Latest CRESST results on low-mass WIMPs

Florian Reindl (MPP Munich)

YSW Ringberg, July 2014

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

Eberhard Karls Universität Tübingen

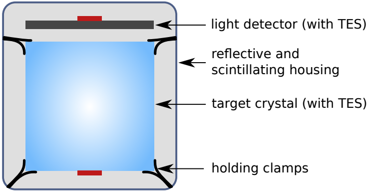
LNGS

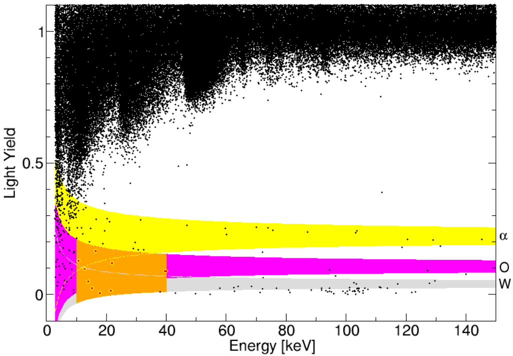
University of Oxford

Technische Universität München

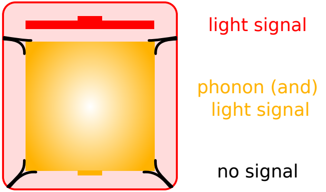
HEPHY
Institut für Hochenergiephysik

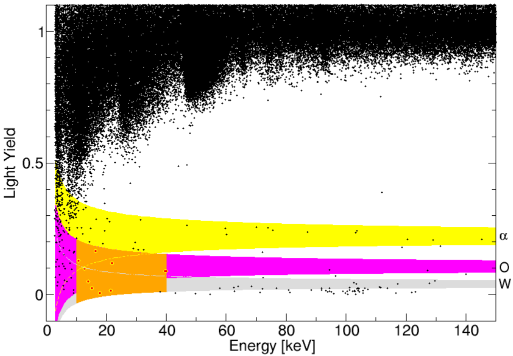
Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)



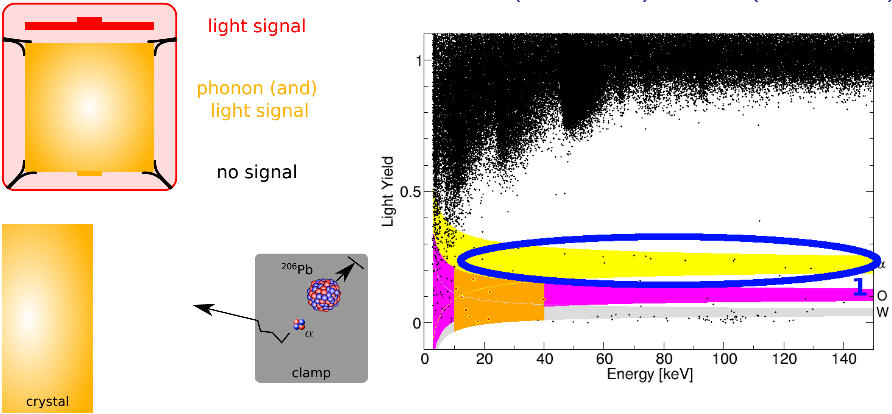


Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)



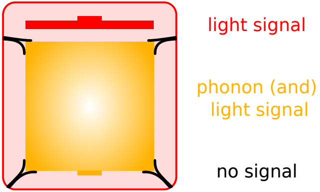


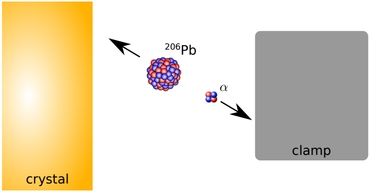
Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)

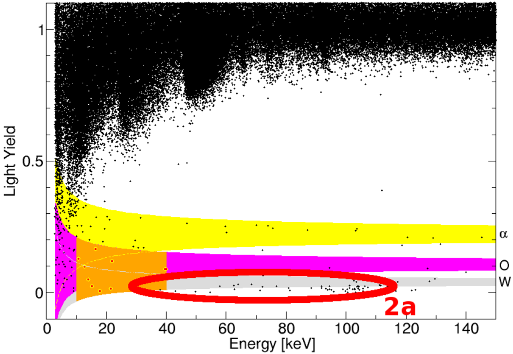


1. decay inside clamp material

Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)

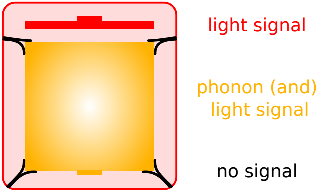


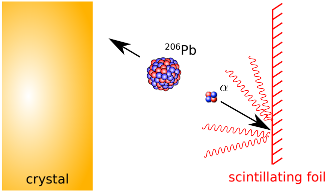


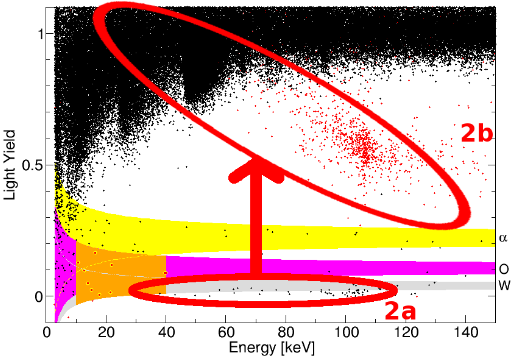


1. decay inside clamp material
2. decay on or slightly below surface of clamp
   (a) α hitting clamp $\rightarrow$ **no** scintillation light

Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)

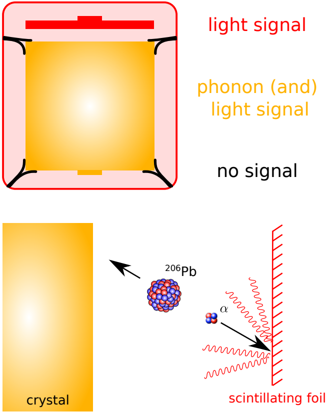


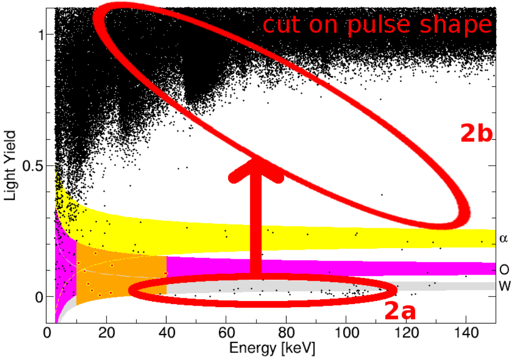




1. decay inside clamp material
2. decay on or slightly below surface of clamp
   (a) α hitting clamp $\rightarrow$ **no** scintillation light
   (b) α hitting foil $\rightarrow$ additional scintillation light from foil (with different pulse shape)

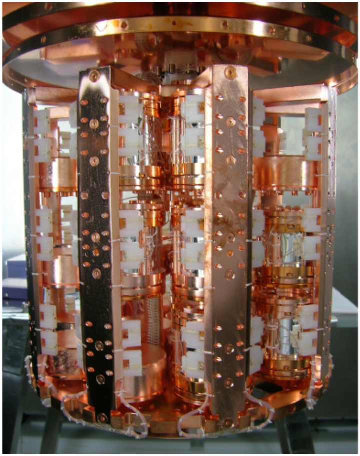
Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)





1. decay inside clamp material
2. decay on or slightly below surface of clamp
   (a) α hitting clamp $\rightarrow$ **no** scintillation light
   (b) α hitting foil $\rightarrow$ additional scintillation light from foil (with different pulse shape)

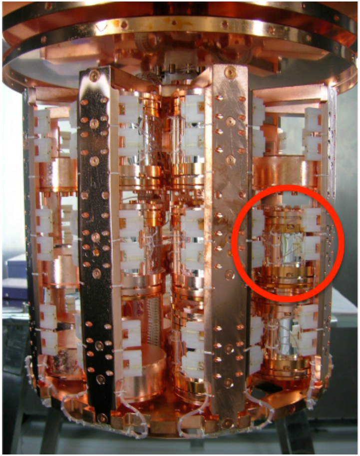
The Current Run 33 - Detector Upgrade



Run 33:

- started in July 2013
- 18 modules: $\sim$ 5kg target mass
- 12 conventional modules
- 6 modules with active recoil veto (three different new designs)

The Current Run 33 - Detector Upgrade



Run 33:

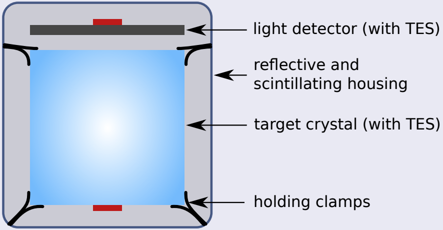
- started in July 2013
- 18 modules: $\sim$ 5kg target mass
- 12 conventional modules
- 6 modules with active recoil veto (three different new designs)

This talk: Focus on single module: TUM40

- 29kg-days of exposure
- nonblinded data set taken from August to December 2013

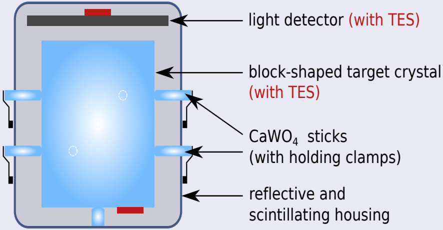
Conventional vs. Stick Design

Conventional Design



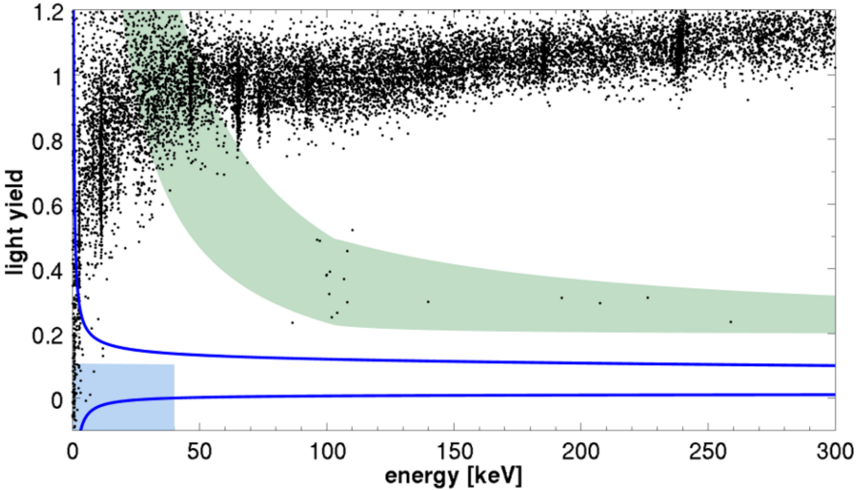
- non-scintillating holding clamps
- recoil background

Stick Design

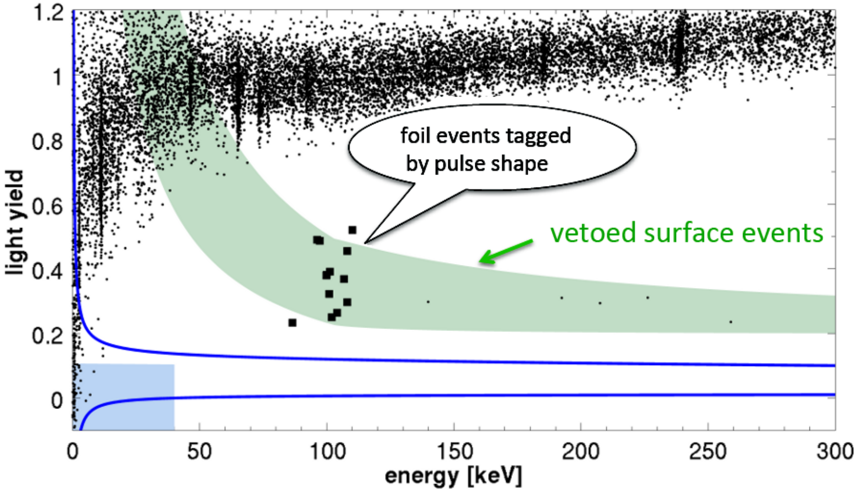


- fully-scintillating
- \+ effective veto for recoil background

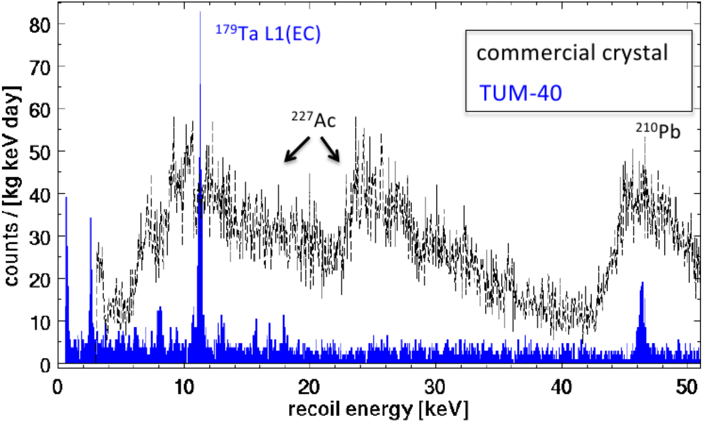
TUM40 - Veto of Surface Backgrounds



TUM40 - Veto of Surface Backgrounds



TUM40 - Radiopurity and Energy Resolution



- crystal growth at TUM $\rightarrow$ improvement of radiopurity by a factor 2-10
- γ-lines from cosmogenic activation

TUM40 - Summary

TUM40:

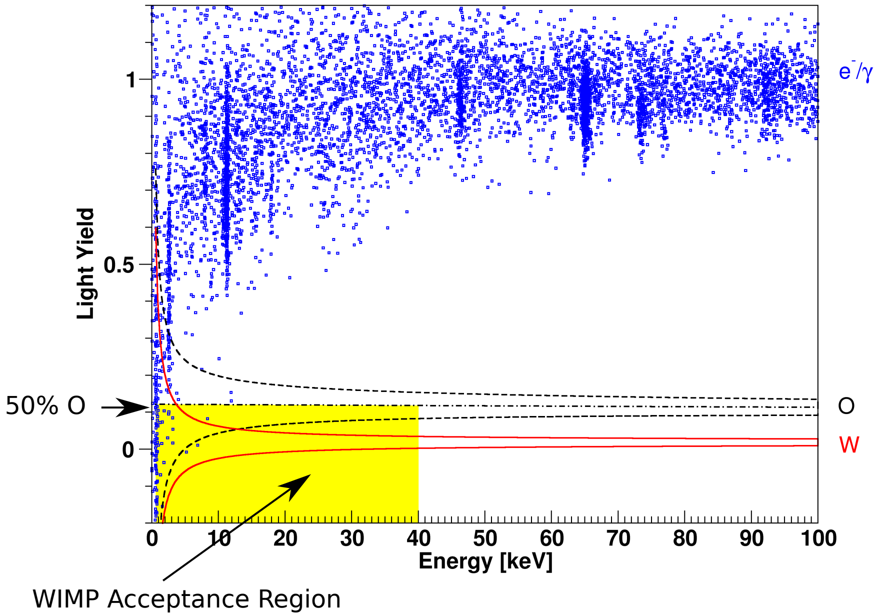
- efficient veto of recoil backgrounds
- best radiopurity of all crystals up to now
- very good energy resolution $\sigma < 100\,\text{eV}$
- very low trigger threshold of 600 eV

$\rightarrow$ low threshold analysis

`Results on low mass WIMPs using an upgraded CRESST-II detector`

- arXiv:1407.3146

Energy / light yield-plane



Yellin Methods

classic way

- number of expected events $\leftrightarrow$ number of observed events

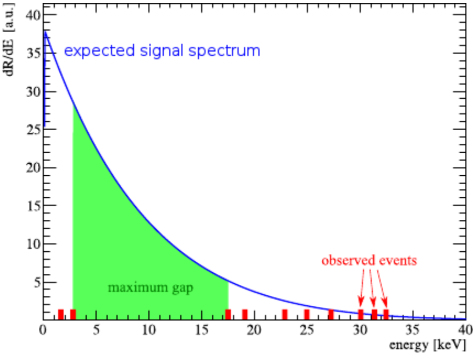
$\rightarrow$ Poissonian probabilities yield limit on WIMP-nucleon cross-section for each WIMP mass

but in case of background: too conservative

Yellin

- also take spectral information of expected signal into account

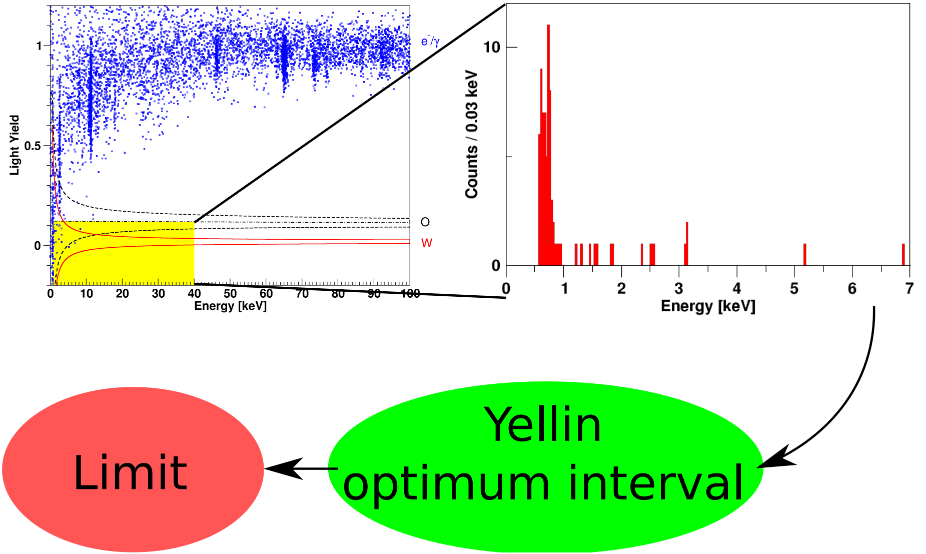
Yellin Maximum Gap



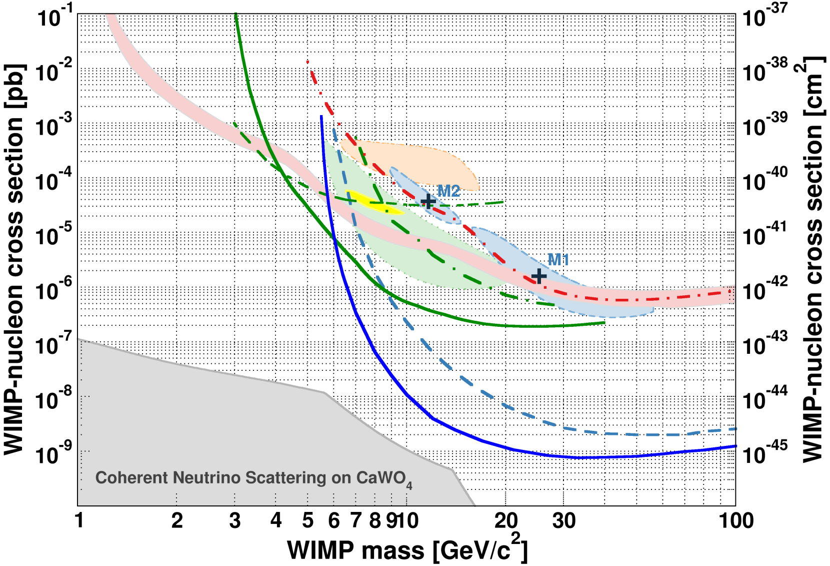
- Generalization to *optimum interval*: Do not only consider largest gap ($N_{events} = 0$), but also largest interval with $N_{events} = 1,2,3 \ldots$

$\rightarrow$ optimum interval method was used for this analysis

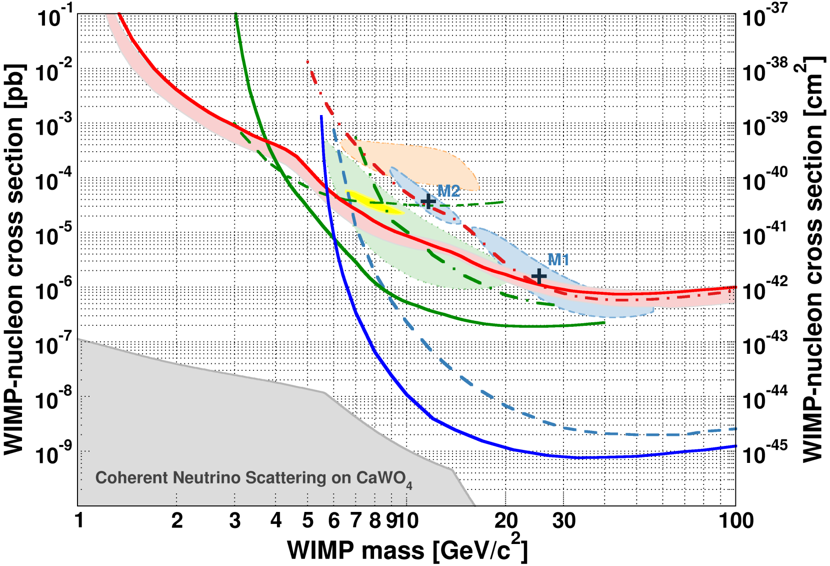
Acceptance Region



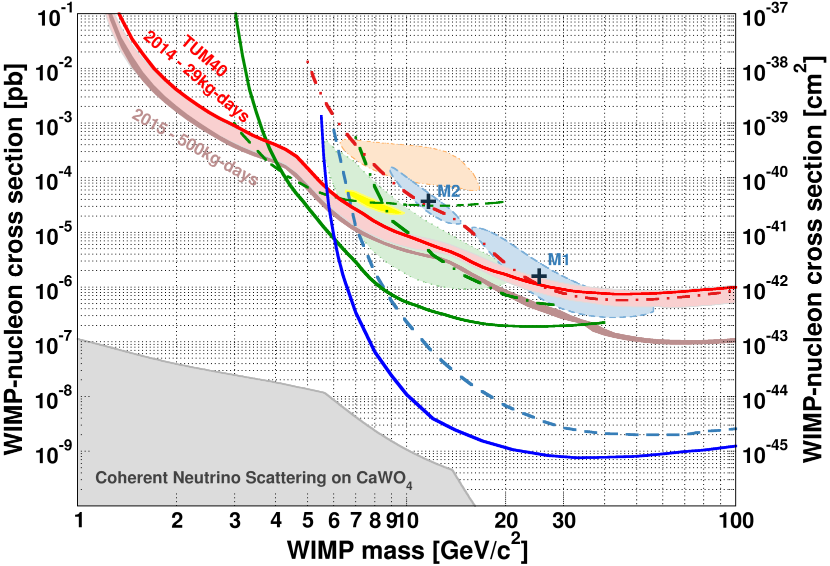
WIMP Parameter Space - Simulation 29 kg-days



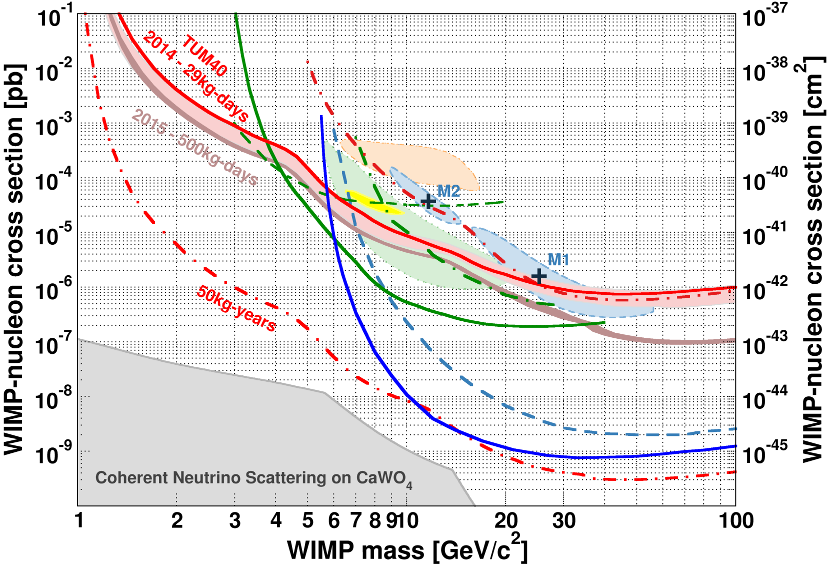
WIMP Parameter Space - Data 29 kg-days



WIMP Parameter Space - End of this Run



WIMP Parameter Space - Future Potential



Conclusion and Perspectives

TUM40:

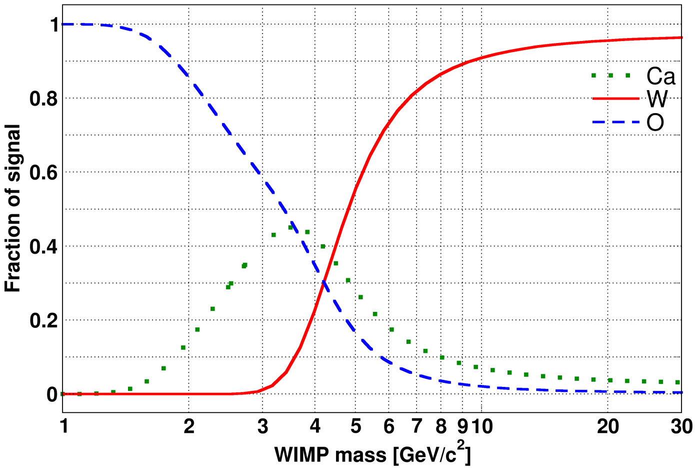
- new working design with efficient active recoil veto
- crystals with significantly improved radiopurity

→ WIMP parameter space ($< 3\,\text{GeV}/\text{c}^2$) explored with a single detector and 29kg-days of exposure

- realistic improvements → substantial gains for low WIMP masses possible

Backup

Signal Composition



Recoil Rates and Spectrum

total interaction rate:

$$R = \frac{M_{\text{target}}}{m_N} \cdot \frac{\rho_\chi}{m_\chi} \cdot \nu \cdot \sigma(\nu)$$

local WIMP flux

WIMP-nucleon cross section

number of nuclei in target

WIMP velocity

differential rate (counts per kg, day and keV recoil energy):

$$\frac{dR}{dE_R} = \frac{\rho_\chi}{m_N m_\chi} \cdot \int_{v_{\text{min}}}^{v_{\text{esc}}} d^3\nu \, f(\vec{\nu}) \nu \, \frac{d\sigma(\vec{v}, E_R)}{dE_r}$$

galactic escape velocity

velocity distribution

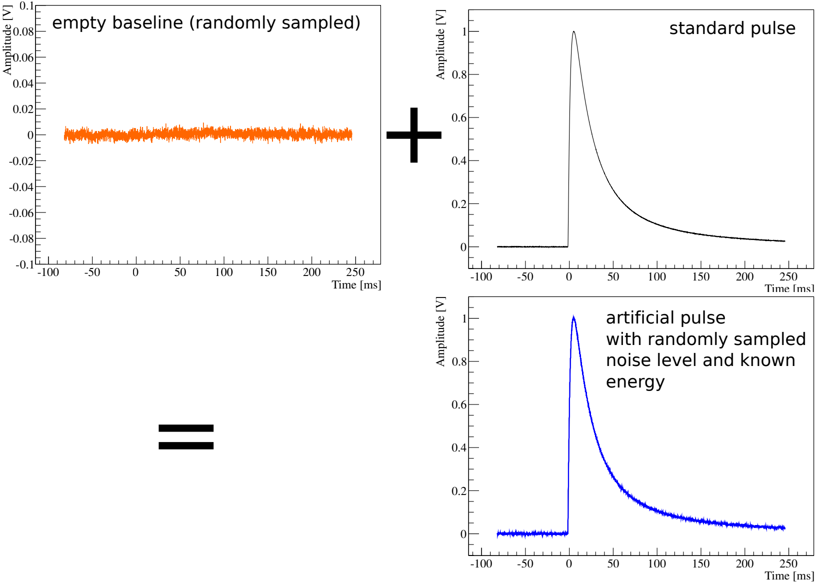
WIMP-nucleon cross section

minimal velocity to produce a recoil above threshold

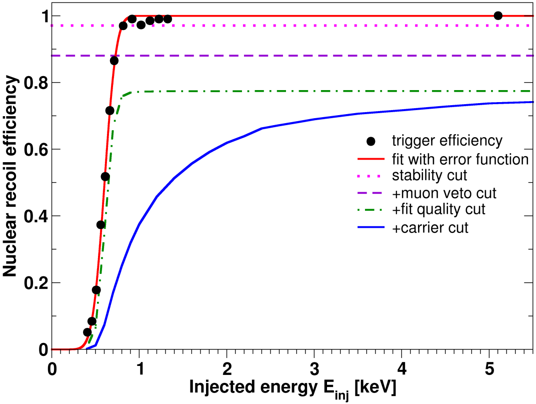
~ A^2

~ form factor

TUM40 - Cut Efficiencies - Determination

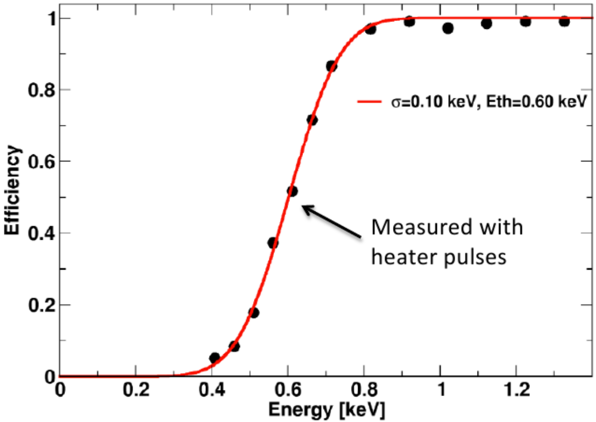


TUM40 - Cut Efficiencies - Result

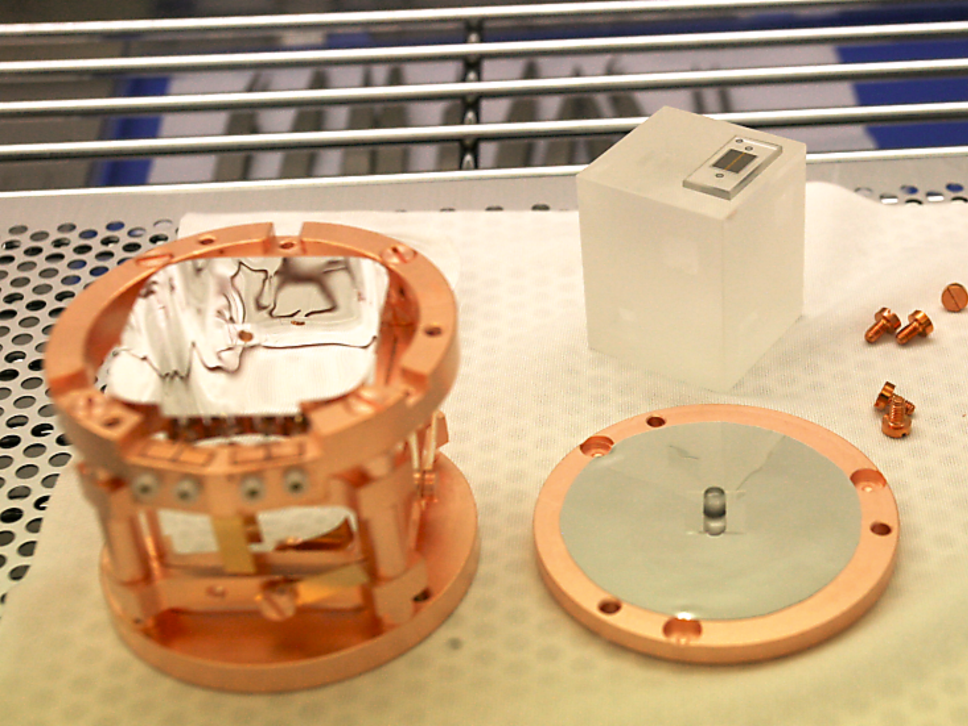


- no time dependence (= stable noise conditions)

TUM40 - Trigger Threshold



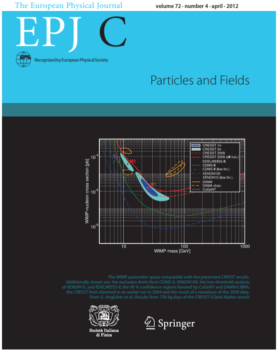
- very low threshold: ∼600eV
- long-term stability



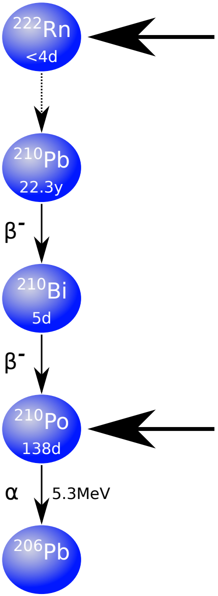
The Previous CRESST Run 32

- extensive physics run between June 2009 and April 2011
- 8 $CaWO_4$ modules used for Dark Matter analysis
- total net exposure (after cuts): **730 kg days**

- **67 events observed in WIMP search regions**
- maximum likelihood analysis
- *Results from 730 kg days of the CRESST-II Dark Matter Search* Eur. Phys. J. C (2012) 72-1971



Origin of ^{206}Pb Recoil Background



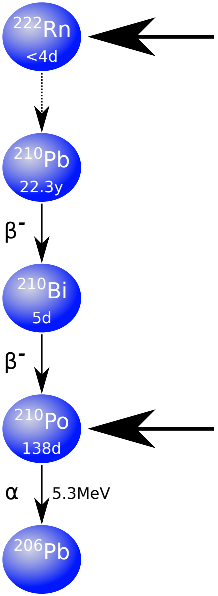
- absorption of ^{222}Rn

$\rightarrow$ ^{210}Po has to build up first $\rightarrow$ increasing rate

- direct deposition of ^{210}Po (in coating of clamps)

$\rightarrow$ decreasing rate

Origin of ^{206}Pb Recoil Background



- absorption of ^{222}Rn

→ ^{210}Po has to build up first → increasing rate

observation

- increasing rate at low energies (<<100keV)
- decreasing rate at full recoil energy ($\sim$ 100keV)

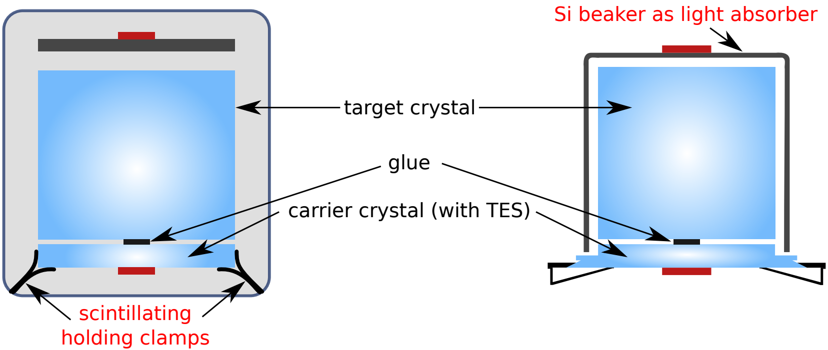
→ both origins contribute

→ **rate at low energies dominated by ^{222}Rn**

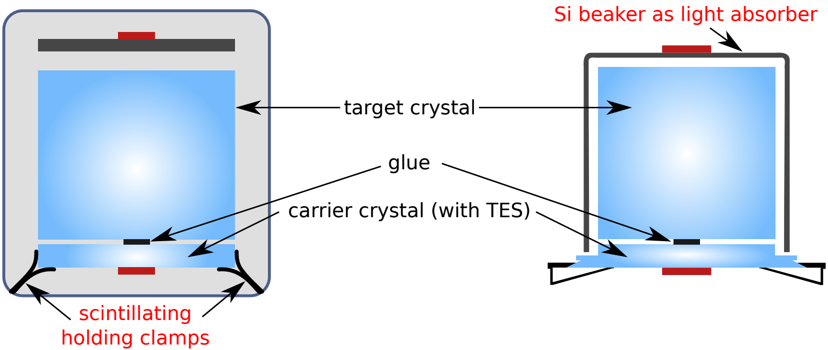
- direct deposition of ^{210}Po (in coating of clamps)

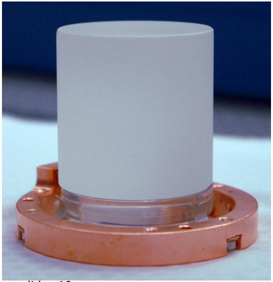
→ decreasing rate

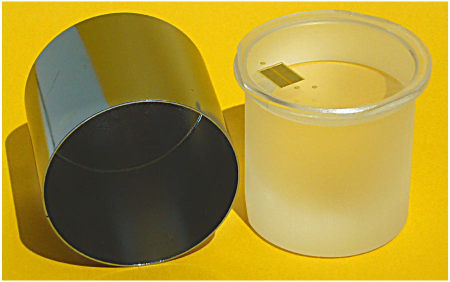
Fully-Scintillating Designs



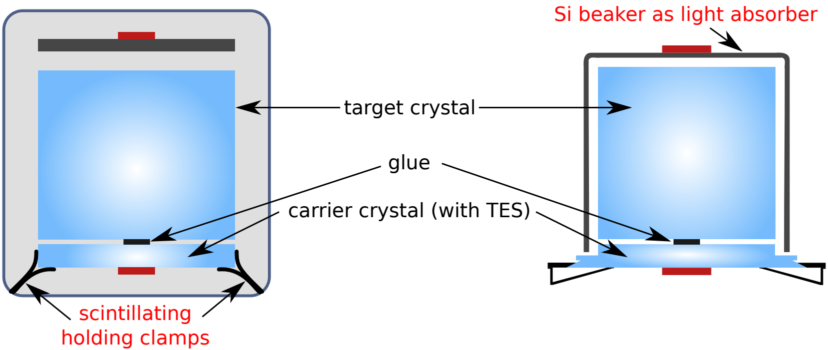
Fully-Scintillating Designs





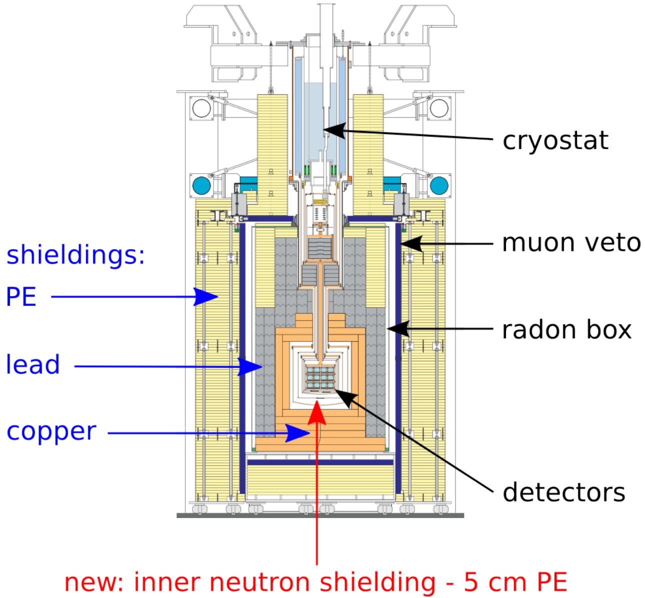


Fully-Scintillating Designs

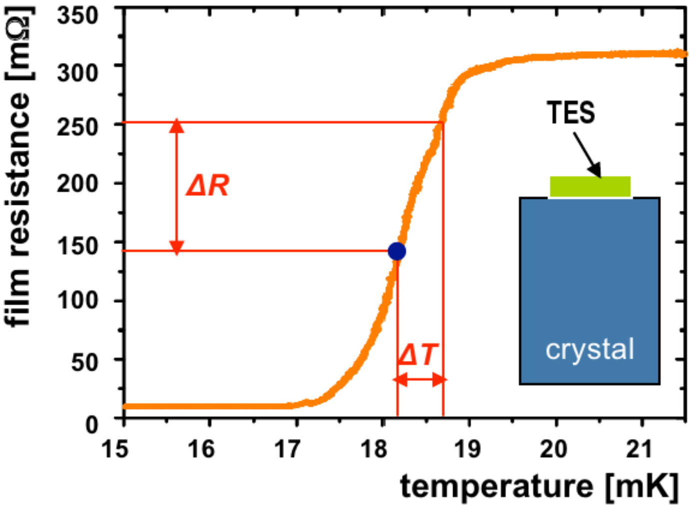


crucial: discrimination between events in carrier and target crystal

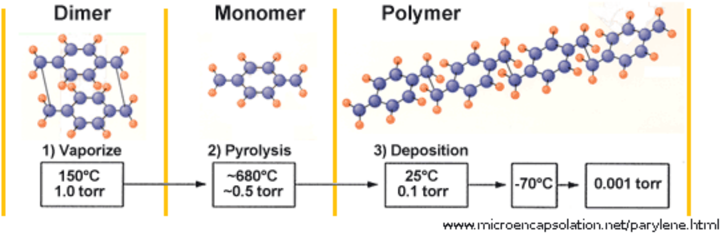
Experimental setup at Gran Sasso Underground Laboratory



Transition Edge Sensor (TES)



Parylene Coating of Reflective and Scintillating Foil



- Exposure of foil to radon-contaminated air cannot be controlled (commercial product).
- strategy: cover/seal foil with Parylene to reset the foils "Rn-history"
- Parylene scintillates (twice as well as the foil)
- clean raw material available

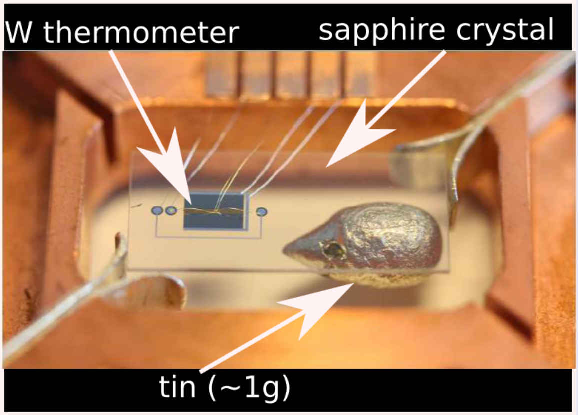
^{210}Pb Activity of Tin

K. Schäffner, PhD Thesis, 2013

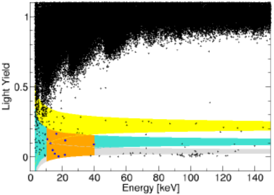
turn a piece of tin into a cryodetector

- tin is source and absorber
- count number of ^{210}Po-decays

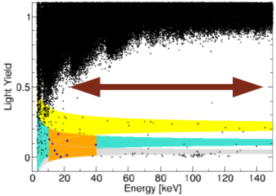
$\rightarrow$ limit:
tin: < 28.2mBq/kg



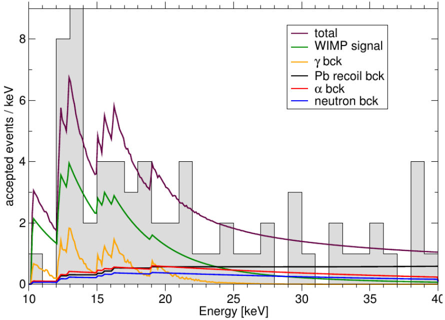
Spectral Distribution of Signal Events



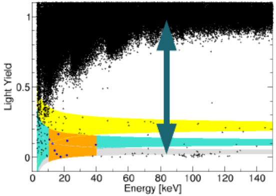
Spectral Distribution of Signal Events



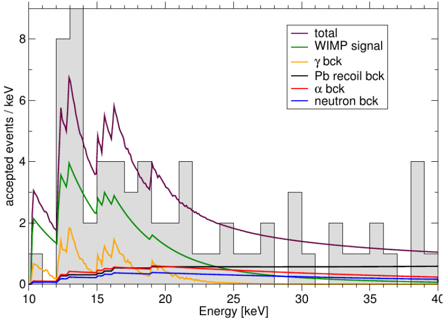
energy distribution (only M1)



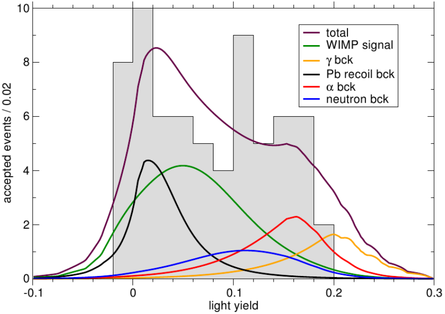
Spectral Distribution of Signal Events



energy distribution (only M1)



light yield distribution (only M1)

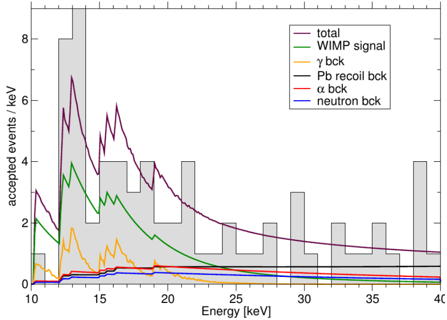


Spectral Distribution of Signal Events

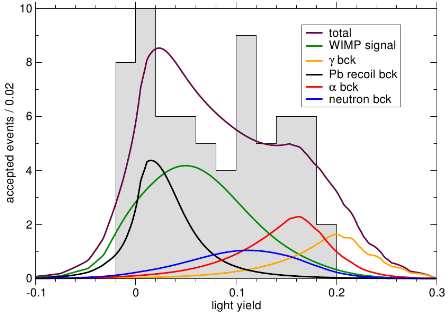
- shape of energy spectra of γ-leakage and possible WIMP signal seem compatible

$\rightarrow$ underestimation of γ-leakage?

energy distribution (only M1)



light yield distribution (only M1)



Spectral Distribution of Signal Events

- shape of energy spectra of γ-leakage and possible WIMP signal seem compatible

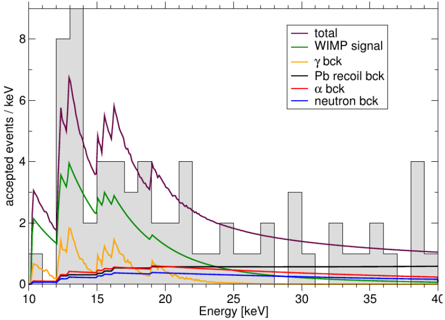
$\rightarrow$ underestimation of γ-leakage?

but

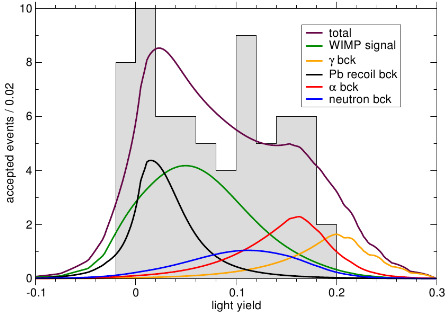
- γ-leakage appears at high light yields
- possible WIMP signal at low light yields

$\rightarrow$ γ-leakage ruled out as explanation for the excess

energy distribution (only M1)



light yield distribution (only M1)

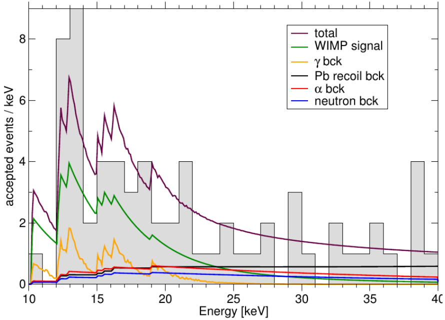


Spectral Distribution of Signal Events

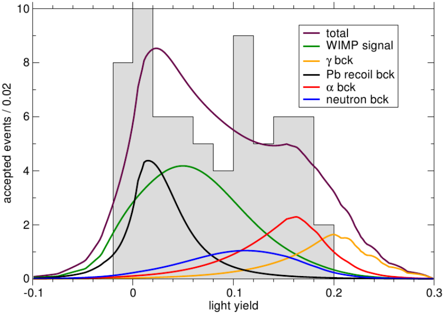
The other way round:

- Only the Pb recoil background has similar light yield as the possible WIMP signal

energy distribution (only M1)



light yield distribution (only M1)



Spectral Distribution of Signal Events

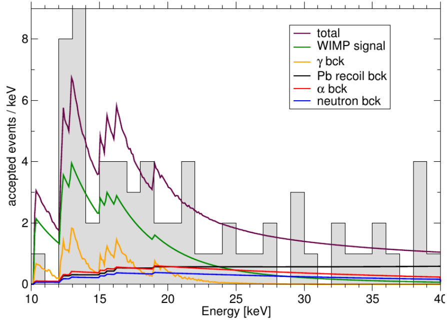
- energy spectrum of Pb recoils incompatible with possible WIMP signal

but

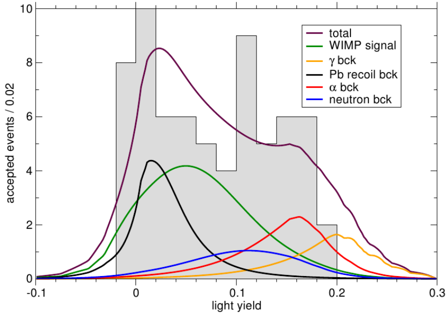
The other way round:

- Only the Pb recoil background has similar light yield as the possible WIMP signal

energy distribution (only M1)



light yield distribution (only M1)

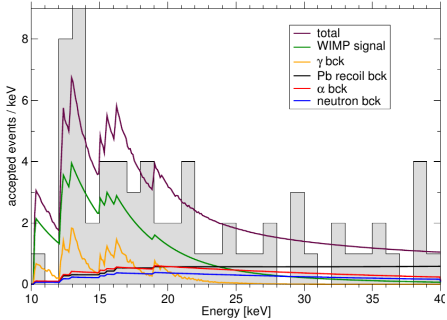


Spectral Distribution of Signal Events

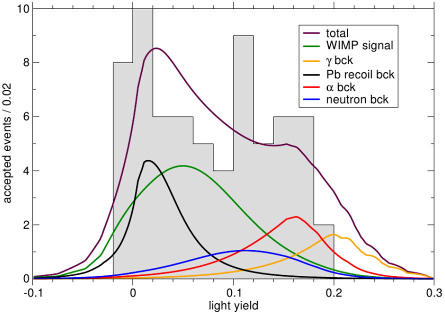
Conclusion:

- Simultaneous measurement of phonon and light is crucial to discriminate a possible WIMP signal from background.
- The excess can not be explained with the known backgrounds alone.

energy distribution (only M1)



light yield distribution (only M1)

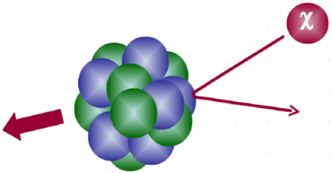


Direct Dark Matter Search with the CRESST Experiment

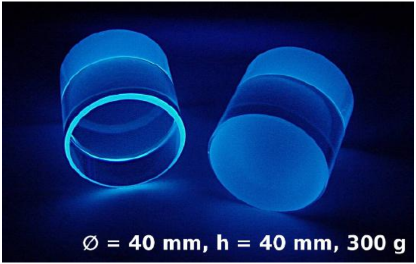
- **C**ryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers
- **W**eakly **I**nteracting **M**assive **P**article

CRESST

- aims for a WIMP detection via their elastic scattering off nuclei.



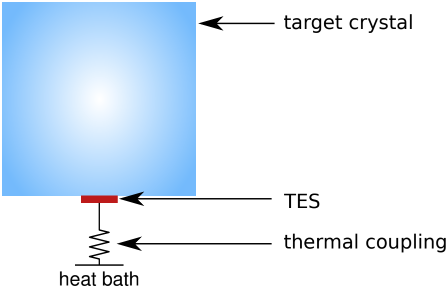
- uses scintillating $CaWO_4$ crystals as target material.



CRESST Detectors - Working Principle

- particle interactions in the crystal $\rightarrow$ mainly excitation of phonons
- temperature rise ($\mathcal{O}(\mu K)$) is detected with W thermometers (TES)

$\rightarrow$ measurement of deposited energy (few keV)



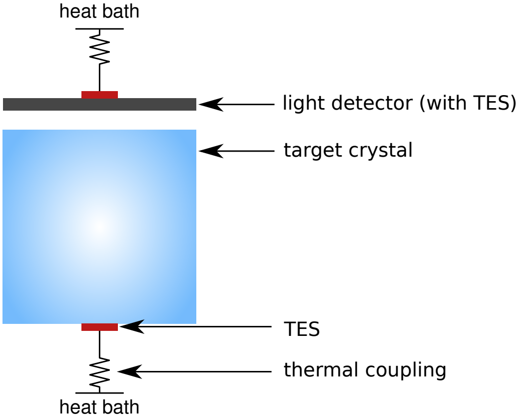
CRESST Detectors - Working Principle

- particle interactions in the crystal $\rightarrow$ mainly excitation of phonons
- temperature rise ($\mathcal{O}(\mu K)$) is detected with W thermometers (TES)

$\rightarrow$ measurement of deposited energy (few keV)

- small fraction of deposited energy $\rightarrow$ scintillation light

$\rightarrow$ add cryogenic light detector $\rightarrow$ detector module



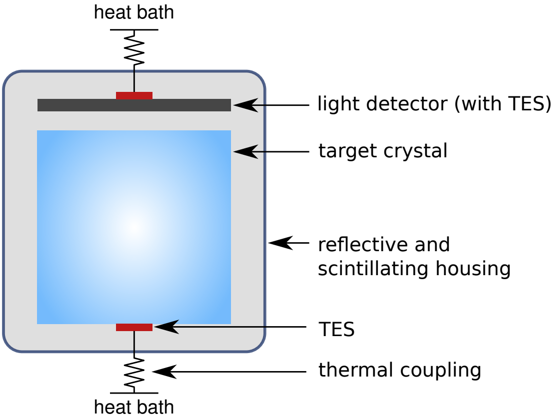
CRESST Detectors - Working Principle

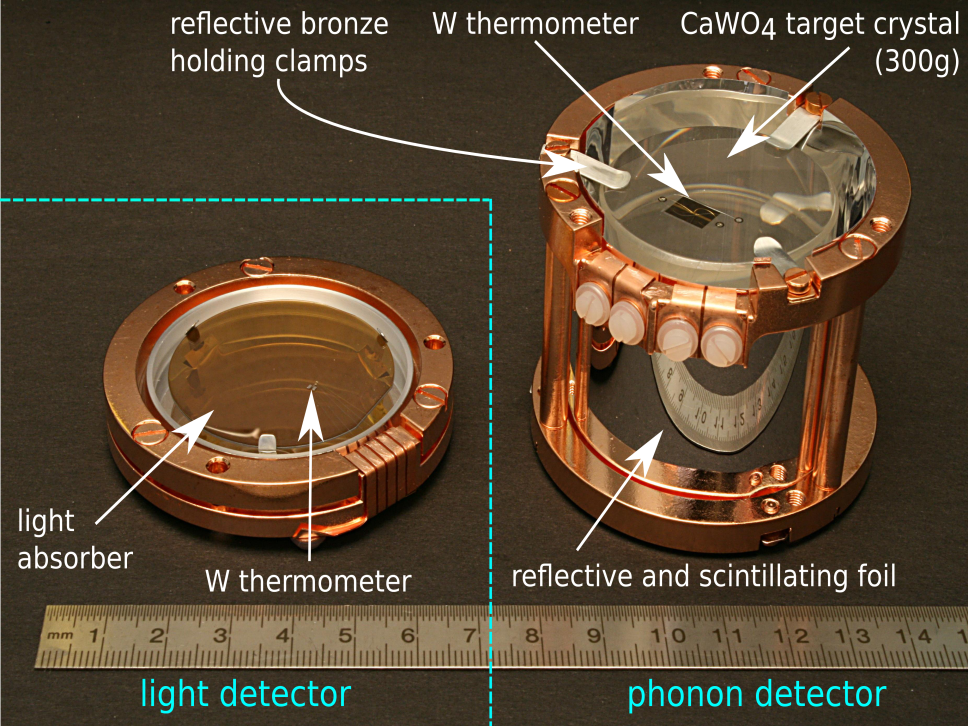
- particle interactions in the crystal → mainly excitation of phonons
- temperature rise ($\mathcal{O}(\mu K)$) is detected with W thermometers (TES)

→ measurement of deposited energy (few keV)

- small fraction of deposited energy → scintillation light

→ add cryogenic light detector → detector module

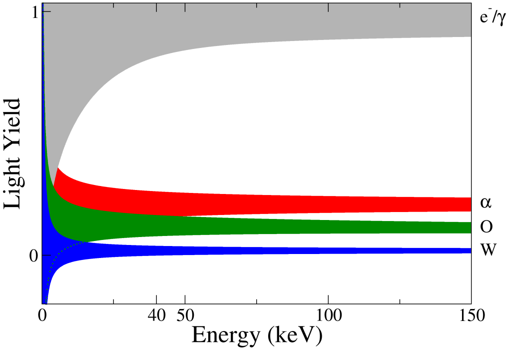



reflective bronze
holding clamps
W thermometer
CaWO4 target crystal
(300g)
light
absorber
W thermometer
reflective and scintillating foil
light detector
phonon detector

CRESST Detectors - Event-by-Event Discrimination

$$\text{light yield} = \frac{\text{light signal}}{\text{phonon signal}}$$

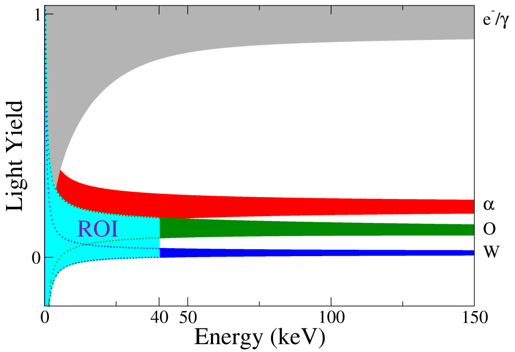
Different event types have a **characteristic** light yield.



CRESST Detectors - Event-by-Event Discrimination

$$\text{light yield} = \frac{\text{light signal}}{\text{phonon signal}}$$

Different event types have a **characteristic** light yield.



excellent discrimination between:

- e^--recoils: dominant radioactive background
- nuclear recoils: potential signal events