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KICP is hosting a workshop "Dark Matter at the LHC" this fall on the University of Chicago campus. The workshop will include both theorists and experimentalists actively working on LHC signals of dark matter. Some topics we plan to cover are monojet, monophoton, and related searches, as well as improvements in theoretical predictions and experimental techniques. The goal of the meeting is to discuss avenues for taking full advantage of the next LHC run for dark matter studies. This includes exploring new signals of DM models that may be challenging for direct detection or indirect detection experiments, as well as more sophisticated calculations and analyses to improve existing searches.

Topics:

Monojet searches for dark matter
Mono-photon, mono-Z, mono-b, and other signatures
Effective field theory constraints
Theoretical improvements in calculations

Organizing Committee

Rocky Kolb
University of Chicago

Tongyan Lin
Kavli Institute for Cosmological Physics

Sarah Malik
Rockefeller

Bjoern Penning
Fermilab/Chicago

Lian-Tao Wang
Kavli Institute for Cosmological Physics

Steven Worm
Rutherford/CERN

1. **Haipeng An**, Perimeter Institute for Theoretical Physics
Monojet constraint on simplified models of dark matter

September 19, 2013 (2:40 PM - 3:00 PM)

Co-authors: Liantao Wang, Xiangdong Ji, Hao Zhang

Z' papers: <http://arxiv.org/abs/arXiv:1202.2894> and <http://arxiv.org/abs/arXiv:1212.2221>.

2. **Yang Bai**, University of Wisconsin-Madison
Fermion Portal Dark Matter

September 20, 2013 (10:10 AM - 10:30 AM)

Co-authors: Joshua Berger

3. **Brian Batell**, University of Chicago
Searching for Light Dark Matter at Neutrino Factories

September 21, 2013 (11:20 AM - 11:40 AM)

I will describe a new way to search for dark matter using an intense proton beam - target - detector setup, such as those used to study neutrino oscillations. This gives new motivation to experiments like MiniBooNE, MINOS, MicroBooNE, NOvA, LBNE and a future Project X facility. A specific proposal to perform the first search of this kind at the MiniBooNE experiment at Fermilab will be presented.

4. **Matthew Buckley**, Fermilab/Rutgers
Dark Matter, New Electroweak Particles, and LHC Searches

September 20, 2013 (11:55 AM - 12:15 PM)

Co-authors: Joseph Lykken, Maria Spiropulu, Chris Rogan

If dark matter is a thermal relic of the early Universe, then we can expect additional new particles coupling to both dark matter and Standard Model fields. Of these, new un-colored electroweak particles are a common UV completion. I describe new search strategies using razor variables at the LHC which will improve our ability to detect such particles.

5. **Marcela Carena**, Fermilab/University of Chicago
Light Dark Matter, Direct Detection and Searches at the LHC

September 21, 2013 (11:40 AM - 12:00 PM)

Co-authors: Carlos Wagner

6. **Spencer Chang**, University of Oregon
Effective WIMPs

September 20, 2013 (9:30 AM - 9:50 AM)

Co-authors: Ralph Edezhath, Jeffrey Hutchinson, Markus Luty

The 'WIMP miracle' for the relic abundance of thermal dark matter motivates weak scale dark matter with renormalizable couplings to standard model particles. We study minimal models with such couplings that explain dark matter as a thermal relic. The models contain a singlet dark matter particle with cubic renormalizable couplings between standard model particles and 'partner' particles with the same gauge quantum numbers as the standard model particle. The dark matter has spin 0, 1/2, or 1, and may or may not be its own antiparticle. Each model has 3 parameters: the masses of the dark matter and standard model partners, and the cubic coupling. Requiring the correct relic abundance gives a 2-dimensional parameter space where collider and direct detection constraints can be directly compared. We focus on the case of dark matter interactions with colored particles. We find that collider and direct detection searches are remarkably complementary for these models. Direct detection limits for the cases where the dark matter is not its own antiparticle require dark matter masses to be in the multi-TeV range, where they are extremely difficult to probe in collider experiments. The models where dark matter is its own antiparticle are strongly constrained by collider searches for monojet and jets + MET signals. These models are constrained by direct detection mainly near the limit where the dark matter and partner masses are nearly degenerate, where collider searches become more difficult.

7. **Alvaro Chavarria**, Kavli Institute for Cosmological Physics
DAMIC and low mass WIMP searches

September 19, 2013 (10:00 AM - 10:30 AM)

8. **Jing-Yuan Chen**, University of Chicago
Dark Matter Coupling to Electroweak Gauge and Higgs Bosons

September 20, 2013 (4:20 PM - 4:40 PM)

Co-authors: Edward W. Kolb, Lian-Tao Wang

If dark matter is a new species of particle produced in the early universe as a cold thermal relic (a weakly-interacting massive particle-WIMP), its present abundance, its scattering with matter in direct-detection experiments, its present-day annihilation signature in indirect-detection experiments, and its production and detection at colliders, depend crucially on the WIMP coupling to standard-model (SM) particles. It is usually assumed that the WIMP couples to the SM sector through its interactions with quarks and leptons. In this paper we explore the possibility that the WIMP coupling to the SM sector is via electroweak gauge and Higgs bosons. In the absence of an ultraviolet-complete particle-physics model, we employ effective field theory to describe the WIMP--SM coupling. We consider both scalars and Dirac fermions as possible dark-matter candidates. Starting with an exhaustive list of operators up to dimension 8, we present detailed calculation of dark-matter annihilations to all possible final states, including $\gamma\gamma$, γZ , γh , ZZ , Zh , $W^+ W^-$, hh , and $f\bar{f}$, and demonstrate the correlations among them. We compute the mass scale of the effective field theory necessary to obtain the correct dark-matter mass density, and well as the resulting photon line signals.

9. **Jordan Damgov**, Texas Tech University
Search for dark matter using mono photon events at CMS

September 19, 2013 (11:40 AM - 12:00 PM)

10. **Andrea De Simone**, CERN & SISSA
On the validity of the EFT for DM searches at the LHC

September 19, 2013 (2:00 PM - 2:20 PM)

Co-authors: Busoni, Morgante, Riotto

I will discuss the limitations to the use of the effective field theory approach to study dark matter at the LHC. I will introduce and study a few quantities, some of them independent from the UV completion of the DM theory, which quantify the error made when using the effective operators to describe processes with very high momentum transfer.

11. **Michael A. Fedderke**, University of Chicago
Indirect constraints

September 20, 2013 (4:40 PM - 5:00 PM)

12. **Johanna Gramling**, University of Geneva
Validity of EFT interpretation of LHC Monojet results

September 19, 2013 (2:20 PM - 2:40 PM)

The interpretation of the Monojet analyses by ATLAS and CMS in terms of dark matter pair production raised some interest, since the limits could be easily compared to results from direct and indirect dark matter detection experiments via an effective field theory (EFT) description of the Standard Model-DM interaction. However, the validity of the EFT approach needs to be reviewed and evaluated, since LHC collisions can occur with very high momentum transfers, where the EFT description may not be accurate or reliable. A numerical study using MadGraph simulations, following an analytical approach outlined in arXiv:1307.2253v1, is presented. Event-by-event momentum transfer and cut-off scale are evaluated to estimate the fraction of events for which the EFT would be applicable. This tries to shed light on the question on how to present LHC limits on DM production and clearly state the limitations of the EFT interpretation used, and could be useful to quantify how much and in which regimes such limits can be trusted.

13. **JoAnne L Hewett**, SLAC/Stanford
Bounds on Dark Matter with Electroweak Gauge Bosons

September 20, 2013 (4:00 PM - 4:20 PM)

14. **Ahmed Ismail**, ANL/UIC
Dark Matter Complementarity in the pMSSM
September 21, 2013 (9:30 AM - 9:50 AM)

Co-authors: Matthew Cahill-Rowley, Randy Cotta, Alex Drlica-Wagner, Stefan Funk, JoAnne Hewett, Tom Rizzo, Matthew Wood
The search for neutralino dark matter in SUSY requires a multi-pronged approach with important roles played by collider, direct and indirect dark matter detection experiments. I summarize the sensitivity of such searches at the LHC, combined with those by Fermi, CTA, IceCube/DeepCore, COUPP and XENON1T, to such particles within the context of the phenomenological MSSM.
15. **Felix Kahlhoefer**, University of Oxford
Theoretical uncertainties in mono-jet searches
September 19, 2013 (4:40 PM - 5:00 PM)

Co-authors: Ulrich Haisch, Emanuele Re
I will discuss the theoretical uncertainties of the mono-jet signal prediction. A particular focus will be on the uncertainties related to scale ambiguities and how these can be reduced by including NLO corrections. In particular, I will present a new extension to the POWHEG BOX, which includes the effects of parton showering consistently at the NLO level. It turns out that these effects are large and significantly modify the results of a parton-level analysis. In this context, the details of the experimental cuts play a crucial role. I will provide simple K-factors which can be applied to existing experimental bounds to estimate the scale uncertainties for constraints on the interactions of dark matter. Finally, I will briefly discuss further uncertainties resulting from the choice of PDFs and the use of effective operators.
16. **Ian Low**, Argonne/Northwestern
The Case for Three-body Decaying Dark Matter
September 21, 2013 (10:20 AM - 10:40 AM)

Co-authors: Hsin-Chia Cheng, Wei-chih Huang, Arjun Menon, Gabe Shaughnessy
based on 1012.5300 and 1205.5270.
17. **Joseph Lykken**, Fermilab
Opening Overview Talk ~ "Prospectus for the Discovery of Dark Matter at the LHC"
September 19, 2013 (9:30 AM - 10:00 AM)
18. **Sarah Malik**, Rockefeller
Search for dark matter using monojet events at CMS
September 19, 2013 (11:00 AM - 11:20 AM)
19. **Mario Martinez**, ICREA/IFAE Barcelona
ATLAS Monophoton results
September 19, 2013 (12:00 PM - 12:20 PM)

Co-authors: ATLAS Collaboration
The most recent results on monojet and monophoton final states from the ATLAS experiment at the LHC would be presented.

20. **Klaas Padeken**, RWTH Aachen
Search for dark matter in the mono-lepton channel at the CMS

September 20, 2013 (2:25 PM - 2:45 PM)

Co-authors: The CMS Collaboration

This presentation will show the results for a search for new physics in final states with an electron or a muon and a neutrino (CMS-PAS-EXO-13-004). The results are interpreted in terms of the cross section of a W-boson recoiling against a pair of dark matter particles in an effective theory. Such process would be visible in the detector as a lepton + MET final state. The dark matter model considers two possible couplings, vector- and axial-vector like. They could couple to up- and down-type quarks with different strengths, parametrized by ξ . Possible consequences on the signal cross section and shape are studied. The results are presented in terms of production cross section limits, which are transformed to limits on the effective parameter Λ and $M(\text{DM})$ -proton cross sections as measured by the direct detection experiments. The limits derived on Λ are Λ

21. **Bjoern Penning**, Fermilab/Chicago
ATLAS Mono-Z

September 20, 2013 (2:50 PM - 3:10 PM)

22. **Christopher S Rogan**, Harvard University
Weakly-interacting particle kinematics at the LHC and the super-razor variables

September 20, 2013 (11:30 AM - 11:50 AM)

Co-authors: M. Buckley, J. Lykken, M. Spiropulu

23. **David Salek**, GRAPPA, Amsterdam
 $H \rightarrow \text{inv}$ at Atlas and CMS

September 19, 2013 (4:00 PM - 4:20 PM)

24. **Steven Schramm**, University of Toronto
Dark Matter searches in the mono-jet channel with the ATLAS Detector

September 19, 2013 (11:20 AM - 11:40 AM)

25. **Gabriella Sciolla**, Brandeis University
collider searches for dark matter with heavy quarks

September 20, 2013 (2:00 PM - 2:20 PM)

Co-authors: G.Artoni, T. Lin, B. Penning, G. Sciolla, A. Venturini

26. **Tim M.P. Tait**, UC Irvine
New Directions in EFTs for Dark Matter

September 21, 2013 (12:00 PM - 12:30 PM)

I would discuss new directions in constructing EFTs and model sketches (simplified models) and the results of comparing them to data.

27. **Sean Tulin**, U Michigan
Beyond collisionless dark matter: implications for astrophysics, direct detection, and colliders

September 21, 2013 (9:55 AM - 10:15 AM)

There are long-standing hints from astrophysical observations that dark matter (DM) may not be collisionless, as is commonly assumed, but rather may possess a sizable cross section for scattering with other DM particles in halos. Within the framework of minimal "simplified" models for self-interacting dark matter (SIDM), I describe how a variety of complementary probes, from astrophysics to terrestrial experiments, can explore SIDM parameter space.

28. **James Unwin**, Notre Dame
Dark matter searches at the LHC - The impact of heavy quark loops

September 19, 2013 (4:20 PM - 4:40 PM)

Co-authors: Ulrich Haisch, Felix Kahlhoefer

If only tree-level processes are included in the analysis, LHC monojet searches give weak constraints on the dark matter-proton scattering cross section arising from the exchange of a new heavy scalar or pseudoscalar mediator with Yukawa-like couplings to quarks. I will discuss the constraints on these interactions from the CMS 5.0/fb and ATLAS 4.7/fb searches for jets with missing energy including the effects of heavy-quark loops. The inclusion of such contributions leads to a dramatic increase in the predicted cross section and therefore a significant improvement of the bounds from LHC searches.

29. **Hao Zhang**, UCSB, ANL, IIT
Dark matter with t-channel mediator: a simple step beyond contact interaction

September 20, 2013 (9:50 AM - 10:10 AM)

Co-authors: Haipeng An, Lian-Tao Wang

Effective contact operators provide the simplest parameterization for dark matter searches at the LHC. At the same time, light mediator can change the sensitivity and search strategies in important ways. Considering simple models of mediators is an important next step for collider searches. In this paper, we consider the case of a t -channel mediator. Its presence opens up new contributions to the monojet $\sigma(\text{jet} + \cancel{E})_T$ searches and can change the reach significantly. We also study the complementarity between monojet $\sigma(\text{jet} + \cancel{E})_T$ and direct pair production of the mediators. There is a large region of parameter space in which the monojet $\sigma(\text{jet} + \cancel{E})_T$ channel provides the stronger limit. We combine the reaches of LHC search and direct detection, and compare it with the requirement from thermal relic abundance. We find that in the Dirac fermion dark matter case, there is no region in the parameter space that reconciles the combined constraint of monojet $\sigma(\text{jet} + \cancel{E})_T$ search and direct detection with constraint from not over closing the universe; and in the Majorana fermion dark matter case, the mass of dark matter must be larger than about 200 GeV. If the relic abundance requirement are not satisfied within the simple model, discovery of dark matter at the LHC in monojet $\sigma(\text{jet} + \cancel{E})_T$ and di-jet $\sigma(\text{jet} + \cancel{E})_T$ channels predicts additional new physics.