The AMIDAS Website: An Online Tool for Direct Dark Matter Detection Experiments

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Abstract. Following our long–term work on development of model–independent data analysis methods for reconstructing the one–dimensional velocity distribution function of halo WIMPs as well as for determining their mass and couplings on nucleons by using data from direct Dark Matter detection experiments directly, we combined the simulation programs to a compact system: AMIDAS (A Model–Independent Data Analysis System). For users’ convenience an online system has also been established at the same time. AMIDAS has the ability to do full Monte Carlo simulations, faster theoretical estimations, as well as to analyze (real) data sets recorded in direct detection experiments without modifying the source code. In this article, I give an overview of functions of the AMIDAS code based on the use of its website.

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INTRODUCTION

Weakly Interacting Massive Particles (WIMPs) χ arising in several extensions of the Standard Model of electroweak interactions are one of the leading candidates for Dark Matter. Currently, direct searches for different candidates for WIMP Dark Matter based on measuring recoil energy deposited by elastic scattering of ambient WIMPs on the target nuclei [1, 2] are one of the promising methods for understanding the nature of Dark Matter particles, identifying them among new particles produced hopefully in the near future at colliders, as well as reconstructing the (sub)structure of our Galactic halo.

However, for conventional data analyses used in direct detection experiments one needs assumptions not only about the Galactic halo from astrophysics but also about the WIMP properties from particle physics [3]. Therefore, since a few years ago we started to develop new methods for analyzing data, i.e., measured recoil energies, from (future) direct detection experiments as model–independently as possible. Up to now we could in principle reconstruct the (moments of the) one–dimensional velocity distribution function of halo WIMPs [4], as well as determine the WIMP mass [5] and (ratios of) their couplings on nucleons [6, 7].

Following the development of these model–independent data analysis procedures, we combined the programs for simulations to a compact system: AMIDAS (A Model–Independent Data Analysis System). For users’ convenience and under the collaboration with the ILIAS Project [8], an online system [9] has also been established at the same time.

In this article, I give an overview of functions of the AMIDAS code based on the use of its website. In Sec. 2 I will describe the AMIDAS’ functions and different working modes for these functions. In Sec. 3 I will talk about the options of the input parameters for simulations which users can modify. In Sec. 4 the use of the AMIDAS website for analyzing user–uploaded data sets will be described. I will conclude and give some future prospects of the AMIDAS code and website in Sec. 5.

FUNCTIONS, MODES, TARGETS

AMIDAS’ Functions

Based on our works on the model–independent data analysis methods for extracting the nature of halo WIMPs [4, 5, 6, 7], AMIDAS has so far the following functions:

1. reconstruction of the one–dimensional velocity distribution function of halo WIMPs;
2. determination of the WIMP mass;
3. determinations of ratios of different WIMP–nucleon couplings/cross sections;
4. estimation of the spin–independent (SI) WIMP–proton coupling.

Reconstruction modes

For reconstructing the one–dimensional WIMP velocity distribution and estimating the SI WIMP–proton coupling, one needs the WIMP mass $m_\chi$ as an input parame-
This information could be obtained either from e.g., collider experiments, or from two direct detection experiments \cite{5}. To allow these two cases, AMIDAS has three options of the input WIMP mass for the reconstruction mode:

1. with only an input WIMP mass from other/collider experiments;
2. with only a reconstructed WIMP mass from other direct detection experiments;
3. with both of them.

In addition, AMIDAS offers two modes for determining the WIMP mass \cite{5}:

1. only the combined result from the estimators for different moments;
2. both the combined result from and each of the estimators for different moments.

**Target(s)**

So far AMIDAS uses $^{28}$Si, $^{76}$Ge, $^{40}$Ar, and $^{136}$Xe for simulations and can analyze data sets with these four targets. For the determination of the WIMP mass, two combinations have been programmed \cite{5}:

1. $^{28}$Si + $^{76}$Ge;
2. $^{40}$Ar + $^{136}$Xe.

**Data type**

The most important and powerful ability of the AMIDAS code is that this system and its website can not only do simulations with self–generated events based on the Monte Carlo method, but also analyze user uploaded data set(s) generated by other event generators or recorded in direct Dark Matter detection experiments without modifying the source code. Users have thus two choices for the data type:

1. a simulation (events will be generated by AMIDAS);
2. real (user–uploaded) data.

A sample file for the uploaded data sets can be downloaded from the AMIDAS website.

**Simulation mode**

All AMIDAS’ functions can be simulated based on the Monte Carlo method. Considering the current experimental sensitivity and the required executing time for these simulations, the AMIDAS website offers full Monte Carlo simulations with maximal 2,000 experiments and maximal 2,500 events on average per one experiment.

However, since the algorithmic procedure for the determination of the WIMP mass, needed also for the reconstruction of the one–dimensional WIMP velocity distribution function and for the estimation of the SI WIMP–proton coupling, takes a (much) longer time than what usual Monte Carlo simulations require, AMIDAS also offers users faster theoretical estimations as an alternative option:

1. a Monte Carlo simulation;
2. a theoretical estimation.

Here integrals over the theoretical predicted recoil spectrum will be used.

Note that, firstly, since for these estimations the statistical fluctuations have not been taken into account, these pure theoretically estimated results, especially for cases with (very) few events, could be (fairly) different from results obtained by more realistic simulations. Secondly, as the alternative option for the Monte Carlo simulation with a much shorter required executing time, the total event number used for theoretical estimations is fixed, and the calculations are limited to be done for only a few times. These restrictions could cause sometimes unexpected zigzag on the result curves.

**RUNNING SIMULATIONS**

In this section, I describe the options of the input factors needed for predicting the recoil spectrum used only for generating events. Note that some commonly used and standard AMIDAS’ values used for our works presented in Refs. \cite{4, 5, 6, 7} have been given as default choices, but all these parameters can be modified by users.

**WIMP properties**

The following information on the WIMP properties are required for predicting the recoil spectrum and/or analyzing user–uploaded data. Note that not all of them are needed for every AMIDAS’ function.

1. the input WIMP mass $m_{\chi}$;
2. an overall uncertainty on the input WIMP mass $\sigma(m_{\chi})$;
3. the SI WIMP–proton cross section $\sigma_{SI}^{p}$.  

\footnote{The actual event number for each Monte Carlo simulated experiment is Poisson–distributed around the expected value set by users.}
Astronomical setup

**AMIDAS** requires the following astronomical parameters for the velocity distribution function of halo WIMPs:

1. the WIMP density near the Earth $\rho_0$;
2. the Sun’s orbital velocity in the Galactic frame $v_0$;
3. the escape velocity from our Galaxy at the position of the Solar system $v_{esc}$;
4. the date on which the Earth’s velocity relative to the WIMP halo is maximal, $t_p$;
5. the experimental running date $t_{expt}$.

Velocity distribution of halo WIMPs

So far users have two options for the one–dimensional WIMP velocity distribution function [4]:

1. the simple Maxwellian velocity distribution $f_{1,Gau}(v)$;
2. the shifted Maxwellian velocity distribution $f_{1,sh}(v)$.

Note that the analytical forms of these velocity distributions can be checked on the website, once one hovers the cursor onto the “analytical form”. By clicking it one can also open another page and get more detailed information and some references about the velocity distribution.

Nuclear form factor for the SI cross section

So far users have four options for the nuclear form factor for the SI WIMP–nucleus cross section:

1. the exponential form factor $F_{ex}(Q)$ [10, 11, 3];
2. the Woods-Saxon form factor $F_{WS}(Q)$ [12, 3];
3. the Woods-Saxon form factor with a modified nuclear radius $F_{WS,Eder}(Q)$ [13, 2];
4. the Helm form factor $F_{Helm}(Q)$ [14, 2].

As for the velocity distribution function, the analytical forms of these form factors can be checked on the website, by hovering the cursor onto the “analytical form” or by clicking it to open another page for more detailed information and references.

Nuclear form factor for the SD cross section

For the nuclear form factor for the spin–dependent (SD) WIMP cross section, due to its dependence on the SD WIMP–nucleon couplings as well as on the individual spin structure of target nuclei, **AMIDAS** offers so far only one analytic form for the SD cross section, namely,

1. the thin-shell form factor, $F_{TS}(Q)$ [2, 15].

Experimental setup

Finally, one needs to set the following experimental information:

1. the minimal and maximal cut–off energies, $Q_{min}$ and $Q_{max}$;
2. the width of the first $Q$–bin, $b_1$;
3. the (expected) total event number between $Q_{min}$ and $Q_{max}$, $N_{tot}$;
4. the number of simulated experiments or uploaded data sets;
5. the number of $Q$–bins between $Q_{min}$ and $Q_{max}$.

Note that, as for the WIMP velocity distribution function and the elastic nuclear form factors, users can hover the cursor onto each notation in the setup tables for checking its definition.

Running simulations

After giving all the required information for the aimed simulation, users have one more chance to check their choices, modify some of them, and then resubmit the whole setup. In case that any required datum is missed, this omission will be detected automatically after the (re)submission; users will be reminded of that with a red block around the table. Note that all data in this table will be reset to the default values and should therefore be checked again and modified eventually to the users’ own choices.

Once all the required data have been checked, users have only to click the “Simulation start” button and wait for the simulation results for a few minutes.

Output results

Simulation results will be given in form(s) of plot(s), and/or eventually table(s). In order to let users understand the output results more conveniently and clearly, each output plot or table will be accompanied with a short caption. On the other hand, for users’ need of self–producing results with different kinds of presentation, the original file of output results with users’ personal simulation setup will also be given and downloadable from the website. Remind that it would be very grateful that
a credit of the AMIDAS program and website could be given for using the output results.

**ANALYZING (REAL) DATA**

The most useful and powerful function of the AMIDAS website is the ability for analyzing user–uploaded data set(s) directly.

**Preparing data set(s)**

As mentioned above, on the AMIDAS website users can find and download a sample file for the uploaded data sets. Note that, for comments a "0" (zero) has to be used at the beginning; and all words in the comment lines must be connected by "_" (underscores). For instance,

0 \text{ sigma\_[chi,\_p]^SI\_\_le-8_pb}
0 \text{ m\_[chi\_\_50_GeV}

1 dataset, 43 events, 12817.27 kg-day:

1 1 5.25 keV;
1 2 5.37 keV;
;

0 \text{ m\_[chi\_\_100_GeV}

2 dataset, 53 events, 15322.9 kg-day:

2 1 6.16 keV;
2 2 4.25 keV;
;

Note also that it is unnecessary to output generated/recorded recoil energies in the ascending or descending order in your uploaded data file(s). AMIDAS will order the events in each data set after reading them.

**Uploading data file(s)**

Users can upload their data file(s) as usual. Note only that the maximal size of each uploaded file is 2 MB.

**Analyzing uploaded data**

As for simulations, after giving all the required information for the aimed analysis, users have one more chance to check their choices and the original name(s) of their data file(s), modify some of them and/or replace the uploaded data file(s), and then resubmit the whole setup. In case that any required datum or data file is missed, this omission will be detected automatically after the (re)submission; users will be reminded of that with a red block around the table. Note that, while all data in this table will be reset to the default values and should therefore be checked again and modified eventually to the users’ own choices, only the missed data file(s) and the replacement(s) of the uploaded file(s) will be required to upload.

Once all the required data and uploaded data file(s) have been checked, users have only to click the “Data analysis start” button and wait for the analyzed results for a few minutes.

**SUMMARY**

In this article, I introduced a new simulation/data analysis code and its website for direct Dark Matter detection experiments. So far users have only a few options for the WIMP velocity distribution function as well as for the nuclear form factors, as a planned improvement user–defined velocity distribution and form factor(s) for their own target(s) should be able to read from an uploaded plain text file in the future. Moreover, the choice(s) of target(s) will also be released for (at least) most of the currently running and projected experiments.

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