2.3 ALICE
Relativistic Heavy-Ion Physics

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One of the most remarkable predictions of the Standard Model of particle physics is that, at sufficiently high densities and temperatures, the protons and neutrons of ordinary matter should melt into a plasma where the quark and gluon degrees of freedom are not anymore confined. This hot and dense primordial state of matter, the Quark Gluon Plasma (QGP), is believed to have existed in the expanding universe up to a few microseconds after the Big Bang, when the phase transition to hadronic matter of confined quarks and gluons took place. At the LHC, by colliding Pb ions at high energies, conditions similar to those in the very early evolution of the universe are reproduced. The main goal of ALICE is to determine the properties of matter under such extreme conditions, and to improve our current understanding of the phenomenon of confinement and the generation of mass by the strong interaction.

Flow studies in Pb–Pb collisions

In ultra-relativistic heavy-ion collisions at the LHC more than 1000 particles can be produced per unit of rapidity. These particles move collectively under the influence of a common velocity field induced by the rapid expansion of the system. A very interesting feature of the collective motion is its anisotropy, originating from the almond-shaped region of the colliding nuclei and the initial inhomogeneities of the system density. These are transformed, through interactions between the produced particles, into an anisotropy in momentum space. This transformation depends on the ratio of shear viscosity over entropy (η/s), which quantifies the friction of the created matter. The resulting anisotropy in particle production can be quantified by a Fourier analysis of the azimuthal distribution relative to the system's symmetry plane, characterised by the Fourier coefficients v_n. The second harmonic, v_2 is known as the elliptic flow coefficient. Elliptic flow studies at the Relativistic Heavy Ion Collider (RHIC) and at the LHC contributed to the astonishing realisation that the hot and dense matter created in ultra-relativistic heavy-ion collisions acts as a system whose value of the shear viscosity to entropy density ratio η/s is very close to the lower bound of $\hbar/4\pi\, k_B$ conjectured based on the anti-de Sitter/conformal field theory duality (AdS/CFT). In other words, it behaves as a nearly perfect liquid.

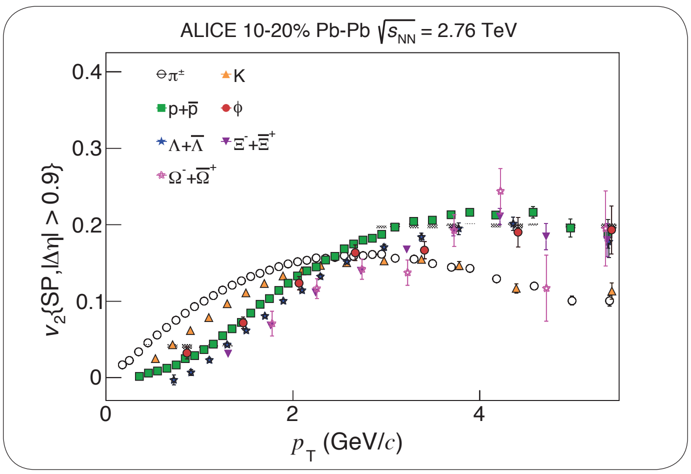

Figure 1. The p_T-differential v_2 for different particle species for the 10–20% centrality interval of Pb–Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV.

Fig. 1 illustrates how v_2 develops for different particle species within the same centrality interval in central Pb–Pb collisions. A clear mass ordering is seen in the low p_T region (*i.e.* $p_T < 2$ GeV/c), which is also evident for all centrality intervals . Comparisons to hydrodynamic calculations in this transverse momentum range indicate that the produced matter at the LHC seems to favour a value of η/s smaller than two times the quantum mechanical limit.

Detector upgrade

Despite the success of ALICE, after only two and three years of Pb–Pb and pp running, respectively, and one p–Pb run, there are several frontiers, including high precision measurements of rare probes over a broad range of transverse momenta, for which the current experimental setup is not fully optimised. ALICE is therefore preparing a major upgrade of its apparatus, planned for installation in the second long LHC shutdown (LS2) in the years 2018–2019.

At this moment the main particle tracking device in the ALICE experiment is limited to a readout rate of approximately 500 Hz for Pb–Pb collisions. The ALICE upgrade will modify the detector such that it will be able to record all Pb–Pb interactions (50 kHz) that the LHC is expected to deliver. Besides a two orders of magnitude increase in data collection speed a new, high-resolution, low-material thickness Inner Tracking System (ITS) will improve the tracking precision significantly and allow the full reconstruction of beauty mesons and the Λ_c baryon, which cannot be separated from background with the current set-up. The improved tracking system will be positioned closer to the interaction point by reducing the diameter of the LHC beam pipe. This new detector, in combination with an upgraded Time Projection Chamber (TPC) and upgraded data acquisition, will allow us to collect about ten billion (10^{10}) lead-lead interactions in the period 2019–2021, two orders of magnitude more data than would be possible without the upgrade. Detailed simulation studies have shown that the improved resolution and significant increase in statistics will allow the ALICE experiment to address the main questions about heavy flavour thermalisation and in-medium energy loss.

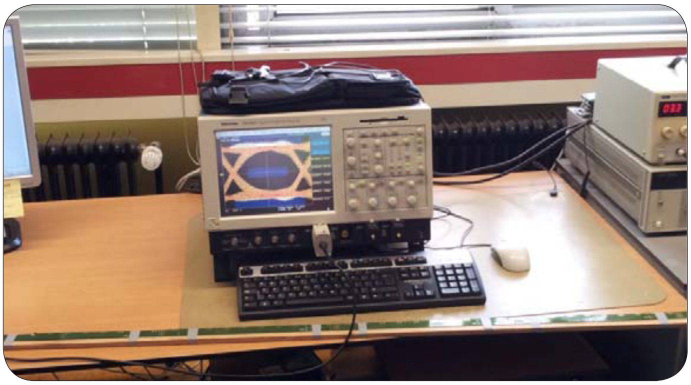

Figure 2. Test set-up for signal transmission tests

In 2013, Nikhef has joined the ALICE inner tracking system upgrade program. Nikhef will benefit from its experience gained with the design and production of the existing ITS to optimise the new system using modern technology. Only by integrating the power regulators into the sensor ASIC and by using a serial powering scheme the material used in the active volume can be reduced to the required amount. In addition, Nikhef is involved in the optimisation of the read-out chain. Due to the limited space available in the central part of the ALICE detector, the design of the data links in the pixel chip, the transmission of the signal through the signal lines on the front-end modules and in the long low mass cables to the data acquisition system are being studied in detail. During the production phase Nikhef will assemble a significant fraction of the detection staves for the two outer layers, using components produced in other laboratories, and assure the quality of the final product in accordance with the foreseen project leadership of Nikhef.

The group is also involved in R&D for a high granularity calorimeter, related to a potential further longterm (> 2023) upgrade of ALICE, to be used for the measurement of forward direct photons.

Outlook

The activities presented here are highlights of early results from ALICE in which the Nikhef group played a significant role. The group is also involved in more advanced topics and analyses using the same data sample. For the flow measurements, a next step is to study higher harmonics of identified hadrons, which are more sensitive to the vale of η/s and can help to constrain the initial conditions of a heavy ion collision.

In addition, the group is involved in several other correlation measurements that address different topics, such as the question whether parity symmetry is violated in strong interactions. Other correlation measurements, such as balance function measurements, may shed more light on the hadronisation dynamics.

In the area of penetrating probes and parton energy loss, the group will continue its strong role in heavy-flavour measurements, in measurements of the jet spectrum and modifications of jet fragmentation due to interactions with the medium, and in the measurement of real and virtual photons.

The upcoming pp and Pb–Pb runs in 2015 will provide the statistics to study in detail not only the intriguing phenomena that emerge in small systems related to the onset of collective effects, but also perform precision measurements while exploring parton energy loss and elliptic flow at higher transverse momentum.