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Study of the sensitivity of the SABRE experiment for direct Dark-Matter search

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Summary. — The orbital motion of the Earth around the Sun is expected to produce a modulation in the interaction rate of hypothetical dark-matter particles in an Earth-based detector. The DAMA experiment has observed a signal compatible with this modulation in the scintillation light of NaI(Tl) crystals with high statistical significance. This claim has not yet been verified since the other experiments involved in this type of research employ different target materials and technologies and can not be compared with DAMA independently of the assumed theoretical model. SABRE will provide a model-independent test of the DAMA claim through the use of ultrapure NaI(Tl) crystals (same target material as DAMA) and by studying the modulation signal in both the hemispheres identifying any possible terrestrial contribution. To further reduce the background level the crystals will be placed in an active veto system. This paper presents the detector sensitivity studies in order to understand its ability to verify the DAMA claim.

1. – The SABRE experiment

SABRE is a dark-matter direct detection experiment aiming to provide a model-independent verification of the DAMA claim [1] by using ~ 50 kg of highly pure NaI(Tl) scintillating crystals. The SABRE concept and goal is to obtain an ultra-low background rate of the order of 0.1 cpd/keV$_{ee}$/kg in the energy region of interest. This challenging goal is achievable by decreasing the level of impurities in the crystals and by employing materials with low radioactivity. To further reduce the background level, each of the crystals will be optically coupled to two PMTs, encased in a highly pure copper enclosure and submerged completely in a liquid scintillator tank that constitutes an active veto system (fig. 1). Events that release energy in adjacent crystals or in a crystal and in the veto will be identified as background. Additionally, a composite passive shielding made of polyethylene and water tanks surrounds the detector in order to suppress external backgrounds. A steel plate is placed on the top and a layer of lead on the floor, under the polyethylene. To identify any seasonal contribution to the measured signal the experiment will be carried out in a double location, the first in the Northern Hemisphere, and

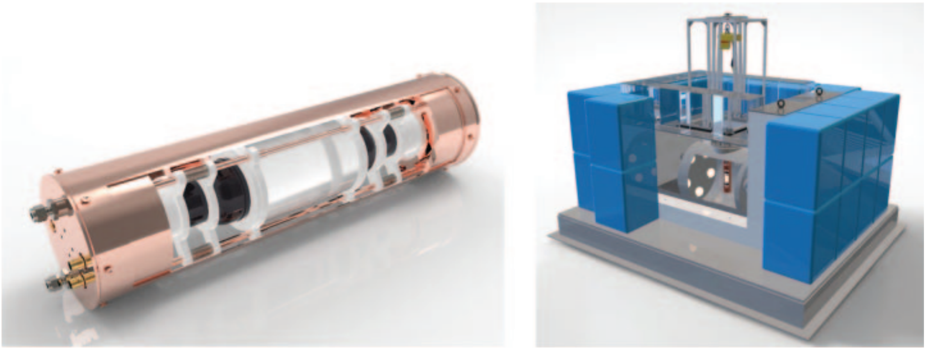

Fig. 1. – Left: copper enclosure where the crystal coupled with 2 PMTs will be located. Right: the SABRE PoP showing the enclosure, the veto PMTs, the vessel, the external shielding and the crystal insertion system to insert the enclosure in the vessel.

specifically at Laboratori Nazionali del Gran Sasso (LNGS) in Italy and the second in the Southern Hemisphere at Stawell Underground Physics Laboratory (SUPL) in Australia. In this way any hypothetical background with seasonal modulation would appear with an opposite phase in the two detectors and, therefore, would be identified. The SABRE experiment is currently in a Proof-of-Principle (PoP) phase at LNGS. In this phase a single NaI(Tl) crystal will be used to measure its radio-purity and to evaluate the efficiency of the detector, in particular of the active veto system. Once the measurements of the PoP phase have been completed, the full-scale experiment will be assembled.

2. – SABRE sensitivity

The SABRE sensitivity to the dark-matter annual modulation has been evaluated in the 2–6 keV$_{ee}$ energy region assuming standard hypotheses for WIMPs and the halo model [2]. The total crystal mass considered is 50 kg and the data-taking time is 3 years. The background has been taken from the PoP Monte Carlo simulations. The nuclear recoil quenching factor of Na is taken from [3] while the I quenching factor is taken from [4]. The sensitivity plot for the experiment has been evaluated by considering a set of values for the WIMP mass m_{DM} in the range 1–1000 GeV and for the WIMP-nucleon scattering cross-section $\sigma_{SI,n}$ in the range 10^{-42}–10^{-38} cm^2. For every couple of values of m_{DM} and $\sigma_{SI,n}$ the 2–6 keV$_{ee}$ energy range has been divided into 8 bins and in every bin the background rate and the WIMP unmodulated interaction rate have been calculated. A pseudo-experimental distribution of rate *vs.* time has been generated by randomly extracting the value of the monthly rate from a Poisson distribution with mean value given by the background plus the theoretical unmodulated WIMP rate. A fit of this pseudo-experimental distribution has been performed with a cosine function (Eq. 1) that describes the modulated rate of the WIMP interaction with a period of 1 year,

$$y = c + A\cos\left(\frac{2\pi}{365}t\right). \tag{1}$$

This random background + unmodulated rate signal has been generated 1000 times and fitted with the cosine function. For every energy bin we compute the χ^2 between

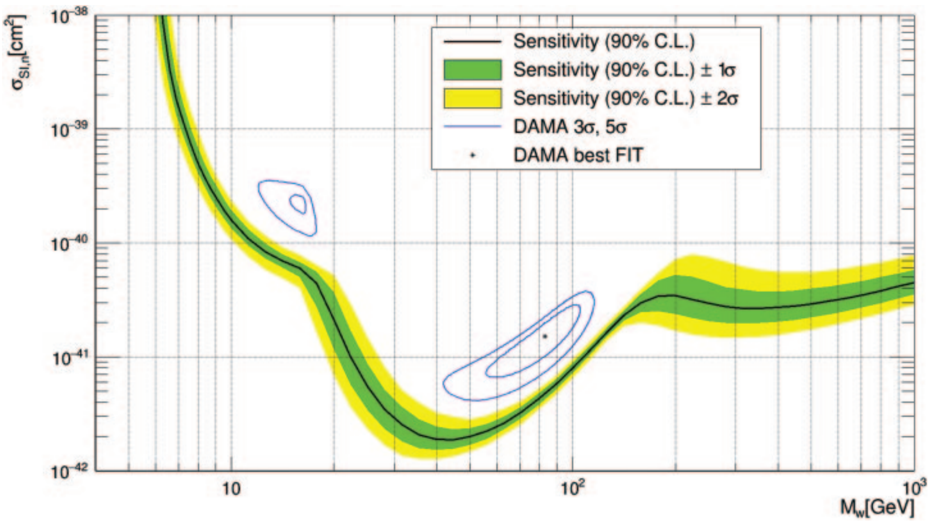

Fig. 2. – 90% C.L. sensitivity plots for 3 years exposure time, 50 kg detector mass, recoil energy range 2–6 keV, background rate calculated with PoP Monte Carlo simulations. The blue curves represent the 3 and 5 sigma confidence regions obtained interpreting the DAMA Phase-1 results [1] in the framework of the standard WIMP model, as described in [5].

the amplitude returned by the fit and the modulation amplitude calculated for the combination of wimp mass and cross-section under analysis. The total χ^2 for every point of the m_{DM}-$\sigma_{SI,n}$ plane is the sum of the χ^2 calculated for every energy bin. The resulting $\chi^2(m_{DM}, \sigma_{SI,n})$ is cut at 90% C.L. and the sensitivity curve is shown in fig. 2. The 1σ and 2σ bands have been obtained by varying the Na and I quenching factors, the energy resolution, the detection efficiency and the background within the uncertainties. Figure 2 shows that, even considering the expected systematics, SABRE will be able to verify the DAMA claim after three years of exposure and with a total mass of 50 kg. The experiment is expected to be sensitive to WIMP-nucleon scattering cross-sections down to $2 \cdot 10^{-42}\,\text{cm}^2$ for a WIMP mass of 40–50 GeV.

REFERENCES

[1] Bernabei R. *et al.*, *Eur. Phys. J. C*, **73** (2013) 2648.
[2] Freese K. *et al.*, *Rev. Mod. Phys.*, **85** (2013) 1561.
[3] Xu J. *et al.*, arXiv:1503.07212v1.
[4] Bernabei R. *et al.*, *Nucl. Instrum. Methods A*, **592** (2008) 297.
[5] Savage C. *et al.*, *J Cosmol. Astropart. Phys.*, **04** (2009) 010.