Thermalization and Flow in 158 AGeV Pb+Pb Collisions

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The WA98 experiment at the CERN SPS measures Pb+Pb Collisions at 158 AGeV. The scaling properties of the charged particle multiplicity at midrapidity with the number of participants are studied using the SPMD and the MIRAC detector. Neutral pion spectra obtained from the LEDA detector are compared to hydrodynamical parametrizations. The collective flow in the target fragmentation region has been studied using the Plastic Ball detector. The results exhibit a strong dependence on centrality and rapidity.

1. Introduction

Ultra-relativistic heavy-ion collisions produce dense matter which is expected to form at sufficiently high energy densities a deconfined phase of quarks and gluons, the Quark Gluon Plasma. A necessary condition for such a phase transition is local equilibrium which might be achievable through rescattering of produced particles. Hints for thermalization can most easily identified by studying the observables as function of centrality. The high $p_T$ pion production is expected to be dominated by hard parton scattering but has recently been shown to be also explainable by a thermal model with hydrodynamic expansion. The comparison of the WA98 $\pi^0$ data with hydrodynamic models provides constraints on the partition of excitation energy in terms of temperature and an average flow velocity. Such a finite thermalized system without any external pressure will necessarily expand and the thermal pressure will generate collective motion which will be reflected in the momentum spectra of the final hadrons. Thus a part of the thermal excitation energy will be converted into collective motion of the hadrons.

2. Scaling of Global Variables

There seem to be qualitative changes in the behaviour of heavy-ion reactions once a certain system size is attained. Strangeness production is enhanced in S+S reactions compared to p+p, but seems to saturate for even larger nuclei\cite{1}. Recent results from the WA98 experiment\cite{2} show significant change of the shape of the $\pi^0$ $p_T$ spectrum in peripheral Pb+Pb collisions compared to p+p data. However, from semi-central Pb+Pb reactions with about 50 participating nucleons up to the most central reactions the shape remains unchanged. In the present analysis the centrality has been selected with the transverse energy $E_T$ measured in the calorimeter MIRAC. Fig. \ref{fig:scaling} shows the scaling behaviour of the charged particle multiplicity $dN_{ch}/d\eta$ with the number of participants $N_{part}$. It can
be seen that $dN_{ch}/d\eta$ follows a power law with the number of participants. The extracted exponent from the data is $\alpha = 1.07$. On the bottom part of fig. 1 the same analysis performed with VENUS 4.12 [3] is displayed. While the simulation result also obeys roughly a power law scaling, the agreement is not as good, and the scaling exponent appears to be significantly larger than that obtained from the experimental data.

### 3. Neutral Pion Spectra

The neutral meson spectra are mainly influenced by thermal and chemical freeze-out in the final state. In the analysis of central reactions of Pb+Pb at 158 $A$GeV it is seen that both predictions of perturbative QCD [4,5] and hydrodynamical parameterizations [5] can describe the measured neutral pion spectra very well. It is particularly astonishing to observe that on the one hand the pQCD calculation gives a good description also at relatively low momenta while on the other hand the hydrodynamical parameterization would yield a sizable contribution even at very high momenta.

Fig. 2a shows a comparison of the neutral pion spectra to a fit of a hydrodynamical parameterization including transverse flow and resonance decays [6]. Using the default Gaussian profile the best fit is obtained with $T = 185$ MeV and $\langle \beta_T \rangle = 0.213$. Fig. 2b shows the best fit parameters as a filled circle – the corresponding $2\sigma$ contour is also shown. The figure also contains the $1\sigma$ allowed region from the $m_T$ dependence of the transverse radii extracted by negative pion interferometry with the WA98 negative tracking arm [7]. The interferometry constraints are very similar to those given in [8] – they favour relatively large transverse flow velocities. Such large velocities are only compatible with the neutral pion spectra, if one assumes a very different spatial profile. However, this
would result in rather low temperatures, thus these parameters are very sensitive to the used profile°.

4. Collective Flow

If the initial state of the evolution is azimuthally asymmetric, as in semi-central heavy-ion collisions, this property will be reflected in the azimuthal asymmetry of the final state particle distributions. The strength of the collective flow will yield information on the nuclear equation of state during the expansion. Collective flow development follows the time evolution of pressure gradients in the hot, dense matter. Thus, collective flow can serve as a probe to provide information on the initial state and to which extent the reaction zone might be thermalized. In particular, the formation of a Quark Gluon Plasma during the early stages of the collision is expected to result in reduced pressure gradients due to a softer nuclear equation of state which results in a reduced collective motion/10/.

Since the Plastic Ball Detector in the WA98 experiment is azimuthally symmetric it is ideal to perform the analysis of azimuthal anisotropies. Fig. 3 shows the centrality dependence of the directed flow in terms of the average transverse momentum \( \langle p_x \rangle \). For protons the maximum directed flow is observed in reactions with intermediate centrality. The corresponding impact parameter of \( b \approx 8 \text{fm} \) results twice as large as observed for AGS energies/12/. Since the observed \( \langle p_x \rangle \) of pions is positive it indicates that the pions are preferentially emitted away from the target spectators, this is called anti-flow/13/. The rapidity dependence of directed flow is given in fig. 4. In addition, pion data measured with the tracking arm in the WA98 experiment/14/ at midrapidity and data near midrapidity measured by the NA49 collaboration/15/ are shown. The maximum flow is observed in the fragmentation regions, while it rapidly decreases near midrapidity. The data follow a
Gaussian distribution.

Hence for a complete description of the rapidity distribution of the collective flow the formerly used slope at midrapidity (e.g. \( d\langle p_x \rangle / dy \big|_{y=0} \)) is not sufficient. It is more reasonable to use the three parameters of the Gaussian distribution to describe the data. The peak position reflects the beam momentum, the peak height gives the strength of the flow and the width of the distribution provides information on how much the participants and the spectators are involved in the collectivity.

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