Improvement of the CRESST Phonon/Light Detectors

Michael Kiefer

Max-Planck-Institut für Physik, München

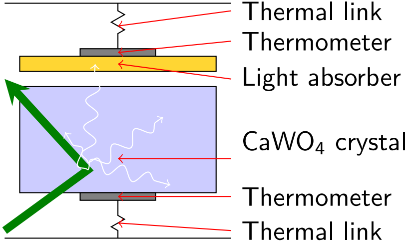
Freiburg, 03/03/2007

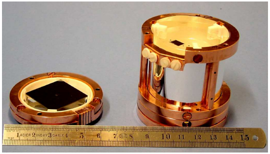
Direct Dark Matter Search

CRESST

- Search for WIMPs
- Cryogenic experiment
- 2 Readout channels:

Phonons: Energy measurement
Light: Particle Identification



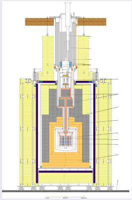


Background suppression

Signal

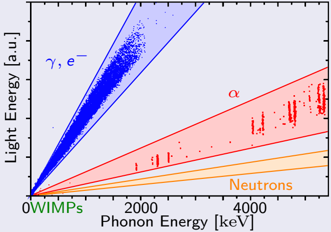
- (Background) $\gg$ (expected WIMP-Signal)

Shielding against cosmics



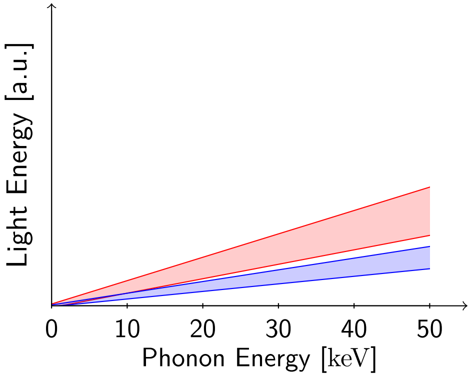
- Underground lab + μ-Veto
- Shields + Radon box

Discrimination of remaining events

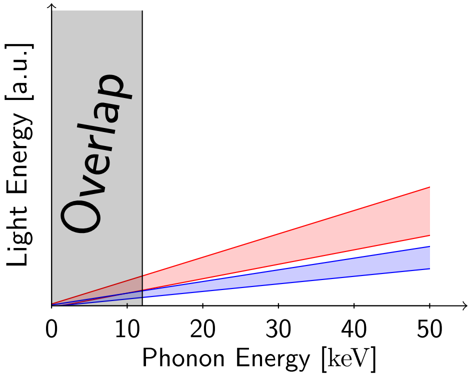


- Phonons give energy
- Light used for identification

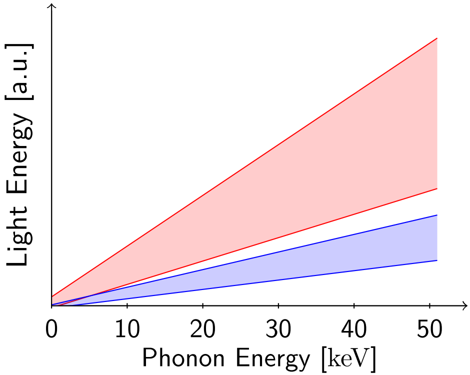
Band separation



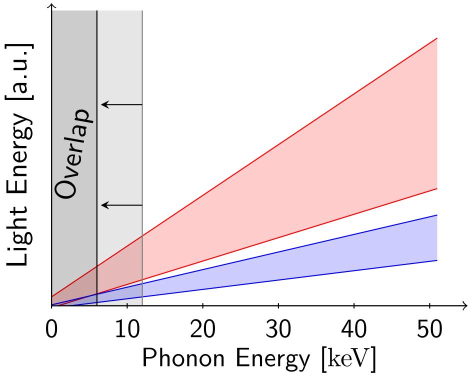
Band separation



Band separation



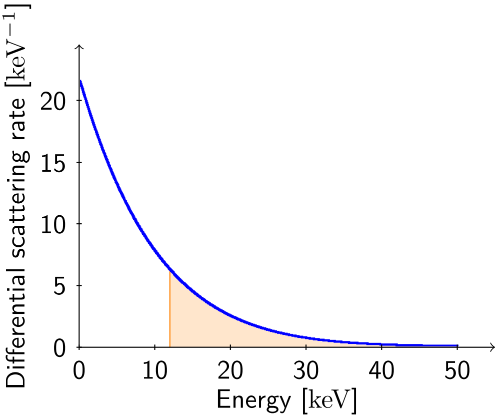
Band separation



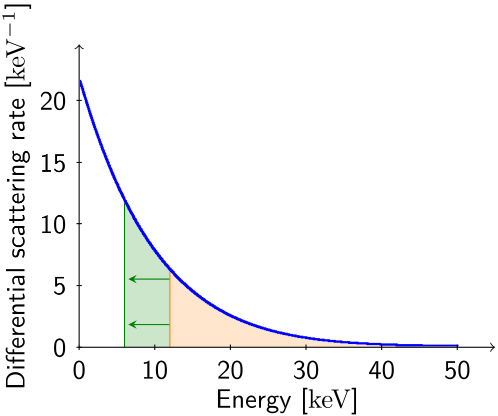
Consequence:

Additional light significantly lowers discrimination threshold

100 GeV WIMPs with $\sigma = 10^{-18}\,\mathrm{b}$ on $1\,\mathrm{kg}$ $CaWO_4$ for 1 yr



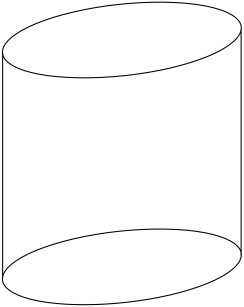
100 GeV WIMPs with $\sigma = 10^{-18}\,\mathrm{b}$ on $1\,\mathrm{kg}$ $CaWO_4$ for 1 yr



Consequence:

Lower discrimination threshold raises expected WIMP count rate

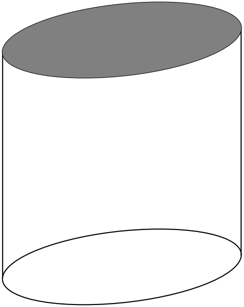
Problem During Detector Production



Steps

- Scintillating crystal

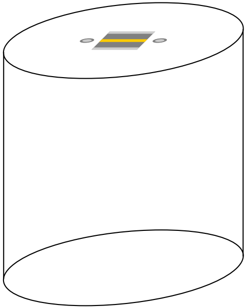
Problem During Detector Production



Steps

- Scintillating crystal
- Evaporation

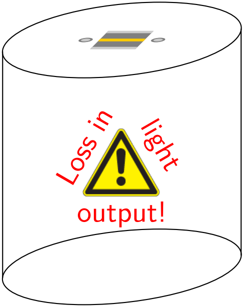
Problem During Detector Production



Steps

- Scintillating crystal
- Evaporation
- Structuring

Problem During Detector Production



Steps

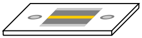
- Scintillating crystal
- Evaporation
- Structuring

Problem

- High temperatures needed for evaporation
- Change in chemical composition
- Degradation of light output by factor of 2

Idea for the Solution

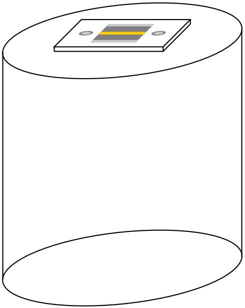
Glue a small thermometer carrier



Idea for the Solution

Glue a small thermometer carrier onto a big absorber

- Improves the light output
- Mass production of detectors



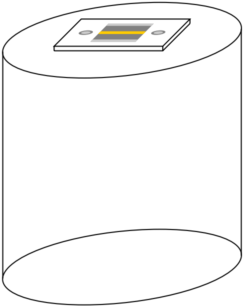
Idea for the Solution

Glue a small thermometer carrier onto a big absorber

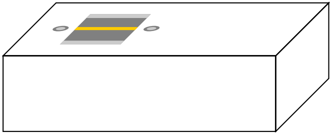
- Improves the light output
- Mass production of detectors

My work: Investigate in gluing technique

- Is it technically possible?
- Is the light gain worth a phonon performance loss?



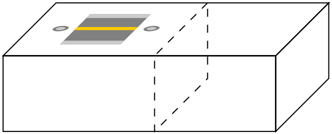
Proof-of-Principle Experiment Set-Up



Steps

- Produce phonon detector

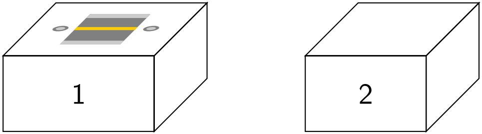
Proof-of-Principle Experiment Set-Up



Steps

- Produce phonon detector
- Cut crystal

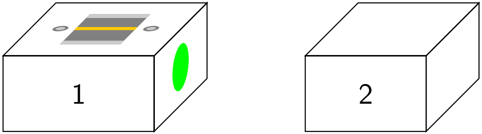
Proof-of-Principle Experiment Set-Up



Steps

- Produce phonon detector
- Cut crystal

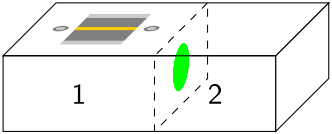
Proof-of-Principle Experiment Set-Up

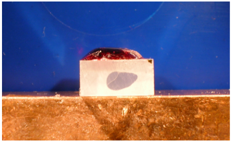


Steps

- Produce phonon detector
- Cut crystal
- Glue crystal

Proof-of-Principle Experiment Set-Up

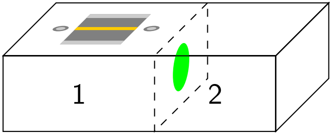


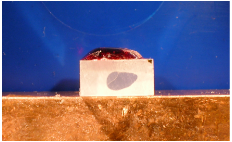


Steps

- Produce phonon detector
- Cut crystal
- Glue crystal

Proof-of-Principle Experiment Set-Up

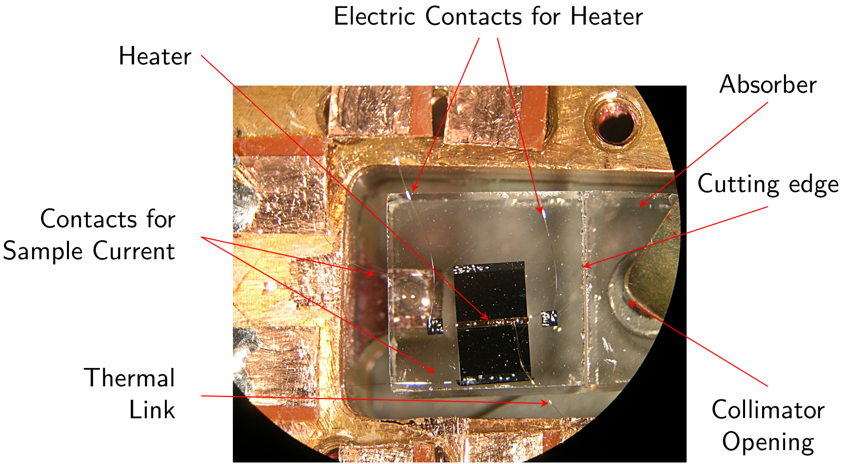




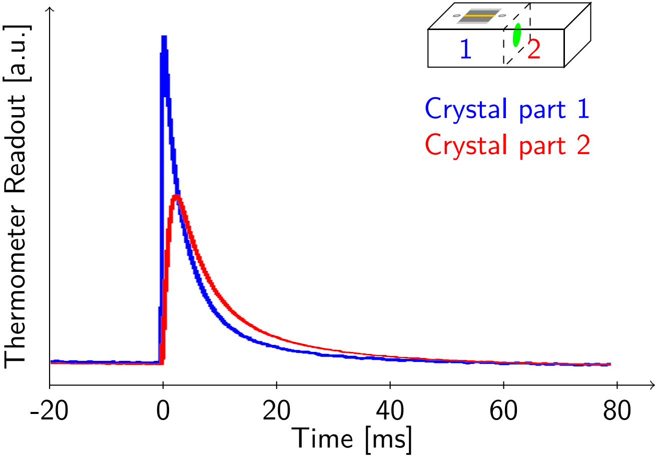
Steps

- Produce phonon detector
- Cut crystal
- Glue crystal
- Measure pulses of known energy

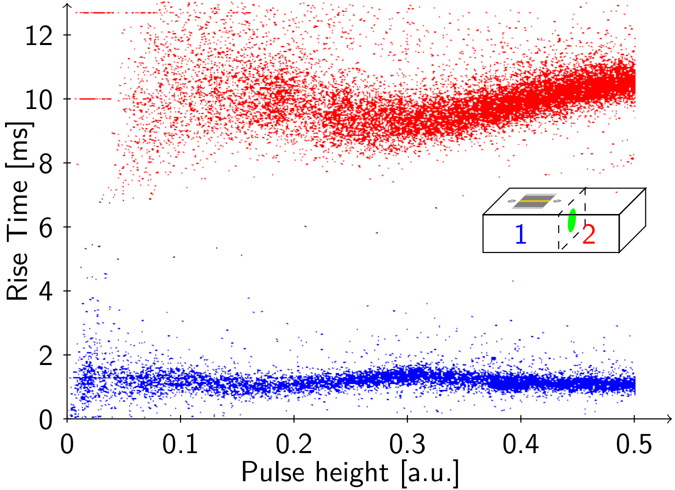
Sample in Holder



60 keV-Pulses

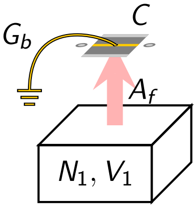


Analysis of Pulses



Theory of Pulse Formation

Mathematical model

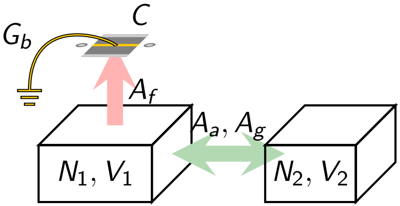


Differential equations for phonon transport

Temp. /Phon. balance		to Thermometer		heat bath	glue transm.	glue abs.
$\frac{\mathrm{d}}{\mathrm{d}t}\Delta T(t) C$	$=$	$\mathcal{E} A_f \frac{N_1(t)}{V_1}$	$-$	$G_b \Delta T(t)$		
$\frac{\mathrm{d}}{\mathrm{d}t} N_1(t)$	$=$	$-A_f \frac{N_1(t)}{V_1}$				

Theory of Pulse Formation

Mathematical model (extended)



Differential equations for phonon transport

Temp. /Phon. balance		to Thermometer		heat bath		glue transm.		glue abs.
$\frac{\mathrm{d}}{\mathrm{d}t}\Delta T(t)C$	$=$	$\mathcal{E}A_f\frac{N_1(t)}{V_1}$	$-$	$G_b\Delta T(t)$				
$\frac{\mathrm{d}}{\mathrm{d}t}N_1(t)$	$=$	$-A_f\frac{N_1(t)}{V_1}$			$-$	$A_g\left(\frac{N_1(t)}{V_1}-\frac{N_2(t)}{V_2}\right)$	$-$	$A_a\frac{N_1(t)}{V_1}$
$\frac{\mathrm{d}}{\mathrm{d}t}N_2(t)$	$=$				$+$	$A_g\left(\frac{N_1(t)}{V_1}-\frac{N_2(t)}{V_2}\right)$	$-$	$A_a\frac{N_2(t)}{V_2}$

Theory of Pulse Formation

Mathematical model (extended) → Solution

$$\Delta T(t) = \alpha_2 \left[\mathrm{e}^{-\frac{G_b}{C} t} - \left(\frac{\gamma_2}{\phi} \sinh(\phi t) + \cosh(\phi t) \right) \mathrm{e}^{-\beta t} \right]$$

where

$$\phi = \frac{\sqrt{([A_f + A_a + A_g] V_2 - [A_a + A_g] V_1)^2 + 4 A_g^2 V_1 V_2}}{2 V_1 V_2}$$

$$\alpha_2 = \frac{A_f E A_g C}{\left(G_b^2 V_1 - [A_f + A_a + A_g] G_b C \right) V_2 + (A_a + A_g)([A_f + A_a] - G_b C V_1) + A_a A_g}$$

$$\beta = \frac{(A_f + A_a + A_g) V_2 + (A_a + A_g) V_1}{2 V_1 V_2}$$

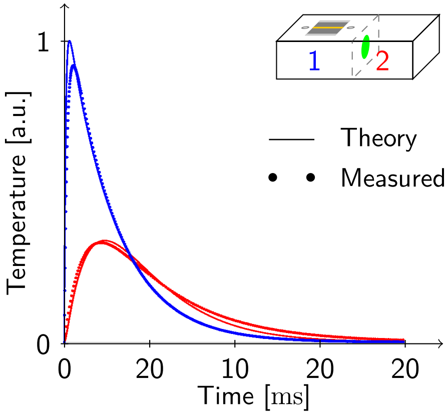
$$\gamma_2 = \beta - 2 \frac{G_b}{C} V_1$$

Differential equations for phonon transport

Temp. /Phon. balance		to Thermometer		heat bath		glue transm.		glue abs.
$\frac{\mathrm{d}}{\mathrm{d}t} \Delta T(t) C$	$=$	$\mathcal{E} A_f \frac{N_1(t)}{V_1}$	$-$	$G_b \Delta T(t)$				
$\frac{\mathrm{d}}{\mathrm{d}t} N_1(t)$	$=$	$-A_f \frac{N_1(t)}{V_1}$			$-$	$A_g \left(\frac{N_1(t)}{V_1} - \frac{N_2(t)}{V_2} \right)$	$-$	$A_a \frac{N_1(t)}{V_1}$
$\frac{\mathrm{d}}{\mathrm{d}t} N_2(t)$	$=$				$+$	$A_g \left(\frac{N_1(t)}{V_1} - \frac{N_2(t)}{V_2} \right)$	$-$	$A_a \frac{N_2(t)}{V_2}$

Theory of Pulse Formation

Mathematical model (extended) → Solution → Information about glue



Transition properties

$$A_f = (5.5772 \pm 0.0093) \cdot 10^{-3}\,\mathrm{m}^3\,\mathrm{s}^{-1}$$
$$A_a = (0.82 \pm 0.34) \cdot 10^{-4}\,\mathrm{m}^3\,\mathrm{s}^{-1}$$
$$A_g = (1.797 \pm 0.090) \cdot 10^{-4}\,\mathrm{m}^3\,\mathrm{s}^{-1}$$

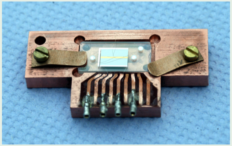
Conclusion

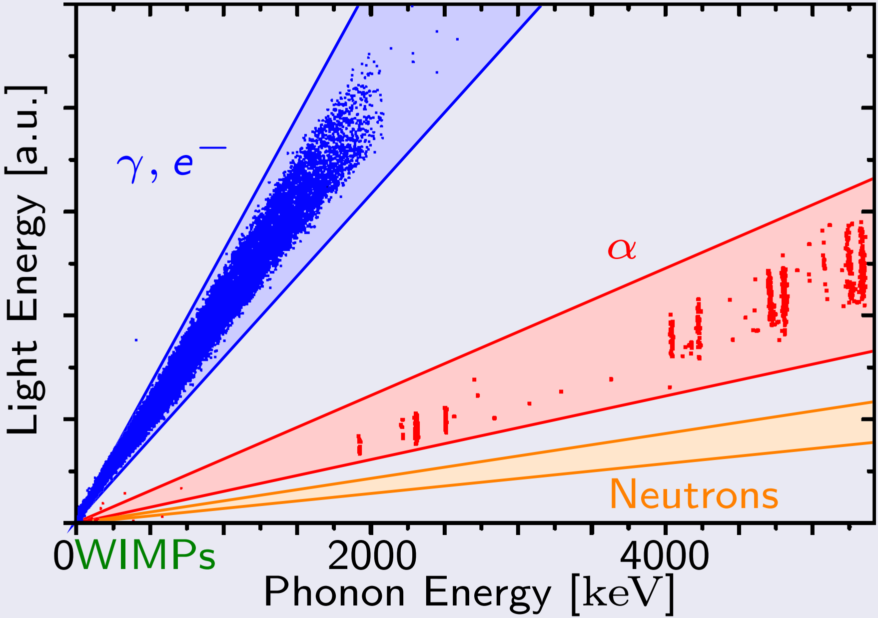
Observations

- Pulses are distinguishable by shape
- Signal loss in phonon channel $\approx 50\%$
- Separation threshold improved by a factor 2
- Overall performance gain
- Model allows prediction of behaviour in different geometry

Future: Prototype detector with Gran Sasso dimensions

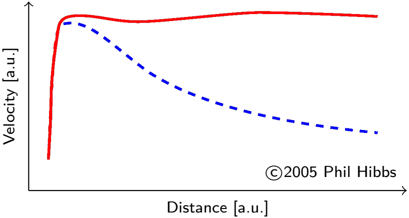
- Detector is being built right now
- Fake signals by stress relaxation?
- Should be included in next run





γ, e⁻
α
Neutrons
0
WIMPs
2000
4000
Phonon Energy [keV]
Light Energy [a.u.]

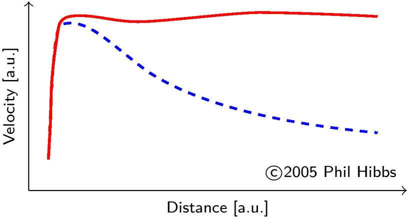
Evidence for Dark Matter



Rotation curves of galaxies

Theory vs. Measurement

Evidence for Dark Matter

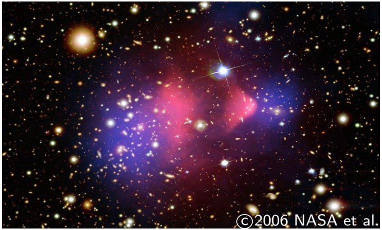


Rotation curves of galaxies

⇒ Dark Matter

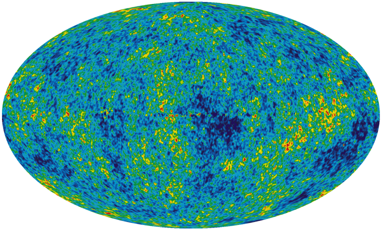
Theory vs.
Measurement

Evidence for Dark Matter 2


©2006 NASA et al.

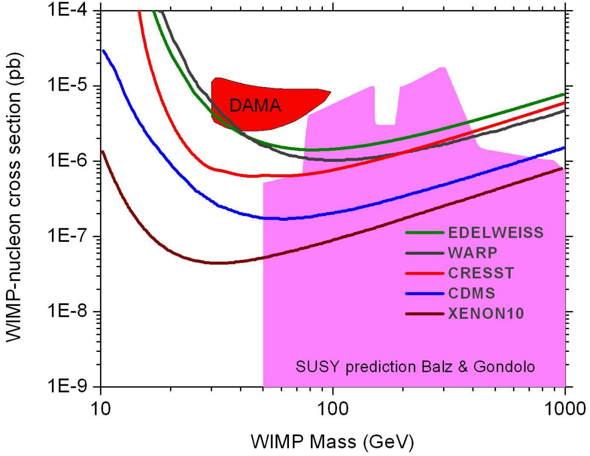
Structures in
the Bullet cluster

⇒ Dark Matter

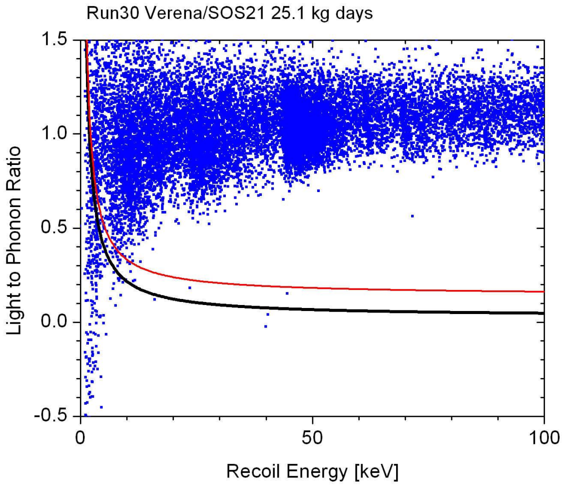

©2007 NASA et al.

Cosmic
Microwave Background

Current Exclusion Limits



Data of one CRESST Detector Module



Dark Matter Experiments