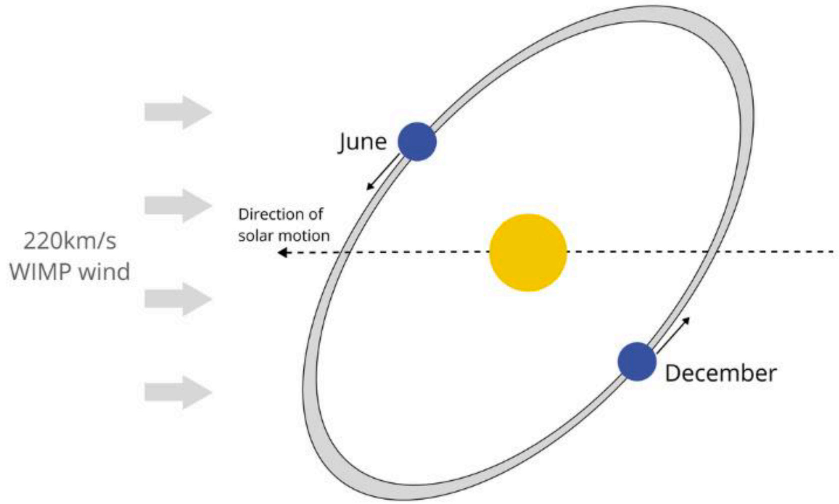
SABRE South Status

Elisabetta Barberio
The University of Melbourne

WIMP Wind Modulation Signal



Period of 1 year, peaking June 2nd (t_0=152.5 days)

Rare and low energy events

Rate < 1 count/day/kg (few % of which modulates)

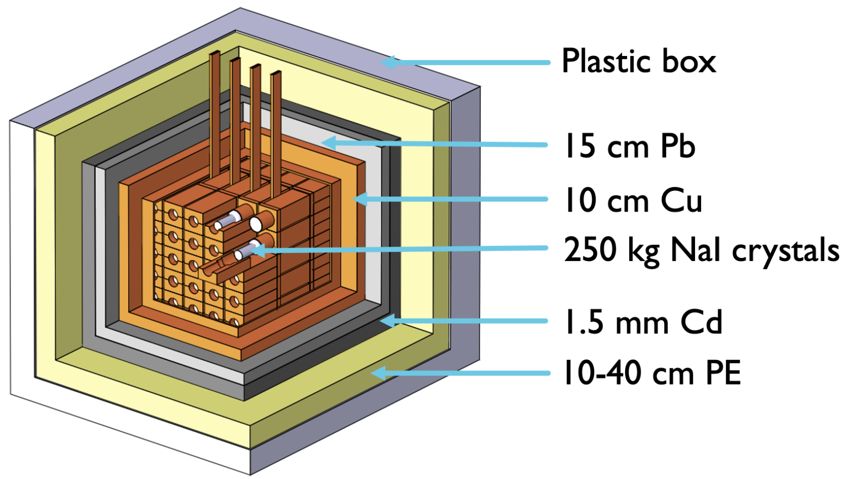
$$R(t) = B + R_0 + \boxed{R_m \cos(\omega(t - t_0))}$$

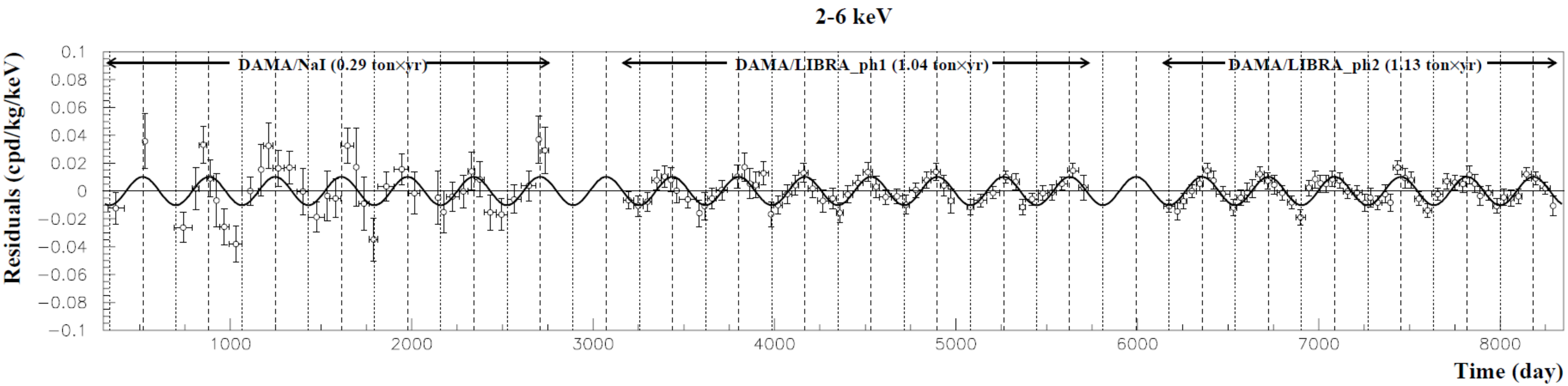
Modulating component ~ 2-10% of R(t)

Expect very low modulation amplitude ~0.01 cpd/kg/keV

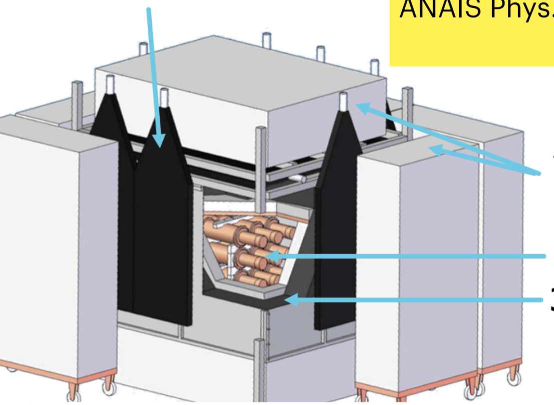
Results from DAMA/LIBRA

- ~20 years of operations: 12.8 σ CL significance
- Period: (0.998±0.002) y
- Phase: (145±5) days (2-6 keV) and (145±7) (1-3 keV)
- Amplitude: (0.0103±0.0008) cdp/kg/keV
- Observed annual modulation ~ 0.01 cpd/kg/keV (dru) in ROI [1,6]keV

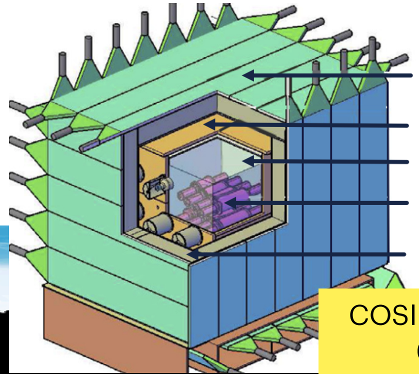




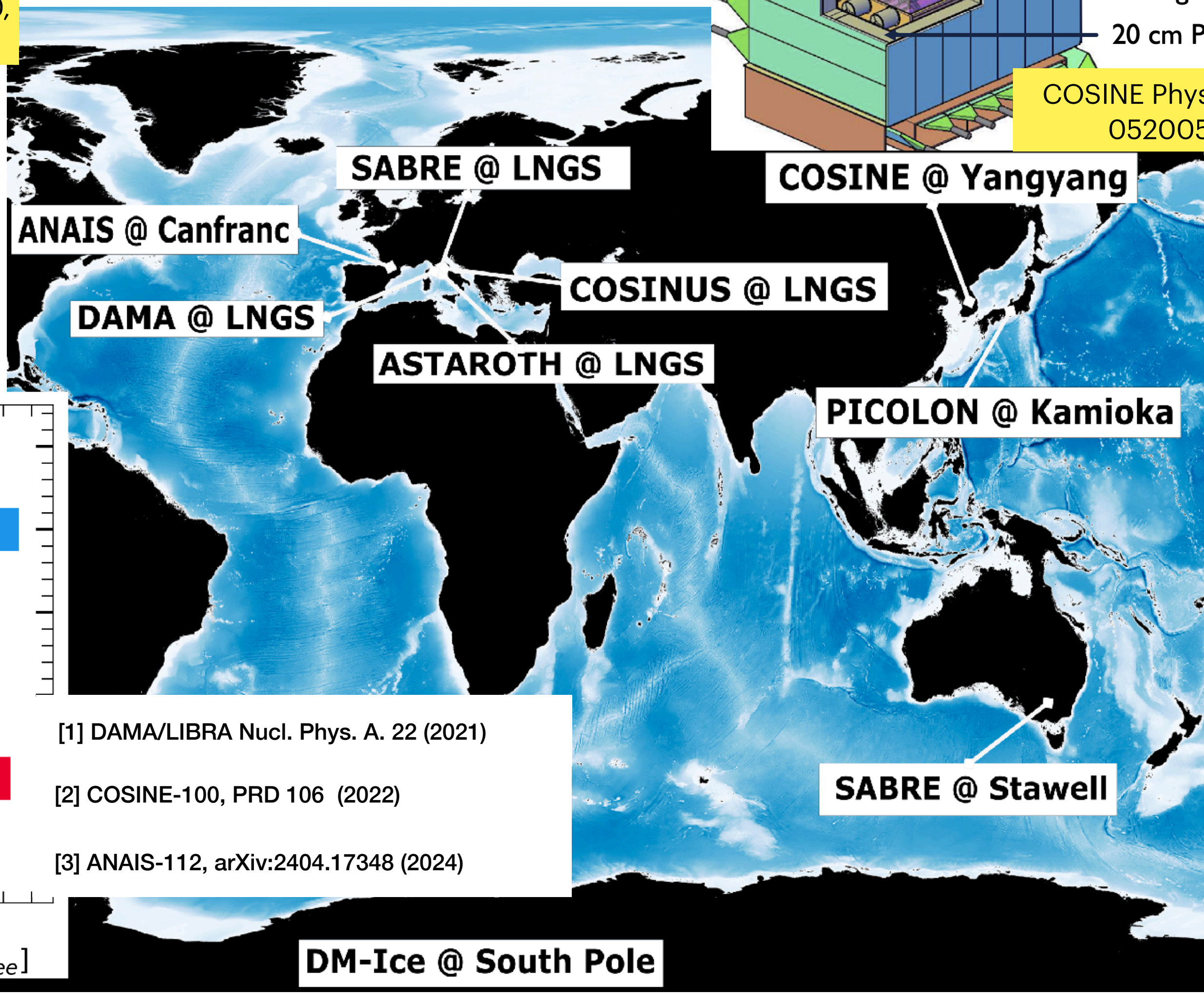
NaI Experimental Landscape

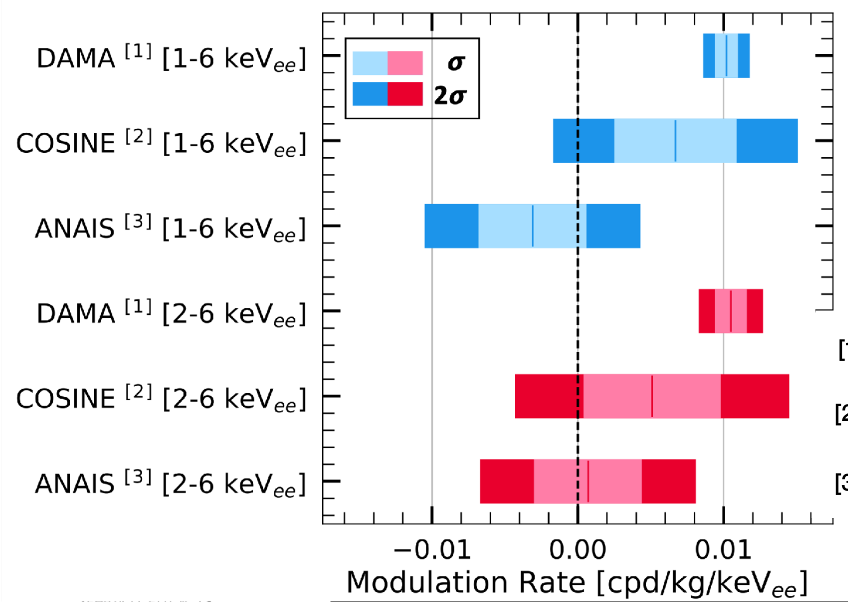


ANAIS Phys.Rev.D 103 (2021) 10, 102005



COSINE Phys. Rev. D 106, 052005 (2022)



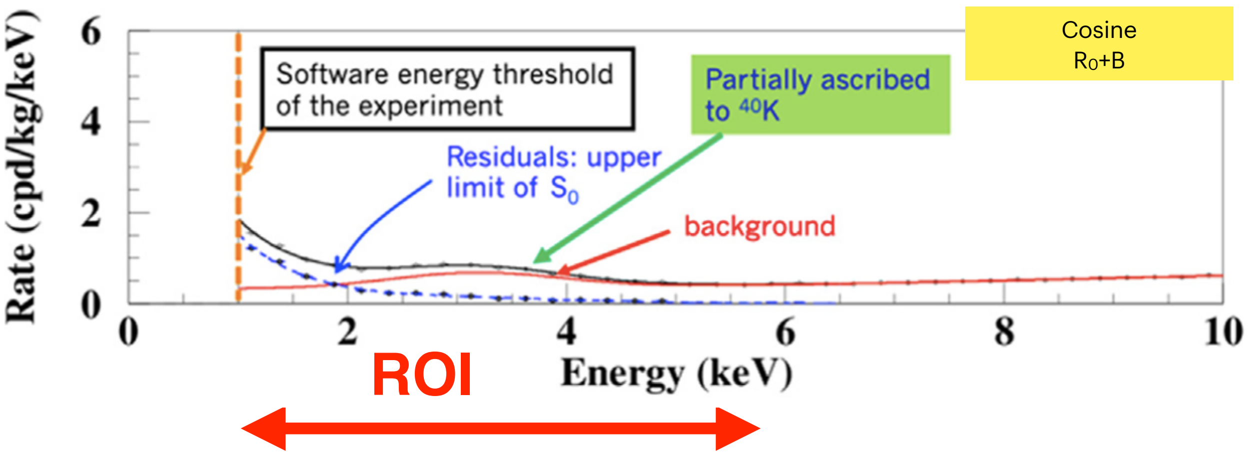


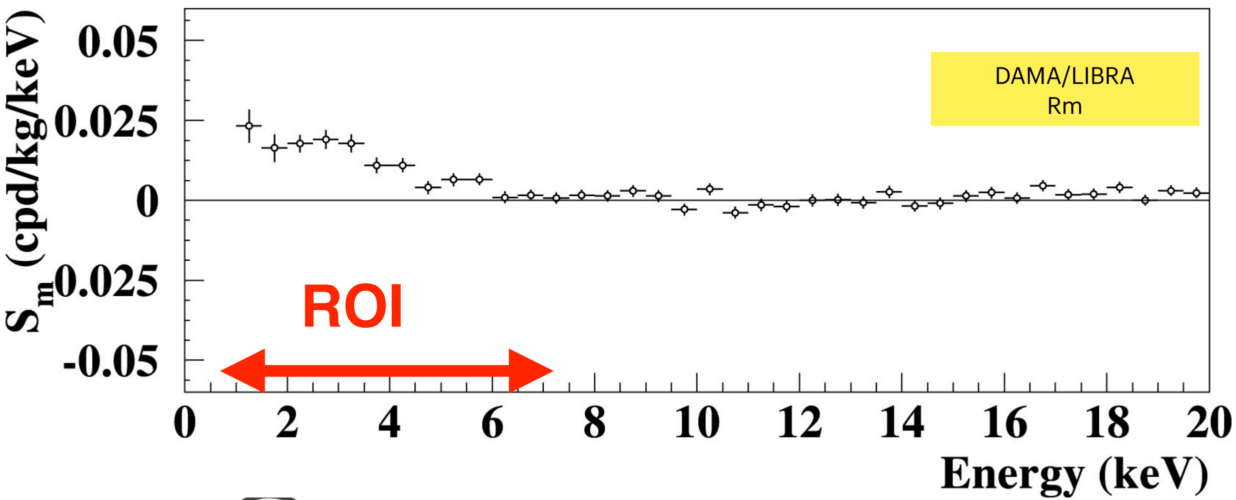
[1] DAMA/LIBRA Nucl. Phys. A. 22 (2021)

[2] COSINE-100, PRD 106 (2022)

[3] ANAIS-112, arXiv:2404.17348 (2024)

Conclusive Test of DAMA/LIBRA



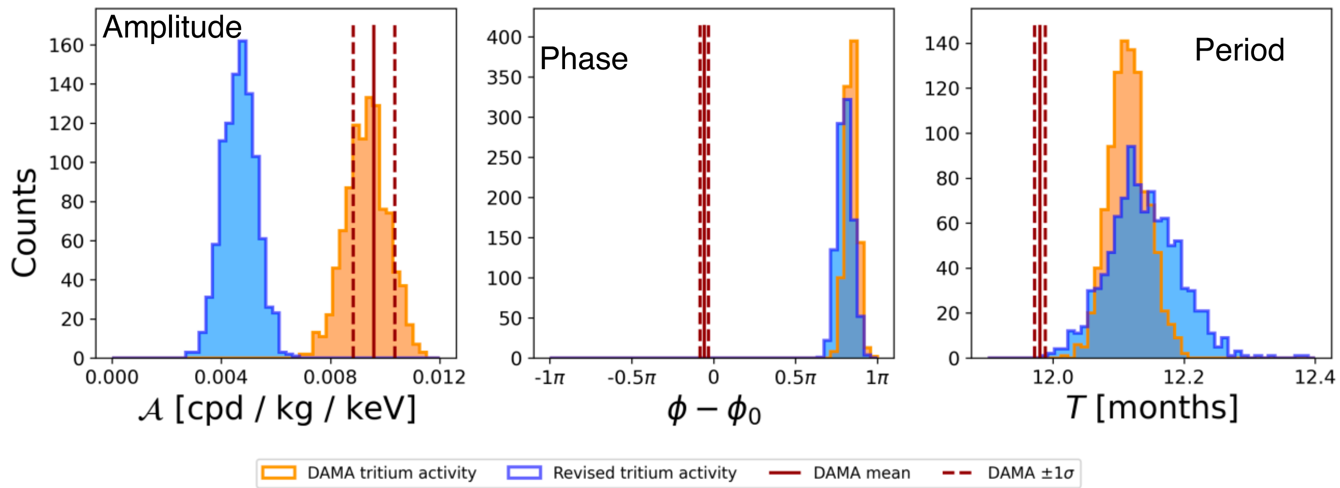


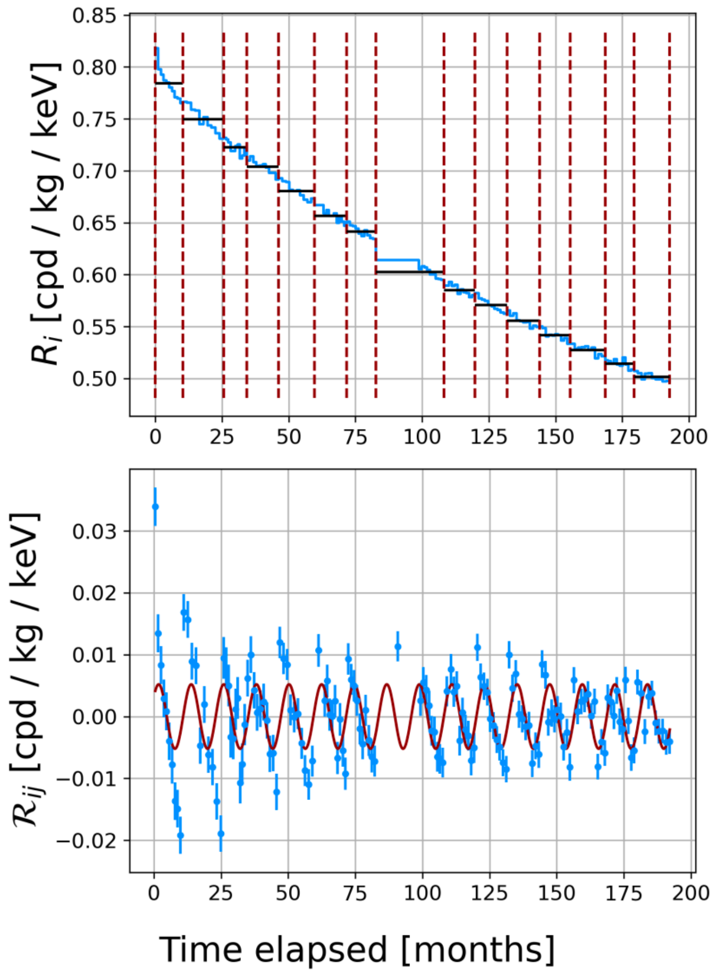
Strategy

- Higher signal-to-background ratio by ultra-high purity NaI(Tl) crystals
- Proof-of-Principle at LNGS
  - In-situ measurements of crystals radio-purity
- North-South «twin» experiments at LNGS(Italy) and SUPL(Australia)
  - Rule out seasonal effects
- Control PMT noise for low threshold (~1 keV)
  - Pre-calibration

Induced Modulation from Analysis Technique?

- DAMA/LIBRA analysis relied on subtracting average rate over ~ annual cycles
- Is this procedure inducing a modulation effect consistent with their signal?
- Using SABRE crystal simulation and DAMA ^{210}Pb and reassess ^{3}H estimations (R .Saldanha et al PRD107, 2023) no sizeable induced modulation was observed with DAMA background subtraction





Paper to be submitted to archive

SABRE

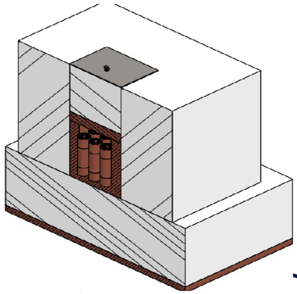
- **Two similar detectors in two underground locations in opposite hemispheres:**
  - SABRE North at Laboratori Nazionali del Gran Sasso (LNGS) in Italy
  - SABRE South at Stawell Underground Physics Laboratory (SUPL) in Australia

PRINCETON UNIVERSITY

UNIVERSITÀ DEGLI STUDI DI MILANO

SAPIENZA UNIVERSITÀ DI ROMA

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



joint effort for crystal production

RMD A Dynasil Company

MELLEN

THE UNIVERSITY OF MELBOURNE

SWINBURNE

KEK

STAWELL UNDERGROUND PHYSICS LAB

ARC CENTRE OF EXCELLENCE DARK MATTER PARTICLE PHYSICS

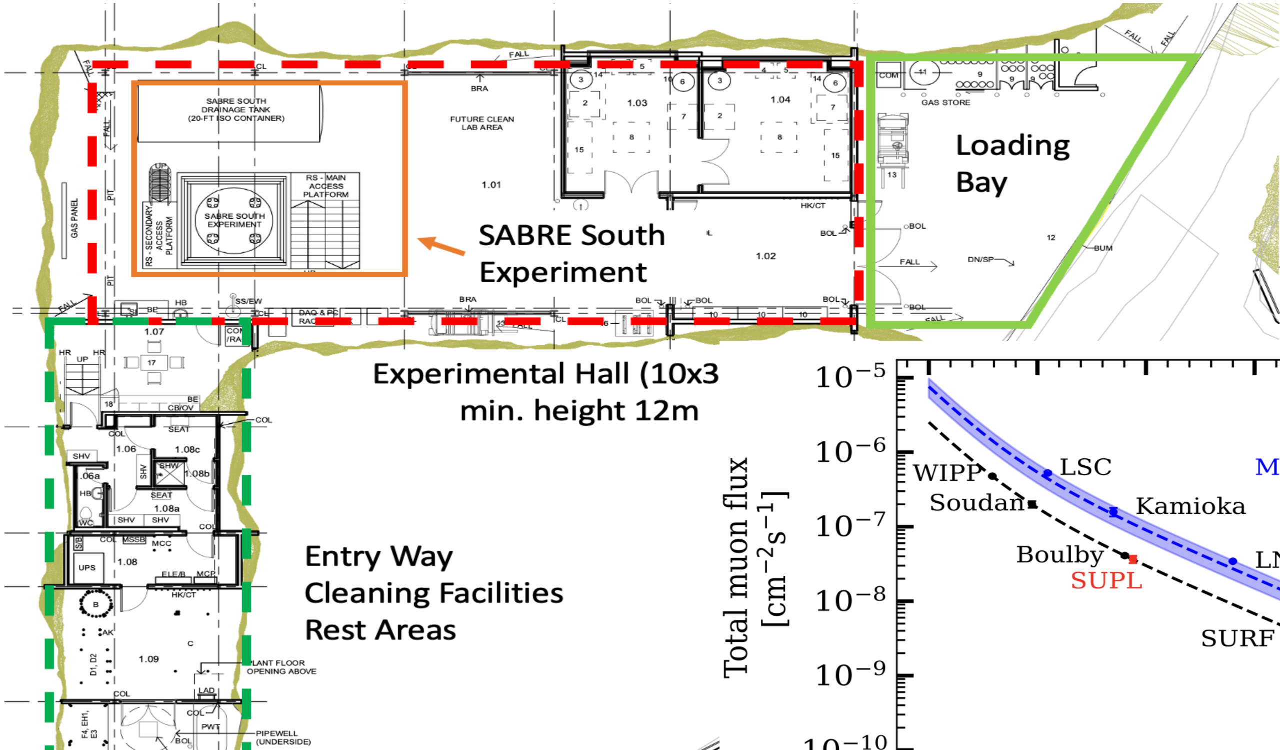
SUPL

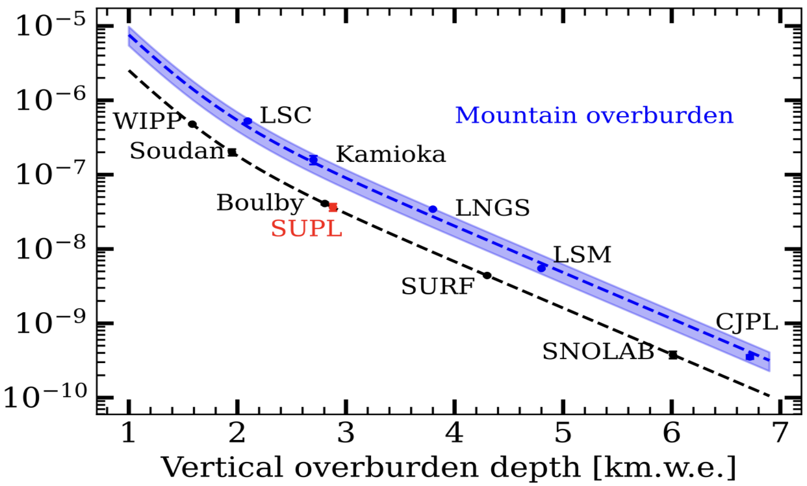
Operating since January 2024

STAWELL UNDERGROUND PHYSICS LAB

https://www.supl.org.au

- First deep underground lab in the Southern Hemisphere
  - 1025 m deep (2900 m w.e.) in an active gold mine (SGM)
  - Flat overburden
  - Helical drive access: 10 km tunnel, max 5 m diameter, up to 10% slope





ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

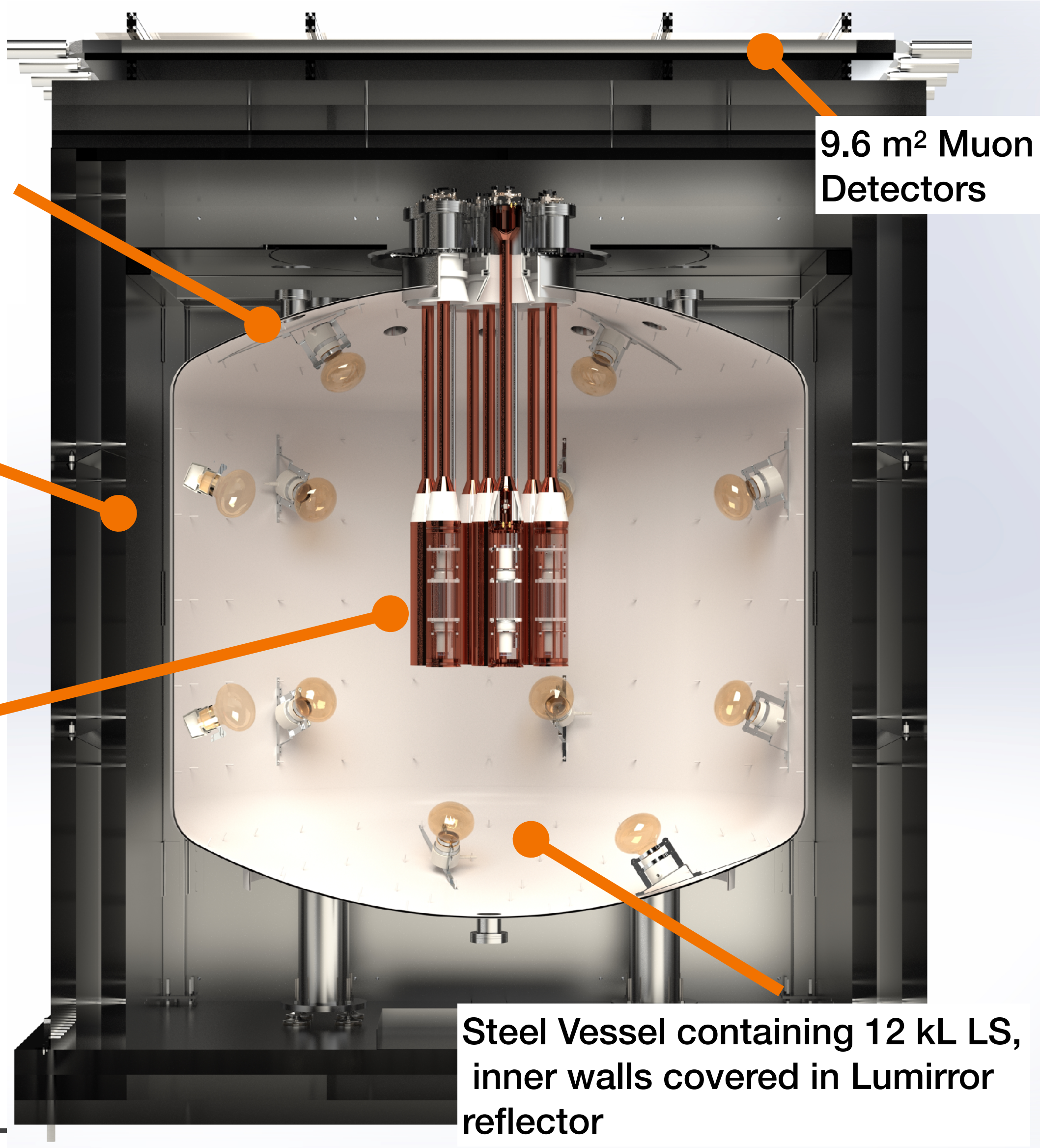
SABRE South detector

Southern hemisphere location

Large Active background veto:
Particle ID, some position reconstruction capabilities

In-situ optical (in LS) and radioactive calibration possible

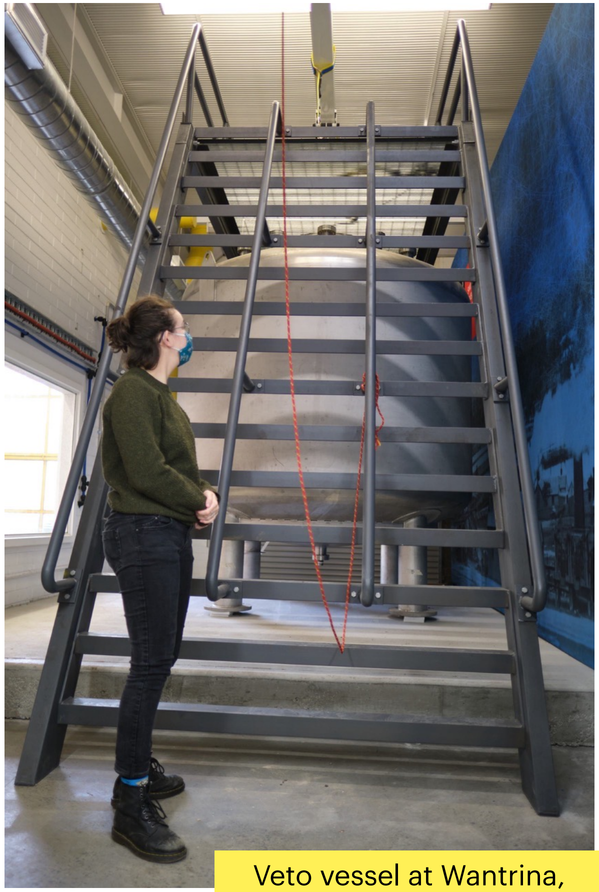
1 keV energy threshold for 1-6 keV ROI in NaI(Tl)



SABRE South TDR, DOI: https://doi.org/10.26188/14618172.v3

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

SABRE South Collaboration



Veto vessel at Wantrina, Swinburne Uni

KEK

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

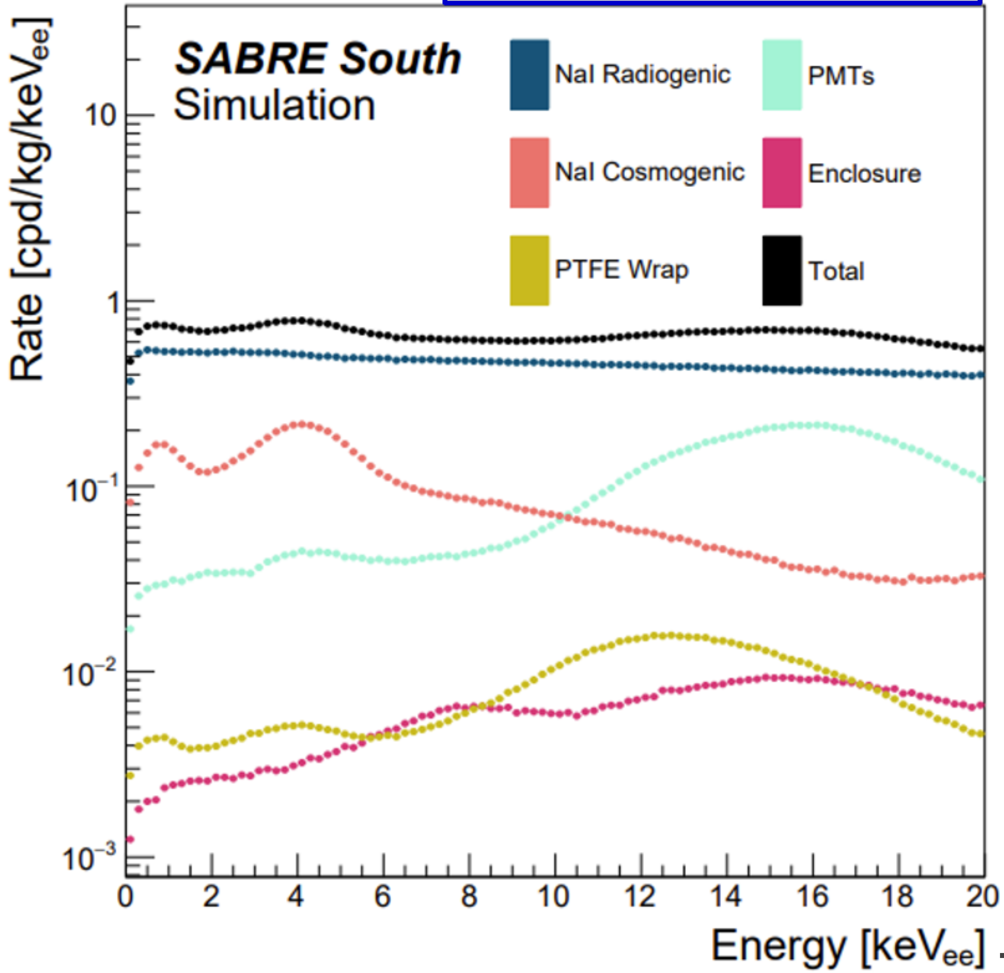
High Purity NaI(Tl) Crystals

Simulated total experimental background Using the veto the expected overall background is 0.72 cpd/kg/keVee.

Experiment designed so that < 10% of background is external to crystals.

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**

EPJC, Vol 83, 878 (2023)
https://doi.org/10.1140/epjc/s10052-023-11817-z



SABRE South NaI(Tl) Crystals Production

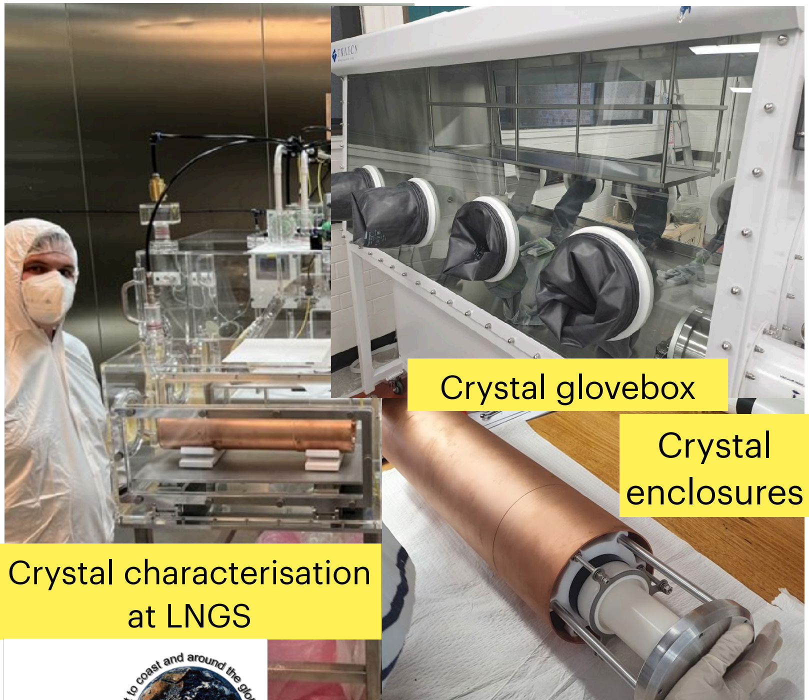
See also Sabre N talk & F. Dastgiri poster

NaI ultra-pure powder from R&D of Princeton-Sigma-Aldrich (now Merck) in hand in Australia

Goal ~50 kg mass, 7 crystal modules

Crystals R&D via SICCAS and RMD with Sabre North

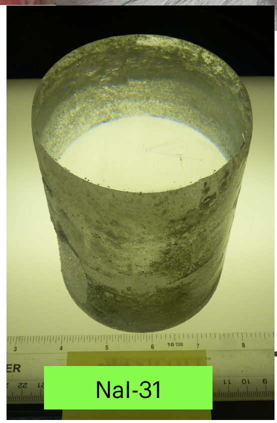
Future characterisation in a lead castle in SUPL



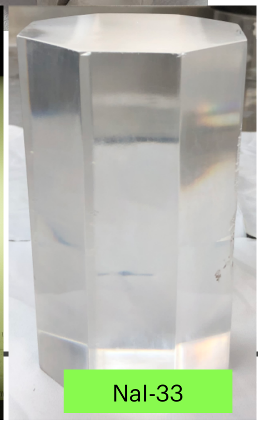
Crystal glovebox

Crystal enclosures

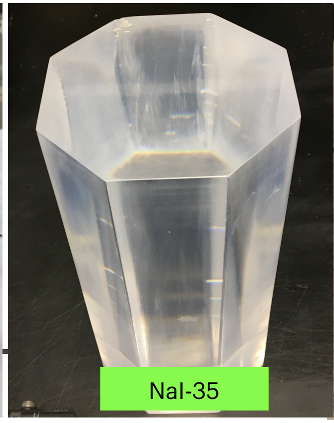
Crystal characterisation at LNGS



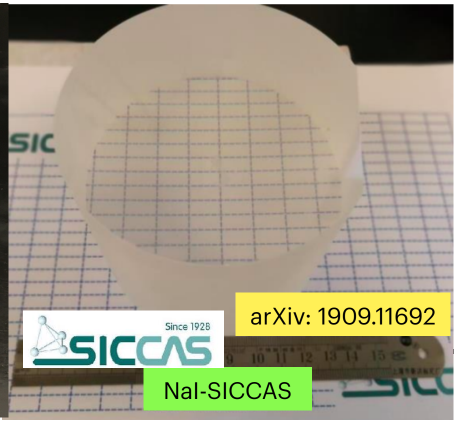
NaI-31



NaI-33

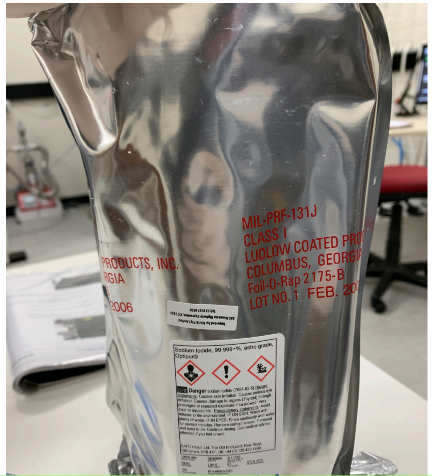


NaI-35



arXiv: 1909.11692

NaI-SICCAS

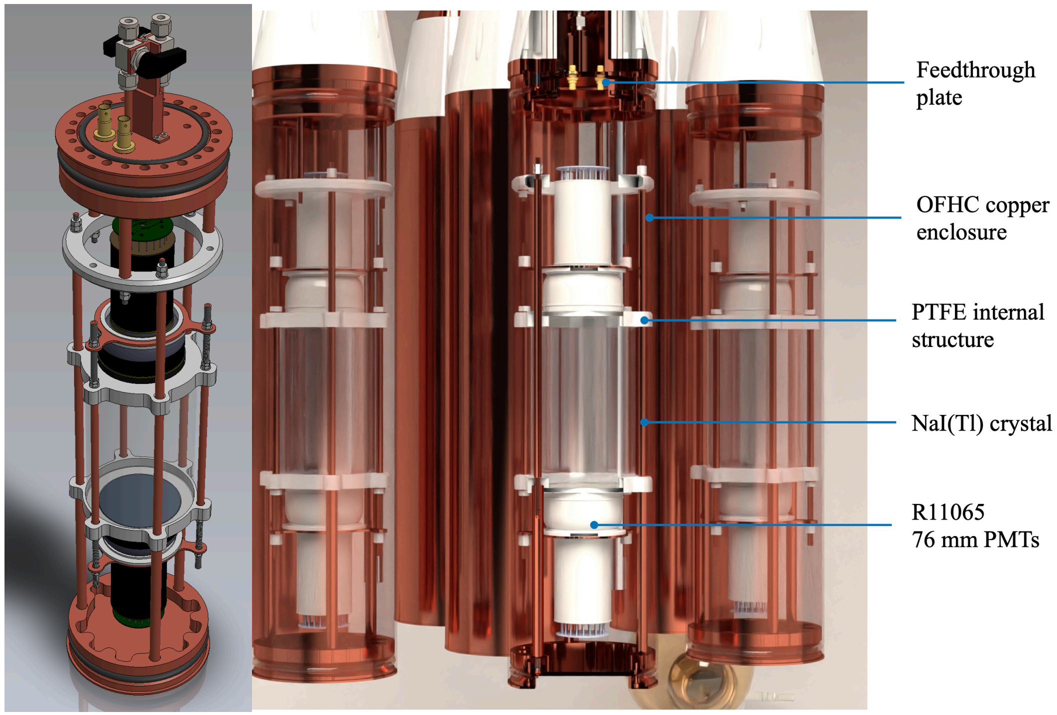


Astrograde powder in hand

NaI(Tl) Detectors

NaI(Tl) detectors immersed in the liquid veto.

Dark matter candidates from single crystal hits (2 PMT signals)



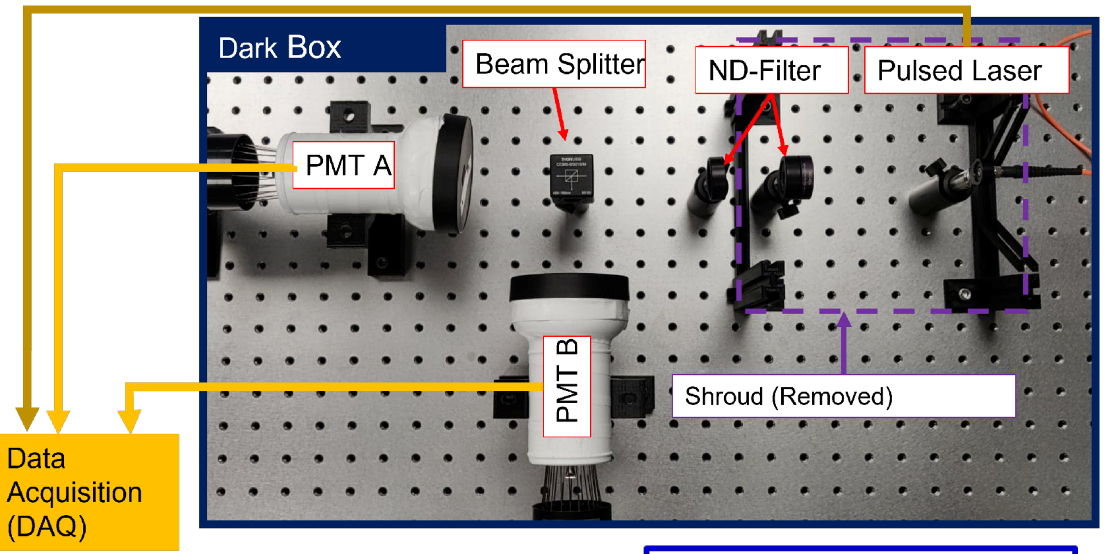
Crystals encapsulated in copper/PTFE enclosures, directly coupled to two R11065 PMTs. Purged with high purity dry N_2.

Assembly process is being finalised using glove box.

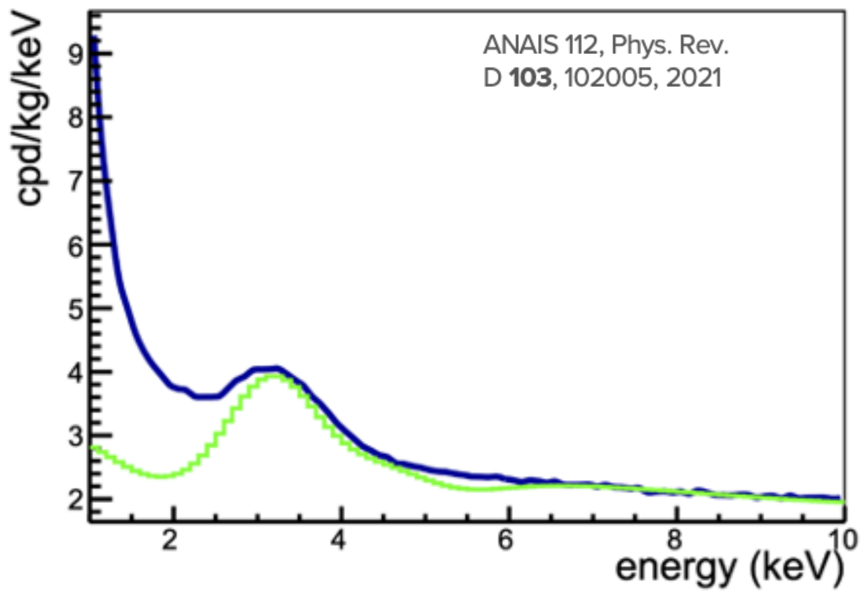
PMT Pre-Calibration

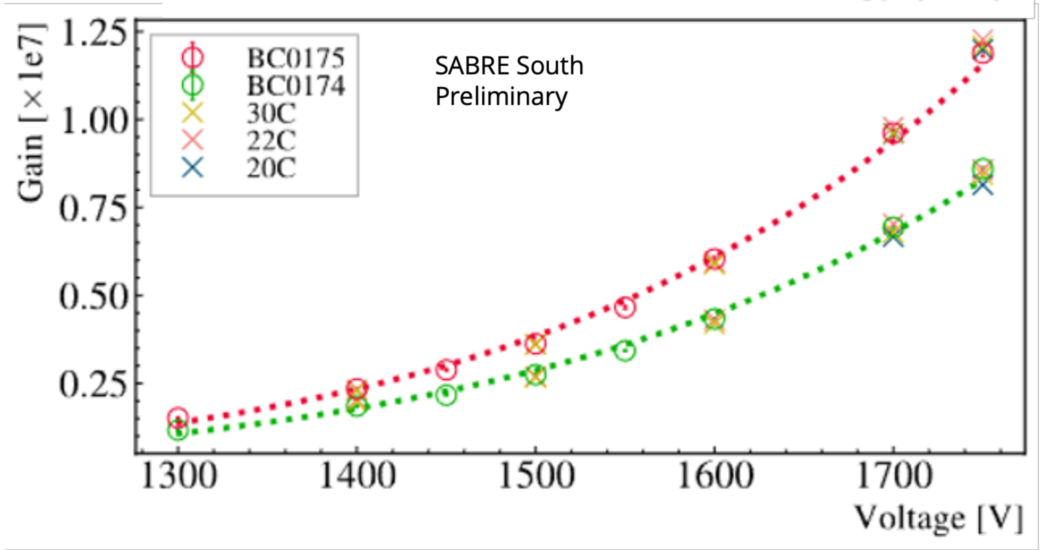
Optimise PE detection efficiency and noise rejection vs number of SPEs detected

Single photoelectron response (SPE) and gain
Dark rate, and temperature dependent dark rate
Relative quantum efficiency, **linearity of response**



Pre-calibration papers to be submitted to journal/arxiv July 2024

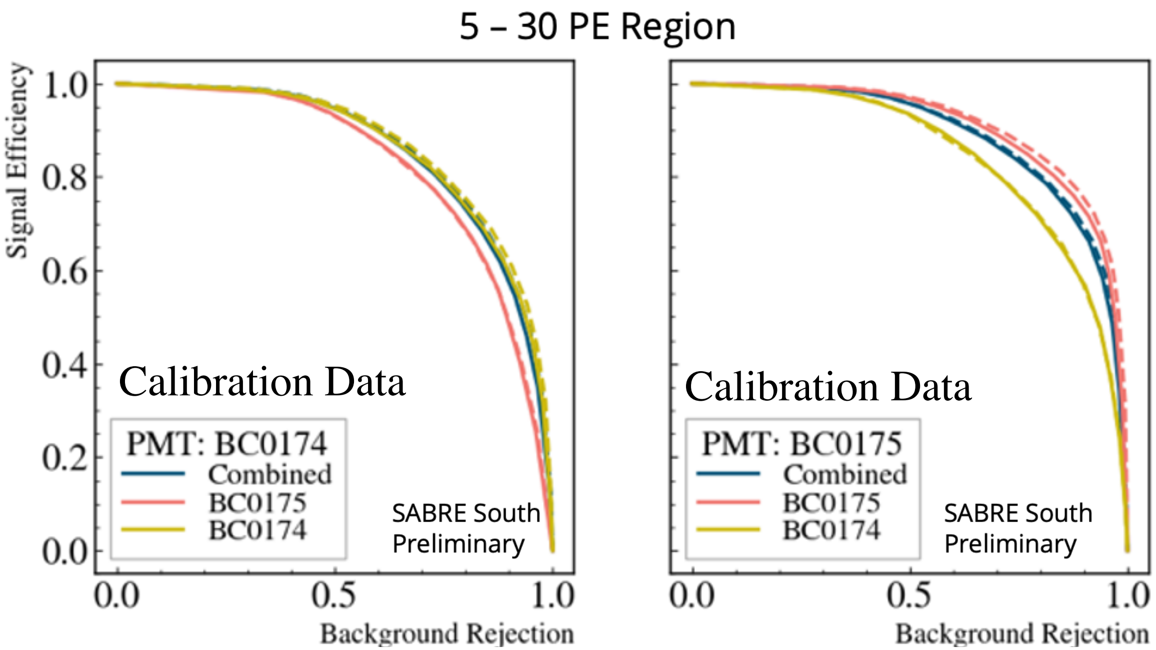


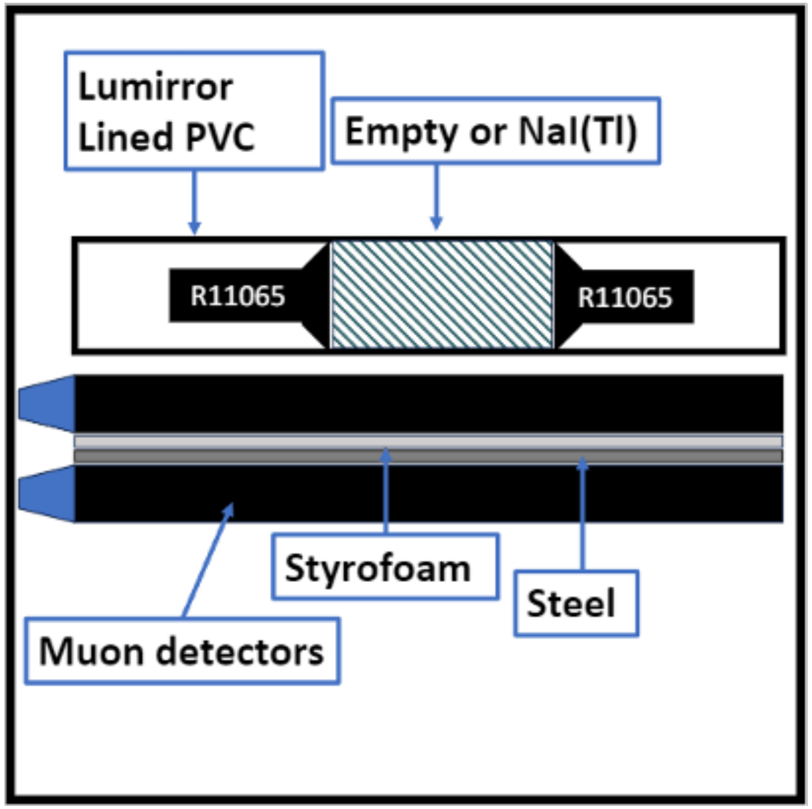


PMT Noise Rejection

BDT classifier has improved performance over linear cuts on traditional pulse shape variables

Improved noise rejection in low energy region—> energy threshold to ~1 keV_{ee}





ROC curves for different PMTs learning models

Active Veto System

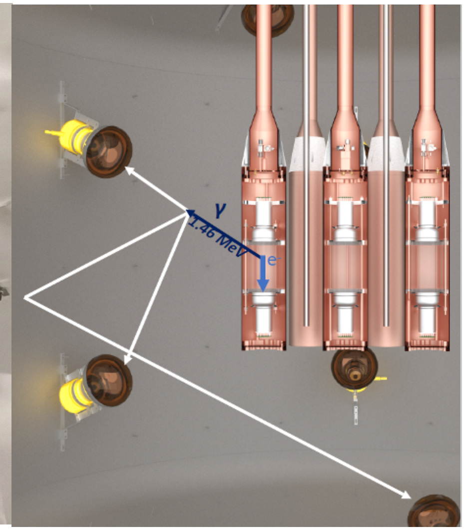
12 kL of linear alkyl benzene (LAB) procured via JUNO production line, doped with PPO and bisMSB

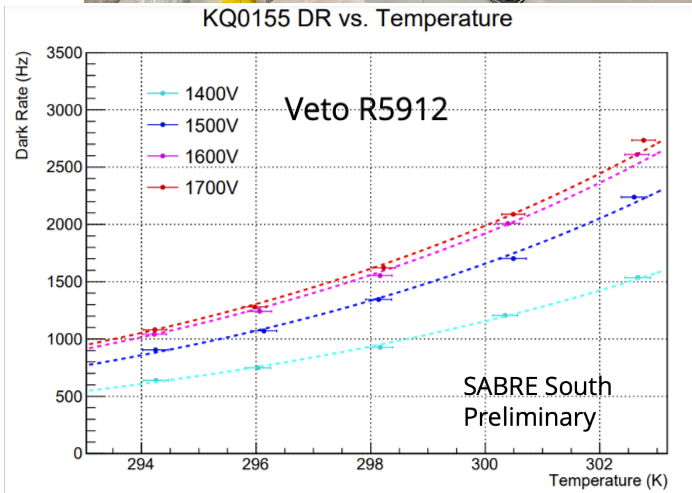
Photon attenuation > 20m

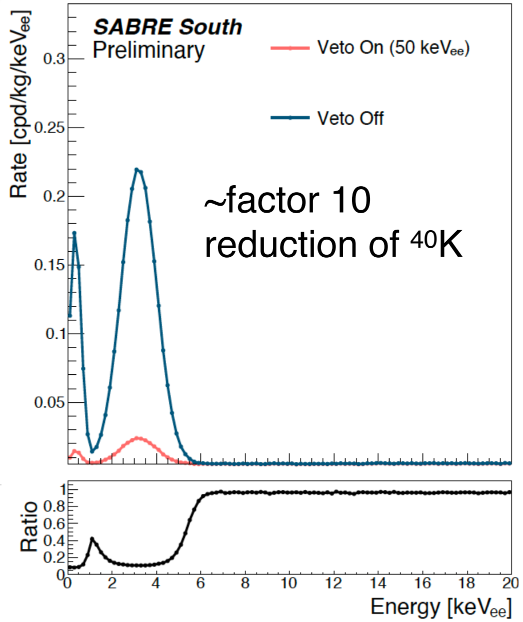
18 R5912 PMTs oil proof, sampled at 500 MS/s +16 from Daya Bay decommissioning (donated by IHEP)

~ threshold of 50 keV (~10 PE) –
~ 0.20 PE/keV detectable by single PMT

Any radioactive decay with gamma > 100 keV can be detected







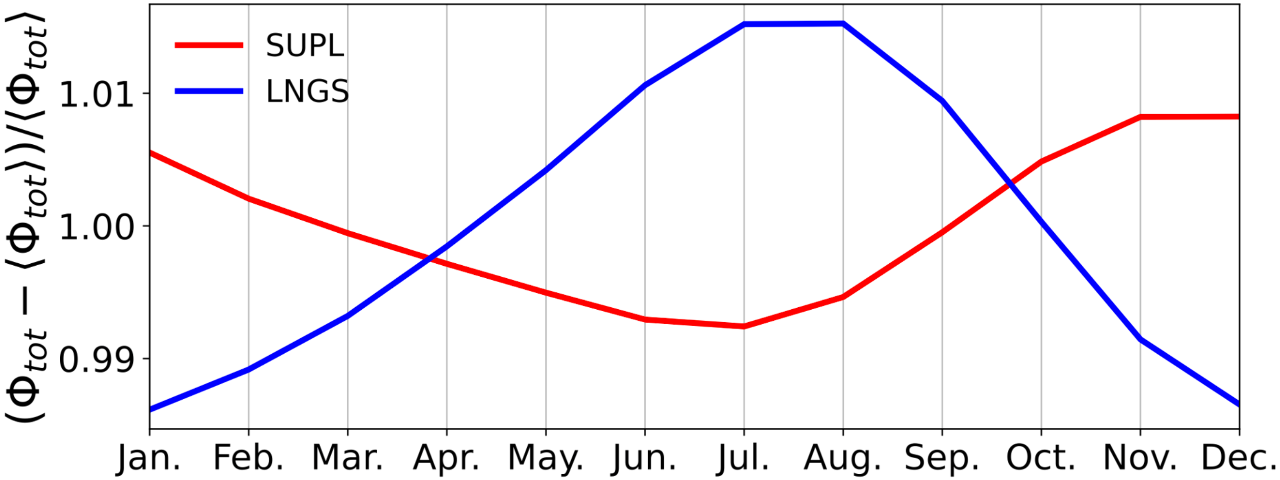
EPJC, Vol 83, 878 (2023)
https://doi.org/10.1140/epjc/s10052-023-11817-z

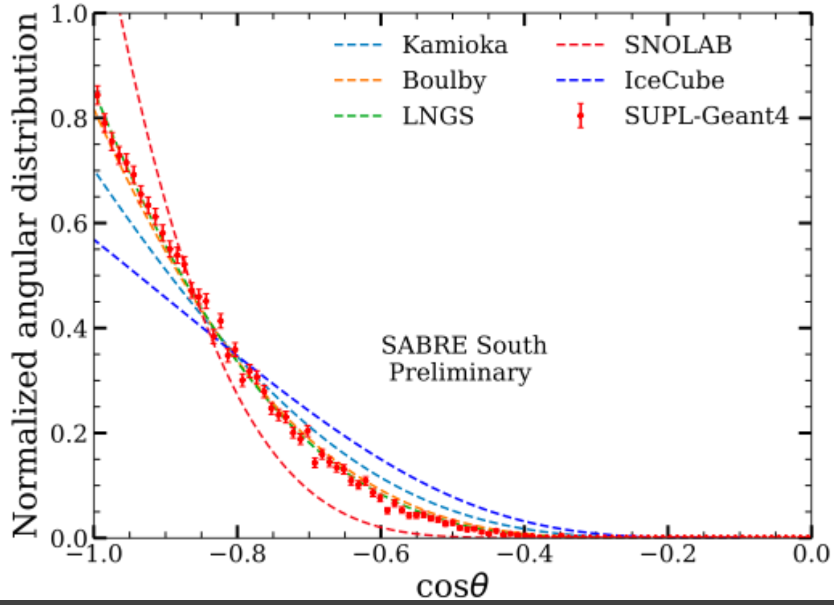
Muon Veto System

First detectors commissioned early 2024 in SUPL

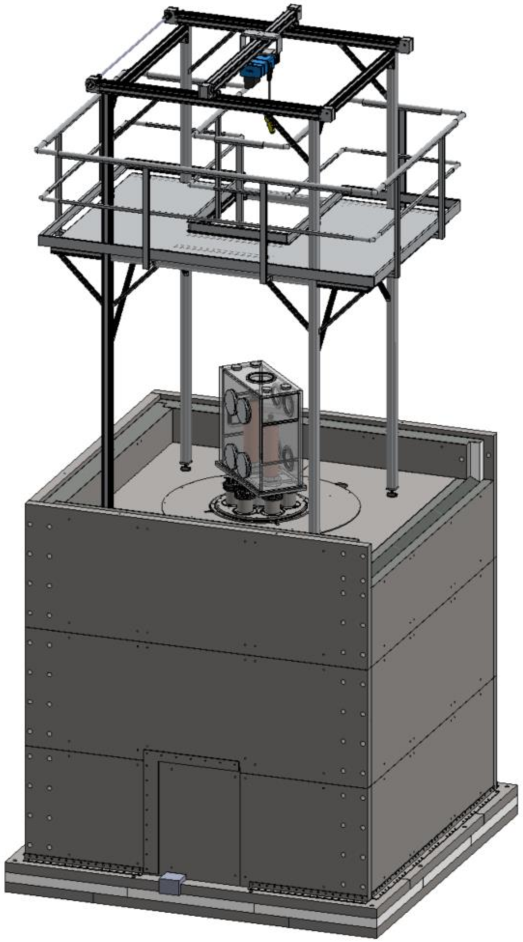
SABRE South **muon veto assembled in "telescope mode"** for measurement of muon flux and angular spectrum
Currently collecting data and analysis is underway

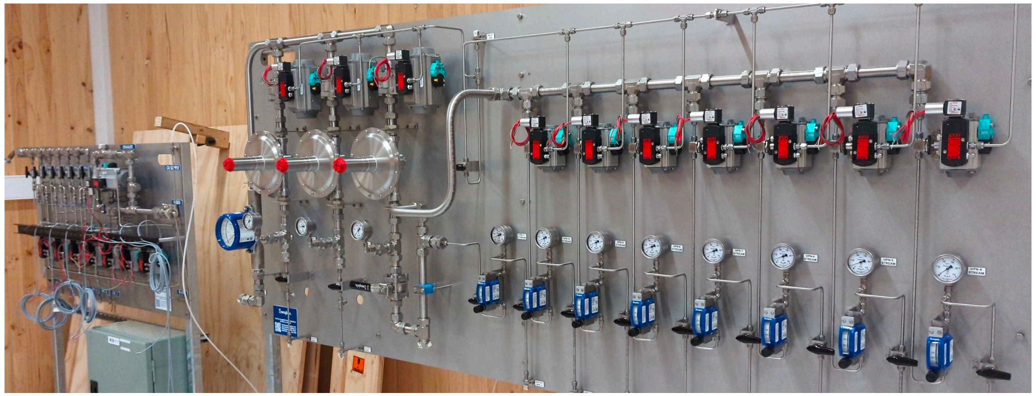
Also providing the first test of the remote data acquisition system (DAQ) and processing pipelines

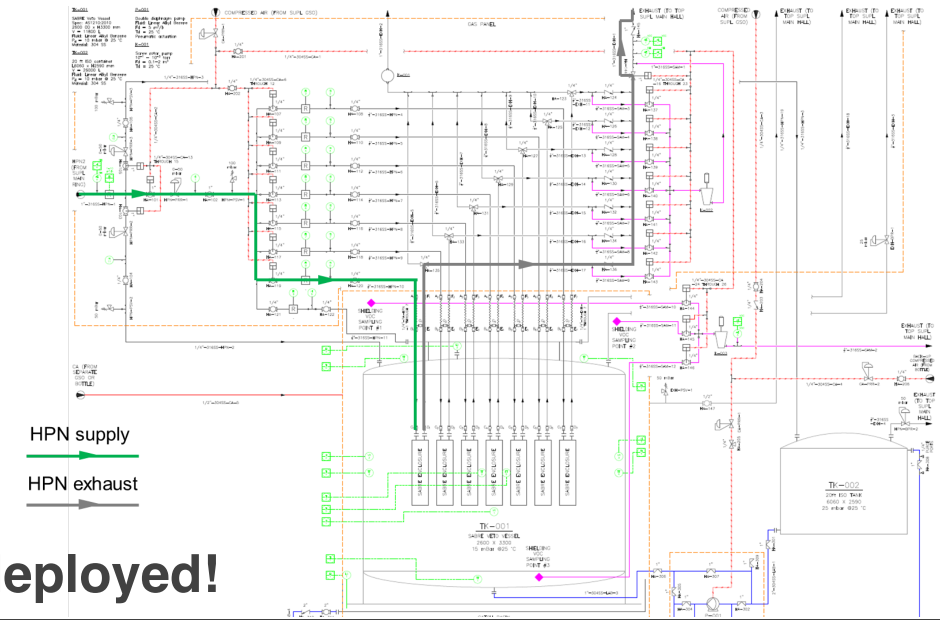




Insertion System and Gas Handling

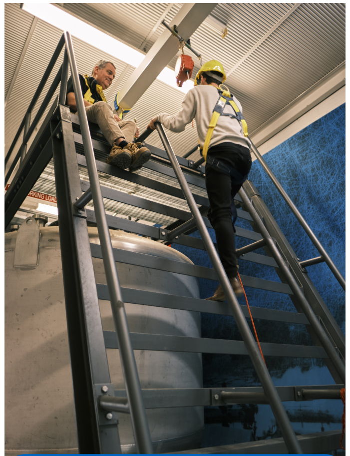




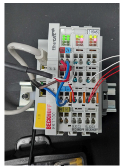


Ready to be deployed!

Other Achievements



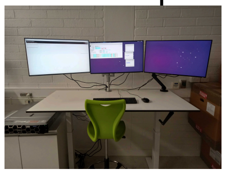
Veto tank

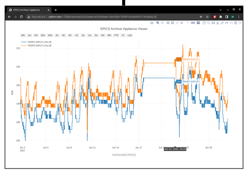


DAQ & Monitor

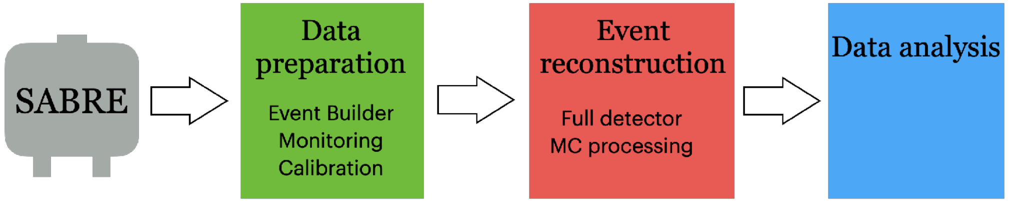
Network

Liquid scintillator (LAB)

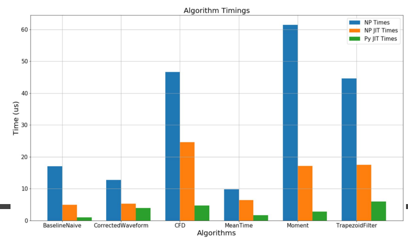


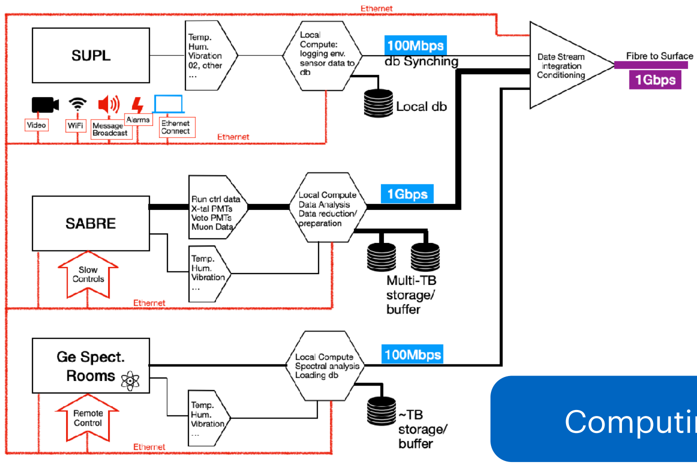


Veto vessel: Lumiror and PMTs installation tests



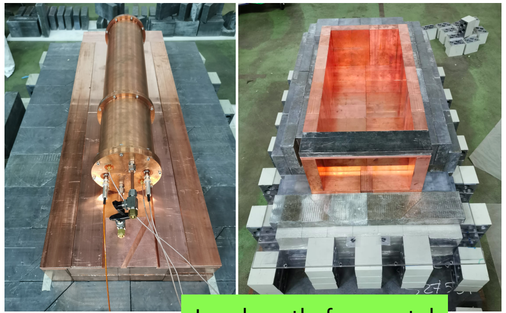
Offline software framework



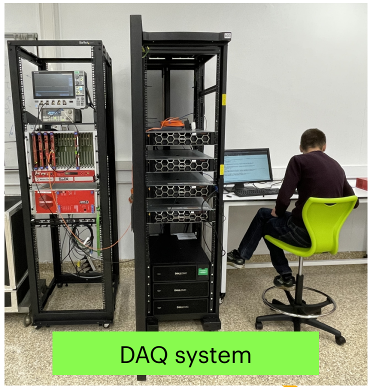


Computing

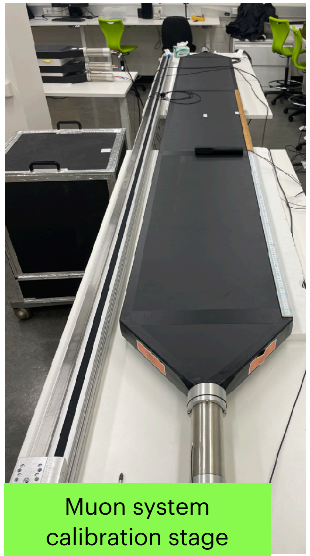
SUPL Activities (near term)



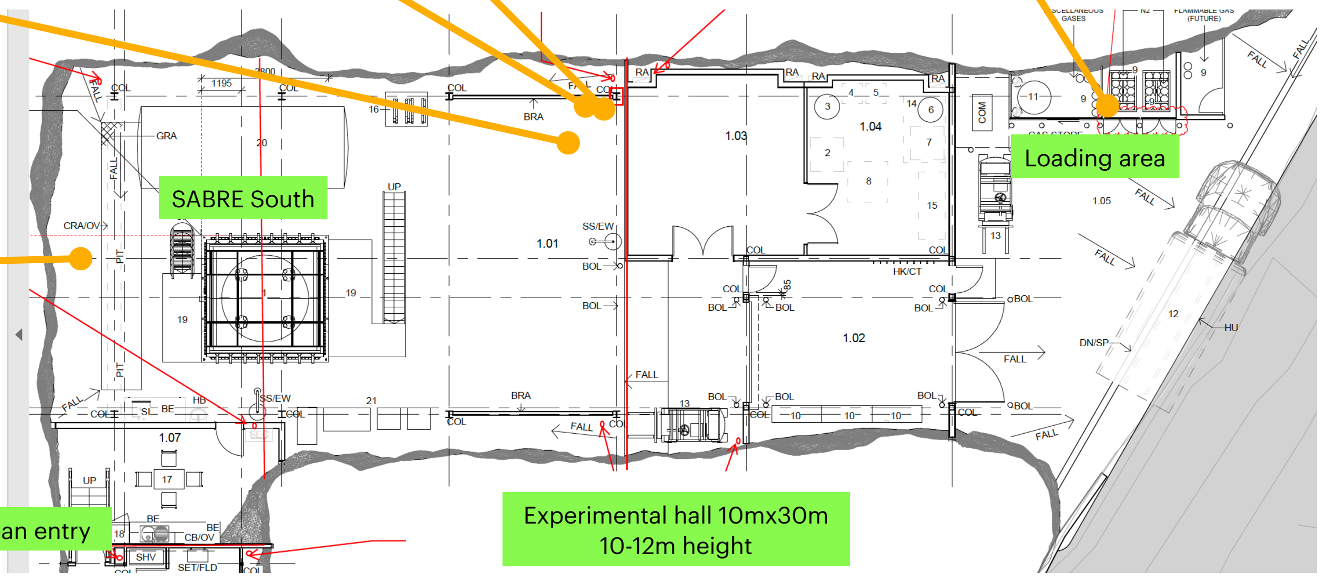
Lead castle for crystal assembly testing (pictured LNGS)



DAQ system



Muon system calibration stage



SABRE South

Loading area

Clean entry

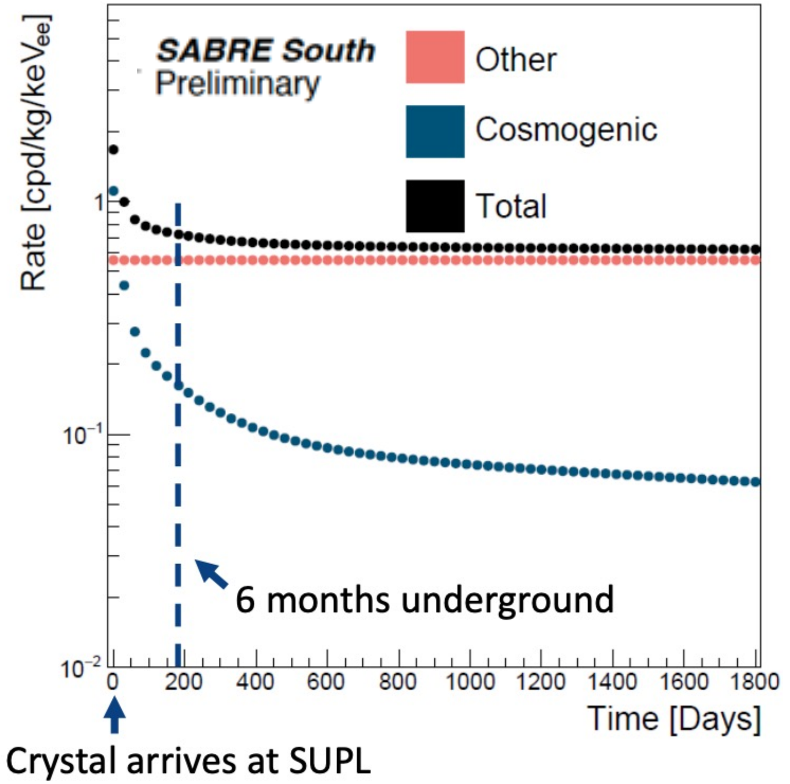
Experimental hall 10mx30m 10-12m height

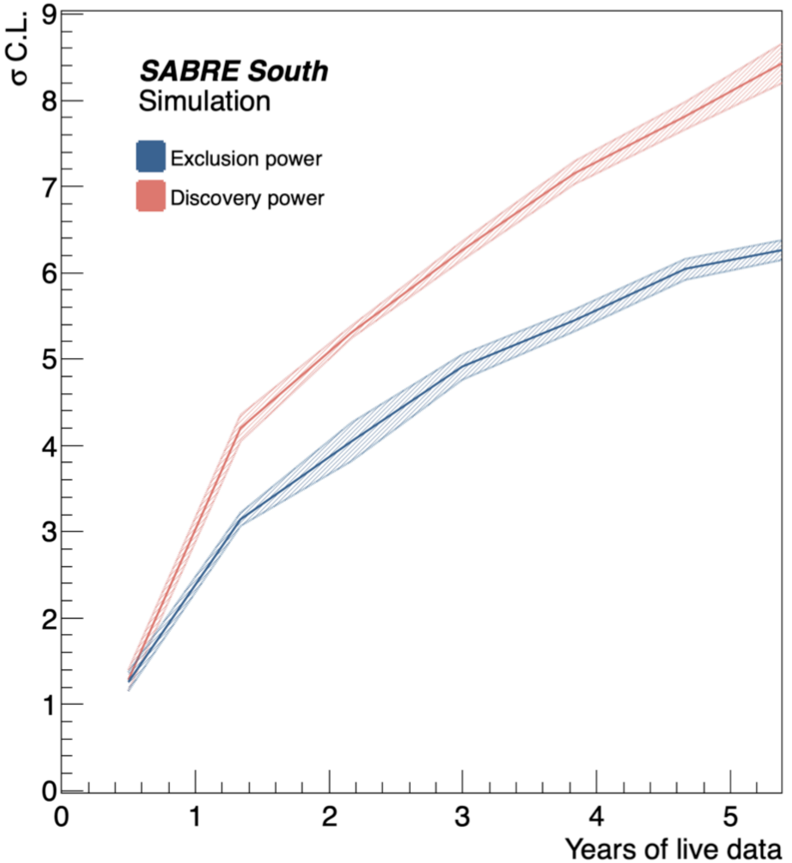
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

SABRE Impact

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

- Crystal background from NaI-33
- Cosmogenic background ^{3}H (half life 12.4 yrs), ^{109}Cd (half life 463 days) and ^{113}Sn (half life 115 days) after 180 days





Sensitivity $\sim\sqrt{M/R_b}$,

Statistically significant results with 2-3 years of exposure

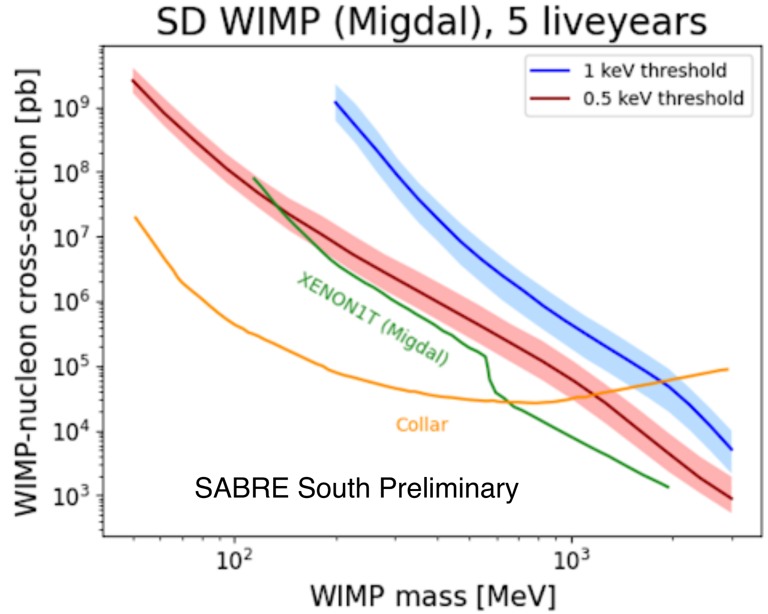
Assuming total crystal mass of 50 kg
Total background ~ 0.7 dru

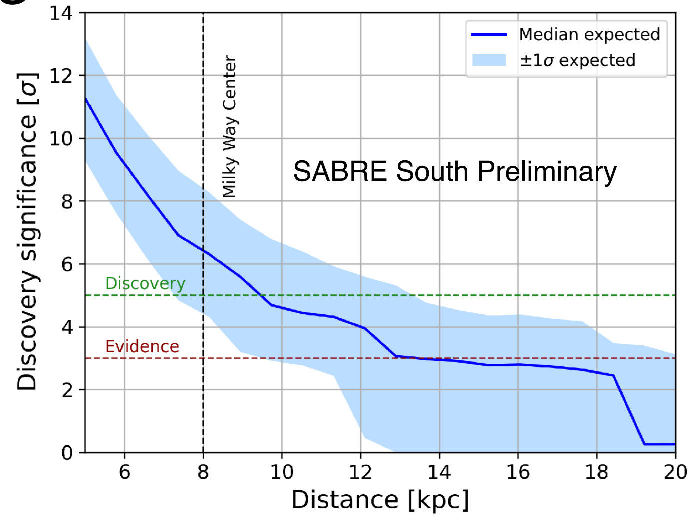
Physics Program

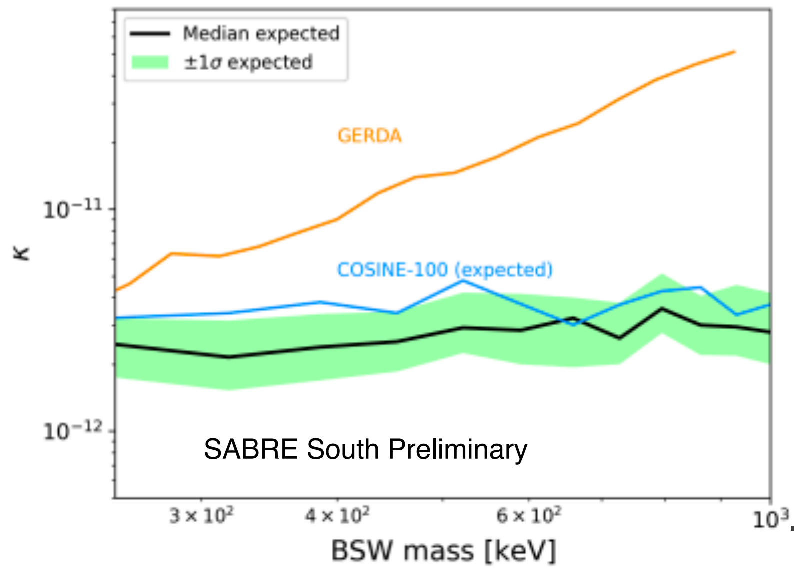
Preliminary sensitivity studies performed on

- Migdal effect
- Bosonic super-WIMPs

Veto (LAB): Sensitivity to supernova neutrinos – possibility to join SNEWS







SABRE South TDR, DOI: https://doi.org/10.26188/14618172.v3

Summary

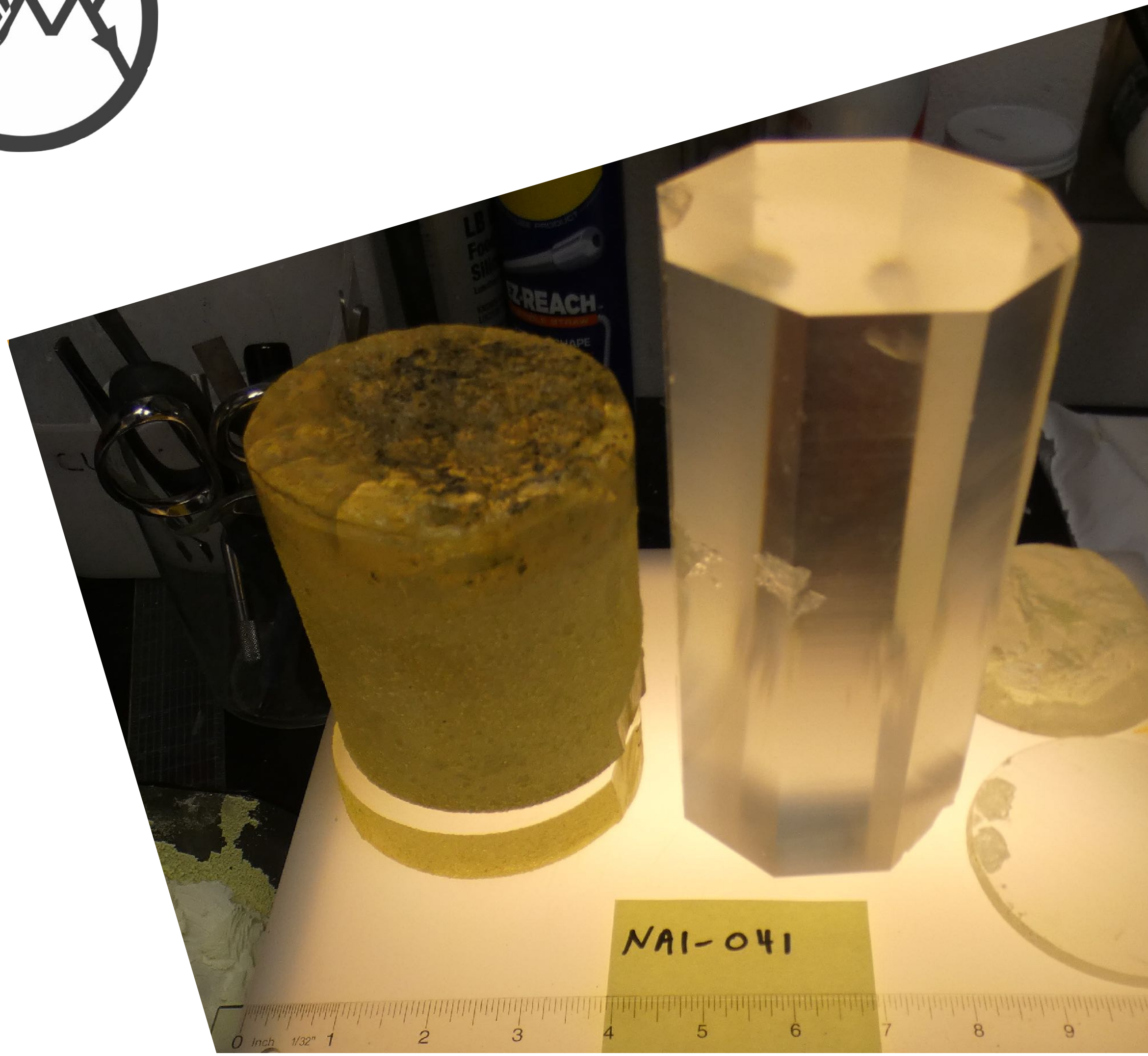
https://www.sabre-experiment.org.au/dm-how

- Excellent progress on crystal production and crystal handling equipment.
- Access to SUPL commenced: first major equipment (muon detectors) in SUPL since February.
- Continued progress on Software/DAQ/Computing/Database. Stress tested with muon plastic scintillator system.
- Gas handling system and insertion system ready to be deployed.
- Shielding fabrication is starting soon —> SABRE South deployment in 2025
- NaI(Tl) experiments (ANAIS, COSINE, SABRE South and North) signed an agreement to collaborate and exchange knowledge to solve the mystery posed by DAMA/LIBRA

SABRE South TDR, DOI: https://doi.org/10.26188/14618172.v3

THE UNIVERSITY OF MELBOURNE

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS



Crystal requirements

- SICCAS and/or RMD could provide suitable crystals that meet requirements.

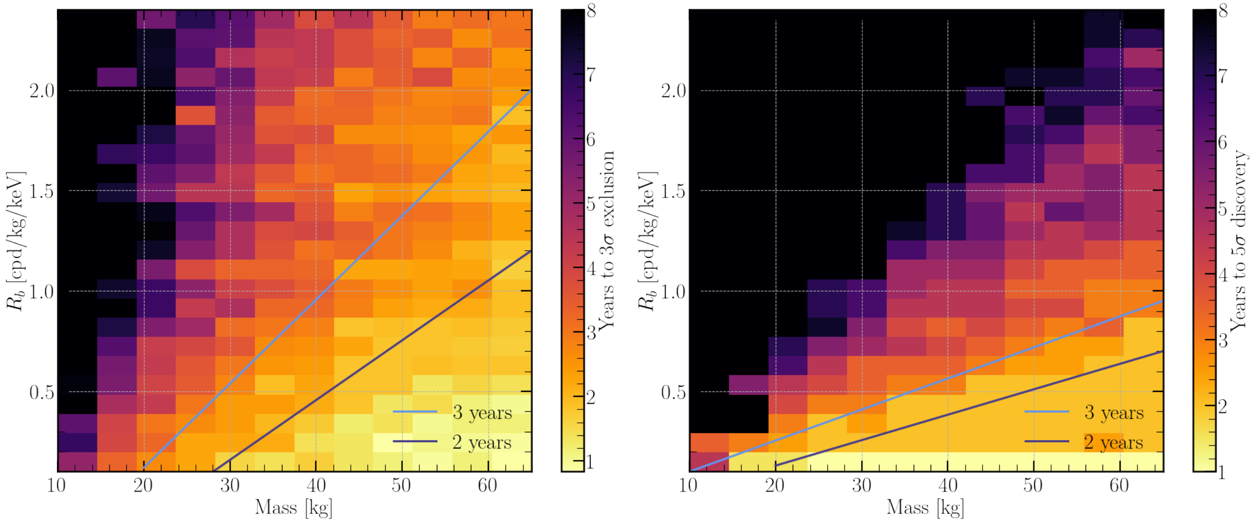


Table 16. Expected background rate for intrinsic crystal contamination for the SABRE South MC [12], the SABRE PoP run [38], and the SABRE PoP run with reduction due to zone refining and veto application. Note that we assume (based on the simulation results from SABRE South) that the "other" category is dominated by ^{87}Rb, which sees a significant reduction from zone refining [37].

Contaminant	SABRE South MC	SABRE PoP	SABRE PoP with ZR and veto
^{40}K	1.3×10^{-2}	1.3×10^{-1}	1.6×10^{-2}
^{210}Pb	2.8×10^{-1}	3.3×10^{-1}	1.7×10^{-1}
^{238}U	5.4×10^{-3}	6.0×10^{-3}	6.0×10^{-3}
^{232}Th	3.4×10^{-4}	3.0×10^{-4}	3.0×10^{-4}
Other	2.2×10^{-1}	3.3×10^{-1}	3.0×10^{-2}
Total	5.2×10^{-1}	8.0×10^{-1}	2.1×10^{-1}

Table 12. Breakdown of contribution limits to the intrinsic crystal radioactivity for the two different total mass scenarios. Note that the 50 kg scenario assumes the use of the Bridgman growth method for the crystals, while the 35 kg uses zone refining, and so can achieve lower background levels.

Isotope	50 kg limit (mBq/kg)	35 kg limit (mBq/kg)
^{210}Pb	0.36	0.32
^{40}K	0.34	0.30
^{87}Rb	0.36	0.04
^{238}U	0.01	0.01
^{85}Kr	0.01	0.01
^{232}Th	0.041	0.041

Table 13. Background requirements for SABRE South, based on the requirement that benchmark sensitivity is achieved within 3 years.

Crystal mass [kg]	External+cosmogenic background [cpd/kg/keV$_{ee}$]	Intrinsic background [cpd/kg/keV$_{ee}$]	
		3σ Exclusion	5σ Discovery
35	0.23	0.53	0.27
50	0.21	1.18	0.52

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