PHYSICAL REVIEW C VOLUME 55, NUMBER 2 FEBRUARY 1997

# Can dileptons be observed in heavy ion collisions at relativistic heavy ion collider energies?

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(Received 3 June 1996)

Both dilepton and charm production at RHIC are considered to be important signatures for quark-gluon plasma production. Recently it was argued by Gavin *et al.* that the background from semileptonic correlated charm decays is so large that it makes dilepton measurements virtually impossible. We show that this conclusion is in fact reversed if the energy loss due to a secondary interaction of charmed quarks is included. [S0556-2813(97)04902-9]

PACS number(s): 25.75.−q, 12.38.Mh, 13.20.−v, 24.85.+p

Dileptons produced in highly excited hadronic matter provide valuable information about the hottest and the most dense stages of nuclear collisions. Together with photons, they are the so-called *penetrating probes* [1] which suffer very little secondary interaction. Consequently, dilepton measurements have attracted a great deal of attention, both of theorists and experimentalists. Referring specifically to the highest energies, let us recall that one of the major RHIC detectors, PHENIX, and ALICE at LHC plan dilepton measurements, both with electron and muon pairs.

Another potential quark-gluon plasma (QGP) signature is *thermal production of new quark flavors*, especially of charm [1,4,5].[1] However, the ordinary partonic production of charm at the first impact is large, and whether it dominates the secondary (and thermal) charm production remains unclear. Nevertheless, the charm signal will also be experimentally addressed at RHIC, by STAR and PHENIX collaborations.

Since charmed hadrons have substantial semileptonic decays, their simultaneous decays create a $l^+l^-$ background for dilepton measurements. This issue was addressed recently by Gavin, McGaughey, Ruuskanen, and Vogt (GMRV) in a detailed paper [6]. Their conclusions are summarized in Fig. 1, and they basically imply that the background from leptonic decays of charmed (and even $b$) quarks is so large that implementation of the dilepton measurements is virtually impossible in the whole kinematic domain.

In this Brief Report we question those pessimistic conclusions and suggest that it should be reversed. We show that a very important effect is missing from the GMRV analysis: Unlike dileptons, the charmed quarks are not ‘‘penetrating probes,’’ and their spectra should be very different in $pp$ and heavy ion collisions. Like any other quarks (and gluons), charmed ones are also subject to energy losses due to multiple secondary interactions in dense matter produced in the collisions. As we will show below, they are mostly stopped in matter.

Our first point is a purely geometrical observation. Consider a collision of two heavy nuclei, and imagine that in it a $\overline{cc}$ pair is produced.[2] The charmed quarks have to pass certain distances $d_1,d_2$ on their way out, and we point out that it is very improbable that the *sum* $d_1+d_2$ is small because the quarks are mostly produced back to back.

If nuclei are approximated as spheres with a well-defined surface and radius $R$, one can easily quantify the relevant distributions. A distribution over a single quark path $d$ (in units of the nuclei radius $R$) is shown by a histogram in Fig. 2. Note that it is basically flat between $d\approx 0.2R$ (or 1 fm for heavy nuclei) and $2R$ (the diameter). However, the distribution of $(d_1+d_2)/R$ (shown by stars in Fig. 2) is quite different. It is sharply peaked at its largest value, but is very strongly suppressed at small ones. In order for both charmed quarks to escape, they not only should be created close to the surface, but also quarks should be emitted in a very small (tangent) solid angle. As we will show shortly, this simple observation is in fact responsible for a significant reduction of the correlated charm- (and bottom-) induced background.

A dynamical ingredient of our analysis is $dE/dx$, the quark energy losses in QGP. We will not comment here on the complicated history of its discussion in theoretical and phenomenological papers. A consistent treatment (generalizing the Landau-Pomeranchuck-Migdal approach to QCD) was recently developed by Baier, Dokshitser, Peigne, and Schiff (BDPS) [7]. The main qualitative difference between QED and QCD cases can briefly be explained as follows. In QED an electron is scattered and has a complicated zigzag-like trajectory, while its fields go without interaction by a straight line. In QCD it is the quark which is going by an approximately straight line, while its gluonic fields suffer multiple rescatterings. The BDPS result for the energy loss is

$$\frac{dE}{dx}=C_R\alpha_s\left(\frac{E\mu^2}{\lambda_g}\right)^{1/2}\ln\left(\frac{E}{\lambda_g\mu^2}\right), \tag{1}$$

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[1] The expected highest temperatures at RHIC [1–3] are $T_i=400$–$500$ MeV, and so the mean energy per parton $\approx 3T$ is comparable to charm quark mass. Note also that the mass of the strange quark is not large enough to suppress its production in the hadronic phase.

[2] The commonly used terminology separates a *correlated* and an *uncorrelated* charm decay. The former is a simultaneous decay into $l^+$ and $l^-$ from a $\overline{cc}$ pair produced in one parton collisions, while the latter comes from the charm quarks produced *independently*. In this paper we concentrate on the correlated background only because the uncorrelated background can be statistically subtracted in a standard way.

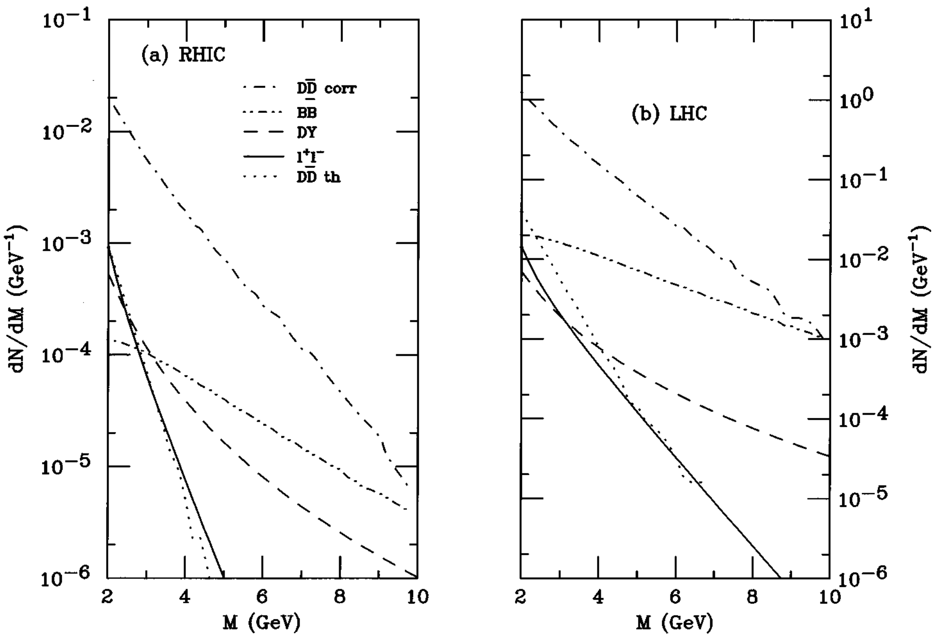

FIG. 1. Contributions of different dilepton production mechanisms according to GMRV for central Au-Au collisions at RHIC (a) and LHC (b). The curves correspond to a correlated charm decays (dash-dotted lines), $b$-quark decays (dash-double-dotted lines), Drell-Yan process (dashed curve), thermal dileptons (solid curve), and decays of thermally produced charm (dotted lines).

where $C_R$ is the Casimir operator for quark color representation, $E$ is the collision energy, $\lambda_g$ is *gluonic* mean free path, and $\mu$ is the rms momentum transferred in each scatterings. Substituting some ''reasonable'' parameters of QGP at RHIC (corresponding to the ''hot glue scenario; see [2,3]) we have estimated $dE/dx \approx 2$ GeV/fm.

Our next step is Monte Carlo simulation of charm production. In order not to introduce any additional points of discussion, we follow Ref. [6] as close as possible. We have ignored the ''thermal charm'' and assumed that each central Au-Au collision at RHIC produces $\overline{cc}$ pairs with a very stiff $p_t$ distribution[3] generated by the leading order and resummed next-to-leading order QCD processes. This approach works in the $pp$ case, and that is why GMRV have found that the correlated charm decay contributes so strongly at large dilepton masses.

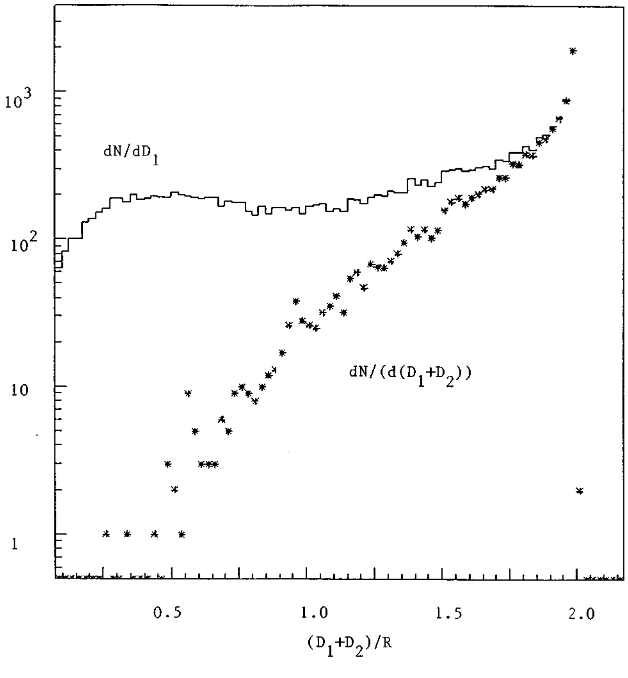

FIG. 2. The histogram shows distribution of the transverse distance $d$ passed by a charm quark on the way out of nuclei (in units of its radius), while stars correspond to the sum $d_1+d_2$ of distances for a charmed quark and antiquark.

However, after the energy losses $dE/dx$ are included, only very few of $c$ or $b$ quarks can in fact escape, while most of them are stopped. Eventually, those should have $p_t$ spectra similar to all other hadrons, governed by low decoupling temperature $T \sim 140$ MeV and hydrodynamic effects. Since both thermal and hydrodynamic velocities are not large, we have ignored them.

We have simulated semileptonic decays of $c$ and $b$ quarks and show the resulting invariant mass $M=(p_{l+}+p_{l-})^2$ spectrum in Figs. 3 and 4. In both cases the histogram shows free decays, while stars include the effect of $dE/dx$. Those two cases are very different: While in free space the invariant mass distribution has a smooth and large tail toward the large masses, with $dE/dx$ one clearly sees two distinct components: charm decay at rest and the contribution of escaping ones. The boundary between two components is at $M_{l^+l^-} \approx 1.7$ GeV for $c$ and 4.5 GeV for $b$ decays. Above it we have found a background suppression, roughly by about two orders of magnitude. These features survive reasonable modification of charm production spectra or of the chosen $dE/dx$ value.

How important may this reduction be in practice? In order to answer this question, one has to evaluate dilepton production, both primary (known as the Drell-Yan process) and secondary (nonequilibrium [8] and thermal [9]) ones. In this

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[3] An approximate parametrization used is $dN/dp_t^2 \sim 1/(p_t^2+0.5)^{2.2}$.

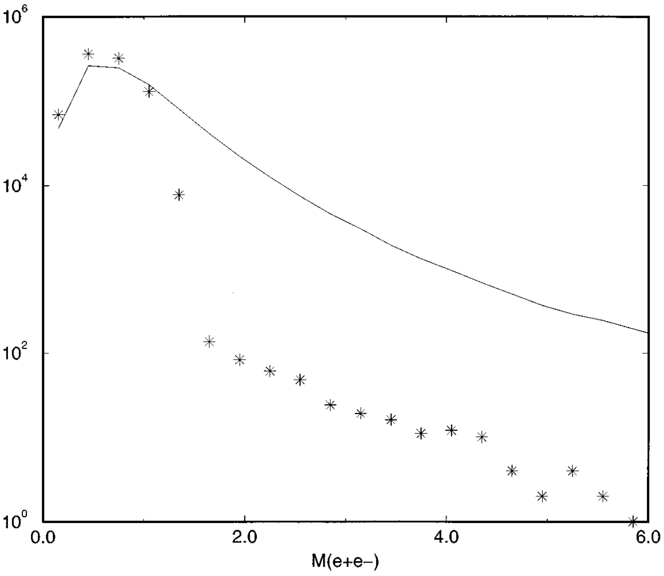

FIG. 3. The distribution of dilepton invariant masses (in GeV) produced by a semileptonic decays of charmed quarks, with (stars) and without (solid line) the matter effect due to $dE/dx$.

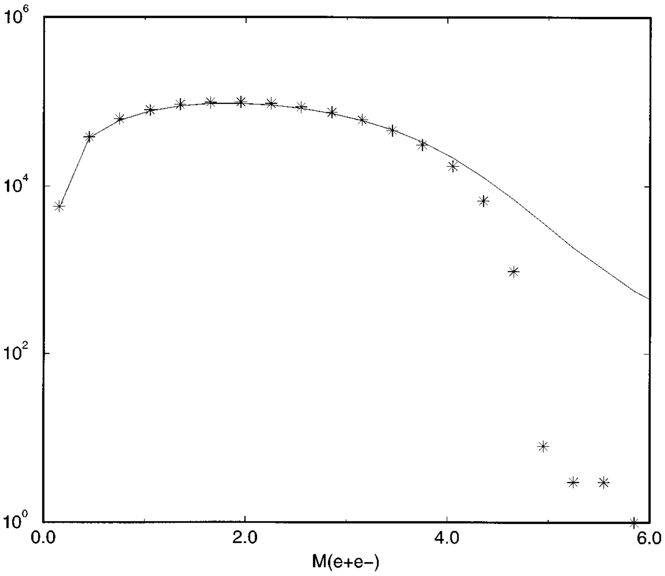

FIG. 4. Same as the previous figure, but for $b$ quark decays.

Brief Report we will not go into discussion of it[4] and simply return to GMRV estimates. As seen from Fig. 1 the ratio (dilepton yield)/(correlated charm background) is about 1/10 for $M=2-8$ GeV, while (dilepton yield)/($b$ decay background) is about 1/3 for $M>5$ GeV. Those are exactly the mass regions where our suppression discussed above appears. Thus we conclude that (dilepton yield)/(correlated charm background) is probably above 1 and that $b$ decays are simply negligible. A more quantitative conclusion is difficult to get now: Also one should consider acceptance of the particular detector, etc.

Since we are still in a situation with the signal/background ratio being around 1, additional experimental tools are needed in order to separate dileptons from charm decays. At least two are available: (i) Dileptons are produced back to back in an azimuthal angle, while leptons from charm decay are nearly isotropic in it; (ii) Drell-Yan pairs have the well-known $(1+\cos^2\theta)$ distribution where $\theta$ is the polar angle between the dilepton direction in its c.m. frame and the beam. Also DY and direct charm should have simple scaling $A^{4/3}$ from light nuclei (or peripheral collisions), and so any excess over it is an indication for secondary processes.

In summary, in contrast to GMRV, we think that $c$ and $b$ quarks produced in high energy heavy ion collisions should be trapped in matter with very high probability. As a result, the background due to correlated semileptonic charm decay does *not* dominate the dilepton spectra for invariant masses above 2 GeV. Optimistically, by using various angular distributions, one may probably measure *both* dileptons and charm.

This work was stimulated by a seminar by Ramona Vogt: I am thankful for her detailed explanations of their work. This work is partly supported by the U.S. Department of Energy under Grant No. DE-FG02-88ER40388.

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[4] Let us only mention that GMRV make a very good job on DY, but do not include the nonequilibrium one. Also, they treat thermal dileptons in the leading order only. Both effects are expected to increase the secondary production substantially.

[1] E. Shuryak, Sov. J. Nucl. Phys. **28,** 408 (1978); Phys. Rep. **61,** 71 (1980).
[2] E. Shuryak, Phys. Rev. Lett. **68,** 3270 (1992).
[3] K. Geiger and B. Muller, Nucl. Phys. **B369,** 600 (1992); K. Geiger, Phys. Rev. D **46,** 4965 (1992); **47,** 133 (1993).
[4] P. Levai, B. Muller, and Xin-Nian Wang, Phys. Rev. C **51,** 3326 (1995).
[5] Zi-wei Lin and M. Gyulassy, Phys. Rev. C **51,** 2177 (1995); **52,** 440 (1995).
[6] S. Gavin, P.L. McGaughey, P.V. Ruuskanen, and R. Vogt, ''How to find charm in nuclear collisions at RHIC and LHC,'' Report No. LBL-37981, hep-ph/9604369.
[7] R. Baier, Yu. L L. Dokshitser, S. Peigne, and D. Schiff, Phys. Lett. B **345,** 277 (1995); Report No. hep-ph/9411409.
[8] E. Shuryak and L. Xiong, Phys. Rev. Lett. **70,** 2241 (1993).
[9] K. Geiger and J.I. Kapusta, Phys. Rev. Lett. **70,** 1920 (1993).