Dark Matter Modulation with SABRE

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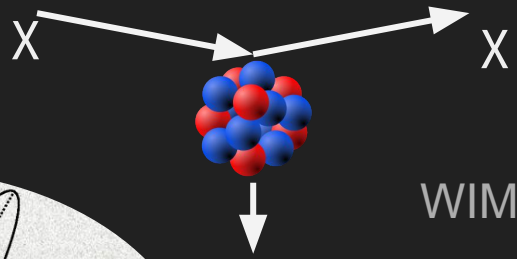
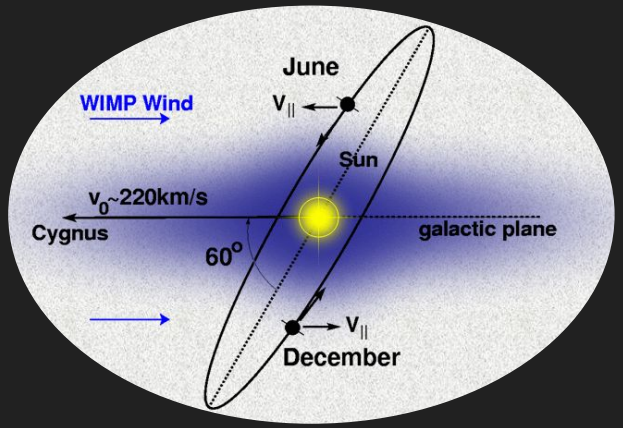
for the SABRE Collaboration

Identification of Dark Matter 2018, Brown University

Australian National University





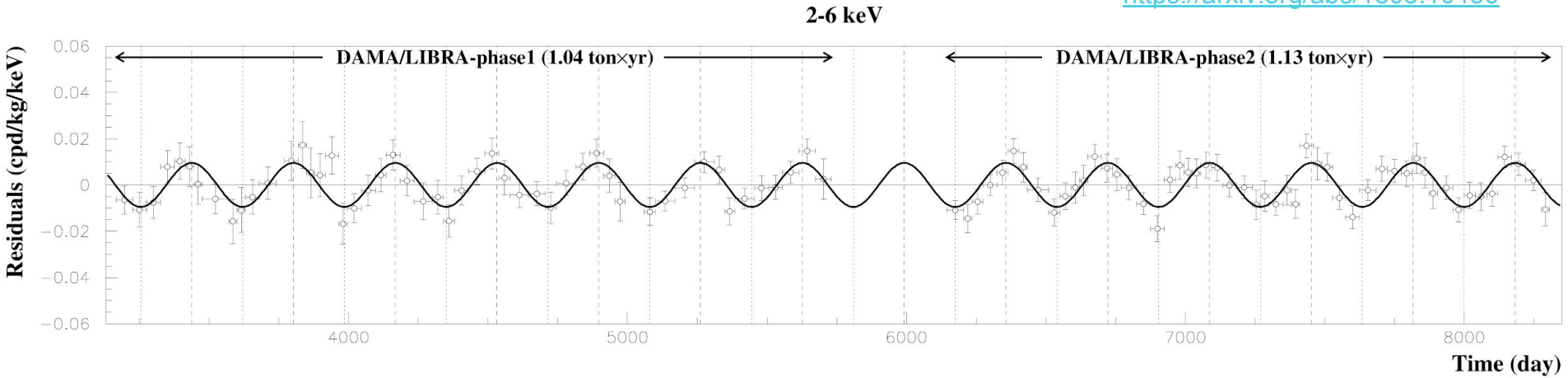
Annual Modulation

WIMP dark matter detection: elastic scattering.

Flux of dark matter modulates through the year.

DAMA: reports a highly significant (11.9 σ) modulation signal consistent with dark matter in their NaI:Tl detector.

https://arxiv.org/abs/1805.10486



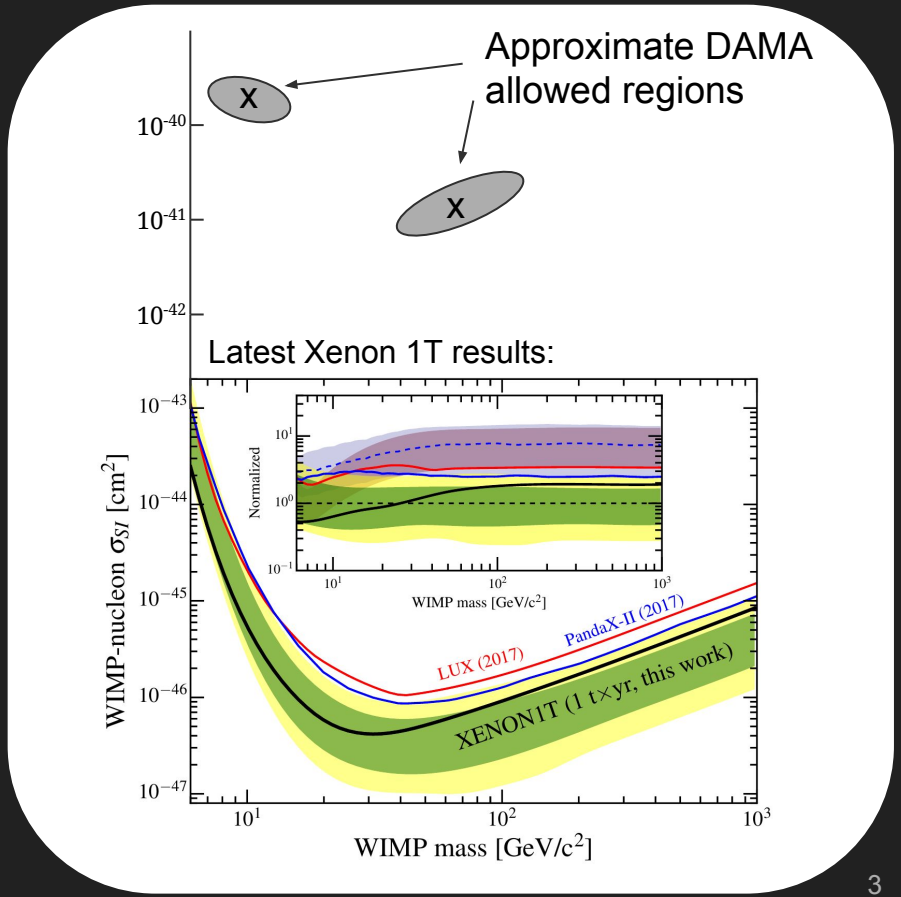
No-one else has seen DAMA's signal

Latest results →~5 orders of magnitude better sensitivity than DAMA.

Model-dependent

Do WIMPs like Na?
Does DAMA have a seasonal systematic?

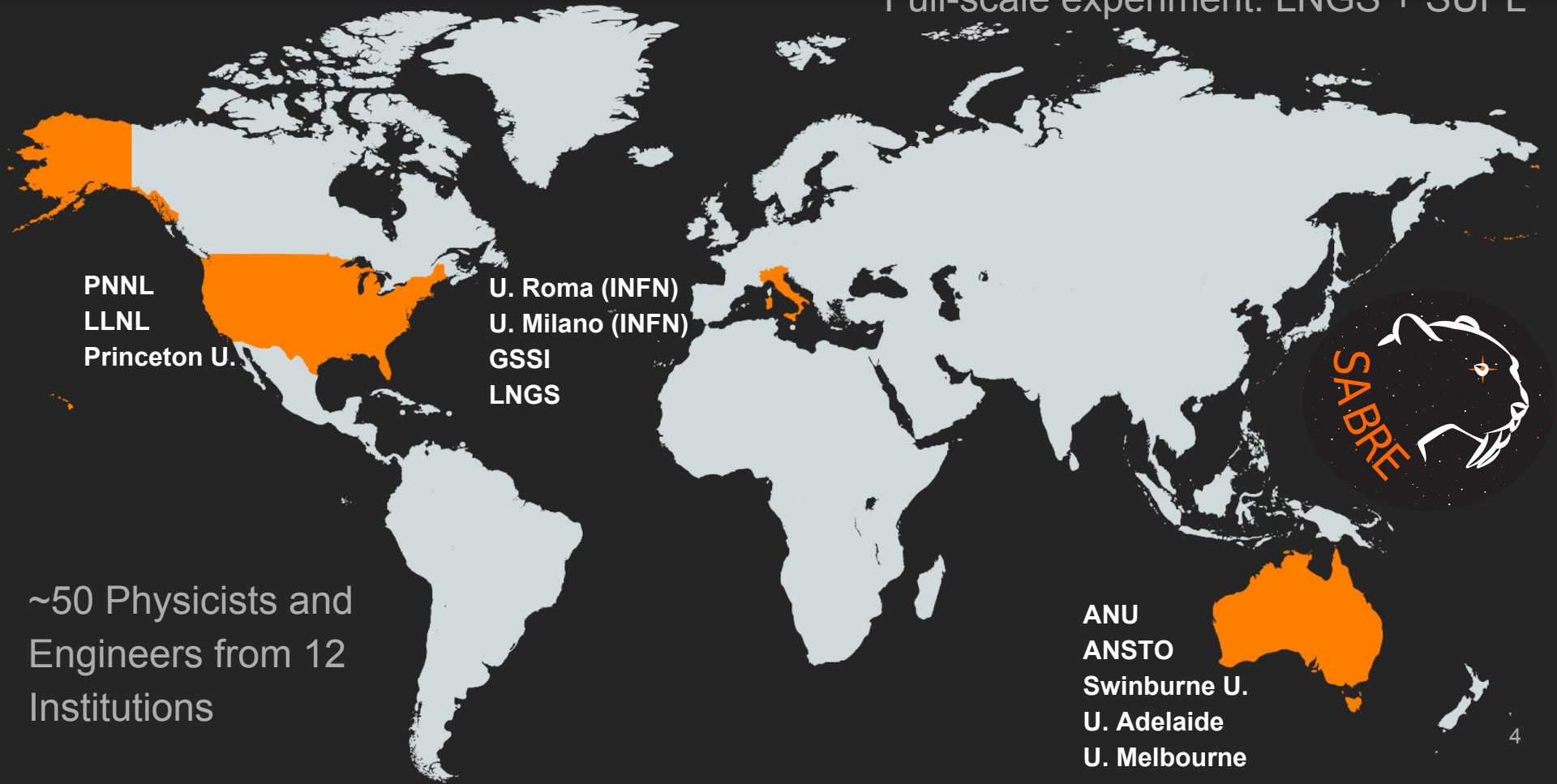
SABRE is a model-independent test of DAMA.



SABRE Collaboration

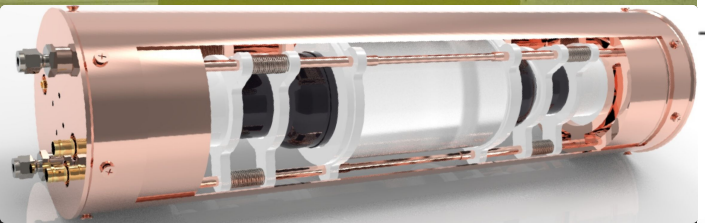
Proof-of Principle: LNGS

Full-scale experiment: LNGS + SUPL



~50 Physicists and Engineers from 12 Institutions

First Production Crystal! (June 2018)



Ultrapure NaI:Tl Target Detector

Intrinsic radioactivity limits WIMP sensitivity.
SABRE has made the most radiopure NaI:Tl to date.

- ‘Astrograde’ powder (Sigma Aldrich).
- Carefully-developed powder preparation and growth protocols (Princeton + RMD).

Lower radioimpurity than DAMA.
Production growth underway.
High QE + low background PMTs: 1 keV threshold design.

Element	DAMA powder [ppb]	DAMA crystals [ppb]	Astro-Grade [ppb]	SABRE crystal [ppb]
K	100	~13	9	9
Rb	n.a.	<0.35	<0.2	<0.1
U	~0.02	0.5-7.5×10^{-3}	<10^{-3}	<10^{-3}
Th	~0.02	0.7-10×10^{-3}	<10^{-3}	<10^{-3}

Liquid Scintillator Veto

External background tagging

- Muons, spallation neutrons, etc.

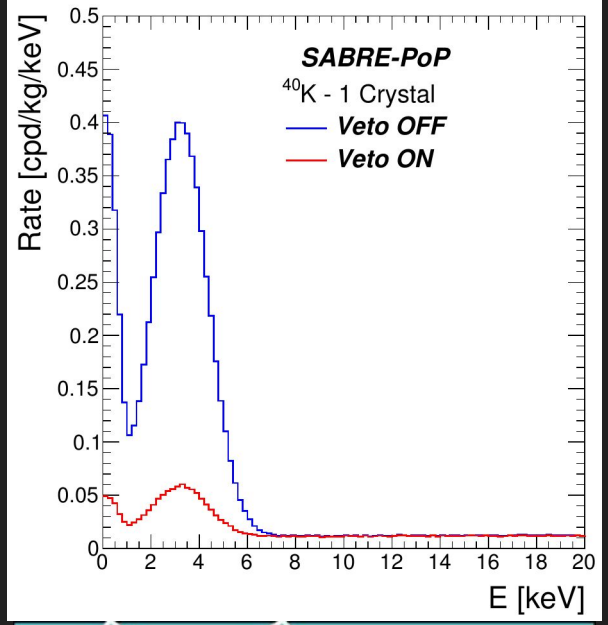
Intrinsic background tagging

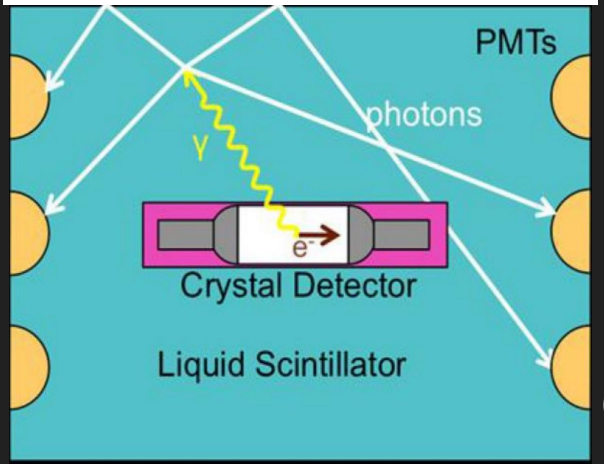
- Correlated gammas from decays
- ^{40}K is especially important

Radiopure Shielding

- SABRE North: Borexino's pseudocumene-based liquid scintillator
- SABRE South: Linear alkylbenzene-based LS, ex-CTF purification

Proof-of-Principle
veto 84% of ^{40}K in signal range.

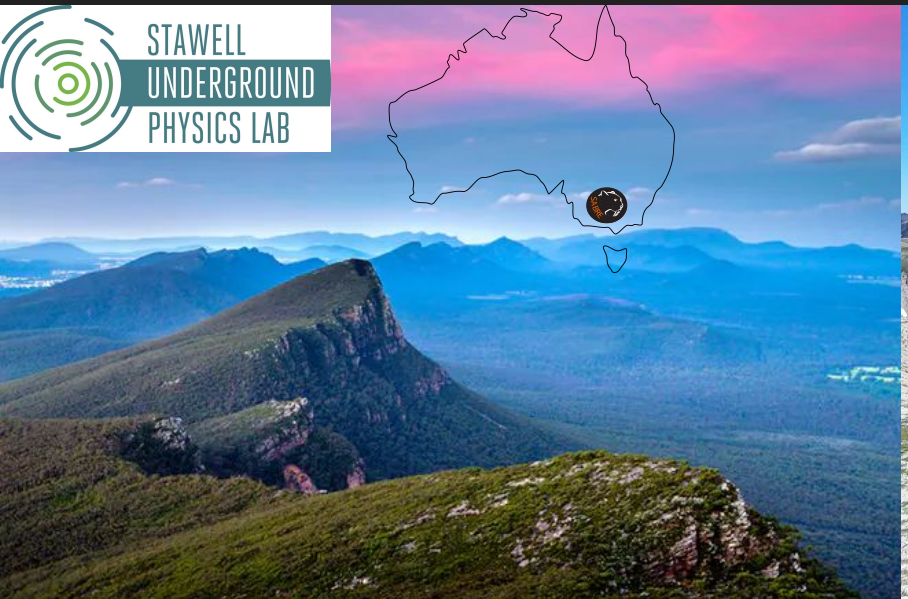




Two Hemisphere Experiment

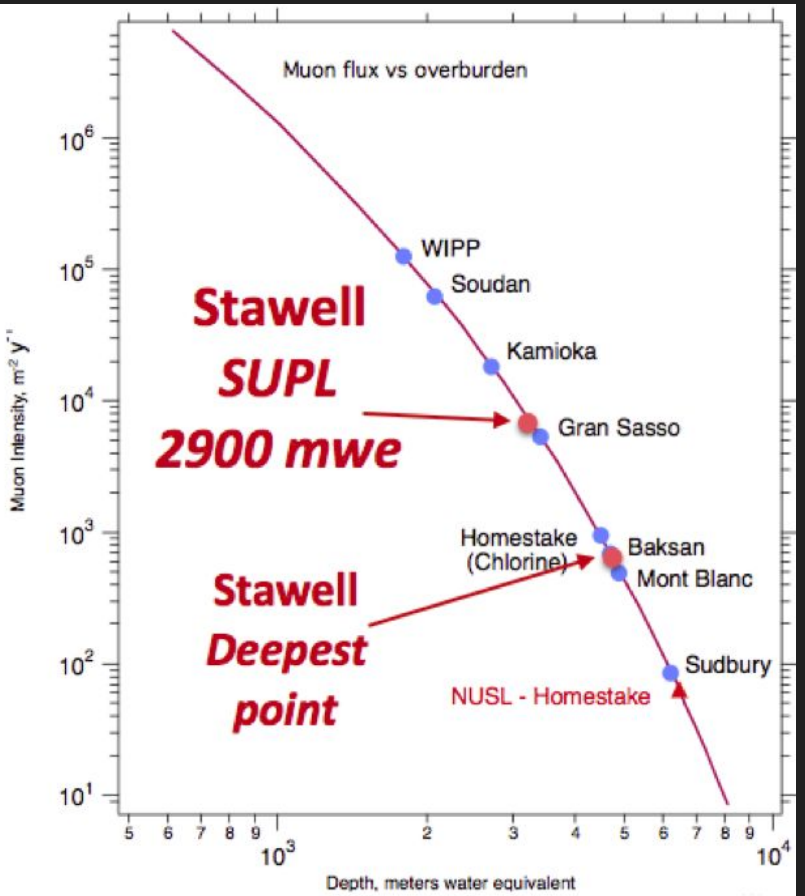
SABRE will be at two underground sites in the Northern/Southern Hemisphere.
Seasonal background modulations are out of phase
Dark matter modulations are in phase (and strong evidence for DM).

Stawell (SABRE South)

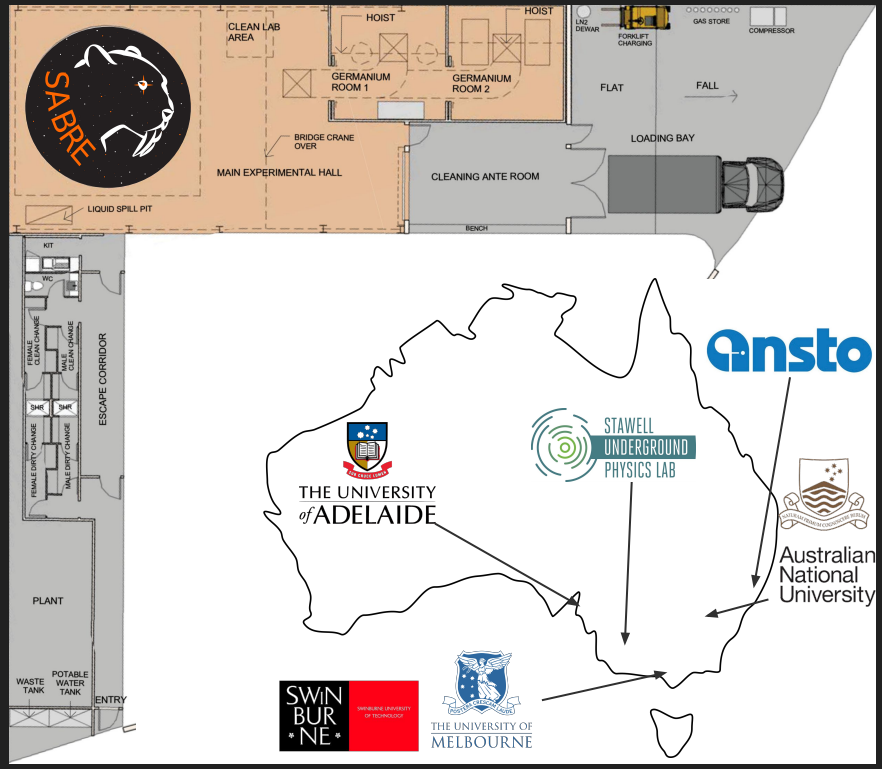


Gran Sasso (SABRE North)

The Stawell Underground Physics Laboratory



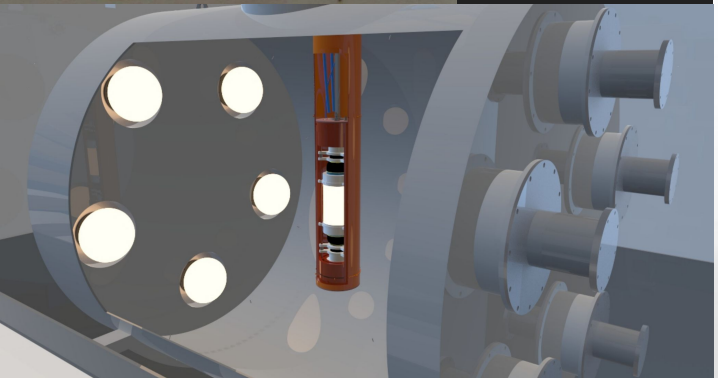
The first underground laboratory in the Southern Hemisphere.

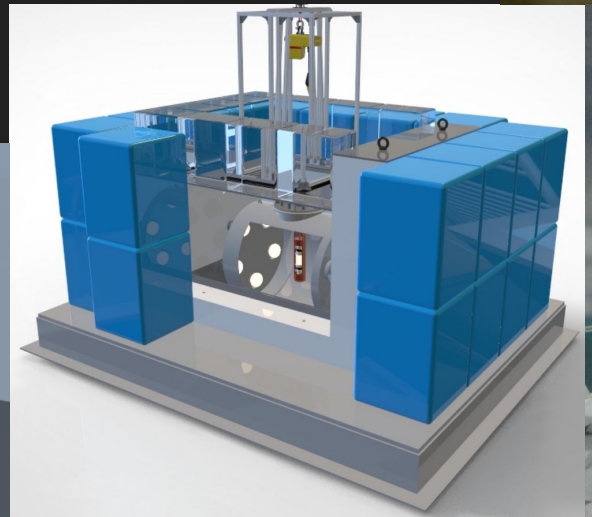


SABRE Proof of Principle at LNGS

Work underway to commission PoP (5.2 kg NaI:Tl).

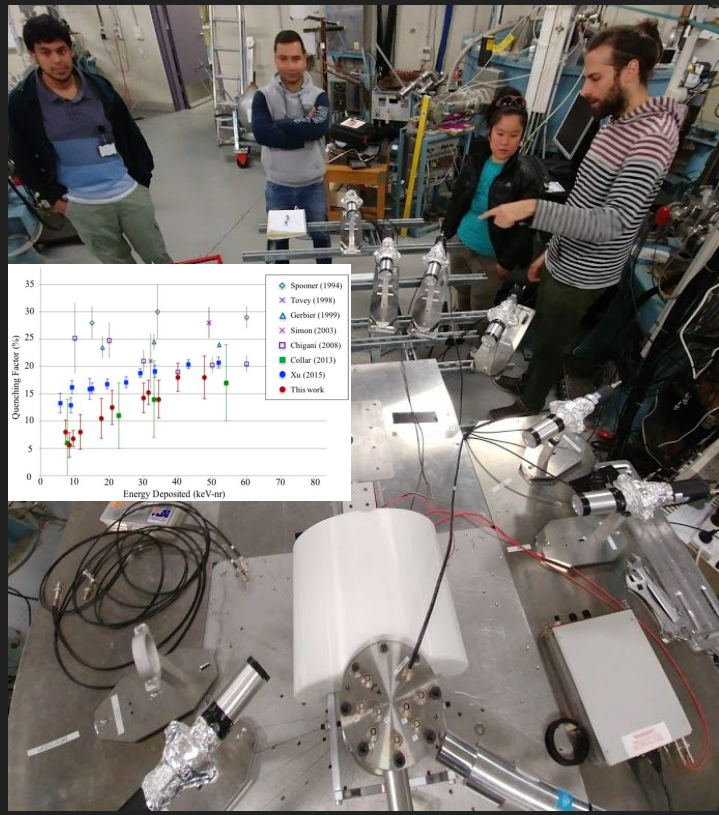
Test veto and background performance, validate simulation model.



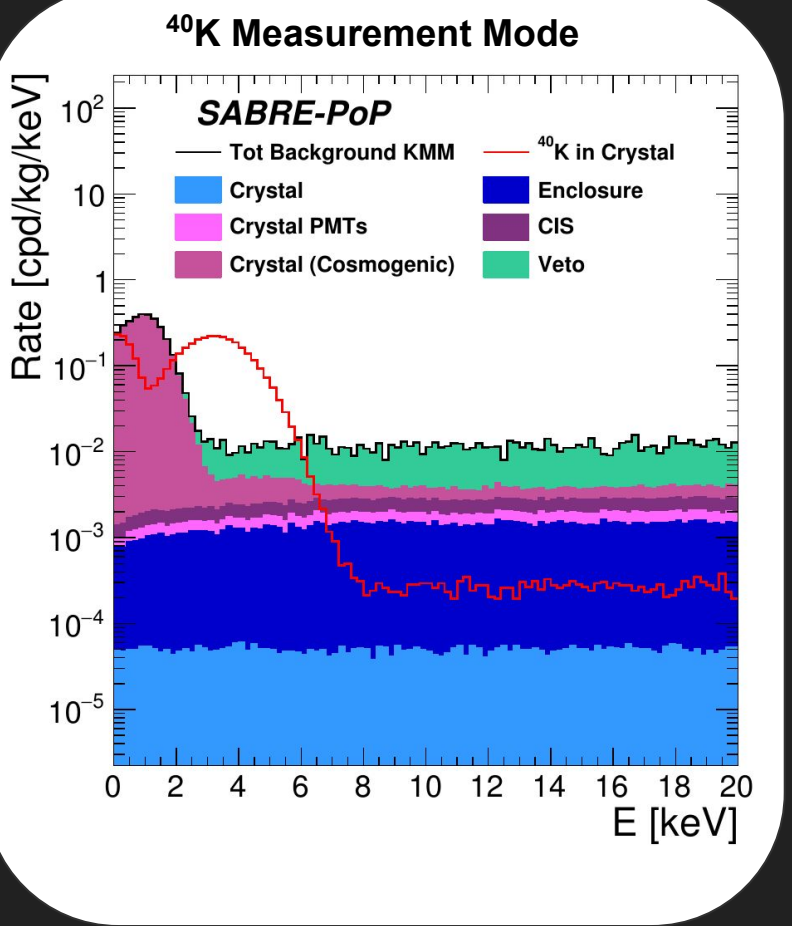


Characterisation Measurements

- Quenching factor:
  - Important to interpretation of signal.
  - Poorly understood/conflicting measurements.
- Accelerator Mass Spectrometry and ICP-MS:
  - Radioimpurity quantification - especially ^{210}Pb (major background for other experiments)
- Liquid scintillator testing
  - Purification, compatibility testing, etc.



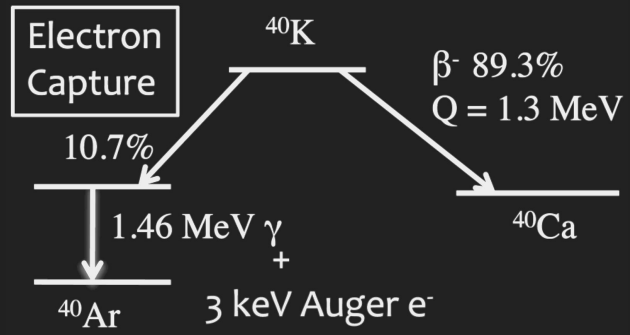
Proof-of-Principle Simulations



Crystal-veto coincidences tag ^{40}K Auger electron + gamma events.

Backgrounds assume 2 months of cosmogenic decay.

10 ppb ^{40}K in crystal (red trace) is detectable above background; 10% precision after 2 months of measurement.



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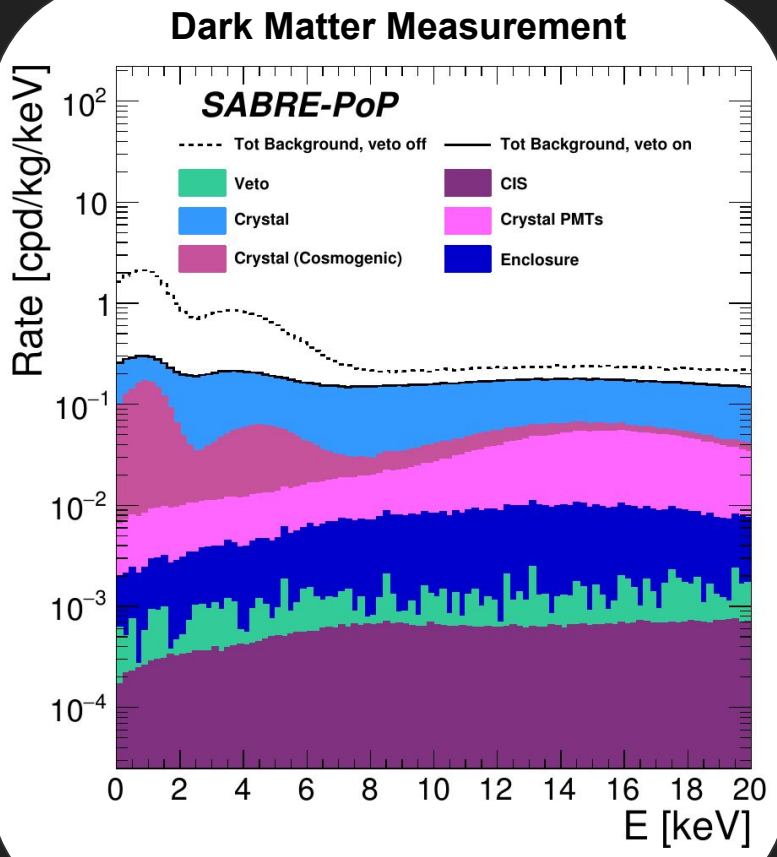


Isotope	Rate, veto OFF [cpd/kg/keV]	Rate, veto ON [cpd/kg/keV]
Intrinsic		
^{87}Rb	$6.1 \cdot 10^{-2}$	$6.1 \cdot 10^{-2}$
^{40}K	$2.5 \cdot 10^{-1}$	$4.0 \cdot 10^{-2}$
^{238}U	$2.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$
^{210}Pb	$2.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$
^{85}Kr	$1.9 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$
^{232}Th	$1.9 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$
Tot Intrinsic	$3.5 \cdot 10^{-1}$	$1.5 \cdot 10^{-1}$
Cosmogenic		
^{121}Te	$2.6 \cdot 10^{-1}$	$3.3 \cdot 10^{-2}$
^{22}Na	$3.6 \cdot 10^{-2}$	$2.7 \cdot 10^{-3}$
^{125}I	$1.8 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$
^{129}I	$3.4 \cdot 10^{-4}$	$3.4 \cdot 10^{-4}$
^{126}I	$2.0 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$
^{121m}Te	$1.3 \cdot 10^{-4}$	$7.0 \cdot 10^{-5}$
^{123m}Te	$7.6 \cdot 10^{-5}$	$5.1 \cdot 10^{-5}$
^{127m}Te	$5.0 \cdot 10^{-5}$	$4.9 \cdot 10^{-5}$
^{125m}Te	$5.3 \cdot 10^{-6}$	$5.1 \cdot 10^{-6}$
^{24}Na	-	-
Tot Cosmogenic (180 days)	$3.0 \cdot 10^{-1}$	$3.9 \cdot 10^{-2}$

Veto threshold: 100 keV.

Total background rejection efficiency = 70%.

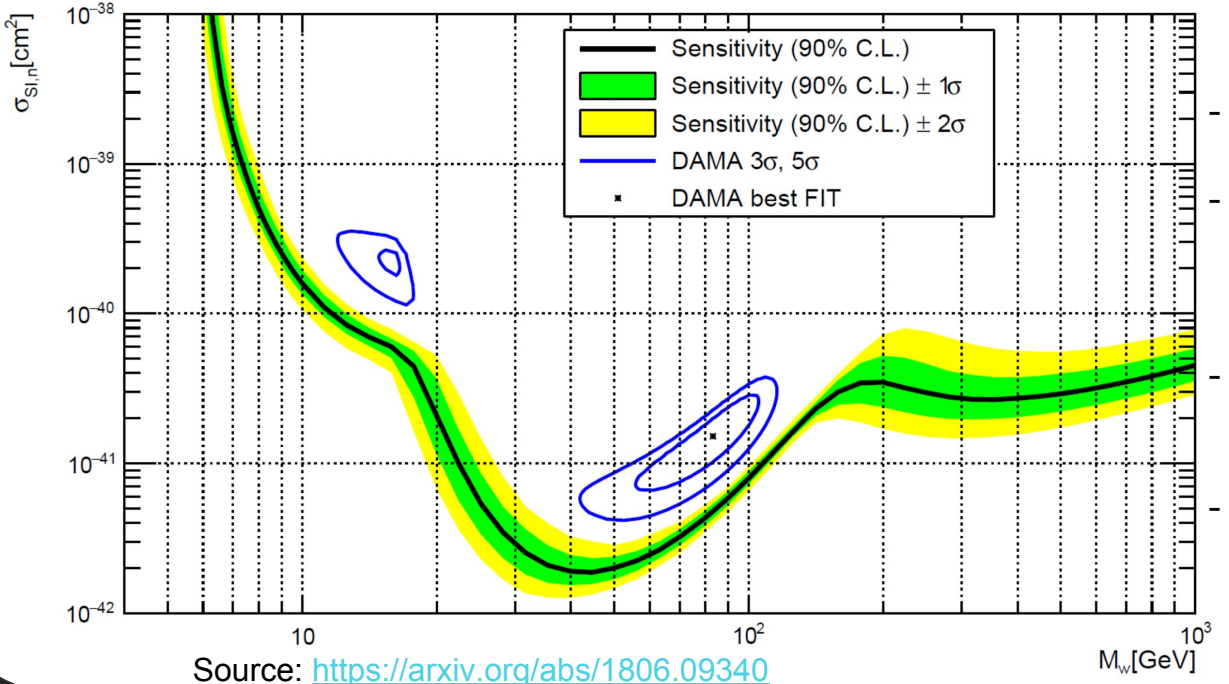
Signal region: 0.22 counts day^{-1} kg^{-1} keV^{-1}.

50% from ^{87}Rb (a measurement limit!)

More details: https://arxiv.org/abs/1806.09344

Full-Scale Sensitivity

- Can rule DAMA in/out in 3 years, using modulation signal alone.
  - Confirm at 6 σ, reject at 5 σ. **Model independent**.



Source: https://arxiv.org/abs/1806.09340

- 50 kg NaI:Tl, for 3 years of measurement.
- 0.22 counts day^{-1} kg^{-1} keV^{-1} (PoP simulation) across [2, 6] keV signal region.
- Quenching factor of Xu (https://arxiv.org/abs/1503.07212).
- Standard halo model and spin-independent interaction.

Conclusion

SABRE will confirm or refute the DAMA signal.

South detector will be housed in the first deep underground laboratory in the Southern Hemisphere.

Proof-of-Principle to start collecting data in Autumn 2018.

Full scale SABRE drawing.

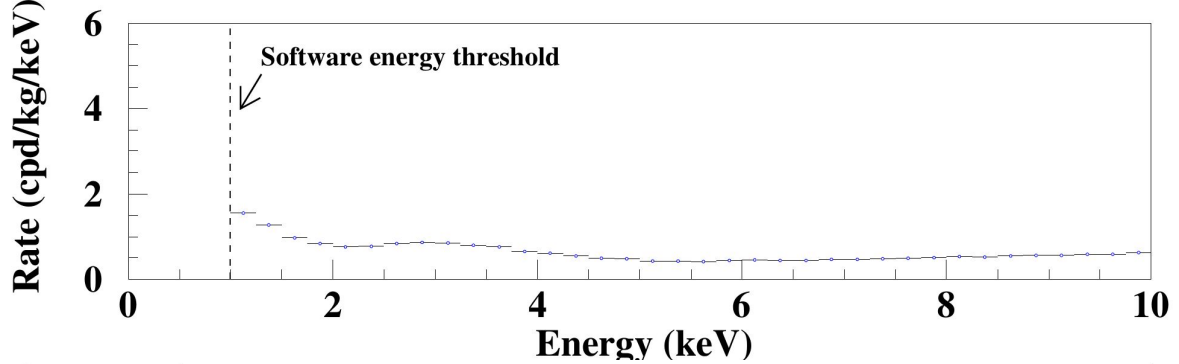
Bonus Slides

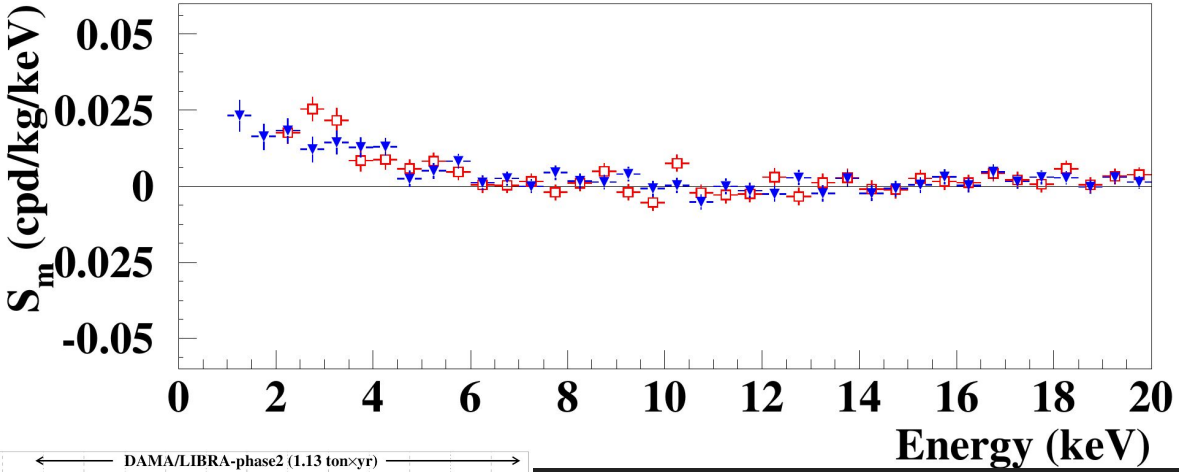
DAMA Details

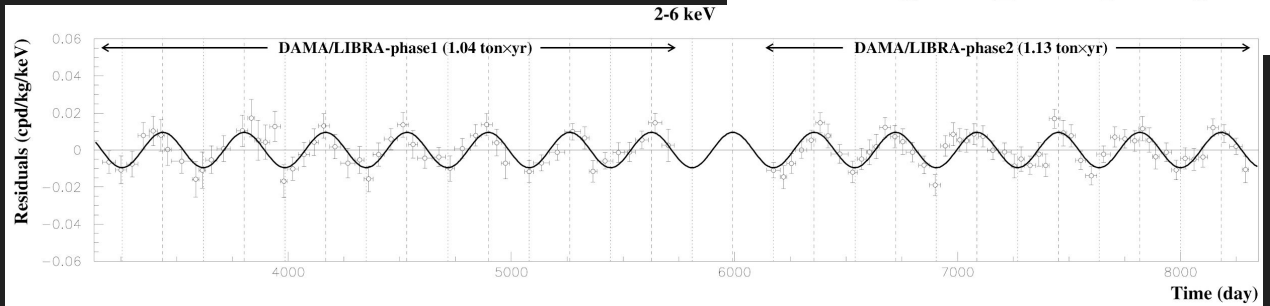
250 kg of ultrapure NaI:Tl

Passive shielding

Temperature control







Sensitivity Calculation

Two independent analyses, both predict similar sensitivities.

Effect of varying the quenching factor: