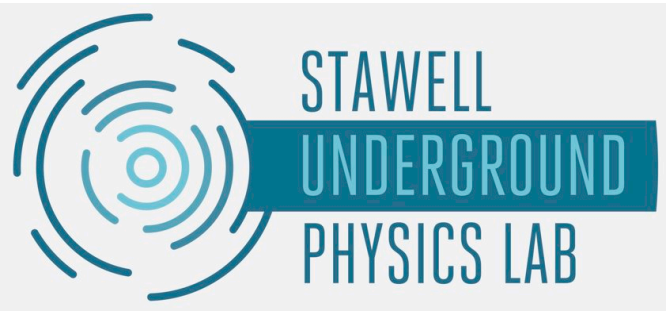
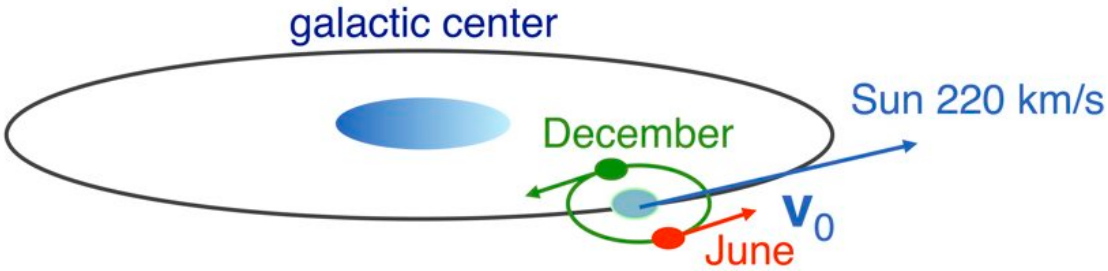
Galactic Dark Matter Search with the SABRE detector

Dr Greg Lane
Australian National University
(For the SABRE collaboration)



Dark Matter: WIMPs in the galactic halo

Solar system moves through a halo of stationary WIMPs that permeate our galaxy



Earth orbit around sun: 30 km/s

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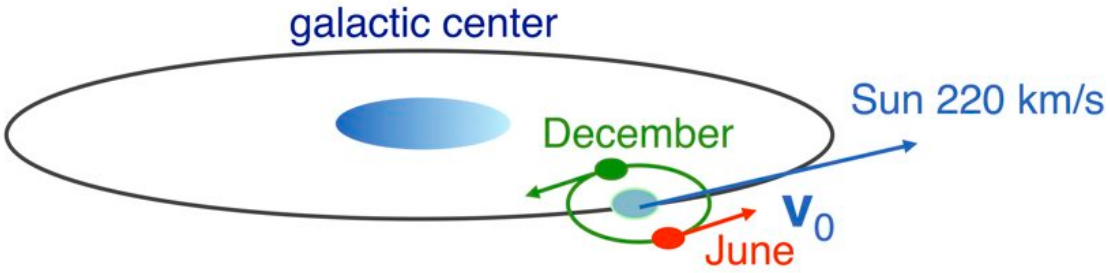
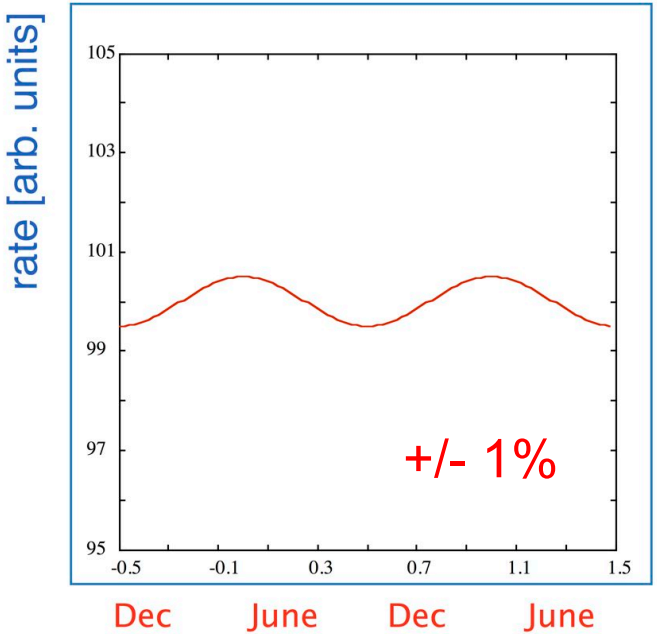


Earth orbit around sun: 30 km/s

WIMP interaction rate should undergo annual oscillations with a predictable magnitude and phase.



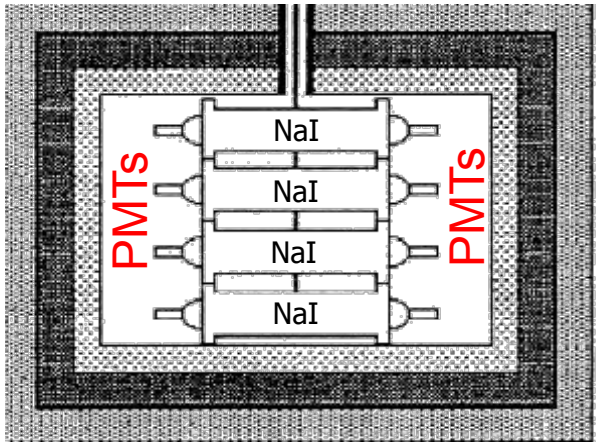
Dark Matter Detectors: Results

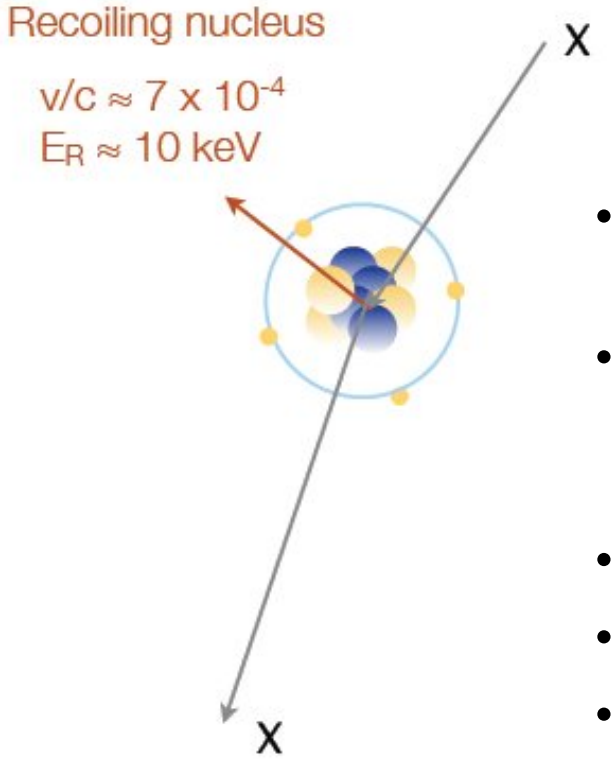
Location	Name	Detector	Started	Findings
Gran Sasso mountain, Italy	CRESST-II	3 kilograms of calcium-tungstate crystals	2009	Possible dark-matter signals later shown to be background
	DAMA/LIBRA	250 kg of sodium-iodide crystals	2003	Annual modulation signal, still unexplained
	DarkSide-50	50 kg of liquid argon	2013	No signals
	XENON1T	3,500 kg of liquid xenon	Due spring 2016	No signals from precursor experiments
Homestake mine, South Dakota	LUX	370 kg of liquid xenon	2013	No signals
Mozumi mine, Kamioka, Japan	XMASS-I	835 kg of liquid xenon	2010	No signals
Vale Inco mine, Sudbury, Canada	PICO-60	37 kg of trifluoromethyl iodide	2013	No signals
Soudan mine, Minnesota	CoGeNT	0.5 kg of germanium crystals	2009	Possible dark-matter signals later shown to be background
	SuperCDMS	9 kg of germanium crystals	2012	No signals

Summary from *Nature News*, Nov 2015

- Low background ➔Underground labs
- All in northern hemisphere
- Some initial signals subsequently shown to be background
- One persistent signal, still unexplained – DAMA/LIBRA
- Tension between experimentally deduced limits

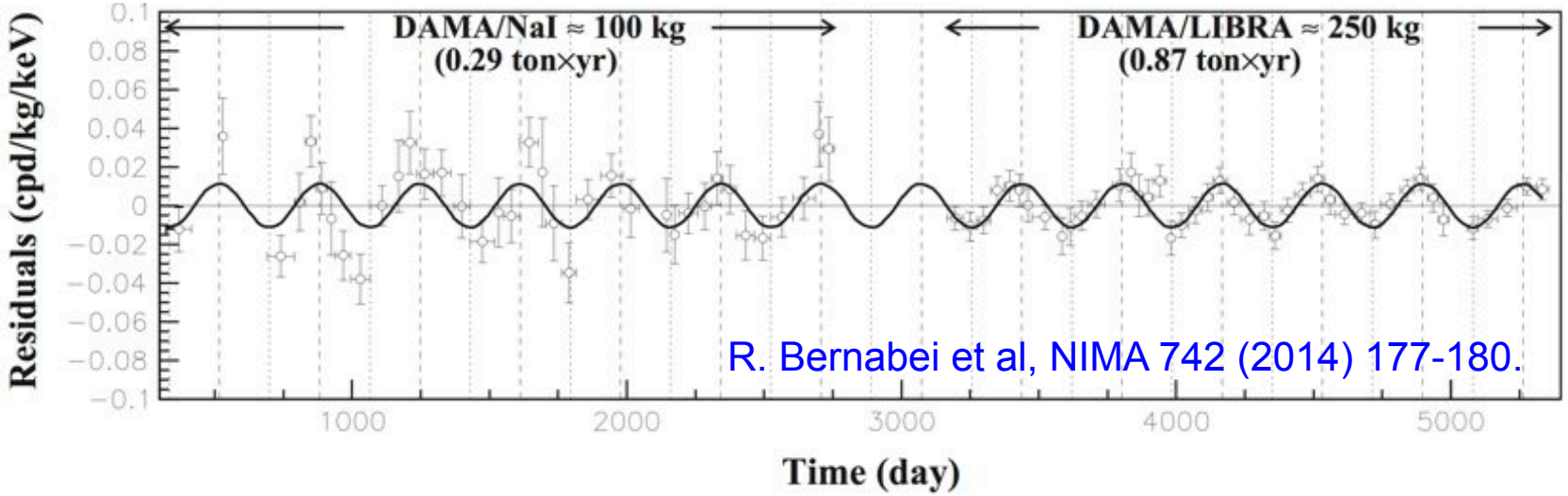
DAMA/NaI ➔ DAMA/LIBRA





- Underground laboratory in Gran Sasso (Italy)
- NaI(Tl) scintillator – WIMPs scatter off Na nuclei
- Operating since 1995
- 100 kg (phase I)
- 250 kg (phase II)

DAMA/LIBRA – 9σ signal – Dark Matter?



R. Bernabei et al, NIMA 742 (2014) 177-180.

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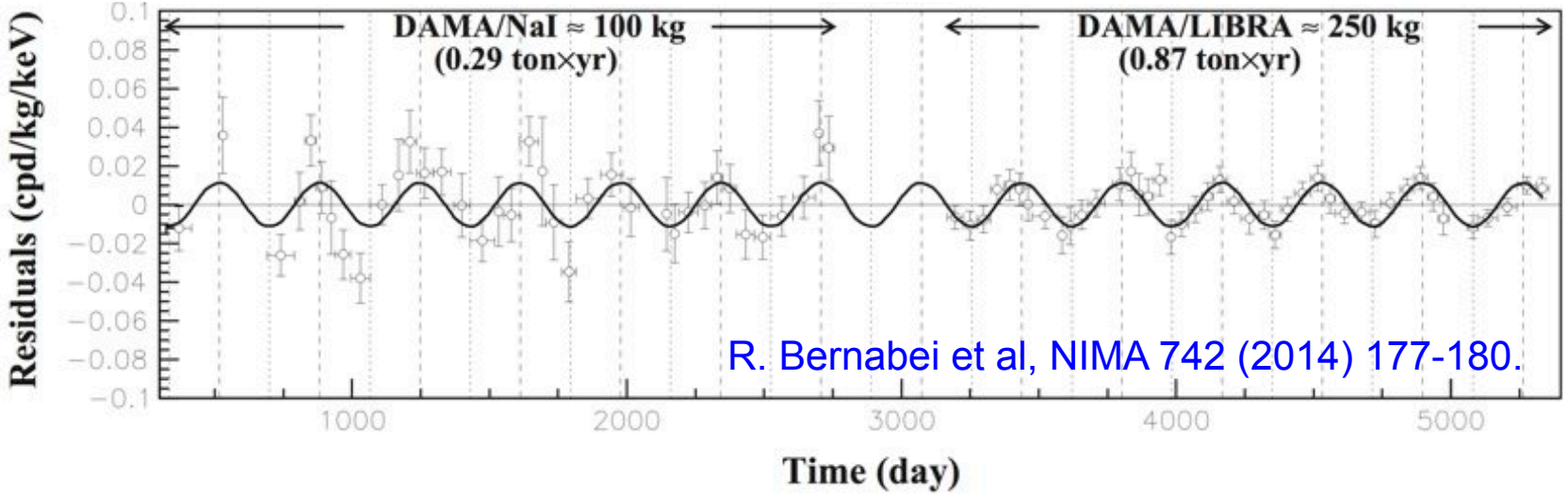

- 13 annual cycles
- Signal observed in cut on E_{ee} = 2-6 keV
- Amplitude: 0.0112(12) cpd/kg/keV
- Phase: 144(7) days vs expected 152.5 days

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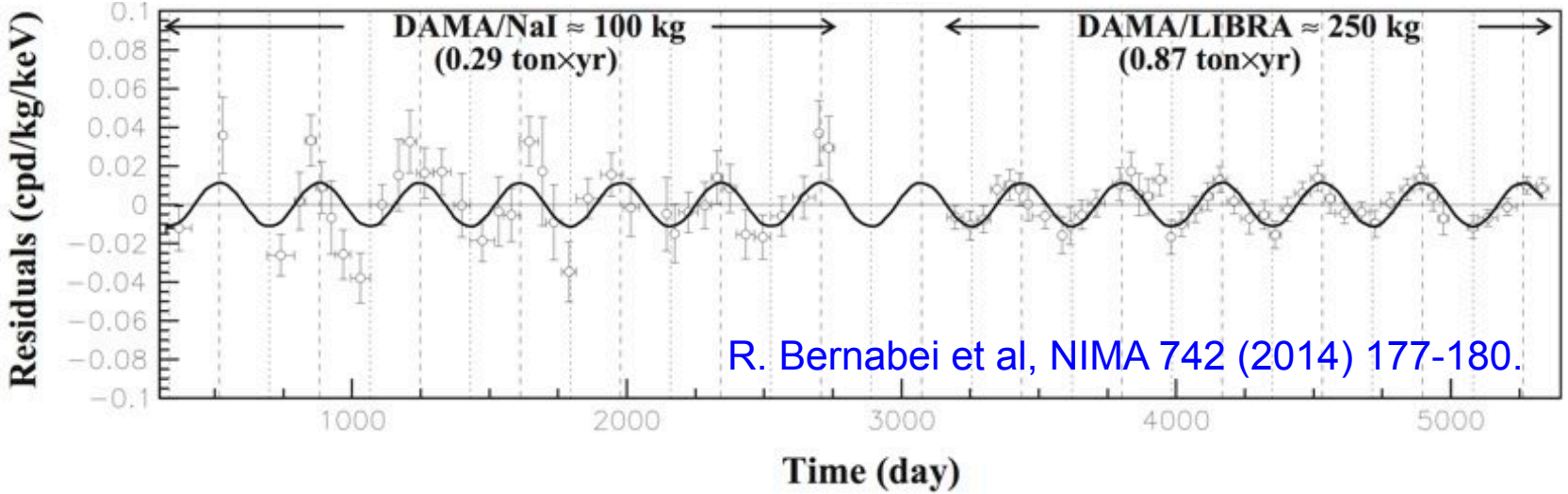

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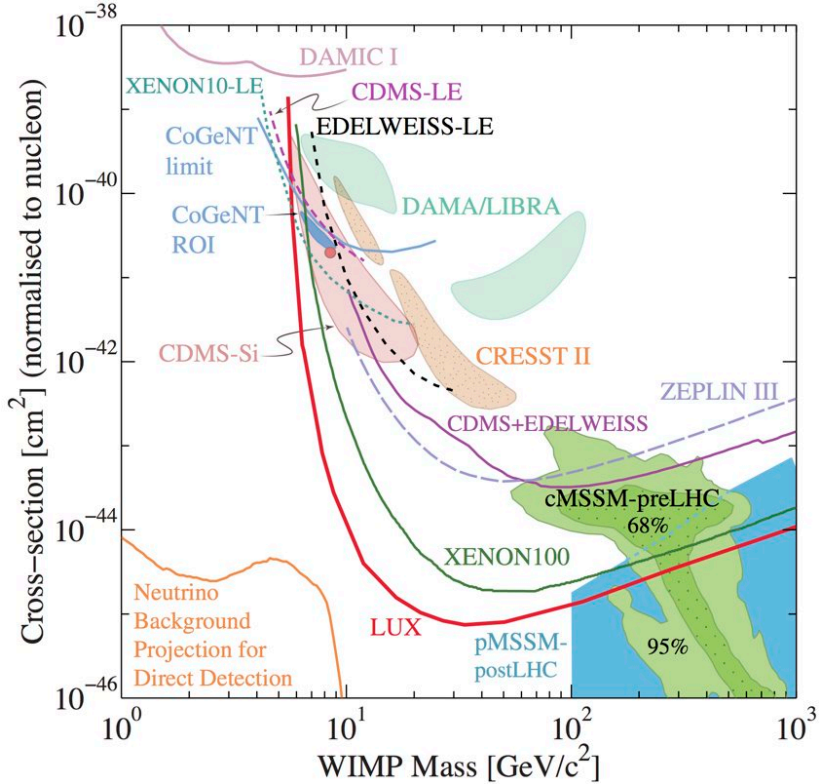
- Tension with other expts (next slide)
- Other seasonal causes?
- Investigated: Radon, temperature, gas pressure, electronic noise, energy scale, efficiencies, environmental neutrons, muons
- Signal persists

Limits on WIMP mass/cross-section



K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C 38, 090001 (2014)

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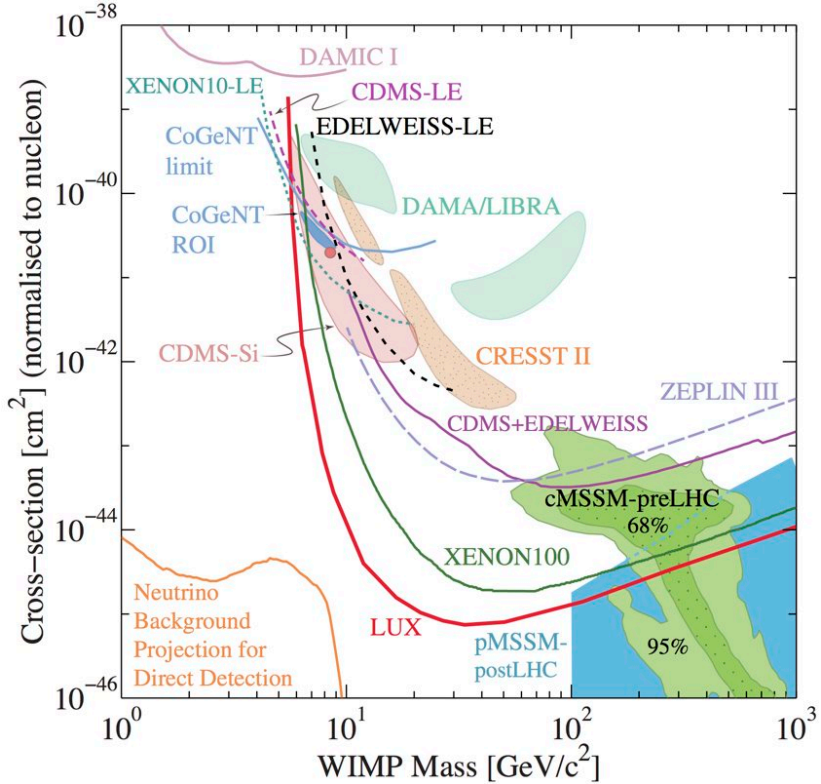

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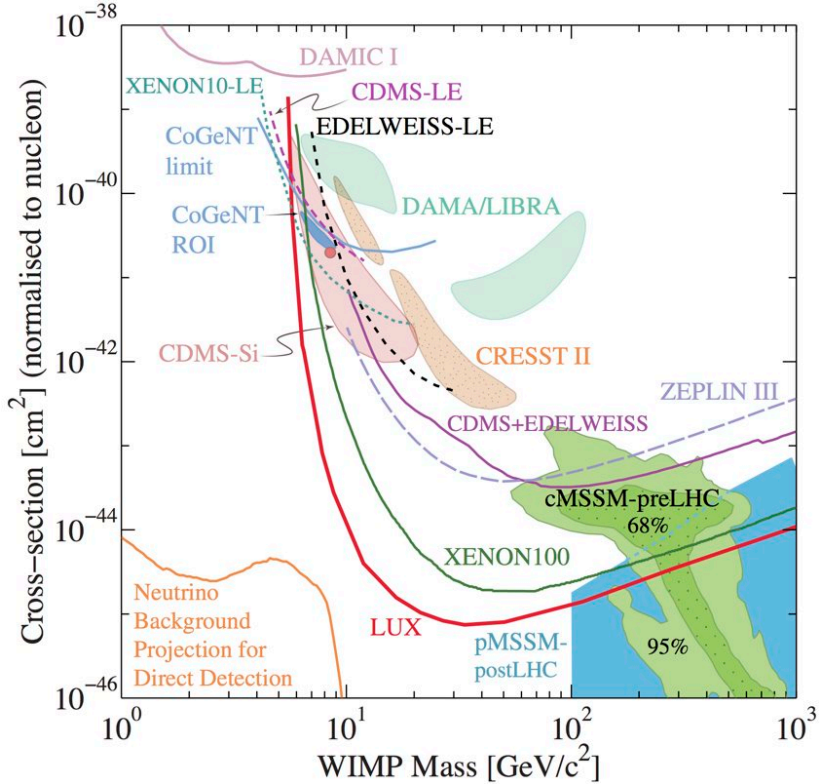
DAMA/LIBRA does not agree with limits from other DM detectors:

- Scintillator response to low energy nuclear recoils is uncertain? (Direct effect on the deduced WIMP mass)
- DM signal in DAMA is near a known ^{40}K background (3 keV Auger electron)
- Other detectors use different materials – are comparisons valid?
- Unique detector – despite extensive investigation of backgrounds, seasonal variations are hard to rule out.

Limits on WIMP mass/cross-section



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- Unique detector – despite extensive investigation of backgrounds, seasonal variations are hard to rule out.

SABRE is a new approach that will confirm or refute the DAMA signal.

Plans and Strategies to Confirm/Refute DAMA Signal

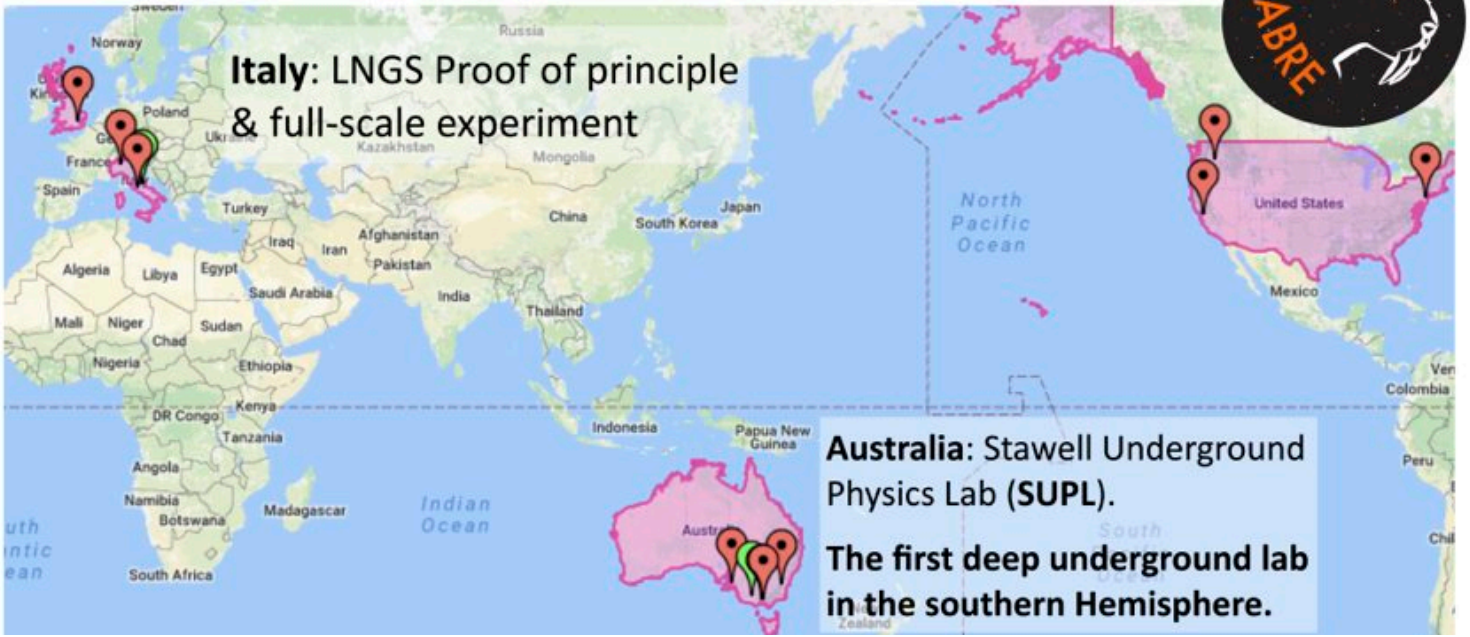
Control seasonality

- Northern/Southern hemisphere detectors – Seasonal backgrounds out of phase, DM signal in phase.
- Gran Sasso & Stawell Underground Physics Laboratory (SUPL). SUPL to be the first deep underground lab for low background measurements in the southern hemisphere.

SABRE – Collaboration

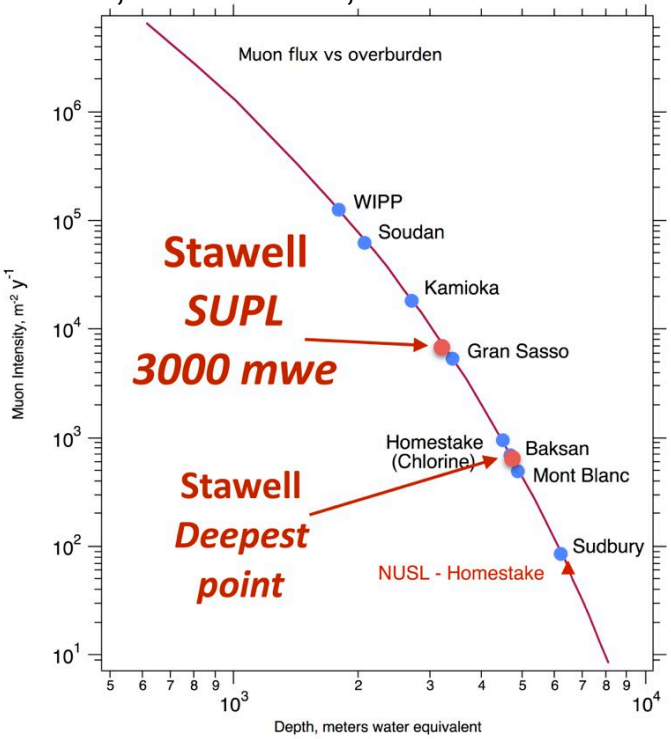
- Twin detectors @ LNGS and SUPL
- Spokesperson: Frank Calaprice (Princeton)

Australia: Uni. Adelaide, Australian National Uni., Uni. Melbourne, Swinburne Uni.
Italy: LNGS, Milano Uni., Roma la Sapienza Uni.
USA: Princeton Uni., PNNL, LLNL
UK: Imperial College London

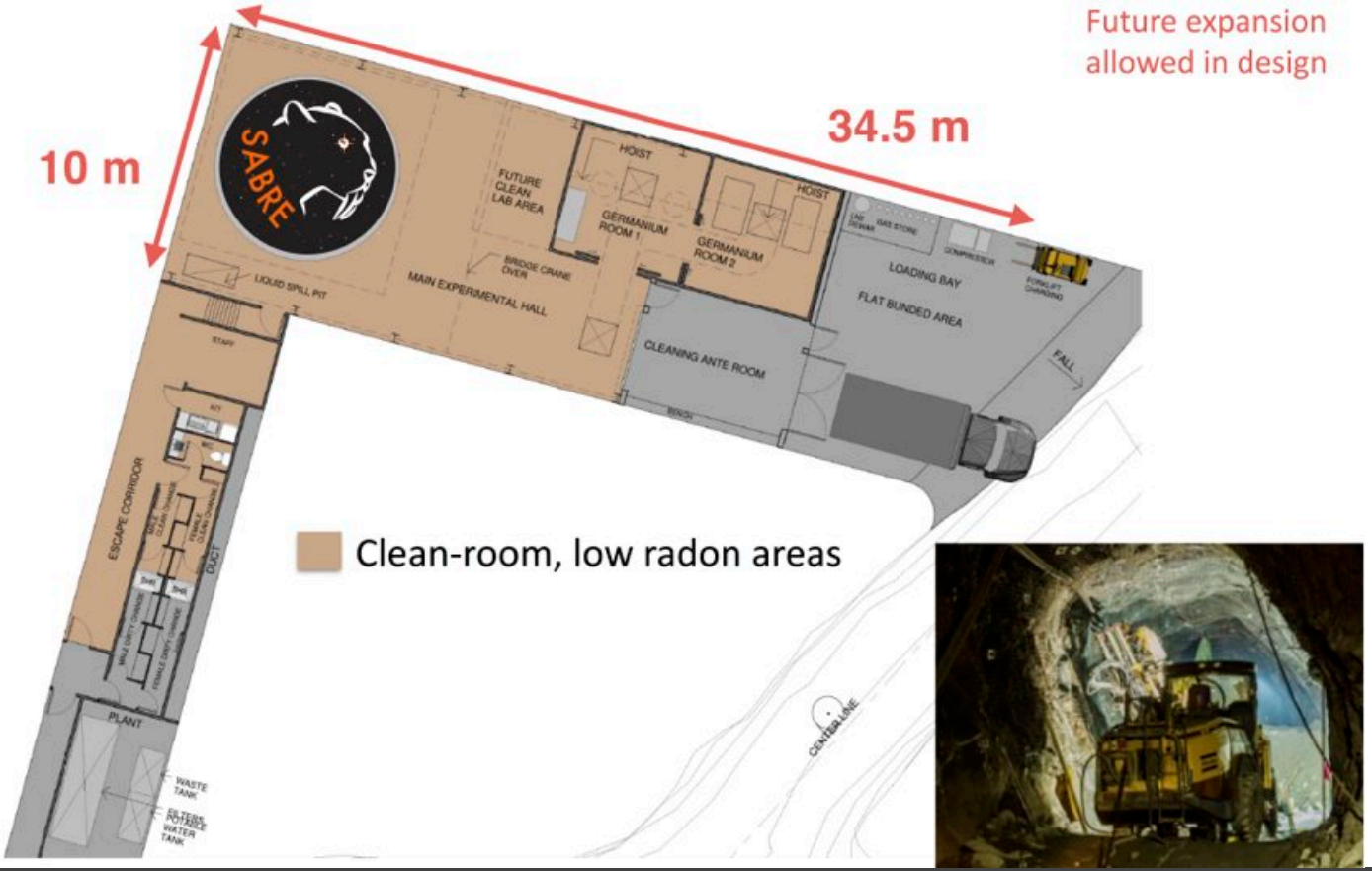


SUPL – Stawell Underground Physics Laboratory

Active gold mine, decline construction, accessible by car/ truck, basalt rock, flat overburden



SUPL – Floor Plan



- Lab proposed in Sep 2014 (E. Barberio, Melb)
- Initial funding secured in May 2015
- Design started Aug 2015
- Construction started in Jul 2016
- Completion in 2017

- Clean lab similar to SNOLab
- Rn activity < 100 Bq/m^3
- Environmental radioactivity comparable to Gran Sasso

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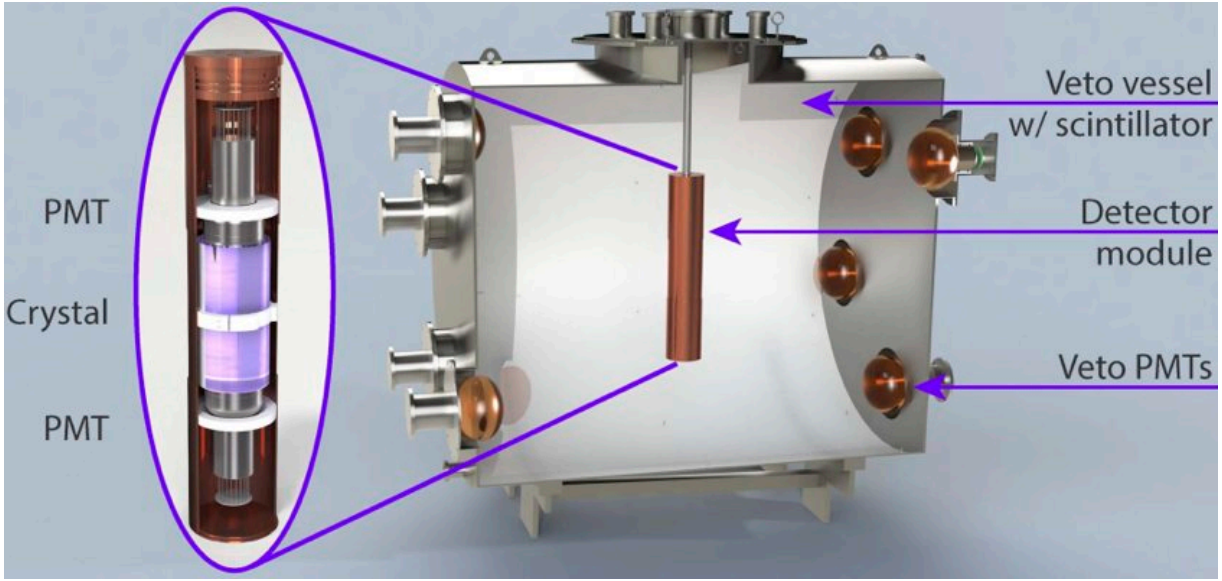
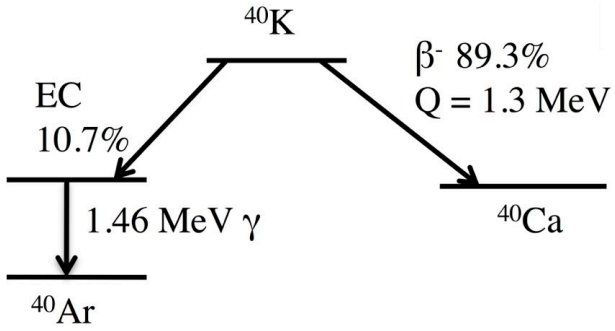
Improved backgrounds via both active and passive approaches

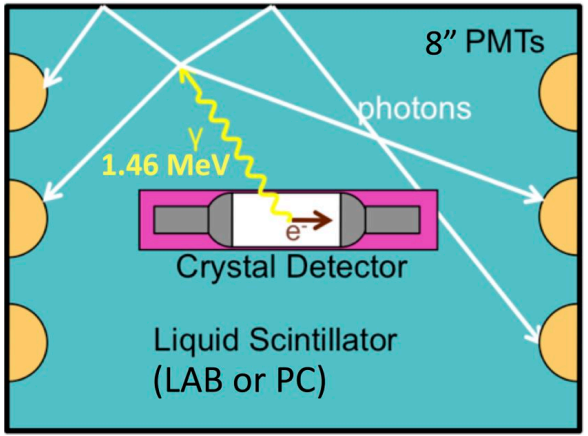
- Active scintillator veto surrounding NaI(Tl) to reduce internal and external background
- NaI(Tl) crystals with higher purity than DAMA
- Low radioactivity enclosures and PMTs

SABRE – Proof of Principle





EC leaves hole in K-shell: 3 keV Auger e-



Proof of principle (LNGS): 5-kg ultra-low background NaI(Tl)

Veto system: 1.4m diam, 1.5m length, LAB liquid scintillator

Full detector (LNGS & SUPL): ~50kg @ each site

SABRE – ultra low background materials

High-purity NaI Powder

- Developed at Princeton with Sigma-Aldrich and Seastar
- ICP mass spectroscopy by Seastar and PNNL
- AMS for ultra-sensitive measurements at ANU

High Purity Crystals

- Crystal growth (RMD, Radiation Monitoring Devices)
- 2kg, 88mm diam achieved (require 5kg, 98mm)
- Good scintillation properties
- <K> ~9 ppb and still improving (DAMA ~ 13 ppb)
- <Rb> < 0.1 ppb (DAMA < 0.35ppb)

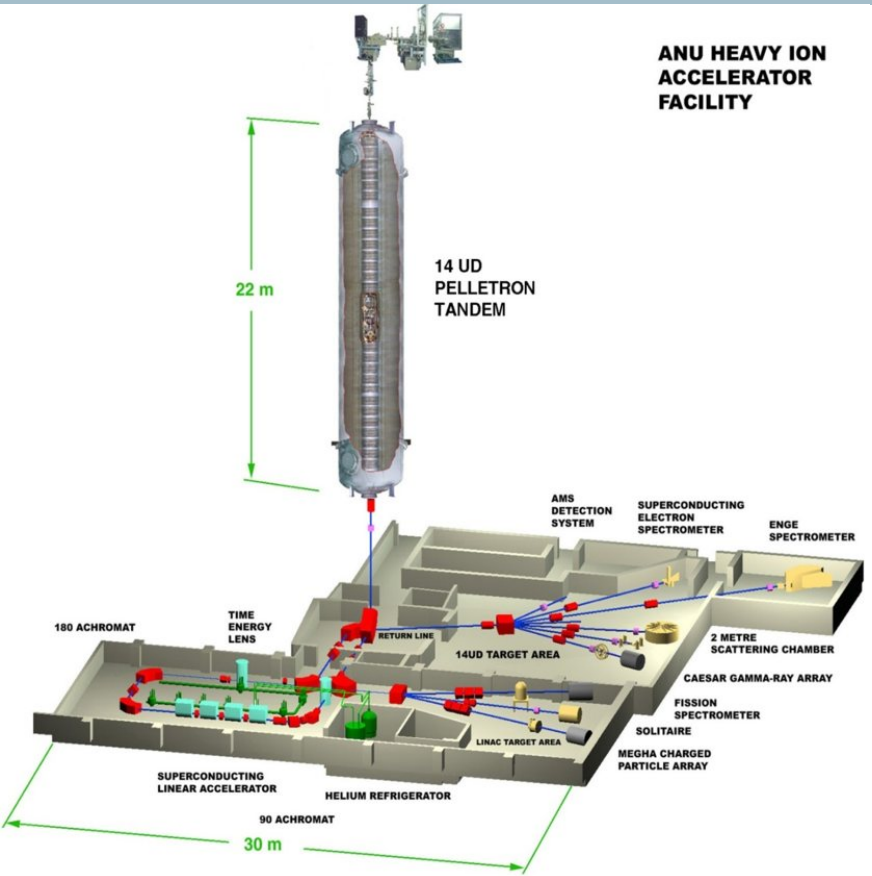
SABRE – Encapsulation and PMTs

3-inch PMTs with direct optical coupling to crystals

- QE 35% (c.f. 12% in DAMA/LIBRA)
- Low radioactivity per PMT
  - ~3 mBq U, ~0.5 mBq Th/Co and ~2 mBq K
- New PMT stem: Ceramic feedthroughs with ultra-high purity alumina
- Packaged in air- and light-tight, low-radioactivity, ultra-pure copper.

Everything related to SABRE is an ultra-pure, low-radioactivity, R&D project

Accelerator Mass Spectrometry at ANU



- Measure contaminant radionuclide isotope ratios through atom counting
- Sensitivity of 10^{-12} – 10^{-17} (relative to stable isotopes, not total)
- No isobaric background (molecules destroyed by stripping in tandem)
- Isotopic backgrounds can be clearly identified

- ^{129}I through activation of crystal
  - sensitivity of $^{129}I/I < 10^{-14}$ demonstrated
- ^{210}Pb environmental contamination
  - Preliminary investigations promising
- Other isotopes?

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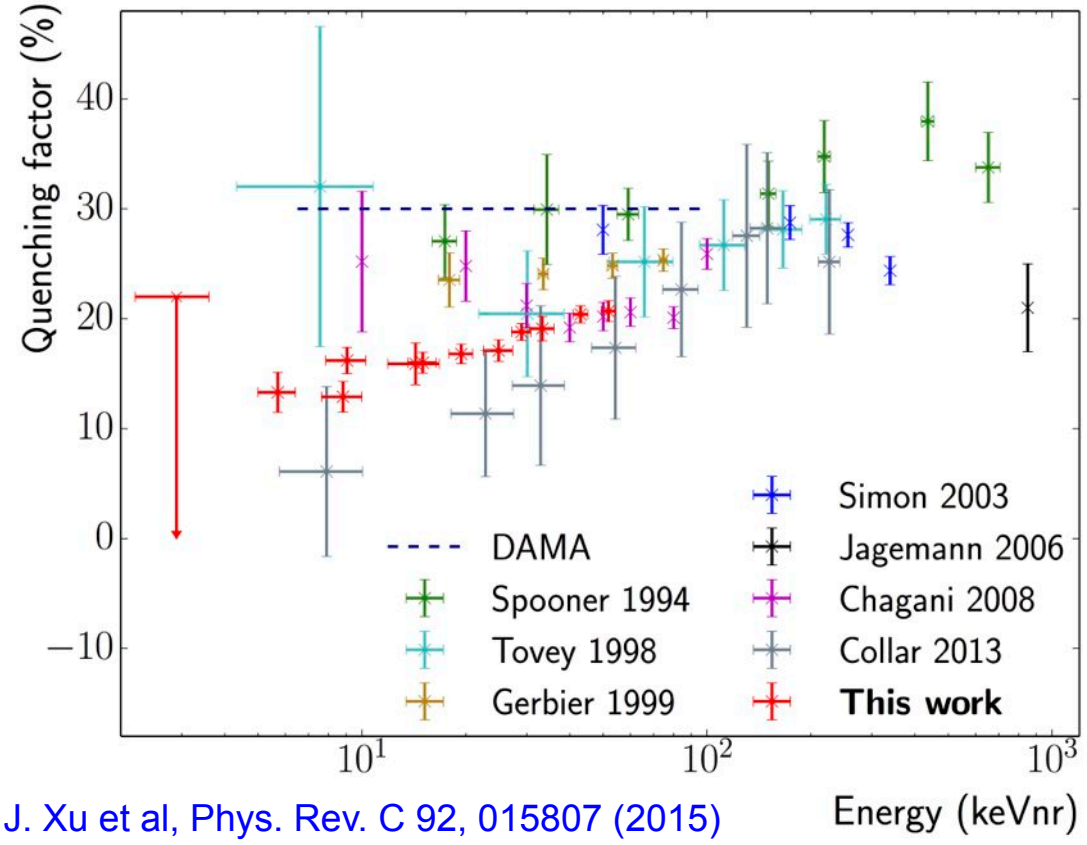
Lower WIMP energy threshold

- High QE PMTs directly coupled to NaI(Tl) crystals
- Fully digital DAQ with PSD based data analysis to give improved backgrounds.
- Clarify conflicting quenching factor measurements.

Quenching Factor



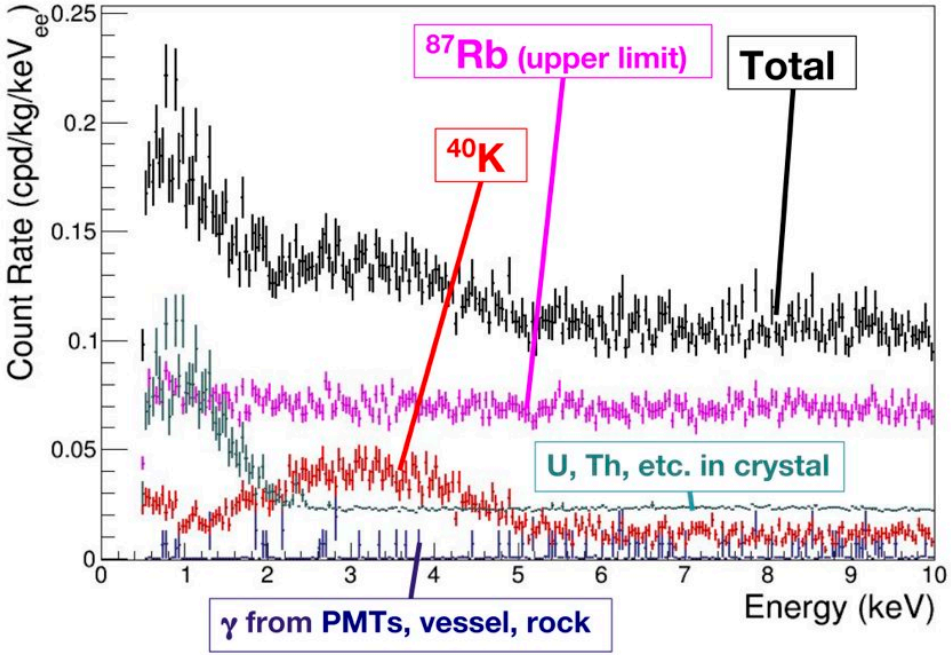
J. Xu et al, Phys. Rev. C 92, 015807 (2015)

Scintillators only measure the part of the nuclear recoil energy, E_{nr}, transferred to electrons, $E_{ee}=Qe_{nr}$

Quenching factor, Q, poorly determined.

- DAMA used Q=0.3
- Conflicts with recent work (red points)
- Pulsed neutron beam from Notre Dame using p(^{7}Li,n) reaction. Scatter neutrons off NaI(Tl) crystal.
- New measurements planned at ANU: better beam pulsing, lower energy threshold
- Confirmation of Xu et al?
- Crystal dependence?

SABRE Performance – Backgrounds



Monte Carlo model of expected SABRE signal from environmental and internal radioactivities, including effect of veto.

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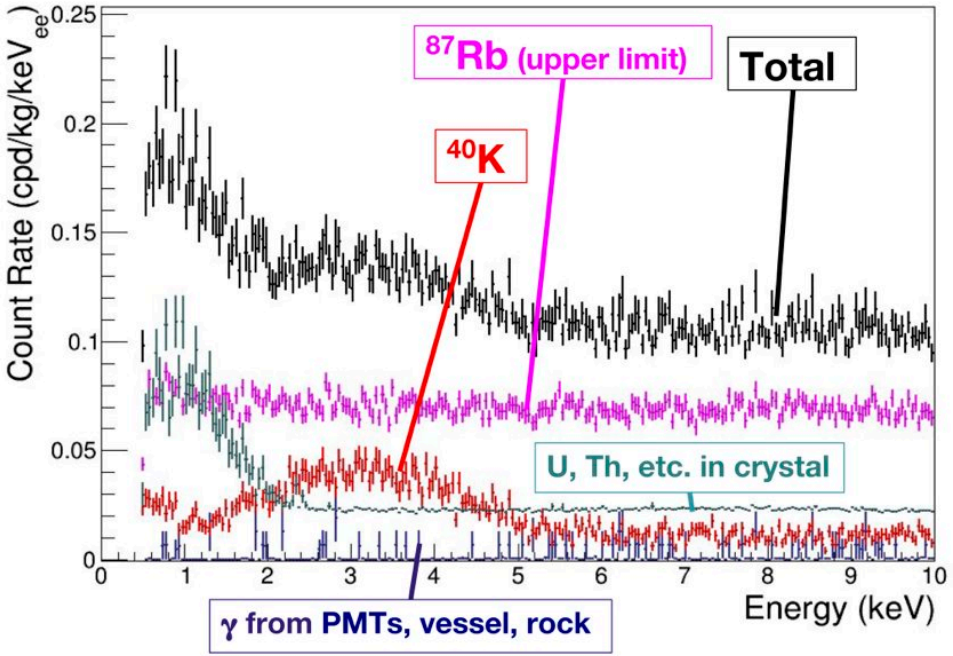

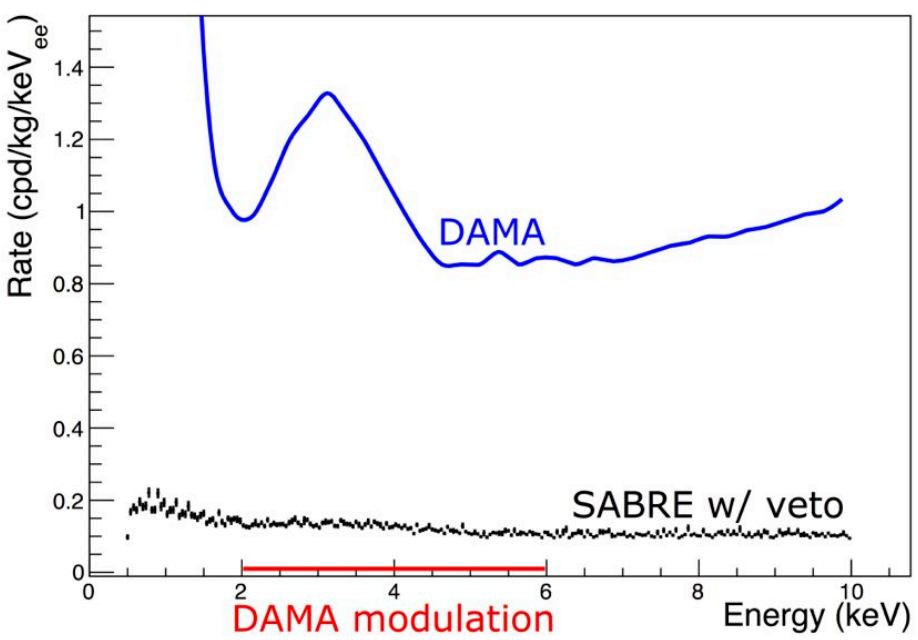

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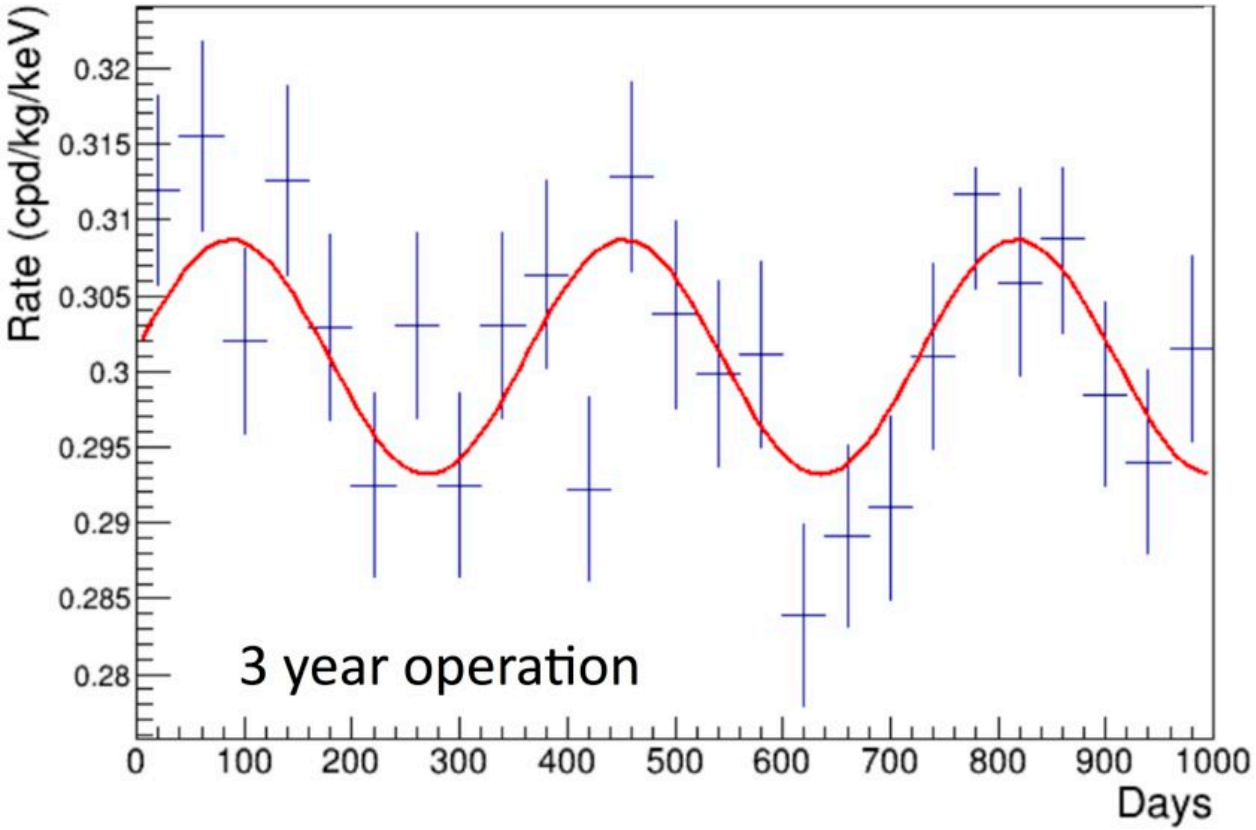
Comparison with measured DAMA response

SABRE Performance – Expected signal



Monte Carlo prediction for a single 50kg NaI(Tl) array

3 year measurement should give either a 6σ refutation or a 4σ verification.

SABRE North and South can be combined if the signal is DM related and not a seasonal background.

Summary

Stawell Underground Physics Laboratory

- First deep underground lab in the southern hemisphere
- Environmental, shielding and radioactivity characteristics broadly comparable to Gran Sasso
- Design completed and excavation commenced in July 2016
- Detector installation and data taking in 2017

SABRE

- Two identical experiments in Gran Sasso and Stawell
- Northern and southern hemisphere measurements – Definitive DM signal?
- Prototype to be deployed in Gran Sasso in Autumn 2016
- Full experiment in 2017
- Statistically definitive results in 2020

Acknowledgements – SABRE Collaboration

- Content from P. Urquijo, A. Stuchbery, F. Calaprice, F. Froborg and E. Barberio