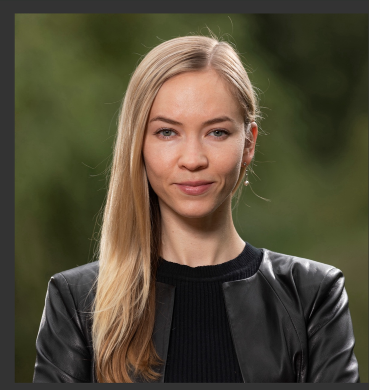
Radio-Impurity Studies for Dark Matter Detection with the SABRE South Experiment

ARC Centre of Excellence for Dark Matter Particle Physics

Australian National University

The Australian National University &
ARC Centre of Excellence for Dark Matter Particle Physics



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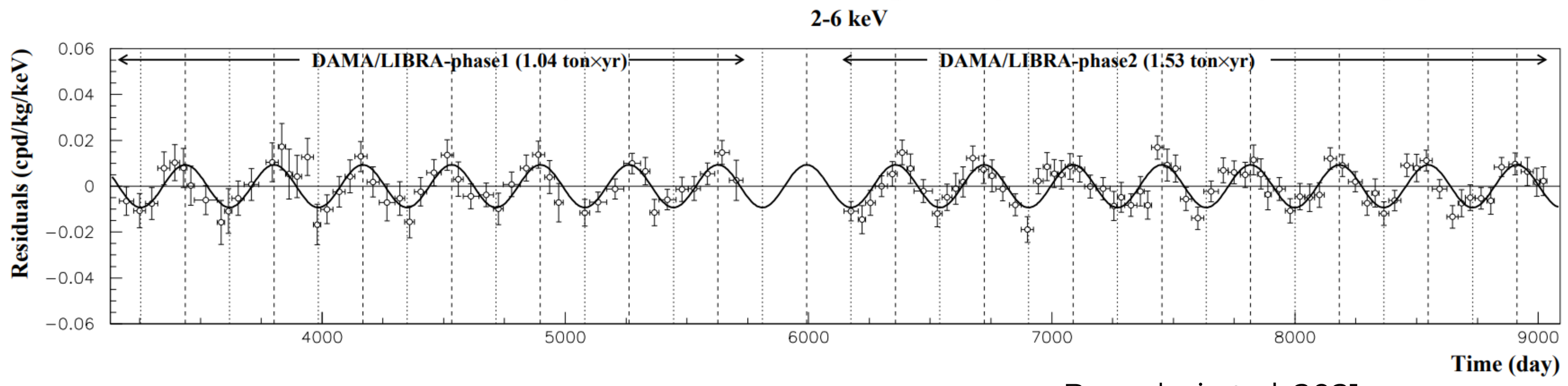
SABRE MOTIVATION

Astronomical observations provide evidence for the existence of dark matter → **85% of the mass density of the Universe.**

The DAMA/LIBRA experiment has been observing a modulating signal consistent with dark matter presence in our galaxy for over 20 years [1]:



Bernabei et al. 2021

However, no other dark matter experiment could confirm their observation.

Is it dark matter signal or seasonal modulation?

The **SABRE experiment** [2] is designed to **test the annual rate modulation** from dark matter interactions observed by DAMA/LIBRA using the same detector material, NaI(Tl) crystals.

This requires for SABRE to be a **double-site experiment with two separate detectors in two underground laboratories on both hemispheres.**

→ **SABRE South** at SUPL in Australia and **SABRE North** at LNGS in Italy.

SABRE South talk: Lachlan Milligan (Thu 15:06) , SABRE North talk: Gabriella Cataldi (Thu 15:26)

SABRE detectors are an array of **ultra-high purity NaI(Tl) scintillating crystals,** aiming to **directly detect dark matter** through scattering off target nuclei.

SABRE South is located 1025 km underground in the **Stawell Underground Physics Laboratory** (cosmic rays are shielded down to a flux of < 10^{-8} cm^{-2} s^{-1}).

BACKGROUND PROJECTIONS

Monte Carlo simulations predict the background with these components [2]:

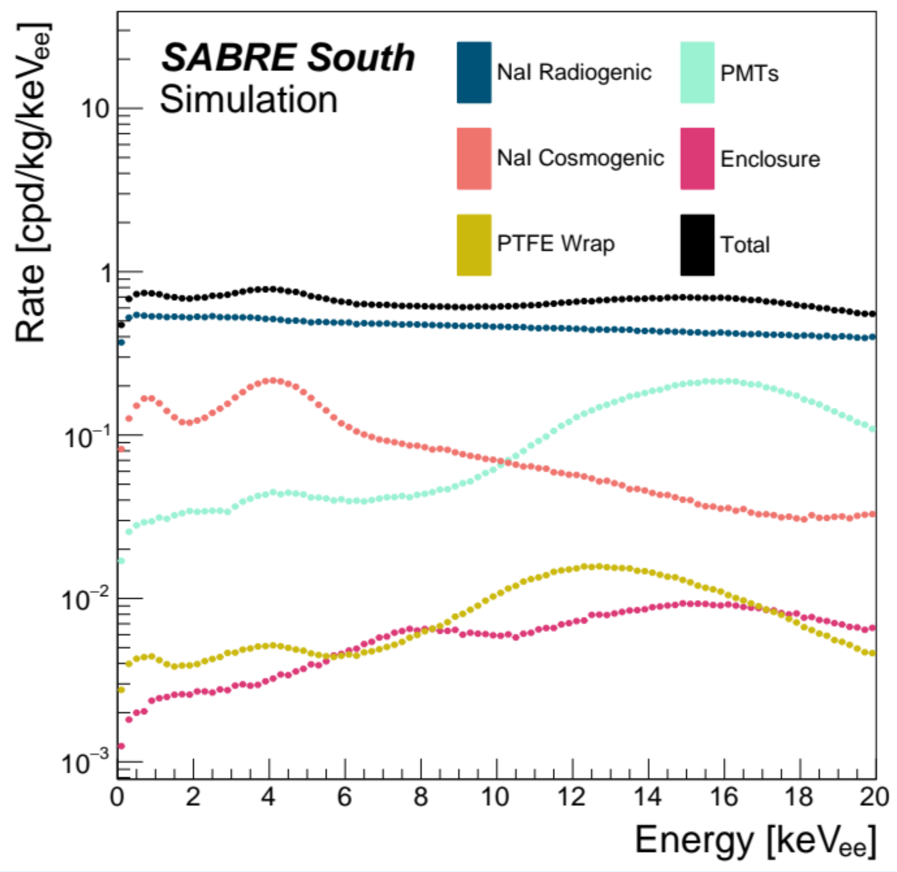
- **crystal intrinsic background** – isotopes naturally occuring in the NaI(Tl),
- **cosmogenic background** – through exposure to cosmic rays,
- **background from material radioactivity** - PMTs, crystal enclosure, PTFE.

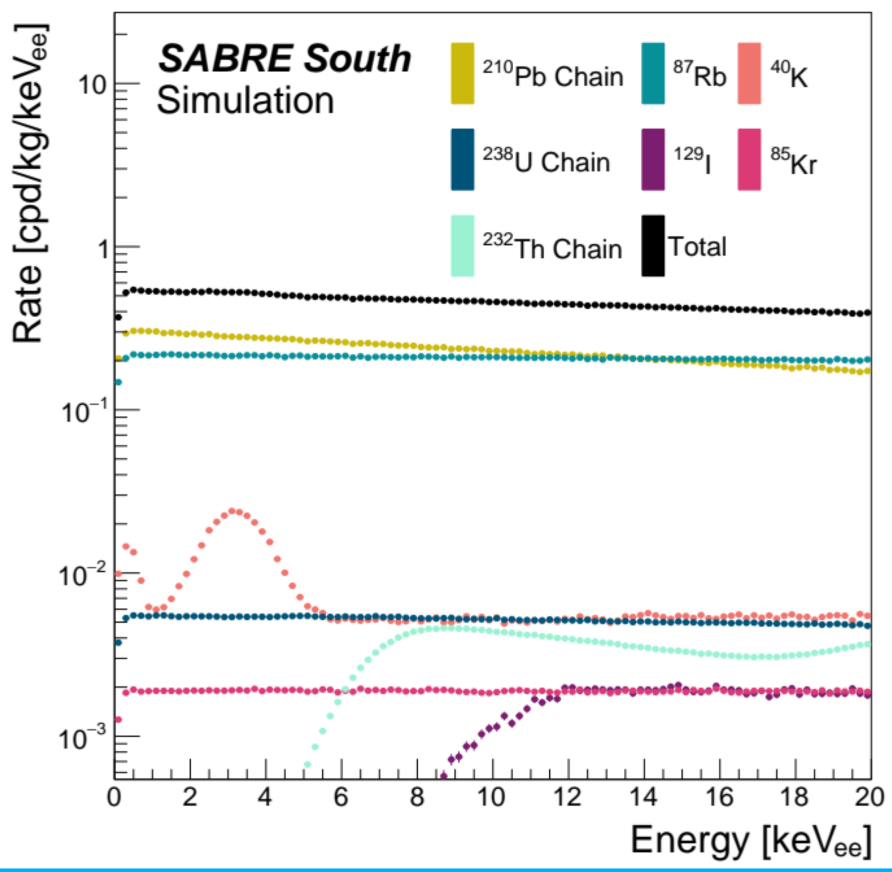
The average background in the 1-6 keV ROI for SABRE is **0.72 counts /day /kg /keV$_{ee}$**.

The activity of **radiogenic isotopes** in SABRE crystals is shown in the table on the right.

^{210}Pb and ^{40}K are the key backgrounds.

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





RADIO-IMPURITY STUDIES

Low background sets a fundamental **limit to SABRE sensitivity,** radio-impurities need to be **identified, screened, quantified and reduced.**

^{40}K – half-life of 1.25 Ga, primordial origin

SABRE South crystals are embedded in 10 tonnes of liquid veto for active background rejection → ^{40}K is **efficiently suppressed by the veto** down to $1.3 \cdot 10^{-2}$ cpd /kg /keV$_{ee}$. However, we aim to quantify the ^{40}K concentration.

^{40}K QUANTIFICATION:

Due to the low abundance of: ^{40}K (0.01%), we measure the highly abundant ^{39}K (93%) and use the well-known ^{40}K/^{39}K ratio to get the ^{40}K concentration.

The required ^{40}K concentration in the SABRE South crystals is **< 10 ppb**.

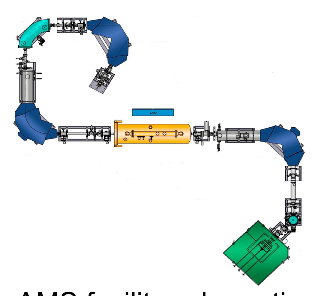
MEASUREMENT TECHNIQUES to characterize ultra-low ^{40}K :

1) **Inductively-Coupled Plasma Mass Spectrometry -** in this analytical technique, plasma is used to ionize and detect elements in a dissolved diluted sample.

2) **Super-Secondary Ion Mass Spectrometry** [3] - using solid samples allows two orders of magnitude lower sensitivity requirement as no dilution needed. Campaign started at HZDR in Germany.

We can measure potassium concentrations down to a few ppb, reaching the required level of < 10 ppb.
We are developing and improving the measurement techniques.

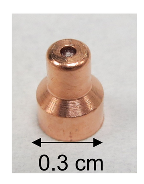
^{210}Pb – half-life of 22.2 a, naturally in environment



AMS facility schematic

^{210}Pb is the **highest radiogenic contaminator** in the crystals.

^{210}Pb atoms can be precisely counted via **accelerator mass spectrometry** (AMS) as an isotopic ratio of ^{210}Pb/^{208}Pb.



AMS sample holder

The goal is a detection sensitivity in ultra-pure NaI(Tl) powder at a **^{210}Pb specific activity of 30 µBq /kg NaI**.

The AMS system has a high selectivity and background suppression capability as it suppresses molecular background by electron stripping in the high voltage terminal of a tandem accelerator.

CHALLENGE:

There is not enough lead to produce an AMS sample after extraction from NaI(Tl) → we search for an **optimal carrier with as low ^{210}Pb content as possible.**

18th century church roof piece

Detector shielding piece

Several aged materials (centuries old) were examined. We found a material with a **^{210}Pb/^{208}Pb ratio in the order of 10^{-16}** – **We found a suitable carrier!**

We can measure ^{210}Pb/^{208}Pb down to the required 10^{-16}, two orders of magnitude lower than previously reported [4].

TAKEAWAY MESSAGES

SABRE aims to test the annual rate modulation measured by DAMA/LIBRA.

Development of radio-impurity quantification methods allowed us to **improve the radio-impurity quantification by two orders of magnitude.**

We can measure **potassium concentrations down to a few ppb** and the **^{210}Pb/^{208}Pb ratio down to 10^{-16}**.

REFERENCES and ACRONYMS

[1] R. Bernabei et al., Eur. Phys. J. C 67 (2010): 39-49
[2] E. Barberio et al., Eur. Phys. J. C 83.9 (2023): 878
[3] G. Rugel et al., Nucl. Instrum. Meth. B 532 (2022): 52-57
[4] M. B. Froehlich et al., Nucl. Instrum. Meth. B 529 (2022): 18-23

SABRE = **S**odium Iodide with **A**ctive **B**ackground **RE**jection
DAMA/LIBRA = **DA**rk **MA**tter **L**arge sodium **B**ulk **RA**re processes

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