MULTIPION COHERENT EFFECTS IN HIGH ENERGY
HEAVY-ION COLLISIONS

G.Z. OBRANT and M.G. RYSKIN

Petersburg Nuclear Physics Institute, Gatchina, Leningrad district, 188350
Russia

Abstract

Multipion production in high energy nucleus-nucleus collisions is considered in the model of the pion radiation by classical current. Strong coherent effects of narrowing of pion longitudinal and transverse momenta distributions are predicted at the RHIC energy. The coherence enhances the large pseudorapidities producing the bump in the distribution. The growth of the average pion multiplicity and the oscillation effect in the multiplicity distribution are caused by the coherence as well.

1 Introduction

The observation of a new physical phenomenon could be done in experiments at RHIC. It is a coherent multipion radiation in heavy-ion collisions analogous to the laser radiation [1, 2] of the electromagnetic field. Besides of its proper interest this is important now both in connection with DCC [3] and classical pion field [4] problems. It is known that quantum statistical correlations change the multiplicity distribution and the momentum spectra of identical hadrons. The effect becomes crucial in a high-energy heavy-ion collisions where the mean number of pions in a unit volume of phase space (ΔxΔk cell) reaches the value of about a unity (or more than a unity). In this case the coherent radiation of pions may lead to the formation of a so-called pion laser [1]. Usually these effects are discussed assuming a thermal emission of pions by a static source with radius R [5].

On the other hand the most popular basic model to describe the underlying events in a heavy-ion collision (assuming no any new physics in a nucleus-nucleus scattering) is a model of independent nucleon-nucleon interactions. Each pair of incoming nucleons produces secondary pions independently.
other words, each pair of colliding nucleons plays the role of a separate source placed at some point $x_i$ within the space-time domain where the beam $A_1$ and target $A_2$ ions overlap. Each source is more or less weak, still the number of sources are as large ($\sim A$) that the density of pions becomes greater than a unity (in a cell of phase space). In the present paper we will study how the quantum statistics (i.e. the permutations) of identical pions modifies the spectra and multiplicity distribution of secondaries in such a simple (basic) model of independent nucleon-nucleon interactions \[1\].

Some possible effects of the pion coherence was considered qualitatively in the simple model of bremsstrahlung of scalar pions with a small pion multiplicity [6]. We do now the next step toward the quantitative understanding of this phenomenon considering more realistic central nucleus-nucleus collisions and accounting true pion amplitudes with the large multiplicity in the nucleon-nucleon interaction. This could be carried out using the model of Gyulassy, Kauffmann and Wilson [7] of the pion radiation by classical current in the nucleus-nucleus scattering. We see the strong coherent narrowing in the pion transverse and longitudinal momenta distribution for such a process. This confirms the analogous result obtained in [6]. The longitudinal momenta are soften strongly by coherence contrary to the model of the scalar pions bremsstrahlung where the monochromatization of pions takes place. In spite of this difference the conclusion [6] about the enhancement of large pseudorapidities by coherence is encouragingly confirmed now. Besides the kinematical variables we have prominent coherent effects in the pion multiplicity taking the large number of radiating nucleons. That is in accordance with the threshold character of the coherence versus the number of radiating nucleons [6].

2 The pion radiation by classical current

The average pion multiplicity in the central heavy-ion collisions at RHIC energy will be of an order $10^4$. The convenient way to do the calculation with such a number of radiated pions is to consider the pion radiation by classical current [7]. The S-matrix for the emittance of m pions by the current $J(k)$ can be

\[1\]This model may be considered as a realistic one if indeed there are no new dynamic effects in a nucleus-nucleus collision
written as

\[ |J> = e^{-\vec{n}/2} \exp(i \int d^3k J(k) a^+(k)) |0> \]  

(1)

\[ \vec{n} = \int d^3k |J(k)|^2 \]  

(2)

\[ S_{fi} = \langle a(k_1) \cdots a(k_m)|J> \]  

(3)

The coherent state \(|J>\) is the state with the indefinite number of quanta and the quantum-mechanical average of the pion annihilation operator \(a(k)\) equals to \(J(k)\). The exclusive cross section, the semiinclusive cross section for the case of \(m\) radiated pions, the inclusive cross section and the pion multiplicity distribution could be easily obtained from Eqs.(1)-(3) using the permutation property of operators \(a(k_i)\) and \(a^+(k_i)\).

\[ \frac{dW^{(m)}}{dk_1 \cdots dk_m} = |J(k_1)|^2 \cdots |J(k_m)|^2 e^{-\vec{n}} \]  

(4)

\[ \frac{dW^{(m)}}{dk_1} = |J(k_1)|^2 \frac{\vec{n}^{m-1}}{(m-1)!} e^{-\vec{n}} \]  

(5)

\[ \frac{dW}{dk_1} = \sum_{m=1}^{\infty} \frac{dW^{(m)}}{dk_1} = |J(k_1)|^2 \]  

(6)

\[ P_m = \frac{\vec{n}^m}{m!} e^{-\vec{n}} \]  

(7)

So, we obtain the Poisson multiplicity distribution in this model, and the physical sense of the value \(\vec{n}\) (Eq.(2)) is clear from Eq.(7) as the average pion multiplicity.

One can write the nuclear current as a sum of currents of the constituent nucleons [7].

\[ J(x) = \sum_{i=1}^{N} J_{\pi}(x - x_i), \quad J(k) = J_0(k) \sum_{i=1}^{N} e^{i\omega t_i - ikx_i} \]  

(8)

Here the space-time points \(x_i\) are the coordinates of some "inelastic scattering centers" where the strength of the current is localized. We obtain all distributions by formulas Eqs.(4)-(7) substituting the following expression for \(\vec{n}\) which...
depends now on the instant space-time coordinates of N nucleons \( x_1, \ldots, x_N \).

\[
\bar{n} = \bar{n}(x_1, \ldots, x_N) = \int d^3k |J(k)|^2 \left( N + 2 \sum_{i<j} \cos k(x_i - x_j) \right)
\]

(9)

The final cross section can be obtained by averaging of the distributions Eqs.(4-7) over the whole space-time region of the nucleus-nucleus collision.

The amplitude of the vacuum-vacuum transition \( \exp(-\bar{n}(x_1, \ldots, x_N)/2) \) gives the right cross section normalization, i.e., provides the unitarity being carried out. This takes into account the radiation of the pion in one point and its absorption in another one.

As an example we study the central Au-Au collisions with the energy \( p_0 = 100 \text{GeV} \) per nucleon in c.m.- system. The number of radiating nucleons \( N=150 \) is fixed. We neglect now spin and isospin variables considering creation of pions only of one sign. The current \( J(k) \) is obtained by fitting the single-inclusive pion longitudinal [8] and transverse momenta distributions with the real average pion multiplicity in a nucleon-nucleon scattering. To average the cross section over the radiation space-time region we approximate this domain by the Woods-Saxon distribution with the radius \( R = 6.3 \text{fm} \) and the diffuse parameter \( a = 0.6 \text{fm} \). The longitudinal coordinate and the time of the radiation was averaged independently, the Lorentz contraction of the nucleus being taken into account.

The resulting distributions on the kinematical variables are shown in Fig.1. The coherence is seen to produce strong effects both in the transverse momentum distribution and in the longitudinal one. Pion transverse momentum is diminished by coherence to the value about of the nucleus inverse radius. To estimate the characteristic pion energy with this transverse momentum lets take the corresponding magnitude in the maximum of the pseudorapidity distribution. This energy \( \omega \approx 0.75 \text{GeV} \) is somewhat lower than the inverse nuclear range shortened by the Lorentz boost. It corresponds to the fact that these pions are radiated from some more wide longitudinal region determined mostly by the longitudinal size of the slow particle space in the nucleon.

The coherent decrease is more strong for pion transverse momenta than that for longitudinal ones. As both \( k_t \) and \( k_l \) tend to the corresponding inverse

\footnote{We are grateful to Yu.M.Shabelsky for providing us with tabulated pion distributions}
Figure 1: Distributions of the pion longitudinal momentum (multiplied by $k_l$)(a), transverse momentum square (b), pseudorapidity (c) and rapidity (d). The solid line - the inclusive cross section with the fixed number of pions in the event $m=7000$, the dotted line - the inclusive cross section, the dashed line - the inclusive cross section without the interference contribution.
nuclear size, one may estimate the effect as follows:

\[ \frac{k_l}{k_{l0}} \sim \frac{p_0}{m R} / < x_{F0} > p_0 \approx 0.3, \quad \frac{k_t}{k_{t0}} \sim \frac{1}{R} / < k_{t0} > \approx 0.1 \]

The values \( k_{l0} \) and \( k_{t0} \) are characteristic pion longitudinal and transverse momenta without the coherence, \( < x_{F0} > \approx 0.1, \quad < k_{t0} > \approx 0.36 \text{GeV} \) - the average Feynman’s \( x \) and pion transverse momentum in the nucleon-nucleon interaction and \( m \) is the nucleon mass. So, the large pseudorapidities must be enhanced by coherence. This effect is really seen in Fig.1(c), the cross section being twice larger than the noncoherent one in the shoulder region having the bump here. One could suppose the behavior of this effect with the growth of \( p_0 \) to be determined by the competition of two factors. Decrease of \( < x_{F0} > \) and increase of \( < k_{t0} > \) must enhance the effect. On another hand the fact that the longitudinal coherent region tends to the hadron size \( r_0 \) appeared to diminish the effect.

The rapidity distribution (Fig.1(d)) shows coherent effect as well. However, this is not convenient kinematical variable now to clear up the physics when pion transverse momenta are lower than the pion mass. All considered inclusive distributions do not distinguish remarkably from the spectra where the number of pions is fixed.

### 3 Multiplicity distribution

The existence of strong coherent effects in the pion multiplicity is suggested by the fact that the laser-type pion radiation has the characteristic \( N^2 \) dependence of the average multiplicity on the number of nucleon-sources [7]. The averaged over the space-time region value \( \bar{n} \) (Eq.(9)) is given by

\[ < \bar{n} > = \bar{n}_0 (N + \epsilon N(N - 1)) \quad (10) \]

Here \( \bar{n}_0 \approx 6 \) is the average multiplicity of one sign pions in the nucleon-nucleon interaction and \( \epsilon \) is the probability for two pions to be in the same state (i.e. in the same \( \Delta x \Delta k \) cell). The strong threshold growth of coherent effects in the pion induced radiation versus the number of radiated nucleons [6] corresponds to the small overlapping of the pion distributions after the averaging according to the first and the second term in Eq.(10).
We have calculated the pion multiplicity distribution Eq.(7) and have shown this in Fig.2. The average multiplicity is seen to be approximately seven times larger than that in the noncoherent case. So, the second term dominates in Eq.(10) and we have the coherent source with thousands of pions in the same state. It is really a pion classical field. The probability $\epsilon \approx 0.04$ could be obtained using Eq.(10).

The prominent distinction of the obtained multiplicity distribution from the Poisson distribution, its large wide and the oscillating shape is the second effect of the pion coherence. To understand the nature of this oscillations let’s consider all the process as a sum of coherent radiations by groups of nucleons, the nucleons in the group being distributed over the whole nucleus. Fitting the places of two maximums in the spectrum by the expressions $\bar{n}_0 \epsilon N_1(N_1 - 1)B$ and $\bar{n}_0 \epsilon N_1(N_1 + 1)B$, correspondent to groups with the number of nucleons distinguishing to a unity we obtain the effective number of nucleons in the group $N_1 \approx 32$. As the radiation of different groups of nucleons is considered to be coherent the factor $B$ is given by $N_g(N_g - 1)$, where $N_g$ is the number of groups. We obtain $N_g \approx 5$ in accordance with the fact that the total number of nucleons is $N = 150$.

The only known for us example of the oscillating multiplicity distribution is such a spectrum in the multireggeon cutting mechanism [9] where the peaks in the distribution correspond to the integer multiple of the single reggeon multiplicity. The principal difference of this from the result being discussed is the fact that the laser type radiation has the characteristic $N^2$ dependence of the average multiplicity on the number of nucleons in the group. Together with the fact that the number of pions $\bar{n}_0$ emitted by each pair of colliding nucleons (each current $J(k)$) increases with energy ($\bar{n}_0 \gg 1$) it provides the reason why contributions of different configurations are separated clear in the spectrum.

4 Spin effects

We have not considered influence of the spin of nucleons to the discussed coherent effects. The multiple pion production at high energy seems not to have the significant dependence on the nucleon spin in the single-inclusive pion spectra, at least in the central rapidity region or in the multiperipheral picture of a pion creation. However, the feature of a pion being a Goldstone particle to couple with spin (for ex. with the spin of a quark in the nucleon) suppressing
Figure 2: The pion multiplicity distribution (the solid line) and the Poisson distribution with the same average multiplicity (the dotted line)
the small transverse momenta demands to clarify the question about the spin dependence of the discussed coherent effects.

First point is the fact that being a Goldstone the pion with zero momentum \( k=0 \) (i.e. the homogeneous pion field) decouple from quarks or barions. Next is the form of the pion-nucleon vertex; in some sense pion is emitted by the spin of fermion. It is not essential for us now either the fermion is a quark or a nucleon but for simplicity below we will consider the nucleon-pion coupling.

In the nucleon rest frame the vertex takes the form \( V = g(\sigma k) \).

At first sight due to the Goldstone nature of pions one might expect the inclusive cross section to go to zero at small \( k_t \), just in the region where we collect the main interference effects. However this is not the fact: i) when the pion is emitted by a fermion, the vanishing of the vertex \( V \sim k \) is compensated by the pole of the fermion propagator and at \( k \to 0 \) the amplitude tends to a constant; ii) in a central rapidity region the majority (more than one half) of pions comes from the resonance (\( \rho, \omega, f, ... \)) decay. Anyway in our calculations we have used the experimental cross section (measured in \( pp \)-collisions) which does not go to zero as \( k_t \to 0 \).

Role of the spin is a more delicate question. First we have to emphasize that in a central region the pions are produced mainly due to the resonances decay and only small part of \( \pi \)-mesons are created directly by fermions. Nevertheless, let us discuss the interference between two identical pions (with momenta \( k_1 \) and \( k_2 \)) emitted by two nucleons with coordinates \( x_1 \) and \( x_2 \). The amplitude reads:

\[
A = g[(\sigma_1 k_1)e^{ik_1x_1}(\sigma_2 k_2)e^{ik_2x_2} + (\sigma_1 k_2)e^{ik_2x_1}(\sigma_2 k_1)e^{ik_1x_2}] \tag{11}
\]

where we keep only the terms (and factors) essential for our discussion. To calculate the cross section one has to square the amplitude Eq.(11) and to average over the nucleon polarizations. It leads to:

\[
\frac{dW}{dk_1dk_2} \sim g^2[k_1^2k_2^2 + 2(k_1k_2)^2e^{i(k_1-k_2)(x_1-x_2)} + k_1^2k_2^2] \tag{12}
\]

Here the second term corresponds to the interference of the amplitudes, where the pions \( k_1 \) and \( k_2 \) are emitted by nucleons 1 and 2 correspondingly, and vise versa. After the averaging over polarizations the product \((\sigma_1 k_1)(\sigma_1 k_2)\) 

\[\text{We wish to thank B.L.Ioffe for paying our attention to this important point and for the interesting discussion.} \]
gives the value \((k_1 k_2)\). Thus in comparison with a spinless case \(dW \sim [1 + \exp(i(k_1 - k_2)(x_1 - x_2))] \) we obtain an extra cosine square \((k_1 k_2)^2/k_1^2k_2^2 = \cos^2 \theta\). Accounting for the spin we get \(dW \sim [1 + \cos^2 \theta \exp(i(k_1 - k_2)(x_1 - x_2))]\).

Note that for \(k_1 = k_2\) the interference is still as strong as before. The only role of this \(\cos \theta\) is a tiny decreasing of an effective volume of elementary cell \((\Delta x \Delta k)\) where the interference do takes place. In other words taking the fermion spin into account we diminished a little bit the value of \(\epsilon\). It should be stressed that in the region of interest \(|\eta| \sim 3\) the pion momenta \(k_1, k_2\) are not too small. In the nucleon rest frame we deal with the values of \(|k_1|, |k_2| \sim 1 GeV\). On the other hand within the interference peak the difference \(\Delta k = |k_1 - k_2|\) is of the order of \(1/R \approx 30 MeV\). So the typical values of \(\cos^2 \theta \approx 1 - (\Delta k)^2/k^2 \approx 0.998\) are very close to 1.

To demonstrate the role of spin we consider numerically the production of two pions emitted by a couple of nucleons in the deuteron-deuteron collision [6], the \(\pi NN\) vertex being taken as \(\gamma_5\). In our model pions are created by bremsstrahlung in the graphs Fig.3 of the old perturbation theory. Here the Goldstone nature of the bozon should reveal itself as much as possible. An one-loop amplitude is given by a threefold integral on the nucleon momentum in the intermediate state

\[
M = \int \frac{d^3p_1}{(2\pi)^3} \frac{1}{2E(p_1)2E(p_2)2E(q_1)2E(q_2)} \frac{G(S_p)}{E_0 - E(p_1) - E(p_2)} \times \frac{1}{G(S_q)} \frac{M_1}{E_0 - E(q_1) - E(q_2)} \frac{M_2}{E_1 + i\eta - E(p_1) - E(q_1)} \times \frac{h_1^2 - m^2 h_2^2 - m^2}{h_1^2 - m^2 h_2^2 - m^2}
\]

\(h_i^2 = (E(p_i) + E(q_i) - E(q_i'))^2 - (p_i - k_i)^2\) \((i = 1, 2)\).
The value $E_0$ is the initial deuteron energy, $E(p)\omega(k)$ - nucleon and meson energies and $E_1 = E(p_1) + E(q_1) + \omega(k_1)$. The formfactors $G(S_p)$ and $G(S_q)$ with the corresponding energy denominators represent the wave functions of rapidly moving deuterons. The parameters of the simplest Hulthen wave-function have been chosen for the formfactor $G(S)$ producing the correct nonrelativistic behavior in the two-nucleon rest-frame system. The imaginary part of the two-nucleon propagator dominates [6] with a good accuracy in Eq.(13).

The invariant amplitudes $M_1$ and $M_2$ contain amplitudes of the nucleon-nucleon elastic scattering multiplied by the spin-dependent part of the pion emission amplitude

$$2m\bar{u}(p)(\hat{p}' - \hat{k} + m)\gamma_5 u(p')S(k_l, k_t).$$

We include there the factor $S(k_l, k_t) = \exp(-k_l/2k_{l0})\exp(-k_t/k_{t0})$ with $k_{l0} = 0.15p_0$ and $k_{t0} = 0.36\text{GeV}$, providing reasonable agreement with experimental meson spectra. The symmetrization of a sum of two time ordered graphs Fig.3 was done for the momenta $k_1$ and $k_2$ taking into account the pion identity. The deuteron was considered as a spinless particle and the resulting cross section was summed over final nucleon polarizations and averaged over polarizations of nucleons in the deuteron. All integrations both internal in Eq.(13) and external over the phase space was done using the Quantum Mechanical Monte Carlo calculation [6].

The results of this calculation on pion distributions are shown in Fig.4 for the interference part of the cross section. Such interference contributions was found to dominate in the cross section with the large number of pion sources [6]. We see strong coherent effects both in the case with the account of the nucleon spin (Fig.4(a,b)) and with its neglect (Fig.4(c,d)). The spin of nucleons in this model demands of some more close momenta of two pions for the interference to exist. As a result the narrowing of the longitudinal and transverse momenta spectra is somewhat larger in this case, the absolute value of the interference in the maximum being approximately the same. We do observe some decrease of the interference contribution (of about 3.5%) but it is too small to change our previous result noticeably.
Figure 4: The distributions of the pion longitudinal momentum (a,c) and the transverse momentum square (b,d) in the case with the account of the nucleon spin by Eq.(14) (a,b) or using the averaged square of Eq.(14) over nucleons polarizations (c,d). The dark histograms - the interference part of the cross section, the light one - the noncoherent contribution.
5 Comparison with data

In spite of the fact that the model of a pion radiation by classical current is rather crude and our results have mostly qualitative character we compare them with the existing experimental data. We use results of two CERN experiments WA98 and NA49 on Pb-Pb interaction with the energy 158A GeV [10]. The high centrality of the event was reached here using the forward veto calorimeter though this is somewhat lower than the value correspondent to N=150. The experimental efficiency falls in the low transverse momenta region $k_t < 0.2\text{GeV}$ in both experiments. This point is the most crucial for the observation of coherent phenomena due to the fact that these effects are mainly situated in the region $k_t \sim 1/R$, i.e., at $k_t < 0.1\text{GeV}$. We roughly approximated this inefficiency by the constant cross section at $k_t < 0.2\text{GeV}$.

In Fig.5 we show the results of the calculation for the Pb-Pb interaction. The theoretical cross section is twice increased reflecting the crude character of our estimation of the experimental efficiency. We see the experimental data do not contradict to the discussed coherent effects both for the pion multiplicity and for the shape of the rapidity distribution. Note that the experimental spectrum in Fig.5(b) is even more narrow than the theoretical one. This fact encourages us and we consider it as an argument in favour of an important role of coherence effects. The future experiments measuring small pion transverse momenta could clearly observe the pion coherence.

6 Conclusions

The nucleons are found to throw off their pion "fur-coats" coherently in the central nucleus-nucleus collisions very willingly. A lot of pions being in one state is created in this radiation. The natural question one could inquire about is the interaction of pions during the short time when the nuclei overlapping and the pions interaction in the final state. The first kind of interactions seems to be not so important. Recall the fact that the experimental pion transverse momentum distribution in heavy-ion collision is not remarkably wider than that in the nucleon-nucleon interaction. We can suggest the scenario of the further evolution of the produced classical pion field as the self-interacting field [4,11]. The basis for such a hope is the smallness of pion transverse momenta. The relative pion energy is small (of the order of the pion mass) in this case.
Figure 5: Inclusive pion rapidity distributions (the average number of particles per event) with the interference contribution (the solid line) and without this (the dashed line). The data are for $\pi^0$ mesons (a) and for negative hadrons (b). The theoretical values are multiplied by the factor two.

and one could use the soft pion theory [4]. The production of a classical field "brizer" [11] corresponding to the space-time region of the nucleus-nucleus collision could take place. When radiated, pions appeared to have some characteristic longitudinal momenta in this case. The usual final state interaction could take out from the coherent volume only small part of pions with large relative energies.

We have to emphasize that at RHIC energies the effect of coherence essentially deforms the momentum spectra of secondary pions and enlarges the multiplicity in comparison with the naive conventional estimates based on the model of independent nucleon-nucleon interactions (without accounting for the
coherence of pions). The crucial point is the longitudinal Lorentz contraction of colliding nuclei. Therefore all the pions produced with $k_t \sim 1/R$ are emitted coherently.

The only way to reduce the effect shown in Fig.1, Fig.2 is to say that the pions are formed much after the collision. For example, if at first stage the Quark Gluon Plasma (QGP) would be created and then (after the expansion and cooling of QGP) the pions would be produced from the domain with the longitudinal size $\Delta z \sim 10 fm$, then the effect of coherence would be suppressed strongly.

So the absence of prominent coherent effects at RHIC may be considered as an argument in favour of QGP (or another new phase) formation; the pions are emitted from a large size domain after the "decay" of this new phase. Of course, in reality there will be the competition between the direct production of a classical (coherent) pion field and the formation of another (like QGP) phase.

References

[1] C. Lam and S. Lo, *Phys. Rev. Lett.* **52**, 1184 (1984), *Phys. Rev. Lett.* **D33**, 1336 (1986), *Int. J. Mod. Phys.* **A1**, 451 (1986), *Phys. Rev. D33*, 1336 (1986)
S. Pratt, *Phys. Lett.* **B301**, 159 (1993)

[2] B. Lorstad, *Int. J. Mod. Phys.* **A12**, 2861 (1989)
W. A. Zajc, in *Particle Production in Highly Excited Matter*, edited by H. Gutbrod and J. Rafelski, NATO ASI. Ser B, Vol. 303, (Plenum Press, New York, 1993), p. 435
U. Heinz, *Nucl. Phys.* **A610**, 264c1996

[3] J. D. Bjorken, *Acta Phys. Polonica* **B23**, 637 (1992)
*Int. J. Mod. Phys.* **A7**, 4189 (1992), SLAC-PUB-6488 (April 1994)

[4] A. A. Anselm, *Phys. Lett.* **B217**, 169 (1989)
A. A. Anselm and M. G. Ryskin *Phys. Lett.* **B266**, 482 (1991)

[5] T. Csorgo and J. Zimanyi, *Phys. Rev. Lett.* **80**, 916 (1998)

[6] G. Z. Obrant, *Phys. Rev.* **C54**, 2624 (1996)
[7] M. Gyulassy, S. K. Kauffmann, and Lance W. Wilson, *Phys. Rev. C* 20, 2267 (1979)

[8] Yu. M. Shabelski, *Yad. Fiz.* 44, 186 (1986)

[9] V. A. Abramovsky and O. V. Kancheli, *JETP Lett.* 15, 559 (1972)
   V. A. Abramovsky, V. N. Gribov and O. V. Kancheli, *Yad. Fiz.* 18, 595 (1973)

[10] P. G. Jones and the NA49 Collaboration, Proceedings of the Twelfth International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, Heidelberg, Germany, 20-24 May, 1996, edited by P. Braun-Munzinger, H. J. Specht, R. Stock and H. Stocker, p. 188;
    Thomas Peitzmann for the WA98 collaboration, Proceedings of the Twelfth International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, Heidelberg, Germany, 20-24 May, 1996, edited by P. Braun-Munzinger, H. J. Specht, R. Stock and H. Stocker, p. 200.

[11] T. I. Belova and A. E. Kudryavtsev, *Usp. Fiz. Nauk* 167, 377 (1997), Preprint ITEP 43-97