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Neutron scattering facility for characterization of CRESST and EURECA detectors at mK temperatures

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ABSTRACT

CRESST (cryogenic rare event search with superconducting thermometers) is an experiment located at the Gran Sasso underground laboratory and aimed at the direct detection of dark matter in the form of WIMPs. The setup has just completed a one year commissioning run in 2007 and is presently starting a physics run with an increased target mass. Scintillating $CaWO_4$ single crystals, operated at temperatures of a few millikelvin, are used as target to detect the tiny nuclear recoil induced by a WIMP. The powerful background identification and rejection of α, e^- and γ events is realized via the simultaneous measurement of a phonon and a scintillation signal generated in the $CaWO_4$ crystal. However, neutrons could still be misidentified as a WIMP signature. Therefore, a detailed understanding of the individual recoil behaviour in terms of phonon generation and scintillation light emission due to scattering on Ca, O or W nuclei, respectively, is mandatory. The only setup which allows to perform such measurements at the operating temperature of the CRESST detectors has been installed at the Maier-Leibnitz-Accelerator Laboratory in Garching and is presently being commissioned. The design of this neutron scattering facility is such that it can also be used for other target materials, e.g. $ZnWO_4$, $PbWO_4$ and others as foreseen in the framework of the future multi-target tonne-scale experiment EURECA (European underground rare event calorimeter array).

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1. Introduction

CRESST (cryogenic rare event search with superconducting thermometers) is located at a depth of 3600 m.w.e. (meter water equivalent) in Hall A of the Laboratori Nazionali del Gran Sasso (LNGS), Italy. The experiment is aimed at the direct detection of WIMPs with cryogenic detectors consisting of 300 g $CaWO_4$ crystals equipped with tungsten transition edge sensors (TESs). These target crystals are additionally monitored by cryogenic light detectors to measure the amount of light emitted per particle interaction. The simultaneous measurement of the heat and the scintillation signal of the $CaWO_4$ crystal allows a highly efficient background rejection [1,2].

After a major upgrade phase (CRESST-I to CRESST-II), the cryostat can now accommodate 10 kg of total target mass in the detector carousel. CRESST-II was also upgraded concerning the shielding which now comprises an additional 45 cm polyethylene shield against neutrons and an active muon veto. With this current setup, CRESST should be able to reach a sensitivity for the spin-independent WIMP-nucleon cross section in the range of 10^{-8} pb.

$CaWO_4$ contains a heavy nucleus (tungsten), which makes it a good target for spin-independent coherent WIMP interactions [2]. The crystals used in the experiment are cylindrical $CaWO_4$ single crystals of 40 mm diameter and 40 mm height with a mass of ~300 g equipped with tungsten transition edge sensors (TESs) directly evaporated onto them. With the TES the phonon signal induced by an event is detected, delivering the primary information about the deposited energy. This part of the detector module is referred to as the phonon detector.

For the detection of the scintillation light, cryogenic light detectors also equipped with tungsten TESs are used. The first generation of light detectors for CRESST consisted of $30 \times 30 \times 0.4\ mm^3$ silicon wafers to absorb the scintillation light emitted by the $CaWO_4$ crystal (~420 nm). The second generation of light detectors

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is made of sapphire discs of 40 mm diameter coated with silicon on one side (SOS: silicon on sapphire). The absorber crystals were changed from silicon to SOS in order to benefit from the excellent phonon transportation properties in sapphire.

Phonon and light detectors are mounted together in a copper housing. The inner surfaces are covered with a highly reflective scintillating polymeric foil for efficient light collection. Fig. 1 depicts a schematic drawing of one such detector module.

The light output of an event is characterized by its light yield Y defined as Y = signal amplitude in light detector/signal amplitude in phonon detector. Y is usually normalized to 1 for electron recoil events. For other event classes, like alphas or nuclear recoils from neutron or WIMP interactions, the light yield is reduced. The reduction of the light yield is expressed by the quenching factor $QF = 1/Y$.

Most neutron recoil events in the relevant energy window between 10 keV and 40 keV are due to scattering off oxygen. On the other hand, WIMP events in this energy window are expected to be mainly scatterings off tungsten nuclei in the $CaWO_4$ crystal. Thus, the identification of the recoiling nucleus is an extremely helpful tool to discriminate the neutron background from a possible WIMP signal. This can be achieved by measuring the quenching of the scintillation light with respect to the recoiling nucleus. There are several approaches to measure the quenching factors for the elements in $CaWO_4$ [3–6]. In this article a neutron scattering facility, set up at the Maier-Leibnitz-Accelerator Laboratory (MLL), using a pulsed monochromatic neutron beam of 11 MeV to measure quenching factors at mK temperatures is described.

The facility described in this article not only is of relevance for CRESST but also for the planned EURECA (European underground rare event calorimeter array) experiment [7]. EURECA will be the future European dark matter experiment using low-temperature detectors. It will combine the efforts of the present CRESST, EDELWEISS (Experience pour DEtecter Les WIMPs en Site Souterrain) [8] and ROSEBUD (Rare Objects SEarch with Bolometers UndergrounD) [9] experiments in a new experimental hall in the Laboratoire Souterrain de Modane (LSM). Once fully set up, EURECA will exhibit a total mass on the tonne scale using multiple target materials.

2. Experimental setup

For a good determination of the quenching factors in a neutron scattering experiment it is desirable that the signals for the three different elements form distinct populations in the data. This can be achieved by performing the scattering with monoenergetic neutrons and selecting a single scattering angle under which a time-of-flight (TOF) measurement is carried out. In this way, the kinematics of the scattering reaction is fixed and the nuclei can be discriminated via the recoil energy. The setup of the neutron scattering facility is depicted in Fig. 2. A similar type of experiment [10] was also performed by the EDELWEISS collaboration [8].

The neutrons are produced via the reaction $^{1}H(^{11}B, n)^{11}C$. Boron ions with a kinetic energy of 60 MeV from the accelerator are directed onto a hydrogen gas target, producing neutrons with an energy of 11 MeV [4]. The pulsing of the boron beam provides the reference time for the time-of-flight measurement of the neutrons. The neutron scattering facility consists of a central detector unit containing the scintillator crystal to be investigated and a set of ~40 neutron detectors placed at a fixed angle with respect to the beam and the central detector, thus defining the scattering geometry. The neutron detectors consist of chambers with NE213 liquid scintillator read out by PMTs. NE213 allows a distinction between neutron and gamma events via pulse shape discrimination.

2.1. Cryostat

The central detector is cooled to its operational temperature in a $^3He/^4He$ dilution refrigerator. A KELVINOX400 with a cooling power of 400 μW at 100 mK and a base temperature of ~10 mK was installed in Hall 2 of the MLL. The cryostat uses a special dewar that is designed such that only a minimum amount of liquid ^4He is present around the detector (see Fig. 2) in order to suppress parasitic neutron scattering on the helium. The cryostat has been equipped with 2 SQUID readout channels for the central cryodetector. The cryostat can be cooled from room temperature to ~10 mK in ~1 day and exhibits an extremely stable base temperature over time. Special care was given to decouple the cryostat as well as possible from the mechanical surroundings in order to avoid microphonics. Fig. 3 shows pictures of the insert of the cryostat and the mounted cryodetector prior to the first beamtime as well as the principle of the SQUID readout design.

2.2. Dedicated cryodetector

A crucial issue in setting up the neutron scattering facility was the development of a dedicated low-temperature detector able to cope with the high count rates. The requirements regarding the

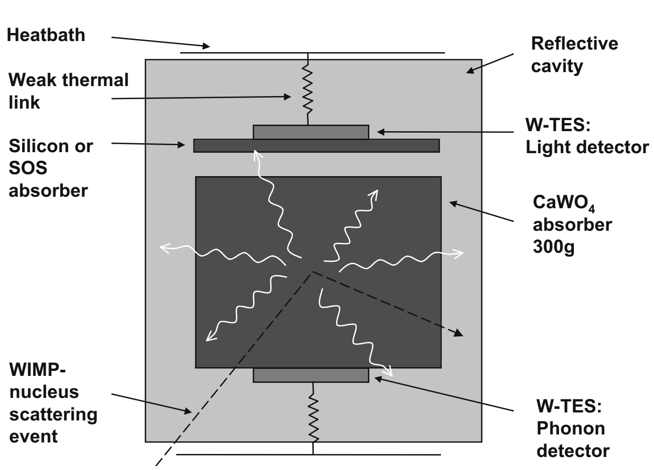

Fig. 1. Schematic setup of a CRESST detector module. The module consists of two independent detectors: one phonon channel and one light channel. Both detectors are located in a reflective housing.

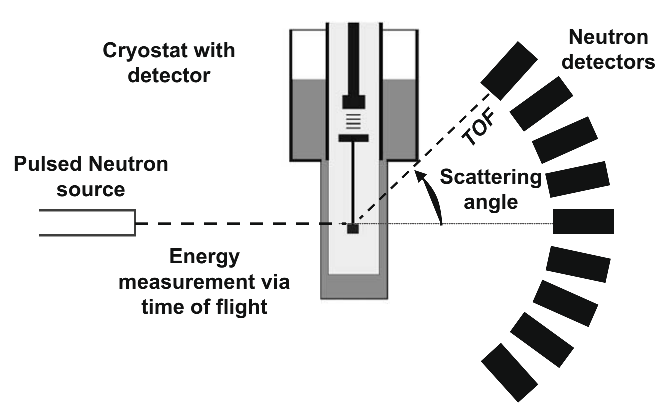

Fig. 2. Schematic of the neutron scattering facility setup. It consists of a pulsed neutron source, a central detector consisting of a $CaWO_4$ cryogenic detector placed inside a cryostat and an array of ~40 neutron detectors. The dewar of the cryostat is designed such that a minimum amount of liquid helium is present in the near surroundings of the $CaWO_4$ crystal to avoid additional scattering of neutrons on the helium.

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