Bari Theory Xmas Workshop 2025

Monday 15 December 2025 - Monday 15 December 2025

Bari, Sezione INFN e Dipartimento Interateneo di Fisica

Book of Abstracts

Contents

Afternoon session 1 / 1

Torque-driven supercoiling transition in open DNA polymers

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In this work, we combine coarse-grained Brownian dynamics simulations and mean-field theory to study supercoiling dynamics, as well as the steady-state profiles of twist and writhe, in an open DNA polymer where one of the free ends is subjected to a constant torque. Even though the other end is free, and hence can spin and release torsional stress, we observe that the entire chain transitions between a swollen and a plectonemic phase as the torque increases beyond a critical threshold. In the plectonemic phase, we observe a non-linear twist profile in the steady state, resulting from the mutual interconversion between the injected twist and geometrical writhe, which distributes inhomogeneously along the chain. We also show that the non-equilibrium dynamics of twist accumulation is diffusive, and that writhe diffusion is negligible in this geometry, as plectonemes remain localised near the end that is being rotated. We discuss the feasibility of testing our results with single-molecule experiments.

Afternoon session 2 / 2

Tensor Network simulation of multi-emitter Waveguide QED

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Waveguide Quantum Electrodynamics (Waveguide QED) is a promising and versatile platform for studying fundamental light-matter interactions and quantum technology implementations. Notably, interesting effects emerge when two or more quantum emitters are coupled to the waveguide, including collective phenomena, e.g., superradiance and formation of bound states in the continuum (BICs).
An effective approach to address the behaviour of such systems is via Tensor Network quantum-inspired simulation techniques, enabling to efficiently simulate the real-time dynamics of many-body quantum systems, i.e, a waveguide QED platform.
In particular, I will present a method based on Matrix Product States (MPS) to model a waveguide QED architecture featuring multiple emitter pairs and simulate its dynamics in the non-Markovian regime. Then, I will discuss the obtained results, focusing on the emergence of BICs and other collective effects in the long-time limit.

Morning session 2 / 3

Multipartite entanglement of random states

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In this talk, we will introduce the key differences between bipartite and multipartite entanglement in quantum systems. We will then show how quantum frustration emerges in multipartite scenarios, namely, situations in which a system cannot achieve globally optimal entanglement because different bipartitions impose conflicting requirements.
Next, we will consider various classes of random states in multipartite qubit systems to investigate their typical entanglement distributions. Special attention will be devoted to comparing these distributions across the different classes of random states, highlighting several unexpected and intriguing behaviors.
These findings contribute to the identification of the best classes of states for the study of multipartite entanglement and the investigation of quantum frustration.

Afternoon session 2 / 4

Constraining gravitational-wave backgrounds from conversions into photons in extragalactic magnetic fields

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High-frequency gravitational waves may provide a unique signature for the existence of exotic physics. The lack of current and future gravitational-wave experiments sensitive at those frequencies leads to the need of employing different indirect techniques. Notably, one of the most promising ones is constituted by graviton-photon conversions in magnetic fields. Our research focuses on the conversion of a gravitational-wave background into photons inside the magnetic fields of the M82 starburst galaxy and the M87 giant elliptical galaxy. By numerically solving the equations of motion of the graviton–photon system, we compute the expected electromagnetic signal generated by the conversions. This signal is then compared with the observed photon flux from the two galaxies. Requiring that the converted-photon signal does not exceed the observed flux yields a constraint on the amplitude of the gravitational-wave background. In our analysis, we use observational data from the NuSTAR high-energy telescope, which operates in the 3–80 keV band; consequently, our bound applies to gravitational waves within the corresponding frequency range. With this techiques, we improved the existing bounds in literature by about two orders of magnitude.

Morning session 2 / 5

Unruh Effect and Entanglement Generation

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The Unruh effect predicts that a uniformly accelerated observer in the Minkowski vacuum perceives a thermal bath, so that an accelerating detector behaves as an open quantum system interacting with an effective thermal environment. We exploited this perspective to study entanglement generation between two identical two-level atoms located at the same spacetime point and weakly coupled to the same external quantum fields, without making assumptions on the spacetime dimension, or on the number and nature of the fields. We derived a Gorini–Kossakowski–Lindblad–Sudarshan (GKLS) master equation for the reduced dynamics of the two detectors and from the corresponding asymptotic state we computed the concurrence in order to measure the entanglement. In particular, we characterised how this depends on the coupling tensor between the detectors and the fields, identifying the regimes in which the Unruh-induced open dynamics can generate or suppress entanglement.

Morning session 1 / 6

Detecting light axion-like particles from supernovae in nearby galaxies

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Axion-like particles (ALPs) coupled to nucleons can be efficiently produced in core-collapse supernovae (SNe) and then, if they couple to photons, convert into gamma rays in cosmic magnetic fields, generating short gamma-ray bursts. Though ALPs from a Galactic SN would induce an intense and easily detectable gamma-ray signal, such events are exceedingly rare. In contrast, a few SNe per year are expected {in nearby galaxies} within $\sim \mathcal{O}(10)$ Mpc, where strong magnetic fields can enable efficient ALP–photon conversions, offering a promising extragalactic target.
This motivates full-sky gamma-ray monitoring, ideally combined with deci-hertz gravitational-wave detectors to enable time-triggered searches from nearby galaxies. We show that, under realistic conditions, a decade of coverage could reach sensitivities {to ALP-photon coupling $g_{a\gamma}$
$gtrsim 10^{-15}$ GeV^{-1} for ALP masses m_a
$lesssim 10^{-9}$~eV,
probing a currently-unexplored large region of the parameter space below the longstanding SN 1987A bound.

Afternoon session 2 / 7

Generation of Wigner-negative states from a coherently driven qubit in waveguide

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In this talk, we will present a powerful protocol, employing the interaction between an electromagnetic field and a qubit, to identify genuinely non-classical states, and we will explain the assumptions underlying this protocol. To discriminate non-classical states from classical ones, we choose

the Wigner function as our diagnostic tool.
We will show how to analyze light–matter interaction without relying on standard open-quantum-system models, in order to obtain information about the light states. In particular, we will use the Virtual Cavity Method, which allows for the direct extraction of the states of selected modes of the field scattered by the emitter, and the Collision Model, which provides an analytical, time-resolved description of the closed emitter–field dynamics.
We then compare and combine the predictions of the two models, exploring how system parameters affect the Wigner function. The main objective is to identify optimal working points for this protocol which generates non-classical states, given the importance of this kind of resources for the development of quantum technologies.

Afternoon session 1 / 8

Wandering range of robust symmetries

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A powerful way to study quantum systems is through their symmetries, or equivalently, the conserved quantities associated with the Hamiltonian. Standard quantum mechanics tells us that these correspond to operators commuting with the Hamiltonian. Once the Hamiltonian is known, its conserved quantities can, at least in principle, be identified.
However, only those symmetries that persist under perturbations are physically observable. If a symmetry survives —perhaps slightly deformed but still effective —we call it robust; if it fails under even small changes of the Hamiltonian, it is fragile.
In this talk, I will focus on robust symmetries and introduce the notion of their wandering range: a quantitative measure of how much a robust symmetry can drift under a perturbation. I will show that this drift admits a bound that depends explicitly on the spectral properties of the Hamiltonian, but which is independent on the size of the system.

Afternoon session 2 / 9

Quantum machine learning: state of the art and perspectives

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Machine learning permeates our everyday life, with applications ranging from disease diagnosis and environmental monitoring to fraud detection. Despite its successes, modern machine learning still faces major challenges, including the need for extensive computational resources, large training datasets, and a high number of trainable parameters. In recent years, an exciting avenue to overcome these limitations has emerged: implementing machine learning algorithms on quantum computers.

This talk will explore the key achievements reached so far and highlight ongoing research within our department. Special attention will be given to a particular class of quantum machine learning models—Equivariant Quantum Neural Networks—designed to exploit symmetries in data to achieve improved performance.

Morning session 2 / 10

Statistical mechanics of multipartite entanglement in Hadamard qubits states

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We investigate the thermodynamic properties of the uniform real-phased submanifold in n-qubit systems, called Hadamard states, represented as a classical ensemble of 2^n spins subject to a potential encoding the multipartite entanglement. For small system sizes (n<6 qubits), we perform an exact enumeration, enabling a complete statistical characterization of the energy landscape and associated thermodynamic observables. For larger systems (n = 6 and 7 qubits), where exact methods become computationally prohibitive, we employ a stochastic annealing approach to efficiently sample the high-dimensional state space. This method accurately reproduces known benchmarks and captures key features of the system's thermodynamic behavior. Our analysis reveals intricate entropic structures arising from the interplay between entanglement constraints and the underlying combinatorial geometry of quantum state spaces. These findings provide new insights into the statistical mechanics of constrained quantum systems and highlight the utility of thermodynamic tools in characterizing complex entangled states.

Morning session 1 / 11

Quantum master equation: from Van Hove to Sauron

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I will give an overview of the derivation of the master equation for open quantum systems, from both a physical and mathematical perspective.

After discussing the structure of the master equation and its derivation along with its key physical assumptions, I will introduce the mathematical instruments needed to formalize the problem: such tools range from *Van Hove's "$\lambda^2 t$"* limit and Projection Method to the novel One Bound technique.

The latter method will be implemented in the context of an exactly solvable model, which consists in a qubit interacting with a bosonic field.

Afternoon session 1 / 12

Error Scaling of Trotter Product Formulas

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Solving the Schrödinger equation is one of the most fundamental tasks in quantum physics. However, obtaining exact solutions is often challenging, if not outright infeasible. In such cases, approximation methods become essential. Among them, Trotter product formulas offer a particularly powerful and versatile approach: they approximate the time-evolution operator by decomposing it into simpler pieces, each corresponding to more tractable dynamics. Owing to their conceptual simplicity and broad applicability, product formulas have become standard tools in quantum simulation and quantum computation.
In this talk, I will give an overview of the theory behind Trotter product formulas, with a special emphasis on their convergence behavior.

Afternoon session 1 / 13

Routes beyond the Standard Model

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Despite the countless experimental confirmations, the Standard Model (SM) leaves many unanswered questions. Tensions have emerged over time between its predictions and experimental data, mostly in the flavor sector. For these reasons, a theory capable to account at least partially for the observed discrepancies is actively sought for.

Notable examples in the exploration of physics beyond the SM (BSM) include models predicting new mediators (e.g. a new Z' boson, leptoquarks, etc.) or extra dimensions, and the class of 331 models, based on the gauge group SU(3) $\times$ SU(3) $\times$ U(1). A complementary approach treats the SM as an effective low-energy approximation of a more fundamental theory at higher scales.

In this seminar, after reviewing the key motivations and strategies driving the search for BSM physics, the different paths currently followed in the quest for New Physics will be presented.

Morning session 1 / 14

Extended Topological Defects in Three-Dimensional Nematics and Majorana Quasiparticles

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Topological defects are stable singular structures that naturally emerge in ordered media. In three-dimensional nematic liquid crystals, extended defects such as disclination loops display a remarkably rich phenomenology, whose full structure and dynamical role are still not completely understood. In particular, we focus on a class of these loops and show that they can be endowed with a Majorana-like character through an algebraic correspondence based on Clifford algebras. By constructing an explicit mapping between the geometry of the loop and suitable spinorial elements, we clarify how specific configurations can be represented within this framework and in what sense they display features analogous to Majorana particles. This correspondence provides new insight into the behaviour of topological defects in three-dimensional nematics and offers a classical setting in which analogues of quantum phenomena can be identified and studied.

Afternoon session 2 / 15

Rheology of a Chiral Active System

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We investigate a two-dimensional chiral fluid composed of Brownian disks interacting via a Lennard-Jones potential and subjected to a nonconservative transverse force, mimicking colloids spinning at a given rate.
Focusing on the liquid phase, characterized by rotating hexatic patches, we demonstrate that increasing chiral activity modifies the system's effective temperature. In the solid phase, the introduction of chiral activity alone induces melting, driving a transition from a yielding regime to Newtonian-like behavior.
Additionally, under sufficiently large shear rates, the particles organize into pronounced string-like flows, where layers of particles slide past each other along the shear direction.
This string formation is further enhanced when the rotation of the particles opposes the shear direction.
These findings clarify how chiral activity influences the rheological behavior of particle assemblies, advancing our understanding of flow dynamics in active chiral fluids.

Afternoon session 2 / 16

Closing

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Afternoon session 1 / 17

Hunting new physics in semileptonic b→u transitions

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Properties and interactions of elementary particles are successfully described by the theory known as the Standard Model (SM). Despite the countless confirmations of the theory, it is generally believed that physics beyond the SM (BSM) should exist. In particular, the increase in the experimental precision has put more stringent constraints on the theory and a number of tensions between the SM predictions and the related experimental results have emerged. In the flavour sector such tensions are usually referred to as flavour anomalies.
A possible way to get insight into BSM physics is a bottom-up approach, mainly driven by experiment. It consists in considering the SM as an effective theory valid at the electroweak scale and investigate the features of the more general theory from which it descends, without any reference to a specific new physics model. This kind of approach is realized in the Standard Model Effective Field Theory (SMEFT). SMEFT assumes that NP exists at the electroweak scale, so that the SM is regarded as an effective theory at that scale.
Within this framework this thesis considers semileptonic decays induced by the underlying $b \to u$ quark level transition. In particular, exclusive $B \to \pi \ell \bar{\nu}_\ell$ and $B \to \rho \ell \bar{\nu}_\ell$ modes are studied. We

extend the Standard Model effective Hamiltonian governing this modes with the inclusion of the full set of Lorentz invariant dimension 6 operators compatible with the gauge symmetry of the SM and weighted by new physics couplings.
Exploiting recent data provided by the Belle Collaboration, the allowed parameter space of the such couplings introduced will be identified. It will be discussed whether the SM performs better or worse than the case in which new physics is present.

Morning session 1 / 18

Improving theoretical precision in the study of B -> D** decays

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The study of semileptonic B decays into charmed mesons $D^{(*)}$ plays a crucial role in the determination of CKM matrix element V_{cb}, improving and studying the nonperturbative dynamics of QCD, in testing heavy-quark symmetry. Indeed, these processes are described by matrix elements between hadronic states, which are nonperturbative. They can be expressed in terms of functions of q^2 called form factors. In order to compute these quantities, QCD sum rules and their variants represent one of the most powerful tools.

Our aim is to improve the theoretical determination of these form factors both at finite heavy-quark mass and in the limit $m_Q \to \infty$.

Morning session 1 / 19

Properties of excited charmed mesons from QCD sum rules

Author: Carlo la Torre[None]

I consider semileptonic B-meson decay to the orbitally excited charmed meson D_2^*, having spin parity $J^P = 2^+$. In particular, I apply the QCD sum rules method (using the original formulation known as short distance sum rules) to compute the decay constant of D_2^* that is a preliminary ingredient for the calculation of the form factors describing the transition $\mathrm{B} \to \mathrm{D}_2^*$.
Afterwards, I consider the variant of the method called light-cone QCD sum rules in order to derive the form factor K_V describing the matrix element of the vector current between the B meson and D_2^*.

Morning session 2 / 20

(ν1 ,ν2) oscillation parameters after first JUNO results

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We present an updated global determination of the neutrino oscillation parameters governing the ($\nu 1$,$\nu 2$) sector, including the latest SNO+ results and the first measurement from JUNO. In the three-neutrino framework, we focus on the solar mass splitting $\delta m2$ and the mixing parameter $\sin 2\theta 12$, which drive solar and medium-baseline reactor oscillations.
The new constraints are incorporated into a recent global fit through external likelihoods in the ($\delta m2$,$\sin 2\theta 12$) plane. While SNO+ induces mild shifts, JUNO already dominates the precision.
We obtain $\delta m2=(7.48\pm 0.10)\times 10-5$ eV2, $\sin 2\theta 12 =0.3085\pm 0.0073$, with correlation $\rho=-0.20$, corresponding to 1.3% and 2.4% uncertainties.

21

TBA