DE- SC0013529

New Models and Methods for the Electroweak Scale

Project Dates: 4/1/2015-3/31/2017

Final Technical Report to the US Department of Energy

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Abstract

This is the Final Technical Report to the US Department of Energy for grant DE-SC0013529, New Models and Methods for the Electroweak Scale, covering the time period April 1, 2015 to March 31, 2017. The goal of this project was to maximize the understanding of fundamental weak scale physics in light of current experiments, mainly the ongoing run of the Large Hadron Collider and the space based satellite experiments searching for signals Dark Matter annihilation or decay. This research program focused on the phenomenology of supersymmetry, Higgs physics, and Dark Matter. The properties of the Higgs boson are currently being measured by the Large Hadron collider, and could be a sensitive window into new physics at the weak scale. Supersymmetry is the leading theoretical candidate to explain the naturalness of the electro-weak theory, however new model space must be explored as the Large Hadron collider has disfavored much minimal model parameter space. In addition, the nature of Dark Matter, the mysterious particle that makes up 25% of the mass of the universe is still unknown. This project sought to address new measurements of the Higgs boson couplings to the Standard Model particles, new LHC discovery scenarios for supersymmetric particles, and new measurements of Dark Matter interactions with the Standard Model both in collider production and space-based annihilation processes.

Accomplishments include new creating tools for analyses of Dark Matter models in which Dark Matter annihilates into multiple Standard Model particles, including new visualizations of bounds for models with various Dark Matter branching ratios; benchmark studies of new discovery scenarios of Dark Matter at the Large Hardon Collider for Higgs-Dark Matter and gauge boson-Dark Matter interactions type; New target analyses to detect direct decays of the Higgs boson into challenging final states like pairs of light jets, and new phenomenological analysis of non-minimal supersymmetric models, namely the set of Dirac Gaugino Models..

Overview: This project was awarded $ 140,000, and lasted for a two year term 4/1/2015-3/31/2017. Funds were employed as summer salary for the PI, travel funds and support for graduate Russell Colburn, who has since defended his thesis. The main thrust of research focused on three topics at the forefront of weak-scale physics research; Dark Matter, Higgs physics, and Supersymmetry. Below I summarize major research accomplishments in each of these subcategories..

Dark Matter: Through this project I produced several works exploring signals and constraints on Dark Matter models. I explored many possible portals for Dark Matter coupling to the standard model. These included analysis of collider and indirect detection constraints for models where Dark Matter couples to the Standard Model through interaction with electroweak gauge bosons. I also produced new limits on annihilating Dark Matter models where Dark Matter couples to multiple Standard Model fermions using the Fermi satellite Dwarf galaxy analyses.

Accomplishments

-Dark Matter Forum Report: I became of member of the ATLAS/CMS LHC Dark Matter forum. This collaboration between experimentalists and theorists produced a large whitepaper setting benchmark search scenarios for the Large Hadron Collider for a wide variety of Dark Matter models. I contributed significantly to this top-cited work, providing models and co-writing sections for Dark Matter couples to the Standard Model through interaction with electroweak gauge bosons and Higgs particles. This work is ongoing as the forum has morphed into the LHC Dark Matter Working Group.

-New indirect detection constraints: I wrote a series of 2 papers analyzing constraints on Dark Matter annihilations to multiple standard model final states. Multiple annihilations, through often called for by symmetries of the theory, had not been extremely well studied in the past. Our constrains came from constructing a least log likelihood analysis given Fermi satellite data from its dwarf galaxy analysis. We analyzed both Dark Matter interactions with Standard Model particles both effective field theory models utilizing contact operators, as well as sets of simplified models with scalar and vector mediators coupling Dark Matter to multiple final state femions or gauge bosons. We also developed a visualization mechanism to display constraints on fractional annihilation rates of Dark Matter into multiple channels.

Higgs Physics: LHC is now hard at work measuring the properties of the Higgs boson. These include the Higgs couplings to the other standard model particles. If these coupling deviate from standard predictions they , would indicate new physics; in particular, the loop level Higg is couplings, such as the coupling to 2 gluons, or to a photon and Z boson , are especially sensitive probes of new states. During the course of this project I have worked to create new analyses to better measure the Higgs' loop level couplings.

Accomplishments

-With collaborators at the University of Pittsburgh, we developed a search for the High Luminosity run of LHC to directly detect the Higgs decay to two light jets. Though the Higgs has an 8 percent branching fraction to gluons, backgrounds make this an extremely challenging scenario to detect. We showed through combination of leptonic channels in Higgs associated production, our search can be sensitive to direct Higgs decay to jets if the Higgs-gluon coupling is just a few times its Standard Model value. In fact, since multiple Higgs decay channels might contribute to this signal, bound can be used to limit the combined Higgs decays to b quarks, charms and light jets.

Supersymmetry- Over the course of this project I have focused on finding new discovery scenarios for non-minimal implementations of weak scale supersymmetry. In particular I have focused on model where guaginos are Dirac as opposed to Majorana particles. This model contain a new supermultiples, an adjoint under the standard model gauge groups. As such there are new adjoint scalar fields. In addition the super-particle mass spectrum is quite different than standard scenarios. Below I detail progress in phenomenological studies in this models.

Accomplishments

-New Discovery Channels for Adjoint Scalars- With grad student Russell Colburn we focused on new discovery channels for new scalar fields in Dirac gaugino models, the di-boson resonance channels. In two works (one with postdoc Jessica Goodman) we wrote the complete set of gauge invariant operators through which a SM adjoint scalar could couple to all pairs of Standard Model gauge bosons. We calculate the couplings, induced through loops of squarks and sleptons, and set out general conditions for the stability for these models. We also created sensitivity studies for the possible signatures of this scenario including new gluon-photon resonance searches for scalar color adjoints, and a top-cited paper on di-photon resonance signatures

-Smoking gun signatures for Dirac Gaugino Models- In the work 'Antisplit Supersymmetry' I explore the general collider signatures for Dirac gaugino-like supersymmetric models with new features of particle mass hierarchies. The main feature of these models is that gauginos are much heavier than scalar particles and Higgsino-like states are the only kinematically accessible neutralinos and charginos. This work is a map of important collider signatures for all models with these mass-hierarchy features. I study all plausible candidates for lightest supersymmetric particle and lay out the search channels for the main sparticle production and decays models in each scenario.

Publications

1. Antisplit Supersymmetry, LM Carpenter, arXiv:1612.09255. Accepted by JHEP, to appear

2. Higgs Boson Decay to Light Jets at the LHC, LM Carpenter with T. Han, K. Hendricks, Z. Qian and N. Zhou, arXiv:1611.05463, Phys.Rev. D.

3. Indirect Detection Constraints on s and t Channel Simplified Models of Dark Matter, LM Carpenter with R. Colburn and J. Goodman, arXiv:1606.04138, Published in Phys.Rev. D94 (2016) 5.

4. Supersoft SUSY Models and the 750 GeV Diphoton Excess, Beyond Effective Operators, LM Carpenter with R. Colburn and J. Goodman, arXiv:1512.06107, Published in Phys.Rev. D94 (2016) 1.

5. Searching for Standard Model Adjoint Scalars with Diboson Resonance Signatures, LM Carpenter with R. Colburn, arXiv:1509.07869, JHEP 1512 (2015) 151.

6.Dark Matter Benchmark Models for Early LHC Run-2 Searches: Re-port of the ATLAS/CMS Dark Matter Forum, with LM Carpenter Abercrombie et. al, arXiv:1507.00966

7. Indirect Detection Constraints on the Model Space of Dark Matter Effective Theories, LM Carpenter with J. Goodman and R. Colburn, arXiv:1506.08841, Phys.Rev. D92 (2015) 9.

Other Accomplishments

Research Presentations

May 2015 Parallel Session Talk at Pheno 2015 Conference
May 2015 Seminar at University of Pittsburgh
Dec 2015 Two Talks at LHC Dark matter Working Group Workshop
Feb 2016 Seminar at Rutgers University
Jul 2016 Talk at CETUP Summer Program on Dark Matter S. Dakota
Sept 2016 Talk at PIKIO Meeting OSU
Sept 2016 Seminar at University of Notre Dame
Oct 2016 Talk at Beyond the Standard Model Workshop U Michigan
Feb 2017 Talk at LHC Workshop University of Pittsburgh
Apr 2017 Talk at Dark Matter at LHC 2017 Conference UC Irvine