STATUS OF THE SABRE SOUTH EXPERIMENT

AT THE STAWELL UNDERGROUND PHYSICS LABORATORY

PPC 2022: XV International Conference on
Interconnections between Particle Physics and Cosmology

Madeleine J. Zurowski on behalf of the SABRE South Collaboration
The University of Melbourne

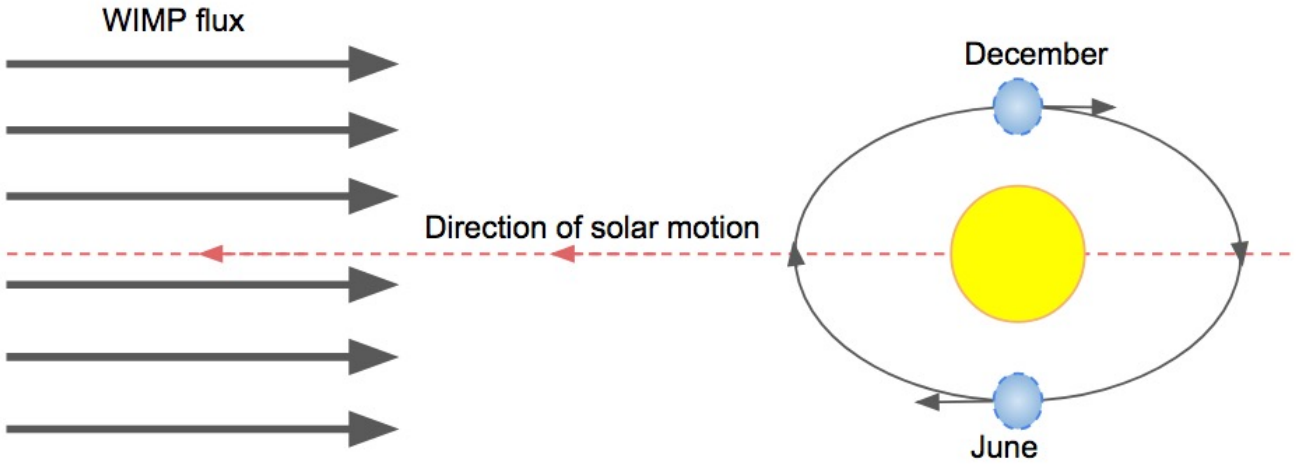
madeleine.zurowski@unimelb.edu.au

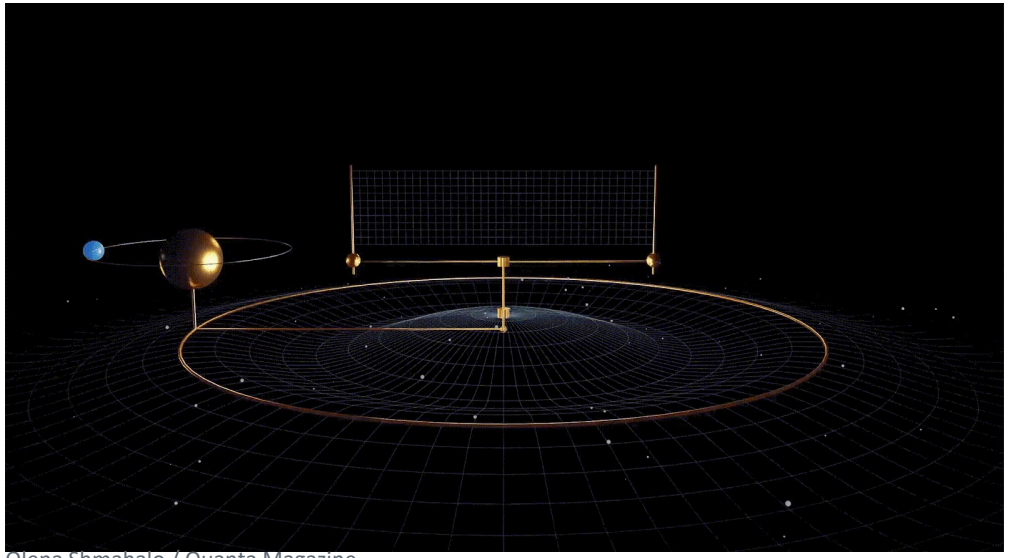
MODULATING SIGNAL

Astrophysical predictions of DM distribution imply a modulating signal due to Earth's rotation around the Sun.

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

- Period should be 1 year
- Phase should produce a peak in June
- Signal should appear in low energy range
- Events should be single hit





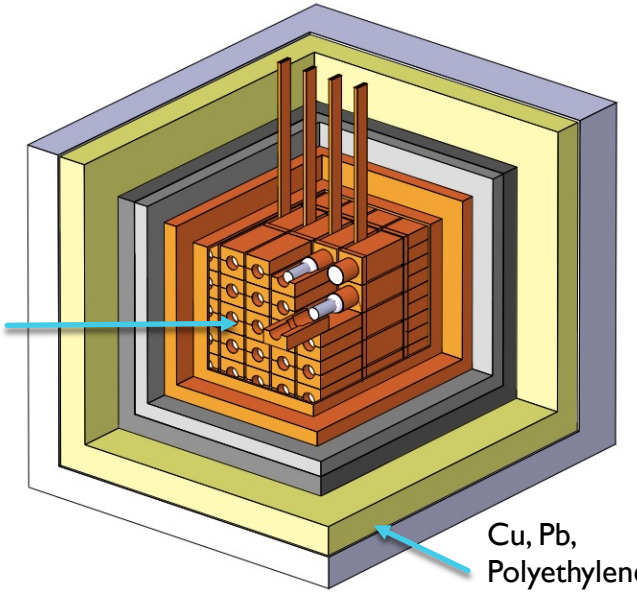
Olena Shmahalo / Quanta Magazine

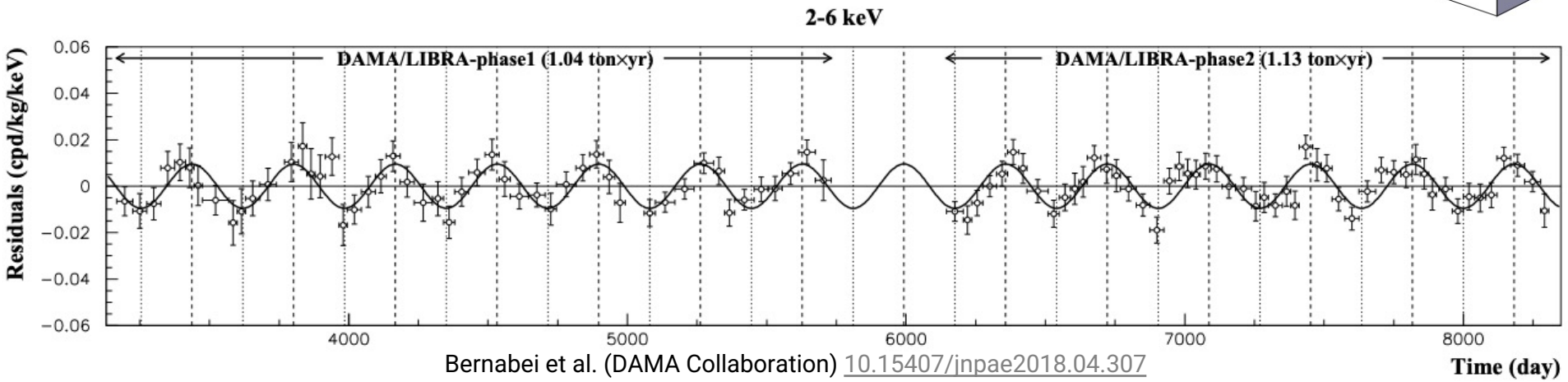
DAMA RESULTS

250 kg NaI(Tl) detector based in LNGS consistently observed modulation rate compatible with DM expectations for ~20 years w/ ~13σ significance.

- R_m: 0.01058±0.00090 cpd/kg/keV
- Phase: 144.5±5.1 days
- Period: 0.999±0.001 yr
- Modulation present in 1-6 keV

<u>No direct fitting to constant rate</u>, but upper limit given of ~0.8 cpd/kg/keV





Bernabei et al. (DAMA Collaboration) 10.15407/jnpae2018.04.307

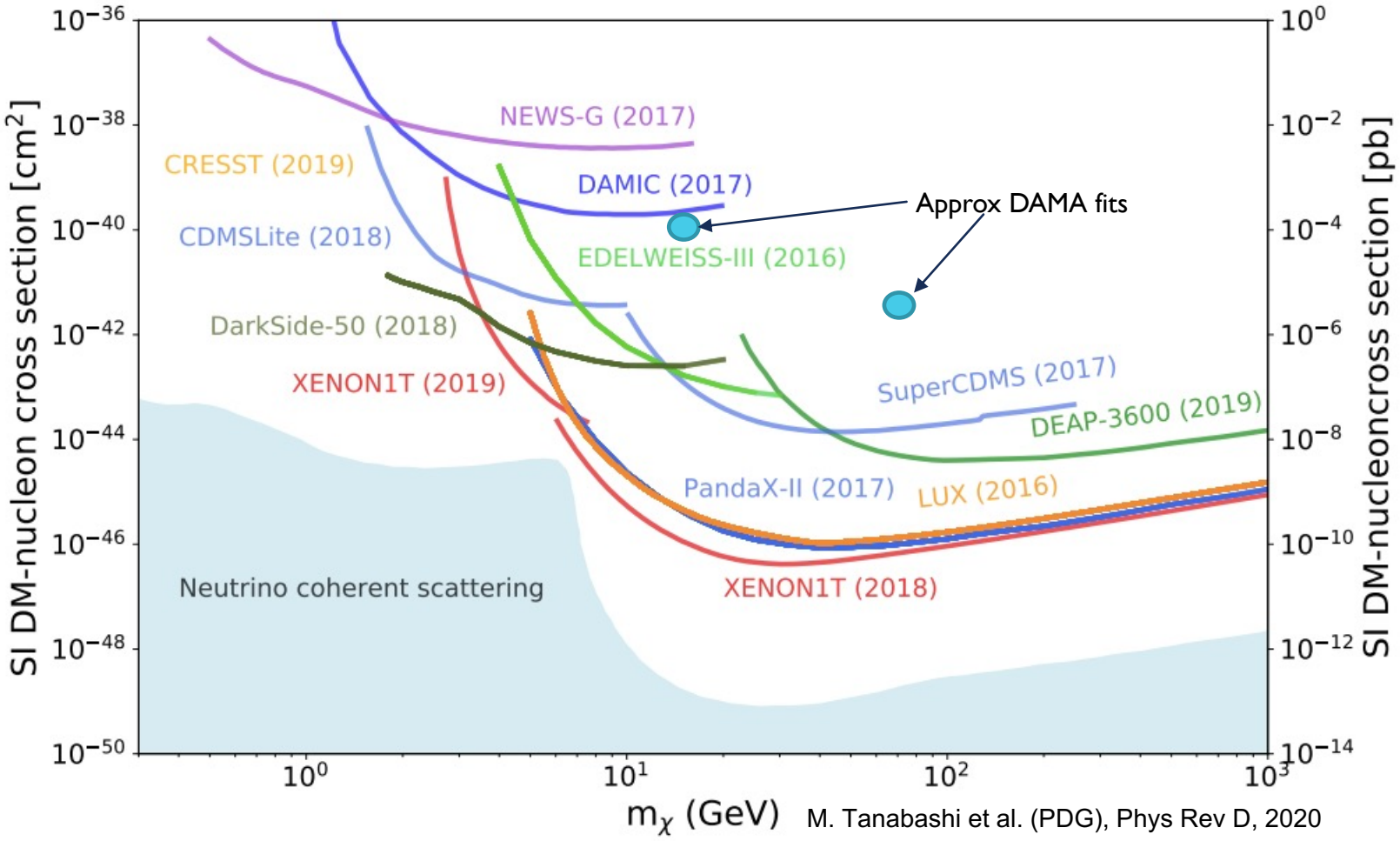
EXPERIMENTAL TENSION

Interpretation as DM is strongly constrained by null results from different targets.

BUT!

These constraints rely on assumption of DM model. Need a model independent test to understand if DAMA is seeing DM.

This requires detectors to use the same target – NaI(Tl).



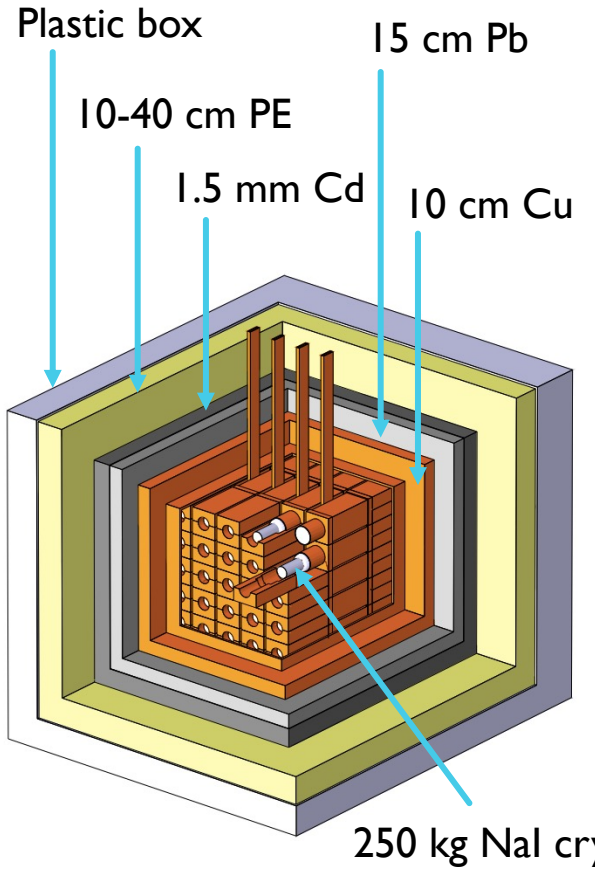
M. Tanabashi et al. (PDG), Phys Rev D, 2020

NAI DETECTORS

[1] Bernabei et al. PPNP114 103810 (2020)
[2] Adhikari et al. EPJC 78, 107 (2018)
[3] Amare et al. PRD 103, 102005 (2021)

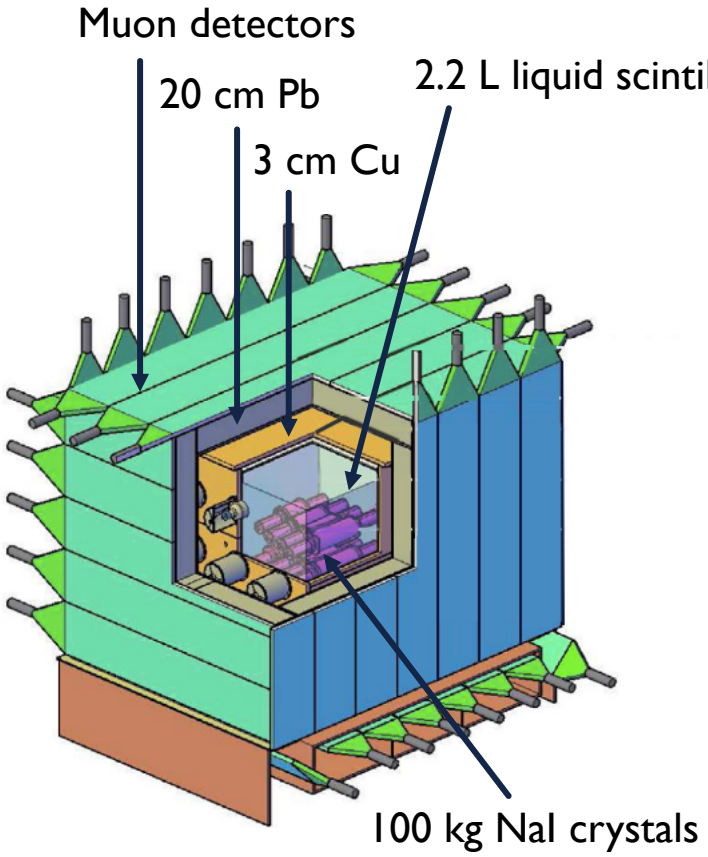
DAMA[1]

Background ~0.8 cpd/kgk/keV



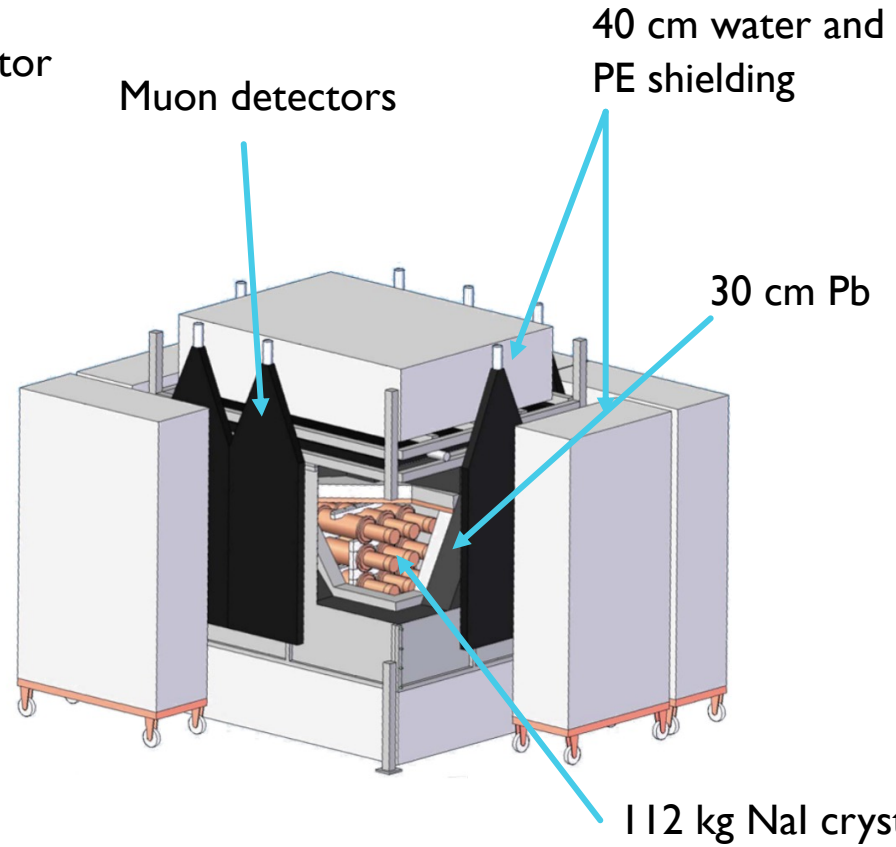
COSINE[2]

Background ~2.9 cpd/kg/keV



ANAIS[3]

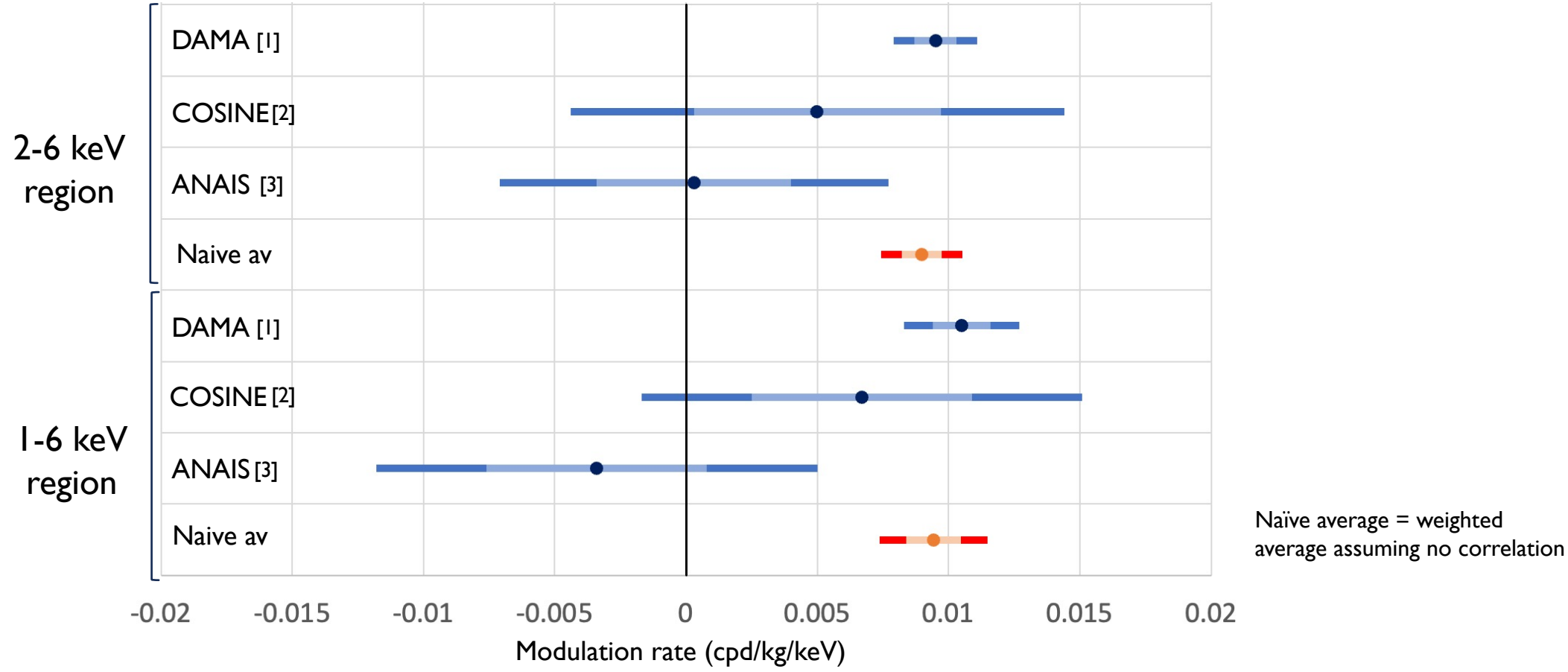
Background ~3.2 cpd/kg/keV



RECENT RESULTS

[1] Bernabei et al. PPNP114 103810 (2020)
[2] Adhikari et al. arxiv:2111.08863
[3] Amare et al. PRD 103, 102005 (2021)

For modulation searches, both COSINE and ANAIS are beginning to reach strong sensitivity, but at present both still compatible with DAMA and null hypothesis within 3σ due to high backgrounds



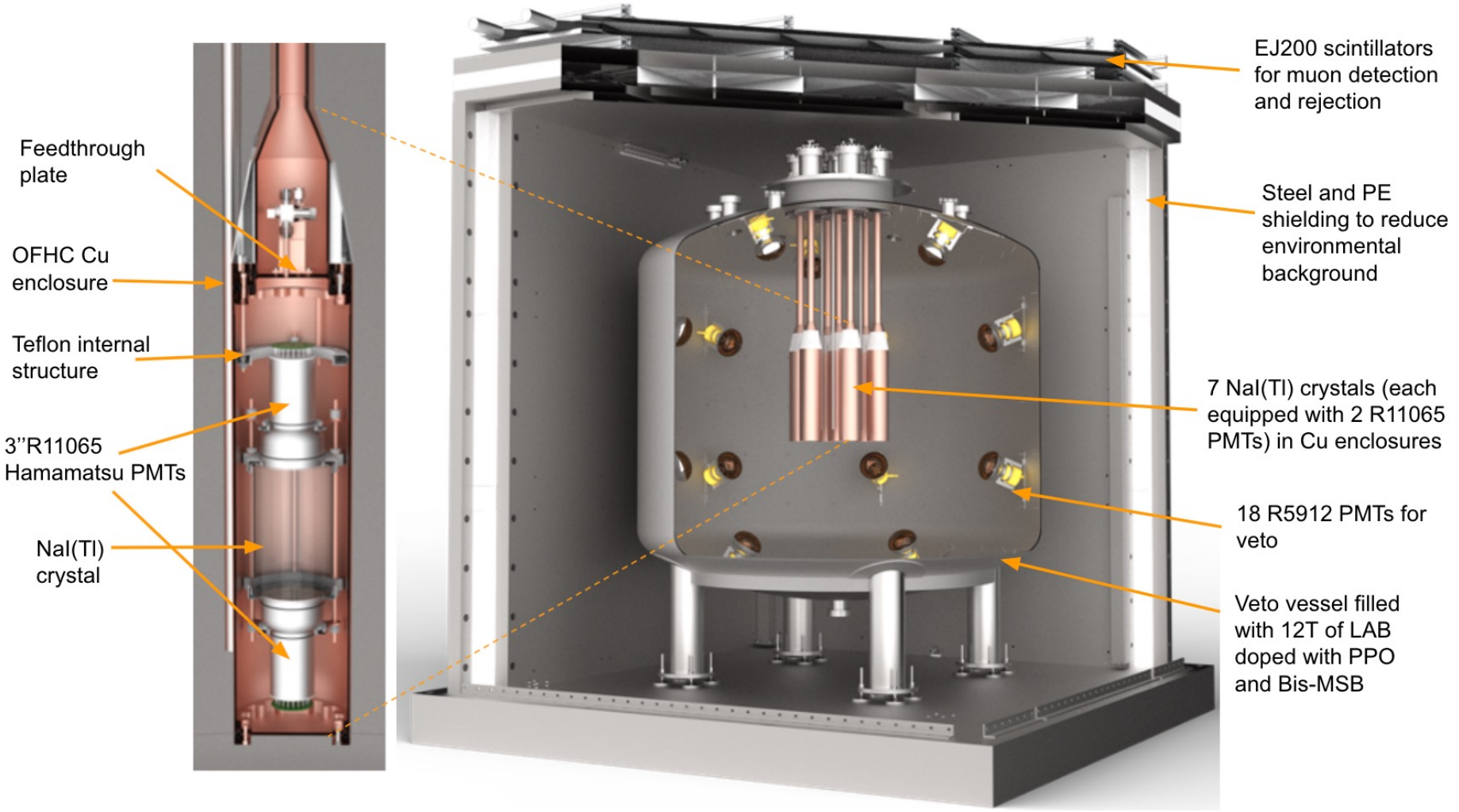
Naïve average = weighted average assuming no correlation

SABRE SOUTH

Purpose of SABRE is to test DAMA with four key improvements:

1. Ultra high purity crystals
2. Active background rejection
3. Low energy threshold
4. Dual hemisphere data

Detectors will be placed at both SUPL (Victoria, Australia) and LNGS (Italy) with data taking planned for 2023.

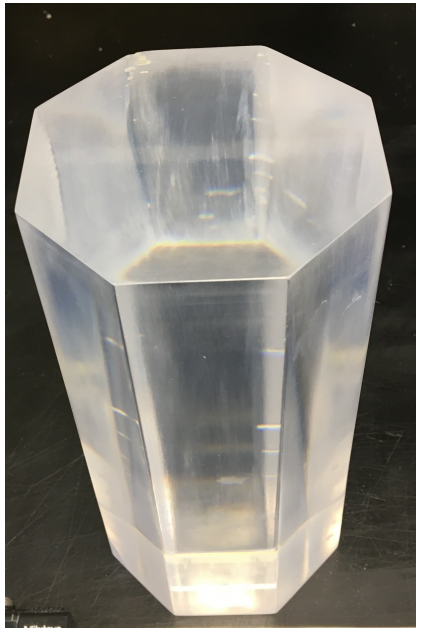


HIGH PURITY CRYSTALS

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)

ACTIVE BACKGROUND REJECTION

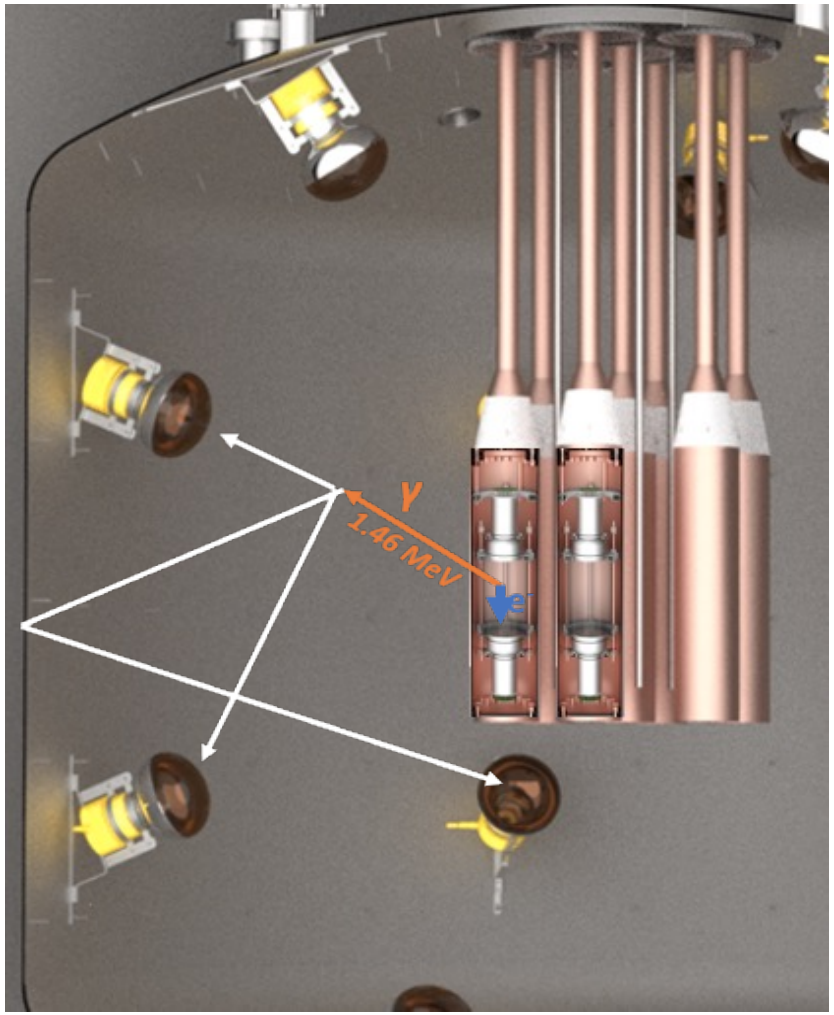
Veto system used to tag and remove high energy decay products observable in the liquid scintillator, e.g., 40K decay

System has 4π coverage made up of:

- 12 kL linear alkyl benzene doped with PPO and Bis-MSB
- 18 Hamamatsu 8" R5912 PMTs sampled at 500 MS/s

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

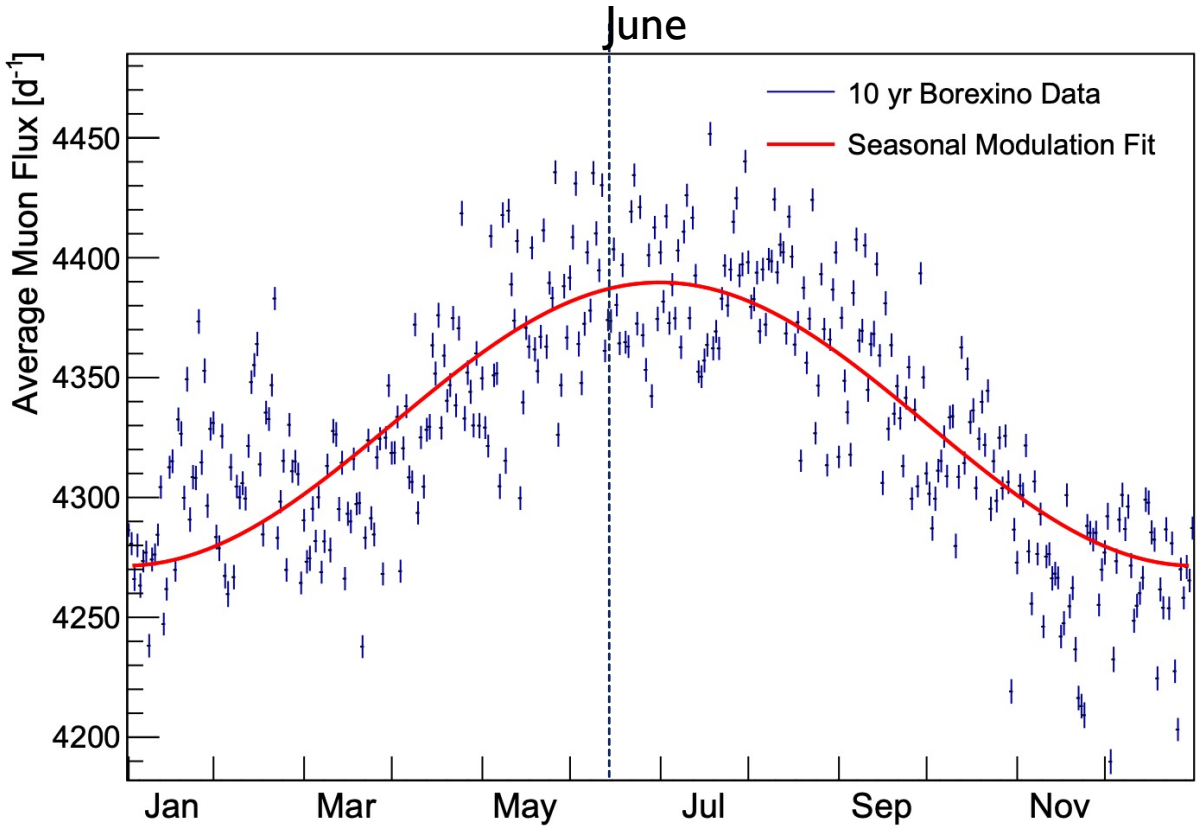
With a threshold of 50 keV it is able to reduce the background by 25% , giving a total background of <1cpd/kg/keV.



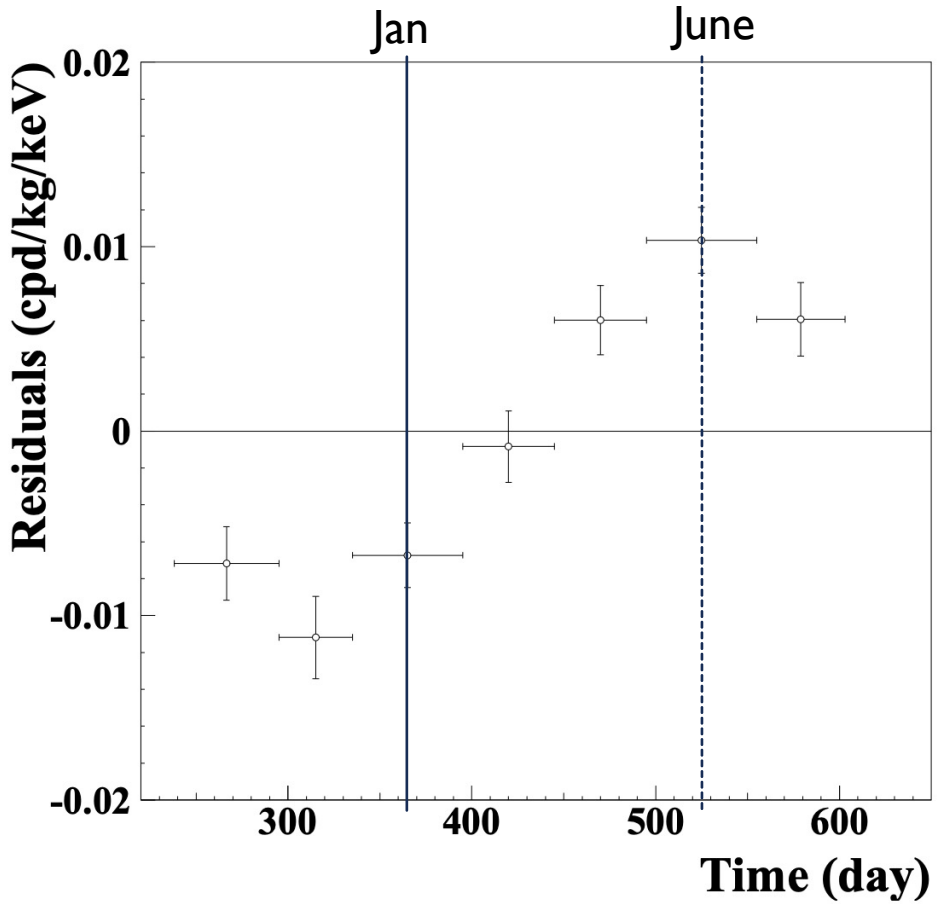
MUON BACKGROUND REJECTION

[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]

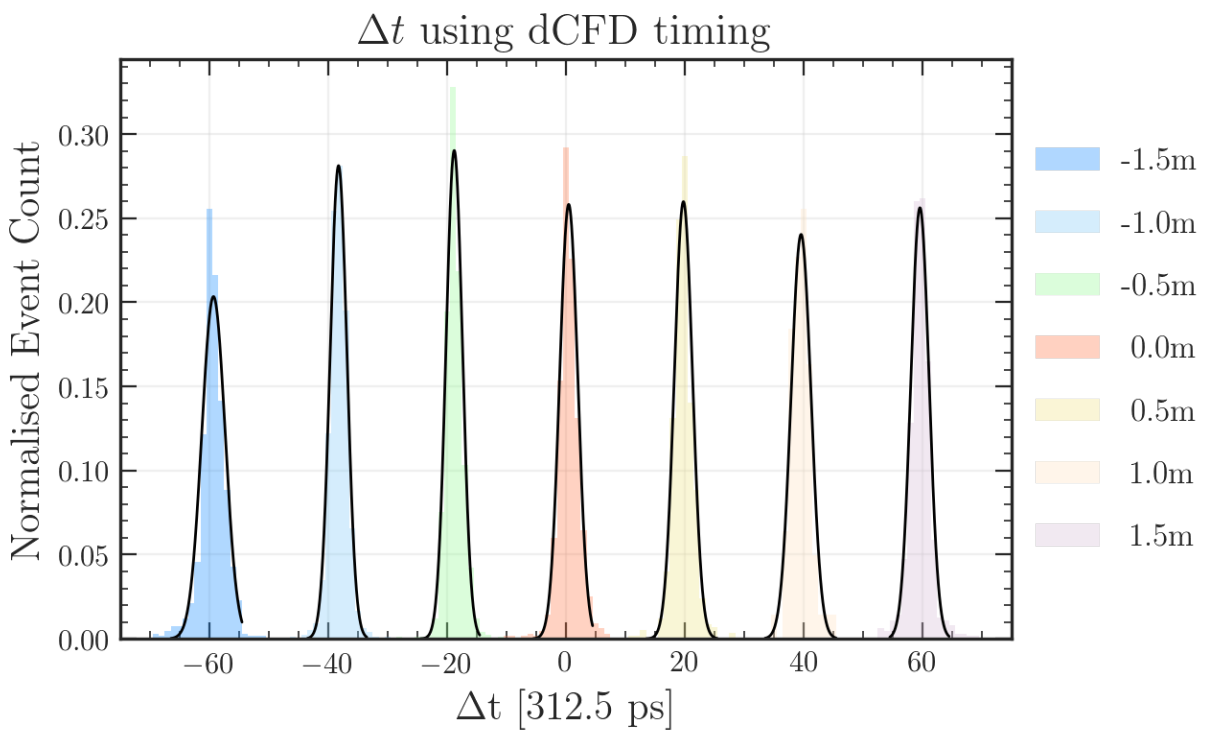


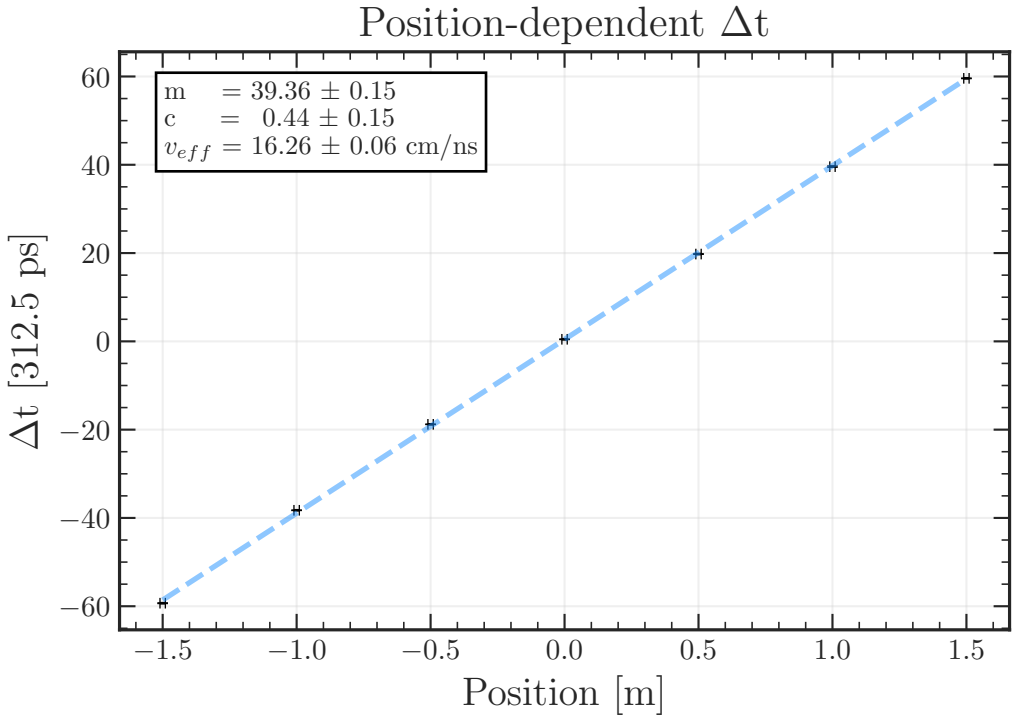
Average modulation at DAMA over 6 yrs[2]

MUON BACKGROUND REJECTION

Muon detection system eight 3 m long EJ200 detector paddles, each coupled to two R13089 PMTs and sampled at 3.2 GS/s. The system has a total coverage of 9.6 m^2 on top of the main vessel.

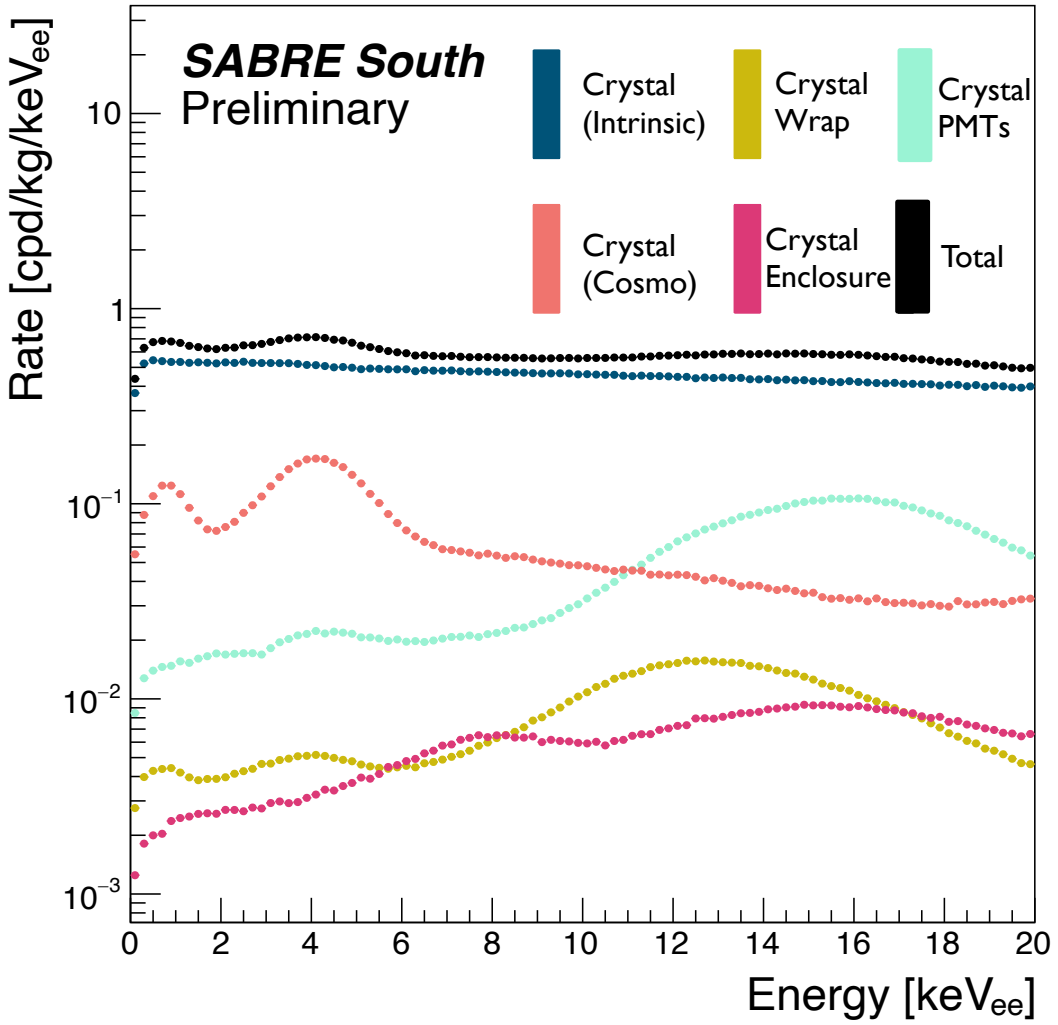
Detectors have 200 ps timing resolution, giving a 5 cm position resolution.
This allows for long term measurement of the muon flux, and particle ID when used with the liquid veto system.





TOTAL BACKGROUND MODEL

[1] SABRE South Collab. arxiv:2205.13849

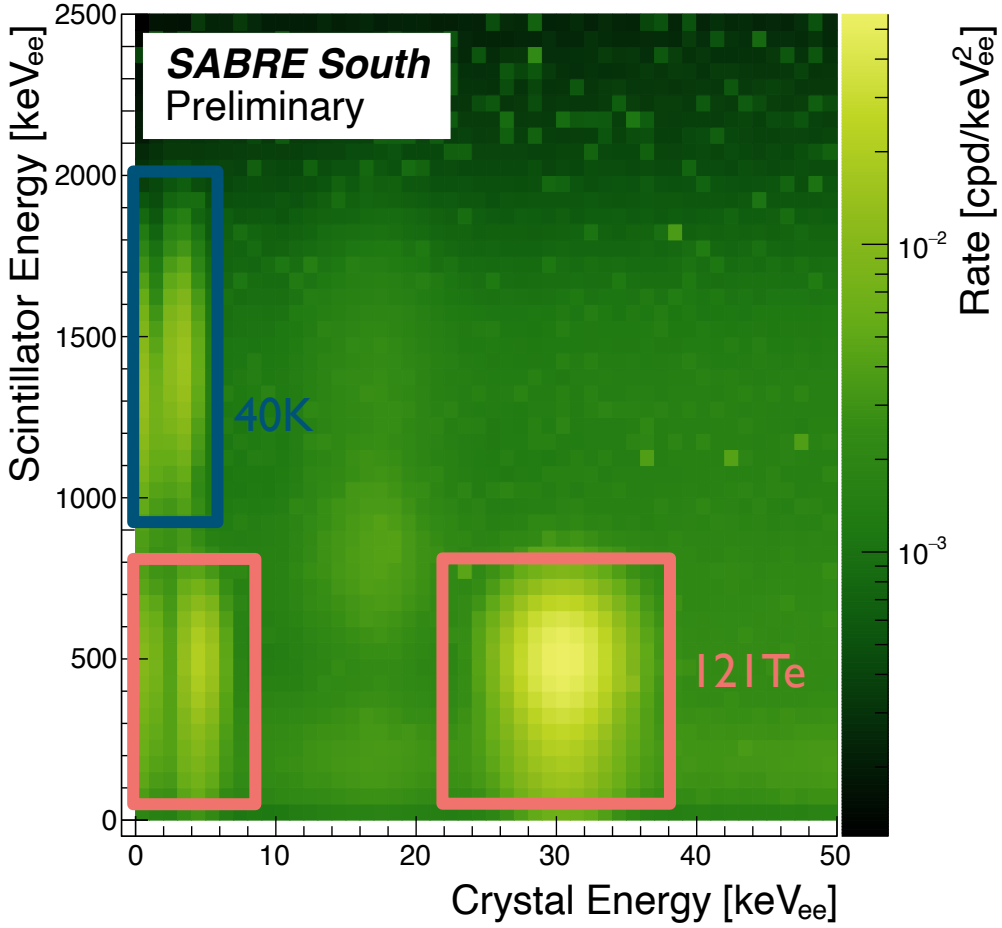


Component	Rate (cpd/kg/keV)	Veto efficiency (%)
Crystal intrinsic	$<5.2 \times 10^{-1}$	13
Crystal cosmogenic	1.2×10^{-1}	45
Crystal PMTs	2.0×10^{-2}	57
Crystal wrap	4.5×10^{-3}	11
Enclosures	3.2×10^{-3}	85
Conduits	1.9×10^{-5}	96
Steel vessel	1.4×10^{-5}	>99
Veto PMTs	1.9×10^{-5}	>99
Shielding	3.9×10^{-6}	>99
Liquid scintillator	4.9×10^{-8}	>99
External	5.0×10^{-4}	>93
Total	**6.6×10^{-1}**	**25**

TOTAL BACKGROUND MODEL

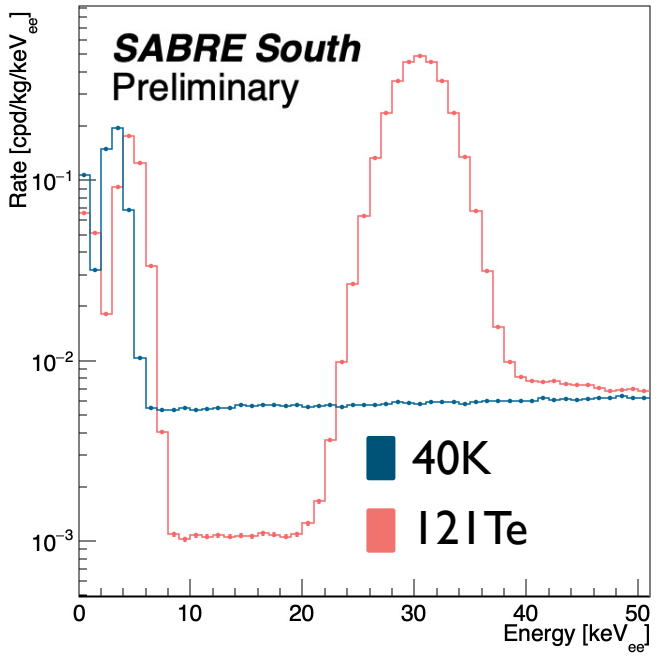
[1] SABRE South Collab. arxiv:2205.13849

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

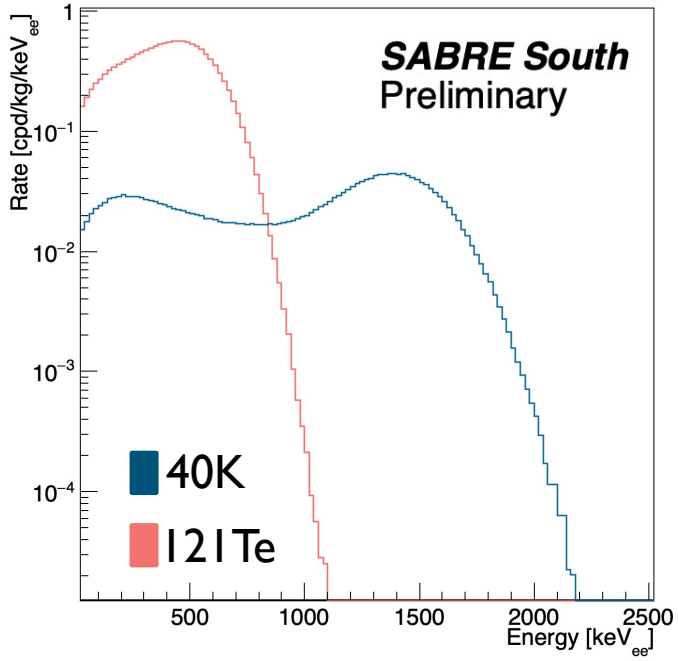


E.g., 40K and 121Te both have distinct islands in crystal-scint energy plane

Rate in crystals



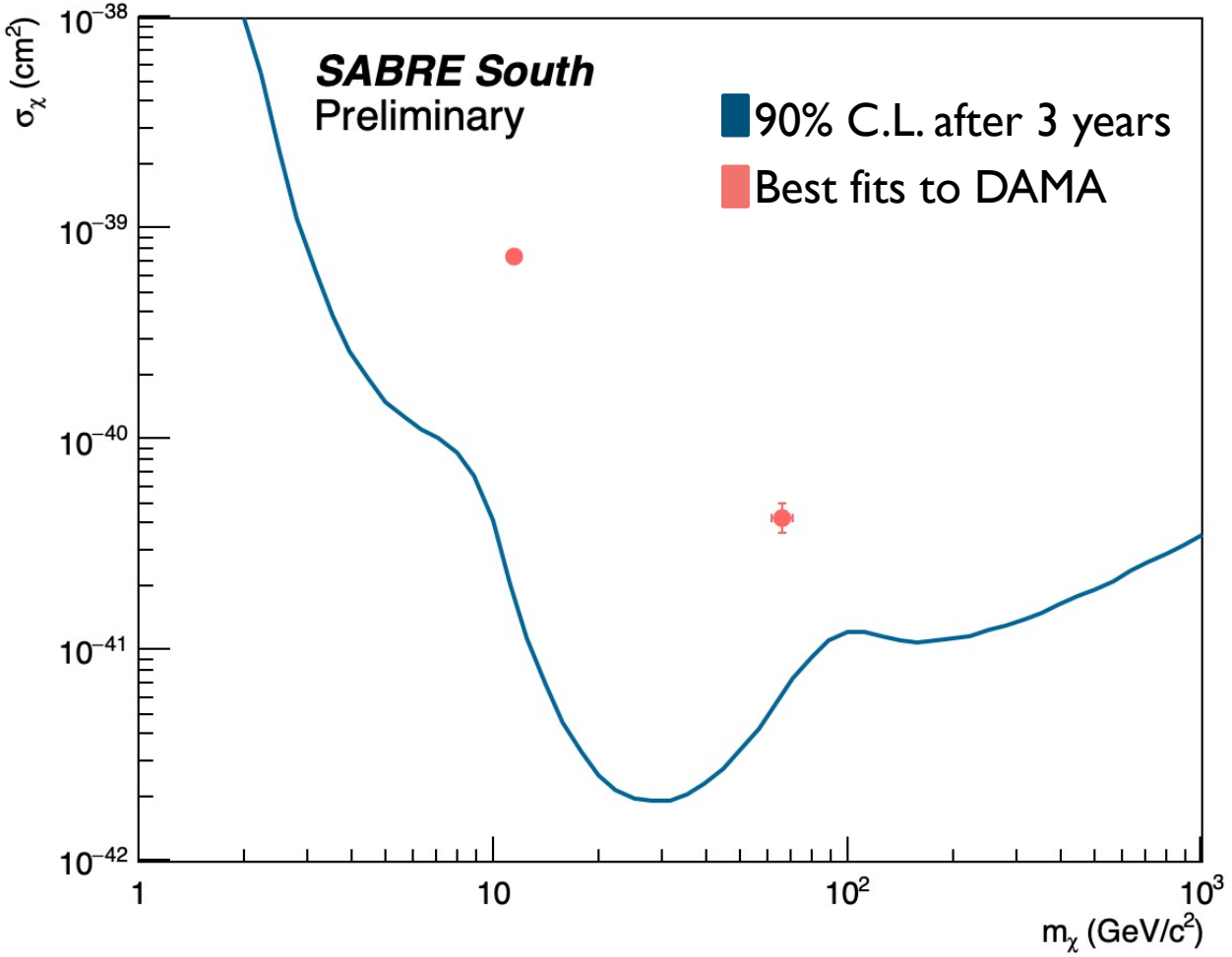
Rate in liquid scintillator

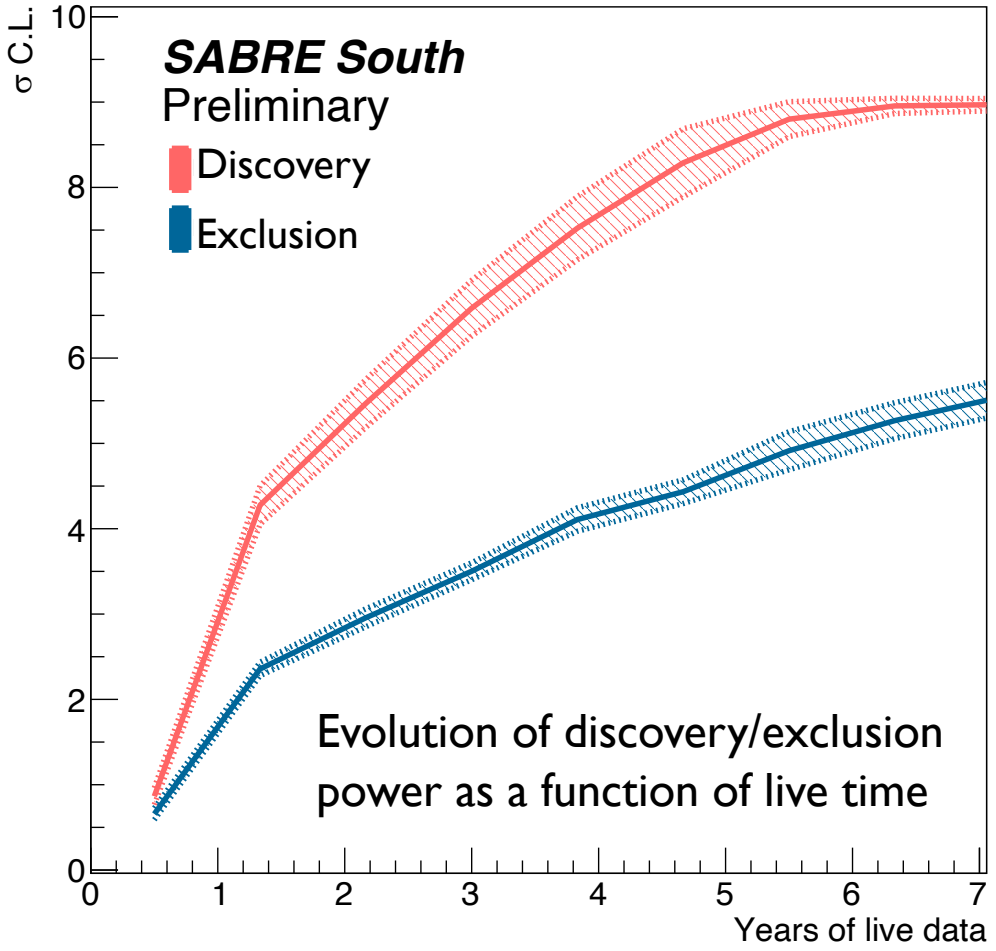


SENSITIVITY

[1] SABRE South Collab. arxiv:2205.13849

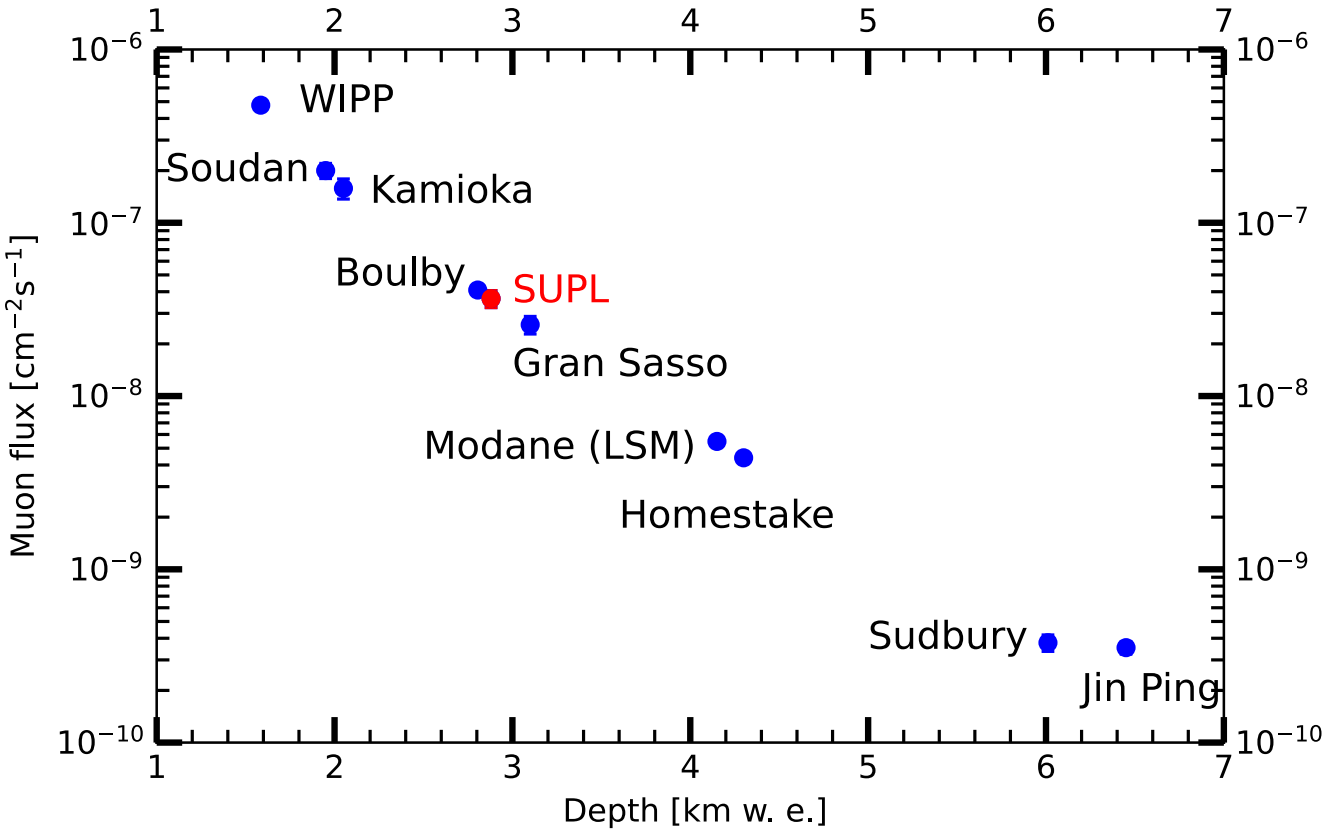
Assuming total crystal mass of 50 kg and background spectrum from simulated radioactivity





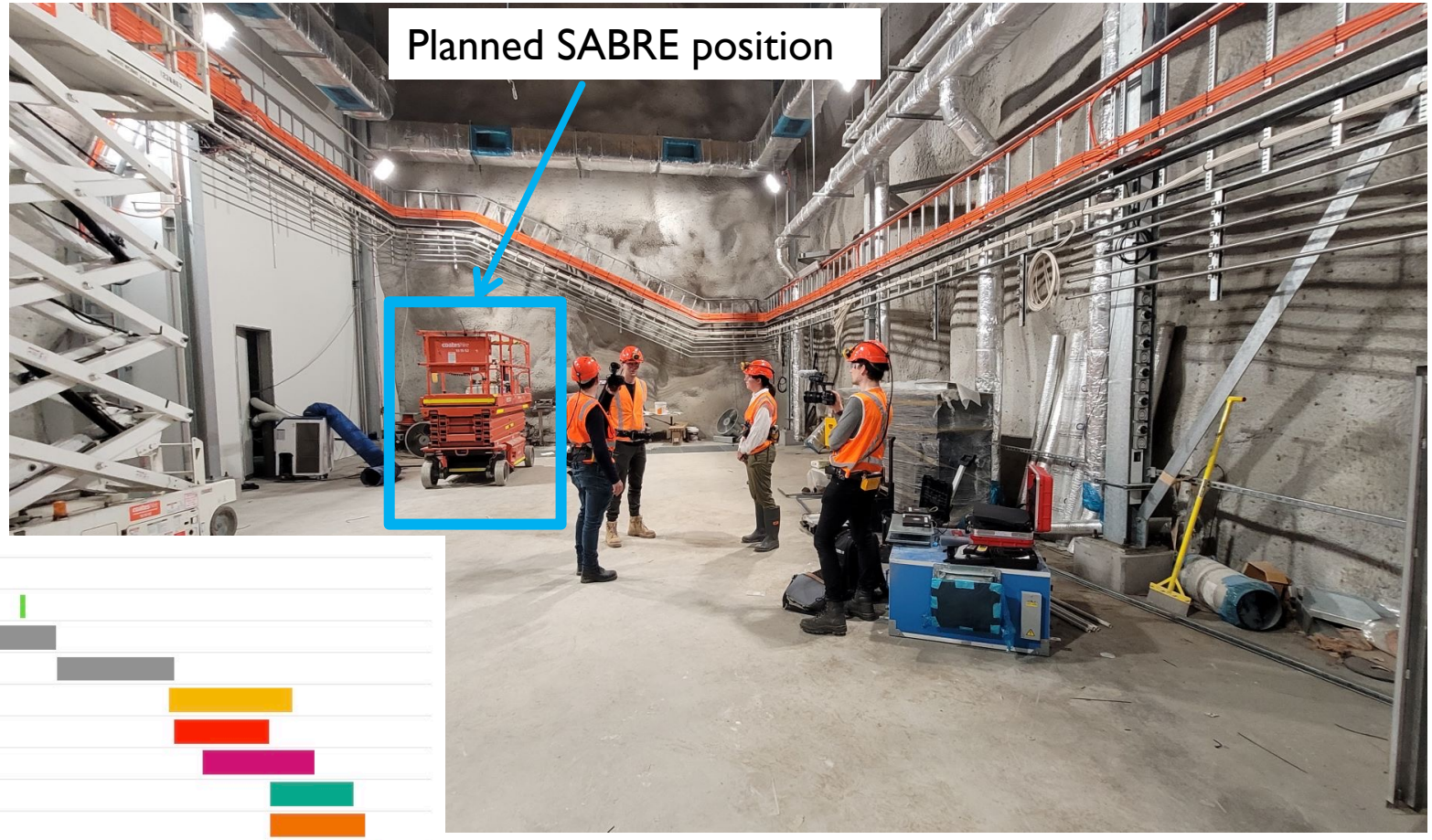
SUPL STATUS

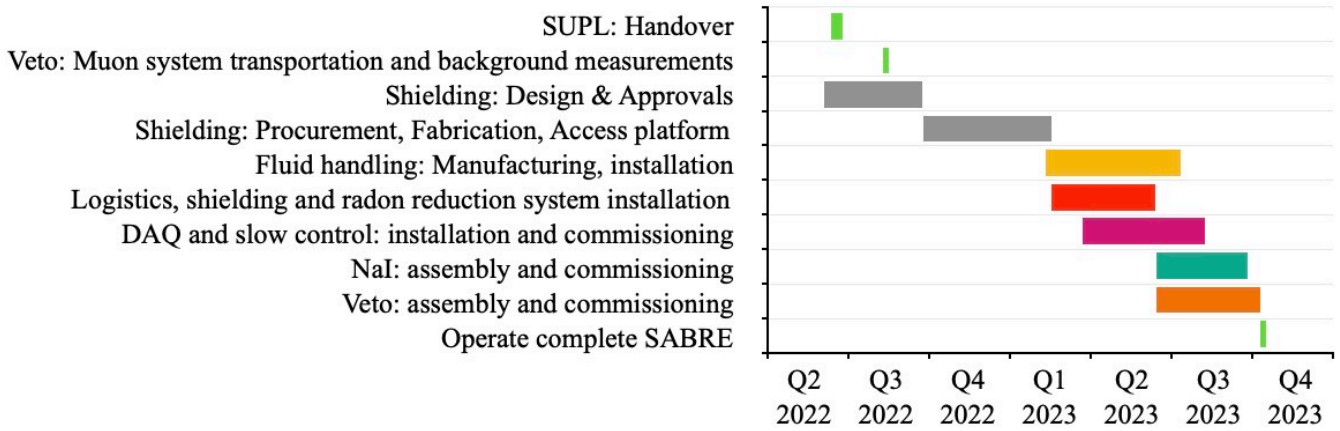
Stawell Underground Physics Laboratory located in Western Victoria 240 km from Melbourne.
Lab is 1025 m below ground with flat over burden.



SUPL STATUS

- Construction completed, handover scheduled for June 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
- Highest purity crystals and largest active veto giving lowest background (<0.7 cpd/kg/keV) of these model independent tests
- Allows for 3σ exclusion or 5σ discovery with two annual cycles of data
- SUPL is a new underground physics lab 1025 m underground being handed over soon
- 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

ACKNOWLEDGEMENTS

ARC CENTRE OF EXCELLENCE FOR DARK MATTER

Australian National University

SWINBURNE UNIVERSITY OF TECHNOLOGY

THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF MELBOURNE

SABRE South

Australian Government

ANSTO
Science. Ingenuity. Sustainability.

SABRE North

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

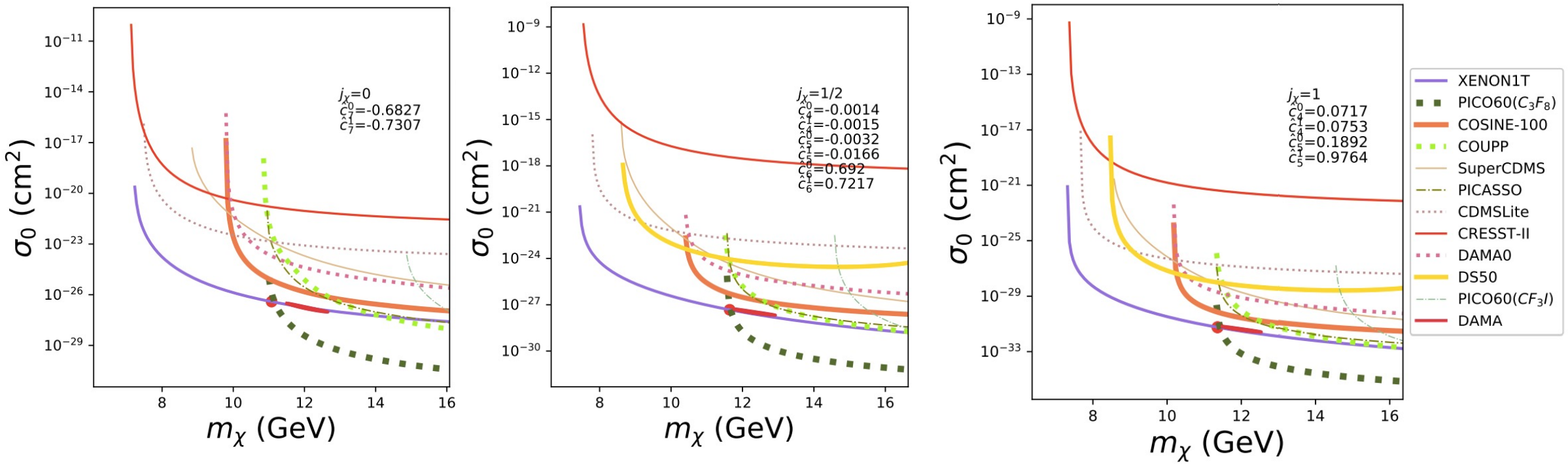
BACK UP

PSIDM MODELS

[1] Kang, Scopel, Tomar, PRD 99, 103019 (2019)

Family of models presented to reduce experimental tension w/ DAMA

Case	Spin (j_χ)	m (GeV)	σ_0 (cm^2)	δ (keV)	Non zero $\hat{\mathbf{c}}_\mathbf{0}$ components	
1	0	11.1	3.9×10^{-27}	22.8	$\hat{c}_7^0 = 0.68$	$\hat{c}_7^1 = 0.73$
2	1/2	11.6	4.7×10^{-28}	23.7	$\hat{c}_4^0 = -0.0014$ $\hat{c}_5^0 = -0.032$ $\hat{c}_6^0 = 0.692$	$\hat{c}_4^1 = -0.0015$ $\hat{c}_5^1 = -0.0166$ $\hat{c}_6^1 = 0.7217$
3	1	11.4	5.7×10^{-32}	23.4	$\hat{c}_4^0 = 0.0717$ $\hat{c}_5^0 = 0.1892$	$\hat{c}_4^1 = 0.0753$ $\hat{c}_5^1 = 0.9764$



PHOTOMULTIPLIER TUBES

Characterisation tests have been developed out of Melbourne to understand and model PMT response at this level using a reliable single photon source.

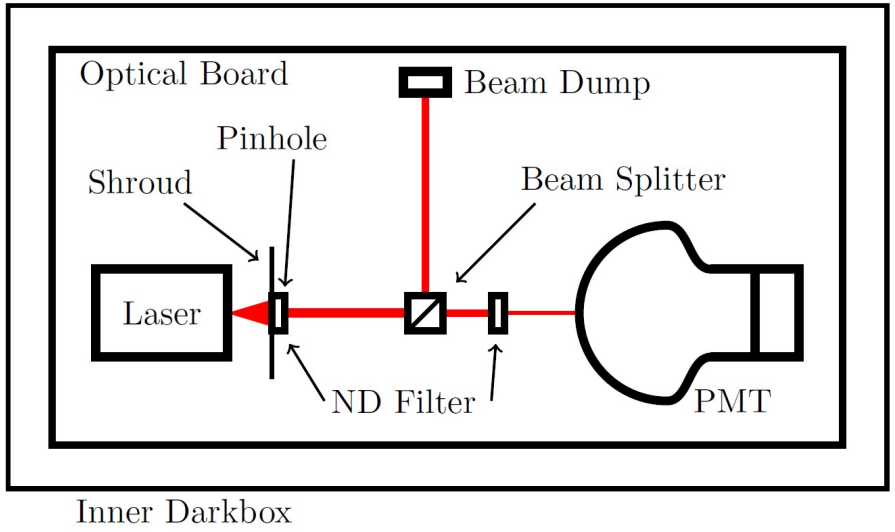
20ps pulsed 405 nm laser.

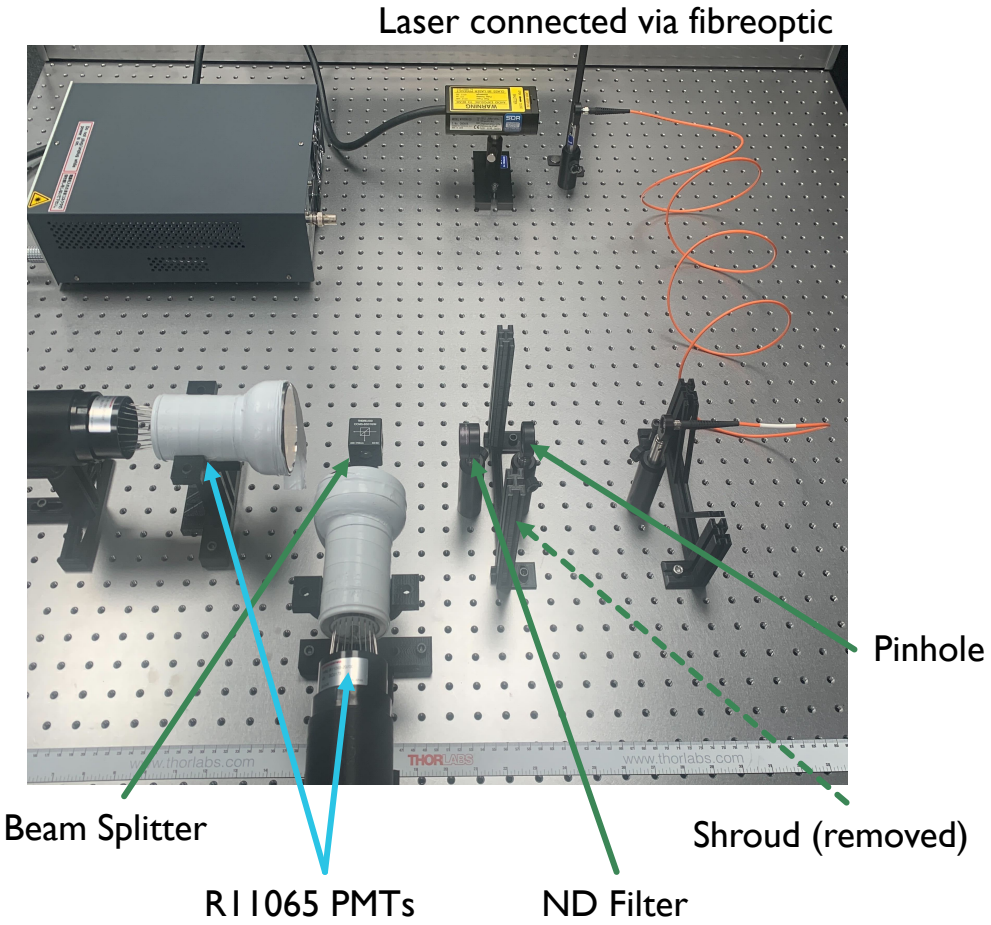
↓

Series of ND filters (metallic reflective) and apertures

↓

Pulses with mean occupancy of 0.1 photons/pulse.



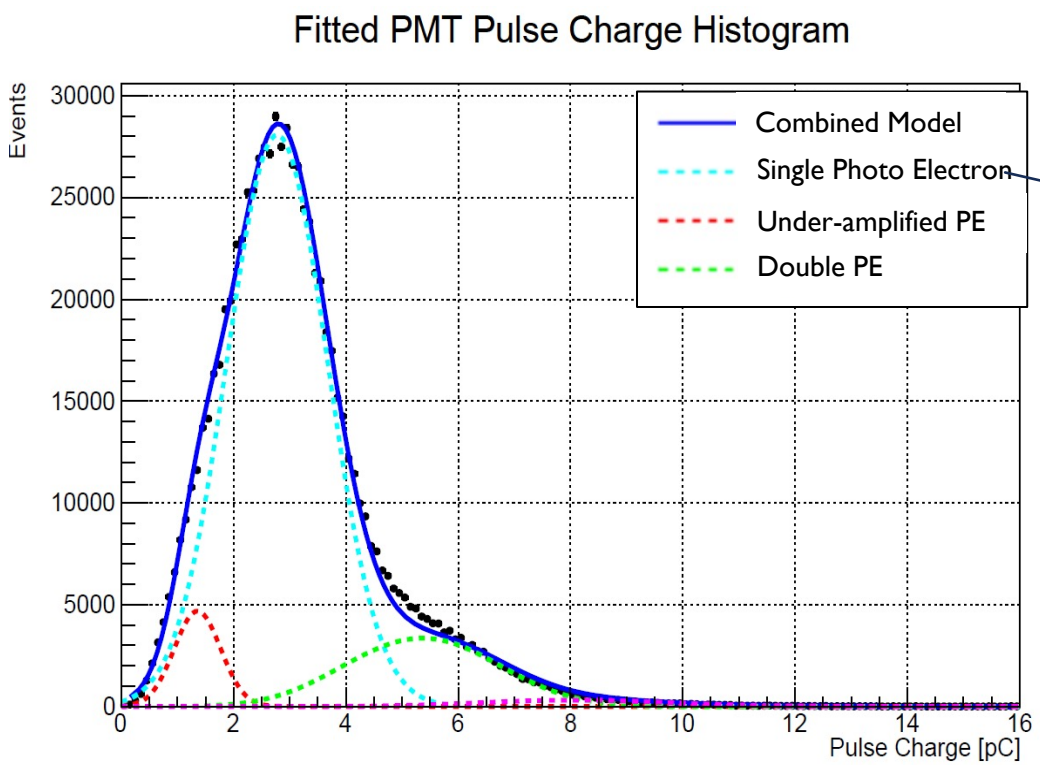


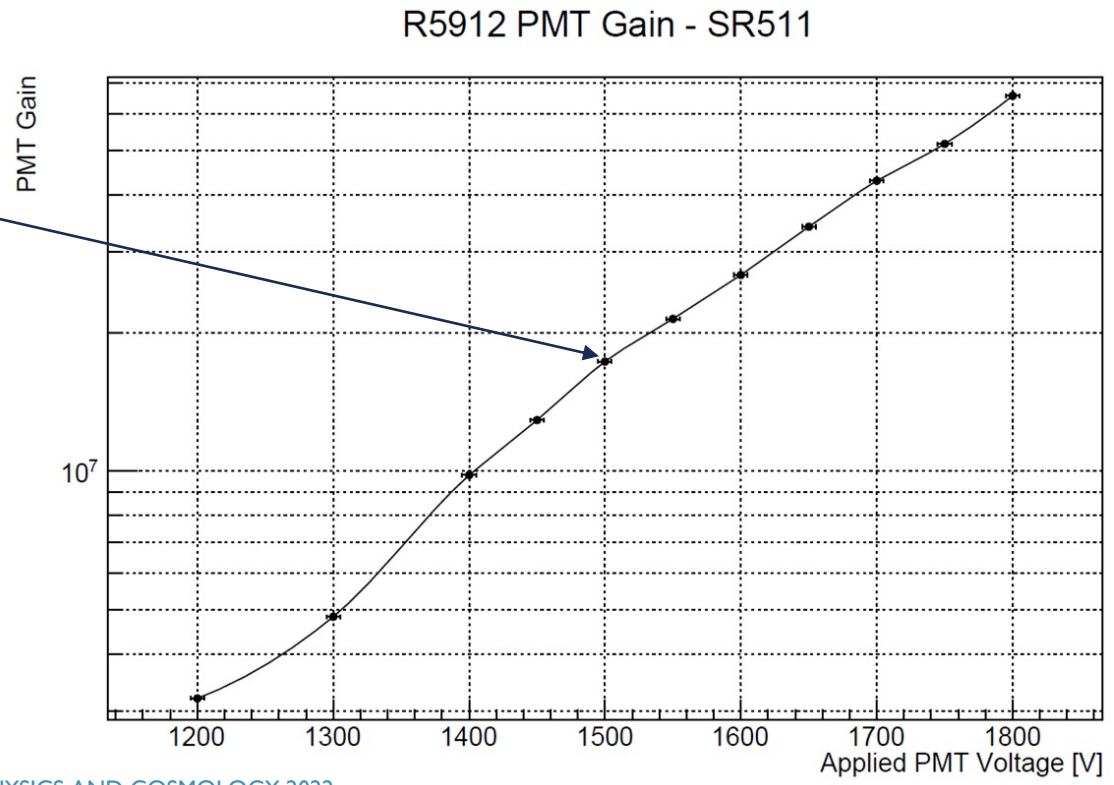
PHOTOMULTIPLIER TUBES

PMT single photoelectron model is a sum of distributions linked by Poissonian coefficients for photon survival:

$$\text{pdf} = \sum_{n=1}^{4} C_n'(\lambda) \times n\text{PE}(q)$$

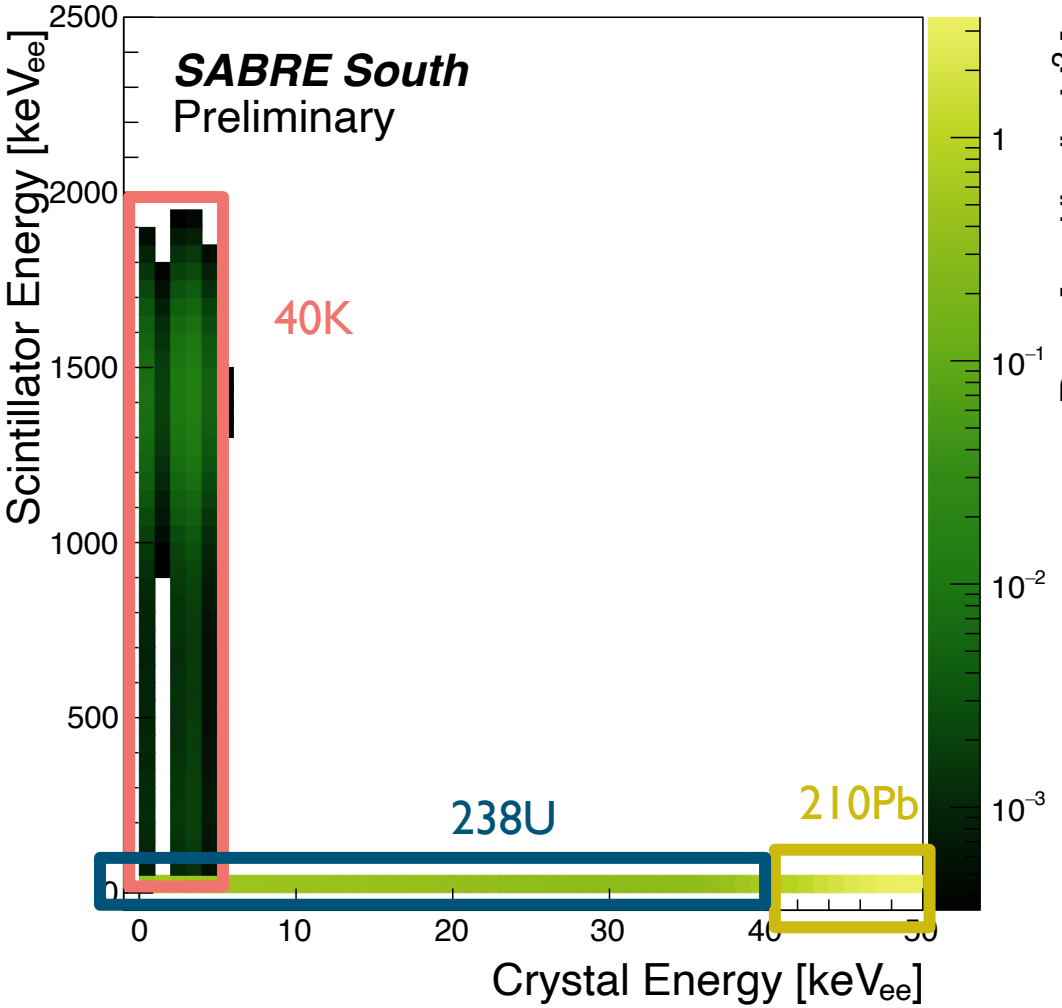
Pulse charge for SPE gives gain – measurement at a range of voltages gives voltage-gain relation





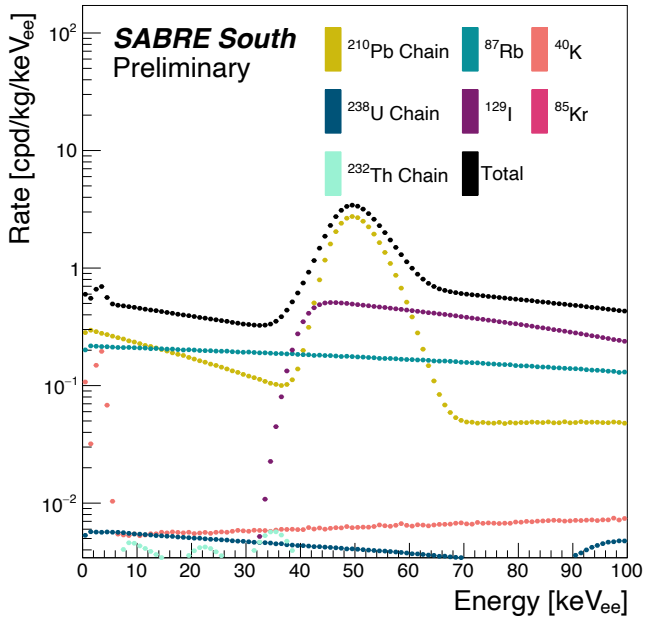
TOTAL BACKGROUND MODEL

[1] SABRE South Collab. arxiv:2205.13849

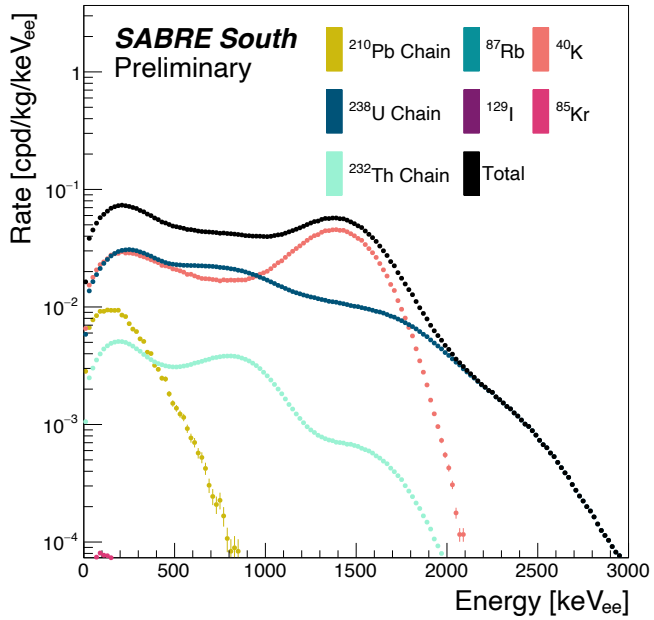


Contamination from intrinsic radiation of crystals

Deposition in crystal

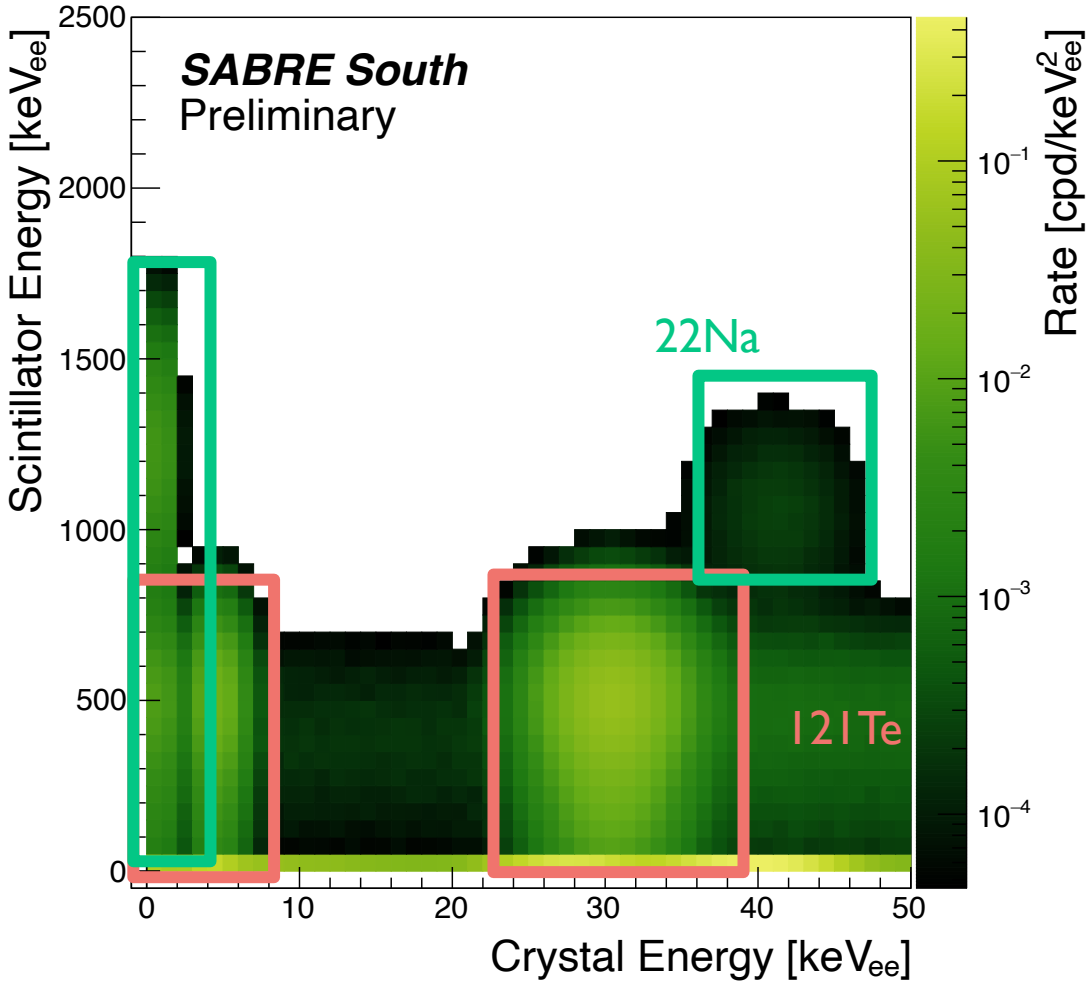


Deposition in veto



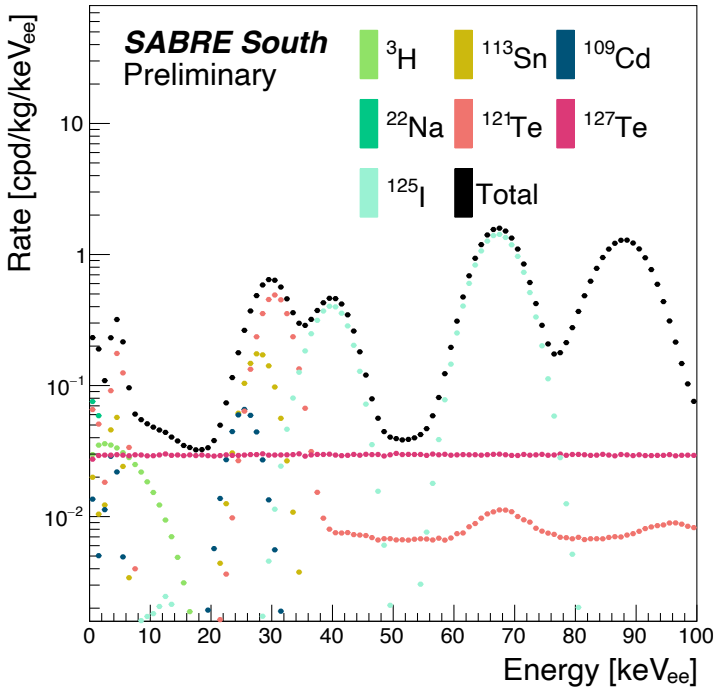
TOTAL BACKGROUND MODEL

[1] SABRE South Collab. arxiv:2205.13849



Contamination from cosmogenic activation of crystals

Deposition in crystal



Deposition in veto