BI-TP 97/22

QCD & QGP:
A SUMMARY*)

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Contents:

The aim of high energy nuclear collisions is to study strong interaction thermodynamics in the the laboratory; we want to explore colour deconfinement and the resulting new state of matter, the quark-gluon plasma. Phenomenological models have done much to form the concepts of the field, but today QCD provides the theoretical basis for our understanding of hot and dense matter and for the tools to probe it. I will therefore begin by summarizing recent results from finite temperature lattice QCD and then turn to the study of colour deconfinement using hard probes; here the recently reported anomalous J/ψ suppression represents a particularly promising signal. Similarly, the observed low mass dilepton enhancement has focussed our attention on the properties of hadrons near chiral symmetry restoration. The hadrosynthesis at freeze-out is yet another region of much present activity, to be addressed in the final part of this summary.

All aspects were covered here in a variety of excellent plenary talks and contributions; I hope the speakers will forgive me for concentrating on the progress in physics as I see it, rather than on individual talks. The field of high energy nuclear collisions is very many-faceted, and so I moreover had to select what I could coherently summarize in the given time. I therefore also apologize to all those whose contributions to this meeting are covered insufficiently or not at all. In particular, I will review neither developments in astrophysics nor the search for disoriented chiral condensates, simply because of my lack of competence in these areas.

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*) Theory Summary, *International Conference on the Physics and Astrophysics of the Quark-Gluon Plasma (ICPA-QGP'97)*, Jaipur/India, March 15 - 21, 1997.

1. The Thermodynamics of Quarks and Gluons

Statistical QCD, as evaluated on the lattice [1] by means of computer simulation [2], is perhaps the only case in statistical physics where critical behaviour can be calculated from first principle dynamics [3], without having to invoke an intermediate "effective" theory. The precision of the predictions thus obtained is limited only by computer performance – with one rather serious restriction: so far, the method is applicable (for what seem to be technical reasons) only to matter at vanishing baryon density.

The power of the appproach is best seen in the thermodynamics of pure SU(2) and SU(3) gauge theory, i.e., for systems consisting of gluons only. The evaluation of these is now essentially complete, largely because of a fruitful interplay of finite-size scaling methods, improved actions and the advent of more powerful computing facilities. The main features considered are the deconfinement transition and the properties of the hot gluon plasma. Below the deconfinement temperature T_c, the constituents of the system are colourless gluonium states (glueballs); above T_c, it consists of coloured gluons. The transition was proposed to lie in the same universality class as Z_N spin systems of the same space dimension [4]; the critical exponents, which govern the singular behaviour of the system at T_c, must then be the same for $SU(N)$ gauge and Z_N spin theory. We see in Table 1 that the SU(2) exponents, obtained for the thermodynamic limit in a finite-size scaling analysis [5], indeed agree very well with those for the corresponding Ising model.

Exponent	SU(2)	Ising
$(1-\beta)/\nu$	1.085(14)	1.072(7)
$(1+\gamma)/\nu$	3.555(15)	3.560(11)
β	0.326(8)	0.3258(44)
γ	1.207(24)	1.239(7)
ν	0.621(8)	0.6289(8)

Table 1:

Critical exponents in SU(2) gauge theory and in the Ising model [5]

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SU(3) gauge theory, just as the corresponding three-state Potts model, leads to a first order transition, for which critical exponents are not directly definable. Again, however, a finite-size scaling analysis can be carried out to extrapolate to infinite spatial volume (thermodynamic limit) and vanishing lattice spacing (continuum limit) [6]. The resulting equation of state, giving the energy density ϵ, the pressure P and the interaction measure $(\epsilon - 3P)$ as functions of T, is shown in Fig. 1. Fixing the open dimension of the critical temperature through the string tension σ, one obtains

$$T_c/\sqrt{\sigma} = 0.629 \pm 0.003, \tag{1}$$

which leads to $T_c \simeq 260$ MeV for the quarkonium string tension value $\sigma \simeq 420$ MeV. The latent heat of deconfinement is found to be $\Delta\epsilon/T_c^4 = 1.40 \pm 0.09$ [7]. From the temperature behaviour of the interaction measure it is evident that in the region $T_c \leq T \leq 2\ T_c$ considerable plasma interactions remain as possible remnants of confinement.

We see in Fig. 1 that even at rather high temperatures ($T \simeq 5\ T_c$), the thermodynamic variables are still some 10 - 15 % below the ideal gluon gas limit. One might expect such high temperature deviations to be accountable by higher order perturbative corrections, implying that we have reached a regime where lattice calculations and perturbation theory meet. Recent calculations have provided the perturbative corrections up to (the highest calculable) order g^5 [8]; however, the results do not explain the deviations from ideal gas behaviour found in lattice calculations. If the coupling is chosen large enough (by suitably tuning the cut-off parameter) to produce deviations of the observed size, the perturbation expansion shows no signs of convergence; the g^2 to g^5 contributions increase in magnitude and alternate in sign, so that their sum varies strongly with the cut-off [9]. On the other hand, if the cut-off in the coupling is tuned to stabilize the perturbative result, then the overall interaction effect is reduced to only 1 - 2 %. The usefulness of conventional perturbation theory in finite temperature gauge field thermodynamics has thus become doubtful, creating the need for a new method to treat the hot, near-ideal QGP.

Such an approach may be given by "screened" perturbation theory, in which one starts from a gas of gluons having effective thermal masses. It has been known for some time [10, 11] that an ideal gas of gluons of mass

$$m_g(T) \simeq g(T)\ T \tag{2}$$

accounts well for the observed equation of state in SU(N) gauge field thermodynamics, provided, however, that the massive gluons retain only the two transverse degrees of freedom of their massless state. In a recent study [12], it was shown that such a scheme can be formulated consistently in scalar ϕ^4 theory, where conventional perturbation theory encounters similar convergence problems. In Fig. 2 we see that screened perturbation theory here leads to much better convergence.

For full QCD, i.e., for SU(3) gauge theory with dynamical quarks, there exist today a number of studies on finite lattices, but not enough yet to carry out a finite-size scaling analysis as in pure gauge theory. To arrive also here at the thermodynamic and continuum limits, more powerful computers are needed, and these are expected to become available within the next few years.

So far, we have some idea of the equation of state in the presence of N_f massless quarks [13, 14]. We know that chiral symmetry restoration coincides with deconfinement, and that for presently used bare quark masses (still too large for a correct pion mass), the sharpness of the two transitions is quite comparable [14], as seen in Fig. 3. It remains unclear at this time [9, 15] if vanishing quark masses lead to a chiral transition in the same universality class as the O(4) spin model [16]. A particularly interesting recent study indicates that the case of real physical interest, two light (u and d) and one heavier (s) quark, may well lead to a first order transition [15, 17]. Hopefully this will soon be clarified by further and more detailed work. In addition, the study of quarkonium states at finite temperature is under way. The most crucial open challenge for lattice gauge theory thus remains the case of non-vanishing baryon density, for which, as already mentioned, so far no viable approach exists.

To summarize the status of the thermodynamics of quarks and gluons: statistical QCD predicts the hadron-quark deconfinement transition and the properties of the QGP through first principle calculations of ever increasing precision.

We can thus turn to the task of studying these phenomena in high energy nuclear collisions. Here the environment will be a rapidly evolving medium, and we will have to find probes for the evolution stages of interest. In this connection, let me quote a bit of advice which guide books give travellers to many countries, including India. They say that if you're lost, you should never ask a local farmer "does this road go to Jaipur?" Out of politeness, he will always agree, even if the road in fact gets you nowhere near Jaipur; instead, you should ask where the road in question leads. Our probes of nuclear collisions are probably at least as polite, and so you should never ask them if they found the QGP; it appears they'll always say that they did. Instead, we should just ask them what they did see.

2. Hard Probes: Colour Deconfinement

The basis for the existence of a deconfined state of matter is that a high density of colour charges leads to a screening of long range confining forces, so that only short range interactions remain operative. How can we probe full or partial colour deconfinement in systems produced in nuclear collisions? Any deconfinement probe

- must be present in the *early* stages of the collision evolution,
- must be *hard* enough to resolve sub-hadronic scales,
- must be able to *distinguish* confinement and deconfinement, and
- must *retain* the information throughout the collision evolution.

The latter feature implies that the probe should not be in thermal equilibrium with the later evolution stages, since this would lead to a loss of memory of previous stages. In the following we shall consider two candidates for probing colour deconfinement: quarkonium states, which show different dissociation patterns, and hard jets, which suffer different energy losses in confined and in deconfined media.

Quarkonium ground states (J/ψ, Υ) are small and tightly bound resonances of heavy quarks. The J/ψ, which we shall consider as prototype, has a radius of about 0.2 fm, much smaller than the normal hadronic scale $\Lambda_{\rm QCD}^{-1} \simeq 1$ fm; its binding energy is with 0.6 GeV much larger than $\Lambda_{\rm QCD} \simeq 0.2$ GeV. It therefore requires hard gluons to resolve and dissociate a J/ψ. As a consequence, the collision of a J/ψ with conventional "light" hadron probes the gluon sub-structure of the light hadron, not its size or mass.

From deep inelastic scattering experiments, the gluon distribution in a light hadron is found to be

$$xg(x) \simeq x^{-a}(1-x)^b, \tag{3}$$

where a, b are constants determined by experiment and/or quark counting rules. The effect of such a distribution on J/ψ-hadron interactions is illustrated in Fig. 4 for the case of elastic forward J/ψ photoproduction [18]. Compared to normal hadronic behaviour, Eq. (3) leads to a strong threshold suppression caused by the factor $(1-x)^b$, with $b > 0$: slow hadrons relative to the J/ψ do not contain sufficiently hard gluons to resolve the quark structure of the small J/ψ. On the other hand, at high energies, the observed anomalous small x behaviour [19] of the proton structure function implies $a > 0$ and leads to an increasing cross section (requiring normal hadron phenomenology to introduce an additional "hard" Pomeron). – A further case where the large x behaviour of the gluon distribution becomes crucial was recently observed in the reaction $\psi' \to J/\psi\ \pi^+\pi^-$ [20].

And it is again this damping of the gluon distribution at large x which makes the inelastic J/ψ-hadron cross section become negligibly small for hadron momenta below 3 - 5 GeV relative to a J/ψ at rest [21]. In contrast, the inelastic cross section for incident deconfined gluons peaks around 1 GeV, corresponding to the photo-effect in QCD. A comparison of the $g - J/\psi$ and $h - J/\psi$ cross sections as functions of the respective projectile momentum k is shown in Fig. 5. Since $k \simeq 3T$, we conclude that confined matter for temperatures up to about 600 MeV cannot dissociate a J/ψ, whereas deconfined matter for $T \geq 200$ MeV easily can. J/ψ suppression thus provides an unambiguous test for colour deconfinement.

Here two caveats should be added. The basic theoretical input, the strong threshold suppression of the inelastic $J/\psi - h$ cross section, is corroborated by the mentioned experiments on J/ψ photoproduction and on ψ' decay. It can and should, however, also be tested directly in the so-called "inverse kinematics" experiment [22]. – The charmonium test for colour deconfinement as discussed here applies to physical J/ψ's. In nuclear collisions, there will in addition be pre-resonance nuclear absorption, and this has to be taken into account properly, using information from p-A data [23].

Once that is done, these considerations can be applied to J/ψ data. It appears [24]-[26] that nuclear collisions up to central S-U interactions show only "normal" pre-resonance absorption in nuclear matter; in contrast, Pb-Pb collisions lead to a further strong "anomalous" J/ψ suppression (Fig. 6), which can be interpreted as the onset of colour deconfinement, though not necessarily in an equilibrated medium [27, 28]. Such a conclusion would be supported by the observation of an anomalous p_T-behaviour of J/ψ suppression in Pb-Pb interactions, as recently predicted [29]. Moreover, the crucial feature of the observed effect, its sudden onset between S-U and Pb-Pb collisions, must certainly be checked by experiments using different A-A combinations and different incident energies.

The use of hard jets as deconfinement probe has a similar basis. Hard partons are formed at very early times, similar to the $c\bar{c}$ formation for charmonium. If such a parton travels through a deconfined medium, it finds much harder gluons to interact with than it would in a confined medium, where the gluons are constrained by the hadronic parton distribution Eq. (3). As a result, jets will suffer a much greater energy loss per unit length in a QGP than in hadronic matter [30]. It should be underlined, however, that to use jet suppression as probe for the confinement status of a given medium, we must know the "normal" suppression in nuclear matter. Hence p-A experiments will also here be essential.

In closing this section, we note that charmonium states and jets probe colour deconfinement in a rather general way. In both cases, suppression does not imply an equilibrated medium, but rather a medium containing gluons which are no longer subject to hadronic parton distribution functions. Thus the smallest region of deconfinement could arise in the overlap of two distinct nucleon-nucleon collisions. If much of the medium were of this nature, we would speak of a QGP.

3. Electromagnetic Probes: Chiral Symmetry Restoration

Real or virtual photons emitted during the evolution of the collision subsequently undergo no (strong) interactions with the medium and hence reflect its state at the time they were produced. On the other hand, they are emitted during the entire collision evolution, and by different dynamical mechanisms at different stages:

- Early hard parton interactions produce hard photons and Drell-Yan dileptons; these provide information about the initial (primary or pre-equilibrium) stages.

- Thermal photon and dilepton emission by the medium, through quark or hadron interactions, occur through its entire evolution, and hence give information about the successive stages, from QGP to final hadronic freeze-out.

- Hadrons produced at any point of the hadronic stage, from the quark-hadron transition to freeze-out, can decay and thereby emit photons or dileptons; depending on the hadron decay time, they provide information about dense interacting hadronic matter or about hadrosynthesis at the end of the strong interaction era.

Let us consider each mechanism and its use as probe in some more detail.

Drell-Yan dileptons and hard photons are the tools to study the effective initial state parton distributions; in particular, they will show any nuclear modifications (shadowing, anti-shadowing, coherence effects) of these distributions. They also indicate the initial state energy loss and the initial state p_T broadening suffered by partons in normal nuclear matter. Since they do not undergo any final state strong interactions, they moreover provide a reference for the effect of the produced medium on quarkonium states or jets. – It should be noted that if measurable, open charm or beauty production would give complementary information concerning these aspects [31].

Thermal emission can in principle serve as a thermometer for the different evolution stages. The *functional form* of thermal spectra,

$$dN/dk_\gamma \sim e^{-k_\gamma/T} \tag{4}$$

for photon momenta, or the corresponding distributions in the dilepton mass $M_{l^+l^-}$, indicate the temperature T of the medium at the time the signal was emitted. The crucial problem here is to find a "thermal window", since the measured spectra are dominated at high photon momenta or dilepton masses by hard primary reactions and at low momenta or masses by hadron decay products. So far, thermal photon or dilepton emission has appearently not been observed, perhaps because of the dominance of the hadronic stage at present energies. The situation may well become more favorable at RHIC or LHC, where one may expect longer life-times for the hot medium.

Since the functional form (4) for thermal production is the same for a hadronic medium and for a QGP, it cannot specify the nature of the emitting medium. There were attempts, however, to use the *rate* of thermal emission as an indirect probe for the composition of the system. But because of the evolution of the medium, it seems that this is a rather model-dependent procedure; moreover, it was shown recently [32, 33] that a purely hadronic resonance gas and an evolving QGP with mixed phase and subsequent hadronisation can lead to very similar results.

The dileptons produced by hadron decay constitute an ideal tool to probe in-medium hadron modifications, provided the hadrons actually decay within the medium. The ρ, with a half-life of about a fermi, appears to be the best candidate for such studies. Chiral symmetry restoration is expected to change the properties of hadrons as the temperature of the medium approaches the restoration point [34]; hence such in-medium changes are of particular interest, since they might be the only experimental tool to address the chiral aspects of deconfinement.

The low mass dilepton enhancement observed by the HELIOS and CERES collaborations at CERN provides the experimental basis for such studies [35]-[37]. In S-Au and Pb-Au collisions, one finds in the mass region below the ρ (from about 200 to 600 MeV) considerably more dilepton production than expected from known hadronic sources ; these do provide the measured distribution in p-A collisions. Thus some new effect appears to set in as we go to nucleus-nucleus collsions.

If at the onset of chiral symmetery restoration, the mass of the ρ decreases sufficiently much [38],

$$\frac{m_\rho(T)}{m_\rho(T=0)} \rightarrow 0 \ \text{ as } \ T \rightarrow T_c, \tag{5}$$

then the observed effect can be accounted for (Fig. 7). We note, however, that the required drop of the in-medium ρ mass (some 50 %) is considerably larger than anything so far observed in finite temperature lattice QCD. On the other hand, the meson masses studied there are generally obtained from correlations and thus correspond to screening masses rather than to those of physical states; hence considerable uncertainties remain also on the level of lattice QCD.

A recent alternative account is based on interaction broadening and leads to in-medium changes of resonance *widths*, rather than *masses* [39, 40]. A very much broader ρ, with the applicable kinematic constraints, is found to also produce something like a low-mass dilepton enhancement (Fig. 8). One would obviously like to find some distinguishing feature for mass vs. width changes; one possible candidate is the p_T dependence of the enhancement [39, 40].

Whatever the underlying mechanism is eventually found to be, the low mass dilepton enhancement seems to indicate the production of a dense interacting hadronic medium in nuclear collisions.

4. Soft Probes: Equilibrium and Expansion

The spectra and relative abundances of the usual "light" hadrons produced in nuclear collisons provide direct information on the state of the system at the end of the strong interaction era. Two aspects have here recently attracted particular attention.

If the system at freeze-out is a gas of hadrons in full (thermal and chemical) equilibrium, its temperature T and baryo-chemical potential μ determine the relative abundances of the emitted hadron species. All measured production ratios of ground state hadrons and hadron resonances (this can be 20 - 30 ratios!) would thus be given in terms of only two parameters – a very stringent test of equilibration, which, if affirmative, would provide an unambiguous way to determine the thermal freeze-out conditions.

This test was recently applied to e^+e^-, pp and $p\bar{p}$ collisions [41, 42], with the surprising result that even these elementary reactions lead *almost* to equilibrium ratios. Only the (long known) suppression of strange particle production causes some deviations, and after the introduction of partial strangeness saturation γ_s as single further parameter in addition to T and μ, one obtains a remarkably good description of up to 30 different ratios (Fig. 9), with $T \simeq 170$ MeV and $\gamma_s \simeq 0.5$. This "Hagedorn-Becattini enigma" – why do elementary interactions lead to thermal hadron abundances? – illustrates once more that an equilibrium system has lost the memory of its formation. An equilibrium hadron gas could be produced through sufficient multiple scattering of primary and secondary hadrons; yet it is difficult to imagine that this has happened in the restricted space-time extension of e^+e^- or pp collisions.

For A-A collisions, the main questions concerning particle ratios thus are if the thermal composition persists and if the increase in nucleon-nucleon interactions and space-time volume leads to an equilibration between the strange and the non-strange sectors [43, 44]. If we would here encounter also full chemical equilibration ($\gamma_s \to 1$), then we could indeed conclude that in nuclear collisions "there is nothing strange about strangeness" [45]. A first look at SPS data (Fig. 10) does show thermal behaviour with essentially the same T and some increase of γ_s [46]-[49], but a conclusive answer to this question will probably have to wait until we have a sufficient number of ratio measurements from Au-Au and Pb-Pb collisions.

Changes in the functional form of hadronic spectra should probe the presence of collective effects in the medium. For some years, this question was mainly considered in terms of transverse hydrodynamic flow, which had been shown to result in a mass-dependent broadening of transverse momentum distributions [50]. In the past year, however, renewed attention was drawn to the fact that there is a "normal" p_T-broadening observed in all reactions involving nuclear targets, from Drell-Yan dilepton production to that of low p_T mesons or baryons. For high p_T hadrons, this is generally referred to as Cronin effect [51]. Here as well as in Drell-Yan or quarkonium production, it is accounted for by the fact that successive parton scatterings rotate the collision axis relative to the beam axis: any given transverse momentum distribution will appear broadened when it is measured in the reference frame fixed by the incident primary beams.

These considerations were recently applied to low p_T hadron production in nuclear collisions [52], assuming that successive collisions in nuclear reactions lead to a random walk in the transverse momentum plane. The displacement δ per collision in transverse rapidity was determined from p-A interactions; the normalized p_T spectra for A-B collisions are then predicted parameter-free and found to agree quite well with preliminary data from S-W [53] and Pb-Pb [54] interactions (Fig. 11). In particular, this "normal" p_T-broadening also reproduces the increase with increasing hadron mass, with more broadening for nucleons than for kaons, and more for kaons than for pions. A very recent study [55, 56] has gone even further and determined the "kick per collision" from p-p rather than from p-A data.

At present, we thus find that the p_T-broadening observed in nuclear reaction can be quite well accounted for by random walk collision axis rotations, apart from possible resonance deviations at very small p_T. Perhaps one might wish to consider such a phenomenon as a precursor of "transverse flow". Nevertheless, any hydrodynamic description of p_T-distributions from A-B collisions, with the flow velocity as open parameter, has to face two tantalizing questions: why is there also broadening in p-A interactions? and why can the "flow velocity" in a random walk approach be determined from p-A or even p-p interactions? Perhaps only two-particle correlations, rather than single particle spectra, can distinguish between hydrodynamic flow and a random walk approach [57].

We close this section with some conceptual remarks. If it is indeed observed experimentally that

- the relative abundances of the most copiously produced hadrons are those of a thermal resonance gas, and

- the p_T broadening of their spectra follows a random walk pattern,

then these are empirical features calling for an explanation. However, the "obvious" one, through multiple scattering of primary and secondary hadrons, is physically not tenable. The incident proton in a high energy p-A collision cannot execute a random walk through a target nucleus which it passes in a proper time of less than 0.1 fm, just as in a p-p collision the produced hadrons cannot scatter until they form an equilibrium hadron gas. Hence finding the real origin of such features is left as home-work for all of us; their occurrence also in Drell-Yan production and e^+e^- collisions may well be a hint to look for the solution on a partonic level.

5. Conclusions

QCD thermodynamics, as evaluated by computer simulation on the lattice, leads to the quark-hadron transition and the existence of the QGP as a new state of matter; calculations are so far performed at vanishing overall baryon density. At a temperature of about 150 - 200 MeV, deconfinement sets in and chiral symmetry is restored; latest lattice studies give some indication that for the three-flavour case, with light u/d quarks and a heavier s quark, the transition may well be of first order.

Hard probes provide a direct test of colour deconfinement in nuclear collisions. The dissociation pattern of quarkonia and the energy loss of hard jets depend on the confinement status of the medium in question: in both cases, this is based essentially on the hardening of gluons no longer confined to hadrons. Since J/ψ dissociation requires hard gluons, the anomalous J/ψ suppression recently observed in Pb-Pb collisions could be a first indication of deconfinement.

Electromagnetic probes, in particular low mass dileptons, can be used as direct test for in-medium changes of hadron properties. Such modifications are expected at the onset of chiral symmetry restoration and thus constitute a way to address this aspect of the quark-hadron transition. The presently observed low-mass dilepton enhancement could be a first instance of such an effect for the ρ; however, an alternative explanation through interaction broadening of the ρ-width so far remains also tenable.

Soft probes test equilibration and the presence of collective effects at freeze-out, i.e., at the end of the strong interaction era for the little bang. Recent studies of hadron abundances are in quite good agreement with a composition as given by a thermal resonance gas; so far, however, some strangeness suppression still remains. The broadening of transverse momentum spectra observed in p-A and A-B collisions agree well with random walk rotations of the collision axis. Species equilibration as well as p_T-broadening in nuclear collisions do not seem understandable in simple hadronic terms; however, a consistent partonic description is also still lacking.

Acknowledgements

It is a pleasure to thank the organizers of this conference for providing such a stimulating meeting in a part of the world which through the ages has seen many intellectual challenges. In preparing this talk, I have benefitted much from discussions, agreements and disagreements with many collegues, in particular with R. Baier, J.-P. Blaizot, P. Braun-Munzinger, J. Cleymans, U. Heinz, F. Karsch, D. Kharzeev, C. Lourenço, L. D. McLerran, M. Nardi, K. Redlich, J. Schukraft, J. Sollfrank, H. J. Specht, D. K. Srivastava, J. Stachel, R. Stock and H. Ströbele; I am very grateful to all of them.

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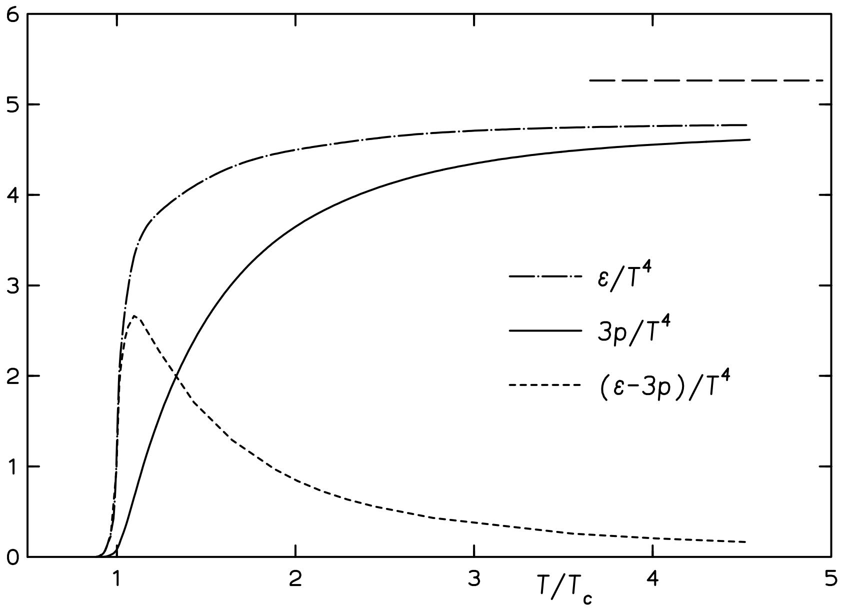

Figure 1:

The equation of state in SU(3) gauge theory [6]; the horizontal dashed line indicates the Stefan-Boltzmann limit.

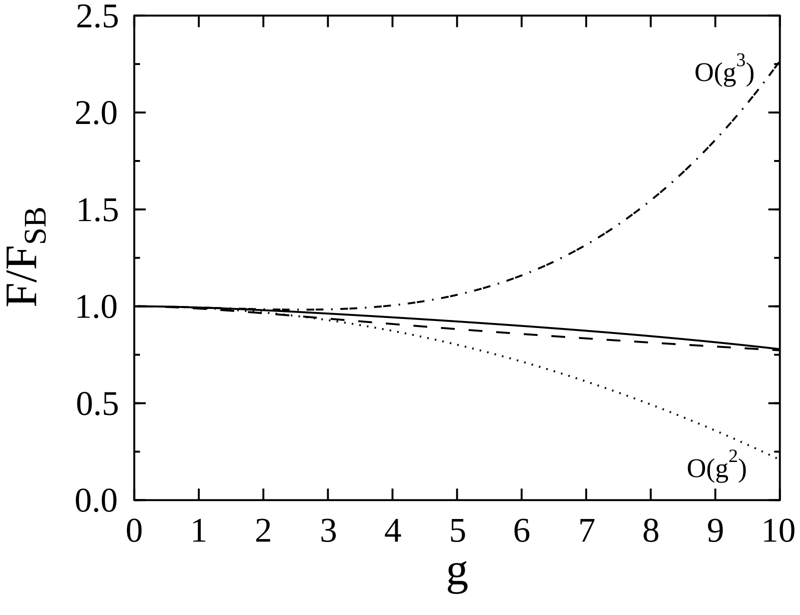

Figure 2:

Free energy in scalar ϕ^4 theory, normalized to the Stefan-Boltzmann value, in conventional perturbation theory of orders g^2 and g^3, compared to two-loop (dashed line) and three-loop (solid line) screened perturbation theory [12].

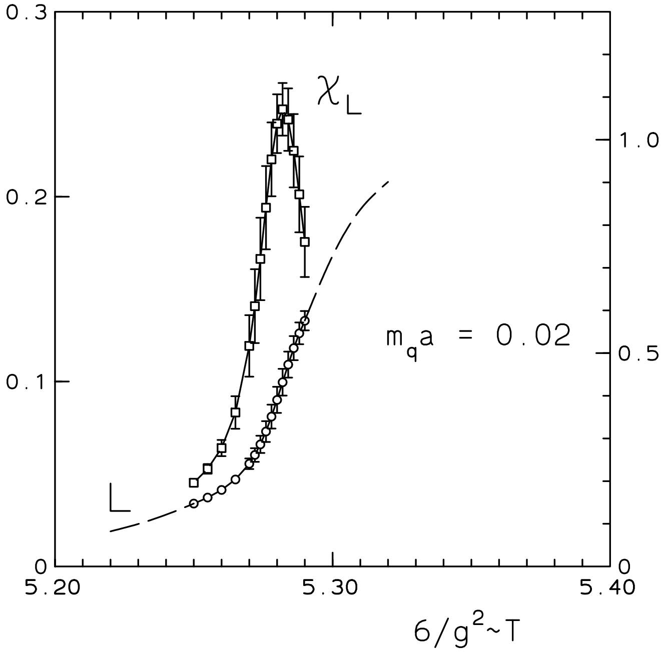

Figure 3a:

Deconfinement and susceptibility for N_f=2 [14].

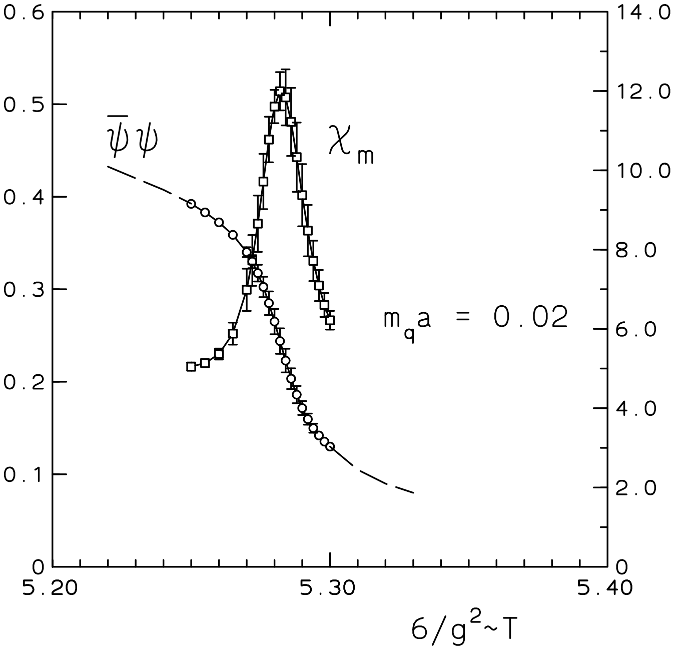

Figure 3b:

Chiral condensate and susceptibility for N_f=2 [14].

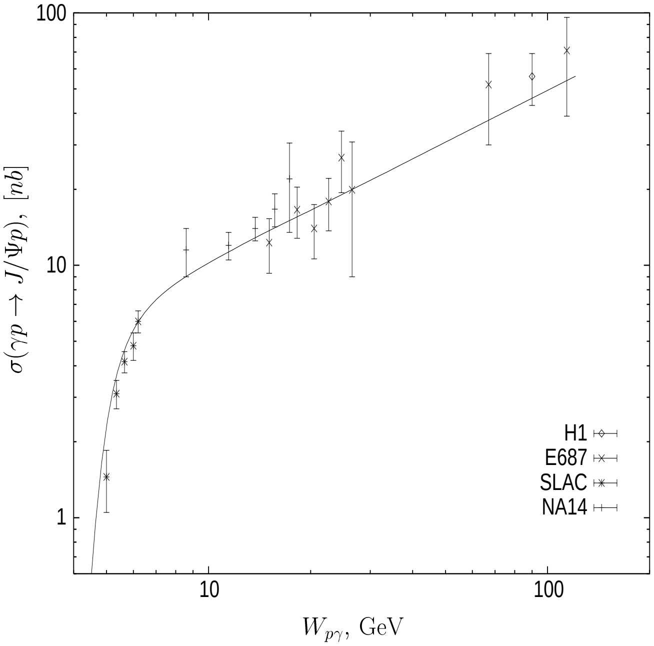

Figure 4:

The energy dependence of J/ψ photoproduction on protons [18].

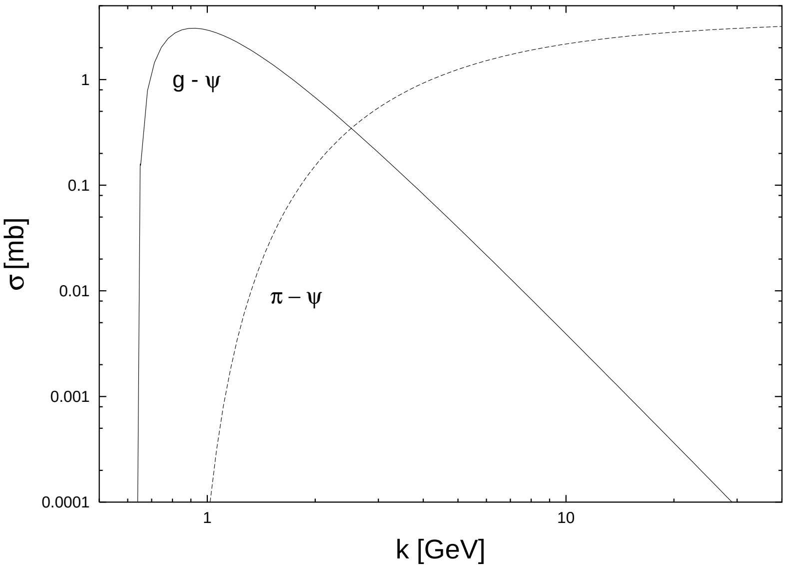

Figure 5:

J/ψ dissociation by gluons and by pions [21]; k denotes the momentum of the projectile incident on a J/ψ at rest.

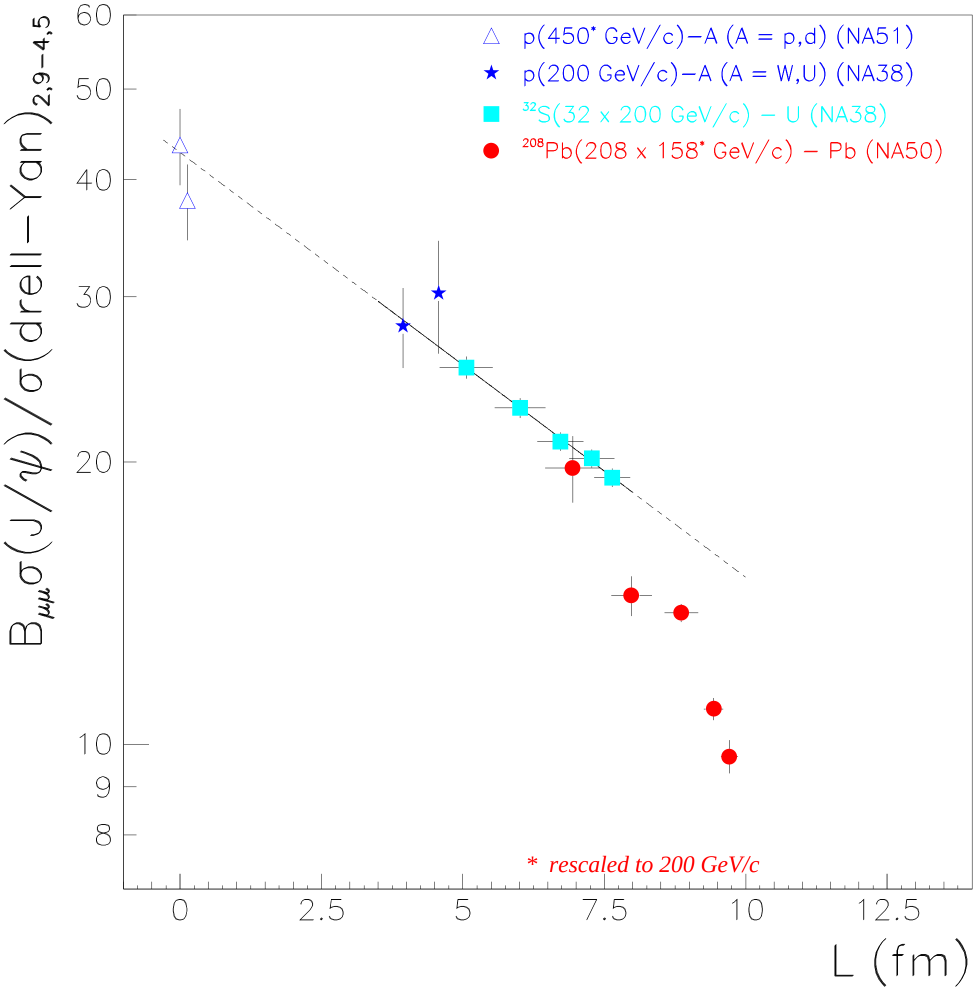

Figure 6:

Anomalous J/ψ suppression in $Pb - Pb$ collisions [26]; the straight line passing through the $p - A$ and $S - U$ points shows pre-resonance absorption in nuclear matter ('normal' J/ψ suppression).

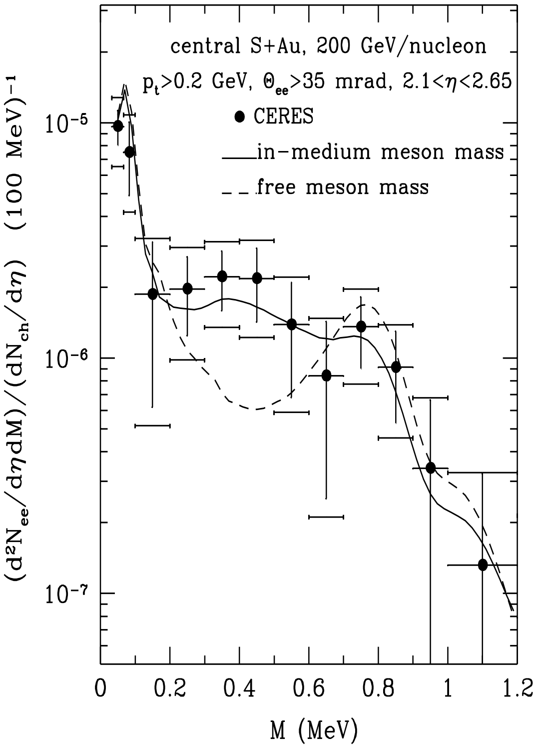

Figure 7:

Dilepton spectrum and predictions using a decreasing in-medium ρ mass [38].

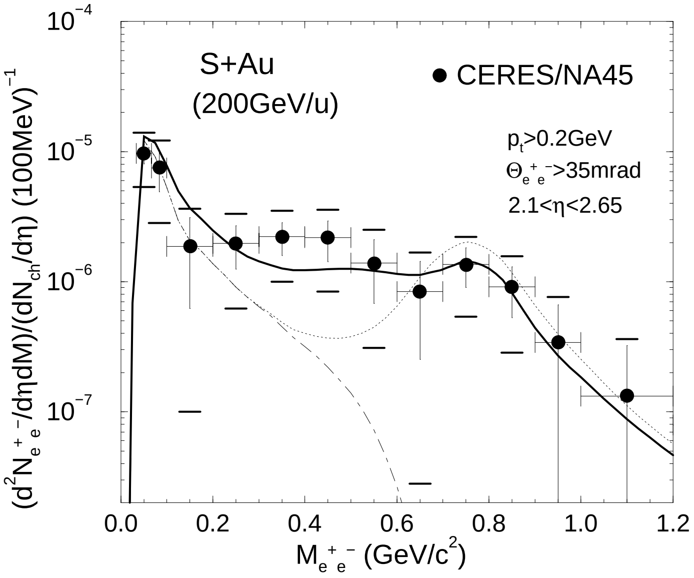

Figure 8:

Dilepton spectrum and predictions from an interacting hadron gas [39,40].

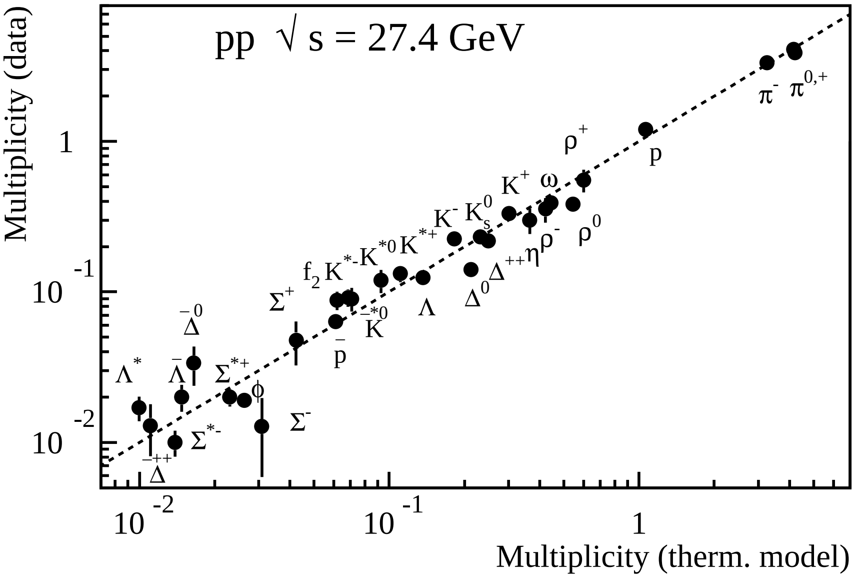

Figure 9:

Multiplicities in $p-p$ collisions and their thermal predictions for $T = 170 \pm 5$ MeV and $\gamma_s = 0.51 \pm .04$ [42].

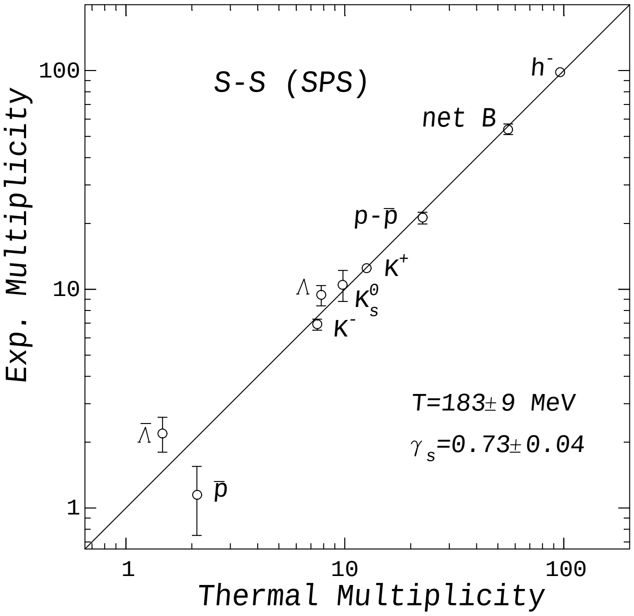

Figure 10:

Multiplicities in $S-S$ collisions and their thermal predictions for $T = 175 \pm 10$ MeV and $\gamma_s = 0.70 \pm .04$ [49].

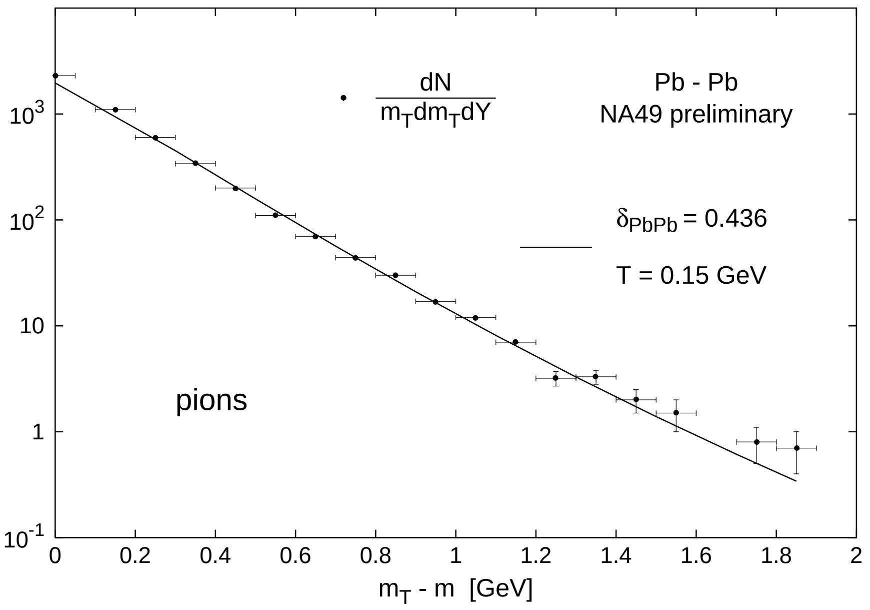

Figure 11a:

Transverse momentum distributions for pions in $Pb - Pb$ collisions at the SPS, compared to random walk broadening [52]

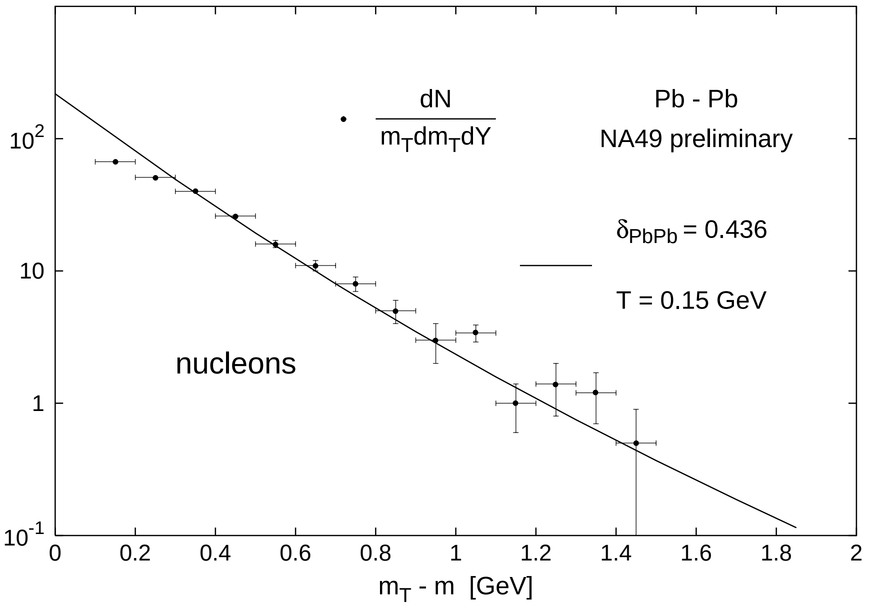

Figure 11b:

Transverse momentum distributions for nucleons in $Pb - Pb$ collisions at the SPS, compared to random walk broadening [52]