

USING THE NUCLEAR REMNANTS AS A NEW SOURCE OF INFORMATION ON THE SPACE-TIME EVOLUTION OF ULTRARELATIVISTIC HEAVY ION COLLISIONS*

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In nucleus–nucleus collisions at high energy (typically in the range of a few or more GeV per nucleon pair in the collision c.m.s.), one usually identifies two different “zones” in the reaction: the *participant zone*, created by the nucleons directly participating in the reaction, and the two *spectator systems* — the two nuclear remnants which do not participate directly to the collision. In this work, we investigate the possibility of using the electromagnetic interaction induced by the two spectator systems as a new source of information on the space-time evolution of the participant zone.

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1. Introduction

The principal physical phenomenon occurring in high energy collisions of nuclei is the production of very numerous new particles. These are mostly π mesons (pions). One of the features of particle production that attract most attention are *azimuthal anisotropies* in particle emission with respect to the reaction plane, which are supposed to reflect *collective phenomena* occurring in the reaction. Among these, this work focuses on the “directed flow” of the emitted pions which reflects their *collective sideways motion*. The directed flow is defined by the first Fourier coefficient of the pion azimuthal distribution [1]

$$v_1 \equiv \langle \cos(\phi - \Psi_{\text{RP}}) \rangle, \quad (1)$$

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where ϕ and Ψ_{RP} denote the azimuthal angle of the emitted pion and the orientation of the reaction plane, respectively. We explore the connection between the electromagnetic field induced by the two charged nuclear remnants (spectator systems), and the directed flow.

2. Electromagnetic effects on directed flow

Figure 1 (a) shows our results on the influence of the electromagnetic repulsion between the two spectator systems and positively charged pions, produced in peripheral Pb + Pb collisions at the c.m.s. energy per nucleon pair equal to $\sqrt{s_{NN}} = 17.3$ GeV. The results of our Monte Carlo simulation are compared to experimental data points coming from the WA98 experiment at the CERN SPS [5]. Both are drawn as a function of the reduced rapidity y/y_{beam} of the pion. Note that the rapidity of the pion can be expressed in terms of its longitudinal velocity along the direction of the beam, $y = \tanh^{-1}(v_L/c)$. Thus, y/y_{beam} equal to unity corresponds to pions moving at the same longitudinal velocity as the spectator system. Negative (positive) values of the directed flow v_1 at positive (negative) rapidity correspond to pions moving away from each of the two nuclear remnants (see, e.g., [3]). As apparent in the figure, the pure electromagnetic effect contained in our very simple model of the nucleus–nucleus collision [2, 6] is almost comparable to the values of v_1 measured in experimental data. This implies that a very large part of the measured effect of azimuthal anisotropy in π^+ emission may come from the electromagnetic origin. The distance d_E between the pion emission point and the spectator system is the unique free parameter in our model; the experimental data suggest that this distance is quite small (below 1 fm) for the considered range of pion rapidities.

Another aspect of the same electromagnetic phenomenon is presented in Fig. 1 (b). This displays a comparison between the directed flow of positive and negative pions produced in intermediate centrality Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV. The data come from the STAR experiment at RHIC [3]. They display a common trend of a smooth decrease with passage through zero at $y/y_{\text{beam}} = 0$; this trend is induced by the strong interaction. However, an additional *charge splitting* effect is visible on top of that trend. As remarked in [2], this charge splitting effect can be attributed to the repulsion of positive and attraction of negative pions by the spectator system. On that basis, the electromagnetic component of the measured directed flow can be extracted from the STAR experimental data (see [4] for more details). This is shown in Figs. 1 (c), (d). Our simulation provides a good description of the data points in the two figures, provided that a distance $d_E \approx 3$ fm is assumed between the pion emission point and the spectator system.

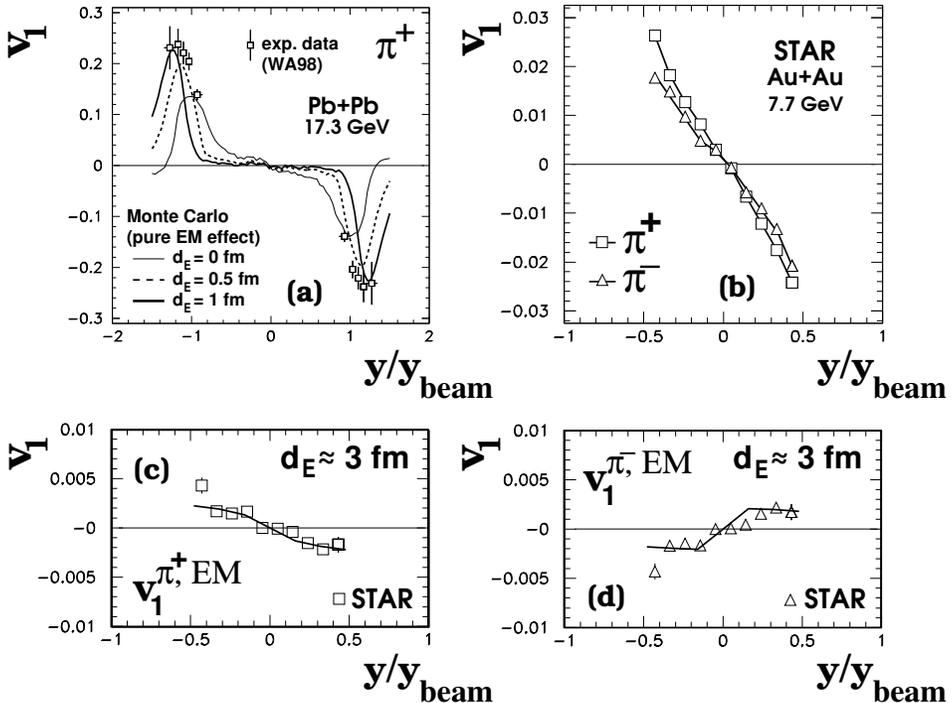


Fig. 1. (a) Directed flow v_1 (defined by Eq. (1)) for positive pions produced in peripheral Pb + Pb collisions [2]. (b) Directed flow for positive and negative pions in intermediate centrality Au + Au collisions (redrawn from [3]). (c), (d) Electromagnetic part of directed flow [4]. Values extracted from the STAR experimental data (squares, triangles) are compared to our Monte Carlo simulation (solid line).

3. Discussion

As it results from our studies above, the distance d_E between the pion emission site and the spectator system appears to decrease with increasing longitudinal velocity (rapidity) of the pion — we obtained values of $d_E \approx 3$ fm for slower pions in Figs 1(c),(d), and d_E below 1 fm for pions at $y/y_{\text{beam}} \approx 1$ in Fig. 1(a). This clearly reflects the longitudinal evolution of the system created in the collision, as schematically illustrated in Fig. 2(a). As such, we conclude that the electromagnetic interaction induced by the presence of the two nuclear remnants constitutes *a new source of information on the space-time properties of this system, and on the space-time evolution of heavy ion collisions*. This information will remain completely independent from that provided by other sources such as pion interferometry.

It is also important to address the *longitudinal evolution* of the pion production process as it is presented in Fig. 2(a). As the emission of high rapidity pions takes place below 1 fm from the spectator system, it is to be expected that lower energy nuclear processes characterising the nuclear remnant will interplay with higher energy phenomena addressed in the present paper. The issue of nuclear fragmentation of the spectator system was discussed elsewhere [7]. However, there are indications that the nuclear remnant also brings *its own contribution to pion production*. This is shown in Fig. 2(b), where a large peak is evidently visible in the ratio of pion production in peripheral Pb+Pb to $p+p$ collisions for pions moving at spectator velocity ($x_F = 0.15 = m_\pi/m_N$) and low transverse momentum ($p_T = 25$ MeV/c). As such, studies of electromagnetic effects induced by nuclear remnants appear as *one more link* between lower energy and high energy nuclear physics.

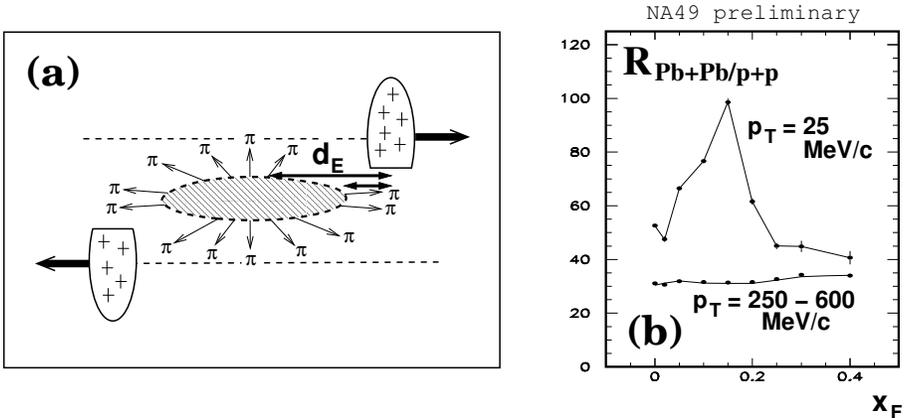


Fig. 2. (a) Schematic illustration of the expanding system created in the heavy ion collision. (b) Ratio of the number of summed charged pions produced in peripheral Pb+Pb to inclusive $p+p$ collisions, both at $\sqrt{s_{NN}} = 17.3$ GeV. The ratio is drawn as a function of $x_F = p_L/p_{beam}$, where p_L and p_{beam} are c.m.s. longitudinal momenta of the pion and of one beam nucleon. It is shown at a fixed value of transverse momentum $p_T = 25$ MeV/c and, for comparison, for a set of p_T values defining the minimum of that ratio as a function of p_T and located always in the range of 250–600 MeV/c. The data come from the NA49 experiment at the CERN SPS [8].

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