DISCRETE 2024 in Ljubljana

Monday 2 December 2024 - Friday 6 December 2024

Book of Abstracts

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New Constraint for Isotropic Lorentz Violation from LHC Data

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New calculations for the kinematics of photon decay to fermions in vacuo under an isotropic violation of Lorentz invariance (LV), parameterized by the Standard-Model Extension (SME), are presented and used to interpret prompt photon production in LHC data. The measurement of inclusive prompt photon production at the LHC Run 2, with photons observed up to a transverse energy of 2.5 TeV, provides the lower bound $\tilde{\kappa}_{\rm tr} > -1.06 \times 10^{-13}$ on the isotropic coefficient $\tilde{\kappa}_{\rm tr}$ at 95% confidence level. This result improves over the previous bound from hadron colliders by a factor of 55. The calculations for the kinematics of photon decay have further potential use to constrain LV coefficients from the appearance of fermion pairs, for instance, top-antitop.

Flavour and CP violation 1 / 6

Search for Baryogenesis and Dark Matter in B-meson decays at BABAR

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We present the most recent BABAR searches for reactions that could simultaneously explain the presence of dark matter and the matter-antimatter asymmetry in the Universe. This scenario predicts exotic B-meson decays of the kind $B \to \psi_D$
$calB$, where
$calB$ is an ordinary matter baryon (proton, Λ, or Λ_C) and ψ_D is a dark-sector anti-baryon, with branching fractions accessible at the B factories. The hadronic recoil method has been applied with one of the B mesons from $\Upsilon(4S)$ decay fully reconstructed, while only one baryon is present in the signal B-meson side. The missing mass of signal B-meson is considered as the mass of the dark particle ψ_D.
Stringent upper limits on the decay branching fraction are derived for ψ_D masses between 0.5 and 4.3 GeV/c^2. The results are based on the full data set of about 430 fb^{-1} collected at the $\Upsilon(4S)$ resonance by the BABAR detector at the PEP-II collider.

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The electron-EDM in the decoupling limit of the aligned 2HDM

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We discuss model-independent contributions to the electron-EDM, focusing on those contributions emerging from a heavy scalar sector. More specifically, we investigate the aligned 2HDM in the decoupling limit. We point out that logarithmically enhanced contributions generated by Barr-Zee diagrams with a fermion loop are present in the aligned 2HDM, an effect encoded by the mixing of effective operators of dimension-6.
The same large logarithms are absent in alternative 2HDMs where a Z2 symmetry is enforced, which thus controls the basis of effective operators. In the aligned 2HDM these contributions are proportional to sources of CP violation that are potentially large. We also discuss the role of non-dipole contact interactions in setting phenomenological constraints on the allowed amount of CP violation.

Plenary session / 8

Baryon number violations involving tau leptons

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Baryon number violation is our most sensitive probe of physics beyond the Standard Model, especially through the study of nucleon decays. Angular momentum conservation requires a lepton in the final state of such decays, kinematically restricted to electrons, muons, or neutrinos. We show that operators involving taus, which are at first sight too heavy to play a role in nucleon decays, still lead to clean nucleon decay channels with tau neutrinos. While many of them are already constrained from existing two-body searches such as $p \to \pi^+\nu$, other operators induce many-body decays such as $p \to \eta\pi^+\bar{\nu}_\tau$ and $n \to K^+\pi^-\nu_\tau$ that have never been searched for.

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How large could CP violation in B meson mixing be? Implications for baryogenesis and upcoming searches

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It is well-known that CP violation is one of the necessary ingredients to generate the observed matter-antimatter asymmetry of the Universe. Neutral B mesons naturally exhibit CP violating oscillations which can be related to the baryon asymmetry through the B-Mesogenesis mechanism. With this in mind, it is interesting to analyze how large this CP violation could be in different scenarios beyond the Standard Model. In this talk, I will consider (i) the effects of heavy new physics in mass mixing following a model-independent approach, (ii) the implications of models going beyond 3x3 CKM unitarity (including, e.g., vector-like quarks), and (iii) the effects of new contributions to the B meson decay mixing. I will present the available parameter space for the relevant CP asymmetries, studying their compatibility with the B-Mesogenesis framework and compare it with the expected experimental sensitivity at LHCb and Belle II.

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Discrete Leptonic Flavor Symmetries in the SMEFT

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Standard Model effective field theory (SMEFT) serves as a powerful and rigorous framework for systematically characterizing deviations from the Standard Model. However, due to its model-independent nature, there is an inevitable trade-off resulting in a significant increase in the number of independent parameters. In this talk, we discuss the charting of the SMEFT parameter space by incorporating a range of flavor assumptions based on the global continuous symmetry groups. The interplay between the flavor symmetries and the UV mediators, yielding valuable phenomenological insights, is outlined accordingly. Expanding upon this analysis, we extend the list of flavor symmetries in the leptonic sector by adding three well-motivated discrete groups, namely A_4, A_5, and S_4. The analysis of the relevant UV mediators under these flavor assumptions is performed, which includes the extraction of flavor tensors as well as the derivation of SMEFT matching relations. Particular emphasis is placed on the leptonic directions, for which a comprehensive phenomenological analysis is conducted.

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Rare charm decays at LHCb

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LHCb is playing a crucial role in the study of rare and forbidden semileptonic decays of charm hadrons, which might reveal interactions beyond the Standard Model. We present the latest measurements of charm decays with two leptons in the final state.

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Cosmology and Astroparticle Physics 2 / 12

Probing Dark Matter with RES-NOVA's archaeological Pb-based Detectors

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The quest to understand dark matter (DM) continues to be a driving force in astrophysics and particle physics. This talk discusses the potential of the RES-NOVA project, envisioned for detecting astrophysical neutrinos via Coherent Elastic Neutrino-Nucleus Scattering (CEvNS), to also serve as a DM observatory. Leveraging the array of cryogenic detectors made from archaeological Pb, known for its ultra-high radiopurity, RES-NOVA is uniquely positioned to detect both neutrino and DM

interactions via nuclear recoils. The use of Pb significantly enhances the interaction cross-section for neutrinos and DM, making it an ideal candidate for astrophysical phenomena investigation. By extending the operational principles and sensitivity of CEvNS-based detectors, RES-NOVA may also be capable of observing DM particles from our galactic halo.
RES-NOVA's sensitivity to low-energy interactions offers a unique avenue to probe discrete symmetries, where any observed deviations could indicate symmetry violations in neutrino and DM interactions beyond the Standard Model.
The theoretical implications for such dual-use of the RES-NOVA detector, the detector design, sensitivity, and a preliminary background model aimed at identifying DM candidate signals, are presented.

Cosmology and Astroparticle Physics 2 / **13**

Searching for proton decay with paleo-detectors

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We present a novel experimental concept to search for proton decay. Using paleo-detectors, ancient minerals acquired from deep underground which can hold traces of charged particles, it may be possible to conduct a search for $p \to \bar{\nu} K^+$ via the track produced at the endpoint of the kaon. Such a search is not possible on Earth due to large atmospheric-neutrino-induced backgrounds. However, the Moon offers a reprieve from this background, since the conventional component of the cosmic-ray-induced neutrino flux at the Moon is significantly suppressed due to the Moon's lack of atmosphere. For a 100 g, 10^9 year old (100 kton·year exposure) sample of olivine extracted from the Moon, we expect about 0.5 kaon endpoints due to neutrino backgrounds, including secondary interactions. If such a lunar paleo-detector sample can be acquired and efficiently analyzed, proton decay sensitivity exceeding $\tau_p \sim 10^{34}$ years may be achieved, competitive with Super-Kamiokande's current published limit ($\tau_p > 5.9 \times 10^{33}$ years at 90% CL) and the projected reach of DUNE and Hyper-Kamiokande in the $p \to \bar{\nu} K^+$ channel. This concept is clearly futuristic, not least since it relies on extracting mineral samples from a few kilometers below the surface of the Moon and then efficiently scanning them for kaon endpoint induced crystal defects with sub-micron-scale resolution. However, the search for proton decay is in urgent need of a paradigm shift, and paleo-detectors could provide a promising alternative to conventional experiments.

Plenary session / **14**

Welcome and introduction to Discrete 2024

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Theoretical Developments 1 / **15**

Hadronic vacuum polarisation contribution to the muon anomaly from first principles to an accuracy of 4.6 per mil

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The anomalous magnetic moment of the muon, as a low energy precision observable, has long served as a test of the Standard Model (SM) of particle physics. The latest muon $g-2$ measurements at Fermilab confirm the previous BNL result, hence emphasizing, up to 5.1 standard deviations, the discrepancy between the experimental world average value and the reference SM prediction. The uncertainty of the latter is dominated by the hadronic vacuum polarisation (HVP) contribution, which is traditionally evaluated using dispersion integrals and experimental hadronic cross section data. However, recent independent HVP evaluations based on lattice QCD calculations and on a new measurement of the $e^+e^- \to \pi^+\pi^-$ cross section are providing hints for a significantly reduced tension with the direct experimental determination. In this invited talk, after briefly reviewing the status of lattice calculations in the field, we present the new result from first principles by the BMW Collaboration at the remarkable precision of 0.32 ppm, with a particular focus on our evolving understanding of the HVP contribution and implications for indirect searches of new physics.

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Unifying Quark and Lepton Flavor Observables through Modular Symmetry

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In this talk, I will present a novel unified analysis of quark and lepton flavor observables within the framework of modular symmetry, focusing specifically on a model based on 2O modular symmetry. Using a single complex modulus \tau and a well-defined set of real parameters, this model provides a comprehensive description of both quark and lepton sectors under a unified theoretical framework. The model successfully reproduces experimental data, including quark masses, CKM angles, and lepton mixing parameters, while also making precise predictions for quantities yet to be measured, such as the Dirac CP-violating phase, Majorana phases, and neutrino mass observables. These predictions are within reach of upcoming experimental investigations. In addition to presenting the overall results, I will examine in greater detail the correlations between quark and lepton observables, emphasizing the predictive capacity of modular symmetry in addressing key challenges in flavor physics.

Neutrinos and ALPs 1 / 17

Search for the X_{17} QCD Axion in the $\eta \to \pi^+\pi^-e^+e^-$ decay with the HADES Detector

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The High-Acceptance Di-Electron Spectrometer (HADES) operates at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt with pion, proton and heavy-ion beams provided by the synchrotron SIS-18 [1]. In February 2022, the HADES Collaboration measured proton-proton collisions at 4.5 GeV momenta using the upgraded setup within the FAIR-Phase0 programme. One of the goals of the physics program of HADES is to test validity of Standard Model predictions and search for hints of new phenomena escaping know schemes. In particular using η meson decays into channels with dileptons (e^+e^- pairs) we are investigating the possible existence of X_{17} boson which is

a candidate to be an axion-like particle (ALP) [2,3]. In this scenario an intermediate state of η decay could involve an existence of QCD axion through the sequence $\eta \rightarrow \pi^+\pi^- X_{17}(\rightarrow e^+e^-)$. The X_{17} particle is suspected to be an axial-vector gauge boson, which may mediate a fifth force with some coupling to SM particles. The conducted studies are moreover stimulated by recently observed anomalies in the invariant mass distribution of e^+e^- in the isoscalar magnetic nuclear transitions of ^8Be and ^4He nuclei [4-6], which have been interpreted as the creation and decay of an intermediate particle X_{17} with mass of about 17 MeV/c^2 which have suppressed mixing with the neutral pion.

In this talk, we introduce general motivations for studies of a X_{17} present analysis methodology and preliminary results from the data collected with high-resolution HADES spectrometer.

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[5] A. J. Krasznahorkay et al., arXiv:1910.10459 (2019).
[6] A. J. Krasznahorkay et al., Phys. Rev. C 104, 044003 (2021).

Collider 1 / **18**

Teaming up MET plus jet with Drell-Yan in the SMEFT

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The Standard Model Effective Field Theory (SMEFT) is a widely utilized framework for exploring new physics effects in a model-independent manner.
In previous studies, Drell-Yan collider data has emerged as a promising signature due to its energy enhancement relative to Standard Model predictions.
In this talk, we present recent works extending this approach by also considering the “missing energy + jet” signature, which can constrain related dineutrino couplings and similarly benefits from energy enhancement.
The combination of these observables allows for constraining a broader selection of operators and helps resolve flat directions in a global analysis.
Overall, the bounds probe the multi-TeV range and are expected to improve with increased luminosity and center-of-mass energy.

Flavour and CP violation 2 / **20**

The n2EDM experiment, a high-sensitivity search for the neutron electric dipole moment

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The quest for new CP violation is a thriving field of experimental particle physics. A wide variety of experiments investigate many different particle species and processes looking for possible sources of CP violation in addition to the Standard Model. The search for a permanent neutron electric dipole moment is considered to be an excellent candidate for a possible discovery.
The n2EDM experiment is currently in its commissioning phase at the ultracold neutron source at

the Paul Scherrer Institut, Switzerland. The international nEDM collaboration published the current best limit of $d_n < 1.8 \cdot 10^{-26}$ ecm in 2020 using data taken over two years with the predecessor apparatus. n2EDM, a new generation experiment is designed to improve the sensitivity by a factor 10 with increased neutron statistics already with the baseline setup. Accordingly, the systematic uncertainties will be reduced due to the new double-chamber setup and a largely improved magnetic field environment.
This talk will give an overview of the experiment and introduce the most important features of the new apparatus. In addition, first results from commissioning data taken with several subsystems will be presented, including measurements with ultracold neutrons, magnetic shielding features, and magnetic field mapping.

Plenary session / **21**

Froggatt-Nielsen ALP

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Froggatt-Nielsen models typically predict the existence of a light axion-like particle, pushing the new dynamic to a very high scale.
In this talk I will focus on models based on Z_N discrete symmetries, which are counterexamples in which the new scale might in fact be much lower.
I will first chart the allowed parameter space from a set of theoretical considerations, and then focus on two models based on Z_4 and Z_8 symmetries. For these, I will introduce explicit renormalizable UV completions and study the models' phenomenology in detail, highlighting the interplay between the effects of the ALP and of the UV fields.

Flavour and CP violation 2 / **22**

Searches for hidden sectors and lepton flavour violation in kaon decays

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Rare kaon decays are among the most sensitive probes of both heavy and light new physics beyond the Standard Model description thanks to high precision of the Standard Model predictions, availability of very large datasets, and the relatively simple decay topologies. The NA62 experiment at CERN is a multi-purpose high-intensity kaon decay experiment, and carries out a broad rare-decay and hidden-sector physics programme. NA62 has collected a large sample of K^+ decays in flight during Run 1 in 2016-2018, and the ongoing Run 2 which started in 2021. Recent NA62 results on searches for hidden-sector mediators and searches for violation of lepton number and lepton flavour conservation in kaon decays based on the Run 1 dataset are presented. Future prospects of these searches are discussed.

Theoretical Developments 1 / **23**

Exploring near-conformal dark sectors

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Dark-showers offer a compelling collider signature for Hidden Valley models featuring a confining dark sector. Our work extends the investigation of these models to near-conformal theories where the running coupling, controlled by renormalization group equations (RGE), flows near to an infrared fixed point. We establish a framework of two classes of RGE solutions which cover much of the parameter space of confining theories, allowing us to present the first phenomenological results of such near-conformal dark sectors.

Plenary session / **24**

Beta decays as probes for fundamental physics

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I will review precision measurements in allowed nuclear beta decays and neutron decay, both within the Standard Model and looking for new physics. I will follow an Effective Field Theory approach, which allows one to carry out a model-independent comparison of measurements using different nuclei, as well as to connect with other searches (e.g. at the LHC).

Plenary session / **26**

Flavor Phenomenology of Light Dark Vectors

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TBA

Plenary session / **27**

Deciphering New Physics through $b \to s\nu\nu$, $b \to c\ell\nu$ and $c \to s\ell\nu$ decays

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Studies of b->s transitions with Belle/Belle II

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TBA

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Branching fractions and CP asymmetries in charm meson decays

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TBA

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Study of b -> sll transitions with LHCb

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TBA

Plenary session / **31**

Top quark operators in SMEFT

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TBA

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Semileptonic decays with Belle and Belle II

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New measurement of the ultra-rare K+ −> pi+ nu nubar decay

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TBA

Plenary session / **34**

Probing CP on lattice

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Plenary session / **35**

Recent results in neutrino physics experiments

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TBA

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Cosmological perspective on neutrinos

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TBA

Plenary session / **37**

Left-Right Symmetry at Hadron Colliders

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Strong CP without axions

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Plenary session / **39**

Future colliders

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Plenary session / **40**

Searches for Long Lived Particles

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Plenary session / **41**

Theory of baryon number violation

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TBA

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P/CP in the UV

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SUSY particle searches at LHC

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TBA

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Malaphoric Z' model for flavour

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Plenary session / **45**

New particle searches at LHC (non-SUSY)

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TBA

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One Born-Oppenheimer Effective field theory to rule them all: hybrids, tetraquarks, pentaquarks, quarkonium and doubly heavy baryons

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TBA

Plenary session / **47**

Is flavor discrete?

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TBA

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Generalized symmetries in particle physics

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TBA

Plenary session / **49**

Fundamental tests with antimatter

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TBA

Plenary session / **50**

Higgs and CP-violation

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Plenary session / **51**

CP violation in baryogenesis

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TBA

Plenary session / **52**

Towards the long distance contributions from lattice

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TBA

Plenary session / **53**

B-meson semileptonic decays from lattice QCD

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Domain Walls in the early Universe and their gravitational signatures

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TBA

Plenary session / **55**

Searches for new physics with muons

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TBA

Plenary session / **56**

Light dark sector searches at accelerators

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TBA

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Baryogenesis and gravitational waves from domain walls

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Axionic domain walls, as they sweep through the early universe plasma, can generate a net baryon and lepton number through the mechanism of spontaneous baryogenesis, provided there is a coupling between the axion and the lepton or baryon current. In this paper, we study systematically the baryon asymmetry produced by these domain walls, within different realisations of the L- or B violating sector. We find that the baryon number is maximised when the DW collapse more or less at the moment when the L or B violating interaction decouples. We study a model of minimal leptogenesis, a model of cogenesis, a model of baryogenesis and finally the possibility that the baryon asymmetry is produced by sphalerons themselves. We finally discuss the expected gravitational wave signal from these domain walls and the prospects for detecting it. We however emphasize that in typical realisations of the DW baryogenesis scenario, there is a suppression induced by the cancellation between the "opposite"asymmetry created by "opposite"(clockwise and counter-clockwise) domain walls. We quantify the level of this cancellation and discuss possible ways to avoid it.

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Spontaneous CP Violation and Flavor Changing Neutral Currents in Minimal SO(10)

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We explore spontaneous CP violation (SCPV) in the minimal non-supersymmetric SO(10) grand unified theory (GUT), with a scalar sector comprising a CP-even 45_H, a 126_H, and a complex 10_H. All renormalizable couplings are real due to CP symmetry, and the Kobayashi-Maskawa phase arises solely from complex electroweak vacuum expectation values. The model requires an additional Higgs doublet fine-tuned below 500 GeV and constrains new Yukawa couplings, linking certain flavor-violating (FV) processes. Future proton decay observations may reveal correlated FV decay ratios, offering a hint on minimal SO(10).

Collider 2 / 60

Type II lepton number violation at the LHC

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We examine the prospect of observing genuine lepton number violating (LNV) signals at hadron colliders in the context of the Type II seesaw mechanism. The model features smoking gun signals involving same-sign di-leptons and jets that may be the primary observable channel in certain regions of the parameter space. The flavour composition of final-state charged leptons in the minimal

model is related to the origin of neutrino masses and is correlated with other rare processes, such as neutrinoless double beta decay. We review existing collider limits and provide sensitivity estimates from LNV signals at upcoming runs of the LHC, for zero and non-zero mass splittings between the scalar triplet components.

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CP-Asymmetries in semileptonic decays

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I will discuss the potential of Direct and Indirect CP-Asymmetries in semileptonic decays. On the one hand I will discuss the role on Direct asymmetries in probing long-distance dynamics in B decays, and the other hand I will discuss the role of indirect CP-asymmetries in probing Cp-violating NP.

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Exploring Constraints on νSMEFT Coefficients in the Presence of an Extra $\mathrm{U}(1)'$

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Constraints on low-energy coefficients of the νSMEFT generalization of the Standard Model effective theory in the simple case of a $\mathrm{U}(1)'$ enlargement of the Standard Model gauge group are studied. In particular, the constraints imposed by the requirement that the extended theory remains free of gauge anomalies are analyzed. Several explicit realisation, showing the obtained correlations among the coefficients of $d = 6$ operators are presented.

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LHCb highlights

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In this talk, the to-date most important results from the LHCb collaboration on the discrete symmetries will be summarised. The LHCb spectrometer is a single arm forward detector designed to study heavy flavour physics. This presentation highlights the latest measurements of the CP violation in the beauty and charm meson decays and the CPT violation searches in the heavy meson oscillations. In addition, main LHCb results on lepton flavour universality tests and on the spectroscopy programme will be given.

Neutrinos and ALPs 1 / **65**

Non-vanilla Axion Solutions to the Strong CP Problem

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I discuss the status of model-building for the strong CP problem, emphasizing the phenomenology non-vanilla models that enhance or lighten the axion mass. Particular importance is placed on the emergence of the global Higgs symmetries in multi-scalar field theories and various explicit, anomalous, and soft-breaking contributions to select the Peccei-Quinn symmetry and the axion. Models with enhanced axion masses feature new colored states that may be accessible at high-energy colliders, while models that lighten the axion mass generally involve fine-tuning. Nonetheless, such fine-tuning can be ameliorated with a Nelson-Barr extension.

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Advancing SMEFT Global Analyses: NLO, RGE contributions, and the Role of Flavour Physics

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The Standard Model Effective Field Theory (SMEFT) is an essential tool for probing physics beyond the Standard Model. With New Physics signals remaining elusive, deriving constraints on SMEFT Wilson coefficients is increasingly important in order to pinpoint its low-energy effects. This talk presents comprehensive global fits of SMEFT under the Minimal Flavour Violation (MFV) hypothesis. We establish global limits on Wilson coefficients using both leading and next-to-leading order SMEFT predictions for various observables. Our findings highlight significant interactions among different observables, emphasizing the necessity of integrating diverse data from multiple energy scales in global SMEFT analyses. Even within this flavour-symmetric framework, where Flavour Changing Neutral Currents (FCNC) cannot be generated at tree-level, they significantly contribute via Renormalization Group Evolution (RGE) effects. More in general a consistent treatment of the RGE in global analyses is an often-overlooked aspect which proves to be crucial for analysing properly datasets spanning various energy scales.

Collider 1 / **68**

A first constraint on CPT violation in top quarks

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CPT invariance is a prediction of local, unitary, and Lorentz invariant quantum field theories in flat spacetime. CPT tests have been performed for all fermions of the Standard Model, except for the top

quark. I this talk, I describe how the first model-independent sensitivity to CPT violation is extracted from top-antitop mass reconstructions performed by the ATLAS and CMS Collaborations.

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Highlights from the LUX-ZEPLIN experiment

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The LUX-ZEPLIN (LZ) experiment is a multi-tonne dark matter direct detection experiment operating 4850 feet underground at the Sanford Underground Research Facility in Lead, South Dakota. At the heart of LZ is a liquid xenon time projection chamber (TPC) with a 7-tonne active mass designed to capture the low energy signals from interactions with WIMP dark matter in our galactic halo, as well as signatures from other rare physics processes. The central TPC is surrounded by an active veto system consisting of an optically separated and instrumented xenon skin layer and a surrounding external liquid scintillator outer detector to provide rejection and characterisation of gamma-rays and neutrons from internal sources. The experiment has been taking data since 2021 and earlier this year released world- leading constraints using 280 live-days of data, excluding spin-independent WIMP- nucleon interactions down to a minimum of 2.1 x 10ˆ{-48} cmˆ2 for a 36 GeV/cmˆ2 WIMP mass. In this talk, I will give an overview of the experiment, discuss the recent WIMP and rare event searches, and outline the status of LZ as it progresses towards a full 1000 live-day exposure.

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Asymmetric dark matter semi-annihilation into long-lived particles

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The talk is focused on an asymmetric dark matter model based on semi-annihilations into long-lived standard-model-sector particles. The dark matter is stabilized by discrete $\mathbb{Z}(3)$ symmetry. It is shown that despite strong dark matter annihilation, the asymmetry obtained from the semi-annihilations may significantly affect the resulting relic density, even at very small coupling values.

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Wash-in leptogenesis from asymmetric Dirac neutrino scatterings

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We present a leptogenesis model in which right-handed neutrinos undergoing ultraviolet freeze-in are the only out-of-equilibrium species necessary to generate the observed matter-antimatter asymmetry in the early universe. It is shown that even though the lepton number source term vanishes, opposite asymmetries of the decoupled right-handed neutrinos and standard model leptons are washed in. The talk is based on Phys. Rev. D 110, 055042.

Collider 2 / **72**

Background processes in Higgs decay to Z gamma

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In measurements by the ATLAS and CMS Collaborations, the number of events for Higgs decay into a Z boson and photon is 2.2 ± 0.7 times higher than predicted by the Standard Model. For the $H \to Z\gamma$ process, this decay is reconstructed from $H \to \ell\ell\gamma$, where $\ell = e,\ \mu$. In our work, we aim to resolve this anomaly by exploring potential additional background contributions to $H \to \ell\ell\gamma$ from various subprocesses within and beyond the Standard Model.

Flavour and CP violation 4 / **73**

Extending the SM with vector-like quarks: consequences for CKM unitarity and CP violation

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Although, a fourth chiral generation of fermions is excluded by experimental data, the possibility of extending the SM with vector-like quarks, where both chiral components transform the same way under SU(2)_L, has not been ruled out. In fact, these fields are present in a great variety of NP models, from GUTs to solutions to the strong CP problem.
Moreover, introducing VLQs leads to the loss of CKM unitarity making them some of the simplest solutions to the Cabibbo Angle Anomaly (CAA). However, this in turn leads to the emergence of flavour changing neutral currents at tree-level and other phenomenological effects. Additionally, their introduction leads to extended mass matrices with a larger content of physical phases and thus new sources of CP violation, which could have important implications for baryogenisis.

Here we explore the main phenomenological effects of adding VLQs, in particular in the context of addressing the CAA, discuss how one may construct weak basis invariants for the extended theory and present some of the most important CP-odd invariants, which may point to potentially observable CP violation even at collisions with energies much higher than the EW scale.

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Freeze-in production of axions in DFSZ-type axion models

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Axion is a strong candidate for dark matter and has several types of production mechanisms. While the misalignment mechanism has been well-known since long ago and is usually assumed, thermal productions are another attractive possibility. In this talk, we will discuss thermal productions of the axion in DFSZ-type axion models, which involve heavy additional Higgs bosons. Interestingly, in this setup, axion is predominantly produced from the heavy Higgs boson decays, assuming that the reheating temperature of the Universe is larger than the mass of the heavy Higgs bosons. This is a characteristic feature of the DFSZ-type models in the sense that this does not happen in KSVZ-type axion models. Focusing on the axion with a mass of keV to sub-GeV scale, we will discuss how cosmological observations such as X-ray and CMB constrain the model parameter space.
Furthermore, we discuss the axion contributions to effective number of the neutrino spices in case that the mass of axion is smaller than the order of 0.1 eV.

Flavour and CP violation 4 / 75

Light states in real multi-Higgs models with spontaneous CP violation

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In models with extended scalar sectors that include multiple Higgs doublets responsible for spontaneous electroweak symmetry breaking, it may appear that the numerous dimensionful quadratic terms in the scalar potential could support a scenario where, aside from the would-be Goldstone bosons and a neutral Higgs-like particle, all additional scalars acquire masses well above the electroweak scale. However, in scenarios where CP symmetry is preserved in the Lagrangian but broken by the vacuum, we show that this expectation is unfounded. Imposing perturbativity constraints on the dimensionless quartic couplings leads to a scalar spectrum that necessarily includes one charged and two additional neutral states, with masses that cannot be much greater than the electroweak scale.

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CP-violating portal to Dark Sectors

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The prospect of a Dark Sector neutral under Standard Model interactions represents a compelling explanation for the existence of Dark Matter. A popular class of models considers kinetic mixing as a portal between the visible and the Dark Sector. The introduction of a non-abelian $SU(N)_D$ group can cause kinetic mixing via higher-dimensional operators, naturally explaining the experimental constraints on kinetic mixing parameters. Assuming the presence of a non-abelian CP-odd portal, we investigate the parameter space allowing for a sizeable electron Electric Dipole Moment (eEDM), taking into consideration present and future experimental sensitivities. We show that potentially observable eEDM can be produced in vast regions of the parameter space compatible with current experimental constraints and observed dark matter abundance.

Neutrinos and ALPs 2 / **77**

Testing the Pauli Exclusion Principle and fundamental symmetries in underground experiments

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The Pauli Exclusion Principle (PEP) is one of the main cornerstones of the Quantum Theory. Violation of the PEP, albeit small, could be motivated by physics beyond the Standard Model which entail extra space dimensions, violation of the Lorentz invariance, non-commutative space-time. These scenarios can be experimentally constrained with stat-of-the-art X-ray spectroscopy, searching for forbidden transition in atomic systems. I shall present the latest results of the VIP-2 and of the Gator experiment, and the impact on Quantum gravity models and fundamental symmetries.

Collider 1 / **78**

Third-Family Lepton-Quark Fusion

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We analyze the signatures of new physics scenarios featuring third-family quark-lepton unification at the TeV scale in lepton-quark fusion at hadron colliders. Working with complete UV dynamics based on the SU(4) gauge symmetry in the third-family fermions, we simulate the resonant production of a vector leptoquark at the next-to-leading order, including its decay and matching to the parton showers. The precise theoretical control over this production channel allows us to set robust bounds on the vector leptoquark parameter space which are complementary to the other production channels at colliders. We emphasize the importance of the resonant channel in future searches and discuss the impact of variations in the model space depending on the flavor structure of the vector leptoquark couplings.

Flavour and CP violation 3 / **79**

Taming Penguins: towards high precision measurements of phi_d and phi_s

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Experimentally, the phases ϕ_d and ϕ_s are determined from CP asymmetry measurements in the "golden modes" $B^0_d \to J/\psi K^0$ and $B^0_s \to J/\psi\phi$. At leading order, the theoretical interpretation of these measurements is straightforward. However, to reach high precision determinations of ϕ_d and ϕ_s, which is desirable in view of the searches for signs of beyond the SM physics, corrections from next-to-leading order effects need to be accounted for. These corrections primarily originate from so-called penguin topologies. Using the SU(3) flavour symmetry, these corrections can be determined using suitably chosen control modes. Recent new CP asymmetry measurement from LHCb on $B \to DD$ and Belle-II on $B^0_d \to J/\psi\pi^0$ decays greatly improve our knowledge on the parameters describing the contribution from penguin topologies. I will show the current constraints on the penguin parameters in $B \to J/\psi X$ and $B \to DD$ decays and highlight what we can expect at the end of the HL-LHC and Belle-II programmes.

Collider 1 / **80**

Collider and astrophysical signatures of light scalars with enhanced τ couplings

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Beyond Standard Model scenarios addressing the flavor puzzle and the hierarchy problem generally predict dominant new physics couplings with fermions of the third generation. In this talk, I will explore the collider and astrophysical signatures of new light scalar and pseudoscalar particles dominantly coupled to the τ-lepton. The best experimental prospects are expected at Belle II through the $e^+e^- \to \tau^+\tau^-\gamma\gamma$, $\tau^+\tau^-\gamma$, $3\gamma, \mathrm{mono}{-}\gamma$ processes, and the τ anomalous magnetic moment. The correlated effects in these searches can unambiguously point toward the underlying new physics dynamics. Moreover, we study astrophysics bounds - especially from core-collapse supernovae and neutron star mergers - finding them particularly effective and complementary to collider bounds. We carry out this program in the well-motivated context of axion-like particles as well as generic CP-even and CP-odd particles, highlighting possible ways to discriminate among them.

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A Strangeness Adventure: Kaonic Atom Measurements with SIDDHARTA-2 at the DAΦNE Collider

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In particle physics, understanding the low-energy strong interaction remains a significant challenge, demanding new experimental data as input and validation. Among the promising approaches, X-ray spectroscopy of kaonic atoms offers a unique window into the antikaon-nucleon interaction at threshold. The SIDDHARTA experiment's measurement of kaonic hydrogen has enhanced our understanding of the antikaon-proton interaction, yet a full determination of the isospin-dependent antikaon-nucleon scattering lengths also requires measurement of kaonic deuterium.
The SIDDHARTA-2 collaboration has leveraged the DAΦNE collider's high-quality low-energy kaon beam, innovative experimental techniques, and state-of-the-art radiation detectors to conduct highly precise kaonic atom measurements. For the first time, X-ray transitions of kaonic deuterium to the ground state have been observed (with data analysis ongoing), in addition to measurements of other low-Z kaonic atoms, including kaonic helium and kaonic neon.
This presentation will discuss the scientific motivation, experimental setup, and findings from these kaonic atom measurements, with a focus on preliminary results from kaonic deuterium. This result, central to kaonic atom research, is expected to provide critical insights into low-energy strong interactions involving strangeness and associated symmetries.

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The SAND detector at the DUNE near site

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DUNE is a next-generation, long-baseline neutrino oscillation experiment with the primary aim of determining the neutrino mass ordering and the CP violation phase in the leptonic sector.
The SAND detector at the DUNE Near Detector complex is designed to perform on-axis beam monitoring, constrain systematic uncertainties in the oscillation analysis and provide precision neutrino physics measurements. SAND consists of a superconducting magnet, an electromagnetic calorimeter, a novel liquid Argon detector, and a modular low-density target/tracker system equipped with different nuclear targets.
In this talk, the current status of the detector and its physics program will be presented.

Flavour and CP violation 2 / 83

Anomaly awareness estimation in $b \to s\ell^+\ell^-$ with VAEs

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Traditional statistical methods often rely on closed likelihood functional forms, which can be problematic when dealing with non-Gaussian distributions and small associated errors. This talk will

address these issues by introducing Machine Learning techniques, particularly Variational Autoencoders (VAEs), to perform likelihood-free analyses. By using VAEs, we can estimate the p-value for anomaly detection in a more model-agnostic manner. The efficacy of these methods will be demonstrated through preliminary results from data on b —> sll transitions. This presentation aims to show how ML techniques can enhance the robustness of statistical analyses, which will be crucial for analysing data with unprecedented precision from the High Luminosity LHC.

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Particle-antiparticle asymmetries in hadronic charm decays at LHCb

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LHCb has collected the world's largest sample of charmed hadrons. This sample is used to precisely measure meson-antimeson mixing and CP violation, and to perform precise measurements of properties and production of charmed mesons. New measurements of several decay modes are presented, including preliminary results obtained with the new LHCb Upgrade I detector.

Cosmology and Astroparticle Physics 1 / 85

Leptogenesis, dark matter and gravitational waves from discrete symmetry breaking

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We analyse a model that connects the neutrino sector and the dark sector of the universe via a mediator Φ, stabilised by a discrete Z_4 symmetry that breaks to a remnant Z_2 upon Φ acquiring a non-zerovacuum expectation value (vϕ). The model accounts for the observed baryon asymmetry of the universe via additional contributions to the canonical Type-I leptogenesis. The Z_4 symmetry breaking scale (vϕ) in the model not only establishes a connection between the neutrino sector and the dark sector, but could also lead to gravitational wave signals that are within the reach of current and future experimental sensitivities.

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Penguin decays of B mesons

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TBA

Collider 2 / 88

Higgs decays into lepton pairs and a photon

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We present a study of Higgs boson decays involving a photon and leptonic or neutrino pairs within the Standard Model. For $H \to \ell^+\ell^-\gamma$ with $\ell = e, \mu$, we calculate differential decay rates, branching fractions, and forward-backward asymmetries, providing analytic expressions for experimental analyses. Our approach distinguishes the resonant $H \to Z\gamma$ contribution from non-resonant contributions enabling precise extraction of $\Gamma(H \to Z\gamma)$. We propose optimized kinematic cuts to effectively separate these components, thereby enhancing the discovery potential for both $H \to Z\gamma$ and the tree-level $H \to \mu^+\mu^-\gamma$ decay. Additionally, for $H \to \nu\bar{\nu}\gamma$, we present leading-order one-loop calculations, highlighting the role of non-resonant box diagrams.

Plenary session / 89

Closing session

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Higher order corrections in dimensional reduction

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TBA

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Baryon number violation in the top sector

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TBA

Neutrinos and ALPs 2 / 92

Heavy neutrino magnetic moments + LLPs

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TBA

Neutrinos and ALPs 1 / **93**

Extending the reach of Mu3e with displaced searches

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A new set of experiments will deliver in the next few years unprecedented sensitivity to Lepton Flavor Violating (LFV) muon decays. Mu3e, proposed at PSI (Switzerland), will focus on observing $\mu \to 3e$ decays, with a projected target of 10^{15} muons decaying at rest, and excellent electron/positron track reconstruction. In this talk I will review the current and future statues of these probes, and I will delve in the potential of Mu3e to search for New Physics. Specifically, I will show that Mu3e has unique sensitivity for new light particles decaying displaced and produced in two-body, three-body and four-body decays of the muon, providing a complimentary opportunity to probe large portions of unexplored parameter space.

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Highlights from the NA64 experiment

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TBA

Collider 2 / **96**

Probing global symmetries with top and Higgs at CMS

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TBA

Collider 2 / **97**

Higgs boson property measurements at the ATLAS experiment

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TBA

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Studies of CP violation at Belle and Belle II

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TBA

Cosmology and Astroparticle Physics 1 / 99

Highlights from space astroparticle physics experiments

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TBA

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Implications of cascade topologies for rare charm decays and CP violation

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The CP violation observed in the hadronic decays of charmed mesons remains a puzzling open question for theorists. Calculations relying on the assumption of inelastic final-state interactions occurring between pairs of pions and kaons fall short of the experimental value. It has been pointed out that a third channel of four pions can leave imprints on the CP asymmetries of the two-body decays. At the same time, plenty of data are available for the 4π decays of charmed mesons, as well as for the rare decays $D^0 \to \pi^+\pi^-\ell^+\ell^-$. With this motivation, we study the cascade topology $D^0 \to a_1^+(1260)\pi^-$, which has been measured to contribute significantly to the 4π decays, and estimate its effect on the branching ratio and angular observables of the rare decays. We also explore

the possibility of this "intermediate" state contributing to the decay amplitude of $D^0 \to \pi^+\pi^-$ and by extension to the related CP asymmetry.

Theoretical Developments 1 / 101

Thermodynamics from the S-matrix reloaded

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Over the past decade and more, S-matrix-based calculational methods have experienced a resurgence, proving to be both an elegant and powerful tool for extracting physical quantities without the need for an underlying Lagrangian formulation. In this seminar I will critically review the formalism introduced by Dashen, Ma, and Bernstein, which connects the thermodynamics of relativistic systems to the information contained in their scattering amplitudes. In revising the computation of the QCD equation of state to leading order in the strong coupling, I will showcase the advantages of this method over traditional Thermal Field Theory techniques.

Theoretical Developments 1 / 102

The Standard Model lifetime is slightly shorter

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The electroweak vacuum of the Standard Model is unstable at very high energies due to the running of the Higgs quartic coupling. Since a vacuum decay rate is a fundamental quantity and the Standard Model parameters are precisely measured, its accurate determination is important. We reexamined the computation of vacuum decay rates at the one-loop level and found that the degeneracy factor of the gauge transverse modes was incorrect in the previous literature. We have derived the correct basis set and the degeneracy factor, and updated the vacuum decay rate in the Standard Model. We found that the decay rate becomes 10ˆ6 times faster than the wrong computation: the lifetime of the Universe is now determined as ˜10ˆ{871} Gyr.

Collider 1 / 103

Constraining the SMEFT Extended with Sterile Neutrinos at FCC-ee

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We examine the prospect of probing extensions of the Standard Model (SM) involving heavy neutral leptons (HNLs) at FCC-ee. Using the effective field theory (EFT) approach, we determine the

impact of new interactions on the production and decay of HNLs at FCC-ee. In particular, we consider EFT operators which induce vector, scalar and tensor four-fermion interactions and effective charged- and neutral-current interactions of HNLs, which may also mix with the active neutrinos of the SM. We first consider constraints on the active-sterile mixing and EFT Wilson coefficients from monophoton searches. We then investigate the constraints from displaced vertex decay signatures. In both analyses, we consider the scenarios where the HNLs are Dirac or Majorana fermions.

Plenary session / **104**

SIMP Miracles and WIMP Dead Ends: Navigating the Freeze-Out of MeV Dark Matter

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TBA

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Complex S_3 Symmetric 3HDM

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We discuss a three-Higgs-doublet model with an underlying S_3 symmetry, allowing in principle for complex couplings. In this framework it is possible to have either spontaneous or explicit CP violation in the scalar sector, depending on the regions of parameter space corresponding to the different possible vacua of the S_3 symmetric potential. We list all possible vacuum structures allowing for CP violation in the scalar sector specifying whether it can be explicit or spontaneous. It is by now established that CP is violated in the flavour sector and that the Cabibbo-Kobayashi-Maskawa matrix is complex. In order to understand what are the possible sources of CP violation in the Yukawa sector we analyse the implications of the different available choices of representations for the quarks under the S_3 group. This classification is based strictly on the exact S_3-symmetric scalar potential with no soft symmetry breaking terms. The scalar sector of one such model was explored numerically. After applying the theoretical and the most important experimental constraints the available parameter space is shown to be able to give rise to light neutral scalars at the O(MeV) scale.

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Test of light-lepton universality in τ-decays at Belle II

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