July. 1995

LU TP 95-17

Smokerings, a Possible Collective Effect in a Multigluon State Stemming From High Energy Heavy Ion Collisions

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Abstract

In the early stage of ultrarelativistic heavy ion collisions both the number density and energy density of the gluons are high and a complex and highly interacting system is formed. In this paper we investigate the possibilty that a colour singlet state may be formed through the gluon-gluon (re)interaction in the system. We present our results using the Monte-Carlo simulation and discuss how the colour singlet state will affect the formation of a QGP and the distributions of hadrons in the final state.

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1 Introduction

A large amount of effort is presently invested into the investigations of high energy heavy ion collisions both because there are beams available ("One climbs a Mount Everest just because it is there") but also in the hope of finding a phase transition to a new kind of matter, the Quark Gluon Plasma (QGP).

It is already known that the present experimental data contain some collective effects, ie features which cannot be understood solely by means of a superposition of multiple independent hadronic interactions. Thus we know that there is an enhancement of strangeness and some noticeable changes in the transverse momentum spectrum as well as some enhanced particle production in the centre of phase space compared to a simple model. All of these signals have been suggested as possible signals for the onset of the QGP. It is also, using Bjorken's estimate of the energy density in terms of the observables[1], possible to make the case that the central collisions in the present data already exhibits a sufficient density for the formation of a QGP.

It is, however, necessary to investigate other possible reasons for the effects. We have in a set of papers, [2], [3], [4], considered some collective effects of a non-QGP type. In a central high energy heavy ion collision there are very many particles produced (although due to the size of the formation time most of them come into being only outside the original nuclei). Nevertheless, there are noticeable effects, in particular increased strangeness and some reshuffling towards smaller transverse momenta, which can be explained in terms of the reinteraction of the produced particles, [2]. This is sufficient to explain away a large part of the observed QGP signals at present. In all the work mentioned in this paper we will use of the basic interaction scenario in the FRITIOF Model, [5].

It is conceivable that the formation of very many string-like forcefields (which with somewhat different names occur in most of the models on the market) in a small space-time region may induce some interaction already on the short-time scale of the collision. In case we would model the QCD vacuum as a color superconductor (as suggested in Ref [6]) we do not know if such an object would behave like a type I, ie contain field regions of bag- or extended flux-tube character, or more like a type II corresponding to string-like vortex lines. In any case it is possible that several force fields will interact and then it is not the individual string energy density but the common large energy density that is available for gluon bremsstrahlung emission. We have in Ref [3] (cf also Ref [7]) considered such a mechanism, "the fire-cracker scenario" and exhibited the consequences, in particular an essentially enhanced "mini-jet" generation in the centre of phase space. If we compare to the "ordinary" FRITIOF model, the firecracker gluons will not only contribute in an essential way to the total inclusive transverse energy spectrum but even (for large transverse momenta > 3 GeV) completely drown the contributions from the usual bremsstrahlung spectrum and the Rutherford scatterings. In this way we obtain another "simple" explanation for some QGP signals.

It is further possible that a set of string fields, which are spanned close by each other, may form a common extra interaction energy during the building up of the force fields. It is well-known that a set of vortex lines in a superconductor type II will have a repulsive interaction, ie there is some energy stored in between them. This means that during the breakup of the strings, ie the fragmentation stage, this extra energy will be brought back into the particles formed. We have in Ref [8] presented the basic properties of such a scenario ("the fragmentation of a color rope") and we will further extend it in Ref [4]. The most noticeable properties are that some (few) particles may in this way obtain much more (longitudinal) energy momentum than it is possible in an "ordinary" single string breakup ("slingshots"). If it is the common energy density, which governs the expected quantum mechanical fragmentation tunneling process then one may obtain both increased (fragmentation) transverse momentum and strangeness production. Most parts of the predictions from the firecracker scenario and the slingshots (as well as from the collective smokering effects in this paper) are not possible to see in the presently available data but will be very noticeable at RHIC and in particular at LHC with the larger A- and energy-values available.

There is also a possible stage in between the (very early) perturbative stage when the bremsstrahlung gluons (and the firecrackers) are formed and the (much later) fragmentation stage. During this time there will in a central collision be a large density of gluonic radiation and it is then conceivable that the gluons will interact via Rutherford scatterings etc. It is well-known that two color octet (8) gluons will in a Rutherford scattering exchange a third (virtual) 8. But it is probably not so well-known (although used in connection with the so-called "bubble vacuum" model of QCD, [9]) that there is an essentially larger cross section for the interaction in case the two original gluons together form a joint color singlet (1) or a color 8 state than if they form a color 27 (there is no interaction in the case of the possible color states 10 and $\bar{10}$). We note that there should in a dense surrounding be many interactions between the gluons and this might then essentially increase the rate of multi-gluon singlets.

In case a singlet two-gluon state (and a singlet three-gluon state, obtained by adding a wee gluon to the interacting two-gluon state in an octet state) is formed and is reasonably stable then such a state should in string language look like a closed string pulled out by the gluons. The fragmentation of such a string state is to some extent known from the decay of the onium states and will be treated according to the Lund Model prescriptions (with a slight extension to variable masses of the gluon states) in the JETSET Monte Carlo routines, [10]. We also note that the lattice calculations on the states formed above a QGP phase transition still tends to exhibit some hadron-like structure. Without getting involved in the present debate on these structures, [11], we may evidently ask if it is multigluon singlets that are observed?

We will in this paper investigate the possible observable effects if such a "smokering" formation scenario is feasible and the smokerings can be treated as independent entities. We find firstly an essential enhancement of the central multiplicity (closed strings produce more particles than open ones) and also some enhanced transverse momentum in the centre. The necessary energy is taken from the surroundings, ie there will be a corresponding depletion region for transverse emissions (which should be noticeable at RHIC and LHC, even inclusively) a few rapidity units from the centre. Finally we point out that in case the large fraction we obtain for the smokering formation (about $10-35\%$ of all gluons will be "neutralised" in this way) actually occur then the Bjorken estimate of the energy density available for QGP formation in a collision (which will obtain a large part from the smokering decays) may be questionable.

The parton cascades in a dense parton scenario have also been studied in Refs [12]. In that case the conclusion is that the gluonic Rutherford scattering interactions will lead to a kinetic equilibration at a very early stage (at about .3 fm/c). The intention is, however, not to consider possible disturbances of the kind we are proposing, ie that color-neutral gluonic states may be formed, thereby "neutralising" the large partonic energy density. We feel that it is necessary that the color-neutral gluon states should have a "small" space-time size or at least not exceed the hadronic size scale before the decay if our scenario should work. We have therefore investigated the sensitivity of the mechanism to different cutoffs based upon semi-classical considerations of the space-time development.

The paper is organised so that in section 2 we consider the basic FRITIOF interaction scenario and after that the gluon production mechanisms in the FRITIOF Model (both the conventional Soft Radiation Model (SRM) scenario, the firecracker extension and also Rutherford scattering). In section 3 we describe the Smokering Formation Model and finally in section 4 we describe the consequences of it. The model is, like the other collective effects which are mentioned above, possible to investigate in detail by means of a Monte Carlo simulation program, LUCIAE, [13] which can be connected to the basic FRITIOF program, [14].

2 Multigluon Formation in the FRITIOF Model

2.1 The Basic Longitudinal FRITIOF scenario

In hadron-hadron collisions in the FRITIOF model, [15] it is assumed that the two hadrons approach each other as two essentially transverse fronts (due to Lorentz contraction) with (large) longitudinal (lightcone) energy momenta P_+ and P_-. Then in case we use a semi-classical string scenario the resulting final state will turn out to be the same both if the process is viewed as a measuring process or if it is treated as repeated (soft) multiparton interactions.

For the measuring process we may imagine that the hadron with P_+ (P_-) will overlap with the wave-function of the other one and determine the (longitudinal) space-time coordinate $x_- = t - x_l$ ($x_+ = t + x_l$) of the front(s) to the degree $\delta x_- \simeq 1/P_+$ ($\delta x_+ \simeq 1/P_-$). This is allowed quantum mechanically because the operators fulfill $[P_\pm, x_\pm] = 0$ (with the same lightcone component signs). But it implies that the final hadronic states are projected onto the possible available states, ie those with lifetimes at least of the order of the projection. Therefore all (virtual) string states with $(P_+ - Q_+, Q_-)$ $((Q_+, P_- - Q_-))$ may occur if $Q_\pm < P_\pm$.

It is, however, possible that the transverse fronts of the hadronic wave-functions are less well-defined. In that case it is reasonable to consider a multiple parton scattering scenario and imagine that there are many energy momentum transfers between the partons ($\{k_{ji}\} \rightarrow \{k_{jf}\}$) and $\{l_{ji}\} \rightarrow \{l_{jf}\}$) (with i and f for initial and final) in the wavefunctions of the two hadrons. Assuming that the (total) transverse momentum transfers $(\sum_j(\vec{k}_{\perp ji} - \vec{k}_{\perp jf}) \simeq \sum_j(-\vec{k}_{\perp jf}) = \sum_j(-\vec{l}_{\perp ji} + \vec{l}_{\perp jf}) \simeq \sum(+\vec{l}_{\perp jf}))$ on the average will vanish, it is nevertheless necessary in order to keep the partons on the mass-shell to obtain positive longitudinal momentum transfers $\simeq \sum_j \vec{k}^2_{\perp jf}/k_{+jf} \simeq Q_-$ $(\simeq \sum_j \vec{l}^2_{\perp jf}/l_{-jf} \simeq Q_+)$.

In the FRITIOF model the hadronic fronts are modeled by means of the massless relativistic string. It is an amusing property of that system that the (energy momentum) transfers $Q_\pm$ will, independently of whether they occur locally or over more extended regions of the transverse fronts, pull out the string(s) in essentially the same way as if the string(s) started out as pointlike (as in an e^+e^--annihilation event) with the whole energy momenta $(P_+ - Q_-+, Q_-)$ $((Q_+, P_- - Q_-))$ in the endpoints.

In FRITIOF it is assumed that the momentum transfers $Q_\pm$ are distributed in a scaling way:

$$\sim \frac{dQ_+ dQ_-}{Q_+ Q_-} \tag{1}$$

There is further in FRITIOF no color exchange between the hadronic entities. The final state of an "ordinary" event in this way corresponds to the stretching and breakup of two longitudinally pulled-out strings. This result turns out to be a good approximation to all the experimental low p_t distributions. It is, however, of some interest to note that in case we would use "the same kind of strings", ie the same fragmentation model in the hadronic interactions as we use in e^+e^--annihilation at LEP ("jet universality") then it is necessary to require the large fluctuations implicit in Eq (1) in order to reproduce the data.

The whole procedure can be extended to hadron-nucleus and nucleus-nucleus collisions, [15], in terms of a simple repeated collision scenario. The projectile pass through the target with a probability for interaction determined by an overlap function assumption. The nuclear density is treated conventionally as a continuous medium but we use a hard-core potential to keep all nucleons apart. The momentum transfers are treated as increasing according to Eq (1), ie if after j collisions a hadron has obtained $Q_{\pm j}$ then in the $(j+1)$st the integration starts at this value. This model again works very well before the onset of gluonic excitations on the string(s), ie below string masses of the order of $10 - 15\ GeV$.

2.2 The production of hard gluons through Rutherford parton-parton scattering

It may happen, however, that anyone of the partonic interactions in FRITIOF actually corresponds to a "hard" scattering interaction. In this case we may use perturbative QCD to treat that part of the interaction. (We use the PYTHIA implementation in the Monte Carlo simulation process). Only the very hardest Rutherford Parton Scattering (RPS) is sampled in the initial stage of a FRITIOF interaction. According to the rules of perturbative QCD it is necessary that that this interaction is "harder" than anyone of the possible bremsstrahlung contributions in the gluon emissions. This is in FRITIOF always introduced as a condition and an RPS is accepted only if it is harder than the associated radiation. If the RPS is "drowned", which is to say that it is softer than the radiation, then the RPS is not acceptable and the collision proceeds as a purely soft collision. With this prescription the RPS spectrum is suppressed smoothly at small to medium $p_\perp$.

2.3 The Bremsstrahlung Gluons and The Soft Radiation Model

A high mass string state will contain associated gluonic bremsstrahlung. Such multiple gluon emission can be treated as a parton branching process. In FRITIOF we use the colour dipole approximation [16], which incorporates the strong angular ordering, ie the QCD coherence condition in a natural way. This means that an initial string with large energy momenta at the endpoints is treated as a colour dipole. It will then split up into two dipoles after emitting one gluon, and with the k_T-ordering of emitted gluons the two dipoles will go on to emit gluons independently. In this way more and more dipoles are formed. As the mass of the emitting dipoles places a limit on the transverse momenta of the bremsstrahlung, the gluonic excitations on the string states quickly become "soft" and in the infra-red stable string fragmentation process such gluons can be neglected. We use the ARIADNE Monte Carlo program [17], to implement the gluon bremsstrahlung radiation.

The bremsstrahlung gluons are emitted according to the formula, [18]

$$d\sigma = \frac{C\alpha_s}{\pi}\frac{dk_\perp^2}{k_\perp^2}dy, \tag{2}$$

where $k_\perp$ and y are the transverse momentum and rapidity of the emitted gluon, C is a color factor ($C = 4/3$ for a $(q\bar{q})$-dipole) and α_s the strong coupling. Energy momentum conservation provides the constraint

$$k_\perp \cosh(y) \leq \frac{M}{2} \tag{3}$$

with M the invariant mass of the emitting dipole. This relation can be approximated by

$$k_\perp < e^{-|y|}M, \tag{4}$$

which means that the kinematically allowed phase space for the bremsstrahlung gluons corresponds to the interior of a triangular region in the $(y, \log(k_\perp^2))$ plane as shown in Fig.1a.

But contrary to an e^+e^--annihilation reaction the energy momentum in a hadronic reaction is not localised in a pointlike color charge but spread over some extended region. The dynamics of FRITIOF will produce (at least) two transversely extended fronts from each hadron containing the energy momentum as well as the color 3 q- and the $\bar{3}$ "diquark" charge. Any bremsstrahlung emission from an extended source will necessarily be influenced by this extension ("the form factor"). In the SRM it is advocated that in case the extension of the emitter is l and the wave length of the radiation is λ then only the part $(\lambda/l)^d$ of the energy momentum in the front (assuming that the front has d dimensions) is involved. From comparison to DIS data it has been found (note that in this case there is one presumably pointlike "kicked-out" quark and one extended "remainder" front) that $d \simeq 1$ (ie the "spectator" front behaves in a "string-like" way) and $l \sim 1/\mu_0$ with $\mu_0 \simeq 0.6$ GeV in case we use $\lambda \simeq 1/k_\perp$ for the gluonic radiation. Therefore the available phase space represented by Eq.(4) in the rest frame of the string for the gluon emission is further restricted into the region

$$k_\perp < e^{-|y|} \frac{\mu}{k_\perp} M, \tag{5}$$

cf Fig.1b. The parameter μ is not necessarily equal to the μ_0 in DIS but we have found that in case we have two fronts (as in FRITIOF) then a good description of high energy hadron-hadron data is provided by $l \rightarrow l/2$, ie $\mu \rightarrow 2\mu_0$.

2.4 Multiple Gluon Emission in the Firecracker Model

Whether it is possible to form a QGP state at high energy density depends upon the structure of the QCD vacuum. We know little about the precise properties of this state but we expect it to be "color field confining" to explain why the quanta of the color fields are not observed individually. It is then possible to use the Meissner effect as a model and assume that the QCD vacuum state behaves like a color superconductor, [6].

An "ordinary" QED superconductor has two different ways, characterised as type I or II, to break down to a normal conductor when the external magnetic field increases. There are two material constants with the dimension of length. One, λ, is the space-size of the (exponential) fall-off of a magnetic field in the superconducting state and the other, ξ, the size of the Cooper pairs. In case $\xi \gg \lambda$ (type I), the boundary regions of the superconducting state are minimized during the approach to the transition between the superconducting and the normal states. This leads to the breakup over bulk regions, which in QCD language would correspond to "bags" or extended "flux tubes" with the color fields confined inside. In the opposite extreme $\xi \ll \lambda$ (type II), there will instead be a tendency to maximize the boundary regions and the magnetic field is "subdivided" into quanta, each one compressed into a vortex line. In QCD this phenomena would correspond to a stringlike behaviour. Such a moving vortex line must have dynamical properties very similar to the massless relativistic string, used in the Lund Model. The size of the quantities λ and ξ are not known from first principles in QCD.

In an electro-magnetic superconductor type II there are three state regions when the magnetic field $\mathcal{H}$ is used as the order parameter. When the field is below a certain number, $\mathcal{H}_1$, the Meissner effect works, but in a region $\mathcal{H}_1 \leq \mathcal{H} \leq \mathcal{H}_2$ the quantized vortex lines start to penetrate the superconducting state and exhibit a repulsive interaction. Above $\mathcal{H}_2$ the field is so strong that the whole region "melts" into a state of the same character as the break-down of a superconductor type I, ie a (transverse space-)extended "bag" or "flux-tube" region. If the QCD vacuum has properties similar to those of a type II superconductor with the energy density as the order parameter, we assume that the Meissner "confinement" effect works in the low energy density states. Then inside an intermediate energy density region there will be string-like color force fields, corresponding to the massless relativistic strings in the Lund Model. At an energy density, exceeding a critical value, the color force fields might eventually "melt" into extended "flux tubes" and this is is the usual intuitive picture of the QGP.

The Firecracker Model (FCM) is assumed to work inside the intermediate energy density region. We assume that several strings are formed inside a small space-time volume in a nucleus-nucleus collision and further assume that they work as a set of quantized vortex lines penetrating a superconductor, still keeping some individuality. We note that the Eq (5) contains the factor μM which effectively corresponds to an energy density over the region $1/\mu$. Then we expect that *in this early stage of the collisions when several (n) excited strings (with energy momenta* (P_{+j}, P_{-j}) *are close by it may be possible for them to emit gluons using their common total energy density* $\mu \sum P_{\pm j}$. In order to estimate the effect we assume for simplicity that the (n) strings are at rest relative to each other with the same masses $W_j = W$. This means that *each string may be able to take energy from the common pool* nW*.* In this way it is possible to emit n gluons, each with a transverse momentum limited by $\sqrt{\mu n W}$. The Firecracker Model has been implemented into LUCIAE generator, [13]. More details about the collective gluon emission can be found in [3].

3 Colourless States as the Result of Gluon-Gluon Interactions

In high energy nucleus-nucleus collisions there will be a lot of gluons produced in a small phase space region at a very early stage of the collision and those gluons will then interact. The interaction x-section depends strongly upon the joint color state of the gluons. The state of two octets can in SU(3) be decomposed as

$$8 \otimes 8 = 1 \oplus 8_S \oplus 8_{AS} \oplus 10 \oplus \overline{10} \oplus 27 \tag{6}$$

There is no interaction in the decuplet states, a small one in the 27 while the 1 and the 8 interactions are strong. Thus there is a strong reinteraction between two gluons if they form either a singlet (in string language a closed string dragged out by the two excitations) or an octet. It is easy to find a soft gluon so that in half of the octet situations one may form a singlet of onia character (again a closed string) from the two "real" gluons and the soft one. The probabilities for the two gluons to interact in a color 1, $8_S, 8_{AS}$ and 27 states are 1/8, 1/4, 1/4 and 3/8, respectively (taking into account the multiplicity of the states). The probability that the two gluons will pass by each other without interaction (ie to be in 10 and $\bar{10}$ states) is about 1/3.

In order to relate the gluons from interacting strings we will make use of the same decomposition as we used for the FCM and assume that only gluons stemming from such a "string cluster" may interact. An algorithm, [4], has been used in LUCIAE to cluster strings in such a way that the relative momentum of any two strings in the same interacting "cluster" is small. We obtain the same (inclusive) result if we decompose the strings in impact parameter space but we will use the momentum space picture because it is both simpler to implement in a simulation program and more in accordance with the basic approach of the FRITIOF Model. In this way we introduce a parameter, $k_{\perp rel}$, for the "cluster size" of the interacting strings. The value of $k_{\perp rel}$ in LUCIAE is taken to be the mean transverse momentum of the strings in the cluster.

A second requirement is that when two gluons are produced from strings moving with rapidities far apart we do not expect them to be able to interact. Therefore we assume that only gluons produced from the overlapping region of two strings in rapidity space (the overlapping region of the two phase space triangles, cf Fig.1a) may interact. A special case is that two gluons produced from the same string (ie which are "color-connected" via a $(q\bar{q})$-propagator) always have the probability 1/8 to form a singlet state, [19]. Any parton-parton interaction of the Rutherford kind is implemented by the use of the PYTHIA, [10] subroutines, using the probabilities described above for the gluon-gluon channel interactions. We will further define the (transverse) distance b between two interacting gluons by means of the (squared) momentum transfer $-t \simeq 1/b^2$. We will finally require (using a semi-classical picture of "charge screening") that as the transverse size of a dipole in the SRM is of the order of $1/\mu$ only the gluons with a transverse distance $1/\sqrt{-t} < 1/\mu$ are able to rescatter.

In this way we are lead to the following algorithm to handle the Rutherford scatterings and the formation of colourless multigluon states:

1. Order all gluons emitted from the same cluster into a sequence according to the formation time, $E/k_\perp^2$ (E and $k_\perp$ are the energy and the transverse momentum of a gluon) and concentrate on the gluon with the smallest formation time

2. Chose the second gluon from the ordering above and check that the first and the second gluon also belong to the overlapping region in the rapidity space for gluon emission of the strings. Continue with the 3rd etc.

3. For each pair, chosen with the formation time ordering, chose a transverse distance by defining the momentum transfer t according to the PYTHIA routines and then find the pair with the smallest transverse distance.

4. Then choose the joint color state $(1, 8_S, 8_{AS}, 27)$ of the pair with the smallest transverse distance according to 3. (if both gluons in the pair stem from the same string then there is the probability 1/8 to form a singlet state).

5. If a singlet or an 8_S state is formed we obtain a colourless state with the mass equal to the cms energy of the two interacting gluons. Otherwise the four momenta of the two gluons after the scattering are calculated by the Pythia routines and the gluons are brought into the correct color connection: if it is a 8_{AS} state the two rescattered gluons are put on one of the two strings; if it is a 27 state each of the two strings gets one of the two rescattered gluons.

6. Then repeat the procedure starting from the step 2. for the second gluon, third gluon $\cdots$ in the ordering until all the gluons have been treated.

In this way we obtain a set of colorless states. We find that the states will have an average invariant mass of around 2 GeV at 160 $AGeV/c$ and around 5 GeV at RHIC energies, cf Fig.2. We expect the decay time of the colourless state, τ_0, to be of the order of 1 fm/c, according to the Lund Fragmentation Model. To find the space-time size of the colourless multigluon states we have used the (classical) distance of separation between the gluons after the corresponding time (assuming that the state is formed at a distance defined by the Rutherford scattering and placed stochastically in transverse space). We assume that the states with a (invariant space-time) size larger than b_0, with $b_0 \simeq 1$ fm (which is the typical size of a hadron), do not survive as bound states and therefore we let them decompose into two gluons, again adjoined according to color ordering to the strings.

In order to estimate the effect of smokering formation we consider different values of τ_0 and b_0 and calculate the (average) percentage of gluons which are "neutralised" into color singlets, see Table 1. The result is that $10-35\%$ of the gluons are neutralised and the result also depends upon the energy and nuclear numbers in the interaction. The states which survive are, however, assumed to decay *independently of the remaining strings and their excitations* according to the JETSET routines (amended to take into account the variable masses of the smokering states).

4 Results

The scenario for gluon-gluon interactions leading to smokering formation, as discussed in the last section, has been introduced into the LUCIAE generator. We find that a lot of the gluons (hard Rutherford gluons, SRM bremsstrahlung gluons as well as firecracker gluons) produced in the collisions will end up in colourless states and the effect increases with the energy. Most of the smokerings are produced in the mid-rapidity region, cf Fig.3. The result is an essential increase in the inclusive multiplicity (as well as transverse energy) in that region, cf Fig.4a. If we plot the multiplicity distributions of the hadrons (both with and without smokering formation) in the two rapidity units around the centre of an Ag-Ag collision at RHIC we find an appreciable increase of high multiplicity events in the case of smokering formation, cf Fig.4b.

It is then of interest to find where the energy to produce this increase is taken. It turns out that if we plot the same multiplicity distributions but this time at cms rapidities $4 > |y| > 3$ then we will find a certain decrease in the case of the smokering formation. The effect can be understood in the following way, cf Fig.5. In case we produce two strings with one gluon on each string (we have for simplicity chosen a symmetric situation with the gluon energy momenta 3.5 GeV and very large endpoint string energies) then there is particle production "on each side" of the gluon jet rapidities. If the two gluons are instead made into a singlet state with the remaining strings stretched longitudinally then we will both obtain more particles (closed "smokering-strings" are more effective, cf the larger multiplicity "on the onia-mass" compared to the "open" strings "in the continuum" in an e^+e^--annihilation event) and the particles will also be produced "in between" the two outmoving gluons. Thus the states become more "concentrated", ie the produced particles will occur both more numerously and also more centrally in phase space.

This brings up a possible problem related to the well-known Bjorken estimate of the energy density obtained in a collision. We are really, if we allow for the firecracker scenario, producing a very large amount of gluons at large energies and large A-values in this version of FRITIOF. But in case so many of the produced gluons as the smokering formation scenario predicts are "neutralised" then although we find very many particles and large transverse energies at central rapidities *we may not consider that as a measure of the energy density available for QGP formation.* The colorless smokering states are in general produced at a very early stage of collisions. Therefore a large amount of the produced gluonic energy is carried away in hadronic form . Using the following version of Bjorken's estimate[1]:

$$\epsilon = \frac{dE_\perp/dy}{V_0}, \qquad V_0 = \pi(1.15A^{1/3})^2\tau \tag{7}$$

(with $dE_\perp/dy$ the observed transverse energy density of the hadrons) we find that the energy density, ϵ (expected to be related to the produced partons) will reach about 7.5 GeV/fm^3 at RHIC energies for Pb+Pb central collisions if there is no smokering formation (we have used the conventional value, $\tau = 1fm/c$, in this calculation). The energy density will, however, be reduced by about $2.4GeV/fm^3$ (ie by about 30%) if the smokering states are allowed to disperse the energy density by rapidly leaving the interacting region in a hadronic form.

5 Concluding Remarks

We have in this paper considered the possibility that a hadronic state can be formed at a very early stage of a high energy heavy ion collision due to a possible color neutralalisation of the gluons. We find that the effect is quite significant and that it will tend to rapidly disperse the energy density obtained in the initial encounter if the formed colourless objects have a life time of the order of $1fm$. We also find that the formation of the hadronic state tends to enhance the multiplicity and transverse energy of final state hadrons at midrapidity region, which implies that the energy density we estimate in the final state (hadronic phase) might not necessarily reflect the energy density reached in the partonic state right after the collisions.

6 Acknowledgments

The authors would like to thank G. Gustafson for helpful discussion of the work. This research is supported in part by the EU Programme "Human Capital and Mobility", Network "Physics at High Energy Colliders", contract CHRX-CT93-0357 (DG 12 COMA).

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Table 1.

$b_0 fm$ / $\tau_0 fm/c$	1.0	1.5	2.0
1.0	21%	32%	35%
1.5	13%	23%	30%
2.0	10%	15%	24%

Table 1: The average percentage of gluons which are "neutralised" into color singlets calculated at different values of τ_0 and b_0 for central Pb−Pb collisions at $\sqrt{s}$=200 GeV.

Figure Captions

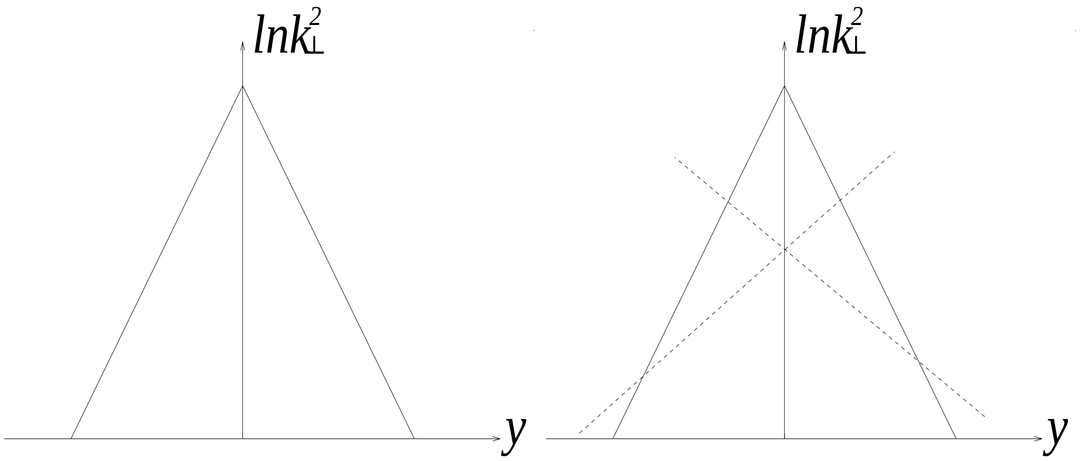
Figure 1: The phase space limit for the emission of a gluon from a colour dipole with no transverse extension. (a) and the available phase space for the gluon emission from an extended colour dipole (b).

Figure 2: The mass spectra of smokerings in central Pb+Pb collisions at two energies: 160 AGeV/c (dashed line) and RHIC energies (solid line).

Figure 3: The rapidity distribution of smokerings in central Pb+Pb collisions at 160 AGeV/c. The mid-rapidity y_c is about 2.9 rapidity units.

Figure 4: Rapidity (a) and multiplicity (b) distributions for central Ag-Ag collisions at RHIC energies with (dashed lines) and without (solid lines) the formation of a singlet state.

Figure 5: Multiplicity (a) and rapidity (b) distributions of two strings and two gluons, cf the text, with (dashed lines) and without (solid lines) the formation of a singlet state.



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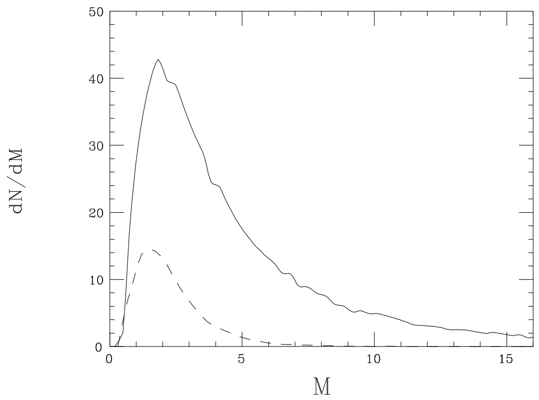
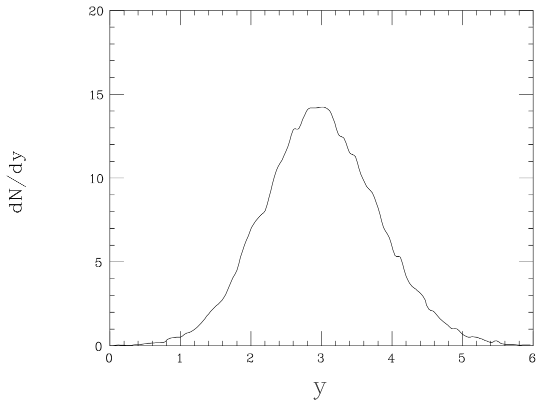
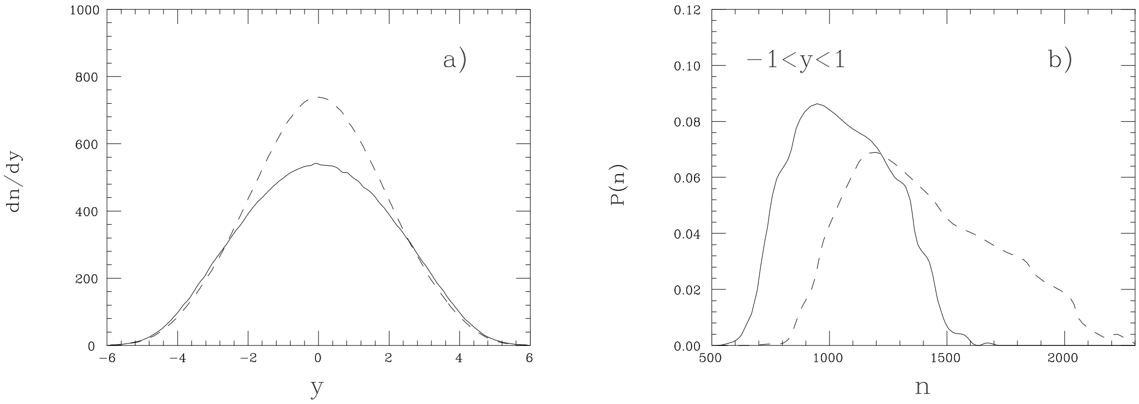
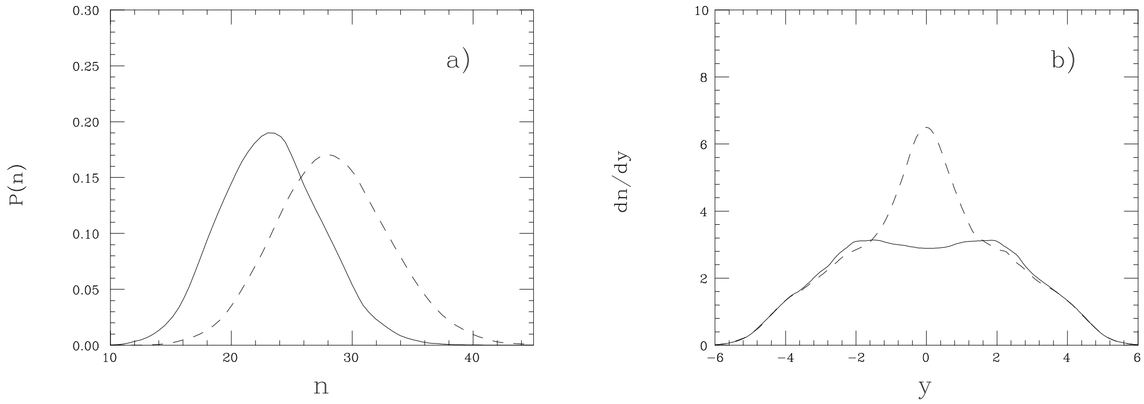

dN/dM
M
0
10
20
30
40
50
5
15


dN/dy
y
0
5
10
15
20
1
2
3
4
6


a)
dn/dy
1000
800
600
400
200
0
-6
-4
-2
0
2
4
6
y
b)
-1<y<1
P(n)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
500
1000
1500
2000
n


a)
P(n)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
10
20
30
40
n
b)
dn/dy
10
8
6
4
2
0
-6
-4
-2
0
2
4
6
y