



# **DISCRETE 2016: Fifth Symposium on Prospects in the Physics of Discrete Symmetries**

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## **Book of abstracts**

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## SEPARATE T, CP, CPT ASYMMETRIES IN NEUTRAL MESON TRANSITIONS

Prof. BERNABEU, JOSE<sup>1</sup>

<sup>1</sup> *IFIC*

**Corresponding Author:** jose.bernabeu@uv.es

Talk on SEPARATE T, CP, CPT ASYMMETRIES IN NEUTRAL MESON TRANSITIONS

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## Reflection on the European Strategy for Particle Physics

NAKADA, Tatsuya<sup>1</sup>

<sup>1</sup> *EPFL, IPIYS*

**Corresponding Author:** tatsuya.nakada@cern.ch

The European Strategy for Particle Physics provides a guideline and direction for the particle physics activities in Europe. The first Strategy had been approved by the CERN Council in July 2006, then it was updated in May 2013. In this talk, we review how the Strategy has shaped the today's particle physics programme in Europe and project how it would evolve by reflecting the current status of physics.

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## Emergence of symmetry from Maximum Entanglement

**Corresponding Author:**

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## Quantum entanglement of mesons & co.

**Corresponding Author:** beatarix.hiesmayr@univie.ac.at

P1: T, C, P, CP, and CPT symmetries / 63

## The NA62 experiment at CERN

LAZZERONI, Cristina<sup>1</sup>

<sup>1</sup> *University of Birmingham*

**Corresponding Author:** francesco.gonnella@cern.ch

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$  is one of the theoretically cleanest meson decay where to look for indirect effects of new physics complementary to LHC searches. The NA62 experiment at CERN SPS is designed to measure the branching ratio of this decay with 10% precision. NA62 took data in pilot runs in 2014 and 2015 and in a physics run in 2016. The quality of data acquired in view of the final measurement will be presented. The experiment is also collecting data to search for exotic processes, like Lepton Flavour and Number violation and Axions. Prospects on these measurements will also be presented.

**P1: T, C, P, CP, and CPT symmetries / 73****Recent discrete symmetries tests at LHCb**Dr. KLIMASZEWSKI, Konrad <sup>1</sup><sup>1</sup> *National Centre for Nuclear Research, Warsaw***Corresponding Author:** konrad.klimaszewski@ncbj.gov.pl

Recent tests of CP and CPT symmetries at LHCb are reviewed. In particular advances in determination of the CP violating phase  $\phi_s$  in decays of the strange-beauty meson  $B_0$ s and measurement of CP violation in  $B_0 \rightarrow D^+D^-$  decays. For c sector the tests of CP symmetry in  $D_0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ ,  $D^\pm \rightarrow \eta'\pi^\pm$  and  $D_s^\pm \rightarrow \eta'\pi^\pm$  decays are presented. Finally first observation of CP violation in baryon decays of  $\Lambda_0 b \rightarrow p\pi^-\pi^+\pi^-$  is reported as well as the first test at LHCb of Lorentz invariance and CPT symmetry in  $B_0$ s mixing.

**P1: T, C, P, CP, and CPT symmetries / 25****Neutral pion form factor measurement by the NA62 experiment**CRISTINA, Lazzeroni <sup>1</sup><sup>1</sup> *University of Birmingham, UK***Corresponding Author:** michal.zamkovsky@cern.ch

The NA62 experiment at CERN collected a large sample of charged kaon decays with a highly efficient trigger for decays into electrons in 2007. The kaon beam represents a source of tagged neutral pion decays in vacuum. A measurement of the electromagnetic transition form factor slope of the neutral pion in the time-like region from  $\sim 1$  million fully reconstructed  $\pi^0$  Dalitz decay is presented. The limits on dark photon production in  $\pi^0$  decays from the earlier kaon experiment at CERN, NA48/2, are also reported.

**P1: T, C, P, CP, and CPT symmetries / 35****Cherenkov-like emission of Z bosons****Author:** Prof. POTTING, Robertus <sup>1</sup>**Co-Authors:** Prof. COLLADAY, Donald <sup>2</sup>; Dr. NOORDMANS, Jacob <sup>3</sup><sup>1</sup> *Universidade do Algarve*<sup>2</sup> *New College of Florida*<sup>3</sup> *Universidade do Algarve / CENTRA***Corresponding Author:** rpotting@ualg.pt

We study CPT and Lorentz violation (LV) in the electroweak gauge sector of the Standard Model in the context of the Standard-Model Extension (SME). In particular, we show that any non-zero value of a certain relevant LV parameter that is thus far unbounded by experiment would imply that for sufficiently large energies one of the helicity modes of the Z boson should propagate with spacelike four-momentum and become stable against decay in vacuum. In this scenario, Cherenkov-like radiation of Z bosons by ultra-high energy cosmic ray protons becomes possible. We deduce a bound on the LV parameter from the observational data on ultra-high energy cosmic rays.

**P3: Discrete symmetries in cosmology / 75****Leptogenesis with GeV-scale right-handed neutrinos****Author:** GARBRECHT, Björn <sup>1</sup>**Co-Authors:** Dr. DREWES, Marco <sup>2</sup>; GUETER, Dario <sup>2</sup>; KLARIĆ, Juraj <sup>2</sup><sup>1</sup> TUM<sup>2</sup> Technische Universität München**Corresponding Author:** garbrecht@tum.de

Provided the produced asymmetries are not largely washed out prior to sphaleron freezeout, flavoured leptogenesis from relativistic right-handed neutrinos stands within the type-I seesaw framework as an alternative to the standard mechanism from the decays and inverse decays of ultraheavy non-relativistic neutrinos. Of particular interest is the case of GeV-scale neutrinos where leptogenesis turns out to be viable with only moderate tuning despite the low seesaw scale. When large mixing angles with the active neutrinos are protected by an approximate conservation of lepton number, this scenario may be testable at the proposed SHiP facility through a measurement of the mixing for the individual flavours .

**P3: Discrete symmetries in cosmology / 37****Higgs doublet decay as the origin of the baryon asymmetry****Prof.** HAMBYE, Thomas <sup>1</sup>; **Dr.** TERESI, Daniele <sup>2</sup><sup>1</sup> ULB<sup>2</sup> Université Libre de Bruxelles**Corresponding Author:** daniele.teresi@ulb.ac.be

In this talk I will start by considering a question which curiously had not been properly considered so far: in the standard seesaw model what is the minimum value the mass of a right-handed (RH) neutrino must have for allowing successful leptogenesis via CP-violating decays? I show that, for low RH neutrino masses and thanks to thermal effects, leptogenesis turns out to proceed efficiently from the decay of the Standard Model scalar doublet components into a RH neutrino and a lepton. If the RH neutrino has thermalized prior from producing the asymmetry, this mechanism turns out to lead to the bound  $m_N > 2$  GeV. If, instead, the RH neutrinos have not thermalized, leptogenesis from these decays is enhanced further and can be easily successful, even at lower scales. This Higgs-decay leptogenesis new mechanism works without requiring an interplay of flavor effects and/or cancellations of large Yukawa couplings in the neutrino mass matrix. Last but not least, such a scenario turns out to be testable, from direct production of the RH neutrino(s).

**P3: Discrete symmetries in cosmology / 28****Baryogenesis of the Universe in cSMCS Model plus Iso-Doublet Vector Quark****Author:** Ms. DARVISHI, Neda <sup>1</sup>**Co-Author:** Ms. DARVISHI, Neda <sup>1</sup><sup>1</sup> University of Warsaw**Corresponding Author:** neda.darvishi.2010@gmail.com

CP violation of the SM is insufficient to explain the baryon asymmetry in the universe and therefore an additional source of CP violation is needed. Here the extension of the SM by a neutral complex scalar singlet with a nonzero vacuum expectation value (cSMCS) plus a heavy vector quark pair is considered. This model offers the spontaneous CP violation and proper description in the baryogenesis, it leads strong enough first-order electro-weak phase transition to suppress the baryon-violating sphaleron process.

**P3: Discrete symmetries in cosmology / 20**

## **Flavored-Universe dispatched via Axion and Neutrino**

Dr. AHN, Y.H <sup>1</sup>

<sup>1</sup> *IBS-CTPU*

**Corresponding Author:** yhahn@kias.re.kr

Axion and neutrino are powerful sources for arguments in favor of a new extension of the SM, in that they stand out as their convincing new physics and the variety of experimental probes. Astrophysical and cosmological observations have placed increasingly tight constraints on parameters for axion, neutrino, and inflationary physics. In this regard, I am going to talk about a new scenario for axion and neutrino in order to mount such an interesting challenge.

**P3: Discrete symmetries in cosmology / 66**

## **Early kinetic decoupling in the models with the resonant annihilation**

**Author:** DUCH, Mateusz <sup>1</sup>

**Co-Author:** GRZADKOWSKI, Bohdan <sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** mateusz.duch@fuw.edu.pl

In the models with dark matter resonant annihilation, the coupling of dark sector to the visible one can be suppressed with respect to the non-resonant scenarios. Consequently the cross section for the scattering of dark matter on lighter states of the thermal bath is diminished and temperatures of the kinetic and chemical decoupling are similar. Moreover, due to the resonant enhancement, annihilation of dark matter to the visible sector is effective, even then both sectors are totally decoupled. The effects of early kinetic decoupling on the dark matter relic abundance will be presented alongside its consequences for direct and indirect detection and dark matter self-interaction.

**P5: Discrete symmetries and models of flavour mixing / 22**

## **Simple signature of CP conservation in the most general 2HDM**

**Author:** Prof. GINZBURG, Ilya <sup>1</sup>

**Co-Author:** Prof. KRAWCZYK, Maria <sup>2</sup>

<sup>1</sup> *Sobolev Institute of Mathematics SB RAS Novosibirsk Russia*

<sup>2</sup> *University of Warsaw*

**Corresponding Author:** ginzburg@math.nsc.ru

We formulate very simple necessary and sufficient condition for CP conservation in the most general 2HDM. The experimental checking of this criterium looks not so difficult.



**P5: Discrete symmetries and models of flavour mixing / 18****CP-odd invariants for scalar potentials and applications with discrete symmetries**Dr. DE MEDEIROS VARZIELAS, Ivo<sup>1</sup><sup>1</sup> *Instituto Superior Tecnico***Corresponding Author:** ivo.de@udo.edu

I discuss powerful methods for constructing basis invariants and determining whether they are CP-odd or CP-even (and useful either for explicit or spontaneous CP violation).

CP-odd invariants are valid for general potentials when expressed in a standard form, and I demonstrate by applying to scalar potentials involving three (or six) Higgs fields which form irreducible triplets under a discrete symmetry.

The considered cases include one triplet of Standard Model (SM) gauge singlet scalars, one triplet of SM Higgs doublets, two triplets of SM singlets, and two triplets of SM Higgs doublets.

For each case, I show results when the potential is symmetric under one of the simplest discrete symmetries with irreducible triplet representations, namely  $A_4$ ,  $S_4$ ,  $\Delta(27)$  or  $\Delta(54)$ , as well as the infinite classes of discrete symmetries  $\Delta(3n^2)$  or  $\Delta(6n^2)$ .

**P5: Discrete symmetries and models of flavour mixing / 19****CP symmetry of order 4 and its consequences**Dr. IVANOV, Igor<sup>1</sup><sup>1</sup> *CFTP, IST, Lisbon***Corresponding Author:** igor.ivanov@tecnico.ulisboa.pt

I will present a 3HDM model with order-4 CP symmetry, the simplest model of the kind. I will discuss the physical fields with unusual CP properties (CP-half-odd scalars), the surprising clash between two different assignments of particle-antiparticle pairs, and the phenomenological consequences, both for the CP-conserving and spontaneously CP-broken cases.

**P5: Discrete symmetries and models of flavour mixing / 31****CP as a Symmetry of Symmetries**Dr. TRAUTNER, Andreas<sup>1</sup><sup>1</sup> *BCTP Bonn***Corresponding Author:** atrautner@uni-bonn.de

In this talk I will point out that charge conjugation (C), space-reflection (P), and time-reversal (T) transformations are outer automorphisms of the symmetries of any model and what that means. Besides its plain relevance for model building, understanding this point is crucial in order to understand the origin of (spontaneous or explicit) geometrical CP violation from discrete groups.

Based on a concrete example, I will also show how the presence of outer automorphisms, in general, gives rise to emergent symmetries in theories with spontaneous symmetry breaking.

**P8: New results from LHC; new facilities / 89****Prospects for charged Higgs searches****Author:** Prof. OSLAND, Per <sup>1</sup>**Co-Authors:** Prof. KRAWCZYK, Maria <sup>2</sup>; SANTOS, Rui <sup>3</sup>; Prof. MORETTI, Stefano <sup>4</sup>; Dr. PRUNA, Giovanni Marco <sup>5</sup><sup>1</sup> *University of Bergen*<sup>2</sup> *University of Warsaw*<sup>3</sup> *ISEL & CFTC Lisboa*<sup>4</sup> *NExT Institute (Southampton & RAL, UK)*<sup>5</sup> *PSI***Corresponding Author:** per.osland@ift.uib.no

A Higgs sector extended with one or more doublets implies the existence of charged Higgs bosons. An extensive experimental program is aimed at searching for these, but there are many constraints making the search difficult.

These constraints will be discussed, and different search channels.

**P8: New results from LHC; new facilities / 9****CP asymmetries tests in  $t\bar{t}$  production with ATLAS detector at LHC****Author:** Dr. MARTI-GARCIA, Salvador <sup>1</sup>**Co-Author:** Dr. CIOCIO, Alessandra <sup>2</sup><sup>1</sup> *IFIC-Valencia (CSIC and UVEG)*<sup>2</sup> *Lawrence Berkeley National Laboratory***Corresponding Author:** ztap042@live.rhul.ac.uk

Top quark pair events provide a source of b-hadrons where the charge of the b-quark at production can be inferred from the lepton from the top-quark decay. We present a measurement of same- and opposite-sign charge asymmetries measured in  $t\bar{t}$  events collected with the ATLAS detector in pp collisions at 8 TeV. The charge asymmetries are based on the charge of the lepton from the top-quark decay and the charge of the soft muon from the semileptonic decay of a b-hadron. Four CP asymmetries (one mixing and three direct) are extracted and are found to be compatible with zero and consistent with the Standard Model.

**P8: New results from LHC; new facilities / 77****Sensitivity of CLIC at 380 GeV to top FCNC decay  $t \rightarrow cH$** **Prof. ŻARNECKI, Aleksander Filip** <sup>1</sup><sup>1</sup> *Faculty of Physics, University of Warsaw***Corresponding Author:** zarnecki@fuw.edu.pl

In the Standard Model, FCNC top decays, possible on loop level only, are very strongly suppressed. Observation of any such decay would be a direct signature of the physics beyond SM. Large enhancements are possible in many "new physics" scenarios and the largest enhancement is in most cases expected for  $t \rightarrow cH$  decay.

Full simulation study for CLIC was based on the WHIZARD simulation of FCNC top decays within the 2HDM(III) model. Beam polarization and beam induced background were taken into account. Top pair production events with FCNC decay  $t \rightarrow cH$  can be identified based on the kinematic constraints and flavour tagging information. Due to large overlap in kinematic space with standard top pair events, final signal selection efficiency is small, at the 10% level. Expected limits on  $BR(t \rightarrow cH) \cdot BR(H \rightarrow b\bar{b})$  are compared with earlier results based on parton level simulation.

P1: T, C, P, CP, and CPT symmetries / 2

## VIP-2 at LNGS: An experiment on the validity of the Pauli Exclusion Principle for electrons

Dr. MARTON, Johann<sup>1</sup>

<sup>1</sup> *Stefan Meyer Institute, Austrian Academy of Sciences*

**Corresponding Author:** johann.marton@oeaw.ac.at

We are experimentally investigating possible violations of standard quantum mechanics predictions in the Gran Sasso underground laboratory in Italy. We test with high precision the Pauli Exclusion Principle (PEP) and the collapse of the wave function (collapse models). We present our method of searching for possible small violations of the PEP for electrons, through the search for "anomalous" X-ray transitions in copper atoms, produced by "fresh" electrons (brought inside the copper bar by circulating current) which can have the probability to undergo Pauli-forbidden transition to the 1 s level already occupied by two electrons and we describe the VIP-2 (Violation of PEP) experiment under data taking at the Gran Sasso underground laboratories. In this talk the new VIP-2 setup installed in the Gran Sasso underground laboratory will be presented. The goal of VIP2 is to test the PEP for electrons avoiding the Messiah-Greenberg superselection rule with unprecedented accuracy, down to a limit in the probability that PEP is violated at the level of  $10E^{-31}$ . We show preliminary experimental results and discuss implications of a possible violation.

P1: T, C, P, CP, and CPT symmetries / 54

## Status and prospects of the Mu2e Experiment at Fermilab

MURAT, Pavel<sup>1</sup>

<sup>1</sup> *Fermilab*

**Corresponding Author:** murat@fnal.gov

While fermion mixing in quark and neutrino sectors is large and well established experimentally, searches for charge lepton flavor violation (CLFV) so far bring null results.

Mu2e experiment at Fermilab will search for a lepton flavor violating process of a coherent muon to electron conversion on Al nuclei. This process is unique in several respects: it provides sensitivity to a wide range of CLFV interactions, it also has a striking experimental signature should allow Mu2e to reach the sensitivity level of  $G(\mu \rightarrow e \text{ conversion})/G(\text{total muon capture}) \sim 10^{-17}$ , four orders of magnitude lower than the current experimental limit.

I will present the status of Mu2e, explain how physics goals of the experiment drive its design, go over factors limiting the experimental sensitivity and discuss prospects for the future.

P1: T, C, P, CP, and CPT symmetries / 24

## Searches for Lepton number violation and resonances in the $K^{+-} \rightarrow \pi \mu \mu$ decays at the NA48/2 experiment

CRISTINA, Lazzeroni <sup>1</sup>

<sup>1</sup> *University of Birmingham, UK*

**Corresponding Author:** lperuzzo@uni-mainz.de

The NA48/2 experiment at CERN collected in 2003-2004 a large sample of charged kaon decays with multiple charged particles in the final state.

A new upper limit on the rate of the lepton number violating decay  $K^{+-} \rightarrow \pi^+ \mu^+ \mu^-$  obtained from this sample is reported.

Searches for two-body resonances in the  $K^{+-} \rightarrow \pi \mu \mu$  decays (including heavy neutral leptons and inflatons) in the accessible range of masses and lifetimes are presented.

P1: T, C, P, CP, and CPT symmetries / 23

## Model independent measurement of the leptonic kaon decay $K^{+-} \rightarrow \mu^+ \nu_e e^-$

CRISTINA, Lazzeroni <sup>1</sup>

<sup>1</sup> *University of Birmingham, UK*

**Corresponding Author:** lperuzzo@uni-mainz.de

The NA48/2 experiment at CERN collected a very large sample of charged kaon decays into multiple final states. From this data sample we have reconstructed about 1500 events of the very rare decay  $K^{+-} \rightarrow \mu^+ \nu_e e^-$  over almost negligible background in the region with  $m(e^+e^-)$  above 140 MeV, which is of great interest in Chiral Perturbation Theory. We present the  $m_{ee}$  spectrum and a model-independent measurement of the decay rate for this region.

P3: Discrete symmetries in cosmology / 60

## Heavy right-handed neutrino dark matter in left-right models

Dr. ZHANG, Yongchao <sup>1</sup>

<sup>1</sup> *Université Libre de Bruxelles*

**Corresponding Author:** yongchao.zhang@ulb.ac.be

Right-handed neutrinos (RHNs) are pure singlets under the electroweak gauge group and could generate the tiny neutrino masses via seesaw mechanisms and play the role of dark matter in specific models. We construct a class of models based on the gauge group  $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{Y_L} \times U(1)_{Y_R}$  in which a heavy copy of the SM fermions are introduced and the RHN DM is stabilized by an automatic  $Z_2$  symmetry in the lepton sector. In such models the active neutrino masses are obtained via the type-II seesaw mechanism, and there is a lower bound on the RHN DM mass at the TeV scale. The RHN DM could be made also long-lived by soft breaking of the  $Z_2$  symmetry and explain the PeV neutrinos observed at IceCube.

**P3: Discrete symmetries in cosmology / 29****General approach to dark matter coannihilation**KAMINSKA, Anna <sup>1</sup><sup>1</sup> *JGU Mainz***Corresponding Author:** akaminsk@uni-mainz.de

I will present a comprehensive classification of simplified models of coannihilating dark matter, based on the quantum numbers of the coannihilation partner and the discrete symmetry protecting the stability of the dark matter candidate. General implications for relic density and collider signatures will be discussed. In particular a very interesting class of models with a colored coannihilation partner, featuring promising LHC phenomenology and non-trivial early Universe production will be pointed out.

**P3: Discrete symmetries in cosmology / 53****Dark Matter and CP-violation in the Three-Higgs Doublet Model**Dr. SOKOLOWSKA, Dorota <sup>1</sup><sup>1</sup> *University of Warsaw***Corresponding Author:** dsok@fuw.edu.pl

In many scalar DM models an imposed discrete symmetry will result in the CP conservation. We present results for the 3HDM, the Standard Model with two additional inert doublets, where it is possible to have CP-violating effects and a stable Dark Matter candidate. We discuss the new regions of DM relic density opened up by CP-violation and constrain the parameter space of the CP-violating model using recent results from the LHC and DM direct and indirect detection experiments.

**P3: Discrete symmetries in cosmology / 52****Direct detection of exothermic dark matter with light mediator**Dr. HUANG, Da <sup>1</sup><sup>1</sup> *University of Warsaw***Corresponding Author:** dahuang@fuw.edu.pl

We study the dark matter (DM) direct detection for the models with the effects of the isospin-violating couplings, exothermic scatterings, and/or the lightness of the mediator, proposed to relax the tension between the CDMS-Si signals and null experiments. In the light of the new updates of the LUX and CDMSlite data, we find that many of the previous proposals are now ruled out, including the Ge-phobic exothermic DM model and the Xe-phobic DM one with a light mediator. We also examine the exothermic DM models with a light mediator but without the isospin violation, and we are unable to identify any available parameter space that could simultaneously satisfy all the experiments. The only models that can partially relax the inconsistencies are the Xe-phobic exothermic DM models with or without a light mediator. But even in this case, a large portion of the CDMS-Si regions of interest has been constrained by the LUX and SuperCDMS data.

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## Nonlinear eigenvalue problems

Prof. BENDER, Carl<sup>1</sup>

<sup>1</sup> *Washington University in St. Louis*

**Corresponding Author:** cmb@wustl.edu

Semiclassical (WKB) techniques are commonly used to find the large-energy behavior of the eigenvalues of linear time-independent Schroedinger equations. In this talk we generalize the concept of an eigenvalue problem to nonlinear differential equations. The role of an eigenfunction is now played by a separatrix curve, and the special initial

condition that gives rise to the separatrix curve is the eigenvalue. The Painleve transcendents are examples of nonlinear eigenvalue problems, and semiclassical techniques are devised to calculate the behavior of the large eigenvalues. This behavior is found by reducing the Painleve equation to the linear Schroedinger equation associated with a non-Hermitian PT-symmetric Hamiltonian. The concept of a nonlinear eigenvalue problem extends far beyond the Painleve equations to huge classes of nonlinear differential equations.

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## PT symmetric interpretation of unstable effective potentials

**Author:** Prof. SARKAR, Sarben<sup>1</sup>

**Co-Authors:** Prof. MAVROMATOS, Nikoloas<sup>1</sup>; Prof. BENDER, Carl<sup>2</sup>

<sup>1</sup> *King's College London*

<sup>2</sup> *Washington University*

**Corresponding Author:** sarben.sarkar@kcl.ac.uk

The conventional interpretation of the one-loop effective potentials of the Higgs field in the standard model and the gravitino condensate in dynamically broken supergravity is that these theories are unstable at large field values. A  $\mathbb{Z}_2$ -symmetric reinterpretation of these models at a quantum-mechanical level eliminates these instabilities and suggests the conjecture that these instabilities may also be tamed at the quantum-field-theory level.

Session / 10

## Review of Higgs Results from the ATLAS experiment

**Author:** Dr. MARTI-GARCIA, Salvador<sup>1</sup>

**Co-Author:** Dr. CIOCIO, Alessandra<sup>2</sup>

<sup>1</sup> *IFIC-Valencia (CSIC and UVEG)*

<sup>2</sup> *Lawrence Berkeley National Laboratory*

**Corresponding Author:** alessandro.calandri@gmail.com

The LHC has delivered a large amount of data at a center of mass energy of 13 TeV. The experimental sensitivity with this data set is equivalent to the one from run-1 for the Higgs boson (125 GeV), and surpasses it for searches for higher mass Higgs-like particles. This talk will review recent ATLAS results on both of these topics.

Session / 45

## Higgs Physics at CMS

COLLABORATION, CMS <sup>1</sup>; Mr. DONATO, Silvio <sup>2</sup>

<sup>1</sup> *CMS Collaboration*

<sup>2</sup> *University of Zurich*

**Corresponding Author:** silvio.donato@cern.ch

Overview of h(125) boson properties as well as searches for extended scalar sectors, with emphasis on LHC Run 2 results.

P8: New results from LHC; new facilities / 72

## Run-II results and the 2HDM

Dr. FERREIRA, Pedro <sup>1</sup>

<sup>1</sup> *ISEL and CFTC, UL*

**Corresponding Author:** pmmferreira@fc.ul.pt

The impact of recent Run-II results on the parameter space of the 2HDM is analysed, with emphasis on the charged higgs mass and the wrong-sign limit.

P8: New results from LHC; new facilities / 81

## Effective Field Theory in quest to parametrise Higgs properties: the transverse momentum spectrum case

Ms. ILNICKA, Agnieszka <sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** ajilnicka@gmail.com

After the Higgs boson discovery, LHC turned into the precision machine to explore its properties. In case new resonances will not be found, the only access to New Physics would be via measuring small deviations from the SM predictions. A consistent approach which can be useful in both above cases is a bottom-up Effective Field Theory, with dimension six operators build of Standard Model fields. We present how this approach would work in case of the transverse momentum spectrum of the Higgs particle. In our calculation we augmented the Standard Model with three additional operators: modifications of the top and bottom Yukawa couplings, and a point-like Higgs coupling to gluons. We present resummed transverse-momentum spectra including the effect of these operators at NLL+NLO accuracy and study their impact on the shape of the distribution. We find that such modifications, while affecting the total rate within the current uncertainties, can lead to significant distortions of the spectrum. We also discuss the effect of the chromomagnetic operator on the Higgs production cross section at LO.

**P8: New results from LHC; new facilities / 7**

## Supersymmetry searches in ATLAS

**Author:** Dr. MARTI-GARCIA, Salvador <sup>1</sup>

**Co-Author:** Dr. CIOCIO, Alessandra <sup>2</sup>

<sup>1</sup> *IFIC-Valencia (CSIC and UVEG)*

<sup>2</sup> *Lawrence Berkeley National Laboratory*

**Corresponding Author:** emma.torro.pastor@cern.ch

Weak scale supersymmetry remains one of the best motivated and studied Standard Model extensions. This talk summarises recent ATLAS results for searches for supersymmetric (SUSY) particles. Weak and strong production in both R-Parity conserving and R-Parity violating SUSY scenarios are considered. The searches involved final states including jets, missing transverse momentum, light leptons, taus or photons, as well as long-lived particle signatures.

**P8: New results from LHC; new facilities / 42**

## Inert scalars at colliders

HASHEMI, Majid <sup>1</sup>; Prof. KRAWCZYK, Maria <sup>2</sup>; NAJJARI, Saereh <sup>2</sup>

<sup>1</sup> *University of Shiraz*

<sup>2</sup> *University of Warsaw*

**Corresponding Author:** saereh.najjari@fuw.edu.pl

Inert doublet model (IDM) is the most natural extension of the scalar sector of the Standard Model which involves a second scalar doublet, odd under a discrete symmetry  $Z_2$ . Due to this discrete  $Z_2$  symmetry the lightest neutral scalar of IDM can constitute a realistic dark matter candidate. In this talk I will discuss the discovery prospects of IDM scalars at the LHC and future  $e^+e^-$  linear colliders.

**P5: Discrete symmetries and models of flavour mixing / 40**

## Phenomenological prospects for two Higgs doublet models with controlled FCNC

Dr. NEBOT GÓMEZ, Miguel <sup>1</sup>

<sup>1</sup> *CFTP - Lisbon*

**Corresponding Author:** negomi@uv.es

Flavour changing couplings of neutral scalar fields, if not tamed, constitute a serious source of concern given the impressive existing experimental constraints. Mixing of the different neutral scalar fields present in such scenarios can yield, in particular, a would-be Standard Model 125 GeV scalar with (i) modified flavour conserving couplings, (ii) flavour changing couplings to (a) quarks in the up or down sectors, and (b) charged leptons or neutrinos. Considering the constraints imposed by the LHC (run I) and flavour data, an analysis of the phenomenological prospects for BGL models, a class of two Higgs doublet models where flavour changing interactions arise in a symmetry-controlled manner, is presented.



**P5: Discrete symmetries and models of flavour mixing / 86****Assessing lepton-flavour non-universality from  $B \rightarrow K^* \ell \ell$  angular analyses**Dr. MATIAS, Joaquim<sup>1</sup>; Dr. DESCOTES-GENON, Sébastien<sup>2</sup>; Dr. VIRTO, Javier<sup>3</sup>; Mr. CAPDEVILA, Bernat<sup>4</sup><sup>1</sup> *Institut de Física d'Altes Energies (IFAE) Universitat Autònoma de Barcelona (UAB)*<sup>2</sup> *Laboratoire de Physique Théorique (UMR 8627), CNRS, Univ. Paris-Sud*<sup>3</sup> *Albert Einstein Center for Fundamental Physics, Universität Bern*<sup>4</sup> *Institut de Física d'Altes Energies (IFAE)***Corresponding Author:** bcapdevila@ifae.es

The  $B \rightarrow K^* \mu \mu$  decay exhibits deviations with respect to Standard Model expectations and the measurement of the ratio  $R_K$  hints at a violation of lepton-flavour universality in  $B \rightarrow K \ell \ell$  transitions. Both effects can be understood in model-independent fits as a short-distance contribution to the Wilson coefficient  $C_9^\mu$ , with some room for similar contributions in other Wilson coefficients for  $b \rightarrow s \mu \mu$  transitions. I will discuss how a full angular analysis of  $B \rightarrow K^* \ell \ell$  and its comparison with  $B \rightarrow K^* \mu \mu$  could improve our understanding of these anomalies and help confirming their interpretation in terms of short-distance New Physics. For this purpose, I will introduce and discuss several observables of interest in this context and show their potential to distinguish between different New Physics benchmark scenarios suggested by the global fits. In particular, I will analyse with special attention the sensitivity of these observables to hadronic uncertainties from SM contributions with charm loops.

**P5: Discrete symmetries and models of flavour mixing / 88****Higgs-Flavon Mixing and  $h \rightarrow \mu \tau$** Mr. KOIVUNEN, Niko<sup>1</sup>; Dr. KEUS, Venus<sup>1</sup>; Prof. HUITU, Katri<sup>1</sup>; Prof. LEBEDEV, Oleg<sup>1</sup><sup>1</sup> *University of Helsinki***Corresponding Author:** niko.koivunen@helsinki.fi

ATLAS and CMS have reported an excess in the flavour violating decay of the Higgs boson,  $h \rightarrow \mu \tau$ . It can be shown that this result can be accommodated through a mixing of the Higgs with the Flavon, the field responsible for generating the Yukawa matrices in the lepton sector. In this talk I will present a model which employs a version of the Froggatt-Nielsen mechanism at the electroweak scale, with only the leptons and the flavon transforming non-trivially under the corresponding symmetry group. This model explains the reported excess. This talk is based on a paper: "Higgs-Flavon mixing and  $h \rightarrow \mu \tau$ ", JHEP 1605 (2016) 026, arXiv:1603.06614.

**P5: Discrete symmetries and models of flavour mixing / 34****Flavour symmetries in THDM type III****Author:** Prof. ZRAŁEK, Marek <sup>1</sup>**Co-Authors:** DZIEWIT, Bartosz <sup>2</sup>; Ms. RICHTER, Monika <sup>1</sup>; HOLECZEK, Jacek <sup>3</sup>; Dr. ZAJĄC, Sebastian <sup>4</sup><sup>1</sup> *University of Silesia*<sup>2</sup> *Univeristy of Silesia*<sup>3</sup> *Institute of Physics, University of Silesia*<sup>4</sup> *Cardinal Stefan Wyszyński University in Warsaw***Corresponding Author:** monikarichter18@gmail.com

Before 2012 it was thought that the ultimate solution to the 'PMNS matrix' mystery has been found. Within the years, the groups of high-energy physicist were trying to predict theoretically the mixing parameters in the lepton sector using the discrete non-abelian symmetry groups. They succeeded: the tribimaximal mixing pattern which was based on the  $A_4$  symmetry gave the right answer. However, the discovery of the non-zero value of the reactor angle which took place in 2012, shed a new light on this branch of physics. It became quite obvious that the tribimaximal mixing must have been rejected and replaced by new one. Since then, the worthy substitute of the tribimaximal mixing pattern is intensively searched for.

In order to obtain some new, innovative results we have decided to begin the studies of THDM type III extended by the discrete non-abelian flavour symmetry groups  $\mathcal{G}_F$ . This enlargement of the scalar sector prevents from the group symmetry breaking simultaneously leading to the non-trivial charged lepton and neutrino mass matrices.

Apart from the test of the feasible mass matrices, the special attention has been also paid to the generated mixing patterns. The results are quite surprising.

**P2: Emergence of symmetries from entanglement / 59****The KLOE-2 experiment at DAFNE****Prof. DI DOMENICO, Antonio** <sup>1</sup><sup>1</sup> *Sapienza University of Rome and INFN sez. Roma***Corresponding Author:** erika.delucia@lnf.infn.it

The KLOE-2 experiment at the INFN Laboratori Nazionali di Frascati (LNF) is currently taking data at the upgraded  $e^+e^-$  DAFNE collider. KLOE-2 represents the continuation of KLOE with a new physics program mainly focused on the study of  $K$  short,  $\eta$  and  $\eta'$  decays as well as on kaon interferometry, test of discrete symmetries, and search for physics beyond the Standard Model. The new data taking campaign aiming to collect more than  $5 \text{ fb}^{-1}$  integrated luminosity in the next couple of years, will allow in particular to perform CPT symmetry and quantum coherence tests using entangled neutral kaons with an unprecedented precision. The general purpose KLOE detector, composed by one of the biggest drift chamber ever built surrounded by a lead-scintillating fiber Electromagnetic Calorimeter among the best ones for energy and timing performance at low energies, undergone several upgrades including State-of-The-art cylindrical GEM detector: the Inner Tracker. To improve its vertex reconstruction capabilities near the interaction region, KLOE-2 is the first high-energy experiment using the GEM technology with a cylindrical geometry, a novel idea that was developed at LNF exploiting the kapton properties to build a transparent and compact tracking system. An overview of the KLOE-2 experiment will be given including present status and achievements together with physics plans.

**P2: Emergence of symmetries from entanglement / 84****Belle achievements and Belle II prospects for CP violation**LI GIOI, Luigi <sup>1</sup><sup>1</sup> *Max-Planck-Institut für Physik***Corresponding Author:** ligioi@mpp.mpg.de

The Belle experiment has accomplished various CP violation measurements, in order to constrain the CKM Unitarity Triangle and to search for New Physics signatures, using a data sample of 772 million B-meson pairs. The Belle II experiment will extend research capabilities in this field, thanks to the 50 times larger integrated luminosity expected at the SuperKEKB e+e- collider. The results from Belle and future prospects at Belle II are presented.

**P2: Emergence of symmetries from entanglement / 1****BABAR results on T and CPT symmetry in B<sub>0</sub>-B<sub>0</sub>bar mixing and in B<sub>0</sub> to c cbar K<sub>0</sub> decays**Prof. SCHUBERT, Klaus R. <sup>1</sup><sup>1</sup> *Johannes Gutenberg Universitaet Mainz***Corresponding Author:** klaus.schubert@tu-dresden.de

The presentation reviews the results obtained by the BABAR experiment on  $|q/p|$ ,  $\text{Re}(z)$  and  $\text{Im}(z)$  in B<sub>0</sub>-B<sub>0</sub>bar mixing as well as on  $|\lambda|$  and  $\text{Im}(\lambda)$  in decays B<sub>0</sub> to c cbar K<sub>0</sub>. The 2016 results on  $|\lambda|$  and  $\text{Re}(z)$  will be presented in more detail.

**P2: Emergence of symmetries from entanglement / 41****Entangled  $B_d$  mesons and genuine T, CP and CPT asymmetry parameters**Dr. NEBOT GÓMEZ, Miguel <sup>1</sup><sup>1</sup> *CFTP - Lisbon***Corresponding Author:** negomi@uv.es

The precise connection between the theoretical T, CP, CPT asymmetries and the experimental asymmetries in a B-factory of entangled states is established.

While the theoretical asymmetries are expressed in terms of transition probabilities between neutral meson  $B_d$  states, the experimental ones correspond to double decay rate intensities. This precise connection allows to identify genuine Asymmetry Parameters in the time distribution of the asymmetries and their measurability by disentangling genuine and possible fake terms. Concentrating on Flavour-CP eigenstate decay products, nine asymmetry parameters — three different observables for each one of the three symmetries — are expressed in terms of the ingredients of the Weisskopf-Wigner dynamical description of the entangled  $B_d$  meson states. They are obtained from a global fit to the experimental results from the BaBar collaboration. Possible fake terms are shown to be compatible with zero while the non-vanishing genuine terms are impressive separate direct evidence of Time-Reversal-violation and CP-violation in these transitions (and compatible with Standard Model expectations). Noticeably, an intriguing 2-sigma effect for the  $\text{Re}(\theta)$  parameter responsible of CPT-violation is found; interpreted as an upper limit, it constitutes the current best limit,  $|M_{\bar{B}^0 B^0} - M_{B^0 \bar{B}^0}| < 4.0 \times 10^{-5}$  eV at 95% C.L., for the diagonal flavour terms of the mass matrix.

**P2: Emergence of symmetries from entanglement / 61****Discrete symmetries and QM studies with entangled neutral kaons at KLOE-2**Prof. DI DOMENICO, Antonio <sup>1</sup><sup>1</sup> *Sapienza University of Rome and INFN sez. Roma***Corresponding Author:** aleksander.gajos@doctoral.uj.edu.pl

Long history of kaon physics results from KLOE is being continued at upgraded KLOE-2 detection system. Entangled neutral kaon pairs produced at DAFNE are a unique tool to probe discrete symmetries and/or QM basic principles at the utmost precision. The status of the latest ongoing analyses using the most refined analyses tools will be presented and discussed:

(i) search for decoherence and CPT violation effects in the

 $\Phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^-$  decay,

(ii) test of CP and CPT symmetries in KS semileptonic decays,

(iii) test of Time reversal and CPT in transitions in

 $\Phi \rightarrow K_S K_L \rightarrow \pi \nu, 3\pi^0, (2\pi)$  decays,(iv) study of the  $K_S \rightarrow \pi^+ \pi^- \pi^0$  decay.**P4: Neutrino masses, mixing, and discrete symmetries / 43****First constrains on CP violation in lepton sector from the T2K experiment**Dr. NOWAK, Jaroslaw <sup>1</sup><sup>1</sup> *Lancaster University***Corresponding Author:** j.nowak@lancaster.ac.uk

T2K is a long-baseline neutrino experiment in which a muon neutrino beam produced at J-PARC in Tokai (Japan) travels 295 km towards the Super-Kamiokande detector with the intention of studying neutrino oscillations via the disappearance of muon neutrinos and the appearance of electron neutrinos. Since the start of operations in 2010, T2K has observed muon neutrino to electron neutrino oscillations, opening the door to the observation of CP violation in neutrino mixing, and performed the most precise measurement of the muon neutrino disappearance parameters to date. In a joint analysis between these two modes, T2K produced the first constraints on the observation of the CP-violating phase. Starting in 2014, T2K

has been running primarily with antineutrino beam to study the corresponding antineutrino oscillations, resulting in leading measurements of the muon antineutrino disappearance parameters. The joint analysis of neutrino and antineutrino data indicates that CP-conserving parameters lie outside the 90% confidence interval. In this talk, I will present recently-updated neutrino oscillation results.

**P4: Neutrino masses, mixing, and discrete symmetries / 67****Results from the NOvA Long-Baseline Neutrino Oscillations Experiment**Dr. HOLIN, Anna <sup>1</sup><sup>1</sup> *University College London***Corresponding Author:** anna.holin@ucl.ac.uk

The NOvA long-baseline neutrino oscillations experiment is currently taking data hoping to determine answers to important questions such as the neutrino mass hierarchy and the quadrant of the atmospheric mixing angle. NOvA uses two functionally identical detectors, one close to the NuMI neutrino beam source at Fermilab in Illinois, and another 810km away in Ash River in Minnesota, to measure muon neutrino oscillations. A summary of NOvA's results so far is presented, focusing especially on the muon neutrino disappearance and the electron neutrino appearance channels.

**P4: Neutrino masses, mixing, and discrete symmetries / 44****Latest results from Daya Bay**VOROBEL, Vit <sup>1</sup><sup>1</sup> *Charles University***Corresponding Author:** vit.vorobel@mff.cuni.cz

The Daya Bay Reactor Neutrino Experiment was designed to measure  $\theta_{13}$ , the smallest mixing angle in the three-neutrino mixing framework, with unprecedented precision. The experiment consists of eight functionally identical detectors placed underground at near (~500 m) and far (~2 km) baselines from three pairs of nuclear reactors in South China. Since Dec. 2011, the experiment has been running stably for more than 4 years, and has collected the largest reactor anti-neutrino sample to date. Daya Bay has precisely measured  $\theta_{13}$  and the effective mass splitting in the electron antineutrino disappearance channel. Daya Bay has also performed a number of other precise measurements, such as a high-statistics determination of the absolute reactor antineutrino flux and spectrum, and a search for sterile neutrino mixing, among others. The most recent results from Daya Bay will be discussed in this talk, as well as the current status and future prospects of the experiment.

**P4: Neutrino masses, mixing, and discrete symmetries / 85****Latest Results from MINOS and MINOS+**Mr. DE RIJCK, Simon <sup>1</sup><sup>1</sup> *University of Texas at Austin***Corresponding Author:** simonderijck@gmail.com

MINOS/MINOS+ is a long-baseline neutrino oscillation experiment employing two functionally identical magnetized steel-scintillator tracking calorimeters located on Fermilab's NUMI beamline axis. MINOS ran for ten years collecting beam neutrino and antineutrino data samples corresponding to a neutrino beam peak energy of 3 GeV, as well as an atmospheric neutrino data sample. MINOS+ is a continuation of MINOS using a neutrino beam with an energy peak shifted to 6 GeV and ran for three years until June 2016. With increased statistics at higher neutrino energies, MINOS+ has improved sensitivity to exotic phenomena including sterile neutrinos, large extra dimensions, and non-standard interactions. We report on the latest results from MINOS, including a combination of the MINOS and Daya Bay/Bugey-3 sterile neutrino searches, and results incorporating the first two years of MINOS+ data.

**P2: Emergence of symmetries from entanglement / 80****Studies of discrete symmetries in a purely leptonic system using Jagiellonian Positron Emission Tomograph**Prof. MOSKAL, Pawel<sup>1</sup><sup>1</sup> Jagiellonian University**Corresponding Author:** p.moskal@uj.edu.pl

The C, CP, T and CPT symmetries are of fundamental importance in physics. Violations of T or CP invariance in purely leptonic systems have never been seen so far. Based on known mechanisms of C and CP violations, one cannot explain the large asymmetry between matter and antimatter in the observable Universe. Positronium is the lightest purely leptonic object decaying into photons. As an atom bound by a central potential, it is a parity eigenstate, and as an atom built out of an electron and an anti-electron, it is an eigenstate of the charge conjugation operator. Therefore, the positronium is a unique laboratory to study discrete symmetries whose precision is limited, in principle, by the effects due to the weak interactions expected at the level of  $10^{-14}$  and photon-photon interactions expected at the level of  $10^{-9}$ . The newly constructed J-PET tomograph enables to perform tests of discrete symmetries in the leptonic sector via the determination of the expectation values of the discrete-symmetries-odd operators, which may be constructed from the spin of ortho-positronium atom and the momenta and polarization vectors of photons originating from its annihilation. We will present the potential of the J-PET detector to test the C, CP, T and CPT symmetries in the decays of positronium atoms and report on the first data-taking campaigns. With respect to the previous experiments performed with crystal based detectors, J-PET built of plastic scintillators, provides superior time resolution, higher granularity, lower pile-ups, and opportunity of determining photon's polarization. These features allow us to expect a significant improvement in tests of discrete symmetries in decays of positronium atom (a purely leptonic system).

J-PET: P. Moskal et al., Acta Phys. Polon. B47 (2016) 509.

J-PET: A. Gajos et al., Nucl. Instrum. Meth. A819 (2016) 54.

J-PET: D. Kamińska et al., Eur. Phys. J. C76 (2016) 445.

J-PET: P. Moskal et al., Phys. Med. Biol. 61 (2016) 2025.

J-PET: P. Moskal et al., Nucl. Instrum. Meth. A775 (2015) 54.

**P2: Emergence of symmetries from entanglement / 27****Overview of BESIII**Prof. HUANG, Guangshun<sup>1</sup><sup>1</sup> University of Science and Technology of China (USTC)**Corresponding Author:** wang@kph.uni-mainz.de

This talk will summarize recent progresses of BESIII physics, including light hadron, charmonium and charmonium-like states, charm physics, etc., based on large data sets taken with BESIII at BEPCII.

**P2: Emergence of symmetries from entanglement / 83**

**Role of entanglement in extracting information on quantum processes**

Dr. DEMKOWICZ-DOBRZANSKI, Rafal<sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** demko@fuw.edu.pl

Quantum metrology aims at utilizing ubiquitous quantum features such as entanglement in order to boost measurement precision in the most challenging metrological tasks including gravitational wave detection or stabilization of atomic clocks. The talk will review theoretical and experimental advances in the field and provide general framework potentially applicable also to high energy physics processes.

**P7: Strings, branes, extra dimensions, and discrete symmetries / 79**

**Gravitational waves from domain walls in the Standard Model**

**Author:** Mr. KRAJEWSKI, Tomasz<sup>1</sup>

**Co-Authors:** Prof. LALAK, Zygmunt<sup>2</sup>; Dr. LEWICKI, Marek<sup>1</sup>; OLSZEWSKI, Pawel<sup>1</sup>

<sup>1</sup> *University of Warsaw*

<sup>2</sup> *IITP UW*

**Corresponding Author:** tkrajewski@fuw.edu.pl

The study of the renormalisation group improved effective potential of the Standard Model has revealed the existence of a local maximum at strengths of the order of  $10^{10}$  GeV. If the Standard Model is valid for very high energy scales, then the possibility of the production of cosmological domain walls in the early Universe occurs. We investigated the dynamics of the network of domain walls using lattice simulations. The spectrum of gravitational waves emitted during the decay of domain walls was computed.

**P7: Strings, branes, extra dimensions, and discrete symmetries / 33**

**The Sym2Int program: going from symmetries to interactions**

Dr. FONSECA, Renato<sup>1</sup>

<sup>1</sup> *IFIC - CSIC/UV*

**Corresponding Author:** renato.fonseca@ific.uv.es

Model builders often need to find the most general Lagrangian which can be constructed from a given list of fields. These fields are actually representations of the Lorentz and gauge groups (and maybe some discrete symmetry group as well). I will describe a simple program (Sym2Int) which helps to automate this task by listing all possible interactions between Lorentz/gauge group representations.

**P7: Strings, branes, extra dimensions, and discrete symmetries / 107**

**Ideal clocks - a convenient fiction**

Dr. DRAGAN, Andrzej <sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** dragan@fuw.edu.pl

We show that no device built according to the rules of quantum field theory can measure proper time along its path. Highly accelerated quantum clocks experience the Unruh effect, which inevitably influences their time rate. This contradicts the concept of an ideal clock, whose rate should only depend on the instantaneous velocity."

**Session / 106**

**Test of discrete symmetries in the kaon system**

Prof. DI DOMENICO, Antonio <sup>1</sup>

<sup>1</sup> *Sapienza University of Rome and INFN sez. Roma*

**Corresponding Author:** antonio.didomenico@roma1.infn.it

Test of discrete symmetries in the kaon system will be reviewed.

**Session / 76**

**CPT Violation: Motivation, theoretical models and (some) experimental searches**

Prof. MAVROMATOS, Nikolaos <sup>1</sup>

<sup>1</sup> *King's College London*

**Corresponding Author:** nikolaos.mavromatos@kcl.ac.uk

CPT is a theorem of flat spacetime, local, relativistic (Lorentz invariant) and unitary quantum field theories. However in many models of quantum gravity or early Universe, where spontaneous breaking of one or more of the theorem's assumptions may occur, CPT may be violated. In the talk I review and discuss critically theoretical motivations and models entailing CPT violation in both the early Universe and today, and discuss some of its searches. In particular, I will discuss how CPT violation in some models of the early universe may lead to phenomenologically acceptable matter-antimatter asymmetry in the Cosmos and I will present scenarios by means of which such models, entailing relatively strong CPT Violation in early epochs, are in agreement with the very stringent bounds of such a violation today. In the second part of the talk, I will describe some experimental searches for CPT Violation, giving emphasis to those associated with the violation (or rather ill-defined nature of the corresponding generator) of CPT as a consequence of unobserved (in local scattering experiments) quantum-gravity degrees of freedom. The latter type of CPT violation, termed "intrinsic", has the interesting feature of affecting the Einstein-Podolsky-Rosen (EPR) correlations in entangled particle states, such as those of neutral mesons in Phi or B factories ("omega-effect"). I describe how such an "omega-effect" can be currently constrained in these systems and give future prospects of such tests.



Session / 102

## Review of the recent anomalies in flavour physics

Corresponding Author: mahmoudi@in2p3.fr

Review of the recent anomalies in flavour physics

Session / 103

## Three Higgs doublet models, spontaneous symmetry breaking with $S_3$ symmetry.

Corresponding Author: rebelo@tecnico.ulisboa.pt

Special Session of the DISCRETE 2016 Symposium and the Leopold Infeld Colloquium / 96

## Gravitational waves: early theoretical work

TRAUTMAN, Andrzej<sup>1</sup>

<sup>1</sup> *University of Warsaw*

Corresponding Author: andrzej.trautman@fuw.edu.pl

Special Session of the DISCRETE 2016 Symposium and the Leopold Infeld Colloquium / 87

## The first detections of gravitational waves from binary black holes

Dr. BEJGER, Michal<sup>1</sup>

<sup>1</sup> *Centrum Astronomiczne im. Mikołaja Kopernika*

Corresponding Author: bejger@camk.edu.pl

Recent direct detections of gravitational waves from coalescing binary black holes systems herald a new era in the observational astronomy, as well as in experimental verifications of the theories of gravity. I will present the principles of detection of gravitational waves, current state-of-art laser interferometric detectors (Advanced LIGO and Advanced Virgo), and the most promising astrophysical sources of gravitational waves.

Special Session of the DISCRETE 2016 Symposium and the Leopold Infeld Colloquium / 57

## Supergravity and its Legacy: Personal Prelude and the Play

Prof. FERRARA, Sergio<sup>1</sup>

<sup>1</sup> *CERN*

Corresponding Author: sergio.ferrara@cern.ch

A recollection of events which preceded the construction of Supergravity in 1976 and its main developments over the four decades which then followed, are presented in this feature

Session / 56

## Natural Alignment in the Two Higgs Doublet Model

Prof. PILAFTSIS, Apostolos <sup>1</sup>

<sup>1</sup> *University of Manchester*

**Corresponding Author:** apostolos.pilaftsis@manchester.ac.uk

The current LHC Higgs data suggest that the couplings of the observed 125 GeV Higgs boson must be remarkably close to the Standard Model (SM) expectations. This implies that any New Physics due to an extended Higgs sector must lead to the so-called SM alignment limit, where one of the Higgs bosons behaves exactly like that of the SM. In the context of the Two Higgs Doublet Model (2HDM), this alignment is often associated with either decoupling of the heavy Higgs sector or fine-tuning the parameters of the 2HDM potential. In the first part of my talk, I will present a novel symmetry justification for ‘natural’ alignment without necessarily decoupling or fine-tuning. I will show that there exist only three different symmetry realizations of such a natural alignment to occur in the 2HDM. In the second part of my talk, I will analyze new collider signatures for the heavy Higgs sector in the natural alignment limit, which dominantly lead to third-generation quarks in the final state and can serve as a useful observational tool during the Run-II phase of the LHC.

Session / 36

## Tests of Lorentz and CPT symmetry with hadrons and nuclei

**Author:** Dr. NOORDMANS, Jacob <sup>1</sup>

**Co-Authors:** Prof. TIMMERMANS, Rob <sup>2</sup>; Dr. DE VRIES, Jordy <sup>3</sup>

<sup>1</sup> *Universidade do Algarve / CENTRA*

<sup>2</sup> *Van Swinderen Institute / University of Groningen*

<sup>3</sup> *Nikhef*

**Corresponding Author:** jpnoordmans@gmail.com

Some theories of quantum gravity allow for the possibility of the breakdown of Lorentz and CPT symmetry. At presently attainable energies, the consequences of the (high-energy) breakdown of these fundamental symmetries are best described by an effective field theory approach, called the standard model extension (SME). To explore the breaking of Lorentz and CPT invariance in strong interactions, we apply the machinery of chiral perturbation theory to the SME. We derive the effective chiral Lagrangian with hadronic and electromagnetic interactions in terms of the effective degrees of freedom (pions, photons, and nucleons), corresponding to a selected set of Lorentz and CPT-violating operators. We derive strict limits on some of the tensors that quantify the symmetry breaking. We also point to possible new opportunities for studying Lorentz and CPT violation, using chiral perturbation theory.

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## Latest measurements on the antiproton-to-electron mass ratio using buffer-gas cooled antiprotonic helium atoms

Dr. SOTER, Anna <sup>1</sup><sup>1</sup> *Max Planck Institute for Quantum Optics***Corresponding Author:** anna.soter@mpq.mpg.de

The CPT symmetry implies that a particle and its antiparticle have the same mass. The antiproton-to-electron mass ratio can be precisely determined from the single-photon transition frequencies of antiprotonic helium. We measured 13 such frequencies with laser spectroscopy to a fractional precision of 2.5 to 16 ppb. About 2 billion antiprotonic helium atoms were cooled to temperatures  $\sim 1.5$  K by using buffer-gas cooling in cryogenic low-pressure helium gas, resulting in sharp spectral lines of small thermal Doppler width. Compared with the results of three-body quantum electrodynamics calculations, the antiproton-to-electron mass ratio was determined as  $1836.1526734(15)$ , which agrees with a recent proton-to-electron experimental value within  $8 \times 10^{-10}$ .

Session / 90

## SUSY models and symmetries in the era of the LHC

Prof. MUNOZ, Carlos <sup>1</sup><sup>1</sup> *UAM IFT, Madrid***Corresponding Author:** c.munoz@uam.es

Since supersymmetry (SUSY) is still one of the most attractive theories for physics beyond the standard model, let us suppose that it will be discovered at the LHC. Then, one key question is: What SUSY model do we expect to be detected? During this talk I will discuss the advantages and disadvantages, from the theoretical viewpoint, of several models that have been proposed in the literature along the years (with and without the discrete symmetry of R parity), as well as its associated phenomenology.

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## Discrete gauge symmetries, fermion masses, mixing angles and CP violation.

Prof. ROSS, Graham <sup>1</sup><sup>1</sup> *Rudolf Peierls Centre for Theoretical Physics, University of Oxford***Corresponding Author:** g.ross1@physics.ox.ac.uk

The possibility that quark, charged lepton and neutrino masses, mixing angles and CP violation can be described by a spontaneously broken family symmetry is explored. An example is presented involving a non-Abelian discrete gauge family symmetry coupled with a Grand Unified relation between quarks and leptons. The difference between quark and lepton mixing angles results from the see-saw mechanism. Quark, charged lepton and neutrino mass matrices have a common texture zero and its implications are determined.

Session / 6

## The MoEDAL experiment at LHC: status and results

Dr. MITSOU, Vasiliki <sup>1</sup>

<sup>1</sup>IFIC, CSIC - Univ. Valencia

**Corresponding Author:** vasiliki.mitsou@cern.ch

The MoEDAL experiment at the LHC is optimised to detect highly ionising particles such as magnetic monopoles, dyons and (multiply) electrically charged stable massive particles predicted in a number of theoretical scenarios. MoEDAL, deployed in the LHCb cavern, combines passive nuclear track detectors with magnetic monopole trapping (MMT) volumes, while spallation-product backgrounds are being monitored with an array of MediPix pixel detectors. An introduction to the detector concept and its physics reach, complementary to that of the large general purpose LHC experiments ATLAS and CMS, will be given. Emphasis will be given to the first MoEDAL results, where the null results from a search for magnetic monopoles in MMTs exposed in 2012 LHC collisions are used to set the first LHC limits on particles with magnetic charges more than 1.5 Dirac charge. The potential to search for heavy, long-lived supersymmetric electrically-charged particles is also discussed.

P7: Strings, branes, extra dimensions, and discrete symmetries / 95

## Late-time quantum backreaction in cosmology

GLAVAN, Drazen <sup>1</sup>

<sup>1</sup> University of Warsaw

**Corresponding Author:** drazen.glavan@fuw.edu.pl

Quantum fluctuations of matter fields carry energy density and pressure associated to them, and represent a source for the Einstein equation. This source in principle alters the classical dynamics - an effect called the quantum backreaction. An open question is whether quantum backreaction ever becomes large enough to appreciably alter the classical dynamics, and if it does, what is its influence and how to quantify it. I will present a cosmological model of a very light, non-minimally coupled scalar field, where the quantum fluctuations of the scalar matter field contribute negligibly to the expansion rate of the Universe throughout most of its history, but start contributing dominantly at late times. When the backreaction becomes dominant its effect is to accelerate the expansion of the Universe mimicking the effect of the cosmological constant today. This effect is inferred by solving self-consistently the quantum corrected Friedmann equations using an adapted stochastic formalism.

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## Peccei-Quinn NMSSM inspired by local F-theory GUTs models

Dr. PAWELCZYK, Jacek <sup>1</sup>

<sup>1</sup> Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Poland

**Corresponding Author:** jacek.pawelczyk@fuw.edu.pl

I shall discuss a particular version of the Peccei-Quinn (PQ) NMSSM characterized by a hierarchical flavor structure based on flavored gauge mediation.

The model construction is inspired by local F-theory GUTs.

In this way we can express the Lagrangian of the PQ NMSSM through very few parameters.

The obtained model is studied

numerically and confronted with the most relevant phenomenological constraints.

**P7: Strings, branes, extra dimensions, and discrete symmetries / 21**

**Discrete and continuous description of physical phenomena**

Prof. GINZBURG, Ilya <sup>1</sup>

<sup>1</sup> *Sobolev Institute of Mathematics SB RAS Novosibirsk Russia*

**Corresponding Author:** ginzburg@math.nsc.ru

In many cases the phenomena in Nature are described by following scheme. Let our phenomenon is described by quantity  $z$ , which changes in some time moments  $t_n$  and  $z(t_{n+1})=f(z(t_n))$ . It is assumed usually that this discrete equation  $z(t_{n+1})=f(z(t_n))$  can be transformed by a standard manner into a differential equation which describe with good accuracy main features of dependence  $z(t)$  at time  $t$  which is much larger than the time spacing between observation of  $z$ .

In this report I compile some well known calculations to show at the very simple example that in a number of cases this approach is mistaken. Existence of lower limit of divisibility of variable  $t$  result in many phenomena which cannot be seen from differential equation. Among them –

- 1) change of possible field of variation of quantity  $z$ ;
- 2) appearance of periodicity without some vibration reason (without restoring force or periodic external force);
- 3) complete unpredictability – emergence of chaotic behavior;
- 4) finishing of process at some finite time.

In other words, in particular

observation of some oscillations not necessarily mean that the system is governed by some oscillator or periodic forces;

the chaotic behavior not necessarily mean that the system is governed by random forces.

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**Effects of non-holomorphic terms in lepton decays**

Ms. FABISIEWICZ, Zofia <sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** zofia.fabisiewicz@fuw.edu.pl

In my talk I will focus on indirect signatures of new physics (NP) through processes which in the Standard Model (SM) are strictly forbidden or extremely suppressed. Lepton flavor violation (LFV) is a particularly powerful probe of new physics due to the fact that it is strictly forbidden in the SM in the limit of vanishing neutrino masses. This work has been done in the framework of the Minimal Supersymmetric Standard Model (MSSM) with a newly developed calculational method, which allows for systematic expansion of the amplitudes for the LFV processes in terms of mass insertions.

**P7: Strings, branes, extra dimensions, and discrete symmetries / 17****Light neutrino masses from a non-Hermitian Yukawa theory**Dr. MILLINGTON, Peter <sup>1</sup><sup>1</sup> *University of Nottingham***Corresponding Author:** p.millington@nottingham.ac.uk

Working within the context of PT-symmetric quantum mechanics, we begin by describing a non-Hermitian extension of QED, which is both Lorentz invariant and consistent with unitarity. We show that the non-Hermitian Dirac mass matrix of this theory exhibits an exceptional point, corresponding to an effectively massless theory whose conserved current is either right- or left-chiral dominated. With this inspiration, we are able to construct a non-Hermitian model of light Dirac neutrino masses from Hermitian and anti-Hermitian Yukawa couplings that are both of order unity. We finish by highlighting potential phenomenological implications of this model.

**P6: Role of symmetries beyond the Standard Model / 26****Self-consistent radiative corrections to false vacuum decay****Author:** Dr. MILLINGTON, Peter <sup>1</sup>**Co-Author:** GARBRECHT, Björn <sup>2</sup><sup>1</sup> *University of Nottingham*<sup>2</sup> *TUM***Corresponding Author:** p.millington@nottingham.ac.uk

With the Higgs mass now measured at the sub-percent level, the metastability of the electroweak vacuum of the Standard Model (SM) motivates renewed study of false vacuum decay in quantum field theory. In this talk, we describe an approach to calculating quantum corrections to the decay rate of false vacua which is able to account fully and self-consistently for the underlying inhomogeneity of the solitonic tunneling configuration. We show that this method can be applied both to theories in which the instability arises already at the level of the classical potential and those in which the instability arises entirely through radiative effects, as is the case for the SM Higgs vacuum. In addition, we consider examples in the thin- and thick-wall regimes, illustrating the relative importance of accounting fully for the background inhomogeneity in each case. Finally, we comment on the potential implications of these studies for the predicted lifetime of the electroweak vacuum.

**P6: Role of symmetries beyond the Standard Model / 62****Scale symmetry and quantum corrections****Author:** Mr. OLSZEWSKI, Paweł<sup>1</sup>**Co-Authors:** Prof. LALAK, Zygmunt<sup>2</sup>; GHILENCEA, Dumitru<sup>3</sup><sup>1</sup> *Physics Department, Warsaw University*<sup>2</sup> *ITP UW*<sup>3</sup> *CERN***Corresponding Author:** pawel.olszewski@fuw.edu.pl

I will discuss a modified version of the dimensional regularization of a classically scale invariant theory of a Higgs field, that manifestly preserves scale invariance and in which the role of the subtraction scale  $\mu$  is played by a dynamic scalar field (dilaton). This field is assumed to have non-zero VEV thus triggering spontaneous breakdown of scale symmetry which in turn triggers EWSB. As a consequence, in this approach there is no anomaly associated with the broken scale invariance. On the other hand, the method generates dynamically (at the quantum level) non-polynomial effective operators to the original Lagrangian. Its intriguing consequence is a qualitatively novel modification of renormalization group and Callan-Symanzik equations, relative to their form in a similar model regularized in the usual way with  $\mu = \text{constant}$  (field-independent).

**P6: Role of symmetries beyond the Standard Model / 38****Towards an Exact RG-Invariant and Symmetry-Improved 2PI Effective Potential****Prof.** PILAFTSIS, Apostolos<sup>1</sup>; **Dr.** TERESI, Daniele<sup>2</sup><sup>1</sup> *University of Manchester*<sup>2</sup> *Université Libre de Bruxelles***Corresponding Author:** daniele.teresi@ulb.ac.be

In this talk I will discuss the renormalization-group properties of the Symmetry-Improved 2PI (SI2PI) effective potential. The 2PI effective potential is a powerful theoretical tool that resums automatically infinite sets of perturbation-theory contributions, in a consistent and systematic way. The SI2PI effective action has been introduced recently to address the long-standing problem of symmetries in the 2PI formalism and has proved to have satisfactory field-theoretical properties. Thus, the formalism can be used for the precision study of the effective potential, in the Standard Model and beyond. In this talk I will discuss the role of the running of the 2PI couplings, and in particular I will show how the SI2PI effective potential is also exactly renormalization-group invariant, once the proper running of the couplings is taken into account, differently from the perturbation-theory potential. I will provide a detailed comparison of the results obtained in the exact RG-invariant SI2PI formalism with those of fixed-order perturbation theory. These results show how this formalism can find application, for instance, also in the study of the stability of the effective potential in the Standard Model and beyond.

**P6: Role of symmetries beyond the Standard Model / 55**

**Scalar color octets and triplets in the SUSY with an R-symmetry**

Mr. KOTLARSKI, Wojciech<sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** wojciech.kotlarski@fuw.edu.pl

The Minimal Supersymmetric Standard Model features a discrete  $Z_2$  symmetry called R-parity. In an extended SUSY models this symmetry may get generalized to a  $Z_n$  or even a continuous  $U(1)$ , called R-symmetry. In the talk I will present a study of squark and color octet scalar production in the Minimal R-symmetric Supersymmetric Standard Model (MRSSM). First results for the NLO SQCD corrections to the squark pair production in the MRSSM will be presented.

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**Multi-Component Dark Matter**

AHMED, Aqeel<sup>1</sup>; DUCH, Mateusz<sup>1</sup>; GRZADKOWSKI, Bohdan<sup>1</sup>; Mr. IGLICKI, Michał<sup>1</sup>

<sup>1</sup> *University of Warsaw*

**Corresponding Author:** aqeel.ahmed@fuw.edu.pl

I will discuss multi-component dark matter scenarios where more than one dark sector particles are stable, and hence contribute to the observed dark matter relic abundance in the Universe. First I will present a generic discussion of a toy model where two or three dark particles are stable and later focus will be on a specific two component dark matter model where a vector and a Majorana fermion are stable. The stability of our multi-component dark matter scenarios is ensured due to the presence of discrete symmetries.

**P4: Neutrino masses, mixing, and discrete symmetries / 30**

**Exploring neutrino mass generation mechanisms via the lepton flavor violating decay of the Higgs boson**

Dr. SUGIYAMA, Hiroaki<sup>1</sup>

<sup>1</sup> *University of Toyama*

**Corresponding Author:** shiro324@gmail.com

There are many new physics models for generating neutrino masses, and it is important to consider how these models can be experimentally discriminated. Classification of models is useful for the efficient discrimination. In this talk, we classify simple models for each of Majorana and Dirac neutrino masses by concentrating on Yukawa interactions with leptons. We see that, if a lepton flavor violating decay of the Higgs boson is discovered, simple models for Majorana neutrino masses are excluded while some models for Dirac neutrino masses can survive.



## P4: Neutrino masses, mixing, and discrete symmetries / 58

**Hierarchical majorana neutrinos from democratic mass matrices**Dr. YANG, Masaki <sup>1</sup><sup>1</sup> *Saitama university***Corresponding Author:** yang@krishna.th.phy.saitama-u.ac.jp

In this study, we obtain the light neutrino masses and mixings consistent with the experiments, in the democratic texture approach.

The essential ansatz is that  $\nu_{Ri}$  are assumed to transform as "right-handed fields"  $\mathbf{2}_R + 1_R$  under the  $S_3 \times S_3$  symmetry.

The symmetry breaking terms are assumed to be diagonal and hierarchical.

This setup only allows the normal hierarchy of the neutrino mass, and excludes both of inverted hierarchical and degenerated neutrinos.

Although the neutrino sector has nine free parameters, several predictions are obtained at the leading order.

When we neglect the smallest parameters  $\zeta_{\nu}$  and  $\zeta_R$ , all components of the mixing matrix  $U_{\text{PMNS}}$  are expressed by the masses of light neutrinos and charged leptons.

From the consistency between predicted and observed  $U_{\text{PMNS}}$ , we obtain the lightest neutrino masses  $m_1 = (1.1 \text{ to } 1.4) \text{ meV}$ , and the effective mass for the double beta decay  $m_{\text{eff}} \simeq 4.5 \text{ meV}$ .

## P4: Neutrino masses, mixing, and discrete symmetries / 32

**A model of radiatively induced Quark and Lepton Masses****Author:** Dr. NOMURA, Takaaki <sup>1</sup>**Co-Author:** Dr. OKADA, Hiroshi <sup>2</sup><sup>1</sup> *Korea Institute For Advanced Study*<sup>2</sup> *National Center for Theoretical Sciences***Corresponding Author:** nomura@kias.re.kr

We discuss a radiatively induced quark and lepton mass model in the first and second generation introducing extra  $U(1)$  gauge symmetry, discrete  $Z_2$  symmetry and vector-like fermions. Then we analyze the allowed regions which simultaneously satisfy the FCNCs for the quark sector, LFVs including  $\mu$ -e conversion, the quark mass and mixing, and the lepton mass and mixing. Also we estimate the typical value for the  $(g-2)_\mu$  in our model.

## P4: Neutrino masses, mixing, and discrete symmetries / 110

**CP violation vs matter effects in long baseline neutrino experiments.**Dr. IOANNISIAN, Ara <sup>1</sup><sup>1</sup> *YerPhi and ITPM***Corresponding Author:** ara@cern.ch

It is well known that MSW matter effect can mimic CP violation at long baseline neutrino oscillation experiments. We derive an approximate expression for  $\nu_\mu \rightarrow \nu_e$  oscillation probability which is both accurate and has all advantages of a full analytic treatment. We also discuss influence of matter density non uniformity (along the neutrino beam) on neutrino oscillation.

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## Neutrinos - experimental status and prospects

Corresponding Author: ewa.rondio@ncbj.gov.pl

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## Lepton Mixing and CP Violation from Discrete Flavour Symmetries

Prof. PETCOV, Serguey <sup>1</sup>

<sup>1</sup> *SISSA/INFN, Trieste, Italy and Kavli IPMU, Univ. Of Tokyo, Japan*

Corresponding Author: petcov@sissa.it

Abstract. The current status of our knowledge about the neutrino masses, neutrino mixing and the Dirac and Majorana CP violation in the lepton sector, will be briefly reviewed.

The discrete symmetry approach to understanding the observed pattern of neutrino mixing, and the related predictions for the leptonic Dirac and Majorana CP violation, will be discussed.

Possible tests of these predictions in current and future planned neutrino experiments will also be considered.

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## In-flight hyperfine spectroscopy of (anti)hydrogen for tests of CPT symmetry

Prof. WIDMANN, Eberhard <sup>1</sup>

<sup>1</sup> *Stefan Meyer Institute*

Corresponding Author: eberhard.widmann@oeaw.ac.at

A measurement of the ground-state hyperfine structure (GS-HFS) of antihydrogen can become one of the most sensitive tests of CPT symmetry on an absolute scale due to the fact that it is a small quantity on an energy scale and can be measured to very high precision. For this reason ASACUSA has chosen to perform a measurement of GS-HFS using a polarized antihydrogen beam. A major mile stone towards a hyperfine measurement was the first observation of a beam of antihydrogen atoms in a field-free region by ASACUSA.

Similar arguments regarding the absolute sensitivity of CPT tests have been brought forward by A. Kostelecky et al. within their Standard Model Extension (SME). Their model is based on Lorentz-invariance violation and also has consequences for the GS-HFS of ordinary hydrogen, notably sidereal and annual variations, which have been tested using hydrogen masers to high precision. In a recent extension to the non-minimal SME further SME coefficients are found that depend on the orientation of the applied static magnetic field in the laboratory for some of the observable HFS transitions.

ASACUSA has used the hyperfine spectrometer line originally developed for antihydrogen spectroscopy with a source of cold polarized hydrogen atoms and measured the  $(F=1, M=0) \rightarrow (0,0)$  (so-called sigma) transition to 2.7 ppb and plans to extend the measurements to the  $(1,1) \rightarrow (0,0)$  pi-transition which within the SME is sensitive to Lorentz and CPT violation. This talk discusses the results and prospects of in-beam GS-HFS measurements using the ASACUSA apparatus in both hydrogen and antihydrogen.

**Session / 104**

## **Fundamental Physics in Low Energy**

**Corresponding Author:**

**Session / 108**

## **Vacuum Stability. Impact of Gravity and New Physics**

Prof. BRANCHINA, Vincenzo <sup>1</sup>

<sup>1</sup> *University of Catania*

**Corresponding Author:** branchina@ct.infn.it

The stability analysis of the electroweak (EW) vacuum plays a crucial role in the search for physics beyond the Standard Model. For the present experimental values of the Higgs and top masses, the EW vacuum turns out to be a metastable state, a "false vacuum", but with a lifetime much greater than the age of the universe. On the basis of a decoupling argument, it is usually expected that new physics at very high energy scales (Planck scale) cannot influence the stability condition of the vacuum. Moreover, it is expected that in a strong gravity regime the decay of the EW vacuum is always inhibited. It was recently realised, however, that these expectations are not fulfilled. In this talk we discuss the reasons and the phenomenological consequences of these findings.

**Session / 109**

## **The Discrete Charm of Flavour and CP Violation**

**Corresponding Author:** gbranco@tecnico.ulisboa.pt