WORKSHOP TALKS
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

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<tr>
<th>Name</th>
<th>Institution and Affiliation</th>
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<tr>
<td>Rocky Kolb</td>
<td>University of Chicago</td>
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<td>Tongyan Lin</td>
<td>Kavli Institute for Cosmological Physics</td>
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<td>Sarah Malik</td>
<td>Rockefeller</td>
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<td>Bjoern Penning</td>
<td>Fermilab/Chicago</td>
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<td>Lian-Tao Wang</td>
<td>Kavli Institute for Cosmological Physics</td>
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<td>Steven Worm</td>
<td>Rutherford/CERN</td>
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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

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)
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, gamma Z, gamma h, ZZ, Zh, W+ W−, hh, and f fbar, 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.
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/IAFE 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 \( \xi \). 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 \( \Lambda \) and \( M(\text{DM})-\text{proton} \) cross sections as measured by the direct detection experiments. The limits derived on \( \Lambda \) are \( \Lambda < \ldots \).  

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->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 $+ \not{E}_T$ searches and can change the reach significantly. We also study the complementarity between monojet $+ \not{E}_T$ and direct pair production of the mediators. There is a large region of parameter space in which the monojet $+ \not{E}_T$ 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 $+ \not{E}_T$ 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 $+ \not{E}_T$ and di-jet $+ \not{E}_T$ channels predicts additional new physics.