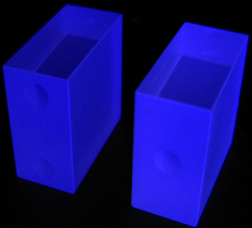
Direct Dark Matter Search with the CRESST-III Experiment

Andrea Münster

TUM

TeVPA 2017



CRESST Collaboration

INFN
Istituto Nazionale di Fisica Nucleare

TUM
TECHNISCHE UNIVERSITÄT MÜNCHEN

TU WIEN

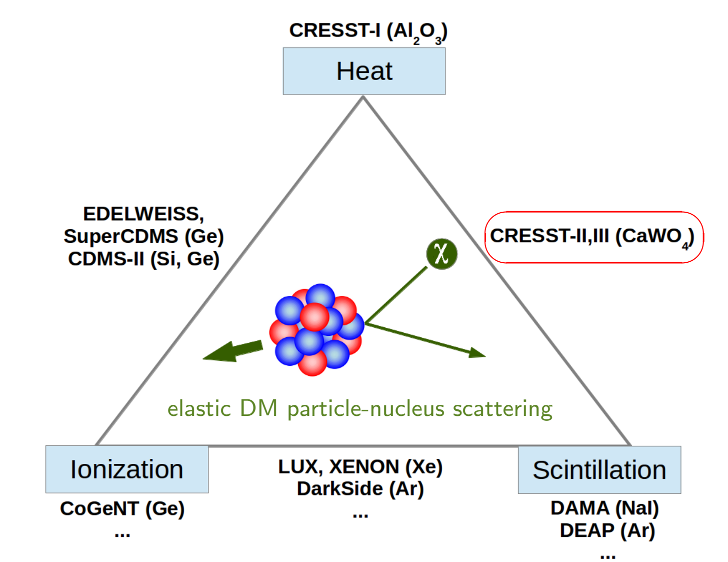
HEPHY
Institut für Hochenergiephysik

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

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

UNIVERSITY OF OXFORD

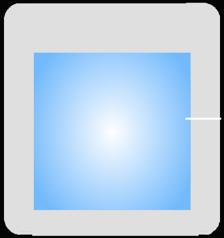
Direct Dark Matter Search with CRESST



Working Principle of CRESST

Cryogenic Rare Event Search with Superconducting Thermometers
located at the Laboratori Nazionali del Gran Sasso (LNGS)

- target material: $CaWO_4$ single crystals



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Cryogenic Rare Event Search with Superconducting Thermometers
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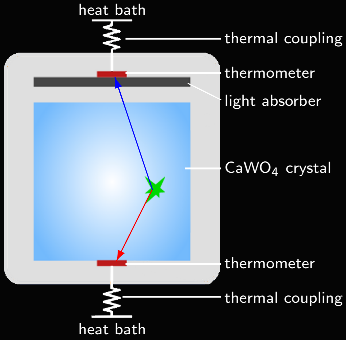
- target material: $CaWO_4$ single crystals
- particle interaction
  → heat (phonon) signal
  read-out with thermometer
  → light signal
  read-out with light absorber + thermometer



Working Principle of CRESST

Cryogenic Rare Event Search with Superconducting Thermometers
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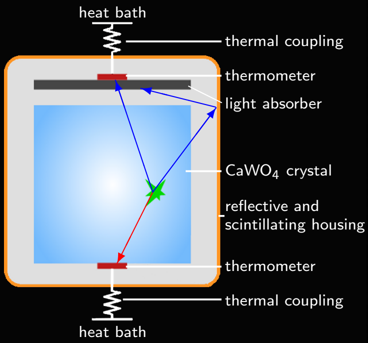
- target material: $CaWO_4$ single crystals
- particle interaction
  → heat (phonon) signal
  read-out with thermometer
  → light signal
  read-out with light absorber + thermometer
- reflective and scintillating housing
  → maximize light collection
  → veto surface events



Background Discrimination

energy deposition

$> 90\,\%$ ↙ ↘ $< 10\,\%$

phonon signal:
precise energy measurement

light signal:
dependent on type of interacting particle

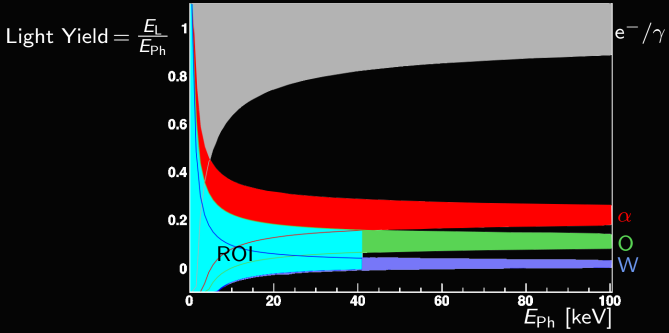
Background Discrimination

energy deposition

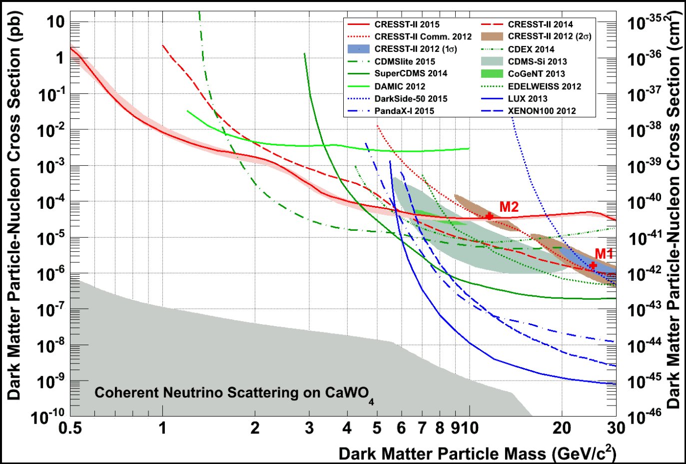
$> 90\,\%$ → **phonon signal:** precise energy measurement

$< 10\,\%$ → **light signal:** dependent on type of interacting particle

$\rightarrow$ active background discrimination on event-by-event basis:



Results of CRESST-II Phase 2 (2013-2015)



CRESST-II 2015:

1 detector – crystal mass ∼ 300 g – exposure 52 kg days – threshold ∼ 300 eV

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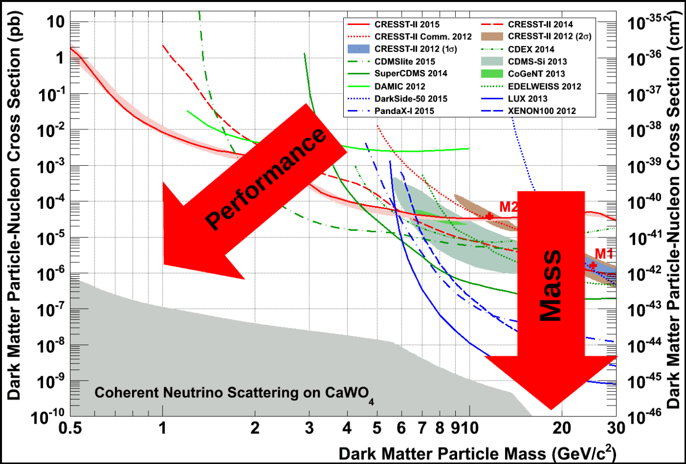
Goal for CRESST-III



Goal:

increase performance via decreasing phonon detector threshold to $\sim 100\,\text{eV}$

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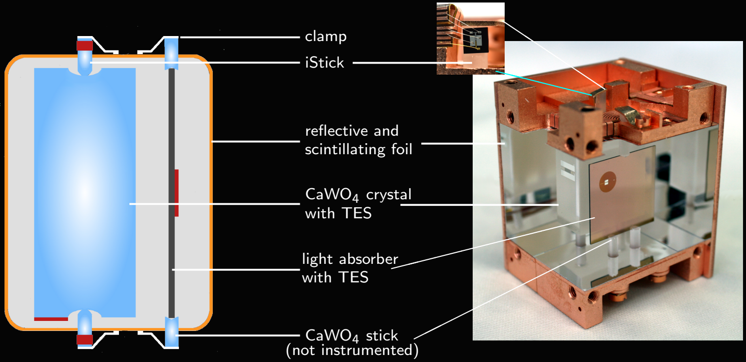
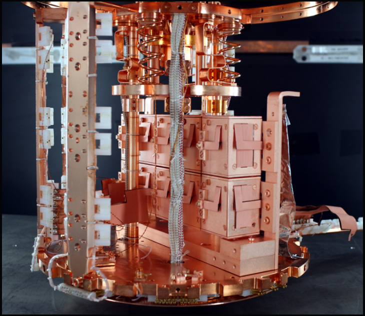
CRESST-III Phase 1: Detector Modules

- crystal mass and dimensions: $\sim 24\,\mathrm{g}$, $(20 \times 20 \times 10)\,\mathrm{mm}^3$
- holding with $CaWO_4$ sticks
  $\rightarrow$ fully scintillating housing
- instrumented sticks (iSticks) for holding main crystal
  $\rightarrow$ veto for events happening in sticks



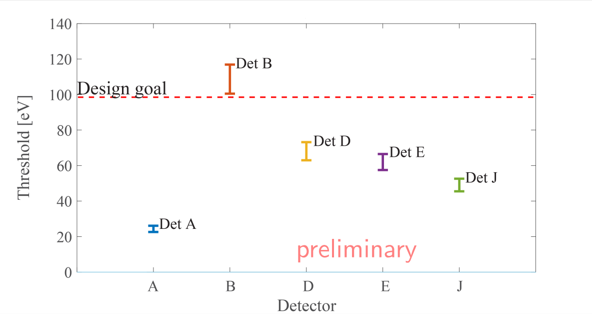
CRESST-III Phase 1: Installed Detectors

- 10 small detector modules installed
- majority of $CaWO_4$ crystals produced at Technical University of Munich (TUM)



→ Data taking started in summer 2016

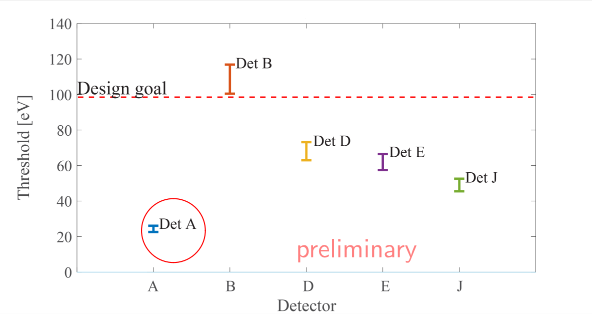
CRESST-III Phase 1: Thresholds



Detector module A

hardware threshold	48 eV
data taking period	31/10/16 - 05/07/17
non-blind data set (dynamically growing)	20 %
total measuring time (blind)	2540 h
total exposure after cuts	2.21 kg days

CRESST-III Phase 1: Thresholds

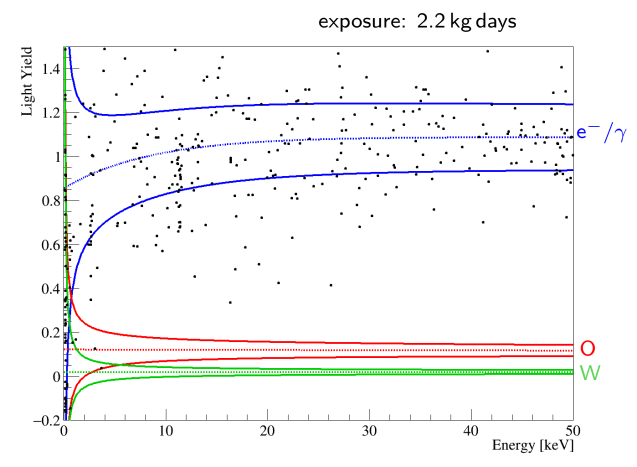


detector module A

data taking period	31/10/16 - 05/07/17
non-blind data set (dynamically growing)	20 %
total measuring time (blind)	2540 h
total exposure after cuts	2.21 kg days

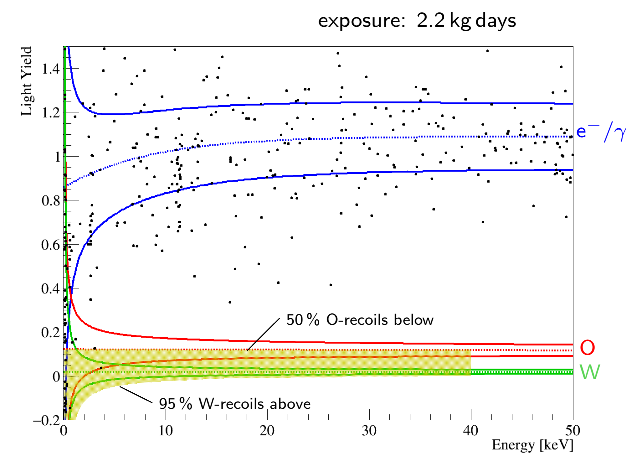
$\rightarrow$ analysis threshold for a 'high-threshold analysis': 100 eV

CRESST-III Phase 1: Detector Module A



acceptance region: 100 eV < Energy < 40 keV

CRESST-III Phase 1: Detector Module A



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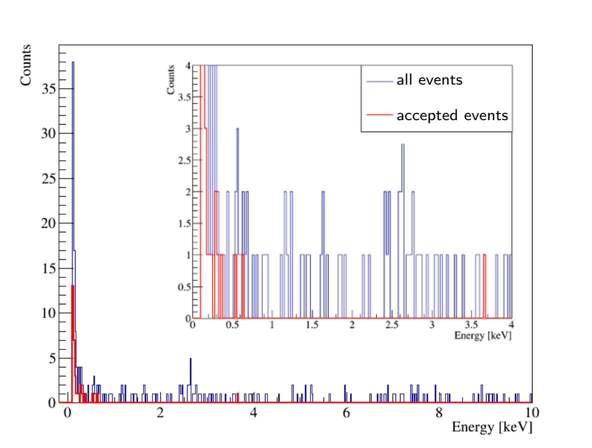
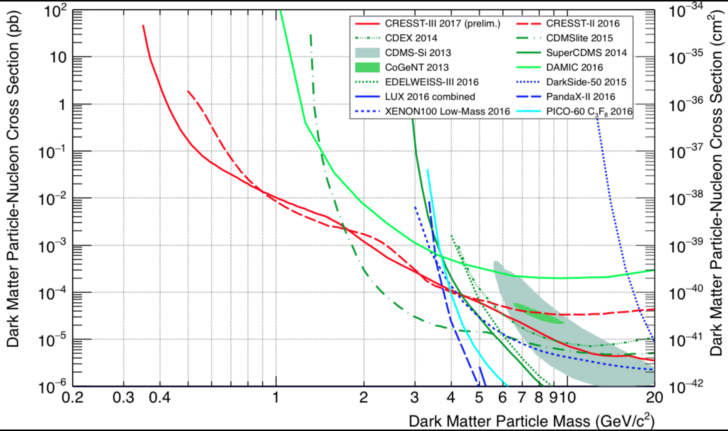
CRESST-III Phase 1: Detector Module A



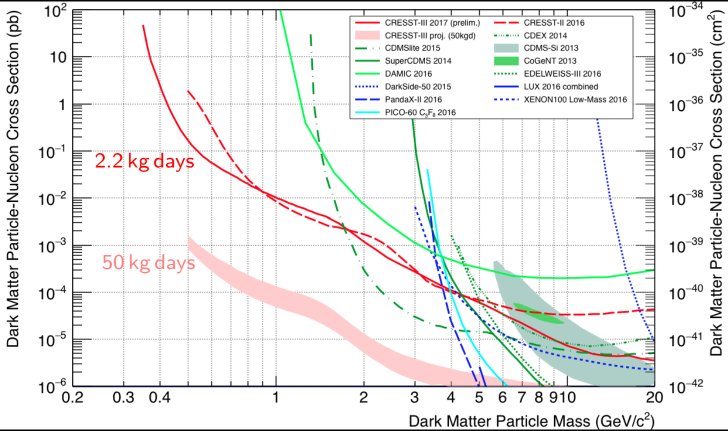
- conservative assumption: all accepted events are DM recoils
- exclusion limit: Yellin's optimum interval method



→ improvement by one order of magnitude at 0.5 GeV/c^2

→ reach of direct DM search experiments extended to 0.35 GeV/c^2

Detector Module A: Exclusion Limit



→ improvement by one order of magnitude at 0.5 GeV/c^2

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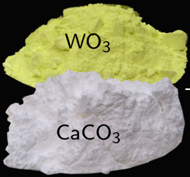
CRESST-III Phase 2

Goal: improve radiopurity by a factor of 100

All steps of $CaWO_4$ crystal production take place at the TUM!



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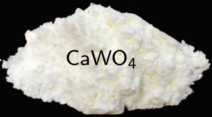

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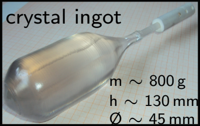
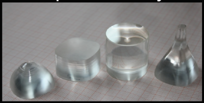


→

cut & polished crystal



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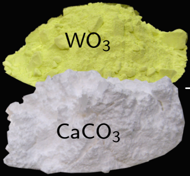

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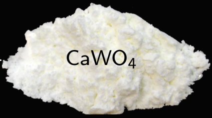

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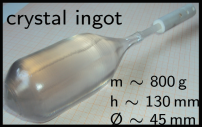

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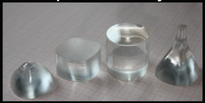
cut & polished crystal



improve radiopurity via

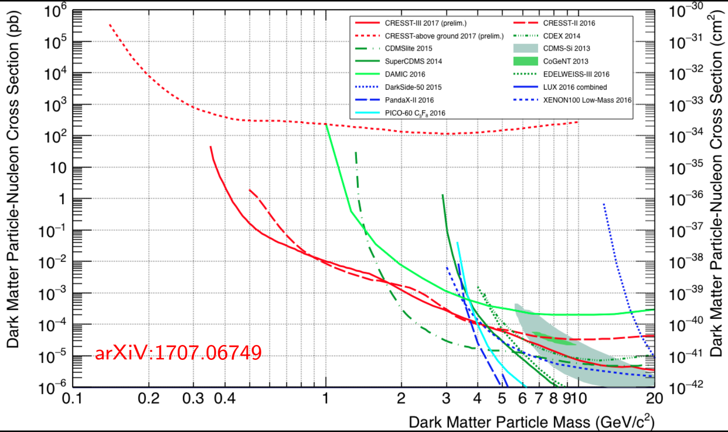
↙ ↘

chemical purification
applied to dissolved raw materials
→ promising results

recrystallization
as Czochralski crystal growth is cleaning process

Gram-Scale Calorimeters: Further Reduction of Threshold

- Al_2O_3 crystal ($m = 0.5\,g$) operated above ground without shielding
- achieved threshold: 19.7 eV



→ sensitivity to a new range of MeV-scale DM

Conclusion

CRESST-II Phase 2 (2013 - 2015)

- leading sensitivity for DM particle masses below $\sim 1.7\,\mathrm{GeV/c^2}$

CRESST-III Phase 1 (since 2016)

- detector design optimized to search for DM particles below $\sim 1\,\mathrm{GeV/c^2}$
- threshold goal of 100 eV achieved for 4 detectors
- first DM analysis with partial data set of 1 detector (2.2 kg days)

→ one order of magnitude improvement at $0.5\,\mathrm{GeV/c^2}$
→ sensitivity extended down to $0.35\,\mathrm{GeV/c^2}$

CRESST-III Phase 2

- goal: improve radiopurity
- promising results achieved by purification of the raw materials for $CaWO_4$ crystal production

Thank you for your attention!

Backup-Slides

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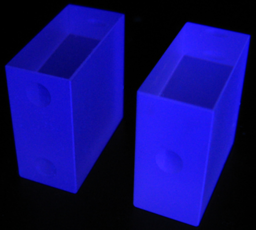
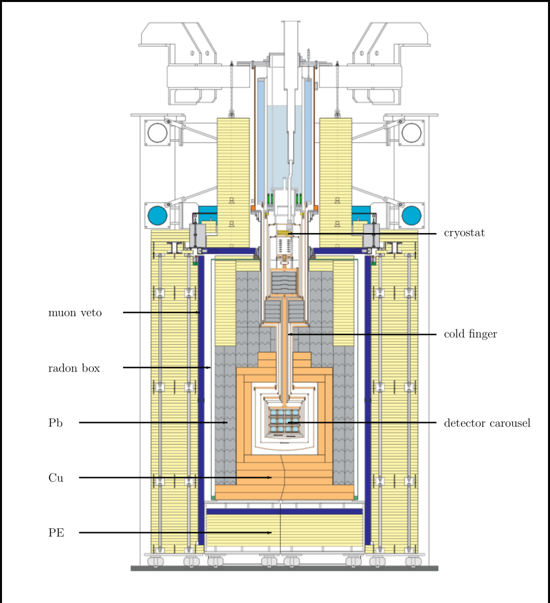
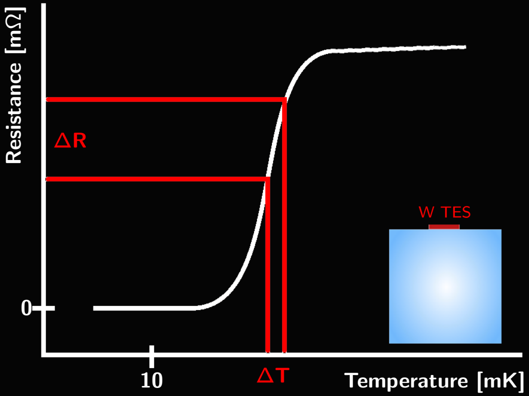


The CRESST Experiment: Setup

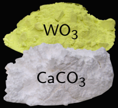


Transition Edge Sensor (TES)



Production of $CaWO_4$ Powder

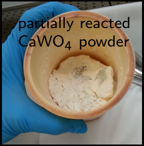
raw materials: selected $CaCO_3$, WO_3 powders



Solid State Reaction

$$CaCO_3 + WO_3 \rightarrow CaWO_4 + CO_2 \uparrow$$

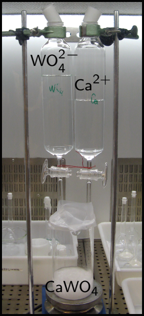
Al_2O_3 crucible – dedicated furnace – (1100 - 1200) °C – 2 repetitions



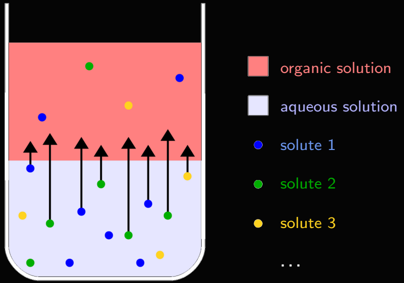
Precipitation Reaction

$$Ca(NO_3)_2 + (NH_4)_2WO_4 \rightarrow CaWO_4 \downarrow + 2\ NH_4NO_3$$

$CaCO_3$ and WO_3 dissolved in HNO_3 and NH_3 – quartz ware – dropping into NH_3 host solution

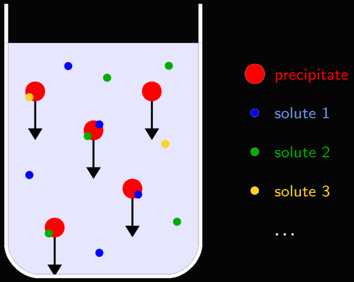


liquid-liquid extraction



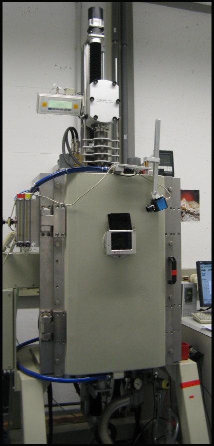
extractant:
trioctylphosphine oxide (TOPO)

coprecipitation

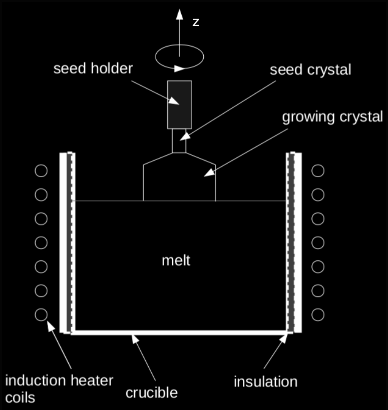


precipitate:
$CaWO_4$

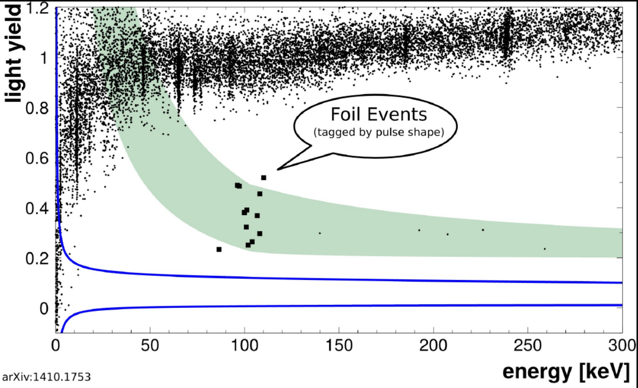
Crystal Growth via Czochralski Method



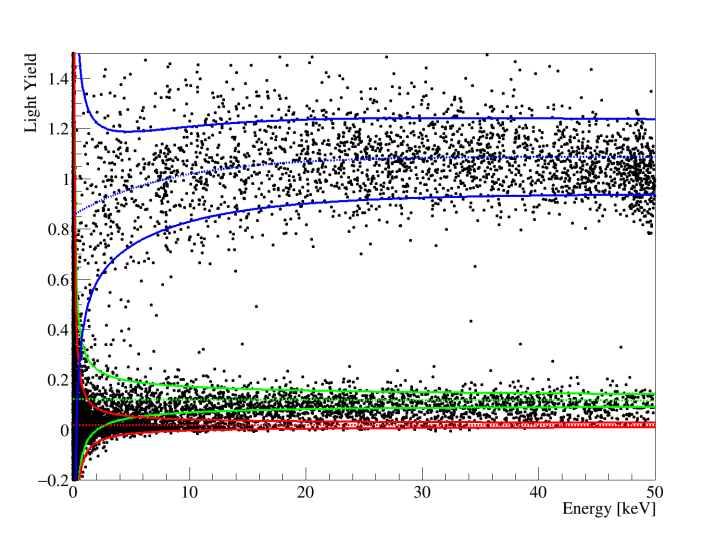
- melt $CaWO_4$ powder in Rh crucible of Czochralski furnace
- lower seed crystal into $CaWO_4$ melt
- draw in z direction under rotation
  ⇒ Formation of a cylindrically shaped crystal with crystallographic orientation of seed crystal



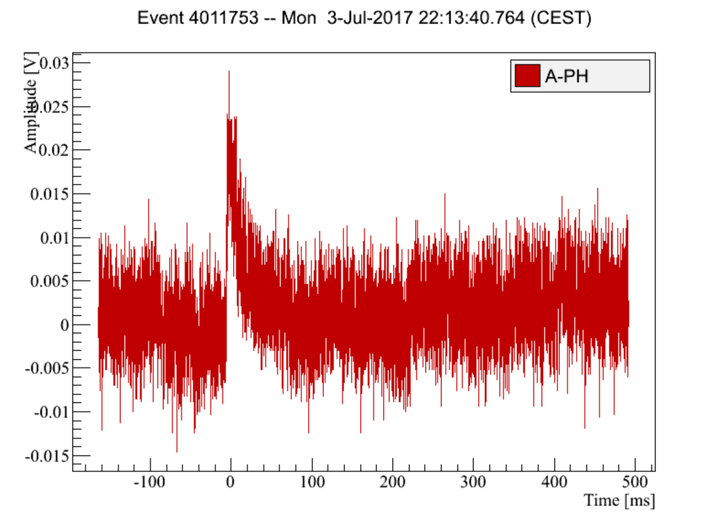
Fully Scintillating Housing: Veto of Surface Backgrounds



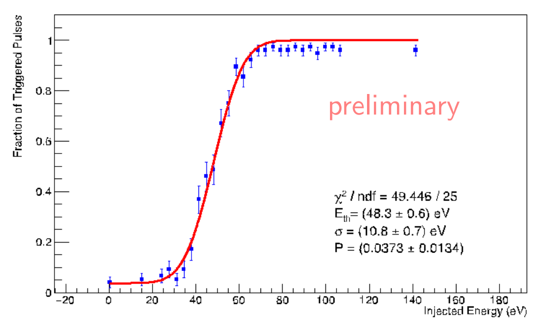
CRESST-III Phase 1: Neutron Calibration



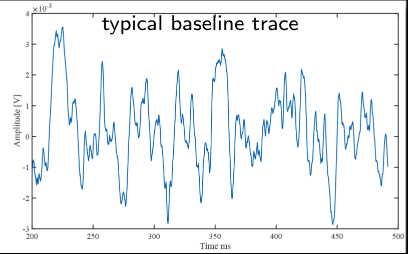
CRESST-III Phase 1: 100 eV Pulse

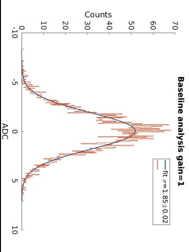


Detector Module A: Hardware Trigger Efficiency

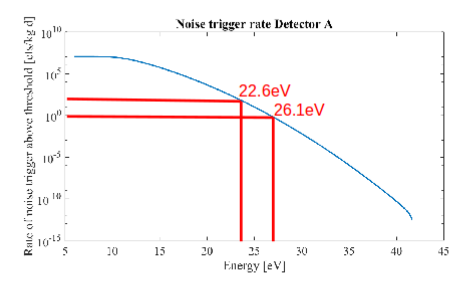


Detector Module A: Software Trigger Efficiency



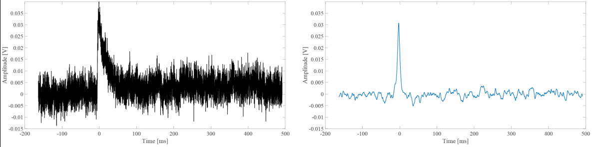


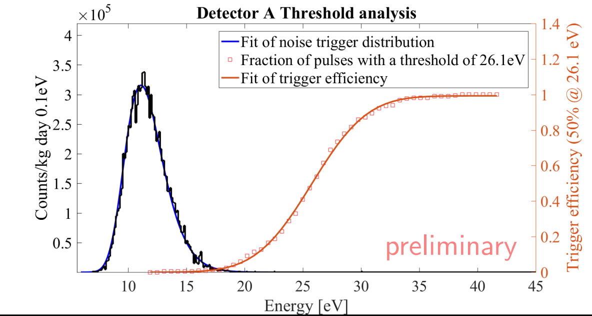
Analytical description of amplitude distribution in empty baselines



Detector Module A: Software Trigger Efficiency

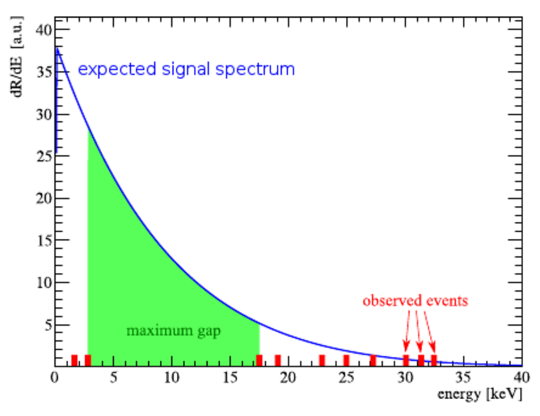
optimum filter (Gatti-Manfredi filter)
→ maximizes the ratio between pulse amplitude and noise RMS





allow 1 count/(kg day) of noise distribution after optimum filter

Yellin Methods



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