Direct searches of dark matter with the SABRE South experiment

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Abstract

The SABRE (Sodium-iodide with Active Background REjection) South experiment is a direct dark matter detector, made of radio-pure NaI(Tl) crystals surrounded by a liquid scintillator veto. The achievement of ultra-low background rate is essential to provide a model independent test of the signal observed by the DAMA/LIBRA experiment whose claim has not been verified yet.
The SABRE South experiment will be located at the Stawell Underground Physics Laboratory (SUPL), Australia, the first deep underground laboratory in the Southern Hemisphere. The laboratory will not only house rare event physics searches but also measurement facilities to support low background physics experiments and applications like radiobiology and quantum computing.
The SABRE South detector commissioning is expected to occur in 2023. This paper details the setup and projections for the experiment, and a brief description of the underground laboratory.

1 Introduction

Dark matter (DM) is a particle hypothesised due to a large variety of astrophysical observations on a range of different scales [1]. One search method for DM particles that live in the WIMP (Weakly Interacting Massive Particles) regime - masses on the Gev/c^2-TeV/c^2 and cross sections on the weak scale - is direct detection, which attempts to observe the recoil of a target after scattering with DM. To date, only one direct detection experiment has observed a signal compatible with that expected from DM: DAMA [2]. However, this signal is in tension with every other direct detection experiment reporting null results for a standard WIMP [3]. The SABRE Collaboration was formed to provide a model independent test of this DAMA signal [4]. It is based around detectors placed at two locations; SABRE North at Gran Sasso National Laboratory, and SABRE South at the Stawell Underground Physics Laboratory. The two detectors have a number of common features as they are centred around the same detector module concept, and use common simulation, DAQ, and software frameworks. The two detectors differ in their shielding designs - where SABRE South will utilise a liquid scintillator system for in-situ evaluation and validation of the background to provide background rejection and particle identification. For information on the SABRE North set up, see Ref. [5].

2 SABRE South setup

SABRE South is made up of three detector subsystems; the NaI(Tl) crystals that serve as a DM target, the liquid scintillator system that provides an active veto, and an array of muon detector paddles to record this distinctive background. The full setup is shown in Fig. 1.

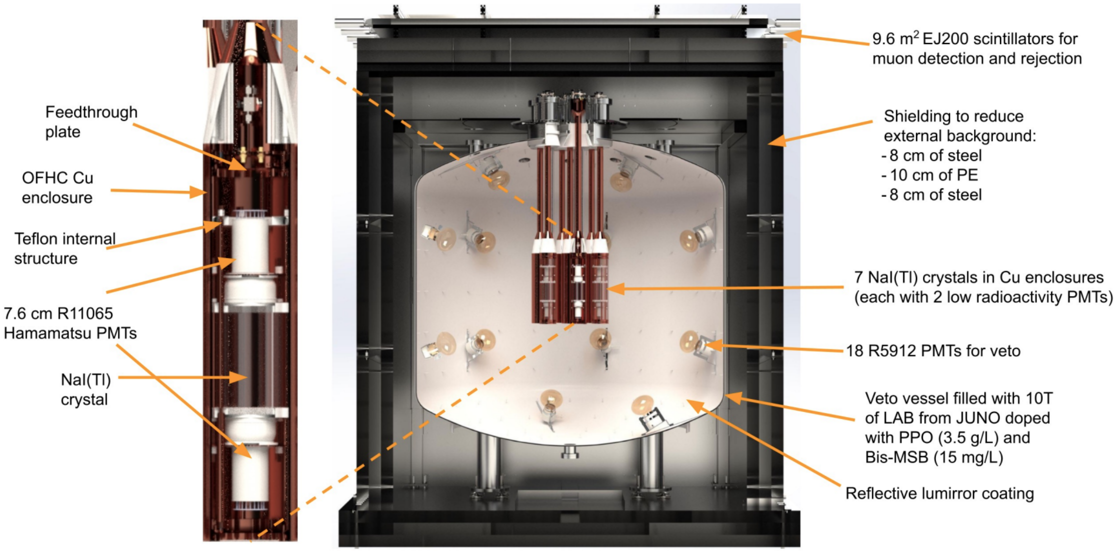

Figure 1: Rendering of the SABRE South detector.

The liquid scintillator system is primarily used to tag and remove high energy decay products such as those from ^{40}K. The system has a 4π coverage, made up of 12 kL of linear alkyl benzene (sourced from JUNO) doped with PPO and Bis-MSB. Around the sides of the steel vessel this is encased in are eighteen 204 mm Hamamatsu R5912 PMTs that are sampled at a rate of 500 MS/s. Based on preliminary optical simulations in Geant4, this system is expected to have a light yield of approximately 0.12 photoelectrons/keV, though this has a strong position dependence. With a threshold of 50 keV the inclusion of this system is able to reduce the total background in by 25%, providing a background of less than 1 cpd/kg/keV [6]. The muon detection system is made up of eight 3 m long EJ200 detector paddles and has a total coverage of 9.6 m^2 above the main vessel. Each paddle is coupled to a Hamamatsu R13089 PMT on each end and sampled at a rate of 3.2 GS/s. Calibrations are still ongoing, but the energy threshold of these detectors is expected to be around 1 MeV. The detectors have approximately 400 ps timing resolution resulting in 5 cm position resolution, allowing for a long term measurement of the muon flux, and particle identification when used with the liquid veto system.

3 Background model and sensitivity

A full detector simulation was conducted and reported in Ref. [6] to provide a background model for the radioactive contamination. This predicts a total radioactive background of less than 0.72 cpd/kg/keV. Studies are ongoing to understand the noise contributions to this [7]. As required by the design of the detector, the crystals themselves account for more than 90% of this radioactive background. These simulations also indicated that as well as providing shielding and vetoing, the liquid scintillator system also allows for in-situ measurements of background contamination to help inform fits due to well defined correlations in the liquid scintillator and crystals, an example of which is shown in Fig. 2.

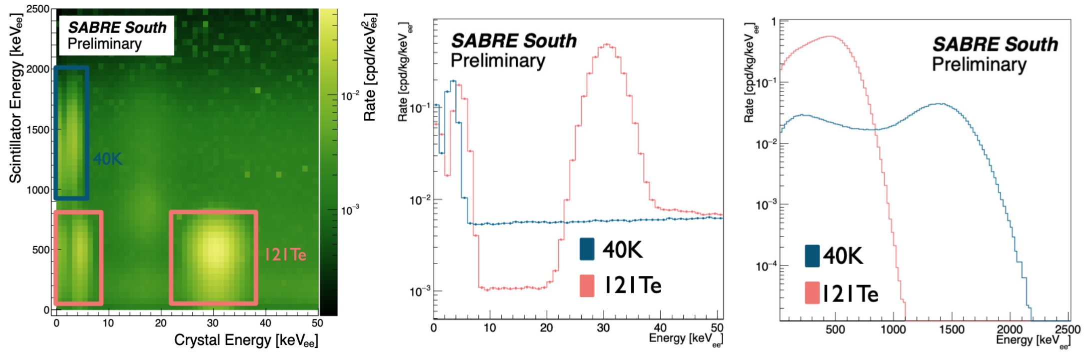

Figure 2: Left: energy depositions in both the crystal and liquid scintillator. Indicated in blue and pink are events due to ^{40}K and ^{121}Te. Centre: rate recorded in crystals from ^{40}K and ^{121}Te. Right: rate recorded in liquid scintillator from ^{40}K and ^{121}Te.

The projected sensitivity of SABRE South assuming this background model from simulated radioactivity and a total crystal mass of 50 kg is shown in Fig. 3 assuming a standard spin independent WIMP (L) and showing the evolution of discovery and exclusion power for the DAMA modulation (R).

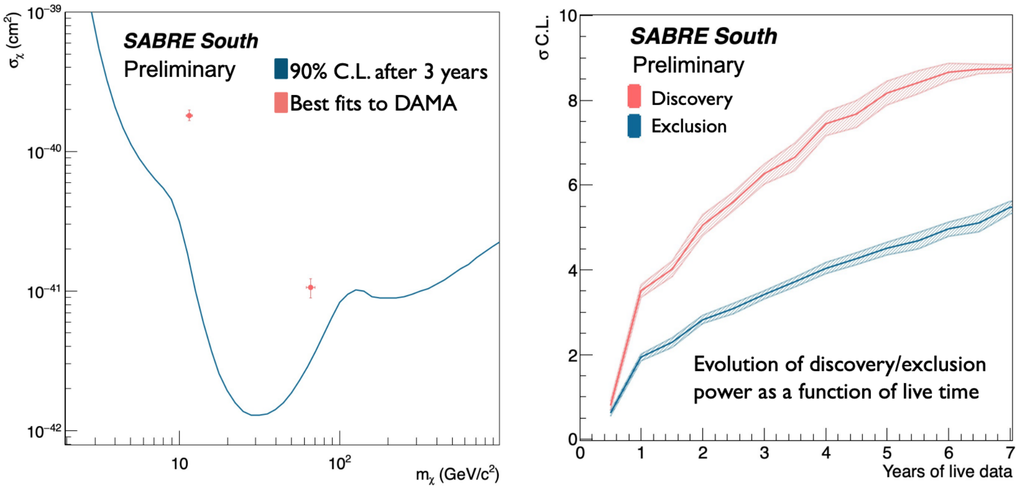

Figure 3: The projected sensitivity of SABRE South assuming a total crystal mass of 50 kg and background of 0.72 cpd/kg/keV. Left: 90% C.L. assuming a standard spin independent WIMP, Right: exclusion and discovery power of SABRE South for the DAMA modulation.

4 The Stawell Underground Physics Laboratory

SABRE South is to be placed at the recently completed Stawell Underground Physics Laboratory (SUPL). This is located in Western Victoria, Australia, 240 km from Melbourne. The laboratory is 1025 m below ground with a flat over burden of basalt, providing almost 3 km of water equivalent shielding, and a muon flux similar to that of Boulby, Fig. 4. Construction was completed in mid-2022, with background muon, gamma, and neutron measurements planned for later 2022. Assembly and commissioning of the main detector components are currently scheduled for late 2023, after which data taking will commence.

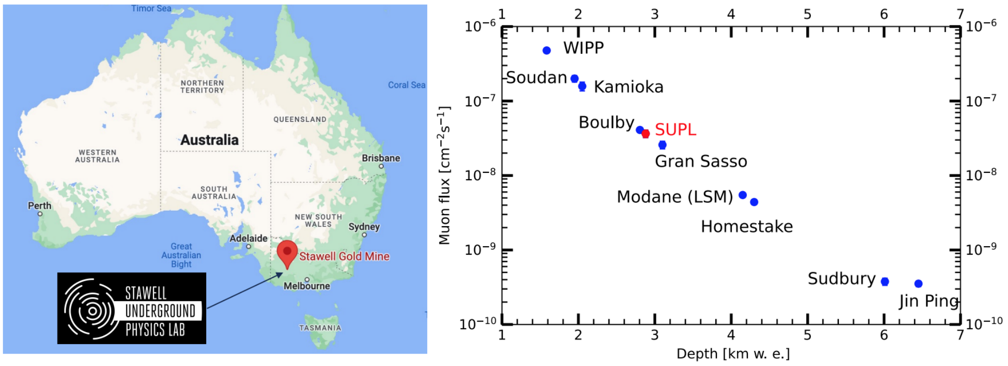

Figure 4: Left: location of SUPL. Right: muon flux at a number of underground laboratories.

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