DIRECT SEARCH OF DARK MATTER WITH THE SABRE SOUTH EXPERIMENT

Australian National University

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The University of Melbourne

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THE SABRE COLLABORATION

Experimental program to test the DAMA modulation based around detectors place in two different locations:

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

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

STAWELL UNDERGROUND PHYSICS LAB

THE SABRE COLLABORATION

SABRE North and South detectors have **common core features**, both employing:

- Same detector module concept (Ultra-pure crystals and HPK R11065 PMTs)
- Common simulation, DAQ and software 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 detectors **have different shielding designs:**

- SABRE North has opted for a fully passive shielding due to the phase out of organic scintillators at LNGS. Direct counting and simulations demonstrate that this is compliant with the background goal of SABRE North at LNGS.

- SABRE South will be the first experiment in SUPL, the liquid scintillator will be used for in-situ evaluation and validation of the background in addition of background rejection and particle identification.

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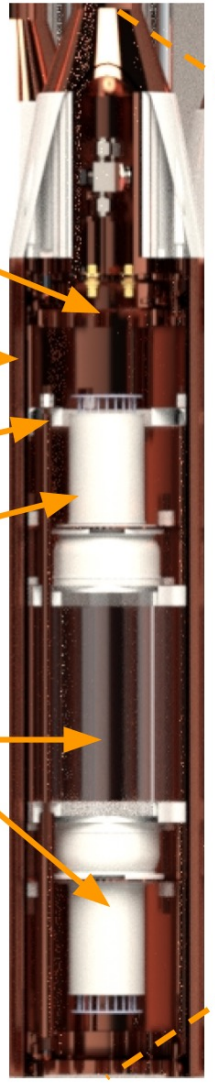
See Ambra Mariani's talk next!

- SABRE South will be the first experiment in SUPL, the liquid scintillator will be used for in-situ evaluation and validation of the background in addition of background rejection and particle identification.

Also see my poster with William Melbourne later today!

SABRE SOUTH



Feedthrough plate

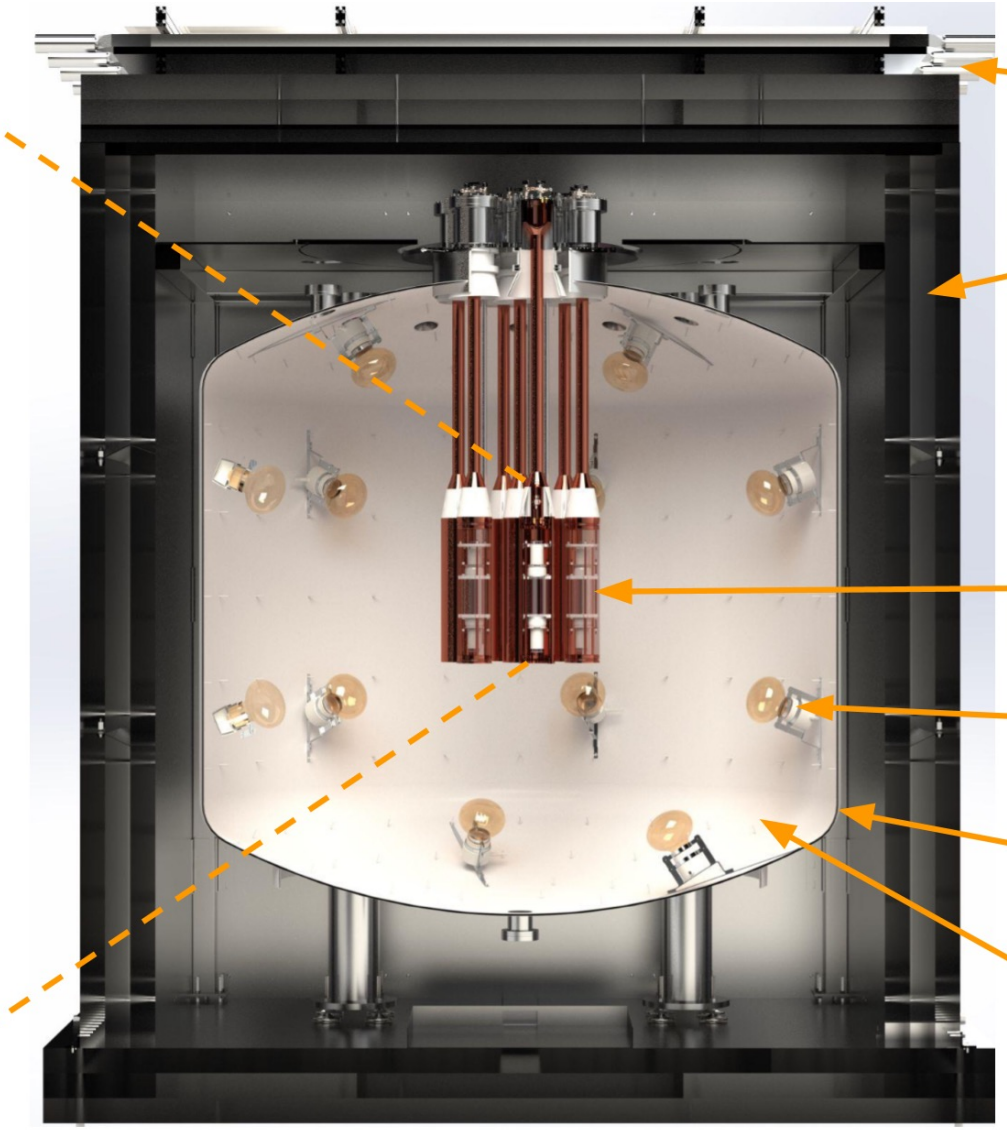
OFHC Cu enclosure

Teflon internal structure

7.6 cm R11065 Hamamatsu PMTs

NaI(Tl) crystal

Crystal procurement ongoing with SICCAS and RMD



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

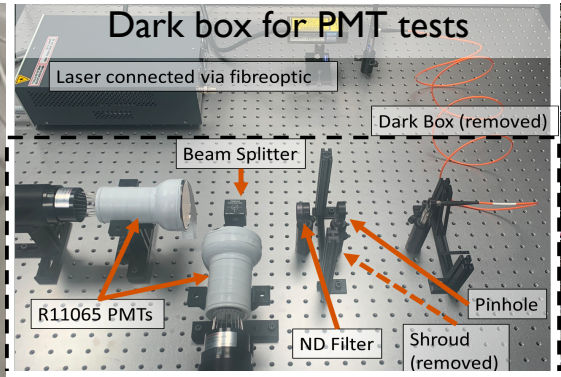
Veto vessel filled with 10T of LAB from JUNO doped with PPO (3.5 g/L) and Bis-MSB (15 mg/L)

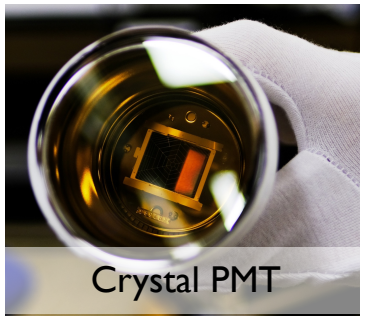
Reflective lumirror coating

SABRE SOUTH

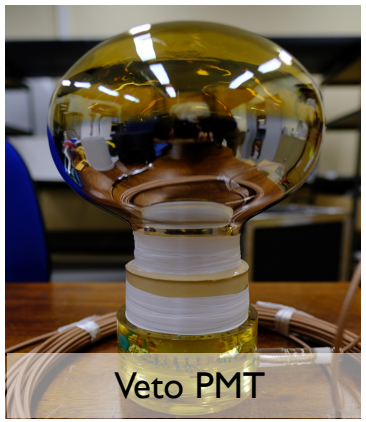
SABRE South vessel, Madeleine for scale

SABRE South crystal currently being characterized at LNGS





Crystal PMT



Veto PMT

Crystal enclosure + conduit

Muon detector

ACTIVE BACKGROUND REJECTION

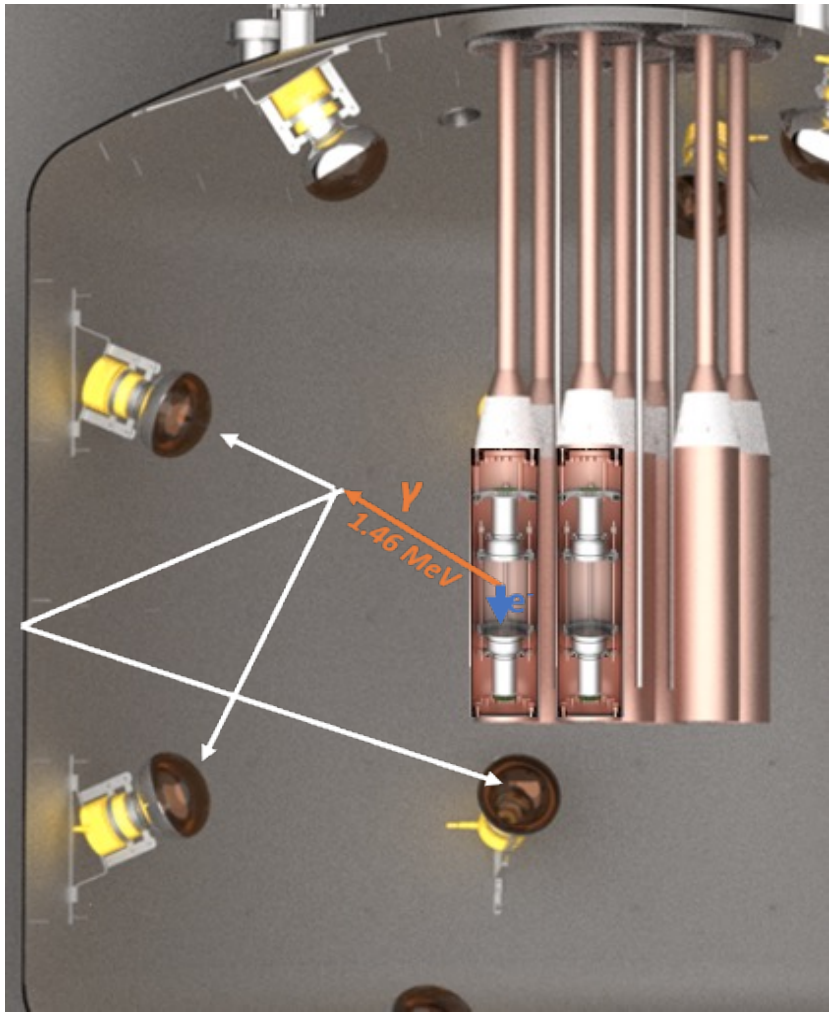
Veto system used to tag and remove high energy decay products observable in the liquid scintillator, e.g., 40K decay

System has 4π coverage made up of:

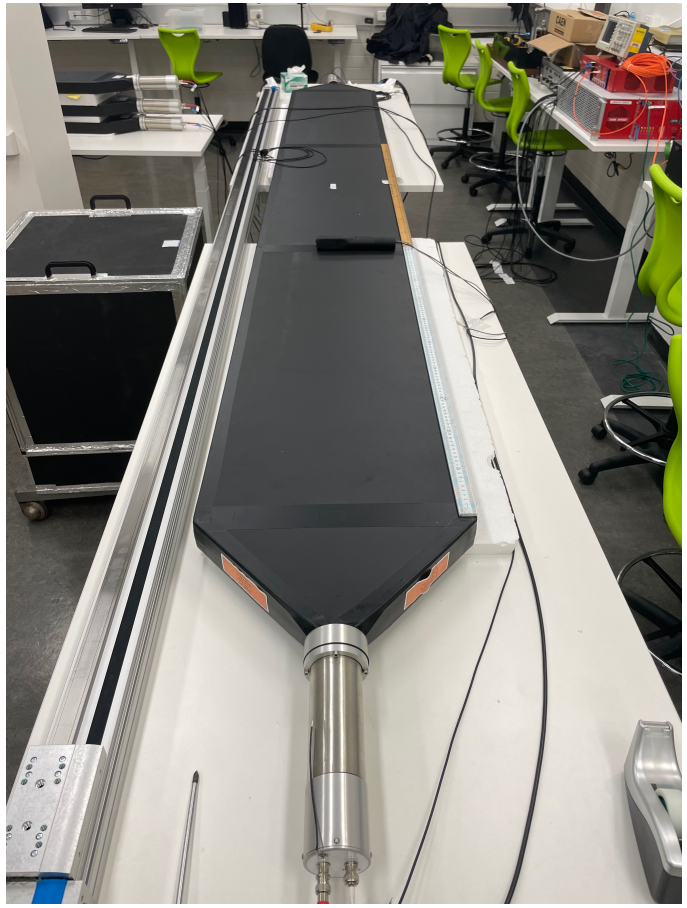
- 12 kL linear alkyl benzene doped with PPO and Bis-MSB
- LAB is sourced from JUNO
- 18 Hamamatsu 20.4 cm R5912 PMTs sampled at 500 MS/s

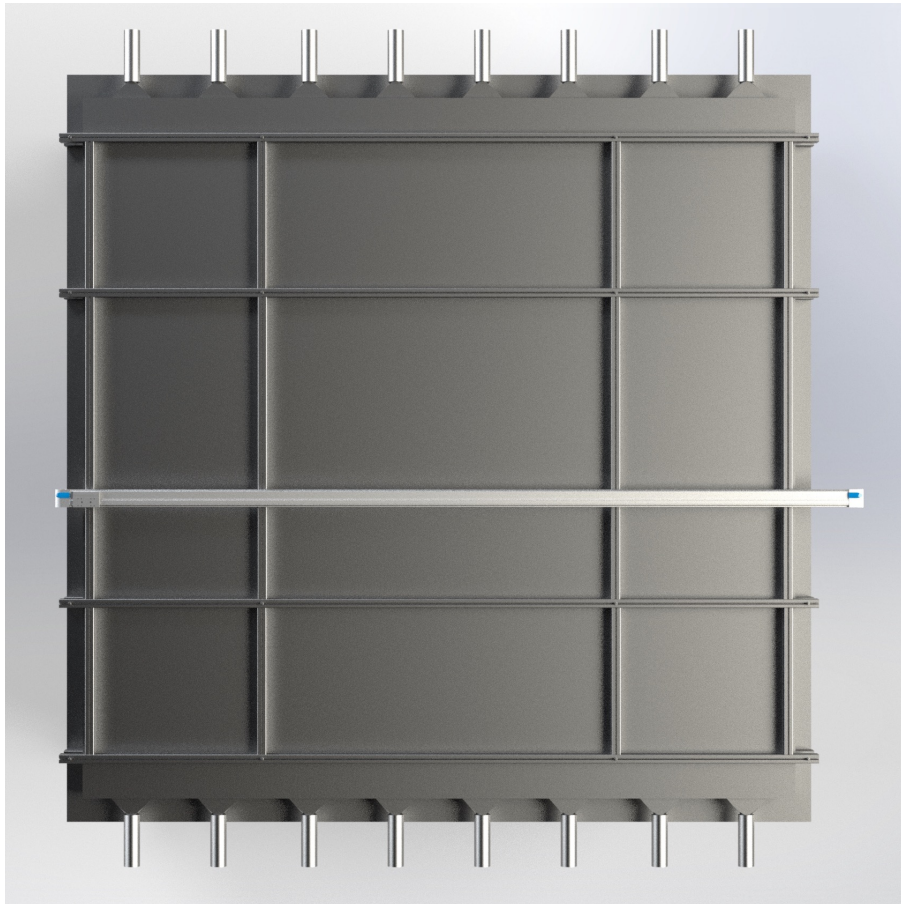
Average light yield of ~0.12 PE/keV, though strong position dependence.

With a threshold of 50 keV it is able to reduce the background by 25%, giving a total background of <1cpd/kg/keV.



MUON DETECTOR SYSTEM



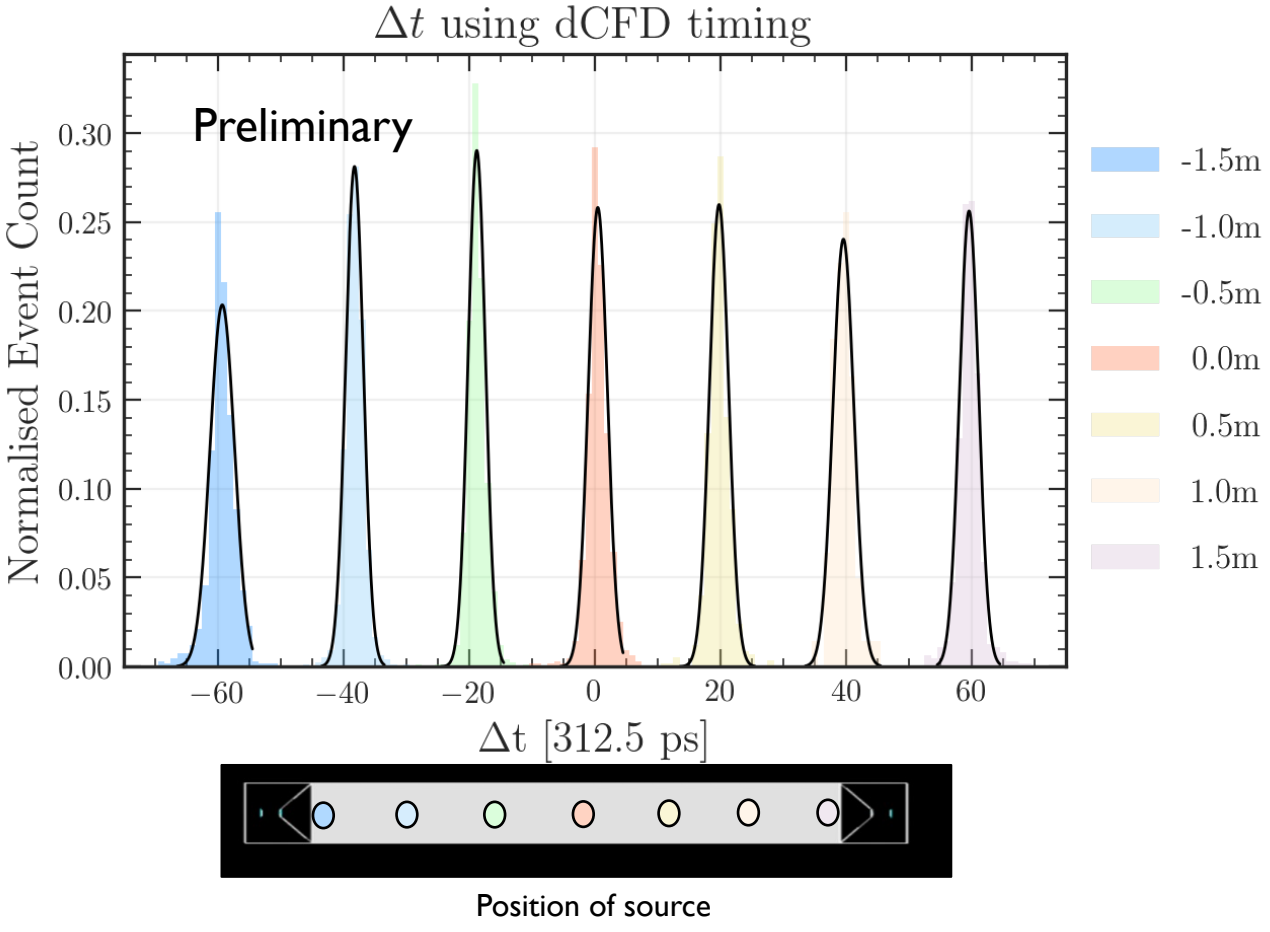


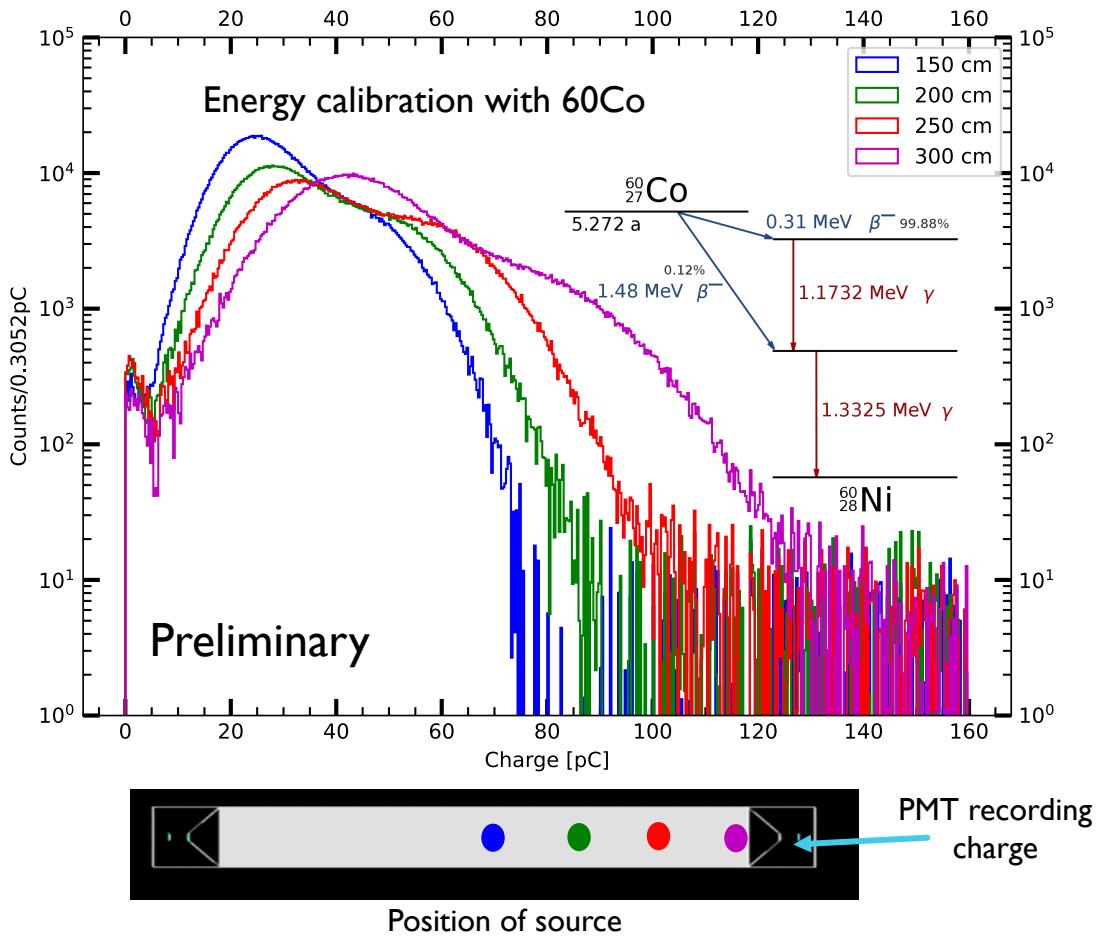
Muon detection system:

- Eight 3 m long EJ200 detector paddles
- Total coverage 9.6 m^2 above main vessel
- Each coupled to two R13089 PMTs and sampled at 3.2 GS/s.
- Calibrated with Festo system, threshold on the MeV scale

MUON DETECTOR SYSTEM

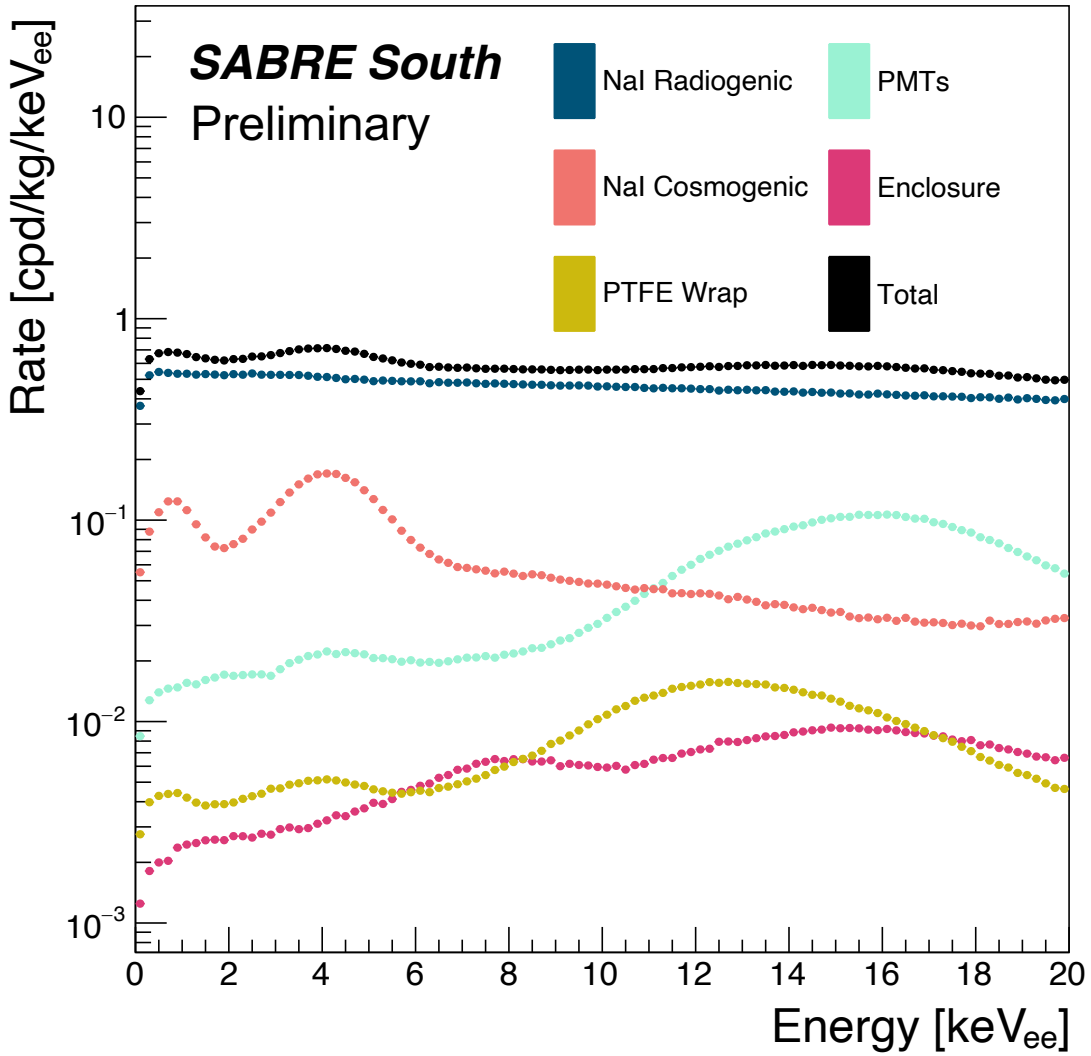
Detectors have 400 ps timing resolution, giving a 5 cm position resolution. Characterisation is ongoing.
This allows for long term measurement of the muon flux, and particle ID when used with the liquid veto system.





TOTAL BACKGROUND MODEL

[1] SABRE South Collab. arxiv:2205.13849



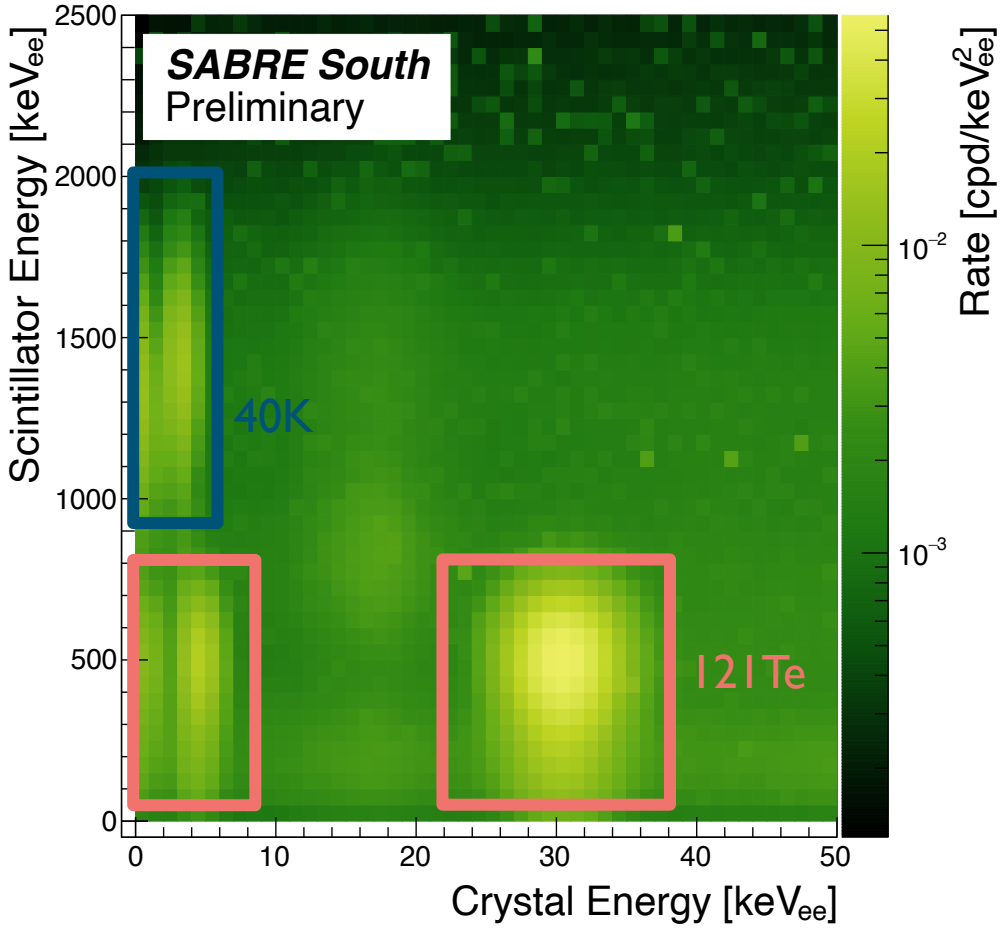
Full detector simulation for background radioactivity

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**

TOTAL BACKGROUND MODEL

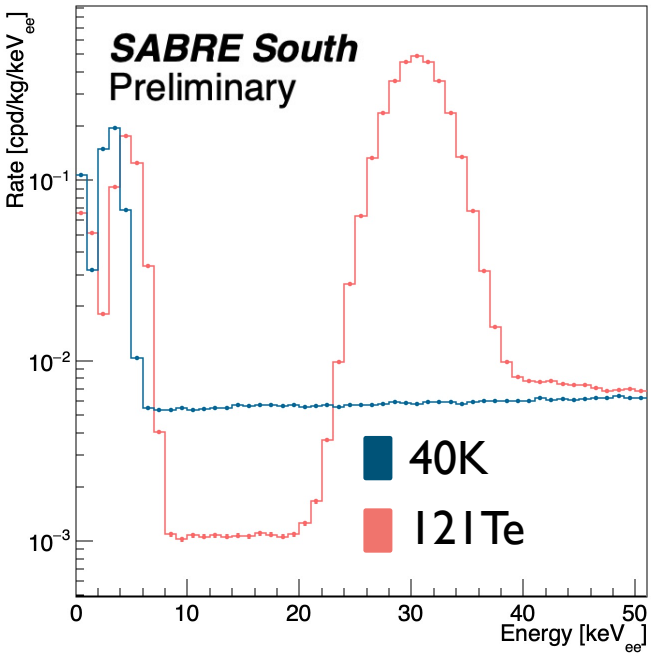
[1] SABRE South Collab. arxiv:2205.13849

Veto system not only reduces background but also allows for in situ measurements and particle ID.

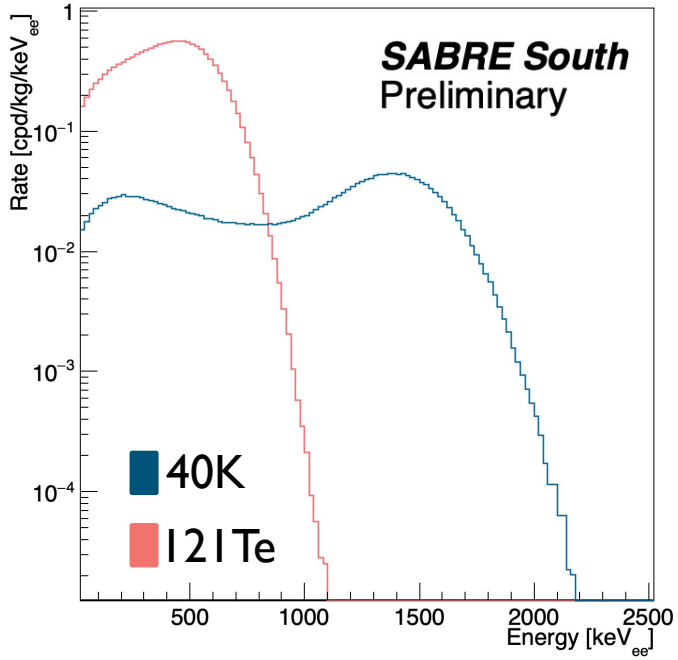


E.g., 40K and 121Te both have distinct islands in crystal-scint energy plane

Rate in crystals



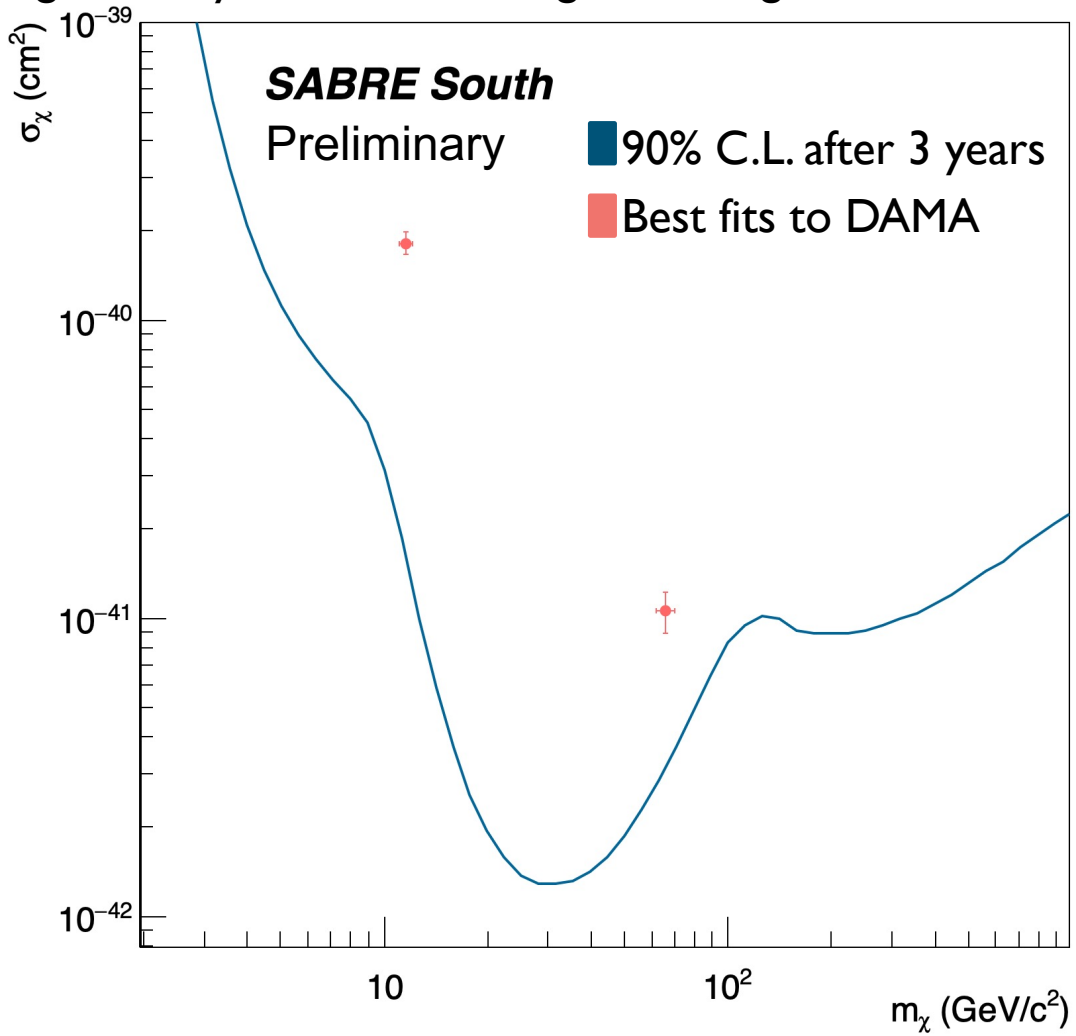
Rate in liquid scintillator

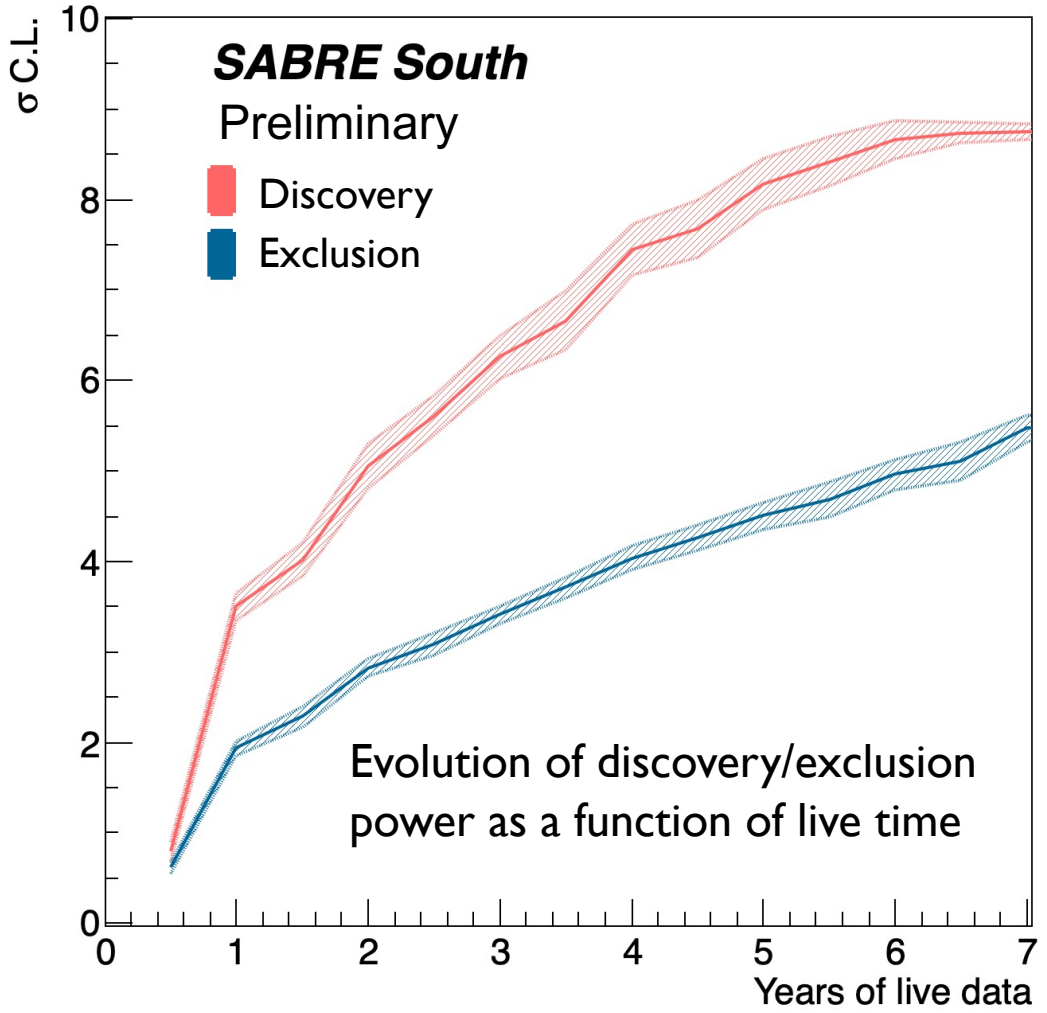


SENSITIVITY

[1] SABRE South Collab. arxiv:2205.13849

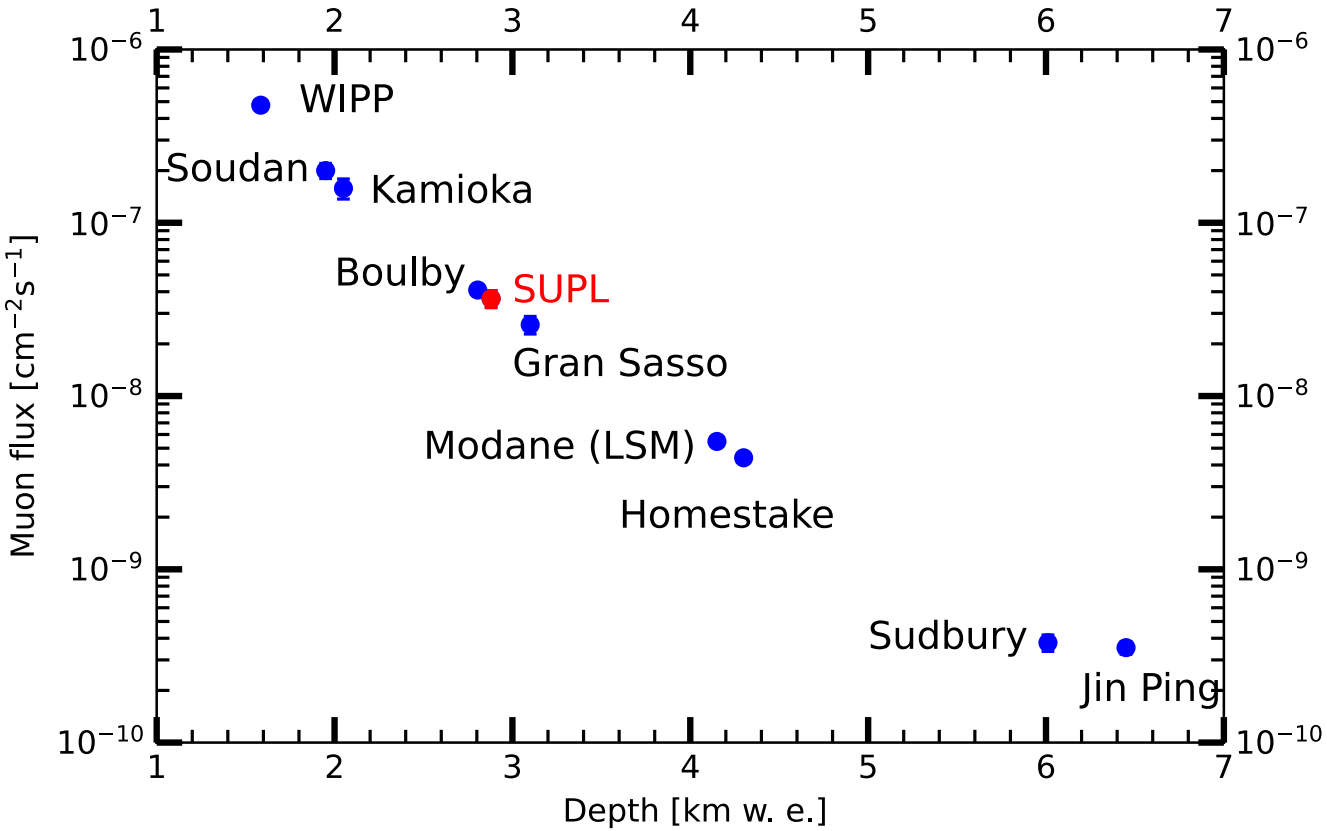
Assuming total crystal mass of 50 kg and background of 0.72 cpd/kg/keV from simulated radioactivity





SUPL STATUS

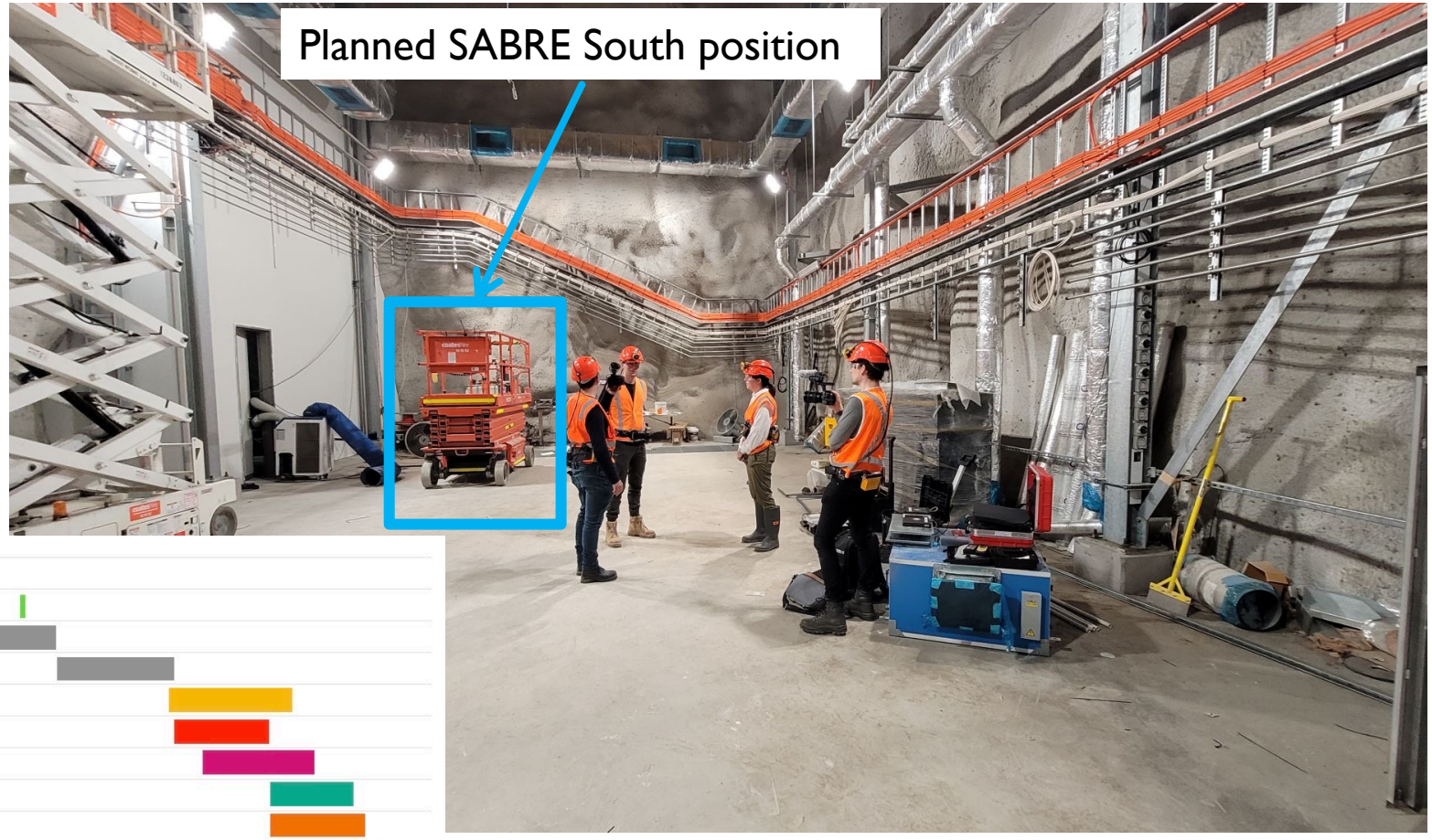
Stawell Underground Physics Laboratory located in Western Victoria 240 km from Melbourne.
Lab is 1025 m below ground with flat over burden.

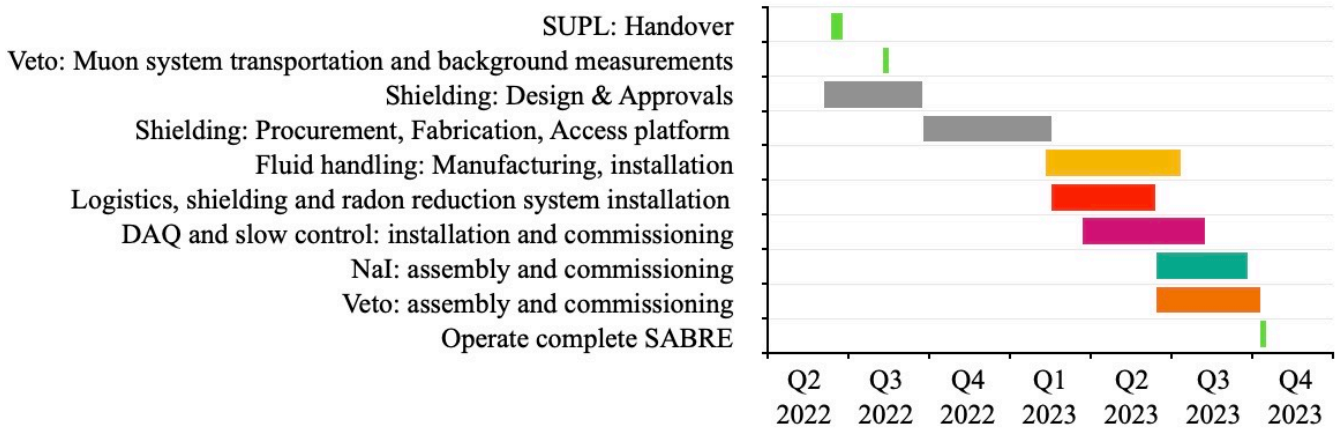


SUPL STATUS

- Construction complete and operations will start in August/September 2022

- Background measurements of muons, gammas, and neutrons planned for late 2022





SUMMARY

- SABRE South is part of the SABRE Collaboration designed to test DAMA modulation
- High purity crystals and large active veto giving ultra-low background (~0.7 cpd/kg/keV)
- Allows for 3σ exclusion or 5σ discovery with just over two annual cycles of data
- SUPL is a new underground physics lab 1025 m underground freshly handed over
- SABRE South will be commissioned over the next 12 months, with data taking commencement planned for mid/late-2023

Unanswered questions? Contact me:
Email: madeleine.zurowski@unimelb.edu.au
Twitter: @mjzurowski
Or scan QR code for my details

Full reference list:

ACKNOWLEDGEMENTS

ARC CENTRE OF EXCELLENCE FOR DARK MATTER

SABRE South

Australian Government

Australian National University

SWINBURNE UNIVERSITY OF TECHNOLOGY

THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF MELBOURNE

SABRE North

INFN Istituto Nazionale di Fisica Nucleare

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

Pacific Northwest NATIONAL LABORATORY

PRINCETON UNIVERSITY

SAPIENZA UNIVERSITÀ DI ROMA

UNIVERSITÀ DEGLI STUDI DI MILANO

RMD A Dynasil Company

Some members of the Australian National University, University of Melbourne, and Swinburne groups

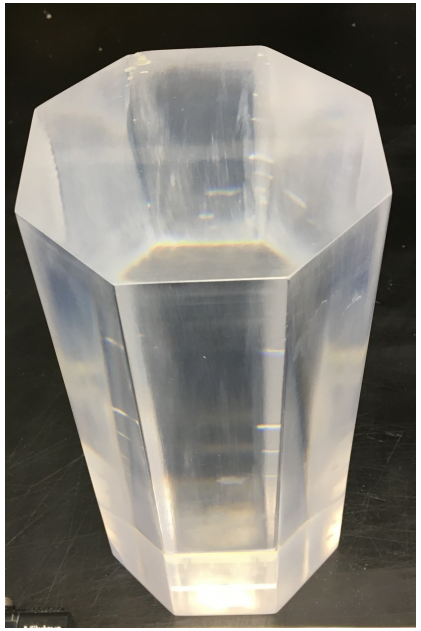
BACK UP

HIGH PURITY CRYSTALS

Through R&D based out of Princeton in collaboration with RMD, SABRE have developed some of the lowest background crystals in the world.

Crystal	^{nat}K (ppb)	^{238}U (ppt)	^{226}Ra (μBq/kg)	^{210}Pb (μBq/kg)	^{232}Th (μBq/kg)
DAMA [1]	13	0.7-10	8.7-124	5-30	2-31
ANAIS [2]	31	<0.81	-	1530	0.4-4
COSINE [3]	<42	<0.12	8-60	10-420	7-35
SABRE [4]	2.2±1.5	0.4	5.9±0.6	410±20	1.6±0.3
PICOLON [5]	<20	-	13±4	<5.7	1.2±1.4

Crystal backgrounds from various groups. Lowest achieved level for each contaminant is highlighted in blue.



NaI-35: a SABRE South crystal currently undergoing characterisation

[1] R. Bernabei et al., NIMA 592(3) (2008)
[2] J. Amare et al., EPJC 79 412(2019)
[3] P. Adhikari et al., EPJC 78 490 (2018)
[4] F. Calaprice et al., PRD 104 (2021)
[5] K. Fushimi et al., PTEP 4 043F01 (2021)

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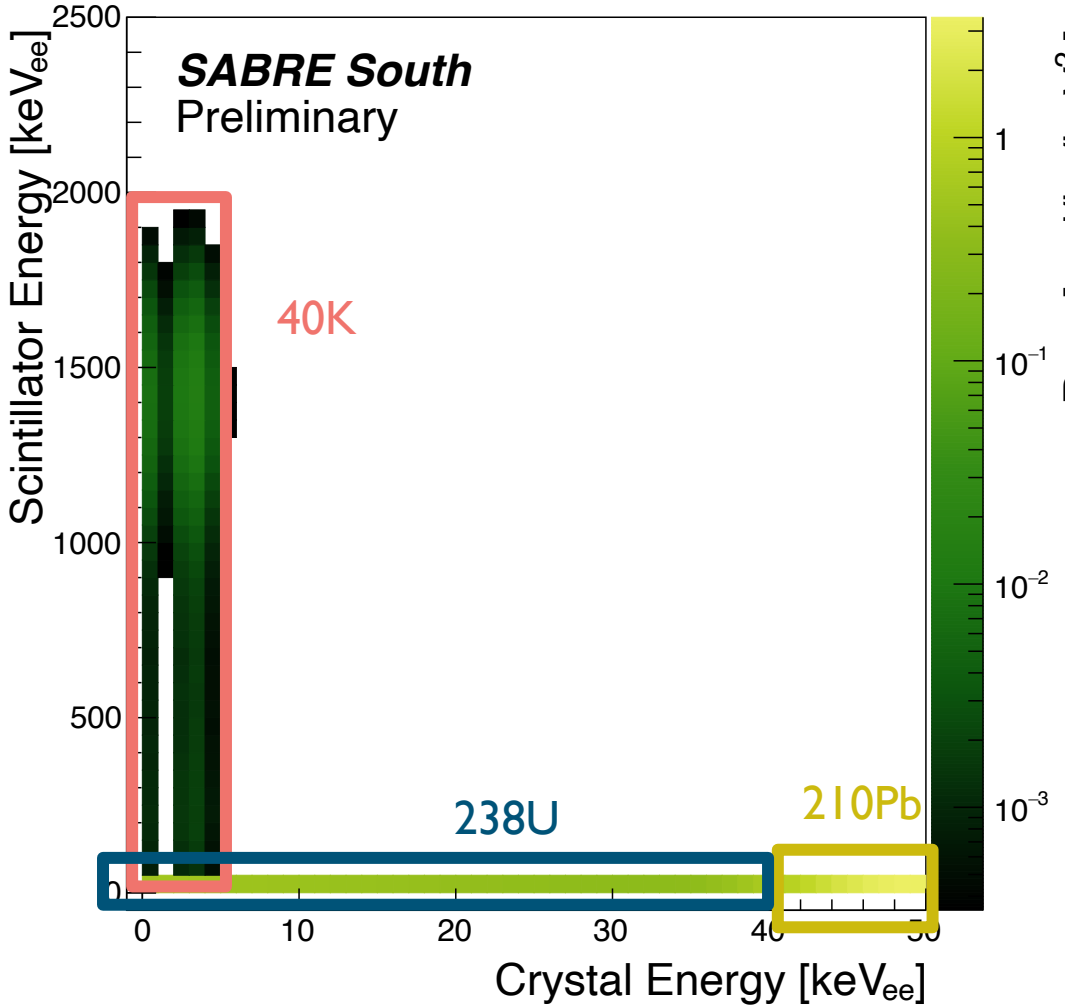
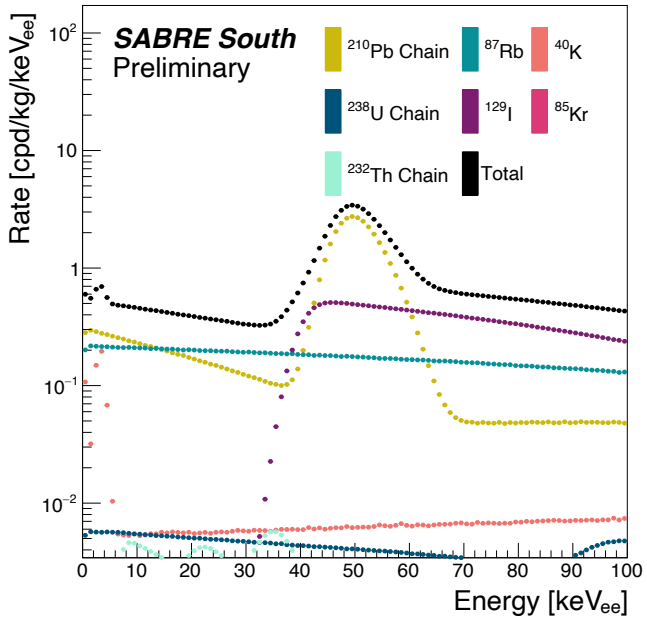
[1] SABRE South Collab. arxiv:2205.13849

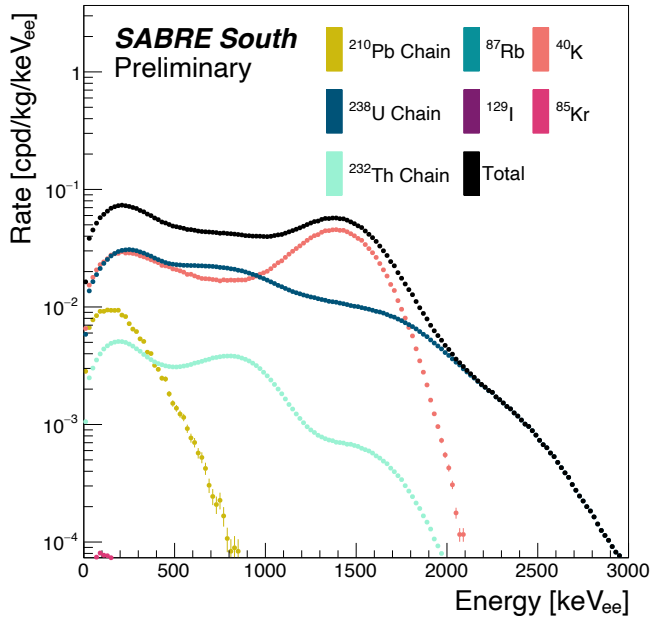


Contamination from intrinsic radiation of crystals

Deposition in crystal



Deposition in veto



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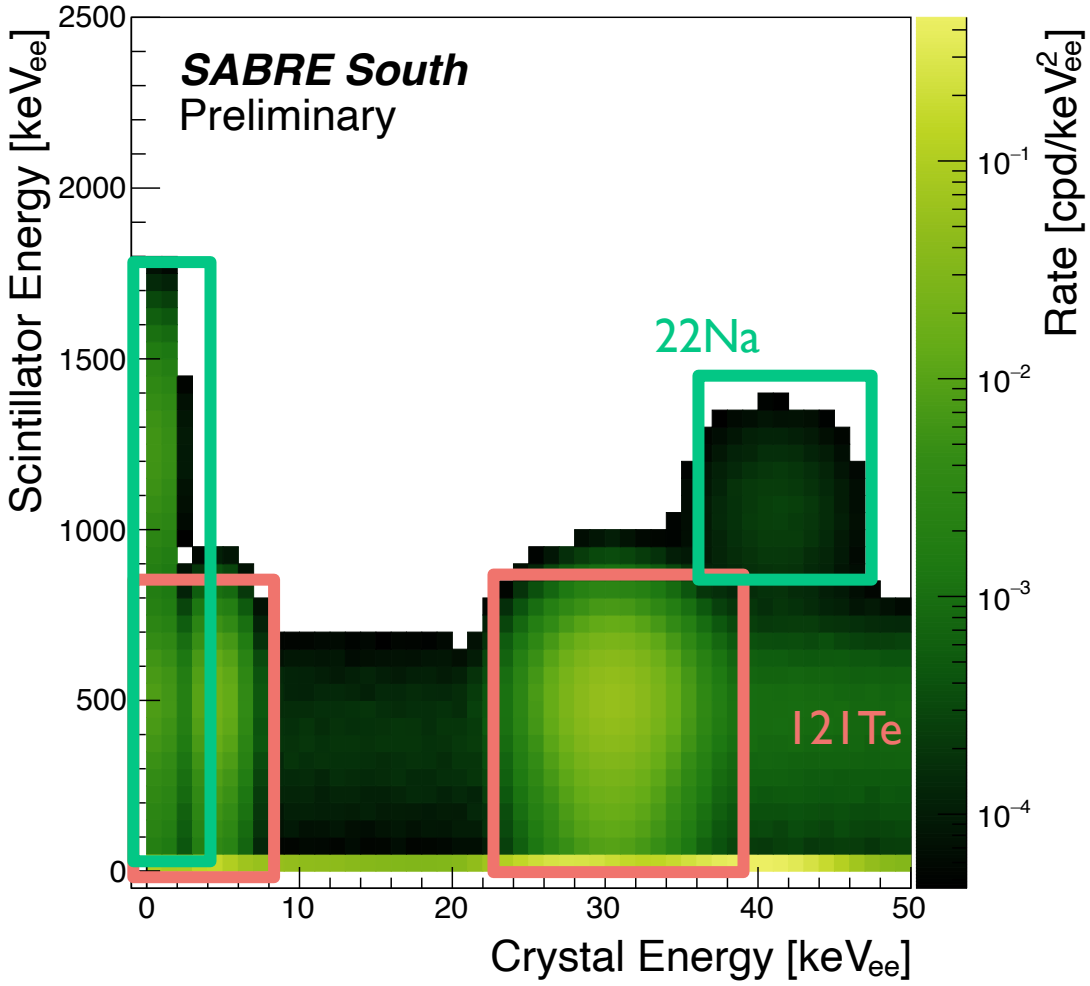
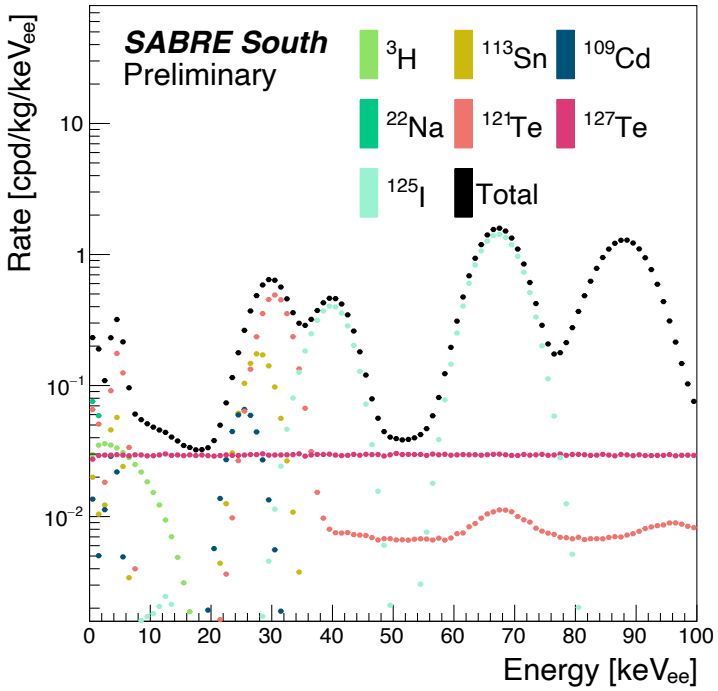
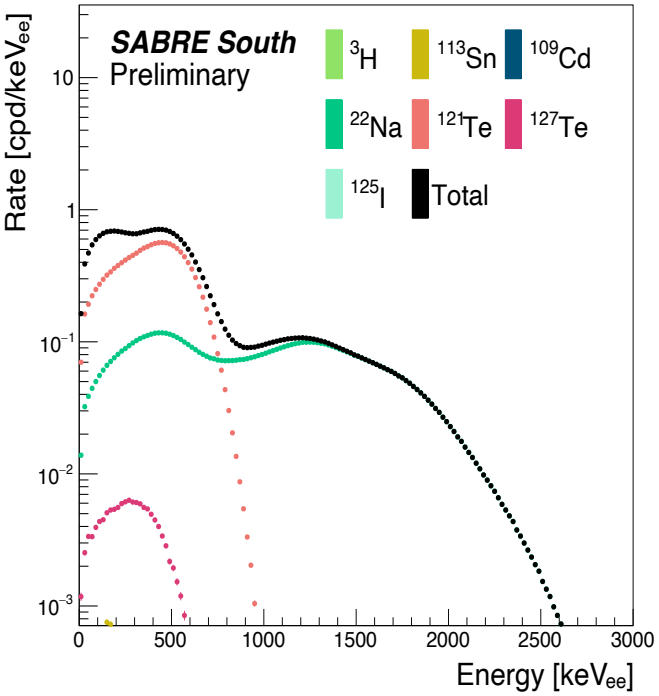


Contamination from cosmogenic activation of crystals

Deposition in crystal



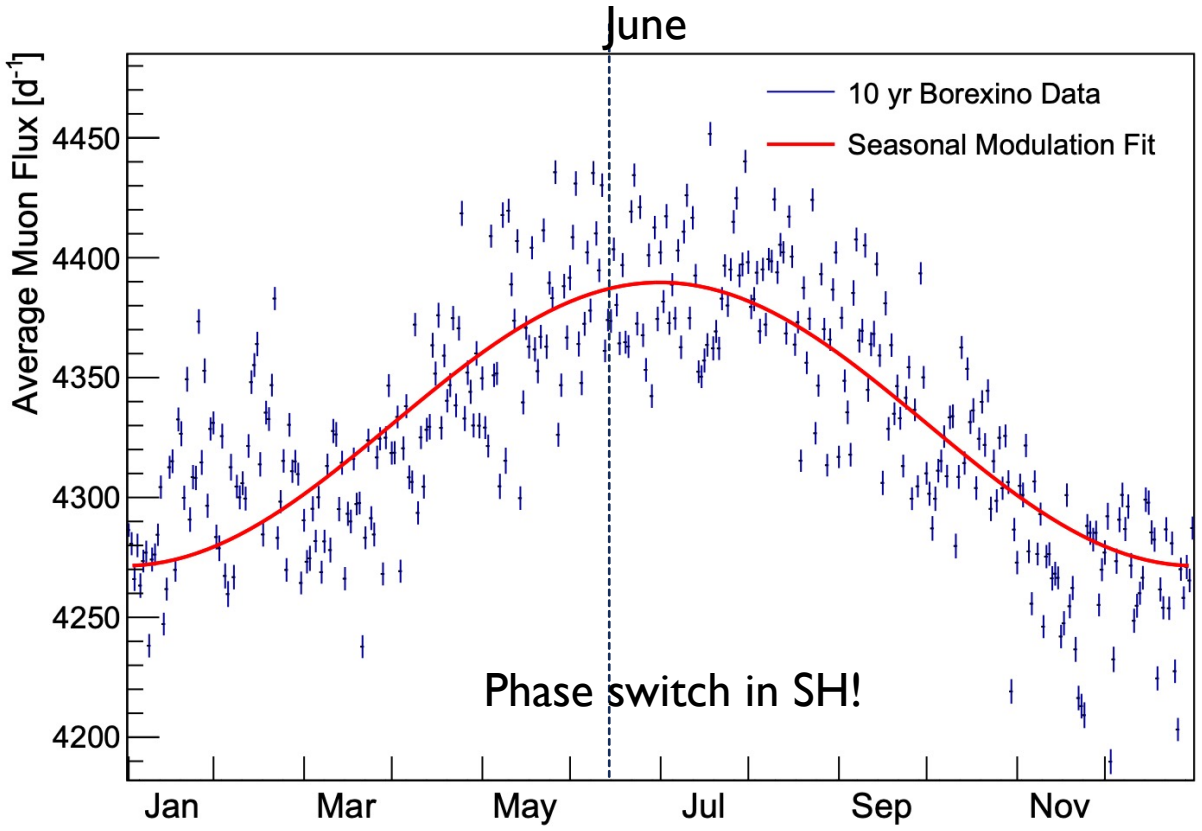
Deposition in veto



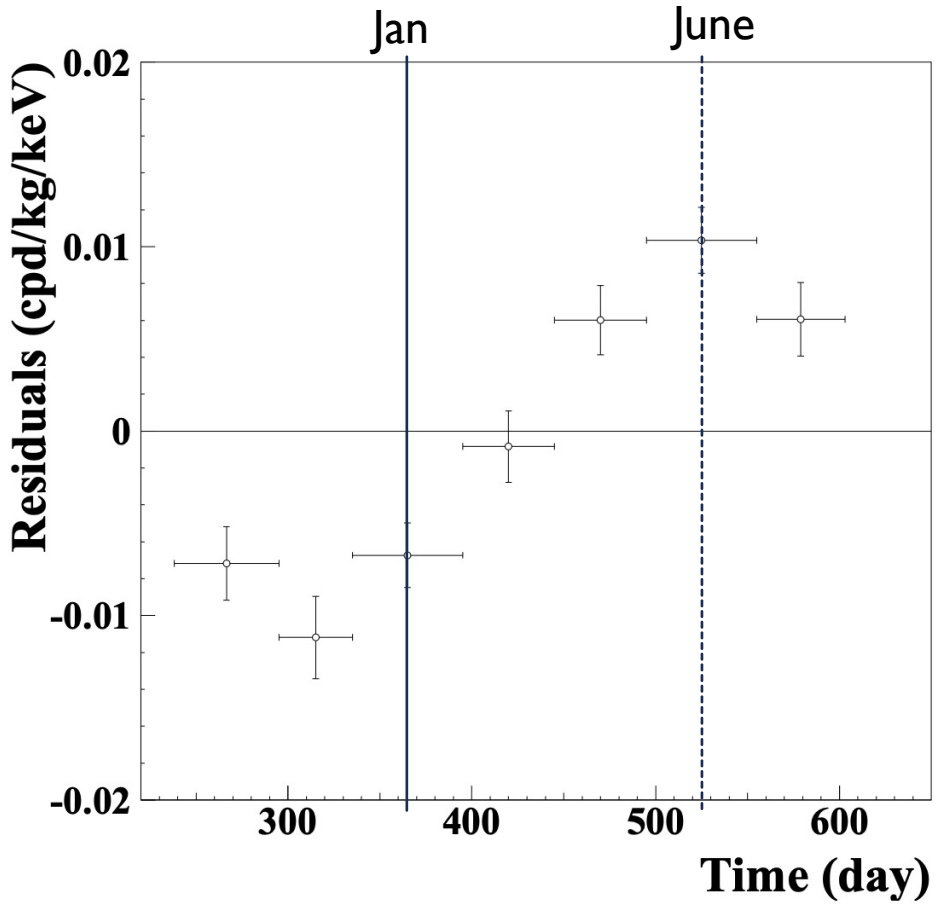
MUON BACKGROUND REJECTION

[1] Borexino collab. JCAP02(2019)046
[2] DAMA collab. Nucl. Phys. At. Energy 19 (2018)

Muons a particular issue for DM modulation searches as they have a similar phase due to seasonal dependence. Need to be carefully measured to understand their impact on the data.



Average muon rate at Borexino over 10 yrs [1]



Average modulation at DAMA over 6 yrs[2]