The ANAIS-112 experiment at the Canfranc Underground Laboratory

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Abstract. The ANAIS experiment aims at the confirmation of the DAMA/LIBRA signal at the Canfranc Underground Laboratory (LSC). Several 12.5 kg NaI(Tl) modules produced by Alpha Spectra Inc. have been operated there during the last years in various set-ups; an outstanding light collection at the level of 15 photoelectrons per keV, which allows triggering at 1 keV of visible energy, has been measured for all of them and a complete characterization of their background has been achieved. In the first months of 2017, the full ANAIS-112 set-up consisting of nine Alpha Spectra detectors with a total mass of 112.5 kg was commissioned at LSC and the first dark matter run started in August, 2017. Here, the latest results on the detectors performance and measured background from the commissioning run will be presented and the sensitivity prospects of the ANAIS-112 experiment will be discussed.

1. Introduction

The ANAIS (Annual modulation with NaI(Tl) Scintillators) experiment intends to confirm the DAMA/LIBRA modulation signal [1] using the same target and technique in a different environment, at the Canfranc Underground Laboratory (LSC, Laboratorio Subterráneo de Canfranc) in Spain. This goal imposes strong experimental requirements: an energy threshold at or below 2 keV$_{ee}$[5], background as low as possible below 10 keV$_{ee}$ and very stable operation conditions. Since the nineties, NaI(Tl) detectors from different suppliers have been in operation in Canfranc [2, 3]; Alpha Spectra Inc. (AS) detectors have shown the best performance and radiopurity (characterized in set-ups with two or three detectors, referred as ANAIS-25 [4] and ANAIS-37 [5], respectively) and have been selected to be used in ANAIS. In 2017, ANAIS-112 experiment has been commissioned: the ANAIS-112 set-up consists of a 3×3 matrix of 12.5 kg NaI(Tl) modules and data taking is underway since August, 2017 for at least the next two years

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in the same conditions. A blind annual modulation analysis is foreseen, as well as the ANAIS data public release after their scientific exploitation. The set-up of ANAIS-112 is described in section 2. Results concerning the detector performance and background are presented in sections 3 and 4. Finally, the sensitivity expected in the search for an annual modulation signal is discussed in section 5.

2. Experimental set-up

The nine modules used in ANAIS-112 were produced by AS in Colorado and then shipped to Spain over several years, the first arriving at LSC at the end of 2012 and the last by March, 2017 (see table 1). Each crystal is cylindrical (4.75" diameter and 11.75" length), with a mass of 12.5 kg. The NaI(Tl) crystals were grown from selected ultrapure NaI powder and housed in OFE (Oxygen Free Electronic) copper; the encapsulation has a mylar window allowing low energy calibration. Two Hamamatsu R12669SEL2 photomultipliers (PMTs) were coupled through quartz windows to each crystal at the LSC clean room. All PMTs have been screened for radiopurity using germanium detectors in Canfranc. The shielding for the experiment consists of 10 cm of archaeological lead, 20 cm of low activity lead, 40 cm of neutron moderator, an anti-radon box (to be continuously flushed with radon-free air) and an active muon veto system made up of plastic scintillators designed to cover top and sides of the whole ANAIS set-up (see figure 1). The hut housing the experiment is at the hall B of LSC under 2450 m.w.e..

Table 1. Features of the nine ANAIS detectors produced by Alpha Spectra: type of NaI(Tl) powder used, date of arrival at LSC, total light collection measured in the ANAIS-112 set-up (except for D1 (*), from previous set-ups) and deduced activity of ^{40}K and ^{210}Pb. Results for detectors D4-D8, obtained from the commissioning run of ANAIS-112, are preliminary.

Detector	Quality powder	Arrival date	Light collection (phe/keV)	^{40}K activity (mBq/kg)	^{210}Pb activity (mBq/kg)
D0	<90 ppb K	December 2012	15.3±1.1	1.1	3.15
D1	<90 ppb K	December 2012	14.8±0.5 *	1.4	3.15
D2	WIMPScint-II	March 2015	15.3±1.4	0.9	0.70
D3	WIMPScint-III	March 2016	14.6±0.8	1.0	1.8
D4	WIMPScint-III	November 2016	14.0±0.8	1.0	1.8
D5	WIMPScint-III	November 2016	14.0±0.8	1.0	0.75
D6	WIMPScint-III	March 2017	12.6±0.8	1.1	0.76
D7	WIMPScint-III	March 2017	17.0±2.0	1.0	0.75
D8	WIMPScint-III	March 2017	14.6±0.9	0.6	0.72
average				1.0	1.5

DAQ hardware and software of ANAIS-112 were tested in previous ANAIS set-ups. For each module, individual PMT charge output signals are digitized and fully processed. Triggering is done by the coincidence (logical AND) of the two PMT signals of any detector at photoelectron level in a 200 ns window, enabling digitization and conversion of the two signals. There is redundant energy conversion by QDC modules and the building of the spectra is done off-line by adding the signals from both PMTs. The muon detection system based on plastic scintillators is fully implemented, allowing the system to tag muon-related events and to monitor on-site the muon flux. The slow control system is also operative, monitoring different parameters like radon activity, humidity, pressure, several temperatures, N_2 flux or PMT High Voltage. In addition,

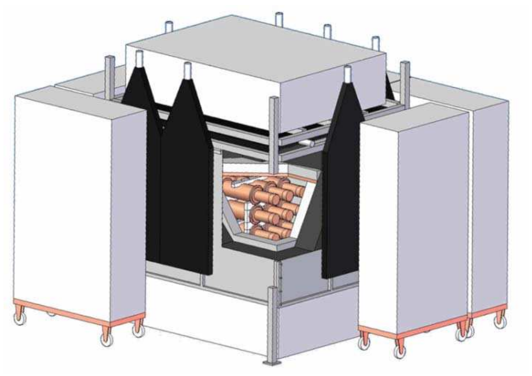

Figure 1. Design of the ANAIS-112 set-up mounted at LSC (see text).

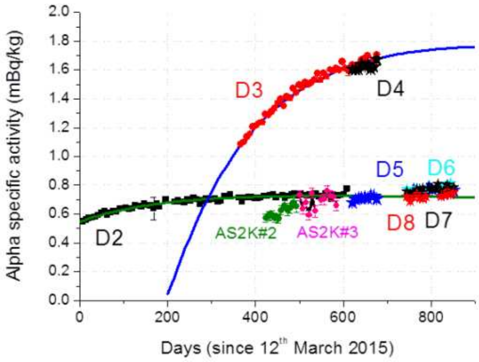

Figure 2. Evolution in time of the alpha specific activity for different crystals as well as for smaller samples (AS2K#2-3) analyzed in the selection of material.

a blank module will be set-up to monitor non-NaI(Tl) scintillation events and build a "blank" population for the study of annual modulation systematics.

3. Detector performance

The light output measured for all AS modules is at the level of ∼15 phe/keV, which is a factor of two larger than that determined for the best DAMA/LIBRA detectors [6]. The fourth column of table 1 shows the preliminary results for the total number of photoelectron per keV using ANAIS-112 data, following the same method applied in ANAIS-25 and ANAIS-37 set-ups, described in [7]. The new estimate is in very good agreement with the previous ones for D0-D5 detectors. This high light collection, which is made possible by the excellent crystal quality and the use of high quantum efficiency PMTs, has a direct impact in energy threshold. Triggering below 1 keV$_{ee}$ is confirmed by the identification of bulk ^{22}Na and ^{40}K events at 0.9 and 3.2 keV$_{ee}$, respectively, thanks to coincidences with the corresponding high energy photons following the electron capture decays to excited levels.

Effective filtering protocols for rejecting non-bulk scintillation events, similar to those described at [3] and optimized for each detector, have been applied. Multiparametric cuts based on the number of peaks in the pulses, the temporal parameters of the pulses and the asymmetry in light sharing between PMTs are considered. Acceptance efficiency curves from external calibration data are obtained for each detector.

4. Radiopurity and background

Detailed background models for the first modules operated in ANAIS-25 and ANAIS-37 set-ups were developed [8], based on Geant4 Monte Carlo simulations and an accurate quantification of background sources: the intrinsic crystal activity directly assessed, the cosmogenic activity in crystals (precisely quantified from ANAIS-25 data [9]) and the activity from external components measured with HPGe detectors in Canfranc. At the region of interest, crystal bulk contamination is the dominant background source. Contributions from ^{40}K and ^{22}Na peaks and the continua from ^{210}Pb and the considered cosmogenic ^{3}H are the most relevant ones.

The ANAIS-112 data taken up to July, 2017 in the commissioning run have been analyzed to make a first quantification of the relevant background sources. The activity of ^{40}K and ^{210}Pb in the nine NaI(Tl) crystals has been determined and preliminary results are reported in the

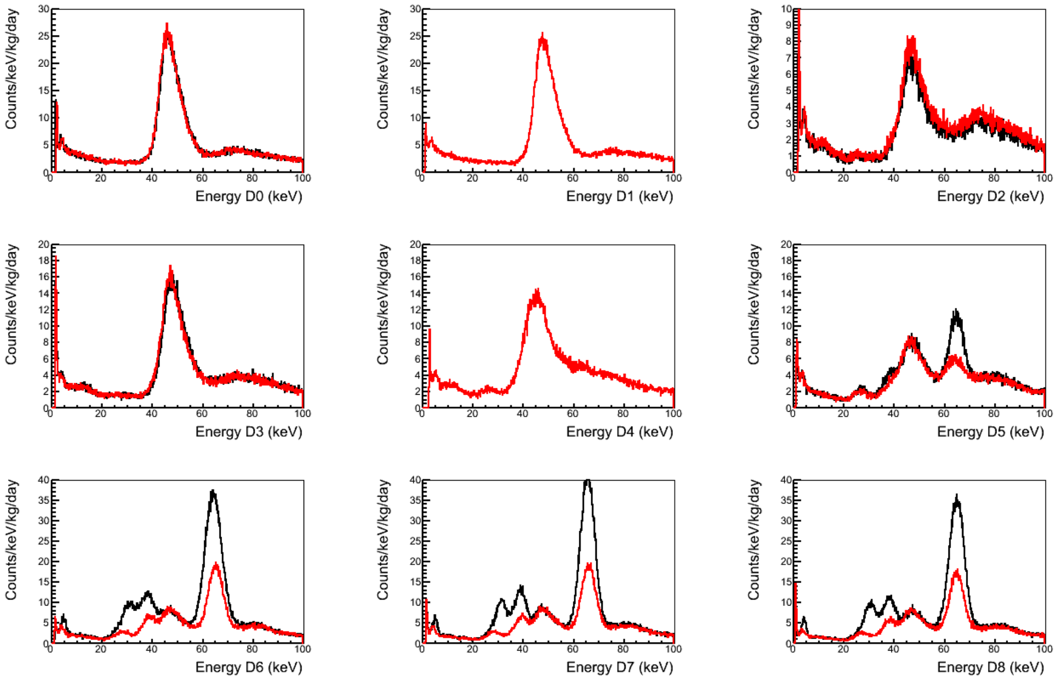

Figure 3. Low energy region of the background spectra registered in the commissioning run of ANAIS-112. Data from the first 29.2 days (March and April, 2017) in black and the last 30.1 days (June and July, 2017) in red are shown (note they correspond to filtered spectra but with no cut efficiency correction yet).

fifth and sixth columns of table 1. As made in previous set-ups, the potassium content has been deduced by identifying coincidences between the 3.2 keV$_{ee}$ emissions and the 1460.8 keV gamma-ray following the electron capture decay of ^{40}K [10]; the obtained values are compatible with estimates from previous set-ups when available. Some detectors have similar content to that of DAMA/LIBRA crystals [6]; the average ^{40}K activity in ANAIS-112, although higher than that of DAMA/LIBRA, is more than one order of magnitude lower than in large, low-background crystals tested from other suppliers. The activity of ^{232}Th and ^{238}U in the crystals is quantified by the measured alpha rates, following Pulse Shape Analysis (to distinguish alpha interactions from beta/gamma ones) and analysis of BiPo sequences; it is at a level of a few μBq/kg, but ^{210}Pb out of equilibrium has been observed for all the modules. The origin of a possible ^{210}Pb contamination was under study in collaboration with AS, which allowed to obtain lower activity in the last produced crystals (see table 1 and figure 2).

Figure 3 presents the background spectra at the low energy region in ANAIS-112 commissioning run; first and latest data are compared, showing the decay of cosmogenics in the last detectors. Preliminary background models for those modules (see one example in figure 4), considering the measured crystal activities and the ANAIS-112 configuration, point to equivalent relevant background sources in the very low energy region. The ^{210}Pb contribution around 50 keV (see figure 3) is consistent with the measured alpha specific activity in all cases.

5. Sensitivity prospects

The prospects of ANAIS-112 for the identification of an annual modulation signal have been evaluated in [11] in terms of the *a priori* critical and detection limits of the experiment. The analysis is based on the detector response and the background level measured for the first

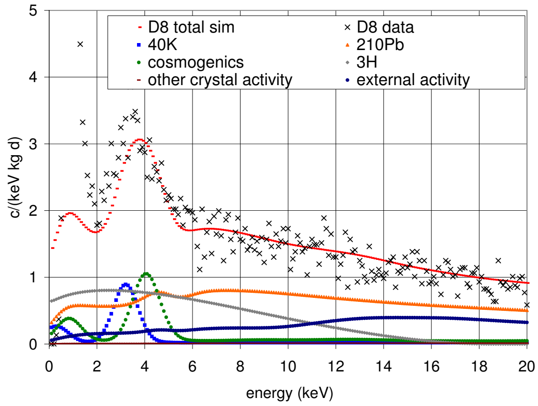

Figure 4. Comparison of low energy data taken in June and July, 2017 with the background model from simulations for detector D8. Individual contributions are shown too; cosmogenics is still relevant due to the short time spent underground.

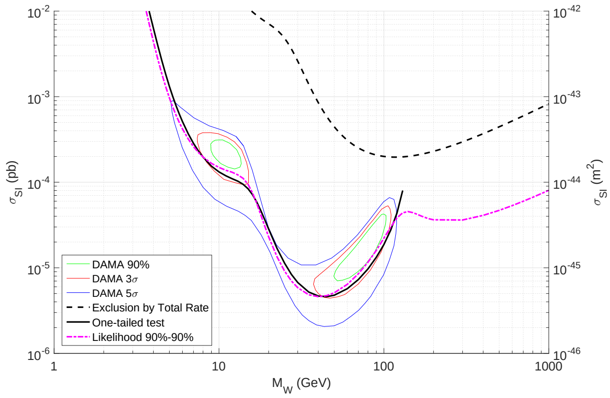

Figure 5. Annual modulation sensitivity prospects for ANAIS-112 after 5 years of measurement, as evaluated in [11].

modules operated in Canfranc. In particular, an average background (corrected for the cut efficiency) has been estimated in the regions of interest and five years of data taking have been assumed. Considering the variance of the estimator of the modulated amplitude, it is shown [11] that ANAIS-112 in 2-6 keV$_{ee}$ has a detection limit for a model-independent annual modulation (not related to a dark matter origin) below the measured amplitude by DAMA/LIBRA [1]. As it can be seen in figure 5 (taken from [11]), under the dark matter hypothesis, for a detection limit at 90% C.L. and a critical limit at 90% C.L., ANAIS-112 can detect the annual modulation in the 3σ region compatible with the DAMA/LIBRA result.

Acknowledgments

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References

[1] Bernabei R *et al* 2013 *Eur. Phys. J. C* **73** 2648
[2] Sarsa ML *et al* 1997 *Phys. Rev. D* **56** 1856
[3] Cuesta C *et al* 2014 *Eur. Phys. J. C* **74** 3150
[4] Amaré J *et al* 2014 *Nucl.Instrum. Meth. A* **742** 197
[5] Amaré J *et al* 2016 *J. Phys. Conf. Ser.* **718** 042052
[6] Bernabei R *et al* 2008 *Nucl. Instrum. Meth. A* **592** 297
[7] Oliván MA *et al* 2017 *Astropart. Phys.* **93** 86
[8] Amaré J *et al* 2016 *Eur. Phys. J. C* **76** 429
[9] Amaré J *et al* 2015 *JCAP* **02** 046
[10] Cuesta C *et al* 2014 *Int. J. Mod. Phys. A* **29** 1443010
[11] Coarasa I *et al* 2017 Annual modulation of dark matter: The ANAIS112 case *Preprint* arXiv:1704.06861v1 [astro-ph.IM]