Cryogenic Detectors with Superconducting Thermometers for Light Dark Matter Direct Search

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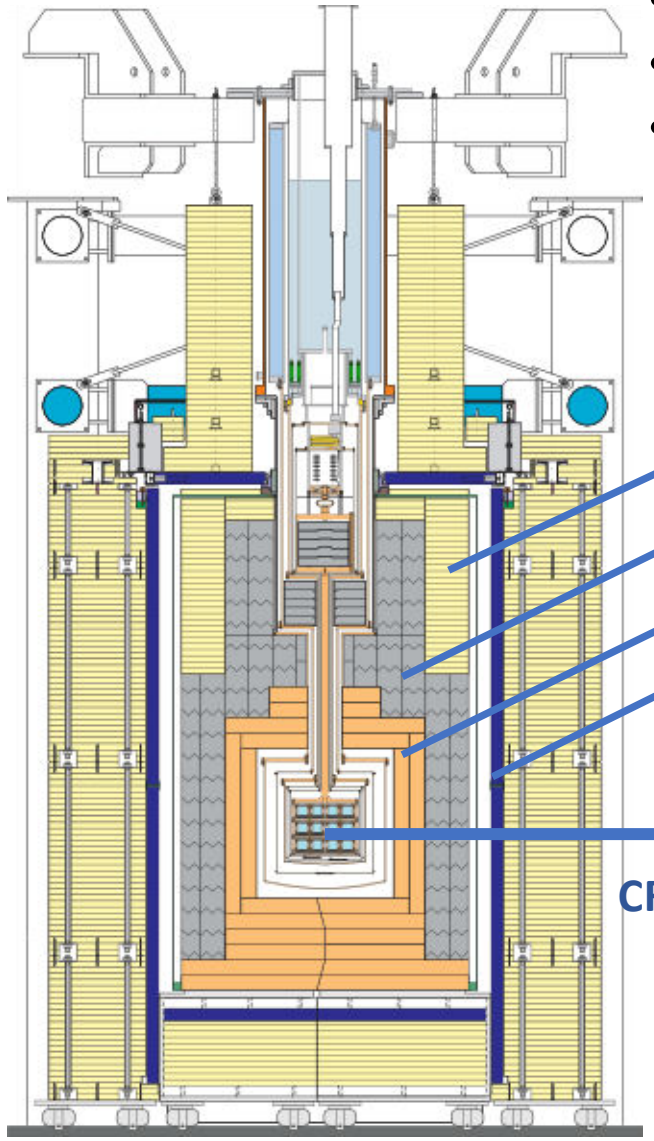
for the CRESST collaboration

Cryogenic Rare Event Search with Superconducting Thermometers

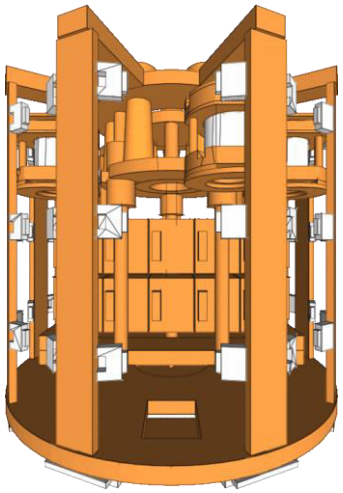
CRESST is located at LNGS (Laboratori Nazionali del Gran Sasso) in Italy

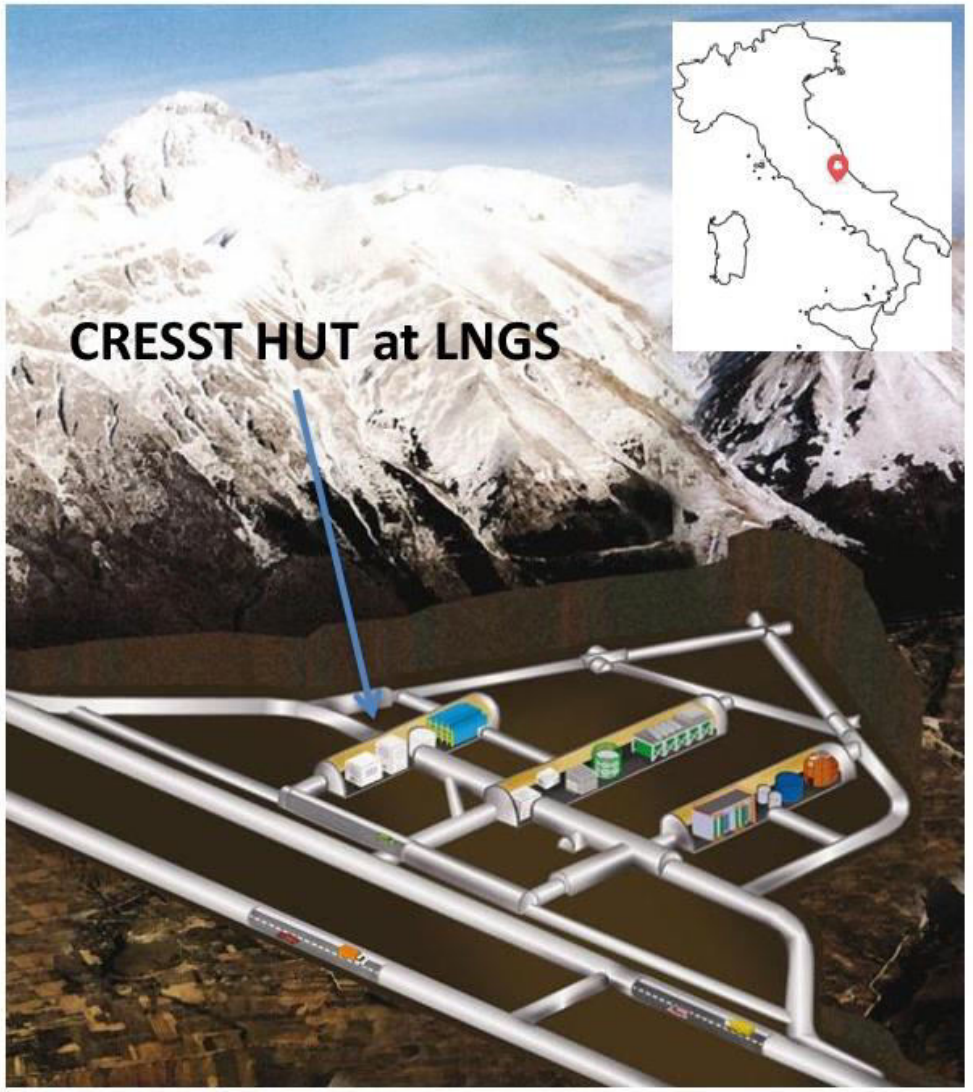


- Cryogenic scintillating calorimeter
- Target material is $CaWO_4$
- Read out channels: phonon and scintillation light

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

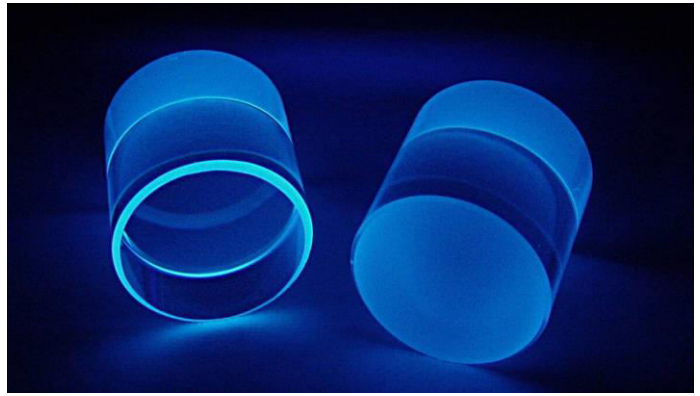
CRESST-III Phase 1

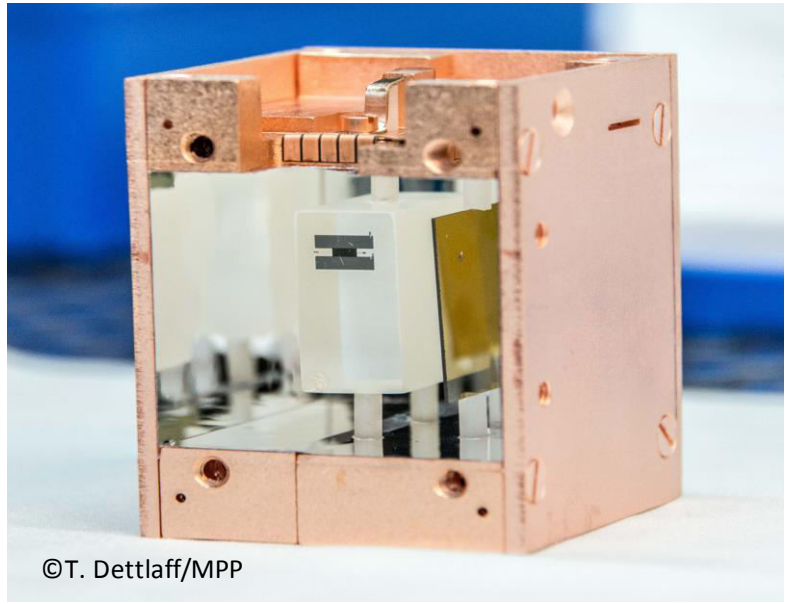




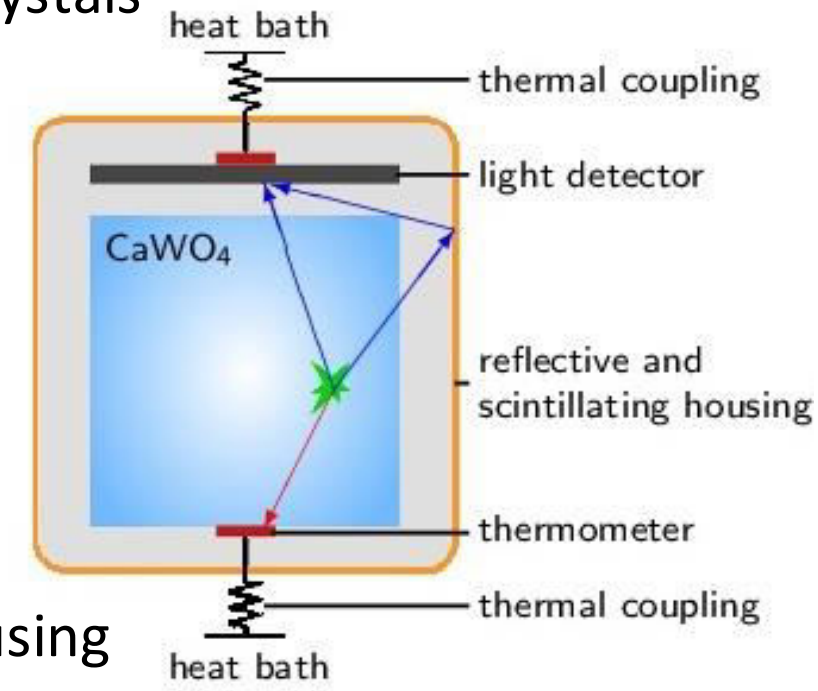
The CRESST experiment

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)

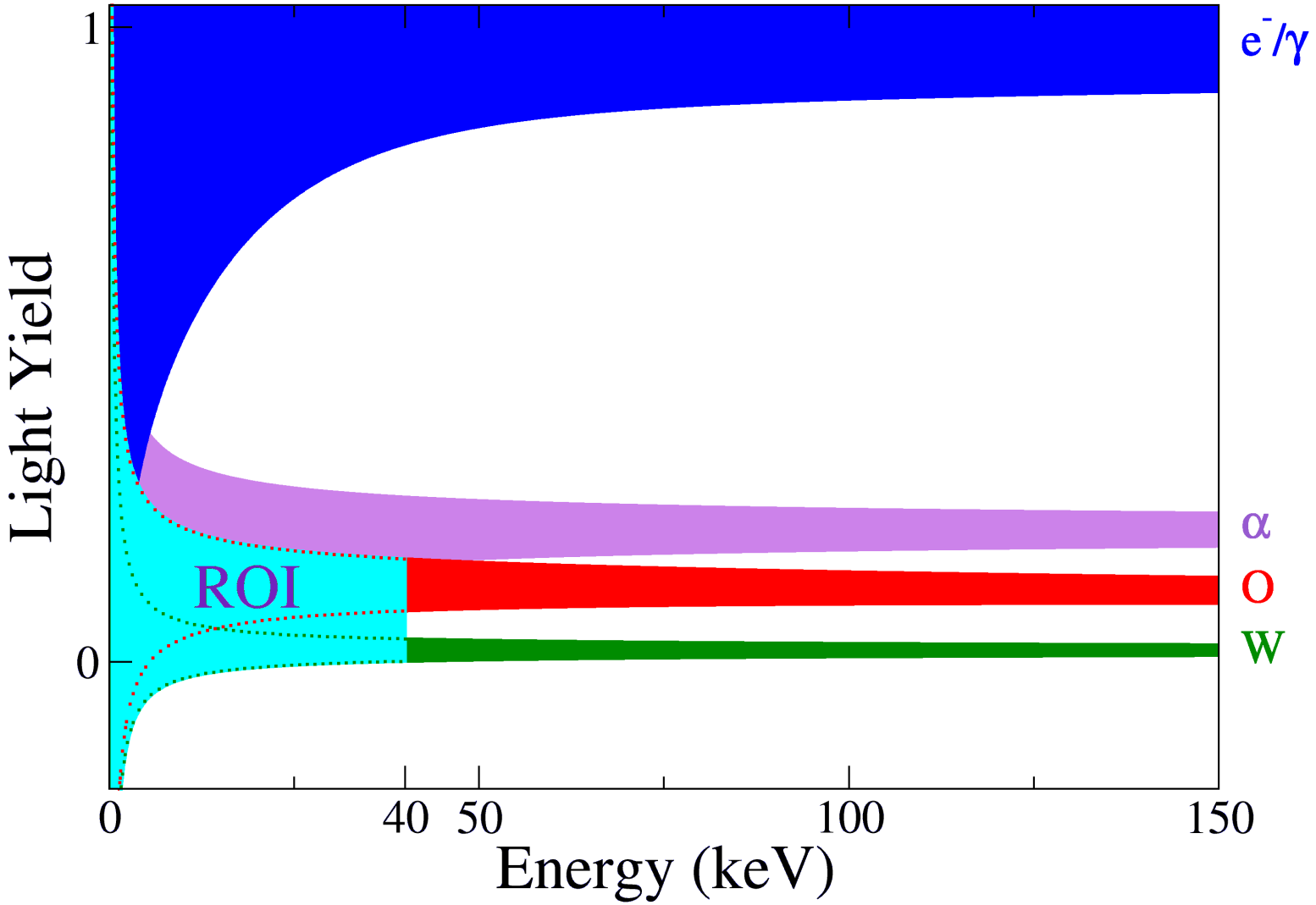
Event discrimination

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

Characteristic of the event type

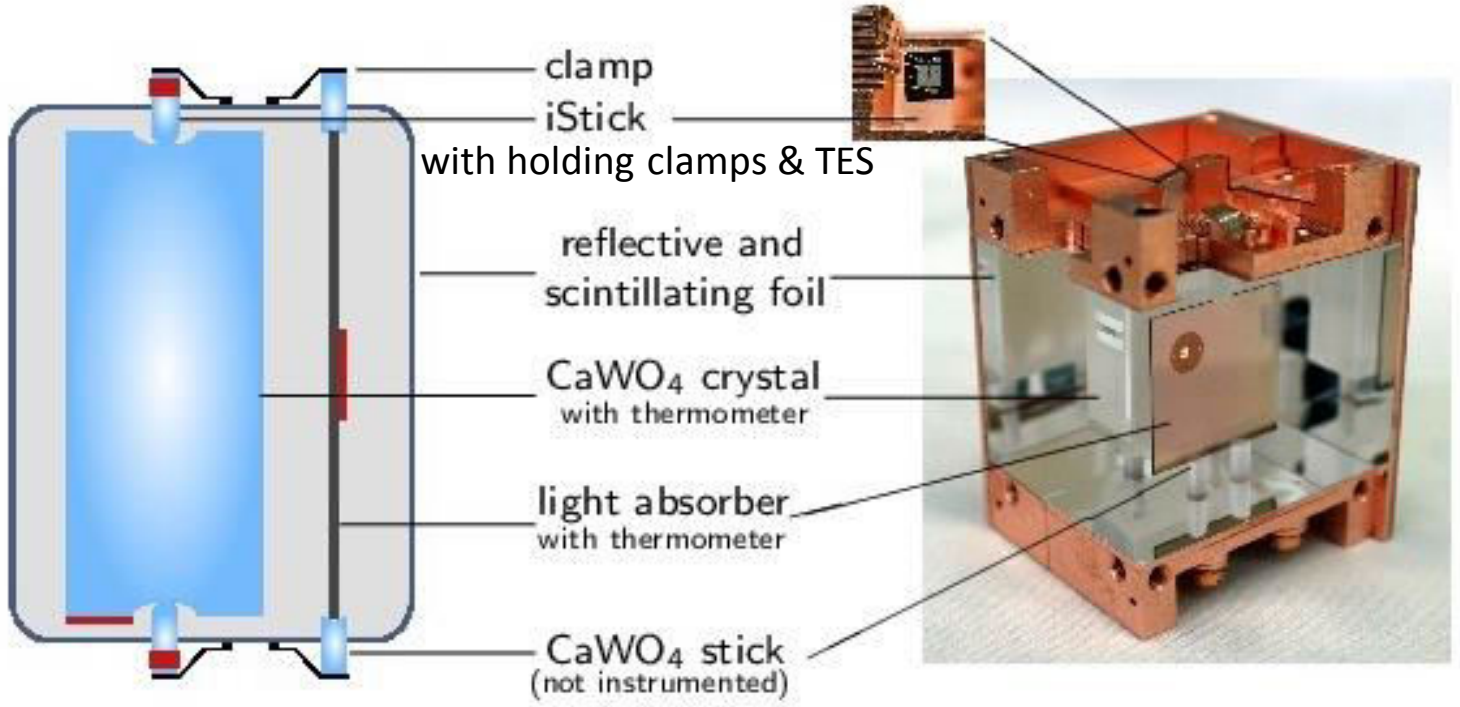
Excellent discrimination between potential signal events (**nuclear recoils**) and dominant radioactive background (**electron recoils**)

ROI: region of interest for dark matter search



CRESST-III Phase 1 low-threshold detectors

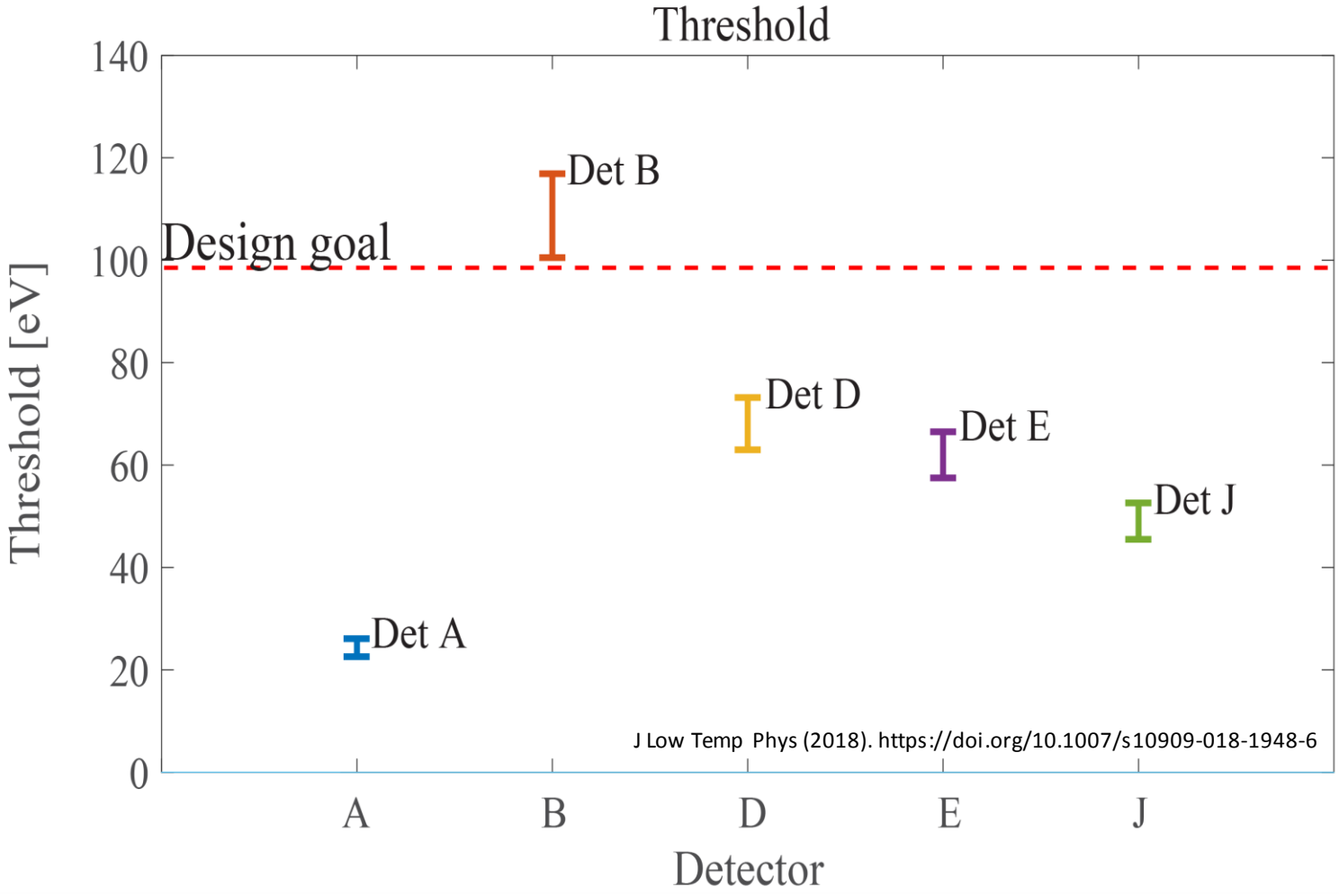
- Cuboid crystals of (20×20×10)mm^3 (**≈25g**) ╳ 10 modules
- Design goal: **100 eV threshold**
- Fully scintillating housing (held by $CaWO_4$ sticks)
- Instrumented sticks (iSticks) for holding main crystal (veto for events happening in sticks)



Data taking from July 2016 to January 2018

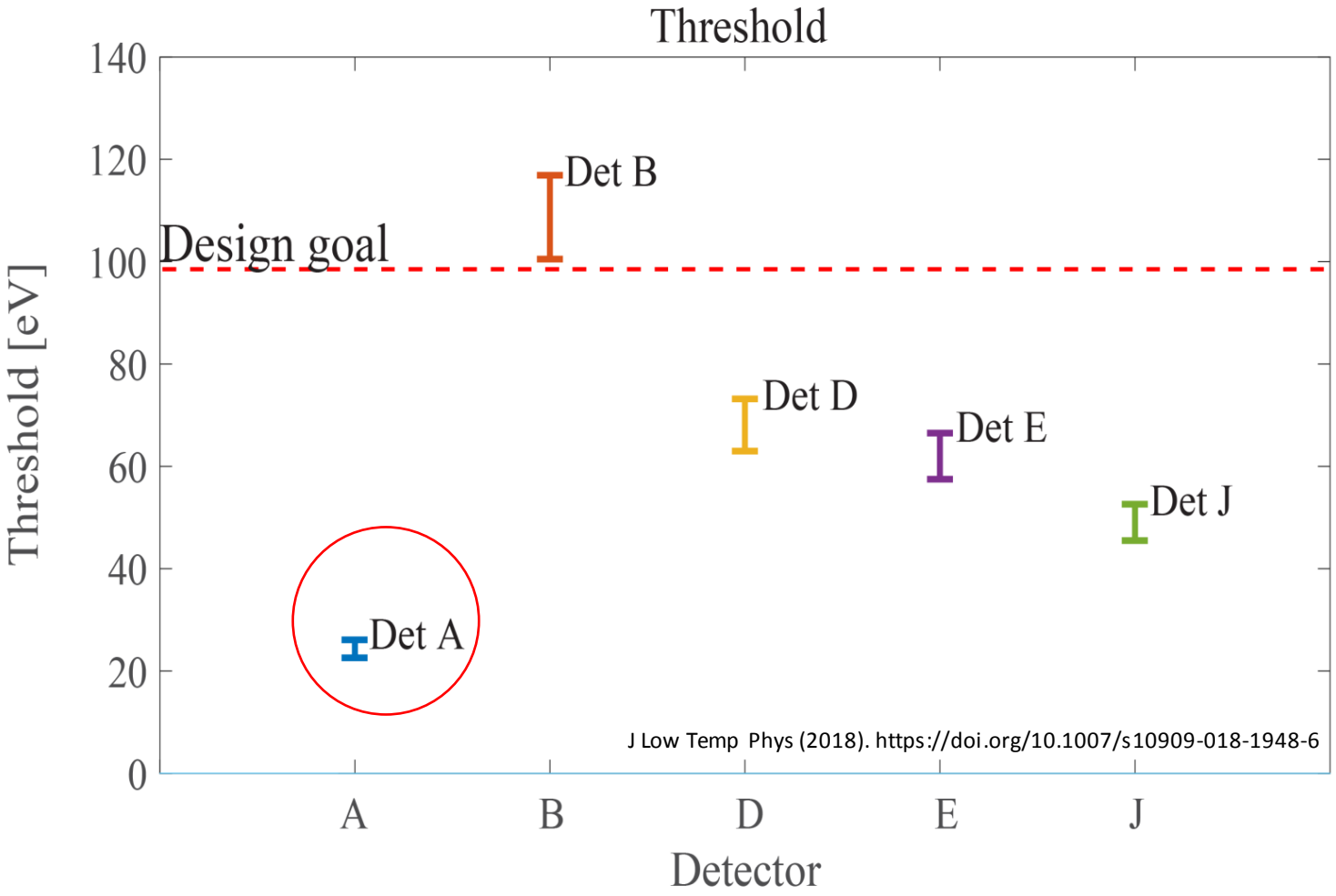
Optimum thresholds

5 detectors reach/exceed the CRESST-III design goal of a threshold < 100eV



Optimum thresholds: Detector Module A

Detector A ⟶ the lowest threshold! New benchmark point in low mass dark matter search.



Data taking period: 10/2016 – 01/2018

Non-blind data (dynamically growing):
20% randomly selected

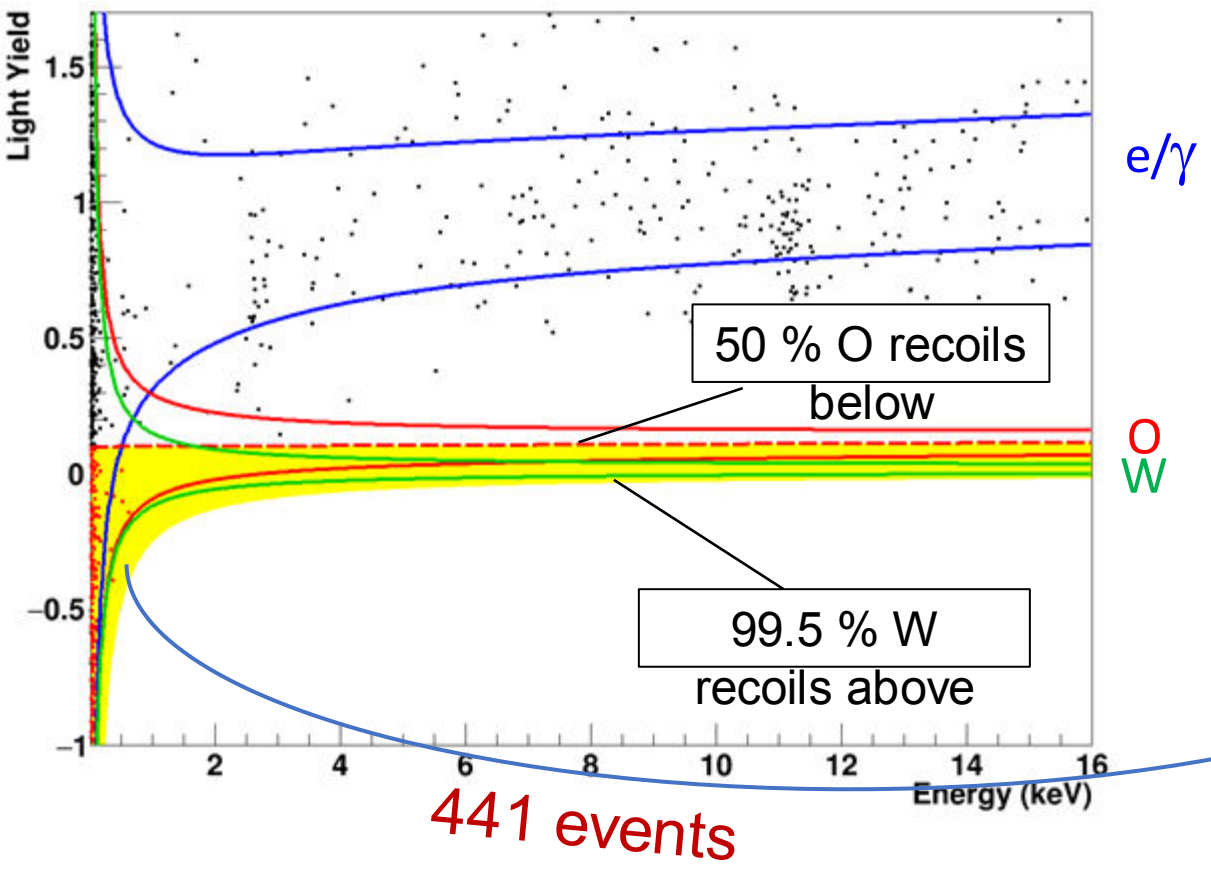
Target crystal mass: 23.6g

Gross exposure (before cuts): 5.7 kg days

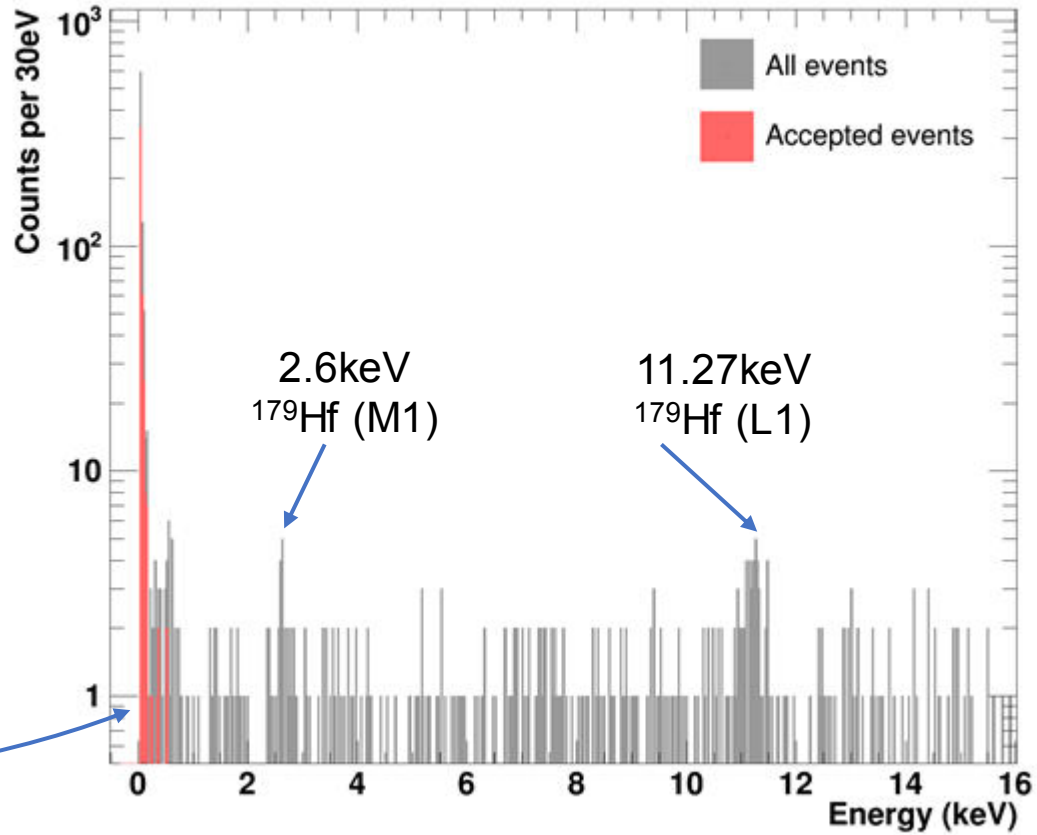
Nuclear recoil threshold: 30.1 eV

Dark matter data

Acceptance region fixed before unblinding



Cosmogenic activation → $^{179}Ta + e^- \rightarrow {}^{179}Hf + \nu_e$ (1.8y)



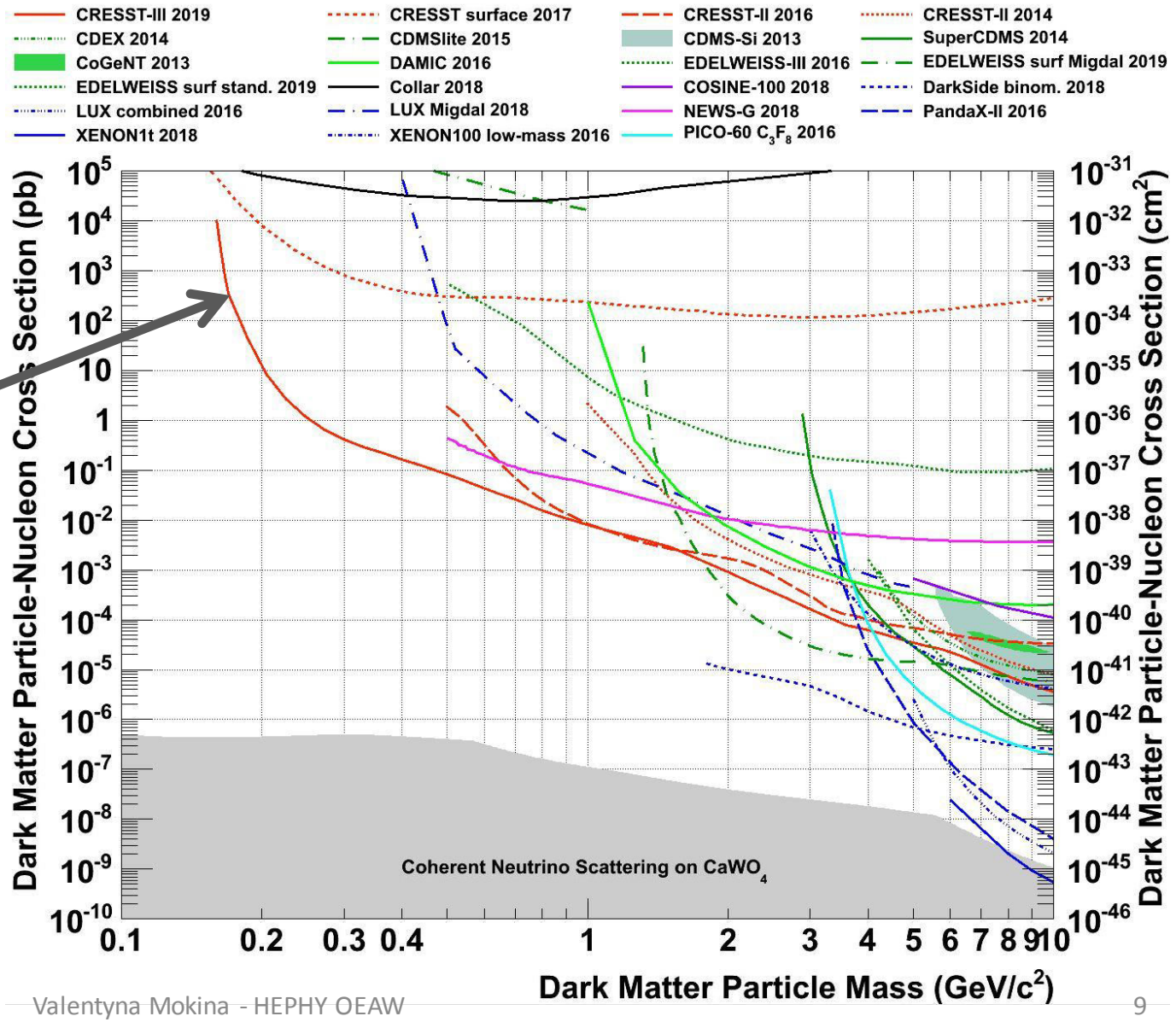
Analysis optimized for very low energies: 30.1eV → 16keV

Result on spin-independent dark matter nucleus scattering

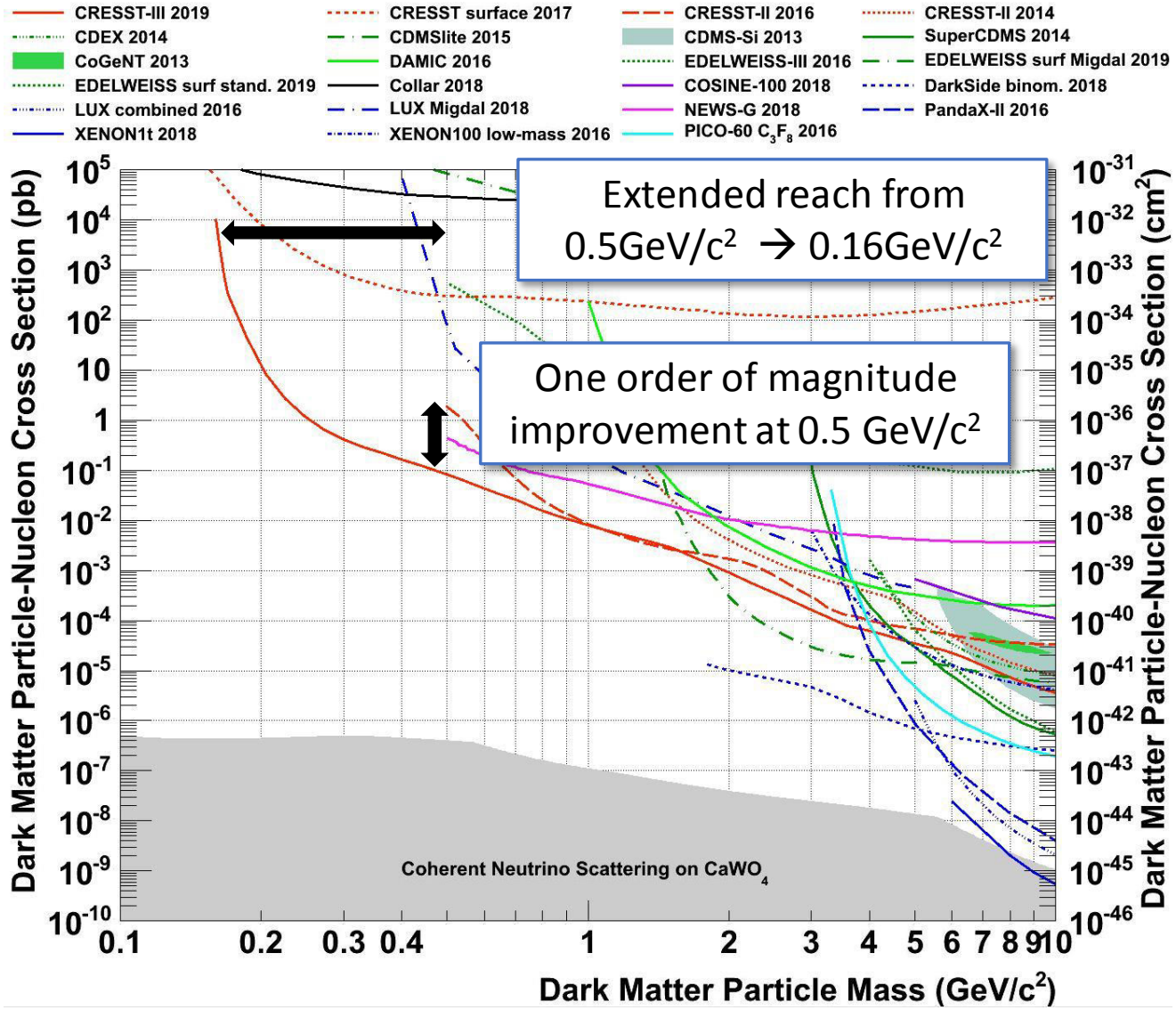
Energy spectrum of accepted events

Yellin 1D optimum interval method

Energy spectrum expected for DM



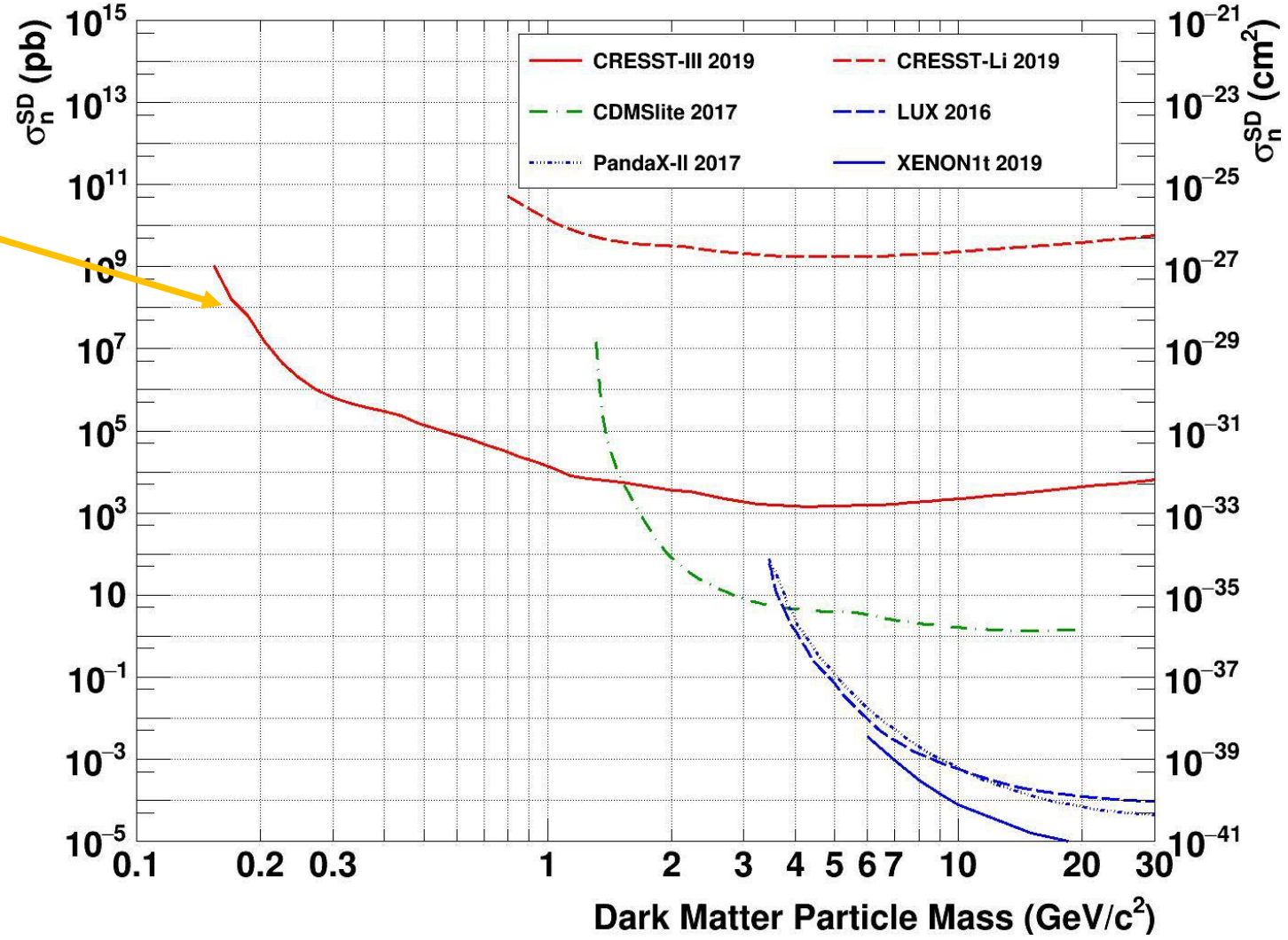
Result on spin-independent dark matter nucleus scattering



arXiv:1904.00498v1

Result on spin-dependent neutron-only interactions

- Natural abundance 0.0367%
- Gross exposure 0.46 g days
- Same analysis
- Signal expectation changed



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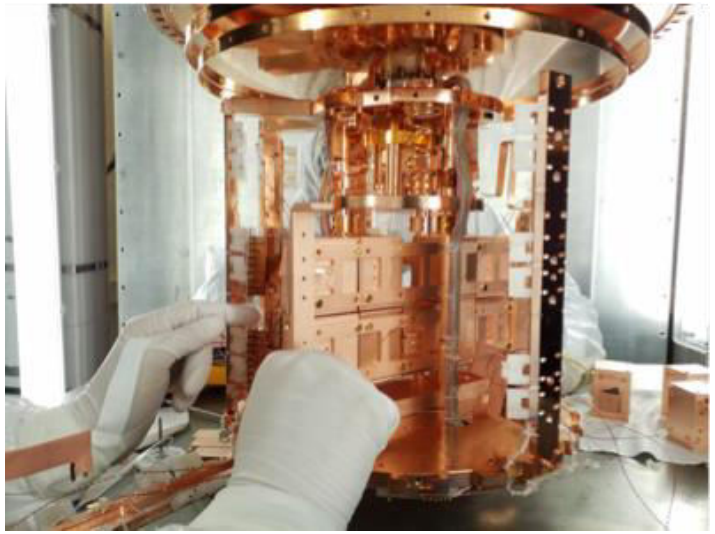
CRESST-III Phase 1 new run: Is ongoing

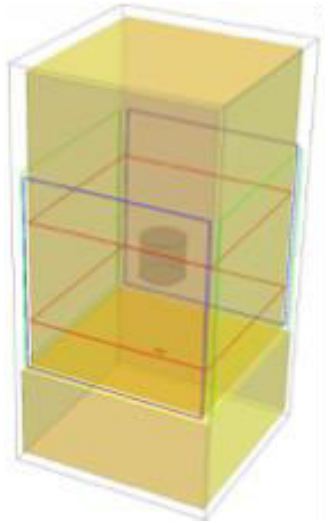
Key innovation

Upgraded detector modules with dedicated hardware changes to understand backgrounds



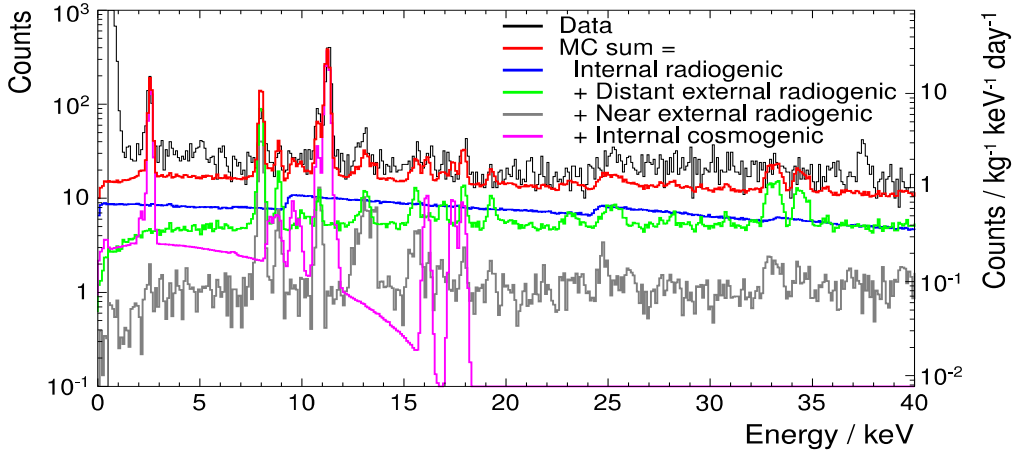
New feature

Active magnetic field compensation with three air coils for x,y & z-axes



Simulation and screening campaign

Simulation

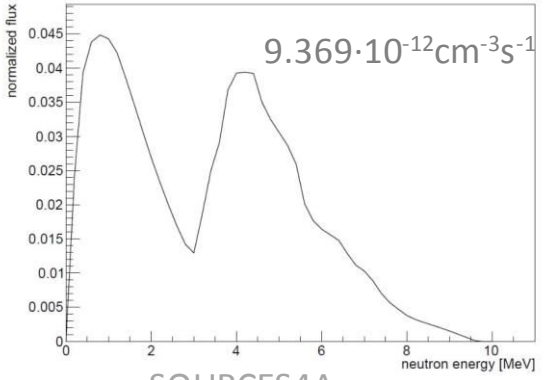


68.5±18% of background can be reproduced with TUM40 detector

-> paper is in preparation

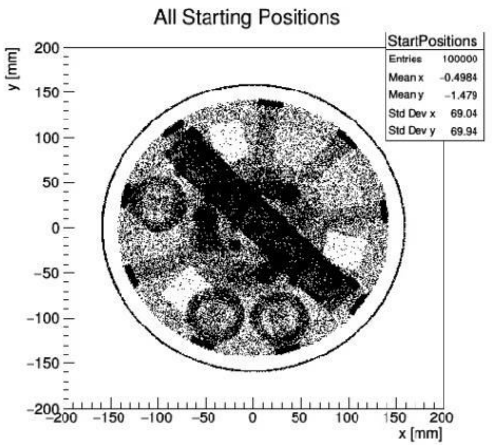
- Geant4 based electromagnetic background model for the CRESST experiment
- Simulation of neutron background
- Study of cosmogenic activation of $CaWO_4$ crystal scintillator

Neutron spectrum and flux in polyethylene

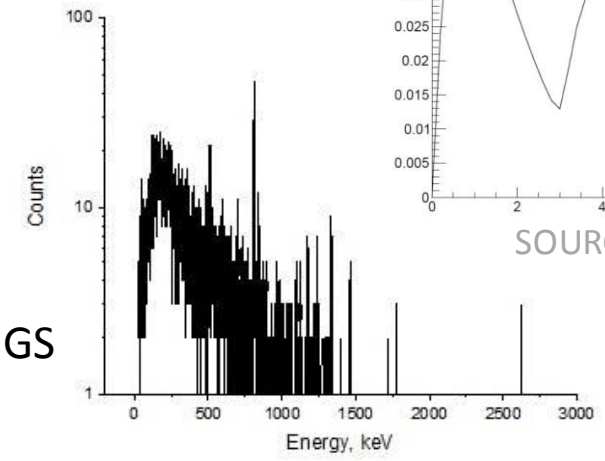


SOURCES4A

^{40}K simulated 10^5 events



GEANT4



Screening campaign

- Activity measurement of Cu with HPGe at LNGS
- Bulk measurements of ^{210}Po

^{232}Th: ^{228}Ra < 24µBq/kg

^{238}U: ^{226}Ra < 20µBq/kg

^{234}Th < 3.5mBq/kg

^{235}U < 50µBq/kg

^{210}Po ~ 20mBq/kg

Conclusions

- Unprecedented low nuclear recoil thresholds of 30.1eV
- Extended sensitivity over one order of magnitude for spin-independent case: 0.5GeV/c^2 → 0.16GeV/c^2
- For spin-dependent interactions: 1.5GeV/c^2 → 0.16GeV/c^2
- New run for understanding of the event excess at low energy is ongoing
- Simulation of the background and screening campaign is ongoing

Waiting for dark matter