Dark Matter Spin-Dependent Limits for WIMP Interactions on ^{19}F by PICASSO

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Abstract. The PICASSO experiment at SNOLAB uses super–heated C_4F_{10} droplets suspended in a gel as a target sensitive to WIMP–proton spin–dependent elastic scattering. The phase II setup has been improved substantially in sensitivity by using an array of 32 detectors with an active mass of ∼65 g each and largely reduced background. First results are presented for a subset of two detectors with target masses of ^{19}F of 65 g and 69 g respectively and a total exposure of 13.75 ± 0.48 kgd. No dark matter signal was found and for WIMP masses around 24 GeV/c^2 new limits have been obtained on the spin–dependent cross section on ^{19}F of $\sigma_F = 13.9$ pb (90% C.L.) which can be converted into cross section limits on protons and neutrons of $\sigma_p = 0.15$ pb and $\sigma_n = 2.45$ pb respectively (90% C.L). The obtained limits on protons restrict recent interpretations of the DAMA/LIBRA annual modulations in terms of spin-dependent interactions.

1. Introduction

The PICASSO experiment (Project In Canada to Search for Super-Symmetric Objects) at SNOLAB searches for cold dark matter through the direct detection of neutralinos via their *spin-dependent* (SD) interactions with ^{19}F nuclei [1, 2]. The active detector material in PICASSO is liquid C_4F_{10}, which is in a metastable, superheated state at ambient temperature and pressure. In this condition a heat spike due to the energy deposited by an ionizing particle can cause the formation of a vapour bubble. This phase transition is explosive in nature and accompanied by an acoustic signal in the audible to ultrasonic frequency range. This can easily be registered by piezoelectric transducers.

By rising the temperature we can increase the superheat stored in the droplet. This results in less amount of energy needed to be deposit in order to trigger the phase transition [1]. Therefore each temperature corresponds to a well defined recoil energy threshold, and the spectrum of the particle induced energy depositions can be reconstructed by ramping the temperature. In such case, the response to different kinds of particle interactions depends on the respective specific energy losses, as shown in Fig. 1 (left).

Alpha particles are the main source of background events for PICASSO, but since the shapes of the WIMP and alpha curves differ substantially (see Fig. 1, left), the alpha background can be efficiently discriminated by measuring the temperature profile of the detector response.

2. Results

The new results presented in this work are based on a set of data collected with two PICASSO modules, detectors 71 and 72, which were deployed at SNOLAB on October 2006. Their ^{19}F target mass is 65.06 ± 3.2 g and 69.0 ± 3.5 g, respectively. The runs used for this analysis covered the period from June 2007 until July 2008, with three neutron source calibration periods interspersed, which allowed monitoring the stability over the period of data taking. The temperatures were varied in the range from 45°C to 18.5°C, which corresponds to a range of threshold energies from 2 keV to 200 keV. A total of 101.5 d (103.5 d) of data taking time has been used in this analysis for det. 71 (72), respectively, which results in a total exposure of 13.75 ± 0.48 kgd. Two independent analyses have been performed and yielded consistent results. For further details on the set up and the data analysis the reader is referred to [3].

The final count rates of det. 71 and 72 as a function of temperature can be seen in Fig. 1 (right). The two detectors exhibit temperature profiles identical to the response of the ^{226}Ra spiked detector shown in Fig. 1 (left) and the observed count rates are attributed to alpha particles.

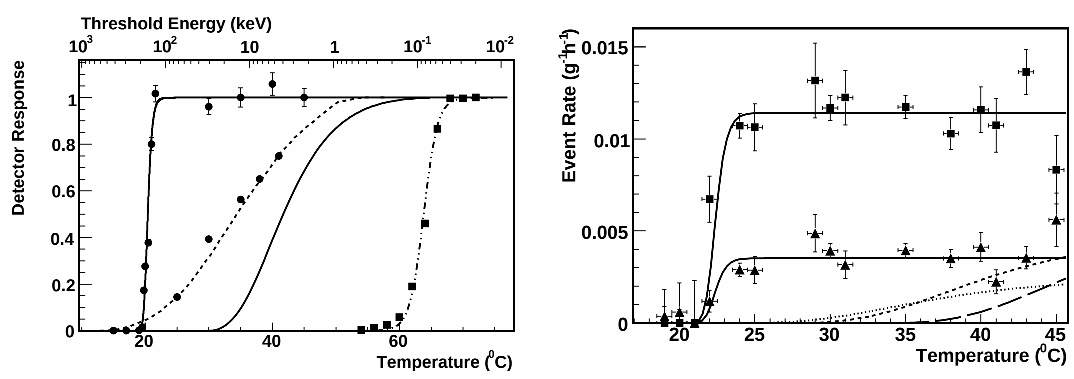

Figure 1: Left: Detector response to different types of particles as a function of temperature for detectors loaded with C_4F_{10} droplets of ∼200μm in diameter. From left to right: alpha particles of 5.6 MeV in a detector spiked with ^{226}Ra (fit to data points represented by continuous line); nuclear recoils from fast neutrons of an AmBe source compared to simulations (dotted line); expected response for nuclear recoils following scattering of a 50 GeVc^{-2} WIMP (continuous line); response to 1.275 MeV gamma rays of a ^{22}Na source (dashed line). All responses are normalized to one at full detection efficiency. Temperatures are converted into threshold energies (upper x-axis). If not visible, experimental errors are smaller than the symbols. Right: Count rates of det. 71 and 72 as a function of temperature. The rates are normalized by the active mass of ^{19}F and indicate the different levels of α-background. Also shown are the expected response curves for WIMP induced nuclear recoils for M_W = 10 GeV c^{-2} (broken), 30 GeV c^{-2} (dashed) and 100 GeV c^{-2} (dotted); a cross section of $\sigma_p = 1$ pb was assumed for clarity.

In order to compare the data of detectors 71 and 72 to the expected ^{19}F recoil spectrum for interactions with WIMPs in our galactic halo, we follow the recommendations in [4]. Keeping the WIMP mass and the cross section as parameters, the expected WIMP induced count rate can be calculated as a function of temperature by applying the PICASSO threshold function [3] to the expected WIMP induced recoil spectrum. The resulting response curves are shown for several WIMP masses in Fig. 1 (right). They differ significantly in shape from the flat alpha background and therefore by fitting the two distributions to the data an upper bound can be set on the interaction cross section σ_F on ^{19}F for a given value of WIMP mass M_W.

The two free parameters of the fit are the scale factor of the alpha plateau and the cross section σ_F (M_W) for a given WIMP mass. The minima of the reduced chi-squares were found

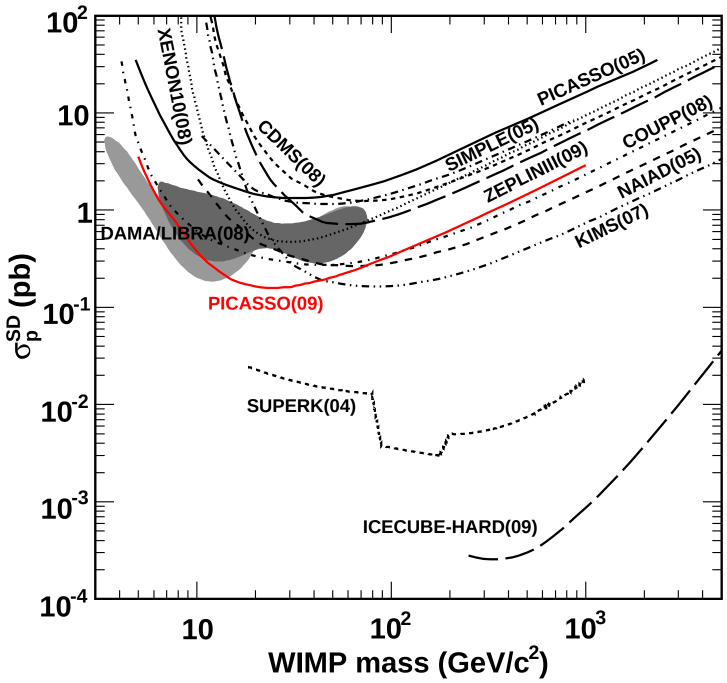

Figure 2: Upper limits on direct spin-dependent WIMP-protons from PICASSO (full lines) compared to other experiments.

to lie around $\chi^2 = 1.2$ and 1.1 for detectors 71 and 72, respectively over a mass range from $M_W = 7$ to 1000 GeVc^{-2}. By combining the fit results of both detectors in a weighted average we obtain the maximum sensitivity for a WIMP mass of $M_W = 24$ GeVc^{-2} and a cross section of σ_F = - 0.446 pb $\pm$ 10.83 pb $\pm$ 0.53 pb (1σ), compatible with no effect. This result can be converted into a limit on the cross section for WIMP induced reactions on ^{19}F of $\sigma_F = 13.9$ pb (90% C.L.). Following [4] we can translate the obtained fit results for σ_F into a cross section measurement on free protons of σ_p = - 0.0051 pb $\pm$ 0.124 pb $\pm$ 0.007 pb (1σ) which results in a limit of $\sigma_p = 0.15$ pb (90%C.L.) for a WIMP mass of 24 GeVc^{-2}. The resulting exclusion plot for the cross section on protons as a function of the WIMP mass is shown in Fig. 2, where we also compare the obtained limits with the most recent results of other experiments in the spin-dependent sector.

In the WIMP-proton spin-dependent sector the new limits rule out a substantial part of the allowed parameter space of the DAMA/LIBRA experiment if no ion channelling is assumed, but leave still some room if the ion channelling hypothesis is adopted [5].

References

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