THE HEAVY-ION PROGRAMME OF THE ALICE EXPERIMENT AT LHC

A. MASTROSERIO on behalf of the ALICE Collaboration
Universitá Degli Studi Di Bari and INFN (Bari)
Via E. Orabona 4, 70126 Bari, Italy

The ALICE experiment at LHC is mainly dedicated to heavy-ion physics. An overview of its performances, some predictions related to its first measurements and QGP observable measurements will be given.

1 Introduction

The heavy-ion programme of the ALICE experiment aims to study nuclear matter at extreme conditions as very high energy densities and temperatures. Lattice QCD calculations predict that above a critical temperature $T_c \sim 170$ MeV and a critical energy density $\epsilon_c \sim 1$ GeV/fm^3, the nuclear matter undergoes a phase transition to the Quark Gluon Plasma (QGP) state [1]. The heavy-ion programme at LHC will start with Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV where energy densities well above the critical value ϵ_c will be reached. Besides the phase transition, other phenomena like hadronic collective flow and new mechanisms at the hadronization stage (e.g.: quark coalescence) are also expected to occur. The ALICE experiment will investigate the features of strongly interacting matter in a new energy domain, hopely leading to unquestionable signatures of the QGP state. Its physics programme will cover many topics in different physics domains to cope with the study of a very complex system with many degrees of freedom. An important benchmark will be provided by pp collisions and also by smaller collision systems as pPb, dPb, αPb and lighter nuclei collisions (e.g.: Ar) [1].
In the next sections, an overview of the ALICE detector capabilities and predictions within first heavy-ion measurements will be given. Also some interesting QGP driven observables that can be measured in ALICE will be shown.

2 The ALICE experiment at the LHC

The ALICE set up consists of a central part and a forward part on one side for muon detection (Muon Arm). The former is inside a magnet, the L3 magnet, which can provide a solenoidal magnetic field between 0.2 T and 0.5 T. Smaller detectors are also present at very forward angles to measure global event characteristics. The tracking detectors, such as the Time Projection Chamber (TPC), the Inner Tracking System (ITS), the Time Of Flight detector (TOF) and the Transition Radiation Detector (TRD), are located in the central part and they have full azimuthal coverage and a pseudorapidity coverage $|\eta| < 0.9$. Inside the magnet there are also smaller acceptance detectors such as the High Momentum Particle Identification (HMPID, based on the Cherenkov detectors), which identifies charged hadrons between 1 - 5 GeV/c, a single arm electromagnetic calorimeter (PHOS) and a Photon Multiplicity Detector (PMD). Recently a new electromagnetic calorimeter (EMCAL), which will be located inside the L3 magnet, has been included in the ALICE experiment.

The detectors have been designed to provide tracking and particle identification capabilities to cope with a primary charged particle multiplicity in central Pb-Pb collisions up to dN/dy = 8000 at midrapidity. Studies performed at dN/dy=6000 have shown a very good momentum resolution, less than 0.8 % at $p_T < 2$ GeV/c up to 3 % at $p_T \sim 100$ GeV/c, with a resolution, on the distance of closest approach of the track to the interaction vertex (DCA resolution), which is better than 60 μm at $p_T > 1$ GeV/c. The ALICE charged particle identification capability allows to identify pions, kaons and protons on a track-by-track basis between 0.15-5 GeV/c (also up to 50 GeV/c in the relativistic rise) and electrons well above 1 GeV/c. Also strange particle detection (e.g.: Λ) and resonance identification (e.g.: $\rho(770)$ and $\phi(1020)$ mesons) have been studied in detail and an important result is that the measured resonance mass resolutions stays below few MeV/c^2.

3 Early measurements: multiplicity and hadron ratios

The very first measurement envisaged by the ALICE heavy-ion physics programme will be the charged particle multiplicity at midrapidity followed by its behaviour along the pseudorapidity range covered by ALICE. So far, different expectations at LHC energies have been predicted based either on models or on extrapolations of current measurements[1]. Nowadays, the expected value at midrapidity ranges between 1200[3] and 2900[4]. According to the Bjorken scenario[5], it is interesting to infer an estimate of the energy density within the nuclei overlapping region which should be reached at LHC energies. At the Relativistic Heavy ion Collider (RHIC), where Au Au collisions were delivered at $\sqrt{s_{NN}} = 200$ GeV), such energy density was measured as $\epsilon =$ 15 GeV/fm^3 [6]. Using the same Bjorken formula and assuming a formation time for the two incoming lead nuclei of the order of 0.2 fm/c, the energy density values at LHC are 3-5 bigger than at RHIC.

Another early measurement of ALICE will be the identified hadron relative abundances. A very successful model, the thermal model[8], shows that hadron ratios follow a statistical pattern within a large $\sqrt{s_{NN}}$ interval (2-200 GeV). The interacting system is considered as a grand canonical ensemble of hadron resonance gas and particles are formed at a *chemical freeze out* stage. The model depends on the temperature and the bariochemical potential and it predicts at LHC energies a chemical freeze out at the temperature $T_{ch} = 161 \pm 4$ MeV and at a bariochemical potential $\mu_{ch} = 0.8^{+1.2}_{0.6}$ MeV[4]. Despite the excellent description of the thermal model of hadron abundances, the dynamics which leads to the equilibrium is still not clear. A different approach to estimate hadron abundances is based on the assumption that the expected increase of strangeness in ultrarelativistic heavy-ion collisions could deviate from the grand canonical description[9]. Another model, the statistical hadronization model[10], has introduced the strangeness phase space occupancy $\gamma_s \neq 1$ (which implies a deviation from the equilibrium condition in the strange sector) to describe particle ratios. The model assumes a sudden hadronization with a $\gamma_s > 1$ which implies a super cooling effect on the system. Further studies show that if $3 < \gamma_s < 5$ the temperature at the freeze out varies respectively in the range $135 < T_c <$ 125[11]. Both multiplicity and relative hadron abundances will provide the first constraints on the models developed so far and also new insights on the mechanisms for particle production in ultrarelativistic heavy-ion collisions.

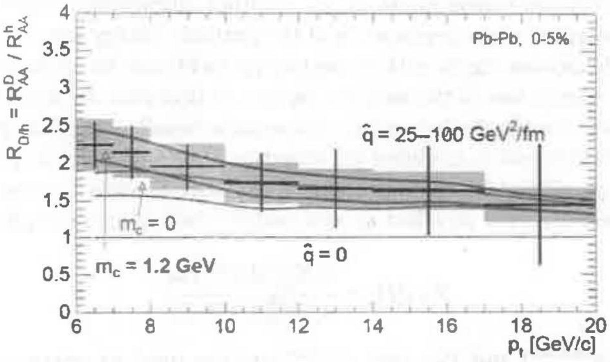

Figure 1: Heavy to light ratio for D^0 mesons and charged hadrons in most central Pb-Pb collisions within a q̂ interval 25-100 GeV/fm^3. The lines define the measured band corresponding to different charm masses. The error bars are the statistical errors, the shaded bands corresponds to the systematic errors. Both are related to the $m_c = 1.2$ GeV case.

4 R$_{AA}$: hadron sector and jet sector

The study of the inclusive hadron production is very important to probe the QGP via the parton energy loss dynamics in the medium. In particular, the nuclear modification factor R^h_{AA} characterizes medium induced effects. If h is an hadron specie, R^h_{AA} is defined as:

$$R^h_{AA}(p_T, \eta, centrality) = \frac{\frac{dN^{AA\to h}}{dp_T d\eta}}{< N^{AA}_{coll} > \frac{dN^{pp\to h}}{dp_T d\eta}} \qquad (1)$$

At a given collision centrality, it quantifies the ratio between the measured yield of the hadron h in AA collisions and its yield in pp collisions, scaled by the factor N^{AA}_{coll} which is the number of binary nucleon nucleon collisions at that specific centrality given by Glauber-type estimates. The formation of a new QCD medium implies that the produced hadrons come from hard scattered partons which traverse the medium before fragmenting in the vacuum. The deviation of the R_{AA} from unity is a signal of different dynamics of parton propagation in heavy-ion collision with respect to pp collisions. Its suppression factor as high as five in most central AuAu collisions at RHIC has indicated the formation of a dense medium where partons lose more energy than in normal nuclear matter. The medium induced energy loss is related to a medium dependent parameter, q̂ ([q̂]= GeV^2/fm), that represents the average squared transverse momentum transferred to a hard parton per unit path length during its multiple scatterings within the medium[2]. At LHC the kinematical accessible range will be wider than at RHIC and for light hadrons it is expected $R_{AA} = 0.1$ at $p_T < 20$ GeV/c followed by a slow rise up to 0.4 at $p_T < 400$ GeV/c[4, 12] due to the quark contribution. The color factor, infact, makes gluon loosing energy more rapidly than quarks.

Furthemore among quarks, the heavy quark gluon radiation in the medium is different from the others, in particular it should be smaller than the light quarks as a consequence of a mechanism known as the dead cone effect[13]. At the same parton energy the higher is the quark mass, the less is the radiated energy. Within this scenario, an interesting measurement aiming to probe parton dynamics in the medium is the heavy to light ratio, $R^{D/h}_{AA} = R^D_{AA}/R^h_{AA}$, which probes the *color charge* dependent energy loss. Figure 1[2] shows the ALICE sensitivity to this measurement at different values of q̂ and charm quark mass. Another interesting measurement is the $R_{AA}^{B/D}$ which can probe the *quark mass* dependence of the partonic energy loss.

The comparison of heavy-ion yields with respect to pp yields can be extended to the jet physics domain. Due to the energy loss in the medium, in fact, in heavy-ion collision the initial energy of fast partons is degraded in the medium with a subsequent broadening of the parton shower along the fast parton direction and a modified jet structure: the soft particle yield should increase whereas its high p_T particle yield would decrease[14]. In ALICE, event by event jet reconstruction is feasible and to quantify such an effect an observable which is under study is $R_{AA}(\xi)$, defined as:

$$R_{AA}(\xi) = \frac{1/N_{jet}^{AA} dN^{AA}/d\xi}{1/N_{jet}^{pp} dN^{pp}/d\xi} \tag{2}$$

where $\xi = ln(E_{jet}/p^{hadron})$ and E_{jet} and p^{hadron} are the total jet energy and the jet hadron momentum respectively. This value would differ from unity in case of medium formation. Ongoing studies on reconstructed jets in ALICE (also with the introduction of the EMCAL) show the expected reduction of $R_{AA}(\xi)$ at low ξ (fast hadrons) and its increase at higher ξ where the influence of systematic errors due to the background source is relevant.

5 Conclusions

The ALICE heavy-ion program at LHC energies will be devoted to understand hadronic matter at extreme conditions and the formation of the QGP state. Only a few topics have been discussed as first measurement expectation values and some interesting observables strictly related to the partonic energy loss in a deconfined medium as the nuclear modification factor R_{AA} for light flavoured hadrons, the heavy to light ratio $R_{AA}^{D/h}$ and its extension to the jet physics domain with the observable $R_{AA}(\xi)$.

The ALICE configuration at the LHC start up in Summer 2008 will consist of fully operating ITS, TPC, TOF, HMPID, Muon Arm, and triggering detectors and partially installed TRD, PHOS, PMD detectors.

References

1. ALICE: Physics Performance Report, Volume I. J. Phys. G: Nucl. Part. Phys. 30 (2004) 15171763
2. ALICE: Physics Performance Report, Volume II. J. Phys. G: Nucl. Part. Phys. 32 (2006) 12952040
3. K. J. Eskola, H. Honkanen, H. Niemi, P. V. Ruuskanen, S. S. Rasanen. Phys. Rev. C 72: 044904, 2005
4. N. Armesto et al. J. Phys. G 35 : 054001, 2008
5. J. D. Bjorken, Phys. Rev. D 27 1983 (140)
6. PHENIX Collaboration (K. Adcox et al.). Nucl. Phys. A 757 : 184-283, 2005
7. Yuri L. Dokshitzer, D. E. Kharzeev. Phys. Lett. B 519 : 199-206, 2001
8. A. Andronic, P. Braun-Munzinger, J. Stachel. Nucl. Phys. A 772: 167-199, 2006
9. J. Letessier, J.Rafelski. Phys. Rev. C 73: 014902, 2006
10. J. Letessier, J. Rafelski. Eur. Phys. J. A 35: 221-242, 2008
11. B. Hippolyte. Eur. Phys. J. C 49: 121-124, 2007
12. N. Borghini, U. A. Wiedemann. J. Phys. G 35: 023001, 2008
13. Yuri L. Dokshitzer, D.E. Kharzeev. Phys. Lett. B 519:199-206,2001
14. N. Borghini, U. A. Wiedemann. ePrint: hep-ph/0506218