PHYSICS OF THE ALICE EXPERIMENT

I. BELIKOV[a] for the ALICE Collaboration
Physics Department, CERN, CH-1211 Geneva 23, Switzerland

A short description of the ALICE detector at CERN is given. The experiment is aiming to study the properties of the quark-gluon plasma by means of a whole set of probes that can be subdivided into three classes: soft, heavy-flavour and high-p_t probes. Each of the classes is illustrated by a few typical examples.

1 Introduction

A Large Ion Collider Experiment (ALICE) [1] at CERN is a general-purpose heavy-ion experiment designed to study the physics of strongly interacting matter and the Quark-Gluon Plasma (QGP) in nucleus-nucleus collisions at the LHC. In addition to heavy systems, the ALICE Collaboration will study collisions of lower-mass ions, which are means of varying the energy density, and protons (both pp and pA), which primarily provide reference data for the nucleus–nucleus collisions. The pp data will also allow for a number of genuine pp physics studies.

The detector consists of a central part (see Fig. 1), which measures event-by-event hadrons, electrons and photons, and of a forward spectrometer to measure muons. The central part, which covers polar angles from 45° to 135° over the full azimuth, is embedded in the large L3 solenoidal magnet. It consists of: an Inner Tracking System (ITS) of high-resolution silicon detectors; a cylindrical Time-Projection Chamber (TPC); three particle identification arrays of: Time-Of-Flight (TOF) detector, Transition-Radiation Detector (TRD) and a single-arm ring imaging Cherenkov (HMPID); and a single-arm electromagnetic calorimeter (PHOS). The forward muon spectrometer (covering polar angles $180^\circ - \theta = 2^\circ$–$9^\circ$) consists of a complex arrangement of absorbers, a large dipole magnet, and fourteen planes of tracking and triggering chambers. Several smaller detectors for global event characterization and triggering are located at forward angles.

[a]On leave from JINR, Dubna, Russia

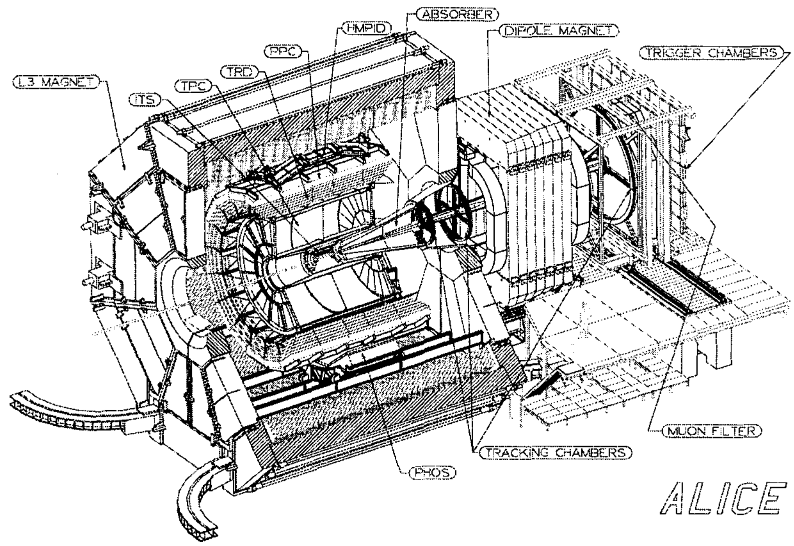

Figure 1: Schematic layout of the ALICE detector.

The detector is optimized for charged-particle density $dN_{ch}/dy = 4000$ and its performance is checked in detailed simulations up to $dN_{ch}/dy = 8000$. The track reconstruction efficiency in the acceptance of TPC is about 80% down to $p_t \sim 0.2$ GeV/c and about 90% for tracks with $p_t > 1$ GeV/c. It is limited only by the particle decays and small dead zones between the TPC sectors. Typical momentum resolution obtained with the magnetic field of 0.5 T is $\sim 1\%$ at $p_t \sim 1$ GeV/c and $\sim 4\%$ at $p_t \sim 100$ GeV/c. The secondary vertices can be reconstructed with the precision better then 100 μm.

The detector has excellent PID capabilities. From $p \sim 0.1$ GeV/c to a few GeV/c the charged particles are identified by combining the PID information provided by ITS, TPC, TRD, TOF and HMPID. Statistically, the charged particles can be identified up to a few tens GeV/c using the relativistic rise of dE/dx in TPC. Electrons above 1 GeV/c are identified by TRD, and muons are registered by the muon spectrometer.

2 Probing the QGP

The properties of the QGP state can be studied by means of many observables. In ALICE, the QGP observables (probes) are traditionally subdivided into three classes: soft probes (with the typical momenta $p \leq 1$ GeV/c), heavy-flavour probes (i.e. using the particles having c- and b-quarks) and high-p_t probes (in the momentum range above several tens GeV/c). Below we give a few examples of the planned observations belonging to each of these classes.

2.1 Soft QGP probes

ALICE will measure the charged-particle multiplicity and the charged-particle pseudo-rapidity distribution over almost 8 units of η by means of Forward Multiplicity Detector (FMD) and the innermost layers of ITS. The way the initial energy is redistributed over the particles in the final state is strictly linked with such an important thermodynamical quantity as the energy density ε reached in the early phase of the collision (see for example [2]).

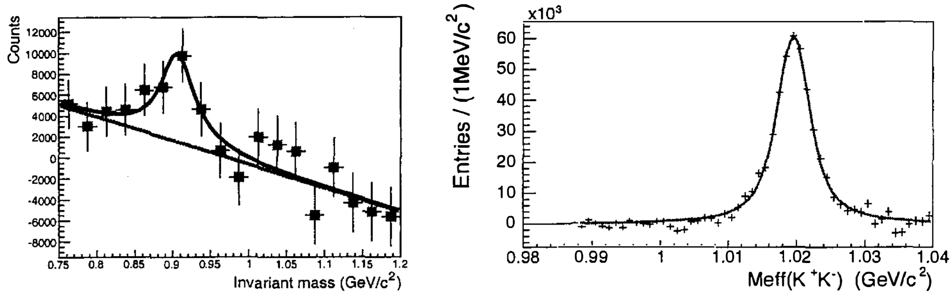

Figure 2: Background subtracted invariant-mass spectra of K*(890)^0 (left panel) and ϕ(1020) (right panel) reconstructed in simulated central Pb–Pb events.

Furthermore, the multiplicity information allows one to constrain the hadroproduction models. Thus, in the phenomenological approach [3], the measured pseudorapidity density $dN_{ch}/d\eta$ is expressed as the sum of a term proportional to the number of participants N_{part} (soft component) and the number of binary collisions N_{coll} (hard component). Measuring $dN_{ch}/d\eta$ as a function of N_{part}, one can estimate the relative number of particles produced in hard and soft scatterings.

Resonances with lifetimes comparable to that of the QGP phase (such as ρ^0, K*(890)^0, ϕ(1020)) may change their properties (mass, width) when they are produced in the dense medium. This may happen due to the final state interaction (which can be sorted out by comparing the results obtained in the hadronic and leptonic decay channels) or due to the partial chiral symmetry restoration. Detection of K*(890)^0 and ϕ(1020) is especially important because of the expected overall strangeness enhancement in heavy-ion collisions [4]. The ALICE detector will be able to register these resonances with sufficient statistics and the mass resolution of the order of a few MeV/c^2 (see Fig. 2).

2.2 Heavy-flavour QGP probes

When traversing the dense matter created in nucleus-nucleus collisions, the initially-produced hard partons lose energy mainly on account of medium-induced gluon radiation. The heavy quarks at intermediate p_t will lose less energy as compared with the light quarks at the same momenta due to the 'dead-cone' effect [5,6]. The ratio of the nuclear modification factor for D (and B) mesons to the one for the normal hadrons is thus suggested to be sensitive to the mass dependence of in-medium parton energy loss. The D mesons needed for these studies will be topologically reconstructed in central ALICE detectors, whereas B mesons can be detected in semi-leptonic decay channels.

Precise detection of the open charm (open beauty) is also need for the normalization of the quarkonia production. In nucleus-nucleus collisions, quarkonium suppression is expected to occur due to the Debye screening in the deconfined matter. Increase of the energy density reached in the collisions leads to break up of first the ψ' and χ_c, and finally the J/ψ. Such a suppression pattern was already observed at SPS [7]. However, at higher energies (RHIC, LHC) the situation becomes more complicated, because the charmonia can be regenerated in the hot medium by recombination.

ALICE will be able to measure the charmonia and bottomonia production both at mid-rapidity (in di-electron channels) and at forward rapidities (in di-muon channels). The statistics of registered Υ's is expected to be enough for the suppression studies. In this case, due to much higher mass, the influence of the regeneration will be negligible.

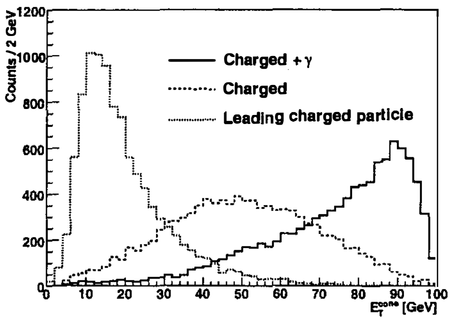

Figure 3: Spectra of reconstructed energy for simulated 100 GeV/c jets. The results for the charged leading particle, all charged particles, and all charged particles and gammas included in the analysis are shown.

2.3 High-p_t QGP probes

High-p_t partons produced in initial hard parton-parton scatterings fragment into jets. In the dense deconfined matter, prior to hadronisation, the partons undergo significant energy losses. The evidence of parton energy loss was observed at RICH as the suppression of high-p_t particles [8,9] and the suppression of back-to-back correlations [10].

Due to harder p_t spectrum of jets at LHC, and ALICE's exceptional tracking capabilities, the experiment will study the jet-jet kinematics with the precision unreachable in the leading-particle approach. Up to 50% of the energy of 100 GeV jet can be reconstructed with the ALICE detectors registering the charged particles only. When ALICE is upgraded with the Electro-Magnetic Calorimeter (EMCAL) [11], the fraction of reconstructed energy will increase even more (see Fig. 3). The EMCAL will also allow for effective triggering on the jets.

For the first time, the expected statistics of reconstructed jets will be enough for differential studies. For example, the k_t spectrum of particles belonging to a jet (k_t being the projection of particle momentum on the plane perpendicular to the jet axis) is predicted to be significantly broader, when jets are produced in dense medium [12]. The effect (especially the mean k_t and the high-k_t tail) is enough stable with respect to the cuts inevitably applied during the jet reconstruction.

Using the ALICE particle-identification capabilities, interesting observations can be also done with jets having identified particles, in particular, the jets initiated by the heavy quarks ('dead cone' related structures).

3 Conclusions

ALICE experiment at LHC is aiming to study the physics of strongly interacting matter at extreme energy densities, where a new state of matter, quark-gluon plasma, is expected to be reached.

The ALICE physics programme ranges from a precision measurements of the bulk of matter created in heavy-ion collisions, with typical momenta below 0.5 GeV/c, to heavy quark physics, quarkonia spectroscopy and jet measurements well above 100 GeV/c. Due to its excellent track, vertex-finding and particle-identification capabilities, ALICE will be able to study the properties of QGP by means of a whole set of different and complementary observables.

References

1. Eds. F. Carminati *et al.* [ALICE Collaboration], *J. Phys.* G **30**, 1517 (2004).
2. J. D. Bjorken, *Phys. Rev.* D **27**, 140 (1983).
3. D. E. Kharzeev and M. Nardi, *Phys. Lett.* B **507**, 121 (2001).
4. J. Rafelski and B. Muller, *Phys. Rev. Lett.* **48**, 1066 (1982).
5. Yu.L. Dokshitzer and D.E. Kharzeev, *Phys. Lett.* B **519**, 199 (2001). [arXiv:hep-ph/0106202].
6. N. Armesto, C.A. Salgado and U.A. Wiedemann, *Phys. Rev.* D **69**, 114003 (2004). [arXiv:hep-ph/0312106].
7. B. Alessandro *et al.* [NA50 Collaboration], *Eur. Phys. J.* C **39**, 335 (2005) and references therein. [arXiv:hep-ex/0412036].
8. K. Adcox *et al.* [PHENIX Collaboration], *Phys. Rev. Lett.* **88**, 022301 (2002).
9. C. Adler *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **89**, 202301 (2002).
10. C. Adler *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **90**, 082302 (2003).
11. ALICE Collaboration, CERN/LHCC 2006-014.
12. C. A. Salgado and U. A. Wiedemann, *Phys. Rev. Lett.* **93**, 042301 (2004).