my favorite topic:
CRESST - Heading for new Dark Matter Results

Florian Reindl (MPP Munich)

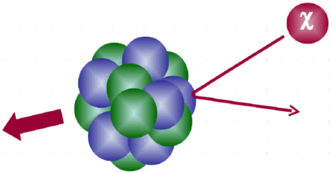
Particle Physics School Munich Colloquium, June 2014

Direct Dark Matter Search with the CRESST Experiment

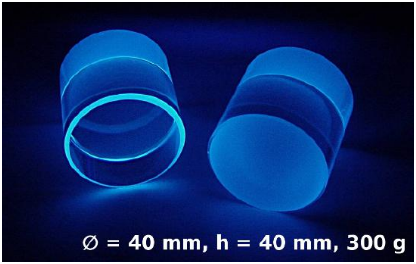
- **C**ryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers
- **W**eakly **I**nteracting **M**assive **P**article

CRESST

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



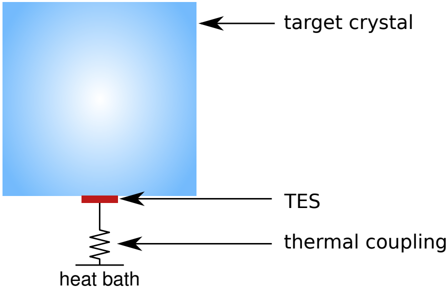
- uses scintillating $CaWO_4$ crystals as target material.



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)



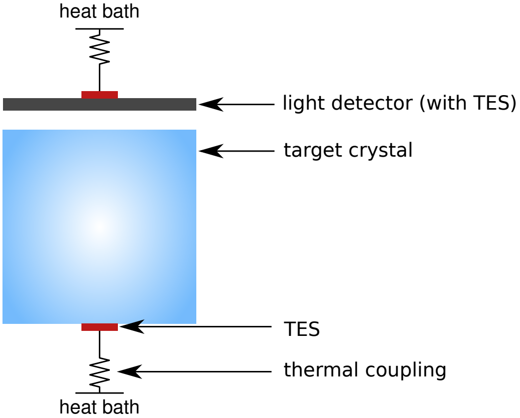
CRESST Detectors - Working Principle

- 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



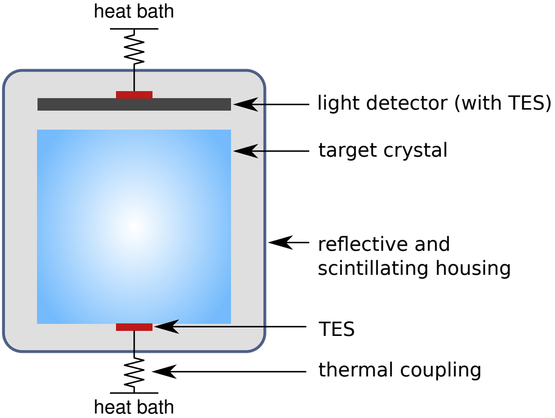
CRESST Detectors - Working Principle

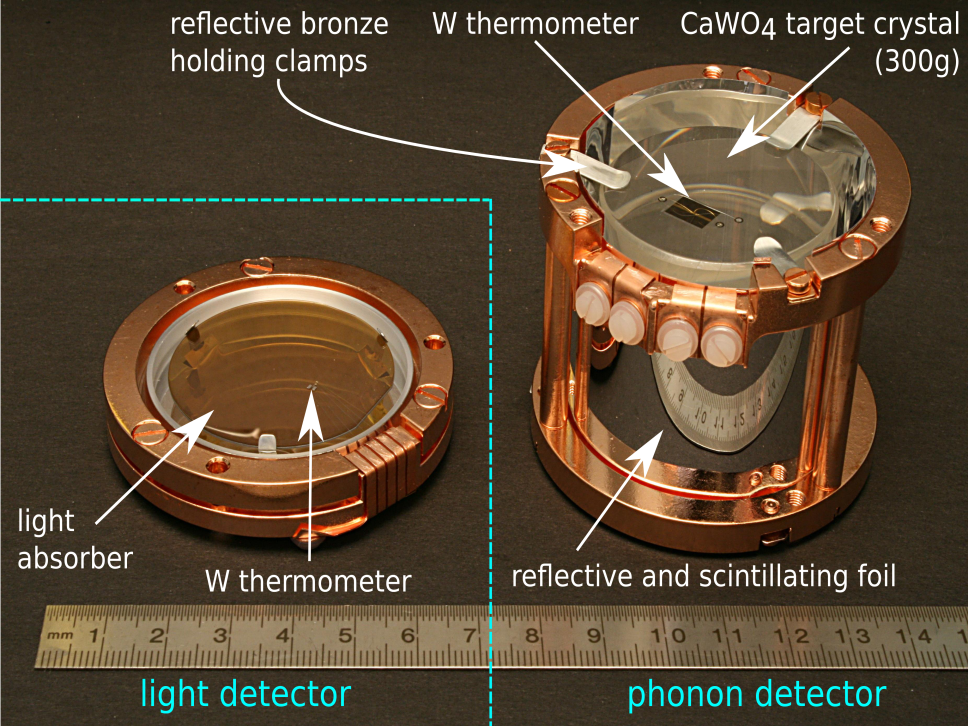
- particle interactions in the crystal $\rightarrow$ mainly excitation of phonons
- temperature rise ($\mathcal{O}(\mu K)$) is detected with W thermometers (TES)

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

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

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



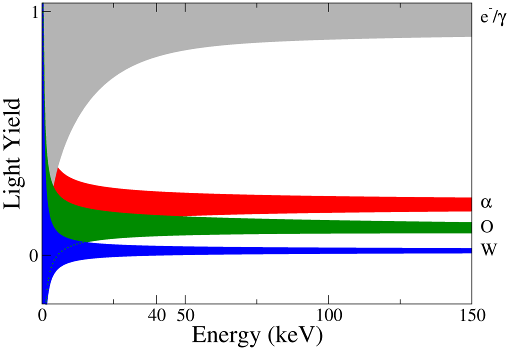


reflective bronze holding clamps
W thermometer
CaWO4 target crystal (300g)
light absorber
W thermometer
reflective and scintillating foil
light detector
phonon detector

CRESST Detectors - Event-by-Event Discrimination

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

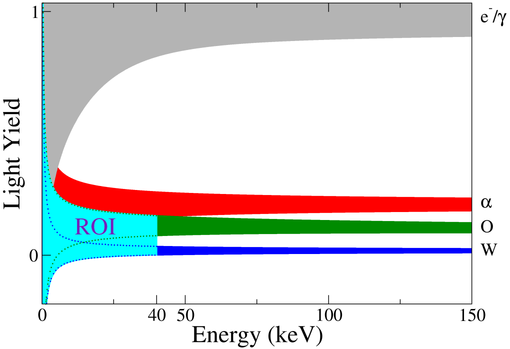
Different event types have a **characteristic** light yield.



CRESST Detectors - Event-by-Event Discrimination

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

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

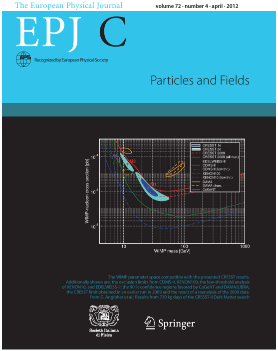


excellent discrimination between:

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

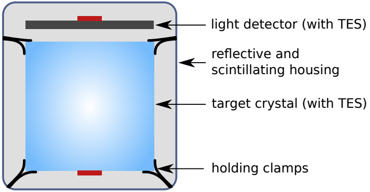
The Previous CRESST Run 32

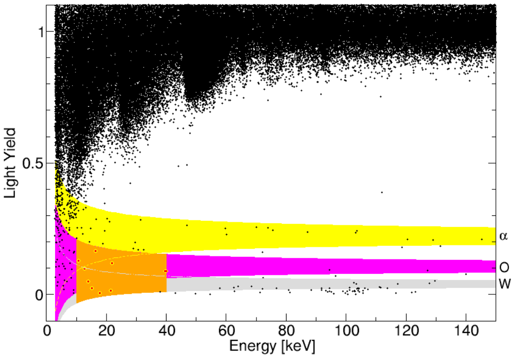
- extensive physics run between June 2009 and April 2011
- 8 $CaWO_4$ modules used for Dark Matter analysis
- total net exposure (after cuts): **730 kg days**



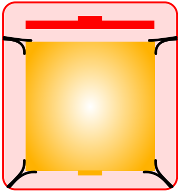
- **67 events observed in WIMP search regions**
- maximum likelihood analysis
- *Results from 730 kg days of the CRESST-II Dark Matter Search* Eur. Phys. J. C (2012) 72-1971

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





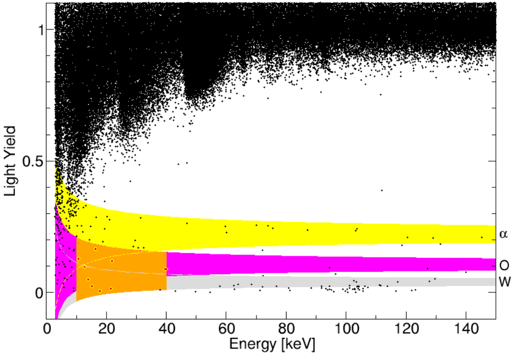
Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)



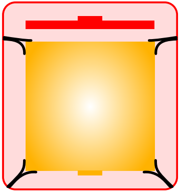
light signal

phonon (and) light signal

no signal



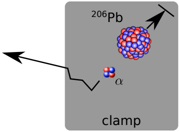
Bck. Induced by $^{210}Po \rightarrow {}^{206}Pb$ (103 keV) + α (5.3 MeV)

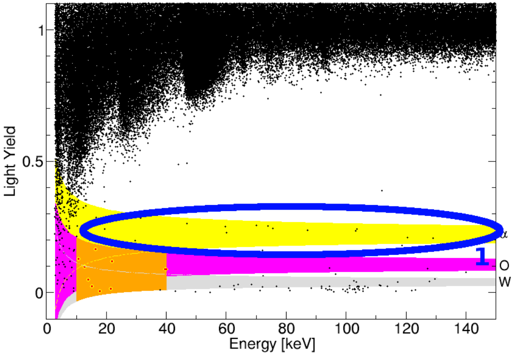


light signal

phonon (and)
light signal

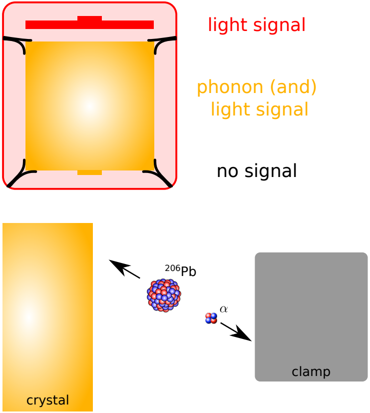
no signal

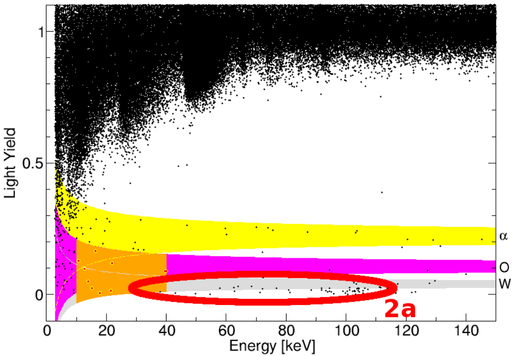




1. decay inside clamp material

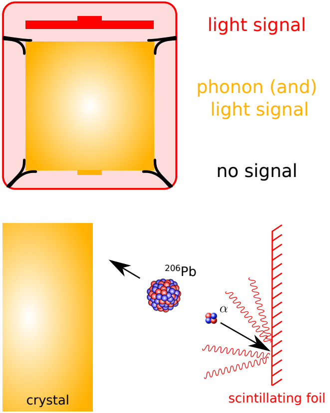
Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)

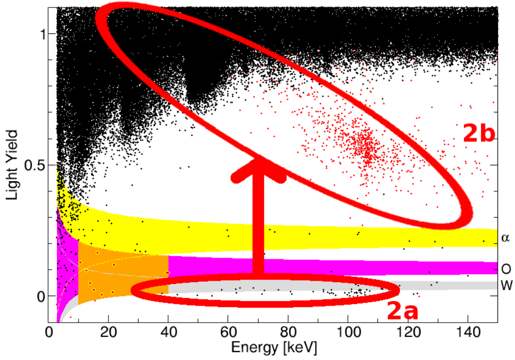




1. decay inside clamp material
2. decay on or slightly below surface of clamp
   (a) α hitting clamp $\rightarrow$ **no** scintillation light

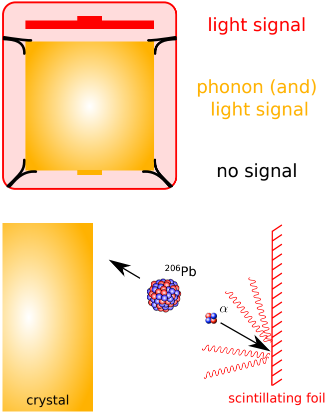
Bck. Induced by $^{210}Po \rightarrow {}^{206}Pb$ (103 keV) + α (5.3 MeV)

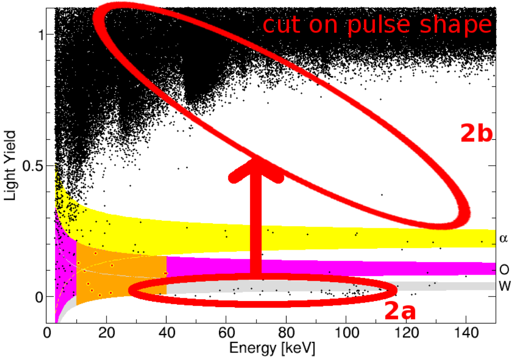




1. decay inside clamp material
2. decay on or slightly below surface of clamp
   (a) α hitting clamp $\rightarrow$ **no** scintillation light
   (b) α hitting foil $\rightarrow$ additional scintillation light from foil (with different pulse shape)

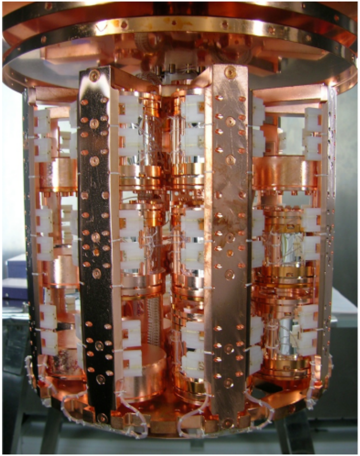
Bck. Induced by ^{210}Po $\rightarrow$ ^{206}Pb (103 keV) + α (5.3 MeV)





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)

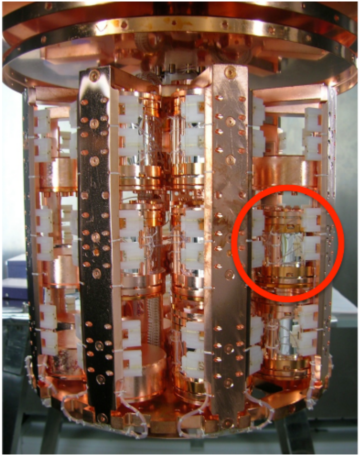
The Current Run 33 - Detector Upgrade



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:

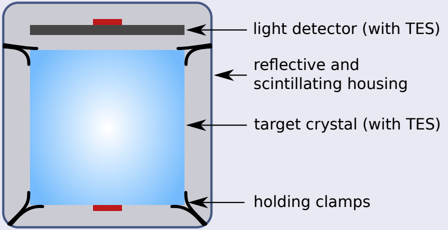
- started in July 2013
- 18 modules: $\sim$ 5kg target mass
- 12 conventional modules
- 6 modules with active recoil veto (three different new designs)

This talk: Focus on single module: TUM40

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

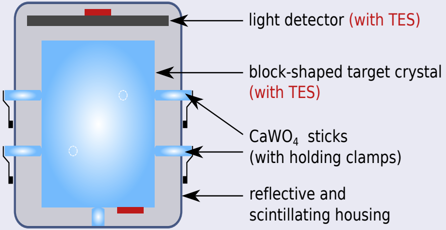
Conventional vs. Stick Design

Conventional Design

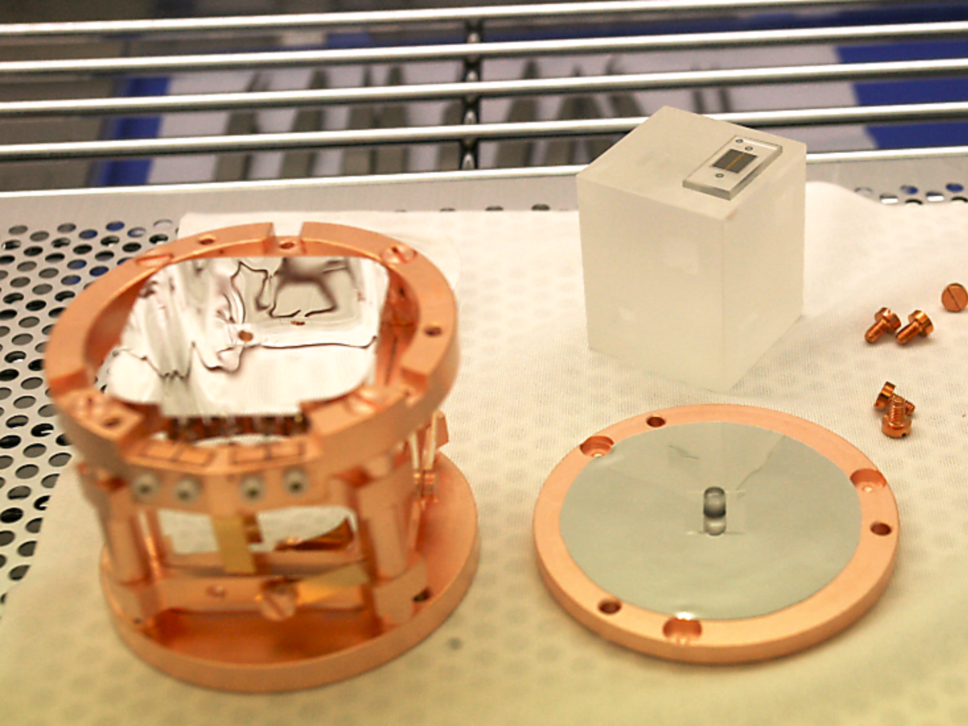


- non-scintillating holding clamps
- recoil background

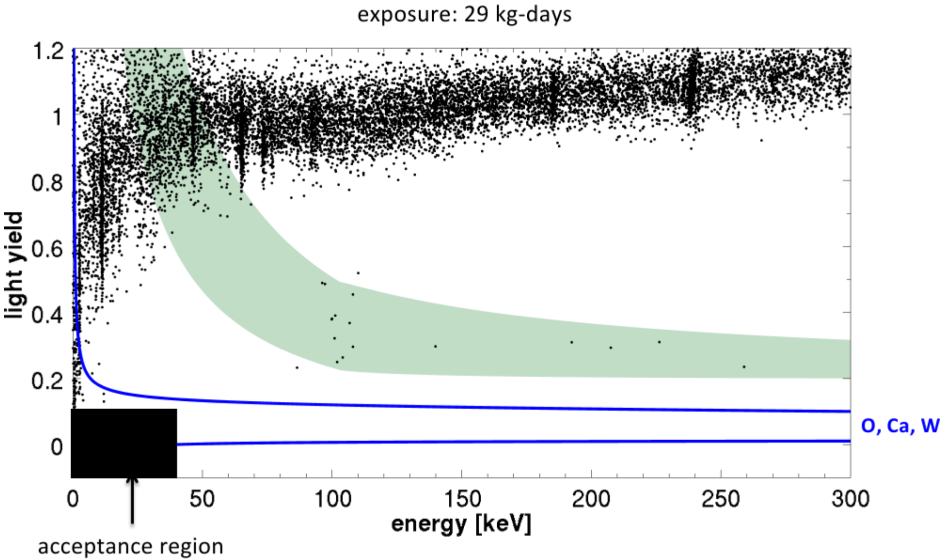
Stick Design



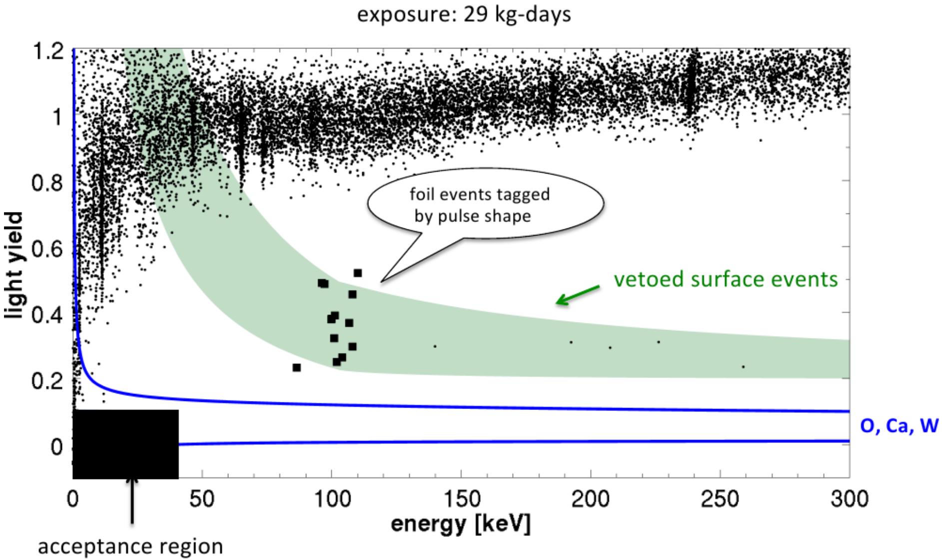
- fully-scintillating
- + effective veto for recoil background



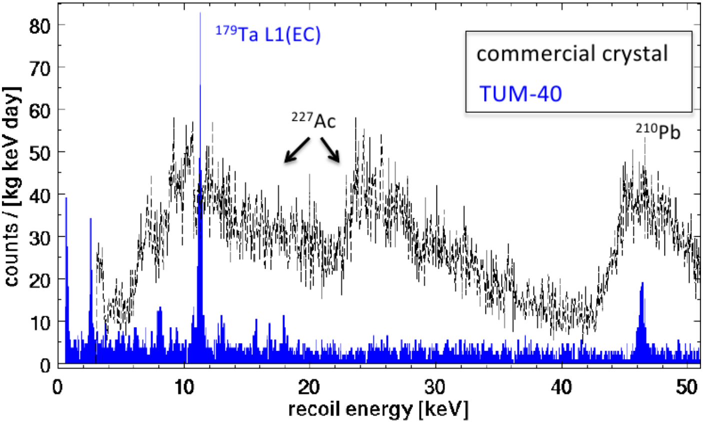
TUM40 - Veto of Surface Backgrounds



TUM40 - Veto of Surface Backgrounds

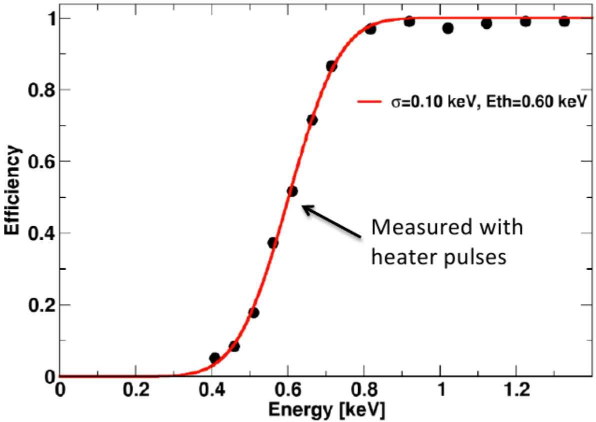


TUM40 - Radiopurity and Energy Resolution



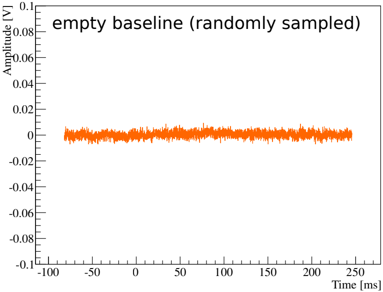
- crystal growth at TUM $\rightarrow$ improvement of radiopurity by a factor 2-10
- energy resolution: $\sigma < 100$eV
- γ-lines from cosmogenic activation
- γ-lines match with tabulated values (Δ <5eV)

TUM40 - Trigger Threshold

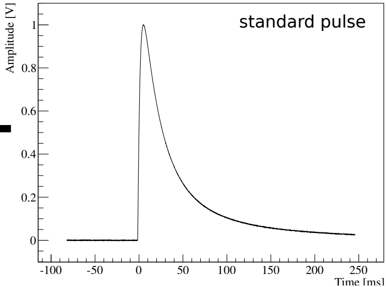


- very low threshold: $\sim$600eV
- long-term stability

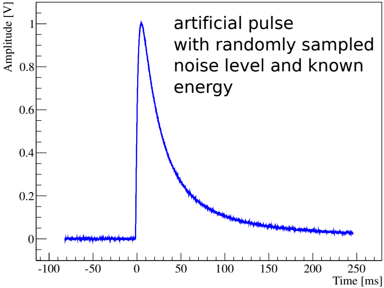
TUM40 - Cut Efficiencies - Determination



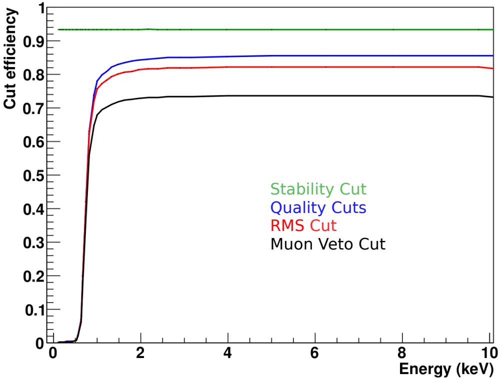
+



=



TUM40 - Cut Efficiencies - Result



- no time dependence (= stable noise conditions)

TUM40 - Summary

- efficient veto of recoil backgrounds
- best radiopurity of all crystals up to now
- very good energy resolution
- very low trigger threshold

$\rightarrow$ low threshold analysis

Recoil Rates and Spectrum

total interaction rate:

local WIMP flux

WIMP-nucleon cross section

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

number of nuclei in target

WIMP velocity

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

galactic escape velocity

velocity distribution

WIMP-nucleon cross section

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

minimal velocity to produce a recoil above threshold

~ A^2

~ form factor

Yellin Methods

classic way

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

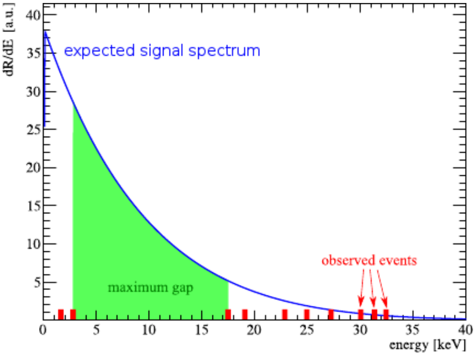
$\rightarrow$ Poissonian probabilities yield limit on WIMP-nucleon cross-section for each WIMP mass

but in case of background: too conservative

Yellin

- also take spectral information of expected signal into account

Yellin Maximum Gap

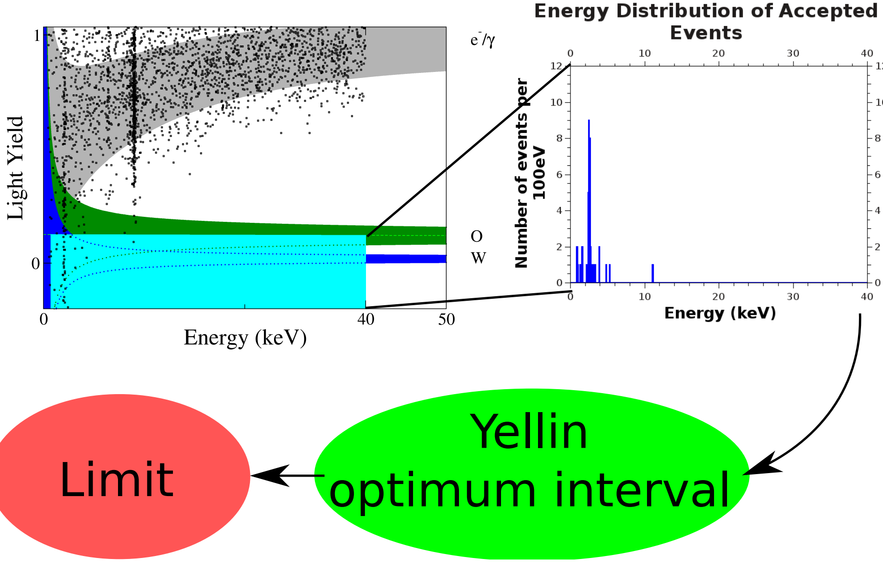


- Generalization to *optimum interval*: Do not only consider largest gap ($N_{events} = 0$), but also largest interval with $N_{events} = 1,2,3 \ldots$

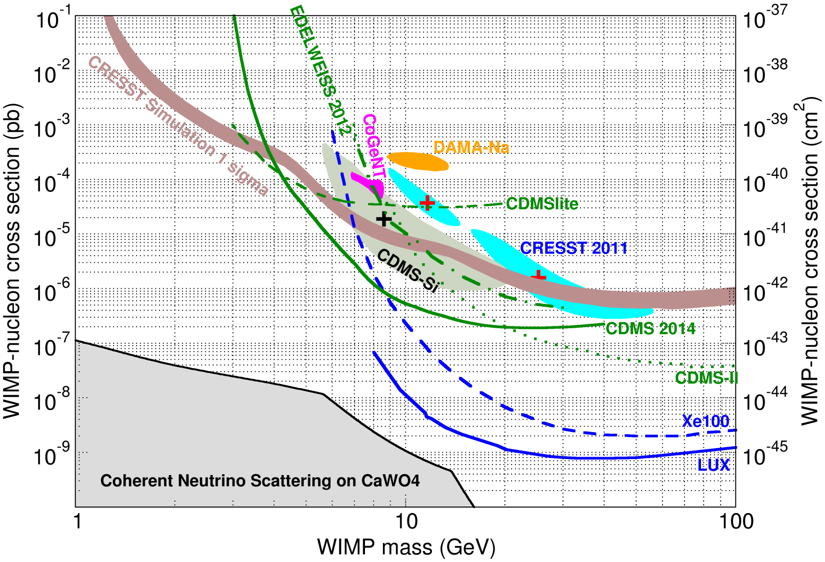
$\rightarrow$ optimum interval method was used for this analysis

Acceptance Region

explained on the basis of simulated data



WIMP Parameter Space



Conclusion and Perspectives

TUM40:

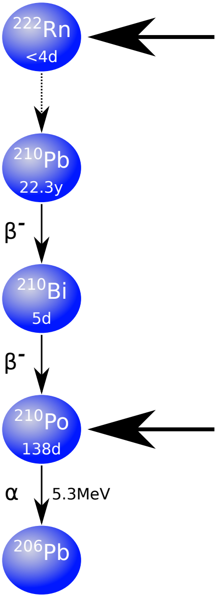
- new working designs with efficient active recoil veto
- new crystal with significantly improved radiopurity

$\rightarrow$ New WIMP parameter space explored with a single detector and 29kg days of exposure

@Ringberg: Real Limit

Backup

Origin of ^{206}Pb Recoil Background



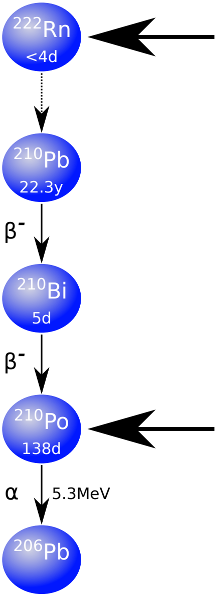
- absorption of ^{222}Rn

$\rightarrow$ ^{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

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

observation

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

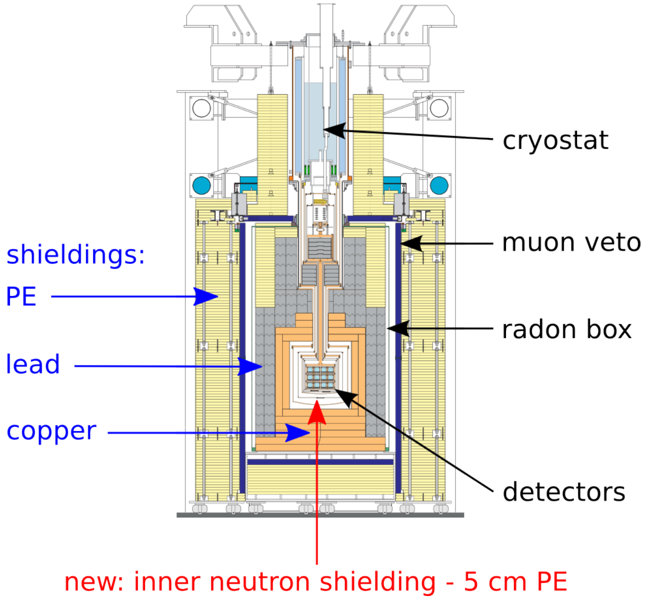
$\rightarrow$ both origins contribute

$\rightarrow$ **rate at low energies dominated by ^{222}Rn**

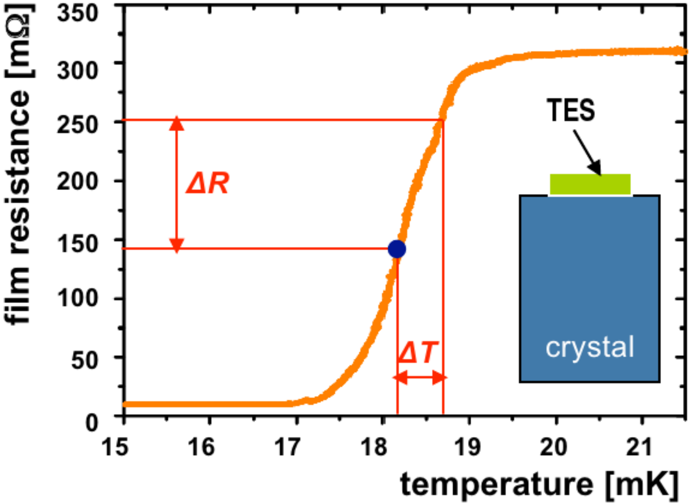
- direct deposition of ^{210}Po (in coating of clamps)

$\rightarrow$ decreasing rate

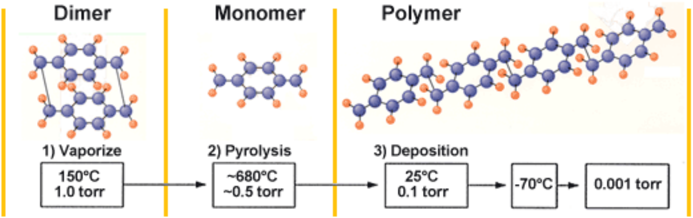
Experimental setup at Gran Sasso Underground Laboratory



Transition Edge Sensor (TES)



Parylene Coating of Reflective and Scintillating Foil



www.microencapsolation.net/parylene.html

- 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

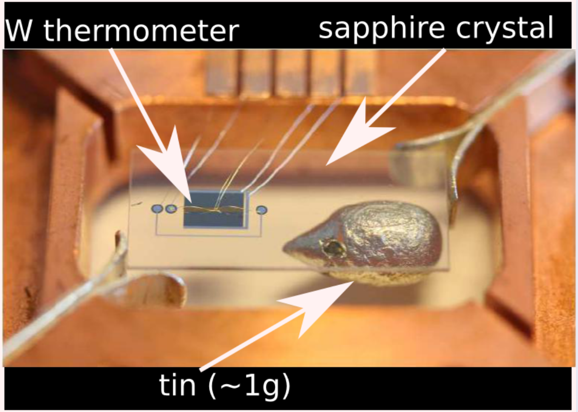
^{210}Pb Activity of Tin

K. Schäffner, PhD Thesis, 2013

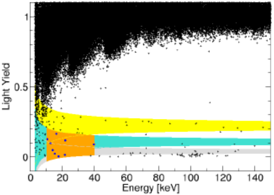
turn a piece of tin into a cryodetector

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

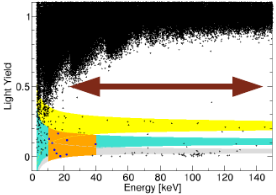
$\rightarrow$ limit:
tin: < 28.2mBq/kg



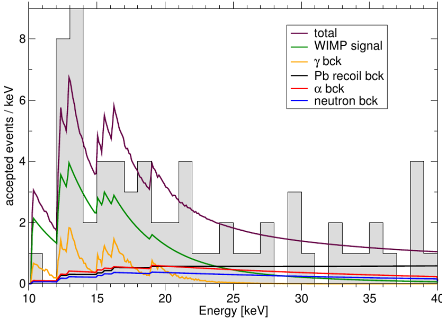
Spectral Distribution of Signal Events



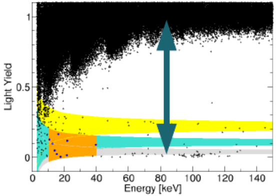
Spectral Distribution of Signal Events



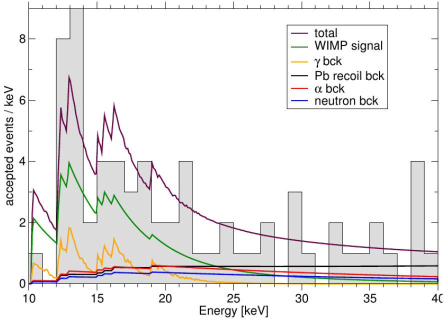
energy distribution (only M1)



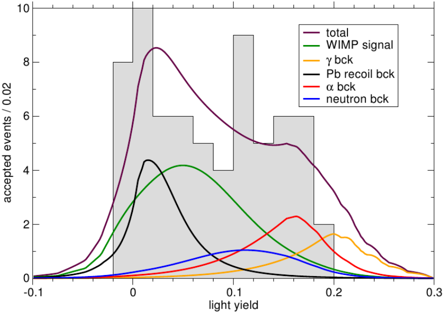
Spectral Distribution of Signal Events



energy distribution (only M1)



light yield distribution (only M1)

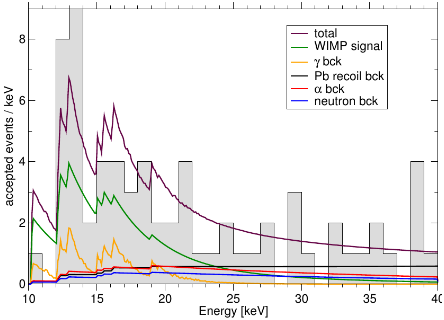


Spectral Distribution of Signal Events

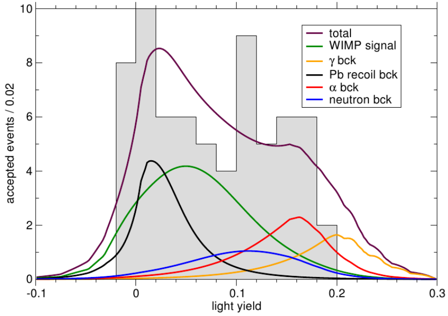
- shape of energy spectra of γ-leakage and possible WIMP signal seem compatible

$\rightarrow$ 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

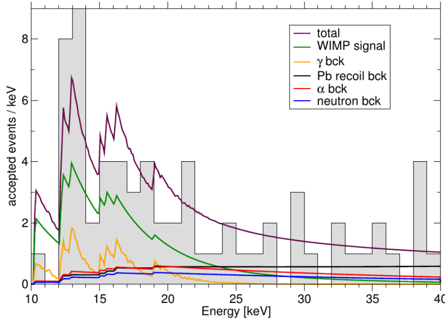
→ underestimation of γ-leakage?

but

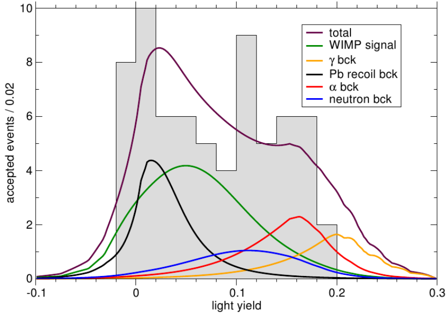
- γ-leakage appears at high light yields
- possible WIMP signal at low light yields

→ γ-leakage ruled out as explanation for the excess

energy distribution (only M1)



light yield distribution (only M1)

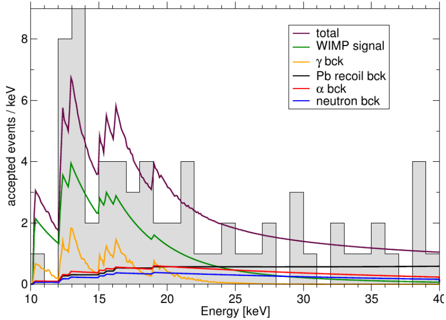


Spectral Distribution of Signal Events

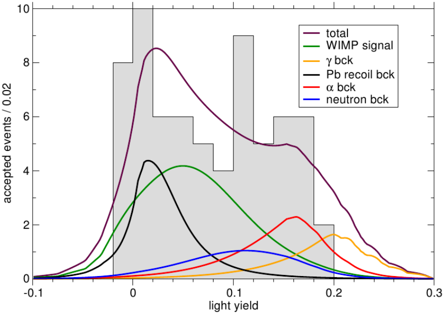
The other way round:

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

energy distribution (only M1)



light yield distribution (only M1)



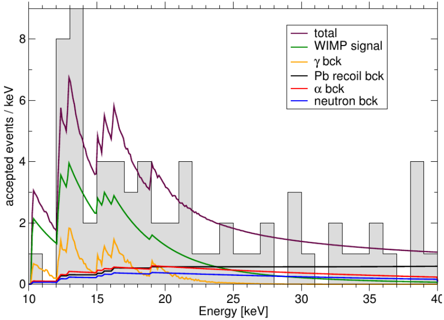
Spectral Distribution of Signal Events

- energy spectrum of Pb recoils incompatible with possible WIMP signal

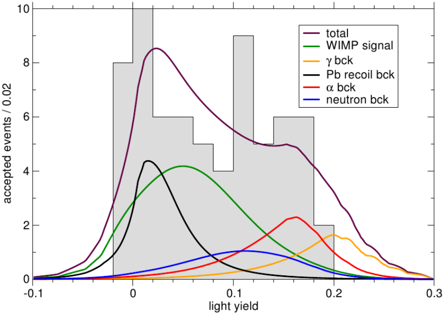
The other way round:

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

energy distribution (only M1)



light yield distribution (only M1)

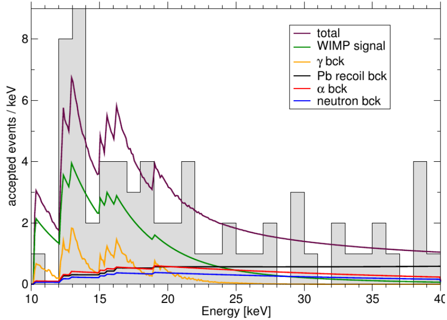


Spectral Distribution of Signal Events

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)