

On the Detection of Dark Matter

Likelihoods and limits on spin-independent and spin-dependent WIMP couplings and the implementation of radiative muon decays in dark matter analyses.



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For Li.

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Abstract

This thesis presents advancements in two of the three avenues for the detection of particle dark matter: direct and indirect searches. The first four chapters provide an introductory overview of particle dark matter and its distribution, evidence and constraints as well as statistical tools used in direct and indirect analyses.

The second main segment of the thesis presents `LUXCalc`, a new utility for calculating likelihoods and deriving WIMP-nucleon coupling limits from the recent results of the LUX direct search dark matter experiment. After a comprehensive review of WIMP-nucleon scattering, we derive LUX limits on the spin-dependent WIMP-nucleon couplings over a broad range of WIMP masses, under standard assumptions on the relevant astrophysical parameters. We find that, under these and other common assumptions, LUX excludes the entire spin-dependent parameter space consistent with a dark matter interpretation of DAMA's anomalous signal, the first time a single experiment has been able to do so. We also revisit the case of spin-independent couplings, and demonstrate good agreement between our results and the published LUX results. Finally, we derive constraints on the parameters of an effective dark matter theory in which a spin-1 mediator interacts with a fermionic WIMP and Standard Model fermions via axial-vector couplings. A detailed section describes the use of `LUXCalc` with standard codes to place constraints on generic dark matter theories.

The final segment looks at the fact that photons can be produced from final state muons, and the consequences of considering such a process in indirect searches. Modern Monte Carlo generators and DM codes include the effects of final state radiation from muons produced in the dark matter annihilation process itself, but neglect the $\mathcal{O}(1\%)$ radiative correction that arises from the subsequent muon decay. After implementing this correction we demonstrate the effect that it can have on dark matter phenomenology by considering the case of dark matter annihilation to four muons via scalar mediator production. We first show that the AMS-02 positron excess can no longer easily be made consistent with this final state once the Fermi-LAT dwarf limits are calculated with the inclusion of radiative muon decays, and we next show that the Fermi-LAT galactic centre gamma excess can be improved

with this final state after inclusion of the same effect. We provide code and tables for the implementation of this effect in the popular dark matter code `micrOMEGAs`, providing a solution for any model producing final state muons.

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