April 14, 2009

**PROPOSAL**

for an International ECT*/HICforFAIR/CATHIE/Nikhef Workshop on

**Flow and dissipation in ultrarelativistic Heavy Ion Collisions**

1. *Tentative date of the workshop:*

   One week (Mo - Fr), Sept. 14–18, 2009

   *Organised by:*

   Marcus Bleicher, Frankfurt, organiser
   Carsten Greiner, Frankfurt, organiser
   Pasi Huovinen, Frankfurt, coordinator
   Peter Petreczky, BNL, organiser
   Raimond Snellings, NIKHEF, organiser

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2. **Scientific Proposal**

The success of ideal-fluid hydrodynamics in reproducing the observed azimuthal anisotropy of particles produced in heavy-ion collisions at RHIC gave rise to the notion of quark-gluon plasma as a perfect fluid. As a matter with, if not zero, with extremely low shear viscosity coefficient to entropy ratio $\eta/s$. Since then there has been a great interest in the heavy-ion physics community to measure and determine how large the shear viscosity coefficient actually is. In this workshop we want to address the bold question of what it takes to measure the ratio $\eta/s$ of partonic matter: How can we extract the ratio from the present data, or do we need additional measurements? Are our models reliable enough and what are their uncertainties and unknowns? How to constrain these unknowns?

So far, the model of choice for interpreting the relativistic heavy-ion collisions at RHIC has been ideal hydrodynamics. By definition, ideal hydrodynamics cannot address the question of the value of the shear viscosity coefficient, but one needs an approach where dissipation is included in the description. Recently there has been tremendous progress in the development of such a models, namely, in the viscous hydrodynamical and in the microscopic parton transport descriptions of the relativistic heavy-ion collisions. These approaches have matured up to the point where practitioners have given limits to the allowed shear viscosity of the plasma. However, neither of these approaches is without problems and unknowns.

To begin with, the correct formalism of the causal and stable relativistic viscous hydrodynamics is still debated, and the accuracy and applicability of viscous hydrodynamics to the relativistic heavy-ion collisions are not very well established. The application of viscous hydrodynamics also suffers from the same unknowns than the ideal hydrodynamics: What is the effect of the equation of state to the flow? Does it make any difference if we use the lattice QCD based equation of state or not? On the other hand, the equation of state of the plasma is something we would like to determine from the data. Is is thus possible to extract both the equation of state and shear viscosity coefficient from the data simultaneously, or do we need to assume the one to determine the other?

Besides the deconfined phase, the hadronic phase affects the final observables and thus complicates the efforts to determine the properties of the plasma. Despite years of work it is still uncertain how much the hadronic phase affects the flow and what is the correct way to describe the hadronic phase. Can it be described using the viscous hydrodynamic model, or does one have to

switch to a hadronic cascade model as is done in so-called hybrid models? In a similar fashion the last stage of hydrodynamical models, freeze-out, is full of uncertainties. It is not known what would be the most physical way of describing it, nor are the effects of the freeze-out procedure studied thoroughly. All these open questions have to be answered before the fluid dynamical model can be used to estimate $\eta/s$ reliably.

The microscopic transport calculations provide an attractive alternative to the hydrodynamical models, since their applicability does not require the system to be close to a local thermal equilibrium. Thus they can describe the evolution of the system before thermalisation and during the late stage of the evolution when scatterings cease and the system freezes out. On the other hand, the phase transition from partonic to hadronic matter in the transport description is still an unsolved problem, nor is it clear at which temperatures the quasi-particle description of quark-gluon plasma is valid. Analogous to the equation of state in the hydrodynamical models, the scattering cross sections crucially affect the results of the transport models and thus the knowledge of them is essential. We aim to discuss the unknowns and recent improvements of the parton transport models and the possibilities to describe the entire evolution of the system, hadronisation included, based on a transport description.

As mentioned, the flow is affected by many variables during the evolution of the system, and the deduction of the properties of the matter requires systematic cross-check of several observables. Recently discovered two- and three-particle correlations unique to the heavy-ion collisions may provide necessary extra information to constrain our models much better than previously. The interpretation of these correlations is still an open issue and we want to discuss the status of the experimental data, the open issues and assumptions in the proposed theoretical models and the constraints these correlations provide to the properties of the interacting matter.

To sum up our proposed workshop shortly: We aim to summarise what we do know about the matter at high temperature: degrees of freedom, EoS and transport coefficients, and what we can expect to learn in the near future, especially what are the prospects of achieving quantitative instead of qualitative understanding of hot QCD matter.

3. **Outline of the workshop program**

The workshop will cover a **duration of 5 days**. We will outline here how we envision the organisation of the workshop with the subjects to be covered and by whom they will be covered. (See also the list of potential participants.)

On the **opening day** we plan to have a series of overview talks (45 min + 15 min discussion each) on the current status of transport and viscous hydrodynamics calculations and experimental flow and correlation measurements. This will enable the participants to be up to date with the latest developments and highlight open questions to be discussed in the subsequent days. On the theory side, the talks would cover i) the present status and the open issues of the viscous hydrodynamics calculations (Heinz), ii) the work done to find the correct formalism of the stable and causal relativistic dissipative hydrodynamics (Rischke), iii) the status of parton cascade calculations (Molnar) and iv) the possible collective behaviour of the collision system before thermalisation (Pratt). On the experimental side, we plan to have a general overview (Voloshin), and a talk concentrating to the status of the two- and three-particle correlation measurements (ridges, cones, etc., Wang).

**On the 2nd day** we want to address mainly theoretical issues. In the morning we wish to cover: i) the lattice calculations of the equation of state (Petreczky) and ii) the transport coefficients (Meyer), iii) pQCD calculations of the transport coefficients (Peshier) and iv) The recent advances in AdS/CFT calculations related to the relativistic heavy-ion collisions (Teaney). During the afternoon we wish to concentrate on the theoretical predictions of the initial state of the hydrodynamic/collective expansion (e.g. Color Glass Condensate) and what effect the initial state, especially its fluctuations, could have on the flow observables (Gelis, Werner, Qian).

**Day 3 and part of day 4** will be devoted to the flow measurements, their hydrodynamical reproduction and recent improvements on the hybrid models. We want to begin by experimental talks by the representatives of the STAR and PHENIX collaborations (Sorensen and Esumi, respectively), and continue by discussion of the state-of-the-art ideal and viscous hydrodynamical and transport calculations (Bosek, Song and Xu, respectively), including hybrid models (Nonaka) and discussion of the effect of the equation of state to the flow observables. In particular we want to discuss how accurate the various models are, and what is their region of applicability.

**On the rest of the day 4** we change the point of view somewhat, and concentrate on one of the open issues of hydrodynamical models: freeze-out (Csernai, Sinyukov, Niemi, students). In particular we want to discuss possible improvements to the standard Cooper-Frye procedure and whether the improvements have any observable results.

**The last day (5)** of the workshop will be devoted to the two- and three particle correlation patterns of high-$p_T$ particles: ridges, cones, etc. In particular we want to address the questions how robust the measurements are, what the open issues and assumptions of various theoretical models are, and what we can learn of the properties of the plasma based on these correlations. We envision broad experimental and theoretical talks (Lacey and Stocker, respectively) and more focused talks by various students and postdocs attending the workshop (Dusling, Torrieri,...).

4. **List of key participants**

The organisers will be present at the workshop. Among the invitees for the workshop (all understood TBC), we plan to have

- Piotr Bozek (Cracow)
- Laszlo Csernai (Bergen)
- Kevin Dusling (BNL)
- ShinIchi Esumi (Tsukuba)
- Francois Gelis (CERN)
- Ulrich Heinz (Ohio State)
- Takeshi Kodama (Rio de Janeiro)
- Tomoi Koide (Frankfurt)
- Roy Lacey (Stony Brook)
- Mike Lisa (Ohio State)
- Harvey Meyer (MIT)
- Denes Molnar (Purdue)

- Azwinndini Muronga (Cape Town)
- Harri Niemi (Frankfurt)
- Chiho Nonaka (Nagoya)
- Andre Peshier (Frankfurt)
- Scott Pratt (Michigan State)
- Weiliang Qian (Sao Paolo)
- Dirk Rischke (Frankfurt)
- Yuri Sinyukov (Bogolyobov Institute)
- Paul Sorensen (Brookhaven)
- Horst Stocker (GSI)
- Derek Teaney (Stony Brook)
- Giorgio Torrieri (Frankfurt)
- Sergei Voloshin (Wayne State)
- Fuqiang Wang (Purdue)
- Zhe Xu (Frankfurt)
- Klaus Werner (SUBATECH)

Besides these senior participants, participation of approximately 12 students and postdocs is planned. Thus the workshop will have altogether 40+5 participants.

5. **External funding**

   We have managed to secure additional funding from LOEWE (the Hessian initiative for scientific and economic excellence). As we have already discussed with Prof. Richter, who was very supportive to our plans, we would like that all the local expenses would be paid for all the participants. For this purpose we are willing to use the LOEWE funds for 55 euros a day per participant. This would leave ECT* 30 euros per day per participant to pay, effectively cutting the local costs for ECT* by half.

   Besides the funding from LOEWE, we have also got a promise for an additional funding from the CATHIE (Center for Analysis and Theory of Heavy Ion Experiments) initiative of Brookhaven National Laboratory and Nikhef (approx. $5000 and 5000 euros, respectively). The funding from CATHIE would be aimed to support the US participants in particular. Because of these funding sources we wish to call the workshop a joint ECT*/HICforFAIR/CATHIE/Nikhef workshop.