The CRESST Experiment

New Results and Future Prospects

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Current Status of Direct Dark Matter Searches

The graph illustrates the current status of direct dark matter searches, showing the exclusion limits on the dark matter particle-nucleon cross section as a function of the dark matter particle mass in GeV/c². Different experiments and collaborations, represented by various colored lines, have set upper limits on the cross section for different dark matter masses. The graph includes data from CRESST-II 2014, CRESST-II 2012 Comm., CDEX 2014, CDMSLite 2014, SuperCDMS 2014, CDMS-Si 2013, CoGeNT 2013, EDELWEISS 2012, DarkSide-50 2015, LUX 2013, XENON100 2012, and CRESST-II 2015. The shaded regions represent the expected sensitivity of future experiments. Coherent Neutrino Scattering on CaWO₄ is also indicated.
Current Status of Direct Dark Matter Searches

- Cryogenic experiments
- Liquid Xe experiments
- Coherent Neutrino Scattering on CaWO₄
The CRESST Experiment

Cryogenic Rare Event Search with Superconducting Thermometers

- Underground installation
- Ultra-low background environment
- Cryogenic detectors (10-15mK)

LNGS, Italy, shielding: 3500 m.w.e.

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The CRESST Detector Module
The CRESST Detector Module

CaWO$_4$ Target Crystal

- scintillating
- multi-element target
- mass: 200 – 300 g

$^{16}\text{O} \, ^{40}\text{Ca} \, ^{184}\text{W}$

In-house production and processing at our institutes

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The CRESST Detector Module

Light Absorber for scintillation-light detection

- silicon-on-sapphire disc
- diameter: 40mm
- thickness: 500μm

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The CRESST Detector Module

**Transition-Edge-Sensors**

→ 2 independent calorimeters

- **Phonon detector** (CaWO$_4$)
  - Threshold: $E_{\text{th}} \geq 300$ eV
  - Resolution: $\sigma \approx 60$-200 eV

- **Light detector** (SOS)
  - Threshold $E_{\text{th}} \approx 5$ eV

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Phonon-Light Technique

Reduced light output for highly-ionizing particles → Quenching
Phonon-Light Technique

Reduced light output for highly-ionizing particles → Quenching

Quenching factors:
- O
- Ca
- W
The CRESST Detector Module

Polymeric Foil

① Highly reflective
  ➢ light collection

② Scintillating
  ➢ rejection of surface events
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The CRESST Detector Module

Dangerous Surface Backgrounds

\[ ^{210}\text{Po} \rightarrow ^{206}\text{Pb} \, (103\text{keV}) + \alpha \, (5.3\text{MeV}) \]

\( E_{\text{dep}} = 0-5.3\text{MeV} \)
\( E_{\text{dep}} \leq 103\text{keV} \)

\( \rightarrow \) Lead/alpha recoils can mimic WIMPs
\( \rightarrow \) Avoid non-scintillating materials!

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STATE-OF-THE-ART

CRESST II
Recently Finished – CRESST-II Phase 2

Data-taking from July 2013 to August 2015

2014 Results: “TUM-40”
- Efficient surface-event rejection
- Best intrinsic background level
- Best overall performance

2015 Results: “Lise”
- No surface rejection
- Lowest threshold
- Factor ~2 more higher background

Final Data: Total exposure
- About 500 kg-days acquired
- Data release end of 2015
“TUM-40”: New Detector Design

- Polymeric foil + CaWO₄ sticks
  - Fully-scintillating detector housing
  - Efficient rejection of surface backgrounds

“TUM-40”: Unprecedented Radiopurity

- CaWO₄-crystal production at TU Munich
- Unprecedented radiopurity (by factor 2-10)
- Room for further improvements

Average rate: ~3.5 counts / [kg keV day]

Gamma-lines from cosmogenic activation

Excellent resolution: \( \sigma \approx 100\text{eV} \)

“TUM-40”: Unprecedented Radiopurity

- CaWO$_4$-crystal production at TU Munich
- Unprecedented radiopurity (by factor 2-10)
- Room for further improvements

All gamma lines agree within < 5eV with tabulated values !!
(not calibrated with these lines)

Average rate:
\~3.5 counts / [kg keV day]

Gamma-lines from cosmogenic activation

Excellent resolution:
$\sigma \approx 100$eV

Status 2014: “TUM-40” Results


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“Lise”: Trigger Threshold

Direct measurement of nuclear-recoil energy with calorimetric detector!
“Lise”: Results 2015

CRESST-II (2014)
52kg-days
Blind analysis
Yellin, optimal interval

CRESST-II (2015)

CDMSlite (2015)

See: CRESST collab. G. Angloher et al. arXiv1509.01515

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Recently Finished – CRESST-II Phase 2

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Final Data: Total exposure
- About 500 kg-days acquired
- Data release end of 2015
Final Data Release: Projections

CRESST-II (2014)
CRESST-II 500kg-days (now)
Results autumn 2015


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Future of Dark Matter Searches

Performance of detectors

Coherent Neutrino Scattering on CaWO₄
NEAR FUTURE

CRESST III
CRESST-III: Low-Mass WIMP Search

Straight-forward approach for near future: CRESST-III Phase 1

Status quo

m = 250g
V = 32x32x40 mm³

Phonon threshold: $E_{th} \lesssim 500$ eV

Light-detector res.: $\sigma \approx 5$ eV

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CRESST-III: Low-Mass WIMP Search

Straight-forward approach for near future: CRESST-III Phase 1

Status quo

\[ m = 250g \]
\[ V = 32 \times 32 \times 40 \text{ mm}^3 \]

 Phonon threshold: \[ E_{\text{th}} \lesssim 500 \text{eV} \] improvement by a factor of 5-10

 Light-detector res.: \[ \sigma \approx 5 \text{ eV} \] improvement by a factor of 2

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Assumptions:

- 24g CaWO$_4$ crystal
- $E_{th} = 100$ eV
- Light detector improved by factor 2 (due to smaller volume)
- 2x more detected light: due to thin crystal
- CRESST-II radiopurity

CRESST-III Detector Prototype

CaWO$_4$ sticks (with holding clamps)

reflective and scintillating housing

light detector (with TES)

block-shaped target crystal (with TES)
CRESST-III Detector Prototype

First modules ready

CaWO$_4$ sticks (with holding clamps)

reflective and scintillating housing

light detector (with TES)

block-shaped target crystal (with TES)
First Results of CRESST-III Detector

Promising results:

- Improvement by factor 6.2 compared to best CRESST-II detector ($E_{\text{th}} = 298\,\text{eV}$)

  → Baseline noise @GS 1.8-3.0mV RMS
  → Threshold: $E_{\text{th}} = 45-60\,\text{eV}$

Design goal ($E_{\text{th}}=100\,\text{eV}$) for CRESST-III Phase 1 exceeded!
Instrumented Holder - iSticks

- Particle events in sticks
- Surface backgrounds
- Stress relaxations
- ...

CaWO$_4$ stick

CaWO$_4$ crystal

Induces degraded signal

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Instrumented Holder - iSticks

- Particle events in sticks
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Instrumented Holder - iSticks

- Particle events in sticks
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Instrumented Holder - iSticks

- Instrumented Holder
- iSticks
- TES
- Full signal
- Induces degradation
- Surface backgrounds
- Stress relaxations
- Particle events in s8cks

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Instrumented Holder - iSticks

Gamma event of ≈40keV in stick

Stick signal

(light signal)

Absorber signal

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Timeline for CRESST-III

Phase 1:

• Prototype detectors ready
• Production of ~ 15 modules ongoing
• All parts ready by Nov 2015
• Assembly & mounting end of 2015
• Start Jan 2016
CRESST-III Phase 2

Reduce intrinsic background level of crystals!
- Growth of CaWO$_4$ crystals in-house (TUM)
- All production steps under control
- Improvement by factor 10 already achieved
- Cleaning procedure e.g. by re-crystallization, purification of raw materials

REALISTIC GOAL (in 2 years):
Reduction of background level to $10^{-2}$ counts /[kg keV day]
(2 orders of magnitude compared to present CaWO$_4$ crystals)
100 x 24g detectors of improved quality operated for 2 year ≈ 1000 kg-days (net)
Summary

• CRESST technology proved high potential for low-mass WIMP search
  ✓ Lowest thresholds in the field: 300eV
  ✓ Nuclear-recoil energy scale precisely known
  ✓ Background discrimination down to low energies
  ✓ Efficient rejection of surface backgrounds
  ✓ Multi-element target

• CRESST-II probed new region of parameter space for WIMP masses below 3GeV/c²

• CRESST-III has unique potential to explore low-mass WIMP region
  ✓ Threshold of <=100eV reached with prototype detector
  ✓ iStick technology to reject holder-related events

Start: Jan 2016
BACKUP SLIDES
TES of Phonon Detector

Old TES design for 300g crystals:

- **bolometric** operation
- large collection area
- strong thermal coupling to bath
- not optimized for low threshold!

Threshold $E_{th} \lesssim 500$eV reached!

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TES of Phonon Detector

New TES design for 24g crystals:

- **calorimetric** operation
- Similar to CRESST light detector
- **W** film: 8 times smaller
- weak thermal coupling to bath
- large-area Al phonon collectors

Theoretical improvement: factor $5-10$ in signal/noise
Thresholds of Cryogenic Experiments

- iZip 600g
- iZip (high-voltage biased) 600g
- "TUM-40" 300g
- "Lise" 300g
- CRESST-II Phase 2, 200-300g
- CRESST-III Projection preliminary 24g
- CRESST-III design goal

EDELWEISS SuperCDMS CRESST-II CRESST-III
Efficient Veto of Surface Backgrounds

![Diagram showing recoil energy vs. light yield for various materials and processes, including \(206\text{Pb} + \alpha\), \(206\text{Pb} + \text{veto}\), and additional light.]
TUM-40: Surface Backgrounds

exposure: 29 kg-days

$^{206}\text{Pb recoils:}$
Phase 1: 8.1 events  Phase 2: 0 events

Degraded alphas:
Phase 1: 6.9 events  Phase 2: 0 events

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Lise: Low Energy Spectrum
Lise: Detector Efficiency
Lise: Observed Events