Research Statement

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My interests lie at the interface of particle physics and astrophysics. In particular, my work to date has focused on Dark Matter (DM) phenomenology.

DM research is in an exciting phase as new astrophysical, direct detection, and collider experiments come online. This data can be coupled with phenomenological predictions to constrain the fundamental properties of DM. For example, in the paper *Conservative Constraints on Dark Matter Annihilation into Gamma Rays* (Phys. Rev. D **78**, 063542 (2008)) – with my advisor Nicole Bell and collaborators John Beacom, Greg Mack and Hasan Yuksel – we calculated the expected signal from DM annihilation to a gamma-ray pair using published estimates of the Galactic and Cosmic DM density distributions, with the self-annihilation cross section as the only free variable. We calculated the flux from the Galactic center, the Andromeda galaxy, and extra-Galactic annihilation. Using the observed flux as an upper limit on the signal, we found an upper limit on the cross section to a gamma-ray pair, shown in Figure 1 (left). At the time, these were the strongest robust upper limits on annihilation into gamma rays.

Many models with a large annihilation rate to charged leptons have been proposed to explain the apparent excess in the observed positron flux. Some of these models will overproduce gamma rays, through a form of radiative correction known as *internal bremsstrahlung.* In the paper *Gamma-ray Constraints on Dark Matter Annihilation into Charged Particles* (Phys. Rev. D **79**, 043507 (2009)), Nicole Bell and I calculated this gamma-ray signal in a model-independent way, and found that gamma rays contribute significantly to the annihilation signal – ruling out some leptophilic models as an explanation for the positron excess. The upper limit on the total cross section can be stronger than the one derived earlier from gamma rays, depending on the relative branching ratios for the model in question, as shown in Figure 1 (left).

Many of these leptophilic DM models are *helicity suppressed*, meaning that the annihilation rate to leptons is suppressed by a factor of the fermion mass squared, required in order to to 'flip the helicity' of the leptons into an allowed state. For example, this suppression of the annihilation rate to leptons is common in SUSY models. In the paper *W/Z Bremsstrahlung as the Dominant Annihilation Channel for Dark Matter* (arXiv:1009.2584 [hep-ph]) with Nicole Bell, Tom Weiler and James Dent, we studied helicity suppression of the annihilation cross section and how this is affected by Electroweak radiative corrections, where a W or Z boson is emitted rather than a gamma-ray. We found that one can use Fierz transformations to understand the relevant suppression for any particular model. Using Fierz transformations, any $t-$ or $u-$channel matrix element can be expressed as a sum of $s-$channel matrix elements. We have determined the suppression of the 'basis' 2-body $s-$channel bilinears, allowing one to easily determine the existence and origin of suppression, in a broad range of models.

While it has long been known that under certain circumstances, emission of a photon can lift suppression, we have shown that W/Z emission can remove suppression under a more general range of cases. We have explicitly calculated the Electroweak bremsstrahlung 3-body final state annihilation cross section, for an example leptophilic model, in order to quantify the lifting of suppression. Figure 1 (right) shows the ratio of the $e^+\nu W^-$ cross section to cross section to an electron-positron pair, $R = v\sigma(\chi\chi \to e^+\nu W^-)/v\sigma(\chi\chi \to e^+e^-)$. In a forthcoming paper, we calculate the signals expected from Electroweak bremsstrahlung annihilations for our example leptophilic model, using PYTHIA with Mathematica to find the W and Z decay spectra.

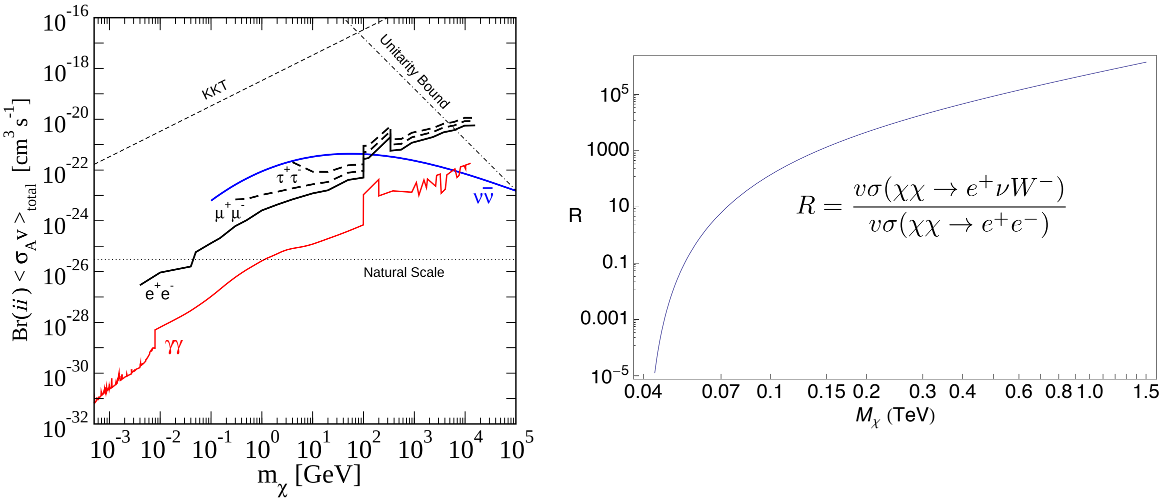

Figure 1: Upper limits on the annihilation cross section to various final states (left), and ratio of cross sections $R = v\sigma(\chi\chi \to e^+\nu W^-)/v\sigma(\chi\chi \to e^+e^-)$, for an example model (right).

Decay of the massive gauge bosons leads to signals that are drastically different from the 2-body signals. For example, there is now an antiproton signal which was entirely absent in the 2-body process. We calculate the signals of standard model particles, including features such as positron energy loss and diffusion. We found that this has dramatic implications for leptophilic models, and must be taken into account, especially when this W/Z emission lifts suppression. Constraints on the annihilation rate from the antiproton signal are significantly stronger than constraints from positrons, and the emission completely alters the annihilation spectrum. In the paper *Electroweak Bremsstrahlung in Dark Matter Annihilation* (Phys. Rev. D **78**, 083540 (2008)), we found that Electroweak Bremsstrahlung can be a significant annihilation channel, even when 2-body annihilation is not suppressed.

Future Plans

The conventional scenario of thermal WIMP production fails to account for the intriguing coincidence between the DM and baryon densities of the universe. A number of models, such as asymmetric DM, have attempted to link DM production to baryogenesis. I am interested in constructing models that establish such a connection. Furthermore I plan to investigate detectability of the distinctive observational signals these models present. For example, DM scattering off baryonic matter may violate baryon number, which could lead to unexpected direct detection signals, or astrophysical phenomena in regions of high density. Whenever testing a model for viability I plan to take advantage of the complementary approaches of different DM searches, and check for consistency between, for example, indirect detection, direct detection, and collider constraints.

In addition, I plan to employ upcoming Fermi and IceCube data to further constrain DM. For Fermi, observation of regions with a high signal to background ratio, like dwarf spheroidals, and regions with a large DM density, like the Galactic center will further strengthen constraints on DM annihilation. Similarly, many DM models predict a unique neutrino signature due to DM capture in the sun. Any of these regions may provide a candidate DM signal in the near future. The techniques I have used in the past could be used to test a particular class of model for compatibility with such a signal, or constrain the annihilation rate in general, if no such signal is seen.