Background simulation for the dark matter search experiment CRESST

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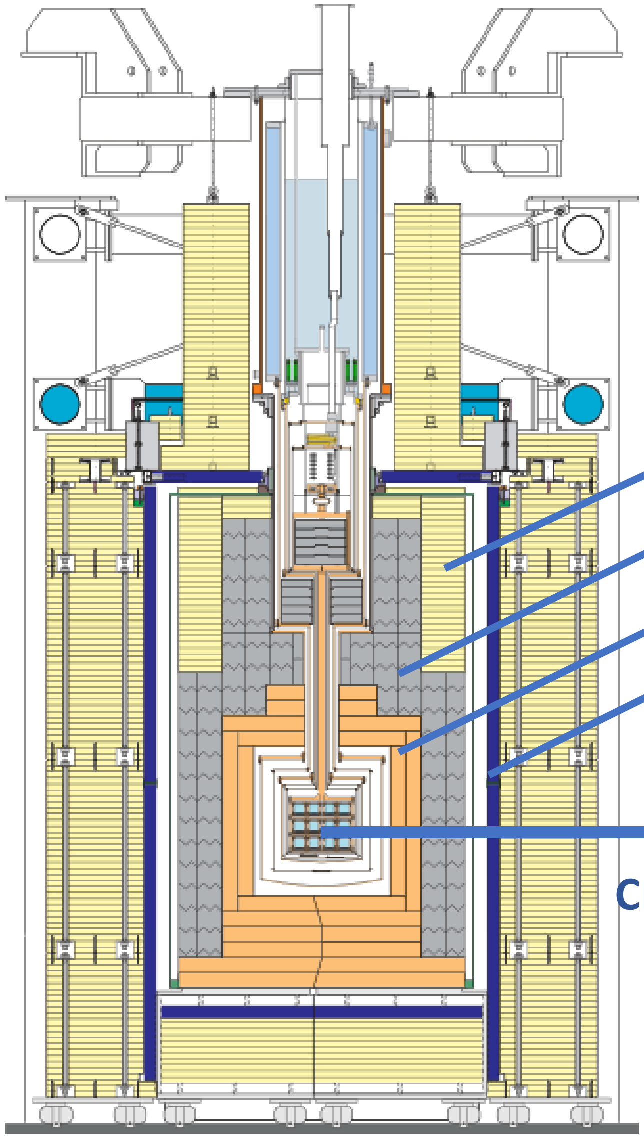
Valentyna Mokina for the CRESST collaboration

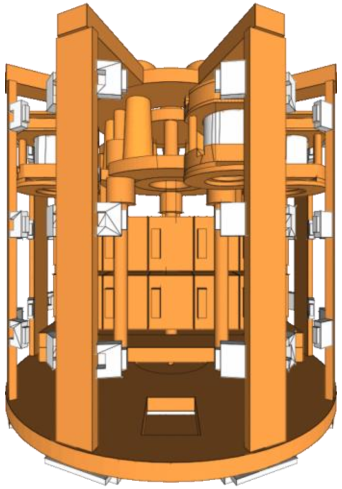
HEPHY OEAW

CRESST is located at LNGS (Laboratori Nazionali del Gran Sasso) in Italy

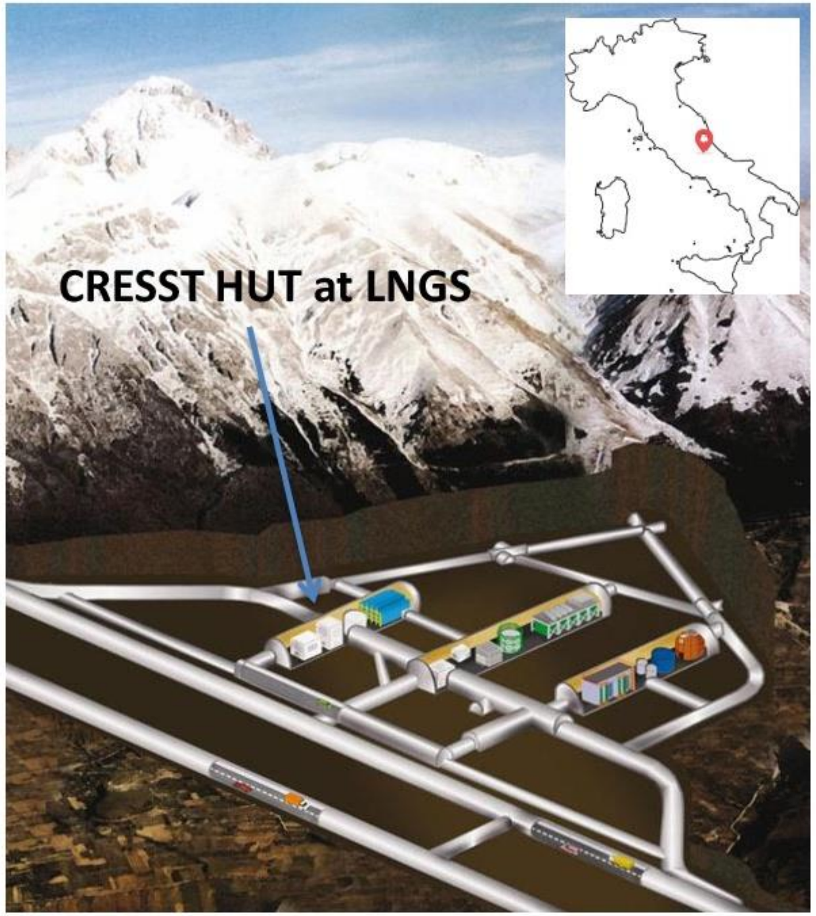


- Cryogenic scintillating calorimeter
- Target materials: $CaWO_4$, Si, $LiAlO_3$, Al_2O_3
- Read out channels: phonon and scintillation light

Shielding:
- polyethylene;
- lead;
- copper;
- muon veto system.



CRESST-III Phase 2



<u>Experimental location</u>:

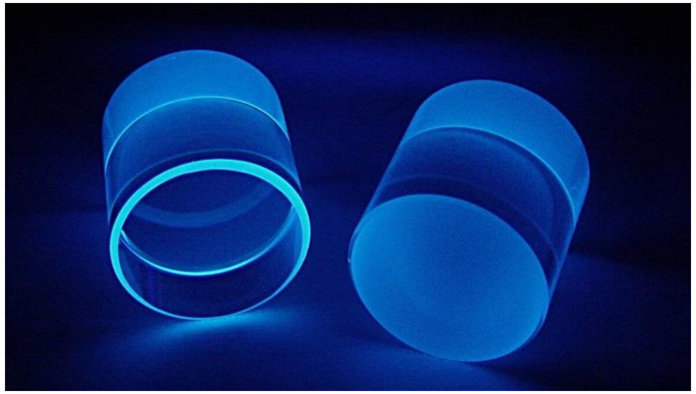
Average depth ~ 3600 m w.e.

Muon flux ~ 2.6×10^{-8} μ/s/cm^2

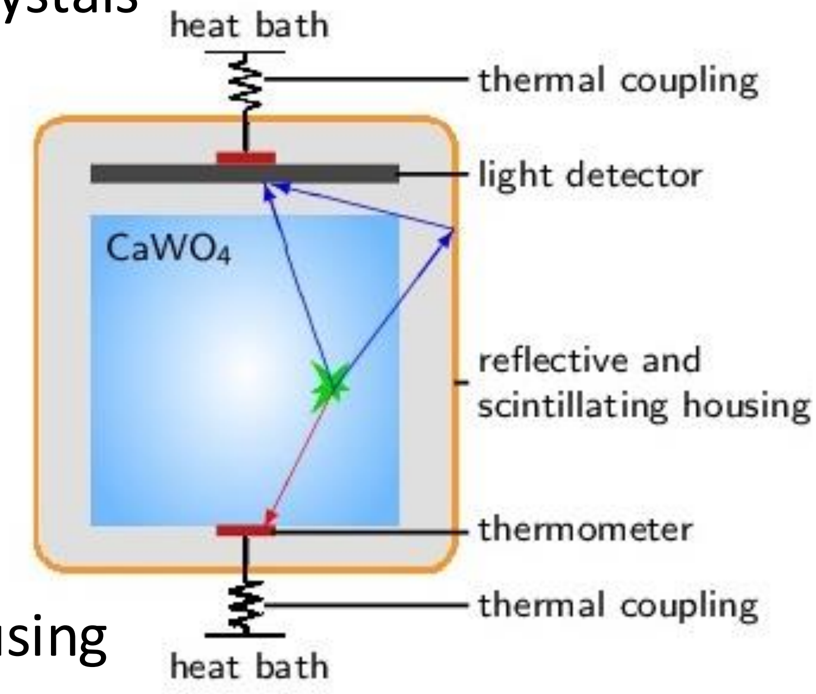
Neutrons < 10 MeV: <10^{-6} n/s/cm^2

The CRESST experiment

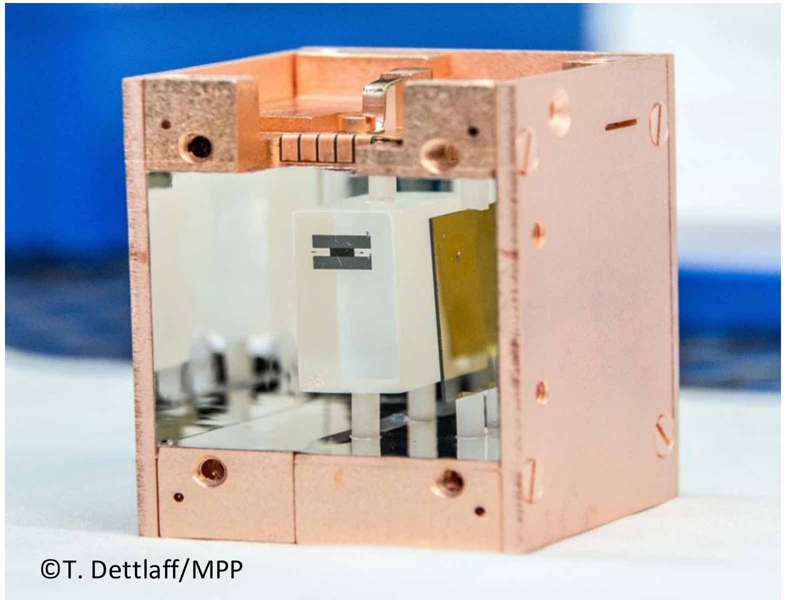
Direct detection of dark matter particles via their scattering off target nuclei



- target material: $CaWO_4$ single crystals



- particle interaction
  - → heat (phonon) signal
    read-out with thermometer
  - → light signal
    read-out with light detector
- reflective and scintillating housing



Target crystals operated as cryogenic calorimeters (~15mK)

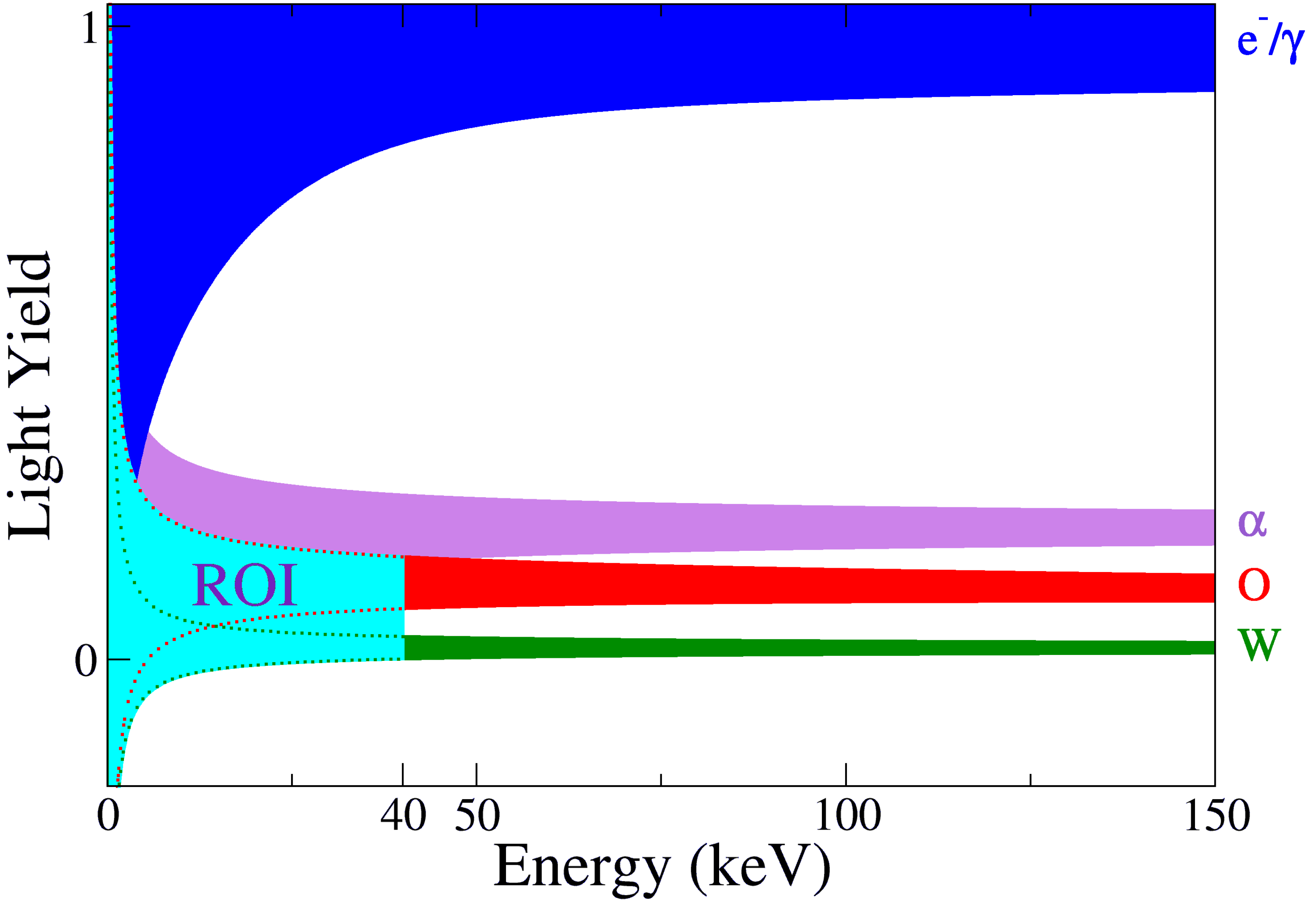
Event discrimination

Light Yield= $\frac{\text{Light signal}}{\text{Phonon signal}}$

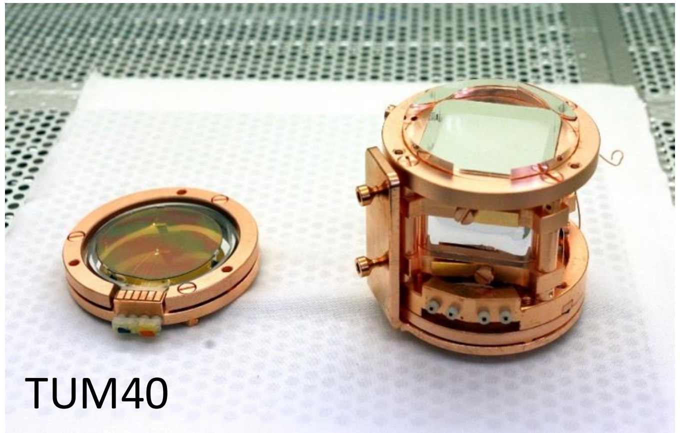
Characteristic of the event type

Excellent discrimination between potential signal events (**nuclear recoils**) and dominant radioactive background (**electron recoils**)

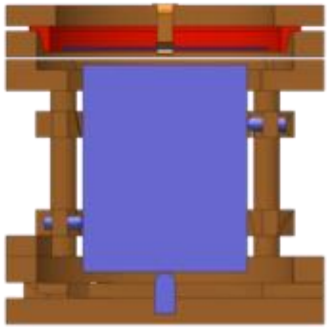
ROI: region of interest for dark matter search

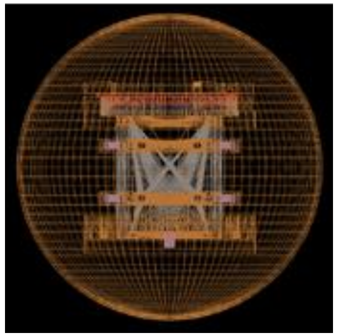


One module background simulation

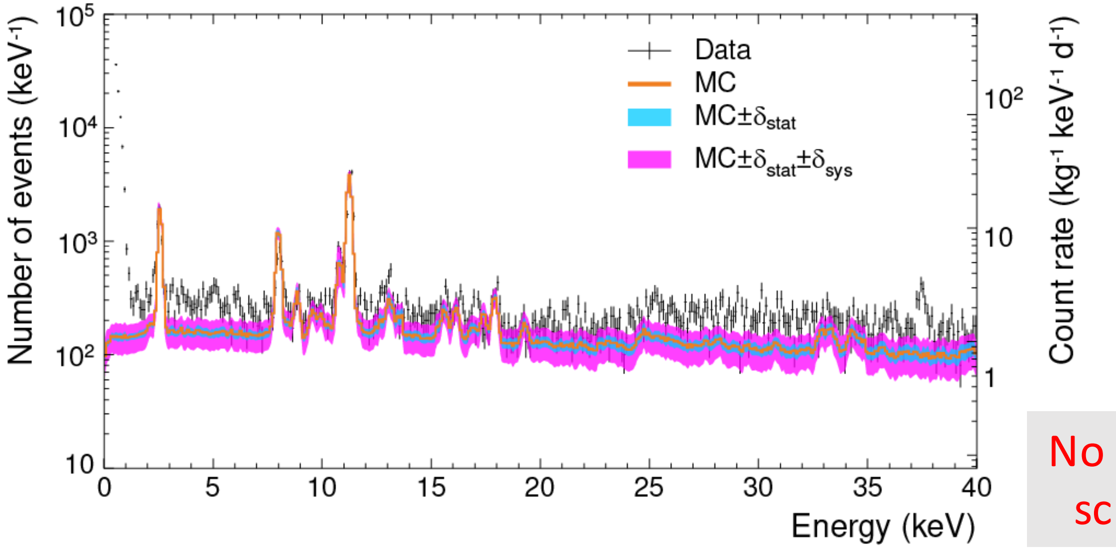


- Geant4 based electromagnetic background model for the CRESST experiment
- Study of cosmogenic activation of $CaWO_4$ crystal scintillator
- Simplified geometry reproduced already up to 68% background in ROI
- Foundation for more detailed models of the actual CRESST detector modules

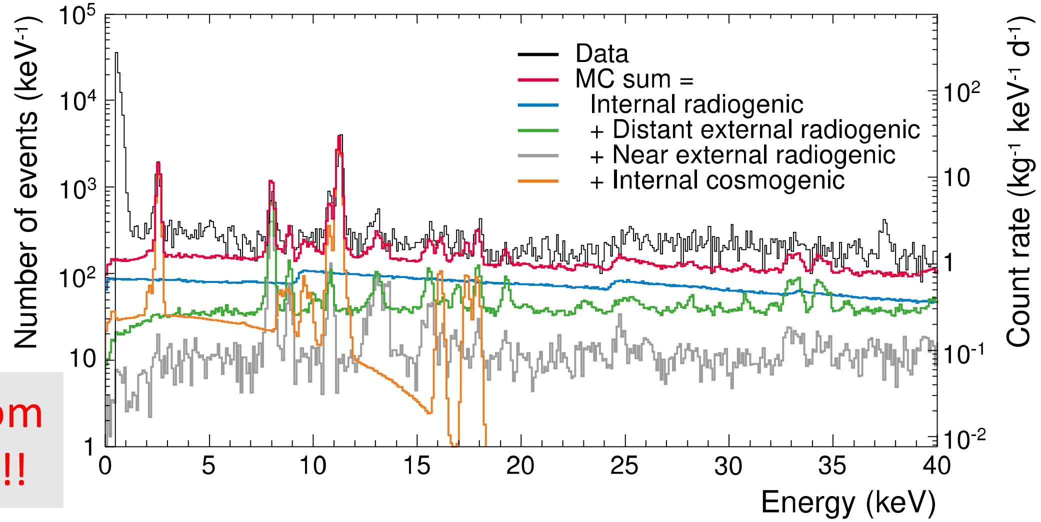




Up to 68±16% of background can be reproduced with simulations

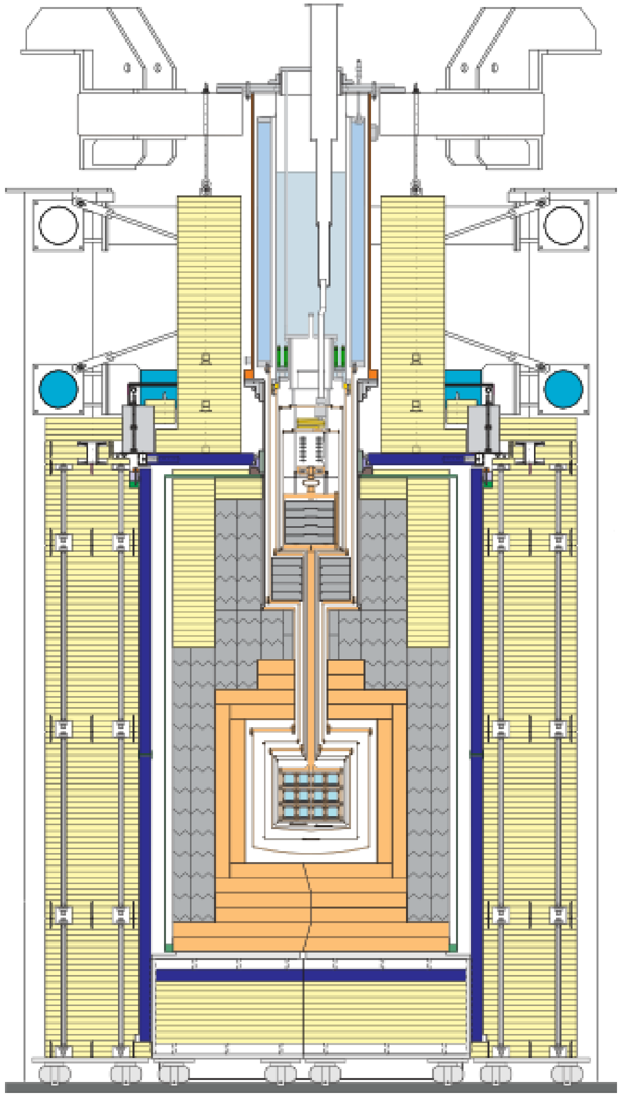


No input from screening!!!



Eur.Phys.J. C79 (2019) 881
Eur.Phys.J. C79 (2019) 987

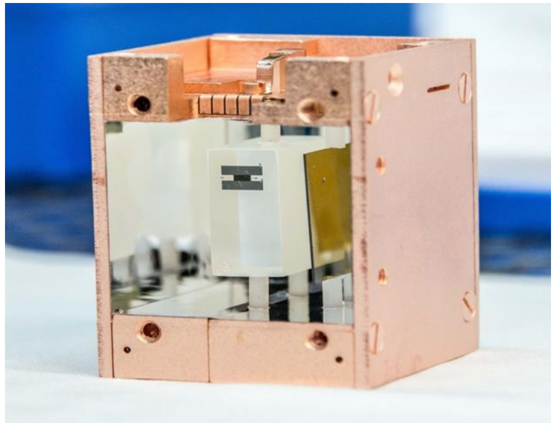
Screening campaign



CRESST set-up

Materials:

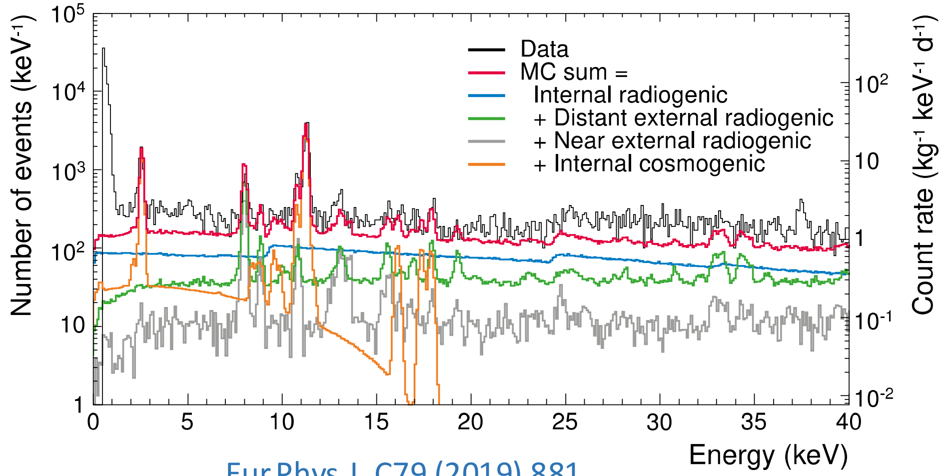
- copper -> HPGe ✓ ICP-MS ✓ bulk ^{210}Po ✓ NAA (in progress)
- crystals ($CaWO_4$) -> bolometric meas. (in progress)
- reflective foil -> ICP-MS ✓
- bronze clams -> ICP-MS ✓
- polyethylene -> HPGe ✓ ICP-MS ✓
- lead -> ICP-MS ✓
- connectors -> HPGe ✓
- brass -> ICP-MS ✓
- pins -> ICP-MS ✓



CRESST-III detector

Simulation

Up to 68±16% of background can be reproduced with simulations



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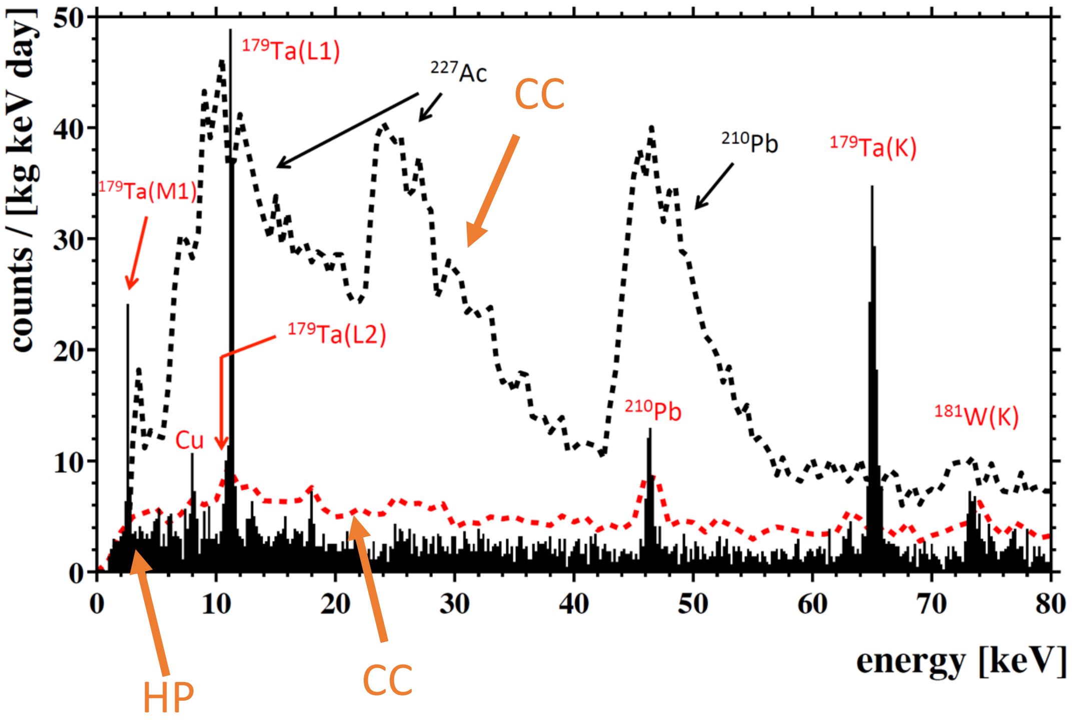
High-purity scintillating $CaWO_4$ crystals



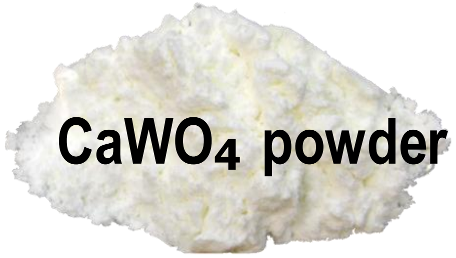
Commercial crystals (CC) → in-house production (HP)

A factor of 2-10 decrease in the background

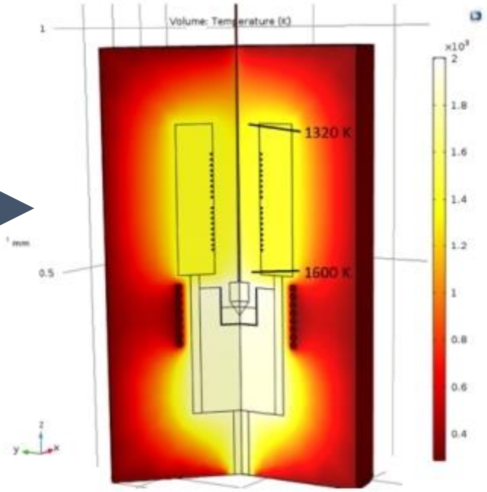
Radiochemical Purification of $CaCO_3$

1. Transform $CaCO_3$ powder into aqueous solution of $Ca(NO_3)_2$
2. Mix solution with an extractor (TOPO) dissolved in n-Dodecan
→ Impurities move from the $Ca(NO_3)_2$ solution to the extractor solution
3. Extraction of $Ca(NO_3)_2$ solution
4. Remove precipitated $CaWO_4$
5. Washing with alkaline solution and water

High-purity scintillating $CaWO_4$ crystals



1.5 kg of purified $CaWO_4$ powder produced via co-precipitation using $(NH_4)_2WO_4$ solution (NEW!)

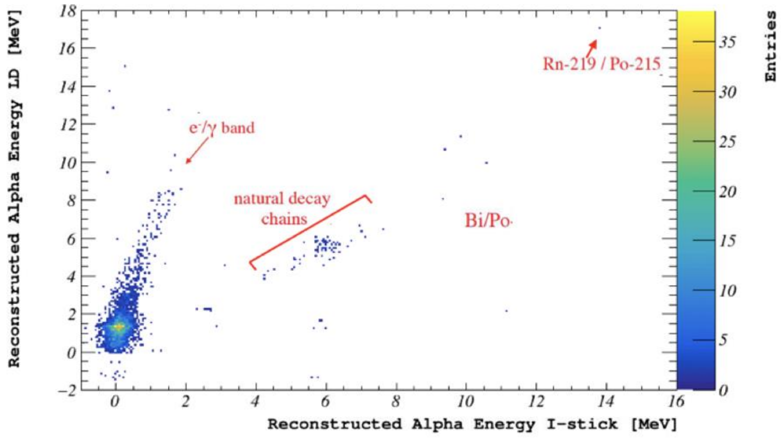


temperature gradients during the growth to study the reduction of internal stresses

New crystal
New level of radiopurity

oxygen atmosphere at 1400°C for 20 h

	Activity, (mBq/kg)
Total alpha activity	0.535 ± 0.055
^{147}Sm and ^{180}W	0.046 ± 0.016
Single alpha lines	0.454 ± 0.051
Bi-Po cascades	0.029 ± 0.013
^{219}Rn - ^{215}Po decay	0.006 (1 event)
Total alpha activity nat. decay chains	0.489 ± 0.053



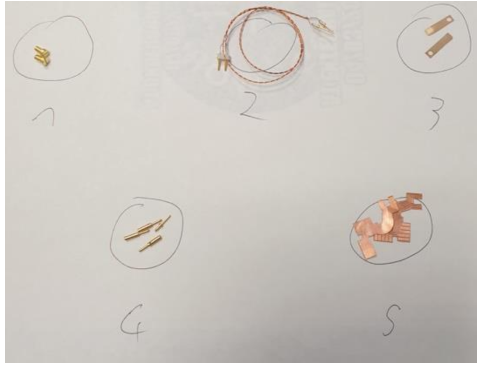
Total α activity (3.08±0.04) mBq/kg for TUM40 [1] and for TUM93 [2] crystal is (0.489±0.05) mBq/kg.

Increase by a factor of 6.3±0.7

[1] R. Strauss et al., JCAP 2015 06, 030 (2015)
[2] A. Kinast et al., J LTPhys. (2022) 10.1007/s10909-022-02743-7

Screening campaign

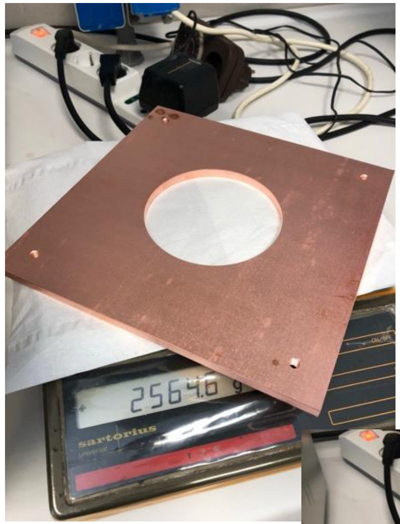
Sample	Th [pg/g]	U [pg/g]
1. brass screw	70 ± 21	14 ± 4
2. superconducting cable with copper matrix	77 ± 23	84 ± 25
3. bronze clamp	162 ± 49	690 ± 207
4. pins	20 000 ± 6 000	176 000 ± 53 000
5. copper circuit	734 ± 220	283 ± 85



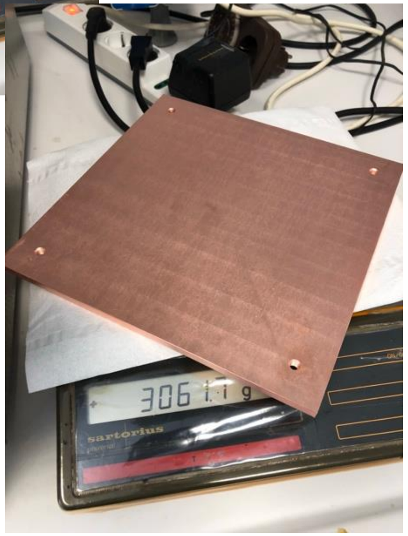
ICP-MS at LNGS

Sample	^{232}Th [μBq/kg]	^{235}U [μBq/kg]	^{238}U [μBq/kg]
Copper *	< 2	< 0.43	< 6.2
Copper CUORE	< 2	< 0.46	< 65

* more sensitive result



16 plates



18 plates

Chain	Nuclide	Activity, (mBq/kg)
^{232}Th	^{228}Ra	<0.024
	^{228}Th	<0.021
^{235}U		<0.05
^{238}U	^{234}Th	<3.5
	^{234m}Pa	<0.76
	^{226}Ra	<0.02
	^{40}K	<0.19
	^{137}Cs	<0.0056
	^{46}Sc(83.8d)	0.029 ± 0.006
	^{48}V(15.97d)	<0.04
	^{54}Mn(312d)	0.051 ± 0.009
	^{59}Fe(44.5d)	0.042 ± 0.011
	^{56}Co(77.2d)	0.054 ± 0.008
	^{57}Co(272d)	< 0.14
	^{58}Co(70.9d)	0.5 ± 0.05
	^{60}Co(5.28y)	0.046 ± 0.006

HPGe at LNGS

ICP-MS and HPGE measurements of shielding materials

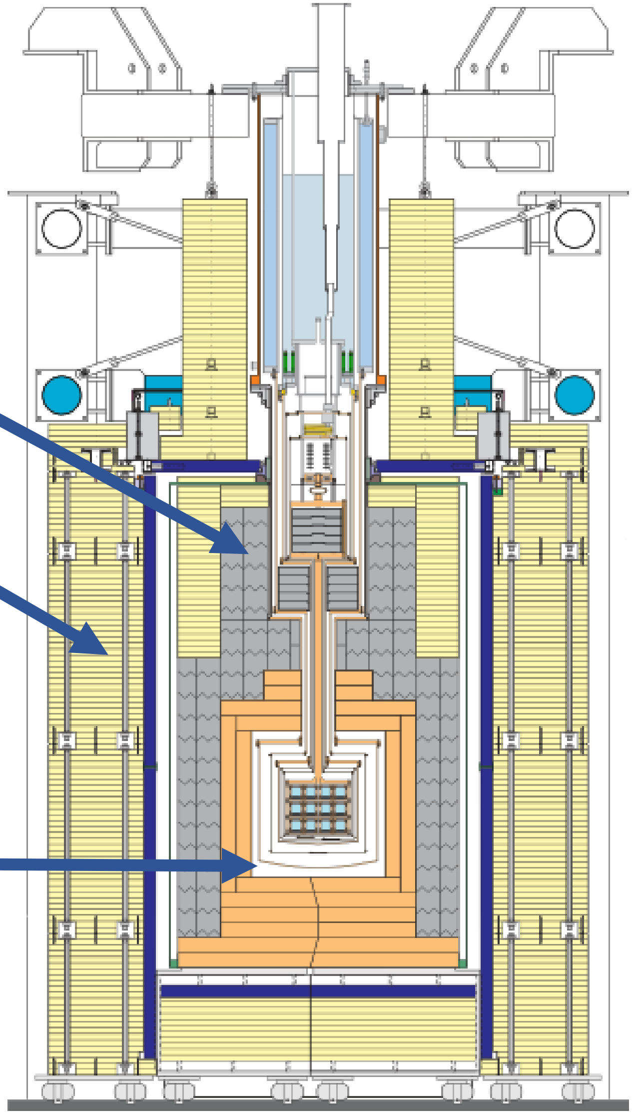
ICP-MS at LNGS

Needs an update!!

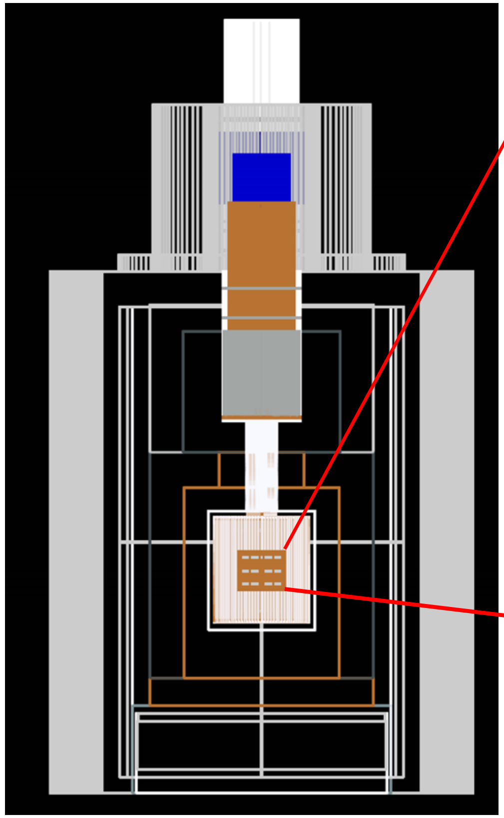
Sample	Th [pg/g]	U [pg/g]
lead	< 200	< 200
polyethylene outer	< 1300	< 500

HPGe at LNGS

Sample	Th [pg/g]	U [pg/g]
polyethylene inner	100 ± 30	82 ± 9

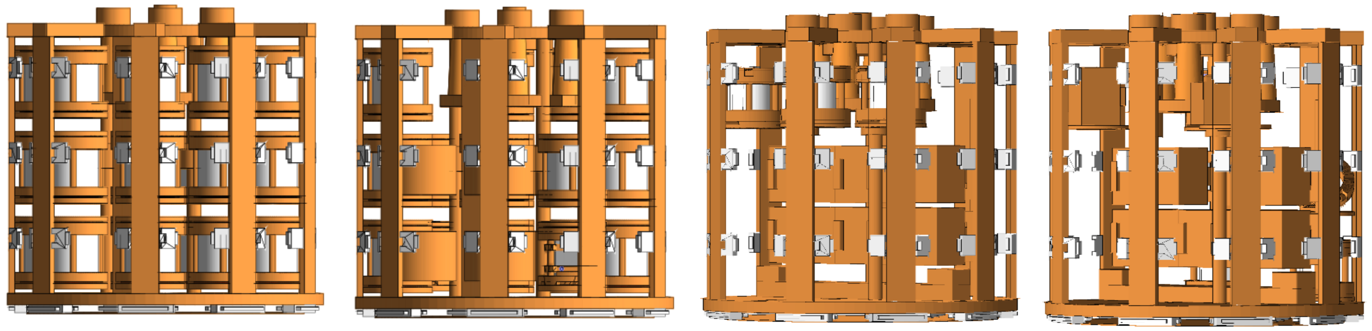


From one module to full setup simulation

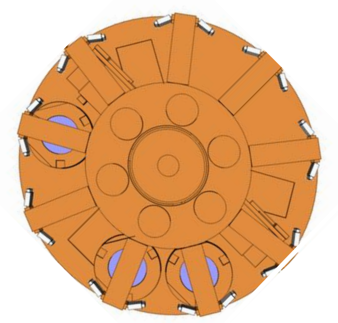


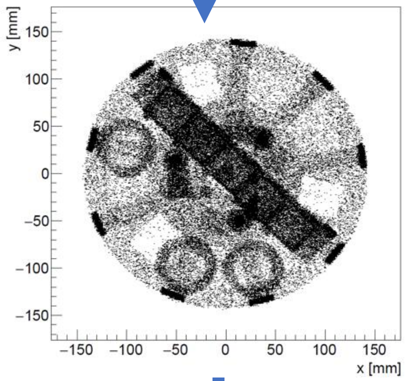
CRESST set-up

DAWN visualization of the Carousel with detectors as implemented in Geant4



CRESST-II phase 1 730kg result Eur.Phys.J. C72(2012)1971	CRESST-II phase 2 TUM40, Lise Eur.Phys.J. C74(2014)3184, C76(2016)25	CRESST-III phase 1 Detector A Phys.Rev. D100(2019)102002	CRESST-III phase 1 Run 2 and so on…

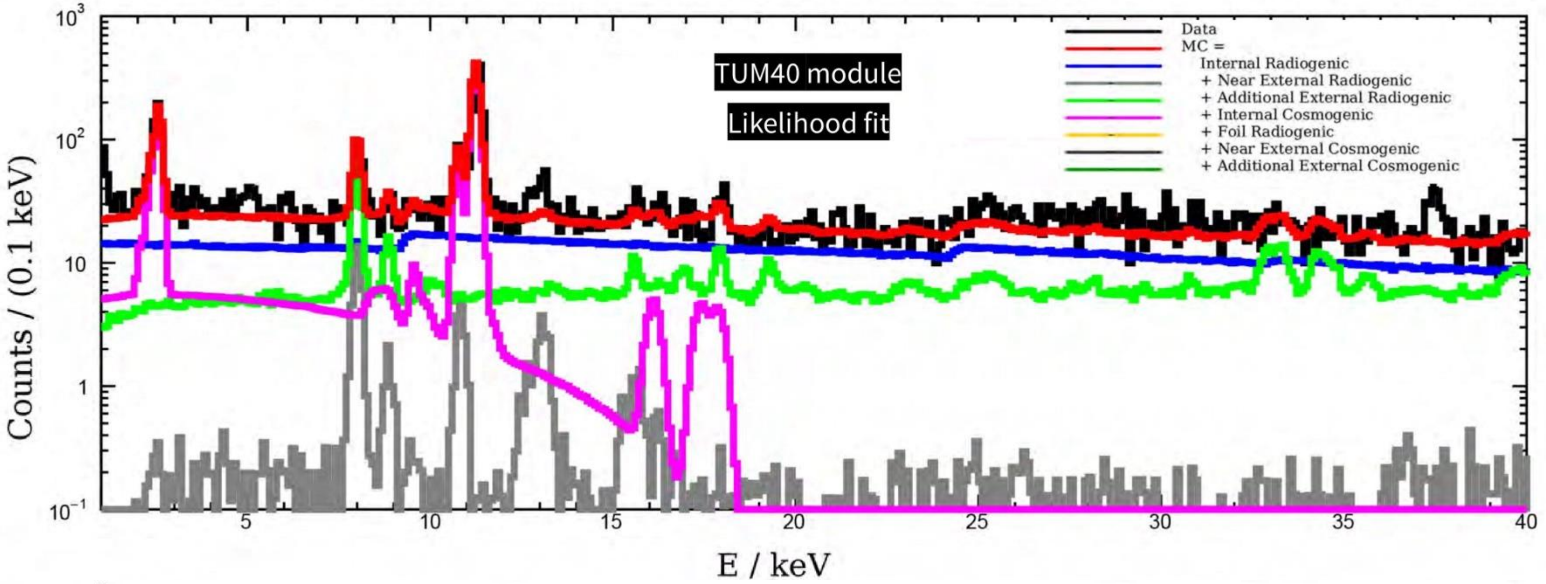


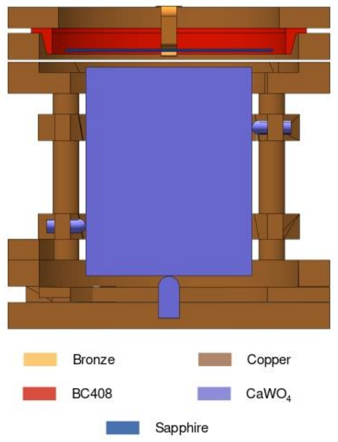


Simulating a homogeneous contamination in all parts made of Cu inside the Carousel.

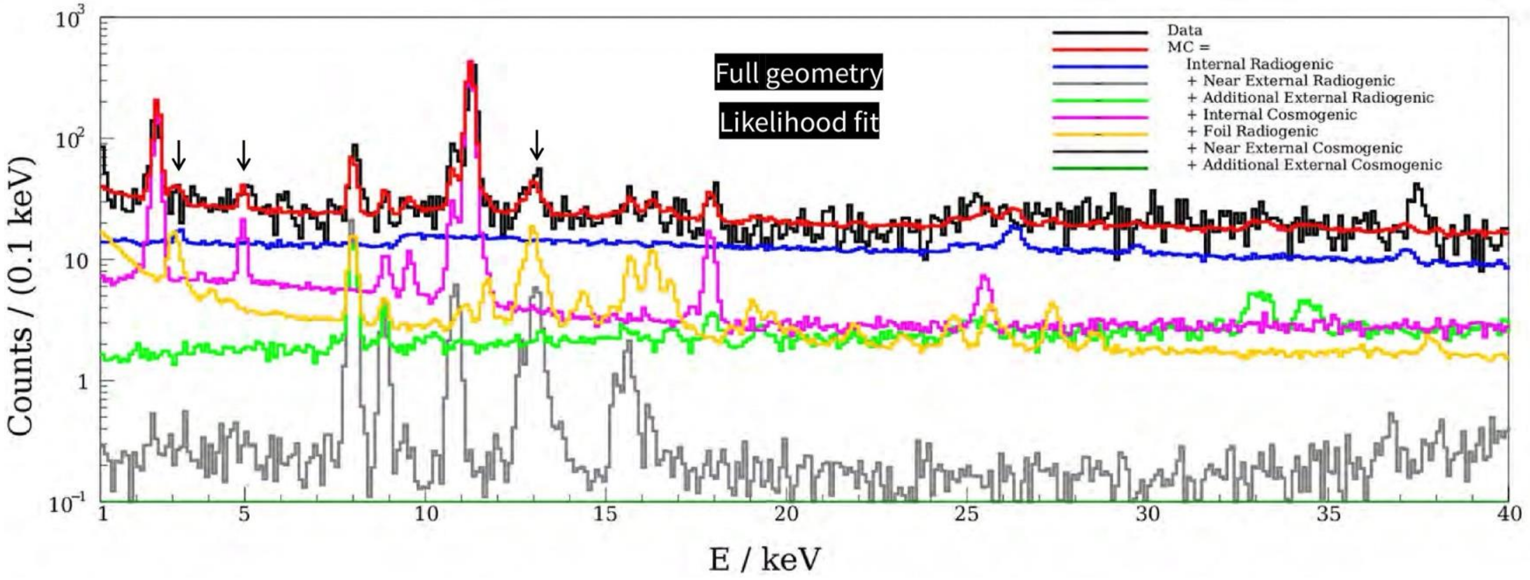
- Implementation of full geometry (each Run, all detectors);
- Adaption of the e.m. background model to the actual CRESST detector modules;
- Contamination levels from material assays conducted within;
- Simulation of neutron background;
- Study of cosmogenic activation of $CaWO_4$ crystal scintillator;
- Surface contaminations studies.

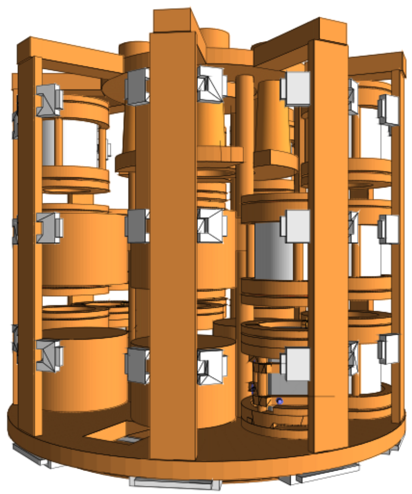
Likelihood model of background





Up to 74.6% of background can be reproduced with simulations





93.9%

2024 JINST 19 P11013

Conclusions

- CRESST operates a new generation of TUM-grown crystals with improved radiopurity due to chemical purification of their raw materials
- The screening campaign is ongoing to understand the activity concentration of different isotopes in materials used in the experiment
- The results of these studies are used as an input for simulation of the background of the CRESST experiment (development of sub-keV Monte Carlo model)
- Likelihood model of the background is developed and allows to reproduce up to 94%

Waiting for dark matter

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