At variance with well known artificial giant atoms for microwave photonics, we'll discuss the basics of a giant-atom working in the optical regime. Our archetype is based on a driven pair of interacting Rydberg atoms coupled to an optical photonic crystal waveguide. Giant-atom effects and a nontrivial internal entanglement are observed respectively during the earlier and the later part of the atomic pair's evolution. Our predictions should be observable in current Rydberg photonic crystals waveguides experiments and may open the way toward giant-atom optical photonics for quantum information processing.

Edoardo Ballini

University of Trento

Thermal averages of non-Abelian D_4 Lattice Gauge Theories via Quantum Metropolis Sampling

Abstract: The future use of fault-tolerant Quantum Computers in the "Beyond the NIQS era" is one of the most important goals of quantum technologies: among other applications, for the study of High Energy Physics, it could open to the implementation of Markov Chain Monte Carlo quantum algorithms on real machines. This would allow to study thermodynamic properties of systems plagued by the infamous sign problem, which prevents classical Monte Carlo simulations from being applied to several interesting systems - such as the QCD in the presence of an external electric field or a finite chemical potential. In this work, we discuss the application of Quantum Metropolis Sampling to non-Abelian gauge theory based on the discrete D_4 simmetry group.

This is the first study of a non-Abelian Lattice Gauge Theory by means of a quantum MCMC algorithm: we simulate the behavior of an ideal quantum Computer, aiming to demonstrate the feasibility and the effectiveness of such simulations.

Alessio Belfiglio

University of Camerino

Inflationary entanglement

Abstract: We investigate the entanglement due to geometric corrections in particle creation during inflation. To do so, we propose a single-field inflationary scenario, nonminimally coupled to the scalar curvature of spacetime. We require particle production to be purely geometric, setting to zero the Bogolubov coefficients and computing the S matrix associated to spacetime perturbations, which are traced back to inflaton fluctuations. The corresponding particle density leads to a nonzero entanglement entropy whose effects are investigated at primordial time of Universe evolution. The possibility of modelling our particle candidate in terms of dark matter is discussed. The classical back-reaction of inhomogeneities on the homogeneous dynamical background degrees of freedom is also studied and quantified in the slow-roll regime.

Alberto Bottarelli

University of Trento

Solving the Electric Vehicle Charging and Routing Problem with qudit quantum computation

Abstract: We show how to exploit qudits for the construction of algorithms for constrained quantum optimization. In particular we define a hybrid classical quantum heuristic strategy that allows to sample constrained solutions while greatly reducing the search space of the problem, optimizing the use of quantum resources. As an example, we focus on the Electric Vehicle Charging and Routing Problem. We define the classical problem, map it into a quantum system and test our proposed methods on a toy example.

Filippo Bregolin

TOPTICA Photonics AG Munich

Transportable industrial ultra-stable laser with instability of 6E-16 at 1 s for quantum computing and quantum sensing

Abstract: Quantum computers and sensors based on cold neutral atoms and ions are enabling a new quantum revolution. Industrial partners are asked to provide industrial-proof components with robust design, enabling compactness, integration, and hands-off operation without compromising on the performance. Ultra-stable lasers based on high-finesse Fabry-Pérot cavities are key components in cold-atoms quantum technologies because of their long coherence time, which anables addressing clock transitions and perform multi-gate operations. Here we present and discuss the TOPTICA ultra-stable laser system, based on a room-temperature 10-cm-long high-finesse cavity. The cavity suspension system allows for a reliable transportability of the system in vacuum. The external-cavity diode-laser source is provided with an intra-cavity EOM to enable a faster locking bandwidth of 4 MHz to suppress the laser noise at large offset frequencies from the carrier. The performance of the laser is quantified by simultaneous comparison with two other reference ultra-stable lasers. The system fractional instability shows white frequency noise up to an integration time of 0.1 s and a flicker floor below 6E-16 @ 1 s (linear drift removed). This frequency stability, together with its industrial grade and integration with the TOPTICA products, makes this laser suitable in quantum simulators, QKD networks and optical clocks.

Luca Brodoloni

University of Camerino

Neural Monte Carlo simulations of quantum spin glasses

Abstract: Simulating the low-temperature properties of disordered quantum Ising models is a paradigmatic problem in condensed matter physics, and it has recently gained strong interest in the context of quantum-enhanced optimization performed via quantum annealers. We use a recently-developed selflearning projective quantum Monte Carlo algorithm [1], which is driven by neural-networks states, to simulate mean-field as well as short-range quantum spin glasses [2]. Our results show that, if the number of hidden neurons is not minuscule, this technique provides unbiased estimates of ground-state properties, especially the spin-glass susceptibility, accessing regimes and system sizes not accessible so far, in particular the quantum spin-glass phase of the Edward-Anderson (ED) model. We discuss preliminary explorations of the quantum critical point of the Sherrington-Kirkpatrick and the ED model. Our findings indicate a promising route to explore replica symmetry breaking in short-range quantum spin glasses.

[1] S. Pilati, E. M. Inack, and P. Pieri. Self-learning projective quantum monte carlo simulations guided by restricted boltzmann machines. Phys. Rev. E, 100:043301, Oct 2019.

[2] Giuseppe Scriva, Emanuele Costa, Benjamin McNaughton, and Sebastiano Pilati. Accelerating equilibrium spin-glass simulations using quantum annealers via generative deep learning. SciPost Phys., 15:018, 2023.

Ciro Bruscino

University of Napoli

Single photon sources g2(0) reduction by means of Photon Number Resolving detectors

Abstract: Quantum Key Distribution (QKD) relies significantly on Single Photon Sources (SPSs) to generate secure information, processed through various protocols [1]. Despite rapid advances in SPS technology, achieving the ideal case where only a single photon is emitted with high efficiency remains a theoretical model [2]. As a result, photon sources with multiphoton components, such as lasers or Spontaneous Parametric Down Conversion (SPDC) sources, are often utilized in QKD, posing potential security risks from eavesdroppers [1]. Therefore, it becomes crucial to characterize the photon number distribution provided by SPSs to mitigate the impact of multiphoton components on communication security.

To enhance the security of key exchange, Photon Number Resolving Detectors (PNRDs) can be employed, particularly with sources like SPDC, to reduce the multiphoton contribution [3]. This work aims to study the reduction of multiphoton effects by estimating the second-order cross-correlation function, g2(0), for signal photons from an SPDC source using a PNR detector. The detector is modeled based on the approach in [4] and implemented on the idler path, enabling analysis at different efficiencies.

[1] Xu, F., Ma, X., Zhang, Q., Lo, H. K., & Pan, J. W. Secure quantum key distribution with realistic devices. Reviews of Modern Physics, 92(2), 025002. (2020).

https://doi.org/10.1103/RevModPhys.92.025002

[2] Somaschi, Niccolo, et al. "Near-optimal single-photon sources in the solid state." Nature Photonics 10.5 (2016): 340-345.

https://doi.org/10.1038/nphoton.2016.23

[3] S.Sempere-Llagostera, G.S. Thekkadath, R.B. Patel, W.S. Kolthammer and I.A. Walmsley. Reducing g2(0) of a parametric down-conversion source via photon-number resolution with superconducting nanowire detectors. Optic Express, Vol. 30, No. 2, pp. 3138-3147 (2022).

10.1364/OE.450172

[4] M. J. Fitch, B. C. Jacobs, T. B. Pittman and J. D. Franson. Photon number resolution using time-multiplexed single-photon detectors. Physical Review A 68.4: 043814. (2003).

https://doi.org/10.1103/PhysRevA.68.043814

Simone Cantori

University of Camerino

Supervised learning of random quantum circuits via scalable neural networks

Abstract: Classical simulations of quantum algorithms play a pivotal role in the development of quantum computing devices. In this study, we investigate the supervised learning of output expectation values of random quantum circuits. Multilayer perceptrons (MLPs), convolutional neural networks (CNNs) and long short-term memory network (LSTMs) are trained to predict single-qubit and two-qubit expectation values using databases of classically simulated circuits. These circuits are built using rotation gates plus entangling gates. Notably, our CNNs and LSTMs are designed to be scalable, allowing us to understand in which regime supervised learning techniques can perform extrapolations to circuits larger than those included in the training set [1,2].

[1] S. Cantori, D. Vitali and S. Pilati, 2023, Quantum Sci. Technol. 8 025022

[2] N. Saraceni, S. Cantori, and S. Pilati, 2020, Phys. Rev. E 102, 033301

Chiara Capecci

University of L'Aquila

Compactness of quantum mutual information in the natural orbital basis set

Abstract: Electron correlation in quantum chemistry theories is nicely described in the natural orbitals basis set [1], obtained by diagonalizing the one-particle reduced density matrix of the ground state in the commonly used Hartree-Fock basis.

In the context of quantum computing calculations, the quantum mutual information matrix[2] built on natural orbitals is highly compact: correlation information is encoded using a small number of qubit pairs. This compactness points out the ability of the natural orbitals to serve as an optimal basis for electron correlation description.

Considering some reference molecules, the achievement of natural orbitals compact encoding is made possible by employing the Wavefunction-Adapted Hamiltonian Through Orbital Rotation (WAHTOR) method [3,4], which significantly reduces the circuit depth required for correlated heuristic ansatz in quantum computing. Moreover, in the natural orbital basis set, the lowest variational energies can be achieved.

[1] E. R. Davidson, Rev. Mod. Phys., vol. 44, pp. 451-464, jul 1972.

[2] N. V. Tkachenko, et al. PRX Quantum, vol. 2, no. 2, p. 1, 2021.

[3] L. Ratini, C. Capecci, F. Benfenati, and L. Guidoni, J. Chem. Theory Comput., vol. 18, no. 2, pp. 899–909, 2022.

[4] L. Ratini, C. Capecci, and L. Guidoni, 2023.

Roberto Capecelatro

University of Napoli

Andreev spin-noise detector

Abstract: We investigate the possibility to employ magnetic Josephson junctions as spin-noise detectors. Spin noise spectroscopy plays a fundamental role for detecting electron-spin dynamics in semiconductor heterostructures as well as in spin glasses and superconductors, both with optical techniques and by the means of SQUID-based magnetometry. We propose to probe the microscopic properties of spin noise sources from Josephson current noise measurements and from the knowledge of the detector equilibrium transport properties. To illustrate our idea, we consider a system consisting of a quantum dot coupled to superconducting leads in the presence of an external magnetic field. We present a detailed study of the microscopic mechanisms underlying the cur rent noise response in the quantum dot Josephson junctions with the aim of exploiting the magnetic field dependence of Andreev tunneling to detect spin noise. Under appropriate assumptions, we relate the noise in the Josephson current to magnetization noise. At the magnetic field driven 0 - \pi transition the junction sensitivity as magnetic noise detector is strongly enhanced and it diverges in the zero temperature limit. The fingerprint of this phenomenon is the presence of jump-discontinuities in the junction current phase relation. We show that, in the optimal working conditions, our detector results much more sensitive to spin rather charge noise, with only the magnetic noise channel contributing to Josephson current noise, and it also is immune to the detrimental effect of quasiparticles on magnetic noise amplification. Temperature behavior of the QD JJ promises even improved performances when operating in the low temperature limit.

Gabriele Cenedese

University of Insubria

Targeting quantum many-body scars with shallow variational quantum circuits

Abstract: Variational Quantum Algorithms (VQAs) have gained significant attention as an effective approach to achieve quantum advantage on NISQ (Noisy Intermediate-Scale Quantum) devices. By utilizing shallow quantum circuits, VQAs offer a versatile framework for solving diverse problems while mitigating noise. One prominent VQA is the variational quantum eigensolver (VQE), a hybrid algorithm that combines classical and quantum computing to determine the ground state of a given physical system.

The success of VQE extends to various domains, including quantum chemistry, many-body physics, and lattice gauge theories. Furthermore, its adaptability enables the exploration of excited states within quantum systems. In this research poster, we present a novel application of VQE: the identification of quantum many-body scar states. These eigenstates, found in non-integrable many-body systems, exhibit distinct entanglement characteristics, such as area-law entanglement entropies. This unique property suggests that these states can be efficiently prepared using shallow quantum circuits.

The proposed methodology can be adapted to a wide range of models, providing valuable insights for practitioners of VQAs.

Francesco Cesa

University of Trieste

Universal Quantum Computation in Globally Driven Rydberg Atom Arrays

Abstract: We develop a model for quantum computation which only relies on global driving, without the need of local addressing of the qubits. Our scheme is based on dual-species processors, and we present it in the framework of neutral atoms subjected to Rydberg blockade constraints. A circuit is imprinted in the (static) trap positions of the atoms, and the algorithm is executed by a sequence of global, resonant laser pulses; we show that this model for quantum computation is universal and scalable.

Reference: arXiv:2305.19220.

Isita Chatterjee

University of Napoli

Noise characterization of Travelling Wave Parametric Amplifier using a Shot Noise Tunnel Junction

Abstract: Travelling wave parametric amplifiers(TWPAs) are superconducting non-linear transmission lines that in presence of a strong pump can provide parametric amplification of a weak microwave signal [1]. The amplification is mediated by a wave-mixing non-linear process between the pump, the signal and a third mode dubbed idler. TWPAs are very useful devices in many areas of quantum technologies since they can provide broadband microwave gain with an added noise potentially as low as the quantum limit. In order to characterize the added noise of TWPAs, a calibrated noise source is needed. In this poster, I will first present the most common experimental methods to calibrate the added noise of a TWPA device using different noise sources, discussing advantages and disadvantages. In particular, I will briefly describe the use of a thermal load, a superconducting qubit and a shot noise tunnel junction (SNTJ) as calibrated noise sources. I will then focus in more detail on the use of an SNTJ, which is the noise source that we decided to adopt in our Lab. The latter is an Al-AlOx-Al tunnel junction cooled down to 10 mk and operated in the non-superconducting state using a local permanent magnet [2]. The voltage dependent electrical noise of the SNTJ can be used for the calibration of TWPA added noise, with the advantage of being broadband and fast compared to the other methods. Finally, I will describe in detail the experimental setup that we are commissioning in our Lab to perform the added noise calibration of a specific TWPA device, ”reversed Kerr TWPA” [3] and briefly present the perspective of investigating correlations between added noise and spurious non-linear processes in such device.

[1] Martina Esposito, Arpit Ranadive, Luca Planat, and Nicolas Roch. Perspective on traveling wave microwave parametric amplifiers. Applied Physics Letters, 119(12):120501, 2021.

[2] Lafe Spietz, KW Lehnert, I Siddiqi, and RJ Schoelkopf. Primary electronic thermometry using the shot noise of a tunnel junction. Science, 300(5627):1929, 2003.

[3] Arpit Ranadive, Martina Esposito, Luca Planat, Edgar Bonet, C´ecile Naud, Olivier Buisson, Wiebke Guichard, and Nicolas Roch. Kerr reversal in josephson meta-material and traveling wave parametric amplification. Nature Communications, 13(1):1737, 2022.

Giuliano Chiriacò

University of Catania

Entanglement dynamics and transition in non-Markovian systems

Abstract: In the last few years there has been great interest in the dynamics of quantum many-body systems. The interplay between unitary evolution and dissipative dynamics leads to many effects, including measurement induced phase transitions in the entanglement. While earlier works all considered Markovian dissipative processes, lately there has been growing interest in non-Markovian dissipation and the effect of memory on entanglement transitions. I will present recent results and developments on the study of entanglement in non-Markovian systems, including the simulation of memory effects in ladder models and a new formulation of a quantum jumps description of the dynamics.

Mario Chizzini

University of Parma

E Qudit-based Quantum Simulation of Fermionic Systems

Abstract: The quantum simulation of Hubbard-like Hamiltonians remains a challenging problem with interesting applications in solid state physics and chemistry. However, the capabilities of today's NISQ devices are limited and do not allow solving relevant cases. The practical limitation stems from the deep sequence on two-body gates required to implement the time evolution. A promising strategy to reduce the complexity of the circuits and thus come closer to solving currently intractable problems is the use of a qudit-based architecture. Indeed, qudits have the potential to store and process more information per unit, which naturally reduces the number of two-body gates and circuit depth. We have extended the recently proposed Auxiliary Fermion Method for a qudit mapping and analyzed the resource requirements and gate-decomposition costs to demonstrate the potential of this approach. Thanks to their intrinsic multi-level structure, easy chemical engineering and high degree of control, molecular nanomagnets are a promising candidate for the physical realization of qudits and through numerical simulations, we have shown how is possible to efficiently implement a Hubbard model. Comparing this approach with standard qubit algorithms we have found a notable reduction of the number of two-body gates and hence of circuit depth.

Carola Ciaramelletti

University of L'Aquila

VQE algorithm for topological one-dimentional many-body systems

Abstract: Among the many applications of quantum computation, there is the possibility to study more efficiently many-body systems and their properties. Here we focus on systems that exhibit topological behavior, which that have attracted great attention in contemporary condensed matter physics due to their theoretical interest and technological potentiality. The aim of this work is the study of Su-Schrieffer-Heeger (SSH) and Kitaev models, which are the simplest model showing topological behavior, with the use of VQE algorithm, to identify the topological phases of the systems. The focus of this work is to implement adapted cost functions for the VQE algorithm by utilizing intrinsic properties of topological systems, to study the convergence to the state of minimum energy with high fidelity in topologically nontrivial phase, where the ground state of these systems is degenerate due the presence of localized zero-energy edge states. This work is intended as starting point for the investigation of nontrivial interacting systems by quantum computers.

Riccardo Cioli

University of Bologna

Digital quantum simulation of the nonequilibrium dynamics of the Lattice Schwinger Model in a noisy environment

Abstract: We propose the implementation of a digital quantum simulation to study the nonequilibrium dynamics of the (1+1)-d Lattice Schwinger Model with discrete gauge group Z3, both on a Rydberg-atom simulator and IBM simulators and devices. We prepare the system in the ground state of the Hamiltonian with given initial parameters, then study the time evolution after a quench to different parameters. The simulations involve lattices with periodic boundary conditions, with staggered fermions located on the sites and gauge degrees of freedom located on the links that connect them. We classically perform a reduction of the number of qubits required for the simulations by pre-selecting the physical Hilbert space encoding only the configurations that satisfy Gauss' law at each site and, moreover, by using symmetries of the model to only encode the subspace associated with the conserved charges of the initial state. Different error-mitigation techniques were adopted for the execution on IBM devices.

Luca Colavecchi

Tyndall National Institute Cork

Coupling novel GaAs site-controlled QDs

Abstract: Coupled dots are promising candidates for cluster state generation. We discuss a first study of coupled site-controlled pyramidal GaAs in AlAs quantum dots (CQDs) using polarization, time resolved photoluminescence and correlation spectroscopy: two GaAs QDs 1.3nm nominally thick are stacked one on top of the other separated by a 10nm nominally thick AlAs spacer in AlAs barriers. We show a relevant pattern reproducibility of the excitonic transitions among different dots of the same sample and a narrow energy distributions of the spectral features. Two groups of peaks separated by ~20meV are seen: an efficient population of higher energy group peaks demonstrates either unusually strong bottleneck of carrier relaxation from the excited states, or presence of a very different energetic structure in comparison to single (S)QDs. Moreover, single-photon correlation measurements have been performed revealing, among separated peak families, either bunching behavior around zero delay for some peaks, clear sign of a recombination cascade, or a very slow anti-bunching curve for others, suggesting the absence of a population mechanism that links the two transitions. These results clearly demonstrate very different energetic structures and charge carrier dynamics within stacked QD structures in comparison to SQDs and other CQD systems.

Emanuele Costa

University of Camerino

Deep learning energy-density functionals for complex quantum systems

Abstract: Density functional theory (DFT) is routinely employed in material science and in quantum chemistry to simulate weakly correlated electronic systems. However, the known energy-density functionals often fail when applied to strongly correlated systems. Recently, deep learning (DL) techniques have been adopted to develop accurate functionals for the strongly correlated regime, but severe instability problems have emerged, and applications to quantum spin models are missing. Here, we first discuss how tailored neural-network architectures allow implementing DL orbital-free DFT theories, avoiding instability problems. A case study is presented, considering a model for one-dimensional ultracold atoms in optical speckle disorder. Next, we investigate DL-based DFTs for random quantum Ising chains, both with nearest-neighbor and up to next-nearest neighbor couplings. Our neural functionals are trained and tested on data produced via the Jordan-Wigner transformation, exact diagonalization, and tensor-network methods. Notably, our non-local functionals drastically improve upon the common local density approximations, and they are designed to be scalable, allowing us to simulate chain sizes much larger than those used for training. Our findings indicate a suitable strategy to extend the reach of other computational methods with a controllable accuracy. E. Costa, G. Scriva, R. Fazio, S. Pilati, Deep-learning density functionals for gradient descent optimization, Phys. Rev. E, 106(4), 045309 (2022) E. Costa, R. Fazio, S. Pilati, Deep learning non-local and scalable energy functionals for quantum Ising models, arXiv:2305.15370 (2023)

Ricardo Costa De Almeida

University of Trento

Multifractality as a signature of fermionic entanglement

Abstract: Entanglement is known to play an important role in the understanding of quantum many-body systems. Systems composed of indistinguishable particles are particularly interesting due to the subtleties introduced by particle statistics and how they affect the entanglement properties. In this presentation, I will show how the multifractality provides a tool for understanding the structure of mode entanglement in bosonic and fermionic quantum many-body systems. Moreover, I will demonstrate that it gives rise to a measure of interacting behavior in such systems, thus providing a rigorous relation between the presence of particle entanglement and strongly correlated phenomena. To showcase this approach, I will discuss numerical results obtained for the Fermi-Hubbard model and a variant of the Su–Schrieffer–Heeger model.

Giulio Crognaletti

University of Trieste

QResNet: a variational entanglement skipping algorithm

Abstract: Variational Quantum Algorithms (VQA) are among the most promising algorithms for near-term devices. Often referred to as hybrid quantum-classical algorithms, VQA employ parameterized quantum circuits as wave-function ansätze and classically store and optimize parameters. Despite their potential, problem agnostic, highly expressive ansätze lead to an exponentially hard optimization step, due to the barren plateau (BP) problem, nullifying all possible advantage. In this work we introduce QResNet, a general ansatz inspired by classical residual networks and show they are immune to BP for local cost functions, regardless of circuit depth. We associate this result to the ability of easily initializing QResNets to low-entanglement states and simultaneously skipping entangling layers during training. Finally, the architecture is tested in the case of ground state estimation for the ANNNI model.

Federico Dell'Anna

University of Bologna

Quantum Fisher Information and multipartite entanglement in spin-1 chains

Abstract: In this work, we study the Quantum Fisher Information in one-dimensional spin-1 models, as witness to Multipartite Entanglement, which can give valuable information about the topological phases. The models addressed are the Bilinear-Biquadratic model, the most general isotropic SU(2)-invariant spin-1 chain, and XXZ spin-1 chain, both with nearest-neighbor interactions and open boundary conditions. In this work we show that the scaling of the QFI of strictly non-local observables can be used for characterizing the phase diagrams and, in particular, it can be used for studying topological phases, where it scales maximally. Analysing its behavior at the critical phases we are also able to recover the scaling dimensions of the order parameters both for local and string observables. The numerical results have been obtained by exploiting Density Matrix Renormalization Group algorithm and Tensor Network techniques.

Giovanni Di Fresco

University of Palermo

Measurement-Induced Phase Transitions: Insights from Quantum Fisher Information Analysis

Abstract: The interplay between the deterministic quantum evolution and a series of measurement processes can cause an abrupt change in the entanglement properties of a system. This phenomenon is called a measurement-induced phase transition (MIPT). In various scenarios, Quantum Fisher information (QFI) is employed to gauge the sensitivity of a quantum system to slight variations in a parameter and is commonly used to identify quantum phase transitions. It is natural to ask if phase transitions driven by measurement processes can also be detected using QFI. The smoking gun signature of an MIPT is the abrupt changes in the entanglement properties of the system, usually detected through entanglement entropy. However, when employing an appropriate metrological approach, QFI not only detects entanglement but also provides more comprehensive information than entanglement entropy, highlighting the presence of useful metrological entanglement and multi-partite entanglement. We show that QFI can distinguish between different phases in an MIPT for a non-Hermitian one-dimensional Ising chain and demonstrate the presence of a QFI divergence at the critical point.

Sandro Donadi, Giovanni di Bartolomeo, Michele Vischi

Queen’s University Belfast & University of Trieste

A novel approach to noisy gates for simulating quantum computers

Abstract: We present a novel method for simulating the noisy behaviour of quantum computers, which allows to efficiently incorporate environmental effects in the driven evolution implementing the gates on the qubits. We show how to modify the noiseless gate executed by the computer to include any Markovian noise, hence resulting in what we will call a noisy gate. We compare our method with the IBM Qiskit simulator, and show that it follows more closely both the analytical solution of the Lindblad equation as well as the behaviour of a real quantum computer, where we ran algorithms involving up to 18 qubits; thus, it offers a more accurate simulator for NISQ devices. The method is flexible enough to potentially describe any noise, including non-Markovian ones.

Beatrice Donelli

University of Napoli, CNR-INO & LENS Firenze

Persistent currents in a superfluid atom ring with many obstacles

Abstract: Persistent currents in closed chains of Josephson junctions are at the forefront of research on quantum phase transitions and quantum circuitry. They provide a testing bed for exploring a variety of fundamental physical effects where macroscopic phase coherence and dissipative mechanisms compete. Here, we engineer atomic supercurrents in an annular Josephson junction array in the limit of strong coupling. We study the stability diagram of the atomic flow by tuning both initial circulation and number of tunneling barriers. We find that the atomic circuit can support higher critical currents by increasing the number of Josephson links, whereas dissipation occurs via phase-slippage processes with the emission of quantized vortices. We identify the connection between critical Josephson current and superfluid fraction by applying the Leggett criterion to our geometry. We compare the experimental results and numerical simulations, finding an excellent agreement. Our results demonstrate atomic superfluids in mesoscopic structured ring potentials as excellent candidates for atomtronics applications, with prospects towards the observation of non-trivial macroscopic superposition of current states.

Lucia Duca

INRIM & LENS Firenze

Towards the realization of a charged rotor in trapped ion crystals

Abstract: Coherent control of the collective motion of trapped ion Coulomb crystals is fundamental to the use of this platform for quantum simulations. Historically, ions have been trapped in a linear chain and the motional modes of the harmonic oscillator have been used for quantum computation. However, motional modes with richer dynamics can increase the complexity available in Hamiltonian engineering and also develop new ways of implementing entanglement between particles. In a quantum rotor, for example, the energy spectrum of the angular momentum eigenstates is quadratic in quantum number, like for the rotation of molecules. This would enable a precise preparation of target rotational states, and superpositions of, to be used for entanglement, quantum simulations and sensing. Here, we describe our planar ion trap, which allows for imprinting a well defined angular momentum, and the current status on the coherent preparation of rotational states of two or more ions.

Rocco Duquennoy

University of Napoli, CNR-INO

Understanding stark shifts for two-emitter quantum interference improvements

Abstract: Hong-Ou-Mandel interference of photons represents a key element of photonic based quantum protocols. It is indeed possible to create photons with a good degree of indistinguishability from single organic dibenzoterrylene (DBT) molecules. However complex quantum protocols require a number of photons that cannot be achieved via demultiplexing the photon flux from a single emitter, thus requiring indistinguishable photons from different sources. We here report on experimental results on two-photon interference with photons from distinct molecular emitters in pulsed excitation, with an integrated visibility of (40+-7)%. We also show the limitations of our system as it is right now and present possible future improvements. In particular we show preliminary experimental results on the combination of two ways to implement stark shifts that, when combined, could reduce the residual spectral fluctuations of our emitters, the main source of photon distinguishability in our current experiment.

Ramin Emadi

University of Napoli

Single Organic Molecules in Integrated Optical Cavities and Waveguides for Quantum Technologies

Abstract: Quantum technologies have shown promising potential for advancements in computing, communication, and sensing. This research focuses on the utilization of single organic molecules integrated into optical cavities and waveguides as quantum emitters. The integration offers benefits such as improved light-matter interactions, efficient photon collection, and scalability. The study primarily considers dibenzoterrylene molecules in anthracene crystals (DBT:Ac) as single photon sources due to their bright and stable single-photon emission in the near-infrared and narrow zero-phonon line transition at cryogenic temperatures. These properties make them suitable for various quantum applications. The research explores two types of optical cavities: inorganic ring and disk resonators based on SiN, fabricated using electron beam lithography, and an organic ring resonator created with a direct laser writing system. Simulation results suggest that these cavities effectively confine photons, facilitating robust light-matter interactions. By incorporating single DBT:Ac molecules into these cavities, the photon emission rates can be significantly enhanced, and spontaneous emission characteristics can be modified. This enhanced interaction enables precise control over quantum states and enables novel quantum operations. Waveguides are essential for guiding and manipulating photons in quantum circuits. By integrating single organic molecules into waveguides, efficient photon collection and improved light-matter interaction along the propagation path can be achieved. This integration enables the development of on-chip quantum devices with enhanced photon extraction efficiencies, leading to higher-fidelity quantum measurements and improved performance in quantum information processing tasks. Overall, the research aims to harness the unique properties of single organic molecules within optical cavities and waveguides to advance quantum technologies.

Pasquale Ercolano

University of Napoli

Superconducting PNR detector for photon sources characterization

Abstract: Photon number resolving (PNR) detectors are essential tools for various fields, such as quantum optics, quantum communication and boson sampling. Indeed, they can reconstruct the distribution of the number of photons emitted by a source from the recorded counts [1]. However, many applications require photons at telecom wavelengths, which are not well detected by conventional silicon detectors. A promising alternative at these wavelengths are superconducting nanostrip photon detectors, which can be arranged in an array that can distinguish the number of incoming photons [2]. In this work, we use a PNR detector based on 8 NbN nanostrips working at 2.2 K. We model the response of the detector by a matrix and reconstruct the statistical distribution of the input photons from the measured counts, taking into account the detection efficiency and timing performance of the detector.

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Davide Ferrari

University of Parma

A Simulation Framework for Distributed Quantum Computing

Abstract: Current quantum processors are characterized by few hundreds of qubits with non-uniform quality and highly constrained physical connectivity. Hence, the increasing demand for large-scale quantum computers is pushing research on Distributed Quantum Computing (DQC) architectures as a scalable approach for increasing the number of available qubits for computational tasks. Recent experimental efforts have demonstrated some of the building blocks for such a design. Indeed, network and communications functionalities provided by the Quantum Internet allow remote quantum processing units (QPUs) to communicate and cooperate for executing computational tasks that each single device cannot handle by itself. Simulation plays a major role in this field. Many simulation tools have been recently developed to support the research community in the design and evaluation of quantum computing and quantum network technologies, including hardware, protocols, and applications. However, a framework for DQC simulation putting equal emphasis on computational and networking aspects has never been proposed, so far. In this talk, we illustrate a general simulation framework for DQC by means of a simulation example. Reference: https: arxiv.org\abs\2306.11539

Diego Forlivesi

University of Bologna

Logical Error Rates of XZZX and Rotated Quantum Surface Codes

Abstract: Surface codes are versatile quantum error-correcting codes known for their planar geometry, making them ideal for practical implementations. While the original proposal used Pauli X or Pauli Z operators in a square structure, these codes can be improved by rotating the lattice or incorporating a mix of generators in the XZZX variant. However, a comprehensive theoretical analysis of the logical error rate for these variants has been lacking. To address this gap, we present theoretical formulas based on recent advancements in understanding the weight distribution of stabilizer codes. Additionally, we observe a particular behavior regarding rectangular lattices in the presence of asymmetric channels. Our findings demonstrate that implementing both rotation and XZZX modifications simultaneously can lead to suboptimal performance. Thus, in scenarios involving a rectangular lattice, it is advisable to avoid using both modifications simultaneously. This research enhances our theoretical understanding of the logical error rates for XZZX and rotated surface codes, providing valuable insights into their performance under different conditions.

Gianluca Francica

University of Padova

Quasiprobability distribution of work in a quantum manybody system

Abstract: A complete understanding of the statistics of the work done by quenching a parameter of a quantum manybody system is still lacking in the presence of an initial quantum coherence in the energy basis. In this case, the work can be represented by a class of quasiprobability distributions. Here, we try to clarify the genuinely quantum features of the process by studying the work quasiprobability for an Ising model in a transverse field. We consider both a global and local quench by focusing mainly on the thermodynamic limit. We find that, while for a global quench there is a symmetric noncontextual representation, for a local quench we can get quantum contextuality as signaled by a negative fourth moment of the work. Furthermore, we examine the critical features related to a quantum phase transition and the role of the initial quantum coherence as a useful resource.

Massimo Frigerio

University of Milan

Swift chiral quantum walks

Abstract: Continuous-time quantum walks are a prominent tool to study quantum transport on discrete networks, interference and they can also be interpreted as models for universal quantum computation. A generalization of them involves new complex degrees of freedom entering as complex phases in the Hamiltonian, with a role reminding that of Aharonov-Bohm phases for charged particles in magnetic fields. We show how this degrees of freedom can be exploited to remove the sedentarity behavior burdening many standard quantum walks, achieving the fastest evolution from the starting vertex and the optimal quantum speed limit over a large class of Hamiltonians. The results have implications, among others, for Grover's search on graphs and for mathematical conjectures in graph theory.

Marco Giovanni Genoni

University of Milan

Daemonic ergotropy in continuously-monitored open quantum batteries

Abstract: The amount of work that can be extracted from a quantum system can be increased by exploiting the information obtained from a measurement performed on a correlated ancillary system. The concept of daemonic ergotropy has been introduced to properly describe and quantify this work extraction enhancement in the quantum regime. We here explore the application of this idea in the context of continuously-monitored open quantum systems, where information is gained by measuring the environment interacting with the energy-storing quantum device. We first show that the corresponding daemonic ergotropy takes values between the ergotropy and the energy of the corresponding unconditional state. The upper bound is achieved by assuming an initial pure state and a perfectly efficient projective measurement on the environment, independently of the kind of measurement performed. On the other hand, if the measurement is inefficient or the initial state is mixed, the daemonic ergotropy is generally dependent on the measurement strategy. This scenario is investigated via a paradigmatic example of an open quantum battery: a two-level atom driven by a classical field and whose spontaneously emitted photons are continuously monitored via either homodyne, heterodyne, or photo-detection.

Farzad Ghafari

Griffith University

Quantum steering with vector vortex states with the detection loophole closed

Abstract: Quantum nonlocality enables secure quantum information tasks like device-independent (DI) quantum communications. Steering (or Einstein-Podolsky-Rosen) nonlocality is a scenario where one party is in a secure location and another remote party is not [1], and is particularly useful for one-sided device-independent protocols. Rigorous nonlocality verification is crucial to minimize reliance on questionable assumptions and prevent eavesdropping, necessitating the closure of multiple loopholes. While strong loophole-free nonlocality has been demonstrated with polarized photons, exploring other photonic degrees of freedom remains limited. In our study [2], we achieve detection-loophole-free quantum steering using a vector vortex state encoding for one qubit. This encoding combines orbital angular momentum and polarization, offering advantages such as rotational invariance. Closing the detection loophole is challenging; it demands high photon transmission and detection efficiencies to rule out statistical corruption caused by cheating strategies disguised as loss [3]. Overcoming this hurdle, we achieve a throughput and detection efficiency of ~0.39-0.48, enabling loophole closure in the steering test. Our measured steering parameter exhibits an average violation of the inequality at a 15-standard-deviation level. Notably, encoding in a vortex state allows violations of the steering inequality across the entire rotation range, while rotation-sensitive polarization encoding quickly fails. This represents a significant step in applying physical encodings beyond conventional polarization qubits to demanding DI-type protocols.

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Giulia Guarda

European Laboratory for Non Linear Spectroscopy Firenze

Quantum key distribution with an integrated photonic receiver

Abstract: Photonic integrated circuits are essential for the deployment of quantum technologies. We demonstrated an efficient BB84 protocol based on an integrated photonic receiver. We showed better performances over a 42 dB channel loss link and 136% higher key rate at 10 dB compared to a fiber-based receiver.

Luca Guariento

University of Napoli

461 nm 3D MOT of Strontium atoms in a glass cell

Abstract: In my poster I will show the latest results obtained during my second PhD year in the Strontium Rydberg lab in Florence. I will introduce the experimental platform, focusing on the assembling of the vacuum system and the implementation of the optical setup for a three-dimensional MOT that is carried out in a glass cell that allows for a large optical access. I will show some measurements for the characterization of the cold atomic beam and the MOT cloud. Finally, I will point out the following steps towards the realization of the machine, giving some perspectives on future studies employing Rydberg atoms in optical tweezer arrays.

Luca Innocenti

University of Palermo

Shadow tomography on general measurement frames

Abstract: We provide a new perspective on shadow tomography by demonstrating its deep connections with the general theory of measurement frames. By showing that the formalism of measurement frames offers a natural framework for shadow tomography --- in which ``classical shadows'' correspond to unbiased estimators derived from a suitable dual frame associated with the given measurement --- we highlight the intrinsic connection between standard state tomography and shadow tomography. Such perspective allows us to examine the interplay between measurements, reconstructed observables, and the estimators used to process measurement outcomes, while paving the way to assess the influence of the input state and the dimension of the underlying space on estimation errors. Our approach generalizes the method described in [H.-Y. Huang et al., Nat. Phys. 16, 1050 (2020)], whose results are recovered in the special case of covariant measurement frames. As an application, we demonstrate that a sought-after target of shadow tomography can be achieved for the entire class of tight rank-1 measurement frames --- namely, that it is possible to accurately estimate a finite set of generic rank-1 bounded observables while avoiding the growth of the number of the required samples with the state dimension.

Gediminas Juska

Tyndall National Institute Cork

GaAs Site-controlled Pyramidal Quantum Dots as Spin Qubit Sources for a Photonic Cluster State Construction

Abstract: GaAs quantum dots (QDs) produced by droplet etching epitaxy have been recently making remarkable progress as state-of-the-art sources of single, indistinguishable, polarization-entangled photons, and also as a low-noise environment for single charge carriers. Herein we present the results of the endeavor to transfer these outstanding properties and advantages to GaAs QDs fabricated by a conceptually different approach – metalorganic vapor-phase epitaxy (MOVPE) growth on (111)B-oriented GaAs substrates pre-patterned by the micrometer-scale tetrahedron recesses. Within the bigger picture, this new generation of site-controlled QDs is being researched as a potential resource of photonic cluster states. We will present a comprehensive study of a typical GaAs QD energetic structure - a fingerprint of a general structural uniformity. A specific emphasis will be placed on states and methods to initialize the QD with a single charge carrier to be utilized as an entangler of the cluster state. We identified and investigated excited positively charged exciton (trion) states of near pure light-hole-like character. They were utilized to initialize QDs with well-defined hole states and to read out the spin state within the magnetic field for a coherent π\/2 rotation control.

Emma King

University of Saarlandes

Analysis of shortcuts to adiabaticity via reservoir engineering for two-level systems

Abstract: E. King, R. Menu, L. Giannelli, J. Kriel, G. Morigi. Inspired by the work of Menu et al. (Phys. Rev. Res. 4 (3), 033005), where a protocol for fast adiabatic transfer is engineered by coupling a qubit to a damped ancilla, we analyze shortcuts to adiabaticity in an open two-level system. The system dynamics is governed by a generic dephasing Lindblad master equation. This simple setting facilitates an investigation into the effect of different control schemes, as well as the loss of coherence induced by a dephasing reservoir, on achieving fast adiabatic transfer to a desired state. We observe that when the coherent dynamics evolves according to a linear schedule, the qubit-reservoir coupling tends to suppress undesirable diabatic transitions. In contrast, evolving the Hamiltonian according to an optimized schedule generally results in decoherence inducing unwanted transitions from the low energy branch of the system to the higher branch. Interestingly, we find that these transitions start being favorably suppressed in the limit of strong dephasing, which is confirmed by exact numeric results. This work paves the way for a deeper understanding into the impact of using different control schemes in noisy settings for adiabatic transfer.

Emre Köse

University of Tübingen

Super-Resolution Imaging with Multiparameter Quantum Metrology in Passive Remote Sensing

Abstract: We study super-resolution imaging theoretically using a distant n-mode interferometer in the microwave regime for passive remote sensing, used, e.g., for satellites like the "Soil Moisture and Ocean Salinity" (SMOS) mission to observe the surface of the Earth. We give a complete quantum-mechanical analysis of multiparameter estimation of the temperatures on the source plane. We find the optimal detection modes by combining incoming modes with an optimized unitary that enables the most informative measurement based on photon counting in the detection modes and saturates the quantum Cramér-Rao bound from the symmetric logarithmic derivative for the parameter set of temperatures. In our numerical analysis, we achieved a quantum-enhanced super-resolution by reconstructing an image using the maximum likelihood estimator with a pixel size of 3 km, which is ten times smaller than the spatial resolution of SMOS with comparable parameters. Further, we find the optimized unitary for uniform temperature distribution on the source plane, with the temperatures corresponding to the average temperatures of the image. Even though the corresponding unitary was not optimized for the specific image, it still gives a super-resolution compared to local measurement scenarios for the theoretically possible maximum number of measurements.

Seid Koudia

University of Napoli

Quantum Internet: an Efficient Stabilizer states Distribution Scheme

Abstract: Quantum networks constitutes a major part of quantum technologies. They will boost distributed quantum computing drastically by providing a scalable modular architecture of quantum chips, or by establishing an infrastructure for measurement based quantum computing. Moreover, they will provide the backbone of the future quantum internet, allowing for high margins of security. Interestingly, the advantages that the quantum networks would provide for communications, rely on entanglement distribution, which suffers from high latency in protocols based on Bell pair distribution and bipartite entanglement swapping. Moreover, the designed algorithms for multipartite entanglement routing suffer from intractability issues making them unsolvable exactly in polynomial time. In this paper, we investigate a new approach for graph states distribution in quantum networks relying inherently on local quantum coding --LQC-- isometries and on multipartite states transfer. Additionally, single-shot bounds for stabilizer states distribution are provided. Analogously to network coding, these bounds are shown to be achievable if appropriate isometries&stabilizer codes in relay nodes are chosen, which induces a lower latency entanglement distribution. As a matter of fact, the advantages of the protocol for different figures of merit of the network are provided.

Aritra Kundu

University of Luxembourg

Unveiling out-of-time-order correlators from stochastic operator variance in fluctuating Hamiltonians

Abstract: This study presents an analysis of the dynamics resulting from a fluctuating Hamiltonian. Our investigation explores an interesting concept: the stochastic variance of operators. We establish an interesting connection between the stochastic operator variance (SOV) and the out-of-time-order correlator (OTOC), a fundamental construct in the field of quantum chaos that defines a quantum Lyapunov exponent. We conduct a detailed examination using a stochastic Lipkin-Meshkov-Glick (sLMG) Hamiltonian undergoing energy dephasing to demonstrate our findings. Through this, we study the influence of noise on the stability region, providing insights into how it differs from the noiseless LMG model. The pivotal relationship between SOV and OTOC serves as a key element in unravelling the effects of noise on the stability region.

Theerthagiri Lakshmanan

University of Camerino

Spreading entanglement through pairwise exchange interactions

Abstract: The spread of entanglement is a problem of great interest. It is particularly relevant to quantum state synthesis, where an initial direct-product state is sought to be converted into a highly entangled target state. In devices based on pairwise exchange interactions, such a process can be carried out and optimized in various ways. As a benchmark problem, we consider the task of spreading one excitation among N two-level atoms or qubits. Starting from an initial state where one qubit is excited, we seek a target state where all qubits have the same excitation-amplitude -- a generalized-W state. This target is to be reached by suitably chosen pairwise exchange interactions. For example, we may have a setup where any pair of qubits can be brought into proximity for a controllable period of time. We describe three protocols that accomplish this task, each with N-1 tightly-constrained steps. In the first, one atom acts as a flying qubit that sequentially interacts with all others. In the second, qubits interact pairwise in sequential order. In these two cases, the required interaction times follow a pattern with an elegant geometric interpretation. They correspond to angles within the spiral of Theodorus -- a construction known for more than two millennia. The third protocol follows a divide-and-conquer approach -- dividing equally between two qubits at each step. For large N, the flying-qubit protocol yields a total interaction time that scales as \sqrt{N}, while the sequential approach scales linearly with N. For the divide-and-conquer approach, the time has a lower bound that scales as \ln N. With any such protocol, we show that the phase differences in the final state cannot be independently controlled. For instance, a W-state (where all phases are equal) cannot be generated by pairwise exchange.

Anna Levochkina

University of Napoli

Circuit disorder in reversed kerr travelling wave parametric amplifiers

Abstract: Quantum-limited microwave parametric amplifiers are widely used in quantum technologies for improving signal redout. There are many types of such amplifiers based on Josephson junction arrays. In this work, we report the results of experimental and numerical simulations of a Reversed Kerr Traveling Wave Parametric Amplifier (TWPA).

The Reversed Kerr TWPA is a non-linear device which consists of an array of repeating unit cells; each unit cell is a superconducting loop with three large (high critical current) and one small (low critical current) Josephson junctions (so-called SNAIL-cell - superconducting nonlinear asymmetric inductive element [1]). When the SNAILs are flux biased in the regime of so called ‘reversed Kerr’, the device can be operated as a large bandwidth (few GHz) parametric amplifier in the four-wave-mixing regime with optimal phase matching [2]. Namely, in presence of an intense input pump at frequency ωp and a weak input signal at frequency ωs, the output signal will be amplified and an idler tone at frequency ωi = 2ωp – ωs will be generated. However, in addition to the parametric amplification, other nonlinear processes, such as harmonics generation, can take place, possibly affecting the amplification performance.

Here we study signal amplification and harmonics generation for different values of magnetic flux applied to the SNAILs. We report a comparison between experimental results and transient circuit simulations [3, 4, 5], focusing on the effect of circuit inhomogeneity/disorder in the unit cells.

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Emilio Macaluso

University of Parma

Initialization, Manipulation and Readout of Molecular Qubits Exploiting Chirality-Induced Spin Selectivity

Abstract: Molecular spins hold great potential as fundamental units of future quantum technologies. Their remarkable chemical engineerability enables the targeted design of intricate structures tailored to specific applications. While their weak interaction with external stimuli grants long coherence times, it also poses a significant challenge to their practical implementation. In particular, crucial processes in quantum computing and quantum sensing, such as efficient initialization and readout of molecular qubits, require extremely low temperatures. To overcome this obstacle, we propose an innovative solution that leverages the Chirality-Induced Spin Selectivity (CISS) effect in photo-excited electron transfer processes. Our vision entails the realization of a molecular complex, where a molecular qubit is connected to a donor-chiral bridge-acceptor system. This configuration aims to convert spin information into charge information, which is more easily accessible in experiments. Through numerical simulations of spin and charge dynamics, we have demonstrated the feasibility of implementing qubit initialization, manipulation, and readout in such systems, even at relatively high temperatures. Furthermore, we have shown that the exceptional chemical engineerability of molecular spins enables the incorporation of multi-level spin qudits. These findings open up promising avenues for the practical implementation of molecular spins and CISS effect in quantum technologies.

Lorenzo Maccone

Univesity of Pavia

Geometric Event-Based Quantum Mechanics

Abstract: We propose a special relativistic framework for quantum fields or particles. It is based on introducing a Hilbert space for events. Quantum systems (e.g. particles) are seen as sequence of quantum events connected to a joint probability amplitude for position and time. Textbook relativistic quantum mechanics and quantum field theory can be recovered by dividing the event Hilbert spaces into space and time (the equivalent of a foliation in classical relativity) and then conditioning the event states onto the time part. Our theory satisfies the full Poincaré symmetry and possesses observables for space (position of an event) and time (position in time of an event). This poster is based on the paper V. Giovannetti, S. Lloyd, L. Maccone, Geometric Event-Based Quantum Mechanics, New J. Phys. 25, 023027 (2023)

Marco Malitesta

QSTAR, INO-CNR & LENS Firenze

Distributed Quantum Sensing with Squeezed-Vacuum Light in a Configurable Array of Mach-Zehnder Interferometers

Abstract: We study an entangled distributed quantum sensing scheme based on an array of Mach-Zehnder interferometers (MZIs) for the estimation of d relative phase shifts. The scheme uses d coherent states and a single squeezed-vacuum that is distributed among the MZIs by a quantum circuit (QC). The protocol can be optimized analytically and overcomes the shot-noise (SN) limit with respect to the average total number of particles used, $\bar{n}_T$, for the estimation of arbitrary linear combinations of the d phases. We also compare the entangled strategy with a separable one that uses d coherent and squeezed-vacuum states, and same $\bar{n}_T$. The entangled strategy benefits for a substantial reduction of resource overhead and can achieve a maximum gain equal to d when using the same total squeezed-light intensity. Interestingly, the entangled strategy using a single squeezed-vacuum state can reach the same sensitivity as the separable strategy that uses d copies of the same state. Viceversa, given a random choices of the QC, we identify the optimal linear combination of the phases that can be estimated with maximum sensitivity. Our scheme paves the ways to a variety of applications in distributed quantum sensing with photonic and atomic interferometers.

Stefano Martina

University of Firenze

Deep learning enhanced noise spectroscopy of a spin qubit environment

Abstract: The undesired interaction of a quantum system with its environment generally leads to a coherence decay of superposition states in time. A precise knowledge of the spectral content of the noise induced by the environment is crucial to protect qubit coherence and optimize its employment in quantum device applications. We experimentally show that the use of neural networks (NNs) can highly increase the accuracy of noise spectroscopy, by reconstructing the power spectral density that characterizes an ensemble of carbon impurities around a nitrogen-vacancy (NV) center in diamond. NNs are trained over spin coherence functions of the NV center subjected to different Carr–Purcell sequences, typically used for dynamical decoupling (DD). As a result, we determine that deep learning models can be more accurate than standard DD noise-spectroscopy techniques, by requiring at the same time a much smaller number of DD sequences.

Francesco Marzioni

University of Camerino

Amplitude and phase noise in two-membrane cavity optomechanics

Abstract: Cavity optomechanics is a suitable field to explore quantum effects on macroscopic objects and develop quantum technology applications. A perfect control of the laser noise is required to operate the system in such extreme conditions necessary to reach the quantum regime. In this work, we consider a Fabry–Perót cavity, driven by two laser fields, with two partially reflective SiN membranes inside it. We describe the effects of amplitude and phase noise on the laser introducing two additional noise terms in the Langevin equations of the system's dynamics. Experimentally, we add an artificial source of noise on the laser. We calibrate the intensity of the noise, inject it into the system, and check the validity of the theoretical model. This procedure provides an accurate description of the effects of a noisy laser in the optomechanical setup and allows for quantifying the amount of noise.

Pasquale Mastrovito

University of Napoli, CNR - SPIN & UOS Napoli

Digital non-demolition readout of superconducting qubits using a tunable phase detector

Abstract: In the last decade, the optimization and engineering of superconducting qubits brought significant technological advancements in their performance, leading to a continuous growth in the scale of quantum processors. However, this growth goes along with a proportional increase in the architecture size and the number of decoherence channels, making it crucial to find alternative schemes and platforms that can effectively scale to large-scale architectures [1].

Conventional approaches for the readout of superconducting qubits, involving heterodyne detection at room temperature, do not scale well with an increase in size and the number of connections.

We propose an alternative readout protocol based on a superconducting flux-tunable circuit named Josephson Digital Phase Detector (JDPD) [2]. We have characterized the system phase dynamics and its dependencies on external flux drives, demonstrating that the circuit can evaluate the phase of an input RF through a dynamic flux tuning of the system. Based on this capability, we propose a protocol for non-demolition readout of a superconducting qubit which can be performed through adequate flux tuning of the system. The readout result can be accessed in situ with a device inductively coupled to the JDPD, which significantly enhances the process speed as well as the scalability in large-scale architectures.

This feature also makes the readout protocol compatible with digital cryogenic technologies such as the Single Flux Quantum (SFQ) [3] one.

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Matteo Mezzadri

University of Parma

Fault tolerant qauntum computing against pure dephasing with qudit embedded quantum error correction

Abstract: Quantum computers are usually built upon a binary computing unit formed by a two-levels system, namely |0> and |1>. In the last few years an alternative approach at building quantum computers has garnered a lot of attentions: the use of d-levels systems, called qudits, as the building blocks. This new approach can bring lots of advantages over the more standard qubit based one. In particular, with the use of qudits we have new opportunities for Error Correction. There is a quite new approach that consists in the encoding of a logical qubit in the d-levels of a single qudit. I will present a scheme for the embedding of error correction into single a qudit. Furthermore, I will show a possible strategy to implement such a scheme (logical gates, error detection and correction) in a Fault Tolerant way, highlighting the requirements that the physical system constituting the qudit must have. As last I will do an analysis of the performance of the code implemented on Molecular Nanomagnets qudits showing the great advantages that Embedded QEC bring over standard qubit based approaches.

Daniele Morrone

University of Milan

Charging a quantum battery in a non-Markovian environment: a collisional model approach

Abstract: We study the effect of non-Markovianity in the charging process of an open-system quantum battery. We employ a collisional model framework, where the environment is described by a discrete set of ancillary systems and memory effects in the dynamics can be introduced by allowing these ancillas to interact. We study in detail the behaviour of the steady-state ergotropy and the impact of the information backflow to the system on the different features characterizing the charging process. Remarkably, we find that there is a maximum value of the ergotropy achievable: this value can be obtained either in the presence of memoryless environment, but only in the large-loss limit, as derived in (Farina et al 2019 Phys. Rev. B 99 035421), or in the presence of an environment with memory also beyond the large-loss limit. In general, we show that the presence of an environment with memory allows us to generate steady-state ergotropy near to its maximum value for a much larger region in the parameter space and thus potentially in a shorter time. DOI to related paper: 10.1088\/2058-9565\/accca4

Faezeh Mousavi

University of Trieste

Practical quantum secure direct communication with squeezed states

Abstract: Quantum Secure Direct Communication is a rapidly developing quantum communication approach, where secure information is directly transmitted, providing an alternative to key-based (de)encryption processes via Quantum Key Distribution. During the last decade, optical Quantum Secure Direct Communication protocols based on discrete variable encodings have been successfully realized. Recently, continuous-variable Quantum Secure Direct Communication schemes have been proposed, benefiting from less-sophisticated implementations with proven security. Here, we report the first table-top experimental demonstration of a continuous-variable Quantum Secure Direct Communication system and assess its security. For this realization, we analyze the security of different configurations, including coherent and squeezed sources, with Wyner wiretap channel theory in the presence of a beam splitter attack. This practical protocol not only demonstrates the principle of Quantum Secure Direct Communication systems based on continuous-variable encoding, but also showcases the advantage of squeezed states over coherent ones in attaining enhanced security and reliable communication in lossy and noisy channels. Our realization, which is founded on mature telecom components, paves the way for future threatless quantum metropolitan networks, compatible with coexisting advanced wavelength division multiplexing systems.

Dilip Paneru

University of Ottawa

Separation estimation with Biphoton Spatial Mode Demultiplexing

Abstract: Recently it was shown that decomposing the light field into its constituent spatial modes (SPADE) allows us to circumvent the so-called Rayleigh's curse which inhibits the precise discrimination of two incoherent point sources. In our work we look at the sensitivity enhancement obtained from spatial entanglement in the separation estimation problem particularly in the case of bi photons generated from parametric down conversion (bi-photon SPADE). Our theoretical and simulation results show that resolution enhancement scales with the Schmidt rank of the entangled system. We also show that the "bi-photon SPADE" also provides better tolerance to modal cross talk and noise as compared to the ordinary SPADE.

Matteo Paris

University of Milan

Nonclassicality of quantum walks is universal up to third order

Abstract: Continuous-time quantum walks on graphs are traditionally defined as the quantum analogue of classical random walks, by promoting the classical transfer matrix, i.e. the graph Laplacian, to a Hamiltonian. However, this association does not encompass all the possible quantum evolutions of a walker on a graph. Upon invoking topological, algebraic and probabilistic constraints for a given graph a correspondence between the graph Laplacian and Hermitian quantum generator H may be established, with the standard association H = L recovered as a special case . As a result, we have that infinitely many bona fide Hamiltonians may be introduced for a given legit classical generator L, consistently with the common intuition that any map from classical to quantum evolutions should be one-to-many. We evaluate the dynamical nonclassicality for all the quantum walks on a given graph and show that such nonclassicality is universal up to third order in time.

Vincenzo Parisi

University of Napoli

Foundations of p-adic quantum information

Abstract: We propose a model of a quantum N-dimensional system (quNit) based on a quadratic extension of the non- Archimedean field of p-adic numbers. As in the standard complex setting, states and observables of a p-adic quantum system are implemented by suitable bounded selfadjoint operators in a p-adic Hilbert space. In particular, owing to the distinguishing features of p-adic probability theory, the states of an N-dimensional padic quantum system are implemented by p-adic statistical operators, i.e., trace-one selfadjoint operators in the carrier Hilbert space. Accordingly, we introduce the notion of selfadjoint-operator-valued measure (SOVM) --- a suitable p-adic counterpart of a POVM in a complex Hilbert space --- as a convenient mathematical tool describing the physical observables of a p-adic quantum system. Eventually, we focus on the special case where N=2, thus providing a description of p-adic qubit states and 2-dimensional SOVMs.

Jacopo Pelini

University of Napoli, CNR-INO Firenze

Towards sub-ppt trace-molecule detection with a doubly-resonant cantilever-enhanced photoacoustic sensor

Abstract: The race towards compact and robust sensors able to detect low concentrations of molecules in the air plays a crucial role in our modern society, impacting sectors such as environmental and climate change monitoring, safety, and medical diagnosis. Photoacoustic sensors offer unique characteristics of flexibility, robustness, and compact size, making them particularly attractive for in-field applications. The most significant step forward in the last decade consisted in their combination with high-finesse optical cavities. Proof-of-concept demonstrations of this technique have been realized with different configurations including quartz- and cantilever-enhanced sensors [1-3], pushing the sensitivities below the ppt-level and achieving record dynamic ranges. Here we present our latest results on advanced configurations of a cantilever-based sensor, combining the advantages of the photoacoustic technique with the sensitivity enhancement provided by a doubly-resonant system. In our setup, a 4.5 μm CW quantum cascade laser addresses fundamental N2O and CO rovibrational transitions. A Silicon MEMS cantilever is used as the acoustic transducer, whose displacement is measured with a custom designed balanced Michelson interferometer. The core of the sensor is the photoacoustic cell, including both a high-Q-factor acoustic resonator and a high-finesse optical resonator. This design, leveraging on a double standing wave effect, achieves a combined acoustic and optical amplification factor of several orders of magnitude compared to the standard configuration, thus strongly enhancing the final detection sensitivity. In parallel, we will present some recent results of other two activities related to the above described setup: (1) the characterization of innovative Silicon-based Micro Electro Mechanical Systems (MEMS) to be used as new acoustic transducers, and (2) the study of alternative and shot-noise limited mid-Infrared Interband Cascade Lasers via Balanced Homodyne detection.

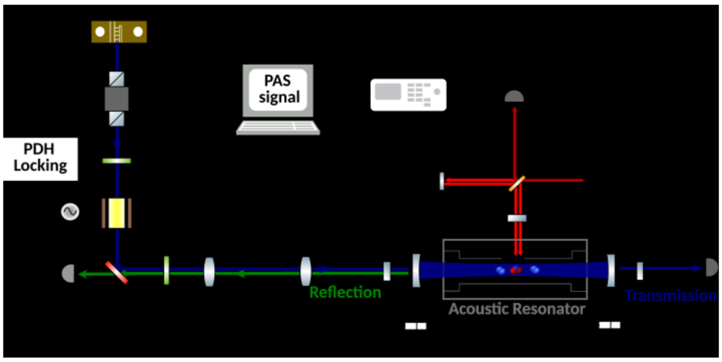

Fig. 1 Schematic representation of the setup. The three main parts are: the mode-matching optics, the sample cell, and the Michelson interfeormeter.

[1] S. Borri et al., Applied Physics Letters 104, 091114 (2014)
[2] T. Tomberg et al., Analyst 144, 2291 (2019)
[3] Z. Wang et al., Photoacoustics 27, 100387 (2022)

Marco Pinel

University of Napoli

Toward Quantum And Optical Wireless Communications In Underwater Scenarios

Abstract: In this work we study the underwater optical channel, making a feasibility analysis on the development of a high-speed communication system with security guaranteed by Quantum Key Distribution (QKD) protocol. In particular, we introduce a new model for the attenuation of the underwater medium which includes the effect of turbulence and misalignments within the marine environment. We report the performance of the system focusing on the most important figures of merit, such as the secret key rate of the quantum channel and the bit rate of the classical channel at the physical layer as a function of the total link range. We carried out these analyses depending on various environmental conditions, such as the geographical area, depth, link-range and turbulence models. The communication protocols considered are the BB84 with time-bin encoding for QKD and various modulation formats (binary and M-ary) for classical data communication.

Marcel Augusto Pinto

University of Palermo

Chiral emission of giant atoms in 2D

Abstract: A giant atom is a quantum emitter that can be coupled to the field non-locally at a set of distinct coupling points [1]. Such a new generation of quantum emitters can nowadays be implemented in circuit QED setups, where some spectacular effects - unachievable with normal atoms - have already been observed. One of these is the recent possibility to enable chiral (i.e. fully uni-directional) emission upon proper engineering of coupling-point complex phases [2,3], which can have important applications for quantum communication. Here, for the first time, we investigate the emission properties of giant atoms coupled to 2D photonic lattices like square or honeycomb lattices (used as case studies). This allows to combine the intrinsically anisotropic light emission across lattices [4] with the topology of coupling points and their phase-difference pattern. Such phases can be used to control the distribution of emitted light among a set of different directions.

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[2] T. Ramos et al., PRA 93, 062104 (2016)
[3] H. Joshi, F. Yang, M. Mirhosseini, PRX 13, 021039 (2023)
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Niccolò Preti

University of Firenze

Towards dipolar supersolids on a ring

Abstract: Ring potentials are one of the best platforms to study the rotational properties of superfluids because they represent the simplest experimental configuration where it's possible to realize periodic boundary conditions. The next step in this direction will be to study supersolids inside these potentials. In my poster, I will report the most recent results that I and my experimental group in Florence have got towards trapping a degenerate gas of dysprosium inside an annular potential. This new geometry will let us study the rotational properties of our supersolid, for the first time, in the configuration imagined by Nobel laureate A. Leggett in his seminal works on supersolidity. Moreover, the ring will allow us to study how persistent currents behave throughout the superfluid to supersolid phase transition.

Leonardo Ratini

University of L'Aquila

Quantum Information Driven Ansatz (QIDA): shallow-depth empirical quantum circuits from Quantum Chemistry

Abstract: Hardware-efficient empirical variational ansatz for Variational Quantum Eigensolver (VQE) simulations of Quantum Chemistry suffer by the lack of a direct connection to classical Quantum Chemistry methods. We propose a method to fill this gap by introducing a new approach for constructing variational quantum circuits, leveraging quantum mutual information associated with classical Quantum Chemistry states to design simple yet effective heuristic ansatz with a topology that reflects the most important correlations of the molecular system. Quantum Chemistry calculations, such as Møller-Plesset (MP2) perturbation theory, firstly provide an approximate natural orbitals basis, shown to be the best candidate basis set for developing compact empirical wavefunctions. Secondly, they provide information about the correlation between qubits of the quantum circuit, enabling the development of a direct design of entangling blocks for the circuit. The resulting ansatz is then utilized with a VQE to obtain a variational groundstate of the electronic Hamiltonian. To validate our approach, we perform a comprehensive statistical analysis over various molecular systems (H_2, LiH, H_2O) and apply it to the more complex NH_3 molecule. Our results demonstrate that the proposed methodology gives rise to highly effective ansatz, surpassing the standard empirical ladder-entangler ansatz in performance. Overall, our approach provides a promising solution for designing efficient variational quantum circuits for large molecular systems.

Domenico Ribezzo

University of Naples- National Institute of Optics Florence

Toward a European Quantum Network: an Overview of Field Tests.

Abstract: Quantum Key Distribution (QKD) stands as the most advanced technology emerging from the second quantum revolution, enabling the exchange of symmetric cryptographic keys whose security is guaranteed by fundamental physical principles. QKD's maturation has been showed by numerous successful experiments conducted in both controlled laboratory environments and real-world field trials. Presently, tangible QKD connections bridging cities across continents have transitioned from theoretical possibilities to practical realities, finding utility in commercial applications as well as in governments.

China already has a quantum network spanning the entire country from Beijing to Shanghai, and many other networks have emerged in various countries, at least on a metropolitan level (Cambridge, Tokyo, etc.). Europe is moving in this direction with the EuroQCI (European Quantum Communication Infrastructure) initiative.

In this overview, we present the initial steps toward a European quantum network. In August 2021, we achieved the first quantum key exchange over a quantum network spanning three countries (Italy, Slovenia, and Croatia), utilizing the pre-existing telecommunications infrastructure and operating in coexistence with it. The following year, we established a link over a submarine optical fiber connecting Malta to Pozzallo (Sicily), and we maximized the key rate by optimizing the protocol and then improving the detection apparatus. Finally, we utilized a multicore fiber laid beneath the perimeter of the city of L'Aquila (Italy) to implement a high-dimensional quantum key distribution (HD QKD) protocol, marking the first field trial of this kind of technology. We demonstrated that by leveraging multiple cores of a multicore fiber, it is possible to double the key rate in HD QKD compared to the classical BB84 protocol, thereby gaining system stability as well.

We believe that the work showcased in this overview paves the way for an upcoming real implementation of a quantum network on our continent.

Federico Roccati

University of Luxembourg

Non-Hermitian Hamiltonian deformations in quantum mechanics

Abstract: The construction of exactly-solvable models has recently been advanced by considering integrable T\\bar{T}-deformations and Hamiltonian deformations in quantum mechanics. We introduce a broader class of non-Hermitian Hamiltonian deformations to account for the description of a large class of open quantum systems, including Markovian evolutions conditioned to the absence of quantum jumps. We relate the time evolution operator and the time-evolving density matrix in the undeformed and deformed theories in terms of integral transforms. Non-Hermitian Hamiltonian deformations naturally arise in the description of energy diffusion that emerges in quantum systems from time-keeping errors in a real clock used to track time evolution. We show that the latter can be related to an inverse T\\bar{T}-deformation with a purely imaginary deformation parameter. In this case, the integral transforms take a particularly simple form when the initial state is a coherent Gibbs or a thermofield double state, as we illustrate by characterizing the spectral form factor. As the dissipative evolution of a quantum system can be conveniently described in Liouville space, we further study the spectral properties of the Liouvillians. As an application, I will discuss the interplay between decoherence and quantum chaos in non-Hermitian deformations of random matrix Hamiltonians and the Sachdev-Ye-Kitaev model.

Somayeh Salimian

Novin laser saba company

Wavelength conversion of orbital angular momentum carrying signals via nonlinear four wave mixing effect in optical fiber

Abstract: Since the quantum systems are developing and expanding dramatically in all fields specially in quantum communication systems, classical fiber networks are a choice to help implement quantum communication protocols. On the other hands wavelength conversion in the communication systems has a crucial role and essential principle. So we use X^((3))-based nonlinear Four Wave Mixing (FWM) as a converter in Wavelength Division Multiplexing (WDM) technique in fiber networks. Combination of WDM technique with high order spatial modes such as Orbital Angular Momentum (OAM) through a channelized bandwidth provides enhanced capacity fiber communication systems. All-optical wavelength converter is a key function in WDM network to overcome the channel blocking problems due to wavelength contentions. We worked on theoretical investigation of wavelength conversion of pulsed OAM carrying signals via X^((3))--based nonlinear FWM effect. A Post-selection free all fiber scheme is proposed to overcome the flipping of the topological charge number for generated idler. The results reveal the ability of FWM-based wavelength conversion of signals carrying OAM for practical networks using special OAM-hosting fibers.

Andrea Santoni

CNR-INO Firenze

Atomic Mach-Zehnder Interferometer with Trapped Bose-Einstein Condensates

Abstract: Trapped atom interferometers are important tools for the measurements of forces with high spatial resolution. My work is based on the realization of a Mach-Zehnder interferometer with Bose-Einstein condensates of 39K trapped in double-well potentials (DWs). The DWs are obtained with an innovative optical potential [1] that uses the superposition of three standard optical lattices with commensurate wavelengths. That allows to implement three identical DWs working simultaneously. Having more than one correlated interferometers is useful, since it's possible cancel out the e_ect of common sources of noise acting on the three DWs via di_erential analysis and relize a trapped atom gradiometer. In our system we cannely tune interactions via a broad Feshback resonance, changing the two-body scattering length from positive to negative values. This allows us to operate the interferometer without interactions and with long coherence times. We are also working on the possibility of generate number squeezed states in our system introducing repulsive interactions. Exploiting non classic states at the interferometer's input will allow us to enhance the sensitivity of our sensor beyond the standard quantum limit.

[1] Masi, L., et al. "Spatial bloch oscillations of a quantum gas in a \beat-note" superlattice." Physical Review Letters 127.2 (2021): 020601.

Paola Savarese

University of Napoli

Quantum Information Processing with Structured Light

Abstract: Light is an optimal candidate to realize quantum information processing, as it carries several degrees of freedom, such as polarization, linear and angular momentum, which can encode quantum information and are easily manipulated. For instance, the optical polarization can be naturally associated with a two-level quantum system, e.g. fermionic spin, and can be controlled via standard birefringent elements like waveplates.

A recent approach has emerged to process quantum information, based on the quantum walk paradigm. Quantum walks are quantum versions of classical random walks. Unlike classical walks with defined states and stochastic transitions, quantum walks feature randomness from superposition, reversible unitary evolution, and wave function collapse due to measurements, enabling unique quantum behaviors. To implement an optical version of a QW, a light beam has to be conveniently manipulated during its propagation via a sequence of step operators. Here we encode the walker position into optical transverse momentum and its internal degree of freedom into optical polarization. Within this framework, the step operator conventionally encompasses a spin rotation, implemented by uniform liquid-crystal (LC) plates serving as standard waveplates, and discrete displacements of the walker in the x and y directions induced through spin-dependent translation operators, that can be realized, for example, through LC polarization gratings.

My project focuses on the engineering of innovative approaches for quantum information processing based on these photonic platforms for quantum walks and the generalization of the latter to non-Hermitian regimes in one and two spatial dimensions. This is possible through the characterization of dichroic waveplates realized with a mixture of LC and absorbing dies, that can manipulate simultaneously on the polarization and the amplitude of light. In this way our compact and versatile platform augments the realm of photonic simulations in the study of quantum dynamics and topological systems, offering promising prospects and avenues for further exploration in the framework of quantum information processing.

Lukas Scarfe

University of Ottawa

The Application of Adaptive Optics to Improve Free-Space Quantum Key Distribution

Abstract: Quantum key distribution (QKD) is a paradigmatic quantum communication protocol to enable secure communications in a post-quantum world, where current encryption schemes can be readily cracked. Free-space QKD can enable secure communication lines where fibre infrastructure is not already in place. One of the major technical challenges for realising effective free-space QKD is compensating for the effects of turbulence on the quantum channel. For higher dimensional QKD, where tolerable quantum bit error rate (QBER) are greater, and the key generation rate is higher, these effects are even more detrimental. Here we demonstrate the compensating effects of adaptive optics on high dimensional (d>2) QKD that is performed using orbital angular momentum (OAM) modes of light. This approach is scalable and can be extended to include compensation in other spatial degrees of freedom. We expect that our results will pave the way for the implementation of adaptive optics in QKD systems, resulting in higher fidelity key distribution where more bits of information are encoded in each photon sent across the quantum channel. This would represent a remarkable step on the way towards the wide-scale commercialization of free-space photonic QKD platforms.

Carlo Schiano

University of Napoli

Engineering quantum states from a spatially structured quantum eraser

Abstract: Quantum interference is a central resource in many quantum-enhanced tasks, from computation to communication protocols. While it usually occurs between identical input photons, quantum interference can be also enabled by projecting the quantum state onto ambiguous properties that render the photons indistinguishable, a process known as a quantum erasing. Structured light, on the other hand, is another hallmark of photonics: it is achieved by manipulating the degrees of freedom of light at the most basic level and enables a multitude of applications in both classical and quantum regimes. By combining these ideas, we design and experimentally demonstrate a simple and robust scheme that tailors quantum interference to engineer photonic states with spatially structured coalescence along the transverse profile, a type of quantum mode with no classical counterpart. To achieve this, we locally tune the distinguishability of a photon pair via spatial structuring of their polarisation, creating a structured quantum eraser. We believe these spatially-engineered multi-photon quantum states may be of significance in fields such as quantum metrology, microscopy, and communications.

Giuseppe Scriva

University of Camerino

Challenges of variational quantum optimization with measurement shot noise

Abstract: Exploiting quantum resources to enhance the optimization of classical problems is a central theme of quantum computing due to its high potential value in science and technology. In the noisy-intermediate scale quantum (NISQ) era, there are two promising systems, i.e., quantum annealers (QA) and gate-based quantum computers. We have recently shown that QA can provide a remarkable advantage by accelerating classical Monte Carlo simulations [1]. For the quantum gate computers, the most viable algorithms are the variational quantum eigensolver (VQE) and the quantum approximate optimization algorithm (QAOA). In this talk, we discuss the scaling of the quantum resources, defined as the required number of circuit repetitions, to reach a fixed success probability as the problem size increases, focusing on the role played by measurement shot noise, which is unavoidable in realistic implementations [2]. The ferromagnetic and disordered Ising chains are analyzed. Our results show that:

1. VQE with the standard heuristic ansatz scales comparably to direct brute-force search when energy-based optimizers are employed. The performance improves at most quadratically using a gradient-based optimizer.
2. When the parameters are optimized from random guesses, also the scaling of QAOA implies problematically long absolute runtimes for large problem sizes.
3. QAOA becomes practical when supplemented with a physically-inspired initialization of the parameters.

[1] G Scriva et al SciPost Phys. 15, 018 (2023)
[2] G Scriva et al preprint arXiv:2308.00044

Andrew Stasiuk

MIT

Observation of a Prethermal U(1) Time Crystal

Abstract: A time crystal is a state of periodically driven matter which breaks discrete time translation symmetry. Time crystals have been demonstrated experimentally in various programmable quantum simulators and exemplify how non-equilibrium, driven quantum systems can exhibit intriguing and robust properties absent in systems at equilibrium. These robust driven states need to be stabilized by some mechanism, with the preeminent candidates being many-body localization and prethermalization. This introduces additional constraints that make it challenging to experimentally observe time crystallinity in naturally occurring systems. Recent theoretical work has developed the notion of prethermalization \\textit{without temperature}, expanding the class of time crystal systems to explain time crystalline observations at (or near) infinite temperature. In this work, we conclusively observe the emergence of a prethermal U(1) time crystalline state at quasi-infinite temperature in a solid-state NMR quantum emulator by verifying the requisites of prethermalization without temperature. In addition to observing the signature period-doubling behavior, we show the existence of a long-lived prethermal regime whose lifetime is significantly enhanced by strengthening an emergent U(1) conservation law. Not only do we measure this enhancement through the global magnetization, but we also exploit on-site disorder to measure local observables, ruling out the possibility of many-body localization and confirming the emergence of long-range correlations.

Xuejian Sun

University of Palermo

Implementing structured spin Hamiltonians via giant atoms and homogeneous photonic lattices

Abstract: It is known that an atom coupled to a photonic band edge can seed an atom-photon bound state (BS) [1], which can mediate an effective spin Hamiltonian when many atoms are present. Provided that the photonic lattice has the right structure (e.g. the well-known SSH mode [2]), such a BS (and corresponding inter-atomic potential) can show exotic properties such as vanishing amplitude on sites of given parity and BS energy fully insensitive to the coupling strength. Here, we show that one can realize these features via a simple pair of standard homogenous photonic lattices coupled to giant atoms (with each atom being coupled to both lattices). Additionally, we find that a tunable phase between the giant-atom coupling points can control the strength of the interatomic potential and make it time-reversal breaking.

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[2] M. Bello, G. Platero, J. I. Cirac, and A. González-Tudela, Unconventional quantum optics in topological waveguide QED, Sci. Adv. 5, eaaw0297 (2019)

Alessia Suprano

University of Rome “Sapienza”

Nonclassicality detection in photonic triangle networks

Abstract: The investigation of complex networks, a crucial research topic in quantum information, allows the disclosure of completely new forms of quantum nonclassicality with respect to the standard Bell scenario. Networks characterized by quantum correlations incompatible with any bipartite nonclassicality exhibit Genuine multipartite nonlocality (GMNL). Although it is a fundamental aspect in the context of quantum networks, its experimental investigation remains far less explored. Surprisingly, it occurs also in networks composed of bipartite quantum resources, such as the triangle scenario. Therefore, we implemented for the first time the triangle network, exploiting only bipartite entangled sources and separable measurement, without the demanding employment of tripartite sources. By investigating each source’s nonlocality, we certified the GMNL of the entire network. In the triangle configuration, another new form of nonclassicality can occur by considering only single measurements performed in each party, with no freedom of choice. However, its witnessing requires a radically different approach. We experimentally realized the triangle structure and detected this form of nonclassicality by introducing new tools, such as entropic inequalities, “inflation technique”, and machine learning-based approach. These results represent an important step toward the future quantum internet paving the way for quantum communications applications involving several sources and measurement stations.

Diana Tartaglia

CNR - INO Firenze

Public engagement evaluation of Quantum Technology related outreach activities

Abstract: The second quantum revolution is expected to bring new technologies in use in the next 5 to 10 years. Investments in Quantum Technology (QT) research in Europe and all over the world include outreach and educational actions towards several sections of the public in order to create awareness on the subject and interest that will hopefully lead to a quantum ready workforce.

Outreach activities are one of the tools that can be used to reach this goal. Nonetheless, outreach efforts on science and technology must be accompanied by some evaluation in order to avoid fertile ground for myths and inaccurate theories.

Public engagement evaluation techniques have been largely employed to assess the efficacy of outreach activities and their impact on the public in several scientific domains.

Our aim would be to employ these tools to evaluate QT outreach events (conferences, exhibitions, etc.) organized by the Italian Quantum Weeks coordination and other national research institutions.

Results of these evaluations will give an insight on what is retained by the attendees and will help identify critical subject that might influence the development and implementation of quantum-based technologies in the future.

Simone Tibaldi

University of Bologna

Bayesian Optimization for QAOA

Abstract: The Quantum Approximate Optimization Algorithm (QAOA) adopts a hybrid quantum-classical approach to find approximate solutions to variational optimization problems. In fact, it relies on a classical subroutine to optimize the parameters of a quantum circuit. In this work we present a Bayesian optimization procedure to fulfil this optimization task, and we investigate its performance in comparison with other global optimizers. We show that our approach allows for a significant reduction in the number of calls to the quantum circuit, which is typically the most expensive part of the QAOA. We demonstrate that our method works well also in the regime of slow circuit repetition rates, and that few measurements of the quantum ansatz would already suffice to achieve a good estimate of the energy. In addition, we study the performance of our method in the presence of noise at gate level, and we find that for low circuit depths it is robust against noise. Our results suggest that the method proposed here is a promising framework to leverage the hybrid nature of QAOA on the noisy intermediate-scale quantum devices.

Alex Ungar

MIT

Scaling up a quantum register of electronic spins in diamond via characterization of interacting spin graphs

Abstract: Optically dark electronic spins in diamond surrounding a single nitrogen vacancy (NV) center can be harnessed as qubits in a multi-spin quantum register. However, to date, initialization and control of electron spins in the environment of a central NV center has been limited to spins which are directly coupled to the NV center. In this work, we demonstrate how to further scale up a quantum register of electron-nuclear spin defects in diamond beyond this first interaction layer by controlling spins beyond the coherence limit of the central qubit. We achieve this by mapping out the graph structure of interacting spins in the environment of a single NV center, and fully characterizing the spin Hamiltonian of a network of four spins. We can then demonstrate polarization transfer over a chain of three spins and implement unitary control and readout on a spin not directly coupled to the central qubit. The control tools we develop and our results provide a roadmap to engineer larger solid-state quantum registers, and further advance their capabilities for quantum sensing, device characterization, and simulation.

Lorenzo Valentini

University of Bologna

Reliable Quantum Communications based on Asymmetry in Purification and Coding

Abstract: The reliable provision of entangled qubits is an essential precondition in a variety of schemes for distributed quantum computing. This is challenged by multiple nuisances, such as errors during the transmission over quantum links, but also due to degradation of the entanglement over time due to decoherence. The latter can be seen as a constraint on the latency of the quantum protocol, which brings the problem of quantum protocol design into the context of latency-reliability constraints. We address the problem through hybrid schemes that combine: (1) indirect transmission based on teleportation and purification; (2) direct transmission, based on quantum error correction (QEC). The intuition is that, at present, the quantum hardware offers low fidelity, which demands purification; on the other hand, low latency can be obtained by QEC techniques. It is shown that, in the proposed framework, the purification protocol gives rise to asymmetries that can be exploited by asymmetric QEC codes, which sets the basis for unique hybrid purification and coding design. Our results show that ad-hoc asymmetric codes give, compared to conventional QEC, a performance boost and codeword size reduction both in a single link and in a quantum network scenario.

Paolo Villoresi

University of Padova

Single photon communications in space for interstellar probes

Abstract: The possibility of reaching near-solar star systems for investigations of extrasolar planets and the search for possible evidence of extraterrestrial life is constrained by the ability to transmit the information back to Earth. Given the significant losses, due to optical diffraction over distances of several light-years, techniques based on communications at single photon level and inspired by quantum communications in space assume a crucial role. The poster will describe techniques for photon encoding and the link budgets assessment for this type of communications. The research were obtained within the Starshot Project supported by the Breakthrough Foundation.

Mara Vizzuso

University of Napoli

Convergence of Digitized-Counterdiabatic QAOA: circuit depth versus free parameters

Abstract: The Quantum Approximate Optimization Algorithm (QAOA) is a promising hybrid quantum- classical algorithm that can solve combinatorial optimization problems [1]. The quantum part of the algorithm involves using parametric unitary operations on a quantum computer to prepare a trial solution state. The parametric QAOA angles are variationally optimized minimizing a cost function using classical methods. Generalizing the results on ref. [2], we study a generalized QAOA ansatz that includes corrections to the Trotter expansion at the first and second order based on the Baker-Campbell-Hausdorff (BCH) expansion [3]. By utilizing terms in the BCH expansion as additional control unitaries, each with its own angle, we can improve convergence compared to standard QAOA. The additional angles are treated as independent free parameters, rather than keeping them fixed to the prescription of the BCH expansion, resulting in a cost function simpler to deal with.

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Gennaro Zanfardino

University of Salerno

Quantum Resource Theory of Bell Nonlocality in Hilbert Space

Abstract: Quantum resource theory studies the structure and properties of the quantum resources needed to realize information and communication protocols which cannot be achieved only with classical resources, like for example quantum teleportation. This theory has been developed for quantum coherence, entanglement and other types of quantum resources, but, strange enough, not for Bell nonlocality, i.e. the strongest form of nonlocal quantum correlations. In our work we introduce a quantum resource theory of Bell nonlocality in Hilbert space by identifying the set of local states that do not violate the CHSH inequality, the transformations that do not create the resource - local operation and shared randomness, and the geometric measures defined as distances from the set of local states. We discuss and verify all the desirable properties that are needed to define a quantum resource theory of Bell nonlocality, and as an application we investigate in detail the case of two-qubit systems.

Danilo Zia

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Optimized Engineering of High Dimensional Quantum States in a Photonic Platform

Abstract: The engineering of arbitrary high-dimensional quantum states (qudits) is a pivotal task in quantum information science. In particular, the ability to produce the desired states with high fidelity and independently of the environmental situation is a highly demanded feature. Several strategies and platforms have been proposed to accomplish this task. However, the inevitable presence of noises, losses, and the lack of accurate characterization of the apparatus significantly decreases the performance. In this work, we focused on the generation of qudits encoded in the Orbital Angular Momentum (OAM) of photons through a quantum walk-based experimental platform. We addressed the engineering with an adaptive optimization protocol that, working in a fully black-box scenario, tunes the relevant parameters relying only on the measured fidelity, without needing a description of the generation setup and automatically accounting for experimental noises. We also studied the certification of the produced states with a machine learning-based approach. Here the measurement is treated as a regression task in which we retrieve the coefficients of arbitrary OAM superpositions, in this way reducing the losses present in interferometric and diffractive measurement approaches. The high values of the fidelities obtained in a 4-dimensional Hilbert space showcase the performance of both the approaches.