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Contents

Identification of cold plasma components responsible for the antitumor response in subcutaneous cholangiocarcinoma models

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Cold atmospheric plasma (CAP) has demonstrated significant therapeutic potential in oncology due to its selective cytotoxic effects [1]. These effects are primarily attributed to oxidative stress induced by reactive oxygen and nitrogen species (RONS) generated by CAP. However, the ability of these RONS to cross the skin and reach subcutaneous tumors remains uncertain. Assuming their penetration is limited, other plasma components, such as the electric field, thermal effects, or UV radiation, could contribute significantly. For this purpose, we propose to identify which CAP components (RONS, electric field, UV radiation, temperature, gas flow) can cross the skin and induce the antitumor response observed in a subcutaneous model of cholangiocarcinoma [2], a primary aggressive tumor of the bile ducts.

Experiments were performed using an atmospheric-pressure plasma jet in a double-annular electrode configuration, powered by a nanopulsed high-voltage source (5 kV, 10 kHz, 10 % duty cycle) and supplied with helium (flow rate 1 L/min). The concentrations of nitrites (NO_2^-) and hydrogen peroxide (H_2O_2) were measured by absorption spectrophotometry in culture medium (Gibco™ DMEM), whether directly exposed to CAP or covered either with a Strat-M® membrane (300 µm), used as a human-skin model, or with ex-vivo C57BL/6J-Tyrc mouse skin (325.8 ± 15.6 µm). Surface temperature was monitored by infrared thermographic imaging before, during, and after CAP treatments lasting 2, 10, and 20 min. The axial electric field generated by the CAP was also measured beneath the skin models using a Pockels probe (Fig. 1) to assess its ability to propagate through them and to quantify its attenuation as a function of depth.

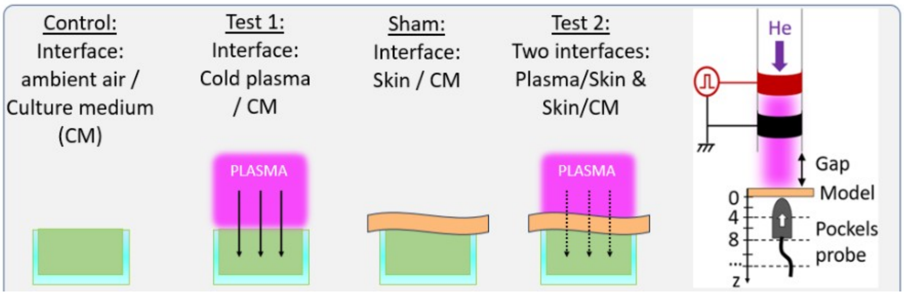

Figure 1. *Experimental setup.*

After 20 min of CAP treatment of the culture medium (Test 1), the concentrations of NO_2^- and H_2O_2 reached 343 ± 13 µM and 1121 ± 192 µM, respectively. In the presence of a skin model (Test 2), NO_2^- concentrations decreased sharply to 3.6 ± 0.2 µM with the Strat-M® membrane and 2.7 ± 0.8 µM with ex-vivo mouse skin. The detection of H_2O_2 in the culture medium is limited by the presence of scavenging compounds, notably pyruvate, which can react with H_2O_2; consequently, low H_2O_2 concentrations may fall below the assay detection limit, preventing accurate quantification. Thermographic measurements showed that the temperature exceeded the biological threshold (40 °C) after 3 min with the Strat-M® membrane and after 15 min with the ex-vivo mouse skin; therefore, only the experiments conducted with a 2 min exposure remained below the biological threshold. Finally, the axial electric field penetrated both skin models, with a transmission efficiency estimated at 88 % for the Strat-M® membrane compared to only 25 % for ex-vivo mouse skin. Although nitrite concentrations remained low (3–4 µM), a significant difference was observed between the Sham and Test 2 after 20 min of treatment. In contrast, H_2O_2 may have been scavenged by the sodium pyruvate present in the culture medium. Ongoing work therefore focuses on the isolation of the components of CAP and their ability to cross the skin models.

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Probing circuit function through dynamics-based comparison of graphlets

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Successive experimental advances are making it possible to study and compare the structural and mechanistic underpinnings of an increasing number of biological systems, from the biochemical networks underlying cell function to the neuronal circuits of animals' brains. Graph theory provides a powerful framework for characterizing the topology of biological networks by representing their functional units as nodes and their interactions as links. However, network topology does not uniquely determine function. Thus, while a host of graph-theoretic measures exist for characterizing and comparing networks, their functional relevance remains unclear, and how best to compare network structures remains an open question.

The goal of my thesis is to develop new theoretical and computational methods for the comparison of biological networks based on the dynamics they support. I will present a framework that maps graphs to a biologically relevant dynamical process taking place on their nodes to build a dynamics-based dissimilarity measure of structural patterns. I will focus on the Kuramoto model, which describes the synchronization of coupled oscillators, and characterize and compare all possible networks of 3 to 5 nodes (approximately 10 000 in total). I will demonstrate how this provides a fine-grained measure that captures essential dynamical features and how they relate to structural features of the networks.

Mechanical response of collagen network to external loading

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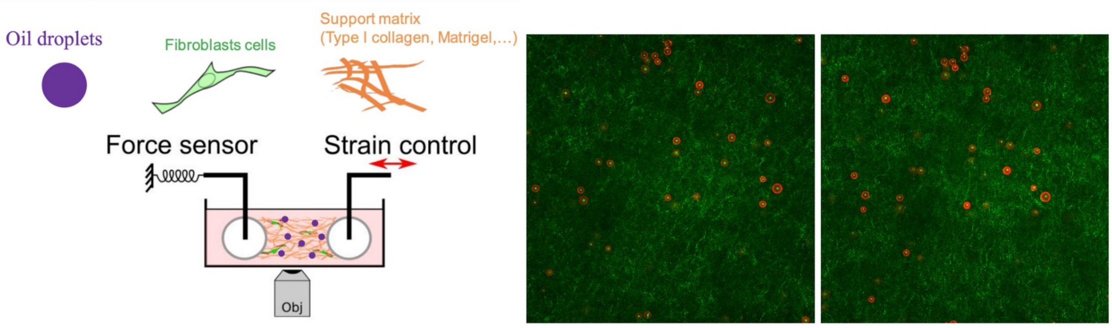
Soft tissue connects, surrounds or supports internal organs and bones. Soft tissues exhibit a large variety of microstructures and mechanical properties, which vary from organ to organ and according to patho-physiological conditions. In these tissues, cells are dispersed away from one another within a collagen-based matrix, the so-called extracellular matrix (ECM). It is known that cells can rearrange the collagen both by biochemical action and by mechanical forces, and that their action can result in drastic changes in both the organization and the mechanical properties of the matrix [1,4]. Here we focus on the mechanical response of the ECM to external constraints and how embedded cells influence this response. On one hand, tissue stiffening is observed in compression, caused by the coupling between the ECM fibrous structure and potentially the steric presence of cells [3]. On the other hand, a cell actively pulling on a collagen network reorganizes the network both by changing its morphology [4] and its mechanical properties [2].

To explore the active and passive influence of cells on emergent tissue mechanical properties, we developed a new set of tools. First, we use suspended in vitro micro-tissues composed of type 1 collagen and mesenchymal stem cells. This setup allows controlled deformation of the tissue and the study of its properties in uniaxial geometry while imaging the tissue in the plane of deformation (a). Second, in order to mimic the steric presence of cells within the tissue, functionalized oil droplets are inserted, functionalized with type 1 collagen antibodies mimicking cell–extracellular-matrix adhesion.

So far, we have observed that the presence of droplets does not affect the mechanical properties of the type 1 collagen network for both small and large deformation. The next step is to understand this behavior by tracking collagen network deformation through confocal microscopy (b, c).



(a) (b) (c)

Figure 1. *(a) Schematic of the suspended device used to measure the mechanical properties of the tissue (mesenchymal stem cells, C3H/10T1/2 line; type 1 collagen; oil droplets); a controlled strain is applied and the force sensor measures the rheological response. (b–c) Confocal microscopy of the collagenous extracellular matrix (green) with functionalized oil droplets (red, ~10 μm) under (b) 0 % and (c) 80 % induced stress.*

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Creep motion of driven disordered systems

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Many disordered materials and interfaces can slowly deform under a constant external drive, even when this drive is too weak to produce immediate motion. This slow, thermally activated dynamics is known as creep.

In this talk, I will present two complementary directions of my PhD work on creep phenomena. The first concerns the motion of a one-dimensional elastic interface in a disordered medium, where creep can be studied through the interplay between thermal activation and avalanche dynamics. The second concerns amorphous solids, where slow deformation under stress is related to plastic rearrangements and possible strain localization.

The goal is to understand how disorder, elasticity, temperature, and external driving combine to produce slow relaxation, intermittent motion, and collective rearrangements in driven disordered systems.

Using symmetry to understand patchy particles self-assembly

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Self-assembly is the process by which small building blocks spontaneously organize into larger structures. To study this process, we use patchy particles: simplified particles whose surfaces carry “patches” that can attract or repel each other. The shape and properties of the structures that these particles form are strongly determined by which pairs of patches attract or repel one another.

We can therefore ask two questions: first, can we predict which structure will emerge from a given set of interactions, and second, can we design interactions that produce a desired structure? In both cases, the main difficulty is to understand how many local interaction rules combine to determine the global properties of the assembly.

Here, we use symmetry to rewrite the many patch–patch interactions exactly as a set of anisotropic modes. These modes can be understood as the elementary ways in which a particle can be anisotropic, for example by having a polar, nematic, or triadic character.

We show that, in this new language, the link between the interactions of the building blocks and the properties of the assembly becomes interpretable. This gives us a practical framework to understand why certain interactions produce certain structures, and to guide the design of interactions that assemble into desired shapes.

Adaptive optics in light-sheet microscopy for high-resolution 3D in vivo imaging

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We are developing an original adaptive-optics approach in light-sheet microscopy based on wavefront sensing using a structured guide star. This method aims to decouple the measurement from the frequency content of the samples, thereby improving the robustness and sensitivity of wavefront sensing.

Light-sheet fluorescence microscopy (LSFM) is a technique particularly well suited for imaging living systems due to its efficient optical sectioning, rapid acquisition, and low phototoxicity. It enables the observation of dynamic processes deep within biological samples at submicrometric scale. However, image contrast and spatial resolution in thick samples can be degraded by wavefront distortion caused by refractive-index inhomogeneities in tissues. Adaptive optics (AO) can correct these optical aberrations and has already demonstrated its ability to improve both signal and resolution in biological microscopy.

To make this technique compatible with light-sheet microscopy for in vivo imaging, we previously proposed an approach based on extended-source wavefront sensing [1], which has shown its benefits in neuroimaging in adult Drosophila and zebrafish larvae [2][3]. Nevertheless, wavefront measurement in densely labeled samples remains challenging, due to the limited spatial resolution of the wavefront-sensor sub-images and the plenoptic effect.

Indeed, extended-source wavefront sensing relies on image correlation and is therefore sensitive to the structural characteristics of samples, particularly when labeling is very dense, as the sub-images produced by the sensor are poorly resolved. The measurement can also be affected by the plenoptic effect, related to the low numerical aperture of the microlenses.

To overcome these limitations, our team developed a new extended-source wavefront-sensing approach using a structured guide star. The goal is to increase both sensitivity and detection robustness. We added a dedicated excitation path to the light-sheet microscope for wavefront measurement, enabling the generation of a cross-shaped structured guide star. We will show how this approach allows wavefront measurement in fluorescent and scattering test samples, as well as in thick biological samples such as live zebrafish larvae, thus paving the way for robust in vivo aberration correction.

Keywords: Fluorescence microscopy; Adaptive optics; Live imaging; Direct wavefront sensing

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Invariant properties of multimode fibers for imaging applications

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Multimode fibres offer unique opportunities for compact imaging systems thanks to their high information-carrying capacity and small footprint. However, light propagation in these fibres is highly sensitive to perturbations such as bending or environmental fluctuations, making image reconstruction particularly challenging. This work investigates invariant propagation properties, specifically memory effects, that can be exploited to recover images without prior calibration.

After introducing the fundamentals of multimode-fibre propagation and conventional memory effects, this study presents a new theoretical approach based on a novel concept called the random memory effect. This newly developed framework aims to provide deeper insight into invariant correlations in complex fibre propagation and their potential use for robust imaging.

Preliminary results demonstrate that the theory is effective in numerical simulations, showing promising capabilities for calibration-free image reconstruction.

The next step of this work focuses on validating these results experimentally and studying the practical limitations of the approach in reality. Understanding and leveraging these invariances could contribute to the development of robust, real-time multimode-fibre imaging systems for biomedical and endoscopic applications.

Enhancing and accelerating photon emission from single molecules in DNA origamis using plasmonic nanocube dimers

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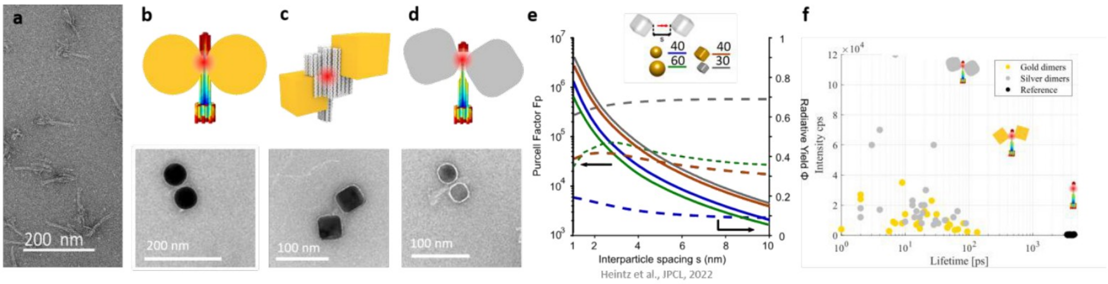
Single quantum emitters, such as single molecules, are essential building blocks of quantum technologies but require cryogenic conditions to produce indistinguishable photons [1]. However, at room temperature, photon emission is mostly incoherent and light interacts only weakly with the emitter. To overcome these limitations and reach coherent light–emitter interactions at room temperature, we designed a tower-like DNA origami structure (Fig. 1a) that precisely positions a single fluorescent molecule within the plasmonic hotspot formed between the tips of two metallic nanocubes. Our group recently proposed this geometry [2] to reach strong-coupling conditions with higher fidelity than using spherical particles [3].

To assemble these hybrid dimer structures, the plasmonic nanoparticles are coated with DNA strands that hybridize with complementary strands extending from the emitter-containing DNA origamis. Two DNA origamis are designed to assemble dimers of either spherical (Fig. 1b) or cubic (Fig. 1c–d) nanoparticles in order to investigate the influence of the lightning-rod effect offered by the tips of plasmonic nanocubes. We produce dimers of gold or silver nanocubes since silver particles should offer higher quantum yields and larger Purcell factors (Fig. 1e).

Correlated fluorescence-lifetime/intensity measurements, conducted in a high-refractive-index glycerol-based aqueous solution, reveal an acceleration of the emission decay rate by up to ~1000 for gold and silver dimers (Fig. 1f) and intensity enhancements reaching up to ~300 for silver dimers. These bright emitters with extremely short lifetimes confirm the potential of hybrid plasmonic DNA nanostructures to produce sources of indistinguishable single photons at room temperature.



Heintz et al., JPCL, 2022

Figure 1. *(a) TEM image of nanocubes' DNA origami. Scheme and TEM image of an assembled structure with (b) gold nanospheres, (c) gold nanocubes and (d) silver nanocubes. (e) Purcell factor (solid lines) and radiative yields (dotted lines) for 40 nm gold nanospheres (blue), 60 nm gold nanospheres (green), 40 nm gold nanocubes (red) and 30 nm silver nanocubes (grey). (f) Distribution of lifetimes–intensities of single molecules with gold nanocube dimer (yellow), silver nanocube dimer (grey) and without any plasmonic dimer (black).*

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Quantum simulation of fermionic matter: single-atom imaging of strongly correlated fermions in the continuum

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Systems of strongly interacting fermions arise in multiple fields of physics: condensed matter (high-temperature superconductors, graphene), particle physics (protons, neutrons, quark–gluon plasma), and astrophysics (neutron stars). However, understanding strongly correlated fermionic systems constitutes a serious challenge of modern physics due to the fermionic nature of their constituents.

Ultracold-gas experiments are powerful platforms for simulating those systems, where one can tune their parameters smoothly and with a high degree of control (interaction, spin composition, potential landscape, density, etc.). In addition, quantum-gas microscopy has emerged in recent years as an unprecedented tool to probe and manipulate quantum many-body systems at the single-atom level.

In this presentation, I will first introduce the physics and experimental techniques supporting research in ultracold Fermi gases and quantum microscopy. I will then briefly show the team's recent work on quantum-gas microscopy of ultracold fermions in continuous space and their characterization at previously inaccessible levels of resolution and precision with a reliable imaging protocol [1–4]. Our approach offers radically new possibilities for the exploration of strongly interacting Fermi gases at the single-atom level.

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Spin-diodes neural chip for low-power RF edge spectrum classification

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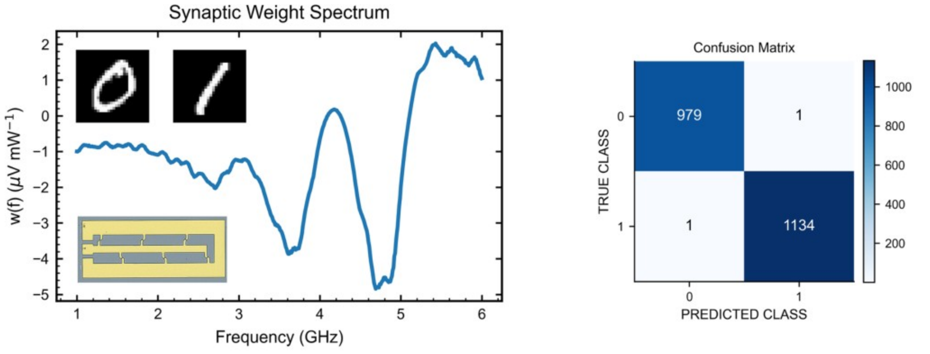
Modern AI systems require enormous energy for both training and inference, motivating the exploration of alternative computing paradigms. Compute-in-memory (CIM) has emerged as a promising approach, with extensive research based on non-volatile memory technologies such as RRAM, MRAM, and PCM memristors.

For radio-frequency (RF) signal processing, conventional digital architectures require extremely high sampling rates and complex digitization hardware, leading to prohibitive size, weight, power, and cost (SWaP-C) constraints [1]. In contrast, spintronic devices enable direct analog processing of RF signals, offering a pathway toward RF-native neuromorphic computing [2,3].

Here we demonstrate the feasibility of using spin diodes to perform large-scale synaptic multiply–accumulate (MAC) operations. Owing to the spin-rectification effect, the rectified DC voltage scales linearly with the injected RF signal power, with a proportionality factor determined by the frequency detuning between the diode resonance frequency and the signal excitation frequency.

The core hardware is a spin-diode chain composed of multiple permalloy microstrips connected in parallel. By placing the device in a magnetic-field gradient, each diode experiences a distinct local field and thus a different resonance frequency, enabling frequency-selective rectification of multiple RF inputs (Fig. 1).

As a first proof of concept, we train a neural network in software to classify MNIST digits (0 vs 1) and transfer the learned weights onto the frequency-dependent responses W(f) of the spin-diode chain. Test images are encoded as distinct RF power spectra, and classification is performed by measuring the DC output voltage of the chain, achieving the same accuracy as the software model (Fig. 2). In this presentation, we will expand this approach towards more complex tasks, including the use of additional diode chains for multi-class classification (e.g., MNIST 0–9).



Figures 1–2. *(Left) Synaptic weight spectrum W(f) measured on the spin-diode chain, with MNIST test digits and a micrograph of the device. (Right) Confusion matrix for MNIST 0-vs-1 classification.*

The architecture and workflows demonstrated by this work open the path to future scaled-up demonstrators in which spin-rectification is employed for efficient AI processing of radio-frequency inputs at a larger scale.

Keywords: Neuromorphic spintronics; radiofrequency; neural network

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Anderson localization on Husimi trees and its implications for many-body localization

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Many-body localization is a striking phenomenon in which an interacting quantum system can fail to thermalize in the presence of strong disorder. A useful way to understand this problem is to view the many-body Hilbert space as a graph of configurations, where each node represents a many-body basis state and the links are the matrix elements coupling different configurations. In this picture, many-body localization becomes closely related to Anderson localization on complex, high-dimensional graphs.

The most common toy model for this analogy is the Bethe lattice, a tree-like graph with large connectivity. However, realistic many-body configuration spaces contain additional structures, such as loops and correlations between nearby configurations. In this talk, I will discuss Anderson localization on the Husimi tree, a generalization of the Bethe lattice built from overlapping fully connected clusters. This model introduces a finite density of local loops while remaining analytically tractable through a cavity approach.

I will show that local loops have two complementary effects. They enhance resonant processes, reducing the critical disorder needed for localization, and they promote local hybridization, increasing the spatial extent of localized eigenstates. These results suggest that local loops are an important ingredient for making single-particle localization models on hierarchical graphs closer to the phenomenology of many-body localization.

Dynamics of music exploration

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We investigate the dynamics of music exploration using several thousand listening histories spanning five years from the Deezer platform.

In a first part, we study the growth of the number of distinct tracks as a function of total play count. We show that this dynamics is largely insensitive to how attention is distributed across tracks, but is strongly shaped by the temporal correlations of the listening process.

In a second part, we model each listener's trajectory in a two-dimensional space of listening and discovery rates using a stochastic process, by analogy with human-mobility models. Validation steps suggest that the model successfully captures individual behavioral signatures, and ongoing work investigates whether a more compact formulation yields similar results.

Transient gamma-ray sky with the future Cherenkov Telescope Array Observatory (CTAO) and validation tests with the NectarCAM camera

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The Cherenkov Telescope Array Observatory (CTAO) will consist of more than 60 telescopes in the northern and southern hemispheres, being the largest and most sensitive instrument for gamma rays from 20 GeV to 300 TeV. The arrays will comprise four Large-Sized Telescopes (LSTs) in the Northern Hemisphere, up to 23 Medium-Sized Telescopes (MSTs) distributed over both array sites for the core energy range, and up to 37 Small-Sized Telescopes (SSTs) in the Southern Hemisphere. The flat-field flasher is a calibration device designed for NectarCAM, the camera that will equip the MSTs of the northern site of the CTAO. Positioned in the centre of the MST dish, 16 metres in front of the camera, the flasher emits short (FWHM < 5 ns), uniform (2–4 %) light pulses at 390 nm to illuminate the entire focal plane.

Accurate calibration is crucial for the optimal operation of NectarCAM, ensuring precise gain computation and mitigating differences in light-collection efficiency among the pixels of the camera. Using the flat-field flasher, two pieces of information are obtained: the pixel gain and the relative efficiency between pixels. The flat-field coefficients account for differences in signal between pixels and are then applied within the camera to ensure a uniform response of a few percent across all 1855 pixels. To improve the precision of the flat-field coefficients, a signal-distribution model is applied to correct for uncertainties in the charge computation. Assuming the light-front shape to be a 2D Gaussian, the required control of 2 % over the light front is achieved. Furthermore, the obtained light-front parameters show good consistency with the results obtained at a dedicated test bench. An accurate calibration of the cameras will be crucial for an unbiased reconstruction of gamma-ray energies and thus for the spectral studies of gamma-ray sources.

Studies of Active Galactic Nuclei (AGN) constitute one of the Key Science Projects of the CTAO. The long-term monitoring of AGNs aims to measure their duty cycle and to constrain the location of the gamma-ray emission regions within these sources. To achieve these scientific objectives within the allocated observation time, the observational program must be carefully optimized, based on simulations. In this study, simulated CTAO observations were performed for a selected list of AGNs of interest. The resulting light curves were fitted and analyzed to estimate the excess variance, which serves as a criterion for identifying the most effective observational strategy among four considered scenarios. The ongoing work focuses on refining the selection of the optimal observation cadence and duration, using the fitted flux distribution to determine under which observational conditions different flux-variability models can be reliably distinguished.

Hyper-Kamiokande: the new-generation water Cherenkov detector

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After years of effort, the excavation of the cavern for the Hyper-Kamiokande (HK) experiment was successfully completed in July 2025. This date marks a huge milestone for the project, which is scheduled to start full-scale operation in summer 2028. Right now the priority is to ensure the robustness of the detector components and the readiness of the real-time analysis pipeline.

The reconstruction and selection algorithms will play a crucial role in the neutrino-oscillation analysis. With an unprecedented level of statistics, HK might be the first experiment to measure CP violation in the lepton sector at 5σ, and will also have world-leading sensitivity to the PMNS mixing angle θ_{23}. On top of that, HK will feature an exceptional supernova-neutrino sensitivity and a proton-decay detection program.

Studying matter–antimatter asymmetry of B-meson decays in the LHCb experiment

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The LHCb experiment is one of the largest detectors located at CERN's Large Hadron Collider (LHC). While the LHC is widely known for the discovery of the Higgs boson, LHCb was specifically designed to study the subtle differences between matter and antimatter at the most fundamental level, also known as CP violation. For this purpose, the detector was built with a unique forward geometry that differs significantly from that of conventional particle-physics experiments. Understanding matter–antimatter asymmetries is one of the major challenges of modern particle physics, as it may help explain why the observable Universe is composed almost entirely of matter, despite matter and antimatter being produced in nearly equal amounts after the Big Bang. However, the current theoretical framework describing elementary particles and their interactions, known as the Standard Model, predicts an amount of CP violation that is insufficient to account for the observed matter dominance of the Universe.

This contribution presents the LHCb detector and the experimental methods used to investigate CP violation in the decays of particles containing beauty quarks. We introduce concepts such as flavour tagging, which allows physicists to determine whether a particle was produced as matter or antimatter, and amplitude analysis, a powerful technique used to disentangle the various quantum processes contributing to a decay. These methods enable extremely precise measurements of CP-violating effects and provide a sensitive probe for phenomena that may lie beyond the Standard Model.

As a case study, we consider the decay $B^0 \to K^+K^-K_S$, in which a neutral B meson decays into three kaons. This decay exhibits a rich resonant structure, where several intermediate states can contribute and interfere with one another according to the laws of quantum mechanics. By studying these interference patterns together with the time evolution of the decay, physicists can extract information about the fundamental parameters governing CP violation. Such measurements represent some of the most stringent tests of the Standard Model and may ultimately provide clues toward understanding the origin of the matter–antimatter imbalance in our Universe.