SABRE – a test of DAMA/LIBRA using NaI(Tl)

Jingke Xu

Princeton University, for the SABRE Collaboration

Workshop on Dark Matter Detection

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The DAMA/LIBRA modulation

~250 kg NaI(Tl), LNGS
ultra-high purity

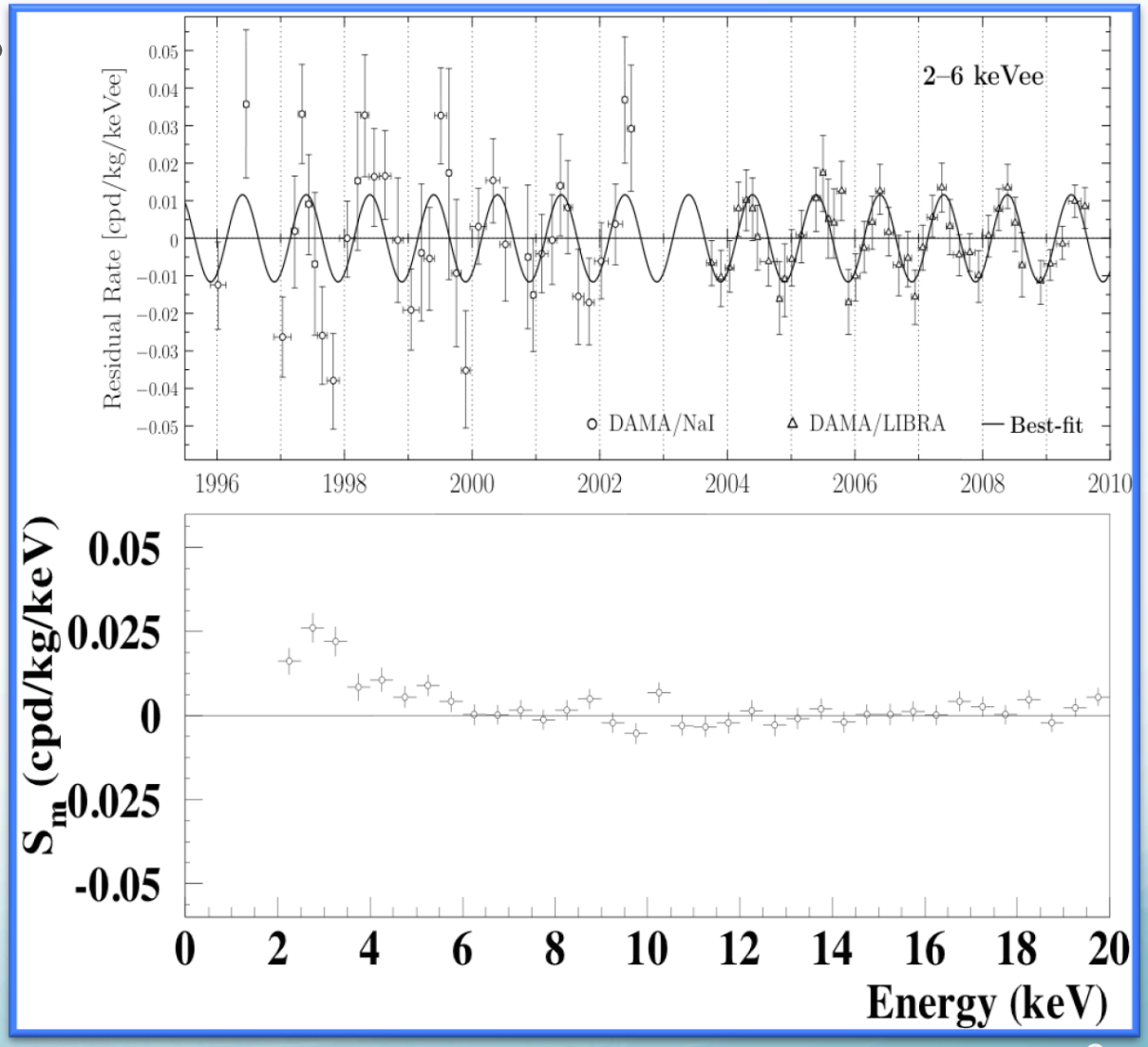
>10 years observation.

Modulation event rate:

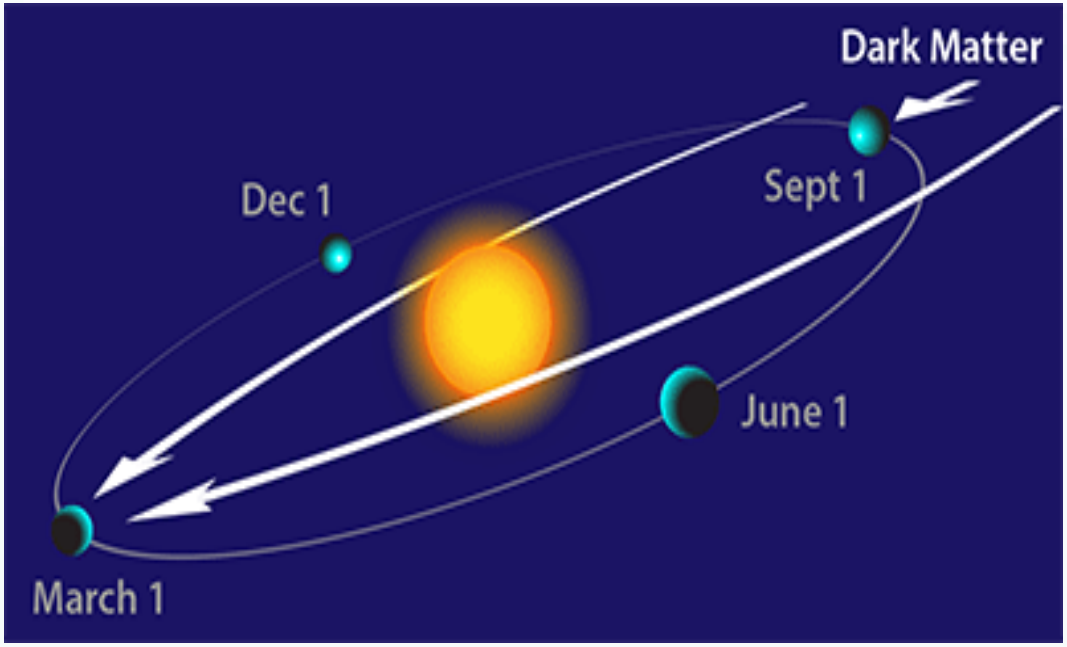
- ~1 year period
- Peak in May
- 9.3-σ significance

Modulation Spectrum:

- Nonzero 2-6 keV_{ee}
- Most prominent at ~ $3keV_{ee}$



Hint for dark matter?



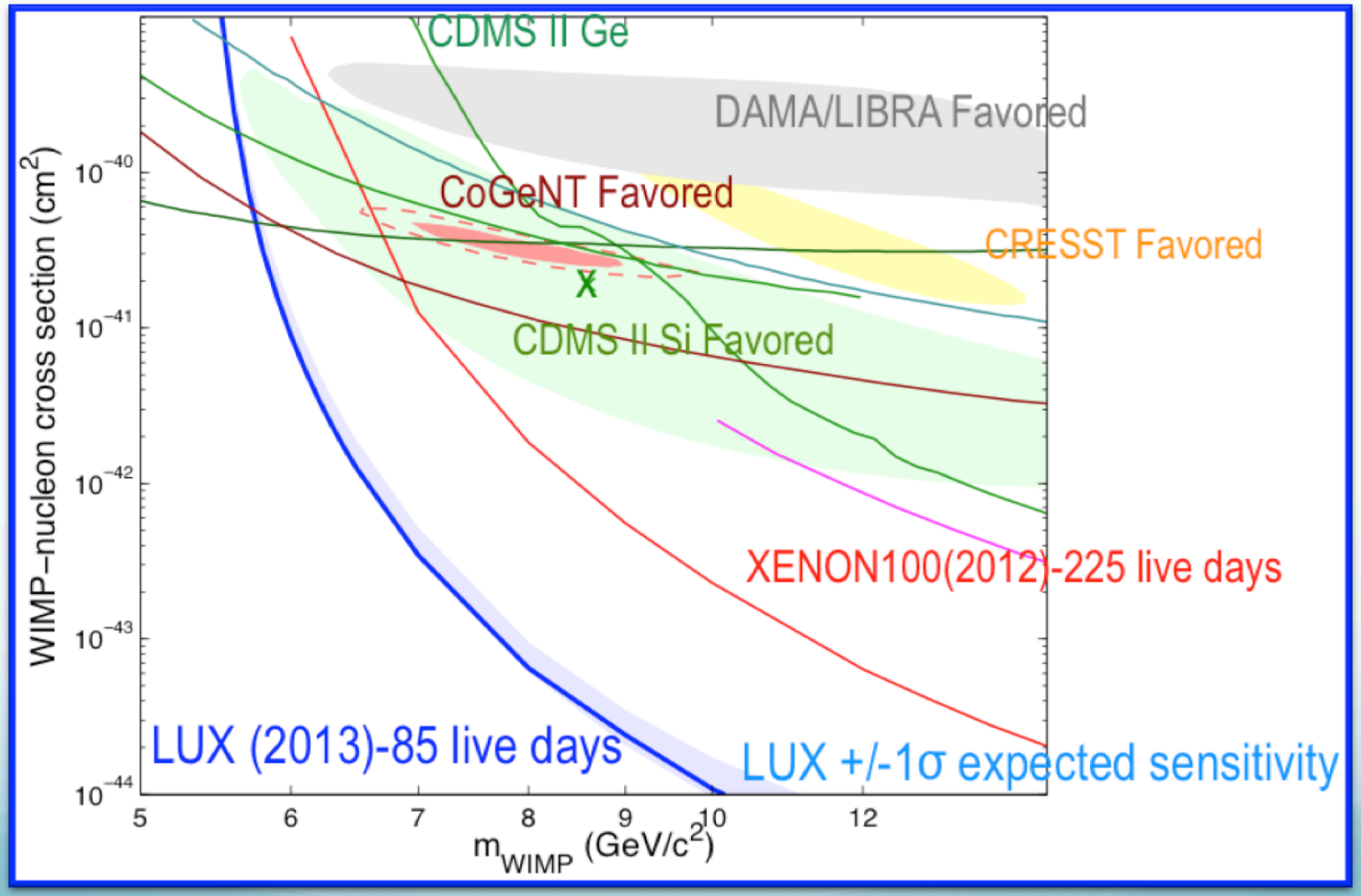
- DAMA modulation is not from known sources
- Possible evidence for dark matter, independent of dark matter – matter interaction models
- Earth's motion w.r.t. the dark halo
- Event rate: highest in June and lowest in Dec

Direct detection experiments

Dozens of experiments worldwide look for WIMP scatterings.

- Xenon (Xe)
- LUX/LZ (Xe)
- CDMS (Si and Ge)
- CoGeNT (Ge)
- DAMA/NaI, DAMA/LIBRA (NaI(Tl))
- CRESST ($CaWO_4$)
- COUPP/PICO (CF_3Br, etc)
- DarkSide (Ar)
- DEAP (Ar)
- CLEAN (Ar, Ne)
- ……

A comparison in the standard dark matter models



Is DAMA/LIBRA ruled out?

Assumptions needed for the standard WIMP sensitivity calculation:

- "Standard WIMP halo"
  - Local WIMP density ~0.3 GeV/cm^3 (perfect halo)
  - Only 1 (dominant) WIMP species
  - Maxwellian velocity distribution (WIMPs in thermal equilibrium)
  - Galactic velocity (v_0~220 km/s, v_{esc}~600km/s)
- "Standard WIMP-nucleon interaction"
  - Equal cross section to protons and neutrons
  - May or may not have spin-exchange
  - Coherent scattering

Which of these assumptions are known? NONE!

Some models are not compatible with DAMA/LIBRA, some are.

➔ Model-independent tests are needed!

The SABRE experiment

SABRE: **S**odium iodide with **A**ctive **B**ackground **Re**jection

- Grow NaI(Tl) crystals with higher purity than DAMA/LIBRA.
  - Develop ultra-high purity NaI powder
  - Develop high purity NaI(Tl) crystal growth method
- Develop NaI(Tl) crystal detectors with higher light yield and lower energy threshold than DAMA/LIBRA
  - High purity electroformed copper
  - High purity, high Q.E. Hamamtasu PMTs (direct coupling)
  - Electronics to reduce PMT coincidence background
- Operate NaI(Tl) detectors in liquid scintillator (LS) veto
  - Reject dangerous ^{40}K background and external backgrounds
- Twin detectors in northern and southern hemisphere
  - Powerful tests against environmental backgrounds

High purity NaI powder

Investigation began ~5 years ago by Prof. Calaprice, Prof. Benziger, and Dr. Wright.

High purity NaI developed with two industrial collaborators

Element	Seastar-MV Lab (ppb)	Sigma-Aldrich (ppb)	DAMA Powder (ppb)	DAMA Crystal (ppb)
[K]	12	3.5 (18)*	100	~13
[Rb]	14	0.2	n.a.	<0.35
[U]	<0.2 (0.003.5)**	<1.7 (<0.001)**	~0.020	0.0005-0.0075
[Th]	<0.1 (<0.001)**	<0.5 (<0.001)**	~0.020	0.0007-0.010

* Independent measurement, not from Sigma Aldrich

** Preliminary measurement at PNNL; full validation needed.

NaI(Tl) crystal growth

Small high purity crystal growth tests using different methods.

Approaches: 1) careful material screening,
2) precision cleaning,
3) ultra-sensitive chemical analysis.

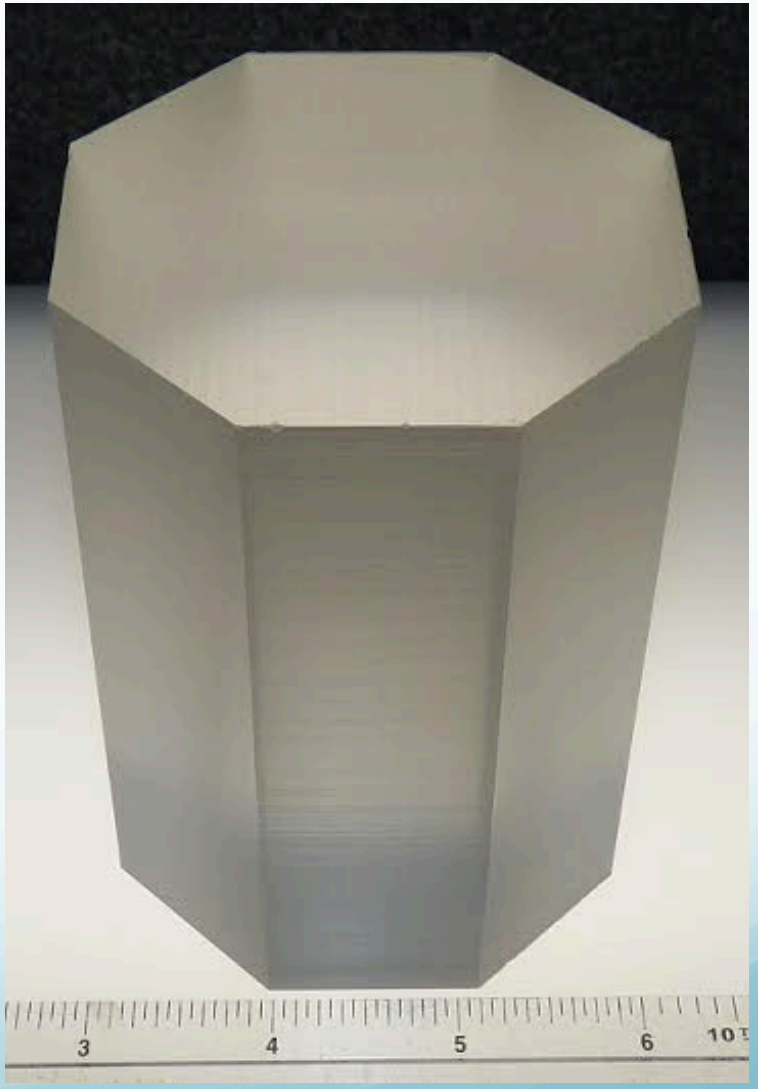
Crucible/ Ampoule	Cleaning Procedure	K ppb	Rb ppb	Th ppb	U ppb
1 with NaI	Normal	65 (10)	N.A	0.2-0.4	0.1-0.2
2 with NaI	Precision	41 (10)	N.A.	N.A.	N.A.
3 with NaI	Precision	63 (10)	N.A.	N.A.	N.A.
4 with NaI	Precision	6 (10)	N.A	N.A.	N.A.
4 Heat w/o NaI	Precision	1.5	0.0040	0.0004	0.00014
Before heat	“	0.025	<0.001	<0.001	<0.0004
Blank	“	0.0010	<0.0001	<0.0001	<0.00005

NaI(Tl) crystal growth

Current effort:

- Grow larger NaI(Tl) crystals
  1) ~3.75” standard purity growth
  2) high purity crystal growth

- Investigate further purification
  1) tested efficient with high K NaI
  2) to be tested with high purity NaI



NaI(Tl) detector

Goal: 1. low background

2. high light yield, low noise

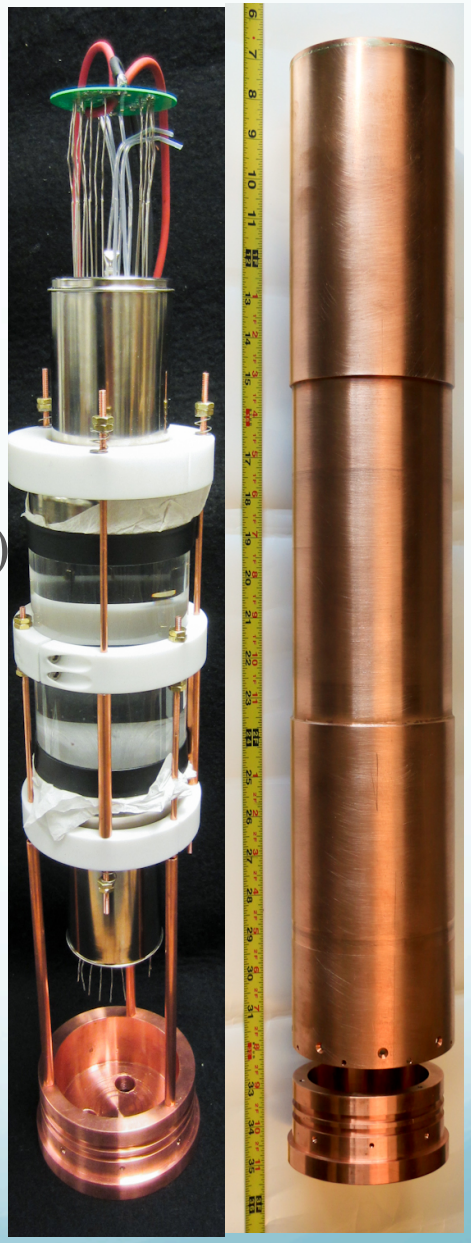
3. low energy threshold

PNNL electroformed copper enclosure (in discussion)

- ~μBq/kg U, Th radioactivity
- Small test piece made

Low radioactivity, high Q.E. (~35%) PMTs

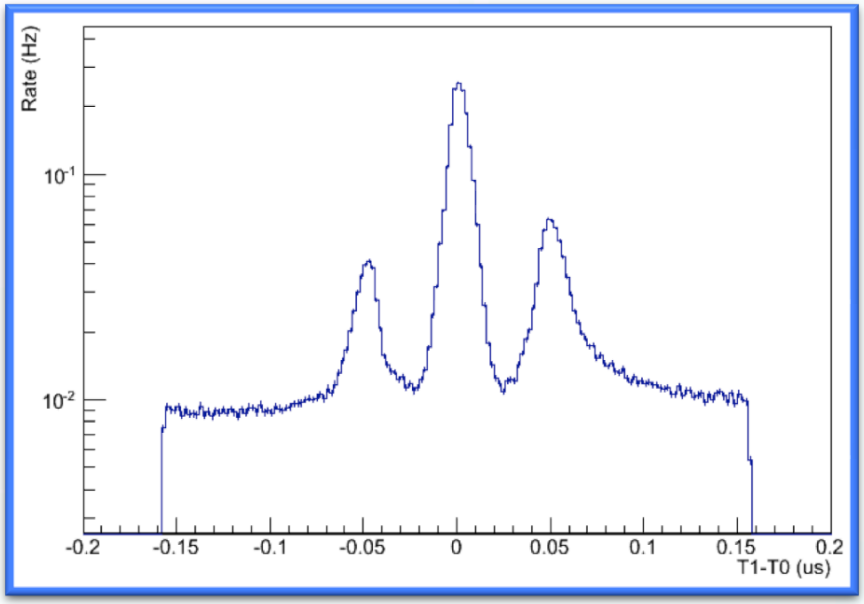
- Direct coupling to NaI(Tl)
- ~1mBq U, Th, ~1mBq Co, ~10mBq K
- Pre-amplifier developed at LNGS to suppress afterglow coincidence rate

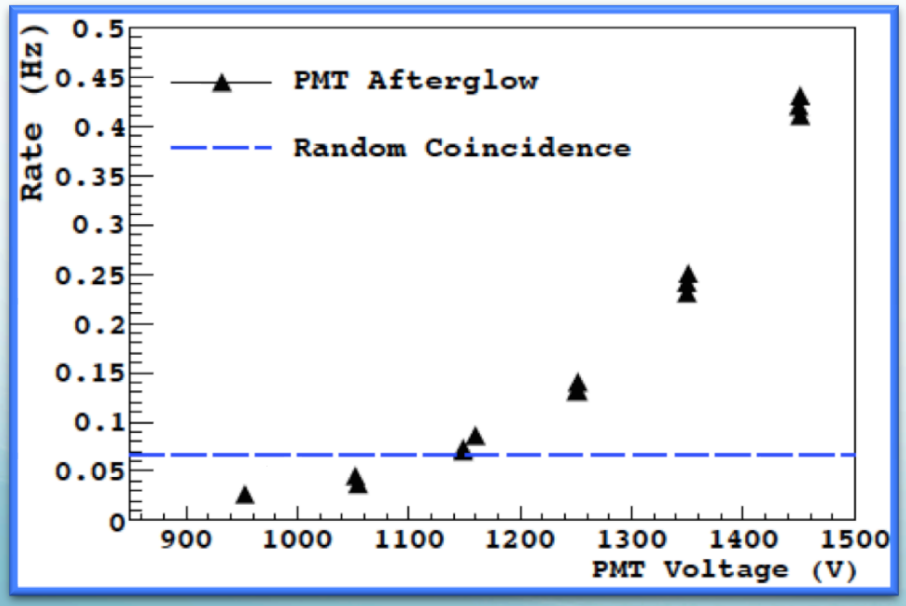


PMT noise study

PMTs can make afterglow light.

This background has been observed and characterized by the SABRE collaboration.





Delay coincidence rate decreases at low HV value.

Below random coincidence of dark count for HV < 1150

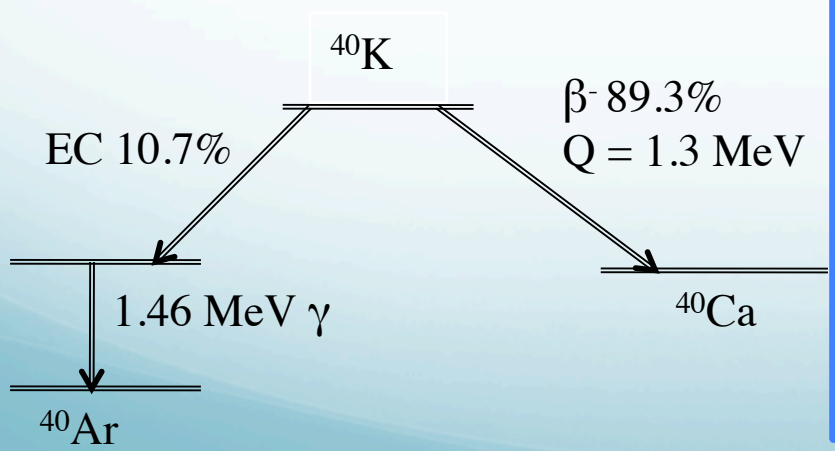
Veto principle

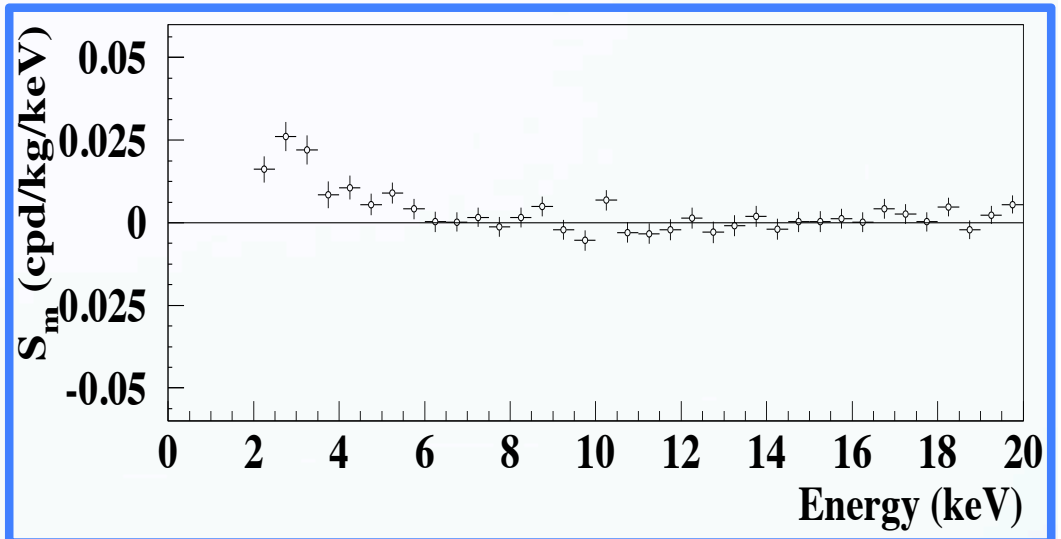
Dangerous ^{40}K in NaI(Tl)

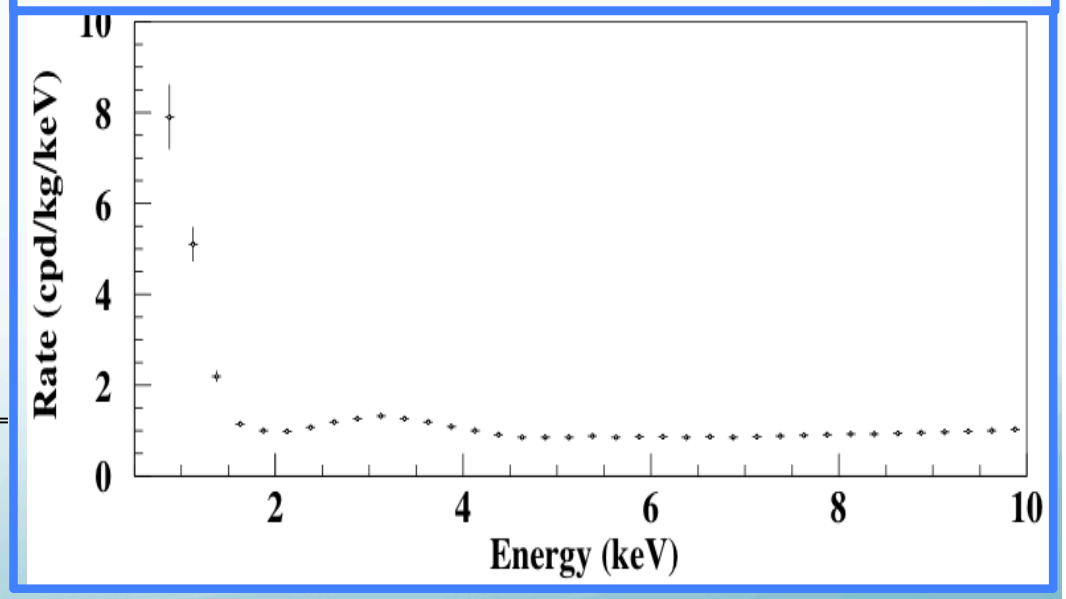
- ~13 ppb K in DAMA crystals
- ~11% B.R. E.C. to ^{40}Ar
- 1.46 MeV γ (may escape)
- ~3keV Auger electron/X-ray

With a LS veto:

- Crystal sees ~3keV: vetoed
- Crystal sees >3keV: rejected



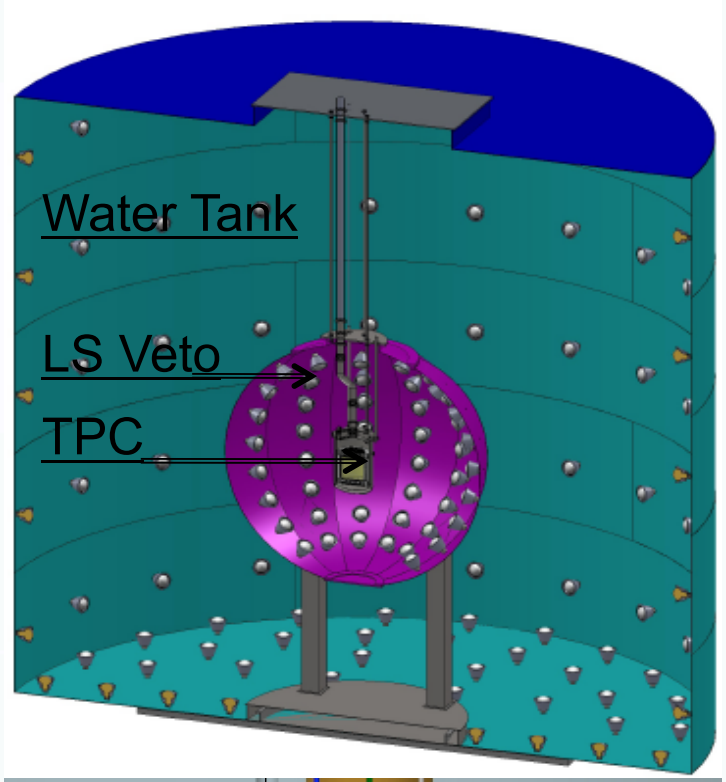


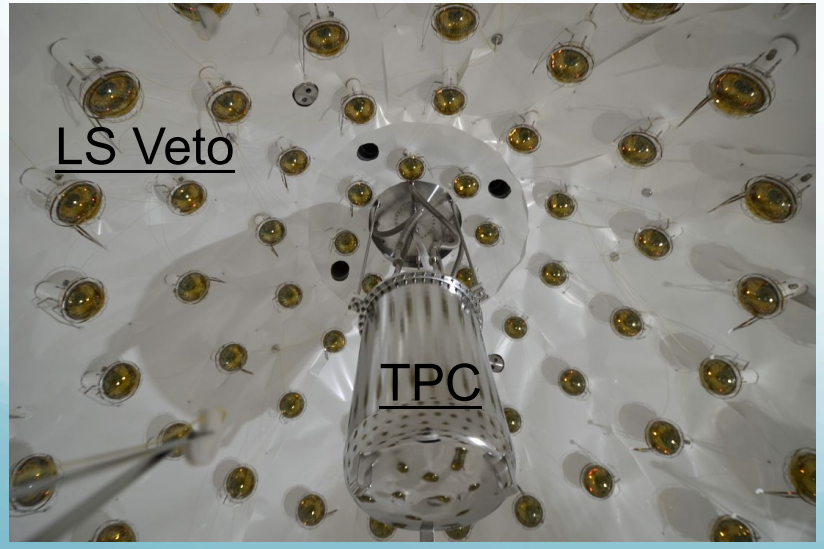


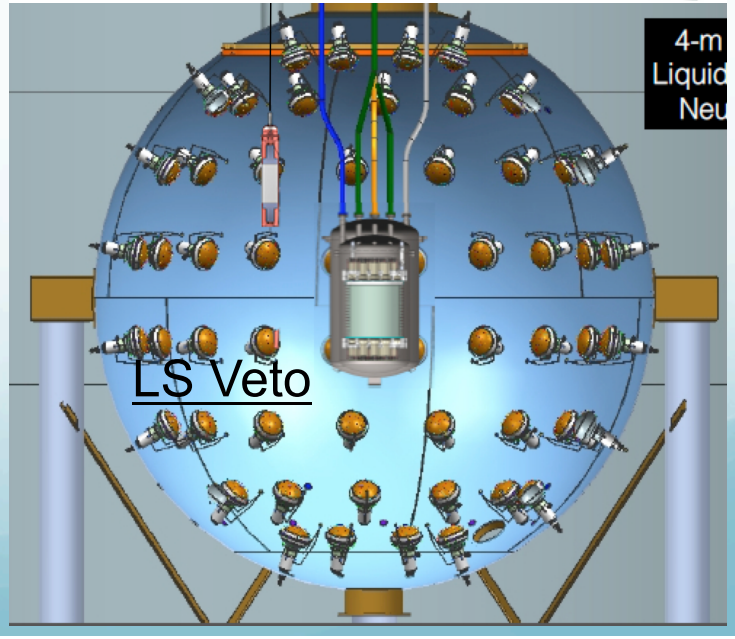
SABRE in DarkSide

DarkSide-50 liquid scintillator veto

- ~3-4m water shielding
- 4m diameter sphere
- ~30 tons of PC + TMB
- 110 PMTs (R5912)
- ~0.5 p.e./keV
- 4 ports available for detector insertion







SABRE in DarkSide

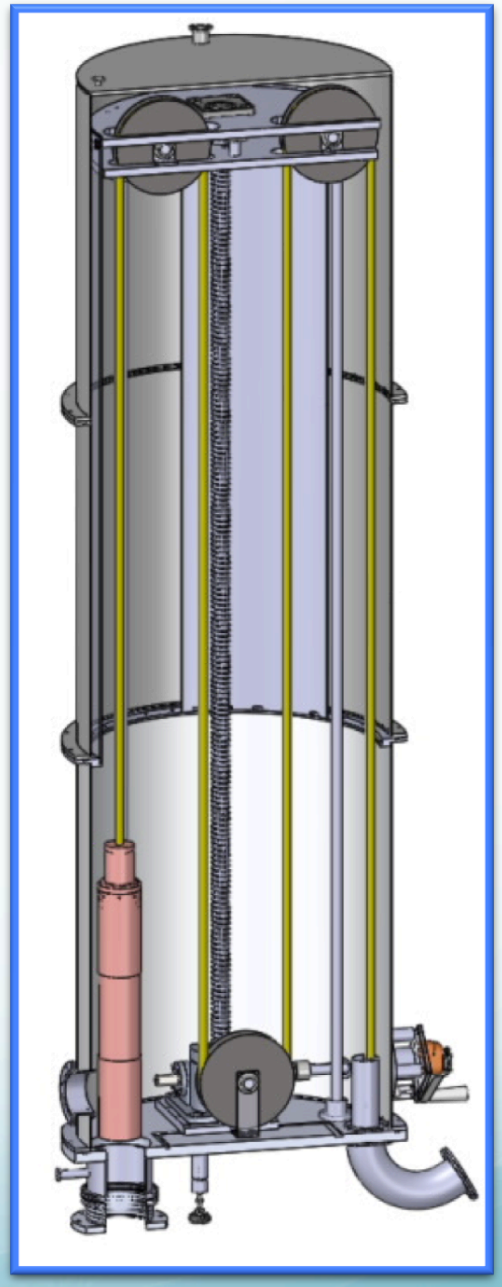
System to insert NaI(Tl) detector into DarkSide:

- Test NaI(Tl) purity
- May be suitable for dark matter run

Requirement:

- Protect LS from air
- Separate air and LS/vapor
- Isolate signal cables from LS
- Bring HV in, take signal out.

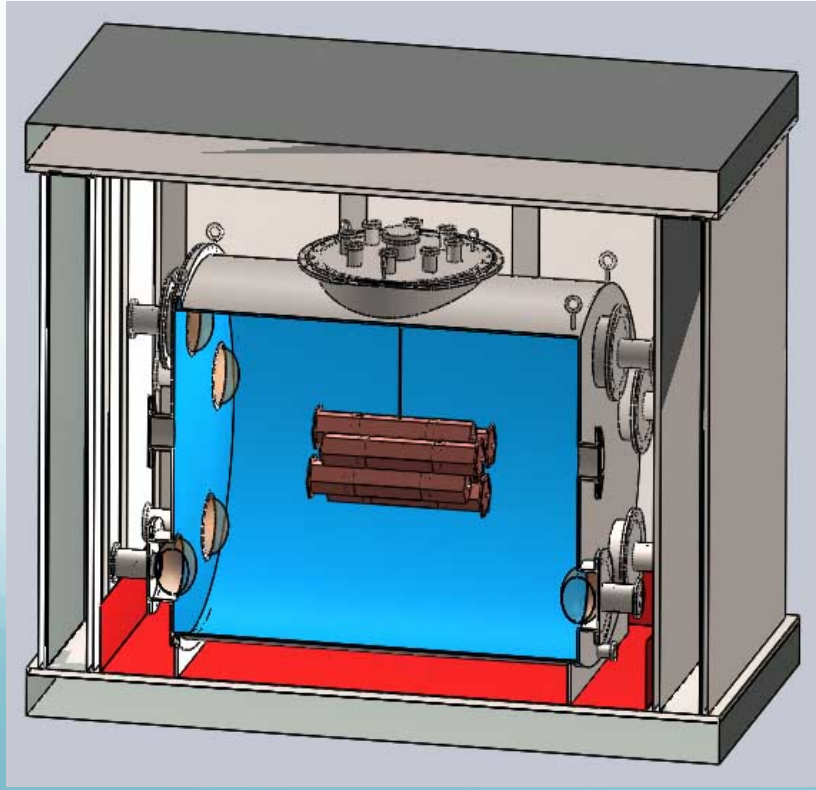
System under fabrication.



Dedicated SABRE veto

1.5m x 1.5m cylindrical veto detector (fabricated).

- ~20-25 cm lead shielding
- ~2 tons of liquid scintillator (PC or LAB), 10 R5912 PMTs
- Expected light yield: ~0.2 p.e./keV



Experimental sites

LNGS and INFN has strong interests (collaborating now).

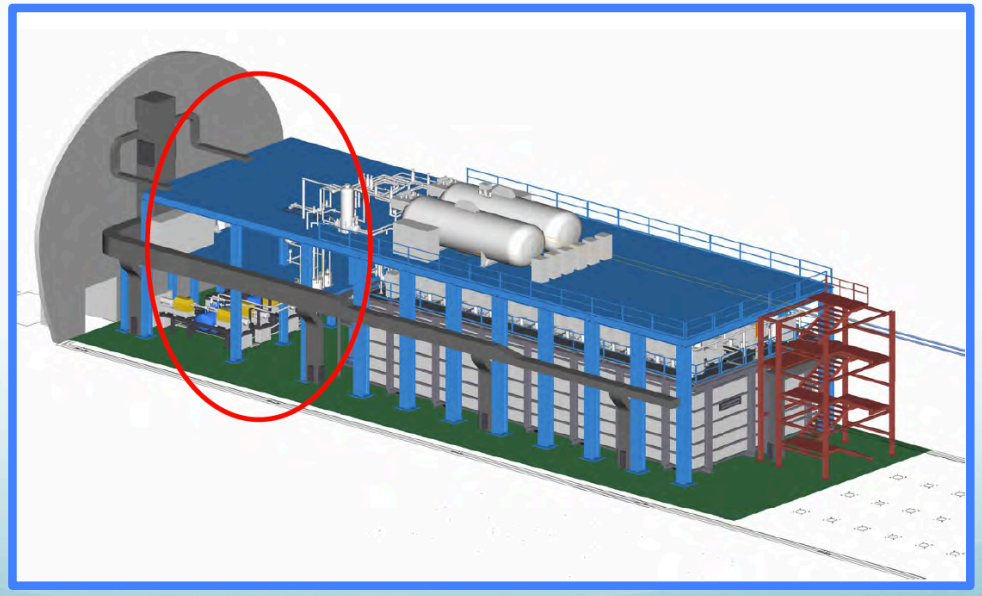
Stawell Underground Laboratory (collaborating now).

SNOLAB might be a future option (to be investigated).

Development at LNGS

LNGS and INFN has strong interests in testing DAMA/LIBRA, and a strong SABRE group has been formed.

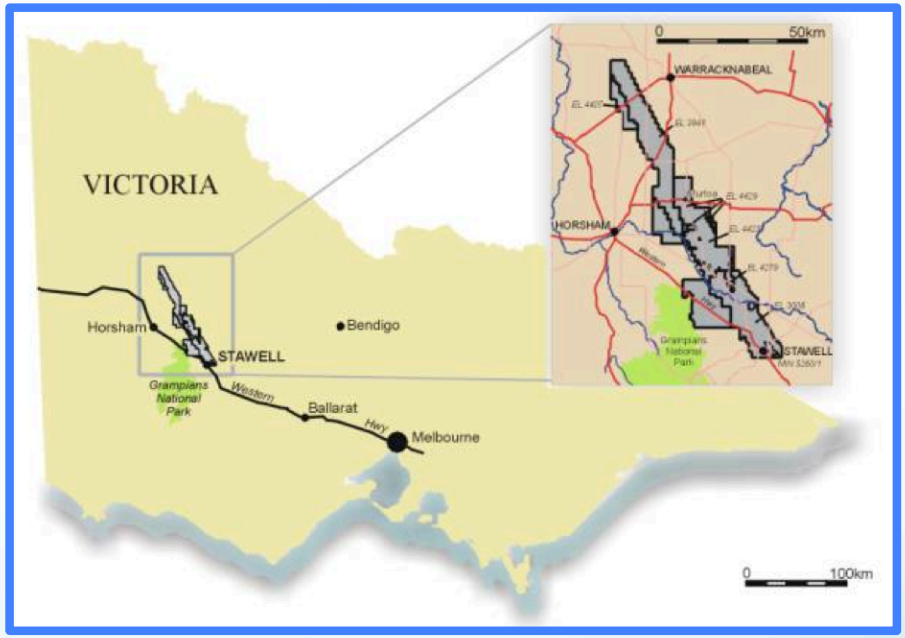
- North side of Hall B (ICARUS site) made available to SABRE.
- ICARUS infrastructure can be taken advantage of.
- Pb shielding available from WArP and OPERA
- PE slabs from WArP



Development at the Stawell Lab

Stawell (under construction) is going to be the first deep underground laboratory in the Southern Hemisphere.

- ~1 km deep, ~2.9 km.w.e
- Converted from a gold mine
- Drive-in access
- Low n flux and low Rn rate
- Funded and being constructed



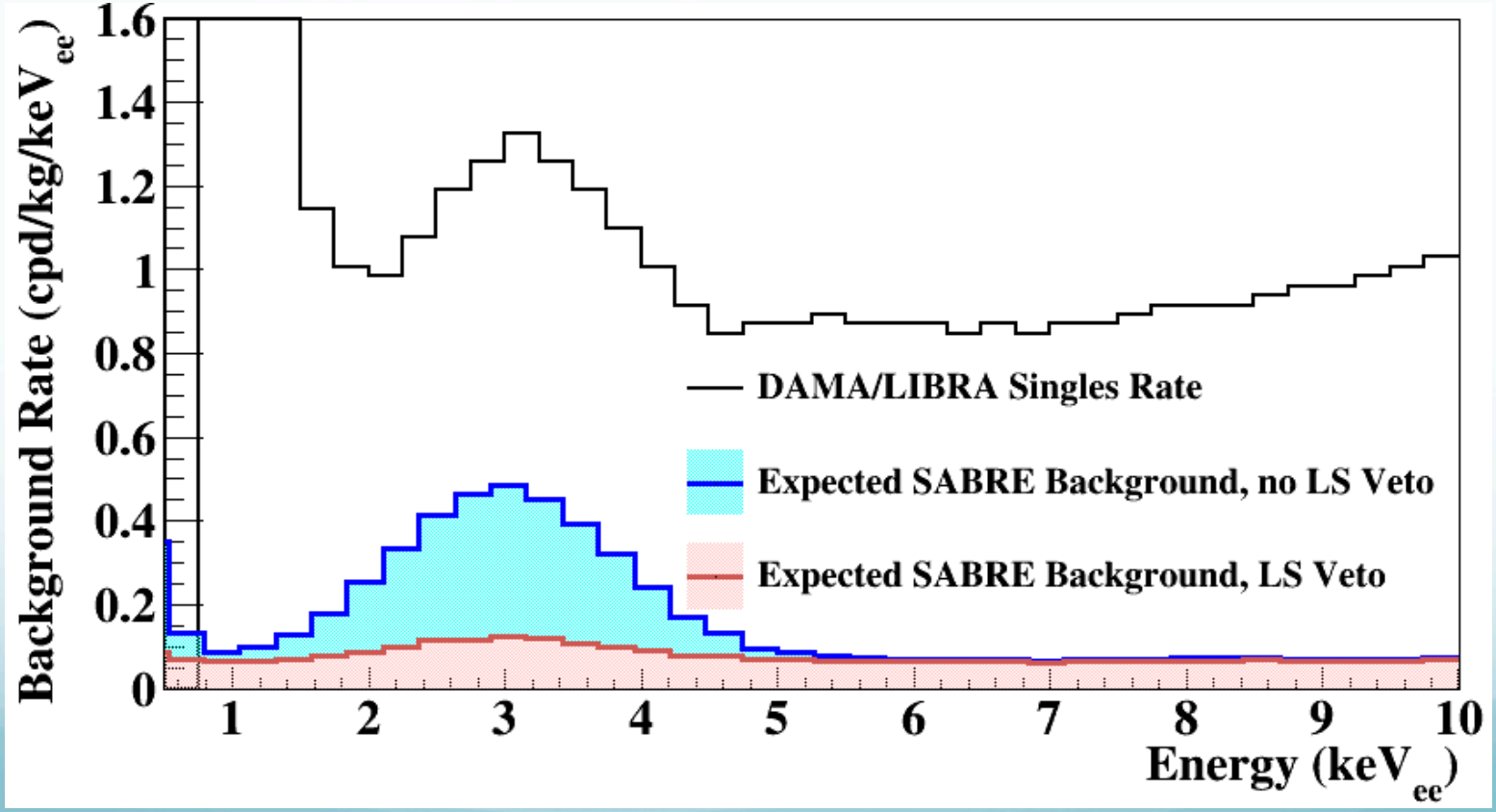
SABRE is expected to be the first dark matter experiment at Stawell, also the first in the Southern Hemisphere.

Background simulation

Assumptions: NaI(Tl) crystal purity the same as NaI powder.

External background can be appropriately shielded.

Radioactivity from detector components was found to be negligible.



Expected sensitivity

Assumption: 1. stable detector operation for a few years

2. no other seasonal effect in the same energy region

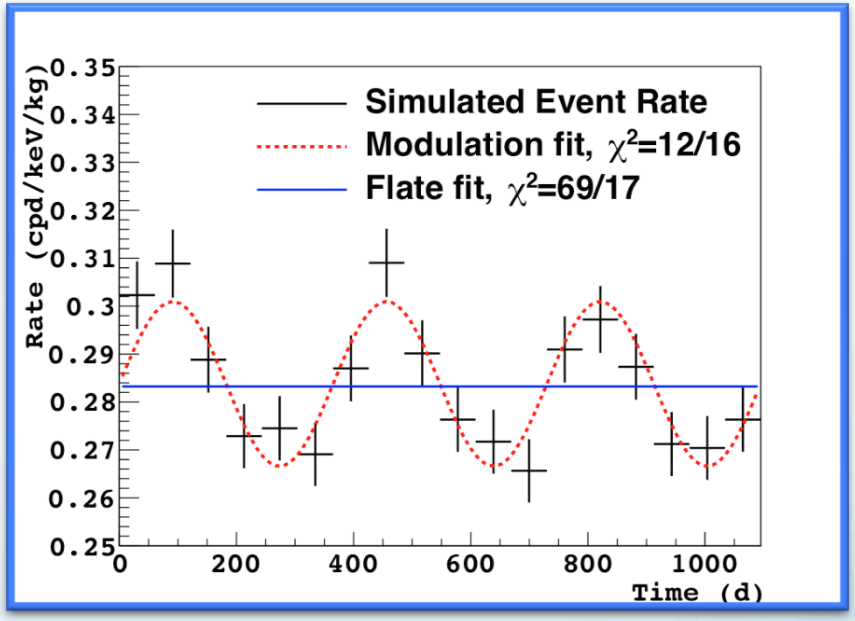
3. ~0.15 cpd/keV/kg background

50 kg NaI(Tl) array, 3 years:

- ~4 sigma power to confirm or refute DAMA/LIBRA

25 kg NaI(Tl) array, 3 years:

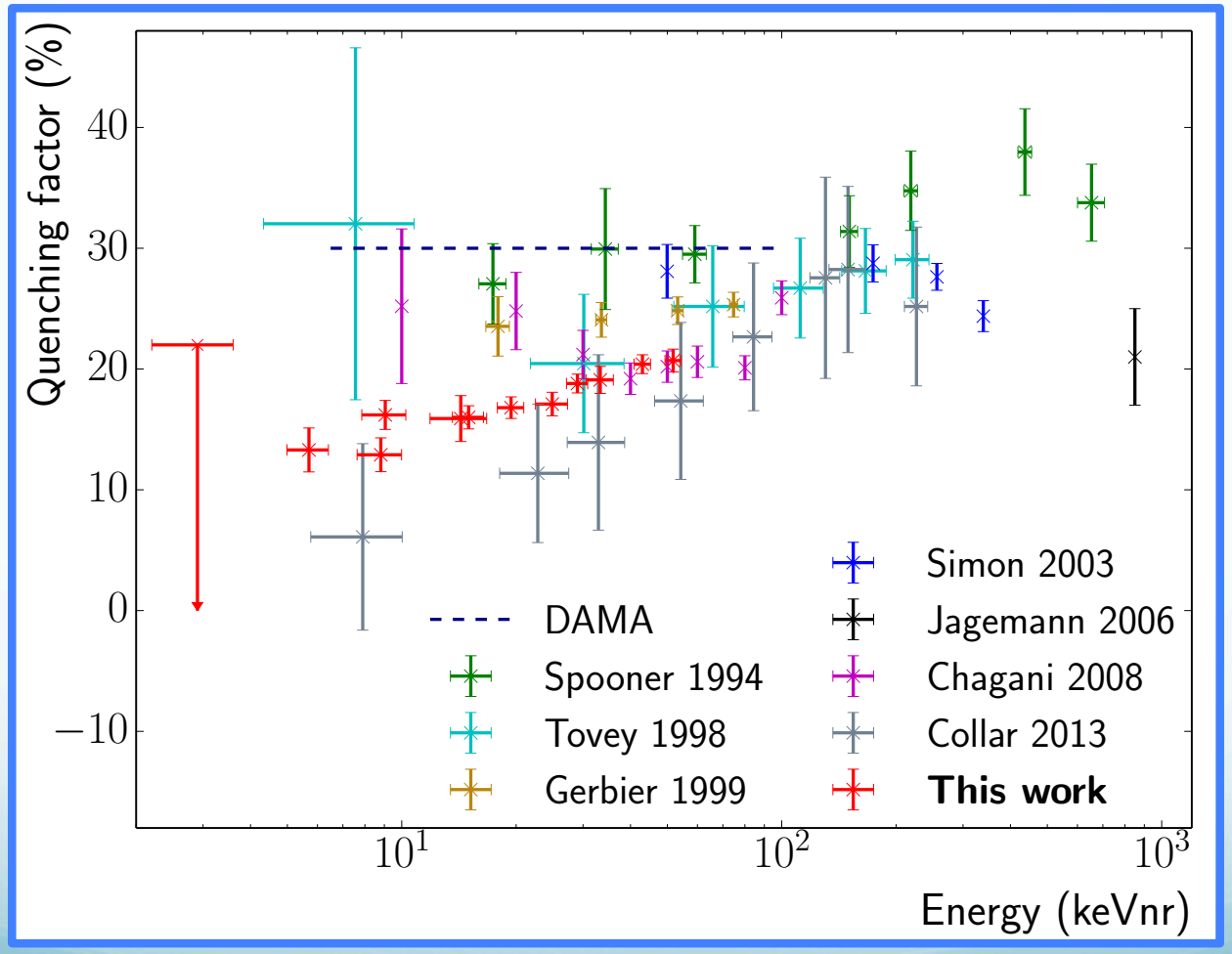
- ~3 sigma power to confirm or refute DAMA/LIBRA



Simulated 50kg experiment

Quenching measurement results

Different from DAMA/LIBRA. May reconcile other measurements.



arXiv:1503.07212

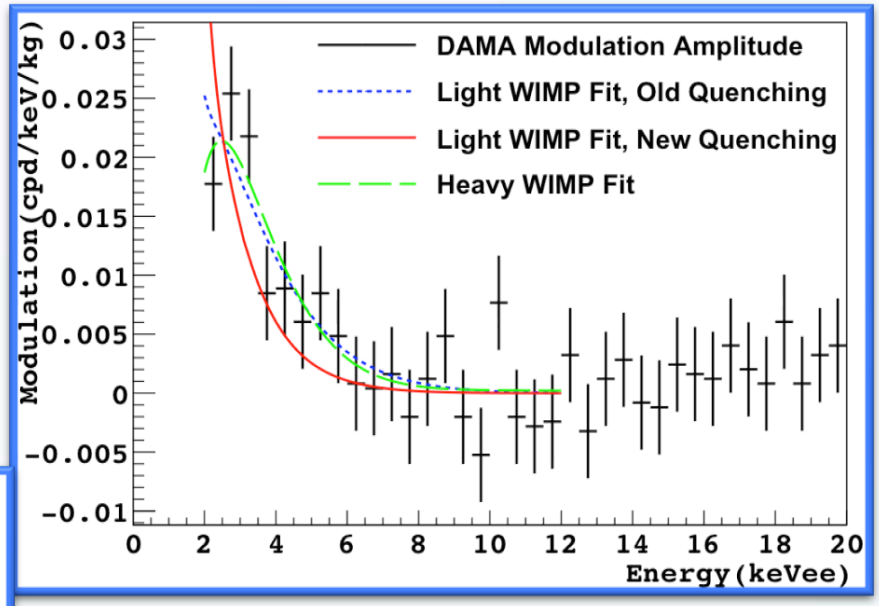
Implications for DAMA/LIBRA

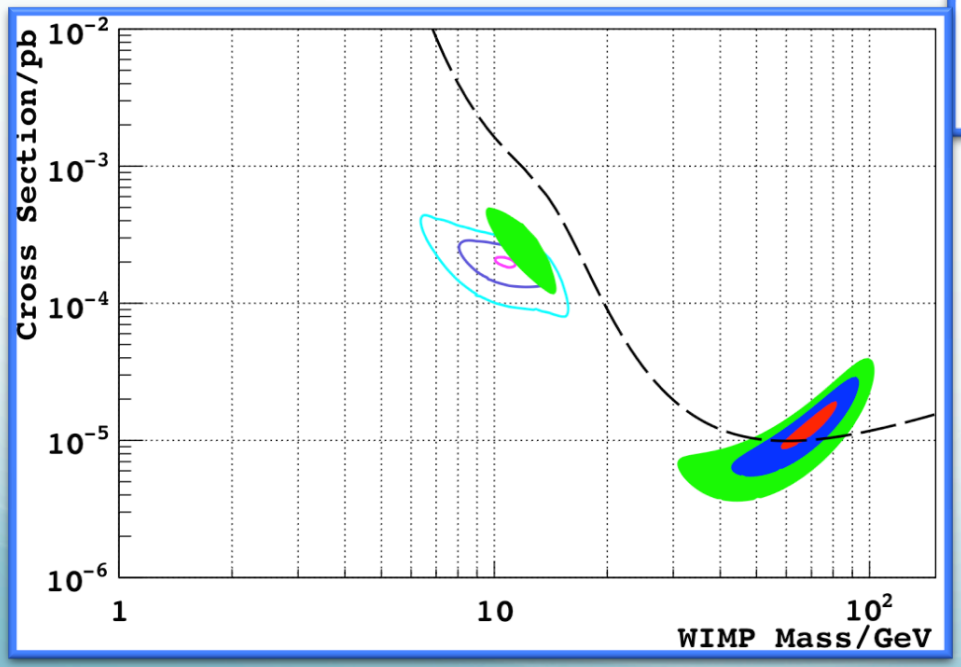
arXiv:1503.07212

Light WIMP fit is disfavored.

χ_{min}/N.D.F. = 38/18, P < 0.01

Large WIMP mass and cross section required. Tension increases.





Heavy WIMP fit not changed.

Best fit yields higher WIMP rate than totally observed.

DAMA/LIBRA is not compatible with a standard WIMP.

The SABRE Collaboration

Australian National University

G. Lane, C. Sinemel, A. Stuchbery, A. Wallner

INFN, LNGS and GSSI :

M. Antonello, G. Di Carlo, Aldo Ianni, F. Lombardi, C. Macolino, S. Nagorny, A. Razeto, C. Vignoli

INFN-Roma 1:

I. Dafinei, P. Mosteiro, G. Piredda, C. Tomei

Milano University:

D. D'Angelo

PNNL:

E. Hoppe, T. Hosbach, J. Orrell, C. Overman

Princeton University:

J. Benziger, F. Calaprice, F. Froborg, E. Shields, B. Suerfu, M. Wada, S. Westerdale, J. Xu

University of Melbourne:

E. Barberio, G. Taylor, P. Urquijo, M. Volpi

Conclusions

The DAMA/LIBRA signal is highly significant and controversial.

Model-independent test of DAMA/LIBRA is necessary.

SABRE is working on a **proof of principal** for a definitive test of DAMA/LIBRA.

- Ultra-high purity NaI powder developed
- High purity NaI(Tl) crystal growth method being developed
- Low background detector enclosure in design
- High light yield, low energy threshold can be expected
- Liquid scintillator veto to reject residual background
- Plans to operate in both southern and northern hemispheres
- Nuclear recoil energy scale calibrated