UNIVERSITÀ DEGLI STUDI
DI TRENTO

Corso di dottorato in Fisica / PhD in Physics
Ciclo 35 / Cycle 35
A.Y. 2019-2020

Borse a tematica vincolata / *Reserved scholarships*

A	Nanosecond Repetitevely Pulsed (NRP) discharges for CO_2 conversion
B	Space data science and technology
C	Cellulose nanostructures as building block for functional materials
D	Quantum Gases and superfluidity
E	Development of coarse-grained modeling methods for biological macromolecules and their application
F	Twin photons and single photon entanglement for QRNG and QKD
G	Neuromorphic silicon photonics
H	- SOCCEr (SupercOnducting Circuits for the Casimir Effect)
I	Photonic Quantum Simulations of Dynamical Gauge Fields
J	QUantum Information Transfer in Positronium Annihilation)
K	Second Order Nonlinearities in p-i-n Silicon waveguides for entangled photon generation towards MIR quantum sensing
L	Machine Learning techniques FOR Quantum Gate Engineering
M	Machine learning for Quantum Many-Body Phases recognition (MalQuPh)
N-O	Particle, astroparticle, nuclear, theoretical physics, related technologies and applications, including medical Physics
P	4D tracking for space application with fast silicon detectors (LGAD)

Scholarship A

Topic: Nanosecond Repetitevely Pulsed (NRP) discharges for CO_2 conversion
University of Trento e Department of Physics
Contacts.: Paolo Tosi, paolo.tosi@unitn.it
Synthetic description of the activity and expected research outcome The conversion of CO_2 into fuels through technologies based on the use of renewable electricity would allow at the same time recycling CO_2 and storing renewable energy into chemical energy, providing a way to establish links between different energy carriers and allowing to decarbonise sectors that are still heavily reliant on fossil fuel. The project aims to develop a technology for the conversion of CO_2 based on ultra-short gas discharges. Time-resolved laser diagnostics will be used for monitoring the microscopic kinetics.
Ideal candidate (skills and competencies)**:** The ideal candidate should have experience in gas discharges and gas analysis.

Scholarship B

Topic: Space Data Science and Technology
University of Trento e Department of Physics
Contacts: Roberto Iuppa, Roberto Battiston, Paolo Zuccon, Rita Dolesi, William J. Weber e Stefano Vitale
Synthetic description of the activity and expected research outcome The student will dedicate her/his research work to the study of critical aspects of scientific space missions in the field of gravitational wave astronomy and astroparticle physics at large. Missions in the framework of which the research work may be carried out include LISA Pathfinder, LISA, AMS, Limadou, and the development of future missions in Astroparticle Physics. The specific subject of the thesis can be negotiated and may be on: the development of data analysis methods and algorithms; the analysis of data and the performance of scientific observations with those missions that are or have been in operation; the development of instrumentation including laboratory studies in support of such developments.
Ideal candidate (skills and competencies)**:** A graduate in physics or engineering, with a genuine passion for scientific space missions

Scholarship C

Topic: Cellulose nanostructures as building block for functional materials
University of Trento e Department of Physics
Contacts: Paolo Bettotti, paolo.bettotti@unitn.it
Synthetic description of the activity and expected research outcome Nanosized structures obtained from cellulose are finding a large scientific and economical interest. Their recover from food industry wastes using an eco-friendly approach will make nanocellulose a sustainable material with broad foreseen uses (from food chemistry to flame retardant and gas barrier film, to cite a few). The project is aimed at the set-up of non conventional procedures to extract the nanostructures and investigate the physical and chemical mechanisms to assemble them into composite functional materials.
Ideal candidate (skills and competencies)**:** Ideal candidate is an experimentalists with solid knowledge of chemical physics (and/or physical chemistry). Since the project multidisciplinarity, the candidate will interacts with researchers with different scientific background, thus he/she needs to be open to learn from different scientific disciplines. A solid knowledge of general chemistry and spectroscopic methods are valued skills. During the PhD the student will perform both synthesis and characterization of the nanomaterials, but he/she will do also detailed data analysis using standard as well as unconventional methods, thus computational skills will be required too.

Scholarship D

Topic: Quantum Gases and superfluidity
University of Trento and CNR-INO BEC
Contacts: Gabriele Ferrari, gabriele.ferrari@unitn.it
Synthetic description of the activity and expected research outcome Ultracold atomic gases offer a flexible platform to address open problems in fundamental physics such as many-body properties in quantum gases, transport phenomena, and quantum simulation of fundamental interactions. The PhD student will work in the interdisciplinary environment of the BEC Center (http://bec.science.unitn.it), where research both on theory and experiments is done covering a wide range of themes.
Ideal candidate (skills and competencies)**:** the ideal candidate should posses good knowledge of statistical physics, atomic physics, quantum mechanics with applications either to experimental or theoretical research. The PhD student will work in the interdisciplinary environment of the BEC

Center (http://bec.science.unitn.it), where research both on theory and experiments is done covering a wide range of themes.

Scholarship E

Topic: Development of coarse-grained modeling methods for biological macromolecules and their application
Department of Physics (H2020-ERC StG VARIAMOLS)
Contacts: Raffaello Potestio, raffaello.potestio@unitn.it
Synthetic description of the activity and expected research outcome The objective of the research activity is to investigate the properties of large macromolecules by means of coarse-grained models. The methods employed have been developed in the research group, however the candidate is expected to contribute to their extension and application. The focus of the research activity will be on large biomolecules, in particular proteins. The candidate will acquire competence in the foundations of the most common molecular modelling and coarse-grained simulation methods employed in the context of soft matter, and perform and analyze molecular dynamics simulations at the all-atom and coarse-grained level.
Ideal candidate (skills and competencies): The ideal candidate holds a M.Sc. in physics, chemistry, biology, engineering, or interdisciplinary courses involving at least one of the aforementioned ones. The competent use of programming languages (C, C++, python, bash, and similar), as well as a good knowledge of the English language, are required.

Scholarship F

Topic: Development of coarse-grained modeling methods for biological macromolecules and their application
Department of Physics (H2020-ERC StG VARIAMOLS)
Contacts: Raffaello Potestio raffaello.potestio@unitn.it
Synthetic description of the activity and expected research outcome The objective of the research activity is to investigate the properties of large macromolecules by means of coarse-grained models. The methods employed have been developed in the research group, however the candidate is expected to contribute to their extension and application. The focus of the research activity will be on large biomolecules, in particular proteins. The candidate will acquire competence in the foundations of the most common molecular modelling and coarse-grained simulation methods employed in the context of soft matter, and perform and analyze molecular dynamics simulations at the all-atom and coarse-grained level.

Ideal candidate (skills and competencies): The ideal candidate holds a M.Sc. in physics, chemistry, biology, engineering, or interdisciplinary courses involving at least one of the aforementioned ones. The competent use of programming languages (C, C++, python, bash, and similar), as well as a good knowledge of the English language, are required.

Scholarship G

Topic: **Neuromorphic silicon photonics**
Department of Physics
Contacts.: Lorenzo Pavesi lorenzo.pavesi@unitn.it
Synthetic description of the activity and expected research outcome In tight collaboration with the team of the ERC project BACKUP (https://r1.unitn.it/back-up/), we aim investigate a photonic Extreme Learning Machine (PELM) which is an evolution of the so-called Reservoir Computing Network (RCN) paradigm. PELM is characterized by the easiness of training, which makes PELM quite feasible in silicon photonics. The aim of the PhD is to implement PELMs using Silicon photonics to: 1. understand the Si-PELM from the basic rules to the design of the optimal network 2. study how the dimensional increase of the network can boost its performances towards features extraction rather than simple classification problems. Moreover, recent work was focused on the development of single node networks with time delayed feedback architecture. Yet no information is available about how the spatial organization of the network affects its functionality. The reason is the limited availability of "large" photonics networks, made by hundreds of nodes, where spatially localized subdomain can form. Few preliminary results were recently reported but the limited number of nodes does not permit to properly investigate the formation of spatially confined domains. We will adopt this large scale photonic integration for the Si-PELM to tune the optical feedback among the single photonic neurons, i.e. to change the topology of the network during the training as in reconfigurable optical routers. This can be interpreted as the evolution of the PELM plasticity during the training as in a biological system. The overall goal of the PhD is to demonstrate a performant PELM in silicon photonics.
Ideal candidate (skills and competencies): Solid background in photonics and in integrated photonics.

Scholarship H

Topic: SOCCEr (SupercOnducting Circuits for the Casimir Effect)
P.I.: Gianluigi Casse (FBK), Paolo Falferi (IFN-CNR), Iacopo Carusotto (INO-CNR BEC Center)

Contacts: casse@fbk.eu; paolo.falferi@unitn.it; iacopo.carusotto@unitn.it; margesin@fbk.eu
Synthetic description of the activity and expected research outcome Synthetic description of the activity and expected research outcome The main objectives of the research activity are the fabrication and test of coplanar superconducting waveguides and/or resonators terminated by a SQUID acting as a tunable mirror, and to use them in quantum optics experiments to observe the Dynamical Casimir Effect and related zero-point quantum fluctuation effects in the microwave spectral domain. The project will be carried out in a continuous regular interaction between three teams: theoretical team (INO-CNR BEC Center), fabrication team (FBK with photolithography and, in near future, ebeam lithography), and testing team (IFN-CNR with 20 mK dilution refrigerator). The PhD student will be given the opportunity to participate in all the activity, theoretical and experimental, with the support of the three teams. During the PhD, she/he will be trained on the physics of devices such as SQUIDs, Josephson junctions and microwave resonators that are the building blocks of circuit-QED, one of the most promising approaches to quantum technologies.
Ideal candidate (skills and competencies): ● She/he should have a solid knowledge of electromagnetism and a master-level competence in the general concepts of solid-state physics. She/he should be keen on learning experimental techniques in the following fields: low temperature physics, superconducting microwave technologies, microfabrication technologies and material science. She/he should have a good capacity to work in team with experimentalists combined with a good understanding of theoretical concepts and a manifest ability to work in team with theorists. ● She/he should have a proven ability to communicate in scientific english (written and oral)

Scholarship I

Topic: Photonic Quantum Simulations of Dynamical Gauge Fields
Q@TN
Contacts.: Iacopo Carusotto iacopo.carusotto@unitn.it, Francesco Pederiva francesco.pederiva@unitn.it , Philipp Hauke philipp.hauke@kip.uni-heidelberg.de
Synthetic description of the activity and expected research outcome This project aims at designing protocols to quantum simulate dynamical gauge theories, exploiting the pristine control offered by photonic devices. Gauge theories play a central role in modern physics, ranging from fundamental interactions between elementary particles, over emergent phases of matter in magnetic materials, to paradigms of quantum computation. Their numerical treatment, however, is exceedingly difficult. This difficulty has sparked in recent years a strong effort towards realizing gauge theories in tabletop quantum devices, known as quantum simulators. Here, photonic devices offer a unique opportunity, having recently achieved impressive breakthroughs in related contexts.

The time is ripe to harness the opportunity for photonic quantum simulation of dynamical gauge fields. In this project, we aim at laying indispensable and decisive groundwork to achieve this ambitious goal. The selected candidate is expected to carry out theoretical research in the physics underlying the use of photonic devices as a quantum computing tool, beginning with the mapping of simple problems in quantum field theory and progressing towards more complex problems. Through numerical and analytical calculations, he/she will elaborate the novel phenomena that become accessible in photonic devices. Using methods from quantum optics and field theory, he/she is expected to develop a theoretical basis for photonic quantum simulations of dynamical gauge fields, which will enable the assessment of fundamental limitations and possibilities.
Ideal candidate (skills and competencies)**:** He/she should have a solid knowledge of electromagnetism and optics, as well as a master-level competence in the concepts of quantum physics, quantum field theory, quantum optics, open quantum systems, solid-state physics, many-body physics, and photonics. A general familiarity with experimental techniques in these fields is also welcome as well as good capacity for interdisciplinary exchanges. He/she should have at least a basic expertise in numerical simulations and a proven ability to communicate in scientific english (written and oral).

Scholarship J

Topic: QUantum Information Transfer in Positronium Annihilation (QUITPA)
Q@TN
Contacts.: R.S. Brusa
Synthetic description of the activity and expected research outcome QITPA aims to reveal the quantum information transfer in the decay of the spin-polarized positronium atoms. Positronium (Ps) annihilates via two/three gammas (high energetic photons) emission, computations predict that the two and three gammas are entangled in the polarization degree of freedom depending on the energy, the angles related to the decay event and the quantum numbers of positronium atoms. In this project we aim to monitor the change in these entanglement properties and our overarching goal is to produce positronium atoms with definite quantum properties, detect the spatial distribution of two and three gamma events. The project will be carried out in collaboration with a theoretical group and an experimental group expert in gamma ray detecting systems. In Trento we will develop a pulsed spin polarized positronium source and will take care of the production of Ps in defined quantum states. The PhD, during the first year, will take care of the design, building and commissioning tests of the Surko trap while in the second year he/she will follow the

development of the buncher and the tests of positron/spin-polarized positronium converters. The development of the experimental system will require a constant connection with the other groups that will provide important feedbacks. The PhD student will work also in strict contact with the laser expert for setting the whole experiment. The third year he/she will be central in the production of spin polarized positronium, installation of the detector developed one of the partner.

Ideal candidate (skills and competencies)**:**
The candidate should have experimental competencies: familiarity with cryogenic systems, Ultra High Vacuum technology, detection of single gamma rays and burst of gamma rays. Knowledge about penning traps for charge particles are also welcome.

Scholarship K

Topic: Second Order Nonlinearities in p-i-n Silicon waveguides for entangled photon generation towards MIR quantum sensing – SiPDC (Q@TN)

Q@TN

Contacts: L. Pavesi, lorenzo.pavesi@unitn.it

Synthetic description of the activity and expected research outcome
In this project, we aim to demonstrate the process where a photon splits into two correlated photons through the Spontaneous Parametric Down Conversion (SPDC) process in a silicon waveguide. An interesting way to do so relies on the application of strong DC fields across a Si waveguide by means of a series of lateral p-i-n junctions, which can enable processes like the Electric-Field-Induced Second Harmonic Generation (EFISH). This is a third order nonlinear process where a pump wave couples with the DC field and generates a second-harmonic wave through an effective second order nonlinear coefficient. The PhD student will take care of the measurements and will set-up quantum interferometry experiments to demonstrate the generation of entangled photons in silicon. In particular, since the pump photons are in the region where silicon is transparent (in the NIR), the generated entangled photons will be in the MIR (1.55 to 3 μm). Tunability of the entangled photon frequencies will be achieved by tuning the frequency of the pump or the temperature of the crystal. The SPDC experiment requires a careful design of the waveguides, which should propagate both the NIR and the MIR photons, and of the experimental setup, which requires single photon counters in the MIR. Then, the student will take profit of the entangled MIR photons to test quantum sensing capabilities for relevant gases. The student will develop schemes for assessing the performance of the system and demonstrate a novel concept of sensing in the MIR by using entangled photons.

Ideal candidate (skills and competencies):
Solid background in nonlinear optics and quantum optics

Scholarship L

Topic: **M**achine **L**earning techniques **FOR Q**uantum **G**ate **E**ngineering (**ML Q-FORGE**)
Q@TN
Contacts: Francesco Pederiva (francesco.pederiva@unitn.it); Simone Taioli (taioli@ectstar.eu); Johnatan Dubois (dubois9@llnl.gov); Kyle Wendt (wendt6@llnl.gov)
Synthetic description of the activity and expected research outcome The project is part of a joint effort between researchers at the Lawrence Livermore National Laboratory (LLNL) and the University of Trento for developing a quantum computing (QC) framework based on circuit-QED inspired, reconfigurable quantum gates. Reconfigurable quantum gates are based on the concept that the implemented unitary evolution can be controlled by an external electromagnetic pulse, the form of which can be explicitly calculated. In the quantum computation of the time evolution of a many-body quantum system, the necessity of repeatedly solving for the controlling waveforms is a very serious limitation of the overall efficiency of this QC scheme, in particular when the system size increases. However, the Hamiltonian used often depends on a family of (continuous) parameters, which in turn correspond to a (continuous) family of pulses. This fact can be leveraged to reduce the computational effort by systematically mapping specific properties of the Hamiltonian describing the systems under investigation onto properties of the corresponding controlling waveforms. The Ph.D. student hired on this project will explore, understand, and develop novel optimization and interpolation techniques, exploiting Machine-Learning based methods, that will eventually allow such mapping. The theoretical tools found are expected to be interfaced and implemented on the LLNL quantum testbed. At present applications of QC at LLNL relative to this project are focused on reproducing simple nuclear reactions based on realistic interactions that include explicit spin/isospin dependencies. The work will be carried out in collaboration between the Physics Department of the University of Trento (Francesco Pederiva) and the LISC group at ECT*/FBK (Simone Taioli), together with the Quantum Coherent Device group (Jonathan Dubois) and the Nuclear Theory group (Kyle Wendt) at LLNL, where the student is supposed to spend a substantial amount of time during his Ph.D. curriculum.
Ideal candidate (skills and competencies)**:** The candidate must possess the equivalent of a M.S. in physics, mathematics or related areas. The call is open to international students. Good general skills in numerical methods and programming would be highly preferable, and a strong interest in the world of quantum computing is required. Although applications are mostly in the area of nuclear physics, no previous special knowledge of the field is necessary.

Scholarship M

Topic: Machine learning for Quantum Many-Body Phases recognition (MalQuPh)
Q@TN

Contacts.: Alessio Recati alessio.recati@unitn.it (INO-CNR BEC Center, Physics Dep.), Matteo Rizzi (Uni. Köln/Jülich, Physics Dep.), Elisa Ricci (Uni. Trento, DISI)
Synthetic description of the activity and expected research outcome One of the most formidable task in many-body systems is the determination and characterisation of their possible phases and phase transitions. The emergent phenomena leading to the macroscopic phase has required the development of sophisticated analytical and numerical tools. The effort is worth since understanding emergent phenomena is relevant from both a fundamental, technological (e.g., ferromagnetism, high-Tc superconductivity, biological systems) and even philosophical and social point of view (traffic, crowd behaviour, emergence of life). The MalQuPh PhD project aims at exploring the combination of Tensor-Network methods with machine (deep) learning for improving the identification and characterisation of the possible phases of quantum many-body systems. Tensor-Network approaches have been demonstrated to be a powerful tool to exactly compute the physics of many-body Hamiltonian even near critical regions, however the problem of state space's prohibitive growth still represents a barrier for the determination of phase diagrams. On the other hand the machine learning community has developed a number of techniques with remarkable ability to recognise, classify, and characterise complex patterns in large-scale datasets. Since any phase of matter can be thought as specific configurations/instances in some huge parameter space, it is immediate to ask whether by combining machine learning approaches to a method able to efficiently generate the proper configurations of a physical system phase could lead to a new way of obtaining the phases of complex systems. We will explore the use of machine (deep) learning for phase recognition for quantum phase transitions, whose configurations can be drawn from microscopic Hamiltonian using Tensor-Network techniques. The focus will be on system that can be simulated in a clean way within the present cold-gases technology opening the possibility to check the validity of our results and, in principle, apply our learning method to the experimental outcomes. The detailed analysis for phase recognition required by our project could also lead to a better understanding of the reason why deep learning is so efficient which is an open issue in the machine learning community.
Ideal candidate (skills and competencies)**:** Master Degree in Physics or Informatics, with acquaintance with at least one of the following topics: many body quantum systems, quantum phase transitions, tensor networks or deep learning algorithms. Basic knowledge of programming languages like Python and Fortran is of advantage, as well as the will to deal with and develop complex codes. A strong motivation to spend a medium-to-long research period in Germany (Köln) during the doctoral studies is required.

Scholarship N-O

Topic: Particle, astroparticle, nuclear, theoretical physics, related technologies and applications, including medical Physics (2 positions)

INFN
Contacts: For further information on the possible research topics see www.infn.it or contact Rita Dolesi for experimental Physics (Rita.Dolesi@unitn.it); Francesco Pederiva for theoretical Physics (Francesco.Pederiva@unitn.it) Chiara La Tessa for applied and medical physics (chiara.latessa@unitn.it)
Synthetic description of the activity and expected research outcome The thesis topics will be selected within the many areas of forefront research pursued at Trento Institute for Fundamental Physics and Applications (TIFPA) of INFN. Current main activities include: 1) experimental particle and astroparticle Physics, 2) experimental gravitation both earth and space based, 3) gravitational wave astronomy, 4) antimatter related experiments, 5) R&D on particle and radiation detectors and other solid state quantum micro devices, 6) computational Physics and AstroPhysics, 7) theory of fundamental interactions, 8) theoretical cosmology , 9) medical physics applied to therapy with high energy charged particles

Scholarship P

Topic: 4D tracking for space application with fast silicon detectors (LGAD)
INFN
Contacts.: casse@fbk.eu
Synthetic description of the activity and expected research outcome Fine granularity detectors with high intrinsic time resolution (below 50 ps) can achieve very effective 4-dimensional tracking capabilities. This solution is for example implemented in the upcoming upgrade of the CMS and ATLAS experiments at CERN, to correctly assign particle tracks to their correct originating vertex. A novel detector concept has been developed in recent years to this purpose, called Low Gain Avalanche Detector. The scope for this type of sensors is very wide, and it is of interest to space experiments. This project targets the development of sensors for a time-position (4D) tracking system for space applications. These sensors are based on the LGAD technology with the capability of measuring the position (to 10 µm precision or less) and time (with < 50 ps resolution) of crossing particles providing particle identification by mean of the Time-of-Flight (ToF) technique. The LGAD design is a particularly good fit for space application as it provides large signals with minimum power, reducing the overall power consumption in the front-end electronics. The project aims to push the design to explore time resolution as small as 20 ps with no dead area (100% fill factor) on a detector plane.

Ideal candidate (skills and competencies): Interested in particle and astroparticle physics, and especially in designing and handling the instrumentation used for sensing, identifying and measure the energy of events in ground or space based high energy physics experiments. Basic knowledge of electronics will be an advantage. Knowledge of radiation matter interaction, basis of particle physics, methods for radiation detection and data analtsis will be required for the project.
Topic: 4D tracking for space application with fast silicon detectors (LGAD)