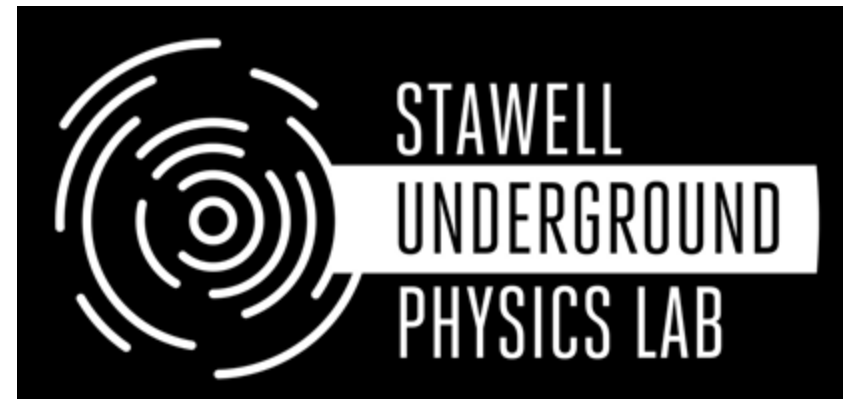




Underground Laboratories in the Southern Hemisphere

Greg Lane

Australian National University
(Stawell Underground Physics Laboratory)
(ARC CoE for Dark Matter Particle Physics)





Underground Laboratories in the Southern Hemisphere

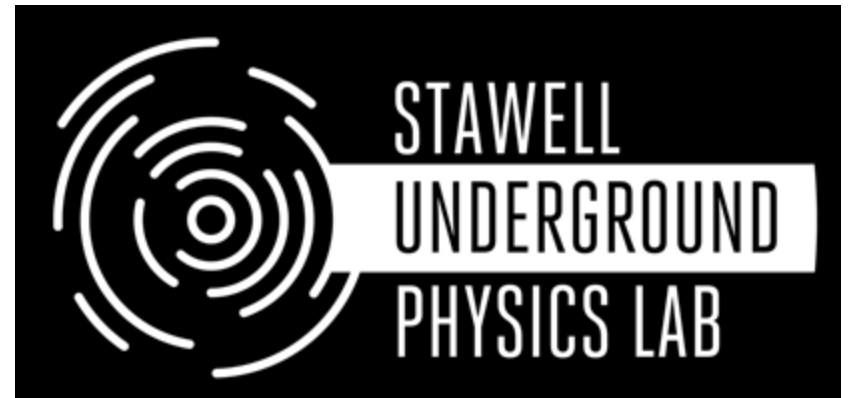
Greg Lane

Australian National University
(Stawell Underground Physics Laboratory)
(ARC CoE for Dark Matter Particle Physics)



PAARL AFRICA UNDERGROUND LABORATORY

Fairouz Malek



Kim Mintern-Lane, Sue Barrell

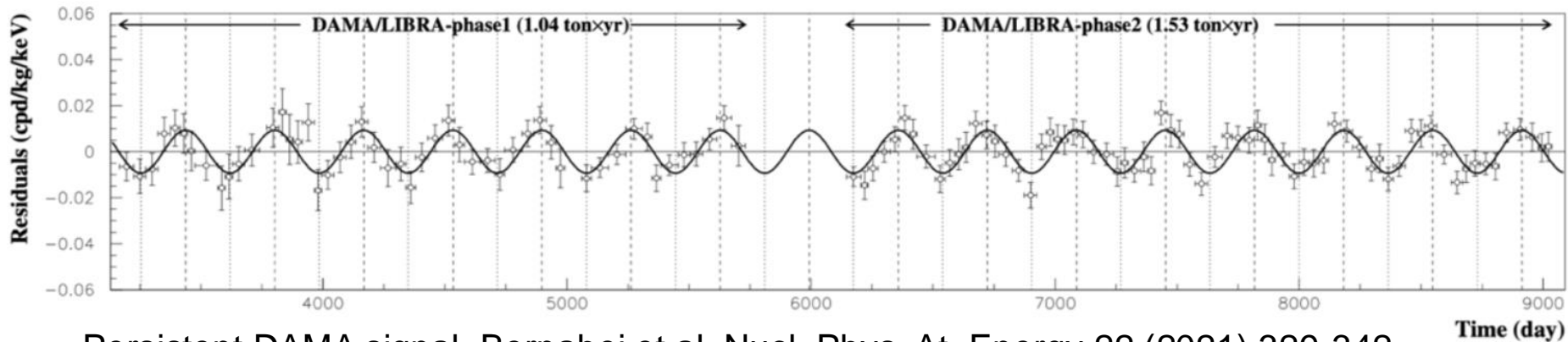
Current Underground Labs



ANDES – Discussion / PAUL – Planning / SUPL – Operating

Why Southern Hemisphere?

- Dark Matter annual modulation signal (e.g. DAMA)
 - Seasonally modulating backgrounds would be reversed
 - Potential "proof" of dark matter origin



Persistent DAMA signal, Bernabei et al, Nucl. Phys. At. Energy 22 (2021) 329-342

- Timing / Directional sensitivity
 - Enhanced global coverage to observe times of arrival
 - Neutrinos / dark matter

Paarl Africa Underground Lab

South Africa
(SAUL, 2015)



International
(PAUL, 2023)



Physics Procedia
Volume 61, 2015, Pages 586-590



arXiv > hep-ex > arXiv:2306.12083

Search...
Help | Adv

High Energy Physics - Experiment

[Submitted on 21 Jun 2023]

Paarl Africa Underground Laboratory (PAUL)

Robert Adam (5 and 1), Claire Antel (14), Munirat Bashir (23), Driss Benchekroun (18), Xavier Bertou (20), Markus Böttcher (8), Andy Buffler (7), Andrew Chen (4), Rouven Essig (22), Jules Gascon (12), Mohamed Goughri (19), Trevor Hass (1), Gregory Hillhouse (6), Abdeslam Houmada (18), Anslyn John (1), Pete Jones (3), Youssef Khoulaki (18), Luca Lavina (13), Lerothodi Leeuw (2), Mantile Lekala (9), Robert Lindsay (2), Roy Maartens (2), Yin-Zhe Ma (1), Fairouz Malek (11), Peane Maleka (3), Jacques Marteau (12), Rachid Mazini (21), Thebe Medupe (8), Bruce Mellado Garcia (4), Marcello Messina (15), Lumkile Msebi (2), Chilufya Mwewa (26), Zina Ndabeni (3 and 7), Richard Newman (1), George O'Neill (16), Fabrice Piquemal (10), Lydia Roos (13), Daniel Santos (11), Silvia Scorza (11), Fedor Simkovic (24), Ivan Stekl (25), Yahya Tayalati (17), Smarajit Triambak (2), Zeblon Vilakazi (4), Shaun Wyngaardt (1), JJ van Zyl (1) ((1) Stellenbosch University–South Africa, (2) University of the Western Cape–South Africa, (3) iThemba LABS–South Africa, (4) University of the Witwatersrand Johannesburg–South Africa, (5) Square Kilometre Array Observatory–South Africa, (6) Botswana International University of Science and Technology–Botswana, (7) University of Cape Town–South Africa, (8) North West University Potchefstroom–South Africa, (9) The University of South Africa, (10) LP2I, CNRS–IN2P3, Université Bordeaux–France, (11) LPSC, CNRS–IN2P3, Université Grenoble Alpes–France, (12) IP2I, CNRS–IN2P3, Université Claude Bernard Lyon–France, (13) LPNHE, CNRS–IN2P3, Sorbonne Université Paris–France, (14) Université de Genève–Switzerland, (15) LNGS, Gran–Sasso–Italy, (16) European Spallation Source ERIC Lund–Sweden, (17) Mohammed V university of Rabat–Morocco, (18) Hassan II university of Casablanca–Morocco, (19) Ibn Tofail University of Kenitra–Morocco, (20) Centro Atómico Bariloche, CNEA/CONICET–Argentina, (21) Institute of Physics, Academia Sinica, Taipei–Taiwan, (22) Stony Brook University, USA, (23) Ibrahim Badamasi Babangida University–Nigeria, (24) Comenius University Bratislava–Slovakia, (25) IEAP CTU Prague–Czechia (26) Brookhaven National Laboratory, USA)

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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^d iThemba LABS, P.O. Box 722, Somerset West, 7129, South Africa

^e Military Academy, Private Bag X2, Saldanha, 7395

PAUL Founding Symposium



Symposium on Science at PAUL (Paarl Africa Underground Laboratory)

14–18 Jan 2024
Du Kloof Lodge, Du Toitskloof Mountains
Africa/Johannesburg timezone

January 2024
Du Kloof Lodge
South Africa

arxiv:2306.12083

Overview
Timetable
Book of Abstracts
Participant List
Speaker List
Venue and Accommodation
↳ Important dates
↳ Excursions and social programme
↳ Fees payment
Organizing Committee
Contact at SSP
✉ ssp@sun.ac.za

The Paarl Africa Underground Laboratory (PAUL) is envisaged being established off the Huguenot Tunnel in the Du Toitskloof Mountains, between the towns of Paarl and Worcester in the Western Cape Province of South Africa. PAUL is envisaged to be an underground laboratory with a floor space of about 600 square metres and a total volume of 10240 cubic metres, Ref: [arXiv:2306.12083](https://arxiv.org/abs/2306.12083) [hep-ex]

The following are some of the research topics being considered at PAUL:

- Dark Matter search
- Ultra-low level radioactivity measurements for climate science
- Double beta-decay search
- Radiation biology
- Studies of antineutrinos from the Koeberg PWR (about 70 km away)

Supporting Institutions



Sponsors



science & innovation
Department
Research and Innovation



PAUL

PAARL AFRICA UNDERGROUND LABORATORY

<https://pauline.in2p3.fr/paul/paul-en.html>

PAUL Science

- **Dark Matter** searches (compare Northern and Southern hemisphere data)
- **Complement** indirect searches for dark matter (e.g. with the SKA that is based in South Africa)
- Ultra-low level radioactivity measurements
- 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**)?

PAUL Location



~70 km from Cape Town in a road tunnel, c.f. LNGS / Modane

PAUL Concept

Du Toitskloof Mountain

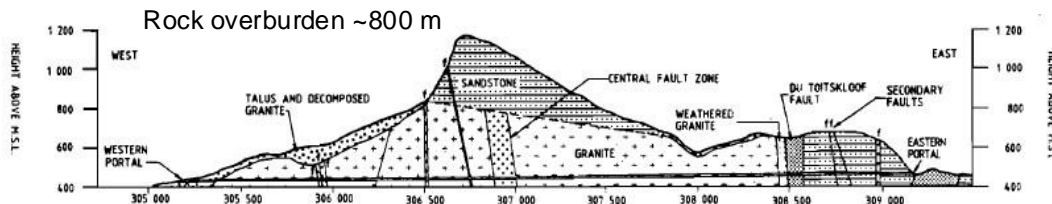
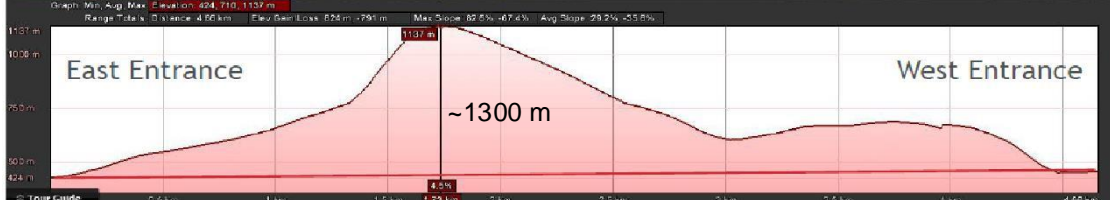


Fig 3: Post-pilot bore geology

176

THE CIVIL ENGINEER in South Africa — April 1988



South Bore (Worcester -> Paarl)

- Car traffic since 1988
- Tunnel length: 3900 m



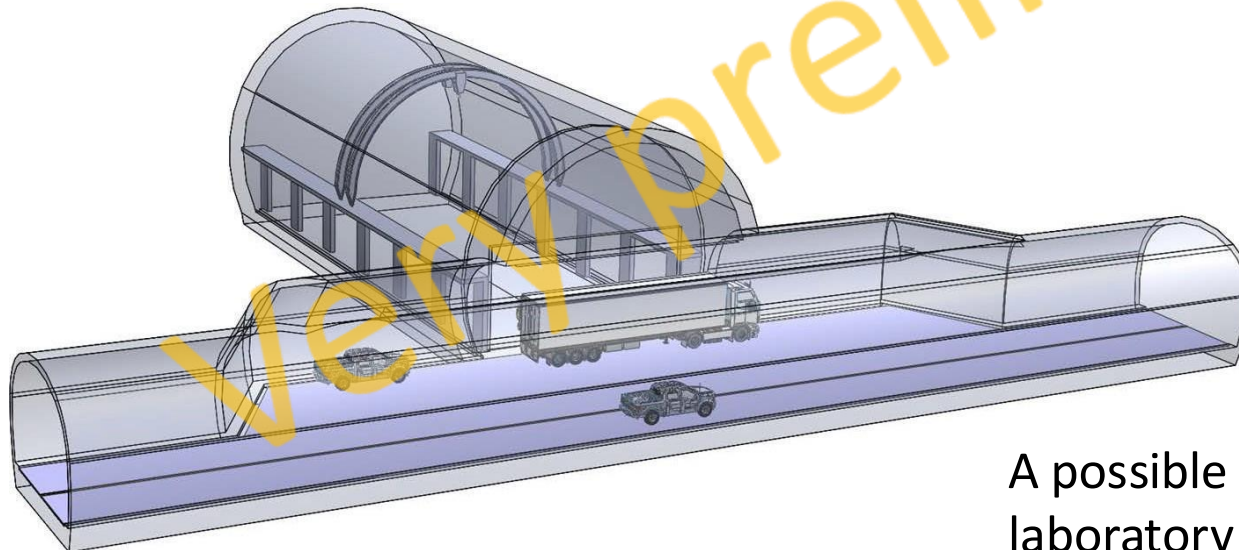
North Bore (Paarl -> Worcester)

- Service tunnel since 1988
- Upgrade in 2025 for 2 lanes of car traffic

PAUL Concept

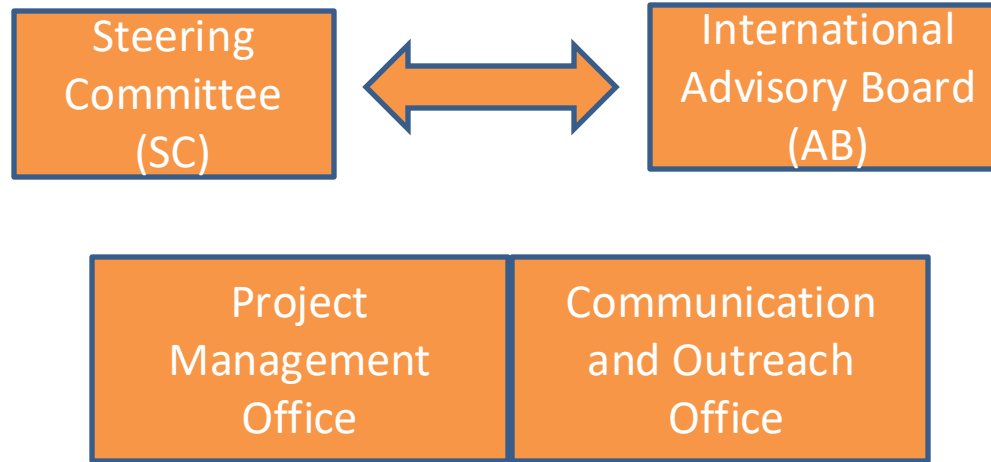
One of the options (Sept 2024)

- ① PAUL cavern adjacent to the **South Bore**.
- ② South Bore widened locally to allow for staff drop-off/collection and minimal parking.
- ③ Direct access tunnel between PAUL and Huguenot Tunnel South Bore
- ④ Auxiliary access tunnel between the PAUL and South Bore for emergency egress.



A possible 10,000 m³
laboratory (40x16x16)

PAUL Organisation



Task Forces



 Operational

 Not yet kicked off – call for volunteers to coordinate

Note: PAUL not yet a legal entity

PAUL Timeline / Status

PROGRESS

- May 2024 – agreement signed between University of Stellenbosch (US) and SMEC Engineering Consultants to prepare a Conceptual Design
- August 2024 - Requirements redefined; Regular Design meetings commence
- Conceptual Design through design Sprints rather than a full design at a later period, allowing PAUL SC members to provide input and make changes
- September 2024 - Stakeholder list compiled
- September 2024 - Draft Risk Register. Major identified risks are Access, geotechnical and land acquisition

TIMELINE

- SANRAL (South African National Roads Agency Limited) tender to be issued on 31 October 2024 - tender to close 10 January 2025
- Draft Concept Design for PAUL - May 2025
- Preliminary and Detailed Design are estimated to each take 6 months to complete
- Tunnel construction to start in late 2025 up to 2032
- Experiment installation?
 - PAUL in South Bore – 2032
 - PAUL in North Bore – 2030

Very preliminary

PAUL Funding / Partners

- PAUL project launched January 2024 with **R 5M (250 K€) DSI Seed-Funding**
- Feasibility Study on-going
- 5 year grant for the International Research Network program with CNRS:
 - **PAULINE** :<https://pauline.in2p3.fr/>
- Other programs being submitted or on-going:
 - PHC PROTEA: <https://www.campusfrance.org/fr/protea> (submitted 30/05/2024)
 - Horizon Europe MSCA Staff Exchange (call deadline 05/02/2025)



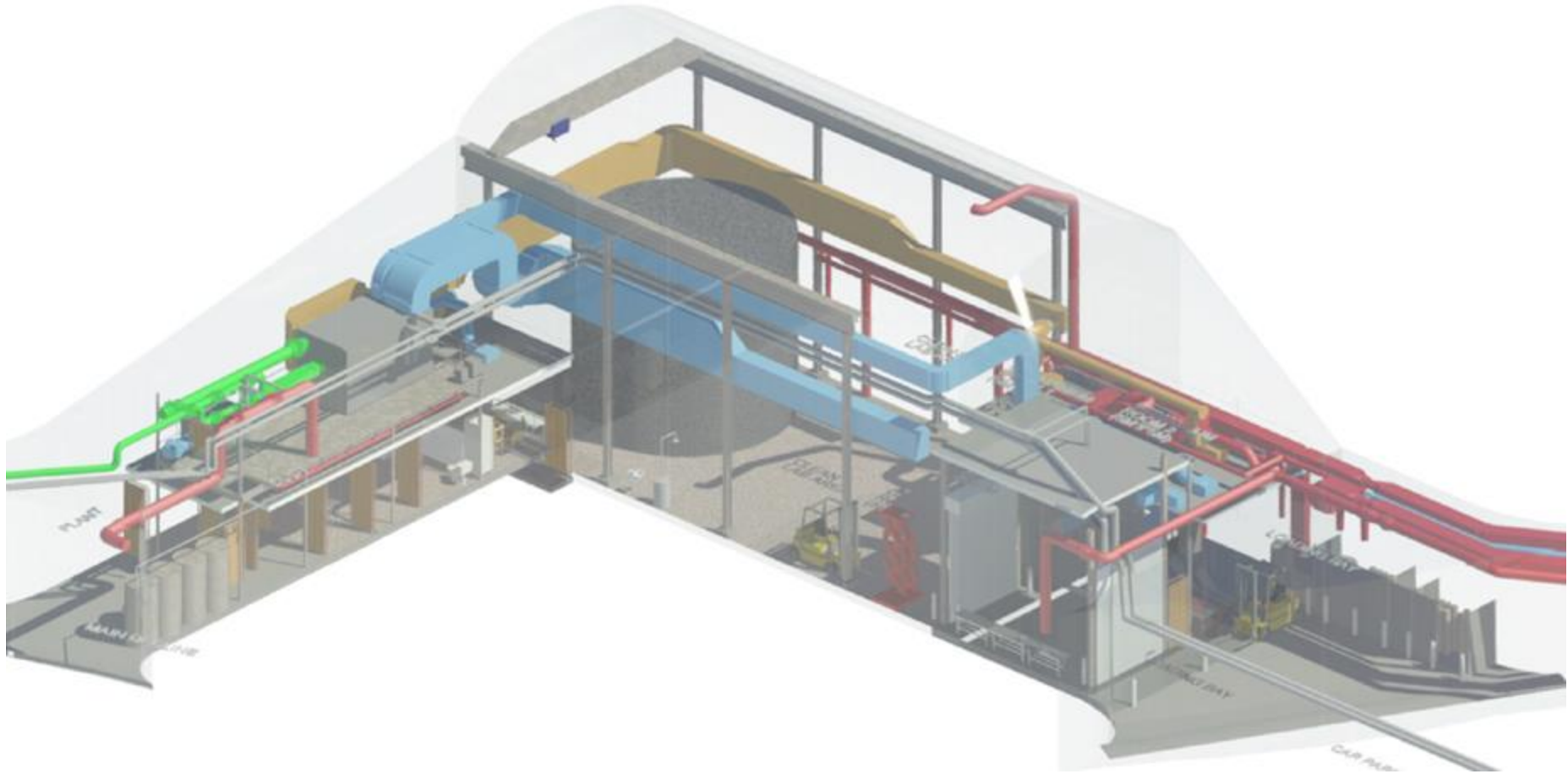
African partners



European partners



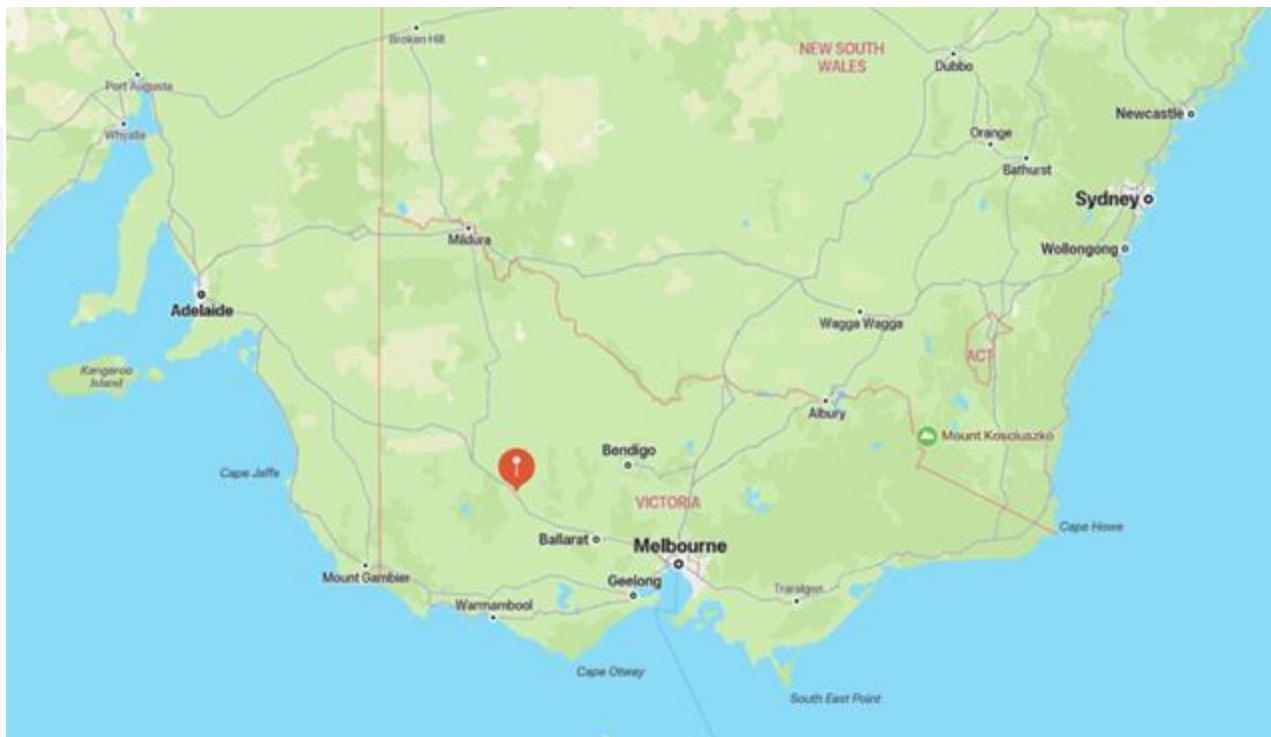
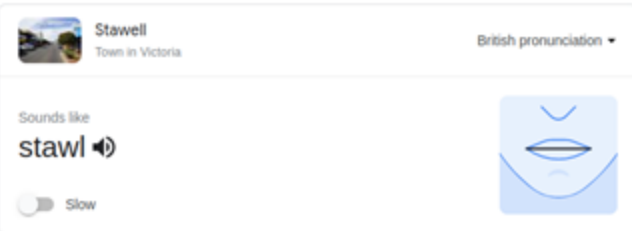
Stawell Underground Physics Lab



Most important update: SUPL is operational and some detectors are now collecting data in the lab

Stawell Underground Physics Lab

Stawell

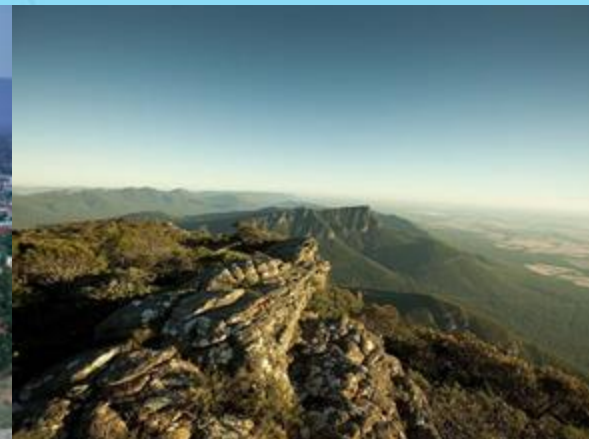


Population: 6000

Home to first nations people, Djab Wurrung speakers.

European settlers arrived in 1853 during the Victorian gold rush.

Mining and tourism.



Stawell Gold Mine

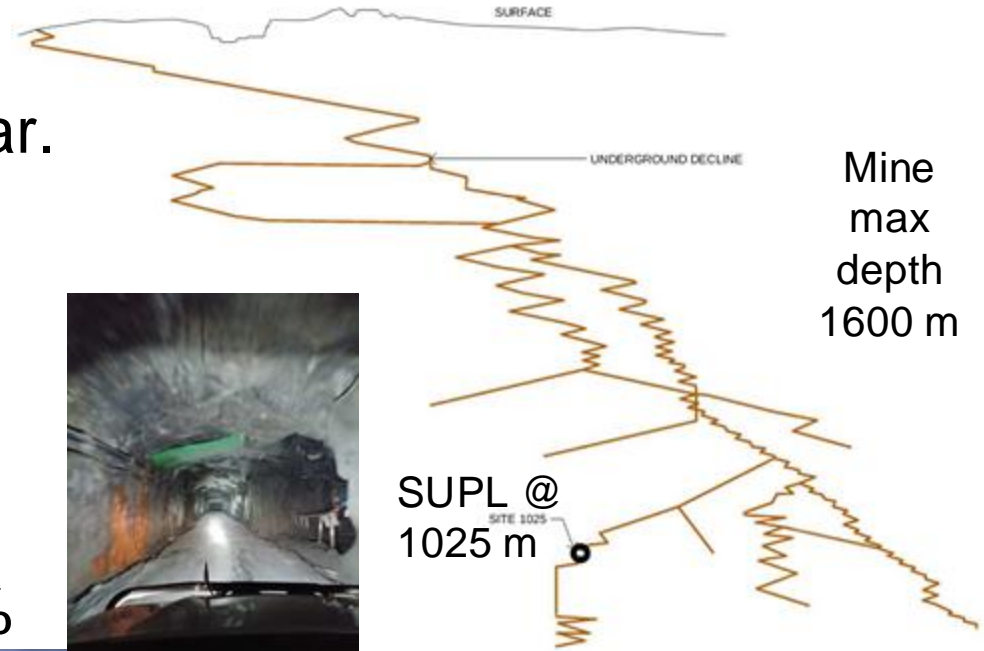
Gold ore (basalt) mine and processing plant. 850 kT ore/year.

Decline mine (single portal), flat overburden.

30 minute drive to laboratory.

Tunnel: 28 °C, humidity >90 %

Lab: 21+/-2 °C, humidity 40-60%



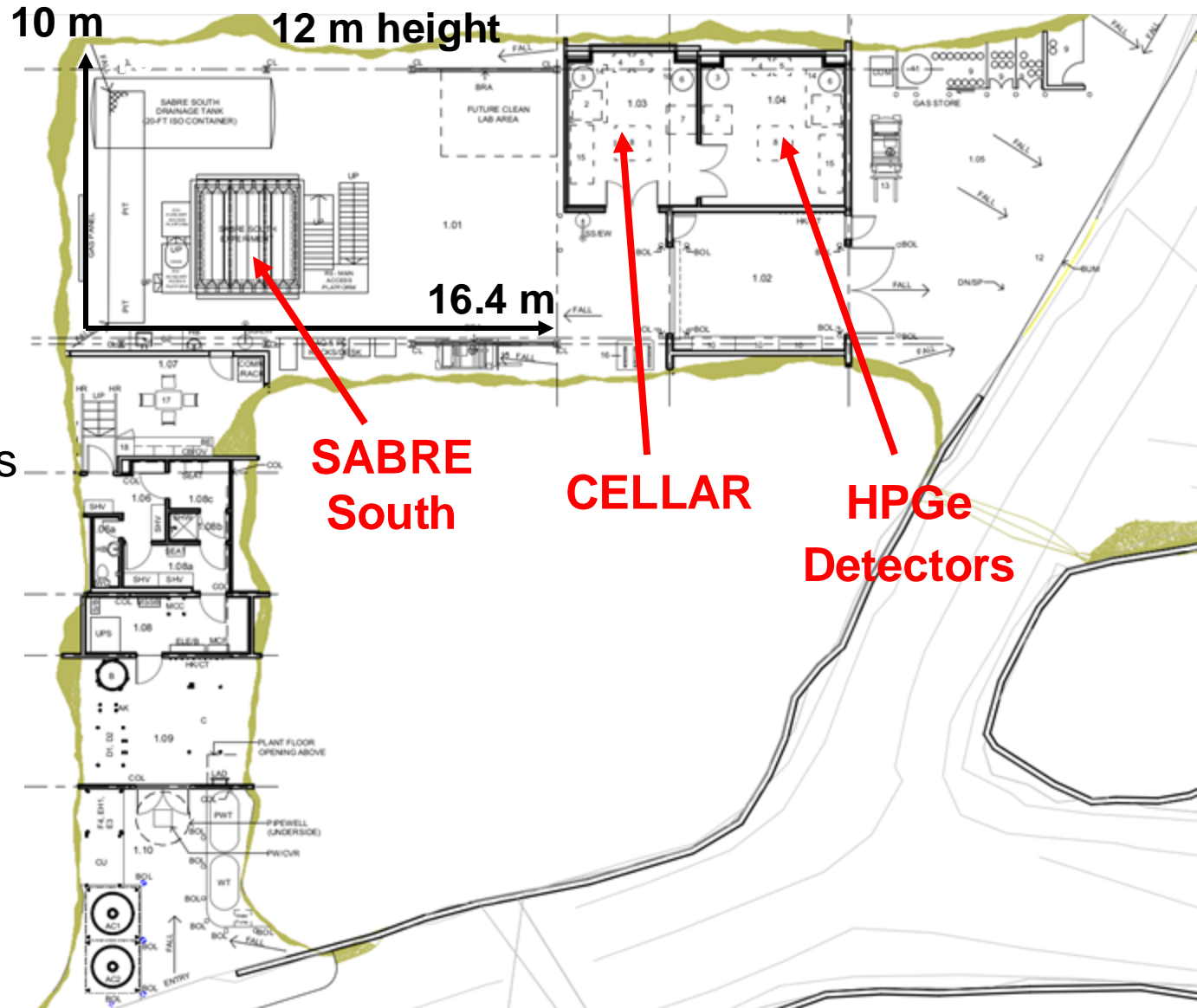
SUPL Detailed Layout

10 x 16.4 x 12 m³
experimental hall.

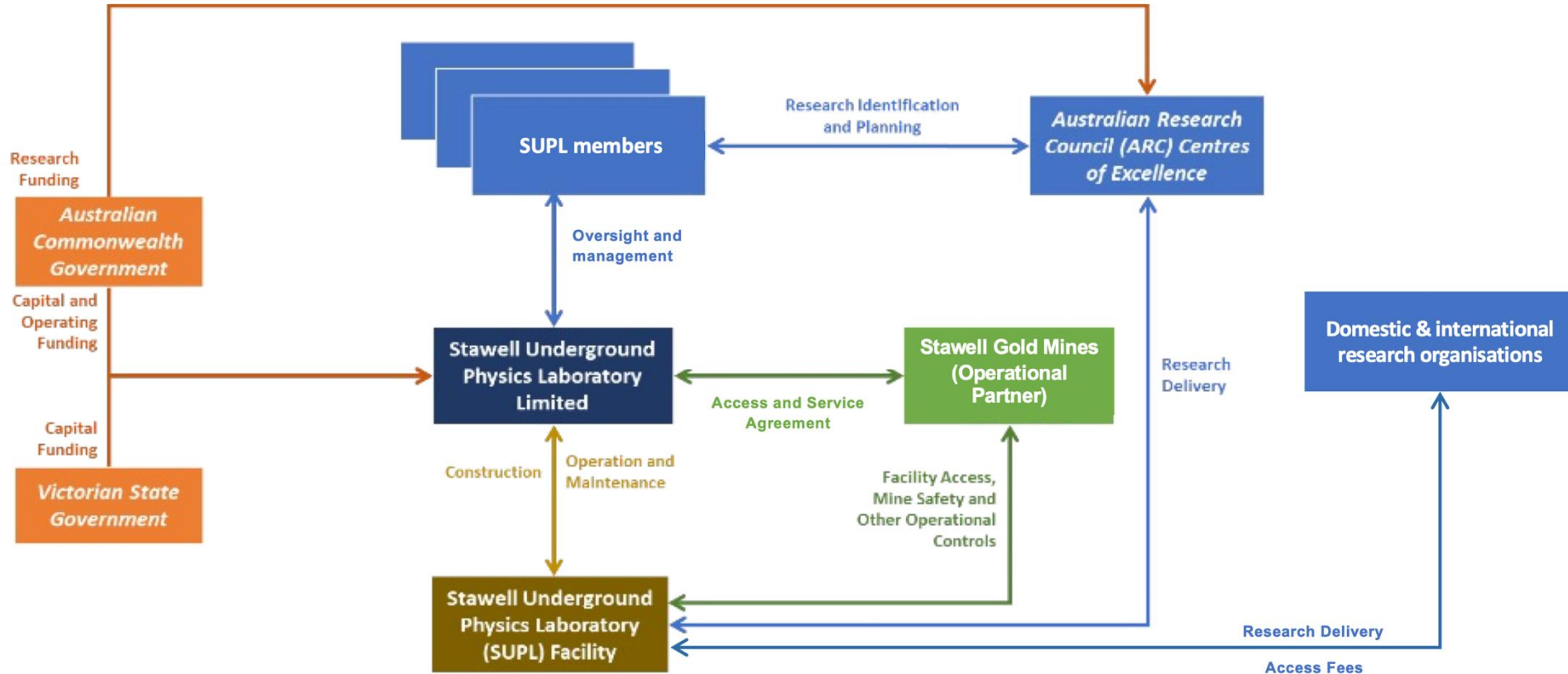
Two smaller rooms.

Future general-
purpose clean area

- 10 T overhead crane
- Plumbed cylinder gas
- Bunded spill pit
- Clean electrical ground
- Fibre connection to surface
- Air conditioned
- Radon ~450 Bq/m³



SUPL Relationships



- SUPL Ltd operates the laboratory.
- Access and service agreement with Stawell Gold Mines.
- Operational funding from SUPL members and experiment access fees.
- Discussion with potential new members and new agreement pending.
- Ongoing operational funding being sought from various sources.

SUPL Management

SUPL Ltd. Board of Directors

Chair: Dr. Sue Barrell, AO, Deputy Chair: Prof. Virginia Kilborn

Members: ANU, ANSTO, SUT, UOA, UOM

Scientific Research Committee (SRC)

Chair: Prof. Geoffrey Taylor

- Evaluates the merits of proposed research programs
- Ensures that the research to be undertaken by the company is scientific research and is, or may prove to be, of value to Australia
- Determines the research activities to be undertaken by the company
- Ensures that research results will be openly published and that any patent licensing will be available on equal terms to all interested parties

Finance, Audit and Risk Management Committee (FARMC)

Chair: Ms. Virginia Deegan

- Assists and advises the SUPL Board in the effective discharge of its responsibilities regarding the financial position and performance of SUPL
- Monitors the systems of control and accountability
- Oversees the assessment and management of risk across the activities of the organisation

Outreach and Coordination Facility Committee (to be established)

Chair: TBC

- Oversee the delivery of the outreach and coordination facility
- Oversee the operations of the outreach and coordination facility

Govt funding received for feasibility study into Outreach Facility



Australian National University



THE UNIVERSITY of ADELAIDE



THE UNIVERSITY of MELBOURNE

SUPL Ltd employs CEO (0.2 FTE), Facility/Lab manager, Laboratory Officer
Planned: 0.6 FTE Head of Science/CEO (EoI) and an Outreach Coordinator

SUPL Research Agenda

Precision Measurement

Dark Matter Direct Detection

- SABRE
- CYGNUS
- Liquid He
- ...

Fundamental Physics

- Neutrinos
- Radon emanation and filtering

Quantum Technology

- Radiation effects on quantum systems
- Quantum Computing

High Definition Sensors

- Low-background counting for defence, DM etc
- Quantum sensing (gravimetry)
- Remote operation
- Low “noise”

Biology / Geology

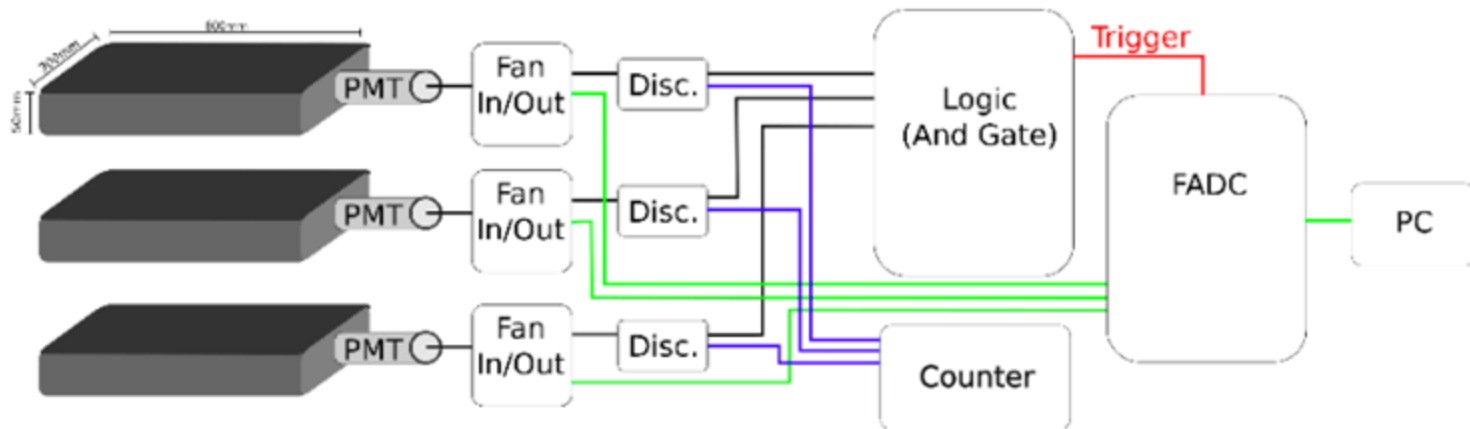
- Life in extreme conditions
- Radiobiology
- Seismology
- Geology

SUPL Muon Background

Prior to SUPL construction

Telescope made of three plastic (PVT) scintillator paddles of size, 60x30x5 cm³, coupled to 2" PMTs

Flux: $(3.7 \pm 0.4) \times 10^{-8} \text{ cm}^{-2}\text{s}^{-1}$

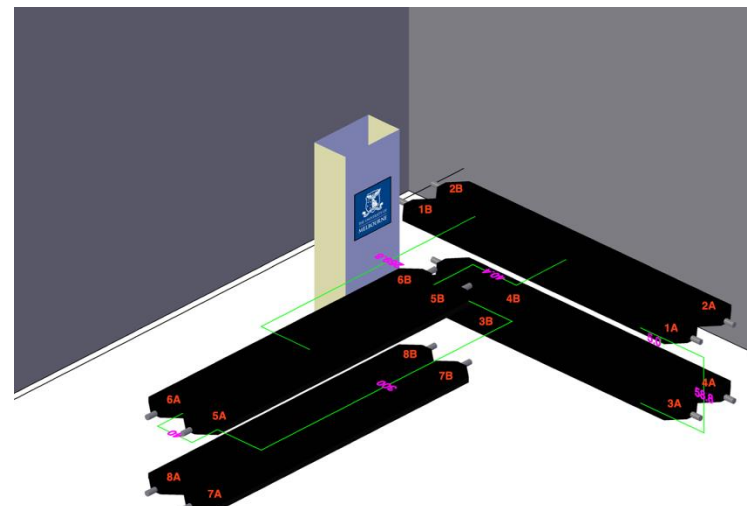


SABRE Muon Veto

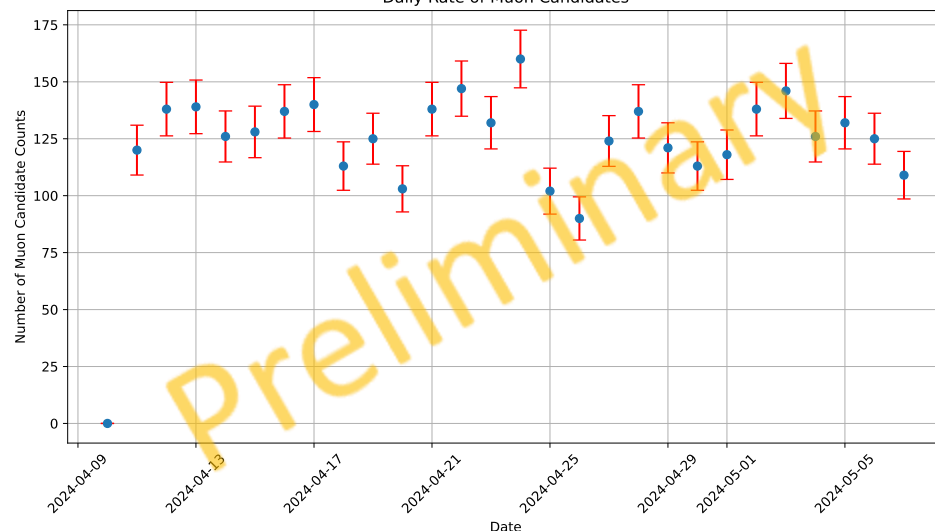
Counting underground since April 2024

Position-sensitive muon panels ($300 \times 40 \times 5 \text{ cm}^3$)

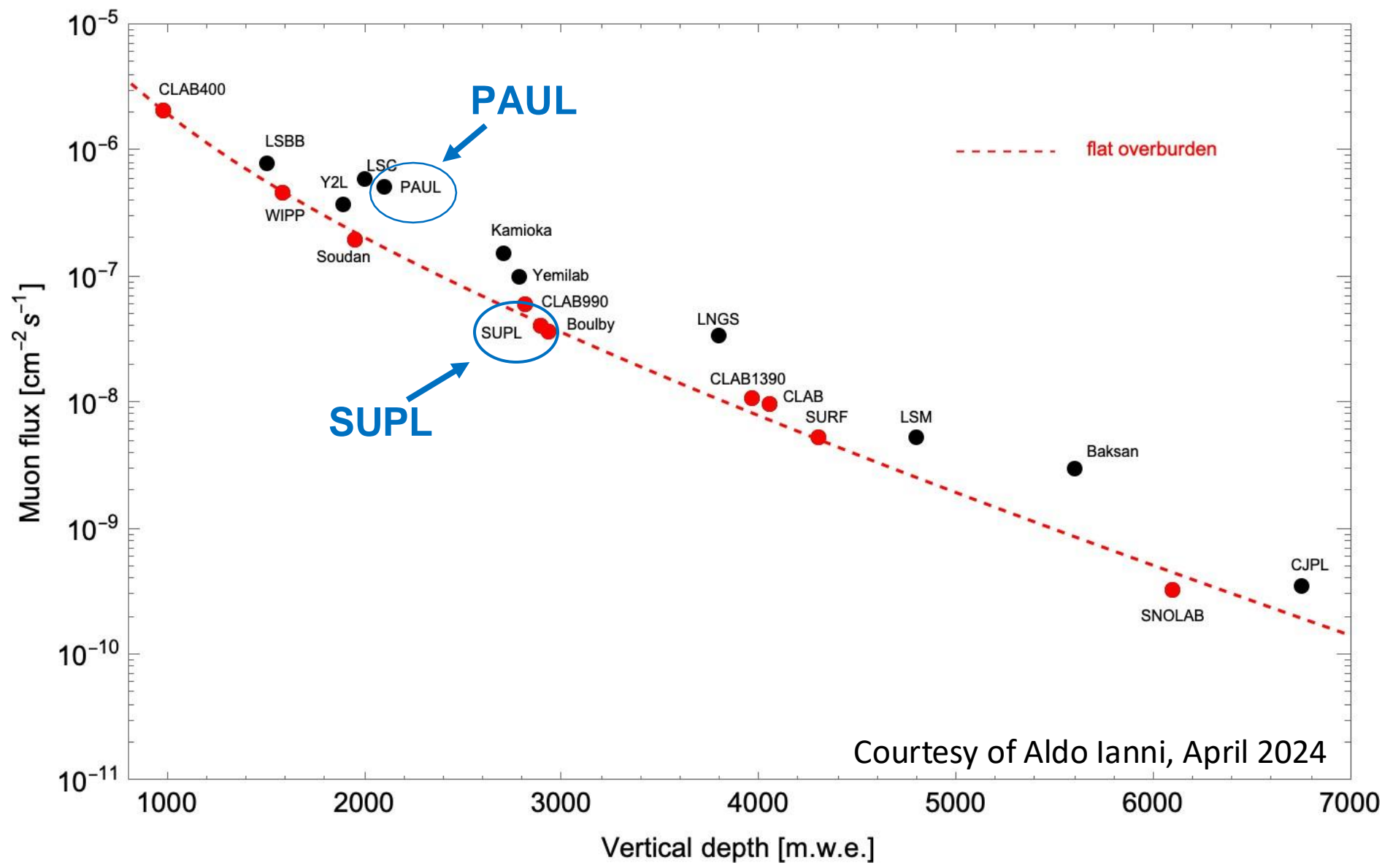
- Telescopes with different orientations
- Confirm absolute muon rate
- Measure annual modulation
- Measure angular dependence



Daily Rate of Muon Candidates



SUPL / PAUL Muon Reduction



Courtesy of Aldo Ianni, April 2024

SUPL n/ γ Background

Measurements at SUPL site prior to construction:

Gamma ray flux

Nal:TI detector measurements:

	E>100 keV	E>600 keV	^{40}K (1461 keV)	^{208}Tl (2614 keV)
Flux ($\text{cm}^{-2}\text{s}^{-1}$)	0.23	0.089	1.3×10^{-2}	2.1×10^{-3}

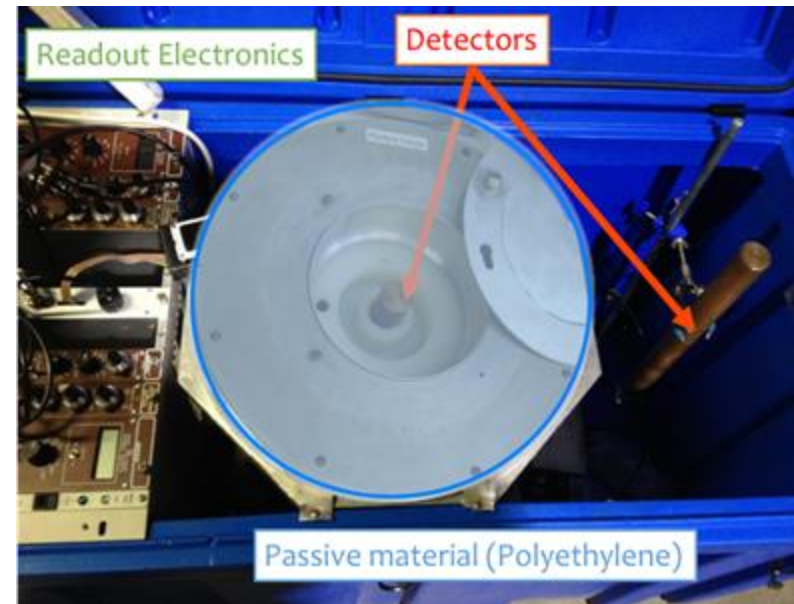
LNGS flux (> 7 keV) is $0.25 \text{ cm}^{-2}\text{s}^{-1}$ [1]

Neutron flux

BF_3 tube counter measurements:

	Thermal	Fast
Flux ($\text{cm}^{-2}\text{s}^{-1}$)	1×10^{-4}	2×10^{-5}

LNGS is $(1.7 - 3.8) \times 10^{-6} \text{ cm}^{-2}\text{s}^{-1}$ [2]



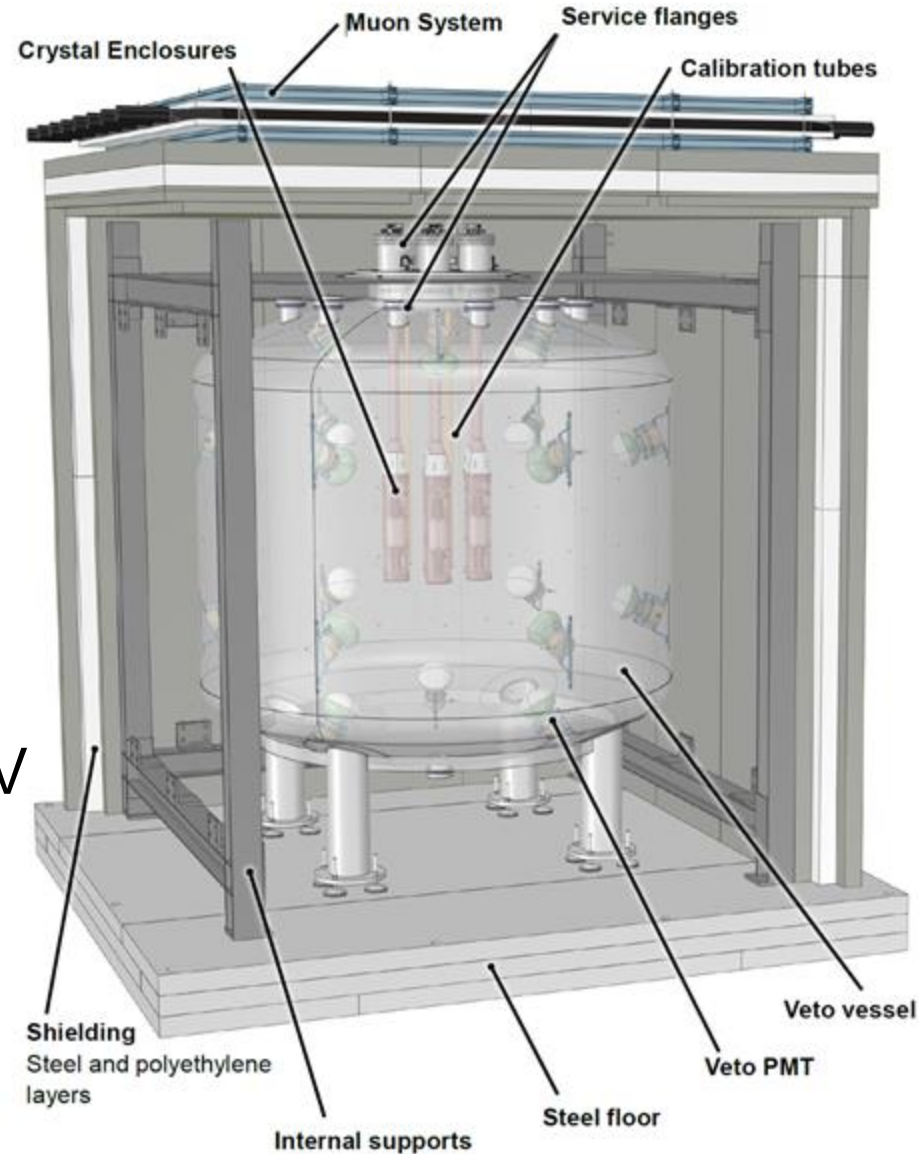
[1] Malczewski et al., J Radioanal Nucl Chem, 295(1):749–754 (2013)

[2] H. Wulandari et al., Astropart Phys 22:313–322 (2004)

SABRE South

Flagship experiment at SUPL

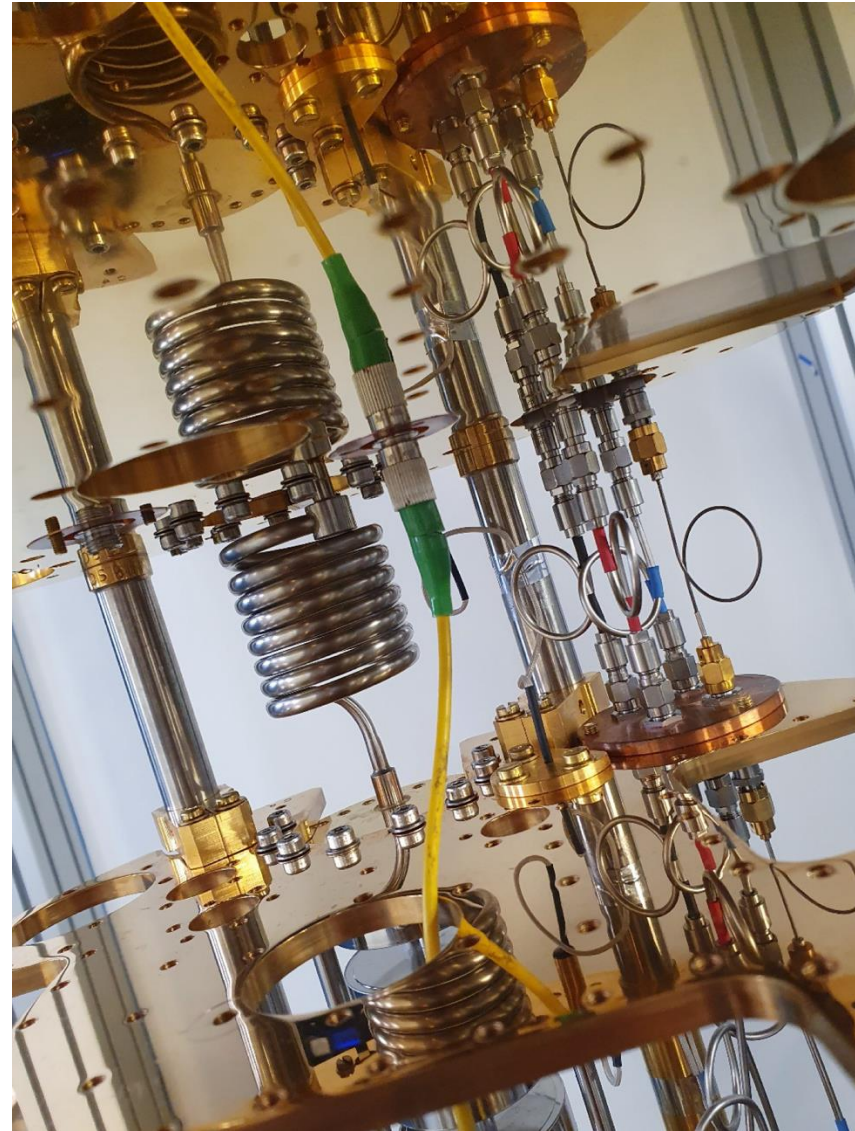
- 35-50 kg ultrapure NaI:TI
- 10 T liquid scintillator veto (linear alkylbenzene)
- Muon veto (9.6 m²)
- 26 cm steel/HDPE/steel shield.
- Expected background in 2-6 keV region: 0.72 cpd/kg/keV
- Rule in/out DAMA based on annual modulation signal
- Installation has begun...



CELLAR

Cryogenic Experimental Laboratory for Low-background Australian Research

- mK dilution fridge (one in SUPL, one above ground at Swinburne for development and comparison measurements)
- Brings new partners to SUPL: Univ of Queensland and Univ of Western Australia
- Funded, with delivery imminent
- Quantum sensing/computing
- Low-mass WIMP direct detection with Liquid He



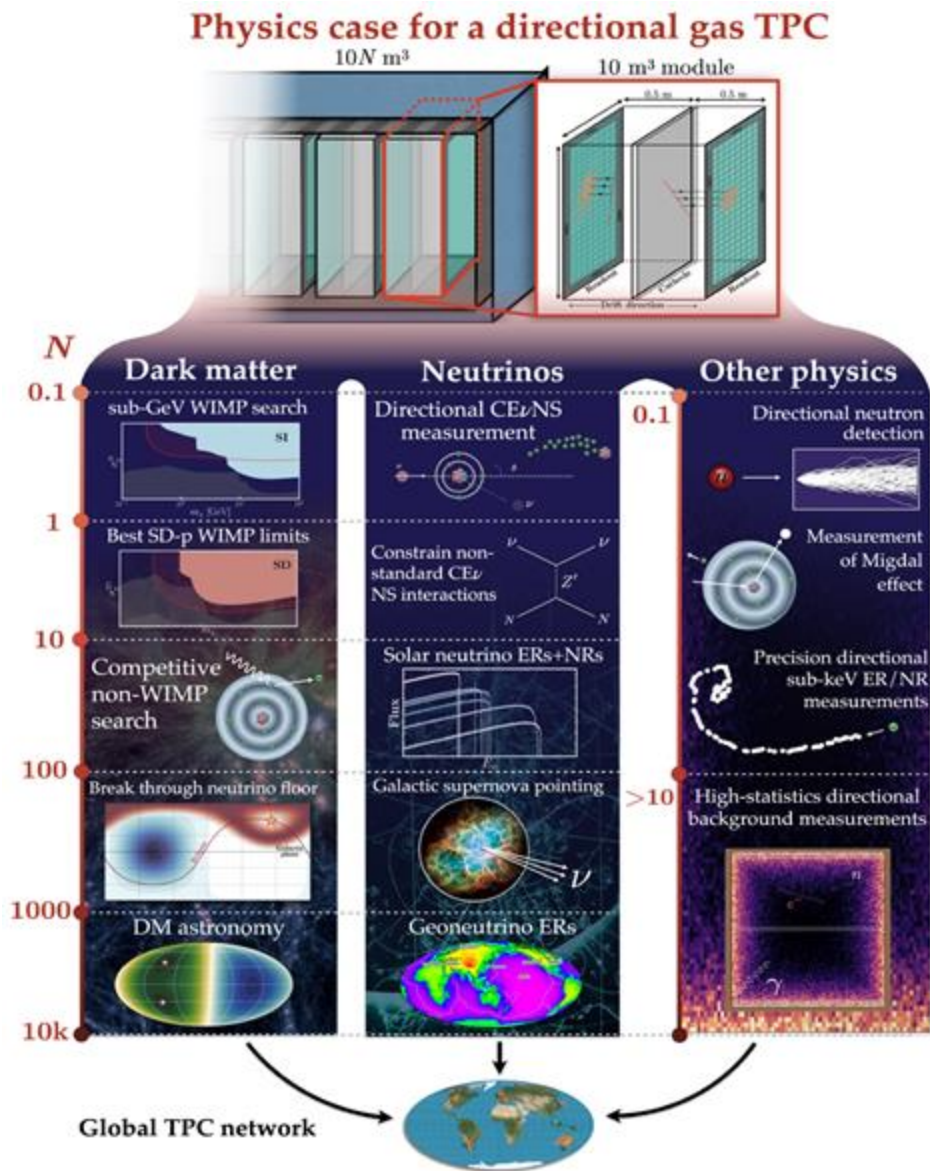
Further SUPL Plans

Low-background HPGe

- ANSTO will install one of their existing low-background HPGe detectors for radio-assay measurements

CYGNUS-Oz

- Australian contribution to the international CYGNUS effort aiming to achieve directional detection of WIMP DM.
- R&D to develop micro-patterned gas TPC technology
- Distinguish solar neutrinos from DM and see into the neutrino fog (see arxiv 2102.04596 and 2404.03690)



SUPL Preliminary Timeline

- Q4 2024: Clean-room/lead castle for SABRE NaI crystal testing
- Q1 2025: CELLAR installed in larger of SUPL rooms
SABRE crystal glovebox installation
ANSTO HPGe detector to be installed
- Q2 2025: SABRE low-background crystals start arriving
SABRE shielding installation
- Q3 2025: SABRE veto vessel installation
- Q4 2025: SABRE South commissioning
- 2026: SABRE South begins measurement.
Optimisation of space to release 1/2 of main hall
- 2027- CYGNUS-Oz demonstrator and other potential expts

Keen to hear from any parties interested to use SUPL

Conclusions

Major progress on deep-underground laboratories in the Southern Hemisphere.

- Plans for PAUL are progressing with significant international collaboration and the possibility of decisions being made on funding and construction during 2025.
- SUPL construction is complete and the lab is operational with two major experiments (SABRE South and CELLAR) being installed now and over the next 12-18 months.

