Establishing an Underground Science Laboratory for Dark Matter and other Rare Event Searches in India

SATYAJIT SAHA
SAHA INSTITUTE OF NUCLEAR PHYSICS, I/AF BIDHAN NAGAR, KOLKATA 700064, INDIA

ABSTRACT

An underground laboratory has been recently established in India at an initially shallow depth inside an existing mine with the aim of establishing a dark matter (DM) search experiment in the near future. Possible detection techniques to be utilized involve the detection of scintillation light and phonons resulting from the recoil of the constituents of the scintillator. The laboratory will also host several other proof-of-principle (PoP) type experiments in the future to look for rare events in, for example, nuclear fission and double beta decay of nuclei.

INTRODUCTION

As a result of various astronomical observations spanning over a century, the scientific community has inferred that more than 83% of the gravitating matter in the Universe is dark matter (DM) [1], a strange form of matter with extremely weak interaction with normal matter, which interacts among itself via electromagnetic and other standard forms of interaction. Apart from only a few experimental endeavors, it has eluded direct or indirect detection in terrestrial experiments involving the possible interaction of the particle dark matter candidates with the active mass of a detector under observation. DM candidates are generally assumed to be weakly interacting massive particles (WIMPs), though there are other candidates where the nature of the interactions are entirely different. However, the common denominator for all possible DM candidates is their extremely difficult and limited detectability in terrestrial experiments. Direct detection of the DM candidates, with mass spanning in the range of a few GeVs to several TeVs, is one of the most challenging goals in contemporary physics, which involves multidisciplinary endeavours and the development of new techniques in detectors, electronics, signal processing and data analysis. Furthermore, such experiments must be stationed at a deep underground site to reduce the background caused by cosmic ray particles by several orders of magnitude.

The direct search for DM involves a remarkably simple principle. A DM candidate should interact with the detector medium to deposit an amount of energy such as, for example, nuclear recoil. The amount of energy should be detectable by the detection methods devised for such purposes. For a typical DM candidate, such as WIMPS with a mass of a few GeV to a few 1000s of GeV, the recoil kinetic energy is only a few keV to $\sim$ 100 keV. The tiny magnitude of the recoil energy, though detectable, is not easy to measure in a clean way because of the contributions from several reducible and irreducible backgrounds. The reducible background can be managed and reduced by significant amount by 1) going underground to a significant depth, 2) employing a passive shield surrounding the detectors, and 3) by employing an active veto shield that uses detectors for charged particles and neutrals, dominated by neutrons. The irreducible background, caused mostly by the impurity inside the detector and its surrounding materials, can be reduced through proper care in the selection of materials that have an extremely low content of U / Th and other common radioactive contaminants from natural resources (such as ^{14}C, ^{40}K, ^{137}Cs, etc.). The background can also be reduced by applying proper purification procedures to the materials.

Quite a handful of direct DM search experiments are under way or proposed at various underground laboratories around the world. A comprehensive summary of the experiments can be found in review articles (eg. see Ref. [2]). The best possible exclusion limit so far has been giv-

Fig. 1: A photograph of the tunnel in the mine leading to the underground science laboratory.

Fig. 2: Scientists at work at the Underground Science Laboratory in India.

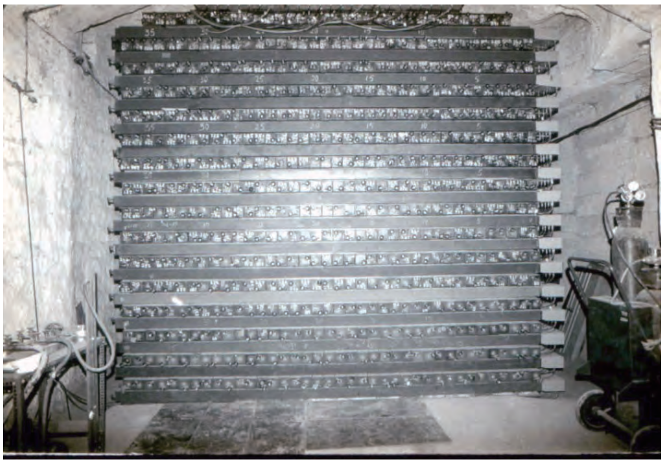

Fig 3: Nucleon decay detector at the KGF in the 1980s (adopted from Ref [3]).

en by Xenon-based large scale experiments that cover the WIMP mass range of ~ 10 GeV and above. The low mass range of below ~ 10 GeV is relatively unexplored, but quite a few experiments with sensitivity targeted for the low mass region have started taking data. In fact, some of the experiments have come up with unprecedented sensitivity and have detection thresholds of ~ 0.1 keV and below. These experiments are optimized to look for electron recoil events at the sub GeV DM candidate mass region, where the energy transferred to recoiling nuclei is expected to be much smaller than that dumped into electron recoil.

INDIA'S UNDERGROUND LABORATORY

In India, an underground laboratory was established in 2017 at shallow depth inside an existing mine with the aim of establishing a dark matter search experiment in the near future (see Figs. 1 and 2). The laboratory is situated at Jaduguda in the East Singhbhum district of Jharkhand state, which is located in the eastern part of India. This laboratory is, at present, the only underground science laboratory in India to carry out rare event search experiments, which are otherwise impossible to do at the Earth's surface because of the extremely large cosmic radiation background.

In the last century, India had one of the deepest underground science laboratories (vertical depth of ~ 2.8 km) in the world at Kolar Gold Fields (KGF). The KGF underground laboratory (see Fig 3) was operational for more than 40 years, from 1951 – 1992 The atmospheric neutrino was detected for the first time at KGF way back in 1965 [3]. The first experiment to study the stability of protons was also carried out at KGF during the early 80s [3]. After the closure of the KGF underground laboratory, Indian scientists searched for an alternate facility that would be suitable for carrying out fundamental particle physics experiments that needed low background environment. With support from the Department of Atomic Energy, Government of India, Saha Institute of Nuclear Physics (SINP) has set up a small underground science laboratory at 555 m depth of the mine. To begin with, the laboratory is used to study the performance of detectors under development for a future dark matter search and neutrino physics experiments in which, scientists from the Saha Institute of Nuclear Physics, Kolkata, the Uranium Corporation of India Limited (UCIL), Jharkhand, the National Institute of Science Education & Research (NISER), Bhubaneswar, the Bhabha Atomic

Research Centre (BARC), the Variable Energy Cyclotron Centre (VECC), Kolkata, the Institute of Physics, Bhubaneswar, Tata Institute of Fundamental Research (TIFR), Mumbai and other institutions are participating. The laboratory is also used for studying various environmental parameters like radon levels and corresponding mitigation measures to reduce the background due to rock radioactivity, etc. These studies will be immensely useful for the design of various future underground experiments in fundamental physics.

In the first phase of the underground laboratory, we plan to set up a reasonably large experiment with CsI(Tl) scintillators, operated at room temperature. This will be developed and set up in the present laboratory, complete with active and passive shields. We hope to improve upon or set comparable limits as done by similar experiments. Based on these studies, we can come up with suggestions for specific developments leading to a cryogenic dark matter search experiment involving either a scintillation or an ionization detection technique, along with phonon signal detection at the sub keV threshold. In another endeavour, we propose to set up a low mass dark matter (DM) search experiment targeted for below 20 GeV/c^2 WIMP mass using a superheated liquid technique. Using the low cosmic muon background environment of the laboratory, scientists plan to study features of the high energy gamma rays produced in spontaneous fission and assess their origin.

Based on the results obtained from various direct search experiments till date, the best exclusion limits come from the Xenon based experiments for WIMP masses > 10 GeV. However, for the low mass region (< 10 GeV), there are competing experiments, which have reached extremely low energy threshold and have sensitivity to a few hundreds of MeV masses. Challenges in the next phase will be to push down the threshold and the background contribution even further to reach higher sensitivity at the relatively low DM mass region.

References

[1] G Hinshaw et al., Astrophys. J. Suppl. 208 19 (2013).
[2] T M Undagoitia and L Rauch, J. Phys G: Nucl. Part. Phys. 43, 013001 (2016).
[3] Perspectives of Neutrino Physics in India, V. S. Narasimham, Proc. Indian National Science Academy 70A, 11 (2004).

Satyajit Saha is a senior professor and head of the Applied Nuclear Physics Division of the Saha Institute of Nuclear Physics (SINP), Kolkata. His current interest is in the application of nuclear radiation detectors in exploring fundamental physics problems. He, along with his colleagues at SINP, is working toward establishing an underground science laboratory in India to study rare event processes.