Heavy Ion Physics at RHIC and in CMS and the participation of the US nuclear physicists in CMS

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The field of relativistic heavy ion physics entered a new era with the start of the physics program at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, New York. This dedicated facility allows extensive studies of the nuclear matter phase diagram at the highest temperatures so far available in the laboratory. The goal of the program is to conclusively establish the existence of the deconfined state of nuclear matter predicted by QCD, the Quark Gluon Plasma (QGP), and study its properties.
First collisions were observed at RHIC in June 2000. In its first, rather brief, year, RHIC achieved 10% of design luminosity with Au+Au collisions at center of mass energy of 130 GeV per nucleon pair ($\sqrt{s_{NN}}$ =130 GeV), 65% of the design energy. A second run in 2001 was very successful achieving both full energy, $\sqrt{s_{NN}}$ =200 GeV, and design luminosity, 2 10^{26}cm^{-2}s^{-1}, ≈1400 minimum bias collisions/s. In addition the inaugural 200 GeV run of the polarized proton program to study the spin structure of the proton was also completed in 2002.
The initial data addressed the bulk properties of nuclear collisions that are amenable to study with low integrated luminosity: particle multiplicities, energy flow, transverse momentum spectra of several particle species, and azimuthal distributions of produced particles in non-central collisions. The four RHIC heavy ion experiments (BRAHMS, PHENIX, PHOBOS and STAR) have analyzed and published all or part of this data at 130 and 200 GeV.

Particle production at RHIC is characterized, as expected, by the very low net baryon density at midrapidity. The ratio $\overline{p}/p$ is about 0.75 (0.6) at 200 (130) GeV, implying that most of the initial nucleons are swept away to the fragmentation regions leaving the baryon content in the central region dominated by baryon-antibaryon pair production. The charged particle multiplicity is on the low side of the predicted range with N_{ch} ≈4900 in the most central collisions or $dN_{ch}/d\eta_{\eta=0}$ ≈650 at 200 GeV. Multiplicity increases gradually with energy, consistent with the absence of a first-order phase transition between confined hadrons and the QGP.

Some of the most striking early results involve collective motion of the produced particles. Asymmetries in the azimuthal particle distributions in peripheral collisions (elliptic flow) were larger than expected and different from a superposition of simultaneous nucleon-nucleon interactions. Detailed comparisons of these results to hydrodynamic models indicate very early near-equilibration of the hot matter.

The first relatively high p_T result at RHIC, a comparison of RHIC p_T spectra at 130 GeV with UA1 spectra from minimum bias 200 GeV $p\overline{p}$ collisions, also generated great excitement. The number of particles with p_T ≈2-4 GeV at RHIC is lower than expected from extrapolation of the UA1 data. This apparent suppression may indicate significant particle energy loss in a QGP, also known as jet quenching. The quenching effect may be confirmed in the next few months when the 2001 Au+Au data is compared with *pp* reference data, both at 200 GeV and in the same acceptance and detectors. The first charm data at RHIC, reported at 130 GeV, do not indicate any significant jet quenching for heavy quarks.

The QGP signal that generated the most excitement at the CERN SPS, J/ψ suppression, has yet to be reported at RHIC. The initial J/ψ results may be presented at Quark Matter 2002, the major conference of the field, to be held in Nantes, France in July, along with all the latest results at 200 GeV.

While RHIC program is expected to provide very detailed studies of Au+Au collisions at 200 GeV, the radius of the ring and the strength of its magnets limit its maximum energy. A significant increase in energy is only possible at the LHC. The energy increase will open new physics channels for heavy ion studies. Copious production of hard processes such as identified high p_T jets, Y, Z^0 and $W^{\pm}$ will only be possible at the LHC. Jet-jet jet-photon and jet Z^0 correlations can provide new insight in the high temperature properties of QCD.

The CMS detector, with its large acceptance calorimeters and muon spectrometers, together with its silicon tracker, has excellent capabilities to study the heavy ion phenomena new to the LHC. Interestingly, the relatively low particle multiplicity observed at RHIC may have practical consequences for CMS. If the multiplicity in heavy ion collisions is lower than originally expected ($dN_{ch}/d\eta_{\eta=0}$ 2000 rather than 8000), then the use of the full CMS tracker for high multiplicity ion collisions will be significantly simpler.

To explore the opportunities for US collaboration in heavy ion physics at the LHC and with CMS in particular, the 6th Workshop on Heavy Ion Physics with the CMS was held at the Massachusetts Institute of Technology on February 8 and 9. About 50 physicists from CMS and the US heavy ion community attended the workshop. The goal of the meeting was to review the current status of the field in view of the RHIC results and to explore US involvement in the LHC heavy ion program.
At the meeting, a group of seven US Universities: University of Illinois, Chicago; University of California, Davis; University of California, Riverside; University of Iowa; Rice University; Texas A&M; and MIT decided to submit a proposal to the Division of Nuclear Physics in the US Department of Energy on direct participation in the CMS heavy ion program. Our proposal focused on two specific areas: data acquisition and Zero Degree Calorimeters (ZDCs) to measure the forward energy flow. We would like to contribute to the preparation of the High Level Trigger since the algorithms used in the Filter Farms will have to be adapted to heavy ion physics.

We also proposed to construct two small ZDCs to measure forward neutrons traveling along the beam line unaffected by the accelerator magnets. The number of forward neutrons is proportional to the number of spectators and thus to the impact parameter of the collision. ZDCs are being successfully employed by all four RHIC experiments for this purpose. Particle multiplicity, total produced energy and the volume of the interaction region are functions of the impact parameter. The CMS ZDCs will be installed in the region where the single beam pipe separates into two, 141 m from the center of the detector.

The final acceptance of our proposal is contingent upon further evaluation and documentation of the capabilities of CMS as a heavy ion detector. In particular, the possibility of using the silicon tracker in the heavy ion collisions must be explored with full detector simulations. To fulfill these goals, we plan to work together with the existing heavy ion group in CMS to conduct these studies. We are confident that the simulations will prove that CMS is extremely robust for ion studies as well as *pp* collisions. We look forward to full participation in the CMS program.