Direct dark matter search with the CRESST-III experiment

Michele Mancuso
on behalf of the CRESST Collaboration

7 July 2018
The CRESST collaboration

Cryogenic Rare Event Search with Superconducting Thermometers

6 institutions
45 members: 16 senior scientists
2 guest scientists
11 Post Docs
16 PhDs
CRESST located at LNGS (Laboratori Nazionali del Gran Sasso) in Italy

- Cryogenic scintillating calorimeter
- Target material CaWO$_4$
- Read out channels: phonon scintillation light

CRESST-III Phase 1

- 10 detector modules

Overview

Introduction

CRESST-III detector

CRESST-III first results

Conclusions
The signature of dark matter in a direct detection experiment consists of a recoil spectrum of single scattering events.

\[
\frac{dR}{dE}(E, t) = \frac{\sigma_0}{m_\chi} \cdot F^2 \cdot \frac{\rho_0}{2\mu_A^2} \int_{v_{min}}^{v_{esc}} \frac{f(v, t)}{v} d^3v
\]

- \(\rho_0\): local DM density
- \(\sigma_0\): cross section at 0 momentum transfer
- \(m_\chi\): DM particle mass
- \(\mu_A\): reduced mass
- \(F\): nuclear form factor
- \(\int_{v_{min}}^{v_{esc}} \frac{f(v, t)}{v} d^3v\) Integral of the velocity distribution
- \(v_{min}\): minimal velocity to produce a recoil of energy E

Dark matter particles scatter
- off nuclei
- elastically
- coherently: ~\(A^2\)
- (spin-independent)

➢ The comparison between experiments is done using standard astrophysical assumptions.

Target material
Towards low mass dark matter

For a given cross section:
- The rate increases exponentially towards lower energy
- End point of the spectrum decreases for lower DM particle mass

CRESST has the best nuclear recoil threshold in the field
CRESST-II result

Limit of the detector with the lowest threshold achieved in CRESST-II Phase2 (307 eV)

Target mass: 300g
Phonon threshold: Eth ≈ 307eV
Light detector res.: $\sigma \approx 10$ eV
Crystals: commercial
Background: ≈ 8.5 cts/(keV kg d)
Exposure: ≈ 52 kg d

New region of the parameter space explored down to $500 \text{ MeV}/c^2$ dark matter particle mass

CRESST-III detector module

New improved detectors have been developed to enhance the desired characteristics.

Target mass: ~25g
Phonon threshold: Eth $\lesssim 100$ eV
Light detector res.: $\sigma \approx 5$ eV
Crystals: only TUM

improvement by at least a factor of 3
improvement by a factor of 2
improvement radio-purity

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Scintillating 24 g CaWO$_4$ crystals as target
• Cryogenic detector $T_0 \approx 10\text{mK}$
• W-TES sensor for T read-out
• 100 eV threshold

- The temperature readout is made with a tungsten transition edge sensor

- To an energy deposit in the target corresponds a proportional temperature rise

\[ \Delta T = \frac{\Delta E}{C} \cdot e^{-\frac{G}{C}t} \]
**Energy resolution**

Scintillating 24 g CaWO$_4$ crystals as target
- Cryogenic detector $T_0 \approx 10$ mK
- W-TES sensor for T read-out
- 100 eV threshold

**Particle discrimination**

Light detector SOS
- Cryogenic detector $T_0 \approx 10$ mK
- W-TES sensor for T read-out

Light yield characteristic of the type of particle → **Particle discrimination**

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Light yield characteristic of the type of particle → **Particle discrimination**

**Background rejection**

**Veto surface related background**

**Housing**

- Reflecting & scintillating foil
- Fully scintillating

**Instrumented holding system**

- CaWO$_4$ stick instrumented with W-TES

\[ \Delta T = \frac{\Delta E}{C} \cdot e^{-\frac{G}{C}} \]

\[ \begin{align*}
\Delta T &= \frac{\Delta E}{C} \cdot e^{-\frac{G}{C}} \\
\text{Light Yield} &= \text{Energy (keV)}
\end{align*} \]
CRESST-III Phase one Run commissioning

- May 2016  ➢ 10 detector modules mounted
- June 2016  ➢ Cool down to mK temperature
- Sept 2016 ➢ Start physics run
- Oct 2016  ➢ Energy calibration
- April 2017 ➢ Neutron calibration
- Feb 2018  ➢ End of run

Today ➢ Total raw exposure collected as of 02.2018: ~30 kg · day
➢ Unblinded 1 detector module above 100eV: 2.39 kg · day

New data release and results will come soon
Threshold optimization

• In-depth study of energy calibration at low energy.
• Optimum Filter: Maximization of the signal-to-noise ratio

Rigorous threshold analysis:
threshold determined by accepted noise trigger rate

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Physics data Detector A

- **Data taking period:** 31/10/16 to 05/07/17
- **Detector mass:** 24 g
- **Total exposure:** 2.39 kg days
- **Net exposure (after cuts):** 2.21 kg days
- **Analysis Threshold:** 100 eV

**Survival Probability of Nuclear Recoil Events After Cuts**

- 79.4% survival probability at 100 eV

**Tot background level:**
3.5 counts / (keV kg day)

Background events from cosmogenic activation of tungsten

\[ ^{182}W + p \rightarrow ^{179}Ta + \alpha \]

\[ ^{179}Ta + e^- \rightarrow ^{179}Hf + \nu_e \]
Neutron Calibration Det A

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Physics data

Detector A - 2.39 kg \cdot day

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Limit with Det A 2.39 kg · day

Yellin 1D optimum interval method

Replicated and improved result from CRESST-II with only small fraction of the data set

Exponential background rising towards low energies limits the sensitivity at low DM masses
Limit with Det A 2.39 kg \cdot day

Rising background \sim 100\text{eV}

One single event @ 3.6\text{keV}

F. Petricca et al. [CRESST Collaboration], "First results on low-mass dark matter from the CRESST-III experiment"  arXiv:1711.07692
Limit with Det A 2.39 kg · day

Extend reach from 0.5 GeV/c² to 0.35 GeV/c²

One order of magnitude improvement at 0.5 GeV/c²

CRESST-II
52 kg days

CRESST-III
2.39 kg days

Projection
CRESST-III 50 kg days

- Upgraded detector modules with dedicated hardware changes to understand low energy spectrum
Outlook

CRESST has an outstanding potential to explore the low mass region of the parameter space for DM nucleus scattering with unprecedented sensitivity

CRESST-III Phase 1 RUN1 07/2016 – 02/2018

➤ Analysis ongoing:
  • 26.1eV optimum threshold for detector A
  • 3 other detector with sub-100eV thresholds
➤ Background investigation (in analysis) at low energies before the total unblinding

Data with full exposure and threshold about to be published

CRESST-III Phase 1 RUN2 07/2018

➤ Upgraded detector modules with dedicated hardware changes to understand low energy spectrum