One of the main objectives of the Large Hadron Collider (LHC) is the study of the properties of matter at the largest temperatures ever achieved in a laboratory. This is pursued by colliding lead nuclei at extremely high energy and observing the many particles produced in the collision. The temperatures reached by this method are so high that the protons and neutrons that form the colliding nuclei melt liberating the quarks and gluons they are made off. For a short period of time these partons form a new state of matter, the Quark Gluon Plasma (QGP), with very interesting and unusual properties, such as very low viscosity and extreme opacities. One of the most fascinating of those properties is that in the plasma the quarks and gluons, instead of behaving as (quasi) particles that scatter scarcely, they interact so much that they loose their identity and they cannot be told apart from one another.

The description of plasma with no (quasi) particles poses a big theoretical problem. The standard theoretical tools available for analyzing the interactions amongst quarks and gluons, which are described by Quantum Chromo Dynamics (QCD), are not suitable for this problem. As a step towards developing those tools, there has been a lot of effort in understanding the dynamics of other theories different from QCD but for which techniques able to address this physical regime are available. These techniques, which originate from string theory, are known under the generic name of gauge/gravity duality and relate, in a mathematical way, complicated field theories which govern interactions among particles with much simpler gravitational theories. However, since these tools are not available for QCD itself, but only for theories alike, it is important to design tests, both theoretical and experimental, which can address how reliable the studies based on the gauge/gravity duality can be. Developing some of these tests has been the major objective of this project.

The work in this project has concentrated mainly in the way the heavier quarks produced in energetic collisions interact with the rest of the formed QCD matter. The reason for this is two-fold: first of all, the theoretical treatment of those quarks within the gauge/gravity duality is well understood; secondly, unlike previous experiments, at the LHC heavy quarks will be produced copiously allowing both their unambiguous identification and detailed experimental studies. The consequences of this line of work can be summarized into two main results:

1. The effective equation of motion for slowly moving heavy quarks was determined. When the motion of the quark is not resolved at very short times, they follow brownian motion. However, with higher time resolution the microscopic interactions of the quark with the surrounding system reflect themselves into memory effects in the effective forces they suffer. The time structure of these forces was determined and a very strong growth of the memory effects with the quark velocity, characteristic to strong coupling, was established. Similarly, a reduction of the effective mass of the quark with the velocity was also obtained. These equations were written in a way suitable for phenomenological studies. The main source of fluctuations at finite velocity was also determined and studied. These findings led to a published paper:

[1] *Stochastic String Motion Above and Below the World Sheet Horizon*, J. Casalderrey-Solana, K-Y Kim and D. Teaney, JHEP 0912 (2009) 066

2. A new mechanism of energy loss, characteristic of theories with a gravity dual, was identified. This mechanism is a consequence of the fact that in all those theories there is a set of particles, mesons, which have a maximum speed of propagation in plasma. As a consequence, those heavy quarks which traverse the plasma at a speed larger than that maximum can spontaneously emit meson loosing part of their energy. This is similar to Cherenkov radiation in a medium with index of refraction smaller than 1. Possible experimental signatures of this mechanism were identify which can be tested at the LHC. Since this mechanism has no parallel in any other theoretical framework, identifying its signals could serve as an strong indication that the main dynamics of the QGP are captured by the gauge/gravity duality. These findings led to two publications:

[2] *A New Mechanism of Quark Energy Loss*, J. Casalderrey-Solana, D. Fernandez and D. Mateos, Phys. Rev. Lett. 104 (2010) 172301 [1]

[3] *Cherenkov Mesons as in-Medium Quark Energy Loss*, J. Casalderrey-Solana, D. Fernandez and D. Mateos, JHEP 1011 (2010) 091

Finally, a different line of research, not foreseen at the time of application, was started during this project. This direction takes advantage of the fact that the LHC also collides protons and not just nuclei. In fact the proton program is the main program of the LHC and, thus, much more data in proton collisions is available. One of the many question under investigation is whether in a particular set of very rare proton collisions the QGP could be formed. This search is complicated by the fact that, if formed, the QGP in this system would be much shorter lived than in nuclear collisions. In this context, the role of fluctuations in the internal structure of the proton was identified as one of the key features that enable the identification of this state of matter also in these elementary interactions. The results of these finding led to the publication

[4] *Eccentricity fluctuations make flow measurable in high multiplicity p-p collisions.*, J. Casalderrey-Solana and U. A. Wiedemann, Phys. Rev. Lett. 104 (2010) 102301

[1] This work was highlighted in the American Physical Society project *Physics* aimed at spotlighting exceptional research.