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TOWARDS DECAY ANISOTROPY OF DILEPTONS

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Attention is attracted to the study of angular characteristics of e^+e^- pairs created in hadronic and nuclear collisions. Due to spin and angular momentum constraints, the dilepton decay anisotropy is found to be quite sensitive to the contribution of different sources. This is illustrated by the anisotropy coefficients estimated for various processes of dilepton production.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

Об анизотропии распада дилептонов

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Обращается внимание на исследование угловых характеристик e^+e^--пар, рожденных в адронных и ядерных столкновениях. Обнаружено, что из-за ограничений, накладываемых сохранением проекций спина и углового момента, анизотропия распада дилептонов оказывается весьма чувствительной к вкладу от различных источников. Это иллюстрируется рассмотрением коэффициентов анизотропии, оцененных для различных процессов образования лептонных пар.

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Leptonic probes are quite attractive since they provide weakly disturbed information on hot and dense nuclear matter at different stages of its evolution in heavy-ion collisions at intermediate and ultrarelativistic energies. Information carried out by leptons may tell us not only about interaction dynamics of colliding nuclei but also on properties of hadrons in nuclear environment and on a possible phase transition of hadrons into quark gluon plasma. However there exist a lot of hadronic sources of lepton pairs because the electromagnetic field couples to all charges and magnetic moments. It is very desirable to have additional information which would allow one to disentangle various sources experimentally. For this aim, we propose to study a new observable — the decay anisotropy of a lepton [1].

Till the recent time, the invariant mass spectra $d\sigma/DM$ was the only observable to be investigated for the e^+e^- pairs created in heavy ion collisions. As is seen from Fig.1, the variety of hadronic sources of lepton pairs gives rise to a very complicated picture. Really, lepton pairs may be produced due to the electromagnetic decay of time-like virtual photons which can result from the bremsstrahlung process or from the decay of baryonic and mesonic resonances including the direct conversion of vector mesons into virtual photons in accordance with the vector dominance hypothesis. The last processs has turned out [2] to be quite competing with $\pi\pi$ annihilation which was considered as the most promising

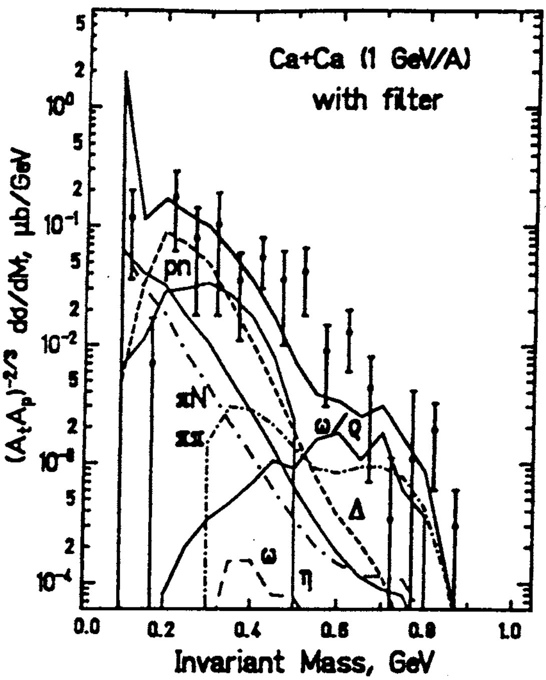

Fig.1. Invariant mass distribution for dileptons produced in Ca + Ca (2 GeV/A) collisions. Contribution of different sources calculated within QGSM [4] is shown. Experimental points are taken from [7] .

channel for investigating properties of hadrons in nuclear matter [3]. In addition, there are rather large uncertainties in theoretical calculations. The most complete list of hadronic sources has been included into Quark Gluon String Model calculations [4] presented in Fig.1. Inspite of the fact that other models [5,6] predict different contributions of sources and/or even neglect some of them, they also reproduce these data within available large experimental error bars. So, to disentangle various leptonic channels experimentally the necessity of a new approach to this problem becomes quite evident. We see that spin variables taken into consideration may help in solution of this problem.

Indeed, in all hadronic sources, the e^+e^- pairs are created due to electromagnetic decay of time-like virtual photons. In the rest frame, the decay of an unpolarized photon gives rise to isotropy of the angular distribution for a created lepton pair since there is no preferential direction. However, the coupling of the virtual photon to hadrons may induce some dynamical spin alignment of both resonances and virtual photons. So, one can expect [1] that the angular distribution of a lepton will be anisotropic with respect to the direction of dilepton emission. This decay anisotropy defined for the given dilepton mass is carrying some information on the spin alignment of the virtual photon as well as on spins of interacting hadrons and thereby allows one to disentangle different production processes, in principle.

Let characterize the decay anisotropy by the azimuthal and polar angles, φ, θ of the momentum $\mathbf{l}_-$ of a created electron with respect to the momentum of a virtual photon in the rest frame of this photon. For comparing the shape of the angular distribution in different channels, the differential cross section for dilepton production may be represented in the following form:

$$\frac{d\sigma}{dM^2\, d\cos\theta} = A\,(1 + B\cos^2\theta). \quad (1)$$

In a general case, the B coefficient may be a function of M, φ and masses of particles involved into the reaction.

The Dalitz decay of a pseudoscalar meson, say η, is one of the simplest cases since the zero spin of the meson disentangles the spin indices of the initial and final stated allowing one to factorize the production $\sigma^{\eta}(s)$ and decay probabilities. In particular, the angular distribution can be written as follows:

$$\frac{d\sigma^{\eta}}{dM^2 d\Omega} = \sigma^{\eta}(s)\,\frac{1}{\Gamma^{\eta}_{\rm tot}}\,\frac{d\Gamma^{\eta\to e^+e^-\gamma}}{dM^2 d\Omega}, \tag{2}$$

where the decay matrix

$$|T^{\eta\to e^+e^-\gamma}|^2 \sim \frac{1}{M^4}\,(\varepsilon_{\mu\alpha\beta\gamma}\,q_{\beta}\,q_{1\gamma}\,\varepsilon_{\nu\alpha\rho\sigma}\,q_{\rho}\,q_{1\sigma})\cdot L_{\mu\nu} \tag{3}$$

entering the decay width $\Gamma^{\eta\to e^+e^-\gamma}$ is directly related to the lepton tensor $L_{\mu\nu} = \mathrm{Tr}\,\hat{l}_-\gamma_{\mu}\hat{l}_+\gamma_{\nu}$. Here q, q_1 are the four momenta of a virtual and real photon. The final distribution is reduced to the following one*:

$$\frac{d\sigma^{\eta}}{dM^2\, d\cos\theta} \sim 1 + \cos^2\theta. \tag{4}$$

The same answer results from the Dalitz decay on any pseudoscalar meson, in particular, for the π^0 decay which dominates at $M \le 0.14$ GeV. These results are plotted in Fig.2.

Due to 3/2 spin of the delta, the dilepton differential cross section for the $\Delta \to Ne^+e^-$ decay cannot be reduced to the factorized form of eq.(2) though $d\sigma/dM$ is described quite well in this approximation. If the Δ alignment effect is neglected for a moment we get in this very crude approximation $B = +1$. As was shown in [8], the value $B = 1$ is reached only in the limit of a real photon, $M \to 0$ what illustrates a high sensitivity of anisotropy to the spin structure of the transition matrix element.

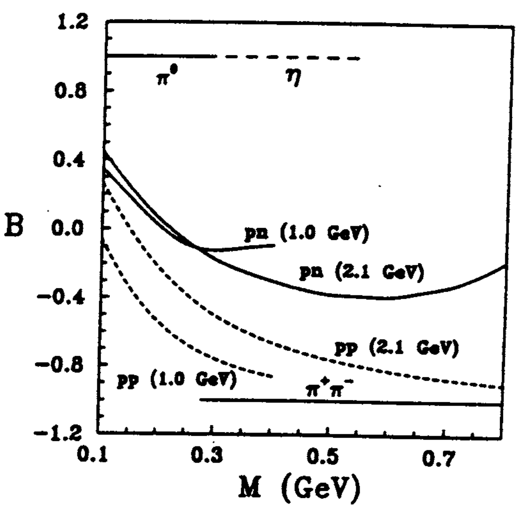

Fig.2. M-dependence of the decay anisotropy coefficient for different elementary dilepton sources: the Dalitz decay of η and π^0 mesons, $\pi^+\pi^-$-annihilation, pn and pp bremsstrahlung (at two energies)

Bremsstrahlung channel for e^+e^- production is estimated in the soft photon approximation. One can see from Fig.2 that B

*Strictly speaking, this simple result corresponds to a particular case of vanishing meson momentum (or the rest frame of the η meson). In general, the decay anisotropy coefficient will be energy- and M-dependent [9].

becomes M-dependent quantity changing its sign around $M \sim 0.2$ GeV. The distribution is not isotropic in this case what introduces axial symmetry breaking.

For the pion annihilation differential cross section we get $B = -1$ [1] which is also plotted in Fig.2. This result has not yet been averaged over the production angle, because the production and decay frames coincide for the $\pi\pi \to e^+e^-$ process. In contrast with all previous cases, averaging procedure for this channel depends on the dymamical distribution of pions and dilepton anisotropy for pion annihilation is vanishing when a system reaches an equilibrium state [1]. Thus, the B values predicted for different channels are ranging from $+1$ to -1 and may depend on the invariant mass M. A convolution of these B values with $d\sigma/dM$ for every source corresponds to the measured B values. We hope that this new observable will allow one to discriminate different models fitting equally well the available data on dilepton production but predicting different contributions of dilepton sources.

The decay anisotropy can give some feeling as to the strength of in-medium effects since only form factors, vertices, coupling constants and decay width of hadrons but not the spin structure of interaction does be changed. [1]. A possible appearance of a new phase characterized by a four-velocity v^{μ} may be indentified too in this way what is useful as a possible signal of quark-gluon plasma [1]. The proposed new observable, dilepton decay anisotropy, seems to be quite hopeful in attempt to disentangle various dilepton sources as weel as different theoretical models.

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