The Light Channel of the CRESST Experiment

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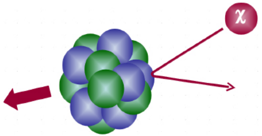
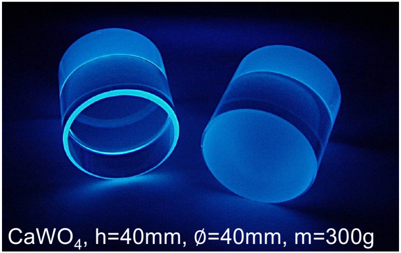
Direct Dark Matter Search with the CRESST Experiment

CRESST (Cryogenic Rare Event Search with Superconducting Thermometers)

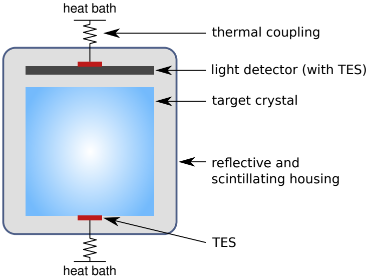
- Direct detection of Dark Matter in the form of **WIMPs** (Weakly Interacting Massive Particles) via **elastic scattering off nuclei**
- located at the LNGS (Laboratori Nazionali del Gran Sasso) in Italy
- Scintillating **$CaWO_4$ crystals** as target material

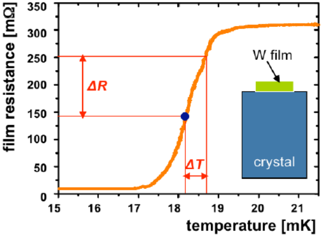




CRESST Detection principle

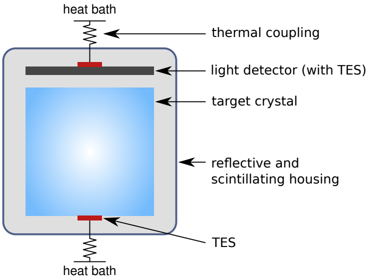
- Energy depositions in the crystal mainly excite **phonons**
  - temperature rise in the crystal ($\mathcal{O}(\mu\mathrm{K})$) $\rightarrow$ detectors operated at **mK temperatures**
- small fraction of deposited energy produces **scintillation light** $\rightarrow$ separate light detector
- both signals measured with **Transition Edge Sensors** (TES) made of a W film
- change of resistance in the film measured with a SQUID based readout

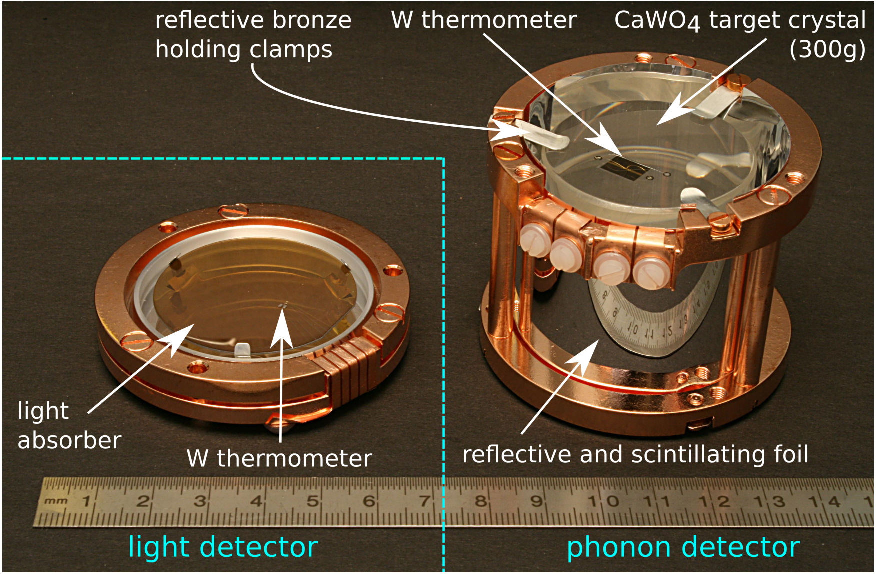




Detector module

- **Detector module**: Phonon detector + Light detector surrounded by a reflective and scintillating housing
- simultaneous measurement of
  - **Phonon Channel**: deposited energy in the crystal (independent of type of particle)
  - **Light Channel**: scintillation light $\rightarrow$ allows discrimination of different types of particles



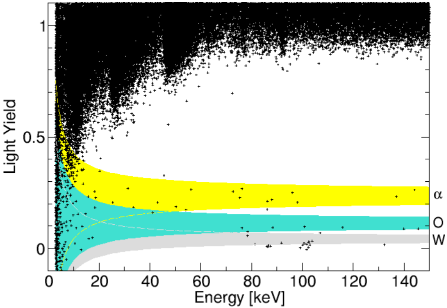

reflective bronze
holding clamps
W thermometer
CaWO4 target crystal
(300g)
light
absorber
W thermometer
reflective and scintillating foil
light detector
phonon detector

Event discrimination

- Phonon signal = Energy deposited in the crystal
- Light signal used to discriminate different types of interactions

Light Yield = light signal/phonon signal

- Light Yield characteristic for each event type



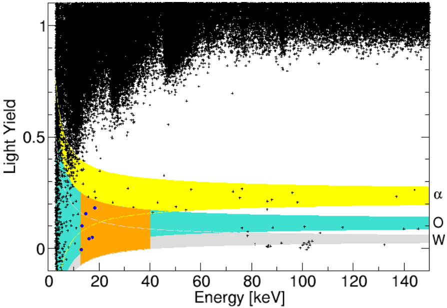
- excellent discrimination between dominant background (e^--recoils) and potential signal events (nuclear recoils)

Event discrimination

- Phonon signal = Energy deposited in the crystal
- Light signal used to discriminate different types of interactions

Light Yield = light signal/phonon signal

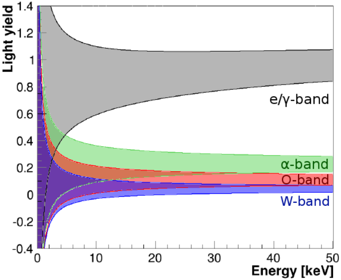
- Light Yield characteristic for each event type
- WIMP search region (ROI) including O, Ca and W bands below 40keV



- excellent discrimination between dominant background (e^--recoils) and potential signal events (nuclear recoils)

Light Channel Energy Resolution

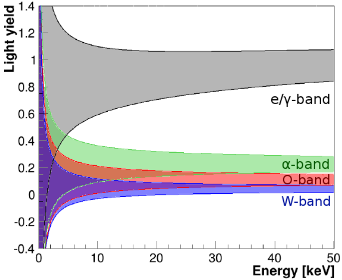
Width of the bands is mainly determined by the light channel energy resolution

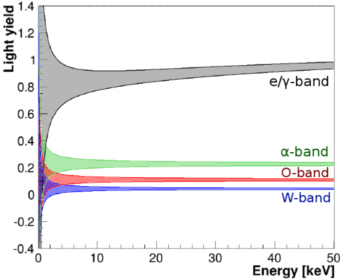


- Energy resolution of a typical CRESST detector module

Light Channel Energy Resolution

Width of the bands is mainly determined by the light channel energy resolution





- Energy resolution of a typical CRESST detector module
- Light channel energy resolution improved by a factor of 5

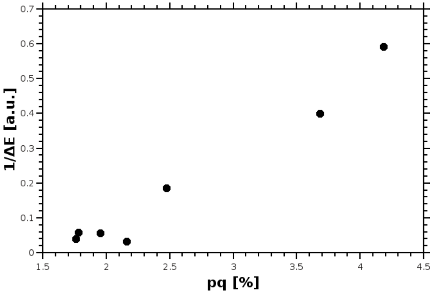
Improved light channel's energy resolution increases discrimination power

Light Detection

- Energy resolution of the light detector ΔE depends on the fraction of recoil energy that is absorbed by the light detector pq
- Energy fraction absorbed by the light detector pq
  - energy fraction transformed into scintillation light p
  - fraction of scintillation light absorbed by the light detector q
  - p and q are difficult to distinguish $\rightarrow$ only pq can be determined
  - absolute calibration of the light detector with an X-ray (^{55}Fe) to determine pq
- Energy resolution of the light detector ΔE
  - determined for small energies
  - also depends on other parameters (e.g. the transition of the TES) than pq, but can be corrected for these

Energy Fraction absorbed by the Light Detector pq

Energy fraction absorbed by the light detector pq for different modules currently running in CRESST (Run33)



larger fraction of absorbed light $pq \rightarrow$ better energy resolution ΔE

How to increase the amount of absorbed Light?

produced scintillation light

$$= p \cdot E_{rec}$$

$\downarrow$

crystal

- increase light output
- material with higher light output

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produced scintillation light

$$= p \cdot E_{rec}$$

absorbed scintillation light

$$= q \cdot p \cdot E_{rec}$$

crystal

- increase light output
- material with higher light output

light detector

- better light absorber
- improve detector design

How to increase the amount of absorbed Light?

produced scintillation light

$= p \cdot E_{rec}$

absorbed scintillation light

$= q \cdot p \cdot E_{rec}$

crystal

- increase light output
- material with higher light output

foil

- larger reflectivity

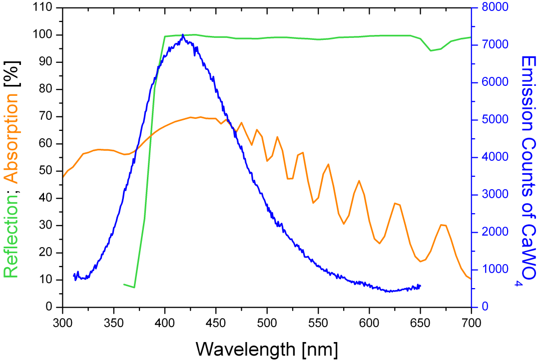
light detector

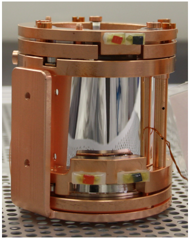
- better light absorber
- improve detector design

Foil VM2002

Reflective and scintillating multi-layer polymeric foil VM2002

- Reflectivity measurement at 300K
- cut-off wavelength at 375nm
- Emission spectrum of $CaWO_4$ (at 300K)
- Absorption of SOS (silicon on sapphire) Light Detector (at 300K)

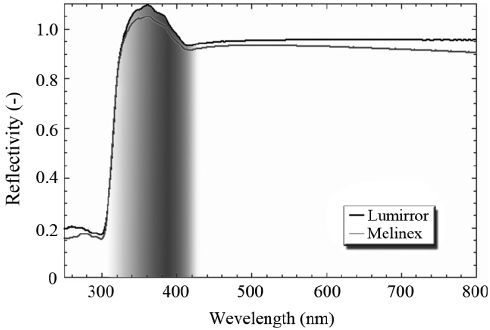


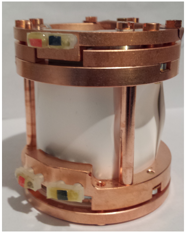


Foil Lumirror

Reflective Foil Lumirror

- Reflectivity measurement at 300K
- cut-off wavelength at 325nm
- fluorescence contribution between 320 and 420 nm





Comparison of VM2002 and Lumirror

- Reflectivity can change when foil is cooled down to mK temperatures
- Compare the reflectivity at mK temperatures:
  - 2 cryogenic measurements with the same detector module (one with each foil)
  - everything except the foil stays the same

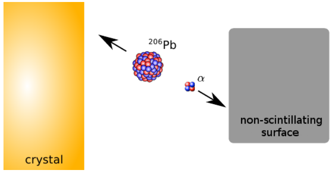
Result

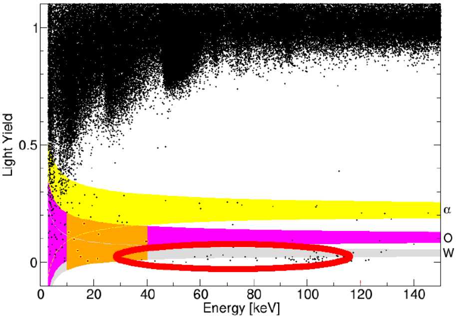
- VM2002: $pq = 1.58\%$
- Lumirror: $pq = 1.42\%$

Lumirror foil reflects 10% less light of $CaWO_4$ at mK temperatures

Background from α contamination on surfaces

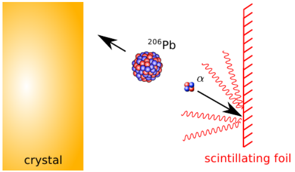
- alpha contamination on surfaces inside the detector module can induce background
- main source is ^{222}Rn from ambient air which deposits on the detector and the housing
- ^{222}Rn decays to ^{210}Po, which induces a background by its decay $^{210}Po \rightarrow ^{206}Pb(103keV) + \alpha(5.3MeV)$

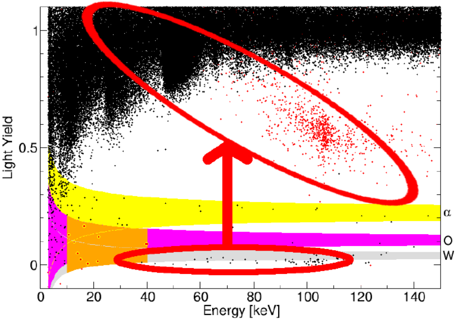




Scintillation as veto for surface α decays

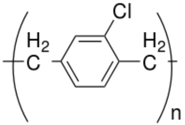
- alpha hitting the foil $\rightarrow$ additional scintillation light
- Foil events can be cut due to a different pulse shape





- Improvement possible with a material scintillating better than the foil VM2002

Parylene C

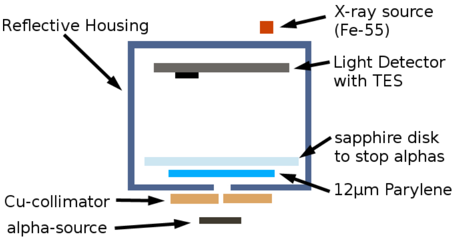


- **Parylene C** is a good scinillator at room temperature
- clean raw material available
- Foil can be coated via polmerization (commercial process)
- additional cleaning during production process
- additional advantage: **Reset of the "radon-history" of the foil**
  - Exposure of foil to radon contaminated air cannot be controlled (comercial product)
  - Coat the foil with a homogeneus Parylene layer

→ Measurement of scintillation of Parylene C at mK temperatures

Scintillation of Parylene C

Setup to measure the scintillation of Parylene C at mK temperatures



- Energy calibration with an X-ray source (^{55}Fe)
- Sapphire disk to prevent alphas hitting the light detector directly

Result

- a 5.6MeV alpha produces 4.7keV scintillation light in 12μm Parylene
- comparison: a 5.6MeV alpha produces 2keV scintillation light in the foil VM2002

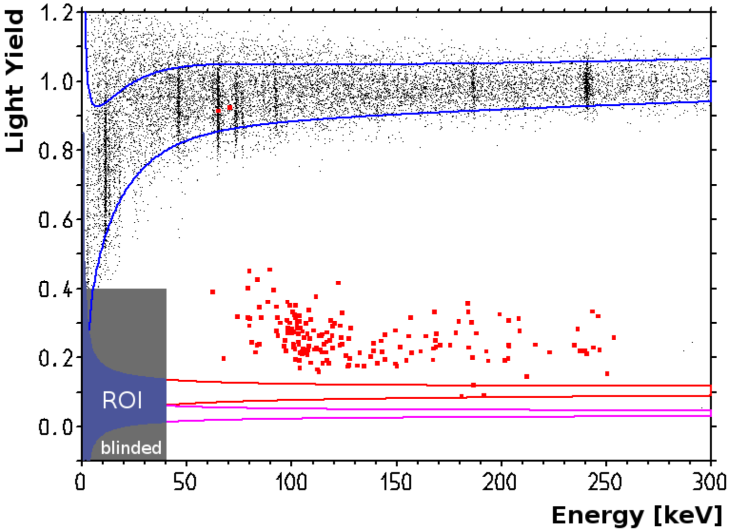
$\rightarrow$ Parylene C scintillates more than twice as well as the foil VM2002

Parylene coated Foil in CRESST

- due to low count rates foil events can only be measured in CRESST
- 7 modules in the current CRESST Run (Run33) were equipped with Parylene coated foil

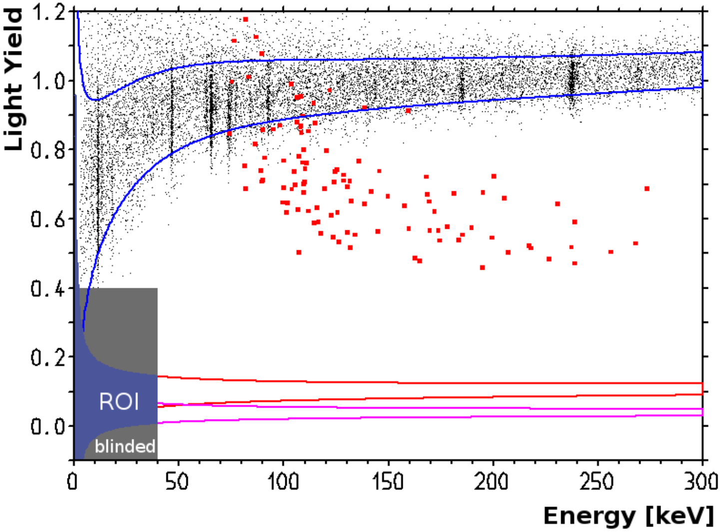
- **Comparison of uncoated foil and Parylene coated foil**
  - 2 modules with the same module design
  - both are equipped with an X-ray source for the absolute calibration of the light detector
  - module 1: equipped with uncoated VM2002 foil
  - module 2: equipped with a VM2002 foil coated with 10μm Parylene

Module with VM2002 Foil (uncoated)



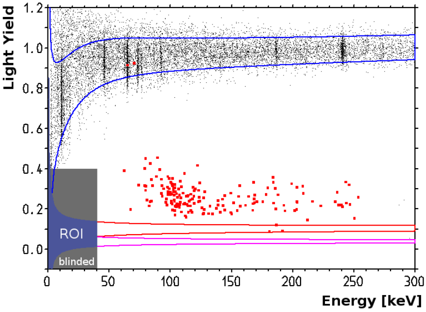
a foil event with 100keV recoil energy produces 0.78keV detected light

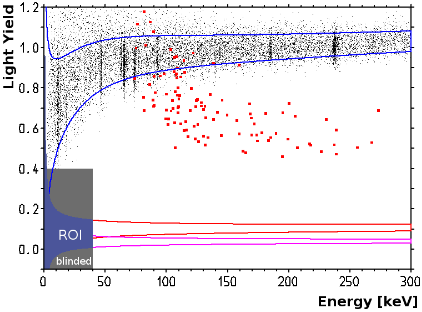
Module with Parylene coated Foil



a foil event with 100keV recoil energy produces 1.45keV detected light

Comparison





foil event with 100keV recoil energy produces 0.78keV detected light

foil event with 100keV recoil energy produces 1.45keV detected light

Result

- Parylene coated foil produces twice as much light

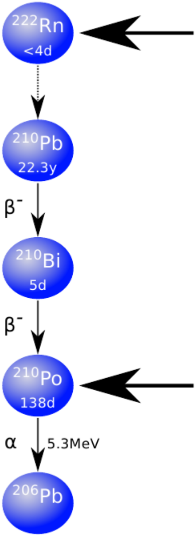
→ foil events are higher in the light yield-energy plane

Results

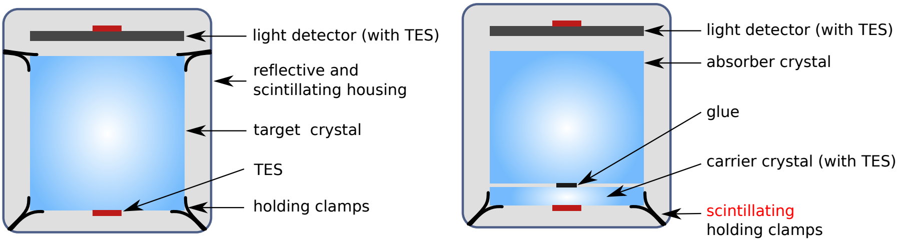
- Resolution of the light channel is improved with more detected light
- VM2002 foil is (up to now) the most reflective foil for $CaWO_4$
- Parylene C is a good scintillator at mK temperatures
- Scintillation of the foil can be improved with a Parylene coating

Backup

Radon decay chain



Module Designs



Parylene Coating