13th Italian Quantum Information Science Conference

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Book of Abstracts

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Remote Phase Sensing by Coherent Single Photon Addition

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In this work, we introduce a new kind of nonlocal interferometer based on the delocalized addition of a single photon onto distinct field modes. Since the quantum state produced by this conditional operation strongly depends on the phase set in a physically-separated heralding station, we propose and experimentally demonstrate a remote phase estimation technique, characterized by a sensitivity that scales with the intensity of light that never interacted with a distant sample.

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Quantum information from spacetime dynamics

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Quantum information from spacetime dynamics

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A multimode framework to describe photon subtraction operation

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Optical non-Gaussian quantum states can be generated in a heralded manner by applying a photon subtraction operation to a Gaussian input state. In our work, we develop a theoretical framework to describe this operation in the case where the input state is spectrally multimode. This framework allows the optimal design of photon subtraction experiments. We give the exact expression of the generated non-Gaussian state in the general case. We apply this framework to the case of

Schrodinger kitten state generation using a multimode squeezed vacuum as input state. We show that the quality of the generated state (in terms of fidelity and Wigner function negativity) can be enhanced by adapting the different experimental parameters.

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Quantum speed-ups in reinforcement learning

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Within artificial intelligence, of particular interest is reinforcement learning (RL), where autonomous agents learn to accomplish tasks via feedback exchange with their environment (the world they interact with). Thanks to rapid advances in quantum technologies, the idea of using quantum physics to boost the performance of RL agents was developed. I will focus on the bridge between RL and quantum mechanics, and show that a reduction in the agent's learning time is possible if agents and environments also interact quantum-mechanically[1]. This idea was implemented on a fully-tunable photonic processor. The achieved speed-up in learning time, compared to the fully classical picture, confirms the potential of quantum technologies for future RL applications.

[1] Saggio, V. et al. Nature 591, 229–233 (2021).

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Improving quantum teleportation with a quantum dot-based entangled photon source

Francesco Basso Basset[1] ; Francesco Salusti[1] ; Lucas Schweickert[2] ; Michele B. Rota[1] ; Davide Tedeschi[1] ; Saimon F. Covre da Silva[3] ; Emanuele Roccia[1] ; Val Zwiller[2] ; Klaus D. Jöns[4] ; Armando Rastelli[3] ; Rinaldo Trotta[1]

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All-optical quantum teleportation relies on properties of entangled states that, in the prospect of operation in quantum networks, should be encoded on photon pairs on demand. Quantum dots are a promising solution, as shown in recent multi-photon experiments [1]. Here, we demonstrate quantum teleportation with quantum dot photons achieving improved protocol fidelity [2]. The experimental results are predicted based on entanglement fidelity and photon indistinguishability. The Bell state measurement implementation and spectral filtering are investigated within the same model. Finally, we envision the next steps towards realization with remote nodes. [1] F. Basso Basset, M. Rota, C. Schimpf, D. Tedeschi, et al., Phys. Rev. Lett. 123, 160501 (2019). [2] F. Basso Basset., et al., npj Quantum Inf. 7, 7 (2021).

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The four postulates of quantum mechanics are three

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The tensor product postulate of quantum mechanics states that the Hilbert space of a composite system is the tensor product of the components' Hilbert spaces. All current formalizations of quantum mechanics that do not contain this postulate contain some equivalent postulate or assumption (sometimes hidden). Here we give a natural definition of composite system as a set containing the component systems and show how one can logically derive the tensor product rule from the state postulate and from the measurement postulate. In other words, our paper reduces by one the number of postulates necessary to quantum mechanics.

This talk is based on the paper: G.Carcassi,L.Maccone,C.A.Aidala, The four postulates of quantum mechanics are three, Phys. Rev. Lett. 126, 110402 (2021).

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There is only one time

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We draw a picture of physical systems allowing us to recognize what is the thing we call "time". Elements of the picture are two non-interacting, entangled quantum systems: one acting as a clock, and the other one as the evolving system. The setting is based on the "Page and Wootters mechanism", with tools from Lie-Group and large-N quantum approaches. The theoretical framework, based on a parametric representation with generalized coherent states, allows us to take the classical limit either of the clock only, or of the clock and the evolving system; we derive the Schrödinger equation in the first case, and Hamilton's equations in the second one, showing that there is only one time, that is a manifestation of entanglement.

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Quantum gravitational decoherence

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We discuss a decoherence process due to quantum gravity effects. We assume a foamy quantum spacetime with a fluctuating minimal length coinciding on average with the Planck scale. Considering deformed canonical commutation relations with a fluctuating deformation parameter, we derive a Lindblad master equation that yields localization in energy space and decoherence times consistent with the available observational evidence. Finally, we comment on possible experimental tests based on cavity optomechanics setups with ultracold massive molecular oscillators and provide preliminary estimates on the values of the physical parameters needed for actual laboratory implementations

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On the notion of causal influence

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We address the question whether a reversible transformation produces a causal influence from one of its input systems to one of its outputs. In quantum theory causal influence is typically identified with signalling. A second notion is borrowed from the theory of quantum cellular automata. We adopt an extension of the latter, in the context of general probabilistic theories. We show that in the quantum case the two notions coincide, while in classical theory they are different. Following the proof of equivalence in the quantum case, we identify a general condition under which the two definitions coincide, i.e. "no interaction without disturbance". We show an algebraic construction that is useful for the analysis of causal influence in reversible processes.

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Thouless pumping of photons

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Non-abelian gauge fields emerge naturally in the description of adiabatically evolving quantum systems. In this talk we show that they also play a role in Thouless pumping in the presence of degenerate bands. Specifically, we consider a photonic Lieb lattice and show that when the lattice parameters are slowly modulated, the propagation of the photons bear the fingerprints of the underlying non-abelian gauge structure. The non-dispersive character of the bands enables a high degree of control on photon propagation. Our work paves the way to the generation and detection of non-abelian gauge fields in photonic and optical lattices. The talk includes a review of abelian pumping in photonic and superconducting systems and perspectives on quantum applications of photonic pumps.

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Entanglement between remote ions interfaced with cavities

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In a quantum network, entanglement between qubits located in remote nodes is a fundamental resource for different applications including distributed quantum computing and quantum repeaters. Once can generate entanglement between distant ions by creating an ion-photon entangled pair

at each of the two network nodes, steering the photons to opposite ports of a beamsplitter, and subsequently detect them. Specific photon detection patterns herald the generation of the ion-ion entangled state. Two remote ions have previously been entangled over a separation of a few meters. Here, we present entanglement generation between ions stored in remote nodes in separate buildings in Innsbruck, connected via a fiber link of 400 m, where the trapped ions are interfaced with optical cavities.

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Optimal energy conversion through anti-adiabatic driving

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A key question for the development of quantum thermos-machines and more generally of quantum technologies is what are the ultimate bounds to the performance of heat engines. We have shown [1] that in the antiadiabatic limit a periodically driven isothermal heat engine can approach the ideal (unit) energy conversion efficiency with finite output power and vanishingly small relative power fluctuations. The simultaneous realization of all three desiderata of a heat engine is possible thanks to the breaking of time-reversal symmetry. Moreover, non-Markovian dynamics, obtained by suitably engineering the bath, can further improve the power-efficiency trade-off.

[1] L. M. Cangemi, M. Carrega, A. De Candia, V. Cataudella, G. De Filippis, M. Sassetti, and G. Benenti, Phys. Rev. Res. *3*, 013237 (2021).

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Quantum Energy Lines and the optimal output ergotropy problem

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We study the possibility of conveying useful energy (work) along a transmission line that allows for a partial preservation of quantum coherence. As a figure of merit we adopt the maximum values that ergotropy, total ergotropy, and non-equilibrium free-energy attain at the output of the line for an assigned input energy threshold. When the system can be modelled in terms of Phase-Invariant Bosonic Gaussian Channels (BGCs), we show that coherent inputs are optimal. For generic BGCs which are not Phase-Invariant the problem becomes more complex and coherent inputs are no longer optimal. In this case, focusing on one-mode channels, we solve the optimization problem under the extra restriction of Gaussian input signals.

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A hybrid classical-quantum approach to improve Q-learning

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A classical-quantum hybrid approach to computation is presented, allogwing for a (quadratic) performance improvement in the learning stage of a neural network. In particular, a quantum computing routine is described, which helps to prepare/update the probability distributions that drive the agent operations. This algorithm can be used not only in a reinforcement learning scenario, but also in several other contexts. After intrudicing the algorithm and presenting a formal evaluation of its performance (in terms of required qubits, number of required operations, and maximum approximation error), the way it can be exploited in a reinforcement learning set-up is discussed in details.

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Towards the detection of quantum light in the mid-infrared

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Quantum Cascade Laser (QCL) frequency combs could emit nonclassical light and multimode entanglement thanks to a third order nonlinearity that allows for Four Wave Mixing in the device (Faist 2016), which makes them ideal candidates for free-space communication applications. However, in the mid-infrared, the lack of efficient and low-noise detectors compromises enormously the ability to investigate non classical features of light. In addition, the laser gain of the device itself can introduce noise due to the amplification. Having a signature of non classical light, such as squeezing, is a challenging task in these conditions. We demonstrate the possibility of investigating continuous-variable quantum physics in the mid-infrared through a novel Balanced Homodyne Detector (Gabbrielli 2021), tested with QCLs.

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New applications of twin beams: from quantum reading to quantum conformance test

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We present quantum reading [3] realisation, describing theoretically and experimentally, as that quantum advantage is obtained by practical photon-counting measurements combined with a simple maximum-likelihood decision [4], demonstrating that quantum entanglement and simple optics are able to enhance the readout of digital data. Then we consider [5] a protocol on conformance test. We formulate the problem in the context of quantum hypothesis demonstrating that quantum resources, namely twin beams [1,2], and a simple receive are able to outperform any classical strategy in recognizing whether or not a certain quantum channel conforms to a reference one. [1] M.Genovese,J.Opt.18 (2016) 073002. [2] M.Genovese, arXiv2101.02891 [3] S. Pirandola, PRL106, 090504 (2011). [4] G.Ortolano et al. Sci.Adv.(2021) 7, eabc7796. [5] G.Ortolano et al.arXiv:2012.15282

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Robust engineering of universal Gaussian cluster states for continuous variable measurement-based quantum computation

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We first show that any Gaussian cluster state of N bosonic modes can be generated by a multi-mode squeezing transformation. and provide the explicit recipe. We then use this result to show that a large class of pure entangled CV Gaussian states, including 2D-cluster states, can be robustly generated as a unique steady state of a dissipative dynamics employing minimal resources. In fact, this is achievable using only a single-site squeezed driving and passive bilinear interactions. We provide the explicit protocol which corresponds to the engineering of a suitable excitation number conserving Hamiltonian.This fact can be used for the implementation of universal continuous variable measurement-based-quantum computation on various platforms.

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Unconventional superconducting devices and designs for quantum architectures

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We will report on special properties of smart superconducting circuits and of hybrid tunnel-ferromagnetic Josephson junctions (JJs) on how to engineer the macroscopic phase in quantum circuits.

The possibility to control and drive tunnel-ferromagnetic JJs through different physical means allows for novel tuning mechanisms that are not susceptible to specific noise sources in a transmon configuration. Moreover, digital control based on classical superconducting ultra-low power electronics is being adapted to perform qubit control and readout for scalable architectures in this linked digital-quantum hybrid system. In this framework, we will discuss how the macroscopic phase of carefully designed superconducting circuits can be manipulated to perform digital phase detection of weak coherent radiation, thus constituting a phase-readout protocol for a superconducting qubit.

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Tensor network algorithms for high-dimensional quantum many-body systems

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We review some recent results on the development of tensor network algorithms and their application to high-dimensional many-body quantum systems and machine learning problems in High Energy Physics. In particular, we present results on topological two-dimensional systems, two dimensional Rydberg atom systems, and two and three-dimensional lattice gauge theories in presence of fermonic matter. Finally, we present their application to LHCb event classification and to the study of open many-body quantum systems, specifically to the computation of the entanglement of formation in critical many-body quantum systems at finite temperature.

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Thermal rectification through a nonlinear quantum resonator

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We present a systematic study of thermal rectification, R, in a nonlinear resonator. In the strongly anharmonic regime and weak system-bath coupling we derive general upper bounds on R. Beyond the weak-coupling regime we employ different methods: (i) including cotunneling processes, using (ii) nonequilibrium Green's function formalism and (iii) Feynman-Vernon path integral approach. We find that the weak coupling bounds are violated for strong coupling, providing signatures of high-order coherent processes. For weaker anharmonicity heat rectification is calculated with the equation of motion method and in mean-field approximation. We find that the former method predicts, for small or intermediate anharmonicity larger R.

B. Bhandari, P. A. Erdman, R. Fazio, E. Paladino and F. Taddei Phys. Rev. B 103, 155434 (2021)

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Quantum estimation reaching for the continuum

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We discuss two experimental results on the problem of quantum estimation applied to functions. We illustrate quantum function estimation of the phase response of a liquid crystal employing both quantum and classical resources, providing evidence of the superiority of the former strategy. Including function estimation in the toolkit of quantum metrology opens up opportunities for quantum enhancement in problems such as evaluating time-dependent signals and mapping fields. The second experiment concerns semiparametric methods applied to the frequency two-photon wavefunction, based on Hong-Ou-Mandel interferometry. Tools from classical statistics and quantum estimation have shown their usefulness in analysing and engineering metrological schemes based on Hong-Ou-Mandel interference: we expect that advanced statistical methods will bring further insights.

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Observation of Larmor precession of a single spin in a semiconductor quantum dot

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In semiconductor quantum dots, the spin of a confined charge carrier, whether electron or hole, attracted a lot of interest since spin-polarized optical transitions enable the efficient generation of spin-photon and photon-photon entanglement. This could be extended to generate multi-photon entangled states, which are building blocks for quantum technologies such as measurement-based quantum computing. In this work, we exploit a phonon-assisted, off-resonant excitation scheme that enables access to the polarization degree of freedom to probe the spin dynamics, whilst maintaining efficient single-photon generation and high purity. We demonstrate that we can address the spin-selective transitions, observing the Larmor precession of a single-hole spin around an in-plane magnetic field, opening the route towards an efficient generation of polarization-encoded multi-photon entangled states.

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Coherent Manipulation and Readout of Molecular Spins through Planar Superconducting Microwave Resonators

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Molecular spins hold potential for quantum information when integrated into planar superconducting microwave resonators extbackslash[AdvPhysX3,1435305(2018) extbackslash]. Along this line, we present our recent results on developing protocols (i.e. microwave sequences) for initializing, manipulating and reading out molecular spin ensembles. We first apply a storage/retrieval protocol on an Oxovanadyl (VO(TPP)) sample, showing that it's possible to use it as a memory for individually-controllable pulses extbackslash[AdvPhysX3,1435305(2018) extbackslash]. We then demonstrate an advanced transmission spectroscopy on a crystal of Diphenyl-Nitroxide (DPNO) in the dispersive

limit of the coupling with the resonator, where no resonant exchange of photons occurs extbackslash[AdvPhysX3,1435305(2018) extbackslash]. Finally, we shall present our preliminary results on applying a Machine Learning approach in recognising and treating spin echo signals.

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Entanglement recovery and state robustness via spatial deformation of identical particle wave functions

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We discuss the problem of entanglement protection against surrounding noise by a procedure suitably exploiting spatial indistinguishability of identical subsystems. To this purpose, we take two initially separated and entangled identical qubits interacting with two independent noisy environments. Three typical models of environments are considered: the amplitude damping channel, the phase damping channel and the depolarizing channel. After the interaction, we deform the qubits wave functions to make them spatially overlap before performing spatially localized operations and classical communication (sLOCC). By computing the concurrence of the resulting state we show that this protocol partially recovers the spoiled entanglement thanks to the induced spatial indistinguishability. A general behavior emerges: the higher the indistinguishability achieved, the larger the amount of recovered correlations.

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Entanglement in indistinguishable particle systems

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For distinguishable particles, there exists an agreed upon notion of entanglement based on the possibility of addressing individually each particle. Instead, the indistinguishability hinders their individual addressability and has prompted diverse, discordant definitions of entanglement. I will present a formulatiom of emtamglement in terms of correlation functions, that provides a general setting to discuss non-local effects. I will focus on the following general criteria: i) entanglement corresponds to non-local correlations; ii) when, by "freezing" suitable degrees of freedom, identical particles can be effectively distinguished, entanglement must reduce to the standard notion; iii) entanglement is a resource for quantum information protocols. These requests are satisfied by the so-called mode-entanglement theory which accounts for correlations between physical modes rather than particles.

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Single Microwave Photon Detection with Josephson Junctions for Axion Search: First Tests

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The fast development of quantum technologies based on superconducting devices is particularly important for the search of light dark matter, such as Axions and Axion-like particles, where it is required the efficient detection of single microwave photons with low dark-count rates. We present SIMP, an experiment for the axion search based on the use of a current biased Josephson junction detector, and discuss the experimental results obtained with a first test system.

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Quantum decay at short, intermediate, and long times: Observation in integrated photonics

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The decay of an unstable system is usually described by an exponential law. However, quantum mechanics generally predicts deviations from the exponential at both short and long times. The latter case, in which a power-law decay is predicted, is particularly elusive, as its onset commonly occurs when the survival probability is heavily depleted. We describe a hopping model on a semi-infinite array, in which a power-law quantum decay can be observed. We report the experimental observation non-exponential decay dynamics, including power-law regimes, in arrays of parallel single-mode

optical waveguides, fabricated by femtosecond laser direct inscription. We finally comment on the features of state propagation in the array, highlighting the behavior of wavefronts.

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Entanglement detection in Noisy Intermediate-Scale Quantum devices

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With the recent advent of noisy intermediate-scale quantum devices implemented in various platforms, entanglement and quantum coherence detection are in the focus of interest. We propose an ordered set of experimentally accessible conditions for detecting entanglement in mixed states. The k-th condition involves comparing moments of the partially-transposed density operator up to order k. Our empirical studies highlight that the first four conditions already detect mixed state entanglement reliably in a variety of architectures. Exploiting symmetries can help to further improve their detection capabilities. We also show how to estimate moment inequalities based on local random measurements of single state copies (classical shadows). We illustrate the method by applying it to a variety of physical systems and to experimental data.

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Dressed emitters as impurities

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Here, we present a compact formulation of the resolvent-based theory for calculating atom-photon dressed states built on the idea that the atom behaves as an effective impurity *(i)*. This establishes an explicit connection with the standard impurity problem in condensed matter. When the impurity reduces to a vacancy, the resulting class of dressed states play a central role in the emerging area of topological quantum optics *(ii)* in that any topologically-robust dressed state is a VDS *(iii)*.

(i) L. Leonforte, D. Valenti, B. Spagnolo, A. Carollo, F. Ciccarello, arXiv:2108.11963

(ii) M. Bello, G. Platero, J. I. Cirac, and A. González-Tudela, Sci. Adv. 5, eaaw0297 (2019)

(iii) L. Leonforte, A. Carollo, F. Ciccarello, PRL 126, 063601 (2021)

Session 6 / 32

Exotic interactions mediated by a non-Hermitian photonic bath

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We study the exotic interaction between emitters mediated by the photonic modes of a lossy photonic lattice described by a non-Hermitian Hamiltonian, where structured losses can seed exotic emission properties. Photons can mediate dissipative, fully non-reciprocal, interactions between emitters with range critically dependent on the loss rate. At the bare-lattice exceptional point, the effective couplings are exactly nearest-neighbour, implementing a dissipative, fully non-reciprocal, Hatano-Nelson model. Counter-intuitively, this occurs irrespective of the lattice boundary conditions. Thus photons can mediate an effective emitters' Hamiltonian which is translationally-invariant despite the fact that the field is not. We interpret these effects in terms of metastable atom-photon dressed states, which can be exactly localized on only two lattice cells or extended across the entire lattice.

Session 6 / 2

Few- and many-body photon bound states in quantum nonlinear media

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The emergence of multi-photon bound states is an intriguing phenomenon that can occur in quite different quantum nonlinear media, such as arrays of quantum emitters coupled to photonic waveguides and Rydberg atomic ensembles. To theoretical study these bound states within an unified framework we propose a spin-model formulation of quantum atom-light interactions. We solve the few- and many-body correlated dynamics of such states, investigating how their propagating properties within the media manifest themselves in the spatio-temporal correlations of the output field. For sufficiently large photon number we recover a classical soliton-like behavior that suggests that a quantum-to-classical transition from quantum bound states to classical solitons is a general property inherent to quantum nonlinear media.

Session 6 / 4

Light-Matter interactions in synthetic magnetic fields: Landau-Photon polaritons

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We study light-matter interaction in two dimensional photonic systems in the presence of a spatially homogeneous synthetic magnetic field for light. Specifically, we consider one or more two-level emitters located in the bulk region of the lattice, where for increasing magnetic field the photonic modes change from extended plane waves to circulating Landau levels. This change has a drastic effect on the resulting emitter-field dynamics, which becomes intrinsically non-Markovian and chiral, leading to the formation of strongly coupled Landau-photon polaritons. The peculiar dynamical and spectral properties of these quasi-particles can be probed with state-of-the-art photonic lattices in the optical and the microwave domain and may find various applications for the quantum simulation of strongly interacting topological models.

Session 7 / 68

Virtual photons in ultra-strongly coupled systems or Quantum Nonlinear Optics without Photons

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The talk will begin with a very quick pedagogical overview of cavity QED, circuit QED, and the ultra-strong coupling limit of these. Afterwards, present some more recent results, in the context of quantum nonlinear optics of qubits and resonators, coupled in various different configurations, and these qubits and resonators exchanging energy in various ways.

Session 7 / 66

Advancements on QKD networking in space and on the ground

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Recent cyber-attacks to national networks have highlighted the importance of developing an Italian cybersecurity infrastructure where QKD could play an important role by enabling the generation of secure cryptographic keys. The QuantumFuture group is involved in various research projects (eg., OPENQKD) aimed at developing fully-functioning and innovative QKD systems able to operate in the existing fiber telecommunication networks. Moreover, free-space ground-to-ground links and satellite channels will be an integral part of future quantum networks, and we are working on the inter-modal implementation of free-space and fiber links. An overview of the QKD methods developed by QuantumFuture will be given, as well as a presentation of the recent results obtained in field-trials over the Padua network will be presented.

Session 7 / 43

On the properties of the asymptotic incompatibility measure in multi-parameter quantum estimation

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In multiparameter quantum metrology, asymptotic incompatibility (AI) is a recently introduced measure quantifying the quantumness of statistical models. Starting from its definition, we found that it is possible to set an upper bound on the maximum number of asymptotic compatible parameters in the statistical model. We numerically investigate the AI for the full tomography of d-dimensional quantum systems ($2 < d \leq 4$). Using exponential coordinates, numerical results suggest that, once we fix the spectrum of the corresponding Hamiltonian, the AI measure is a function of the fictitious temperature β only. In addition, the maximum number of asymptotic compatible parameters is a function of the dimension d. We conjecture that these results are valid for any finite dimension d.

Session 7 / 5

Mesoscopic twin-beam states propagating through noisy and lossy channels for novel Quantum Communication protocols

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Quantum states of light represent a useful tool for encoding and transmitting information. The main obstacle to the successful implementation of communication protocols, especially over long distances, is given by the losses and noise sources affecting the transmission channels, which can irreversibly change the statistical properties of the employed nonclassical states of light. At variance with the usual schemes, based on single-photon quantum states, in our work we show that mesoscopic twin-beam states exhibit very good robustness to both losses and noise sources. This result suggests the implementation of novel communication protocols based on twin-beam states in which information is encoded in noise superimposed on the quantum states and losses simulate an eavesdropper's interference.

Session 8 / 80

QFold: A Quantum Metropolis Optimization Algorithm

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QFold: A Quantum Metropolis Optimization Algorithm

Session 8 / 42

Quantum Machine Learning

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Quantum Machine Learning (QML) is where nowadays machine learning is going to meet quantum information science in order to realize more powerful quantum technologies. In particular, several QML schemes can arise according to the fact that the data to be processed and the algorithm processing them can be either classical or quantum. Moreover, the learning algorithms can be unsupervised, supervised and goal-oriented (reinforcement learning). Here, we will discuss our recent theoretical and experimental results focusing on quantum embedding, quantum state discrimination, noise sensing, quantum generative adversarial networks, and quantum reinforcement learning. QML is expected to provide huge advantages over its classical counterpart, and deeper investigations are timely needed since they can be already tested on the commercially available quantum devices.

Session 8 / **29**

Measurement induced topological entanglement transition in a free fermion model

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Quantum measurements have been recently exploited as a tool to induce e phase transition between volume- and area-law scaling of entanglement entropy. For free fermions, the transition occurs between sub-volume (logarithmic) and area-law scaling. Here we present a free fermion model where two sets of non-commuting measurements induce a transition between area-law entanglement scaling phases of distinct topological order. We find numerically that, in the presence of unitary dynamics, the two topological phases are separated by a sub-volume scaling region and that the transition universality class differs from that of interactive models with projective measurements. We further show that the different phases are qualitatively captured by an analytically tractable non-Hermitian Hamiltonian model obtained via partial post-selection.

Session 9 / **3**

Atom-photon bound states in an array of high-impedance superconducting resonators

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Engineering the electromagnetic environment of a quantum emitter gives rise to a plethora of exotic light-matter interactions. In particular, photonic lattices can seed long-lived atom-photon bound

states inside photonic band gaps. We report on the implementation of a novel microwave architecture consisting of an array of high-impedance superconducting resonators forming a 1 GHz-wide pass band, in which we have embedded two frequency-tuneable artificial atoms. We study the atom-field interaction and access previously unexplored coupling regimes, in both the single- and double-excitation subspace. In addition, we demonstrate coherent interactions between two atom-photon bound states, in both resonant and dispersive regimes. The presented architecture holds promise for quantum simulation with tuneable-range interactions and experiments in nonlinear photon transport. Reference: arXiv:2107.06852

Session 9 / 46

Quantum hypothesis testing for exoplanet detection

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Detecting the faint emission of a secondary source in the proximity of the much brighter one has been the most severe obstacle for using direct imaging in searching for exoplanets. Using quantum state discrimination and quantum imaging techniques, we show that one can significantly reduce the probability of error for detecting the presence of a weak secondary source, especially they are closely separated. If the weak source has intensity $\epsilon \ll 1$ relative to the bright source, we find that the error exponent can be improved by a factor of $1/\epsilon$. We find linear-optical measurements optimal in this regime. Our result serves as a complementary method in the toolbox of imaging, with applications ranging from astronomy to microscopy.

Session 9 / 56

Genuine multipartite nonlocality with collective postselection strategies

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In the certification of (genuine multipartite) nonlocality, measured data are often postselected to purify the nonlocal features of the data. However, if this postselection requires communication between the measurement parties, it can potentially create fake correlations that mimic nonlocal features via the postselection bias. Here, we show that certain postselection strategies that require partial communication between the parties, are valid to certify the presence of genuine multipartite nonlocality between all parties. The results are proven by the use of causal diagrams and the no-signalling principle. Finally, the results are applied to an optical setup to demonstrate the creation of genuine three-partite nonlocality from independent photon sources.

Session 10 / 63

Coherent and dissipative dynamics at quantum phase transitions

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I will present a dynamic scaling theory aimed at addressing the out-of-equilibrium behavior of many-body systems in proximity of quantum phase transitions of any order. This can be obtained by extending the equilibrium scaling laws ruled either by the critical exponents at continuous transitions, or by the energy gap of the lowest levels at first-order transitions. I will also discuss some aspects related to the effects of dissipative mechanisms, highlighting a nontrivial competition that may arise between the coherent dynamics at quantum transitions and some non-unitary perturbations, such as the coupling with an external Markovian bath or to a quantum-measurement apparatus.

Session 10 / 14

Topological multiterminal superconducting systems

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Multiterminal Josephson junctions (MJJs) constitute engineered topological systems. In 1 we studied the properties of Andreev states in a circuit with a quantum dot (QD) coupled to superconducting leads (SCs) and demonstrated that the quantum geometric tensor can be extracted by synthetically polarized microwaves. In 1 we investigated a linear chain of QDs connected to SCs and showed that nontrivial topology appears beyond a threshold value of the nonlocal proximity-induced pairing potential. Finally we demonstrated such systems can implement higher-dimensional topological systems (second Chern number) and admit non-Abelian Berry phase 1.

1 R. Klees et al., PRL 124, 197002 (2020).

2 R. L. Klees et al., PRB 103, 014516 (2021).

3 H. Weisbrich et al., PRX Quantum 2, 010310 (2021).

Session 10 / 18

Device-independent certification of quantum technologies

Iris Agresti[1] ; Davide Poderini[2] ; Beatrice Polacchi[None] ; Emanuele Polino[2] ; Alessia Suprano[2] ; Gonzalo Carvacho[2] ; Rafael Chaves[3] ; Daniel Cavalcanti[4] ; Leandro Aolita[5] ; leonardo guerini[6] ; Michele Mancusi[1] ; Fabio Sciarrino[2]

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With the development of quantum technologies, it is pivotal to discern devices exploiting quantum phenomena from faulty ones. This essential task is elusive, since eventual imperfections may go unnoticed to a direct verification. A solution to this deadlock exploits the discrepancies between classical and quantum causal predictions, which can detect nonclassical correlations, with no assumptions on the apparatus (device-independently). This talk will present two demonstrations of this approach, applied to instrumental processes and experimentally implemented on photonic platforms. Firstly, nonclassical correlations will be revealed through the violation of an inequality constraint and used to bound the randomness of a bit string. Then, a novel and more general approach will be adopted, exploiting the quantification of causal influence between two variables.

Session 10 / 6

Probe incompatibility in multiparameter noisy quantum metrology

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We derive fundamental bounds on the maximal achievable precision in multiparameter noisy quantum metrology, tighter than a direct use of single-parameter results. This allows us to study the effect of incompatibility of optimal probe states for simultaneous estimation of multiple parameters in generic channels, so far studied mostly in noiseless scenarios. We apply our results to several paradigmatic example, such as lossy multiple-phase interferometry. Going beyond the multiparameter estimation paradigm, we introduce the concept of random quantum sensing and show how the tools developed may be applied to multiple-channel discrimination. As an illustration, we prove the loss of the quadratic advantage of time-continuous Grover algorithm in presence of dephasing or erasure noise.

Session 11 / 79

Entangling solid-state quantum repeater nodes

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Entangling solid-state quantum repeater nodes

Session 11 / 45

Witnessing Bell violations through probabilistic negativity

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Bell's theorem shows that no hidden-variable model can explain the measurement statistics of a quantum system shared between two parties, thus ruling out a classical (local) understanding of nature. In this work we demonstrate that by relaxing the positivity restriction in the hidden-variable probability distribution it is possible to derive quasiprobabilistic Bell inequalities whose sharp upper bound is written in terms of a negativity witness of said distribution. This provides an analytic solution for the amount of negativity necessary to violate the CHSH inequality by an arbitrary amount, therefore revealing the amount of negativity required to emulate the quantum statistics in a Bell test.

Session 11 / 12

Underground tests of Quantum Mechanics: Collapse Models and Pauli Exclusion Principle

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We are experimentally investigating possible departures from the standard quantum mechanics' predictions at the Gran Sasso underground laboratory in Italy. In particular, we are searching signals predicted by the collapse models which were proposed to solve the "measurement problem" in quantum physics. I shall discuss our recent results published in Nature Physics, where we ruled out the natural parameter-free version of the gravity-related collapse model. I shall then present more generic results on testing CSL collapse models and discuss future perspectives. Finally, I shall briefly present the VIP experiment with which we look for possible violations of the Pauli Exclusion Principle by searching for "impossible" atomic transitions and comment the impact of this research in relation to Quantum Gravity models.

Session 11 / 85

Single-shot simulations of prolonged quantum dynamics with structured light

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Standard photonic simulations of lattice quantum dynamics rely on our ability to shape optical modes and their relative couplings. In these platforms, reproducing temporally-long evolutions is challenging, as required setups are complex and lossy. Here we report the realization of long-time photonic quantum walks, based on light propagation through a limited number of birefringent optical elements. The walk is engineered in the particles quasi-momentum space, encoded into a spatial coordinate transverse to the optical axis. Considering optical polarization as the internal degree of freedom, the evolution operator is built in terms of a spatially-varying polarization transformation, realized through liquid-crystal metasurfaces. We report up to 320 timesteps of quantum-walk evolutions, even affected by disorder, far beyond state-of-the-art simulations of such dynamics.

Session 12 / 53

Integrated quantum photonics in femtosecond-laser-written devices

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Integrated photonics is a key enabler for quantum technologies, with significant improvements introduced in quantum computing, sensing and communications. Femtosecond laser writing of photonic circuits brings key advantages in terms of unprecedented 3D circuit layouts, possibility to manipulate polarization encoding, multimaterial devices and rapid prototyping. All these advantages are widely exploited in integrated quantum photonics applications and a few examples will be reviewed in this presentation. Progress towards the specific goal of developing a complete quantum photonic platform encompassing all the relevant functionalities will be discussed.

Session 12 / 23

Fundamental thresholds of realistic quantum error correction circuits from classical spin models

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Mapping quantum error correcting codes to classical statistical mechanics models has proven a powerful tool to study the fundamental error thresholds of quantum error correcting codes under phenomenological noise models. In this work, we extend this mapping to realistic faulty quantum circuits by deriving the associated strongly correlated classical spin models for the example of a quantum repetition code. We then use Monte-Carlo simulations to study the resulting phase diagram of the associated interacting spin model and benchmark our results against a minimum-weight perfect matching decoder. The presented method provides an avenue to assess the fundamental thresholds of QEC codes and associated readout circuitry, independent of specific decoding strategies, and can thereby help guiding the development of near-term QEC hardware.

Session 12 / 37

Trapped ions for hybrid quantum systems

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Ultracold atoms and trapped ions have proven to be valuable resources for getting new insights on fundamental physical phenomena. Trapped ions can be individually addressed and coherently manipulated. Ultracold gases, instead, provide large atomic samples where trapping potentials and interactions are controlled externally, making them well suited for systematic studies of many-body quantum phenomena. An atom-ion hybrid system brings together the advantages of each physical system and provides an ideal platform to investigate fundamental quantum mechanics, like localized impurities in a Fermi gas. Here we present the first step towards the realization of such hybrid system: the trapping of Ba ions, together with the current state of advancement of the apparatus that will allow us to reach coherent atom-ion coupling.

Session 12 / 67

Speeding up quantum annealing: schedule engineering and optimal driving

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Shortcuts to adiabaticity in adiabatic quantum computation can be realized either by optimal designs of the annealing schedules or by using external control fields, such as counterdiabatic (CD) driving operators. I will discuss how genetic algorithms can help in determining optimal annealing schedules. Secondly, I will introduce the variational approach to CD driving in closed quantum systems to build approximate CD operators, satisfying locality constraints. Finally, I will discuss a generalization of the variational approach to open quantum systems.

1. P. R. Hegde, GP, A. Scocco, P. Lucignano, arXiv:2108.03185 (2021)
2. GP, V. Cataudella, R. Fazio, P. Lucignano, PRResearch 2, 013283 (2020)
3. GP, R. Fazio, P. Lucignano, arXiv:2109.13043 (2021)

Session 13 / 71

A Bose-Einstein condensate in holographically-generated optical traps

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We simulate the preparation of a superposition of vortex states in a Bose-Einstein condensate trapped in a ring geometry. It has been proposed that a vortex-antivortex superposition can be used as an inertial sensor, e.g. to measure rotations, or as a magnetic field sensors [1,2]. In both cases, the external influence causes a precession of the BEC standing wave, which can be measured experimentally. In this talk I will show how computer-generated holography 3 can be used for the efficient preparation of these states, and I will demonstrate their stability by simulating their subsequent evolution.

1 S. Thanvanthri et_al., Journal of Modern Optics 59,1180(2012).

2 G Pelegrí et_al., New J.Phys. 20,103001(2018).

3 D. Bowman et_al., Opt.Express 25,11692(2017).

Session 13 / 13

Variational Quantum Eigensolver for SU(N) Fermions

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Variational quantum algorithms aim at harnessing the power of noisy intermediate-scale quantum computers, by using a classical optimizer to train a parameterized quantum circuit to solve tractable quantum problems. The variational quantum eigensolver is one of the aforementioned algorithms designed to determine the ground-state of many-body Hamiltonians. Here, we apply the variational quantum eigensolver to study the ground-state properties of N-component fermions. With such knowledge, we study the persistent current of interacting SU(N) fermions, which is employed to reliably map out the different quantum phases of the system. Our approach lays out the basis for a current-based quantum simulator of many-body systems that can be implemented on noisy intermediate-scale quantum computers.

Session 13 / 52

Transient dynamics in Rydberg-EIT

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Ensembles of Rydberg atoms, in the Electromagnetic Induced Transparency setup, have proved to be a possible route to obtain photon-photon nonlinear interaction. Thanks to the Rydberg blockade mechanism, a single photon is indeed able to saturate the atomic response of a considerably large portion of the ensemble, that appears opaque to a second incoming one. While the continuous wave (CW) response of such a medium was largely studied in the past, here we present the analysis of the

pulse dynamics. We show that the transient light can be more antibunched than the CW one, and how this could pave the way to the development of new protocols to turn light from classical into quantum.

Session 14 / 64

Symmetry resolved entanglement

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Entanglement and symmetries are two pillars of modern physics. Surprisingly, only in very recent times the interplay between these two fundamental concepts became the theme of an intense research activity merging together notions and ideas from quantum information, quantum field theory, quantum optics, holography, many-body condensed matter, and many more. In this talk, I will review some of the more interesting findings for symmetry resolved entanglement ranging from purely field theoretical ones to microscopical lattice models for disordered systems. The focus of the talk will be on the results and outlooks rather than on the the technical derivations.

Session 14 / 48

Quantifying the difference between many-body quantum states

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The quantum state fidelity is the textbook measure of the difference between two quantum states. Yet, it is inadequate to compare the complex configurations of many-body systems. We introduce the weighted distances, a new class of information-theoretic measures that overcome these limitations. They quantify how hard it is to discriminate between two quantum states of many particles, factoring in the structure of the required measurement apparatus. We also show that the newly defined "weighted Bures length" between the input and output states of a quantum process is a lower bound to the experimental cost of the transformation. The result uncovers an exact quantum limit to our ability to convert physical resources into computational ones. Ref.: PRL 126, 170502 (2021)

Session 14 / 41

Generalized coherence vector: definition and applications

Author(s): Gustavo Martin Bosyk[1]

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A notion of coherence vector of a general quantum state is introduced on the framework of quantum coherence resource theory 1. This generalized coherence vector completely characterizes the notions of being incoherent, as well as being maximally coherent. Moreover, using this notion and the majorization relation, a necessary condition for the conversion of general quantum states by means of incoherent operations is obtained. Finally, a new family of coherence monotones based on the coherence vector is introduced.

1 G.M. Bosyk, *et al.*, Phys. Rev. A 103, 012403 (2021)

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Closing