R&D for Dark Matter Experiments

Recent R&D Results and New Concepts for CRESST/EURECA

R. Strauss,
Max-Planck-Institut München,
Workshop on Future DM Experiments,
Wien, 15.10.2013

TUM
LMU
ESO

Eberhard Karls
Universität
Tübingen

TUM
Technische
Universität
München

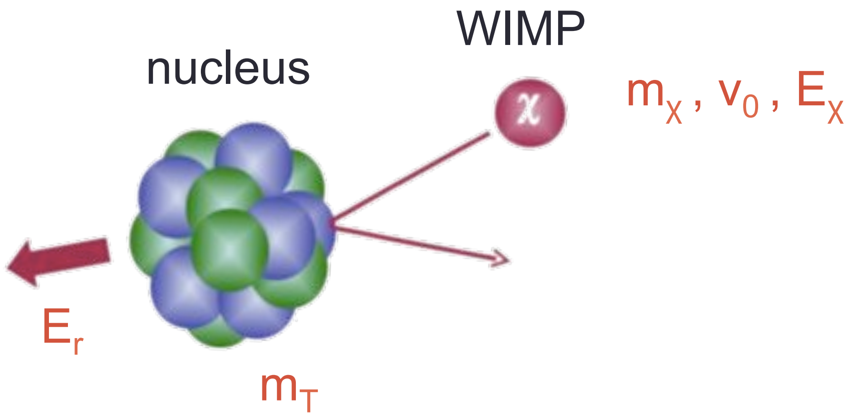
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

LNGS

University of
Oxford

Direct Dark Matter Search

Coherent, elastic WIMP-nucleon scattering



$$E_r = E_\chi \frac{2\mu^2}{m_\chi m_T}(1 - \cos\Theta)$$

Example:

- $m_\chi = 100$ GeV/c^2
- $v_0 = 230$ km/s
- $m_T = 184$u (tungsten)

➢ E_r(max) ~ 38 keV

Differential WIMP Rate

M_T: total target mass
m_T : target mass (nucleus)
A : mass number of nucleus
μ : reduced mass

m_χ : WIMP mass
v_0 : mean velocity Earth-WIMP
ρ_χ : WIMP density @ Earth
σ_0 : WIMP-nucleon cross-section

$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

Differential WIMP Rate

M_T: total target mass
m_T : target mass (nucleus)
A : mass number of nucleus
μ : reduced mass

m_χ : WIMP mass
v_0 : mean velocity Earth-WIMP
ρ_χ : WIMP density @ Earth
σ_0 : WIMP-nucleon cross-section

rate

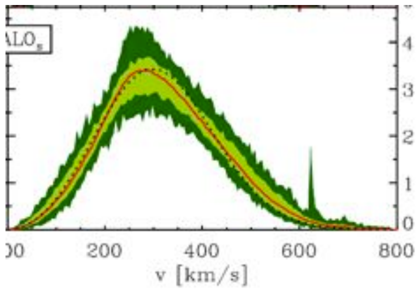
$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

recoil energy

measure in experiment

exponential spectrum due to Maxwellian velocity distribution of WIMPs

$$f(\mathbf{v}, \mathbf{v_e}) = e^{-(\mathbf{v}-\mathbf{v_e})^2/v_0^2}$$



Differential WIMP Rate

M_T: total target mass
m_T : target mass (nucleus)
A : mass number of nucleus
μ : reduced mass

m_χ : WIMP mass
v_0 : mean velocity Earth-WIMP
ρ_χ : WIMP density @ Earth
σ_0 : WIMP-nucleon cross-section

rate

$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

recoil energy

measure in experiment

nuclear physics input

Form factor: $F^2(q)$

Differential WIMP Rate

M_T:	total target mass
m_T :	target mass (nucleus)
A :	mass number of nucleus
μ :	reduced mass
m_χ :	WIMP mass
v_0 :	mean velocity Earth-WIMP
ρ_χ :	WIMP density @ Earth
σ_0 :	WIMP-nucleon cross-section

rate

$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

recoil energy

measure in experiment

Astrophysics input

local WIMP density:	0.3 GeV < ρ_χ < 0.9 GeV
mean WIMP velocity:	~ 230 km/s
WIMP mass:	1 GeV < m_χ < 1000 GeV

Differential WIMP Rate

M_T: total target mass
m_T : target mass (nucleus)
A : mass number of nucleus
μ : reduced mass

m_χ : WIMP mass
v_0 : mean velocity Earth-WIMP
ρ_χ : WIMP density @ Earth
σ_0 : WIMP-nucleon cross-section

rate

$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

recoil energy

measure in experiment

Scattering cross-section

Coherent scattering (assumption): ~ A^2

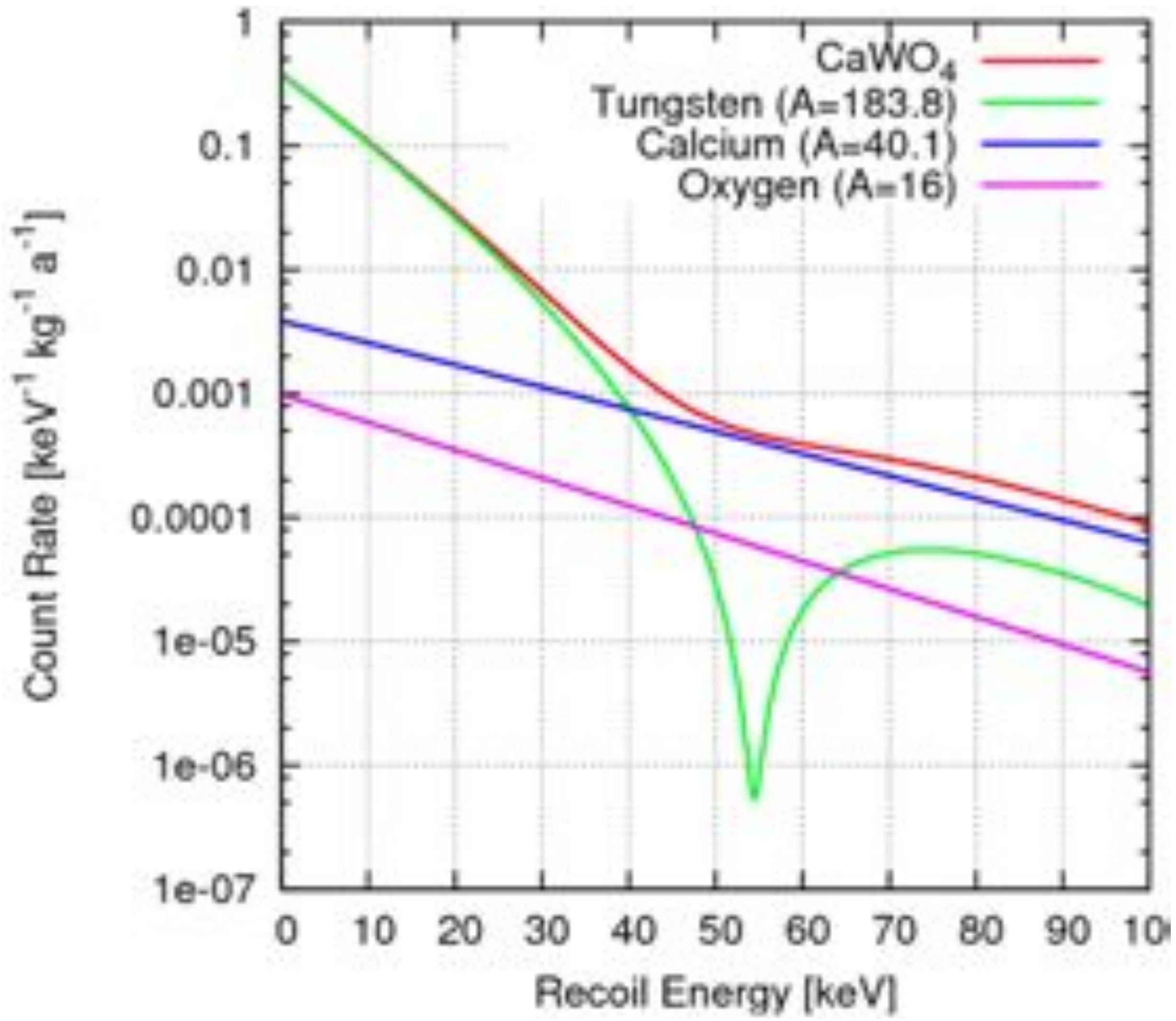
WIMP-nucleon cross-section: << 1pb

e.g. $CaWO_4$

W ~ 95%
Ca ~ 4%
O ~ 1%

(no threshold effects)

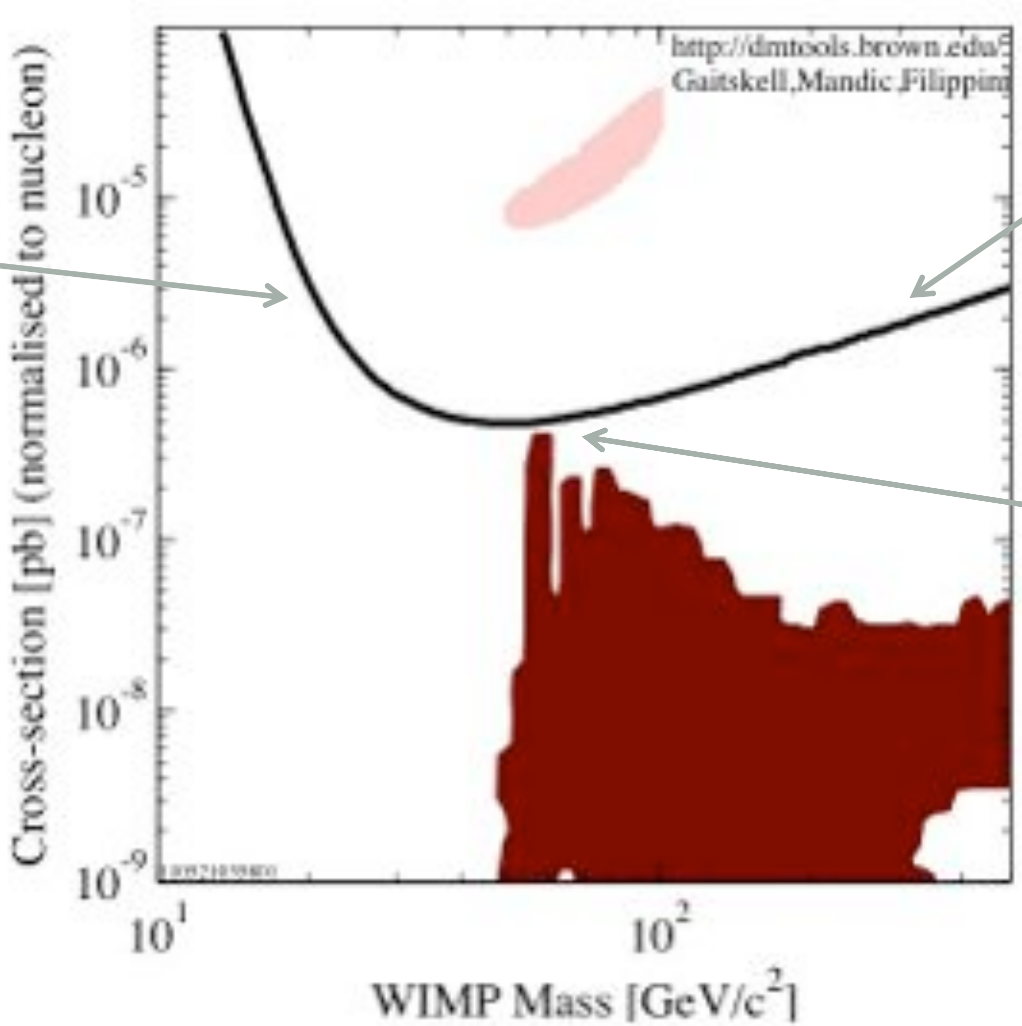
Expected Recoil Spectra



Features:

- A^2 dependency
- Exponential shape
- Influence of Form factor

Constraints on WIMP Parameter Space



Influence of threshold (typ. ~10keV)

$$\frac{dR}{dE_r} \sim \frac{1}{m_\chi}$$

Maximum sensitivity:

$$m_\chi \approx m_T$$

+ influence of Form factor

Improving Direct Dark Matter Experiments

Active detector mass

$$\frac{dR}{dE_r} \sim \boxed{M_T}\frac{}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

Strategies:

1. **Increase of target mass**

Improving Direct Dark Matter Experiments

Strong dependence on choice of target

$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \boxed{\sigma_0 A^2} \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

Strategies:

1. **Increase of target mass**
2. **Use of different targets (multi-material approach)**

Improving Direct Dark Matter Experiments

Sensitivity

•	**~ t**	in case of no background
•	**~ $\sqrt{t}$**	in case of background
•	**= const**	in case of background (not subtracted)

Measuring time

$$\frac{\boxed{dR}}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

<u>Strategies:</u>

1. **Increase of target mass**
2. **Use of different targets (multi-material approach)**
3. **Reduction of backgrounds**

Improving Direct Dark Matter Experiments

exponential dependence

threshold

$$\frac{dR}{dE_r} \sim \frac{M_T}{\mu^2} \cdot \frac{\rho_\chi}{m_\chi v_0} \cdot \sigma_0 A^2 \cdot F^2(q) \cdot e^{-(m_T/2v_0^2\mu^2)\cdot E_r}$$

Strategies:

1. **Increase of target mass**
2. **Use of different targets (multi-material approach)**
3. **Reduction of backgrounds**
4. **Reduction of the threshold**

Outline

- Recent R&D for CRESST
    1. Increase of target mass
    2. Use of different targets (multi-material approach)
    3. Reduction of backgrounds
    4. Reduction of threshold

- New Concepts for CRESST
    - Alternative Detector Concepts
    - Low-Threshold Analysis
    - Limits on Rare Processes

R&D Activities for CRESST – An Overview

Uni Tübingen:

- Data analysis
- Detector development

TU München:

- Crystal growth and characterization
- Quenching-Factor measurements
- Data analyis
- Detector development

HEPHY Wien

- ...

MPI München

- Detector production
- Detector development
- Data analysis
- Operation of CRESST

LNGS Assergi

- Operation of CRESST
- Data analysis

R&D Activities for CRESST – An Overview

Uni Tübingen:

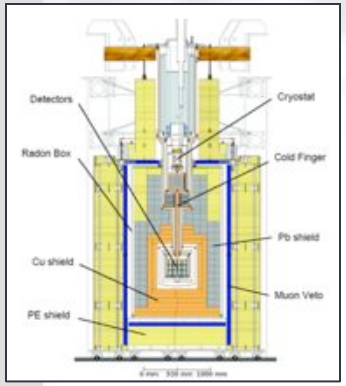
- Underground laboratory
- Dilution refrigerator
- Evaporation system

TU München:

- Crystal laboratory
- CRESST neutron scattering facility at MLL
- 3 dilution refrigerators
- Extended Underground lab

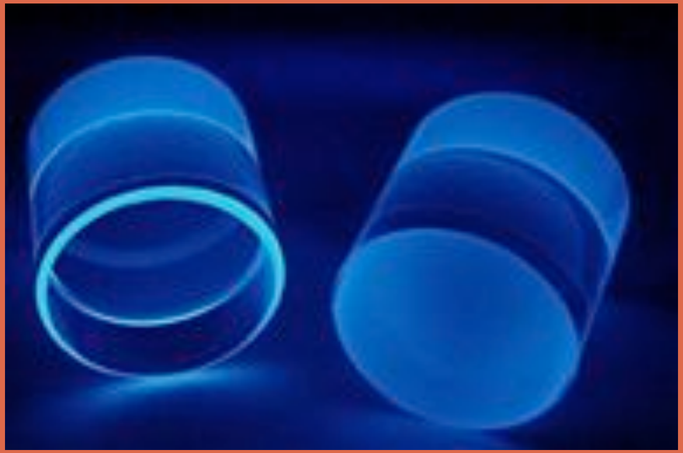
MPI München

- Evaporation systems
- 2 dilution refrigerators



LNGS Assergi

- CRESST experiment
- CRESST test cryostat

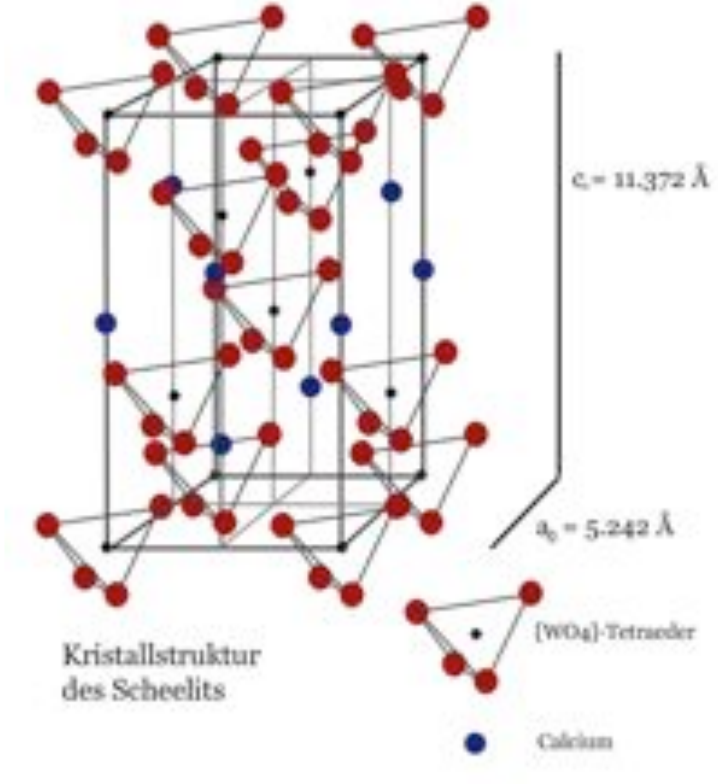


CRYSTAL GROWTH

$CaWO_4$ production at TUM

CaWO$_4$ Crystals as DM Target

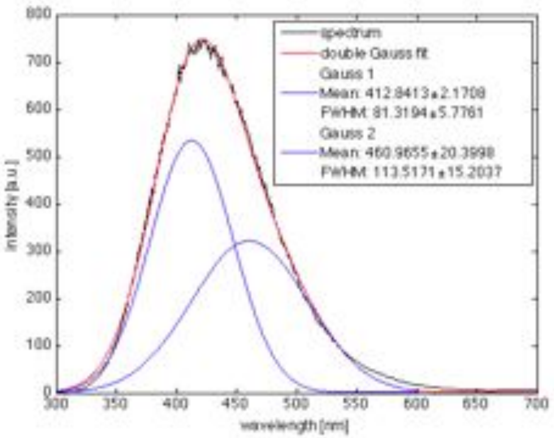
- Basic properties
  - Density: 6.1 g/cm^3
  - Melting point: 1600°C
  - Crystal structure: tetragonal-dipyramidal
  - Refractive index: 1.95
  - Debye temperature: ~250K



- **Multi-material target**
  - Heavy W isotopes (A≈184): enhancement for coherent scattering
  - O(A=16), Ca(A=40): sensitivity for low-mass WIMPs
  - ^{183}W(14%): some sensitivity for spin-dependent scattering
  - ^{48}Ca(0.2%): 0v2β candidate

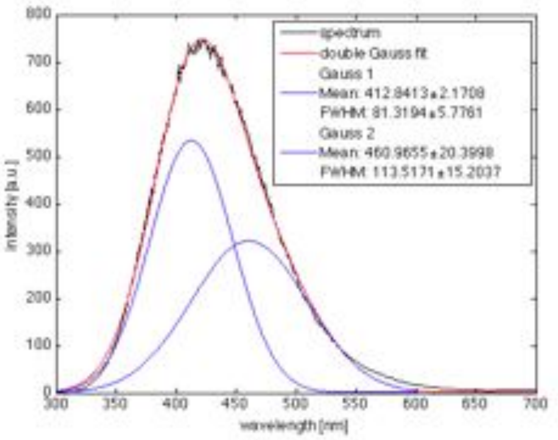
$CaWO_4$ Crystals as DM Target

- Scintillating crystals
  - Luminescence centers: WO_4^{2-}
  - Emission maximum: 420nm
  - Light yield (@300K): ≤ 20.000ph/MeV
  - Decay time (@300K): ~ 9µs
  - Light yield (@ mK): ~1.8 x LY(300K)
  - Decay time (@mK): ~400µs



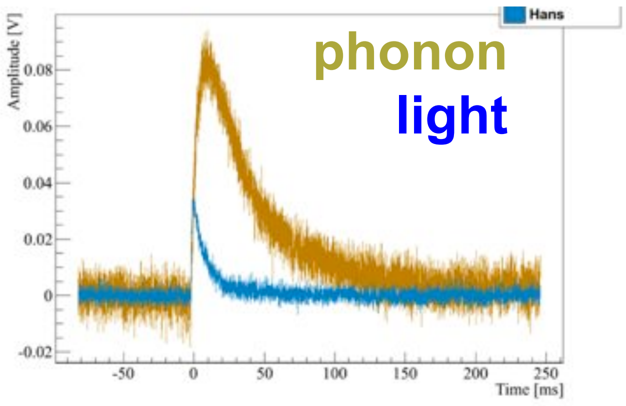
$CaWO_4$ Crystals as DM Target

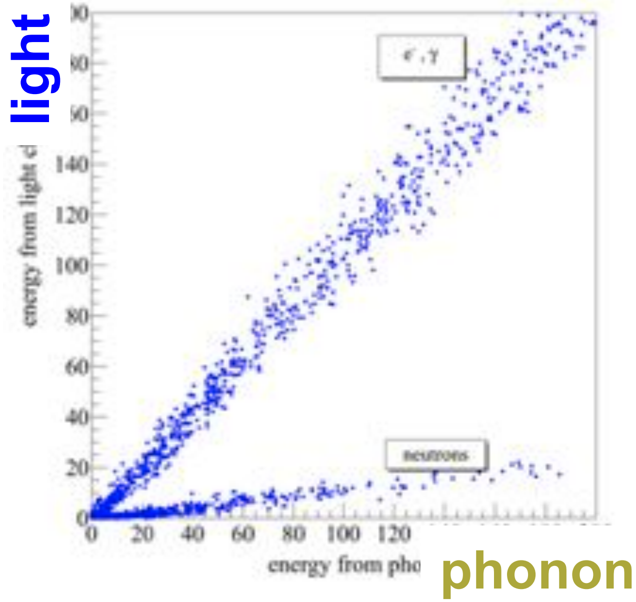
- Scintillating crystals
  - Luminescence centers: WO_4^{2-}
  - Emission maximum: 420nm
  - Light yield (@300K): ≤ 20.000ph/MeV
  - Decay time (@300K): ~ 9µs
  - Light yield (@ mK): ~1.8 x LY(300K)
  - Decay time (@mK): ~400µs



- Active background discrimination

CRESST detector





In-House Production of $CaWO_4$ – Why?

1. Increase of target mass:
   - Current mass CRESST (run33): ~5kg
   - Maximal mass CRESST: ~30kg
   - Future bolometric experiments (e.g. EURECA): 100-1000kg

2. Reduction of backgrounds
   - Control of all production steps
   - ➢ Reduction of radioactive contaminations
   - ➢ Increase of light output (transmittance)

$CaWO_4$ Crystal Growth at TUM

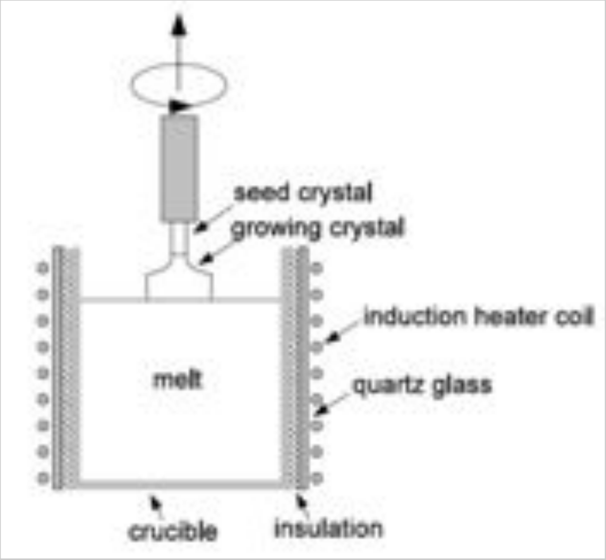
Czochralski Growth at TUM
Cyberstar Oxypuller 20-04 Czochralski furnace

- 80mm/120mm diameter Rh crucibles
- Continuous weighing of crystal during growth
- After-heater on top of crucible
- Growth under flow of 99% Ar,
- 1% O2 → reduce oxygen deficiency of crystals

$CaCO_3 + WO_3$

➔

$CaWO_4 + CO_2$

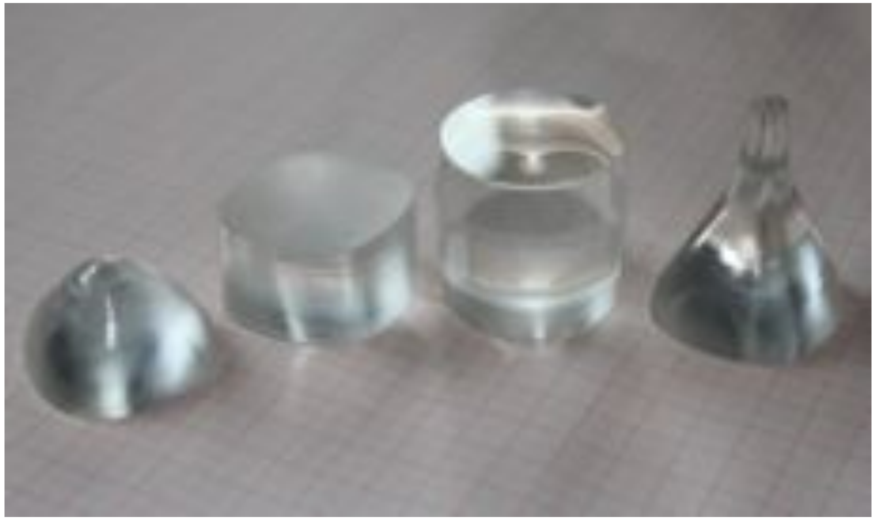


A. Erb, M. v. Sivers

Successful Growth of CRESST-size Crystals

raw ingot

m=890g
D=44mm, h=65mm



Cylindrical detector crystal (standard CRESST size):

- m=300g
- D=40mm, h=40mm

- ➢ **Reproducible production cycle**
- ➢ **1 growth per week possible**

CRESST Test Cryostat at Gran Sasso

K.Schäffner (PhD 2013)

Unique facility to operate CRESST-size detector modules

- dilution fridge, base temperature ~7mK
- muon flux reduced to ~$1 m^{-2} h^{-1}$
- Pb shielding (4tons)
- Dominated by external radiation (e.g. ^{230}Th)

e^-/γ - rate: ~10^3 $keV^{-1}kg^{-1}day^{-1}$

Neutron-rate: $O(10\ kg^{-1}day^{-1})$ above 10keV

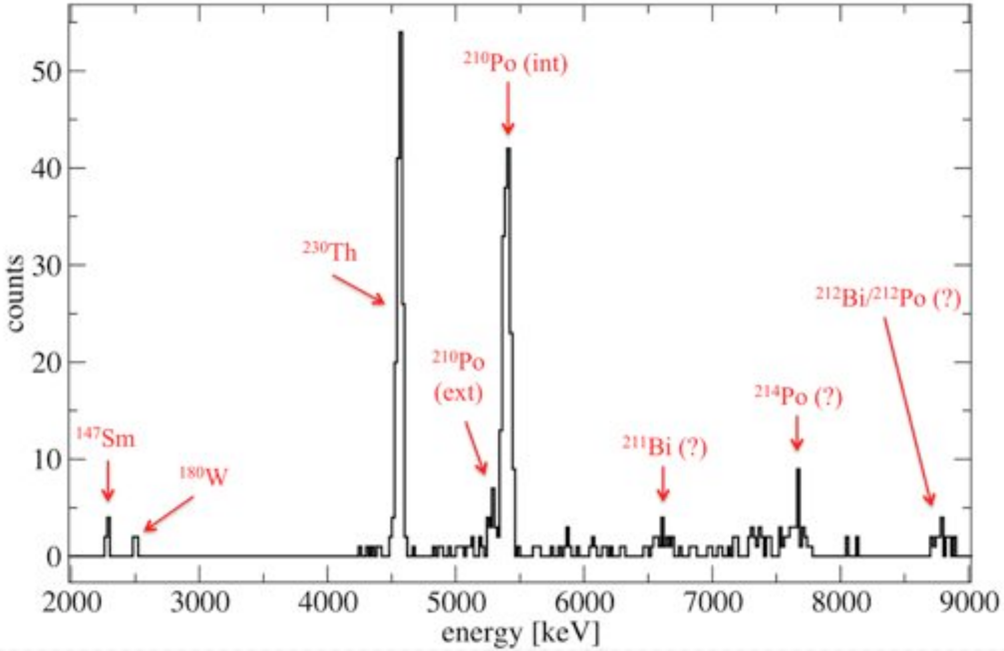
First Test of TUM-Grown Crystal

Rudolph VI (TUM-27)

- Standard CRESST size h=40mm ⌀40mm
- 300g

Commissioning run at the test cryostat at Gran Sasso:

- Excellent phonon properties
- ➢ Phonon-energy resolution (σ≈1.5keV @ 122keV)
- Reasonable light output

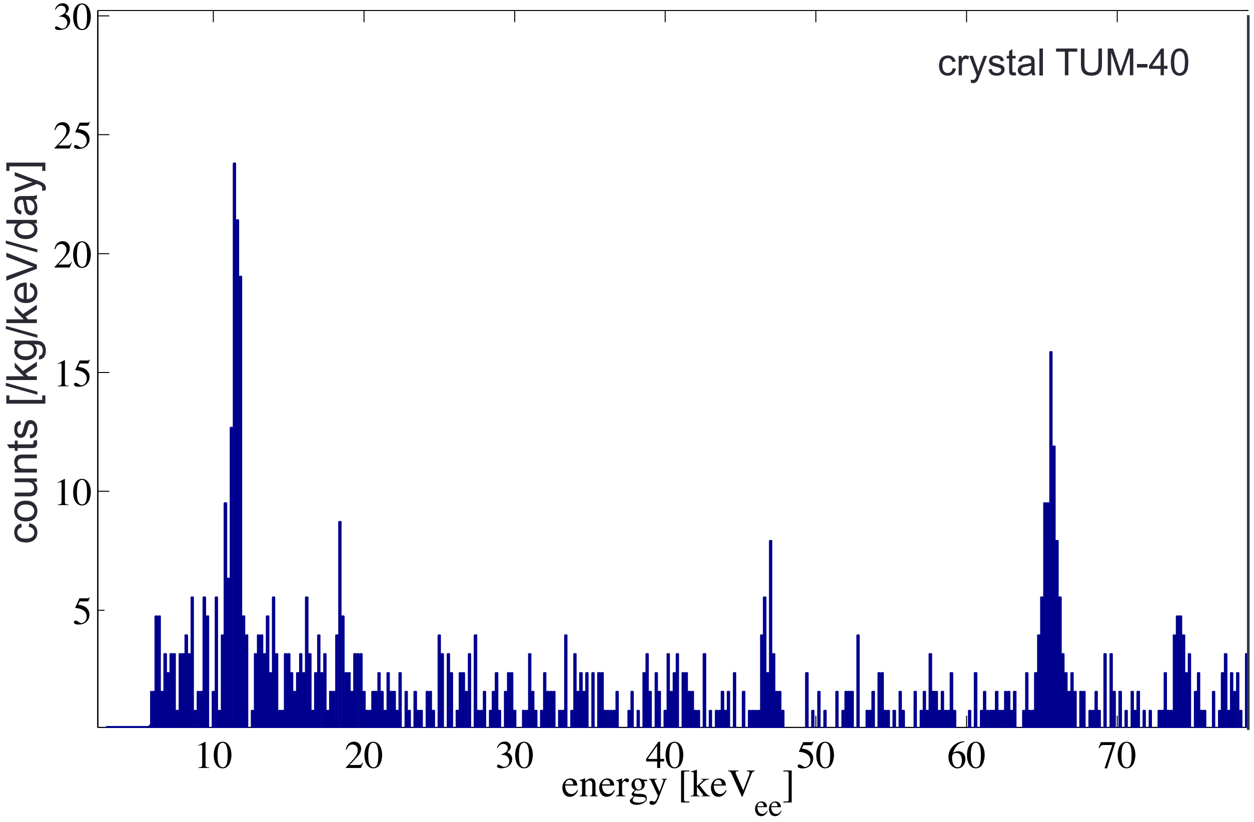


Radiopurity (α analysis):

- Exposure: 1.82 kg-days
- Total activity (1.5-7MeV): 2.93±0.17mBq/kg
- ➢ Well-competitive with best commercial crystals

Radioactive Contamination of TUM Crystals

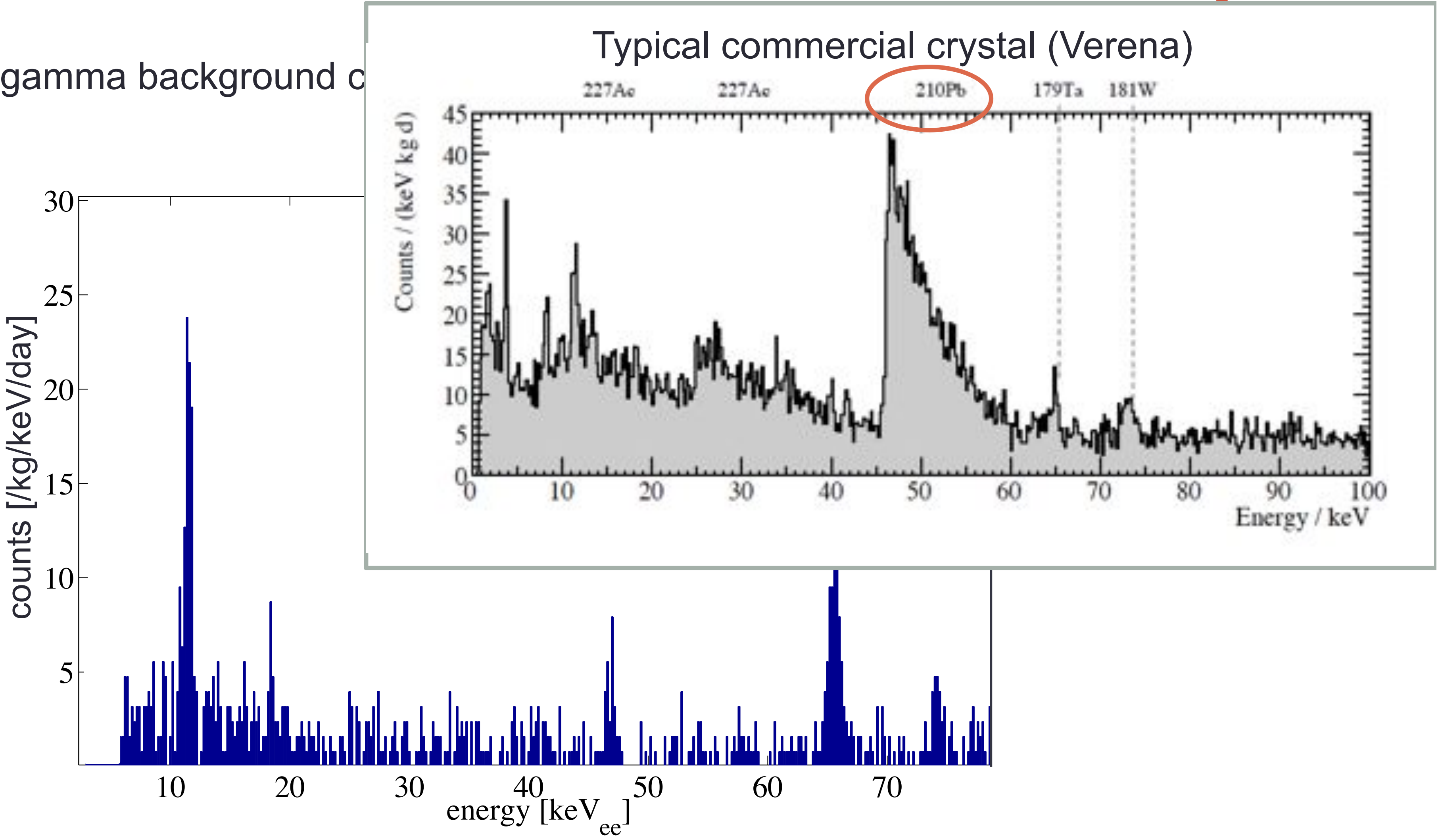
e$^-$/gamma background can only be studied in CRESST – First glance on run33 data



- very clean crystals

Radioactive Contamination of TUM Crystals

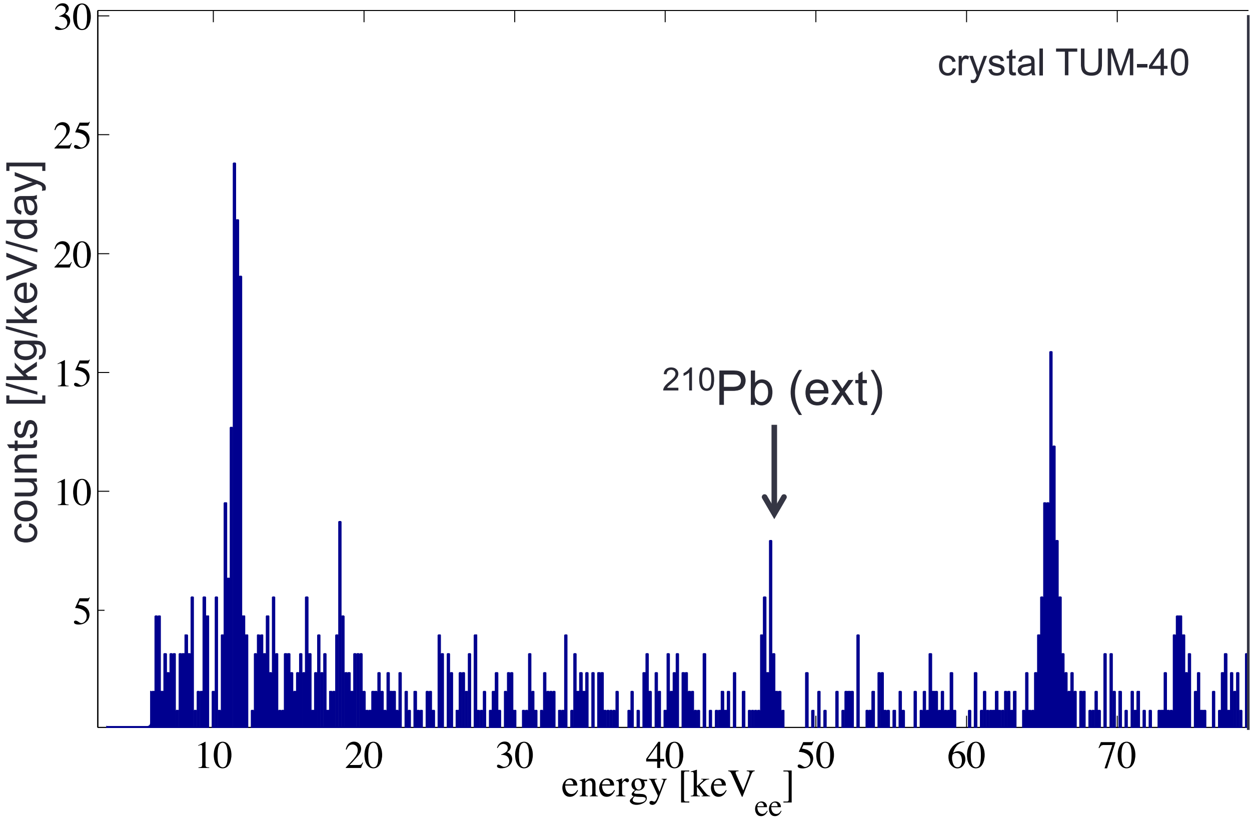
e$^-$/gamma background c



Typical commercial crystal (Verena)

Radioactive Contamination of TUM Crystals

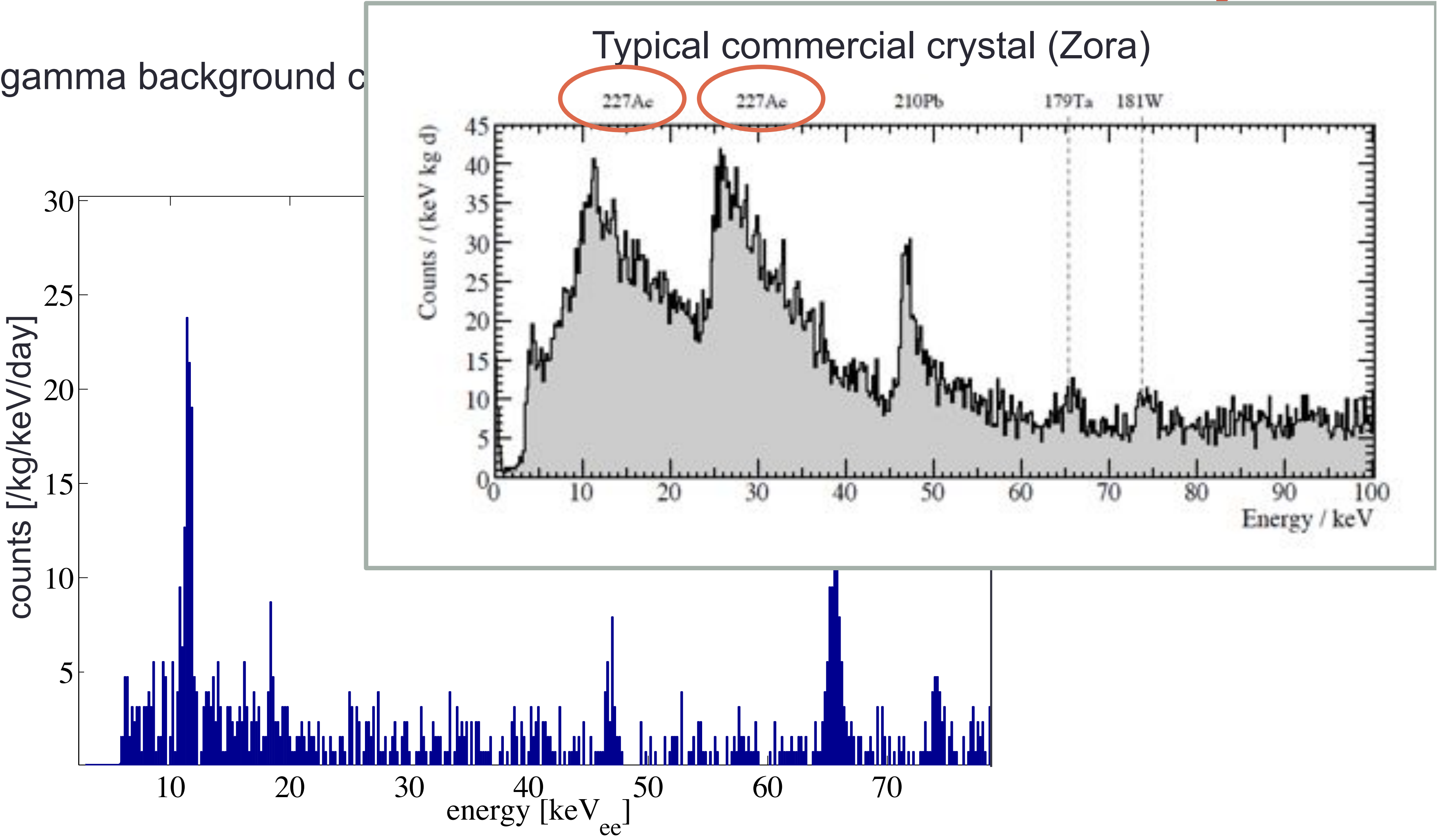
e$^-$/gamma background can only be studied in CRESST – First glance on run33 data



- very clean crystals
- Very low intrinsic ^{210}Pb contamination ➔Small contribution from ^{238}U chain

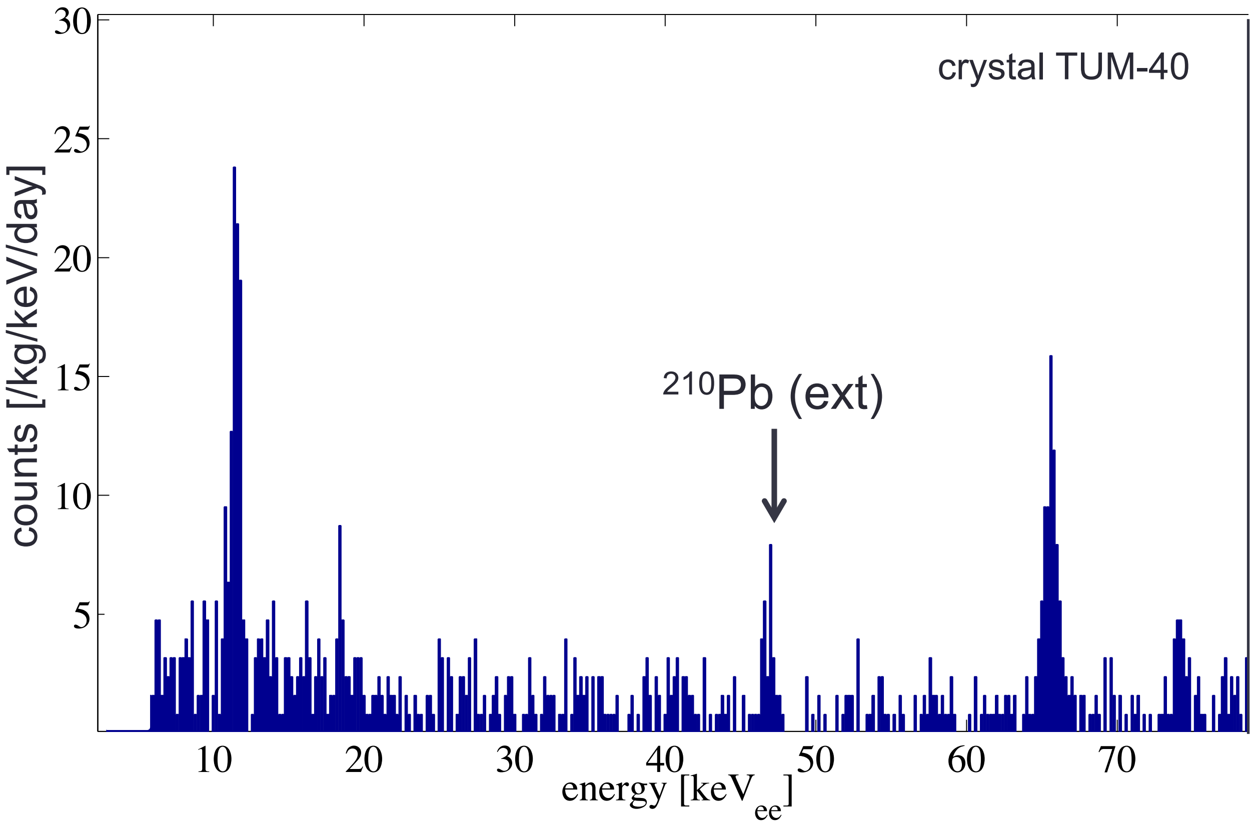
Radioactive Contamination of TUM Crystals

e^-/gamma background c



Radioactive Contamination of TUM Crystals

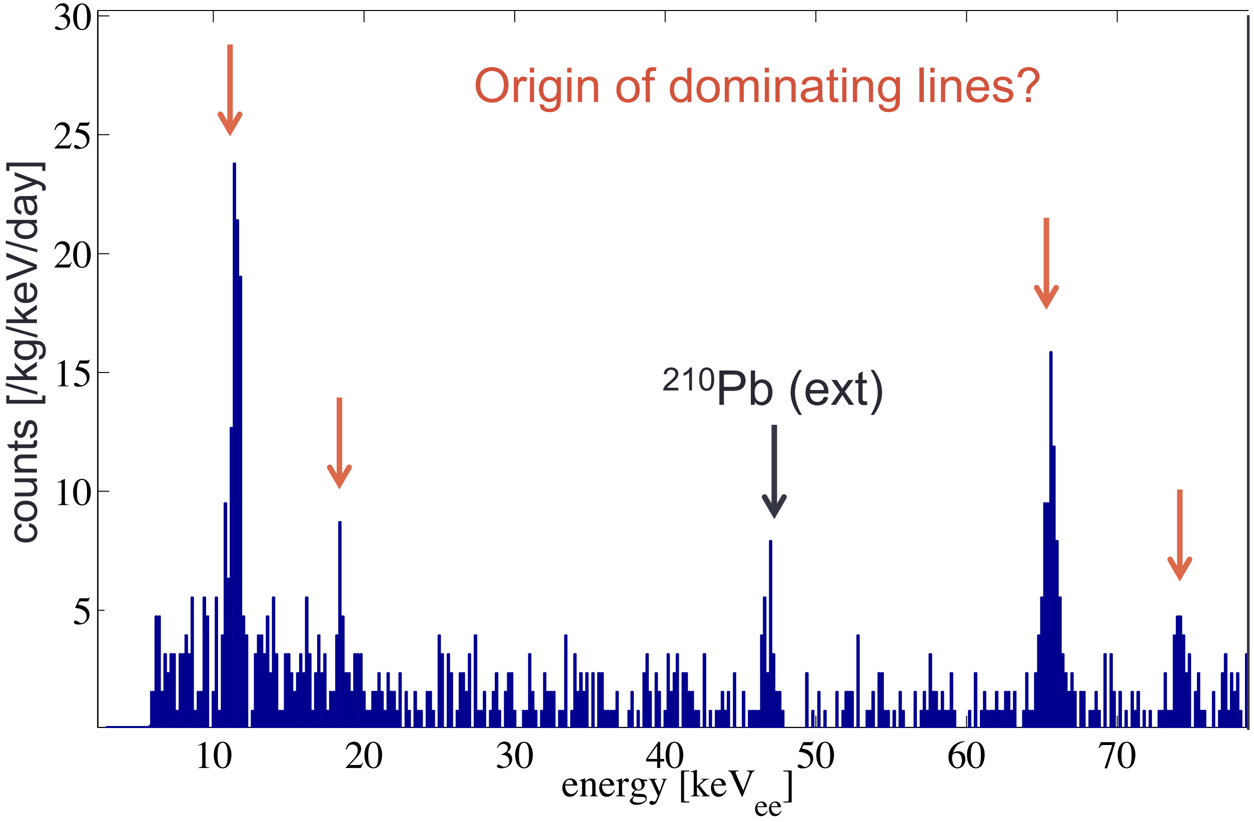
e$^-$/gamma background can only be studied in CRESST – First glance on run33 data



- very clean crystals
- Very low intrinsic ^{210}Pb contamination ➔Small contribution from ^{238}U chain
- No indications for ^{227}Ac contamination

Radioactive Contamination of TUM Crystals

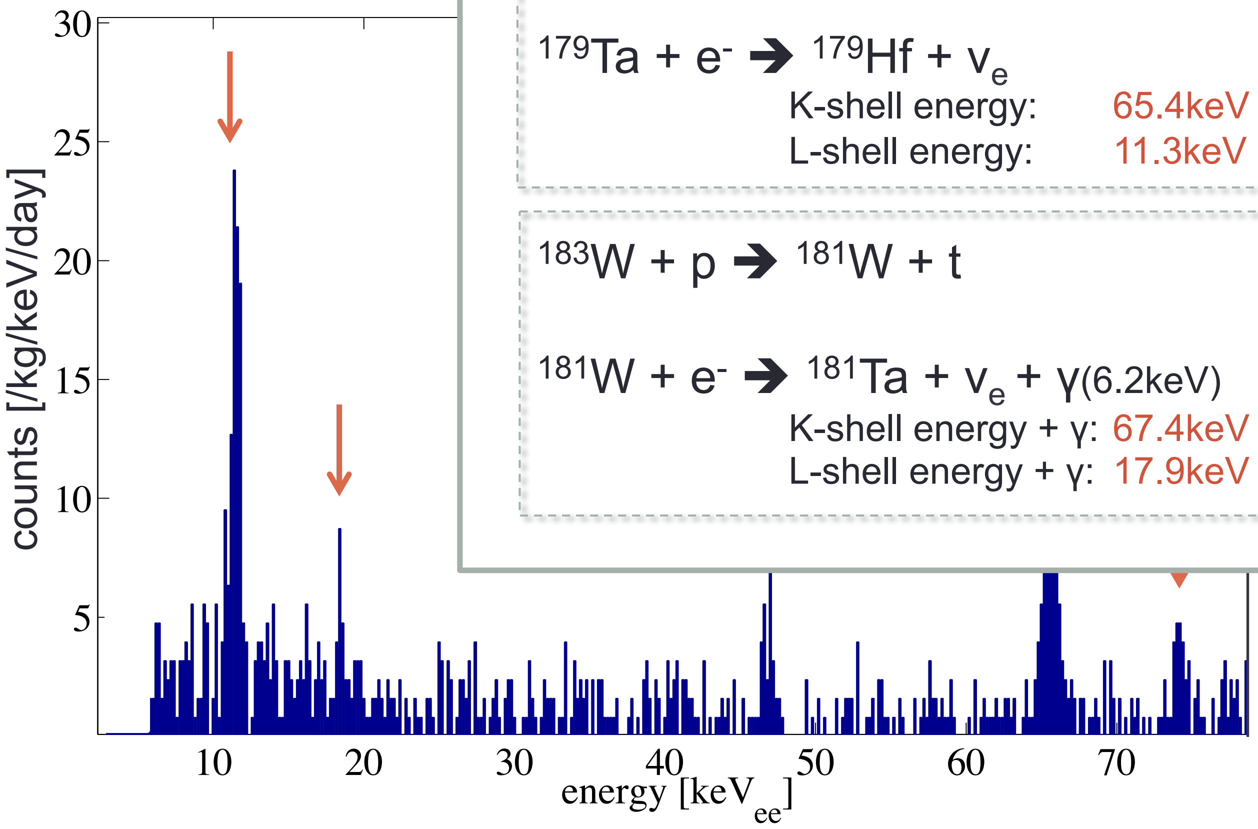
e^-/gamma background can only be studied in CRESST – First glance on run33 data



- very clean crystals
- Very low intrinsic ^{210}**Pb** contamination ➔Small contribution from ^{238}U chain
- No indications for ^{227}Ac contamination

Radioactive Contamination of TUM Crystals

e^-/gamma background c



Cosmogenic activation of W isotopes:

$^{182}W + p \rightarrow {}^{179}Ta + \alpha$ (proton capture)

$^{179}Ta + e^- \rightarrow {}^{179}Hf + \nu_e$ (EC, $T_{1/2}$=1.82y)

K-shell energy: 65.4keV
L-shell energy: 11.3keV (L/K ~ 1)

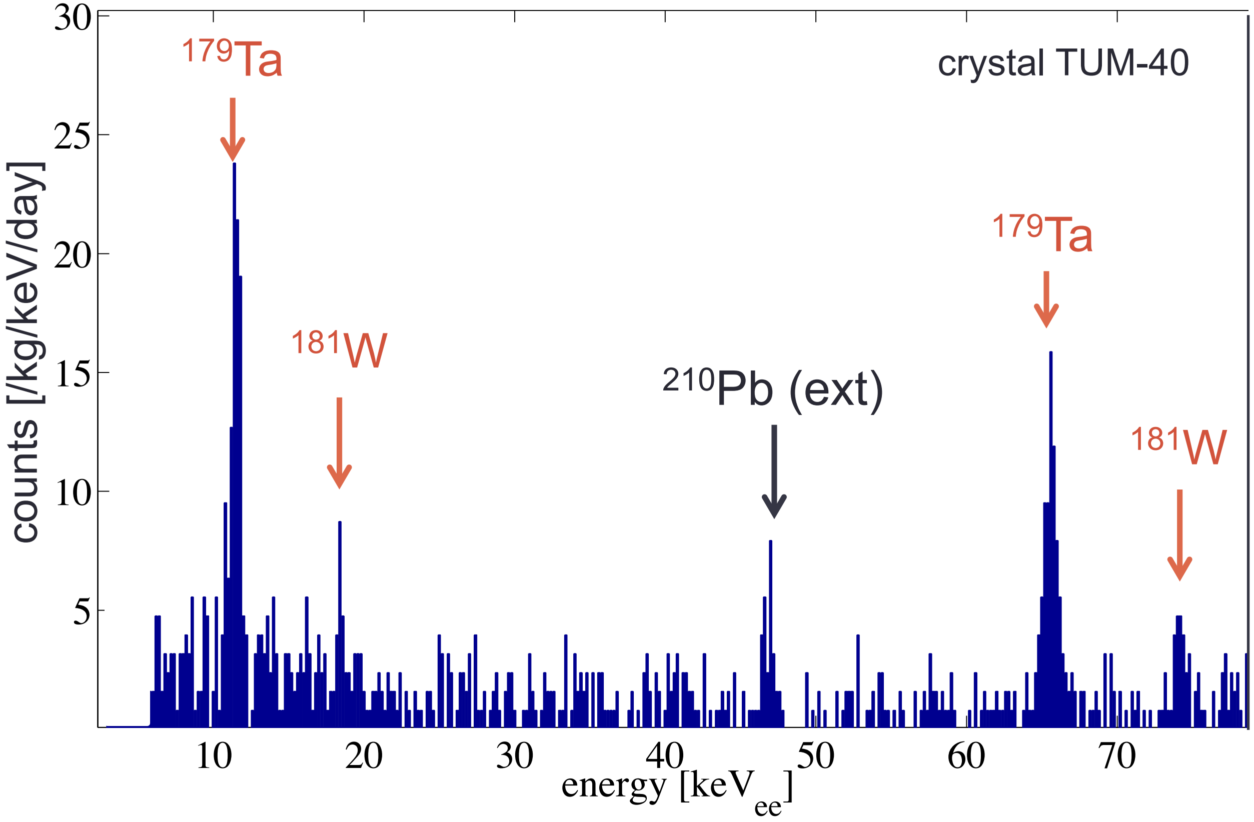
$^{183}W + p \rightarrow {}^{181}W + t$ (proton capture)

$^{181}W + e^- \rightarrow {}^{181}Ta + \nu_e + \gamma(6.2keV)$ (EC, $T_{1/2}$=121d)

K-shell energy + γ: 67.4keV
L-shell energy + γ: 17.9keV

Radioactive Contamination of TUM Crystals

e$^-$/gamma background can only be studied in CRESST – First glance on run33 data



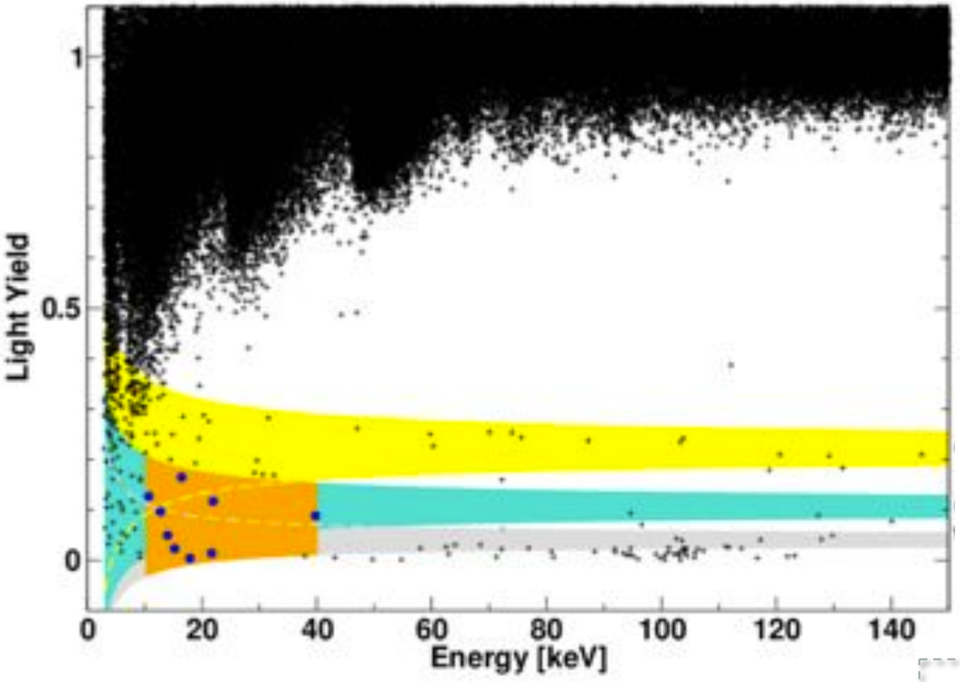
- Very clean crystals
- Very low intrinsic **^{210}Pb** contamination
  ➔Small contribution from ^{238}U chain
- No indications from ^{227}Ac contamination
- Radiation from cosmogenic activation of W dominates

ACTIVE BACKGROUND SUPPRESSION

Phonon-Light Technique

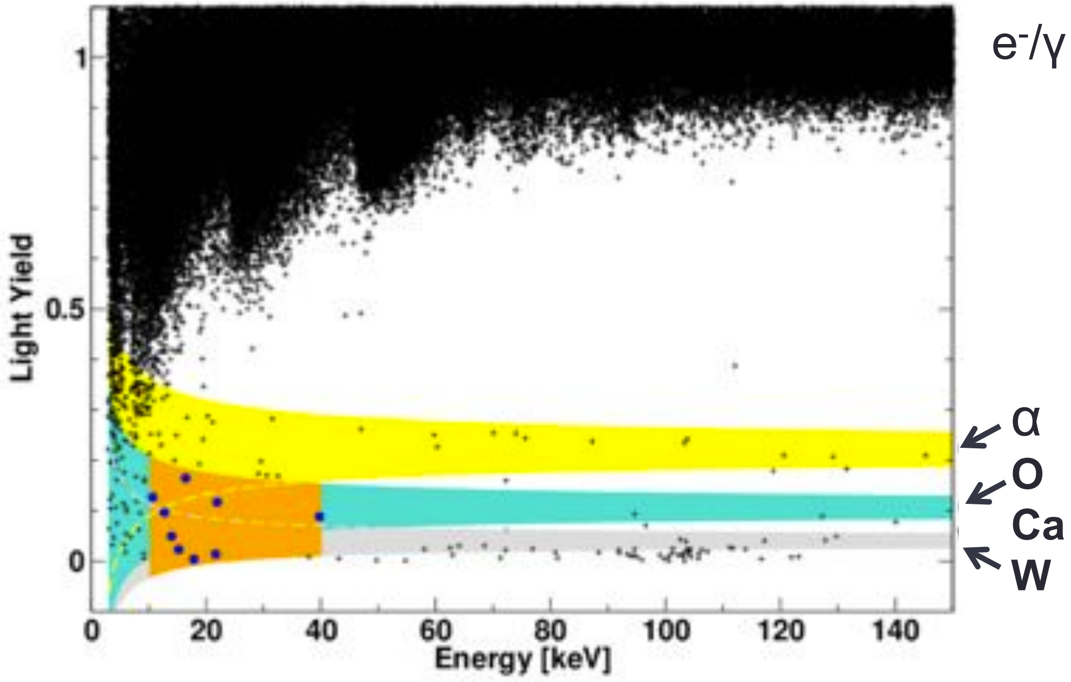
Typical CRESST Detector Module (Run32)

light yield = $\frac{\textbf{light}}{\textbf{phonon}}$



phonon

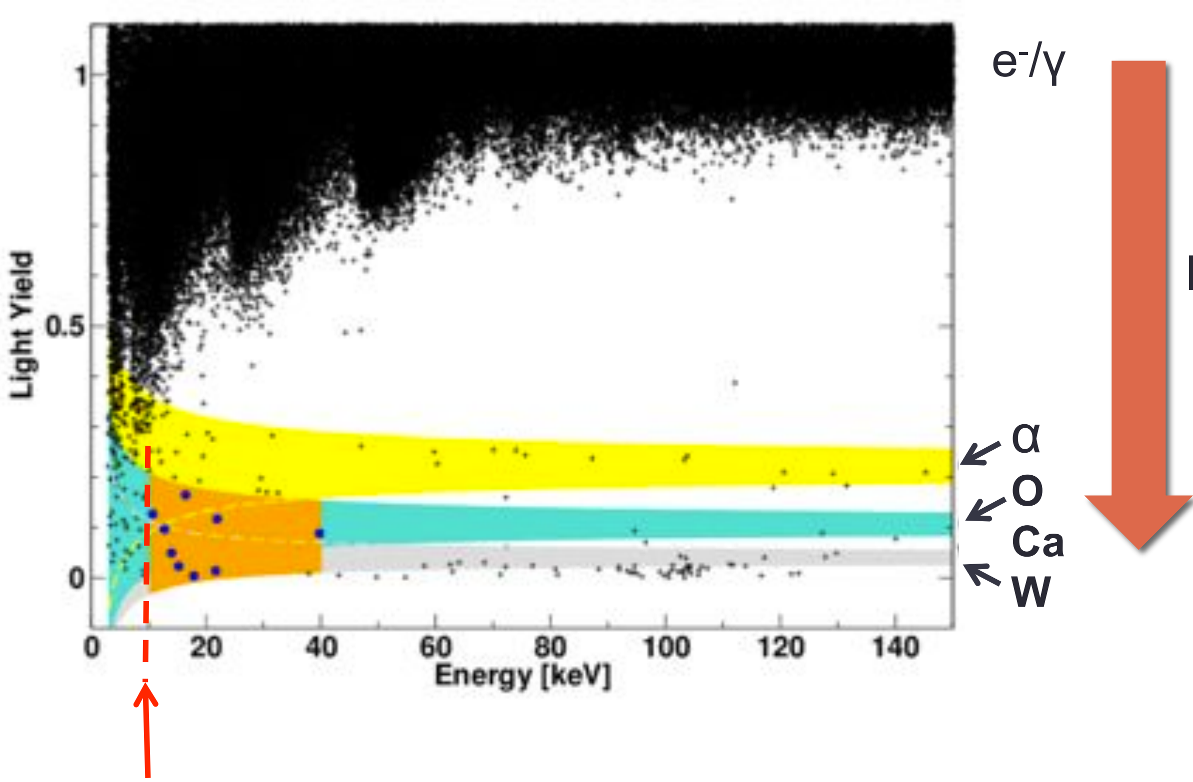
Typical CRESST Detector Module (Run32)



Reduced light output for highly ionizing particles

quenching

Typical CRESST Detector Module (Run32)



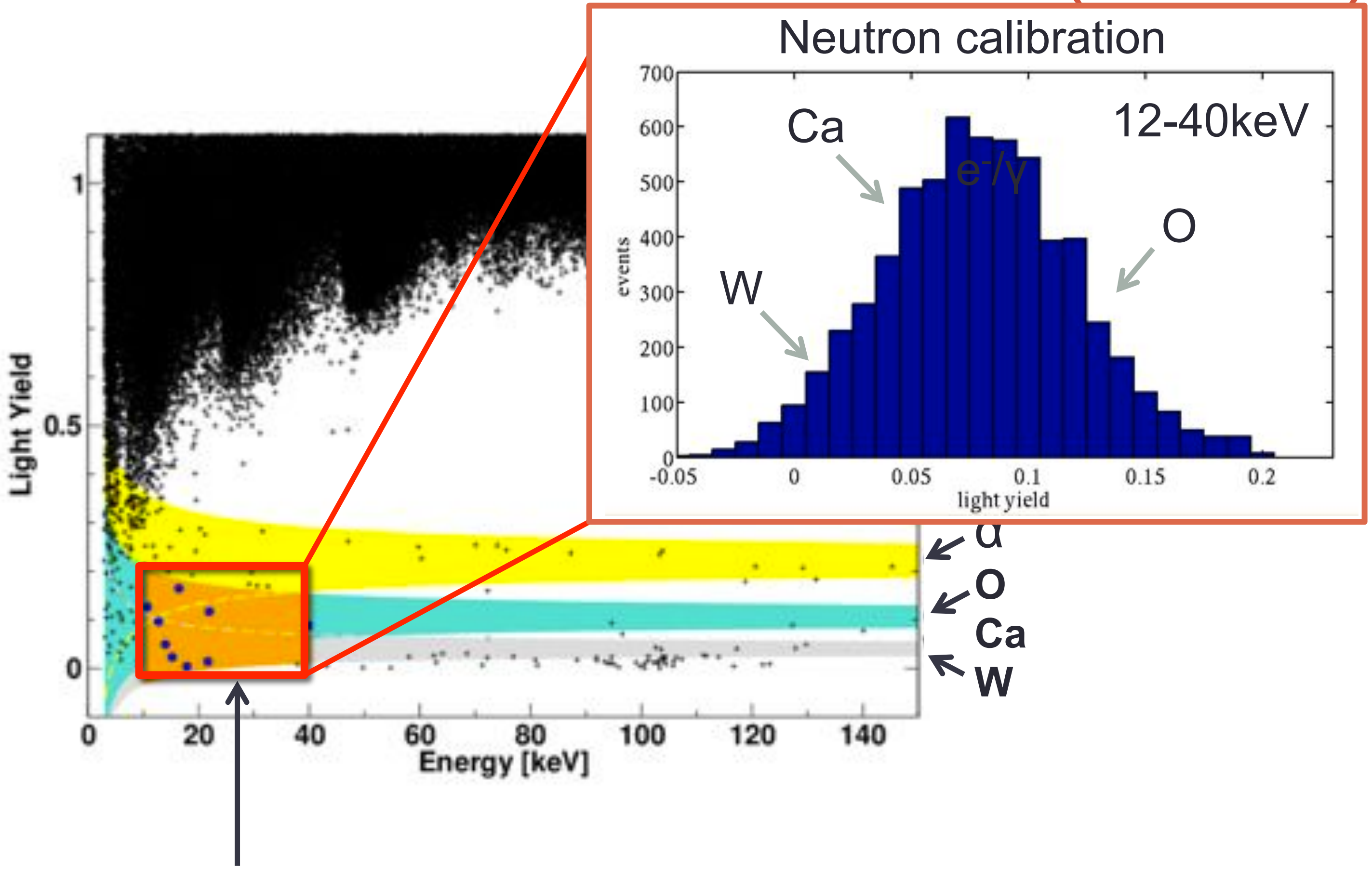
Reduced light output for highly ionizing particles

quenching

Lower bound defined by e/gamma leakage

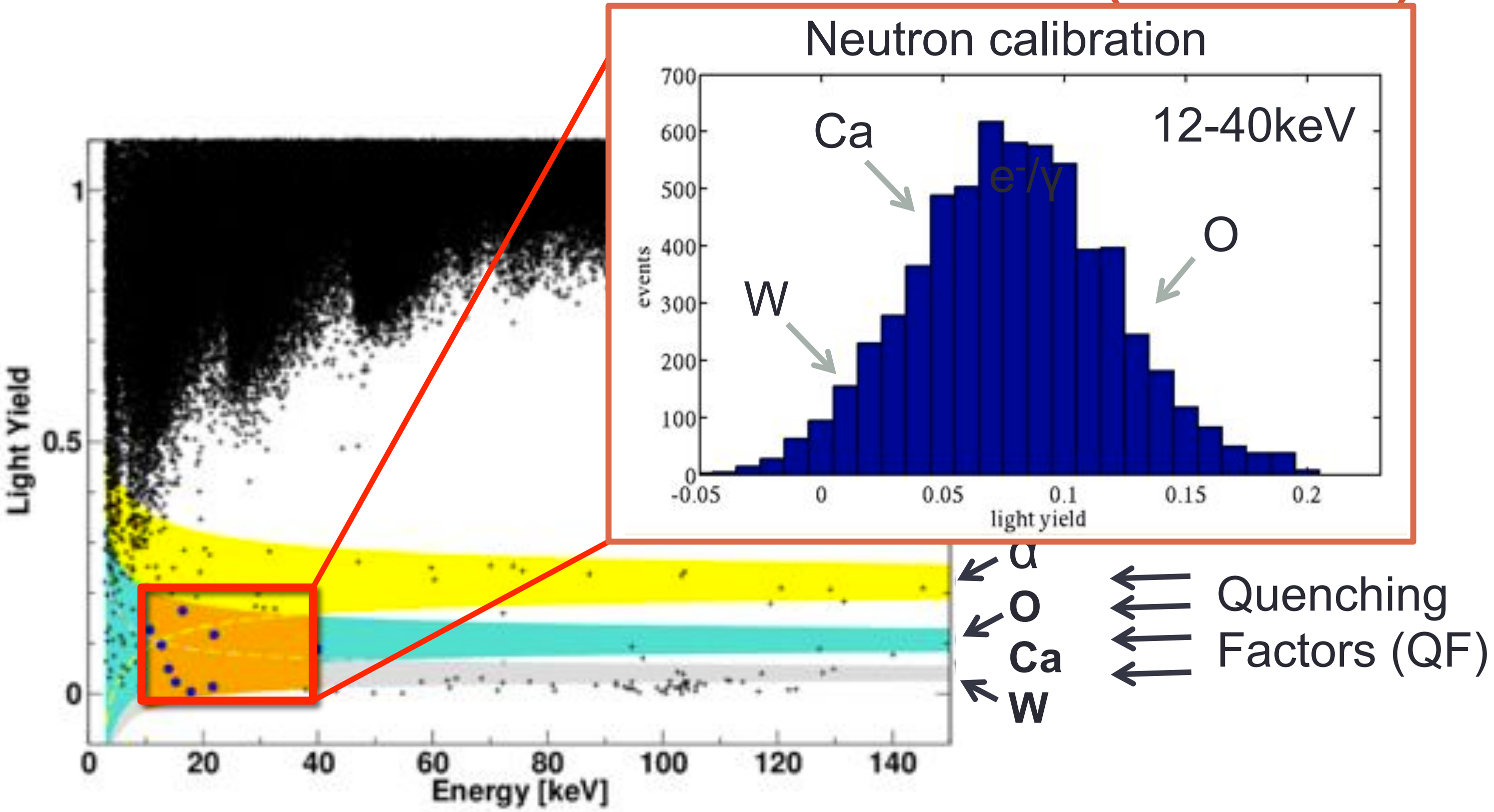
Reduced intrinsic contamination ➜ reduced discrimination threshold

Typical CRESST Detector Module (Run32)



Acceptance region for WIMP scattering
typ. 12-40 keV (O, Ca, W)

Typical CRESST Detector Module (Run32)

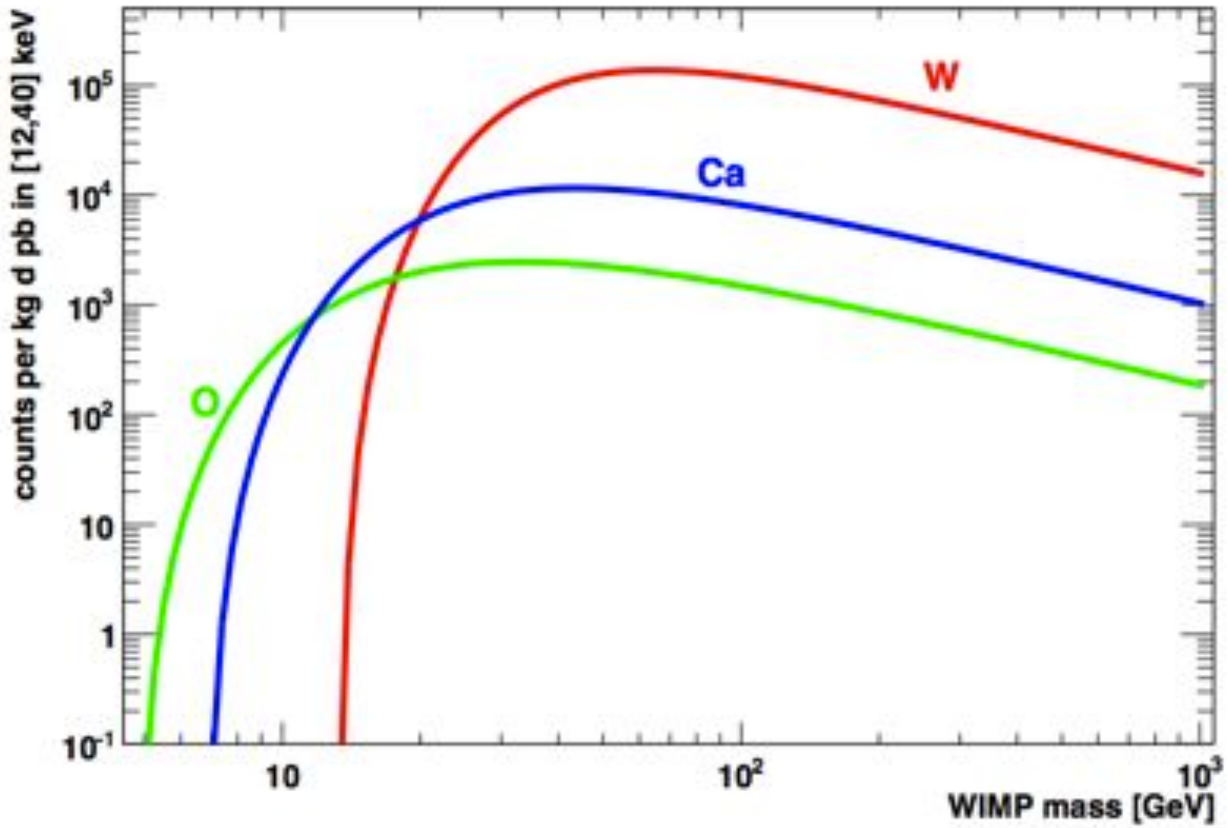


Light-channel resolution limits the experiment!

Challenge:

- Improvement light detectors and light collection
- Precise measurement of the Quenching Factors

Motivation I: Sensitivity to Different WIMP Masses



Low WIMP masses ≤20GeV: only O, Ca recoils above threshold

High WIMP masses ≥30GeV: dominated by W recoils

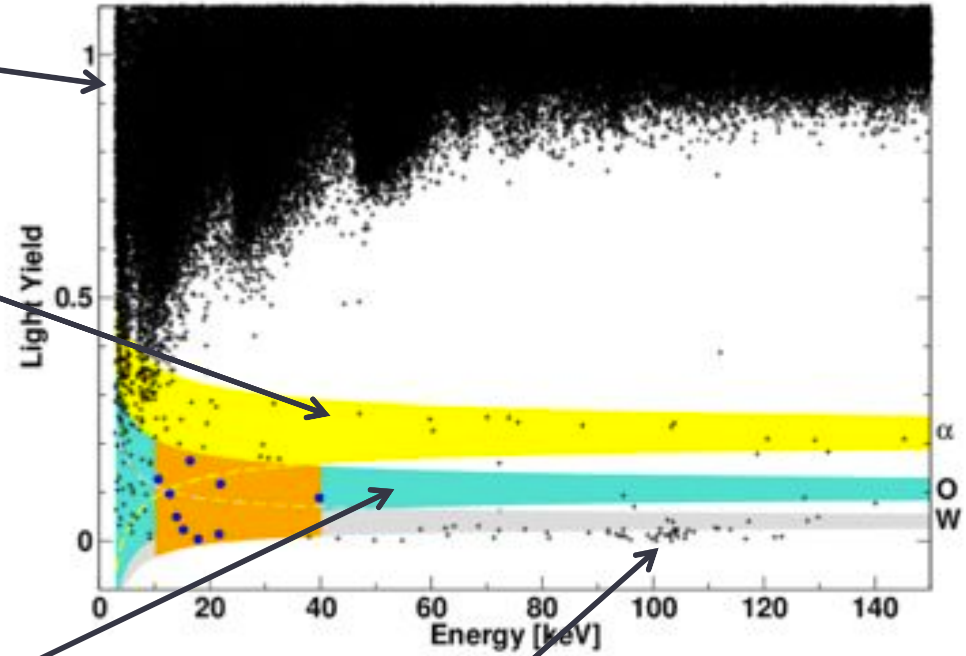
Neutrons mainly visible as O scatters

$$\frac{\partial R}{\partial E_R} \propto \sigma_{\chi n} A^2 e^{-\frac{E_R}{E_0}}$$

differential recoil rate

mass number

Motivation II: Background Discrimination



e^-/γ background

- Excellent discrimination
- Dominant background source

α background (degraded)

Neutrons

- Strong energy degradation
- Due to kinematics: mainly O scatters

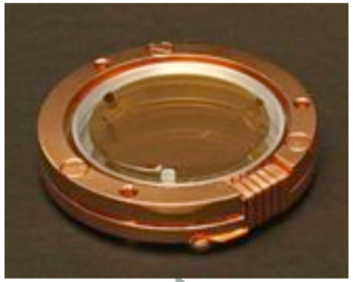
^{206}Pb recoils

- from surface contamination of clamps
- low light yield

LIGHT DETECTORS

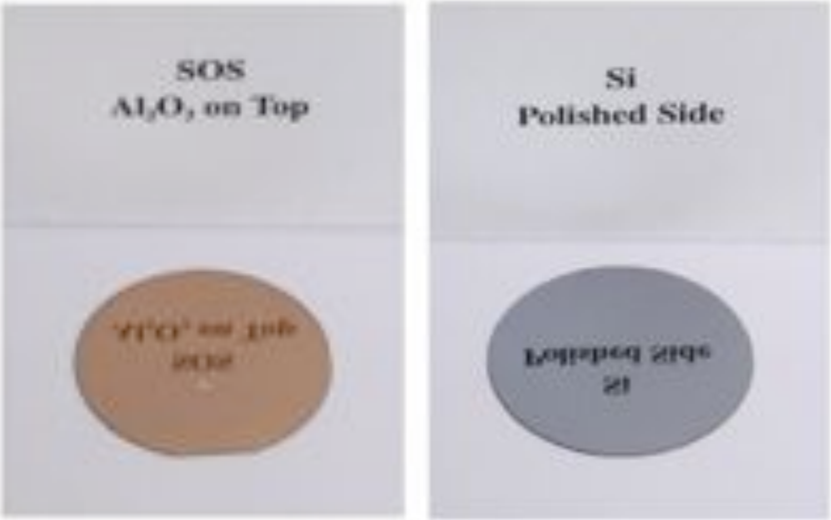
R&D to improve CRESST light detectors

CRESST Light Detectors

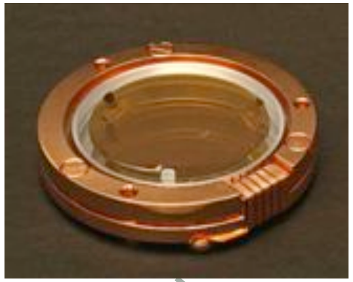


Standard CRESST light detector

- Si on sapphire (SOS), 40mm diameter
- W-TES (1.5mm x 2mm)
- typ. Threshold: 20eV



CRESST Light Detectors



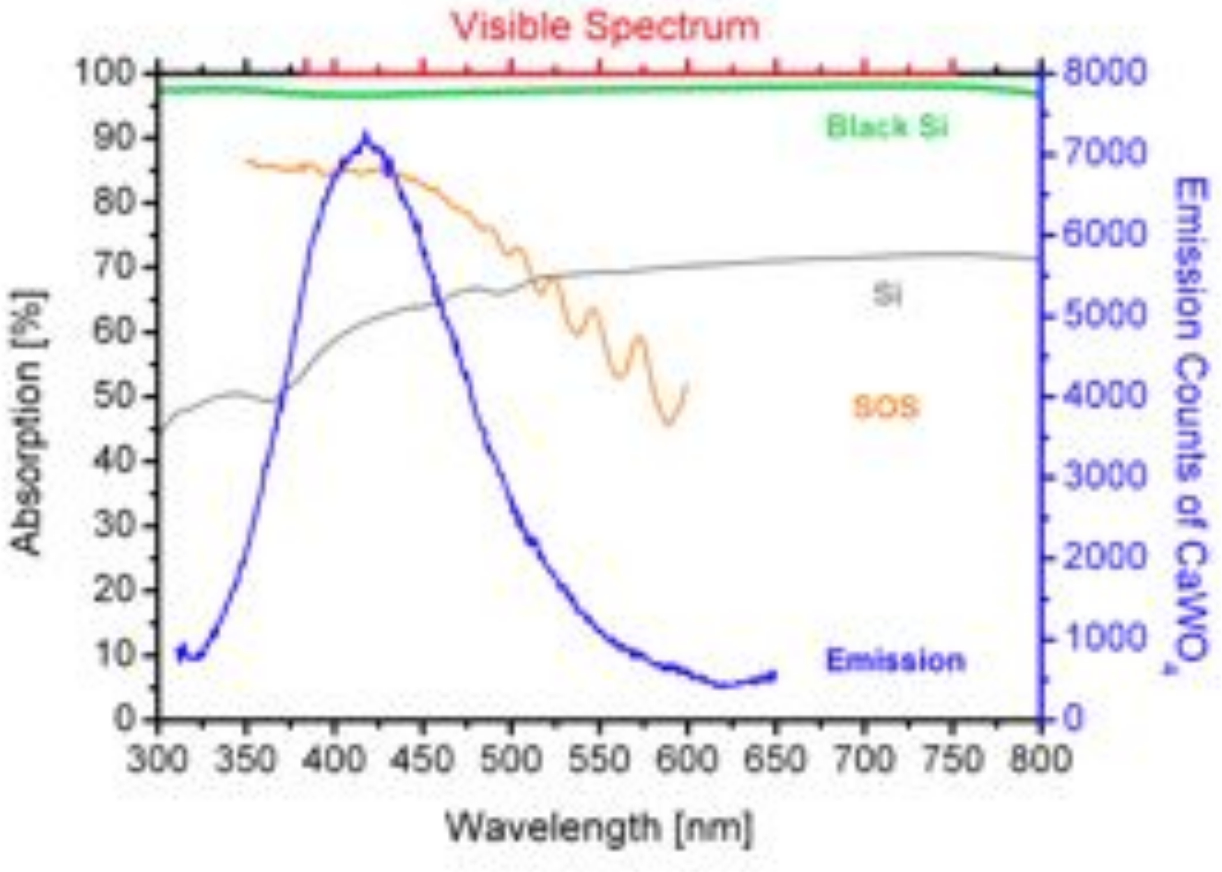
Standard CRESST light detector

- Si on sapphire (SOS), 40mm diameter
- W-TES (1.5mm x 2mm)
- typ. Threshold: 20eV

Black silicon

- Nano holes by surface etching
- High absorption over wide wavelength range

Alternative Absorbers for Light Detector



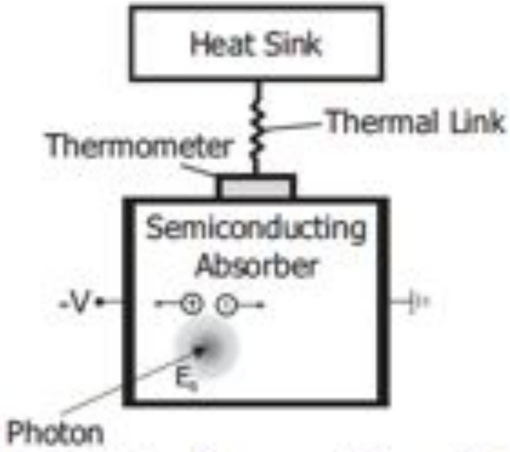
Alternative scintillating crystals require broad absorption spectrum !

Black silicon as cryogenic detector? – currently under investigation at MPI *(A.Tanzke)*

+ Investigation of superconducting absorption layers on Al_2O_3 *(F.Petricca)*

Neganov-Luke Amplified Light Detectors

- Photon absorption in light detector ⇒ free charge carriers
- Recombination of charge carriers ⇒ phonons
- Application of Neganov-Luke voltage across absorber
- Drifting charge carriers ⇒ additional phonons



scheme of the Neganov-Luke principle

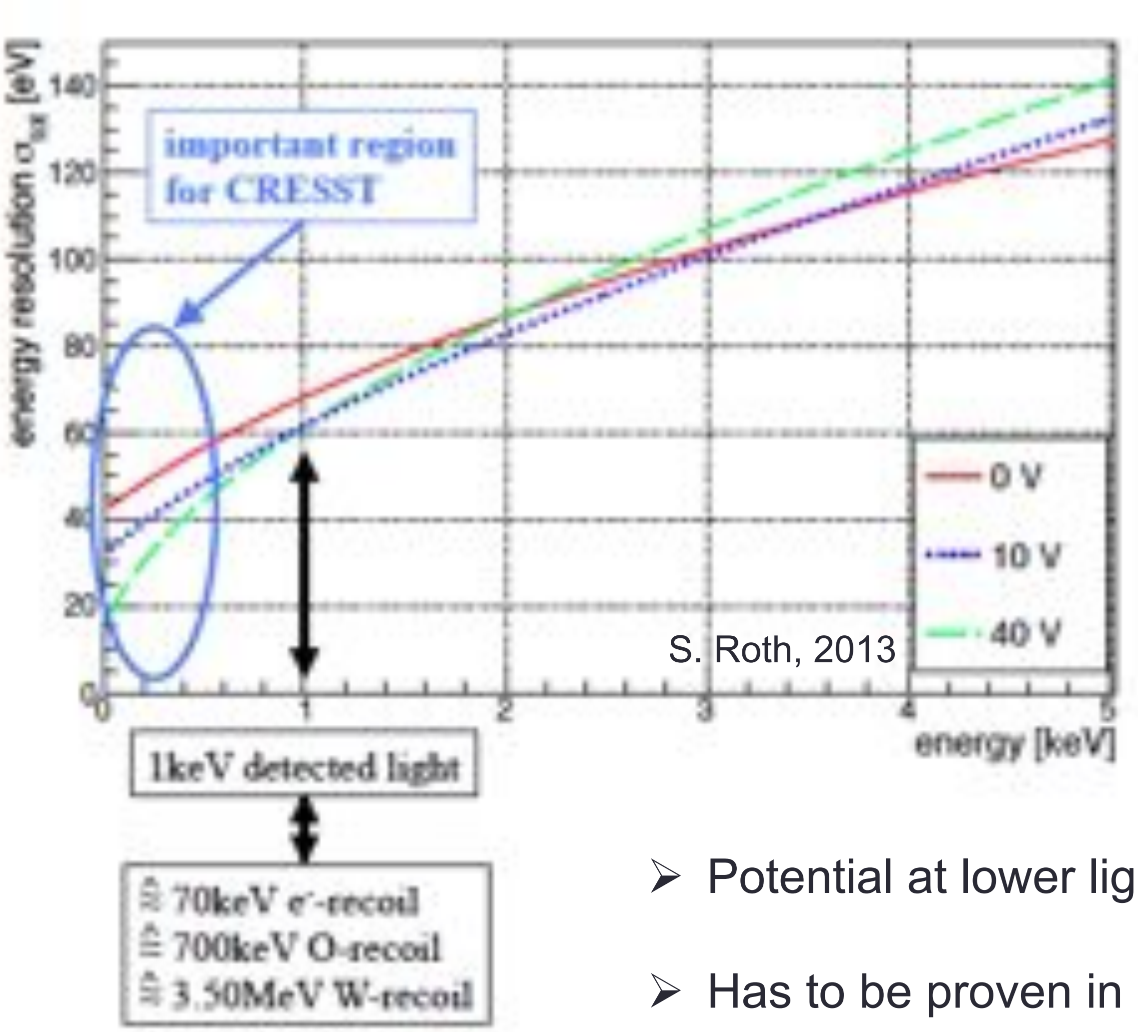
composite light detector with Al electrodes for Neganov-Luke amplification

Total energy E_{tot} deposited in the absorber: $E_{tot} = \left(1 + \frac{e\cdot V_{NL}}{\epsilon}\right)\cdot E_0$

e.g.: $V_{NL} = 40\text{V} \leftrightarrow$ signal amplification by $A(V_{NL} = 40\text{V}) \approx 4$

S. Roth, TUM, PhD 2013

Neganov-Luke Amplified Light Detectors



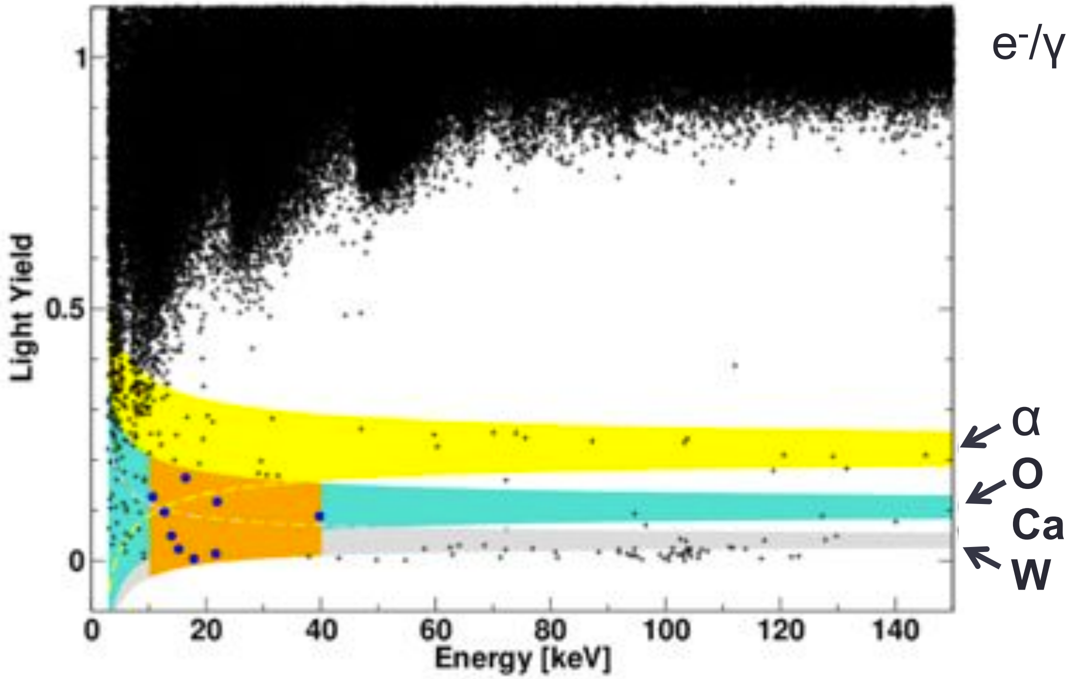
S. Roth, 2013

- Potential at lower light energies
- Has to be proven in realistic measurements

QUENCHING FACTORS

New Measurements at mK Temperatures

Quenching Factors (QF)

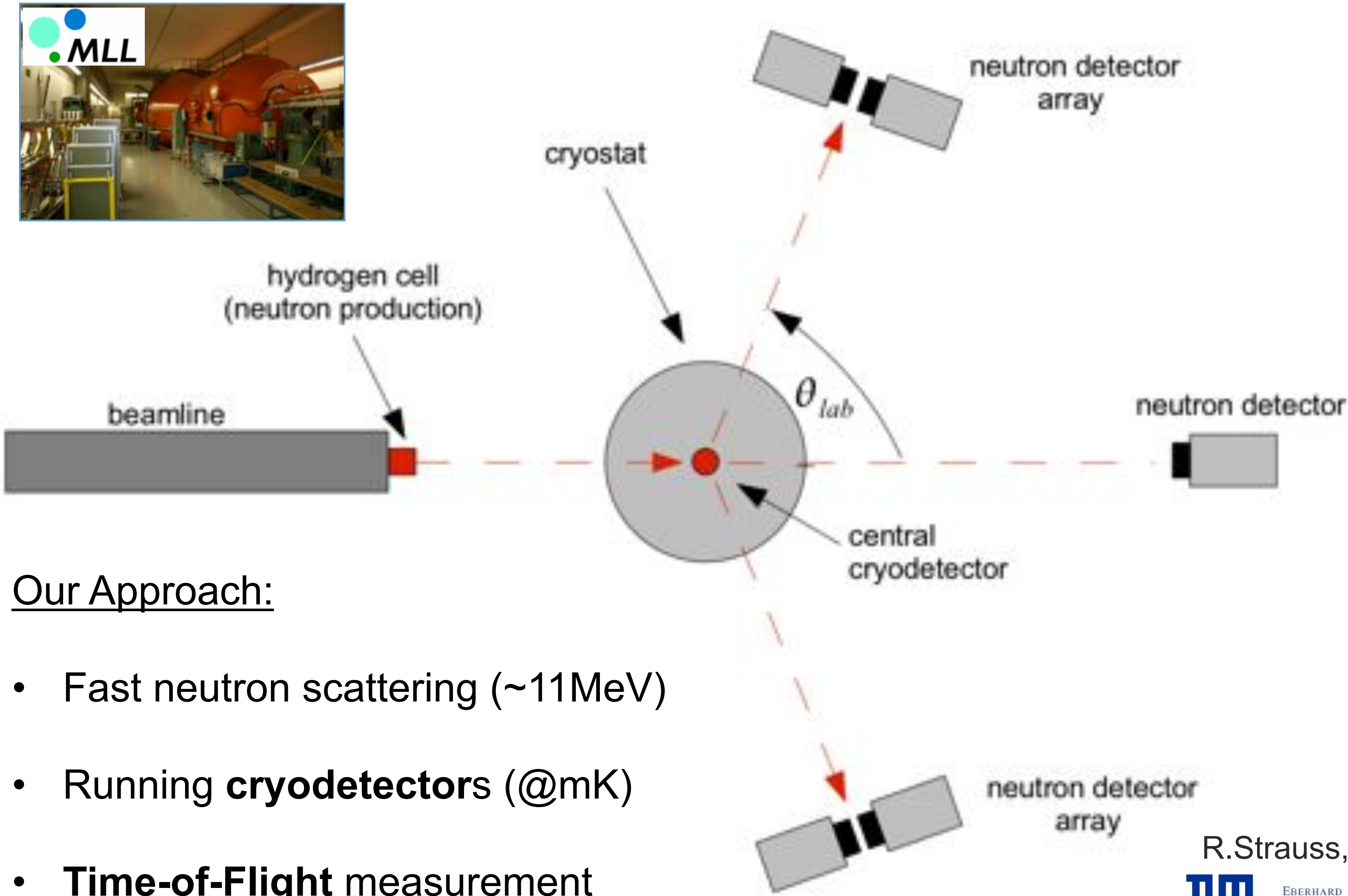


Dedicated measurement required!

Quenching Factors (QF)

Definition: $$QF_x(E_r) = \frac{LY_x(E_r)}{LY_{\gamma,\mathrm{np}}(E_r)} = \frac{\text{Light yield of nuclear recoil}}{\text{Light yield of e}^-/\gamma\text{ recoil}}$$

Neutron Scattering Facility – Experimental Setup



Our Approach:

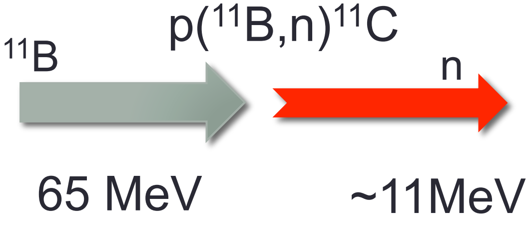
- Fast neutron scattering (~11MeV)
- Running **cryodetectors** (@mK)
- **Time-of-Flight** measurement

R.Strauss, PhD 2013

TECHNISCHE UNIVERSITÄT MÜNCHEN

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Neutron Scattering Facility – Experimental Setup



^{11}B

p(^{11}B,n)^{11}C

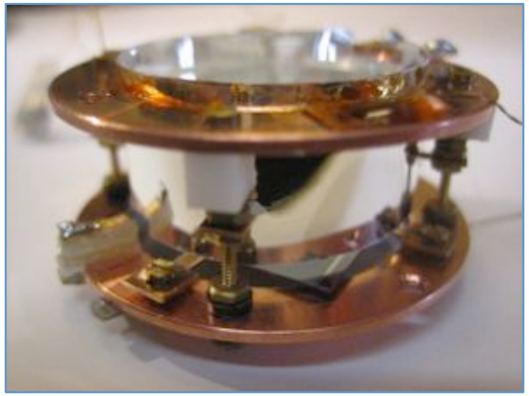
n

65 MeV

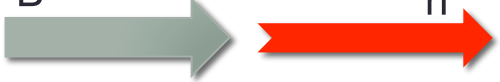
~11MeV

pulsed beam

“CRESST–like“ detector module



Neutron Scattering Facility – Experimental Setup



^{11}B

$p(^{11}B,n)^{11}C$

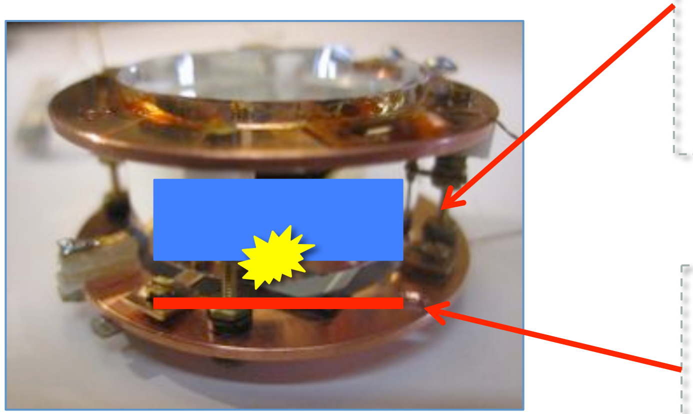
n

65 MeV

~11MeV

pulsed beam

“CRESST–like“ detector module



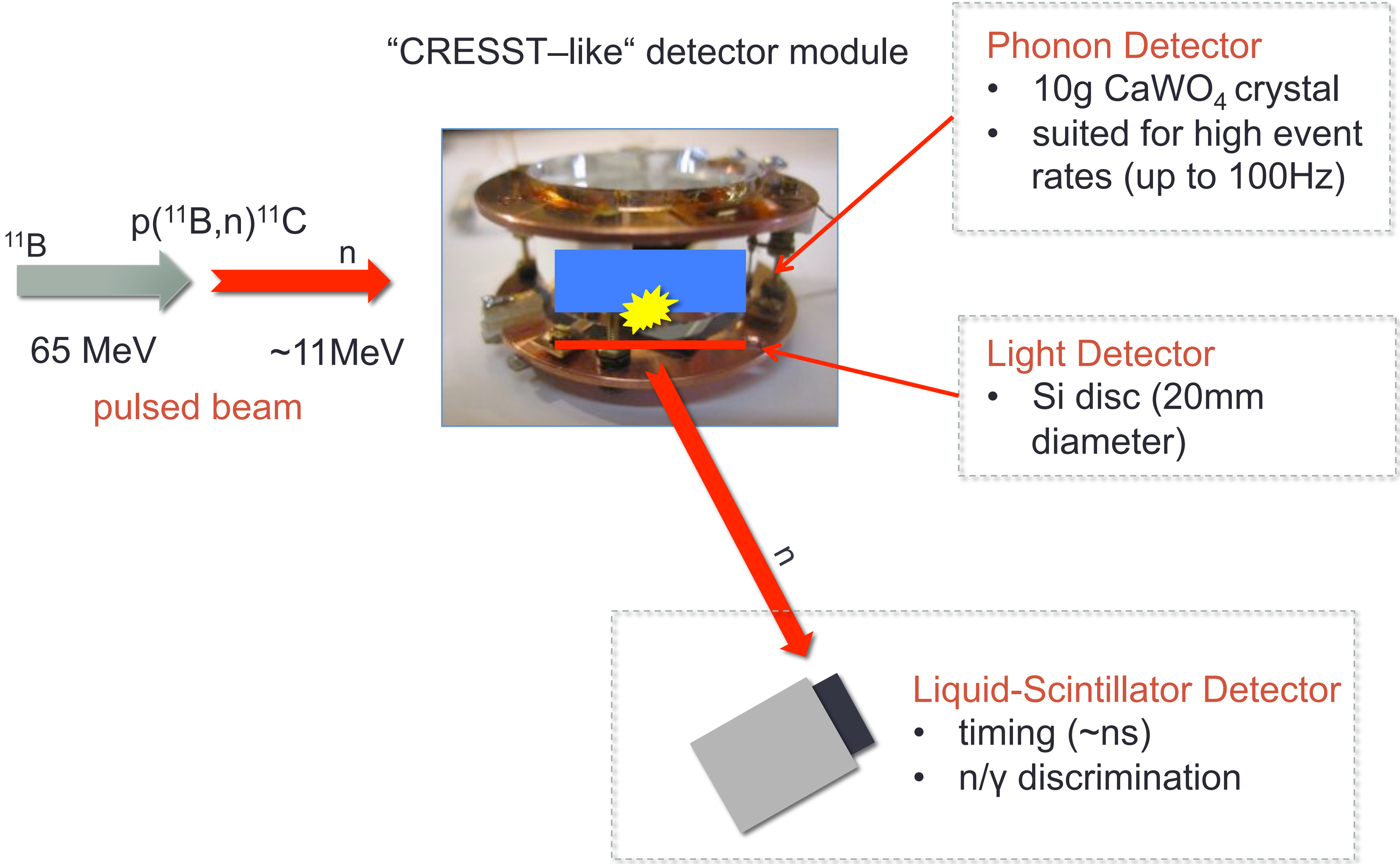
Phonon Detector

- 10g $CaWO_4$ crystal
- suited for high event rates (up to 100Hz)

Light Detector

- Si disc (20mm diameter)

Neutron Scattering Facility – Experimental Setup



“CRESST–like“ detector module

^{11}B

$p(^{11}B,n)^{11}C$

n

65 MeV

~11MeV

pulsed beam

n

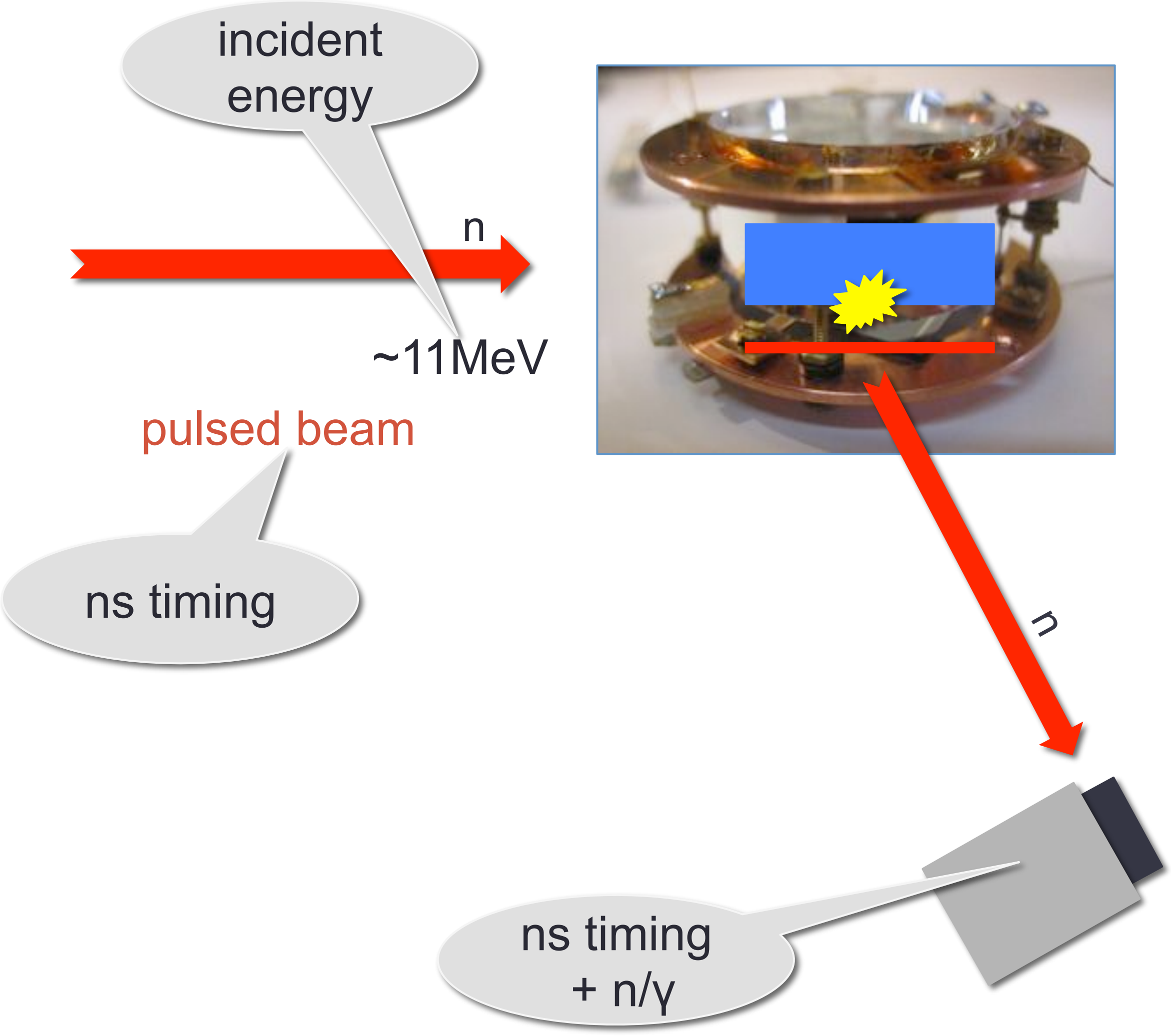
Phonon Detector
- $10g\ CaWO_4$ crystal
- suited for high event rates (up to 100Hz)

Light Detector
- Si disc (20mm diameter)

Liquid-Scintillator Detector
- timing (~ns)
- n/γ discrimination

Neutron Scattering Facility – Working Principle

“CRESST–like“ detector module



incident energy

n

~11MeV

pulsed beam

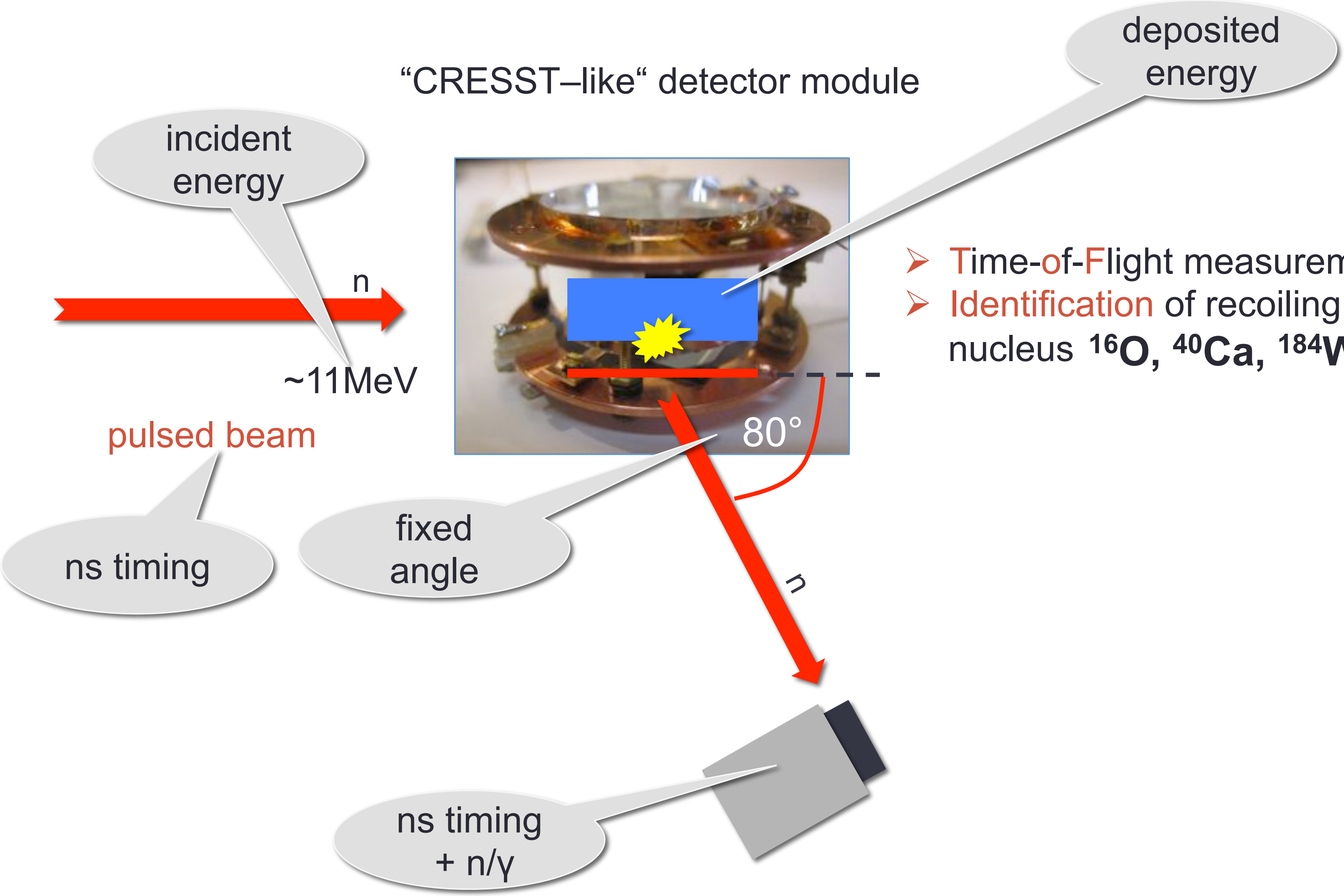
ns timing

n

ns timing + n/γ

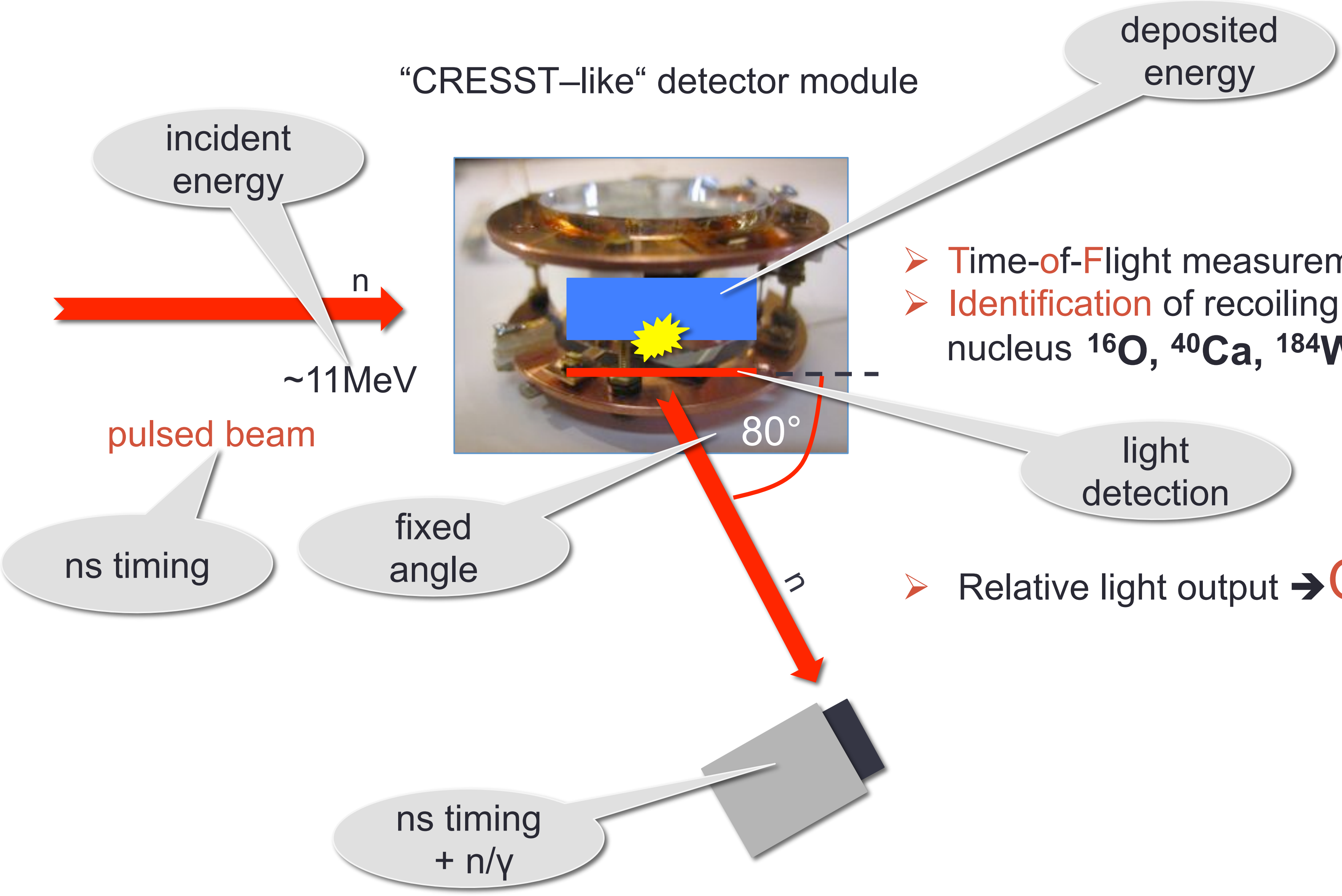
- Time-of-Flight measurement

Neutron Scattering Facility – Working Principle



- Time-of-Flight measurement
- Identification of recoiling nucleus ^{16}**O**, ^{40}**Ca**, ^{184}**W**

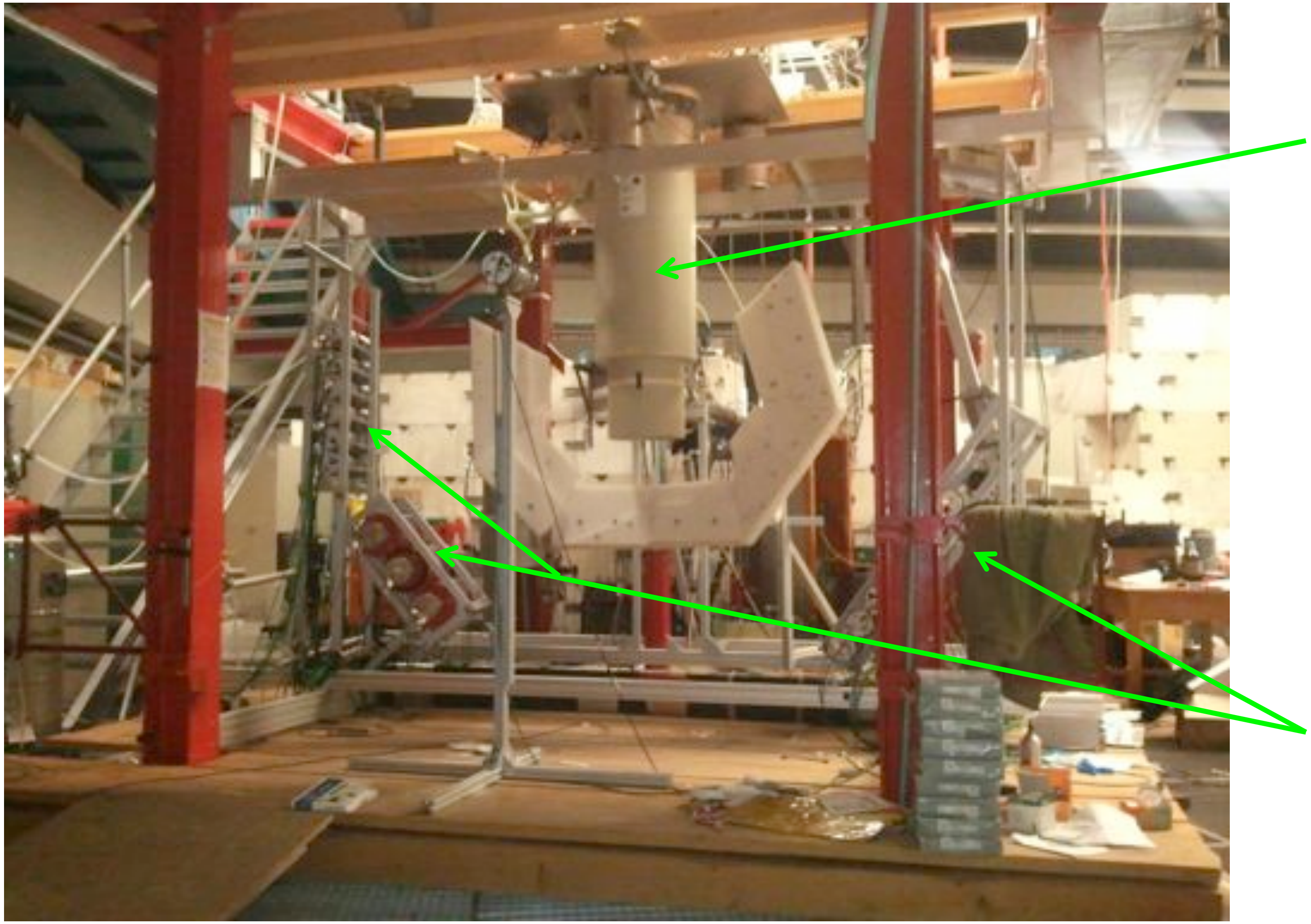
Neutron Scattering Facility – Working Principle



- Time-of-Flight measurement
- Identification of recoiling nucleus ^{16}**O**, ^{40}**Ca**, ^{184}**W**

- Relative light output → QF

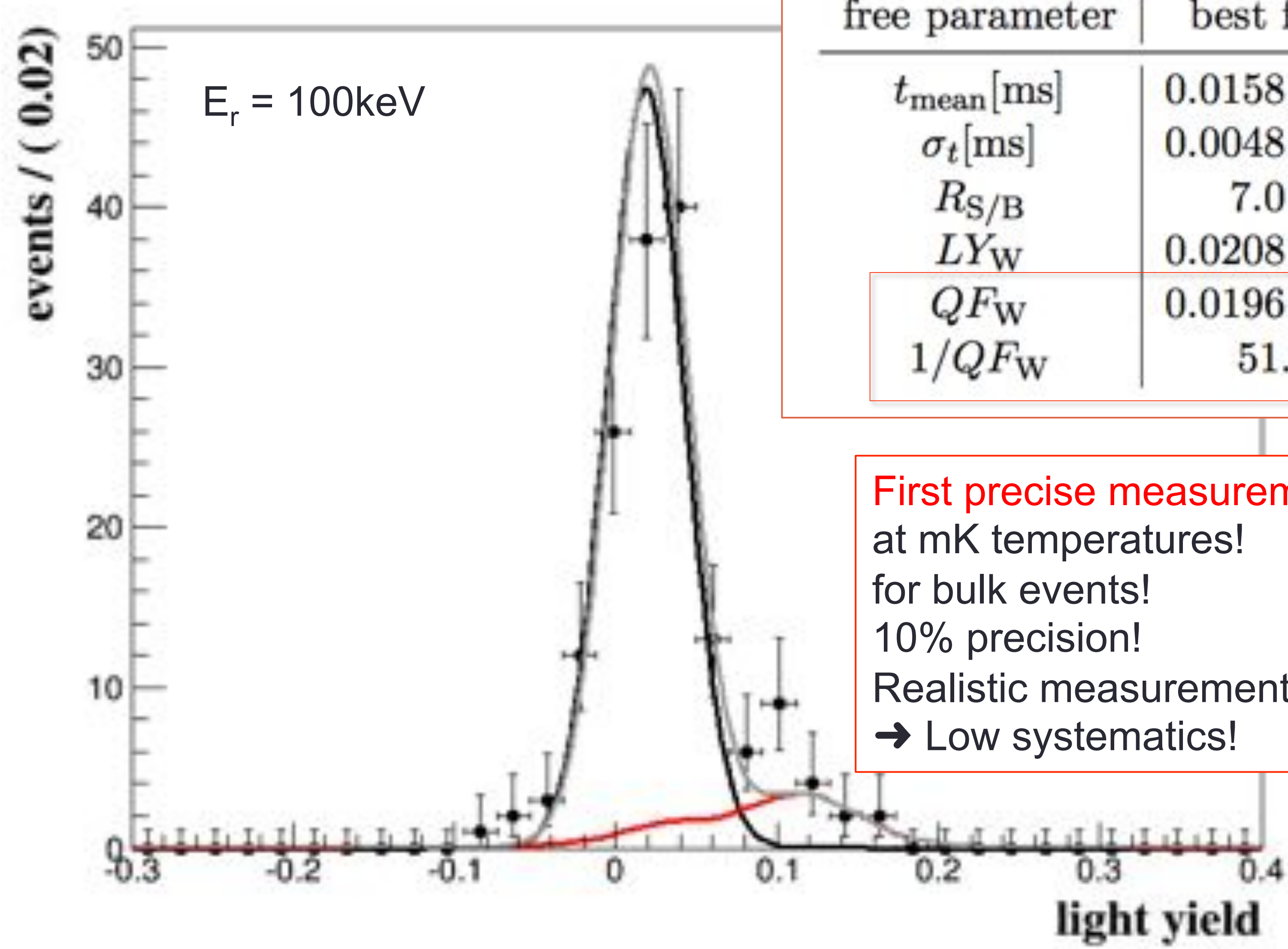
Neutron Scattering Facility in Garching



cryostat

neutron
detectors

Final Result for W



free parameter	best fit value
t_{mean}[ms]	0.0158 ± 0.0005
σ_t[ms]	0.0048 ± 0.0004
$R_{\text{S/B}}$	7.0 ± 0.6
LY_{W}	0.0208 ± 0.0024
QF_{W}	0.0196 ± 0.0022
$1/QF_{\text{W}}$	$51.0^{+6.5}_{-5.1}$

First precise measurement of QF_W
at mK temperatures!
for bulk events!
10% precision!
Realistic measurement conditions:
➜ Low systematics!

Energy-Dependent Quenching Factors

With precise measurement of the QF_W @ 100keV:

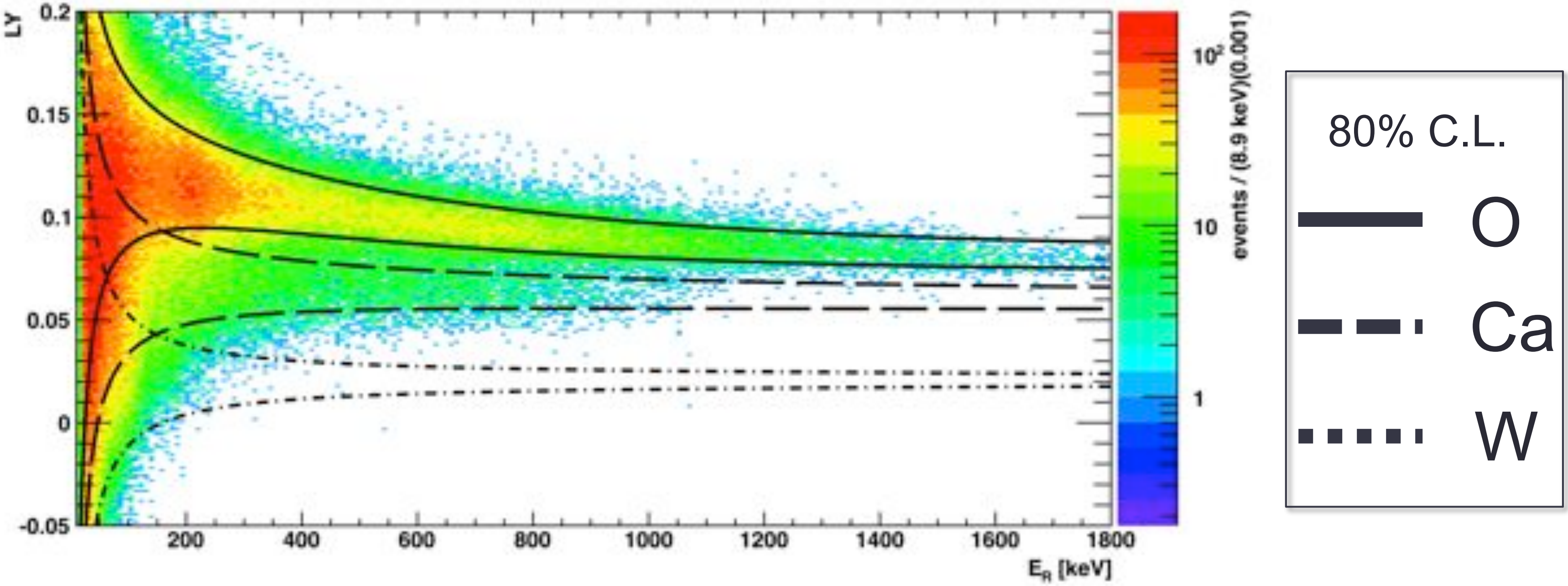
- Fit of entire nuclear recoil bands (20-1800keV) possible
- Dedicated maximum likelihood framework

➢ Precise determination of QF_O, QF_{Ca} ,QF_W

➢ Energy dependence measured for the first time

QF_O =0.1212±0.0035
QF_{Ca}=0.0667±0.0030
QF_W =0.0196±0.0022

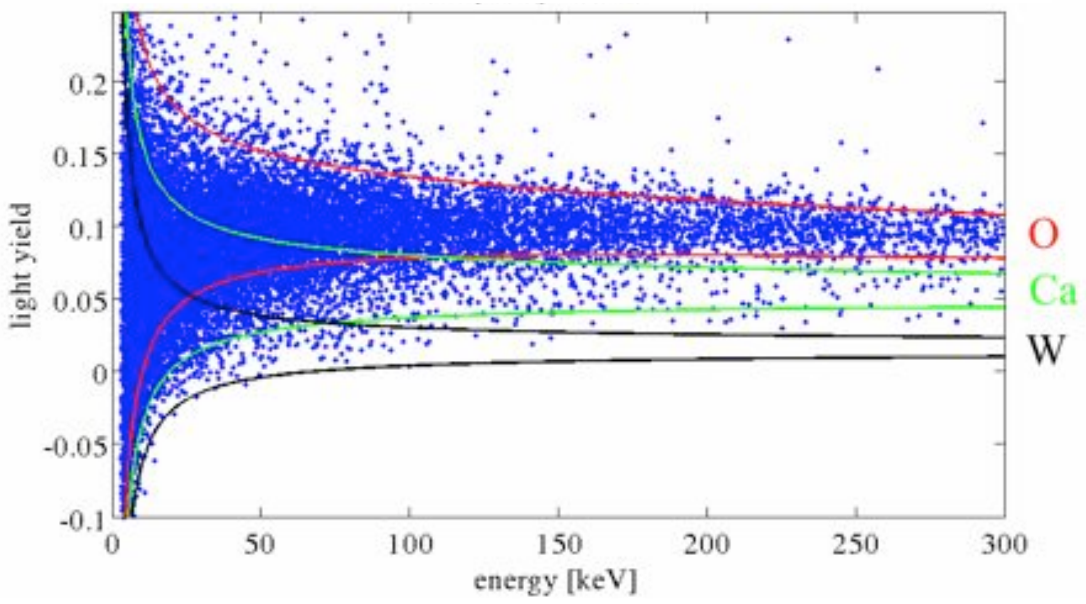
@100keV



Energy-Dependent Quenching Factors

Nuclear recoil behaviour of CRESST detectors (run32) well described by energy-dependent QFs!

Typical CRESST module (run32): neutron calibration

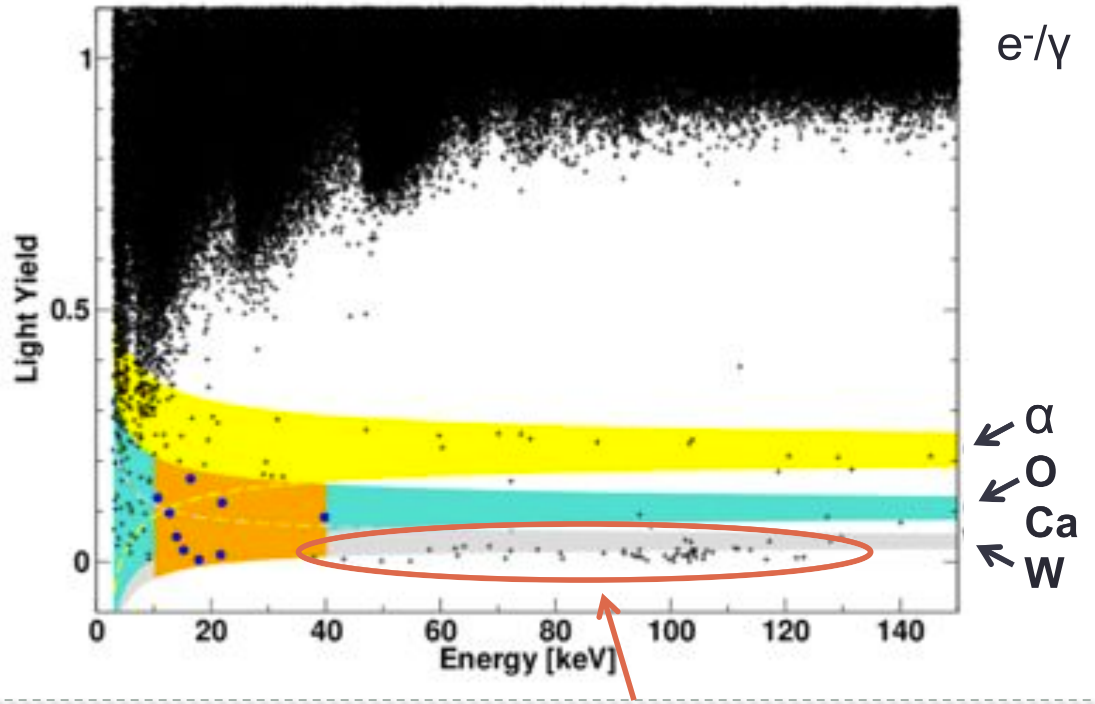


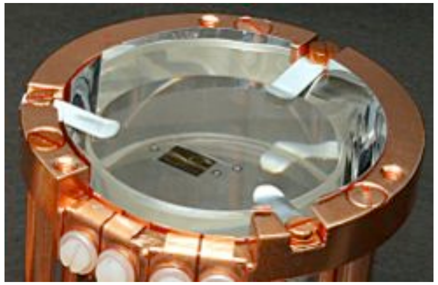
- ➢ Impact on CRESST data
- ➢ Implementation of results (energy dependence) into CRESST analysis framework
- ➢ Re-analysis of run32 data

NEW DETECTOR CONCEPTS

Fully-Scintillating Detector Designs

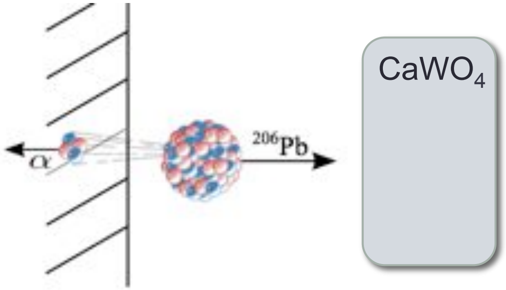
Surface Backgrounds in CRESST (run32)





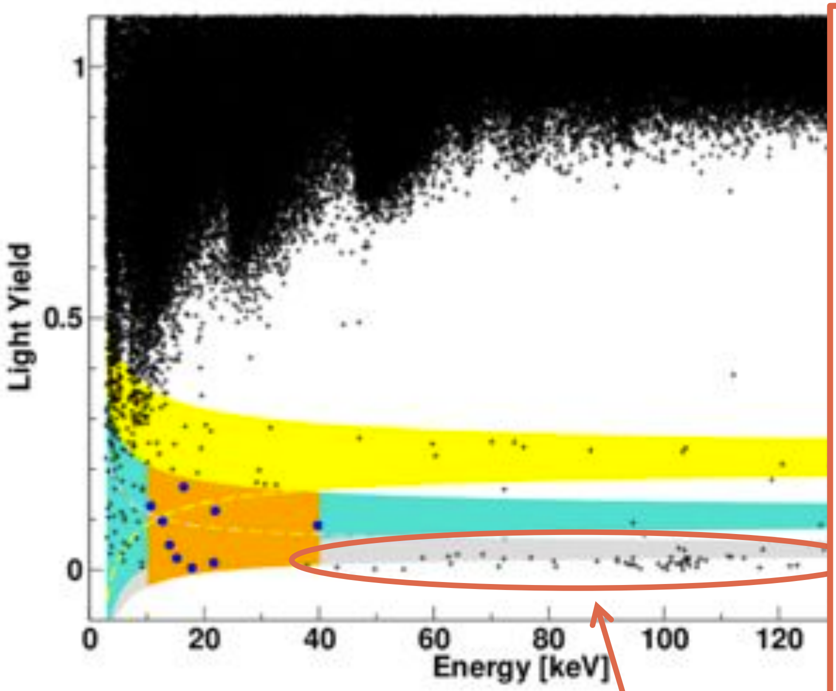
$^{210}Po \rightarrow {}^{206}Pb(103keV)+\alpha(5.3MeV)$

Dangerous events with less light!



$E_{dep} \leq 103keV$

Surface Backgrounds in CRESST (run32)



CRESST – run32
(*730 kg-days*)

67 events observed in 8 modules
Likelihood Analysis:

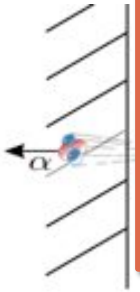
	M2
e/γ-events	8.00 ± 0.05
α-events	$11.2^{+2.5}_{-2.3}$
neutron events	$9.7^{+6.1}_{-5.1}$
Pb recoils	$18.7^{+4.9}_{-4.7}$
signal events	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	11.6
σ_{WN} [pb]	$3.7 \cdot 10^{-5}$

Statistical significance: >4σ

European Physical Journal C, 2012;72(4):279-300

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

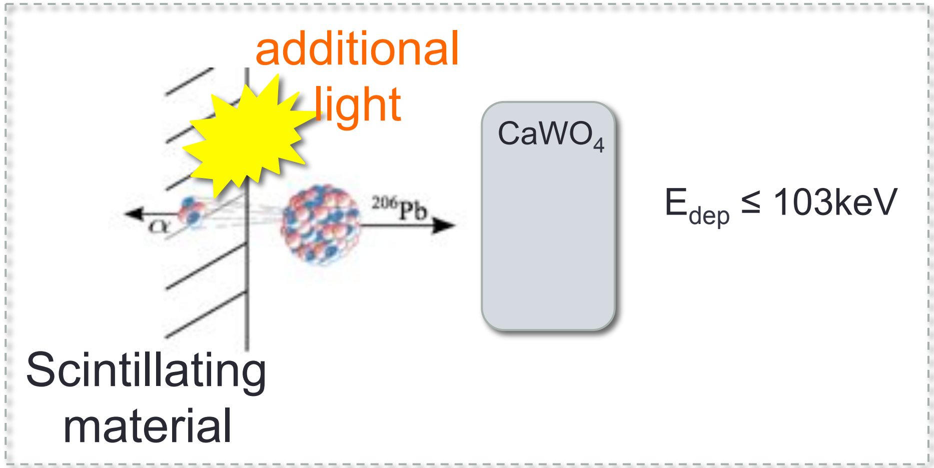
Dangerous events with less light!

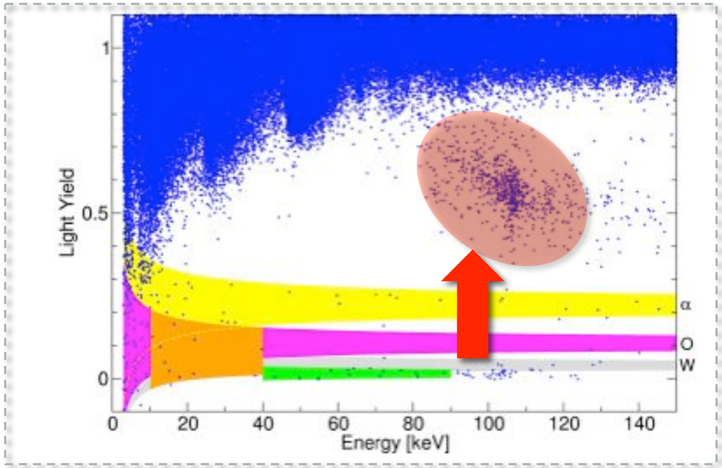


The Challenge of a Fully-Scintillating Housing

If all material inside housing were scintillating

➜ Highly-efficient veto against surface backgrounds



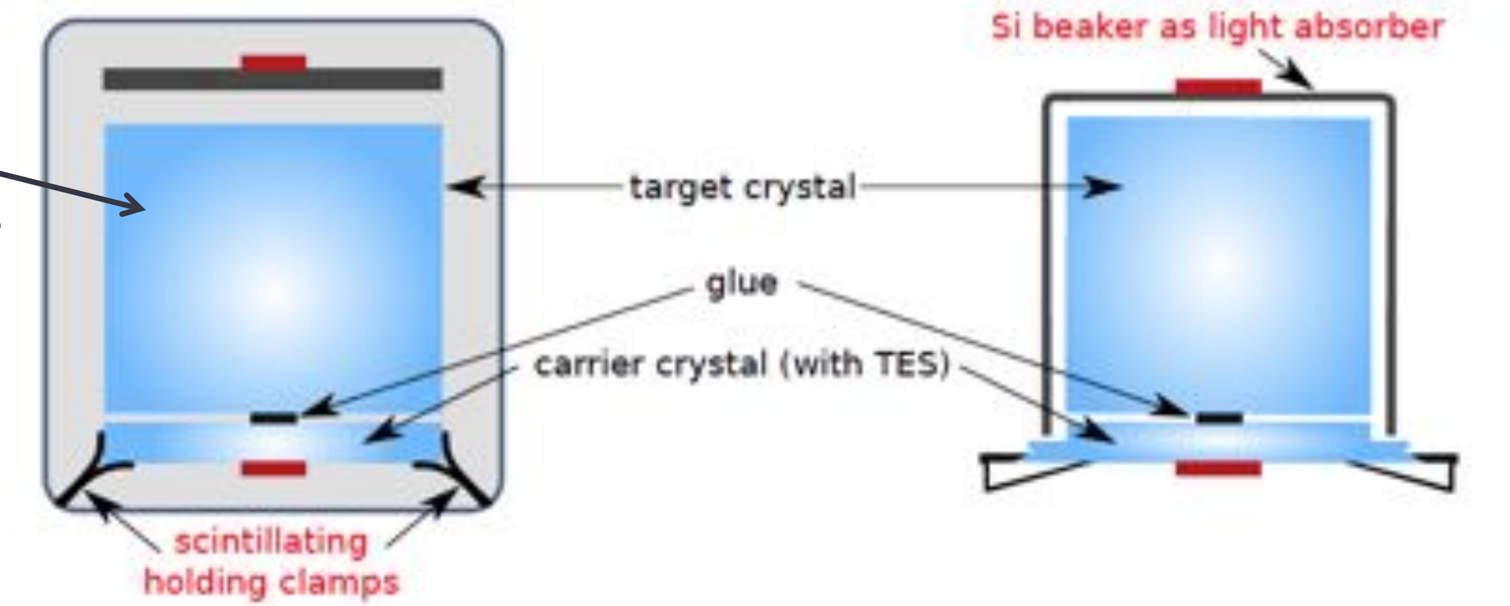


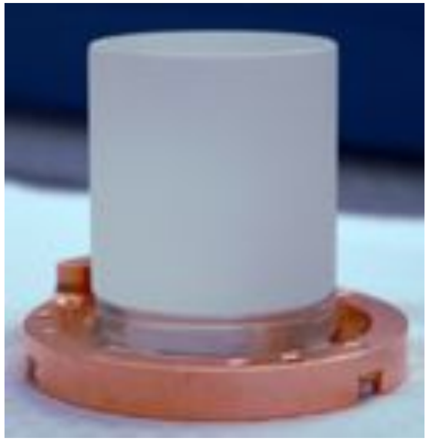
Mechanical stress induced by scintillating material in contact with crystal

➜ All attempts failed so far (phonon-only events)

Fully Scintillating Detector Designs

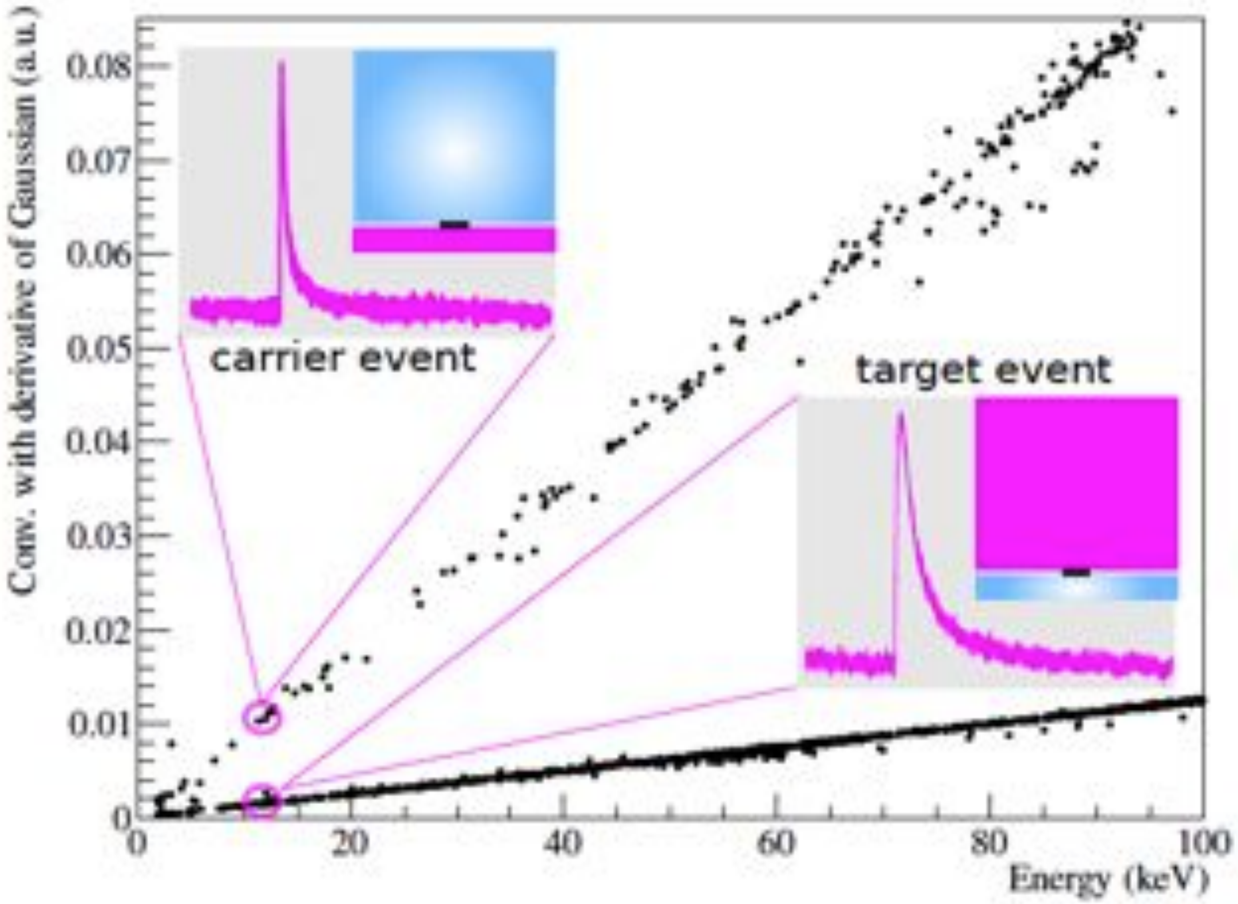
2 TUM crystals





G. Angloher, MPI

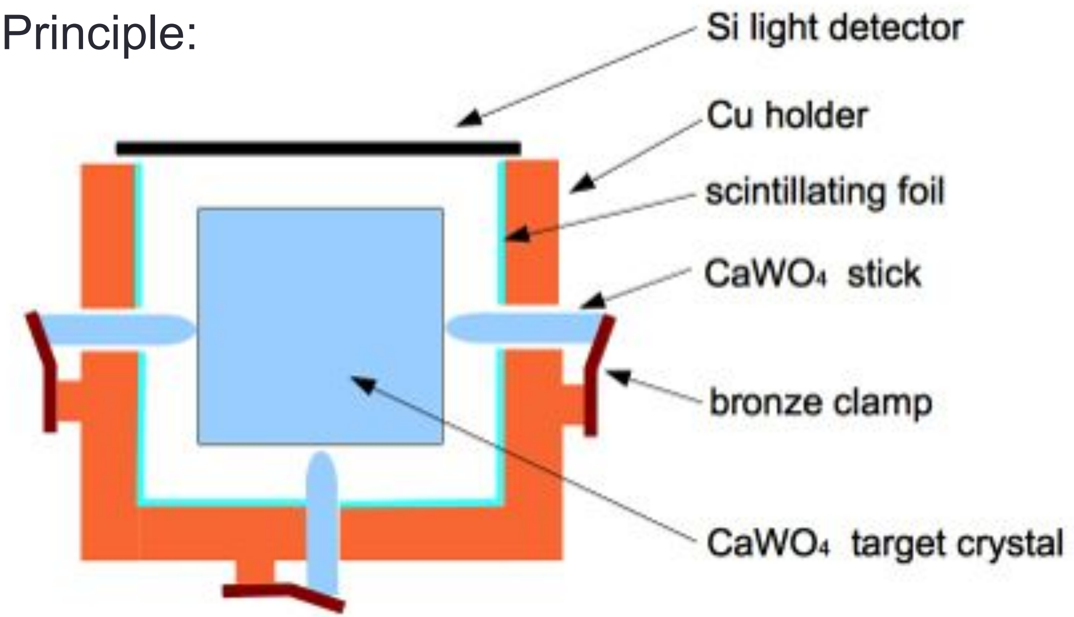
Discrimination of Carrier Events



Discrimination possible down to energies well below 10keV!

Fully-Scintillating Detector Module

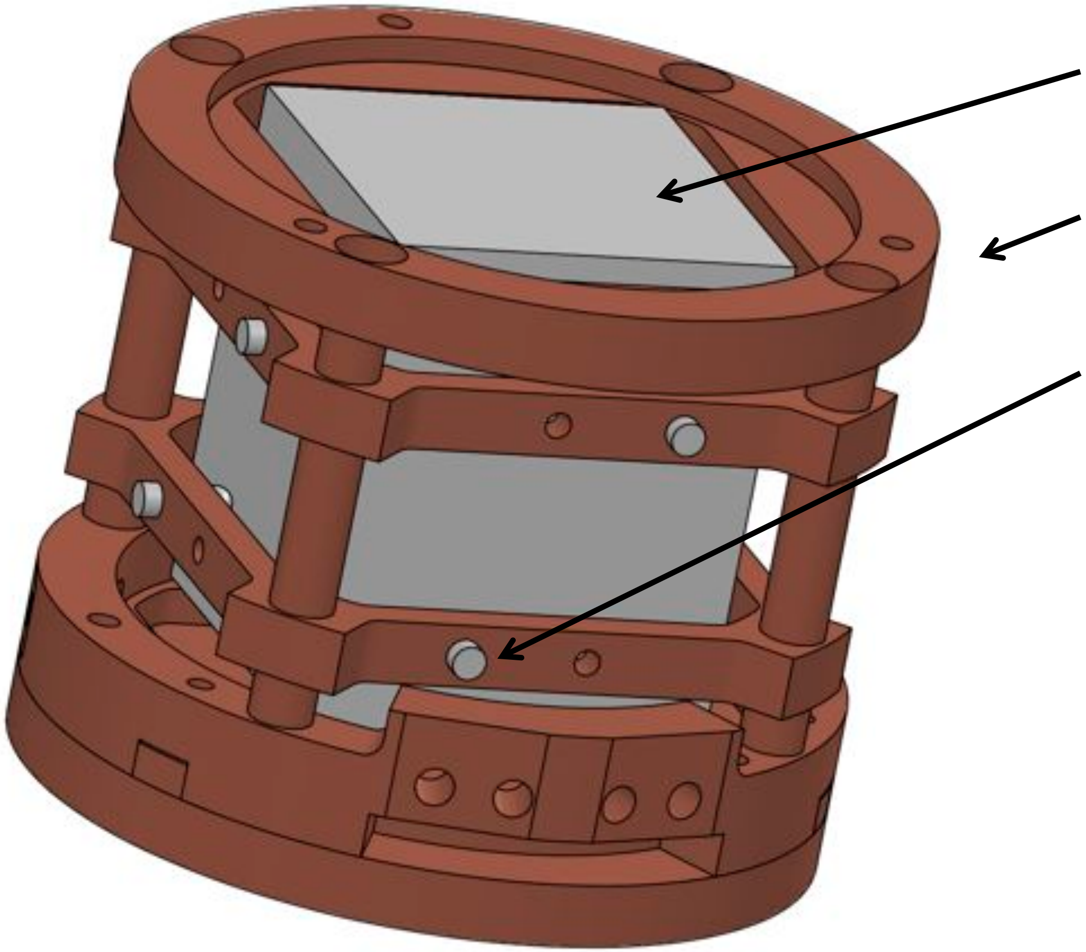
Principle:



- Highly efficient **veto against surface background events**!
- Promising **block-shaped** crystal design

R.Strauss, PhD 2013

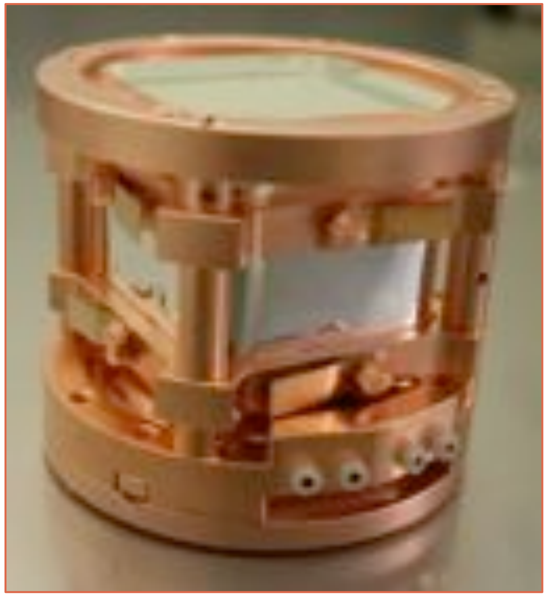
Fully-Scintillating Detector Module



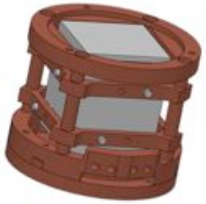
$CaWO_4$ crystal

Copper structure

$CaWO_4$ stick



First Glance at run33 Data



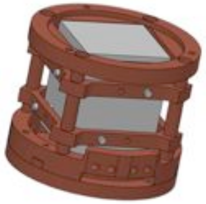
TUM-40 (CaWO$_4$ sticks) – 12.6 kg-days

plot removed – internal use only

Best radiopurity
(3 counts/kg/keV/day)

Scintillation veto
works

First Glance at run33 Data



TUM-40 (CaWO$_4$ sticks) – 12.6 kg-days

plot removed – internal use only

ROI

Best radiopurity
(3 counts/kg/keV/day)

Scintillation veto works

Clean region-of-interest (ROI)

- Background free
- No phonon-only events

New Detector Concepts for CRESST

3 fully scintillating detector prototypes in current CRESST run (2 each)

- ➢ Successful operation
- ➢ So-far: background free

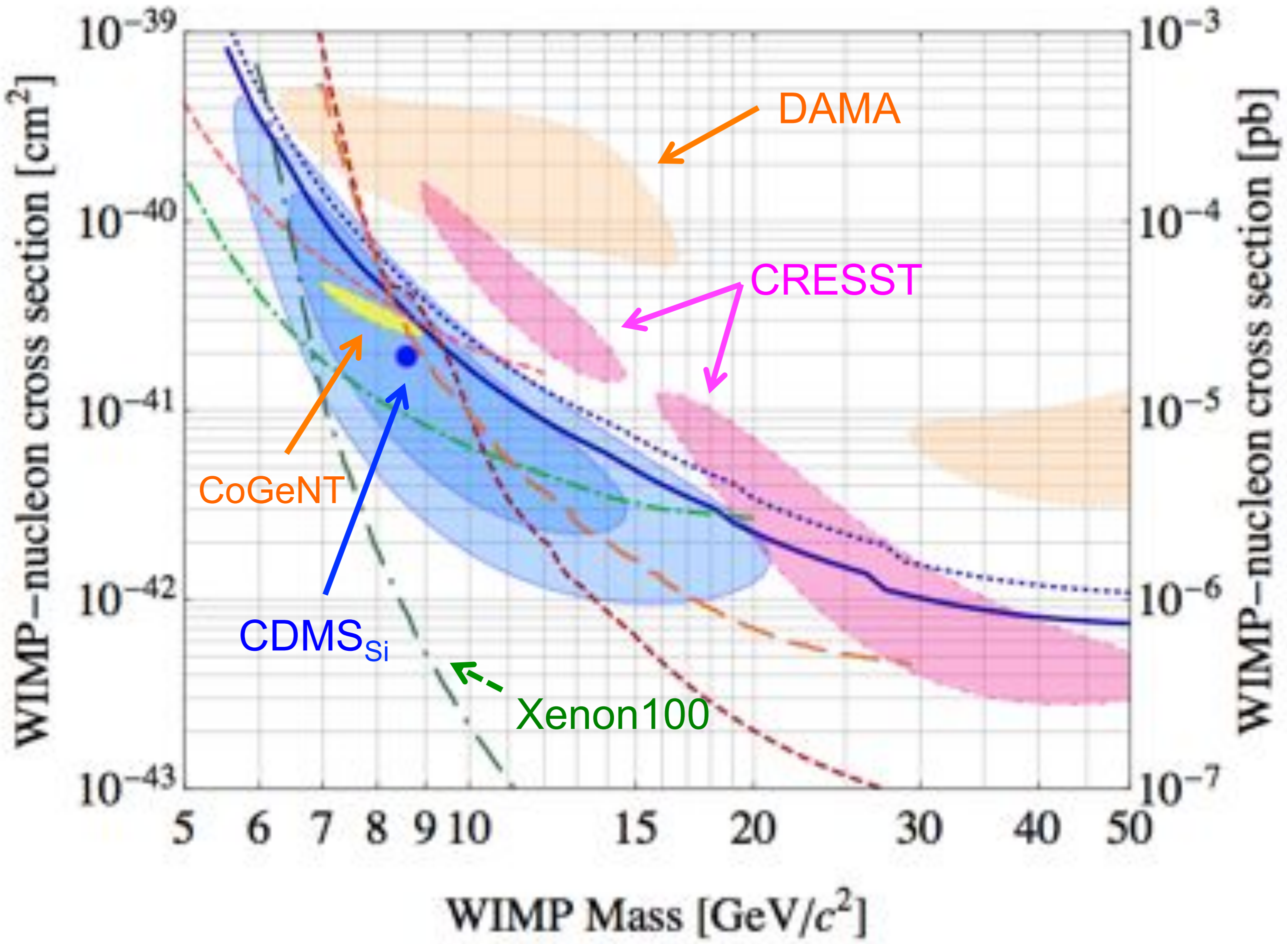
Next tasks?

- Production of more clean crystals at TUM
- Fully equip CRESST cryostat with new detector designs (up to 10kg)

LOW THRESHOLD ANALYSIS

Promising with TUM-Grown Crystals?

Low Mass WIMP Scenario ?

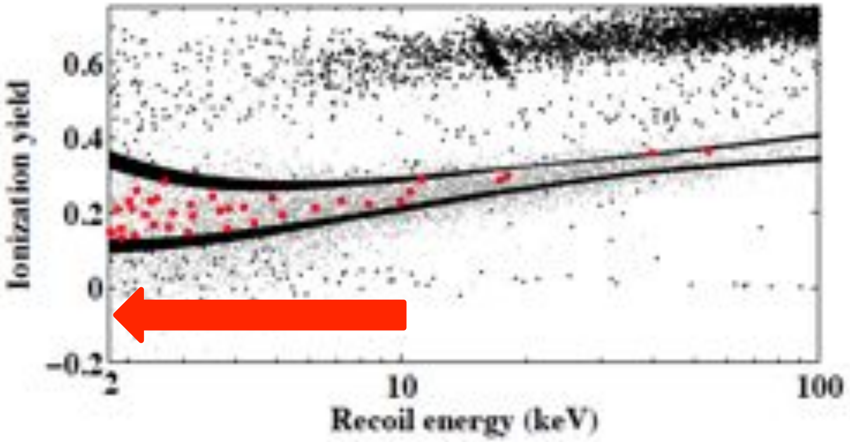


Low Threshold Analysis – General Idea

- Lower the threshold of measurement of recoil energy (typ. 10keV ➜ $\lesssim$1keV)
  ➜ Give up discrimination between electron and nuclear recoils
- High sensitivity to low mass WIMPs

Low Threshold Analysis – General Idea

- Lower the threshold of measurement of recoil energy (typ. 10keV ➜ ≲1keV)
  ➜ Give up discrimination between electron and nuclear recoils
- High sensitivity to low mass WIMPs
- Done already by other DM experiments
  - EDELWEISS (phonon-ionization): *Phys. Rev. D 86, 051701(R) (2012)*
  - CDMS (phonon-ionization): *Phys. Rev. Lett. 106, 131302 (2011)*

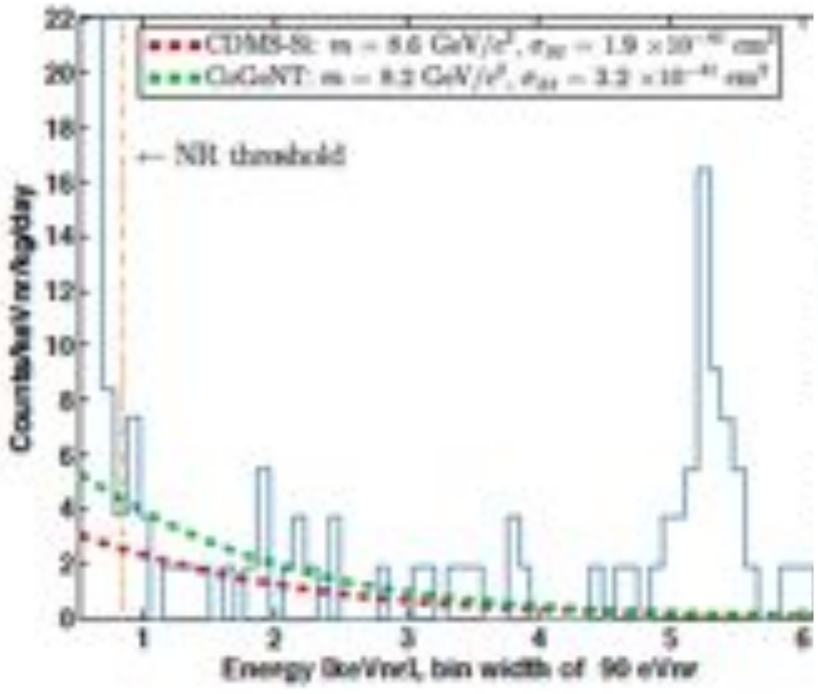


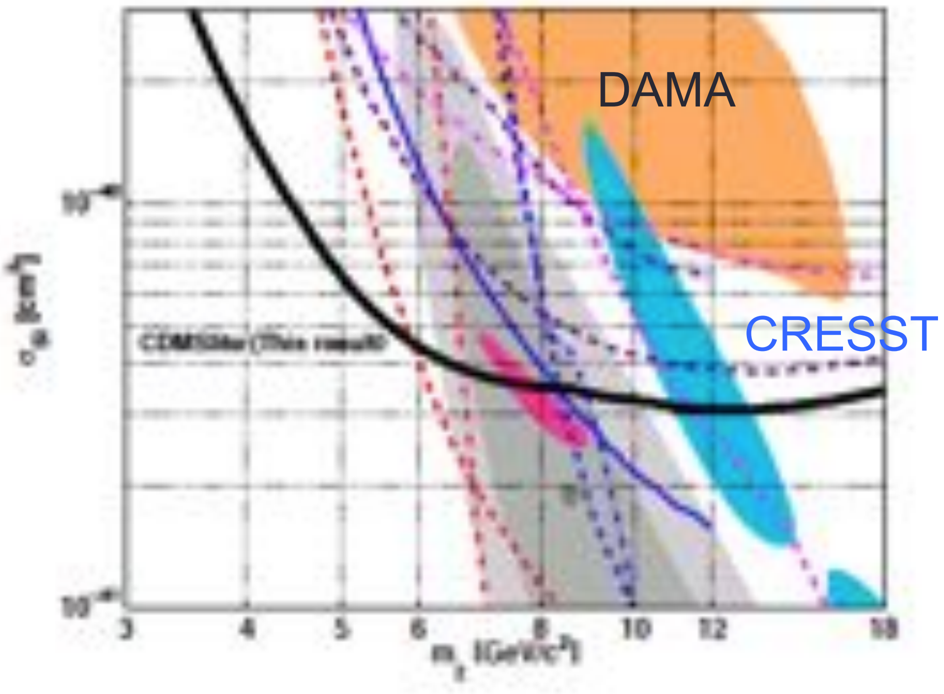
Red dots: possible DM candidates

  - XENON (S2 only): *Phys. Rev. Lett. 110, 249901 (2013)*
  - CDMSlite (NL-amplified phonon): *arxiv:1309.3259v2*

Recent Results from CDMSlite

- Single SuperCDMS detector (0.6kg) for 10 live-days
- Neganov-Luke voltage applied on electrodes → no discrimination
  - Gain in phonon signal by a factor of ~24
  - Baseline resolution: σ = 14eV
  - Analysis threshold: 170eV$_{ee}$
- Low energy threshold for nuclear recoils: ~840eV$_{nr}$ (phonon quenching)





Low-Threshold Analysis for CRESST?

- TUM-grown crystals have low intrinsic background level: ~3/kg/keV/day

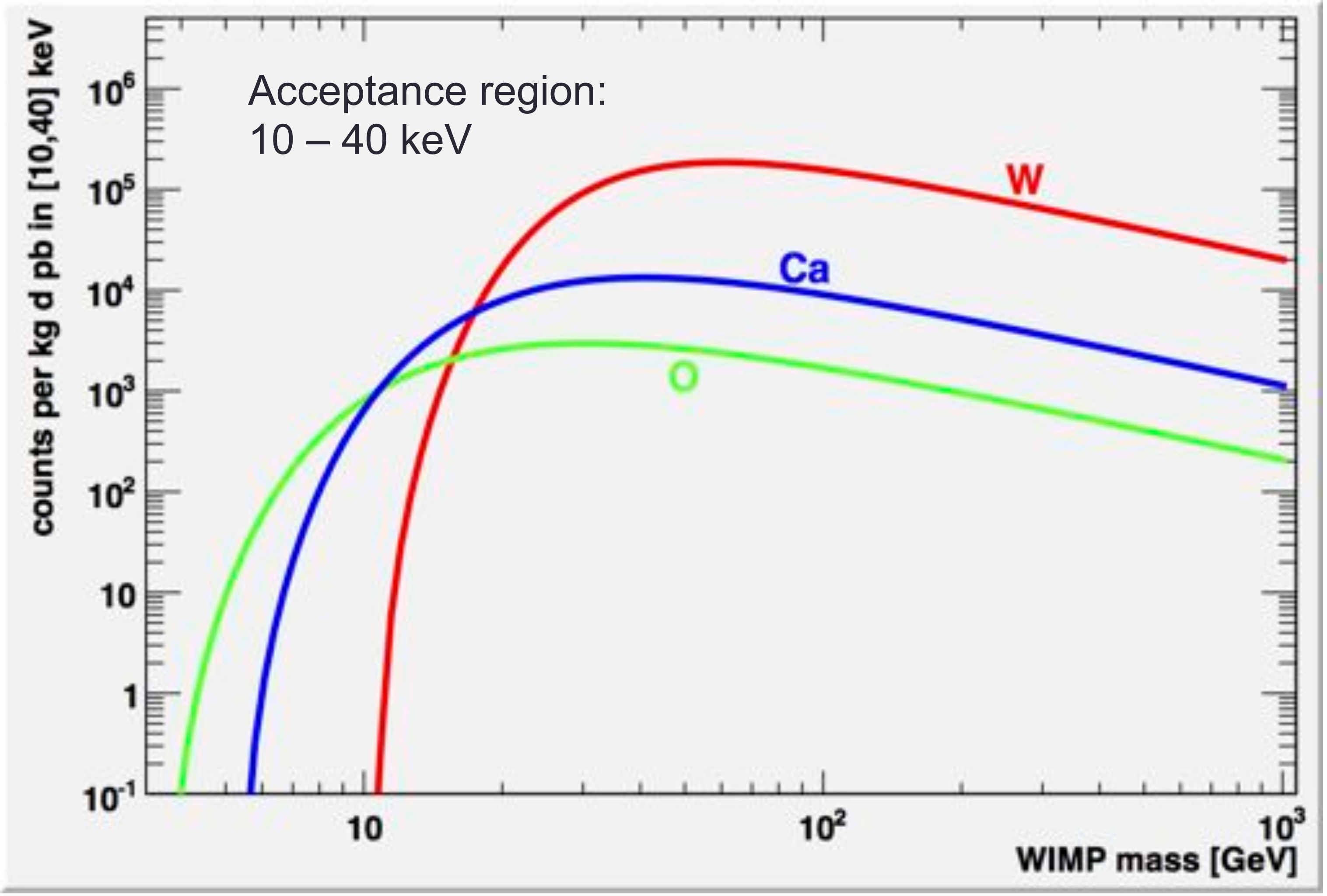
plot removed – internal use only

TUM-40

- Low energy threshold of CRESST detectors: $E_{th} \lesssim 1\mathrm{keV}$

Low Threshold Analysis for CRESST?

- T

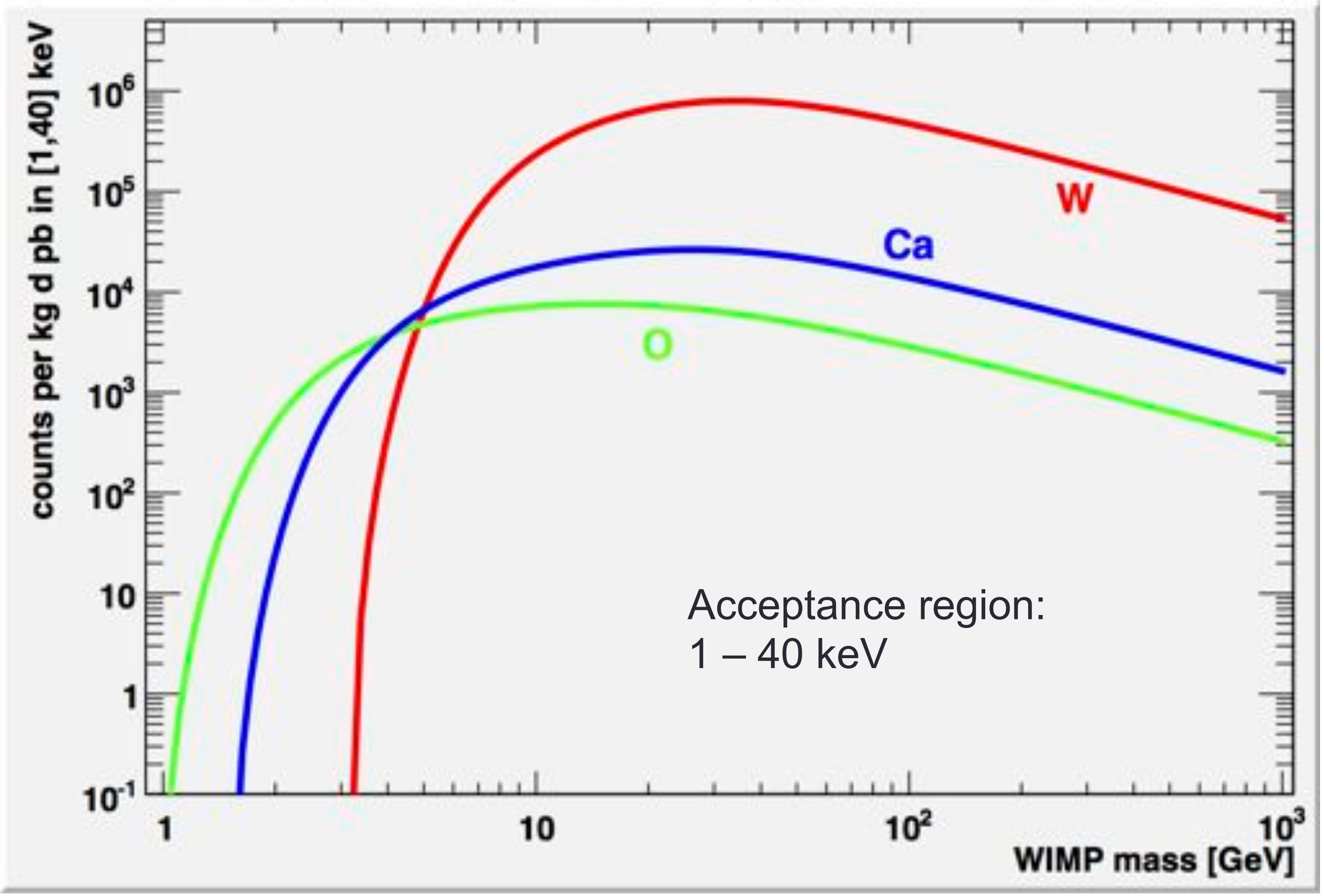


- L
- S

Low Threshold Analysis for CRESST?

- T

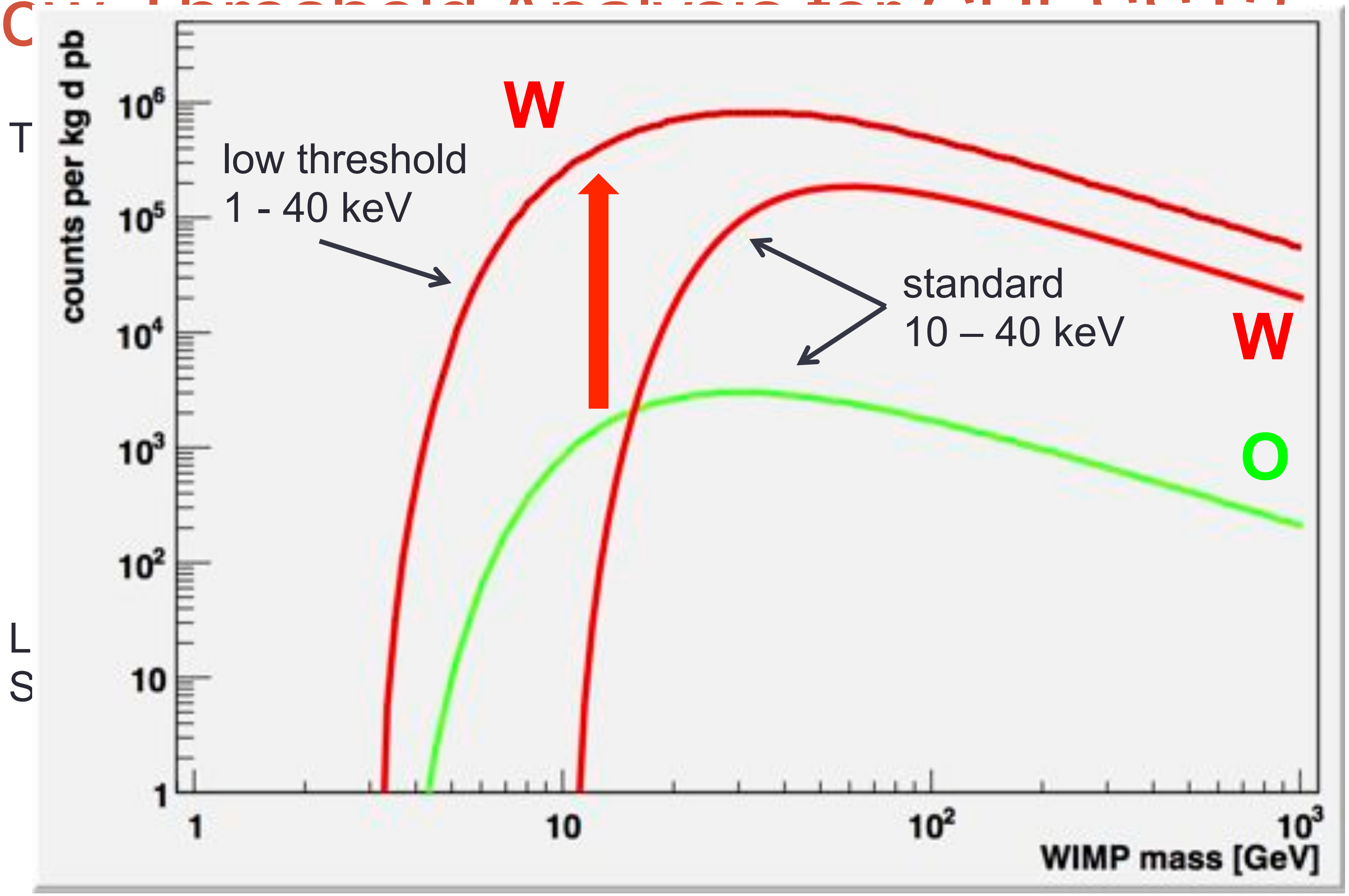
- L
- S



Acceptance region:
1 – 40 keV

Low Threshold Analysis for CRESST?

- T



- L
- S

Low-Threshold Analysis for CRESST?

- TUM-grown crystals have low intrinsic background level: ~3/kg/keV/day

plot removed – internal use only

TUM-40

- Low energy threshold of CRESST detectors: $E_{th} \lesssim 1\,\mathrm{keV}$
- Increased sensitivity at 3-10 GeV by ~2 orders of magnitude

Low-Threshold Analysis for CRESST?

- TUM-grown crystals have low intrinsic background level: ~3/kg/keV/day

plot removed – internal use only

TUM-40

- Low energy threshold of CRESST detectors: $E_{th} \lesssim 1\text{keV}$
- Increased sensitivity at 3-10 GeV by ~2 orders of magnitude
- Strong enhancement of W scatters (due to A^2 dependence)
    - ➢ Compared to Ge (CDMS) enhanced by a factor of ~ 6.3

Low-Threshold Analysis for CRESST?

- TUM-grown crystals have low intrinsic background level: ~3/kg/keV/day

plot removed – internal use only

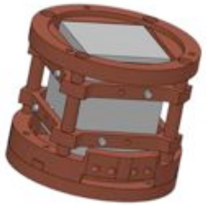
TUM-40

- Low energy threshold of CRESST detectors: $E_{th} \lesssim$ 1keV
- Increased sensitivity at 3-10 GeV by ~2 orders of magnitude
- Strong enhancement of W scatters (due to A^2 dependence)
  - Compared to Ge (CDMS) enhanced by a factor of ~ 6.3
- Further reduction of background due to light yield information

Low-Threshold Analysis for CRESST?

- TUM-grown crystals have low intrinsic background level: ~3/kg/keV/day

plot removed – internal use only



TUM-40

- Low energy threshold of CRESST detectors: $E_{th} \lesssim 1$keV
- Increased sensitivity at 3-10 GeV by ~2 orders of magnitude
- Strong enhancement of W scatters (due to A^2 dependence)
  - ➢ Compared to Ge (CDMS) enhanced by a factor of ~ 6.3
- Further reduction of background due to light yield information

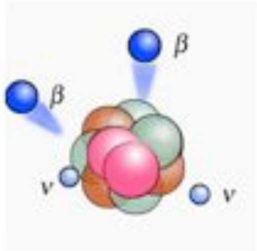
➢ Low-threshold analysis of CRESST detectors seems promising
➢ Only small mass and few exposure necessary!
➢ Can we probe our own “WIMP region“ ?

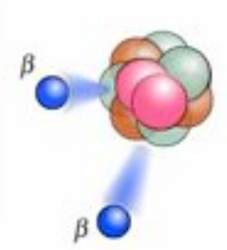
LIMITS ON 2β PROCESSES

Potential 2β Isotopes in $CaWO_4$

2 neutrino-double beta (2ν2β)
2 neutrino-double EC (2ν2ε)

0 neutrino-double beta (0ν2β)
0 neutrino-double EC (0ν2ε)



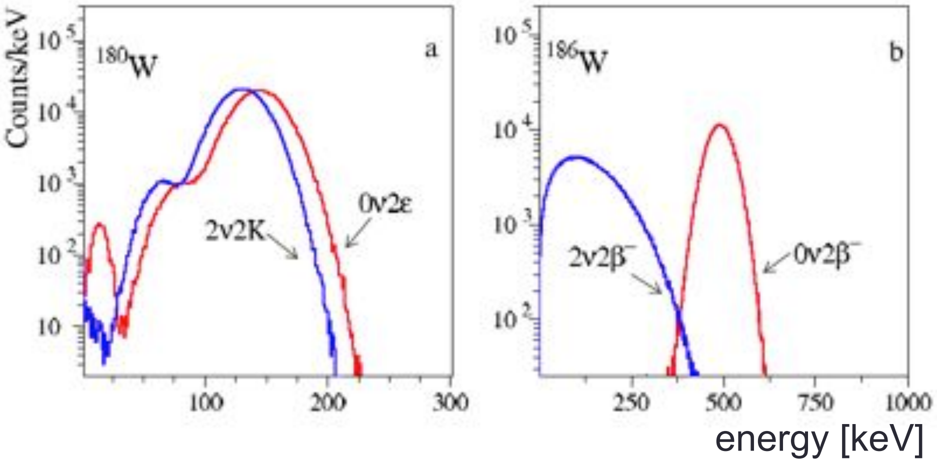


- Several potential 2**β** isotopes present in $CaWO_4$
- So far only limits for $T_{1/2}$ could be obtained

Isotope	Abundance, % [2]	2β process	$Q_{2\beta}$, keV [3]
^{40}Ca	96.941	2ε	193.62
^{46}Ca	0.004	$2\beta^-$	988.3
^{48}Ca	0.187	$2\beta^-$	4274
^{180}W	0.12	2ε	144
^{186}W	28.43	$2\beta^-$	489.9

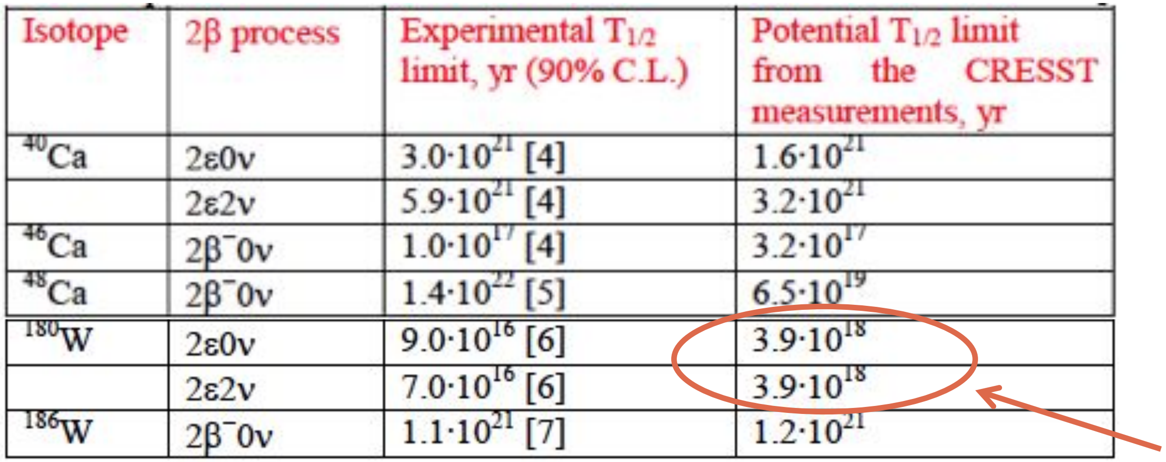
M.v.Sivers, TUM in collaboration with *V.I. Tretyak, KINR Kiev*

Limits for 2β Processes with CRESST



- Simulation to derive 2β energy spectrum
- Search for excess above background (flat)

Expectation for $T_{1/2}$:



Isotope	2β process	Experimental $T_{1/2}$ limit, yr (90% C.L.)	Potential $T_{1/2}$ limit from the CRESST measurements, yr
^{40}Ca	2ε0ν	$3.0\cdot10^{21}$ [4]	$1.6\cdot10^{21}$
	2ε2ν	$5.9\cdot10^{21}$ [4]	$3.2\cdot10^{21}$
^{46}Ca	2β$^-$0ν	$1.0\cdot10^{17}$ [4]	$3.2\cdot10^{17}$
^{48}Ca	2β$^-$0ν	$1.4\cdot10^{22}$ [5]	$6.5\cdot10^{19}$
^{180}W	2ε0ν	$9.0\cdot10^{16}$ [6]	$3.9\cdot10^{18}$
	2ε2ν	$7.0\cdot10^{16}$ [6]	$3.9\cdot10^{18}$
^{186}W	2β$^-$0ν	$1.1\cdot10^{21}$ [7]	$1.2\cdot10^{21}$

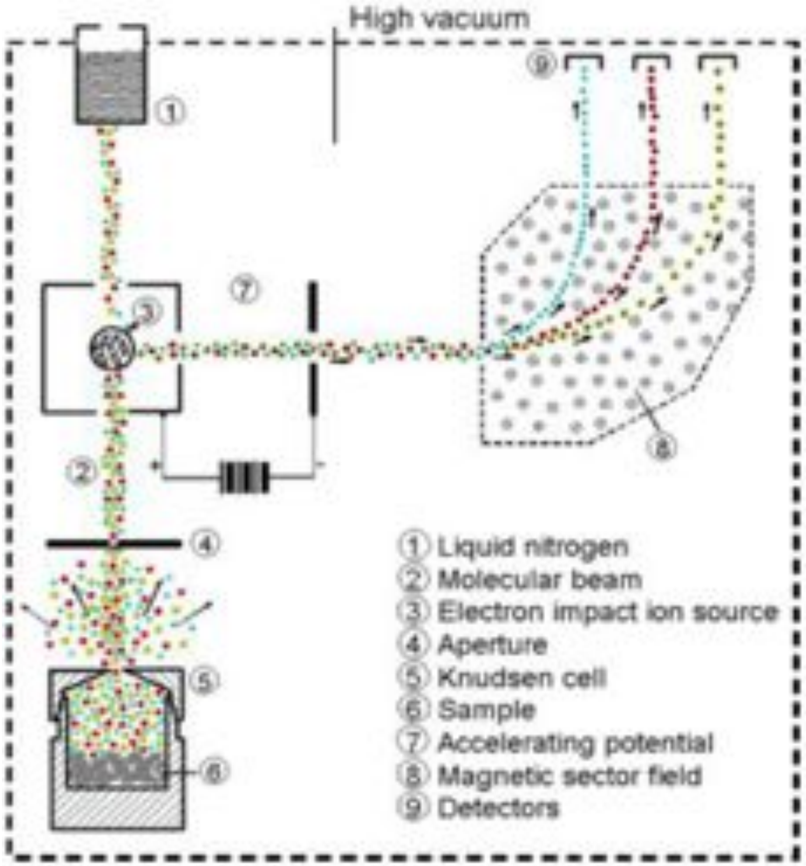
Background assumption:
~6/kg/keV/day

➜ Even better in run33 with TUM crystals!

better by ~2 orders of magnitude

Possible Enrichment of ^{48}Ca ?

Knudsen Effusion Mass Spectroscopy (KEMS) (*T. Markus, IEK-2 Jülich)*



- Vaporisation studies up to 2800K
- Precise measurement of partial pressures
- In case of Ca isotopes: not measured before
- Difference of partial pressures between ^{40}Ca and ^{48}Ca enough for separation on large scale?
- Enrichment of ^{48}Ca(0.2%) ➜ ??

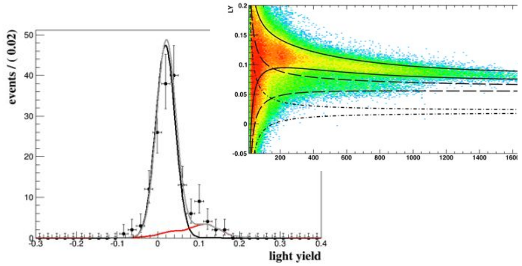
➢ Great potential for 0ν2β
➢ Q-value: 4.2MeV
➢ Above natural gamma region
➢ Alpha discrimination
➢ Established CRESST technique

Summary

- $CaWO_4$ production successfully established at TUM
  - Reproduclible production cycle
  - Low instrinsic contamination (now dominated by cosmogenics)

~3.0 /kg/keV/day

- Light detector optimization



- Quenching Factor measurements at mK temperatures
  - Precise measurement of the QF of W
  - Energy Dependence

- New detector concepts successfully operated in present run
  - So-far: background free
  - Great potential for next CRESST runs / EURECA
- Low-threshold analysis seems feasible with low-background detectors (TUM)
- Some potential on 2**β** processes