Letter to the Editor

MEASURING DILEPTONS PRODUCED IN A QUARK-GLUON PLASMA BY THE QCD COMPTON EFFECT[1)]

ИЗМЕРЕНИЕ ДИЛЕКТОНОВ, ПОЛУЧАЕМЫХ В КВАРК-ГЛЮОННОЙ ПЛАЗМЕ ПРИ ПОМОЩИ КХД КОМПТОНОВСКОГО ЭФФЕКТА

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1. The search for photons and dileptons produced by the quark-gluon plasma is an important objective in the study of relativistic heavy ion collisions. An abundant production of photons and dileptons with low masses M and low transverse momenta $p_T (M \sim p_T \sim T \sim 200$ MeV) was predicted long ago [1]. However, the QCD theory cannot make any definite statement when $M \sim p_T \sim \Lambda$, where the use of perturbative methods is incorrect. Therefore, one cannot unambiguously connect the exceptional photon and dilepton production observed experimentally [2—9] with the QGP signal.

At higher M and p_T the QGP model predicts a power-like behaviour of spectra [10]. Testing a M_T^{-6} dependence of a dilepton spectrum in the M_T region of $6.5T_c \div 6.5T_i \simeq 1 \div 3$ GeV/c^2(T_i, T_c are the initial and the final QGP temperatures) is the main aim of the NA-38 experiment.

For photons produced in the quark-gluon plasma the QCD-based model predicts [11]:

i) for $p_T \geq 3.5\, T_i \simeq 2$ GeV/c - the exponential damping of spectrum

$$d\sigma^{\gamma}/dp_T^2 \sim \exp(-p_T/T_i), \tag{1}$$

ii) in the region $3.5T_c \lesssim p_T \lesssim 3.5T_i (0.7 \lesssim p_T \lesssim 2$ GeV/c) the power-like dependence of the spectrum

$$d\sigma^{\gamma}/dp_T^2 \sim 1/p_T^4, \tag{2}$$

iii) at lower $p_T < 0.7$ GeV/c (where a QCD prediction is uncertain) the photon spectrum becomes even less steeper and effectively may follow, say

$$d\sigma^{\gamma}/dp_T^2 \sim 1/p_T^3. \tag{3}$$

Testing the power-like dependence of a photon spectrum in heavy ion collisions is a very difficult task, as the QGP photon signal disappears under hundreds of photons from $\pi^0 \to \gamma\gamma$ decays.

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A close approximation to a real photon production is the measurement of e^+e^- pairs at low masses $M \to 0$ and high transverse momenta $p_T \sim 0.7 - 2$ GeV/c, as the e^+e^- (virtual photon) production is related to the real photon production [12, 13]

$$\frac{E\,d\sigma^{ll}}{dM^2/d^3p} = \frac{\alpha}{2\pi}\frac{1}{M^2}\frac{E\,d\sigma^{\gamma}}{d^3p}. \tag{4}$$

The same method was used by the R806 experiment [13] in search for direct photons at ISR in the p_T range of 2—3 GeV.

In Section 2 we consider the advantages of this method in ion collisions. In Section 3 we compare the relative yield of different processes of the lepton pair production and show the dominance of the QCD Compton effect in the region of small M and $p_T \sim 1$ GeV/c. In Section 4 we present a Monte Carlo model of the lepton pair production by the QCD Compton effect. In Section 5 we compare the experimental data on real photon and low mass dilepton spectra to test the validity of relation (4) in the region of low $p_T < 0.7$ GeV/c and to determine whether these photons and dileptons are produced by the same mechanism.

2. The extrapolations of a real photon cross-section of dilepton spectra based on relation (4) have important advantages over the direct measurement of real photons in heavy ion collisions:

i) Only one tenth of electrons is falling upon a detector apperture in heavy ion collisions, in contrast to several hundreds of photons.

ii) Selecting e^+e^- pairs with $M > M_{cut}$ ($M_{cut} \simeq 100$ MeV) we can suppress the π^0 Dalitz decay background [14].

iii) The remaining background is a combinatorial one, when two e^+e^- pairs from the π^0 Dalitz decays have lost partners due to detector inefficiencies. This background can be studied in the same detector by measuring like-sign pairs. Contrary to this the $\pi^0 \to \gamma\gamma$ background in real photon measurements should be calculated.

iv) A combinatorial background in terms of the e^+e^-/π^0 ratio has to be less than a γ/π^0 background because the background is proportional to (γ-conversion probability)$^2 \sim 10^{-4}$ in the first case.

v) The $D\bar{D} \to ee$ background seems to be small for low mass dilepton pairs [15].

The low mass dimuon pairs with $p_T \sim 1$ GeV/c can also be used to obtain a real photon cross-section from (4), as the background conditions are improving with lower masses and higher $p_T > 0.7$ GeV/c [16].

3. The dileptons can be produced in QGP by the following processes:

i) quark-antiquark annihilation

$$q + \bar{q} \to l^+ + l^-, \tag{5}$$

with cross-section $\sigma \sim \alpha^2$.

ii) the QCD-Compton effect and its crossed reaction

$$q + g \to q + \gamma^*, \quad q + \bar{q} \to g + \gamma^*, \tag{6}$$

followed by the internal conversion of the virtual photon $\gamma^* \to l^+ + l^-$, with the cross-section $\sigma \sim \alpha_S \alpha^2$.

iii) Bremsstrahlung processes of the virtual photon emission

$$q + q \to q + q + \gamma^*, \quad q + g \to q + g + \gamma^*, \ldots, \tag{7}$$

with $\sigma \sim \alpha_S^2 \alpha^2$.

The annihilation process (5) contribution is described by [11]

$$\frac{d\sigma^{ll}_{annih.}}{dM^2\,dY\,d^2p_T} = \frac{\alpha^2}{4\pi^4}\left(0.69\,\frac{dn^{\pi}}{dY}\right)^2 \int_{-Y_{max}}^{Y_{max}} d\chi \int_{T_c}^{T_i} \frac{dT}{T^7} \exp\left[-\frac{M_T}{T}\cosh(Y-\chi)\right]. \tag{8}$$

The contribution of the QCD Compton processes (6) is

$$\frac{d\sigma^{ll}_{QCDC}}{dM^2\,dY\,d^2p_T} = \frac{6\alpha_S\alpha^2}{\pi^5}\frac{1}{M^2}\left(0.69\,\frac{dn^{\pi}}{dY}\right)^2 \times$$

$$\times \int_{-Y_{max}}^{Y_{max}} d\chi \int_{T_c}^{T_i} \frac{dT}{T^7} T^2 \left\{\ln\left[\frac{6M_T\cosh(Y-\chi)}{\pi\alpha_S T}\right] - 1.577\right\} \exp\left[-\frac{M_T}{T}\cosh(Y-\chi)\right]. \tag{9}$$

We obtain this formula by a proper combination of the relation (4) and the expression for $d\sigma^{\gamma}_{QCDC}/dY\,d^2p_T$ taken from [11].

Usually the annihilation process (5) is considered as the main contribution to the ll production from QGP. However, it is not the case of low mass ll pairs with $p_T \sim 1$ GeV/c. Fig. 1 shows the ratio $R = d\sigma^{ll}_{QCDC}/d\sigma^{ll}_{annih.}$ for different sets of α_S, T_c, T_i. Roughly $R \sim (p_T/M)^2$, therefore for dileptons with $M \ll p_T$ the QCD Compton process is dominant in the p_T region of $3.5T_c + 3.5T_i \simeq 0.7 \div 2$ GeV/c. Here $\alpha_S(p_T \sim 1\ \text{GeV/c}) < 1$, thus higher order corrections for the processes (5—6) are small (perturbative QCD). The contribution of the bremsstrahlung processes (7) is exponentially damped in the region $p_T \gtrsim 1.5\ T_i \simeq 0.7$ GeV/c [11].

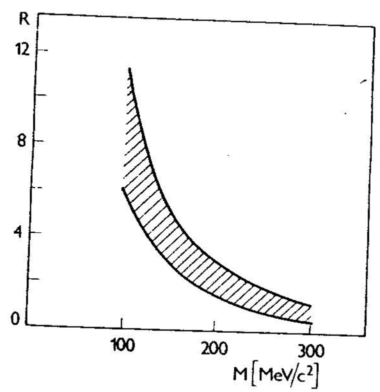

Fig. 1. The ratio R of the contribution to a dilepton production cross-section $d\sigma^{ll}/dM^2\,dY\,d^2p_T$ at $p_T = 1$ GeV/c of the QCD Compton effect (9) to that of a $q\bar{q}$ annihilation (8). The shaded band represents different sets of QGP parameters bounded by $T_i = 0.3$ GeV, $T_c = 0.25$ GeV, $\alpha_S = 0.3$ set (upper curves) and $T_i = 0.3$ GeV, $T_c = 0.2$ GeV, $\alpha_S = 0.2$ set (lower curve).

4. For a more careful study of the feasibility of the QGP Compton effect measurements in heavy ion collisions we need a Monte Carlo model of a low mass high p_T dilepton production. A proper combination of (4) and (2) gives:

$$\frac{d\sigma^{ll}}{dM^2\,dY\,d^2p_T} \sim \frac{1}{M^2M_T^4}. \tag{10}$$

We normalized this model to a high p_T tail of anomalous dilepton production data at 225 GeV/c [5] (Fig. 2c).

Fig. 2c also presents an upper limit to the ll production obtained from the R 806 measurements of $\gamma/\pi = (0.55 \pm 0.92)$ % at $\sqrt{S} = 55$ GeV, $Y = 0$, $p_T = 2 - 3$ GeV/c [13] to conditions of experiment [5] (225 GeV/c, $x > 0.07$). One can see that for $p_T > 2$ GeV/c an exponential damping (1) should be taken into account. Fig. 2a, b shows the M and x distributions. When we compare the model (10) to the 225 GeV/c data we use a flat Y distribution in the range of $|Y_{cms}| < 2$ of our calculations. Fig. 2 shows that the model (10) can reproduce one half of a total anomalous dilepton production cross-section. Thus an overall QGP Compton signal normalization is:

$$\int_{200\ \mathrm{MeV}}^{600\ \mathrm{MeV}} \mathrm{d}M \frac{\mathrm{d}\sigma^{ll}}{\mathrm{d}M\,\mathrm{d}Y} = 3 \times 10^{-5} \frac{\mathrm{d}\sigma^{\pi^0}}{\mathrm{d}Y}. \tag{11}$$

This is 1/2 of an anomalous pair signal normalization obtained in [14].

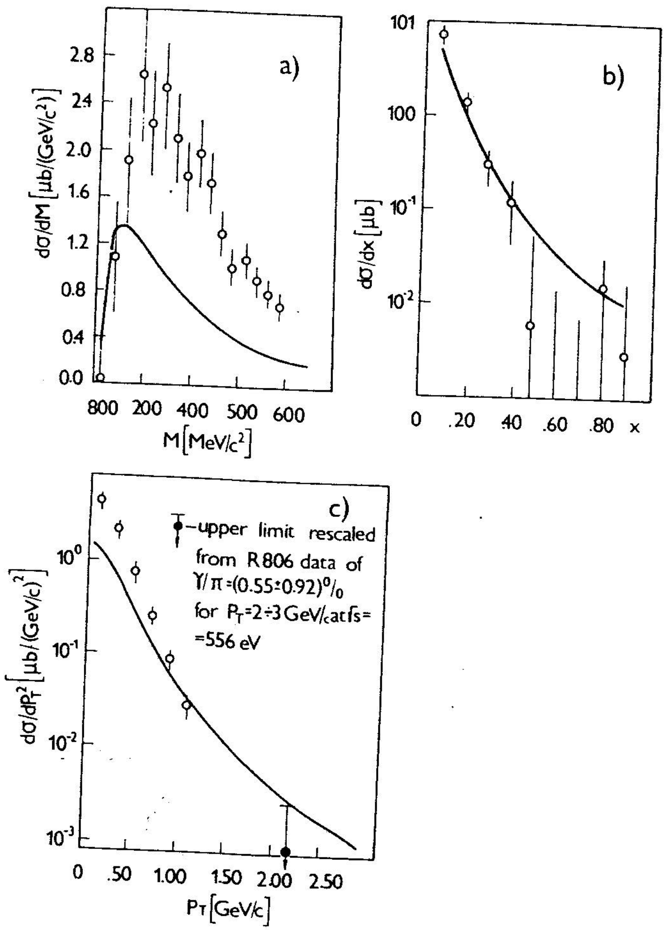

Fig. 2. The result of a QGP Compton effect normalization to a high p_T tail of an anomalous dilepton production. Open circles — data of a 225 GeV c $\pi N \to \mu^+\mu^- X$ experiment [5]. Solid line — results of a MC calculation using formula (10) for dimuons. a — $\mathrm{d}\sigma^{ll}/\mathrm{d}M$ distribution, b — $\mathrm{d}\sigma^{ll}/\mathrm{d}x$, c — $\mathrm{d}\sigma^{ll}\,\mathrm{d}p_T^2$. A closed circles in Fig. 2c represents the upper limit of R806 [13] rescaled to 225 GeV/c data.

5. If the photons and dileptons are produced by the sames mechanism, then the relation (4) should hold. It can easily be shown that to reproduce the experimentally observed $1/M^2$ dependence of anomalous pair $\mathrm{d}\sigma^{ll}/\mathrm{d}M$ spectra [5—9, 14] one needs the $1/p_T^2$ dependences of a $\mathrm{d}\sigma^{\gamma}/\mathrm{d}p_T$ spectrum (3), which is also in agreement with observations [2, 3] in the region $p_T > 20$ MeV/c. Thus to check the relation (4) one needs to plot $\mathrm{d}\sigma^{ll}/\mathrm{d}M\,\mathrm{d}Y$ versus M and $(\alpha/\pi)\,\mathrm{d}\sigma^{\gamma}/\mathrm{d}p_T\,\mathrm{d}Y$ versus p_T in the sames figure. It is convinient to compares experimental data normalized to poin rapidity density at $Y = 0$. The result is shown on Fig. 3. To plot the data of [3] we have used the approximation

$$\left.\frac{\mathrm{d}\sigma^{\gamma}/\mathrm{d}p_T\,\mathrm{d}Y}{\mathrm{d}\sigma^{\pi^0}/\mathrm{d}Y}\right|_{Y=0} \simeq \frac{\mathrm{d}\sigma^{\gamma}/\mathrm{d}p_T}{\sigma^{\pi^0}}. \tag{12}$$

The observed agreement of experimental data with the $1/M^2(1/p_T^2)$ dependence in Fig. 3 suggests that the soft photon and dilepton production mechanisms are of a common origin. One can arrive at analogous conclusions analysing the M_T spectra of photons and dileptons [17].

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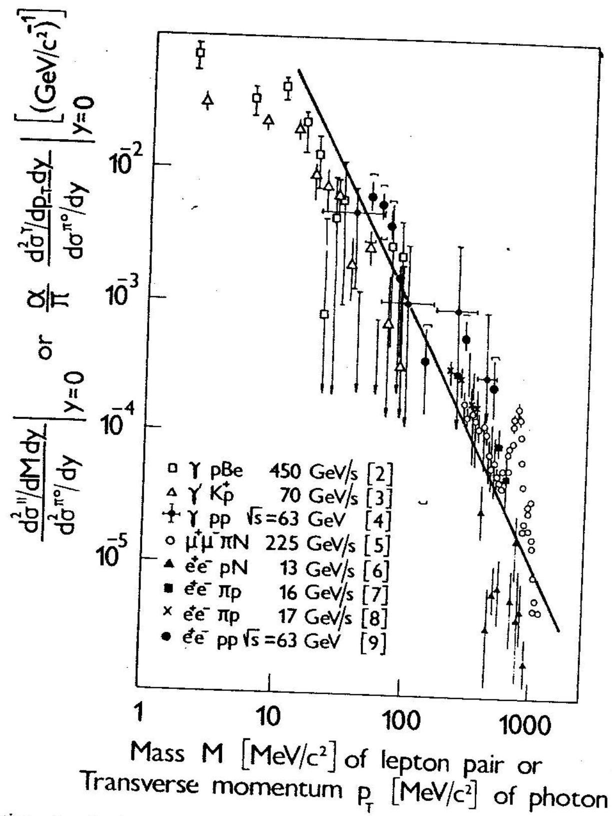

Fig. 3. A compilation of soft photon and dilepton spectra exhibits an universal $1/p_T^2(1/M^2)$ dependence, suggesting that these photons and dileptons are of the same origin.

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