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SIMPLE limits on spin-dependent WIMP interactions

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Abstract. An improved SIMPLE experiment comprising four superheated droplet detectors with a total exposure of 0.42 kg.d yields ~factor 10 improvement in the previously-reported results. Despite the low exposure, the result provides restrictions on the allowed phase space of spin-dependent coupling strengths almost equivalent to those from the significantly larger exposure NAIAD-CDMS/ZEPLIN searches.

SIMPLE is a project to detect spin-sensitive WIMP dark matter interactions, and one of only two [1] such projects based on superheated droplet detectors (SDDs). The basics of these devices have been described previously [2]. We report the results of our most recent measurement [3].

The detectors were fabricated in-house from C_2ClF_5 (R-115) according to previously-described procedures [2]. These were installed in the 1500 mwe LSBB laboratory [4], inside a thermally-regulated 700 liter water bath, surrounded by three layers of sound and thermal insulation, resting on a dual vibration absorber. To reduce ambient noise, a hydrophone was placed within the detector water bath, and a second acoustic monitor positioned outside the shielding. Apart from temperature control, the surrounding water bath acts as a ~ 30 cm thick neutron moderator, further reducing any ambient neutron flux by at least two orders of magnitude.

A bubble nucleation is detected by a piezoelectric transducer immersed in a glycerine layer at the top of the detector. Whenever an event in any one of the detectors occurs, the temperature, pressure, and threshold voltage level for each device, plus its waveform trace and fast Fourier transform, are recorded in a Labview platform.

The detectors were operated for 10.2 days at 8.9ºC (2.0 atm), and 14.3 days at 3.3ºC (1.9 atm). Additional measurements were performed at 14ºC in order to insure that all low rate devices were operating properly.

In a first analysis stage, the individual detectors were physically inspected for fractures (which lead to spontaneous nucleations at the fracture sites), and their responses monitored over the measurement period. Three of the devices were rejected as a result of fractures and/or performances outside specification tolerances.

The data record was anti-coincidence filtered on an event-by-event basis, with the criteria that (i) one and only one of the in-bath detectors had a signal, and (ii) no monitoring detector had a simultaneous signal.

Table 1. Data results, without acoustic detection efficiency or background correction.

			Filter N°1		Filter N°2	
Detector	Active Mass (g)	Acoustic Efficiency	8.9ºC (evts/kg.d)	3.3ºC (evts/kg.d)	8.9ºC (evts/kg.d)	3.3ºC (evts/kg.d)
2	9.9	0.52 ± 0.10	278 ± 52.6	21.2 ± 12.2	179 ± 42.1	7.1 ± 7.1
4	10.8	1.11 ± 0.19	54.6 ± 22.3	25.9 ± 13.0	36.4 ± 18.2	25.9 ± 13.0
5	10.4	0.83 ± 0.17	66.2 ± 25.0	13.4 ± 9.5	28.4 ± 16.4	0
7	11.1	1.21 ± 0.21	558 ± 70.3	271 ± 41.3	407 ± 60.1	221 ± 37.3

A second filtering was imposed in which only the Filter N°1 events with a primary harmonic between 5.5-6.5 kHz were accepted, since the frequency spectrum of the transducer signal comprises a well-defined response with a primary harmonic at ~ 6 kHz. The rate reductions are shown in Table 1.

Backgrounds and their treatment have been discussed elsewhere [3]. The difference (n) between the fully filtered measurements at 9ºC and 3ºC is most likely a sum of background and microleak events: a 90% C.L. upper limit to the unobserved WIMP rate was set from the expectation value of the total number of events, μ_n, such that the probability of observing at least n events is 90%. Subtracting the expected number of background events (computed by maximum likelihood) from μ_n yields an estimate of 24.0 events/(kg.d) (corrected for acoustic detection efficiency) for the expected, unobserved WIMP events.

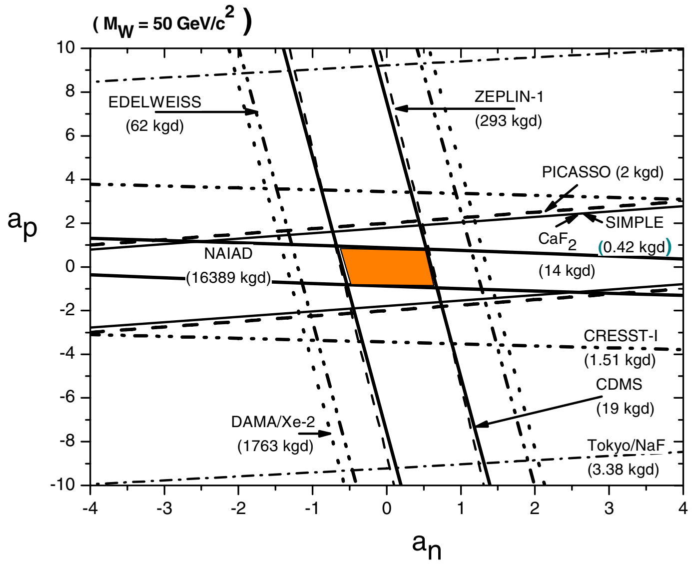

Figure 1. a_p - a_n for SIMPLE (thick dashed), PICASSO (thick solid), NAIAD (dotted), CRESST-I and Tokyo/NaF for WIMP mass of 50 GeV/c^2. Also shown are the single nuclei DAMA/Xe2, and spin-INdependent EDELWEISS, CDMS and ZEPLIN-I. The region permitted by each experiment is the area inside the respective contour, with the shaded central region the allowed intersection of the NAIAD-CDMS/ZEPLIN measurements [3].

The results were analyzed in a model-independent formalism following reference [5] using the cosmological parameters and method described in reference [6], in which the spin-dependent interaction cross section for a WIMP interaction with a nucleon is $\sigma_{SD} \sim [a_p\langle S_p\rangle + a_n\langle S_n\rangle]^2$, where $a_{p,n}$ ($S_{p,n}$) are the proton and neutron coupling strengths (proton and neutron group spins) respectively. These are shown in figure 1 at 90% C.L. for M_W = 50 GeV/c^2 (masses above or below this choice yield slightly increased limits), using the spin values of reference [7]; use of the reference [8] values would rotate the SIMPLE and PICASSO curves about the origin to a more horizontal orientation.

The region excluded by an experiment lies outside the indicated band, and the allowed region is defined by the intersection of the various bands. The new SIMPLE result eliminates a large part of the parameter space allowed by the significantly larger exposure Tokyo/NaF [9], NAIAD/NaI [10] and CRESST-I/Al_2O_3 [11] measurements at this mass cut, as well as the neutron-sensitive DAMA/Xe2 experiment [12]. The SIMPLE result provides slightly more restrictive bounds than the most recent 2 kg.d PICASSO report [1], but with a factor ~5 less exposure; the difference most likely results from the higher intrinsic backgrounds owing to the CsCl salts used in density-matching their gel and refrigerant. The allowed area of the SIMPLE-CDMS/ZEPLIN intersection ($|a_p| \leq 2.4$, $|a_n| \leq 0.8$) at 50 GeV/c^2 is only slightly larger than that of NAIAD-CDMS/ZEPLIN ($|a_p| \leq 1.4$, $|a_n| \leq 0.7$), and corresponds to [5] $\sigma_p \leq 0.7$ pb, $\sigma_n \leq 0.2$ pb.

Penetrating the frontier of the current allowed region of the a_p - a_n phase space shown in figure 1 would require only a modest 3 kg.d exposure at the current SIMPLE performance, which is relatively easily achievable. The recent application of pulse shape analysis techniques to the data records has moreover identified the possibility of discriminating between signal and microleak events, suggesting the ability to reach overall measurement rates of ~ 1 event/(kg.d) for the same 3 kg.d exposure, corresponding to a factor of 10 further reduction in the exclusion. The SIMPLE project has recently received funding for conduct of the 3 kg.d measurement.

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