8th RED LHC workshop

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Universidad Complutense de Madrid (UCM)

Book of Abstracts

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A dynamical implementation of canonical second quantization on a quantum computer

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We provide the necessary theoretical methods for the implementation of creation and destruction operators in separate registers of a quantum computer, allowing for a transparent and dynamical creation and destruction of particle modes in second quantization in problems with variable particle number. We establish theorems for the commutation (anticommutation) relations and provide the needed symmetrizing and antisymmetrizing operators. Finally, we provide formulae in terms of these operators for unitary evolution under conventional two- and four-body Hamiltonian terms.

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Emerging jet probes of strongly interacting dark sectors

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Emerging jets are jets with multiple displaced tracks, which originate from the decay of long-lived bound states of a strongly interacting dark sector. In this talk I will summarize our attempts to "validate" the CMS emerging jet search, showing that we are able to reproduce, within reasonable accuracy, the limits obtained by the CMS collaboration in their benchmark model.

The derived efficiencies are then used to consider a novel emerging jet scenario, namely using the SM Higgs exotic decay into a pair of long-lived "dark pions". We find that emerging jets can be the leading probe in regions of parameter space, being able to probe at the HL-LHC exotic Higgs branching ratios below the 1\% level, which is below the "undetected" exotic Higgs decays expectation of 2.5 - 4 %.

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S-wave contribution to rare $D^0 \to \pi^+\pi^-\ell^+\ell^-$ decays in the Standard Model and sensitivity to New Physics

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Physics of the up-type flavour offers unique possibilities of testing the Standard Model (SM) compared to the down-type flavour sector. Here, I discuss SM and New Physics (NP) contributions to the rare charm-meson decay $D^0 \to \pi^+\pi^-\ell^+\ell^-$. In particular, I discuss the effect of including

the lightest scalar isoscalar resonance in the SM picture, namely, the $f_0(500)$, which manifests in a big portion of the allowed phase space. Other than showing in the total branching ratio at an observable level of about 20%, the $f_0(500)$ resonance manifests as interference terms with the vector resonances, such as at high invariant mass of the leptonic pair in distinct angular observables. Recent data from LHCb optimize the sensitivity to P-wave contributions, that I analyse in view of the inclusion of vector resonances. I propose the measurement of alternative observables which are sensitive to the S-wave and are straightforward to implement experimentally. This leads to a new set of null observables, that vanish in the SM due to its gauge and flavour structures. Finally, I study observables that depend on the SM interference with generic NP contributions from semi-leptonic four-fermion operators in the presence of the S-wave.

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Standard Model Extensions and matching to SMEFT/HEFT

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Although Effective Field Theories (EFTs) can be used to describe physics up to a given energy scale, the question of what lies beneath the EFT subsides, and eventually, a connection between the Ultra-Violet (UV) Theory and the EFT becomes necessary. In the last decade, the description of the electroweak sector has been addressed by two EFTs: the Standard Model Effective Field Theory (SMEFT) and the Higgs Effective Field Theory (HEFT). I will discuss the procedure of matching a UV theory to both EFTs in the context of decoupling and non-decoupling effects, as well as the importance of choosing specific parameters to describe the EFT.

Based on 2311.16897 and 2305.07689

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Multi-Higgs Production in EFT

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We have studied the phenomenological implications of multiple Higgs boson production from longitudinal vector boson scattering in the context of effective field theories. We found compact representations for effective tree-level amplitudes with up to four final state Higgs bosons. Total cross sections are then computed for scenarios relevant at the LHC in which we found the general Higgs Effective Theory (HEFT) prediction avoids the heavy suppression observed in Standard Model Effective Field Theory (SMEFT).

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Early measurements with Run3 data by the CMS experiment

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After more than three years of upgrade and maintenance work, a new period of LHC data taking started in 2022 with a record collision energy of 13.6 TeV. This presentation will be focused on top quark and standard model measurements performed with 2022 data collected by the CMS experiment at this new energy regime. The measurements of single top tW inclusive and differential cross sections and the WZ inclusive cross section will be shown and compared with the latest theoretical predictions and with previous measurements at 13 TeV.

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Constraints on anomalous Higgs boson couplings in the HWW channel

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High precision Higgs coupling measurements are mandatory to establish the exact nature of the electroweak symmetry breaking mechanism and to pin down possible effects of BSM physics. Higgs coupling measurements are generally done in the kappa framework, which is based on inclusive production and decay rates, it is therefore blind to any tension in differential distributions. It also assumes that only SM particles contribute. If deviations were to be observed, this framework by itself cannot provide clear BSM physics guidance. We report an Effective Field Theory (EFT) based approach for studying the Higgs couplings in the HWW channel which avoids these issues and maximizes the sensitivity to BSM physics. The analysis uses the full Run 2 dataset and results in some of the tightest constraints yet placed on anomalous contributions to the Higgs couplings.

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Di-Higgs Production at the LHC: Theory vs. Experiment

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We investigate di-Higgs production at the (HL-)LHC in the Two Higgs Doublet Model (2HDM). We discuss the impact of higher-order corrections and interference effects. We demonstrate the problems applying experimental limits to realistic UV-complete models

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SUSY searches at the LHC: Consistent Excesses at ATLAS and CMS

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We review recent searches for SUSY at the LHC in the channel $pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \to Z\tilde{\chi}_1^0\ W^\pm \tilde{\chi}_1^0$. For masses at $\sim$ 200 GeV and small mass differences between the lightest and next-to-lightest SUSY particles these searches show consistent excesses at ATLAS and CMS. We interpret these excesses for the cases of wino/bino Dark Matter and higgsino Dark Matter.

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New WW Cross Section Measurement at sqrt(s) = 13.6 TeV with the CMS detector.

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A measurement of the WW boson pair production cross section in proton-proton collisions at sqrt(s) = 13.6 TeV is presented. The data used in this study are collected with the CMS detector at the CERN LHC in 2022, and correspond to an integrated luminosity of 35fb-1. The WW candidate events are selected by requiring one electron and one muon of opposite charge. A sequence of requirements on kinematic quantities is applied allowing a measurement of the total production cross section. Inclusive
fiducial and differential cross sections as a function of the jet multiplicity are also reported.

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Di-Higgs Production via Axion Like Particles

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Due to the pseudo-scalar nature of the axion-like particle (ALP), the CP-conserving production of two Higgs bosons via the ALP necessarily involves an additional Z or γ boson. We examine the existing constraints from di-Higgs searches at Run 2 of the LHC and find that, despite the presence of extra objects in the final state, these searches are sensitive to ALP couplings. We compare the Higgs EFT predictions to the SMEFT linear realization of the EWSB and the ALP couplings. Finally we propose a dedicated search for these final states.

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Search for supersymmetric particle pair production in final states with two oppositely charged leptons and large missing transverse momentum in the full RunII data set

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We report the results of a search for symmetric particle pair production in 138 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV collected by the CMS detector during the LHC RunII data taking period. We use a sample of events with two oppositely charged leptons (electrons or muons) and large missing transverse momentum to perform the search. The results are interpreted in terms of several simplified supersymmetric models with R-parity conservation, where the lightest neutralino is assumed to be the lightest supersymmetric particle.

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Long-lived particles searches with the CMS experiment. Present and future.

Authors: Alberto Escalante Del Valle[1]; Pablo Martinez Ruiz Del Arbol[2]; Santiago Folgueras[3]

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Long-lived particles (LLPs) are predicted in many well-motivated theories of BSM physics, and naturally arise from the presence and breaking of symmetries, which can be motivated by cosmology and the nature of dark matter, neutrino masses, as well as solutions to the hierarchy problem. If these long-lived particles (LLPs) were to be produced at the LHC, they could decay far from the interaction point and thus show distinct signatures from those of promptly decaying particles that are targeted by the vast majority of BSM searches at the LHC. These signatures often require specialized triggering, reconstruction, and identification techniques, and dedicated analysis strategies and do offer excellent prospects for the discovery of new physics at the LHC. The first search for new physics using data collected in Run 3 during 2022, is dedicated to the search for LLPs in events with two displaced muons in the final state (arXiv:2402.14491). Additionally the collaboration is progressing towards the HL-LHC upgrades which foresees several hardware improvements, including new detectors (MTD and HGCal) and an improved DAQ and triggering system which will significantly enhance the discovery potential of LLPs with the CMS experiment. The prospects for future searches will also be discussed.

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Measurement of differential cross sections in t¯t and t¯t+jets production in the lepton+jets decay mode in pp collisions at √s= 13 TeV using 140 fb−1 of ATLAS data

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Differential cross sections for top-quark pair production, inclusively and in association with jets, are measured in pp collisions at a centre-of-mass energy of 13 TeV with the ATLAS detector at the LHC using an integrated luminosity of 140 fb−1. The events are selected with one charged lepton (electron or muon) and at least four jets. The differential cross sections are presented at particle level as functions of several jet observables, including angular correlations, jet transverse momenta and invariant masses of the jets in the final state, which characterize the kinematics and dynamics of the top-antitop system and the hard QCD radiation in the system with associated jets. The typical precision is (5–15)% for the absolute differential cross sections and (2–4)% for the normalised differential cross sections. Next-to-leading-order and next-to-next-to-leading-order QCD predictions are found to provide in general an adequate description of the rate and shape of the jet-angular observables. The description of the transverse momentum and invariant mass observables is improved when next-to-next-to-leading-order QCD corrections are included.

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EFT Working Group activities

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I will summarize some of the recent activities of the Effective Field Theory (EFT) Working Group, with special emphasis on those in area 5 (Benchmark Scenarios from UV Models). I also will review the current status of automated tools for EFT matching, highlighting their potential and applications to the field.

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Aligned two Higgs doublet model and the global fits

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Aligned two Higgs doublet model (ATHDM) is one of the simplest extensions of the Standard Model (SM). It assumes the existence of two scalar doublets with similar Yukawa structure. This assumption forbids undesirable flavour changing neutral currents (FCNCs) at tree level without imposition of any Z_2 symmetry. A2HDM also provides the opportunity to study different varieties of 2HDMs under a generic framework. Here, we demonstrate a global fit of A2HDM with the help of the package HEPfit, that relies on bayesian approach, using various theoretical and experimental constraints on the model.

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Theoretical predictions to differential cross sections and decay rates from the loop-tree duality

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Understanding the cancellation of ultraviolet and infrared singularities in perturbative quantum field theory is of central importance for the development and automation of various theoretical tools that make accurate predictions for observables at high-energy colliders. The loop-tree duality aims to find an efficient solution by treating loop and tree-level contributions under the same foot to achieve a local cancellation of singularities at integrand level, and thus avoid dimensional regularisation. In this talk, we exploit the causal properties of scattering amplitudes in the loop-tree duality representation to present different applications to physical processes at higher orders.

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Machine-Learning Collider Analysis of Radiative Neutralino Decays at the LHC

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The search for weakly interacting particles is one of the main objectives of the high luminosity LHC. In the Minimal Supersymmetric Extension of the Standard Model (MSSM), these particles include the lightest neutralino, which is a good Dark Matter (DM) candidate and whose relic density may be fixed to realistic values through its co-annihilation with the second lightest neutralino and lightest chargino. Moreover, its direct DM detection rate is suppressed for the same region of parameters in which the radiative decay of the second lightest neutralino into a photon and the lightest neutralino is enhanced. This motivates the search for radiatively decaying neutralinos, which, however, suffers from strong backgrounds. In this work we provide an analysis of the reach of the LHC, for a center-of-mass energy of 14 TeV and a luminositiy of 100 fb^{-1}, in the search for these radiatively decaying particles by means of cut-based and machine learning methods, defining the LHC discovery potential in this well motivated region of parameters in the high luminosity era.

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COmpact DEtector for EXotics at LHCb: CODEX-b

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The COmpact DEtector for EXotics at LHCb (CODEX-b) is a particle physics detector dedicated to displaced decays-in-flight of exotic long-lived particles (LLPs), compelling signatures of dark or hidden sectors Beyond the Standard Model, which arise in theories containing a hierarchy of scales and/or small parameters. CODEX-b is planned to be installed near the LHCb interaction point and makes use of fast gaseous detector technology (RPCs), which provides both a good space and temporal sensitivity and also a zero background environment, hence complementing the new-searches program of other detectors like ATLAS or CMS. At present, ongoing efforts are being made to install a demonstrator detector, CODEX-β, which will take data during LHC Run 3 and validate the design and physics case for the future CODEX-b. Specifically, validating the background estimations for CODEX-b and their reconstruction, the seamless integration in the LHCb readout system, and the suitability of the baseline tracking baseline and its mechanical support will be the challenges this detector will face in the short term.

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Di-Higgs Production Associated with Dark Matter at the LHC: A Machine-Learning Analysis

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Di-Higgs production at the LHC associated with missing transverse energy is explored in the context of simplified models that generically parameterize a large class of models with heavy scalars and dark matter candidates. Our aim is to figure out the improvement capability of machine-learning tools over traditional cut-based analyses. In particular, boosted decision trees and neural networks are implemented in order to determine the parameter space that can be tested at the LHC demanding four b-jets and large missing energy in the final state. We present a performance comparison between both machine-learning algorithms, based on the maximum significance reached, by feeding them with different sets of kinematic features corresponding to the LHC at a center-of-mass energy of 14 TeV. Both algorithms present very similar performances and substantially improve traditional analyses, being sensitive to most of the parameter space considered for a total integrated luminosity of 1/ab, with significances at the evidence level, and even at the discovery level, depending on the masses of the new heavy scalars. A more conservative approach with systematic uncertainties on the background of 30% has also been contemplated, again providing very promising significances.

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Study of exclusive processes in ultra-peripheral collisions at LHCb

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The study of exclusive processes in lepton-hadron and in ultra-peripheral hadron-hadron collisions provides information on the three-dimensional distribution of quarks and gluons as a function of their longitudinal momentum and transverse position inside the hadron, where the longitudinal

direction corresponds to the direction of the probe used to investigate the hadron. This will be introduced and an overview of the measurements of exclusive processes performed at LHCb will be given. Where applicable, parallels with measurements in lepton-hadron interactions will be highlighted.

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The ABC of RPV: classification of R-parity violating signatures at the LHC

Author: Victor Martin Lozano[1]

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We perform a classification of all potential supersymmetric R-parity violating signatures at the LHC to address the question: are existing bounds on supersymmetric models robust, or are there still signatures not covered by existing searches, allowing LHC-scale supersymmetry to be hiding? We analyze all possible scenarios with one dominant RPV trilinear coupling at a time, allowing for arbitrary LSPs and mass spectra. We consider direct production of the LSP, as well as production via gauge-cascades, and find 6 different experimental signatures for the LLE-case, 6 for the LQD-case, and 5 for the UDD-case; together these provide complete coverage of the RPV-MSSM landscape. This set of signatures is confronted with the existing searches by ATLAS and CMS. We find all signatures have been covered at the LHC, although not at the sensitivity level needed to probe the direct production of all LSP types. For the case of a dominant LLE-operator, we use CheckMATE to quantify the current lower bounds on the supersymmetric masses and find the limits to be comparable to or better than the R-parity conserving case. Our treatment can be easily extended to scenarios with more than one non-zero RPV coupling.

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Direct measurement of the top-quark mass with ATLAS

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In this talk, the measurement of the top-quark mass in top-quark pair production using the full Run 2 dataset collected with the ATLAS experiment at $\sqrt{s}$ = 13 TeV will be presented. The measurement is carried out in the dilepton channel using a template method. The talk will have a special emphasis on the theoretical uncertainties affecting experimental measurements of the top-quark mass, as more and more often, these are becoming the limiting factors to further improve the precision of current measurements. Recent developments in the ATLAS collaboration towards an improved modelling of the top-quak pair production will be discussed.

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Search for heavy scalar and pseudo-scalar in ttbar and four-top final states in pp collisions with the ATLAS detector

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New massive scalar or pseudo-scalar states with strong couplings to the top quark are predicted in numerous extensions of the Standard Model. These include models with an extended Higgs sector, such as Two-Higgs-Doublet Models (2HDMs). In this talk, two recent searches for new scalar and pseudo-scalar particles with couplings to the top quark using the full LHC Run-2 dataset are presented. Final states with two and four top quarks, targeting production of the heavy Higgs-like states via gluon-gluon fusion (gg→A/H) and associated production with a top-antitop-quark pair (ttA/H) are considered. The search in four-top final state is one of the first dedicated searches for tree-level A/H production with t-A/H coupling only. The gg→A/H→tt search takes into account interference with the SM process and provides the first full Run-2 search of this kind at the LHC. The two searches provide complementary coverage in the 2HDM parameter space.

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LFU measurements at LHCb in semileptonic B decays

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Lepton flavour universality is conserved in the Standard Model, however still nowadays, many experimental measurements of lepton flavor universality ratios exhibit a non-negligible tension with respect the theory predictions, which has a notable low uncertainty. This makes LFU measurements a gateway for the search of new physics which must be investigated to solve this tension. The LHCb measurement provides several measurements that contribute to this tension, with the newest measurement of the LFU ratios R(D) and R(D*) using three prong tau hadronic decays, which will be presented in this talk. The measurement provides an independent and complementary addition to the global combination of both R(D) and R(D*), which could potentially accentuate this tension.

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A dynamical implementation of canonical second quantization on a quantum computer

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Long-lived particle searches with the CMS experiment. Present and future

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The ABC of RPV: classification of R-parity violating signatures at the LHC

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