# PhD School on QCD in Extreme Conditions 2025

**Monday 30 June 2025 - Tuesday 1 July 2025**

**Faculty of Physics and Astronomy**

# Scientific Programme

The school will feature four block lectures 2 x 90 min, given by internationally recognized theoretical physicists, covering cutting-edge research topics centred on recent advances in the theory and phenomenology of QCD under extreme conditions, providing an in-depth review of these fields for PhD students before the XQCD conference.

# Lattice QCD

**Lecturer:** Prof. Jana Günther (Wuppertal University)

Lattice QCD is the key non-perturbative tool for studying the strong interaction from first principles. This short lecture series will introduce the basic concepts behind the lattice formulation of gauge theories and focus on the practical aspects of simulating them. Using SU(2) gauge theory as a starting point, we will explore simplified code and perform live simulations to build intuition for how Monte Carlo methods work in practice. The second part of the lecture connects these tools to current research questions, such as the QCD phase diagram, the equation of state, and the challenges posed by finite-density simulations. The aim is to provide a hands-on introduction that bridges methodological understanding and recent developments in the field.

# Critical point, fluctuations and correlations

**Lecturer:** Prof. Masakiyo Kitazawa (Osaka University)

One of the fascinating aspects of Quantum Chromodynamics (QCD) is that the medium described by this theory is expected to undergo various phase transitions under hot and dense conditions. In this lecture, I will begin with an overview of QCD and its phase diagram, and then discuss the properties of individual phase transitions, with a particular focus on the conjectured QCD critical point and the characteristic behavior of fluctuation observables around the phase transitions. I will also highlight recent progress in the experimental exploration of the QCD phase diagram through relativistic heavy-ion collisions, along with future prospects in this area.

# Scattering Theory and Hadron Gas

**Lecturer:** Prof. Pok Man Lo (University of Wrocław)

This lecture is about the scattering matrix (S-matrix) formulation of statistical mechanics.

We review the most relevant aspects of scattering theory (phase shifts, resolvent operators, Riemann sheets, resonance poles, etc.) and establish their connection to the density of states and statistical operators. As a demonstration, we show how repulsive interactions and resonances can be consistently included in thermodynamics, and how model-independent constraints on thermal observables can be obtained when scattering experimental data are directly implemented.

We then discuss how the detailed structure of the interacting baryon spectrum, obtained from partial wave analyses, can be used to improve thermal models for heavy ion collisions. In fact, some well-known inconsistencies, such as the proton yield puzzle and the proton-to-Lambda ratio, may be resolved once key features of the empirical spectrum are taken into account. These

features are also crucial for understanding lattice QCD results, such as the baryon-electric charge correlation.

Finally, we explore recent theoretical developments: understanding in-medium hadron modifications from the scattering theory perspective and modelling N > 2-body interactions. These aspects are essential for developing a theoretical framework for dense QCD matter.