A new phase of matter in Oakland

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Recent results from the Relativistic Heavy Ion Collider (RHIC) and the phase diagram of matter at very high energies were the focal points of Quark Matter 2004, held January 10-17, 2004 in the Oakland, California convention center. About 700 participants, including 125 students, from 28 countries gathered for 5 days of plenary and parallel sessions. Besides the scientific discussions, participants enjoyed an afternoon of excursions; choices included visits to San Francisco, the Muir woods, and, of course, a chance to sample Napa Valley wines. There was also a day of introductory lectures for graduate students and a separate afternoon program for 50 local high school teachers.

The "Quark Matter" conference series has evolved into the premier venue for relativistic heavy ion collisions, and QM2004 was no exception. The 44 plenary and 92 parallel session talks featured a veritable flood of data from STAR (Kai Schweda, LBNL), PHENIX (Tony Frawley, Florida State), PHOBOS (Peter Steinberg, BNL) and BRAHMS (Michael Murray, Kansas), at RHIC. This was accompanied by contributions from HERMES (Pasquale DiNezza, Frascati) and HERA-B (Joakim Spengler, Heidelberg) and continuing analyses from NA-49 (Marek Gazdzicki, Frankfurt) and NA-57 (Giuseppe Bruno, Bari) at the CERN SPS. The theoretical contributions presented a broad range of models and calculations, from microscopic particle-by-particle simulations to hydrodynamic models that model the bulk behavior using an equation of state.

A focus of much discussion was the question "Have we found the Quark Gluon Plasma (QGP)?" This search was the prime motivation to build RHIC. Although the RHIC experiments made no formal statement, most conference attendees seemed to feel that the answer was yes. No single measurement makes the case, but the variety of data featured at QM2004 seems most easily explained in the context of a QGP. Some of the signatures included the suppression of high transverse momentum (p_T) particles and, disappearance of back-to-back correlated high-p_T particles (showing that produced particles underwent very strong energy loss before escaping from the medium), the strong elliptical flow (showing that the pressure was very high early in the collision), and the species dependent elliptical flow (showing behavior as an almost perfect fluid, as expected for a QGP). Data on deuterium-gold collisions presented at QM2004 provided important cross-checks, ruling out models that explained the observed phenomena as initial-state effects present in the undisturbed gold nuclei. Many of these signatures were reviewed in the 5 rapporteur talks covering high-p_T and jets (Kirill Filimonov, LBNL), bulk properties and collective flow (Zhangbu Xu, BNL), correlations and HBT (Harald Appelhäuser, GSI), leptons, photons and heavy quarks (Ralf Averbeck, Stony Brook) and theory (Ralf Rapp, Texas A & M). In addition, Mike Lisa (Ohio State), Miklos Gyulassy (Colombia) and Peter Braun-Munzinger (GSI) gave their personal views on the QGP.

The fireballs produced in relativistic heavy ion collisions have an extremely short lifetime, so it is difficult to probe them directly. Many analyses relied on particles

produced early in the collisions to probe the matter produced in the collision. Early data from RHIC showed that the production of mesons with high transverse momenta (p_T) in central (head-on) heavy ion collisions was only about 20% of that expected from theoretical predictions based on perturbative QCD, and also compared to peripheral heavy ion collisions and proton-proton reactions. This suppression has been attributed to energy loss by the produced particles in the dense post-collision medium. The origin of this energy loss was much discussed; it appears to require very high densities which are not consistent with hadronic matter.

At high p_T, above 6 GeV/c, all types of final state particles show comparable suppression. However, at intermediate momenta ($2 < p_T < 5$ GeV/c), only mesons are suppressed; baryons are seemingly unaffected. The cause for this meson-baryon distinction prompted much discussion. In one class of models, hadrons are formed by recombination of already existing quarks. So, the baryons acquire momentum from 3 quarks, while the mesons come from 2 quarks. In this model, baryon production at intermediate momenta should be enhanced.

High p_T two-particle correlations were also on the QM2004 agenda. These correlations are expected from jets. In pp collisions, jets are created in pairs, usually back-to-back in azimuth. High p_T particles are therefore often either near other high p_T particles (from the same jet) or roughly back-to-back in azimuth (from the opposite jets). However, in central AA collisions, the back-to-back correlations are absent, while the same-side correlations remain. This disappearance may be due to a very dense, very strongly absorptive central region. Only particles produced near the surface of the system escape.

Other probes discussed at the conference included direct photons and J/ψ. The PHENIX collaboration has measured direct photons, i.e. photons not coming from hadron decays, in gold-gold collisions. The yield is well described by quantum chromodynamics. Although the RHIC statistics for J/ψ are still limited, this will clearly be a focus of future runs.

Final state particles from late in the collision were also discussed at QM2004. Presentations covered many different particle species, including several that have very short lifetimes. The particle abundances are generally well described by thermal models, where particle ratios depend on the particle mass and temperature.

Many presentations considered the overall event shape. The final-state anisotropies are due to the elliptical overlap region when two nuclei collide at moderate impact parameters. Pressure converts this spatial anisotropy into a momentum anisotropy. RHIC data show strong fluid-like behavior, as expected for a QGP. The apparent partonic nature of the interactions may be seen in the data on Λ and kaon flow: they are the same when scaled to the number of constituent quarks; an observation clearly favoring a partonic interpretation.

Many other correlation measurements were presented. The RHIC experiments have measured the system size via Hanbury-Brown Twiss (HBT) interferometry. They found

that the system is small, with a Gaussian radius of about 6 fm and a lifetime of 8-10 fm/c. This small size and short lifetime are difficult to reconcile with other observables..

The cold nuclear medium was also discussed. Considerable controvery arose over the possible existence of a new state of matter, known as the colored glass condensate (CGC). When gluon densities become very high, a CGC might form. It may be visible in protons in very high energy collisions, and in ions at somewhat lower energies. The existence of the CGC was hotly debated at QM2004; most attendees felt that more data were needed, along with more quantitative calculations.

RHIC has added photoproduction to its repertoire. A photon from the electromagnetic field of one nucleus can interact with the other. Unlike electron-nucleus reactions, in heavy-ion reactions photoproduction can occur at either of the two beam nuclei. The STAR collaboration has observed destructive interference between ρ^0 production at the two sites.

QM2004 also looked to the future. RHIC has plans for an extensive set of detector upgrades, and an electron cooling ring to increase the luminosity by a factor of 40. Members of the ALICE, CMS and ATLAS collaborations are all preparing for heavy ion collisions at the LHC.

The Proceedings of Quark Matter 2004 will appear in the Journal of Physics G. Transparencies from the talks are available on the conference website, qm2004.lbl.gov. Quark Matter 2005 will be August 1-6, 2005 in Budapest, Hungary.

Figure Caption

1 - The Oakland Convention Center exhibit hall provided a congenial place for posters and refreshments.