GLOBAL OBSERVABLES AND IDENTIFIED HADRONS IN THE PHENIX EXPERIMENT AT RHIC

HANS-ÅKE GUSTAFSSON

Division of Experimental High Energy Physics,
Department of Physics,
Lund University,
Box 118,
SE-221 00 Lund,
Sweden,
For the PHENIX Collaboration,
E-mail: hans-ake.gustafsson@hep.lu.se

The PHENIX experiment is one of the two large experiments at RHIC. It addresses most of the signals suggested from the Quark-Gluon Plasma. This paper focuses on the measurements of global observables and identified hadron spectra and particle ratios from the two first runs with Au+Au collisions at 130A GeV and 200A GeV. The energy density reached in the most central collisions is about 5 GeV/fm^3. The spectral shape of the transverse momentum spectra as well as the $< p_T >$ dependence on centrality indicate a strong collective expansion of the system in central collisions. The observed number of protons and $\bar{p}$ is about the same indicating that we are approaching a net baryon free region at mid rapidity. A larger number of protons than pions above about 2 GeV/c is observed.

1. Introduction

The aim of high-energy heavy-ion physics is to study strongly interacting matter under extreme conditions of high energy density and high temperature. The theory of strongly interacting matter, Quantum Chromodynamics (QCD), describes colored particles (quarks and gluons) as being confined into hadrons. However, in systems of temperatures above 150-200 MeV and energy densities above 1-2 GeV/fm^3, deconfinement of quarks is expected, i.e. quarks are no longer bound into hadrons but can move "quasi-freely" over volumes where supercritical conditions are prevailing. In high-energy heavy-ion collisions the volumes are of the size of the colliding nuclei. At very high collision energies we expect to observe the transition from hadronic matter to a plasma of deconfined quarks and gluons, the so-called Quark-Gluon Plasma (QGP). This new state of matter is sup-

posed to have been present till about 10^{-5}s after the Big Bang. Thereafter, matter condensed into hadronic matter.
After more than a decade of experiments at CERN SPS the general understanding is that compression effects have been observed and that they are strong enough to reach energy densities in the interesting regime for the phase transition to occur. Most experiments at CERN have shown anomalies that seem to be consistent with the formation of the QGP.
The PHENIX experiment at RHIC addresses all those observables that showed anomalies in the CERN experiments. Since large energy densities are produced at RHIC energies, the QGP should be produced more abundantly compared to SPS energies. PHENIX together with the other RHIC experiments are very well suited to give better evidence of QGP formation.

2. RHIC and PHENIX

The Relativistic Heavy Ion Collider (RHIC) [1] at Brookhaven National Laboratory is the first dedicated high-energy heavy-ion collider in the world. It consists of two indepedent rings of superconducting magnets with a circumference of about 4 km. The collider is accelerating and storing beams of ions ranging from H (proton) to Au at maximum energy of 250 GeV for protons and 100A GeV for Au nuclei. Polarized protons for spin physics studies are also available. The PHENIX experiment [2] is a two arm central spectrometer with an axial field magnet and two muon endcap spectrometers. The experiment covers $|\eta| < 0.35$ for electrons, photons and hadrons and $1.2 < |\eta| < 2.5$ for muons.

3. Global observables

3.1. *Centrality selection*

An important parameter in high-energy heavy-ion collisions is the number of nucleons that interacted inelastically, i.e. the number of participants. The PHENIX experiment is determining this quantity by using Zero Degree Calorimeters (ZDC) in combination with Beam-Beam Conters (BBC). The ZDC measures the energy carried by the spectator neutrons while the BBC measures the number of charged particles in the region $3.1 < |\eta| < 3.9$. The relation between the ZDC and BBC signals could be used to calculate the event classes corresponding to a certain percent of the cross-section [3].

3.2. *Charged particle multiplicity and Transverse Energy distributions*

The production of charged particles in high-energy heavy-ion collisions arises from many different physics processes. Together with contributions from soft processes seen at lower energies also contributions from hard processes, rescattering and shadowing play important roles [4]. The extracted values of $(dN_{ch}/d\eta)_{\eta=0}$ and $(dE_T/d\eta)_{\eta=0}$ per participant pair as a function of the number of participating nucleons are shown in figure 1 for the two energies 130A GeV and 200A GeV. From these distributions the achieved energy density as a function of centrality can be determined by using the Bjorken description [5] based on the longitudinal expansion of the system. For the most central collisions we obtain an energy density of about 5 GeV/fm^3 that is well above the critical value for a phase transition to the QGP of about 1 GeV/fm^3 predicted from lattice QCD calculations. The obtained energy density at RHIC is about a factor 1.5 times higher that what was found at the SPS energy. The yield grows faster than the number of participants indicating a contribution from hard processes. The distributions can be confronted with different model calculations. The high energy QCD gluon saturation model KNL [6] and the two component mini jet model with nuclear shadowing [7] fit the data fairly well while others like the HIJING-model [8] and EKRT saturation model [9] fail to fully describe the data.

4. Identified hadrons

4.1. *Transverse Momentum Spectra*

The produced hadrons carry important information about the collision dynamics along with the evolution of the system from the early stage of the collisions to the final state interactions. The PHENIX experiment has a very good capability for particle identification for both charged hadrons and neutral pions over a broad transverse momentum range.

Figure 2 shows the transverse momentum spectra of protons and $\bar{p}$. The spectra show a smooth behaviour over many orders of magnitude and they can for all centralities be characterized by a Boltzman distribution in m_T. A striking feature of these distributions is that there is almost as many $\bar{p}$ as protons indicating that we are approaching a net baryon free region at central rapidity. The same smooth behaviour of the transverse momentum spectra is also seen for the other particle species.

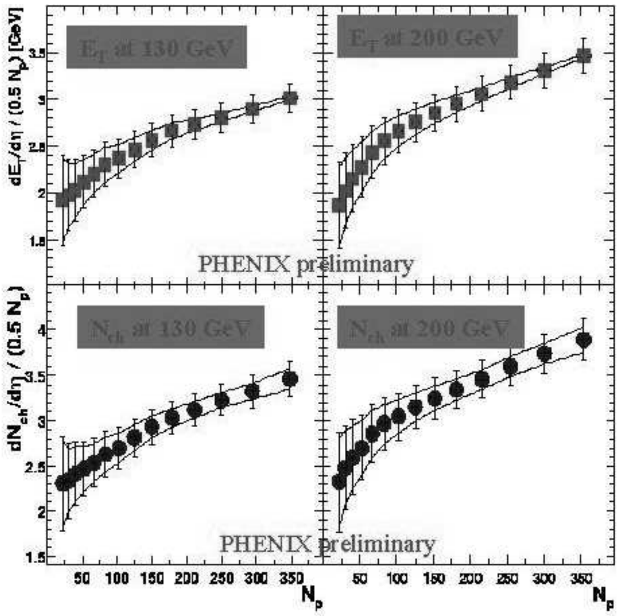

Figure 1. $dE_T/d\eta$ (top panel) and $dN_{ch}/d\eta$ (bottom panel) per participant pair versus the number of participants N_p measured at $\sqrt{s_{NN}}$= 130 GeV (left panel) and $\sqrt{s_{NN}}$= 200 GeV (right panel)

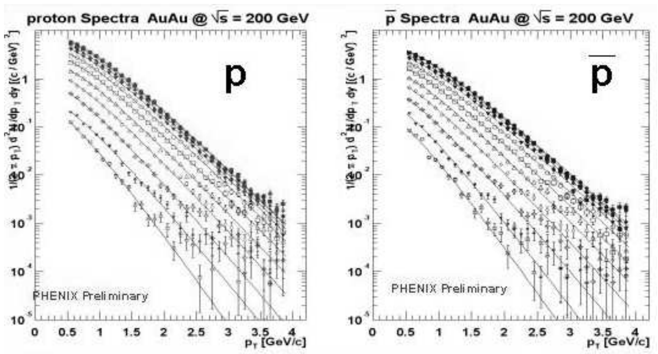

Figure 2. Transverse momentum spectra for protons (left panel) and $\bar{p}$ (right panel) for different centrality classes ranging from the most central at the top to the most peripheral at the bottom

4.2. *Mean Transverse Momentum*

In order to quantify the observed mass dependence of the slopes of the transverse momentum spectra, the mean transverse momenta $< p_T >$ were extracted for the different centralities and for different particle species. The results as a function of the number of participating nucleons are shown in figure 3. In both the 130 GeV and 200 GeV results, $< p_T >$ increases from the most peripheral to the most central and tends to saturate at large N_{part}. The mean transverse momentum also increases with particle mass which suggests the existence of a collective hydrodynamical expansion of the system.

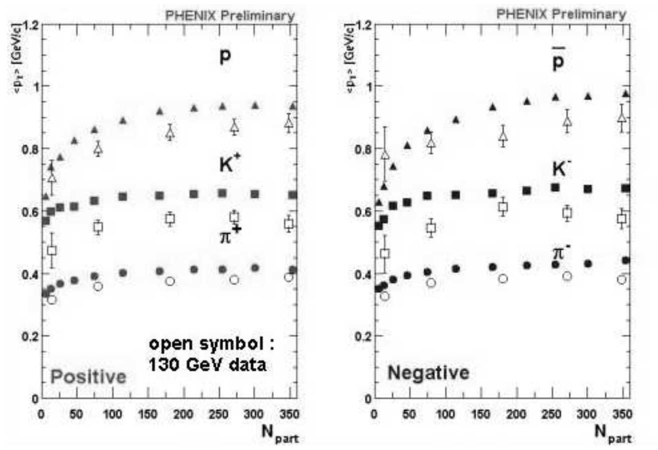

Figure 3. Mean transverse momentum of identified charged hadrons as a function of the number of participants N_{part}. The left panel shows the positive particles and the right panel shows the corresponding negative particles. Open symbols are the 130 GeV data and the closed are the 200 GeV data.

5. Particle Ratios

Particle ratios provide information on the chemical properties of the collision system. Ratios like π^-/π^+, K^-/K^+, $\bar{p}$/p and others have been measured as a function of centrality by PHENIX. Independently of particles species, centrality or energy, the particle ratios are almost flat as a function of p_T with the exception for the $\bar{p}$/p ratio for peripheral collisions where a decrease at high p_T is observed.

The particle composition at high p_T is interesting in order to understand the baryon production, system evolution and the interplay between soft and hard processes as well as jet quenching in hard processes. Figure 4 shows the p/π ratio as a function of transverse momentum for central and peripheral collisions. The data has a clear centrality dependence and the ratio for central collisions reach unity at a p_T of 2-3 GeV/c, while the ratio for peripheral collisions saturates at a value of 0.3-0.4. The observed behaviour in central collisions may be attributed to a combination of two effects namely a larger flow effect for protons as compared to pions and a pion suppression effect at high p_T.

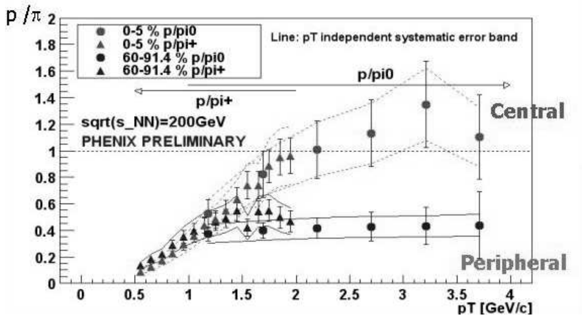

Figure 4. p/π ratios for central and peripheral collisions as a function of transverse momentum.

6. References

1. www.bnl.gov/rhic.
2. www.bnl.gov/rhic/PHENIX.htm.
3. K. Adox et al., *Phys. Rev. Lett.* **86**, 3500 (2001).
4. X.N. Wang and M. Gyulassy, *Phys. Rev.* **D44**, 3501 (2001).
5. J.D. Bjorken, *Phys. Rev.* **D27**, 140 (1983).
6. D. Kharzeev and M. Nardi, *Phys. Lett.* **B503**, 121 (2001) and D. Kharzeev and E.Levin *Phys. Lett.* **B523**, 79 (2001).
7. S. Li and X.N. Wang, *Phys. Lett.* **B527**, 85 (2002).
8. X.N. Wang and M. Gyulassy, *Phys. Rev. Lett.* **86**, 3498 (2001).
9. K.J. Eskola et al., *Nucl. Phys.* **B570**, 379 (2001) and *Phys. Lett.* **B497**, 39 (2001).