RECENT RESULTS FROM THE CANFRANC DARK MATTER SEARCH WITH GERMANIUM DETECTORS

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Two germanium detectors are currently operating in the Canfranc Underground Laboratory at 2450 m.w.e looking for WIMP dark matter. One is a 2 kg $^{76}$Ge IGEX detectors (RG-2) which has an energy threshold of 4 keV and a low-energy background rate of about 0.3 c/keV/kg/day. The other is a small (234 g) natural abundance Ge detector (COSME), of low energy threshold (2.5 keV) and an energy resolution of 0.4 keV at 10 keV which is looking for WIMPs and for solar axions. The analysis of 73 kg-days of data taken by COSME in a search for solar axions via their photon Primakoff conversion and Bragg scattering in the Ge crystal yields a 95\% C.L. limit for the axion-photon coupling $g_{a\gamma\gamma} < 2.8 \times 10^{-9}$ GeV$^{-1}$. These data, analyzed for WIMP searches provide an exclusion plot for WIMP-nucleon spin-independent interaction which improves previous plots in the low mass region. On the other hand, the $\sigma(m)$ exclusion plot derived from the 60 kg-days of data from the RG-2 IGEX detector improves the exclusion limits derived from other ionization (non thermal) germanium detector experiments in the region of WIMP masses from 30 to 100 GeV recently singled out by the reported DAMA annual modulation effect.

1 Introduction

Substantial evidence exists suggesting most matter in the universe is dark, and there are compelling reasons to believe it consists mainly of non-baryonic particles. Among these candidates, Weakly Interacting Massive Particles (WIMPs) and Axions are among the front runners. The lightest stable particles of supersymmetric theories, like the neutralino, describe a particular class of WIMP\textsuperscript{1}.

Direct detection of WIMPs rely on the measurement of their elastic scattering off target nuclei in a suitable detector\textsuperscript{4}. Slow moving ($\sim 300$ km/s)
and heavy \((10 - 10^3 \text{ GeV})\) galactic halo WIMPs could make a Ge nucleus recoil with a few keV, at a rate which depends on the type of WIMP and interaction. Ultra–low background detectors with very low energy thresholds are needed for such purpose. Germanium detectors have reached one of the lowest background levels of any type of detector and have a reasonable ionization yield\((\sim 0.25)\). Thus, with sufficiently low energy thresholds, they are attractive devices for WIMP direct detection. In addition, solar axions can also been searched with these crystal detectors by looking for the Primakov conversion into photons and Bragg diffraction.

Two experiments with germanium detectors are currently running at the Canfranc Underground Laboratory: IGEX-DM and COSME-2. Data obtained with both experiments are presented in this work, as well as the WIMP exclusions obtained from the analysis of both sets of data. COSME data has also been analyzed looking for the solar axion signal mentioned above.

2 COSME-2 and IGEX-DM experiments

The IGEX experiment, optimized for detecting \(^{76}\text{Ge}\) double-beta decay, has been described in detail in refs.\(^6\), \(^7\). The IGEX detectors are now also being used in the search for WIMPs interacting coherently with germanium nuclei. The COSME detector, which has already been used in the past for dark matter searches\(^3\), is now operating in the same shield that IGEX at a deeper location in Canfranc. Details about the features of the detectors as well as the techniques used in their construction can be found in the literature\(^2\), \(^3\), \(^7\), \(^11\).

The IGEX detector used for dark matter searches, designated RG-II, has an active mass of \(\sim 2.0 \text{ kg}\). The full-width at half-maximum (FWHM) energy resolution of RG-II was 0.8 keV at the 75-keV Pb X-ray. The COSME detector has an active mass of 234 g and its FWHM energy resolution is 0.43 keV at the 10.37 keV gallium X-ray. Energy calibration and resolution measurements were made every 7–10 days using the lines of \(^{22}\text{Na}\) extrapolating to the low energy region using the X-ray lines of Pb.

The detectors shielding is as follows, from inside to outside. The innermost shield consists of 2.5 tons of 2000-year-old archaeological lead \((^{210}\text{Pb} < 10 \text{ mBq/kg})\) forming a 60-cm cube. The detectors fit into precision-machined holes in this central core, which minimizes the empty space around the detectors available to radon. Nitrogen gas, at a rate of 140 l/hour, evaporating from liquid nitrogen, is forced into the detector chambers to create a positive pressure and further minimize radon intrusion. The archaeological lead block hosting the detectors is, at its turn, surrounded by bricks \((\sim 10 \text{ tons})\) of low activity lead \((^{210}\text{Pb} < 30 \text{ Bq/kg})\) forming a total cube of...
1 m side. A minimum of 15 cm of archaeological lead separates the detectors from the outer lead shield. A 2-mm-thick cadmium sheet surrounds the main lead shield, and two layers of plastic seal this central assembly against radon intrusion. A cosmic muon veto consisting of plastic scintillators covers the top and sides of the central core, except where the detector Dewars are located. An external polyethylene neutron moderator 20 cm thick (1.5 tons) completes the shield. The entire shield is supported by an iron structure resting on noise-isolation blocks. The experiment is located in a room isolated from the rest of the laboratory and has an overburden of 2450 m.w.e., which reduces the measured muon flux to $2 \times 10^{-7} \text{cm}^{-2} \text{s}^{-1}$.

3 WIMP exclusion plot

The results presented in this talk correspond to 30 days (60 kg-d) of data obtained with the IGEX RG-II detector as well as 311 days (73 kg-d) obtained with COSME detector. Both spectra are plotted in figure 1. The COSME spectrum shows a threshold of 2.5 keV and a low energy background (2.5 – 10 keV) of 0.7 c/(keV-kg-day). On the other hand, the detector RG-II features an energy threshold of 4 keV and the background rate recorded was $\sim 0.37$ c/(keV-kg-day) between 4–10 keV, $\sim 0.12$ c/(keV-kg-day) between 10–20 keV, and $\sim 0.05$ c/(keV-kg-day) between 20–40 keV.

The exclusion plots are derived from the recorded spectrum in one-keV
Figure 2. Exclusion plot for spin-independent interaction obtained with IGEX-DM data (thick solid line) as well as COSME-2 data (thick dashed line). Results obtained in other Germanium experiments are also shown: Canfranc COSME-1 data (dot-dashed line) and the previous Ge-combined bound (thin dashed line) —including the last Heidelberg-Moscow data. The result of the DAMA NaI-0 experiment (thin solid line) is also shown. The "triangle" area corresponds to the (3σ) annual modulation effect reported by the DAMA collaboration (including NaI-1,2,3,4 runnings). The IGEX-DM projection (dotted line) is shown for 1 kg-year of exposure with a background rate of 0.1 c/(keV-kg-day).

Bins from threshold to 50 keV. The predicted signal in an energy bin is required to be less than or equal to the (90% C.L.) upper limit of the (Poisson) recorded counts. The derivation of the interaction rate signal supposes that the WIMPs form an isotropic, isothermal, non-rotating halo of density $\rho = 0.3 \text{ GeV/cm}^3$, have a Maxwellian velocity distribution with $v_{\text{rms}} = 270 \text{ km/s}$ (with an upper cut corresponding to an escape velocity of 650 km/s), and have a relative Earth-halo velocity of $v_r = 230 \text{ km/s}$. The cross sections are normalized to the nucleon, assuming a dominant scalar interaction. The Helm parameterization is used for the scalar nucleon form factor, and the ionization yield used is 0.25. The exclusion plots derived from the IGEX-DM (RG-II) and COSME data are shown in Fig. 2. In particular, IGEX results exclude WIMP-nucleon cross-sections above $1.3 \times 10^{-8} \text{ nb}$ for masses corresponding to the 50 GeV DAMA region. Also shown is the combined germanium contour, including the last Heidelberg-Moscow data (recalculated from the original energy spectra with the same set of hypotheses and parameters, but with a suitable ionization yield), the DAMA experiment contour plot derived from Pulse.
Shape Discriminated spectra, and the DAMA region corresponding to their reported annual modulation effect. The IGEX-DM exclusion contour improves sizably on that of other germanium ionisation experiments for masses corresponding to that of the neutralino tentatively assigned to the DAMA modulation effect, and results from using only unmanipulated data.

Based on present IGEX-DM performance and reduction of the background to ~ 0.1 c/(keV-kg-day) between 4–10 keV, Fig. shows also the projection of IGEX for 1 kg-y of exposure.

4 Limit on axion-photon coupling

Crystal detectors provide a simple mechanism for solar axion detection. Axions can pass in the proximity of the atomic nuclei of the crystal where the intense electric field can trigger their conversion into photons. In the process the energy of the outgoing photon is equal to that of the incoming axion. The axion production rate in the Sun –through Primakoff conversion of the blackbody photons in the solar plasma– can be easily estimated within the standard solar model, resulting in an axion flux of average energy of about 4 keV that can produce detectable X-rays in a crystal detector. Depending on the direction of the incoming axion flux with respect to the planes of the crystal lattice, a coherent effect can be produced when the inverse momentum transfer equals the distance between crystal planes (Bragg condition), leading so to a strong enhancement of the signal. A correlation of the expected rate with the position of the Sun in the sky follows providing a distinctive signature of the axion which can be used, at the least, to improve the signal/background ratio.

A suitable statistical analysis to look for this signature in the COSME data has been applied, and the negative result leads to a limit on the axion-photon coupling $g_{a\gamma\gamma} < 2.8 \times 10^{-9}$ GeV$^{-1}$ practically equal to the one obtained by the SOLAX Collaboration which is the (mass independent but solar model dependent) most stringent laboratory bound for the axion-photon coupling obtained so far for axion masses above 0.26 eV. Below this mass value a recent result from a magnet telescope (the Tokyo helioscope) improves a factor 3-5 the $g_{a\gamma\gamma}$ COSME and SOLAX bounds.

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