PROCEEDINGS OF SCIENCE

Paving the way for the Paarl-Africa Underground Laboratory

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The Southern hemisphere offers a wonderful opportunity for scientists to explore unique initiatives offered by a low level radiation facility. Establishing a deep underground physics laboratory to study, amongst others, double beta decay, geo-neutrinos, reactor neutrinos and dark matter has been discussed for more than a decade within the austral African physicists' community. The Paarl-African Underground Laboratory (PAUL) is foreseen as an open international laboratory, a unique opportunity for Africa, devoted to the development of competitive science in the region. It has the advantage that the location, the Huguenot tunnel, exists already and the geology and the environment of the site is appropriate for an experimental facility. A report of the most recent developments in the modelling of muon flux and muon measurements which are required for the establishment of the PAUL and the envisaged research programs is presented.

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1. The Context

Underground laboratories (ULs) create the ideal environment to study physical phenomena which require a low level radiation background. Such facilities are located in mines, or tunnels which are effectively shielded from natural cosmic radiation. Currently 11 of the 12 operating underground laboratories are found in the Northern hemisphere. There is, therefore, an opportunity to develop a similar integrated network of research facilities in the Southern hemisphere. Neutrinos and the search for Dark Matter have been big drivers in the field of experimental physics, sitting at the frontier between nuclear physics, particle physics, astroparticle physics and cosmology. The addition of underground laboratories in the Southern Hemisphere will add to the global study of Neutrino physics and the search for dark matter.

Figure 1: Map of the existing or planned underground laboratories [1]. Green dots: the operating facilities. Orange dot: under commissioning SUPL facility in Australia. Red dots: ANDES at the Argentina-Chile border and INO in India. Yellow star: the future Paarl Africa underground lab facility, in the Western Cape Province of South Africa.

Figure 1 shows the map of the existing or planned underground laboratories. At present, there are 11 ULs in operation (green dots), one is under commissioning (orange dot), SUPL in Ausralia, and two more (red dots) are planned, ANDES at the Argentina-Chile border and INO in India. ANDES (Ague Negra Deep Experiments Site) [2] is planned as a 4000 m^2 general purpose deep underground laboratory with 1750 m of overburden in the Agua Negra tunnel between Argentina and Chile. INO (India-based Neutrino Observatory) [3] is a planned laboratory in Pottipuram, India, with 1200 m of overburden to host an iron calorimeter (ICAL) for neutrino studies. The yellow star is the foreseen location of the future Paarl Africa underground lab facility, in the Western Cape Province of South Africa, under the 1300 m Du Toitskloof mountain with ~ 800 m of rock overburden for the Huguenot tunnel itself. About 100 experiments are running or are under construction in the ULs currently in operation and roughly 6000 researchers are involved.

From the experimental point of view, the events which may lead to the identification of dark matter particles and rare electroweak decays, have extremely low counting rates and would be observed at energies where an overwhelming background of radioactive decays and cosmic rays is present. Given the high energy and penetration of the cosmic radiation, the detectors need to be shielded by going underground. One can get a reduction of the cosmic radiation effects by orders of magnitude by digging labs some kilometers under the surface, or by building them under mountain rocks - see Figure 2 showing the laboratory depth (in meter water equivalent [1]) as a function of the cosmic-ray muon flux for each continent. Circles represent the volume of science space.

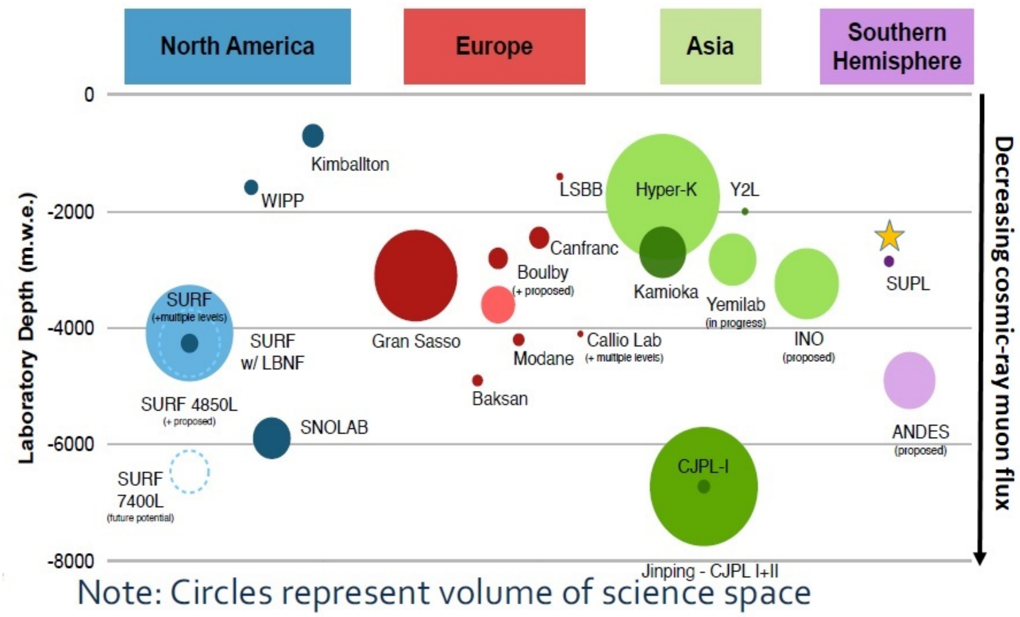

Figure 2: Effective depth (in meter water equivalent [4]) vs decreasing cosmic-ray muon flux (cm^2 s^{-1}) [5]. The yellow star indicate the corresponding numbers for the future Paarl Africa underground lab facility in the Western Cape Province of South Africa, under the 1300 m Du Toitskloof mountain with ~ 800 m of rock overburden for the Huguenot tunnel.

The scientific work can expand to research projects in multiple fields including biology, geosciences, chemistry, mining technology, underground construction and architecture.

As one of the world's largest producers of gold, South Africa has a number of the world's deepest gold mines (TauTona Gold Mine of 3.9 km deep). In 1965 the Nobel Prize laureate Frederich Reines along with South African Physicist, Friedel Sellschop detected the first atmospheric neutrino events in the East Rand mine near Johannesburg, South Africa [6]. Initial focus by the South African nuclear physics community was on establishing an underground facility in one of South Africa's deep gold mines. The alternative is to develop such an underground laboratory inside the Huguenot

[1]The meter water equivalent (m.w.e.) [4] is a standard measure of cosmic ray attenuation in underground laboratories. A laboratory at a depth of 1000 m.w.e is shielded from cosmic rays equivalently to a lab 1,000 m below the surface of a body of water.

tunnel, which is conveniently located between the towns of Paarl and Worcerster in the Western Cape Province of South Africa, see Figure 1 and section 3.

2. Research Purpose

The underground laboratory will provide a dynamic environment for advances in ultra-sensitive detectors and ultra-low radiation techniques and highly trained graduates ready to lead innovation in both the global search for **rare events and cutting-edge technological development** to benefit South Africa industry. However, physics research is not the only field which is of interest.

The need for very low radioactive material for dark matter and neutrino underground experiments gave birth to the study of new detectors able to measure **extremely low radiation levels**. These very sensitive detectors, able to detect levels of radiation of a millionth of the natural radiation of the human body, have to be located deep underground to be shielded from cosmic ray radiation. The industry has shown interest in these techniques to select pure materials with almost no radioactive content. Researchers involved in this work can contribute to many needs in South Africa for accurate measurements, such as the detection of the radioactive gas radon that has been identified as a major radiation hazard in South African underground mines [7].

The research of endolithic bacteria and technologies for bio-leaching are a subject of continuously increasing interest. New ideas in **underground biology** [8–10] have also included initiatives related to **astrobiology** [11], impact of radiation (or the lack of it) to evolutionary processes or formation of bio-aerosols.

Underground laboratories are excellent sites to investigate new technologies for geothermal energy production or energy storage as well as the characterization of the geology of the earth [12].

3. The Paarl Africa Underground Laboratory and the experimental facility

The existence of the Huguenot tunnel, which is located between the towns of Paarl and Worcester in the Western Cape Province of South Africa, see Figure 3, offers a unique possibility to build up a scientific complex suitable for the detection of events under ultra-low radiation exposure, as required for dark matter and neutrino studies, as well as for other areas of research.

The development of the Huguenot tunnel as an underground low-level radiation facility holds a number of strategic advantages. Such a facility is located approximately 25 km from Stellenbosch University and 40 km from the iThemba LABS. It will provide quick and easy access to the local research communities. Research programs done at such a facility will also support postgraduate training programs at Stellenbosch University, the University of the Western Cape and the University of Cape Town. Furthermore, the research at the PAUL will support national and international research activities in astronomy, nuclear and particle physics, as well as many of the research topics already discussed in section 2.

According to the geological survey, which was done during the excavation period (1973 - 1984), the composition of the mountain range consists mainly of quartzitic sandstone (also referred to as Table mountain sandstone), see Figure 4. It is therefore expected that radon concentration levels within the tunnel should be low, and should therefore not have a considerable contribution

Figure 3: Map of the Western Coast of Cape Town and the location of the Huguenot tunnel [1]. Modified image extracted from Google Map.

to the background radiation signature. The height of the Du Toitskloof mountain range is about 1300 m, providing ~ 800 m of rock overburden for the Huguenot tunnel itself [13].

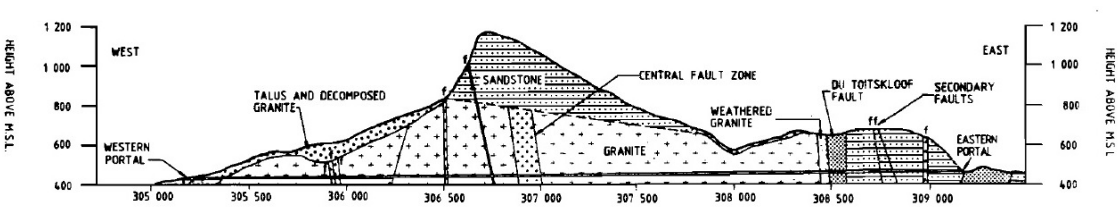

Figure 4: Geological mapping and analysis of the rock of the tunnel [13].

In 2013, the environmental radiation groups at Stellenbosch University and iThemba LABS performed a preliminary radon measurement [14].The concentrations measured at three sites confirm that the level of radon is well below any degree of consideration. In addition to the gamma ray spectra and radon, the background measurements were performed using bio monitors placed at strategic locations within the tunnel in order to measure the air pollution levels within the tunnel.

There is a real opportunity for a dedicated underground research facility to be established inside the Huguenot tunnel. The ideal would be to build the laboratory at the north of the service tunnel [15] (to be built itself to the north of the current one, driving from Paarl to Rawsonville). The laboratory will consist of a surface facility, located near the road freeway Huguenot tunnel, and potentially extensive underground spaces and various connecting tunnels. The experimental hall will be covered by about 800 m of rock, under the Du Toitskloof Mountains, protecting the experiments from cosmic rays. It will not be a deep underground laboratory but can be driven to without using mine elevators, just like LSM [16] or LNGS [17] facilities.

For a small or medium size lab, the LSM concept [16], where one has a deceleration line and then stops on the side, is an appropriate design. The fact that one access tunnel to the lab is large allows one to stop a large truck in the proper space and then discharge the truck contents with a crane to move it inside the cavern. See Figure 5 for a minimal design of a possible 600 m^2 laboratory (40x16x16 m^3), based on the medium cavern design of ANDES [2].

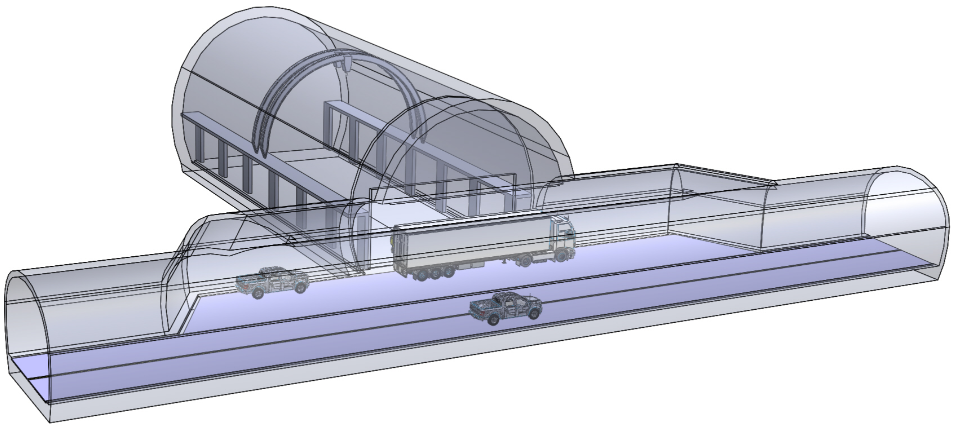

Figure 5: Mock-up of a possible 600 m^2 laboratory (40x16x16 m^3) in the Huguenot tunnel. Courtesy: Joaquín Venturino (CNEA), April 2023. [1]

The future underground laboratory is currently being designed; It directly involves the company operating the Huguenot tunnel since earthworks and infrastructure construction are planned over the next five to ten years.

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