INT Program Proposal:

Quantifying the Properties of Hot QCD Matter

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Summary

We propose a two-month INT program focused on quantitative study of hot QCD matter, through realistic dynamical modeling of relativistic heavy-ion collisions and their extensive comparison to data. The program will primarily address the data-to-theory comparison of RHIC (and initial LHC) measurements of collective flow and jet quenching, with the goal of reaching validated, quantitative conclusions about properties of hot QCD matter such as the equation of state, viscosity, and parton stopping power.

The program will in part aim at an assessment of the activities of TECHQM, an ongoing collaboration addressing these and similar issues, but membership in TECHQM is in no way required for full participation in the proposed INT program.

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Introduction

The study of QCD matter at high temperature is of fundamental and broad interest, forming one of the pillars of nuclear physics research in the United States as well as world-wide. Bulk QCD matter and its possible phase transitions can be explored in the laboratory, through the collision of heavy atomic nuclei at ultra-relativistic energies. Experimental study of relativistic heavy ion collisions has been carried out for three decades, beginning with the Bevalac at LBNL, and continuing with the BNL AGS and CERN SPS. The experimental program reached full maturity with the advent of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven, operating since 2001, whose spectacular and surprising results have altered our view of hot QCD matter in a fundamental way.

The most significant experimental discoveries at RHIC thus far are the large collective flow, apparently created at the partonic level, and the large energy loss of high-energy partons due to interactions in the hot medium. When combined with theoretical calculations and phenomenological modeling, these measurements indicate that the medium formed in nuclear collisions at RHIC is a strongly coupled, near-inviscid fluid, with initial energy density many times that of normal, cold nuclear matter.

These results have had an enormous impact in other areas, seeding new insights into the structure of hadrons at very high energy, the properties of strongly coupled fluids, and the nature of the gauge/gravity correspondence.

The RHIC program will continue to develop and expand in the coming years, with extensive upgrades both to the accelerator and to the experiments. The next major experimental milestone in the field will be achieved in 2009, with the start of the heavy ion program at the LHC. This is a unique moment in the history of the field.

Quantitative Measurement of Hot QCD Matter

Ultra-relativistic nuclear collisions are by their nature highly dynamic. The connection between experimental observables and theoretical calculations of equilibrium properties of QCD matter requires accurate and reliable dynamical modeling of the various stages of a heavy ion collision. Similarly detailed and accurate modeling is required for dynamical probes of hot QCD matter, such as the energy loss of gluon and light quark jets or heavy quarks.

At present, the conclusion that the medium generated at RHIC is a strongly coupled, near-inviscid fluid, with large initial energy density, should be considered to be qualitative, based on dynamical models with in some cases poorly constrained assumptions or approximations. There is a clear consensus that the field must now aim to achieve quantitative understanding of hot QCD matter, going beyond the current qualitative insights. Recent years have seen the accumulation of a wealth of data and significant advances in theory, which together will enable quantitative assessment and systematic improvement in the accuracy of modeling of relativistic heavy ion collisions. Our proposed INT program, which is detailed further below, is intended to bring together theorists and experimentalists who are experts in various aspects of this problem, at an opportune moment to evaluate the progress and to exploit it for a deeper understanding of the properties and behavior of hot QCD matter.

The transition from a qualitative, discovery-oriented research phase to a phase aiming for quantitative and verifiable measurement is not only timely, but also urgent. Two milestones in the DOE performance measures for research into QCD at high temperature for the 2009-10 time period are: (1) Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC; (2) complete realistic calculations of jet production in a high density medium for comparison with experiment. Successful attainment of these milestones will require a coordinated collaborative effort among theorists and experimentalists and an appropriate forum to reach scientific consensus.

In the past, INT programs have played an important role in advancing the theory of hot QCD matter and its relation to the relativistic heavy ion experiments. Examples from the past decade are: INT-08-2b (QCD critical point), INT-06-3 (From RHIC to LHC), INT-03-1 (The first 3 years of RHIC physics), INT-98-1 (Probes of dense matter). Our proposal can be viewed as the logical next step in this series of programs, which have helped shape RHIC physics.

The TECHQM Initiative

The TEC-HQM Initiative (Theory-Experiment Collaboration for Hot QCD Matter) was formed in Spring 2008 by a group of interested theorists and experimentalists, to provide an ongoing collaborative framework for discussion and coordination of efforts world-wide in heavy ion collision modeling. The emphasis of TEC-HQM is on quantitative, validated calculations. Its initial activities are therefore focused on those sub-areas that are most amenable to quantitative study from both the theoretical and experimental standpoints: collective flow and jet quenching (and the connection between them).

The inaugural TEC-HQM meeting was held at Brookhaven in May 2008, with over 100 people in attendance. TEC-HQM is not a formal collaboration in the sense of a collaboration carrying out an experiment at an accelerator facility, but is rather a collaboration in the literal sense of “working together”. Its structure is still evolving, but it currently comprises two “Working Groups” (Bulk Evolution and Hard Probes) that meet monthly by phone and carry out email and web-based discussions. Specific short-term and medium-term goals have been agreed to, and various theory groups are carrying out benchmark calculations that will initially be compared amongst themselves, and where appropriate gauged against experimental data.

Two joint WG phone meetings have been held thus far (July 2008), each with attendance of about 30 people from the U.S., Canada, Europe, India and Japan. A second collaboration meeting is planned for December 2008. The collaboration web site is:

https://wiki.bnl.gov/TECHQM/index.php/Main_Page

The goals and activities of the TEC-HQM Collaboration overlap substantially with those of the proposed INT program, and the author list of this proposal is identical with the TEC-HQM Steering Committee. However, we stress that the intent of the proposed INT program is *not* to hold an extended TECHQM Collaboration Meeting. Rather, the timing of our proposal is chosen such that significant results from TEC-HQM will be available, which will enable the wider Heavy

Ion physics community to make substantial progress toward the goal of drawing quantitative physics conclusions from RHIC and preliminary LHC data. Scientists interested in any aspect of the program are actively encouraged to participate, whether or not they are members of or participants in TEC-HQM. One of the aims of the program will be to disseminate the tools developed, and results obtained, by TEC-HQM.

Proposed INT Program

We anticipate that by Spring 2010, a number of lines of research essential for the proposed program will be reaching maturity. By then, three-dimensional viscous hydrodynamics calculations should be fully mature and ready for detailed confrontation with experimental data. The relationship between the various theoretical approaches to jet quenching should be fully understood, and the coupling of jet quenching calculations to hydrodynamic models will be ready for detailed confrontation with the wealth of RHIC jet quenching data. First heavy ion results from the LHC will also become available during this period. We expect it to be an extremely active and fertile period for heavy ion physics, and an extended INT program would serve as the right venue to enable those working on the problem (both TEC-HQM collaborators and others) to come together to complete and write up the mature work, and to initiate new projects inspired by LHC and recent RHIC results.

In our view, two months would be the optimal duration for an INT program, providing sufficient time for both broad-based and more narrow technical meetings, as well as periods where experts in particular sub-areas could collaborate extensively. A two-month INT program would contain the following elements:

- A series of two-week expert workshops on specific aspects of quantitative modeling;
- Extensive experimental seminars, with emphasis on reconciling data across experiments, accurate assessment of systematic uncertainties, and rigorous comparison to calculations;
- Seminars and discussion of new approaches and conceptual advances
- A TEC-HQM collaboration meeting [Note: If the INT National Advisory Committee believes that this meeting should be decoupled from the INT program, we will hold the collaboration meeting at a different location, before the beginning of the program.]
- Preparation of comprehensive publications ("Physics Reports" or similar), reporting results of particular quantitative studies (e.g., equation of state, shear viscosity, jet quenching parameters).

We expect participation in various stages of the proposed program by many members of the TEC-HQM collaboration. Current subscription to the TEC-HQM email list include 130 scientists from the US, Canada, Europe and Asia. In addition, we will invite and expect attendance of other scientists who are interested in the problems being addressed. We hope for the initiation of future joint projects based on the results and achievements discussed during the workshop.

Scheduling of the program is a complex issue, given the diversity of the targeted community. Here are the (somewhat conflicting) constraints we are currently aware of:

- Experimentalists play a central role in the program and care must be taken to avoid expected periods of intense activity at accelerator facilities. Run start-up at RHIC is typically at the end of the calendar year and into the New Year, while the LHC heavy ion runs will always be held in the late fall.
- It is necessary to schedule around the Quark Matter 2010 conference, currently expected to take place in September 2010 in Annecy, France. One of the proposers of this program (Wiedemann) is QM10 co-chair, while other participants in the program will be involved in organizing the conference or preparing talks. Consequently, August and September 2010 should be avoided
- Summer months (mid-May to mid-August) are preferred for faculty, who are then less constrained by teaching schedules

With these limitations in mind, the periods June-July or slightly earlier in the spring are preferred. However, if the INT approves this program, we request that you not schedule it immediately but rather provide us with possible options, so that we can then optimize the schedule within our constraints.