The Paarl Africa Underground Laboratory (PAUL)

Rob Adam (SKAO), for the PAUL collaboration, TIPP2023

08/09/2023

Outline of presentation

- Science motivation for PAUL
- Advantages of locating PAUL in the Huguenot tunnel
- Design of PAUL
- Timeframes
- Conclusions

Science Motivation for PAUL

Studying **Neutrinos** and the searching for **Dark Matter Particles** is an important and frontier interdisciplinary science with implications for nuclear, particle and astrophysics as well as cosmology.

Underground Laboratories, with shielding from cosmic rays by more than about 1000 m of rock, make experiments that require low-noise background possible.

Of the currently operating laboratories 11 of 12 are to be found in the Northern Hemisphere: Europe, USA, Russia, Canada and Japan, and none are in **Africa**.

PAUL is an initiative to build one of these in the **Huguenot Tunnel** or one of the mines **in South Africa**.

Multi-Messenger Physics

Neutrinos are **probes of the high-energy universe**, because unlike photons that can be absorbed in such environments, they traverse them carrying imprints of where they originate (see ICECUBE).

High-energy astrophysical neutrinos from blazars (e.g. TXS 0506+056) were detected in underground laboratories, e.g. ICECUBE, 2017, opening a window to understanding the **unique acceleration mechanisms of blazars**, the origin of the **associated cosmic-rays and their high-energy universe**.

The detections from the underground laboratories provide **alerts for multi-messenger follow-up and study with astrophysics observatories** and South Africa is well suited for that.

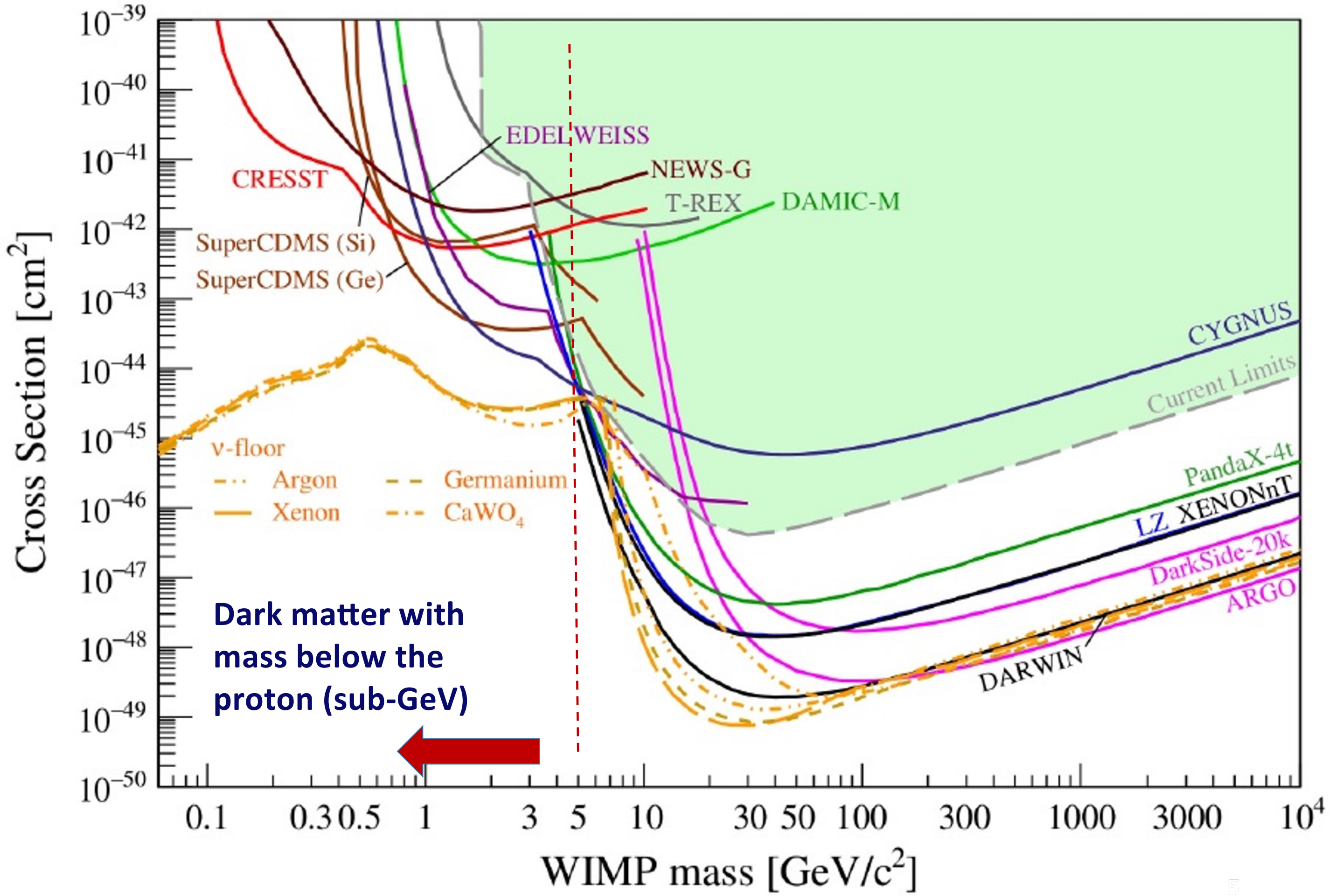
Plus PAUL will provide a **training facility to do this low background physics**

Potential for Astroparticle research

The challenge is to develop detectors with very low energy thresholds and excellent control over detector backgrounds.

Technology

- ✓ Charge Coupled Devices (CCDs), Skipper-CCD (SENSEI, DAMIC, OSCURA)
- ✓ Solid-state cryogenic detectors (Ge, Si, ..), operating at T<15 mK, (Edelweiss)
- ✓ Noble Liquid target (Xe, Ar)



Other research possibilities

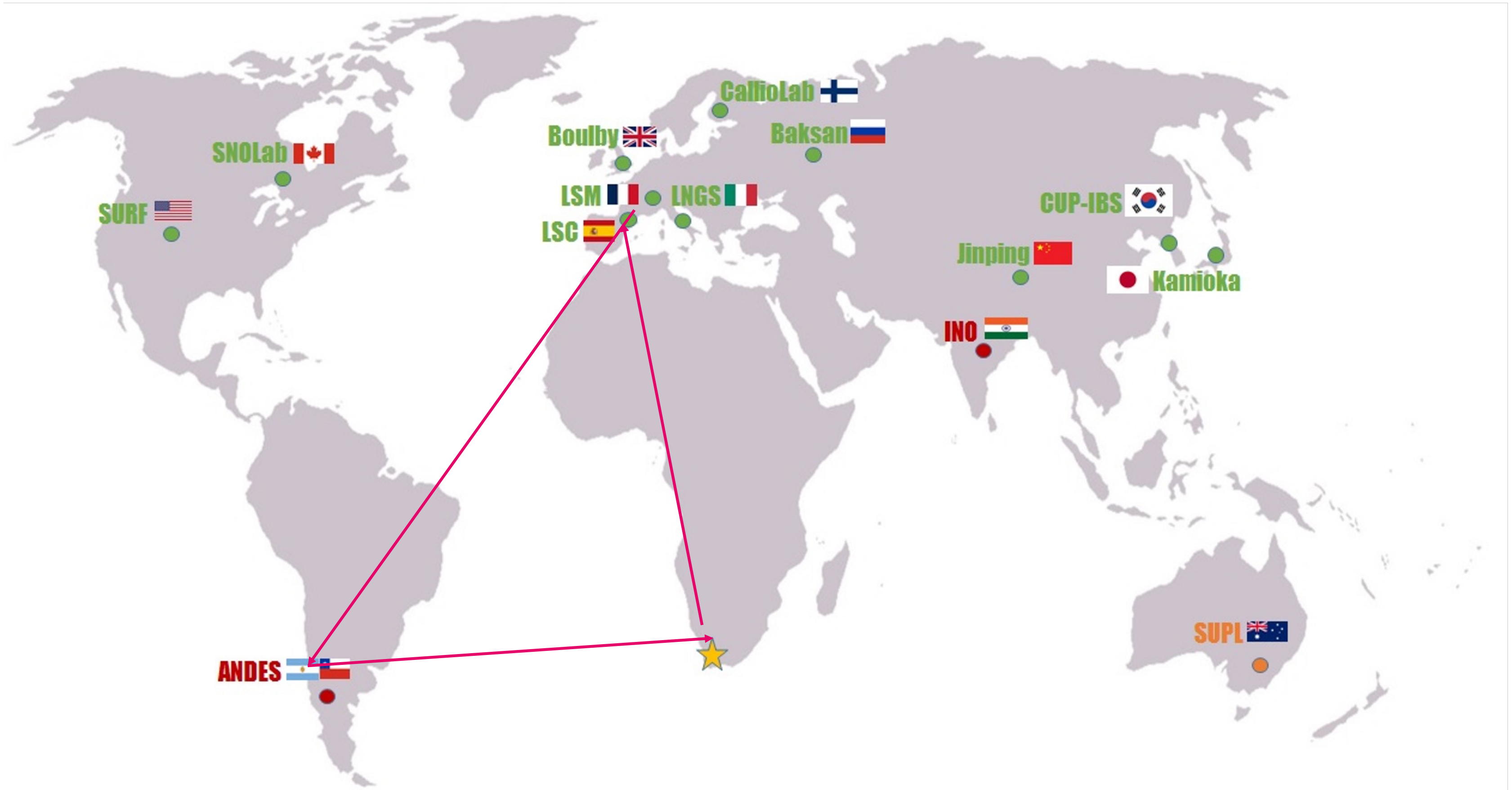
- Measurement of **extremely low radiation levels**. These very sensitive detectors, able to detect levels of radiation a millionth of the natural radiation of the human body. Researchers involved in this work can contribute to many needs in South Africa for accurate measurements, such as the detection of the radioactive gas radon that has been identified as a major radiation hazard in South African underground mines.

- The research of **endolithic bacteria** and technologies for bio-leaching

- **Astrobiology** , examining the impact of radiation (or the lack of it) to evolutionary processes or formation of bio-aerosols.

- In glaciology, the study of **ice samples from the Arctic, Antarctic** etc. allows mapping of the **evolution of climatic parameters** and contamination both in space and over time for the last centuries. The measurement of 137Cs and 241Am is the only way to get a precise dating of ice.

New global UL developments 2022-2023



The Huguenot tunnel

Historical Interest in South Africa

2015: Towards the South African Undergrounc

ELSEVIER

Physics Procedia
Volume 61, 2015, Pages 586-590

Towards the South African Underground Laboratory (SAUL) ☆

S.M. Wyngaardt [a], R.T. Newman [a], R. Lindsay [b], A. Buffler [c], R. de Meijer [b], P. Maleka [d], J. Bezuidenhout [e], R. Nchodu [d], M. van Rooyen [a], Z. Ndlovu [a]

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2019: Latest Updates on Developments of the Underground Neutrino Facility in South Africa

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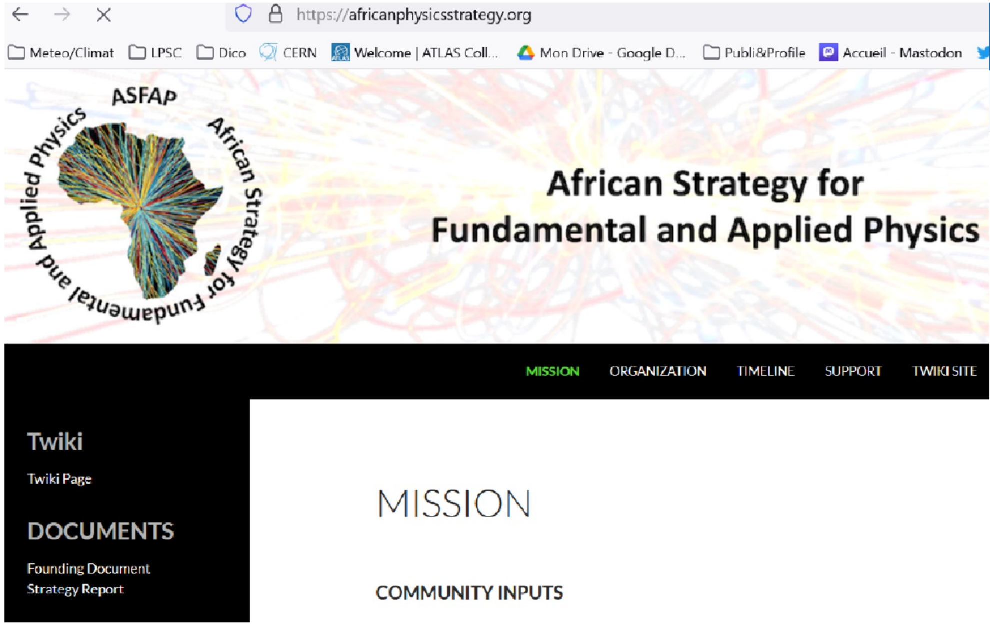
Exotic Nuclei, pp. 478-485 (2019) | No Access

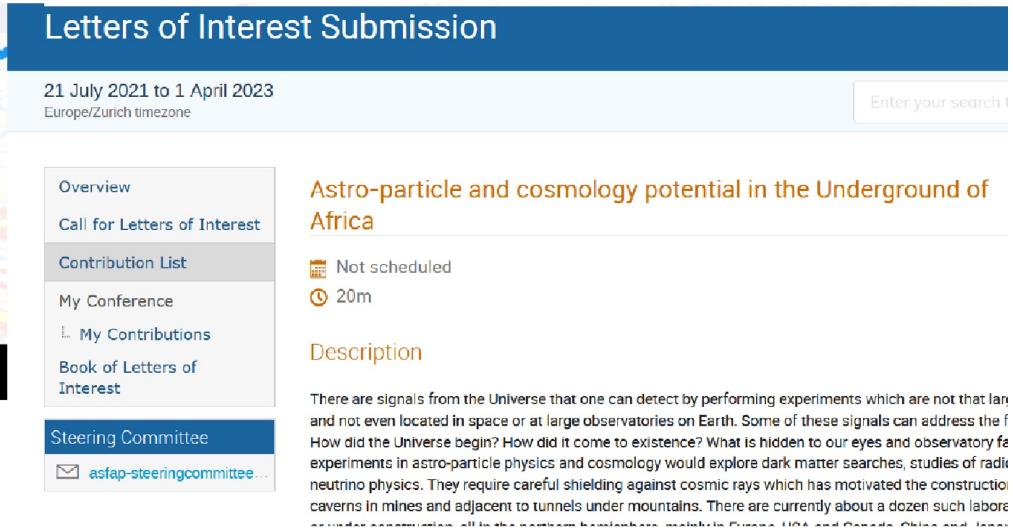
Latest Updates on Developments of the Underground Neutrino Facility in South Africa

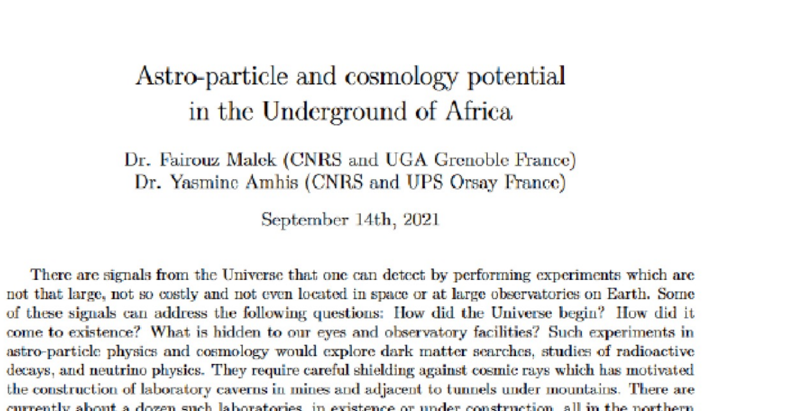
Z. Z. Vilakazi, S. M. Wyngaardt, R. T. Newman, R. Lindsay, A. Buffler, R. de Meijer, P. Maleka, J. Bezuidenhout, R. Nchodu, M. van Rooyen and Z. Ndlovu

https://doi.org/10.1142/9789811209451_0069 | Cited by: 0

New Impetus







Astro-particle and cosmology potential in the Underground of Africa

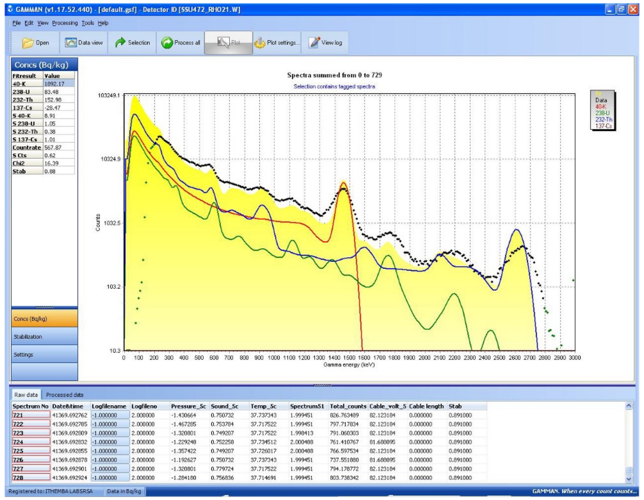
Dr. Fairouz Malek (CNRS and UGA Grenoble France)
Dr. Yasmine Amhis (CNRS and UPS Orsay France)

September 14th, 2021

There are signals from the Universe that one can detect by performing experiments which are not that large, not so costly and not even located in space or at large observatories on Earth. Some of these signals can address the following questions: How did the Universe begin? How did it come to existence? What is hidden to our eyes and observatory facilities? Such experiments in astro-particle physics and cosmology would explore dark matter searches, studies of radioactive decays, and neutrino physics. They require careful shielding against cosmic rays which has motivated the construction of laboratory caverns in mines and adjacent to tunnels under mountains. There are

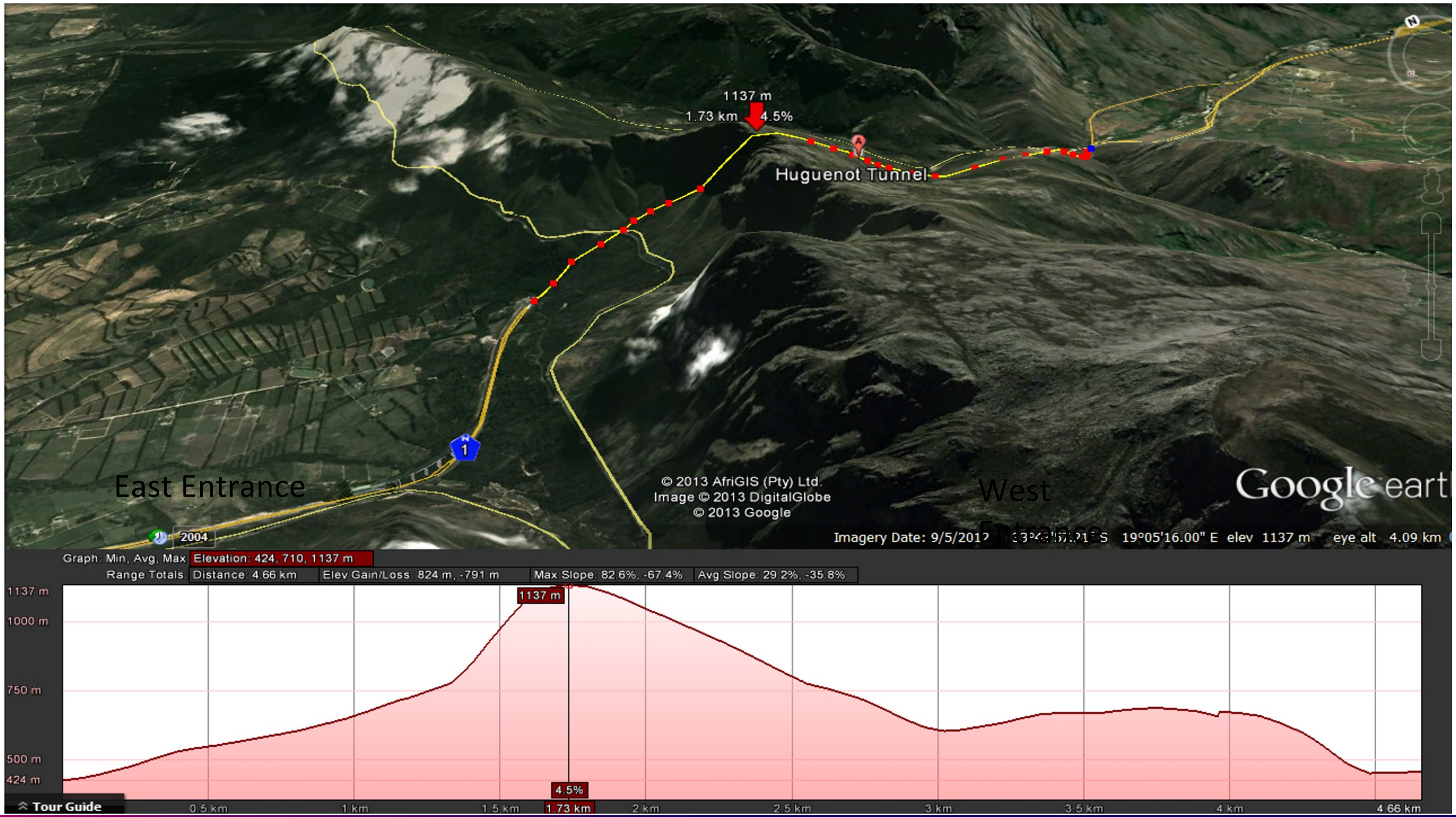
Location of the Huguenot tunnel

γ-ray mapping in the Huguenot tunnel, 2013
Phys. Proc. 61 (2015) 586-590



The concentrations measured at three sites confirm that the level of radon is well below any degree of consideration, with a mean level of radon no more than ~50 Bqm^{-3}

1300m Du Toitskloof mountain with ~800 m of rock overburden for the Huguenot tunnel



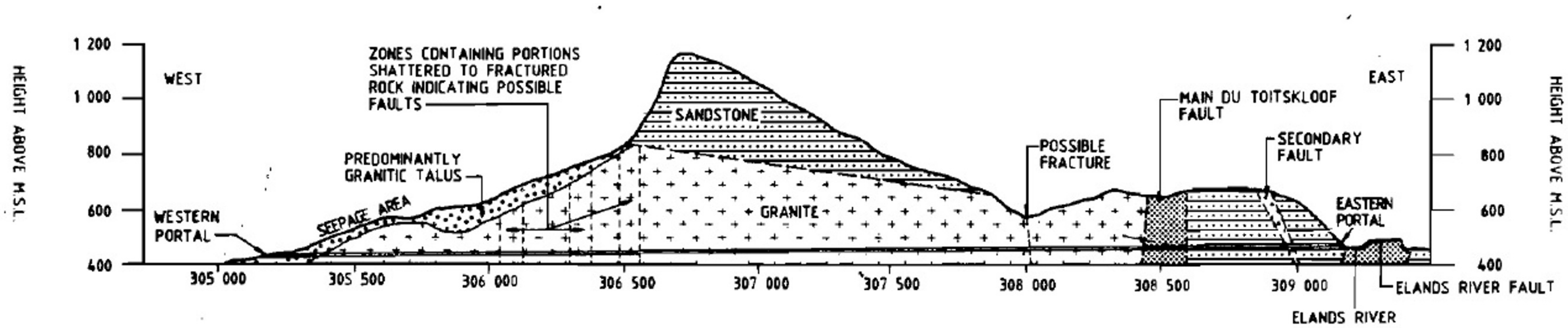
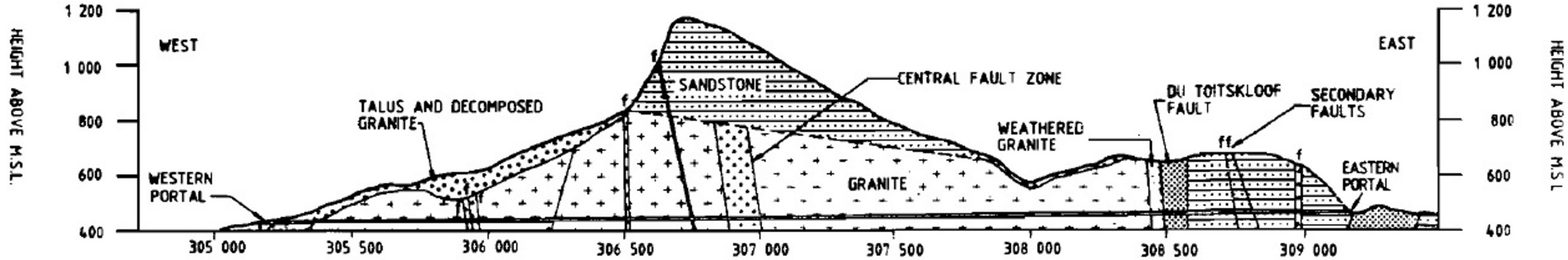
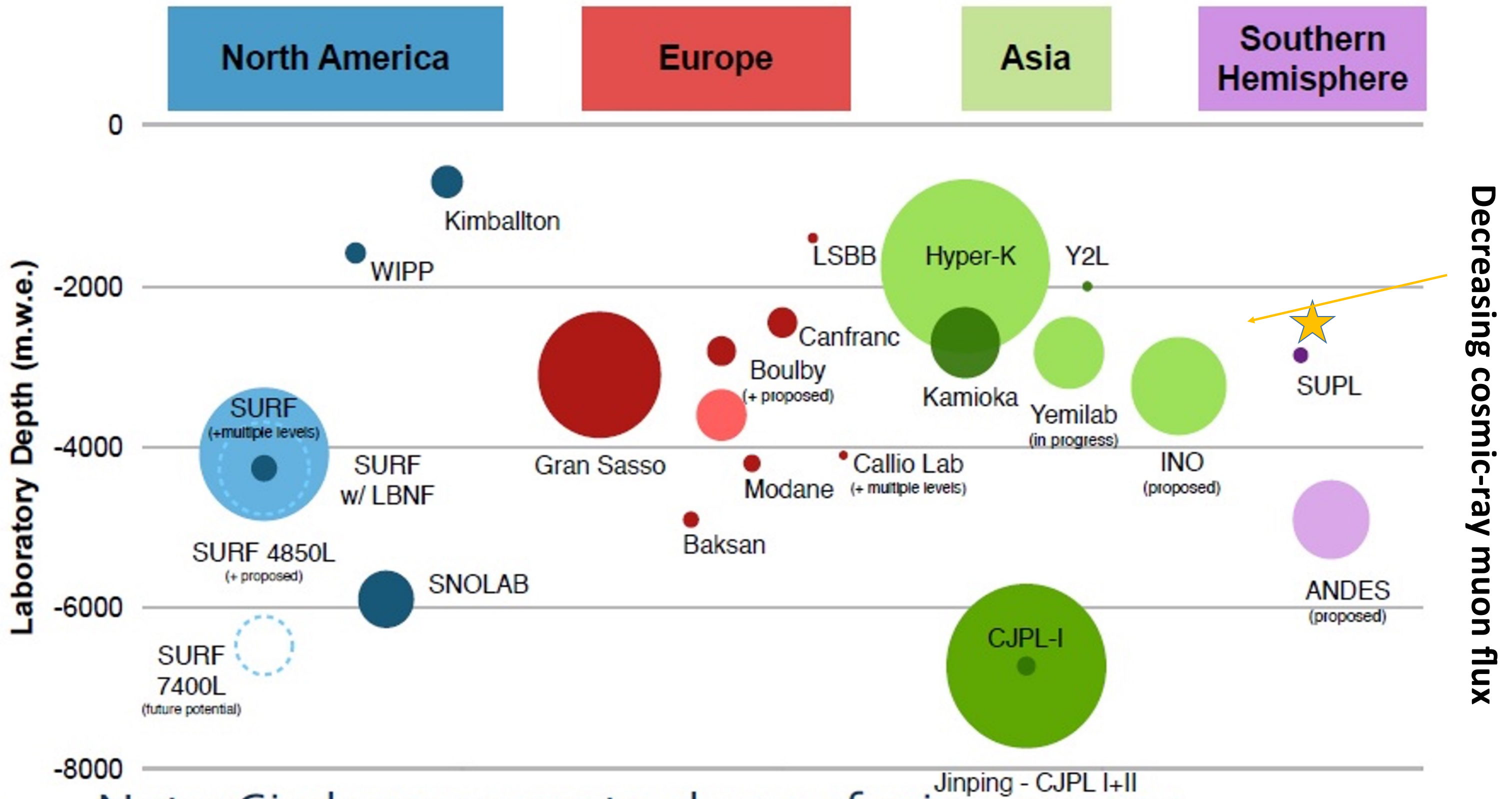


Fig 2: Pre-pilot bore geology



The range mostly consists of Table Mountain sandstone, an erosion-resistant quatzitic sandstone

Lab Depth (mwe) vs Decreasing cosmic-ray muon flux



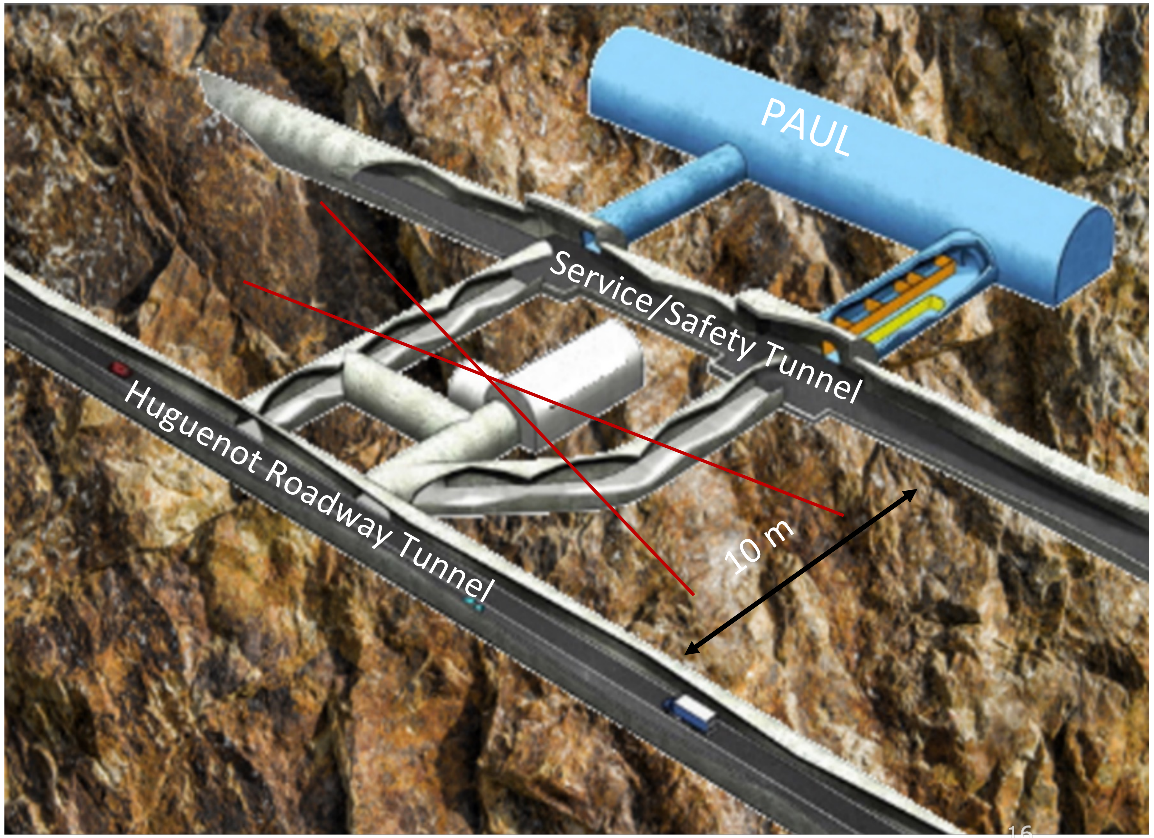
Note: Circles represent volume of science space

For PAUL, it is only an estimate as the cosmic-ray muon flux is not yet well measured, nor the real rock overburden known exactly (~800 m, ~2000 mwe)

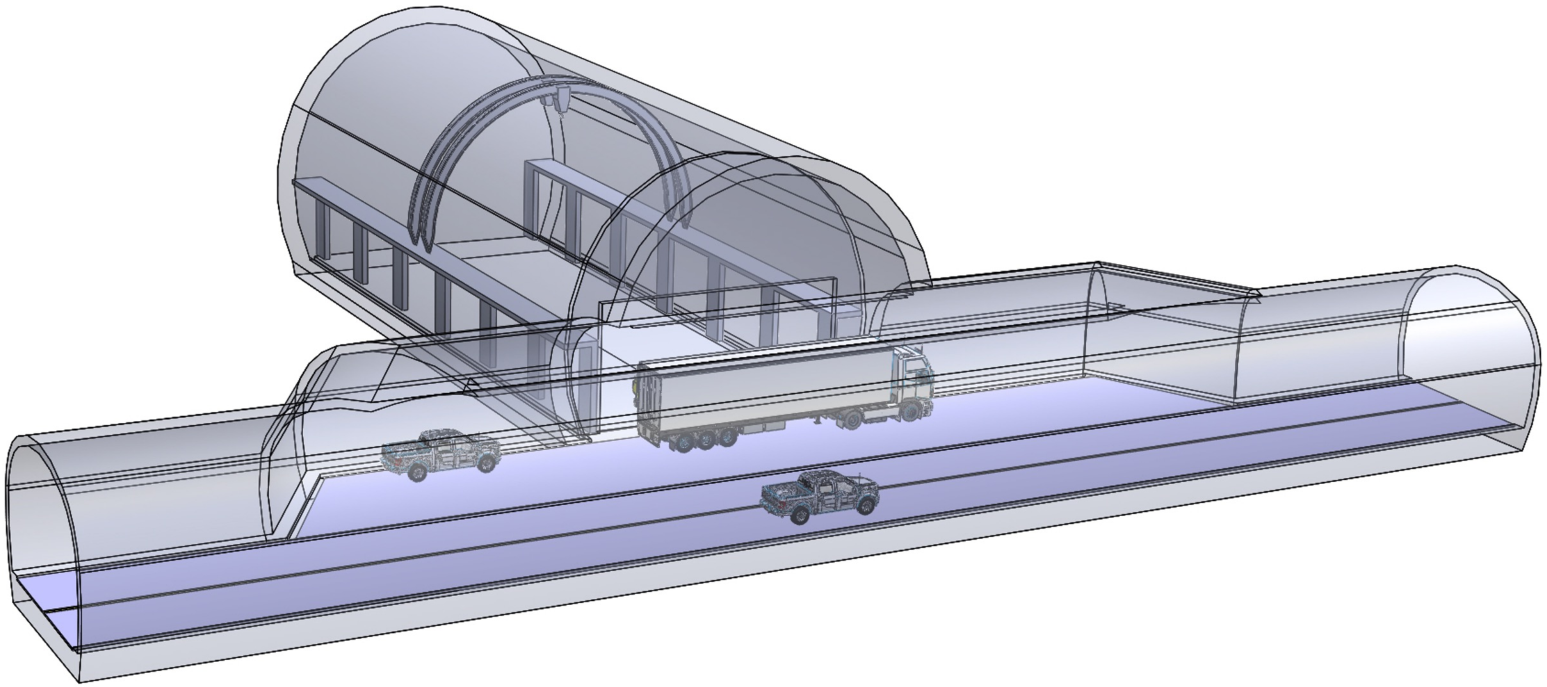
Design of PAUL in the Huguenot Tunnel

The design of LSM-Modane, France
was used for the purpose
of the illustration

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



Mock up of PAUL facility



A possible 600m^2 laboratory (40x16x16 m^3) in the Huguenot tunnel.
Courtesy: Joaquin Venturino (CNEA), April 2023.

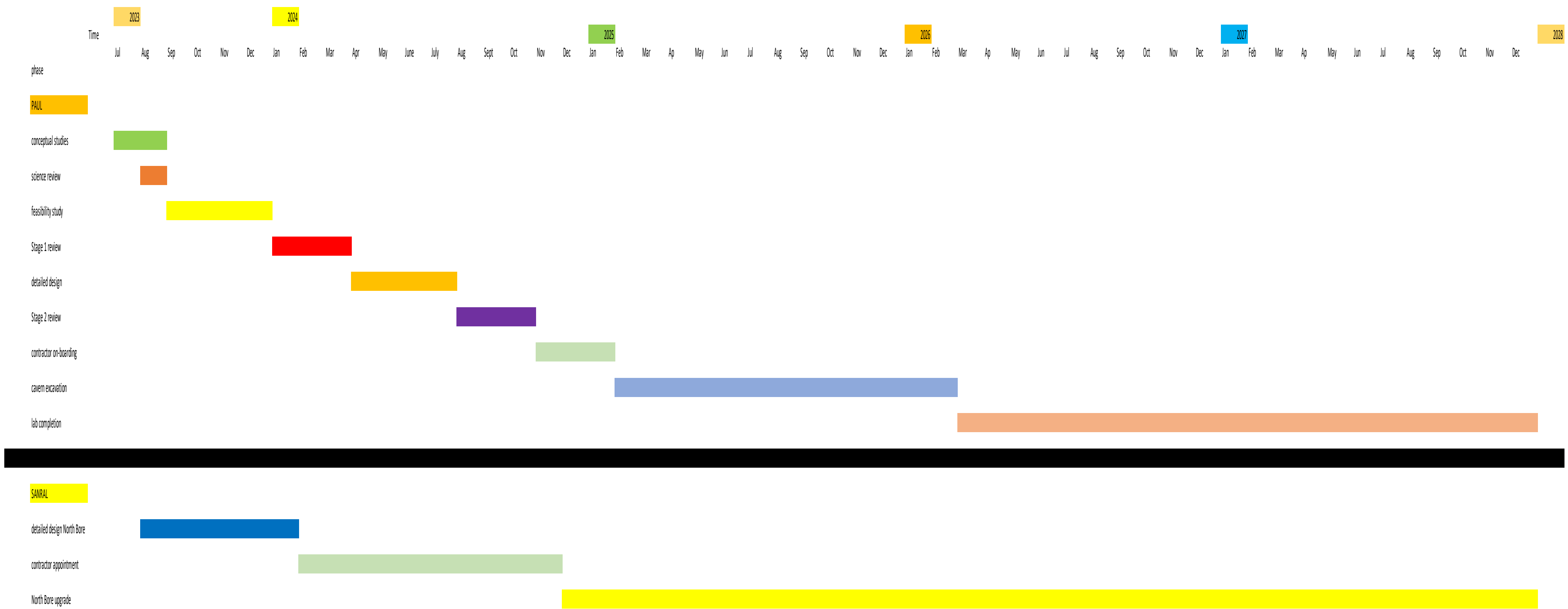
The current PAUL collaboration

- 46 scientists, 1 engineer
- 13 countries represented
- 4 African countries (SA, Botswana, Morocco, Nigeria)
- 6 European countries (France, Switzerland, Italy, Sweden, Slovakia, Czechia)
- includes: USA, Argentina and Taiwan

The PAUL project budget

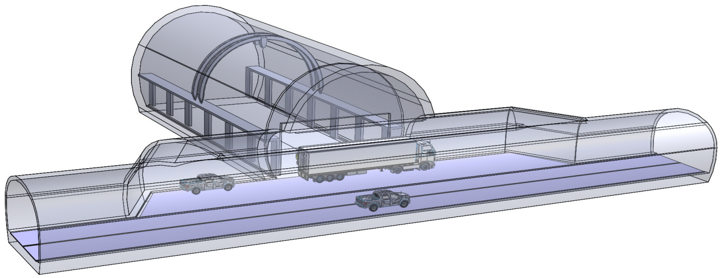
										01-Aug-23
item	total volume	cost per m^3	US$/R	total floor area	cost per m^2	assumed cost per m^2	cost	cost		Ask from SA gov
	m^3	US$			US$	US$	US$	Rands		
excavation	10240	100	20		(from ChatGBT)		1024000	20480000	1,00E+07	2,20E+07
structural reinforcement				600	1000 - 3000	2000	1200000	24000000		2,40E+07
foundation work				600	500 - 1500	1000	600000	12000000		1,20E+07
utilities				600	500 - 2000	1200	720000	14400000		1,44E+07
interior finishes				600	1000-5000	2500	1500000	30000000		3,00E+07
Ultra-low background facility								8000000		
Dark Matter Facility							400000	8000000		
Biological Science Facility								5000000		
above ground offices/workshops								5000000		5,00E+06
						Grand Total		126880000	105880000	1,07E+08
										1,29E+08
									Rands	1,30E+08
safety	include									
electricity (significant)	include	ventilation	air conditioning						US$	6,50E+06

Timelines


2023
2024
2025
2026
2027
2028
Time
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Ap May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Ap May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Ap May Jun Jul Aug Sep Oct Nov Dec
phase
PAUL
conceptual studies
science review
feasibility study
Stage 1 review
detailed design
Stage 2 review
contractor on-boarding
cavern excavation
lab completion
SANRAL
detailed design North Bore
contractor appointment
North Bore upgrade

Next steps

- Due diligence (DSI)
- Due diligence (DoT)
- Formal engineering feasibility study and costing
- Review – go/no-go
- Detailed engineering design and updated costing
- Review and approvals – go/no-go



Conclusions

- PAUL is planned to be 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 are appropriate for an experimental facility of this nature.

- Performing an experiment to directly detect dark matter in an underground laboratory located in the Southern Hemisphere involves **comparing results with those of an identical detector in the Northern Hemisphere**. Any seasonal variation will have an opposite phase, giving an opportunity to distinguish such signals from dark matter signals. It also opens different regions of parameter space when searching for daily modulations

- The other advantage to build an UL facility in South Africa is to **combine the direct detection with indirect dark matter detection from radio astronomy** surveys that South Africa is leading (SKA, MeerKAT, etc.). Therefore, the strong synergy between the astrophysical (indirect) probes and Paarl Africa Underground Laboratory (direct probe) can jointly measure and constrain dark matter effects, which may shed lights on new physics.

We recognise and acknowledge the Indigenous peoples and cultures that have traditionally lived on the lands on which our facilities are located.

SKAO

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