

6 – 10
July
20
25

26th International Workshop on
*Radiation Imaging
Detectors*

The SABRE South Experiment at the Stawell Underground Physics Laboratory



Dr. Zuzana Slavkovská
on behalf of the SABRE
South collaboration



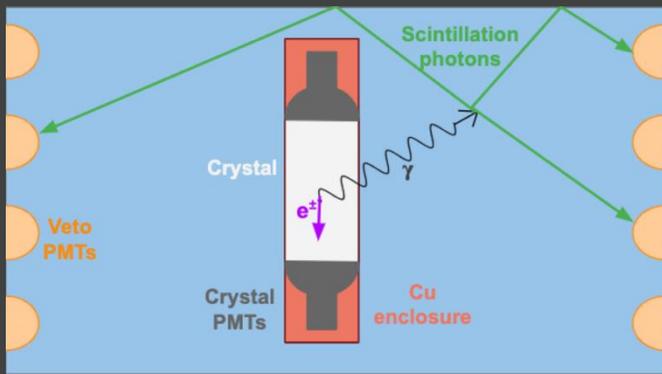
Australian
National
University



The SABRE South Experiment at SUPL

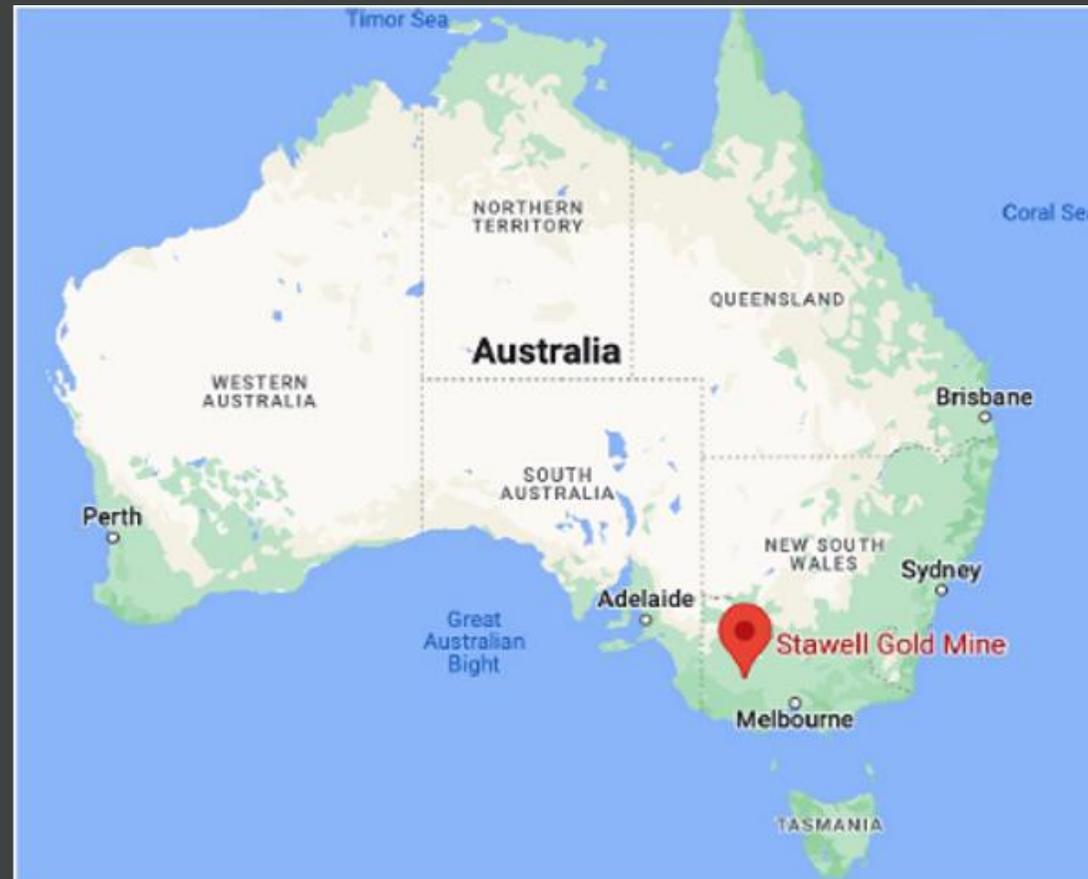
SABRE South dark matter experiment

Aims to observe dark matter through scattering off NaI



First deep underground lab in the Southern Hemisphere

SUPL underground lab in an active gold mine

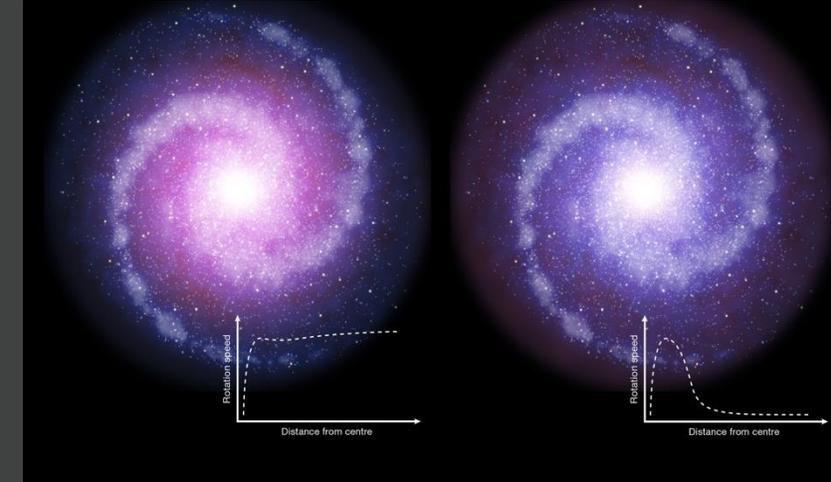


Dark Matter Motivation

- Existence of DM is inferred from its **gravitational interaction**

<https://scitechdaily.com>

- Astronomical observations provide evidence for **existence of dark matter (85% of the mass density of the Universe)**

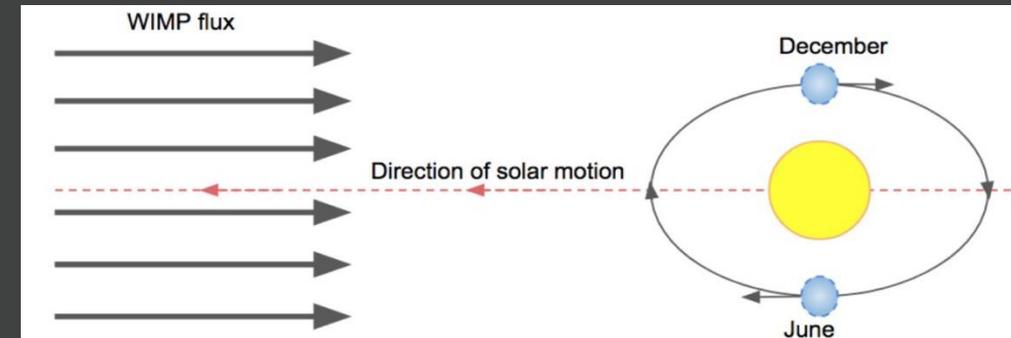


Galactic rotational velocity

- **Candidate: WIMPs** (Weakly Interacting Mass Particles)

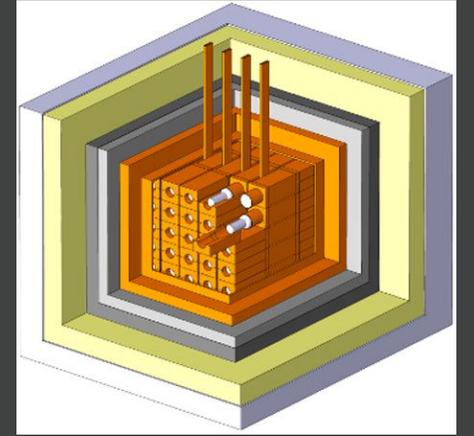
Rare low energy events < 1 count per day/kg/keV

- **Annual modulation** due to Earth orbiting the Sun
(maximum on 2nd June, minimum on 2nd December)

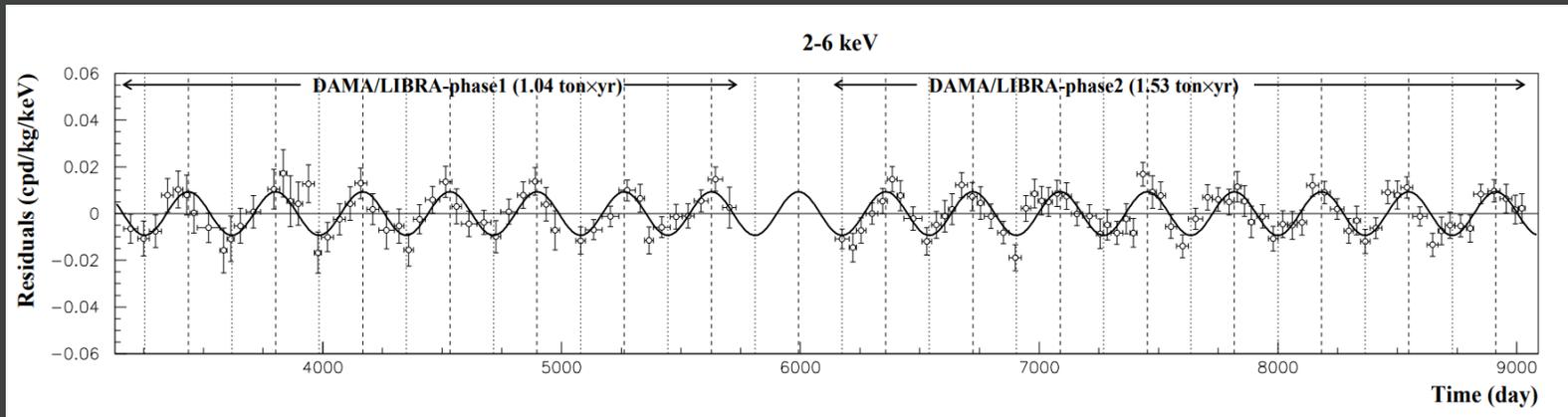


SABRE Motivation

- **DAMA/LIBRA** at Laboratori Nazionali del Gran Sasso (**LNGS**) in Italy
250 kg pure NaI(Tl) crystals with shielding
- ~ 22 years of observation, **signal modulation period of exactly 1 year**
- Observed **~0.01 cpd/kg/keV modulation** in the 1-6 keV energy range
- Claiming 13.7σ discovery



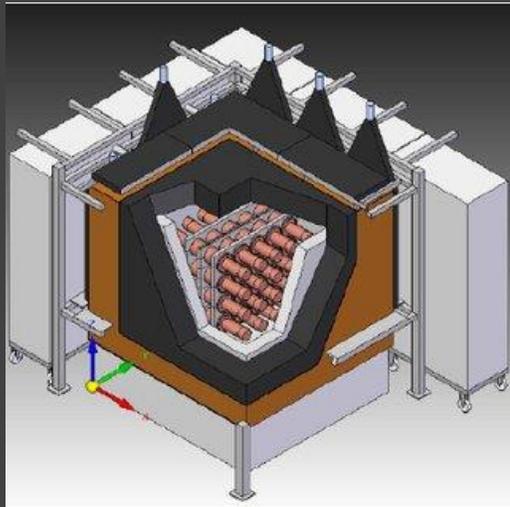
R. Bernabei et al., *EPJ Web of Conferences*.
Vol. 319., EDP Sciences, 2025.



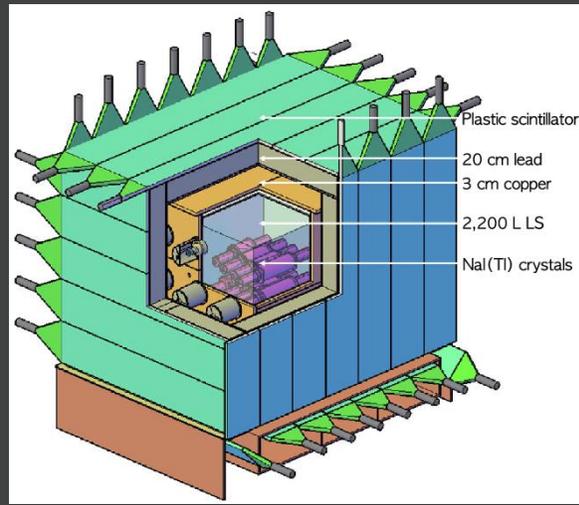
R. Bernabei et al., *Nucl. Phys. At. Energy*,
Vol. 22, Issue 4, Pages 329-342, 2021.

Other NaI(Tl) Experiments

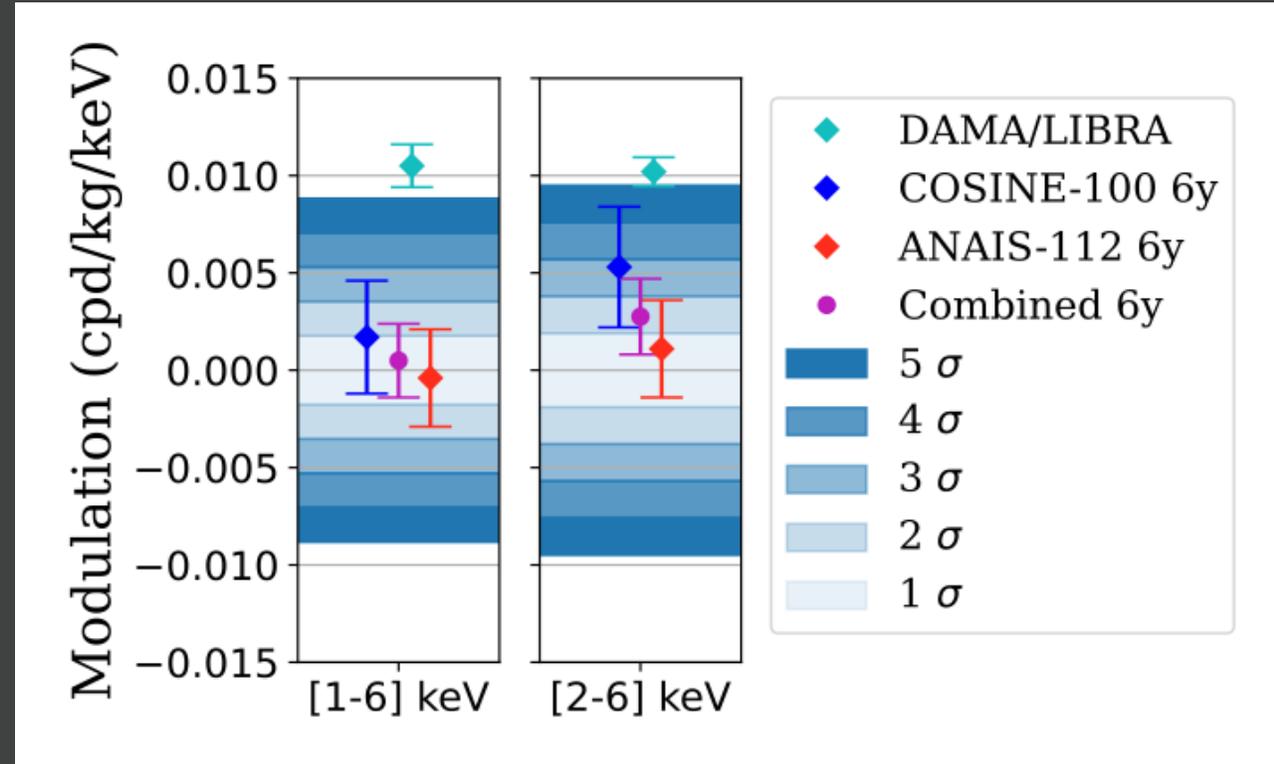
- **Anomaly tested by similar improved detectors:** DAMA has the smallest uncertainty and best sensitivity)
- **ANAIS** - at Canfranc underground lab, Spain
- **COSINE** at Yangyang lab, South Korea



ANAIS



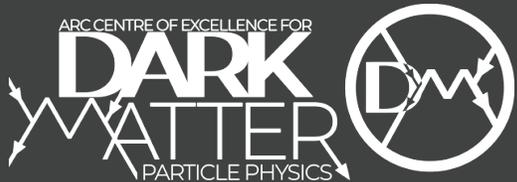
COSINE



ANAIS-112, Commun.Phys. 7.1, 345 (2025)

COSINE-100, PRD 106 (2022)

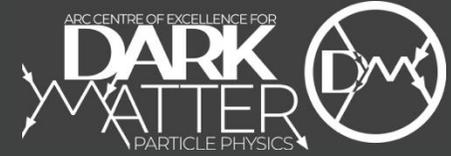
N. Carlin, et al., arXiv:2503.19559 (2025)



SABRE: A Dual Site Experiment

The scientific program of SABRE foresees two detectors in two underground locations:

- **SABRE North** at Laboratori Nazionali del Gran Sasso (LNGS) in Italy
- **SABRE South** at Stawell Underground Physics Laboratory (SUPL) in Australia



SABRE (Sodium iodide with **A**ctive **B**ackground **RE**jection)

A world map with Italy and Australia highlighted in teal. A blue arrow points from the Italian location to the top-left corner, and another blue arrow points from the Australian location to the bottom-right corner. The top-left corner contains logos for Sapienza Università di Roma, Università del Salento, Princeton University, INFN LNGS, Università degli Studi di Milano, and RMD. The bottom-right corner contains logos for Stawell Underground Physics Lab, Australian National University, The University of Sydney, Swinburne, The University of Melbourne, and The University of Adelaide. A photograph of the Stawell Underground Physics Lab is shown in the top-right corner, depicting a large underground cavern with workers and equipment.

SAPIENZA
UNIVERSITÀ DI ROMA

UNIVERSITÀ DEL SALENTO

PRINCETON UNIVERSITY

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

MELLEN
Come to meet and around the world

RMD
A Dynasil Company

STAWELL UNDERGROUND PHYSICS LAB

Australian National University

THE UNIVERSITY OF SYDNEY

SWINBURNE

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF ADELAIDE

SICCAS Since 1928

KEK
High Energy Accelerator Research Organization

SABRE: A Dual Site Experiment



The SABRE Collaboration



SABRE North and South have **common core features:**

- Same crystal **production and R&D.**
- Same **detector module** concept (ultra-pure crystals and HPK R11065 PMTs)
- Common **simulation, DAQ and data processing frameworks**
- Exchange of **engineering** know-how with official collaboration agreements between the ARC Centre of Excellence for Dark Matter and the INFN



The SABRE Collaboration



SABRE North and South have **common core features:**

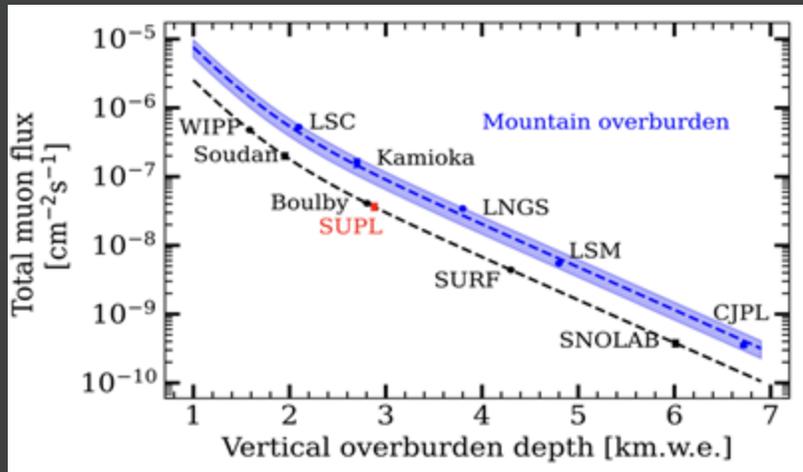
- Same crystal **production and R&D.**
- Same **detector module** concept (ultra-pure crystals and HPK R11065 PMTs)
- Common **simulation, DAQ and data processing frameworks**
- Exchange of **engineering** know-how with official collaboration agreements between the ARC Centre of Excellence for Dark Matter and the INFN

SABRE North and South have **different shielding designs:**

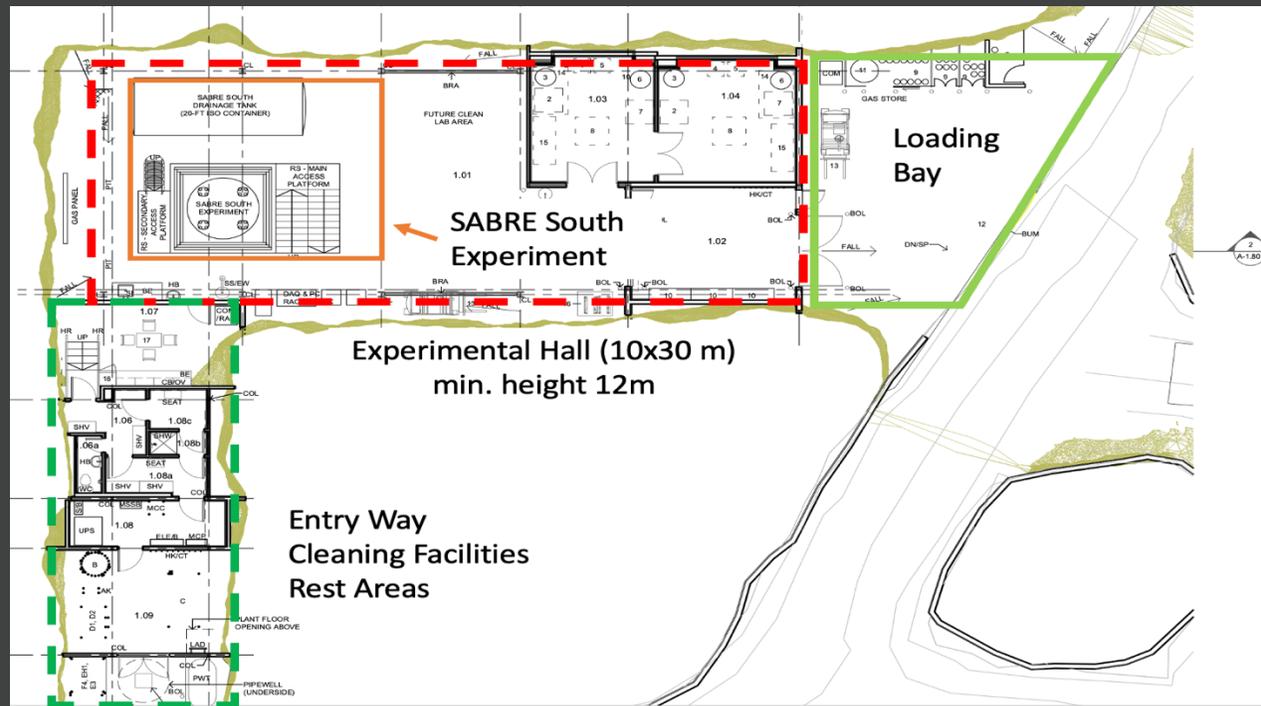
- SABRE North has a **fully passive shielding**
- **SABRE South** uses **liquid scintillator**: it will be used for in-situ evaluation and validation of the background in addition to background rejection and particle identification.

SUPL (Stawell Underground Physics Laboratory)

- In an **active gold mine** in Stawell, Victoria, Australia
- **1,025 m** underground (2900 m water equivalent)
- Decline mine with a single portal
- 30-minute drive to the laboratory
- 40°C (104 F)
- First underground lab in the **Southern Hemisphere**



Construction complete and installation of SABRE South experiment started in 2024
 First detectors commissioned in early 2024, collecting data
 10 m x 16.4 m x 12 m **experimental hall**, two small **gamma spectroscopy rooms** + **clean tent**



The SABRE South Experiment

Three detector systems: **Crystal**, **Liquid Scintillator** and **Muon** detectors.

7 NaI(Tl) crystals in Cu enclosures
(each with 2 low radioactivity PMTs)

Feedthrough plate

OFHC Cu enclosure

Teflon internal structure

7.6 cm R11065
Hamamatsu PMTs

NaI(Tl)
crystal



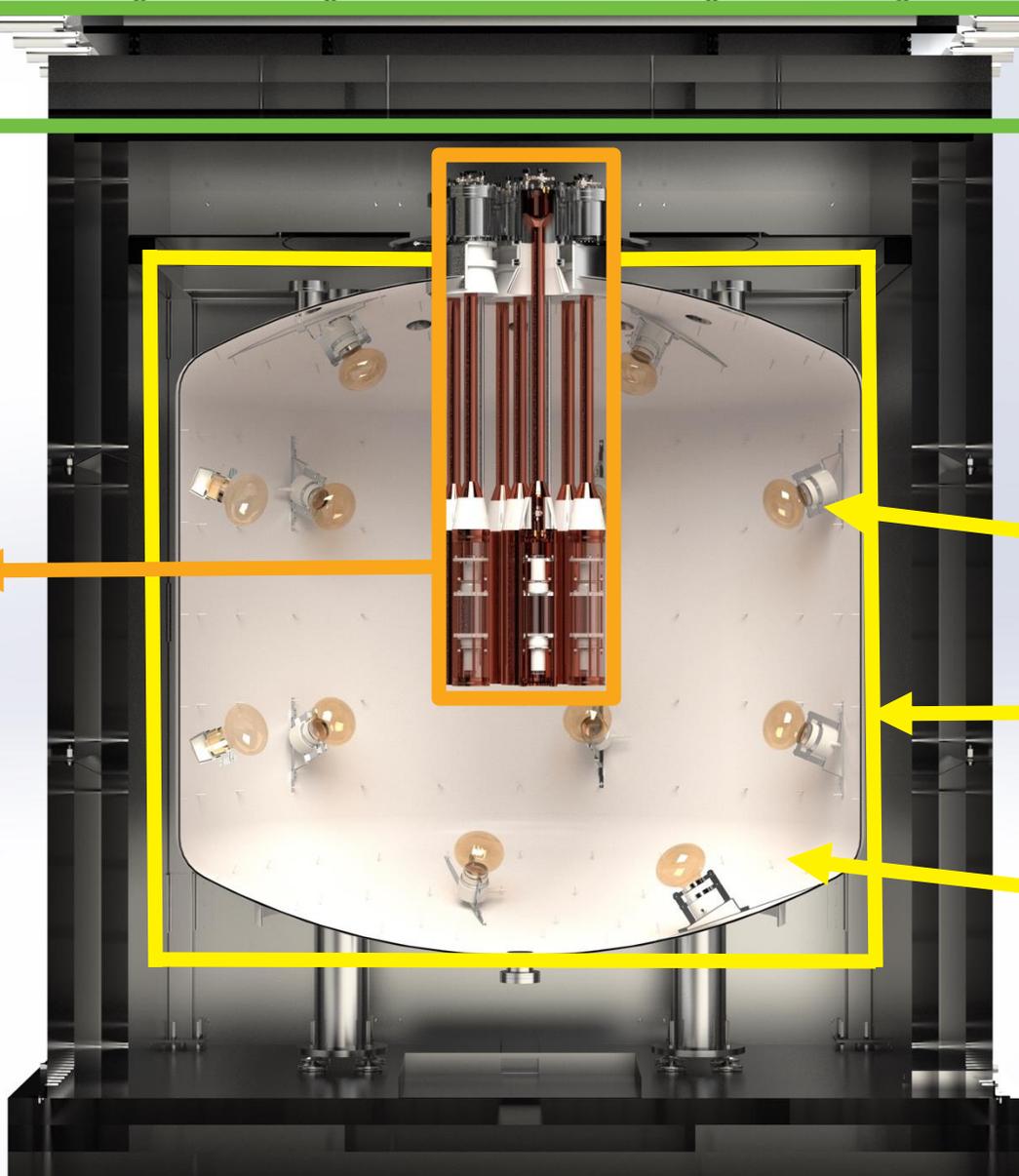
9.6 m² EJ200 scintillators for
muon detection and rejection

Shielding to reduce
external background:
- 8 cm of steel
- 10 cm of PE
- 8 cm of steel

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



E. Barberio, et al., JINST 20 T04001 (2025)

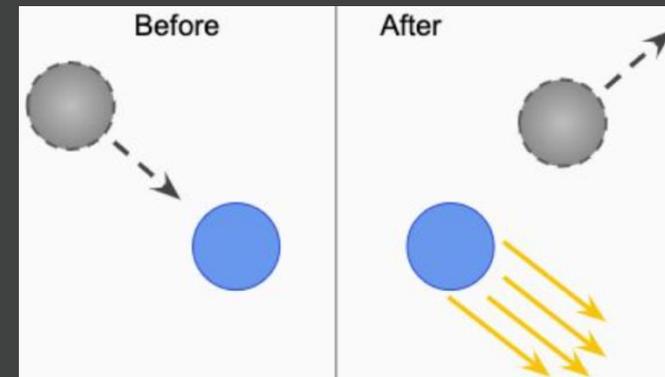
SABRE Principle

SABRE aims to observe WIMPs through **scattering off target nuclei**.



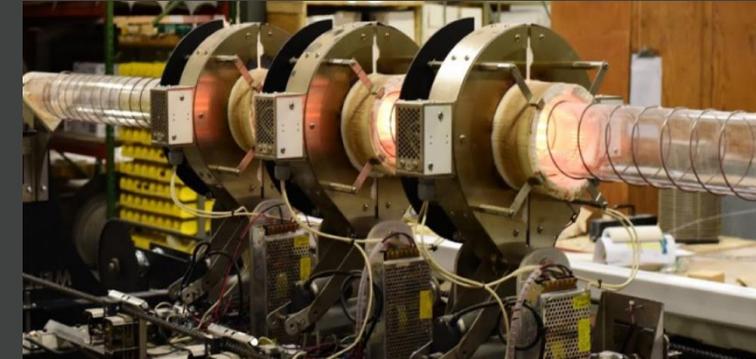
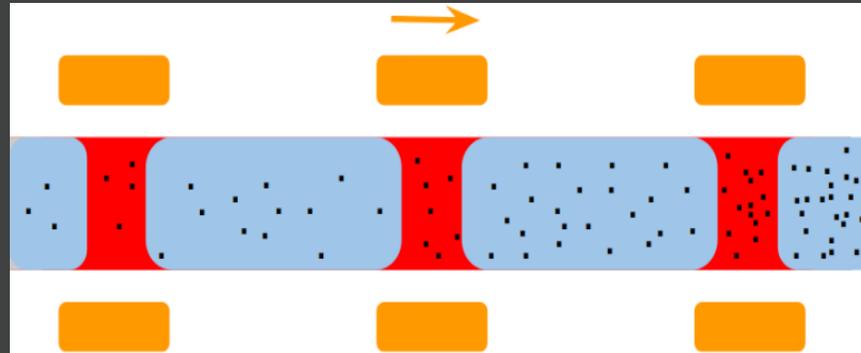
When this happens, the particle the dark matter scatters off will recoil with an energy related to **the dark matter properties**.

We use **ultra-pure NaI(Tl) crystals** as target.



SABRE Crystals

- **SABRE** (Sodium Iodide with **A**ctive **B**ackground **RE**jection)
- **Ultra-pure astro-grade quality** NaI powder from Merck.
- **Seven ultra-pure NaI(Tl)** crystals for (50 kg total mass).
- Test crystals have been grown at RMD (US) and SICCAS (China).
- **Surface treatment** optimization ongoing.
- **Light yield** 9-12 phe/keV.
- 1 keV **energy threshold** for 1-6 keV RoI in NaI(Tl).
- Handled in a **glove box**.
- **Zone refining**: Impurities are segregated to the end of the crystal.



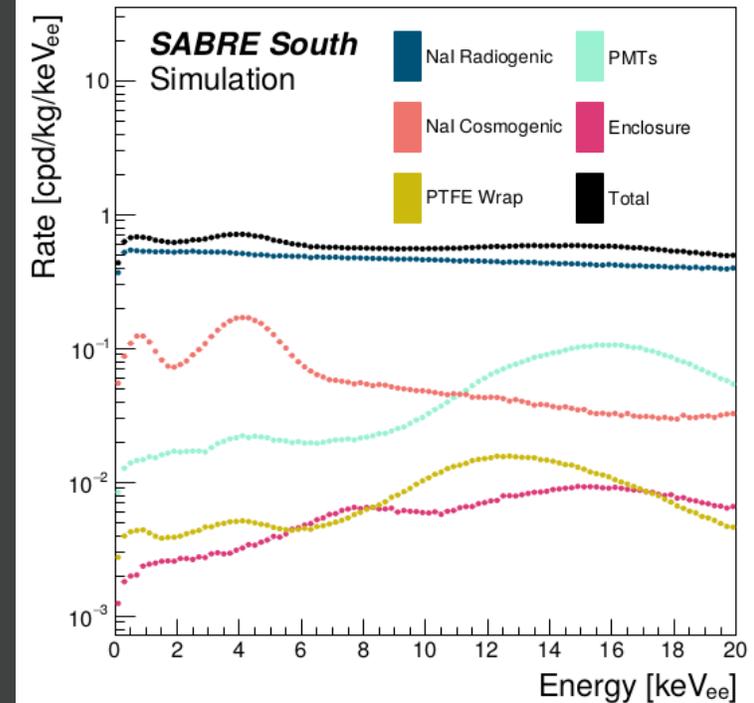
SABRE Crystals

- **Crystal intrinsic background** – naturally occurring isotopes in the NaI(Tl) powder (94% of the total).
- **Cosmogenic background** – through exposure to cosmic rays at sea-level.
- Cool-down period of 6 months to decrease activities.
- **Background from material radioactivity** – various components (PMTs, PTFE wrap, crystal enclosure,...).

We expect 0.72 cpd/kg/keV in RoI, based on a background from the test crystal NaI-33.

Barberio, E. et al. Eur. Phys. J. C 83, 878 (2023).

	Rate [cpd/kg/keV]	Veto Efficiency [%]
Crystal radiogenic	$5.2 \cdot 10^{-1}$	13
Crystal cosmogenic	$1.6 \cdot 10^{-1}$	40
Crystal PMTs	$3.8 \cdot 10^{-2}$	60
PTFE wrap	$4.5 \cdot 10^{-3}$	13
Enclosures	$3.2 \cdot 10^{-3}$	85
Conduits	$1.9 \cdot 10^{-5}$	96
Liquid scintillator	$4.9 \cdot 10^{-8}$	> 99
Steel vessel	$1.4 \cdot 10^{-5}$	> 99
Veto PMTs	$1.9 \cdot 10^{-5}$	> 99
Shielding	$3.9 \cdot 10^{-6}$	> 99
External	$O(10^{-4})$	> 99
Total	$7.2 \cdot 10^{-1}$	27



SABRE Crystals

- One of the biggest challenges: **Purity**
- **Radioactive and cosmic contaminants**
- might mimic dark matter signals

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

Isotope	Activity [mBq/kg]
^{40}K	$1.4 \cdot 10^{-1}$
^{238}U	$< 5.9 \cdot 10^{-3}$
^{232}Th	$< 1.6 \cdot 10^{-3}$
^{87}Rb	$< 3.1 \cdot 10^{-1}$
^{210}Pb	$4.1 \cdot 10^{-1}$
^{85}Kr	$< 1.0 \cdot 10^{-2}$
^{129}I	1.3

Activity of **radiogenic isotopes** in SABRE crystals

$t_{1/2}$ (^{40}K) = 1.25 Ga, primordial origin

Inductively Coupled Plasma – Mass Spectrometry



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

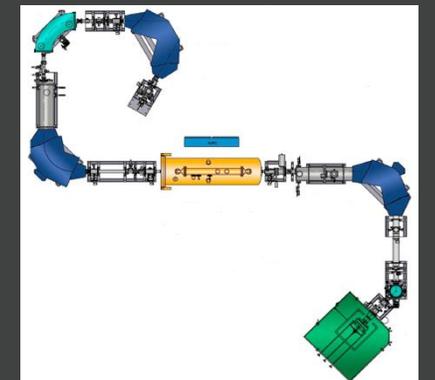
α -counting + development of Accelerator Mass Spectrometry

Ratio of $^{210}\text{Pb}/^{208}\text{Pb}$

Nuclear Instruments and Methods in Physics
 Research Section B: Beam Interactions with
 Materials and Atoms
 Volume 529, 15 October 2022, Pages 18-23

Scavenger hunt: Searching for the optimal target material for low-level ^{210}Pb accelerator mass spectrometry

M.B. Froehlich ^{a, b, *}, Z. Slavkovská ^{a, b}, D. Koll ^{a, 1}, S. Pavetich ^a, F. Dastgiri ^{a, b}, L.K. Fifield ^a, M.A.C. Hotchkis ^c, S. Merchel ^{a, d, 2}, S.G. Tims ^a, A. Wallner ^{a, 1}

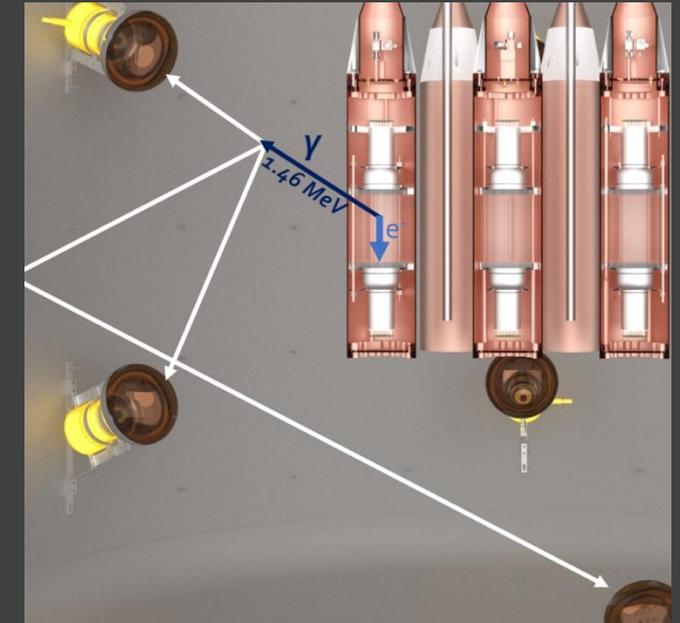


SABRE Veto

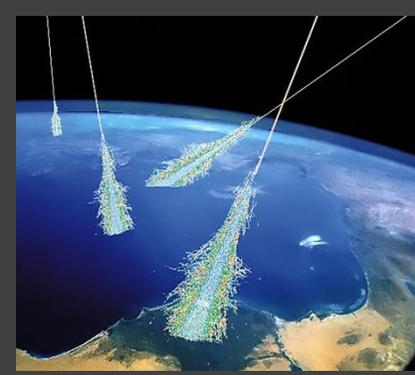
- Crystals embedded in a **veto system** for active background rejection
 - > tag and remove high energy background decay products with 4π coverage.
- **Submerged in 12,000 litres LAB** (Linear Alkyl Benzene) Scintillator.
- Key requirement: Reduction of ^{40}K by a factor of 10 (down to $1.3 \cdot 10^{-2}$ cpd/kg/keV $_{ee}$).



Veto PMT



SABRE Muon Detectors

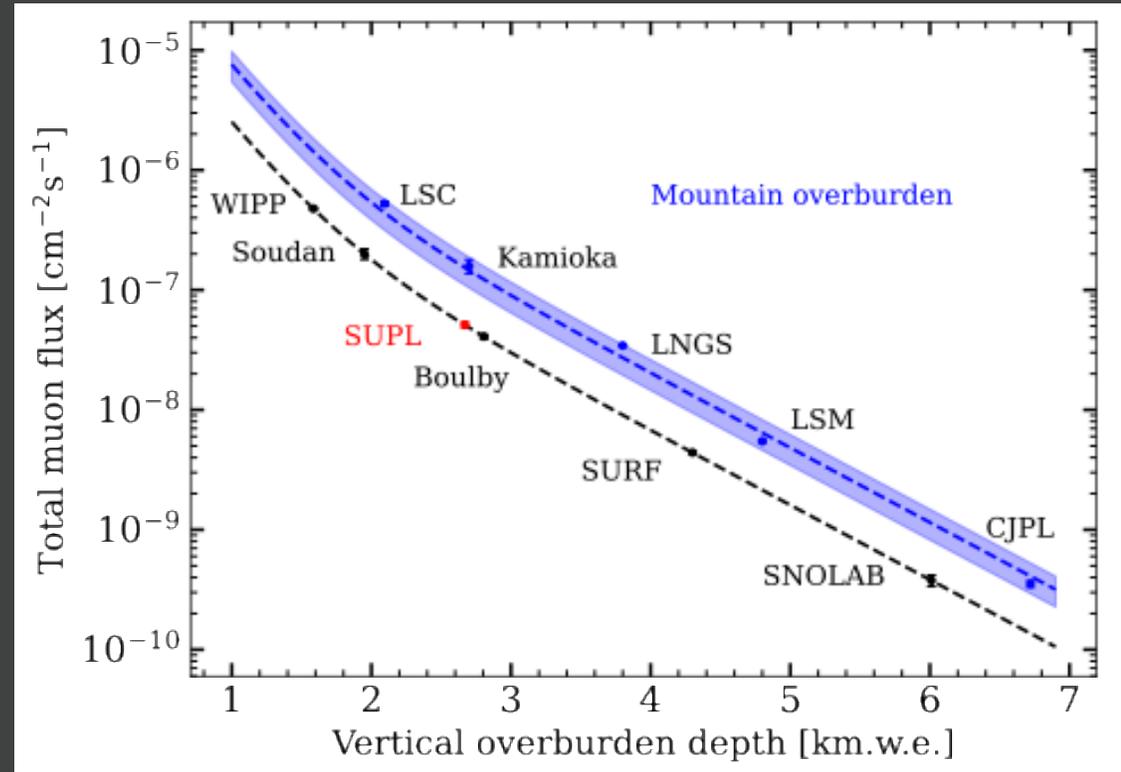
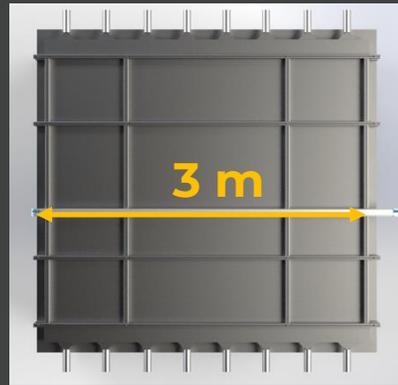


- Tagging of **cosmic rays by muon flux measurements.**
- **Plastic scintillator** 300 cm x 40 cm x 5 cm,
- **8 muon panels** covering 9.6 m².
- **Information combined** with liquid veto
- to reconstruct tracks.

E. Barberio, et al., Muon flux paper in preparation

- Muon detectors **installed in SUPL and are collecting data:**

- 1) Measuring muon flux and angular distribution.
- 2) First test of remote DAQ and processing pipelines.

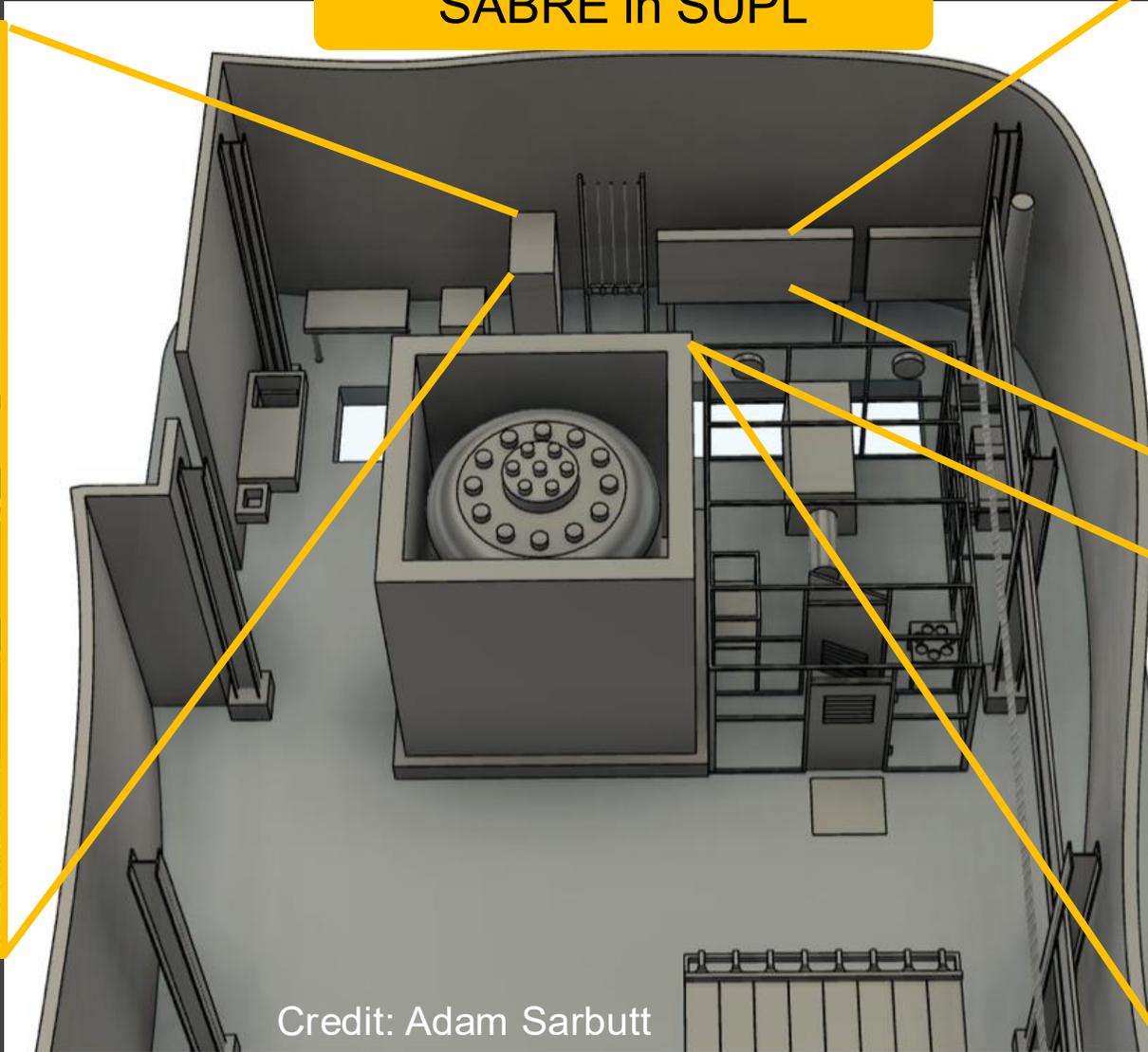


SABRE DAQ & Server, Gas handling, Crystal Insertion

DAQ & Server



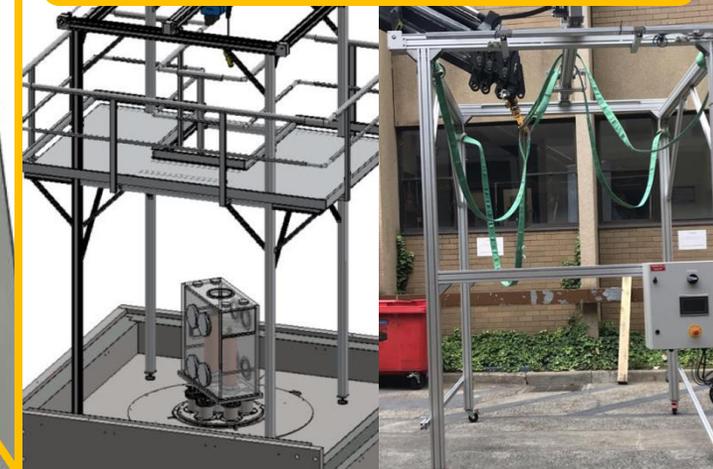
SABRE in SUPL



Gas handling system



Crystal insertion system

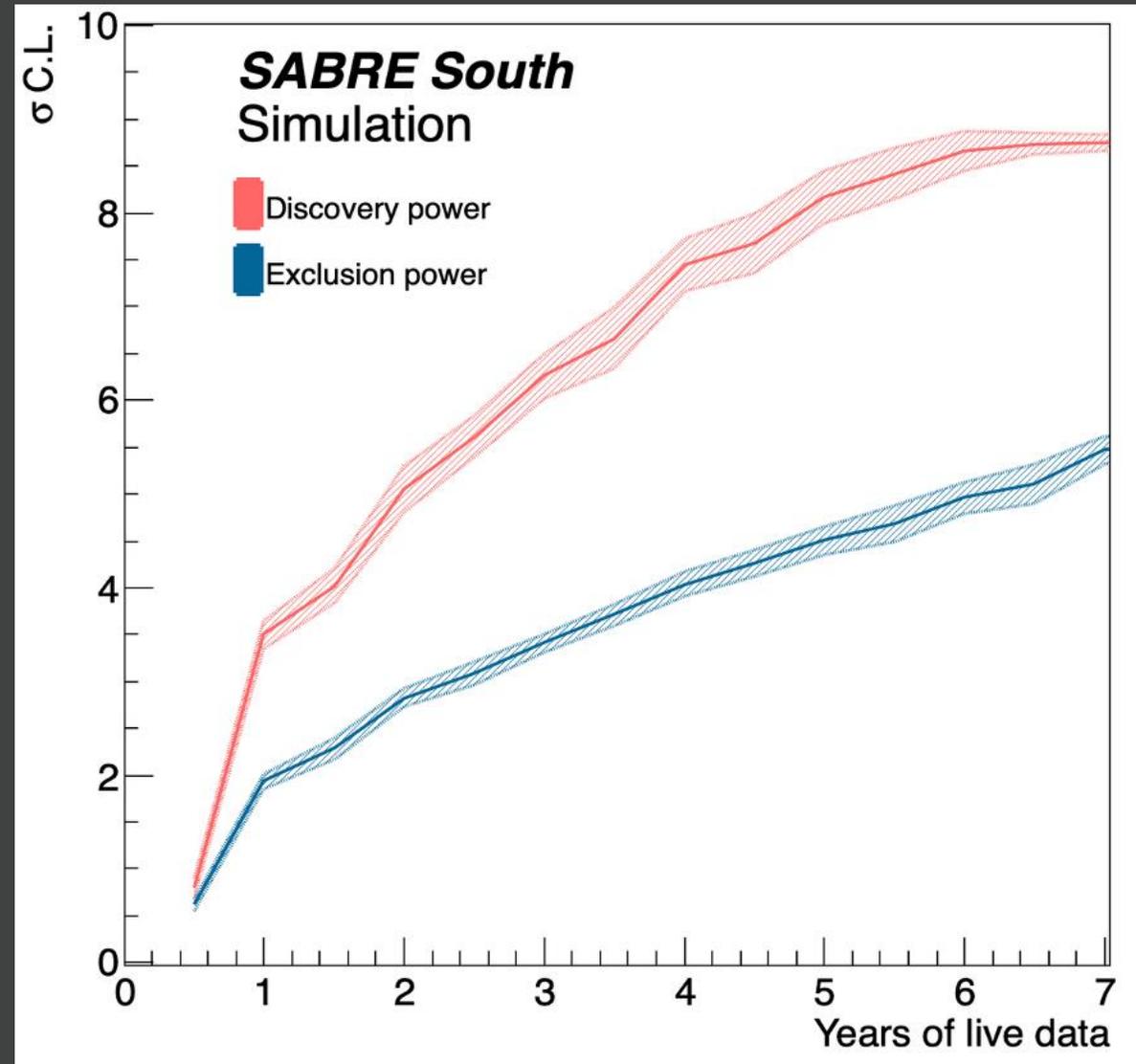


Credit: Adam Sarbutt

SABRE Sensitivity

SABRE South will have a **5 σ discovery** (**3 σ exclusion**) power to a DAMA-like signal within 2.5 years of data taking.

(The shaded regions indicate 1 sigma statistical uncertainty bands).



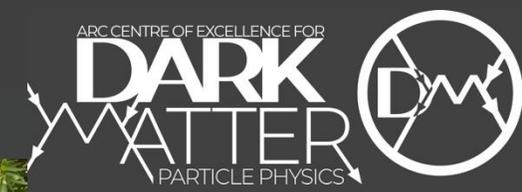
SABRE Summary



- **SABRE is a dual site experiment** with two similar detectors:
 - **SABRE South** at SUPL in Australia and
 - **SABRE North** at LNGS in Italy.
- SABRE uses **ultra-high purity NaI(Tl) crystals**.
- Key design focus is the **low background**.
- **Data taking has begun in early 2024**.
- With the expected backgrounds, we expect a **discovery or exclusion after about 2.5 years** of continuous operation.



SABRE South Collaboration



THE UNIVERSITY
of ADELAIDE



Australian
National
University



THE UNIVERSITY OF
MELBOURNE



THE UNIVERSITY OF
SYDNEY



THE UNIVERSITY OF
WESTERN
AUSTRALIA



INTERNATIONAL PARTNER ORGANISATIONS:



The University of Sheffield.

