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Hot QCD in the laboratory: the ALICE upgrades for LHC Run 4 and beyond

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At extreme temperature and energy density conditions, achievable in the laboratory by colliding heavy nuclei at ultra-relativistic energies, strongly-interacting matter undergoes a transition from its condensed, hadronic phase to the deconfined, partonic phase named quark-gluon plasma (QGP). The main goal of the ALICE physics program is to investigate the properties of the QGP at the CERN LHC, and to understand how its properties emerge from the fundamental interactions governed by quantum chromodynamics (QCD).

A major upgrade was performed on the ALICE detector during the LHC Long Shutdown 2 (2019–2022), and further improvements, including the upgrade of the inner tracker (ITS3) and the installation of a forward calorimeter (FoCal), are planned for the Long Shutdown 3 (2026-2029). For the future, beyond LHC Run 4, the ALICE Collaboration pursues developments for a next-generation detector, named ALICE 3, optimized for high-precision tracking and particle identification in heavy-ion collisions

The proposed ALICE 3 detector exploits a new superconducting magnet and consists of a large pixel-based tracking system covering eight units of pseudorapidity, complemented by multiple systems for particle identification, including silicon time-of-flight layers, a ring-imaging Cherenkov detector, and a muon identification system. Cutting-edge technologies are under development to pursue a track-pointing resolution better than 10 microns for particles with transverse momentum above 200 MeV/c, achievable by designing the vertex detector as a retractable structure inside the beam pipe.

The ALICE 3 detector represents a unique opportunity to address key questions in the QGP physics which will be left open at the end of the LHC Run 4, and will offer important physics opportunities in other areas of QCD and beyond. The physics program in the QGP sector will focus on heavy-flavor measurements at low-p_{T}, including beauty hadrons, multi-charm baryons and charm-charm correlations, as as well as on precise multi-differential measurements of dielectron emission to probe the mechanism of chiral-symmetry restoration and the time-evolution of the QGP temperature. Besides QGP studies, ALICE 3 is expected to give unique contributions to hadronic physics, with femtoscopic studies of the interaction potentials between charm mesons and searches for nuclei with charm, and to fundamental physics, by testing the Low's theorem for ultra-soft photon emission.

This presentation will provide an overview of the planned ALICE upgrades, discussing the physics potential out of reach with other existing or planned experiments, and the status of the R&D for the chosen technologies.

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