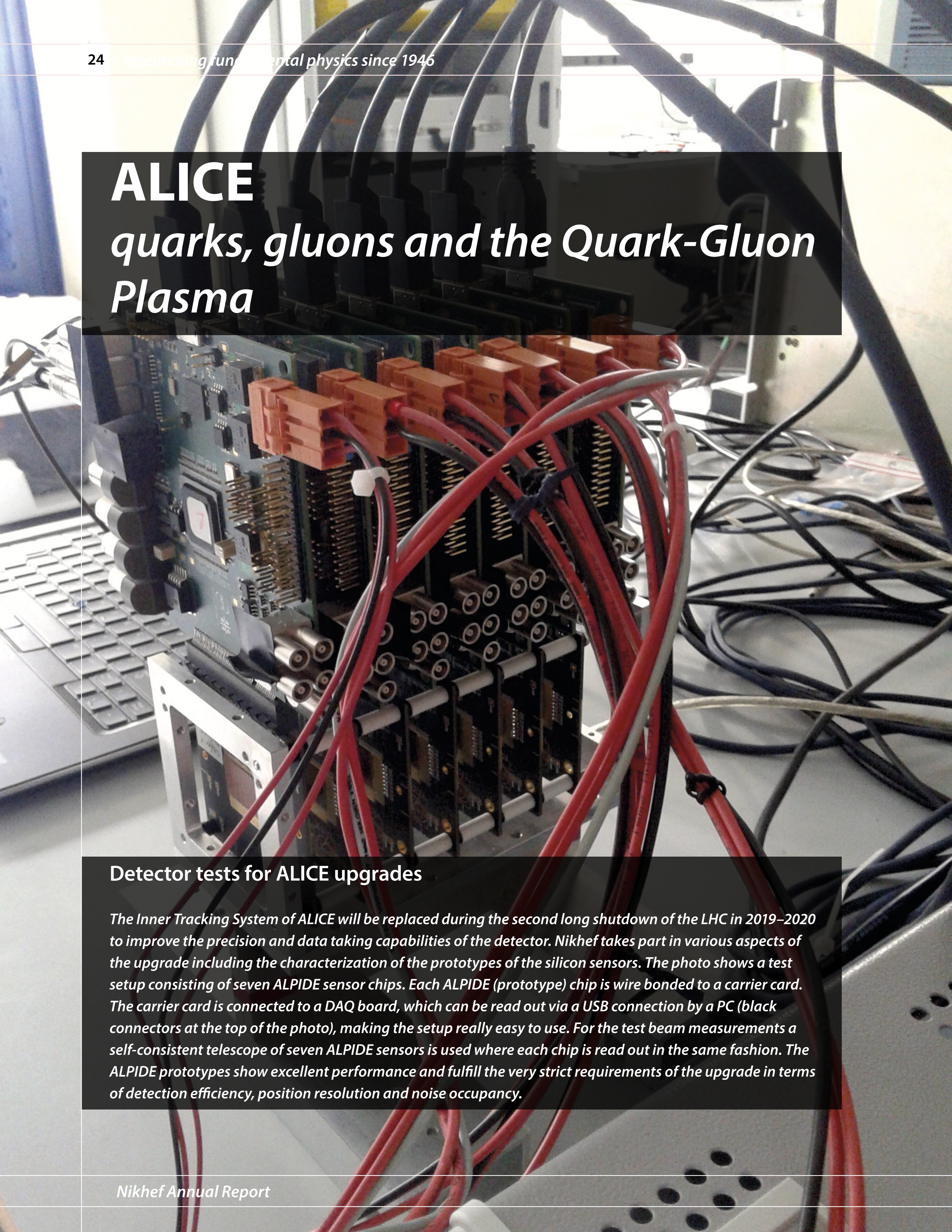


ALICE
quarks, gluons and the Quark-Gluon Plasma

Detector tests for ALICE upgrades

The Inner Tracking System of ALICE will be replaced during the second long shutdown of the LHC in 2019–2020 to improve the precision and data taking capabilities of the detector. Nikhef takes part in various aspects of the upgrade including the characterization of the prototypes of the silicon sensors. The photo shows a test setup consisting of seven ALPIDE sensor chips. Each ALPIDE (prototype) chip is wire bonded to a carrier card. The carrier card is connected to a DAQ board, which can be read out via a USB connection by a PC (black connectors at the top of the photo), making the setup really easy to use. For the test beam measurements a self-consistent telescope of seven ALPIDE sensors is used where each chip is read out in the same fashion. The ALPIDE prototypes show excellent performance and fulfill the very strict requirements of the upgrade in terms of detection efficiency, position resolution and noise occupancy.

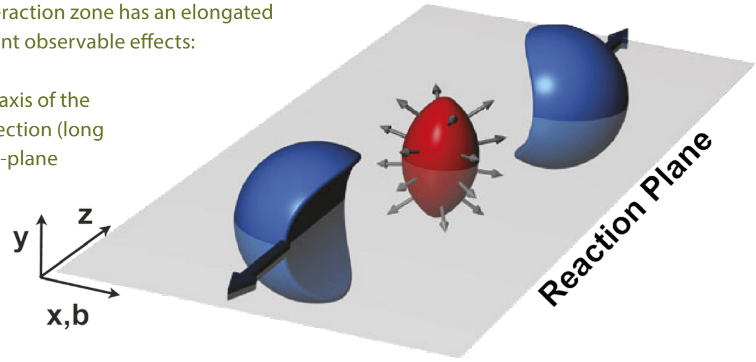


Figure 1. In non-central collisions of lead nuclei, the interaction zone has an elongated shape in the transverse (*xy*) plane. This has two important observable effects:

- The pressure gradient in the in-plane direction (short axis of the interaction zone) is larger than in the out-of-plane direction (long axis). This leads to larger expansion velocities in the in-plane direction, and hence more particles with a higher momentum.
- Produced particles that leave the interaction zone in the in-plane direction typically traverse a smaller amount of hot dense Quark-Gluon-Plasma and lose less energy by interactions, than particles that propagate in the out-of-plane direction.

Both effects lead to azimuthal asymmetries of the produced particles yields. The former effect (pressure gradients) is expected to be more important at low transverse momentum (pT) while the latter effect (the path length dependence of parton energy loss) is more important at large transverse momentum.

Management
prof.dr. R. Snellings

The ALICE group at Nikhef studies the strong interaction, which binds together quarks inside protons and neutrons, which are the constituents of the atomic nucleus. The strong interaction is quite different from the more familiar interactions like gravity and the electrostatic force. Maybe the most important difference is that the strong interaction has an effective range that is limited to about the size of a proton. Moreover, there is no simple formula for the dependence of the strong force on the distance, like the 1/r dependence for the electrostatic and gravitational forces, due to non-linear effects. The unusual properties of the strong interaction make it a very intriguing topic to study. The ALICE group studies the strong interaction in high-energy collisions of nuclei at the Large Hadron Collider (LHC). In such collisions, a very high density and a very high temperature (of order 10^{12} K) are reached and a so-called Quark-Gluon Plasma is formed in which quarks can travel over much larger volumes than the typical size of a nucleon.

In 2015, the ALICE group focused on completing a number of studies using the data collected in run 1 of the LHC, which took place from 2010 to 2013, after which LHC was shut down for almost two years for maintenance and upgrades. Several studies were completed, including measurements of azimuthal anisotropies with identified particles, which are indicative of the pressure that builds up inside the Quark-Gluon-Plasma and allow us to determine fundamental properties of the Quark-Gluon Plasma like the viscosity. A related topic is the azimuthal anisotropy of jet production (see Fig. 2), in which high-energy quarks and gluons, which fragment into jets, are used to probe the Quark-Gluon Plasma. The measured anisotropy in this case is related to the different path lengths for emission in different directions (see Fig. 1) and the resulting difference in energy loss due to interactions with the medium.

The ALICE group is also strongly involved in the study of heavy quarks, which are good probes of the Quark-Gluon Plasma, since they are produced at early times in the collision and are sensitive to the medium density and expansion velocity via interactions with the plasma.

The group was closely involved in a total of five papers on various topics regarding heavy quark production in proton-proton, proton-lead and lead-lead collisions in 2015. One of the PhD students (Deepa Thomas) received the 2015 ALICE Thesis Award for work in this area.

In 2015, the LHC accelerator was restarted after a break for maintenance and upgrades of almost two years (2013-2014). In November and December, the LHC provided collisions of lead nuclei at a new energy of 5.02 TeV per nucleon pair, almost twice the energy of the collisions that we have studied so far (2.76 TeV per nucleon pair). The first analyses of the new data sample with the higher energy have started, and new results will soon be published; it will be very interesting to see whether predictions based on the lower energy collisions will turn out to be accurate.

The 2015 ALICE Thesis Award went to Deepa Thomas.

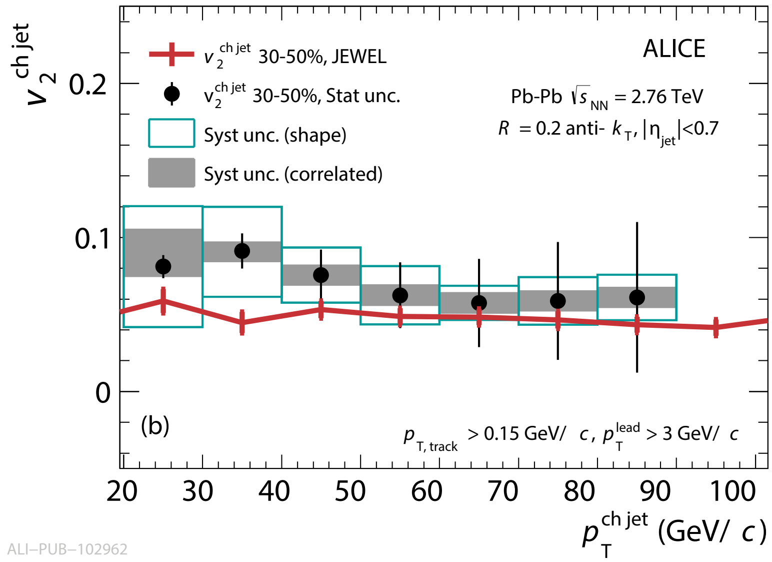
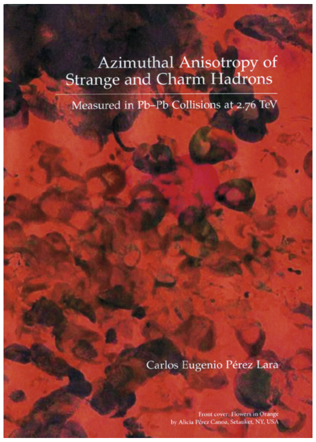
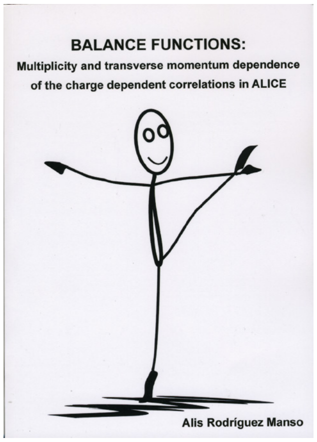


Figure 2. Azimuthal anisotropy coefficient v_2 for jet production in Pb+Pb collisions at the LHC as measured by ALICE. Different energy loss mechanisms have been proposed for energetic partons (quarks and gluons) that traverse the Quark Gluon Plasma, with different characteristic dependence on the path length through the plasma: linear for elastic energy loss, quadratic for radiative loss, and cubic for strong-interaction energy loss. The measured anisotropy v_2 is the (relative) difference between in-plane yield and the out-of-plane (see Fig 1) yield, which probes the path length dependence of the energy loss in the Quark-Gluon Plasma. The measurement shown here is the first measurement of jet v_2 for jets with relatively low $p_T < 50$ GeV, which are most sensitive to interactions with the Quark-Gluon Plasma. The experimental challenge is to distinguish the azimuthal anisotropy of jet production from the anisotropy in the underlying event; a new background subtraction technique has been developed to separate the two effects. The positive value of $v_2 \approx 0.1$ indicates that the high-energy quarks and gluons lose more energy when their path through the Quark-Gluon Plasma is longer. The red line shows the prediction of the JEWEL event generator, which includes a parton energy loss model and a realistic geometry of the collision zone. The measured effect is in agreement with the prediction, confirming that the energy is mostly radiative in nature, and has a quadratic path length dependence, due to quantum-mechanical interference effects. The current experimental uncertainties are still sizeable, and ALICE is upgrading its readout systems to collect larger data samples, which will significantly improve the uncertainties on the measurement, and provide more insight in the nature of energy loss in a Quark Gluon Plasma.



Carlos Eugenio Perez Lara
27 August 2015



Alis Rodriguez Manso
25 November 2015

Grants

Vici Grant
Andre Mischke

NWO granted **Andre Mischke** a Vici grant for his proposal *"Tomography of the Quark-Gluon Plasma - beauty quarks as a key probe"*. This form of grant is for senior researchers who have shown that they have the ability to successfully develop their own innovative lines of research and to act as coaches for young researchers.

> "After the Big Bang the young, evolving universe was in a quark-gluon plasma state. This research focuses on the study of the dynamics of this fundamental matter, that also – but just for a very short moment- occurs when laboratory atomic nuclei collide at very high energies."

Vidi Grant
Alessandro Grelli

Alessandro Grelli was awarded a Vidi grant for his proposal *"The hottest place in the Universe"*. The Vidi grants are aimed at young excellent researchers with several years of successful postdoctoral research experience to start their own research groups.

> "Atoms are accelerated up to almost the speed of light and then they collide. The heat developed during such collision is so intense that ordinary matter melts. As a consequence the same state of matter present in our Universe, a few fractions of a second after the Big Bang, is created. In the study its properties will be investigated by using heavy-quarks as a probe. "

FOM Projectruimte
Thomas Peitzmann

Thomas Peitzmann received a FOM *'projectruimte'* grant for his proposal *"Solving the direct photon puzzle in heavy-ion reactions with direct photon interferometry"*.

> "The measurement of the spectrum of thermal photon radiation is considered to be one of the 'holy grails' of heavy-ion physics. From this spectrum one expects to obtain the best estimates for the initial temperature of the hot quark-gluon plasma state studied in heavy-ion collisions at the LHC. Measurements at the RHIC accelerator reveal a very high temperature (exceeding 10^{12} K), however, the results are not fully understood theoretically – this situation is commonly referred to as the 'direct photon puzzle'. While there is thus considerable theoretical interest in these measurements, they are extremely challenging. The ALICE experiment has also performed similar measurements at the LHC, where the temperature is expected to be still higher, however the significance of the results is limited. In this project we will apply a new, very different method using the intensity interference of photons to measure the thermal photon spectrum and significantly reduce the current uncertainty."