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MOSCAB: direct dark matter search using the geyser technique

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Abstract

The MOSCAB experiment (Materia OSCura A Bolle) uses the Geyser technique for dark matter search. The results of the first 0.5 kg mass prototype detector using superheated C_3F_8 liquid were very encouraging, achieving a 5 keV nuclear recoil threshold with high insensitivity to gamma radiation. Additionally, the technique seems to be easily scalable to higher masses for both in terms of complexity and costs, resulting in a very competitive technique for direct dark matter search, especially for the spin dependent case. Here, we report as well in the construction and commissioning of the big detector of 40 kg at the Milano-Bicocca University. The detector, the calibration tests and the evaluation of the background will be presented. Once demonstrated the functionality of the detector, it will be operated at the Gran Sasso National Laboratory in 2015.

Keywords: Geyser detector; Dark Matter; Bubble Chamber;

1. Introduction

WIMPs (Weak Interacting Massive Particles) are one of the more suited hypotheses for the non-baryonic candidate for dark matter. Direct detection of WIMPs is usually based on measuring the nuclear recoils produced by WIMPs hitting on normal nuclei. Several techniques (or combination of techniques) have been proposed for this aim. These detectors can be classified in three types:

- Cryogenic types (CDMS, CRESST, EDELWEISS, EURECA) based on the heat produced when a particle hits a crystal absorber such as germanium.
- Noble liquid types (ZEPLIN, XENON, DEAP, ArDM, WARP, DarkSide and LUX) based on scintillation light produced by a particle collision in liquid xenon or argon.
- Superheated detector experiments (COUPP, SIMPLE, PICASSO, PICO) based on signals coming from the nucleation of bubbles in a superheated liquid in a gel matrix or in special vessels.

Each of those techniques has its particular pros and cons, but most of them have difficulties for scaling up to ton-scale experiments in terms of complexity and/or costs. In this paper, we present the idea of using a Geyser detector for this, and describe the status of MOSCAB prototypes.

2. The Geyser technique

The Geyser detector is based on the bubble nucleation in superheated liquids. The local energy release in the track length (0.01 – 0.10 µm) due to a recoiling ion induced by a particle interaction through a superheated liquid can produce a vapour bubble

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which can grow to visible size. There are two important parameters for bubble production: the critical energy, Ec, and the critical radius, Rc. Not only the total available energy should be higher enough, that is larger than Ec, but also concentrated in a small region so (dE/dx)2Rc> Ec. This is the reason why this kind of detectors is very efficient for nuclear recoils, but quite insensitive to electrons or gamma radiation. Since this is important for direct dark matter searches, several experiments have been tried (PICO/PICASSO-COUPP [1-3], and SIMPLE [4]).

The Geyser technique or condensation chamber is a variant of the superheated liquid technique, first used in 1964 by Hahn and Reist who built the first Geyser detector to detect transuranic nuclei [5]. The setup is very simple. The apparatus is composed of a bottom chamber and a top chamber, connected by a narrow pipe. In the bottom chamber we find the target liquid (in our case Freon 218, i.e. C_3F_8), kept at a constant temperature in a superheated state close to its boiling point. In the top chamber we find its vapour, kept at a slightly lower temperature. The whole system is within a water bath regulated by cooling and heating sources. When a dark matter (WIMP) particle hits the target liquid, the energy released produces a vapour bubble which rises up, eventually pushing the liquid in the small pipe into the secondary chamber, producing a geyser-like effect. At this point, the bubble condenses in the top chamber (colder), and the liquid is recovered into the bottom chamber in a few seconds. The process is automatic, which makes this technique very simple and effective, and thus also easily scalable.

The main advantages of the technique are basically those of superheated experiments [1-4], adding a simpler setup and a short dead time operation:

- Strong rejection of particles at minimum ionization (e- and γ).
- Simplicity of the mechanical construction, also for large size detectors, and at relatively low cost.
- Subtract the neutron background by count multiple neutron interactions.
- Possibility to distinguish the spin dependent interaction of WIMP from spin independent by changing the liquid used.
- Automatic and very short dead time (< 5 s).

3. MOSCAB prototypes: status and plans

The design and results with the first prototype is extensively described in [7]. It consisted on a 0.5 kg geyser detector extensively tested over the last couple of years under different conditions in the physics department laboratories of the Milano-Bicocca University. The temperature of the liquid and vapour have been varied, and also the amount of liquid Freon and Glycol (used for thermal buffer) in order to find a device that was stable over very long periods of time, sensitive to Carbon and Fluorine recoils of about 5 keV kinetic energy and insensitive to minimum ionizing particles and gamma radiation.

Later, a new prototype with a larger vessel (22L, able to hold 40 kg of active liquid) has been designed and developed. A diagram of this prototype is shown in Fig. 1. Scaling up the detector, some problems need to be addressed in order to avoid instabilities:

- Instability induced by the walls of the vessel, which was solved by covering the internal wall of the vessel with a special layer with nanotechnological deposition properties.
- Instability from the interface Freon (target) / glycol (buffer), solved by varying the relative quantity of Freon with respect to glycol and using a fiducial volume.

This prototype is being tested in the Milano-Bicocca University lab, using 0.3 L and 2 L vessels (the 22 L should be tested in an underground lab in order to have a reasonable background rate). Using neutron and sources the efficiency for nuclear recoils with 5 keV threshold has been checked. The electron and gamma rejection, which is of the order of 10^{-10} according to COUPP [2], has also been tested and not having observed an enhancement of signal with respect to background. An acoustic system with hydrophones has also been added in order to discriminate alpha background acoustically [7,8]. The acoustic signal of alphas is expected to have a larger intensity with respect to that of neutron or WIMP signals. Finally, the larger vessel allows quantifying the neutron background from the multibubble events. With all this included, the estimated expected background is 0.2event/year for a 40-kg Geyser detector operated in the Gran Sasso underground lab (LNGS).

This prototype is going to be commissioned in LNGS in 2015. If the performance is the expected one, a physics run in 2015 will result in competitive limits on proton-WIMP spin dependent interaction. Next phase will be MOSCAB/BIG (Bubble International Geyser) aiming to build 13 modules (half a ton experiment) during the period 2014-2019, concluding with a large detector with a sensitivity 4 orders of magnitude better than the existing superheated liquid dark matter detectors.

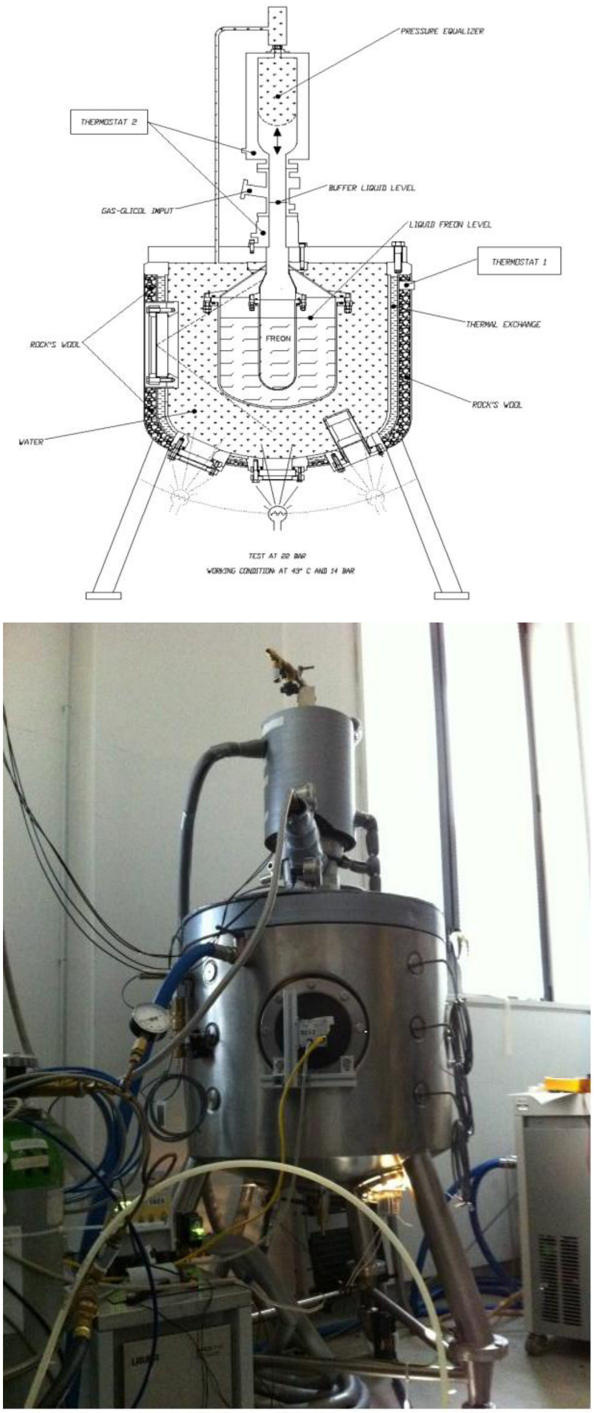

Fig. 1. Diagram and picture of the 40 kg Geyser detector

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