BACKGROUND SIMULATION STUDIES FOR THE CRESST AND COSINUS DIRECT DETECTION DARK MATTER EXPERIMENTS

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INTRODUCTION: DARK MATTER SEARCH WITH SCINTILLATING CALORIMETERS

Dark matter (DM) is one of the big mysteries still persistent in the physical picture of our universe. According to the standard cosmological model, visible matter contributes less than 20% to the total existing matter content. Among the experiments searching for DM via direct detection are CRESST (Cryogenic Rare Event Search with Superconducting Thermometers), a long-standing pioneer in the direct search for very low-mass DM particles, and COSINUS (Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches), a more recently initiated project which is only starting to build up the experiment this year. As the interaction between DM and standard model particles is presumably very weak, a crucial task for both experiments is background minimization and optimal understanding of residual background signals.
CRESST and COSINUS are searching for signatures of DM particles scattering elastically off nuclei in their detectors. Both experiments operate their scintillating target crystals ($CaWO_4$ in CRESST, NaI in COSINUS) at mK-temperatures and employ a two-channel readout – using transition edge sensors (TESs) developed in CRESST – allowing to simultaneously measure the phonon (heat) and the scintillation light signal. This feature provides the possibility to distinguish β/γ-backgrounds from the expected nuclear recoils. However, neutrons entering the detectors can easily mimic signals of the sought-after DM particles, which is why we consider them as the most dangerous background. We distinguish radiogenic neutrons, originating from spontaneous fission and (α,n) reactions due to environmental radioactivity and radioactive contaminations inside materials surrounding the detectors, and cosmogenic neutrons produced in interactions of cosmic muons.

BACKGROUND MODELING FOR CRESST

Searching for the very rare DM-nucleus scattering processes is like looking for a needle in a haystack, if the detectors are not shielded optimally against any kind of background in the signal region. For this reason, the CRESST experiment is located undergound at the Laboratori Nazionali del Gran Sasso (LNGS), where a rock overburden of 3600 meter water equivalent reduces the cosmic muon flux by a factor of 10^6 with respect to the surface. Furthermore, the detectors have to be surrounded by a dedicated shielding setup. A classical approach uses a sequence of an outer shield made of a low-Z material to moderate ambient neutrons, a high-Z shield mitigating the ambient gamma flux and an inner (thin) low-Z layer shielding against neutrons produced in the high-Z materials. Additionally, plastic scintillator panels are used as an active muon veto. The respective shielding structure of CRESST is shown in Fig. 1. For developing a neutron background model, we use the Monte Carlo toolkit Geant4 [1], in which a detailed geometry of the experimental setup has been implemented.

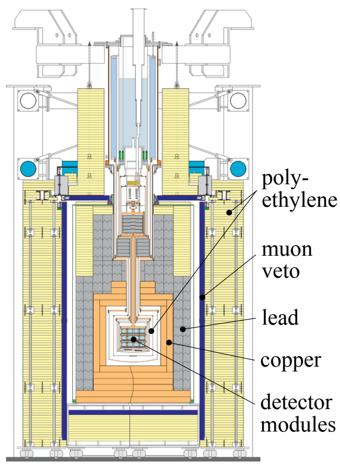

Figure 1: The shielding setup of CRESST.

Currently, we are studying radiogenic backgrounds, for which we feed energy spectra and fluxes of neutrons obtained with the SOURCES4C [2] code to the Geant4 simulations, where we have developed a dedicated primary particle generator, which allows us to efficiently simulate radioactive contaminations. As an example, Fig. 2 shows the detector carousel and a homogeneous radioactive contamination in all its Cu parts. Additionally, an enhanced detector response model is under development, which will allow us to include the energy resolution of our multiple detectors and to directly compare simulated to real data.

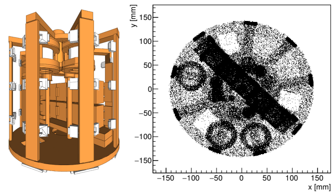

Figure 2: left: CRESST detector carousel visualized in Geant4. right: radioactive contamination in its Cu parts

DEVELOPING A SHIELDING CONCEPT FOR COSINUS

In COSINUS, our current simulation task focuses on evaluating an optimal shielding structure for the eventual buildup of the experiment. The idea is to use an approach, in which the outer low-Z shield consists of a big steel tank filled with ultra-pure water, as schematically depicted in Fig. 3. An advantage of this structure is, that the water tank can serve two tasks simultaneously. First, it acts as a passive shield against ambient radioactive decay particles and second, it can be instrumented with photomultiplier tubes to function as an active Cerenkov muon veto. Results of our simulation studies let us conclude that inner layers made of polyethylene and lead (see Fig. 3) should likely be omitted, due to higher radiogenic and cosmogenic neutron yields, respectively. We find that 3 m of water together with an inner layer of 8 cm copper would be sufficient in reducing ambient particle fluxes, while at the same time minimizing the expected background. In addition, a dedicated optical simulation of the Cerenkov light produced in the water tank is employed to estimate the efficiency of the muon veto system. All results of these simulations contribute to the conceptual design report of COSINUS, which is currently being written up.

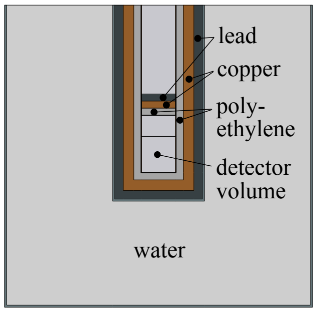

Figure 3: Schematic design of the COSINUS shielding.

CONCLUSION

A main task in rare event search experiments is optimal background mitigation and modeling of residual backgrounds. For CRESST, developments both in enhancing the simulation code and improving the post-processing of simulated data are thus ongoing. Eventually, all radiogenic and cosmogenic background contributions shall be analyzed, leading up to a background model for the experiment. For COSINUS, current simulations are laying ground for the shielding concept of the experiment and help estimating the efficiency of the muon veto, resulting in important contributions to the conceptual design report.

ACKNOWLEDGEMENTS

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[1] S. Agostinelli et al. *"Geant4–a simulation toolkit"*. NIMA 506.3 (2003), pp. 250-302.

[2] W. B. Wilson et al. *"SOURCES 4A: A Code for Calculating (α,n), Spontaneous Fission, and Delayed Neutron Sources and Spectra"*. LA-13639-MS (1999).