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Update on the Scintillating Bubble Chamber (SBC) collaboration

H. Hawley-Herrera* and for the SBC collaboration

[a]*Department of Physics, Engineering Physics, and Astronomy, Queen's University, 64 Bader Ln, K7L 3N6, Kingston, ON, Canada*

E-mail: hawleyherrera.h@queensu.ca

The main objective of the Scintillating Bubble Chamber (SBC) collaboration is to detect 1-10 GeV/c^2 dark matter by combining the electron recoil suppression of conventional bubble chambers with the scintillation properties of liquid noble elements. The use of noble elements provides two benefits. First, there is the potential to reduce the energy threshold to 100 eV by efficiently converting most of the energy deposited by electron recoils to light to suppress bubble creation. Second, there is the ability to collect event-by-event energy information from the scintillation. To test this technology, SBC is building its first prototype at Fermilab called SBC-LAr10. This prototype includes the scintillation system using liquid argon doped on the order of 100 ppm of Xe as the scintillator, and the light collection devices are 32 Hamamatsu VUV4 silicon photomultipliers (SiPMs). Then, for the dark matter search SBC will build an identical chamber in SNOLAB. This proceedings documents the progress being made on both SBC chambers and the calibration strategy.

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1. Introduction

The Scintillating Bubble Chamber (SBC) collaboration aims to understand the nature of dark matter and an explanation for the observed matter/antimatter asymmetry. When dark matter is modelled as a weakly-interactive massive particle (WIMP), its mass in the order of 100 GeV can account for the observed relic abundance [1, 2]. In the past decade, however, many null results from direct, indirect, and accelerator measurements have left unexplored parameter space at lower dark matters [3]. Asymmetric dark matter (ADM) proposes an alternative solution by assuming that the mechanism that created the asymmetry in visible matter must happen in the dark matter sector. One ADM prediction is indirect detection null results are expected as the lack of abundance of dark matter pairs for annihilation reduces the amount of signal available for a successful detection [4]. Therefore, direct detection becomes the only method to detect dark matter, and some ADM mechanisms can justify the dark matter masses in the single GeV scale lower than expected for WIMP masses.

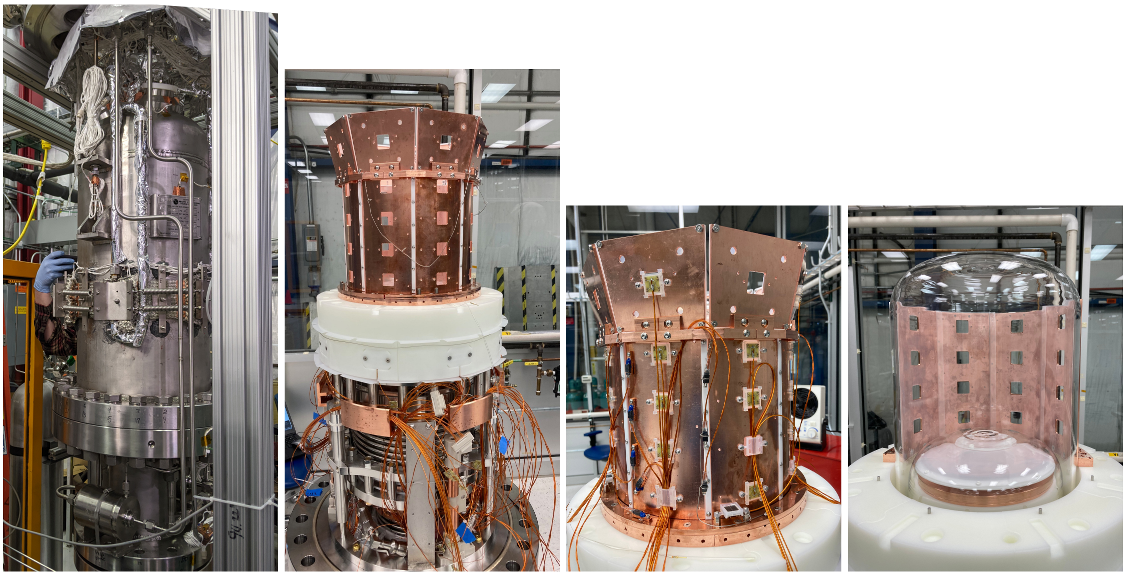
Currently, most ionization-based dark matter detectors are background dominated in the energy scales expected for ADM. SBC proposes a quasi-background free experiment with a 100 eV energy threshold that combines the proven high electron-recoil (ER) suppression and scalability of bubble chambers with event-by-event event reconstruction of scintillation-based detectors. Using a liquid-noble element as the target medium not only improves the bubble chamber ER suppression with an additional energy channel but, as hypothesized in Ref. [5], removes the ability to create bubbles since there is a lack of molecular degrees of freedom for ER to deposit energy. Also, in Ref. [5], nuclear recoil (NR) at energies higher than 10 keV can be identified and vetted using the collected light. For SBC chambers, only low-energy NR remains the source of irreducible backgrounds.

SBC is building a first chamber at Fermilab called SBC-LAr10 which objective is to test the engineering and run ER and NR calibrations. Following the successful operation of the prototype, an almost identical copy of the Fermilab chamber will be built at SNOLAB called SBC-SNOLAB with the objective of searching for dark matter. Concurrently, the Fermilab chamber has the potential to be re-used at a nuclear reactor to observe coherent elastic neutrino-nucleus scattering (CEνNS). These proceedings will summarize the current progress, the calibration plans, and the ongoing efforts to reduce the backgrounds for SBC-SNOLAB. For a more detailed description of SBC chambers, goals, and challenges, see [6, 7].

2. SBC-LAr10

SBC-LAr10 is a 10 kg liquid argon (LAr) bubble chamber. The chamber consists of four fundamental systems: the thermo-mechanical system, the light collection system, the camera system, and the piezoelectric system.

The thermo-mechanical system is responsible for setting the temperatures and pressures required to start the period of sensitivity of the detector and to end a bubble nucleation event. Similar to other bubble chambers, pressure is decreased until a superheated state is achieved. The state is maintained until a bubble nucleation begins. To stop the expansion of the bubble, the chamber is pressurized until it is stable. Finally, a new event starts again when the pressure is decreased. SBC-LAr10 uses the buffer-free, dual-temperature-zone strategy used by PICO-40L [8]. The thermo-mechanical system consists of the inner vessel seen in Fig. 1 (a) which contains liquid CF_4 (LCF_4) and the "inner assembly" seen in (b).



(a) **(b)** **(c)** **(d)**

Figure 1: (a) SBC-LAr10 pressure vessel. (b) SBC-LAr10 inner assembly with partial insulation. (c) with SiPMs installed. (d) view of the jars.

The inner assembly contains the light collection system consisting of two concentric UV transparent fused silica vessels (constructed of Hereaus Suprasil 310) that hold the LAr doped in the order of 100 ppm of Xe. Xe is used to increase the light yield and waveshift the scintillation light to be transmittable through the silica vessels [9, 10]. As the LAr scintillation collection devices, 24 Hamamatsu VUV4 silicon photomultipliers (SiPMs) are used. As of the writing of this proceedings, a paper is being prepared on the bulk characterization of the Hamamatsu devices. LCF_4 surrounds the silica vessel, and its scintillation is also collected using 8 SiPMs. The collected LCF_4 scintillation will be used as an active veto. Documentation of the scintillation of LCF_4 does not exist, so the collaboration is also preparing a paper detailing the LCF_4 scintillation properties. Also part of the scintillation system, but found outside the chamber, is the SiPM acquisition chain. It consists of two 16-ch TRIUMF-made SiPM amplifiers which output is digitized by a single 64-ch CAEN 1740D. The installed SiPMs can be seen in Fig. 1 (c), the silica vessels in (d).

Testing of the inner assembly and partial aspects of the scintillation system were conducted at Queen's University. Cryogenic tests were used to check the reliability of spring-energized polytetrafluoroethylene (PTFE) seals found between the jars and the steel frame of the inner assembly. Aspects of the SiPM acquisition pipeline were also tested such as the electrical noise and the acquisition chain software. The SiPMs were also tested at several temperatures to test the reliability of the system at different temperatures.

The camera system is responsible for imaging the bubbles as they expand. There are three Arducam OV9281 1-Megapixel cameras located outside the cryogenic area. They will record at 100 frames-per-second, and each connected to a Raspberry Pi for processing and storing. As the cameras are located relatively far from the jars, a fused silica relay lens system was developed. The chamber is illuminated with three 850 nm LED rings pulsed at the same 10% duty cycle as the cameras. The camera system has been designed to minimize any stray photons from being emitted outside the imaging cycle. The SiPMs acquisition is also stopped during the imaging cycle.

In conventional bubble chambers, the piezos are installed to collect acoustic information used to identify single-bubble alpha events. However, in SBC, the scintillation system is now responsible for discriminating against alpha events. Nevertheless, the piezoelectric system remains critical in the estimation of the bubble formation starting time. The piezoelectric devices are textured lead zirconate titanate (PZT) piezoelectric elements. The acoustic signal are pre-amplified with two amplifiers located in the cryogenic space. The acoustic signal chain ends at a single CSE8387 Gage Octopus Express Compuscope digitizer.

3. SBC-LAr10 calibration strategy

The strategy for calibration, which is expected to begin in 2024, will try to answer questions about the ER discrimination and NR sensitivity.

The ER discrimination will be determined by a mCi gamma source. The information provided will also help in determining the target operating conditions (pressure and temperature). A weaker source will be used to calibrate for the light yields and the photon detection efficiency found in the chamber.

The NR sensitivity calibrations are more complex and limited by the number of events the chamber can detect per day. For low to high energy NR (100 eV to 1 keV recoil energies), three different photoneutron sources will be used with three different energy spectra that cover different parts of the expected energy region of the detector. Bubble multiplicity will be studied with these sources as it is insensitive to uncertainties on the source strength. The second NR calibration proposes to study Thomson scattering by high-energy gamma rays in the chamber. This characterization is only possible in bubble chambers, given the insensitivity to ER. The information obtained from these sources will be used to study NR in the 100 eV to 500 eV regime. The final technique for NR calibrations is with the thermal neutron capture on ^{40}Ar. The recoiling energy of the resulting ^{41}Ar will be important to study bubble nucleation in the 100 eV region.

4. SBC-SNOLAB

In the construction of SBC-LAr10, two major challenges were encountered that impact the targeted quasi-background free requirement for SBC-SNOLAB chamber.

The first problem encountered early in the development of SBC-LAr10 is the ceramic package of the Hamamatsu VUV4 was found to have a level of high U/Th content which is unacceptable given the background levels needed for SBC-SNOLAB. To solve this issue, SBC in collaboration with nEXO procured two FBK VUV SiPM wafers [11], and designed a package using materials which were measured to have the low-background properties desired for both experiments. Currently, the SiPMs are being built at TRIUMF for the full 32 SiPM surrounding the silica vessels and 16 SiPMs looking at the LCF_4 space.

The other major challenge was found in the temperature sensors used in SBC-LAr10. After gamma-counting them, they were also found to have a high background content. The origin was identified to be plastics of the mounts. The final temperature sensors new design is ongoing and currently there is a study to understand if the PT100 will also need to be replaced.

Currently, SBC-SNOLAB is in the design phase with plans of starting construction mid 2024. No other major changes are expected apart from minor modifications to the vacuum jacket, and pressure vessel. The projected sensitivity of SBC-SNOLAB is expected to be 10^{-43} cm^2 at 1 GeV.

References

[1] P.A.R. Ade et al., *Planck2013 results. i. overview of products and scientific results*, *Astronomy Astrophysics* **571** (2014) A1.

[2] P.D. Group, R.L. Workman et al., *Review of particle physics*, *Progress of Theoretical and Experimental Physics* **2022** (2022) .

[3] D.S. Akerib et al., *Snowmass2021 cosmic frontier dark matter direct detection to the neutrino fog*, March 01, 2022, 2022. 10.48550/arXiv.2203.08084.

[4] K. Petraki and R.R. Volkas, *Review of asymmetric dark matter*, *International Journal of Modern Physics A* **28** (2013) 1330028.

[5] D. Baxter et al., *First demonstration of a scintillating xenon bubble chamber for detecting dark matter and coherent elastic neutrino-nucleus scattering*, *Physical Review Letters* **118** (2017) .

[6] E. Alfonso-Pita et al., *Snowmass 2021 Scintillating Bubble Chambers: Liquid-noble Bubble Chambers for Dark Matter and CEvNS Detection*, `2207.12400`.

[7] E. Alfonso-Pita et al., *Scintillating bubble chambers for rare event searches*, *Universe* **9** (2023) 346.

[8] M. Bressler et al., *A buffer-free concept bubble chamber for pico dark matter searches*, *Journal of Instrumentation* **14** (2019) P08019.

[9] A. Neumeier et al., *Intense vacuum ultraviolet and infrared scintillation of liquid Ar-Xe mixtures*, *Europhysics Letters* **109** (2015) 12001.

[10] V. Gehman et al., *Fluorescence efficiency and visible re-emission spectrum of tetraphenyl butadiene films at extreme ultraviolet wavelengths*, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **654** (2011) 116.

[11] M. Capasso et al., *FBK VUV-sensitive silicon photomultipliers for cryogenic temperatures*, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **982** (2020) 164478.

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