CENTRALITY DEPENDENCE OF THERMAL PARAMETERS IN HEAVY ION COLLISIONS AT SPS AND RHIC[1]

B. KÄMPFER[a], J. CLEYMANS[b], K. GALLMEISTER[c], S. WHEATON[b]

[a] *Forschungszentrum Rossendorf, PF 510119, 01314 Dresden, Germany*
[b] *University of Cape Town, Rondebosch 7701, Cape Town, South Africa*
[c] *Institut für Theoretische Physik, Universität Giessen, Giessen, Germany*

Abstract

We analyze the centrality dependence of thermal parameters describing hadron multiplicities, hadron spectra and dilepton spectra in heavy-ion collisions at SPS and RHIC energies.

1 Introduction

It has been shown that different observables of relativistic heavy-ion collisions can be well described by statistical-thermal or hydrodynamical models. In such a way, a selected subset of a large number of observables can be reproduced by a small number of characteristic parameter, such as temperature, density or flow velocity. It is the subject of the present note to pursue this idea and to analyze the centrality dependence of the thermal parameters describing hadron multiplicities, hadron spectra and dilepton spectra. This will provide further information about the effects of the size of the excited strongly interacting system and help in the systematic understanding of the experimental data.

2 Hadron Multiplicities

Hadron multiplicities can be reproduced [1, 2] by the grand-canonical partition function $\mathcal{Z}_i(V, T, \mu^\alpha) = \mathrm{Tr}\left[\exp\{-(\hat{H} - \mu^\alpha Q_i^\alpha)/T\}\right]$, where $\hat{H}$ is the statistical operator of the system, T denotes the temperature, μ^α and Q_i^α stand for the chemical potentials and corresponding conserved charges. The net-zero strangeness and total electric charge constrain the components μ^α. The particle numbers are accordingly

$$N_i^{\rm prim} = V(2J_i+1)\int \frac{d^3p}{(2\pi)^3}\, dm_i \left[\gamma_s^{-S_i} \mathrm{e}^{\frac{E_i-\mu^\alpha Q_i^\alpha}{T}} \pm 1\right]^{-1} \mathrm{BW}(m_i), \qquad (1)$$

---

[1] Supported by BMBF 06DR921.

where we include phenomenologically a strangeness saturation factor γ_s (with S_i as the total number of strange quarks in hadron species i) to account for incomplete equilibration in this sector, $E_i = \sqrt{\vec{p}^2 + m_i^2}$; BW is the Breit-Wigner distribution (to be replaced by a δ function for stable hadrons). The final particle numbers are $N_i = N_i^{\rm prim} + \sum_j {\rm Br}^{j\to i} N_j^{\rm prim}$ due to decays of unstable particles with branching ratios ${\rm Br}^{j\to i}$. Such a description can be justified for multiplicities measured over the whole phase-space, since many dynamical effects cancel out in ratios of hadron yields.

We have analyzed two data sets: (i) NA49 4π multiplicities of $\langle\pi\rangle = \frac{1}{2}(\pi^+ + \pi^-)$, $K^\pm$, $\bar{p}$, ϕ, and $N_{\rm part}$ (taken as sum over all baryons) in 6 centrality bins in the reaction Pb(158 AGeV) + Pb [3, 4] (it should be emphasized that protons are not included in our analysis [5] as they are not only to participants in non-central collisions), and (ii) PHENIX mid-rapidity densities of $\pi^\pm$, $K^\pm$, and $p^\pm$ in the reaction Au + Au at $\sqrt{s} = 130$ AGeV in 5 centrality bins [6]. Results of our fits are displayed in fig. 1. Note that our model tends to underestimate the NA49 ϕ yields for peripheral collisions.

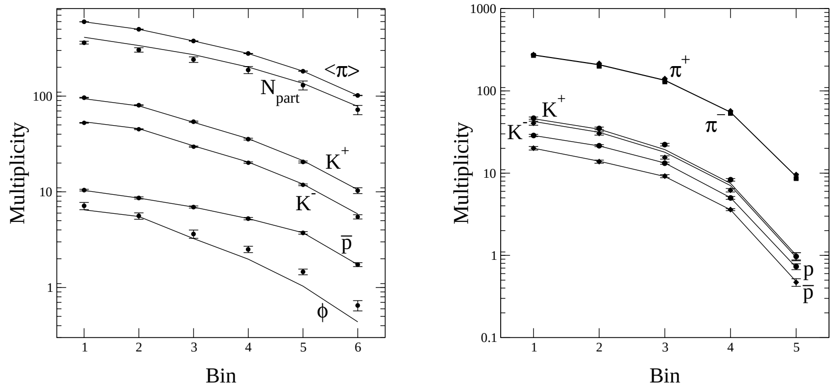

Fig. 1: Comparison of NA49 data (left panel, symbols, [3, 4]) and PENIX data (right panel, symbols, [6]) with our model (lines).

A comparison of the individual thermal parameters of both data sets is displayed in fig. 2. Most remarkable is the drop of the baryo-chemical potential μ_B and the rise of the strangeness saturation factor γ_s when going from $\sqrt{s} = 17$ AGeV to 130 AGeV. The parameter μ_B is fairly independent of the centrality. T seems to stay constant for $\sqrt{s} = 17$ AGeV, while at 130 AGeV it rises with $N_{\rm part}$. The strangeness saturation factor and, of course, the volume-equivalent system size increase significantly with centrality. (Note the fiducial meaning of the volume for the mid-rapidity data of PHENIX.) Despite the rather limited set of analyzed hadron species, the extracted thermal parameters describe

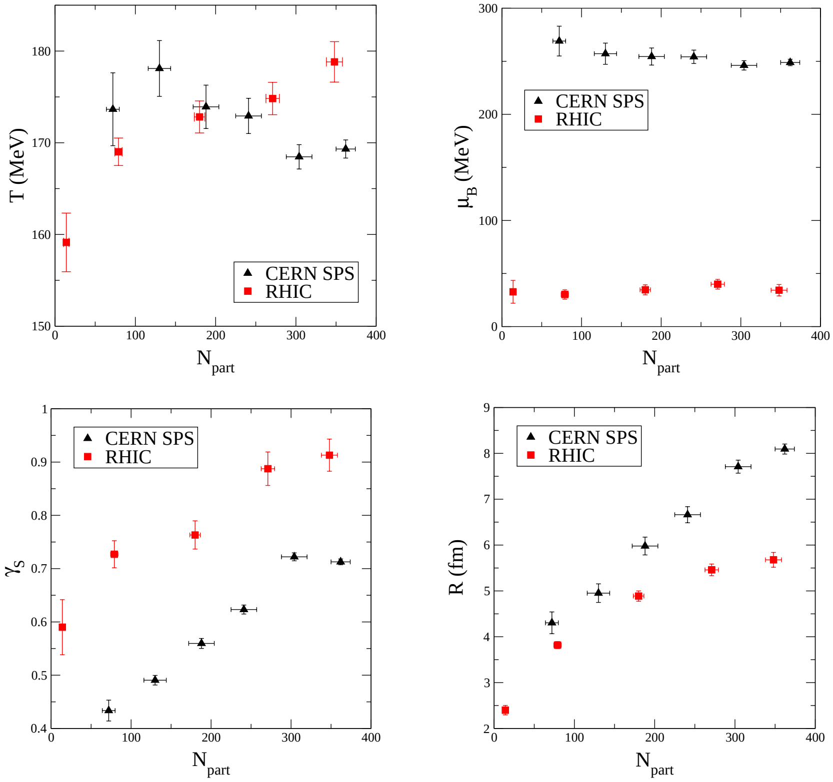

Fig. 2: Temperature, baryo-chemical potential, strangeness saturation factor and volume-equivalent radius as a function of $N_{\rm part}$. Triangles (squares) are for the NA49 (PHENIX) data [3, 4] ([6]).

other hadron yields, which are at our disposal in central collisions, fairly well.

3 Hadron Spectra

For the reaction Pb(158 AGeV) + Pb, transverse momentum spectra at mid-rapidity are available also in 6 centrality bins [7]. However, the raw data analysis in [7] needs refinements and cross checks[2]. We, therefore, mention here only that our preliminary analysis along the lines in [8] seems to point to a larger transverse flow with increasing centrality.

---

[2] We are grateful to R. Stock, P. Seyboth, F. Sikler, and P. Jacobs for explaining us the status of the data analyses.

4 Intermediate-Mass Dileptons

As pointed out in [10], the dilepton spectra can be analyzed in the same spirit as the hadron multiplicities and hadron momentum spectra, i.e., one discards any detail of the dynamics and asks only for a simple parameterization. As a result, one gets for the thermal dilepton spectrum [10]

$$\frac{dN}{d^4Q} = \frac{5\alpha^2}{36\pi^4} N_{\rm dil} \exp\left\{ -\frac{M_\perp \cosh(Y - Y_{\rm cms})}{T_{\rm dil}} \right\}, \tag{2}$$

where Q is the lepton pair's four-momentum, $M_\perp$ its transverse mass and Y its rapidity; $Y_{\rm cms}$ denotes the fire ball rapidity, and $N_{\rm dil}$ is a normalization factor characterizing the space-time volume of the fire ball; flow effects are negligible for invariant mass spectra. In [10, 11] we have shown that the space-time averaged temperature parameter $T_{\rm dil} \approx 170$ MeV (i.e., a value coinciding with the chemical freeze-out temperature) provides a <u>common</u> description of the low-mass CERES data and the intermediate-mass NA50 data at $\sqrt{s} = 17$ AGeV; also the WA98 photon data are consistent with this value. It was, therefore, a surprise to us that our analysis of the efficiency corrected and centrality binned NA50 data [9] <u>separately</u> give as optimum fit a temperature scale in the order of 250 MeV,[3] see figs. 3 and 4. At this temperature the spectral shapes of thermal dileptons and dileptons from correlated decays of open charm mesons are nearly identical within the NA50 acceptance.

We have also checked the temperature sensitivity of the parameterization eq. (2) by analyzing the new low-mass dilepton CERES data [12] for the reaction Pb(40 AGeV) + Au and find, when using as important ingredient the hadronic cocktail, $T_{\rm dil} = 145$ MeV (which also coincides with the chemical freeze-out temperature deduced for this beam energy), see fig. 5.

5 Summary

The analyses of hadron multiplicities, hadron momentum spectra and intermediate-mass dilepton spectra point to a centrality independence of the chemical freeze-out temperature and baryo-chemical potential for $\sqrt{s} = 17$ AGeV, while the strangeness saturation increases with centrality for both $\sqrt{s} = 17$ AGeV and 130 AGeV. The very preliminary data on transverse momentum spectra of hadrons indicate a stronger flow in central events at $\sqrt{s} = 17$ AGeV. The NA50 data indicate that the space-time averaged temperature determining the shape of dilepton spectra stays fairly independent of centrality.

---

[3] $T_{\rm dil}$ in bins 1 and 2 (very peripheral collisions) deviates from this value. The extracted values are not safe and depend sensitively on the normalization of the Drell-Yan yield.

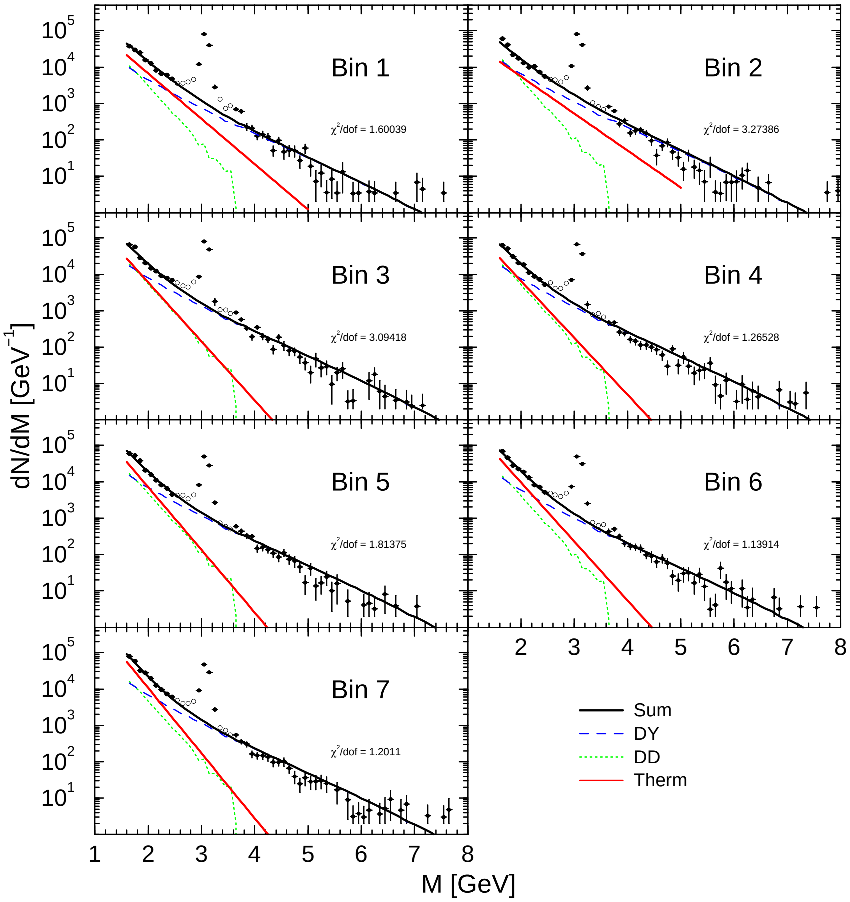

Fig. 3: Fits of the thermal contribution according to eq. (2) to the NA50 data [9] in 7 centrality bins ($E_T = 19, 36, 52, 67, 80, 93, 110$ GeV for bin 1 - 7). The Drell-Yan yield and the open charm contributions are calculated as described in detail in [10, 11].

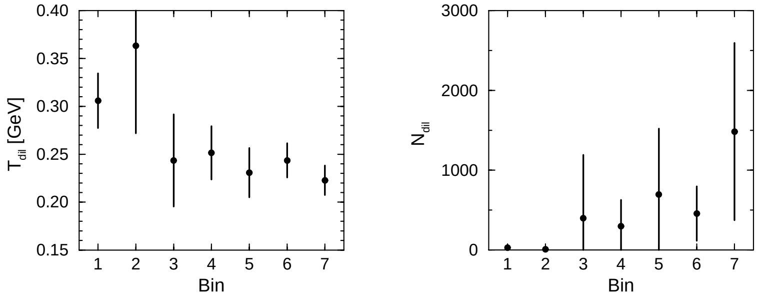

Fig. 4: Temperature and space-time normalization factor used in fig. 3.

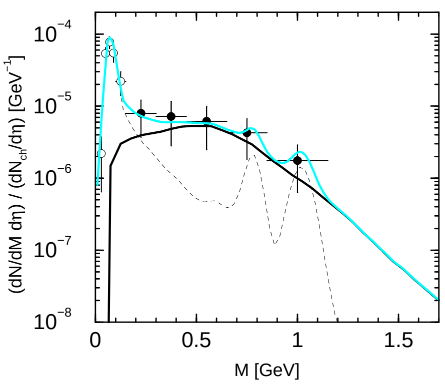

Fig. 5: Comparison of the parameterization eq. (2) (solid black curve) with the CERES data [12] for the reaction Pb (40 AGeV) + Au. The thin dashed line is the hadronic cocktail, the gray curve shows the sum.

References

[1] P. Braun-Munzinger et al., Phys. Lett. **B344** (1995) 43, **B365** (1996) 1, **B465** (1999) 15, **B518** (2001) 415
J. Cleymans, K. Redlich, Phys. Rev. Lett. **81** (1998) 5284

[2] F. Becattini, J. Cleymans, A. Keranen, E. Suhonen, K. Redlich, Phys. Rev. **C64** (2001) 024901

[3] F. Sikler (NA49 collaboration), Nucl. Phys. **A661** (1999) 45c

[4] V. Friese (NA49 collaboration), Nucl. Phys. **A698** (2002) 487c

[5] J. Cleymans, B. Kämpfer, S. Wheaton, Phys. Rev. **C65** (2002) 027901

[6] K. Adcox et al. (PHENIX collaboration), nucl-ex/0112006

[7] G. Cooper, Ph. D. thesis, Berkeley 2000, unpublished

[8] B. Kämpfer, hep-ph/9612336
B. Kämpfer, A. Peshier, O.P. Pavlenko, M. Hentschel, G. Soff, J. Phys. **G23** (1997) 2001

[9] L. Capelli (NA50 collaboration), Ph. D. thesis, University of Lyon, 2000

[10] K. Gallmeister, B. Kämpfer, O.P. Pavlenko, C. Gale, Nucl. Phys. **A688** (2001) 939, **A698** (2002) 424c

[11] K. Gallmeister, B. Kämpfer, O.P. Pavlenko, Phys. Lett. **B473** (2000) 20, Phys. Rev. **C62** (2000) 057901

[12] K. Filimonov et al. (CERES collaboration), nucl-ex/0109017,
S. Damjanovic et al. (CERES collaboration), nucl-ex/0111009