Scientific report

1. Summary

Thanks to the generous support by ESF (Holograv network), we successfully held a workshop on holography and QCD at Kavli IPMU. The main focus of the workshop was the gauge/string duality with emphasis on the application to QCD and related topics. We had a relatively relaxed schedule and provided an environment to encourage people to discuss and initiate new projects.

The format of the workshop was as follows.

Title: Holography and QCD – Recent progress and challenges -
Dates: September 24-28, 2013
Place: Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), the University of Tokyo, Kashiwa city, Japan
Organizers: Michal P. Heller (Amsterdam/Warsaw), Elias Kiritsis (APC/Crete), Mukund Rangamani (Durham), Jacob Sonnenschein (Tel Aviv), Shigeki Sugimoto (Kavli IPMU, LOC, chair), Taizan Watari (Kavli IPMU, LOC), Hirosi Ooguri (Caltech/Kavli IPMU, advisor)
URL: http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=9

There were 25 talks and we also had plenty of free discussion time.
The number of participants was 58. (See the list of speakers and participants in section 4 for the details) 8 people were supported by the ESF funds.

2. Description of the scientific content of and discussions at the event

Over the last decade it has become apparent that the gauge/string duality is a powerful tool for unearthing various features of large classes of strongly coupled systems, enabling first principle calculations in the regimes unaccessible before. A very significant part of these developments was motivated by the physics of non-perturbative phases of QCD (spectrum of hadrons, chiral symmetry breaking, the phase diagram, real-time dynamics, etc.). The goal of the workshop was to discuss recent progress and challenges of holography with applications to QCD.

The gauge/string duality is a duality between gauge theory and string theory. The string theory side is also called a holographic description, because it is defined in a space-time higher than that of the corresponding gauge theory. A

natural question is whether one can apply this idea to QCD or QCD-like theories to learn physics of hadrons and strong interaction. There have been a lot of works aimed to establish the duality between QCD and string theory, or to construct better bottom-up holographic models of QCD. We had several talks in this direction. Brodsky reported his recent works on light-front QCD and holography. He argued that the light-front Schrodinger equation can be interpreted as a Schrodinger equation for a particle in soft-wall holographic model of QCD, and discussed its implications. Jarvinen proposed a holographic model that can be used to describe QCD in the Veneziano limit, in which number of colors (Nc) and flavors (Nf) are both large. This situation is theoretically very interesting, because QCD is believed to have a conformal window when the number of flavors (Nf) is larger than some value. He discussed how the hadron spectrum, phase diagram, etc., depend on the ratio Nf/Nc. Sonnenshein studied the excited string states in top-down holographic models of QCD. The excited string states correspond to excited hadrons. He derived a mass formula for such excited states and compared with the experimental data. Zayas also considered excited string states. He argued that the spectrum of the observed hadrons is compatible with that of a chaotic system and discussed its explanation using string theory.

One of the strong evidences that the holographic description of QCD really describes the physics of QCD is that the massed and interactions obtained in the holographic approach are in reasonable agreement with experimental data as well as various phenomenological models of hadrons proposed before. Hong reported his new calculation of the corrections of hadron masses due to electro-magnetic interactions using the top-dowin holographic QCD.

Decays and scattering processes are also considered. Mueller reviewed recent discussion about energy flow and energy-momentum tensor matrix elements in decays in CFT and discussed possible applications to QCD. Djuric gave a nice review of pomeron physics and its holographic description. Applications to deep inelastic scattering, deeply virtual compton scattering and vector meson production are discussed and many of the results fit very well with the experimental data.

One of the highlights of the workshop was possible applications to the physics related to quark gluon plasma (QGP) created by heavy ion collision experiments, such as RHIC and LHC. Taliotis and van der Schee showed their analyses of colliding two shock waves using the holographic description. Taliotis argued a condition of formations of QGP by relating it to a condition required to create trapped surfaces. Van der Schee studied the collisions and the thermalization process by solving the time dependent Einstein equation numerically.

It was observed that the QGP realized in the RHIC and LHC experiments behave as an almost perfect fluid. The holographic approach provides powerful tools to analyze such systems. For this reason, application of holography to the hydrodynamics is one of the hot topics discussed in the workshop. Janik considered time dependent solutions corresponding to a boost invariant flow of plasma in N=4 supersymmetric Yang-Mills theory. His approach was to solve the Einstein equation, as a power series with respect to $1/t^{2/3}$, where t is the time. He calculated 240 coefficients numerically and, by Borel resuming the power series, extracted the components interpreted as quasi-normal modes, that represent the deviation from the hydrodynamics. Stephanov discussed the effects of the noise term that is usually neglected in the in the hydrodynamics. Rebhan considered some models with anisotropy and showed that the ratio of shear viscosity to entropy violates the conjectured lower bound. Kuperstein's approach is in a different direction. He claimed that the bulk space-time metric can be reconstructed from holographic RG flow in the long wavelength limit, which corresponds to hydrodynamics in the gauge theory side.
Chesler showed many beautiful movies of numerical gravity solutions corresponding to turbulence in the fluid and discussed their properties. Casalderrey-Solana, Arnold and Nitti studied the energy loss of particles travelling through the plasma.

Another important topic in the workshop was to understand the phase structure of QCD or related strongly coupled gauge theories. Hashimoto analyzed a gauge theory with strong electric field. He pointed out that the classical calculation of Schwinger effect can be reproduced from the Dirac-Born-Infeld action of the probe D-brane used to construct the holographic model. Applications of holography to QCD with strong magnetic field were discussed by Gursoy, Fukushima, Callebaut. Gursoy presented his calculations for the chiral magnetic effect and induced currents in QGP with strong magnetic field. Fukushima studied the effect of magnetic field in holographic QCD with finite temperature and chemical potential. He showed that the spatially modulated phase is less favored for a stronger magnetic field. Callebaut analyzed holographic QCD at zero temperature and claimed that rho meson field will condense when the magnetic field is stronger than the critical value determined by the rho meson mass. The effect of chemical potential at low temperature was discussed by Heller. He showed that vector and axial vector mesons can have nearly degenerate masses in the dense medium and discussed its possible interpretation as chiral symmetry restoration.

There were some talks that considered supersymmetric gauge theories. Kutasov 's talk was about a supersymmetric QCD with magnetic field. He showed that the classical Coulomb branch is lifted quantum mechanically. Morita proposed a surprisingly simple way to understand how free energy density of a D-brane

system depends on Nc and the coupling constant. In particular, his results reproduce mysterious Nc dependence of the free energy of M2 and M5-branes predicted by the holographic descriptions. Argurio applied holographic methods to calculate two point functions of operators in the supercurrent multiplet and discussed some implications to gauge mediation of SUSY breaking.

3. Assessment of the results and impact of the event on the future directions of the field

As summarized in the previous section, the workshop covered vast topics related to holography and QCD. Holography has now accepted to be one of the powerful methods to analyze QCD and related strongly coupled gauge theories. In particular, it can be used to calculate a lot of physical quantities in the presence of the background fields, temperature and chemical potential. It can also be applied to systems with time evolution. These are the situations where other non-perturbative methods like lattice QCD are not useful enough and holography is likely to get ahead. In fact, we had a lot of very nice talks along these directions in the workshop. None of them used supercomputers, but managed to get some impressive results. They are very important subjects, because these systems are realized in the nature, as well as the heavy ion collision experiments, and we expect that many people will continue to study them and there will be more developments to come in the near future.

One of the successes of the workshop was that we were able to gather together experts of both string theory and hadron physics, and provided a good opportunity to interact with each other. There were many string theorists showing results in hadron physics and hadron theorists using holography and string theory. They were discussing and debating together without a serious language barrier. We also had many people from younger generations educated in both fields. It will be very nice to see further fruitful collaborations among us.

After all the talks, many participants came to me and said they enjoyed the workshop, learned a lot, initiated new projects, etc. Although it is hard to predict the future, I believe that many ideas discussed at the workshop will lead to interesting results and further developments.

4. Annexes: programme of the meeting and full list of speakers and participants.

Kavli IPMU focus week workshop, September 24-28, 2013

Holographic QCD - Recent progress and challenges -

Lecture Hall (1F), Kavli IPMU main building

	Sep 24 (Tue)	Sep 25 (Wed)	Sep 26 (Thu)	Sep 27 (Fri)	Sep 28 (Sat)
08:45 – 09:15	shuttle bus to IPMU	shuttle bus to IPMU	shuttle bus to IPMU	shuttle bus to IPMU	shuttle bus to IPMU
09:25 – 09:30	opening				
09:30 – 10:20	Mueller	Casalderrey-Solana	Janik	Hashimoto	Kutasov
10:20 – 10:50	coffee break	coffee break	coffee break	coffee break	coffee break
10:50 – 11:40	Djuric	Arnold	Stephanov	Heller	Kuperstein
11:50 – 12:20	Hong	Morita	Taliotis	Callebaut	Argurio
12:20 – 14:00	lunch	lunch	lunch	lunch	closing (12:20–12:25)
14:00 – 14:50	Jarvinen	Chesler	Brodsky		
14:50 – 15:40	coffee break & IPMU teatime	coffee break & IPMU teatime	coffee break & IPMU teatime	coffee break & IPMU teatime	
15:40 – 16:30	Sonnenschein	Nitti	Gursoy	Rebhan	
16:40 – 17:10	Pando Zayas		van der Schee	Fukushima	
17:10 – 18:00	free discussion	free discussion	free discussion	free discussion	
18:00 – 18:30	shuttle bus to hotel	Banquet (18:00–20:00)	shuttle bus to hotel	shuttle bus to hotel	
20:15 – 20:45		shuttle bus to hotel			

Speakers / Titles

R. Argurio (ULB)	(Super)Current Correlators in Strongly Coupled Gauge Theories
P. Arnold (Virginia)	Tidal stretching of gravitons into classical strings: application to jet quenching
S. Brodsky (SLAC)	Light-Front Holography and the Uniqueness of the QCD Confinement Potential
N. Callebaut (Ghent)	Holographic study of magnetically induced rho meson condensation
J. Casalderrey-Solana (UB)	Towards a Hybrid Approach to Jet Energy Loss in Heavy Ion Collisions
P. Chesler (MIT)	Holographic Turbulence
M. Djuric (Porto)	Small x scattering using gauge/gravity duality
K. Fukushima (Keio/Tokyo)	Spatial modulation and topological current in holographic QCD matter
U. Gursoy (Utrecht)	QCD in strong magnetic fields
K. Hashimoto (Osaka/RIKEN)	Vacuum instability in holography
M. P. Heller (Amsterdam/ Warsaw)	Towards a holographic realization of the quarkyonic phase
D. Hong (Pusan)	Holographic estimate of electromagnetic mass of hadrons
R. Janik (Jagiellonian)	Hydrodynamics and beyond
M. Jarvinen (Crete)	Holographic models for QCD in the Veneziano limit
S. Kuperstein (Saclay)	Spacetime emergence via holographic RG flow from incompressible Navier-Stokes at the horizon
D. Kutasov (Chicago)	Challenges for holographic SQCD
T. Morita (KEK)	Comments on the universality of strongly coupled field theories at finite temperature
A. Mueller (Columbia)	Decays in weak and strong coupling conformally invariant field theories
F. Nitti (Paris)	The Trailing String in Confining Holographic Theories
L. Pando Zayas (Michigan)	A String Theory Explanation for Quantum Chaos in the Hadronic Spectrum
A. Rebhan (Vienna)	Comparing holographic models of strongly coupled anisotropic plasmas
J. Sonnenschein (Tel Aviv)	Holographic stringy hadrons
M. Stephanov (Illinois)	Hydrodynamic noise
A. Taliotis (VUB)	QGP in central collisions for suficiently large energy
W. van der Schee (Utrecht)	Collisions in AdS and the thermalisation of heavy-ion collisions

Participants list:

Name	Institution
Mr. ALI-AKBARI, Mohammad	IPM
Dr. ARGURIO, Riccardo	Universite Libre de Bruxelles
Prof. ARNOLD, Peter	University of Virginia
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Prof. BRODSKY, Stanley J.	SLAC National Accelerator Laboratory, Stanford University
Ms. CALLEBAUT, Nele	Ghent University
Prof. CASALDERREY-SOLANA, Jorge	Universitat de Barcelona
Dr. CHESLER, Paul	MIT
Dr. DJURIC, Marko	Centro da Fisica do Porto, University of Porto
Dr. EBRAHIM, Hajar	Institute for studies in fundamental sciences (IPM)
Dr. FUJITA, Mitsutoshi	Tokyo U., Kavli IPMU
Prof. FUKUSHIMA, Kenji	Keio University
Dr. GIATAGANAS, Dimitrios	University of Patras

Prof. GURSOY, Umut	Utrecht University
Prof. HASHIMOTO, Koji	Osaka University
Dr. HATTA, Yoshitaka	Yukawa institute
Mr. HE, BingRan	Nagoya University
Dr. HELLER, Michal P.	Institute of Physics, University of Amsterdam
Prof. HONG, Deog-Ki	Pusan National University
Mr. HOSHINO, Hironori	Nagoya University
Prof. JANIK, Romuald	Jagiellonian University
Dr. JARVINEN, Matti	University of Crete
Dr. KATASAWA, Shintaro	Kyoto U.
Prof. KIRITSIS, Elias	APC and University Of Crete
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