

# High Energy Nuclear Physics at the Relativistic Heavy Ion Collider

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*I was a visiting researcher with a Fulbright Scholarship at the Brookhaven National Laboratory and the State University of New York at Stony Brook from October 2006 until June 2007 under the supervision of Professor Sebastian White and Professor Roy Lacey. I was working on the experimental data of the PHENIX experiment at the Relativistic Heavy Ion Collider. Besides my professional results, I gained many many unforgettable experiences and memories that will last decades. The present report is a summary of the experiences and professional results I acquired during my Fulbright scholarship.*

## 1. Introduction

The motto of the Fulbright Program is:

*I have thought of everything I can think of, and the one thing that gives me some hope is the ethos that underlies the educational exchange program. That ethos, in sum, is the belief that international relations can be improved, and the danger of war significantly reduced,*

*by producing generations of leaders, who through the experience of educational exchange, will have acquired some feeling and understanding of other peoples' cultures why they operate as they do, why they think as they do, why they react as they do and of the differences among these cultures. It is possible not very probable, but possible that people can find in themselves, through intercultural education, the ways and means of living together in peace.*

J. William Fulbright:  
The Price of Empire

Following this motto, one finds that even though a Fulbright Scholarship can be professionally very successful and inspiring, its cultural part is at least that important. Thus I tried to get to know my environment and surroundings in the USA, and I tried to get to know as many people outside work, as possible, and learn about different habits and customs.

My host institutions were on Long Island in New York, 60 miles east from Manhattan (see Figure 1). You will read about my professional experiences in the second part of this report, but in the first part I will write about the personal and cultural details of my scholarship.

## 2. Cultural part

### 2.1. Insurance

In the US (as well as in many other countries in the world) health care is not free, unless one has accident and sickness insurance. This is a very important issue, as the simplest medical intervention, let alone hospital treatment, costs a fortune.

Luckily, the Fulbright Scholarship includes a basic accident and sickness insurance plan. Many universities, however, require a higher level of insurance with a smaller deductible and/or larger coverage. In



Figure 1. The location of my host institutions on Long Island, east of Manhattan

my case, Stony Brook required it, so I needed to take this other policy, as well. Again, luckily, the Fulbright Commission decided to pay this for me (many thanks to Huba Brückner and Csanád Nagypál).

Whichever insurance plan one takes in the end, it is very important to check what it covers and how one can access it, since it is very uncomfortable to learn in the casualty department of a hospital that our insurance does not cover snowboard accidents that happened outside of the groomed area, and we have to pay \$5,000 out of pocket.

The Social Security Card or Social Security Number (SSN) is an issue that belongs here, as well. As a Fulbrighter it was mandatory to have one, as the IIE (Institute of International Education) requested it. According to the Social Security Administration (SSA) Offices, however, one can get such a card only if one is working. Thus IIE gave a letter to me that was written to a Social Security Administration Officer saying that they should still give me an SSN. It turned out, however, that in the Long Island SSA office a policy was introduced of not giving an SSN to J-1 visa holders unless they are actually working. So, I went to another SSA office, but there I was told I have to go to the office that is nearest to my place of residency (that would be the office on Long Island where they did not give me the SSA despite the letter from IIE). Finally, I was told by the local IIE office, that there is a small SSA office in Manhattan where they usually give out the

SSN, so I went there and finally managed to get an SSN. The good thing is that during this process, I went around a lot on Long Island and learned much about the US social security system...

## **2.2. Travel**

When buying an airplane ticket it is very important to be careful, as the price of the ticket varies by at least a factor of two when choosing different dates for travel and/or different departure, arrival and stopover airports. After arrival and a short settling in, the first thing one notices is jet-lag. One just has to get over it, everyone goes through it. For a couple of days, one is tired all the time and understands things more slowly, but after a short time, it is just gone.

If one is already in the US, domestic air travel is relatively (per mile) cheaper, than in Europe. This, one has to keep in mind and make the best of it during the Christmas season or spring break: if living in New York, for example, a holiday in California with 4-5 nights, housing and car rental might be as cheap as \$400-\$500, if one searches the best offer, and Florida is even cheaper, and Hawaii also not much more. If one has the time for it, it is an unrefusable possibility, since starting from home one gets to such places only for way more money.

There are long distance bus companies and a useable railroad network as well, but both of them are quite pricey. It is worth orienting oneself with local public transport possibilities, although

it is unlikely they will provide a good alternative to buying a car (except if one finds good housing near the school or institute one is hosted at – but more about that in the next subsection).

For me the best decision turned out to be buying a car, because on Long Island there was hardly any public transportation, and I had to travel around 20 miles to and between my hosting institutions. I also tried using a bike, but that distance was too much for the everyday travel even in nice autumn weather.

About buying a car, I wrote an article for the popular Hungarian consumer blog called “Tékozló Homár”<sup>1</sup>. For the Hungarian reader it might be worth the 10 minutes reading it...

In New York state buying a car is administered by the fairly (in)famous DMV<sup>2</sup>. If I would have acquired enough information about this, I would have had a much easier time with this process, but I heard from everyone that in the US, buying a car is easier (from the administrative point of view) than one could imagine. Well, in NY, for me it was not that easy... Finding a nice but cheap (see figure 2) car was easy considering the price of pre-owned vehicles, but the rest... First, I could not get a New York State issued Driver’s License, as I don’t have my current visa status for at least one year. Second, because of this, I could not get an insurance policy under my name for a reasonable price. Third, I could not transfer the ownership of the car officially due to not having a New York State issued Driver’s License – but this turned out to be just a mistake; when I tried it the

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1 [http://homar.blog.hu/2005/11/07/vilagpremier\\_a\\_8211\\_a\\_naiv\\_ugyfel\\_amerik](http://homar.blog.hu/2005/11/07/vilagpremier_a_8211_a_naiv_ugyfel_amerik)

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2 <http://www.metrolyrics.com/dmv-lyrics-primus.html>



Figure 2: Me and my nice and cheap car, the '91 red Honda Civic

second time there was no problem with it. All together, the whole process lasted for two months, out of which I could not use the car for a full month – and that meant I could hardly go anywhere without asking someone to take me. But because of that, I got more work done and read more books than at any other time, and finally everything got fixed. Well, end is well, all is well.

### **2.3. Housing**

If one lives on the university campus, there will be no problems with everyday travel at all, but for meeting newly acquired friends, visiting different places and events or making a larger shopping trip, one still needs to know local travel possibilities; and that's not even mentioning the possibility of not finding housing directly on campus.

Finally, my future professor at Stony Brook helped me to find a room in the house of this nice, middle-aged lady of Jamaican origin, Margaret Morant. Even though she is most probably not reading

this, I owe a big thank you to her for all the help, kindness, and trust she showed me. Her youngest child was just moving out of the family home, thus only the two of us were living in the house from then on. It was very nice and easy to live there, and I had the opportunity to gain insight into everyday American life, even though it was through the life of a family of Jamaican origin. I got to know all the family, I attended a Thanksgiving-dinner, a Halloween-party, birthdays, and a Lutheran christening, and I learned about the everyday life of Jamaican-American people.

My conclusion from all of the above is that it is worth the search trying to rent a room or apartment in a family home or a flat share (which is similar to “WG” in German) – of course only if one is flexible and adaptable enough. One can even save money with it, as this kind of housing is mostly cheaper than on-campus dorms or renting a full flat or apartment.



Figure 3: Left: Margaret's house; Right: Azariah's christening

It makes sense to choose a family home in the suburbs also if one studies in a big city; it might not be that expensive or complicated to commute from there, and it would be worth the price difference; not even mentioning the possible cultural surplus.

#### **2.4. Shopping, finances**

As a Fulbrighter, one receives the scholarship amount from home usually in three portions. The first amount is given out in check or cash; my experience shows that it is a good idea to ask for it in cash, as one might need it quite fast in order to buy a car or pay the deposit/security for the housing.

One eventually needs to open a bank account (the further portions of the scholarship will also arrive here); it is best to do this right at the beginning. In some states there are Credit Unions, for example in New York there is the Teacher's Federal Credit Union, which is like a nonprofit bank (even though this sounds like an oxymoron), where almost everything is free (no account or debit card fee, as well as no ATM withdrawal fee). One does not even need a Social Security Number to open an account at such a Credit Union. Thus, I chose this solution, but every other bank would have done it in basically the same way.

It is worthwhile to try to make a smart living out of the scholarship money. The best way to spare a little money is to find reasonable housing, or even to change housing when finding a cheaper but

also acceptable place to live. Otherwise, the costs of basic living are quite low, especially if one knows the not-the-fanciest shopping places (for which one really needs a car – or the regular shopping shuttle of the university). The usually abundant selection in most of the supermarkets fulfills every need, but if one is enthusiastic about organic food, then one needs to be careful (and ready to pay more).

Clothing and apparel are mostly way cheaper than in Hungary (comparing the same brand products), thus it is worthwhile visiting the big clothing stores. But girls and women, be aware, sometimes things are really amazingly cheap and one cannot (or maybe can?) buy five suitcases of clothing. The prices in an average brand's store are half the ones in Hungary, thus one should come rather with fewer clothes and buy some here rather than buying everything needed at home in advance. This holds for electronics, as well (iPod was The thing to buy during my stay), but one has to keep in mind the difference in the electric system (110/220 V, 50/60 Hz). It is also important to check whether or not the guarantee is valid at home.

It is also important to mention that one can pay with a debit- or credit-card (even with a Hungarian one) almost everywhere, especially with an embossed one. One usually cannot rent a car or buy gas at night with cash, so having an ATM card is really very important. It is good to know, as well, that most of the time stores give the money back if one is not satisfied with

the product and returns it, whether it is a shoe that one has worn and is too small, or an mp3 player that does not work like one would have wanted it to work, or even a shirt which one would like to have in a different color. And it is not just that one can buy something else for the same price, but most of the time they actually give the cash back without any further investigation.

### **2.5. Communication**

It is more or less important for everyone to keep in touch with friends and family at home. For me, it was a basic issue. What I found was that calling home is the cheapest over the Internet, even if one wants to call a regular phone at home. Several companies<sup>3</sup> offer cheap or even cost-free calling and text messaging possibilities to landlines and mobile phones in most European countries. If both parties have internet, however, then calling is free, and one can even arrange video-calls<sup>4</sup>, and this really makes the distance to home way smaller. Some people use calling cards, and this is useful if there is no Internet-connected computer anywhere near, but if someone works with a broadband connection all the time, the above software provides the best alternative.

One also might want to consider having a mobile phone; in case of an emergency, it might be helpful. In the US, the network

(1900 MHz) is different from the one in Europe (900 and 1800 MHz), thus only at least tri-band phones work there. Pre-paid phones are not too expensive (starting from \$50-\$100), and the per minute charges are also acceptable (around 10-20 cents). One, however, has to be prepared for the fact that not only the caller pays, but the called party pays, as well (charges are airtime based), and sometimes one has to pay even for text messages (SMS)... Using a Hungarian phone here is, of course, more expensive, but if it works in the US, then it is perfect for emergency purposes, and receiving text messages from home is free.

### **2.6. Cultural shock**

Even if one is prepared for everything and knows all the tricks that make life easier in the US, there is a point when one just has to face the so-called cultural shock. At first, everything is interesting and people are all nice and one just wonders about all the funny things they are experiencing. But then, at some point, one starts to get annoyed with the little irritating differences, that even door handles and windows are different, that they don't understand our perfect "British Council" English, and that one just cannot get that kind of butter one is used to getting at home.

There are the bigger differences, as well, for example the relationship culture of American people. They are more open to new friendships, but sometimes also more shallow in relationships. Sometimes invitations to go to visit someone in his

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<sup>3</sup> For example VoipStunt ([www.voipstunt.com](http://www.voipstunt.com)), NeoPhone ([www.neophone.hu](http://www.neophone.hu)) or Skype ([www.skype.com](http://www.skype.com))

<sup>4</sup> For example the Windows Live Messenger ([get.live.com/messenger/](http://get.live.com/messenger/))

house (“Come by sometime”) are not meant literally – the inviter would be quite surprised if one would just show up there. What is also interesting is that sometimes, American people share private details of their relationships or family life, but don’t understand how you could ever imagine to ask how much he or she had to pay for his or her laptop or car. These things can be explained by the fact that mobility is very high in the United States, people do not often choose a university in their home-state, and even more seldom choose one in their home-city.

But all these differences can be handled, and one makes the best out of it if one tries to understand and learn.

### 3. Professional part

As I wrote in the first section, my host institutions were the Brookhaven National Laboratory’s (BNL) Physics Department and the Nuclear Chemistry Department of the State University of New York at Stony Brook. At BNL I was working on the PHENIX Experiment and Collaboration with Professor Sebastian White. At Stony Brook, my leader was Professor Roy Lacey. In the next subsection I would like to shortly describe our field of investigation.

#### 3.1. *Little bangs and the Big Bang*

Our world is made out of atoms which are made out of electrons and nucleons (a nucleon is a proton or a neutron), as shown in Fig. 4. In high energy heavy ion (called also heavy nucleus, a heavy ion is a ‘naked’ atom of many protons and neutrons, i.e. without its electrons) colliders these nuclei are accelerated up to a speed near

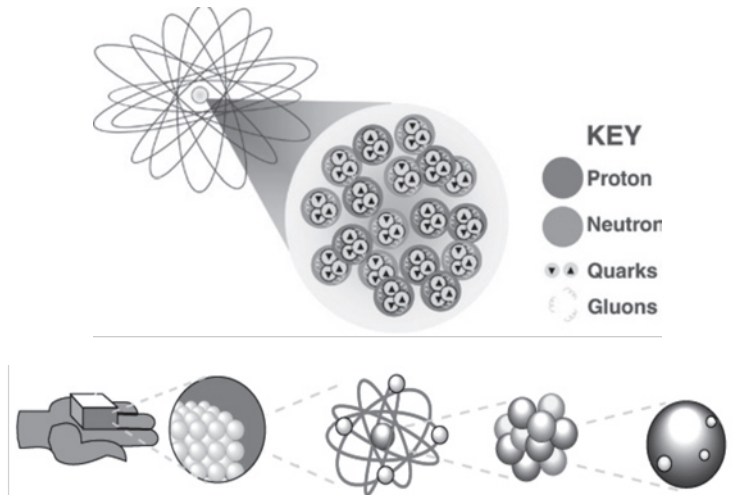


Figure 4: The building blocks of our World: materials are made out of molecules; molecules out of atoms; atoms out of electrons, protons and neutrons; protons and neutrons out of quarks and gluons.



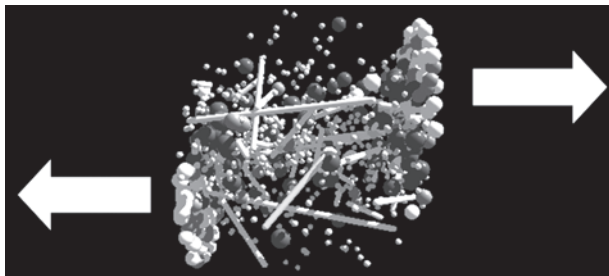
to the speed of light, and then collided. In these very high energy reactions (called also little bangs) circumstances are similar to the ones present at the very beginning of the history of our Universe.

Theoretical and experimental researchers discovered many years ago that protons and neutrons are not the fundamental building blocks of our World. Later on it became clear that they are made out of quarks and gluons, but these we do not see 'alone', i.e. not confined or 'frozen' into a bigger particle. It was proposed that at the birth of the Universe, quarks and gluons would have existed in a deconfined state, referred to as Quark Gluon Plasma, and governed by the so-called Strong Interaction. Since then, huge effort was put into finding experimental evidence for the possible existence of such matter and to better understand the interaction that is keeping our ions together against the repelling force of electromagnetic interaction of the positively charged protons.

We would see a similar situation if there were researchers living in a frozen world, who proposed the possible existence of a liquid form of ice, and if mankind were not able to produce such heat that would melt

ice. People would then build accelerators where chunks of ice would be accelerated and collided. Researchers would then detect and analyze the outgoing ice-fragments and they would try to find out whether (even if for a very short time) this possible melted form of ice (water) was produced and then refrozen to the detected pieces.

The quest for the above mentioned Quark Gluon Plasma (QGP) in high energy nuclear and heavy ion physics involves long-lasting and difficult research of a fundamental nature. Experimental searches for the QGP began more than 20 years ago at the Berkeley Bevalac, by studying collisions of heavy nuclei and analyzing the fragments created. In the ensuing years, a significant effort has been made to increase the center of mass energy per pair of colliding nucleons. At Bevalac of the Lawrence Berkeley National Laboratory, 1 GeV was reached (1 eV is the amount of energy one electron reaches if accelerated by 1 V of electric potential; 1 GeV is  $10^9$  eV). This was raised to 5 GeV at BNL's Alternate Gradient Synchrotron, and to 17 GeV at the SPS at CERN. These efforts culminated in the construction of a dedicated heavy ion



**Figure 5:** Before (left) and after (right) the collision. The ions (which are flat due to their speed because of the so-called Lorentz-contraction) are collided, and in their collision zone, probably a new form of matter is created.

accelerator, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, with center of mass energies per pair of colliding nucleons of 200 GeV. The reactions at RHIC are measured with the help of two “large” detectors, called PHENIX and STAR, and two “small” detectors, BRAHMS and PHOBOS. A vigorous experimental program with a primary focus on the creation and study of the QGP has already produced three milestone results. First is the discovery of a new form of matter that quenches even high momentum particles travelling through it<sup>5</sup>, the identification of the phase of this matter as a very high temperature (more than  $2 \cdot 10^{12}$  K, million times hotter than the core of the Sun) perfect (viscosity-less) liquid<sup>6</sup>. Recently, it was determined<sup>7</sup> that quarks are the relevant degrees of freedom in this perfect liquid that is created.

After this short introduction to my field of study I would like to discuss my experiences and results.

### 3.2. Experiences

Besides deepening my knowledge in almost all subjects of our field, I learned things I would have never imagined I would learn. For example, one of my important projects turned out to be the investigation of so-called J/Psi particles at PHENIX with Professor Sebastian White. I did not know anything before about such an analysis, but I had to master

it. This is one of the things that is priceless when having the time to learn. With Professor Roy Lacey I was working on flow measurements and their theoretical analysis. I did not stop working with my supervisor at home, Professor Tamás Csörg. We continued our common research projects while I was here. To manage all these projects was not easy, but in the end I found time for everything, for even more than I thought.

Absolutely unexpectedly, I had to learn many things in web-development and informatics (e.g. programming in html, xml and php, using psql databases). These just turned out to be necessary in order to participate in the work of our collaboration, as well as to inform our group at home about the results here, and it was helpful also for widening my communication with family and friends at home. My homepage <http://csanad.web.elte.hu> and our group homepage <http://phenix.elte.hu> grew out of these studies.

I also managed to give lectures at several conferences, for example at the RHIC and AGS Users’ Meeting<sup>8</sup> and at the Winter Workshop on Nuclear Dynamics<sup>9</sup>. It is important to mention here that this was possible because it is quite cheap to travel within the United States, as described in subsection 2.2. I was also invited to give a lecture at the Ordinary Meeting of the Hungarian Academy of Sciences<sup>10</sup>, for which I still feel much honored. Here I

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5 <http://arxiv.org/abs/nucl-ex/0306024> and <http://arxiv.org/abs/nucl-ex/0306021>

6 <http://arxiv.org/abs/nucl-ex/0410003> and <http://arxiv.org/abs/nucl-ex/0501009>

7 <http://arxiv.org/abs/nucl-ex/0703024>

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8 [http://www.bnl.gov/rhic\\_ags/users\\_meeting/Past\\_Meetings/2006/](http://www.bnl.gov/rhic_ags/users_meeting/Past_Meetings/2006/)

9 <http://rhic.physics.wayne.edu/~bellwied/sandiego06/>

10 [http://www.mta.hu/index.php?id=esemenyek&tx\\_calendar\\_pi1\[view\]=6&tx\\_calendar\\_pi1\[showUid\]=3351](http://www.mta.hu/index.php?id=esemenyek&tx_calendar_pi1[view]=6&tx_calendar_pi1[showUid]=3351)

was asked to talk about our group's work at the PHENIX experiment, as well as about the latest discoveries at RHIC. Finally, in August, i.e. when I was already at home, I was invited to the International School of Subnuclear Physics at Erice<sup>11</sup>, organized by A. Zichichi and Nobel Laureate G. 't Hooft. In this school highly ranked scientists give lectures in the morning, and then short talks are presented by young "new talents", as they call it. Here I presented my work done during my Fulbright scholarship. I won the Paul A. M. Dirac diploma and was asked to publish my results in the conference proceedings. Among the 60 invited young scientists, 20 received diplomas, while 8 were asked to contribute to the proceedings, thus this also showed the professional success of my time as a Fulbright scholar.

### 3.3. Tasks, results

#### *Work done for PHENIX-Hungary*

- Working on data acquisition at PHENIX, as a Data Monitoring person and as Shift Leader.
- Working on the ZDC detector of PHENIX, developing and maintaining its online monitoring software (supervisor: Sebastian White).
- Involvement in processing a whole PHENIX analysis (search for so-called J/Psi particles in ultra-peripheral type of collisions), starting a new Paper Preparation

Group (PPG #81) and giving internal talks on this subject (supervisor: Sebastian White).

- Involvement in the second phase work of the PPG #62 (analysis of scaling properties of flow in the created matter) and in the actual preparation of the paper (supervisor: Roy Lacey).
- Involvement in the work of the PPG #52 (analysis of spatial correlations), giving internal talks (supervisor: Roy Lacey and Tamás Csörgő)

#### *Theoretical work*

- Investigating properties of flow anisotropy, the existence of which is a cornerstone of the theory that the high temperature matter created at RHIC is a perfect liquid (which was also the top physics story of 2005 according to the American Institute of Physics<sup>12</sup>) using the Buda-Lund hydrodynamic model.
- Investigating new solutions of relativistic hydrodynamics, in cooperation with Márton Nagy, a physics student, and Tamás Csörgő.
- Publishing the material of previous conferences (Quark Matter 2005, Budapest, Workshop on Particle Correlations and Femtoscopy 2005, Kromeriz).

#### *Important talks, conferences*

- 22<sup>nd</sup> Winter Workshop on Nuclear Dynamics, San Diego, California March 11-19, 2006  
Talk: "Flow and correlations in

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11 <http://www.ccsem.infn.it/issp2006>

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12 <http://www.aip.org/pnu/2005/split/757-1.html>

- heavy ion collisions”
- 2006 RHIC & AGS Annual Users’ Meeting, Brookhaven National Laboratory  
June 5-9, 2006  
Posters: “Scaling of the elliptic flow at RHIC” and “Improving the Bjorken estimate”
- Ordinary Meeting of the Hungarian Academy of Sciences, Budapest  
May 10, 2006  
Talk: “Perfect fluid at the RHIC accelerator”
- International School of Subnuclear Physics, Erice, Italy  
August 29-September 7, 2006  
Talk: “Behind Quark Gluon Plasma”

- AIP Conf. Proc. 828, 479 (2006), <http://arxiv.org/abs/nucl-th/0510027>
- M. Csanád, T. Csörgő, B. Lörstad and A. Ster,  
Universal scaling of the rapidity dependent elliptic flow and the perfect fluid picture...  
Nucl. Phys. A 774, 535 (2006), <http://arxiv.org/abs/nucl-th/0509106>
- M. Csanád for the PHENIX Collaboration  
Measurement and analysis of two- and three-particle correlations  
Nucl. Phys. A 774, 611 (2006), <http://arxiv.org/abs/nucl-ex/0509042>
- Scaling properties of azimuthal anisotropy in Au+Au and Cu+Cu collisions ...  
A. Adare et al. (PHENIX Collaboration)  
Phys.Rev.Lett.98:162301,2007, <http://arxiv.org/abs/nucl-ex/0608033>
- Evidence for a long-range component in the pion emission source in Au+Au ...  
S. S. Adler et al (PHENIX Collaboration)  
Phys.Rev.Lett.98:132301,2007, <http://arxiv.org/abs/nucl-ex/0605032>

*Publications*

- T. Csörgő, M. I. Nagy and M. Csanád  
A New Family of Simple Solutions of Perfect Fluid Hydrodynamics  
In review at Physics Letters B, <http://arxiv.org/abs/nucl-th/0605070>
- M. Csanád, T. Csörgő, R. A. Lacey and B. Lörstad  
Universal scaling of the elliptic flow at RHIC  
22nd WWND Proceedings, <http://arxiv.org/abs/nucl-th/0605044>
- M. Csanád et al.  
Universal scaling of the elliptic flow and the perfect hydro picture at RHIC  
In review at Nuclear Physics A, <http://arxiv.org/abs/nucl-th/0512078>
- M. Csanád, T. Csörgő, B. Lörstad and A. Ster  
Understanding the rapidity dependence of the elliptic flow and the HBT radii at RHIC

## 4. Acknowledgements

I would like to thank the Hungarian-American Fulbright Commission and the Fulbright Family for making all the above possible. It was an enormous honor to be a Fulbright Scholar. I tried to capitalize on all the possibilities offered by this, the cultural and the professional ones, as well, and the staff of the Hungarian-American Fulbright Commission gave all the help for this. I owe special thanks to Huba Brückner, Csanád Nagypál, Krisztina Dietz and Éva Gottwald.