SABRE

(Sodium iodide with Active Background REjection)
A New NaI(Tl) Experiment for Dark Matter

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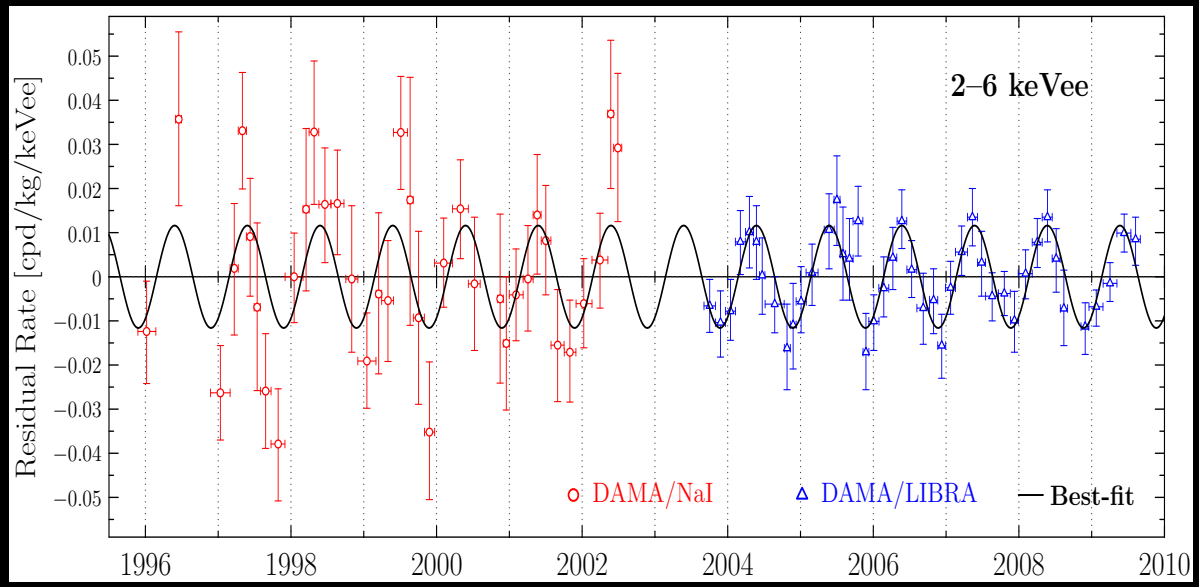
The DAMA/LIBRA Modulation

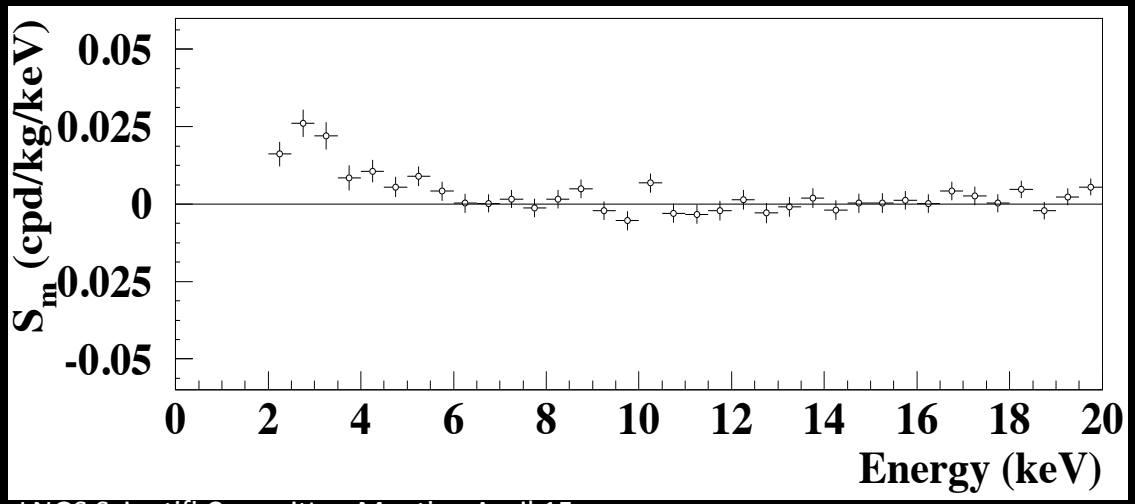
Modulation:

- 1 year period
- Peak in May (WIMP phase)
- ~9 σ significance



Amplitude:

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



Motivation for a NaI(Tl) Experiment

DAMA/LIBRA observes an annual modulation in count rate on NaI(Tl) target consistent with a WIMP dark matter signal.

- The modulation has very high (~9 s) statistical significance.
- The array consists of 250-kg of unique low-background NaI(Tl) scintillating crystals.
- No explanation yet of the modulation due to normal-matter effects.
- Results favor light WIMPS, but are seemingly inconsistent with experiments using other targets. (LUX, XENON, CDMS…)
- Other hints of light WIMPS come from CoGeNT, CDMS-Si, and CRESST.
- Confirmation or refutation of DAMA-LIBRA by another NaI(Tl) experiment is lacking.

SABRE addresses the need for an independent NaI(Tl) experiment.

Background Suppression

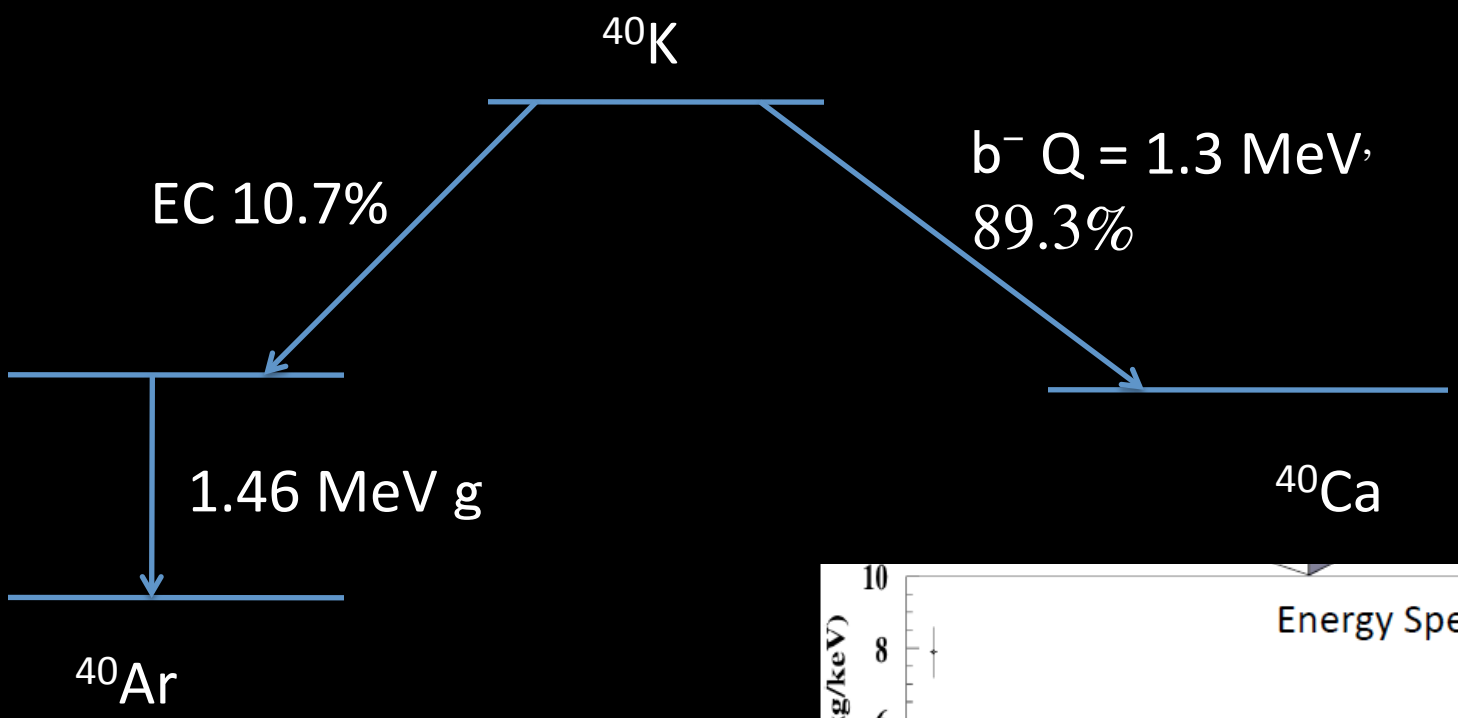
- The DAMA-LIBRA (D-L) collaboration achieved a significant result in developing a NaI(Tl) detector with low background and large mass.
  - A good measure of their achievement is that no group has been successful in matching their background with NaI(Tl).
- SABRE will attempt to suppress background well below the level achieved by DL to enhance signal/noise ratio of a possible WIMP signal.
  - Lower background allows a small detector mass to be as effective as a large mass with higher background.
  - The first phase of SABRE is to demonstrate the feasibility of low background NaI(Tl) modules.

Summary of SABRE

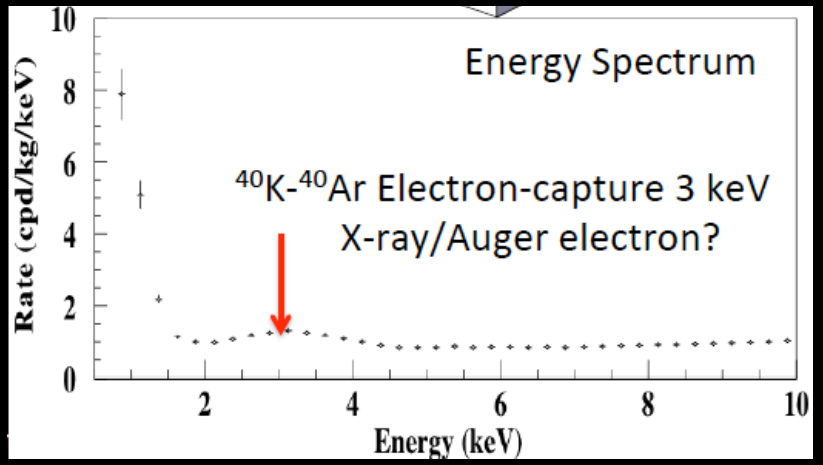
SABRE is designed to test the DAMA/LIBRA dark matter claim.

- New radio-pure NaI(Tl) crystals
  - Higher purity NaI powder than ever achieved
  - Further purification during crystallization
  - Background control in processing and handling.
- Low background PMT
  - Higher light yield without light guide.
  - Less noise with lower operating voltage (LNGS pre-amp)
- Low radioactivity detector enclosure
  - Electroformed copper from PNNL [U] [Th] <μBq/kg U, Th
- Large liquid scintillator veto to reject residual background
  - Reject internal 3 keV background due to ^{40}K decay.
  - Suppress external cosmic ray and environmental gamma background.

Decay Scheme of ^{40}K

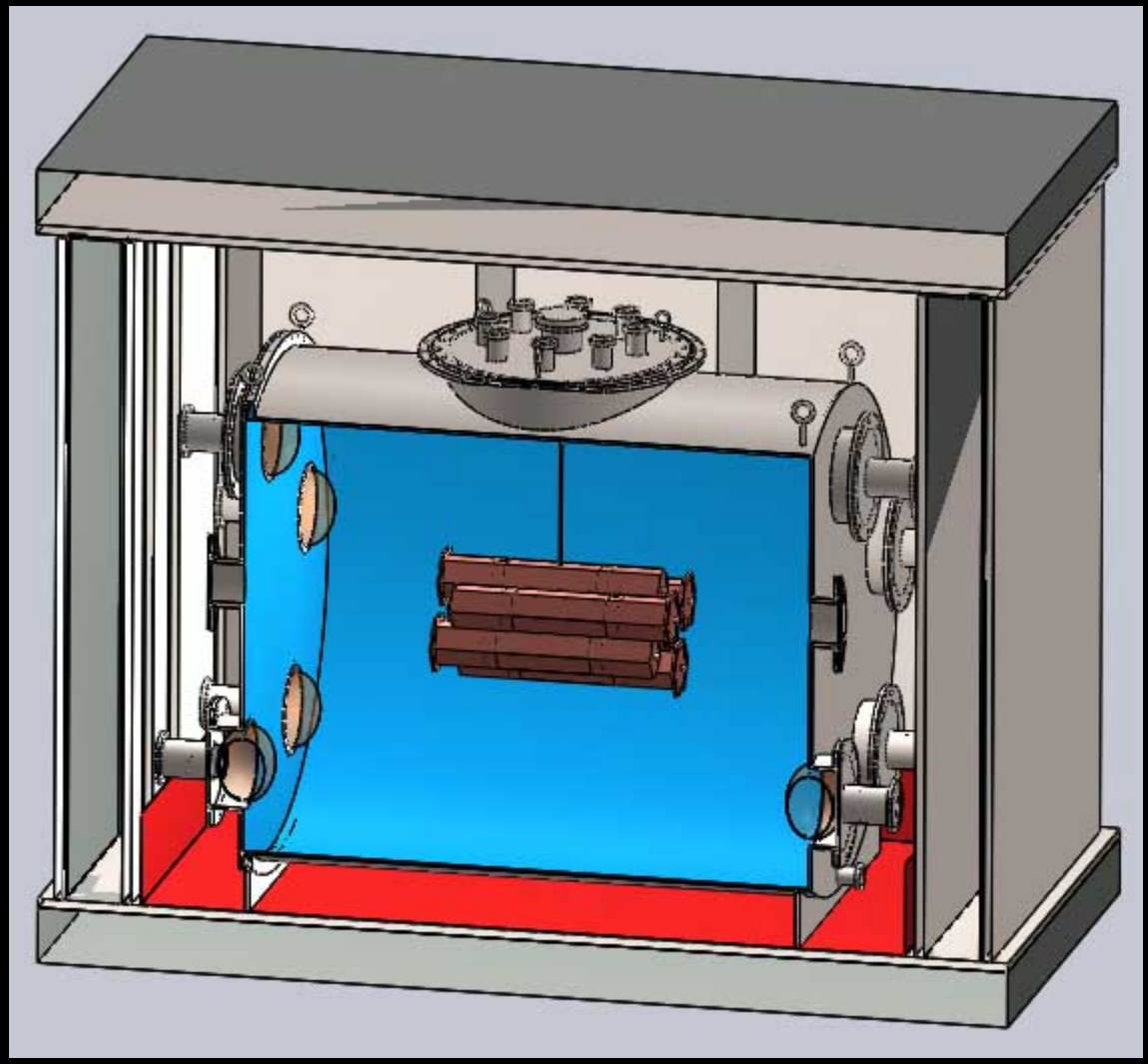


EC decay produces 1.46 MeV **g** and hole in ^{40}Ar K-shell, which then fills giving 3 keV X-ray/Auger electron.



SABRE Veto Detector for 50-60 kg NaI(Tl)

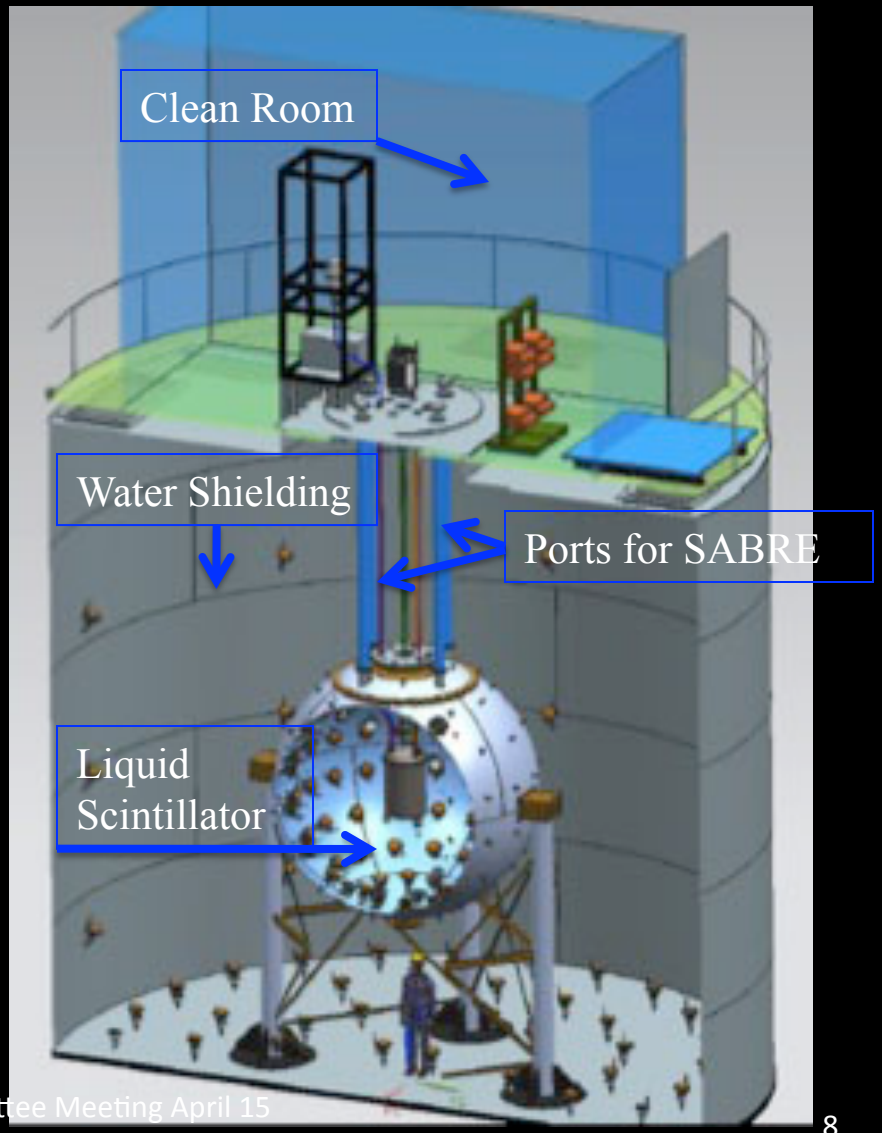
- Sufficient NaI(Tl) mass
  - Bkgnd < 0.4 cpd/kg/keV
- Cylinder: 1.5 m x 1.5 m
- LAB scintillator: 2 tons
- PMTs: Ten 8-inch Ham.
- Reflector: Lumirror
- L.Y.: 0.22 p.e./keV
- Shielding: 25cm steel.
  - Small footprint.
- Portable: LNGS, SNOLab, Australia?
- Funded by NSF.
  - In construction.



DarkSide Liquid Scintillator Neutron Veto

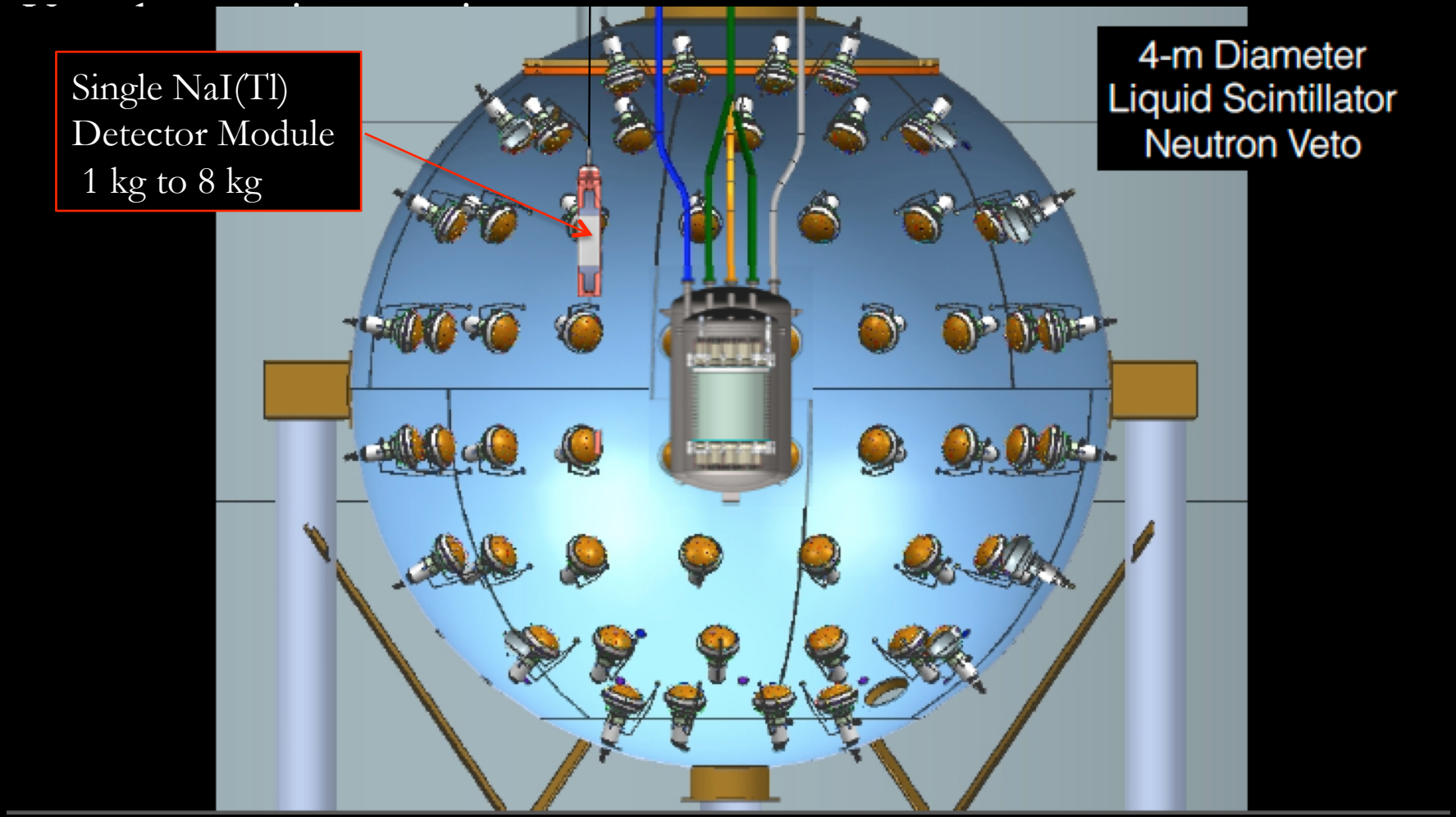
Darkside L.S. Veto is Operating.

- 4 m diameter sphere
- ~30 tons of PC + TMB
- 110 high QE PMTs
- Light-yield ~0.52 p.e./keV with same Lumirror reflector used for SABRE.
- Shielded by >3-4 m of water
- NaI(Tl) 1-kg detector radio-purity tests start Summer 2014.
- Use of 3 ports for 70-kg SABRE to be decided by schedules of SABRE and large Darkside G2 detector.



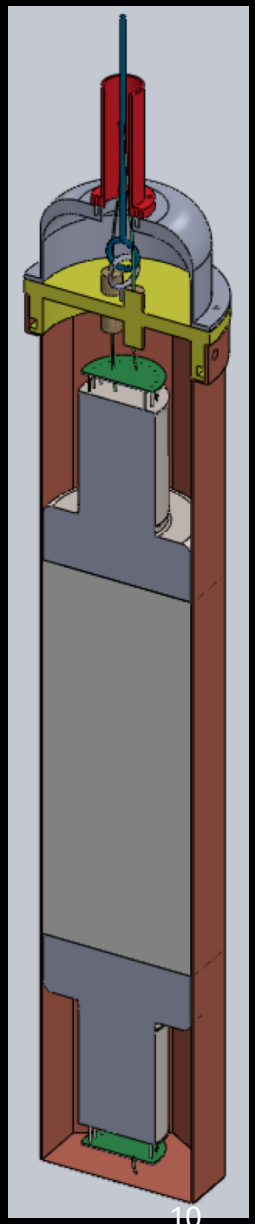
DarkSide Liquid Scintillator Neutron Veto

Initially to test NaI(Tl) radiactivity: Later for 70-kg SABRE?



NaI(Tl) Detector Module

- Hamamatsu R11065-series Low Radioactivity PMT
  - ~30-35% Q.E.
  - ~1 mBq U and Th (lower chain activity)
  - ~1 mBq Co, ~10 mBq K
- New 4-inch Hamamatsu PMT available soon.
  - Lower background with synthetic ceramic feedthrough plate.
- Negligible background due to low radioactivity & veto.
  - High light collection efficiency without light guide used in DL.
- LNGS pre-amp (A. Razeto) to reduce PMT dark rate.
  - Feasibility of lower threshold energy in test phase. (< 1 keV).
- PNNL electroformed copper for enclosure
  - U, Th radioactivity: ~μBq/kg
  - Same as used in the Majorana 0νββ decay experiment



Development of Radio-pure NaI Powder

- Research started 4 years ago in Princeton by Benziger, Calaprice,Wright in collaboration with commercial companies:
  - SAFC, Urbana (Later purchased by Sigma-Aldrich)
  - Seastar-MV Laboratories

- Successful research focused on chemical reactions to produce NaI.

$$Na_2CO_3\ (aq) + 2HI\ (aq) \rightarrow 2\ NaI\ (aq) + H_2O + CO_2\ (g)$$

- Development aided by new measurement capabilities:
  - Measurement of [K] to ~10 ppb:
    - Developed by Seastar (calibrated by g counting) and Sigma Aldrich.
  - Measurement of [U] [Th] to < 1 ppt
    - Developed by E. Hoppe at PNNL

Radio-pure NaI Powder for Crystals

	MV Laboratories (Seastar)	**Sigma Aldrich "Astro-Grade"**	**DAMA Powder (*Level in Crystal*)**
K	12 ppb	3.5 ppb / 18 ppb[+]	<100 ppb *~13 ppb in crystal*
Rb	14 ppb	0.2 ppb	Upper limit: 0.35 ppb crystal
Th	<200 ppt ~3.5ppt*	<1700 ppt <1ppt*	~20 ppt (*0.5-7.5 ppt in crystal*)
U	<100 ppt <1ppt*	<500 ppt <1ppt*	~20 ppt *(0.7 -10 ppt in crystal*)

[+] 3.5 ppb from Sigma Aldrich specs, 18 ppb measured by Seastar ICP-MS

* Preliminary measurement at PNNL by ICPMS isotope dilution method.

NaI(Tl) Crystal Growth

Collaboration with RMD (Boston, MA).

Techniques to further purify NaI powder

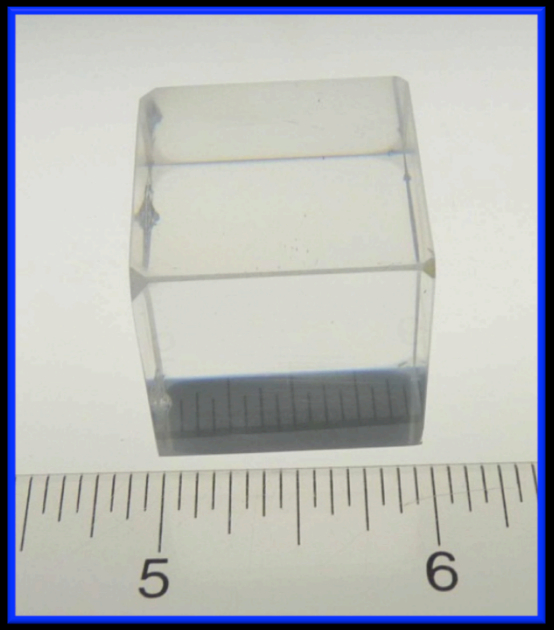
- Zone refining of standard purity NaI effective.
- Purification of crystal growing process effective.

Vertical Bridgman method studied in 2013

- High light-yield observed (>10 p.e./keV)
- ^{40}K reduced by ~4 in standard purity NaI test
- PNNL measured reduction reduction of in high purity test

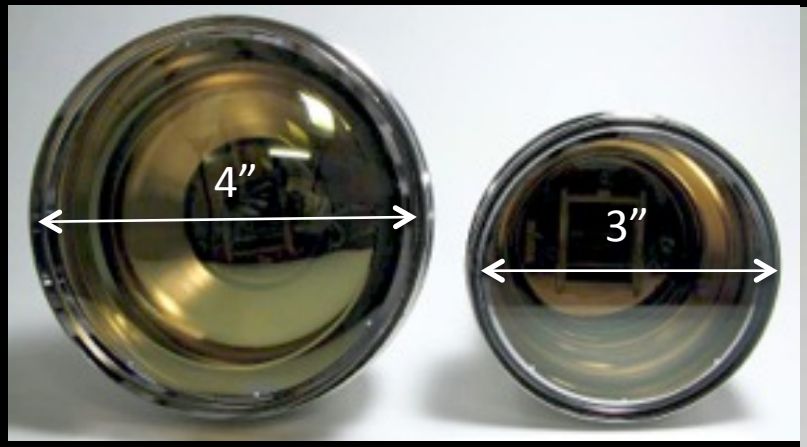
Kyropoulos method studies 2013-2014

- Higher purity, larger NaI(Tl) crystals
- Platinum/Suprasil 310 crucible



Large Low-background PMT R&D

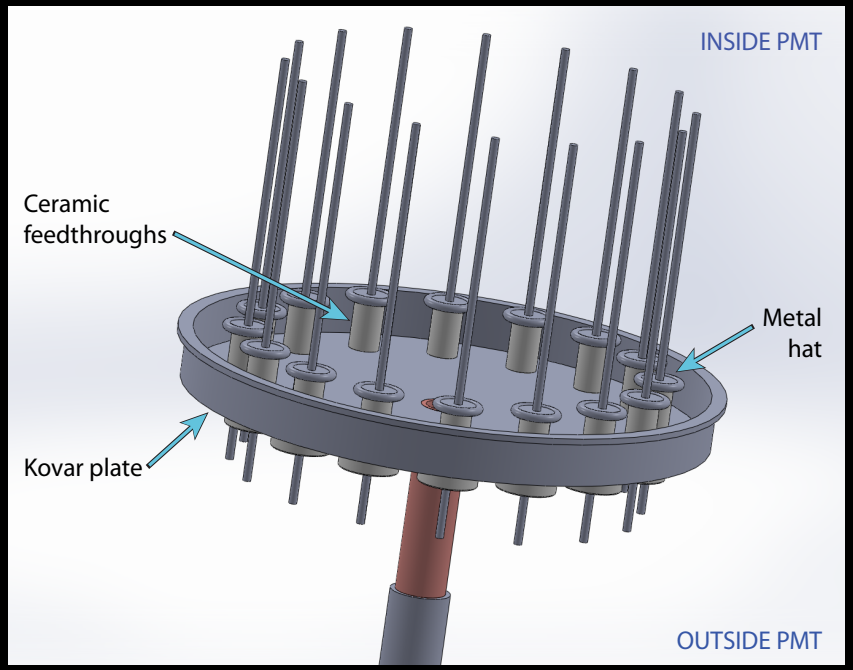
Hamamatsu 4” Version of 3” R110065 Metal Bulb Series



Light yield of large NaI crystals to be used in SABRE will increase with larger PMTs matched to crystals.

A 4” version of the low background R11065 PMT is well matched to crystals and is in development.

Reducing PMT Radioactivity
Synthetic Alumina Ceramic Feedthrough



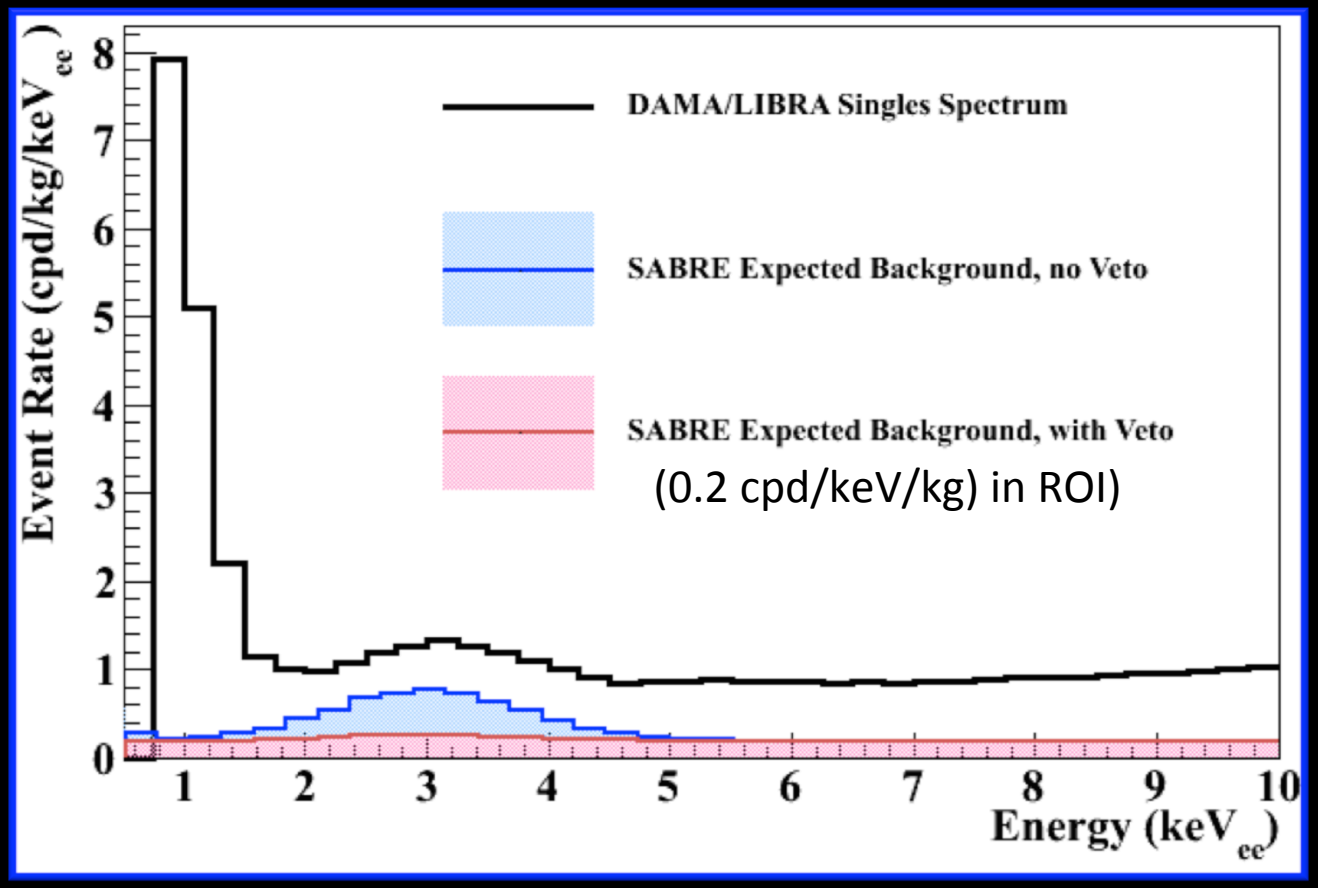
Hamamatsu pin-ceramic plate

Radio-pure synthetic ceramic plate

Main background in R11065-20 is due to ceramic pin feed-through plate. Radio-pure synthetic ceramic has been developed by Princeton and OxiMaTec for PMT feedthroughs.

SABRE Background Simulation

Based on radio-purity of NaI powder

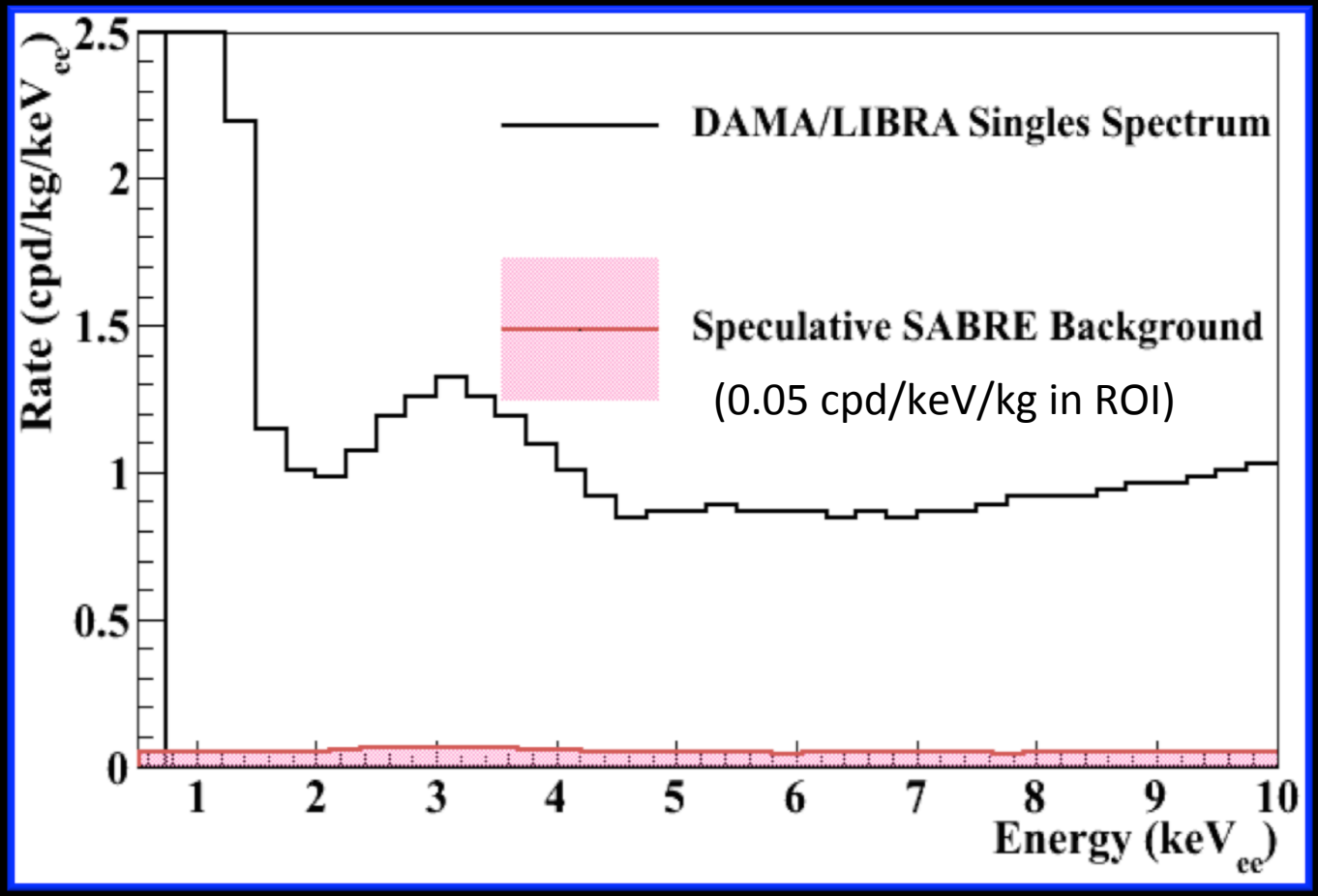


* This spectrum is based on measured radioactivity in NaI powder.

* External background is estimated to be relatively small compared to internal.

Speculative SABRE Background

Based on reduction of U, Th, K, Rb by x4 during crystal growth.



Reduction of [K] by x4 was observed in test of standard NaI.

Running Time Needed to Test DAMA

- Running time is strongly dependent on background achieved.
- With "conservative" background of 0.4 cpd/kg/keV (twice that measured in powder by company and PNNL), a 3-year run with 50-kg NaI(Tl) array will give high confidence result confirming or refuting DL.
  - If DL effect is not WIMPs, there is only 1.5% chance SABRE will agree with it.
  - If DL effect is really WIMPS, there is < 1% chance SABRE will obtain null effect.
- With lower background, the time is shorter or significance is higher.

- DL modulation is ~0.018 cpd/kg/keV in 2-4 keV energy window.
- With standard WIMP halo, a 10 GeV WIMP has most of its nuclear recoil energy spectrum below the 2 keV DL threshold.
  - Observed modulation implies following non-modulating rates for 10 GeV WIMP:
    - Whole nuclear recoil spectrum: 1.13 cpd/keV/kg
    - ROI (2-4 keV): 0.13 cpd/keV/kg.
  - The modulation and total WIMP in ROI imply a 14% modulation for 10 GeV WIMP.
    - The modulation is diluted by background.
  - The SABRE 50-kg array with expected low backgroun should detect big modulation.

Current Status and Estimated Schedule

- Current goal is to demonstrate high radio-purity, high light-yield 3-inch crystal modules.
  - Under construction with NSF funding.
  - Shielded in Darkside liquid scintillator veto.
  - Hamamatsu 3" R11065-X PMTs.
  - Electroformed copper encapsulation.
  - Schedule: Expecr to start taking data summer 2014.
- Next goal, not yet funded, will be an array of 8-kg NaI(Tl) modules (50-60 kg) using new 4" PMTs.
  - Start construction in 2015 and 2 years to complete.
  - Taking data as modules are constructed is an option.

SABRE Collaboration
(growing)

Princeton University:

F. Calaprice, C. Galbiati, J. Benziger, F. Froborg, M. Wada, J. Xu,

E. Shields, S. Westerdale, A. Nelson

University of Houston:

E. Hungerford, S. Davini, G. Korga

LNGS:

A. Razeto, Aldo Ianni

Milano University:

D. D'Angelo

PNNL:

E. Hoppe, J. Orrell, C. Overman

Summary

- SABRE is developing low-background NaI(Tl) detector modules for independent check of the DAMA-LIBRA modulation.
- Good progress has been achieved on:
  - Production of high purity NaI powder.
  - Reduction of radioactivity by crystal growth by zone refining & crystal growth.
  - Development of low-background PMTs.
  - Development of low-background detector encapsulation.
  - Active shielding with liquid scintillator.
- Production of NaI crystals is underway to confirm background in NaI(Tl) modules by direct counting.
  - Background tests planned this summer in Darkside liquid scintillator veto.
- The 50-kg SABRE with low background should produce definitive results.

Other NaI Experiments

- DM ICE (Antarctic)
- KIMS (Korea)
- ANAIS (Spain)
- Kamland NaI (Japan)

Thank You!