Lawrence Berkeley National Laboratory
Recent Work

Title
SUMMARY OF THE HEAVY ION PHYSICS SESSIONS AT LAKE LOUISE

Permalink
https://escholarship.org/uc/item/7xv7z22q

Author
Harris, J.W.

Publication Date
1986-06-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

SUMMARY OF THE HEAVY ION PHYSICS SESSIONS
AT LAKE LOUISE

J.W. Harris

June 1986

NUCLEAR SCIENCE
DIVISION

DISCLAIMER

SUMMARY OF THE HEAVY ION PHYSICS SESSIONS AT LAKE LOUISE

John W. Harris

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

SUMMARY OF THE HEAVY ION PHYSICS SESSIONS AT LAKE LOUISE

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

In the last several years the intersections between particle and nuclear physics have grown rapidly to the point where many particle and nuclear physicists now speak the same language and even work together on the same experiments. In heavy ion physics this interdisciplinary communication ranges from describing ground state nuclei and highly excited nuclear matter in terms of quark degrees of freedom to searching for quark deconfinement in high energy nucleus-nucleus interactions utilizing nuclear beams from high energy physics accelerators. Presentations in the Heavy Ion Physics Sessions encompass this range and can for the most part be divided into two subcategories. The first is the study of different phases of nuclear matter. This typically refers to understanding the nuclear equation of state from low baryon densities and temperatures (where a liquid-gas phase transition should occur) through nuclear structure, neutron star formation and supernova explosion to the high densities and temperatures where the onset of deconfinement of quarks in nuclear matter is predicted. Beyond this is the second region, that of the study of quark matter.

In the quest to understand the nuclear equation of state considerable advances have been made on several fronts. A semi-empirical equation of state has been extracted from pion production data in the Streamer Chamber[1] in relativistic nucleus-nucleus collisions at the Bevalac. This is shown in Fig.1 along with theoretical equations of state labelled FP,[2] BCK,[3] and VUU [4] which are used in nuclear matter calculations, supernova simulations and microscopic calculations for relativistic nucleus-nucleus collisions, respectively. The FP and BCK equations of state are considerably "softer" than that extracted from the data and VUU. This apparent discrepancy is assuaged by the fact that relativistic nucleus-nucleus collisions, supernova explosions and nuclear structure effects are governed by the nuclear equation of state in different regions of temperature and density. Nuclear structure studies and nuclear matter calculations near the ground state of nuclei reflect the equation of state at zero temperature near saturation density ρ_0 while neutron star formation and supernova explosions are governed by the nuclear equation of state at low temperatures (T ~ 15 MeV) and densities $\rho \sim 2 \rho_0$. In contrast relativistic nucleus-nucleus collisions are sensitive to the nuclear equation of state at high temperatures (T ~ 60 - 100 MeV) and densities $\rho \sim$ 3-4 ρ_0. The behavior of the nuclear equation of state under these different conditions has yet to be fully understood. However, it should be stiffer at higher temperatures partly due to a decrease in the effective nucleon mass and an increase in prominence of the repulsive ω-interactions at high temperatures.

Another important result from the Bevalac is the recent observation and systematic study of collective sidewards flow of matter. Shown in Fig.2 are
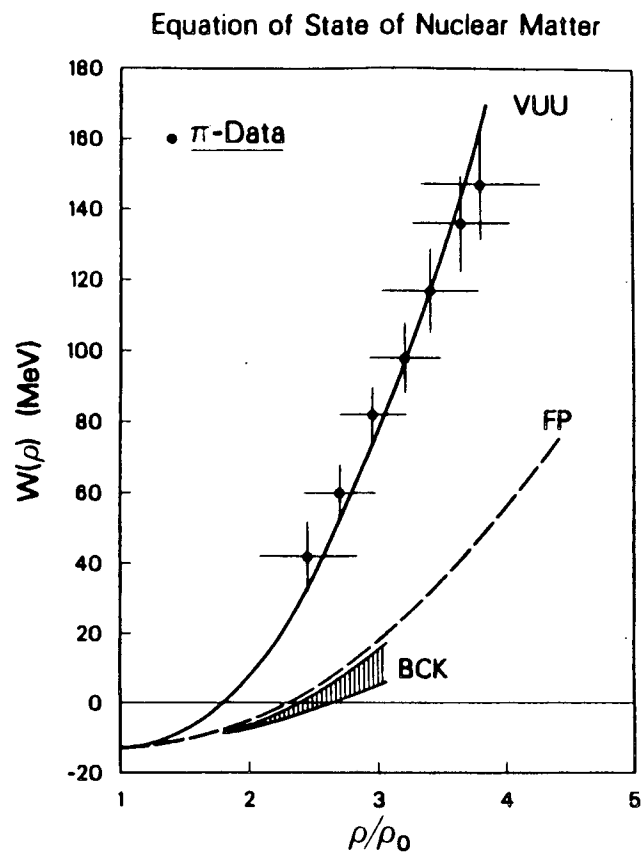
Equation of State of Nuclear Matter

Fig.1. Internal energy per baryon as a function of nuclear density extracted from pion multiplicity data (points). Also displayed are three theoretical equations of state (curves). See text for details.
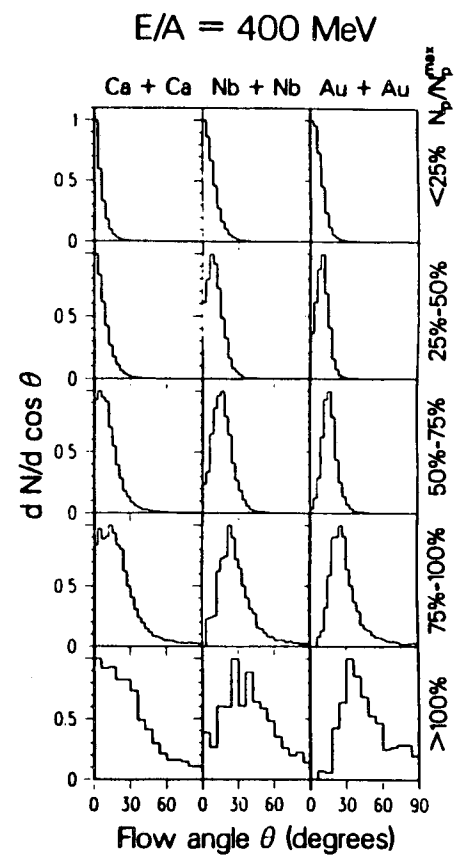
E/A = 400 MeV

Fig.2. Flow angular distributions for three systems as a function of the fractional multiplicity.

results from the Plastic Ball[5] for three different systems at fixed incident energy. Plotted as a function of fractional multiplicity N_p/N_p^{max} (which is inversely related to the impact parameter) are the distribution of flow angles, defined as the angle of the major axis of the event ellipsoid with respect to the beam axis, as determined from a sphericity analysis. The flow angle is observed to increase with the mass of the system and the multiplicity. These data provide strong evidence for the collective flow of matter. A rather stiff nuclear equation of state is necessary to describe these and other flow data[6] along with the pion production data.

An interesting result[7] from the Bevalac and possibly another approach[8] to the equation of state is the recent study of subthreshold kaon production. Whereas the threshold for associated production of K^- in nucleon-nucleon reactions occurs at $E_{lab}(NN \rightarrow NNK^{+0}K^-) = 2.5$ GeV, K^-'s have been observed in Si + Si collisions at incident energies as low as $E_{lab}=1.3$ GeV/n. In an attempt to understand the production mechanism, predictions have recently been made for the K^- yields assuming various theoretical models. An estimate assuming thermal and chemical equilibrium, which is unreasonable below threshold, overpredicts the yields by a factor of 20 as would be expected. Quite surprisingly, a single collision Fermi momentum model[9] underpredicts the yield by a factor of 20. Two more sophisticated microscopic models, the hadrochemical model[10] and semianalytic transport theory[11] predict the energy dependence of the data but not the correct magnitude of the K^- yields or all the systematics observed in the data. These models and experiments are still somewhat in their infancy. However, subthreshold kaon production, which should be more sensitive than pion production to the available energy and in turn to the compressional degrees of freedom, may provide new information on the nuclear equation of state as the experimental techniques become more refined and the models better developed.

On the way to studying the properties of nuclear collisions in the quark matter regime, several interesting experiments have already taken place. In T. Ludlam's talk[12] he discussed the mechanism by which gammas and dileptons should probe the early stages of relativistic nucleus-nucleus collisions, and specifically may be signatures for the formation of a quark-gluon plasma. Single leptons, namely electrons, have been measured over a large incident energy range from KEK in Japan to the ISR at CERN and the e/π ratio has been found to be relatively independent of projectile-target-energy combinations.[13] Experiments on the lepton and dilepton production in pp, pA and AA reactions are underway[13] at the Bevalac and should provide valuable and necessary information for understanding the lepton production in future searches for the quark-gluon plasma.

Results from the ISR light ion running periods have also shed first light on nuclear effects in very high energy nuclear reactions. Displayed in Fig.3 are results for the total neutral energy spectra from pp and $\alpha\alpha$ by the R110-BCMOR collaboration.[14] The pp data are well fit by a single gamma function over nine orders of magnitude in cross section as represented by the solid curve. The fit
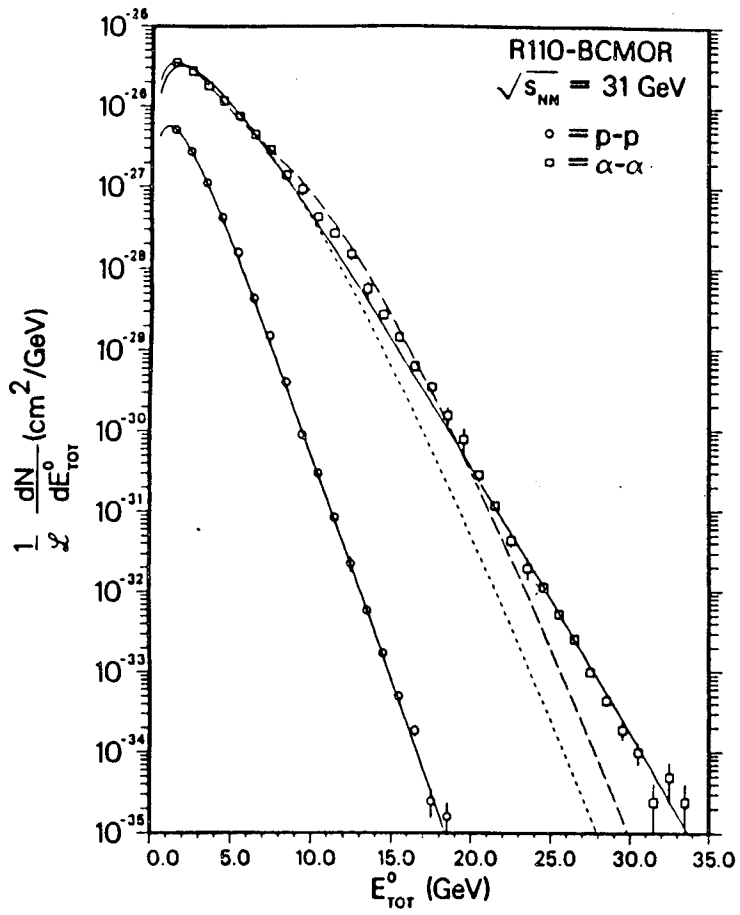
Fig.3. Total neutral energy spectra for pp and αα
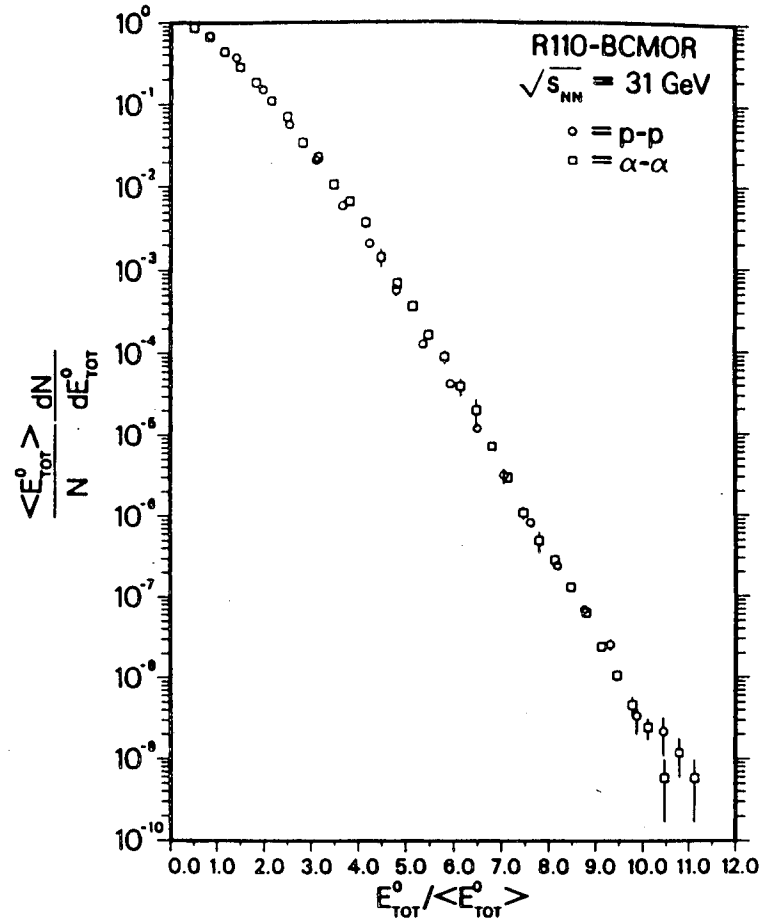interactions with fits described in the text.

Fig.4. Total neutral energy spectra of Fig.2 plotted
as a function of the scaled energy variable.

corresponds to fitting the function $f(E) = a(aE)^{p-1}e^{-aE}/\Gamma(p)$ to the data with parameters a and p. The dotted curve on the $\alpha\alpha$ data corresponds to the best fit using the n-collision probabilities derived by the AFS collaboration[15] from particle multiplicity data. This only fits the data at the lowest neutral energies. The dashed curve corresponds to the wounded nucleon model in the extreme case where all nucleons are assumed to participate in the collision. It still underpredicts the high neutral energy part of the spectrum. Only the solid curve where a gamma function was fit to the $\alpha\alpha$ data with all parameters free can fit the data over the entire range of neutral energies. It was found that the parameters p for the pp and $\alpha\alpha$ cases were identical thereby obeying KNO scaling.[16] This can be seen by plotting the pp and $\alpha\alpha$ data as a function of the scaling variable $E_0^{tot}/\langle E_0^{tot}\rangle$ where $\langle E_0^{tot}\rangle$ is the average value of the total neutral energy E_0^{tot}. This is shown in Fig.4 where the pp and $\alpha\alpha$ data overlay each other identically. A fundamental description for this simple phenomenon has not been presented but the results strongly suggest that nucleons in the helium nuclei are strongly correlated. A final comment on these data. The tail of the $\alpha\alpha$ data above 20 GeV (at a level of 10^{-5} of the interaction cross section) exhibits tremendous energy density, 15 GeV per unit rapidity. This corresponds approximately to an energy density of 1.3 GeV/fm^3 which is already quite near the predicted critical energy density for formation of the quark-gluon plasma.

Insight into the quark matter regime has come recently from advances in QCD lattice gauge calculations. A consistent set of results appears to be emerging from calculations which employ different approximation schemes for solving finite temperature QCD on the lattice. Displayed in Fig.5 are results from three different approaches[17] each indicating two coupled, weak, first order phase transitions. Plotted as a function of $\beta = 6/g^2$, where g is the coupling constant, are the order parameter for chiral symmetry $\langle\bar{\psi}\psi\rangle$ and the quantity $\langle L\rangle$, the expectation value of the thermal Wilson line (or Polyakov loop). $\langle L\rangle$ is a measure of the change in free energy of the system. If the free energy F of an isolated quark diverges, i.e. $e^{-F/T} = \langle L\rangle \to 0$, then a deconfinement transition appears as a sudden increase in $\langle L\rangle$ to some nonzero value. This is observed in all three calculations. The order parameter for chiral symmetry $\langle\bar{\psi}\psi\rangle$, which is a measure of the quark-antiquark mass, is also observed to abruptly change at this same value of β approaching zero where chiral symmetry restoration occurs. It appears that the deconfinement transition and chiral symmetry restoration may be related as they appear coincidentally. To better understand this and the effects of the various approximation schemes, more physical observables will have to be investigated through the use of faster calculations, requiring large amounts of supercomputer time (hundreds of Cray CPU hours).

Of considerble recent interest and uncategorizable in the present heavy ion physics summary of intersections between particle and nuclear physics are the positron lines observed at the GSI in heavy ion collisions. J. Greenberg[18] presented the experimental results in the plenary sessions. Theoretically there is still no consistent explanation which adequately describes the systematics of the experimental measurements.[19] The singles measurements rule out internal nuclear conversion ($A^* \to A\ e^+\ e^-$) primarily from the line width ($t_{source} >$
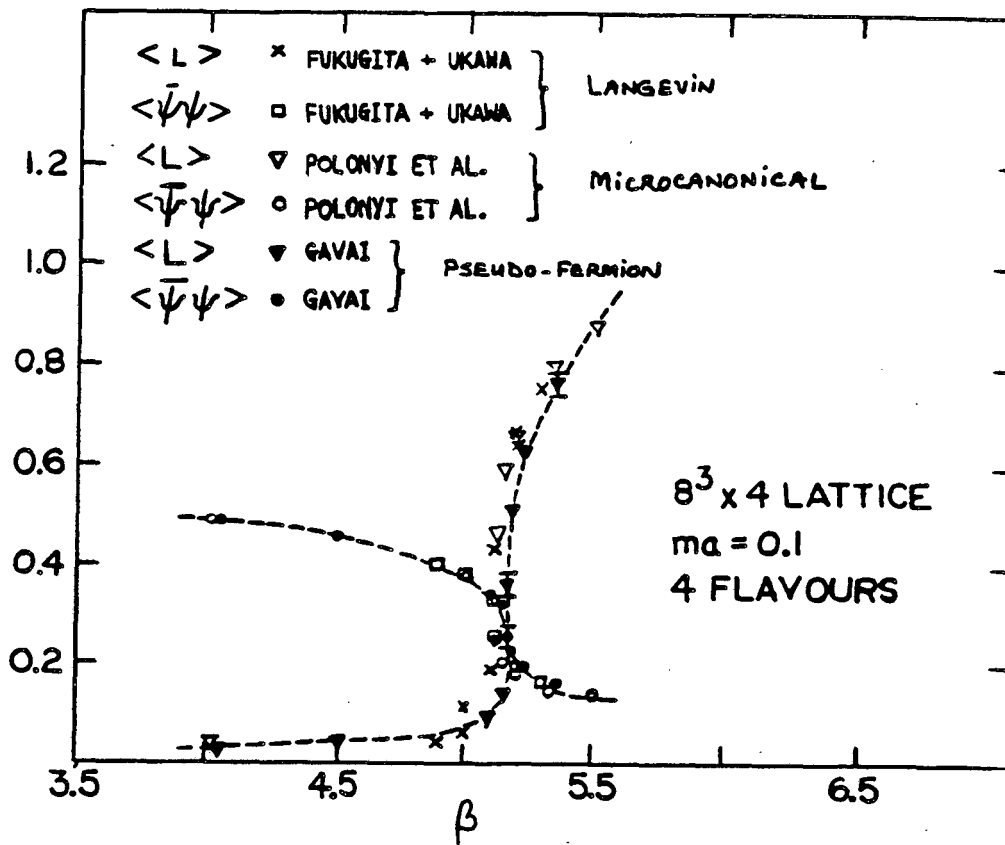
Fig.5. Expectation values of thermal Wilson line <L> and chiral symmetry order parameter <YY> plotted as a function of B=6/g^2 from QCD lattice gauge calculations.

3×10^{-20} s) and gamma and electron spectra. In the coincidence measurements the narrow energy sum peak and similar energies of the e^+ and e^- peaks leave open the possibility of two-body decay of a slowly moving particle (momentum < 100 KeV/c) in the c.m. system. The narrow energy difference peak for e^+ and e^- implies decay far away from the nuclei (distance > 13000 fm). From the energy of the peaks, E_{e+} and E_{e-}, the mass of such a particle would be M = $2m_e + E_{e+} + E_{e-}$ = 1.78 MeV. A problem arises from the coincidence lines observed in Th + Th. At incident energy E_{lab} = 5.70 MeV/n the e^+ and e^- peaks are observed at approximately 310 KeV and at E_{lab} = 5.75 MeV/n they appear at around 370 KeV. Is this one line that moves abruptly as the incident energy is increased slightly or are there two different lines? There still seems to be a large sentiment among experimentalists and theoreticians alike that a "simple" explanation may still loom in the future explanation of these lines, but for now there are none. The more exotic explanations[19,20] involve the decay of a pseudoscalar particle produced from the nuclear current where the presence of multiple lines could be explained by a particle with internal structure.

In conclusion, the intersection between particle and nuclear physics research is entering a very interesting period where in the next year there will be high energy nucleus-nucleus experiments[21] on both the European (CERN-SPS) and American (BNL-AGS) continents which for the first time may have the capability to transcend the nuclear matter to quark matter barrier. Furthermore, a proposal to build a relativistic heavy ion collider (RHIC) at even higher energies in the US has received strong support from NSAC. These experiments will all involve a large number of high energy and nuclear physicists working together to understand the common physics of nuclear and quark matter.

REFERENCES
1. R. Stock et al., Phys. Rev. Lett. 49 (1982) 1236; J.W. Harris et al., Phys. Lett. 153B (1985) 377 and J.W. Harris, "The Nuclear Matter Equation of State from Relativistic Heavy Ions to Supernovae", presented at this conference.
2. B. Friedman and V.R. Pandharipande, Nucl. Phys. A361 (1981) 502.
3. E. Baron, J. Cooperstein and S. Kahana, Nucl. Phys. A440 (1985) 744.
4. H. Kruse, B.V. Jacak and H. Stöcker, Phys. Rev. Lett. 54 (1985) 289; J.J. Molitoris, D. Hahn and H. Stöcker, MSU Preprint MSUCL-530, June 1985.
5. H.G. Ritter et al., Nucl. Phys. A447 (1985) 3c.
6. H.A. Gustafsson et al., Phys. Rev. Lett. 52 (1984) 1590; R.E. Renfordt et al., Phys Rev. Lett. 53 (1984) 763; P. Danielewicz and G. Odyniec, Phys. Lett. 157B (1985) 146; D. Keane, "Collective Flow and the Stiffness of Compressed Nuclear Matter", presented at this conference; also see comparisons in J.J. Molitoris and H. Stöcker, Phys. Rev. C32 (1985) 346.
7. S. Trentalange, "Subthreshold Production of Strange Hadrons in Relativistic Heavy Ion Collisions" presented at this conference.
8. J. Aichelin and C.M. Ko, Phys. Rev. Lett. 55 (1985) 2661.
9. A. Shor et al., Phys. Rev. Lett 48 (1982) 1597.
10. H.W. Barz et al., Z. Phys. A311 (1983) 311.
11. W. Zwermann and B. Schürmann, Phys. Lett. 145B (1984) 315.
12. T. Ludlam, " Relativistic Heavy Ion Collisions" presented at this conference.
13. G. Roche, " Universality of Lepton Production in pp, pA and AA Collisions", presented at this conference.
14. A.L.S. Angelis, Phys. Lett. 168B (1986) 158 and M. Tannenbaum, " Observation of KNO Scaling in the Neutral Energy Spectra from aa and pp Collisions at ISR Energies", presented at this conference.
15. T. Akesson et al., Phys. Lett. 119B (1982) 464.
16. Z. Koba, H.B. Nielsen and P. Olesen, Nucl. Phys. B40 (1972) 317.
17. R. Gavai, "Phase Transitions from Lattice QCD Perspectives", presented at this conference.
18. J.S. Greenberg, " Anomalous Positron Production", presented at this conference.
19. B. Muller, " Positron Lines - New Particle or Decaying Vaccum?", presented at this conference.
20. M.S. Zahir, " Production Mechanism for a Light Pseudoscalar Boson (m = 1.6 MeV) and Anomolous Positron Spectra", presented at this conference.
21. L.S. Schroeder, " Relativistic Heavy Ion Facilities", Presented at this conference.

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