

Search for Dark Matter with the PICO-500 Experiment

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Abstract. The PICO collaboration searches for WIMPs using large superheated liquid detectors, or bubble chambers. Recent results from the complete exposure of the PICO-60 C_3F_8 detector at SNOLAB set the world's most stringent limits on WIMP-proton spin-dependent interactions. PICO-500, the next generation, tonne-scale experiment to be constructed at SNOLAB, is set to explore WIMP-proton spin-dependent interactions with unprecedented sensitivity.

1. Introduction

There is convincing evidence that dark matter is composed to thermally produced particles with some weak coupling with Standard Model particles [1]. The so-called weakly interacting massive particles (WIMPs) are left as a relic after freeze-out. Extensions to the SM such as (but not limited to) supersymmetry (SUSY) [2] are required to explain the nature of WIMPs and their interaction with SM particles. The nature of the WIMP and its coupling to SM matter remains unknown, therefore searches with various target nuclei are essential to probe a wide range of WIMP masses and coupling with matter. No new physics has been observed so far at the Large Hadron Collider, and WIMPs still elude current large direct detection experiments [3, 4]. There is new theoretical work on phenomenological supersymmetric Standard Models (pMSSM) that are not excluded by LHC, provide a dark matter candidate and an explanation for the $g-2$ anomaly, while remaining minimally fine-tuned [5]. Direct detection searches are complementary in regions of the MSSM parameter space where the LHC has little sensitivity.

2. The PICO bubble chamber

The PICO collaboration searches for WIMP dark matter particles using large superheated liquid detectors, or bubble chambers, located at SNOLAB. In a bubble chamber, a superheated fluorinated compound (C_3F_8) is contained in a smooth-walled synthetic silica jar. The fluorine nucleus has an unpaired proton spin and is therefore an ideal target to probe for WIMP-proton SD interactions. The detector's concept is illustrated in Figure 1 and described in detail in [6]. Following the interaction with a WIMP, a recoiling nucleus deposits enough energy locally to trigger a phase transition that can be observed as a growing gas bubble. According to Seitz theory of bubble chambers [7], to nucleate a bubble, the energy deposit must be greater than a thermodynamic threshold, and within a small enough volume. These conditions are the bubble chamber's key strength as a low background detector since the thermodynamic threshold can



be chosen such that the recoiling electrons from gamma and beta-emitting backgrounds will not nucleate bubbles due to their energy deposits occurring in a too diffuse volume. Further background reduction is achieved with the rejection of multi-bubble events corresponding to fast neutron multiple scattering, and the measurement of the nucleation's acoustic signal, which allows the discrimination of nuclear recoils and alpha particles [8]. Recent operation of the PICO-60 detector at SNOLAB achieved the current world's best sensitivity to WIMP-proton SD interactions [9].

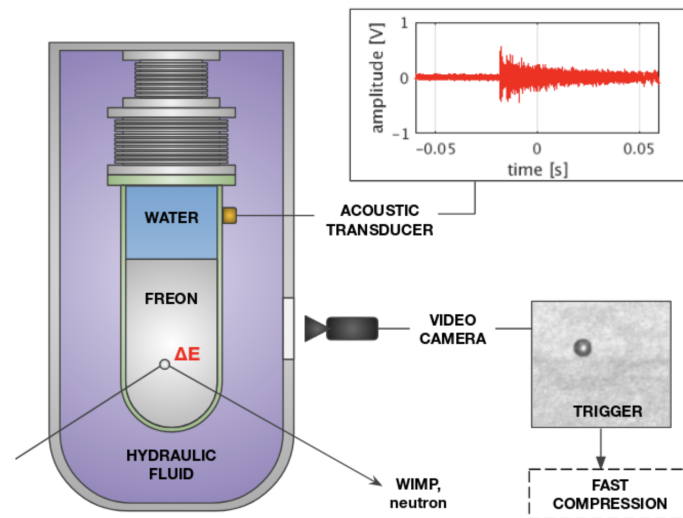


Figure 1. The PICO bubble chamber concept. The nucleation of a bubble in superheated liquid is captured by video cameras and acoustic transducers. After the data acquisition, a trigger is sent for the rapid compression of the chamber to prevent boiling.

3. Status of the PICO-40L detector at SNOLAB

The PICO Collaboration is currently commissioning the PICO-40L detector, a 50 kg bubble chamber that does not use any buffer fluid due to a temperature gradient that establishes the active and inactive region of the detector in order to provide a greater control on the fluid purity of the active target. With a comparable target mass to PICO-60, PICO-40L is expected to be more sensitive to WIMP interactions thanks the lower expected neutron background conferred by a larger pressure vessel that shields the active target with more mineral oil. The installation of PICO-40L was completed in 2019, and commissioning data was acquired. Shortcomings of the thermal design were identified, while a leak in the cooling coils triggered the interruption of operations. PICO-40L will be recommissioned in the Winter 2022 with a revised thermal design and a new quartz jar with an updated surface treatment method. The first physics run expected in the first half of 2022. The PICO-40L detector, shown in figure 2, is a prototype for the next generation, tonne-scale PICO experiment: PICO-500.

4. Status of the PICO-500 detector at SNOLAB

PICO-500 is the next generation PICO detector to be installed at the SNOLAB cube hall. The pressure vessel is designed to hold a 1000 L active target vessel, but fused silica forming methods currently limit the size of the quartz vessel at 260 L (420 kg of C_3F_8). Construction of PICO-500 is set to begin in 2022. A schematics of the PICO-500 detector and its implementation in the SNOLAB cube hall is shown in figure 3.

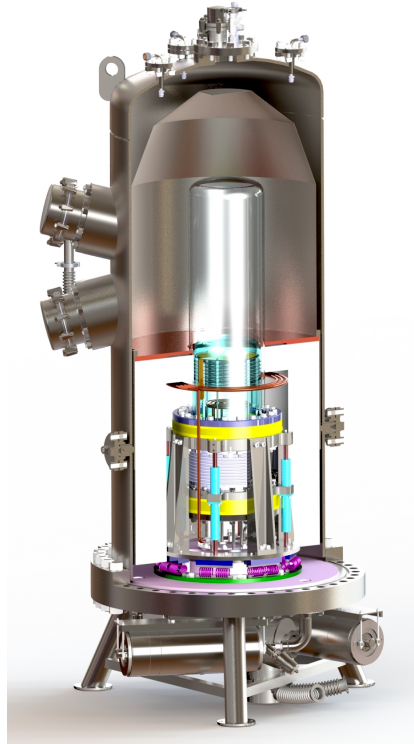


Figure 2. The PICO-40L bubble chamber. Inside a stainless steel pressure vessel filled with mineral oil, two nested synthetic silica jars hold approximately 50 kg of C_3F_8 . A bellows system insures that the pressure difference between the hydraulic fluid and the active target stays small. A temperature gradient renders C_3F_8 in the bellows regions inactive. Four cameras capture the bubbles nucleating in the active target. A set of three piston accumulator situated under the pressure vessel achieve the fast compression of the detector after an event.

Figure 4 shows the projected sensitivity for PICO-500 in the spin-dependent sector on WIMP-proton interaction, along with the projection of the LZ liquid xenon experiment on the WIMP-neutron interaction [10]. PICO-500 will be able to test the entire set of allowed pMSSM models presented in [5].

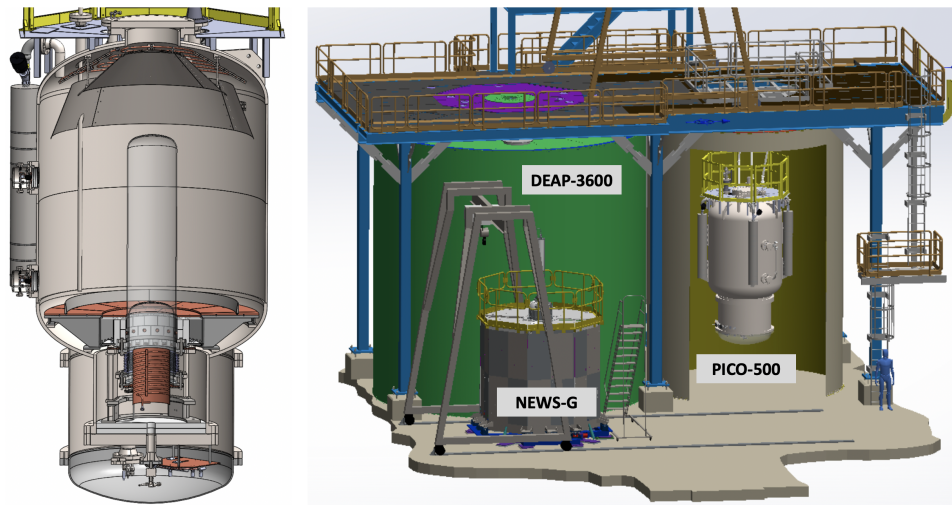


Figure 3. The PICO-500 stainless steel pressure vessel hold a 260 L active volume in two nested synthetic silica jars. PICO-500 will be installed in the water shielding previously used by the MiniCLEAN experiment [11] in the SNOLAB Cube Hall.

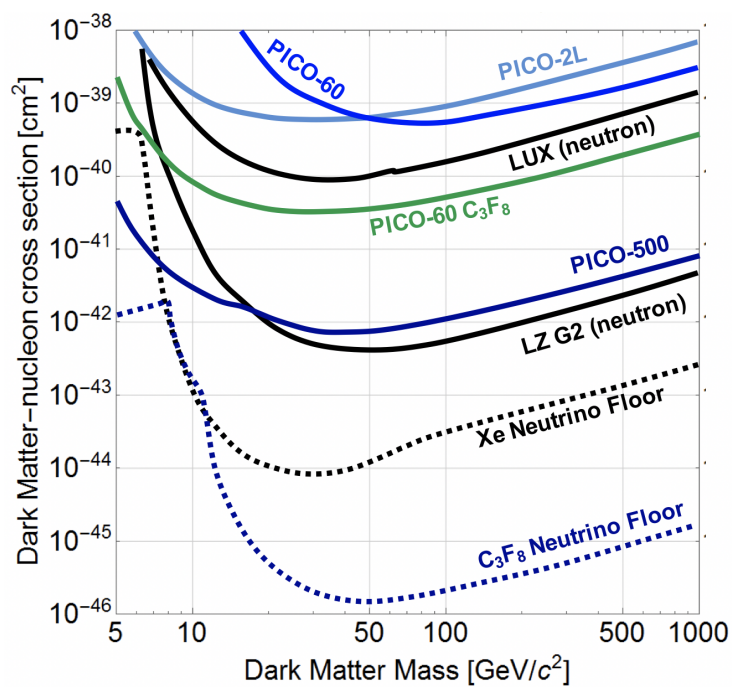


Figure 4. Projected sensitivity of the PICO-500 experiment, with a 0.5 live year exposure at 3.2 keV threshold and a 1 live-year exposure at 8 keV with a 350 L fiducial target. The longer, higher threshold run is to mitigate the background from solar neutrino coherent scattering. The neutrino floors [12] are drawn for both xenon and fluorine, showing a larger parameter space yet to explore with fluorine targets until the neutrino background limits the searches.

References

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