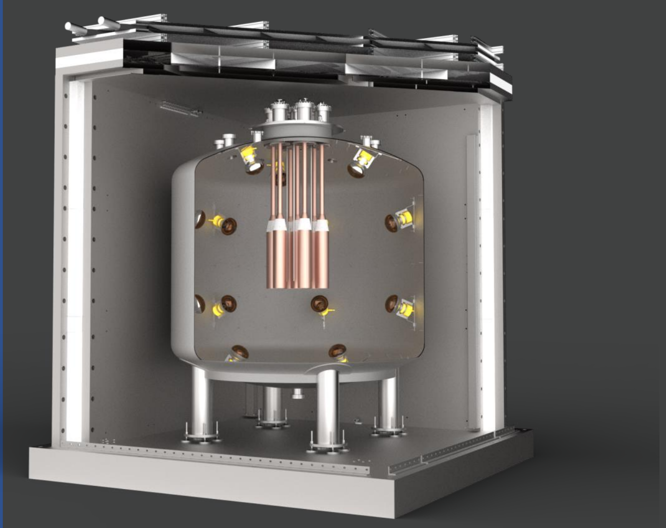


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Radio-impurity studies for dark matter detection with the SABRE South experiment

Dr. Zuzana Slavkovská

Australian National University

DSU2022

On behalf of the SABRE South collaboration

Australian National University

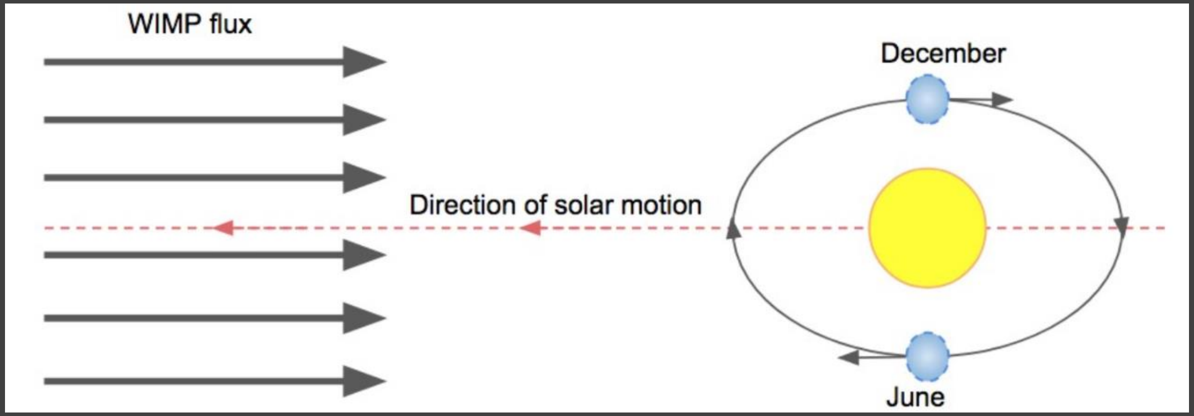
The Guardian

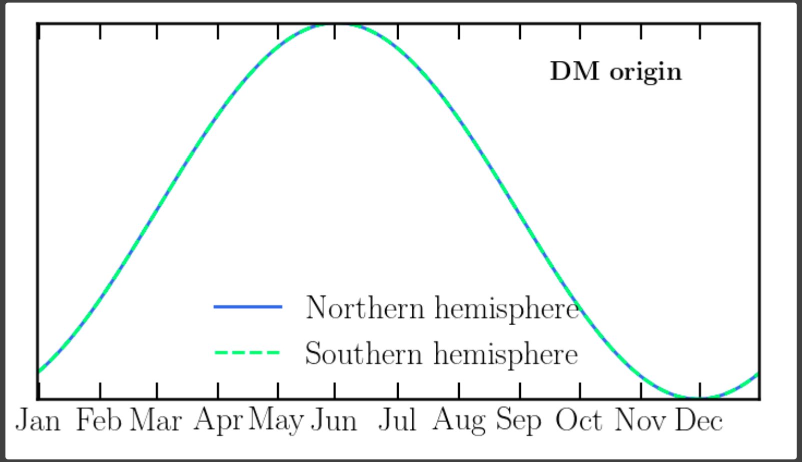
Australia news

Laboratory to study dark matter opens 1km under Australian town – with no bananas allowed

From deep inside a gold mine in Stawell, Victoria, researchers are hunting for the invisible substance thought to make up 85% of the matter in the universe

SABRE Motivation





Plot from M.Zurowski

Standard halo model hypothesis: Spherical halo of cold, dark matter (WIMP particles) permeating the galaxy

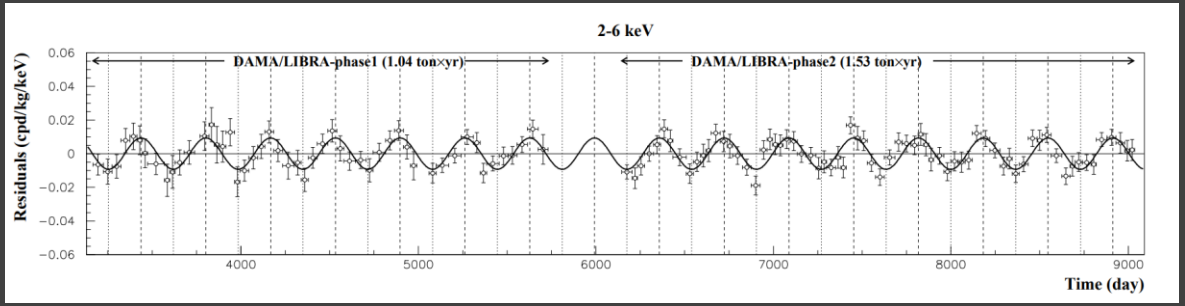
Annual modulation with a 1 year period due to Earth orbiting the Sun

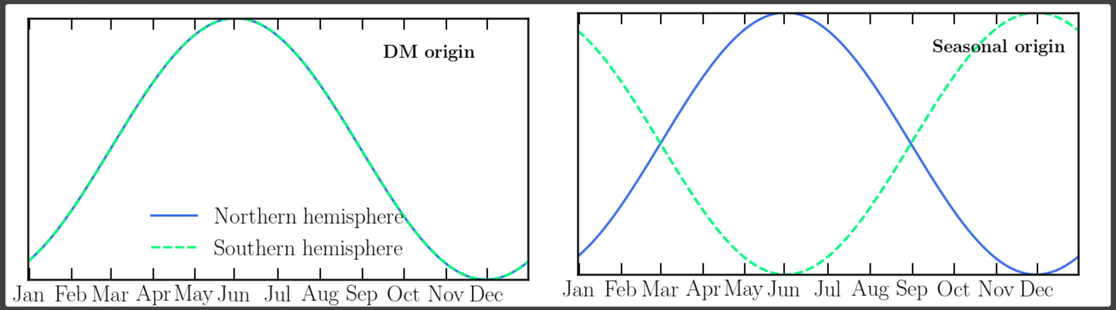
Maximum and minimum expected on June 2nd and December 2nd

SABRE Motivation – DAMA results

- **DAMA/LIBRA** (**DA**rk **MA**tter **L**arge sodium**I**odide **B**ulk **RA**re processes) experiment
- Located at **L**aboratori **N**azionali der **G**ran **S**asso (**LNGS**) in Italy
- 250 kg of NaI(Tl)
- Observed **~0.01 cpd/kg/keV modulation** in the 1-6 keV energy range

- DM signal? Seasonal modulation?





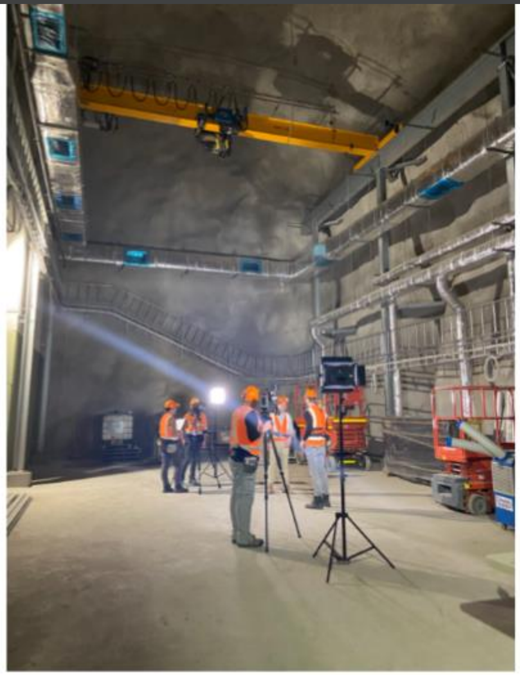
Berbabei et al. 2021
https://arxiv.org/abs/2110.04734

Plots from M.Zurowski

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

SABRE Collaboration

INFN
LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso



STAWELL UNDERGROUND PHYSICS LAB

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Scientific program includes the deployment of two detectors

SABRE South

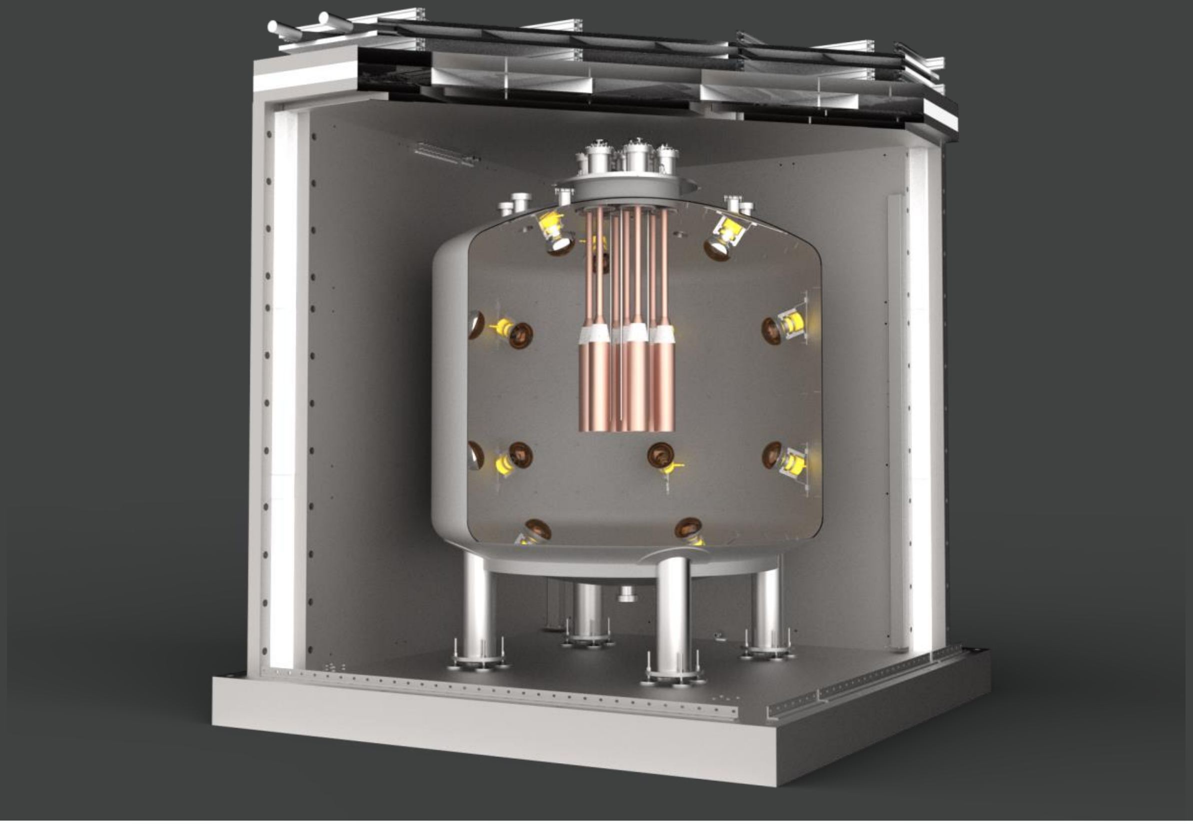
Stawell **U**nderground **P**hysics **L**aboratory (**SUPL**)

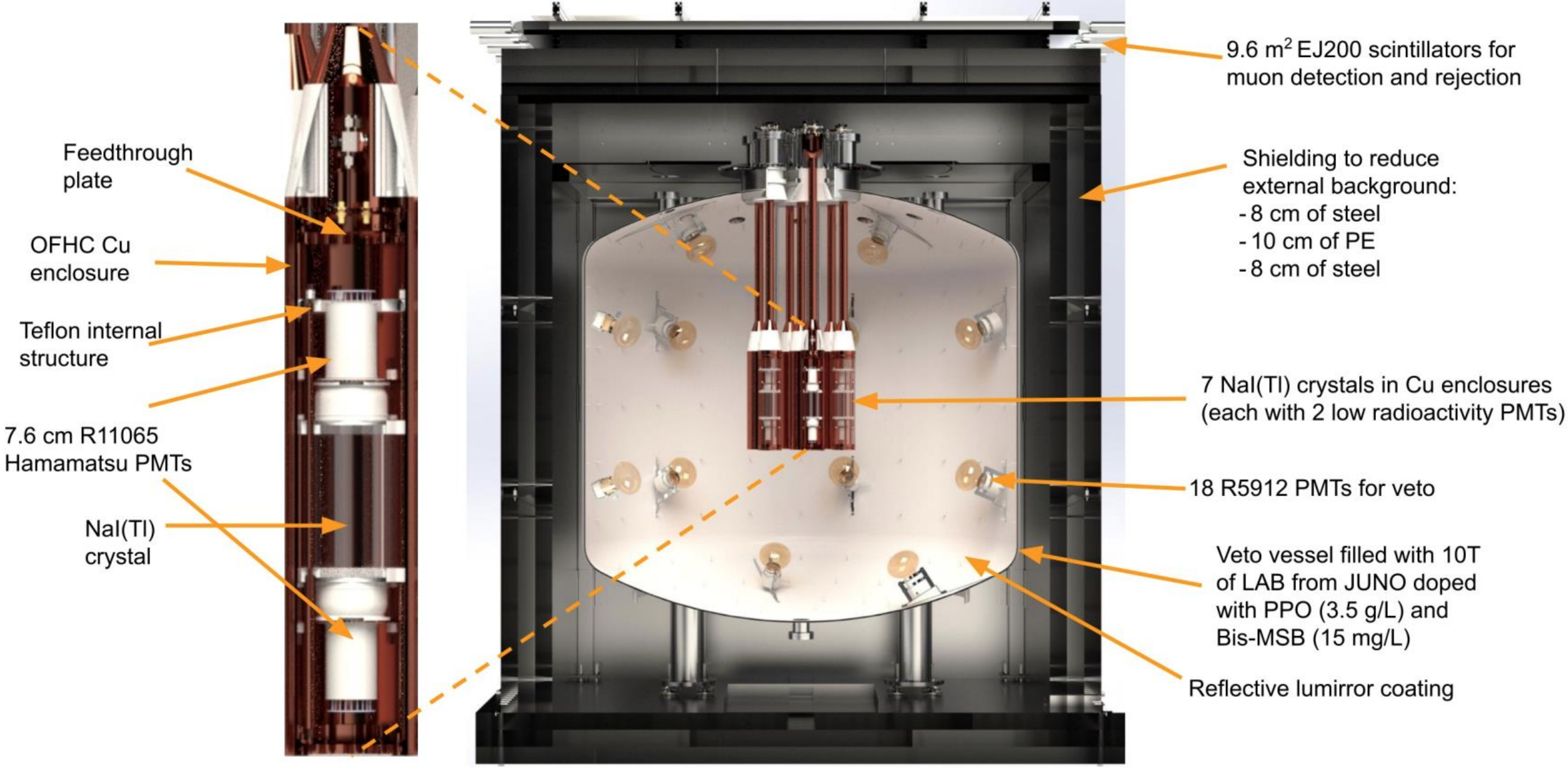
- Within a working **gold mine**
- **1,025 m** underground
- Protection from interference from cosmic radiation
- In site in the **Southern hemisphere** important to exclude seasonal effects

SABRE Collaboration

SABRE (**S**odium Iodide with **A**ctive **B**ackground **RE**jection) experiment

- The detector is an array of **ultra-pure NaI(Tl)** scintillating crystals
- Principle: **direct detection** of DM via scattering off nuclei




Feedthrough plate
OFHC Cu enclosure
Teflon internal structure
7.6 cm R11065 Hamamatsu PMTs
NaI(Tl) crystal
9.6 m^2 EJ200 scintillators for muon detection and rejection
Shielding to reduce external background:
- 8 cm of steel
- 10 cm of PE
- 8 cm of steel
7 NaI(Tl) crystals in Cu enclosures (each with 2 low radioactivity PMTs)
18 R5912 PMTs for veto
Veto vessel filled with 10T of LAB from JUNO doped with PPO (3.5 g/L) and Bis-MSB (15 mg/L)
Reflective lumirror coating

Introduction to SABRE South

One of the challenges of SABRE South: **Radio-purity**

Radioactive and cosmic contaminants

-> might mimic dark matter signals

- **Identify +**
- **Quantify +**
- **Reduce**

the radio-impurities in the crystal + the detector material

Radio-impurities in SABRE South

Radioactive isotopes -> in detector materials

SABRE South Collab arxiv:2205.13849

-> around the detector material (+ environment)

^{40}K, ^{87}Rb, ^{129}I, ^{210}Pb, ^{232}Th, ^{238}U

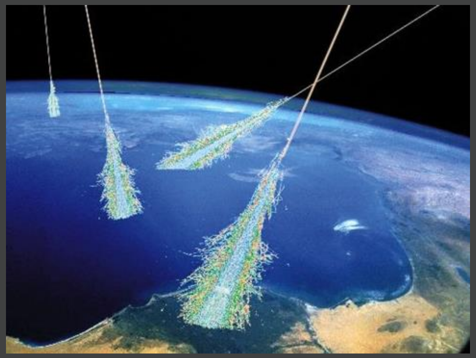
- in particular radon (radioactive chains from Th and U, decays in ^{210}Pb)

Neutrinos: solar and from outside the Solar System (Supernovae), atmospheric

Cosmic rays: originate from the Sun or outside the Solar System

interaction with atmosphere particles -> particle shower

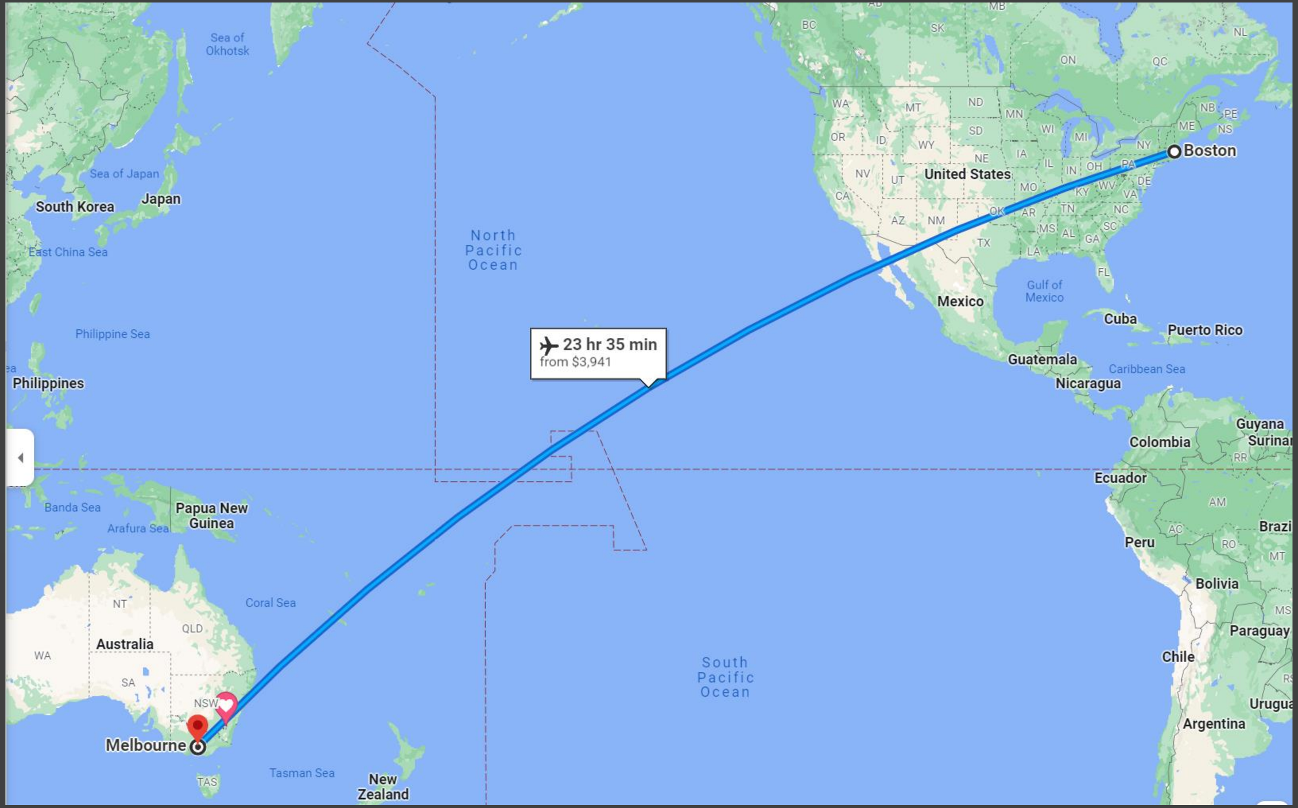
(important for crystal transport)



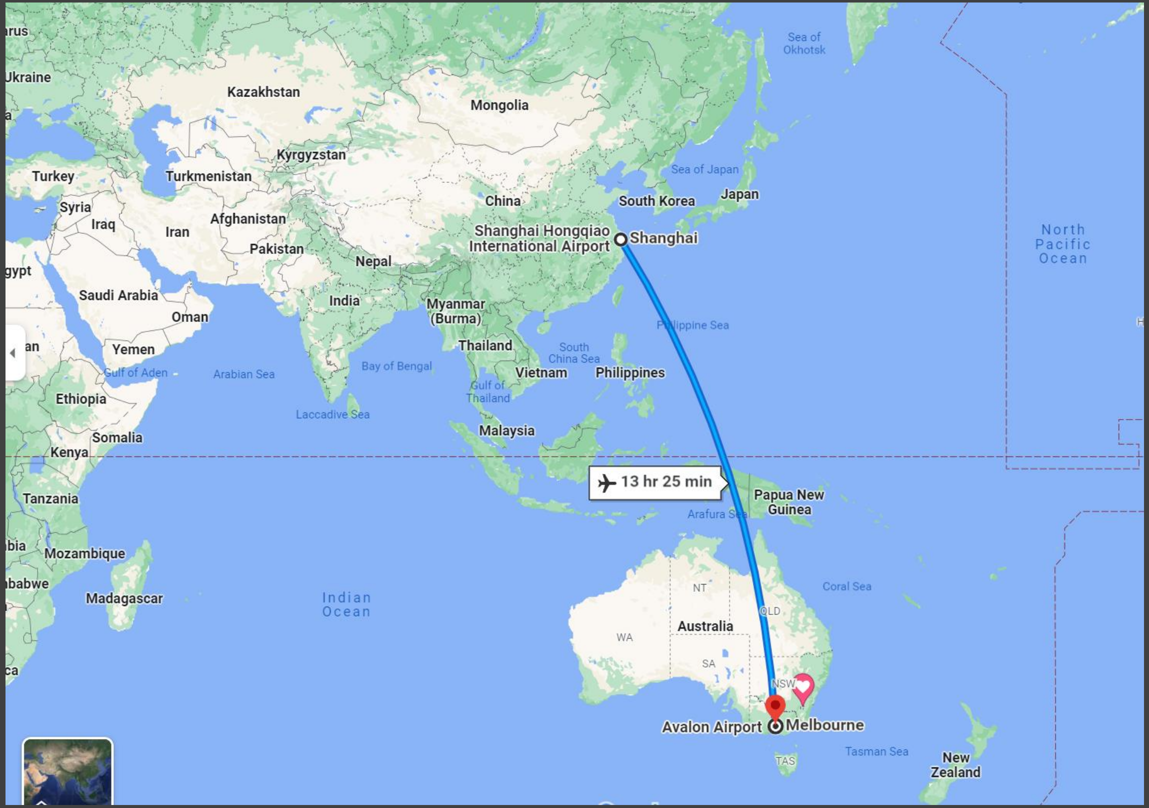
Potential crystal providers

RMD (Radiation **M**onitoring **D**evices, Boston, MA, US)

SICCAS (**S**hanghai **I**nstitute or **C**eramics, **C**hinese **A**cademy of **S**ciences)



Boston to Stawell



Shanghai to Stawell

Radio-impurities in SABRE South

- Crystal powder

- Crystal growing

- Crystal handling

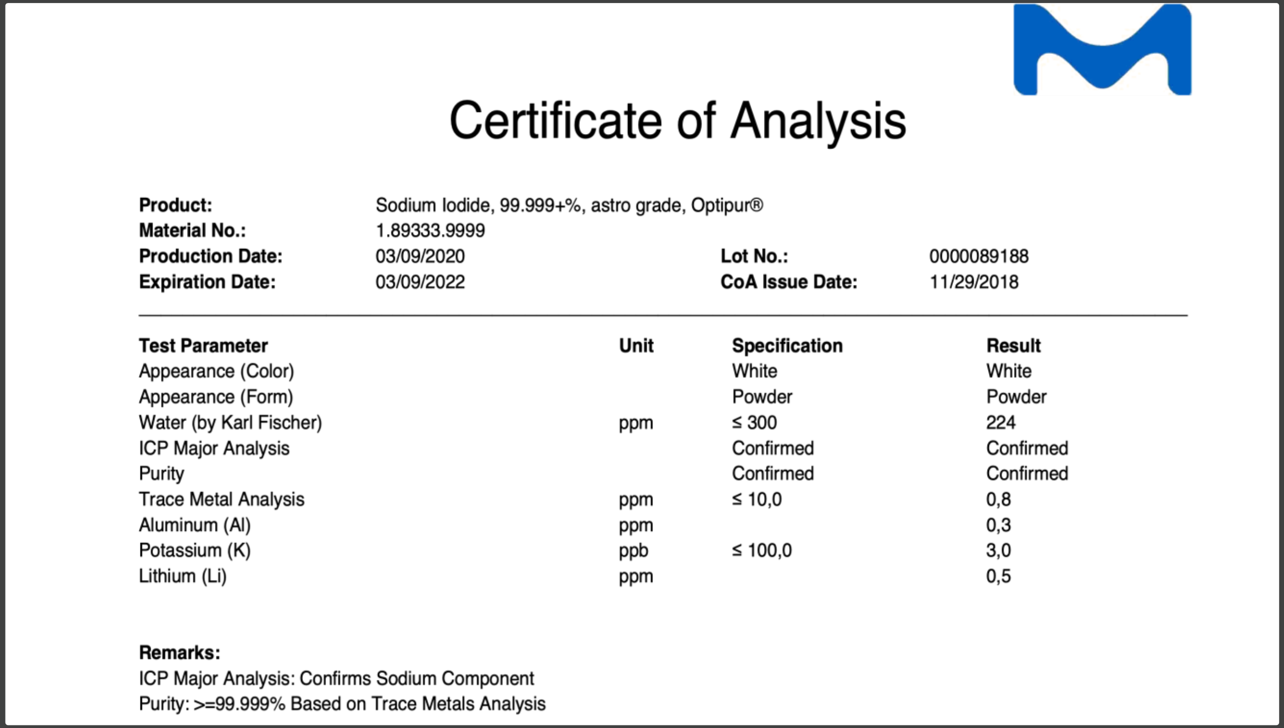
- Material screening, cleaning and selection

Radio-impurities in SABRE South

Crystal powder

- Ultra-pure Astro-grade quality powder
- 100 kg at University of Melbourne

- Powder dried based on a process designed at Princeton: vacuum baking and inert purging
- SICCAS also uses Kunshan powder for crystal growth development



Certificate of Analysis

Product: Sodium Iodide, 99.999+%, astro grade, Optipur®
Material No.: 1.89333.9999
Production Date: 03/09/2020 **Lot No.:** 0000089188
Expiration Date: 03/09/2022 **CoA Issue Date:** 11/29/2018

Test Parameter	Unit	Specification	Result
Appearance (Color)		White	White
Appearance (Form)		Powder	Powder
Water (by Karl Fischer)	ppm	≤ 300	224
ICP Major Analysis		Confirmed	Confirmed
Purity		Confirmed	Confirmed
Trace Metal Analysis	ppm	≤ 10,0	0,8
Aluminum (Al)	ppm		0,3
Potassium (K)	ppb	≤ 100,0	3,0
Lithium (Li)	ppm		0,5

Remarks:
ICP Major Analysis: Confirms Sodium Component
Purity: >=99.999% Based on Trace Metals Analysis

Radio-impurities in SABRE South

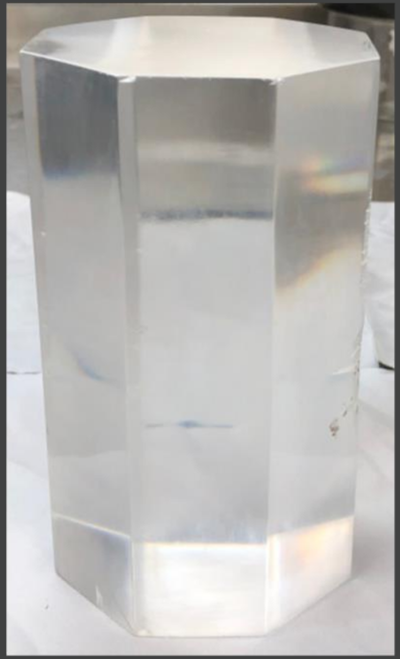
Crystal growing

- Crystals grown in a carbon coated synthetic fused quartz crucible
- Cut into an octagonal shape using a diamond saw
- Polished with semiconductor grade ethanol/isopropyl alcohol to remove any surface contamination

B. Suerfu et al., Phys. Rev. Research 2, 013223 (2020)

- **Purification techniques**
- INFN-Princeton zone refining -> contribution from ^{210}Pb reduced
- Combined with ^{210}Pb removal from PTFE

Phys. Rev. Applied 16 (2021), 01406

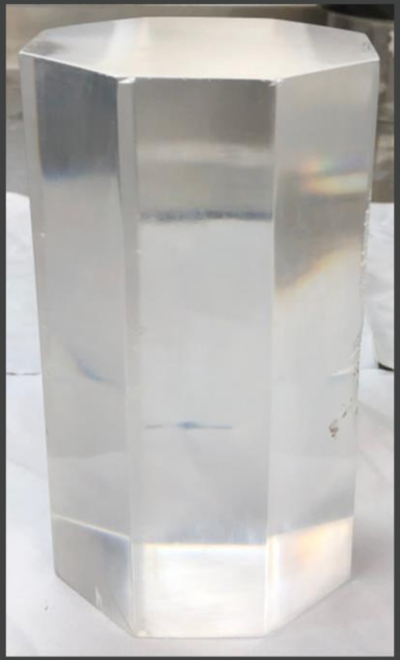


Crystal NaI-33

Radio-impurities in SABRE South

Crystal growing

- **Requirements** based on simulations and DAMA/LIBRA purity
- Desired **total intrinsic radiogenic crystal background** < 0.4 cpd/kg/keV
- **^{210}Pb and ^{40}K** levels of critical importance
- Desired light yield > 10 pe/keV corresponding to ~ 30 photons/keV

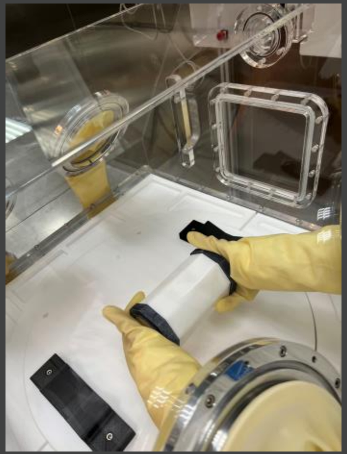


Crystal NaI-33

Radio-impurities in SABRE South

Crystal handling

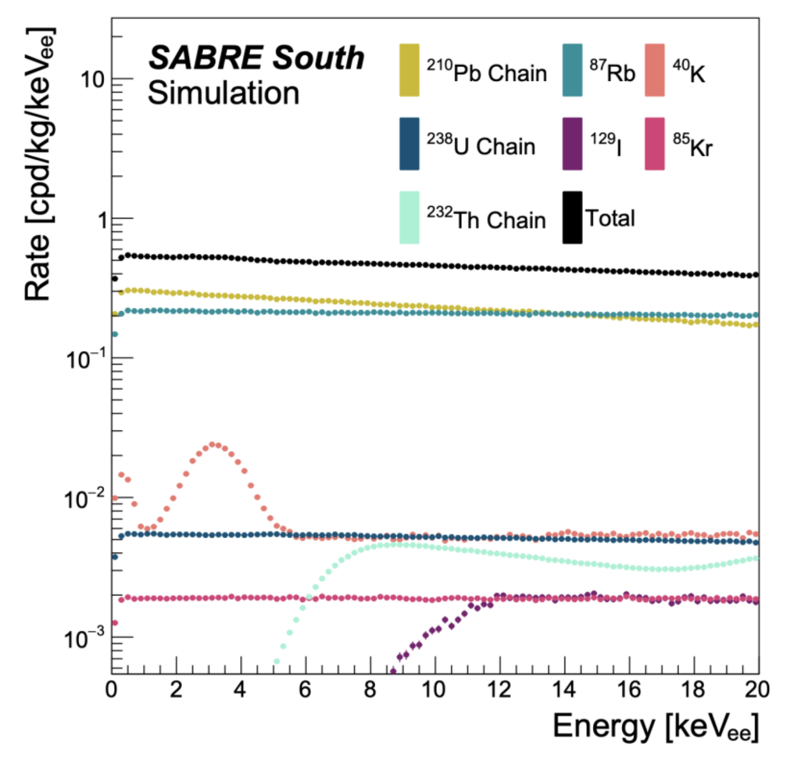
- Crystal glove box design complete and in production
- Testing with a mock-up glove box successful



LNGS design

Radio-impurities in SABRE South

Material screening, cleaning and selection: intrinsic + cosmogenic crystal radiation > 90% total background



	Rate [cpd/kg/keV$_{ee}$]
Crystal radiogenic	$5.2 \cdot 10^{-1}$
Crystal cosmogenic	$1.6 \cdot 10^{-1}$
Crystal PMTs	$3.8 \cdot 10^{-2}$
PTFE wrap	$4.5 \cdot 10^{-3}$
Enclosures	$3.2 \cdot 10^{-3}$
Conduits	$1.9 \cdot 10^{-5}$
Liquid scintillator	$4.9 \cdot 10^{-8}$
Steel vessel	$1.4 \cdot 10^{-5}$
Veto PMTs	$1.9 \cdot 10^{-5}$
Shielding	$3.9 \cdot 10^{-6}$
External	$O(10^{-4})$
Total	$7.2 \cdot 10^{-1}$

Isotope	Rate, veto ON [cpd/kg/keV$_{ee}$]
^{210}Pb	$2.8 \cdot 10^{-1}$
^{87}Rb	$< 2.2 \cdot 10^{-1}$
^{40}K	$1.3 \cdot 10^{-2}$
^{238}U	$< 5.4 \cdot 10^{-3}$
^{85}Kr	$< 1.9 \cdot 10^{-3}$
^{232}Th	$< 3.4 \cdot 10^{-4}$
^{129}I	$9.2 \cdot 10^{-5}$
Total	$< 5.2 \cdot 10^{-1}$

Careful cleaning in **clean room environment**

Radio-impurities in SABRE South

Material screening, cleaning and selection: intrinsic + cosmogenic crystal radiation > 90% total background

Isotope	Rate, veto ON [cpd/kg/keV$_{ee}$]
^{210}Pb	$2.8 \cdot 10^{-1}$
^{87}Rb	$< 2.2 \cdot 10^{-1}$
^{40}K	$1.3 \cdot 10^{-2}$
^{238}U	$< 5.4 \cdot 10^{-3}$
^{85}Kr	$< 1.9 \cdot 10^{-3}$
^{232}Th	$< 3.4 \cdot 10^{-4}$
^{129}I	$9.2 \cdot 10^{-5}$
Total	$< 5.2 \cdot 10^{-1}$

$t_{1/2}$ (^{210}Pb) = 22.2 a

^{210}Pb produces spectrum in the low energy region that cannot be vetoed

Present in environment due to naturally occurring ^{238}U and ^{226}Rn, also in dust

Need to develop a measurement technique for material screening

Radio-impurities in SABRE South

Material screening, cleaning and selection

https://doi.org/10.1016/j.nimb.2022.08.015

- Focus on ^{210}**Pb**
- **Accelerator Mass Spectrometry used:** Not enough Pb to produce AMS sample after NaI extraction
- **Optimal carrier,** as low ^{210}Pb content as possible
- 18th century roof, detector shielding, Roman lead, Hampton Court Palace roof



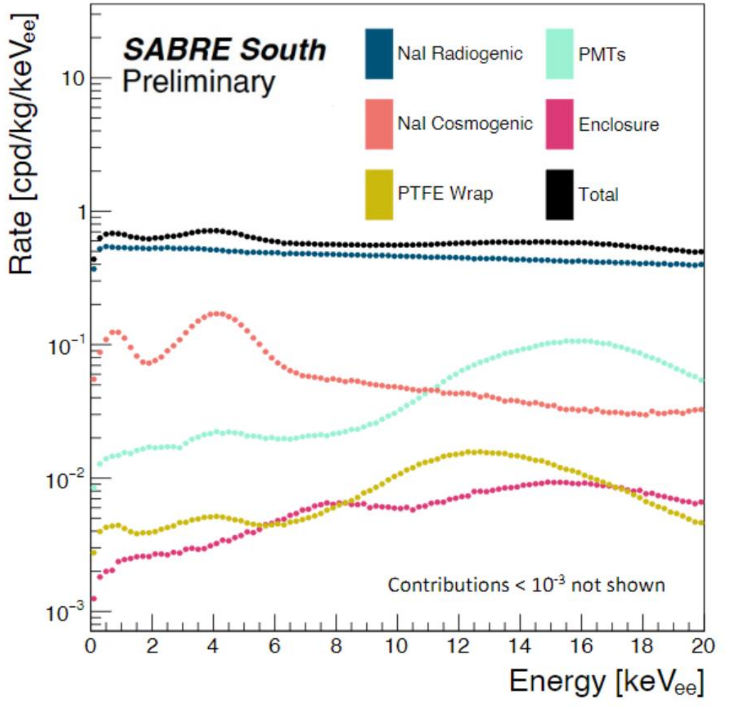
- Chemical processing


+ Accelerator Mass Spectrometry

Radio-impurities in SABRE South

Material screening, cleaning and selection

- All materials in the copper enclosure will require careful cleaning in a clean room environment
- Total background model:



Component	Rate (cpd/kg/keV)	Veto efficiency (%)
Crystal intrinsic	$<5.2 \times 10^{-1}$	13
Crystal cosmogenic	1.6×10^{-1}	45
Crystal PMTs	3.8×10^{-2}	57
Crystal wrap	4.5×10^{-3}	11
Enclosures	3.2×10^{-3}	85
Conduits	1.9×10^{-5}	96
Steel vessel	1.4×10^{-5}	>99
Veto PMTs	1.9×10^{-5}	>99
Shielding	3.9×10^{-6}	>99
Liquid scintillator	4.9×10^{-8}	>99
External	5.0×10^{-4}	>93
Total	**0.72**	**27**

SABRE South Collab arxiv:2205.13849

Radio-impurities in SABRE South

- **Crystal powder**
- **Crystal growing**
- **Crystal handling**
- **Material screening, cleaning and selection**

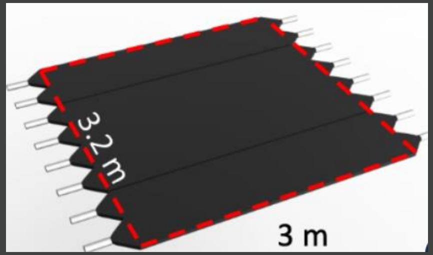
+

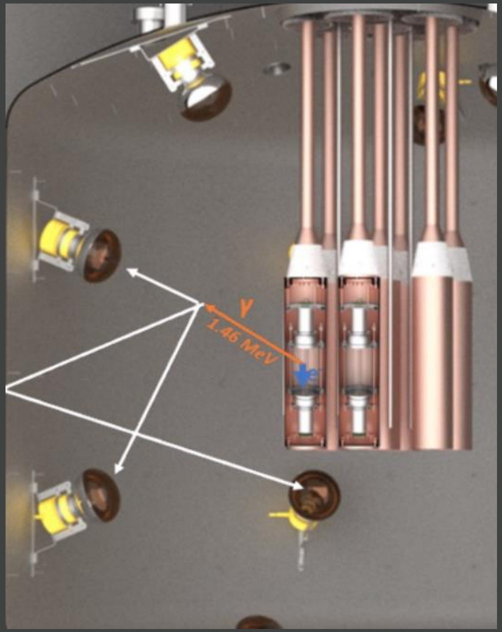
- **Active background rejection**

  removal of decay products observed in the veto scintillator

- **Muon detection system**

  tagging of muon modulation at SUPL





Introduction to SABRE South

One of the challenges of SABRE South: **Radio-purity**

Radioactive and cosmic contaminants

-> might mimic dark matter signals

- **Identify +**
- **Quantify +**
- **Reduce**

the radio-impurities in the crystal + the detector material

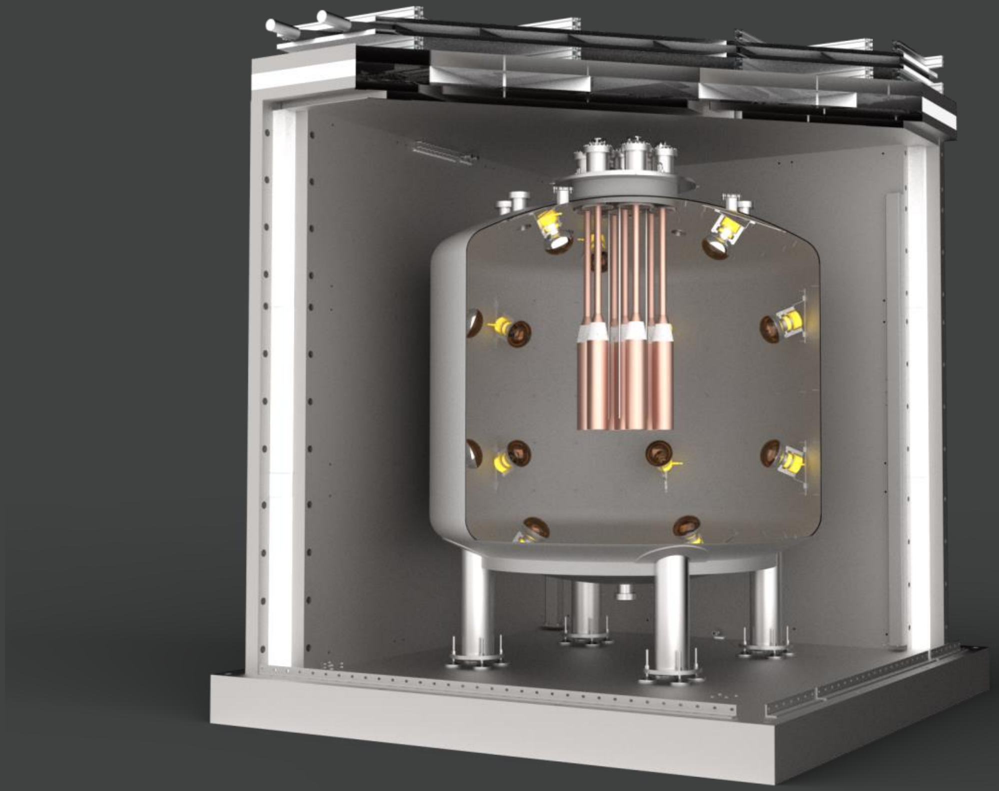
SABRE South

SABRE South is the first dark matter direct detection experiment in the Southern

It will be located in SUPL

SUPL completed in 2022

SABRE South commissioning in late 2023



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Australian Government
Australian Research Council

THE UNIVERSITY of ADELAIDE

Australian National University

THE UNIVERSITY OF MELBOURNE

SWINBURNE

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF WESTERN AUSTRALIA

ANSTO

DST GROUP

INTERNATIONAL PARTNER ORGANISATIONS:

California Institute of Technology

INFN LNGS

Massachusetts Institute of Technology

Stockholms Universitet

UNI FREIBURG

Universiteit van Amsterdam

The University Of Sheffield.

University of Washington