CRESST: First results with phonon light technique

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Outline:
• CRESST-II detector concept
• Quenching factor measurements
• First results with two CRESST-II prototype detector modules (CRESST-I setup without neutron shield)
• Status of Upgrade for CRESST-II
Detector Requirements for WIMP direct detection

Nuclear recoil signals:
- Small energy transfers to nucleus (
  < 40 keV for W)
- Featureless spectrum
- Very low event rate < 0.1/kg/day

→ Low threshold very low background detectors

Typical background rates deep underground:
- Radioactive $\beta+\gamma$ background: ~100/kg/day → need efficient $\beta+\gamma$ background discrimination
- Neutrons from rock (LNGS) ~ 1 /kg/day → can be moderated
- High energetic neutrons from muons in Pb/Cu shield: ~0.02 /kg/day → need muon veto for $\sigma_{WIMP-nucleon} < 10^{-8}$ pb
CRESST type Detectors

- Particle interaction in absorber creates a temperature rise in thermometer which is proportional to energy deposit in absorber.

Width of transition: ~1mK
Signals: few µK
Stability: ~ µK

Temperature pulse (~6keV)
CRESST-I: 262 g sapphire detectors

Test with x-ray source

Low background run

Excellent energy resolution:

133 eV @ 1.5 keV

Threshold: 500 eV

Very low background: (0.73±0.22) counts/(kg keV day) in 15 keV to 25 keV range

< 0.3 counts/(kg keV day) @ 100 keV
CRESST-II Detector Concept

Discrimination of nuclear recoils from radioactive $\beta+$γ backgrounds by simultaneous measurement of phonons and scintillation light

- Works with CaMoO$_4$, BGO, Al$_2$O$_3$, ...

- Separate small calorimeter as light detector

- 300 g scintillating CaWO$_4$ crystal

- Light reflector (scintillating polymeric foil)

- W-thermometer
Proof of principle experiment

Irradiation with $e^{-}$ and $\gamma$  

Irradiation with $e^{-}$, $\gamma$ and $n$

- Efficient discrimination of $e^{-}$ and $\gamma$ background: 99.7% 15 to 25 keV

- No degradation of light yield for $e^{-}$ surface events
300 g CRESST-II Prototype Detector Module

CRESST-II: 33 detector modules → 66 readout channels
Recoil energy spectrum in CaWO$_4$ expected from neutrons at Gran Sasso (no neutron shield)

Monte Carlo simulation dry concrete (H. Wulandari et al)

Contribution of W recoils negligible above 12 keV

$\sigma \propto A^2$ for WIMPs with spin independent interaction

- WIMPs dominantly scatter on W ($A=184$) nuclei
- Neutrons mainly on Oxygen
Quenching Factor measurement with neutron scattering

Thomas Jagemann, TUM

mono energetic n

CaWO₄

neutron detector

Measured value for oxygen: Q = 12.8±0.5
Only lower limit for W: Q > 33
Quenching factor measurement with TOF

- UV Laser desorbs singly or doubly charged ions from almost any material. Acceleration to 18 keV (or 32 keV for double charged).
- Mount CaWO₄ crystal on PMT at end of flight tube and record single photon counts with fast digitizer.
- Adjust laser intensity such that more than 1 ion arriving per laser shot is negligible.
Single photon counting after arrival of ion
Quenching factor measurement with TOF

Photon counts per laser shot

Light curve of CaWO$_4$

Comparision with photon counts per 6 keV x-ray yields quenching factor

Averaging digitizer traces for many laser shots yields light curve
Quenching Factors for various nuclei in CaWO$_4$

High value of Q=40 for tungsten $\Rightarrow$ very little light for recoils <40 keV

Discriminate W recoils (WIMPS) from O recoils of neutrons
Run 28 (1.5 month) with two 300 g prototype modules

Pulse height of heater pulses

Energy resolution of phonon channel

Very stable response over a period of 40 days

Very good energy resolution:
\[ \gamma : 1.0 \text{ keV} @ 46.5 \text{ keV} \]
\[ \alpha : 6.7 \text{ keV} @ 2.3 \text{ MeV} \]
Run 28: Low Energy Event Distribution

no neutron shield

10.72 kg days

90% of oxygen recoils below this line.

Rate=0.87±0.22 /kg/day compatible with expected neutron background (MC).

90% of tungsten recoils Q=40 below this line.
Upper limit for spin independent WIMP nucleon cross section

6.17 kg days W exposure
Stability of exclusion limit

Variation of threshold

Including the 2 events at 10.5 and 11.2 keV has practically no effect on result.

Variation of quenching factor

Variation of Q well beyond uncertainties has only small effect:

\[ \sigma = 1.6 \times 10^{-6} \rightarrow 2.3 \times 10^{-6} \text{ pb} \]
Detector Performance at high Energies

- Excellent linearity and energy resolution at high energies
- Perfect discrimination of $\beta + \gamma$ from $\alpha$'s
- Identification of alpha emitters
$^{232}$Th calibration: Linearity of detector response at high energies
Identification of $\alpha$-Emitters

- Same light for extern and intern 210Po ➞ no surface degradation
- Relatively low alpha rates: total ~ 2mBq/kg.
  $^{238}$U ~2 $10^{-12}$g/g
$^{144}\text{Nd}$

$^{152}\text{Gd}$

$^{147}\text{Sm}$

\[ \alpha \] Decay of stable $^{180}\text{W}$
Half-life for the $\alpha$-decay of $^{180}\text{W}$

<table>
<thead>
<tr>
<th>exposure</th>
<th>$28.62 \text{ kg days}$</th>
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<tbody>
<tr>
<td>Half life</td>
<td>$T_{1/2} = (1.8\pm0.2) \times 10^{18} \text{ years}$</td>
</tr>
<tr>
<td>Energy</td>
<td>$Q = (2516.4\pm1.1 \text{ (stat.)}\pm1.2 \text{ (sys.)}) \text{ keV}$</td>
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Status of Upgrade

• Read out electronics:
  66 SQUIDs for 33 detector modules and DAQ ready

• Neutron shield:
  50 cm polyethylene (installation complete)

• Muon veto:
  20 plastic scintillator panels outside Cu/Pb shield and radon box. Analog fiber transmission through Faraday cage (ready)

• Detector integration in cold box and wiring (entering fabrication stage)
Detector integration in existing cold box

- Mounting of 33 detector modules at end of cold finger
- Detectors individually exchangeable
- Spring suspension for vibration decoupling from cryostat.
**Conclusion**

- Two CRESST II prototype detectors have been operated for two months.
- Discrimination threshold \((\gamma\beta)\) well below 10 keV
- Type of recoiling nucleus identified above 12 keV
- Upgrade to 66 readout channels (10 kg target), installation of neutron shield and muon veto almost complete. Restart in summer/autumn 2005
- CRESST-II is aiming for a sensitivity of \(\sigma<10^{-8}\) pb
Readout and Heater Circuits