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SPIN AS AN ADDITIONAL TOOL FOR **QGP** INVESTIGATIONS

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Спин как дополнительный инструмент в исследованиях КГП

В ближайшие два года планируется модернизация установки STAR, которая позволит идентифицировать частицы с импульсом до ~ 3 ГэВ/c. Это даст возможность проводить новые и более детальные исследования свойств ядерной материи, образованной в ядро-ядерных столкновениях на RHIC. В этой работе мы предлагаем проведение поляризационных исследований, которые могут дать важную дополнительную информацию о процессе образования нового состояния ядерной материи, а также о свойствах образованного состояния.

Дилептоны являются уникальными пробниками, несущими информацию обо всех стадиях образования и эволюции ядерной материи, так как взаимодействуют с ядерной материей посредством электромагнитного взаимодействия. В этой работе мы уделяем особое внимание исследованиям поляризационных характеристик дилептонов.

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Spin as an Additional Tool for QGP Investigations

Within the next two years, on experiment STAR the upgrade is planned, which will make it possible to identify particles up to momentum ~ 3 GeV/c. This will open up a possibility to carry out new and more detailed researches of properties of nuclear matter formed in nucleus–nucleus collisions at RHIC. In this work, we offer to carry out polarization studies, which can give important additional information about the process of forming a new state of nuclear matter and also about properties of the formed state.

A unique probe of information about all stages of formation and evolution of nuclear matter is dileptons, due to their electromagnetic interaction with the nuclear matter. In this work, we pay main attention to the examination of polarization characteristics of dileptons.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energies, JINR.

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INTRODUCTION

The first studies on the accelerator RHIC (BNL) have shown that properties of the nuclear matter formed in Au–Au collisions substantially differ from those of the nuclear matter formed at collisions of nuclei on the accelerator SPS (CERN) [1]. It made it necessary to reconsider theoretical views on the properties of formed quark-gluon plasma [2]. Up to the present time, the search of unequivocal signatures of formation of quark-gluon plasma remains active. From our point of view, polarization studies give an additional tool allowing us to detect the formation of new states of nuclear matter.

The upgrade of STAR setup [3] will allow one to identify particles with momenta up to ~ 3 GeV/c. In particular, it will allow us to investigate dilepton production in the range of effective masses $m_{e^+e^-} < 5$ GeV. It is exactly in this range of effective masses that the majority of particles produced by quark-gluon plasma are expected. Dileptons and photons are unique probes because they interact with nuclear matter only via electromagnetic interaction. Due to their weak interaction dileptons and photons carry information about all stages of nucleus–nucleus collisions without noticeable distortion. This is a principal distinction of photons and leptons from hadron probes. Comparison of characteristics received by electromagnetic and hadron probes will allow us to investigate properties of the forming nuclear matter.

It is expected that in nucleus–nucleus collisions the quark-gluon plasma (QGP) is formed, which is essentially a new source of secondary particles. Characteristic features of this new source, which we attempt to find as signals of QGP formation, are the object of studies. The thermalization may be the main feature of the QGP.

The thermalization means that the information about initial states of nucleus–nucleus collisions has been lost (for example, the information about the initial direction of collisions is lost due to multiple secondary interactions). As a consequence we should see disappearance of all types of polarization connected with the direction of initial state for particles produced by the plasma source. The polarization for particles produced by the plasma can depend only on hadronization characteristics and the plasma collective motion. Therefore, there should be no transverse polarization or longitudinal polarization connected with the direction of initial collision. That is why we can use polarization studies as an additional important information to identify the QGP formation.

But it is very important to determine the processes and energy ranges where the absence of polarization can be regarded as a proof of the QGP formation. For the first time, this type of possibility has been proposed and discussed in detail about ten years ago. In 1994 one of the authors (S. S. S.) proposed to CERES/NA45 collaboration to carry out polarization studies of low-mass dileptons ($0.2 < m_{ee} < 0.6$ GeV/c^2) to explain the nature of dilepton enhancement in the nucleus–nucleus collisions. However, further analysis showed that CERES/NA45 had a very narrow acceptance [4]. Nowadays there are new setups with possibilities to carry out polarization investigations of dileptons to find formation of the QGP phase in nucleus–nucleus collisions. That is why we think that it is important to analyze the possibility for polarization studies now. Some experiments have been carried out for some years (HADES, NA60, STAR and PHENIX).

1. POLARIZATION AND THERMALIZATION

CERES/NA45 studies [5] of the dilepton production in nucleus–nucleus collisions with nuclear beams at SPS (CERN) have shown an enhancement of the dilepton production in the mass region $0.2 < m_{e^+e^-} < 0.8$ GeV. If this enhancement comes from the thermalalized source, we should not see any dilepton anisotropy. That is not so for a secondary $\pi^+\pi^-$-annihilation process where a strong anisotropy of the electron (positron) emission should occur. Moreover, there must be energy dependence of this anisotropy which is opposite to a thermalized source case which has no energy dependence. Therefore, we have a real possibility to distinguish these two subprocesses. That time there were no quantitative theoretical estimations of these effects. The author (S. S. S.) had asked theoreticians from JINR for theoretical examination of these effects [6]. This work was continued in collaboration with a theoretical group of Giessen [7, 8]. These are the only quantitative theoretical predictions up to now. Theoretical predictions for the anisotropy of leptons in the region of small masses and for energies from SIS (GSI) to SPS (CERN) were based on the Hadron-String Dynamics (HSD) model [9]. At that time there was no possibility to carry out studies in the region of the dilepton masses $m_{e^+e^-} > 1$ GeV that is why all predictions had been limited to the region of small masses.

Theoretical studies have shown that the dilepton polarization characteristics allow one to separate different subprocesses (and models) not only in nucleus–nucleus collisions but also in nucleon–nucleon interactions. In 1998 CERES/NA45 has obtained the data for p_T dependences of the dilepton pair production [10]. These data have shown that the dilepton enhancement comes from a low-p_T region of pairs. Theoretical description of this enhancement for $p_T \sim 0$ GeV [11] remains difficult, which can be partly explained by a combination of a strong polarization with the narrow CERES/NA45 acceptance. It implies the domination of the process by the annihilation of nonthermalized pions. May be this is the first indirect proof which tells us that the main source that is crucial for the dilepton enhancement is not a thermalized source. If it is so, we have the first direct observation of the annihilation process of secondary pions and its studies have some independent interest.

RHIC has opened essentially new opportunities for polarization studies of dileptons. It is the possibility to carry out investigation of the thermalized source in a wider range of dilepton masses and immediately in the center-of-mass system. The article [12] examines the contribution of the thermalized dilepton source for energies SPS and RHIC. At these energies there is an additional interesting region of masses $1 < m_{e^+e^-} < 5$ GeV, where the thermalized source of dileptons competes with the Drell–Yan annihilation. As well as in a case of small dilepton masses, we have competition of two subprocesses: the thermalized source and the Drell–Yan process. The latter gives a strong alignment of virtual photons and, as a consequence, of the anisotropy in the lepton angle distribution. Different energies of nucleus–nucleus collisions, the possibility to select events with different impact parameters make a real possibility to unambiguously reveal the appearance of the thermalized source. In our opinion such studies now are unique in the sense that they allow us to detect directly the occurrence of a thermalized source of particle production.

There are independent reasons to study the polarization characteristics of dileptons in nucleon–nucleon collisions at RHIC for small and middle mass regions with polarized proton beams. These investigations will give an additional information about polarized structure of nucleons in the region $x \sim 10^{-2}$.

RHIC setups have possibility to detect hadrons, that is why we can propose to compare hadron and dilepton polarization characteristics in nucleus–nucleus collisions to investigate influence of formed nuclear matter. For example, the comparison polarization characteristics of dileptons and $\pi^+\pi^-(K^+K^-)$ pairs gives new information about the QGP formation. There are many other hadron probes where polarization should be used to prove the QGP formation. We can propose to investigate the polarization of Λ which comes from $\Lambda K^+(\overline{\Lambda}K^-)$ back-to-back pairs.

Till now we discuss the so-called regions of continuous dilepton mass spectrum. The resonance regions are very interesting too. But we do not have so many quantitative predictions. The ρ-meson alignment can serve as a sensitive tool to study mechanisms of formation [13]. Article [14] proposed to investigate J/ψ polarization in nucleus–nucleus collisions. The QGP formation should give a huge value of the alignment for J/ψ in contrast to nucleon–nucleon collisions where the alignment must be zero. It is very useful to compare characteristics of resonance polarizations from dilepton (photon) and hadron decay modes.

CONCLUSION

In this report we have discussed some ideas which allow one to receive the new additional experimental information which can help to prove the QGP formation. Polarization characteristics are a thin tool, and these experimental data will give possibility to speak about the detection of the thermalized state unequivocally. The authors are grateful to E. L. Bratkovskaya and O. V. Teryayev for interest and support.

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