Quantum Science Generation | QSG 2024

Report of Contributions

Contribution ID: **3** Type: **Talk**

Exciton-polaritons as a platform for quantum optics in solid-state systems

Tuesday, 7 May 2024 12:00 (30 minutes)

Exciton-polaritons are hybrid light-matter excitations arising from the strong coupling between an electromagnetic mode and an excitonic transition of a semiconductor material. As mixed particles, they get the best of two worlds: low effective mass and long coherence from their photonic component and strong interactions from their matter component.
This unique mixture of features makes them an excellent playground to explore the physics of interactive bosons in solid state systems. As bosons, polaritons tend to macroscopically occupy the same macroscopic quantum state resulting in the celebrated Bose-Einstein polariton condensate [1,2].
A question that has naturally risen and is currently highly debated is if polariton-polariton interactions can be used in quantum optics, namely as interactive qubits. Should this be the case, a new generation of solid-state chips could provide quantum optics functionalities like deterministic C-NOT quantum gates, qubits routing, and entangling.
To explore the potential of quantum polaritonics, we have excited polaritonic semiconductor microcavities with quantum light. We have observed the propagation of single polaritons and directly proved their wave-particle duality [3]. We have also demonstrated that entanglement is conserved in the photon-polariton-photon conversion and that it can be retrieved after polariton propagation inside a nonlinear medium [4].
More recently, we have been studying polariton waveguides acting as nonlinear integrated circuits [5], showing that these systems provide a promising platform for deterministic quantum gates operating at the few particles level [6].
These results confirm that polaritons are an alternative, promising platform for quantum information processing in solid-state systems.

[1] I. Carusotto and C. Ciuti, Quantum fluids of light, Review of Modern Physics, 2013;
[2] V. Ardizzone et al., A Bose Einstein condensate from a bound state in the continuum Nature, 2022;
[3] D. Suarez et al. Quantum hydrodynamics of a single particle, Light Science and Application, 2020 ;
[4] A. Cuevas et al., First observation of the quantized exciton-polariton, Science Advances, 2018;
[5] D. Suarez et al., Enhancement of parametric effect in polariton waveguides induced by dipolar interactions, Physical Review Letters, 2021;
[6] V. Ardizzone et al., in preparation;

Abstract category

Quantum Optics

Primary author: ARDIZZONE, Vincenzo (CNR Nanotec)

Co-authors: Dr SANVITTO, Daniele (CNR Nanotec); Dr BALLARINI, Dario (CNR Nanotec); Dr DE GIORGI, Milena (CNR Nanotec)

Presenter: ARDIZZONE, Vincenzo (CNR Nanotec)

Session Classification: Talks

Contribution ID: **4** Type: **Talk**

Quantum Optics near Photonic Flat Bands

Thursday, 9 May 2024 11:30 (30 minutes)

Flat Bands (FBs) are dispersionless energy bands, feature that makes such systems extremely sensitive to small perturbations and non-linearities. Here, we examine the case in which the non-linearity is introduced through the coupling of two-level emitters (almost) resonant to the FB energy.
Surprisingly, we find that a FB seeds a new type of *detuning independent* exponentially localized dressed bound state, never discussed before in literature, whose appearance is tightly linked to the **non-orthogonality** of the Flat Band basis made by *Compact Localized States* (CLSs). Indeed, we prove that the localization length λ_{BS} of such states is analytical related to the overlap between neighbouring CLSs in both 1D- and 2D-systems, effectively representing a measure of non-orthogonality. Furthermore, if the FB is **symmetry-protected**, the shape of such states is robust against all kind of disorder, being exactly invariant under non-symmetry breaking disorder. This robustness is naturally inherited by the ensuing photon-mediated interactions, induced between the emitters in the dispersive regime.
Finally, we also investigate this class of systems when the emitter is made by a *giant atom*, which couples to the photonic bath at several distinct locations. We show that the high degeneracy of the FB subspace permits the tuning of the photonic wavefunction through an appropriate choice of the coupling points and their strength. Indeed, the photonic wavefunction *mirrors* the structure of the coupling points, allowing to virtually engineer any possible BS shape as, for instance, a single CLS by using a finite number of coupling points. In this case, the resulting mediated-interactions will be strictly finite-ranged.

Abstract category

Quantum Optics

Primary author: DI BENEDETTO, Enrico (Università degli Studi di Palermo)

Co-authors: Dr GONZALEZ-TUDELA, Alejandro (CSIC- Instituto de Fisica Fundamental); Prof. CICCARELLO, Francesco (Università degli Studi di Palermo)

Presenter: DI BENEDETTO, Enrico (Università degli Studi di Palermo)

Session Classification: Talks

Contribution ID: **5** Type: **Talk**

Calculating the many-body density of states on a digital quantum computer

Thursday, 9 May 2024 10:00 (30 minutes)

Quantum statistical mechanics allows us to extract thermodynamic information from a microscopic description of a many-body system. A key step is the calculation of the density of states, from which the partition function and all finite-temperature equilibrium thermodynamic quantities can be calculated. In this work, we devise and implement a quantum algorithm to perform an estimation of the density of states on a digital quantum computer which is inspired by the kernel polynomial method. Classically, the kernel polynomial method allows us to sample spectral functions via a Chebyshev polynomial expansion. Our algorithm computes moments of the expansion on quantum hardware using a combination of random-state preparation for stochastic trace evaluation and a controlled unitary operator. We use our algorithm to estimate the density of states of a nonintegrable Hamiltonian on the Quantinuum H1-1 trapped ion chip for a controlled register of 18 qubits. This not only represents a state-of-the-art calculation of thermal properties of a many-body system on quantum hardware, but also exploits the controlled unitary evolution of a many-qubit register on an unprecedented scale.

Abstract category

Quantum Simulations

Primary author: SUMMER, Alessandro (Trinity College Dublin)

Presenter: SUMMER, Alessandro (Trinity College Dublin)

Session Classification: Talks

Contribution ID: **6** Type: **Talk**

Quantum Many-Body Scars in Dual-Unitary Circuits

Monday, 6 May 2024 16:30 (30 minutes)

Dual-unitary circuits are a class of quantum systems for which exact calculations of various quantities are possible, even for circuits that are nonintegrable. The array of known exact results paints a compelling picture of dual-unitary circuits as rapidly thermalizing systems. However, in this Letter, we present a method to construct dual-unitary circuits for which some simple initial states fail to thermalize, despite the circuits being "maximally chaotic,"ergodic and mixing. This is achieved by embedding quantum many-body scars in a circuit of arbitrary size and local Hilbert space dimension. We support our analytic results with numerical simulations showing the stark contrast in the rate of entanglement growth from an initial scar state compared to nonscar initial states. Our results are well suited to an experimental test, due to the compatibility of the circuit layout with the native structure of current digital quantum simulators.

Abstract category

Quantum Simulations

Primary authors: Prof. GOOLD, John (Trinity College Dublin); LOGARIC, Leonard (Trinity College Dublin); Dr DOOLEY, Shane (Trinity College Dublin); Prof. PAPPALARDI, Silvia (University of Cologne)

Presenter: LOGARIC, Leonard (Trinity College Dublin)

Session Classification: Talks

Contribution ID: **7** Type: **Poster**

Topological quantum dissipative phases with trapped ions

Tuesday, 7 May 2024 17:30 (1h 30m)

We simulate topological dissipative phases in a one-dimensional chain of trapped ions with their vibrational degrees of freedom. First, we study non-reciprocity in a two-ion parametric dimer and then we analyze topological amplification in large chains where Coulomb long-range couplings become apparent.

The existence of topologically non-trivial phases leads to the presence of edge states that produce amplification being robust against disorder. The control of the parametric driving terms is achieved by taking advantage of state-of-the-art Floquet engineering techniques. We characterize the stability of the system and find stable topological amplifiers and two-mode Gaussian steady-states that can produce entanglement.

Abstract category

Quantum Simulations

Primary author: CLAVERO RUBIO, Miguel (Instituto de Física Fundamental IFF-CSIC)

Presenter: CLAVERO RUBIO, Miguel (Instituto de Física Fundamental IFF-CSIC)

Session Classification: Poster session

Contribution ID: **8** Type: **Talk**

Harnessing quantum emitter rings for efficient energy transport and trapping

Thursday, 9 May 2024 11:00 (30 minutes)

Efficient transport and harvesting of excitation energy under low light conditions is an important process in nature and quantum technologies alike. Here we formulate a quantum optics perspective to excitation energy transport in configurations of two-level quantum emitters with a particular emphasis on eciency and robustness against disorder. We study a periodic geometry of emitter rings with subwavelength spacing, where collective electronic states emerge due to near-field dipole-dipole interactions. The system gives rise to collective subradiant states that are particularly suited to excitation transport and are protected from energy disorder and radiative decoherence. Comparing ring geometries with other configurations shows that that the former are more ecient in absorbing, transporting, and trapping incident light. Because our findings are agnostic as to the specific choice of quantum emitters, they indicate general design principles for quantum technologies with superior photon transport properties and may elucidate potential mechanisms resulting in the highly ecient energy transport eciencies in natural light-harvesting systems.

Abstract category

Quantum Optics

Primary author: HOLZINGER, Raphael (Institute for Theoretical Physics, University of Innsbruck)

Co-authors: Prof. RITSCH, Helmut (Institute for Theoretical Physics, University of Innsbruck); Mr PETER, Jonah (Harvard University); Dr OSTERMANN, Stefan (Harvard University); Prof. YELIN, Susanne (Harvard University)

Presenter: HOLZINGER, Raphael (Institute for Theoretical Physics, University of Innsbruck)

Session Classification: Talks

Contribution ID: **10** Type: **Poster**

Chiral-symmetry-protected dressed states of giant atoms

Tuesday, 7 May 2024 17:30 (1h 30m)

In the previous work Rhy. Rev. Lett 126, 063601, we have established a general framework for studying vacancy-like dressed state (VDS) in a generic photonic bath coupled to a normal atom. Here we extend this theory to giant-atom case. We point out that only if a giant atom is coupled to a bath whose energy spectrum possess chiral-symmetry (not necessarily transitionally invariant) and the atom's translation frequency is centralized at zero-energy, then a chiral-symmetry-protected VDS must exist. Exotic properties of VDSs can be realized 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. The properties of the dressed-state in squre lattices are also studied.

Abstract category

Quantum Optics

Primary author: SUN, Xuejian (University of Palermo)

Co-authors: Mr CICCARELLO, Francesco (University of Palermo); Mr LEONFORTE, Luca (University of Salerno)

Presenter: SUN, Xuejian (University of Palermo)

Session Classification: Poster session

Contribution ID: **12** Type: **Poster**

A Parameter-Free Approach for Modeling Valence and Core-Level Photoelectron Spectroscopy

Tuesday, 7 May 2024 17:30 (1h 30m)

Core-level spectroscopy provides valuable information about the local chemical environment of atoms in molecules by probing core-electronic structure whereas valence-level spectroscopy offers valuable insight into hybridization and bonding via valence-electronic structure. Despite their similarity, modeling core-electronic structure is challenging owing to large orbital-relaxation effects and relativistic corrections. We overcome these challenges by combining the generalized Kohn–Sham semicanonical projected random phase approximation (GKS-spRPA) mehod with the spin-free exact two-component theory in its one-electron variant (SFX2C-1e) followed by a perturbative treatment of spin-orbit coupling (SOC) to model the K- and L-edge X-ray photoelectron spectroscopy (XPS), valence-level PES and non-resonant X-ray emission spectroscopy (XES) of molecular systems. The core and valence-electron one-particle states, required for the computation of the XES spectra, are obtained directly in a single calculation of the neutral system without any use of core-hole reference states. A comprehensive analysis demonstrates that the X2C-GKS-spRPA method achieves an accuracy of approximately 0.2 eV for valence-level PES and XES, while mean absolute errors (MAEs) of less than 1 eV are observed for core K-edge and L-edge XPS of third-period elements. We also show that an analytic continuation technique, with a O(N4) computational cost, can be used to obtain highly accurate X-ray emission spectra of molecules such as C60 and S8 with multiple core-hole states.

Abstract category

Quantum Chemistry

Primary authors: SAMAL, Bibek (Tata Instititue of Fundamental Research); Dr VOORA, Vamsee (Tata Instititue of Fundamental Research)

Presenter: SAMAL, Bibek (Tata Instititue of Fundamental Research)

Session Classification: Poster session

Contribution ID: **13** Type: **Poster contribution**

Noise classification in small quantum networks by Machine learning

Tuesday, 7 May 2024 17:30 (1h 30m)

Characterizing the effects of the interaction between quantum systems and their environment is a key challenge in the development of Quantum Technologies. Among the several possibilities, classifying whether the noise is correlated and Markovian has important implications on the dynamics of the system. In this work we consider the simplest quantum network in which correlations can be identified: the three level system. In particular we consider the position eigenbasis of three quantum dots with time-dependent tunneling rates $\Omega_p(t)$ and $\Omega_s(t)$ and employ the Coherent Tunneling by Adiabatic Passage (CTAP) protocol for system control. We focus on distinguishing among five distinct types of noise: three non-Markovian (quasistatic correlated, anti-correlated, and uncorrelated) and two Markovian (correlated and anti-correlated) through supervised learning. Using different pulse configurations as inputs, we train a feedforward neural network to classify these noise types. Our results show that, while the correlations of the non-Markovian noises can be readily distinguished from each other and from Markovian noise, achieving approximately 99% classification accuracy, the correlations in Markovian noise cannot be classified with our method. Moreover, our approach proves robust against statistical measurement errors, maintaining its efficacy even with a limited number of measurements.

Abstract category

Other

Primary author: MUKHERJEE, SHREYASI (UNIVERSITY OF CATANIA, ITALY)

Co-authors: Prof. FALCI, Giuseppe (University of Catania, INFN Sez. Catania, CNR-IMM Catania); Prof. PALADINO, Elisabetta (University of Catania, INFN Sez. Catania, CNR-IMM Catania); Prof. PATERNOSTRO, Mauro (Centre for Theoretical Atomic, Molecular, and Optical Physics, School of Mathematics and Physics, Queens University, Belfast); Mr CIRINNÀ, Fabio (Leonardo S.p.A., Cyber & Security Solutions); Mr PENNA, Dario (Leonardo S.p.A., Cyber & Security Solutions); Dr GIANNELLI, Luigi (University of Catania, INFN Sez. Catania)

Presenter: MUKHERJEE, SHREYASI (UNIVERSITY OF CATANIA, ITALY)

Session Classification: Poster session

Contribution ID: **14** Type: **Poster contribution**

Chiral emission mediated by a giant atom in a honeycomb photonic bath.

Tuesday, 7 May 2024 17:30 (1h 30m)

A giant atom is a quantum emitter that can be coupled to the field non-locally at a set of coupling points [1]. Such a new generation of 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 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 a giant atom coupled to a 2D honeycomb photonic lattice. This allows combining 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.

References:

[1] A. F. Kockum, arXiv:1912.13012

[2] T. Ramos et al., PRA 93, 062104 (2016)

[3] H. Joshi, F. Yang, M. Mirhosseini, PRX 13, 021039 (2023)

[4] A. G. Tudela & I. Cirac, PRA 96, 043811 (2017)

Abstract category

Quantum Optics

Primary author: PINTO, Marcel Augusto (Università degli Studi di Palermo)

Co-authors: Dr DE BERNARDIS, Daniele (Ino-cnr); CICCARELLO, Francesco (Università degli Studi di Palermo); SFERRAZZA, Giovanni Luca (Università degli studi di Palermo)

Presenter: PINTO, Marcel Augusto (Università degli Studi di Palermo)

Session Classification: Poster session

Contribution ID: **16** Type: **Talk**

Spectroscopic characterization of the Markov to non-Markov transition in qubit-impurity systems

Tuesday, 7 May 2024 17:00 (30 minutes)

The behavior of many dissipative systems is generally described by a non-Markovian dynamics. Memory effects associated to non-Markovianity may lead to revival of coherence and entanglement and may be exploited as resources for quantum computation [1,2]. In this work, we study a toy model system of a qubit coupled to an incoherent impurity [3-5] which has been shown to exhibit a transition from a Markovian regime to a non-Markovian dynamics [6,7], depending on tunable parameters of the system. We investigate this behavior by quantifying the non-Markovianity [8] and by studying the frequency spectrum of the qubit coherence [9]. We study the phase diagram in several regimes and show that the transition is tuned by the qubit-impurity interaction strength and by the temperature of the impurity. Our work aims at introducing spectroscopic witnesses that are easy to measure and are able to quantify the non-Markovianity of a system.

[1] M. Tsitsishvili, D. Poletti, M. Dalmonte, and G. Chiriacò, "Measurement induced transitions in non-markovian free fermion ladders,"(2023), arXiv:2307.06624 [quant-ph].

[2] D. Gribben, J. Marino, and S. P. Kelly, "Markovian to non-markovian phase transition in the operator dynamics of a mobile impurity,"(2024), arXiv:2401.17066 [quant-ph].

[3] E. Paladino, L. Faoro, G. Falci, and R. Fazio, Phys. Rev. Lett. 88, 228304 (2002);

[4] E. Paladino, L. Faoro, A. D'Arrigo, and G. Falci, Physica E: Low-dimensional Systems and Nanostructures 18, 29–30 (2003).

[5] Paladino, E., Faoro, L., Falci, G. Advances in Solid State Physics, 43 747 (2003)

[6] E. Paladino, M. Sassetti, G. Falci, and U. Weiss, Phys. Rev. B 77, 041303 (2008).

[7] E. Paladino, Y. M. Galperin, G. Falci, and B. L. Altshuler, Rev. Mod. Phys. 86, 361 (2014).

[8] H.P. Breuer, E. Laine and J. Piilo, Phys. Rev. Lett. 103, 210401 (2009)

[9] C. Benedetti, M. G. A. Paris, and S. Maniscalco, Phys. Rev. A 89, 012114 (2014).

Abstract category

Quantum Optics

Primary author: CHIATTO, Giuseppe Emanuele (Università degli Studi di Catania)

Co-authors: PALADINO, Elisabetta (University of Catania, INFN Sez. Catania, CNR-IMM Catania); Dr CHIRIACÒ, Giuliano (University of Catania); FALCI, Giuseppe (University of Catania, INFN Sez. Catania, CNR-IMM Catania)

Presenter: CHIATTO, Giuseppe Emanuele (Università degli Studi di Catania)

Session Classification: Talks

Contribution ID: **20** Type: **Talk**

Attractive binary Bose mixtures at finite temperature

Monday, 6 May 2024 15:30 (30 minutes)

I will present recent results on the thermodynamic behavior of attractive binary Bose mixtures in three and two dimensions. The focus is on the regime of interspecies interactions where the ground state is in a self-bound liquid phase, stabilized by beyond mean-field effects. Monte Carlo computations at finite temperature and fixed density reveal a fascinating phase diagram, with a first order transition line separating the liquid and gas phases. Across this line, Bose-Einstein condensation occurs in a discontinuous way that could be observed in experiments of mixtures in traps. I will also characterize the tricritical point, where the first-order transition line ends, within the framework of Landau theory.

Abstract category

Numerical Methods

Primary author: SPADA, Gabriele

Co-authors: PILATI, Sebastiano (University of Camerino); GIORGINI, Stefano (University of Trento)

Presenter: SPADA, Gabriele

Session Classification: Talks

Contribution ID: **27** Type: **Talk**

Quantum optics with atoms and molecules

Tuesday, 7 May 2024 09:00 (1 hour)

Light-matter platforms are fundamental for a variety of applications in quantum information processing, among others [1].
At the level of pure electronic systems coupled solely to light, such as in the case of structured subwavelength arrays of quantum emitters trapped in optical lattices, I will describe the emergence of cooperative behavior: the optical response can be efficiently enhanced by controlling the hopping of surface excitations via the quantum electromagnetic vacuum induced dipole-dipole interactions.
I will then move to the case of single quantum emitters embedded in solid state platforms. Such emitters, when used in quantum sensing or as qubits, strongly suffer from decay and decoherence induced by their intrinsic complexity, such as is the case for molecules, where the electron is coupled to nuclear vibrations, or by their coupling to crystal phonons, as is the case for vacancy centers, quantum dots etc. I will provide a simple theoretical introduction of electron-vibron coupling [2] and discuss the physics on non-radiative relaxation brought on by non-adiabatic effects. This is aimed at understanding the limitations for the quantum efficiency of solid state based quantum emitters.

[1] M. Reitz, C. Sommer, and C. Genes, Cooperative Quantum Phenomena in Light-Matter Platforms, PRX Quantum 3, 010201 (2022).
[2] M. Reitz, C. Sommer and C. Genes, Langevin approach to quantum optics with molecules, Phys. Rev. Lett. 122, 203602 (2019).

Abstract category

Primary author: Prof. GENES, Claudiu (Max Planck Institute for the Science of Light)

Presenter: Prof. GENES, Claudiu (Max Planck Institute for the Science of Light)

Session Classification: Invited contributions

Contribution ID: **28** Type: **Talk**

Realization and Characterization of Topological States on Quantum Processors

Wednesday, 8 May 2024 09:00 (1 hour)

The interplay of quantum fluctuations and interactions can yield novel quantum phases of matter with fascinating properties. Understanding the physics of such systems is a very challenging problem as it requires to solve quantum many body problems—which are generically exponentially hard to solve on classical computers. In this context, universal quantum computers are potentially an ideal setting for simulating the emergent quantum many-body physics. In this talk, I will discuss two different classes of quantum phases: First, we consider symmetry protected topological (SPT) phases and show that a topological phase transition can be simulated using shallow circuits. We then utilize quantum convolutional neural networks (QCNNs) as classifiers and introduce an efficient framework to train them. Second, we focus on the realization of topological ordered phases and simulate the braiding of anyons. Taking into account additional symmetries, we then investigate phase transitions between different symmetry enriched topological (SET) phases.

Abstract category

Presenter: Prof. POLLMANN, Frank (Technische Universität München)

Session Classification: Invited contributions

Contribution ID: **29** Type: **Talk**

TBA

Thursday, 9 May 2024 09:00 (1 hour)

Abstract category

Presenter: Prof. WIEBE, Nathan (University of Toronto)

Session Classification: Invited contributions

Contribution ID: **32** Type: **Talk**

Recent advances in quantum communication and random number generation

Friday, 10 May 2024 09:00 (1 hour)

Within the last two decades, Quantum Technologies have made tremendous progress, from proof of principle demonstrations to real life applications, such as Quantum Key Distribution (QKD) and Quantum Random Number Generators (QRNGs). We will discuss the results that we have recently obtained in our group at the University of Padova towards the realization of secure QRNGs and mature and efficient QKD systems.

Abstract category

Presenter: Prof. VALLONE, Giuseppe (Università di Padova)

Session Classification: Invited contributions

Contribution ID: **33** Type: **Talk**

Quantum Photonics for applied quantum technologies

Friday, 10 May 2024 11:00 (1 hour)

Quantum technologies based on guided and integrated photonics represent a field in fully expansion due to the possibility of covering a wide panel of quantum light-based applications while exploiting system miniaturization to develop and test ambitious and scalable architectures. In this talk, I will present our results on the development of telecom-compatible photonics solutions, for immediate applicability to long-range quantum communication as well as for the investigation of more fundamental quantum optical aspects. In particular I will focus on multimode quantum light out of integrated optical sources as a key resource for light-based quantum applications. The generation, manipulation and detection of quantum states of light, coded on various degrees of freedom, will be discussed by presenting plug-n-play as well as integrated optics solutions relying on different technological platforms.

Abstract category

Presenter: Prof. D'AURIA, Virginia (Institut de Physique de Nice)

Session Classification: Invited contributions

Contribution ID: **34** Type: **Poster**

Light-matter interactions in the vacuum of ultra-strongly coupled systems

Tuesday, 7 May 2024 17:30 (1h 30m)

We theoretically study how the peculiar properties of the vacuum state of an ultra-strongly coupled system can affect basic light-matter interaction processes. In this unconventional electromagnetic environment, an additional emitter no longer couples to the bare cavity photons, but rather to the polariton modes emerging from the ultra-strong coupling, and the effective light-matter interaction strength is sensitive to the properties of the distorted vacuum state. Different interpretations of our predictions in terms of modified quantum fluctuations in the vacuum state and of radiative reaction in classical electromagnetism are critically discussed. Whereas our discussion is focused on the experimentally most relevant case of intersubband polaritons in semiconductor devices, our framework is fully general and applies to generic material systems.

Abstract category

Quantum Optics

Primary author: Dr DE BERNARDIS, Daniele (Ino-cnr)

Presenter: Dr DE BERNARDIS, Daniele (Ino-cnr)

Session Classification: Poster session

Contribution ID: **38** Type: **Poster contribution**

Integrated conversion and photodetection of virtual photons in an ultrastrongly coupled superconducting quantum circuit

Tuesday, 7 May 2024 17:30 (1h 30m)

The ground-state of an artificial atom coupled to quantized modes in the Ultra-Strong Coupling regime is entangled and contains an arbitrary number of virtual photons.
The problem of their detection, raised since the very birth of the field, still awaits experimental demonstration despite the theoretical efforts in the last decade.
In a recent work [1] it has been shown that experimental limitations can be overcome by leveraging an unconventional design of the artificial atom with advanced coherent control techniques.
In this work we study a simple scheme of control-integrated continuous measurement which makes remarkably favourable the tradeoff between measurement efficiency and backaction showing that the unambiguous detection of virtual photons can be achieved within state-of-the art quantum technologies [2].
Work supported by the PNRR MUR project PE0000023-NQSTI

[1] L. Giannelli et al. "Detecting virtual photons in ultrastrongly coupled superconducting quantum circuits". In: Phys. Rev. Res. 6 (1 Jan. 2024), p. 013008. doi: 10.1103/PhysRevResearch.6.013008. url: https://link.aps.org/doi/10.1103/PhysRevResearch.6.013008.
[2] Luigi Giannelli et al. "Integrated conversion and photodetection of virtual photons in an ultrastrongly coupled superconducting quantum circuit". en. In: The European Physical Journal Special Topics (Sept. 2023). issn: 1951-6355, 1951-6401. doi: 10.1140/epjs/s11734-023-009890. url: https://link.springer.com/10.1140/epjs/s11734-023-00989-0 (visited on 11/17/2023).

Abstract category

Quantum Simulations

Primary author: GIANNELLI, Luigi (University of Catania, INFN Sez. Catania)

Co-authors: Mr ANFUSO, Giorgio (Università degli studi di Catania); GRAJCAR, Miroslav (Department of Experimental Physics, Comenius University, SK-84248 Bratislava, Slovakia); PARAOANU, Gheorghe Sorin (QTF Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland); PALADINO, Elisabetta (University of Catania, INFN Sez. Catania, CNR-IMM Catania); FALCI, Giuseppe (University of Catania, INFN Sez. Catania, CNR-IMM Catania)

Presenter: Mr ANFUSO, Giorgio (Università degli studi di Catania)

Session Classification: Poster session

Contribution ID: **39** Type: **Talk**

Data-driven self-calibration of quantum circuits

Tuesday, 7 May 2024 15:00 (30 minutes)

Any circuit is in one-to-one correspondence with a logical table that specifies, upon any given input state, what the output state of the ideal circuit should be. Since classical states are perfectly distinguishable in principle, at least at a fundamental level the calibration of classical circuits does not therefore present any difficulty. This is in stark contrast with the quantum case where, due to the existence of superposition of states, neither input nor output states can in general be jointly distinguished perfectly, thus rendering the calibration of quantum circuits a problem in principle.

Here, we address this fundamental issue by adopting a Bayesian approach to the calibration of quantum circuits that is data-driven, i.e. it avoids any assumption on the quantum description of the states input and output of the circuit, and solely relies on correlations between their classical labels, thus de facto representing a self-calibration of the circuit. In particular, our approach automatically inherits from Bayes theorem an Occam's razor-like minimality criterion that favors the simplest inference that is consistent with the observations. We show that data-driven self-calibration is equivalent to a particular clustering problem in the correlation space that can be solved adopting John's theory on minimum volume enclosing ellipsoids.

This presentation is based on:
[1] M. Dall'Arno, On the role of designs in the data-driven approach to quantum statistical inference, arXiv:2304.13258.
[2] M. Dall'Arno, F. Buscemi, A. Bisio, and A. Tosini, Data-Driven Inference, Reconstruction, and Observational Completeness of Quantum Devices, Phys. Rev. A 102, 062407 (2020).
[3] M. Dall'Arno and F. Buscemi, Data-Driven Inference of Physical Devices: Theory and Implementation, New J. Phys. 21, 113029 (2019).
[4] M. Dall'Arno, S. Brandsen, F. Buscemi, and V. Vedral, Device-independent tests of quantum measurements, Phys. Rev. Lett. 118, 250501 (2017).

Abstract category

Other

Primary author: DALL'ARNO, Michele (Toyohashi University of Technology, Aichi-ken, Japan)

Presenter: DALL'ARNO, Michele (Toyohashi University of Technology, Aichi-ken, Japan)

Session Classification: Talks

Contribution ID: **40** Type: **Poster contribution**

A semi-device-independent approach to quantum simulability

Tuesday, 7 May 2024 17:30 (1h 30m)

Quantum statistical models (i.e., families of normalized density matrices) and quantum measurements (i.e., positive operator-valued measures) can be regarded as linear maps: the former, mapping the space of effects to the space of probability distributions; the latter, mapping the space of states to the space of probability distributions. The images of such linear maps are called the testing regions of the corresponding model or measurement. Testing regions are notoriously impractical to treat analytically in the quantum case.

Our first result is to provide an implicit outer approximation of the testing region of any given quantum statistical model or measurement in any finite dimension: namely, a region in probability space that contains the desired image, but is defined implicitly, using a formula that depends only on the given model or measurement. The outer approximation that we construct is minimal among all such outer approximations, and close, in the sense that it becomes the maximal inner approximation up to a constant scaling factor. Finally, we apply our approximation formulas to characterize, in a semi-device independent way, the ability to transform one quantum statistical model or measurement into another.

This presentation is based on:
[1] M. Dall'Arno and F. Buscemi, Tight conic approximation of testing regions for quantum statistical models and measurements, arXiv:2309.16153.
[2] M. Dall'Arno, F. Buscemi, and V. Scarani, Extension of the Alberti-Ulhmann criterion beyond qubit dichotomies, Quantum 4, 233 (2020).

Abstract category

Other

Primary author: DALL'ARNO, Michele (Toyohashi University of Technology, Aichi-ken, Japan)

Co-author: Prof. BUSCEMI, Francesco (Nagoya University, Japan)

Presenter: DALL'ARNO, Michele (Toyohashi University of Technology, Aichi-ken, Japan)

Session Classification: Poster session

Contribution ID: **41** Type: **Talk**

Ground-state bistability of cold atoms in a cavity

Thursday, 9 May 2024 12:00 (30 minutes)

We experimentally demonstrate an optical bistability between two hyperfine ground states of trapped, cold atoms, using a single mode of an optical resonator in the collective strong coupling regime. Whereas in the familiar case, the bistable region is created through atomic saturation, we report an effect between states of high quantum purity, which is essential for future information storage. The source of nonlinearity is a cavity-assisted pumping between ground states of the atoms and the stability depends on the intensity of two driving lasers. We interpret the phenomenon in terms of the recent paradigm of first-order, driven-dissipative phase transitions, where the transmitted and driving fields are understood as the order and control parameters, respectively. A semiclassical mean-field theory is invoked to describe the nontrivial two-dimensional phase diagram arising from the competition of the two drive. The saturation-induced bistability is recovered for infinite drive in one of the controls. The order of the transition is confirmed experimentally by hysteresis in the order parameter when either of the two control parameters is swept repeatedly across the bistability region. [1]

[1] B. Gábor, D. Nagy, A. Dombi, T. W. Clark, F. I. B. Williams, K. V. Adwaith, A. Vukics, and P. Domokos Phys. Rev. A 107, 023713

Abstract category

Quantum Optics

Primary authors: GÁBOR, Bence (HUN-REN Wigner RCP); Dr NAGY, Dávid (HUN-REN Wigner RCP); Dr DOMBI, András (HUN-REN Wigner RCP); Dr CLARK, Thomas W. (HUN-REN Wigner RCP); Dr WILLIAMS, Francis (HUN-REN Wigner RCP); Dr ADWAITH, Kalluvayal Varooli (HUN-REN Wigner RCP); Dr VUKICS, András (HUN-REN Wigner RCP); Dr DOMOKOS, Péter (HUN-REN Wigner RCP)

Presenter: GÁBOR, Bence (HUN-REN Wigner RCP)

Session Classification: Talks

Contribution ID: **42** Type: **Poster contribution**

Qutrit quantum battery: comparing different charging protocols

Tuesday, 7 May 2024 17:30 (1h 30m)

In recent years, the investigation of quantum systems out of equilibrium contributed to the advancement of quantum thermodynamics. In particular, the study of quantum batteries, small quantum mechanical systems able to temporarily store energy and further release it on-demand, recently emerged as a fast-growing subject in this field.
In this framework we have characterized the performances of IBM quantum devices, based on superconducting circuits in the transmon regime, as quantum batteries, establishing the optimal compromise between charging time and stored energy [1].
Considering this result, motivated by recent experimental observations [2] and encouraged by the the growing interested in exploring systems with more then two levels also in the framework of quantum computing, we have investigated the possibility of realizing charging protocols addressing two excited states of a superconducting qubit in the transmon regime, namely realizing a qutrit quantum battery [3]. This extension allows to store a greater amount of energy in the system and opens the door to a richer variety of charging protocols. We have compared two different charging protocols: in the first case the complete charging is achieved through the application of two sequential pulses, while in the second the charging occurs in a unique step applying the two pulses simultaneously. The latter approach is characterized by a shorter charging time, and consequently by a greater charging power. Moreover, both protocols are analytically solvable leading to a complete control of the dynamics of the quantum system and opening new perspectives in the manipulation of the so called qutrits. To support this analysis we have tested both protocols on IBM quantum devices. The minimum achieved charging time represents the fastest stable charging reported so far in solid state quantum batteries.

[1] G. Gemme et al., Ibm quantum platforms: A quantum battery perspective, Batteries 8, 10.3390/batteries8050043 (2022)
[2] C.-K. Hu et al., Optimal charging of a superconducting quantum battery, Quantum Science and Technology 7, 045018 (2022)
[3] G. Gemme et al., Qutrit quantum battery: comparing different charging protocols, arXiv:2306.14537 (2023)

Abstract category

Quantum Simulations

Primary author: GEMME, Giulia (Università degli studi di Genova)

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Presenter: GEMME, Giulia (Università degli studi di Genova)

Session Classification: Poster session

Contribution ID: **43** Type: **Poster**

Enhancing energy storage crossing quantum phase transitions in an integrable spin quantum battery

Tuesday, 7 May 2024 17:30 (1h 30m)

We investigate the performance of a one dimensional dimerized XY chain as a quantum battery. Such integrable model shows a rich quantum phase diagram which emerges through a mapping of the spins into auxiliary fermionic degrees of freedom. We consider a charging protocol relying on the double quench of an internal parameter, notably the strength of the dimerization. Within this picture we observe a substantial enhancement of the energy stored per spin as a consequence of driving the system across certain quantum phase transitions.

R. Grazi, D. Sacco Shaikh, M. Sassetti, N. Traverso Ziani, D. Ferraro, arXiv:2402.09169

Abstract category

Quantum Simulations

Primary authors: Mr SACCO SHAIKH, Daniel (Università degli studi di Genova); Prof. FERRARO, Dario (Università degli studi di Genova); Prof. SASSETTI, Maura (Università degli studi di Genova); Dr TRAVERSO ZIANI, Niccolò (Università degli studi di Genova); GRAZI, Riccardo (Università degli studi di Genova)

Presenter: GRAZI, Riccardo (Università degli studi di Genova)

Session Classification: Poster session

Contribution ID: **47** Type: **Poster**

Does a good quantum tomography bring a good quantum metrology?

Tuesday, 7 May 2024 17:30 (1h 30m)

This study is concerned with the investigation of the continuity of Quantum Fisher Information (QFI) between two states, one experimentally generated , σ=(σ,∂_x σ), and one theoretically derived, ρ=(ρ,∂_x ρ), in different systems such as qubits, exponential density matrices and noise-free quantum dynamics [1, 2, 3, 4].
In quantum parameter estimation, the QFI exhibits universal continuity, where neighboring states with similar derivatives have nearly equal QFIs [1, 5, 6]. This property, independent of the dynamics or the form of parameter detection, extends the classical Fisher information concept to density matrices [7, 8, 9].
The investigation aims at determining the minimum error and defining the lower bound for ΔF^Q=|F^Q (ρ)-F^Q (σ)|. Calculations of the relative error are discussed, ranging from Δ_min to Δ_max indicating that if the ΔF^Q values are close to each other, the relative error has been adequately accounted for in the experimental calculations; otherwise, recalibration may be required [1, 10].
References

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Abstract category

Quantum Simulations

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Presenter: Dr EBRAHIMI ASLMAMAGHANI, Samira (university of palermo)

Session Classification: Poster session

Contribution ID: **48**   Type: **Talk**

Algebraic techniques for quantum computing in quantum chemistry

Thursday, 9 May 2024 14:00 (1 hour)

Quantum chemistry problem is one of the attractive targets for demonstrating quantum advantage of quantum computing technology. Having strongly correlated systems as the main target, I would like to discuss what new classical computing techniques need to be developed to help quantum computing algorithms to solve the electronic structure problem. Encoding the electronic Hamiltonian in the second quantized form on a quantum computer is not a trivial problem, and its efficiency can become a bottleneck for the entire quantum solution. Dealing with this Hamiltonian can be facilitated by partitioning it into a sum of fragments diagonalizable using rotations from either small Lie groups or the Clifford group. These fragments are convenient for performing various algebraic manipulations required in circuit compiling and quantum measurement. I will illustrate how the Hamiltonian partitioning can be used to improve performance of several quantum algorithms for quantum chemistry (e.g. Variational Quantum Eigensolver and Quantum Phase Estimation).

Abstract category

Presenter: Prof. IZMAYLOV, Artur (University of Toronto)

Session Classification: Invited contributions

Contribution ID: **49** Type: **Poster contribution**

Solving the homogenous Bethe-Salpeter equation with a quantum annealer

Tuesday, 7 May 2024 17:30 (1h 30m)

The purpose of this work is to use a Quantum Annealer (QA) to solve the homogeneous Bethe-Salpeter equation (hBSE)[1] for two massive scalars interacting via the exchange of a massive scalar, a problem previously addressed with classical computation [2]. To achieve this, we transform the hBSE,by a suitable discretization, into a non-symmetric generalized eigenvalue problem (GEVP) (see Ref. [2] for details) from which we need to determine the maximum real eigenvalues along with their corresponding eigenvectors. This involves solving a quadratic minimization problem, which, after transformation into a Quadratic Unconstrained Binary Optimization (QUBO) form, becomes manageable by the QA.

We have developed a hybrid algorithm for this task. First, we reduce the non-symmetric GEVP to a standard eigenvalue problem classically. Then, we employ the QA to solve the variational problem. Drawing inspiration from approaches for symmetric matrices [3], we generalize the algorithm to accommodate the non-symmetric case, which involves complex eigenvalues (see Ref. [4] for details). Notably, the GEVP is a problem of broad interest across various fields, thus the results obtained could have wide-reaching implications.

We benchmark and analyze the statistical distribution of results using different parameters of the algorithm, employing a simulated annealing sampler (SA)[5].After that, very nice results for the target eigenpair have obtained by using a quantum annealer provided by D-Wave Systems, thanks to the D-Wave-CINECA agreement[6], as part of an international project approved by Q@TN (INFN-UNITN-FBK-CNR)[7]. We investigate how the algorithm's performance scales with the dimension of the matrices involved by comparing results obtained with QA and SA.

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[7] https://quantumtrento.eu/

Abstract category

Numerical Methods

Primary authors: ROGGERO, Alessandro; GNECH, Alex; FORNETTI, Filippo (Università degli Studi di Perugia, INFN Sezione di Perugia); PEDERIVA, Francesco; SALME', Giovanni; RINALDI, Matteo; VIVIANI, Michele; FREDERICO, Tobias; SCOPETTA, sergio

Presenter: FORNETTI, Filippo (Università degli Studi di Perugia, INFN Sezione di Perugia)

Session Classification: Poster session

Contribution ID: **51** Type: **Talk**

Quantum technologies with atomic systems

Monday, 6 May 2024 14:30 (1 hour)

Ultracold atoms and trapped ions are among the most promising platforms for implementing quantum technologies. On the one hand, neutral atoms form large ensembles of particles that behave coherently at ultra-low temperatures and can be individually confined using optical tweezers. On the other hand, trapped ions form much smaller clouds that can be controlled at the single-particle level. Moreover, the typical depth of the electrical potential used to confine ions ensures a long particle lifetime, with coherence times exceeding one hour having been reported.

In my talk, I will provide an overview of the most recent results and current challenges in the physics of atoms and ions within the quantum technology framework. I will discuss the principles of the methodologies used to manipulate, detect, and entangle ultracold atoms and trapped ions. Finally, I will introduce atom-ion hybrid systems, where ultracold atoms and trapped ions are confined together and made to interact. I will explain how atom-ion interactions represent a promising new tool in quantum technologies.

Abstract category

Presenter: Dr SIAS, Carlo (LENS, INRIM)

Session Classification: Invited contributions

Contribution ID: **52** Type: **Talk**

Quantum Information Perspective on the Ground State Problem: What is Electron Correlation?

Tuesday, 7 May 2024 14:00 (30 minutes)

Describing strongly interacting electrons is one of the crucial challenges of modern quantum physics. A comprehensive solution to this electron correlation problem would simultaneously exploit both the pairwise interaction and its spatial decay. By taking a quantum information perspective, we explain how this structure of realistic Hamiltonians gives rise to two conceptually different notions of correlation and entanglement. The first one describes correlations between orbitals while the second one refers more to the particle picture. We illustrate those two concepts of orbital and particle correlation and present measures thereof. Our results for different molecular systems reveal that the total correlation between molecular orbitals is mainly classical, raising questions about the general significance of entanglement in chemical bonding. Finally, we also speculate on a promising relation between orbital and particle correlation and explain why this may replace the obscure but widely used concept of static and dynamic correlation.

Abstract category

Presenter: SCHILLING, Christian (LMU Munich)

Session Classification: Talks

Contribution ID: **54** Type: **Talk**

Optimal and Variational Quantum Metrology

Tuesday, 7 May 2024 15:30 (30 minutes)

Quantum sensors are an established technology that has opened up new possibilities for precision sensing in various scientific fields. The use of entanglement for quantum-enhancement is paving the way for the development of next-generation sensors that can reach the ultimate precision limits set by quantum physics. However, determining how state-of-the-art sensing platforms may be used to converge to these ultimate limits is an outstanding challenge. In this talk, I will discuss how concepts from the field of quantum information processing can be merged with metrology to implement experimentally a *programmable quantum sensor* that operates near the fundamental quantum mechanical limits. Looking forward, I will briefly discuss how the principles of variational quantum metrology can be expanded and applied to the Fisher framework for many-measurement scenarios and multiparameter sensing.

Abstract category

Presenter: Dr VASILYEV, Denis (University of Innsbruck / Institut für Quanteninformation)

Session Classification: Talks

Contribution ID: **55** Type: **Poster contribution**

Utilizing quantum computing for mechanistic modeling of reactions in hydrogen fuel cells.

Tuesday, 7 May 2024 17:30 (1h 30m)

Fuel cells offer an elegant means of harnessing the chemical energy stored within the bonds of hydrogen and oxygen, converting it into electrical energy. However, existing fuel cell technologies suffer by a significant overpotential during the oxygen reduction reaction (ORR) at the cathode. Given hydrogen's pivotal role as a promising low-carbon and sustainable fuel for the future, there is a growing endeavour to simulate its reactivity under various operational conditions and using diverse catalysts.

In this context, we explore of the cathodic reduction of oxygen employing quantum computing techniques. Our approach involves modelling the reaction pathways and determining energy levels through multiconfigurational methods, all structured within a NISQ-friendly workflow. We adopt a Variational Quantum Eigensolver strategy, leveraging the Unitary Coupled Cluster Singles and Doubles ansatz wavefunction within a compact active orbital space to capture static correlation energy. Subsequently, we measure the expectation value of energy and reduced density matrices enabling us to perform the perturbation expansion necessary for capturing dynamical correlation on a classical computer.

We demonstrate that the catalyst's structure significantly impacts the reaction pathway of the ORR, as well as the electronic wavefunction's nature, which becomes highly correlated when a sublayer of cobalt is introduced beneath the surface of platinum. This scenario presents an ideal opportunity for quantum computers, as they may offer advantages over conventional strongly correlated methodologies.

Abstract category

Quantum Chemistry

Primary author: Dr DI PAOLA, Cono (Quantinuum)

Co-author: MARSILI, Emanuele

Presenter: MARSILI, Emanuele

Session Classification: Poster session

Contribution ID: **59** Type: **Poster contribution**

Classical shadows with Brownian quantum circuits

Tuesday, 7 May 2024 17:30 (1h 30m)

Classical shadows are a powerful method for learning many properties of quantum states in a sample-efficient manner, by making use of randomized measurements. Random local Pauli measurements [1] and shallow shadows [2–4] provide optimal protocols for estimating expectation values of local observables.
On the contrary, the Clifford global-twirling protocol [1] is optimal for estimating global quantities such as pure-state fidelity or the system's purity. However, this protocol may be difficult to implement in practice, due to the need to apply a global random unitary U.
In this work, we are interested in classical shadow protocols based on Brownian quantum circuits [5], which may be implemented using two-qubit gates only. We put forward a very simple approximate estimation scheme which, for a deep enough circuit, performs similarly to the global-twirling protocol, without the need to apply global unitary operators. We support this scheme with a systematic numerical study of its validity and performance.

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Abstract category

Quantum Simulations

Primary author: CIOLI, Riccardo (University of Bologna)

Co-authors: Prof. ERCOLESSI, Elisa (University of Bologna); Dr PIROLI, Lorenzo (University of Bologna)

Presenter: CIOLI, Riccardo (University of Bologna)

Session Classification: Poster session

Contribution ID: **61** Type: **Talk**

Towards a quantum-limited, broadband amplifier for the readout of superconducting qubit arrays

Monday, 6 May 2024 17:00 (30 minutes)

Parametric amplifiers have become indispensable for superconducting qubit readout. While Josephson Parametric Amplifiers (JPAs) are an established technology providing noise performance reaching the standard quantum limit (SQL), their severely limited bandwidth restricts their utility to the multiplexed readout of only a few qubits at the same time. The demand for scaling current qubit systems to larger arrays with low error rates, necessary for implementing error correction schemes towards fault-tolerant quantum computation, has determined the emergence of Traveling Wave Parametric Amplifiers (TWPAs), offering both near quantum-limited amplification and gigahertz bandwidths. Specifically, Josephson Junction-based TWPAs (J-TWPAs) are now commonly employed in qubit readout chains, with some even making their way into commercial products in recent years. However, Kinetic Inductance Traveling Wave Parametric Amplifiers (KI-TWPAs), which leverage the nonlinearity of high kinetic inductance materials, promise further enhancements. Maintaining high gain and low noise, KI-TWPAs also feature remarkably high dynamic range, up to 40 dB greater than J-TWPAs, and are relatively simple to fabricate, requiring only few lithography and etching steps without overlapping structures. Additionally, they exhibit resilience to high magnetic fields and can operate at temperatures up to 4 K, making them also potentially suitable for spin-qubit readout, axion search, and space applications. The DARTWARS project aims to develop KI-TWPAs with high gain, large bandwidth, and SQL noise performance. The work here presented addresses the ongoing efforts within DARTWARS to advance KI-TWPAs for the readout of superconducting qubits, which include the characterization of the first prototypes produced at FBK, as well as advancements in transmission line modeling techniques and in the design of readout chains suitable for amplifying the weak signals emitted by qubits.

Abstract category

Other

Primary author: CAMPANA, Pietro

Presenter: CAMPANA, Pietro

Session Classification: Talks

Contribution ID: **62** Type: **Poster contribution**

Simulations of effective Hamiltonians to study the effects of non-computational levels of two coupled qubits via a cavity bus

Tuesday, 7 May 2024 17:30 (1h 30m)

<h3>Abstract</h3>

Superconducting quantum circuits stand out as a prominent platform for quantum computers. The most diffused qubit design is the transmon qubit, a type of charge qubit that operates at a significantly different ratio of Josephson energy (E_J) to charging energy (E_C). This unique feature exponentially reduces the sensitivity to $1/f$ charge noise without increasing the sensitivity to other noise sources. Nonetheless, the transmon limit decreases, with a slow power law in E_J/E_C, the anharmonicity that is necessary to prevent qubit operations from exciting non-computational levels.

Although single-qubit operations are well established, two-qubit gates demand greater design, precision, and control. Various architectures have been explored to facilitate these operations: transmon qubits interconnected via capacitive coupling are constrained to local interactions, limiting coupling to nearest-neighbor qubits. A more reliable solution lies in implementing a cavity bus, a distributed circuit element enabling non-local coupling among multiple qubits. However, when qubits are connected, always-on parasitic interactions affect the fidelity of multi-qubit gates. In addition, the small anharmonicity of the transmon regime can cause transitions between computational and non-computational levels to be inevitable. Sometimes, this interaction is wanted and should be strengthened to perform the desired entanglement. Most of the time it is unwanted and sets limits to the error correction algorithms. More precisely, the parasitic interaction accumulates phase error in the computational states and eventually destroys the multi-qubit gates. Therefore, it must be carefully suppressed during the gate operations. Particularly, the parasitic ZZ interaction between a pair of transmon qubits is a limiting factor for two-qubit gates and quantum error correction. Although the ZZ interaction is always one or two orders of magnitude weaker than the coupling strength, it degrades the performance of many quantum gates.

One of the objectives of the Qub-IT project is the development of a chip with two coupled qubits via a cavity bus. To reach this goal, a preliminary study of the case is conducted to identify optimal parameters for the chip design to reduce the known parasitic effects due to the presence of non-computational levels of each transmon. We performed several simulations using QuTiP, an open-source software for simulating the dynamics of open quantum systems, to model the circuit Hamiltonian. These simulations exploit a perturbative method known as the Schrieffer-Wolff transformation, which helps to decouple lower-energy dynamics from higher-energy degrees of freedom through a unitary transformation, resulting in an effective Hamiltonian. Starting from this Hamiltonian, studies of the parameters of interest such as transmon and cavity frequencies, anharmonicities, coupling constants, etc. are performed to minimize these parasitic effects.

<h3>Acknowledgments</h3>

This work is supported by the Italian Institute of Nuclear Physics (INFN), through the Technological and Interdisciplinary Research Commission (CSN5) under the Qub-IT project, and from PNRR MUR projects PE0000023-NQSTI and CN00000013-ICSC.

Abstract category

Other

Primary author: GOBBO, Marco (University of Milano-Bicocca / INFN)

Presenter: GOBBO, Marco (University of Milano-Bicocca / INFN)

Session Classification: Poster session

Contribution ID: **63** Type: **Poster contribution**

Open-source control of quantum devices via RFSoC FPGAs

Tuesday, 7 May 2024 17:30 (1h 30m)

Abstract

The control of superconducting qubits demands advanced instruments and software capable of handling rapid pulses with arbitrary waveforms across microwave frequencies. Traditionally, achieving such precision involved up and down-conversion techniques, merging lower-frequency pulses with higher-frequency tones. This approach often requires multiple instruments per qubit, presenting scalability challenges for larger chip designs. Several companies have therefore engineered their own hardware solutions, selling all essential components into single boxes with FPGAs for coordinating the instruments. Despite their apparent convenience, these off-the-shelf products lack flexibility and are often cost-prohibitive for research laboratories.

In recent years, Radio Frequency System on Chip (RFSoC) FPGAs have emerged as robust alternatives to conventional up/down-conversion schemes. These RFSoC boards are highly customizable, making them versatile tools for both general-purpose and quantum applications. Notably, RFSoC boards allow for direct pulse synthesis within the gigahertz range, which is where resonance and qubit frequencies typically are. The use of RFSoC boards also provides a huge simplification of the experimental setup: indeed, a single board can be the sole instrument required to control multiple qubits.
For Quantum Control, the research community achieved open firmware through the QICK (Quantum Instrumentation Control Kit) project by FNAL (Fermi National Accelerator Laboratory.) Presently, QICK provides firmware for various RFSoC boards manufactured by Xilinx, allowing control of up to 7 qubits with a single instrument.

Over the past year, we have developed an open-source software named Qibosoq to augment the functionalities of QICK. Qibosoq integrates the FPGA platforms supported by QICK into the Qibo framework, an open-source project that provides fast simulation tools for quantum circuits, as well as various tools for controlling and calibrating self-owned qubits. In particular, one of the components of Qibo is Qibolab, which aims to provide researchers a common frontend to control custom quantum processing units independently from the lab setup and the controller instrument. At the moment, various commercial instruments are supported, as well as all the QICK-supported RFSoC boards, through Qibosoq.
Through the Qibo integration, it is straightforward to launch both pulse-based experiments and circuit-based algorithms on self-owned qubits.

Extensive testing of Qibosoq across all three RFSoC boards supported by QICK has yielded promising results, effectively characterizing both flux-tunable and non-tunable qubits with fidelities competitive against those obtained through commercial instruments. Moreover, Qibosoq has been successfully employed in a Quantum Machine Learning demonstration.

Acknowledgements

This work is supported by Qub-IT, a project funded by the Italian Institute of Nuclear Physics (INFN) within the Technological and Interdisciplinary Research Commission (CSN5), and PNRR MUR projects PE0000023-NQSTI and CN00000013-ICSC.
This work was supported by the Technology Innovation Institute (TII) of Abu Dhabi.

Abstract category

Other

Primary author: CAROBENE, Rodolfo (UNIMIB / INFN)

Presenter: CAROBENE, Rodolfo (UNIMIB / INFN)

Session Classification: Poster session

Contribution ID: **64** Type: **Poster**

Genuine multipartite entanglement in Quantum Annealing

Tuesday, 7 May 2024 17:30 (1h 30m)

Generating bipartite entanglement in quantum computing technologies is widely regarded as a pivotal benchmark. However, multipartite entanglement can appear when solving a complicated optimization problem where the correlation between multiple qubits is beneficial. Understanding whether such entanglement contributes to achieving a feasible solution is crucial from both algorithmic and hardware standpoints. Here, we tackle this query by analyzing genuine multipartite entanglement generated in quantum annealing with respect to its occurrence in the annealing schedule and how the quantitative value correlates to the algorithm's success probability.

Abstract category

Quantum Simulations

Primary author: SANTRA, Gopal Chandra (Universität Heidelberg, Germany)

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Presenter: SANTRA, Gopal Chandra (Universität Heidelberg, Germany)

Session Classification: Poster session

Contribution ID: **67** Type: **Poster**

Development of cross-type Al/Al-Ox?Al Josephson junctions

Tuesday, 7 May 2024 17:30 (1h 30m)

Josephson junctions are one of the fundamental building blocks of superconducting quantum devices. With applications ranging from circuit quantum electrodynamics experiments to quantum information processing and quantum sensing, reliable and reproducible devices, and related microfabrication processes, represent a corner stone for every experimental group in the field. There are different microfabrication approaches to produce Josephson junctions, i.e. the trilayer process, the Dolan shadow evaporation, the cross-type junction. The trilayer process allows for high quality junctions but involves many lithography steps and both metal and dielectric deposition/patterning. On the other hand, shadow evaporation has dominated the quantum computing community since, with a single e-beam lithography, few tens of nanometer wide junctions can be produced, allowing for critical currents in the order of tens of nA, facing however sever geometrical limitations. Our effort at Fondazione Bruno Kessler focuses on the development of cross-type Al/Al-Ox/Al Josephson junctions. This method allows for scalability and high geometrical flexibility. Cross junction can be fabricated with just two optical lithography steps and relatively low resources while still reaching state-of-the-art performances. Here we outline the microfabrication process that we have developed, which includes: first layer Al sputtering and relative lithography patterning followed by wet etching of the unwanted metal, then a second layer lithographic definition, followed by the oxidation step to create the junction barrier and, in the end, the second layer Al sputtering and relative lift-off. We then describe our results starting from room temperature DC measurements for different oxidation doses and the cryogenic characterization. By tuning the oxidation dose, specific normal resistance values between 150 Ωμm2 and 5 kΩμm2, corresponding to critical current density values between 50 μA/μm2 and 150 nA/μm2, can be reached. These results imply a large flexibility in the critical current tuning, allowing for a wide range of applications. Finally, we demonstrate the process validity via the characterization of a Josephson parametric amplifier, comprising a planar microwave resonator terminated by two Josephson junctions in parallel. We also investigate towards possible post processing methods to decrease the junctions critical current and to bypass the resolution limitations of optical lithography via thermal annealing, reaching critical current density values in the order of 50 nA/μm2.

Abstract category

Presenter: IRACE, Alessandro (Fondazione Bruno Kessler / Università Bicocca)

Session Classification: Poster session

Contribution ID: **68** Type: **Talk**

Quantum dynamics and entanglement in non-Markovian systems

Tuesday, 7 May 2024 10:00 (30 minutes)

The study of the dynamics of open quantum systems is of great importance both for the theoretical implications and for the practical applications to quantum technologies. While the Markovian regime is a good approximation in most cases, many systems and environments display a non-Markovian behavior. In this talk, I will present some work done on the dynamics of non-Markovian systems, including random unitary circuits and free fermionic ladders. Interestingly, non-Markovian systems exhibit a range of phenomena, including a transition of the entanglement, monogamy effects and more.

Abstract category

Presenter: CHIRIACÒ, Giuliano (Università di Catania)

Session Classification: Talks

Contribution ID: **69** Type: **Poster**

Shallow NV- colour centres in diamond

Tuesday, 7 May 2024 17:30 (1h 30m)

Negatively charged Nitrogen-Vacancy (NV-) colour centre in diamond is a well-known and characterized point defect with notable properties such as photostable bright fluorescence and spin states that can be initialised and read out, making it of great appeal for quantum technology applications.

Specifically, the latter can benefit from forming NV- defects in the proximity of the diamond surface. As an example, for nuclear magnetic resonance (NMR) sensing, it is necessary to have the NV- spins close to the surface as the coupling strength between magnetic dipoles decreases with the distance of the defects from the surface1,2. Shallow NV- defects can also be easily coupled with nanophotonic cavities for photon extraction. Furthermore, shallow NV- can be beneficial also in the biomedical field since the proximity to the surface allows the coupling with biomaterials for sensing applications, such as nano thermometry.

Our study focused on creating shallow and low-density NV defects in a CVD epitaxial diamond ('electronic grade') using 30 keV broad beam nitrogen ion implantation and subsequent thermal annealing. In particular, to produce shallow distributions of NV-, the implantation was carried out through a screen layer deposited on the diamond surface before the irradiation3. The screen layer makes possible to tune both the nitrogen depth distribution and the actual fluence reaching the diamond surface while keeping a good acceleration of the ions and a bright beam. Furthermore, using an amorphous screen layer, it is also possible to prevent ion channelling effects that would hinder the formation of a shallow distribution. At this aim, a 100 nm layer of SiO2 was deposited by CVD on the diamond surface to act as a screen layer. Ion energy and incidence angles were tuned in order to have nitrogen ions implanted in the top 10-20 nm of the diamond, while several fluences were tested in order to achieve the desired N concentrations.

After annealing at 1000℃ for three hours in ultra-high vacuum, we optically characterised the implanted samples by Raman and photoluminescence (PL) analysis, while angle-resolved x-ray photoemission spectroscopy revealed a distribution of implanted ions confined in the first 15 nm depth below the surface for the sample with the most intense PL signal.

References

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2. H. Yamano et al., Jpn. J. Appl. Phys., 56 (2017), 04CK08
3. K. Ito et al., Appl. Phys. Lett., 110 (2017), 213105

Abstract category

Presenter: MISSALE, Elena (Fondazione Bruno Kessler)

Session Classification: Poster session

Contribution ID: **72** Type: **Talk**

Dicke superradiant enhancement of the heat current in circuit QED

Tuesday, 7 May 2024 11:30 (30 minutes)

Collective effects, such as Dicke superradiant emission, can enhance the performance of a quantum device. Here, we study the heat current flowing between a cold and a hot bath through an ensemble of N qubits, which are collectively coupled to the thermal baths. We find a regime where the collective coupling leads to a quadratic scaling of the heat current with N in a finite-size scenario. Conversely, when approaching the thermodynamic limit, we prove that the collective scenario exhibits a parametric enhancement over the non-collective case. We then consider the presence of a third uncontrolled {\it parasitic} bath, interacting locally with each qubit, that models unavoidable couplings to the external environment. Despite having a non-perturbative effect on the steady-state currents, we show that the collective enhancement is robust to such an addition. Finally, we discuss the feasibility of realizing such a Dicke heat valve with superconducting circuits. Our findings indicate that in a minimal realistic experimental setting with two superconducting qubits, the collective advantage offers an enhancement of approximately 10% compared to the non-collective scenario

Presenter: ANDOLINA, Gian Marcello (College de France, Paris.)

Session Classification: Talks

Contribution ID: **75** Type: **Talk**

Automated Active Space Selection Using Large Language Models

The Multi-Reference Electronic Structure Theory involves choosing an active space with knowledge of the subspace's spatial and energetic information within the Hilbert space of a molecular electronic Hamiltonian that exhibits strong correlation. This process can be automated with the help of an AI assistant. This paper presents such an assistant that utilizes tools like the Approximate Pair Coefficient (APC) and the Atomic Valence Active Space (AVAS). Additionally, the assistant has a fine-tuned Large Language Model that can determine the active space required for a given molecular state with informed decisions.

Primary author: CHAKRABORTY, Romit (University of Chicago, University of California, Berkeley)

Presenter: CHAKRABORTY, Romit (University of Chicago, University of California, Berkeley)

Session Classification: Talks

Contribution ID: **77** Type: **Talk**

Statistical evaluation and optimization of entanglement purification protocols

Wednesday, 8 May 2024 11:00 (30 minutes)

Quantitative characterization of two-qubit entanglement purification protocols is introduced. Our approach is based on the concurrence and the hit-and-run algorithm applied to the convex set of all two-qubit states. We demonstrate that pioneering protocols are unable to improve the estimated initial average concurrence of almost uniformly sampled density matrices, however, as it is known, they still generate pairs of qubits in a state that is close to a Bell state. We also develop a more efficient protocol and investigate it numerically together with a recent proposal based on an entangling rank-two projector. Furthermore, we present a class of variational purification protocols with continuous parameters and optimize their output concurrence. These optimized algorithms turn out to surpass former proposals and our new protocol by means of not wasting too many entangled states.

Presenter: PRETI, Francesco (FZJ)

Session Classification: Talks

Contribution ID: **78** Type: **Talk**

Early Fault-Tolerant Quantum Algorithms in Practice for Ground State Energy Estimation

Wednesday, 8 May 2024 11:30 (30 minutes)

In this talk, we will explore the practicality of early fault-tolerant quantum algorithms, where quantum computers are error-corrected, but still severely limited in depth, focusing on ground-state problems. Specifically, we address the computation of the cumulative distribution function (CDF) of the spectral measure and the identification of its discontinuities. Scaling to bigger system sizes unveils three challenges: the smoothness of the CDF for large supports, the absence of tight lower bounds on the overlap with the actual ground state, and the complexity of preparing high-quality initial states. To tackle these challenges, we introduce a signal processing technique for identifying the inflection point of the CDF. Our claims are supported by numerical experiments conducted on a 26-qubit fully connected Heisenberg model using a truncated density-matrix renormalization group initial state of low bond dimension.

Along the way, we also develop error mitigation techniques and provide proof-of-concept experiments that these algorithms can be run on current superconducting quantum devices.

Presenter: KISS, Oriel (CERN)

Session Classification: Talks

Contribution ID: **81** Type: **Talk**

From trilobite molecules to tight-binding models

Wednesday, 8 May 2024 12:00 (30 minutes)

When a Rydberg atom and a ground state "perturber"atom encounter one another in an ultracold gas, they interact via an oscillatory potential mediated by the scattering of the Rydberg electron off of the perturber. Sufficiently deep wells form in the oscillations of this potential that the perturber becomes trapped, binding the two atoms together into a molecule. This unusual mechanism is also able to bind several atoms together into trimers, tetramers, and even larger clusters. As the number of perturbers increases, it becomes impractical to describe this system within the framework of molecular physics, inviting a turn to the language of solid-state physics. In this talk, I will investigate how a dense environment of immobile perturbers modifies the spectrum of the Rydberg electron, which would otherwise be highly degenerate due to the SO(4) symmetry of the Kepler problem. I will show that this degeneracy leads to an exact mapping - familiar from supersymmetric quantum mechanics - between the perturbed Rydberg states and the states of a particle in a tight-binding lattice. The confluence of the infinite-ranged Coulomb potential and the zero-range electron-atom potentials leads to a plethora of possible lattice parameters. Using this mapping, I demonstrate how to realize a thermodynamic limit in the Rydberg electron and, as a result, the localization of the Rydberg electron in a disordered lattice.

Presenter: EILES, Matthew (Max Planck Institute for the Physics of Complex Systems)

Session Classification: Talks

Contribution ID: **83** Type: **Talk**

Bose-Fermi mixtures with pairing interactions in two dimensions

Wednesday, 8 May 2024 14:00 (30 minutes)

Ultracold dilute Bose-Fermi mixtures are systems that offer a large degree of tunability and are highly controllable, allowing for the investigation of substantially different conditions and quantum effects in matter. In such a mixture with a pairing interaction, one can study the competition between the formation of fermionic composite molecules and the tendency of bosons towards condensation. One possible application is a recent proposal to obtain a quantum simulator for p-wave superfluidity ([1]).

I will present the study of a 2D ultracold Bose-Fermi mixture at zero temperature. We describe the system applying to two dimensions an (imaginary time) T-matrix many-body approach in the ladder approximation. This has been previously used successfully for 3D systems ([2], [3]). Using both analytical and numerical techniques to solve the resulting integrals, we obtain quantities like the chemical potentials and the momentum distributions for both species, and the bosonic condensate fraction.

We also study the minimum value of boson-boson repulsion necessary for the mixture to be stable against phase separation or mechanical collapse. To this end, we extend the Bogoliubov approximation to Popov theory, in order to better consider boson-boson interaction.

Finally, we focus on single-particle spectral properties, which could be relevant for future experiments performing radio-frequency spectroscopy (like for 3D systems in [4]) on 2D Bose-Fermi mixtures. To calculate these dynamic quantities, we need to reformulate our theory for real time and frequencies (as done in 3D in [5]). Our results for the fermionic spectral weight function, from weak to strong boson-fermion attraction, show the presence of unexpected single-particle excitations at low-momenta, and a new branch at positive frequencies for sufficiently strong couplings.

References

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Presenter: BOVINI, Pietro (Alma Mater Studiorum Università di Bologna)

Session Classification: Talks

Contribution ID: **84** Type: **Talk**

Remote entanglement of optically levitated nanoparticles

Tuesday, 7 May 2024 16:30 (30 minutes)

Optomechanics studies the interaction of light with moving objects, an essential resource for sensing, metrology, and the investigation of fundamental aspects of quantum mechanics with mesoscopic systems. By eliminating clamping losses and the background gas, optically levitated objects can reach an extreme degree of isolation from the environment, enabling free-space quantum control of mechanical motion even at room temperature [1]. Furthermore, the light mass and low dissipation of levitated oscillators results in remarkable force sensing capabilities [2]. Recent works showed that levitated particles in distinct optical tweezers can be coupled via Coulomb or optical binding forces at micron-scale distances [3]. Coupling strengths exceeding the total decoherence rate are a prerequisite to generate motional entanglement among nanoparticles. While Coulomb-mediated entanglement has been recently proposed as a mean to probe force-gradients below the standard quantum limit [4], entanglement via optical forces cannot be achieved in free space in absence of some reservoir engineering [5].

Our analysis shows how to entangle the motion of two optically levitated nanoparticles held by optical tweezers at a dozen meter distance solely harnessing optical forces. The scheme relies on the directional circulation of the light scattered off the nanoparticles via optical transmission lines. Interference with the background laser field both renormalizes the optical density of states and induces a two-mode squeezing interaction that can be adjusted via the transmission line phase. We analyse the system dynamics and show that both transient and conditional state entanglement between distant nanoparticles can be achieved for realistic experimental conditions.

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[2] C. Gonzalez-Ballestero et al. - Science 374, 6564 (2021)
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Presenter: CARLON ZAMBON, Nicola (ETH Zürich)

Session Classification: Talks

Contribution ID: **85** Type: **Talk**

Tensor Network approach for factoring RSA numbers

Wednesday, 8 May 2024 14:30 (30 minutes)

Current public-key cryptography standard is based on the RSA algorithm [1], whose security relies on the practical difficulty of factoring semiprimes as the product of two large prime numbers. While traditionally applied for encryption, lattice-based cryptography, as exemplified by Schnorr's algorithm [2], offers a different avenue to decompose RSA keys. This algorithm encodes prime factors into optimal solutions of NP-hard mathematical lattice problems, specifically the closest vector problem (CVP). However, the inherent difficulty in solving CVPs, even for moderately sized RSA integers, hinders efficient factorization.
A recent alternative approach [3] encodes optimal CVP solutions into low-energy eigenstates of a spin-glass Hamiltonian. Leveraging tensor network (TN) methods for extensive simulation of many-body systems [4], we present a quantum-inspired approach to efficiently extract optimal solutions from these CVP spectra.
We report a systematic numerical analysis of our TN-factoring method and we factorize RSA semiprimes up to more than 100 bits. This is the largest RSA number reached with Schnorr's sieving method to date. Moreover, we present a detailed resource assessment for targeting cryptographic keys of hundreds of bits on a standard cluster. Finally, we discuss the extrapolation of these findings towards the widely adopted RSA-2048 cryptosystem. Our TN approach provides insights into the practical implications of Schnorr's lattice-based quantum algorithm, contributing to the ongoing discussion on cryptographic security in the context of emerging quantum computing methodologies.

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Presenter: TESORO, Marco (Univesità di Padova)

Session Classification: Talks

Contribution ID: **88** Type: **Talk**

Digitized Counterdiabatic Quantum Computing

Wednesday, 8 May 2024 16:30 (30 minutes)

I will introduce digitized counterdiabatic quantum computing (DCQC) as a novel paradigm for compressing digital quantum algorithms. It consists of a suitable digitization of the accelerated counterdiabatic dynamics of an adiabatic quantum computation, which encodes the chosen industry use case. I will exemplify DCQC to the class of optimization problems: digitized counterdiabatic quantum optimization (DCQO). In particular, I will present an advanced method called bias-field digitized counterdiabatic quantum optimization (bf-DCQO) for tackling combinatorial optimization problems on a digital quantum computer.

Along with the selected counterdiabatic (CD) terms in the adiabatic Hamiltonian, we introduce additional bias terms obtained either through classical methods, quantum annealers, or with iterations of DCQO itself. This combination of CD protocols and bias fields offers a way to address large-scale combinatorial optimization problems on current quantum computers with limited coherence time. By examining an all-to-all connected general Ising spin-glass problem, we observe a polynomial scaling enhancement in the time to solution compared to both DCQO and finite-time adiabatic quantum optimization. Moreover, the proposed method is purely quantum, eliminating the need for any classical optimization schemes. In this manner, we overcome the trainability drawbacks faced by variational quantum optimization algorithms.

Additionally, bf-DCQO significantly outperforms the quantum approximate optimization algorithm (QAOA) in terms of success probability and approximation ratio. Finally, I will present the experimental results of the proposed method on a trapped-ion quantum computer, tackling a fully connected spin-glass problem with 33 qubits and a maximum weighted independent set problem with 36 qubits. This represents the realization of the largest quantum computing problem of this nature, solved on a gate-based quantum computer by using a pure quantum algorithmic approach.

Presenter: Dr HEGADE, Narendra (Kipu Quantum)

Session Classification: Talks

Contribution ID: **89** Type: **Talk**

Quantum Circuit Discovery for Fault-Tolerant Logical State Preparation with Reinforcement Learning

Wednesday, 8 May 2024 17:00 (30 minutes)

One of the key aspects in the realization of large-scale fault-tolerant quantum computers is quantum error correction (QEC). The first essential step of QEC is to encode the logical state into physical qubits in a fault-tolerant manner. Recently, flag-based protocols have been introduced that use ancillary qubits to flag harmful errors. However, there is no clear recipe for finding a compact quantum circuit with flag-based protocols for fault-tolerant logical state preparation. It is even more difficult when we consider the hardware constraints, such as qubit connectivity and gate set. In this work, we propose and explore reinforcement learning (RL) to automatically discover compact and hardware-adapted quantum circuits that fault-tolerantly prepare the logical state of a QEC code. We show that RL discovers circuits with fewer gates and ancillary qubits than published results without and with hardware constraints of up to 15 physical qubits. Furthermore, RL allows for straightforward exploration of different qubit connectivities and the use of transfer learning to accelerate the discovery. More generally, our work opens the door towards the use of RL for the discovery of fault-tolerant quantum circuits for addressing tasks beyond state preparation, including magic state preparation, logical gate synthesis, or syndrome measurement.

Presenter: COLMENAREZ, Luis (Max Planck Institute for the Physics of Complex Systems)

Session Classification: Talks

Contribution ID: **90** Type: **Talk**

Scalable silicon quantum photonics

Friday, 10 May 2024 12:00 (30 minutes)

Over the past two decades, quantum photonic devices have exploded in scale and complexity, with application to every corner of quantum information science. However, the writing is on the wall: to make scalable photonic quantum technology, we must do away with postselection and its exponentially poor scaling. This means building dynamic quantum circuits, featuring measurement and feedforward, and closing the loop on detection and modulation within our photons' lifetime. The challenge is extensive—ultra-low-loss circuitry and high-speed modulation must be packaged together with low-latency logic, likely in a cryogenic environment. Furthermore, all of these elements must be co-packaged in a holistic design, with each domain (electronic, photonic, cryogenic) placing strict requirements on the others. In this talk, I will discuss our efforts to build scalabe quantum photonic systems in the Big Photon Lab at the University of Bristol, featuring 2-micron-band silicon photonics, DC-Kerr modulation, space/frequency filters, detector readout ASICs, and tools for the co-design of photonic, electronic and quantum systems.

Presenter: C. ADCOCK, Jeremy (University of Bristol / Qontrol Systems)

Session Classification: Talks

Contribution ID: **91** Type: **Talk**

Enhancing readout in nitrogen vavancy center in diamond: leveraging photon statistics for analyzing ionization dynamics

Tuesday, 7 May 2024 14:30 (30 minutes)

Nitrogen-vacancy (NV) centers in diamond have emerged as exceptionally promising candidates for the implementation of quantum technologies. These centers exhibit atom-like properties, characterized by long-lived spin quantum states and well-defined optical transitions, all within a robust solid-state device. Notably, the electron spins of NV centers can be easily initialized, controlled, and read out at room temperature in ambient atmosphere, simplifying the experimental setup and providing practical advantages for the development and application of quantum technologies.

The interest in charge state dynamics has grown significantly in recent years, driven partly by the observation of spin-to-charge conversio. This phenomenon serves as the foundation for photoelectric detection of the magnetic resonance of NV centers (PDMR) and their coherent dynamics, even at the single-defect level. The development of this mechanism eliminates the necessity for collection optics and single-photon detectors, rendering the NV center system more adaptable to integrated technological applications, particularly in compact diamond quantum sensors.

Our objective is to scrutinize the presented ionization model using the photon statistics formalism for further refinements in the readout sequence. The treatment begins with an effective rate equation model, encompassing both spin and charge dynamics to replicate experimental time traces and derived spin contrasts. The model involves decay rates Γ_{ji} and absorption cross-sections σ_{ji}, where i and j correspond to the involved levels.

To explore the readout capabilities of our system, we analyze the photon statistics from the emission of both NV^- and NV^0. This analysis facilitates the introduction of the Chernoff information as a metric for readout quality, indicating the rate of information gain per measurement repetition when discerning the state of the NV center.

While earlier research primarily focused on exploring the initialization capabilities of the ionization model, our current investigation shifts its emphasis towards scrutinizing the readout process. We propose the use of a ramp readout pulse, in which the power of the laser is increased linearly instead of suddenly switch on. Consistently employing a ramp pulse results in a superior Chernoff value increase of 4%. Moreover, a ramp pulse allows for a higher contrast, increasing from 45.0\% to 45.1\%. Although this improvement may appear modest, it signifies a meaningful advancement in performance.

The maximum values are achieved under specific conditions: 1.6 mW power and a pulse length of 335 ns for the ramp pulse, while the square pulse attains its maximum with 1.1 mW power and a shorter excitation time of 305 ns. Despite the square pulse being marginally shorter and requiring a lower maximum power, the energy consumption is 17\% higher than that of the ramp pulse.

At lower powers, the square pulse provides a slightly better contrast of approximately 0.5\%. However, beyond its peak, the contrast diminishes rapidly, while for ramp pulses, this decay is more gradual. Around 2 mW, we achieve the same contrast with both protocols, but the ramp pulse attains a better Chernoff value.

Abstract category

Presenter: PANADERO MUÑOZ, Ivan (Arquimea Research Center / Universidad Carlos III de Madrid)

Session Classification: Talks

Contribution ID: **92** Type: **Talk**

Simulating non-equlibrium dynamics of Rydberg atom arrays

Wednesday, 8 May 2024 10:00 (30 minutes)

Experiments with Rydberg atom arrays open up new possibilities to investigate two-dimensional interacting quantum systems away from equilibrium and they call for us to push also numerical simulations in this regime. I will discuss how combining the time-dependent variational principle with two families of ansatz for the variational wave function —artificial neural networks and tree tensor networks —allows us to address some of the challenges. Thereby, we gain insights into the dynamics across a quantum phase transition and of ferromagnetic domain interfaces in the two-dimensional quantum Ising model that is experimentally realized in Rydberg quantum simulators.

Abstract category

Presenter: SCHMITT, Markus (Regensburg University)

Session Classification: Talks

Contribution ID: **94** Type: **Talk**

Simulating condensed systems on quantum computers with quantum embedding

Thursday, 9 May 2024 15:00 (30 minutes)

Quantum computers hold promise to improve the efficiency of quantum simulations of materials and to enable the investigation of systems and properties that are more complex than tractable at present on classical architectures. Here, we discuss a computational framework to carry out electronic structure calculations of solids on noisy intermediate-scale quantum computers using embedded Green's function theory [1]. We give examples for a specific class of materials, that is, solid materials hosting spin defects, e.g., the NV center in diamond. These are promising systems to build future quantum technologies, such as quantum sensors and quantum communication devices. The defect is described by an effective Hamiltonian, whose parameters are evaluated from first principles on a pre-exascale computer [2], and whose ground and excited states are obtained using the variational quantum eigensolver (VQE) and the quantum subspace expansion (QSE) method, respectively [3]. Although quantum simulations on quantum architectures are in their infancy, we show that promising results for realistic systems appear to be within reach combining zero-noise extrapolation techniques and symmetry-constraining ansätze [4].

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Abstract category

Presenter: GOVONI, Marco (University of Modena and Reggio Emilia)

Session Classification: Talks

Contribution ID: **96** Type: **Talk**

Generation of entangled photonic states from semiconductor quantum dots

Friday, 10 May 2024 10:00 (30 minutes)

Single-photon sources based on semiconductor quantum dots find several applications in quantum
information processing due to their high single-photon indistinguishability, on-demand generation, and low
multiphoton emission. In this context, the generation of entangled photons represents a challenging task with
a possible solution relying on the interference in probabilistic gates of identical photons emiAed at different
pulses from the same source. In this work, we show the results of entangled state generation by using two
different approaches. The first is based on a probabilistic gate that generates entangled photon pairs in the
polarization and in the orbital angular momentum degree of freedom. We then characterize the entangled
two-photon states by developing a complete model considering relevant experimental parameters, such as
the second-order correlation function and photons indistinguishability. The second approach investigates the
properties of the excitation scheme. The resonant configuration enables the generation of states in
superposition in the photon's number basis. We show the results regarding the quality of the generation of
such quantum states of light together with possible protocol for teleportation tailored to such a degree of
freedom.

Abstract category

Presenter: GIORDANI, Taira (Sapienza University of Rome)

Session Classification: Talks

Contribution ID: **97** Type: **Talk**

Quantum Networks by QTI

Monday, 6 May 2024 17:30 (30 minutes)

The advances in quantum communications and quantum key distribution (QKD) during the past 30 years have been outstanding in terms of reachable distance and key generation rate. However, multiple challenges arise from the effective implementation of quantum systems in real telecommunication networks. Along with well-known challenges, including the fiber or wavelength availability between remote locations and the complicated scheme/topology of current telecommunication networks (which include optical amplifiers), other practical problems have to be taken into account. Examples are the temperature range of telecom data centres, the amount of noise emitted by the equipment, as well as the optical crosstalk coming from commercial signals into the quantum channels due to spurious effects on fibre.
In this talk, we will present the latest implementations we have conducted to both improve current quantum technology, and integrate commercial QKD systems in standard telecommunication networks. Thanks to our unique value proposition, which includes in the same family a quantum vendor (QTI), a cryptographic company (Telsy) and the largest Italian telecom operator (TIM), we present a series of concrete and existing use-cases implemented in the last two years in Europe and Italy.

Abstract category

Presenter: PERETI, Claudio (QTI)

Session Classification: Companies

Contribution ID: **98** Type: **Talk**

An editorial view on peer review in PRX and all the Physical Review journals

Wednesday, 8 May 2024 15:00 (1 hour)

Published by the American Physical Society (APS), Physical Review X (PRX) is an open-access publication that aims to publish outstanding research in all areas of physics.

In this talk, I will introduce the APS, the Physical Review family of journals, and PRX in particular. I will then explain in detail all phases of the peer review process, and how editors reach their decisions. Finally, I will provide concrete practical tips on how to write scientific papers and prepare successful submissions to journals. I will also explain how referee reports should be written, and how to respond to the comments received by the referees when resubmitting a manuscript.

Abstract category

Presenter: SCHIULAZ, Mauro (APS)

Session Classification: Companies

Contribution ID: **99** Type: **Talk**

Quantum Computing for Industry Applications

Wednesday, 8 May 2024 17:30 (30 minutes)

I will describe digital, analog, and digital-analog quantum computing paradigms. Furthermore, I will discuss the possibility of reaching quantum advantage for industry use cases with current quantum computers in trapped ions, superconducting circuits, neutral atoms, and photonic systems.

Abstract category

Presenter: SOLANO, Enrique (Kipu Quantum)

Session Classification: Companies

Contribution ID: **100** Type: **Talk**

Single Quantum SNSPDs for Quantum Science and Technology

Tuesday, 7 May 2024 11:00 (30 minutes)

Single Quantum is the leading manufacturer of Superconducting Nanowire Single Photon Detectors (SNSPDs), devices increasingly essential for research laboratories and companies all over the world. This talk will begin with an introduction of the company and our main products, to then focus on our R&D activities, aiming at developing SNSPDs as an enabling technology for quantum applications, covering the three hardware pillars of Quantum Communication, Computing and Sensing.

Presenter: FACCHIN, Federica (Single Quantum)

Session Classification: Companies

Contribution ID: **101** Type: **Talk**

TBA

Thursday, 9 May 2024 15:30 (30 minutes)

TBA

Presenter: Prof. POLINI, Marco (Planckinan)

Session Classification: Companies

Contribution ID: **102** Type: **Talk**

Photonic Quantum Technologies with Single Organic Molecules

Friday, 10 May 2024 14:00 (30 minutes)

The generation and manipulation of quantum states of light is required for key applications, such as photonic quantum simulation, linear optical quantum computing, quantum communication protocols, and quantum metrology. In this context, I will present our recent achievements in using single organic molecules as bright and stable sources of coherent single photons in the solid state. Among our recent results, I will show the successful coupling strategies of single molecules to hybrid nanophotonic structures, two-photon interference experiments performed between distinct molecules on the same chip, and the use of organic molecules for quantum communication, as deterministic single-photon sources at room temperature for Quantum Key Distribution protocols. I will conclude with some latest results on the use of molecules as nanoprobes for quantum thermometry and with some insights on the impact of the microscopic electric field environment on the emitter photo-stability and on how we can control it via the combination of two tuning techniques.

Abstract category

Primary author: COLAUTTI, Maja (CNR-INO, c/o LENS)

Presenter: COLAUTTI, Maja (CNR-INO, c/o LENS)

Session Classification: Talks

Contribution ID: **103** Type: **Talk**

From euroQCI to SAGA: an overview on European Quantum Communication programs

Friday, 10 May 2024 14:30 (30 minutes)

In the last years, key European projects have lead the acceleration of technology readiness for the quantum Communication ecosystem. ThinkQuantum, spin-off of Unipd, provider of technologies and solutions for fiber networks, free-space terrestrial links and the Space domain (form satellites payloads to Optical Ground Station) and key player in the European QComm ecosystem will report about its role in European Quantum Communication programs.

Abstract category

Presenter: Dr CAPELETO, Simone (Think Quantum)

Session Classification: Companies

Contribution ID: **105** Type: **Poster**

Simulating Vibronic Spectra by Direct Application of Doktorov Formulae on Superconducting Quantum Simulator

Tuesday, 7 May 2024 17:30 (1h 30m)

In this work, a direct quantum implementation of the Doktorov formulae for calculating the vibronic
spectrum of molecules under the harmonic approximation is presented. The classically hard problem of estimating the Franck-Condon (FC) factors is solved by using the Duschinsky matrices as the only input via the Doktorov quantum circuit. This approach offers the advantage of avoiding
basis changes and symmetry dependencies, while making use of the inherent computational advantages of quantum computers. In other words, it is a general method that can be extended to molecules of any size. Its application is demonstrated with the three-atom molecules SO2 and ZnOH.

References

E. Doktorov et al. Dynamical symmetry of vibronic transitions in polyatomic molecules and the Franck-
Condon principle. J. Mol. Spectrosc. 1977, 64, 302–326.

Abstract category

Primary author: Mr OLARTE HERNANDEZ, Renato (University of Namur)

Co-authors: SOLDERA, Armand (University of Sherbrooke); CHAMPAGNE, Benoît (University of Namur)

Presenter: Mr OLARTE HERNANDEZ, Renato (University of Namur)

Session Classification: Poster session

Contribution ID: **106** Type: **Poster**

Long Range Interactions in Synthetic Dimensions

Tuesday, 7 May 2024 17:30 (1h 30m)

In recent cold atom experiments, the utilization of internal degrees of freedom as synthetic dimensions has enabled the simulation of higher-dimensional systems. Specifically, magnetic quantum numbers have been employed to transform a 1D chain of atoms into a synthetic 2D lattice, resulting in the realization of an integer quantum Hall state. However, this configuration introduces highly anisotropic and long-range particle interactions. To facilitate theoretical analysis, we develop a 1D effective model in the limit of infinite interaction anisotropy. This model serves as a simplified representation, allowing us to explore the impact of long-range interactions on the phases realized in the system. Our investigation delves into the emergence of new phases, the study of phase transitions, and the stability of configurations under the influence of extreme long-range interactions. This research contributes to a deeper understanding of the intricate interplay between synthetic dimensions and particle interactions in cold atom systems.

Abstract category

Presenter: Mr GERAGHTY, Patrick (University of Cologne)

Session Classification: Poster session

Contribution ID: **107** Type: **not specified**

ECT* Director welcome

Wednesday, 8 May 2024 10:30 (10 minutes)

Presenter: VAN KOLCK, Ubirajara (IJCLab Orsay & University of Arizona)

Session Classification: ECT* Director Welcome

Contribution ID: **108** Type: **Talk**

Exponential Speedup for Simulation of Harmonic Oscillators

We present a quantum algorithm for simulating the classical dynamics of
2n coupled oscillators (e.g., 2n masses coupled by springs). Our approach leverages a mapping between the Schrödinger equation and Newton's equation for harmonic potentials such that the amplitudes of the evolved quantum state encode the momenta and displacements of the classical oscillators. When individual masses and spring constants can be efficiently queried, and when the initial state can be efficiently prepared, the complexity of our quantum algorithm is polynomial in n, almost linear in the evolution time, and sublinear in the sparsity. As an example application, we apply our quantum algorithm to efficiently estimate the kinetic energy of an oscillator at any time. We show that any classical algorithm solving this same problem is inefficient and must make 2Ω(n) queries to the oracle, and when the oracles are instantiated by efficient quantum circuits, the problem is bounded-error quantum polynomial time complete. Thus, our approach solves a potentially practical application with an exponential speedup over classical computers. Finally, we show that under similar conditions our approach can efficiently simulate more general classical harmonic systems with 2n modes.

Abstract category

Quantum Simulations

Primary author: WIEBE, Nathan (University of Toronto)

Presenter: WIEBE, Nathan (University of Toronto)