6 JUL 1982

CERN - PRE 82 - 024

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QUARK MATTER FORMATION AND HEAVY ION COLLISIONS

A WORKSHOP HELD AT BIELEFELD

10-14 May, 1982

Centre for Interdisciplinary Research, University of Bielefeld, Germany.

SUMMARY REPORT PREPARED BY THE ORGANIZING COMMITTEE

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The Proceedings of the Workshop will be Published by
World Scientific Publishing Company, Singapore

CERN LIBRARIES, GENEVA

CM-P00061332

1. INTRODUCTION

A Quark matter formation and heavy ion collisions Workshop was held at Bielefeld from 10 to 14 May 1982. Proceedings will be issued when all the material which originated from the Workshop is at hand. They will include the talks presented during the plenary sessions and summaries by the conveners of the material put together during the specialized working sessions.

It was deemed appropriate to issue as quickly as possible a paper which would provide a summary of the outcome of the discussions which took place during the Workshop. Questions raised by heavy ion collisions are assessed. Experimental set ups, for the CERN PS/SPS Complex in particular, look as if they might soon be in shape. An important purpose of the Workshop was in fact to provide a detailed document for anyone wishing to obtain a survey of the field and to assess the potential and the practicability of this research. While the proceedings will later provide the needed detailed status report, the present summary should readily indicate where consensus prevails and where doubts or important questions remain. This is its purpose.

Heavy ion collisions, as here discussed, leads us indeed into a novel domain both in energy and in matter density. We have in mind center of mass energies of the order of 10 GeV per nucleon or larger, and ions massive enough that head on collisions could result in very large energy densities, of the order of 1 GeV/fm^3 or larger, over volumes which would greatly exceed that occupied by a single hadron. Such energies, translated in terms of incident beam energy are two orders of magnitude above what is presently considered as "high energy" in heavy ion collisions, as discussed for instance in the proceedings of the Vth High Energy Heavy Ion Study, Berkeley 81 (LBL-12652, Oct. 81)

Experimental information is at present limited to heavy ion interactions at probably too low energies; to cosmic ray events too few in number to provide any decisive information; and to ISR energy interactions among ions probably not massive enough to be highly relevant. However,

the recent developments of Quantum Chromodynamics provide great confidence in the existence of a new phase of matter - the quark-gluon plasma - which could be reached at high enough densities or temperature. This is what motivates present enthusiasm for heavy ion collisions at very high energies.

This enthusiasm if fueled by some promising results may provide enough support for dedicated projects such as Venus but their completion will probably require quite some time. Meanwhile, some effective (and may be decisive) use could be made of existing proton machine(s), which, provided with proper ion sources and injection system, could be used for accelerating medium size ions at a relatively limited cost. It is this last feature which gives to this Workshop its timely character.

Section 2 of this report is a general presentation of the Workshop. It provides some information on how it was organized and actually took place. The reader already familiar with the Workshop needs not read it. Section 3, is an attempt to bring into focus some of the key physics issues which were under discussion at the Workshop. While making many references to the far more detailed papers to be found in the proceedings, it provides an overview of the field as it appeared to the participants. Section 4 presents the very original outcome of the Workshop, summarizing the conclusions and the ideas for experiments reached in the specialized working groups.

Appendix A gives the list of participants. It bears witness to the existence of an already wide geographical base for this research. Appendix B gives the programme of the plenary sessions. The papers thus presented will all be included in the proceedings. Appendix C lists the specialized experimental working groups with their conveners. In each case a summary prepared by the respective conveners will also appear in the proceedings. Appendix D lists the contributions presented in the theory parallel sessions. Some of them are referred to explicitly in Section 3 and will be included in the proceedings.

2. THE BIELEFELD WORKSHOP

Activity in this field has been already rather intense but very diffuse. On the one hand theoretical studies, including in particular a non-perturbative approach to Quantum Chromodynamics with calculations on the lattice, have recently bloomed. They have provided much confidence in the existence of a phase transition between standard hadronic matter and a quark gluon plasma. On the other hand, the wealth of data accumulated with present heavy ion accelerators, and in particular the Bevalac, has borne out many features which lead to think that experimentation at much higher energy is feasible and of great potential interest. This research has already contributed much in providing a meeting ground for nuclear and particle physics, which had to a large extent split apart since the late fifties. In addition to this, the possibility of using existing proton machine(s) and also existing detectors for this research has triggered much interest among some high energy experimentalists.

Time seemed therefore ripe to convene a Workshop which would include nuclear as well as particle physicists, experimentalists as well as theorists, all associated in a common endeavour, trying to assess as well as possible present knowledge and problems, and to prepare for the most appropriate experimental and theoretical developments. Organized at the Centre for Interdisciplinary Research of the University of Bielefeld (ZIF) it brought together over 100 participants, among them a roughly equal number of experimentalists, theorists, nuclear and particle physicists. A very good spirit prevailed throughout and in particular, the output of the specialized groups (section 4) bears witness to the effectiveness of the meeting. It was clear from the start that even if such a session could be conducive to intense intellectual effort, only a limited amount of work could be achieved during 4 days, the last day being set aside for a general summary. The working groups were therefore set up as soon as the whole project was initiated in order to provide time for some extensive work in preparation for the meeting proper. They were organized along 7 different lines, namely:

- (i) Light ion physics
- (ii) Photons and leptons
- (iii) Few particle correlations
- (iv) Peripheral interactions
- (v) Inclusive spectra and particle identification
- (vi) Visual and imaging detectors
- (vii) Large solid angle calorimeters

The latter two eventually preferred to merge. Boundaries between the different groups were kept to a minimum and theorists participated in many of them. On the last day, M. Albrow summarized their conclusions, presented in some detail already in Section 4. They can often already be phrased in terms of experimental designs, conceived in order to face large multiplicity reactions and to use specific triggers.

The activities of these specialized groups extended over the 4 afternoons of the Workshop proper. In parallel to that, theoretical discussions took place every afternoon with particularly detailed discussions of gauge theory calculations on the lattice. The first afternoon was indeed devoted to pure Yang Mills systems while the second afternoon was the occasion to discuss present success and problems with the inclusion of fermions. The third afternoon allowed for a discussion of a priori interesting signals (photons, lepton pairs and strange particles...). It was a welcome input to the experimental discussions. During the fourth afternoon, the discussion of models for matter at high densities was an interesting meeting ground for nuclear and particle theorists.

The Workshop was also the occasion to put together a large amount of relevant material which was so far scattered, as expected for a frontier domain touching field theory, nuclear, particle and cosmic ray physics. Plenary talks were scheduled in such a way as to provide all participants with approaches to the key issues from different points of view, and with available information. Their purpose was to bring everyone abreast with features and questions related to high energy heavy ion interactions and more generally with the possible existence of a new state of matter at very high temperature or density.

These plenary talks covered general physics questions about possible phase transitions, and about the determination of the pertinent values of the parameters; they discussed the values actually expected in heavy ion collisions provided that centre of mass energies greater than 10 GeV/nucleon would be available. Present information about $\alpha\alpha$ collisions at ISR energy, heavy ion interaction at Bevalac energy and very high ion interactions as observed in Cosmic Rays was also reviewed. These review talks also covered present models for nucleus-nucleus interactions at Bevalac and much higher (ISR, SPS fixed targets...) energies.

Also discussed were present experimental possibilities in the framework of existing machines especially the SPS and KEK or of machines at the construction stage or mere design or conception stage (Isabelle, TRISTAN...). The list of these plenary talks, which filled the four morning sessions, is given in Appendix B.

Also given in Appendix B is the list of the talks given during the last day of the Workshop which was organized as an Open Conference. While the actual number of participants made us use the capacity of ZIF almost to the full, we were happy to welcome a number of colleagues coming to hear the global status report presented at the end of the Workshop. During that day, S. Nagamiya (Tokyo) reviewed present energy heavy ion physics (Bevalac). Machine prospects were surveyed by H. Pugh (Berkeley). H. Gutbrod (Darmstadt) presented the medium ion (^{16}O) "medium" energy proposal at the CERN-PS. Van Hove (CERN) concluded the meeting with a review of the theoretical situation. Prior to that M. Albrow (Rutherford) had presented the very large amount of work which the different experimental study groups had done. Heavy ion collisions as discussed in Bielefeld could well be the way to achieve in the laboratory conditions which could have prevailed in the very early Universe, less than 10^{-4} s. after the Big Bang which gave it birth. There are good reasons to expect that significant signals could already be obtained in experiments the completion of which would call for only a relatively limited effort.

3. A NEW STATE OF MATTER: THE QUARK-GLUON PLASMA

Heavy ion collisions offer the possibility to reach very high densities and very high temperatures over extended domains, many times larger than the size of a single hadron. The energy densities considered are of the order of 0.5 to 1.5 GeV/fm³ and the relevant temperatures are in the 200 MeV range. The great interest of reaching such conditions originates from recent developments in Quantum Chromodynamics, QCD, which make it very plausible that, while colour confinement should prevail under standard circumstances, deconfinement should occur at sufficiently high density and (or) sufficiently high temperature. Under such conditions a new phase of matter, a quark-gluon plasma, is likely to exist. This phase should be viewed as due to a coalescence, or perhaps a percolation, of hadrons into larger entities and not as an actual separation of free quarks! If the colour symmetry of QCD is only an approximate symmetry, more peculiar effects could of course occur. Over an extended volume where the required density or temperature conditions would prevail, one expects that the properties of the physical vacuum would be modified. While the normal vacuum excludes the gluon field, the colour-equivalent of the dielectric constant being zero (or practically zero), one would get a new vacuum state where quarks and gluons could propagate while interacting perturbatively. The equivalent of the dielectric constant would now be unity. The required conditions may be reached at high enough densities, hadrons being squeezed into one another, or at high enough temperature, the calculation of the partition function no longer favouring confining configurations whereby a colour flux tube of fixed cross section extends between two colour sources. The temperature at which the phase transition is expected to occur depends on the density, or on the quark chemical potential. One may thus separate two phases, a hadron phase and a quark gluon plasma, on a density-temperature diagram, as is shown in Fig. 1.

The history of a particular system (the case of a projectile nucleus say) during a heavy ion collision can then be sketched as done with the path drawn as a solid line in Fig. 1. Starting from nuclear density and low temperature, one increases the density and eventually the temperature, reaching the quark gluon plasma phase before the system comes back to the usual hadron phase. The dashed line sketches the evolution proper to the early Universe where the temperature decreases while the quark density remains low.

The presence of a phase transition could long be expected from phenomenological models with an exponentially increasing hadron spectrum. The limiting Hagedorn temperature, obtained as the specific heat of the hadron gas diverges, can be interpreted as a critical temperature beyond which the relevant description should be in terms of a quark-gluon plasma reaching eventually a Stephan-Boltzman behaviour. The actual presence of a phase transition finds however its strongest present support in lattice gauge calculations. The thermodynamics of Yang-Mills field has been studied on the lattice and one may say that a solid consensus prevails. The rapid variation of the energy density (scaled in term of the Stephan-Boltzman asymptotic limit) or the sharp peak of the specific heat divided by T^3 as the temperature falls beyond 160-240 MeV (depending on the calculation) signals an at least second order transition. Fig. 2 shows such a typical curve. There is a dramatic fall of the energy density (divided by T^4) with decreasing T . It corresponds to the gluon radiation, with its many degrees of freedom "freezing" into glueballs. If the transition were a first order one (step function) this would correspond to a very large latent heat! The present status of such Yang Mills calculations using Monte Carlo techniques to calculate the partition function associated with a Gauge field on the lattice at finite temperature, is presented in detail in the proceeding by J. Engels (as a special contribution to the first theory parallel session).

The weight of present theoretical activity now appears to be on the inclusion of quarks in the calculation. Much still has to be done for a precise and very reliable picture to emerge. Nevertheless, it does not seem that the value of the transition temperature obtained in the pure Yang-Mills case should change much when including quarks. There is however the very interesting possibility that two successive transitions could take place. The first one (moving up in temperature) would "melt" all hadrons into quarks and gluons but keep quark-antiquark aggregates acting as Goldstone mesons in the spontaneous breaking of Chiral symmetry, thus giving a sizeable (constituent) mass to the lighter quarks. Only at the second transition would these aggregates disappear and the actual quark gluon plasma phase (with practically massless light

quarks) be reached. At low quark density (Fig. 1) one could quote 200 and 300 MeV as the two temperatures associated with these two transitions respectively, but such a clear separation is still much under debate. The contributions of J. Montvay, F. Karsch and J. Kuti to the proceedings (contributions to the second theory parallel session) present the situation as of now in great detail. These questions were moreover beautifully surveyed in the review talks of G. Baym and L. Van Hove appearing in the proceedings (plenary talks). The question of the infrared property of the gluon propagator at high temperature is also related strongly to the deconfinement problems. Contributions to the parallel sessions by J. Kapusta, K. Kajantie and E. D'Hoker are briefly reviewed by J. Kuti in the proceedings (summary of a first theory parallel session).

Granting the fact that one phase (or two phase) transition(s) exist(s), the next question is to assess whether or not the required conditions could be met in heavy ion collisions with centre of mass energy in excess of 10 GeV/nucleon. At present there also appears to be a consensus that this is the case as is also reviewed in L. Van Hove's talk. The question was of course the object of special contributions to the Workshop and this will be discussed at some length in the proceedings through the contributions of K. Kajantie, L. McLerran and M. Gyulassy. The expected mean energy density is of the order of 2 GeV/fm³ for the (most favourable) case of head on U-U collisions and still of the order of 1.2 GeV/fm³ for Fe-Fe collisions. This applies to the fragmentation region, considering the energy trapped in what remains of the projectile or target nucleus just after the collision. Estimates for the energy density reached in the central region are similar. In this case one uses heavily the fact that nucleus-nucleus collisions are expected to yield very large central multiplicities (with a density which could increase as A, typically). Models for particle production at very high energy as discussed by A. Biatas (plenary talk) indeed predict very large yields. Evidence from Cosmic Ray results, as discussed in detail in the proceedings by G.B. Yodh (plenary talk), supports that.

The study of heavy ion collisions at the Bevalac has been a very good testing ground for models of nuclear matter and of ion-ion collisions. Neither of the two extreme pictures, namely the nuclear cascading of

hadrons on the one hand, and the hydrodynamical model on the other hand, is satisfactory. When compared to actual results the former one predicts too much production of secondaries at small angle whereas the latter one predicts far too much at wide angle. Actually the relevant mean free path scaled to the nucleus size, is certainly too small for a mere knock out picture to work, and certainly too large for the hydrodynamical model to be valid. Questions associated with the generation of entropy and of the rapid evolution toward chemical equilibrium appear as very interesting and certainly of great potential interest for reactions at much higher energies, as those discussed more particularly at the Workshop. The reviews of J. Knoll and of J. Kapusta (plenary talks) will provide the reader of the proceedings with a detail status report. While one may consider that Bevalac energies are still too low for striking new features to occur, at least of the type of those under focus at the Workshop, one should bear in mind that very sizeable compressions could still be reached in some cases and that very peculiar effects, such as the production of anomalons, are still unexplained. The question of anomalons was indeed the object of a thorough discussion during one of the parallel sessions (peripheral interactions). It was then reviewed by H. Pugh in his plenary talk on the Bevalac results. Anomalons can be briefly described as follows: The observed mean free path of some nuclear fragments appear to be much smaller than the normal ones, when observed close to production. Such objects (anomalons) appear to be long lived (lifetime longer or equal to 10^{-10} sec) with the peculiar property of having a total cross section very large when compared to their ionizing power, the effect being persistent from generation to generation in successive collisions.

Discussions between nuclear and particle physicists made it clear that a very important effect at high energy is the increased transparency of nuclear matter, the hadron production time becoming much larger than the transit time during which the two nuclei cross each other. This must of course be taken into account estimating the energy densities which could be achieved. While centre of mass energies of 10 GeV/nucleon or more are required, with large associated mean multiplicities of secondaries, the further gain to be expected at much larger energies (100 GeV/nucleon say) are still unsettled. Uncertainties stem from the fact that nothing is

known about fluctuations at such energies and also from the fact that the strongest gain should apparently occur in the central region for which present estimates cannot be considered as as reliable as those made for the fragmentation region.

The question of the behaviour of nuclear matter in high energy collision and that of reaching thermal and chemical equilibrium were much discussed during a theory parallel session (Summary of L. Bertocchi in the Proceedings). One may say that while there appears to be a consensus that the conditions required for the predicted phase transition should be reached in head on heavy ion collisions (large enough energy density should be obtained) the question of whether or not thermalization can take place and of whether or not chemical equilibrium (with a large fraction of strange quarks then present in the plasma) can be reached is still under debate, with optimistic as well as skeptical points of view (this is discussed in the summaries by M. Guylassy and L. Bertocchi). A consensus seems to prevail that a sufficient number of collisions will take place to achieve some thermalization.

Granting the fact that a thermalized quark gluon plasma is formed during the collision, it will very rapidly destroy itself through instabilities, expansion and cooling. One should then watch for specific signals which could be associated with its transient (but most interesting) presence. The key point is perhaps the existence of very important fluctuation of some parameters on an event to event basis, whether a sizeable blob of plasma is formed or not. Several signals have attracted particular attention. One of them is provided by the prompt photon or lepton pairs radiated (a volume effect!) by the thermalized plasma, with abundant production at large x (the Feynman scaling variable) when originating from the glow of the projectile, in a region where (standard) Drell Yan production is not expected to be strong and hadronic resonance decay provide only a surface effect.

Another interesting signal may be provided by strange particles originating in relatively large number from the plasma, once it has reached chemical equilibrium.

There may also be more violent effects, with abnormal density fluctuations in the overall energy flow associated with secondaries. Size and lifetime could be determined through pion/photon interferometry since each violent event with head on collision could produce pions in the thousands!

These questions were debated at length in one of the theory parallel sessions, summarized in the proceedings by M. Guylassy. They were of course also much discussed during the parallel experimental sessions and carried much weight at selecting specific triggers, as discussed by M. Albrow in his summary report.

Concluding this rapid survey of the physics of heavy ion collisions studied at the Workshop, one may say that there is practically no doubt that a phase transition exists, even if the exact form which it takes is not yet precisely known. There is also practically no doubt that the energy density to be achieved in heavy ion collisions, with incident ion beams in the 200 GeV/nucleon energy range, should reach the critical value. It seems therefore very reasonable to expect the formation of blobs of quark gluon plasma in an appreciable fraction of the events. The glow left over by this plasma for an actual experimental observation is still rather poorly predictable in its form and intensity. This however makes experimentation with heavy ion at such energies all the more interesting. It moreover does appear feasible from what follows.

4. CONCLUSIONS OF THE EXPERIMENTAL WORKING GROUPS

Six working groups studied experimental questions from the point of view of physics goals and their technical realization. The emphasis was on fixed target experiments with projectile mass A up to 16 at incident energy greater than 100 GeV per nucleon, though colliding beam experiments and heavier projectiles were also discussed.

One group studied measurement of inclusive particle distributions (Conveners were S. Nagamiya and H. Specht). It became clear that the measurements wanted were really single particle spectra, not necessarily truly inclusive, but with various triggers to select central collisions and those with large multiplicity or energy deposit in the target.

From the physics side, it was established that a good way to investigate the effects in the quark-gluon plasma such as the suppression of u-quarks and the chemical equilibrium of s-quarks, should be to measure distributions of strange particles, mesons and especially strange and multiply strange baryons and anti-baryons.

The wide range of laboratory energies present in fixed target experiments led the group to design three spectrometers with very different solid angles and momentum ranges to cover the range of rapidities and transverse momenta of interest for charged secondary particles. Given the great interest in hyperon and antihyperon fluxes, it was realized that the spectrometer covering the large laboratory rapidities might profitably be adapted from some existing hyperon beam. Similar considerations were made for neutral hyperons and neutral hyperon beams. The measurement of hyperon distributions in the target rapidity region in dedicated setups was also considered. It was concluded that the presence of very high multiplicities does not present a major obstacle to these experiments.

A second group (Conveners R. DeVries and H.G. Fischer) worked on the subject of peripheral interactions. A major part of their time was devoted to the study of the experiments at Berkeley giving particles with very short interaction lengths, the "anomalons". Experiments in progress and ideas for the future were considered.

Also properly belonging to this category were suggestions for experiments on hypernuclei produced among the projectile fragments. It is certainly reasonable to expect to find many strange quarks (and some charmed quarks) lodged in the fragments of the projectile. The large Lorentz factor will then allow the use of beams similar to the existing hyperon beams to provide momentum analysed, mass and charge identified hypernuclei. There should also be usable numbers of multiply strange hypernuclei. This is a radically new approach to the study of these particles and should give rise to a major step forward.

Experiments on correlations among a few particles were considered by the group convened by I. Otterlund and H. Boggild. The idea here was to

handle the high multiplicities by using spectrometers with a solid angle just large enough to cover the angles between two particles in the range of interest, but small enough so that the number of particles to be measured is still close to that commonly encountered. For example, that in the most difficult rapidity region, the spectrometer needed to handle about twenty five particles on the average. The physics studied includes the phenomenon of clustering already observed in high energy hadron collisions, and suggested on a more spectacular scale by some the cosmic ray events. The topic of identical particle intensity interferometry by study of few particle correlations was given special attention. This technique has already proved its worth in nuclear collisions and is expected to be a major tool in high energy nucleus-nucleus interactions. It is used to measure the size and shape of the interaction volume, and give information about phase coherence in the particles radiated. It seemed likely that the technique proposed by this group is the most efficient for this purpose. This apparatus also seems suited for studies of V^0 's. The group also designed a special spectrometer to study photon correlations.

This group devoted a substantial effort to the study of various triggers to select central or peripheral events, including measurement of the forward particles and a "plastic ball" type of detector covering most of the solid angle of target fragmentation.

G. London and K. Nakai convened a group working on the production of leptons and photons. They established that several distinct kinematic regions seemed to be of interest. For intermediate and high mass muon pair production in the projectile fragment region, they showed that an experiment using the NA3 apparatus at the SPS with small modification could be very effective. They designed a new experiment to study electron pair production in the target fragmentation region, with particular emphasis on the "cumulative region", that region which lies beyond the limit allowed by p-p kinematics. It is clear that such measurements are particularly sensitive to multiparticle effects. They included both "large mass" pairs, $m_{ee} > 2 \text{ GeV}$, usually explained by the Drell-Yan process and the small mass pairs where $m_{ee} < 1 \text{ GeV}$, where hadronic effects are evidently important even in p-p collisions. The difficult problem of triggering in the presence of a large multiplicity of charged particles was given particular attention and some solutions were found.

A very different setup was designed for studying photon production on an internal target in the synchrotron. The target would be a gas jet or a series of thin fibres. The advantages of this technique include the very small mass of the target with high effective luminosity, and the automatic provision of an energy scan as the beam is accelerated.

Another working group (conveners M. Faessler and S. Frankel) studied the case of deuteron and alpha particle beams. They emphasized two points, the particular physics possible when the number of nucleons is small, and the advantages of high luminosities known to be available with alpha beams compared with heavier ions. They pointed out that alpha beams on heavy targets may already provide large energy deposits. One point which became clear in this kind of discussion is that possible rare events with high energy deposit in heavy targets by high energy protons have not really been studied.

This group described practical experiments using a slightly modified Omega spectrometer at the SPS as a model. Some original ideas for triggering were developed.

A combined group studied calorimetric techniques and tracking devices in large solid angle detectors (conveners: C. Fabjan, H. Gutbrod, A. Sandoval and A. Wagner). The beauty of energy flow measurements with calorimeters is well recognized, but this group took the attitude that there would be powerful arguments for an apparatus which could make nearly complete measurements on an event by event basis and set out to investigate if it is technically feasible using methods presently available. It was soon understood that the particle density, (the number of particles per unit solid angle), anticipated in a nucleus-nucleus collision is not higher than that encountered in the core of jets at PETRA or LEP. This led to designs based on experiments existing or proposed, for example a JADE-type detector estimated to handle multiplicities of 500 charged particles in the peak two units of rapidity... Several different magnetic configurations of different degrees of ambition were considered. The most powerful consisted of a large solenoid covering the target fragmentation region, with a dipole spectrometer for the forward region and a special beam

fragmentation detector, with complete solid angle coverage by electromagnetic and hadron calorimeters. It was agreed that such a large new device would be justified only after evaluation of results using more modest equipment, but it was interesting to see that such a complete solution seemed to be feasible.

The large variety of experiments devised by the working group indicates a need to run several experiments at one time. The intensity requirements of the experiments are such that this should be possible. The technical questions of beam-sharing were not considered. It is clearly a very important question to be resolved at each particular accelerator, because heavy ion beams are apt to be available only for a limited fraction of the time at a machine with heavy obligation toward proton physics programmes.

ACKNOWLEDGEMENTS

This Workshop would not have been possible without the support of the Centre for Interdisciplinary Research of the University of Bielefeld which is here gratefully acknowledge. The members of the Organizing Committee would like to express their gratitude to the staff of the Centre whose congenial and efficient cooperation was instrumental at making the Workshop so much worthwhile having. They are here warmly thanked.

We thank Ms M. Mazerand for her help in bringing this paper to its present form.

Figure 1: The general shape of the phase diagramme with temperature and density, scaled according to nucleon density d_0 , as coordinates. the curve separates a hadron gas region (inside, I) from a quark gluon plasma region (outside, II) Cooling of the early Universe (dashed line), and heavy ion collisions (solid line) are sketched. Meaning should be attached to the overall shapes, not so much to the actual values which are indicated.

Figure 2: The general behaviour of the energy density, scaled according to the Stephan-Boltzman density ϵ_{SB} for the gluon gasd at very high temperature, as a function of temperature. This sketches the type of results obtained when the thermodynamics of the Yang Mills field is studied on the lattice using Monte Carlo techniques. The corresponding specific heat (divided by T^3) is found to have a singularity-type behaviour.

APPENDIX A - LIST OF PARTICIPANTS

Albrow, M.	CERN	Gorodetzky, Y.	Strasbourg
Ali, A.	DESY	Grossiord, J.Y.	Lyon
Baacke, J.	Dortmund	Gruhn, C.	Berkeley
Baumgart, H.	Frankfurt	Gutay, L.	Purdue
Badier, J.	CERN	Gutbrod, H.	Berkeley
Barton, M.	Brookhaven	Guichard, A.	Lyon
Baym, G.	Illinois	Gyulassy, M.	Berkeley
Beckmann, R.	Marburg	Hansen, P.-G.	CERN
Bemporad, C.	Pisa	Haseroth, H.	CERN
Bertocchi, L.	Trieste	Haustein, P.	Brookhaven
Bialas, A.	Kraków	Heinz, U.	Frankfurt
Biyajima, M.	Marburg	Hilf, E.	Darmstadt
Bock, R.	Darmstadt	Imrie, D.C.	London
Bøggild, H.	Copenhagen	Irvine, J.M.	Manchester
Bouchez, J.	Saclay	Jacob, M.	CERN
Bouyssy, A.	Orsay	Jones, K.	NORDITA
Brockmann, R.	Berkeley	Kajantie, K.	Helsinki
Carroll, J.	UCLA	Källmann, C.-G.	Helsinki
Castillejo, L.	London	Kapusta, J.	CERN & Los Alamos
Chao, W.Q.	Heidelberg	Karsch, F.	Bielefeld
Chemtob, M.	Saclay	Knoll, J.	Darmstadt
Cleymans, J.	Bielefeld	Koch, P.	Frankfurt
Csernai, P.	Budapest	Kögerler, R.	Bielefeld
von Dardel, G.	Lund	Köhler, P.	Siegen
Decamp, D.	CERN	Kripfganz, J.	Leipzig
de Groot, E.	Bielefeld	Krzywicki, A.	Orsay
DeTar, C.	Utan & Helsinki	Kuroda, M.	Bielefeld
D'Hoker, E.	MIT	Kuti, J.	MIT & Budapest
Elze, T.H.	Frankfurt	Liu Lian-sou	Berlin & Peking
Engels, J.	Bielefeld	London, G.W.	Berkeley
Ericson, T.	CERN	Ludlam, T.	Brookhaven
Fabjan, C.	CERN	McLerran, L.	Helsinki
Faessler, M.	CERN	Miettinen, H.	Helsinki
Fischer, G.	CERN	Miller, D.E.	Bielefeld
Fowler, G.N.	Exeter	Morrisson, G.C.	Birmingham
Frankel, S.	Philadelphia	Montvay, I.	Hamburg
Friedländer, E.	Berkeley	Müller, B.	Frankfurt

APPENDIX B - THE PROGRAMME OF THE WORKSHOP (Plenary part)

Plenary Talks

G. Baym	Three Phases of Strongly Interacting Matter.
K. Kajantie	Parameter and Signals for Quark Matter Formation.
L. McLerran	Space-Time Pictures of Heavy Ion Collisions.
M. Gyulassy	
H. Haseroth	Heavy Ion Prospects at CERN.
M. Barton	Accelerator Prospects in the US.
K. Nakai	Accelerator Prospects in Japan.
M. Faessler	Experimental Results from Light Ion Physics.
H. Pugh	Experimental Results from Heavy Ion Physics.
G.B. Yodh	Results from Cosmic Ray Physics.
J. Knoll	Reaction Dynamics in Intermediate Energy Nucleus-Nucleus Collisions.
J. Kapusta	Collective Aspects of Hadrons and Quarks in Nucleus-Nucleus Collisions.
A. Bialas	Models of Particle Production in Nucleus-Nucleus Collisions.

Open Conference, May 14

S. Nagamiya	Present Heavy Ion Experiments and Their Theoretical Interpretation.
H. Pugh	Accelerator Prospects for High Energy Heavy Ion Collisions.
H. Gutbrod	The GSI-LBL-Heidelberg-Marburg-Warsaw Proposal for the CERN-PS.
M. Albrow	Future Heavy Ion Experiments.
L. Van Hove	Summary of the Theoretical Situation.

Nagamiya, S.	Berkeley	Willis, W.	CERN
Nakai, K.	Tokyo	Yodh, G.B.	Maryland
Olive, K.A.	CERN	Zimanyi, J.	Budapest
Otterlund, I.	Lund	Zinovjev, G.	Kiev
Palumbo, F.	Frascati		
Paschos, E.A.	Dortmund		
Petersson, B.	Bielefeld		
Pirner, H.J.	Heidelberg		
Polley, L.	Darmstadt		
Polonyi, I.	Darmstadt & Budapest		
Pugh, H.	Berkeley		
Radvanyi, P.	Saclay		
Rafelski, J.	Frankfurt		
Ray, P.S.	Bielefeld		
Redlich, K.	Wrocław		
Rinaudo, G.	Torino		
Sandoval, A.	Berkeley		
Santo, H.	Münster		
Satz, H.	Bielefeld		
Scott, D.K.	Michigan State		
Sinha, B.	Bombay		
Siotis, I.	London		
Soyeur, M.	Saclay		
Specht, H.	Heidelberg		
Suhonen, E.	Oulu		
Schäfer, M.-L.	Bremen		
Schildknecht, D.	Bielefeld		
Schopper, E.	Frankfurt		
Schroeder, L.	Berkeley		
Stelte, N.	Marburg		
Stöcker, H.	Darmstadt		
Toimela, T.	Helsinki		
Trinchero, R.C.	Bielefeld		
Van Hove, L.	Leiden & CERN		
de Vries, R.	Los Alamos		
Wagner, A.	Heidelberg		
Wegner, H.E.	UCLA		
Weiner, R.	Marburt		

APPENDIX C - THE EXPERIMENTAL WORKING GROUPS

- (i) Light Ion Physics
Conveners : M. Faessler - S. Frankel
- (ii) Photons and Leptons
Conveners : G. London - K. Nakai
- (iii) Few Particle Correlations
Conveners : I. Otterlund - H. Bøggild
- (iv) Peripheral Interactions
Conveners : R. DeVries - H. Fischer
- (v) Inclusive Spectra and Particle Identification
Conveners : H. Specht - S. Nagamiya
- (vi) Visual and Imaging Detectors
Large Solid Angle Calorimeters
Conveners : A. Sandoval - W. Wagner
C. Fabjan - H. Gutbrod

APPENDIX D - THE THEORY SESSIONS

(i) Monday, May 10 - Gauge Fields on the Lattice

Chairman

J. Kuti

J. Engels (Bielefeld)
The $SU(N)$ Yang-Mills System at Finite Temperature.

J. Kripfganz (Leipzig)
Monte Carlo Results on the Vacuum Structure at $T \neq 0$.

C.-G. Källman (Helsinki)
What Lattice Calculations Can Tell us About the Gluon Gas?

K. Kajantie (Helsinki) / J. Kapusta (CERN)
Infra-red Limit of the Gluon Propagator at High Temperature.

E. D'Hoker (MIT)
Infra-red Problems at Finite Temperature.

J. Polonyi (Budapest)
Instantons on the Lattice.

(ii) Tuesday, May 11 - Lattice Gauge Theory with Fermions

Chairman

K. Kajantie

I. Montvay (Hamburg)
Lattice Methods for QCD with Fermions.

J. Kuti (Budapest)
The Numerical Study of Lattice Fermions.

F. Karsch (Bielefeld)
Finite Temperature QCD with Fermions.

A. Krzywicki (Orsay)
Chiral Symmetry in the Mean Field Approach at Large N .

B. Petersson (Bielefeld)
Fermions on the Lattice in the Strong Coupling Limit.

(iii) Wednesday, May 12 - Signals

Chairman

M. Gyulassy

H. Miettinen (Helsinki)
Muon Pair Production in Very High Energy Nucleus-Nucleus Collisions.

J. Zimanyi (Budapest)
Relaxation Times for Strangeness Production.

J. Rafelski (Frankfurt)
Strangeness as Signal for a Phase Transition.

E. Suhonen (Oulu)
Photon Spectra from Critical Matter.

J. Cleymans (Bielefeld)
Cosmic Ray Evidence for Quark Matter Formation.

H. Pirner (Heidelberg)
Multiplicities in Nucleon-Nucleon and α - α Collisions.

M. Lev (Bielefeld)
Large p_T Events in Nucleus-Nucleus Collisions.

(iv) Thursday, May 13 - Miscellaneous Questions Concerning the Phase Transitions Between Hadronic Matter and Quark Matter

Chairman

L. Bertocchi

K. Olive (CERN)
Cosmology, Astrophysics, and Heavy Ion Collisions.

G. Zinovjev (Kiev)
A Phase Transition Model for Hadronic Matter.

L. Csernai (Budapest)
Fluid Dynamics Descriptions of Heavy Ion Collisions.

U. Heinz (Frankfurt)
Classical Field Description of Heavy Ion Collisions.

L. Polley (Darmstadt)
Bag Formation in an Effective Yang-Mills Theory.

F. Palumbo (Frascati)
Many-Body Content of Quantum Gauge Theories and Dynamical Symmetry Breaking.

R. Hagedorn (CERN) / J. Rafelski (Frankfurt)
Temperature in Heavy Ion Collisions.