

Energy dependence of transverse particle production from SPS to RHIC

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Transverse momentum spectra up to 4.5 GeV/c were measured around midrapidity in Pb+Pb collisions at $\sqrt{s_{NN}} = 17.3$ GeV, for π^\pm , p , \bar{p} and K^\pm , by the NA49 experiment. The nuclear modification factors R_{AA} , $R_{AA/pA}$ and R_{CP} were extracted and are compared to RHIC results at $\sqrt{s_{NN}} = 200$ GeV. The modification factor R_{AA} shows a rapid increase with transverse momentum in the covered region. The modification factors $R_{AA/pA}$ and R_{CP} shows a saturation well below unity in the π^\pm channel. The extracted R_{CP} values follow the 200 GeV RHIC results closely in the available transverse momentum range for all particle species, except for π^\pm . For π^\pm above 2.5 GeV/c transverse momentum, the measured suppression is smaller than that observed at RHIC. The K^+/π^+ and K^-/π^- ratios were also extracted from the data and are compared to the 200 GeV RHIC results. The values of the former ratio is above, whereas the values of the latter ratio is slightly below the 200 GeV RHIC points.

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1. Introduction

One of the most interesting features discovered at RHIC is the suppression of particle production at high transverse momenta in central nucleus-nucleus reactions, relative to peripheral ones as well as to p+nucleus and to p+p collisions [2, 3, 4, 5, 6]. This is generally interpreted as a sign of parton energy loss in hot and dense strongly interacting matter.

The aim of the presented analysis is to investigate the energy dependence of these effects via a systematic study of Pb+Pb reactions at top ion-SPS energy, 158A GeV ($\sqrt{s_{NN}} = 17.3$ GeV), with the CERN-NA49 detector [7]. A similar study has been published by the CERN-WA98 collaboration for the π^0 channel [8, 9]. Our analysis extends the existing results to all charged particle channels, i.e. π^\pm , p , \bar{p} and K^\pm .

Invariant yields were extracted as a function of transverse momentum p_T in the range from 0.3 to 4.5 GeV/c in the rapidity interval $-0.3 \leq y \leq 0.7$ (midrapidity), at different collision centralities [1, 10]. Identification of particle types is crucial, because the particle composition of hadron spectra changes rapidly with transverse momentum and differs significantly from that observed at RHIC energies.

Using the identified single particle spectra from [1] and the charged pion spectra from [11, 12, 13], the nuclear modification factors were calculated. These are defined as

$$R_{A_1+A_2/A_3+A_4}^{BC} = \frac{\langle N_{BC}(A_3 + A_4) \rangle}{\langle N_{BC}(A_1 + A_2) \rangle} \cdot \frac{\text{yield}(A_1 + A_2)}{\text{yield}(A_3 + A_4)},$$

$$R_{A_1+A_2/A_3+A_4}^W = \frac{\langle N_W(A_3 + A_4) \rangle}{\langle N_W(A_1 + A_2) \rangle} \cdot \frac{\text{yield}(A_1 + A_2)}{\text{yield}(A_3 + A_4)},$$

where $\langle N_{BC} \rangle$ and $\langle N_W \rangle$ are, respectively, the average number of: binary collisions and wounded nucleons, calculated for the reactions $A_1 + A_2$ and $A_3 + A_4$ [14, 15]. R_{AA} , R_{pA} and R_{CP} are used to denote the special cases $R_{A+A/p+p}$, $R_{p+A/p+p}$ and $R_{\text{Central/Peripheral}}$ for $A + A$ reactions, whereas $R_{AA/pA}$ abbreviates $R_{A+A/p+A}$. These were calculated and compared with the $\sqrt{s_{NN}} = 200$ GeV RHIC results [3, 5].

Also the K^+/π^+ and K^-/π^- ratios were extracted from the data and are compared to $\sqrt{s_{NN}} = 200$ GeV RHIC results of [3].

2. Analysis details

The centrality of events was determined using the energy of projectile spectators deposited in a downstream Veto Calorimeter (VCAL). Careful study of the detector response and Glauber calculations were performed in order to obtain $\langle N_{BC} \rangle$ and $\langle N_W \rangle$ as a function of centrality [1, 14, 15].

Due to the rapid decrease of the p_T spectra, special care was taken to achieve good signal-to-noise ratio in the high- p_T region. Possible background tracks were rejected with a twofold filtering procedure: (1) discontinuous tracks were discarded, and (2) tracks originating from the acceptance border were rejected [1, 10].

Particles were identified at the spectrum level, using specific ionization ($\frac{dE}{dx}$) fits [1, 10].

The resulting particle spectra were corrected for feed-down (5 to 30%), decay loss (20% to 0%), tracking inefficiency (below 10%), non-target contribution (below 5%), and geometric acceptance. The fake-rate, momentum smearing, and momentum scale uncertainty proved to be negligible. The correction details are discussed in [1, 10].

After full correction, the systematic errors are about 2.2% for π^+ , π^- and K^- , 3.7% for p , 4.5% for K^+ , and 6.5% for \bar{p} [1, 10].

3. Results and discussion

The inclusive particle spectra of [1, 11, 12, 13] allow to calculate the nuclear modification factors R_{AA} , R_{pA} , $R_{AA/pA}$ and R_{CP} for top ion-SPS energy. Additionally, a close-by energy data set [16] was considered for the p+W/p+p yield ratios. These results are compared to similar quantities at the top RHIC energy [3, 5]. All of this is shown in Fig. 1, along with pQCD-based energy loss model predictions for R_{CP} [17].

It is seen that the R_{AA} and the R_{pA} at the top ion-SPS energy increase monotonically with p_T in the covered region. This is sometimes referred to as the Cronin effect. A widely accepted explanation for this phenomenon is initial multiple scattering on either partonic or hadronic level depending on the valid particle production picture. It is also observed that the R_{AA}^{BC} points stay below R_{pA}^{BC} , whereas the R_{AA}^W points are above R_{pA}^W both at top ion-SPS energy and at RHIC. The R^W modification factors start approximately from unity.

If the multiple scattering interpretation of the Cronin effect is valid, it is natural to expect it to contribute much less to the nuclear modification factors $R_{AA/pA}$ and R_{CP} . Therefore, if looking for nuclear effects other than multiple scattering, these ratios should also be considered. The $R_{AA/pA}^{BC}$ and R_{CP}^{BC} stay well below unity at top ion-SPS energy, but show much less suppression than at the top RHIC energy in the π^\pm channel above $p_T > 2 \text{ GeV}/c$. For other particle channels, the behavior of the R_{CP}^{BC} points at SPS and at RHIC seem to be rather similar, except for \bar{p} , which may be affected by the larger systematic errors due to the antiproton detection technique at the experiment NA49. The pQCD-based energy loss model seems to give a fair description of the R_{CP} data points at SPS energy.

To further test the predictions of the pQCD-based model, other particle ratios may also be looked at. It is found that the \bar{p}/π^- data are not reproduced, as shown in Fig. 2.

To get information about the strangeness production differentiated in centrality and p_T , the K^+/π^+ and K^-/π^- ratios were also extracted from the data, and are compared to $\sqrt{s_{NN}} = 200 \text{ GeV}$ data [3]. All this is shown in Fig. 3. A monotonic increase of both ratios with centrality and p_T is observed. The K^-/π^- points at top ion-SPS energy are slightly below the top RHIC energy points, whereas the K^+/π^+ points at top ion-SPS energy are above the RHIC points.

4. Summary

The measured R_{AA} and R_{pA} data show a monotonic increase in the covered p_T region at SPS energy. The R_{AA}^{BC} points stay below R_{pA}^{BC} . The $R_{AA/pA}^{BC}$ and R_{CP}^{BC} stay well below unity at SPS energy for π^\pm , but much less suppression is observed than at RHIC above $p_T > 2 \text{ GeV}/c$.

The R^W data start from one and R_{AA}^W is above R_{pA}^W both at SPS and at RHIC energy.

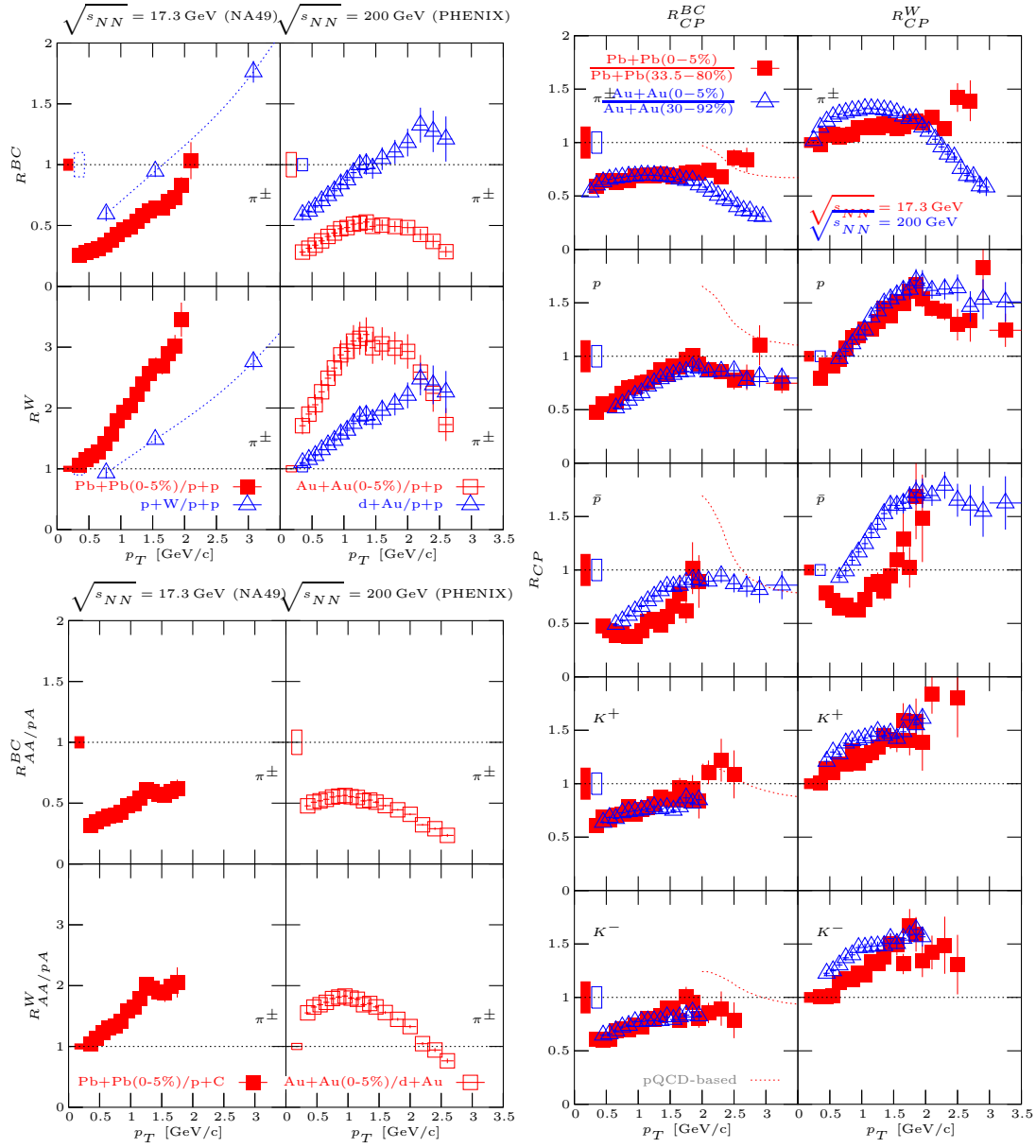


Figure 1: R_{AA} (top left), $R_{AA/pA}$ (bottom left), and R_{CP} (right) nuclear modification factors, measured at $\sqrt{s_{NN}} = 17.3$ GeV [1, 11, 12, 13], and compared to $\sqrt{s_{NN}} = 200$ GeV data [3, 5]. To supplement the existing SPS energy data, a $\sqrt{s_{NN}} = 19.4$ GeV p+W/p+p data set was also used [16]. The dotted lines in the top left panel are drawn to guide the eye. The dotted lines in the right panel indicate a pQCD-based energy loss model prediction [17].

The R_{CP}^{BC} data follow the RHIC points closely, except for \bar{p} particles and for π^\pm at $p_T > 2$ GeV/c.

The R_{CP}^{BC} points are explained by pQCD-based energy loss calculation as in [17], however the produced-baryon/meson ratios are not reproduced. Possibly pQCD is not applicable in this kinematic region.

The K^+/π^+ and K^-/π^- ratios show a monotonic increase in centrality and p_T both at SPS

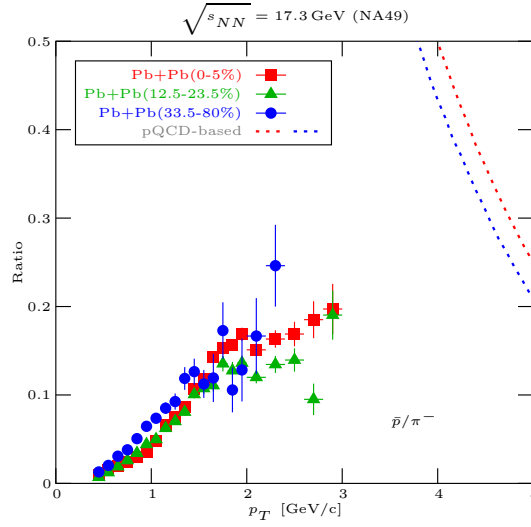


Figure 2: Produced-baryon to meson ratios in Pb+Pb collisions, at $\sqrt{s_{NN}} = 17.3$ GeV [1]. The dotted lines indicate a pQCD-based energy loss model prediction [17].

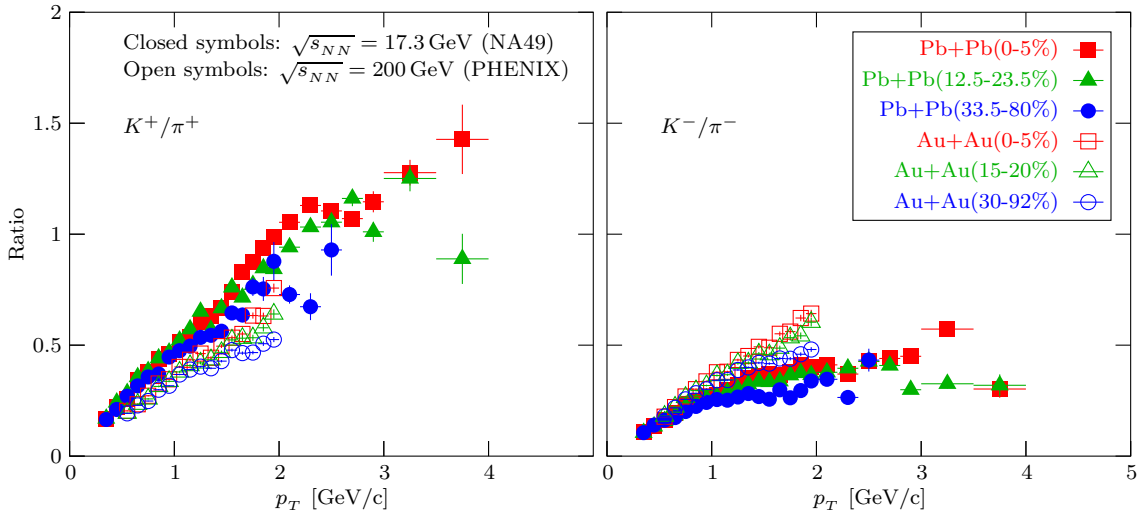


Figure 3: K^+/π^+ and K^-/π^- ratios in Pb+Pb collisions, at $\sqrt{s_{NN}} = 17.3$ GeV [1] and at $\sqrt{s_{NN}} = 200$ GeV [3].

and RHIC energy. The K^-/π^- points are slightly below the RHIC points, whereas the K^+/π^+ points are above the points measured at RHIC energy.

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