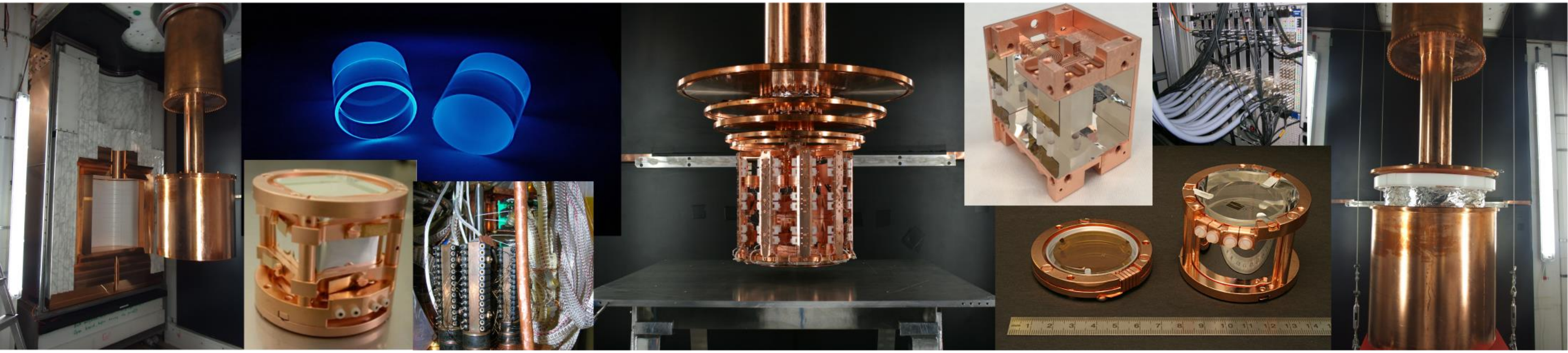
CRESST



Cryogenic Rare Event Search with Superconducting Thermometers

Search for low-mass dark matter with the CRESST-III experiment

Holger Kluck

on behalf of the CRESST collaboration

UCLA Dark Matter 2018 symposium
February 21-23, 2018

February 23, 2018

Outline

- CRESST basics:
  How the experiment works

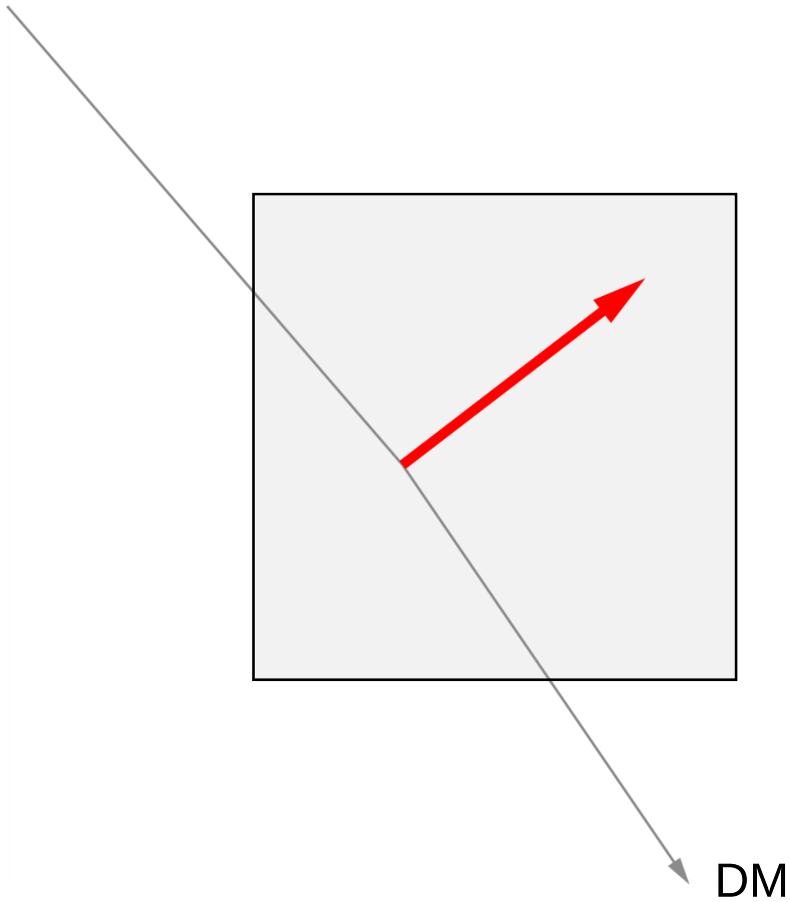
- Searching for low-mass DM with CRESST-III

CRESST basics

The CRESST collaboration

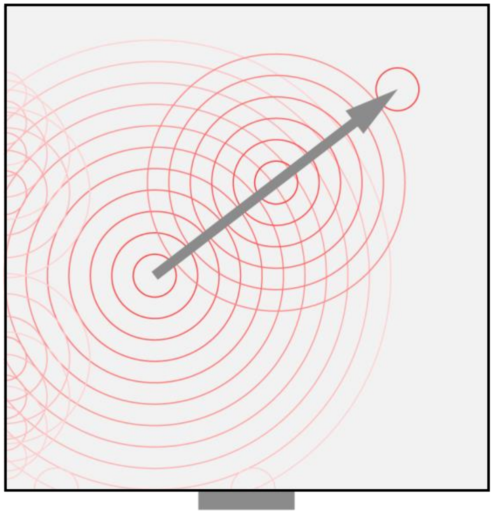
University of Oxford · Eberhard Karls Universität Tübingen · Max-Planck-Institut für Physik · TU Wien · INFN Laboratori Nazionali del Gran Sasso · HEPHY Institute of High Energy Physics · TUM

The CRESST experiment



- Target: $CaWO_4$ @ O(10mK)
- Signature: recoiling nucleus induced by scattering off dark matter particle

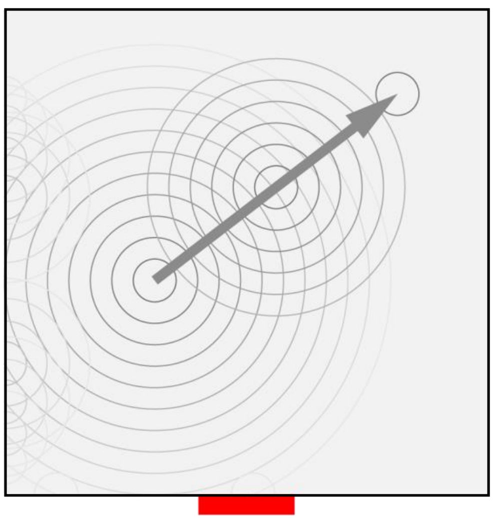
The CRESST experiment



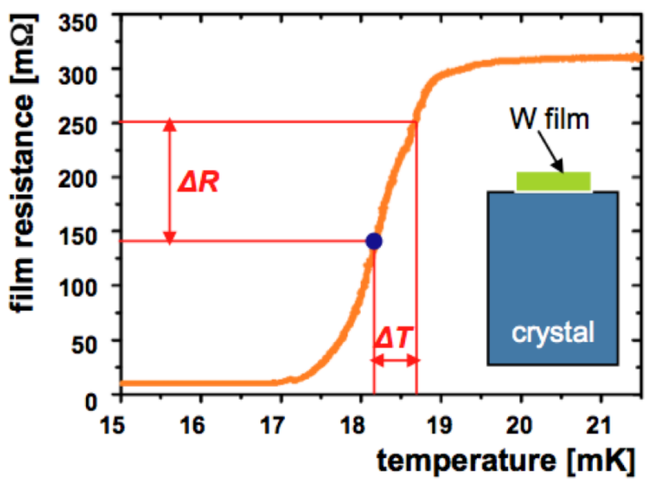
- Target: $CaWO_4$
- Signature: recoiling nucleus
- Phonon signal: measurement of recoil energy

$\Delta E/C = \Delta T$
1keV ~ 1µK

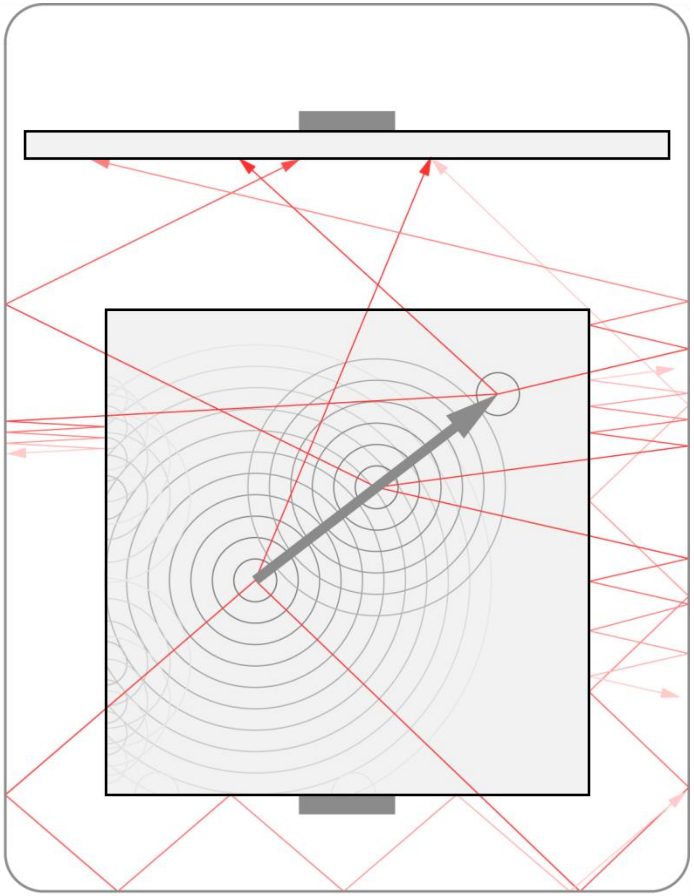
The CRESST experiment



- Target: $CaWO_4$
- Signature: recoiling nucleus
- Phonon signal: energy
- Read-out by a TES (transition edge sensor)

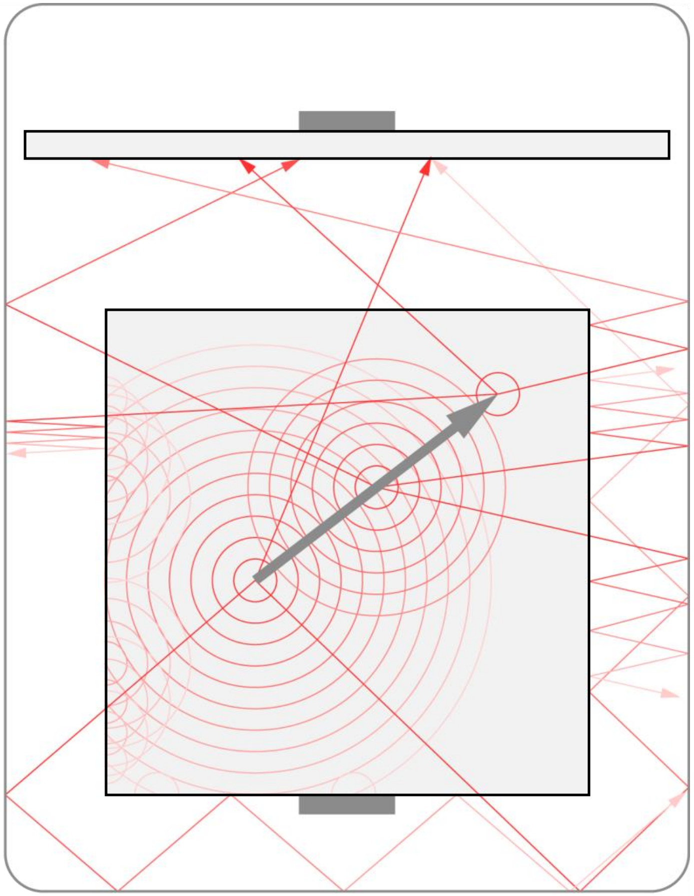


The CRESST experiment



- Target: $CaWO_4$
- Signature: recoiling nucleus
- Phonon signal: energy
- Read-out by a TES
- Scintillation light signal: separated detector inside a reflective & scintillating housing, particle dependent

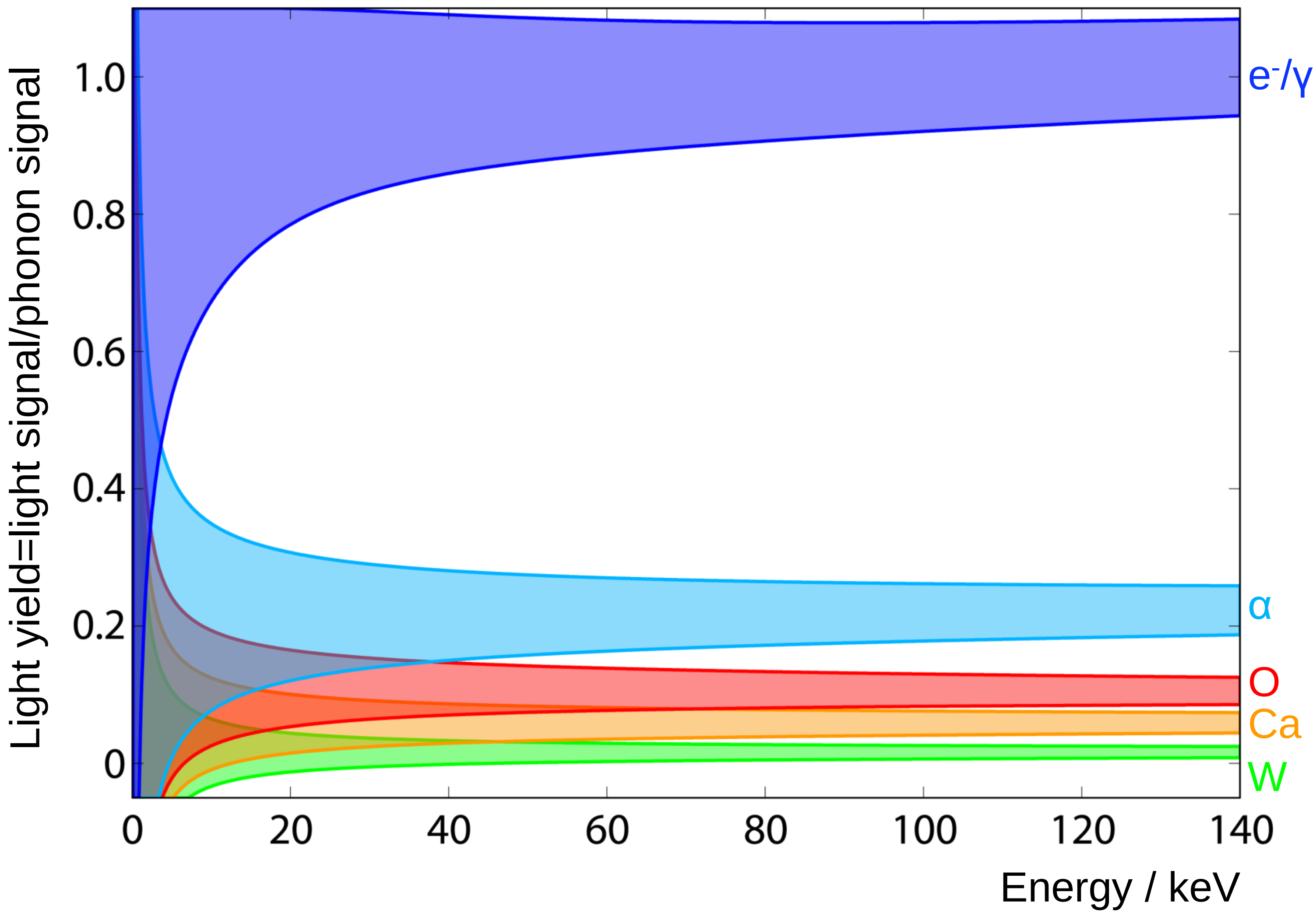
The CRESST experiment



- Target: $CaWO_4$
- Signature: recoiling nucleus
- Phonon signal: energy
- Read-out by a TES
- Scintillation light signal: particle dependent

→ Particle identification

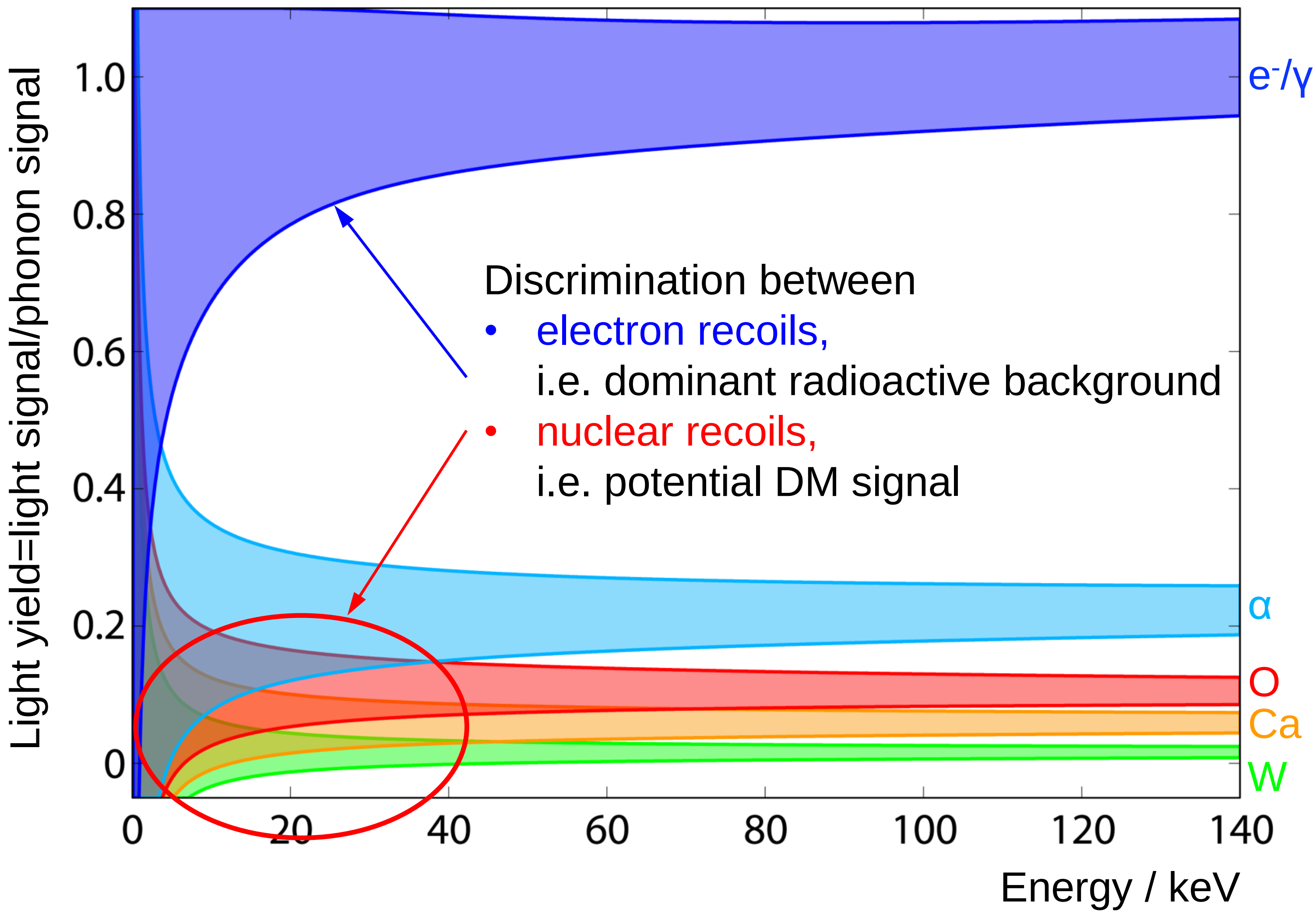
The CRESST experiment



Normalized to 1 by calibration

Quenched light for nuclear recoils

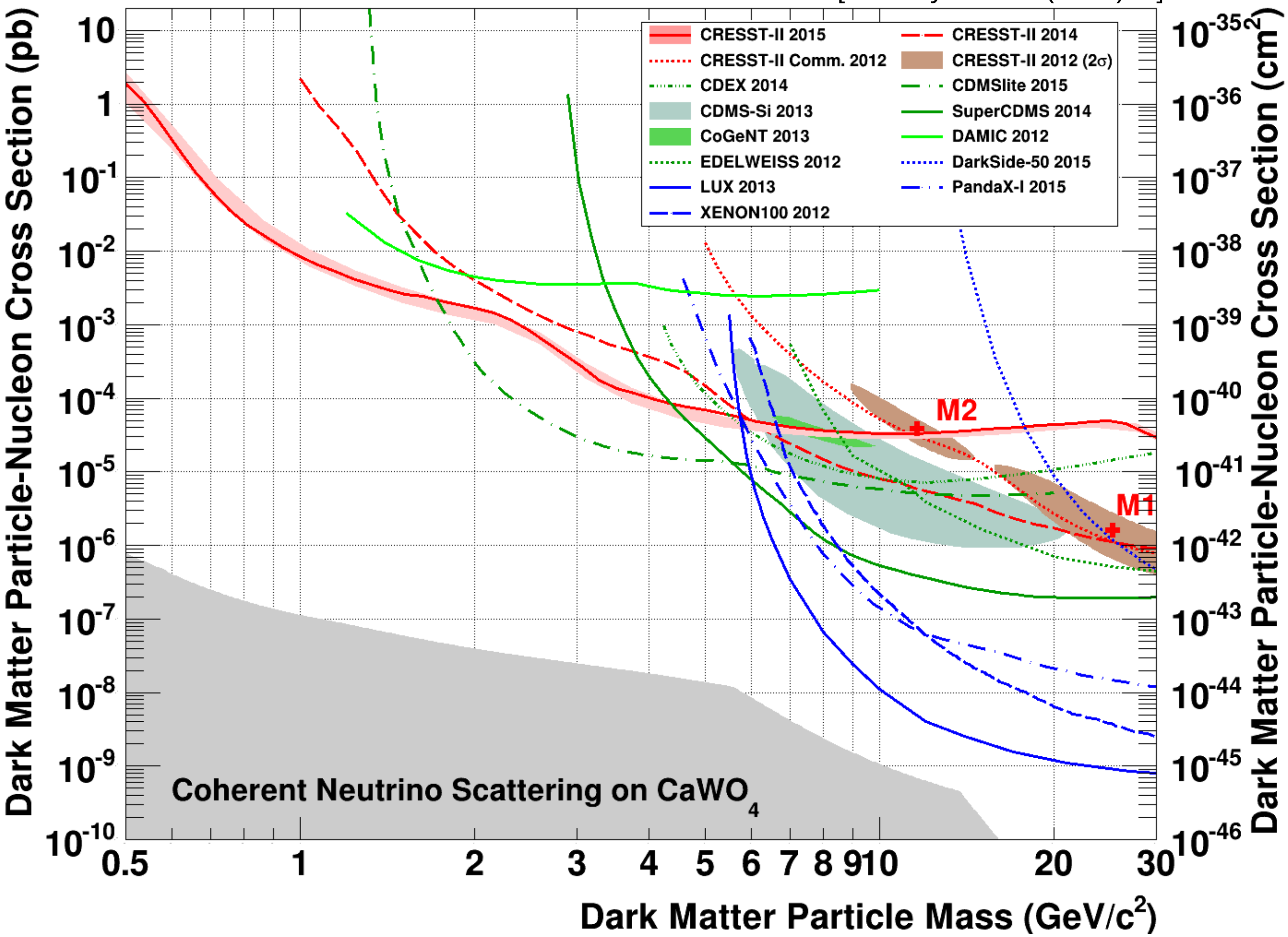
The CRESST experiment



Searching for low-mass DM with CRESST-III

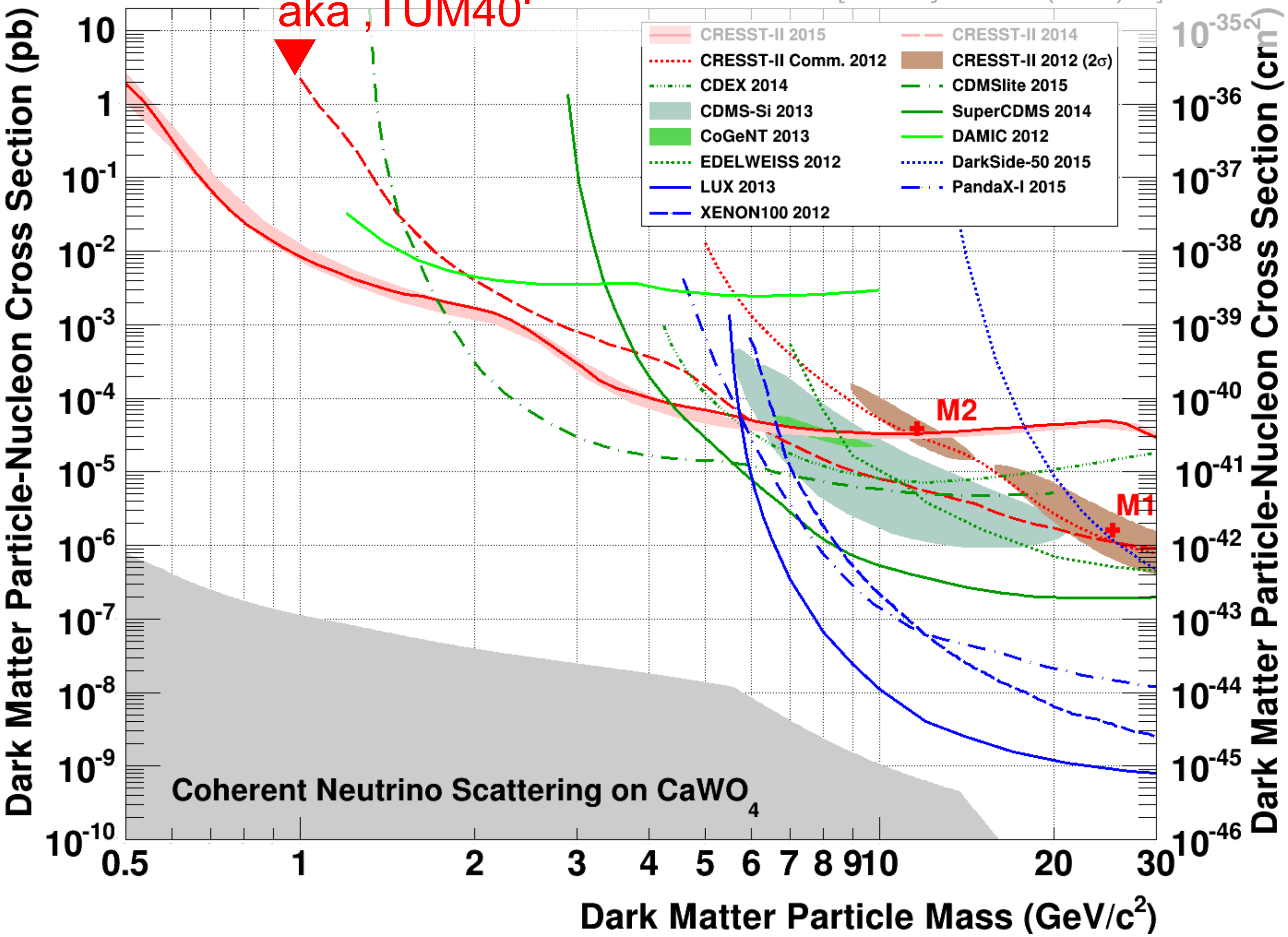
Results of CRESST-II phase 2

[Eur.Phys.J. C76(2016)25]

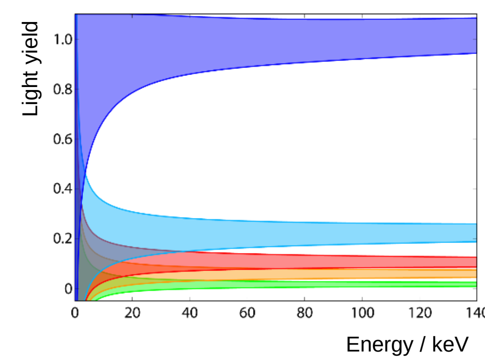


Results of CRESST-II phase 2

CRESST-II phase 2 (2014), Eur.Phys.J. C74 (2015)3184
[Eur.Phys.J. C76(2016)25]
aka ‚TUM40‘

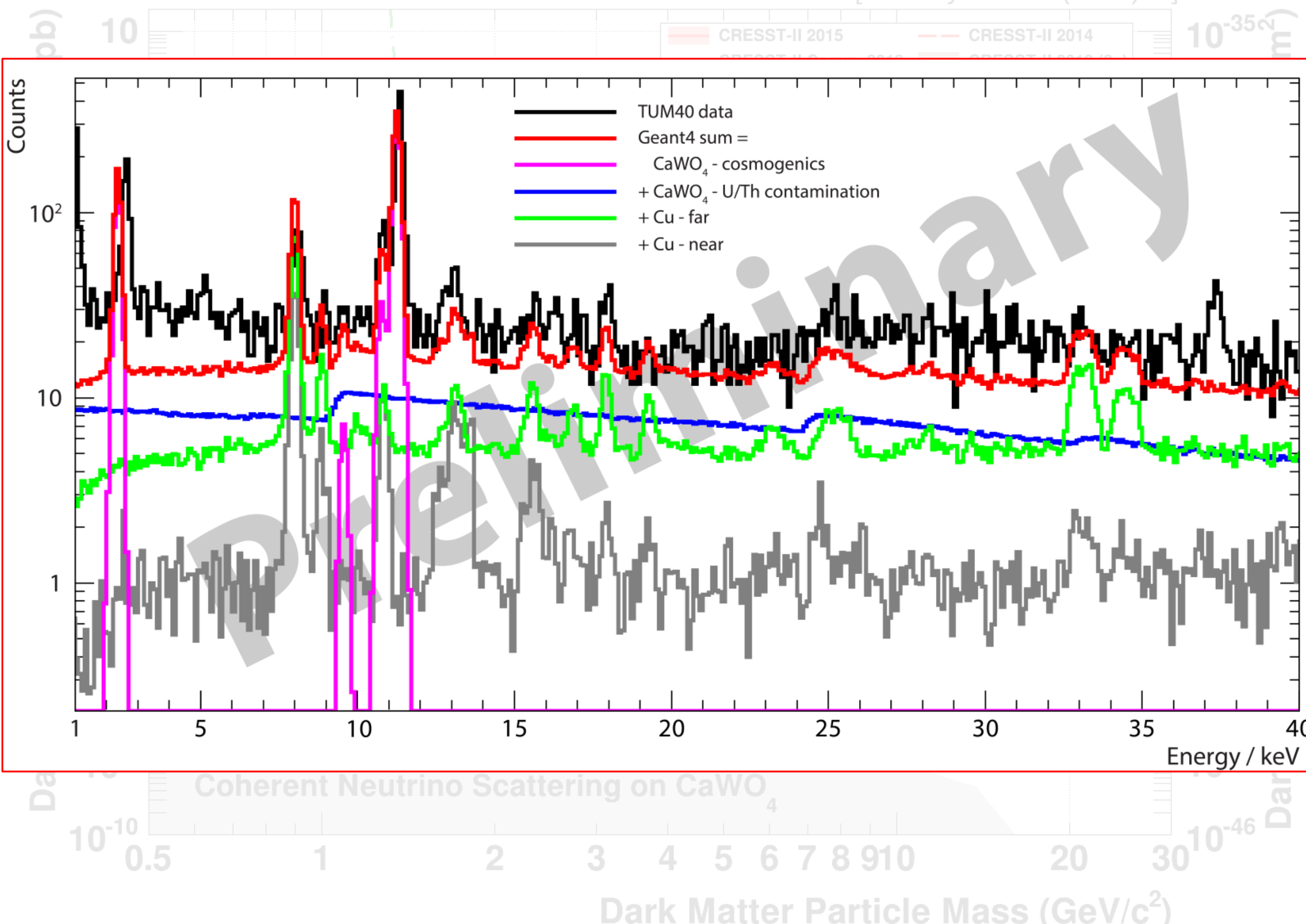


- TUM40: successfully reduced intrinsic background

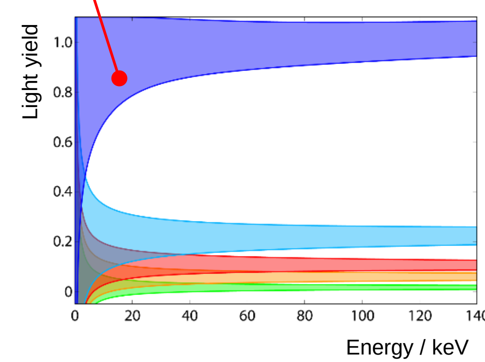


Results of CRESST-II phase 2

[Eur.Phys.J. C76(2016)25]



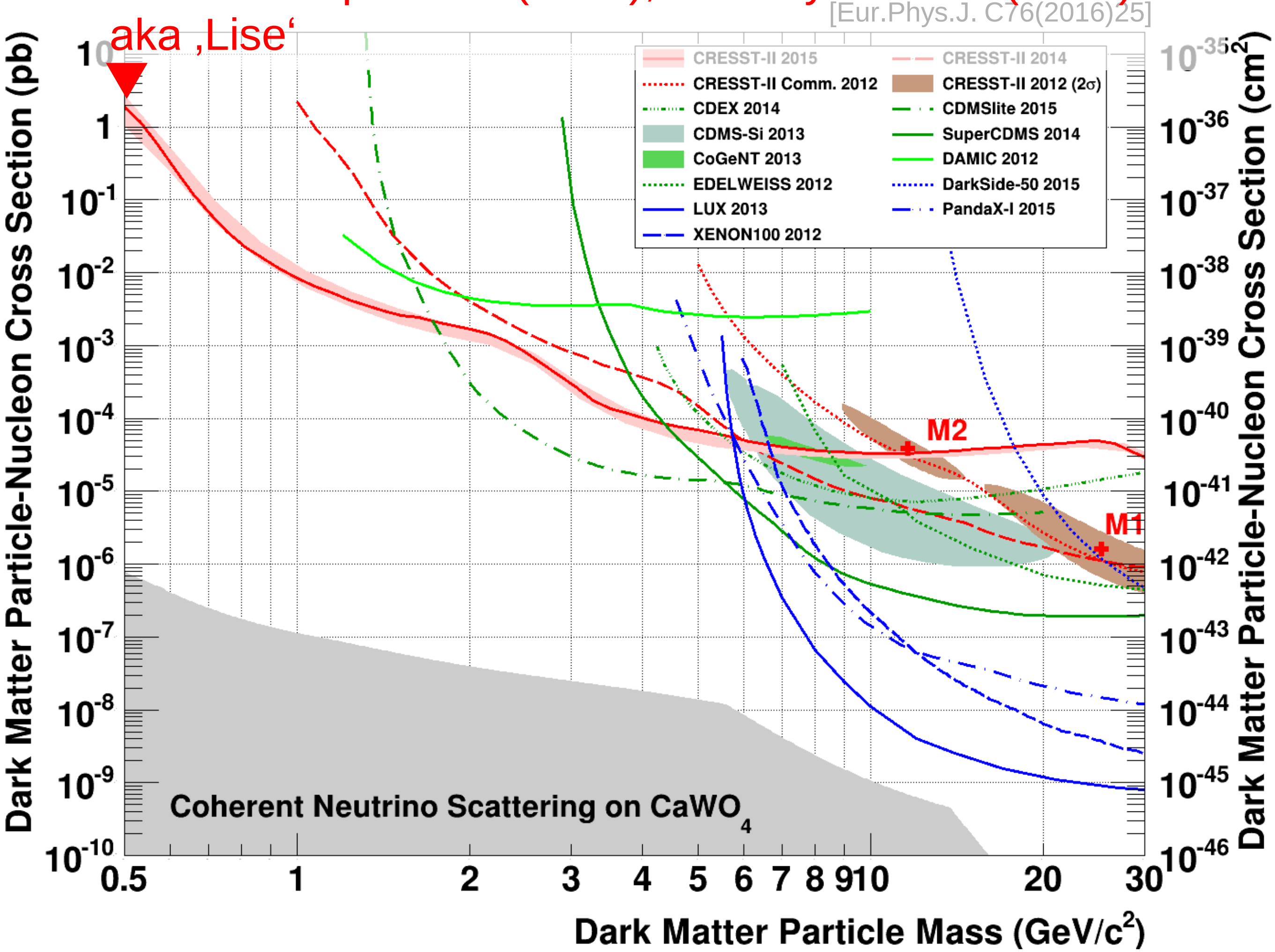
- TUM40: successfully reduced intrinsic background
- Ongoing modelling of em. background with Geant4



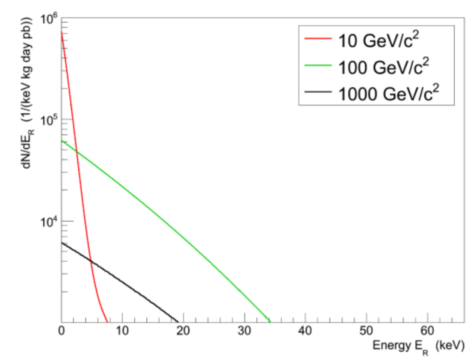
Results of CRESST-II phase 2

CRESST-II phase 2 (2015), Eur.Phys.J. C76 (2016)25

aka ‚Lise‘

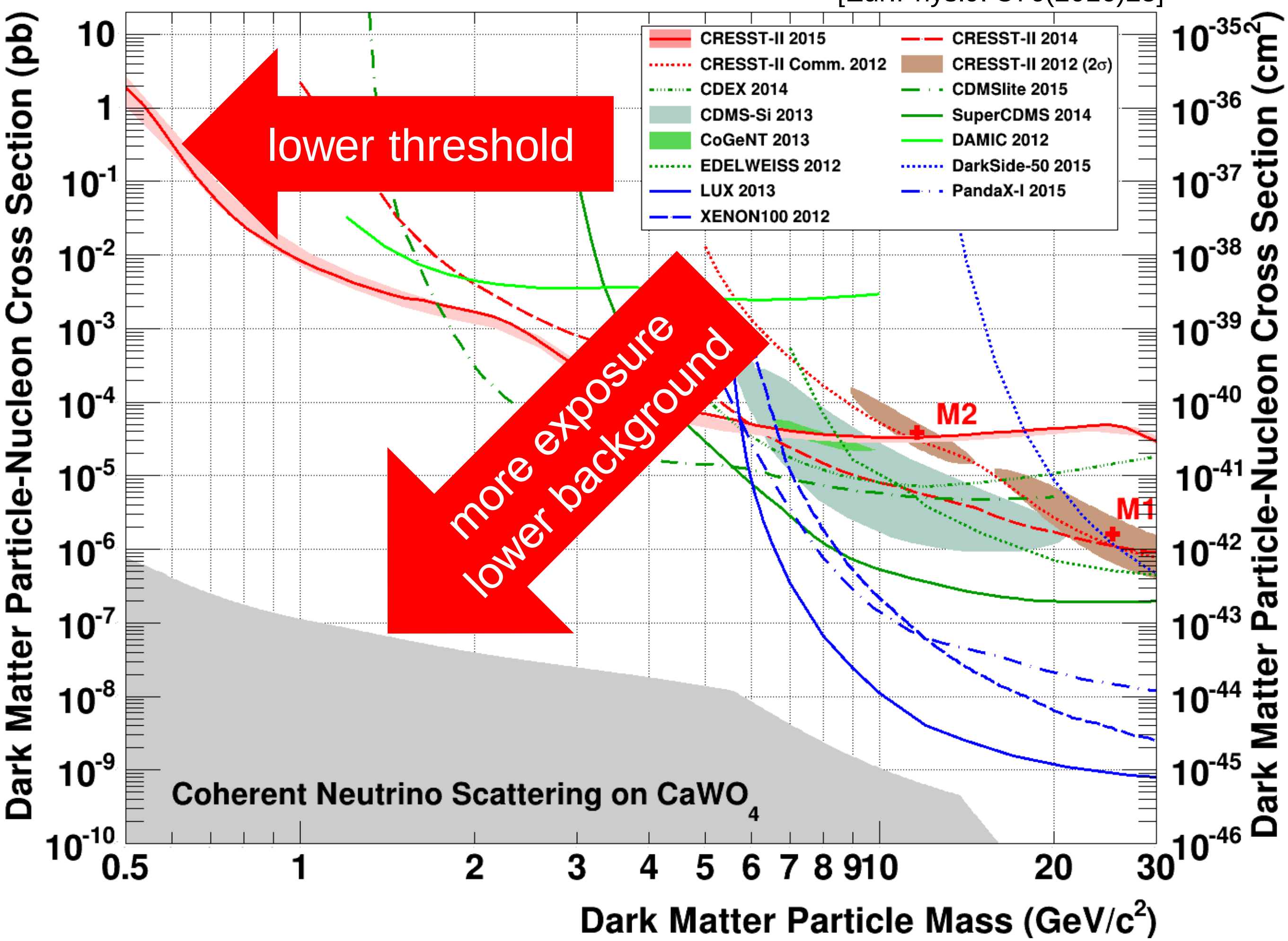


- TUM40: successfully reduced intrinsic background
- Low-mass search → low threshold Lise: 307eV



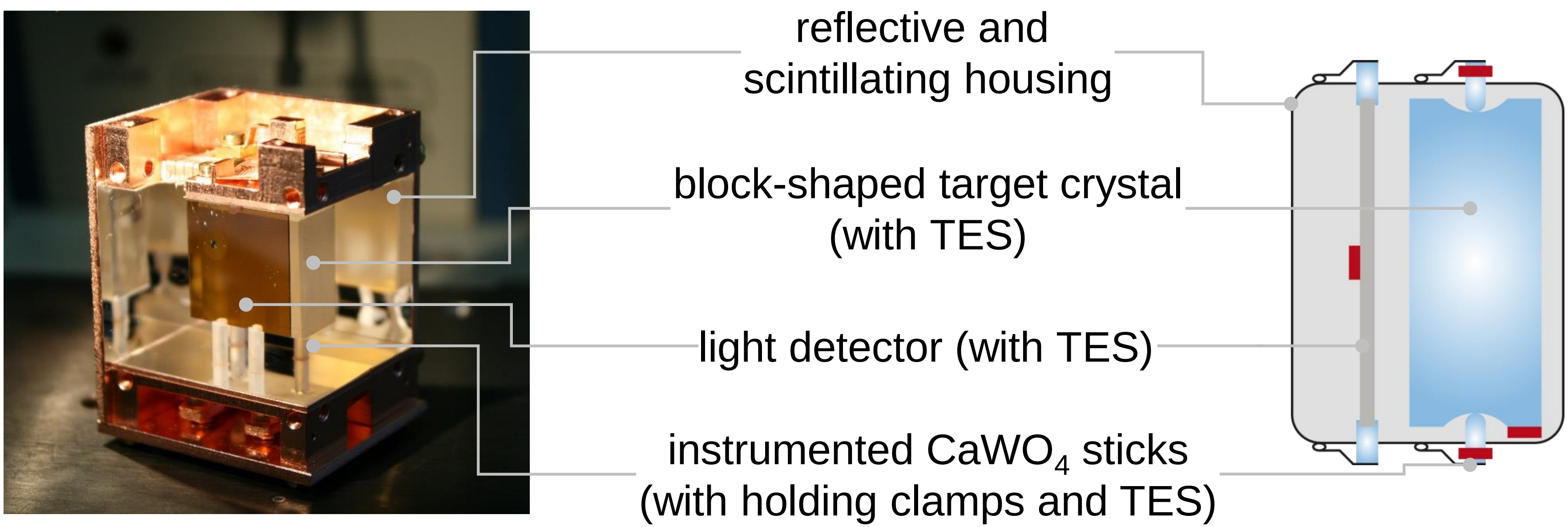
Results of CRESST-II phase 2

[Eur.Phys.J. C76(2016)25]



- TUM40: successfully reduced intrinsic background
- Low-mass search → low threshold
  Lise: 307eV
- ➔combine both in CRESST-III

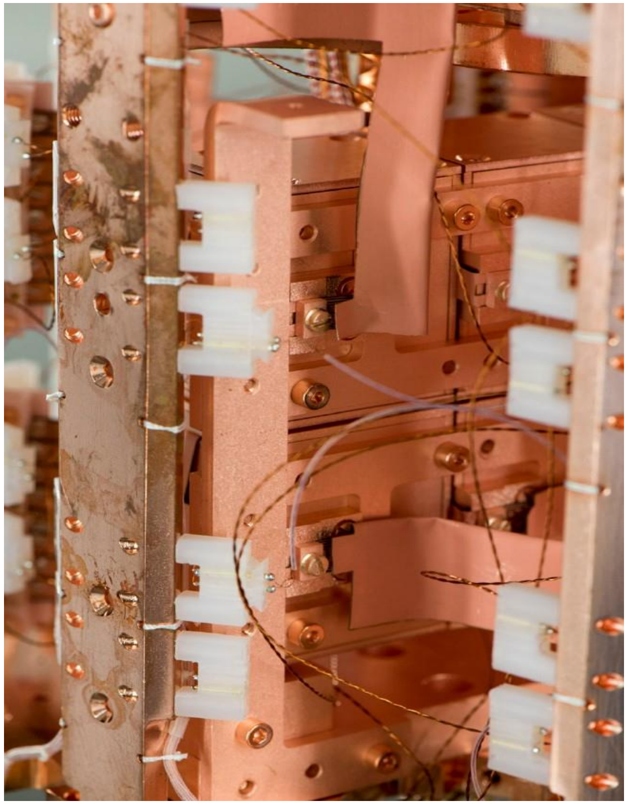
Optimized detector design



Detector design **optimized for low-mass dark matter**:

- cuboid crystal with **strongly reduced dimension**: $(20 \times 20 \times 10)\mathrm{mm}^3$ and $\approx 24\mathrm{g}$
- goal: detection **threshold of 100 eV**
- **self-grown crystal** with low total background of $\approx 3\ \mathrm{keV}^{-1}\mathrm{kg}^{-1}\mathrm{d}^{-1}$ in $[1{,}40]\mathrm{keV}$
- **veto against surface related background**: fully scintillating housing + instrumented sticks (“iSticks”)

Status of CRESST-III phase 1

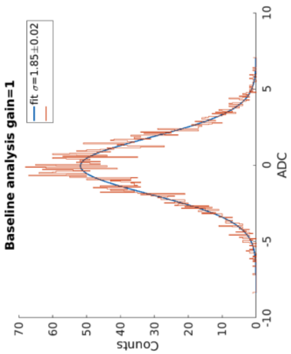


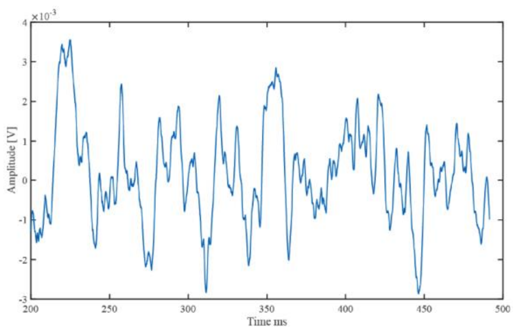
- May 2016:
  10 CRESST-III modules installed
- Oct 2016:
  extensive γ-calibration
- Since Nov 2016:
  data taking (80% blinded, 20% training set)
- ~April 2017:
  extensive n-calibration
- July 2017:
  first results @TAUP2017

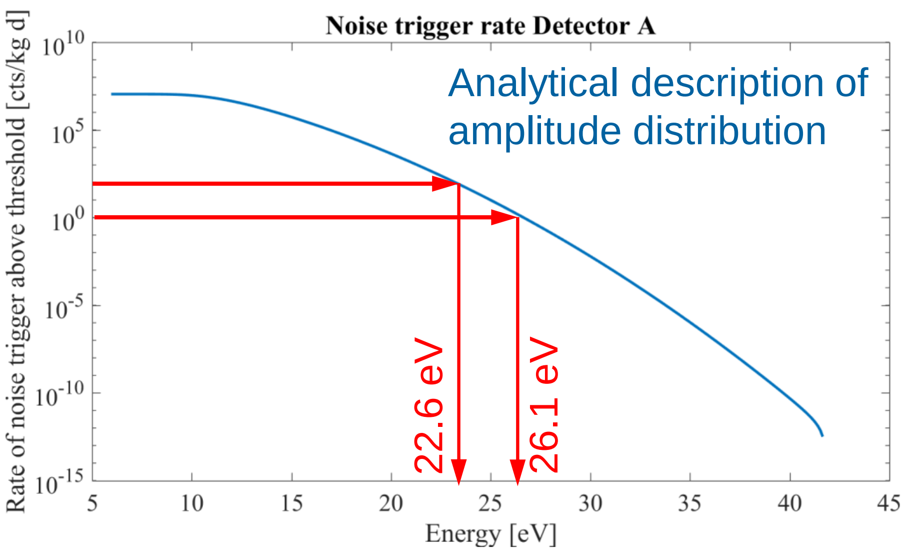
Threshold

- New DAQ in CRESST-III:
  continuous sampling of pulse traces
- Set threshold based on noise distribution after optimum filter

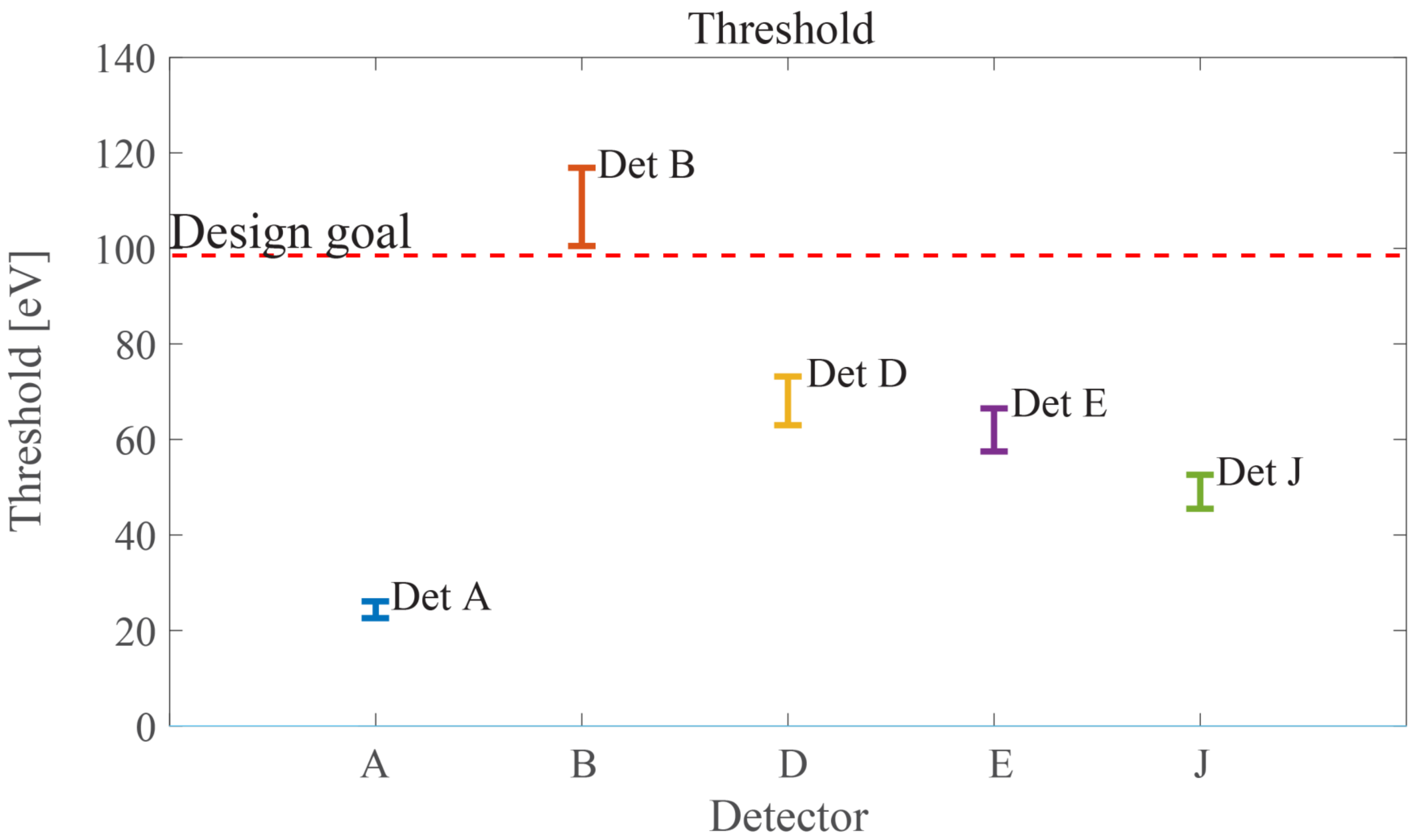
Amplitude distribution of a typical **empty base line pulse trace**



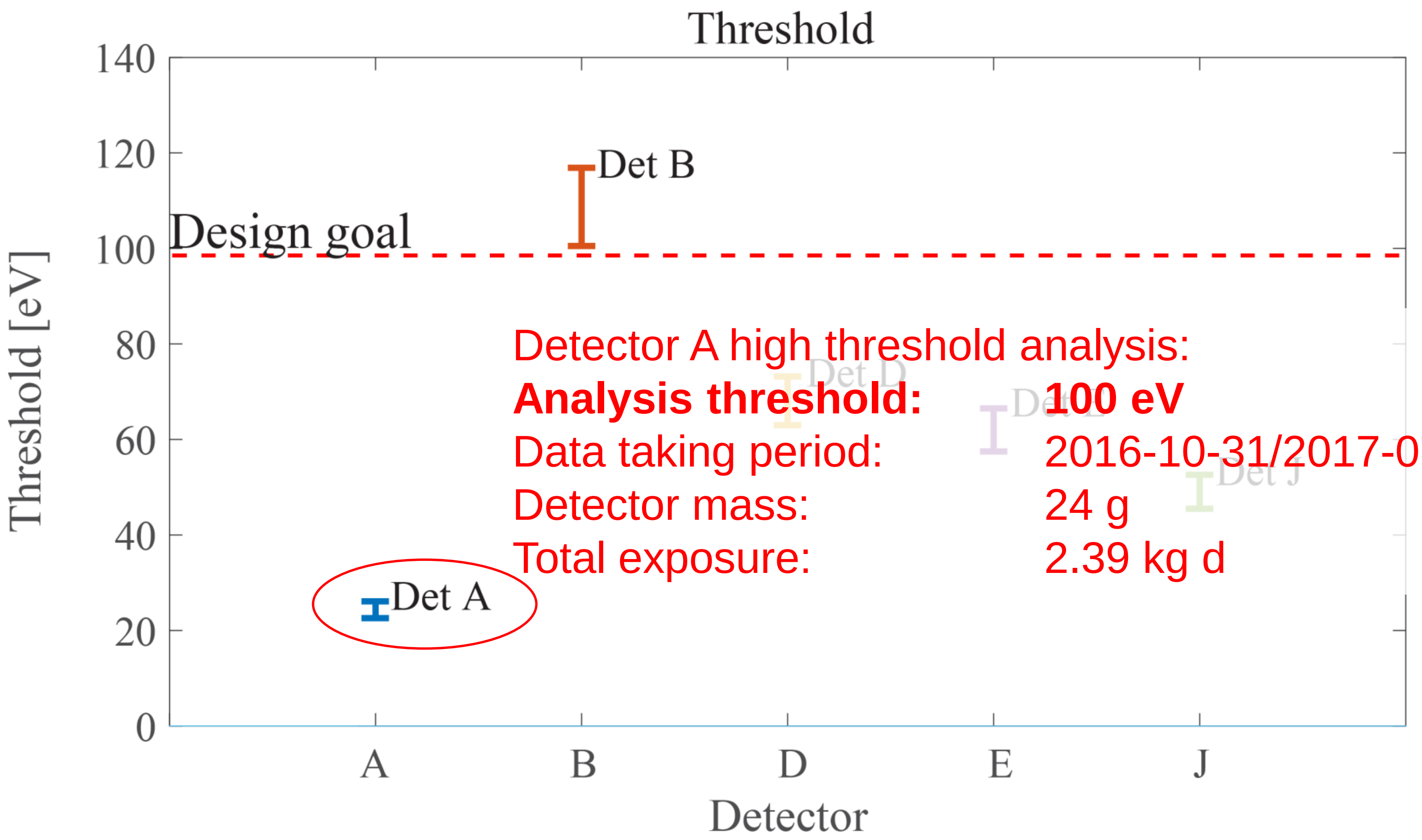




First results from CRESST-III phase 1



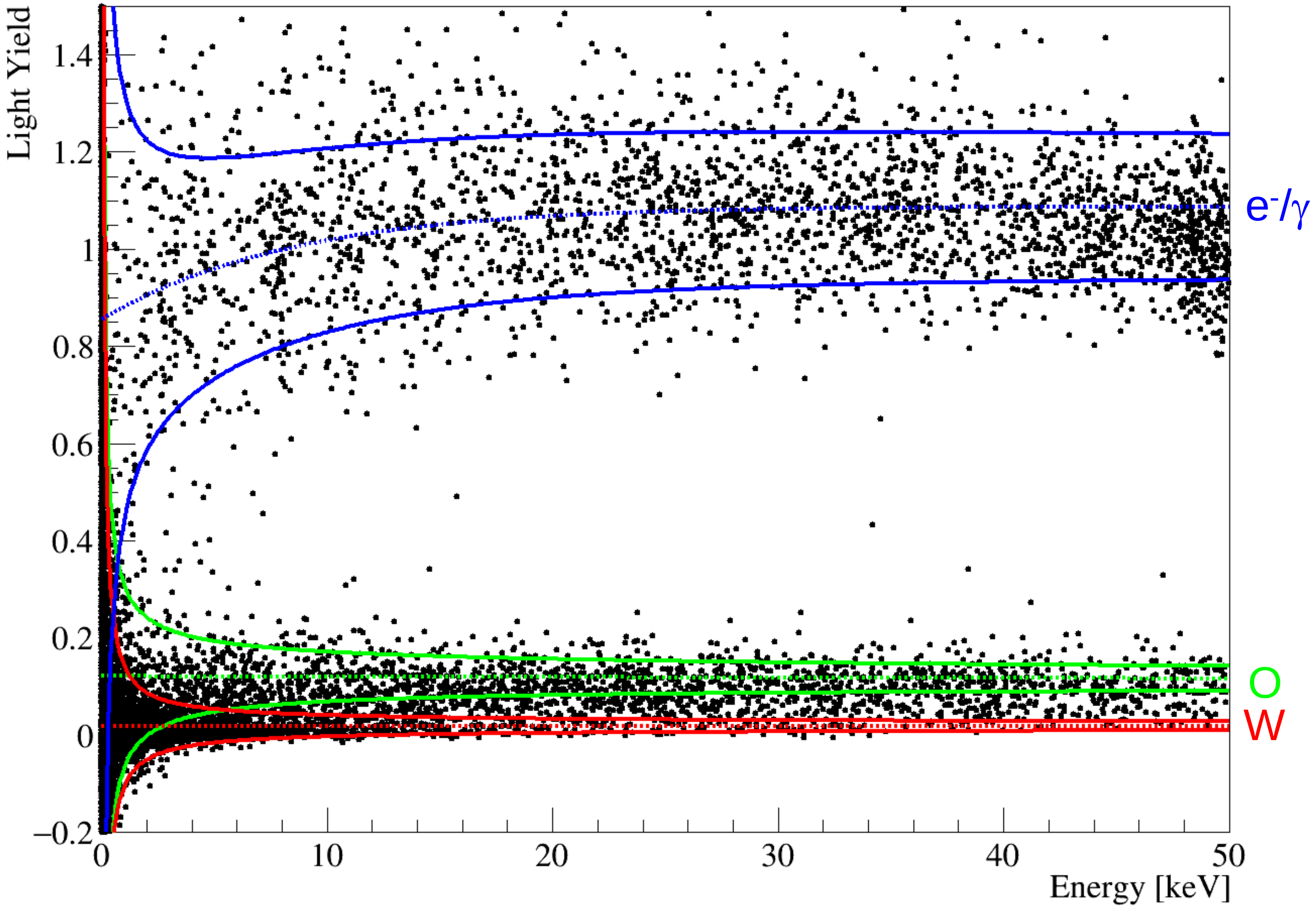
First results from CRESST-III phase 1



Detector A high threshold analysis:

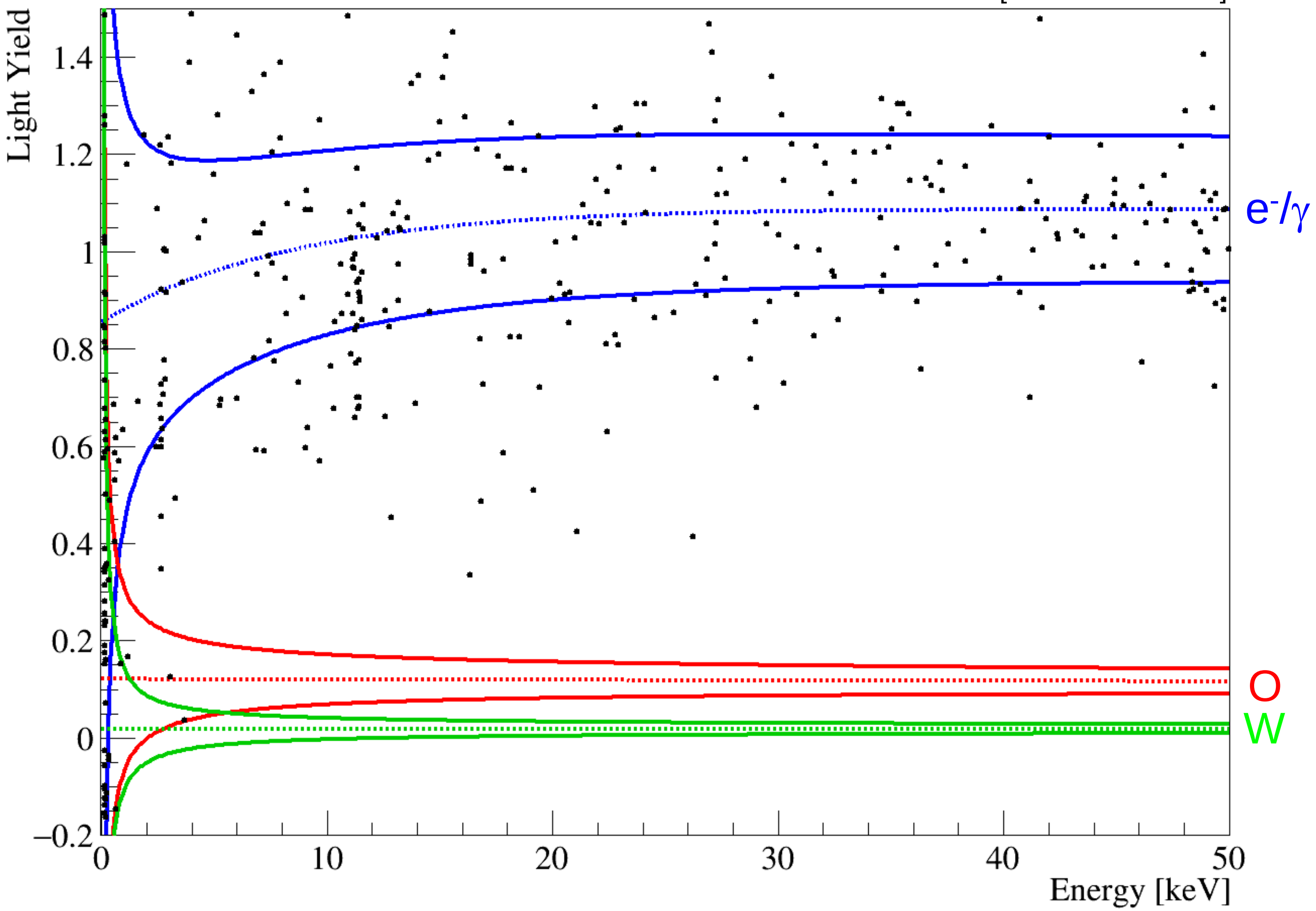
Analysis threshold:	**100 eV**
Data taking period:	2016-10-31/2017-07-05
Detector mass:	24 g
Total exposure:	2.39 kg d

Detector A: neutron calibration



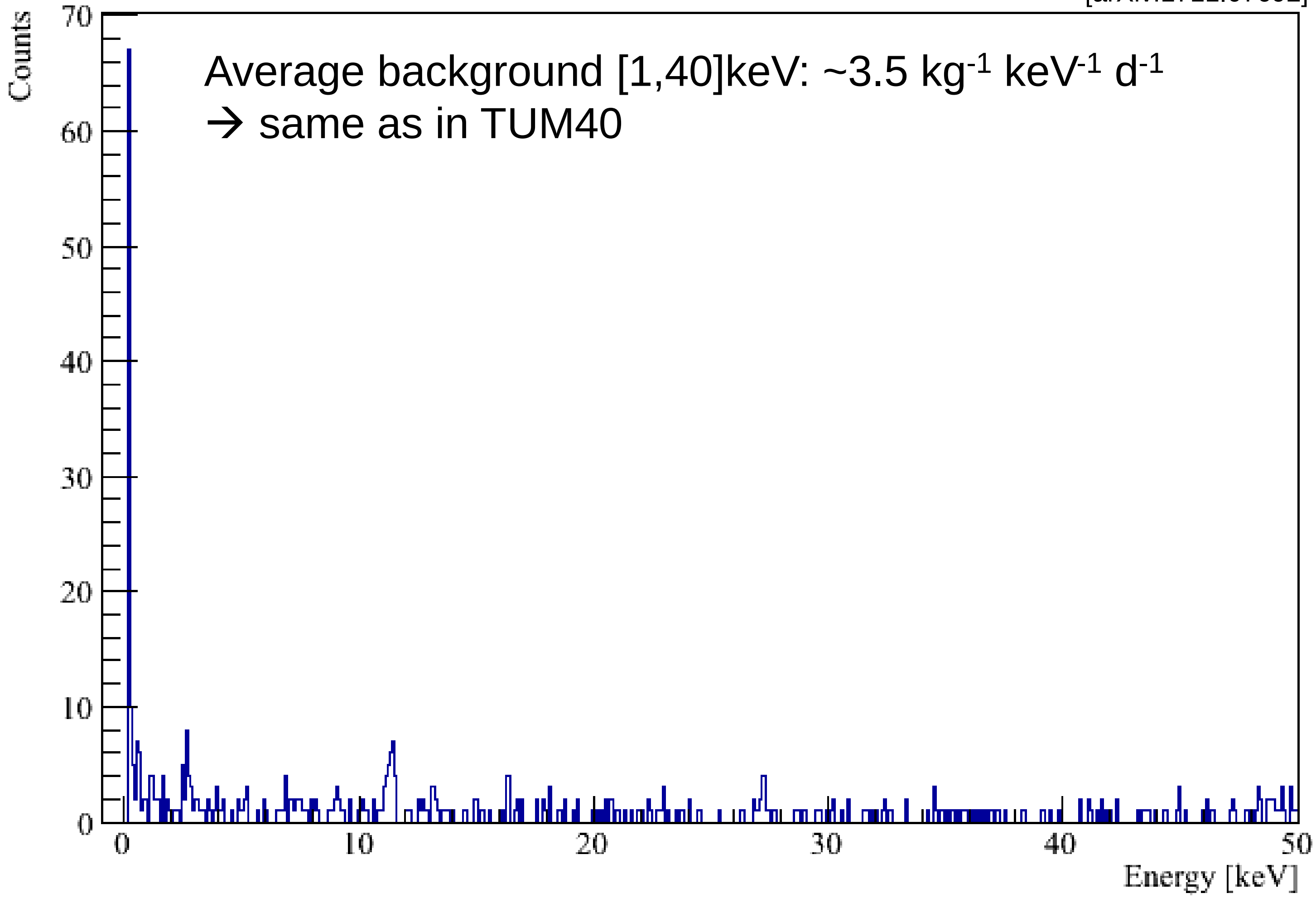
Detector A: physics data

[arXiv:1711.07692]



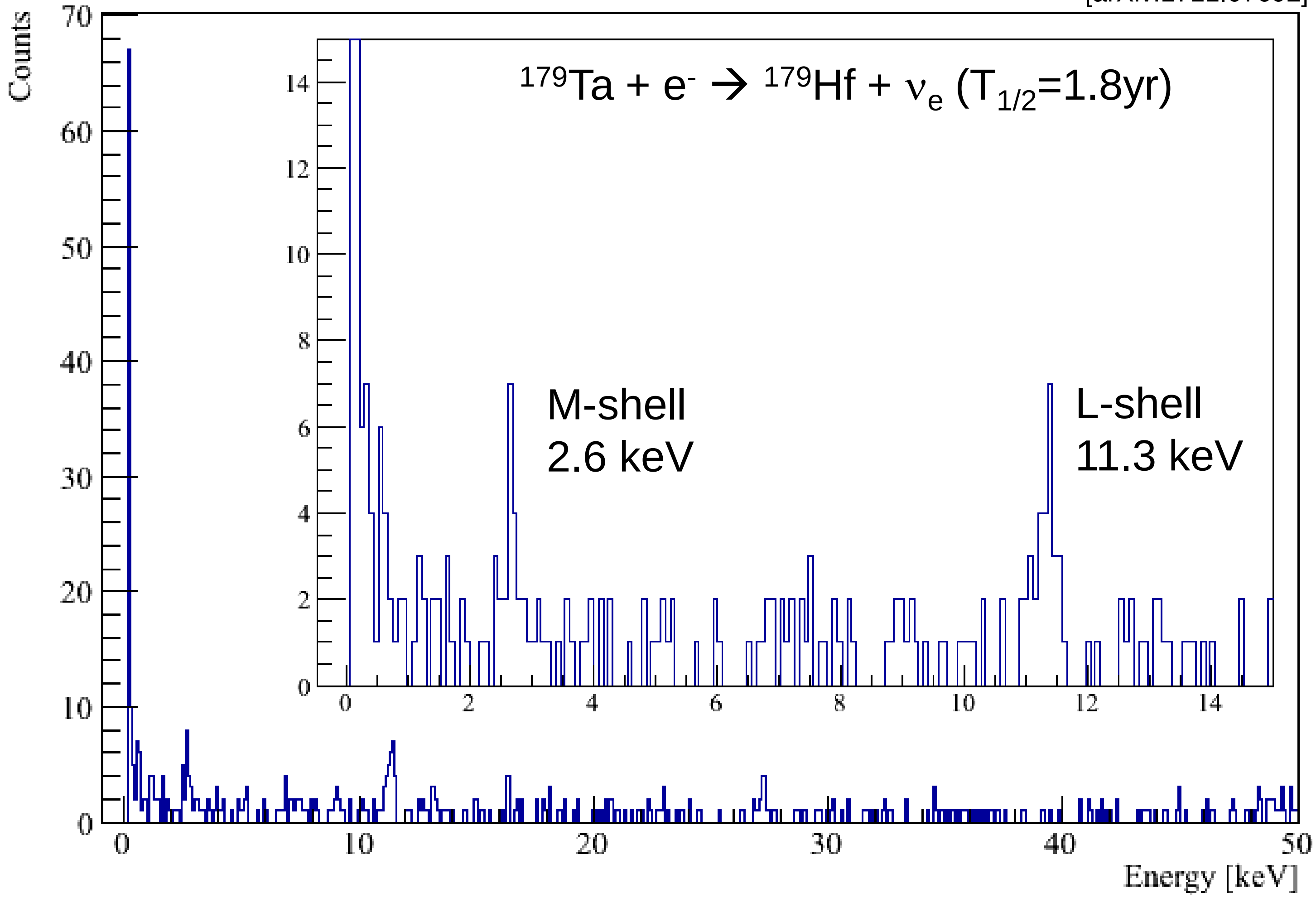
Detector A: energy spectrum

[arXiv:1711.07692]



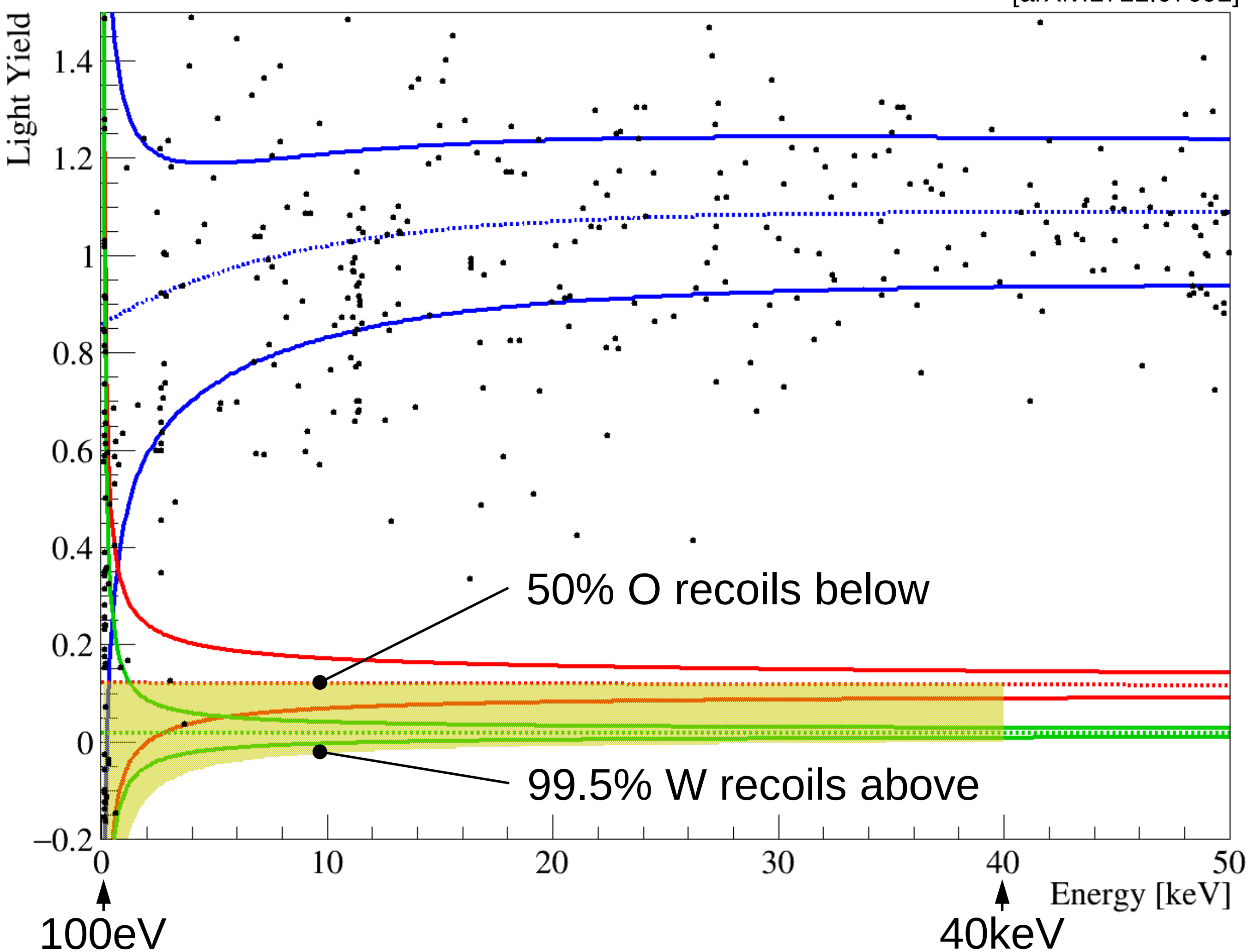
Detector A: energy spectrum

[arXiv:1711.07692]

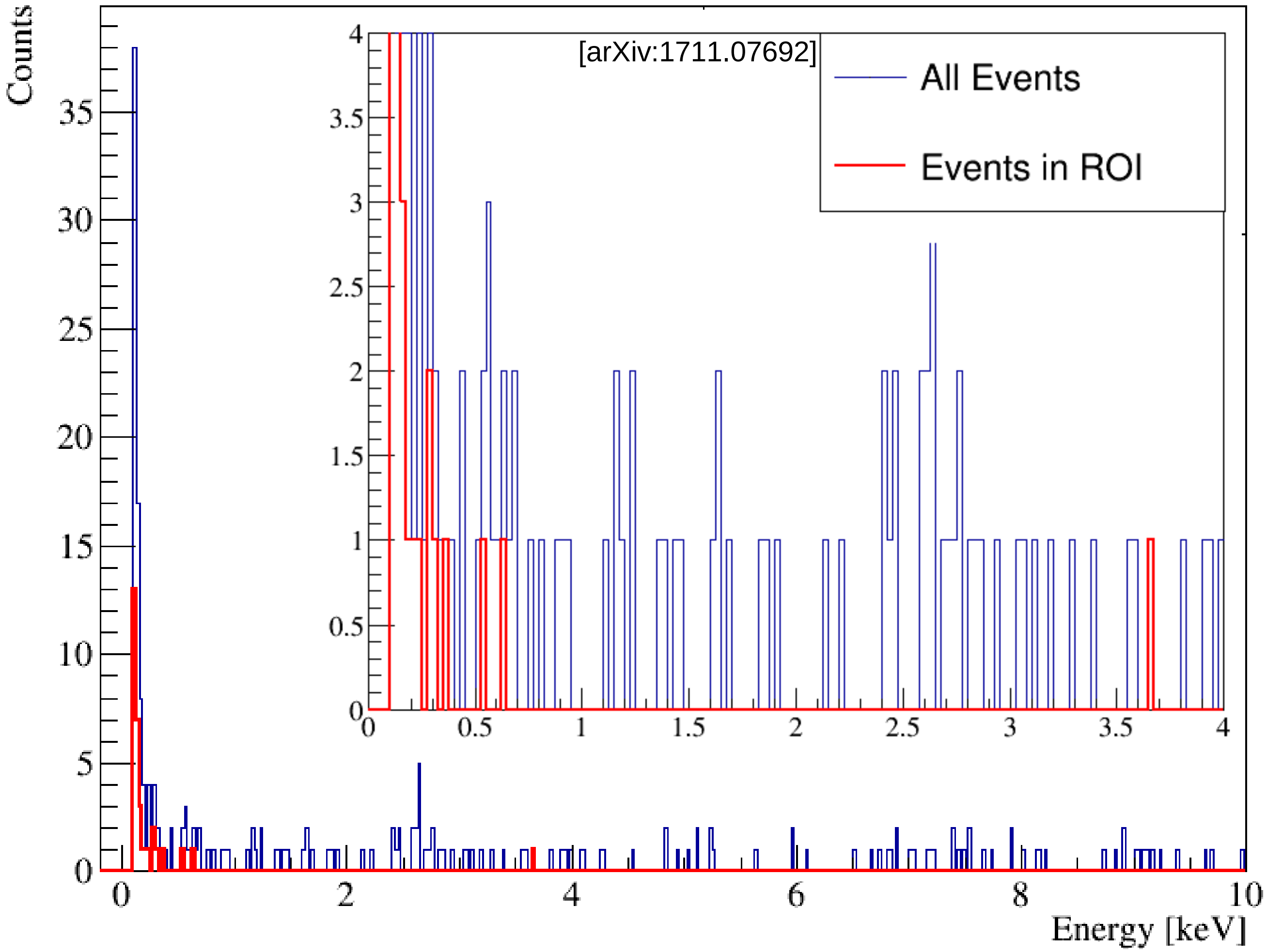


Detector A: acceptance region

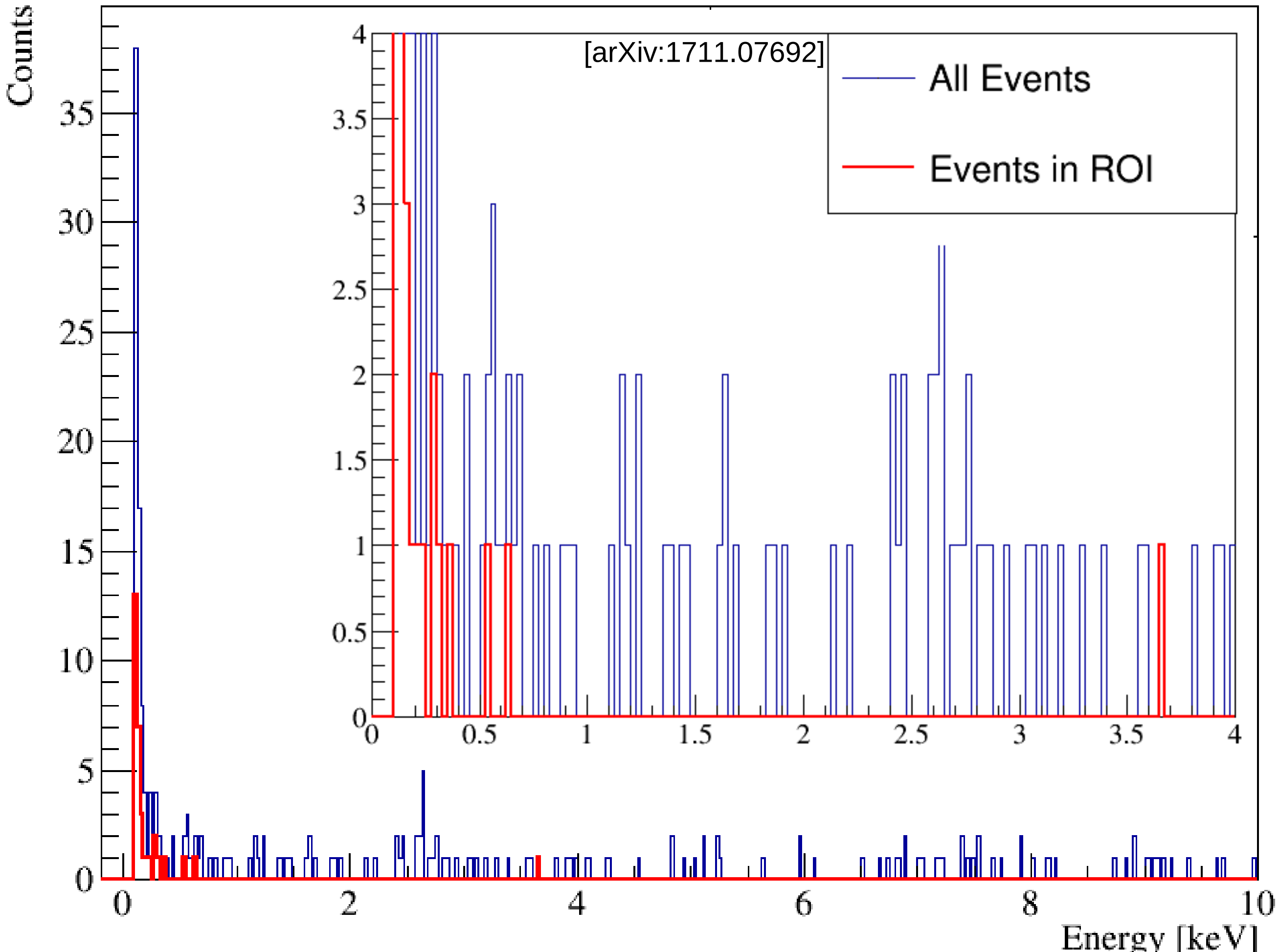
[arXiv:1711.07692]



Detector A: accepted events



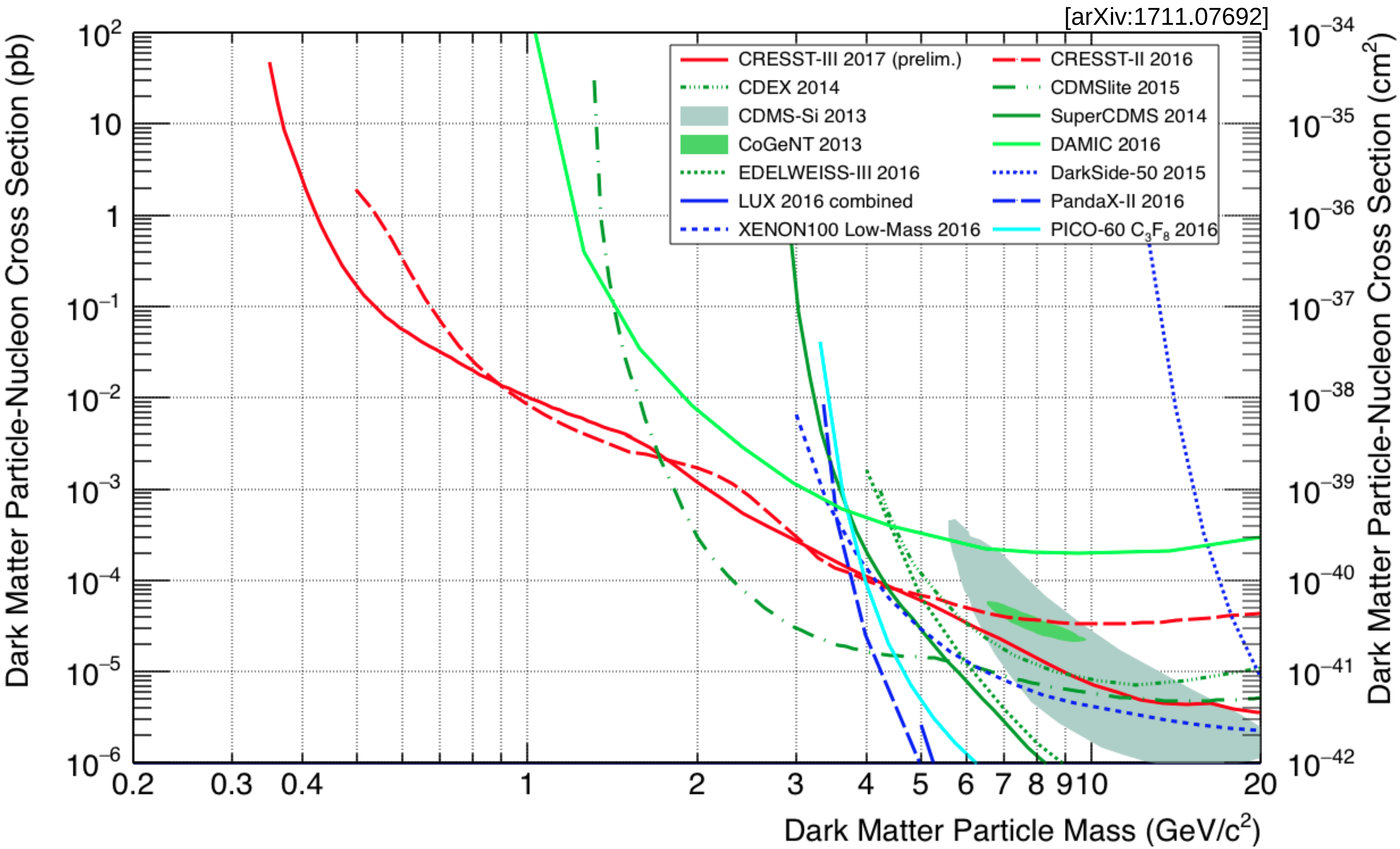
Detector A: accepted events



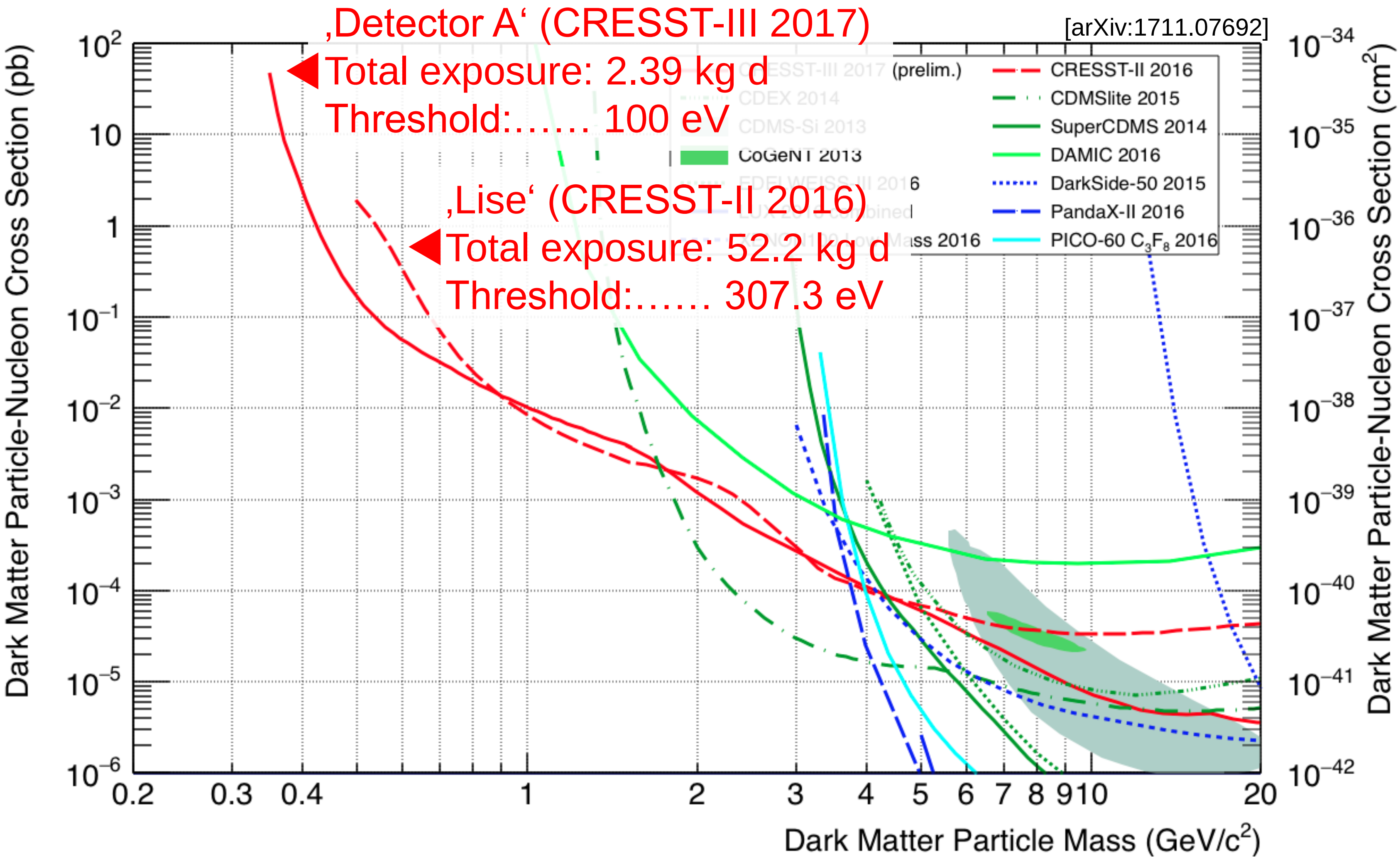
Assume all accepted events are dark-matter caused

→ Use Yellin's optimum interval method to set an exclusion limit

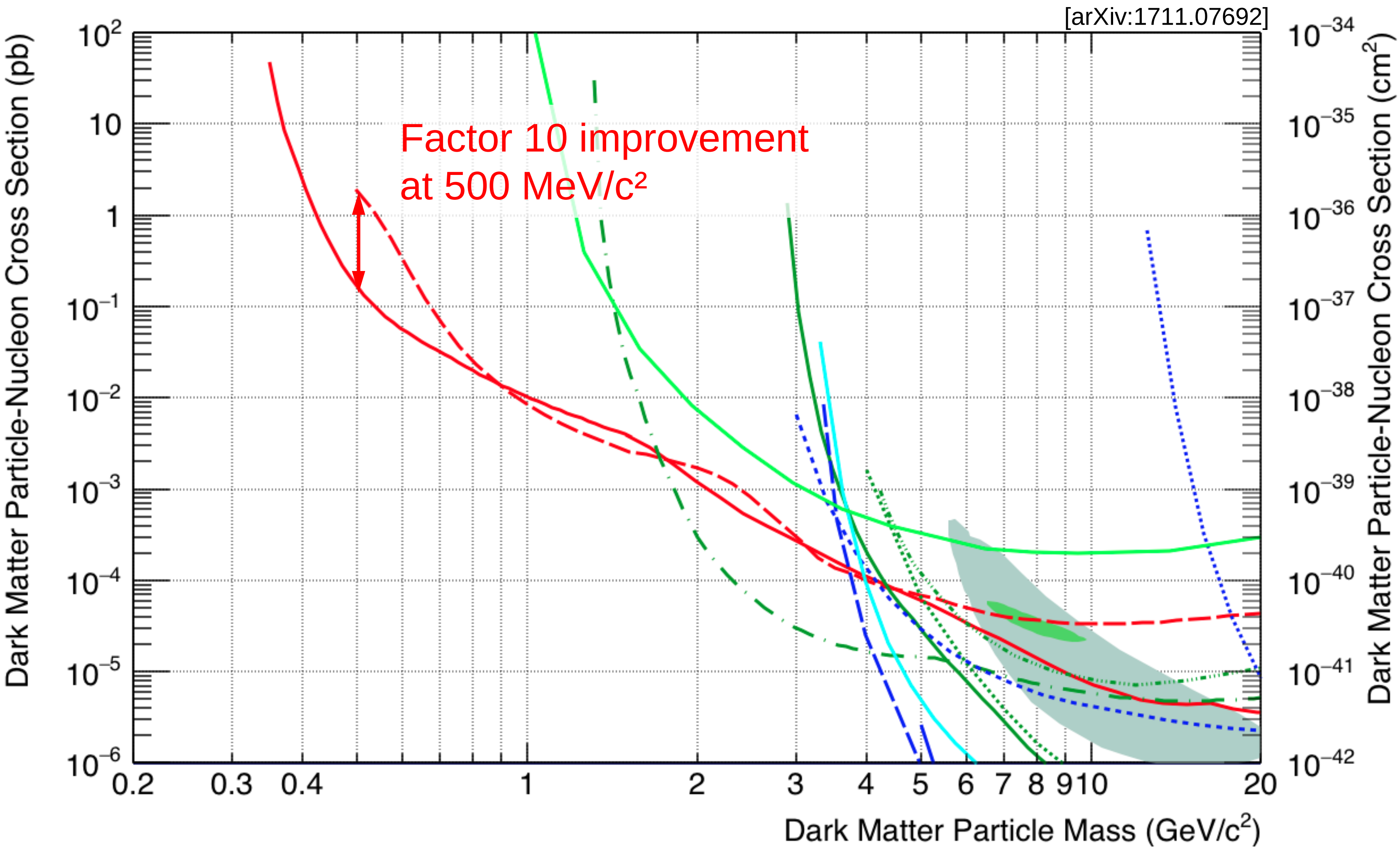
Detector A: exclusion limit



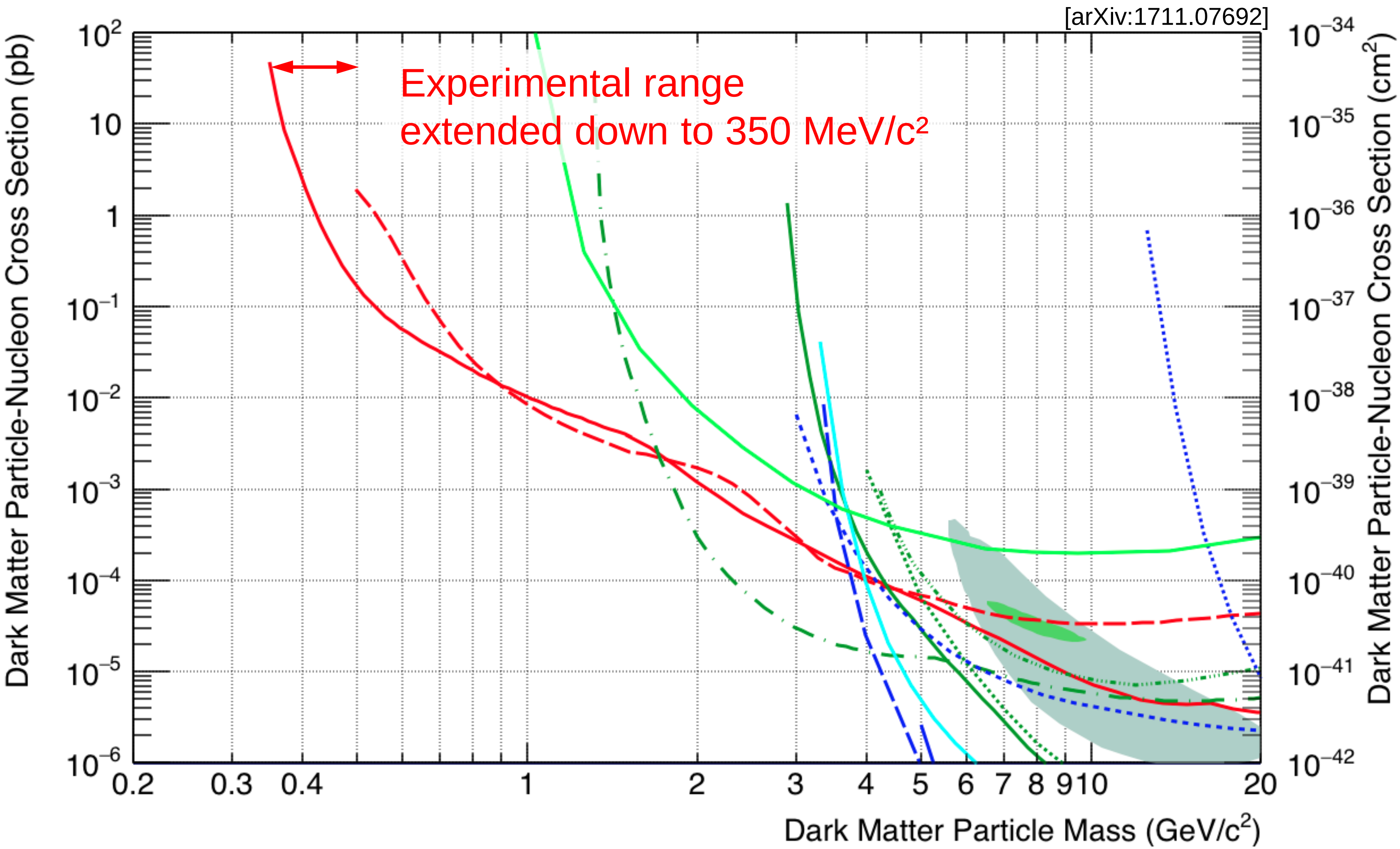
Detector A: exclusion limit



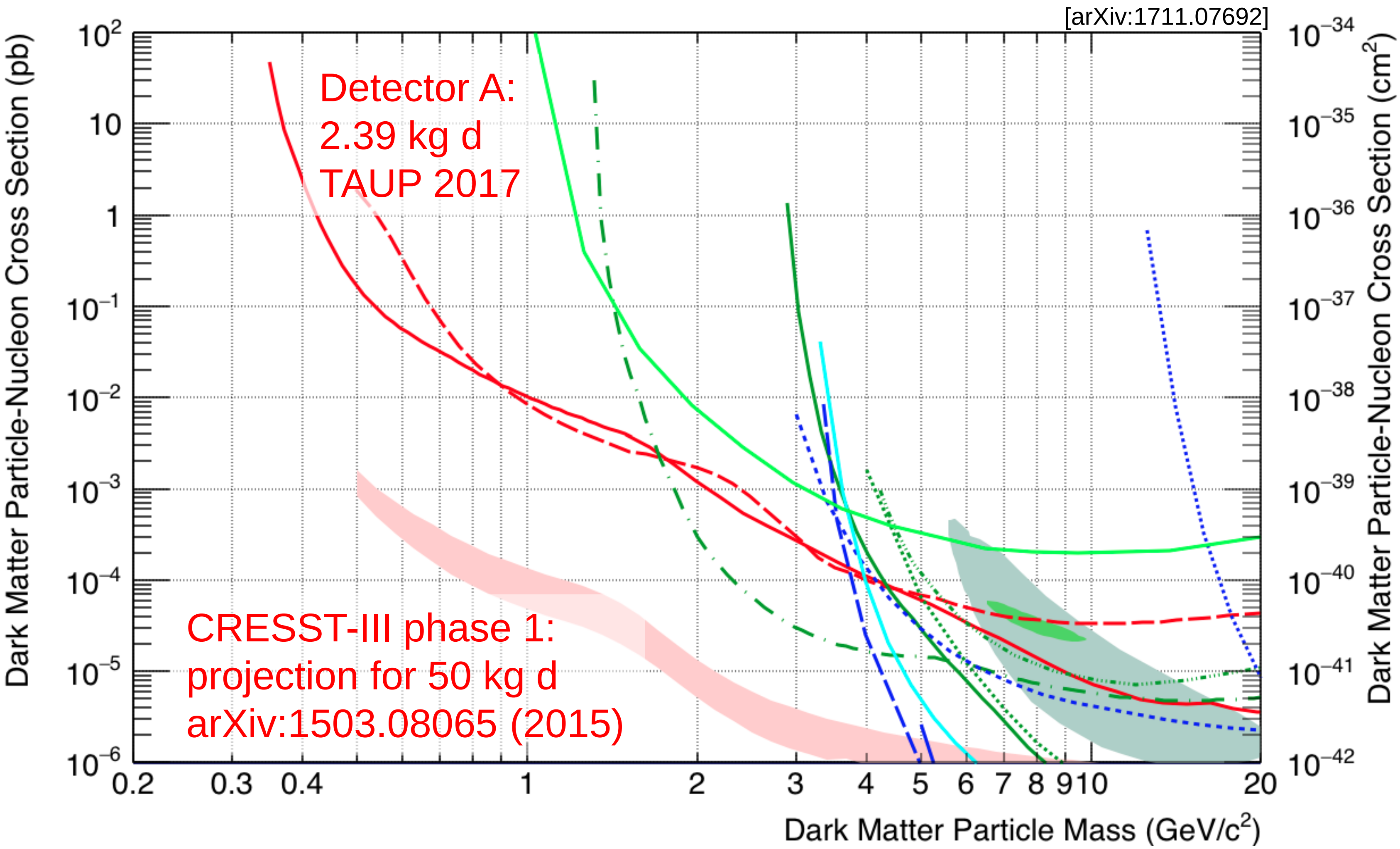
Detector A: exclusion limit



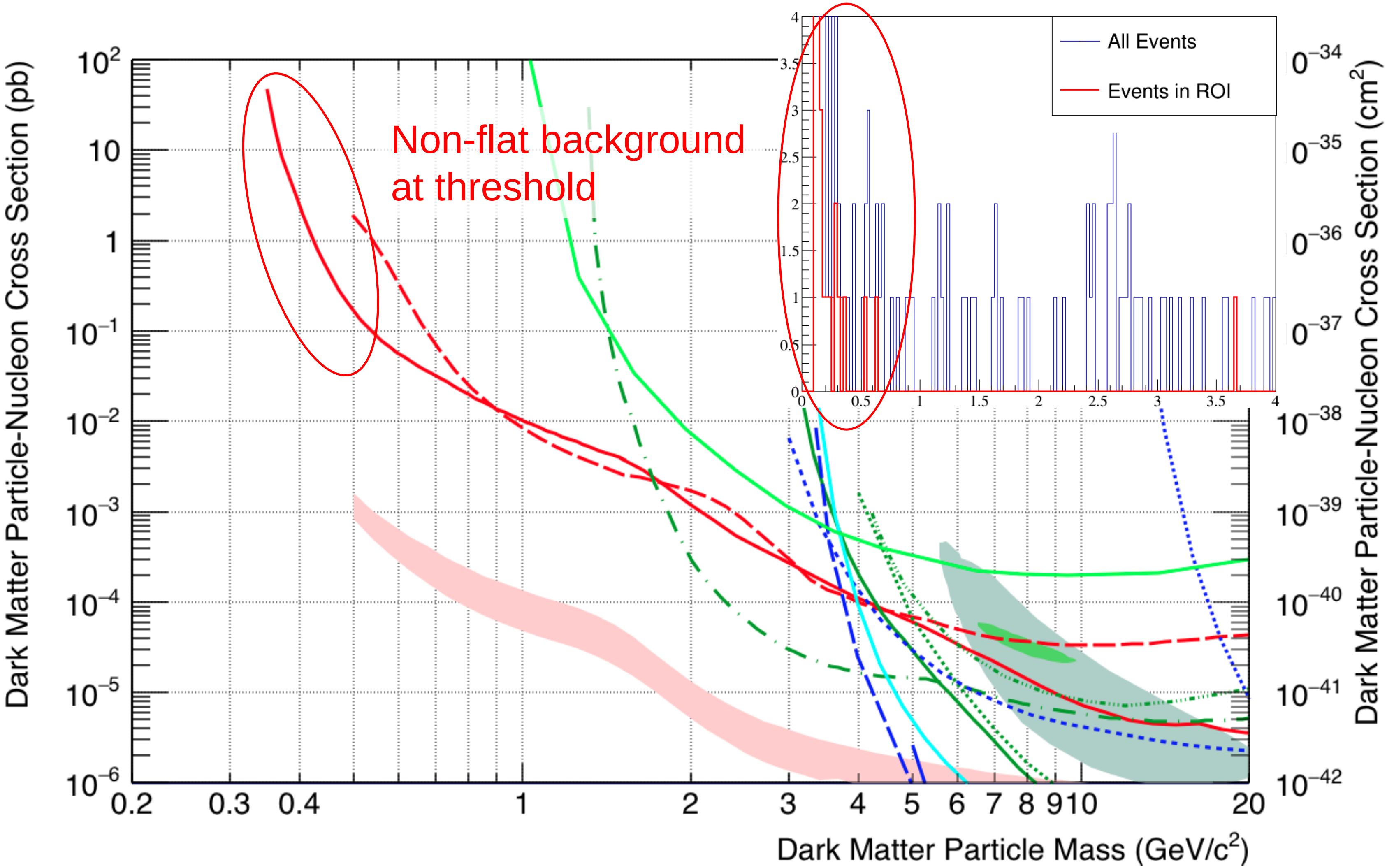
Detector A: exclusion limit



Detector A: limitations



Detector A: limitations



Summary

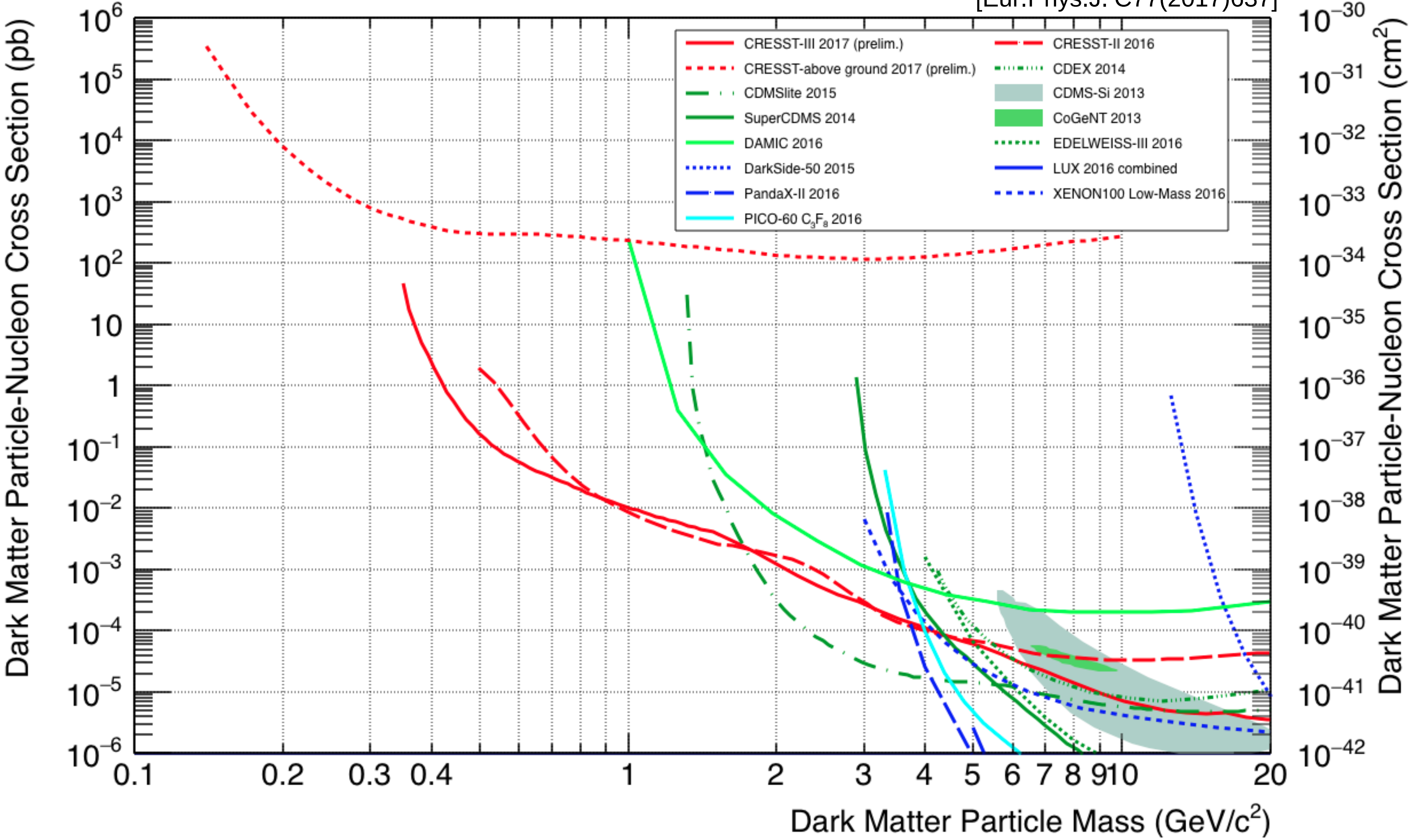
- **First** results of CRESST-III phase 1: detector A
  - 100eV-analysis
  - x10 improvement @ 500 MeV/c²
  - extend range down to 350 MeV/c²

- but that is **not the end**:
  - continue data taking → better understanding of backgrounds
  - 3 more detectors with threshold $\ll 100\mathrm{eV}$
  - 3 times lower optimum threshold for detector A

➔New frontiers: new potentials & new challenges!

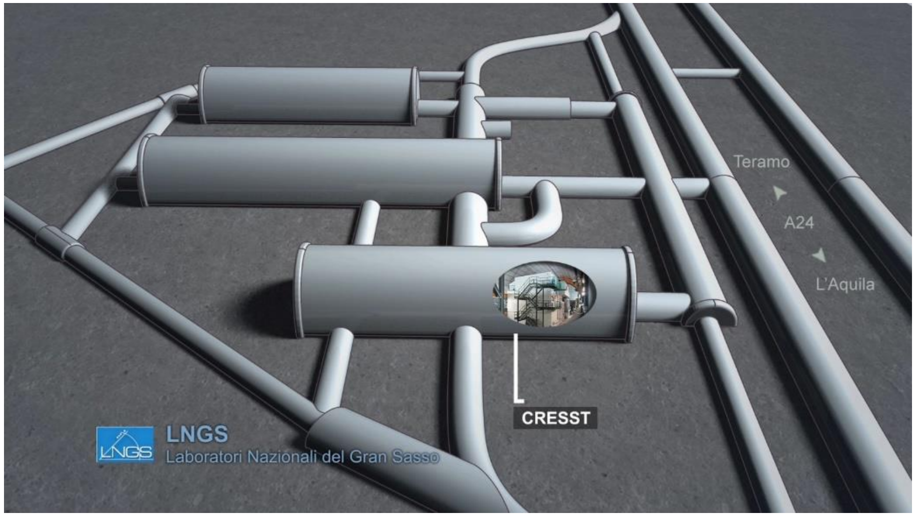
Above ground limit

[Eur.Phys.J. C77(2017)637]



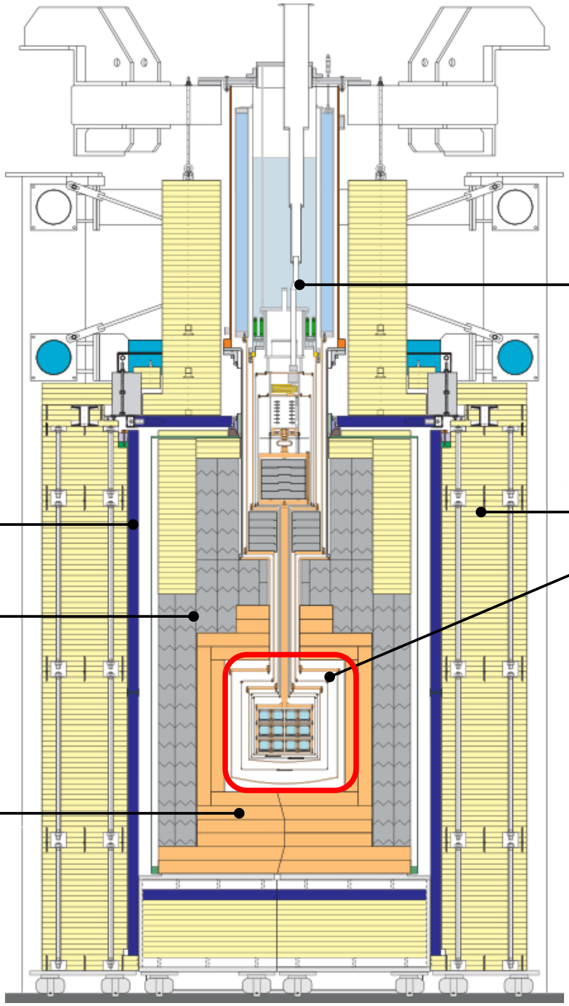
Additional slides

The CRESST experiment



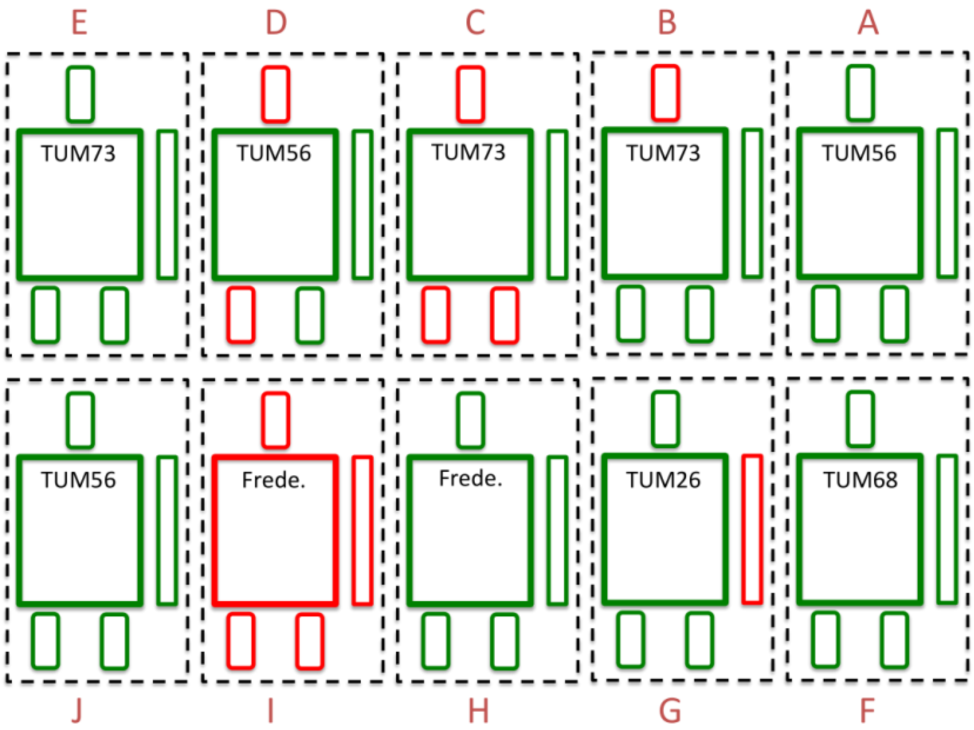
Located in Italy,
under the Gran Sasso mountain,
at the LNGS @ ~3600mwe

μ's	$\sim 3 \cdot 10^{-8}\,\mathrm{s^{-1}cm^{-2}}$
γ's	$\sim 7 \cdot 10^{-1}\,\mathrm{s^{-1}cm^{-2}}$
n's	$\sim 4 \cdot 10^{-6}\,\mathrm{s^{-1}cm^{-2}}$



Max-Planck-Institut für Physik

CRESST-III: detectors

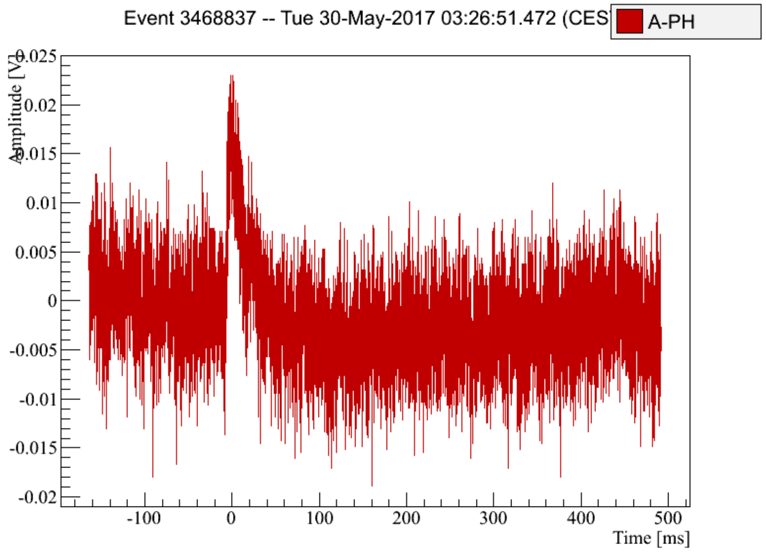


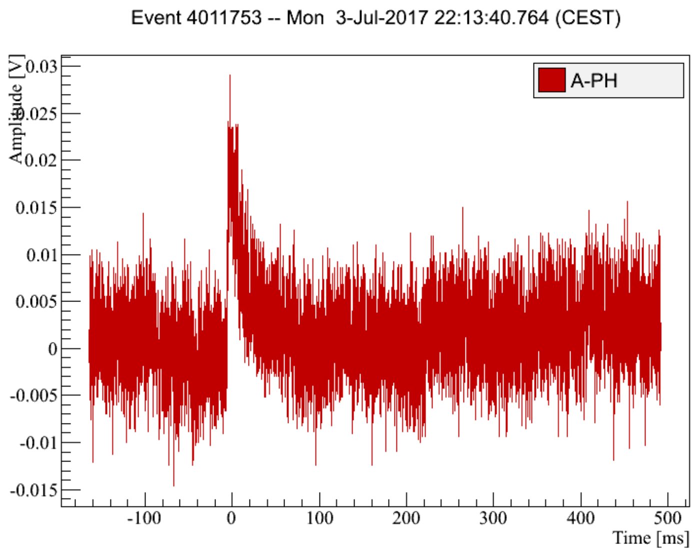
- G-LD: no transition
- I-all: no transitions
- B- one iStick : heater broken cannot be operated
- C and D - iStick system: working, but introduces strong noise on phonon channel

6/50 TES not working (including the 5 of detector I)

- The wiring is >10 years old
- A TES is a sensitive but challenging device

100 eV-pulses

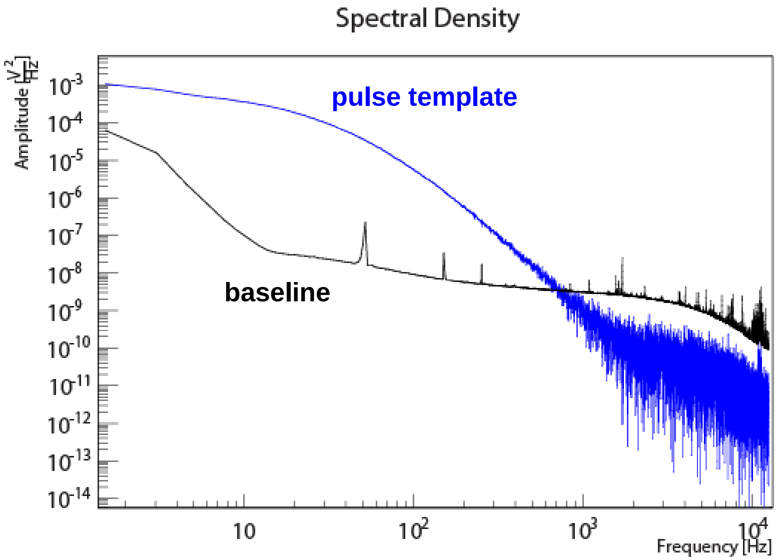


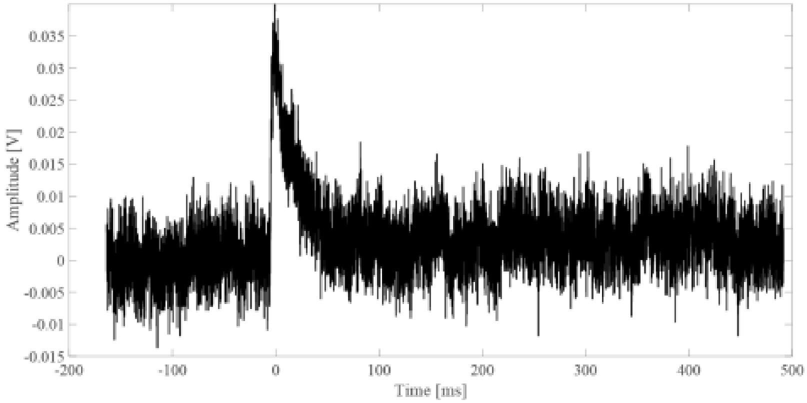


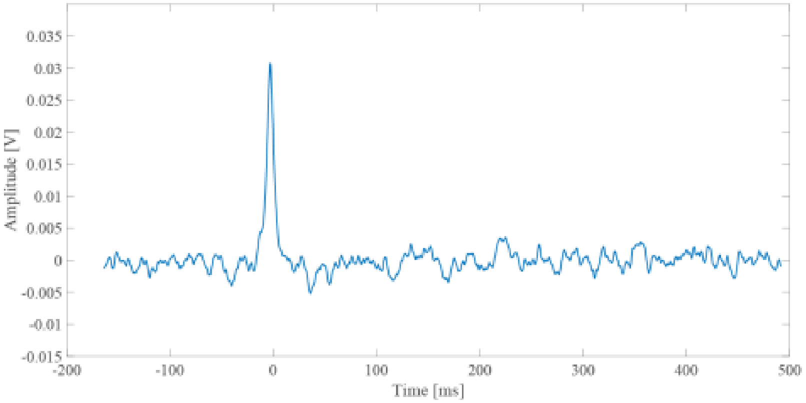
Optimum filter

Pulse-height evaluation
with optimum filter:

The Gatti-Manfredi filter maximize the ratio between the amplitude of the treated pulse and the noise RMS







Resolution typically improved by factor 2 to 3

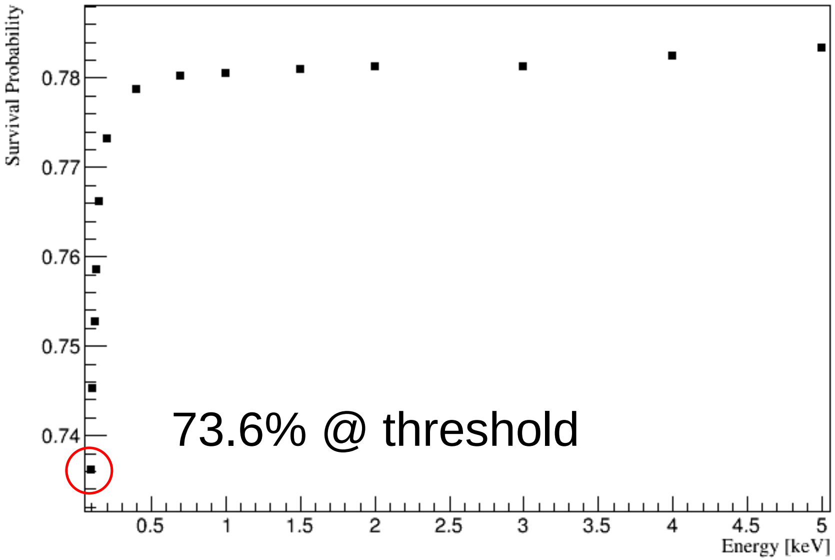
Detector A: selections & efficiencies

Remove pulses where a correct determination of the amplitude is not guaranteed. Designed on non blind data (20% of physics data randomly selected) not included in the final exposure

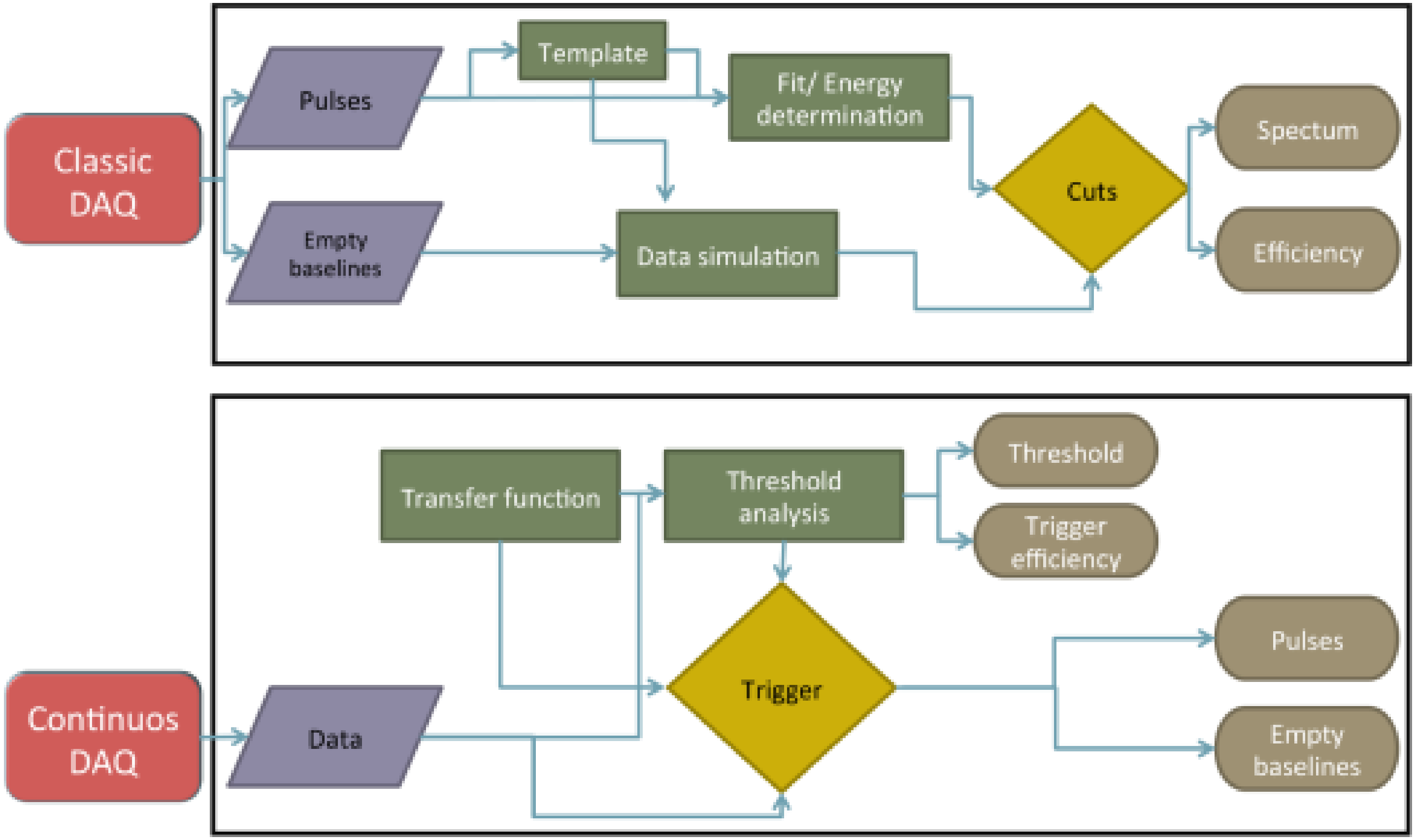
- Data quality
  events which cannot properly be analyzed

- Pulse shape
  e.g. events in iSticks, pileup

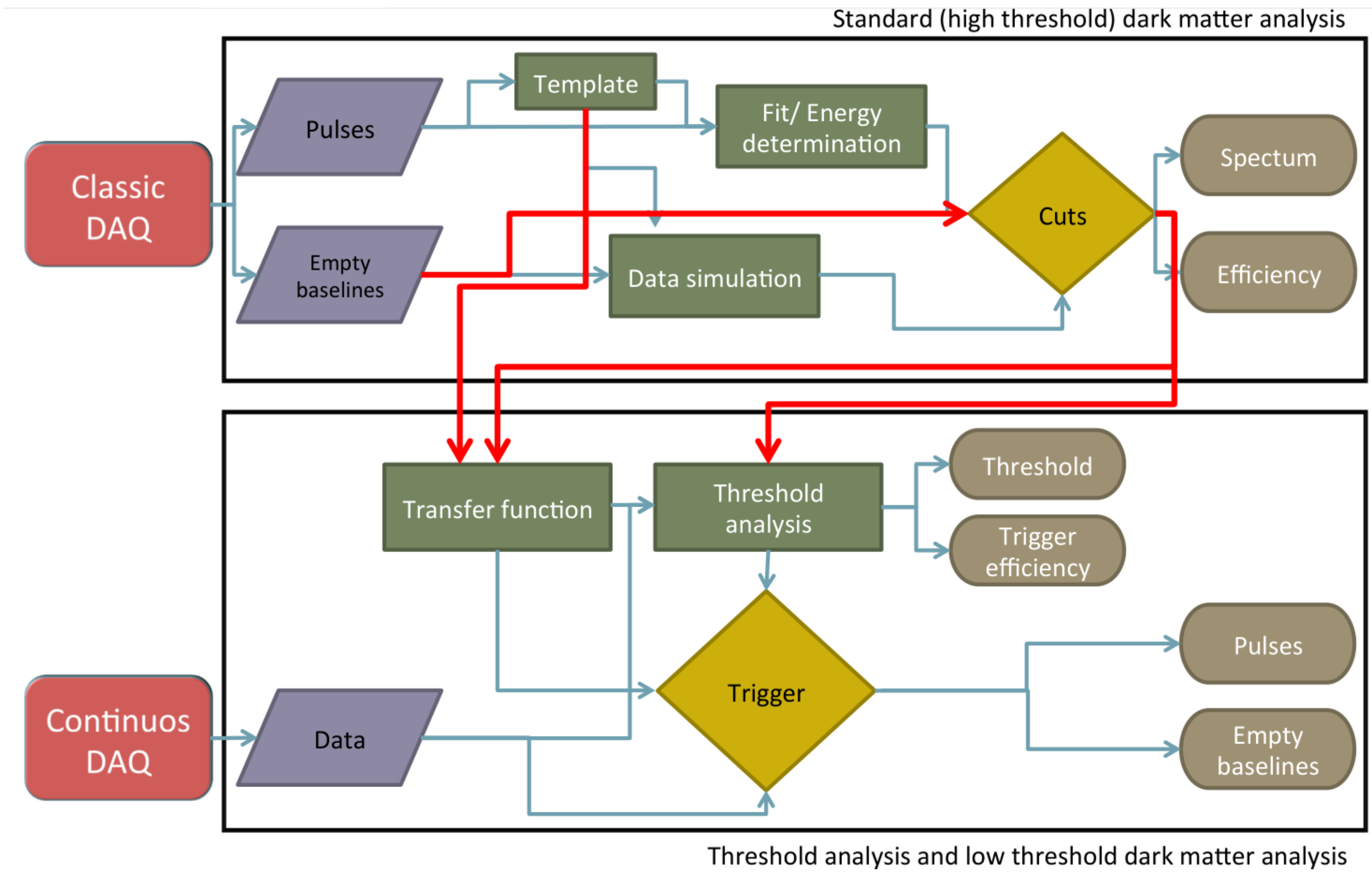
- Coincidences
  here: only with muon veto and iSticks



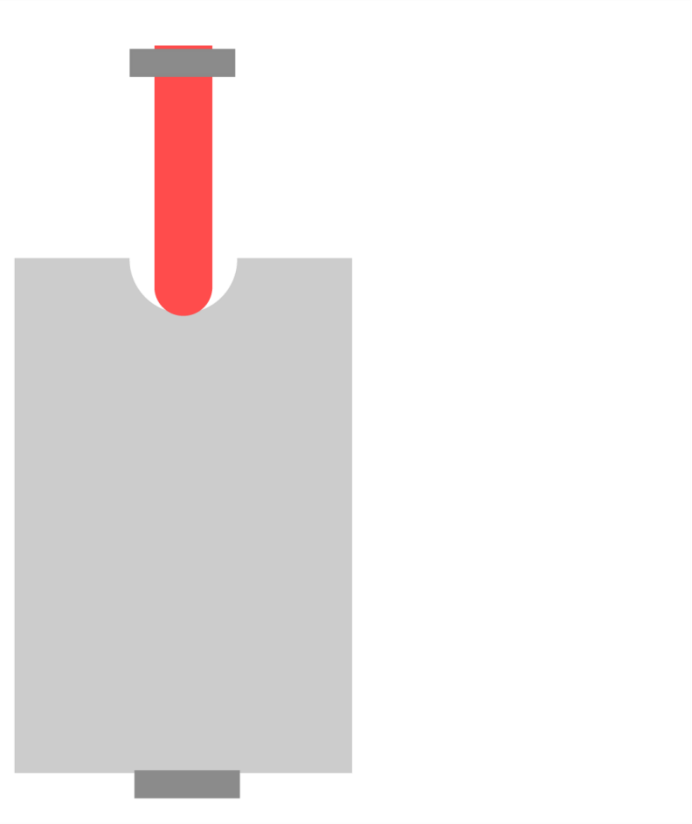
DAQ


Classic DAQ
Pulses
Template
Fit/ Energy determination
Cuts
Spectum
Efficiency
Empty baselines
Data simulation
Continuos DAQ
Data
Transfer function
Threshold analysis
Threshold
Trigger efficiency
Trigger
Pulses
Empty baselines

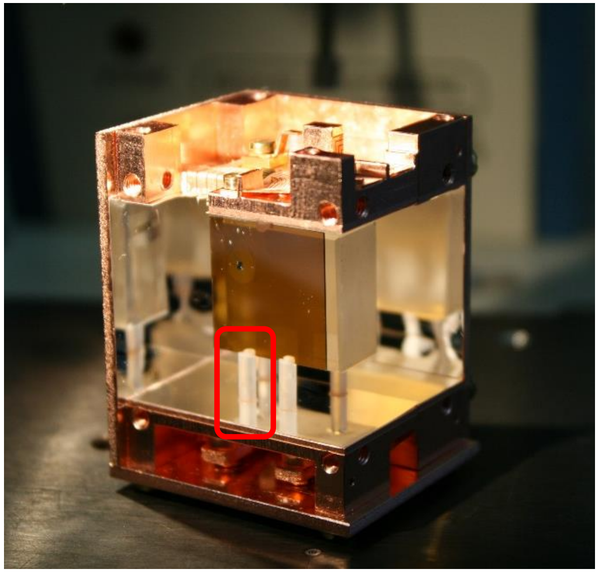
DAQ


Standard (high threshold) dark matter analysis
Classic DAQ
Pulses
Empty baselines
Template
Fit/ Energy determination
Data simulation
Cuts
Spectum
Efficiency
Transfer function
Threshold analysis
Threshold
Trigger efficiency
Continuos DAQ
Data
Trigger
Pulses
Empty baselines
Threshold analysis and low threshold dark matter analysis

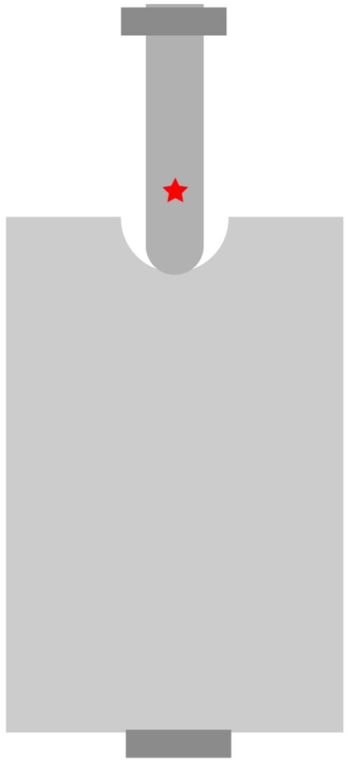
Holder-related backgrounds



- Target is held by $CaWO_4$ sticks

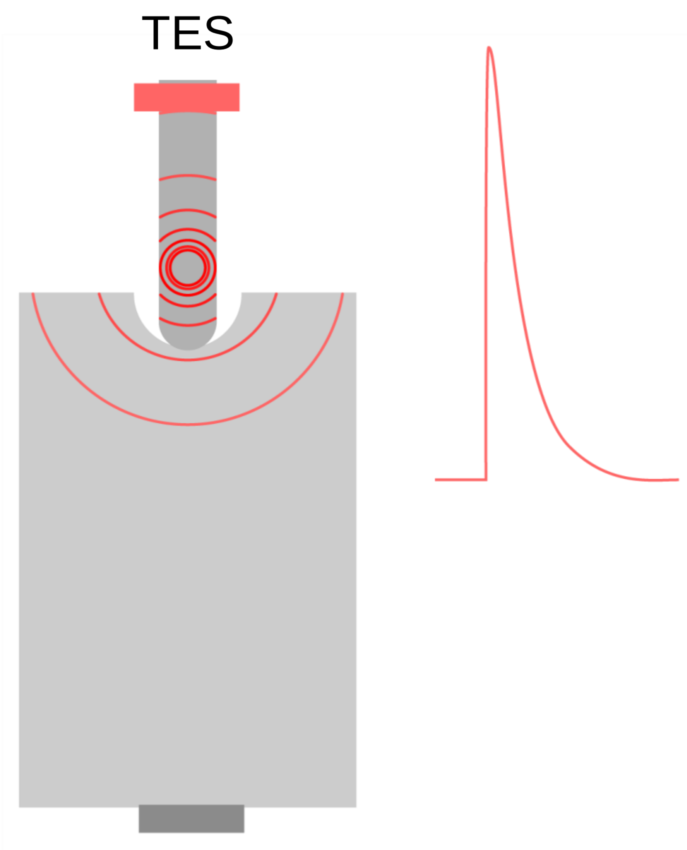


Holder-related backgrounds

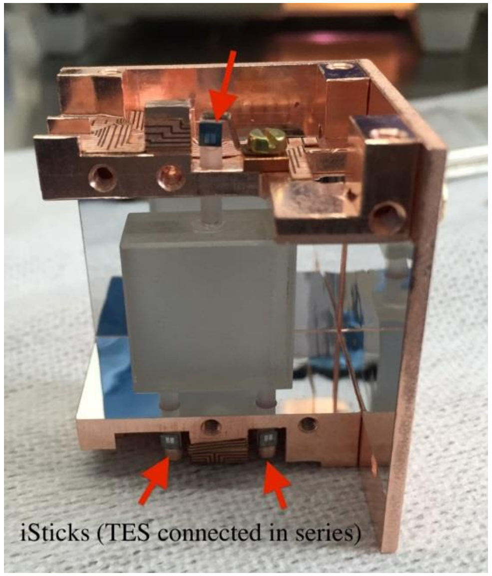


- Target is held by $CaWO_4$ sticks
- Event in stick: surface background, relaxation, …

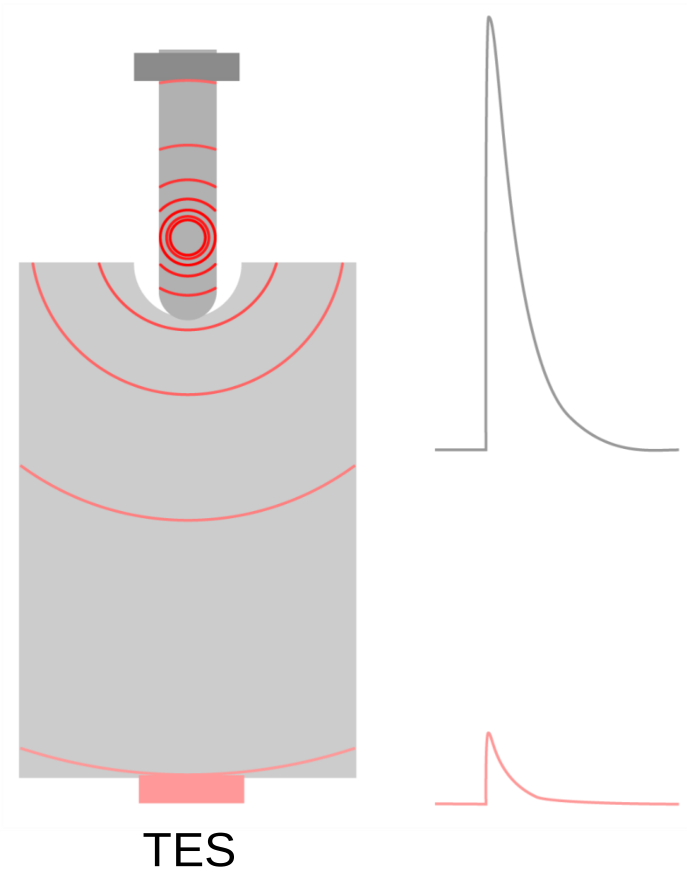
Holder-related backgrounds



- Target is held by $CaWO_4$ sticks
- Event in stick: surface background, relaxation, …
- Signal in instrumented stick (iStick)

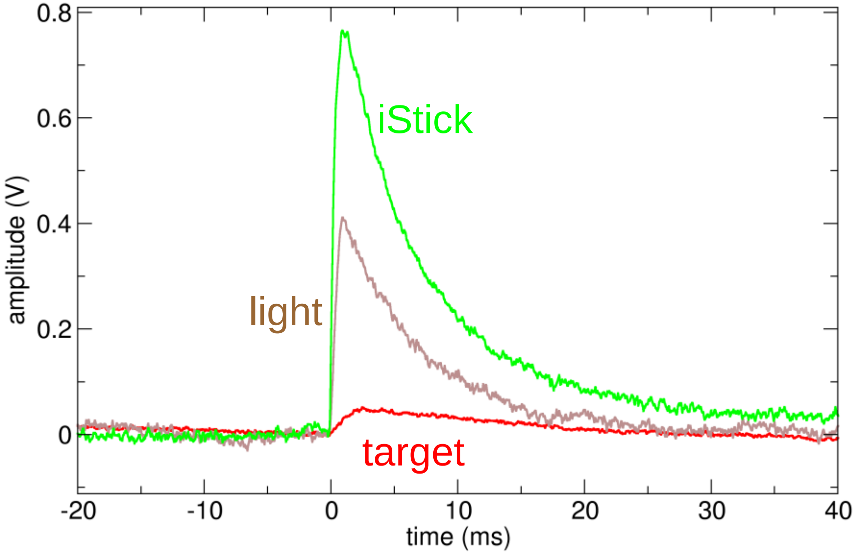


Holder-related backgrounds



- Target is held by $CaWO_4$ sticks
- Event in stick: surface background, relaxation, …
- Signal in instrumented stick (iStick)
- Degraded signal in target

Holder-related backgrounds

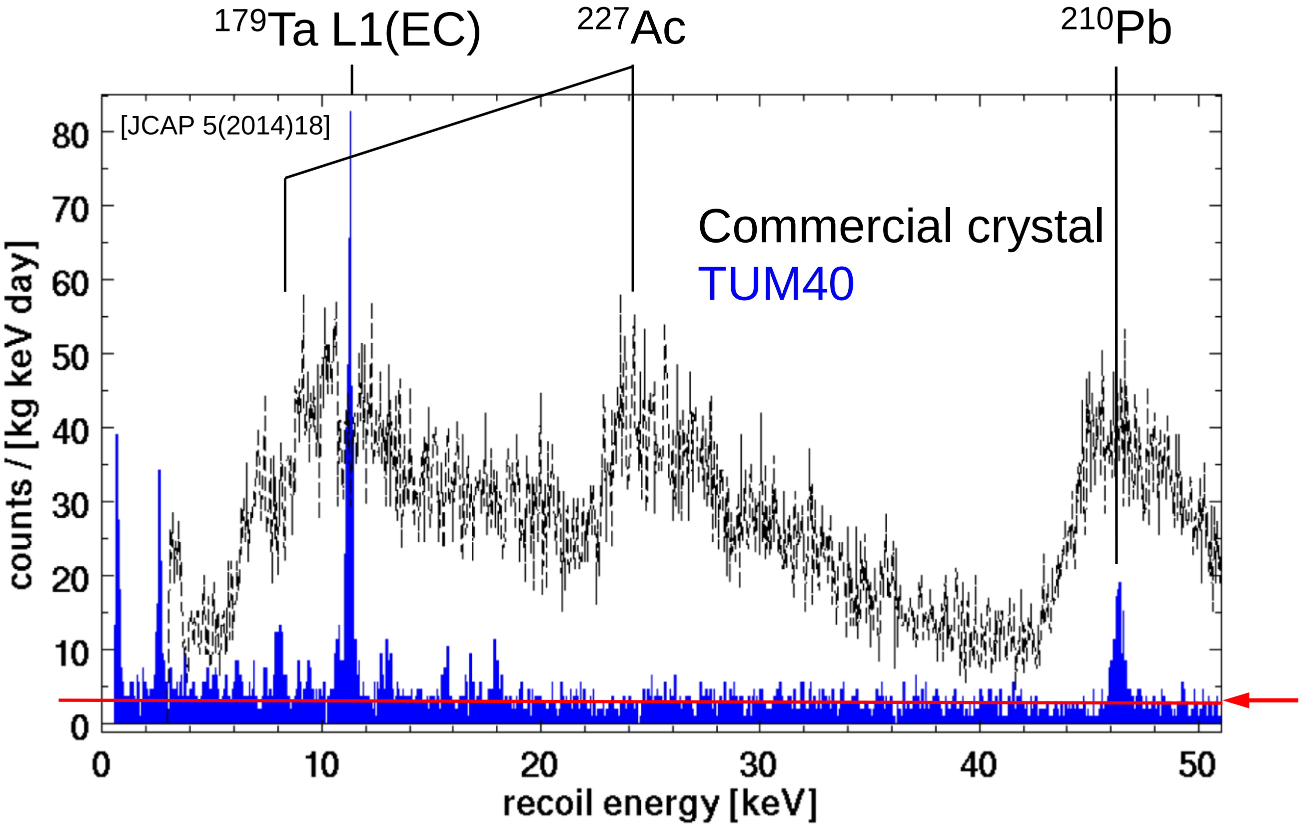


- Target is held by $CaWO_4$ sticks
- Event in stick: surface background, relaxation, …
- Signal in instrumented stick (iStick)
- Degraded signal in target

➔iStick/target is a powerful tool to reject holder-related backgrounds

'TUM40' radiopurity

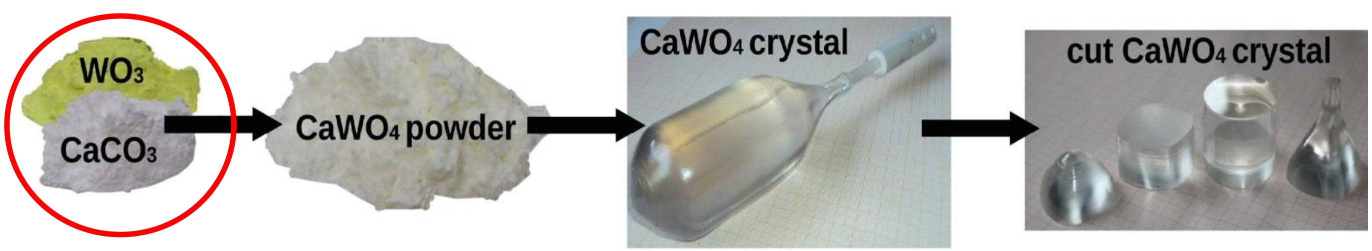
- $CaWO_4$ crystal production at TU Munich
- TUM40: radiopurity improved by factor 2-10



~3.5 counts/kg.d keV on average

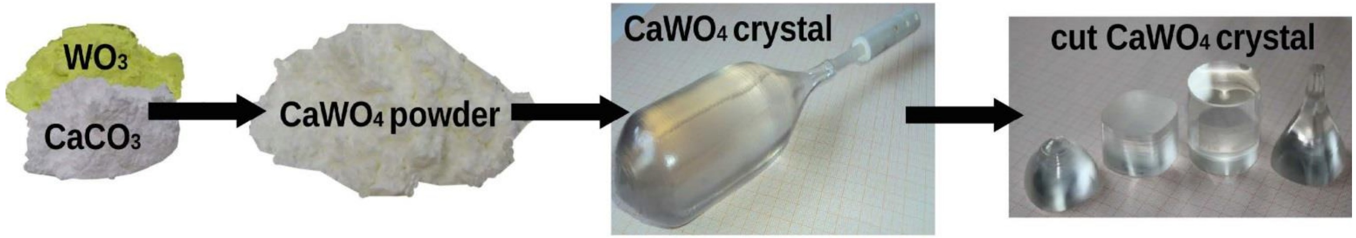
Going beyond 'TUM40' radiopurity

- Cleaning procedure e.g. by re-crystallization, chemical purification of raw materials
- Recently: First steps in chemical purification of $CaCO_3$ powder.
  work by H.H. Trinh Thi, A. Münster, A. Erb

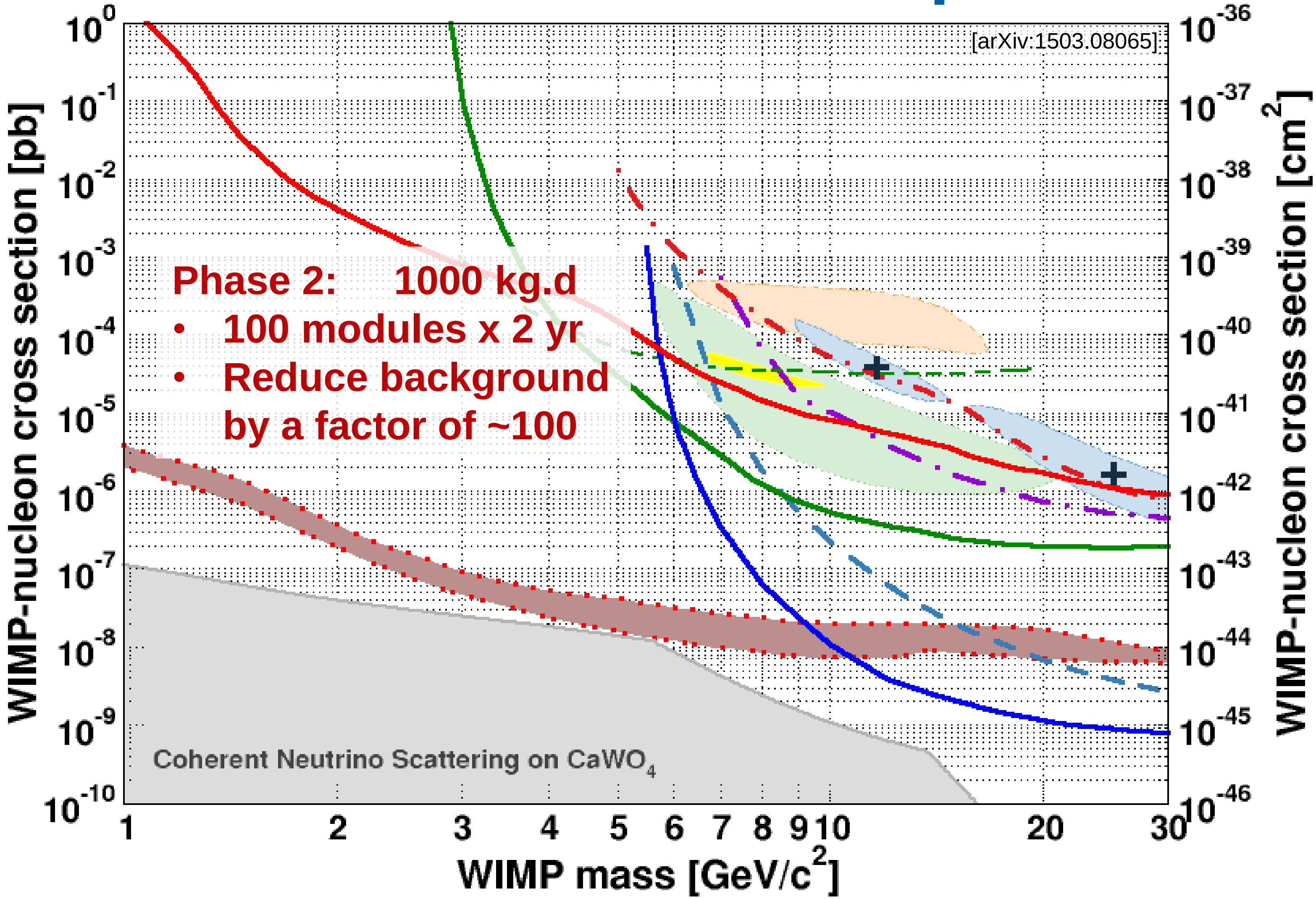


Going beyond 'TUM40' radiopurity

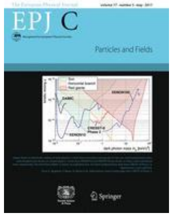
- Cleaning procedure e.g. by re-crystallization, chemical purification of raw materials
- Recently: First steps in chemical purification of $CaCO_3$ powder.
  work by H.H. Trinh Thi, A. Münster, A. Erb
- Measured contamination decreased by …
  - factor 2-7 for Th
  - factor 15-35 for U



Outlook to CRESST-III phase 2



Dark photon limits



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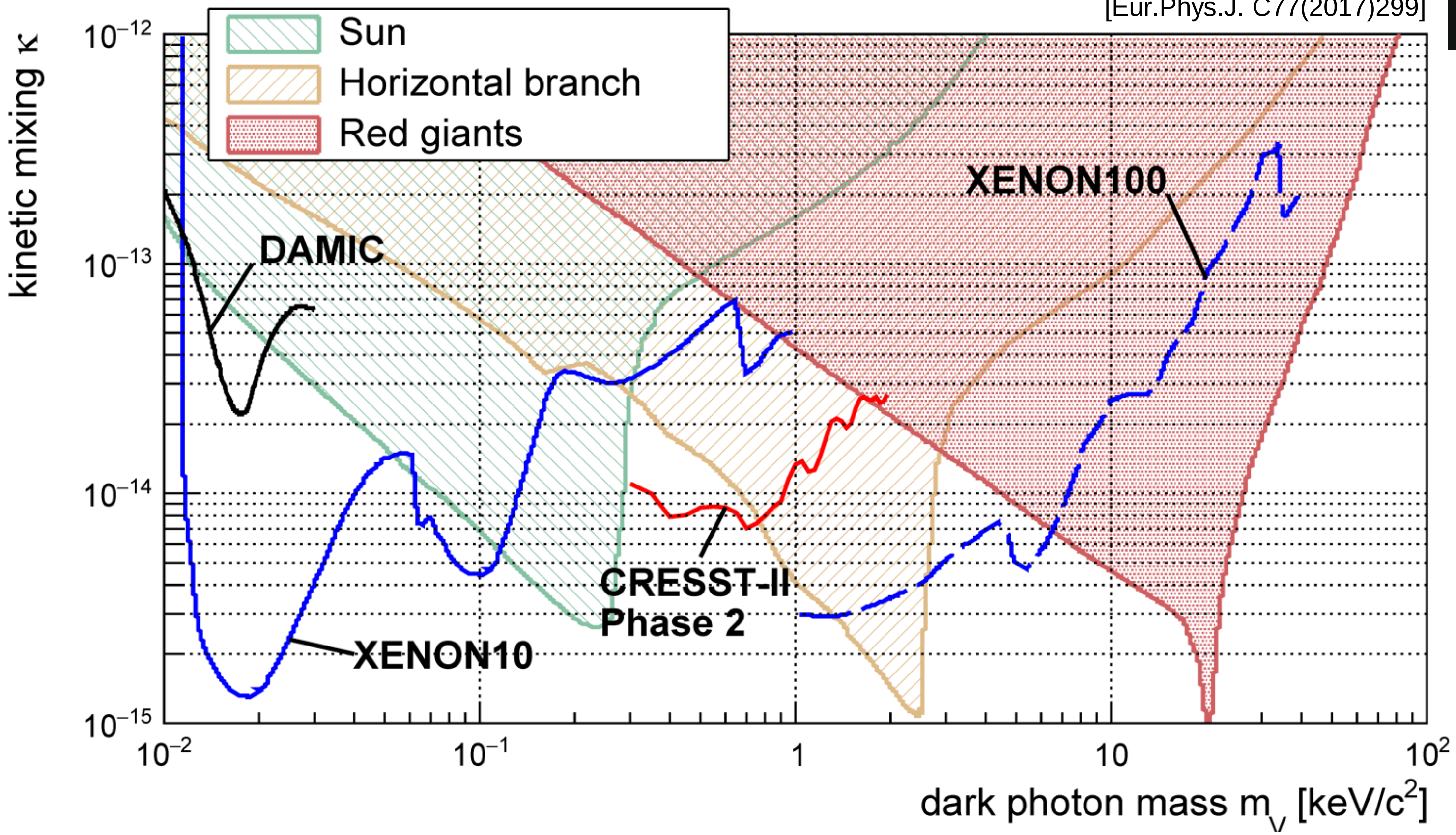
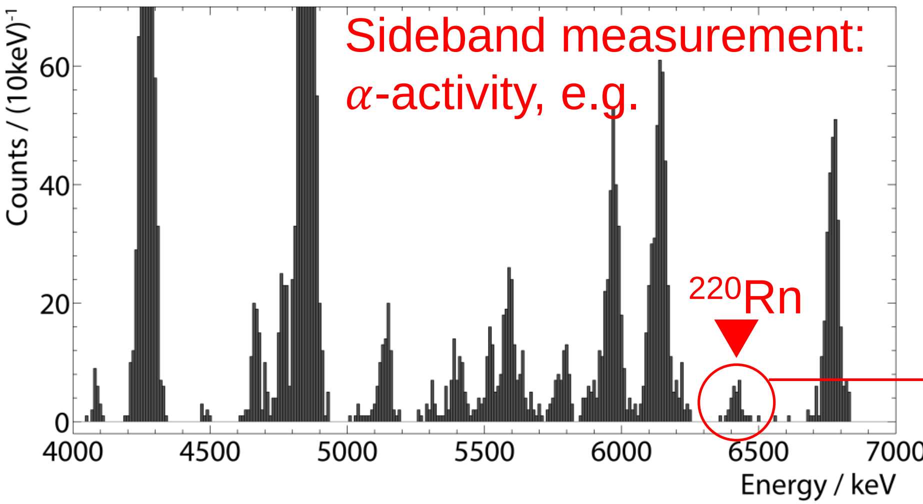
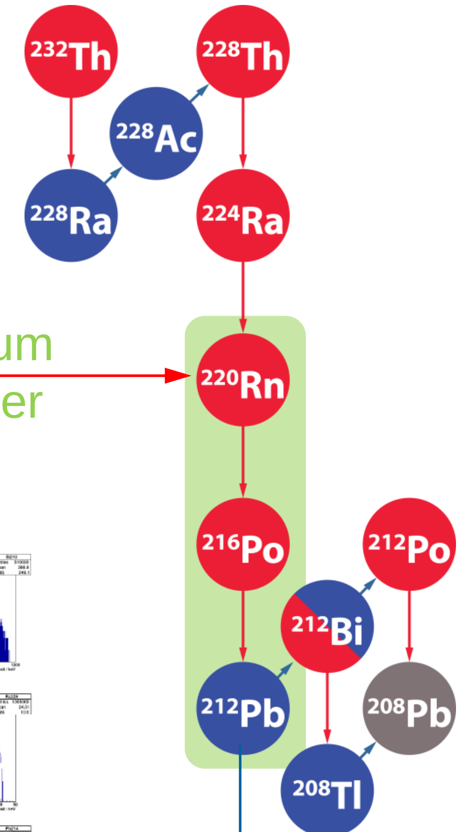
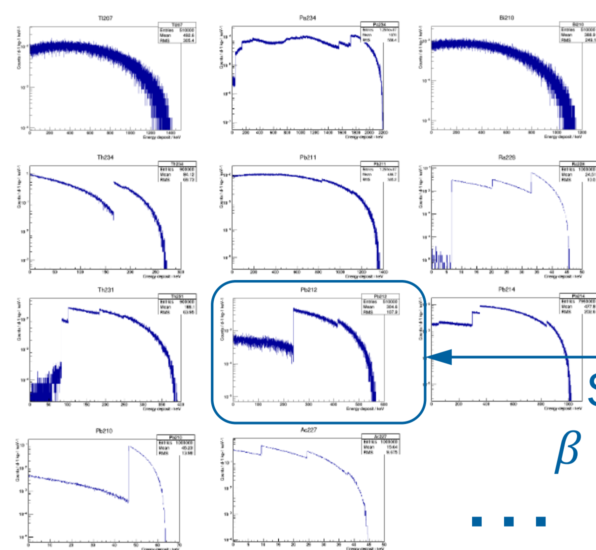


U/Th background modelling



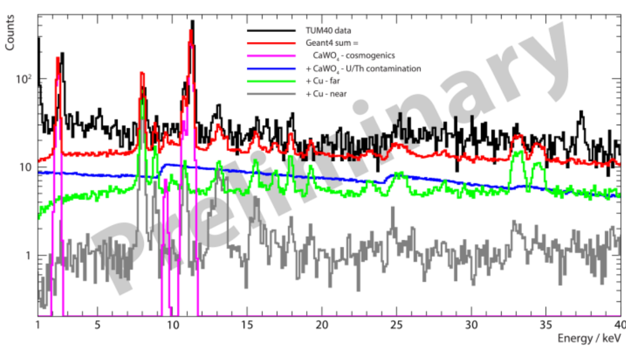
Piecewise equilibrium between α/β emitter





Scale each simulated β spectrum individually

...



EURECA

- Coordinated effort for a joint next generation DM search
- ~100 members from 23 institutes, including CRESST + EDELWEISS
- Cooperation with SuperCDMS on …
  - exp. site: study possibilities to install future EURECA detectors at SNOLAB
  - common tower infrastructure
  - electronic development
  - background simulation: geometries of potential EURECA detectors fully implemented in SuperCDMS' Geant4 code "SuperSIM"