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PHYSICS AT RHIC: WHAT DO WE WANT TO KNOW, AND WHAT DO WE WANT TO MEASURE?

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PHYSICS AT RHIC

The central topic of this workshop is the planning and design of experiments for the Relativistic Heavy Ion Collider (RHIC) to be constructed at Brookhaven National Laboratory. I was asked to survey, as a short introduction, the main features of nuclear collisions which we would like to measure at RHIC. Let me therefore begin by asking: what do we want to know about the physics of high energy heavy ion collisions, and why? I shall list what to me are the main questions here. Following that, I shall indicate some possible experimental ways of addressing these questions.

1) Did the collision produce a system showing statistical or collective behavior? The most exciting aspect of nuclear collisions is the possibility to use them as a tool in the analysis of strongly interacting matter. For this, the collision should produce a "macroscopic" system, whose properties are determined by the collective action of many degrees of freedom. We thus hope that an A-A collision is more than something like a superposition of A nucleon-nucleon interactions.

2) What was the initial energy density in the different collision regions (central, fragmentation)? If we want to study strongly interacting matter at very high density, it is important to assure that nuclear collisions do indeed lead to densities higher than those found in heavy nuclei or in the neutron stars.

3) Was the produced system in thermal equilibrium? If this is the case, then we can apply the results of statistical QCD for the behavior of strongly interacting matter, and we can make use of hydrodynamic studies of the expansion and cooling of such matter. Pre-equilibrium systems appear much more difficult to analyse and understand.

4) If the system was thermal, what was its temperature? Both statistical QCD and strong interaction phenomenology suggest something like $T_H \sim 200$ MeV as a limiting (Hagedorn) temperature for hadron physics. Can we pass this to enter a new regime?

5) Was there initially a "chemical" equilibrium? With this, we want to ask if the constituents of different quantum numbers were present in the initial state according to their thermodynamical weights, or whether there still remains some "memory" of the quantum number structure of the incident beams.

Let me emphasize that all questions asked so far deal quite generally with strong interaction thermodynamics. They do not yet ask anything about color deconfinement or quark plasma formation. We now turn to these particularly exciting aspects.

6) Did the collision produce an extended system showing color deconfinement? If spatial size and lifetime of the system considerably exceed the hadronic scale of one fermi, this would mean that we have indeed created a new state of matter: the quark-gluon plasma.

7) How did this quark-gluon plasma subsequently expand and hadronize? Here we would particularly like to learn something about the nature of the transition to confinement (first order or continuous), possible hysteresis behavior (superheating, supercooling), the nature of the expansion and the formation of hadronic matter (hydrodynamic flow, deflagration/detonation, etc).

There will certainly be many further questions; nevertheless, the answers to these would give us some basis for the understanding of strongly interacting matter. What kind of experiments could provide us with these answers? I have summarized in table 1 those that have been most extensively discussed. It should be emphasized that the references listed are meant only to provide further information; they give in no way a complete coverage of the considerable amount of theoretical work on signatures. Let me now elaborate a little on each point.

1) Hanbury-Brown-Twiss type interferometry for hadronic secondaries should provide information about the spatial size of the system from which they were emitted. The photon-to-pion ratio gives an indication about collective effects, by measuring volume-to-surface emission.

2) Knowing multiplicity and energy of the hadronic secondaries allows us to reconstruct the initial energy density, if we know the longitudinal formation length; the initial transverse size is given by the nuclear radii. The formation length can be estimated on the basis of nuclear stopping experiments.

3) If the system is thermal, the dilepton spectrum should fall exponentially with the pair mass, in contrast to power-low fall-off for Drell-Yan production. Thermalization will also destroy the memory of the collision axis; thermal lepton pairs should therefore have

an isotropic angular distribution. Drell-Yan pairs, in contrast, are predicted to be aligned with the incident beam axis.

4) The initial temperature T_0 can be obtained from the thermal dilepton spectrum, if this shows a clear exponential fall-off ($\exp -M/T_0$) in the pair mass. It should be noted here that thermal dileptons can be emitted from a meson gas as well as from a quark plasma and hence do not provide evidence for plasma formation.

5) The measurement of particle ratios (such as strange to non-strange baryons) may be able to give information on the flavor distribution at the early stages of the process. It appears, however, that details do depend on the nature of the expansion process.

6) The study of the heavy quark resonance peaks in the dilepton spectra ($J/\psi, \psi', \Upsilon, \Upsilon'$) should provide a direct test of a quark deconfinement. In a deconfined medium, a $c\bar{c}$ pair cannot bind to form a J/ψ, and late production at the hadronization point is excluded because there are almost no thermal c or $\bar{c}$ quarks in the system. Hence if there is deconfinement in nuclear collisions, J/ψ production (and similarly that of ψ', Υ and Υ') should show a much suppressed signal-to-background ratio in comparison to that observed in nucleon-nucleon collisions.

7) The transverse momentum distribution of hadronic secondaries is expected to increase with multiplicity, since the latter is related to the initial energy density, and a higher energy density should result in stronger collective flow. The form of the (dN/dy) dependence of p_T may also indicate something about the nature of the transition. Moreover, both momentum distributions and energy flow behavior can be compared directly to the results of hydrodynamic calculations.

In summary: we have thus indeed some basis for the hope that high energy nuclear collisions will provide the key to the analysis of strongly interacting matter.

Table 1

Feature	**Measurement**	**Reference**
Macroscopic size and collective behavior	Interferometry; γ/π ratio	1
Energy density	Multiplicities and energies of secondaries; nuclear stopping	2
Thermal equilibrium	Spectrum and polarization of lepton pairs	3
Initial temperature	Dilepton spectrum	4
Chemical equilibrium	Particle ratio	5
Color deconfinement	$J/\psi, \psi', \Upsilon, \Upsilon'$ production	6
Plasma expansion and hadronization	Momentum distribution of secondaries; p_T vs. dN/dy	7

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