Results on light dark matter particles with a low threshold CRESST-II detector

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Hints for the existence of dark matter

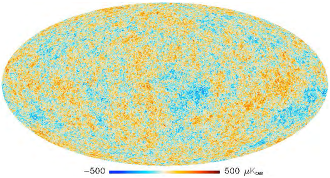
- Hints for the existence of dark matter on several length and time scales
- Precise measurement of temperature fluctuations of cosmic microwave background

$\rightarrow$ Dark matter contribution: $\sim 27\,\%$

- Nature and origin of dark matter remains unknown
- Promising candidate: Weakly Interacting Massive Particle (WIMP)

$\rightarrow$ Masses of $\mathcal{O}(\text{GeV})$ to $\mathcal{O}(\text{TeV})$

- Several models for low masses (e.g., asymmetric dark matter)



The CRESST collaboration

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

HEPHY Institut für Hochenergiephysik

INFN Laboratori Nazionali del Gran Sasso

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

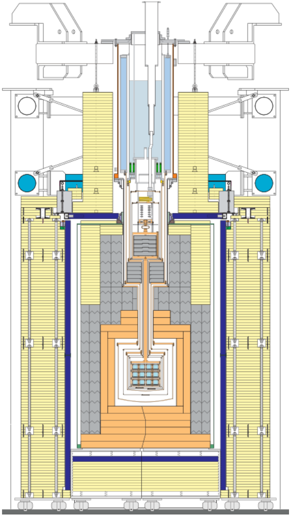
Technische Universität München

University of Oxford

Eberhard Karls Universität Tübingen

$\sim$ 40 scientists from 6 institutions

The CRESST experiment



- Direct dark matter search
- Aim: observation of dark matter particles scattering off detector material
- Located at Laboratori Nazionali del Gran Sasso (LNGS) in Italy
- Rare event search

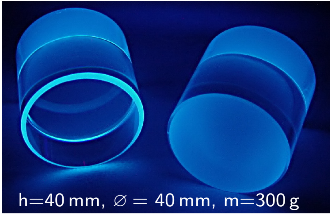
$\rightarrow$ Massive shielding (Pb, Cu, PE)

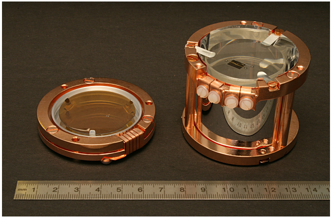
$\rightarrow$ Underground ($\sim$ 3000 m.w.e)

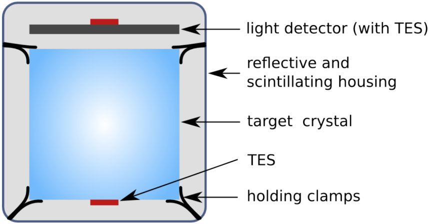
- CRESST-II Phase 2: 18 detector modules operated from June 2013 to August 2015

$\rightarrow$ This talk: Results from blind analysis of one module (best threshold $\sim$ 300 eV)

Detector module





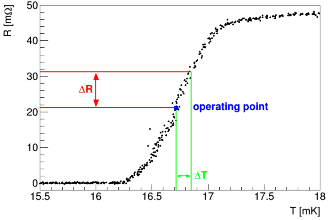


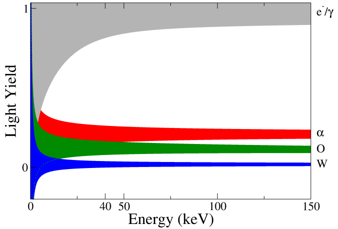
- Target crystal: scintillating calcium tungstate ($CaWO_4$), mass: 250 - 300 g

$\rightarrow$ Measurement of deposited energy (via phonon signal)

- Separate light detector (silicon on sapphire, SOS) for measurement of scintillation light

Detection principle





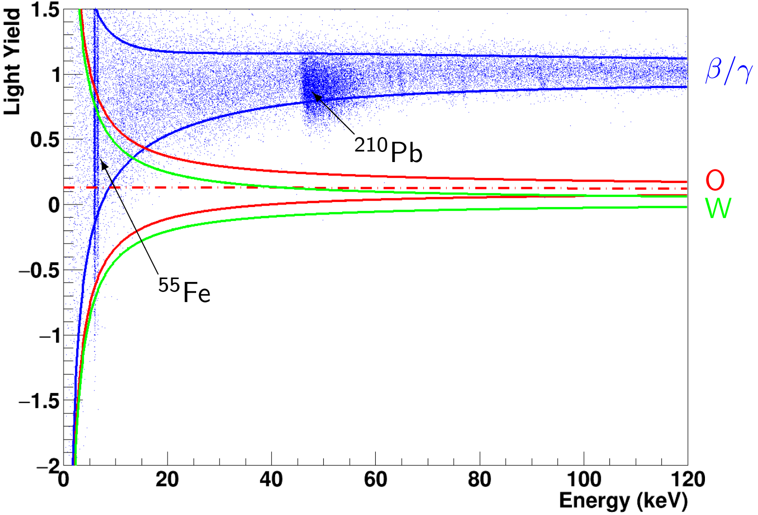
- Both detectors equipped with Transition Edge Sensors (TES)
  - Superconducting tungsten film
  - Stabilized at steep phase transition
  - Deposited energy leads to small temperature rise of TES.
  - $\rightarrow$ Measurable resistance change induced by small temperature rise
- Simultaneous measurement of deposited energy and scintillation light

$\rightarrow$ Different amounts of scintillation light for electron and nuclear recoils

$\Rightarrow$ Rejection of β/γ backgrounds

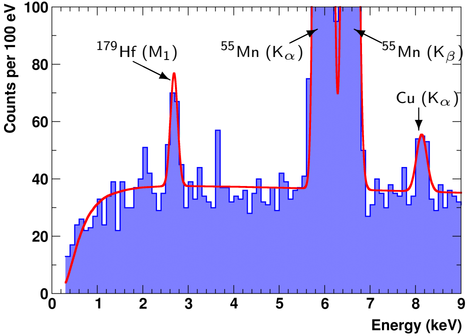
$\rightarrow$ Light yield: Ratio of measured scintillation light and deposited energy

Light-yield/energy plane



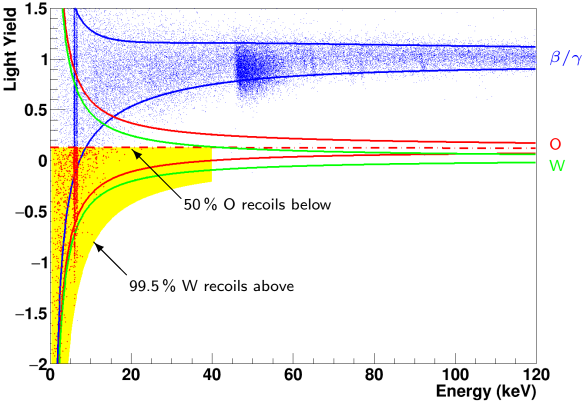
→ CRESST collaboration, G. Angloher, et al., arXiv: 1509.01515 (2015), submitted to EPJ C

Energy spectrum at low energies



- Dominating feature: accidental irradiation with ^{55}Fe source
- Cosmogenic activation: ^{179}Ta (EC decay to ^{179}Hf; binding energy M_1)
- External copper fluorescence
- Flat background down to threshold
- $\lesssim 1\,$keV: Influence of finite survival probability

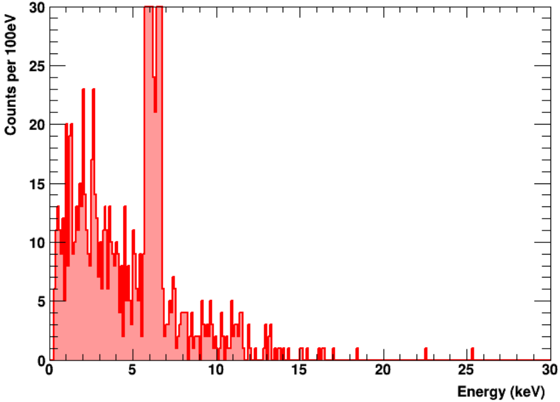
Event selection



- Acceptance region (yellow) from threshold (300 eV) to 40 keV
- Different choices of upper bound on light yield lead to similar results

$\rightarrow$ Accepted events (red) compatible with leakage from β/γ band

Accepted events

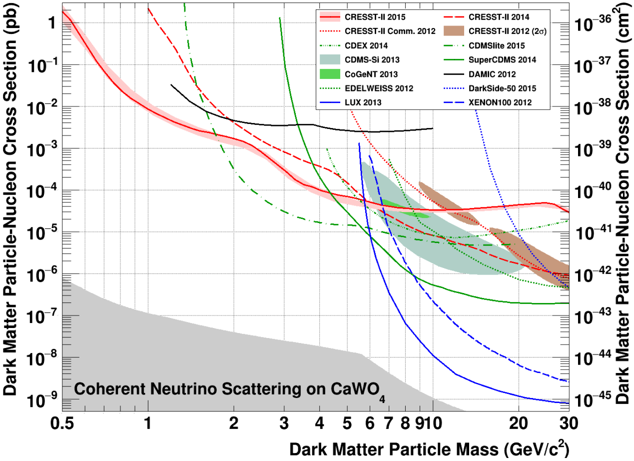


- Accepted events compatible with leakage from β/γ band

$\rightarrow$ Conservative limit determined by Yellin's optimum-interval method

- Mn x-rays: No effect for dark matter masses $\lesssim 3\,\mathrm{GeV/c^2}$

Limit on light dark matter



- Best limit for dark matter masses $\lesssim 2\,\mathrm{GeV/c^2}$
- Exploring new parameter space below $1\,\mathrm{GeV/c^2}$

Summary

- Blind analysis of detector with lowest threshold of $\sim 300\,\mathrm{eV}$
- Exposure: $\sim 51\,$kg-days
- Average background rate of $\sim 8\,\mathrm{keV}^{-1}\,\mathrm{kg}^{-1}\,\mathrm{day}^{-1}$

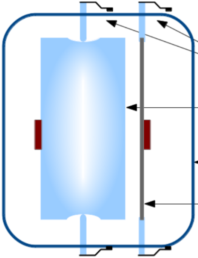
$\rightarrow$ Further details: CRESST collaboration, G. Angloher, et al., arXiv: 1509.01515 (2015), submitted to EPJ C

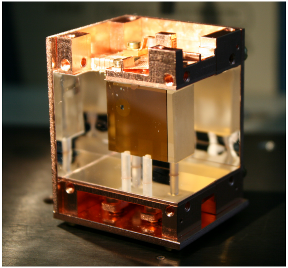
- Below $\sim 6\,\mathrm{GeV/c^2}$: better than 2014 limit obtained with different detector (threshold 600 eV, bg-rate: $\sim 3.5\,\mathrm{keV}^{-1}\,\mathrm{kg}^{-1}\,\mathrm{day}^{-1}$)

  $\rightarrow$ CRESST collaboration, G. Angloher, et al., EPJ C **74**, 3184 (2014), arXiv:1407.3146 (2014)

$\Rightarrow$ **Energy threshold is key for light dark matter**

Outlook: New detector module for CRESST-III

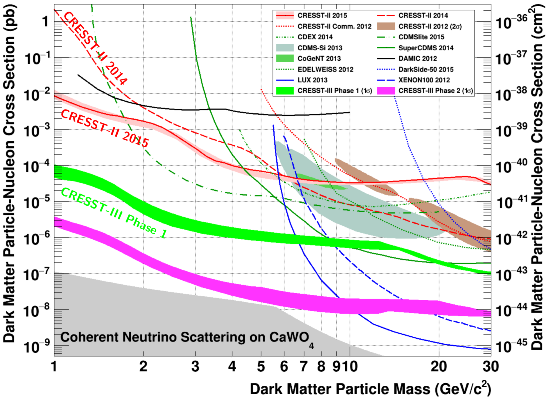




- Optimized for low energy threshold (goal $\lesssim 100\,\mathrm{eV}$)
- Target mass 25 g (10x less than for CRESST-II)
- Fully scintillating housing (scintillating foil, $CaWO_4$ sticks)
- Instrumented sticks to reject events in sticks (phonon detector only)
- First tests very successful (threshold goal exceeded)

→ **Start of CRESST-III beginning of 2016**

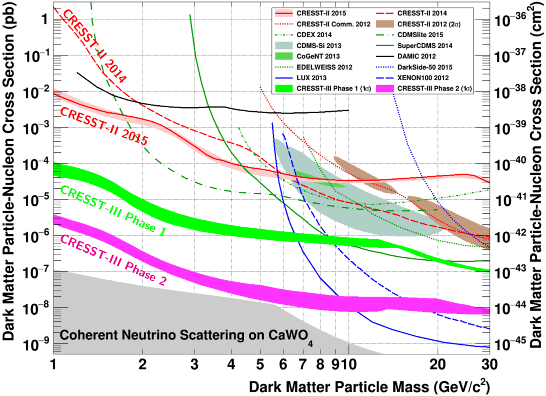
Outlook: Projection for CRESST-III Phase 1



- Energy threshold 100 eV
- Exposure 50 kg-days (10 modules operated for one year)
- Background rate: $\sim 3.5\,\mathrm{keV}^{-1}\,\mathrm{kg}^{-1}\,\mathrm{day}^{-1}$

→ CRESST collaboration, G. Angloher, et al., arXiv: 1503.08065 (2015)

Outlook: Projection for CRESST-III Phase 2

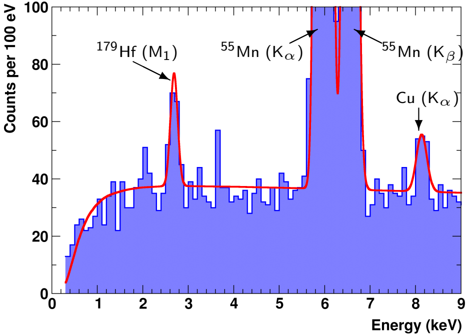


- Energy threshold 100 eV
- Exposure 1000 kg-days (100 modules operated for two years)
- Background rate: $\sim 3.5\mathrm{x}10^{-2}\,\mathrm{keV}^{-1}\,\mathrm{kg}^{-1}\,\mathrm{day}^{-1}$

→ CRESST collaboration, G. Angloher, et al., arXiv: 1503.08065 (2015)

Backup slides

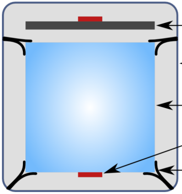
Energy reconstruction



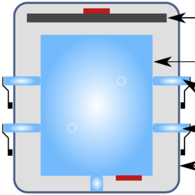
Origin	E_{lit} [keV]	E_{fit} [keV]	$\frac{E_{fit}-E_{lit}}{E_{lit}}$ [%]	σ [eV]
Hf M_1	2.601	2.687 ± 0.020	+3.3	79 ± 1
Mn K_α	5.895	5.972 ± 0.002	+1.3	101 ± 1
Mn K_β	6.490	6.562 ± 0.003	+1.1	105 ± 2
Cu K_α	8.041	8.133 ± 0.034	+1.1	115 ± 2

Detector-module designs

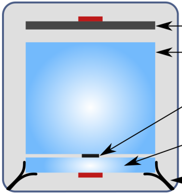
Conventional design



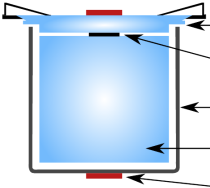
Stick design



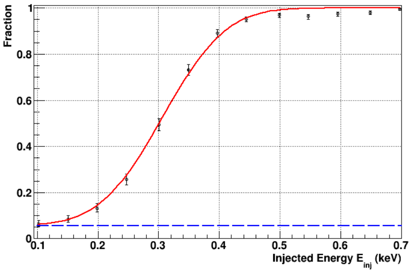
Carrier design

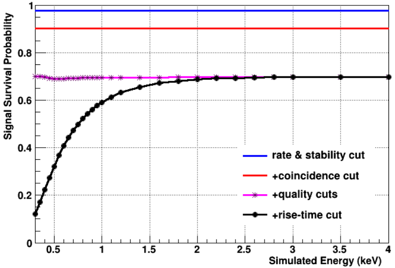


Beaker design



Detector module with low threshold





- Trigger threshold determined by electric signals injected into the TES

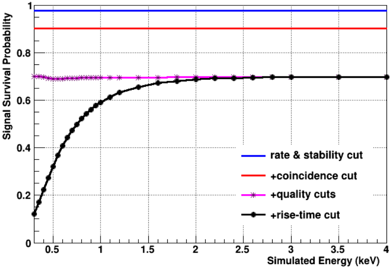
$\rightarrow$ Module with best threshold: $\sim 300\,\text{eV}$

- Signal-survival probability estimated by artificial pulses (measured baseline noise + pulse template)

$\rightarrow$ Survival probability $\gtrsim 10\,\%$ at trigger threshold

$\rightarrow$ CRESST collaboration, G. Angloher, et al., arXiv: 1509.01515 (2015), submitted to EPJ C

Data analysis - signal survival-probability

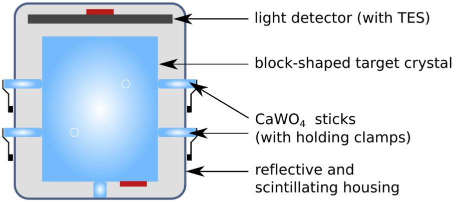


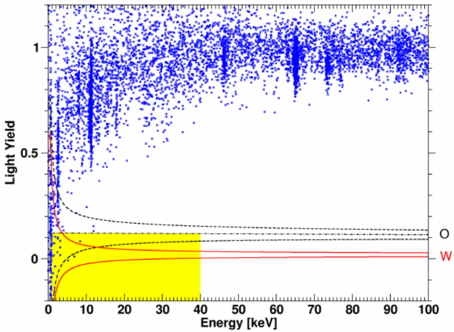
- Rate cut - removes periods of abnormal high trigger rates
- Stability cut - both detectors (phonon, light) in operating point
- Quality cut - remove pulses where correct energy reconstruction is not guaranteed
- Rise-time cut - removes events in TES-carrier crystal

→ Cuts defined on non-blind data set (not used for limit)

→ Signal survival-probability determined by artificial pulses

2014 result

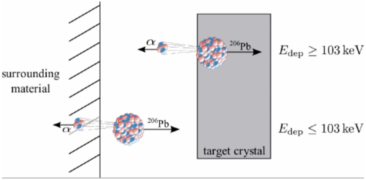


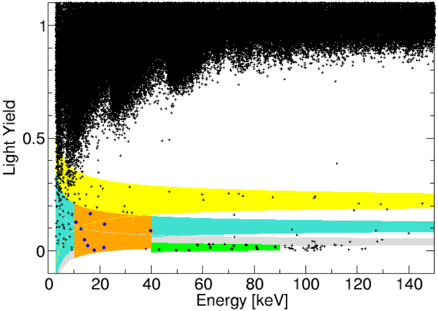


- Detector with smallest background rate: ~ 3 keV^{-1} kg^{-1} day^{-1}
- Energy threshold ~ 600 eV
- Exposure ~ 29 kg-days
- Analysis of non-blinded data set

$\rightarrow$ Partial exclusion of WIMP interpretation of excess observed in 2011

Conventional modules - α decays on surfaces





- Origin ^{226}Rn
- ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)
- Bronze clamps not scintillating

$\Rightarrow$ Dangerous background source