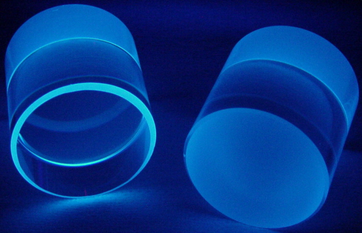
Status of the CRESST-II Experiment for Direct Dark Matter Search

Andrea Münster for the CRESST collaboration

PATRAS Workshop on Axions, WIMPs and WISPs

25/06/2015



The CRESST Collaboration

INFN
Laboratori Nazionali del Gran Sasso

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

HEPHY
Institut für Hochenergiephysik

TUM
TECHNISCHE UNIVERSITÄT MÜNCHEN

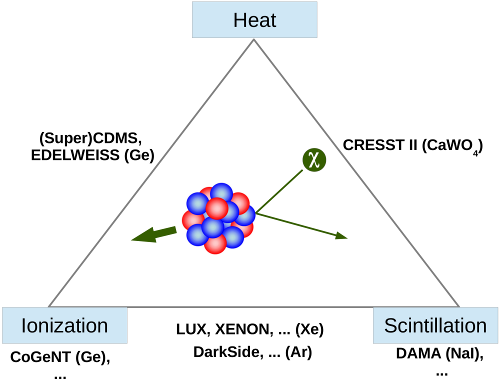
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

UNIVERSITY OF OXFORD

Outline

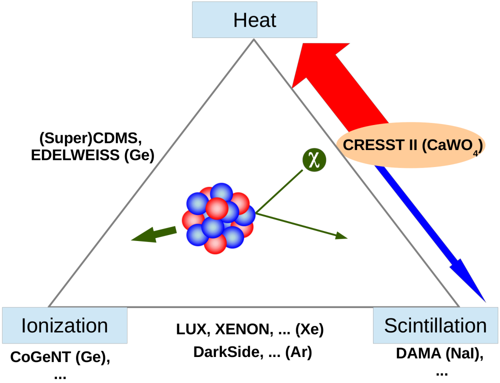
Direct Dark Matter Detection

Direct dark matter search: Elastic WIMP-nucleus scattering



Direct Dark Matter Detection

Direct dark matter search: Elastic WIMP-nucleus scattering



- Cryogenic Rare Event Search with Superconducting Thermometers
- Scintillating $CaWO_4$ single crystals as target material

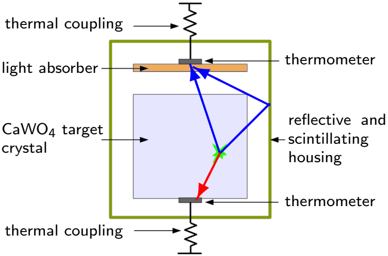
CRESST-II: Detector Module

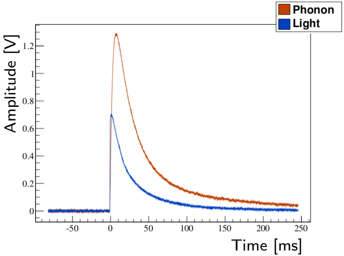
- $CaWO_4$ single crystals are

→ operated as cryogenic detectors at mK temperatures
→ **Phonon signal**
recorded by W thermometer directly connected to crystal

→ scintillating at mK temperatures
→ **Light signal**
recorded by light absorber (usually silicon on sapphire) connected to another W thermometer

- Both detectors enclosed in reflective and scintillating housing
- Particle interaction in crystal
→ simultaneous read-out of both signals



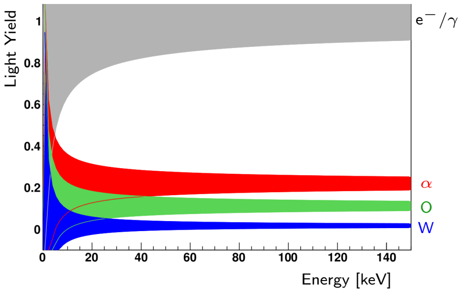


CRESST-II: Background Discrimination

- Phonon signal ($\sim 95\,\%$ of energy) $\rightarrow$ precise energy measurement
- Light signal dependent on kind of interacting particle

$$\text{LY} = \text{Light Yield} = \frac{E_{\text{light}}}{E_{\text{phonon}}}$$

Band	average Light Yield
e^-/γ	1 (normalized)
α	~ 0.22
O	0.112 ± 0.005
Ca	0.0594 ± 0.0049
W	0.0172 ± 0.0021



$\rightarrow$ Active background discrimination on event-by-event basis

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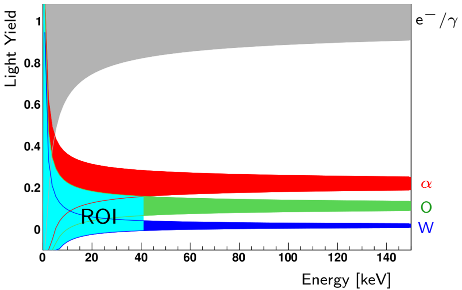
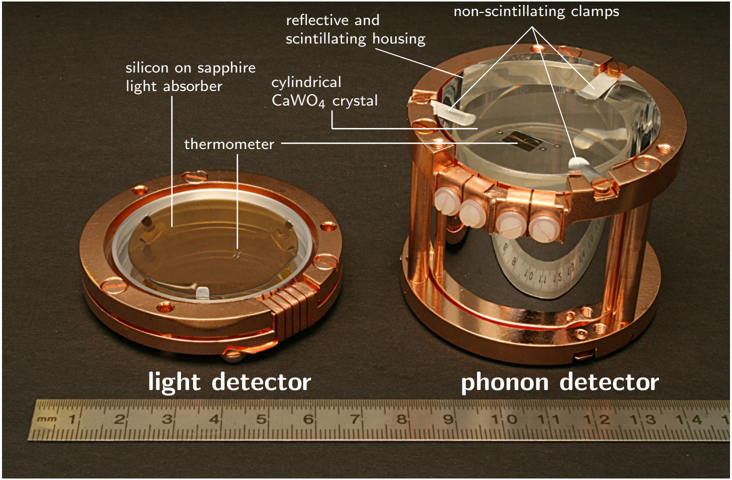


$\rightarrow$ Active background discrimination on event-by-event basis

- Region of interest (ROI) for DM search:
  Nuclear recoil bands (O, Ca, W), detector threshold $<$ E $<$ 40 keV

CRESST-II Phase 1: Conventional Detector Module



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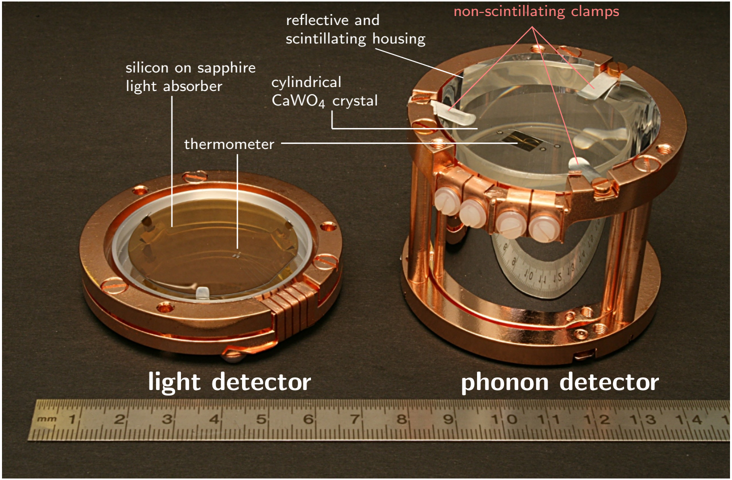
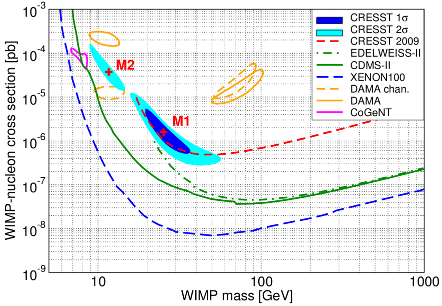


Problem: Reflective, but non-scintillating clamps holding the crystal

CRESST-II Phase 1: Results

- Data taking 2009-2011 (730 kg days)
- Observation of excess above known backgrounds
- Two maxima M1 (mainly W recoils) and M2 (O and Ca recoils)



	M1	M2
e/γ events	8.00 ± 0.05	8.00 ± 0.05
α events	$11.5^{+2.6}_{-2.3}$	$11.2^{+2.5}_{-2.3}$
n events	$7.5^{+6.3}_{-5.5}$	$9.7^{+6.1}_{-5.1}$
Pb events	$15.0^{+5.2}_{-5.1}$	$18.7^{+4.9}_{-4.7}$
excess events	$29.4^{+8.6}_{-7.7}$	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	25.3	11.6
σ_{WN} [pb]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

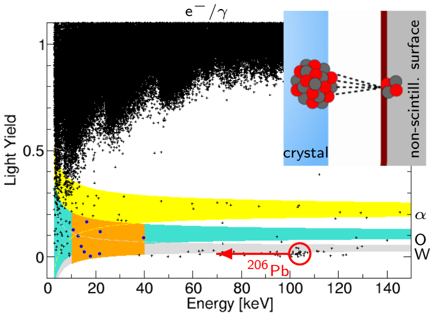
Angloher et al., EPJ C 72, 4 (2012)

But: Uncertainties in background models?

CRESST-II Phase 1: Non-Scintillating Surfaces

Surface contamination with ^{210}Po (originating, e.g., from ^{222}Rn):

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



If ^{206}Pb loses part of its energy in non-scintillating surfaces: leakage towards ROI

- Considered as flat, but rising towards lower energies?
- Additional: Sputter events possible

Kuźniak et al., Astroparticle Physics 36, 77 (2012)

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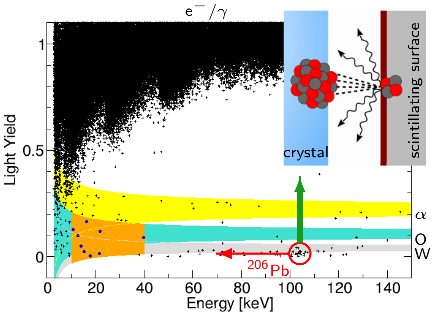

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Kuźniak et al., Astroparticle Physics 36, 77 (2012)

Approach for CRESST-II Phase 2

- Minimization of Rn exposure
- Fully active housing → Shifts surface events to higher LY

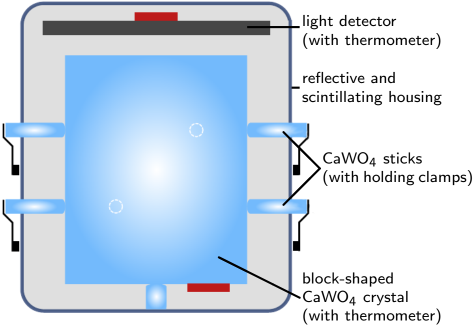
CRESST-II Phase 2: Detector Modules

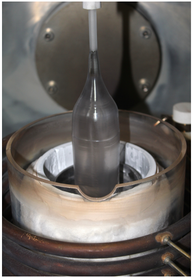
- Detectors mounted in Rn-reduced atmosphere
- 11 conventional detector modules
- 3 new detector designs with fully active housing (2 detectors of each design)

→ In this talk: Concentration on stick design

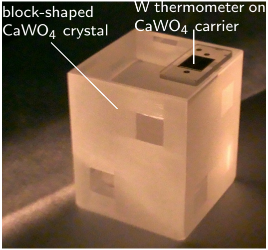
- Data taking since summer 2013

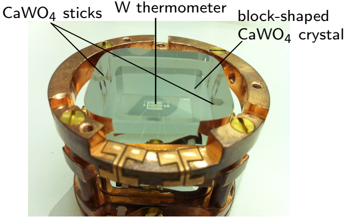
Stick design





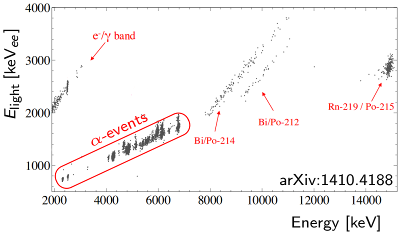
- TUM40 (+ 3 other crystals installed in CRESST-II Phase 2) directly grown at Technische Universität München (TUM) via Czochralski method
- Block-shaped $CaWO_4$ crystal ($\sim$250 g) held by $CaWO_4$ sticks





TUM40: Radiopurity

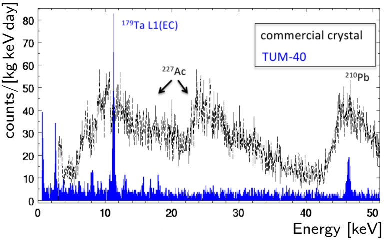
Total α-activities $A_{\alpha,total}$ (1.5-7 MeV)



- $A_{\alpha,\ total}$ of TUM40:
  3.07 ± 0.11 mBq/kg
- $A_{\alpha,\ total}$ of commercial crystals:
  3-107 mBq/kg

Münster et al., JCAP 2014, 018 (2014)

Background events below 50 keV



- e^-/γ-background below 50 keV:
  TUM40: 3.44/(kg keV day)
  commercial crystals: 6-30/(kg keV day)
- γ-lines mainly originating from cosmogenic activation: $^{182}W(p,\alpha)^{179}Ta$

Strauss et al., arXiv:1410.4188

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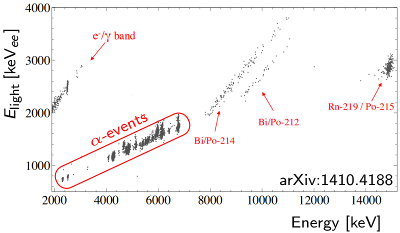

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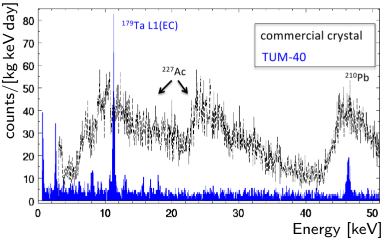

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  TUM40: 3.44/(kg keV day)
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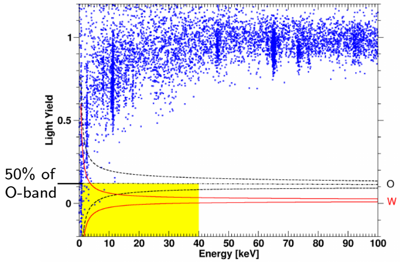
Significant improvement in radiopurity!

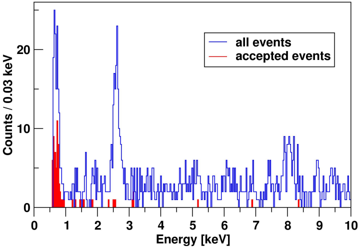
TUM40: Results after 29 kg days

- Fully efficient veto of surface backgrounds
- Low trigger threshold of 603 eV
- Excellent resolution of ~ 100 eV

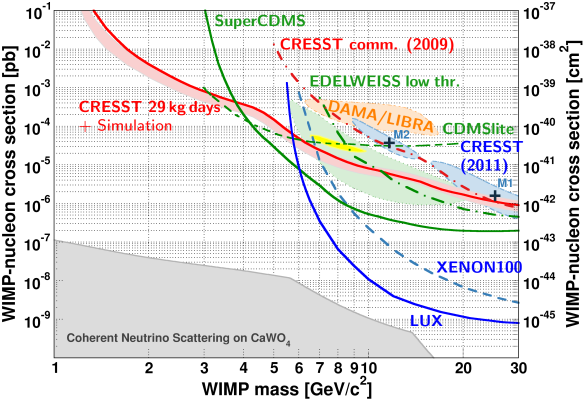
→ **Low-threshold dark matter analysis**

- Acceptance region: 603 eV $<$ E $<$ 40keV, LY $<$ 50% O
- All accepted events conservatively considered as WIMPs





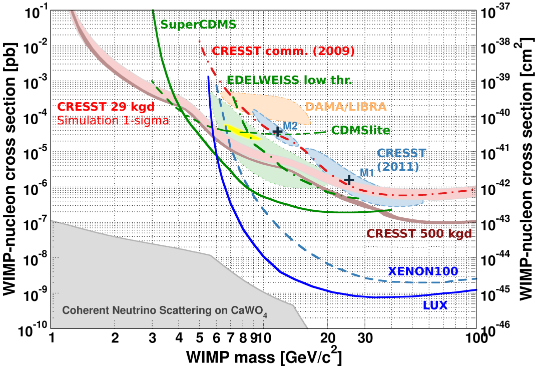
TUM40: Results



Angloher et al., EPJ C 74, 12 (2014)

- M2 completely ruled out
- New parameter space explored for WIMP masses below 3 GeV/c^2
- 1σ simulation only including e^-/γ-background

Goal for CRESST-II Phase 2

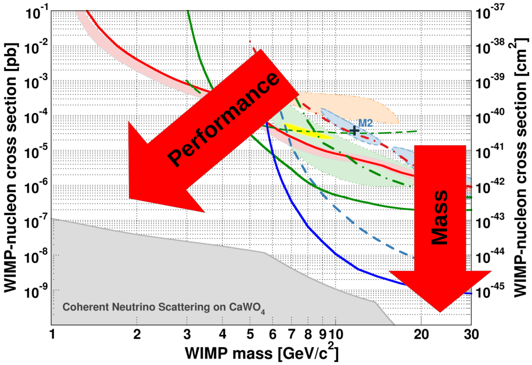


- 500 kg days reached end of May 2015
- Threshold of several detector modules lowered below 400 eV
  → further improvement in low WIMP-mass region
  → data will be presented at TAUP 2015!

⇒ Analysis currently ongoing

1. Use non-blinded data set (115 live days) for definition of data quality cuts, trigger efficiencies. . .
2. Apply to blinded data (since January 2014)

CRESST-III

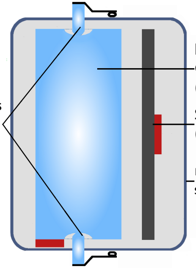


Concentration on low WIMP-mass region

→ Increase performance of detectors by operating small crystals (∼25 g) with at least TUM40 quality

CRESST-III: Detector Module

Small $CaWO_4$ crystals (~25 g, 10x20x20mm^3):



Assumptions:

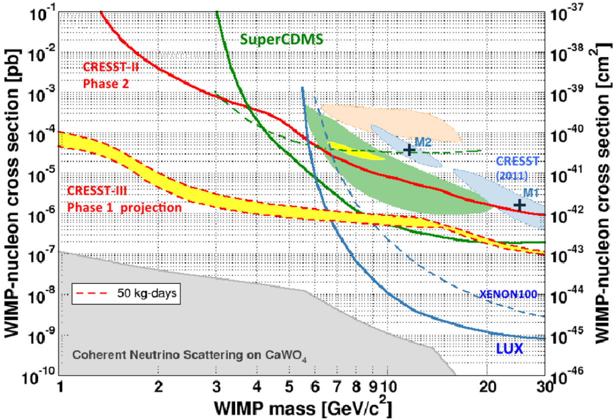
- TUM40 quality
- Phonon detector threshold ~ 100 eV
- 2x more light detected (due to smaller crystal)
- Improvement of light detector resolution by factor 2 (due to smaller volume)

- Prototype successfully tested → threshold < 100 eV achieved
- Detector production ongoing

Start of CRESST-III end of this year

CRESST-III Phase 1

10 small crystals ($\sim$ 25 g) with TUM40 quality operated for 1 year $\equiv$ 50 kg days

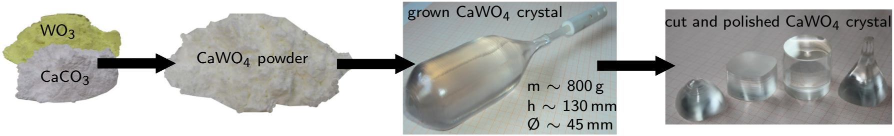


CRESST-III Phase 2

Goal:

- Increase exposure
- Improve radiopurity of crystals by a factor of 100 to $\sim 10^{-2}$ counts/[kg keV day]

Feasible as all crystal production steps ($CaWO_4$ powder production, $CaWO_4$ crystal production) taking place at TUM!



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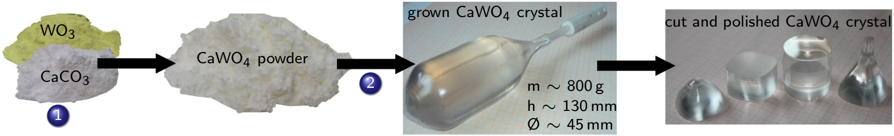
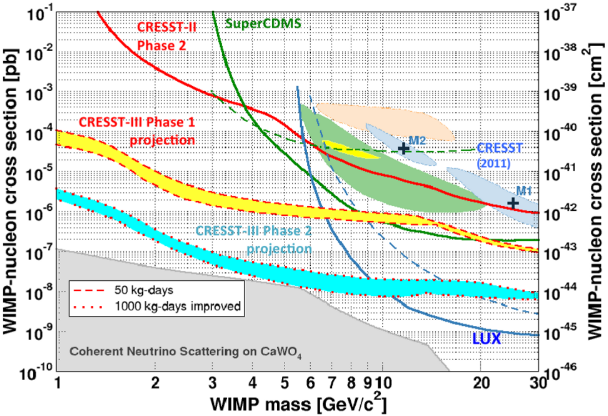


Ways to achieve improvements:

1. Cleaning of raw materials (first tests currently ongoing)
2. Recrystallization (as crystal growth itself is a cleaning process)

Projection of CRESST-III Phase 2

100 small crystals (~25 g) with improved radiopurity operated for 2 years ≡ 1000 kg days



Conclusion

CRESST-II Phase 2

- Goal: Confirm or disprove result of CRESST-II Phase 1
- Operation of 3 new detector designs with fully active housing

→ **Efficient rejection of surface background events with fully active housing**

- $CaWO_4$ crystals grown at TUM included

→ **Improvement in radiopurity**

- Crystal TUM40 (stick design): Low threshold analysis with 29 kg days

→ **M2 already ruled out**

→ **New parameter space explored below 3 GeV/c^2**

- 500 kg days to clarify M1 reached end of May
- Additional low-threshold analysis of selected detectors → TAUP 2015
- Analysis currently ongoing, final results in autumn 2015

Outlook

CRESST Potential

- Present technology in principle suitable for large-scale experiment
- But: Huge potential to probe low WIMP-mass region due to very low thresholds

CRESST-III

- Phase 1: Smaller detector modules with TUM40 quality

→ Projection: Exclusion limit improved by ∼3 orders of magnitude in low WIMP-mass region

- Phase 2: Radiopurity of $CaWO_4$ crystals improved by a factor of 100
    1. Cleaning of raw materials for $CaWO_4$ production at TUM
    2. Recrystallized crystal growth at TUM

→ Projection: Exclusion limit improved by ∼5 orders of magnitude in low WIMP-mass region

Thank you for your attention!

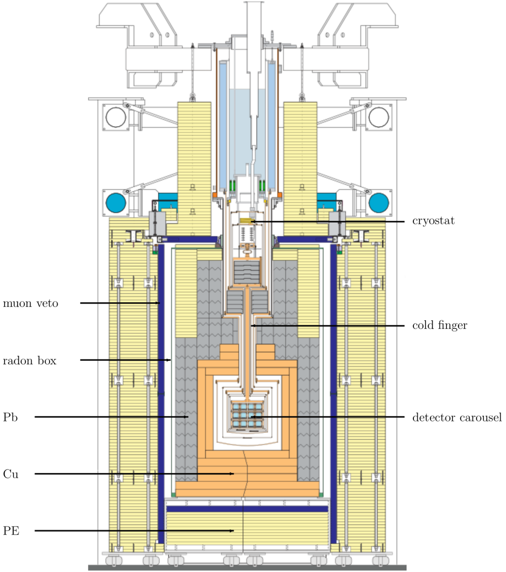
Backup-Slides

Andrea Münster

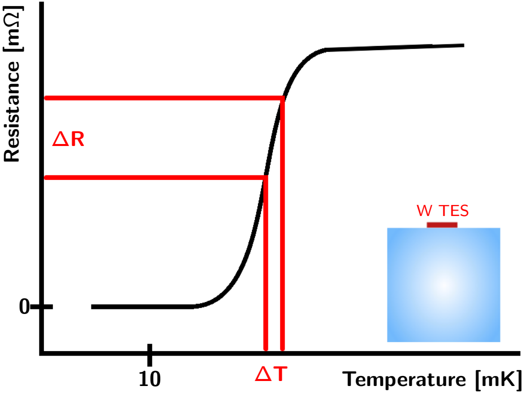
Patras Workshop on Axions, WIMPs and WISPs

25/06/2015

The CRESST Experiment: Setup

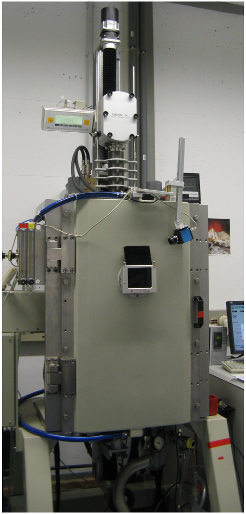


Transition Edge Sensor (TES)

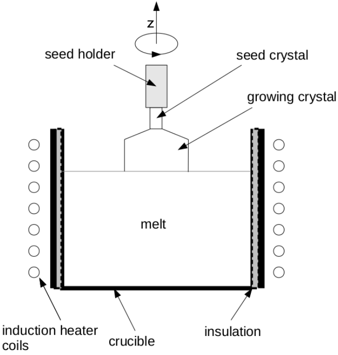


Crystal Growth via Czochralski Method

- Production of $CaWO_4$ powder via solid state reaction: $CaCO_3 + WO_3 \rightarrow CaWO_4 + CO_2$



- Melting of $CaWO_4$ powder in Rh crucible of Czochralski furnace
- Lowering of seed crystal into $CaWO_4$ melt
- Drawing in z direction under rotation
  $\Rightarrow$ Formation of a cylindrically shaped crystal with crystallographic orientation of seed crystal



HPGe Spectroscopy and Segregation of Radioimpurities

Material Sample mass measured at	WO_3 (powder) 83 g LSC[2]	$CaCO_3$ (powder) 53 g LSC	$CaWO_4$ (powder) 57 g LSC	$CaWO_4$ (crystal) 155 g LNGS[3]
Isotope	Activity [mBq/kg]			
^{228}Ra	< 23	< 27	< 17	< 0.96
^{228}Th	< 6	< 33	< 10	< 1.2
^{238}U	< 400	< 260	< 450	40 ± 20
^{226}Ra	< 10	26 ± 6	28 ± 6	< 3.4
^{40}K	< 43	< 83	< 65	< 13
^{137}Cs	< 7	< 7	< 5.5	1.0 ± 0.4
^{60}Co	< 2	< 6	< 2.6	< 0.22
^{227}Ac	< 36	< 31	< 36	-

- Only measurable contamination in raw materials: ^{226}Ra in $CaCO_3$-powder

$\rightarrow$ transferred to $CaWO_4$ powder

- But: No such contamination in grown crystal

$\rightarrow$ Improvement of radiopurity achievable via recrystallization

^{226}Ra segregation coefficient

$$s_{Ra} = \frac{\text{Ra concentration in crystal}}{\text{Ra concentration in melt}} < 0.12 \ (90\,\%\ \text{CL})$$

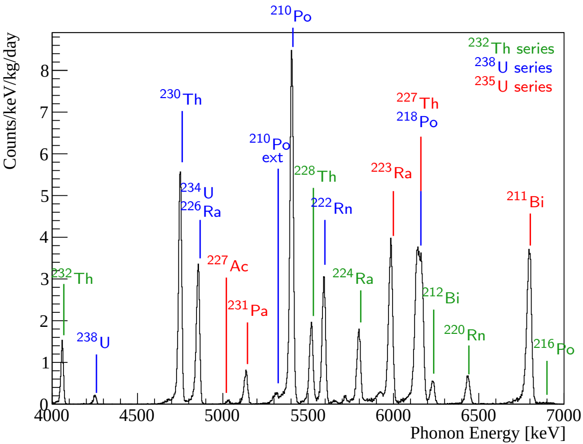
[2] Laboratorio Subterráneo de Canfranc

[3] Laboratori Nazionali del Gran Sasso

α-Activity Determination

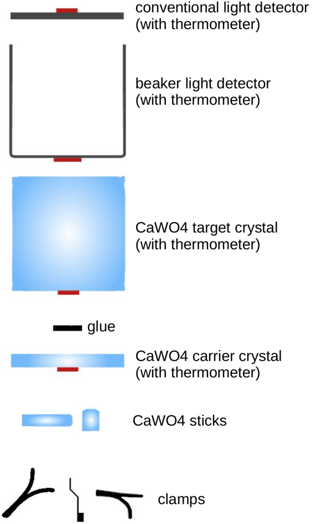
- Main background in $CaWO_4$ crystals due to intrinsic radioactive contamination
- Crystals operated as cryogenic detectors
  - Absolute activity determination possible
  - α-events in MeV range of α-band well separated from all other events, α-detection efficiency $\sim 100\,\%$
  - α- and β-activities connected in natural decay chains

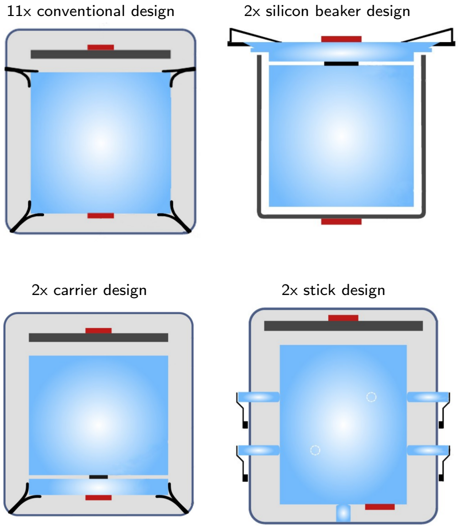
$\Rightarrow$ Total α-activities as good measure for radiopurity of crystal



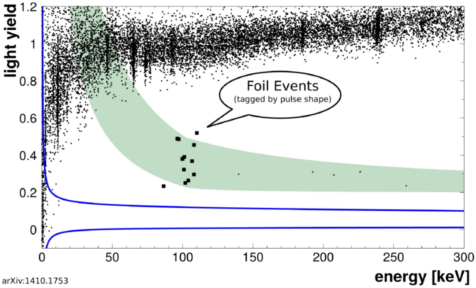
$\rightarrow$ Activitiy determination of single α-lines possible
(but due to technichal reasons only for a few detectors)

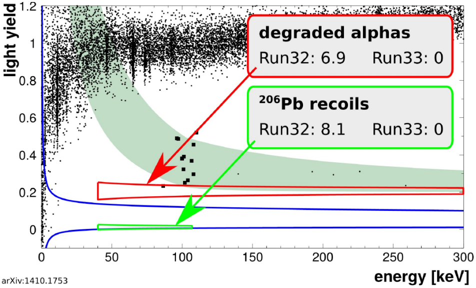
Detector Designs Installed in CRESST-II Phase 2



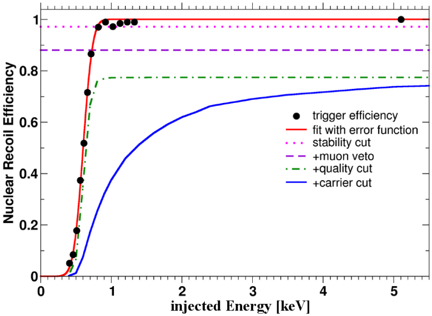


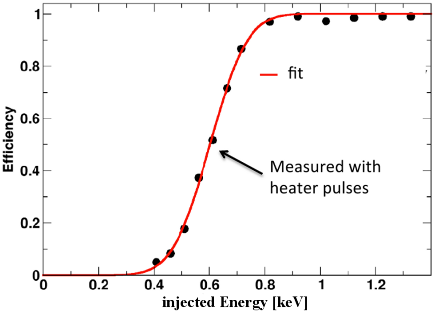
TUM40: Veto of Surface Backgrounds



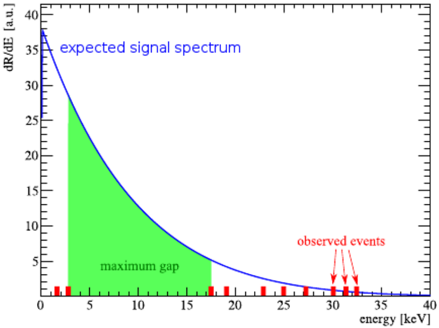


TUM40: Trigger Efficiency





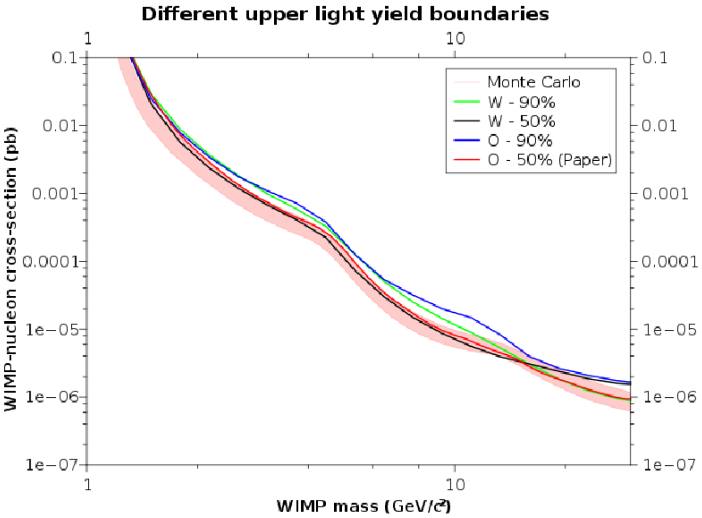
Yellin Methods



- Maximum gap method: Consider largest gap (0 events observed)
- Optimum interval method: Consider largest interval with certain number of events observed

→ Optimum interval method used for this analysis

Influence of LY Boundary on Limit



Multi Element Target $CaWO_4$