Minutes of the Quark-Gluon Plasma Panel *

In spite of previously announced panel discussion on QGP, Heavy Quarks and Exotics the actual discussion was focused on the QGP issues.

The Quark-Gluon Plasma panel moderator *Valentin Zakharov* (ITEP, Moscow) introduces the panelists and reads the questionnaire for the discussion:

· *In which case experiment could unambiguously (dis)prove the existence of Quark-Gluon Plasma?*
· *If the investigations of HI collisions can clarify the confinement problem?*
· *Is there time enough for establishing the local thermodynamic equilibrium in the course of the HI collision?*
· *Can HI collisions imitate the early instants of the Universe evolution?*

He also suggests as an additional question for the discussion:

· *Can we observe magnetic chiral effects in HI collisions?*

S. Kabana starts the discussion from the 1st question arguing that at the moment we have a number of observables which point towards the existence of some dense and hot matter. There are evidences of a first order phase transition to this state. And, in particular, there are evidences that it conformed where the test additional kewshiral can solve because experimentally we cannot support it, at least the second order for the crossover once there different separate. The first order is something we can discuss, maybe, discussing the volume, for example, the square root of s dependence of the volume. So these adfig that have to be done.
They are done already but it is not yet completely conclusive. We study of the volume, concerning the order of tension. However, just to remind you what am I discussing for the onset of the plateau, saying without temperature, this is a temperature we find at the freeze out from the ratios' (analysis?)sekaduns (or "of the hadrons"?); so, this is quite high vanied desigulay; so, we have, let's say, first of all the ratio of this onset of the plateau on the initial than can and its densty function were van cube… and we'd sis at $\sqrt{s}$ for let that collisions obatum tenmine 8 to10 GeV. And with all that motivation, PHOBOS this is the diminatscome RHIC also for this SPS to do and it is come and for the colliders to be built let me count for. Of course, if you have a phase transition, the best we can do is to go and measure around the critical temperature. If you want to really pin down the characteristics of this transition. So this is the one part of the problem… that engians you know these colliders, I mean the future colliders they will be … a lot of years to come, to really study this. Except if start learning faster and something valued the critical point, what this can bjotafast. We can expect new things coming that concerning the critical point from this program. And on the other side we have very…, I mean, there are this quarkonia suppression, sequential suppression, this is a major experimental observable which points to quark-gluon plasma , however, as I have discussed, it is not yet fully analyzed the way it should,

because we have not the data yet. In SPS we do not have a contern to divide the term do wake. The hidden term to contern and then in LHC we just have got a new pA data, so a lot of work has to be done to analyze the completely modern facts to really understand there is, at all, this sequential suppression.

This is something for the future which will say something about quark-gluon plasma.

O. Evdokimov continued with the remark on the first question that experimentalists' view of the subject differs from that which theorists used to have. Actually, there are multiple experimental results which are consistent with our expectations of quark-gluon plasma but which cannot be reproduced by theoretical models on the market. Concerning the confinement problem we rather deal with deconfined degrees of freedom, a need the half in that system over an extended range of our quite more extended volume of expanding system we do know a universal freeze out curves which point to the universality of the breakdown of that confinement limit full fit final density, experimental result need to be more understandable in theory. Concerning the parity violation, being conservative experimentalists, what we can say? We do observe a significant signal. That leads, if your comparable charge separation, would we call charge separation observable, of course we do not measure, unfortunately ever, directly colour separation, we do measure final state charges of the particles. So, we do correlations with respect to reaction plane, scoverning of the particle correlator that tells you how likely you to find two particles of the same charge in one direction of the reaction plane does abailst in opposite directions, and if we see significant differences evolving the centrality which gives you the differences in an event shape, so, and that's consistent with expectations from local parity violation. However, from local parity violation scenario there is not a single quantitative prediction, so we are not at the better point yet that we can cross-check the data terms with the theoretical predictions. And there are a couple of theoretical discussions that claim that you could introduce the data term, at least, qualitatively, without invoking a local parity violation, such as just local charge conservation, and move to radial flow source.

S.Troshin

I'm still wondering what is it, quark-gluon plasma. We have first to define what we are looking for, what is quark-gluon plasma. The main idea, as mentioned by Collins in 1975, is the asymptotic freedom not the deconfinement. And after that many experimental observations were made and even "strongly interacting quark-gluon plasma" was discovered at RHIC. I don't like this term which sounds to me as oxymoron consisting of mutually contradicting parts, something like "violent relaxation". I think that another name for this state has to be used because this is rather a liquid and not a plasma at all, it has properties very different from the properties of free quark-gluon gas . I think, many properties of the state may be understood if to suppose that this is strongly interacting hadronic matter which could provide peripheral collisions with rising mean transverse momenta (p_t –dependence). For example, we could explain ridge and double ridge effect by rotation caused by strong interaction in a transient state. And this rotation could be responsible for many observations, but it is difficult to say how the strongly interacting matter can transform into a state of free gluons and quarks in which case rotation should be absent ,e.g.

transverse momentum should stop rising . The main point to understand is, I repeat again, what we are looking for ?

S. Sadovsky:

I would like to answer to the questions which are in panel discussion concerning the Quark-Gluon Plasma, and I would like to tell that these questions are interesting. The first question is: "In which case experiment could unambiguously (dis)prove the existence of Quark-Gluon Plasma?".

I would like to answer to this question that it is a bit obsolete. At least we have heard today the talk of *Sonja Kabana* and I think that nobody think now that Quark-Gluon Plasma does not exist. But maybe this is not a bit good term "QGP", because, I would like to tell that this is a trivial question, trivial statement: "QGP exists". I would like to compare the answer that QGP exists, with the statement of antique Greeks which teach us that all consist of atoms. Several hundred years elapsed from that time and we all know now that indeed they were right: everything consist of atoms. But from that time we have understood, that atoms exist at least in hundreds of kinds. We know that there is a core (nucleus) in atoms, we know that there are electrons, we know that there some energy levels of electrons and so on, and so on, and so on. And I think that now we are in the same stage as antique Greeks, if we speak about the Quark-Gluon Plasma. We can tell, that indeed there is QGP, but the point is that we don't understand, what it is. This is the first. Second, our understanding of QGP. I would like to tell that this is some category which is not clear for people for the moment. This category, this understanding of category is changing from time to time: at the first time we heard that this should be free quarks and gluons, then we have understood that this is some color glass condensate or something like this, and, say, after five years more, I believe, our theorists will understand and introduce something else. But what for me is absolutely clear, that we come to the stage of study of the matter, not only QGP, but matter at high temperatures, high densities of energy, high pressure and so on. And this is a very long journey.

After the above comment I would like to answer to question 4 of the panel: "Can HI collisions imitate the early instants of the Universe evolution?". My answer is: yes, it can. But we have to understand in which moment, because definitely, if we believe in the Big Bang there is some energy, some state of the matter in very short period of its development, which we can also create in our accelerator, and, definitely, what we have seen already in HI collisions have some relation with this matter but in very-very specific cases. This is the first statement. The second statement from my understanding is that when we study this matter we come to QGP, and we start to understand the variables which are critical for description, for understanding of this matter. I repeat that these are density, entropy, temperature and so on, and so on. But the results of our efforts should be the model of matter at extreme conditions. This is very big task and we are only in the beginning of it. And I would like to wish everybody to start and to obtain good results in this direction.

V.Zakharov: concerning the use of the term “strongly coupled quark-gluon plasma” I’d like to notice that recently we asked Vladimir Fortov, a renowned expert in ordinary plasma physics and the acting President of Russian Academy of Scences : “if there exists a strongly interacting plasma”? His reply was definite:”Yes!”.

Question from the audience (V.Petrov):

It seems that we observe something which has some strange properties and call this “quark-gluon plasma”. Maybe this is the matter of convention? Because prior to say if this is quark-gluon plasma or not we have first to know what is it. If we don’t know what exactly quark-gluon plasma is we are free to call by this name everything we observe and which has some particular signatures.

S. Sadovsky: So, you see, when Rutherford tells us that there is a core in atom, in a beginning it was only a drop of dense matter in the center of atom and nothing else. And only after many years of study people have understood, that this core (nucleus) consist of protons and neutrons, that there are strong interactions, that there are gluons and quarks so on and so on. So my answer to your question is that at the present moment we understand QGP as a mixture of quarks and gluons which are not more combine in hadrons. But after some time, after several years, I believe, this understanding will be changed, improved, updated and so on. We can't now make definite description, give definite name of this state and its properties because we are only in the beginning in study of these phenomena and matter.

Comment from the audience (V.Rubakov):

I’m afraid to be provocative but I have a simple argument that the answer to the first question should be in the negative. As you know, some properties of the new state of matter are described within AdS QCD framework. AdS QCD framework doesn’t deal with quark and gluons, it works entirely with colourless objects. So, if AdS QCD has anything to do with reality then we have not discovered yet any colored object in this new state of matter which is colorless.

O. Evdokimov : There are recent developments which try to reproduce experimental results within this framework but I should say that of all approaches this is the farthest-out before we can say that the data are described within the AdS/CFT …

V.Rubakov: Well, what about the shear viscosity? The shear viscosity was calculated within AdS/CFT , $1/4\pi$! *)

O. Evdokimov: This is a CFT quantum limit, it’s not calculated from the plasma at all.

V.Rubakov: Oh, it was!

O. Evdokimov : This is consistent with the data as a quantum CFT limit…

S.Kabana: We have our data, we compare with the lattice, we do dynamic assumptions of plasma and this is one possibility, also I don't know the degree of conclusiveness we can do for all this just from the data. The idea here is that it is very difficult to get something in terms of proving or disproving results, so you just focus on one thing which is also very new and has a little time to develop an understanding of what happens to date at the CFT. Then one can ask about validity of the CFT for such things like the coupling constant which has to be strong enough to be valid. That's the question.

O. Evdokimov: What's concerning the shear viscosity, there are three completely different approaches that lead to minimal values of the data including that we heard here. So do the Hydro, the Glasma , the AdS/CFT; there is no disagreement on viscosity.

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*) The specific shear viscosity as extracted from the LHC data is
$(\eta/s)_{\rm QGP} \approx 0.2 = 2.5 \times \frac{1}{4\pi}$ at LHC temperatures

(Added by the editors).

Comment from the audience (B.Adeva): just one short question, perhaps, a less provocative. Concerning the fourth question *(of questionnaire*) I don't completely understand how high energy HI collisions have something to do with the initial conditions of the Universe because there were no heavy ions in the early Universe.

S. Sadovsky:

I would like to add something. Actually we understand very little what does happen after 10^{-6} sec of the Big Bang I think, and I would like to tell that probably what we try to study now in heavy ion collisions has some relation with this time or with this state of matter, but I would like to tell also that situations is a bit more complicated even from the present point of view. If we try to learn which is the size of Universe in time of 10^{-6} sec, it is of the order, I don't remember exactly, of hundred thousand kilometers only and you know that the mass estimation of Universe is around 10^{50} ton, so we can image which gravitation field was there. This is the first. The second, if we speak about thermal properties of quarks and gluons in that moment, we have to take into account the gravitational potential in this case as well, which we don't have in the case of heavy ion collisions because the gravitational field is negligible here. So, we can image, that we try to understand this time of the Universe development but definitely it can not be fully reproduced in heavy ion collision at least due to gravitational effects.

V.Rubakov: No, the gravitation was negligible at this stage. The rate of the cosmological expansion was 10^{-6} sec, a typical time which is much larger than the typical time of heavy–ion collisions. That is a characteristic of gravity as compared to conventional interactions.

S. Sadovsky: I mean the Boltzmann distribution in the presence of gravitational field.

Comment from the audience (A. Mitra): String theory is a hypothetical description of nature that claims to accommodate both gravity and the quantum physics that describe the other three fundamental forces: electromagnetism and the strong and weak nuclear forces. Traditionally, gravity and quantum physics don't play well together, but string theory uses extra dimensions of space to reconcile the two.

Theorists found that the mathematics of certain quantum theories and that of objects described by gravity in one EXTRA dimension.

Formally this is known as AdS/CFT correspondene: the **Anti-de Sitter/conformal field theory correspondence**, sometimes called **Maldacena duality** or **gauge/gravity duality**, is a conjectured relationship between two kinds of physical theories. On one side of the correspondence are conformal field theories (CFT) which are quantum field theories, including theories similar to the Yang–Mills theories that describe elementary particles. On the other side of the correspondence are anti-de Sitter spaces (AdS) which are used in theories of quantum gravity, formulated in terms of string theory or M-theory.

So QCD is 3+1 dimension is described by gravity in 4+1 dimension through a HYPOTHETICAL correspondence. Note the physics of the quark-gluon plasma (QGP) is governed by QCD. And eventually string theorists connected study of QGP to black holes in 4+1 dimension by extending the same conjecture for which there is no basis from deductive physics. So they translate problems from the quark-gluon plasma into the language of gravity, where the equations become much simpler. Although the translation can't provide precise calculations they justify this, approach because on the plea that solving a problem in one realm can give valuable insights into the other.

Even if we momentarily admit that QGP & higher dimensional gravity correspondence is correct, the conclusion that higher dimensional EXACT black holes are balls of QGP or anything is self-contradictory. This is so because, in any dimension, by definition BH is a VACUUM solution.

On the other hand we have shown that during general relativistic continued gravitational collapse, in the regime of $z \gg 1$ (z= Surface Gravitational Redshift), at a certain stage, the collapsing object will become so hot that it would be almost a ball of radiation where trapped radiation density >> rest mass (baryonic) density, and the outward radiation pressure becomes equal to the inward pull of gravity.

At this stage, the estimated mean temperature of the ball of plasma is

$T = 600 \text{ MeV } (M/M_{solar})^{-1/2}$

Thus a stellar mass BH with M <10 Msolar will have

T > 200 MeV

i.e., it will be ball of QGP.

In other words the so-called black hole candidates are Balls of QGP. And this is not only REAL but fully self-consistent without the hand waiving arguments like (1) QGP is related to gravity in 4+1 dimension and further (2) QGP corresponds to a BH in 4+1 dimension and vice-versa.

Comment from the audience (E. Anderson): let us consider the equation of state of the neutron star. Neutron star physics is some kind of partner question to number four of this panel discussion. Our discussion on the early Universe is being used in neutron star physics.

O. Evdokimov

…concerning the temperature versus baryon density. Experimentally in HI collisions we probe the other corner of this diagram. So, main happen in its, for example, shantelmen interaction similar, but it is definitely different limit. So, we are dealing with the high temperature nearly zero baryon potential in HI collisions while in neutron star it is a cold matter with extreme density.

Kabana : That is why we can use the data, for example, which are taken at lower energies, where the baryon potential is very high, for to see the equation of state for neutron stars. For example, at this time people can use the data from the TAS(??) collaboration. This is an input to models describing neutron stars.

Ezhela : The question concerns the effect of called "Efimov physics", when one can argue about nuclear molecules. Three nuclear fragments each in pair have no bound states while together and at high densities they have. You may produce such unusual nuclear molecular fragments because at lower energies it's difficult.

O. Evdokimov: In the fragments of the HI collisions one really see unusual nuclear objects like anti helium etc.

V. Zakharov: Actually this is a suggestion of a new line of research.

V. *Petrov*: At the session I asked about the average number of participating particles. The answer was : about some thousand particles. I don't understand how it's possible with so small number of particles, at such short times and tiny spatial sizes to have a local thermodynamic equilibrium.

S. Kabana: There are some thermodynamical models like the one formulated by Yurii Sinyukov. They have developed the models which happened to became have partons describing QGP and partons has no hadronic interaction. Along this they test the data to predict pt-spectra, and have an excellent agreement with data. So, given this, they can then study the relaxation scale, and also they left them. And what is known up to now, is that they left them of the plasma, for example, a trick, is about 5 at ILC, while at LHC it is a factor of 2, something like 10 at LHC. And now you can compare this with the relaxation scale of the order of 0.1 at ILC until 0.4, his model agrees well with the data, for the relaxation time 0.4 at the LHC. You see, that it is quite valuable information. We learn that it is possible to come to this.

E. Anderson: Are there any other astrophysical applications of QGP?

O. Evdokimov: This probably addresses the last of panel questions. And for maycanthispear again relates how well you know what the state of the early Universe was, to be able to say about to be help it. But as far as current experiments are too the valuable to assert that short again. It may not be exactly the same state, because we just do not know enough exact conditions for the weakly coupled plasma that we anticipated to some probably strongly coupled plasma. So, it is clear to me from astrophysical prospective from other thing that theory that easy to do same things, but this is out shut on face the partonic nature and study that in the partonic phase.

V. Petrov: the question concerns the spacetime curvature at the initial state of the Universe evolution which probably was very much different from that of the present environment in HI collisions.

S. Sadovsky: I think, that we understand the state, which we call Quark-Gluon Plasma, better than the Universe in time of 10^{-6} sec after the Big Bang. And second, due to this to compare these two objects we should at first to understand the quantities, variables which could be measured now in the Universe, to be compared with the already measured quantities, properties of the state called Quark-Gluon Plasma.

V. Zakharov: Instructions oblige me - as moderator - to give a concise and clear summary. I'm also professor at the university and I think we have to teach students the Quark-Gluon Plasma.