Hadron collisions at the LHC offer a unique opportunity to study strong interactions. The exciting data collected by the four RHIC experiments suggest that in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV, an equilibrated, strongly-coupled partonic system is formed. An extrapolation of the existing data toward LHC energies suggests that the heavy-ion program at the LHC is in a situation comparable to that of the high-energy program, where new discoveries near the TeV-scale are expected. Similarly, heavy-ion studies at the LHC are bound to either confirm the theoretical picture emerging from RHIC or challenge and extend our present understanding of strongly interacting matter at extreme densities. The experience at RHIC shows that the ideal detector for future heavy-ion studies should provide large acceptance for tracking and calorimetry, high granularity, high resolution and use fast detector technologies as well as sophisticated triggering. The CMS detector at the LHC excels in each of these categories.

1 Introduction

Heavy-ion collisions at the LHC will explore strongly interacting matter at higher densities, higher temperatures and longer lifetimes than ever before. The high collision energies at the LHC provide a new set of probes that are, at best, available with low statistics at presently accessible energies. Examples include very high $p_T$ jets and photons, Z bosons, the $\Upsilon$, D and B mesons and high-mass dileptons. These probes will provide new and quantitative diagnostic tools for the study of the dense matter produced in heavy-ion collisions.

2 The CMS Detector and Heavy-Ion Collisions

The discoveries in the first years of RHIC operation have not only transformed the current understanding of nuclear matter at extreme densities, but also greatly shifted the emphasis in the observables best suited for extracting the properties of the initial high-density QCD system.
Future studies of heavy-ion collisions and particle physics at very high luminosity accelerators require large acceptance, high rate and high resolution detectors. The following list illustrates the assets which make the CMS apparatus an ideal state-of-the-art heavy-ion detector.

1. **High Rate:** CMS is designed to deal with pp collisions at luminosities of up to $10^{34}$ cm$^{-2}$s$^{-1}$, corresponding to pp collision rates of 40 MHz. Accordingly, the fast detector technologies chosen for tracking (Si-pixels and strips), electromagnetic and hadronic calorimetry and muon identification will allow CMS to be read out with a minimum bias trigger at the full expected Pb+Pb luminosity. This fast readout will allow detailed inspection of every event in the high level trigger farm.

2. **High resolution and granularity:** The high granularity of the silicon pixel layers, in combination with the 4T magnetic field, gives a world best momentum resolution, $\Delta p_T/p_T < 1.5\%$ up to $p_T \approx 100$ GeV/c. At the same time, a track impact parameter resolution at the event vertex of less than 50 $\mu$m ($< 20 \mu$m at $p_T > 10$ GeV/c) is achieved. The calorimetry provides 16% jet energy resolution for 100 GeV jets with a background charged multiplicity of $dN/dy = 5000$. The ECAL spatial resolution in $\eta$ and $\phi$ is 0.028 and 0.032, correspondingly.

3. **Large acceptance tracking and calorimetry:** CMS offers high resolution tracking and calorimetry over a uniquely large range in pseudo rapidity ($\eta$) and $2\pi$ in azimuth ($\phi$). The acceptance of the tracking detectors, calorimeters and muon chambers can be seen in Fig. 1. In addition, CMS proposed the CASTOR Calorimeter and the T2 Silicon detector to extend the acceptance out to very large rapidity ($|\eta|$ up to 7).

4. **Particle identification:** At the LHC, charm and bottom quarks will be copiously produced. The large acceptance, high resolution muon system, in combination with the tagging of secondary decays by the silicon tracker, will provide the opportunity to study the interaction of not only identified hadrons, but also identified quarks with the medium. In addition, the physics of meson vs. baryon production at large $p_T$ can be studied using the results for reconstructed $\pi^0$s, as well as the information provided by the silicon tracker in combination with the electromagnetic and hadron calorimeters.
3 Physics Studies

The physics program of the Compact Muon Solenoid (CMS) encompasses many aspects of heavy ion physics. The evaluation of simulated data indicates that the CMS detector will be well suited for (i) event-by-event charged particle multiplicity and energy flow measurements as well as azimuthal asymmetry, (ii) production of quarkonia and heavy quarks, (iii) high $p_T$ particles and jets, including detailed studies of jet fragmentation, jet shapes and jet+jet, jet+$\gamma$ and jet+$Z$ correlations, (iv) energy flow measurements in the very forward region, including neutral and charged energy fluctuations, (v) studies of ultraperipheral collisions, (vi) comparison studies of pp, pA and AA collisions.

Quarkonia Physics

The study of the properties and yields of quarkonia is an important part of the LHC heavy-ion program. To date, CMS has focused on the detection of these resonances through their decays to muon pairs. The muon momentum resolution of the CMS detector translates into a $\Upsilon$ mass resolution of 50 MeV/$c^2$, which provides a clear separation between the $\Upsilon$ family members and a high signal-to-background ratio, as shown in Fig. 2. The yields are large, allowing studies of resonance production as functions of $p_T$, rapidity and centrality, with high statistics in a one month run.

Hadron yields and jet structure

Recent results from RHIC\textsuperscript{5,6} on the suppression of the hadron yields above $p_T \geq 3$ GeV/$c$, and the reduction of back-to-back hadron correlations based on the underlying nucleus-nucleus collisions\textsuperscript{9}, indicate a pronounced energy loss of fast partons. The absence of these effects in central dAu collisions suggests that the suppression is an effect of the dense medium created during the collision. Due to the large increase in the yield of high $p_T$ hadrons at the LHC, suppression studies can be extended to higher $p_T$ and to fully formed jets. In addition to the yield suppression, jet fragmentation and jet shape are expected to be modified by the presence of the hot medium. At the LHC, $10^7$ dijets with $E_T^{\text{jet}} > 100$ GeV are produced in $|\eta| < 2.6$ over a one month Pb+Pb run\textsuperscript{3}. The number of dijets is reduced by about a factor of two if only the barrel is considered, $|\eta| < 1.5$. High energy jets appear as localized energy deposits.
in the calorimeters. The jet energy and direction are reconstructed using an iterative cone type jet-finding algorithm modified to include background subtraction. The jet-finding efficiency and purity are shown in Fig. 3. Even jets with energies as low as 50 GeV can be reconstructed with good efficiency and low background using the calorimeters.

The CMS high resolution silicon tracker, together with its pixel detector, allows to reconstruct charged particles of $p_T > 1$ GeV/c with good efficiency, low levels of contamination and precise momentum reconstruction at the highest particle densities expected at the LHC. The $p_T$ distribution of particles reconstructed within an embedded 100 GeV jet with respect to jet axis is shown in Fig. 4. The presence of a plasma is expected to modify this distribution compared to jets produced in pp collisions.

The good performance of the CMS apparatus allows the study of jet quenching in dijet production. Ideal tests of direct jet energy loss arise from processes where a hard parton jet is tagged by an “unquenched” (i.e. not strongly interacting) particle such as a Z or γ. Given the known initial parton energy measured by the photon, it is possible to perform energy calibrated studies of the properties of the quark jets on the opposite side.

4 Summary

The CMS detector is a unique tool to study heavy ion collisions at the LHC. It probes hot matter through studies of $J/\psi$ and $\Upsilon$ production rates. Its excellent calorimetry and high resolution tracker provides large coverage and good energy resolution for jet quenching studies. These capabilities have been extensively simulated and evaluated. In addition, studies of its capabilities for event-by-event charged particle multiplicity, particle flow, and jet fragmentation indicate superb detector performance.

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