DISCRETE 2020-2021

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UiB

DISCRETE 2020-2021

Book of Abstracts

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Underground tests of Quantum Mechanics: Collapse models and Pauli Exclusion Principle

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We are experimentally investigating possible departures from the standard quantum mechanics'predictions at the Gran Sasso underground laboratory in Italy.
In particular, with radiation detectors we are searching signals predicted by the collapse models (spontaneous emission of radiation) which were proposed to solve the "measurement problem"in quantum physics and signals coming from a possible violation of the Pauli Exclusion Principle.
I shall discuss our recent results published in Nature Physics under the title "Underground test of gravity-related wave function collapse", where we ruled out the natural parameter-free version of the gravity-related collapse model. I shall then present more generic results on testing CSL (Continuous Spontaneous Localization) collapse models and discuss future perspectives.
Finally, I shall briefly present the VIP experiment with which we look for possible violations of the Pauli Exclusion Principle by searching for "impossible"atomic transitions and comment the impact of this research in relation to Quantum Gravity models.

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Dark CP violation

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I will discuss CP-violation in non-minimal Higgs frameworks and the exotic possibilities arising therein, such as CP-violating Dark Matter and CP-violating inflation. I will point out their implications for cosmology and collider searches.

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$\mathcal{T}_{13}$ Flavor Symmetry for Quarks and Leptons

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We show that T_{13}, the order 39 discrete subgroup of $SU(3)$, is the smallest discrete symmetry that naturally explains the $SU(5)$ "asymmetric texture" for quarks and leptons. We construct an $SU(5)\times\mathcal{T}_{13}$ model that yields the GUT scale mass ratios and mixing angles of Standard Model fermions. We then extend this model to the seesaw sector and achieve sharp predictions for neutrino masses, CP violation in the lepton sector and neutrinoless double-β decay. We then study both high-scale and low-scale leptogenesis in the model and show that experimentally observable GeV-scale right-handed neutrinos are predicted in this model.

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Searches for baryon number violation via neutron conversions at the European Spallation Source

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The observation of neutrons converting to antineutrons and/or sterile neutrons would demonstrate Baryon Number Violation (BNV) for the first time. BNV is an essential condition needed to produce the matter/anti-matter asymmetry in the universe and appears in a number of theories beyond the Standard Model. The existence of sterile neutrons would address the issue of a possible dark sector of particles. The HIBEAM/NNBAR project is a proposed series of experiments for the European Spallation Source (ESS), in Lund, Sweden, that can open up a discovery window for BNV by observing free neutrons transforming to antineutrons and/or sterile neutrons. A series of competitive searches are planned with an ultimate improvement in sensitivity of three orders of magnitude compared with the previous free neutron to anti-neutron search at Institut Laue-Langevin. This talk describes the HIBEAM/NNBAR experiment. The motivation for the experiment and theories predicting neutron conversions are described, followed by a description of the ESS and those ESS facilities which can be exploited for the experiment. The set-ups and sensitivities of the neutron conversion searches are shown. Special focus is placed on the annihilation detector which would use a Time Projection Chamber and calorimeter system exploiting scintillators and lead-glass. Geant-based simulations of the annihilation signature within a detector are shown and compared with background predictions. Finally, it is also shown how the program of work benefits from important but lower sensitivity searches ongoing by the Oak Ridge National Laboratory and being performed by many of the same collaborators as those on HIBEAM/NNBAR. Although it is a dedicated particle physics experiment, HIBEAM/NNBAR is a multi-disciplinary milieu, bringing together experts in neutronics, magnetics, detector design, and data analysis.

Plenary / 6

Automorphic forms and fermion masses

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Symmetry principles have long been applied to the flavour puzzle. In a bottom-up approach, the variety of possible symmetry groups and symmetry breaking sectors is huge, the predictability is reduced and the number of allowed models diverges. A relatively well-motivated and more constrained framework is provided by supersymmetric theories where a discrete subgroup Γ of a non-compact Lie group G plays the role of flavour symmetry and the symmetry breaking sector spans a coset space G/K, K being a compact subgroup of G. For a general choice of G, K, Γ and a generic matter content, we show how to construct a minimal Kaehler potential and a general superpotential, for both rigid and local N = 1 supersymmetric theories. We also describe a concrete model of lepton masses, specializing the construction to the case G = Sp(2g,R), K = U(g) and Γ = Sp(2g, Z).

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Measurement of the very rare K+ to pi+ nu nubar decay

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The decay K+⟶π+ νν̄ , with a very precisely predicted branching ratio of less than 10-10, is among the best processes to reveal indirect effects of new physics.
The NA62 experiment at CERN SPS is designed to study the K+⟶π+ νν̄ decay and to measure its branching ratio using a decay-in-flight technique. NA62 took data in 2016, 2017 and 2018, reaching the sensitivity of the Standard Model for the K+⟶π+ νν̄ decay by the analysis of the 2016 and 2017 data, and providing the most precise measurement of the branching ratio to date by the analysis of the 2018 data. This measurement is also used to set limits on BR(K+⟶π+X), where X is a scalar or pseudo-scalar particle.
The final result of the K+⟶π+ νν̄ branching ratio measurement and its interpretation in terms of K+⟶π+ X decay from the analysis of the full 2016-2017-2018 data set is presented, and future plans and prospects reviewed.

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Search for lepton number and flavour violation in K+ and pi0 decays

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The NA62 experiment at CERN collected a large sample of charged kaon decays into final states with multiple charged particles in 2016-2018. This sample provides sensitivities to rare decays with branching ratios as low as 10-11.
Results from searches for lepton flavour/number violating decays of the charged kaon and the neutral pion to final states containing a lepton pair based on this data set are presented.

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Search for K+ decays to a lepton and invisible particles

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The NA62 experiment at CERN reports searches for K+ ⟶ e+N, K+⟶μ+N and K+⟶μ+νX decays, where N and X are massive invisible particles, using the 2016-2018 data set.
The N particle is assumed to be a heavy neutral lepton, and the results are expressed as upper limits of O(10−9) and O(10−8) of the neutrino mixing parameter |Ue4|2 and |Uμ4|2, improving on the earlier searches for heavy neutral lepton production and decays in the kinematically accessible mass range.
The X particle is considered a scalar or vector hidden sector mediator decaying to an invisible final state, and upper limits of the decay branching fraction for X masses in the range 10-370 MeV/c2 are reported for the first time, ranging from O(10−5) to O(10−7).
An improved upper limit of 1.0 10−6 is established at 90% CL on the K+⟶μ+ννν branching fraction.

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New measurement of radiative decays at the NA62 Experiment at CERN

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[1] *INFN Perugia (IT)*

The NA62 experiment at CERN reports new results from studies of radiative kaon decays K+ ⟶ pi0 e+ gamma (Ke3g), using a data sample recorded in 2017-2018. The sample comprises O(100k) Ke3g candidates with sub-percent background contaminations. Preliminary results with the most precise measurement of the Ke3g branching ratios and T-asymmetry measurement in the Ke3g decay, are presented.

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Orbifold brane-Higgs

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The problematic huge hierarchy between the usual 4-dimensional Planck mass scale of gravity and the ElectroWeak symmetry breaking scale can interestingly disappear at some point-like location along extra space-like dimensions where the effective gravity scale is reduced down to the TeV scale. Field theories with point-like particle locations (3-dimensional brane-worlds) or point-like interactions deserve special care. In particular it can be shown that, in contrast with usual literature, brane-scalar fields –like the Standard Model Higgs boson –interacting with fermions in the whole space (bulk) do not need to be regularized if rigorous 4- or 5-dimensional treatments are applied: standard regularization introduces a finite width wave function for scalar fields localized along extra dimensions. The variational calculus of least action principle must also be applied strictly to derivate the fermion (Kaluza-Klein) masses and couplings, in particular by distinguishing the natural and essential boundary conditions: the higher-dimensional model –based in particular on extra compact spaces of type interval or circle (orbifold with parity symmetry) –must be defined either completely through the action expression [necessity then for new specific brane terms bilinear in the fermion fields] or partially from additional so-called essential boundary conditions. Besides, the correct action integrand definition requires to introduce improper integrals in order to remain compatible with the fermion wave function discontinuities induced by point-like Higgs interactions. These presented new brane-Higgs treatments have phenomenological impacts and in particular the relaxing of previously obtained strong bounds on Kaluza-Klein masses, induced by flavour changing reactions generated through exchanges of the Higgs field.

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Testing CPT symmetry in ortho-positronium decays with J-PET detector

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In the talk we demonstrate test of combined charge, parity, and time-reversal transformation (CPT) in the annihilations of the lightest leptonic bound system, the positronium atom. With the Jagiellonian Positron Emission Tomograph (J-PET) we have collected an unprecedented range of kinematical configurations of exclusively-recorded annihilations of the positronium triplet state (ortho-positronium) into three photons. Employing a novel technique for estimation of positronuium spin

axis on the basis of a single event, we determined the complete distribution of an angular correlation between spin and annihilation plane of ortho-positronium. We present recently published result of determined expectation value of this correlation at the precision level of 10^{-4}, with an over three-fold improvement on the previous measurement. We discuss also the prospects for reaching the precision level of 10^{-5} with the CPT symmetry test at the J-PET detector.

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CP symmetry test at J-PET with angular coleration of photons from ortho-positronium annihilation

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A bound state of electron and positron (positronium) as the lightest matter-antimatter system and at the same time an eigenstate of the C and P operators is an unique probe to test the CP symmetry. The test is performed at the J-PET detector which enables determination of polarization of photons from positronium annihilation. This allows exploration of a new class of discrete symmetry odd operators that were not investigated before. The novelty of the experimental setup is based on usage of plastic scintillators as active detection material and trigger-less data acquisition system. In the talk we describe first result of CP symmetry test in the decays of ortho-positronium in a whole available phase-space and experimental techniques developed by the J-PET collaboration.

Plenary / **14**

On the equivalence between Starobinsky and Higgs inflation in gravity and supergravity

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The Starobinsky inflation and Higgs inflation in gravity, and their equivalence based on the common inflationary potential are extended to supergravity in the proper framework where the Starobinsky and Higgs descriptions of inflation arise in two different gauges of the same supergravity model.

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Belle II experiment: status and prospects

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The Belle II experiment at the SuperKEKB energy-asymmetric e+e− collider is a substantial upgrade of the B factory facility at the Japanese KEK laboratory. The target luminosity of the machine is

6×1035 cm−2s−1 and the Belle II experiment aims to record 50 ab−1 of data, a factor of 50 more than its predecessor. With this data set, Belle II will be able to measure the Cabibbo-Kobayashi-Maskawa (CKM) matrix, the matrix elements and their phases, with unprecedented precision and explore flavor physics with B and charmed mesons, and τ leptons. Belle II has also a unique capability to search for low mass dark matter and low mass mediators. We also expect exciting results in quarkonium physics with Belle II. In this presentation, we will review the status of the Belle II detector, the results of the planned measurements with the full available Belle II data set, and the prospects for physics at Belle II.

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Feynman diagrams: index, topology and current inflow for massless fermions

Authors: David B. Kaplan[None]; Srimoyee Sen[None]

When considering symmetry protected topological materials, the necessity for gapless fermionic edge states can in some cases be deduced from the "anomaly flow" of currents from the bulk onto the edge. There are examples of theories where this picture does not apply, for example when there are only discrete symmetries and no currents at all. In every case we are familiar with, however, the existence of edge states can be deduced from a nontrivial index. We offer here a convenient Feynman diagram approach to computing the index, not of the d-dimensional bulk Hamiltonian but of the (d+1)-dimensional Euclidean fermion operator. We give a number of examples, and in every case the edge states can be associated with the divergence of a current, even when the edge theory has no continuous symmetries or chiral anomalies.

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A decade of dark sector and light dark matter searches at BABAR

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Elucidating the nature of dark matter remains a central challenge in fundamental physics. A growing interest in light (sub-GeV) dark matter consisting of new particles coupling only feebly to ordinary matter has recently emerged. Low-energy, high luminosity colliders such as BABAR are ideally suited to probe these possibilities. In this talk, we will review searches for dark sectors and light dark matter performed during the last decade at BABAR. These measurements demonstrate the importance of B-factories in fully exploring dark matter and light BSM physics.

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Does antimatter fall like matter? : the GBAR experiment (CERN)

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One of the main questions of fundamental physics is the problem of the asymmetry matter/antimatter in the universe and the action of gravity on antimatter. Tests on antimatter gravity have currently a limited precision, with the sign of gravity acceleration not yet known experimentally. Ambitious projects are developed at CERN facilities to produce low energy antihydrogen with the aim of measuring the free fall of antihydrogen atoms. Among them, the GBAR experiment (*Gravitational Behaviour of Antihydrogen at Rest*) aims at measuring the gravity acceleration of antihydrogen atoms during a free fall in Earth's gravitational field. The simulation of the free-fall chamber includes the Monte-Carlo generation of trajectories and the statistical analysis. A precision of the measurement beyond the % level is confirmed by taking into account the experimental design. We also propose a new method using quantum reflection of antiatoms above a reflecting mirror followed by a classical free fall; the quantum interference pattern obtained at detection improves the accuracy of the experiment by approximately 3 orders of magnitude.

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Horizontal Symmetry and Large Neutrino Magnetic Moment in the Light of Recent Experiments

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The excess in electron recoil events reported recently by the XENON1T experiment may be interpreted as evidence for a sizable transition magnetic moment of Majorana neutrinos. We show the consistency of this scenario when a single component transition magnetic moment takes values ϵ (1.65 - 3.42) × 10^{-11} μ_B. Such a large value typically leads to unacceptably large neutrino masses. We show that new leptonic symmetries can solve this problem and demonstrate this with several examples. We first revive and then propose a simplified model based on SU(2)$_H$ horizontal symmetry and also generalize to a three-family SU(3)$_H$ -symmetry. Collider and low energy tests of these models are analyzed. We have also analyzed implications for the Zee model and its extensions which naturally generate a large neutrino magnetic moment with suppressed m_ν via a spin symmetry mechanism, but found that it is not large enough to explain recent data. We also propose a mechanism to evade stringent astrophysical limits on neutrino magnetic moments arising from stellar evolution by inducing a medium-dependent mass for the neutrino. Results will be discussed in this talk.

Plenary / **21**

Modular Invariance, Residual Modular Symmetries and Lepton (/Quark) Masses, Mixing and CP Violation

Author: Serguey Petcov[1]

Co-authors: Joao Penedo [2]; Pavel Novichkov [1]

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We will discuss the approach to the flavour problem
based on modular invariance.
In modular-invariant models of flavour,
hierarchical fermion mass matrices may arise

solely due to the proximity of the modulus τ
to a point of residual symmetry.
This mechanism does not require flavon fields, and modular
weights are not analogous to Froggatt-Nielsen charges.
We show that hierarchies depend on the decomposition
of field representations under the residual symmetry group.
We systematically go through the
possible fermion field representation choices which may yield
hierarchical structures in the vicinity of symmetric points,
for the four smallest finite modular groups, isomorphic
to S_3, A_4, S_4, and A_5, as well as for their double covers.
We find a restricted set of pairs of representations for which the
discussed mechanism may produce viable fermion (charged-lepton and quark)
mass hierarchies. After formulating the conditions for obtaining a viable lepton
mixing matrix in the symmetric limit, we construct a model in which both
the charged-lepton and neutrino sectors are free from fine-tuning.

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A complete description of P- and S-wave contributions to the $B^0 \to K^+\pi^-\ell^+\ell^-$ decay

Authors: Alexander Mclean Marshal[1]; Marcel Algueró[2]; Joaquim Matias[2]; Konstantinos A. Petridis[3]; Mark Smith[4]; Michael Andrew McCann[4]; Mitesh Patel[4]; Paula Alvarez Cartelle[5]; Pere Masjuan[2]

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In this study of the four-body decay $B^0 \to K^+\pi^-\ell^+\ell^-$, where tensions with the Standard Model predictions have been observed, we analyse the decay with P- and S-wave contributions to the $K^+\pi^-$ system, developing a complete understanding of the symmetries of the distribution. These symmetries determine relations between the observables in the $B^0 \to K^+\pi^-\ell^+\ell^-$ decay distribution. This enables us to define the complete set of observables accessible to experiments, including several that have not previously been identified. The new observables arise when the decay rate is written differentially with respect to $m_{K\pi}$. We demonstrate that experiments will be able to fit this full decay distribution with currently available data sets and investigate the sensitivity to new physics scenarios given the experimental precision that is expected in the future. The symmetry relations provide a unique handle to explore the behaviour of S-wave observables by expressing them in terms of P-wave observables, therefore minimising the dependence on poorly-known S-wave form factors. Using this approach, we construct two theoretically clean S-wave observables and explore their sensitivity to new physics. By further exploiting the symmetry relations, we obtain the first bounds on the S-wave observables using two different methods and highlight how these relations may be used as cross-checks of the experimental methodology and the parametrization of the $B^0 \to K^+\pi^-\ell^+\ell^-$ differential decay rate. We identify a zero-crossing point that would be at a common dilepton invariant mass for a subset of P- and S-wave observables, and explore the information on new physics and hadronic effects that this zero point can provide.

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Additional Baryons and Mesons

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In a particle theory model whose most readily discovered new particle is the ~1TeV bilepton resonance in same-sign leptons, currently being sought at CERN's LHC, there exist three quarks D, S, T which will be bound by QCD into baryons and mesons. We consider the decays of these additional baryons and mesons whose detailed experimental study will be beyond the reach of the 14 TeV CERN collider and accessible only at an O(100 TeV) collider.

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The limits of the strong CP problem

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While CP violation has never been observed in the strong interactions, the QCD Lagrangian admits a CP-odd topological interaction proportional to the so called theta angle, which weighs the contributions to the partition function from different topological sectors. The observational bounds are usually interpreted as demanding a severe tuning of theta against the phases of the quark masses, which constitutes the so-called strong CP problem. In this talk we challenge this view and show that a careful treatment of the limit of infinite spacetime volume leads to the theta angle dropping out of correlation functions, so that it becomes unobservable and the CP symmetry is preserved. We arrive at this result either by using instanton computations or by constraining the dependence of the partition function on the spacetime volume and the fermion masses by imposing cluster decomposition and compatibility with the index theorem.

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On the Klein Symmetry of Majorana Mass Matrices and the Electroweak Hierarchy Problem

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I will show how the global symmetries manifest in the Type-I seesaw model can be understood to prohibit (natural) perturbative scale generation in its Majorana mass matrix, and therefore severely limit the types of ultraviolet (UV) completions that may be conceived of for the Neutrino Option (NO) resolution to the Electroweak Hierarchy Problem (Brivio & Trott 2017). After a brief review of the basics of the NO, its phenomenology, and the global symmetries present in its Lagrangian, I will systematically demonstrate how they conspire to generate no-go limitations in the simplest instances. I will also show that perturbative scenarios with enhanced BSM field content also face significant symmetry-driven constraints, before concluding with speculative comments on non-perturbative alternative(s) that may lead to elegant resolutions to the NO's UV problem.

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Diagonal reflection symmetries and universal four-zero texture

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In this talk, we consider a set of new symmetries in the SM: {\it diagonal reflection} symmetries $R\, m_{u,\nu}^*\, R = m_{u,\nu}$, $m_{d,e}^* = m_{d,e}$ with $R = \text{diag}\,(-1,1,1)$.These generalized CP symmetries predict the Majorana phases to be $\alpha_{2,3}/2 \sim 0$ or $\pi/2$.

By combining the symmetries with the four-zero texture, the mass eigenvalues and mixing matrices of quarks and leptons are reproduced well. This scheme predicts the normal hierarchy, the Dirac phase $\delta_{CP} \simeq 203^\circ$, and $|m_1| \simeq 2.5$ or 6.2 [meV].

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Inflaton Dark Matter

Authors: Jong-Hyun Yoon[1]; Oleg Lebedev[1]

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We examine an intriguing possibility that a single field is responsible for both inflation and dark matter, focusing on the minimal set–up where inflation is driven by a scalar coupling to curvature. We study in detail the reheating process in this framework, which amounts mainly to particle production in a quartic potential, and distinguish thermal and non–thermal dark matter options. In the non–thermal case, the reheating is impeded by backreaction and rescattering, making this possibility unrealistic. On the other hand, thermalized dark matter is viable, yet the unitarity bound forces the inflaton mass into a narrow window close to half the Higgs mass.

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The search for lepton flavour violation with the MEG II experiment

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Lepton flavour conservation, being an accidental symmetry in the Standard Model (SM) of particle physics, is prone to be violated in most of the models of new physics. Although lepton flavour violation (LFV) has been already observed in the form of neutrino oscillations, the consequent effect in the charged lepton sector is unobservably small. Hence, charged LFV is both a very sensitive probe for physics beyond the SM and a phenomenon whose observation would provide an unambiguous evidence for such new physics. The goal of the MEG II experiment is the search for the LFV decay $\mu \to e\gamma$, with a sensitivity below 10^{-13}, a factor 10 better than the phase-1 MEG experiment. The construction and commissioning of MEG II have been recently completed and the first physics data are expected to be collected at the end of year 2021. In this talk I will present the current status of the experiment and its expected performances. A recent result for the search of the $\mu \to e\gamma\gamma$ decay in the dataset of MEG will be also reviewed, and the perspectives for similar exotic searches at MEG II will be briefly discussed.

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Next-to-minimal supersymmetric Standard Model

Author: Mohamed-Amine OUAHID[1]

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We propose a next-to-minimal supersymmetric Standard Model (NMSSM) extended by a D_4 discrete flavor symmetry to explain the current neutrino oscillation data. Neutrino masses are generated from the type I seesaw mechanism where the associated mixing matrix is trimaximal. We have shown that the CP is always violated in this sector. The phenomenology of neutrino parameters is investigated for normal hierarchy. In particular, we numerically evaluated the observables related to neutrino masses and mixing, namely, the sum of absolute neutrino masses Σm_{i}, the electron neutrino mass m_{ν_{e}}, and the effective Majorana mass |m_{ee}|.

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Dark matter in three-Higgs-doublet models with S_3 symmetry

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The Standard Model of particle physics has been extensively tested for a few decades and is the most successful description of nature. Nearly all theoretical Standard Model predictions have been experimentally verified and the last missing piece, the Higgs boson, was discovered in 2012. This is undoubtedly a fascinating discovery in the field of particle physics and might be the final missing piece. Nevertheless, there is no experimental verification that it is the only Higgs boson, and it will be tested at the LHC and future colliders. While the Standard Model keeps on triumphing, there is a vast amount of both theoretical and experimental phenomena that cannot be resolved within the Standard Model framework. Our main focus is dark matter. The multi-Higgs models could resolve some of the issues and are commonly invoked when models beyond the Standard Model are constructed. Thus, we propose and are motivated that such extension could potentially solve several problems.

Models with two or more scalar doublets with discrete or global symmetries can have vacua with vanishing vacuum expectation values in the bases where symmetries are imposed. If a suitable symmetry stabilises such vacua, these models may lead to interesting dark matter candidates, provided that the symmetry prevents couplings among the dark matter candidates and the fermions. We analyse three-Higgs-doublet models with an underlying S_3 symmetry. These models have many distinct vacua with one or two vanishing vacuum expectation values which can be stabilised by a remnant of the S_3 symmetry which survived spontaneous symmetry breaking. In our framework the stability of the dark matter sector results from a $\mathbb{Z}_2$ symmetry. We identify all possible dark matter models based on vacua in the context of S_3-symmetric three-Higgs-doublet models, allowing also for softly broken S_3.

We focus on a specific S_3-symmetric scalar model R-II-1a. In the case we explore, one of the doublets provides the dark matter sector, while the other two are active. The way the fermions couple to the scalar sector is constrained by the S_3 symmetry and is such that the flavour structure of the model is solely governed by the V_{CKM} matrix which, in our framework, is not constrained by the S_3 symmetry. In the model there is no CP violation in the scalar sector. The R-II-1a model is compatible with several constraints, both theoretical and experimental. After performing the numerical analysis we found a possible dark matter mass range [52.5, 84] GeV.

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CPT violation and neutrino oscillation experiments

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In this talk I discuss neutrino oscillations with different oscillation parameters for neutrinos and antineutrinos. According to the CPT theorem neutrinos and antineutrinos should behave same, except for effects of the CP-phase δ. I discuss the bounds that can be put on the differences between neutrino and antineutrino parameters from current neutrino and antineutrino data. I also discuss prospects for future experiments, and in particular some interesting scenarios that arise in the context of CPT violation, such as impostor solutions. I also discuss mimicking effects between CPT-violating neutrino oscillations and non standard neutrino interactions.

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Measurement of the CP violation in B_sˆ0 -> J/psi phi decays in pp collisions at sqrt(s) = 13 TeV with the ATLAS detector

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The Standard Model predicts the CP violating mixing phase, phi_s, to be very small and its SM value is very well constrained, while in many new physics models large phi_s values are expected. Measurements of the time–dependent decay rate of the B_sˆ0 —> J/psi phi decays provide a theoretically clean method for extracting phi_s.
This talk will focus on the latest results from ATLAS on the CP-violating mixing phase phi_s and on several other parameters describing the B_sˆ0 —> J/psi phi decays.

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Measurements of the Higgs boson properties and their interpretations with the ATLAS experiment

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With the full Run 2 pp collision dataset collected at 13 TeV, very detailed measurements of Higgs boson properties and its interactions can be performed using its decays into bosons and fermions, shining light over the electroweak symmetry breaking mechanism. This talk presents the latest measurements of the Higgs boson properties by the ATLAS experiment in various decay channels, including production mode cross sections, simplified template cross sections, differential and fiducial cross sections, as well as their combination and interpretations. Specific scenarios of physics beyond the Standard Model are tested, as well as a generic extension in the framework of the Standard Model Effective Field Theory.

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Probing the nature of electroweak symmetry breaking with Higgs boson pair-production at ATLAS

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In the Standard Model, the ground state of the Higgs field is not found at zero but instead corresponds to one of the degenerate solutions minimising the Higgs potential. In turn, this spontaneous electroweak symmetry breaking provides a mechanism for the mass generation of nearly all fundamental particles. The Standard Model makes a definite prediction for the Higgs boson self-coupling and thereby the shape of the Higgs potential. Experimentally, both can be probed through the production of Higgs boson pairs (HH), a rare process that presently receives a lot of attention at the LHC. In this talk, the latest HH searches by the ATLAS experiment are reported, with emphasis on the results obtained with the full LHC Run 2 dataset at 13 TeV. In the case of non-resonant HH searches, results are interpreted both in terms of sensitivity to the Standard Model and as limits on the Higgs boson self-coupling. Search results on new resonances decaying into pairs of Higgs bosons are also reported.

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Searching for new symmetries in the Higgs sector at ATLAS

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The discovery of the Higgs boson with the mass of 125 GeV confirmed the mass generation mechanism via spontaneous electroweak symmetry breaking and completed the particle content predicted by the Standard Model. Even though this model is well established and consistent with many experimental measurements, it is not capable of solely explaining some observations. Many extensions of the Standard Model introduce additional scalar fields to account for the electroweak symmetry breaking and thereby extra Higgs-like bosons, which can be either neutral or charged. This talk presents recent searches for additional low- and high-mass Higgs bosons, as well as decays of the 125 GeV Higgs boson to new light scalar particles, using LHC collision data at 13 TeV collected by the ATLAS experiment in Run 2.

Plenary / 37

MoEDAL, MAPP and future endeavours

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The unprecedented collision energy of the LHC has opened up a new discovery frontier, however, without any signs of new physics in sight. The first LHC dedicated search experiment, MoEDAL, started data taking for Run-2. MoEDAL is designed to search highly ionising particle avatars of new physics using pp and heavy-ion collisions at the LHC. The planned upgrade for MoEDAL at Run-3 - the MAPP detector (MoEDAL Apparatus for Penetrating Particles) - will extend MoEDAL's physics reach to include feebly interacting, long-lived messengers of physics beyond the Standard Model. This will allow us to explore a number of models of new physics, including dark sector models, in a complementary way to that of conventional LHC collider detectors. Further to this, a possible astroparticle extension to MoEDAL, called Cosmic-MoEDAL, will allow the search for

magnetic monopoles to be continued from the TeV scale to the GUT scale. The presentation focuses on recent results and plans for the LHC Run 3.

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Muon anomalous magnetic moment

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The ideas and formulas presented in the article will help to bring together the theoretical predictions for the anomalous magnetic moment of muon and the results of the "Muon g-2" experiment. In doing so, we are discussing the new effect exclusively within the Standard Model. In quantum physics a state with spin perpendicular to a magnetic field can be expressed as a superposition of energy eigenstates with spins parallel and antiparallel to the field: the resultant spin precession is due to the energy difference between the two eigenstates. If the state, like the muon, is unstable and can decay, it will have a natural energy spread. As a result the frequency of the spin precession can vary. For a constant magnetic field the measured spin precession velocity will be spread according to the Lorentzian distribution with width (γτ)^{−1}, for Lorentz gamma factor γ=E/m, and particle lifetime τ. Although the true mean and variance of a Lorentzian distribution is undefined, the latter can be estimated by the maximum likelihood method to be 2N(γτ)^{-2}, twice that of a normal distribution. Thus, the statistical error on the anomalous magnetic moment in reality should turn out to be wider than with χ2 analysis of the experiment.

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Measurements of multi-boson production including vector-boson scattering at ATLAS

Author: ATLAS Collaboration[None]

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Measurements of multiboson production at the LHC probe the electroweak gauge structure of the Standard Model for contributions from anomalous couplings. In this talk we present recent ATLAS results on the measurement of electroweak production of a Zgamma pair in association with two jets, the first observation of three W boson production, as well as the observation of the W pair production in photon-induced collisions. Also discussed is the measurement of differential cross-sections of four-lepton events and constraints on a model based on spontaneously broken B-L gauge symmetry. Moreover, precise boson and diboson differential cross-section measurements are interpreted in a combined Effective Field Theory analysis, allowing to systematically probe gauge boson self-interactions.

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Precision measurements of top-quark couplings and cross sections with the ATLAS detector at the LHC

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The Standard Model of particle physics (SM) connects symmetries to the interactions of elementary particles. Effective field theories (EFT) extend the SM with higher-dimension operators that maintain the SM's symmetries in the low-energy limit. The high center-of-mass energy of proton-proton collisions and the high integrated luminosities at the CERN Large Hadron Collider allows to use the large sample of top quark events to test SM theoretical predictions and constrain the effects of EFT operators with unprecedented sensitivity. Using data taken with the ATLAS detector at the LHC, recent measurements of the associated production of top quarks with Z bosons, photons and an additional top-quark pair (4-top production), a recent search for flavor-changing interactions of the top quark and the Z boson, as well as recent precision measurements of top-quark processes are presented that constrain EFT operators via observables related to the polarization of single-top-quark events, the transverse momentum of high-momentum top quarks in top-quark pair production and the energy asymmetry in top-quark pair production events with an additional jet.

Plenary / **42**

Floquet Time Crystals

Author: Frank Wilczek[None]

In recent years spontaneous breaking of discrete time translation symmetry has become a fertile area of theoretical, experimental and computational research. New, dynamic states of matter have been discovered, that challenge traditional ideas about the nature of thermal equilibrium. I will give an overview of this work, and then suggest possible future directions and applications.

Plenary / **43**

On naturalness and UV infinities in perturbative QFT

Author: Sander Mooij[None]

We review and generalise renormalisation methods in QFT in which no intermediate divergences show up. Moreover, in two-field models with a large mass hierarchy between the fields, the usual fine-tunings proportional to the large mass are absent. Therefore, in this formulation of perturbative QFT there is no naturalness problem at all: there is no influence from the "heavy" sector on the dynamics of the "light" sector. This strengthens the intuition that there is no physical meaning in the concept of naturalness.

Plenary / **44**

CP Violation in Non-leptonic B Decays as a Portal to New Physics

Author: Robert Fleischer[1]

[1] *NIKHEF*

CP violation offers a powerful probe for testing the Standard Model. In this endeavour, non-leptonic decays of B mesons play a key role. I will discuss benchmark decays and puzzling patterns emerging from theoretical analyses of the current data.

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Tests of LFU and searches for LFV at LHCb

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An embedded feature of the Standard Model is that different leptons have the same interaction strengths with the electroweak-force carriers. This is known as Lepton Universality. The LU is an accidental symmetry of the SM, not the result of some fundamental underlying principle. Recent results on LFU tests in semileptonic $b \to cl\nu$ transitions and rare $b \to sll$ decays, point to a violation of the LFU. If confirmed by further measurements, this would be clear evidence of New Physics in which new heavy particles couple preferentially to 2nd or 3rd generations of leptons. Any extension of the SM that includes violation of the LFU, predicts Lepton Flavour Violating processes in hadron decays with charged leptons in the final state. In this talk, the recent results from LHCb on LFU tests along with searches of charged-LFV are reported.

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Latest results from the CUORE experiment

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The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for 0νββ decay that has been able to reach the one-tonne mass scale. The detector, located at the LNGS in Italy, consists of an array of 988 TeO2 crystals arranged in a compact cylindrical structure of 19 towers. CUORE began its first physics data run in 2017 at a base temperature of about 10 mK and in April 2021 released its 3rd result of the search for 0νββ, corresponding to a tonne-year of TeO2 exposure. This is the largest amount of data ever acquired with a solid state detector and the most sensitive measurement of 0νββ decay in 130Te ever conducted, with a median exclusion sensitivity of 2.8×10ˆ25 yr. We find no evidence of 0νββ decay and set a lower bound of 2.2×10ˆ25 yr at a 90% credibility interval on the 130Te half-life for this process. In this talk, we present the current status of CUORE search for 0νββ with the updated statistics of one tonne-yr. We finally give an update of the CUORE background model and the measurement of the 130Te 2νββ decay half-life, study performed using an exposure of 300.7 kgxyr.

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Spontaneously stabilised dark matter from a fermiophobic U(1)' gauge symmetry

Author: Bowen Fu[None]

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In model building, discrete symmetries can not only play an important role in preserving the structure of Yukawa interactions but also provide a pathway to stabilise dark matter candidates. However, such discrete symmetries are not necessarily be imposed directly by hand. Instead, they can arise from the spontaneous symmetry breaking (SSB) of continuous symmetries. As an example, we study the type Ib seesaw model, where the effective neutrino mass operator involves two different Higgs doublets and two right-handed (RH) neutrinos forming a single heavy Dirac pair. The heavy neutrino, together with the Higgs doublets, is charged under a $U(1)'$ gauge symmetry which helps to

preserve the special structure of the type Ib seesaw mechanism. After the SSB, the $U(1)'$ symmetry turns into a Z_2 symmetry which stabilises a dark matter candidate. The dark matter candidate interacts with the other particles in the thermal bath through the massive boson resulting from the $U(1)'$ symmetry breaking. We explore how the correct dark matter relic abundance can be produced thermally in both a low energy effective model and a renormalisable model with a complete fourth family of vector-like fermions.

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Searching for New Physics in Rare K and B Decays without |Vcb| and |Vub| Uncertainties

Authors: Andrzej Buras[1]; Elena Venturini[None]

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The branching ratios B(K+ ⟶ π+ν¯ν) and B(KL ⟶π0ν¯ν) have a strong dependence on |Vcb|, that is stronger than in rare B decays, in particular for KL ⟶ π0ν¯ν. Thereby the persistent tension between inclusive and exclusive determinations of |Vcb| weakens the power of these theoretically clean decays in the search for new physics (NP). In this talk, I show how this uncertainty can be practically removed by considering within the SM suitable ratios of the two branching ratios between each other and with other observables like the branching ratios for KS ⟶ μ+μ−, Bs,d ⟶ μ+μ− and B ⟶K(K∗)ν¯ν. As a complementary test of the Standard Model, I show the extraction of |Vcb| from different observables as a function of β and γ. In particular, I illustrate this with εK, ΔMd and ΔMs finding tensions between these three determinations of |Vcb| within the SM. I point out that from ΔMs and SψKS alone one finds |Vcb| = 41.8(6)×10−3 and |Vub| = 3.65(12)×10−3. Furthermore, from |εK| and SψKS alone one can determine, independently of |Vcb|: B(K+ ⟶ π+ν¯ν)_SM = (8.60 ± 0.42) × 10−11 and B(KL ⟶ π0ν¯ν)_SM = (2.94 ± 0.15) × 10−11. This is the most precise determination to date, for these branching ratios.

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Long-lived highly charged particles at Run-3 and High Luminosity LHC

Author: Rafal Maselek[None]

Co-authors: Priyanka Lamba [1]; Mohammad Mahdi AlTakach [2]; Kazuki Sakurai [3]

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In recent years more attention was attracted by studies on long-lived charged particles predicted by some of BSM scenarios. We present a highly model independent study targeting colour-singlet and colour-triplet particles, with electric charges up to 8 times the elementary charge. In our work, we assess the possibility to detect such particles during Run-3 and at HL-LHC, by estimating the sensitivity of MoEDAL and ATLAS detectors. We present for the first time the expected upper mass limits on highly charged LLPs.

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Gravitational anomalies, CPT violation and leptogenesis

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We consider physics beyond the standard model, which incorporates a see-saw mechanism for neutrino masses. This physics is augmented by incorporating gravitational degrees of freedom (dilaton, graviton and Kalb-Ramond field) found in the theory of closed strings. In the inflationary era the gravitational degrees of freedom and inflatons dominate. Due to quantum effects there is a gravitational anomaly term (breaking of diffeomorphism invariance). This leads to a background which breaks local Lorentz invariance in the radiation and matter domination era. This lays the foundation for a model for leptogenesis based on spontaneous breaking of Lorentz and CPT symmetry. The model involves, apart from standard model particles, a single very heavy right-handed neutrino and the above axion background. We explicitly show how leptogenesis leads to baryogenesis. With current bounds, our model is a viable model for baryogenesis. This model is more economical, in requiring only one right handed neutrino particle, than other similar models for leptogenesis. Furthermore, the coupling of our axions to standard model gauge fields may allow these axions to be dark matter candidates.

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Multiple modular symmetries as the origin of flavour

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I present a framework where multiple modular symmetries are used and then broken to a single modular symmetry. Doing so justifies the use of multiple modulus, which can be stabilisers of distinct residual symmetries after acquiring the respective VEVs. Models based on multiple S4 and A4 lead to viable Tri-Maximal mixing schemes for the leptons.

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Model-independent test of T violation in neutrino oscillations

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As a function of the baseline L, neutrino oscillation probabilities are linear combinations of sin2(⊠⊠) and sin(2⊠⊠), with oscillation frequencies ⊠ that depend on the neutrino energy. Even though the frequencies depend on the oscillation model, in general the presence of L-odd terms in the probability requires the existence of Time Reversal Violation. We propose a ⊠2 test of T violation based on fitting oscillation data at a given energy to the functional form of the oscillation probability P(L) with and without the L-odd terms. A large Δ⊠2 between these two cases would show that L-odd terms are necessary to describe the data, and thus signal the presence of T violation. We use expected number of events at compatible energies in future accelerator neutrino experiments to illustrate that such a test can be applied at planned next-generation experiments. This allows to search for T violation in a largely model independent way, since the argument applies to a wide class of beyond-standard model scenarios.

Plenary / **54**

Theoretical implications of direct dark matter searches

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Direct detection experiments push the limits for WIMP dark matter, but they are also sensitive to many other ideas for new physics. The talk will cover implications for theory from limits of direct detection experiments and from the low E_R excess in XENON1T.

55

A common origin of CKM and PMNS phases within 2HDM

Authors: Fernando Cornet Gómez[None]; Gustavo Branco[1]; João Alves[2]; francisco j. botella[3]; Miguel Nebot[None]

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We present a two Higgs doublet model (2HDM) with controlled scalar Flavor Changing Neutral Couplings(FCNC) that is able to generate a connection between CP violation in the quark and lepton sectors. We show that both the CKM and PMNS phases can be generated by a vacuum phase in a class of 2HDM. This class of models is falsifiable since FCNC arise at a level which can be probed experimentally in the near future, specially in the processes $h \to e^{\pm}\tau^{\mp}$ and $t \to hc$.

Plenary / **56**

Discreteness and Determinism in Quantum Mechanics

Authors: Gerard 't Hooft[1]; Gerardus 't Hooft[2]

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Quantum mechanics is usually considered to be a theory based on indeterminism. Here we show that its mathematics actually suggests a completely deterministic underlying theory. This requires evolution operators that describe discretised jumps in space and time. To understand how the known

elementary particles, arranged in the Standard Model, can be reconciled with this picture, the discrete and continuous symmetries must be understood. This could open new avenues towards model building.
We also briefly discuss the implications regarding Bell's theorem.

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Design, Status and Physics Potential of JUNO

Author: Hans Theodor Josef Steiger[1]

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The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton multi-purpose liquid scintillator detector currently being built in a dedicated underground laboratory in Jiangmen (PR China). Data-taking is expected to start in 2023. JUNO's main physics goal is the determination of the neutrino mass ordering using electron anti-neutrinos from two nuclear power plants at a baseline of about 53 km. JUNO aims for an unprecedented energy resolution of 3% at 1 MeV for the central detector, which will allow determining the mass ordering with 3 σ significance within six years of operation. Furthermore, measurements in neutrino physics and astrophysics, such as estimating the solar oscillation parameters and the atmospheric mass splitting with an accuracy of 0.5% or better, will be performed.
In this talk, JUNO's design, the status of its construction, and its physics potential, will be presented alongside a short excursion into its rich R&D program.

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String Condensation and Gravitational Collapse - or why AdS may be closer than you think!

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The AdS/CFT correspondence provides a heuristic justification for the Bekenstein-Hawking entropy of certain black holes, but despite great effort a concrete description of the supposed microstates of a Schwarzschild black hole remains elusive. We suggest that this may be because the wrong problem may be being addressed, and that a string condensation mechanism previously proposed may intervene during gravitational collapse to forestall horizon formation. The end state of the conversion mechanism during collapse has been predicted to be a hot string phase with a hyperbolic spatial geometry with no gravitational field in the bulk that would be practically indistinguishable from a Hawking black hole to a distant observer. Here we propose a modified version with AdS spacetime geometry with torsion in the bulk. The AdS/CFT correspondence would provide the link between the states of the string phase and the level zero modes in the exterior. One advantage of this approach is that it avoids the T asymmetry that is built into black hole backgrounds and so allows for greater consistency between the processes of formation and decay of collapsed systems.

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Models with (broken) Z2 symmetries

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I will discuss the allowed parameter space as well as collider prospects of several new physics models containing (broken) Z2 symmetries. I focus on effects of current constraints on these, and will touch on several future collider options.

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Light hyperon physics at BESIII

Author: Beijiang Liu[None]

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Baryons consisting of one or more heavy quarks, so called hyperons (Y), are a powerful diagnostic tool that allows to shed light on some of the most challenging questions in contemporary physics. One such intriguing questions concerns the matter-antimatter asymmetry of the Universe. A possible explanation for this poorly understood discrepancy could be due to a dynamical, CP-violating, mechanism beyond the Standard Model. By comparing two-body weak decays of hyperons and anti-hyperons tests on CP symmetry can be performed. Hyperon and antihyperons can be produced simultaneously in the process $e^+e^- \rightarrow J/\Psi \rightarrow Y\bar{Y}$, where the BESIII experiment has collected the world's largest J/Ψ data sample.
If the hyperons are produced in a polarized state it becomes possible to make direct and precise CP-tests. This was recently shown for the first time for the process $J/\Psi \rightarrow \Lambda\bar{\Lambda}$ measured by the BESIII experiment. The experimental results showed that the asymmetry decay parameter for the decay $\Lambda \rightarrow$
$p\pi^-$ was nearly twenty percent larger compared to the PDG tabulated value. In addition, due to symmetric, excellent detector conditions and low hadronic background the experiment offers a clean environment for CP-violation tests in processes like e.g.
$J/\Psi \rightarrow \Lambda\bar{\Lambda}$, $J/\Psi \rightarrow \Sigma\bar{\Sigma}$ and $J/\Psi \rightarrow \Xi\bar{\Xi}$.
In this talk, an outline of the methods, recent results and future prospects from the BESIII experiment will be given.

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Cutting rules on cylinder and simplified diagrammatic approach to CP violation in quantum kinetic theory

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In this talk, we introduce a novel diagrammatic method for including thermal corrections in CP asymmetric reaction rates entering the quantum Boltzmann equation. In thermal equilibrium, the asymmetries have to cancel precisely due to the S-matrix unitarity and CPT invariance. Such cancelations are easy to track in zero-temperature leading-order calculations. However, accounting for medium effects requires modification of the on-shell part of propagators and, consequently, the CP-violating rates. In the literature, the correct form of the statistical factors in the asymmetry source term has been obtained employing the real-time-formalism of non-equilibrium field theory in a certain approximation. We demonstrate that the same results can be obtained by summing an infinite sequence of zero-temperature asymmetries. Those are derived from cuttings of forward diagrams drawn on a cylindrical surface, while thermal corrections come from windings of their propagators. The procedure is entirely diagrammatic, and the CPT and unitarity cancelations are formulated for thermally corrected reaction rate asymmetries. The simplification achieved is the primary focus of our work. The aspect of infrared finiteness in higher-order perturbative corrections will also be discussed. The talk is primarily based on arXiv:2104.06395, arXiv:2102.05914, and arXiv:2111.03419.

63

Extending the Reach of Leptophilic Boson Searches at DUNE and MiniBooNE with Bremsstrahlung and Resonant Production

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New gauge bosons coupling to leptons are simple and well-motivated extensions of the Standard Model. We study the sensitivity to gauged $L_\mu - L_e$, $L_e - L_\tau$ and $L_\mu - L_\tau$ both with the existing beam dump mode data of MiniBooNE and with the DUNE near detector. We find that including bremsstrahlung and resonant production of Z', which decays to $e^\pm$ and $\mu^\pm$ final states leads to a significant improvement in existing bounds, especially for $L_\mu - L_e$ and $L_e - L_\tau$ for DUNE while competitive constraints can be achieved with the existing data from the MiniBooNE's beam dump run.

64

SUSY g-2 with and without neutralino dark matter

Author: Kazuki Sakurai[1]

Co-authors: Rafal Maselek ; Sho Iwamoto [2]; Manimala Chakraborti ; Jong Soo Kim

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Supersymmetry is an attractive new physics candidate that may explain the observed anomaly in the muon g-2. In the MSSM, this requires either (a) large higgsino-gaugino mixing, or (b) large L-R mixing in the smuon sector. Both cases are strongly constrained if the lightest neutralino is the dark matter. For example, the former case is severely constrained by the direct detection measurements, while the latter case suffers from overproduction of the Bino-like neutralino. We will first show how those constrains restrict the parameter space favoured by the muon g-2. In the second part of the talk, we study two scenarios where the neutralino is not the dark matter; (1) RPV and (2) GMSB with the gravitino LSP. We carefully study the collider constraints on these scenarios and show how they can open up the parameter regions favoured by the muon g-2, otherwise excluded in the MSSM with neutralino dark matter.

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Natural supersymmetric dark matter in Twin Higgs models

Author: Marcin Badziak[None]

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Supersymmetric twin Higgs models have a discrete symmetry for which each standard model particle and its supersymmetric partner have a corresponding state that transforms under a mirror standard model gauge group. This framework is able to accommodate the nondiscovery of new particles at the LHC with the naturalness of the electroweak scale. I will show that this framework provides also natural dark matter candidates with promising signals at future direct-detection experiments.

67

An eclectic approach to the flavor (symmetry) problem

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The origin of the number of generations and their mixings in the standard model is a very interesting question. Traditionally, this has been addressed by introducing some non-Abelian global symmetry as a sort of hidden structure governing the Yukawa couplings and thereby the mixing matrices. More recently, it has been shown that discrete modular symmetries provide a better tool constraining those mixings with less input parameters. We shall discuss in this talk how this new idea is in fact non-trivially intertwined with the traditional flavor approach, leading to the new picture of *eclectic flavor symmetries*. Further, we shall describe how the eclectic scenario arises naturally in string compactifications, and discuss some of its consequences for future phenomenological studies.

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Pulsed Production of Antihydrogen in AEgIS

Authors: Nicola Zurlo[1]; on behalf of the AEgIS collaboration[None]

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Cold antihydrogen atoms are a powerful tool to probe the validity of fundamental physics laws, and it's clear that colder atoms allow an increased level of precision, generally speaking.

After the first production of cold antihydrogen in 2002 1, experimental efforts have progressed impressively (trapping, beam formation, spectroscopy), with highly competitive results already achieved by adapting to cold antiatoms techniques previously well developed for ordinary atoms. Unfortunately, the number of antihydrogen atoms that can be produced in dedicated experiments is many orders of magnitude smaller than available for hydrogen atoms, which are at hand in large amount, so the development of novel techniques that allow the production of antihydrogen with well defined conditions (and possibly under control) is essential to improve the sensitivity of the methods applied by the different experiments.

We present here experimental results on the production of antihydrogen in a pulsed mode in which the time when 90\% of
the atoms are produced is known with an uncertainty of ˜250 ns [2] . The pulsed antihydrogen source is
generated by the charge-exchange reaction between Rydberg ($n \simeq 17$) positronium atoms and antiprotons (trapped, cooled and manipulated in electromagnetic traps):
+Ps* $\rightarrow \bar{H}^{*} + e^{-} where Rydberg positronium atoms, in turn, are produced through the implantation of a pulsed positron bea$

The pulsed production allows the control of the antihydrogen temperature, and facilitates the tunability of the Rydberg states, their de-excitation by pulsed lasers and the manipulation through electric field gradients.

In fact, the production of pulsed antihydrogen is a major milestone in the AEgIS experiment to perform direct measurements of the validity of the Weak Equivalence Principle for antimatter.

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Status of the $K_L^0 \to \pi^0\nu\bar{\nu}$ Search at the KOTO Experiment

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KOTO is a dedicated experiment to search the ultra-rare decay $K_L^0 \to \pi^0\nu\bar{\nu}$. This decay channel is sensitive to New Physics because of the rareness and precision in the Standard Model (SM). In 2019, KOTO examined the sensitivity of 7.20×10^{-10}, which is 24 times larger than the SM sensitivity, and revealed three signal candidate. An exhaustive investigation of possible missing background sources showed the contamination from $K^{\pm}$ and K_L^0 produced at the beam collimator is considerable. The number of background events were subsequently updated to be (1.22 ± 0.06) and the signal strength is therefore not statistically significant. Projecting forward, we have upgraded the KOTO detector to further detect background-induced particles. Algorithms to further suppress the collimator-interacting particles are also developed. With those new tools, KOTO is prepared to explore the unprecedented sensitivity of $O(10^{-10})$.

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Anatomy of a top-down approach to discrete and modular flavor symmetry

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The framework of compactified heterotic string theory offers consistent UV completions of the Standard Model of particle physics. In this approach, the existence of flavor symmetries beyond the Standard Model is imperative and the flavor symmetries can be derived from the top-down. I will show how such a derivation uncovers a unified origin of traditional discrete flavor symmetries, discrete modular flavor symmetries, discrete R symmetries of supersymmetry, as well as CP symmetry - altogether called the eclectic flavor symmetry. I will show a specific example of such a top-down derived eclectic flavor symmetry, discuss the different sources of breaking of the eclectic flavor symmetry, as well as the possible lessons for bottom-up flavor model building.

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e-mu Lepton Flavour Violation and tau-mu Lepton Flavour Universality Studies at the Upsilon(3S) with BaBar

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We report on the first search for electron-muon lepton flavor violation (LFV) in the decay of a b quark and b antiquark bound state. We look for the LFV decay Upsilon(3S)-> e mu in a sample of 118 million (3S) mesons from 27/fb of data collected with the BABAR detector at the SLAC PEP-II e+e- collider operating with a 10.36 GeV center-of-mass energy. No evidence for a signal is found and we set a limit on the branching fraction B(Y(3S)-> mu e) < 3.6 E-7 at 90% CL. This result can be interpreted as a limit on Lambda_NP / g_NP^2 > 80 TeV on the energy scale Lambda_NP, divided by the coupling-squared g_NP of relevant new physics.
We also report on a precision measurement of the ratio B(Y(3S)-> tau tau)/ (B(Y(3S)-> mu mu) The ratio is measured to be 0.966 +/- 0.008 (stat) +/- 0.014 (sys) and is in agreement with the Standard Model prediction of 0.9948 within 2 standard deviations. The uncertainty is almost an order of magnitude smaller than the only previous measurement.

Plenary / **72**

Challenges in supersymmetric cosmology

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I will discuss a framework of natural inflation within supergravity dubbed 'inflation by supersymmetry breaking'. The main idea is to identify the inflaton with the superpartner of the goldstino, in the presence of a gauged R-symmetry that may contain the R-parity of the supersymmetric Standard Model.

Plenary / **73**

A natural mechanism for a SM-like Higgs boson in the 2HDM without decoupling

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I survey mechanisms that can guarantee a SM-like Higgs boson in the 2HDM without a fine tuning of parameters.
Discrete symmetries play a pivotal role in achieving an approximate Higgs alignment limit naturally.

Plenary / **74**

The Future Circular Collider (FCC) at CERN

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With the LHC about to start its last data-taking period before being upgraded to the High-Luminosity LHC, it is time for the international high energy physics community to define the future of collider particle physics. The European Strategy for Particle Physics highlights an e+e- Higgs boson factory as the main priority and as a first step towards a very high-energy future hadron collider.

A staged Future Circular Collider (FCC), consisting of a luminosity-frontier highest-energy electron-positron collider (FCC-ee) followed by an energy-frontier hadron collider (FCC-hh), promises the most far-reaching physics program for the post-LHC era. FCC-ee is a precision instrument to study the Z, W, Higgs and top particles, and offers unprecedented sensitivity to signs of new physics. Most of the FCC-ee infrastructure can later be reused for the subsequent hadron collider, FCC-hh.

The FCC-hh provides proton-proton collisions at a centre-of-mass energy of 100 TeV and can directly produce new particles with masses of up to several tens of TeV. This collider will also measure the Higgs self-coupling and explore the dynamics of electroweak symmetry breaking. Thermal dark matter candidates will be either discovered or conclusively ruled out by FCC-hh.

Heavy-ion collisions and ep collisions (FCC-eh) further contribute to the breadth of the overall FCC program. The integrated FCC infrastructure will serve the particle physics community through the end of the 21st century.

This presentation will summarize the feasibility of such a plan, possible implementation and conceptual designs of FCC-ee and FCC-hh, as well as physics potential.

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B-$\bar{\mathrm{B}}$ mixing: decay matrix at high precision

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B-$\bar{\mathrm{B}}$ mixing involves three observables, the mass difference Δm between the two neutral B eigenstates, their width difference $\Delta\Gamma$, and the CP phase characterising CP violation in mixing. The latter two quantities involve the off-diagonal element Γ_{12} of the 2×2 decay matrix Γ. I briefly discuss possible insights into new physics to be gained from a better knowledge of Γ_{12} and then describe the calculation of the Standard-Model prediction of Γ_{12} at next-to-next-to-leading order of QCD. This calculation is necessary to match the experimental precision of the LHCb measurement of $\Delta\Gamma$ in the $\mathrm{B_s}$ system.

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Neutrinos: recent phenomenological developments

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Challenges in supersymmetric cosmology

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Going beyond the Standard paradigm of Cosmology: Torsion, gravitational anomalies and inflation without inflaton fields

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Plenary / 80

Modular Invariance, Residual Modular Symmetries …

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Rare b-decays and tests of lepton flavour universality at LHCb

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Flavour-changing neutral-current decays are loop-suppressed in the SM and are thus an ideal laboratory to look for contributions from new heavy particles and/or new interactions beyond the SM. At LHCb tensions are observed in measurements of branching fractions and angular observables for rare semileptonic decays, as well as in lepton flavour universality tests. I will review the current experimental status and prospects.

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Neutrinos: recent phenomenological developments

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Modular Invariance, Residual Modular Symmetries …

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Hints for New Physics in Rare B Decays

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Underground tests of Quantum Mechanics

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CPV in non-leptonic decays

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Dark matter

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Dark Matter searches at future colliders

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Rare b-decays and tests of lepton flavour universality at LHCb

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Quantum correlations in neutrino oscillations

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On naturalness and UV infinities in perturbative QFT

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New ideas on quantum mechanics related to entanglement

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B-$\bar{\mathrm{B}}$ mixing: decay matrix at high precision

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Discreteness and Determinism in Quantum Mechanics

Quantum mechanics is usually considered to be a theory based on indeterminism. Here we show that its mathematics actually suggests a completely deterministic underlying theory. This requires evolution operators that describe discretised jumps in space and time. To understand how the known elementary particles, arranged in the Standard Model, can be reconciled with this picture, the discrete and continuous symmetries must be understood. This could open new avenues towards model building.
We also briefly discuss the implications regarding Bell's theorem.

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The Future Circular Collider (FCC) at CERN

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Searches for Charged Lepton Flavor Violation

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Vector-like quarks

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Flavour and Symmetries

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Symmetries and Topological Defects in the 2HDM and Beyond

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A natural mechanism for a SM-like Higgs boson in the 2HDM without decoupling

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MoEDAL, MAPP and future endeavours

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Search for the neutron Electric Dipole Moment at the Paul Scherrer Institute

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Antihydrogen hyperfine structure

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On the equivalence between Starobinsky and Higgs inflation in gravity and supergravity

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Neutrinos: recent phenomenological developments

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Modular Invariance, Residual Modular Symmetries …

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Neutrinos: recent phenomenological developments

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Fermion mass hierarchies from residual modular symmetries

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Lepton g–2 anomalies in general flavour conserving two Higgs doublets models

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Current measurements of the anomalous magnetic dipole moments g-2 of the electron and the muon can be interpreted as deviations from Standard Model expectations which require the presence of some new physics contribution. Both anomalies are analysed simultaneously in the context of two-Higgs-doublet models in which (i) the quark Yukawa couplings coincide with the Z2 symmetric type I and II models, (ii) the lepton sector corresponds to the general case without scalar flavor changing neutral couplings. This framework is stable under renormalization group evolution and allows to decouple the electron, muon, and tau interactions with the new scalars. Two types of solutions to the g-2 puzzles, compatible with a large set of experimental constraints, are found and discussed: while the electron anomaly is obtained through 2-loop Barr-Zee contributions, the muon anomaly can be obtained either through 2-loop Barr-Zee or through 1-loop contributions. In the first type of solution, all the new scalars have masses in the 1–2.5 TeV range and the vacuum expectation values of both doublets are similar in magnitude. In the second type of solution, all new scalars have masses below 1 TeV and the ratio of vacuum expectation values is large. Additional phenomenological implications of both solutions are discussed.

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Light states from weak CP violation in the aligned Weinberg 3HDM

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We explore the scalar spectrum resulting from the potential of the Weinberg 3-Higgs-doublet model (3HDM). In the absence of the terms leading to CP-violation via complex vacuum expectation values, the $Z_2 \times Z_2$ symmetry is enhanced to $U(1) \times U(1)$. When broken, this symmetry leads to two massless pseudoscalar states. In a realistic implementation however, the CP-violating part of the potential is non-zero, and those two states acquire finite masses, rather than being massless. A scan over parameters, close to the alignment limit, shows that the spectrum typically contains at least one state below 125˜GeV with a large CP-odd component.

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Hints for New Physics in Rare B Decays

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Underground tests of Quantum Mechanics

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CPV in non-leptonic decays

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CPV in non-leptonic decays

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Dark matter

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Dark matter

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Dark matter searches at future e+ e- colliders

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Challenges in supersymmetric cosmology

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g-2

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Going beyond the Standard paradigm of Cosmology: Torsion, gravitational anomalies and inflation without inflaton fields

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A flavor model for neutrino mixing and leptogenesis

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We explore a model to understand the cobimaximal (CBM) lepton mixing ansatz based on A4 non-Abelain discrete flavour symmetry with type-I seesaw which predicts maximal value for the atmospheric mixing angle and Dirac CP phase to be -pi/2 . Here the construction is such that the charged lepton mass matrix is diagonal and the heavy right-handed neutrino mass matrix primarily dictates the features of CBM mixing. Here we also predict the absolute neutrino mass and effective neutrino mass parameter responsible for neutrinoless double beta decay.
We finally estimate the lepton asymmetry of the universe in the context of the present model. Here the set-up is such that the lepton asymmetry vanishes at tree level. However, if we consider next to leading contributions in the Dirac Yukawa coupling, leptogenesis becomes viable.

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Inflaton Dark Matter

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Does antimatter fall like matter? : the GBAR experiment (CERN)

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CPT violation and neutrino oscillation experiments

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Belle II experiment: status and prospects

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A decade of dark sector and light dark matter searches at BABAR

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Muon anomalous magnetic moment

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Lepton g–2 anomalies in general flavour conserving two Higgs doublets models

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SUSY g-2 with and without neutralino dark matter

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Orbifold brane-Higgs

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Gravitational anomalies, CPT violation and leptogenesis

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Feynman diagrams: index, topology and current inflow for massless fermions

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Diagonal reflection symmetries and universal four-zero texture

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Horizontal Symmetry and Large Neutrino Magnetic Moment in the Light of Recent Experiments

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Parity from a gauge symmetry

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A flavor model for neutrino mixing and leptogenesis

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Testing CPT symmetry in ortho-positronium decays with J-PET detector

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CP symmetry test at J-PET with angular coleration of photons from ortho-positronium annihilation

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Light hyperon physics at BESIII

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String Condensation and Gravitational Collapse - or why AdS may be closer than you think

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Natural supersymmetric dark matter in Twin Higgs models

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Next-to-minimal supersymmetric Standard Model

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The search for lepton flavour violation with the MEG II experiment

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Measurement of the CP violation in B_sˆ0 -> J/psi phi decays in pp collisions at sqrt(s) = 13 TeV with the ATLAS detector

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Measurements of the Higgs boson properties and their interpretations with the ATLAS experiment

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Probing the nature of electroweak symmetry breaking with Higgs boson pair-production at ATLAS

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Searching for new symmetries in the Higgs sector at ATLAS

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Measurements of multi-boson production including vector-boson scattering at ATLAS

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Precision measurements of top-quark couplings and cross sections with the ATLAS detector at the LHC

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Additional Baryons and Mesons

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New measurement of radiative decays at the NA62 Experiment at CERN

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Search for K+ decays to a lepton and invisible particles

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Searches for baryon number violation via neutron conversions at the European Spallation Source

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Dark CP violation

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Dark matter in three-Higgs-doublet models with ⊠3 symmetr

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Models with (broken) Z2 symmetries

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Light states from weak CP violation in the aligned Weinberg 3HDM

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Search for lepton number and flavour violation in K+ and pi0 decays

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A complete description of P- and S-wave contributions to the ⊠0⟶⊠+⊠−ℓ+ℓ− decay

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Searching for New Physics in Rare K and B Decays without |Vcb| and |Vub| Uncertainties

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An eclectic approach to the flavor (symmetry) problem

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Anatomy of a top-down approach to discrete and modular flavor symmetry

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Multiple modular symmetries as the origin of flavour

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Measurement of the very rare K+ to pi+ nu nubar decay

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Long-lived highly charged particles at Run-3 and High Luminosity LHC

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Spontaneously stabilised dark matter from a fermiophobic U(1)' gauge symmetry

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Status of the K0L to pi0nunu — Search at the KOTO Experiment

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Latest results from the CUORE experiment

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e-mu Lepton Flavour Violation and tau-mu Lepton Flavour Universality Studies at the Upsilon(3S) with BaBar

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A common origin of CKM and PMNS pases within 2HDM

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The limits of the strong CP problem

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Extending the Reach of Leptophilic Boson Searches at DUNE and MiniBooNE with Bremsstrahlung and Resonant Production

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Pulsed Production of Antihydrogen in AEgIS

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On the Klein Symmetry of Majorana Mass Matrices and the Electroweak Hierarchy Problem

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T_{13} Flavor Symmetry for Quarks and Leptons

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Design, Status and Physics Potential of JUNO

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Measurement of CP violation in B0s decays at CMS

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Recent measurements of CP violation in Bos –> Jpsi phi decay by the CMS collaboration are presented

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Floquet Time Crystals

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Parity from a gauge symmetry

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We argue that Left-Right parity symmetry P can arise as a discrete remnant of a unified gauge symmetry. The high-energy unification necessarily includes the gauging of the Lorentz symmetry, bringing into the game gravitational interactions, and leading to a gravi-GUT scheme. Parity emerges unbroken below the Planck scale, and can be broken spontaneously at lower energies making contact with the Standard Model. This framework motivates the spontaneous origin of parity violation as in Left-Right symmetric theories with P. The possible unifying gauge groups are identified as SO(7,1) for gravitational and weak interactions, or SO(7,7) for a complete unification.

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Measurement of CP violation in B0s decays at CMS

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Model-independent test of T violation in neutrino oscillations

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