Scientific Activity Report

Proiect: PN-II-RU-TE-2011-3-0184, no. 9/05/10/2011

The results of the research team funded in this project will be presented as follows:

- Scientific Publications
- Conferences and Scientific Meetings and Talks
- Dissemination Activities

Scientific Publications

In the article "Lepton number violating effects in neutrino oscillations" (Phys.Rev. D85 (2012) 053004, ISI impact factor 4.56, DOI: 10.1103/PhysRevD.85.053004, arXiv:1112.1523), together with Drd. Sebastian Hollenberg (Technische Universitat Dortmund) and Dr. Palash B. Pal (Saha Institute for Nuclrear Physics), we develop a nonadiabatic perturbation theory for oscillations involving an arbitrary number of neutrino and antineutrino species, including the possibility of lepton-number violation which we treat as a small effect. We interpret the physics of such an approach for the one generation case by introducing the notion of adiabaticity for neutrino and antineutrino oscillations in analogy to flavor oscillations. We find that in a CP-odd matter environment a small lepton-number violation in vacuo can be enhanced. Eventually, we apply the perturbation theory to the two generation case and work out an example for manifestations of lepton-number violation, which can be solved both perturbatively as well as analytically thereby further clarifying the nature of the perturbation expansion.

Two of the members of the team (Dr. Micu and Drd. Caramete) together with Dr. Xavier Calmet (University of Sussex) next published the article "Quantum Black Holes from Cosmic Rays" (JHEP 1211 (2012) 104 (DOI: 10.1007/JHEP11(2012)104, ISI impact factor 5.83). In this paper we investigate the possibility for cosmic ray experiments to discover non-thermal small black holes with masses in the TeV range. Such black holes would result due to the impact between ultra high energy cosmic rays or neutrinos with nuclei from the upper atmosphere and decay instantaneously. They could be produced copiously if the Planck scale is in the few TeV region. As their masses are close to the Planck scale, these holes would typically decay into two particles emitted back-to-back. Depending on the angles between the emitted particles with respect to the center of mass direction of motion, it is possible for the simultaneous showers to be measured by the detectors.

The next article published by members of the team was "Minimum black hole mass from colliding Gaussian packets" (R. Casadio, O. Micu, A. Orlandi. Eur.Phys.J. C72 (2012) 2146, ISI impact factor 3.631 DOI: 10.1140/epjc/s10052-012-2146-3). In this article we study the formation of a black hole in the collision of two Gaussian packets. Rather than following their dynamical evolution in detail, we assume a horizon forms when the mass function for the two packets becomes larger than half the flat areal radius, as it would occur in a spherically symmetric geometry. This simple approximation allows us to determine the existence of a minimum black hole mass solely related to the width of the packets. We then comment on the possible physical implications, both in classical and quantum physics, and models with extra spatial dimensions.

Next Dr. Micu co-authored the article "Charged Black Hole Remnants at the LHC" (G.L. Alberghi, L. Bellagamba, X. Calmet, R. Casadio, O. Micu. 10.1140/epjc/s10052-013-2448-0. Eur.Phys.J. C73 (2013) 6, 2448. ISI impact factor ISI 3.631). In this article the researchers investigate possible signatures of long-lived (or stable) charged black holes at the Large Hadron Collider. In particular, we find that black hole remnants are characterised by quite low speed. Due to this fact, the charged remnants could, in some cases, be very clearly distinguished from the

background events, exploiting dE/dX measurements. We also compare the estimate energy released by such remnants with that of typical Standard Model particles, using the Bethe–Bloch formula.

In “Back-to-Back Black Holes decay Signature at Neutrino Observatories”, Nicusor Arsene, Xavier Calmet, Laurentiu Ioan Caramete, Octavian Micu, (Astropart.Phys. 54 (2014) 132-138, DOI: 10.1016/j.astropartphys.2013.12.005, Impact factor ISI 4.023) the researchers propose a decay signature for non-thermal small black holes with masses in the TeV range which can be discovered by neutrino observatories. The black holes would result due to the impact between ultra high energy neutrinos with nuclei in water or ice and decay instantaneously. They could be produced if the Planck scale is in the few TeV region and the highly energetic fluxes are large enough. Having masses close to the Planck scale, the typical decay mode for these black holes is into two particles emitted back-to-back. For a certain range of angles between the emitted particles and the center of mass direction of motion, it is possible for the detectors to measure separate muons having specific energies and their trajectories oriented at a large enough angle to prove that they are the result of a back-to-back decay event.

In “Quantum Black Holes Effects on the Shape of Extensive Air Showers ”, Nicusor Arsene, Lauretiu Ioan Caramete , Peter B. Denton , Octavian Micu, (http://arxiv.org/abs/1310.2205), the possibility to find a characteristic TeV scale quantum black holes decay signature in the data recorded by cosmic rays experiments is investigated. TeV black holes can be produced via the collisions of ultra high energetic protons (E > 10^{18} eV) with nucleons the from atmosphere. We focus on the case when the black holes decay into two particles moving in the forward direction in the Earth reference frame (back-to-back in the center of mass reference frame) and induce two overlapping showers. When reconstructing both the energy and the shape of the resultant air shower, there is a significant difference between showers induced only via standard model interactions and showers produced via the back-to-back decay of black holes as intermediate states.

A quantum version of the Hoop Conjecture is proposed in “Quantum hoop conjecture: Black hole formation by particle collisions”, R. Casadio, O. Micu, F. Scardigli, (Phys.Lett. B732 (2014) 105-109 ,DOI:10.1016/j.physletb.2014.03.037, Impact Factor ISI 4.156). We address the issue of (quantum) black hole formation by particle collision in quantum physics. We start by constructing the horizon wave-function for quantum mechanical states representing two highly boosted non-interacting particles that collide in flat one-dimensional space. From this wave-function, we then derive a probability that the system becomes a black hole as a function of the initial momenta and spatial separation between the particles. This probability allows us to extend the hoop conjecture to quantum mechanics and estimate corrections to its classical counterpart.

In the article “Ultra-High-Energy Cosmic Rays from Low-Luminosity Active Galactic Nuclei” (Ioana Dutan, Laurentiu I. Caramete, Astropart.Phys. 62 (2015) 206-216 Impact factor ISI 4.023), the researchers investigate the production of ultra-high-energy cosmic ray (UHECR) in relativistic jets from low-luminosity active galactic nuclei (LLAGN). We start by proposing a model for the UHECR contribution from the black holes (BHs) in LLAGN, which present a jet power Pjr 10^{46} erg s^{−1}. This is in contrast to the opinion that only high-luminosity AGN can accelerate particles to energies Ś50 EeV. We rewrite the equations which describe the synchrotron self-absorbed emission of a non-thermal particle distribution to obtain the observed radio flux density from sources with a flat-spectrum core and its relationship to the jet power. We find that the UHECR flux is dependent on the {\it observed radio flux density, the distance to the AGN, and the BH mass}, where the particle acceleration regions can be sustained by the magnetic energy extraction from the BH at the center of the AGN. We use a complete sample of 29 radio sources with a total flux density at 5 GHz greater than 0.5 Jy to make predictions for the maximum particle energy, luminosity, and flux of the UHECRs from nearby AGN. These predictions are then used in a semi-analytical code developed in Mathematica (SAM code) as inputs for the Monte-Carlo

simulations to obtain the distribution of the arrival direction at the Earth and the energy spectrum of the UHECRs, taking into account their deflection in the intergalactic magnetic fields. For comparison, we also use the CRPropa code with the same initial conditions as for the SAM code. Importantly, to calculate the energy spectrum we also include the weighting of the UHECR flux per each UHECR source. Next, we compare the energy spectrum of the UHECRs with that obtained by the Pierre Auger Observatory.

In "Black holes as self-sustained quantum states, and Hawking radiation" R. Casadio, A. Giugno, O. Micu, A. Orlandi, (acceptat spre publicare in Phys. Rev. D., e-Print: arXiv:1405.4192, Impact Factor ISI 5.156), we employ the recently proposed formalism of the "horizon wave function" to investigate the emergence of a horizon in models of black holes as Bose-Einstein condensates of gravitons. We start from the Klein-Gordon equation for a massless scalar (toy graviton) field coupled to a static matter current. The (spherically symmetric) classical field reproduces the Newtonian potential generated by the matter source, and the corresponding quantum state is given by a coherent superposition of scalar modes with continuous occupation number. Assuming an attractive self-interaction that allows for bound states, one finds that (approximately) only one mode is allowed, and the system can be confined in a region the size of the Schwarzschild radius. This radius is then shown to correspond to a proper horizon, by means of the horizon wave function of the quantum system, with an uncertainty in size naturally related to the expected typical energy of Hawking modes. In particular, this uncertainty decreases for larger black hole mass (with a larger number of light scalar quanta), in agreement with semiclassical expectations, a result which does not hold for a single very massive particle. We finally speculate that a phase transition should occur during the gravitational collapse of a star (ideally represented by a static matter current and Newtonian potential) that leads to a black hole (again ideally represented by the condensate of toy gravitons), and suggest an effective order parameter that could be used to investigate this transition.

The principal investigator also coauthored the book chapter "Minimum length effects in black hole physics". This is part of the book "Quantum Aspcets of Black Holes" (ISBN 978-3-319-10851-3) published by Springer in the series Fundamental Theories of Physics.

Conferences and Scientific Meetings and Talks

The team members participated to several international conferences where they presented the results of the research papers which were detailed in the previous section:

Scientific Meetings:

- 1st INFN FLAG Meeting "The Quantum and Gravity", University of Bologna, Italy, 25-20 Mai 2014.
- Black Holes in a Violent Universe, Potstam, Germany, 20-22 Mai, 2014.
- Anual meeting JEM-EUSO, Palermo, Italia, 9-13 Iunie 2014.
- 12.11.2012 – 22.11.2012 On the possibility of stable charged black hole remnants at the LHC" short term scientific mission (COST european project), Bologna U, Italy;
- 06.05.2012 – 12.05.2012 "A search for micro black hole signatures" short term scientific mission (COST european project), U. of Sussex, Brighton, UK.
- 17.01.2012 – 21.01.2012 "Predicted power in ultra high energy cosmic rays from active galaxies" scientific discussions at the Max-Planck Institute for Radioastronomy, Bonn, Germany.

Conference talks:

- Quantum Black Holes: from the Hoop Conjecture to possible searches for their decay signatures, University at Buffalo, Buffalo, NY, USA.
- Horizon wave-function, the quantum hoop conjecture and black holes as BEC of gravitons,

University of Pittsburgh, Pittsburgh, PA, USA.

- Horizon wave-function, the quantum hoop conjecture and black holes as BEC of gravitons, The City College of New York, New York, NY, USA.
- The Quantum Hoop Conjecture. Univerrsity of Aveiro, Aveiro, Portugal, June 2014.
- The Quantum Hoop Conjecture. 1st INFN FLAG Meeting "The Quantum and Gravity", University of Bologna, Italy, May 2014. - Invited Talk.
- Quantum black hole decay signatures in the UHECR data, Black Holes in a Violent Universe, Potstam, Germany.
- Non-thermal micro black hole decay searches in the UHECR and neutrino data. U of Alabama, Tuscaloosa AL, USA. April 2013;
- Non-thermal micro black hole decay searches in the UHECR and neutrino data. Vanderbilt U., Nashville TN, USA. April 2013;
- Possible searches for the non-thermal micro black holes back-to-back decay signature. NASA, Huntsville AL, USA, April 2013;
- Possible searches for the non-thermal micro black holes back-to-back decay signature. "Seventh Gulf Coast Gravity Meeting", U of Missisippi, Oxford MS, USA, April 2013;
- Where to search for the micro black holes back-to-back decay signature."The biggest accelerators in Space and on Earth", CERN, March, 2013 – Invited talk;
- Micro black holes @ the LHC and in the Cosmic Ray Data. Technische Universitat Dortmund, Germany, June 2012;
- Micro black holes @ the LHC and in the Cosmic Ray Data."Black holes in a Violent Universe", Malta, April, 2012 – **Invited talk.**
- Black Holes and Galaxies."Black holes in a Violent Universe", Manchester, November, 2011.

The team was also visited by two scientists from abroad who collaborate with the members of the team and who gave lectures at the Institute of Space Science:

- 01.09.2013 – 08.09.2013, Dr. Roberto Casadio (The University of Bologna).
- 02.06.2013 – 10.06.2013, Prof. Dr. Benjamin Harms (The University of Alabama, Tuscaloosa).

Dissemination Activities

The members of the team participated to several scientific outreach activities throughout the duration of this project:

- Researchers Night 2014, September 2014
- Saptamana Scoala Atlfel la ISS, April 2014
- Researchers Night 2014, September 2013
- Saptamana Scoala Atlfel la ISS, April 2013
- Octavian Micu participare la Saptamana Scoala Altfel, Liceul Tasnad, Tasnad, Satu Mare
- Wandering through the Universe 2012
- Researchers Night 2012
- Job Shadow 2012

More informations can be found from the project webpage which contains links to the event webpages and to photos taken at the events.