

27th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY2019)

Monday, May 20, 2019 - Friday, May 24, 2019

Omni Hotel

Book of Abstracts

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Formal Field Theory and Strings / 200

Numerical Moduli Stabilisation towards Calabi-Yau Data Exploration

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String compactifications with stabilised moduli and flat directions make it possible to constrain the theory using phenomenological constraints or data. The base geometry typically has many, analytically intractable, moduli fields and flux quanta that characterise the kind of physics which could be explained. Numerical moduli stabilisation will facilitate the connection of Calabi-Yau data, phenomenology and machine-learning of the string theory landscape. We explore the possibility of this by applying nested-sampling algorithms for minimising supergravity potentials.

Dark Matter, Astroparticle Physics / 172

Loop corrections to dark matter direct detection in a pseudoscalar mediator dark matter model

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In fermionic dark matter (DM) models with pseudoscalar mediators, the tree-level amplitude for the DM-nucleon elastic scattering is suppressed by the momentum transfer in the non-relativistic limit. However, it is not suppressed at the loop level, and thus the loop corrections are essential to discuss the sensitivities of the direct detection experiments for the model prediction. In particular, two-loop diagrams give a leading order contribution for an operator with gluon fields but were not correctly evaluated. Moreover, some interaction terms which affect the scattering cross section were overlooked. In this talk, we show the cross section obtained by the improved analysis and discuss the region where the cross section becomes large.

Plenary Session / 294

Dark Matter Models

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Supersymmetry: Models, Phenomenology and Experimental Results / 65

Detecting hidden sector dark matter at HL-LHC and HE-LHC via long-lived stau decays

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We investigate a class of models where the supergravity model with the standard model gauge group is extended by a hidden sector $U(1)_X$ gauge group and where the lightest supersymmetric particle is the neutralino in the hidden sector. We investigate this possibility in a class of models where the stau is the lightest supersymmetric particle in the MSSM sector and the next-to-lightest supersymmetric particle of the $U(1)_X$ -extended SUGRA model. In this case the stau will decay into the neutralino of the hidden sector. For the case when the mass gap between the stau and the hidden sector neutralino is small and the mixing between the $U(1)_Y$ and $U(1)_X$ is also small, the stau can decay into the hidden sector neutralino and a tau which may be reconstructed as a displaced track coming from a high p_T track of the charged stau. Simulations for this possibility are carried out for HL-LHC and HE-LHC. The discovery of such a displaced track from a stau will indicate the presence of hidden sector dark matter.

Electroweak, Top and Higgs Physics / 253

FCNC and EFT interpretations at LHC (Includes EFT interpretation of $t\bar{t}V$)

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Top quark production can probe physics beyond the SM in different ways. Some processes, and especially certain angular correlations, are sensitive to the existence of anomalous top quark couplings. In the SM, flavour-changing neutral currents (FCNC) are forbidden at tree level and are strongly suppressed in loop corrections. Several extensions of the SM incorporate significantly enhanced FCNC behaviour that can be directly probed in top quark processes. Current approaches adopting an EFT framework allow describing effects of new physics in a model independent way. This talk reviews the current limits on FCNC searches in the top sector, and EFT interpretations.

Alternatives to Supersymmetry / 69

Search for BSM Physics using Challenging Signatures with the ATLAS detector

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Various theories beyond the Standard Model predict unique signatures which are difficult to reconstruct and for which estimating the background rates is also a challenge. Signatures from displaced decays anywhere from the inner detector to the muon spectrometer, as well as those of new particles with fractional or multiple value of the charge of the electron or high mass stable charged particles are all examples of experimentally demanding signatures. The talk will focus on the most recent results using 13 TeV pp collision data collected by the ATLAS detector.

Supersymmetry: Models, Phenomenology and Experimental Results / 143

Strong SUSY Production in leptonic channels - CMS Experiment

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Results from the CMS experiment are presented for searches for strong supersymmetric particle production. The results target a variety of gluino and squark production channels with decays to final states with one or more leptons. The searches use proton-proton collision data with luminosity up to 137 fb⁻¹ recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Supersymmetry: Models, Phenomenology and Experimental Results / 230

Searches for direct pair production of third generation squarks with the ATLAS detector

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Naturalness arguments for weak-scale supersymmetry favour supersymmetric partners of the third generation quarks with masses not too far from those of their Standard Model counterparts. Top or bottom squarks with masses less than or around one TeV can also give rise to direct pair production rates at the LHC that can be observed in the data sample recorded by the ATLAS detector. The talk presents recent ATLAS results from searches for direct stop and sbottom pair production, using the data collected during the LHC Run 2.

Cosmology and Gravitational Waves / 189

Multistep Strongly First Order Phase Transitions from New Fermions at the TeV Scale

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Despite the vast literature on first order Electroweak Phase Transitions (EWPT), which can provide the necessary conditions for generating the Baryon Asymmetry in the Universe, fermion-induced EWPTs still remain a rather uncharted territory. In this talk, we consider a simple fermionic extension of the Standard Model (SM) involving one $SU(2)_L$ doublet and two singlet Vector-Like Leptons (VLLs), strongly coupled to the Higgs scalar and with TeV-scale masses. We show how such a simple scenario can give rise to a non-trivial thermal history of the Universe, involving strongly first order multistep phase transitions occurring at temperatures close to the electroweak (EW) scale. Afterwards, we investigate the distinct Gravitational Wave (GW) signatures of these phase transitions at future GW detectors, such as LISA, and briefly discuss the LHC signatures of the VLLs. Finally, we compare the full model GW results with the ones obtained in an Effective Field Theory coming from integrating out the VLLs.

Dark Matter, Astroparticle Physics / 192

Search for New Physics at BABAR

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Many extensions of the Standard Model include the possibility of light new particles, such as axions or dark matter candidates. These scenarios can be probed using the large data sets collected by B-factories, complementing measurements performed at the LHC. The BABAR collaboration has conducted an extensive program to search for axions in B decays, self-interacting or non-minimal dark forces, as well as six-quark dark matter candidates. In this talk, we'll report on recent the most recent results.

Neutrinos: Models, Phenomenology, Experiments / 301

CP violating effects in coherent elastic neutrino-nucleus scattering processes

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Abstract:

The presence of new neutrino-quark interactions can enhance, deplete or distort the coherent elastic neutrino-nucleus scattering (CEvNS) event rate. The new interactions can involve CP violating phases that can potentially affect these features. Assuming vector light mediators we study the effects of CP violation on the CEvNS process, and for that aim we consider the COHERENT sodium-iodine (NaI), liquid argon (LAr) and germanium detectors. We identify a region in parameter space for which the event rate always involves a dip and another one for which this is never the case. We show that the presence of a dip in the event rate can be used to constraint CP violating effects, in such a way that the larger the detector volume the tighter the constraints. In the region where no dip is present, we find that CP violating parameters can mimic the SM CEvNS prediction or spectra induced by real parameters. Thus, we point out that the interpretation of CEvNS data in terms of new physics should take into account possible CP violating effects.

Plenary Session / 255

Overview

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Alternatives to Supersymmetry / 89

Twin Turtles

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We present an ultraviolet extension of the Twin Higgs in which the radial mode of twin symmetry breaking is itself a pseudo-goldstone boson. This “turtle” structure raises the scale of new colored particles in exchange for additional states in the Higgs sector, making multiple Higgs-like scalars the definitive signature of naturalness in this context. We explore the parametrics and phenomenology of a concrete Twin Turtle model and demonstrate its robustness in two different supersymmetric completions.

BSM in Flavor Physics / 90

Asymmetry Observables and the Origin of $R_{D^{(*)}}$ Anomalies

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The $R_{D^{(*)}}$ anomalies are among the longest-standing and most statistically significant hints of physics beyond the Standard Model. In this talk, we investigate future measurements at Belle II that can be used to tell apart the various new physics scenarios for these anomalies. We show that Belle II can use a number of τ asymmetry observables (forward-backward asymmetry and polarization asymmetries) which can be reconstructed at Belle II to distinguish between various possible new-physics scenarios.

Neutrinos: Models, Phenomenology, Experiments / 222

Nonstandard neutrino interactions in radiative neutrino mass models

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In models of radiative neutrino masses, new scalar bosons that generate the masses can also induce significant nonstandard neutrino interactions (NSI). In this talk I will present our results of a comprehensive analysis of NSI in such models. Diagonal NSIs of order several percent are found to be possible, especially in the Zee model that utilizes charged scalars. Tests of this scenario at DUNE and LHC will be outlined.

Dark Matter, Astroparticle Physics / 117

Energetic ALPs From Decaying Dark Matter

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We consider a model of decaying axino-like particle dark matter with lifetime around the age of the universe. Its late decay to gravitino plus axion-like particle can solve small scale problems. We will also show a distinct signature of the axion-like particle from the axino-like particle decay.

Supersymmetry: Models, Phenomenology and Experimental Results / 61

Motivation for weak scale SUSY

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SUSY with weak scale soft breaking terms is highly motivated theoretically and is also supported by a variety of measured virtual effects. The question is: where are the sparticles and where are the WIMPs? A more nuanced view of naturalness can reconcile TeV-scale soft terms and $m_h=125$ GeV with naturalness but where now only the higgsinos need lie close to the weak scale while top-squarks may range up to ~ 3 TeV and gluinos may range up to ~ 6 TeV at little cost to naturalness. To be natural in both the EW and QCD sectors, then both axions and WIMPs are expected where axions typically make up the bulk of dark matter, bringing SUSY into accord with WIMP search limits.

The view of SUSY from the string landscape motivates the notion of “stringy naturalness” which ends up predicting $m_h=125$ GeV along with sparticles typically well beyond current LHC limits.

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SUSY Phenomenology

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Dark Matter, Astroparticle Physics / 68

Dark Matter searches with the ATLAS Detector

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The presence of a non-baryonic dark matter component in the Universe is inferred from the observation of its gravitational interaction. If dark matter interacts weakly with the Standard Model it would be produced at the LHC, escaping the detector and leaving a large missing transverse momentum as their signature. The ATLAS detector has developed a broad and systematic search program for dark matter production in LHC collisions. The results of these searches on 13 TeV pp data, their

interpretation, and the design and possible evolution of the search program, including prospects for the HL-LHC, will be presented.

Dark Matter, Astroparticle Physics / 3

Non-Abelian Vector Boson Dark Matter, its Unified Route and signatures at the LHC

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Non-abelian vector boson dark matter (DM), although not widely studied, offers very important phenomenological outcome. In this talk, we highlight some possibilities that can be accommodated in an $SU(2)$ extension of the the Standard Model (SM). One important feature of DM of such kind is realized via t -channel annihilation for relic abundance and s -channel direct search interaction, that helps the DM survive severe direct search guillotine, which has otherwise excluded many simple DM realizations. In another scenario, we explore a multipartite DM framework, where, in addition to the non-abelian vector boson DM, a scalar DM may exist and the DM-DM interaction alters the viable parameter space quite significantly. We also elaborate signatures of these DM scenarios at the Large Hadron Collider (LHC) and show that multi-lepton final states offer as a good probe over direct searches. In addition, generation of correct neutrino masses, unification of such extensions in a high scale $E(6)$ framework via consistent intermediate symmetries and *freeze-in* production of DM are also discussed.

Plenary Session / 295

Alternative to SUSY/Composite Higgs

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Plenary Session / 285

Astroparticle Physics

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Dark Matter, Astroparticle Physics / 31

Dark Sector Phenomenology at Neutrino Experiments

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Several models of the dark sector beyond the minimal Weakly Interacting Massive Particle paradigm are accessible at current and upcoming neutrino experiments. I present two well-motivated models to which the experiments at Fermilab are sensitive: boosted dark matter and the Higgs portal. Several regions of hadronically interacting boosted dark matter parameter space will be accessible to DUNE. I discuss the detailed phenomenology of the interactions of this dark matter candidate in liquid argon time projection chamber experiments, such as DUNE, including a new Monte Carlo simulation tool. I further explore the sensitivity of the short baseline experiments at Fermilab to light scalars coming from beam-produced mesons. I present projected sensitivities to both models.

Cosmology and Gravitational Waves / 174

Minimal Warm Inflation

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“Warm inflation is an interesting alternative implementation of a period of accelerated expansion and reheating in the early universe. It turns out to be easy to have a concurrent quasi-thermal radiation bath if energy is extracted from the rolling scalar field via friction. The benefits of warm inflation include automatic reheating at the end of inflation when the thermal bath begins to dominate over the vacuum energy, and a new form of friction that does not require super-Planckian field excursions and suppresses contributions to the scalar-to-tensor ratio r . We show that with an axion-like coupling to a non-Abelian group, a thermal bath can be generated with all of these benefits and describe what we call the ‘minimal model’.”

Alternatives to Supersymmetry / 76

ATLAS Searches for VH/HH Resonances

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The discovery of a Higgs boson at the Large Hadron Collider (LHC) motivates searches for physics beyond the Standard Model (SM) in channels involving coupling to the Higgs boson. A search for a massive resonance decaying into a standard model Higgs boson (h) and a W or Z boson or two a standard model Higgs bosons is performed. The results of a search for non-resonant Higgs boson pair production in a combination of six decay modes with 36fb^{-1} is given, along with two new and ground-breaking results with 140fb^{-1} .

Supersymmetry: Models, Phenomenology and Experimental Results / 149

Search for SUSY with tau final states - CMS Experiment

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Results from the CMS experiment are presented for searches for supersymmetric particle production with tau leptons in the final state. The searches use proton-proton collision data with luminosity up to 137 fb⁻¹ recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Dark Matter, Astroparticle Physics / 11

Phenomenological Implications of Multipartite Dark Sector

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Multipartite dark sector has several motivations, one of the key issues being to evade stringent direct search bound. In this talk, we highlight some interesting phenomenological features of having two component dark matter models constituted of scalar-scalar or scalar-fermion dark matter, where the interaction between the dark matter components not only yields a larger available parameter space but also can aid to a observable signal excess at the Large Hadron Collider experiment in near or distant future. We also comment on the prospect of addressing neutrino mass in the same framework(s).

Formal Field Theory and Strings / 125

Testing the weak gravity conjecture in type I strings with broken supersymmetry

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I will discuss tests of the weak gravity conjecture in the presence of supersymmetry breaking, performed in the framework of type I string theory with supersymmetry broken by compactification (à la Scherk-Schwarz). Such a (perturbative string theory) setting allows for the presence of runaway potentials (here for the compactification radius), which is the only possibility if one accepts the non-existence of de Sitter vacua, thus enabling one to test the mutual consistency of the weak gravity and the de Sitter conjectures.

Although the weak gravity conjecture is valid in the decompactification limit, for fixed values of the radius there are short-ranged attractive D1 brane-brane interactions, which would naively imply a violation of the weak gravity conjecture for the associated Ramond-Ramond 2-form. I will argue however that at one-loop level the effective tension of the branes decreases such that there is a long-ranged repulsive force, which should come from higher-loops. The conclusion is that the weak gravity conjecture should be respected provided that the string coupling is not extremely small.

Electroweak, Top and Higgs Physics / 132**Effect of flavor-dependent partonic transverse momentum on the determination of the W mass at hadron colliders****Author:** Giuseppe Bozzi¹¹ *Università di Pavia***Corresponding Author:** giuseppe.bozzi@unipv.it

Within the framework of transverse-momentum-dependent factorization, we investigate for the first time the impact of a flavor-dependent intrinsic transverse momentum of quarks on the production of W bosons in hadronic collisions. We study the transverse-mass, lepton transverse momentum, and missing transverse momentum distributions of the W-decay products by means of a template-fit technique and we estimate the shift in the W boson mass induced by different choices of flavor-dependent parameters for the intrinsic quark transverse momentum. Our findings call for more detailed investigations of flavor-dependent non-perturbative effects linked to the proton structure at hadron colliders.

Electroweak, Top and Higgs Physics / 204**Two-loop corrections to the Higgs trilinear coupling in models with extended scalar sectors****Authors:** Johannes Braathen¹; Shinya KANEMURA¹¹ *Osaka University***Corresponding Author:** braathen@het.phys.sci.osaka-u.ac.jp

The precise study of the properties of Higgs boson offers a unique and crucial opportunity to probe Physics beyond the Standard Model (BSM) indirectly. One important example of such property is the Higgs trilinear coupling, which determines the shape of the Higgs potential and in turn the nature of the electroweak phase transition (EWPT). It has been known for some time that, in a variety of BSM models with extended Higgs sectors (e.g. with doublets, singlets, etc.), the value of the Higgs trilinear coupling can deviate significantly from its Standard-Model prediction at one-loop order, because of non-decoupling effects in the radiative corrections involving the additional scalar states. Indeed, deviations from the SM can reach a hundred percent or more without violating perturbative unitarity. Such effects would ensure that the EWPT is of strong first order, which is necessary for the success of the scenario of electroweak baryogenesis. It is then natural to ask if two-loop corrections can modify this result, and whether new large corrections can appear again.

In this talk, I will present new results on the calculation of dominant two-loop corrections to the Higgs trilinear coupling in two models with extended scalar sectors, namely a Two-Higgs-Doublet Model and the Inert Doublet Model, using the effective-potential approximation. I will illustrate the analytical results with numerical examples and show that, while they remain smaller than their one-loop counterparts and do not modify significantly the non-decoupling effects observed at one loop, the two-loop corrections are not entirely negligible – a typical size being 10-20% of the one-loop corrections.

Supersymmetry: Models, Phenomenology and Experimental Results / 240**Search for Supersymmetry at the 100 TeV Future Circular Collider****Authors:** Anadi Canepa¹; Anadi Canepa²

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The proposed 100 TeV pp collider (FCC-hh) is designed to collect a total luminosity of 20/ab providing an un-precedented discovery opportunity for physics beyond the Standard Model. This presentation focuses on the prospects for discovering supersymmetry at the future circular proton-proton collider.

Plenary Session / 288

BSM Higgs Physics: Theory and Phenomenology

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Neutrinos: Models, Phenomenology, Experiments / 302

Probing Neutrino Dirac Mass in Left-Right Symmetric Models at the LHC and Next Generation Colliders

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Abstract:

We assess the sensitivity of the LHC, its high energy upgrade, and a prospective 100 TeV hadronic collider to the Dirac Yukawa coupling of the heavy neutrinos in left-right symmetric models (LRSMs). We focus specifically on the trilepton final state in regions of parameter space yielding prompt decays of the right-handed gauge bosons (WR) and neutrinos (NR). In the minimal LRSM, the Dirac Yukawa couplings are completely fixed in terms of the mass matrices for the heavy and light neutrinos. In this case, the trilepton signal provides a direct probe of the Dirac mass term for a fixed WR and NR mass. We find that while it is possible to discover the WR at the LHC, probing the Dirac Yukawa couplings will require a 100 TeV pp collider. We also show that the observation of the trilepton signal at the LHC would indicate the presence of a non-minimal LRSM scenario.

Supersymmetry: Models, Phenomenology and Experimental Results / 46

Searches for sleptons with the ATLAS detector

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Many supersymmetry models feature gauginos and sleptons with masses less than a few hundred GeV. These can give rise to direct pair production rates at the LHC that can be observed in the data sample recorded by the ATLAS detector. The talk presents recent ATLAS results from searches for slepton pair production.

Formal Field Theory and Strings / 67**SUSY enhancement via T-branes and Hitchin systems****Author:** Federico Carta¹**Co-authors:** Raffaele Savelli²; Simone Giacomelli³¹ *DESY*² *Roma Tor Vergata*³ *Oxford***Corresponding Author:** federico.carta@desy.de

In the last couple of years it was discovered that some 4d N=1 quantum field theories flow in the IR to 4d N=2 superconformal field theories (often of generalized Argyres-Douglas type), therefore showing a phenomenon of Supersymmetry Enhancement at the IR fixed point. The N=2 IR theory is often non-lagrangian while the N=1 UV theory is lagrangian, therefore such flows are extremely useful to learn features of the IR non-lagrangian theory, by using the UV formulation to compute RG flow protected quantities as for example the superconformal index. However, up to date it is not completely clear why such flows exist, and how the SUSY enhancement happens. Limiting ourself to the case of rank one theories, we show how it is possible to understand the enhancement phenomenon in a geometric way, by condering a D3 brane probing a local singularity in F-theory corresponding to a T-brane of seven-branes. It is also possible to understand the enhancement via the moduli space of solutions of the (generalized) Hitchin system associated to such theories.

Electroweak, Top and Higgs Physics / 83**Rare top quark production: ttZ, ttW, ttgamma, tZ, tgamma, and tttt production****Corresponding Author:** richard.j.cavanaugh@gmail.com

A comprehensive set of measurements of top quark pair and single top quark production in association with EWK bosons (W, Z or γ) is presented. The results are compared to theory predictions and re-interpreted as searches for new physics inducing deviations from the standard model predictions. The status of the search for four top quark production, to which the LHC experiments are starting to be sensitive, and that has important BSM re-interpretations, is also reported.

Supersymmetry: Models, Phenomenology and Experimental Results / 232**Prospects for SUSY searches at the HL-LHC****Corresponding Author:** alberto.cervelli@cern.ch

The search for weak-scale SUSY is one of the highest physics priorities for the current and future LHC runs. The high luminosity upgrade of the LHC (HL-LHC) is expected to deliver proton-proton collisions at a centre-of-mass-energy of 14 TeV, with an integrated luminosity of around 3000 fb⁻¹. The large dataset expected at the end of HL-LHC offers an unprecedented discovery potential for several supersymmetric particles, both in the strong and electroweak sectors. This talk will review the prospects for SUSY searches with the ATLAS and CMS experiments at the end of the HL-LHC.

Electroweak, Top and Higgs Physics / 107**A 96 GeV Higgs Boson in the N2HDM****Authors:** Thomas Biekötter¹; Manimala Chakraborti²; Sven Heinemeyer³¹ *Instituto de Física Teórica UAM-CSIC, Cantoblanco, 28049 Madrid, Spain, Departamento de Física Teórica, UAM, Campus de Cantoblanco, 28049 Madrid, Spain*² *Instituto de Física Teórica UAM-CSIC, Cantoblanco, 28049 Madrid, Spain*³ *Instituto de Física Teórica UAM-CSIC, Cantoblanco, 28049 Madrid, Spain, Campus of International Excellence UAM+CSIC, Cantoblanco, 28049 Madrid, Spain, Instituto de Física de Cantabria (CSIC-UC), 39005 Santander, Spain***Corresponding Author:** mani.chakraborti@gmail.com

We discuss a $\sim 3\sigma$ signal (local) in the light Higgs-boson search in the diphoton decay mode at ~ 96 GeV as reported by CMS, together with a $\sim 2\sigma$ excess (local) in the $b\bar{b}$ final state at LEP in the same mass range. We interpret this possible signal as a Higgs boson in the 2 Higgs Doublet Model with an additional real Higgs singlet (N2HDM). We find that the lightest Higgs boson of the N2HDM can perfectly fit both excesses simultaneously, while the second lightest state is in full agreement with the Higgs-boson measurements at 125 GeV, and the full Higgs-boson sector is in agreement with all Higgs exclusion bounds from LEP, the Tevatron and the LHC as well as other theoretical and experimental constraints. We show that only the N2HDM type II and IV can fit both the LEP excess and the CMS excess with a large ggF production component at ~ 96 GeV. We derive bounds on the N2HDM Higgs sector from a fit to both excesses and describe how this signal can be further analyzed at the LHC and at future $e+e-$ colliders, such as the ILC.

Cosmology and Gravitational Waves / 59**Multifield D5-brane Inflation in the Throat****Author:** Dibya Chakraborty¹¹ *PhD student of University of Guanajuato***Corresponding Author:** 1992dibyac@gmail.com

Given the ongoing debate by Vafa et al on inflation and the swampland, I will discuss a multifield D-brane model of inflation consistent with observational bounds. We study the model, which was previously been done as a single field, by focusing on the multifield cosmological evolution of a probe D5 brane moving in both radial and angular directions in the Warped Resolved Conifold (WRC) throat of a type IIB string flux compactification. I will show that the model allows for super planckian decay constants when the brane moves along the angular direction with a cosine potential, consistent with the supergravity approximations. I will show that this can be achieved thanks to the warping, presence of geometrical flux quanta and wrapping number. I will discuss the mass hierarchies between inflatons and other mass scales that are present in this model. I will then show the cosmological observables, n_s , r and f_{NL}^{local} which are consistent with the current Planck-X bounds.

Dark Matter, Astroparticle Physics / 38**A Search for Dark Matter Annihilation in the Milky Way Halo****Authors:** Laura Chang¹; Mariangela Lisanti¹; Siddharth Mishra-Sharma²¹ *Princeton University*

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The Milky Way halo is the brightest source of dark matter annihilation on the sky. Indeed, the potential strength of the Galactic dark matter signal can supersede that expected from dwarf galaxies and galaxy groups even in regions away from the Inner Galaxy. We present the results of a search for dark matter annihilation in the smooth Milky Way halo for $|b| > 20^\circ$ and $r < 50^\circ$ using 413 weeks of Fermi Pass 8 data within the energy range of $\sim 0.8\text{--}50$ GeV. We exclude thermal dark matter with mass below ~ 70 GeV that annihilates to $b\bar{b}$ at the 95% confidence level using the p6v11 cosmic-ray foreground model, providing the strongest limits on the annihilation cross section in this mass range. These results exclude the region of dark matter parameter space that is consistent with the excess of $\sim\text{GeV}$ photons observed at the Galactic Center for the $b\bar{b}$ annihilation channel and, for the first time, put the $\tau^+\tau^-$ explanation under tension. We explore how these results depend on uncertainties in the foregrounds by varying over a set of reasonable models.

Neutrinos: Models, Phenomenology, Experiments / 24

Gauged Lepton Number and Implications for Collider Physics

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Lepton number has a deep connection with the neutrino mass generation. A new minimal anomaly-free gauged $U(1)_l$ lepton-number model, with four exotic chiral leptons, is studied. Motivated by phenomenology, we discuss a simplified case which has the universal Yukawa couplings. It agrees with all the experimental constraints and predicts $m_e, m_\mu \ll m_\tau$, and the latter is of the electroweak scale. Due to the interference between the SM and $U(1)_l$ gauge interactions, this model robustly predicts that e, μ, τ have distinctive forward-backward asymmetries at the e^+e^- colliders. It can be searched for at the e^+e^- machine with $\sim\text{TeV}$ center-of-mass energy and an integrated luminosity $\sim ab^{-1}$.

Electroweak, Top and Higgs Physics / 112

Electroweak splitting functions and high energy shower

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We derive the electroweak (EW) collinear splitting functions up to single logs. We first derive the splitting functions in the unbroken limit, and then we systematically incorporate effects of EW symmetry breaking (EWSB), by imposing a particularly convenient gauge choice (dubbed “Goldstone Equivalence Gauge”) that disentangles the effects of Goldstone bosons and gauge fields in the presence of EWSB. As a result, we are able to derive splitting functions up to leading power corrections in v/k_T . We also implement a comprehensive, practical EW showering scheme based on these splitting functions using a Sudakov evolution formalism. The implementation of EW showering includes

novel features such as “ultra-collinear” splittings, matching between shower and decay, and mixed-state evolution of neutral bosons ($\gamma/Z/h$) using density-matrices, kinematic back-reaction corrections in multi-stage showers. We demonstrate those new phenomena and features at $O(1-10 \text{ TeV})$ energies with some examples.

BSM in Flavor Physics / 202

Recent Flavor Physics Results at CMS

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We report recent flavor physics results, using pp collision data collected by the CMS experiment at the LHC, including the observation of two excited Bc states, the study of the $B \rightarrow J/\Psi \Lambda b p$ decay, and a search for charged lepton flavor violating decays $\tau \rightarrow 3\mu$. The first analysis is based on an event sample corresponding to a luminosity of 143 fb^{-1} at $\sqrt{s}=13 \text{ TeV}$. The Bc excited states are observed in the Bc $\pi\pi$ invariant mass spectrum, with the ground state reconstructed through its decay to $J/\Psi \pi$. The second analysis uses a data set of 19.6 fb^{-1} collected at $\sqrt{s}=8 \text{ TeV}$. The BR of this decay is measured with respect to $\text{BR}(B^+ \rightarrow J/\Psi K^*)$ and the invariant mass distributions of $J/\Psi \Lambda b$, $J/\Psi p$ and $\Lambda b p$ systems are investigated. The third analysis uses the data collected by CMS in 2016, corresponding to a luminosity of 33 fb^{-1} .

Supersymmetry: Models, Phenomenology and Experimental Results / 87

Indirect Studies of Electroweakly Interacting Particles at 100 TeV Hadron Colliders

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There are many models beyond the standard model which include electroweakly interacting massive particles (EWIMPs), often in the context of the dark matter. We study the indirect search of EWIMPs using a precise measurement of the lepton pair production cross sections at future 100 TeV hadron colliders. It is revealed that this search strategy is suitable in particular for Higgsino and that the Higgsino mass up to about 850 GeV will be covered at 5 sigma level irrespective of the chargino and neutralino mass difference. We also show that the property of the observed signal, in particular its weak charges and mass, can be independently read off by using both the neutral and charged current processes.

Formal Field Theory and Strings / 241

Connected vacua of heterotic orbifolds

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We study the global structure of vacua of heterotic strings compactified on orbifolds T^4/Z_N in the presence of heterotic 5-branes. Gauge symmetry breaking associated with orbifold is described by instantons in the field theory. Phase transition between small instantons and heterotic 5-branes provides top-down, stringy account to the spectrum and modular invariance condition. Also it takes us from one vacuum to another by emitting and absorbing instantons. This means that many vacua with different gauge theory are in fact connected and are inherited from perturbative vacua. It follows that there are also transitions among twisted fields, heterotic 5-branes and instantons.

Plenary Session / 283

String+ Inflation

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Alternatives to Supersymmetry / 70

Search for New Resonances in Hadronic Final States with the ATLAS and CMS Detectors

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Many theories beyond the Standard Model predict new phenomena which decay to jets. Such final states are of particular interest at the LHC since new phenomena produced in parton collisions are likely to produce final states with (at least) two partons. This talk presents the latest 13 TeV ATLAS and CMS results, covering exclusive searches for dijet and dibjet resonances along with searches for dijet events produced in association with additional particles, such as an additional isolated lepton or radiated photons/jets. The latter overcomes the trigger limitations to extend to lower dijet masses.

Dark Matter, Astroparticle Physics / 119

Indirect detection constraints on a p-wave model through an s-wave bremsstrahlung process

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Dark matter annihilation to a two-body final state is difficult to probe for many models because the dominant annihilation channel is velocity suppressed. The inclusion of gauge boson radiation in these models creates a three-body final state that lifts the suppression, allowing for a velocity-independent cross section that can dominate. This inclusion provides a means to investigate these types of models. We look at constraints that current indirect experiments can place on dark matter annihilation to two leptons plus a bremsstrahlung boson. In particular, we consider Fermi-LAT measurements for both its diffuse photon data as well as sourced from dwarf spheroidal galaxies. We also compare these results to constraints implied by current 21 cm measurements.

Supersymmetry: Models, Phenomenology and Experimental Results / 51

Reconstruction techniques in supersymmetry searches in the ATLAS experiment

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Many supersymmetric scenarios feature final states with non-standard final state objects. The production of massive sparticles can lead to the production of boosted top quarks or vector bosons, high-pt b-jets. At the same time, transitions between nearly mass-degenerate sparticles can challenge the standard reconstruction because of the presence of very soft leptons or jets (including the flavour tagging of very soft jets). The talk will review the application of innovative reconstruction techniques to supersymmetry searches in ATLAS.

Electroweak, Top and Higgs Physics / 85

Electroweak production of vector bosons at the LHC

Authors: ATLAS Collaboration^{None}; CMS Collaboration^{None}

Vector-boson fusion and vector-boson scattering processes are studied using the data collected by the ATLAS and CMS detectors at the LHC.

Alternatives to Supersymmetry / 226

Search for heavy BSM particles coupling to third generation quarks at CMS

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We present results from searches for resonances with enhanced couplings to third generation quarks, based on proton-proton collision data at a centre-of-mass energy of 13 TeV recorded by CMS. The signatures include single and pair production of vector-like quarks and heavy resonances decaying to third generation quarks. A wide range of final states, from multi-leptonic to entirely hadronic is covered. Jet substructure techniques are employed to identify highly-boosted heavy SM particles in their hadronic decay modes.

Dark Matter, Astroparticle Physics / 32

Search for Dark Matter at Belle II

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The Belle II experiment is a substantial upgrade of the Belle detector and will operate at the SuperKEKB energy-asymmetric e^+e^- collider. The design luminosity of the machine is $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ and the Belle II experiment aims to record 50 ab^{-1} of data, a factor of 50 more than its

predecessor. From February to July of this year, the machine has completed a commissioning run, achieved a peak luminosity of $5.5 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, and Belle II has recorded a data sample of about 0.5 fb^{-1} . Already this data set with specifically designed triggers offers the possibility to search for a large variety of dark sector particles in the GeV mass range complementary to LHC and dedicated low energy experiments but these searches will benefit from more data soon to be accumulated. This talk will review the state of the dark sector searches at Belle II with a focus on the discovery potential of the early data.

Plenary Session / 275

Hidden Sectors and Long-Lived Particle Signatures

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Plenary Session / 260

String Models

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Neutrinos: Models, Phenomenology, Experiments / 13

Jet substructure shedding light on heavy Majorana neutrinos at the colliders

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The existence of tiny neutrino masses and flavor mixings can be explained naturally in various see-saw models, many of which typically having additional Majorana type SM gauge singlet right handed neutrinos (N). If they are at around the electroweak scale and furnished with sizable mixings with light active neutrinos, they can be produced at high energy colliders such as LHC and ILC. A characteristic signature at the LHC would be same sign lepton pairs, violating lepton number, together with light jets – $pp \rightarrow N\ell^\pm$, $N \rightarrow \ell^\pm W^\mp$, $W^\mp \rightarrow jj$. We propose a new search strategy utilising jet substructure techniques, observing that for a heavy right handed neutrino mass M_N much above M_{W^\pm} , the two jets coming out of the boosted W^\pm may be interpreted as a single fat-jet (J). Hence, the distinguishing signal topology will be $\ell^\pm\ell^\pm J$. Performing a comprehensive study of the different signal regions along with complete background analysis, in tandem with detector level simulations, we compute statistical significance limits. We find that heavy neutrinos can be explored effectively for mass ranges $300 \text{ GeV} \leq M_N \leq 800 \text{ GeV}$ and different light-heavy neutrino mixing $|V_{\mu N}|^2$. At the 13 TeV LHC with 3000 fb^{-1} integrated luminosity one can competently explore mixing angles much below present LHC limits, and moreover exceed bounds from electroweak precision

data. We also study the production of such particles at the linear collider so that a higher mass of N ($M_N > 800\text{GeV}$) can be probed using the jet substructure technique. In this talk we will also cover the scenario at the prospective Large electron Positron Collider (LHeC).

Electroweak, Top and Higgs Physics / 160

Searching for Higgs from the heavy resonance under the general $U(1)_X$ scenario

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The production of Higgs (h) in association with a Z boson from the neutral beyond the Standard Model (SM) gauge boson such as Z' . We consider a scenario where the SM is extended by a general $U(1)_X$ group. The charges can be constrained by solving the anomaly free conditions. The $U(1)_X$ charge sector can be expressed in terms of charges of the Higgs and the BSM scalar such as x_h and x_Φ respectively. These charges will participate in the couplings between the Z' and the other particles of the model. We have examined that there are certain possibilities where the $Z h$ production from the Z' can be successfully tested at the colliders such as Large Hadron Collider (LHC) and Linear Collider (LC) followed by the reconstruction of Z' . In this scenario the presence of the x_H and x_Φ play a key role in the enhancement of the production cross section, followed by the decay of the h and Z bosons. We also show the current limits on the $U(1)_X$ gauge coupling (g_X) vs the Z' mass comparing with the current bounds obtained by the LHC.

Plenary Session / 290

Flavor Physics

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Machine Learning, Big Data and Quantum Information / 113

Automating the Construction of Jet Observables with Machine Learning

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Machine-learning assisted jet substructure tagging techniques have the potential to significantly improve searches for new particles and Standard Model measurements in hadronic final states. Techniques with simple analytic forms are particularly useful for establishing robustness and gaining physical insight. We will look at a method that applies machine learning to identify the amount of information in a jet that contributes to discrimination power using sets of observables that minimally and completely span the kinematic phase space of M subjets. Then we introduce a procedure to automate the construction of a class of product observables formed from these sets of variables that are chosen to completely specify M -body phase space. The procedure is validated on the task of distinguishing $H \rightarrow b\bar{b}$ from $g \rightarrow b\bar{b}$, where $M = 3$ and previous brute-force approaches to construct an optimal product observable for the M -body phase space have established the baseline performance. We then use the new method to design tailored observables for the boosted Z' search, where $M = 4$ and brute-force methods are intractable. The new classifiers outperform standard 2-prong tagging observables, illustrating the power of the new optimization method for improving searches and measurement at the LHC and beyond.

Neutrinos: Models, Phenomenology, Experiments / 63

Flavoured SUSY GUTs in Extra Dimensions

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Flavour, SUSY and GUTs are some of the best motivated BSM symmetries, although it is hard to make them work together consistently. It is shown how through Extra Dimensions we can greatly simplify the flavour alignment process. We show different mechanisms to obtain the flavour symmetries and highly predictive flavon alignments, such as CSD3 and the TBM, through different orbifolds.

Dark Matter, Astroparticle Physics / 219

Light Dark Matter Constraints and the Neutrino Background

Author: James Dent¹

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I will be discussing constraints on light dark matter and the effects of the astrophysical neutrino background. This will include a discussion of bremsstrahlung, the Migdal effect, and dark matter scattered by cosmic rays, as well as the effect of these processes on the background induced by coherent elastic neutrino-nucleus scattering.

Supersymmetry: Models, Phenomenology and Experimental Results / 164

IR fixed point pattern of couplings in the MSSM+1VF

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I will discuss an intriguing observation that the values of all the couplings in the standard model except those related to first two generations can be understood from the IR fixed point structure of renormalization group equations in the minimal supersymmetric model extended by one complete vectorlike family with the scale of new physics in a multi-TeV range.

Dark Matter, Astroparticle Physics / 169

Evidence against the decaying dark matter interpretation of the 3.5 keV line from blank sky observations

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X-ray observations of clusters and galaxies have detected an unexplained X-ray emission line around 3.5 keV. This line has been the subject of many recent works due to its potential explanation as due to decaying dark matter. In particular, sterile neutrinos with a mass of 7 keV and mixing angles of $\sim 10^{-10}$ provide a good fit to the data. I discuss recent work in which we exploit the fact that the Milky Way halo is as bright in dark matter decay as previous targets but has significantly reduced backgrounds. Furthermore, all X-ray observations look through the halo, so there is an abundance of available data. In particular, we used over 30 Ms of XMM-Newton observations of the ambient dark matter halo to search for evidence of this line. We report the strongest limits to-date on the lifetime of dark matter in this mass range and strongly disfavor the possibility that the 3.5 keV line originates from dark matter decay.

Plenary Session / 271

Neutrino Models at Colliders

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Machine Learning, Big Data and Quantum Information / 201

Uncovering latent jet substructure

Authors: Barry Dillon¹; Jernej F. Kamenik¹; Darius Faroughy¹

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We apply techniques from Bayesian generative statistical modeling to uncover hidden features in jet substructure observables that discriminate between different a priori unknown underlying short distance physical processes in multi-jet events. In particular, we use a mixed membership model known as Latent Dirichlet Allocation to build a data-driven unsupervised top-quark tagger and tbar event classifier. We compare our proposal to existing traditional and machine learning approaches to top jet tagging. Finally, employing a toy vector-scalar boson model as a benchmark, we demonstrate

the potential for discovering New Physics signatures in multi-jet events in a model independent and unsupervised way.

Supersymmetry: Models, Phenomenology and Experimental Results / 66

Suppressed SUSY and Grand Unified SuperGravity Models

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Suppressed SUSY is a mechanism for generating a realistic model based on SUSY, but without spontaneous or explicit breaking of SUSY. It arises from a canonical transformation, which preserves the BRST Master Equation of Supergravity, coupled to, for example, SU(5) Grand Unified Supersymmetric Gauge Theory with Matter. The canonical transformation preserves the Master Equation, but the physical interpretation changes because we choose an ‘Exchange Transformation’, which makes old Quantized Fields become new Zinn-Justin type Sources, and vice versa. This generates a new kind of theory, which clearly preserves its origin from SUSY, but which does not have the usual problems of SUSY.

Poster Session / 252

The Gravitino as Dark Matter for Suppressed SUSY

Author: John Dixon¹

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Suppressed SUSY is a new way of generating a reasonable model for SU(5) GUT theory coupled to Supergravity. The minimal version predicts an extremely heavy stable gravitino as a candidate for dark matter. The rest of the model appears to be consistent with the standard SU(5) model without SUSY. However, Suppressed SUSY improves things: the X, Y vector boson masses are increased to Planck mass, and the questions about scalar bosons are resolved, as is the issue of the cosmological constant (at tree level). But there is a very serious problem: the predicted heavy gravitino is so heavy that it may be impossible to observe it.

Dark Matter, Astroparticle Physics / 180

Higgs Parity, Strong CP, and Dark Matter

Authors: David Dunsky¹; Keisuke Harigaya²; Lawrence Hall³

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An exact spacetime parity replicates the $SU(2) \times U(1)$ electroweak interaction, the Higgs boson H , and the matter of the Standard Model. This ‘Higgs Parity’ and the mirror electroweak symmetry are spontaneously broken at scale $v' = \langle H' \rangle \gg \langle H \rangle$, yielding the Standard Model below v' with a

quartic coupling that essentially vanishes at v' : $\lambda_{SM}(v') \sim 10^{-3}$. The strong CP problem is solved as Higgs parity forces the masses of mirror quarks and ordinary quarks to have opposite phases. Dark matter is composed of mirror electrons, e' , stabilized by unbroken mirror electromagnetism. These interact with Standard Model particles via kinetic mixing between the photon and the mirror photon, which arises at four-loop level and is a firm prediction of the theory. Physics below v' , including the mass and interaction of e' dark matter, is described by *one fewer parameter* than in the Standard Model. The allowed range of $m_{e'}$ is determined by uncertainties in (α_s, m_t, m_h) , so that future precision measurements of these will be correlated with the direct detection rate of e' dark matter, which, together with the neutron electric dipole moment, will probe the entire parameter space.

Neutrinos: Models, Phenomenology, Experiments / 239

Breaking of CPT due to quantum decoherence tested at DUNE

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In this work we study the intrinsic CPT violation in the neutrino oscillations phenomena produced by quantum decoherence as sub-leading effect. In the usual representation, we find that only fifteen elements of the decoherence matrix violate the CPT symmetry intrinsically. We find exact solutions for the CPT asymmetry function in vacuum. We define an observable \mathcal{R} to make predictions of this model for the future Long-Baseline experiment, DUNE. We found values of the decoherence parameters with 5σ of discrepancy to standard physics which are allowed by the current experimental limits, suggesting hints for new physics by this model in the context of future experiments.

arXiv:1811.04982

Electroweak, Top and Higgs Physics / 133

Radion Activated Higgs Mechanism

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The Randall-Sundrum models provide an appealing foundation to engineer BSM models, especially the ones which attempts to explain the small Higgs mass. The modulus field in these models (the “radion”) should play a role in determining the value of the Higgs vacuum expectation value (VEV), and vice versa, as the Higgs VEV itself should backreact on the geometry. This would imply that the Higgs mass is a function of the brane separation. Hence a moderate separation of scales between the electroweak scale, and the scale associated with the conformal symmetry breaking can be generated if the minimum of the modulus potential coincides with the region where the Higgs mass is small. In this talk, I will discuss the interplay between the radius stabilization mechanism and the Higgs mechanism in two-brane Randall-Sundrum models by paying particular attention to models where electroweak symmetry breaking occurs at specific points of the moduli space.

Alternatives to Supersymmetry / 33

Testing Lorentz and CPT invariance through ultra-high-energy cosmic rays

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We study CPT and Lorentz violation in the tau-lepton sector of the Standard Model in the context of the Standard-Model Extension, described by a coefficient which is thus far unbounded by experiment. We show that any non-zero value of this coefficient implies that, for sufficiently large energies, standard-model fermions become unstable against decay due to the emission of a pair of tau-antitau leptons. We calculate the induced fermion energy-loss rate and we deduce the first limit on the Lorentz- and CPT-violating coefficient.

Unification of Forces / 64

Supersymmetric Super-GUT Models

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Although SUSY is less natural than hoped, it is still able to explain several correlations beyond the standard model. A persistently appealing feature of supersymmetry is that it leads to gauge coupling unification, which suggests that the forces unify. For even minimal supersymmetric SU(5) unification, there are previously unexplored avenues. I will focus on the effect of pushing the boundary scale of supersymmetric models beyond the GUT scale in the context of minimal SU(5) unification. If right-handed neutrinos are included in these models, CP and flavor violation in the low-scale is unavoidable and could be seen in future experiments looking for EDM's and $\mu \rightarrow e \gamma$. For pure gravity mediation models, including higher dimensional operators can lead to dimension-six proton decay visible at Hyper-Kamiokande and to new possible dark matter candidates.

Plenary Session / 276

FASER

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Dark Matter, Astroparticle Physics / 249

An Elastically Decoupling Relic Within the Not-Forbidden Dark Matter Scenario

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We explore the Elastically Decoupling Relic (ELDER) scenario in a general context where $3 \rightarrow 2$ annihilations play an important role in determining the late-time abundance of dark matter (DM), whether the dark sector coupling is strong or weak (the Not-Forbidden Dark Matter, or NFD, scenario). In the conventional weakly-interacting massive particle (WIMP) paradigm the thermal relic density of DM is set by two body annihilations. There has been interest in exploring alternative DM candidates with novel freezeout scenarios, including models in which dark matter has strong number-changing self-interactions. Examples of such candidates are the Strongly Interacting Massive Particle (SIMP) and Elastically Decoupling Relic (ELDER) scenarios, in which the current DM density is determined either by the cross section of the number-changing ($3 \rightarrow 2$) self-interaction process or by the cross section of elastic scattering between the DM and the standard model (SM), respectively. In the NFD scenario a generic mechanism was found in which $3 \rightarrow 2$ annihilations play a critical role in determining the late-time abundance of DM in any situation in which $2 \rightarrow 2$ self-annihilations within the dark sector are kinematically suppressed. In this talk I will present preliminary results which realize a freezeout scenario in which the relic abundance of DM is set by elastic scattering with the SM (the ELDER scenario) for a Dirac fermion DM charged under a dark $U(1)$ symmetry, where $3 \rightarrow 2$ annihilations play an important role in maintaining chemical equilibrium within the DM sector after thermal decoupling with the SM and until freezeout (the NFD scenario). These results will show that the ELDER freezeout scenario can be realized even for simple and weakly coupled dark sectors, simultaneously with the NFD mechanism in the context of a dark photon model which is compatible with all of the NFD, ELDER, and WIMP paradigms.

Plenary Session / 292

Genesis

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Alternatives to Supersymmetry / 141

”Unitarity in Extra-Dimensional Gravity Models”

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Massive spin-2 particles cause trouble in 4D quantum field theory: not only are their tree-level matrix elements sometimes complicated, but some diagrams grow like ten powers of incoming energy! As a result, these theories violate unitarity even at small energy scales. However, massive spin-2 particles naturally appear when projecting nicely-behaved higher-dimensional models down to 4D. If their matrix elements are typically so bad, then how are these full models so nice? The answer is elucidated via gravity on a 5D orbifolded torus, and then extended to a Randall-Sundrum model.

Dark Matter, Astroparticle Physics / 216

A Solar System Test of Self-Interacting Dark Matter

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Dark matter (DM) self-interactions affect the gravitational capture of DM in the Sun and Earth differently as a simple consequence of the differing kinematics of collisions within the two potential wells: the dominant effect of self-interactions in the Sun is to provide an additional channel for capture, while the dominant effect in the Earth is to eject previously captured DM. I will discuss how this simple observation can be used to deduce the existence of DM self-interactions by comparing the annihilation rates of DM gravitationally bound within the Sun and Earth. I will present the computation of the Sun and Earth annihilation fluxes for DM with spin-independent nuclear cross-sections and thermal annihilation cross-sections and demonstrate that, for cross-sections allowed by direct detection, self-interactions can easily suppress the expected Earth flux by multiple orders of magnitude. This suppression is potentially significant even for self-interaction cross-sections orders of magnitude below the Bullet Cluster bounds, making this solar system comparison a leading test of dark matter self-interactions.

Neutrinos: Models, Phenomenology, Experiments / 20

Neutrino oscillation results from NOvA

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NOvA is a long-baseline neutrino oscillations experiment designed to precisely measure the neutrino oscillation parameters. We do this by directing a beam of predominantly muon neutrinos from Fermilab towards northern Minnesota. The experiment consists of two functionally equivalent detectors each located 14.6 mrad off the central axis of Fermilab's 700 kW NuMI neutrino beam, the world's most intense neutrino beam. Both the Near Detector, located 1 km downstream from the beam source, and the Far Detector, located 810 km away in Ash River, MN, were constructed from plastic extrusions filled with liquid scintillator. The three-flavour long-baseline search probes undetermined physics parameters such as the neutrino mass hierarchy (ordering), CP violation in the lepton sector and the octant of θ_{23} (the large mixing angle). To extract these parameters, we compare the neutrino interactions in the detectors to observe the disappearance of muon neutrinos and the appearance of electron neutrinos, due to oscillations. I will present results based on the combined neutrino-mode and antineutrino-mode beam data-sets, collected by the NOvA experiment up to April 2018. I will also discuss the future physics reach of NOvA.

Cosmology and Gravitational Waves / 15

Curvature Perturbations From Stochastic Particle Production During Inflation

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There is no guarantee that the reductionist point of view championed by simple effective field theories is realized during inflation and the subsequent (p)reheating. In fact, many supersymmetric and string-inspired UV completions of inflation involve a myriad of fields with complicated interactions. This may lead to a random, chaotic evolution as a function of the initial conditions and values of

the model parameters. Nevertheless, in the limit of many fields/interactions, emergent universal properties may arise.

In this talk I will present a statistical framework to characterize the evolution of scalar spectator fields in a de Sitter universe, with non-adiabatic, time-dependent effective masses sourced stochastically by complicated background dynamics. I will show how the non-trivial evolution of coarse-grained quantities, such as particle occupation numbers, can be derived from a Fokker-Planck equation. As the main result, I will demonstrate that the field magnitude describes a geometric (Brownian) random walk in cosmic time *independently of the details of the disorder*, and I will discuss the imprints of this evolution on density perturbations from the early universe. Specifically, the stochastic sourcing of the amplitude and tilt of the curvature power spectrum as functions of the disorder strength.

Electroweak, Top and Higgs Physics / 254

Top quark pair and single top t-channel cross sections

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Latest results on inclusive and differential top quark pair and single top quark production cross sections are presented using proton-proton collision data collected by CMS and ATLAS. The differential cross sections are measured as a function of various kinematic observables of the top quarks and the jets and leptons of the event final state. The results are confronted with precise theory calculations and used to constrain Standard Model parameters. For the first time, multi-differential tt cross sections are used to constrain simultaneously the top quark pole mass, α_S , and PDFs. Moreover, constraints on top Yukawa from differential cross sections are presented.

Electroweak, Top and Higgs Physics / 80

SM Higgs boson measurements at the LHC

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A review of the recent measurements of the SM Higgs couplings and properties will be given, covering both ATLAS and CMS. Whilst it is an overview talk, the speaker can choose a couple of subjects to develop in more details.

Alternatives to Supersymmetry / 225

Searches for long-lived particles with the CMS detector

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The CMS detector explores a wide range of non-standard signatures including displaced and delayed particles, which allow to explore various models from supersymmetry and beyond standard models. Newly set limits on long-lived exotic particles will be presented. These results are obtained with data recorded in proton-proton collisions at $\sqrt{s} = 13$ TeV in Run 2 of the LHC.

Dark Matter, Astroparticle Physics / 223**A sub-GeV dark matter model****Authors:** Sumit Ghosh¹; Bhaskar Dutta¹; Jason Kumar²¹ *Mitchell Institute for Fundamental Physics and Astronomy, Department of Physics and Astronomy, Texas A&M University*² *Department of Physics, University of Hawaii***Corresponding Author:** ghosh@tamu.edu

We propose an extension of the Standard Model gauge symmetry by the gauge group $U(1)_{T3R}$ in order to address the Yukawa coupling hierarchy between the third generation fermions and the first two generation fermions of the SM. We assume that only the right-handed fermions of the first two generations are charged under the $U(1)_{T3R}$. In addition to the new dark gauge boson, we have a dark scalar particle whose vacuum expectation value breaks the $U(1)_{T3R}$ symmetry down to Z_2 symmetry and also explain the hierarchy problem. A vev of $O(\text{GeV})$ is required to explain the mass parameters of the light flavor sectors. The dark matter particle arising from the model naturally has mass in the $O(1-100)$ MeV range. The model satisfies all the current constraints. We discuss the various prospects of the Direct detection of the dark matter. The dark sector contains a Dirac fermion which gives two Majorana physical fields, one or both of which are dark matter. They have diagonal interactions with the dark scalar and off-diagonal interactions with the dark boson. Thus we get both elastic and inelastic Spin Independent DM-nucleon scattering mediated via the dark scalar and the dark gauge boson respectively. The model gives correct thermal relic density by annihilation via the dark scalar or dark gauge boson resonances.

Cosmology and Gravitational Waves / 131**Complementarity between Higgs searches at the LHC and Gravitational Waves signals****Authors:** Alexandre Alves¹; Daniel Vagie²; Huai-ke Guo²; Kuver Sinha³; Tathagata Ghosh⁴¹ *Universidade Federal de Sao Paulo, UNIFESP*² *University of Oklahoma*³ *Dept. of Physics and Astronomy, University of Oklahoma*⁴ *University of Hawaii at Manoa***Corresponding Author:** tghosh@hawaii.edu

The Higgs boson was postulated as a key component of the Standard Model (SM) of particle physics to explain the origin of mass. After 45 years of rigorous experimental searches, the Higgs boson was finally discovered on July 4th, 2012 at the CERN Large Hadron Collider (LHC). The discovery of the Higgs boson completes the SM and confirm one of its most mysterious predictions. The SM, although very effective, fails to address many important questions of nature. In this talk, I will discuss how the newly discovered Higgs boson is connected with one of the most critical puzzles of the nature that is not explained by the SM - how the asymmetry between matter and antimatter was created in the early universe? A first order phase transition is an out-of-equilibrium process, and this is needed for the generation of the observed baryon asymmetry (as stated by the third Sakharov condition). However, the newly discovered 125 GeV Higgs boson by itself cannot bring about a first-order phase transition, but an additional real singlet scalar field added to the SM can. Such strongly first-order phase transition in the early universe can also generate gravitational waves signals observable at future space-based interferometers like LISA. On the other hand, the presence of the additional scalar particle in the model will lead to interesting signatures of physics beyond the SM at the LHC. In this talk, I will discuss the possibility for complementary searches for electroweak phase transition in collider and gravitational wave experiments within the SM augmented by a real singlet scalar.

Supersymmetry: Models, Phenomenology and Experimental Results / 147

Search for long-lived SUSY decays - CMS Experiment

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Results from the CMS experiment are presented for searches for supersymmetric particle production in decays channels with long-lived particles. Long-lived final states can arise in many SUSY scenarios resulting in a diverse array of striking signatures. Results are presented here from several such scenarios. The searches use proton-proton collision data with luminosity up to 137 fb^{-1} recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Supersymmetry: Models, Phenomenology and Experimental Results / 171

Status of global SUSY fits

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Supersymmetric models are some of the most popular and well-motivated extensions of the Standard Model, and hence they have been constrained by a vast array of different experimental searches. The diversity of experimental constraints, combined with a large number of parameters, makes the systematic study of SUSY models increasingly complicated and old-school parameter scans are insufficient. Hence, to properly assess the impact of experimental searches on these models, combining their results in a statistically rigorous way and efficiently scanning the multi-dimensional parameter space, one must perform a global fit. In this talk I will discuss the benefits of global fits over traditional parameter scans, and I will give an overview of the status of global fits on several SUSY models, from GUT-inspired models such as the CMSSM or NUHM1, to phenomenological weak-scale MSSM models.

Plenary Session / 265

Axion and ALP Dark Matter

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BSM in Flavor Physics / 43

ATLAS measurements of Rare decays and CP Violation in Beauty mesons

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The ATLAS experiment has performed accurate measurements of mixing and CP violation in the neutral B mesons, and also of rare processes happening in electroweak FCNC-suppressed neutral B-mesons decays.

This talk will focus on the latest results from ATLAS, such as rare processes: $B^0_s \rightarrow \mu \mu$ and $B^0 \rightarrow \mu \mu$, and CPV in B_s to $J/\psi \phi$.

Cosmology and Gravitational Waves / 220**Varying Physical Constants from Astrometric and Cosmological Analysis****Author:** Rajendra Gupta¹¹ *Macronix Research Corporation***Corresponding Author:** sonice810@gmail.com

We have developed a cosmological model by allowing the speed of light c , gravitational constant G and cosmological constant Λ in the Einstein field equation to vary in time, and solved them for Robertson-Walker metric. Assuming the universe is flat and matter dominant at present, we obtain a simple model that can fit the supernovae 1a data with a single parameter almost as well as the standard Λ CDM model with two parameters, and has the predictive capability superior to the latter. The model, together with the null results for the variation of G from the analysis of lunar laser ranging data determines that at the current time G and c both *increase* as $dG/dt = 5.4GH$ and $dc/dt = 1.8cH$ with H as the Hubble parameter, and Λ *decreases* as $d\Lambda/dt = -1.2\Lambda H$. This variation of G and c is all what is needed to account for the Pioneer anomaly, the anomalous secular increase of the Moon eccentricity, and the anomalous secular increase of the astronomical unit. We also show that the Planck's constant \hbar increases as $d\hbar/dt = 1.8\hbar H$ and the ratio D of any Hubble unit to the corresponding Planck units increases as $dD/dt = 1.5DH$. We have shown that it is essential to consider the variation of *all* the physical constants that may be involved directly or indirectly in a measurement of expression rather than only the one whose variation is being considered. The impact of these evolutionary physical constants on the standard model is discussed.

Plenary Session / 258**Physics Motivation for Future Colliders****Corresponding Author:** than@pitt.edu**Unification of Forces / 181****Higgs Parity, strong CP problem, GUT****Authors:** Keisuke Harigaya¹; Lawrence Hall²¹ *Institute for Advanced Study*² *University of California Berkeley***Corresponding Author:** keisukeharigaya@ias.edu

Precise measurements of the standard model parameters by the LEP has shown that supersymmetry realizes precise coupling unification. We introduce a non-supersymmetric scheme of coupling unification via the Higgs parity and show how precise unification is realized. We discuss the prediction on the proton decay rate and the importance of the precise measurement of the standard model parameters. We also show that the strong CP problem can be solved.

Plenary Session / 291

B Physics Anomalies

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Neutrinos: Models, Phenomenology, Experiments / 62

Neutrino masses and lepton flavor violation

Author: Julian Heeck¹

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The lepton flavor symmetries of the Standard Model are clearly broken in neutrino oscillations, yet we have not observed any charged-lepton flavor violation. I will review the connection between neutrino masses and flavor violation in some popular models and highlight the importance and complementarity of different experimental search channels.

BSM in Flavor Physics / 158

Pati-Salam models and B-meson anomalies

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Recent hints for lepton-flavor non-universality in B -meson decays can be interpreted as hints for the existence of leptoquarks. We show that scalar leptoquarks unavoidably arise in grand unified theories, using the well-known Pati–Salam model as an example. These GUT-motivated leptoquarks can have a number of appealing features including automatic absence of proton decay, purely chiral couplings, and relations between the various leptoquark couplings. We show that $R(K^{(*)})$ can be connected to the neutrino mass matrix that arises via type-II seesaw, resulting in testable lepton flavor violation. In order to also explain $R(D^{(*)})$ one instead has to assume the existence of light right-handed neutrinos, once again with testable predictions in other B -meson decays and at the LHC.

Supersymmetry: Models, Phenomenology and Experimental Results / 99

Impact of improved SUSY Higgs-boson mass calculations

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we first briefly review the recent progress in the calculation of the MSSM Higgs-boson masses. The new and improved calculations are then applied to several GUT-based and low-energy scenarios.

The impact of the improved Higgs-boson mass calculation on the preferred parameter space(s) is analyzed.

Supersymmetry: Models, Phenomenology and Experimental Results / 97

Where is SUSY?

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We review the predictions of the favored SUSY parameter spaces. They are based on fits to all relevant experimental data. The implications of these predictions for the HL-LHC and ILC/CLIC are discussed.

Supersymmetry: Models, Phenomenology and Experimental Results / 96

DM predictions from the LHC

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We present the predictions for the properties of DM based on LHC searches and all other relevant constraints. This is done in Supersymmetric models as well as in Simplified Models.

Electroweak, Top and Higgs Physics / 98

SUSY Higgs bosons at the HL-LHC and the ILC

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We present the prospects of direct and indirect heavy SUSY Higgs boson searches for the HL-LHC and the ILC. They are based on the new set of benchmarks scenarios recently developed for SUSY Higgs-boson searches at the LHC.

Electroweak, Top and Higgs Physics / 101

A SUSY Higgs boson at 96 GeV?

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CMS presented a 3 sigma (local) excess in light Higgs-boson searches in the diphoton final state at around 96 GeV. ATLAS results do not exclude this possible signal. LEP published a 2 sigma (local) excess in the same mass range in the bb final state. We present two SUSY models that can simultaneously explain both excesses, while being in agreement with all direct and indirect Higgs boson measurements and searches.

Electroweak, Top and Higgs Physics / 100

New Benchmarks for MSSM Higgs-boson searches at the LHC

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We present the recently developed benchmark scenarios for MSSM Higgs-boson searches at the LHC. They take into account the recently improved Higgs-boson mass calculations as well as the latest data from direct Higgs-boson searches and measurements of the 125 GeV Higgs boson. The different phenomenology of these scenarios is highlighted.

Neutrinos: Models, Phenomenology, Experiments / 127

Neutrino masses from Planck-scale lepton number breaking in models with multiple Higgs doublets

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We explore how the observed characteristics of neutrino masses —small mass scale, mild hierarchy, large mixing angles— can be explained in a simple extension of the standard model, where lepton number is broken at the Planck-scale.

While the correct mass scale for the light neutrinos is naturally explained in this model without the need for a new scale in the theory, the mild hierarchy can be taken to point to the presence of a second Higgs doublet.

Dark Matter, Astroparticle Physics / 93

The Inflaton Portal to a Highly decoupled EeV Dark-Matter Particle

Author: Lucien Heurtier¹

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We explore the possibility that the relic abundance of dark matter is generated in a context where the inflaton is the only mediator between the visible and the hidden sectors of our universe. Due to the relatively large mass of the inflaton field suggested by large-field inflation scenarios, such a portal leads to an extremely feeble interaction between the dark sector and the Standard Model suggesting that the dark sector cannot reach any thermal equilibrium with the visible sector. In the context of highly-decoupled dark sector scenarios the entropy dilution mechanism, which is necessary to produce the correct relic abundance, requires the presence of a very late decay of a dark component into the Standard Model. Assuming that the only contact between the dark and the visible thermal baths is the inflationary sector, the decay width of this dark component is naturally suppressed by the inflaton propagator. We show that an inflaton mass of order 10^{13} GeV – as is predicted by various large-field inflation models – together with natural values of the couplings are fully compatible with a dark-matter relic abundance $\Omega h^2 \sim 0.1$. As a general feature of the model, the entropy dilution mechanism is systematically accompanied by a period of early matter domination. The existence of such a period modifies the amount of e-folds between horizon crossing and the end of inflation. Besides, the coupling of the inflaton to the dark and visible sectors brings loop contributions to the inflationary potential which can destabilize the inflation trajectory. Considering all these complementary constraints, we show that, in the context of a plateau-inflation scenario such as the α -attractor model, the inflaton can constitute a viable mediator between the Standard Model and $O(10-500)$ EeV dark-matter candidate. Furthermore, we show that better constraints on the tensor-to-scalar ratio and spectral index could potentially rule out such dark-matter production scenario in the future.

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Enhanced $B \rightarrow \mu \bar{\nu}$ Decay at Tree Level

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The presence of extra Yukawa couplings, in particular $\rho_{\tau\mu}$ and $\rho_{t\mu}$, can enhance $B \rightarrow \mu \bar{\nu}$ rate but leave $B \rightarrow \tau \bar{\nu}$ unchanged, thereby their ratio can deviate from the value common to the Standard Model and two Higgs doublet model type II. With recent hint of enhancement in $B \rightarrow \mu \bar{\nu}$ using full Belle data, the Belle II experiment could probe this New Physics with just a few ab^{-1} .

Dark Matter, Astroparticle Physics / 92

Exploring the dark matter and baryogenesis by SKA-like and LISA-like experiments

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Motivated by the absence of new physics signals at LHC and dark matter direct detections, we study new approaches to explore the dark matter and baryogenesis by SKA-like and LISA-like experiments.

BSM in Flavor Physics / 175

q^2 dependence for R_{K^*}

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The LHCb experiment has recently reported evidence of deviation from the Standard Model from B decays. The experimental data also suggests that there can be a q^2 dependence in R_{K^*} . In this talk, I will address the q^2 dependence in two possible scenarios. The first scenario is that the q^2 dependence is actually due to hadronic effects. The hadronic effects are kinematically suppressed in the SM but not in new physics. I will show that, with modifications of one of the form factors, one can explain the q^2 dependence in R_{K^*} . In the second scenario, I will introduce an additional light Z' to account for the q^2 dependence. I will discuss the current constraints with a light Z' and will show how a light Z' together with some other new physics can explain the experimental data.

Neutrinos: Models, Phenomenology, Experiments / 120

Confronting Neutrino Mass Generation Mechanism with Mini-BooNE Anomaly

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We present a novel framework that provides an explanation to the long-standing excess of electron-like events in the MiniBooNE experiment at Fermilab. We suggest a new dark sector containing a dark neutrino and a dark gauge boson, both with masses between a few tens and a few hundreds of MeV. Dark neutrinos are produced via neutrino-nucleus scattering, followed by their decay to the dark gauge boson, which in turn gives rise to electronlike events. This mechanism provides an excellent fit to MiniBooNE energy spectra and angular distributions. We propose here to use this fact to connect the generation of neutrino masses to a light dark sector, charged under a new U(1)D dark gauge symmetry. We introduce the minimal number of dark fields to obtain an anomaly free theory with spontaneous breaking of the dark symmetry, and obtain automatically the inverse seesaw Lagrangian. In addition, the so-called μ -term of the inverse seesaw is dynamically generated and technically natural in this framework.

BSM in Flavor Physics / 17

New Mass Matrix Ansatz and Enhanced Di-Higgs Production in the Two Higgs Doublet Model

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We show that the rate for di-Higgs production at the LHC can be enhanced by a factor as large as 25 compared to the Standard Model value in the two Higgs doublet model, while being consistent with the known properties of the observed Higgs boson h . There are correlated modifications in $t\bar{t}h$ and resonant Zh production rates, which can serve as tests of this model. Our framework treats both Higgs doublets on equal footing, each with comparable Yukawa couplings to fermions. The Cheng-Sher ansatz for multi-Higgs doublet model is shown to be strongly disfavored by current experiments. We propose a new ansatz for the Yukawa couplings of the Higgs doublets Φ_a is proposed, where $Y_{ij}^{(a)} = C_{ij}^{(a)} \cdot \min\{m_i, m_j\}/v$, with $C_{ij}^{(a)}$ being order one coefficients, m_i the mass of fermion i and v the electroweak vacuum expectation value. Such a pattern of couplings can explain the observed features of fermion masses and mixings and satisfies all flavor violation constraints arising from the exchange of neutral Higgs bosons. The rate for $\mu \rightarrow e\gamma$ decay and new contributions to CP violation in $B_s - \bar{B}_s$ mixing are predicted to be close to the experimental limits.

Machine Learning, Big Data and Quantum Information / 197

Learning to Discover A Broad Resonance: Have We Learned Any Unexpected

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Broad resonances are generic predictions of many BSMs. But their discovery is expected to be challenging at the LHC and future collider experiments. It is because traditional resonance searches are based on the invariant mass distribution that will not be sharp enough for a broad resonance.

We used the deep neural network to develop a method to discover broad resonances at collider experiments. The network remarkably revealed that the invariant mass is still one of the most useful observables, but in addition that there are significantly more information used in the optimal network. Extracting what the network had learned, we present the implications on (broad) resonance searches.

Dark Matter, Astroparticle Physics / 198

Probing Dark Matter at LIGO and Beyond: Gravitational-Wave Fringes and More

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What can we learn about the Dark Matter frontier with Gravitational-Wave (GW) observations at LIGO and future detectors?

We first introduce a new GW observable – GW Fringe – that allows LIGO alone to probe compact dark matter such as primordial black holes or dark stars. Furthermore, by augmenting LIGO with

mid-frequency detectors, one can also probe various other dark matter kinds via yet other new ways. Such dark matter candidates include fuzzy axion-like dark matter and cosmic strings. A capability of ideal localization is a bonus of such broadband detection. All these new opportunities utilize the unique features of GWs from binary mergers.

The new opportunities will not only strengthen LIGO capabilities, but also motivate future mid-frequency detectors. And most importantly, they are precious new ways to understand the particle-physics nature of dark matter.

Plenary Session / 299

Summary Talk

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Alternatives to Supersymmetry / 238

Perspective of Perihelia Precession in Torsion Modified Gravity

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We revisit the Killing symmetries of the Schwarzschild geometry with a renewed interest to reveal the constants of motion in the General Relativity (GR). A term (ML^2/r^3) in the effective potential on an equatorial plane is known to hint

at a quantum gravity phenomenon! However no exact geometry underlying the new conserved charge (ML^2) is known GR and in a lower or many higher dimensional Einstein gravity. In the context we show that the new conserved charge may source

a dynamical torsion correction leading to a 4-form field strength in a modified theory of gravity in higher dimensions. Interestingly the higher dimensional dynamical correction incorporates a non-perturbative quantum effect into the GR and elegantly explains the known precession of the perihelia along the azimuthal angle.

BSM in Flavor Physics / 205

A complete vector-like fourth family model for muon anomalies

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The Standard Model (SM) is extended by introducing a complete vector-like fourth family and a vector-like U(1)' gauge symmetry. This model can explain experimental values of the muon anomalous magnetic moment and anomalies for $b \rightarrow s\mu^+\mu^-$ processes simultaneously without conflicting with the other observations, e.g. lepton flavor violating processes, CKM matrix, neutral meson mixings and so on. The U(1)' charge assignment compatible with Pati-Salam gauge group is favored compared to that compatible with the SO(10) gauge group in order to explain the muon anomalous magnetic moment. We will discuss observables which can be tested in future experiments.

Alternatives to Supersymmetry / 218

Beyond the standard model physics at the HL-LHC

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The Large Hadron Collider (LHC) has been successfully delivering proton-proton collision data at the unprecedented center of mass energy of 13 TeV.

An upgrade is planned to increase the instantaneous luminosity delivered by the LHC in what is called HL-LHC, aiming to deliver a total of about 3000/fb of data to the ATLAS detector at a center of mass energy of 14 TeV. To cope with the expected data-taking conditions ATLAS is planning major upgrades of the detector.

In this contribution we present an overview of the physics reach expected for a wide range of searches for beyond Standard Model physics at the HL-LHC for the ATLAS experiment, ranging from standard-candle processes as Z' to leptons to other resonance and non-resonance searches; prospects for long-lived particle and other exotic benchmark scenarios will also be presented. Particular focus would be given to implications for non-supersymmetric models.

Such studies formed the basis of the ATLAS Collaboration input to one of the chapters of the recent HL/HE-LHC Yellow-Report. An executive summary of this report was then submitted as input to the European Strategy process.

Alternatives to Supersymmetry / 156

Probing the Twin Higgs at colliders

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The Twin Higgs mechanism can address the naturalness problem without introducing partner particles that are produced at colliders with a large cross section. Only the scalar modes and optionally the twin hypercharge gauge boson have direct couplings to the Standard Model states and are therefore the first modes that can be accessed at colliders. We comment on measurements that can be performed at the LHC and at future colliders in order to establish discovery, and to test generic predictions arising from the Twin Higgs mechanism.

Electroweak, Top and Higgs Physics / 130

Hadronization and Top Quark Matter Determination

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Most of the methods to measure the top quark mass suffer from the jet energy scaling issue in achieving better precision. As a way to get around this issue, the study of B-hadron observables is motivated. While they do not involve such an issue, understanding underlying hadronization models is a key to achieve ~0.5% precision or better. In this presentation, I discuss the impact of the hadronization model parameters - for example, implemented in Pythia8 - on precision measurements of the top quark mass through B-hadron observables. I study the sensitivity of the top quark mass to relevant hadronization and showering parameters, followed by a discussion on observables to be used for constraining the hadronization and showering parameters.

Plenary Session / 262

Neutrino Models

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Electroweak, Top and Higgs Physics / 106

The status of HH searches at the LHC.

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The status of HH searches at the LHC will be presented, covering both resonant and non-resonant searches. This is an overview talk. However results on some selected topics will be presented with more details,

Dark Matter, Astroparticle Physics / 137

Deformation of Axion Potentials: Implications for Spontaneous Baryogenesis, Dark Matter, and Isocurvature Perturbations

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We show that both the baryon asymmetry of the universe and dark matter (DM) can be accounted for by the dynamics of a single axion-like field. In this scenario, the observed baryon asymmetry is produced through spontaneous baryogenesis—driven by the early evolution of the axion—while its late-time coherent oscillations explain the observed DM abundance. Typically, spontaneous baryogenesis via axions is only successful in regions of parameter space where the axion is relatively heavy, rendering it highly unstable and unfit as a dark matter candidate. However, we show that a

field-dependent wavefunction renormalization can arise which effectively “deforms” the axion potential, allowing for efficient generation of baryon asymmetry while maintaining a light and stable axion. Meanwhile, such deformations of the potential induce non-trivial axion dynamics, including a tracking behavior during its intermediate phase of evolution. This attractor-like dynamics dramatically reduces the sensitivity of the axion relic abundance to initial conditions and naturally suppresses DM isocurvature perturbations. Finally, we construct an explicit model realization, using a continuum-clockwork axion, and survey the details of its phenomenological viability.

Cosmology and Gravitational Waves / 60

Late universe dark matter decays can relieve the H_0 tension

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I will discuss how late universe dark matter decays to a massive and a massless daughter particles can relieve the tension between measurements of the Hubble parameter in the local universe and at the CMB.

Dark Matter, Astroparticle Physics / 19

NLO corrections to dark matter annihilation with light scalar quarks

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We will present the current results of our analyses of SUSY-QCD corrections to dark matter annihilation cross-section in pMSSM scenarios with a light scalar quark of the third generation. Such scenarios are extremely appealing as they have not yet been ruled out by LHC searches and at the same time the lightest Higgs mass in these scenarios is predicted to be consistent with the measured value of 125 GeV. In case the light scalar quark is almost degenerate with the dark matter candidate, the neutralino, the dark matter annihilation cross-section is dominated by co-annihilations of the neutralino and the scalar quark as well as the annihilations of scalar quarks.

The focus of our analysis are the annihilations of scalar quarks into heavy quarks. The SUSY-QCD corrections to these processes have been implemented in our analysis code DM@NLO and a thorough analysis of typical pMSSM scenarios will be presented.

Dark Matter, Astroparticle Physics / 217

SuperCDMS SNOLAB Status

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There is strong evidence that $\sim 27\%$ of the energy density of our universe is composed of a dark matter component which has been inferred by observing its gravitational effects. Many well motivated models predict candidate particles with mass below 10 GeV which offer compelling solutions to the dark matter mystery but have yet to be experimentally detected. The Super Cryogenic Dark Matter Search (SuperCDMS) experiment uses cryogenic silicon and germanium crystals instrumented to detect signals produced by such particles, through phonon and ionization measurements using iZIP detectors or by ionization induced Luke-Neganov phonons using HV detectors. After decommissioning of the successful experimental setup at the Soudan Underground Laboratory, focus has shifted to the next phase of SuperCDMS which is now being constructed at SNOLAB in Sudbury, ON Canada. Rapid progress continues towards this new phase, for example the recent successful fabrication of the first full tower of payload detectors. This talk will review the status and plans for the SuperCDMS SNOLAB experiment.

Neutrinos: Models, Phenomenology, Experiments / 105

Clockwork Neutrinos

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The Clockwork (CW) mechanism can explain the smallness of neutrino masses without introducing unnaturally small input parameters. We study the simplest CW neutrino model, the “uniform” clockwork, as well as a broader class of “generalized” clockwork models. We derive constraints on such models from lepton-flavor violating processes, as well as precision electroweak fits. These constraints allow excited CW neutrino states with masses of order 100 GeV - 1 TeV, within reach of the LHC and proposed lepton colliders, as long as the input neutrino Yukawa coupling is of order $10^{-1} - 10^{-2}$. We study collider phenomenology of these models. At the LHC, models with light (~ 100 GeV) CW neutrinos can be discovered using the $3\ell + \text{MET}$ signature. Lepton colliders will be able to discover the CW neutrinos as long as they are within their kinematic range.

BSM in Flavor Physics / 138

Measurements of $B \rightarrow D^{(*)} \tau \nu$ and $B \rightarrow \mu \nu$ at Belle

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Indications for lepton flavour universality violation in the mode $B \rightarrow D^{(*)} \tau \nu$ have been of interest and can be a hint for the New Physics effect.

We report a new measurement on $R(D)$ and $R(D^*)$, branching ratio of $B \rightarrow D^{(*)} \tau \nu$ over $B \rightarrow D^{(*)} \mu \nu$ where $l = e, \mu$, using semi-leptonic tag method.

We also report our new measurement on $B \rightarrow \mu \nu$, which is also sensitive to New Physics.

The analyses are based on the full data set recorded by the Belle detector at the $\Upsilon(4S)$ resonance containing 772 million $B\bar{B}$ pairs from e^+e^- collisions produced by the KEKB collider.

BSM in Flavor Physics / 139**Electroweak penguin B decays at Belle****Author:** Youngjoon Kwon¹¹ *Yonsei University***Corresponding Author:** yjkwon63@yonsei.ac.kr

The electroweak penguin B decay process $b \rightarrow s l^+ l^-$ is a flavour changing neutral current process, and is sensitive to New Physics because of the possible contribution of the heavy particles in the loop. Recently, Belle and LHCb obtained interesting results, where the lepton flavor universality violation effects might be seen.

We report our new measurement of $R(K)$ and $R(K^*)$, *the branching ratio of $B \rightarrow K(l) \mu^+ \mu^-$ to $B \rightarrow K(l^*) e^+ e^-$* , as well as other B decay modes.

The analyses are based on the full data set recorded by the Belle detector at the $\Upsilon(4S)$ resonance containing 772 million $B\bar{B}$ pairs from $e^+ e^-$ collisions produced by the KEKB collider.

Dark Matter, Astroparticle Physics / 199**Dark sources of cosmic ray spikes on Earth's doorstep****Authors:** Adam Coogan¹; Benjamin Lehmann¹; Stefano Profumo²¹ *UC Santa Cruz*² *University of California, Santa Cruz***Corresponding Author:** blehmann@ucsc.edu

Multiple space-borne cosmic ray detectors have detected line-like features in the electron and positron spectra. Most recently, the DAMPE collaboration reported the existence of such a feature at 1.4 TeV, sparking interest in a potential dark matter origin. Such quasi-monochromatic features, virtually free of any astrophysical background, could be explained by the annihilation of dark matter particles in a nearby dark matter clump. Here, we explore the consistency of producing such spectral features with dark matter annihilation from the standpoint of dark matter substructure statistics, constraints from anisotropy, and constraints from gamma-ray emission. We demonstrate that if indeed a high-energy, line-like feature in the electron-positron spectrum originates from dark matter annihilation in a nearby clump, a significant or even dominant fraction of the dark matter in the Solar System likely stems from the clump, with dramatic consequences for direct dark matter searches.

Formal Field Theory and Strings / 182**Moduli Stabilisation and Inflation in superstring theories****Author:** George Leontaris¹¹ *University of Ioannina***Corresponding Author:** leonta@uoi.gr

The problem of moduli stabilisation and inflation are discussed in type IIB/F-theory. Considering a configuration of three intersecting D7 branes with fluxes, it is shown that higher loop effects induce logarithmic corrections to the Kähler potential which can stabilise the Kähler moduli. When

a new Fayet-Iliopoulos term is included, it is also possible to generate the required number of e-foldings and satisfy the conditions for slow-roll inflation.

Dark Matter, Astroparticle Physics / 167

Latest Constraints on Millicharged Particles Using ArgoNeuT

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Millicharged particles (mCPs) are theoretical particles with fractional electric charge, which could constitute part of the dark matter present in the Universe and can naturally arise in dark sectors with $U(1)'$ gauge symmetries. We report the latest constraints to the parameter space of mCPs using data from ArgoNeuT, a 0.24 ton Liquid Argon Time Projection Chamber (LArTPC), with a novel phenomenological proposal of aligning doublet hits. ArgoNeuT was placed in the Neutrinos at the Main Injector (NuMI) neutrino beamline at Fermilab from 2009-2010. The 120 GeV proton beam which produced the neutrinos could also produce a large flux of mCPs which would interact in ArgoNeuT. In addition to setting limits, we describe the manner in which mCPs would be detected in LArTPCs.

Electroweak, Top and Higgs Physics / 104

Anomalous Gauge Couplings from diboson production

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Double gauge boson production is one of the most important processes under study at the LHC. Of particular importance is the measurement of the trilinear electroweak gauge boson coupling, which sheds light on the gauge structure of the Standard Model. We study the impact of anomalous gauge boson and fermion couplings on the production of $W+W-$ pairs at the LHC and how these couplings affect the measurements of the trilinear gauge boson couplings. Although constrained to be very small by LEP, anomalous fermion-gauge boson couplings can have important effects in LHC fits to anomalous couplings due to a strong growth with energy. We perform this study at NLO in QCD, determining the effects of higher order corrections as well.

Neutrinos: Models, Phenomenology, Experiments / 114

Short and Medium Baseline Reactor Neutrino Experiments

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Neutrinos emitted nuclear reactors have played an important role for both discovery and measurement in the history of neutrino physics. The short baseline reactor neutrino experiments, Daya Bay, Double Chooz, and RENO, have brought neutrino physics into the precision era. The next generation medium baseline reactor neutrino experiments JUNO will explore the neutrino mass hierarchy and other new physics beyond the standard model. In this talk, we will review the past, current and future of short and medium baseline reactor neutrino experiments. The opportunities for future discoveries will be discussed.

Alternatives to Supersymmetry / 71

Searches for new phenomena in leptonic final states with the ATLAS and CMS detectors

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Many particles predicted by theories beyond the Standard Model, including for example new heavy vector bosons, decay into final states which contain high-pt leptons and possibly other objects such as missing transverse energy or jets. Searches for new physics models with these signatures are performed using the ATLAS and CMS experiments at the LHC. The talk will focus on the most recent results using 13 TeV pp collision data.

Neutrinos: Models, Phenomenology, Experiments / 186

DUNE as the Next-Generation Solar Neutrino Experiment

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We show that the Deep Underground Neutrino Experiment (DUNE) has the potential to deliver world-leading results in solar neutrinos. With an exposure of 100 kton-year, DUNE could detect 10^5 signal events above 5 MeV electron energy. Separate precision measurements of neutrino-mixing parameters and the 8B flux could be made using two detection channels and the day-night effect. New particle physics may be revealed through the comparison of solar neutrinos (with matter effects) and reactor neutrinos (without), which is discrepant by $\sim 2\sigma$ (and could become 5.6σ). New astrophysics may be revealed through the most precise measurement of the 8B flux (to 2.5%) and the first detection of the hep flux (to 11%). DUNE is required: No other experiment, even proposed, has been shown capable of fully realizing these discovery opportunities.

Plenary Session / 272

LHC Higgs/BSM Higgs at ATLAS & CMS

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Plenary Session / 270

SUSY Models

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Plenary Session / 306

SUSY 2020 Announcement

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Alternatives to Supersymmetry / 74

ATLAS Searches for VV Resonances

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The full Run-2 ATLAS results on searches for resonant production of vector (W,Z) are presented, comprising 140fb-1 of data. Searches for such diboson resonances have been performed in final states with different numbers of leptons and jets where new jet substructure techniques to disentangle the hadronic decay products in highly boosted configuration are being used.

Machine Learning, Big Data and Quantum Information / 88

Machine Learning Templates for QCD Factorization in the Search for Physics Beyond the Standard Model

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High-multiplicity all-hadronic final states are an important, but difficult final state for searching for physics beyond the Standard Model. A powerful search method is to look for large jets with accidental substructure due to multiple hard partons falling within a single jet. One way for estimating the background in this search is to exploit an approximate factorization in quantum chromodynamics whereby the jet mass distribution is determined only by its kinematic properties. Traditionally, this approach has been executed using histograms constructed in a background-rich region. We propose a new approach based on Generative Adversarial Networks (GANs). These neural network approaches are naturally unbinned and can be readily conditioned on multiple jet properties. In addition to using vanilla GANs for this purpose, a modification to the traditional WGAN approach has been investigated where weight clipping is replaced with a naturally compact set (in this case, the circle). Both the vanilla and modified WGAN approaches significantly outperform the histogram method, especially when modeling the dependence on features not used in the histogram construction. These results can be useful for enhancing the sensitivity of LHC searches to high-multiplicity final states involving many quarks and gluons and serve as a useful benchmark where GANs may have immediate benefit to the HEP community.

Neutrinos: Models, Phenomenology, Experiments / 77

Neutrino Cross-Section Measurements in the NOvA Near Detector at Fermilab

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Current and future experiments aimed at making precision measurements of neutrino properties require better understanding of neutrino interactions with the nucleus to achieve their ultimate sensitivities. The NOvA (NuMI Off-axis ν_e Appearance) experiment is a long-baseline neutrino oscillation experiment designed to observe neutrinos in Fermilab's NuMI (Neutrinos at the Main Injector) beam. NOvA consists of two detectors, a near detector at Fermilab, and a far detector at Ash River, MN. With the most intense neutrino beam in the world, a rich spectrum of neutrino cross-section measurements are carried out with the NOvA near detector, including inclusive and exclusive measurements with $\bar{\nu}_\mu$ and $\bar{\nu}_e$. In this talk, I present progress and results of various neutrino cross-section measurements conducted by NOvA.

Neutrinos: Models, Phenomenology, Experiments / 190

Recent Results from Short-Baseline Reactor Antineutrino Experiments

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Current models of antineutrino production in nuclear reactors predict absolute detection rates and energy spectra at odds with the existing body of direct reactor antineutrino measurements. If these discrepancies are taken seriously, then they must be indicative of a misunderstanding of neutrino production in nuclear reactor cores and/or the fundamental properties of neutrinos. New short-baseline reactor antineutrino measurements performed at highly-enriched and commercial reactors are enabling independent testing of these two explanations for existing flux and spectrum anomalies. In this talk, I will focus on recent reactor antineutrino measurements performed by the PROSPECT, STEREO, NEOS, and DANSS short-baseline reactor experiments, which have demonstrated the feasibility of precision on-surface reactor antineutrino detection, advanced understanding of antineutrino production by the primary fission isotopes, and placed new limits on sterile neutrino oscillations.

Supersymmetry: Models, Phenomenology and Experimental Results / 16

High Scale Supersymmetry and neutrino Phenomenology

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Supersymmetry was proposed to be the underlying physics of the flavor puzzle. The charged lepton mass hierarchy was naturally understood. The model is predictive. CP violation in the lepton sector,

and other aspects of neutrino physics, are studied. In addition to the sneutrino vacuum expectation values (VEVs), the heavy vector-like triplet also contributes to neutrino masses. Phases of the VEVs of relevant fields, complex couplings and Zino mass are considered. The approximate degeneracy of neutrino masses $m_{\nu 1}$ and $m_{\nu 2}$ can be naturally understood. The neutrino masses are then normal ordered, ~ 0.020 eV, 0.022 eV, and 0.054 eV. Large CP violation in neutrino oscillations is favored. The effective Majorana mass of the electron neutrino is about 0.02 eV.

Alternatives to Supersymmetry / 195

Composite Higgs models at the LHC and beyond

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In this talk, I will discuss about the phenomenology of the composite Higgs models at the LHC and future lepton colliders. Spin-1 resonances and the top partners are the smoking gun of the composite Higgs models, their strong interactions will play an important role in the searching for the resonances and cascade decay channels can be important. I will discuss about their prospectives at the HL-LHC and highlight the possibility of left-handed third generation doublet as the massless bound state of the strong sector. In the meanwhile, I will briefly discuss about the universal relationship between the Higgs couplings predicted by the non-linearity and their phenomenological relevance.

Alternatives to Supersymmetry / 154

Enhancing long-lived particles searches at the LHC with precision timing information

Author: Jia Liu¹

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We explore the physics potential of using precision timing information at the LHC in searches for long-lived particles (LLPs). In comparison with the light Standard Model particles, the decay products of massive LLPs arrive at detectors with time delays around nanosecond scale. We propose new strategies to take advantage of this time delay feature by using initial state radiation to timestamp the collision event and require at least one LLP to decay within the detector. This search strategy is effective for a broad range of models. In addition to outlining this general approach, we demonstrate its effectiveness with the projected reach for two benchmark scenarios: Higgs decaying into a pair of LLPs, and pair production of long-lived neutralinos in the gauge mediated supersymmetry breaking models. Our strategy increases the sensitivity to the lifetime of the LLP by two orders of magnitude or more and particularly exhibits a better behavior with a linear dependence on lifetime in the large lifetime region compared to traditional LLP searches. The timing information significantly reduces the Standard Model background and provides a powerful new dimension for LLP searches.

Plenary Session / 280

LHC Top and EWK - ATLAS & CMS

Corresponding Author: liumy871227@gmail.com

Machine Learning, Big Data and Quantum Information / 72

A key variable; Missing Transverse Energy - reconstruction, pile-up and its significance

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Missing transverse momentum (MET) plays an essential role in many searches for Supersymmetry. However, increasing pile-up and other detector miss-measurements mean that separating signal events from those with no real missing transverse momentum can not always be trivial. The recent improvements in the reconstruction of the MET at the ATLAS experiment will be detailed including the use of particle flow reconstruction, and the selection against pile-up of jets used to form the MET. Additionally, a significance based approach using the resolutions of all the objects used to form the MET will be described along with its application in several searches for Supersymmetric particles, including the gain in significance over more traditional approaches.

Neutrinos: Models, Phenomenology, Experiments / 140

Low scale seesaw models and leptogenesis

Author: Michele Lucente¹

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The addition of right-handed neutrino fields to the SM field content provides a minimal and viable solution to account for the observed neutrino masses and lepton mixing. Remarkably, the very same extension contains all the necessary ingredients to account for the observed BAU as well. In this talk I will focus on the possibility that the right-handed neutrinos have masses below the EW scale, and present how these light states can simultaneously account for neutrino physics and the BAU, stressing as well the experimental perspectives to test this hypothesis.

Plenary Session / 289

Sterile Neutrinos

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Electroweak, Top and Higgs Physics / 81

Exotic Higgs seaches with CMS

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The speaker is invited to select 2 or 3 topics amongst the most recent results on exotic Higgs bosons, that will be presented in details.

Alternatives to Supersymmetry / 227

Search for heavy resonances in diboson final states at CMS

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Searches for new resonances in di-boson final states (VV, VH, HH, where $V = W, Z$) with the CMS detector are presented. The results are based on the large dataset collected during Run 2 of the LHC at a centre-of-mass energy of 13 TeV. The analyses are optimised for high sensitivity over a large range in resonance mass. Jet substructure techniques are used to identify hadronic decays of highly-boosted W, Z, and H bosons. A statistical combination of these searches provides the most stringent constraints on heavy vector bosons with large couplings to standard model bosons and fermions.

Supersymmetry: Models, Phenomenology and Experimental Results / 150

Search for SUSY with Higgs final states - CMS Experiment

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Results from the CMS experiment are presented for searches for supersymmetric particle production with Higgs bosons in the final state. Strong and electroweak production are considered in a variety of Higgs decay channels. The searches use proton-proton collision data with luminosity up to 137 fb⁻¹ recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Precision Calculations and MC tools / 103

Tools for the Simulation of Long-Lived SUSY Particles in the ATLAS experiment

Authors: Lawrence Lee Jr¹; Emma Sian Kuwertz²; Jennifer Kathryn Roloff¹; Zachary Louis Marshall³

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Searches for long-lived particles have garnered increased attention in recent years, demanding the development of more complex Monte Carlo simulation methods. The ATLAS experiment has recently updated its infrastructure for the generation, simulation, and in-flight decays of R-hadrons, some of the most complex long-lived SUSY states to model. In this talk, the tools and configuration that are used, including the configuration of Geant4 and Pythia8, are described. The recently-revised complex mass spectrum of R-hadrons is also explained and justified. This publicly-documented configuration is put forward as the next standard for R-hadron simulation.

Electroweak, Top and Higgs Physics / 196**Precision Standard Model parameters for matching to SUSY and other ultraviolet completions****Author:** Stephen Martin¹¹ *Northern Illinois University***Corresponding Author:** spmartin@niu.edu

I will discuss the precision determination of the \overline{MS} parameters of the Standard Model and their relation to observable quantities such as the top, Higgs, Z, and W pole masses at full 2-loop order with higher-order QCD effects. I describe a new computer program SMDR, which incorporates all of the known higher loop order effects. The program includes, for the first time, the relation of the Higgs squared mass parameter to the vacuum expectation value, defined as the minimum of the Landau gauge effective potential, at full 3-loop order. This program can be used to provide matching boundary conditions for SUSY, or other ultraviolet completions of the Standard Model.

Supersymmetry: Models, Phenomenology and Experimental Results / 47**Searches for promptly decaying squarks and gluinos with ATLAS****Author:** Aurelio Juste Rozas¹¹ *ICREA and IFAE (ES)***Corresponding Author:** jmaurer@cern.ch

Despite the absence of experimental evidence, weak-scale supersymmetry remains one of the best motivated and studied Standard Model extensions. This talk summarizes recent ATLAS results on inclusive searches for supersymmetric squarks of the first two generations and gluinos. It covers both R-parity conserving models that predict dark matter candidates and R-parity violating models that typically lead to high-multiplicity final states without large missing transverse momentum. The searches target final states including jets, leptons, photons, and missing transverse momentum.

Neutrinos: Models, Phenomenology, Experiments / 244**Natural Neutrino Masses and Mixing Angles in an Intersecting D-brane World****Authors:** Van Mayes¹; Evan Howington¹; Jordan Gemmill¹¹ *University of Houston - Clear Lake***Corresponding Author:** mayesv@uhcl.edu

The correct quark and charged lepton mass matrices along with a nearly correct CKM matrix may be naturally accommodated in a Pati-Salam model constructed from intersecting D6 branes on a $T^6/(Z_2 \times Z_2)$ orientifold. Furthermore, near-tribimaximal mixing for neutrinos may arise naturally due to the structure of the Yukawa matrices in the model. Consistency with the quark and charged lepton mass matrices in combination with obtaining near-tribimaximal mixing fixes the Dirac neutrino matrix completely. Then, applying the seesaw mechanism for different choices of right-handed

neutrino masses and running the obtained neutrino parameters down to the electroweak scale via the Renormalization Group Equations (RGEs), we are able to make generic predictions for the neutrino masses and mixing angles. We find that the neutrino masses are normal ordered (NO) with $\Delta m_{32}^2 \approx 0.0025 \text{ eV}^2$, $\Delta m_{21}^2 \approx 0.000077 \text{ eV}^2$, and $\sum m_\nu \approx 0.088 \text{ eV}$ consistent with experimental observations and cosmological constraints. Finally, we also obtain neutrino mixing angles which are consistent with observations.

Formal Field Theory and Strings / 21

High U(1) charge models in type IIB and their F-theory lift

Author: Damian Kaloni Mayorga Peña¹

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In the quest of obtaining models with U(1) symmetries singlets with charges higher than 4 there is no systematic prescription from the point of view of F-theory. Following early work, where we worked out Sen's weak coupling limit for a family of F-theory standard models we now are able to systematically construct higher U(1) charge models in type IIB applying matrix factorization techniques, in this fashion we are able to obtain models with singlet charges $q \leq 6$.

Unification of Forces / 213

IR fixed point predictions for third generation masses in the MSSM with a vectorlike family

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In the MSSM extended by a complete vectorlike family, precise top, bottom and tau Yukawa coupling unification can be achieved assuming SUSY threshold corrections which are typical for comparable superpartner masses. Furthermore, the unification is possible with a large unified coupling, implying that all three fermion masses can be simultaneously close to their IR fixed points. Assuming unified Yukawa couplings of order one or larger, the preferred common scale of new physics (superpartners and vectorlike matter) is in the 3 TeV to 30 TeV range, with larger couplings favoring smaller scales. Splitting superpartner masses from masses of vectorlike fields, the preferred scales extend in both directions. The multi-TeV scale for superpartners is compatible with and independently suggested by the Higgs boson mass.

BSM in Flavor Physics / 234

Status and prospects of charged lepton flavor violation searches with the MEG-II experiment

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The MEG experiment took data at the Paul Scherrer Institut in the years 2009-2013 and published the most stringent limit on the charged lepton flavor violating decay $\mu \rightarrow e\gamma$: $\text{BR}(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$ @90% C.L.

The MEG detector has been upgraded in order to reach a sensitivity of 5×10^{-14} , which corresponds to an improvement of one order of magnitude.

The basic idea of MEG-II is to achieve the highest possible sensitivity by making the maximum use (7×10^7 muons/s) of the available muon intensity at PSI with an improved detector, since MEG ran at a reduced intensity (3×10^7 muons/s) in order to keep the background at a manageable level.

The key features of the MEG-II are the increase of the rate capability of all detectors to enable running at the intensity frontier, and to increase the resolutions while maintaining the same detector concept.

A new mass, single volume, high granularity tracker, together with a thinner muon stopping target, leads to better spatial, angular and energy positron resolution.

A new highly segmented timing counter improves positron timing capabilities. The detector acceptance for positrons is increased by more than a factor 2 by diminishing the material between these two detectors. The liquid Xenon calorimeter has new smaller photosensors (VUV-sensitive SiPM) that replace current phototubes and improve in particular photon energy resolution.

The results of the 2018 pre-engineering run, the first with all the sub-detectors, and the current schedule will be presented.

Supersymmetry: Models, Phenomenology and Experimental Results / 165

Partially composite supersymmetry

Author: Andrew Miller¹

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Supersymmetric models are subject both to direct constraints from collider searches and to indirect limits from electroweak observables such as the Higgs mass and flavor-changing processes. A minimal scenario consistent with current experimental data suggests a supersymmetric spectrum with a split sfermion sector. Such a spectrum can naturally be realized when partial compositeness is used to explain the fermion mass hierarchy and predict the sfermion mass spectrum. We present a model in which the Higgs and third-generation matter superfields are elementary, while the first two generations are composite. Assuming supersymmetry is broken by the strong dynamics, a sfermion mass hierarchy arises that inverts the ordering of the fermion mass hierarchy. Third-generation sfermions are 10-100 TeV, consistent with the observed 125 GeV Higgs boson mass, and the first- and second-generation sfermions are above 100 TeV, ameliorating the flavor problem. Gauginos and Higgsinos are typically $\mathcal{O}(10)$ TeV. The gravitino, in the keV to TeV mass range, is the LSP, providing a warm dark matter candidate. We explore the rich parameter space of the model and discuss benchmark sparticle spectra and their calculation in the gravitational dual theory.

Precision Calculations and MC tools / 54

Measurements of jet substructure observables and jet fragmentation at the LHC

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In this talk, we present measurements of jet substructure quantities and jet fragmentation properties using data collected by the CMS and ATLAS experiment. These measurements are significant not

only for probing a new regime of QCD at a hadron collider, but also for improving the understanding of the internal properties of jets that are used in SUSY searches.

Supersymmetry: Models, Phenomenology and Experimental Results / 45

Searches for charginos and neutralinos with the ATLAS detector

Author: David W. Miller^{None}

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Charginos and neutralinos are typically the lightest new particles predicted by a wide range of supersymmetry models, and the lightest neutralino is a well motivated and studied candidate for dark matter in models with R-parity conservation. The talk presents recent results from searches for pair produced charginos and neutralinos in final states with leptons and missing transverse momentum. The search for higgsinos represents an experimental challenge due to the near mass-degeneracy resulting in soft decay products, and the low production cross section. This talk also presents recent ATLAS results of analyses explicitly targeting the higgsino with a variety of experimental techniques, as well as searches for electroweak production of supersymmetric particles in final states involving the Higgs boson.

Alternatives to Supersymmetry / 122

Theoretical and experimental considerations of a multi-brane world

Author: Rashmish Mishra¹

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Simple generalizations of well known BSM scenarios can lead to dramatic signals at colliders, providing interesting theoretical playgrounds and motivating new methods to isolate non-standard experimental signals. In this talk, I will consider warped extra-dimensional models with multiple branes in the IR and discuss the theoretical possibilities and related collider signals. The resulting signals require dedicated strategies at LHC, with varying sophistication. In addition, these strategies are relevant for a broad class of BSM scenarios. A specific realization of this multi-brane setup presents a way to study conformal dark sectors, with non-gravitational interactions to the SM. Motivating the minimal interaction needed, I will discuss the collider and cosmological bounds on this scenario.

Dark Matter, Astroparticle Physics / 108

Discovering Galactic substructure with astrometric lensing using the power spectrum

Authors: Siddharth Mishra-Sharma¹; Ken Van Tilburg²; Neal Weiner¹

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Dark matter (DM) substructure is expected to exist over a large range of scales in our Galaxy. Its properties, such as its spatial distribution and abundance at different mass scales, can strongly correlate with the underlying particle physics properties of dark matter. Inferring DM substructure properties can thus hold the key to pinning down the particle nature of DM. In this talk, I will describe how the pattern of correlated velocities and acceleration induced due to gravitational lensing by subhalos in our Galaxy on the motions of extragalactic objects such as quasars can be used to infer the nature of substructure by directly and statistically probing the subhalo mass function. I will show how this measurement can be used to test the cold dark matter (CDM) hypothesis and distinguish it from alternative scenarios, and how this can be practically achieved with future astrometric surveys and/or radio telescopes such as the Square Kilometer Array.

Supersymmetry: Models, Phenomenology and Experimental Results / 231

Searches for supersymmetry in R-parity violating signatures at the LHC

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R-parity violation introduces many viable signatures to the search for supersymmetry at the LHC. The decay of supersymmetric particles can produce leptons or jets, while removing the missing transverse momentum signal common to traditional supersymmetry searches. The talk presents recent results from searches of supersymmetry in these unusual signatures of R-parity violation with the ATLAS and CMS detectors.

Unification of Forces / 208

On the origin of fermion masses and mixing from a unified description of flavour and gauge interactions

Authors: Antonio Morais¹; Roman Pasechnik²; Werner Rudolf Porod³

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We present a Grand Unified Theory where the usual E_6 gauge coupling unification is supplemented by a local $SU(2)_F \times U(1)_F$ family symmetry. We discuss its origin inspiring our model by an embedding into E_8 which can be seen as an unifying force. We argue that the presence of such a family symmetry has remarkable implications for both high-scale and low scale physics: First, while the usual 27^3 cubic interactions in the superpotential are forbidden, tree-level Yukawa terms are generated via dimension-four operators upon the breaking of E_6 down to its trification maximal subgroup. Such a breaking will also induce sizable threshold corrections to the gauge couplings at the E_6 scale which modifies their running in such a way that it becomes possible to attain a low scale unification picture not far from the reach of a Future 100 TeV Circular Collider. On the other hand we demonstrate that the masses of leptons and first generation quarks are of radiative origin whereas second and third quark families are tree-level generated. This results in a CKM-mixing with the Cabibbo where deviations from unitarity are induced via mixing with down-type vector-like quarks as well as radiative corrections.

Formal Field Theory and Strings / 86**Thraxions****Author:** Jakob Moritz¹¹ *DESY***Corresponding Author:** jakob.moritz@desy.de

We argue that a new type of ultra light axion is generically present in the type IIB part of the string theory landscape. It arises when fluxes stabilize Calabi-Yau manifolds near a conifold transition locus in moduli space. After accounting for ten-dimensional backreaction the scalar potential features a finite axion monodromy with overall scale far smaller than the weak gravity conjecture for axions would predict. Moreover we identify a mechanism for generating super-Planckian axionic field ranges which we call drifting monodromies. However, in the examples we consider, the potential oscillates on sub-Planckian distances in field space, preventing us from building a natural inflation model on the basis of this idea.

Dark Matter, Astroparticle Physics / 210**Testing Dark Matter and Modifications to Gravity using Local Milky Way Observables****Author:** Matthew Moschella¹¹ *Princeton University***Corresponding Author:** moschella@princeton.edu

The observed flattening of rotation curves is usually considered strong evidence for the existence of dark matter on galactic scales. However, observations such as the Baryonic Tully-Fisher Relation and the Radial Acceleration Relation, suggest that the observed dynamics in galaxies are strongly correlated with the distribution of baryonic matter. Because they are challenging to explain in the context of dark matter, these observations have motivated low-acceleration modifications to gravity as an alternative to the dark matter hypothesis. I will present a framework to test a general class of modifications to gravity using local Milky Way observables, including the vertical acceleration field, the rotation curve, the baryonic surface density, and the stellar disk profile. For concreteness, I will focus on modifications to gravity that increase the magnitude but do not change the direction of the gravitational acceleration. MODified Newtonian Dynamics (MOND) is one such example. I will show that a modification to gravity of this type is in tension with observations of the Milky Way's baryonic profile and that dark matter provides a better fit to the data.

Dark Matter, Astroparticle Physics / 6**Gamma Lines from the Hidden Sector****Author:** Clara Murgui Galvez^{None}**Corresponding Author:** clara.murgui@ific.uv.es

We discuss the visibility of gamma lines from dark matter annihilation. We point out a class of theories for dark matter which predict the existence of gamma lines with striking features. In these theories, the final state radiation processes are highly suppressed and one could distinguish easily the gamma lines from the continuum spectrum. We discuss the main experimental bounds and show that one could test the predictions for gamma lines in the near future in the context of simple gauge theories for dark matter.

Formal Field Theory and Strings / 35**Deep Autoencoders in the Heterotic Orbifold Landscape****Author:** Andreas Mütter^{None}**Co-authors:** Erik Parr ; Patrick Vaudrevange**Corresponding Author:** andreas.muetter@ph.tum.de

In orbifold compactifications of heterotic string theory, the four-dimensional effective theory (like the gauge group and the particle spectrum) is fully determined by the so-called gauge embedding. However, it is difficult to see directly whether a given gauge embedding leads to “good” phenomenological properties of the resulting model (such as containing the Standard Model spectrum). In this talk, we present an approach using methods from machine learning that allows one to identify and characterize fertile patches in the landscape, i.e. classes of gauge embeddings that have a good chance to give rise to promising models. The information extracted in this way is instrumental for new search strategies for MSSM-like models in the heterotic orbifold landscape.

Dark Matter, Astroparticle Physics / 211**Limit on the Axion Decay Constant from the Cooling Neutron Star in Cassiopeia A****Authors:** Jiaming Zheng¹; Keisuke Yanagi¹; Koichi Hamaguchi¹; Natsumi Nagata¹¹ *University of Tokyo***Corresponding Author:** natsumi@hep-th.phys.s.u-tokyo.ac.jp

The observed rapid cooling of the neutron star (NS) located at the center of the supernova remnant Cassiopeia A (Cas A) can be explained in the minimal NS cooling scenario. This consequence may be changed if there exists an extra cooling source, such as axion emission. In this work, we study the Cas A NS cooling in the presence of axion emission, taking account of the temperature evolution in the whole life of the Cas A NS. We obtain a lower limit on the axion decay constant, $f_a > (5-7) \times 10^8$ GeV, if the star has an envelope with a thin carbon layer. This is as strong as existing limits imposed by other astrophysical observations such as SN1987A.

Supersymmetry: Models, Phenomenology and Experimental Results / 23**Stueckelberg superfield in supergravity****Author:** Silvia Nagy¹¹ *University of Nottingham***Corresponding Author:** silvynagy@googlemail.com

It is known that de Sitter solutions in supergravity require supersymmetry breaking. I will present a new construction that allows the inclusion of the goldstino into supergravity, based on applying the Stueckelberg trick to a novel superfield formulation of unimodular supergravity. I will show the existence of de Sitter solutions and also the connection to the Volkov-Akulov model in the flat limit of our theory.

Machine Learning, Big Data and Quantum Information / 118

Searching for New Physics with Deep Autoencoders

Authors: David Shih¹; Marco Farina²; Yuichiro Nakai¹

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We introduce a potentially powerful new method of searching for new physics at the LHC, using autoencoders and unsupervised deep learning. The key idea of the autoencoder is that it learns to map “normal” events back to themselves, but fails to reconstruct “anomalous” events that it has never encountered before. The reconstruction error can then be used as an anomaly threshold. We demonstrate the effectiveness of this idea using QCD jets as background and boosted top jets and RPV gluino jets as signal. We show that a deep autoencoder can significantly improve signal over background when trained on backgrounds only, or even directly on data which contains a small admixture of signal. Finally we examine the correlation of the autoencoders with jet mass and show how the jet mass distribution can be stable against cuts in reconstruction loss. This may be important for estimating QCD backgrounds from data. As a test case we show how one could plausibly discover 400 GeV RPV gluinos using an autoencoder combined with a bump hunt in jet mass. This opens up the exciting possibility of training directly on actual data to discover new physics with no prior expectations or theory prejudice.

Plenary Session / 268

Proton Decay, Unification – Perspective

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Alternatives to Supersymmetry / 209

Lattice investigation of a composite Higgs model

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In composite Higgs models, relating the many parameters of the low-energy effective theory to the fundamental UV parameters requires dealing with the underlying non-perturbative interactions responsible for compositeness. Lattice field theory calculations allow this connection to be made numerically, giving significant model constraints. I will present several results from a detailed lattice study of a particular composite Higgs model, based on an SU(4) gauge group with fermions in two different representations.

Neutrinos: Models, Phenomenology, Experiments / 36

Probing new physics with CEvNS: an overview

Author: Jayden Newstead¹

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The field of coherent elastic neutrino-nucleus scattering (CEvNS) has grown immensely in recent years. In this talk I will provide an overview of the field, summarizing the running experiments, phenomenological implications and theoretical challenges. With the first detection made by COHERENT in 2017, the goal is now to make more precise measurements using a diverse set of target nuclei and neutrino sources. This approach will maximize sensitivity to new physics in the neutrino sector, including NSI and sterile neutrinos. New physics searches, wanting to make use of CEvNS data, need a consistent approach to predicting CEvNS rates for the various experiments. I will briefly review the tools necessary to make such predictions.

Supersymmetry: Models, Phenomenology and Experimental Results / 152

Di-Higgs Production in SUSY Models

Author: Yu Hang Ng¹

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I will discuss the di-Higgs production via gluon fusion within the context of Minimal Supersymmetric Standard Model (MSSM) and Next-to-Minimal Supersymmetric Standard Model (NMSSM). The calculation is based on the analytical expression of the leading order Feynman amplitudes (which includes both quark and squark loops), and therefore, both off-shell effects and interference between resonant and non-resonant contributions are accounted for. We choose the parameter space that is allowed by the current experimental constraints, and also relevant to the LHC experiments in the near future. I am going to show the parameter space where the di-Higgs production can be enhanced significantly in each case.

Electroweak, Top and Higgs Physics / 84

Vector-boson processes at the LHC

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Material should contain inclusive DY production of Z and W, which includes A-FB, angular coefficient, M_W , W helicity, and V+jets measurements including heavy-flavour (W+c, W+b, Z+b, Z+c). The speaker can choose to concentrate more on 2 or 3 recent results.

Unification of Forces / 170

Spontaneous SUSY breaking in natural GUT and axino LSP

Authors: maekawa nobuhiro¹; omura yuji^{None}; shigekami yoshihiro^{None}; yoshida manabu²

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In natural GUT, most of problems in SUSY GUT can be solved under natural assumption in which all interactions including higher dimensional interactions are introduced with $O(1)$ coefficients. Interestingly, small deviation from the complete natural GUT makes spontaneous SUSY breaking possible. We study the possibility that axino becomes the LSP in this scenario.

Poster Session / 246

Toward a direct measurement of Coherent Radio Reflections from an Electron-Beam Induced Particle Cascade

Author: Aleksandra Nozdrina¹

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The T-576 experiment at the SLAC National Accelerator Laboratory was designed to make the first direct measurement of a coherent radio reflection ('radar') off the particle shower produced by an electron beam (>10 GeV/particle; 10^9 electrons per bunch) directed into a high-density polyethylene target. This beam is approximately equivalent to the shower produced by an EeV energy neutrino interacting in cold Antarctic ice. Secondary particles created during shower development result in a short-lived ionization plasma. Depending on the initial particle energy and the parameters of the generated plasma, atomic electron ionization may become dense enough as to reflect at radio wavelengths. Coherent radar scattering is expected at frequencies below the plasma frequency, which is directly calculable from the free charge density. In such cases, electromagnetic waves will scatter off the surface of the full plasma volume.

Our preliminary results are obtained using a singular value decomposition (SVD) analysis technique and indicate a signal consistent with a radio reflection at 2.36 sigma significance above background. A detector based on coherent radio reflections may therefore allow lowering the detectable neutrino energy threshold from a few EeV (corresponding to the threshold of currently operating Askaryan radio detectors) to several PeV, where the IceCube experiment runs out of statistics, thus filling the currently existing gap in sensitivity for neutrino registration.

Unification of Forces / 129

Neutrino masses, Inflation and Dark Matter in Grand Unified Theories

Author: Nobuchika Okada¹

¹ *University of Alabama*

The Grand Unified Theory (GUT) is a very interesting paradigm beyond the Standard Model. However, in simple GUT models, there are still missing pieces, such as neutrino masses, cosmological inflation, and a dark matter candidate. In this talk, I will discuss simple GUT models in which these missing pieces are supplemented.

Dark Matter, Astroparticle Physics / 34

A natural Z' -portal Majorana dark matter in alternative $U(1)$ extended Standard Model

Authors: Digesh Raut¹; Nobuchika Okada¹; Satomi Okada^{None}

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We consider a non-exotic gauged $U(1)_X$ extension of the Standard Model (SM), where the $U(1)_X$ charge of a SM field is given by a linear combination of its hypercharge and Baryon-minus-Lepton (B-L) number. All the gauge and mixed gauge-gravitational anomalies are cancelled in this model with the introduction of three right-handed neutrinos (RHNs). Unlike the conventional minimal $U(1)_X$ model, where a universal $U(1)_X$ charge of -1 is assigned to three RHNs, we consider an alternative charge assignment, namely, two RHNs ($N^{\{1,2\}}_R$) have $U(1)_X$ charge -4 while one RHN (N_R) has a $+5$ charge. With a minimal extension of the Higgs sector, the three RHNs acquire their Majorana masses associated with $U(1)_X$ symmetry breaking. While $N^{\{1,2\}}_R$ have Yukawa coupling with the SM lepton doublets and play an essential role for the ‘minimal seesaw’ mechanism, N_R is isolated from the SM particles due to its $U(1)_X$ charge and hence it is a natural candidate for the dark matter (DM) without invoking additional symmetries. In this model context, we investigate the Z' -portal RHN DM scenario, where the RHN DM communicates with the SM particles through the $U(1)_X$ gauge boson (Z' boson). We identify a narrow parameter space by combining the constraints from the observed DM relic abundance, the results of the search for a Z' boson resonance at the Large Hadron Collider Run-2, and the gauge coupling perturbativity up to the Planck/Grand Unification scale. For a special choice of $U(1)_X$ charges for the SM fields allows us to extend the model to $SU(5) \times U(1)_X$ grand unification. In this scenario, the model parameter space is more severely constrained, which will be explored at future high energy collider experiments.

Plenary Session / 267

High Scale SUSY

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Plenary Session / 284

Swampland and Its Physical Implications

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Supersymmetry: Models, Phenomenology and Experimental Results / 48

Searches for supersymmetric particles with macroscopic or stable lifetimes using the ATLAS detector

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Supersymmetric models present a wide variety of signatures that might be accessible at the LHC. In some cases supersymmetric particles may acquire finite lifetimes, and once produced in collisions, their direct trajectories or decay products can be observed as highly distinctive signatures with relatively small backgrounds. In recent years, the capability of the ATLAS experiment to search for

such long-lived supersymmetric particles has been expanded, as these scenarios have been capturing more attention. The latest results of these searches will be presented in this talk.

Plenary Session / 296

Clockwork Mechanism

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Dark Matter, Astroparticle Physics / 58

SEARCH FOR EXOTIC DECAYS WITH NA62

Author: Christopher John Parkinson^{None}

The features of the NA62 experiment at the CERN SPS – high-intensity setup, trigger-system flexibility, high-frequency tracking of beam particles, redundant particle identification, and ultra-high-efficiency photon vetoes – make NA62 particularly suitable to search for long-lived, weakly-coupled particles within Beyond the Standard Model physics, using kaon and pion decays as well as operating the experiment in dump mode.

The NA62 sensitivity for production and decay searches of Heavy Neutral Lepton, Axion-Like Particles (ALP) and Dark Photons are presented, together with prospects for future data taking at the NA62 experiment.

BSM in Flavor Physics / 233

Phenomenology of family-nonuniversal Three Higgs Doublet models

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In this talk, I overview prospects for New Physics searches offered by recently suggested family-nonuniversal Three-Higgs Doublet models such as those based upon $U(1)$, $U(1)\times U(1)$, $U(1)\times Z_2$ and CP_4 family symmetries. Implications of these scenarios for explanation of fermion mass and mixing hierarchies as well as the observed flavour anomalies are outlined.

Dark Matter, Astroparticle Physics / 245

Searches for dark matter with CMS

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Searches for dark matter in various final states with invisible particles recoiling against standard model particles are presented. Various topologies and kinematic variables are explored, as well as jet substructure as a means of tagging heavy bosons. The focus of the talk is on the recent CMS results obtained using data collected in the LHC run 2.

Neutrinos: Models, Phenomenology, Experiments / 162

Neutrino mass models and dark matter

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Neutrino masses and the existence of non-baryonic Dark Matter (DM) are together with the Baryon asymmetry in the Universe three evidences that the Standard Model is not the final theory to describe our nature. In this talk I intend to give a brief review of models to generate neutrino masses. I will in particular discuss scenarios where the generation of neutrino masses is linked to the stability of the DM sector.

Supersymmetry: Models, Phenomenology and Experimental Results / 142

Strong SUSY Production in hadronic channels - CMS Experiment

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Results from the CMS experiment are presented for searches for strong supersymmetric particle production. The results target a variety of gluino and squark production channels with decays to hadronic final states. The searches use proton-proton collision data with luminosity up to 137 fb⁻¹ recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Unification of Forces / 14

Minimal SO(10)-based GUT Model

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Contrary to SUSY-based GUT models, the gauge couplings in non-SUSY models do not unify naturally. However, gauge coupling unification may still be achieved by intermediate symmetry breaking steps or new physics around the TeV scale. Motivated by this, we perform fits to an SO(10)-based GUT model with one-step symmetry breaking to the SM. Neutrino masses are generated by the type-I or type-II seesaw mechanism, or a combination of both. We find that in order to fit the SM observables, we need either type-I seesaw or both. These fits are performed in a consistent way, by evolving the parameters from the GUT-scale to the electroweak scale, where the fit is performed.

In order to keep the fits general, we do not impose gauge coupling unification, but show that the results are insensitive to changes in the GUT scale and the exact values of the gauge couplings there. We also construct a specific realisation of this model, which achieves gauge coupling unification by the addition of two SU(3) octets originating in the scalar 210-dimensional representation. We also derive predictions on the proton lifetime in such a model.

BSM in Flavor Physics / 57

PHYSICS BEYOND SM WITH KAONS AT NA62

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The NA62 experiment at CERN SPS was designed to measure $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ with in-flight decays, a novel technique for this channel. NA62 took its first physics data in 2016, reaching the sensitivity to the decay at the Standard Model BR. The experiment collected 10 times more statistics in 2017 and a similar amount of data is expected from the 2018 run.

The final result on $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ from the full 2016 data set and the expected improvement and background evaluation from the analysis on 2017 data will be presented.

A large sample of charged kaon decays into final states with multiple charged particles was also collected in 2016-2018. The sensitivity to a number of Lepton Flavour and Lepton Number violating K^+ decays provided by this data set is an order of magnitude beyond the current state of the art. Results of the search for these processes with a partial NA62 data sample are available for presentation.

Plenary Session / 274

Cosmological Signatures of New Light Particles/Dark Sector

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Dark Matter, Astroparticle Physics / 153

Primordial Black Holes and Dark Matter

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I will discuss a few questions connecting dark matter and primordial black holes: are they THE dark matter? If so, how can we tell? Did LIGO detect primordial black holes? Do light black holes stop evaporating around the Planck scale? If so, are they detectable? Did primordial black holes generate the dark matter and/or the baryon asymmetry?

Electroweak, Top and Higgs Physics / 136

Probing Higgs Sector New Physics in Vector Boson Longitudinal Mode

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Off-shell Higgs at the high mass tail may shed light on the underlying mechanism of the electroweak symmetry breaking. Due to the large cancellation in the standard model (SM) between the box and Higgs-mediated triangle diagrams, the $gg \rightarrow WW(ZZ)$ process in the SM is dominated by the VT VT transverse-mode at the high mass tail. The cancellation does not necessarily hold, when there is a sufficiently large new physics contribution resulting in VLVL longitudinal mode, which is commonly the case when the Higgs sector is modified. Thus the VLVL final states in the high mass tail can be utilized as a sensitive probe for such models. In the paper we focus on a study of the $gg \rightarrow ZZ$ process in the fully leptonic decay modes, proposing to utilize the polarization modes of the off-shell Higgs to probe new physics, whose contribution mainly shows in the longitudinal mode. As examples, we analyze three different Higgs sector new physics cases (Higgs portal with a light scalar, a broad-width scalar that mixes with the Higgs, and quantum critical Higgs models), and demonstrate that the angular information relating to the polarization serves as very sensitive probe for such new physics.

Plenary Session / 293

Extra Dimensions

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Plenary Session / 282

String GUT's

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Dark Matter, Astroparticle Physics / 184

The Global Argon Dark Matter Collaboration

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The LAr technology has strong potential to push the sensitivity for WIMP detection several orders of magnitude beyond current levels. The Global Argon Dark Matter Collaboration (GADMC) will pursue a sequence of future detectors to follow this potential. The immediate objective is the DarkSide-20k two-phase detector, currently under construction at LNGS. DarkSide-20k will have ultra-low backgrounds and sensitivity to WIMP-nucleon cross sections down to $1.2 \times 10^{-47} \text{ cm}^2$ for WIMPs

of $1 \text{ TeV}/c^2$ mass with a LAr exposure of 100 t yr. In parallel to DarkSide-20k there will be a detector of the order of 1 t in mass, DarkSide-LowMass, also installed at LNGS and specifically optimized for the observation of the electroluminescence signal below $10 \text{ GeV}/c^2$. This dedicated search will have excellent discovery capability, reaching the so-called neutrino floor in the low-mass search region. A subsequent objective will be the construction of the ARGO detector which will achieve a LAr exposure of 1000 t yr to push the sensitivity to the neutrino floor region for high mass WIMPs. The combination of the three experiments will cover the WIMP hypothesis down to the neutrino floor for masses from $1 \text{ GeV}/c^2$ to several hundreds of TeV/c^2 .

Neutrinos: Models, Phenomenology, Experiments / 95

Minimal radiative Dirac neutrino mass models

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Neutrinos may be Dirac particles whose masses arise radiatively at one-loop, naturally explaining their small values. In this work we show that all the one-loop realizations of the dimension-five operator to effectively generate Dirac neutrino masses can be implemented by using a single local symmetry: $(1)_{-}$. Since this symmetry is anomalous, new chiral fermions, charged under $-$, are required. The minimal model consistent with neutrino data includes three chiral fermions, two of them with the same lepton number. The next minimal models contain five chiral fermions and their $-$ charges can be fixed by requiring a dark matter candidate in the spectrum. We list the full particle content as well as the relevant Lagrangian terms for each of these models. They are new and simple models that can simultaneously accommodate Dirac neutrino masses (at one-loop) and dark matter without invoking any discrete symmetries.

Plenary Session / 277

Physics – LHCb and Belle2

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BSM in Flavor Physics / 193

Search for forbidden decays of the D^0 meson and observation of $D^0 \rightarrow K^- \pi^+ e^+ e^-$

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Decay modes with two oppositely charged leptons of different flavor correspond to lepton flavor violating (LFV) decays and are essentially forbidden in the Standard Model (SM) because they can occur only through lepton mixing. Decay modes with two leptons of the same charge are lepton-number violating (LNV) decays and are forbidden in the SM. Hence, decays of the form $D^0 \rightarrow hh' ll'$ provide sensitive tools to investigate new mediators or couplings in physics beyond the SM. In this talk, we report on a search for decays of the type $D^0 \rightarrow hh' ll'$ (with $h, h' = K/\pi$ and $l, l' = e/\mu$) using data taken by the BABAR experiment at the PEP-II e^+e^- collider at the SLAC National Accelerator Laboratory. Upper limits on the branching fractions are improved by up to two orders of magnitude.

We also report the observation of the flavor-changing neutral current (FCNC) decay $D^0 \rightarrow K^- \pi^+ e^- e^+$, which is strongly suppressed in the SM by the Glashow-Iliopoulos-Maiani (GIM) mechanism. We measure $\mathcal{B}(D^0 \rightarrow K^- \pi^+ e^- e^+) = (4.0 \pm 0.5) \times 10^{-6}$ in the di-lepton mass range $0.675 < m(e^+ e^-) < 0.875 \text{ GeV}/c^2$, where the production of the intermediate state $\rho \rightarrow e^+ e^-$ dominates, and set upper limits for decays outside this interval where long-distance effects are not expected to be significant.

Neutrinos: Models, Phenomenology, Experiments / 206

NEXT: Measuring $0\nu\beta\beta$ in High Pressure Xenon Gas Time Projection Chambers

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The NEXT collaboration is developing a sequence of high pressure xenon gas time projection chambers with the aim of creating a ton-scale, very low background neutrinoless double beta decay search. Finding evidence of neutrinoless double beta decay would give insight into the origins of the matter-antimatter asymmetry in the universe, the smallness of neutrino mass, and the symmetry structure of the Standard Model. This talk will present the status of the NEXT program, including results from the operating NEXT-White detector, construction of NEXT-100, and ongoing R&D efforts to tag the barium ion produced in the decay.

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Lepton flavor and lepton number violation prospects at Belle II

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The Belle II experiment is a substantial upgrade of the Belle detector and will operate at the SuperKEKB energy-asymmetric e^+e^- collider. The design luminosity of the machine is $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ and the Belle II experiment aims to record 50 ab^{-1} of data, a factor of 50 more than its predecessor. From February to July 2018, the machine has completed a commissioning run and main operation of SuperKEKB has started in March 2019. Belle II has a broad τ physics program, in particular in searches for lepton flavor and lepton number violations (LFV and LNV), benefiting from the large cross section of the pairwise τ lepton production in e^+e^- collisions. We expect that after 5 years of data taking, Belle II will be able to reduce the upper limits on LF and LN violating τ decays by an order of magnitude. Any experimental observation of LFV or LNV in τ decays constitutes an unambiguous sign of physics beyond the Standard Model, offering the opportunity to probe the underlying New Physics. In this talk we will review the τ lepton physics program of Belle II.

Plenary Session / 263

Ultra-High Energy neutrinos

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Supersymmetry: Models, Phenomenology and Experimental Results / 188**The PeV-Scale Split Supersymmetry from Higgs Mass and Electroweak Vacuum Stability****Author:** Joydeep Roy¹**Co-authors:** Tianjun Li²; Shabbar Raza³¹ *Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing*² *Chinese Academy of Sciences*³ *University of Delaware***Corresponding Author:** joyroy.phy@gmail.com

The null results of the LHC searches have put strong bounds on new physics scenario such as supersymmetry (SUSY). With the latest values of top quark mass and strong coupling, we study the upper bounds on the sfermion masses in Split SUSY from the observed Higgs boson mass and electroweak (EW) vacuum stability. To be consistent with the observed Higgs mass, we find that the largest value of supersymmetry breaking scales M_S for $\tan\beta = 2$ and $\tan\beta = 4$ are $\mathcal{O}(10^3 \text{ TeV})$ and $\mathcal{O}(10^{1.5} \text{ TeV})$, thus putting an upper bound on the sfermion masses around 10^3 TeV . In addition, the Higgs quartic coupling becomes negative at much lower scale than the Standard Model (SM), and we extract the upper bound of $\mathcal{O}(10^4 \text{ TeV})$ on the sfermion masses from EW vacuum stability. Therefore, we obtain the PeV-Scale Split SUSY. The key point is the extra contributions to the Renormalization Group Equation (RGE) running from the couplings among Higgs boson, Higgsinos, and gauginos. We briefly comment on the lifetime of gluinos in our study and compare it with current LHC observations. Additionally, we comment on the prospects of discovery of prompt gluinos in a 100 TeV proton-proton collider.

Unification of Forces / 134**Peccei-Quinn Symmetry and Nucleon Decay in Renormalizable SUSY $\mathbb{Z}_2(10)$** **Author:** shaikh saad¹¹ *oklahoma state university***Corresponding Author:** shaikh.saad@okstate.edu

Simple ways of implementing Peccei-Quinn (PQ) symmetry to solve the strong CP problem in renormalizable SUSYSO(10) models with a minimal Yukawa sector is suggested. Realistic fermion mass generation requires that a second pair of Higgs doublets survive down to the PQ-scale. How unification of gauge couplings can be achieved in this context is demonstrated. Higgsino mediated proton decay rate is strongly suppressed by a factor of $(M_{PQ}/M_{GUT})^2$, which enables all SUSY particles to have masses of order TeV. With TeV scale SUSY spectrum, $p \rightarrow \nu K^+$ decay rate is expected to be in the observable range. Lepton flavor violating processes $\mu \rightarrow e\gamma$ decay and $\mu - e$ conversion in nuclei, induced by the Dirac neutrino Yukawa couplings, are found to be within reach of forthcoming experiments.

Neutrinos: Models, Phenomenology, Experiments / 221**Dark Matter annihilation to neutrinos: New limits and future prospects****Authors:** Aaron Vincent¹; Ali Kheirandish^{None}; Andres Olivares²; Carlos Arguelles³; Ibrahim Safa⁴

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Since the confirmation of neutrino oscillations in the late 90s, it became apparent that the road to new physics is paved with neutrinos. On top of that, a plethora of evidence suggests the existence of a dark matter component that cannot be described without an extension to the Standard Model (SM). As a result, many proposed solutions that reconcile the SM with dark matter incorporate a new particle or introduce a dark sector that is connected to the SM via neutrinos. In this work, we provide new model-independent limits on dark matter annihilation into neutrinos based on measurements of neutrinos in a wide energy range. Thus, in this talk, I present the most up-to-date and comprehensive results on dark matter annihilation into neutrinos.

Poster Session / 7

LHC SUSY and WIMP dark matter searches confront the string theory landscape

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The string theory landscape of vacua solutions provides physicists with some understanding as to the magnitude of the cosmological constant. Similar reasoning can be applied to the magnitude of the soft SUSY breaking terms in supersymmetric models of particle physics: there appears to be a statistical draw towards large soft terms which is tempered by the anthropic requirement of the weak scale lying not too far from ~ 100 GeV. For a mild statistical draw of m_{soft}^n with $n=1$ (as expected from SUSY breaking due to a single F term) then the light Higgs mass is preferred at ~ 125 GeV while sparticles are all pulled beyond LHC bounds. We confront a variety of LHC and WIMP dark matter search limits with the statistical expectations from a fertile patch of string theory landscape. The end result is that LHC and WIMP dark matter detectors see exactly that which is expected from the string theory landscape: a Standard Model-like Higgs boson of mass 125 GeV but as yet no sign of sparticles or WIMP dark matter. SUSY from the $n=1$ landscape is most likely to emerge at LHC in the soft opposite-sign dilepton plus jet plus MET channel. Multi-ton noble liquid WIMP detectors should be able to completely explore the $n=1$ landscape parameter space.

Dark Matter, Astroparticle Physics / 191

Model-independent constraints on dark matter annihilation in dwarf spheroidal galaxies

Author: Pearl Sandick¹¹ *University of Utah***Corresponding Author:** sandick@physics.utah.edu

Dwarf spheroidal galaxies (dSphs) are exceptionally clean targets for searches for gamma rays from dark matter annihilation. Here, I will discuss a general, model-independent formalism for determining bounds on the production of photons from dark matter annihilation in dSphs. This formalism is applicable to any set of assumptions about dark matter particle physics or astrophysics. As an illustration, I'll present an analysis of gamma-ray data from the Fermi Large Area Telescope, which can be used to derive constraints on a variety of nonstandard dark matter models, several of which have not previously been studied in the context of dwarf galaxy searches. Finally, I'll provide an update on the release of a public code for calculating limits on dark matter annihilation in dSphs.

BSM in Flavor Physics / 185

CP Violation in Charm Decays

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We discuss the implications of the recent discovery of CP violation in charm decays at LHCb, and the question if it is physics beyond the Standard Model. Furthermore, we show in which modes to search for charm CP violation next and present U-spin sum rules for CP asymmetries of charmed baryon decays.

Plenary Session / 261

Neutrino Programs

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Plenary Session / 279

LHC Exotic - ATLAS & CMS

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Precision Calculations and MC tools / 27

Analysis description languages for LHC BSM searches

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An analysis description language (ADL) is a human readable declarative language that unambiguously describes the contents of an analysis in a standard way, independent of any computing framework. Adopting ADLs would bring numerous benefits for the LHC experimental and phenomeno-

logical communities, in particular for beyond the standard model physics analyses, ranging from analysis preservation beyond the lifetimes of experiments or analysis software to facilitating the abstraction, design, visualization, validation, combination, reproduction, interpretation and overall communication of the analysis contents. Several attempts were made recently to develop ADLs, and tools to use them, and an effort is underway to arrive at the core of a unified ADL. This talk will introduce the ADL concept, use cases for BSM searches and interpretation, and current status of development.

Supersymmetry: Models, Phenomenology and Experimental Results / 148

Search for compressed electroweak SUSY signatures - CMS + ATLAS Experiments

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Results from the CMS and ATLAS experiments are presented for searches for supersymmetric electroweak gauge bosons. Small mass splittings between electroweak states known as a compressed spectrum present unique experimental challenges. This talk describes the new techniques utilized by CMS and ATLAS to address such difficult scenarios. The searches use proton-proton collision data with luminosity up to 137 fb^{-1} at the center of mass energy of 13 TeV collected during the LHC Run 2.

Supersymmetry: Models, Phenomenology and Experimental Results / 126

Gravity safe, electroweak natural axionic solution to strong CP and SUSY μ problems

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Particle physics models with Peccei-Quinn (PQ) symmetry breaking as a consequence of supersymmetry (SUSY) breaking are attractive in that they solve the strong CP problem with a SUSY DFSZ-like axion, link the SUSY breaking and PQ breaking intermediate mass scales and can resolve the SUSY μ problem with a naturalness-required weak scale μ term whilst soft SUSY breaking terms inhabit the multi-TeV regime as required by LHC sparticle mass limits and the Higgs mass measurement. In spite of so many advantages these models have a major disadvantage in that global symmetries are incompatible with gravity and hence suffer a generic gravity spoliation problem. We present two models based on the discrete R-symmetry \mathbf{Z}_{24}^R -which may emerge from compactification of 10-d Lorentzian spacetime in string theory-where the μ term and dangerous proton decay and R-parity violating operators are either suppressed or forbidden while a gravity-safe PQ symmetry emerges as an accidental approximate global symmetry leading to a solution to the strong CP problem and a weak-scale/natural value for the μ term. Though there are many other solutions to the μ problem, the models based on discrete R-symmetry \mathbf{Z}_{24}^R seem highly motivated. A general consideration of string theory landscape imply a mild statistical draw towards large soft SUSY breaking terms. We can extend this reasoning to the models considered here in which PQ symmetry is broken by a large negative quartic soft term. The pull towards large soft terms also pulls the PQ scale as large as possible. However, this is tempered by the cosmological requirement to avoid overproduction of mixed axion-WIMP dark matter in the early universe. Such requirements lead to an upper bound

of $f_a \sim 10^{14}$ GeV with a most probable value of $f_a \sim 7 * 10^{11}$ GeV, which is well below the typical expectation that $f_a \sim 10^{16}$ GeV from string theory.

Plenary Session / 269

LR symmetry: from Majorana to LHC

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Neutrinos: Models, Phenomenology, Experiments / 247

Lepton Flavor Violation with Decoupled Sfermions

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We present experimental implications of lepton flavor-violating processes within a supersymmetric type-I seesaw framework in three-extra-parameter non-universal Higgs model (NUHM3) where right handed neutrinos act as the source of lepton flavor violation. Our numerical analysis includes full 2-loop renormalization group running effects for the three neutrino masses and mass matrices. We show discovery potentials of the prospected LFV process experiments (i.e. Mu2e, Mu3e, MEG-II), and specify regions that have already been excluded and will be probed by LHC and dark matter searches.

Alternatives to Supersymmetry / 135

Mirror Sectors and Mirror Stars

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Mirror sectors – hidden sectors that are approximate copies of the Standard Model – are a generic prediction of many models, notably the Mirror Twin Higgs model. Such models can have a rich cosmology and many interesting detection signatures beyond the realm of colliders. In this talk, I will focus on the possibility that mirror matter can form stars which undergo mirror nuclear fusion in their cores. I will discuss the mechanisms by which these objects can emit Standard Model light and estimate their luminosity and prospects for their detection.

Electroweak, Top and Higgs Physics / 243

THE Higgs and MORE Higgs: Making Sense Out of Chaos

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Many BSM models, including SUSY, include extra scalars. A particularly well motivated model is the NMSSM and its corresponding 2HDM+S Higgs sector. I will discuss the challenges and opportunities presented for LHC searches due to the presence of such an extended Higgs sector.

Supersymmetry: Models, Phenomenology and Experimental Results / 235

Gaugino Portal Baryogenesis

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We will discuss baryogenesis via a gaugino portal, the supersymmetric counterpart to the widely studied kinetic mixing portal, to a hidden sector. We will examine this mechanism within various scenarios, including freeze-in or freeze-out of the hidden sector gaugino, as well as extended frameworks where the hidden sector contains a weakly interacting massive particle (WIMP) dark matter candidate. This mechanism can produce the desired asymmetry over a wide range of mass scales, including for hidden gaugino masses as low as 10 GeV. We will also discuss possible related signals with direct collider searches, at low energy experiments, and in dark matter direct and indirect detection.

Supersymmetry: Models, Phenomenology and Experimental Results / 303

Heavy Higgs as a Portal to the Supersymmetric Electroweak Sector

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We discuss prospects of searching for decays of heavy Higgs bosons into electroweak superpartners at the high luminosity LHC. In addition to the kinematic handles offered by the presence of a resonant particle in the production chain, heavy Higgs decays can be the dominant production mode of these superpartners, making it possible to extend coverage to otherwise inaccessible regions of the supersymmetry and heavy Higgs parameter space. We illustrate our ideas with detailed collider analyses of two specific topologies: heavy Higgs decay to a pair of neutralinos, which can probe heavy Higgs bosons up to 1 TeV in the intermediate $\tan\beta$ ($\sim 2 - 8$) region, where standard heavy Higgs searches have no reach. Similarly, we show that targeted searches for heavy Higgs decays into staus can probe stau masses up to several hundred GeV.

Alternatives to Supersymmetry / 187

Consistent Constraints on SMEFT from Dileptons and Flavor

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I present constraints derived in a consistent and conservative way on the Wilson coefficients of the SMEFT from dilepton data at Tevatron and the LHC, and present the calculation of loop-level matching needed to utilize flavor data to constrain flavor-blind SMEFT effects. These are important new sources of constraint that will ultimately feed in to a global analysis of generic, model-independent heavy new physics based on the totality of data available in particle physics, a promising modern-day update to the LEP ElectroWeak Working Group efforts.

Cosmology and Gravitational Waves / 111

Electroweak Baryogenesis Driven by an Axion-like Particle

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An axion-like particle (ALP) offers a new direction in electroweak baryogenesis because the periodic nature enables it to trigger a strong first-order phase transition even if it is weakly coupled to the Higgs sector. This is essentially because the axion periodicity naturally allows the structure of phase transition to be insensitive to the axion decay constant that determines the strength of axion interactions. Furthermore, the axion can serve as a CP phase relevant to electroweak baryogenesis without causing any problem with respect to the recent measurement of an electron EDM. Depending on the scale of f , non-local or local generation of baryon asymmetry scenarios can be realized. In this talk, I will introduce the basic set-up of the axionic electroweak baryogenesis, and discuss allowed parameter ranges of the axion mass and the implications for future ALP studies.

Electroweak, Top and Higgs Physics / 176

Indirect Probe of Electroweak-Interacting Particles with Lepton Signatures at Hadron Colliders

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Electroweak-interacting massive particles (EWIMPs) exist in a broad class of new physics models beyond the Standard Model. The EWIMP generally affects the LHC signatures through quantum corrections even without direct productions. By measuring the Standard Model processes precisely, we can indirectly probe the EWIMPs. In this talk, we discuss the current constraint and future prospect of the EWIMPs by using the precision measurements of the Drell-Yan processes at hadron colliders.

Formal Field Theory and Strings / 177

Low Energy Trends from Zeroth Order Properties of the Landscape

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I will discuss certain long-standing features of the string landscape: the ubiquity of scalar and pseudoscalar fields, and the statistical bias towards a large SUSY breaking scale. In particular, scalars present the possibility of an early matter dominated era with important implications for dark matter, while the statistical draw towards large F-terms may be relevant for low-energy phenomenology. These features have become more relevant today given that neither the thermal WIMP nor superpartners have materialized so far.

Dark Matter, Astroparticle Physics / 178

ALPs: What can we learn from neutron stars and X-ray astronomy?

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Axion-like particles (ALPs) produced in the core of a neutron star can convert to photons in the magnetosphere, leading to possible signatures in the soft and hard X-ray emission from these sources. We study these signatures taking the magnetar SGR 1806-20 as an example. In particular, assuming ALP emission rates from the core that are just subdominant to neutrino emission, the parameter space of ALPs can be constrained by the requirement that the luminosity from ALP-to-photon conversion should not exceed the total observed luminosity from the magnetar. Up to astrophysical uncertainties pertaining to the core temperature, these constraints are competitive with constraints from helioscope experiments in the relevant part of ALP parameter space. Another class of signatures in this context are polarized X-rays, since ALPs only mix with the parallel component of the photon. These polarization signals may be observable by IXPE (in the 2-8 keV range) and X-Calibur (in the 15-60 keV range).

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Dark Matter – Indirect Detection

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Electroweak, Top and Higgs Physics / 123

EFT analysis of double Higgs production

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I will talk about a double Higgs production via gluon fusion in the Effective Field Theory (EFT) framework where effects from new physics are parametrized by local operators.

Supersymmetry: Models, Phenomenology and Experimental Results / 194

MSSM under the Higgs precision measurements

Authors: Huayang Song^{None}; Wei Su^{None}

Co-authors: Honglei Li ; Jinmin Yang ; Shufang Su ¹

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Studying the properties of Higgs boson becomes one important method to explore the physics beyond the Standard Model (SM). In this work, we present studies on the implications of the Higgs precision measurements at future Higgs Factories on the Minimal Supersymmetric Standard Model (MSSM). A multi-variable global fit to various Higgs search channels and also Higgs mass based on both the effective method and full one-loop hgg and $h\gamma\gamma$ results is performed to obtain the 95% C.L. constraints on the parameter space. The strong constraints on the CP-odd Higgs mass m_A and stop mass scale m_{SUSY} are complementary to the direct searches at the HL-LHC. The accurate measurements for the $h \rightarrow bb$ channel can also rule out most of parameter space at large $\tan\beta$.

Neutrinos: Models, Phenomenology, Experiments / 102

Accelerator-based Neutrino Experiments at Short Baselines

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The discovery of a light sterile neutrino would have profound implications for particle physics, astrophysics, and cosmology. A number of anomalous neutrino measurements at short distances may be indicative of the active neutrinos mixing to at least one sterile flavor. A worldwide program, involving reactor, source, and accelerator-based experiments is currently underway and searching for these possible new oscillations. This talk will provide an overview and status of this crucial experimental effort, with a focus on accelerator-based searches. The impactful non-oscillation physics and R&D associated with these experiments will also be covered.

Plenary Session / 256

LHC SUSY at ATLAS

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Supersymmetry: Models, Phenomenology and Experimental Results / 242

New techniques for use of public likelihoods for reinterpretation of search results

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With the lack of experimental evidence for weak-scale SUSY in simple scenarios, focus is shifting to strengthening exclusion limits on many models. One of the simplest mechanisms has been by the introduction of multi-bin fits in analyses. However, these pose a difficult problem for phenomenologists wanting to test their models: insufficient information is made available to fully evaluate the search strength in a different model, and when the information is made available, it is difficult to use and interpret, and comes in a format that cannot be easily read by a person. New software has been developed for the purpose of working with likelihoods, particularly for reinterpretation, entirely outside of the ROOT framework. This software includes a human-readable JSON format for the search likelihood, and can completely replace the traditional ROOT HistFactory implementation. It relies on modern software libraries, and can therefore run on GPUs as well as CPUs. In this talk, the tools for the use of this likelihood software towards reinterpretation will be discussed.

Plenary Session / 273

LHC Dark Matter at ATLAS & CMS

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Electroweak, Top and Higgs Physics / 75

BSM Higgs results from ATLAS

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Searches for Higgs bosons in different extensions of the Standard Model (SM) are presented. These include models with additional scalar singlets, doublets, or triplets, and generic searches for models with couplings modified with respect to the SM or for non-SM Higgs boson decay channels. Results are based on data collected by the ATLAS in 2015 and 2016 at the LHC.

Electroweak, Top and Higgs Physics / 110

Learning from Higgs Physics at Future Higgs Factories

Author: Shufang Su¹

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Future Higgs factories can reach impressive precision on Higgs property measurements. In this talk, we explore its sensitivity to new physics models at the electron-positron colliders. In particular, we focus on Type-I and Type-II Two Higgs Double Models as illustrative examples. We perform a global fit to various Higgs search channels to obtain the 95 C.L. constraints on the model parameter space. We also compare the sensitivity of various future Higgs factories, namely Circular Electron Positron Collider, Future Circular Collider-ee and International Linear Collider.

Supersymmetry: Models, Phenomenology and Experimental Results / 28

A Tale of Two Anomalies: from LHCb to ANITA

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We propose a simultaneous explanation of two recent anomalous observations at very different energy scales. The first one concerns hints of lepton flavor universality violation in rare B-meson decays, as observed by LHCb, and to some extent, by Belle and BaBar. The second anomaly is the observation made by the ANITA balloon experiment of two EeV upgoing air showers. Both these observations are challenging to explain within the Standard Model. We show that there exists a natural explanation for both the anomalies in the framework of R-parity violating supersymmetric extension of the Standard Model with TeV-scale squarks and a GeV-scale bino, which are consistent with all existing constraints from the LHC and low-energy experiments. This scenario could be fully tested in the near future and provides a complementary way to discover supersymmetry.

Plenary Session / 286

SUSY Collider

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Dark Matter, Astroparticle Physics / 168

Primordial black holes as SUSY dark matter

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Supersymmetry predicts a large number of scalar fields, some of which carry baryon and lepton numbers. I will discuss how fragmentation of scalar fields with an approximate U(1) symmetry into lumps is a general mechanism for primordial black hole formation. There are $O(100)$ of such scalar fields (flat directions) in MSSM, which can naturally result in primordial black holes.

Dark Matter, Astroparticle Physics / 215

Towards a New Window into Supernovae with Super-Kamiokande Gadolinium (SK-GD) Detector

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Super-Kamiokande is world's largest water Cherenkov experiment, with physics studies broadly ranging from probing theories of unification with proton decay to neutrino interactions and astrophysics. Upcoming near-future upgrade of the experiment with dissolution of gadolinium will open a new window into supernovae physics. In particular, potential first detection of supernovae relic

neutrinos (diffuse supernovae neutrino background) is within reach. Further, gadolinium will allow to reduce backgrounds for proton decay studies, increasing the discovery potential.

Supersymmetry: Models, Phenomenology and Experimental Results / 124

A Statistical Analysis of the MSSM in the context of Dark Matter and Muon $g-2$

Authors: John Tamanas¹; Stefano Profumo¹

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The MSSM provides a natural dark matter candidate and an explanation for the 3.5 sigma discrepancy between experimental measurements of the muon's anomalous magnetic moment and Standard Model predictions. By utilizing Monte Carlo Markov Chains, we reconstruct the probability distribution characterize phenomenologically-motivated and theoretically-sound MSSM configurations that satisfy limits set by direct detection searches, $g-2$, and dark matter relic density measurements. We also determine the utility of limits set by current and future LHC searches for electroweak-inos and for scalar leptons.

Dark Matter, Astroparticle Physics / 12

Dark Matter Bound State Formation in a Z_2 model with Light Dark Photon and Light Dark Higgs Boson

Authors: Yi-Lei Tang¹; pyungwon ko²; Toshinori Matsui^{None}

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In this talk, I will show how to calculate the bound state formation cross section in this model. Unlike the usual calculations, "mono-pole" emission becomes significant, and the process emitting the longitudinal dark photon/Goldstone boson becomes very important in the annihilation processes. I will also show the numerical results.

Supersymmetry: Models, Phenomenology and Experimental Results / 229

Is SUSY hiding from us?

Author: Xerxes Tata¹

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Experiments at the LHC have not yet seen any direct signs of superpartners. Many authors have suggested mechanisms that reduce the SUSY reach of the LHC from its canonical expectation. After a lightning review of these, I will

reexamine the fine-tuning arguments that led to these canonical expectations and argue that the non-appearance of superpartners may not be at odds with SUSY naturalness. I will conclude with an outlook for natural SUSY at the proposed luminosity and energy upgrades of the LHC.

Dark Matter, Astroparticle Physics / 151

The Search for Lightly Ionizing Particles Using the 90-day Run Data of the Large Underground Xenon Experiment

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The question of the nature of dark matter has become increasingly puzzling as more experiments exclude larger portions of the favored WIMP parameter space. Previous theoretical work has suggested the existence of Lightly Ionizing Particles (LIPs) with charge $e-f$, where e is the electron charge and $f < 1$. At least a part of the dark matter could consist of these LIPs. We seek to utilize data from the 90-day WIMP search of the Large Underground Xenon (LUX) experiment to search for LIPs in the charge range $f = 0.01$ to 0.3 . To accomplish the aforementioned search new methods of Geant4 based simulation and data processing have been implemented.

Dark Matter, Astroparticle Physics / 159

Dynamical Dark Matter at the Lifetime Frontier

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Dynamical Dark Matter (DDM) is an alternative framework for dark-matter physics in which the dark sector consists of large ensembles of dark states which exhibit a broad range of masses and lifetimes. While some of the states in this ensemble must be sufficiently long-lived that they contribute to the dark-matter abundance at present time, other states in the ensemble may have far shorter lifetimes. These latter states could give rise to observable signals at dedicated experiments such as the proposed MATHUSLA detector — a detector capable of resolving the decay signatures of long-lived particles (LLPs) with a broad range of masses and lifetimes. In this talk, I examine the discovery reach of the MATHUSLA detector within the parameter space of DDM scenarios and demonstrate that MATHUSLA may be capable of providing direct confirmation of certain unique aspects of the DDM framework which might be difficult to probe in other ways.

Plenary Session / 278

Dark Sector

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BSM in Flavor Physics / 26

Addressing Dark Matter and B-physics anomalies in the context of R-parity violating SUSY

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In recent years, significant experimental indications that point towards Lepton Flavor Universality violating effects in B-decays, involving $b \rightarrow c\tau\nu$ and $b \rightarrow s\ell^+\ell^-$ have been accumulated. A possible New Physics explanation can be sought within the framework of R-parity violating Supersymmetry, which contains the necessary ingredients to explain the anomalies via both leptoquark, tree-level exchange and one-loop diagrams involving purely leptonic interactions. In addition, an approximate $\mathcal{G}_f = U(2)_q \times U(2)_\ell$ flavour symmetry successfully controls the strength of these interactions. Nevertheless strong constraints from leptonic processes and Z boson decays exclude most of the relevant parameter space at 2σ level. Moreover, R-parity violation deprives Supersymmetry of its Dark Matter candidates. Motivated by these deficiencies, we introduce a new gauge singlet superfield, charged under the flavour symmetry and show that its third-generation, scalar component may alleviate the above-mentioned tensions, while at the same time reproduce the observed relic abundance. Remarkably, we obtain an exact solution to both anomalies that is also fully consistent with the numerous bounds from Flavour and Dark Matter phenomenology. Finally, we assess the prospect to probe the model at future experiments.

Supersymmetry: Models, Phenomenology and Experimental Results / 109

New Signatures of Electroweakino Sectors

Author: Douglas Tuckler¹

Co-author: Stefania Gori¹

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Electroweak sectors of beyond the Standard Model theories can contain several new degrees of freedom that are lighter than the 125 GeV Higgs boson, and hidden to present LHC searches. One example is the Next-to-Minimal Supersymmetric Standard Model (NMSSM) augmented with a Peccei-Quinn (PQ) symmetry. In this talk we highlight many new signatures arising from this model that can be looked for at the LHC. This includes new cascade decays of the neutralinos, as well as those of the 125 GeV Higgs boson. We also discuss the role of dark matter (DM) experiments in covering regions of parameter space for scenarios in which the lightest neutralino is a DM candidate.

BSM in Flavor Physics / 173

Flavorful Higgs bosons at the LHC

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LHC searches for extended Higgs sectors have so far focused on scenarios that conserve flavor i.e. the additional Higgs bosons couple to fermions in a flavor diagonal way and the signatures of the additional Higgs bosons dominantly involve third generation fermions. Much of the the focus of LHC searches have been on Type I and Type II two Higgs doublet models (2HDMs). However, there may exist models that break flavor conservation and lead to very different and distinct signatures that are missed if we only focus on flavor conserving models. In this talk I will present a particular 2HDM that breaks flavor conservation and features collider signatures that may dominantly involve second generation fermions rather than third generation fermions, as well as flavor violating signatures. Current LHC searches are insensitive to this kind of model, and I will present the novel collider signatures that can be expected. Along the way, we will see how this model can address the SM flavor puzzle, and explore the effects on low energy flavor processes.

Supersymmetry: Models, Phenomenology and Experimental Results / 146

Search for Supersymmetric gauge boson partners and sleptons - CMS Experiment

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Results from the CMS experiment are presented for searches for supersymmetric electroweak gauge bosons and for direct production searches for supersymmetric lepton partners. A variety of electroweak production channels are considered with results presented for different final state decays. The searches use proton-proton collision data with luminosity up to 137 fb⁻¹ recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Alternatives to Supersymmetry / 224

Beyond the standard model physics at the HL-LHC with CMS

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The High-Luminosity Large Hadron Collider (HL-LHC) is expected to deliver an integrated luminosity of up to 3000 fb⁻¹. The very high instantaneous luminosity will lead to about 200 proton-proton collisions per bunch crossing (“pileup”) superimposed to each event of interest, therefore providing extremely challenging experimental conditions. The sensitivity to find new physics Beyond the Standard Model (BSM) physics with the CMS detector is significantly improved and will allow to extend the reach for particles that are proposed as alternatives to SUSY.

Machine Learning, Big Data and Quantum Information / 207

End-to-end particle and event identification for regular and boosted topologies with CMS Open Data

Authors: John Alison¹; Sitong An²; Michael Andrews¹; Bjorn Burkle³; Sergei Gleyzer⁴; Ulrich Heintz³; Meenakshi Narain³; Manfred Paulini¹; Barnabas Poczós⁵; Emanuele Usai³

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From particle identification to the discovery of the Higgs boson, neural network algorithms have become an increasingly important tool for data analysis at the Large Hadron Collider. We present a novel approach to event and particle identification, called end-to-end deep learning, that combines deep learning image classification algorithms with low-level detector representation. Using two physics examples as references: quark and gluon discrimination and top quark jet tagging, we demonstrate the performance of the end-to-end approach using high-fidelity detector simulations from the CMS Open Data. Additionally, we explore the relevance of the information collected from various sub-detectors and describe how end-to-end techniques can be useful for full-event interpretation.

Cosmology and Gravitational Waves / 8

μ -hybrid inflation with low reheat temperature and observable gravity waves

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In μ -hybrid inflation a nonzero inflaton vacuum expectation value induced by supersymmetry breaking is proportional to the gravitino mass $m_{3/2}$, which can be exploited to resolve the minimal supersymmetric standard model μ problem. We show how this scenario can be successfully implemented with $m_{3/2} \sim 1 - 100$ TeV and reheat temperature as low as 10^6 GeV by employing a minimal renormalizable superpotential coupled with a well defined nonminimal Kähler potential. The tensor-to-scalar ratio r , a canonical measure of primordial gravity waves in most cases is less than or of the order of $10^{-6} - 10^{-3}$.

Alternatives to Supersymmetry / 161

Detecting Magnetic Dark Matter

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The evidence for dark matter is overwhelming, but its nature is unknown. Dark matter can be composed of the magnetic monopoles of a hidden sector, which acquire small coupling to the visible photon through kinetic mixing. When the hidden sector U(1) is broken, the monopoles confine, connected by a tube of magnetic flux. These flux tubes give rise to phase shifts in Aharonov-Bohm

experiments. I show the existing experimental constraints on this scenario, and explain how to search for dark matter with Aharonov-Bohm type detectors.

Dark Matter, Astroparticle Physics / 163

Vector Portals to the Twin Sector

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The twin Higgs scenario protects the Higgs mass from large quantum corrections through symmetry partners without standard model (SM) color charge. The particles belong to a “twin” sector, related to the SM by a discrete exchange symmetry. The gauge symmetries in each sector forbid all but a few renormalizable connections between the sectors. Vectors portals, either through twin particles or singletons (which have no twin under the discrete symmetry), allow the twin sector to be probed at colliders. They can also be leveraged to confirm that newly discovered states belong to a twin Higgs construction.

Supersymmetry: Models, Phenomenology and Experimental Results / 214

The Unified No-Scale Inflation

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One of the outstanding problems in theoretical physics is the cosmological constant problem. In the context of supersymmetry, the origin of supersymmetry breaking remains a mystery. We present a self-contained no-scale supergravity model which incorporates the Starobinsky-like inflation, an adjustable supersymmetry breaking scale $\mathcal{O}(10^3)$ GeV, and a small positive cosmological constant (dark energy density) at a scale $\mathcal{O}(10^{-120})$. The mechanism also avoids the problem of AdS vacua, which are often found in supergravity models and are corrected a posteriori. This provides a framework which can be combined with various inflationary potentials, including the α -attractors.

Alternatives to Supersymmetry / 305

Reducing the Quadratic Divergence in the Higgs Mass Squared Without Top Partners

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Precision Calculations and MC tools / 304**Cutting with AEACuS and Plotting with RHADAManTHUS****Author:** Joel Walker¹¹ *Sam Houston State University***Corresponding Author:** jwalker@shsu.edu

AEACuS is a software package for the computation of collider event statistics and the application of event selection cuts. It interfaces with the LHCO format output of the popular detector simulation packages Delphes. A compact and powerful card file syntax unambiguously separates reusable user instructions from the code library. Support for most event discriminants employed by ATLAS and CMS is built in, and users may easily define custom variables as well as multivariate channel sorts.

RHADAManTHUS is a software package for the plotting and optimization of collider event statistics. Any function of variables computed by AEACuS may be used as a one- or two-dimensional histogram key or for secondary event selection. Histogram channels may be arbitrarily merged or transformed bin-by-bin, for example in visualization of signal-to-background significance versus cut threshold. Cross-section weighting and recombination of distinct or multiply sampled data sets is handled transparently. A simple card file control syntax facilitates automation and reuse.

Poster Session / 42**Measurement of ttH production in multileptonic final states****Author:** Andreas Warburton¹¹ *McGill University, (CA)***Corresponding Author:** andreas.warburton@cern.ch

Associated production of top anti-top quark pairs along with a Higgs boson is an important Standard Model process. The top-Yukawa coupling can be directly measured from this process. Being the heaviest of the Standard Model particles, the coupling of top quark to the Higgs field is expected to be large. Any significant deviation in the rate of this process from the Standard Model expectation is a sign for New Physics. We report the latest measurement of this process where the top, anti-top and Higgs bosons decay into a multileptonic final state.

Electroweak, Top and Higgs Physics / 55**Measurements of multiboson production at the LHC: (Includes dibosons, tribosons and light-by-light scattering in Pb-Pb collisions)****Author:** Andreas Warburton¹¹ *McGill University, (CA)***Corresponding Author:** andreas.warburton@cern.ch

The production of multiple electroweak bosons at the LHC constitutes a stringent test of the electroweak sector and provide a model-independent means to search for new physics at the TeV scale.

Constraining the multiboson production through direct measurements also allows to constraint such backgrounds in SUSY searches.

Poster Session / 115

Sensitivity study for the $\mu^+ \rightarrow e^+e^+e^-$ search with the mu3e experiment and work to prepare for Mupix pixel tracker module in Liverpool module

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Co-author: Joost Vossebeld

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The Mu3e experiment will search for the neutrinoless (lepton flavour violating) decay of an anti-muon to two positrons and an electron $\mu^+ \rightarrow e^+e^+e^-$, with a sensitivity to a branching ratio smaller than 10^{-15} (phase I) and 10^{-15} (phase II). To achieve the proposed sensitivity, the mu3e experiment requires excellent vertex resolution, accurate timing, and momentum measurements. These are needed to reduce the main background processes: Michel decays with an internal conversion, and combinatorial backgrounds. The proposed poster will present an overview of the mu3e experiment. A study of the projected sensitivity of the experiment is presented as well as work preparing for quality assurance measurement that will take place as part of the assembly work on the Mupix-HV-MAPS pixel tracker in Liverpool.

Machine Learning, Big Data and Quantum Information / 128

Quantum Entanglement and Proton-Proton Collisions at the LHC

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The proposed link between quantum entanglement and the apparent thermalization in particle production at the Large Hadron Collider (Rev. D 98, 054007 (2018)) will be presented. The large amount of collected data at 13 TeV center of mass energy in proton-proton collisions has enabled this initial systematic study of the relationship between Quantum Information Science and particle production at the energy frontier, and confirms the expected behavior in all cases that were analyzed. Implications for future studies will also be discussed.

Neutrinos: Models, Phenomenology, Experiments / 121

Low scale seesaw models and collider phenomenology

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Heavy neutral leptons are part of many extensions of the Standard Model, in particular seesaw models that can explain the light neutrino masses and mixing. Many search strategy have been proposed, either via the direct production of the new heavy neutral leptons or via their indirect effects in processes like lepton flavour violation. We will discuss a direct search strategy at hadron colliders based on dynamical jet vetoes and its application to the trilepton + missing transverse energy final state. We will also discuss an indirect search strategy based on the modifications of the production cross-sections of W or Higgs bosons at linear collider. These searches are complementary to other observables and would allow to probe the multi-TeV mass regime at future colliders.

Plenary Session / 257

LHC SUSY at CMS

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BSM in Flavor Physics / 155

bsll Transitions in Two-Higgs-Doublet Models

Authors: Andreas Crivellin¹; Dario Müller¹; Christoph Wiegand²

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We studied $b \rightarrow s\mu^+\mu^-$ transitions and possible correlations with the anomalous magnetic moment of the muon (a_μ) within two-Higgs-doublet models with generic Yukawa couplings, including the possibility of right-handed neutrinos. We performed the matching on the relevant effective Hamiltonian and calculated the leading one-loop effects for $b \rightarrow s\ell\ell^{(\prime)}$, $b \rightarrow s\gamma$, $\Delta B = \Delta S = 2$, $b \rightarrow s\nu\bar{\nu}$ and $\ell \rightarrow \ell'\gamma$ transitions in a general R_ξ gauge. Concerning the phenomenology, we find that an explanation of the hints for new physics in $b \rightarrow s\mu^+\mu^-$ data is possible once right-handed neutrinos are included. If lepton flavour violating couplings are allowed, one can account for the discrepancy in a_μ as well. However, only a small portion of parameter space gives a good fit to $b \rightarrow s\mu^+\mu^-$ data and the current bound on $h \rightarrow \tau\mu$ requires the mixing between the neutral Higgs bosons to be very small if one aims at an explanation of a_μ .

Dark Matter, Astroparticle Physics / 183

Enhanced multi-body annihilation of dark matter

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Most indirect dark matter searches consider only signals from decay or two-body annihilation. I will discuss the general scenario where more than two dark matter particles participate in the annihilation process. Such processes can be greatly enhanced at low velocities, and generically have

different redshift dependence than standard decay/annihilation signals. I will describe and examine the cosmological and astrophysical constraints on such multi-body annihilation processes.

BSM in Flavor Physics / 22

Correlation between $R_{D^{(*)}}$ and top quark FCNC decays in leptoquark models

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Some interpretations of $R_{D^{(*)}}$ anomaly in B meson decay using leptoquark models can also generate top quark decays through flavor changing neutral current (FCNC). In this work we focus on two leptoquarks, i.e. scalar S_1 and vector U_1 which are both singlet under the $SU(2)_L$ gauge group in the Standard Model (SM). We investigate their implications on top FCNC decays $t \rightarrow c\ell_i\ell_j$ at tree level and $t \rightarrow cV$ at 1-loop level, with ℓ being the SM leptons and $V = \gamma, Z, g$ being the SM gauge bosons. We utilize the 2σ parameter fit ranges from existing literatures and find that the branching ratios $Br(t \rightarrow c\ell_i\ell_j)$ at tree level can reach $10^{-6} \sim 10^{-5}$ and 1-loop process $Br(t \rightarrow cg)$ can reach $10^{-9} \sim 10^{-8}$. Some quick collider search prospects are also analyzed.

Supersymmetry: Models, Phenomenology and Experimental Results / 144

3rd generation squark production - CMS Experiment

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Results from the CMS experiment are presented for searches for supersymmetric stop and sbottom production. A variety of final state decays are considered with an emphasis on targeting difficult to reach kinematic regions. The searches use proton-proton collision data with luminosity up to 137 fb⁻¹ recorded by the CMS detector at center of mass energy 13 TeV during the LHC Run 2.

Supersymmetry: Models, Phenomenology and Experimental Results / 18

Light Exotic Higgs Bosons in the Supersymmetric Georgi-Machacek Model

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We show that the well known Georgi-Machacek (GM) model can be realized as a limit of the recently constructed Supersymmetric Custodial Higgs Triplet Model (SCTM) which in general contains a significantly more complex scalar spectrum. We dub this limit as the Supersymmetric GM (SGM) model, which gives a weakly coupled origin for the GM model at the electroweak scale. We derive a mapping between the SGM and GM models using it to show how a supersymmetric origin implies constraints on the Higgs potential in conventional GM model constructions which would generically not be present. We point it out under what circumstance, the SGM can mimic the GM model, and when they can be distinguished. Then we perform the phenomenological study of the collider searches, such as the di-Boson signals (diphoton, WW, ZZ) and the global collider constraints. We also consider the possibility of the Lightest Supersymmetric Particles (LSP) in the SGM model as a Dark Matter candidate and explore the relic density and direct detection constraints.

Unification of Forces / 79

Unification of the Standard Model and Self-Interacting Dark Matter in $[SU(5) \times U(1)]^4$ GUT

Authors: Ayuki Kamada¹; Masaki Yamada²; Tsutomu Yanagida³

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A spontaneously broken hidden $U(1)_h$ gauge symmetry can explain both the dark matter stability and the observed relic abundance. In this framework, the light gauge boson can mediate the strong dark matter self-interaction, which addresses astrophysical observations that are hard to explain in collisionless cold dark matter. Motivated by flavoured grand unified theories, we introduce right-handed neutrinos and a flavoured $B-L$ gauge symmetry for the third family $U(1)_{B-L}$. The unwanted relic of the $U(1)_h$ gauge boson decays into neutrinos via the kinetic mixing with the $U(1)_{(B-L)_3}$ gauge boson. This model can also explain the lepton flavour universality violation in semi-leptonic B meson decays that is recently found in the LHCb experiment. We found that the dark sector is naturally obtained when there is a strong $SU(5)$ gauge interaction, $U(1)$ gauge interaction, and fermions with appropriate representations at a UV scale. This implies that the whole sector can be unified by a $[SU(5) \times U(1)]^4$ gauge theory. The first three sets of gauge groups are spontaneously broken to the SM gauge groups while the last one becomes strong at an intermediate scale and gives a self-interacting dark matter at a low energy scale.

Machine Learning, Big Data and Quantum Information / 73

Boosted Jets; identifying highly boosted W, Z, top, Higgs and more

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As we probe higher energy scales of potential new physics the boost of Standard Model particles can be extremely high. When these decay hadronically their decay products are boosted and therefore collimated such that they can be reconstructed a single large-radius jets with distinctive internal structure. The process of calibrating these jets will be described. Additionally innovative techniques,

including the use of machine learning, have been developed to identify such objects. These will be described as well as how their performance is evaluated in data. How these techniques are then used in searches for Supersymmetry and other new physics models will also be demonstrated.

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Recent top quark properties

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Measurements of top quark properties using data collected by the ATLAS and CMS experiment at 13 TeV are presented. Among them, latest results on top mass, $t\bar{t}$ spin correlations and charge asymmetries will be discussed.

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Non-Standard Cosmology

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Plenary Session / 297

Gravitational Waves

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Plenary Session / 259

Low Mass Dark Matter

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Direct Dark Matter Detection

Neutrinos: Models, Phenomenology, Experiments / 300

TBD