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# A bubble chamber for dark matter detection (the COUPP project status)

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**Abstract.** Heavy-liquid bubble chambers can be made stable-enough to be used in searches for Weakly Interacting Massive Particles (WIMPs). Advantages of this approach are optimal choice of target liquid–$CF_3I$, maximally sensitive to both spin-dependent (SD) and spin-independent (SI) WIMP interactions, low cost, good scalability, room temperature operation, extraordinary intrinsic rejection of minimally-ionizing backgrounds, and a number of features permitting rejection of irreducible neutron backgrounds. A 2 kg prototype chamber is currently operating at the depth of 300 meters water equivalent (m.w.e.) NuMi gallery of Fermilab. Even with the small prototype mass, results competitive in the SI channel and surpassing current limits in the SD channel are expected.

Searches for cold dark matter particles require extraordinary background-rejection capability: signal rates as small as one low-energy nuclear recoil (a few keV) per ton detector mass per year are predicted for the nuclear scattering of supersymmetric WIMP candidates. The COUPP (Chicagoland Observatory for Underground Particle Physics) collaboration has recently shown that highly stable bubble chambers, where the detection medium is a superheated heavy fluorinated liquid, are a promising approach for inexpensive ton-scale low-background dark matter detectors [1].

A 2 kg prototype chamber operating with $CF_3I$ as the detection fluid has been constructed. The pressure spike arising from bubble nucleation is used to trigger two orthogonal cameras as well as recompression of the chamber. Fig. 1 shows a photographed neutron multiple-scattering event and reconstruction of bubble positions for many hours of data. Wall events are rejected with a high degree of confidence based on photographed bubble shape and on position reconstruction.

In such a detector, the degree of superheat is less than in conventional bubble chambers, so that the small stopping power of minimally ionizing particles (MIPs) prevents them from causing nucleations. Fig. 2 demonstrates a $\gamma$-rejection factor of $> 10^9$ and shows the ability to reject neutron events based on multiple scattering. As shown in Fig. 3, observed nucleation rates at the surface and at 6 m.w.e depth are in good agreement with expected rates from cosmogenic neutrons. Also shown in Fig. 3, sensitivity to low-energy nuclear recoils has been demonstrated.

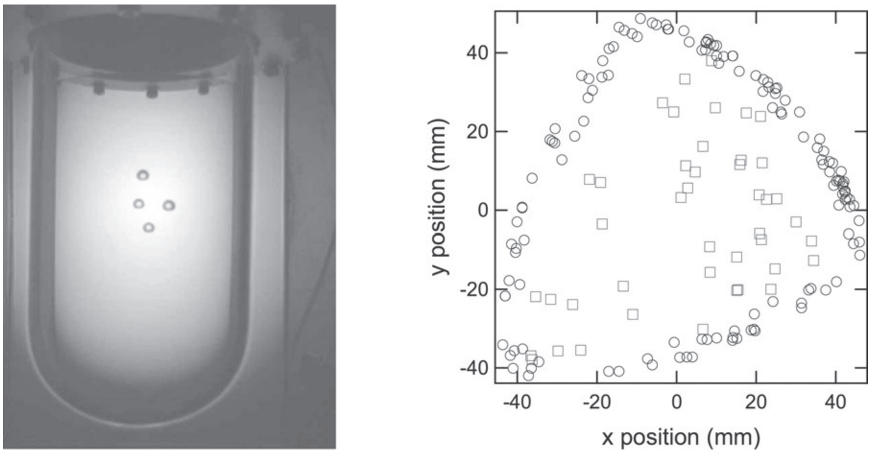


**Figure 1.** Left: A neutron multiple-scattering event. Right: Position reconstruction of events projected onto the x-y plane, where the vessel is aligned along the z-axis. The non-circular projection occurs since optical effects such as lensing of the vessel are not yet taken into account. One camera is located on the positive x-axis, and the other is the same distance from the center on the positive y-axis. Despite the image distortion, separation of surface events (circles) from bulk events (squares) is good.

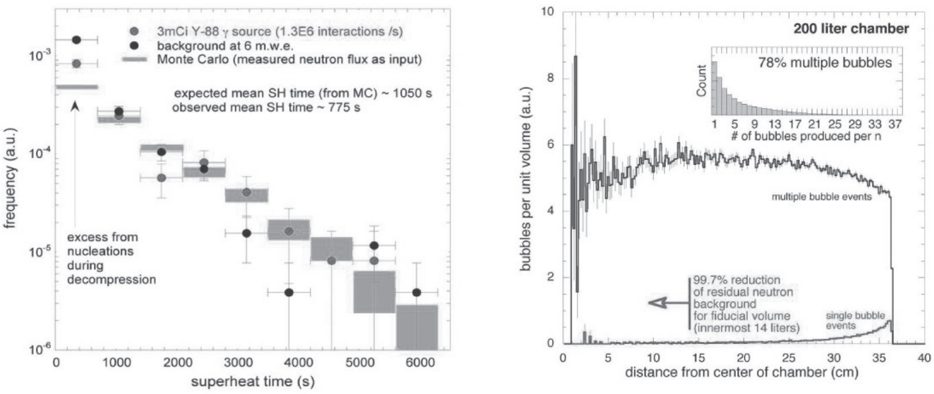


**Figure 2.** Left: Demonstration of $\gamma$ rejection of $> 10^9$. The histogram of elapsed time between bubbles for a small chamber at 6 m.w.e. shows no evidence of an increased nucleation rate in the presence of a strong $\gamma$ source. Agreement with the expected rate from cosmogenic neutrons is good. Right: Monte Carlo results showing the ability to reject neutron events based on bubble counting in a larger chamber.

The 2-liter prototype chamber is currently operating in the NuMi gallery of Fermilab at 300 m.w.e. The data from the first few live-days at this depth are still being analyzed. Preliminary analysis of bulk events suggests a rate of approximately 70 events/L/day. The observed excess of single-bubble events indicates that the dominant background is from $\alpha$-decays rather than from neutrons. In this chamber, no precautions (besides washing) were taken to reduce $\alpha$-backgrounds. Known sources of radon emanation (tungsten weld lines, dirty gaskets, and sub-optimal valves) which were used in this first prototype are removed in second-generation chambers now under construction.

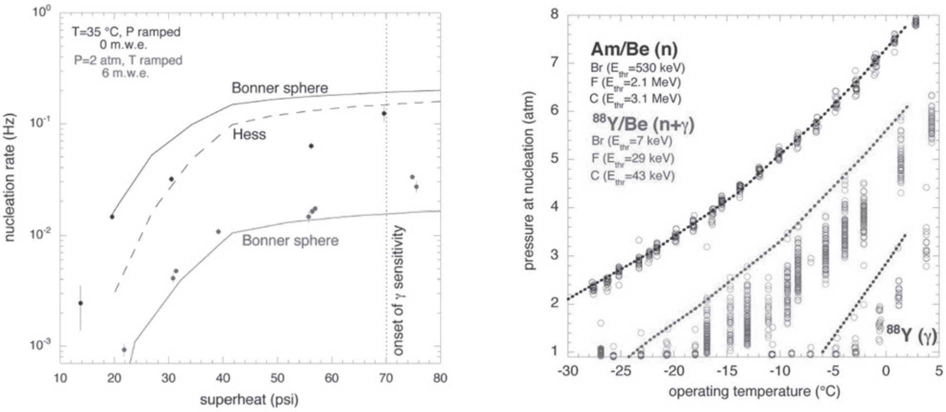


**Figure 3.** Left: Nucleation rate versus superheat for the 2 kg chamber operated on the surface (upper points) and at 6 m.w.e. (lower points). Agreement with expected rates from the measured neutron flux is good. Right: Response of superheated $CF_3Br$ to radioactive sources, where the chamber is held at a constant temperature and slowly decompressed until a nucleation occurs. Lines are fits to theory [2], which has one free parameter.

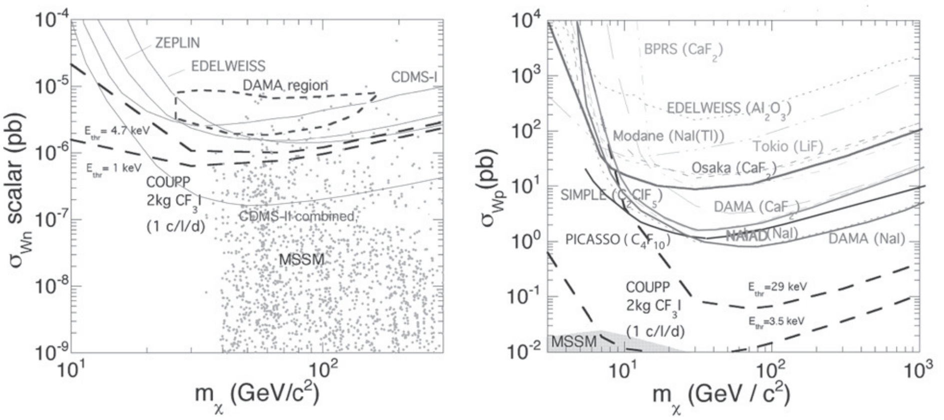


**Figure 4.** Projected results of operating at 300 m.w.e., with a reasonable background rate, compared with dark matter limits from other experiments.

Even with this small 2 kg prototype chamber with no precaution against $\alpha$-contamination, dark matter limits extremely competitive with the best searches for WIMP SD interaction are expected. However, demonstration of a good understanding of nucleation thresholds is required before exclusion plots can be made. Next-generation chambers of the same size, currently under construction, are expected to achieve substantially lower $\alpha$-contamination. Projected exclusion plots for 2 kg chambers, given reasonable background levels, are shown in Fig. 4.

## References

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