CRESST - Results from 730kg d

UCLA Dark Matter Symposium 2012

Marina del Rey

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J.-C. Lanfranchi, TU München, „Universe“ Cluster
The CRESST Experiment at Gran Sasso

Cryogenic Rare Event Search with Superconducting Thermometers

INFN / Laboratori Nazionali del Gran Sasso

Collaborating institutes:

CRESST in Hall A
3500 m.w.e.
The CRESST Setup

Jens Schmaler

Latest Results of the CRESST Dark Matter Search

Target material:
scintillating CaWO\(_4\) crystals

Detector carousel:
up to 10kg of target mass
CaWO$_4$ Multi-Material WIMP Target

- **low WIMP masses** $\leq 20\text{GeV}$: only O, Ca recoils above detection threshold
- **high WIMP masses** $\geq 30\text{GeV}$: dominated by W recoils
- **neutron background** mainly O recoils above detection threshold

\[
\Gamma = \frac{M_{\text{Target}}}{m_N} \frac{\varrho_\chi}{m_\chi} \langle v \rangle \sigma_\chi A^2
\]
CRESST II Detector Modules

Working principle & read out of Transition Edge Sensors (TES)

- **Silicon or SOS absorber**
- **CaWO₄ absorber 300g**
- **W-TES: Light detector**
- **W-TES: Phonon detector**

Scintillating and reflective cavity

Temperature dependence of resistance

\[ \Delta R \]

\[ \Delta T \]
CRESST II Detector Modules

Silicon on sapphire light detector

Reflective bronze clamps

TESs

Reflective and scintillating foil

~300g CaWO$_4$ target crystal
Identification of Event Type

• Characteristic light yield (LY) for each type of event:
  
  e-recoil: 1 (by def.)
  \( \alpha \): \( \sim 0.22 \)
  O-recoil: \( \sim 0.10 \)
  Ca-recoil: \( \sim 0.06 \)
  W-recoil: \( \sim 0.04 \)  
  
  ("Quenching factors")

• Excellent discrimination between dominant radioactive background (electron recoils induced by \( \gamma \) and \( \beta \)) and nuclear recoils
• To some extent identification of recoiling nucleus possible (depends on achievable separation of Ca, W and O nuclear recoil bands)
• Possibility to probe different WIMP mass scenarios in same target (unique feature of CRESST)
Acceptance region:
includes O, Ca and W recoil bands

$E_{\text{max}}$: 40keV (WIMP signal negligible above)
$E_{\text{min}}$: $e/\gamma$-leakage of 1 event per module in whole data set (10 – 19keV, module dependent)

$p$-events: from surfaces

O-band: neutrons or „light“-WIMPs

W-band: expect „heavy“-WIMP interaction -> band is contaminated by recoiling $^{206}$Pb nuclei from $^{210}$Po $\alpha$-decays (clamps), 103keV downwards

67 events at low energy observed in O, Ca and W-bands in all detector modules (~730kg d)
CRESST II – Run 32

- First long physics run of CRESST-II (July 2009 – March 2011)
- Net exposure: ~730kg-days
- Dedicated neutron ($^{241}$Am-Be) and $\gamma$-calibration ($^{57}$Co and $^{232}$Th) campaigns
- 8 out of 18 fully operational detector modules (300g each)
  - Observation of 67 events in acceptance region for WIMP interactions
  - Detailed likelihood analysis including all backgrounds + potential WIMP signal

“Results form 730kg days of the CRESST-II Dark Matter Search”
submitted to European Physical Journal C, arXiv: 1109.0702

Here: qualitative discussion of relevant backgrounds
e/$\gamma$-Background

Modelling of e/$\gamma$-background:
Parameterize distribution of events observed in physics run
  - very high statistics -> negligible fluctuations

Expected leakage into acceptance region:
1 event per module expected by definition of respective threshold
\(\alpha\)-Background

- Low-energy \(\alpha\)\'s from clamps
- events in \(\alpha\)-band have flat energy spectrum, i.e. constant spectral density \(dN_\alpha/dE\)
- define overlap-free reference region to estimate \(dN_\alpha/dE\)
- extrapolation to acceptance region
- simple estimate of total \(\alpha\)-background \((dN_\alpha/dE = \text{const.})\):
  \(~9.2\ \text{events}\)
- full likelihood analysis very similar
Possible $^{210}\text{Po}$ Signatures

Surface contamination:

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

- Pb recoil events can appear at low energy with similar low light yield as W-recoils
- Scintillating foil vetos events (additional scintillation light from $\alpha$-particle)
- **Problem:** clamps are reflective but non-scintillating
Pb-Recoils

- Module with strong population of Pb-recoil events from surface $\alpha$-decay
- Distribution of Pb recoils tails to low energies

- Use overlap-free reference region to model $dN_{\text{Pb}}/dE$

- Model observed spectrum in reference region:

$$\frac{dN_{\text{Pb}}}{dE} = A \left[ C + \exp\left( \frac{E - 90\text{keV}}{E_{\text{decay}}} \right) \right]$$

- Extrapolate to acc. region for simple estimate: $\sim 17$ events
- Full likelihood analysis gives similar result
Neutron Background

- **Like** (light)-WIMPs neutrons are dominantly visible as **0 scatters** in detector
- **Unlike** WIMPs neutrons have a certain probability for **multiple scatters**
  -> experimental approach no MC!

**source-like neutrons**

![Graph showing source-like neutrons](image)

- In total data set 3 multiple scatters
- Assuming all 3 multiple scatters due to source-like neutrons (limiting case)
  - ~11.4 single events expected

**muon-induced neutrons**

![Graph showing muon-induced neutrons](image)

- (2 with multiplicity m=3 and 1 with m=5)
- Assuming all 3 multiple scatters due to Muon-induced neutrons
  - ~1.5 single events expected

Excess of events cannot be explained by neutrons alone!
Results from Likelihood Analysis

**Backgrounds**
- Include:
  - all spectral information
  - reference regions
  - calibration measurements

**Potential WIMP Signal**
- WIMP mass
- cross section

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e/\gamma$-events</td>
<td>$8.00 \pm 0.05$</td>
<td>$8.00 \pm 0.05$</td>
</tr>
<tr>
<td>$\alpha$-events</td>
<td>$11.5^{+2.6}_{-2.3}$</td>
<td>$11.2^{+2.5}_{-2.3}$</td>
</tr>
<tr>
<td>neutron events</td>
<td>$7.5^{+6.3}_{-5.5}$</td>
<td>$9.7^{+6.1}_{-5.1}$</td>
</tr>
<tr>
<td>Pb recoils</td>
<td>$15.0^{+5.2}_{-5.1}$</td>
<td>$18.7^{+4.9}_{-4.7}$</td>
</tr>
<tr>
<td>signal events</td>
<td>$29.4^{+8.6}_{-7.7}$</td>
<td>$24.2^{+8.1}_{-7.2}$</td>
</tr>
<tr>
<td>$m_x$ [GeV]</td>
<td>25.3</td>
<td>11.6</td>
</tr>
<tr>
<td>$\sigma_{WN}$ [pb]</td>
<td>$1.6 \cdot 10^{-6}$</td>
<td>$3.7 \cdot 10^{-5}$</td>
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Simple estimate:
- 8
- 9.2
- 11.4
- 17

Statistical significance in this analysis: $4.7 \sigma$ $4.2 \sigma$
Spectral Distribution of Observed Events
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Energy spectrum
Spectral Distribution of Observed Events

Energy spectrum

Light yield distribution
Spectral Distribution of Observed Events

Energy spectrum

Light yield distribution
Spectral Distribution of Observed Events

Energy spectrum

Light yield distribution

WIMP-signal spectrum is exponential like:
gamma background
unlike:
$^{206}$Pb, neutron, alpha background

*Is the signal due to gamma leakage?*
**Spectral Distribution of Observed Events**

**Energy spectrum**

- WIMP-signal spectrum is exponential like:
  - gamma background
- unlikely:
  - $^{206}$Pb, neutron, alpha background

Is the signal due to gamma leakage?

**Light yield distribution**

- Unlikely!
- WIMP-signal and gamma leakage differ significantly in the light yield distribution!
WIMP Parameter Space

WIMP mass [GeV]

WIMP-nucleon cross section [pb]

CRESST 1σ
CRESST 2σ
CRESST 2009
EDELWEISS-II
CDMS-II
XENON100
dAMAd AMAd
CDMS-II
CoGeNT

M2
M1

Latest Results of the CRESST Dark Matter Search
Conclusions

• First long physics run of CRESST II: ~730kg-days of data collected
• The multi-target approach (in the same set-up) is a powerful tool for DM identification and unique for CRESST
• 67 observed recoil events in oxygen-band are difficult to explain with conventional backgrounds only
• Could there be light WIMPs of the 10-30GeV type?
• High sensitivity to low-mass WIMPs, future adaptability of target material conceivable, e.g. Al$_2$O$_3$:Ti$^{3+}$
• Goal of next CRESST run:
  - strongly reduced alpha background by new clamping design
  - additional internal neutron shielding (inside Pb/Cu shield) to pin down the nature of the observed signals with high confidence
  - increase of target mass, i.e. number of modules
• Start of next CRESST run scheduled for 2012