Title
SUMMARY OF THE RELATIVISTIC HEAVY ION SESSIONS

Author
Harris, J . W.

Publication Date
1988-07-01

LBL-25573 c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Presented at the 3rd Conference on the Intersections between Particle and Nuclear Physics, Rockport, ME, May 14–19, 1988

Summary of the Relativistic Heavy Ion Sessions

J.W. Harris

July 1988

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

SUMMARY OF THE RELATIVISTIC HEAVY ION SESSIONS

John W. Harris
Nuclear Science Division, Lawrence Berkeley Laboratory,
University of California, Berkeley, CA 94720, USA

The topics covered in the Relativistic Heavy Ion Sessions span 4 orders of magnitude in energy in the laboratory and a few more in theory. In the two years since the last Intersections conference, experiments in the field of very high energy heavy ion research have begun at CERN and Brookhaven. The prime motivation for these experiments is the possibility of forming *quark matter*. The formation of a quark-gluon plasma in very high energy collisions of nuclei is predicted to occur when the energy density in a collision increases above a critical value where the quark constituents of the incident nucleons, bound in nuclei, form an extended volume of freely interacting quarks, antiquarks and gluons. Recent lattice quantum chromodynamics calculations[1–3] predict a phase transition from a hadronic gas to a quark-gluon plasma at an energy density $\epsilon^{critical} \approx 2$ GeV/fm^3, and temperature $T^{critical} \approx$ 200-250 MeV. At lower energies progress continues towards understanding the behavior of *nuclear matter* in terms of the nuclear equation of state from the low baryon densities and temperatures of a possible liquid-gas phase transition through the densities and temperatures of stable and excited nuclei, neutron star formation and supernova explosions.

From among the various signatures predicted for the quark-gluon plasma, *suppression of J/ψ production* has received most of the recent attention. Matsui and Satz[4] predicted that screening of the quark color charge will prevent $c\bar{c}$ binding into a J/ψ in the deconfinement region. In hadron-hadron collisions $c\bar{c}$ pairs can be produced in either gg or $q\bar{q}$ interactions. However, if a plasma is formed in nucleus-nucleus collisions the $c\bar{c}$ will appear in a deconfining environment. In analogy to Debye screening in electrodynamics, if the Debye radius is less than the radius of the J/ψ at temperature T, then formation of the J/ψ is prohibited assuming the plasma lifetime is longer than the formation time of the J/ψ from $c\bar{c}$. Thus observation of J/ψ suppression in nucleus-nucleus interactions might signify formation of the plasma. The NA38 Collaboration[5] has reported preliminary finding of J/ψ suppression in high transverse energy ($E_\perp$) events, which are associated with small impact parameter collisions. Using a muon pair spectrometer with associated calorimetry the group observes a reduction in the J/ψ peak-to-continuum ratio of approximately 50 percent for high $E_\perp$ events. This is observed in 200 GeV/nucleon $^{16}O + U$ and $^{32}S + S$ collisions but not for p + U collisions. The group also sees no $E_\perp$ dependence of the continuum below the J/ψ. The J/ψ suppression is reported to occur for low transverse momentum pairs of $\mu^+\mu^-$ as predicted[6] for plasma formation. These results are very tantalizing, but the NA38 group states that the continuum below the J/ψ as measured by the experiment must still be understood before solid conclusions can be drawn. Furthermore, recent results[7] from Fermilab in 125 GeV/c $\bar{p}$ and π^- interactions on nuclear targets exhibit a similar suppression of the J/ψ. Much theoretical work is underway to quantitatively understand the J/ψ signal from the NA38 measurements. Recent theoretical efforts have concentrated on understanding the detailed evolution of the $c\bar{c}$ in a plasma[8] and hadron gas[9] as well as the role of nuclear absorption in the J/ψ signal.

Two pion interferometry measurements, which lend insight into the underlying collision dynamics have been performed by the NA35 Collaboration[10] at CERN. This interferometry technique was first proposed by Hanbury Brown and Twiss[11] to determine the size of distant stars by measuring the interference pattern of two photons. It is now used to measure the size of the pion-emitting source in high energy collisions of particles and nuclei. One approach[10] involves a Gaussian parameterisation of the pion-emitting source where R_T is the transverse radius, R_L the longitudinal radius and Λ the chaoticity parameter. When $\Lambda = 1$ the emission is totally chaotic. Values of $\Lambda < 1$ correspond to decreasing chaoticity, with $\Lambda = 0$ total coherence. Pions near midrapidity in the effective ^{16}O + Au center-of-mass are observed to originate from a large ($R_T = 8.1 \pm 1.6$ fm), almost spherical($R_L \approx R_T$), and chaotic (almost thermal) source ($\Lambda \approx 0.8$). Pions over the entire rapidity range of the collision reflect a much smaller source ($R_T = 4.1 \pm 0.4$fm), with much less chaoticity($\Lambda \approx 0.3$). This picture suggests the formation of a thermalised fireball at midrapidity. Away from midrapidity the transverse size is near that of the incident projectile, the longitudinal size is small reflecting a correlation length[12] of one unit of rapidity, and the chaoticity parameter is low, near that of e^+e^- and hadron-hadron collisions. Techniques have recently been suggested[13,14] to determine the effect of the lifetime of the source on the measured source sizes. Such measurements may even be sensitive to the expected increase in lifetime if a quark-gluon plasma were formed. The spacetime evolution of these collisions is of course quite complicated and will be the source of much interest and debate for some time to come.

Transverse energy ($E_\perp$) distributions reflect the degree to which the incident energy of the nuclei thermalises in the collision process, i.e. the "stopping power". Results from CERN ion experiments NA34,[15] NA35[16] and WA80[17] and from Brookhaven ion experiment E814[18] are consistent with a description of the central nucleus-nucleus $E_\perp$ distributions by an A_p-fold convolution of the proton-nucleus $E_\perp$ distributions, where A_p is the number of nucleons in the projectile. Most models which reproduce the proton-nucleus $E_\perp$ distributions and are extended to include the nucleus-nucleus collision geometry usually fit the measured nucleus-nucleus $E_\perp$ distributions. However, the models must also be able to predict the behavior of other observables in the collision process. Werner[19] has shown that string models are able to fit the $E_\perp$ and multiplicity distributions. Using a model based upon the formation and breakup of hadronic fireballs, Stachel[18] concludes that the $E_\perp$ distributions exhibit complete stopping of the ^{28}Si projectile incident on targets from Al to Pb at Brookhaven energies of $\approx$10 GeV/nucleon, whereas at the higher CERN energy of 200 GeV/nucleon the ^{16}O + Au data show only partial stopping of approximately 60 percent of the incident energy. The latter is consistent with previous estimates from various CERN experiments.[2] The incident energy where it is possible to convert the most energy of relative motion into energy density in the center-of-mass will be of most interest for studying the question of the existence of the quark-gluon plasma. Furthermore, this should be studied for the heaviest nuclear systems. If the $E_\perp$ distributions from current CERN experiments are translated into energy densities[20] using the Bjorken formula.[21], fairly large energy densities are reached with values at the extrema near those necessary for plasma formation.

Particle abundances and spectra are important to determining the flavor content and mean transverse momenta (temperatures) of the various constituents of the collisions. This information as a function of rapidity would provide a wealth of information on the dynamics of the collision process. Many of the results on particle abundances and spectra are preliminary due to the tremendous difficulty in tracking and particle identification at such high multiplicities and energies. Results from the NA34,[15] NA35,[22] and WA80[17] Collaborations show that the pion spectra in 200 GeV/n ^{16}O and ^{32}S -nucleus collisions are identical to those of proton-nucleus collisions at the same incident energy. This is not surprising since the pion spectra basically reflect conditions after hadronisation and freezeout. Direct photon or lepton spectra might provide information on the temperature at earlier stages of the collision process. However, preliminary results from NA34[15] on photon spectra show that there is little, if any, direct photon signal observed since the measured photon spectra are reproduced by emission from hadronic sources.

One of the earliest predictions for a signature of the deconfinement transition is an enhancement of s and $\bar{s}$ quarks in a quark-gluon plasma in thermal and chemical equilibrium.[23] The strangeness enhancement is a result of suppression of $u\bar{u}$ and $d\bar{d}$ pair production in favor of $s\bar{s}$ pairs in the initial u and d-rich environment remaining from the incident nuclei. Furthermore, the $\bar{u}$ and $\bar{d}$ quarks annihilate with u and d quarks, while the $\bar{s}s$ annihilation occurs less frequently until saturation of the s and $\bar{s}$ abundances. Most calculations predict a significant enhancement in the observed $\bar{s}$ yield as a signature of plasma formation while s quark yields, although enhanced, differ only slightly in a plasma compared to a hadron gas. The actual observation of $\bar{s}$ enhancement after plasma formation is severely complicated by the spacetime evolution of the collision process,[24] making it difficult to discriminate between the hadronisation products of a quark-gluon plasma and those of a chemically-equilibrated hadron gas. However, it is highly unlikely that hadronic processes in the nonplasma phase are best represented by an equilibrium hadron gas. Dynamical approaches have recently predicted[25,26] a separation of strangeness during the hadronisation process in a baryon-rich region. During the mixed phase, consisting of plasma and hadron gas and following the plasma phase, the hadron gas becomes $\bar{s}$-rich due to radiation-cooling from K^+ and K^0 emission. This leaves behind an s-enriched plasma and may manifest itself in the slopes of the observed K^+ and K^- spectra[27] as well as the possible production of strange droplets of matter.[28] Results on *strange particle production* are at a preliminary stage of analysis. The E802 group has reported[29] K^+/π^+ and K^-/π^- results for ^{28}Si + Au at 14.5 GeV/c per nucleon in a limited solid angle range. They find $K^+/\pi^+ = 19$ and 23 percent in peripheral and central interactions, respectively, with typical errors of $\pm$ 5 percent. These ratios are measured to be in the 5 to 10 percent range for proton-nucleus collisions in the same phase space region measured by the E802 experiment. The K^-/π^- ratios from E802 are found to be 5 percent for both types of interactions. The actual cross sections for strangeness production over a larger solid angle is anxiously being awaited. The NA35 Collaboration has reported[30] Λ, $\bar{\Lambda}$ and K^0 ratios for 60 and 200 GeV/n ^{16}O + Au and p + Au reactions. The ratios are similar for the the nucleus-nucleus and proton-nucleus cases, although both exhibit somewhat higher Λ production and slightly lower $\bar{\Lambda}$ production than observed in proton-proton studies.

The work at the Bevalac accelerator in Berkeley has centered around determining the *equation of state of nuclear matter* at high densities and temperatures although somewhat lower than those where the hadron gas to quark matter phase transition is predicted to occur. Progress in this field has been made in determining systematics of the observed collective sidewards flow[31,32] of matter in collisions of heavier systems ($A \geq 40$) at incident energies of 100 MeV/n to 2.1 GeV/n. The flow is observed to increase with the mass and energy of the incident system as well as the centrality of the collision. The data provide strong evidence for compression effects in these collisions and are best described by a stiff nuclear equation of state. This finding is also supported by recent measurements[33] of the entropy production and the transverse energy distributions in these collisions. Progress has been made on the theoretical side with the inclusion of the momentum dependence of the nuclear potential which has a large effect on these observables. It is imperative that microscopic calculations which include momentum dependent potentials be performed and compared to the large body of observables available in the data in order to better determine the equation of state. Experimental and theoretical work on dilepton production at Bevalac energies is also underway. It has been predicted[34] that dilepton production at these energies is very sensitive to the initial stage of the collisions as is the case at higher energies. The leptons escape the interacting nuclear matter with very little absorption or interaction in the surrounding matter. Thus the dilepton spectrum should be very sensitive to the temperature and density of the system at the time of their creation. This could provide an experimental handle on the actual densities and temperatures that are reached in the compressional stage of the collision process.[34]

The *narrow positron lines* first observed at the GSI in Darmstadt in collisions of very heavy ions just above the Coulomb barrier remain a focal point of much cross-disciplinary research. Some of the positron peaks observed in singles[35] have now been observed as back-to-back e^+e^- coincidences.[36] The data suggest that the lines are a product of a two-body decay near the center-of-mass of the colliding system but at a time when the decaying object is far away from the nuclei. There is in fact evidence for more than one peak, perhaps three have been observed so far. Recently, experimentalists have measured Bhabha scattering of positrons from electrons in attempts to observe narrow resonances at the energies of the positron lines produced in the heavy ion collisions.[36] The results from two different groups are still inconclusive at this time. A third experiment which has the capability to measure with much-increased statistics is presently underway. Another group has measured the production of coincident photons[37] in order to investigate a possible photon decay mode of the object producing the narrow positron lines. These experiments find no coincident photon peaks at the energies of the observed positron peaks. However, a line for emission of back-to-back photons at much lower energy (1062 KeV), slightly above the positronium energy (1022 KeV) was observed in one of the three nuclear systems studied. Theoretically there is no consistent description for the observed systematics of the measurements, especially the connection to the nuclear properties of the system.[38] Furthermore, results from the e^+e^- experiments and further analysis of the photon experiments may provide additional information. Most explanations involve the decay of a neutral particle with internal structure. The particles properties and how it was formed are the subject of more exotic theoretical inquiries.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under contract DE-AC03-76SF00098.

References

1. J. Cleymans, R.V. Gavai and E. Suhonen, Phys. Rep. 130 217(1986).
2. see Proceedings of the Sixth International Conference on Ultra- Relativistic Nucleus-Nucleus Collisions - Quark Matter 1987, Nordkirchen, FRG, 24-28 August 1987, Z. Phys. C38 (1988).
3. J. Kogut, H. Matsuoka, M. Stone, H.W. Wyld, S.Shenker, J. Shigemitsu and D.K. Sinclair, Phys. Rev. Lett. 51 869(1983).
4. T. Matsui and H. Satz, Phys. Lett. B178 416(1986).
5. G. Landaud, Proceedings of this Conference; A. Bussiere et al., Z. Phys. C38 117(1988).
6. F. Karsch and R. Petronzio, Phys. Lett. B193 105(1987).
7. S. Katsanevas et al., FERMILAB-Pub-87/57-E (1987) to be published in Phys. Rev. Lett.
8. M. Chu, Proceedings of this Conference; M. Chu and T. Matsui to be published in Phys. Rev. D; see also J.P. Blaizot and J.Y. Ollitrault, Phys. Lett. B199 499 (1987).
9. S. Gavin and M. Gyulassy, private communication.
10. T. Humanic, Proceedings of this Conference; A. Bamberger et al., Phys. Lett. B203 320(1988).
11. R. Hanbury Brown and R. Twiss, Nature 177 27(1956) and Nature 178 1046(1956).
12. B. Andersson and W. Hofmann, Phys. Lett. B169 364(1986).
13. S. Pratt, Proceedings of this Conference; S. Pratt, Phys Rev. D33 72(1986).

14. G. Bertsch, M. Gong and M. Tohyama, MSU Preprint (1987) to be published in Brief Reports of Phys. Rev. C (1988).
15. B. Jacak, Proceedings of this Conference.
16. A. Bamberger et al., Phys. Lett. B184 271(1987).
17. A. Franz, Proceedings of this Conference.
18. J. Stachel, Proceedings of this Conference.
19. K. Werner, Proceedings of this Conference.
20. R. Albrecht et al., Phys Lett. B199 297(1987).
21. J.D. Bjorken, Phys. Rev. D27 (1983) 140.
22. H. Stroebele et al., Z. Phys. C38 89(1988).
23. R. Hagedorn and J. Rafelski, Phys. Lett. 97B 180(1980).
24. K.S. Lee, M.J. Rhoades-Brown and U. Heinz, Stony Brook Preprint (1987).
25. U. Heinz, K.S. Lee and M.J. Rhoades-Brown, Mod. Phys. Lett. A2 153(1987).
26. C. Greiner, P. Koch and H. Stöcker, U. Frankfurt Preprint UFTP 189 (1986).
27. U. Heinz, K.S. Lee and M.J. Rhoades-Brown, Phys. Rev. Lett. 58 2292(1987).
28. E. Witten, Phys. Rev. D30 272(1984).
29. R. Ledoux, Proceedings of this Conference.
30. G. Vezstergombi et al., Z. Phys. C38 129(1988).
31. H.G. Ritter, Proceedings of this Conference; see also Proceedings of the 8^{th} High Energy Heavy Ion Study, 16-20 November 1987, Berkeley, California, LBL report LBL-24580 (1988).
32. K.G.R.Doss et al., Phys. Rev. Lett. 59 2720(1987).
33. H.R. Schmidt et al., Proceedings of the 8^{th} High Energy Heavy Ion Study, 16-20 November 1987, Berkeley, California, LBL report LBL-24580 142(1988); K.H. Kampert et al., Proceedings of the 8^{th} High Energy Heavy Ion Study, 16-20 November 1987, Berkeley, California, LBL report LBL-24580 154(1988).
34. C. Gale, Proceedings of this Conference.
35. J. Greenberg, Intersections between Particle and Nuclear Physics, Lake Louise, Canada 1986, published by the AIP New York 1986, p. 112.
36. W. Koenig, Proceedings of this Conference.
37. K. Danzmann, Proceedings of this Conference.
38. A. Chodos, Proceedings of this Conference.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720