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The ALICE Upgrades: Toward a Next-Generation Heavy-Ion Experiment at the LHC

A Large Ion Collider Experiment (ALICE) is currently undergoing major upgrades to get ready for the start of the Large Hadron Collider (LHC) Run 3 in 2022 (see Figure 1). Already in Run 1 (2009–2013) and Run 2 (2015–2018), the experiment has allowed us to pursue a rich program of quantum chromodynamics physics with collisions of heavy ions and protons, pushing the energy frontier of ultrarelativistic heavy-ion collisions by more than an order of magnitude compared to previous heavy-ion programs at the Alternating Gradient Synchrotron (AGS) and the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in the United States and the Super Proton Synchrotron (SPS) at CERN. Profiting from the hotter, denser, and longer-lived quark–gluon plasma (QGP) phase in nucleus–nucleus collisions at the LHC, we have sharpened our prior understanding in several areas through

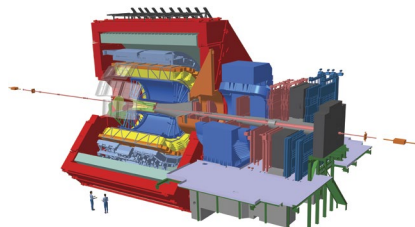


Figure 1. Schematic view of the ALICE detector after the ongoing upgrades. The new Inner Tracking System is shown in green. It is surrounded by the Time Projection Chamber (blue), which has been upgraded with GEM-based readout chambers. The muon tracking and identification chambers on the right side of the diagram profit from the addition of the Muon Forward Tracker.

more precise measurements (e.g., of the viscosity and high-momentum transport coefficients of the QGP). We have also gained completely new insights in the LHC era (e.g., the discovery of the smooth evolution of strangeness enhancement from low-multiplicity pp to high-multiplicity Pb–Pb events). Also, the production of J/Ψ mesons ($c\bar{c}$), for which a suppression relative to the expectation from scaled pp collisions was measured at SPS and RHIC due to melting of this state in the quark gluon plasma, is less suppressed at the LHC at low momenta. This suggests “regeneration” of J/Ψ mesons by formation via coalescence of independently produced charm and anticharm quarks.

The ongoing upgrades shall allow us to profit from the improved LHC performance and collect 50 to 100 times more collisions during the upcoming Runs 3 (2022–2024) and 4 (2027–2030). They comprise the new Inner Tracking System (ITS) and Muon Forward Tracker (both based on Monolithic Active Pixel Sensors), new readout chambers based on Gas Electron Multiplier foils for the Time Projection Chamber, and the new Fast Interaction Trigger detectors. In addition, all existing detector systems have been upgraded to provide a larger readout rate, with the core detectors being operated in continuous readout. A dedicated compute farm consisting of ~ 250 many-core nodes with 8 GPUs each is being commissioned for data acquisition and synchronous reconstruction of the collected events with a completely overhauled software stack (O^2).

The vastly improved pointing resolution of the upgraded ITS makes

it possible to reconstruct the decays of charmed mesons at low momenta. This is essential to determine the total charm quark production cross-section, which is a fundamental ingredient to understand the interplay between initial state production and energy loss effects in the QGP. Moreover, the new detector system will enable us to analyze a larger number of different hadron species containing heavy charm and beauty quarks, including charmed baryons, to further disentangle hadronization effects from initial state and parton energy loss effects.

The upgrades will also provide more precision for measurements of electron–positron pairs, which are produced as thermal radiation throughout the time evolution of the collision system and provide a unique window on the temperature of the Quark Gluon Plasma before hadronization. Electron–positron pairs also provide an important tool to study imprints of chiral symmetry restoration on resonances decaying to di-electrons. These two fundamental measurements have so far been out of reach due to the small production cross-section and the large combinatorial background. The larger data samples together with the light construction and improved vertex resolution of the new ITS will make it possible to see these signals.

Future Upgrades for LHC Run 4

In parallel to the installation and commissioning of the upgraded systems for Run 3, preparations for further detector upgrades in the next Long Shutdown (2025–2027) are ongoing. A research and development (R&D) program has been started to

develop a novel system of wafer-scale silicon sensors thinned to less than $50\ \mu\text{m}$ that can be bent to form truly cylindrical tracking layers to replace the inner layers of the ITS (see Figure 2). The program also aims to reduce power consumption to the point where air cooling can be used to further reduce the material budget to approximately 0.05% of a radiation length per layer. This is of particular importance to minimize the impact of conversions in the detector material on dielectron measurements. Together with the reduced radius of the first layer to $\sim 18\ \text{mm}$, this also results in a significant improvement of the vertexing capabilities.

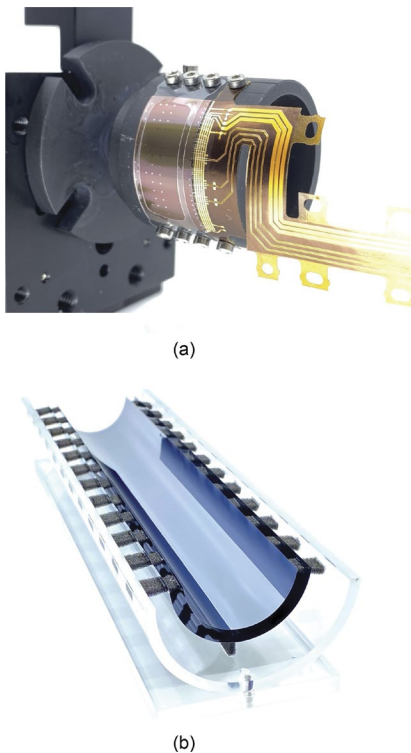


Figure 2. A prototype for the ITS3 used to demonstrate the operation of bent silicon sensors with no loss in performance. (top) and an engineering model used to demonstrate the mechanical construction using large wafers (bottom).

A second major upgrade planned for Long Shutdown 3 is the Forward Calorimeter (FoCal) which consists of an electromagnetic sampling calorimeter with high granularity silicon pad and pixel sensors and a conventional hadronic calorimeter. This detector provides excellent two-shower separation for the reconstruction of neutral pion decays and the identification of direct photons in pp and p-Pb collisions, which directly probe the gluon density in protons and nuclei down to a very small momentum fraction, $x \sim 10^{-5}$.

ALICE 3 for LHC Run 5 and Beyond

Even with Runs 3 and 4, several key measurements (e.g., the production of multicharmed baryon, elliptic flow of electron-positron pairs, and photon production at very low momentum, will remain out of experimental reach. A next-generation heavy-ion experiment [1] has been proposed with the goal to provide excellent electron identification and secondary vertex finding, as well as high reconstruction efficiency down to extremely low momenta and to collect data samples sig-

nificantly larger than those from Runs 3 and 4. Additional studies are currently ongoing to prepare a more complete proposal (Letter of Intent) for this experiment, ALICE 3, to be installed at the LHC Interaction Point 2 during the LHC Long Shutdown 4 (~ 2031).

One of the goals of this experiment will be to obtain new insights in the production mechanism of charmed hadrons by measuring production rates of multiply charmed baryons as well as other exotic hadrons. Charm quarks are produced in charm-anticharm pairs by initial hard scatterings of incoming partons from the colliding nuclei. Most charm quarks end up in single-charmed mesons and baryons, with only a small fraction binding together into J/Ψ mesons. While J/Ψ mesons can be produced from a $c\bar{c}$ pair produced in a single hard scattering, multiply charmed baryons provide a unique sensitivity to the recombination of charm quarks from independent production processes. This process is expected to lead to a large enhancement in their production in heavy-ion collisions w.r.t. proton-proton collisions. This will allow us for the first time to test the

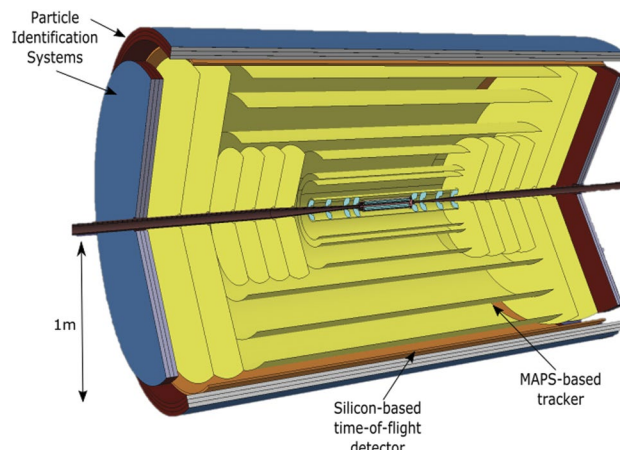


Figure 3. A next-generation experiment (ALICE 3) with an all-silicon tracker and various detectors for particle identification is proposed for a heavy-ion program for LHC Run 5 and beyond.

statistical hadronization model and coalescence models for particles containing multiple charm quarks (see Figure 4).

While hadron production is mostly determined by relatively late times in the collision evolution, photons and di-leptons provide a unique sensitivity to the early QGP stages of the collisions, since they couple directly to quarks and escape the collision without being affected by the strong interaction. To illustrate the potential of di-electron measurements at the LHC, Figure 5 shows the expected di-electron mass distribution in heavy-ion collisions at the LHC [2]. Two distinct processes are shown in the figure: thermal production from the plasma (orange dashed line) and hadronic production via vector mesons (blue dash-dotted line). The hadronic production channels are sensitive to chiral symmetry restoration; this is seen in the figure by comparing the blue dash-dotted and green lines. The purple line shows the expected total di-lepton mass spectrum. The momentum dependence of these spectra provide crucial information to further disentangle the various effects and to access the time dependence of the temperature. In addition, elliptic flow measurements will be used to fur-

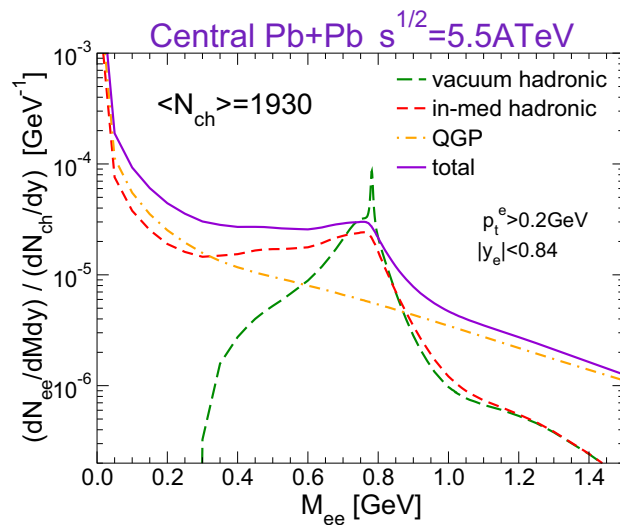


Figure 5. Predicted mass distribution for electron–positron pairs produced in heavy-ion collisions at the LHC. The different contributions by thermal emission from the Quark Gluon Plasma (orange dash-dotted line) and in-medium hadron decays (red dashed line) are shown separately and compared to hadron decays without medium effects (green dashed line) [2]. Figure used with permission.

ther understand the time evolution of these processes.

Another intriguing opportunity arises from the detection of ultra-soft photons with transverse momenta of the order of 10 MeV/c. In quantum field theories, the production of these soft photons is linked to the charged final state through fundamental “soft theorems.” Studying photon production in this regime requires a detector

setup that is specifically designed to detect low-energy photons and reject the potentially large background of photons that are produced in detector material. A dedicated forward conversion tracker concept is being studied for this purpose.

Besides these topics, an advanced heavy ion detector experiment that collects very large samples of heavy-ion collisions will allow us to push the boundaries in a number of areas, for example, by measuring correlated charm–anticharm pairs and photon–charm pairs at moderate and high transverse momenta to study collisional and radiative medium interactions, the production of nuclei and resonances to study final state interactions, correlations of hadrons to study interactions between unstable hadrons, and even the use of produced particles to determine, for example, the life time and binding energy of hypernuclei and more exotic bound states. In addition, the combination of increased luminosity and detector performance will also enable us to pursue searches

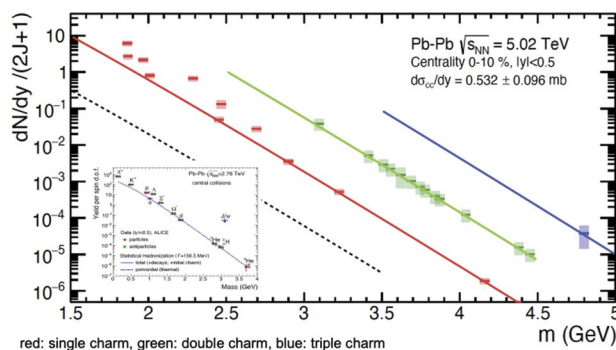


Figure 4. Yields of charmed baryons as predicted by the statistical hadronization model [4]. A clear hierarchy of yields is visible for particles with one (red points and line), two (green), and three charm quarks.

for new physics (e.g., previous limits on dark photons could be significantly improved).

In order to gain experimental access to these physics questions, a high-rate experiment with good tracking, excellent decay vertex resolution, and particle identification capabilities is needed. Because the expected intensities of Pb beams in the LHC are limited, collisions of lighter ions are considered to increase the nucleon–nucleon luminosity. Based on the technological advances for silicon pixel sensors, we plan an all-silicon tracker with unprecedentedly small material budget. A combination of cylindrical detection layers with forward/backward disks makes it possible to cover a large pseudo-rapidity range (Figure 3). In order to achieve the best possible impact parameter resolution for decay vertex reconstruction, it is fundamental to have a first measurement as close as possible to the interaction point. A retractable inner tracker system within the beampipe with the first layer at a radial distance of about 5 mm is being explored for this purpose. The outer tracker, also based on silicon pixel sensors, provides a transverse momentum resolution of $\sim 2\%$ as well as the ability

to reconstruct strange baryons that are the decay products of some charmed baryon states.

For particle identification, we foresee silicon-based detectors for time-of-flight measurements, using both a dedicated timing layer and time measurements in the tracking layers. To extend the particle identification capabilities to higher p_T , a Ring Imaging Cherenkov detector based on a combination of aerogel and single photon efficient sensors. As an alternative approach to extend electron identification to transverse momenta of a few GeV/c and beyond, a preshower detector (passive conversion layers and silicon pixel sensors) is investigated. For the measurement of photons with very low transverse momenta, a dedicated conversion tracker could be installed in the forward region ($\eta \sim 4$) to benefit from the longitudinal boost.

The proposed experiment opens unprecedented physics opportunities with a continued heavy-ion program in LHC Runs 5 and beyond. For a more detailed overview of the physics program, the results of performance studies and the detector concept, the reader is referred to the presentations

of the ALICE 3 workshop that took place on October 18 and 19, 2021 [5].

References

1. D. Adamová et al., arXiv:1902.01211.
2. R. Rapp, *Adv. High Energy Phys.* 2013 (2013) 148253.
3. H. van Hees and R. Rapp, *Nucl. Phys. A* 806 (2008) 339.
4. P. Braun-Munzinger and J. Stachel, *JHEP* 07 (2021)035.
5. <https://indico.cern.ch/e/alice3>



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