CRESST

sfb 1258 neutrinos darkmatter messengers

Excellence Cluster Universe

Cryogenic Light Detectors for Rare Event Searches

ELIZABETH MONDRAGÓN[1✿], A. KINAST[1], A. LANGENKÄMPER[1], A. MÜNSTER[1], T. ORTMANN[1], L. PATTAVINA[1], F. PETRICCA[2], W. POTZEL[1], S. SCHÖNERT[1,2]

1)TECHNICAL UNIVERSITY OF MUNICH 2) MAX PLANCK FÜR PHYSIKS

✿E-MAIL: ELIZABETH.MONDAGON@TUM.DE TELF. 089 289 12504

Frontier Detectors for Frontier Physics

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Introduction & Motivation

For rare event searches, such as the direct dark matter search experiment **CRESST** (Cryogenic Rare Event Search with Superconducting Thermometers), highly sensitive temperature sensors and cryogenic detectors are indispensable. A very low energy threshold (<100 eV) and excellent energy resolution are required to increase the experimental sensitivity, particularly for low mass dark matter particles (m_{DM}< 5 GeV/c^2) and to differentiate between these rare events and other particle interactions such as, e.g., natural radioactive backgrounds.

For background suppression, CRESST and other rare event search experiments, benefit from using simultaneously two detection channels from scintillating calorimeters, in this case of heat and light . Measuring a heat signal and its corresponding scintillating light, allows event-by-event particle identification down to certain energies (see Fig. 1). Therefore, **the development of cryogenic light detectors that can achieve single photon sensitivity and high quantum efficiency, is a key point to improve the experiment's sensitivity at low energies**. In other words, the outcome of such experiments highly depends on the performances of the light detectors.

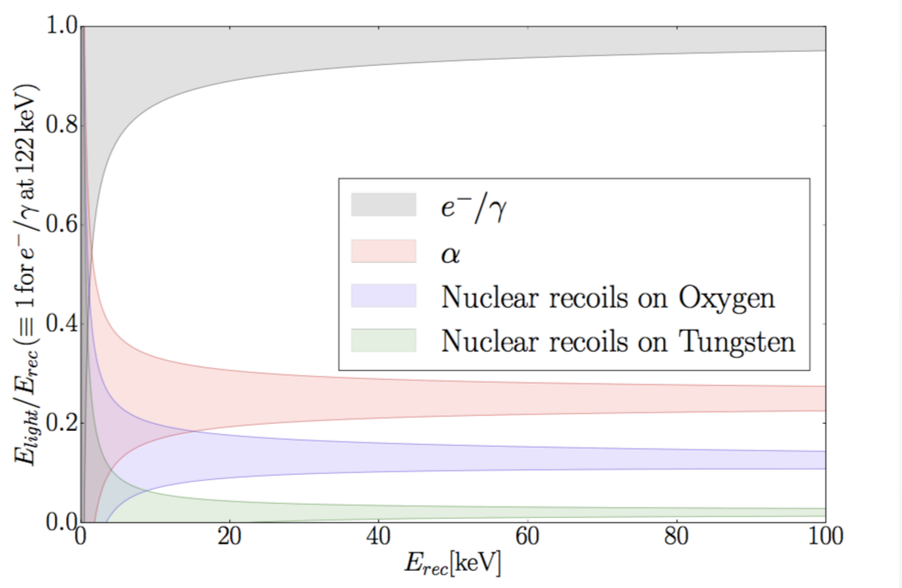

Fig. 1: Light yield (LY) plot obtained from a detection module of CRESST. On the X-axis the energy of the nuclear recoils onto the $CaWO_4$ target crystal (phonon detector), on the Y-axis the ratio between the energy deposited in the light detector (Silicon on Sapphire) and the recoil energy onto the target crystal.

Light Detection Technique

Calorimeters cooled at cryogenic temperatures (~mK) are used as light detectors. Calorimeters can combine high radio purity and high energy resolution at cryogenic temperatures which make them the most suitable technology with standard absorbers. These light detectors measure the phonon signal induced by the interaction of photons in an absorber. The absorber is linked to a temperature sensor, in our case we use Transition Edge Sensors (TES). The signal is collected at cryogenic temperatures and consists of a thermal pulse read by the sensor.

The TES consists of a superconducting film which is maintained around its transition temperature T_c. When a particle deposits energy the T varies. This ΔT generates a change in the film's resistance (see Fig. 2) that is then read out by a SQUID (Superconducting Quantum Interference Devise) resulting in an excellent energy resolution.

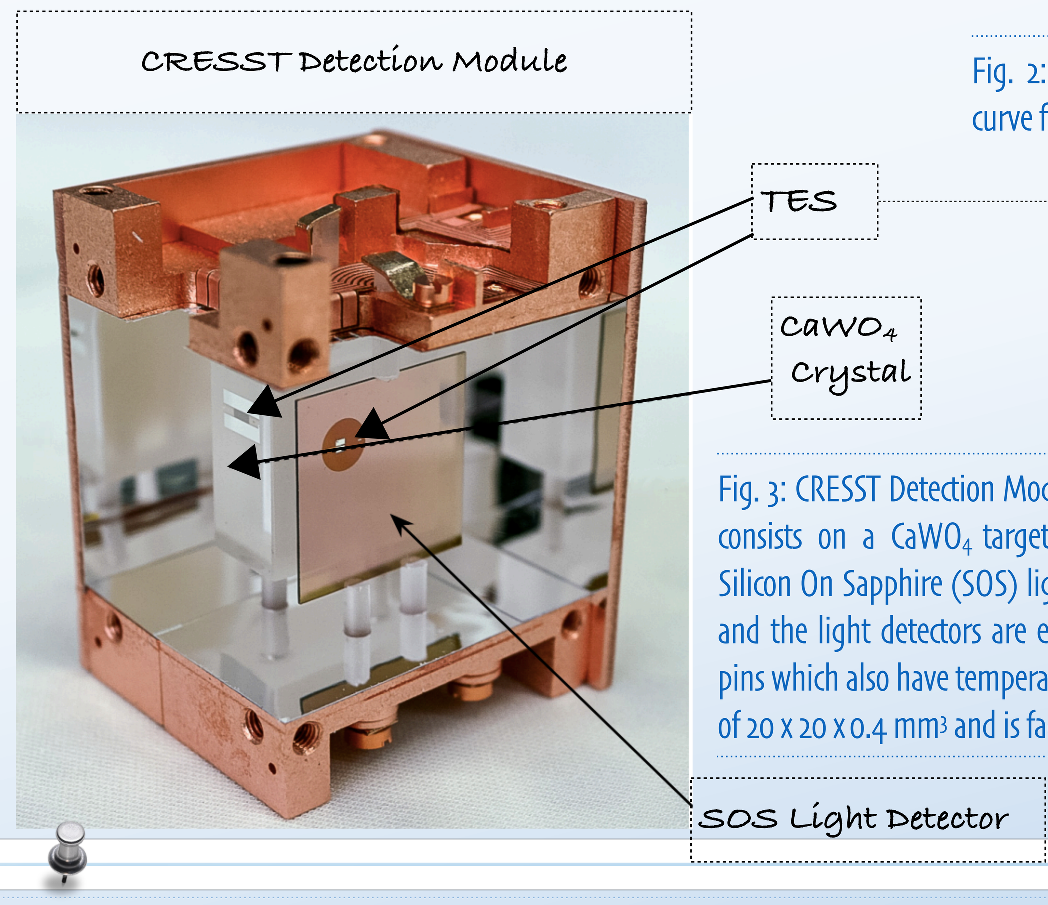

Fig. 2: Transition curve from a TES.

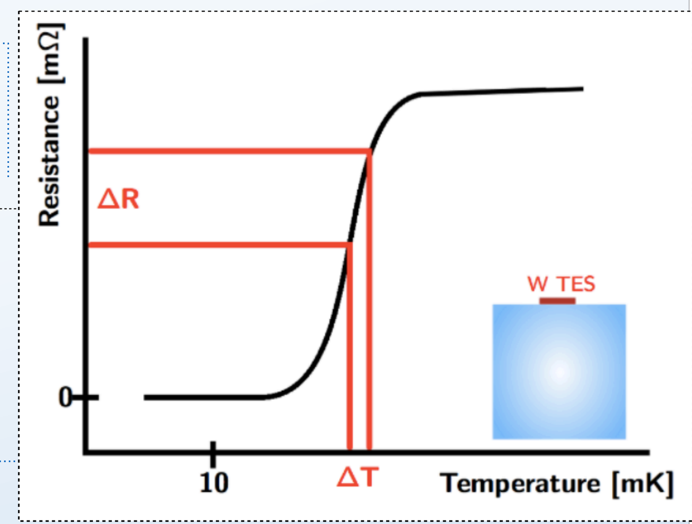

Fig. 3: CRESST Detection Module, which consists on a $CaWO_4$ target crystal, a Silicon On Sapphire (SOS) light detector and a reflective housing. Both the phonon and the light detectors are equipped with TESs. The detectors are held by $CaWO_4$ pins which also have temperature sensors and scintillate light. The SOS has a volume of 20 x 20 x 0.4 mm^3 and is facing the 25 g, 20 x 20 x 10 mm^3 target crystal.

Detectors for Study

Doped Si crystals modify the transmission properties of pure Si and open up the detection range without loosing much of the benefits in using Si, i.e., price and phonon mobility. By changing the reflective index the maximum angle of incidence also changes and allows for longer wavelengths to be absorbed. In CRESST the TES is evaporated directly onto the Si which results in a better performance and allows to reduce the energy threshold. Nb films are superconducting at mK temperatures and become completely black to radiation. The Nb films can be sputtered onto sapphire and Si. Sapphire has very good thermal properties and it is not as delicate as Si. The first steps of this study are listed below:

Highly doped Si crystals

1. Adequate 200mm diameter highly doped Si crystals to the size and shapes of the CRESST light detectors. This will be done using laser cutting.
2. Glue Si-TESs onto the crystals as temperature sensors.
3. Cool down the detectors at the cryostat facilities and use the radiation of different LEDs for detection investigation.
4. Study the wavelength detection window of these detectors and their energy resolution and sensitivity.

Nb films sputtered on Sapphire

1. Install a Nb target at the sputtering facilities of the astro-particle physics group at the TUM.
2. Sputter Nb films of different thickness onto Sapphire crystals.
3. Determine the influence of the thickness on the superconducting properties at low temperatures.
4. Install temperature sensors and cool down to low temperatures. Irradiate the films with light sources and study if it is possible to detect the light.

Production & Experimental set-up

For the production of the Nb films, we will make use of a Dual Magnetron Sputtering (DMS) facility (Fig. 4). The vacuum chamber is equipped with two 2 inch magnetron sputtering sources. The chamber can reach a vacuum of ~10^{-8} mbar. With heating bands wrapped around the chamber it is possible to reach temperatures of about 120ºC when heating the chamber. The deposition monitor consists of an oscillating quartz, which measures the deposition rate and thickness via the change of its oscillation frequency. We will implement two new features to the facility: a new Nb target will be installed, and a holder temperature control system will be implemented. These improvements are currently being installed.

The detectors will be cooled down using a dilution refrigerator (Fig. 5). The detectors are mounted at the bottom where the temperature is of the order of few mK. All parts below the top flange are inside the Inner Vacuum Chamber (IVC). Below the top flange is the 1K-pot is at around 1.5 K. From the 1K-pot the temperature decreases in top-down direction until the mixing chamber is reached. The still is located at the centre part. It is surrounded by heating wires for boiling out the ^3He from the mixture. Here the temperature is at approx. 600 mK. On the right beneath the still, the SQUIDS are placed. The bottom part contains the mixing chamber, which keeps the temperature at the base temperature of the cryostat. Beneath the mixing chamber, the copper holding structure and the detector holder are located.

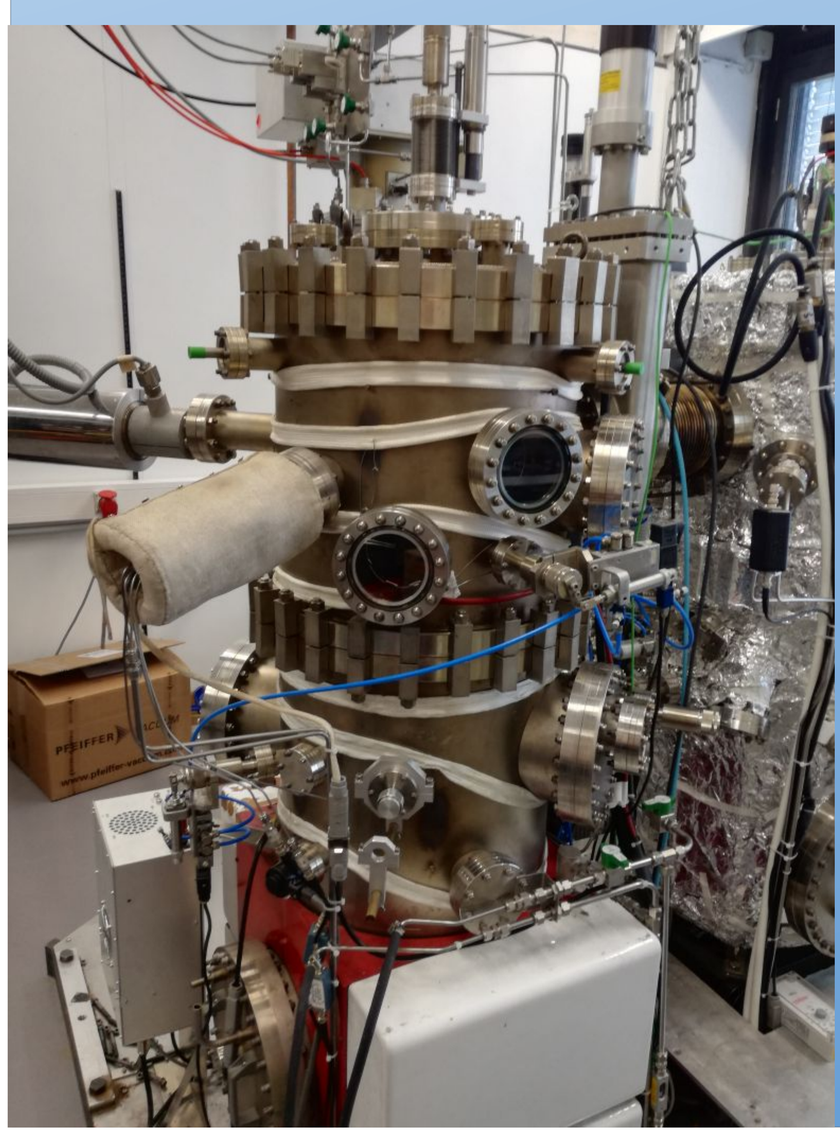

Fig. 4 Dual magnetron sputtering facility. Shown is the vacuum chamber and the matchbox. The chamber is connected via a lock to the aluminium evaporation chamber and from there to the load lock. Only one of the two sputtering sources is visible from this angle. The chamber is equipped with an oscillating quartz for measuring the amount of material deposition and the deposition rate. Furthermore heater bands are installed for heating out the chamber to provide a better vacuum.

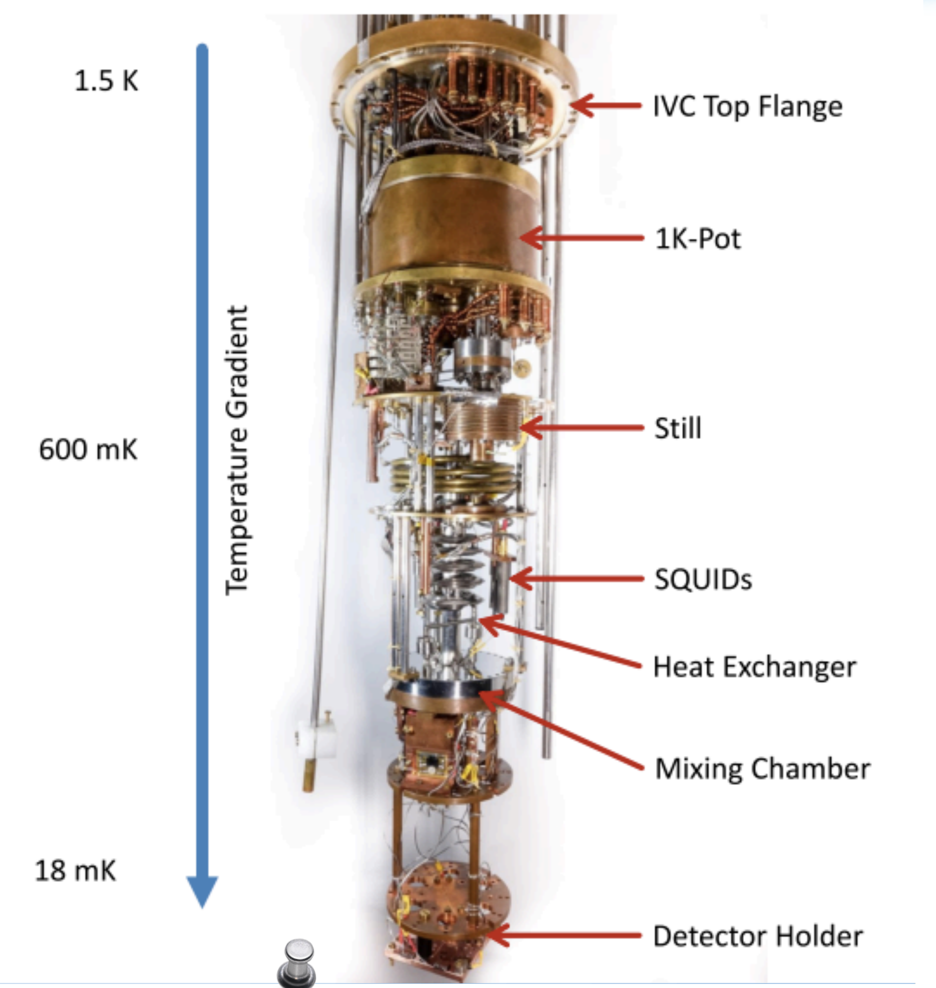

Fig 5: Scheme of a dilution refrigerator or cryostat. The detectors are mounted at the bottom where the cryostat reaches mK temperatures.

Acknowledgements

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