Dark matter identification with CRESST-III

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Overview

1. Principle of the CRESST experiment

2. Looking for low-mass dark matter with CRESST
Dark matter evidence
Complementarity in searches for dark matter

Direct detection

Production at colliders

Indirect detection

DM

SM

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Principle of the CRESST experiment
Looking for low-mass dark matter with CRESST
Complementarity in searches for dark matter
Direct detection

Expected signatures of the elastic scattering of dark matter particles off target nuclei:

- Single scatter nuclear recoils at low energy (a few tens of keV max)
- Low interaction rate
- \( \sim \) Exponential shape of the energy spectrum
- Dependence on the target material (\( \sim A^2 \))
- Earth’s velocity relative to the galactic rest frame is largest in summer (WIMP flux has annual modulation (\( \sim 3\% \) effect))
Background mitigation

- Underground facility in Laboratori Nazionali del Gran Sasso
- Radioactive shielding / Muon veto / Radon mitigation
- High purity materials
- Event discrimination
The CRESST setup

Principle of the CRESST experiment
Looking for low-mass dark matter with CRESST
Cryogenic calorimeters

- Phonon signal measures the recoil energy $\Delta E/C = \Delta T$

- Read out by a Tungsten Transition Edge Sensor (TES)
Particle identification

- **CaWO$_4$** Crystals operated at $\sim$10mK
- Simultaneous measurement of heat and scintillation signals for particle identification
Particle identification 2
Particle identification 2

Dominant radioactive background

Light yield = Light signal / Phonon signal

Acceptance region

Energy (keV)
Previous results: CRESST-II phase 2

- Low threshold: 307eV (with 300g crystal)
- In-house production of crystal with higher radiopurity
Aim of CRESST-III: lower the threshold for low-mass DM search.
CRESST-III, phase 1: Optimization of the detector design for low-mass search

- Goal: threshold of 100eV (Decrease detector mass: from ∼300g to ∼24g, optimized thermal link)
- High purity crystals grown at TUM
- Veto surface related background: scintillating housing
- Veto holder related background: instrumented holder
Data analysis

- Selection of events where the energy is measured properly. The selection criteria:
  - Rate: noise conditions
  - Stability: the detector is at the operating point
  - Non-standard pulse shapes (e.g. pileup)
  - Remove coincidental events: with muon-veto, holder related, or with other detector modules

- Optimum filter trigger implemented in the software

- Unbiased analysis: 20% of the data is randomly selected as a non-blind training set to determine cuts, these cuts are applied to the blind data set (80%)
Determination of the thresholds

- New DAQ with continuous sampling
- Threshold set according to the empty baseline distribution (after optimal filtering)
Experimental thresholds

Detector A:

- Lowest threshold: 26.1 eV
- Preliminary results with a net exposure of 2.21 kg.day (total: 2.39 kg.day)
- Analysis threshold: 100 eV
Neutron calibration, detector A

- 79.4 % of survival probability for nuclear recoil events after cuts (at 100 eV)
Unblinding of detector A (E\(>\)100eV)

Net exposure = 2.21 kg.day
Spectrum of the background

Background level : 3.5 counts/(keV.kg.day)
Accepted events

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Accepted events
Accepted events
Limit obtained with Yellin’s optimal interval method (using the spectrum of accepted events and the expected spectrum for DM)

(arXiv:1711:07692)
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(arXiv:1711.07692)
Outlook

- Preliminary results of CRESST-III:
  - 100 eV analysis threshold reached
    → Leading sensitivity for low-mass dark matter
  - Extension of DM search down to 350 MeV.c$^{-2}$

- Analysis ongoing with:
  - a much lower threshold
  - 3 times more statistics
  - 3 more detectors

- Run ongoing dedicated to the understanding of the rise of the event rate at low energies by implementing hardware modifications
Thank you for your attention
Backup slides
Optimal filter

- Implemented in the software
- Maximisation of the signal/noise in frequency space
- Typical improvement of the resolution: factor 2-3
Threshold and target mass

![Graph showing the number of counts above threshold as a function of dark matter particle mass for different elements and energies. The graph includes lines for Total (0.3keV), Calcium (0.3keV), Tungsten (0.3keV), Oxygen (0.3keV), Total (10keV), Calcium (10keV), Tungsten (10keV), and Oxygen (10keV).]
Determination of the quenching factors

Neutron beam form Maier-Leibnitz-Lab.

Quenching factors determined at low temperature for each elements of the $\text{CaWO}_4$:

$\text{O}$: $(11.2 \pm 0.5)\%$
$\text{Ca}$: $(5.94 \pm 0.49)\%$
$\text{W}$: $(1.72 \pm 0.21)\%$
Exclusion limit with a gram-scale detector prototype

- Al₂O₃ crystal of 0.5g
- Operated above ground, without shielding
- Measuring time 5.3h, no quality cut
- Threshold = 19.7 ± 0.9 eV