Proposal for an INFN Research Project (Iniziativa Specifica)

Section I:

Title: Statistical Field Theory, Low-Dimensional Systems, Integrable Models and Applications

Acronym: SFT

National Coordinator (Responsabile Nazionale):

Name: **Roberto Tateo**
INFN Unit: Torino
e-mail: roberto.tateo@to.infn.it

Local Coordinators (Responsabili Locali):

- Name: **Giuseppe Mussardo**
  INFN unit: Trieste
  e-mail: mussardo@sissa.it

- Name: **Filippo Colomo**
  INFN unit: Firenze
  e-mail: filippo.colomo@fi.infn.it

- Name: **Marco Gherardi**
  INFN unit: Milano
  e-mail: marco.gherardi@unimi.it

- Name: **Roberto Tateo**
  INFN unit: Torino
  e-mail: roberto.tateo@to.infn.it

- Name: **Domenico Giuliano**
  INFN unit: Cosenza
  e-mail: domenico.giuliano@fis.unical.it

- Name: **Davide Rossini**
  INFN unit: Pisa
  e-mail: davide.rossini@unipi.it

- Name: **Andrea Amoretti**
  INFN unit: Genova
  e-mail: andrea.amoretti@ge.infn.it

Keywords related to the topic of the proposal:
- Quantum field theories out of equilibrium
- Entanglement, quantum information and quantum computation
- Low-dimensional quantum field theory, integrable models and deformations
- Conformal invariance, conformal bootstrap and universality classes
- Topological phases of matter, field theories and bosonization

Abstract of the proposal:

This project is centered on a series of outstanding questions of statistical field theory. Guiding lines are the exact non-perturbative methods of quantum field theory, based on the developments in conformal theories, exactly solvable lattice models and quantum integrable systems. A key feature of all these approaches is their ability to enlighten and account for strong coupling phenomena in quantum systems with infinite degrees of freedom. Applications of quantum field theory beyond the realm of particle physics nowadays form an extremely rich research area, dealing with quantum devices, cold atom gases, quantum spin chains, topological phases of matter and quantum systems out of equilibrium.

We plan: (1) to tackle important aspects of quantum field theory out of equilibrium and work out applications thereof (thermalization, exact solutions in quantum spin chains, generalized quantum hydrodynamics, computation of multipoint correlators); (2) to understand the physical properties of entanglement (in particular its relation with symmetries and symmetry breaking patterns both in and out-of-equilibrium, the evolution of quantum information in open systems, the development of new protocols to measure the entanglement both in numerical simulations and experiments, the modelization of quantum computations, the use of the gauge/gravity correspondence also in connection with the information paradox in black holes); (3) to study the emergence of new physical phenomena related to quantum integrability, its deformation and breaking (irrelevant perturbations and Hagedorn-type phase transitions, cold atoms in a trap, limit-shape phenomena, confinement of topological excitations, spectrum of neutral excitations, Majorana zero modes, massless renormalization group flows, many-body localization); (4) to explore new universality classes of critical phenomena by using conformal invariance combined with conformal perturbation theory and very efficient numerical methods, such as the conformal bootstrap, truncated conformal space approach, DMRG, tensor networks, Monte Carlo and exact diagonalization techniques (applications to wetting phenomena, percolation, KPZ model, Potts model and Ising-like models above two dimensions, as well as to effective string theory); (5) to investigate the properties of topological phases of matter (identification of corresponding topological field theories in three spatial dimensions, bosonization and dynamics of massless boundary excitations, and transport properties).

Composition of the participant Research Units:

1] INFN unit: Trieste

Staff members

- Pasquale Calabrese (SISSA, PO, 100%)
- Gesualdo Delfino (SISSA, PA, 100%)
- Andrea Gambassi (SISSA, PO, 100%)
- Giuseppe Mussardo (SISSA, PO, 100%)
- Antonello Scardicchio (ICTP, PR, 70%)
- Erik Tonni (SISSA, PA, 100%)
- Andrea Trombettoni (UniTS, PA, 100%)

Other participants

- Filiberto Ares (SISSA, postdoc, 100%)
- Feng He (SISSA, postdoc 100%)
- David Horvath (SISSA, postdoc 100%)
- Nina Javerzat (SISSA, postdoc 100%)
- Diego Pontello (SISSA, postdoc 100%)
- Colin Rylands (SISSA, postdoc 100%)
- Stefano Scopa (SISSA, postdoc100%)
- Lenart Zadnik (SISSA, postdoc 100%)
- Zhao Zhang (SISSA, postdoc 100%)
- Francesco Andreucci (SISSA, PhD student 100%)
- Luca Capizzi (SISSA, PhD student 100%)
- Lorenzo Correale (SISSA, PhD student 100%)
- Rajat Kumar Panda (SISSA, PhD student 100%)
- Marianna Sorba (SISSA, PhD student 100%)
- Davide Venturelli (SISSA, PhD student 100%)
- Francesco Codagnone (SISSA, PhD student 100%)
- Federico Rottoli (SISSA, PhD student 100%)
- Andrea Solfanelli (SISSA, PhD student 100%)
- Poetri Tarabunga (SISSA, PhD student 100%)
- Carlo Vanoni (SISSA, PhD student 100%)
- Cristiano Muzzi (SISSA, PhD student 100%)
- Michele Fossati (SISSA, PhD student 100%)
- Francesco Gentile (SISSA, PhD student 100%)
- Gabriele Bandini (SISSA, PhD student 100%)
- Giovanni Bracci Testasecca (SISSA, PhD student 100%)
- Kostantinos Chalas (SISSA, PhD student 100%)
- Marcin Pruszczyk (SISSA, PhD student 100%)
- Andrea Stampiggi (SISSA, PhD student 100%)

2] INFN unit: Firenze

Staff members

- Leonardo Banchi (UniFi, PA,70%)
- Andrea Cappelli (INFN, DR, 100%)
- Fabio Cinti (UniFi, PA,80%)
- Filippo Colomo (INFN, PR, 100%)
- Alessandro Cuccoli (UniFi, PA,90%)
- Maria Cristina Diamantini (UniPG, PA,100%)
- Paola Verrucchi (CNR, R, 50%)

Other participants

- Matteo Ciardi (UniFi, PhD student, 100%)
- Andrea Maroncelli (UniFi, PhD student, 100%)
- Riccardo Villa (UniFi, PhD student, 100%)
- Jacopo Viti (UniFi, postdoc, 100%)

3] INFN unit: Milano

Staff members

- Marco Gherardi (UniMi, RTDB, 100%)
- Luca Guido Molinari (UniMi, PA, 50%)
- Mario Pernici (INFN, PR, 100%)

Other participants

- Sergio Caracciolo (UniMi, Associato Senior, 100%)

4] INFN unit: Torino

Staff members

- Michele Caselle (UniTo, PO, 40%)
- Andrea Cavaglià (UniTo, RTDB, 100%)
- Marco Panero (UniTo, PA, 100%)
- Roberto Tateo (UniTo, PO,100%)

Other participants

- Nicolò Brizio (UniTo, PhD student, 100%)
- Andrea Bulgarelli (UniTo, PhD student, 100%)
- Elia Cellini (UniTo, PhD student, 100%)
- Alessandro Nada (UniTo, Postdoc, 100%)
- Junichi Sakamoto (INFN, Postdoc, 100%)
- Antonio Smecca (UniTo, PhD student, 100%)

5] INFN unit: Cosenza

Staff members

- Domenico Giuliano (UniCS, PA, 100%)
- Francesco Plastina (UniMe, PA, 50%)

Other participants

- Emmanuele Cinnirella (UniCS, PhD student, 100%)
- Bidyut Dey (INFN, postdoc, 100%)
- Jacopo Settino (UniCS, RTDA, 100%)

6] INFN unit: Pisa

Staff members

- Vincenzo Alba (UniPi, RTDB, 100%)
- Davide Rossini (UniPi, PA, 100%)
- Ettore Vicari (UniPi, PO, 100%)
- Alessandro Vichi (UniPi, PA, 100%)

Other participants

- Francesco Bertucci (UniPi, PhD student, 100%)
- Ilija Buric (UniPi, postdoc, 100%)
- Fabio Caceffo (UniPi, PhD student, 100%)
- Alessio Franchi (UniPi, PhD student, 100%)
- Stefanos R. Kousvos (UniPi, postdoc, 100%)
- Mihail H. Mintchev (INFN, Associato Senior, 100%)
- Francesco Perciavalle (UniPi, PhD student, 100%)
- Francesco Russo (UniPi, PhD student, 100%)
- Francesco Tarantelli (UniPi, PhD student, 100%)

7] INFN unit: Genova

Staff members

- Andrea Amoretti (UniGe, RTDB, 100%)
- Nicodemo Magnoli (UniGe, PA, 100%)

Other participants

- Luca Martinoia (UniGe, PhD student, 100%)
- Ionas Rongen (UniGe, borsista, 100%)

Section II:

Status of the relevant research field; scientific context, objectives and envisaged achievements of the proposed program.

The project encompasses five interconnected research domains, namely:

1. **Quantum field theories out of equilibrium**
2. **Entanglement, quantum information and quantum computation**
3. **Low-dimensional quantum field theory, integrable models and deformations**
4. **Conformal invariance, conformal bootstrap and universality classes**
5. **Topological phases of matter, field theories and bosonization**

We now provide an overview of the current status of each topic and outline the milestones we aim to achieve.

(1) Quantum field theories out of equilibrium: A fundamental question in statistical physics is to determine the conditions under which an extended quantum system, subjected to a quench (an abrupt change of parameters in the Hamiltonian), reaches a stationary state characterized by an effective "thermal" equilibrium distribution. Conformal field theory, integrable systems, and generalized quantum hydrodynamics provide powerful methods to address this question and uncover various aspects of out-of-equilibrium dynamics. In conformal or integrable field theories, the concept of Boundary State is particularly useful as it encodes properties of the initial states and describes subsequent out-of-equilibrium dynamics. For integrable quantum field theories out of equilibrium, the presence of an infinite number of conservation laws leads to Generalized Gibbs Ensembles that better capture the long-time behavior of the system.
Milestones: Attaining full control of the time evolution of extended quantum systems. Refining the methods of Generalized Gibbs Ensembles and establishing the connection with generalized hydrodynamics. Investigating the AdS/CFT correspondence for out-of-equilibrium systems. Understanding the restoration of symmetry under time evolution. Examining the dynamics of mixtures of boson and fermion gases. Developing quantum algorithms for out-of-equilibrium quantum field theories.

(2) Entanglement, quantum information and quantum computation: Entanglement measures can effectively characterize many states of matter, particularly in non-equilibrium scenarios where the traditional spontaneous symmetry-breaking description may not apply. However, the relationship between entanglement and symmetries is not fully understood yet, and will be investigated using methods of conformal field theory, AdS/CFT correspondence, topological field theory, and integrable models. Another important aspect is the study of the entanglement Hamiltonian and its modular flow as a mean to identify different topological phases of matter. Furthermore, recent experiments with cold atoms have opened up possibilities for measuring entanglement through randomized measurements and classical shadows, also promoting the development of new numerical algorithms for accessing entanglement. Extracting quantum information from many-particle systems is difficult because of the measurement postulate of quantum mechanics and the exponentially large Hilbert space. We will develop novel quantum algorithms capable of learning to classify complex quantum systems, e.g. according to their topological phase or entanglement structure, directly from measurement data.
Milestones: Understanding the interplay between entanglement, symmetry, and symmetry breaking. Investigating entanglement Hamiltonians in conformal and topological states. Exploring entanglement in open quantum systems and developing methods for entanglement transfer to achieve high-quality information flow. Developing a toolbox for

randomized measurements. Exploring the application of quantum algorithms to integer factorization and primality testing.

(3) Low-dimensional quantum field theory, integrable models and deformations: Quantum integrability has proven to be a valuable tool for understanding the critical properties of quantum systems in equilibrium. The Bethe Ansatz and the associated non-linear integral equations have provided insights into the analytic structure of the free energy for many models. Exploring deformations of integrable models through irrelevant perturbations and breaking integrability has also yielded fascinating results, and the identification of new physical phenomena. These include Hagedorn-type phase transitions, connections with quantum gravity and effective string theory, confinement of topological excitations, and quantum chaotic behavior in physical amplitudes.
Milestones: Computing the excitation spectrum in weakly non-integrable field theories and studying the confinement of topological excitations and non-local perturbing operators. Investigating many-body localization in integrable models and exploring duality relations, including Chang duality for Landau-Ginzburg theories. Obtaining exact solutions for the spectrum of planar string theory on integrable AdS3 backgrounds with generic fluxes. Classifying integrability and its breaking for deformations of 2D conformal field theories. Achieving a comprehensive description of the TTbar perturbation within the framework of the 4D extension of Chern-Simons theory introduced by Costello.

(4) Conformal invariance, conformal bootstrap and universality classes: Conformal field theory exactly describes the properties of strongly interacting physical systems at criticality in one and two dimensions, such as their excitations, correlation functions, and finite-size scaling. The conformal bootstrap approach allows to solve theories in higher dimensions, using both numerical and analytic techniques. These have led to extremely precise determinations of critical exponents in statistical models and field theories in three and four dimensions.
Milestones: Develop refined numerical and analytic bootstrap methods. New algorithms for conformal gauge theories in conjunction with integrability can compute bulk and defect correlation functions in planar N=4 Super-Yang-Mills theory. We would also investigate the universality classes of 3d statistical models, gauge theories and fermionic systems, and study wetting transitions and interfaces. Explore the universal properties of cold atoms in traps by means of finite-size theories.

(5) Topological phases of matter, field theories and bosonization: Topological phases of matter exhibit non-local coherent effects, such as long-range topological correlations (Aharonov-Bohm phases) and boundary massless excitations, without being characterized by local order parameters. These phases can be described by topological gauge theories and conformal field theories. The research in this area has gained significant momentum with the experimental observation of topological phases in insulators and semiconductors in two and three space dimensions.
Milestones: Investigate non-Abelian statistics in the quantum Hall effect and explore experimental signatures like interferometry and heat transport in different geometries. Develop bosonic effective field theories for interacting fermions in topological insulators and superconductors, thus realizing bosonization of fermions in two and three space dimensions. Classify stable interacting topological phases by using quantum anomalies. Describe topological phases in lattice spin systems of the Kitaev and Wen type and study their applications for Topological Quantum Computation.

Proposed activities and role of the various Research Units.

The project is carried out by seven teams, tied by well-established scientific collaborations, that include a large part of Italian research in Statistical Field Theory. Let us mention the top expertises in each group, keeping in mind that the methods of conformal field theory are shared by all members of the proposal. The Trieste team (TS) is the largest one and its activities cover all the five research lines of the project: its members have substantially contributed to the study of systems out of equilibrium (Calabrese, Mussardo, Gambassi), to the computation of correlation functions in integrable systems (Mussardo, Delfino), to the analysis of entanglement measures (Calabrese, Tonni), to the description of cold atoms systems and quantum computation (Trombettoni, Calabrese, Mussardo), and integrability breaking (Mussardo, Delfino). The Florence (FI) team has a leading expertise in conformal field theory (Cappelli). Research topics involve the quantum Hall effect and topological phases of matter (Cappelli), integrable spin systems (Colomo), entanglement measures in spin systems, and quantum information dynamics and protocols (Banchi, Cuccoli, Verrucchi). The Torino (TO) group has a strong expertise in lattice field theory (Caselle, Panero), integrable models and integrable deformations (Cavaglià, Tateo). The Genova (GE) team has a good record in the use of the AdS/CFT correspondence in condensed matter systems as well as the perturbative analysis near conformal invariant theories (Amoretti, Magnoli). The unit of Pisa (PI) has remarkable expertises on phase transitions (Vicari), and low-dimensional systems (Alba, Mintchev); it hosts a leading group in the conformal bootstrap approach (Vichi). Researchers of the Cosenza (CS) team are experts in correlated electron systems on the lattice and their continuum quantum field theories (Giuliano) and quantum-time evolution (Plastina). The unit of Milan (MI) includes experts in statistical field theory, neural networks and machine learning (Gherardi, Caracciolo), and random matrices (Molinari, Pernici).

The specific research projects are listed hereafter together with the team collaborations that will develop them, divided in the five domains mentioned before.

(1) Quantum field theories out of equilibrium.

(TS, CS, PI): Study the consequences of coupling correlated electronic systems to external baths. We expect to find the relevant response functions in physically interesting systems. This includes cases where the parameters are suddenly changed, for istance by adding a bath (quantum quench), where the invariants characterizing the topological phase are expected to depend on time. This is also relevant for the possibility of realizing optical simulators of topological systems using quantum walk protocols. Additionally, modeling the Lindblad master equation would be useful for systems in contact with an external environment to describe realistic thermal baths. We also plan to go beyond the weak system-bath coupling regime (Lindblad equation), where non-Markovian effects become important.

(CS, GE, TS): Develop a systematic method for characterizing stable phases of junctions of correlated systems or quantum spin chains based on their electric and thermal transport properties. Specifically, we will investigate the role of subleading boundary operators in determining these properties.

(TS, PI, FI): Analyze quantum integrable dynamics after a quench, determining Generalized Gibbs Ensembles and generalized hydrodynamics. We will employ techniques from random matrix theory and exactly solvable models, and study bosonic and fermionic mixtures using supersymmetry.

(TS, CS): Study out-of-equilibrium dynamics in one-dimensional fermionic systems. Analysis of transport properties at a junction between a topological superconductor and multiple interacting spinless quantum wires (Luttinger liquids). Study of stable phases where Majorana fermions emerge at the contact and investigation of impurity problems for trapped fermion gases, focusing on their out-of-equilibrium thermodynamics.

(2) Entanglement, quantum information and quantum computation.

(TS, FI, CS, PI): Investigating and characterizing topological states, including quantum Hall states, Chern insulators, and topological insulators. We will achieve this by analyzing their entanglement spectra through numerical methods suitable for large systems. We will also explore the relationship between entanglement and symmetries using conformal and integrable field theories, and exact lattice techniques. Finally, we will study symmetry breaking patterns through the analysis of entanglement asymmetry.

(TS, CS, FI): Study out-of-equilibrium properties of spin systems, particularly in connection with the decoherence dynamics of simple quantum objects coupled to spin environments. We will also investigate the dynamics of entanglement and optimal information transfer along quantum spin chains and consider different models of interaction with the environment to model and control quantum measurements.

(TS, PI): Analyze the entanglement Hamiltonian, modular flow, and complexity. We will compute the entanglement Hamiltonians and negativity Hamiltonians, as well as their modular flow, for subsystems consisting of multiple disjoint parts, including cases at finite temperature and finite volume. We will also study the complexity of quantum states, employing the holographic correspondence and applying the results to the information paradox in black holes.

(TS, TO, PI, FI): Develop a toolbox for randomized measurements and utilize it to study entanglement entropy and negativity in lattice field theory. We will employ a simulation algorithm based on Jarzynski's theorem to investigate entanglement entropy in models that are not exactly solvable. Our study will involve Monte Carlo calculations of Rényi entropies and entropic c-functions in O(N) models and other three-dimensional statistical models and, compare these results with analytical calculations at criticality.

(PI, TS): Study quantum systems under monitoring: see how entanglement properties can be affected by the interplay between unitary quantum dynamics and the quantum measurement process; characterize the occurrence of measurement-induced phase transitions. Furthermore, we will explore integer factorization based on an algorithm that genuinely exploits quantum measurements.

(MI): Concepts from statistical mechanics of disordered systems have found successful applications in theoretical computer science and machine learning. Our research will address key open questions regarding the impact of structured disorder on the non-trivial properties of real-world datasets. We will investigate phase transitions and criticality in systems featuring structured disorder, such as combinatorial optimization problems and constraint satisfaction problems related to deep learning. Our methods will encompass replica theory, random matrices, and novel combinatorial approaches.

(FI): We will study statistical bounds on the generalization error, which quantifies, via information theoretic quantities, how many examples are needed to learn from data some desired features of quantum states, e.g. the entanglement structure or the quantum phase of the system. We will focus on models displaying Haldane-like symmetry-protected topological phases, and investigate how the theoretical bounds deviate from numerical results.

(3) Low-dimensional quantum field theory, integrable models and deformations.

(TS, CS, GE): Majorana fermions at the endpoints of topological superconducting wires may affect transport properties of mesoscopic hybrid rings. Our focus will be on characterizing the Majorana states within a generalized version of the Fu-Akhmerov interferometer that encompasses a floating superconducting island.

(TS, FI): Study of phase separation phenomena in the scaling limit of two-dimensional vertex models. Analysis and characterization of interfaces, their fluctuations and other universal properties. Calculation of correlation functions in different regimes.
(TO, FI, TS): Study the Quantum Spectral Curve (QSC), a mathematical structure governing the spectrum of integrable AdS/CFT dualities. Our goal is to establish the connection between the QSC and correlation functions. Using the QSC method, we will tackle new problems, such as determining the spectrum of string theories on integrable AdS3 backgrounds with generic fluxes and investigating line defects in ABJM theory.
(TO, FI): Study of deformations of conformal field theories in two-dimensional AdS, to characterize the conditions for integrability in curved space. We will explore the interplay of these deformations with the locality and conformality of the associated boundary theory. An important case will be the study of the irrelevant deformation induced by the TTbar operator in AdS2, where we anticipate finding an exact solution. Moreover, we will also study TTbar-type perturbations in 4D Chern-Simons theory.

(4) Conformal Invariance, conformal bootstrap and universality classes.

(TO, PI, GE, TS): Employ bootstrap methods to investigate phase transitions in three and four dimensions, as well as scattering amplitudes in high-energy physics. By utilizing key principles like unitarity and symmetries, we aim to extract information about the underlying theory. We will explore the interplay between conformal bootstrap constraints and different types of spectral data derived from integrability. This will allow us to study correlation functions in N=4 Super-Yang-Mills theory, and gain insight into the behavior of physical systems near criticality using conformal perturbation theory and Monte Carlo simulations.
(GE): Utilize hydrodynamics and holographic models as effective field theories (EFTs) for strongly correlated systems. In these theories, the (almost)-conserved currents, such as charge and heat currents, represent the long-lived fundamental degrees of freedom. By combining hydrodynamic tools with AdS/CFT-related methods, we will construct EFTs that describe strongly correlated electronic materials, including high-temperature superconductors. We collaborate with experimental groups in Dresden and Pisa,

(5) Topological phases of matter, field theories and bosonization.

(TS, FI, PI): Investigate the boundary excitations of topological theories in two and three spatial dimensions in the presence of interactions and their characterization in terms of field theory anomalies. Furthermore, the hydrodynamic theory generalized in presence of chiral anomalies can provide a framework for bosonization of fermionic excitations in two and three spatial dimensions.
(TS, FI): Understand Quantum Hall states in ultracold atomic systems. Our exploration will involve dynamically deforming the rotating gas from a ring-shaped to a harmonic trapping potential. This will allow us to study the transition between the Tonks-Girardeau regime in rotating rings and the fractional quantum-Hall regime. Furthermore, we will analyze fermionic gases under non-Abelian gauge potentials and investigate possible scenarios for simulating the Spin Hall effect.
(TS, PI): Apply non-relativistic field theory to cold-atom systems, particularly those with dipolar and long-range interactions. Moreover, we are working on proposing theoretical frameworks to implement gauge field dynamics and (3+1) Dirac fermions by utilizing suitable settings in cold atom systems.
(GE, FI): Study phase transitions in topological superconductors and examine the resulting discontinuities in the Josephson current-phase relation, which can be experimentally observed through a characteristic temperature dependence of the current.

Section III:

List of the most significant publications of the last five years of each Research Unit related to the proposal:

- **INFN Unit: Trieste**

[1] M. Lencsés, **G. Mussardo**, G. Takács, *Variations on vacuum decay: The scaling Ising and tricritical Ising field theories*, Phys. Rev. D 106, 105003 (2022)

[2] B. Bertini, K. Klobas, **V. Alba**, V., G. Lagnese, **P. Calabrese**, *Growth of Rényi entropies in interacting integrable models and the breakdown of the quasiparticle picture*, Phys. Rev. X 12, 031016 (2022)

[3] **G. Delfino**, W. Selke, A. Squarcini, *Vortex mass in the three-dimensional O(2) scalar theory*, Phys. Rev. Lett., 122, 050602 (2019)

[4] A. Lerose, F.M. Surace, P.P. Mazza, G. Perfetto, M. Collura, **A. Gambassi**, *Quasilocalized dynamics from confinement of quantum excitations,* Phys. Rev. B 102, 041118 (2020)

[5] **M. Mintchev**, **E. Tonni**, *Modular Hamiltonians for the massless Dirac field in the presence of a defect,* JHEP 03 (2021) 205

- **INFN Unit: Firenze**

[1] **A. Cappelli,** L. Maffi, S. Okuda*, Critical Ising Model in Varying Dimension by Conformal Bootstrap*, JHEP 01 (2019) 161

[2] **F. Colomo**, A.G. Pronko, A. Sportiello, *Arctic curve of the free-fermion six-vertex model in an L-shaped domain*, J. Stat. Phys. 174 (2019) 1

[3] **L. Banchi**, G.E, Crooks, *Measuring analytic gradients of general quantum evolution with the stochastic parameter shift rule*, Quantum 5 (2021) 386

[4] A. Tononi, **F. Cinti**, L. Salasnich, *Quantum bubbles in microgravity*, Phys. Rev. Lett. 125 (2020) 010402

[5] L. Buffoni, A. Solfanelli, **P. Verrucchi, A. Cuccoli**, M. Campisi, *Quantum Measurement Cooling,* Phys. Rev. Lett. 122, 070603 (2019)

- **INFN Unit: Milano**

[1] **G. Molinari,** G. Cicuta, **M. Pernici,** *Sparse random block matrices*, J. Phys. A 55, 175202 (2022)

[2] **S. Caracciolo**, R. Fabbricatore, **M. Gherardi**, R. Marino, G. Parisi, G. Sicuro, *Criticality and conformality in the random dimer model*, Phys. Rev. E 103, 042127 (2021)

[3] D. Benedetto, E. Caglioti, **S. Caracciolo**, M. D'Achille, G. Sicuro, A. Sportiello, *Random Assignment Problems on 2d Manifolds*, J. Stat. Phys. 183, 34 (2021)

[4] P. Rotondo, M. Pastore, **M. Gherardi,** *Beyond the storage capacity: data-driven satisfiability transition*, Phys. Rev. Lett. 125, 120601 (2020)

[5] **S. Caracciolo**, A. Di Gioacchino, E.M. Malatesta, **L.G. Molinari**, S*elberg integrals in 1D random Euclidean optimization problems*, J. Stat. Mech., 063401 (2019)

- **INFN Unit: Torino**

[1] **M. Caselle, N. Magnoli, A. Nada, M. Panero,** M. Scanavino, *Conformal perturbation theory confronts lattice results in the vicinity of a critical point*, Phys. Rev. D 100, 034512 (2019)

[2] **M. Caselle, A. Nada, M. Panero,** D. Vadacchino, *Conformal field theory and the hot phase of three-dimensional U(1) gauge theory*, JHEP 05 (2019) 068

[3] R. Conti, J. Romano, **R. Tateo,** *Metric approach to a TTbar-like deformation in arbitrary dimensions,* JHEP 09 (2022) 085

[4] R. Conti, S. Negro, **R. Tateo,** *The TTbar perturbation and its geometric interpretation*, JHEP 02 (2019) 085

[5] **A. Cavaglià,** N. Gromov, J. Julius, M. Preti, I*ntegrability and conformal bootstrap: One dimensional defect conformal field theory*, Phys.Rev. D 105 (2022)

- **INFN Unit: Cosenza**

[1] A Nava, M. Rossi, **D. Giuliano**, *Lindblad equation approach to the determination of the optimal working point in nonequilibrium stationary states of an interacting electronic one-dimensional system: Application to the spinless Hubbard chain in the clean and in the weakly disordered limit,* Phys. Rev. B 103, 115139 (2021)

[2] **D. Giuliano**, A. Nava, R. Egger, P. Sodano, F. Buccheri, *Multiparticle scattering and breakdown of the Wiedemann-Franz law at a junction of N interacting quantum wires,* Phys. Rev. B 105, 035419 (2022)

[3] F. Buccheri, A. Nava, R. Egger, P. Sodano, **D. Giuliano**, *Violation of the Wiedemann-Franz formula in the topological Kondo model*, Phys. Rev. B 105, 035419 (2022)

[4] **J. Settino**, N. Lo Gullo, **F. Plastina,** A. Minguzzi, *Exact spectral function of a Tonks-Girardeau gas in a lattice*, Phys. Rev. Lett. 126, 065301 (2021)

[5] G. Francica, F. C. Binder, G. Guarnieri, M. T. Mitchison, J. Goold, **F. Plastina,** *Quantum Coherence and Ergotropy*, Phys. Rev. Lett. 125, 180603 (2020)

- **INFN Unit: Pisa**

[1] D. Poland, S. Rychkov, **A. Vichi**, T*he conformal bootstrap: Theory, numerical techniques, and applications*, Rev. Mod. Phys. 91, 015002 (2019)

[2] **D. Rossini** and **E. Vicari**, *Coherent and dissipative dynamics at quantum phase*

transitions, Phys. Rep. 936, 1 (2021).

[3] **V. Alba,** B. Bertini, M. Fagotti, L. Piroli, P. Ruggiero, *Generalized-hydrodynamic approach to inhomogeneous quenches: correlations, entanglement and quantum effects,* J. Stat. Mech. (2021) 114004

[4] S. M. Chester, W. Landry, J. Liu, D. Poland, D. Simmons-Duffin, N. Su, **A. Vichi**, *Carving out OPE space and precise O(2) model critical exponents,* JHEP 2020, 142 (2020)

[5] **M. Mintchev, E. Tonni**, *Modular Hamiltonians for the massless Dirac field in the presence of a defect,* JHEP 03, 205 (2021).

- **INFN Unit: Genova**

[1] **A. Amoretti**, D. Areán, B. Goutéraux, D. Musso, *Universal relaxation in a holographic metallic density wave phase,* Phys. Rev. Lett. 123 (2019) 211602

[2] **A. Amoretti**, D. K. Brattan, **N. Magnoli**, Marcello Scanavino, *Magneto-thermal transport implies an incoherent Hall conductivity,* JHEP 08 (2020) 097

[3] P. Solinas, **A. Amoretti**, F. Giazotto, *Sauter-Schwinger effect in a Bardeen-Cooper-Schrieffer superconductor,* Phys. Rev. Lett. 126 (2021) 117001

[4] F. Caristo, **M. Caselle**, **N. Magnoli**, A. Nada, **M. Panero**, A. Smecca, *Fine corrections in the effective string describing SU(2) Yang-Mills theory in three dimensions,* JHEP 03 (2022) 115

[5] **A. Amoretti**, D. Arean, D. K. Brattan, **L. Martinoia**, *Hydrodynamic magneto-transport in holographic charge density wave states,* JHEP 11 (2021) 011

List of the main national or international collaborations related to the proposal:

Brookhaven Nat. Lab (NY-USA); Department of Physics, Ecole Normal Superieure (Paris-France); Oxford University (Oxford-UK); Institute of Theoretical Physics, (Amsterdam-The Netherlands); Dept. of Physics, Univ. British Columbia (Vancouver-Canada); LPTHE, Univ. Paris VI; IPhT, Saclay (Paris-France); LAPTH Annecy; Durham Univ.; PDMI-Steklov, St. Petersbourg; Theoretical Physics; LIPN Univ. Paris 13; Dept. of Physics, Melbourne (Australia); DESY Theory Group, Hamburg; King's College, London; Dept. of Physics and Astronomy, Univ. College London; Rutherford Appleton Laboratory, Oxford; IFT Madrid; Physics and Astronomy Dept., Durham Univ.; Queen's University, Belfast; H. Heine Universitaet, Duessledorf; T.D.L. Institute Shanghai (China). Shanghai Jiao Tong University (China); University of Dresden (Germany); École Polytechnique (Paris-France); LPMMC, CNRS Grenoble (France).