

Prospects for a Phase III SIMPLE Measurement

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Abstract. Current plans of the SIMPLE project include a Phase III measurement based on a new device under development the past two years which contains a large superheated liquid “droplet” within a gel-sheathed vessel (effectively a bubble chamber). Apart from a change in refrigerant and instrumentation, the experiment is to be re-shielded to provide an additional factor 10^4 in neutron suppression. We briefly describe the chamber and its instrumentation, the projected run configuration, and expected results.

1. Introduction

The recently-reported Phase II SIMPLE measurements [1] yielded the most restrictive exclusion contour in the spin-dependent (SD) sector of WIMP-proton interactions from a direct search experiment to date, overlapping for the first time results previously obtained only indirectly. In the spin-independent (SI) sector, a contour challenging the recent CoGeNT result [2] was also obtained.

The measurements were executed in two Stages of 15 superheated droplet detectors (SDDs) each, each stage comprising ~ 0.2 kg active mass, over periods of ~ 100 days without recompression. The surrounding neutron shielding, following improvements between the two Stages, provided an on-detector background rate estimate of 0.253 evt/kgd, arising mainly from the U/Th content of the water-shield itself.

In order to obtain an improved sensitivity over the Phase II measurements in a fashion competitive with other experiments in the field, any next-phase measurement requires larger exposure

measurements over shorter observation times with significantly improved neutron shielding. With a continued use of SDD's, this is beyond the capacity of the activity: detector fabrication alone requires two days per detector; the analysis of the matrix signals, more.

2. The Phase III plan

Phase III replaces the SDDs with a prototype bubble chamber (BC) variant of $\sim 25x$ the current matrix SDD active mass in a volume of ~ 8 SDDs, combined with additional neutron shielding using purified water.

2.1. Change of detector

Unlike a SDD, a BC involves no distribution of superheated liquid in a gel matrix, so that the active volume \sim device volume. A 300 g BC variant [3], prototyped by SIMPLE in 2010, differs from that of COUPP [4] and more conventional devices in the use of a purified food-gel based-sheathing of the containment, providing the same smooth gel-freon interface as with the SDDs (to reduce the probability of spontaneous nucleation: recompression times of up to ~ 12 h have been observed [3]) and maintaining the containment radio-purity (α -induced events < 0.5 evt/kgd), while preserving the reduced cost of detector fabrication.

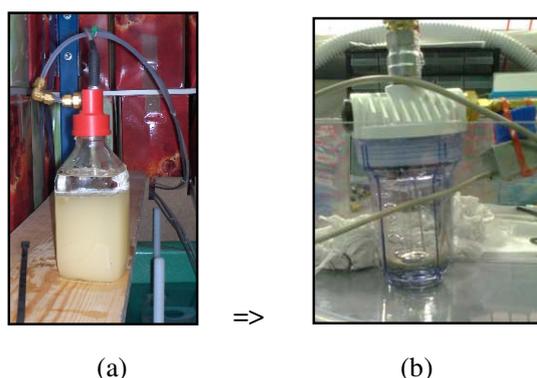


Fig. 1: (a) standard Phase II SDD, containing 10-20 g C_2ClF_5 ; (b) the 300g BC prototype of the about the same volume undergoing testing.

At present, the “home water filter” prototype is recompressed using a pressure-activated system; a new piston-based recompression prototype to separate the recompression gas (N_2) from the gel and superheated liquid has been developed. The prototype scale-up to a 5 kg liquid containment, constrained by commercial plastics and their ability to sustain a 10 bar recompression, is shown in Fig. 2, and differs from Fig. 1 (b) in having the acoustic instrumentation and recompression mounted at opposing ends of the chamber.

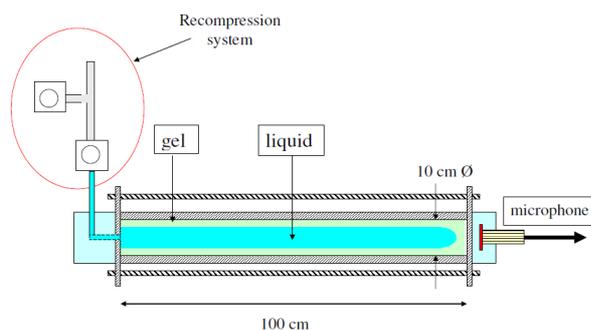


Fig. 2: schematic of a 5 kg chamber in prototyping.

Owing to dwindling stocks of C_2ClF_5 and its general unavailability in Europe, Phase III is anticipated to use C_3F_8 as the active superheated liquid. This implies operation at $10^\circ C$ and 2 bar to preserve the 8 keV or lower recoil energy threshold of Phase II; other refrigerants (C_2ClF_5 , C_2ClF_2) can also be used with little change, whereas CF_3I and C_4F_{10} require some attention to the temperature control (which is to be effected by the water bath immersion as in Phase II).

2.2. Instrumentation

The loss of the viscoelastic gel matrix as the response medium precludes the use of the previous low frequency instrumentation (the signal deriving from the gel response to a bubble nucleation event). As recently demonstrated by COUPP [4], the primary particle-induced event signal obtains from the differing number of proto-bubbles formed in the superheated liquid by neutrons and α 's. The proto-bubble signal however lies in the high frequency regime of ~ 130 kHz, requiring a replacement of the current sensors.

At present, the prototype BC is instrumented by an externally-polarized condenser (CM16/CMPA40-5V) microphone with a flat response over 10–250 kHz. Experiments are currently in progress to establish neutron- α discrimination criteria comparable to Phase II.

2.3. Change of shielding

Phase II was operated in the 60 m^3 GESA cavern at the 505m depth of the LSBB; its shielding configuration as described in [1] is shown in Fig. 3(a). The final primary source of on-detector neutrons was (α,n) and spontaneous fission neutrons from the U/Th contamination of the shield water itself.

Ultimately, a Phase IV experiment is to be relocated to the 1250 m^3 , 505 m deep “capsule” of the LSBB, which although similar in structure to GESA (2 m concrete lining, 1 cm internal steel sheathing to form a Faraday cage) requires extensive revisions of its current internal configuration, which are not anticipated before 2013: accordingly, Phase III is intended to be executed in GESA.

To further decrease the on-detector neutron flux in GESA, we envision an increase of the current water shield thickness to 1.3 m, which is constrained by the cavern definition as seen in Fig. 3(b). The water was however obtained from locally-available, untreated tap water with U/Th concentrations of xxxx; treated tapwater already yields a factor 10 reduction in the radio-contaminants. The Phase III water is to be replaced by purified reactor containment water, which involves a resin-based tapwater treatment process which reduces the heavy metals content by 10^2 - 10^3 . The design involves the immediate surrounding of the detectors, to include the thermal waterbath itself, with the purified water, with the previous water shield moved to the GESA periphery as an external baffle.

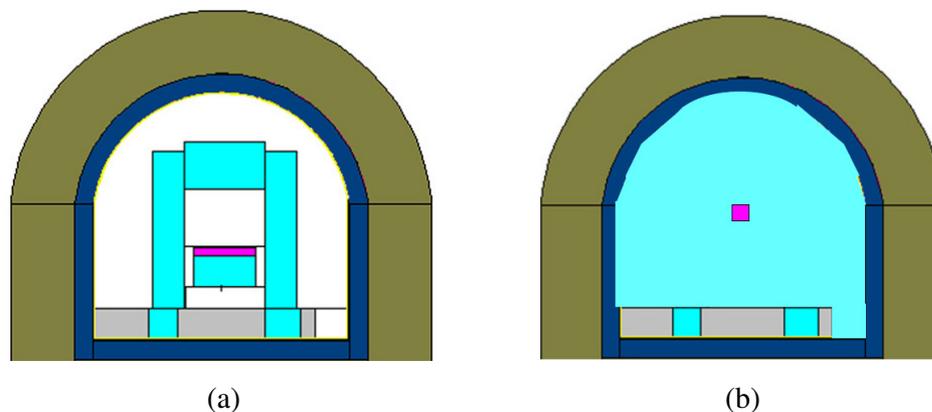


Fig. 3: (a) GESA and its neutron shield (color) in Phase II configuration; (b) projected Phase III configuration; the indicated grey areas are either water or concrete, as included in the simulations.

Reducing the on-detector neutron background by $\sim 10^4$ provides an overall 10^3 improvement in experiment sensitivity, and suggests a neutron background rate well below zero for exposures of $\sim 10^3$ kgd.

3. Projected Phase III Sensitivities

Figure 4 shows the estimated levels of sensitivity in the two sectors of the dark matter search for exposures of 100 and 500 kgd, using two 5 kg prototypes and assuming the same particle-induced event discrimination as in Phase II and zero candidate events, in comparison with the current Phase II results [1].

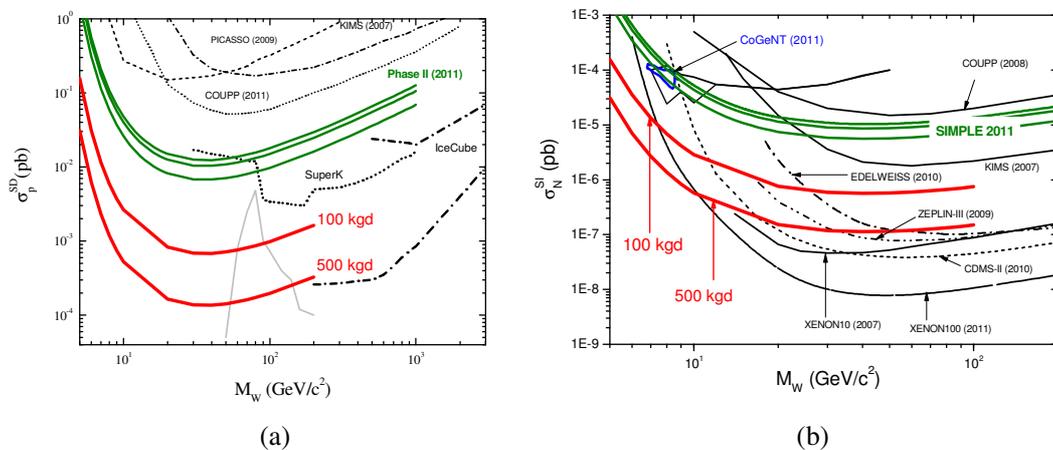


Fig. 4: (a) projected sensitivity levels in the SD sector; (b) same in the SI sector for the same exposures.

In the SD sector, a two week exposure, assuming a 20% loss of measurement time due to recompressions, is expected to provide more than a factor 10 improvement in the current exclusion. For the SI sector, the same result provides a similar improvement, and should confirm/deny SIMPLE's current tension with CoGeNT. While this level remains above those established by XENON, CDMS, and CRESST-II, extension of the exposure to two months will address the situation.

4. Summary

The Phase III measurement, as described above, if realized in scope and time scale, is clearly competitive with other WIMP searches in the field, and would both confirm/deny the light WIMP possibility as well as serve to itself discover a WIMP candidate. The involved cost of the developments discussed above remains at the level of a few hundred k\$. The Phase III plan, in generality, has recently been funded, with a completion date of December 2012.

Acknowledgments

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