SABRE – a test of DAMA/LIBRA with ultra-high purity NaI(Tl) crystals

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For the SABRE Collaboration

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The DAMA/LIBRA modulation

~250 kg NaI(Tl), LNGS

ultra-high purity

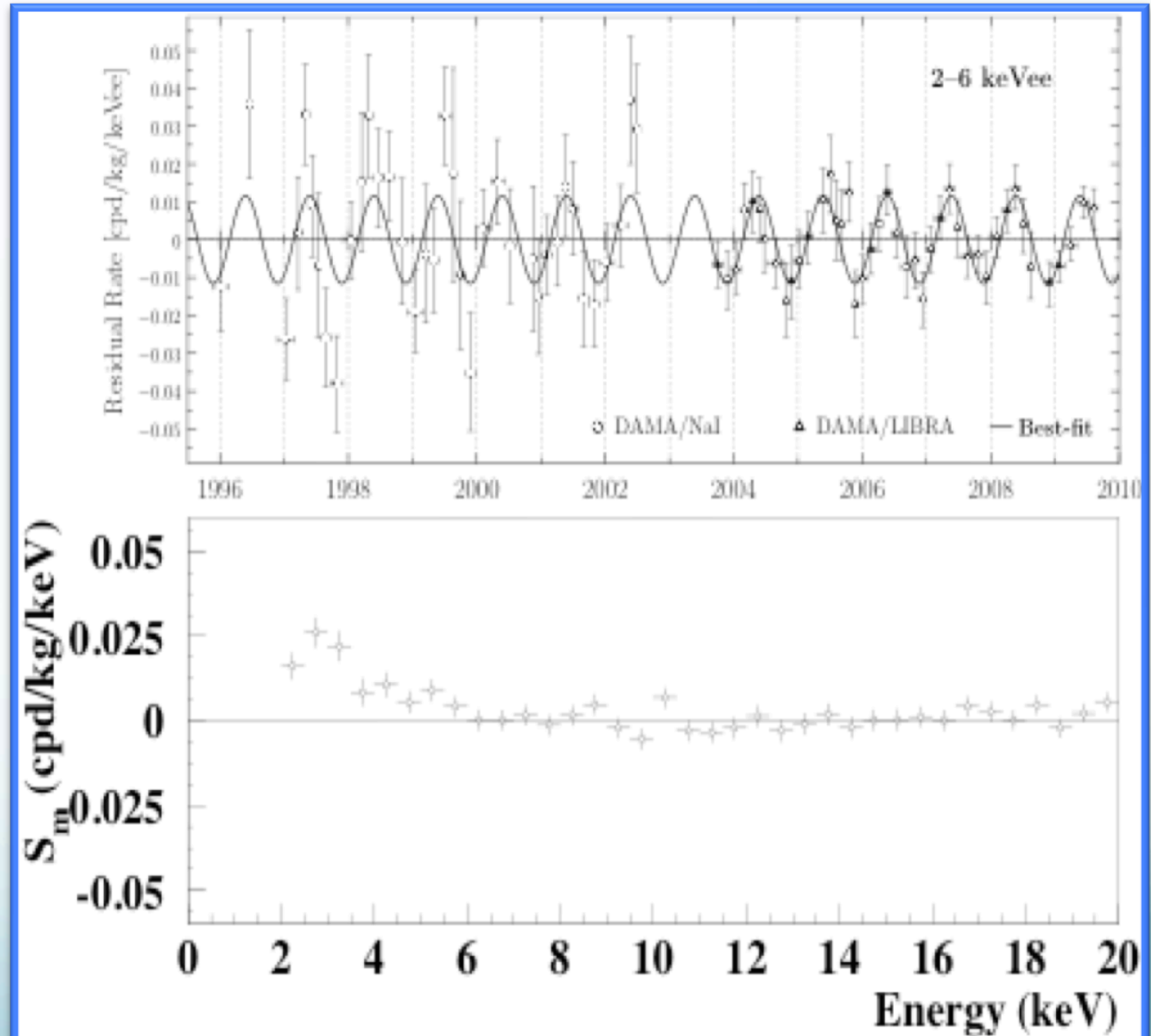
>10 years observation.

Modulation event rate:

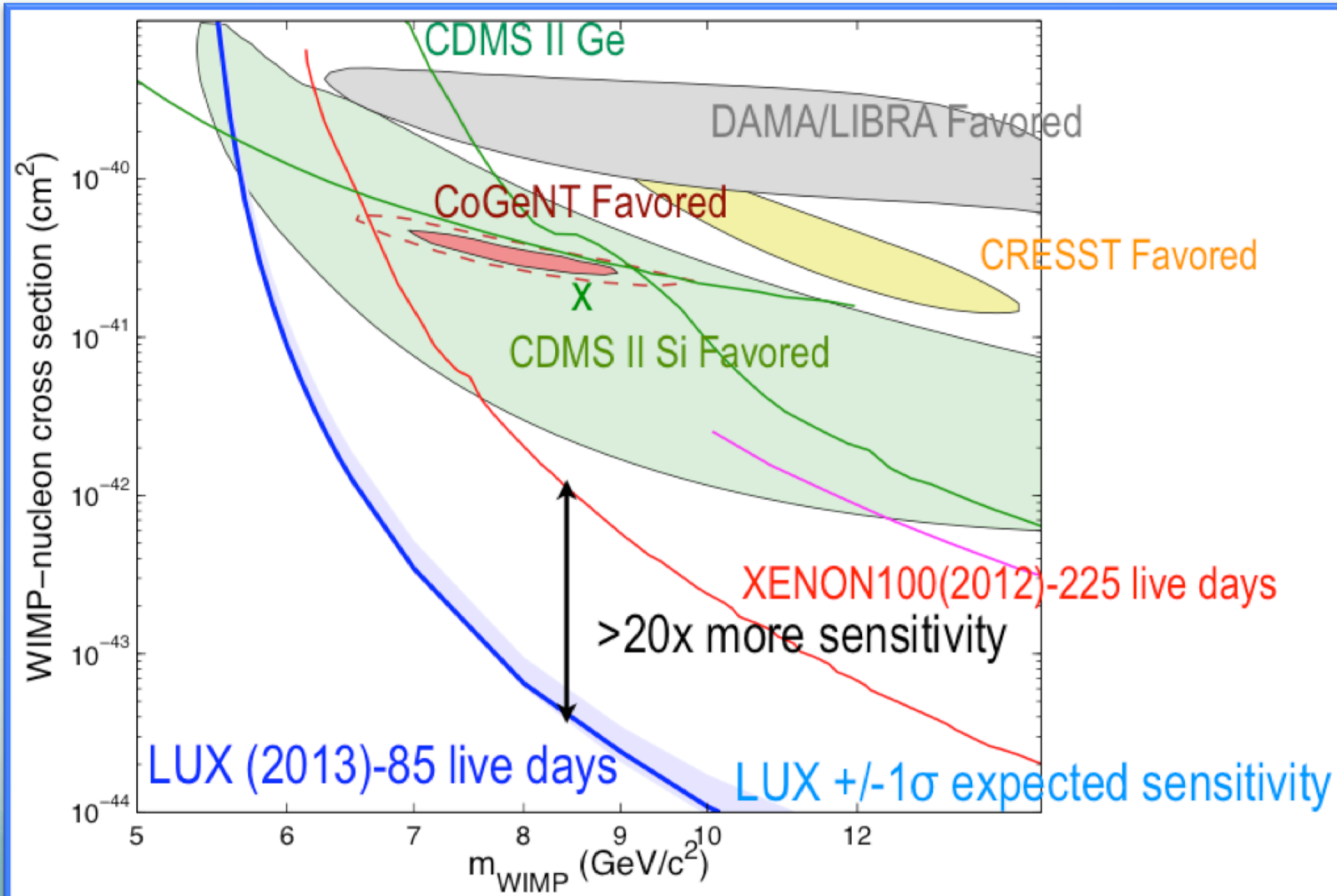
- ~1 year period
- Peak in late May
- 9.3 σ significance

Modulation Amplitude:

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



The controversy



Is DAMA/LIBRA ruled out?

Assumptions in standard WIMP sensitivity calculation:

- "Standard WIMP halo"
  - Local WIMP density ~0.3 GeV/cm^3 (perfect halo)
  - Only 1 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 (nuclear form factor)
  - …

Which of these assumptions are known? NONE!

Model-independent test of DAMA/LIBRA is necessary.

The SABRE approach

SABRE: <u>S</u>odium iodide with <u>A</u>ctive <u>B</u>ackground <u>Re</u>jection

Approaches of the SABRE experiment:

- 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 to reject background.
  - Reject dangerous ^{40}K background and external backgrounds

Ultra-high purity NaI power

Investigation began ~6 years ago by Prof. Calaprice, Prof. Benziger, and Dr. Wright.

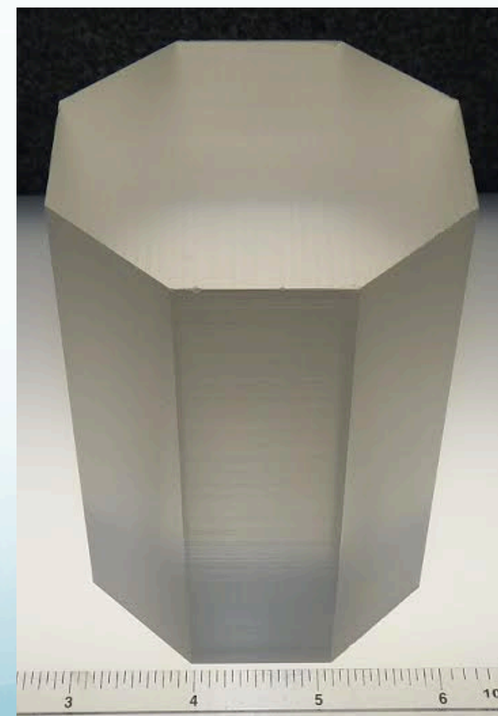
High purity NaI developed with two industrial collaborators

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 (0.0035)**	<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.

SABRE NaI(Tl) crystal growth



Small crystal growth tests

1) different crystal growth methods
2) careful material screening
3) precision surface cleaning
4) ultra-sensitive chemical analysis

We have identified a method that doesn't introduce significant impurity in the process.

Large crystal growth tests

1) use method identified with small growths
2) ~3.75” standard purity crystal grown
2) high purity crystal growth in preparation

SABRE NaI(Tl) detectors

Goal: low background

high light yield, low noise

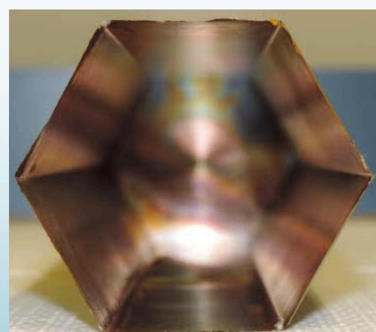
low energy threshold

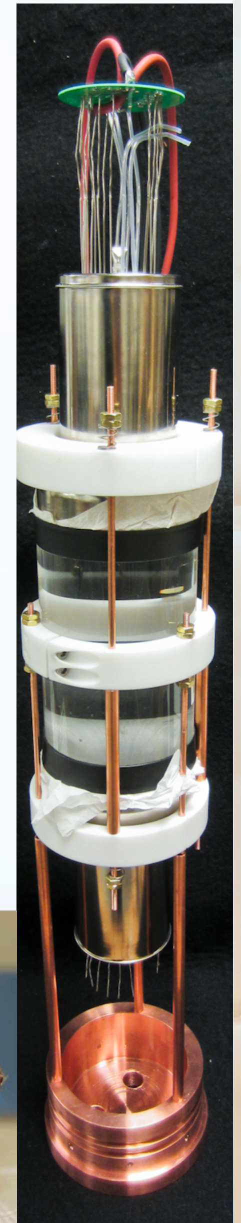
Low radioactivity, high Q.E. (~35%) PMTs

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

PNNL electroformed copper enclosure

- ~μBq/kg U, Th radioactivity
- used in the Majorana experiment



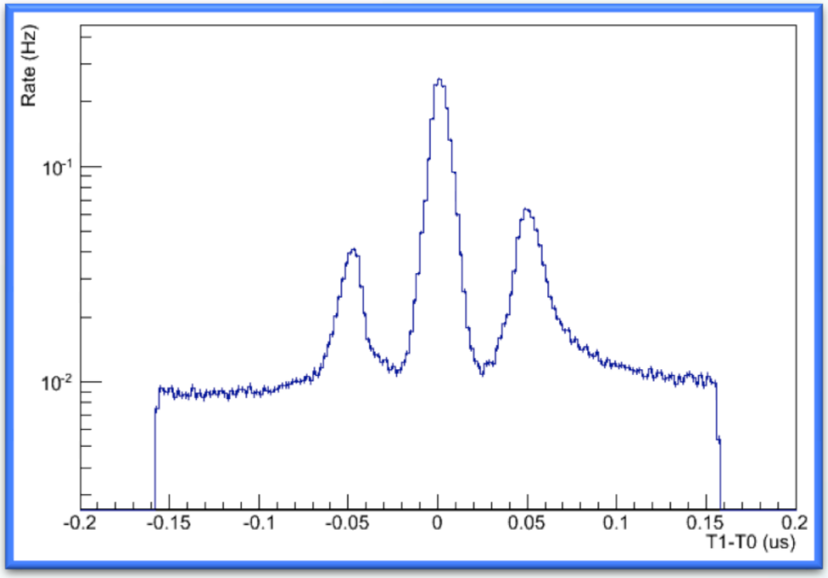


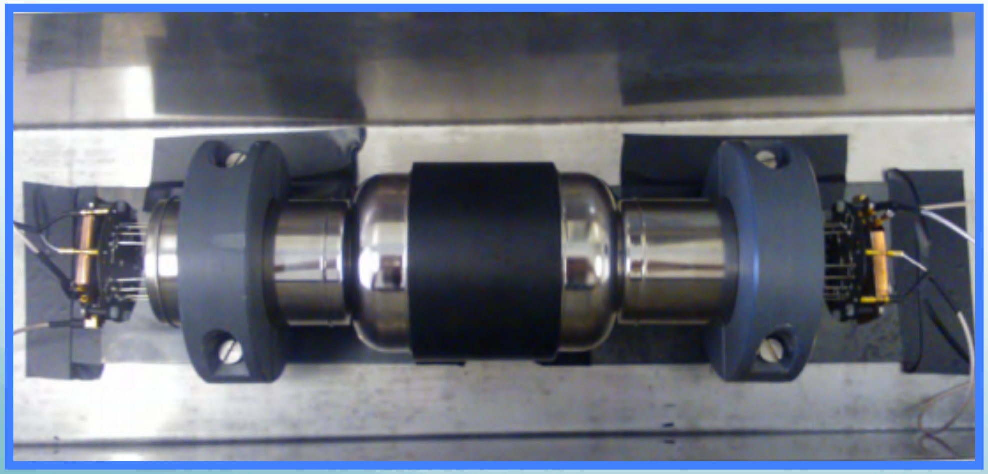
PMT noise suppression

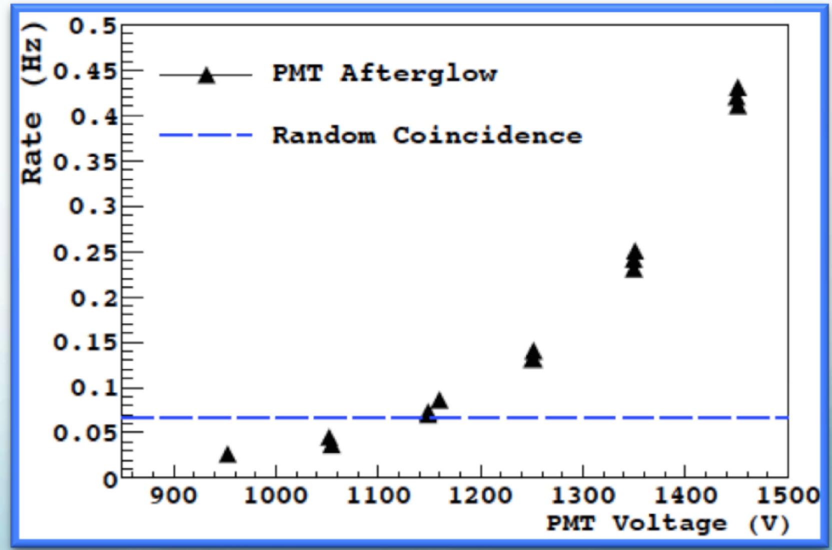
PMT dark count can be reduced by coincidence trigger.

Afterglow is a coincidence background. PMTs may generate light and cause real coincidence.

After glow rate drops with voltage (LNGS-developed electronics enables low PMT HV).







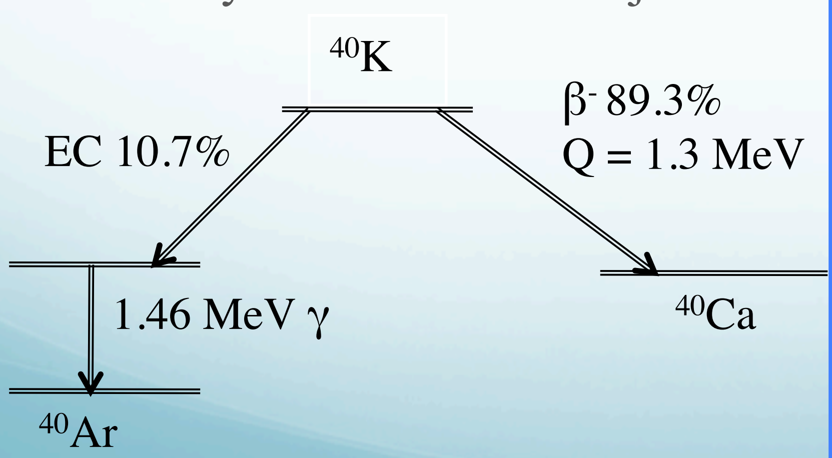
SABRE veto principle

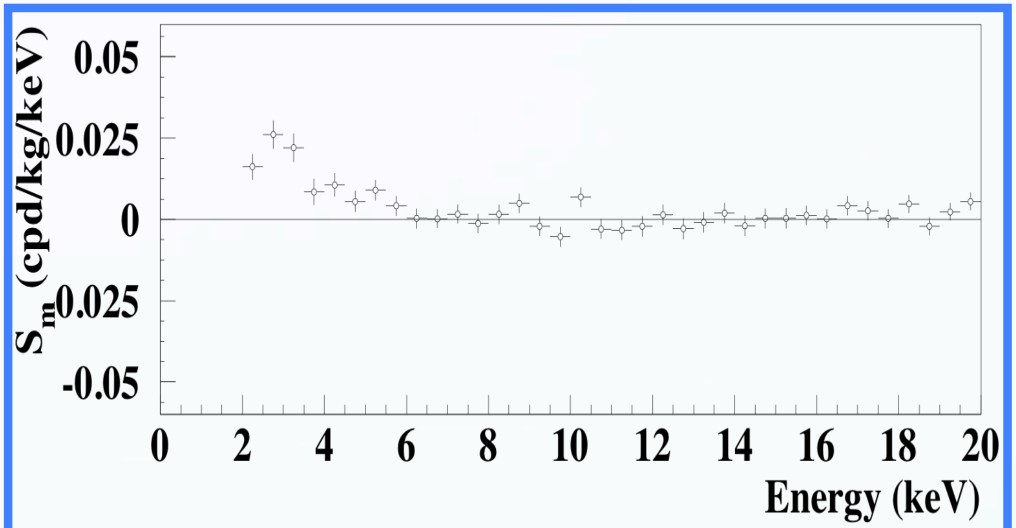
Dangerous ^{40}K in NaI(Tl)

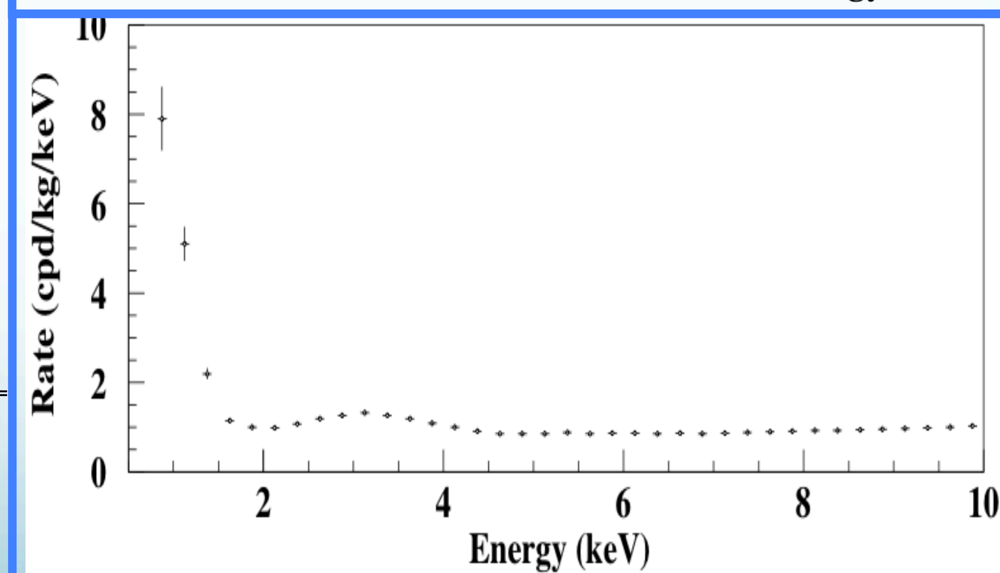
- ~13 ppb K in DAMA crystals
- ~11% B.R. E.C. to ^{40}Ar
- 1.46 MeV γ (may escape)
- ~3keV Auger electron/X-ray

With a LS veto:

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



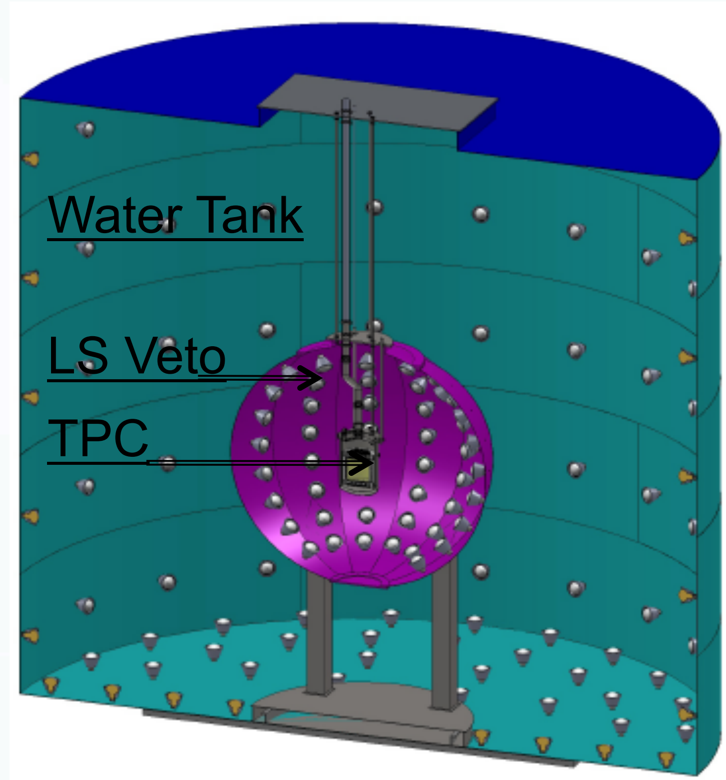


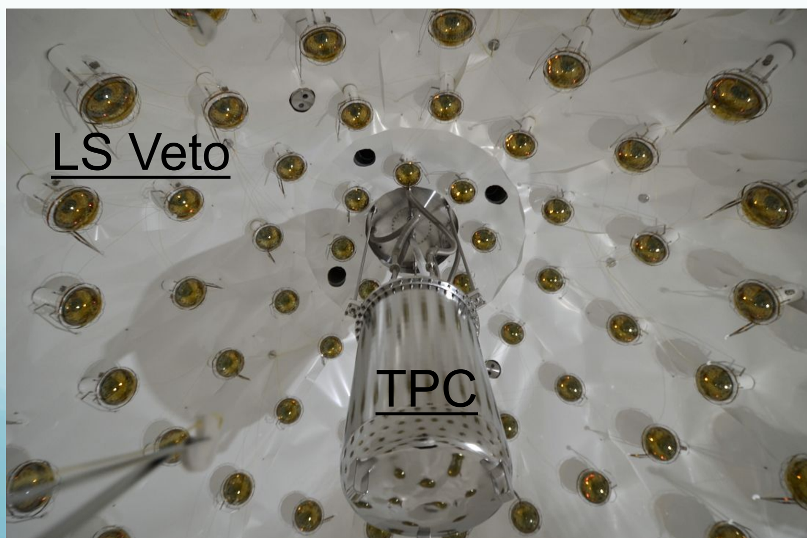


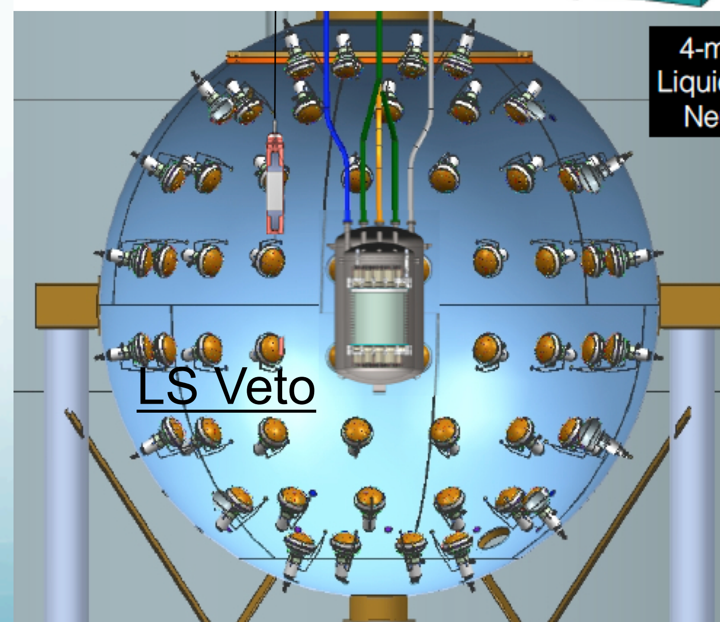
SABRE in DarkSide

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
- ports available for detector insertion



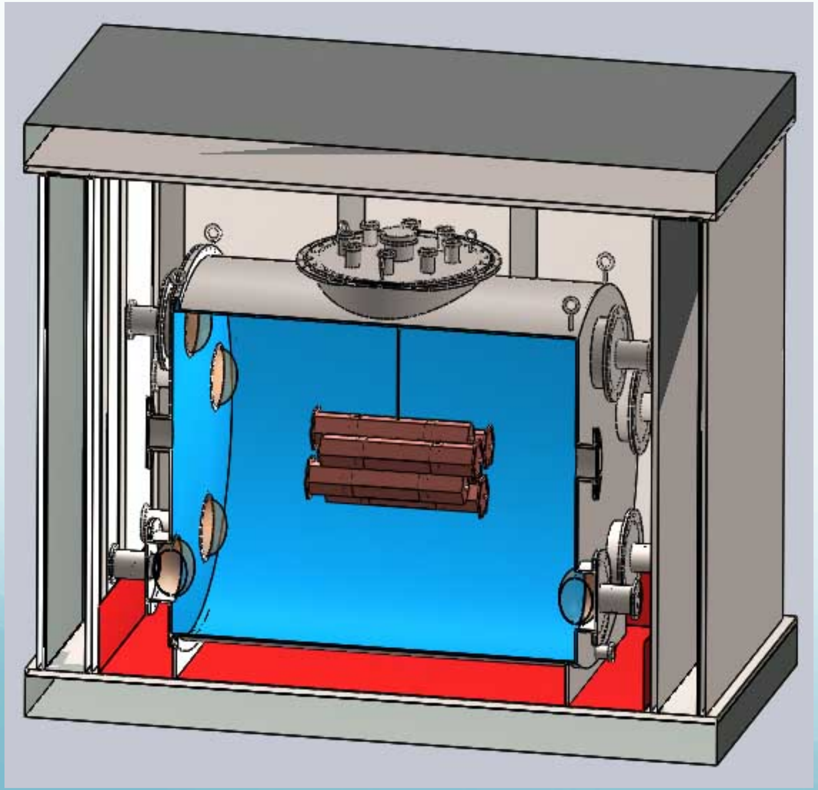




Dedicated SABRE veto

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

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

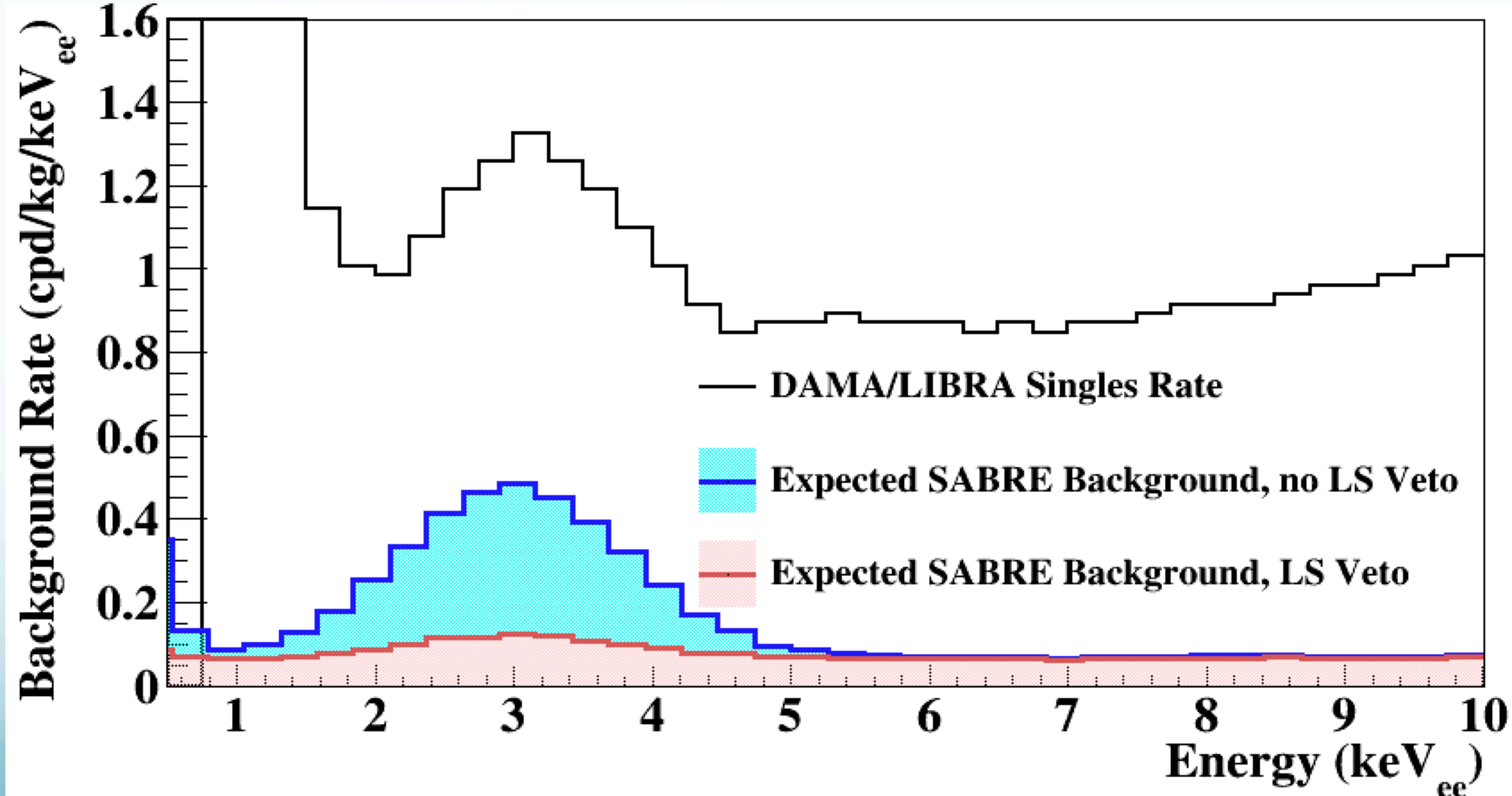


Background simulation

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.



Credited to E.Shields

Expected sensitivity

Assumption: stable detector operation for a few years

no other seasonal effect in the same energy region

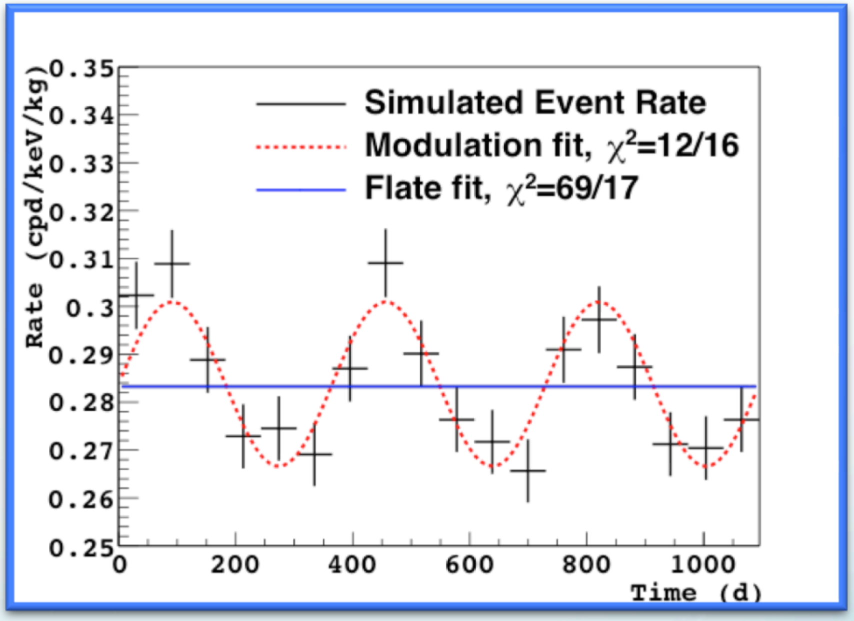
~0.15 cpd/keV/kg background

50 kg NaI(Tl) array, 3 years

~4 sigma power to confirm or refute DAMA/LIBRA

25 kg NaI(Tl) array, 3 years

~2.5-3 sigma power to confirm or refute DAMA/LIBRA



Simulated 50kg experiment

New Na quenching measurement in NaI(Tl)

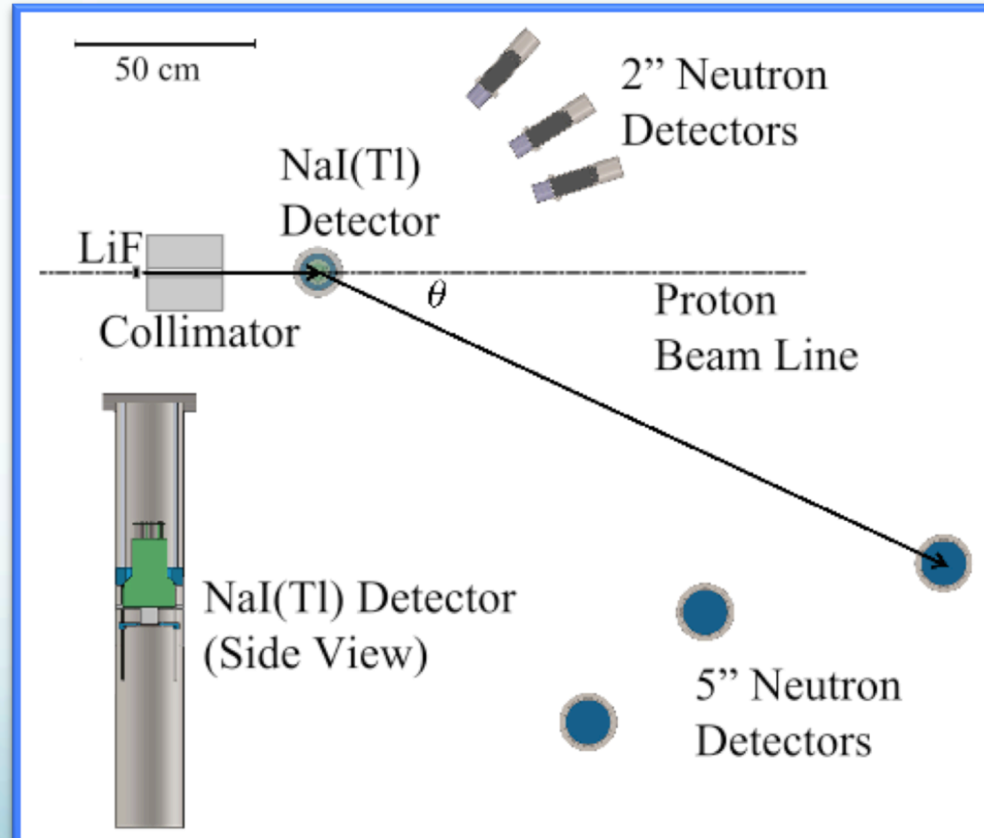
DAMA/LIBRA modulation energy: (2, 6) keV_{ee}

What is the nuclear recoil energy? Conflicting measurements reported.

DAMA/LIBRA result: 0.3 for Na, 0.09 for I, ^{252}Cf neutron calibration

SABRE measurement:

- Low energy neutrons
- Pulsed beam (TOF)
- Small NaI(Tl) crystal
- High light yield
- PSD methods
- Multiple angles measured at the same time



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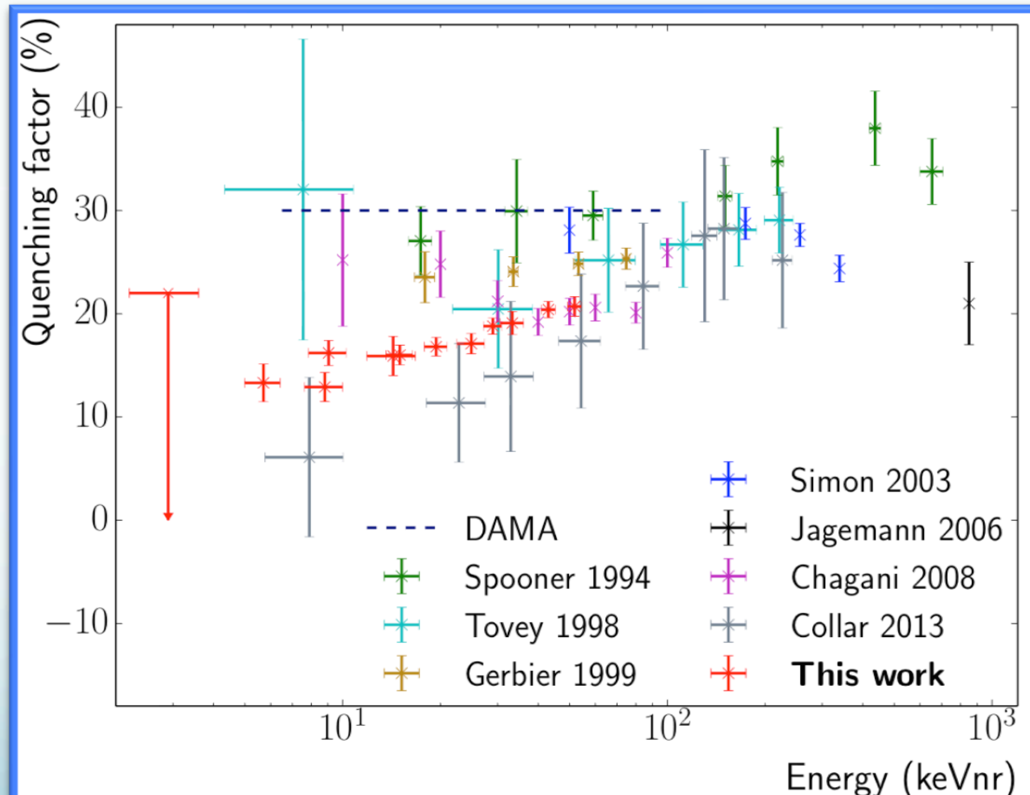
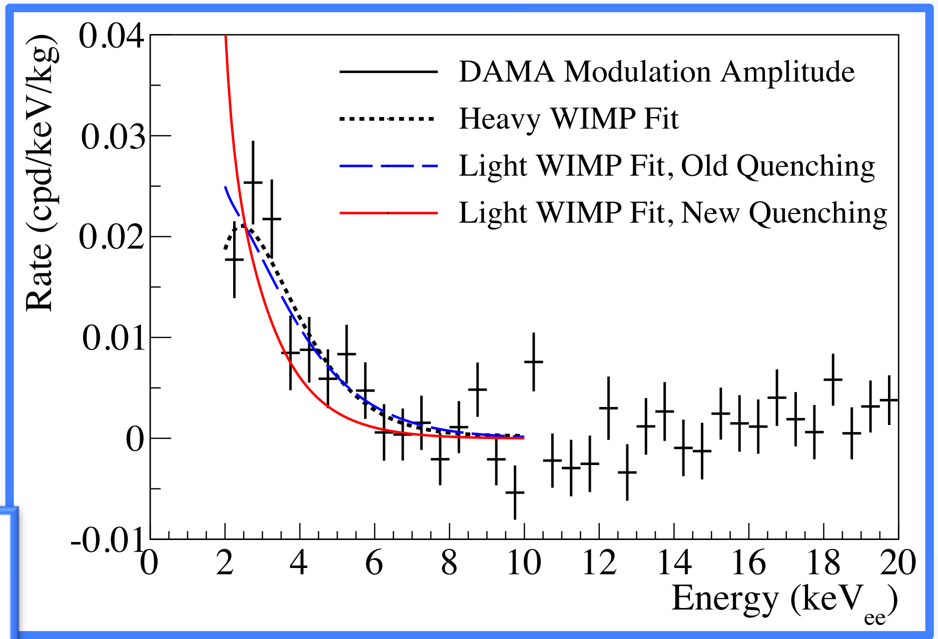


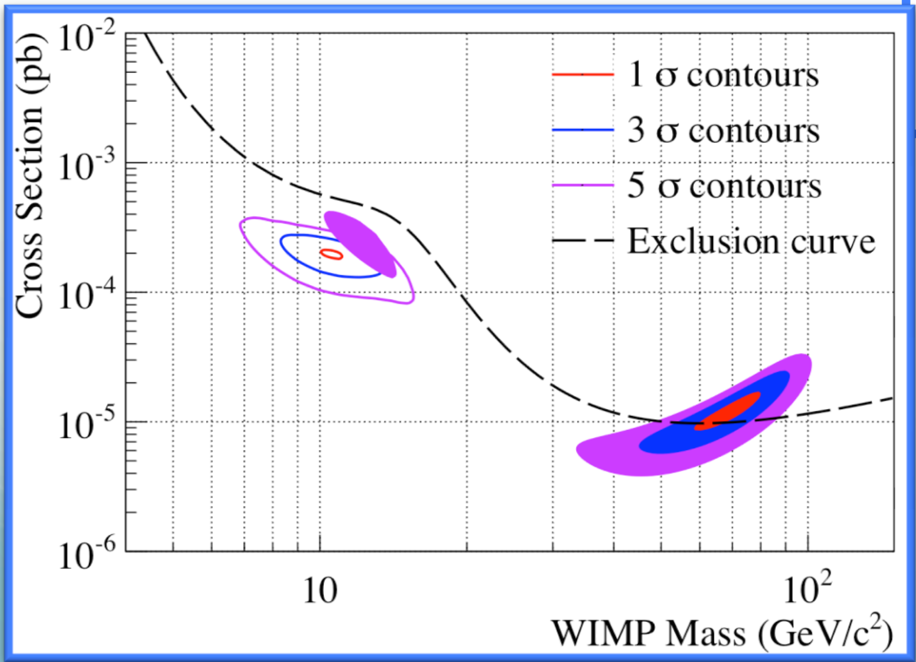
Implications of new Na quenching results

Light WIMP fit is disfavored.

$\chi_{min}/NDF = 36/14$, $P < 0.01$

DAMA/LIBRA signal is not compatible with the standard WIMP picture.





Best fit at high mass WIMP predicts a total rate higher than observed.

KIMS ruled out the DAMA/LIBRA heavy WIMP model-independently using CsI crystals.

Summary

The DAMA/LIBRA signal is significant and controversial.

SABRE aims to test DAMA/LIBRA independent of any WIMP models.

- Progress has been made in the developments of ultra-high purity NaI powder and high purity NaI(Tl) crystals.
- Designs of high purity NaI(Tl) detector modules are being developed and tested.
- Liquid scintillator veto detectors are being investigated/fabricated.
- Na recoil calibration in NaI(Tl) has been studied with high accuracy.

Backup Slides

Potential experimental sites

LNGS has strong interest in participating (collaborating now).

SNOLAB is possible (vessel designed to fit SNOLAB elevator).

Stawell Underground Laboratory (we help develop their experiment).

The SABRE Collaboration

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