HEAVY FLAVOURS PRODUCTION IN QUARK-GLUON PLASMA
FORMED IN HIGH ENERGY NUCLEAR REACTIONS

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ABSTRACT

Results on compression and temperatures of nuclear fireballs and on relative yield of strange and charmed hadrons are given in this paper. The results show that temperatures above 300 MeV and large compressions ( \( \gtrsim 10 \) ) are unlikely achieved in average heavy ion collision. In consequence thermal production of charm is low. Strange particle production is, however, substantial and indicates clear temperature - threshold behaviour.

1. Introduction: Observation of QGP is one of the most desired arguments in favour of correctness of our understanding of strong interactions. Its formation needs a large deposition of energy in large enough volume. The interactions of cosmic ray particles, primarily nuclei, offer the unique opportunity of its detection.

One of the signatures of QGP formation is increased rate of heavy flavours as compared to the hadronic systems at the same temperature without QGP formation (1). The role of charm may be also peculiar; we forsee charmed quarks as a centers of hadronic bubble formation in hot QGP and as a stabilizing factor in cold multicharmed globs (2). Both phenomena may lead to unusual events. Here we present only some of our results. The full paper will be published elsewhere.

2. The model: Several arguments, based on experimental observations (the transparency of nuclei being strongest one) and on results of relativistic of two fluid - hydrodynamics allows us to treat the beam nucleus (for definitness we will work in the lab frame) as a penetrating, shock-like discontinuity propagating with (almost) velocity of light through the nuclear matter. In equations of hydrodynamics its propagation is represented
as a source term of energy, momentum and colour (but not baryon number) transferred to the nuclear matter. These equations allow us to find (with assumed equation of state for nuclear matter) the heating curve i.e. temperature $T$ and compression factor $f$ ($= n_B/n_0$, $n_0 = 0.17$/fm$^3$) behind the front. Whenever $T$ and $f$ are in QGP sector of QGP-hadron phase diagram we assume that, within the slice 1-2 fm behind the traversing beam nuclei thermalized QGP is formed.

We tried several models of nuclear matter to get equation of state, but finally our results represented here are based on Walecka mean field model, Statistical bootstrap model of point particles, and Hybrid model of free N,$\Delta$,\pi- gas with phenomenological repulsion potential fitted at low energies. The qualitatively the results for all models are the same.

QGP is described by standard model of four fermions ($u,d,s$, $c$ - quarks) and eight bosons (massless gluons). The partition function with several sets of parameters tried, has been calculated up to the lowest order of perturbative expansion. The masses and coupling constant are taken density and temperature dependend with the running momentum $q = ( (2T)^2 + (\mu B/3)^2 )^{1/2}$.

The evolution of QGP (its expansion and flow) is governed by hydro- and thermodynamics. One of the strongest constraints is given by baryon number conservation and entropy production condition (1), (3): i.e. surface hadronic deflagration of QGP at thermal and chemical equilibrium is forbidden prior to the reversed phase transition QGP-Hadronic gas. In consequence all hadrons are produced at transition temperature, which (for $f \leq 10$) is roughly 160-180 MeV and, as entropy production in deflagration is low, they preserve degrees of freedom of QGP close to the transition.

3. Results: Our model gives a unique possibility to relate $T$ and $f$ when equation of state is given. According to the authors knowledge this result is unique and original (4). In the approximations used the result for $T(f)$ do not depend on size of the neither beam not target nuclei. The result for assumed (ud), (uds), (udsc) QGP is presented on Fig. 1.

The second result of our model which we wish to present to the Conference is strangeness and charm relative yield when QGP is formed in nuclear collision. Due to high entropy per baryon and, in principle, unlimited temperature as well as due to peculiar properties of QGP evolution its presence offers more abundant production of heavy flavours than any hadronic process without QGP.
Due to the finite relaxation times the production of heavy flavours at lower temperatures is damped by finite life time of QGP. In consequence the production of strangeness and charm displays a pronounced temperature-threshold enhancements. For nuclear fireball created according to the our scenario the strange particles start to be copiously produced at $T \gtrsim 240 \text{ MeV}$, (see Fig. 2) whereas charmed particles have threshold at $T \sim 500 \text{ MeV}$.

4. Conclusions: According to our model and within the approximations done our results indicates:

(1) High temperatures in nuclear fireballs are not likely to be common phenomena at high energy interactions. It is relatively easy to heat nuclear fireball up to $T = 200 - 240 \text{ MeV}$. 

Fig. 1

Temperature $T$ and compression factor ($f$) of nuclear fire-ball together with phase diagram for Walecka (WAL), Hybrid (HYB) and stat. Bootstrap (SB) models of hadronic gas.

T-$f$ curve for hadronic fire-ball has been got for ud, uds and udsc flavours. WAL-curve has been got when compressed matter is assumed to be Walecka nuclear matter. K is "Kajantie point". All numbers refer to energy per baryon.
(ii) Nuclear fireball decays in a deflagration-like process at $T = 160-180$ MeV when almost all hadrons are produced.

(iii) Heavy flavours are easily produced provided relaxation time is shorter than life time of QGP droplet. Their production displays threshold-like enhancement which may serve as indicator of QGP-formation.

(iv) Energy transferred to heavy flavour component is almost steady ($\approx 30\%$) fraction of total energy.

(v) Charmed quarks and consequently charmed particles are produced in very low amount (at $T = 500$ MeV $n_c/n_B$ is $\approx 10^{-6}$).

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References: