HEAVY ION PHYSICS AT LHC

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The study of heavy ion interactions constitutes an important part of the experimental program outlined for the Large Hadron Collider under construction at CERN and expected to be operational by 2006. ALICE [1] is the single detector having the capabilities to explore at the same time most of the characteristics of high energy heavy ion interactions. Specific studies of jet quenching and quarkonia production, essentially related to μ detection are also planned by CMS [2].

1 Introduction

The main goal of ultrarelativistic heavy ion collisions is to study the thermodynamics of strongly interacting plasma of quarks and gluons. At high energy densities, QCD calculations predict a deconfinement of quark and gluons resulting in a new state of matter: the Quark Gluon Plasma (QGP). Recent lattice calculations [3] show that for a system of vanishing baryonic density, the transition temperature between the confined hadron and the parton phases is $T_c \sim 150$ - 200 MeV and the critical energy density ε_c of the order 1 - 3 GeV/fm^3. Furthermore the transition is expected to be accompanied by the restoration of the chiral symmetry of the QCD interactions, spontaneously broken at low energy density.

Relativistic Heavy Ion Collisions (HIC) offer an hitherto unprecedented possibility to investigate experimentally the QGP phase diagram. In fact, lead ion collisions at the LHC ($\sqrt{s} = 5.5$ A TeV) will allow exploration of a new domain in energy density, kinematic and dynamic conditions, typically an order of magnitude higher then what has been observed at SPS energies at CERN ($\sqrt{s} \sim 20$ A GeV) [4]. At the LHC the collision evolution will be governed by hard parton production due to concomitant increase of p-p total inelastic cross section and $A^{4/3}$ scaling in the collision of large nuclei with a shorter production time of the order of $\tau_h \simeq 0.1$ fm/c. Soft processes (hadronization) will be completed later, typically at $\tau_s \sim 1/\Lambda_{QCD} \sim 1.$ fm/c. Furthermore, as the system created by the initial collision will be dominated by gluons [5] (up to 80%) characterised by small $x = 2p_T/\sqrt{s}$, the baryon density in the central rapidity region will be substantially diluted.

2 The Observables

The system produced in a relativistic heavy ion collision (Pb-Pb) is extended and collective with a large volume ($\gg 1000 fm^3$) and a long lifetime (> 1 fm/c). Such a system can only be controlled as far as the initial parameters i.e. the ion mass and the collision energy. A posteriori events can be classified (triggered) according to the total multiplicity and energy observed at zero degree (c.m.s.) this being strongly correlated to the collision impact parameter. The study of the space-time evolution of the collision must, therefore, be inferred from the observables measured in the final state.

The strategy ALICE will adopt is to measure at the same time in the same detector global characteristics of the collision like multiplicity, forward and transverse energy as well as specific final state observables like hadron p_t distributions, particle ratios, strangeness production indicative of the expected phase transition and real and virtual photons, charmonium production, vector meson properties (mass) indicative of the QGP phase during the very first stage of the collision.

Some of the final state characteristics are controlled by the very first instance of the ion collision. This is the case for the direct photons, electron pairs, J/Ψ and open charm production.

Direct photons [6] originate from the quark-gluon phase, it is therefore expected that their momentum distribution is shaped by the thermodynamical state at the very early stage of the collision.

Electron pairs mass distributions show, as seen at the SPS, an interesting anomalous excess in the low mass region 250 to 700 MeV not observed in p-nucleus reactions. Suggestions vary from ρ meson mass broadening to modification of its mass due to the surrounding dense hadronic medium [7]. J/Ψ suppression [8] is considered a clear signal of the screening of the binding of $c\bar{c}$ formed by gluon fusion within the quark-gluon plasma.

Open charm [9] will mostly be produced in the early interaction stage (because of the heavy mass) and will survive to the final state.

The bulk of the particle in the final state will however derive from hadronic production occurring after the freeze out of the system. The signals are usually very strong to the point that some characters of the reactions can be studied on an event by event base where correlations and non statistical fluctuations are predicted for critical phenomena in a phase transition scenario.

3 ALICE

ALICE is a dedicated heavy ion detector aimed at the study of hadrons, leptons and photons produced in Pb-Pb collisions at the LHC. The detector is designed to cope with the highest particle multiplicity anticipated for Pb-Pb reactions at $\sqrt{s} = 5.5$ A TeV: $dN_{ch}/dy \sim 8000$. Lower mass ion collisions like Ca-Ca, as well as p-p and p-nucleus are also included in the LHC program as they will provide reference data and a way of varying the initial energy density.

The main components of the ALICE detector shown in fig. 1 consists of a central part embedded in the 0.2 (0.4) T field of the LEP L3 magnet, a dimuon detector, a forward multiplicity detector and a zero degree calorimeter in the forward region some 100 m from the interaction region. The central rapidity ($\pm$ 0.9) is instrumented with:

- The inner tracking system ITS, a high resolution silicon tracker consisting of 6 cylindrical layers (inner radius 4 cm and outer radius 44 cm) whose basic functions are the determination of the primary and secondary vertices necessary to study charm and hyperon decays, identification and tracking for low momentum particles ($\leq$ 100 MeV/c), improve the momentum and angle resolution of the TPC.

- The Time Projection Chamber (TPC), ALICE main tracking system with an inner radius of 90 cm, determined by the maximum sustainable hit density, and outer radius 250 cm determined by the minimum track length for a 10% dE/dx measurement.

- The particle identification complex consisting of a Transition Radiation Detector (TRD) to identify electrons with momentum greater then 1 GeV/c. A Time Of Flight (TOF) system consisting of 160K channels of multi gap RPC located at 3.5 meters radius with an intrinsic time resolution better then 100 ps. Complemented by two smaller coverage detector, the High Momentum Particle Identification Detector (HMPID), a proximity focus rich detector for high p_t particle identification and the Photon Spectrometer (PHOS) a $PBWO_4$ calorimeter capable to detect in a about 5% of the phase space of the central barrel γ's and high p_t neutral mesons.

The forward dimuon spectrometer arm covers η = 2.5 - 4. and consists of a composite absorber to stop most of the hadrons, photons and electrons. Muons trajectories bent by a 3 Tm magnetic dipole are then measured by 10 plane tracking system consisting of cathode pad chambers, and finally identified by four more detector planes located behind a second iron absorber. The set-up is completed by the forward multiplicity detector (FMD), a preshower detector with fine granularity and full azimuthal coverage in the pseudorapidity region $1.8 \leq \eta \leq 2.6$ and the forward electromagnetic and hadronic calorimeter, CASTOR, having full azimuthal coverage in the pseudorapidity region $5.6 \leq \eta \leq 7.2$.

4 CMS

The Compact Muon Solenoid detector is constructed around a large magnet (14 m long and 3 m radius) operated at a magnetic field of 4. T. The coverage of the central tracker (layers of silicon pixels and strips), electromagnetic and hadronic calorimeters followed by μ detector, relevant to the heavy ion physics run is $\pm$ 2.4 [10]. The good momentum resolution (p $\geq$ 3.5 GeV/c) and μ identification will be used to study:

i) Suppression within quark-antiquark resonances ($\Upsilon, \Upsilon', \Upsilon'', J/\Psi, \Psi'$).

ii) Z $\rightarrow$ $\mu^+ \mu^-$ production (jet tagging, reference for Υ suppression)

iii) Jet production: jet pairs, Z + jet, γ + jet, possibly a study of jet quenching.

5 Conclusions

ALICE covers in depth most of the experimental parameters relevant to the study of heavy ion collision at the LHC. The CMS detector will contribute to the study of jet quenching and quarkonia production.

References

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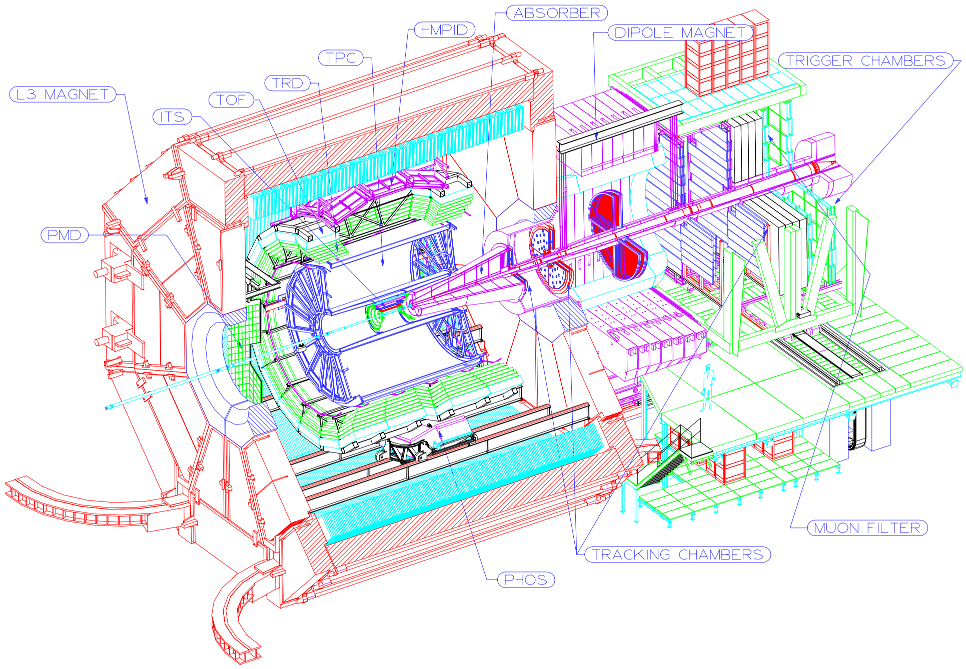

Figure 1. Artist view of the ALICE detector.

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