First cryogenic operation of diamond detector for low-mass dark matter searches

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Abstract

Despite the multiple and convincing evidence of the existence of dark matter (DM) in our Universe, its identification is one of the most pressing questions in particle physics. As of today there is no unambiguous hint which could clarify the particle nature of DM. For these reasons, a huge experimental effort is ongoing, trying to realise experiments which can probe the particle properties of DM. In particular, direct search experiments are trying to cover the largest possible mass range, from a few MeV up to TeVs. Particularly suited for the sub-GeV mass region are detectors containing light nuclei, which are sensitive to the scattering-off of light DM candidates. Among them we investigate a carbon-based absorber to explore DM masses down to the MeV region. Thanks to their cryogenic properties (high Debye temperature and long-lived phonon modes), carbon-based materials operated as low temperature calorimeters could reach an energy threshold in the eV range and would allow for the exploration of new parameters of the DM-nucleus cross section.

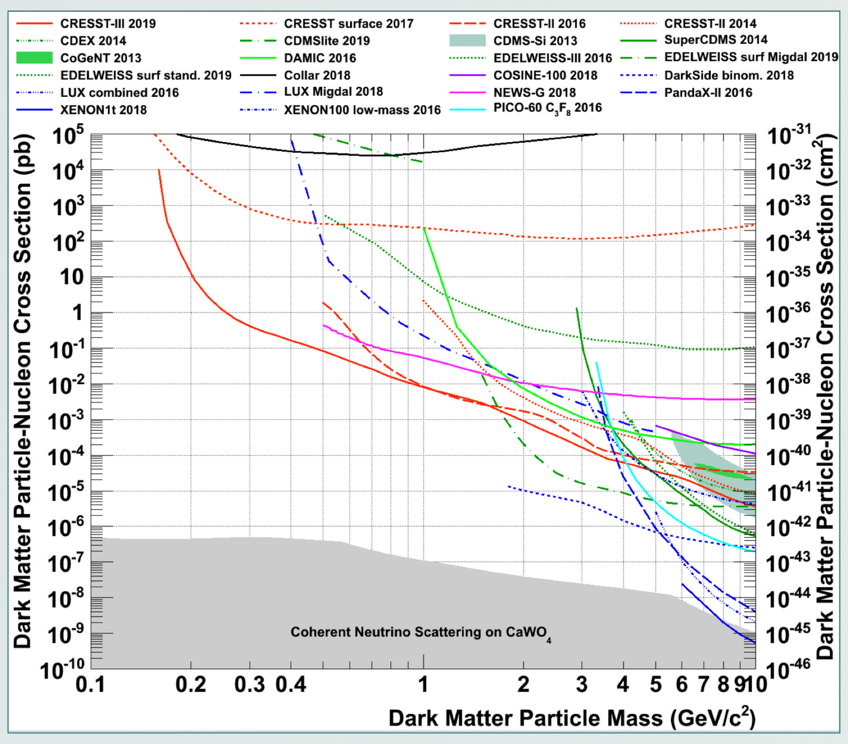
Despite several proposals, the possibility of operating a carbon-based cryogenic detector is yet to be demonstrated. In this contribution the preliminary results obtained with a diamond absorber operated with a TES temperature sensor will be reported. The potential of such a detector in the current landscape of dark matter searches will be also illustrated.

Detectors for direct detection of light DM

Light DM particles (M_{DM}<GeV) are well motivated candidates, which arise from hidden sectors theories.

Cryogenic detectors are well suited for the search of light DM interactions with target nuclei.

They are currently leading the sensitivity for DM particles with mass < 1.6 GeV.



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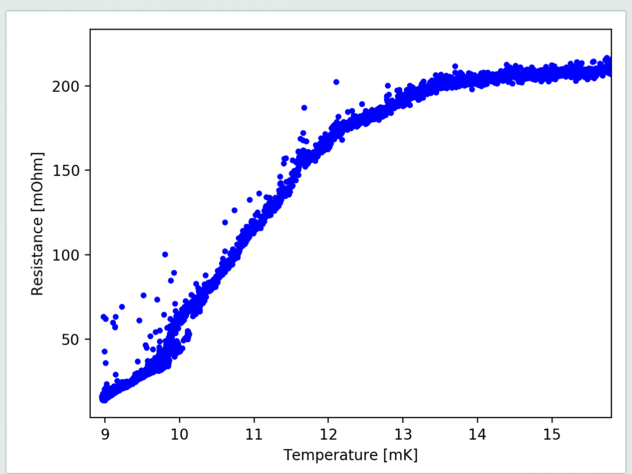
Cryogenic performance

The detector was operated in a dilution refrigerator at the Max-Planck-Institut for Physics in Munich, Germany.



The resistance variation of the TES as a function of the temperature is shown in the Figure. The resistance value was measured with a DC-SQUID based read-out system.

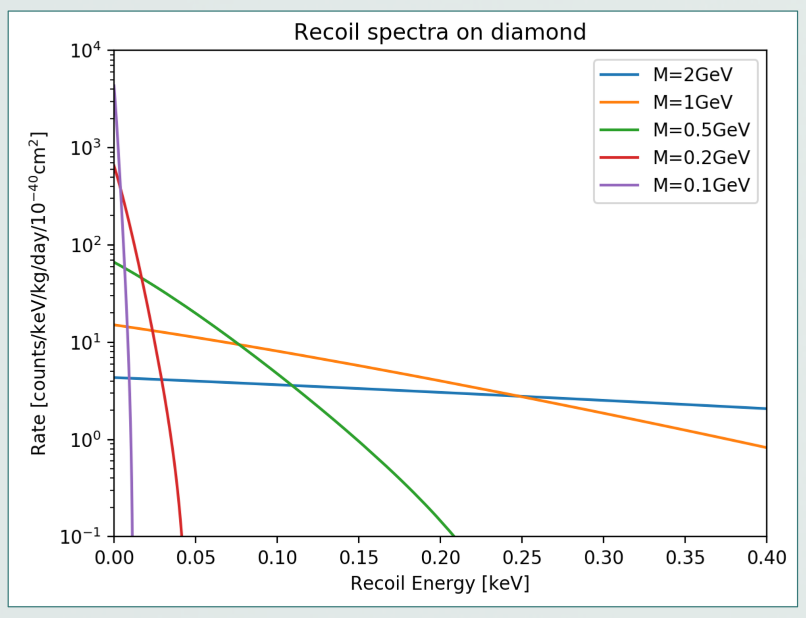
The tungsten TES showed a normal-to-superconducting transition between 9 mK and 14 mK.

Even with an non optimized TES design, this demonstrates the first successful fabrication and operation of a W TES on a diamond substrate.

Diamond target

Diamond is a promising candidate target for light DM detection. Its Debye Temperature (2220 K) ensures low heat capacity and makes it an ideal cryogenic detector, thanks to high-energetic and long-lived phonon modes.

The energy threshold is the key parameter to reach unexplored region of the parameter space.



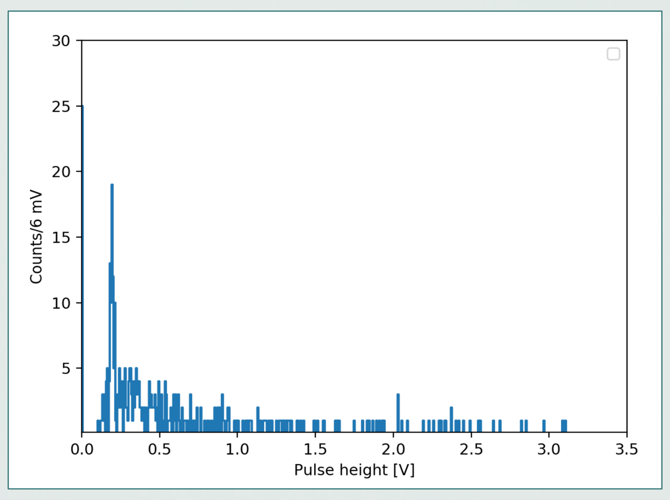
Low threshold required!

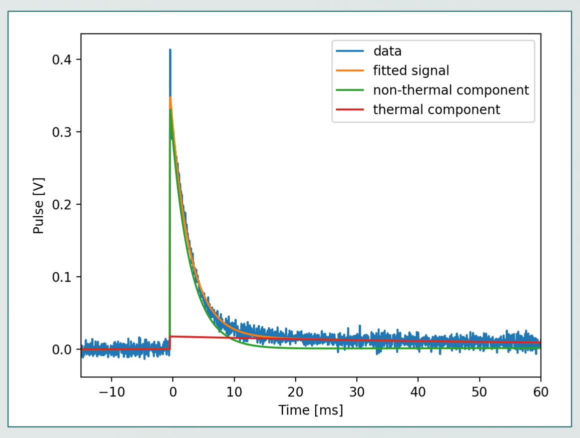
Cost and purity are the main constrains for a large use of diamonds in the scientific community.

Preliminary results

The preliminary energy spectrum acquired with the diamond detector is shown in the Figure. It corresponds to a 2 hours measurement.

Assuming that the peak at 0.2V is the line at 5.9 keV from ^{55}Fe, we can estimate an energy resolution at 0 keV of **70 eV**.





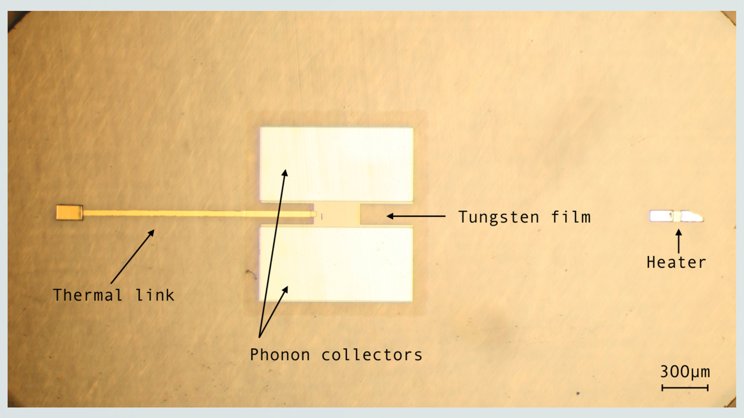
This preliminary result will be confirmed by a further cryogenic measurement that will be performed in the very near future.

Diamond detector: proof of principle

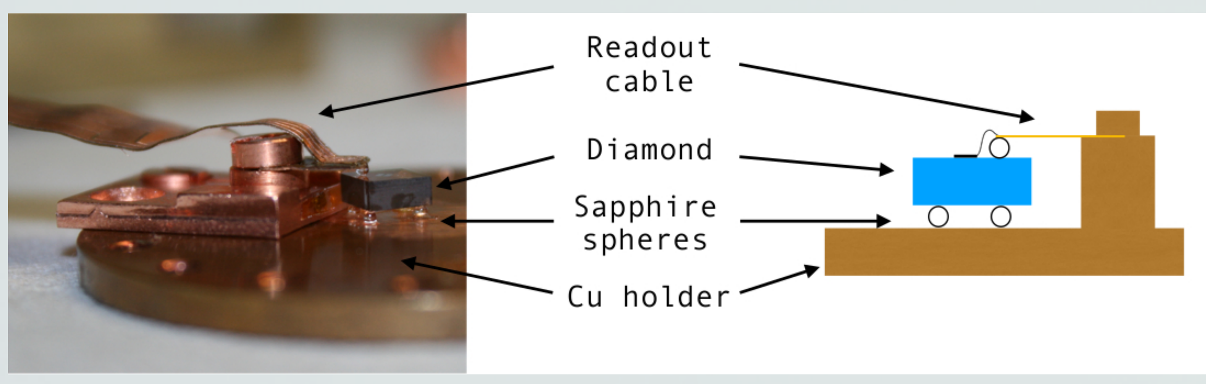
We operated a diamond detector (size 50×50×2 mm^3) from AuDiaTec GmbH.
It is a single crystal CVD diamond, grown on a substrate of Ir/YSZ/Si.
Upper limits on the purity: 1 ppm for Nitrogen and 10^{16}cm^{-3} for Boron.

W Transition Edge Sensor

- Thin film - 200 nm thick- of Tungsten - 0.42 mm^2 area - directly evaporated onto the diamond surface.
- Weak thermal link to the heat bath (Au stripe)



- Large-area Al phonon collectors to increase collection area
- Ohmic heater (Au) for calibration and stabilization
- TES design for CRESST-III target, not optimized for diamond.

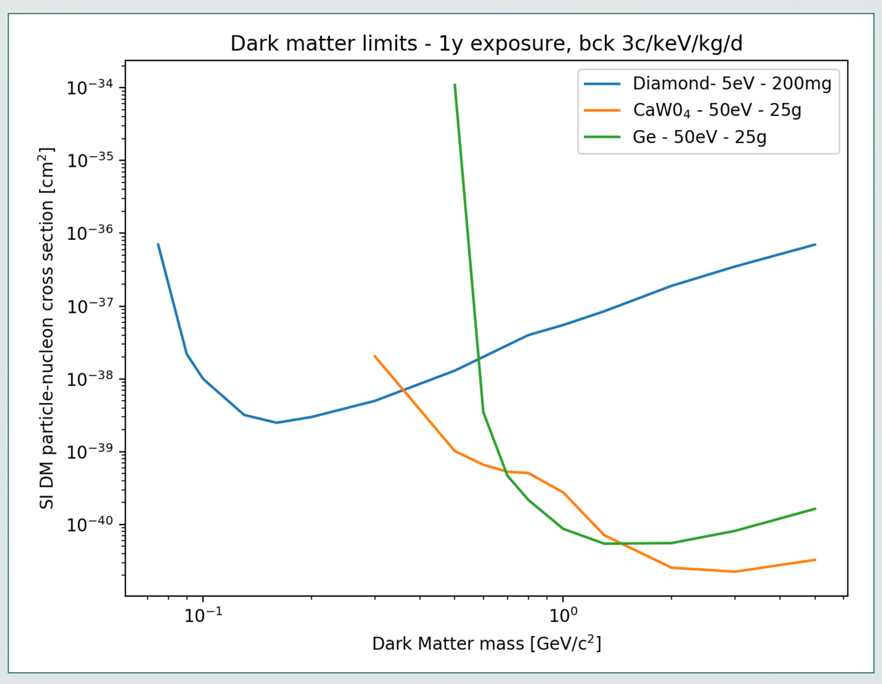


Outlook and perspectives

The standard assumption for the DM properties used to obtain spin-independent limits are:

- local dark matter density of ρ = 0.3(GeV/c^2)/cm^3
- asymptotic velocity of v = 220km/s
- escape velocity of v_{esc} = 544 km/s

A conservative background of of 3 c/keV/kg/d is considered.
For comparison, we considered targets of $CaWO_4$ and Ge with energy threshold of 50 eV.



For diamond, we assumed a low-energy threshold of 5 eV. This seems achievable, based on the state of the art TES technology.

Even with a limited amount of target material, a diamond target would allow to study regions of the parameter space that are currently unexplored.