Physics Beyond the Standard Model in Leptonic & Hadronic Processes and Relevant Computing Tools

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Contents

About

Physics Beyond the Standard Model in Leptonic and Hadronic Processes and Relevant Computing Tools

This workshop provides a platform for presentations and open discussions on current and future directions on Electro-Weak, Strong and Beyond the Standard Model (SM) Processes. In particular, the recent advances on Beta and Double Beta Decay Modes, related processes in Neutrino-Nucleus (Neutral/Charged Current) reactions along with Dark Matter/Dark Energy physics will be discussed. Also, presentations on Measuring Fundamental Physical Constants as well as on Precision Physics in Purely Leptonic Atoms combined with accurate predictions coming from Advanced Solutions of the Governing Differential Equations are included.

Extended aims of this Workshop include, complementary scientific areas where the same detection techniques are applied, namely: in Rare Electroweak Decays, in Neutrino Properties (DUNE, T2K, etc. experiments), in Coherent Elastic Neutrino-Nucleus Scattering, CEvNS (COHERENT, ESS, Coherent CAPTAIN Mills, Dresden-II, CONUS, NUCELUS, CONNIE, RICOCHET, vGEN, NEWS-G etc. experiments) and in Dark Matter Detection (XENONnT, LUX-LEPLIN, PandaX experiments). Furthermore, the current status of Observations and Phenomenology in Dark Energy are also included.

Organizing committee

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List of Abstracts – Talks

Recent progress with the nuclear matrix elements for double beta decay

M. HOROI, Central Michigan University, United States

In my talk I will review recent progress in calculations of the nuclear matrix elements for twoneutrino double beta decay, two-neutrino double electron capture double beta decay, and neutrinoless double beta decay. Emphasis will be on the extension of the strength function approach for the two-neutrino decay matrix elements, and on the statistical approach to estimate the neutrinoless nuclear matrix elements and their uncertainty.

Primary author: HOROI, Mihai (Central Michigan University)
Presenter: HOROI, Mihai (Central Michigan University)

Neutrinoless Double-Beta Decay & Realistic Shell Model

N. ITACO, Università della Campania "Luigi Vanvitelli" & Istituto Nazionale di Fisica Nucleare, Italy

I'll report on the calculation of the nuclear matrix element for the neutrinoless double-β decay process using the realistic shell model.

In this approach, we start from a realistic nucleon-nucleon potential and then derive the effective shell-model Hamiltonian and $0\nu\beta\beta$ decay operator within the many-body perturbation theory. I'll focus my attention on a few candidates for the $0\nu\beta\beta$ decay detection, in a mass interval ranging from A = 76 up to A = 136.

To validate the reliability of the approach, the calculated spectroscopic properties and spin- and spin-isospin-dependent decay properties of the nuclei under investigation will be compared with the available experimental data.

Primary author: ITACO, Nunzio (Università della Campania "Luigi Vanvitelli" & Istituto Nazionale di Fisica Nucleare)
Presenter: ITACO, Nunzio (Università della Campania "Luigi Vanvitelli" & Istituto Nazionale di Fisica Nucleare)

Current topics in weak interaction processes

S. STOICA, CIFRA, Romania

We briefly review the investigation of some current topics in weak interaction processes. First, we present some methods used to get the electrons'wave functions emitted in these processes. Next, we use these wave functions to compute relevant kinematic quantities such as Fermi functions, phase space factors, electron spectra and angular correlation between the emitted electrons. Further, we present applications of these calculations to the experimental data analysis related to the search of the Lorentz invariance violation in two-neutrino double-beta decay and description of the decay rates and decay rate ratios for allowed and unique forbidden electron capture (EC) processes.

Primary author: STOICA, Sabin (CIFRA)
Presenter: STOICA, Sabin (CIFRA)

Quest for New physics of Charged Lepton Flavor Violation; The COMET experiment at J-PARC

Y. KUNO, Osaka University, Japan

Charged Lepton Flavor Violation (CLFV) is as one of prime arena for probing new physics beyond the Standard Model (BSM), given its rate being highly suppressed in the SM, yet substantial predictions on the rate in new physics models. Notably, muon to electron conversion in a muonic atom serves as a promising process in this exploration. The upcoming COMET experiment in Japan, characterized by innovative muon sources, is to push the ultimate sensitivity limit by four orders of magnitude or more. This report will present the physics motivation behind the experiment and provides an outlook, while also highlighting concurrent CLFV experiments worldwide.

Primary author: KUNO, Yoshitaka
Presenter: KUNO, Yoshitaka

The Mu2e experiment

S. DI FALCO, Universita & INFN Pisa, Italy

The Mu2e experiment, currently under construction at Fermilab, will search for neutrinoless mu-¿e conversion in the field of an aluminum atom. A clear signature of this charged lepton flavor violating two-body process is given by the monoenergetic conversion electron of 104.97 MeV produced in the final state.

An 8 GeV/c pulsed proton beam interacting on a tungsten target will produce the pions decaying in muons; a set of superconducting magnets will drive the negative muon beam to a segmented aluminum target where the stopped muons will eventually convert to electrons; a set of detectors will be used to both identify conversion electrons and reject beam and cosmic backgrounds.

The experiment will need 3-5 years of data-taking to achieve a factor of 10^4 improvement on the current best limit on the conversion rate.

After an introduction to the physics of Mu2e, we will report on the status of the different components of the experimental apparatus. The updated estimate of the experiment's sensitivity and discovery potential will be presented.

Primary author: DI FALCO, Stefano (Universita & INFN Pisa (IT))
Presenter: DI FALCO, Stefano (Universita & INFN Pisa (IT))

Comments: on behalf of Mu2e collaboration

Searching for dark matter axions via atomic excitations

J. VERGADOS, University of Ioannina, Greece

Axions can be considered as good dark matter candidates. The detection of such light particles can be achieved by observing axion spin induced atomic excitations. The target is in a magnetic field so that the m-degeneracy is removed the energy levels can be suitably adjusted. Using an axion-electron coupling indicated by the limit obtained by the Borexino experiment, which is quite stringent, reasonable axion absorption rates have been obtained for various atomic targets. The obtained results depend, of course, on the atom considered, through the parameters ε (the spin orbit splitting) as well as the δ (the energy splitting due to the magnetic moment interaction). This assumption allows axion masses the tens of μeV within members of the same multiplet, i.e. —J1 M1=-J-1¿–¿—J1 M1=-J1 +1¿ and axion masses in the range 1meV-1eV involving transitions of the spin orbit splitting type —J1 M1=-J1¿–¿—J2 M2=-J-1 +q¿, q=-1,0,1 i.e. in all four types of transitions allowed by the angular momentum selection rules. The axion mass that can be detected is very close to the excitation energy involved, which can vary by adjusting the magnetic field. Furthermore, since the axion is absorbed by the atom, the calculated cross section exhibits resonance behavior, which can be exploited by experiments in minimizing any background events.

Primary author: Prof. VERGADOS, John (University of Ioannina)
Presenter: Prof. VERGADOS, John (University of Ioannina)

A Critical Examination of the Standard Model of Particle Physics

E. COMAY, OPRA Association, Israel

In this talk I focus on the coherence of the present theories of electromagnetic, strong, and weak interactions that comprise the three sectors of the Standard Model of particle physics. The analysis performed, provides us with high confidence that well-established physical laws yield useful acceptability criteria for a given quantum field theory. In particular, radiation and bound fields of electrodynamics come out as different physical entities. Inconsistencies of the 4-potential and its gauge transformations are validated.

In addition, I am going to discuss several examples of experimental data which seem to disprove QCD, i.e. the strong interactions sector of the Standard Model. Moreover, the electroweak theory, which is the weak interaction sector of the Standard Model, seem to be inconsistent with self-evident physical principles. In conclusion, many elements of the Standard Model of particle physics require a fundamental revision.

Primary author: Dr COMAY, Eliahu
Presenter: Dr COMAY, Eliahu

Neural Networks for solving fundamental Differential Equations of Physical Significance with focus on the Dirac Equation

A. GKREPIS, University of Western Macedonia, Greece

In this work we discuss a Neural Networks scheme falling in the category of the Physics Informed Neural Networks (PINN), that has recently aroused the intense interest among the researchers. After discussing the state of the art of the topic we focus on some important applications that are connected to the fundamental Differential Equations of Physical Significance (such as the the Dirac and the Breit equations).

As a concrete application, we utilize the aforementioned computational tool to obtain accurate wave functions and energies of prominent leptonic atomic systems such as the Muonium, the Positronium etc. by solving numerically these differential equations. The developed algorithms, in Python, read as input the parameters of the quantum system in question and may provide predictions for a set structure and evolution properties.

Primary author: GKREPIS, Athanasios (University of Western Macedonia)
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Presenter: GKREPIS, Athanasios (University of Western Macedonia)

Comments: This work is financially supported by: "The Association for Advancement of Research on Open Problems in Nuclear Physics & Particle Physics (OPRA Association)", Tel Aviv, Israel.

Object Oriented Structuring of Physics Informed Neural Network Solvers

A. GIOTIS, University of Ioannina, Greece

In this work, we present an end-to-end system leveraging neural networks for objective function optimization in solving the Schrödinger and Dirac Differential Equations. We propose an object-oriented Python programming framework, enabling dynamic adaptation of user input for solving such equations via tunable hyper-parameters. This framework facilitates testing of various network architectures and minimization parameters through structured and extendable classes and methods that share essential attributes required for both equations.

This algorithm is initially applied to the 2-lepton system Muonium (Mu), characterized by a bound energy spectrum, but it can also be utilized for the description of other similar quantum systems. Through a series of ablation experiments, we have examined the effect of various correction terms (Breit, Darwin, etc.) of the Schrödinger Hamiltonian on the optimization in obtaining the corresponding wave functions and energies. Specifically, in solving the Dirac equation we explore several choices of network architecture (e.g., number of neurons, activation functions) for the low-lying energy levels. Our preliminary results indicate that only a few correction terms affect significantly the accuracy of the numerical solution compared to the analytical one.

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Comments: This work is financially supported by: "The Association for Advancement of Research on Open Problems in Nuclear Physics & Particle Physics (OPRA Association)", Tel Aviv, Israel.

Induced Isotensor Interactions in Heavy Ion Double Charge Exchange Reactions

H. LENSKE, Justus-Liebig-Universität Giessen, Germany

In collisional heavy ion double charge exchange (DCE) reactions A(Z,N) → B(Z±2,N∓2) the isospin structure of hadrons and the isospin response of the nuclear medium are probed by the exchange of charged mesons[1-3]. This may happen either as a second order Double Single Charge Exchange (DSCE) reaction [4,5] or as a first order Majorana DCE (MDCE) reaction. DSCE reactions proceed by acting twice with the NN isovector T-matrix, while in MDCE reactions the charge conversion process evolves by a pair of virtual ($\pi^{\pm}$, $\pi^{\mp}$) reactions, each of them given by a pair of pion-nucleon single charge (SCE) reactions [2]. In both cases, the reaction process relies on effective rank-2 isotensor interactions, dynamically generated at the time of interaction [6,7]. The transformation of the DCE interactions from the reaction-theoretical t-channel formalism to the s-channel scheme of nuclear structure physics is performed, resulting in intranuclear two-body interactions. The DSCE and MDCE transition form factors are considerably simplified in closure approximation which different to double beta decay (DBD) is well justified in nuclear DCE reactions by reasons of the involved scales. The important role of initial state (ISI) and final state (FSI) ion–ion interactions in heavy ion DCE reactions are elucidated. In momentum representation [6,7] the DCE reaction amplitudes factorize into products of reaction kernels, containing the full amount of ISI and FSI, and nuclear transition form factors, accounting for the spectroscopic content of the reaction. The deep imaginary parts of heavy ion optical potentials, acting as sinks for the probability flux, strongly suppress DCE reaction in the ion-ion overlap region which in shape and extension is defined by the total reaction cross section. The nuclear matrix elements are derived as sums over products of two–body matrix elements describing directly the n^2p^{-2} and p^2n^{-2} DCE transitions complementary in projectile and target nucleus. The two-nucleon character of MDCE reactions is established explicitly by the exchange of neutral mesons between the pion-nucleon SCE vertices. ISI/FSI effects are illustrated by comparing results of DSCE and MDCE distorted wave calculations to data and to approximate, but surprisingly realistic Black Sphere result. The later are especially useful for understanding the role of absorption of probability flux for cross sections and angular distributions. Similarities and differences of DSCE reactions to two–neutrino and MDCE reactions to neutrinoless Double Beta Decay (DBD), respectively, and perspectives for investigations of NME in DCE reactions are discussed.

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7. Lenske, H.; Bellone, J.; Colonna, M.; Gambacurta, D., Lay, J.-A.,Heavy Ion Double Charge Exchange Reactions by Induced Pion-Nucleon Isotensor Interactions, Universe (2024), in print.

Primary author: Prof. LENSKE, Horst (Justus-Liebig-Universitaet Giessen)
Presenter: Prof. LENSKE, Horst (Justus-Liebig-Universitaet Giessen)

The Muon g-2 Experiment at Fermilab: Principles, Status, and Simulations

E. VALETOV, Michigan State University, United States

The Muon g-2 Experiment (E989) at Fermilab, whose physics runs have concluded in July 2023 after six years of data collection, aims to provide the measured muon anomaly (α_μ) with unprecedented precision. This project was motivated by the substantial deviation between the Brookhaven aμ measurement and the Standard Model prediction. In the experiment, positive muons were circulated in a storage ring, and the muon anomalous precession frequency (spin precession relative to momentum) was determined with high precision from decay positron time and energy measurements gathered by calorimeters. Accurately measuring the average magnetic field encountered by the muons was critical, achieved through a finely shimmed and continuously monitored storage ring magnetic field using nuclear magnetic resonance (NMR) probes. The results from runs 2 and 3 were announced on August 10, 2023, yielding a new world average of $\alpha_\mu = 0.00116592059$ (22). This outcome represents a two-fold improvement in precision from the 2021 results and a 5.1σ deviation from the 2020 Standard Model theory prediction. We will discuss the principles and current progress of the Muon g-2 Experiment. Our presentation will include an overview of the simulation tools and methods employed in the experiment, including the high-statistics simulations of the Muon Campus and the storage ring. We will highlight the phase-acceptance studies, which required simulations of 10 billion events. We will outline the precise modelling of the Muon g-2 storage ring using *COSY INFINITY*, with a focus on the accurate computation of the storage ring's tunes, chromaticity, and amplitude-dependent tune shifts, which are key for the study of resonances that impact the beam stability.

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Presenter: Dr VALETOV, Eremey (Michigan State University)

Comments: This work was supported by the U.S. Department of Energy under Contract No. DE-FG02- 08ER41546 and Contract No. DE-SC0018636.

Precision Spectroscopy of Muonium

I. CORTINOVIS, ETH Zürich, Switzerland

Muonium, the purely leptonic bound state of an anti-muon and an electron, is an excellent candidate to probe bound state QED and search for new physics beyond the Standard Model. I will introduce MuMASS, aiming to improve the Muonium 1S-2S transition and Lamb Shift by orders of magnitude. I will present our latest experimental progress and results, with a special focus on the New Physics reach of the measurements, as well as up to date theoretical calculations for the transition frequencies.

Primary authors: CORTINOVIS, Irene (ETH Zurich (CH)); CRIVELLI, Paolo (ETH Zurich (CH))
Presenter: CORTINOVIS, Irene (ETH Zurich (CH))

Comments: on behalf of the MuMASS collaboration

Deformed shell model applications to weak interaction processes

R. SAHU, National Institute of Science and Technology, Berhampur, India

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The deformed shell model (DSM) was successful in describing many spectroscopic properties of medium mass nuclei like energy spectra, electromagnetic transition probabilities, band crossings, shape coexistence etc. [1]. In the last 15 years, this model has been employed successfully for the nuclear structure parts in the description of many weak interaction processes such as double beta decay, dark matter detection rates and neutrino-nucleus scattering cross sections. In this contribution, besides giving an overview of the past work, we will present results for: (i) 2ν double beta decay half-life of 100 Mo obtained using DSM with a realistic effective interaction; (ii) event detection rates for the WIMP-nucleus scattering with 127 I example; (iii) neutral-current neutrino scattering on Mo isotopes with 96 Mo example.

[1] V.K.B. Kota and R. Sahu, Structure of Medium Mass Nuclei: Deformed Shell Model and SpinIsospin Interacting Boson Model (CRC Press, Taylor and Francis group, Florida, 2017).

Primary author: SAHU, Rankanidhi (National Institute of Sciene and Technology)
Presenter: SAHU, Rankanidhi (National Institute of Sciene and Technology)

Probing new physics with DUNE, CEvNS and dark matter direct detection experiments

D. PAPOULIAS, National and Kapodistrian University of Athens, Greece

Intense neutrino beams with keV-GeV energies produce sizeable event rates through the elastic neutrino-electron scattering (EvES) and coherent elastic neutrino-nucleus scattering (CEvNS) chanels. In this talk, I will focus on solar as well as accelerator neutrinos from the Spallation Neutron Source at Oak Ridge and the Long Baseline Neutrino Facility (LBNF) at Fermilab. I will present recent constraints on beyond the Standard Model scenarios such as neutrino generalized interactions (NGIs) and new opportunities for the production of a novel final state dark fermion (DF) via neutrino upscattering on electrons and nuclei.

Primary author: Dr PAPOULIAS, Dimitrios (National and Kapodistrian University of Athens)
Presenter: Dr PAPOULIAS, Dimitrios (National and Kapodistrian University of Athens)

Charged-current neutrino scattering off I-127 and Cs-133 and the effect of quenching and two-body currents.

M. HELLGREN, University of Jyväskylä, Finland

The stable iodine and caesium isotopes are the primary constituents of several detectors including the CsI[Na] neutrino detector operational from 2015 to 2019 at the SNS. Theoretically computed cross sections for these nuclei are therefore of considerable interest. The goal of the research outlined in this abstract was to obtain accurate theoretical scattering cross sections for stopped pion neutrino scattering off these nuclei using both the impulse approximation and with the two-body current included. The results were compared to recently measured experimental cross section of the cc-scattering off iodine. The contributions to the quenching of the weak axial-vector coupling constant from the two-body currents and other sources were investigated. The nuclear model employed was the microscopic quasiparticle-phonon model (MQPM). It was found that the impulse approximation produced good agreement with experiment when the quenched value of the coupling constant used was obtained from a linear fit from a comprehensive study of the quenching in beta-decays.

Primary author: HELLGREN, Matti
Presenter: HELLGREN, Matti

Bound-spectra predictions in exotic muonic atoms through advanced numerical solutions of the Dirac Equations

T. KOSMAS, University of Ioannina, Greece

Recently, appreciably sensitive experiments operating in frontier muon facilities at J-PARC in Tokio, PSI in Switzerland, Fermilab in USA, RCNP in Osaka, etc., provide ultra-high precision measurements in muon physics for open problems in muon-nucleus processes and purely leptonic atomic systems [1,2]. A plethora of such processes are well analysed and described by theories falling within (SM) and beyond the Standard Model (BSM) of the electroweak interactions and they constitute promising tests of the quantum electrodynamics (QED) and several BSM physical theories. Up to the present, the muon hyperfine spectroscopy [1], the muonic-atoms [3] etc., played essential role in understanding atomic, nuclear and particle physics.

Our main aim in this work is to provide systematic predictions coming out of advanced numerical solutions of the fundamental differential equations (Dirac-Coulomb-Breit, DiracBreit-Darwin, etc.) entering the description of structure and reactions appearing in exotic purely leptonic atoms as the Muonium ($\mu^+ e^-$), the Muonium ion ($\mu^+ e^- e^-$) etc., in muon to e^- (or to e^+) conversion in nuclei [1], and others [2,3,4]. The structureless Muonium leptonic atom is promising for testing QED and BSM theories and for testing fundamental physical laws as the lepton number conservation in experiments searching for Muonium to antiMuonium transition [1,2].

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[1] Y. Kuno and G. Pignol, C.R. Physique 21, 121 (2020), and references therein.
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[4] I. Tsoulos, O.T. Kosmas, and V.N. Stavrou, Comput. Phys. Commun. 236, 237 (2019).

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Presenter: Prof. KOSMAS, Theocharis (University of Ioannina)

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Using simulated annealing techniques in solving partial differential equations governing structure and evolution of exotic atoms.

G. GARTZONIKAS, University of Ioannina, Greece

In this work, deterministic optimization techniques based on artificial neural networks are employed in order to solve partial differential equations governing the structure and evolution of exotic atomic systems. To this aim, a new method based on simulated annealing [1,2,3] with deterministic optimization is derived that optimizes appropriate parametric expressions representing the reduced radial Klein-Gordon wave functions U(r). The method is applied to concrete physical systems in order to calculate the relevant wave functions and corresponding energies of bound spinless particles orbiting around the complex nuclei of the exotic atoms.

The fundamental interaction is assumed to be the Coulomb electrostatic potential. Such systems are of current experimental interest in atomic, molecular, particle and nuclear physics. The efficiency of the method is proven for also other similar systems [4].

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[3] Tsoulos, I. G., Kosmas, O. T., & Stavrou, V. N. DiracSolver: A tool for solving the Dirac equation. Computer Physics Communications, 2019, 236, 237-243.
[4] Gkrepis, A., Kosmas, O. T., Vlachos D., & Kosmas, T. Numerical solution of the Schrödinger equation using Neural Networks in Python, IC-MSQUARE 2023

Primary author: GARTZONIKAS, George (University of Ioannina)
Co-authors: Dr KOSMAS, Odysseas; KOSMAS, Prof. Theocharis (University of Ioannina)
Presenter: GARTZONIKAS, George (University of Ioannina)

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Galactic Stellar Black Hole Binaries: spin effects on jet emissions of high energy neutrinos and gamma rays

D. RARRAS, University of Ioannina, Greece

In this work we discuss the effect of the Black hole spin on the jet emissions of high energy neutrinos and gamma rays emanating from Galactic Stellar Black Hole X-ray Binaries (BHXRBs). In this case, the black hole accretes mass out of its companion star, forming an accretion disk. At the same time, two collimated jets are launched perpendicularly to the disk's plane. The assumed Stellar black hole masses range up to $30M_{\odot}$. We are interested in black holes, ones that are located inside our Galaxy, so that they can be observed by operating or designed terrestrial detectors.

Inside the jets of the black hole, multiple reactions occur leading to the emission of particles and radiation, including neutrinos and high-energy gamma-rays. Our interest on the latter is piqued by the observational data giving rise to expectations of such emission reaching the Earth. After discussing the mechanisms involved in the production of gamma rays and neutrinos we calculate gamma rays and neutrino intensities that may be observed at the Earth.

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Co-authors: Prof. KOSMAS, Theocharis (University of Ioannina); PAPAVASILEIOU, Theodora (University of Western Macedonia)
Presenter: Mr RARRAS, Dimitrios (University of Ioannina)

Quantum Hydrodynamics in External Magnetic Fields: From Nonrelativistic to Relativistic Regimes

M. STEPHENSON, University of Alabama at Huntsville, Canada

We explore nonrelativistic quantum electrodynamics in a background magnetic field, maintaining gauge invariance through a vector potential. The Lagrangian incorporates electron self-interactions and electromagnetic field interactions. The path integral formalism elucidates the effective action, focusing on the photon propagator and screening effects. Analyzing density and current components reveals Laurent expansions in the hydrodynamic limit. Equations of motion in real space are derived, including a discussion on Poiseuille-like flow and the Navier-Stokes equation. Nonrelativistic and relativistic hydrodynamics are discussed, with linearized equations presented. The study concludes with insights into the nonrelativistic limit, providing a comprehensive framework for quantum electrodynamics analysis.

Primary author: STEPHENSON, Matthew
Presenter: STEPHENSON, Matthew

Muon g−2 and lepton flavor violation in SUSY models

M. GOMEZ, Universidad de Huelva, Spain

We present a class of SUSY−GUT models that can explain the discrepancy between SM predictions and experimental values of the muon $g-2$ while providing testable signals for lepton flavor violation in charged lepton decays. Moreover, these models predicts neutralinos that are also compatible with Planck bounds on the Dark Matter relic abundance. We found that these scenarios provide interesting benchmark for the search of SUSY by correlating possible manifestation of it as DM, rare lepton decays and LHC signals.

Primary author: Prof. GOMEZ, Mario (Universidad de Huelva)
Presenter: Prof. GOMEZ, Mario (Universidad de Huelva)

Nuclear muon capture, a perfect probe of neutrinoless double beta decay

J. SUHONEN, University of Jyväskylä, Finland

The ordinary muon capture (OMC) is a process where a nucleus captures a negative muon from the lowest atomic orbital, the 1s orbital. Modern muon facilities in Japan and Switzerland produce these muons and shoot them at target atoms, some of which capture the muon and thus enable the OMC. The OMC resembles the electron capture (EC), except the mass of the captured muon is some 200 times the mass of an electron, thus introducing momentum exchanges in the range of 100 MeV, in the ballpark of the momentum exchanges involved in the neutrinoless double beta decay (NDBD). In NDBD-minus decaying nuclei the OMC on the NDBD daughter populates the states of the intermediate nucleus of the NDBD, like in the case of 136-Xe NDBD the capture on 136-Ba populates the states of 136-Cs. Since in both processes, NDBD and OMC, the momentum exchange is similar, both processes populate intermediate/final states of high excitation energies and high angular momentum. This is how the OMC probes effectively the wave functions of all the intermediate states relevant for the NDBD. Furthermore, the rates of both processes depend on the value of the weak axial coupling, g_A, and the induced pseudoscalar coupling, g_P, the effective values of which are not well known in the nuclei that double beta decay. In particular the NDBD rate is highly sensitive to the value of g_A. This dependence of the OMC on weak couplings adds to its importance as a probe of the NDBD. In my talk I review what is known about the effective values of g_A in medium-heavy and heavy nuclei and highlight the recent advances in calculating the rates of the OMC, relevant for the NDBD candidates.

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Shell model calculations for the neutrinoless double-beta decay of 82Se

A. NEACSU, International Center for Advanced Training and Research in Physics (CIFRA), Magurele, Romania

We perform a statistical analysis of several observables in the 82Se and 82Kr nuclei that we calculate using shell model methods. Following this analysis, we make predictions for the probable range for the value of the neutrinoless double-beta decay nuclear matrix element, which enters the equation for the decay rate. The statistical study performed is useful for testing the stability of the shell model calculations in the jj44 model space (consisting of the 1p3/2, 1p1/2, 0f5/2, 0g9/2 orbitals) by inducing random variations in the two-body matrix elements of the effective Hamiltonian.

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Contribution of many-particle coherent neutrino scattering to core-collapsing supernova explosion

T. SHIMA, Research Center for Nuclear Physics, Osaka University, Japan

It has been a long standing problem that the available kinetic energy is not sufficient to make a successful explosion in the simulations of core-collapsing supernova explosion. The importance of many effects such as the neutrino heating, stellar rotation, vortex and turbulence, magnetic field, have been extensively studied, but now we are still on the way to perfect understanding. In this talk, a new possible contribution of the coherent neutrino scattering off many particles in the shock wave region will be discussed.

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The NUMEN project: a new way to provide data-driven information on neutrino-less double-beta decay

A. SPATAFORA, Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud (INFN-LNS), Italy

The search for neutrino-less double beta ($0\nu\beta\beta$) decay has attracted much interest in the last years due to the extraordinary consequences that could derive from its observation. In the view to provide experimental information on the nuclear matrix elements involved in the expression of $0\nu\beta\beta$-decay half-life, the NUMEN project is measuring cross-sections of double charge exchange (DCE) and other quasi-elastic nuclear reactions. The experiments are performed in Catania, at the Laboratori Nazionali del Sud of the Istituto Nazionale di Fisica Nucleare, using the MAGNEX large acceptance magnetic spectrometer. A fully consistent and coherent study of several reaction channels, including the DCE one, both from the experimental and the theoretical side is the new method exploited by the project. The application of this multichannel approach to a case study will be presented during the conference. New data from the first experimental measurements of the absolute DCE cross-sections will be also presented for some of the $0\nu\beta\beta$ candidates.

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Calculations for neutrino mass determination using atomic electron capture

V. SEVESTREAN, CIFRA; IFIN-HH; FF-UB, Romania

We present the normalized distributions of released energy in the EC decay, a tool to obtain the neutrino mass. Our calculations include the exchange and overlap corrections, the shake-up and shakeoff atomic effects, the electron screening effects and the intrinsic line widths of Breit–Wigner resonances.

In computing the electrons' wave functions, we used the Dirac-Hartree-Fock-Slater self-consistent method, which was validated in a previous study for such calculations. We consider two allowed transitions of ^{95}Tc to ^{95}Mo for our calculations using the first direct measurement of the gs-to-gs EC Q value of ^{95}Tc with the JYFLTRAP penning trap mass spectrometry.

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Presenter: SEVESTREAN, Vasile

Update on Supersymmetric Dark Matter Models

V. SPANOS, National and Kapodistrian University of Athens, Greece

In this talk we will revisit models that predict dark matter in the context of supersymmetric theories. In particular, we will discuss models that yield neutralino, gravitino and/or primordial black holes dark matter.

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Tensions in Cosmology: Are we Approaching New Physics?

E. SARIDAKIS, National Observatory of Athens, Greece

We summarize the famous tensions between various observational datasets and theoretical predictions of the Standard Model of Cosmology, such as the H0 and S8 tensions, that could be a sign that we are approaching New Physics. Then we provide possible solutions, arising from modifications/extensions of the standard lore.

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Observational Challenges for the Standard Cosmological Model and Theoretical Models

L. PERIVOLAROPOULOS, University of Ioannina, Greece

I will briefly review the main challenges for the standard cosmological model that have been persisting and amplifying during the past few years and in particular the Hubble tension, the growth of perturbations tension and the cosmic dipoles that challenge the cosmological principle. Then I will focus on the Hubble tension which is effectively a calibrator tension and review the classes of models that attempt to address it. Special attention will be paid to models that involve an abrupt transition event either in the gravitational constant or in the dark energy density.

Primary author: PERIVOLAROPOULOS, Leandros (University of Ioannina)
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Spherical Collapse and Sudden Singularities: Insights from the ΛsCDM Model

E. A. PARASKEVAS, University of Ioannina, Greece

The ΛsCDM model, which posits a rapid transition from anti-de Sitter (AdS) to de Sitter (dS) vacua around redshift $z_\dagger \approx 2$, aims to resolve cosmological tensions, including those related to H_0 and S_8. This study examines the impact of a type II singularity at $z = z_\dagger$ on the evolution of cosmic structures, specifically the generalization of the spherical collapse model to incorporate the sudden singularity. We analyze the matter overdensity, indicating deviations of the ΛsCDM model from the Planck-ΛCDM expectations. The observable effects of sudden singularities on virialized overdensities will be discussed.

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Using computational tools to reconstruct cosmology

K. DIALEKTOPOULOS, Transilvania University of Brasov, Romania

One of the biggest open questions in contemporary cosmology is whether ΛCDM, and by extension General Relativity, is the correct description of our Universe. On top of the existing problems, like the nature of dark matter and dark energy, the coincidence problems, the existence of singularities etc, there came another one, that is the tensions in cosmology. Local measurements of the current rate of acceleration predict a larger value than the one inferred from CMB measurements. At the same, time there is a disagreement in the value of the amplitude of matter fluctuations. Thus, the reconstruction of cosmological parameters in a nonparametric and model-independent way would help us shed more light on the topic. Up to now, nonparametric reconstructions of cosmological parameters from observational data sets are usually associated with Gaussian processes (GP). It is known though, that GPs are plagued with overfitting issues and they introduce some statistical bias through the selection of the kernel. The last few years, with the advent of Machine Learning, Artificial Neural Networks (ANN) are being used in cosmology for the reconstruction of parameters in a model independent way, both from the physical and from the statistical point of view. That is what I will focus on in this talk.

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Unsupervised learning of constrained Hamiltonian dynamics with Hamilton-Dirac Neural Networks

D. KALTSAS, University of Ioannina, Greece

The effectiveness of the Physics Informed Neural Networks (PINNs) for the unsupervised learning of constrained Hamiltonian dynamics is demonstrated using the Dirac theory of constraints for regular systems with holonomic constraints and systems with non-standard Lagrangians. By utilizing Dirac brackets we derive the Hamilton-Dirac equations and we minimize their residual incorporating also energy conservation and the Dirac constraints using appropriate regularization terms in the loss function. The resulting PINNs, referred to as Hamilton-Dirac Neural Networks (HDNNs), successfully learn the constrained dynamics in a completely unsupervised manner, without deviating from the constraint manifold.

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Heterogeneous Island Evolutionary Optimisation for High Intensity Muon Beams at PSI

E. VALETOV, Paul Scherrer Institut, Switzerland

The High Intensity Muon Beams (HIMB; part of IMPACT) project at the Paul Scherrer Institute (PSI) will provide muon unprecedentedly high intensities of the order of 10^{10} muons/s for particle physics and material science experiments, two orders of magnitude higher than state of the art also provided by PSI. We have performed design optimisation and studies for HIMB beamlines MUH*2* and MUH*3* using a custom build of *G4beamline* with measured π^+ cross-sections and with variance reduction. We used asynchronous Bayesian optimisation with *DeepHyper* for many of the optimisations. We are now developing an island-based evolutionary optimisation (EO) software program, where we implemented MPI islands with OpenMP parallellisation within each island. Furthermore, we implemented a distributed island model with asynchronous communication via a Redis database. The optimisation program interfaces with the codes *COSY INFINITY*, *G4beamline*, and *DeepHyper*. Our heterogeneous island algorithm will provide hybrid optimisation utilising both EO and local search methods, and it will provide part-wise optimisation of the beamlines with dynamic progression through overlapping stages. The island method enables a two-way communication between adjacent stages, addressing the consideration that an overall optimal solution may not have an optimal fitness within a beamline segment.

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Measuring the Impact of the Black Hole's Spin on the Emission from X-ray Binary Systems

T. PAPAVASILEIOU, University of Western Macedonia, Greece

Black hole X-ray binary systems consist of a black hole devouring mass out of its companion star, forming an accretion disk. Perpendicularly to the disk, two relativistic plasma ejections (jets) are launched towards opposite directions. The X-ray binary system emits a wide range of frequencies from radio to high-energy gamma-rays. The main contributors are thermal emission from the disk and non-thermal jet components (i.e., synchrotron emission, inverse Comptonization of less energetic photons, etc.). Pseudo-Newtonian potentials are often incorporated as an alternative solution to general relativity and successfully replicate the inner disk boundary conditions. However, most theoretical studies ignore the black hole's rotation and, thus, the Kerr metric properties that significantly impact the accretion disk modeling and the corresponding energy output. In this work, we implement a very efficient pseudo-Newtonian potential around Kerr black holes derived by Mukhopadhyay, and we propose a generalized disk temperature profile that involves the spin's contribution on the emission spectrum of the accretion disk. In addition, we measure the spin's impact on the relativistic jet emission due to photon absorption and the inverse Comptonization of the disk's thermal photons on the jet's accelerated particles.

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Neutron star-dark matter admixture stability in the mass gap region

M. VIKIARIS, Aristotle University of Thessaloniki, Greece

Till today, the nature of dark matter (DM) remains elusive despite all our efforts.This missing matter of the universe has not been observed by the already operating DM direct-detection experiments, but we can infer its gravitational effects. Galaxies and clusters of galaxies are most likely to contain DM trapped to their gravitational field. This leads us to the natural assumption that compact objects might contain DM too. Among the compact objects exist in galaxies, neutron stars considered as natural laboratories, where theories can be tested, and observational data can be received. Thus, many models of DM they have proposed it's presence in those stars. By employing the two fluid model, we discovered a stable area in the M-R diagram of a celestial formation con- sisting of neutron and DM that is substantial in size and vast in dimensions. This implies that a supramassive stellar compact entity can exist without encountering any issues of stability and without undergoing a collapse into a black hole. Furthermore, we found that such stable stellar structures might in fact exist in the mass gap region, where compact objects in the mass of 3-4 solar masses can hold an ordinary 1.4 solar mass neutron star in the center. In any case, the present theoretical prediction can, if combined with corresponding observations, shed light on the existence of DM and even more on its basic properties.

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Hadron-quark phase transition and unstable inertial modes of twin stars

P. LASKOS-PATKOS, Aristotle University of Thessaloniki, Greece

One of the most intriguing unresolved questions of theoretical nuclear physics concerns the structure of the Quantum Chromodynamics (QCD) phase diagram. Lattice QCD calculations have shown that at zero baryon chemical potential and sufficiently high temperatures a transition from hadronic to deconfined quark matter occurs in the form of a crossover. A similar phase transition is conjectured in the region of low or moderate temperatures and high densities. Interestingly, this regime of the QCD phase diagram is occupied by neutron stars. Considering that rigorous theoretical predictions are unattainable (at the moment) due to the so-called lattice QCD sign problem; compact stars could serve as unique astrophysical laboratories for probing the nuclear equation of state and the structure of the QCD phase diagram. In particular, a signature implication of strong hadron-quark phase transition in nuclear matter is the existence of the so-called twin star solutions (i.e., compact stars with an identical mass but different radii). Motivated by several studies that examine the differences in the bulk properties of twin configurations, we investigate the differences that appear in their r-mode instability windows. More precisely, we systematically study the influence of the relevant parameters (energy density jump, crust elasticity) on the differences that manifest in the r-mode instability windows and spin-down evolution of twin pairs. We conclude that two stars with equal mass and fairly similar spin frequency and temperature may behave differently with respect to r-modes. As a consequence, the future possible detection of gravitational waves (associated with the r-mode instability) from a star that lies in the stable region of the frequency-temperature plane would be a strong indication of hadron-quark phase transition.

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