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PAUL Overview
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- “It is a remarkable fact that we do not know what the vast majority of the universe is made of. Everything we can see, planets, stars, galaxies and gas, makes up just a tiny fraction of the matter in the universe. The rest invisible to us was dubbed “**dark matter**” by Fritz Zwicky ...”
- *A. Murphy and S. Paling, Nucl. Phys. News, Vol. 22, No. 1, 2012*



- Visible matter: about 5 % of mass/energy in universe
- Dark matter: about 27 % of mass/energy in universe

- “Quantum Physics in minutes”, by Gemma Lavender, Quercus, 2017

<https://www.lngs.infn.it/it/raggi-cosmici>

*Schematic representation of cosmic-ray shower. By locating a laboratory underground (inside a mountain or down a mine) one can **shield** experiments from unwanted background signal produced by the cosmic-ray showers. Such laboratories are called deep underground laboratories (**DULs**).*





Map of the existing or planned underground laboratories. 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

What is PAUL ?

- acronym for **P**aarl **A**frica **U**nderground **L**aboratory
- a proposed Deep Underground Laboratory (**DUL**)
- proposed location: inside the Huguenot Tunnel on the N1 highway between the towns of Paarl and Worcester (in the Western Cape Province, South Africa)



Map of the Western Coast of Cape Town and the location of the Huguenot tunnel. Modified image extracted from Google Map.

Paarl derived from Dutch word for pearl, “parel”

Paarl Mountain



Background on the Huguenot Tunnel

- The tunnel is managed by the South African National Roads Agency Limited (SANRAL)
- SANRAL is a parastatal falling under the Ministry of Transport



- Edict of Fontainebleau (1685), by King Louis XIV overturning Edict of Nantes (1598) by King Henry IV.
- Huguenots = Calvinist Protestants in France
- Revoked rights of Huguenots to practice their religion
- Fled France, some to South Africa



Louis XIV



The Edict of Fontainebleau in the Archives Nationales



Source: Wikipedia

Cross-section of the Huguenot Tunnel

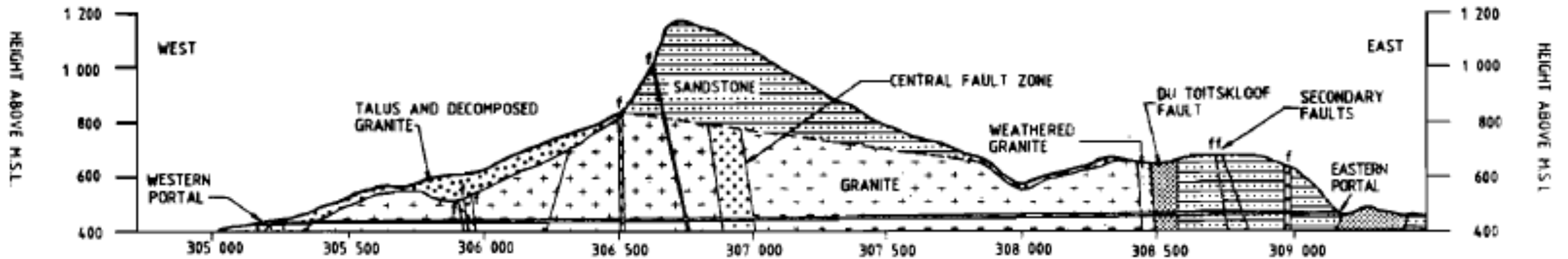


Fig 3: Post-pilot bore geology

Background on the Huguenot Tunnel

- constructed between 1984 and 1988



Joint Venture project

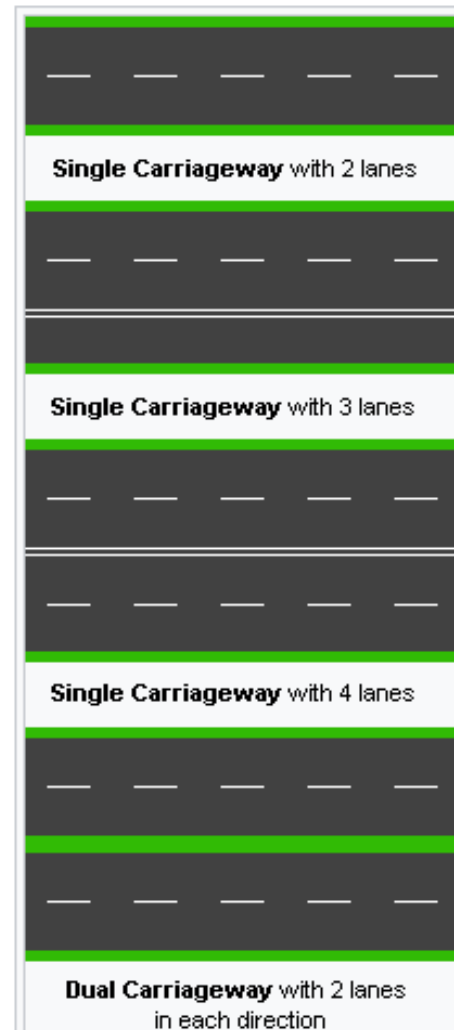
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Background on the Huguenot Tunnel

- Source: Wikipedia



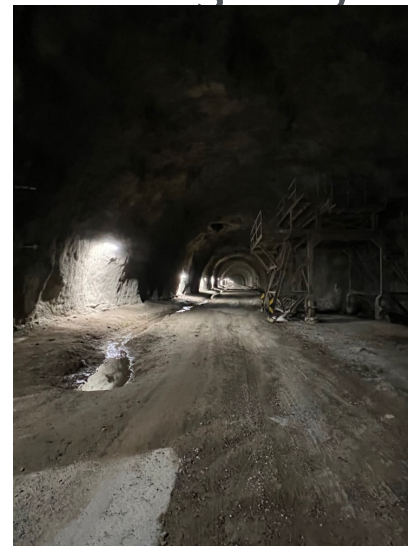
Background on the Huguenot Tunnel

- Tunnel has South and North bores
- 3.9 km long, longest road tunnel in South Africa
- currently: single-laned highway or single carriageway (one lane in each direction) in Huguenot Tunnel South Bore [no physical barrier between lanes]
- Currently: North Bore is used as service/emergency tunnel

South Bore Tunnel at the Huguenot Tunnel Complex



North Bore Tunnel at the Huguenot Tunnel Complex



- SANRAL is planning to upgrade the North Bore Tunnel in order for it to lower traffic volumes in the existing South Bore Tunnel.
- current traffic in South Bore: up to 20k vehicles per day
- Will have two-lane highway (one way) in both bores.
- This project is estimated to cost ~ R 4 billion.
- Engineering firm SMEC is contracted to design plans for the North Bore upgrade.
- SANRAL would like upgrade work to start by end of 2024.

SMEC

- Snowy Mountains Engineering Corporation (founded 1970)
- Member of Surbana Jurong Group (since 2016)



- We propose to locate PAUL off the North Bore Tunnel adjacent to the Central Fault Zone inside the tunnel.

Cross-section of the Huguenot Tunnel

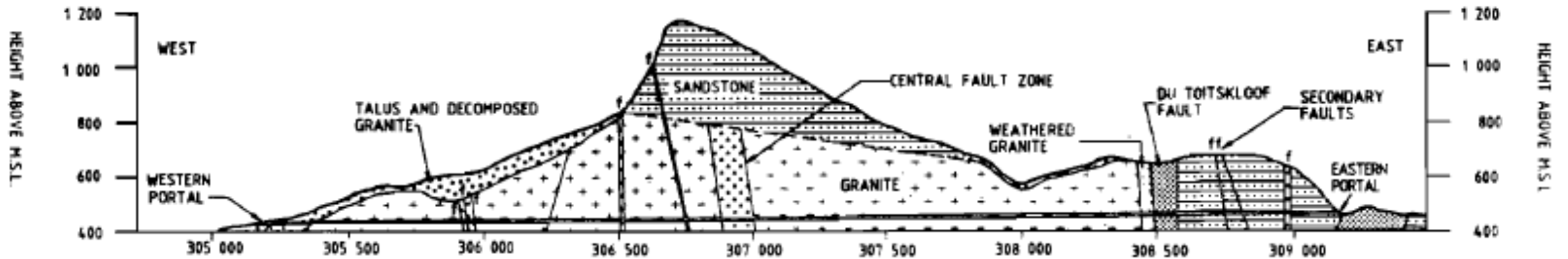
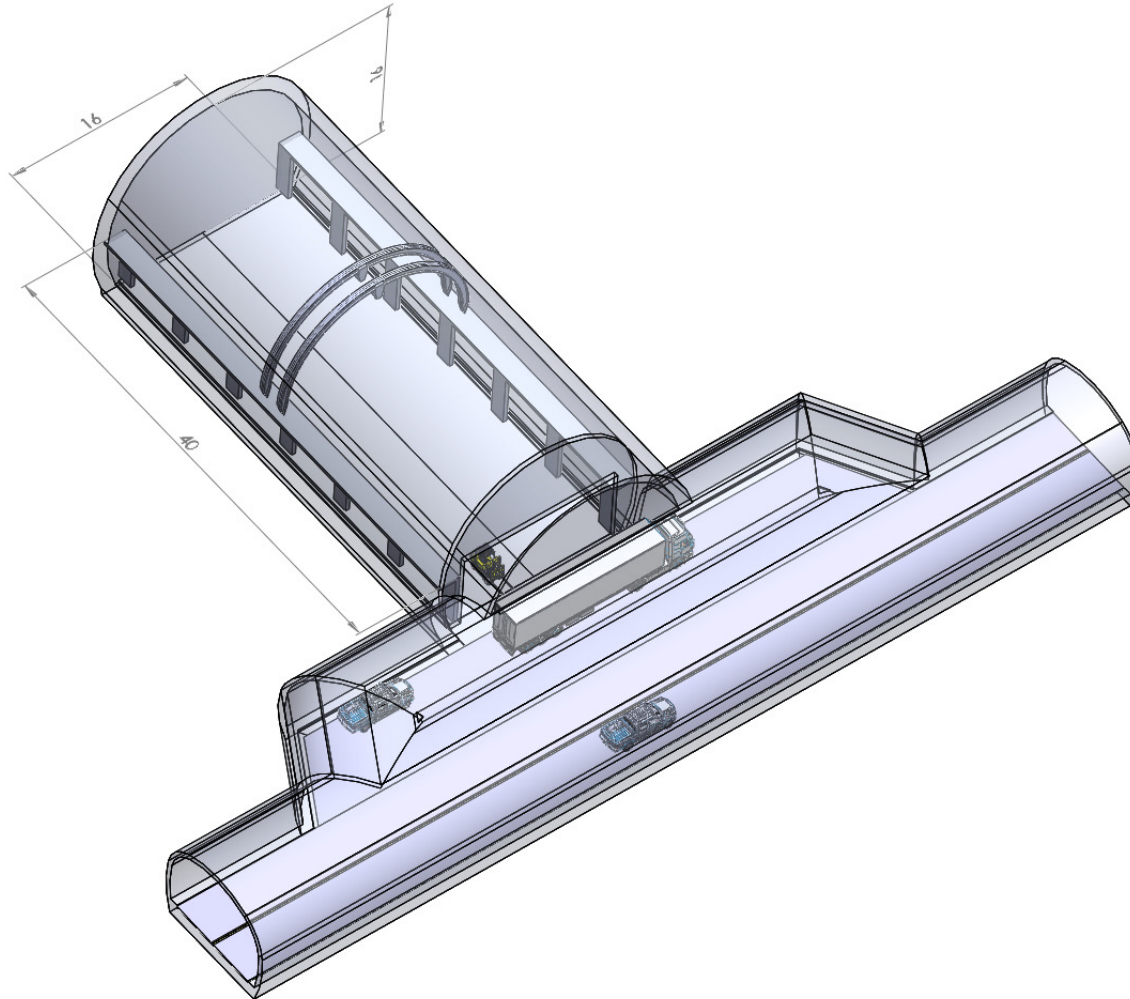


Fig 3: Post-pilot bore geology

Why establish PAUL ?

- To allow **comparison of results**, especially related to attempts to detect Dark Matter, from other DULs in the Northern Hemisphere and the only other one in the Southern Hemisphere (Stawell Underground Physics Laboratory in Australia).
- To **complement** indirect searches for Dark Matter (via e.g. SKA)
- The planned upgrade of the North Bore tunnel at the Huguenot Tunnel complex presents a **unique geographic, time-sensitive opportunity** to build a DUL in South Africa and **first in Africa**.

PAUL Concept Design



Floor space: 640 m²

Volume: 10240 m³

Inside view of LSC laboratory (Spain, France border)



- Ultra-low radioactivity measurements
(related to **climate science** amongst others)
- **Dark Matter** search
- Biological science (effect of cosmic radiation on cells and reference organisms - **radiation biology**)
- possibly anti-neutrino monitoring (radiated from Koeberg Nuclear Power Station) (**neutrino physics**)

The PAUL collaboration (as at 15 Jan 24)

- 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 collaboration (as at Jan 24)

- PAUL not yet a juristic person
- PAUL is led by an Executive Committee (see members on next slide)
- Stellenbosch University is the lead institution of the collaboration
- Prof. Richard Newman from SU was appointed PAUL Project Manager by the PAUL Executive Committee

The PAUL collaboration (as at Jan 24)

- **Executive Committee:**

- Dr Rob Adam (SKA International, Stellenbosch University)
- Dr Xavier Bertou (CNEA, Argentina)
- Prof. Trevor Haas (Stellenbosch University)
- Prof. Lerothodi Leeuw (Univ. of the Western Cape)
- Prof. Robbie Lindsay (Univ. of the Western Cape)
- Prof. Fairouz Malek (CNRS, France, and Stellenbosch University)
- Prof. Richard Newman (Stellenbosch University)
- Prof. Shaun Wyngaardt (Stellenbosch University)

- current proposal is to use the same model as for SALT Telescope
- Create non-profit PAUL Foundation
- PAUL Foundation governed by a Board of Directors (BoD)
- Directors are representatives of shareholders/funders
- PAUL Foundation BoD to appoint PAUL Foundation Managing Director (MD)

Envisaged consortium contributions to PAUL

- Provision of fully serviced PAUL cavern (**South Africa**) - step 1
- Provision of detector systems (**SA partners** and **international partners**) - step 2

Reviewers

- Dr Aldo Ianni (LNGS, Italy),
- Dr Jeter Hall (SNOLAB, Canada), and
- Prof. Azwinndini Muronga (Nelson Mandela University, South Africa)
- review period 8 - 28 August 2023
- reviewed PAUL arXiv paper and basic engineering design guidelines document

PAUL Basic Engineering Design Guidelines

- location: close to largest mountain overburden
- layout: one large cavern or multiple smaller ones, connected
- preferred layout: one cavern (16 m width, height 16 m, length 40 m)
- ventilation: 1 air exchange per hour
- radon levels: < 15 Bq/m³ (ideal), < 150 Bq/m³ (minimum)
- maximum electrical power: 2 MW
- clean room (whole lab ?)
- air lock
- alarms: smoke, oxygen, carbon monoxide
- external PAUL Support Building
- fibre internet/copper cable connection to Paarl side

Scientific reviews of PAUL

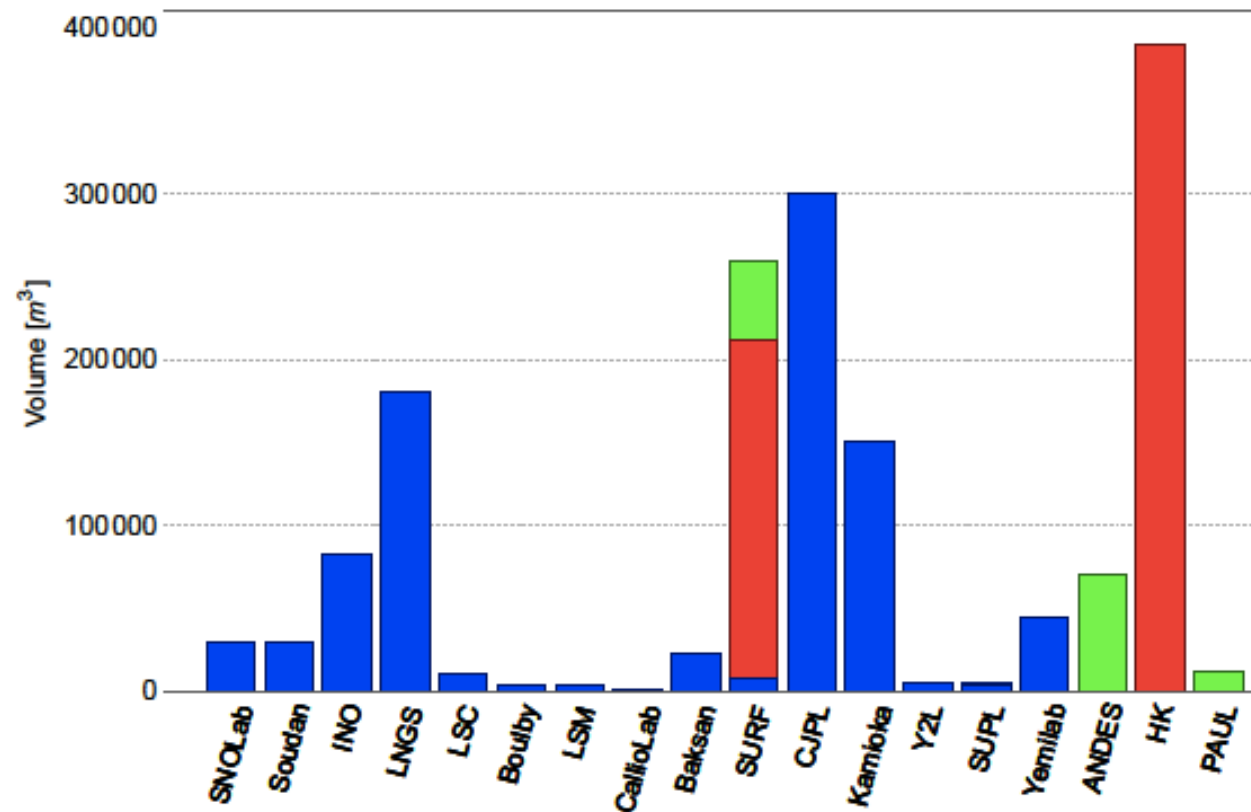


Fig. 1. Excavated volume in existing and planned ULs. Blue: in operation. Red: being excavated. Green: planned.

Source: A. Ianni report

Scientific reviews of PAUL

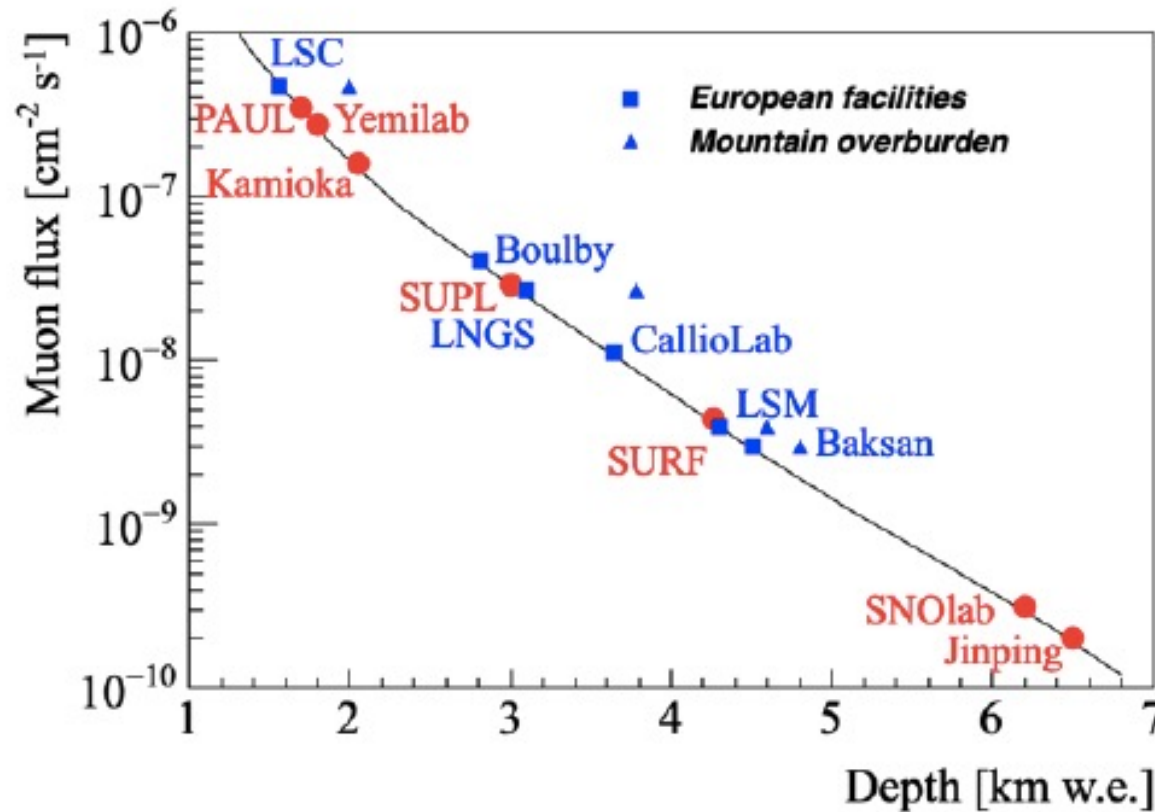


Fig. 2 Cosmic muons flux in ULs. The solid line shows the flux under a flat surface. The approximate position of PAUL in this line is shown. For ULs under a mountain the maximum overburden is also reported (this will also be the case for PAUL – here not shown).

Source: A. Ianni report

Scientific reviews of PAUL: notable quotes

Dr Aldo Ianni (LNGS, Italy),

- “PAUL will be located in the Southern hemisphere and this point is **valuable.**”
- “...any experimental activity on DM ... has to be equipped with a **muon veto detector.**”
- “It is recommended that all materials being used in making PAUL will be selected through **radio-purity assay.**”
- “Considering the size and depth, with a **clean room standard** infrastructure at ISO6 PAUL could offer a more valuable opportunity for future science activities.”

Scientific reviews of PAUL: notable quotes

Dr Jeter Hall (SNOLAB),

- “The proposed Paarl Africa Underground Laboratory (PAUL) would be a **valuable addition** to the African and global research enterprise.”
- “ ... so there are **scientific niches** that have not been exploited in many of the areas listed in the PAUL concept paper.”
- “There are scientific opportunities in **combining** the most sensitive underground searches with the most detailed astronomical surveys to narrow down the possibilities for dark matter, and to gain the most insights into any discoveries regarding the dark matter problem.”

Prof. Azwinndini Muronga (NMU),

- “I would like to emphasize that an Underground Laboratory (UL) facility in South Africa will unleash the county’s untapped resources and capability in science and technology. Tapping into the UL space will open new avenues of innovation which will spin off into sectors such as archaeology, health, agriculture, mining, and future underground infrastructure.”

Scientific reviews of PAUL: SWOT Analysis

- Strength, Weakness, Opportunity, Threat
- SWOT analysis of reviews by RT Newman
- **Healthy competition = Threat !**

Scientific reviews of PAUL: SWOT Analysis

A. Ianni

a. Strengths

- will provide an opportunity to small/medium sized experiments
- will create a new underground laboratory in the southern hemisphere complementary to SUPL laboratory in Australia
- radon levels inside the tunnel are relatively low

b. Weaknesses

- will not be able to host large next-generation experiments because limited mountain overburden available

c. Opportunities

- will provide opportunity to design and test new detectors and in so doing make a crucial contribution to international effort
- will provide community in SA with unique opportunity to be involved in science carried out in underground laboratories
- to expand research activities on biology and quantum computing in underground laboratories

d. Threats

- competition from SUPL (Australia)

Scientific reviews of PAUL: SWOT Analysis

J. Hall

a. Strengths

- will provide only underground laboratory in Africa
- will create a new underground laboratory in the southern hemisphere, complementary to SUPL laboratory in Australia

b. Weaknesses

- not be the deepest laboratory in the world

c. Opportunities

- to host low-mass dark matter searches
- to develop local human resources through e.g. workshops.
- opportunity to work alongside SKA, astronomy community in studying dark matter
- to make connections with nuclear power industry by detecting anti-neutrinos

d. Threats

- competition from SUPL (Australia)

Scientific reviews of PAUL: SWOT Analysis

A. Muronga

a. Strengths

- will unleash SA's untapped resources and capability in research and innovation
- will complement and enhance flagship projects in SA such as SKA project and SA-CERN programme
- will enhance links with international research community and thereby increase competitiveness of local researchers
- will train many students and produce new knowledge across a number of fields
- will expand network of underground research facilities globally

b. Weakness

- lack of authors from historically black universities (HBUs) on PAUL concept paper

Note in response: AM did not see that a number of authors of the PAUL concept paper are from the University of the Western Cape (UWC).

c. Opportunities

- to strengthen buy-in into PAUL by stakeholders by consulting with e.g. communities and researchers
- to effect transformation by consciously promoting inclusion/diversity in the roll-out of PAUL

d. Threats

- lack of stakeholder support if there is no consultation/engagement
- lack of a human resource pipeline for PAUL if no proactive steps are taken.
- lack of SA government support if the envisaged PAUL staff and users lack diversity

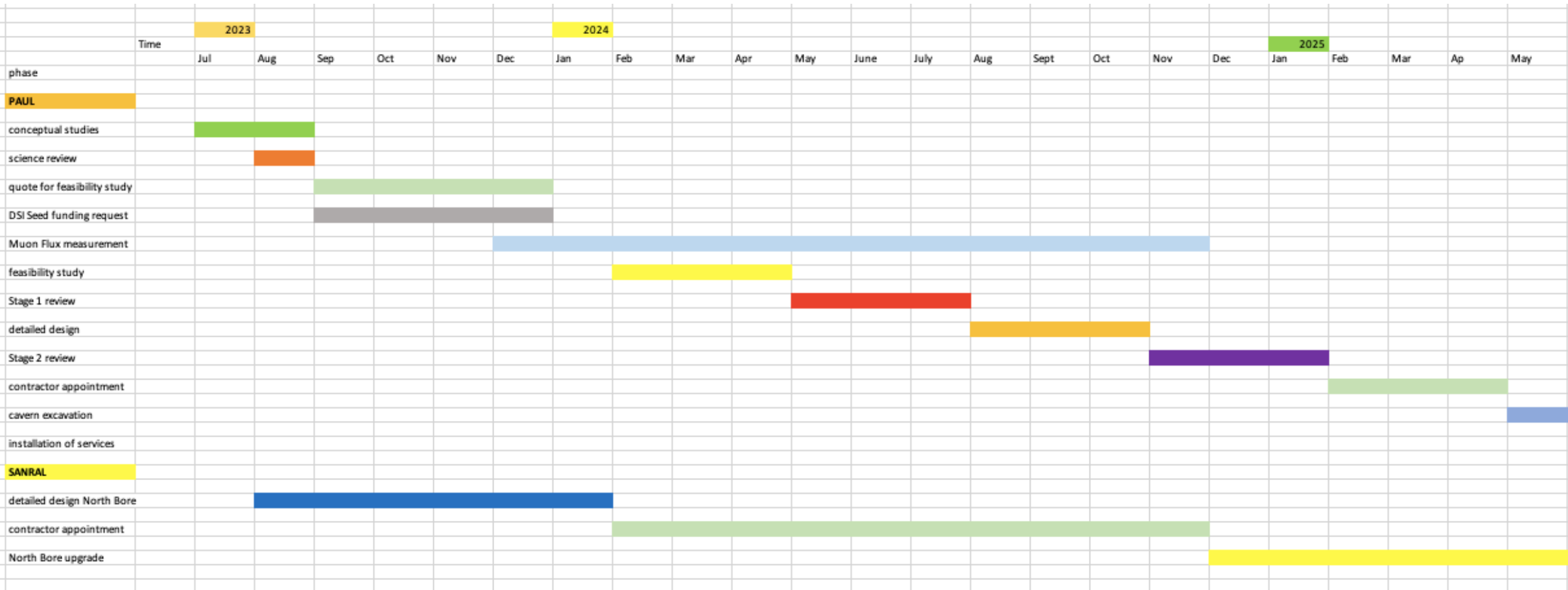
- Assume excavation rate (drill and blast):

30 m³ per day

- According to current timeline, fully serviced laboratory to be completed by mid 2027.

- Had a meeting with SANRAL and SMEC on 7 Aug.23
- SANRAL agreed to allow SMEC to do an engineering feasibility study for PAUL
- SMEC Engineering feasibility study start in next 2-3 weeks

PAUL Project Timelines (Jan 24)



- Assume excavation cost (drill and blast):

100 US\$ per m³

- Assume a contingency of 20 %.
- Includes estimated cost (R 5 million) to build a PAUL Support Facility outside tunnel on Paarl side.

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
								US\$		6,50E+06

- Current estimate to construct PAUL:
 - R 130 million (~ US\$ 6.5 million)

- Use ideas/discussions from SSP to update case for PAUL and engineering design guidelines
- next step: discussions with consulting engineers towards feasibility report

Thank you

