COHERENT PION EFFECTS AT LARGE RAPIDITIES IN NUCLEUS-NUCLEUS COLLISIONS

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The large pion's multiplicity in STAR-project at RHIC ($\sim 10^3$) could allow to observe the new physical phenomenon - the classical pion field, analogous to the laser electromagnetic field. Such effects have been considered in connection with Centauros - the events in the cosmic ray physics [1,2] in the works [3-6] and are widely discussed now due to the idea of the disoriented chiral condensate (DCC) [7]. Besides isospin fluctuations the important feature of Centauros is the large rapidity value of emitted hadrons [2]. The aim of this work is to explain how the coherence could enhance the large rapidity region in nucleus-nucleus collisions.

We consider the pion bremsstrahlung mechanism in the nucleus-nucleus collisions creating pions with large rapidities. If there is the strong interference of pion waves from different sources in such scattering then the narrowing of the transverse and longitudinal momenta region for pions could take place. As a consequence the pseudorapidity distribution could move towards large values.

In the model studied central nucleus-nucleus collisions take place with the energy 100 GeV per nucleon in c.m.- system. Only one pion is created in every nucleon-nucleon interaction. It is convenient to begin from the deuteron-deuteron case as the simplest first step.The one-loop graph of the old perturbation theory gives the amplitude

$$M = \int \frac{d^3p_1'}{(2\pi)^3}\frac{1}{2E(p_1')2E(p_2')2E(q_1')2E(q_2')}\frac{G(S_p)}{E_0 - E(p_1') - E(p_2')} \times$$
$$\times \frac{G(S_q)}{E_0 - E(q_1') - E(q_2')}\frac{1}{E_1 + i\eta - E(p_1') - E(q_1')}\frac{M_1}{h_1^2 - m^2}\frac{M_2}{h_2^2 - m^2} \qquad (1)$$
$$h_i^2 = (E(p_i) + E(q_i) - E(q_i'))^2 - (\mathbf{p}_i' - \mathbf{k}_i)^2 \qquad (i = 1, 2).$$

The value E_0 is the initial deuteron energy, $E(p)$,$E(q)$,$\omega(k)$ - nucleon and meson energies and $E_1 = E(p_1) + E(q_1) + \omega(k_1)$. The formfactors $G(S_p)$, $G(S_q)$ with the corresponding energy denominators give wave functions of rapidly moving deuterons. Spin and isospin variables are neglected. The invariant amplitudes of the nucleon-nucleon elastic scattering M_1 and M_2 with propagators of nucleons give amplitudes of the pions emission. The amplitude as a sum of two time ordered graphs was symmetrized for the momenta $\mathbf{k}_1$ and $\mathbf{k}_2$ taking into account the pion's identity. The significant feature of this amplitudes is that the imaginary part of the intermediate state propagator dominates in Eq.(1) with a good accuracy.

For the collision of heavy nuclei in the case of N interacting nucleon pairs the scattering amplitude has the next view

$$M = \prod_{i=1}^{N-1}\int \frac{d^3p_i'}{(2\pi)^3}\frac{\phi(p_i^*)\phi(q_i^*)}{2E(p_i')2E(q_i')}(-i\pi)\delta(E_i - E(p_i') - E(q_i'))\frac{M_i}{h_i^2 - m^2} \times$$
$$\times \frac{\phi(p_N^*)\phi(q_N^*)}{2E(p_N')2E(q_N')}\frac{M_N}{h_N^2 - m^2}. \qquad (2)$$

The single-particle wave function $\phi(p^*)$ for the gold nucleus could be taken as the Fourier transform of the square root of the the nuclear density with the radius $R = 6.3fm$ and the diffuse parameter $a = 1.0fm$. For large N it approximates to the product of one-loop amplitudes analogous to the deuteron case (the factorization property).

Due to a large number both of internal variables of the integration in Eq.(1), Eq.(2) and external ones in the cross-section calculation it is naturally to do the Quantum Mechanical Monte Carlo calculation (QMMC). It is the usual MC method of the manifold integration where the integral is written as a sum of weighted simulated events. It allows to obtain distributions of the arbitrary variable as usual MC-simulation. The real situation with the inner one-loop integration in the amplitude could be reduced to the QMMC procedure as

$$\int dx |\int dx_1 f(x,x_1)|^2 = \int dx dx_1 dx_2 f(x,x_1) f^*(x,x_2) \sim$$
$$\sim \frac{1}{N} \sum_{i,j,k} f(x_i, x_{1j}) f^*(x_i, x_{2k}). \qquad (3)$$

So it is possible to do both internal and external integrations in a general manner increasing the integral dimension. To avoid the narrow behaviour of the integrand a change was done of p_l and p_t^2- variables to those with a flat dependence of the integrand.

The results of the particle spectra calculation for the deuteron-deuteron case are shown in Figs.1a-1c for one-inclusive pion distributions. The light picture show the noncoherent contribution in the cross-section. The pion coherence increases the cross-section in the maximum for about 20% both for the longitudinal and for the transverse momentum. The dark histograms gives the interference contribution connected with the pion identity. It is dominate in the cross-section in the case of heavy nuclei due to the strong coherent enhancement with the large number of pion sources. The pion coherence produces some narrowing of momentum distributions, both the longitudinal and the transverse momentum distribution being narrowed. The longitudinal momentum spectrum is narrowed around the value $\sim (\mu/m)p$,where μ, m are pion and nucleon masses and p-the characteristic nucleon momentum.As a consequence the pseudorapidity distribution is shifted to the right slightly.

In the case of gold-gold collisions two and three interacting nucleon pairs are considered. The value of the coherent increase of the cross-section in the maximum of the transverse momentum spectra is approximately 3.8% in the first case and 7.8% in the second one.It corresponds to the estimation based on the factorization property of the amplitude Eq.(2) giving for this value to be roughly twice lager than that in the first variant. All qualitative results for the deuteron-deuteron case are confirmed in the pion momentum spectra. The narrowing of longitudinal and transverse momentum spectra is stronger in this case. So the shift of the pseudorapidity distribution to the right is rather large.It is about one unit in the rapidity scale.

We can do some Glauber screening correction in the framework of the QMMC approach. The nucleus-nucleus collision can be considered as the sequence of collisions of the corresponding layers of the nuclei. The layer thickness 2σ is a freepath length of a nucleon. The single-particle nucleus wave-function can be represented as the superposition of layer wave-functions. As a result the next substitution has to be done in Eq.(2)

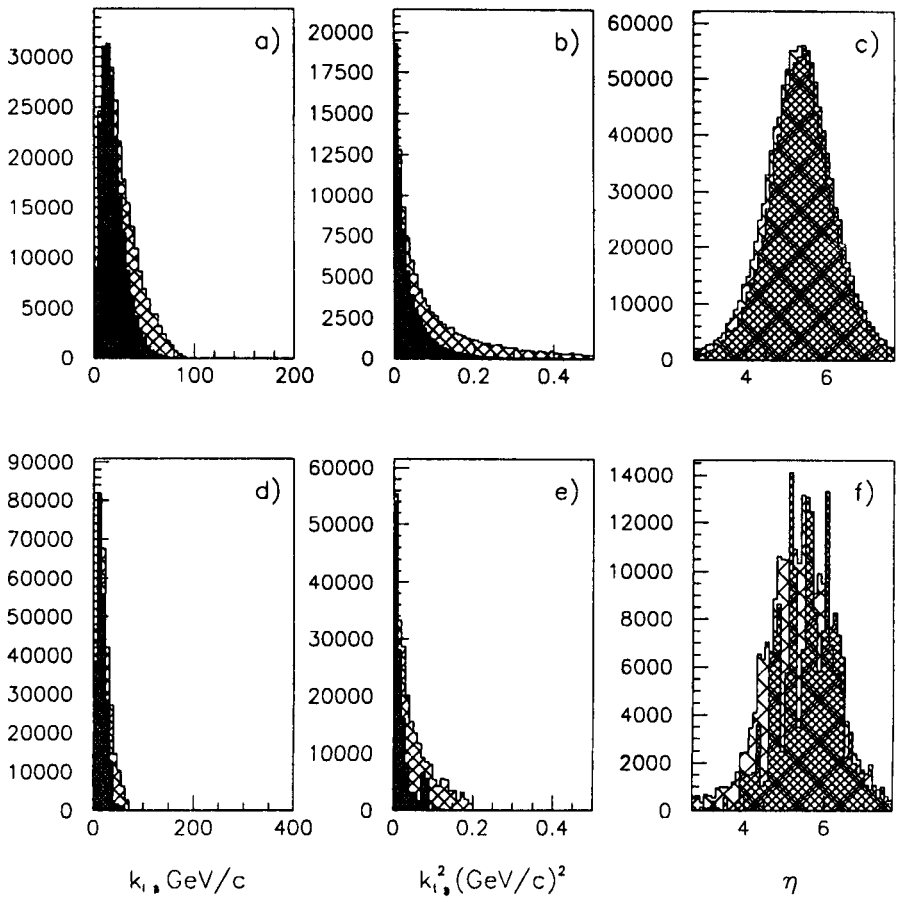

Fig. The distributions of the pion longitudinal momentum, transverse momentum square and pseudorapidity for the deuteron case (1*a*–1*c*) and the gold nucleus case (1*d* –1*f*), the Glauber screening being taken into account. The dark histograms – the interference contribution, the light one – the noncoherent contribution

$$\phi(p_i^*)\phi(q_i^*) \to \phi_0(p_i^*)\phi_0(q_i^*) + 2\sum_{k=1}^{M}\cos((p_{il}^* - q_{il}^*)z_k)\phi_k(p_i^*)\phi_k(q_i^*) \qquad (4)$$

$$\phi_k(p^*) = g(p_l^*)\phi_2(p_t, R_k).$$

Here the function $g(p_l)/\sqrt{2\pi}$ is a square root of Gauss-distribution with the dispersion $(2\sigma)^{-1}$,z_k-the coordinate of k-th layer and $\phi_2(p_t, R_k)$ is the transverse momentum layer wave-function. The nuclear density as a function of z was fitted in the calculation by square of a sum of eleven Gauss-distributions (M=5).The distance between the layers is 2.3σ ($\sigma = 0.5fm$). The results of the calculation are shown in Figs.1d-1f.The Glauber screening leads to some decrease of the coherent narrowing of the longitudinal momentum distribution. The coherent shift of the pseudorapidity spectrum to the right is smaller. Nevertheless it is about one-half of a unit in the rapidity scale and seems to be observable in the experiment.

One can calculate the coherent enhancement of the cross-section in the maximum point of the momentum distribution using the factorization property of the amplitude Eq.(2). The ratio of the interference contribution to the noncoherent one demonstrates the strong threshold behaviour as a function of N. It is the manifestation of the laser type induced radiation. In the region of N about scores the interference contribution dominates. So coherent effects appeared to be observable in experiments. The growth of the cross-section as a function of N is determined by the value of ϵ - the probability for two pions to be in the same state. From a number of different mechanisms of an elementary pion creation the most important could be the mechanism with the smallest $< p_t >$ (the pion bremsstrahlung mechanism) due to the largest ϵ - value. It could be the second reason for the large rapidity region to be enhanced due to a coherence because the pion bremsstrahlung mechanism gives pions with the largest rapidities.

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