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ON THE SIZE OF THE PION EMITTING SOURCE IN HEAVY ION COLLISIONS AT 1 AGeV*

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A method to determine the size of the pion emitting source in central collisions from the energy differential π^-/π^+ ratio is proposed. This approach was applied to the experimental results for a medium-mass and a heavy-mass system.

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Information on the size of the excited nuclear matter (fireball) formed in heavy ion collisions is usually obtained by Hanbury–Brown and Twiss correlation experiments [1]. In this contribution we propose an alternative method to determine the size of the pion emitting source in central collisions from the energy differential π^-/π^+ ratio which reflects the Coulomb energy of the particles in the field of the reaction zone. A large data set on π^-/π^+ ratios has been measured in nucleus–nucleus collisions in the last 15 years. The influence of Coulomb effects was examined for different reaction systems and energies but all experiments had drawn rather qualitative conclusions in discussing the Coulomb effect caused by the projectile spectator [2] or the expanding fireball [4–7].

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We have measured double differential production cross sections of positively and negatively charged pions measured for the mass systems ^{58}Ni+$^{\rm nat}$Ni and ^{197}Au+^{197}Au at 1.0 AGeV incident kinetic energy. Based on these data we discuss the influence of the Coulomb force acting on oppositely charged pions and we propose a method to relate the size of the pion emitting reaction zone to the strength of the experimentally deduced Coulomb energy.

The experiments were performed with the Kaon spectrometer [10] at the heavy ion synchrotron SIS at GSI (Darmstadt). The spectrometer covers a momentum-dependent solid angle of $\Delta\Omega = 15$–35 msr with a momentum resolution of $\delta p/p \simeq 1\%$ over the full momentum range. The momentum acceptance is $(p_{\rm max} - p_{\rm min})/p_{\rm min} = 2$ and the measured laboratory momentum varies between 0.15 and 1.6 GeV/c. The particle identification is performed by the reconstruction of the trajectory and by the determination of the particle velocity. The collision centrality is determined by means of the hit multiplicity of charged particles in the Large Angle Hodoscope, a 96-fold segmented detector close to the target covering polar angles between 200 and 840 mrad. In this angular range participating protons are the most abundant charged particles.

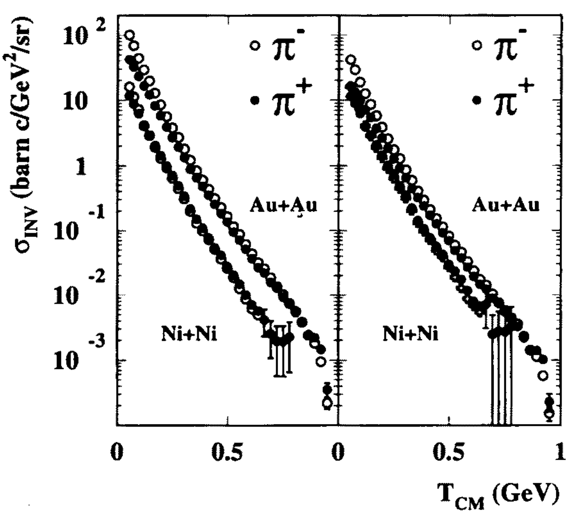

Fig. 1. Inclusive (left) and central (right) invariant production cross section for negative and positive pions from the reaction systems ^{58}Ni+^{nat}Ni (lower) and ^{197}Au+^{197}Au (upper) at an incident beam energy of 1.0 A·GeV and at $\theta_{CM} = (90\pm10)$degrees (preliminary). For the Au+Au system the selected events represent the most central 0.8 barn reaction cross section.

Figure 1 shows the invariant production cross section as a function of the kinetic energy for both reaction systems at mid-rapidity in inclusive (left) and central reactions (right). For the Au+Au system, the π^- yield clearly exceeds the π^+ yield at lower energies and approaches it at higher energies.

The energy differential ratios of π^- to π^+ are shown in Fig. 2 for the most central 0.8 barn of the reaction cross section in the Au+Au system (right) and an equivalent cut for the Ni+Ni system (left). The π^-/π^+ ratio is 3.1±0.3 (1.5±0.2) for Au+Au (Ni+Ni) at the lowest measured energy and drops to about 1.1±0.1 (0.90±0.1) at higher energies.

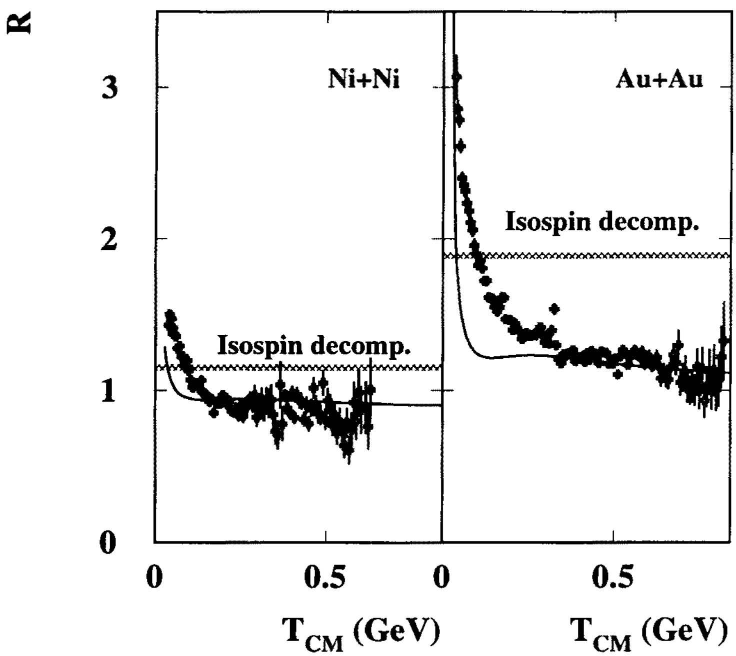

Fig. 2. π^-/π^+ ratio for the reaction systems ^{58}Ni+^{nat}Ni and ^{197}Au+^{197}Au as a function of the pion kinetic energy measured at $\theta_{\rm lab} = 44 \pm 4$ degrees (preliminary). The horizontal lines give the value of the isospin decomposition (see text). The curve shows the calculated ratio for a Coulomb energy of 12 MeV (24 MeV) for the Ni+Ni (Au+Au) system.

The energy integrated π^-/π^+ ratio $R^{\rm tot}_{\rm exp} = (d^2\sigma(\pi^-)/d\Omega)/(d^2\sigma(\pi^+)/d\Omega)$ is determined by extrapolating the energy distribution to $T_{CM} = 0$ assuming a Maxwell–Boltzmann shaped distribution.

The experimental values shown in Table I agree rather well to the ratios derived from an isospin decomposition of the reactions at the given beam energy as described in [11]. This motivates the assumption that the primor-

TABLE I

Number of protons N_p, neutrons N_p, isospin z-component, and ratios of the momentum-integrated cross sections of π^-/π^+ for the studied systems at an incident beam energy of 1.0 AGeV and a laboratory angle of $(44 \pm 4)^\circ$. (Note that for the Ni+Ni system only the most probable isotope is given) The last column gives the ratios derived from an isospin decomposition.

system	N_p	N_n	T_z	$R^{\rm tot}_{\rm exp}$	$R^{\rm tot}_{\rm iso}$
^{58}Ni + $^{\rm nat}$Ni	28	30	-4/2	1.22±0.05	1.15
^{197}Au + ^{197}Au	79	118	-78/2	1.94±0.05	1.90

dial π^-/π^+ ratio is given by the isobar model for all energies and that the observed energy dependence is determined by Coulomb effects. Therefore, we will propose in the following a method to extract the freeze-out radii from the experimental π^-/π^+ ratio.

Following the ideas in [3], the Coulomb force disturbes the pion spectra by modifying the kinetic energies of the particles and the available phase space. One derives the following relations for the measured cross sections

$$\frac{d^3\sigma}{dp^3} = \sigma(\vec{p}) = \sigma_0(\vec{p_0}(\vec{p})) \cdot \left|\frac{\partial^3 p_0}{\partial^3 p}\right| ;$$
$$\left|\frac{\partial^3 p_0}{\partial^3 p}\right| = \left|\frac{p_0 E_0 \partial E_0}{p E \partial E}\right| = \frac{p_0 E_0}{pE} \tag{1}$$

with the undisturbed momentum (total energy) $\vec{p_0}$ (E_0).

The Jacobian in equation (1) is evaluated relativistically using the identity $p\partial p = E\partial E$. If the differential cross section follows an exponential distribution $\sigma_0 \propto \exp(-E_0/T)$ with an inverse slope parameter T the resulting π^-/π^+-ratio is

$$R = \frac{\sigma_-}{\sigma_+} = R^{\rm tot}_{\rm iso} \cdot \exp(-\frac{2V_{\rm coul}}{T}) \cdot \frac{p_+ E_+}{p_- E_-} \tag{2}$$

with

$$E_\pm = E_0 \pm V_{\rm coul}; \qquad p_\pm = \sqrt{E_\pm - m^2}.$$

In the relativistic limit $p \cdot c \gg m \cdot c^2$ and with the Coulomb energy being small compared to the total particle energy the transcendental equation (2) for $V_{\rm coul}$ can be solved, leading to

$$V_{\rm coul} = \frac{T}{2} \cdot \frac{1}{1 - 2T/E_0} \cdot \ln(R_{\rm iso}^{\rm tot}/R).$$

With these relations it is possible to determine the variation in the kinetic energy of charged particles in the Coulomb field of the charged reaction volume. For the Coulomb energy derived in the high-energy limit and taking the measured slope parameter for each pion energy the results are shown as lines in figure 2. The high-energy slopes have been determined by Maxwell-Boltzmann fits to the data in the kinetic energy range above 0.44 GeV. The results are T = (77±4) MeV for the Au+Au system and T = (82±2) MeV for the Ni+Ni system. It is worth to mention that the slopes for the inclusive measurements in the Au+Au system agree very well with the results for π^0 production measured in the same system at the same incident energy [9].

The π^-/π^+ ratios are described well in the energy range between 0.3 and 0.8 GeV kinetic energy by a Coulomb potential of 11±2 MeV (25±2 MeV) for the Ni+Ni (Au+Au) system whereas the ratio at lower energies is clearly underestimated. This leads to the conclusion that the Coulomb field acting on low energy pions is weaker than the field acting on high energy pions. It indicates a more dilute charge distribution at freeze-out for low energy pions (possibly at an later stages of the reaction), as indicated by other observables in [8].

In the next step we want to estimate the radius of the pion emitting source from these results. For central collisions the number of participating charges $Z_{\rm part}$ has been measured as 110±8 for the Au+Au system and 43±4 for the Ni+Ni system. In a simple assumption of an emission of pions from the surface of a charged sphere the Coulomb potential is given by

$$V_{\rm coul} = \alpha\hbar c \frac{Z_{\rm part}}{r_{\rm eff}} \quad \text{and effective radii of}$$

$$r_{\rm eff} = (\mathbf{6.3 \pm 1.1})\text{fm (Au+Au)} \quad \text{and} \quad r_{\rm eff} = (\mathbf{5.6 \pm 1.0})\text{fm (Ni+Ni)}$$

are obtained for pion kinetic energies above 0.3 GeV.

To summarize, we have presented a new approach to determine the size of the fireball during pion freeze-out and applied it to our experimental results for a medium-mass and a heavy-mass system. Future work will be dedicated to more systematics for the beam energy dependence, mass of the reaction system, and variations with the CM emission angle.

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