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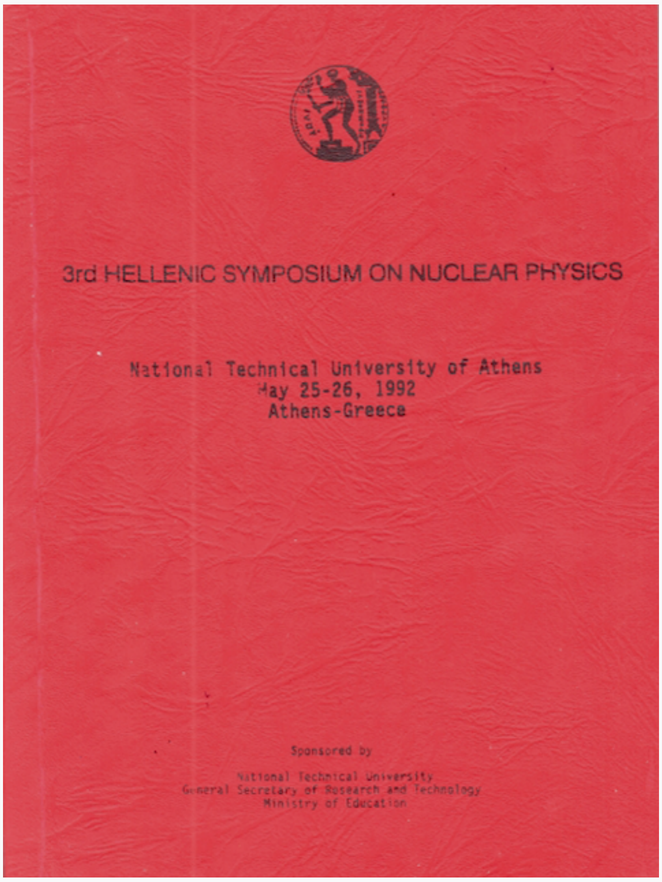

Understanding the "CENTAURO" cosmic ray events in terms of a transition to quark matter

Apostolos D. Panagiotou

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UNDERSTANDING THE CENTAURO COSMIC RAY EVENTS IN TERMS OF A TRANSITION TO QUARK MATTER

Apostolos D. Panagiotou

UNIVERSITY OF ATHENS, PHYSICS DEPARTMENT
NUCLEAR AND PARTICLE PHYSICS DIVISION
PANEPISTIMIOPOLIS, GR-157 71 ATHENS, HELLAS

In the past twenty years, cosmic ray experiments have detected numerous most unusual events, whose nature is still not well understood [1-3]. Some of these events, the so-called "Centauro" and "Mini-Centauro" [1], show complete absence or very much reduced electromagnetic energy. This fact may be interpreted as complete absence, or strong suppression of all pion species, if isotopic spin is to be conserved. Therefore, these events are considered as predominantly baryon emitting events.

Monte Carlo simulations [2,4] have shown that the Centauro events could not originate from any kind of rare statistical fluctuations in the hadronic and photonic (energy - multiplicity) contents of normal hadronic interactions, viz. by pion multiple production or heavy nucleus hadronic interaction. Therefore, new types of interactions, or the creation of a new kind of matter, Quark matter, was conjectured to be responsible for these extremely unusual phenomena [1,2,4].

I. THE CENTAURO MODEL

We shall shall discuss the "Centauro" model developed in references [5,6]. We consider in detail the basic ingredients and assumptions of the model and justify them on phenomenological grounds and self-consistency. We use the experimental data for the (5) Centauro events, obtained by the Chacaltaya Collaboration [1].

I-1. Centauro Fireball.

We consider the central collision of an ultra relativistic cosmic ray nucleus with a nucleus in the upper atmosphere and the formation of a fireball. The observed chemical composition of primary cosmic rays in the mass region of Fe, with energy in the range $10^3 - 10^4$ TeV, is about 15% of the total flux [7]. It is, therefore, reasonable to consider a medium- mass primary cosmic ray nucleus colliding with a stationary ^{14}N nucleus, which constitute the bulk of the atmospheric nuclei.

The incident nucleus is highly contracted ($\gamma_{cm} \simeq 260$) and has the shape of a cylinder with crossectional radius $R = 1.15 \langle A_{pr} \rangle^{1/3}$. After the collision, a very compressed and dense fireball is produced, traveling with ultra-relativistic velocity. The very high density of the fireball's matter may allow it to reach and explode above the Chacaltaya detector, situated at 5200 m above sea level [8].

The larger mass of the incident nucleus, compared to the stationary target, causes the colliding system center of mass to move with almost the velocity of the projectile, since for the average Centauro event:

$$1 - \beta_{cm}/\beta_{pr} = M_{tg}/(E + M_{tg}) \simeq 7\times10^{-6} ,$$

where β_{cm}, β_{pr} are the velocity of the center of mass and projectile, respectively, in the LAB frame, E is the incident energy of the heavy nucleus of order 10^6 GeV and M_{tg}, the mass of the target, is of order 10 GeV. We thus consider the produced fireball to contain the nucleons of both the projectile and target nuclei. Since the Centauro fireball decays into baryons, to conserve baryon number we make the assumption that the average mass of the incoming nucleus is approximately

$$\langle A_{pr} \rangle \simeq \langle N_h \rangle - 14$$

where $\langle N_h \rangle$ is the measured average Centauro (baryon) multiplicity.

In this highly dense and moderately hot nuclear matter of the Centauro fireball, the hadron states of the compound system disolve into the state consisting of their deconfined constituents, the quarks and gluons. This new state is characterized by a very large baryon number density. After the formation of the quark matter fireball at a moderate temperature, $T^i_{fb} \simeq T_c(\mu_b) \simeq T^f_{fb}$, where $T_c(\mu_b)$ is the critical temperature for the phase transition in this very high μ_b environment and i(f) denote initial(final) stages, the volume may not increase appreciably, since the final entropy (which is $\simeq VT^3$) should be nearly equal to the initial one in order to conserve baryon number. Actually, the entropy should increase in the hadronization phase in view of the second law of thermodynamics. This increase which may be realized in the fragmentation of the original gluons into strange quarks only, as it will be discussed later, may lead to the formation of strange hadrons and strange matter globs, however unaccounted at present experimntally.

I-2. Pion Suppression.

The effects of the large baryochemical potential of the fireball on particle production, in particular on the relative pion/nucleon multiplicities, are profound. In the quark-gluon plasma formalism, the pion to nucleon density ratio is proportional to

$$N(\text{pion})/N(\text{nucleon}) \sim C^{-1} \exp(-\mu_b/T) \,, \qquad (1)$$

where C is the normalization factor in the gluon fragmentation to $\bar{q}q$ process (see rel. 3 below).

The (T,μ_b)-pair of values in rel. (1) are obtained from a T versus μ_b phase diagramme, with boundary values $T(\mu_b=0) = 250$ MeV and $\mu_b(T=0) = 2.07$ GeV (corresponding to baryon density of $\sim 2.1\ \text{fm}^{-3}$, or ~ 14 times the nuclear matter density at $a_s = 0.4$), which satisfies the equal pressure condition at the Quark matter - Hadron matter boundary: $P_{QM} = P_{HM}$,

$$(37/90-11a_s/9\pi)\pi^2 T^4 + (1-2a_s/\pi)\mu_q^2 T^2 + [(1-2a_s/\pi)/2\pi^2]\mu_q^4 - B = (3\pi^2/90)T^4 \qquad (2)$$

where $B = (304\ \text{MeV})^4$ is the vacuum pressure. Fig. 1 shows the phase diagramme in the T vs μ_q plot, rel. (2), where $\mu_b = 3\mu_q$, the quarkchemical potential.

Fig. 2 shows the plot of the pion to nucleon multiplicity, rel.(1), as a function of μ_q. We observe a strong suppression of pions relative to nucleons with increasing baryochemical potential of many orders of magnitude for large μ_q values.

Another important effect of the baryochemical potential may be the reduction of the particle multiplicity in the hadronization of a Quark matter fireball with large μ_b. Since pions constitute, in general, the bulk of the multiplicity, a strong suppression of their production by the large baryochemical potential will cause a reduction of the event multiplicity. Thus, we may observe - contrary to common expectations - the hadronization of a "Quark matter fireball", produced with very large μ_b in A+A collisions, to exhibit a smaller multiplicity than a normal hadronic fireball of the same energy. The stored energy in the QM fireball will show up in the explosive decay as very large average transverse momentum of the hadronization products .

I-3. Strangelet Production.

The strong suppression of new u,d (anti)quarks rases an interesting question as to what happens to the original gluons in the quark matter fireball. In the flux tube model [9], the relative probability of gluon fragmentation into a quark pair of mass m_i, is controlled by the parameter

$$x_i = C \exp(-\pi m_i^2/\kappa) , \qquad (i=u,d,s) \qquad (3)$$

where $\kappa \simeq 1$ GeV.fm^{-1} is the QCD string constant and the normalization constant

$$C = 1/[2 + \exp(-\pi m_s^2/\kappa)] \simeq 0.38$$

for three quark flavors with current masses $m_u = m_d = 0$ MeV, $m_s \simeq 170$ MeV. This leads to $x_u = x_d \simeq 0.38$ and $x_s \simeq 0.24$ in normal hadronic interactions.

In the case of the Centauro fireball with very large baryochemical potential, the creation of $u,\bar{u}$ and $d,\bar{d}$ is prohibited, thus allowing predominantly for $g \rightarrow s,\bar{s}$ fragmentation. To get a feeling for the relative probability of gluon fragmentation, we may take indicatively $m_u = m_d \simeq \mu_q \simeq 600$ MeV, which we calculate later on to be the fireball quarkchemical potential. We find that $x_u = x_d \simeq 1.2\text{x}10^{-3}$ and $x_s \simeq 0.998$. Therefore, in the quark matter fireball there are the primary (constituent) quarks for each flavor (u,d) and the $s,\bar{s}$ quarks generated by gluon fragmentation. Since the fireball hadronizes predominantly into baryons, there will remain an excess of (anti)strange matter, which cannot hadronize and may form strangelets, stable baryonic states with very high mass to charge ratio [10]. These strange matter states should be created and sustained more easily in a low temperature and high density environment, prevailing in the Centauro fireball [8]. The existense of this kind of matter is, however, still not undoubtedly verified experimentally [11].

II. CENTAURO CHARACTERISTICS

In the following we shall discuss the observed characteristics of the (5) Centauro events and we shall estimate several thermodynamic and kinematical quantities characteristic of the "quark matter fireball", based on the outlined Centauro model. The calculation will be carried out assuming no interaction between the quarks ($\alpha_s = 0$).

II-1. Centauro Multiplicity.

The observed multiplicity of the five Centauro events [1] is in the range 63 - 90 hadrons, with an average $\langle N_h \rangle = 75$. Since no primary gamma showers were identified, one may conclude that, in order to conserve isospin, these hadrons cannot contain pions. It has been, therefore, widely accepted that the hadrons must be baryons. The hadrons are emitted isotropically from the fireball and their energy and transverse momentum distributions have an exponential form.

II-2. Interaction Energy.

The five Centauro events have an average observed energy $\langle E_h(\gamma) \rangle = 348$ TeV. If we take the gamma inelasticity coefficient $K_\gamma = 0.2$, the total average Centauro interaction energy is $\langle E_h \rangle = \langle E_h(\gamma) \rangle / K_\gamma = 1740$ TeV. It should be noted that the incident energy is at least equal to (and probably larger than) this interaction energy. Assuming that the incident nuclei have an average mass $\langle A_{pr} \rangle \simeq 60$, the interaction energy in the N-N center of mass system is $\sqrt{s}_{N-N} = 233$ GeV. The total interaction energy in the CM is equal to

$$\sqrt{s} = \sqrt{[M_{pr}^2 + M_{tg}^2 + 2M_{tg} \langle E \rangle]} = 6760 \text{ GeV} \tag{4}$$

corresponding to $\gamma_{cm} = [\langle E \rangle + M_{tg}]/\sqrt{s} = 257$. The above energies should be considered as <u>lower limits</u>.

II-3. Transverse Momentum.

The average observed transverse momentum, as estimated from the deduced fireball decay point of Centauro I event, is $\langle p_T(\gamma)\rangle = 0.35 \pm 0.14$ GeV/c. Taking $K_\gamma = 0.2$, the average transverse momentum of the Centauro events is $\langle p_T\rangle = \langle p_T(\gamma)\rangle/K_\gamma = 1.75 \pm 0.7$ GeV/c. This is a very large transverse momentum, about three times larger compared to the average transverse momentum measured for baryons in nucleus-nucleus collisions at 200.A GeV at the SpS [12]. It necessitates the notion of an explosive decay of the superdense fireball rather than of a typical nuclear fragmentation.

II-4. Mass of Fireball.

In the fireball frame each isotropically emitted particle (nucleon) has an energy given by:

$$\langle E_n\rangle = \{[(4/\pi)\langle p_T\rangle]^2 + M_n^2\}^{1/2} = 2.4 \pm 0.8 \text{ GeV} ,$$

where M_n is the nucleon mass. With the average multiplicity being $\langle N_h\rangle = 75$, the mass of the average Centauro fireball becomes:

$$M_{fb} = \langle N_h\rangle.\langle E_n\rangle = 180 \pm 60 \text{ GeV}, \qquad (5)$$

II-5. Volume of Fireball.

Our picture of the Centauro event assumes the collision of a Lorentz-contracted incident nucleus, $\langle A_{pr}\rangle \simeq 60$, with an ^{14}N nucleus in the upper atmosphere and the production of a quark matter fireball from the combination of the two nuclei. The quark matter fireball retains the contracted, cylinder-like shape of the incident heavy nucleus, with volume

$$V_{fb} \simeq d\,\pi R^2 \simeq 75 \text{ fm}^3 , \qquad (6)$$

where we have used $R = 1.15 \langle N_h \rangle^{1/3}$ fm, and $d \simeq 1$ fm, equivalent to the formation time $\tau_o = 1$ fm, since $2R/\gamma_{cm} \ll 1$ fm. This volume is a lower limit, since there should be a number of unidentified strange particles and some expansion of the fireball before hadronization. It is, however, about five times smaller than the volume of a nucleus with A = 75.

We can make another estimate of the fireball volume in terms of the freeze-out volume, accepting that the freeze-out radius $R_F \simeq \lambda_h$, the hadron mean free path. More precisely, in the Centauro case where the hadrons are mostly baryons, $\lambda_b \lesssim R_F < \lambda_\pi$, where the baryon mean free path $\lambda_b \simeq (3/4)\,\lambda_\pi$, for $1 < p_\lambda < 20$ GeV/c, as obtained from π-p and p-N total cross sections. Since the freeze-out radius $R_F \simeq 0.7\,(dN/dy)^{1/2}$, [13], we calculate $65 < V^F_{fb} < 115$ fm^3, in agreement with (6).

II-6. Energy Density of Fireball.

The average energy density of the Centauro fireball can be estimated from the fireball mass and volume:

$$\varepsilon_{fb} = M_{fb}/V_{fb} = 2.4 \pm 1 \text{ GeV.fm}^{-3}, \qquad (7)$$

The uncertainty in the energy density is calculated assuming a 30% variance in the volume estimation. The magnitude of the fireball energy density is -despite the large error - sufficiently high for the phase transition from (the incident) nuclear matter to the quark matter. Recent lattice QCD calculations [14] have shown that for a two-flavor QGP, the critical temperature and energy density have been reduced to the range of 150 MeV and 1 GeV.fm^{-3}, respectively. This reduction of the critical quantities is even larger if heavier quarks are included.

The energy density is fundamental in the estimation of many other thermodynamic quantities of the fireball and its accurate knowledge is very desirable. The energy density varies as $\langle N_h \rangle^{1/3}$ and hence even a large increase of $\langle N_h \rangle$, say by a factor 2, will produce only about 25% change in ε.

II-7. Quark - Baryon Densities of Fireball.

We have considered the Centauro fireball to consist mainly of constituent u,d quarks in the initial stage. Assuming that quarks carry on the average 300 MeV of energy in the rest frame (as in the case of confinement in the nucleon) the quark density of the Centauro fireball is:

$$\langle N_q \rangle = \varepsilon_{fb}/0.3 = 8 \pm 3 \ \mathrm{fm}^{-3} \qquad (8)$$

Here we implicitly consider the energy density of the fireball to reside mainly in its quark content. Therefore, the estimated $\langle N_q \rangle$ value is an <u>upper limit</u>.

The baryon density can be simply estimated from the quark density:

$$\langle N_b \rangle = 1/3 \ \langle N_q \rangle = 2.7 \pm 1 \ \mathrm{fm}^{-3} \qquad (9)$$

This value of the baryon density is approximately 18 times larger than that in nuclear matter (~ 0.15 fm^{-3}). It indicates a fireball of superdense matter with, perhaps, different characteristics (binding energy, collision mean free path, etc.) capable of penetrating down to the Chacaltaya detector altitude and exploding into baryons with very large $\langle p_T \rangle$.

II-8. Baryochemical Potential of Fireball.

The energy density of an ideal quark-gluon plasma as a function of the temperature and the baryochemical potential, resulting from both the quark and gluon degrees of freedom, is given by [15]:

$$\varepsilon = (\pi^2/30)(N_g + 7/4 \ N_q)T^4 + N_q \mu_q^2 T^2/4 + (1/8\pi^2)N_q \mu_q^4 , \qquad (10)$$

where $N_g = 16$ and $N_q = 12$ are the gluon and quark degrees of freedom respectively, for two quark flavors and $a_s = 0$.

To obtain a first estimate of the baryochemical potential, we consider the case $T \simeq 0$. Then the relation contains only the contribution from the quarks (at $T = 0$) and reduces to

$$\varepsilon = (12/648\pi^2)\,\mu_b^4 ,$$

which gives $\mu_b = 1.8 \pm 0.3$ GeV for $\varepsilon = \varepsilon_{fb} = 2.4$ GeV.fm^{-3} and $a_s = 0$. For $a_s =$ 0.4, μ_b is equal to 1.9 GeV. This is a large quantity and its effects on $q\bar{q}$ production will be profound, as we will discuss later. It should be reminded that for cold nuclear matter the baryochemical potential is $\mu_b = 0.77$ GeV.

If we calculate the baryochemical potential from the relation between quark density, quark chemical potential and temperature,

$$N_q = 2(\mu_q T^2 + \mu_q^3/\pi^2), \qquad (11)$$

working again in the $T \simeq 0$ limit, we find that $\mu_b \simeq 2 \pm 0.4$ GeV. In a more realistic situation with $T > 0$, the baryochemical potential will be smaller, since at high T the first term of (11) causes the baryochemical potential to drop as T^{-2}, if the baryon density remains constant.

II-9. Temperature of Fireball.

The fireball temperature can be estimated from the relation

$$N_q = 2[\mu_q T^2 + \mu_q^3/\pi^2] \qquad (12)$$

With $\langle N_q\rangle = 8$ fm^{-3} and $\mu_b = 1.8$ GeV, the fireball temperature takes on the value $T_{fb} = 130 \pm 6$ MeV. It is a moderate temperature, which could sustain the quark matter in the large ε and μ_b environment. In Fig. 1 we indicate on the phase diagramme the location of the pair (T_{fb}, μ_b) and notice that it is well within the Quark matter phase.

The value of μ_b was estimated from rel. (11) assuming $T = 0$. If we now substitute in (4.4) the above calculated values of μ_b and T_{fb} and require that $\varepsilon = 2.4$ GeV.fm^{-3}, we find that μ_b and T should be reduced by about 6%.

II-10. Emitted Particle Ratios.

It was discussed in the Centauro model how the large baryochemical potential, inherent in the quark matter fireball, will influence the hadronization process. The pion to nucleon density ratio was found to be proportional to the expression (3-2). Evaluating this ratio, taking for the Centauro fireball μ_b = 1.8 GeV and T_{fb} = 130 MeV, we find that $N(\pi)/N(n) \simeq 2.5\times10^{-6}$. Indeed, we observe the total disappearance of pions and, hence, of gammas in the hadronization of the Centauro quark matter fireball. This is in agreement with the accepted observed final state of the Centauro events. We indicate in Fig. 2 the location of the particle ratio for the (μ_b, T) values of the average Centauro event.

II-11. Rapidities.

The incident nucleus rapidity of the Centauro event can be calculated from the average projectile energy per nucleon,

$$y_{pr} = \ln(2\langle E_h\rangle/\langle A_{pr}\rangle M_n) = 11.03 , \qquad (13)$$

where $\langle E_h\rangle$ = 1740 TeV and $\langle A_{pr}\rangle \simeq 60$, according to our Centauro model. The rapidity is not a sensitive function of the projectile mass, since it varies as $\ln A_{pr}$.

The average pseudorapidity of the Centauro fireball decay products is calculated from the lateral spread of the family hadrons, measured from the center of gravity of the family (which coincides with the projectile direction) and the height of the interaction point. We estimate the average pseudorapidity of the five Centauro events to be $\langle\eta_{cnt}\rangle \simeq 9.9 \pm 0.2$. The incident nucleus rapidity and the mean fireball pseudorapidity enable us to calculate, in a model-dependent way, the Centauro fireball mass using the relation [16]:

$$M_{fb} = M_n A_{pr} \exp(y_{pr} - \langle\eta_{cnt}\rangle) \simeq 175 \pm 20 \text{ GeV} ,$$

a value equal to the one calculated from the experimental $\langle p_T \rangle$ of the Centauro events (5). This shows an internal consistency of the proposed Centauro model.

The midrapidity of the colliding nuclei can be estimated from the relation

$$y_{cm} = 1/2\ y_{pr} - 1/2\ \ln(A_{tg}/\langle A_{pr}\rangle) = 6.24\ , \qquad (14)$$

since all target and projectile nucleons participate. The hadronization of the central rapidity for the <u>Centauro</u> <u>I</u> event should be seen at an average angle of approximately 0.22^o with respect to the direction of the incoming fireball. This corresponds to about 20 cm away from the family center of gravity. It is not known from the analysis of the Centauro I event if any showers of hadronic and electromagnetic nature are found there and what their characteristics are. One expects to observe both types of showers. There should be no inhibition on $q\bar{q}$ production and consequently on $\pi^{\pm}$ and π^{o}, since the midrapidity is almost totally free of baryon number density at these incident energies. Such an observation would be very interesting and would give credit to this Centauro model.

Table I. summarizes the various observed and estimated characteristic thermodynamic and kinematical quantities of the average cosmic ray Centauro event.

II-12. Centauro Event Rate.

An important point of the model is the assumption of the collision of a medium-mass cosmic ray nucleus with an ^{14}N in the upper atmosphere. The rate of incidence of such nuclei is of the order 15% of the total cosmic ray flux, in the energy range $10^3 - 10^4$ TeV. To examine the rate expected for nucleus-induced events, let us follow the syllogism: the 5 observed Centauro events were among about 600 cosmic ray events, recorded in the Chacaltaya chamber [1]. Of the 600 events, about 0.15x600 = 90 events could be induced by medium-mass nucleus collisions. Therefore, the 5 Centauro events may constitute about 5.6% of the nucleus-induced cosmic ray events. Now for these 90 nucleus-nucleus events, the fraction of the total inelastic cross section, $\sigma_{tot} = \pi b^2_{max}$, which corresponds to central collisions, possibly leading to a Centauro event, is equal to

$$f = \sigma_{DI}/\sigma_{tot} = \pi b^2_{DI}/\pi b^2_{max} = (R_{pr} - R_{tg})^2/(R_{pr} + R_{tg})^2 = 5.4\% , \quad (15)$$

where $R = 1.15\ A^{1/3}$ and σ_{DI} is the "dive in" cross section. The five Centauro events could be considered as the <u>central</u> <u>collisions</u> of the nucleus-induced cosmic ray events.

II-13. Comments on the Model and Estimated Quantities.

The values of the various thermodynamic quantities of the Centauro fireball, ε_{fb}, μ_b, T_{fb} were calculated for an ideal QGP, which is not the condition in the Centauro fireball. The effect of the (massive) q-q interaction are estimated to change these values by only about 10%. The values of these quantities are reasonable and within the range necessary for the phase transition from nuclear to quark matter.

The estimation of the mass of the Centauro fireball gives a measure of consistency of the model. The mass was calculated by two methods, one using the accepted experimental value of the average p_T and the other using the model-estimated rapidity of the incident nucleus and the experimentally measured pseudorapidity of the fireball decay products. The two methods gave the same mass for the fireball.

We may attempt to get another estimate of the energy density using the Bjorken formalism,

$$\varepsilon = [\langle m_T\rangle/\tau_o A_T](\Delta N/\Delta\eta)$$

where: $A_T = \pi(1.15\langle N_h\rangle^{1/3})^2 \simeq 74\ fm^2$, $\langle m_T\rangle = [\langle p_T\rangle^2 + M_n^2]^{1/2} \simeq 2$ GeV and $\tau_o \simeq 1$ fm.

We take as $\Delta N/\Delta\eta = \langle N_h\rangle/\langle\Delta\eta\rangle$, where $\langle\Delta\eta\rangle$ is estimated from the height of the interaction point and the corresponding distance of the showers measured from the center of family for the five Centauro events [16]. We find: $\langle\Delta\eta_{cnt}\rangle = \langle\eta_{cnt}\rangle_{max} - \langle\eta_{cnt}\rangle_{min} \simeq 10.4 - 9.4 = 1 \pm 0.2$. With these values, the Bjorken formula for the energy density gives: $\varepsilon \simeq 2 \pm 0.4$ GeV.fm^{-3}. This is of the same order of magnitude as the previous estimation (7), showing a consistency of our Centauro model.

Therefore, the syllogism and assumptions made in the formulation of the Centauro model and in calculating the characteristic thermodynamic quantities are reasonable, plausible and self-consistent.

III. SUMMARY

We have developed a phenomenological model, based on the \Iavailable\i and accepted information for the Centauro events. Our model attempts to explain the observed features of the average event and to estimate characteristic thermodynamic quantities, such as ε, μ, T, whose knowledge is necessary for an educated suggestion of a possible phase transition to quark matter in a highly dense nuclear system.

The model we presented makes certain plausible assumptions and arguments, which do not conflict with any known theory nor contradict any existing experimental data. The important assumptions are: the collision of a medium-mass cosmic ray nucleus with an ^{14}N nucleus and the small changes of the fireball entropy, volume and temperature during the phase transition. The justification of these assumptions is given by the self- consistency of the model and the estimated quantities and the reasonable and plausible values of these quantities, which are also within the range considered to be necessary for the phase transition.

Our "Centauro" model is (to our knowledge) the only one capable of being tested at RHIC and the LHC. In view of the highly interesting and still puzling Centauro events, we believe that every effort should be made to implement appropriate measurements of particle multiplicity, ID, energy content and $\langle p_T \rangle$ in the fragmentation rapidity region. It may give a direct and undoubted indication of quark matter formation in a highly dense nuclear system and solve the mystery of the Centauro and other exotic cosmic ray events. At the same time, the possibility of observing "strangelets" adds a new dimension of excitement to these measurements.

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Table I. Summary of Observed and Estimated Thermodynamic and Kinematical Quantities characteristic of the Cosmic Ray Centauro Events.

Hadron multiplicity, $\langle N_h \rangle$			63 - 90, <75>
Gamma multiplicity			0
Average total incident energy	$\langle E \rangle$	$\geq$	1740 TeV
Total interaction energy in "60+14" CM	$\sqrt{s}$	$\geq$	6760 GeV
Total interaction energy in N-N CM	$\sqrt{s}_{N-N}$	$\geq$	233 GeV
Average transvesre momentum	$\langle p_T \rangle$	=	1.75 $\pm$ 0.7 GeV/c
Mass of fireball	M_{fb}	=	180 $\pm$ 60 GeV
Volume of fireball	V_{fb}	=	75 - 100 fm^3
Energy density of fireball	ε_{fb}	=	2.4 $\pm$ 1 $GeV.fm^{-3}$
Quark density of fireball	$\langle N_q \rangle$	=	8 $\pm$ 3 fm^{-3}
Baryon density of fireball	$\langle N_b \rangle$	=	2.7 $\pm$ 1 fm^{-3}
Baryochemical potential of fireball	μ_b	=	1.8 $\pm$ 0.3 GeV
Temperature of fireball	T_{fb}	=	130 $\pm$ 6 MeV
Predicted particle ratio	N(pion)/N(nucleon)	$\simeq$	2.5×10^{-6}
Incident nucleus rapidity in LAB	y_{pr}	=	11.03
Midrapidity of "60 + 14" system	y_{cm}	=	6.24
LAB pseudorapidity of emitted baryons	$\langle \eta_{cnt} \rangle$	=	9.9 $\pm$ 0.2
Width of Pseudorapidity distribution	$\langle \Delta\eta_{cnt} \rangle$	$\simeq$	1 $\pm$ 0.2

FIGURE CAPTIONS

Fig. 1. The calculated phase diagramme in a T vs μ_b plot, rel. (2). The boundary values are given in the text. The star denotes the location of the corresponding values for the average Centauro event.

Fig. 2. The calculated particle ratio vs μ_b, rel. (1). The star denotes the location of the corresponding values for the average Centauro event.

Fig. 1

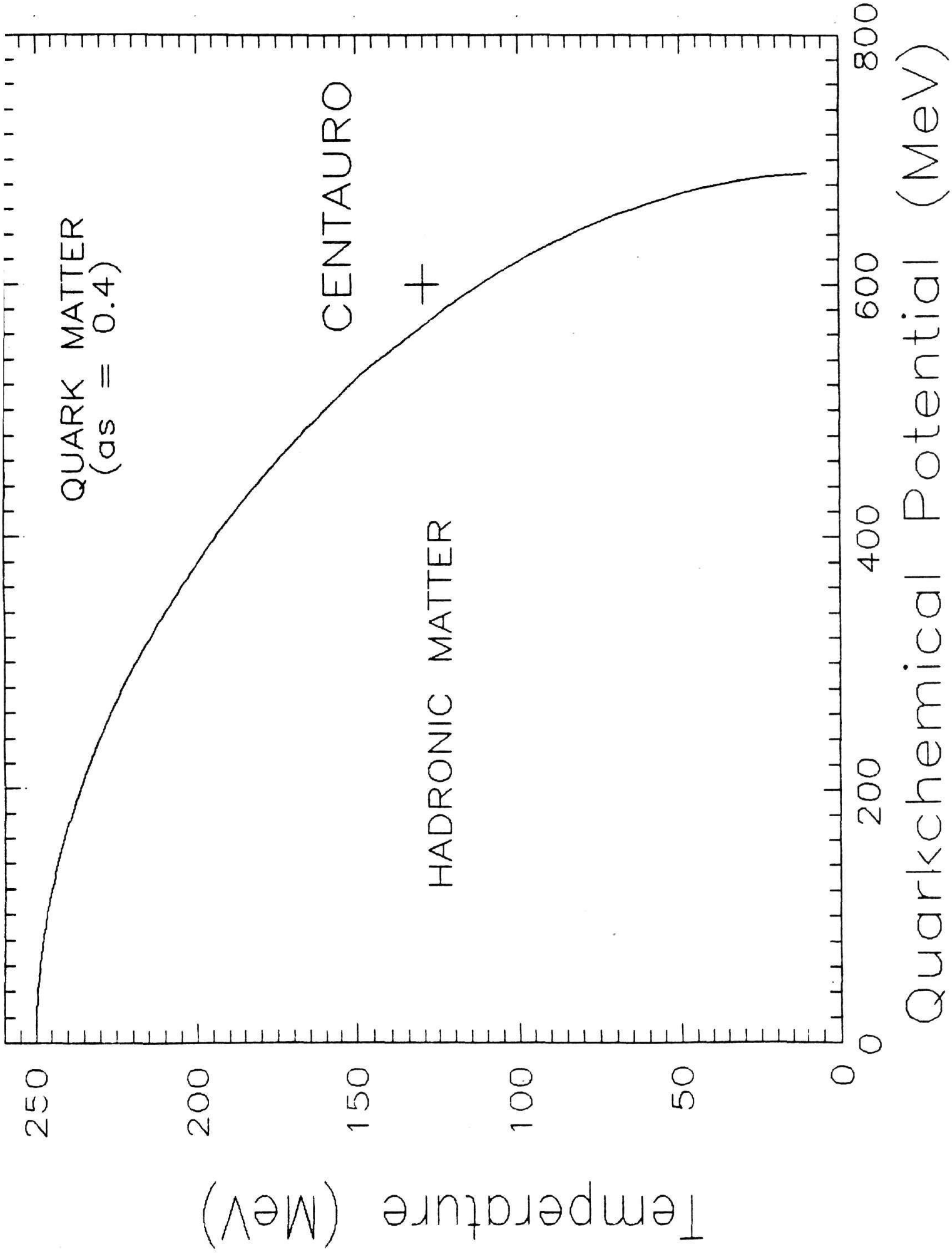
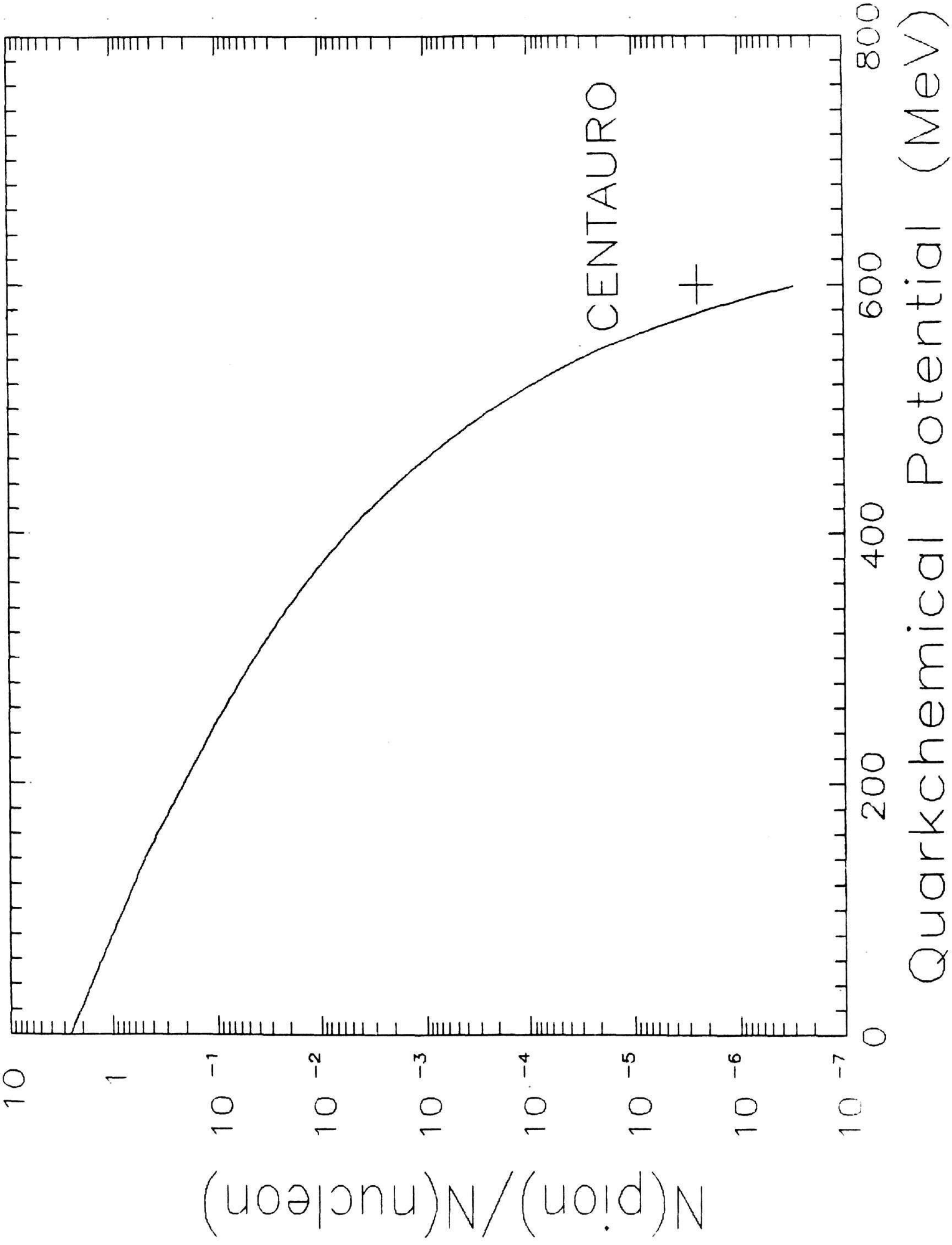

QUARK MATTER
(as = 0.4)
CENTAURO
HADRONIC MATTER
Quarkchemical Potential (MeV)
Temperature (MeV)
0
200
400
600
800
0
50
100
150
200
250

Fig.


N(pion)/N(nucleon)
10
1
10 -1
10 -2
10 -3
10 -4
10 -5
10 -6
10 -7
0
200
400
600
800
Quarkchemical Potential (MeV)
CENTAURO