Phystat-DM low threshold effort

Treating and comparing results from low-threshold dark matter direct detection experiments

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On behalf of the Phystat-DM collaboration.

Outline

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https://arxiv.org/pdf/2105.00599.pdf

Phystat DM first white paper

Recommended conventions for reporting results from direct dark matter searches

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Abstract

The field of dark matter detection is a highly visible and highly competitive one, with many collaborations around the world now seeking to directly detect dark matter in very sensitive detectors. To translate experimental data into a final published result, direct detection collaborations must make a series of choices in their analysis, choices ranging from how to model astrophysical parameters in projecting particle fluxes at the detector to how to make statistical inferences based on observed data. While many collaborations follow a standard set of recommendations in some areas, for example the expected flux of dark matter particles (to a large degree based on a paper from Lewin and Smith in 1995), in other areas, particularly in statistical inference, they have taken different approaches, often from result to result by the same collaboration. In this paper, we set out a number of recommendations on how to apply the now commonly used Profile Likelihood Ratio method to direct detection data. In addition, updated recommendations for the Standard Halo Model astrophysical parameters and relevant neutrino fluxes are provided, which are important for assessing dark matter sensitivity. The authors of this note include members of the DAMIC, DarkSide, DARWIN, DEAP, LZ, PandaX, PICO, SENSEI, SuperCDMS, and XENON collaborations, and these collaborations provided input to the recommendations laid out here. Wide-spread adoption of these recommendations will make it easier to compare and combine future dark matter results.

1 Introduction and Purpose of this Paper

The nature of dark matter (DM) is one of the highest-priority topics in high energy particle physics. Many collaborations around the world are building exquisitely sensitive detectors to search for dark matter particles, often in direct competition with each other, and in the future, collaborations may wish to combine data from complementary targets to draw even stronger conclusions about dark matter models, especially in light of neutrino backgrounds [1] and model uncertainties [2].

In going from data to a final dark matter result, or even in projecting the potential sensitivity of a proposed experiment, direct detection collaborations make a series of choices, ranging from how to model the dark matter halo in the Milky Way to which test statistic to use to perform statistical inference. Different approaches can lead to significant differences in the interpretation of a result even if the underlying data are the same, complicating comparisons and combinations of results. In a recent example, the LUX collaboration deployed a power constrained limit [3] (discussed in Sec. 2.2.1) for their dark matter limits [4,5], but chose a different power threshold in the two results; making the same choice in Ref. [4] as in Ref. [5] would have changed the resulting limit by a factor of $\sim$2. Similarly, the XENON1T collaboration presented a first result by approximating their likelihood ratio with an asymptotic distribution [6], an approximation that led incorrectly to a $\sim$50% more sensitive result. For their second science run, XENON1T corrected this treatment [7].

Background modeling is another area where collaborations make choices with potentially significant implications on inferred results. While many backgrounds are unique to each detector, there are some elements that are shared by all direct detection experiments, such as those induced by astrophysical neutrinos. To model solar or atmospheric neutrino backgrounds, collaborations rely on external data, with varying possible interpretations of the rates in dark matter detectors. As direct detection experiments increase in exposure, measurements of these astrophysical neutrino fluxes will be among the primary determinants of sensitivity [8].

Phystat DM first white paper motivations

- Different Direct Detection DM experiments use different conventions in their statistical analysis leading to different results.
- Establish a set of recommended conventions with individuals from many of the largest Direct Detection experiments (DAMIC, DarkSide, DARWIN, DEAP, LZ, PandaX, PICO, SENSEI, SuperCDMS, and XENON) for reporting results from direct dark matter searches.

[2105.00599]

Phystat DM first white paper

- PLR method
  - Confidence intervals
  - Discovery
  - Power limited bounds
  - Look elsewhere
- Conventions of:
  - Standard Halo Model
  - Neutrino Backgrounds

Phystat DM low-threshold white paper

- Many of the needs and problems of low threshold experiments were left unanswered in the first paper.
- Some of these problems are not entirely statistical, and a discussion of systematic uncertainties is critical.
- Started meetings roughly 3 months ago.
- Paper structure and exact topics are still not rigidly set.

Paper overview: PLR and its alternatives

- The PLR has several problems, mostly stemming from:
  - Problems with unmodeled uncertainties
  - Computationally expensive
- Discussion of some of the alternatives to the PLR, and where they might be useful:
  - Optimum Interval
  - Counting Events
  - Machine learning algorithms

Paper overview: Detector, Background, and Signal Conventions

- Low threshold experiments have a much weaker hold on systematic uncertainties
- Detector Physics:
  - Threshold effects.
  - Detector microphysics.
  - Post interaction detector response.
- Background estimation:
  - Qualifying Radioactive Bkg models
  - Unmodeled backgrounds
- Signal modeling
  - Effects of systematic uncertainties in the signal model.

Paper Overview: Discovery Potential

- Current low-energy systematics (e.g. poorly understood backgrounds and detector response) complicate discovery potential assessments.
- Weigh in on the possibility of changing that in the future

Paper Overview: Enabling Collective Analysis

- As we’ve discussed, different experiments have different problems of varying severity
- Is there a way to compare the results of different experiments?
- Can we quantify at which regions of the parameter space an experiment has fewer systematic uncertainties?
- Can multi-experiment analyses be performed? Different experiments have different information (e.g. time vs spatial resolution), can that be used?
- This section is where it is hoped that the EXCESS workshop could contribute the most.

Discussion Preamble

- I will summarize the discussion, and spread that within the phystat-DM collaboration.
- The EXCESS workshop and the contribution of this discussion will be acknowledged by the paper.
- Anyone who wants to further help the effort, is invited to join the white paper, by sending me an email to: ItayBlochM@gmail.com

Discussion Leading Questions

What type of information should collaboration publish to ease comparison and multi-experiment analyses

- How can one compare between experiments that used different analysis methods. Is there some more “raw” data that can be published to make this easier?
- Different experiments have different level of knowledge for their background models. Is there a way to quantify this?
- The level of reliability of the detector modeling varies significantly between experiments. Can that be quantified? Is an exclusion plot more reliable if two detectors of very different microphysics exclude the same region?

Note: It’s important to not only compare different experiments, but also compare a single experiment’s exclusion capabilities for different DM model parameters (e.g. mass).