Coulomb Effect in Single Particle Distributions

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Abstract

Single particle distributions from heavy-ion collisions show the effect of Coulomb interactions on the final state. While a rather strong effect is seen in the ratio π^-/π^+ from central 158A·GeV/c Pb+Pb collisions, at most a small enhancement is found in the ratios from S+S and S+Pb collisions at 200A·GeV/c.

A number of interesting phenomena have been proposed and possibly observed in the region of low transverse momenta from 100 to 300 MeV/c. Enhanced production of pions at low p_T has been observed in heavy ion ([1],[2]) and proton-nucleus collisions [3] at various bombarding energies. While this enhancement is understood as arising from resonance decays in heavy ion collisions, there are predictions of modifications for kaon and antiproton spectra which have not yet been confirmed experimentally. Several models, developed to describe new physics in heavy ion collisions, predict phenomena at low p_T. For example, due to the attractive vector potential in the σ model, Shuryak predicted a low p_T enhancement in the negative charged kaon spectrum [4]. Several years ago, V. Koch *et al* [5] predicted an antiproton enhancement at p_T near zero due to mean-field effects in heavy ion collisions.

With the advent of truly heavy beams, these predicted phenomena may now be observable. However, the large amount of positive charge in the heavy systems can introduce additional distortions of the particle distributions. The Coulomb interaction between the emitted particles and the charged system produced may inflence the final particle spectra. Though it represents a background to the study of other phenomena at low p_T, it is important to understand this before discussing new physics from heavy ion collisions. In addition, observation of the Coulomb interaction may provide information on the collision dynamics, such as collective expansion, and the net charge of the system produced in the central region of the collisions. In this paper, we investigate the Coulomb interaction through the ratio of negative to positive pions produced in high energy heavy ion collisions at the CERN SPS.

The NA44 spectrometer is a magnetic focusing spectrometer with two angular settings (44 and 131 mrad). The magnetic system includes two room temperature dipoles and three superconducting quadrupoles; the momentum ranges cover $\pm$ 20% around the nominal values of 4 and 8 GeV/c. Particles originating from the target are focused at a plane about 10 meters downstream and detected by a tracking system consisting of a Cherenkov counter - pad chamber - strip chamber - time-of-flight (TOF) complex. Particle identification is done with two threshold Cherenkov counters (C1 and C2) and two highly segmented TOF hodoscopes [6]. The time-of-flight start signal is derived from a Cherenkov beam counter [7] with a time resolution of $\approx$ 35 ps. The coverage (transverse momentum p_T vs. rapidity y) is optimized by combination of spectrometer momentum and angular settings. For the 4 and 8 GeV/c low angle settings, the NA44 spectrometer acceptance for pions is shown in Fig.1 in transverse momentum p_T vs. rapidity y. The momentum resolution is approximately 10MeV/c and the TOF counters have an average time resolution of 100ps. More details of the spectrometer can be found elsewhere (see reference [8]).

Identified charged pions were used to construct the ratio π^-/π^+ as a function of transverse kinetic energy ($m_T - mass$). The result is shown in Fig. 2. In order to maximize the transverse momentum coverage, both 4 and 8 GeV/c low angle(44 mrad) pions were used in the rapidity window 3.0$\leq y \leq$ 4.1 (see dot-dashed lines in Fig. 1). Consequently, particles with $p_T \geq$ 0.2GeV/c are used from the 8 GeV/c setting and particles with $p_T \leq$ 0.2GeV/c are used from the 4 GeV/c setting where electrons were vetoed online with a threshold Cherenkov counter. It should be noted that the two settings overlap and the results in the overlap region agree.

Figure 2 (a) shows the ratio π^-/π^+ from 158A$\cdot$GeV/c Pb+Pb central collisions. A pronounced enhancement in the π^-/π^+ ratio at low transverse kinetic energy is evident. For comparison, the ratios π^-/π^+ from 200A$\cdot$GeV/c S+Pb[2] and S+S collisions are shown in Fig. 2(b) and (c), respectively. These data were taken with the same spectrometer and similar analysis methods were used. The centralities of the data discussed here are 10$\pm$2%, 14$\pm$2%, and 15$\pm$1.5% of total cross section for S+S, S+Pb and Pb+Pb collisions, respectively. Unlike the case for Pb+Pb collisions, the ratios from the lighter collision systems are found to be almost flat with respect to $m_T - mass$. A similar feature was reported [9] from lower energy collisions.

The enhancement observed in Pb+Pb collisions might be expected if low p_T π^+ are pushed towards higher p_T by a large net positive charge at midrapidity; conversely, negative pions would be attracted. The Coulomb interaction potential energy is relatively small compared to the mean kinetic energy of the particles, therefore the effect is likely only visible at transverse momentum near zero. In central Pb+Pb collisions, if stopping is significant, a large amount of positive charge from the beam and target nuclei will concentrate around the mid-rapidity ($y_{cm} = 2.9$) of the colliding system. The magnitude and transverse kinetic energy extent of the peak in the π^-/π^+ ratio is determined by the charge and size of the system created in the central region. The maximum net positive charge in the fireball is roughly $Z = 30$ and 50 for S+S and S+Pb collisions, respectively. On the other hand, the total charge can easily go up to $Z = 120 - 150$ in Pb+Pb collisions. The result observed in Fig. 2(a) reflects the larger projectile size of the Pb, and also the higher nuclear stopping power in Pb + Pb collisions[10] compared to that of lighter ion collisions.

Ratios of K^-/K^+ and $\overline{p}/p$ were also studied in Pb+Pb collisions. The distributions are flat with respect to the transverse momentum. At beam energy of 0.25 - 2 A$\cdot$GeV [11], heavier particles were also found to be insensitive to the Coulomb effect. It has been suggested that the ratio for heavy particles should not be sensitive to the Coulomb field [12].

Strong Coulomb effects were observed at beam energy of 0.25 - 2 A$\cdot$GeV (see references [11]-[15]) in pion spectra and several theoretical models were developed incorporating final stage Coulomb interaction into the collision dynamics (see [16] and [17]). However, a quantitative description of the effect at the SPS energies does not exist. Instead, the Gamow method is typically used to describe the experimental phenomena [18].

It is interesting to test if the effect observed in the ratio π^-/π^+ might be caused by hadronic interactions. We used the cascade model RQMD(v1.08) [19] to calculate the charged pion distributions in central Pb+Pb collisions. RQMD is a microscopic transport model, and includes the physics of string-string and hadron-hadron interactions including resonance effects, however the Coulomb interaction is not considered. The result of the calculated ratio π^-/π^+ is shown in Fig. 3 as solid line. A realistic centrality selection and spectrometer acceptance were used in the model calculation. Long lived hyperons (Λ and Σ for example) were included in the calculation. The slight excess of the π^- above π^+ in this calculation is mainly due to Λ decays, where about 25% of the pions from decays survive the reconstruction. It can be seen from the figure that the calculated ratio has an enhancement as $p_T \to 0$. The peak is about 1.1, much smaller than the data. Without the long lived hyperon decays, RQMD calculations predict a flat distribution. We conclude that the observed enhancement at p_T near zero in the π^-/π^+ ratio is mostly caused by the Coulomb interaction rather than hadronic interactions[1]. Both the NA44 recent measurement [10] and RQMD show a large number of protons around mid-rapidity indicating a large amount of positive charge in the central region. This supports the assertion that the effect observed in the data is indeed due to Coulomb interactions plus some contributions from hyperon decay.

In summary, the ratios of single pion transverse momentum distributions from the heaviest-ion collisions show Coulomb interactions with the emitting source in the central rapidity region. A strong effect is seen in π^-/π^+ from central Pb+Pb collisions, but at most a small effect is found in the pion ratios from either S+S or S+Pb collisions. The hadronic transport model RQMD, without Coulomb interactions, predicts a relatively small peak at $p_T \to 0$, mainly due to the Λ-decays. Both the observed Coulomb effect and a large number of Λ's may be considered a direct consequence of the high stopping power reached in the heavy

[1]However, one should bear in mind that the RQMD model is a classical hadronic transport model. Possible new physics, such as medium effects or chiral symmetry restoration are not included.

system.

Although the data are consistent with Coulomb effects, they do not rule out other possibilities. In the heavy Pb+Pb system, the baryon density is high, and the production, mean-field, and annihilation processes will affect the final distributions. Before one can draw final conclusions from the study of single particle distributions, the above possibilities should be analyzed in detail.

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References

[1] T. Akesson *et al.*, Z. Phys. **C46**, 361(1990); J. Harris *et al.* Nucl. Phys. **A498**, 133c(1989); S. Ahmad *et al.* Phys. Lett. **B281**, 29(1992); J. Barrette *et al.*, Phys. Lett. **B351**, 93(1995).

[2] H. Boggild *et al.*, for the NA44 collaboration, Z. Physik **C.**, in print.

[3] D. Chaney *et al.*, Phys. Rev. **D11** 3210(1979); D.A. Garbutt *et al.*, Phys. Lett. **B67**, 355(1977).

[4] E.V. Shuryak, Nucl. Phys. **A533**, 761(1991).

[5] V. Koch, G. Brown, and C.M. Ko, Phys. Lett. **B265**, 29(1991).

[6] T. Kobayashi and T. Sugitate, NIM **A287**, 389(1990).

[7] N. Maeda *et al.*, NIM **A346**, 132(1994).

[8] H. Beker *et al.*, Phys. Lett. **B302**, 510(1993).

[9] M. Gonin, for the E802/E866 collaboration, Nucl. Phys. **A566**, 601c(1994) and F. Videbæk, for the E802/E866 collaboration, Nucl. Phys. **A591**, 249c(1995).

[10] NA44 Collaboration, to be published.

[11] S. Nagamiya *et al.*, Phys. Rev. **C24**, 971(1981).

[12] V. Koch, Nucl. Phys. **A591**, 531c(1995).

[13] C. Muntz, Ph.D thesis. TH Darmstadt, GSI report 93-4, ISSN 0171-4546.

[14] J.P. Sullivan *et al.*, Phys. Rev. **C25**, 1499(1982).

[15] O. Hashimoto *et al.*, Phys. Rev. **C49**, 420(1994).

[16] M. Gyulassy and S.K. Kauffmann, Nucl. Phys. **A362**, 503(1981).

[17] B.A. Li, Phys. Lett. **B346**, 5(1995).

[18] M.G.H Mostafa and C.Y. Wong, Phys. ReV. **C51**, 2135(1995).

[19] In the past, RQMD predictions agree with experimental observables fairly well. See H. Sorge *et al.*, Phys. Lett. **B243**, 7(1990) and H. Sorge *et al.*, Phys. Lett. **B271**, 37(1991).

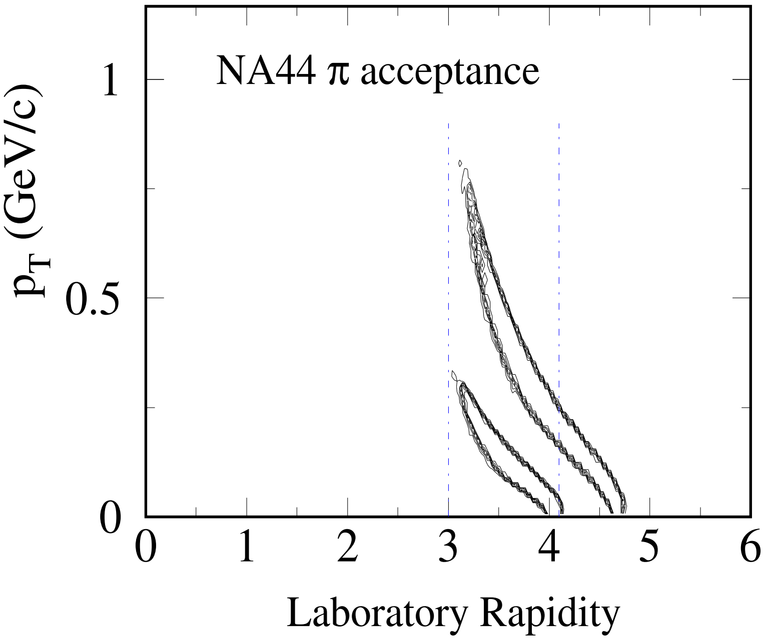

Figure 1. NA44 pion acceptance in rapidity y and transverse momentum p_T. Both 4 and 8 GeV low angle settings are shown in the figure. In this analysis, only pions in $3.0 \leq y \leq 4.1$ *were used. For the 158A·GeV/c Pb beam, y =* 0.0 *and 5.8 correspond to target and beam rapidities.*

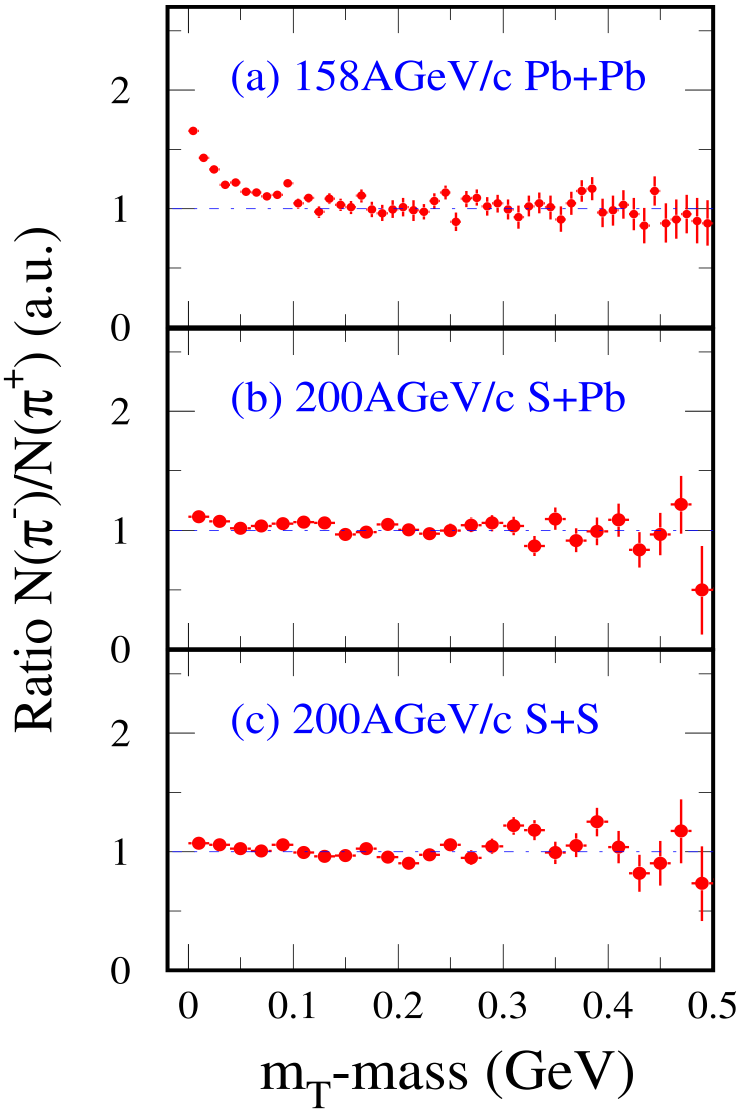

Figure 2. Experimental ratios π^-/π^+ from (a) 158A·GeV/c Pb+Pb, (b) 200A·GeV/c S+Pb, and (c) 200A·GeV/c S+S collisions. The data are arbitrarily normalized to unity at high m_T.

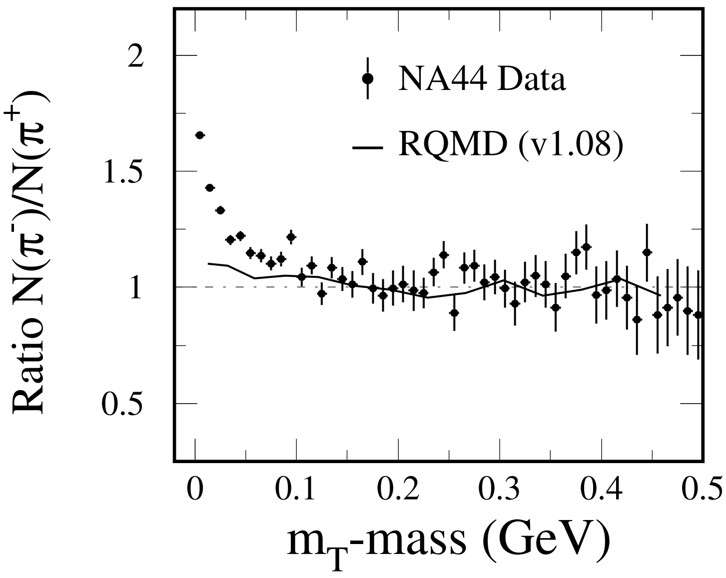

Figure 3. Data (filled circles) compared with results from the RQMD (v1.08) predictions (solid line). The hyperon decay probabilities and the spectrometer acceptance are included in the model calculation.