The Low-Energy Frontier of Particle Physics

Monday, 10 February 2025 - Wednesday, 12 February 2025

INFN-LNF

Book of Abstracts

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Corresponding Author: budker@uni-mainz.de

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Opto-mechanical Resonators

Corresponding Author: francesco.marin@fi.infn.it

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The Archimedes Experiment: a way for exploring the Vacuum-Gravity Interaction

Corresponding Author: paola.puppo@roma1.infn.it

The Archimedes experiment has the goal to measure the vacuum fluctuations interaction with Gravity. A high sensitive balance is employed to measure the small weight variations of high Tc superconducting samples when they pass to their superconductive status.
We descrive the challenging experimental solutions adopted for having a very efficient heat exchange with the samples only through the radiation mechanism and we present the first promising results to reach the goal of this experiment.

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Quantum effects in gravity from a delocalised quantum source

Corresponding Author: fgiacomini@phys.ethz.ch

Understanding the fundamental nature of gravity at the interface with quantum theory is a major open question in theoretical physics. Recently, the study of gravitating quantum systems, for instance a massive quantum system prepared in a quantum superposition of positions and sourcing a gravitational field, has attracted a lot of attention: quantum optics experiments are working towards realising such a scenario in the laboratory, and measuring the gravitational field associated to a quantum source is expected to give some information about the nature of gravity. On the theory side, quantum information tools are used to interpret the results. However, there are still open questions concerning the precise conclusions that these experiments could draw on the quantum nature of gravity, such as whether experiments in this regime will be able to test more than the Newtonian part of the gravitational field.
In my talk, I will present a new result, where a delocalised quantum source gives rise to effects that cannot be reproduced using the Newton potential nor as a limit of classical General Relativity. These effects can in principle be measured by performing an interference experiment, and are independent of graviton emission.
Identifying stronger quantum aspects of gravity than those reproducible with the Newton potential is crucial to prove the nonclassicality of the gravitational field and to plan a new generation of experiments testing quantum aspects of gravity in a broader sense than what proposed so far.

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Atomic fountain

Corresponding Author: poli@lens.unifi.it

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VIP Experiment

Corresponding Author: napolitano.fabrizio@lnf.infn.it

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Probing the electron's EDM using cold and slow molecules

Precision measurements on molecular quantum systems have developed into a powerful way to explore new physics. Such measurements are currently the most sensitive way to probe an effective asymmetry in the charge distribution of the electron - its electric dipole moment. Through a measurement of this property, limits can be set on possible extensions of the Standard model of particle physics. In this talk we will present the context, methods and latest developments in this field where the precision techniques of atomic and molecular physics are used to probe the frontiers of particle

physics. A particular focus is put on our work to produce slow beams and trapped samples of suitable molecules.

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Theory Talk 1

Corresponding Author: joerg.jaeckel@cern.ch

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Fundamental physics with levitated micromagnets

Corresponding Author: anvinante@fbk.eu

Macroscopic and mesoscopic ferromagnets levitated by Meissner effect in vacuum behave as multimode mechanical systems with ultrahigh quality factor and high sensitivity to external magnetic fields. Furthermore, they can be easily coupled to superconducting quantum devices. This suggests the possibility of using this experimental platform for a variety of measurements in the context of fundamental and quantum physics. In this talk I will review our recent experimental work on levitated micromagnets with SQUID-based detection. Among various results, we have recently demonstrated magnetic field resolution beyond the energy resolution limit, atomic-like gyroscopic effects, and ultrafast spinning at MHz frequencies. I will discuss potential applications to fundamental physics, including the search for ultralight dark matter, fifth force measurements, and more speculative investigations on the macroscopic limits of quantum mechanics.

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New Detection of Dark Matter

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ANDROMeDa

Corresponding Author: francesco.pandolfi@roma1.infn.it

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DELight: The Direct Search Experiment for Light Dark Matter

Corresponding Author: eleanor.fascione@kip.uni-heidelberg.de

There is vast parameter space to explore for dark matter masses below a few GeV, and the field of direct dark matter detection is constantly expanding to new frontiers. In particular, low mass dark matter candidates necessitate novel detector designs with lower thresholds and alternative target materials compared to e.g. the xenon-based experiments currently providing the strongest overall constraints on many dark matter models. The Direct search Experiment for Light dark matter (DELight) will deploy a target of superfluid 4He instrumented with large area microcalorimeters (LAMCALs) based on magnetic microcalorimeter (MMC) technology in a setup optimized for low mass dark matter searches. In this talk the motivation, setup, and current status of this novel upcoming experiment will be presented.

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New Frontiers

Corresponding Author: angelo.esposito@roma1.infn.it

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Fifth Force and Variation of Fundamental Constants / **21**

Overview of 229mTh based nuclear clock

Corresponding Author: mikhail.osipenko@ge.infn.it

Nuclear transitions have energy scale a few orders of magnitude larger than atomic ones. This mismatch of energy scales prevented to use laser sources for excitation of nuclear levels. In the 70th it was deduced that 229Th isotope might have an isomeric state at the energy of a few eVs. Recently,

with development of the optical frequency combs, this state stimulated a broad interest, in particular regarding a possible nuclear clock application, allowing to enhance the atomic clock precision and test correlations between fundamental forces. In the last decade many experiments on the 229mTh isomer were performed, including TORIO-229 experiment of INFN, confirming the past expectations. In this presentation an overview of the current knowledge on the lowest nuclear isomer 229mTh will be presented as well as its possible future applications.

Fifth Force and Variation of Fundamental Constants / **22**

Frequency metrology of buffer-gas-cooled molecular spectra for fundamental Physics research

Corresponding Author: pasquale.maddaloni@cnr.it

Based on the production of molecular samples at cryogenic temperatures by the buffer-gas-cooling technique and their combination with cavity-enhanced spectroscopy in the Lamb-dip regime, we present a new generation of high-accuracy physics tests beyond the Standard Model at the eV energy scale. Examples include searching for putative fifth-force interactions and assessing the space-time stability of the proton-to-electron mass ratio.

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Long range forces: A theory review

Corresponding Author: philip.soerensen@pd.infn.it

Various types of BSM physics, in particular new light particles, can lead to long-range forces. We can search for such “fifth force” interactions by sensitivity measuring gravity on various scales. In this talk, I will review how such long-range forces can be generated and how they lead to apparent violations of the inverse-square law and the equivalence principle of gravity. I will also discuss the of different types of long-range forces and give an overview of which kinds of BSM physics that long-range forces can be used to test.

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Discussion on 5th force and variation of fundamental constants