Abstract. Specific results of the computer simulation of dilepton production from expanding pion gas created in Pb+Pb 160 GeV/n collisions are presented. Azimuthal asymmetry of dilepton pairs in non-central collisions and interesting shape of the rapidity distribution of dilepton pairs are predicted. These results are understood on theoretical level as a consequence of momentum and space asymmetries in the initial state of pion gas without any assumption of thermalization. Implication on the production of dileptons in pre-hadronic phase of HIC is drawn.

1 Introduction

Goal of heavy ion collision (HIC) experiments is to reveal properties of the compressed hot nuclear matter created during the collision of heavy nuclei. Final momentum distributions of most abundant particles - hadrons are however influenced during the dilute and late freeze-out stage of heavy ion collision. Interesting information about the early stage of the collision is in this case hidden by subsequent collective effects of strongly interacting hadrons.

Fortunately this is not valid for leptons or photons. Distributions of these types of particles can provide us with more direct information about the early stages of the collision process.

In most of theoretical estimates for production of dileptons from the hadronic matter created in HIC experiments an assumption about the equilibrium - thermalized stage of the collision is used.

Our study of dilepton production from the expanding pion gas is not based on the assumption of thermalization. Phenomena described in next sections are generated also in the case of 1 collision per particle approximation what means that the mean free path of particles participating in mutual interactions is comparable with the size of the system.

In subsequent sections we report about two phenomena revealed by the computer simulation of the dilepton production from expanding pion gas created in Pb+Pb 160 GeV/n collisions: a) Azimuthal asymmetry of dilepton pairs in non-central collisions, b) Rapidity distribution of dilepton pairs.

2 Azimuthal Asymmetry of Dilepton Pairs

Azimuthal asymmetries of secondary produced particles have been clearly identified in relativistic non-central collisions [1]. This phenomenon is well
understood as a consequence of collective behavior of nuclear matter \[2\] or explained by the absorption of secondary produced particles in spectator parts of nuclei \[3\]. Recently also azimuthal asymmetries in transverse momentum distributions of less abundant hadrons - \(K\) mesons and \(A\) baryons \[4\] have been studied in HIC experiments. However azimuthal asymmetries in transverse momentum distributions of dileptons have not been addressed experimentally or theoretically so far.

From theoretical point of view mechanisms generating azimuthal asymmetries in transverse momentum distributions of hadrons are not applicable for dileptons. Dileptons leave freely collision volume after being produced without final state interactions or absorption processes.

![Fig. 1. Azimuthal asymmetry of dilepton pairs and its transverse momentum and invariant mass dependence for Pb+Pb 160 GeV/n \(b = 7\) fm events.](image)

\[R(\phi) = S_0[1 + S_2 \cdot \cos(2\phi)]\] (1)

gives numerical value of the asymmetry coefficient \(S_2 = 0.093 \pm 0.004\). Corresponding value of \(R_p\) parameter \(R_p \approx \langle p_T^2 \rangle / \langle p_T^2 \rangle = 1.202\). Asymmetry of dilepton pairs is oriented in the reaction plane, it increases with \(p_T\) and does not depend on invariant mass region. Theoretical understanding of the origin of this asymmetry is sketched in Section 4 and studied more carefully in \[6\].

3 Rapidity Distribution of Dilepton Pairs

Rapidity distribution of dilepton pairs produced via \(\pi^+\pi^-\) annihilation channel is determined by the rapidity distribution of momentum sum \(p_{\pi^+} + p_{\pi^-}\) of pions annihilating. Result of simulation \[5\] is shown in Fig.2 where also rapidity distribution of pions participating in the rescattering process is shown.

For parameters of the simulation \(\tau_f = 0.5\) fm, \(T_i = 1.0\) fm number of collisions per pion is close to 2.5 and minimum in the rapidity distribution of
dileptons is strong. For higher collision rates (smaller values of $\tau_f$ and $T_i$) the minimum becomes weaker and for $n_c = 10$ coll./$\pi$ the minimum disappears.

![Fig. 2. Rapidity distribution of pions and dilepton pairs predicted by the simulation of Pb+Pb 160 GeV/n collisions for different values of $\tau_f$, $T_i$.](image)

From experimental point of view data on rapidity distribution of dileptons produced in $p - A$ or $A - A$ collisions are rather rare. It seems that the only published rapidity distribution of dileptons which seem to originate from $\pi^+\pi^-$ annihilation was obtained in pioneering experiments of DLS collaboration at Bevalac accelerator in Berkeley.

4 Theoretical understanding of results

Azimuthal asymmetry of dilepton pairs and rapidity distribution of dileptons obtained in the simulation can be understood without the assumption of thermalization. Initial transverse momentum distribution of pions is azimuthally symmetrical - constant in the simulation. Therefore azimuthal asymmetry of dileptons is not generated by transverse momentum asymmetry of pions. It is a consequence of the initial spatial distribution of pions in transverse plane which is asymmetrical in the case of non-central collisions.

![Fig. 3. Vector field $p_{ee}(x, y)$ of dilepton pairs created by $\pi^+\pi^-$ annihilation of pions emitted from two sources. The two-point source serves as a rough approximation of the asymmetrical shape of the initial distribution of pions in transverse plane. Density-plot of the difference $|p_{ee}(x, y) - r_{ee}(x, y)|$ ($r_{ee}(x, y)$ is radial field) shows that the asymmetry is generated between emission points - in the volume of source.](image)
Rapidity distribution of dilepton pairs can be explained as a consequence of the asymmetry of pions in momentum space. Average transverse momentum of pions in Pb+Pb 160 GeV/n collisions is much smaller compared to average longitudinal momentum of pions. This strongly influences distribution of pion-pion collisions in rapidity. In Fig.4 we show distribution of annihilation points of $\pi^+\pi^-$ pairs emitted from two-point source oriented parallel to the beam direction. Momentum distribution of emitted pions is asymmetrical: $< |p_t| > \approx 2 < p_t >; < p_t > = 380$ MeV. Annihilation events in the middle of the sources are suppressed due to the shape of $\pi^+\pi^- \rightarrow e^+e^-$ cross section which is peaked at $M = 770$ MeV (for detailed description see [6]).

Fig. 4. Distribution of annihilation points of pions emitted from two-point source described in the text and rapidity distribution of the generated dilepton pairs. Formation time [8] excludes annihilations close to emission points.

5 Conclusions
Phenomena described in preceding sections are generated in pre-equilibrium stage of the pion gas expansion. Similar effects might occur also in parton gas possibly created in heavy ion collision experiments. In this case the azimuthal asymmetry of dilepton pairs in the invariant mass region 2-5 GeV might be considered as a signature of secondary collisions [9] among partons. Gas-like behavior of the system of partons [10] created in HIC experiments is worth of further theoretical and experimental study.

References

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