THE SPECTATOR-INDUCED ELECTROMAGNETIC EFFECT ON KAON PRODUCTION IN HEAVY ION COLLISIONS*

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The effect of shape modification of charged meson spectra, induced by the presence of the spectator charge in nucleus–nucleus collisions, was studied experimentally and theoretically in our precedent works. The effect was found to cause very large modifications in spectra of light mesons produced in the forward direction. It was also found that due to its sensitivity to initial conditions imposed on final state particle emission, it can be used as a new source of information on the space-time evolution of the non-perturbative particle production process. In this paper, we present the first estimates of the spectator-induced electromagnetic effect on *strange* meson spectra. We discuss its sensitivity to the space-time evolution of strangeness production. Finally, we explore the possibility of using this effect as a new source of information on the evolution of strangeness in space and in time.

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1. Introduction

This paper will be largely focused on phenomena occurring in "peripheral" Pb+Pb collisions, by which reactions involving, say, fifty participating nucleons will be meant[1]. The unquestionable profit from studying such reactions is well known to the community. Most often they are used as a reference for central heavy ion collisions, where much larger systems can be created in the course of the reaction (see *e.g.* [2]). However, here we wish to emphasize another advantage of peripheral collisions, which is the presence

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[1] This is to be clearly differentiated from "ultra-peripheral" heavy ion collisions [1].

of two different “regions” in the reaction, namely the *participant zone* and the *spectator systems*. This gives a unique opportunity of studying, among others, the physical phenomena related to the *interplay* between these two regions. One such phenomenon will be the topic of this paper.

2. Charged pion ratios

Fig. 1 (a) shows the ratios of positive over negative pions in the final state of the peripheral Pb+Pb collision as measured by the NA49 experiment[2] at $\sqrt{s_{NN}} = 17.3$ GeV. Details of the experimental analysis can be found in [4]. As specified therein, the centrality of these collisions is estimated to a mean number of wounded nucleons [5] equal to 54 ± 11 and a mean impact parameter of 10.9 ± 0.5 fm. The π^+/π^- ratios are drawn as a function of the Feynman variable $x_{\mathrm{F}} = \frac{2p_L}{\sqrt{s_{NN}}}$ for a few fixed values of transverse momentum[3]. One should underline the experimental quality of this dataset, its important advantages being its very large coverage in terms of longitudinal momentum (for pions at low p_{T}, $x_{\mathrm{F}} = 0.4$ is well above beam rapidity), as well as in terms of low transverse momentum (down to $p_{\mathrm{T}} = 0$ sharp).

The π^+/π^- ratios shown in Fig. 1 (a) form a two-dimensional, rapidly varying structure in x_{F} and p_{T}, with a deep minimum in the vicinity of $x_{\mathrm{F}} = 0.15$, at lowest transverse momentum. This minimum is close to zero, which right away excludes the strong interaction from being the unique factor defining the observed phenomena. The latter interaction being constrained by isospin symmetry, the π^+/π^- ratio cannot take arbitrarily low values in the final state of the Pb+Pb interaction, where the number of participating protons and neutrons are roughly comparable (40% over 60%, respectively). As the position of the minimum ($x_{\mathrm{F}} = 0.15 \approx \frac{m_\pi}{m_N}$) *corresponds to pions moving longitudinally with spectator velocity*, this points at the spectator system as the source of the effects seen in the experimental data.

Indeed, the high electric charge of the spectator system induces a large *electromagnetic effect*: positive pions are *repelled* while negative pions are *attracted* into spectator vicinity, resulting in the apparently very large distortion of the corresponding π^+/π^- ratios, visible in Fig. 1 (a).

To confirm this hypothesis, we constructed a highly simplified model of the peripheral Pb+Pb reaction, including the electromagnetic interaction induced by the two spectator systems. In this model, Fig. 1 (b), the spectator systems were assumed as two uniformly charged spheres while the emission of pions took place from the interaction point, after a fixed emission time t_{E} which was a free parameter of the model [6, 7]. As it can be seen from

[2] We note the existence of one earlier but far less detailed measurement at the SPS [3].

[3] All the kinematical variables will always be defined in the collision c.m.s.

Fig. 1 (c), even this very simplified simulation gives a fairly reasonable description of the data. This confirms quantitatively our interpretation, and has important consequences which will be discussed below.

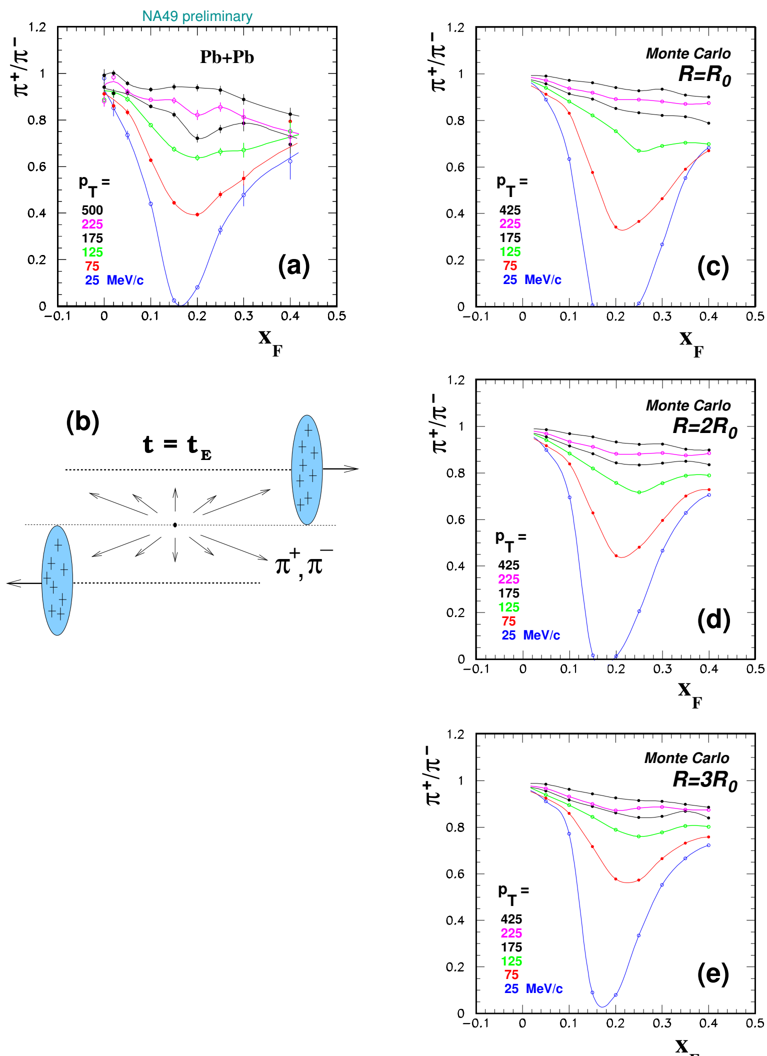

Fig. 1. (a) π^+/π^- ratio measured in peripheral Pb+Pb collisions [7]. The values of pion transverse momentum are listed from the top to the bottom curve. (b) Simplified model of the peripheral Pb+Pb reaction [6]. (c) π^+/π^- ratio simulated assuming the spectator system as a uniform sphere with standard nuclear density [7]. (d), (e) the same as in (c) but assuming the spectator sphere to be extended by factors of two and three, respectively, together with the corresponding decrease of its density [8].

Fig. 2 (left panels) shows the distortion of the π^+/π^- ratios computed within the framework of our model over the full range of x_F ($-1 < x_F < 1$), and for different values of the pion emission time t_E. As it is clearly apparent from the figure, imposing different initial conditions on the electromagnetic effect results in evident differences in the shape of the π^+/π^- ratios in the final state. The exact shape and position of the valley at $x_F \approx 0.15$, seen before in the data in Fig. 1 (a), and most of all, the values of charged pion ratios at large absolute x_F, change with t_E. As the latter quantity is, more realistically speaking, equivalent in our model to the distance between the pion formation zone and the spectator system, we conclude that *the spectator-induced electromagnetic effect brings new information on the evolution of the pion production process in space and in time.*

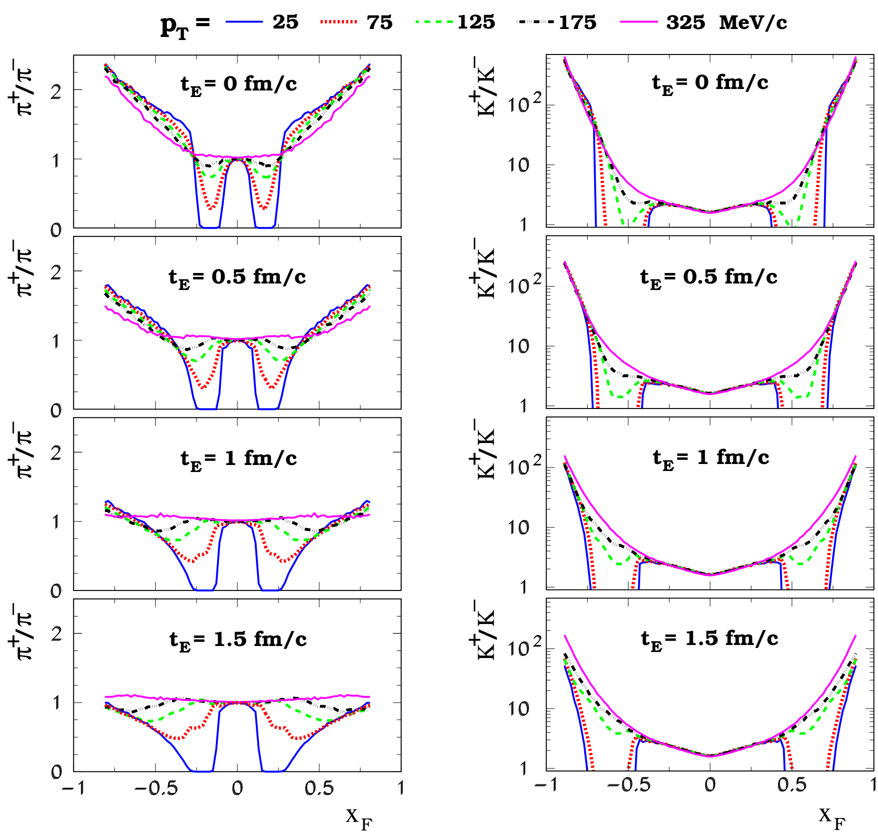

Fig. 2. Electromagnetic distortion of π^+/π^- and K^+/K^- ratios in peripheral Pb+Pb reactions [6, 8], computed assuming different values of the pion (left) and kaon (right) emission time t_E.

Other phenomena are also under study. Fig. 1, panels (c)–(e), demonstrates the sensitivity of the electromagnetic effect to the *fragmentation of the spectator system*. As it appears in the figure, allowing for an increase of the assumed spectator sphere by a factor of two or three relative to its original size changes the shape of the electromagnetic distortion in the vicinity of $x_{\mathrm{F}} = 0.15$–0.2, and improves the agreement between the model and the experimental data. Thus information about the space-time evolution of this latter process also becomes available through the electromagnetic effect.

3. Kaons

The large size of the spectator-induced electromagnetic effect on charged pion spectra, as well as its interesting implications, bring naturally the question whether this effect could also be exploited as a new source of information on the space-time evolution of *strange particle production*, like production of charged kaons. However, methodologically, the situation is much more difficult for kaons than it was for pions. The main difficulty lies in the definition of "initial" emitted kaon spectra, *i.e.*, the spectra of kaons *before* the action of the electromagnetic effect. This is made uncertain by the relatively limited experimental knowledge on charged kaon distributions over the full range of x_{F} in nuclear reactions. Experimental data on kaon rapidity spectra exist, see *e.g.* [9], but these do not extend to high values of x_{F}. On the other hand, data on fast kaons exist for $p+p$ interactions [10], indicating very large differences in K^+ and K^- production and very large K^+/K^- ratios at high x_{F}. After a first set of attempts based on the RQMD model [11], we finally opted for a purely phenomenological approach — we constructed two smooth, two-dimensional shapes in x_{F} and p_{T}, providing a reasonable description of NA49 rapidity spectra [9], but keeping the large values of the K^+/K^- ratio observed at high x_{F} in $p+p$ collisions [10].

The resulting estimate of the electromagnetic effect on charged kaon ratios is presented in Fig. 2 (right panels) for four assumed values of the kaon emission time[4]. If compared to the case of pions shown before in Fig. 2 (left panels), several similarities as well as differences are readily seen. A very large effect is predicted for kaons in the vicinity of $x_{\mathrm{F}} = 0.5 \approx \frac{m_K}{m_N}$ and above, the size of the electromagnetic "hole" being larger than for pions both in x_{F} and in p_{T}. This is then superimposed with the increase of the K^+/K^- ratio at even higher x_{F} as discussed above.

[4] For this introductory analysis, mostly aimed at the delimitation of regions of phase space where the electromagnetic effect will be significant, we neglect the differences between the emission time for positive and negative kaons. We leave this interesting subject for future studies.

The principal issue in this section is the possible sensitivity of the spectator-induced electromagnetic effect on charged kaon spectra to the space-time evolution of strangeness production. A close inspection of the region of highest x_{F} (say, $x_{\mathrm{F}} > 0.75$) in Fig. 2 (right panels) displays indeed some dependence of the K^{+}/K^{-} ratio on the kaon emission time, up to one order of magnitude for the range of emission times considered in the figure. This may give some possibility of obtaining information on the mechanism of kaon production through this specific effect. However, relative to pions, the whole region of sensitivity to initial conditions is clearly shifted towards very high x_{F}. This imposes problems in view of future studies; in particular, also experimental difficulties will require a closer scrutiny.

4. Conclusions

We conclude that the presence of the spectator charge in peripheral (or non-central) heavy ion collisions induces large, characteristic distortions in spectra of charged particles in the final state of the reaction. These distortions may bring new information on the space-time evolution of the collision. However, for the case of strange particles like K mesons, the latter effect is shifted in the direction of very large longitudinal momenta.

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