SABRE: Sodium-iodide with Active Background REjection

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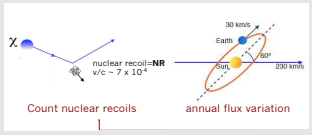
The interaction rate of hypothesized dark matter particles in an Earth bound detector is expected to undergo an annual modulation due to the planets orbital motion. The DAMA experiment has observed such a modulation with high significance in an array of scintillating NaI(Tl) crystals. This claim is still unverified inasmuch as the other experiments involved in this research use different dark matter targets and cannot be compared with DAMA in a model-independent way. The SABRE experiment seeks to provide a much-needed model-independent test of the DAMA modulation by developing highly pure crystal detectors with very low radioactivity and deploying them in an active veto detector that can reject key backgrounds in a dark-matter measurement. The final layout of SABRE will consist in a pair of twin detectors at LNGS (Laboratori Nazionali del Gran Sasso, Italy) and SUPL (Stawell Underground Physics Laboratory, Australia). The combined analysis of data sets from the two hemispheres will allow identifying any terrestrial contribution to the modulating signal.

Dark Matter Signature



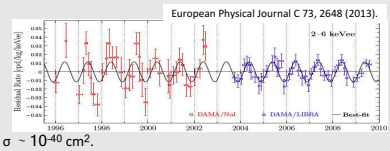
$$\frac{dR}{dE_R}(t) = S_0(E_R) + S_m(E_R)\cos\omega(t - t_0)$$

- ~85% of the existing matter is "Dark".
- Dark Matter particles are slow moving, massive, very feebly interacting, non relativistic, neutral, cold or not too warm.
- Annual modulation is a model independent signature of Dark Matter interaction.
- WIMP Weakly Interacting Massive Particle could be a candidate.

Motivation for the SABRE experiment

DAMA has observed a modulation for 13 years:

- Located at LNGS .
- Total mass: 250 kg of NaI.
- Energy threshold: 2 keV.
- 9.3 σ significance.
- If interpreted as Dark Matter interaction:
  - Interaction on Na nuclei M_{wimp} ~ 10 GeV σ ~ 10^{-40} cm².
  - Interaction on I nuclei M_{wimp} ~ 80 GeV σ ~ 10^{-41} cm².



This claim is still unverified inasmuch as the other experiments are made of different target materials.

A model independent test is therefore required!

Ultra pure NAI Crystals

Collaboration with industrial partners (now Sigma Aldrich) led to NaI crystal with unmatched purity:

- ^{nat}K content ~ 9 ppb.
- Independent impurity assessment of powder and crystal with ICP-MS, ICP-OES, and AMS.
- Record sensitivity achieved.
- R&D on further purification is ongoing.

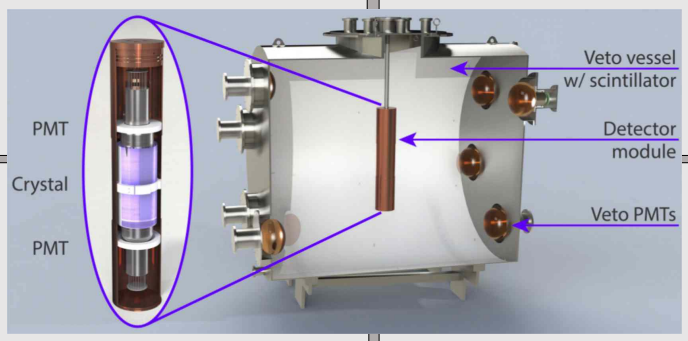
Crystal Growth

- Minimize crystal contamination during growth procedure.
- Test growth of small crystals in different crucibles.
- Careful material selection.
- Precision cleaning.

Full size crystal (5.5 kg) - under production
Growth method validation for big crystals. Larger crucible will improve the surface to volume ratio and the expected backgrounds.

Successfully grown 2kg crystal with breakthrough purity.

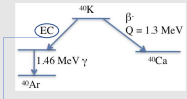
	SABRE	DAMA
^{nat}K	9 ppb	13 ppb
Rb	< 0.1 ppb	< 0.35 ppb
U	0.6 ppt	0.5 – 7.5 ppt
Th	0.5 ppt	0.7 – 10 ppt

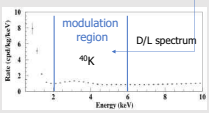


Active Background Rejection

Dangerous long-lived background for the low mass ROI: ^{40}K and cosmogenic ^{22}Na

^{40}K, in 10% of cases, decays in an excited state of ^{40}Ar through electronic capture emitting a 1461 keV gamma.

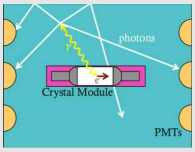




The hole in the ^{40}Ar inner shells produces an Auger electron or X-ray followed by a cascade with a total energy of 3.2 keV which is the region of interest.

^{22}Na emits with a BR of 10% a 0.8 keV X-ray together with a 1275 keV gamma. Particularly relevant since SABRE has the goal to reach an energy threshold lower than 2 keV.

Background will be rejected by an ultra-pure 2 tons active liquid-scintillator veto with efficiency <96%.



Low Energy Threshold

- DAMA/LIBRA modulation region: 2-6 keV
- SABRE goal is to investigate also in the region 1-2 keV → it is essential to lower the energy threshold

- High light yield: the light yield depends on crystals but also on PMTs Quantum Efficiency and how light is collected
- Low dark noise: Less dark rate means better Signalto Noise ratio.

Hamamatsu 3" R11065-20

- Selected PMTs with High QE: > 35%, low radioactivity: ~10 mBq. This allows direct coupling with the crystal, improving the light collection efficiency
- The original ceramic feedthrough plate will be replaced with a synthetic one with significantly lower background.
- To minimize noise is under investigation the usage of super bialkali photocathodes allowing a quantum efficiency improvement up to about 40% and a dark noise reduction from 5 to 10 times.

Twin Experiments

Different environmental conditions:

- Seasonal effects with opposite phase.
- Rock composition and radiopurity.
- Independent radon, temperature, pressure control systems and power supply.

Laboratori Nazionali del Gran Sasso (LNGS)
- 3600 m.w.e.
- Well-known background.
- It will be located in Hall C.

Stawell Underground Physics Laboratory (SUPL)
- 3100 m.w.e.
- Background similar to LNGS.
- Expected to be completed by the end of 2017.

SABRE Proof-of-Principle

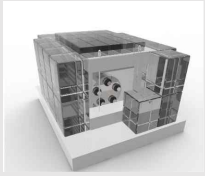
Goals:

- Test active veto performance.
  - K and ^{22}Na.
- Fully characterize the intrinsic and cosmogenic backgrounds.
  - ^{87}Rb.
  - U, Th, ^{210}Pb.
  - ^{3}H.

Location: Hall C.

Layout:

- 1 NaI(Tl) crystal (~5kg).
- Crystal and PMTs will be coupled directly with optical coupling gel and will be encased in a highly radiopure copper enclosure (<1uBq/kg).
- Active veto:
  - Cylindrical vessel (⌀ x h) = (1.35 m x 1.50 m).
  - PC+PPO (3g/l) scintillator (mass ≈ 2ton).
  - 10 Hamamatsu R5912-100 PMTs .



External shielding: Combination of water, PE and lead. The inner space of the shielding is sealed and purged with nitrogen to prevent background from radon.

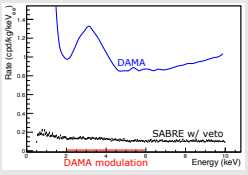
Sensitivity and total background

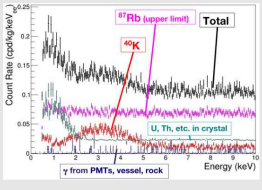
Background is fully simulated thru Monte Carlo.

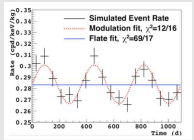
Rate with VETO in the 2-6 keV:

^{40}K : 0.03 cpd(*)/kg/keV$_{ee}$
^{87}Rb: < 0.07 cpd/kg/keV$_{ee}$
^{238}U, ^{232}Th: ~0.02 cpd/kg/keV$_{ee}$
γ from PMTs, enclosure, vessel, rocks are negligible.

Total background: 1.3 x 10^{-1} cpd/kg/keV$_{ee}$
DAMA count rate: ~ 1 cpd/kg/keV$_{ee}$







Sensitivity with 50 kg x 3 years:
~ 4σ power to confirm DAMA.
~ 6σ rejection of modulation.

(*) counts per day

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Imperial College London: F. Froborg
INFN LNGS: S. Copello, G. Di Carlo, A. Ianni, D. Orlandi, C. Vignoli
Lawrence Livermore National Laboratory (LLNL): J. Xu
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