8th MEFT Workshop

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Instituto Superior Técnico

Book of Abstracts

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Integration of the HiRezBrainPET with a clinical PET/CT system: Performance evaluation of a prototype for next-generation brain tomography

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Positron emission tomography (PET) is an extremely sensitive technique of medical diagnosis. A radioactive marker is injected in the patient's body, releasing positrons in the zone to study. When the positrons encounter electrons from neighboring molecules, they annihilate, producing two energetic photons traveling in opposite directions. These photons are identified by the surrounding detectors to create detailed images of the organism and to monitor dynamic processes. This line of work has been pursued by the RPC team at LIP for a number of years.

A high-resolution, small animal RPC-PET scanner developed at LIP is installed at ICNAS since 2014. Hundreds of tests have been performed in mice, with goals such as studying degenerative diseases or testing new drugs. This technology is now being applied for human brain PET, in the framework of the project HiRezBrainPET: neurofunctional cerebral imaging by high resolution positron emission tomography, led by ICNAS-Produção, with LIP at its is main R&D partner

In 2021 all components of the HiRezBrainPET, mostly designed at LIP, have been built. The system has been fully assembled and is ready to start performance evaluation tests. The main objectives of this project are to evaluate the imaging performance of the HiRezBrainPET and study the possibility of integrating this prototype with a clinical PET/CT scanner installed at ICNAS.

This work will contribute to the development and improvement of dedicated brain PET tomography, which ultimately intends to address the currently unmet clinical needs in neurosciences. This equipment has the potential to change the paradigm in the diagnosis and investigation of diseases of the central nervous system by allowing, for example, to see small brain structures involved in neuropsychiatric diseases. The high spatial resolution of the system may play an important role in the characterization of vascular injury or tumours, allowing for better treatment planning.

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Black Holes Information Paradox & Fuzzball model of Blackholes.

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What we found from string theory is that all the mass of a black hole is not getting sucked into the center.
The black hole tries to squeeze things to a point, but then the particles get stretched into these strings, and the strings start to stretch and expand and it becomes this fuzzball that expands to fill up the entirety of the black hole.
The Fuzzball model of Blackhole attempts to resolve two intractable problems that classic black holes pose for modern physics, which are the Information Paradox and point of Infinity Density (Singularity).

The event horizons for both classic black holes and fuzzball lie precisely at the point where spacetime has warped to such an extent that falling bodies just achieve the speed of light. Consider a collection of D3-branes, in their ground state. Suppose a graviton falls onto these branes and is absorbed. The graviton, and its energy is converted into a collection of open strings (gluons) on the D3 branes. As time passes, this excitation spreads on the surface of the D3 branes, the evolution being described by strongly-coupled super-Yang-Mills theory.

This evolution is very complicated, but it does not involve gravity and is unitary because Yang-Mills theory is unitary. The dynamics of a gravitational process can be captured completely by a dual boundary theory, which is manifestly unitary (and does not involve gravity).

There is an enormous body of evidence saying that this duality is correct. In the fuzzball paradigm, this duality covers black holes in a natural way: there are states in the boundary field theory that can be thought of as dual to microstates of a black hole, and, in the gravity description, these states are just fuzzballs, with no horizon. Thus there is nothing conceptually different between non-black-hole states and black-hole states: any state in the boundary field theory is described in gravity as some excitation of string theory without any horizon.
Indeed, in the fuzzball paradigm, the black hole is a very messy quantum state and a graviton falling into this object would evolve in a very complicated way as it reaches the horizon radius.
The dynamics of this process can be captured by either the holographic field theory at the boundary (which is unitary, and does not involve gravity), or through the gravitational dynamics of the fuzzball state. Replacing the convenient general relativistic picture of black holes as empty space, with all its mass located in its center, with a ball-shaped mess of interacting strings is fascinating and will open windows for further explanation in Cosmology.

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Probing quark hadronization with B mesons at the LHC

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In nature, quarks cannot exist by themselves . When produced, like for example in high energy collisions, quarks join together with other quarks to form hadrons. This process, called hadronization, is driven by the strong force (QCD) and is yet not fully understood. Measurements of B mesons at colliders offer unique probes of the hadronization process by which single quarks form color-neutral hadrons.
%The aim of this thesis is to study B mesons (in specific B^+, B_s^0 and B^0 mesons) in pp collisions, exploring the 2017 datasets collected from the CMS experiment at the LHC. By analysing the different meson signals and measuring their relative cross sections, unique sensitive observables become available.
%This work will be performed by exploring dependencies in B mesons kinematics (like transverse momentum and rapidity) as well as environmental observables (like charge multiplicity). The results will then be compared with theory predictions involving relevant hadronization mechanisms, as well as with corresponding measurements performed in heavy ion collisions, allowing us to potentially enhance significantly our current understanding of underlying QCD mechanisms, both in the vaccuum and in the presence of hot QCD matter (QGP).

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Flight data analysis of the BERM radiation monitor aboard the BepiColombo mission

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Space radiation has a large impact on planetary space weather and electronic instruments, both on the ground and in space. For this reason, comprehending the space radiation environment in our solar system, is fundamental for modern society and space exploration.
BepiColombo is the first European mission to Mercury, succeeding NASA's Mariner 10 and MESSENGER (Mercury Surface, Space Environment, Geochemistry and Ranging). It was designed to study the composition, geophysics, atmosphere, magnetosphere and history of the planet. Being one of the least explored planets of our solar system, it still holds many unanswered questions. The main objetives of the mission are to characterize the radiation environment in a planet so close to

the Sun, how radiation and the solar wind interacts with Mercury magnetosphere, better model the character- istics of such a unique magnetosphere, study solar events, among others.
The BepiColombo Environment Radiation Monitor (BERM) is one of the many instruments aboard BepiColombo. Its main objective is to characterize the radiation environment during the entire mission. It is operated continuously, being responsible for monitoring the radiation levels during all phases of the mission, and ultimately, for sending warning signals to the spacecraft. Even though BERM is not a part of the scientific payload, it will provide valuable information regarding highly energetic particles in the innermost part of the Solar System.

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Magnetic Sensor Qualification in an Industrial Environment

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The need for accurate positioning sensors with small dimensions has grown exponentially in recent years, leading to the development of various technologies for this purpose. The primary focus of these technologies is to provide reliable outputs with high resolution, while also minimizing the cost of fabrication. An example of such a technology is Anisotropic Magnetoresistive (AMR) Sensors, which can measure magnetic field variations with incredible accuracy and have a wide range of applications, while still being of easy production. The objective of this work is to optimize the use of AMR sensors in an industrial setting for positioning purposes. This will be achieved by studying various process factors, including the materials used and the deposition conditions during microfabrication, with the goal of increasing the production yield as well as the quality of the devices.

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Deployment of a microwave cavity experiment using the Framework for Remote Experiments in Education

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Remote Controlled Laboratories had a great push during the COVID pandemic. In fact, they were already out there but lacking in visibility. This external trigger pushed the academy to face a global challenge to start offering remote experiments in a more consistent and mature way.

Instituto Superior Técnico (IST) has been offering several remote experiments since 2000 but with the need for an update due to technological aging. As such, the Framework for Remote Experiments in Education (FREE) was created based on new web technologies. In addition to the most diverse experiments that had already been developed, FREE includes a new experiment aimed at advanced-level Physics students: the Microwave Cavity. Allowing users to configure the various parameters and access the results in real-time or check back later. All this access is done using a browser (on a PC or mobile phone) without the need to install additional software. The results of an experimental execution are stored in a database and downloadable, allowing users to do a variety of analyses and determine the corresponding plasma density.

In this workshop, we will introduce how FREE was used in the implementation the microwave cavity and give an insight into didactic approach, such as: (i) how to perform an experimental execution and (ii) the typical data set obtained with (iii) the corresponding analysis necessary for the user to retrieve information from it.

Keywords — Educational technology, e-lab, Electromagnetic Cavity, Remote controlled experiments

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Energy Extraction from Black Holes via Penrose Process and BSW Mechanism

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The theory of general relativity successfully describes a huge variety of phenomena at large scales. This study is focused on one of the most interesting structures allowed by this theory: black holes. To understand the relation between the geometry of a spacetime and the physics of its black holes, it is important to study the orbits of test particles. This work was previously performed for several general relativity black hole solutions. It is also essential to understand how the black holes spacetime structure affects the energy of the surrounding particles. In particular, it can be shown that charged black holes and rotating black holes have regions of negative energy, allowing energy extraction from the black hole to particles, via Penrose process. Particle collisions near black hole horizons can also, under some circumstances, amplify the energy in the center of mass frame, via Bañados-Silk-West mechanism, BSW mechanism for short.
Some new theories beyond general relativity involve a larger number of space dimensions. In order to test those theories, it is important to check the stability of orbits for these d-dimensional spacetimes. Calculations have been previously done for Schwarzschild and Reissner-Nordström spacetimes. In this study, we want to extend this procedure for charged particles, rotating black holes and spacetimes with cosmological constant, investigating also the energy extraction mechanisms in those spacetimes.

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Ga2O3 membrane nanodevices

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The electronics industry is fundamental nowadays and semiconductors play a determining role. The most widely used is, by far, silicon (Si). However, it is not the only one, and many other semiconductors with different properties are explored for specific applications. For example, due to its wide bandgap, gallium oxide (Ga2O3) has aroused interest for optoelectronic applications, such as solar blind UV photodetectors, and power electronic devices. Recently, a new method for exfoliation of Ga2O3 membranes was found, in which a crystal is implanted with ions, causing surface layers to roll into tubes. In this project, the potential of these membranes for application in nanodevices, such as transistors and UV detectors, will be demonstrated. To achieve this goal will require: the improvement of the tube transfer process to new substrates and its unrolling to obtain a membrane; the optimisation of the electrical contacts, Ohmic and Schottky, to these membranes; and, finally, the characterisation of the resulting devices.

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Arbitrarily non-paraxial electromagnetic wave-packets in particle-in-cell codes

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Current laser injection in particle in cell (PIC) codes is based on paraxial solutions to Maxwell's Equation. Up until now, there have been little to no problem in using these methods. However, as the use of ultra short or ultra tightly focused laser pulses gains popularity and applications, a new method needs to be developed to account for this extreme regimes while injecting electromagnetic pulses in PIC codes.
The aim of this project is the development of a novel injection method for electromagnetic fields in PIC codes which exactly satisfies Maxwell's Equations, allowing for the use of lasers with nearly arbitrary pulse shapes (limited only by the dispersion relation), paraxial or non-paraxial.
The generality of this algorithm is shown through examples of simulations with pulses with Lorentz boosts in arbitrary directions, λ^3 regime and spatiotemporal control of the pulse's profile.

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Applying Emerging Deep Learning Techniques to General Relativity

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In this paper, we present a novel approach to studying General Relativity and Gravitational Waves using emerging deep learning techniques. We begin by providing a brief introduction to the basics of General Relativity and Gravitational Waves, highlighting their importance in understanding the universe. We then introduce the concept of Physics-Informed Neural Networks (PINNs) and demonstrate how they can be applied to the Schrödinger equation. We show that PINNs are able to accurately solve this equation with just 10 training points, a task that traditional machine learning methods are not able to accomplish. Our results demonstrate the effectiveness of PINNs in solving complex mathematical equations and have implications for further research in the field of General Relativity and Gravitational Waves.

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Reddening evolution in type Ia supernovae

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Type Ia supernovae are among the brightest objects in the sky, and the estimation of their distances to Earth have been used as proof that the universe is expanding at an accelerated rate. They are the result of the explosion of a carbon-oxygen white dwarf, in a binary system with another star, whose nature is still unknown.
In this project, Machine Learning tools such as Gaussian Processes and clustering are going to be used in an attempt to divide a sample of nearby type Ia supernovae in different subgroups, based on the evolution of their B − V color with time. If they exist, these subgroups could hint at their progenitor systems and improve the estimations of the dust extinction surrounding them and with it obtain more accurate distances for better cosmological constraints.

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Some Aspects of Symmetry Constrained Multi-Higgs Models

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The Higgs particle was predicted in 1964 and discovered at CERN on July 2012, earning Higgs and Englert the 2013 Physics Nobel Prize. This is a spin zero particle (scalar), necessary to give masses to all the other massive particles in the Standard Model of Electroweak interactions. But, there is no fundamental reason why there should be only one such scalar. Thus, as one achieves a more precise determination of the properties of the new particle, one should look for which signals there would be of extra particles; the so-called multi-Higgs theories. We study a 3HDM with softly broken A4 terms in the scalar potential and show that it allows for an excellent fit of quark mass matrices, consistent with the vacuum being a global minimum of the scalar potential.

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Adaptative Neural Networks based on Metal-Insulator-Metal Nanostructures (Memristors)

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The rapid advancement in the field of neural network algorithms has led to their proliferation in a wide range of fields, including image and audio recognition, natural language processing, big data analytics, and decision-making. This is due to their ability to adapt and learn through methods that involve the modification of internal parameters based on input data used for training. However, due to the separation of memory and control units, the traditional Von Neumann architecture of computers poses significant challenges in effectively training these algorithms, resulting in the phenomenon known as the Von Neumann bottleneck, which is exacerbated by the increasing volume and complexity of training data.

To address this issue, a plethora of pioneering architectures have been proposed, drawing inspiration from the human brain and utilizing artificial neurons for data processing and in-memory computation, known as neuromorphic computing. One such neuromorphic architecture is the implementation of physical neural networks, which consist of interconnected artificial neurons. In recent years, there has been a significant amount of innovation in the use of memristors as memory components for these architectures.

This thesis aims to design and fabricate a functional physical neural network device utilizing metal-insulator-metal (MIM) memristors, in collaboration with INESC Lisboa and IFIMUP in Porto. The research will focus on the exceptional properties of memristors, including compatibility with complementary Metal-Oxide-Semiconductor (CMOS) technology, compact device area for high-density on-chip integration, non-volatility, swift speed, low power dissipation, and scalability, which make them an ideal choice for this application.

Keywords: Neuromorphic computing, physical neural network, memristors, Von Neuman bottleneck, artificial neurons, CMOS technology, non-volatility, scalability, high-density on-chip integration, functional device fabrication.

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High Performance Magnetic Tunnel Junctions for Magnetic Scanning

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Optimization of magnetoresistive sensors, tackling noise mitigation for known high sensitivity multi-stack compositions. Development of strategies that enable detection in the picoTesla range at room temperature with a good signal-to-noise ratio, essential for applications such as in the Biomedical imaging field. These strategies address both the TMR sensor fabrication process and design. 3D vertically packing TMR sensors to diminish noise intensity and O_2 plasma post-treatment as a way to increase process yield constitutes some of the possible approaches.

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Linearization of High Sensitivity Out of Plane Magnetic Sensors

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Out-of-plane (OOP) magnetic sensors have become an essential part of a wide range of cutting-edge technologies where 3 axis detection is needed in reduced footprint, from advanced navigation systems to robotics and automation.
The objective of this work is to present a comprehensive study on the enhancement of the linear range and sensitivity of tunneling magnetoresistance OOP magnetic sensors, specifically focusing on increasing the linear range of the sensing layer from its current limit of 200 Oe to 2500 Oe, the limit imposed by the current SAF structure, and subsequently expanding the working range of the SAF structure, to allow for further advancements in the linear range of the sensing layer.
This project aims to achieve this by utilizing an efficient design-fabricate-test cycle to enhance the performance of OOP magnetic sensors. Micromagnetic simulations are used to analyze and fine-tune the sensor's characteristics, followed by fabrication and experimental characterization of the optimized sensor structures. The major advantage of this approach is the use of simulations, which reduces the number of iterations needed in the fabrication process and ultimately leads to a more efficient and optimized sensor design.
By improving OOP magnetic sensors, this research aims to enable new possibilities and advancements in various advanced technologies that rely on precise and accurate measurements of magnetic fields.

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NMR Quantum Information Processing with liquid chloroform and Europium doped organic-inorganic hybrids

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In quantum information processing, it is ubiquitous to reliably be
able to prepare quantum states, manipulate them and measure the resulting state. Additionally, an important device for both of these applications is the quantum memory. While for quantum computers, quantum memories are indispensable for storage, in long distance quantum communication, with a current maximum range of 100km, a possible solution for longer distance communication are quantum repeaters, which require quantum memories in their design..

Presently the best platforms for this are those related to cold atoms. In spite of the large number of different platforms in study there is still
not enough data to conclusively decide on which are the best platforms for a given quantum application. Some Quantum memories with Rare Earth Ion Doped Crystals have already been developed and are already heavily under study.
In this work, we set ourselves to investigate both liquids and solid materials for quantum information processing: liquid chloroform and a platform which has yet to be thoroughly studied, Europium-doped organic-inorganic hybrids (di-ureasil doped with Eu3+ Complex) in solid form. In particular, we will investigate the NMR Spectra of the solid sample, identify the most important interactions and construct its hamiltonian from them, then proceed with the preparation and manipulation of quantum states, and implementation of 1 or 2-qubit quantum gates in both the Liquid Chloroform and the Solid sample, as well as the evaluation of their relaxation
lifetimes, T1 and T2. We investigate these properties using NMR, as it is an easy and efficient way to evaluate
these lifetimes. If an interesting medium is found, a possible next step would be to investigate light-matter interactions of the solid sample, by coupling the relevant transitions with large population and coherence lifetimes
to light, by using a laser at the appropriate transition frequency.

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Energy Communities managed by municipalities- Case study Castelo Branco

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The objective of this thesis is to develop a model that enables to test the management of energy communities by a municipality. the objective is to find the best organizational framework, concerning business model, management algorithms and technological features, that optimizes the gains of the communities, both in environmental and economic terms. The model will be applied to the case study of Castelo Branco.

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A model for the analysis of electric signals in the heart

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The human body is, without a doubt, one of the most intriguing multi-level machines. The whole organization, from the smaller, highly complex unit, the cell, to the larger and well-coordinated building blocks that operate all functions in the body, the organs, has been the object of many studies. For my master thesis, I want to focus my work on the heart, the central organ of the circulatory system and life support for the whole body.
To aid in the analysis of the electrical signal in the heart, feature-based machine learning techniques will be integrated. All data will be taken from patients that have been followed by Santa Marta's Hospital. To substitute the invasive method of catheterization, the focus will be on developing a model to interpret ECG data. As ECG data is inherently noisy, noise filtering methods will be explored to find an optimal and efficient way to pre-process the data. During the initial phase of this thesis, ECG signal data went through a process of noise filtering using a low-pass noise filter with a threshold of 15Hz, which gave a promising end-result.
The model created is expected to be able to classify ECG interpretable cardiopathies and to implement in real-time to aid physicians in their labor.

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Heavy Neutrino-Antineutrino Oscillations at the FCC-ee

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In conflict with the observations of light neutrino masses, the Standard Model of particle physics does not include a neutrino mass term. One possible extension to the Standard Model addressing this deficit is the addition of sterile neutrinos able to generate neutrino masses via the type I seesaw mechanism. Collider detectable low scale seesaw models are generically protected by a lepton-number like symmetry leading to pseudo-Dirac sterile neutrinos. These particles exhibit an interesting phenomenology as they can oscillate between particle and antiparticle states, similar to light neutrinos and neutral mesons. The properties of these oscillations are directly correlated to the amount of lepton number violation generated by the sterile neutrinos. Recently we have shown that the LHC is able to probe this feature for long-lived neutrinos using a full Monte Carlo analysis. Further in the future the FCC-ee will be the perfect tool to probe the parameter space of long-lived neutrinos. In this project you will study the potential of the FCC-ee to discover lepton number violation and neutrino-antineutrino oscillations after sterile neutrinos have been discovered.

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Transport of particles in nuclear fusion devices

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The advent of nuclear fusion energy has been an highly anticipated one for over a century. In this work, we explore a promising concept to achieve it through magnetic confinement, the stellarator, which breaks the tokamak symmetry, allowing steady-state operation. Optimization of this design requires the iterative calculation of the magnetic equilibrium, tending to be computationally expensive. To expedite optimization, an approximation around the magnetic axis was implemented. For this work, we survey the differences between orbits of energetic particles for both the conventional construction and the approximate one. We then obtain optimized configurations with enhanced particle confinement by employing both local and global optimization methods. Finally, we show how machine learning algorithms may help identify novel stellarator designs.

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Information Diffusion on Dynamic Networks

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The study of how information spreads throughout social systems has long been studied by a wide variety of fields. In that context, recent empirical evidence indicates that complex contagion (a situation where individuals revise their behaviour by taking into consideration those of their friends, which, jointly with the complexity of the diffusing information, define the likelihood of an update) happens in the diffusion of human behaviours, innovations, knowledge and opinions.

Furthermore, almost all real world networks are networks whose structure and the state of the nodes co-evolve in time or, in other words, they are adaptive. It is expected that the diffusion of information and the formation of consensus and polarisation in a specific population are affected by these type of networks.

This project will focus on the analysis of competitive scenarios (with and without intervention) under complex contagion in adaptive/dynamic social networks, in order to understand the impact that these networks have in the formation of consensus and polarisation. This analysis will consider various properties related to complex contagion dynamics, bringing together different ideas from statistical physics, network science, evolutionary game theory and opinion dynamics by shifting the focus from individuals to the properties of the diffusing processes.

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Digital Twin of energy, water and material consumption in Instituto Superior Técnico

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Rising electricity prices, high dependencies on imported energy and increasing concerns with sustainability are all driving forces advocating for a larger adoption of renewable resources in the power grid. However, this inclusion is not without its challenges, since there is a need to meet a changing electricity demand with an intermittent energy source, requiring the development of a strong and robust online analysis tool. Furthermore, nowadays' moving trend of decentralization and automatization of processes has imposed a growing pressure to digitalize service grids, with particular interest being taken on the creation of digital twins of the power grid. The latter would include a virtual counterpart of the physical entity, which would be fueled with a continuous stream of data acquired through sensors, as to mirror the grid's behaviors and characteristics to the best extent possible. A virtual element with such features could easily and faithfully simulate the grid's response in any number of scenarios, in near real-time and with little risks and associated costs. Besides optimizing the grid's operation, if forecast data of electricity demand and production is included, digital twins become the best solution to support a safe and reliable integration of renewable resources. Moreover, with the right sensory devices, a digital twin would allow us to monitor and control the grid, perform active diagnosis and conduct predictive maintenance.
The goal of this thesis is to bring all of the aforesaid services into Instituto Superior Técnico by creating a digital twin of the energy, water and material consumption, greatly supporting decision making activities. Furthermore, the DT can provide meaningful insights as for the integration of solar panels and batteries, which are planned to be included in the campus.

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Morphogenesis of Drosophila´s early development: calibration of the distribution of the pair-rule family of proteins

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This research project aims to model, calibrate and validate the mechanisms involved in *Drosophila´s* early development during the pair-rule and, eventually, the segment-polarity phases. With this in mind we will address the morphogenetic interactions during the first two hours of development before cellularisation (Syncythial Phase), anchoring our modelling on the experimental data provided by the FlyEx database.

The gene regulatory network of the Syncythial development phase can be organized into four families of proteins: maternal, gap-gene, pair-rule and segment-polarity. The first class of proteins are transcribed from *mRNA* of maternal origin and form steady gradients along the anterior-posterior axis of the embryo. The gap-gene proteins give rise to one or two broad domains along the embryo. The pair-rule and segment-polarity gene proteins make the transition to a period structure forming a seven and fourteen stripe pattern, respectively. Two of the most studied pair-rule proteins are the

Even-Skipped and *Fushi-Tarazu.* The positional information provided by their seven bands determine the head, the thoracic segments and the anterior region of the *Drosophila´s* larvae.

Since the seminal work of Nusslein-Volhard and co-authors, it is assumed that the gradients and segments form due to a mechanism involving protein diffusion and degradation. However, inconsistencies have been found when measuring diffusion coefficients of the maternal protein *Bicoid*. Moreover, its degradation has never been observed. Later on, it was proposed by *Dilão et al.* (2009) that gradients could be easily explained under the hypothesis of mRNA diffusion. It was also shown that the primary mechanism of pattern formation could not be explained by diffusion of both proteins and mRNA (*R. Dilão, 2014*), with the cover of the journal Comptes Rendus Biology 274 (12) (2014) dedicated to this finding.

The main goal will then be to model, calibrate and validate the seven-band structure of *Even-Skipped* and *Fushi-Tarazu* proteins and, eventually, for a segment-polarity protein. This model calibration has never been achieved before. This process will consider mutation experiments to identify the set of activators and repressors of each stripe, as they are our main building blocks. Previous modelling for maternal and gap genes will be integrated (*F. Alves and R. Dilão, 2006*) and it will be assumed that diffusion does not play an important role at the pair-rule stage. A second goal will be to explain the relationship between the *Even-Skipped* and *Fushi-Tarazu* patterns, following an inhibitory hypothesis.

Main tasks are as follows:

- Modelling and calibrating the Even-Skipped pair-rule expression based on data without the diffusion hypothesis;
- The relationship between Even-Skipped and Fushi-Tarazu. The inhibitory hypothesis;
- The segment polarity family proteins - hypothetical exploration;
- Discussion of results and thesis writing.

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Energetics of Quantum Computation

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Quantum computers, while still being in their infancy, have become a reality since many years. Increasing resources are being devoted to their development, within academic research as well as by many industries, including some of the largest computer companies. So far, all the efforts have been concentrated towards achieving increasingly better time performances, through improving qubit fidelities, single- and multi-qubit gate fidelities, and increasing the number of qubits that can be operated and controlled simultaneously. The matter of energy performance of quantum computers, however, has been largely overlooked, or at least kept in a secondary place.
By contrast, in conventional computing, energy consumption has long been acknowledged as a primary concern, for obvious economic and ecological reasons, and more recently also for the limitations that power consumption places on the enhancement of computing performance.

The matter of energetic consumption of a quantum computer has gained some attention only recently. To date, a precise understanding of the connection between the computational performance of a quantum computer, and the resources required to operate it, is largely missing.

In this thesis work, we aim at investigating the energy requirements and consumption in the different elements of a quantum computer, taking into account the existing experimental platforms for quantum hardware.

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Superfluids of Light in Nonlinear Optical Media

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The first observation of a fluid-like light with characteristics similar to a superfluid was performed by M. Brambilla, who studied a coherent electromagnetic field in a laser cavity and reformulated the temporal evolution in terms of hydrodynamic equations similar to the Gross-Pitaevskii equation, initiating a new discussion about the relationship between hydrodynamic turbulence and optical turbulence. This work is based on another type of experiments, which also allows to observe similar phenomena, using systems where light waves propagate freely in the medium (without the need for confinement in cavities) in an "optically dense" medium. In warm alkaline vapours, photon-photon interactions are non-negligible and rule the dynamics of the system, causing light to behave like a fluid. Superfluidity can be observed in fluids of light by measuring the elementary excitations, its dispersion relation or by observing the formation of vortices near obstacles. Aiming to experimentally observe the formation of superfluids of light in these media, this project is part of the experiments conducted at MotLab part of the Laboratory for Quantum Plasmas at Instituto de Plasmas e Fusão Nuclear (IPFN) @ Técnico.

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The Cauchy Problem in General Relativity

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The complexity and dynamical nature of spacetime, ruled by the Einstein field equations, make it hard (if not downright impossible) to find exact analytical solutions to most scenarios in General Relativity. This has lead physicists and mathematicians to explore, in the last few decades, the framework of the initial value problem. The Cauchy problem, as it is also called, consists of foliating spacetime into a set of (most commonly spacelike) hypersurfaces, also called leaves, which are then evolved through what is known as a propagation equation. Doing so requires an adaptation of the field equations and the introduction of new tensors, like the second fundamental form and the normal vector.

In this presentation we'll describe the mathematical framework behind the foliation of spacetime and formulate the IVP associated with General Relativity.

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From Single-cell Behavior to Collective Dynamics

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The motion of swimming microbes has shown to be a good representation of their behavior, which in turn is unique for a given strain of cells. We want to understand how single-cell behavior relates to collective behavior of microbes. For instance, two mutants from the same species may exhibit distinct single-cell swimming behaviors. Does their collective behavior also differ? And if so, are those

regimes related? To answer these questions, we will focus on the microbe *Chlamydomonas reinhardtii*, a green (photosynthetic) unicellular algae that swims. Their behavior will be characterised by recording cells motion with an in-house built microscope and a recording system consisting of a Raspberry Pi system-on-chip computer coupled to a High-Quality camera. Cells will swim inside microfluidic traps, restricted to the field of view of the microscope. By building an array of about 10 low-cost microscopes, we aim at obtaining a large amount of data, improving statistical significance. Its analysis will allow to relate single-cell behavior to collective dynamics of various *Chlamydomonas* mutants (WT, *mbo1*, *mbo2*, *ida*, *oda*, etc.), with constant environmental conditions, and of one mutant, with varying environmental conditions (e.g., temperature, illumination, chemical composition of the cells media). This will enable the characterisation of models mapping single-cell to collective behaviors, as well as maps between environmental conditions and behavior, both at the single and collective scales. Quantitative descriptions of this kind, relating behavioral to environmental parameters, can be extended to other swimming microbes, giving clues about how these are affected by climate conditions.

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Reinforcement Learning for Coordinating Energy Communities - P2P Trading

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Distributed energy resources (DERs) and energy communities (ECs) are becoming increasingly popular as a way to decarbonize the housing sector. With DERs, traditional end-consumers become prosumers, who both consume and produce electricity. ECs aim at balancing their own energy demand and generation, by engaging in peer-to-peer (P2P) trading. After having their daily demand met, prosumers can sell their energy surplus to other community members who have been unable to fulfill their energy needs.
The P2P trading system challenges the traditional centralized electricity system structure and market. Suddenly, prosumers start playing a more active role in the energy market, while having no knowledge on how to optimally trade. Reinforcement learning and, in particular, multi-agent reinforcement learning (MARL), can be used to support the decision-making process of the market participants, optimizing the trading process and guaranteeing the maximum possible rewards (i.e. profits/savings). The choice of market clearing mechanism, as well as physical characteristics of the grid and the physics of the battery storage unit affect the financial aspects of P2P trading.
This project's main aim is to understand how profit in P2P trading is affected by the degradation in the battery energy storage units. A MARL algorithm will be used to find the optimal policy under different market clearing mechanisms, with and without battery degradation.

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Machine learning for optimizing plasma resource utilization in Mars

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Plasma technologies for *in situ* resource utilization on Mars have been proposed recently, in particular to decompose CO_2 from the Martian atmosphere and extract the oxygen for life-support, fuels and agriculture. However, the underlying plasma chemistry is very complex and efficient prediction of the plasma properties is mandatory. Moreover, some of the reaction constants of the plasma are not yet well determined or have a significant uncertainty associated. The goal of this research is to use machine learning to predict and optimize the set of rate coefficients used in the reaction schemes that describe CO_2 conversion on Mars. An artificial neural network will be trained to learn and optimize the rate coefficients of the reactions given a set of plasma parameters that can be measured experimentally. Furthermore, it is pretended to provide an estimate of confidence for the model

output and identify the most relevant features of the reaction set, eliminating minor species and less important elementary processes.

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Optimization of materials for Metal-Insulator-Metal resistance devices -Memresistor

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Optimization of thin films (5-30 nm thick) with specific and interesting characteristics for the charge transfer process in metal-insulator-metal nanostructures to obtain controlled switching characteristics for integration into nanostructures of artificial neural networks based on memristors and understanding the electrical transport mechanisms in the insulating material. As electrical conductance depends on the amount of electrical charges that have passed through them, this feature makes the device an ideal tool for mimicking a biological synapse.

34

Quantum Clustering Algorithms for Calorimeter Event Reconstruction in CMS

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This thesis aims to investigate the potential use of quantum algorithms in the field of High Energy Physics. Specifically, the focus is on the application of quantum algorithms to track reconstruction and calorimeter reconstruction in the High Granularity Calorimeter of CMS. The study will examine the use of existing quantum algorithms such as k-means and affinity propagation, and explore any necessary modifications to make them suitable for the clustering problem in the calorimeter. The algorithms will be tested using PYTHIA, an event generator for high energy physics experiments, and possibly GEANT4 for simulating the detector and its response. The results of this study will be used to assess the usefulness of quantum algorithms in current and future machines and detectors in High Energy Physics.

35

Thermal and Power Microgrids in Public Buildings - Case Study LNEG

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Greenhouse gas emissions, caused by the burning of fossil fuels, are one of the main causes of climate change. Thus, an energy transition is needed, through the shift of the energy sector from fossil-based systems of energy production and consumption to renewable energy sources. The building sector is the largest energy consumer in Europe, making it essential to achieve the desired energy transition. Nearly zero-energy buildings have a very high energy performance, while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources. The aim of my thesis is to analyze data from the thermal and power microgrid implemented in building C of the Portuguese National Laboratory of Energy and Geology (LNEG), which includes solar photovoltaic, solar thermal, battery, thermal storage, and heat pump technology; and improve the performance of the system. This includes the development of models in Polysun and/or TRNSYS and the evaluation of new solutions, such as the use of an absorption chiller or seasonal thermal storage.

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Confronting Multi-Higgs Models with Experiment: The 3HDM case

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The Higgs particle was predicted in 1964 and discovered at CERN on July 2012, earning Higgs and Englert the 2013 Physics Nobel Prize. This is a spin-zero particle (scalar), necessary to give masses to all the other massive particles in the Standard Model of Electroweak interactions. But, there is no fundamental reason why there should be only one such scalar. In this project, we consider extensions to the SM with three Higgs doublets. We study the necessary and sufficient conditions for boundedness from below in the general 3HDM potential, and confront implementations of the model with different symmetries, with current experimental data.

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Resonant interaction of fusion alphas and shear-acoustic Alfvén eigenmodes in burning plasmas

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In future nuclear-fusion reactors, the energy of the alpha particles produced is expected to ignite and keep the fuel plasma burning. Yet, resonant interaction with Alfvén eigenmodes may transport these alphas away from the fusing core and towards the reactor structure. Research about such resonant interactions has focused mainly on waves from the shear (or incompressible) branch of the Alfvén dispersion relation. However, recent results indicate that shear-acoustic branch couplings may also produce eigenmodes able to resonantly interact with fusion alphas, particularly in burning plasmas. The goal of this project is to understand the physics of such resonant interaction using large-scale numerical simulations to find if coupled shear-acoustic eigenmodes have a role similar to that of the well-known shear ones in the transport of alpha particles in burning plasmas. To this end, a particle tracer code, employed to follow a large alpha-particle population, will be coupled with the equations that evolve the amplitudes and phases of a pre-computed set of shear-acoustic Alfvén waves, in order to identify and describe the resonance and saturation mechanisms at play. Particular emphasis will be placed on ITER burning plasmas

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Quantum Correlations in Atomic Ensembles

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Quantum communication promises to revolutionize telecommunications, upgrading it to a new standard of security, grounded on the laws of Physics. A plethora of implementations for quantum communication have been proposed, but a general principle is that photons are useful for long distance communication, while matter is convenient for storage of quantum information and to generate photonic states.

A particularly fascinating approach to optical quantum memories is the dark-state polariton scheme, which uses electromagnetic-induced transparency to adiabatically transfer the quantum state of the optical field to and from an atomic ensemble, by varying the strength of a control field. We investigate dark-state polaritons in ensembles of rubidium atoms, working towards the improvement of optical quantum memory protocols for cold atoms in magneto-optical traps and warm vapour cells. On a more fundamental level, we study how quantum correlations, in particular entanglement, arise in atomic ensembles when photons are absorbed.

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The role of ion channels in the transmission of signals along axons

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This project aims on fully understanding the ion channels' role in the transmission of electric signals along axons and on developing a physically and mathematically consistent model that describes the evolution of the neurones' membrane potential - the key mechanism for signal propagation. Being the Hodgkin-Huxley's theory our starting point, we will look at the limitations and inconsistencies of this purely empirical model and present possible gateways for its reformulation and correction.

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Acceleration of tracking reconstruction algorithms using GPUs at ATLAS

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The ATLAS detector is one of the two multi-purpose experiments at the Large Hadron Collider. Its main goals are to search for signs of physics beyond the Standard Model of Particle Physics, and to make precise measurements of the Standard Model itself. In order to analyse the data recorded by the detector, one of the most complex operations is to reconstruct the tracks left by electrically charged particles in the middle of the detector, the so called tracker. With the advent of heterogeneous hardware capable of high performance computing, especially General Purpose GPUs, and because ATLAS plans to record data during the High-Luminosity LHC data taking period with a much higher rate than before, using GPUs in the charged particle reconstruction software of ATLAS is currently being investigated very actively. In order to demonstrate that reconstructing charged particles with the help of GPUs would be viable for the High-Luminosity LHC era in ATLAS, a research and development project is under way to implement the majority of track reconstruction using heterogeneous code. In this project I have been implementing and optimising algorithms taking part in charged particle reconstruction, on GPUs. The major goal in the coming months is integrating this code into the production evironment of the software used bythe ATLAS experiment.

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Miniaturized aerosol collector integrating sensors for real-time bio-aerosol detection

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Contamination of people, animals, foodstuffs, objects and several types of materials by biological agents are of major concern, especially by man or animal pathogens. However, some non-pathogenic agents are also relevant, mainly those associate with food spoilage, or those responsible with the breakdown of sterility, in certain types of equipments and health devices. The primary ways involved in the contamination process are: by contact (direct or indirect), or by air. Air spreading of biologic agents is probably the most important contamination pathway, and requires the aerosolization of biologic agents to effective. Most of the diseases that affect animals and humans are spread by air, in indoors and outdoors. Nevertheless, indoor spreading of biologic agents is most effective than outdoor spreading, due to confinement and agent proliferation. This is of particular importance in public places, such as hospitals, airports, covert stadiums, shopping centres, among others, where natural or intentional disease outbreaks can affect more effectively, a higher number of targets. Intentional releases of biologic agents, in bioterrorism actions, pose great concern to public health and to law enforcement authorities. These entities need even more, of technologies capable to sensing the atmosphere in a continuous way, for the presence of pathogens. Real time detection technologies are a crucial tool, to improve the response efficiency of authorities, in outbreaks situations.
The current technologies available in the market to detect aerosolized agents are cumbersome, expensive, have a high logistic foot print and most of them don't give a specific result in real-time. Most of these technologies are poor used and when an air analysis is needed, generally it is split in two main steps: 1) aerosol collection, with dedicated air samplers; 2) aerosol analysis, by culture and molecular methods.
Project outline/goals:
The limitations in the commercially available technologies, for real-time detection of biologic agents in aerosols, need to be improved in several aspects: 1) miniaturized, capable to be transported by hand or installed in robotic interfaces such as UAV (unmaned air vehicle), or UGV (unman ground vehicle); 2) fully integrated with the air sampling module and with the detection module; 3) real-time or near real-time detection of aerosolized agents.
The main project outline will be focused on the development of a compact aerosol detection biosensor based on magnetoresistive sensors and microfluidics, capable to sensing in real-time the presence of biologic agents in air. The model organism to be used in this project will be pure spores of the non-pathogen Bacillus thuringiensis a surrogate of B. anthracis. The project will require the testing of the aerosol detection biosensor, against standard concentrations of aerosolized B. thuringiensis spores in controlled environment.

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The cylinder at spatial infinity and asymptotic charges

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The asymptotic properties of spacetimes play a central role in many aspects of General Relativity (GR). One of the crucial concepts introduced for the realisation of the latter, was the use of conformal compactifications introduced in General Relativity by Roger Penrose [Nobel Prize 2020] to describe in a geometric way the notion of infinity. The formulation that takes Penrose's idea of conformal compactification to its ultimate consequences are the Conformal Einstein Field (CEFE) equations introduced by H. Friedrich in. Although these equations have been available since 1980 the analytical and numerical exploration of spacetimes using the CEFEs is still in its infancy compared with other formulations. An alternative approach to the CEFE that allows to reach a portion of null infinity

is the use of hyperboloidal foliation in more standard formulations of the Einstein Field Equations (e.g. Harmonic Gauge, BSSN or Z4). By construction, hyperboloidal foliations reach the null-infinity but stays away from the region close to spatial infinity. The CEFEs on the other hand give access to this region via the construction of the cylinder at spatial infinity. Both methods, hyperboloidal and conformal, grating access to the different asymptotic regions of spacetimes can be exploited for the analysis of global properties of spacetimes. Asymptotic charges defined at null-infinity will be studied.

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Anti-de Sitter Spacetime: Stability and Instability

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Anti-de Sitter (AdS) spacetime is the maximally symmetric exact solution to the vacuum Einstein field equations with negative cosmological constant. The negative cosmological constant acts like an attractive potential, preventing timelike geodesics from reaching spatial infinity. On the other hand, null geodesics can reach spatial infinity in finite time, and one has to provide boundary conditions at infinity in order to have a well-determined Cauchy problem. Natural boundary conditions to impose are that null geodesics are reflected at infinity, conserving the energy of the spacetime. This makes pure AdS a confined spacetime, providing one with a natural spacetime to study the dynamics of fields in a cavity. In this context, it is important to understand whether AdS is stable against small perturbations, that is, whether small perturbations created in its interior remain small at later times. For AdS, it is found that when perturbed, the corresponding modes oscillate normally, having real frequencies. For asymptotically AdS spacetimes containing a black hole, as it is the case of AdS-Schwarzchild spacetimes, the modes are quasinormal, with frequencies containing both real and imaginary parts, the latter due to the decay of the modes into the black hole. These have been studied for scalar, massless vectorial and massless tensorial perturbations. The quasinormal modes are specially interesting in the context of the AdS/CFT conjecture, where a perturbation in the black hole is dual to a perturbation in the thermal state of the conformal field theory (CFT). In this work, we intend to review the most recent studies on linear stability and non-linear instability of AdS. Then, we want to compute the normal modes of AdS and the quasinormal modes of AdS-Schwarzchild for different scalar, vectorial and tensorial perturbations in dimensions greater or equal than four, interpreting the results within the scope of the AdS stability problem and the AdS/CFT conjecture.

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Pre-equilibrium of the Quark-Gluon Plasma

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Collisions of heavy ion nuclei at relativistic speeds (close to the speed of light), sometimes referred to as the "Little Bang", can recreate conditions similar to the early universe. This high-temperature and very dense form of matter, now known as the Quark-Gluon plasma (QGP), is made of the elementary building blocks - quarks and gluons - whose description lies within the Quantum Chromodynamics, a keystone of the Standard Model of Particle Physics. An early signature of the QGP, both theorized and seen in experiments, was "jet quenching". The concept behind quenching is that a highly energetic quark or gluon undergoes significant energy loss due to its interactions when traversing the created QGP medium. The result of its fragmentation and radiation pattern is the development of a jet of final-state particles that carry information about the produced medium.

With the plethora of experimental results, the theory of jet quenching has matured, and the underlying dynamics of in-medium propagation of quarks and gluons is under theoretical control. However, its exploitation as a tool to unveil the inner workings of the Quark-Gluon Plasma is still in its infancy. Currently, Quark-Gluon Plasma is described as the most perfect liquid. But how this macroscopic behaviour emerges from a Quantum Field Theory as QCD is still unknown. This will be the challenge for the upcoming heavy-ion data taking at the Large Hadron Collider and will be the focus of this master thesis.

The main objectives of this thesis are thus:
1) Delve into the theory of jet quenching to understand the high-energy and high-density corners of the QCD phase diagram;
2) Get acquainted with the newly developed jet algorithms that aim to probe the time structure of the QGP that is produced in heavy-ion collisions;
3) Model different Quark-Gluon Plasma evolution profiles within the allowed QCD phase space;
4) Identify the timescale at which the Quark-Gluon Plasma comes to thermal equilibrium
5) Assess the potential use of jets to constrain the pre-equilibrium phase of QGP

If successful, the result will be an impactful publication with an immediate application in current ultra-relativistic heavy-ion experiments (such as LHC) and in determining the future heavy-ion physics program.

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Characteristic Critical Collapse with Null Infinity

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In this work, we discuss black hole formation in general relativity. We aim to study the critical collapse of scalar field data numerically. We are interested in analysing this collapse from the point of view of an observer located “at” infinity, which allows us to extract global properties of the system from Einstein’s equations [Pürrer, 2005].

We have already successfully implemented a toy model that we’ll further develop to study the scalar field critical collapse. Later on, we will extend Pürrer’s work by studying the collapse of a Yang-Mills field. Furthermore, we aim to compare the obtained results using a null foliation approach with the results of different approaches to the same physical problem, such as spacelike foliation based on truncated Cauchy slices, as well as a hyperboloidal evolution.

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Novel thin-film silicon photodetectors for biosensing

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The development of miniaturized thin-film silicon photodetectors and their integration with microfluidics for point-of-care biosensor microsystems has been studied for years. These photodetectors can operate in the visible range using fluorescent, chemiluminescent, and colorimetric molecular markers and in the UV range, aiming to achieve label-free detection of proteins, nucleic acids, and other organic molecules of interest.
The primary goal of this thesis is to develop a novel microfabricated thin-film silicon photodetector based on a parallel p-i-n junction (as opposed to the standard perpendicular p-i-n junction). This parallel junction will be deposited on top of a gate/insulator to stack. The gate will be used to modulate the position of the Fermi level of the lateral p-i-n junction, allowing fine control of the baseline dark current. This project involves semiconductor device design and simulation, clean room microfabrication (including mask design), and optoelectronic testing. Finally, if the device characteristics

allow, the novel photodetector will be integrated and tested in a microfluidic system for biomolecular sensing.

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Stability of spin-liquid phases against environment-induced dissipation

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Liquid phases are exotic phases of matter that arise in many-body interacting systems. In contrast to more conventional phases, such liquids remain disordered down to zero temperature. Nevertheless, despite the apparent lack of order, their local degrees of freedom are highly correlated.

However, liquid phases can be fragile. The unavoidable coupling to the degrees of freedom of their environment may render them unstable and radically alter their properties. Thus, to guide the experimental search for liquid phases, it is critical to determine their stability to environment-induced dissipation.

The importance of considering the coupling to the environment was demonstrated by recent quantum Monte Carlo simulations which established that the ground-state of the spin-1/2 Heisenberg chain, a well-known spin liquid, is unstable in the presence of an infinitesimal coupling to an ohmic bath. This work opened the prospect of similar phenomena for other liquid phases.

Motivated by these results, this thesis will extend the stability analysis to other liquid phases. Namely, we will examine the charge liquid phase realized in the one-dimensional Bose-Hubbard model, and quantum spin ice - a paradigmatic three-dimensional quantum spin liquid. To perform this analysis, we will develop an algorithm specifically designed to deal with the action of the environment. Concretely, our approach uses a quantum Monte Carlo method based on a continuous-time path integral algorithm with worm update.

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Disentangling QGP response using energy flow correlators

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The study of the Quark-Gluon Plasma, the deconfined phase of QCD matter, is a very active and fast-developing field of research. The QGP is the phase matter of the Universe in its first microsecond of existence and can be formed in collisions of ultra-relativistic Heavy Ions. One of the key ways the internal properties of QGP have been studied is by looking at how it affects the behavior of jets, collimated sprays of hadrons, produced in heavy-ion collisions, given that these jets travel through the QGP and their properties are modified in comparison to their vaccum counterpart (proton-proton collisions). A further contribution to what experimentalists reconstruct as the final jet arises from the QGP response to the jet passage through it, as a result of extra hadrons, created as the plasma freezes out, being dragged in the jet's direction.

This work aims to disentangle the response of the QGP from jets in heavy-ion collisions using energy flow correlators, as at present time a reliable method is yet to be found. By computing and analysing energy flow correlators, which are expcted to contain every possible information about jets, using simulated data, one will hopefuly be able to identify signatures that are specific to the QGP response and separate both contributions.

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De Sitter Spacetime and Fundamental Physics

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The de Sitter spacetime, first found by Willem de Sitter in 1917, is a solution to the Einstein field equations without matter and with a positive cosmological constant. Current observations suggest that our universe has a small positive cosmological constant, Λ, and that it is asymptotically de Sitter, demonstrating the important role of positive Λ solutions and in particular of the de Sitter solution in modern cosmology.
In addition to the "pure" de Sitter solution, other solutions with $\Lambda > 0$ exist. One example is the Schwarzschild-de Sitter solution which represents an asymptotically de Sitter spacetime with a central black/white hole. Considering the connection between event horizons and temperature, which was first understood for BH event horizons and then generalized to cosmological event horizons, this spacetime is characterized by two temperatures: the BH Hawking temperature and the cosmological de Sitter temperature. The two temperatures, which are associated with a stationary state, are different and therefore thermal equilibrium in Schwarzschild-de Sitter spacetime is, in general, unreachable, making a consistent thermodynamical formulation impossible. Nevertheless, there are cases where this formulation is possible and their study is mandatory for a better understanding of the interaction between black holes, cosmological horizons, and matter.
In this talk, I am going to summarize the analyzis of the de Sitter and Schwarzschild-de Sitter solutions. Furthermore, I will briefly comment on the final objective of my master's thesis which is to formulate a consistent thermodynamical framework in a Schwarzschild-de Sitter spacetime through the addition of hot matter has a link between the two different temperatures originating from the existing two types of event horizons.

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Permanent Magnet Design for Nuclear Fusion Reactors

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Nuclear fusion has one of the most promising and exciting end goals of any field. It has the potential of sustaining humanity's ever-growing energy demand. The first approach to fusion was magnetic confinement and it is also the easiest to scale up, with two designs standing above the rest: the stellarator and the tokamak. Although in the early stages, stellarators were plagued by large transport, today with the development of stellarator optimization, they are at the forefront of nuclear fusion research. One of the main challenges stellarators face right now is coil complexity, being the biggest responsible for the delays in the construction of W7-X and the cancelation of NCSX. An alternative to the current design of stellarators is the inclusion of permanent magnets as a way of considerably simplifying the electromagnetic coils. Permanent magnets also offer other advantages, such as having a steady magnetic field that requires no external source of power or cooling, being very inexpensive, and producing less coil ripple than modular coils.
The objectives of this thesis are the use of SIMSOPT, a stellarator optimization framework, to design new stellarator machines, to simplify existing ones, and to explore the possibility of converting tokamaks into stellarators, all with permanent magnets. Different optimization algorithms and machine learning techniques will be tested for this application.

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Particle Physics anomalies from Dark Matter

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In recent years, several experimental measurements have shown deviations from the Standard Model (SM) predictions. One such deviation is the anomaly in the measurement of $b \to sl^+l^-$ decays. Additionally, the long-standing muon $(g-2)$ anomaly has been confirmed, now with a discrepancy of 4.2σ relative to the SM prediction. In this paper, we study the effects of new physics on the $Z \to b\bar{b}$ decay amplitude by considering a specific class of SM extensions that aim to solve these discrepancies and the existence of dark matter. We present a formalism to calculate the radiative corrections to the decay amplitude in this framework and use it to find bounds on the parameters of one of these models.