Collective Expansion in High-Energy Heavy-Ion Collisions at CERN SPS Energies

- single particle distributions and two particle interferometry -

ShinIchi Esumi

to be submitted to the Department of Physics for a Doctor of Science Degree at the Hiroshima University

4th of July, 1995

Abstract

Single particle distributions and two particle interferometry are measured in the NA44 experiment at SPS (Super Proton Synchrotron) CERN (European Organization for Nuclear Research). The proton rapidity distribution implies that higher nuclear stopping power is achieved in lead on lead collisions at 160AGeV/c than in sulphur on sulphur collisions at 200AGeV/c. The measured transverse mass distributions of hadrons (pions, kaons and protons) are found to be well described by a hydro-dynamical model with a single freeze-out temperature and a transverse flow velocity for each colliding system. Transverse flow at the central rapidity is seen to be increasing with the size of the colliding system from sulphur on sulphur collisions to lead on lead collisions. Two particle interferometry measurements with sulphur on lead collisions show that the transverse extension of the particle source is similar for pions with higher transverse momentum (and hence without suffering from any resonance effect) and kaons, suggesting the similar freeze-out volume for all hadrons. A scenario for the evolution and the freeze-out of the interaction region during the high-energy heavy-ion collisions is speculated by the above results: high baryon density caused by high nuclear stopping builds up a fire ball with a high pressure and temperature at the mid-rapidity region, then the rescattering effect creates high transverse flow of matter in the fire ball, and finally hadronization will happen at the same freeze-out time and temperature and the same freeze-out transverse volume and velocity for all hadrons.

Contents

Abstract

Contents

1. Introduction
2. NA44 experiment
   - 2.1 Overview
   - 2.2 Target area
   - 2.3 Focusing spectrometer
   - 2.4 Tracking and TOF hodoscopes
   - 2.5 PID and trigger Cherenkov
   - 2.6 Trigger and DAQ
3. Data reduction
   - 3.1 Hodoscope calibration
   - 3.2 Tracking
   - 3.3 Momentum reconstruction
   - 3.4 data reduced file
4. Analysis
   - 4.1 Centrality
   - 4.2 Particle identification
   - 4.3 Single particle distributions
   - 4.4 Acceptance correction
   - 4.5 Normalization
   - 4.6 Two particles interferometry
   - 4.7 Chi-square mapping method
5. Results
   - 5.1 Transverse mass spectra for pions, kaons and protons
   - 5.2 dN/dy for pion
   - 5.3 Proton rapidity distributions
   - 5.4 Two particles interferometry for pions and kaons
6. Model comparison
   - 6.1 comparison with RQMD
   - 6.2 comparison with hydro-dynamical model calculation
7. Conclusions

Acknowledgements

References

Chapter 1. Introduction

The high-energy heavy-ion collisions in the laboratory at BNL (Brookhaven National Laboratory) and CERN (European Organization for Nuclear Research) in 1986 have triggered to explore a new state of matter, called Quark Gluon Plasma (QGP). Quantum Chromo-Dynamics (QCD) calculations predict that at very high energy densities above a few GeV/fm^3, matter undergoes a phase transition to QGP. At low energy densities, quarks and gluons are bounded by the strong force into colorless objects, the confined hadrons. In addition, quarks acquire a large effective mass ($m_u \approx m_d \approx 300$ MeV, $m_s \approx 500$ MeV) via interactions between themselves and the surrounding physical vacuum as a result of chiral symmetry breakdown. When increasing the energy density by increasing the temperature (heating) or by increasing the matter density (compressing), the phase transition to QGP will occur and the true perturbative vacuum of QCD appears, where partons are deconfined and chiral symmetry is approximately restored ($m_u \approx m_d \approx 5$ MeV, $m_s \approx 150$ MeV). As seen from the phase diagram shown in figure 1-1, the early universe presumably underwent this phase transition 10^{-5} seconds after the Big Bang. Critical phenomena which were expected to occur close to a phase boundary, for example long range density fluctuations, might have a bearing on important aspects of cosmology, such as nucleosynthesis, dark matter, and the large-scale structure of the universe. In astrophysics, the dynamics of supernova explosions and the stability of neutron stars (density $\rho \approx 10\rho_{nucleus}$) depend on the compressibility and the equation of state of nuclear matter, and even a possibility is discussed that the core of neutron stars consists of cold QGP. The study of extreme states of matter created in high-energy heavy-ion collisions provides us an opportunity of gaining insight into many important aspects in different fields of physics [1-1].

The figure 1-2 shows a streamer chamber picture of a heavy-ion reaction (200 AGeV/c sulphur on gold) measured in NA35 experiment at SPS CERN. The resulting mess looks very much like an experimentalist's nightmare, hundreds of final-state particles widely distributed with no discernible structure besides the purely kinematic concentration at small angles with respect to the beam direction. Because of the rapid evolution, experimental observable will be an integral over the complete space-time history of the reaction from the first nucleon-nucleon collision until freeze-out. Resulting that disentangling the various contributions to a signal from the different phases indeed presents a formidable challenge. We try to find simplicity in the apparent chaotic final states of A-A reactions applying macroscopic and statistical concepts: from particles to statistical ensembles described by non-perturbative QCD thermodynamics in terms of macroscopic variables such as pressure, temperature and volume.

In order to have a clear picture on the initial stage of the heavy-ion reactions and the succeeding evolutions, various observables in the final state are measured and analyzed on the basis of simulation calculations. In NA44 experiment, single particle momentum distributions and two particle interferometry for hadrons are studied with 450GeV/c proton, 200AGeV/c sulphur and 160AGeV/c lead induced

reactions on to the several different target nuclei. The rapidity distributions can be used as a tool to measure the energy density, and transverse momentum distributions are used for measuring the temperature by assuming the thermalization of the system. Intensity interferometry is a technique pioneered by Hanbury-Brown and Twiss to measure the size of giant stars by optics means. This technique is now used to measure the space-time evolution of the heavy-ion collision by detecting two identical particles simultaneously, the so-called two particles interferometry. The aim of this thesis is to do the high-energy heavy-ion experiment, and to analyze the measured data to extract the physical distributions, then to compare the data with the model calculations (micro-scopic cascade model RQMD and hydro-dynamics) to make interpretations to the experimental results and to understand dynamical evolution which can not be known from the experimental measurement of the final freeze-out stage of the collisions, finally as a result of the above procedures, a scenario of evolution and freeze-out of fire ball in the high-energy heavy-ion collisions by using the both single particle distributions and two particle interferometry with identified hadrons in NA44 experiment at SPS CERN.

One example of calculation from RQMD is shown in the figure 1-3 in order to know the dynamical evolution. The figure shown here is 'light cone' presenting the produced position longitudinal to the beam direction and the produced time measured in the nucleon-nucleon center-of-mass frame of pions in 160 AGeV/c Pb+Pb collisions to visualize the space-time evolution of the colliding matter.

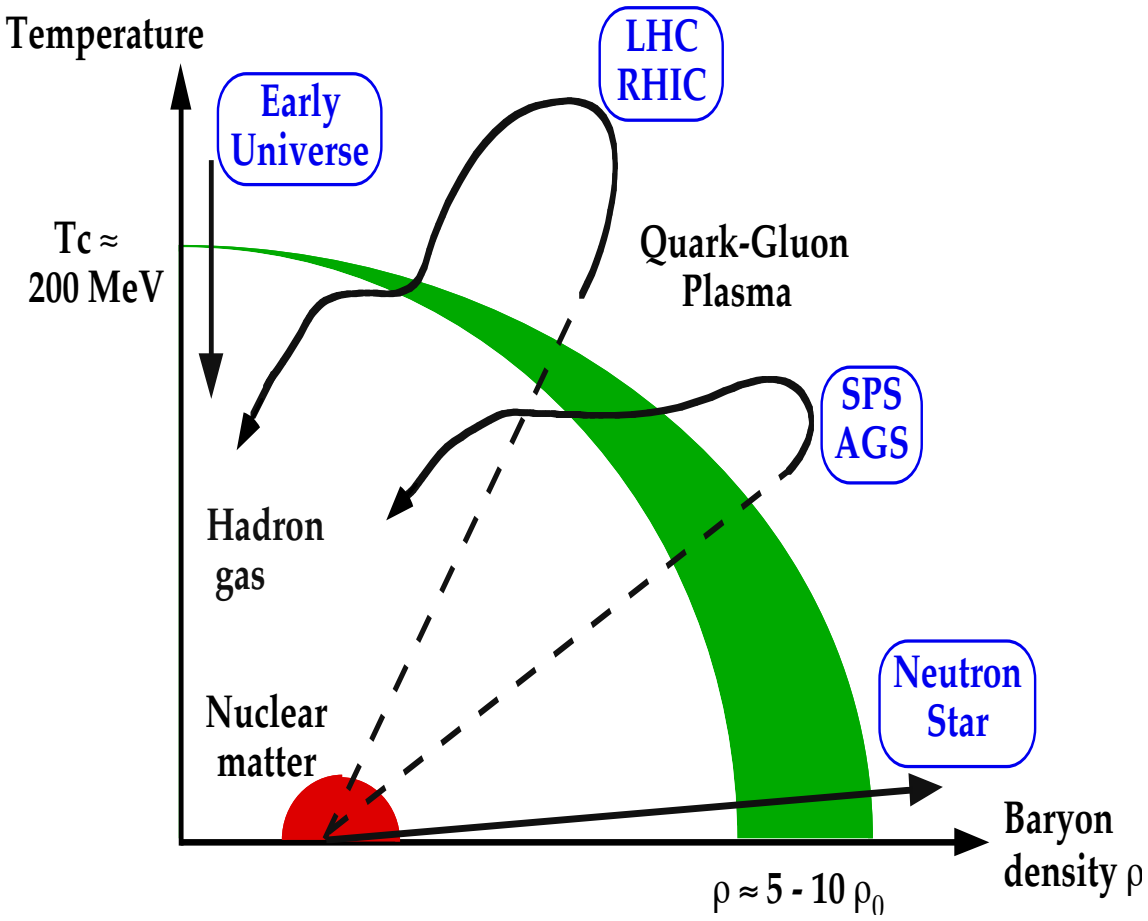

Figure 1-1: phase diagram for QGP

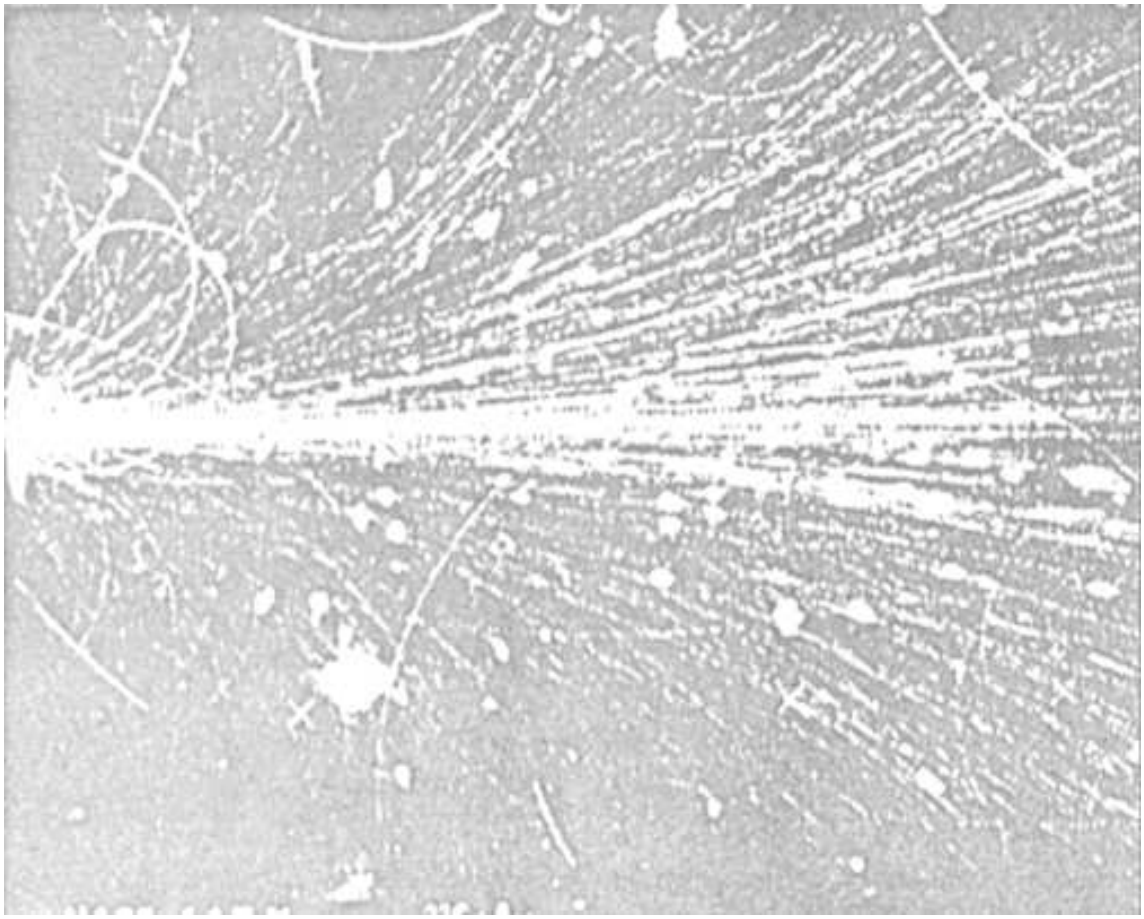

Figure 1-2: 200 AGeV/c sulphur on gold collision

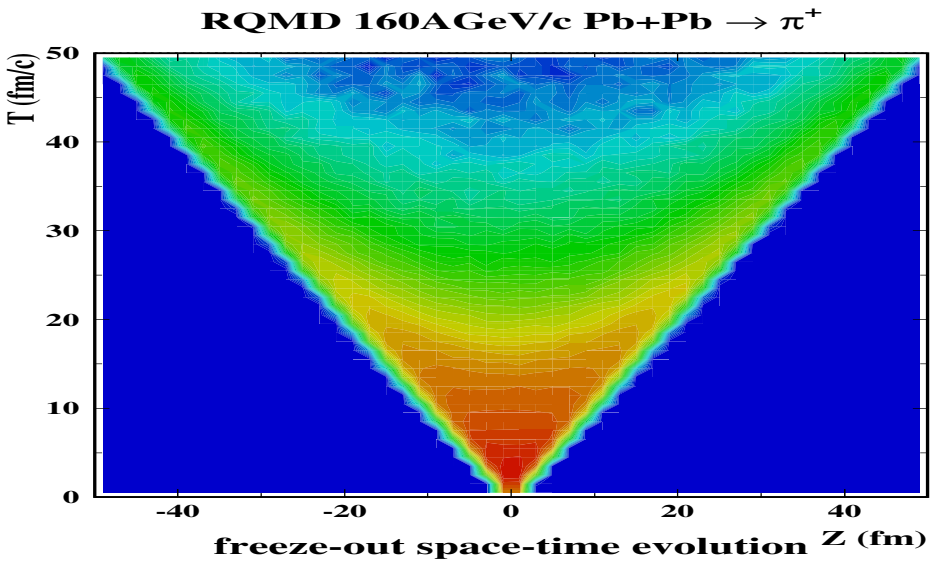

Figure 1-3: light cone created by RQMD event generator