

Update on the ANAIS experiment. ANAIS-0 prototype results at the new Canfranc Underground Laboratory

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Abstract. ANAIS experiment will look for dark matter annual modulation using NaI(Tl) scintillators at the Canfranc Underground Laboratory (LSC). Highly purified NaI(Tl) crystals are being developed to reach the required sensitivity. In a parallel way, the ANAIS-0 module (made with a low background St Gobain NaI(Tl) crystal) has been taking data at the LSC, testing different configurations: various photomultiplier tubes (PMTs) models with/without light guides. Low background PMTs with light guides and ultra low background PMTs without light guides have shown a similar contribution to the background. A complete simulation of the ANAIS-0 module with shielding in the different configurations tested has been carried out and compared with the experimental data, considering contributions to the background from NaI bulk contaminants, PMTs, light guides, quartz windows and shielding materials. A good understanding of the background above 500 keV can be reported.

1. The ANAIS experiment

ANAIS is a project aiming to set up, at the new facilities of the Canfranc Underground Laboratory, a large scale NaI(Tl) experiment in order to explore the DAMA/LIBRA [1] annual modulation positive result using the same target and technique. For this goal, some of the experimental features of ANAIS should be: energy threshold below 2 keVee in order to improve sensitivity for the annually modulated WIMP signal, background at low energy kept as low as possible and very stable operation conditions. The original proposal consisted of 100 kg NaI(Tl) crystals, but an enlargement up to 250 kg was recently proposed and funds allocated.

New NaI(Tl) crystals with very low content in potassium should be used in ANAIS to reach the required sensitivity for the dark matter signal. ANAIS collaboration signed an agreement to purify commercial NaI powder below 100 ppb and 1 kg samples are being characterized at our HP Ge test bench in the LSC. The terms of the crystal growing agreement are under discussion.

Different photomultipliers have been tested. Two options are still under consideration for ANAIS: Low background (LB) photomultipliers (Hamamatsu R6233-100 or Electron Tubes Limited 9302B) with 10-cm methacrylate light guides and ultralow background (ULB) photomultipliers (Hamamatsu R11065SEL) without light guides. Regarding the acquisition code and electronics, the new VME acquisition system is completed and first tests at the University of Zaragoza have been carried out. It

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will be installed at LSC for further testing with ANAIS-0 in the next weeks. Stability conditions and environmental parameters are being monitored with the ANAIS-0 module at the new facilities of LSC.

2. The ANAIS-0 module

The ANAIS-0 module consists of an old NaI(Tl) ultrapure crystal (9.6 kg), made by Saint-Gobain and encapsulated by us in OFHC copper in the University of Zaragoza (figure 1). It was designed to characterize and fully understand ANAIS background at low energy, optimize NaI scintillation events selection, determine the calibration method and test the electronics. The detector encapsulation allowed for testing different configurations of light guides and photomultipliers.



Figure 1. ANAIS-0 module with light guides.

Main results concerning background for ANAIS on site show that ultra low background photomultipliers (ULB PMTs) are radiopure enough to be a small contribution to the background of the ANAIS-0 module, and using light guides has not an important effect in the measured background (figure 2). ULB PMTs background without light guides is comparable to the background obtained with the low background photomultipliers (LB PMTs) with light guides. Work is in progress to establish the cuts to select of real bulk NaI scintillation events, mandatory before estimating the background at the very low energy region.

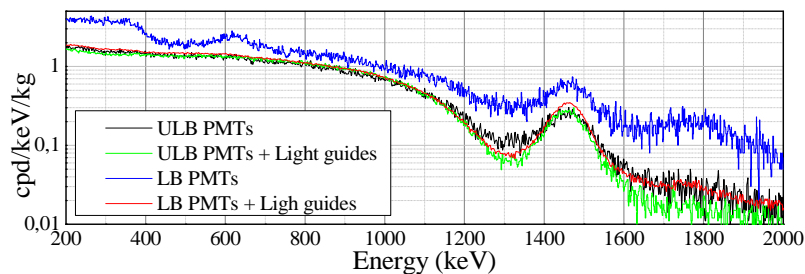


Figure 2. High energy raw background data for the different ANAIS-0 set-ups.

3. Background simulation

A complete simulation (using the GEANT4 package [2]) of the ANAIS-0 module with shielding in the different configurations tested has been carried out. Version Geant4.9.4.p01 has been used for all the simulations presented here. Physical processes and models commonly used in the context of underground experiments have been implemented for interactions of alpha, beta and gamma particles. The GEANT4 Radioactive Decay Model has been used for simulating radioactive contaminations, after checking carefully the energy conservation in the decay of all the isotopes taken into account; problems encountered in previous versions of GEANT4 code seem to be surpassed.

The simulated geometry (figure 3) includes the NaI crystal, Teflon and reflector lining, quartz windows, light guides (optional), photomultipliers, copper encapsulation as well as the shield made of both archaeological and standard low activity lead.

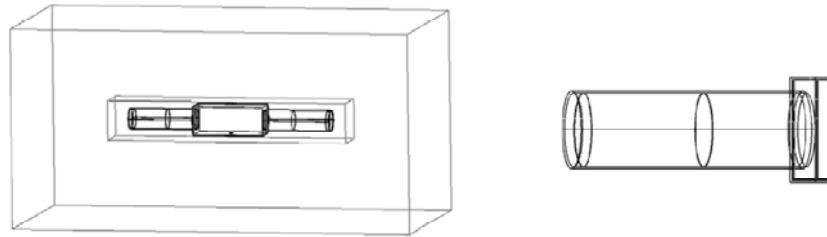


Figure 3. Geometry used in the ANAIS-0 module simulations (left). Detail of the PMT and light guide coupling (right).

Decays of radioactive impurities in the most relevant materials of the set-up, including mainly ^{238}U and ^{232}Th chains and ^{40}K , have been simulated assuming a uniformly distributed bulk contamination. Activities used to normalize simulation results come mostly from specific measurements made for ANAIS-0 building materials:

- For the ANAIS-0 module NaI crystal, the ^{40}K bulk content is determined through the coincidence method [2] to be 12.7 ± 0.6 mBq/kg. Activities of the different isotopes in the ^{238}U and ^{232}Th chains, assuming broken equilibrium, have been quantified after identifying their alpha emissions by means of Pulse Shape Analysis (PSA) and fitting the obtained alpha spectrum. The values obtained are: 0.075 ± 0.005 mBq/kg for $^{238}\text{U}/^{234}\text{U}$, 0.023 ± 0.007 mBq/kg for ^{230}Th , 0.098 ± 0.004 mBq/kg for ^{226}Ra , 0.188 ± 0.005 mBq/kg for ^{210}Pb , 0.013 ± 0.005 mBq/kg for ^{232}Th and 0.035 ± 0.003 mBq/kg for ^{228}Th . Concerning the activity of ^{129}I , the value deduced for DAMA/LIBRA crystals [3], produced (as the ANAIS-0 module crystal) by Saint Gobain company, has been used (9.01 mBq/crystal).

- The activities for the several ETL and Hamamatsu photomultiplier models employed in the different ANAIS-0 set-ups were measured using our HP Ge detector operated at LSC [4].

- For quartz windows, light guides and copper encapsulation the upper limits on the activities derived in specific measurements using a HP Ge detector operated at LSC have been considered.

- For archaeological lead, an upper limit on ^{210}Pb activity quoted at [5] has been used.

The energy spectrum of alpha emissions identified in the data taken for a long background measurement of ANAIS-0 has been compared with the corresponding simulation (figure 4), assuming a volumetric distribution of ^{238}U and ^{232}Th , and daughters, isotopes in NaI crystal and the activity values deduced by PSA analysis. Effect of acquisition dead time on ^{214}Po emission and the summing of alpha and beta emissions for the $^{212}\text{Bi-Po}$ sequence have been properly taken into account.

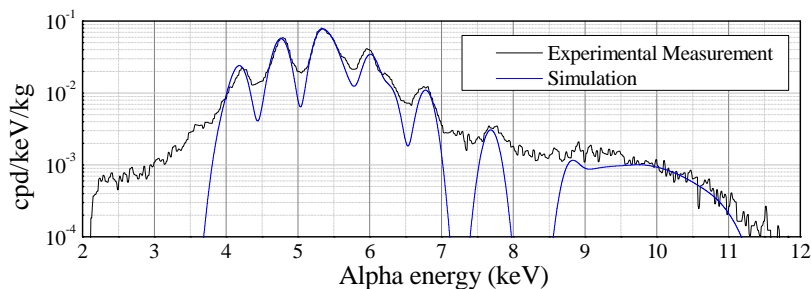


Figure 4. Simulation of the alpha spectrum compared with real data. Alpha+beta coincident events (Bi-Po sequence) are also shown.

The energy spectrum in ANAIS-0 due to beta-gamma events in a background measurement with the ULB PMTs without light guides has been compared with the simulated contribution of the different components (NaI crystal, copper encapsulation, photomultipliers, etc.) (figure 5). Looking at the high energy region, from 0.2 to 3 MeV, the main conclusion is that above 500 keV the measured background seems to be nicely reproduced by the simulated considered contributions; ^{40}K from the bulk NaI crystal is clearly the dominant background source from 500 keV to the 1460.8 keV peak.

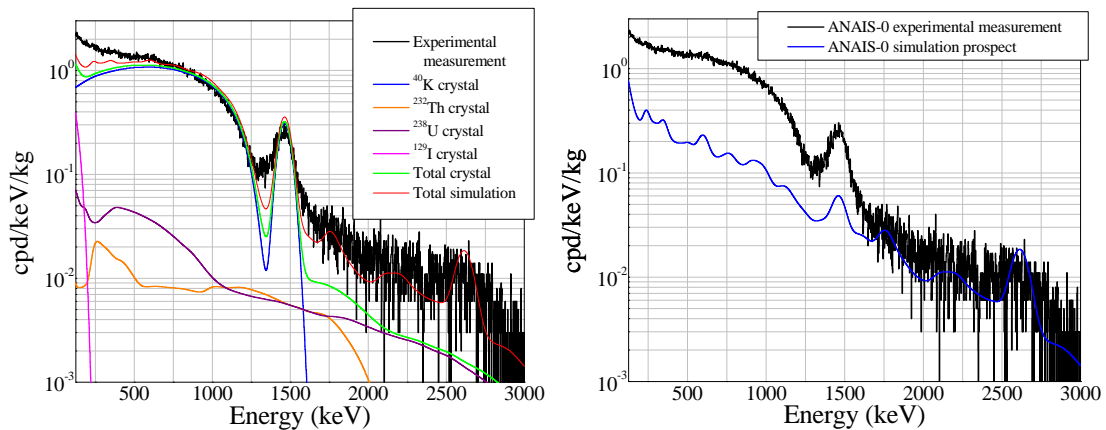


Figure 5. Simulation of the beta/gamma spectrum compared with real data. Contributions of bulk contaminations in NaI crystal are detailed in the plot and the total simulated spectrum is shown as red solid line (left). Prospect for the K contamination had as a goal for the new NaI crystals (20 ppb) keeping the same of all other contributions (right).

However, in the low energy region, below 0.2 MeV, agreement between the measured data and the total simulated contributions is worse, pointing to some non-explained component(s) in the background. Different possibilities are under study.

Drawn conclusions are equivalent for all the available configurations, either from the high or the low energy regions of the spectra.

Using the performed simulations, an estimate of the ANAIS new detectors achievable background levels has been attempted by reducing the K concentration in the NaI crystal down to 20 ppb, keeping activities for all the other emissions as presented before for the ANAIS-0 prototype (figure 5). It seems that the expected background will fulfill the ANAIS requirements provided if this K purity is effectively reached in the bulk crystal and the unexplained components (not included in the simulation for the moment) are kept under control.

4. Conclusions

New ultrapure NaI crystals are being developed, the NaI purification is on-going and crystal growing terms are under discussion. Besides, ANAIS-0 (old NaI crystal) is taking data at the LSC. Two configurations with ANAIS-0 have been tested: ultra low background photomultipliers and low background ones with light guides, both contribute equivalently to the background.

The ANAIS-0 background above 500 keV seems to be explained by the considered contributions. However, at low energy we find some non-explained components that are under study. Encapsulation materials and procedure allow us to reach the required background level if the new NaI crystals have a potassium content less than 20 ppb.

Acknowledgments

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