Dark Matter @ LHC 2019 (DM@LHC)

Tuesday, 13 August 2019 - Friday, 16 August 2019

Kane Hall 225

Book of Abstracts

Contents

[YSF] Search for dark matter, dark energy and other new phenomena in events with an energetic jet and large missing transverse momentum using the Run-2 data from the ATLAS detector 2 1

Low mass dijet resonances search using ISR with ˜80fb-1 sqrt(s)=13TeV ATLAS Data 5 . . 1

Search for long-lived particles decaying into displaced hadronic jets in the ATLAS Calorimeter 6 1

[YSF] Search for dark matter in third generation quarks in ATLAS 7 2

Search for dark matter in events with missing transverse momentum and a Z boson with the ATLAS detector 8 2

Dark matter mediators in the dilepton final state at ATLAS 9 2

Probing dark sectors with enhanced long-lived particles at the LHC 10 3

Search for BNV and LNV at BESIII 11 3

Dark Matter and Dark Sector with the SHiP experiment at CERN 12 3

[YSF] Search for low-mass resonances decaying into two jets and produced in association with a photon with ATLAS 13 4

Search for New Phenomena in Dijet Events using 139 fb−1 of p p collisions at √ s = 13 TeV collected with the ATLAS Detector 14 4

[YSF] Constraints on $U(1)_{l_\mu - l_\tau}$ from LHC Data 15 5

Dark Neutrino interactions phase out Hubble tension (.. also make Gravitational Waves Blue) 16 5

Improved constraints on a t-channel simplified model of Majorana Dark matter 18 5

[YSF] The unexplored landscape of two-body resonances 19 6

New long-lived particle searches at the LHC with FASER: the ForwArd Search ExpeRiment 20 6

Searching DDM through gamma radiation 21 7

RECAST for Mono-S(bb) with ATLAS 22 7

Searches for invisible Higgs decays with the ATLAS detector 23 7

[YSF] Searching for Dark Matter with Semi-Visible Jets at CMS 24 . . . 8

[YSF] Freeze-in and Freeze-out of Dark Matter with Charged Long-lived Partners 25 . . . 8

Search for dark matter produced in association with a Higgs boson decaying to a pair of bottom quarks in proton-proton collisions at sqrt(s) = 13 TeV with the CMS detector 26 9

[YSF] Cosmology and LHC phenomenology of simplified SIMP models 27 . . . 9

[YSF] Search for dark matter produced in association with a Z boson decaying to pair of leptons at CMS 29 . . . 9

[YSF] Search for inelastic dark matter with the CMS detector 30 . . . 10

Cancel: [YSF] Electroweak Symmetric Dark Matter Balls 31 . . . 10

Understanding backgrounds of ultra long-lived particle searches with the MATHUSLA test stand 32 . . . 11

Search for supersymmetry with a compressed mass spectrum in the vector boson fusion topology with 1-lepton and 0-lepton final states 33 . . . 11

[YSF] Search for the compressed SUSY in stau-neutralino coannihilation region with a soft tau lepton and ISR jets 34 . . . 12

Exploring light Supersymmetry with GAMBIT 35 . . . 12

One-loop contributions to dark matter-nucleon scattering in scalar and vector DM models 36 . . . 12

Introduction 38 . . . 13

Theory Overview of Dark Matter Search at the LHC 39 . . . 13

Experiment overview of Dark Matter search at the LHC 40 . . . 13

LHC DM Working group report 41 . . . 13

Detector upgrade at Run3 and HL-LHC 42 . . . 13

ETmiss + Standard Model particles 43 . . . 13

Dark Matter and Flavor at the LHC 44 . . . 14

Toward Run3: uncovered signatures (TBC) 45 . . . 14

WIMP search summary 46 . . . 14

Axion search summary 47 . . . 14

Interplay between Direct Detection and Collider searches 48 . . . 14

Indirect search: Gamma ray 49 . . . 14

Indirect search: neutrino 50 . . . 15

Interplay between Indirect Search and collider search 51 . . . 15

DM theory in Higgs and SUSY sector 52 15
Invisible Higgs search at the LHC 53 15
Dark Matter SUSY search at the LHC (prompt signatures) 54 15
Dark Matter mediator search: dijet signature 55 15
Dark Matter interpretation with global fitting 56 15
State-of-the-art calculations of the dark matter abundance 57 16
Monte Carlo tools: successes and failures 58 16
Machine Learning in particle theory 59 16
Machine Learning in particle experiments 60 16
Direct LLP searches at the LHC 61 16
Indirect LLP searches at the LHC 62 16
New experiment proposals 63 16
Dark Sectors at Direct Detection Experiments 64 17
Dark Photon at the LHC 65 17
Dark Sector search at the LHCb 66 17
Dark Sector search at Belle II and BaBar 67 17
Gravitational Wave, Multimessenger Physics and DM 68 17
Dark Blobs, Nuggets and Quark Nuggets – Exponentially Large Composite Dark Matter 69 17
Dark Matter search at the HL-LHC 70 17
Dark Matter search at future lepton colliders 71 18
Dark Matter search at future hadron colliders 72 18
Experiment summary 73 18
Theory summary 74 18
Dark Photon Search in LIGO 75 18
The warped dark sector 76 18
Collider signatures of minimal freeze-in models 77 19
Ann Nelson: Brilliant Physicist and Advocate of Diversity 79 19
SUSY with a light Dirac bino: B meson baryogenesis & sneutrino asymmetric DM 80 . . 19

Collider Search I / 2

[YSF] Search for dark matter, dark energy and other new phenomena in events with an energetic jet and large missing transverse momentum using the Run-2 data from the ATLAS detector

Author: Jack Lindon[1]

[1] *University of Birmingham (GB)*

Corresponding Author: jack.henry.lindon@cern.ch

This talk will report the results of a search for new phenomena in final states with at least one energetic jet and large missing transverse momentum. The search uses 80 fb^{-1} of pp collision data at $\sqrt{S} = 13$ TeV collected in Run-2 with the ATLAS detector at the Large Hadron Collider. Results are interpreted in the context of Dark Matter, Dark Energy, Supersymmetry, Higgs invisible and Large Extra-Dimensions models.

Poster pitch / 5

Low mass dijet resonances search using ISR with ˜80fb-1 sqrt(s)=13TeV ATLAS Data

Author: ATLAS Collaboration[None]

Corresponding Author: ying.wun.yvonne.ng@cern.ch

One of the ways to look for evidence of dark matter (DM) at a collider experiment is through s-channel processes where a DM mediator decays to two quarks. At ATLAS, analyses looking for di-jet resonances are limited to mediator masses above a TeV, due to the high transverse momentum (pT) requirements of jet triggers. However, sub-TeV mass regions can be explored if the resonance is produced with a large relativistic boost provided by an initial state radiation jet. B-tagging the final state can further reduce backgrounds for mediators with democratic decays to all quarks; this final state also allows access to Higgs boson production through gluon-gluon fusion, which at high Higgs pT can be increased to up to 50% by the presence of BSM couplings. This talk will give an overview of the strategy and first results of this kind of study at ATLAS, both for a scalar DM mediator and Higgs interpretations.

Poster pitch / 6

Search for long-lived particles decaying into displaced hadronic jets in the ATLAS Calorimeter

Author: ATLAS Collaboration[None]

Corresponding Author: felix.cormier@cern.ch

Based on a benchmark Hidden Sector model, this analysis explores the possibility of new physics being present at the LHC through long-lived particles. Given that the lifetime of these particles is mostly unconstrained, this raises the possibility of these particles decaying before they leave ATLAS detector. The specific scenario of two of these long-lived particles decaying to standard model particles in the ATLAS calorimeters is considered, leading to non-standard analysis methods being used to reconstruct this signature. This talk will describe the work that goes into designing complex signature-driven techniques and machine learning algorithms to take advantage of this promising

signature, and a search for these long-lived particles at $\sqrt{s}$ = 13 TeV, using either 10.8 fb^{-1} or 33.0 fb^{-1} of data depending on trigger, at the ATLAS experiment will be discussed.

Collider Search I / **7**

[YSF] Search for dark matter in third generation quarks in ATLAS

Author: ATLAS Collaboration[None]

Corresponding Author: matthew.thomas.anthony@cern.ch

Discovering dark matter particles and understanding their connection to the Standard Model is one of the greatest quests in particle physics and cosmology today and the Large Hadron Collider (LHC) offers a large range of important search channels. The first searches for weakly interacting massive particle dark matter produced in association with top quarks based on the complete dataset at 13 TeV collected by the ATLAS Collaboration are presented. In models with enhanced couplings to third generation quarks or heavy fermions, this production mechanism is the dominant mode at the LHC. A particular focus is given to target signals with a moderate missing transverse energy signature.

Poster pitch / **8**

Search for dark matter in events with missing transverse momentum and a Z boson with the ATLAS detector

Author: ATLAS Collaboration[None]

Corresponding Author: kaylamc@uvic.ca

Abstract: Dark matter models predict the production of weakly interacting massive particles (WIMPs) in proton-proton collisions. Many of these theories are tested at the LHC using the ATLAS detector, in which events are characterised by large missing transverse momentum carried by a dark matter particle-antiparticle pair. These models predict that the dark matter pair may be produced via a new dark matter mediator particle or though an invisible decay of the Higgs boson. This search focuses on events where the hypothesized particles recoil against a Z boson decaying to e+e- or mu+mu-. In this talk an overview of the search will be presented, including the signal models studied, the estimation techniques used to measure Standard Model backgrounds, and the procedure used to set limits on the dark matter particles. Results will be presented using the 2015+2016 dataset of 36.1 fb-1 at 13 TeV centre-of-mass energy.

Poster pitch / **9**

Dark matter mediators in the dilepton final state at ATLAS

Author: ATLAS Collaboration[None]

Corresponding Author: etienne.dreyer@cern.ch

The LHC offers the best prospects for direct production of WIMP Dark Matter (DM) and gauge bosons arising from a dark sector beyond the Standard Model (SM). In particular, a neutral Z'{DM} boson mediating DM-SM interactions is a prime target for resonance searches, and its couplings can thereby be constrained within the broad context of mediator-based simplified DM models. In this poster I introduce the Z'{DM} phenomenology in the dilepton final state and present the latest

bounds on the relevant simplified models imposed by searches for high mass dilepton resonances with the ATLAS detector.

Long-lived particles / **10**

Probing dark sectors with enhanced long-lived particles at the LHC

Author: Zhen Liu[1]

[1] *U of Maryland*

Corresponding Author: zliuphys@umd.edu

Long-lived particles provide a unique probe for dark sectors. The searches for such signatures are challenging at the LHC. In comparison with the light Standard Model particles, the decay products of massive LLPs arrive at detectors with time delay around the nanosecond scale. We propose new strategies to take advantage of this time delay by using initial state radiation jets to timestamp the collision event and subsequently require at least one LLP to decay within the detector volume. This search strategy can be effective for a broad range of models.

Flavor & Dark sector / **11**

Search for BNV and LNV at BESIII

Author: Huijing Li[1]

[1] *Fundan University*

Corresponding Authors: ke.li@cern.ch, lihuijing@ihep.ac.cn

The observed matter-antimatter asymmetry in universe poses a serious challenge to our understanding of nature. BNV decay has been used in experiments to study this large scale fact. BESIII searches for BNV and LNV processes with the world largest J/psi data sets directly produced in e+e- collision. The BNV/LNV channel J/psi -> Lambda_c+ e- +c.c. is analyzed, no signal event is observed. The upper limit for the branching fraction is set to be 6.9*10ˆ-8 at 90% C.L., which is still much larger than the SM estimation. The Majorana neutrino is searched in LNV decays D-> (K-pi-/Kspi-/K-pi0) e+e+, no significant signal is observed, the upper limits of the branching fractions are set to be 2.7*10ˆ-6, 3.3*10ˆ-6 and 8.5*10ˆ-6 at 90% C.L., respectively. The Majorana neutrino is also looked for with different mass assumption, ranging from 0.25 to 1.0 GeV/c2, in the decays D0 -> K-e+nu_N(pi-e+) and D+->Kse+nu_N(pi-e+), and the upper limits of the branching fractions are extracted to be at the level of 10ˆ-7 to 10ˆ-6 at 90% C.L..

Poster pitch / **12**

Dark Matter and Dark Sector with the SHiP experiment at CERN

Author: Lesya Shchutska[1]

[1] *EPFL - Ecole Polytechnique Federale Lausanne (CH)*

Corresponding Authors: federico.redi@cern.ch, lesya.shchutska@cern.ch

The SHiP Collaboration has proposed a general-purpose experimental facility operating in beam dump mode at the CERN SPS accelerator with the aim of searching for light, long-lived exotic particles of Hidden Sector models. The SHiP experiment incorporates a muon shield based on magnetic sweeping and two complementary apparatuses. The detector immediately downstream of the muon shield is optimised both for recoil signatures of light dark matter scattering and for tau neutrino physics, and consists of a spectrometer magnet housing a layered detector system with heavy target plates, emulsion film technology and electronic high precision tracking. The second detector system aims at measuring the visible decays of hidden sector particles to both fully reconstructible final states and to partially reconstructible final states with neutrinos, in a nearly background free environment. The detector consists of a 50 m long decay volume under vacuum followed by a spectrometer and particle identification with a rectangular acceptance of 5 m in width and 10 m in height. Using the high-intensity beam of 400 GeV protons, the experiment is capable of integrating 2×10^{20} protons in five years, which allows probing dark photons, dark scalars and pseudo-scalars, and heavy neutrinos with GeV-scale masses at sensitivities that exceed those of existing and projected experiments. The sensitivity to heavy neutrinos will allow for the first time to probe, in the mass range between the kaon and the charm meson mass, a coupling range for which baryogenesis and active neutrino masses can be explained. The sensitivity to light dark matter reaches well below the elastic scalar Dark Matter relic density limits in the range from a few MeV/c^2 up to 200 MeV/c^2. Following the review of the Technical Proposal, the CERN SPS Committee recommended in 2016 that the experiment and the beam dump facility studies proceed to a Comprehensive Design Study phase. These studies have resulted in a mature proposal submitted to the European Strategy for Particle Physics Update.

Collider Search II: mediators / **13**

[YSF] Search for low-mass resonances decaying into two jets and produced in association with a photon with ATLAS

Author: ATLAS Collaboration[None]

Corresponding Author: gang.z@cern.ch

Many models predict new particles with sizeable couplings to quarks and gluons. A search is performed for localised excesses in dijet mass distributions of low-dijet-mass events produced in association with a high transverse energy photon. The search uses up to 79.8 fb-1 of LHC proton–proton collisions collected by the ATLAS experiment at a centre-of-mass energy of 13 TeV during 2015–2017. Two variants are presented: one which makes no jet flavour requirements and one which requires both jets to be tagged as b-jets. The observed mass distributions are consistent with multi-jet processes in the Standard Model. The data are used to set upper limits on the production cross-section for a benchmark Z'model and, separately, on generic Gaussian-shape contributions to the mass distributions, extending the current ATLAS constraints on dijet resonances to the mass range between 225 and 1100 GeV.

Poster pitch / **14**

Search for New Phenomena in Dijet Events using 139 fb−1 of p p collisions at √ s = 13 TeV collected with the ATLAS Detector

Author: ATLAS Collaboration[None]

Corresponding Author: trine.poulsen@cern.ch

A search for new resonances decaying into two hadronic jets is reported using the entire dataset of proton-proton collisions recorded at sqrt(s) = 13 TeV with the ATLAS detector at the Large Hadron Collider between 2015 and 2018, corresponding to an integrated luminosity of 139 fb−1. The dijet invariant mass distribution is compared to a smoothly-falling background prediction obtained by

fitting the data. No significant excess is observed. Excited quarks with masses below 6.7 TeV are excluded at the 95% confidence level. Model-independent limits on Gaussian-shaped signals of various widths in dijet mass distribution are also set.

From Models to Signatures / **15**

[YSF] Constraints on $U(1)_{l_\mu - l_\tau}$ from LHC Data

Author: Zhongyi Zhang[1]

[1] *Bonn University*

Corresponding Author: gohit.yu@gmail.com

In this study, we apply LHC data to constrain the extension of the Standard Model by an anomaly-free $U(1)_{l_\mu - l_\tau}$ gauge group; this model contains a new gauge boson (Z) and a scalar dark matter particle (ϕ_{DM}). We recast a large number of LHC analyses from ATLAS and CMS of multi-lepton final states. We find that for 10 GeV < m_Z < 60 GeV the strongest constraint comes from a dedicated Z search in the 4μ final state by the CMS collaboration; for larger Z masses, searches for final states with three leptons plus missing E_T are more sensitive. Searches for final states with two leptons and missing E_T, which are sensitive to Z decays into dark matter particles, can only probe regions of parameter space that are excluded by searches in the 3 and 4 lepton channels. The combination of LHC data excludes values of Z mass and coupling constant that can explain the deficit in $g_\mu - 2$ for 4 GeV < m_Z < 500 GeV. However, for much of this range the LHC bound is weaker than the bound that can be derived from searches for trident events in neutrino-nucleus scattering. Therefore, we are trying some optimizations for the event selection based on Machine Learning algorithms, especially XGBoost.

Innovative Ideas / **16**

Dark Neutrino interactions phase out Hubble tension (.. also make Gravitational Waves Blue)

Authors: Subhajit Ghosh[1]; Tuhin S. Roy[2]; Rishi Khatri[2]

[1] *Tata Institute of Fundamental Research (TIFR)*

[2] *Tata Institute of Fundamental Research*

Corresponding Author: subhajit.tifr@gmail.com

New interactions of neutrinos can stop them from free streaming in the early Universe even after the weak decoupling epoch. This results in the enhancement of the primordial gravitational wave amplitude on small scales compared to the standard ΛCDM prediction. We calculate the effect of dark matter neutrino interactions in CMB tensor B-modes spectrum. We show that the effect of new neutrino interactions generates a scale or ℓ dependent imprint in the CMB B-modes power spectrum at $\ell \geq 100$. In the event that primordial B-modes are detected by future experiments, a departure from scale invariance, with a blue spectrum, may not necessarily mean failure of simple inflationary models but instead may be a sign of non-standard interactions of relativistic particles. Dark matter - neutrino interaction models also have interesting collider signatures. So, in future CMB - B mode can act as a probe of non-standard neutrino interactions and complement collider searches of new physics models.

Collider Search I / **18**

Improved constraints on a t-channel simplified model of Majorana Dark matter

Author: Kirtimaan Mohan[1]

Co-authors: Tim M.P. Tait [2]; Bin Yan ; C.-P. Yuan [1]; dipan sengupta

[1] *Michigan State University*

[2] *University of California, Irvine*

Corresponding Authors: dip.theranger@gmail.com, yuan@pa.msu.edu, ttait@uci.edu, binyanpku@gmail.com, kamohan@pa.msu.edu

An interesting class of models posits that the dark matter is a Majorana fermion which interacts with a quark together with a colored scalar mediator. Such a theory can be tested in direct detection experiments, through dark matter scattering with heavy nuclei, and at the LHC, via jets and missing energy signatures. Motivated by the fact that such theories have spin-independent interactions that vanish at tree level, we examine them at one loop (along with RGE improvement to resum large logs), and find that despite its occurrence at a higher order of perturbation theory, the spin-independent scattering searches typically impose the strongest constraints on the model parameter space. We further analyze the corresponding LHC constraints at one loop and find that it is important to take them into account when interpreting the implications of searches for jets plus missing momentum on this class of models, thus providing the corresponding complementary information for this class of models.

Collider Search II: mediators / **19**

[YSF] The unexplored landscape of two-body resonances

Author: Yvonne Ng[1]

[1] *University of California Irvine (US)*

Corresponding Author: ying.wun.yvonne.ng@cern.ch

We propose a strategy for searching for theoretically-unanticipated new physics. Searches for resonances decaying into pairs of visible particles are experimentally very powerful due to the localized mass peaks and have a rich history of discovery. Yet, due to a focus on subsets of theoretically-motivated models, the landscape of such resonances is far from thoroughly explored. We survey the existing set of searches, identify untapped experimental opportunities and discuss the theoretical constraints on models which would generate such resonances.The landscape could provide insight on the future of Dark matter mediator search strategies. arXiv:1610.09392

Poster pitch / **20**

New long-lived particle searches at the LHC with FASER: the ForwArd Search ExpeRiment

Author: Aaron Soffa[1]

[1] *University of California, Irvine*

Corresponding Author: aaronsoffa@gmail.com

Probing the energy frontier with increasingly large particle colliders has culminated at the beginning of the current decade with the discovery of the Higgs boson, the final particle predicted by the

Standard Model of particle physics. Nevertheless, the energy frontier program has so far failed to find any particles of the dark sector comprising the 95% of the Universe's energy density not described by the Standard Model. One way to continue making progress with collider experiments is to explore regions of phase space that have so far been inaccessible. Embarking on this endeavor, the ForwArd Search ExpeRiment (FASER) is a new experiment at the LHC that aims to detect long-lived particles that may be produced in the far-forward region, remaining undetectable by current LHC experiments. Such dark sector particle candidates include dark photons, dark Higgs bosons, axion-like particles, heavy neutral leptons, and other light and weakly interacting candidates that would be able to travel through hundreds of meters of concrete and rock before decaying into Standard Model particles. FASER is now an approved experiment with installation set for LHC Long Shutdown 2 and data taking to begin in 2021 at the start of LHC Run 3. Discussed will be the current status of FASER along with its timeline, challenges, and prospects for shedding new light on dark matter.

Indirect Search / **21**

Searching DDM through gamma radiation

Authors: A. Avilez[1]; E. Barradas-Guevara[1]; C. Arellano Celiz[1]; O. Felix-Beltran[1]

[1] *Benemerita Universidad Autonoma de Puebla*

Corresponding Authors: ana.avilez.lopez@gmail.com, barradas@fcfm.buap.mx, conchoarellanoc@gmail.com, olga.felix@correo.buap.mx

We are interested in the purpose of a dipolar fermionic particle as a viable candidate of Dark Matter (DDM). Then, we study the annihilation of dark matter, considering it as a neutral particle with magnetic (M) and electric (D) dipolar moments not vanishing. Total cross section $\sigma(\chi\chi \to \gamma\gamma)$ is computed by starting from a general form of coupling $\chi\chi\gamma$ in the framework of beyond to Standard Model (BSM). We found that for small masses like $m_\chi \leq 10\,\text{GeV}$, $D \sim 10^{-16}$ e cm is required to satisfy the current residual density, while for the greater sensitivity range of HAWC, $10\,\text{TeV} < E_\gamma < 20\,\text{TeV}$, $D \sim 10^{-18}$ e cm.

Poster pitch / **22**

RECAST for Mono-S(bb) with ATLAS

Author: ATLAS Collaboration[None]

Corresponding Author: alexander.joseph.schuy@cern.ch

A RECAST of an existing ATLAS analysis is used to perform a search for dark matter produced in association with a dark Higgs boson decaying to two b-quarks from pp collisions at a centre-of-mass energy of sqrt(s) = 13 TeV. RECAST is an analysis reinterpretation framework; since analyses are often sensitive to a range of models, RECAST can be used to constrain the plethora of dark matter models without the significant investment required for a new analysis. In this case, the ATLAS Z' -2HDM Mono-H(bb) analysis at 79.8 fbˆ-1 integrated luminosity is used, due to the Z'-2HDM model' s similar experimental signature to the dark Higgs model.

Poster pitch / **23**

Searches for invisible Higgs decays with the ATLAS detector

Author: Othmane Rifki[1]

[1] *Deutsches Elektronen-Synchrotron (DE)*

Corresponding Author: othmane.rifki@cern.ch

The total decay width of the Higgs has not yet been constrained precisely, which allows for up to 30% of the branching fraction to be from beyond the standard model decays. If sufficiently light, dark matter motivates a decay of the Higgs to invisible final states. This talk will discuss searches for invisible decays of the Higgs produced in all production modes in pp collisions at $\sqrt{s}$= 13 TeV with the ATLAS detector, with a particular emphasis on the vector boson fusion, the most sensitive search channel. The statical combination of the different channels as well as a comparison between these searches and the constraints from the visible decay modes will be addressed. Finally, these results will be compared to direct detection dark matter experiments, assuming the Higgs portal model.

Collider Search II: mediators / **24**

[YSF] Searching for Dark Matter with Semi-Visible Jets at CMS

Author: Colin Fallon[1]

[1] *University of Rochester (US)*

Corresponding Author: colin.terrence.fallon@cern.ch

Most theories that predict dark matter production at colliders rely on weakly coupled dark matter and the existence of WIMPs, or weakly interacting massive particles; however, there can be dark matter signatures in colliders that emerge from strongly coupled dark matter. These signatures are varied, ranging from emerging jets to Stealth Dark Matter. Another possible signature is semi-visible jets. These occur if the dark sector is comprised of a strong-like structure with dark hadrons made up of dark quarks. Once produced, a heavy dark quark would then hadronize into stable dark "pions", which leave the detector as dark matter, and unstable dark hadrons that shower and appear as SM hadronic showers. Since the true jet is made up of visible SM quarks and missing transverse energy closely aligned with the shower, the jet is called semi-visible. This presentation will discuss a Hidden Valley theory that results in such a signature, as well as a work-in-progress analysis by members of the CMS Collaboration trying to find this signature.

Long-lived particles / **25**

[YSF] Freeze-in and Freeze-out of Dark Matter with Charged Long-lived Partners

Authors: Sreemanti Chakraborti[1]; Poulose Poulose[1]; Victoria Martin[2]

[1] *Indian Institute of Technology, Guwahati, India*

[2] *University of Edinburgh, UK*

Corresponding Authors: victoria.martin@ed.ac.uk, poulose@iitg.ac.in, sreemanti@iitg.ac.in

We present a novel framework capable of addressing the dark matter problem through freeze-in and freeze-out mechanisms, separately or together depending on the region of the parameter space considered. Apart from the fermionic dark matter candidate, the model features two charged partners, one fermionic and another scalar, which often have delayed decays leading to distinct features of such long-lived particles in the colliders like the LHC. Our analysis shows that the model is compatible with observation for masses in the 100 GeV to TeV range. The not-so-slow production of the dark matter particle with the otherwise over-abundant case tamed through sizable annihilation cross section is a distinct characteristic of this scenario, which is not present in the usual Feebly Interacting

Massive Particle (FIMP) freeze-in scenarios. A bonus feature is the requirement of a heavy neutrino leading to Type-I seesaw mechanism without disturbing the dark matter side.

Poster pitch / **26**

Search for dark matter produced in association with a Higgs boson decaying to a pair of bottom quarks in proton-proton collisions at sqrt(s) = 13 TeV with the CMS detector

Author: Shu-Xiao Liu[1]

[1] *National Central University (TW)*

Corresponding Author: d3a2s1l@gmail.com

A search for dark matter produced in association with a Higgs boson decaying to a bottom quark-antiquark pair is performed in proton-proton collisions at a center-of-mass energy of 13 TeV collected with the CMS detector at the LHC. The analyzed data sample corresponds to an integrated luminosity of 35.9 fb-1. The signal is characterized by a large missing transverse momentum recoiling against a bottom quark-antiquark system that has a large Lorentz boost. The number of events observed in the data is consistent with the standard model background prediction. Results are interpreted in terms of limits on parameters of various mono-higgs models.

Collider Search II: mediators / **27**

[YSF] Cosmology and LHC phenomenology of simplified SIMP models

Author: Elias Bernreuther[1]

Co-authors: Felix Kahlhoefer [2]; Michael Kramer [3]; Patrick Tunney [4]

[1] *RWTH Aachen University*

[2] *RWTH Aachen*

[3] *Rheinisch Westfaelische Tech. Hoch. (DE)*

[4] *King's College London*

Corresponding Authors: pjtunney@gmail.com, ebernreuther@physik.rwth-aachen.de, kahlhoefer@physik.rwth-aachen.de, mkraemer@physik.rwth-aachen.de

I will discuss the cosmology and LHC phenomenology of a consistent, strongly interacting dark sector coupled to Standard Model particles through a Z' mediator. I will lay out the requirements for the model to be cosmologically viable, consider the dominant freeze-out processes, and discuss bounds from direct detection. Using this consistent SIMP sector, I will then focus on the sensitivity of LHC searches to semi-visible jets originating from dark showers. This includes recasting existing searches and investigating proposed dedicated analyses. I will also argue that displaced decays are a generic feature of viable SIMP models.

Collider Search I / **29**

[YSF] Search for dark matter produced in association with a Z boson decaying to pair of leptons at CMS

Author: Chad Wells Freer[1]

[1] *Northeastern University (US)*

Corresponding Author: chad.freer@cern.ch

A search for beyond standard model (BSM) physics in events with a Z boson recoiling against missing transverse momentum at the CMS experiment at the LHC is presented. This search is interpreted for a spin-1 simplified dark matter vector or axial-vector mediator as well as for a Higgs-like scalar or pseudoscalar mediator. The search utilises the full Run II dataset corresponding to an integrated luminosity of 137.1/fb at 13 TeV

Collider Search II: mediators / **30**

[YSF] Search for inelastic dark matter with the CMS detector

Author: Andre Frankenthal[1]

Co-authors: Yangyang Cheng [2]; Tres Reid [2]

[1] *Cornell University*

[2] *Cornell University (US)*

Corresponding Authors: michael.george.reid@cern.ch, yangyang.cheng@cern.ch, as2872@cornell.edu

Searches for dark matter at the LHC have largely focused on Weakly Interacting Massive Particles (WIMPs). But what if instead of just one type of dark matter particle, there exists a richer dark sector hidden from ordinary view? This opens up a whole new paradigm for dark matter searches, allowing us to focus not only on the coupling between dark matter and the Standard Model, but also on the interactions between dark matter constituents themselves. The LHC is in a unique position to investigate such a rich dark sector which is otherwise difficult to probe with direct and indirect detection techniques. In this talk, I will describe a new, ongoing search for dark matter with the CMS detector, using Inelastic Dark Matter (iDM) predictions as a guide. The iDM model offers a unique and striking long-lived final-state signature at the LHC, which can be exploited to access a significant fraction of unexplored dark matter parameter space. I will review the iDM model, describe the main features of the expected signature, and discuss the ongoing efforts at CMS to look for this signal.

Collider Search: Higgs and SUSY / **31**

Cancel: [YSF] Electroweak Symmetric Dark Matter Balls

Authors: Yang Bai[1]; Eduardo Ponton[None]; Bithika Jain[2]

[1] *University of Wisconsin, Madison*

[2] *ICTP-SAIFR, IFT-UNESP*

Corresponding Authors: bjain@ictp-saifr.org, eponton@ift.unesp.br, yangbai@physics.wisc.edu

We show that a simple Higgs-portal dark matter model can contain stable non-topological soliton states of dark matter. This macroscopic dark matter candidate has its interior in an electroweak symmetry unbroken vacuum. These dark matter balls can have its radius around the atomic scale and mass as large as 10^{34} GeV. We discuss the formation of these dark matter balls from the first-order electroweak phase transition in the early universe. We describe the existence of bound states of standard model particles inside the dark matter balls and its scattering off from normal matter such as heavy nuclei, quarks or even an electron. Such dark matter candidates can be searched in

a wide range of experiments. We provide constraints from the WIMP-like direct detection and also from multi scatter events.

Poster pitch / **32**

Understanding backgrounds of ultra long-lived particle searches with the MATHUSLA test stand

Author: Mason Proffitt[1]

[1] *University of Washington (US)*

Corresponding Author: mason.louis.proffitt@cern.ch

Long-lived particles (LLPs) are a feature of many theories beyond the Standard Model and would be generically produced in exotic decays of the Higgs boson. No known search strategy with current experiments will be able to observe the decay of neutral LLPs with masses above $\sim 1\ \mathrm{GeV}$ at lifetimes near the upper limit of $c\tau \sim 10^7\ \mathrm{m}$ set by effects on Big Bang nucleosynthesis. The proposed MATHUSLA experiment would search for these ultra long-lived particles by implementing existing technology into a new detector at ground level above one of the interaction points of the LHC by the start of high luminosity runs in 2026. A small-scale MATHUSLA test stand was installed on the surface above the ATLAS detector during part of its operation in 2017 and 2018. We describe this test stand, designed to study the background rates of downward-going muons originating from cosmic rays and upward-going muons created in LHC pp collisions, as well as the ability of tracking to distinguish between these two sources, and present the initial results.

Poster pitch / **33**

Search for supersymmetry with a compressed mass spectrum in the vector boson fusion topology with 1-lepton and 0-lepton final states

Author: Brenda Fabela Enriquez[1]

[1] *Vanderbilt University (US)*

Corresponding Author: brenda.fabela.enriquez@cern.ch

In R-parity conserving supersymmetric extensions of the standard model, the lightest neutralino $\tilde{\chi}_1^0$, which is also the lightest supersymmetric particle (LSP), plays the role of the canonical dark matter particle candidate. The traditional $\tilde{\chi}_1^0$ searches using Drell-Yan processes suffer in the compressed spectrum scenarios, where the LSP mass is only slightly less than the masses of other charginos and neutralinos. Therefore, new experimental techniques are needed in order to facilitate the detection of missing $\tilde{\chi}_1^0$ momentum in the event and the identification of the soft decay products characterizing these scenarios. In this talk, we present a summary of the search for chargino ($\tilde{\chi}_1^{\pm}$) - neutralino ($\tilde{\chi}_2^0$) production via pure electroweak vector boson fusion processes using data from pp collisions at = 13 TeV collected in 2016 with the CMS experiment at the LHC. The final states considered consist of one or zero leptons, large missing transverse momentum, and two jets with a large separation in rapidity. The observed dijet invariant mass and lepton-neutrino transverse mass distributions are consistent with the standard model predictions. Upper limits on the cross section for chargino $\tilde{\chi}_1^{\pm}$ and neutralino $\tilde{\chi}_2^0$ production associated with two jets are set. In the compressed mass spectra scenario, where 1 (30) GeV, gaugino masses up to 112 (215) GeV for the mass-degenerate particles $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ are excluded at 95\% CL. This analysis obtains the most stringent limits to date on the production of chargino and neutralinos in the compressed mass spectrum scenarios with $1 \leq \Delta m <$ 3 GeV and $25 \leq \Delta m <$ 50 GeV, where $\Delta m \equiv m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0)$.

Collider Search: Higgs and SUSY / 34

[YSF] Search for the compressed SUSY in stau-neutralino coannihilation region with a soft tau lepton and ISR jets

Authors: Alfredo Gurrola[1]; Andrew Malone Melo[1]; Carlos Andres Florez Bustos[2]; Klaas Padeken[1]; Manuel Alejandro Segura Delgado[2]; Paul Sheldon[1]; Savanna Rae Starko[1]; Teruki Kamon[3]; Willard Johns[1]

[1] *Vanderbilt University (US)*

[2] *Universidad de los Andes (CO)*

[3] *Texas A & M University (US)*

Corresponding Authors: teruki.kamon@cern.ch, andrew.malone.melo@cern.ch, padeken@cern.ch, willard.johns@cern.ch, andres.florez@cern.ch, savanna.r.starko@vanderbilt.edu, manuel.segura@cern.ch, paul.sheldon@vanderbilt.edu, alfredo.gurrola@cern.ch

A search for compressed supersymmetry in the stau-neutralino ($\tilde{\tau}\tilde{\chi}_1^0$) coannihilation region is presented. The search targets final states with exactly one low-energy ("soft") hadronically-decaying τ lepton and large missing transverse momentum ($\vec{E}_T^{miss}$) due to the natural kinematic boost from a high transverse momentum jet from initial state radiation (ISR). The data sample corresponds to an integrated luminosity of 77.2 fb^{-1} of proton-proton collisions at $\sqrt{s} = 13$ TeV collected with CMS detector at the CERN LHC in 2016 and 2017. The distribution of the transverse mass between the τ_h and the $\vec{E}_T^{miss}$ is found to be consistent with the standard model predictions. Upper limits are set on the cross section for chargino ($\tilde{\chi}_1^{\pm}$) and neutralino ($\tilde{\chi}_2^0$) production with an associated ISR jet. For a compressed mass spectrum scenario in which the mass difference between the $\tilde{\chi}_1^0$ and the $\tilde{\chi}_1^{\pm}$ is 50 GeV, an upper limit of 290 GeV is set on the mass of the $\tilde{\chi}_1^{\pm}$, which exceeds the sensitivity obtained by other $\tilde{\tau}$ searches to date. Finally, the results are also interpreted considering direct production of $\tilde{\tau}$ pairs with associated ISR jets.

Interpretations and ML / 35

Exploring light Supersymmetry with GAMBIT

Author: Matthias Danninger[1]

[1] *University of British Columbia (CA)*

Corresponding Author: matthias.danninger@cern.ch

I will summarize recent studies by the GAMBIT Collaboration in which we investigated the combined collider constraints on the chargino and neutralino sector of the Minimal Supersymmetric Standard Model. Through a large fit using GAMBIT we found that current ATLAS and CMS results with 36\,fb^{-1} of 13\,TeV LHC collision data do not provide a general constraint on the lightest neutralino and chargino masses. Further, we found that a pattern of excesses in some of the LHC analyses can be fit in a subset of the model parameter space. In addition, I will discuss recent extensions to this work including fits to NMSSM models and models with gravitino Dark Matter candidates.

Direct Search / 36

One-loop contributions to dark matter-nucleon scattering in scalar and vector DM models

Author: Rui Santos[1]

[1] *ISEL & CFTC (Lisbon)*

Corresponding Author: rasantos@fc.ul.pt

Dark matter direct searches place very stringent constraints on the possible DM candidates proposed in extensions of the Standard Model. There are however models where these constraints are avoided. One of the simplest and most striking examples comes from a straightforward Higgs portal pseudoscalar DM model featured with a softly broken U(1) symmetry. In this model the tree-level DM-nucleon scattering cross section vanishes in the limit of zero momentum-transfer. It has also been argued that the leading-order DM-nucleon cross section appears at the one-loop level. We have calculated the exact cross section at the one-loop level, which is several orders of magnitude larger than the tree-level one. We will also present results for a simple model with a vector dark matter particle.

Opening / **38**

Introduction

Corresponding Author: schsu@uw.edu

Opening / **39**

Theory Overview of Dark Matter Search at the LHC

Corresponding Author: spchang123@gmail.com

Opening / **40**

Experiment overview of Dark Matter search at the LHC

Corresponding Author: adish.vartak@cern.ch

Opening / **41**

LHC DM Working group report

Corresponding Author: ttait@uci.edu

Opening / **42**

Detector upgrade at Run3 and HL-LHC

Corresponding Author: sudhir.malik@cern.ch

Collider Search I / **43**

ETmiss + Standard Model particles

Corresponding Author: nicolas.koehler@cern.ch

Collider Search I / **44**

Dark Matter and Flavor at the LHC

Corresponding Author: ben.kilminster@cern.ch

Collider Search I / **45**

Toward Run3: uncovered signatures (TBC)

Corresponding Author: mbuckley@physics.rutgers.edu

Direct Search / **46**

WIMP search summary

Corresponding Author: chavarri@uw.edu

Direct Search / **47**

Axion search summary

Corresponding Author: grybka@u.washington.edu

Direct Search / **48**

Interplay between Direct Detection and Collider searches

Corresponding Author: elhed001@uni-mainz.de

Indirect Search / **49**

Indirect search: Gamma ray

Corresponding Author: smurgia@uci.edu

Indirect Search / **50**

Indirect search: neutrino

Corresponding Author: carsten.rott@gmail.com

Indirect Search / **51**

Interplay between Indirect Search and collider search

Corresponding Author: rleane@mit.edu

Collider Search: Higgs and SUSY / **52**

DM theory in Higgs and SUSY sector

Corresponding Author: nausheen.shah@wayne.edu

Collider Search: Higgs and SUSY / **53**

Invisible Higgs search at the LHC

Corresponding Author: alison.elliot@cern.ch

Collider Search: Higgs and SUSY / **54**

Dark Matter SUSY search at the LHC (prompt signatures)

Corresponding Author: zhenbinwu@gmail.com

Collider Search II: mediators / **55**

Dark Matter mediator search: dijet signature

Corresponding Author: kate.whalen@cern.ch

Interpretations and ML / **56**

Dark Matter interpretation with global fitting

Corresponding Author: a.kvellestad@imperial.ac.uk

From Models to Signatures / 57

State-of-the-art calculations of the dark matter abundance

Corresponding Author: jharz@lpthe.jussieu.fr

Interpretations and ML / 58

Monte Carlo tools: successes and failures

Interpretations and ML / 59

Machine Learning in particle theory

Corresponding Author: jack.collins@cern.ch

Interpretations and ML / 60

Machine Learning in particle experiments

Corresponding Author: daniel.hay.guest@cern.ch

Long-lived particles / 61

Direct LLP searches at the LHC

Corresponding Author: rachel.rosten@cern.ch

Long-lived particles / 62

Indirect LLP searches at the LHC

Corresponding Author: martina.vit@cern.ch

Long-lived particles / 63

New experiment proposals

Corresponding Author: cristiano.alpigiani@cern.ch

Flavor & Dark sector / 64

Dark Sectors at Direct Detection Experiments

Corresponding Authors: tientien.yu@gmail.com, tientien@uoregon.edu

Flavor & Dark sector / 65

Dark Photon at the LHC

Corresponding Author: yangyang.cheng@cern.ch

Flavor & Dark sector / 66

Dark Sector search at the LHCb

Corresponding Author: federico.redi@cern.ch

Flavor & Dark sector / 67

Dark Sector search at Belle II and BaBar

Corresponding Author: paolo.branchini@roma3.infn.it

Innovative Ideas / 68

Gravitational Wave, Multimessenger Physics and DM

Corresponding Author: dcroon@triumf.ca

Innovative Ideas / 69

Dark Blobs, Nuggets and Quark Nuggets – Exponentially Large Composite Dark Matter

Corresponding Author: dorota.grabowska@cern.ch

Outlook / 70

Dark Matter search at the HL-LHC

Corresponding Author: laura.barranco.navarro@cern.ch

Outlook / **71**

Dark Matter search at future lepton colliders

Corresponding Author: xin.shi@cern.ch

Outlook / **72**

Dark Matter search at future hadron colliders

Corresponding Author: caterina.doglioni@cern.ch

Outlook / **73**

Experiment summary

Corresponding Author: christian.ohm@cern.ch

Outlook / **74**

Theory summary

Corresponding Author: rocky.kolb@uchicago.edu

Innovative Ideas / **75**

Dark Photon Search in LIGO

Corresponding Author: zhaoyue@physics.utah.edu

From Models to Signatures / **76**

The warped dark sector

Corresponding Author: sylvain.fichet@gmail.com

Five-dimensional braneworld constructions in anti-de Sitter space naturally lead to dark sector scenarios in which parts of the dark sector vanish at high 4d momentum or temperature. In the language of modified gravity, such feature implies a new mechanism for hiding light scalars, as well as the possibility of UV-completing chameleon-like effective theories. In the language of dark matter
phenomenology, the high-energy behaviour of the mediator sector changes dark matter observational
complementarity. A multitude of signatures—including exotic ones—are present from laboratory to cosmologic scales, including long-range forces with non-integer behaviour, periodic signals at

colliders, "soft bombs"events well-known from conformal theories, as well as a dark phase transition and a typically small amount of dark radiation.

Ref: https://arxiv.org/abs/1906.02199

From Models to Signatures / **77**

Collider signatures of minimal freeze-in models

Author: dipan sengupta[None]

Corresponding Author: dip.theranger@gmail.com

We propose simple freeze-in models where the observed dark matter abundance is explained via the decay of an electrically charged and/or coloured parent particle into Feebly Interacting Massive Particles (FIMP). The parent particle is long-lived and yields a wide variety of LHC signatures depending on its lifetime and quantum numbers. We assess the current constraints and future high luminosity reach of these scenarios at the LHC from searches for heavy stable charged particles, disappearing tracks, displaced vertices and displaced leptons. We show that the LHC constitutes a powerful probe of freeze-in dark matter and can further provide interesting insights on the validity of vanilla baryogenesis and leptogenesis scenarios.

Opening / **79**

Ann Nelson: Brilliant Physicist and Advocate of Diversity

Corresponding Author: ttait@uci.edu

Poster pitch / **80**

SUSY with a light Dirac bino: B meson baryogenesis & sneutrino asymmetric DM

Author: Huangyu Xiao[1]

Co-authors: Ann Nelson [2]; Gilly Elor

[1] *University of Washington (US)*

[2] *University of Washington*

Corresponding Authors: huangyu@uw.edu, anelson@phys.washington.edu, gelor84@gmail.com

CP violation has been observed in neutral meson oscillations, which may explain the matter-antimatter asymmetry of the Universe. We found that a supersymmetric theory with an unbroken U(1)R symmetry and Dirac gauginos can accommodate baryogenesis and asymmetric sneutrino dark matter production via B meson oscillations. This model can be tested via semileptonic asymmetries of B mesons, Flavor violation, exotic B decays, and decay of long-lived particles.