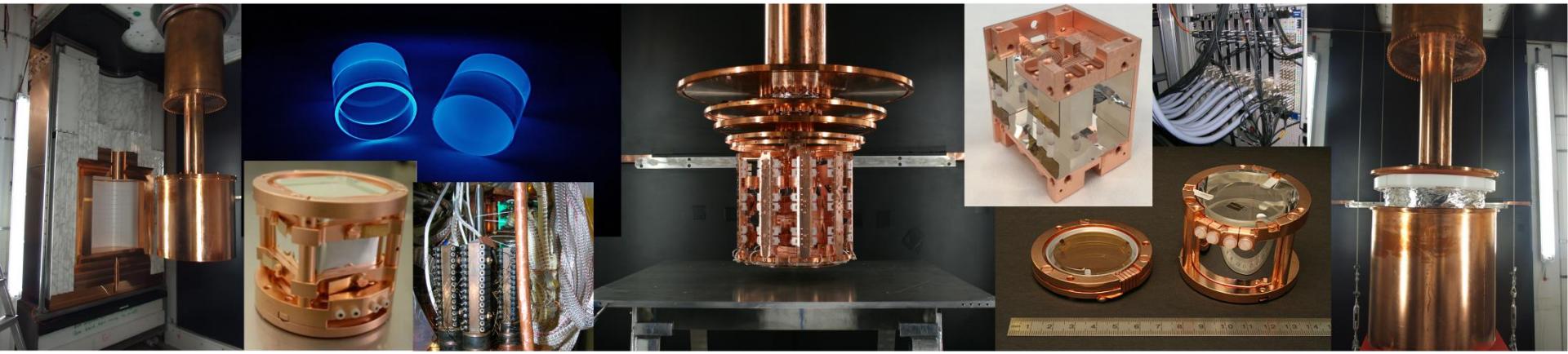
HEPHY Institute of High Energy Physics

TU WIEN

CRESST



UNIVERSITY OF OXFORD

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

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

TU WIEN

INFN Laboratori Nazionali del Gran Sasso

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

Cryogenic Rare Event Search with Superconducting Thermometers

Modelling of electromagnetic backgrounds in the CRESST experiment

Holger Kluck & Cenk Türkoğlu
for the CRESST collaboration

July 27, 2018

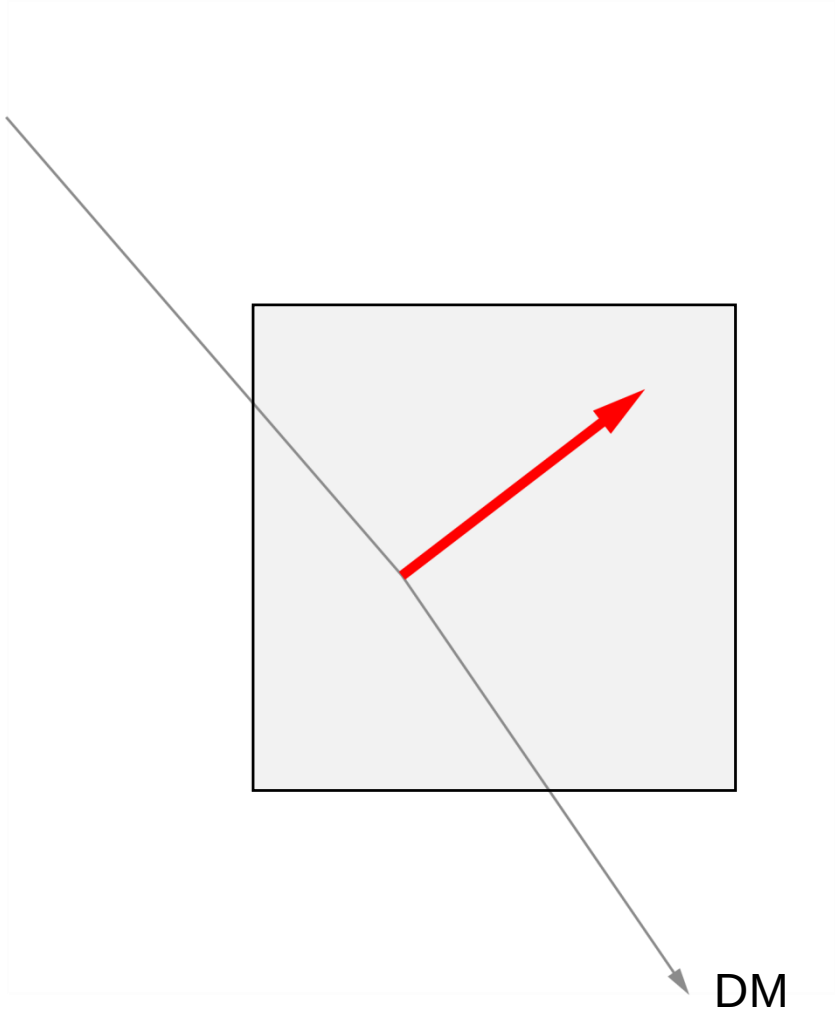
Outline

- CRESST basics (a short reminder)
- Modelling the electromagnetic backgrounds

(*No* current status → F. Reindl's talk in the morning)

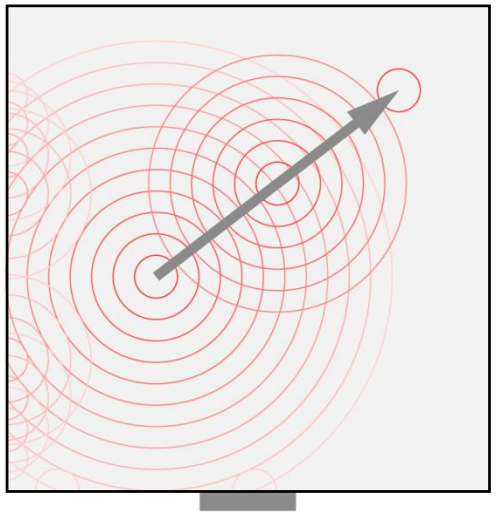
CRESST basics

The CRESST experiment



- Target: $CaWO_4$
- Signature: recoiling nucleus induced by scattering off Dark Matter particle

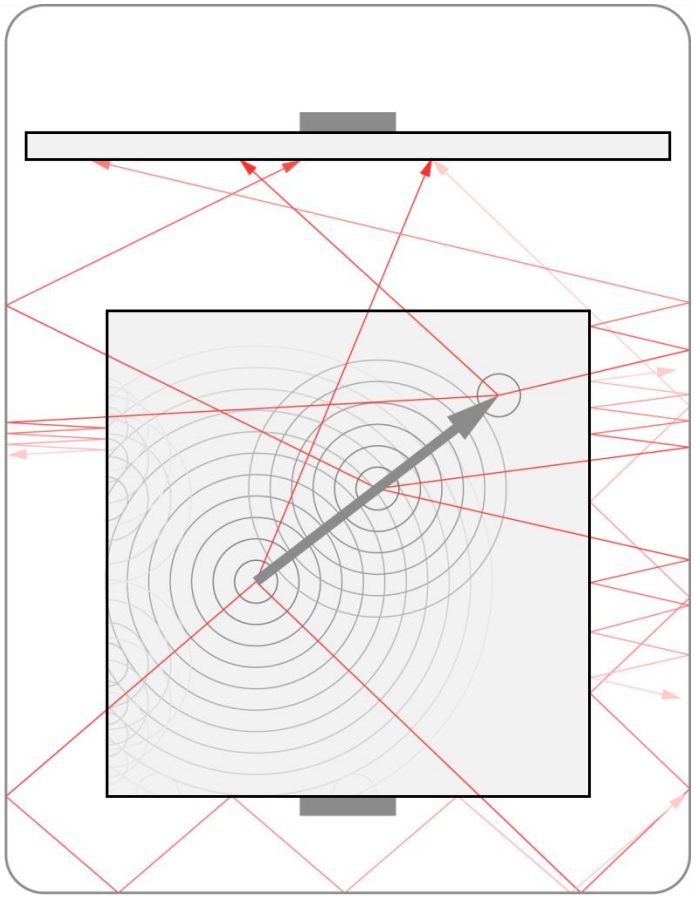
The CRESST experiment



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

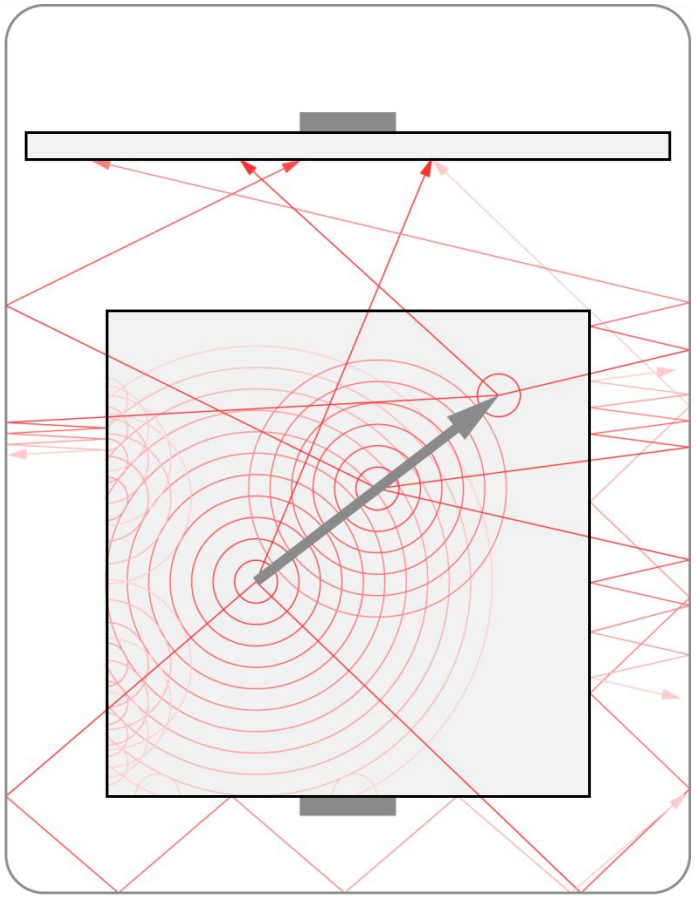
$\Delta E/C = \Delta T$
1keV ~ 1µK

The CRESST experiment



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

The CRESST experiment



- Target: $CaWO_4$
- Signature: recoiling nucleus
- Phonon signal: energy
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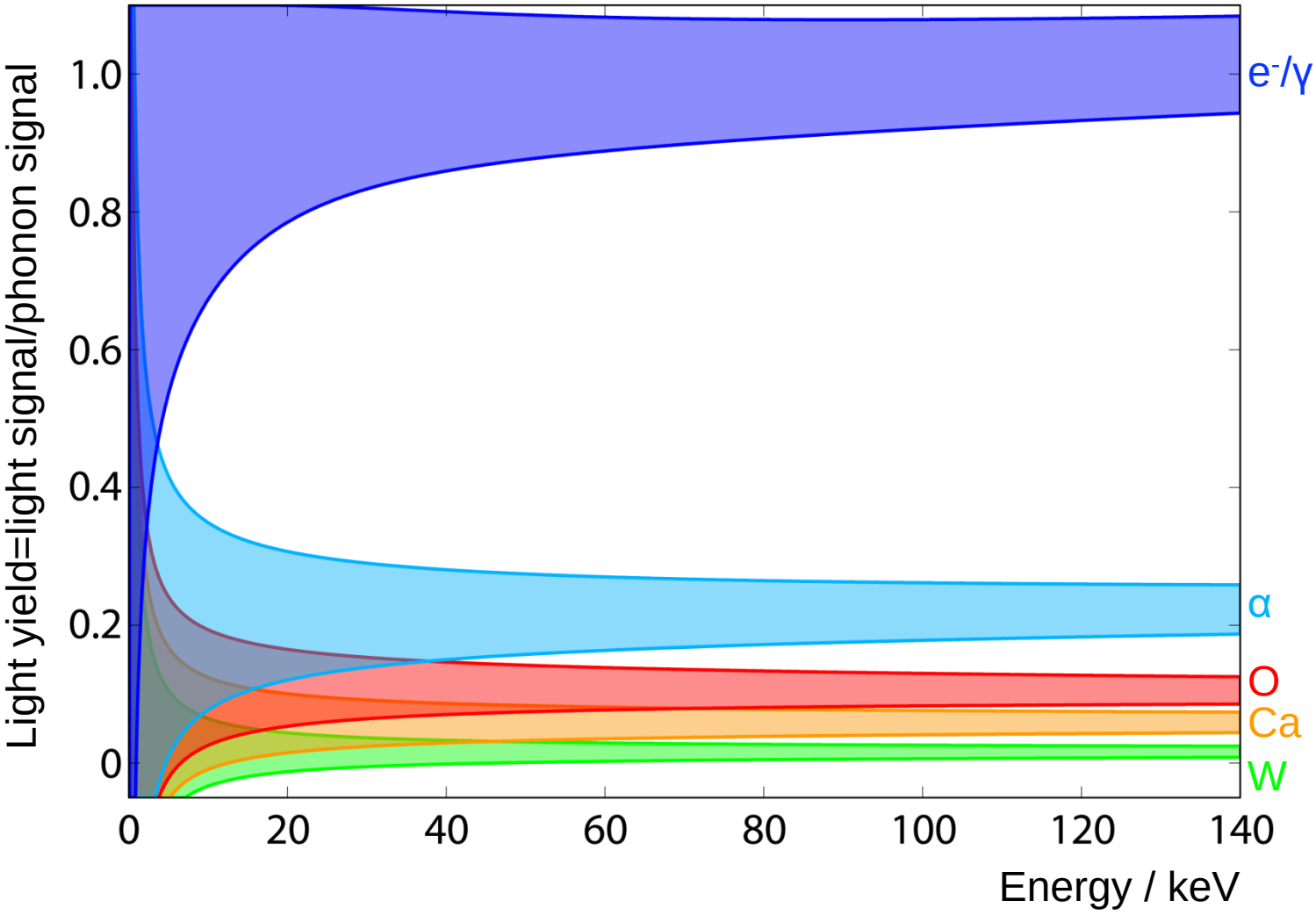
- Scintillation light signal: particle dependent

→ Particle identification

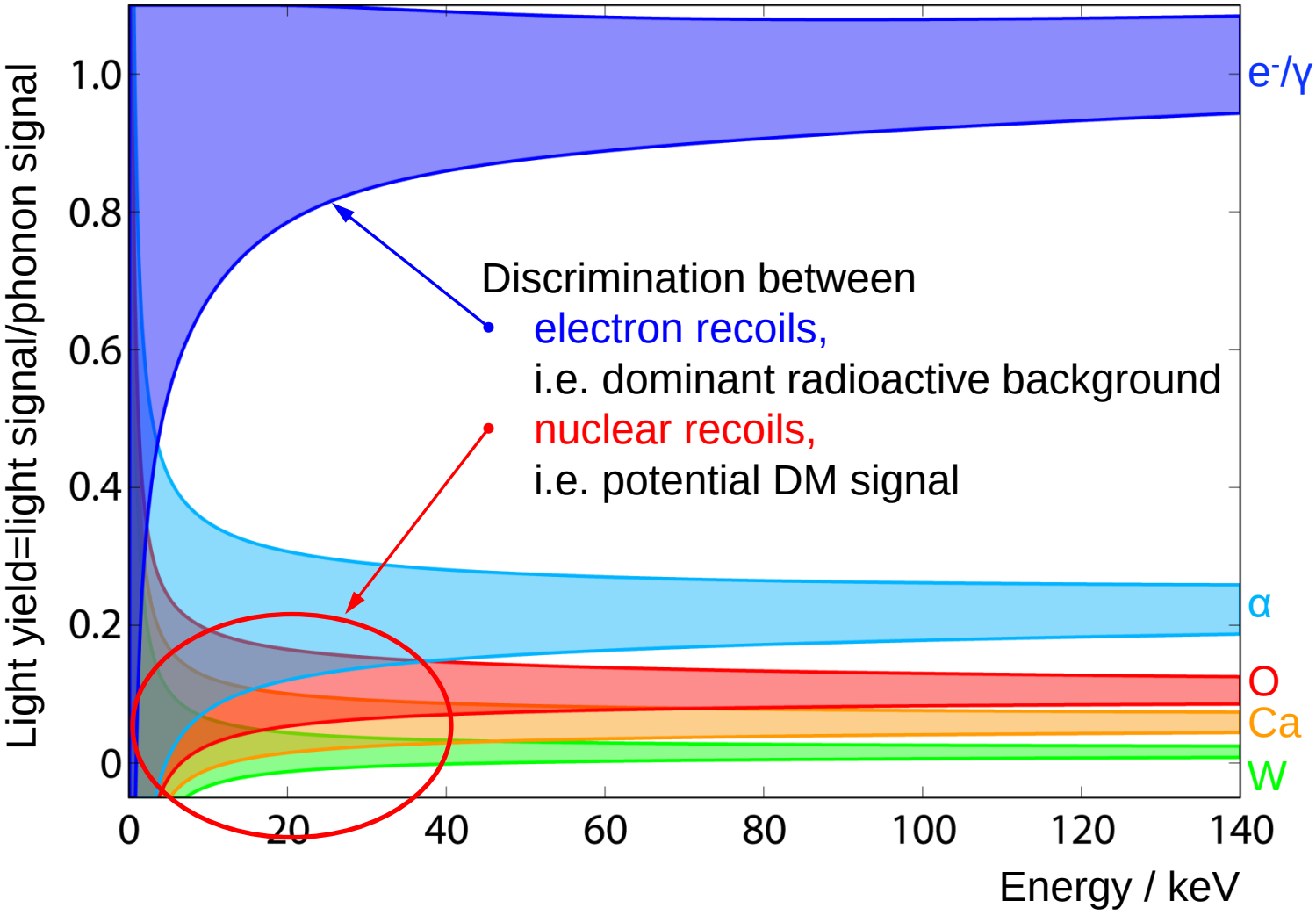
The CRESST experiment



Normalized to 1 by calibration

Quenched light for nuclear recoils

The CRESST experiment



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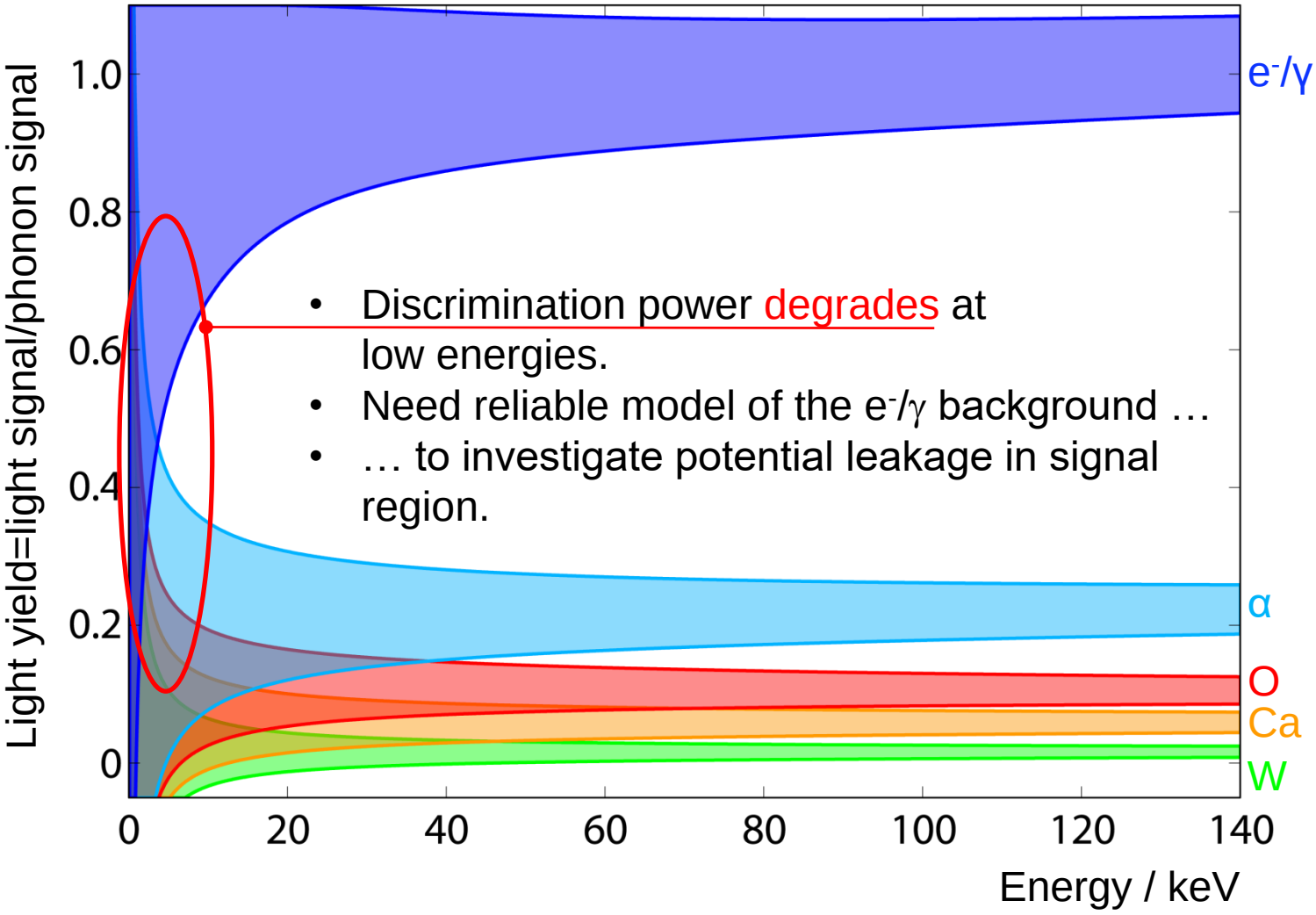

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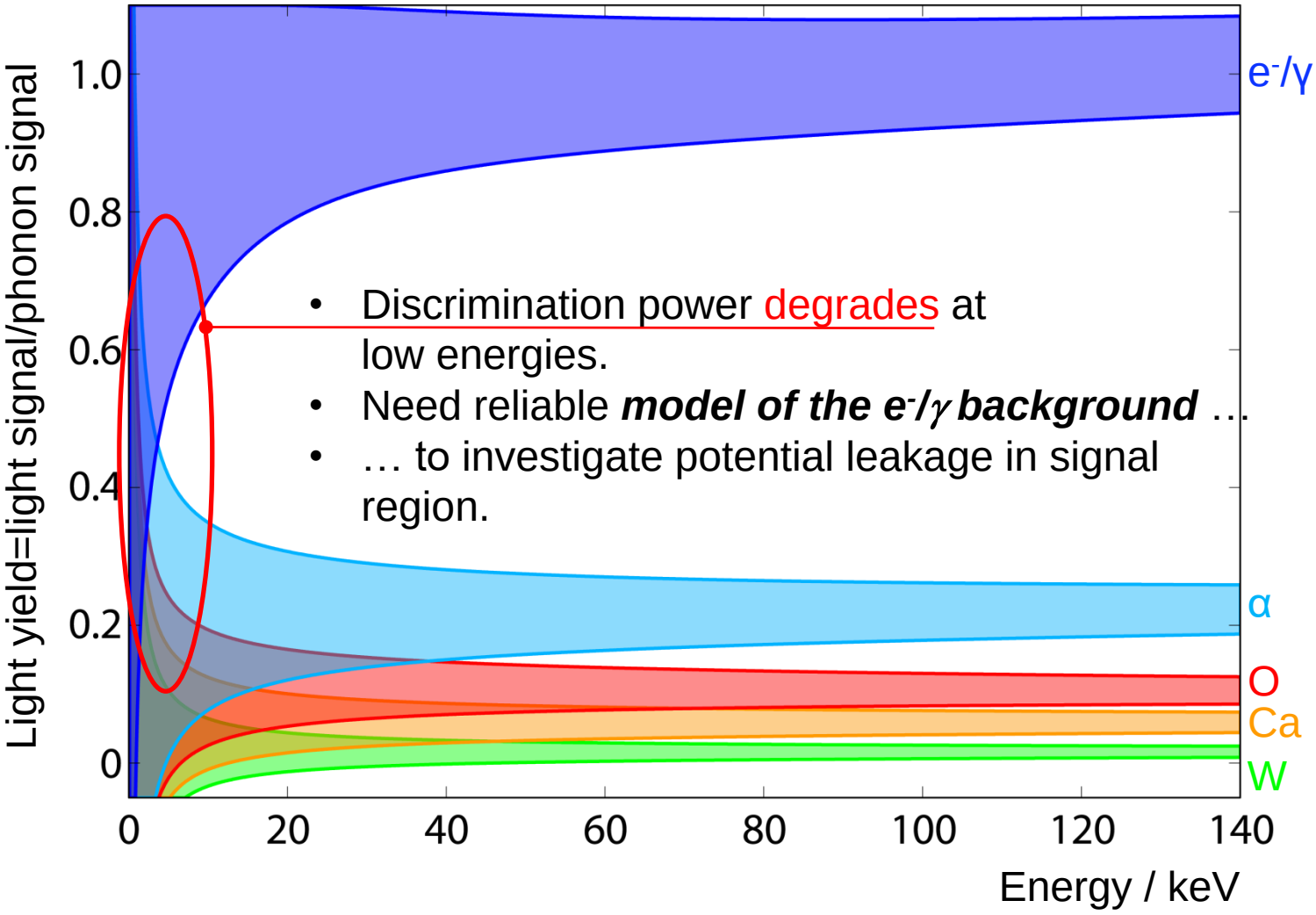


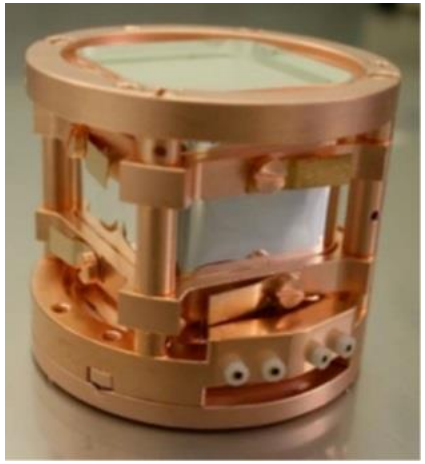
Modelling the electromagnetic backgrounds

Reference data

Need of an experimental reference data set which …

- … has high statistic
- … is well understood
- … covers a wide energy range up to the MeV scale (from atomic de-excitation to α-decays)

→ use detector module “TUM40” of CRESST-II Phase 2 [Eur.Phys.J. C74.12 (2014) 3184]



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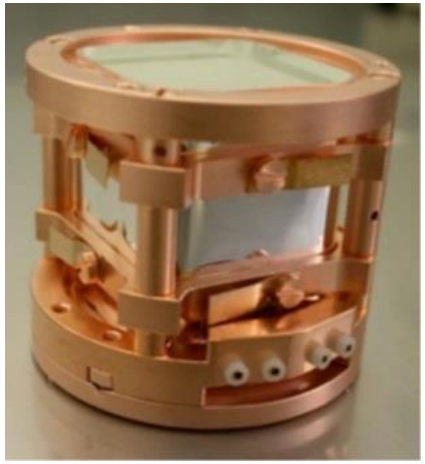
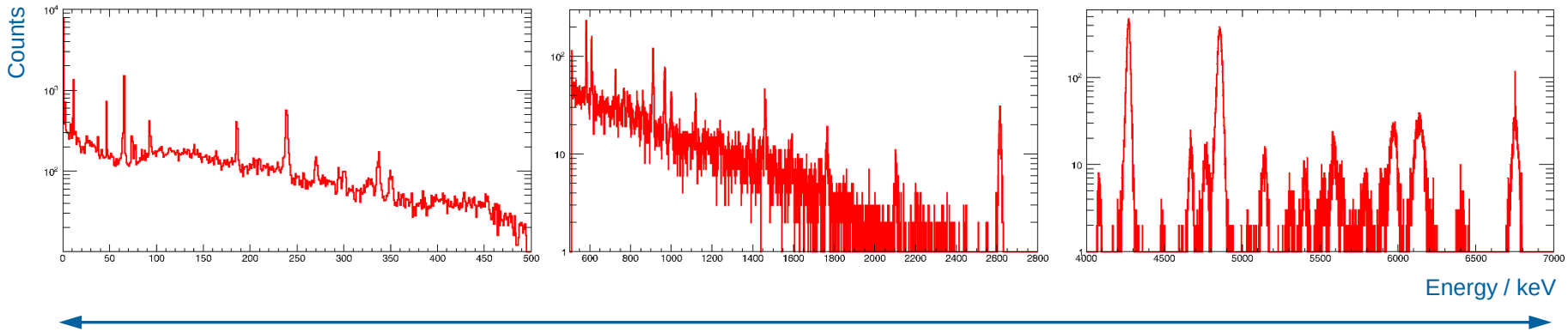


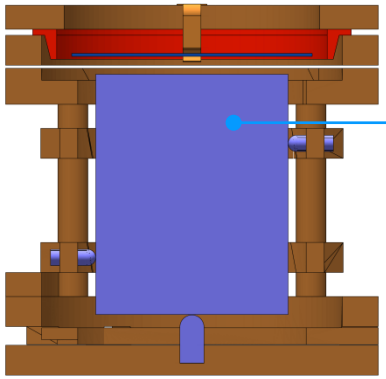


Coherent data set covering up to 7MeV

based on [F. Reindl, PhD thesis, TUM 2016; A. Münster, PhD thesis, TUM 2017; P. Bauer, PhD thesis, TUM in preparation; C. Türkoğlu, PhD thesis, TU Wien in preparation]

Background types in TUM40

Dominant background is electromagnetic



e.g. detector „TUM40“, Geant4 geometry

Major sources for TUM40 [JCAP 2015.6 (2015) 30]

- internal ($CaWO_4$ crystal 248g)
  - contamination with U/Th + daughter nuclides
  - cosmogenic production of ^{3}H, ^{179}Ta, ^{181}W

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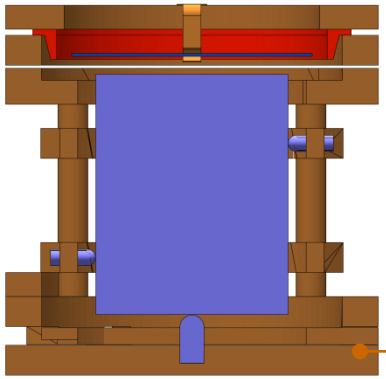

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- external (Cu of detector holder 469g, …)
  - contamination with U/Th + daughter nuclides, ^{40}K

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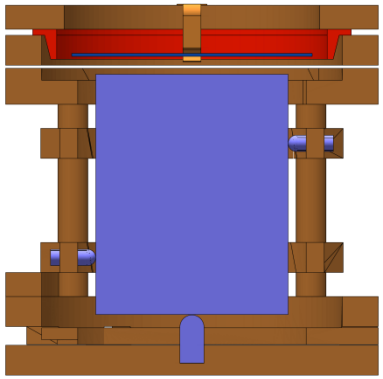

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- external (Cu of detector holder 469g, …)
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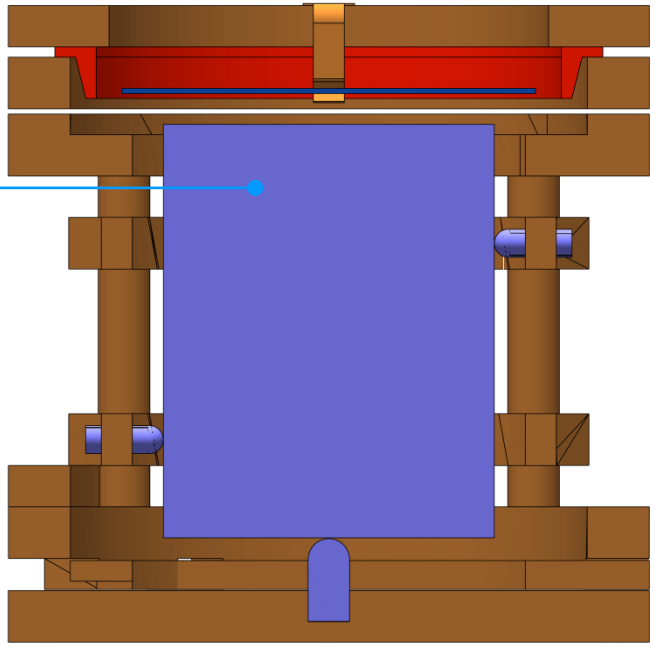
➔ Use Geant4 to investigate the background ≤40 keV

Internal background – U/Th

- Implement a highly accurate model of TUM40
- Place nuclides from ^{238}U, ^{235}U, ^{232}Th decay chain inside the $CaWO_4$ crystal
- Use Geant4 10.2p1*
- Let the nucleus decay, track secondaries, record energy deposition
- Apply detector response model**

→ Normalizing simulation to sideband measurements

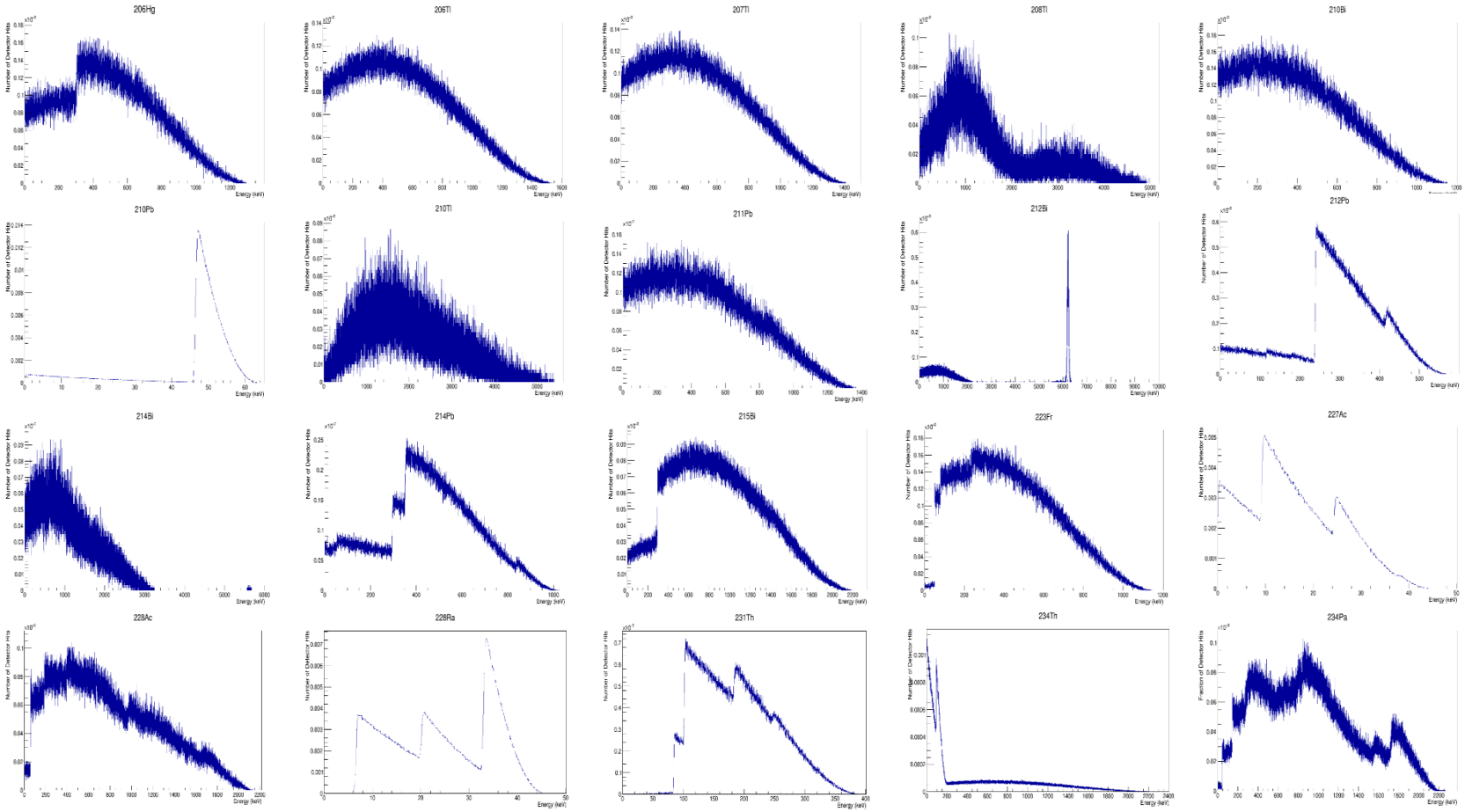


[C. Türkoğlu, TU Wien 2018]

* With "G4EmStandardPhysics_option4" and a production cut of 250eV

** Accumulate energy depositions over 2ms, convolve spectrum with a Gaussian kernel and energy dependent resolution estimate from data

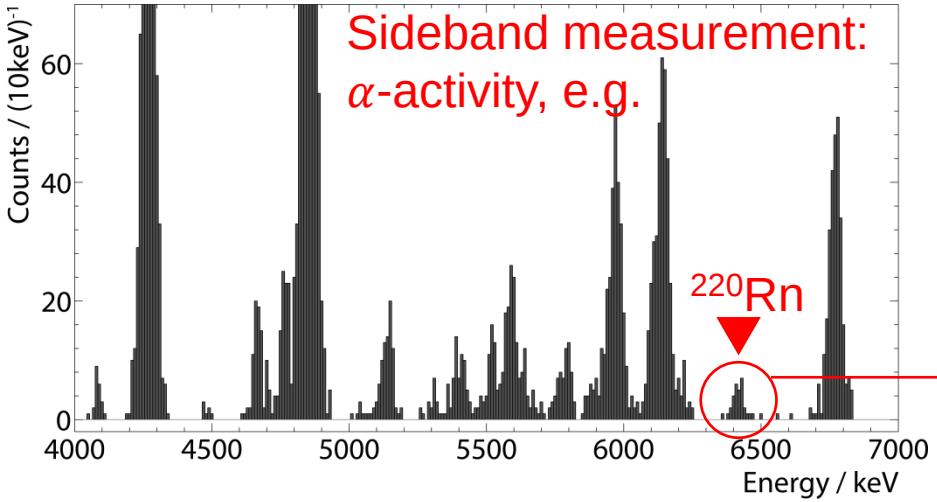
β-decays



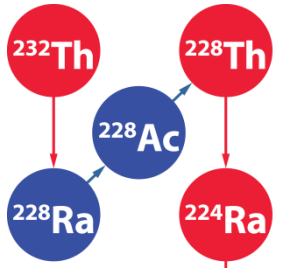
...

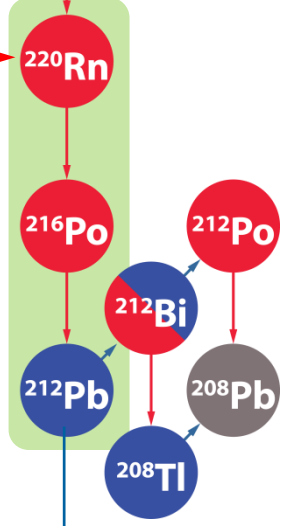
[C. Türkoğlu, TU Wien 2018]

Methodology

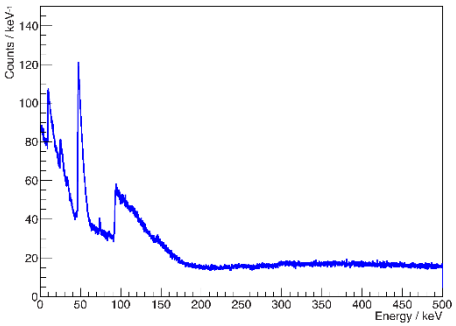


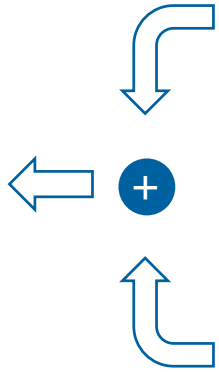
Piecewise equilibrium between α/β emitter

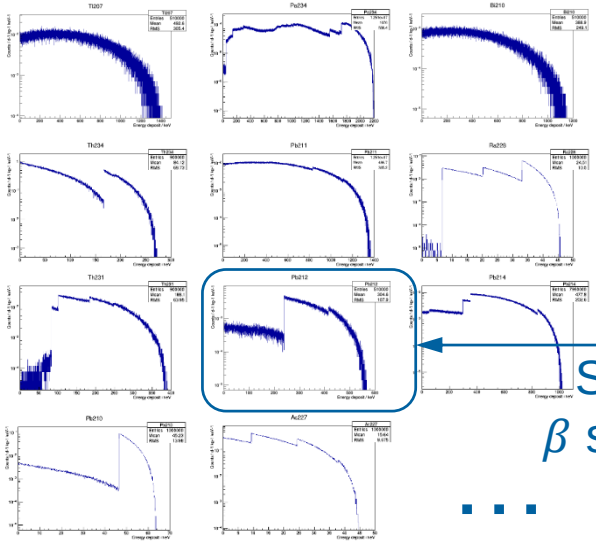




Study background ≤40keV



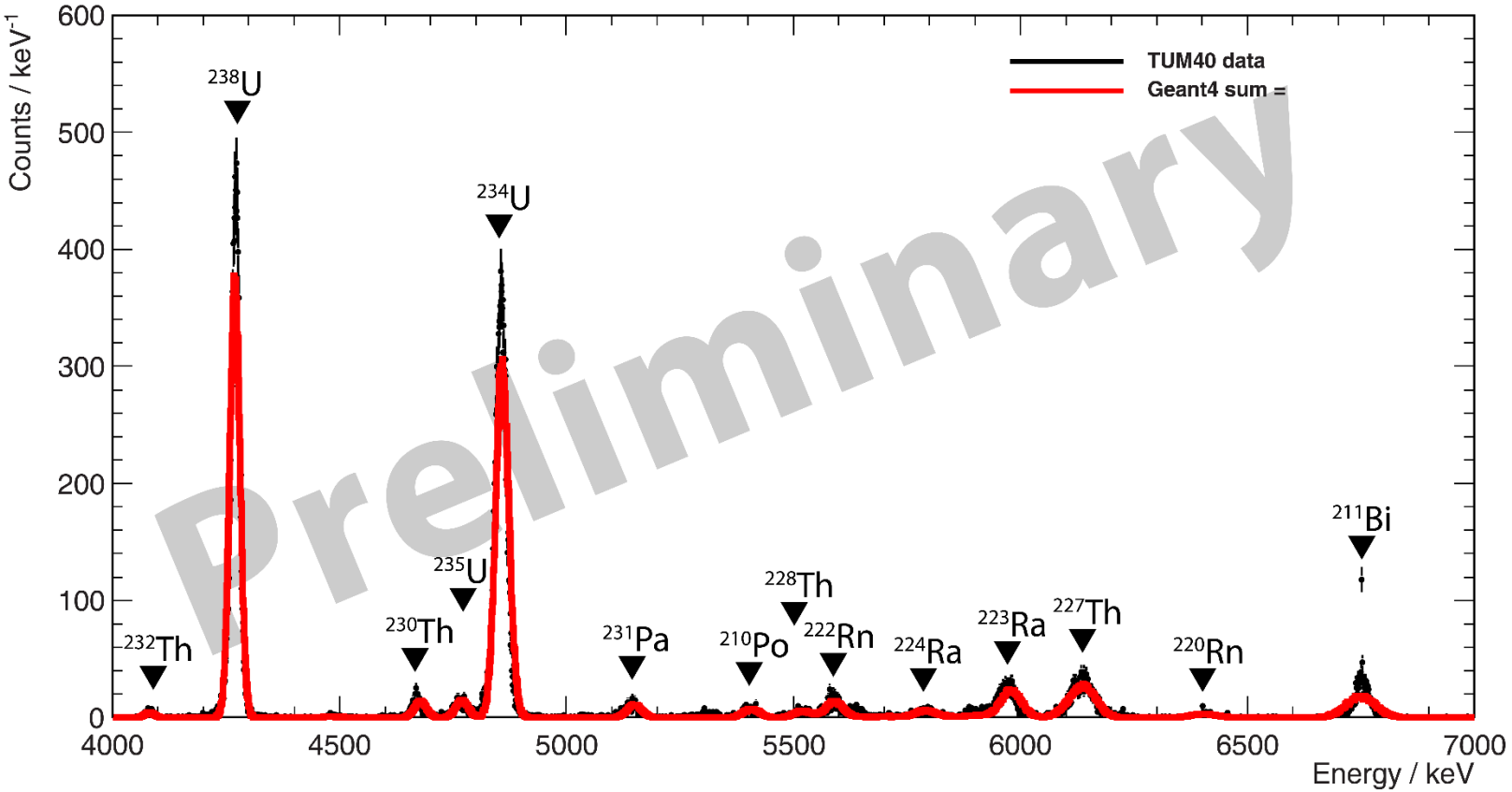




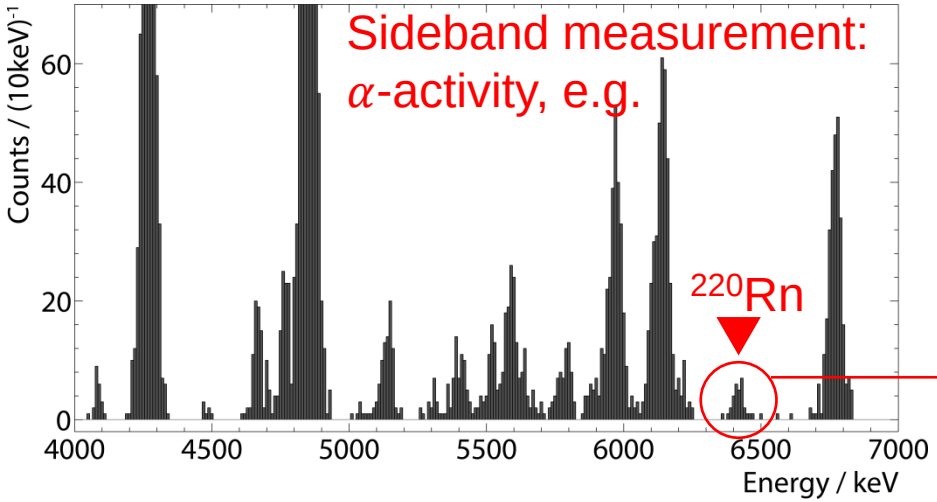
Scale each simulated β spectrum individually

. . .

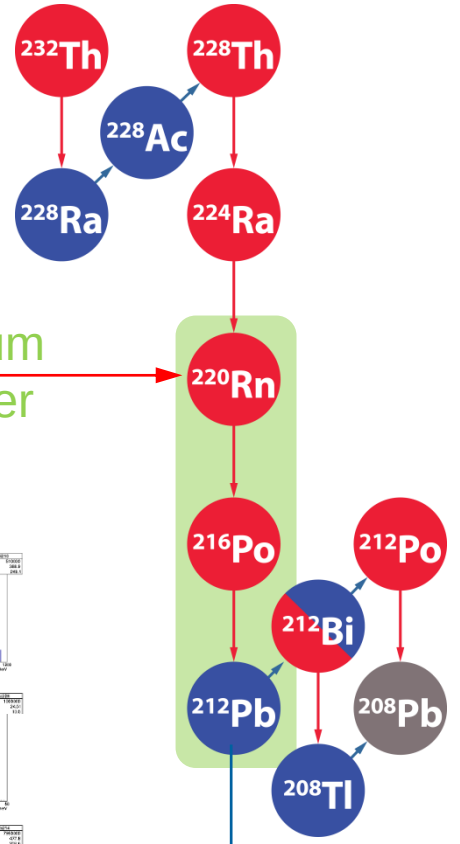
α-decays


Counts / keV⁻¹
Energy / keV
TUM40 data
Geant4 sum =
Preliminary
238U
234U
235U
232Th
230Th
231Pa
210Po
228Th
222Rn
224Ra
223Ra
227Th
220Rn
211Bi

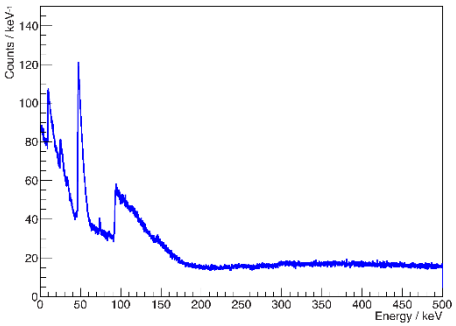
Methodology

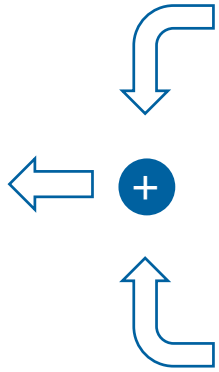


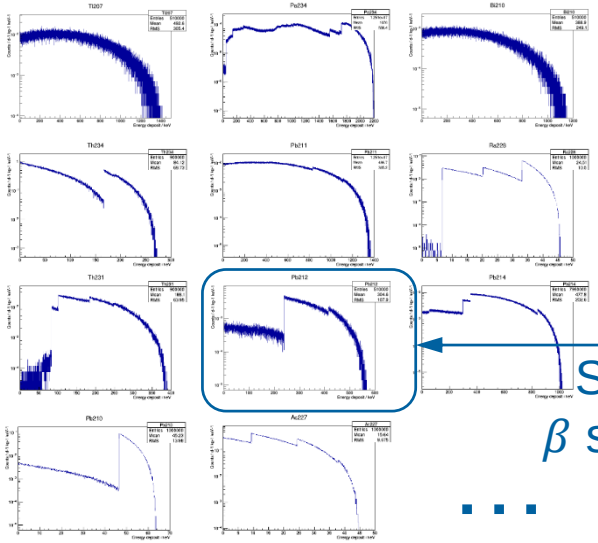
Piecewise equilibrium between α/β emitter



Study background in ≤40keV





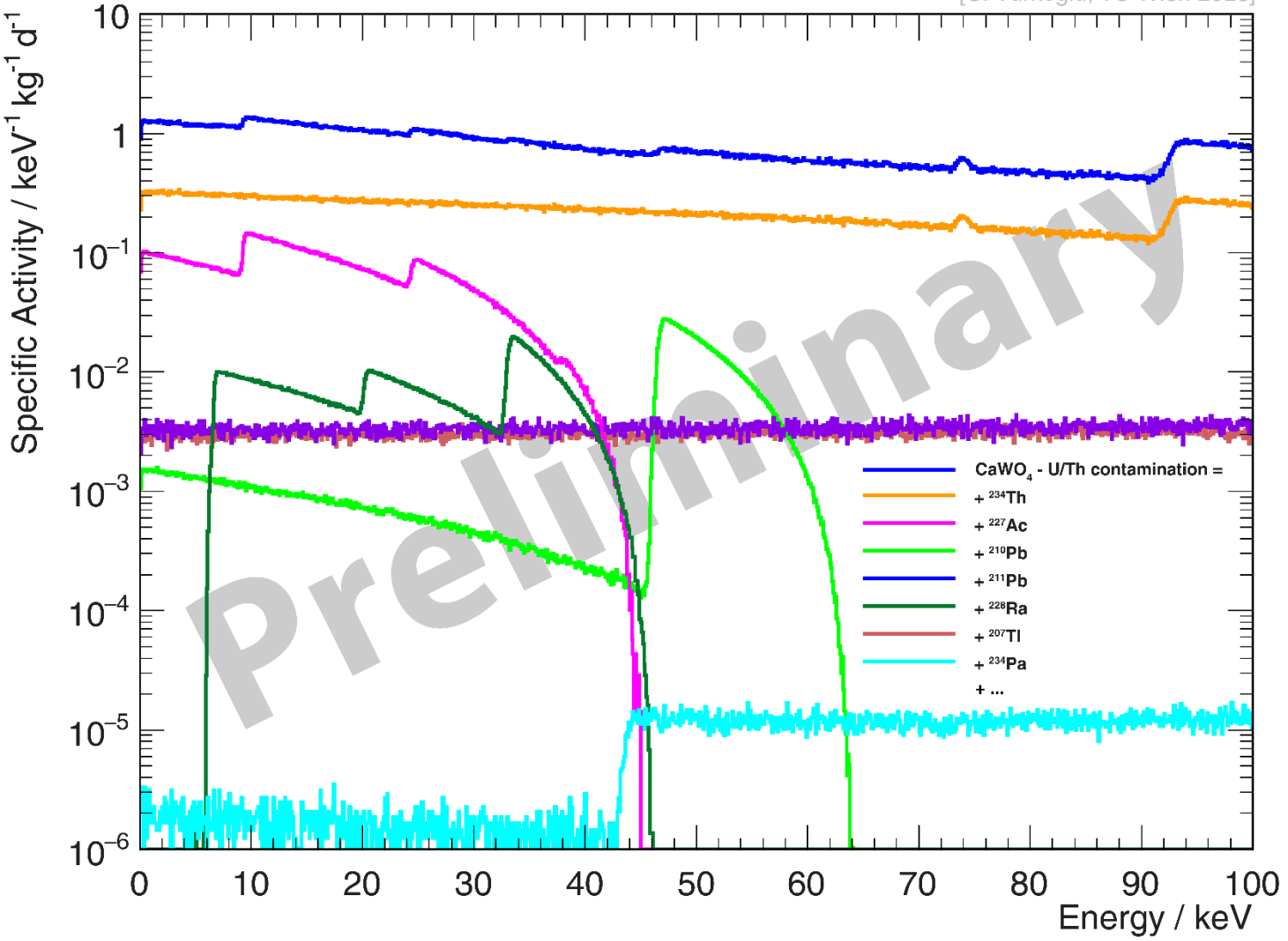


Scale each simulated β spectrum individually

. . .

Combined β-spectra

[C. Türkoğlu, TU Wien 2018]



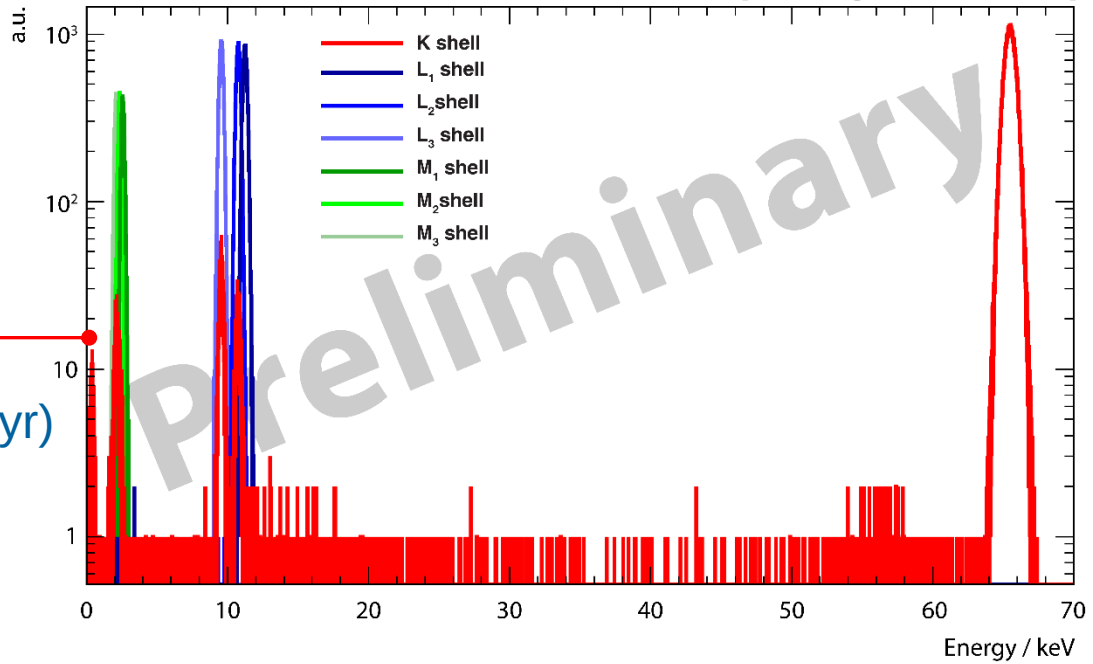
Internal background – ^{3}H, ^{179}Ta, ^{181}W

- Produced by cosmic rays above ground:
  $^{182}W+p \rightarrow {}^{183}W \rightarrow {}^{179}Ta+\alpha$
  $^{183}W+p \rightarrow {}^{181}W+{}^{3}H$

- Decay via beta-decay/EC:
  $^{179}Ta + e^{-} \rightarrow {}^{179}Hf + \nu_e$ ($T_{1/2}$=1.8yr)
  $^{181}W+e^{-} \rightarrow {}^{181}Ta + \nu_e$ ($T_{1/2}$=121d)
  $^{3}H \rightarrow {}^{3}He+ e^{-} + \nu_e$-bar ($T_{1/2}$=12.32yr)

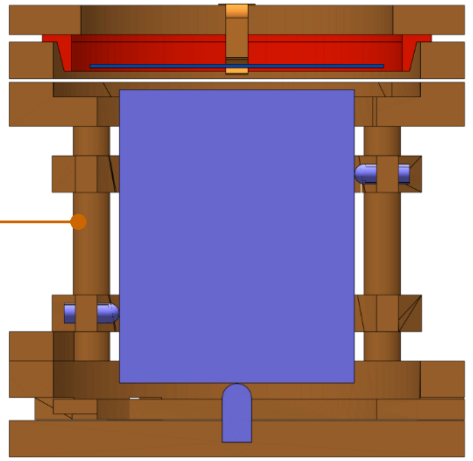
- Place ^{3}H, ^{179}Ta, ^{181}W inside the $CaWO_4$ crystal
- Procedure similar to U/Th simulation for ^{179}Ta, ^{181}W
- ^{3}H activity based on preliminary ACTIVIA 1.3.1 study

[C. Türkoğlu, TU Wien 2018]



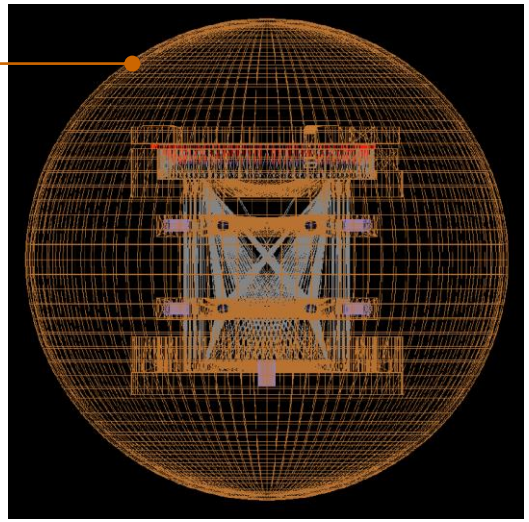
External background

- Near Cu parts: detect β's + γ's
- Place nuclides from ^{238}U, ^{235}U, ^{232}Th decay chain inside the Cu of the detector holder
- *Assume* specific activity of NOSV Cu* is batch independent



[C. Türkoğlu, TU Wien 2018]

- Distant Cu parts: detect mostly γ's
- *Approximate cryostat*, etc. as Cu sphere
- Place the *8 most prominent nuclides*** inside the sphere
- Normalize simulation to characteristic γ-lines in the reference data ≥40keV

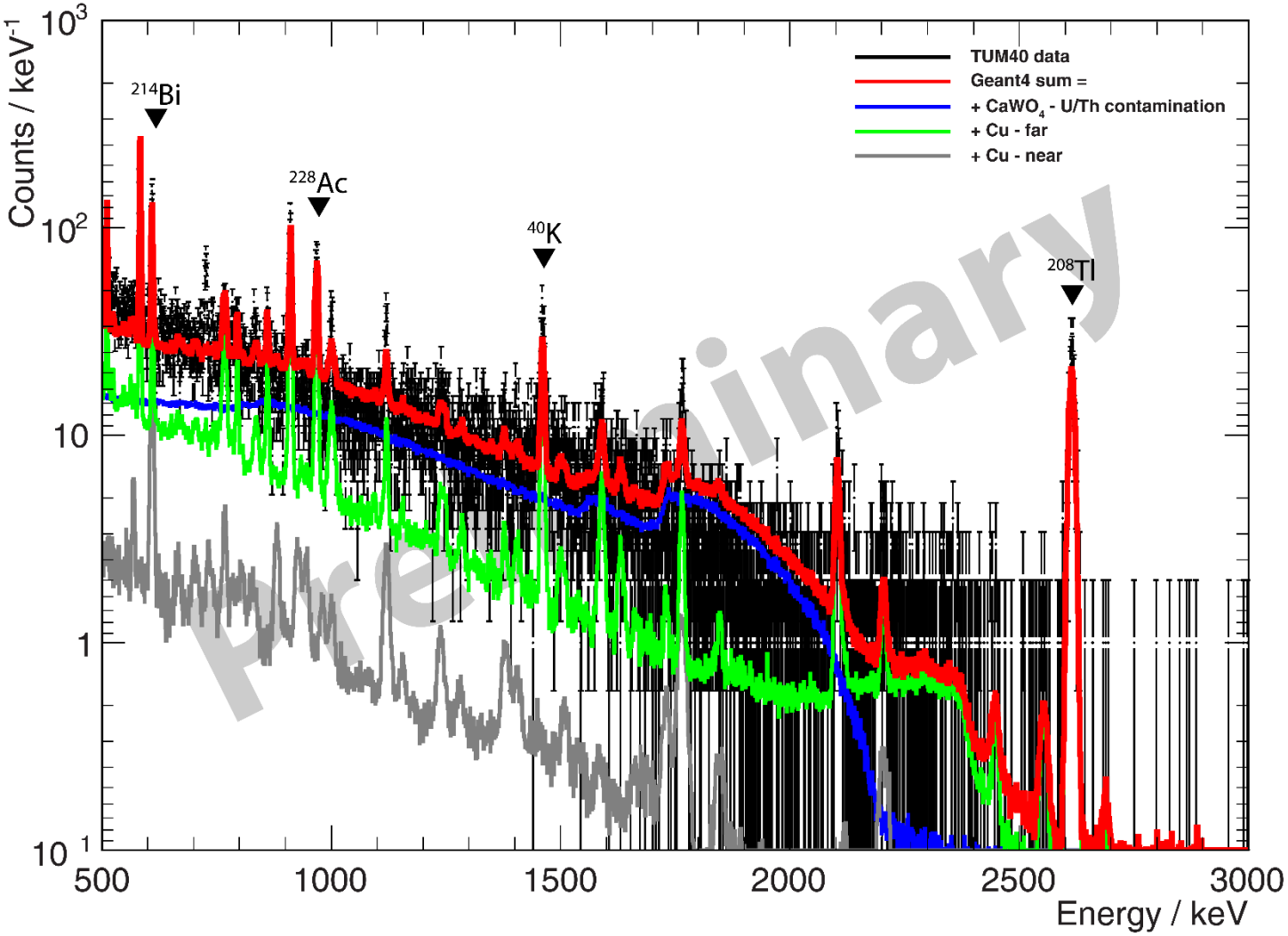


* Based on [JINST 2016.11(2016)P07009], *Norddeutsche Affinerie NOSV copper:*
^{232}Th < $2.0 \cdot 10^{-6}$ Bq kg^{-1}
^{238}U < $6.5 \cdot 10^{-5}$ Bq kg^{-1}
Assume ^{235}U=0.7% ^{238}U

** Acc. to [JCAP 2015.6 (2015) 30]: ^{40}K, ^{208}Tl ,^{210}Pb, ^{212}Pb, ^{214}Bi, ^{226}Ra, ^{228}Ac, ^{234}Th

Characteristic γ-lines I

Normalized to peaks



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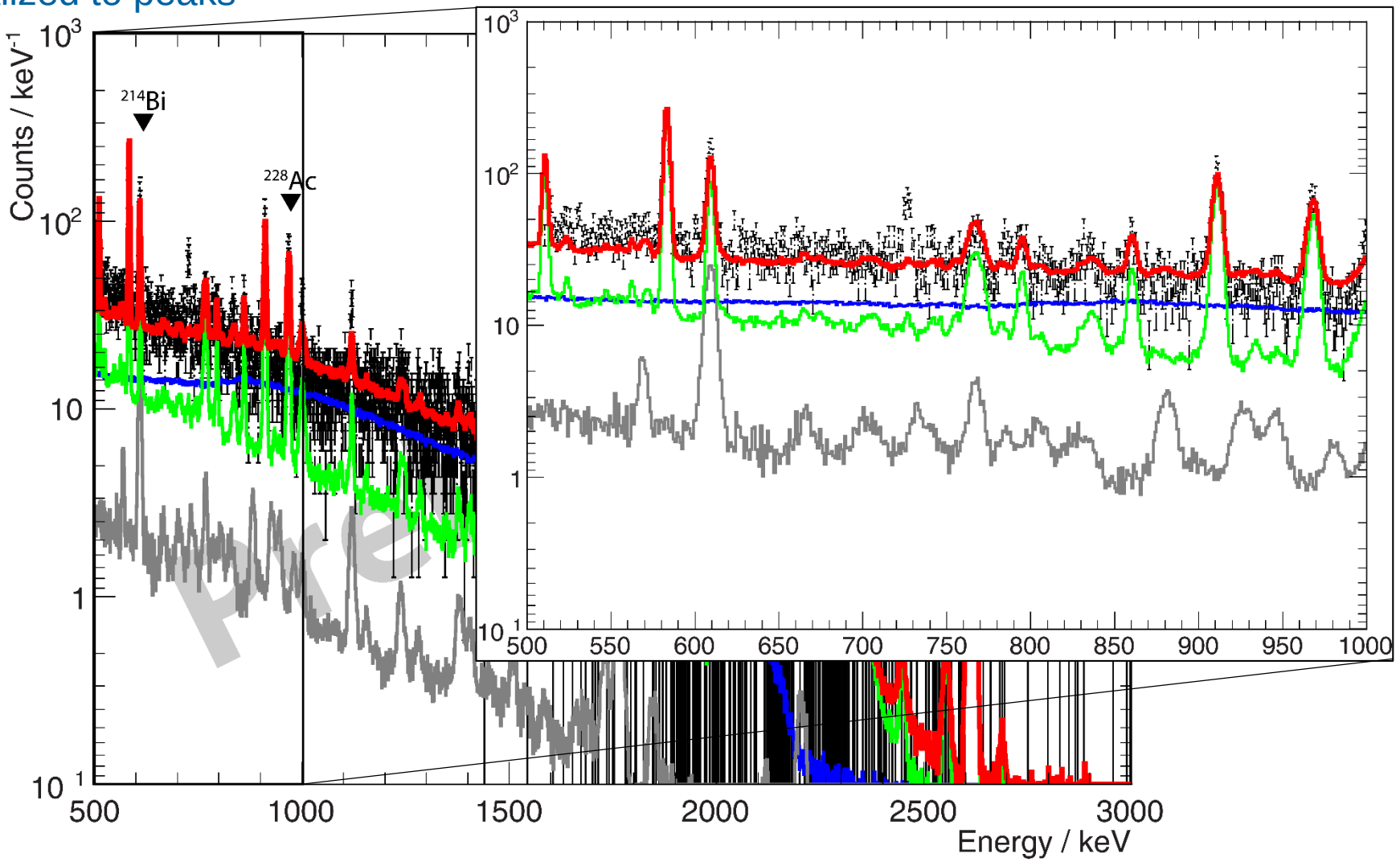
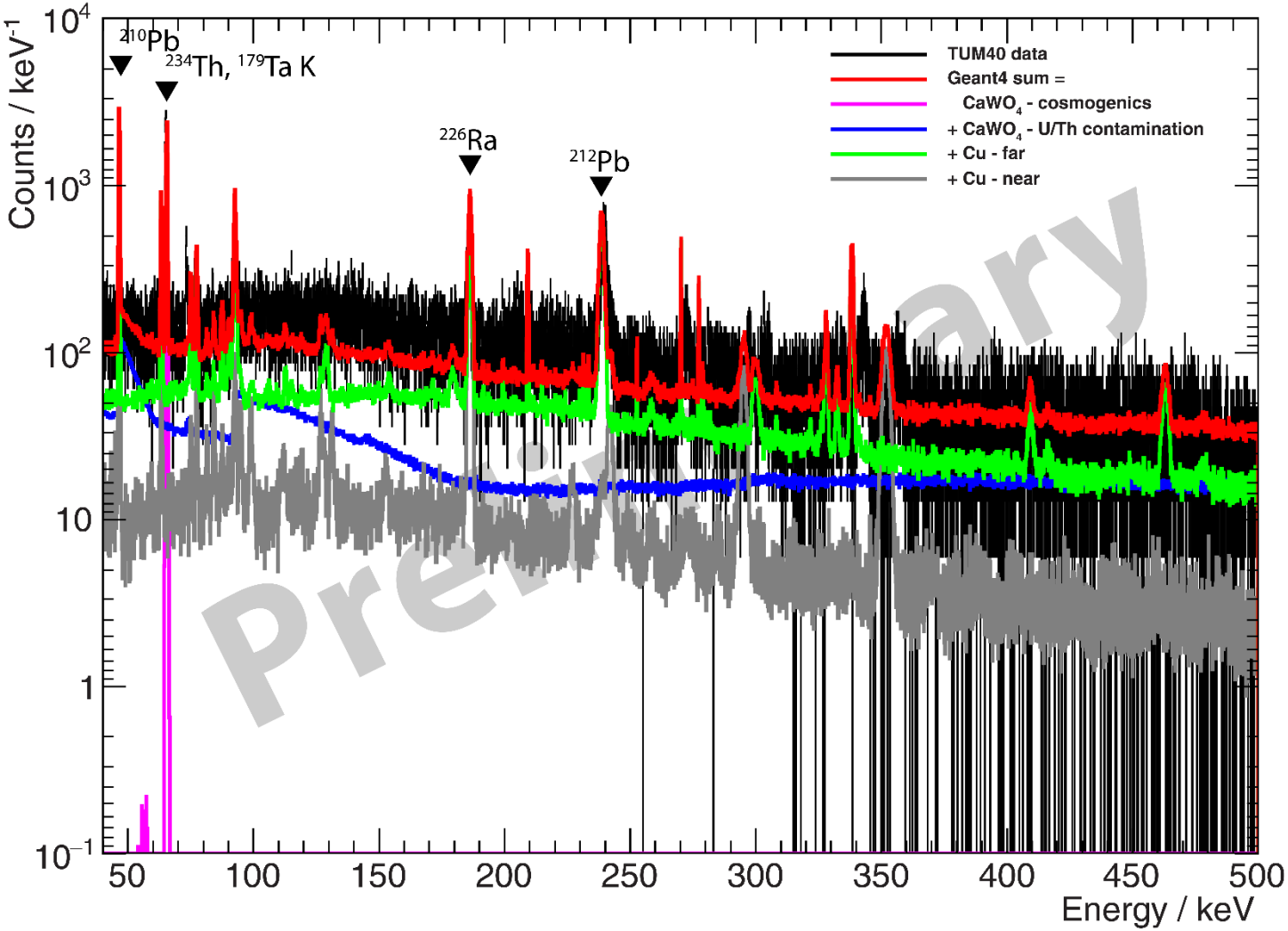
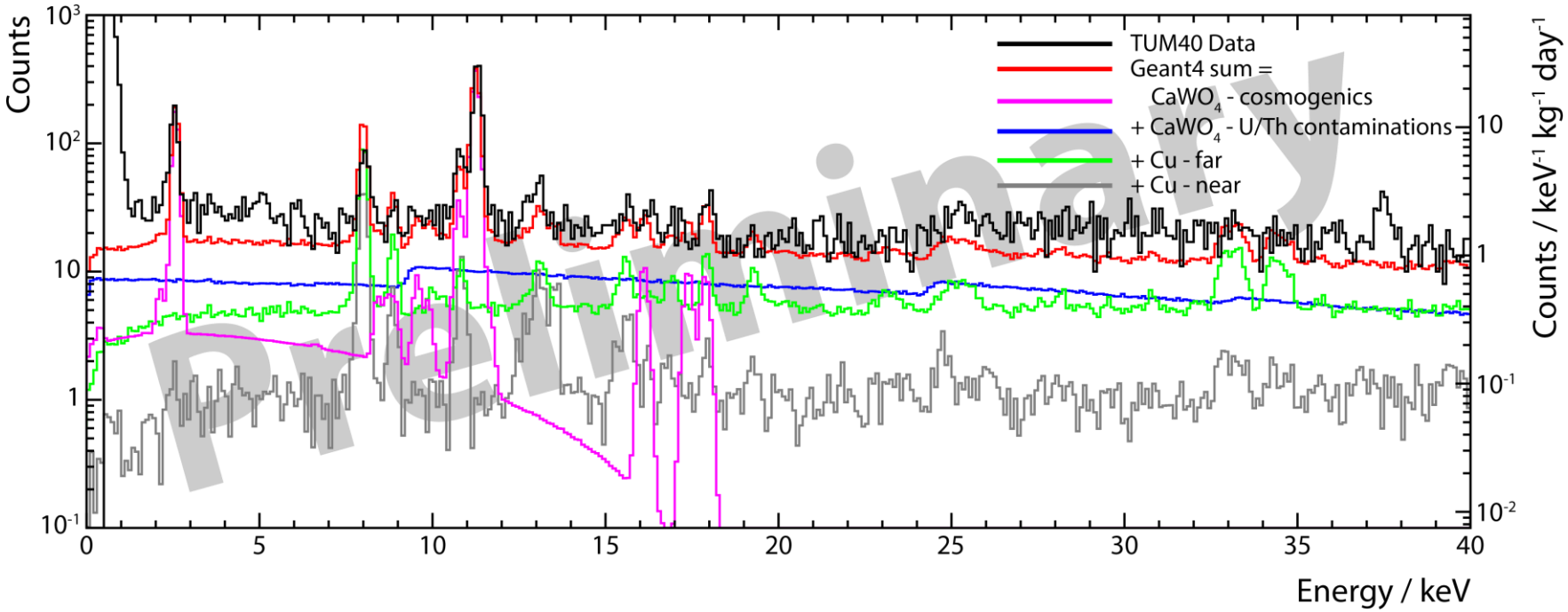


Characteristic γ-lines II

Normalized to peaks



Simulation vs reference data



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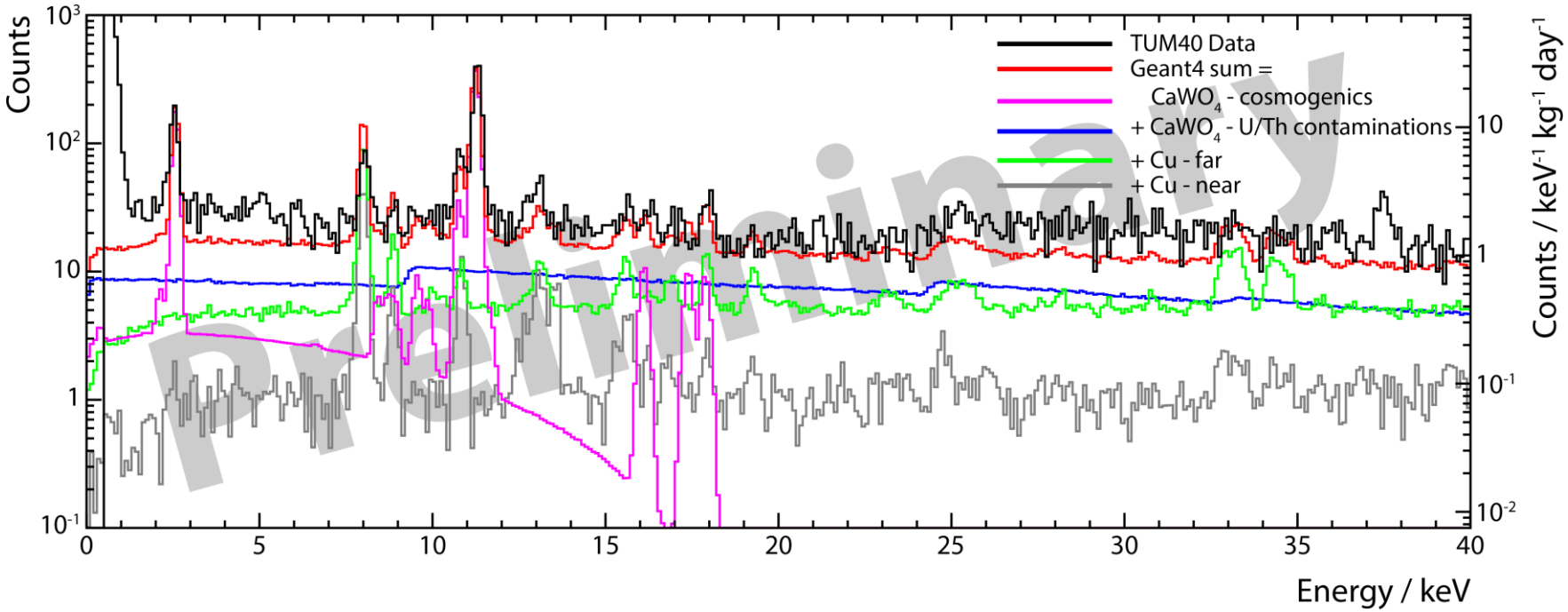
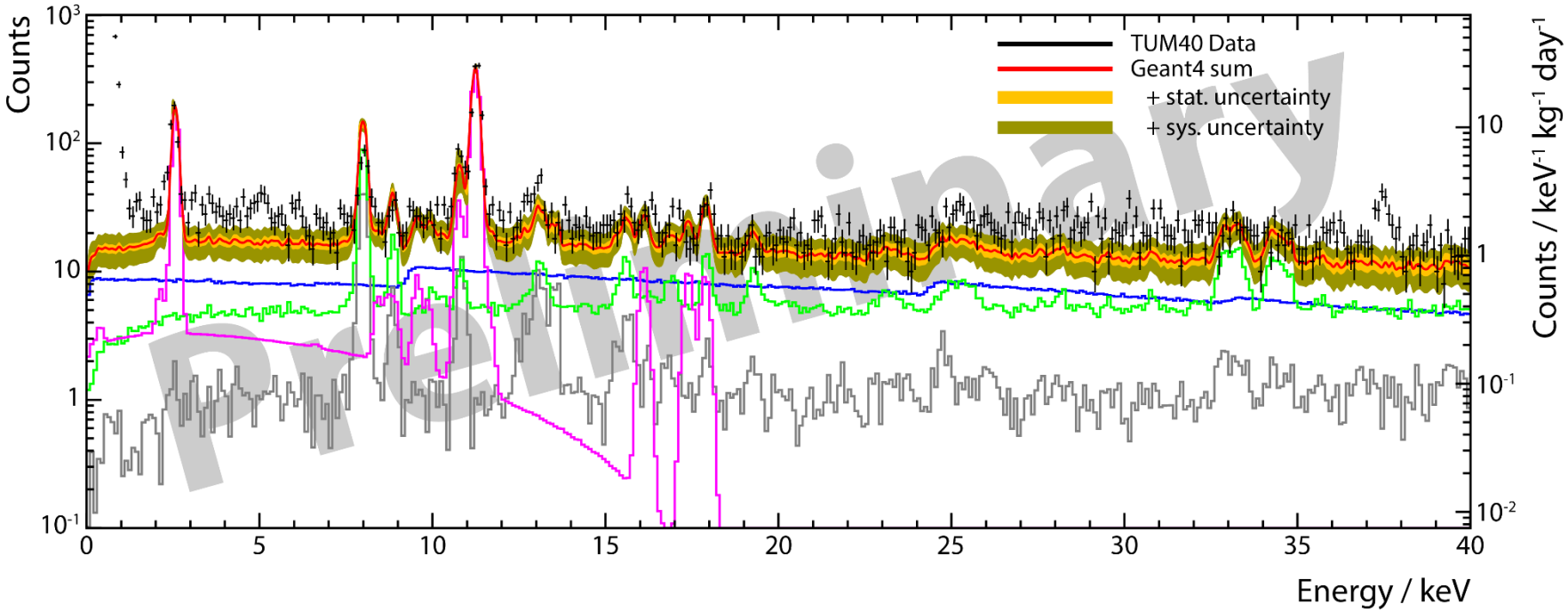


Simulation/data:		
	$CaWO_4$ – U/Th	(27±5)%
	+Cu – far	(23.7±6.4)%
	+Cu – near	(6.3±2.1)%
	+$CaWO_4$ – cosmo.	(17.8±3.8)%
	Sum	(75±19)%

Simulation vs reference data



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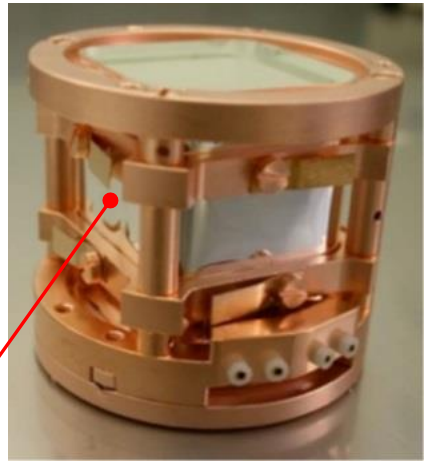
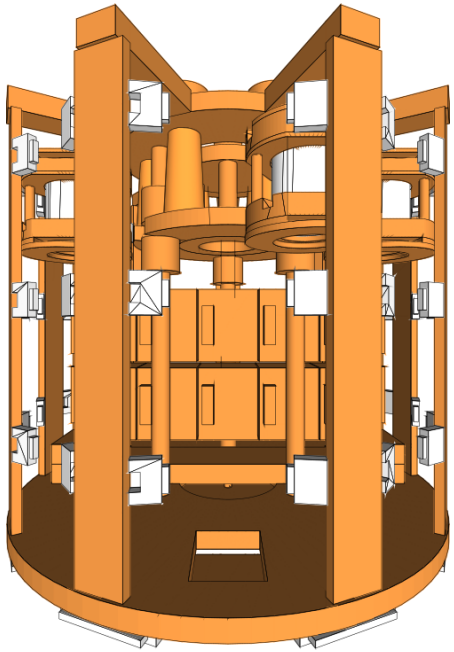
Outlook

- Simulate all nuclides in all detector parts, e.g. also in the scintillating foil (VM2000, ~2g)



- Normalize Cu background via dedicated activity measurements

- Implement full geometry of set-up, including the detector carousel



[provided by A. Fuß]

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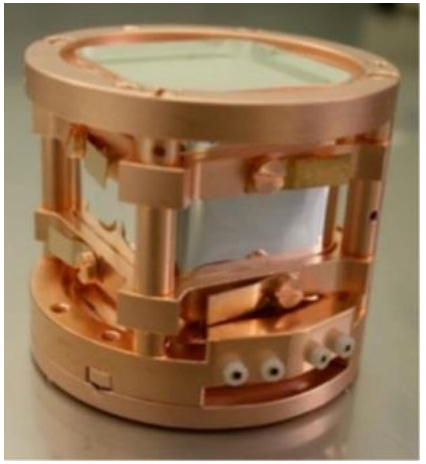

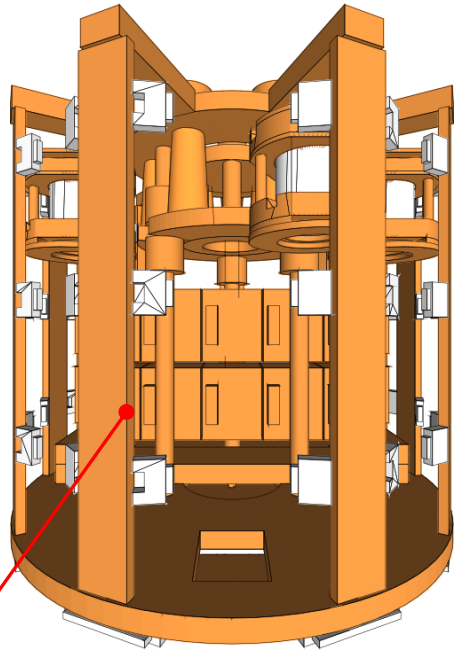

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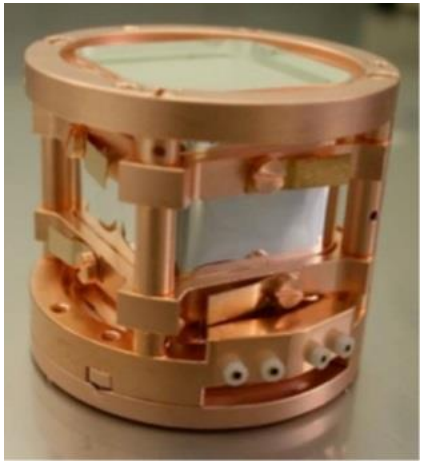
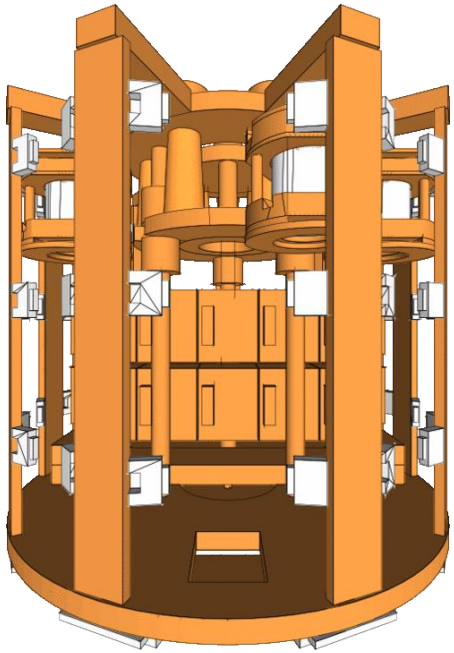
- Normalize Cu background via dedicated activity measurements
- Implement full geometry of set-up, including the detector carousel





[provided by A. Fuß]

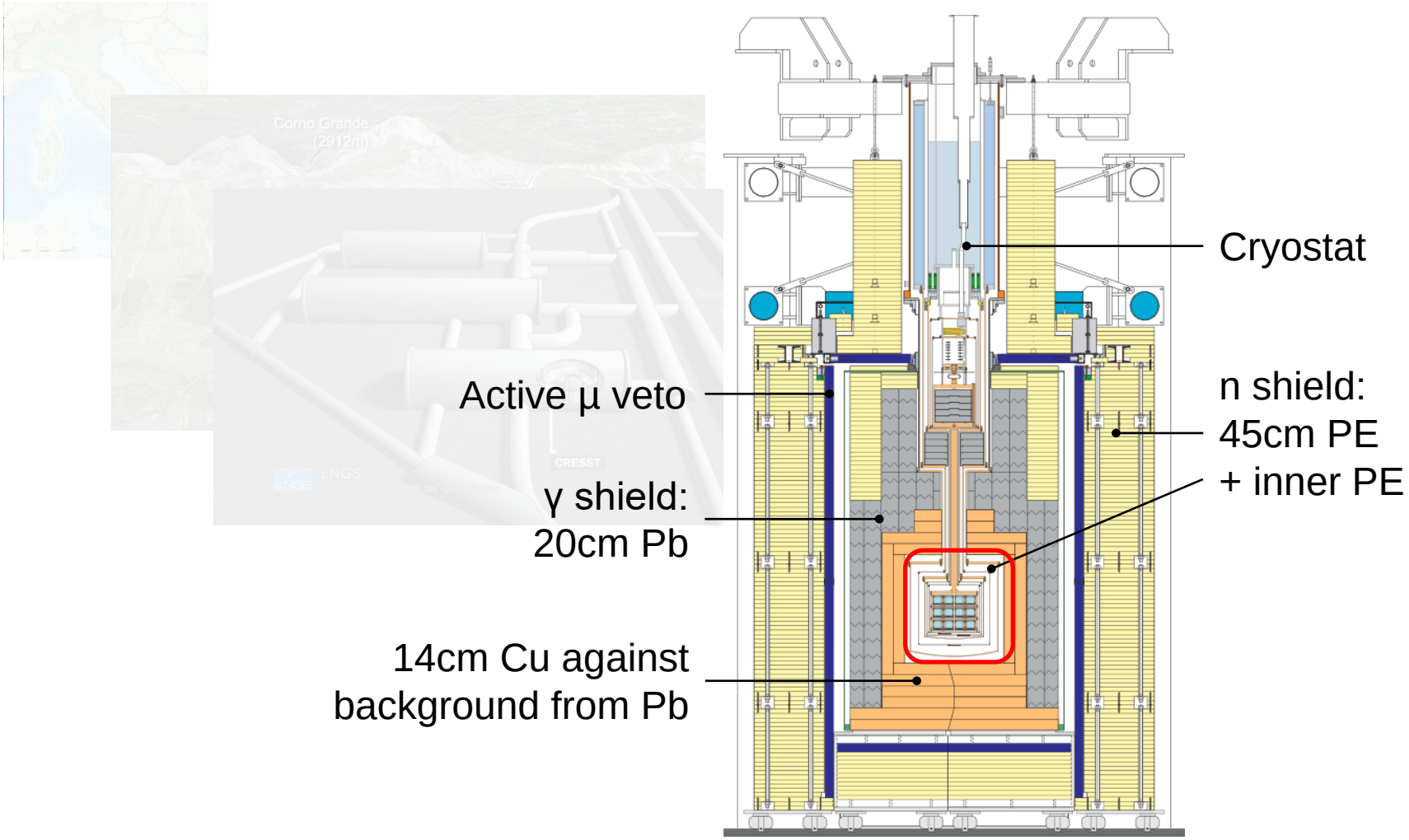
Summary

- CRESST's **event-by-event discrimination** between nuclear recoils and electromagnetic background starts to **degrade** below O(1keV)
- A reliable **background model is needed** to investigate expected leakage
- First iteration of a **validated, full Geant4-based model** was developed
- **Simplified** simulations reproduce 75% of the activity observed with TUM40
- **Known** CRESST background is **dominated by electromagnetics,** major sources: U/Th, ^{179}Ta in $CaWO_4$; γ's from near and far Cu
- Improvements are **ongoing**

→ **Stay tuned** for future results!

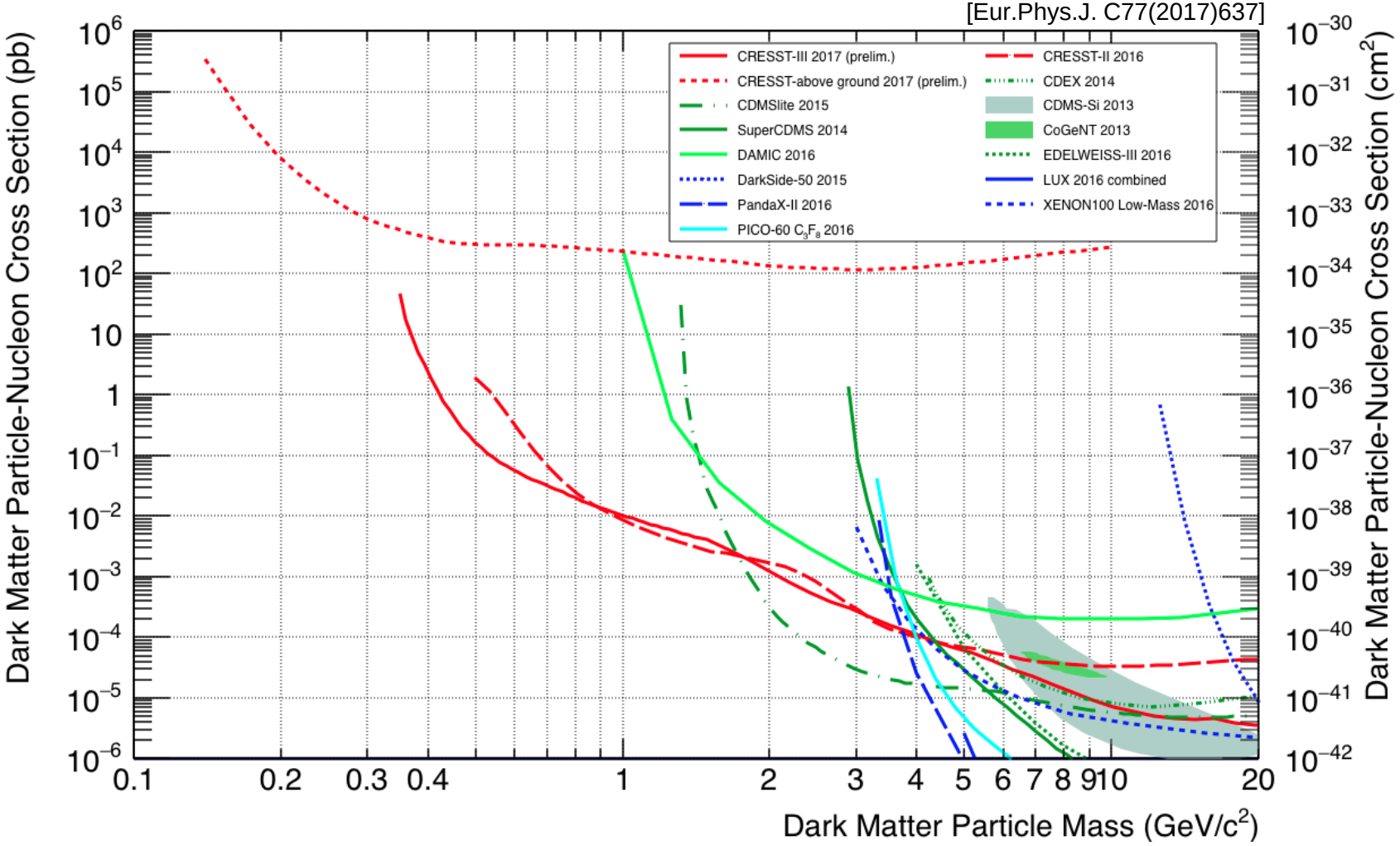
Additional slides

The CRESST experiment



Above ground limit

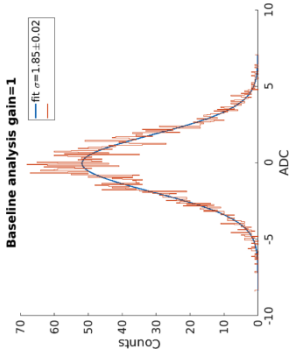
[Eur.Phys.J. C77(2017)637]

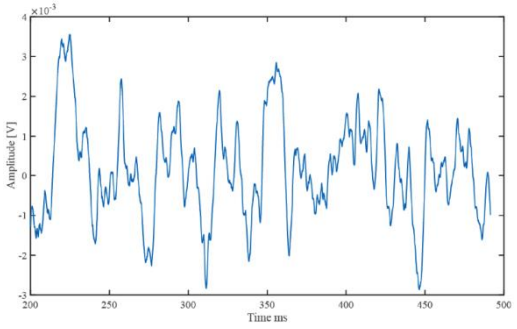


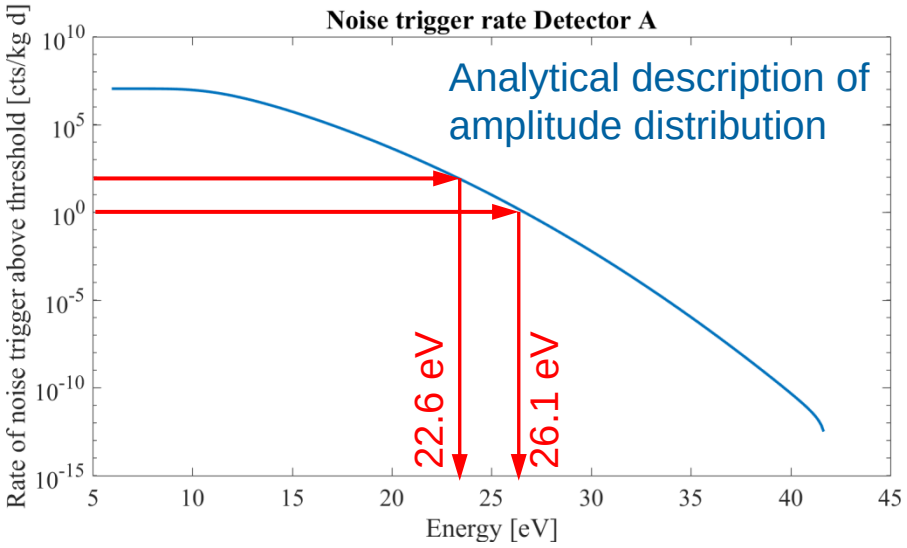
Threshold

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

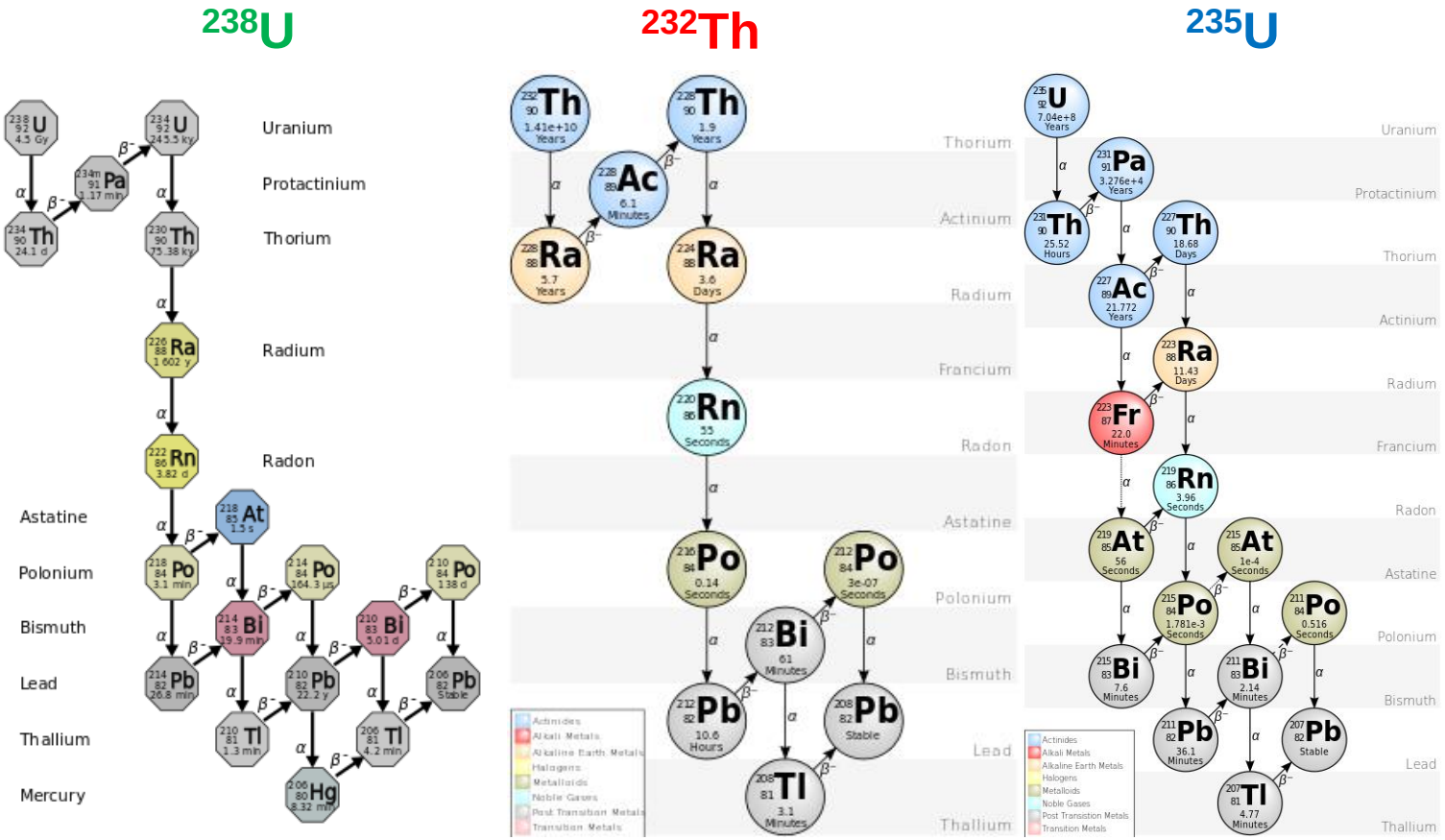
Amplitude distribution of a typical **empty base line pulse trace**







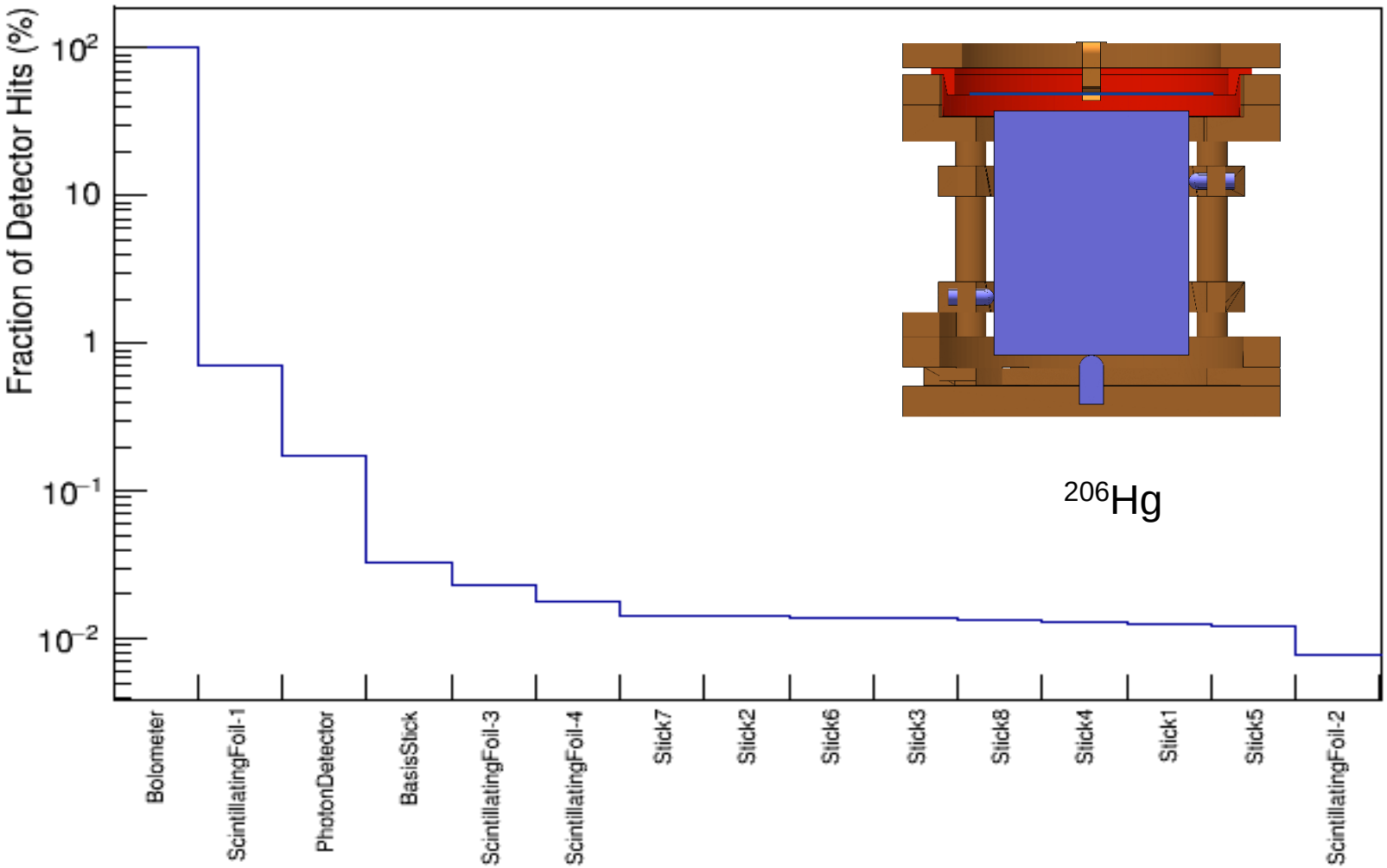
Decay chains



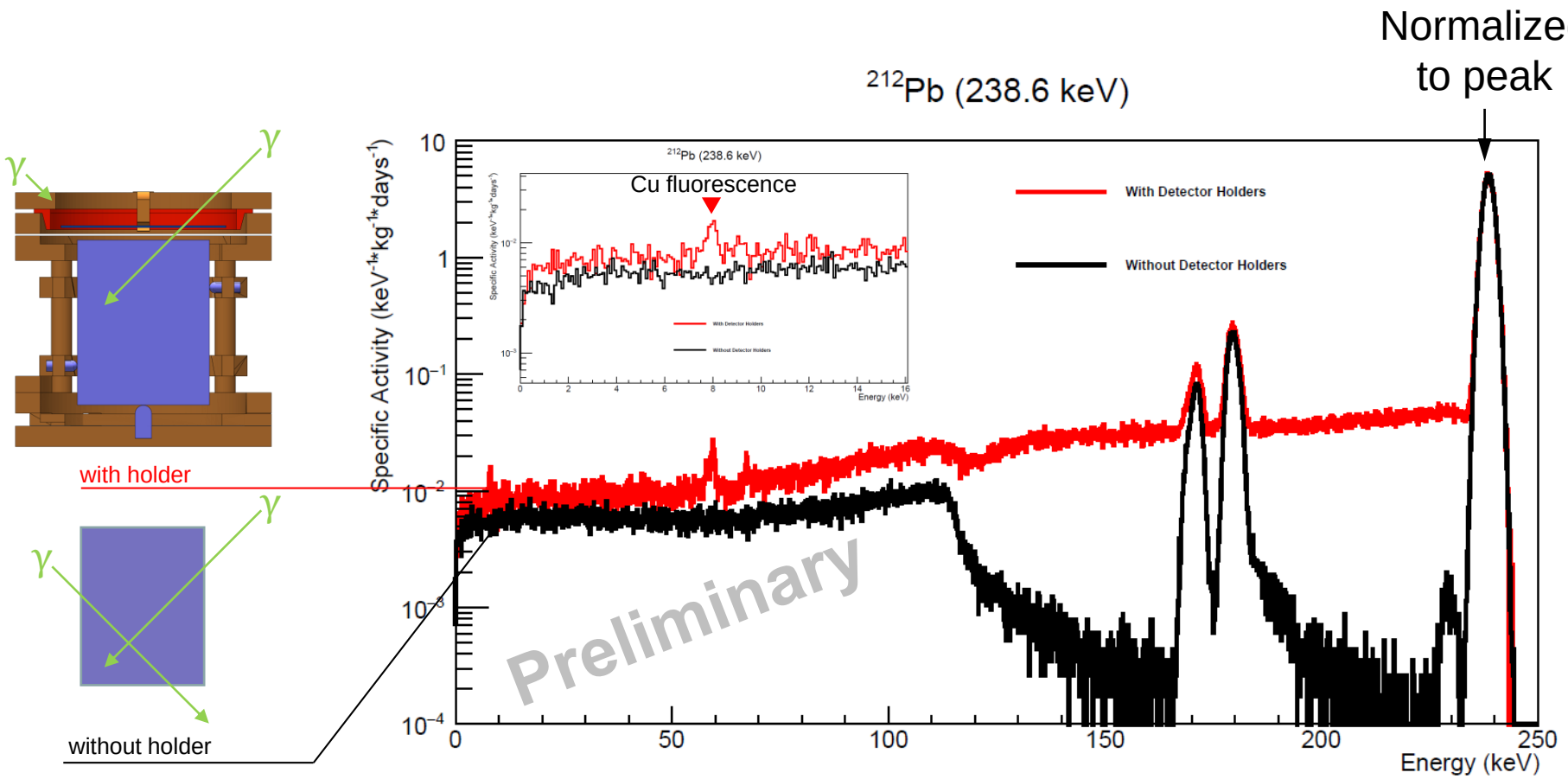
[https://en.wikipedia.org/wiki/Decay_chain]

Sensitive detectors

[C. Türkoğlu, TU Wien 2018]

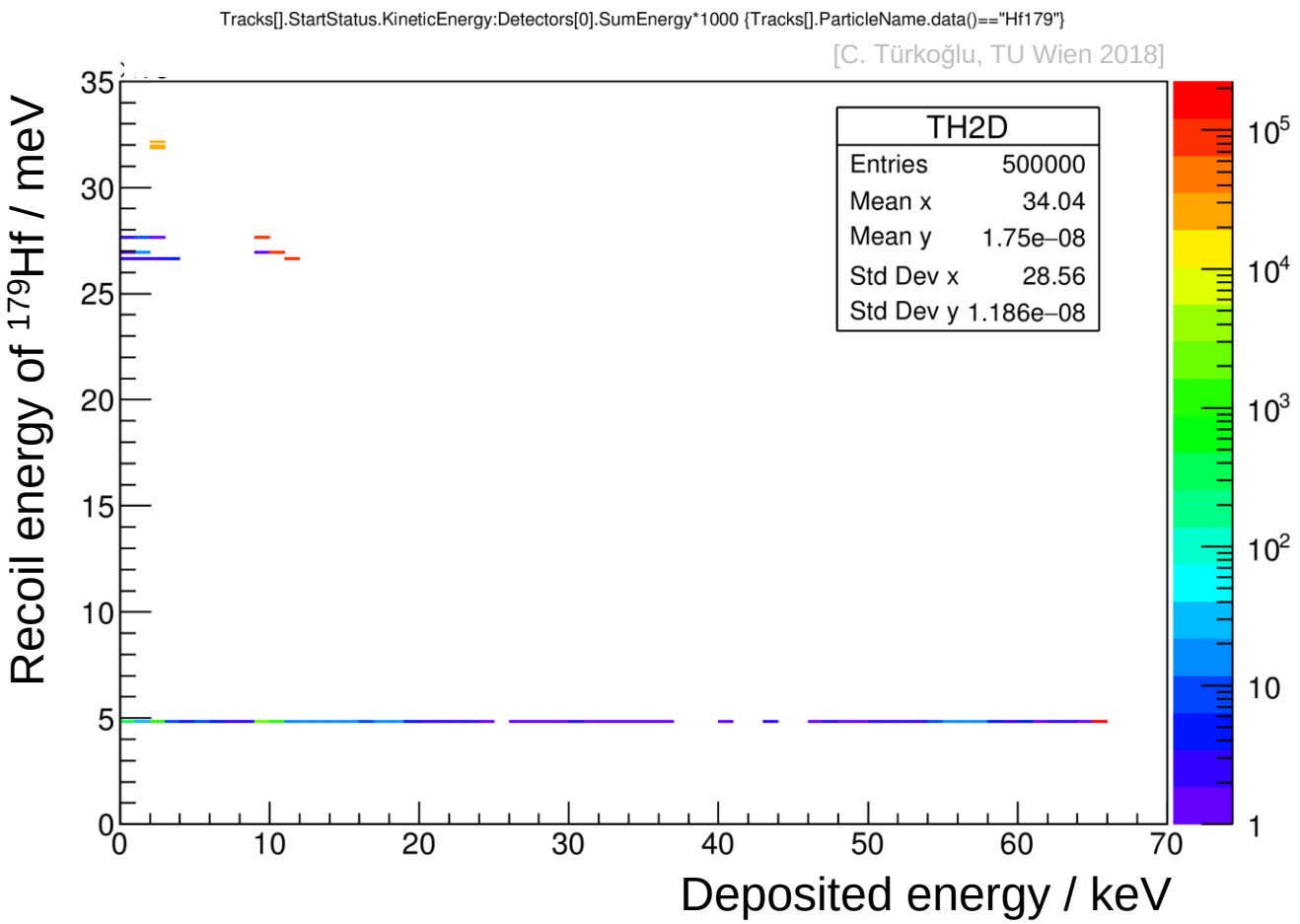


Effect of near Cu on ext. γ-lines

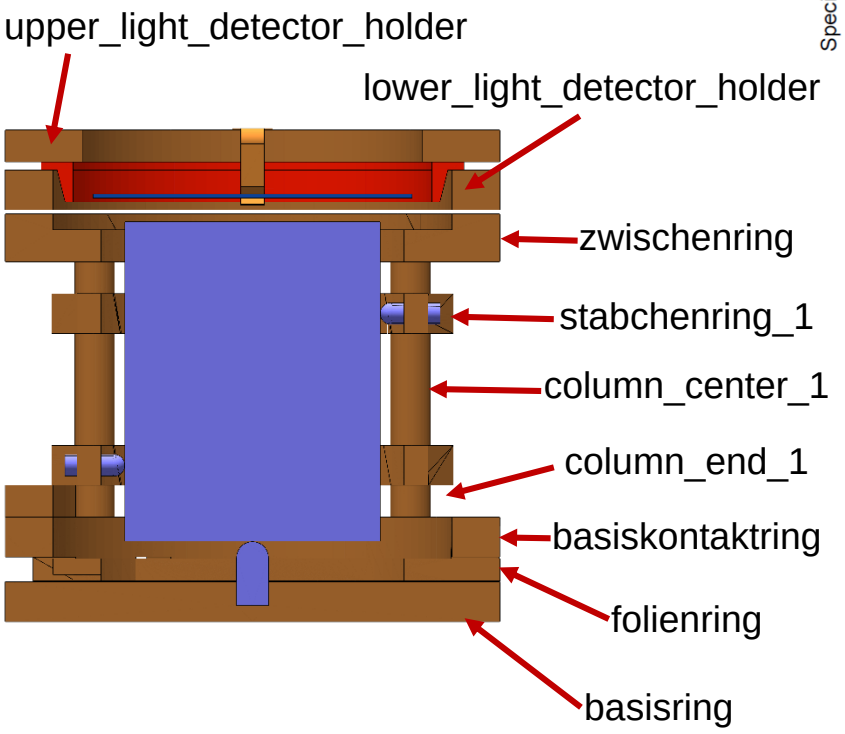


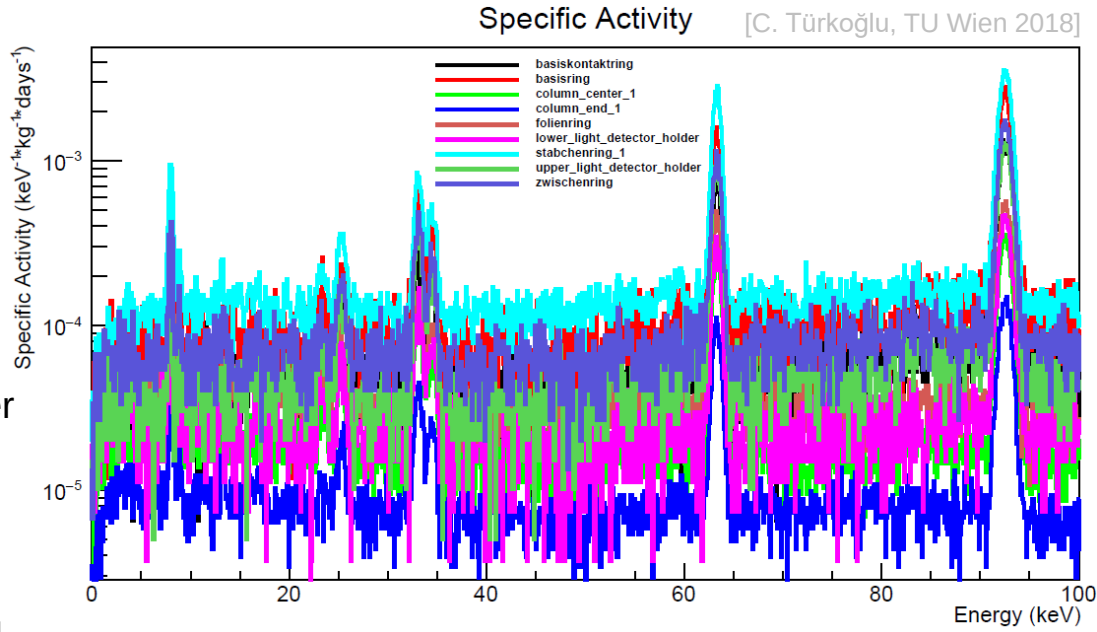
[C. Türkoğlu, TU Wien 2018]

Separate EC branches via nuclear recoils



Position dependence of Cu – near background





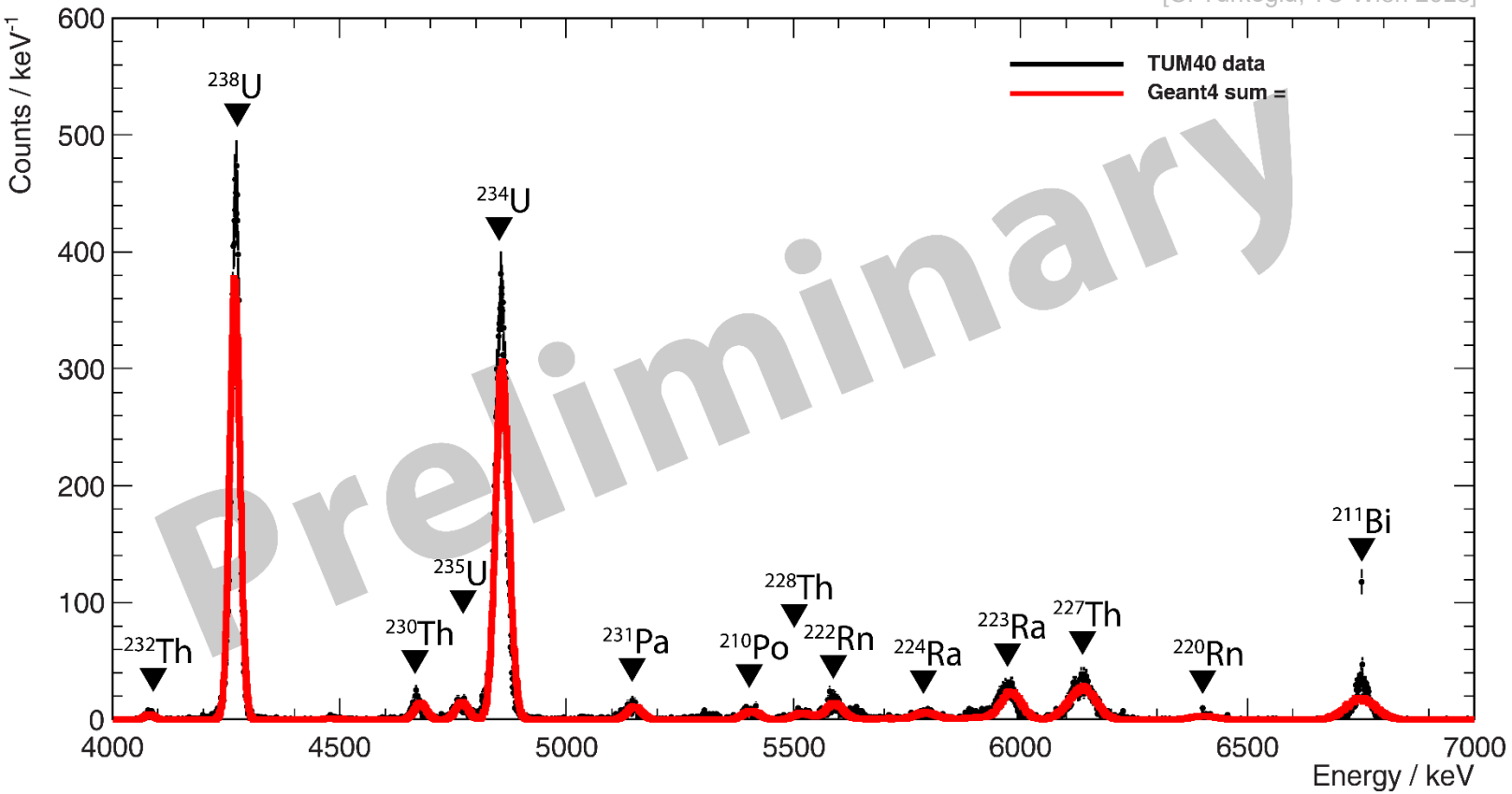
Integrals of events from copper parts from the highest to the lowest:

1) stabchenring_1 = 0.0624721
2) basisring = 0.0487353
3) zwischenring = 0.0337823
4) basiskontaktring = 0.0264344
5) upper_light_detector_holder = 0.0172679
6) folienring = 0.0123547
7) lower_light_detector_holder = 0.00958061
8) column_center_1 = 0.00653818
9) column_end_1 = 0.00306402

α-decays

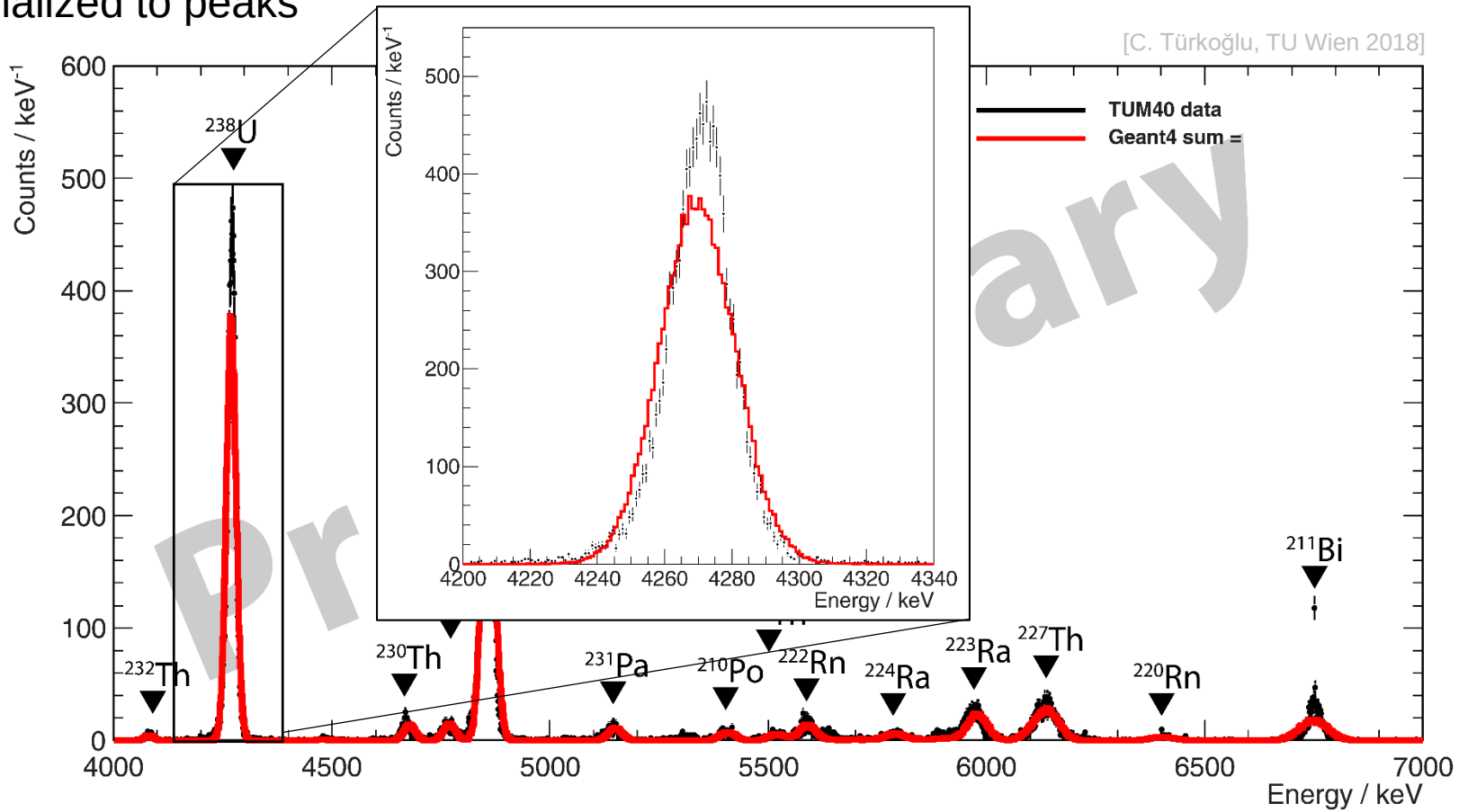
Normalized to peaks

[C. Türkoğlu, TU Wien 2018]



α-decays

Normalized to peaks

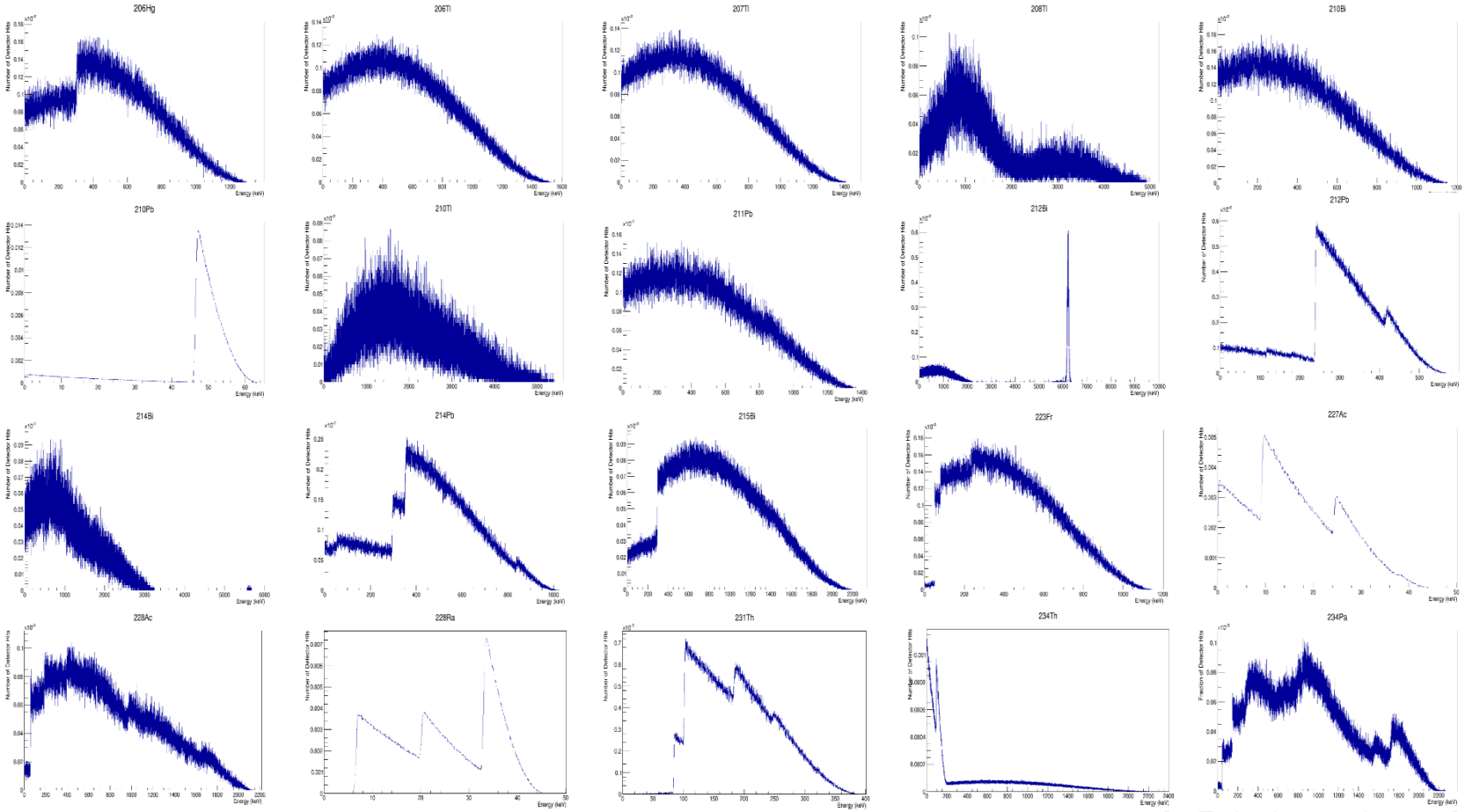


Detector response model overestimate peak width

→ Developing likelihood fit with free peak resolution

β-decays

Scale simulated β templates accordingly



...

[C. Türkoğlu, TU Wien 2018]

Reference data

Energy range / keV	Exposure / kg.d	Efficiency / %
0.6 – 500	127.50	84.96*
500 – 4000	127.50	98.14
4000 – 7000	127.50	86.48

* for E>92.36keV, below see [Eur.Phys.J. C74.12 (2014) 3184]