Wavelength-shifting materials & liquid argon instrumentation of the neutrinoless double beta (0νββ)-decay search experiment LEGEND

Gabriela Araujo

University of Zürich, Switzerland

The LEGEND-200 experiment was designed to search for the 0νββ-decay of ^{76}Ge (0νββ: ^{76}Ge $\rightarrow ^{76}$Se+2e^{-}) in high-purity germanium detectors operated in liquid argon. One of the aims of searching for this lepton-number violating decay is to explain the matter-antimatter asymmetry that might be induced in case neutrinos are their own antiparticles. To possibly detect this *(hypothetical*) *rare* event, instrumented liquid argon (LAr) is used to veto backgrounds: 128-nm vacuum ultraviolet (VUV) scintillation is produced in LAr in response to radioactive decays from materials surrounding the germanium crystals inside the liquid. To facilitate the collection and detection of the short VUV scintillation, materials such as TPB and PEN shift the light to longer (visible) wavelengths. These wavelength-shifters are currently employed in LEGEND-200 in reflectors and as active support material to hold the detectors. In this poster, I will show the LEGEND experiment with its full LAr instrumentation as well as the R&D on wavelength-shifting materials and reflectors for its planned successor, LEGEND-1000.

Non-product spectral geometries as source for modified gravity models

Arkadiusz Bochniak

Jagiellonian University in Krakow, Poland

The possibility of deriving Einstein-Hilbert action from spectral data associated to manifolds can be further extended into models that go beyond the General Relativity. We discuss how this approach can be used to get models possessing features of bimetric gravity theories, analyse properties of these models and stability of their solutions, compare them to classical bimetric theories, and reinterpret in terms of interacting branes. Based on joint work with A. Sitarz.

Non-thermal dark flux from cosmic string emission

Xiaoyong Chu

HEPHY, Vienna, Austria

Primordial non-thermal particles can play important roles in shaping our observable Universe at present. Although the early Universe is supposed to be dominated by the thermal radiation, a non-negligible abundance highly-relativistic particles may originate from non-gravitational emission of cosmic strings. We discuss the energy spectrum of such a non-thermal dark flux, the relevant astrophysical observables, and its potential role in the production of dark matter abundance and baryon asymmetry.

Standing gravitational waves decay to matter via parametric resonance

Paola Delgado

Jagiellonian University in Krakow, Poland

When a superposition of two travelling waves of same amplitude and opposite directions takes place, a standing wave is formed. This phenomenon is present in the very early universe, when primordial perturbations are squeezed outside the Hubble horizon, and might happen in other configurations, such as topological defects. In this work we show that a long-lasting standing gravitational wave decays to matter via parametric resonance, even within the framework of general relativity minimally coupled to the standard model.

Exploring the limits of quantum theory inside nucleons

Michal Eckstein

Jagiellonian University in Krakow, Poland

Quantum mechanics is a paradigm, on which the Standard Model of particles is founded. Is it however a universally valid description of fundamental interactions, or does it break down in some physical regime? If so, then how could we observe the possible deviations from quantum theory? In the talk I will present a new conceptual framework, based on quantum information, which allows to formulate these questions rigorously and design suitable experimental tests. I will also discuss a possible implementation using elastic polarized electron-proton scattering. The talk is based on my recent paper with Pawel Horodecki (arXiv:2103.12000).

Fast Timing Detectors based on Nanomaterials

Isabel Frank

CERN, Switzerland

Fast Timing Detectors based on Nanomaterials

Isabel Frank [1,2], Fiammetta Pagano [1,3], Roberto Cala' [1,3], Nicolaus Kratochwil [1], Michael Doser [1], Etiennette Auffray [1]

[1] CERN, Esplanade des Particules 1, 1211 Meyrin, Switzerland
[2] Ludwig Maximilian University of Munich, Geschwister-Scholl-Platz 1, 80539 Munich, Germany
[3] UniMIB, Piazza dell'Ateneo Nuovo, 1-20126 Milano, Italy

February 2022

Abstract

Particle physics experiments running at future accelerator facilties will rely on fast timing detectors to cope with high event pileup and to enhance particle identification capabilities. Standard bulk scintillating materials are limited by stringent requirements, due to their low light output and slow scintillation response. On the other hand, direct band gap engineered semiconductor nanostructures show a high potential for the emission of prompt photons due to quantum confinement, thus triggering interest in the high energy physics community. In this contribution we provide an overview on light based detector designs utilizing quantum confinement. Characterization results of a few promising materials based on semiconductor quantum dots/quantum wells such as CdSe, InGaN or perovskite nanocrystals (2D perovskite, CsPbBr) are presented. Strategies on the design and manufactore of these novel detector designs and the implementation in a macroscopic detector structure were discussed.

A Cold-Atom Approach to Chiral Symmetry Restoration and Charge Confinement

Daniel Gonzalez-Cuadra

IQOQI and University on Innsbruck, Austria

Understanding the nature of confinement, as well as its relation with the spontaneous breaking of chiral symmetry, remains one of the long-standing questions in high-energy physics. The difficulty of this task stems from the limitations of current analytical and numerical techniques to address non-perturbative phenomena in non-Abelian gauge theories. In this talk, I will show how similar phenomena emerge in simpler models, and how these can be further investigated using state-of-the-art cold-atom quantum simulators [1]. More specifically, I will introduce the rotor Jackiw-Rebbi model, a (1+1)-dimensional quantum field theory where interactions between Dirac fermions are mediated by quantum rotors. Starting from a mixture of ultracold atoms in an optical lattice, I will show how this quantum field theory emerges in the long-wavelength limit. For a wide and experimentally relevant parameter regime, the Dirac fermions acquire a dynamical mass via the spontaneous breakdown of chiral symmetry. I will consider the effect of both quantum and thermal fluctuations and show how they lead to the phenomenon of chiral symmetry restoration. Moreover, I will uncover a confinement-deconfinement quantum phase transition, where meson-like fermions fractionalize into quark-like quasiparticles bound to topological solitons of the rotor field. The proliferation of these solitons at finite chemical potentials again serves to restore the chiral symmetry, yielding a clear analogy with the quark-gluon plasma in quantum chromodynamics, where the restored symmetry coexists with the deconfined fractional charges. These results indicate how the interplay between these phenomena could be analyzed in more detail in realistic atomic experiments.

[1] D. González-Cuadra et al., PRX Quantum 1, 020321 (2020)

Towards Quantum Simulations of the Standard Model

Dorota Grabowska

CERN, Switzerland

There are many fundamental questions in particle and nuclear physics that cannot be addressed via classical computing techniques. These include the equation of state for finite density nuclear matter, real-time dynamics of quantum field theories from first-principles and non-perturbative aspects of chiral gauge theories. In recent years quantum computing hardware has seen dramatic advancements. These improvements have brought with them the possibility to apply quantum computing to these and other open problems in high energy physics. In this talk, after a brief introduction to quantum computing, I will discuss two examples of my recent work in this field: the simulation of lower-dimensional lattice gauge theories and the augmentation of Monte Carlo event generation via quantum machine learning methods.

BRAND – Exploration of correlation coefficients in neutron decay

Ghnashyam Gupta, on behalf of the BRAND collaboration

Jagiellonian University in Kraków, Poland

The BRAND experiment aims to measure simultaneously 11 correlation coefficients (a, A, B, D, H, L, N, R, S, U, V) that are sensitive to exotic scalar and tensor interactions in a model capturing physics beyond the Standard Model (BSM). Particularly interesting are seven of the above correlation coefficients (H, L, N, R, S, U, V). They directly depend on the transverse polarization of the electron from neutron beta decay. In addition, the correlation coefficients H, L, S, U, and V have never been attempted to measure before. A prototype detector system has been tested in a demonstration setup using a cold neutron beam PF1b at the Institute Laue-Langevin, Grenoble, France. In that experiment, electron and proton momenta were registered simultaneously, making it possible to reconstruct the decay kinematics. The recoil protons were accelerated using a DC electric field and converted in a thin film of LiF into bunches of secondary electrons. The secondary electrons were detected using a thin plastic scintillator. The direct and scattered electrons were tracked using a multiwire drift chamber. Further calibration and testing of detector systems are in process. The result of the test run will be presented with details of the apparatus used and the applied procedure.

Status and latest results of CRESST experiment

Shubham Gupta

HEPHY, Vienna, Austria

CRESST (Cryogenic Rare Event Search with Superconducting Thermometers) is an experiment located at the underground facility at the LNGS (Laboratori Nazionali del Gran Sasso) that aims at detecting direct dark matter signatures via scattering of dark matter particles off nuclei. The experiment uses scintillating cryogenic calorimeters as target materials to measure the recoil energy of the DM-nucleus scattering. The scintillation light signature helps discriminating the potential candidate events from the known background (electron/gamma or alpha events). In the latest results from the experiment using a 24 g $CaWO_4$ crystal operated at around 15 mK, an unprecedented threshold value of 30 eV for nuclear recoils was reached allowing for exploration of dark matter masses down to 160 MeV/c 2 . The sensitivity is currently limited by an excess of events of unknown origin, observed from threshold up to a few hundreds of eV. Thus, dedicated measurements using many different target materials with different modifications are currently being performed with the aim of understanding and identifying the origin and time-dependence of this excess. In this contribution, the current stage of CRESST-III, with the latest dark matter results, and implications will be presented.

New Physics in missing transverse energy tails with *b*-tagged jets

Arman Korajac

Jozef Stefan Institute, Ljubljana, Slovenia

Dilepton tail distributions have proven to be a very good ground for limiting different New Physics (NP) scenarios and also the Standard Model Effective Field Theory (SMEFT) Wilson Coefficients. Assuming NP in left-handed particles (motivated usually by the fact that B-anomalies can be explained via such interactions), the operators $c^{(1)}_{ijkl}(\bar{Q}_{iL}\gamma^\mu Q_{jL})(\bar{L}_k\gamma_\mu L_l)$ and $c^{(3)}_{ijkl}(\bar{Q}_{iL}\gamma^\mu\sigma_a Q_{jL})(\bar{L}_k\gamma_\mu\sigma^a L_l)$, i.e. their linear combination $[c^{(1)}+c^{(3)}]_{3333}$ can be very well constrained by dilepton collider searches [1, 2]. These operators, however, also induce a neutral-current interaction with neutrinos, with the interaction strength being proportional to $[c^{(1)}-c^{(3)}]_{3333}$.
We therefore take a look into the analysis of E_T^{miss} tails with accompanying b-jets, experimentally done in ATLAS searches [3, 4], and derive current bounds on $[c^{(1)}-c^{(3)}]_{3333}$. Furthermore, we investigate in detail different cuts and their efficiencies and finally see how these limits, together with the ones derived in the aforementioned papers, can give us an insight about the preferred region in the parameter space of these Wilson Coefficients. Finally, we also take into account constraints from low-energy experiments, like $K\to\bar{\nu}\nu(\gamma)$ and $B\to K\bar{\nu}\nu$ transitions.

References

[1] D. A. Faroughy, A. Greljo, J. F. Kamenik, *Phys. Lett. B*, 764:126–134, 2017.

[2] A. Greljo, D. Marzocca, *Eur. Phys. J. C*, 77(8):548, 2017.

[3] Morad Aaboud et al. (ATLAS Collab.), *Eur. Phys. J. C*, 78(1):18, 2018.

[4] Georges Aad et al. (ATLAS Collab.), *Eur. Phys. J. C*, 75(2):92, 2015.

On the nearly scale invariant spectrum as the result of a finite-temperature cosmological phase transition

Fotis Koutroulis

University of Warsaw, Poland

Electroweak and Finite-Lifetime Corrections for Boosted Top Quark Production

Daniel Lechner
University of Vienna, Austria

High-precision jet mass measurements for processes involving boosted top quark pair production relevant for the determination of the top quark mass eventually require the systematic inclusion of electroweak and finite-lifetime effects. For boosted top quark initiated inclusive jets we apply an electroweak Soft-Collinear-Effective-Theory (SCET) framework that allows for a coherent resummation of electroweak Sudakov logarithms and finite-lifetime effects together with large logs from QCD. Apart from double top resonant effects, the factorization approach can also account for single-resonant effects which are related to the interference of final states originating from top quark decays and background processes leading to the top decay final state. Concretely we address electroweak effects in inclusive (hemisphere mass) top-dijet production at lepton colliders.

COSINUS: direct dark matter detection using NaI as a cryogenic scintillating calorimeter

Rituparna Maji, on behalf of the COSINUS Collaboration
HEPHY and TU-Wien, Vienna, Austria

Today we observe overwhelming evidence for the existence of dark matter (DM) from its gravitational effect on baryonic matter. Among many earth-bound experimental attempts to investigate the nature of DM, the DAMA/LIBRA experiment has been claiming to observe the annual modulation of DM in the Milkyway for more than 2 decades with a high statistical significance of 13.7 sigmas. With different target materials, numerous other experiments have reported null results and could not confirm the DAMA/LIBRA signal. To resolve this tension, a model-independent cross-check is necessary using the same target material as DAMA/LIBRA: sodium iodide (NaI). COSINUS (Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches) is a NaI-based experiment that will be located at the Gran Sasso underground laboratory (LNGS), Italy. The unique feature of COSINUS compared to other NaI-based experiments is the operation of NaI as scintillating calorimeters at mK temperatures which is non-trivial, but highly rewarding. Along with a better energy resolution and a lower nuclear recoil energy threshold, a cryogenic scintillating calorimeter provides the unique feature of identification of nuclear recoils, which is a signature of a possible dark matter particle interaction. Therefore, COSINUS would provide a conclusive statement with a reliable model-independent comparison with DAMA/LIBRA with an additional feature of signal to background discrimination. After successful years of detector prototype development, currently, COSINUS is in its construction phase at LNGS, Italy. In this contribution, we will present the COSINUS experiment: the current status of the experiment and its future goal.

Analytic thin wall false vacuum decay rate

Marco Matteini

Josef Stefan Institute, Ljubljana, Slovenia

Local ground states in physical systems, described by a field theory, may not be stable. A deeper minimum may exist, or appear with varying temperature, and quantum or thermal tunneling can trigger a first-order phase transition, which takes the system from the metastable false vacuum (FV) to a deeper stable minimum, called the true vacuum (TV). This transition is initiated by the sudden appearance of bubbles of TV upon the homogenous configuration of FV, and the probability of such events is given by the FV decay rate. In this work, we present a closed-form false vacuum decay rate at one loop in the thin wall limit, where the true and false vacua are nearly degenerate. We obtained the bounce configuration in D dimensions, together with the Euclidean action at next-to-leading-order, counter-terms and renormalization group running. We extracted the functional determinant via the Gel'fand-Yaglom theorem for low and generic orbital multipoles. The negative and zero eigenvalues appear for low multipoles and the translational zeroes were removed. We computed the fluctuations for generic multipoles, multiplied and regulated the orbital modes. We found an explicit finite renormalized decay rate in D = 2, 3, 4 and a closed-form expression for the finite functional determinant in any dimension.

CRESST – Direct Dark Matter Search Experiment

Valentyna Mokina, for the CRESST Collaboration

HEPHY, Vienna, Austria

CRESST is a direct dark matter search experiment, located at the LNGS in Italy. Scintillating crystals are used as target materials for elastic DM-nucleus scattering and operated as cryogenic detectors at ~15mK temperatures.
In the first run of CRESST-III an unprecedented low energy threshold for nuclear recoils allowed to probe dark matter particle masses as low as $160\mathrm{MeV/c}^2$. Due to the limit discrimination power at low recoil energies, the sensitivity for such low masses starts to be limited by the residual electromagnetic background. Further sensitivity improvements rely on identifying and reducing background. To understand its components a detailed Geant4 model of the contaminations is under development. In parallel we study the radiopurity of materials used in the experiment.
In this contribution an overview of experiment, current status of the background model simulations will be presented together with the status of a material screening campaign.

Low-energy effective description of dark Sp(4) theories

Marco Nikolic

HEPHY, Vienna, Austria

Dark matter (DM) makes up a large amount of matter in our Universe ($\sim$ 26%), but we don't know its nature. Whereas weakly interacting massive particles (WIMPs) - a promising DM candidate - were intensively studied in the past, the theory of strongly interacting massive particles (SIMPs) has been comparably less investigated. A possible way to generate such SIMPs is through chiral symmetry breaking, similar to the production of pions in QCD. We consider a dark gauge group Sp(4) and Nf = 2 fermions in the pseudo-real fundamental representation. In absence of the mass term in the Lagrangian, a global flavor symmetry is present. Whenever a continuous global symmetry is broken, the Goldstone theorem guarantees the existence of low-energy massless Goldstone bosons. The dynamics of these bosons is described by the chiral Lagrangian (low energy effective theory). However, in presence of a mass term, the flavour symmetry is explicitly broken and the Goldstone bosons - SIMPs - gain non-zero masses. We determine the chiral Lagrangian with the inclusion of the Wess-Zumino-Witten term for degenerate and non-degenerate flavors. We analyse the breaking patters and mutiplet structure including a coupling to the Standard Model with a dark U(1) sector. This opens the door to phenomenology. In addition, we introduce vector and axial-vector states of the theory. The complete model is supported by lattice simulations.

Recent Developments in 3d Flat Space Holography

Max Riegler

University of Vienna, Austria

A comprehensive understanding of a consistent theory of quantum gravity remains a daunting task, even today. One way to tackle this problem is via the holographic principle that gives a precise duality between a theory of quantum gravity in d+1 dimensions and a dual quantum field theory in d dimensions. While there has been impressive progress towards a fundamental understanding of quantum gravity in the presence of a negative cosmological constant via the Anti-de Sitter/Conformal field theory (AdS/CFT) correspondence over the last two decades, extensions to other, more realistic setups have only gained momentum recently. In this talk I will present recent developments towards a better understanding of quantum gravity without a cosmological constant in 3 spacetime dimensions via the holographic principle

Heavy quarkonium-like states in lattice QCD

Mitja Sadl

University of Ljubjana, Ljubljana, Slovenia

I will present an investigation of the spectrum of exotic quarkonium-like mesons using lattice QCD. We focus on $\bar{c}c\bar{q}q$ and $\bar{b}b\bar{q}q$ $J^P = 1^+$ states with isospin 0, 1/2, and 1. Many mesons with properties incompatible with a $\bar{c}c$ or $\bar{b}b$ structure have already been discovered. To analyze the charmonium-like states, we extract the exited hadron spectrum, use Lüscher's formalism, and determine the $D\bar{D}^*$ phase shift to identify new states. We make a study of bottomonium-like states with static $\bar{b}b$ quarks and determine the static potential, which can also be used in the Schrödinger equation.

SUSY solution to the muon (g-2) anomaly with and without stable neutralino

Kazuki Sakurai

University of Warsaw, Poland

Supersymmetry is an attractive new physics candidate that may explain the observed anomaly in the muon g-2. MSSM can give large enough contribution to the muon g-2 only if there is (a) a large higgsino-gaugino mixing or (b) a large L-R mixing in the Bino-like LSP scenario. Both cases are strongly constrained by the dark matter (DM) constraint. For example the former case is severely constrained by the direct DM detection experiments, while the latter case suffers from overproduction of Bino-like neutralinos. We will first show how those constrains restrict the parameter space favoured by the muon g-2 in the ordinary MSSM (with the stable LSP neutralino). In the second part of the talk we study two scenarios where the neutralino is not stable: (1) RPV and (2) GMSB with the gravitino LSP. We study the collider constraints on these scenarios and show how they open up (or close down) the muon g-2 parameter regions compared to the ordinary MSSM scenario.

Searches for Long Lived Particles at the LHC with the CMS experiment - an overview

Mangesh Sonawane

HEPHY, Vienna, Austria

After over 10 years of data taking, and the many successes of the LHC, candidates for physics beyond the standard model (BSM) are still elusive. However, there is still a class of models yet to be probed. In these models, one can produce BSM particles which can decay into visible sector particles; however this decay is suppressed through various means, giving rise to visible particles that are macroscopically displaced from the proton collision vertex. Such late-decaying particles are called Long Lived Particles (LLPs), and are the new frontier of BSM searches at the LHC. Here, I present an overview of the current status of LLP searches at the LHC with the CMS experiment, discussing the strategies, latest results, as well as plans for the future.

Silicon sensors for the High Granularity Calorimeter for the CMS experiment

Moritz Weihe

HEPHY, Vienna, Austria

The CMS Collaboration is preparing to build replacement endcap calorimeters for the HL-LHC era. The new high-granularity calorimeter (HGCAL) is a sampling calorimeter with approximately six million silicon sensor channels with a size of ~1.1cm^2 or 0.5cm^2 per cell, resulting in 600m^2 of silicon active area. In addition, about four hundred thousand scintillator tiles readout with on-tile silicon photomultipliers will be used. The calorimeter is designed to operate in the harsh radiation environment at the HL-LHC, where the average number of interactions per bunch crossing is expected to exceed 140. Besides measuring energy and position of the energy deposits the electronics is also designed to measure the time of their arrival with a precision on the order of 50 ps. In this contribution, the reasoning behind the HGCAL, the current status of the project and recent results from silicon sensor and module development will be presented.