The SABRE South Experiment at the Stawell Underground Physics Laboratory

Antoine Cools (University of Melbourne)

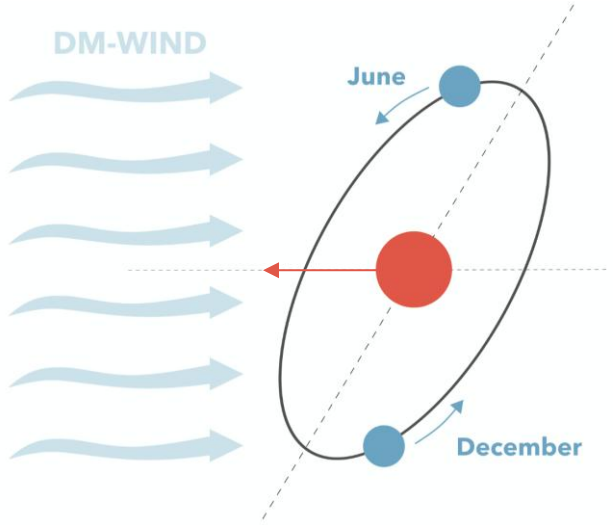
On behalf of the SABRE South collaboration

Les Rencontres de Noirmoutier 2026

MOTIVATION

Model for spherical halo of cold dark matter

Maximum DM flux on June 2nd and minimum December 2nd



DM Rate:

$$R(E) = R_0(E) + R_m \cos(\omega(t - t_0))$$

Constant DM Rate

Modulating DM rate

Rare and low energy events:

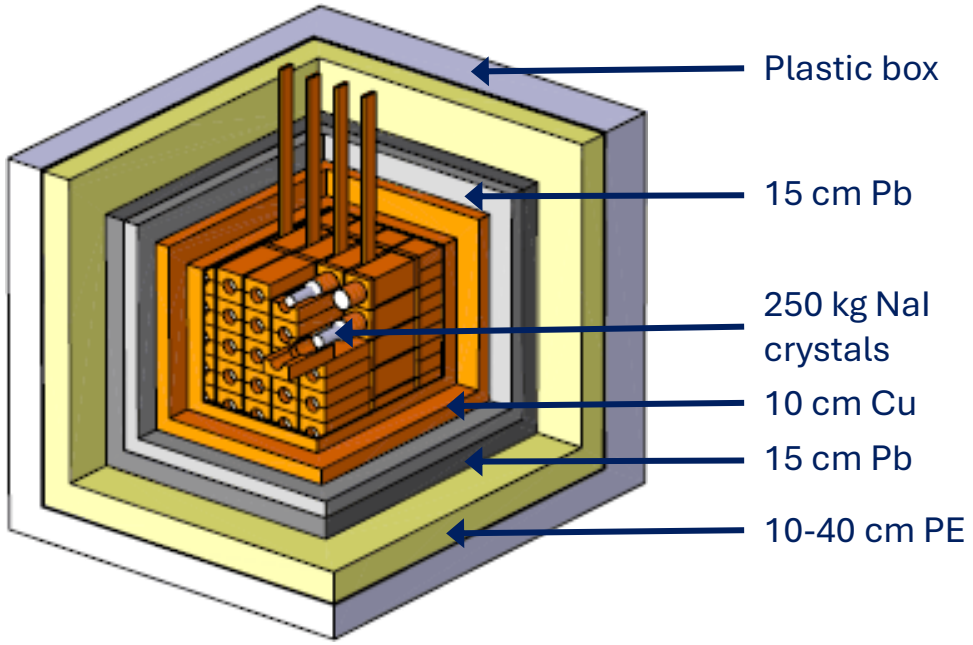
- **Very low expected rate** < 1 counts/day/kg ($R_m \approx 0.01 * R_0$)
- For GeV-scale **WIMP,** we expected a recoil energy at the **keV scale**

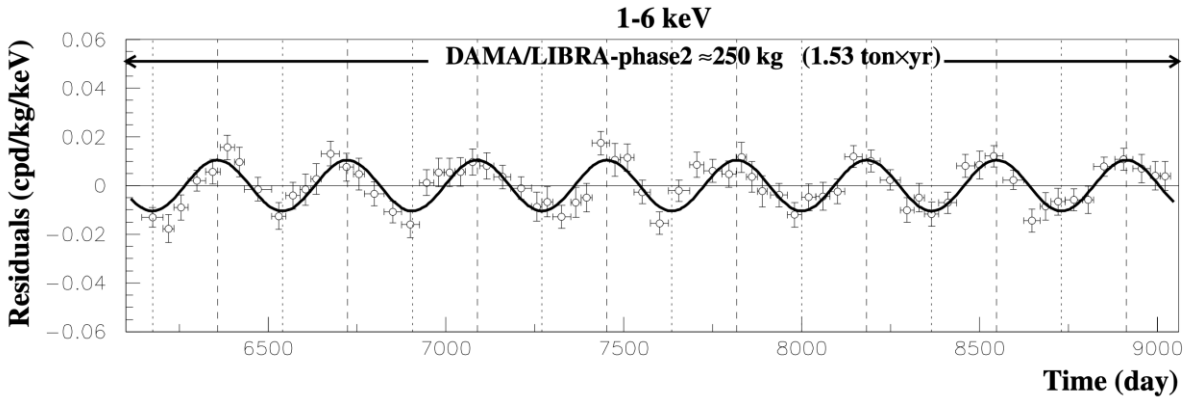
DAMA/LIBRA

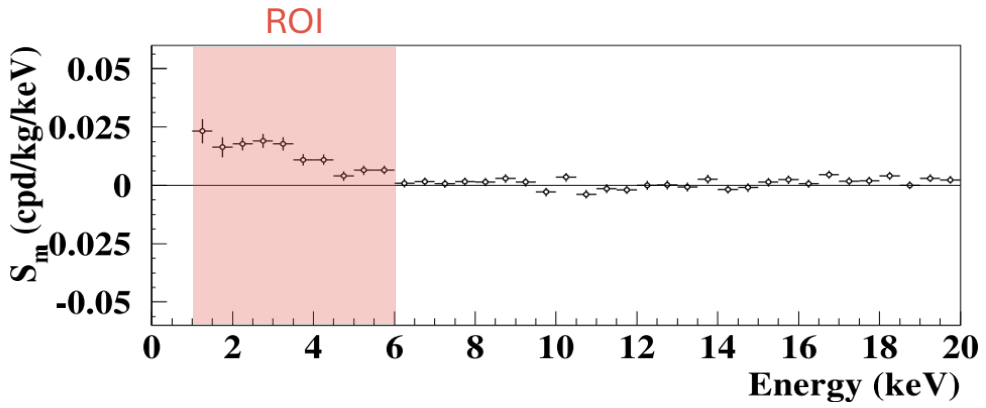
DAMA/LIBRA[1]
LNGS, Italy

Only experiment to have observed an **annual modulation signal**

- 250 kg pure NaI(Tl) crystals with passive shielding
- ~ 20 years of operation, 1 year period, peak on June 2nd
- Modulation signal of ~ 0.01 cpd/kg/keV over 1-6 keV energy region (phase II) @ 13.7 σ significance





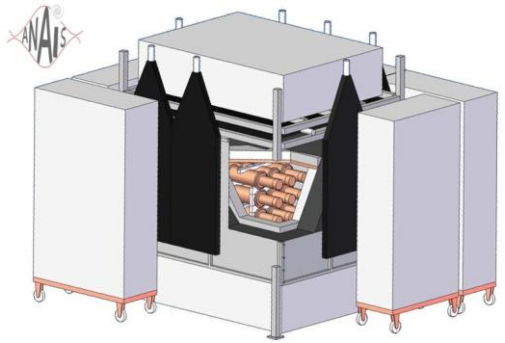


[1] R. Bernabei et al., Prog. Part. Nucl. Phys. 114 (2020) 103810

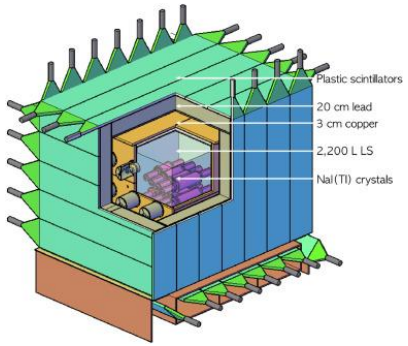
NAI EXPERIMENTS

Experiment with identical target material
to test DAMA/LIBRA

No DAMA/LIBRA's signal claimed
Uncertainties make comparison difficult

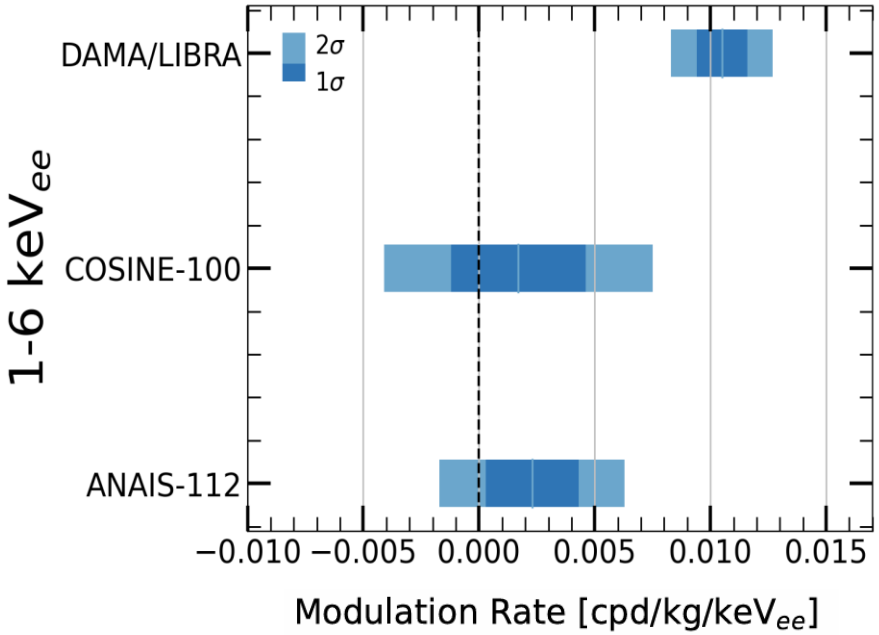


ANAIS-112
LSC, Spain



COSINE-100
Y2L, South Korea

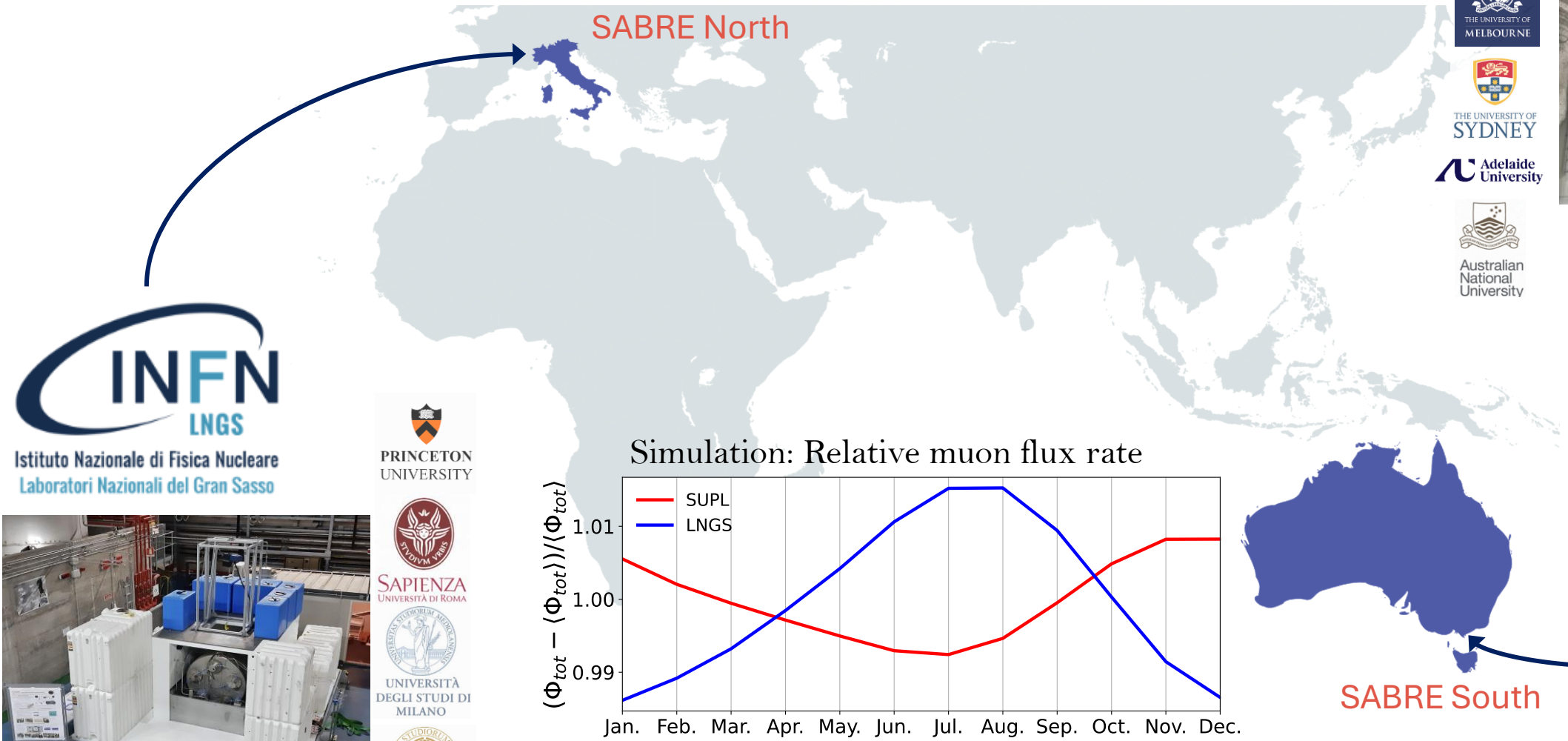
Setup	Mass (kg)	Bkg. (cpd/kg/keVee)
DAMA/LIBRA-phase2[1]	250	0.8
COSINE-100[2]	61.3	2.7
ANAIS-112[3]	112.5	3.2
SABRE[4]	49 (+ 45 = 94)	0.8

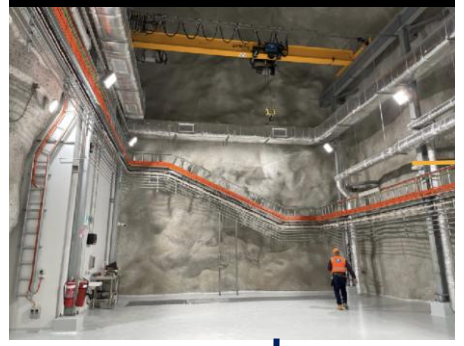


[1] R. Bernabei et al., Int. J. Mod. Phys.: Conf. Ser. 51 (2023) 2361008
[2] N. Carlin et al. [COSINE-100], Sci. Adv. 11 (2025) eadv6503, COSINE-100, PRD 106 (2022)
[3] J. Amaré et al. [ANAIS-112], Phys. Rev. Lett. 135 (2025) 051001, J. Amaré et al., EPJC 79 (2019) 412
[4] B. Suerfu et al., Phys. Rev. Research 2, 013223 (2020), M. Antonello et al., Astropart. Phys. 106 (2019) 1

SABRE (Sodium iodide with Active Background Rejection)

A DUAL SITE EXPERIMENT

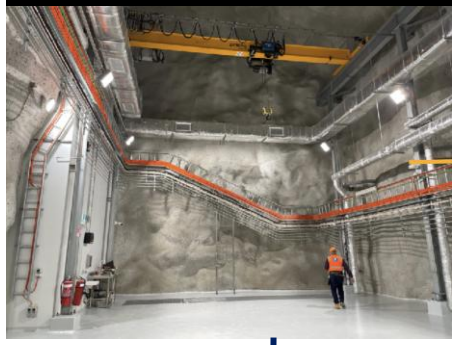




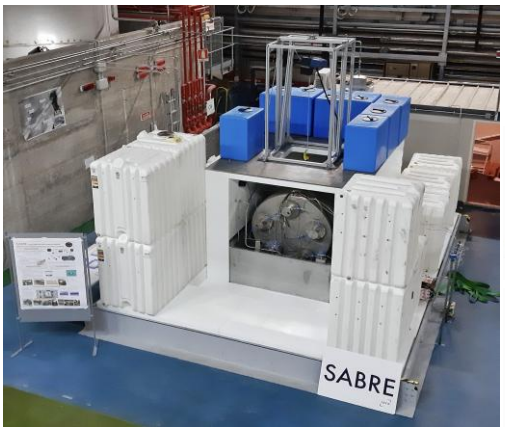
SABRE (Sodium iodide with Active Background Rejection)

A DUAL SITE EXPERIMENT

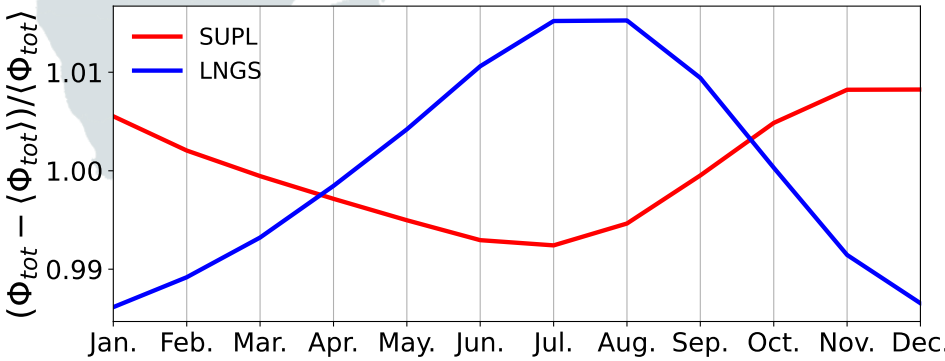
SABRE North



- Similar set-ups and R&D, SABRE North passive shielding only
- Dual hemisphere design allows for better discrimination of seasonal backgrounds



Simulation: Relative muon flux rate



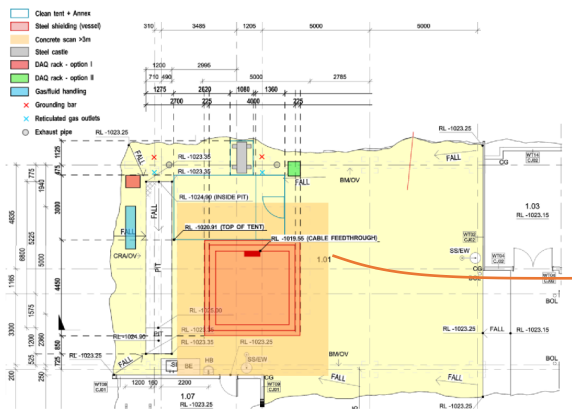
SABRE South

SUPL: Stawell Underground Physics Laboratory

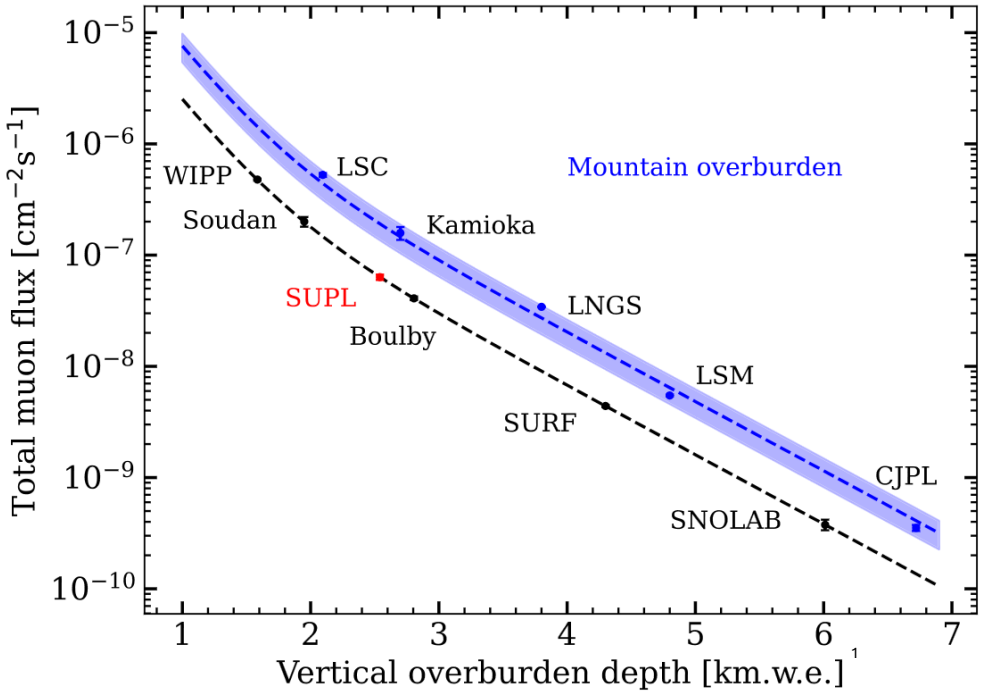
- **First deep underground lab** in the Southern Hemisphere (37° South), completed in 2023

Located 240 km west of Melbourne, Lab is **1025 m** underground (~ 2900 m w.e.), with a **flat overburden**

- Muon flux is attenuated to **10^{-6}** of the surface

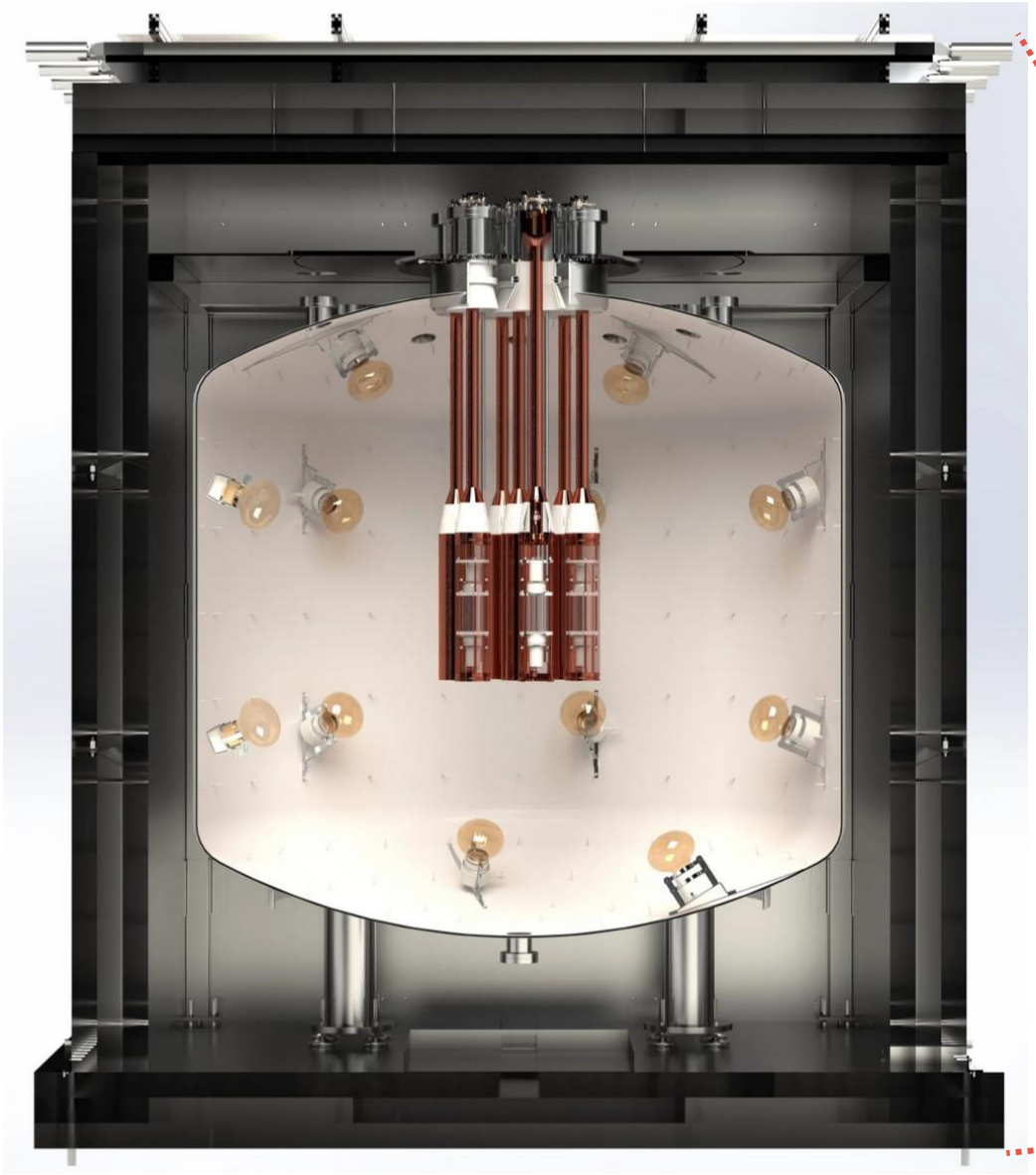


Main hall, 10 x 20 x 12 m



[1] G. Fu et al., Astropart. Phys. 179 (2026) 103240

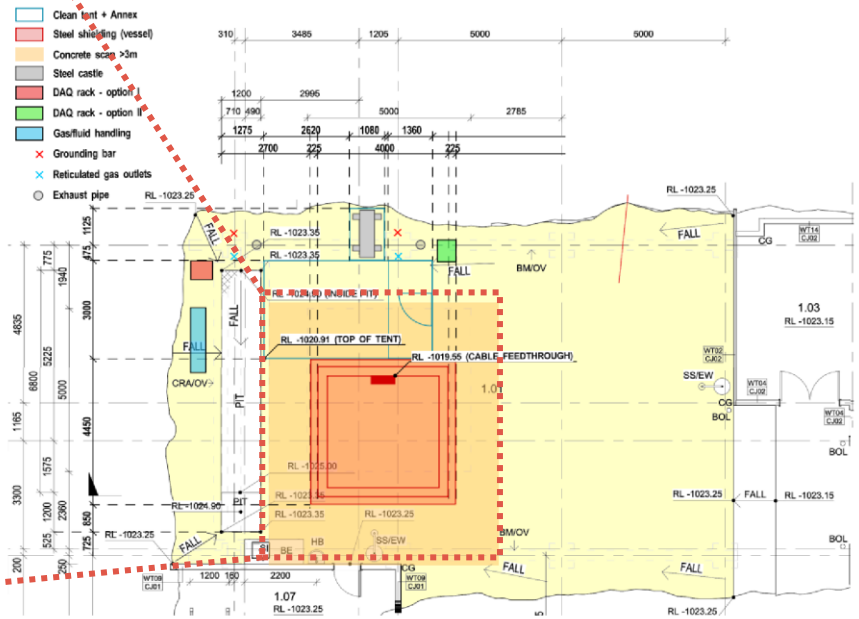
SABRE SOUTH DETECTOR



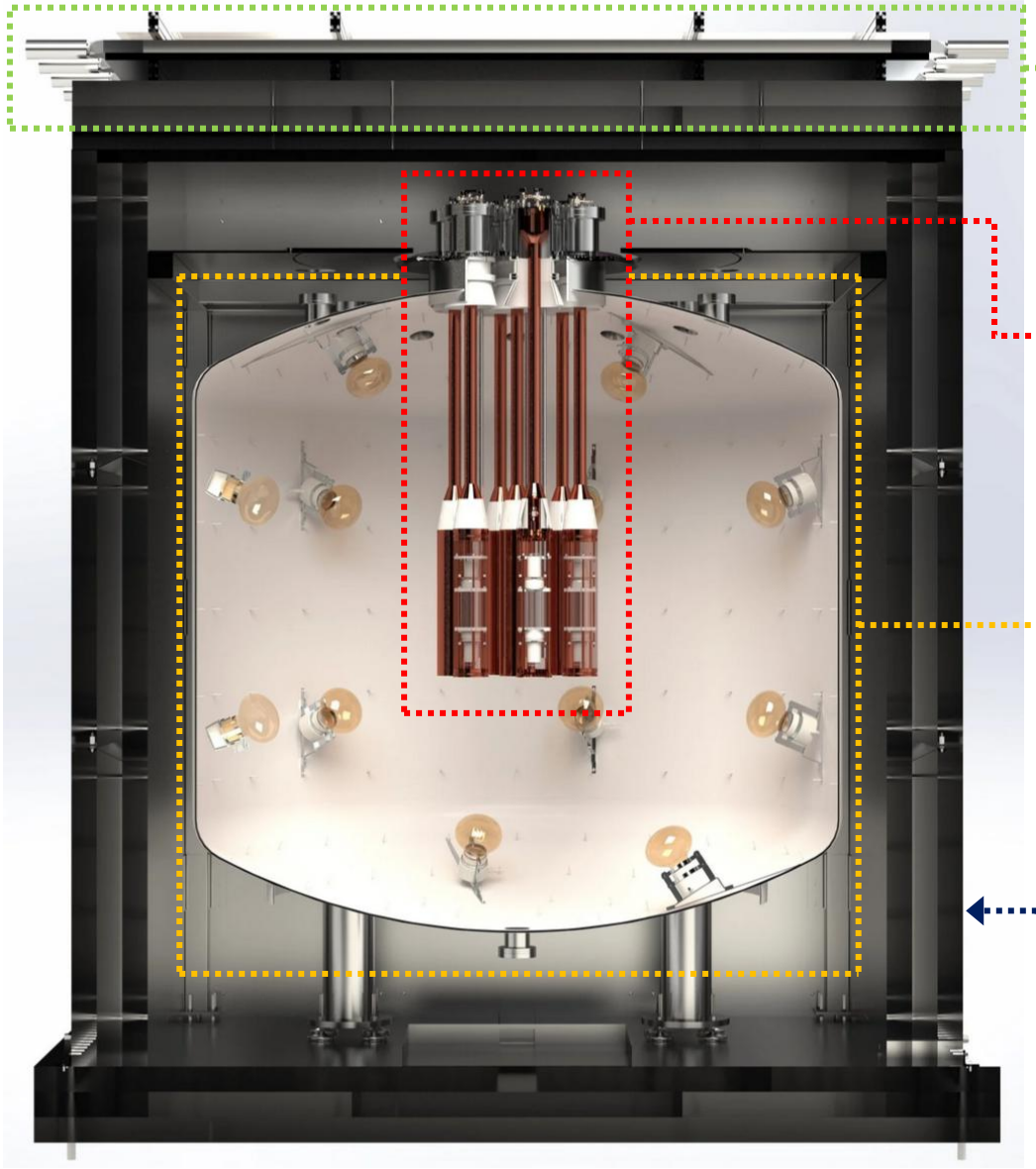
Features of SABRE South:

- **< 1 keV** energy threshold for the crystals
- Ultra **high purity** NaI(Tl) crystal
- LAB liquid scintillator for **active veto**
- **0.72 cpd/kg/keV** expected background

E. Barberio et al 2025 JINST 20 T04001



SABRE SOUTH DETECTOR



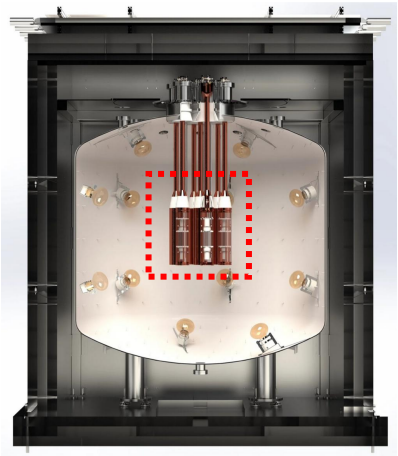
Muon System: 9.6 m^2, 8 x EJ200, 16 x R13089 PMT

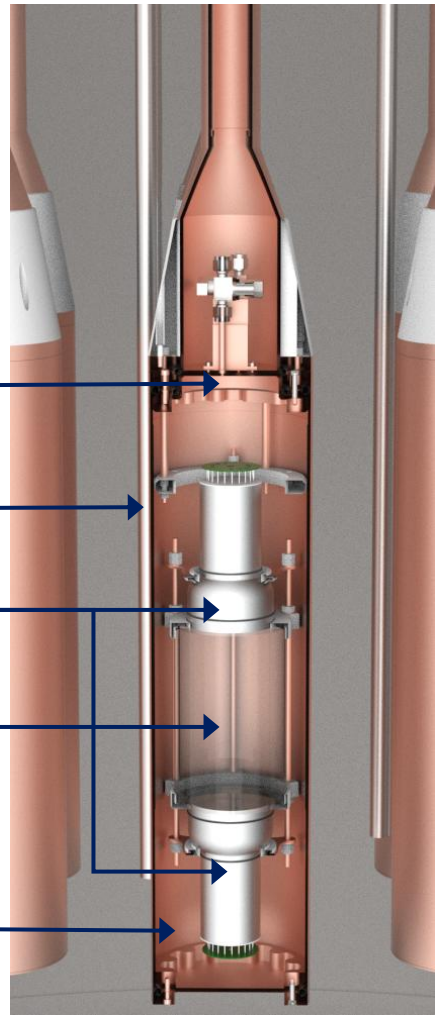
7 ultra pure NaI(Tl) Crystals in Cu enclosure
50 kg of NaI(Tl) Crystals in 7 modules
14 x R11065 low radioactivity PMT
<1 keV energy threshold for 1-6 keV ROI in NaI(Tl)

Liquid Scintillator Veto System:
12kL Linear Alkyl Benzene + PPO & Bis-MSB
Lumirror lining, Oil-proof base 32 x R5912 PMT

Passive shielding
Steel & HDPE

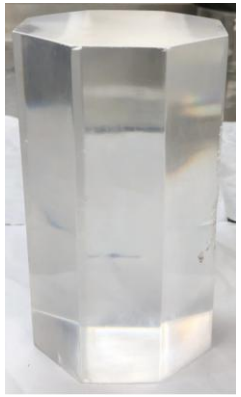
SABRE SOUTH CRYSTAL DETECTOR





Oxygen-free copper enclosure

R11065 PMT

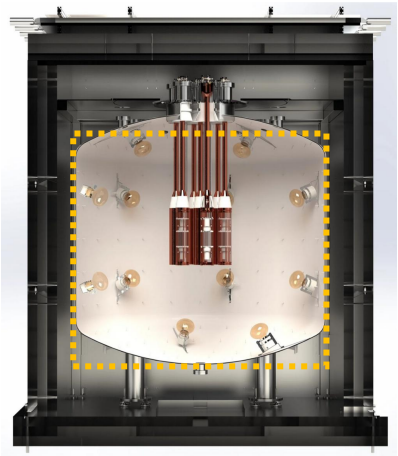


RMD NaI crystal[1]

SICCAS NaI crystal

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

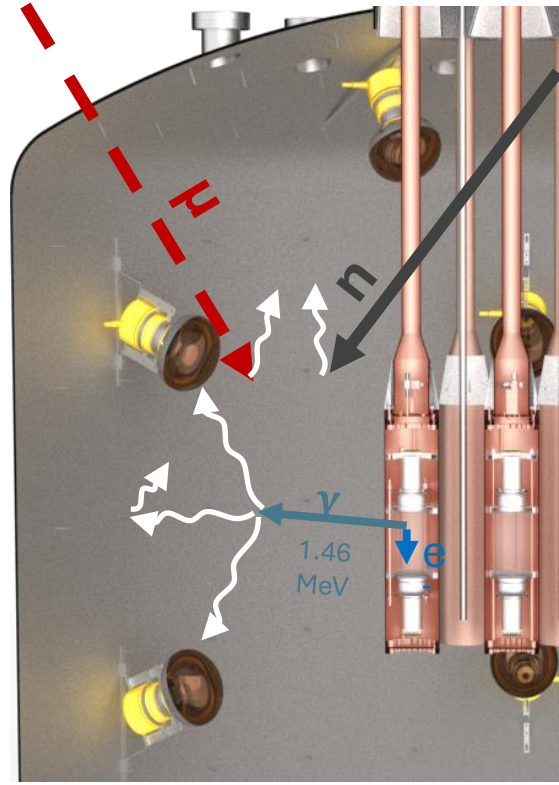
LIQUID VETO SYSTEM

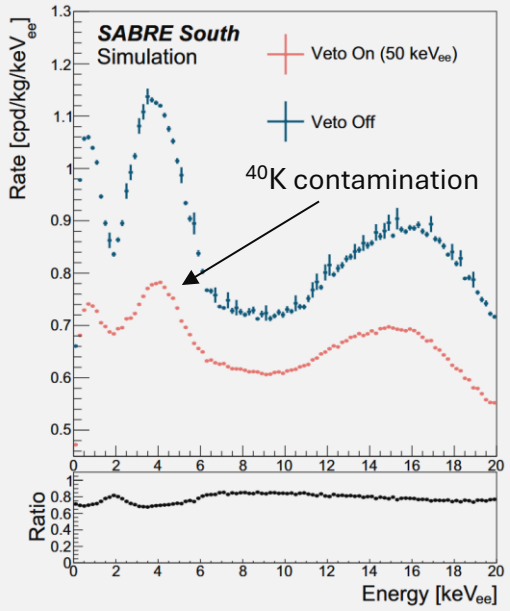


12 kL of **linear alkyl benzene (LAB)**, doped with PPO and bisMSB

LAB is coupled with **32x R5912 PMTs**

Average photo-detection efficiency of **0.75 PE/keV/PMT**





Reduces background down to **0.72 cpd/kg/keVee[1]:**

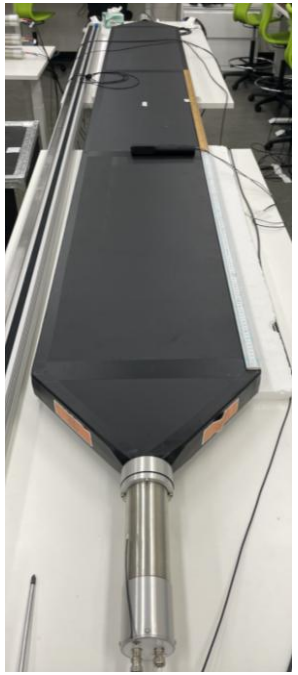
- **85% ^{40}K background reduction**
- Shielding from **external radiation background**

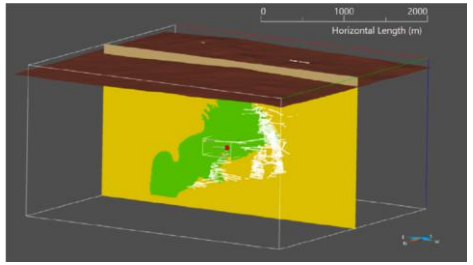
The liquid veto provides **PID:**

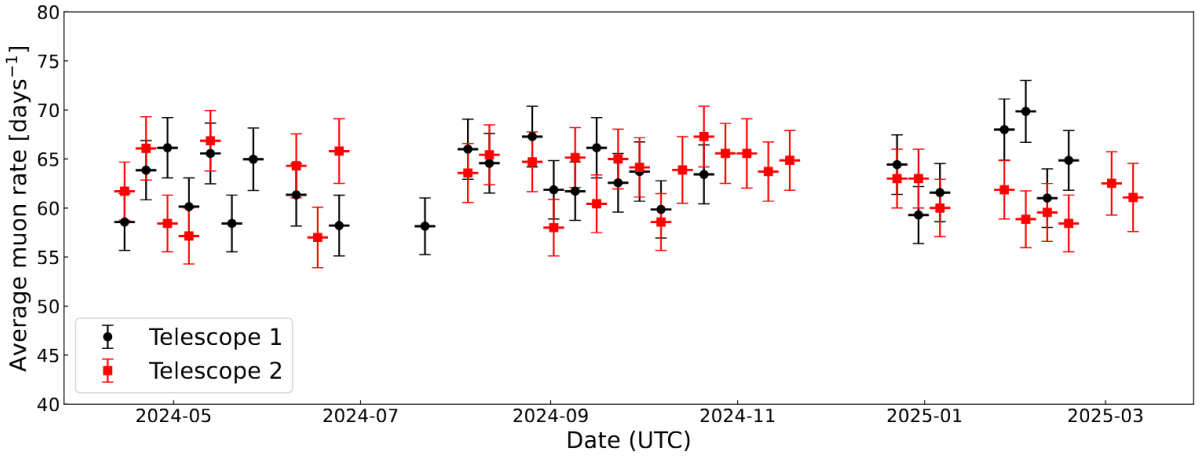
- In-situ study of background processes
- Extend our physics program

[1] Eur. Phys. J. C 83, 878 (2023)

MUON VETO SYSTEM







- **8 x panels** (EJ200 plastic scintillators with 2xPMTs)
- Provides a **9.6 m²** coverage above the SABRE vessel

Veto system for **external muon and neutrons** (induced via spallation processes)

- Measurement of the **cosmic muon flux** now **published** in Journal of Astroparticle Physics[1]
- First test of the **Muon DAQ** and **processing pipeline**
- Analysis of the muon **annual modulation** and **angular distribution** is ongoing

[1] G. Fu et al., Astropart. Phys. 179 (2026) 103240

ACHIEVEMENTS

[1] O. Stanley et al., JINST 20 (2025) P07052
[2] L.J. Milligan *JINST* 20 (2025) P07049

PMTs

Crystal PMT: Energy threshold at **<1 keV** [1]

Veto PMT: Energy threshold at **20-50 keV** [2]

Ongoing **characterization** of the **ambient noise at SUPL**

Crystals

NaI(Tl) Astrograde crystal (SICCAS) **grow** and upcoming **transport** to SUPL

12 ppb of ^{40}K measured using ICP-MS technique

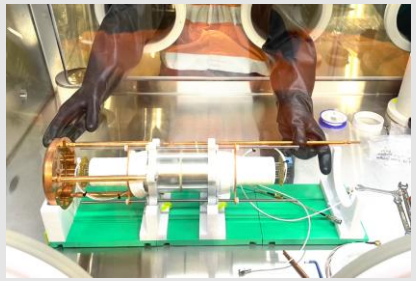
Veto vessel and shielding

Test assembly of **steel shielding** and **vessel** fit-test

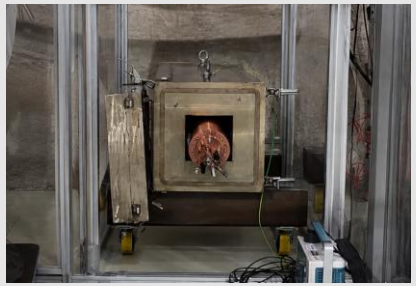
ONGOING WORK

Crystal assembly test

Preparation for the NaI **crystal assembly** in **glove box**



In-situ test of the **assembly procedure**

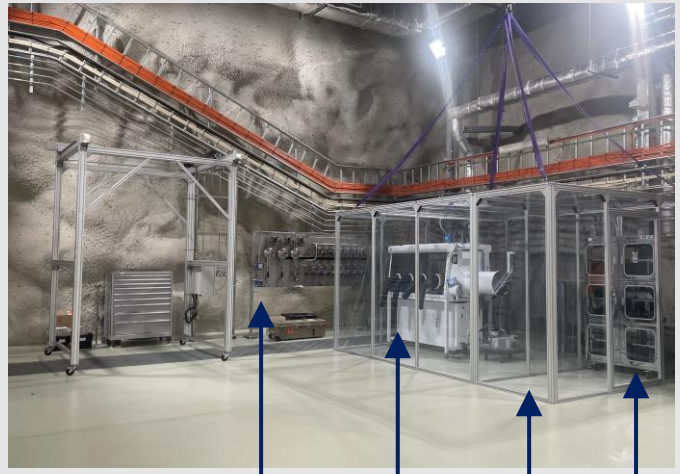


Slow Control and conditions

Monitoring of **conditions** at SUPL in operation

Gas handling system control

Infrastructure



Glove box

Gas handling system

Clean tent

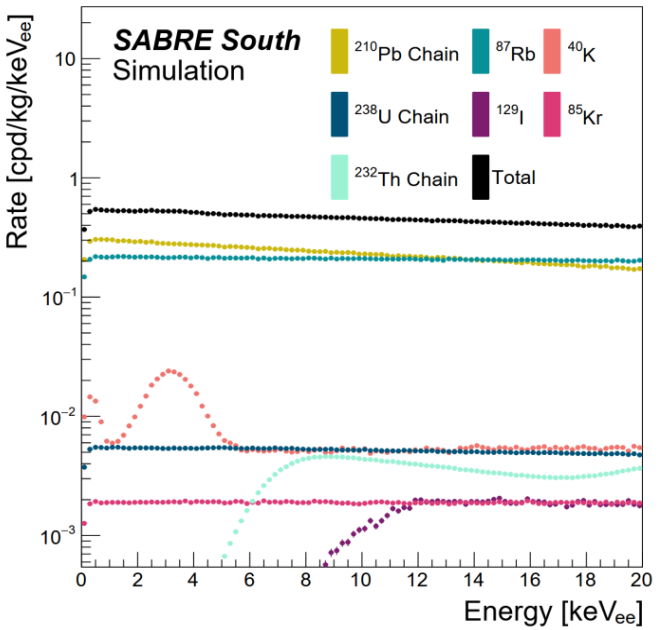
Low humidity cabinet

SABRE SOUTH BACKGROUND

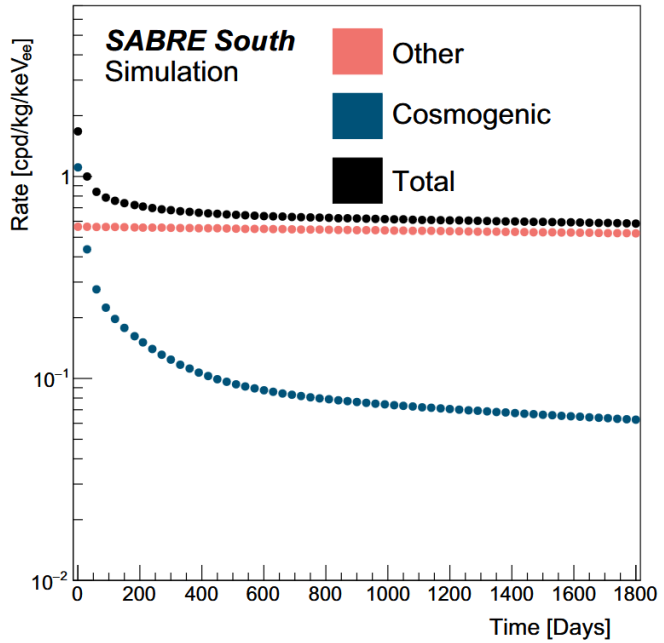
Assuming **6-month cooldown**, expected SABRE South **background**:

- **0.72** cpd/kg/keV$_{ee}$ (1 - 6 keV$_{ee}$)
- Dominated by ^{210}Pb, ^{87}Rb and ^{40}K

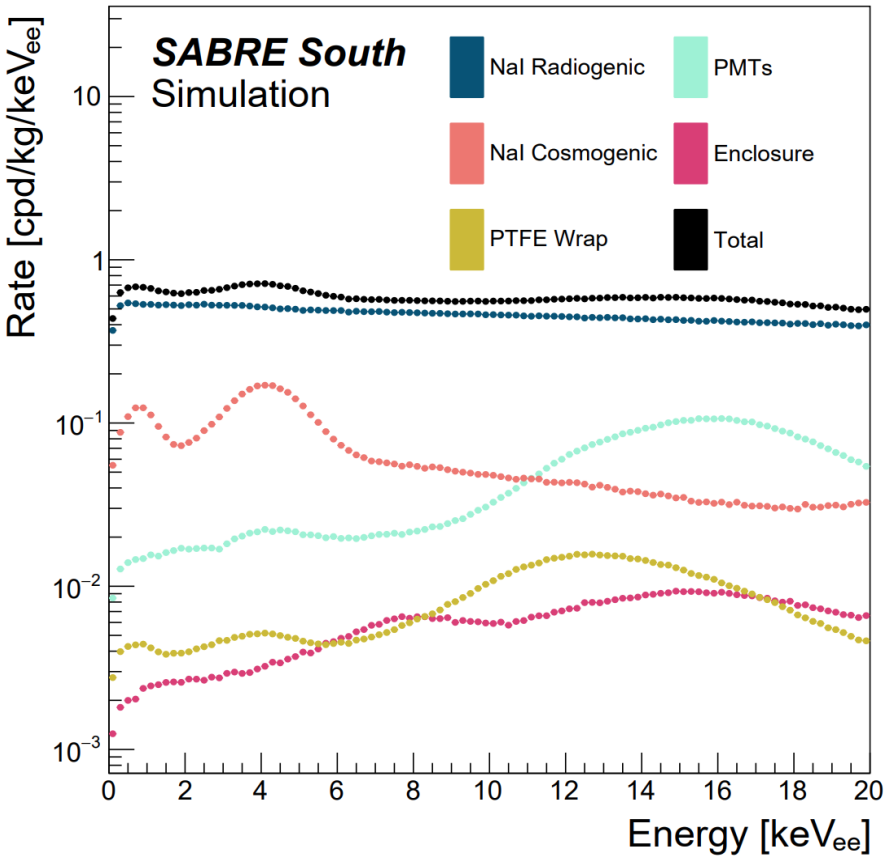
Radiogenic background



Time-dependent background



SABRE South background



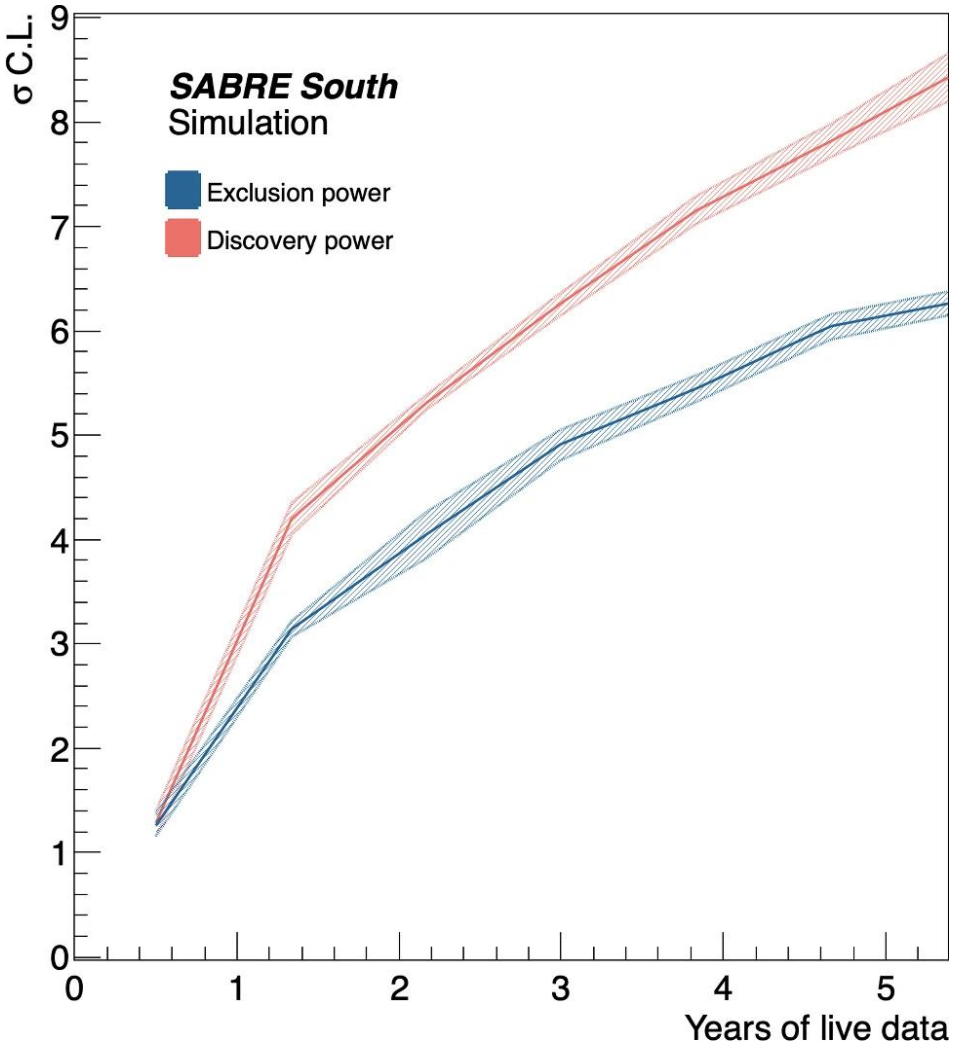
Eur. Phys. J. C 83, 878 (2023)
Eur. Phys. J. C 82, 1122 (2022)

SABRE SOUTH ANNUAL MODULATION SENSITIVITY

SABRE South expects:

- 5σ **exclusion** in **~3 years**
- 5σ **discovery** in **~2 years**

Of data collection for a DAMA/LIBRA-like modulation signal



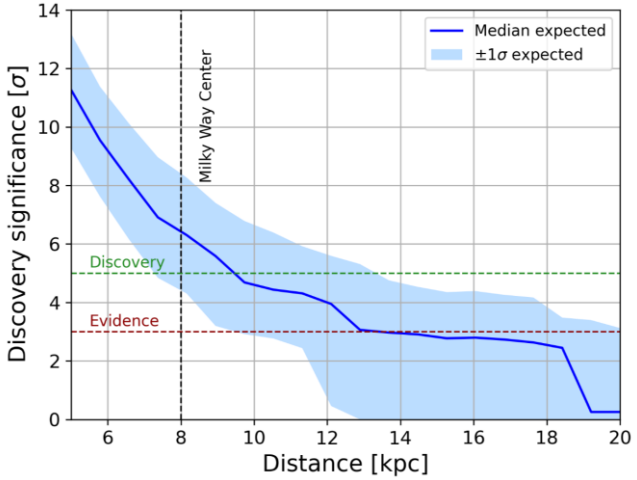
Eur. Phys. J. C 83, 878 (2023)
Eur. Phys. J. C 82, 1122 (2022)

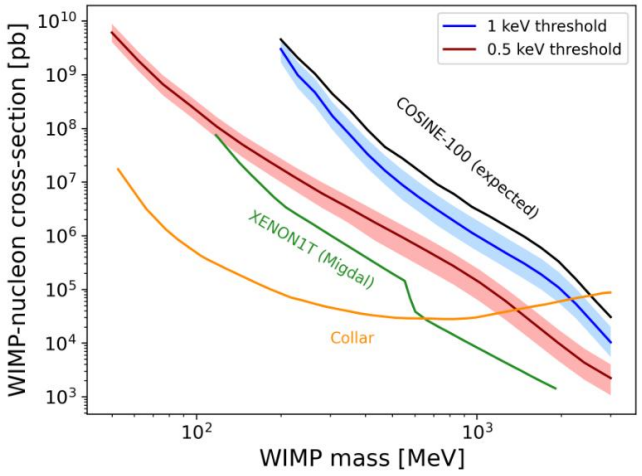
FURTHER EXPENDING THE PHYSICS PROGRAM

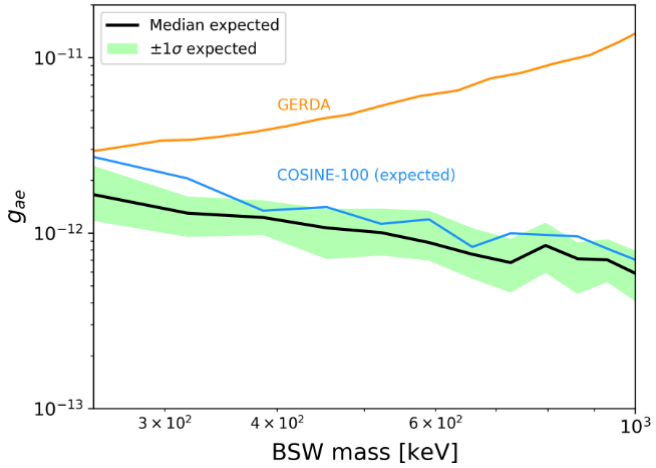
Supernova neutrinos
Sensitivity to core-collapse supernovae out to ~8 kpc (Milky Way centre) via the liquid scintillator veto

Migdal sensitivity studies
Sub-GeV WIMP reach via electron emission

Bosonic super-WIMPs
Competitive limits on BSW-electron coupling g_{ae} across 300–1000 keV mass range

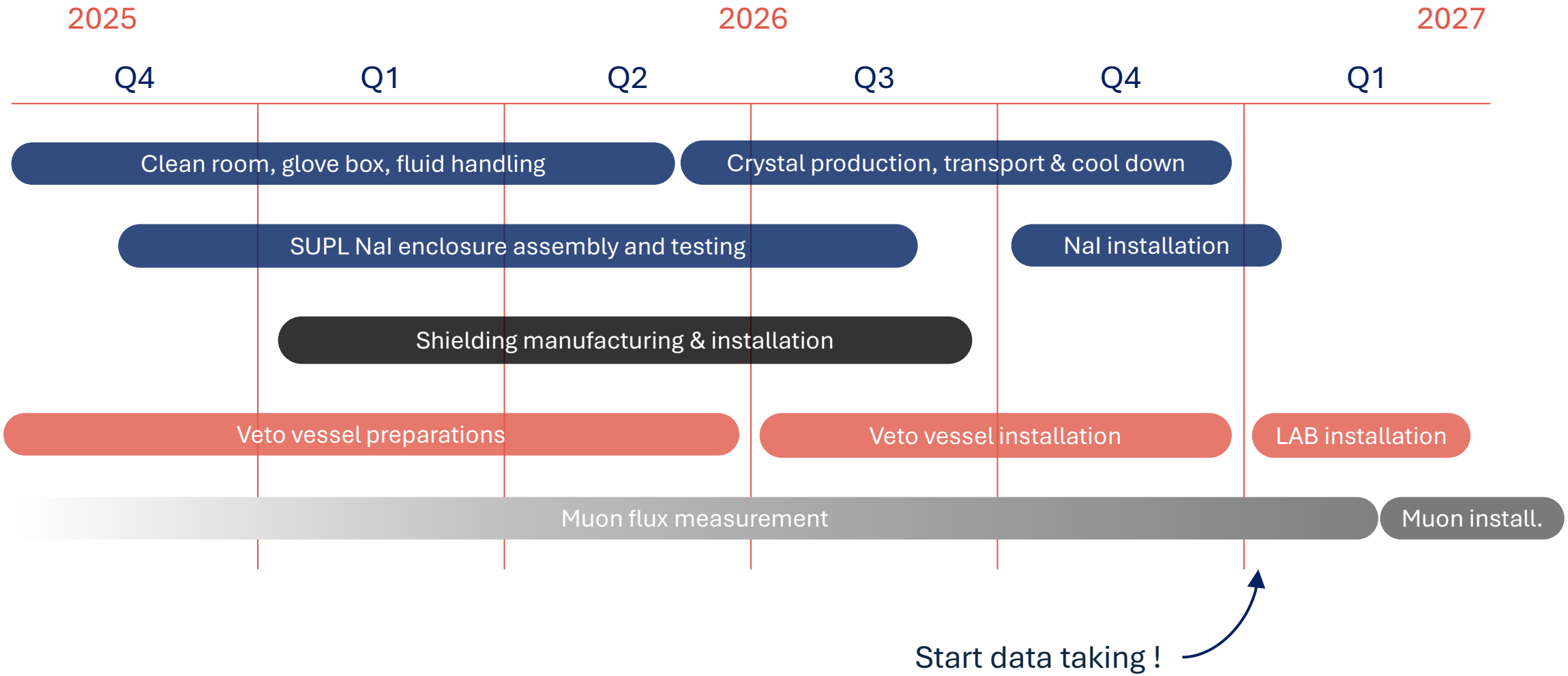






P. Urquijo et al., 2024, DOI: 10.26188/14618172.v3

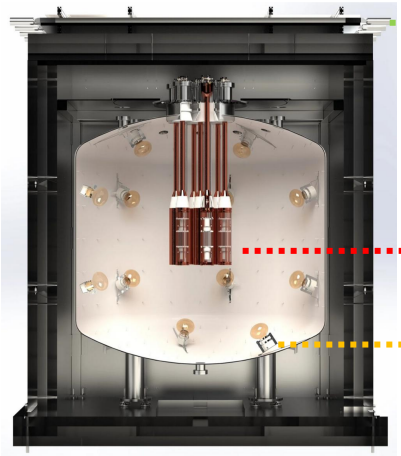
TIMELINE AND OUTLOOK



Thank you !

Back up

SABRE South DAQ and conditions



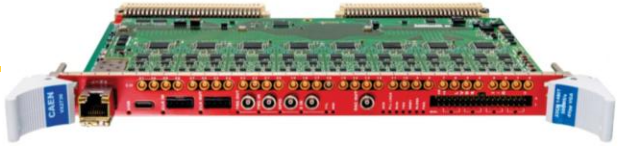
Muon veto system
1 x **V1743**
16-channel, 3.2 GS/s, 12-bit ADC

Crystal detector
2 x **V1730**
8-channel, 500 MS/s, 14-bit ADC

Logic Unit
V2495

Calibration system
V1730

Liquid veto system
1 x **V2730**
32-channel, 500 MS/s, 14-bit ADC



Data online processing

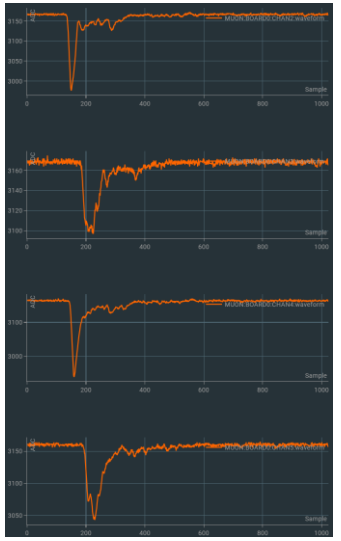
Conditions sensors

EPICS

Run Control

DAQ

Monitoring



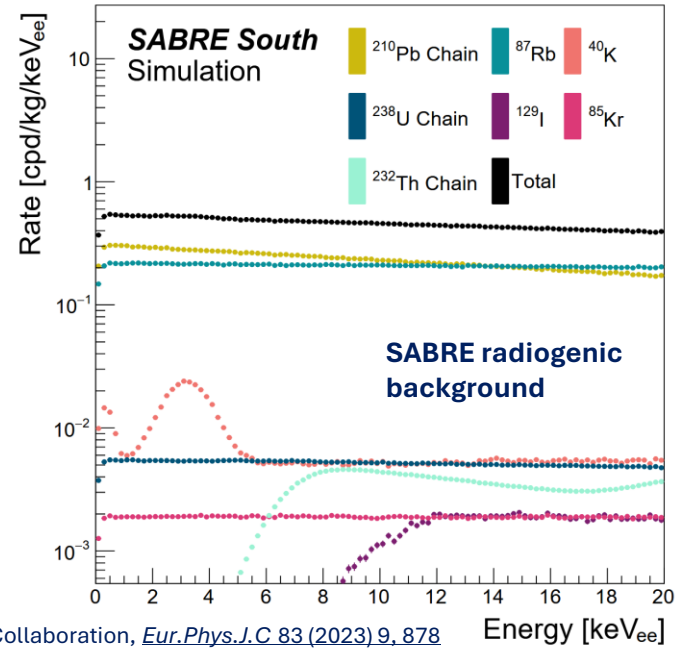
Run Control: REACT

Monitoring: Grafana

SABRE South crystal characterisation

The SABRE NaI(Tl) crystals are grown from Astrograde powder, by RMD & Princeton and SICCAS

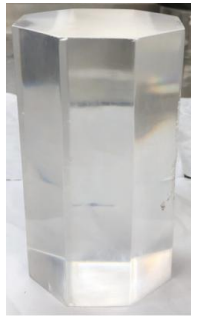
- Crystal growth on-going
- 4 crystals from RMD has been characterized



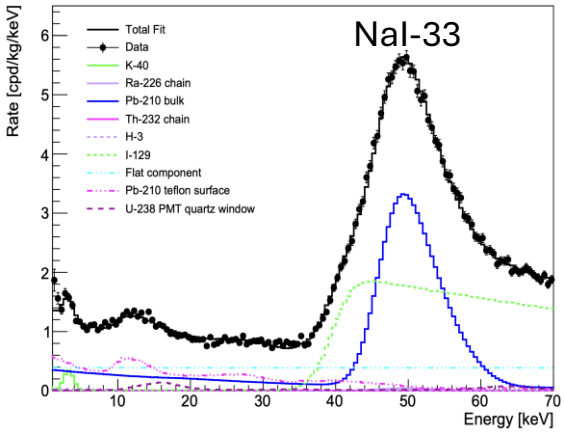
SABRE Collaboration, *Eur.Phys.J.C* 83 (2023) 9, 878

[1] R. Bernabei et al., NIMA 592(3) (2008)
[2] J. Amare et al., EPJC 79 412(2019)
[3] P. Adhikari et al., Phys. Rev. Lett. 123, 0.31302 (2019)
[4] B. Suerfu et al., Phys. Rev. Research 2, 013223 (2020)

Crystal	^{nat}K (ppb)	^{238}U (ppt)	^{210}Pb (mBq/kg)	^{232}Th (ppt)	Active Mass (kg)
DAMA [1]	13	0.7-1.0	(5-30)x10^{-3}	0.5-7.5	250
ANAIS [2]	31	<0.81	1.5	0.36	112
COSINE [3]	35.1	<0.12	1-1.7	<2.4	~60
SABRE [4]	12	0.4	0.49	0.2	49 (+ 45 = 94)



NaI-33

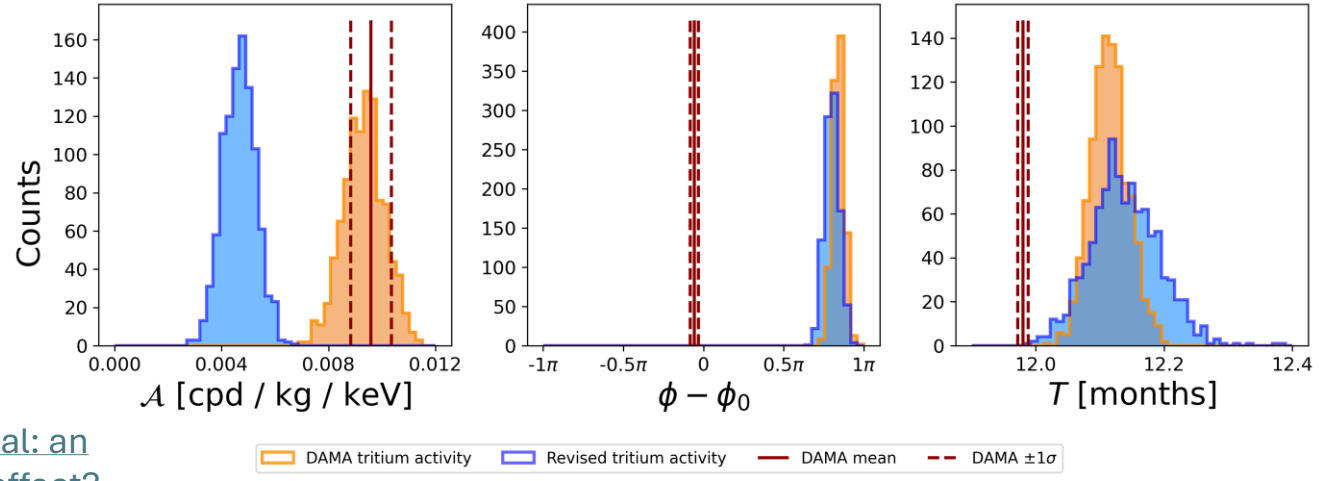


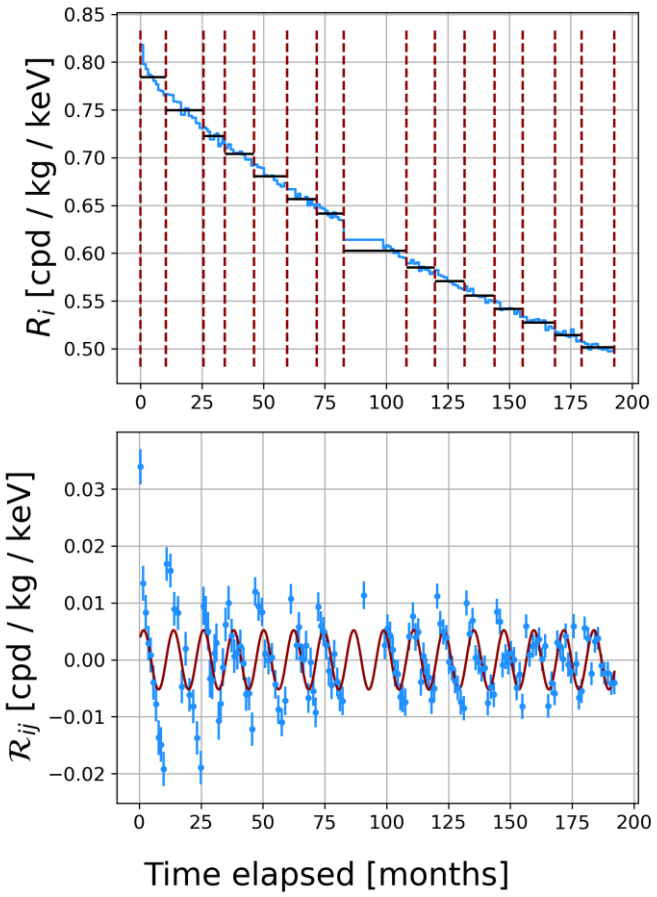
A.Mariani., Status and prospects of SABRE North

The DAMA/LIBRA signal: An induced modulation ?

- DAMA/LIBRA analysis relied on subtracting average rate over approximately annual cycles to calculate 'residuals'
- There are claims that this procedure can induce a modulation effect consistent with their signal in the presence of a decaying background rate
- Whilst the amplitude could be consistent if the levels of ^{3}H (0.09 mBq/kg) and ^{210}Pb reflected their reported upper limits, **the phase is opposite**
- A **re-assessment** of the likely ^{3}H background (0.031 mBq/kg) shows that even the **amplitude** would be **inconsistent**

$$R_{ij} = R_i - \langle R_i \rangle_j$$





The DAMA/LIBRA signal: an induced modulation effect?

The SABRE Collaboration

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

- Will use the same crystal growth powder and crystal PMTs (HPK R11065)
- Will share simulation, DAQ and software frameworks
- Exchange of engineering knowledge: collaborative agreements between INFN and ARC Centre of Excellence for Dark Matter Particle Physics

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

- Phase-out of organic scintillators at LNGS → SABRE North will use fully passive shielding. Will achieve required low background levels through zone refining process
- SABRE South will use LAB liquid scintillator for active background rejection → less stringent requirements on crystal background levels

SABRE South Techincal design report

Further expanding the physics programme

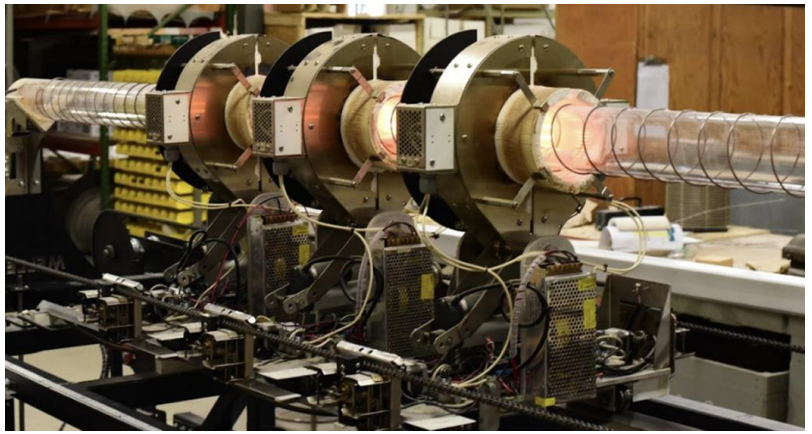
Supernova neutrinos	Sensitivity to core-collapse supernovae out to ~8 kpc (Milky Way centre) via the liquid scintillator veto
Bosonic super-WIMPs	Competitive limits on BSW-electron coupling gae across 300–1000 keV mass range
Migdal sensitivity studies	Sub-GeV WIMP reach via electron emission (see full TDR)

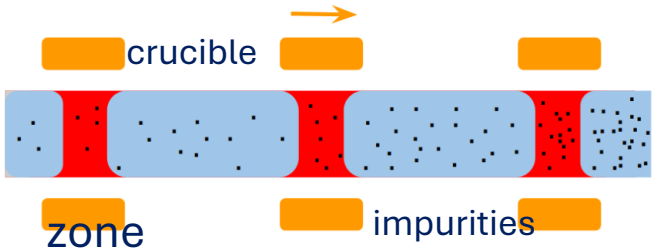
Model	**Comments**
Boosted DM (inelastic and elastic)	MeV-scale signal: multiple-scatter in the inelastic case. Certain parameter values would enable exploration of unprobed dark photon parameter space
Solar axions	Bragg-Primakoff photoconversion in crystal lattice
Pauli Exclusion Principle violation	Search for exotic nuclear transitions that would only be allowed given a small level of PEP violation. Direct muon hits dominant background, muon veto will aid this search
Upscattered MIDM	Currently has no direct experimental constraints – signal from upscattering of MIDM in the Earth's crust, then a decay into a photon in the detector volume. Scales with volume not mass, so promising channel via the LS veto

Zone Refining

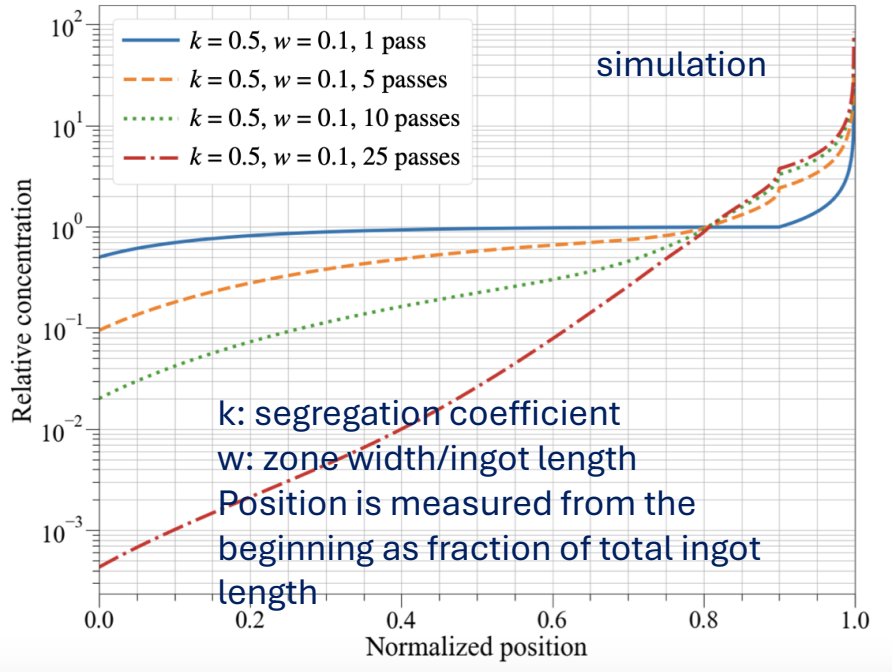
Working with SABRE North, RMD, Princeton University, MELLEN to use zone refining to further purify ultrahigh-purity NaI powder

- A zone is melted and moved across the ingot in the same direction.
- As the zone is moved, newly formed crystal has less impurities than the molten liquid.
- This process is repeated multiple times so that the impurities are pushed towards the end.
- Suitable for ~ 100 kg powder
- Th doping after zone refining





Isotope	Impurity concentration (ppb)					
	Sample location (mm)					
	Powder	7 ± 7	325 ± 9	492 ± 10	635 ± 20	783 ± 30
^{39}K	7.5	< 0.8	< 0.8	1.0 ± 0.3	16 ± 1	460±6
^{85}Rb	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.7±0.1
^{208}Pb	1.0	0.40±0.03	0.40±0.03	< 0.4	0.50±0.03	0.50±0.03
^{65}Cu	7	<2	<2	<2	2.0±0.5	620±11
^{133}Cs	44	0.30±0.01	0.20±0.01	0.50±0.02	23.30±0.05	760±1
^{138}Ba	9	0.10±0.01	0.20±0.01	1.40±0.04	19.0±0.1	330.0±0.6



Suerfu B et al . Phys Rev (2021) 16:014060.

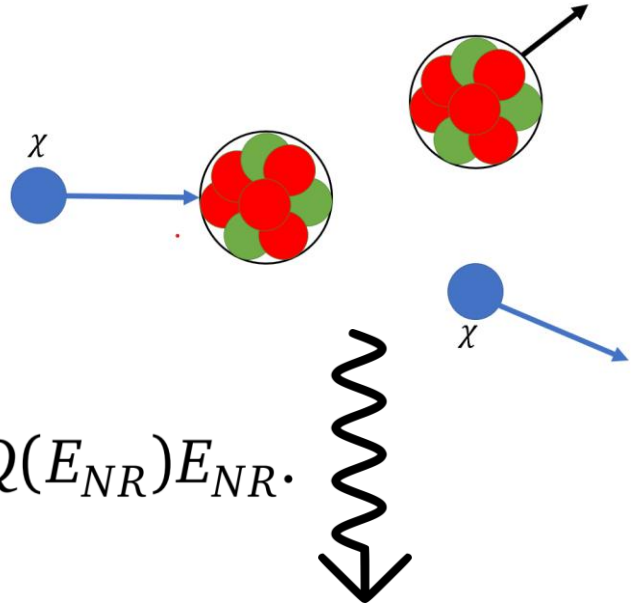
Interaction Mechanism

Search for nuclear recoils of WIMP of Na/I nuclei

Properties of dark matter imply low energy (keV) scatters

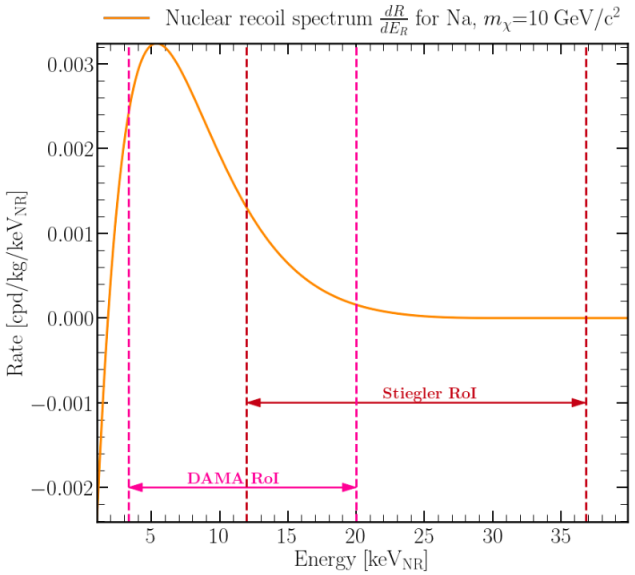
Observable: scintillation light in crystal

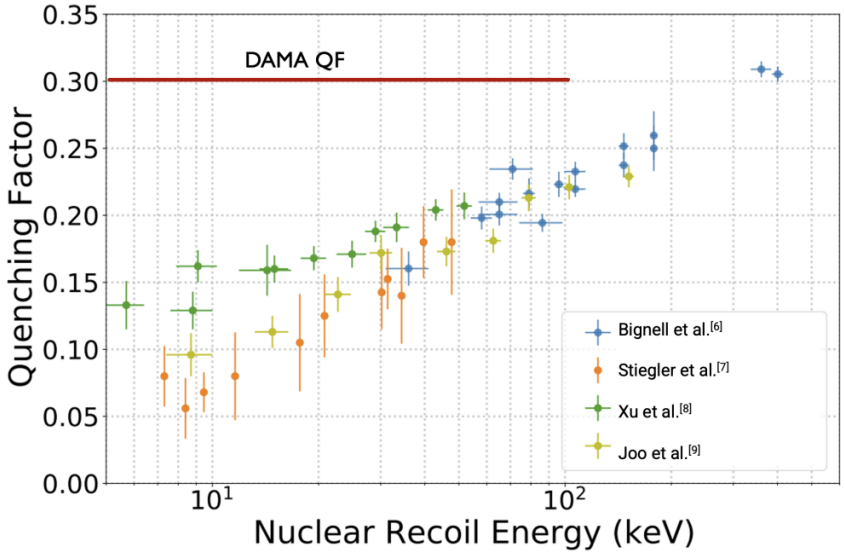
Reconstruction of recoil energy -> understanding of quenching factor

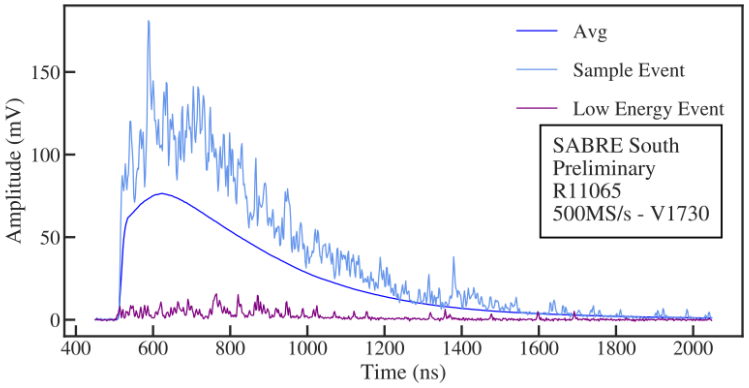


$$E_{ee} = Q(E_{NR})E_{NR}.$$

M. J. Zurowski, arXiv: 2211.15861

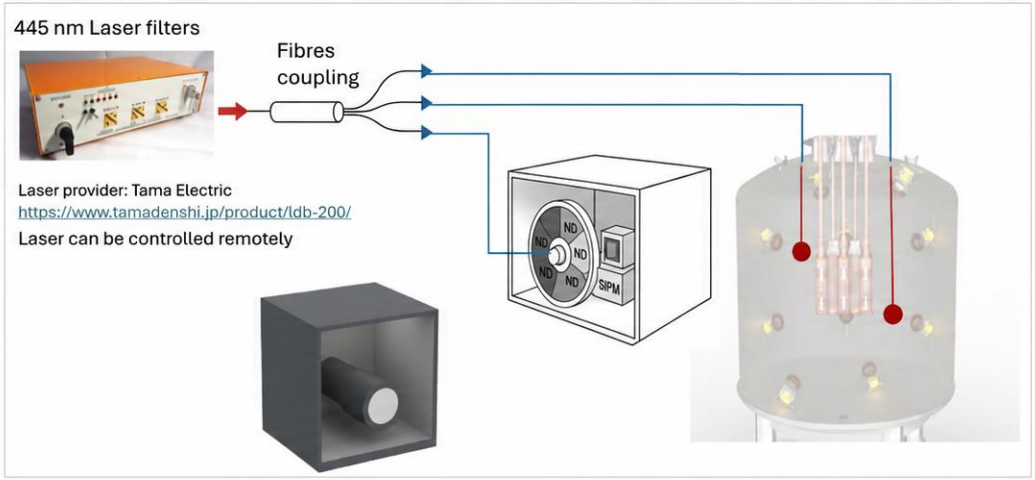






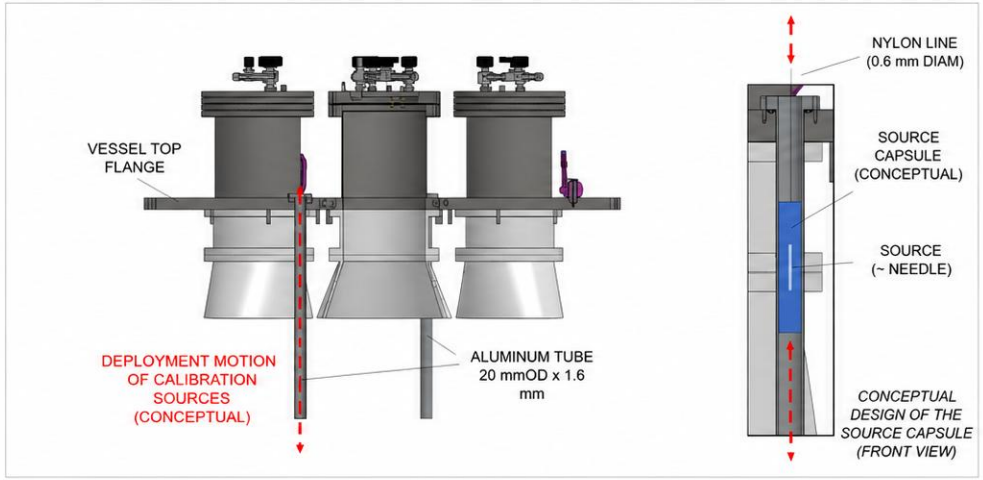
CALIBRATION SYSTEMS

Optical Calibration



Full in-situ optical calibration system with laser balls permanently lowered into LAB on optical fibres.
Successfully tested and procurement is ongoing.

Radioactive Calibration



Automatic deployment of various sources into the vessel for calibration of veto and crystal modules.
Available sources: 137Cs, 207Bi, 22Na, 133Ba, 241Am and 109Cd