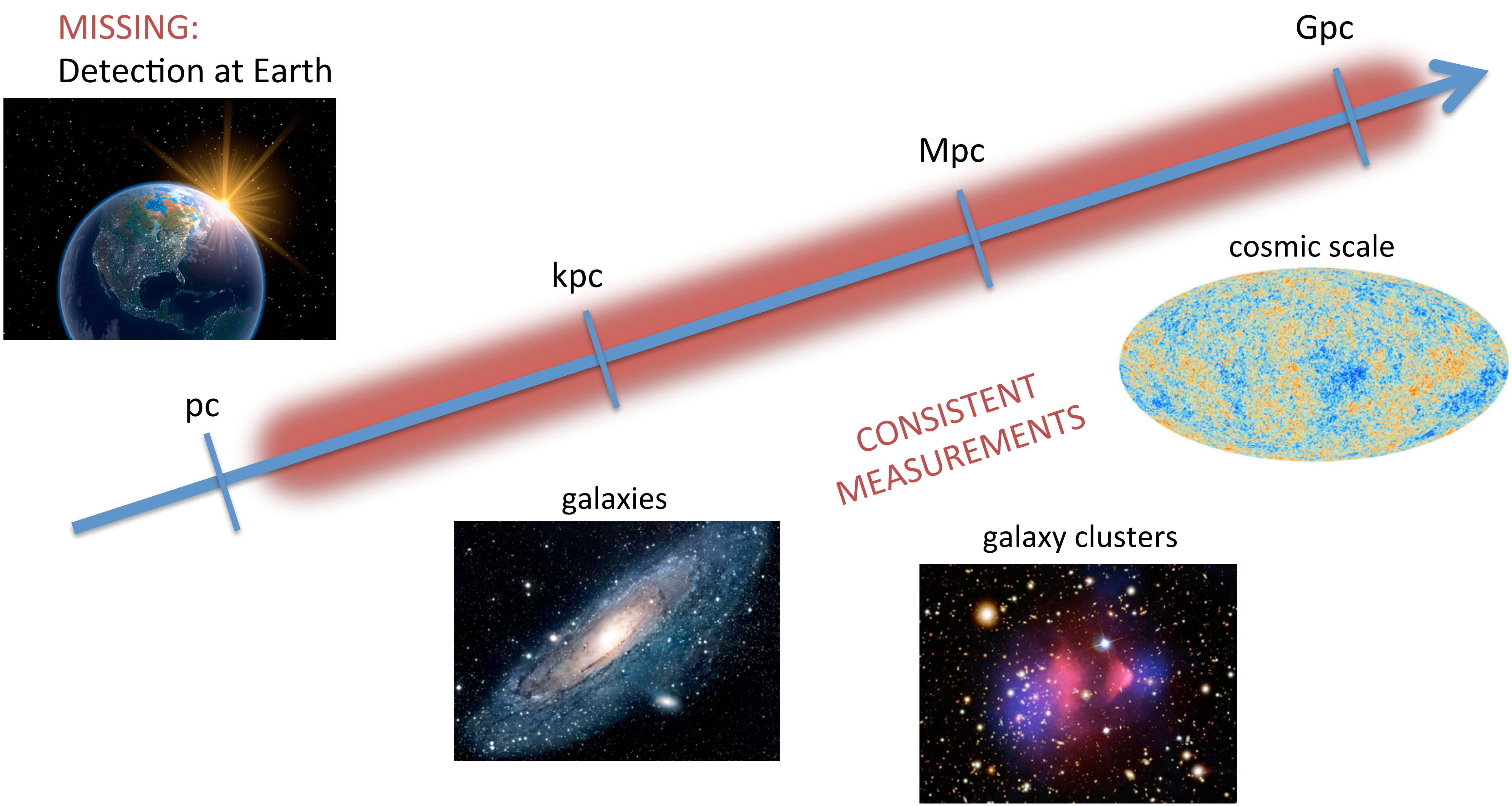
Low-Mass Dark Matter Search with the **CRESST-III** Experiment

Raimund Strauss on behalf of the CRESST Collaboration

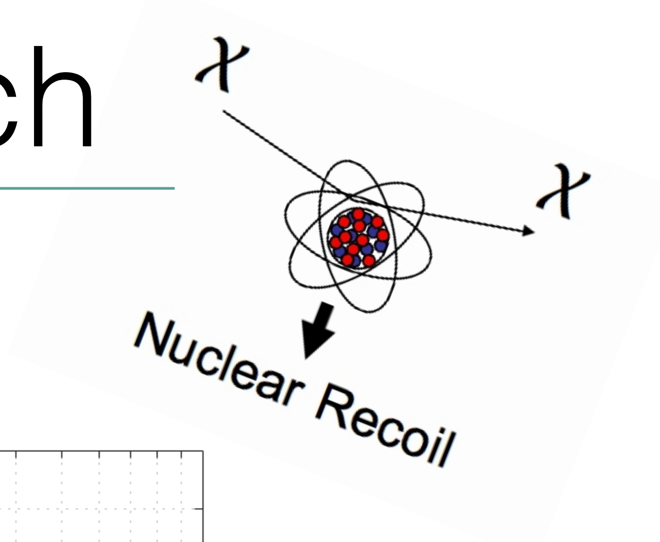
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

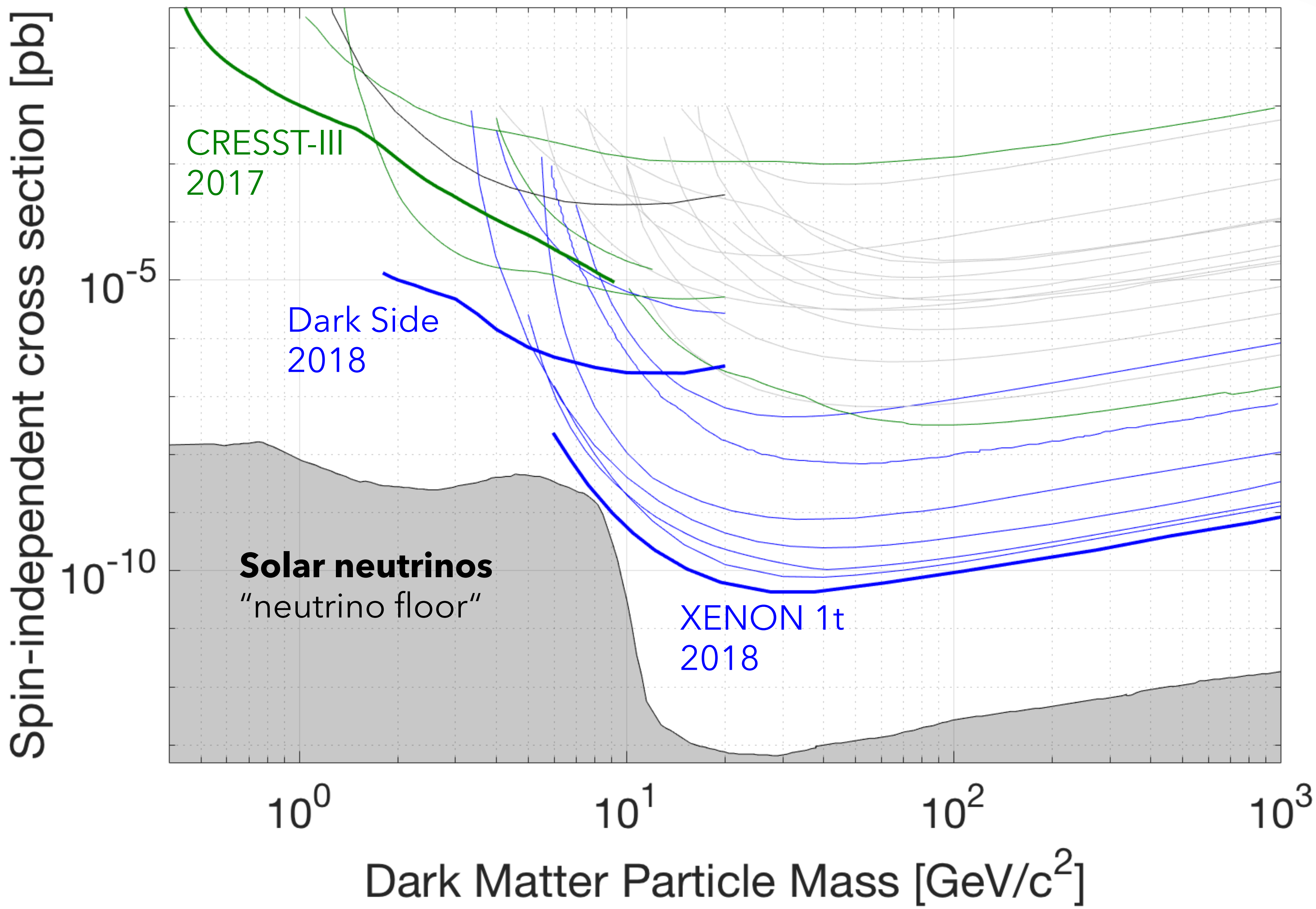
NDM 2018, Daejeon, Korea
30.6.2018

Evidence for Dark Matter



Direct Dark Matter Search





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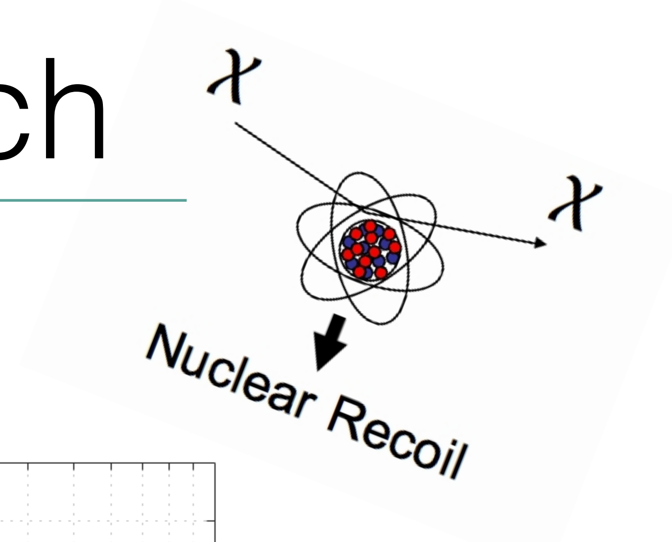
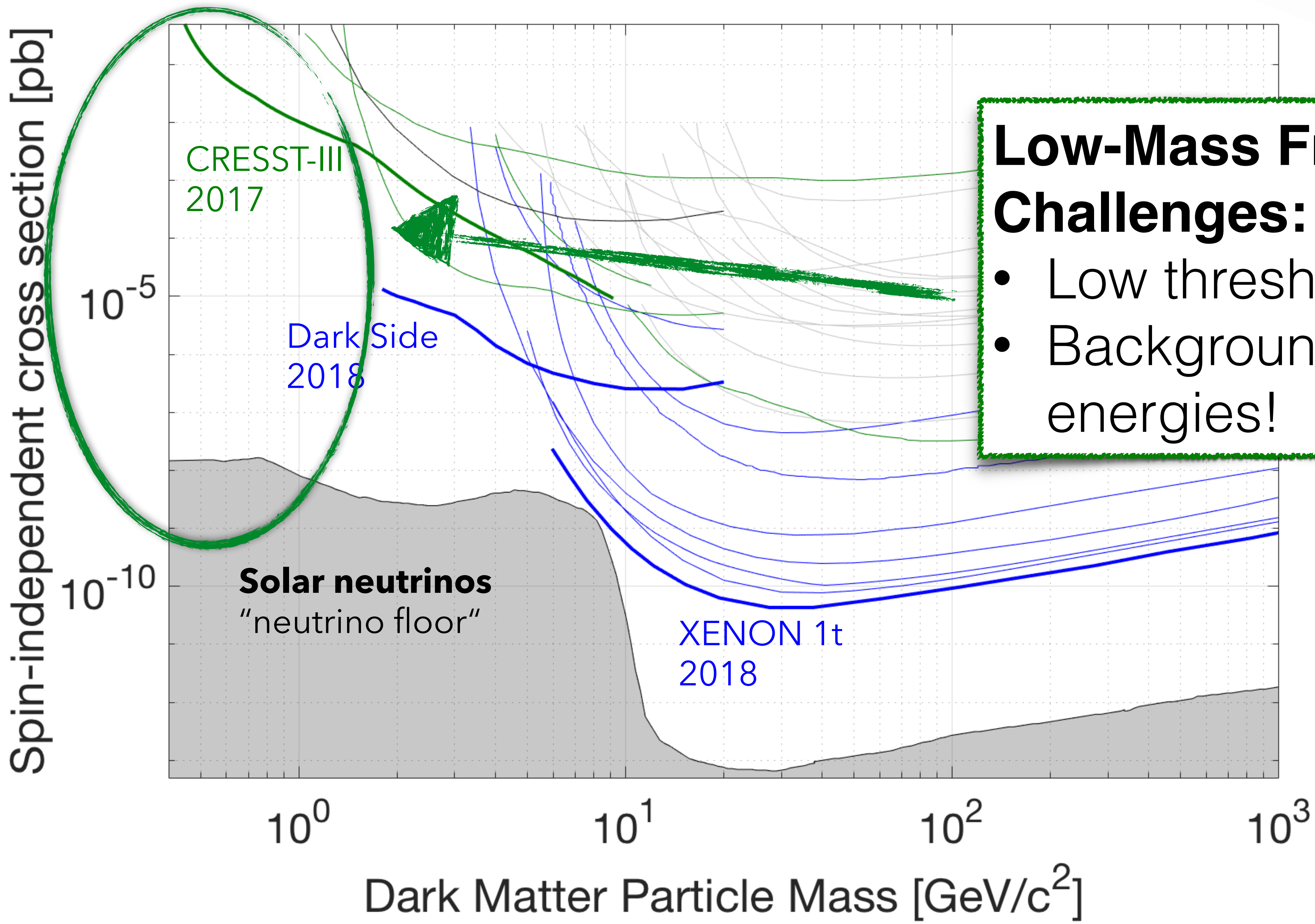




Low-Mass Frontier Challenges:
- Low threshold
- Background at low energies!

THE CRESST COLLABORATION

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

TUM
TECHNISCHE UNIVERSITÄT MÜNCHEN

ÖAW
ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

INFN
Istituto Nazionale di Fisica Nucleare

UNIVERSITY OF OXFORD

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

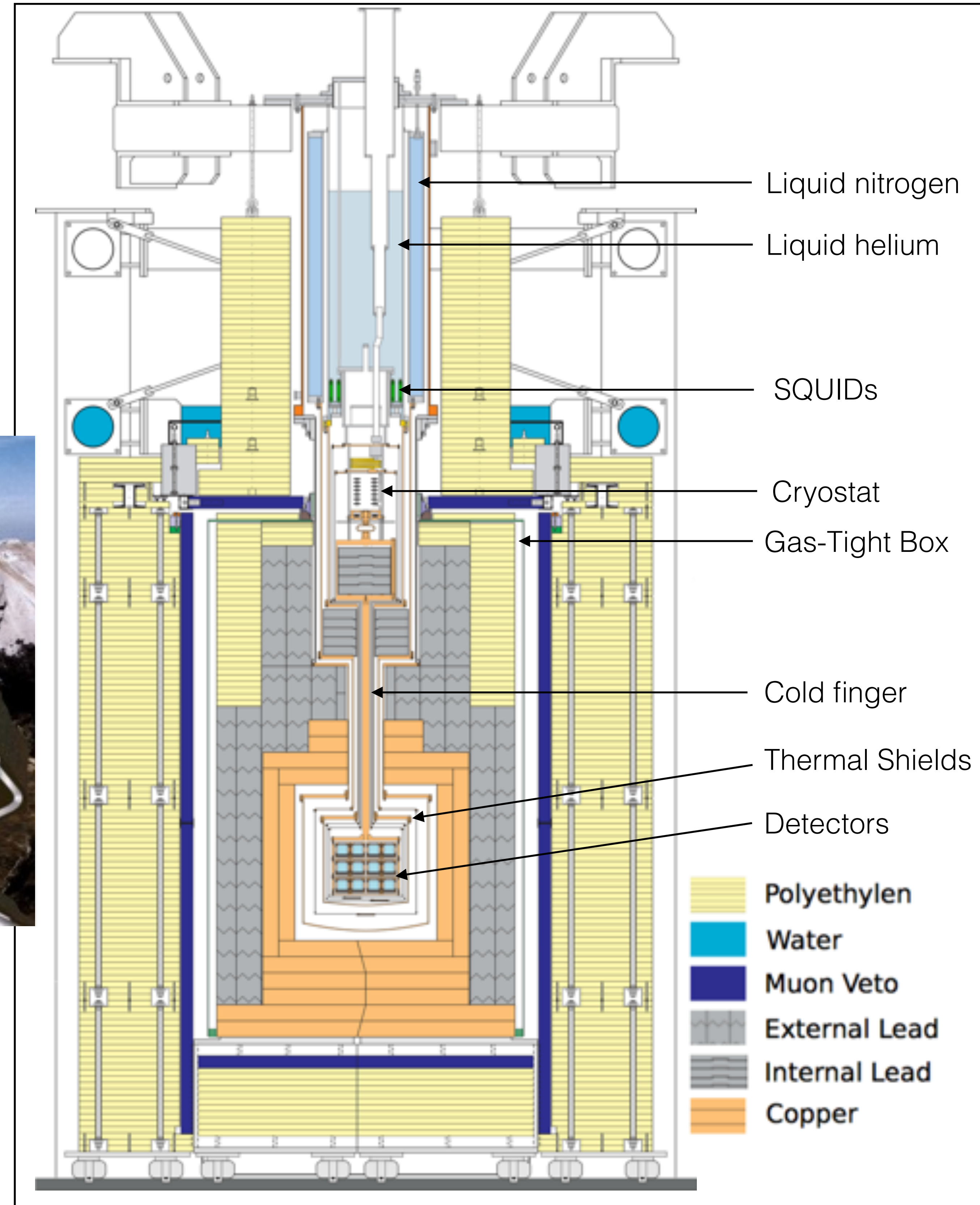
TU WIEN

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

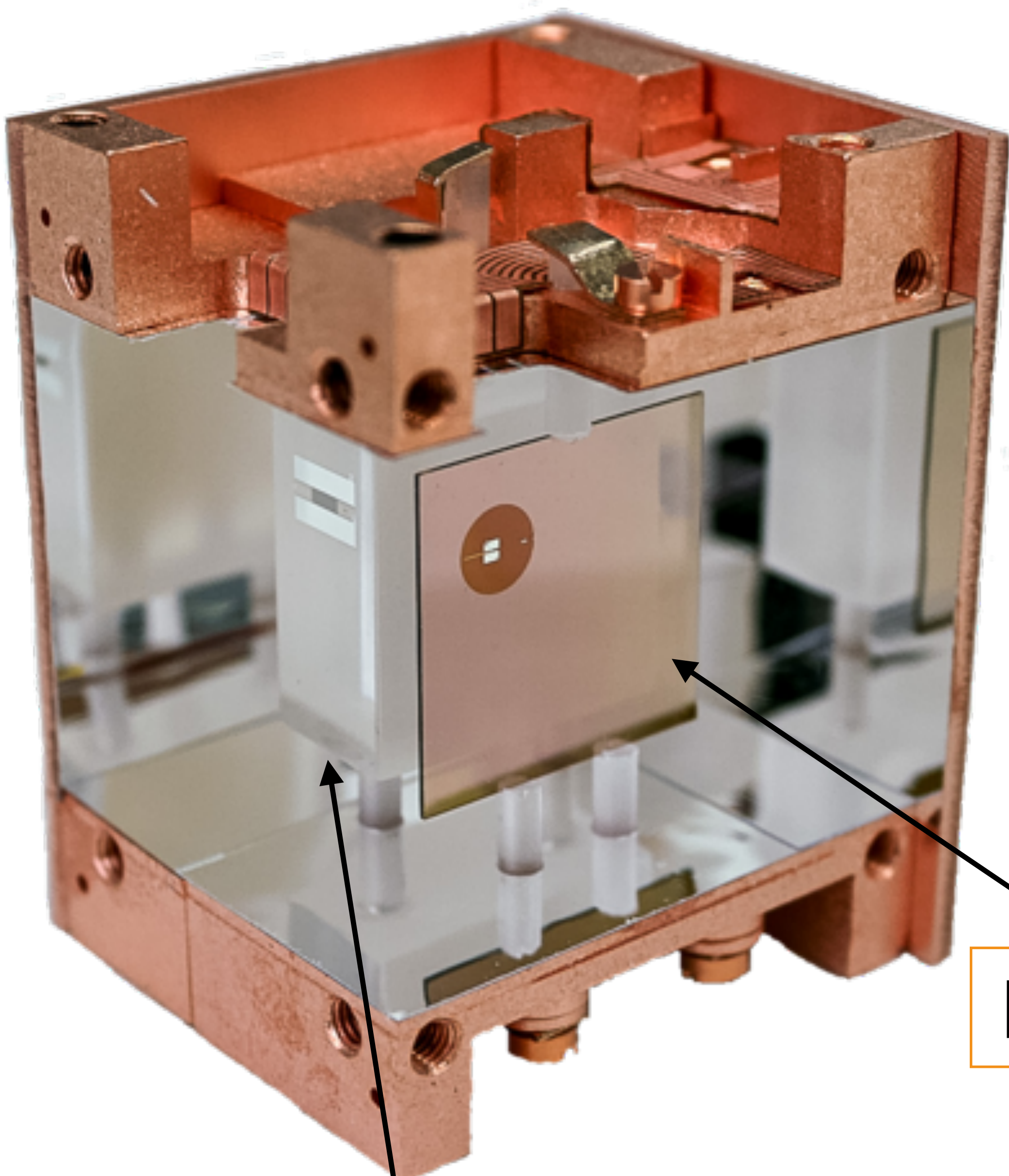
Laboratori Nazionali del Gran Sasso

INFN
LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

Located under Gran Sasso mountain:
~ 3600 wme (water meter equivalent)



THE CRESST-III DETECTOR



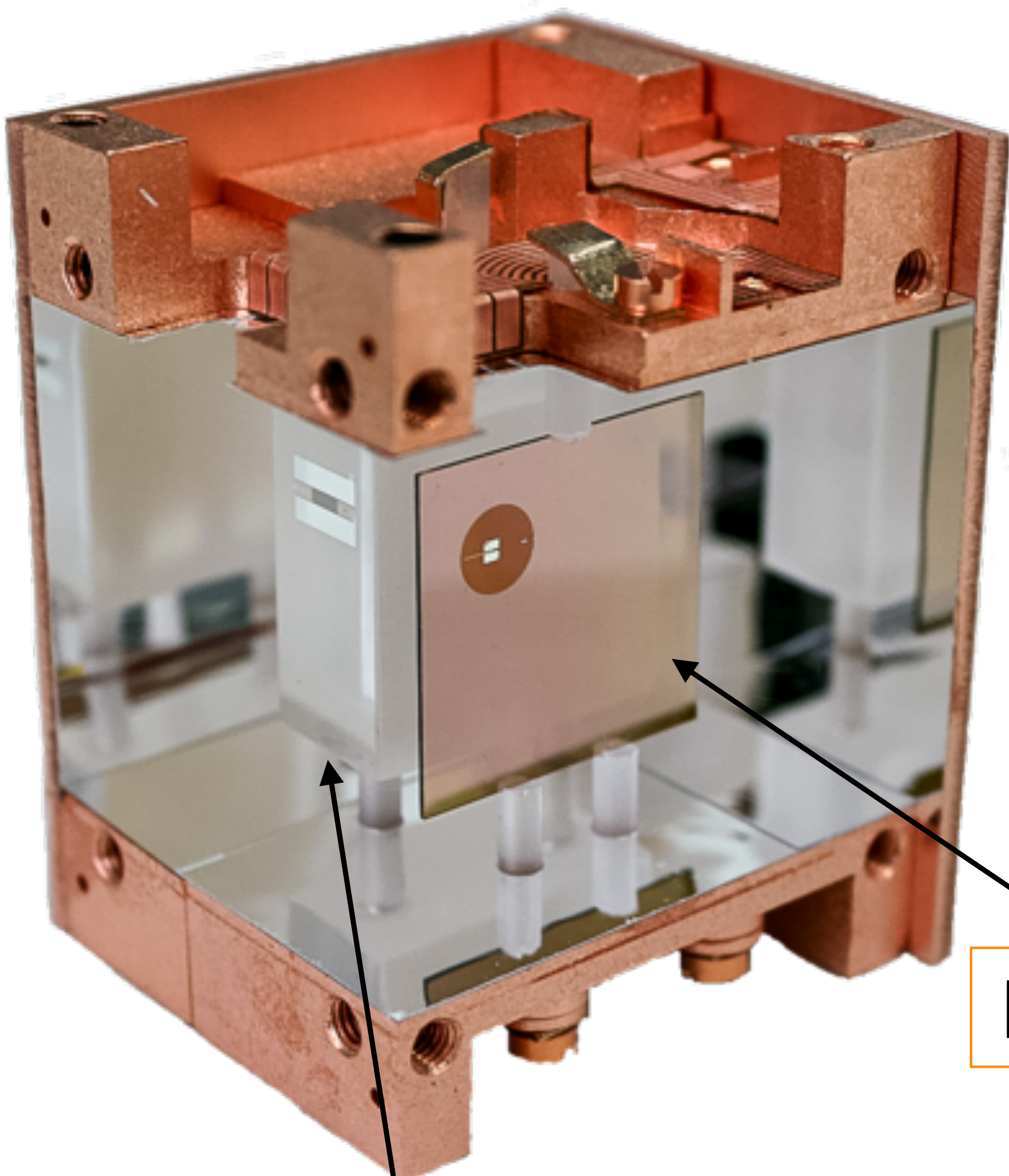
$CaWO_4$ as target material

- scintillating crystal
- mass: 24g
- cryogenic detector (operated at ~10 mK)

Light detector: Silicon-on-sapphire

Phonon detector: CaWO crystal

THE CRESST-III DETECTOR



$CaWO_4$ as target material

- scintillating crystal
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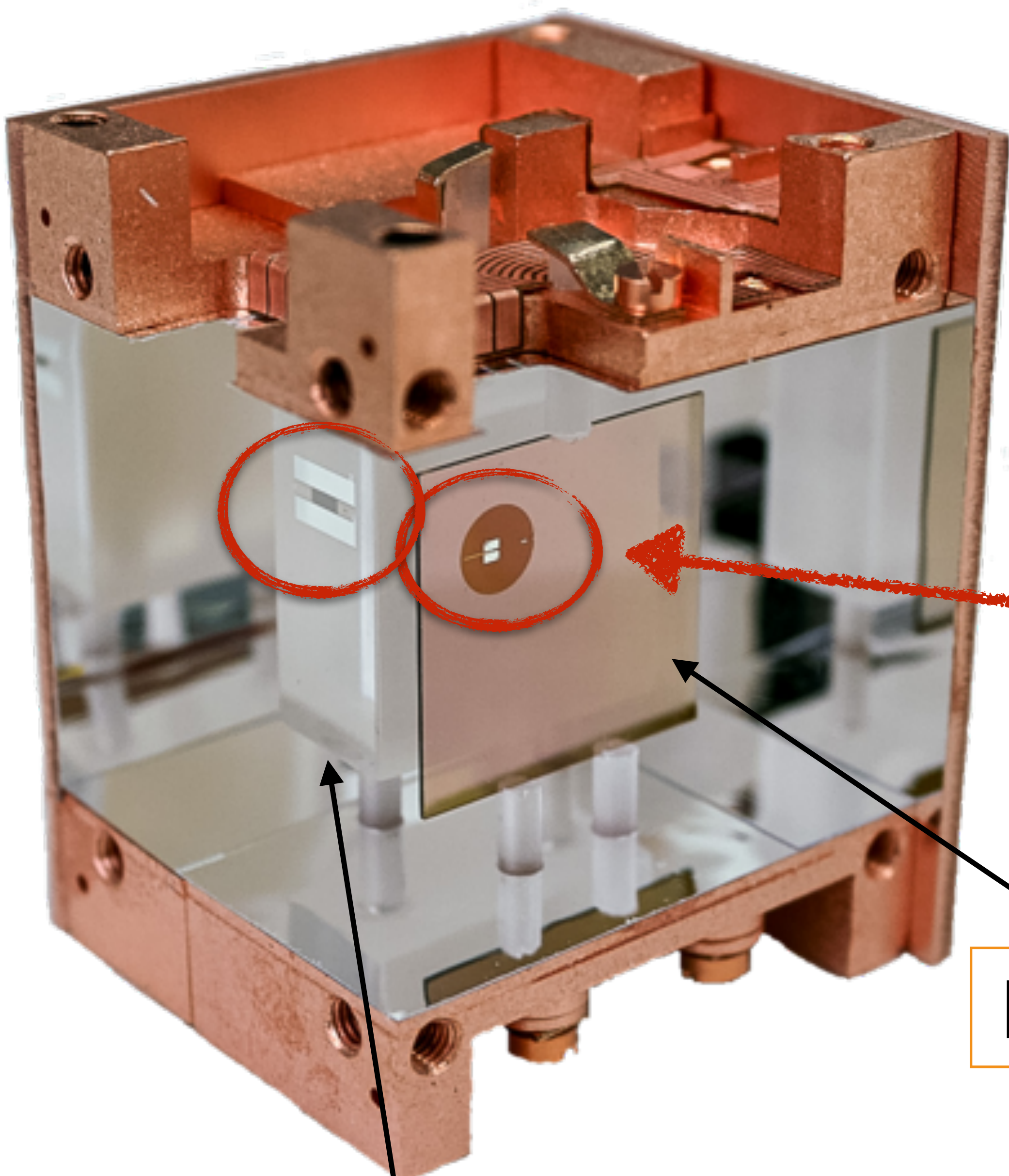
Light detector: Sili pphire

scintillation light output

Phonon detector: C tal

total energy deposit

THE CRESST-III DETECTOR



$CaWO_4$ as target material

- scintillating crystal
- mass: 24g
- cryogenic detector (operated at ~10 mK)

Thermometers

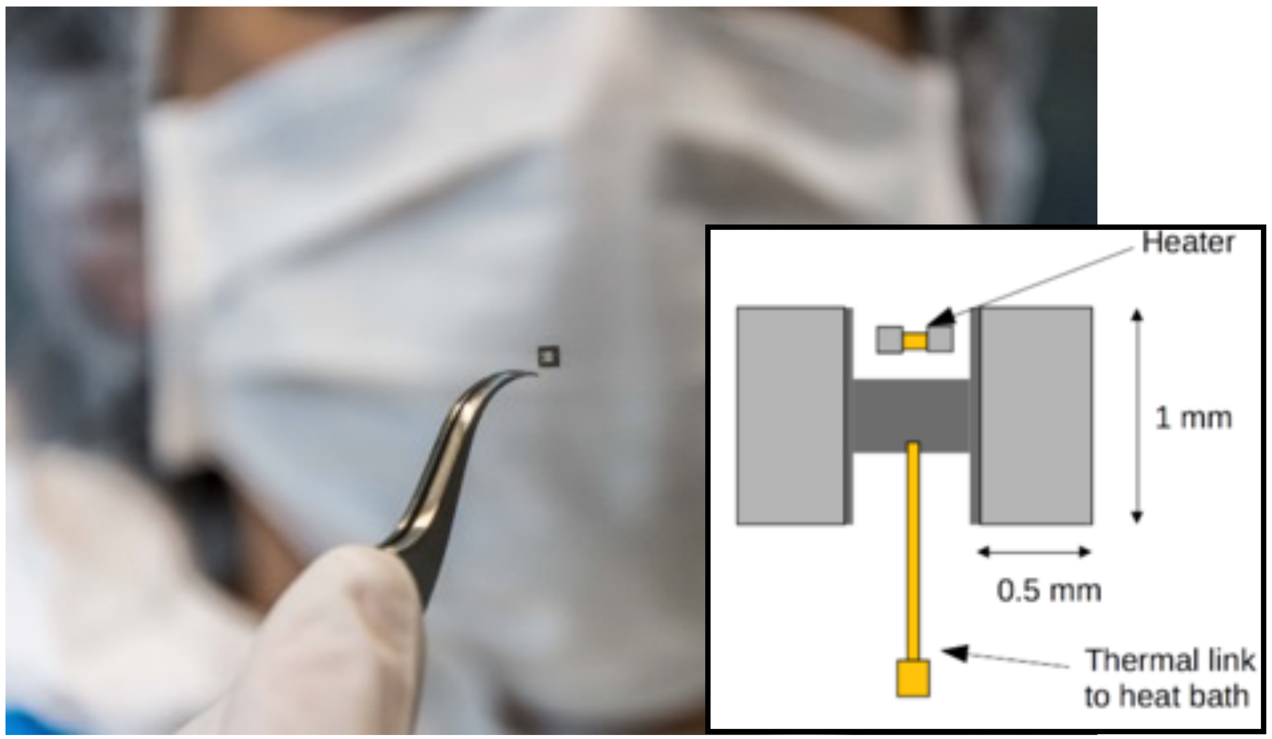
Light detector: Sili pphire

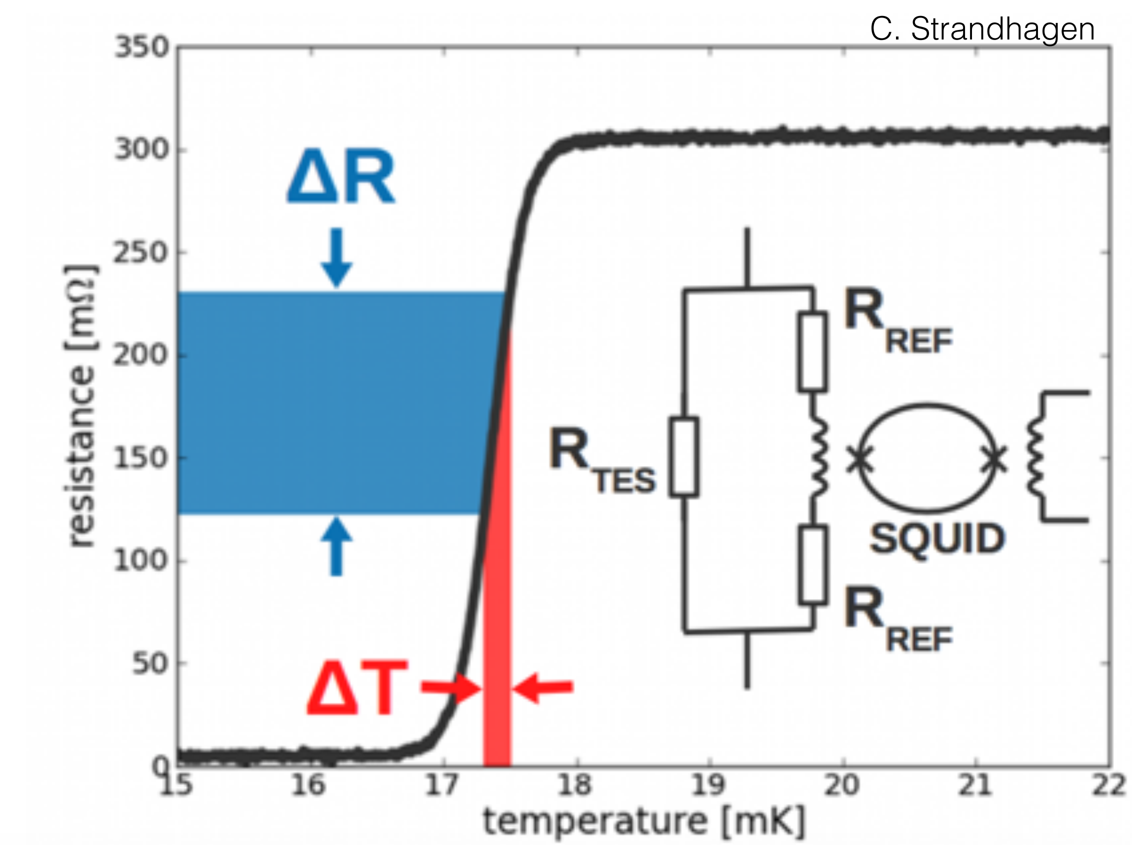
scintillation light output

Phonon detector: C stal

total energy deposit

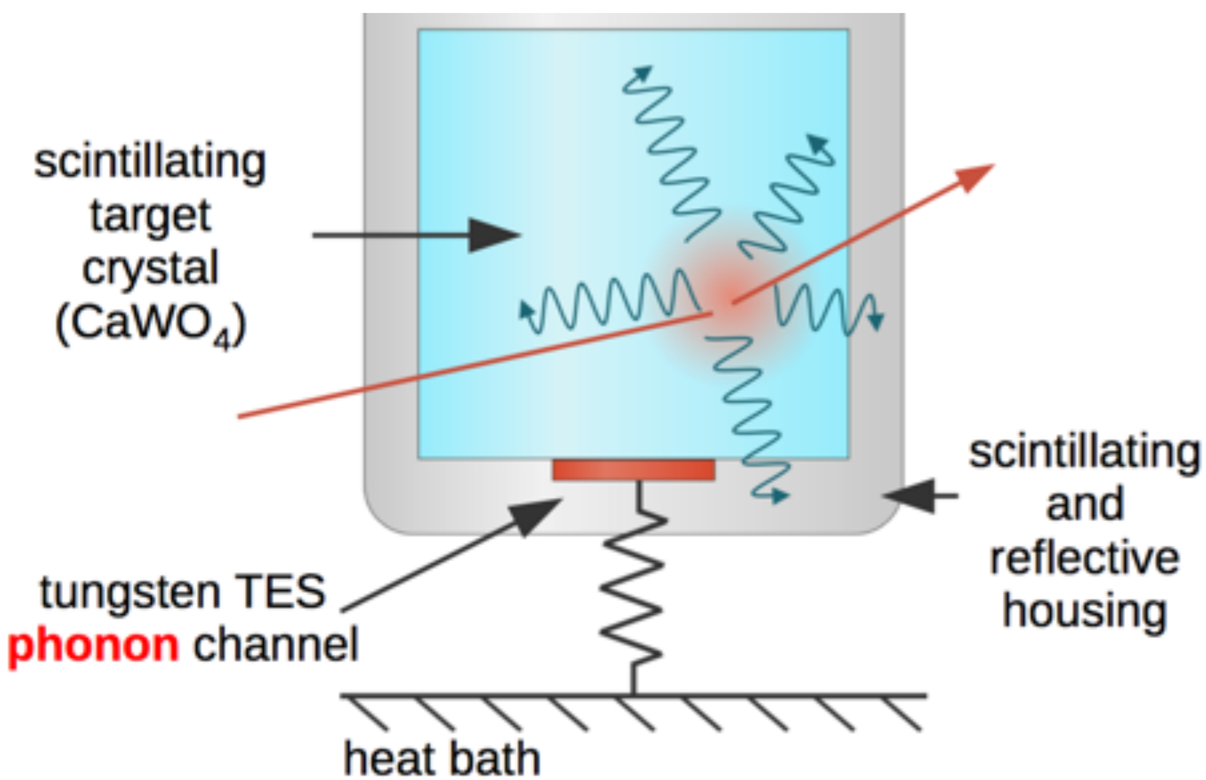
TES: Transition-Edge-Sensor



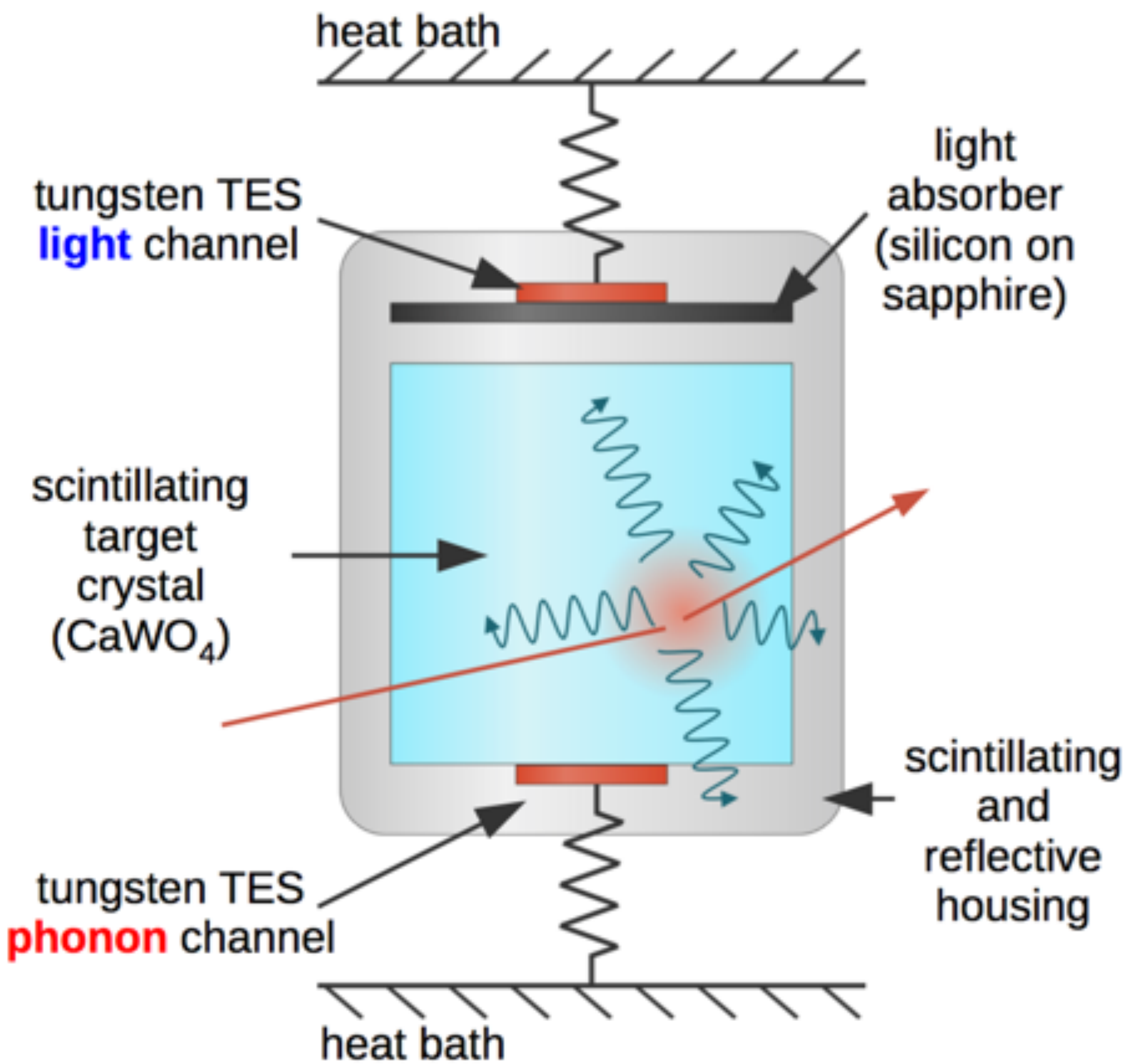


Energy Deposition (keV) → Temperature Increase (μK) → Superconducting Transition of the Resistance (mΩ)

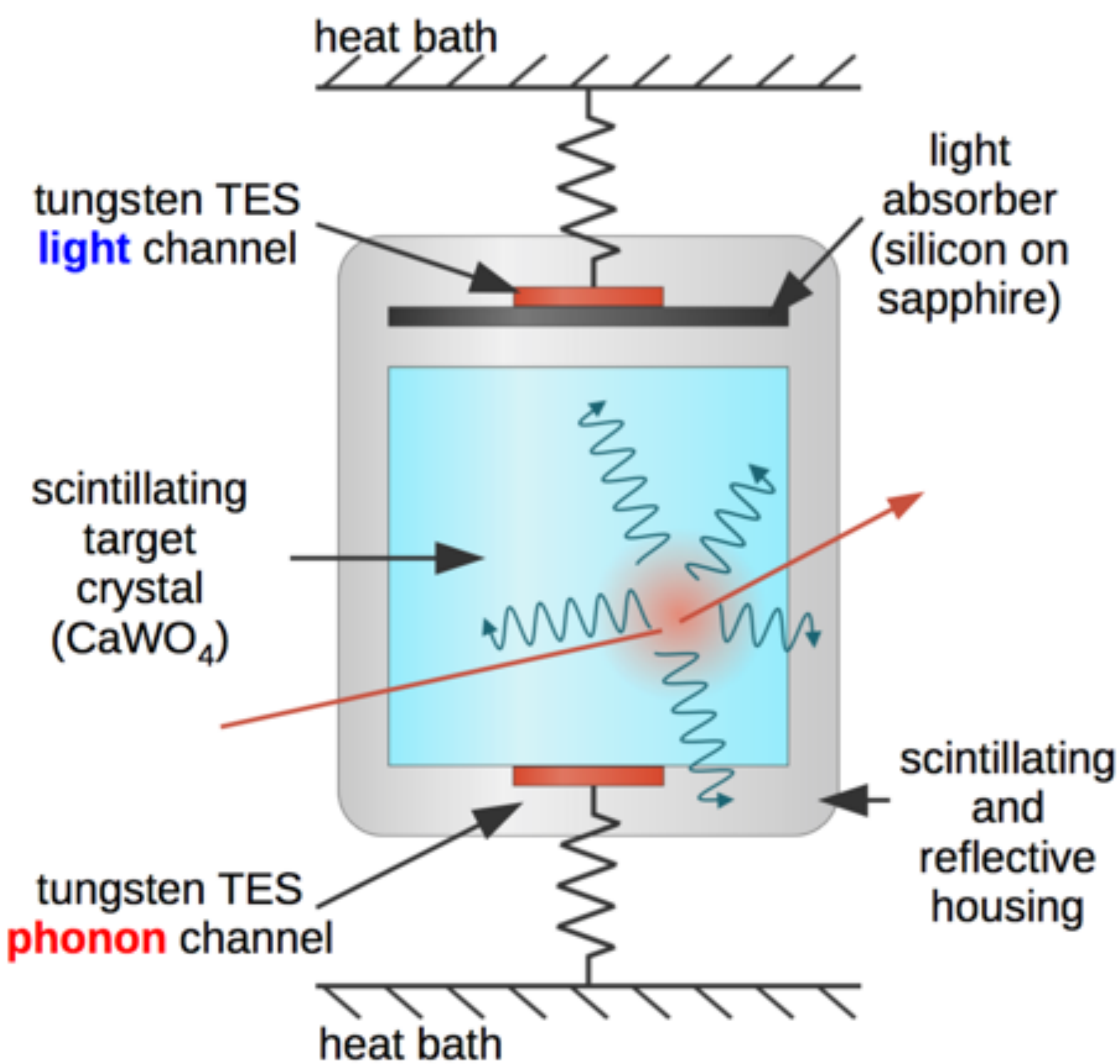
Working Principle



Working Principle

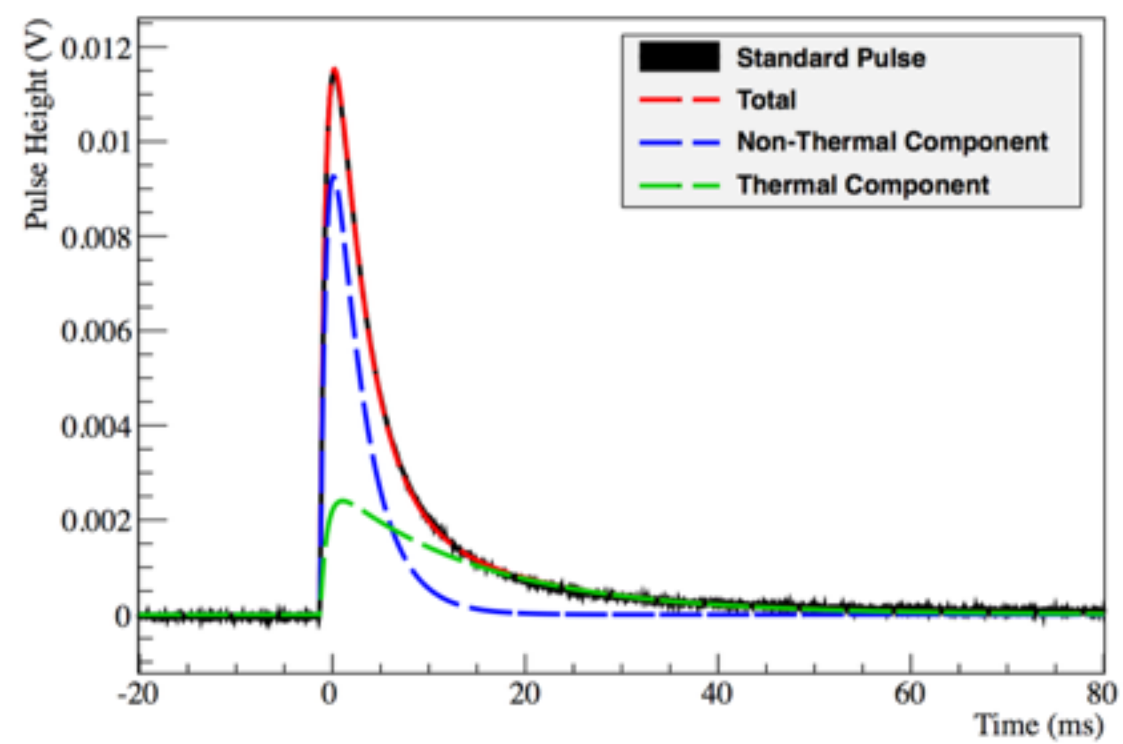


Working Principle

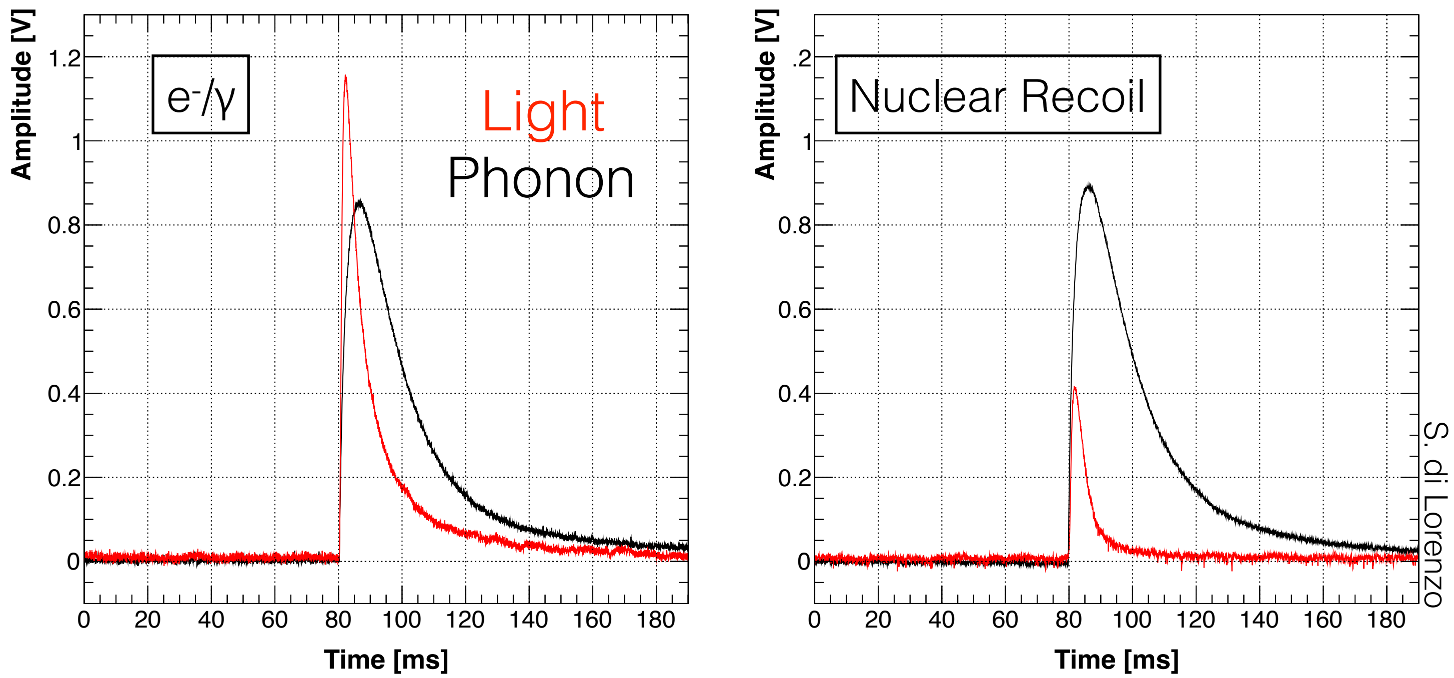


F. Pröbst et al, J. Low Temp. Phys. 100,69 (1995)

$$\Delta T_e(t) = \Theta(t) \cdot \left[\underbrace{A_n(e^{-t/\tau_n} - e^{-t/\tau_{in}})}_{\text{Non-thermal}} + \underbrace{A_t(e^{-t/\tau_t} + e^{-t/\tau_n})}_{\text{Thermal}} \right]$$



Particle Discrimination

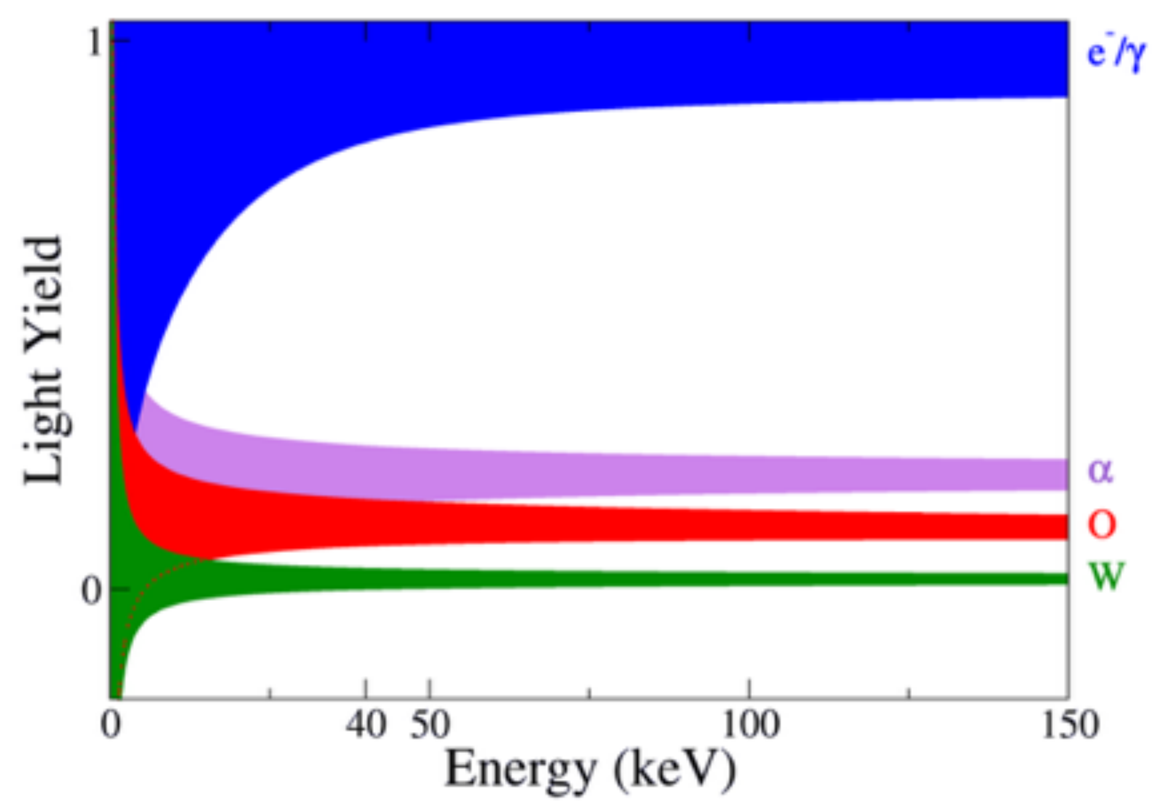


$$\text{Light Yield} = \frac{\text{Light Pulse Energy}}{\text{Phonon Pulse Energy}}$$

This difference in the light yield is described by **Quenching Factors (QF).**

QF in CRESST is roughly scales with the **atomic mass A**.

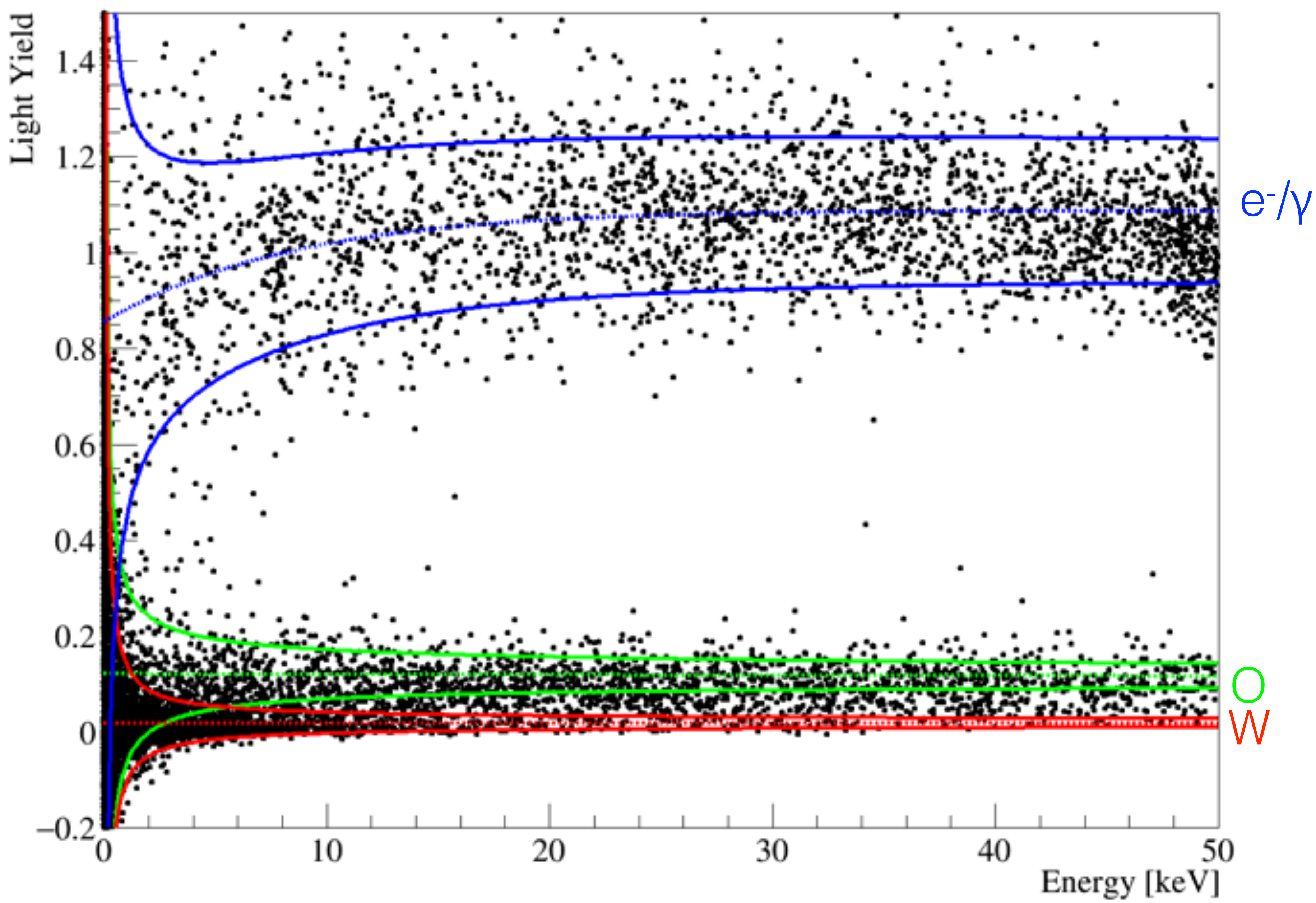
A multi-target crystal (as O, Ca and W) could be a Dark Matter mass spectrometer



Neutron Calibration

Quenching factors measured at the Maier-Leibnitz-Laboratory (MLL)

RS, et al. Eur. Phys. J. C (2014) 74: 2957

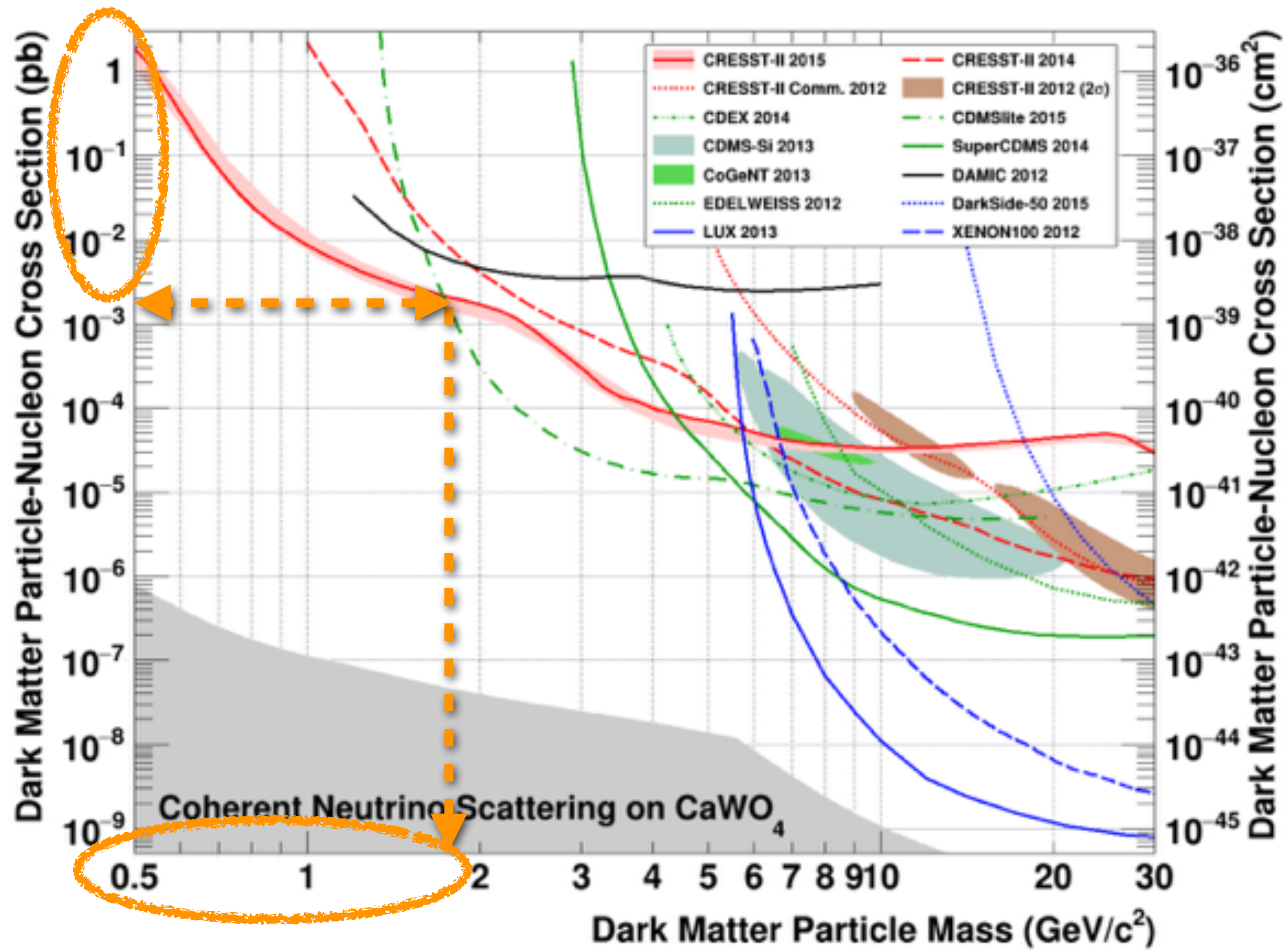


CRESST-II (2015)

- Mass: ~ 300 g x 18 $CaWO_4$ crystal
- Background: ~ 8.5 cpd/ (keV kg) commercial crystals
  ~ 3.5 cpd/ (keV kg) TUM crystals (Technische Universität München)

“Lise“ Detector
Best energy threshold in CRESST-II
(307 eV)

New region of the parameter space explored down to
500 MeV/c²



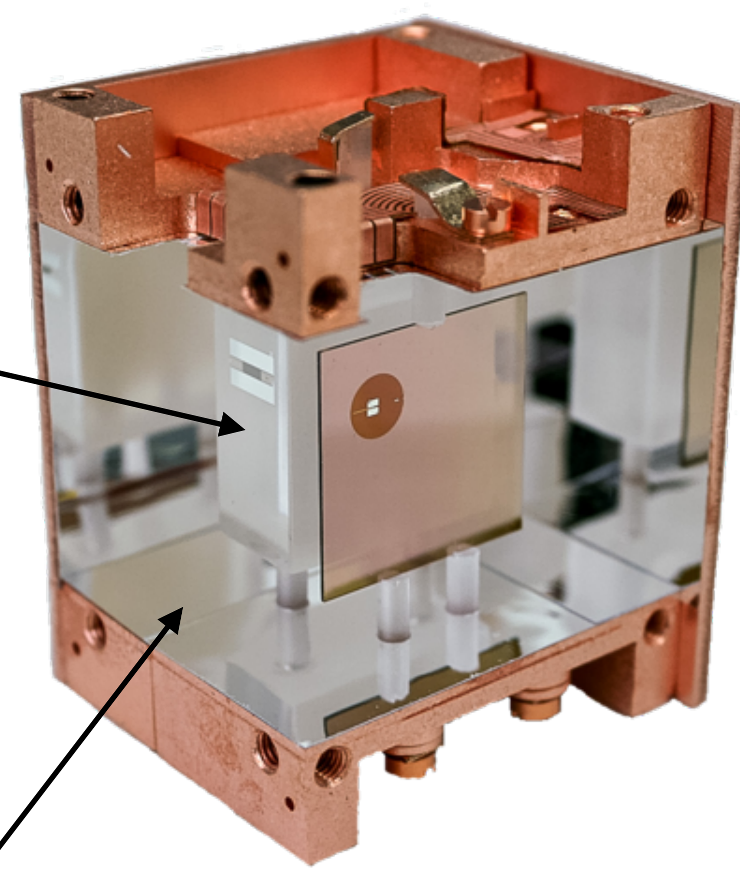
[What’s next?]

From CRESST-II to CRESST-III

Dedicated experiment for low-mass dark matter search

Goal: Threshold of 100eV

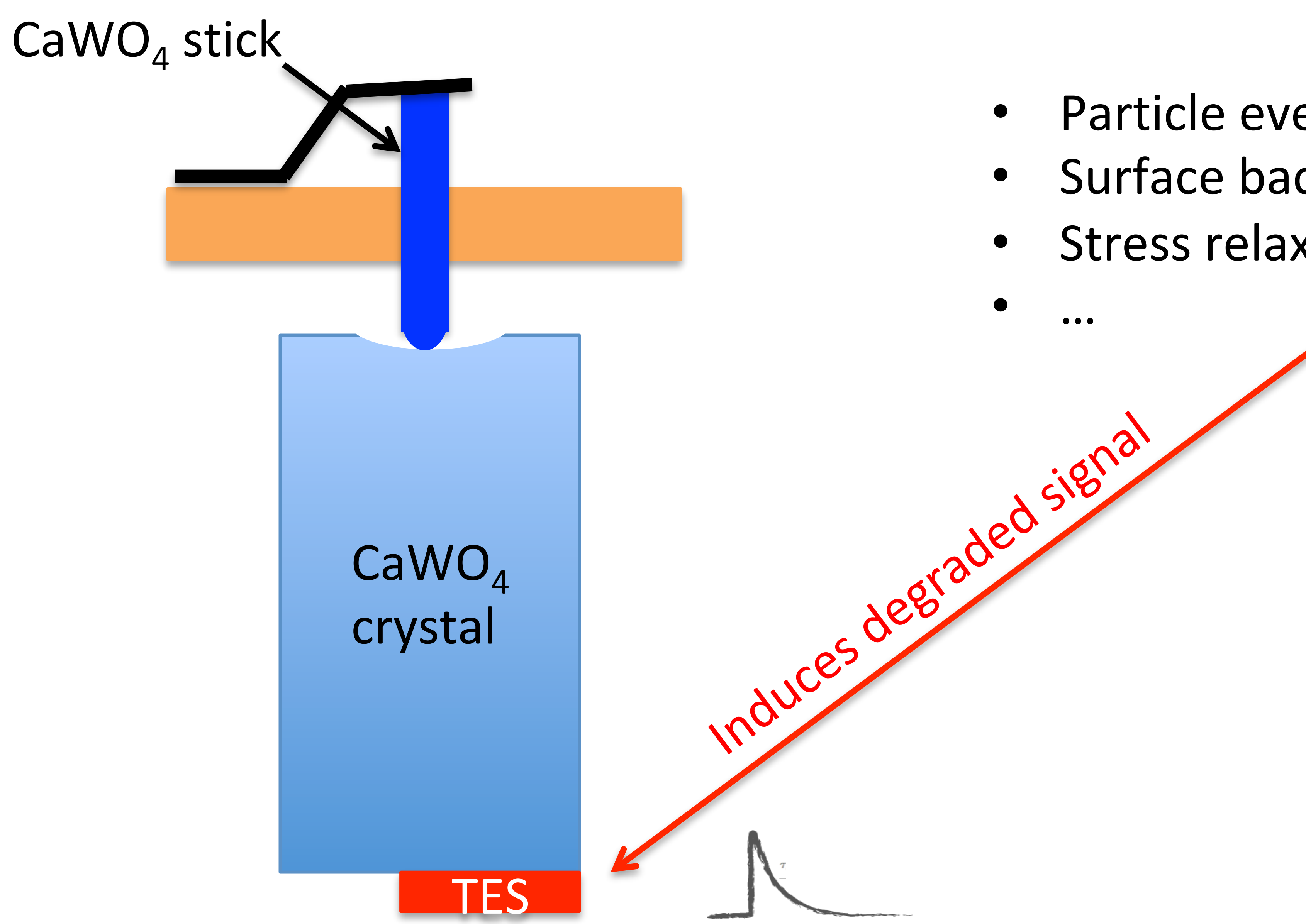
Mass reduction by a factor 10: from 300 g to 24 g crystals



Instrumented detector holder (iSticks)

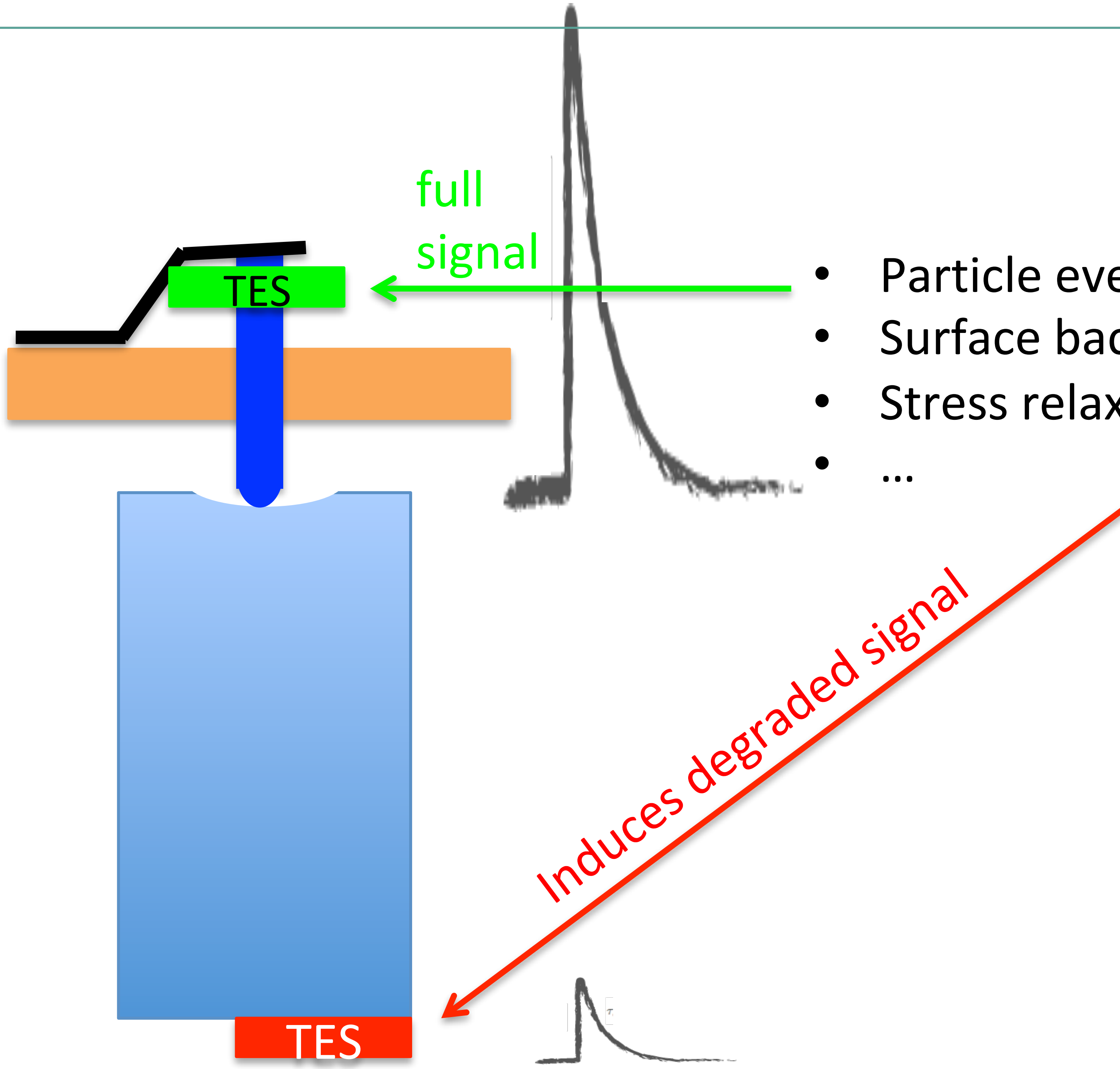
Fully scintillating housing (surface-alpha event discrimination, e.g. $^{210}Po \rightarrow ^{206}Pb + \alpha$)

CRESST-III: Instrumented Holder



- Particle events in sticks
- Surface backgrounds
- Stress relaxations
- …

CRESST-III: Instrumented Holder



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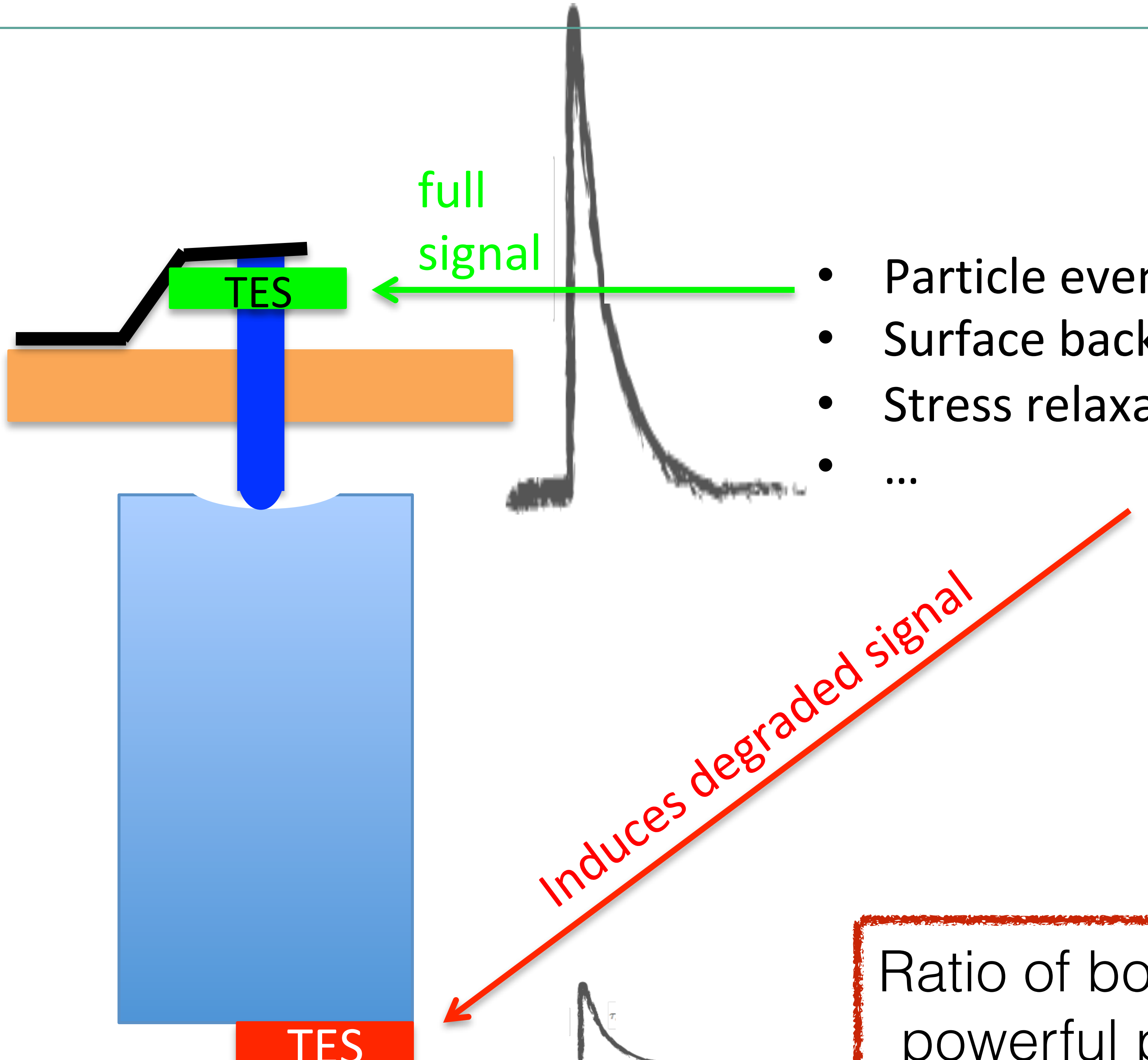
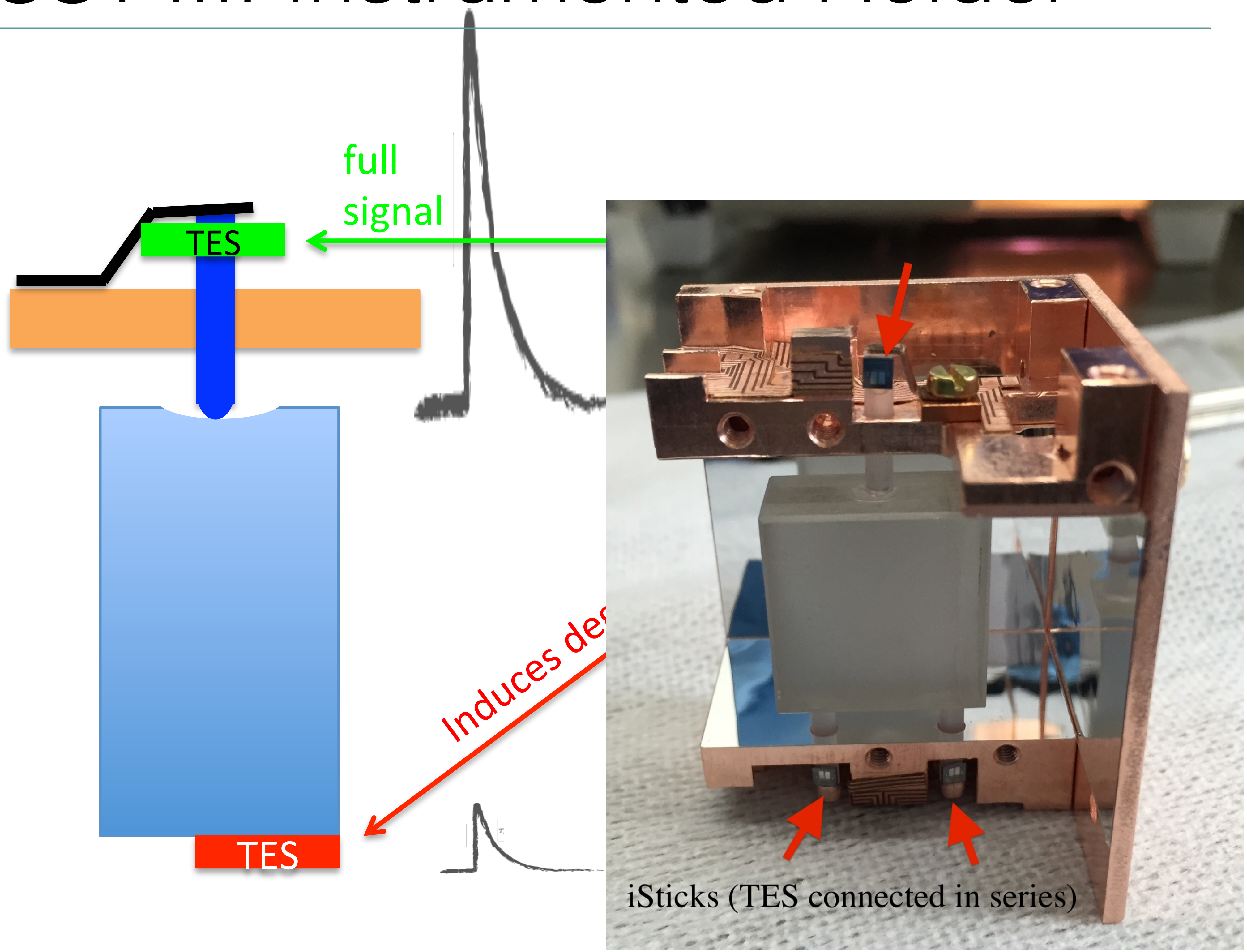
CRESST-III: Instrumented Holder



- Particle events in sticks
- Surface backgrounds
- Stress relaxations
- …

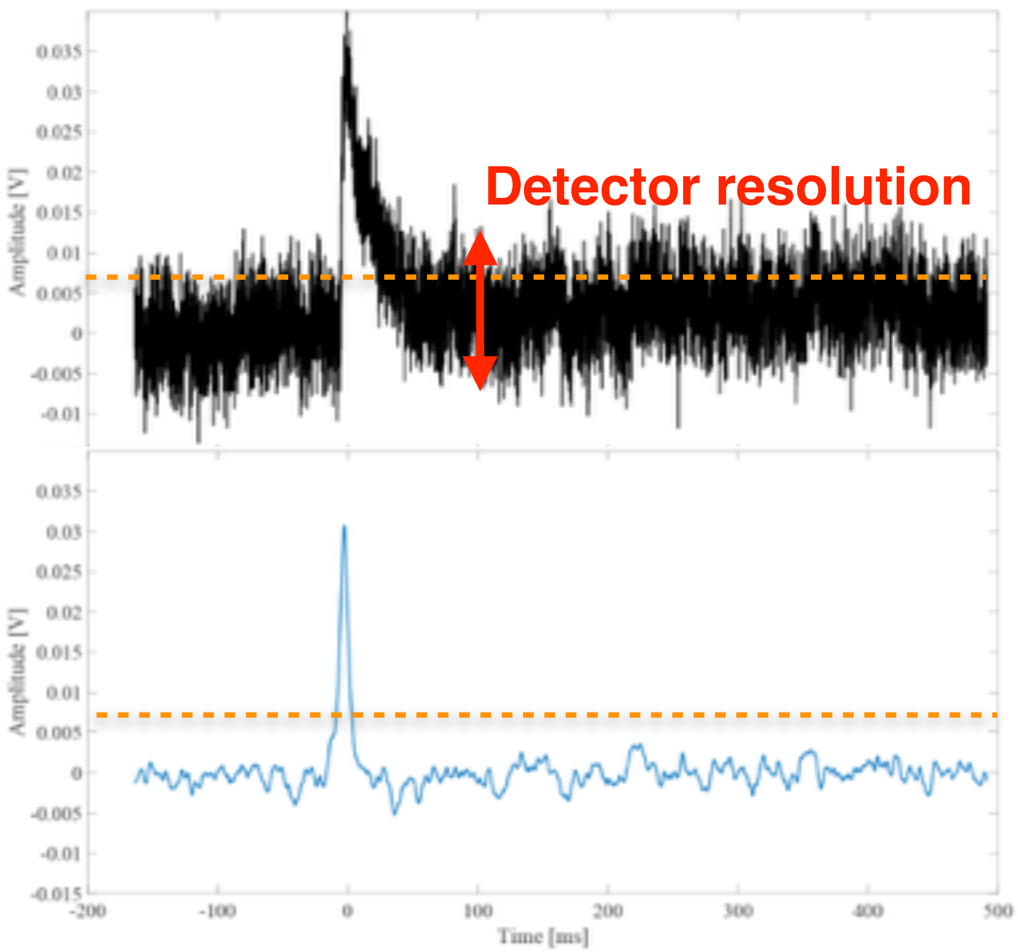
Ratio of both signals is a powerful parameter for background reduction

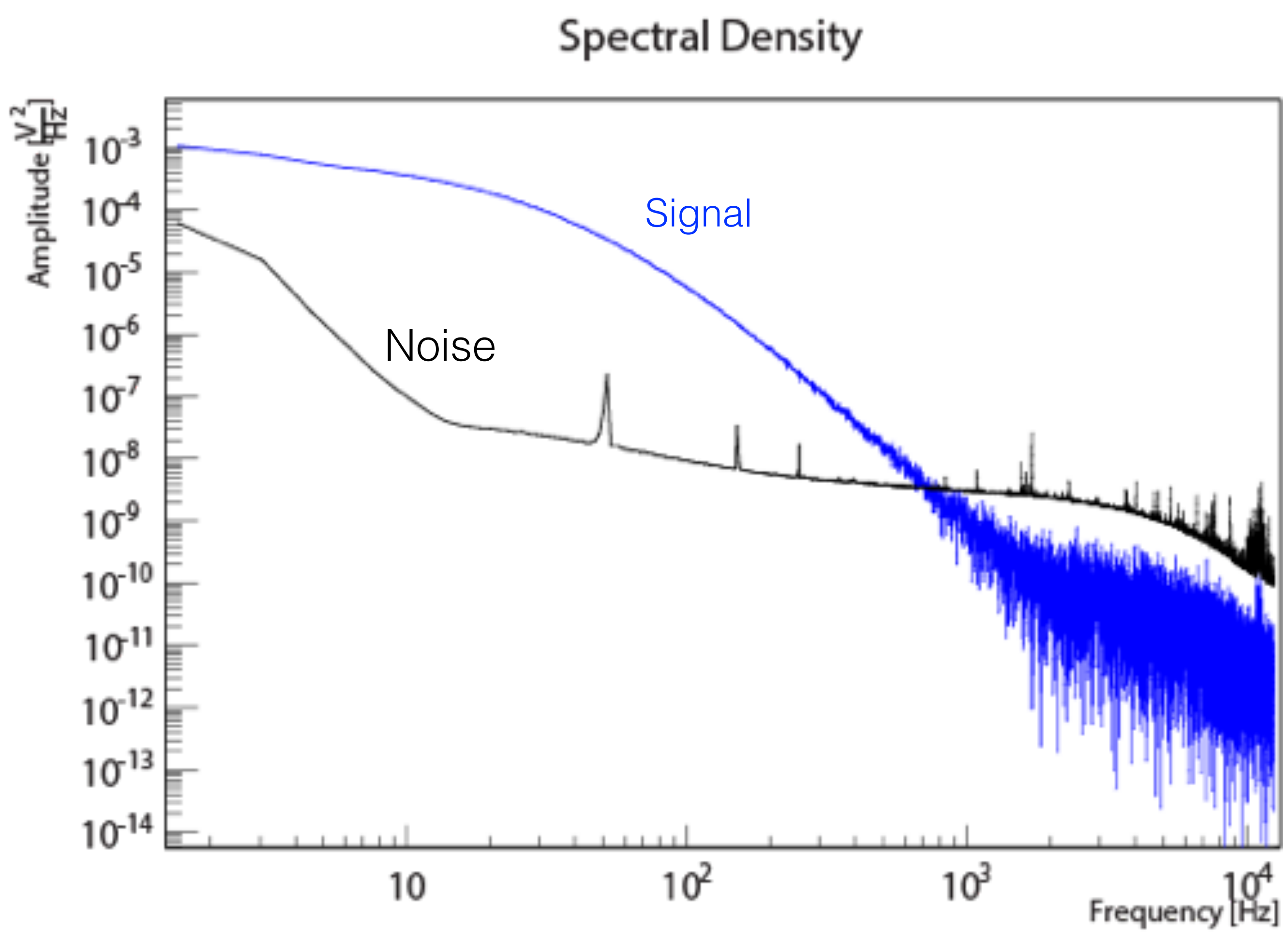
CRESST-III: Instrumented Holder



New Trigger Mode

- **Optimum Filter:** Maximization of the signal-to-noise ratio (**J Low Temp Phys (2018).** https://doi.org/10.1007/s10909-018-1948-6)
- **Continuous data acquisition system**
- **Software trigger**

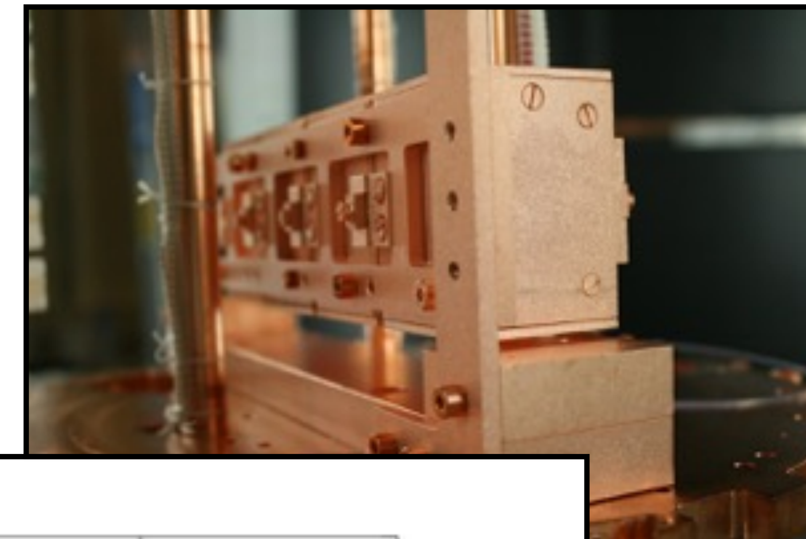


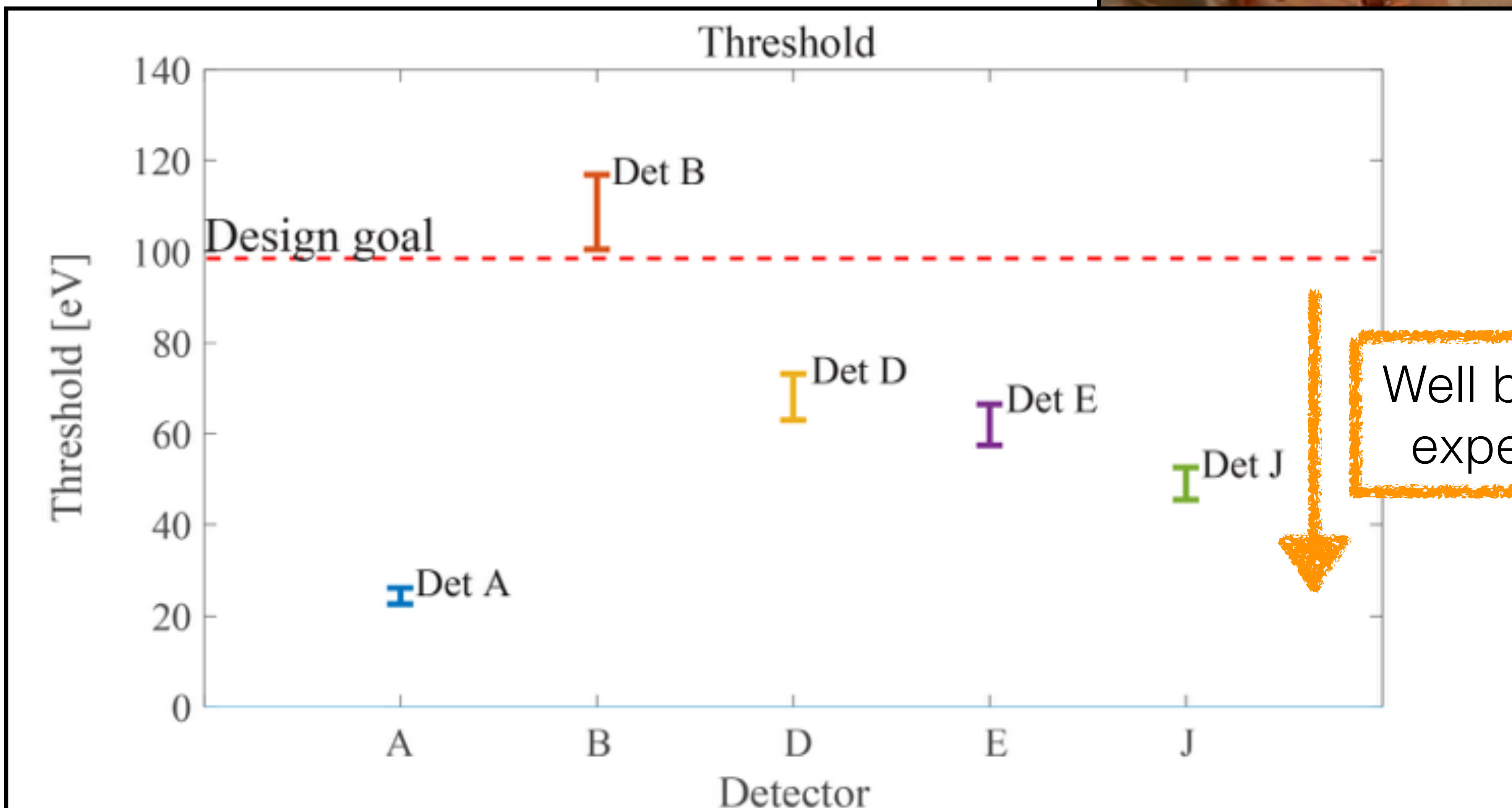


Typical improvement in S/N: factor 2-3

CRESST-III Phase 1: Threshold Results

- 10 crystals, 24 g each, (20x20x10) mm^3
- Background ~ **3 counts/(day kg keV)***
- Run from July 2016 to February 2018

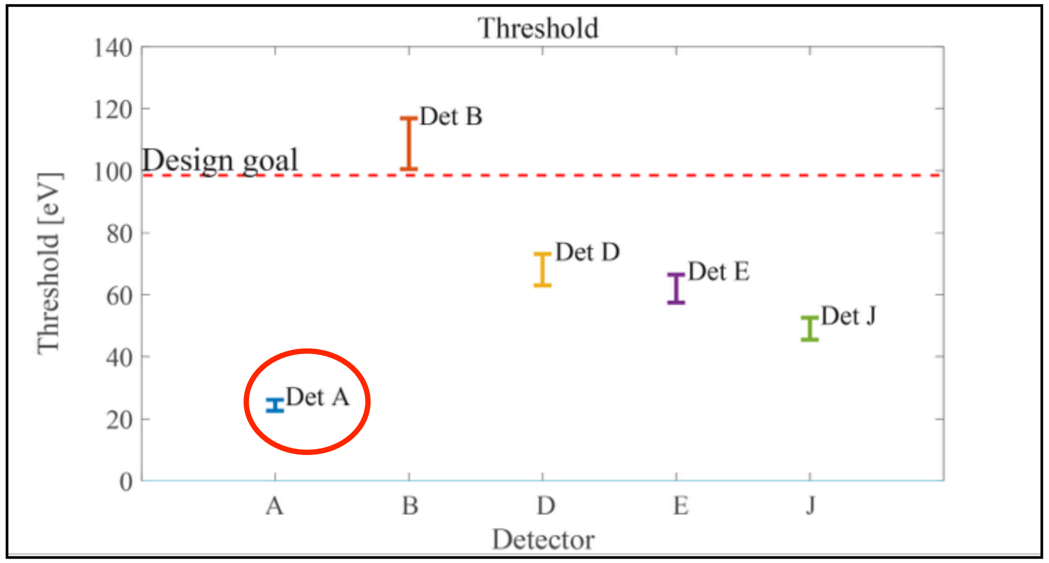




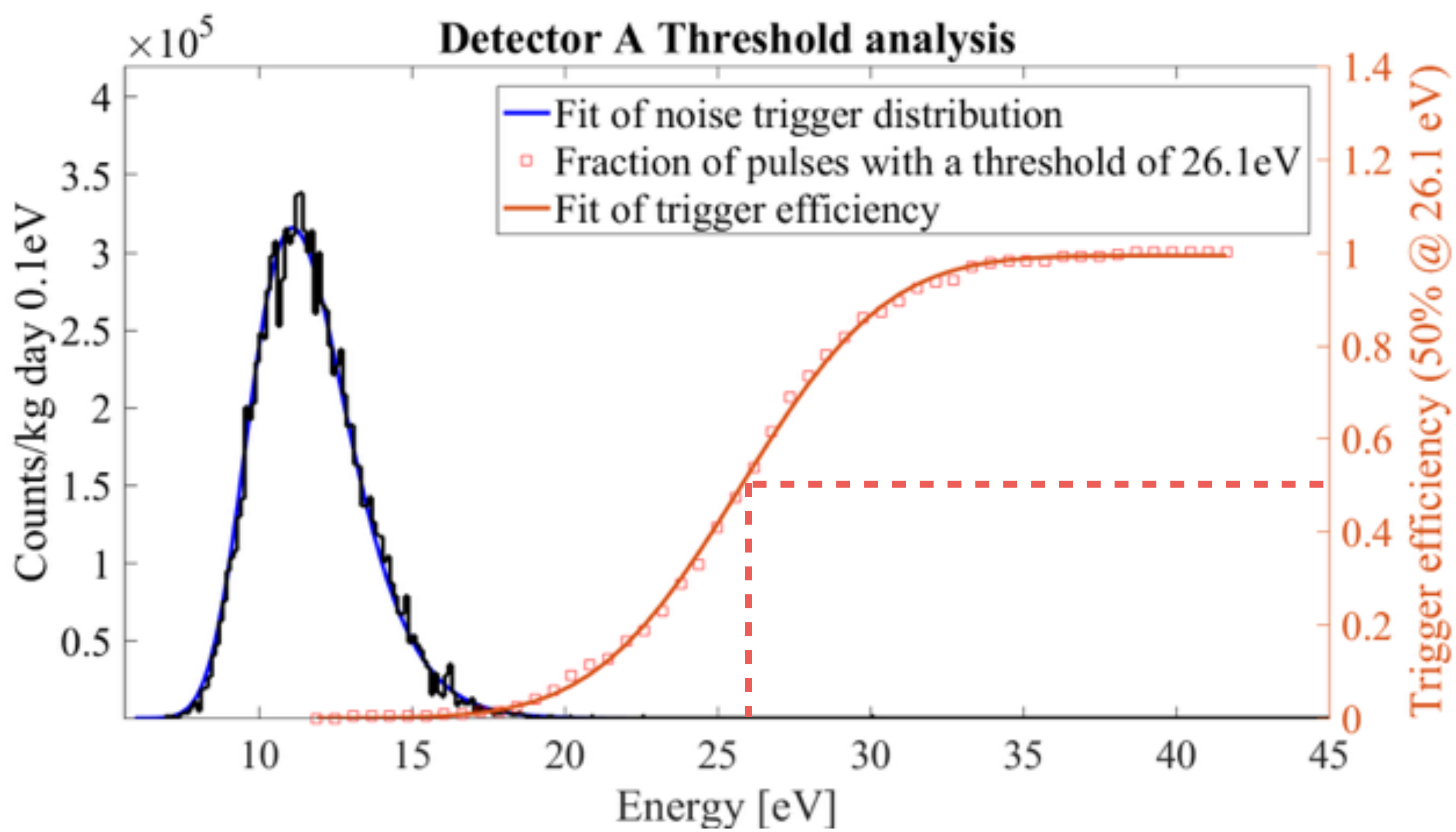
Well beyond the expectations!

*above 2-3 keV

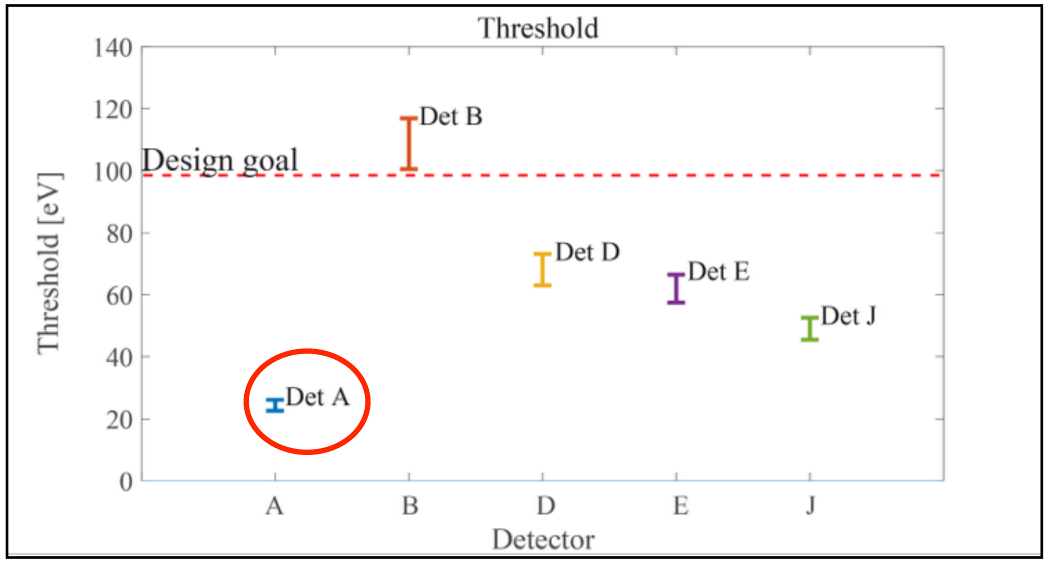
DETECTOR A



Threshold = 26.1 eV
Corresponds to 50% of trigger efficiency



DETECTOR A: First Data Analysis



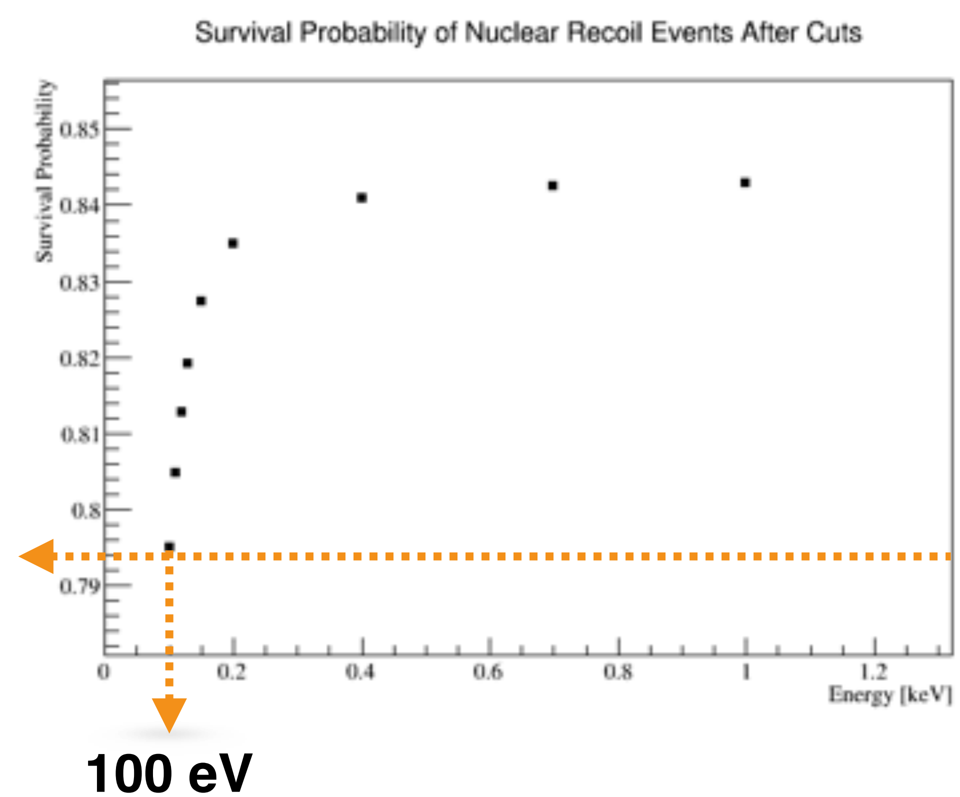
- Data taking period : 31/10/16 to 05/07/17
- Un-blinded data for cut selection: 20% of data set, not included in the final exposure
- Detector mass: 24 g
- **Total exposure: 2.39 kg days**
- **Blind analysis**
- Net exposure (after cuts): 2.21 kg days
- **Analysis Threshold: 100 eV**

Cut selection and efficiency

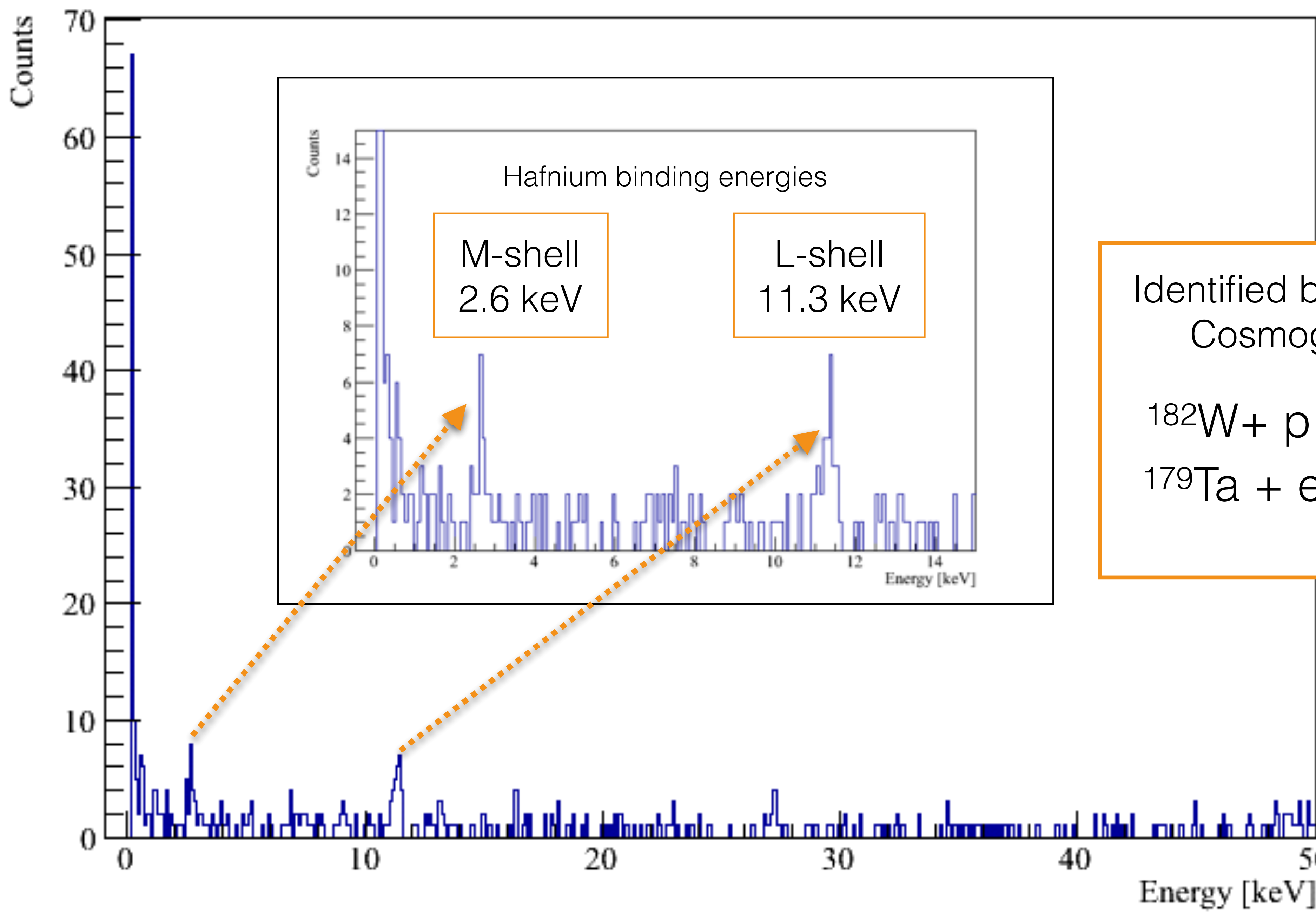
Removing…

- Periods of unstable detector operation
- Any event deviating from the nominal pulse-shape

After cuts, efficiency 79.4% at 100 eV



DETECTOR A: Background Spectrum



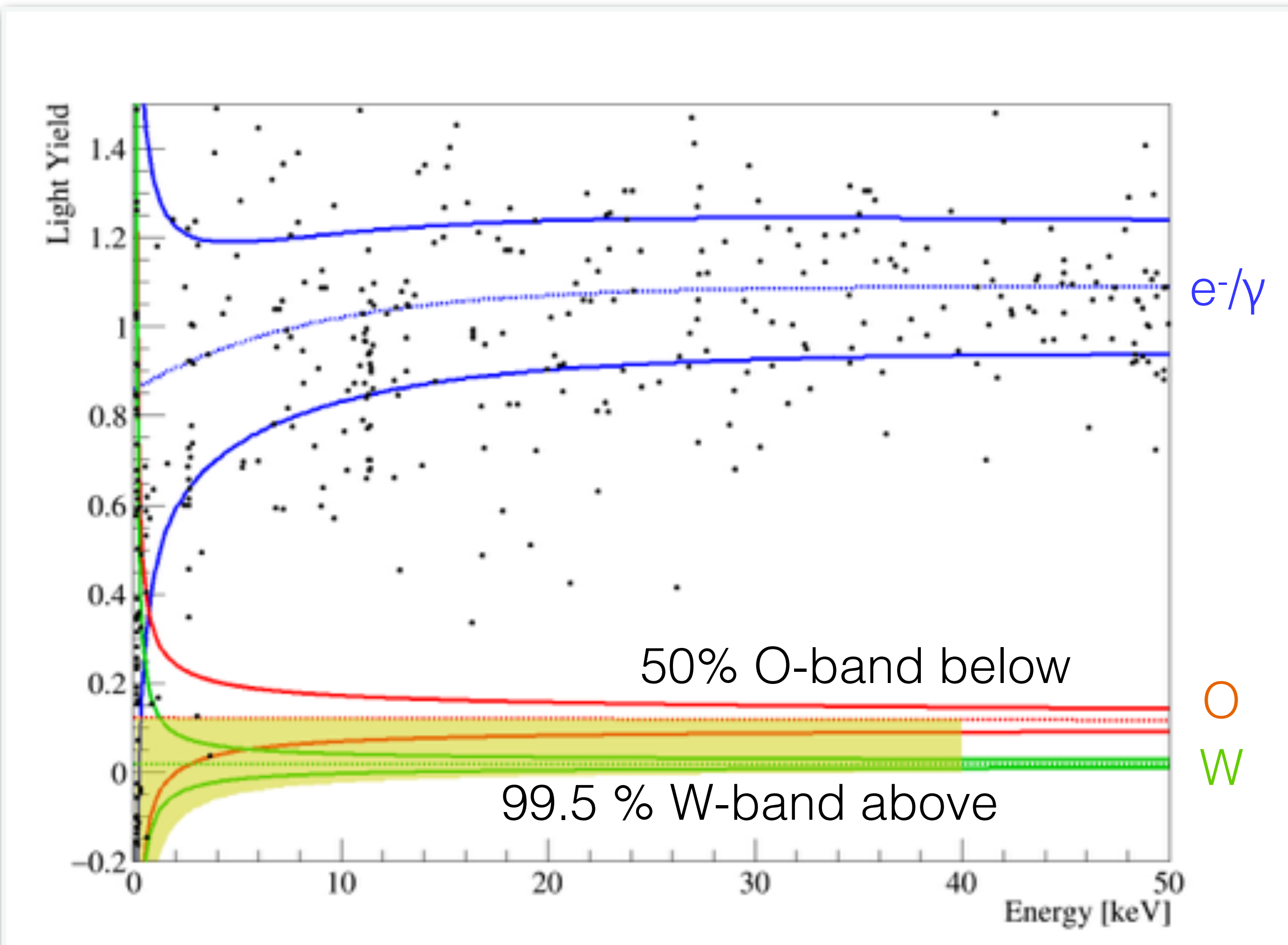
Identified background events:
Cosmogenic activation

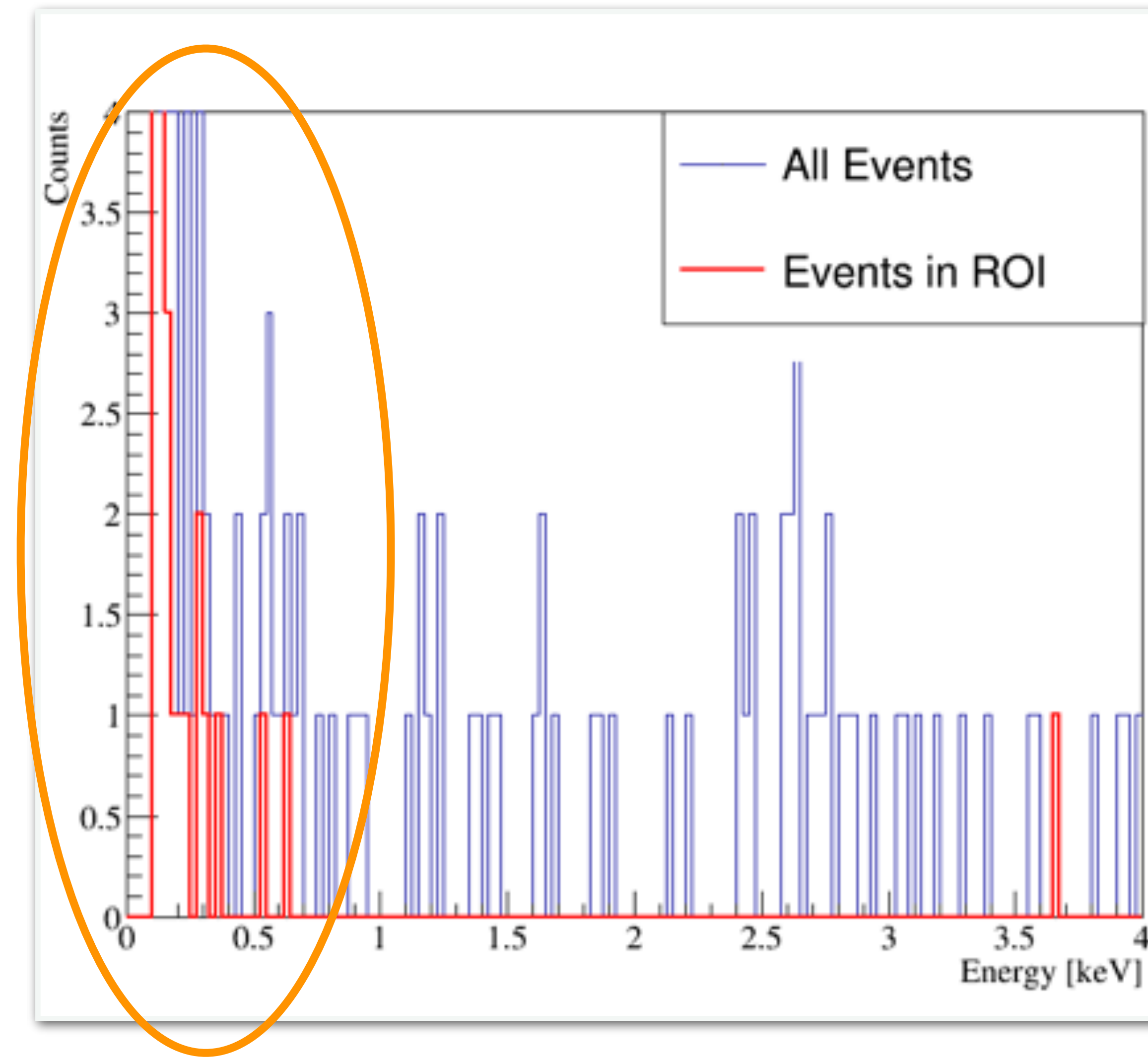
$^{182}W + p \longrightarrow {}^{179}Ta + \alpha$

$^{179}Ta + e^- \longrightarrow {}^{179}Hf + \nu_e$

DETECTOR A

Event Rate in the Region of Interest (ROI)

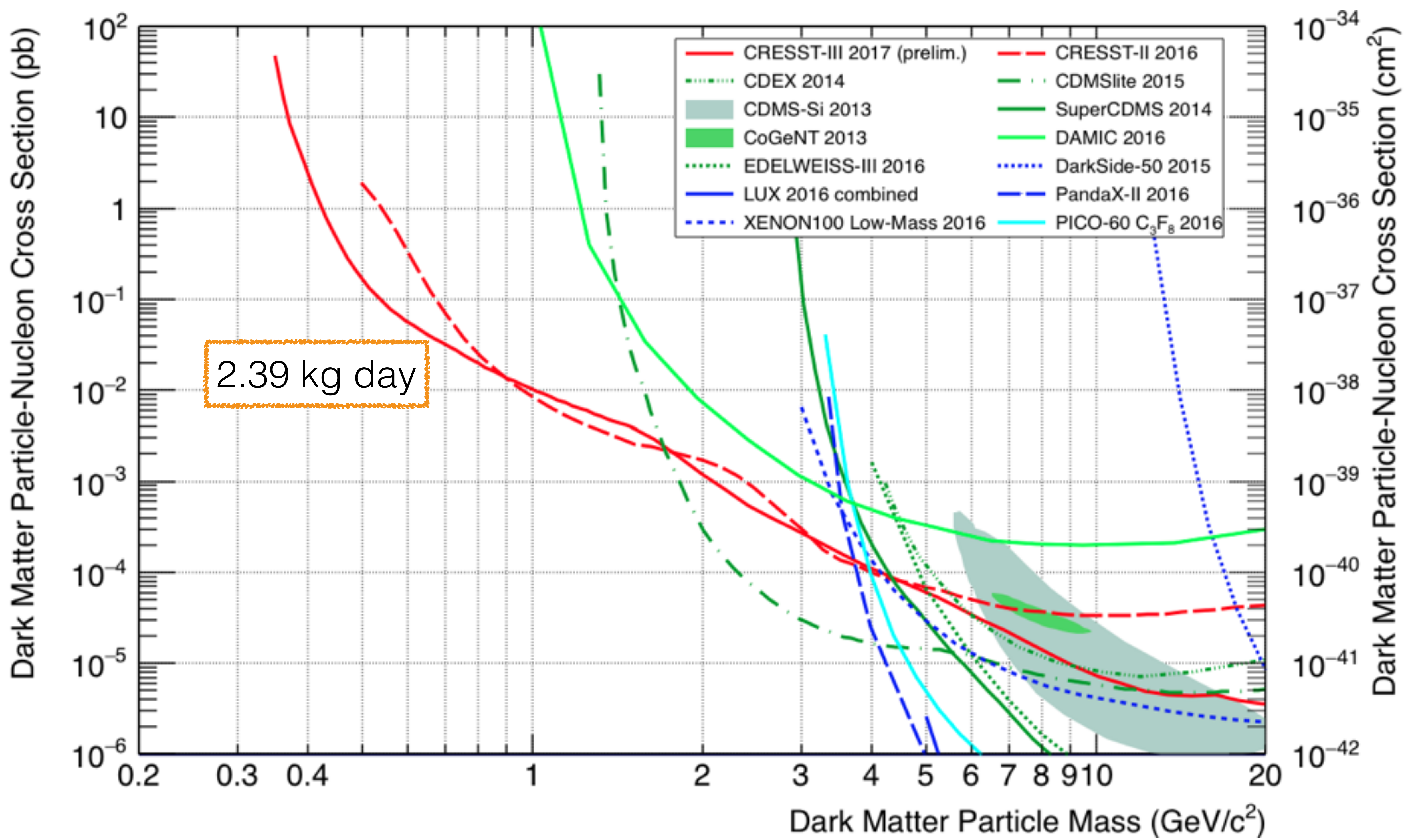




acceptance region

Excess of events below 0.5 keV

First Results from CRESST-III



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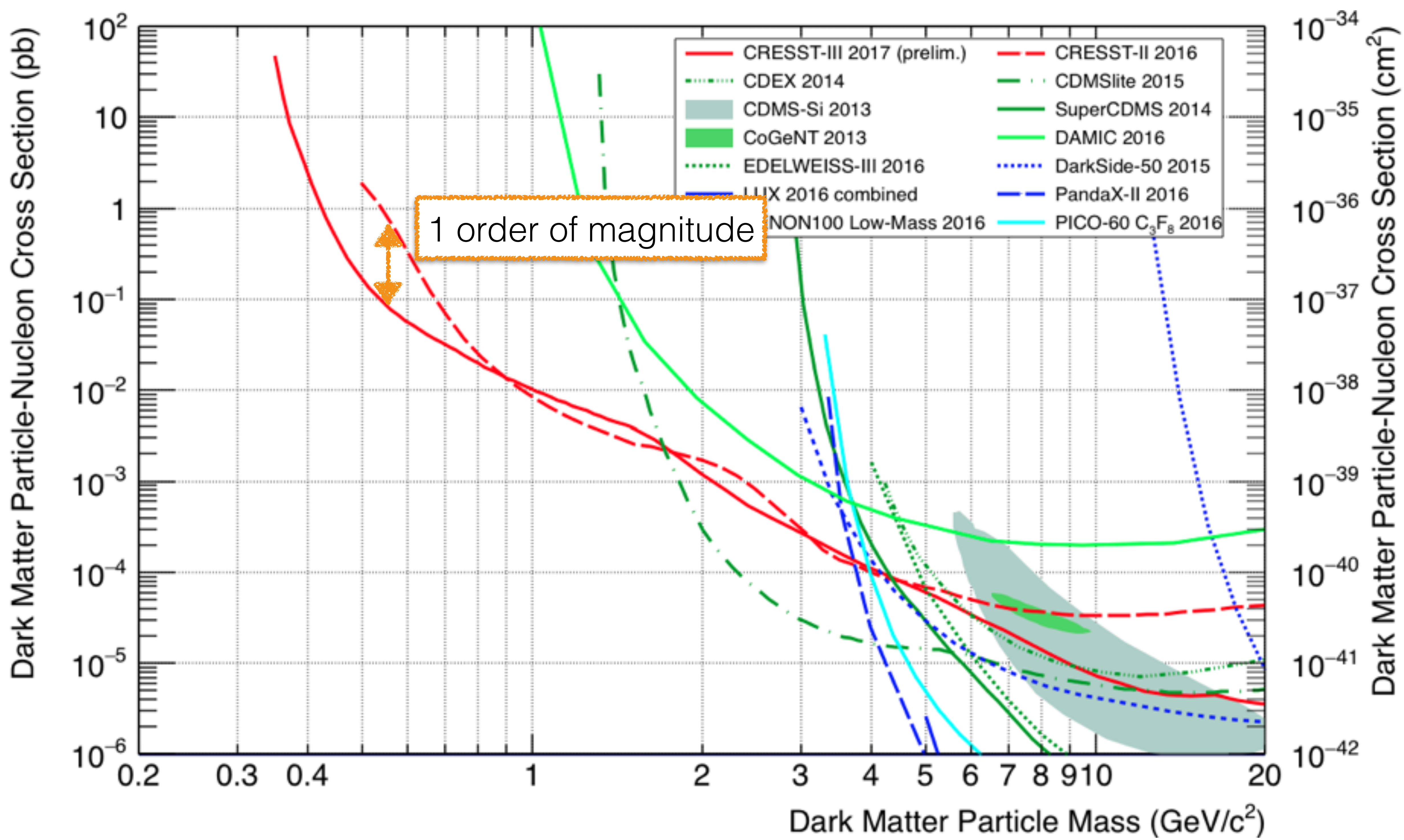

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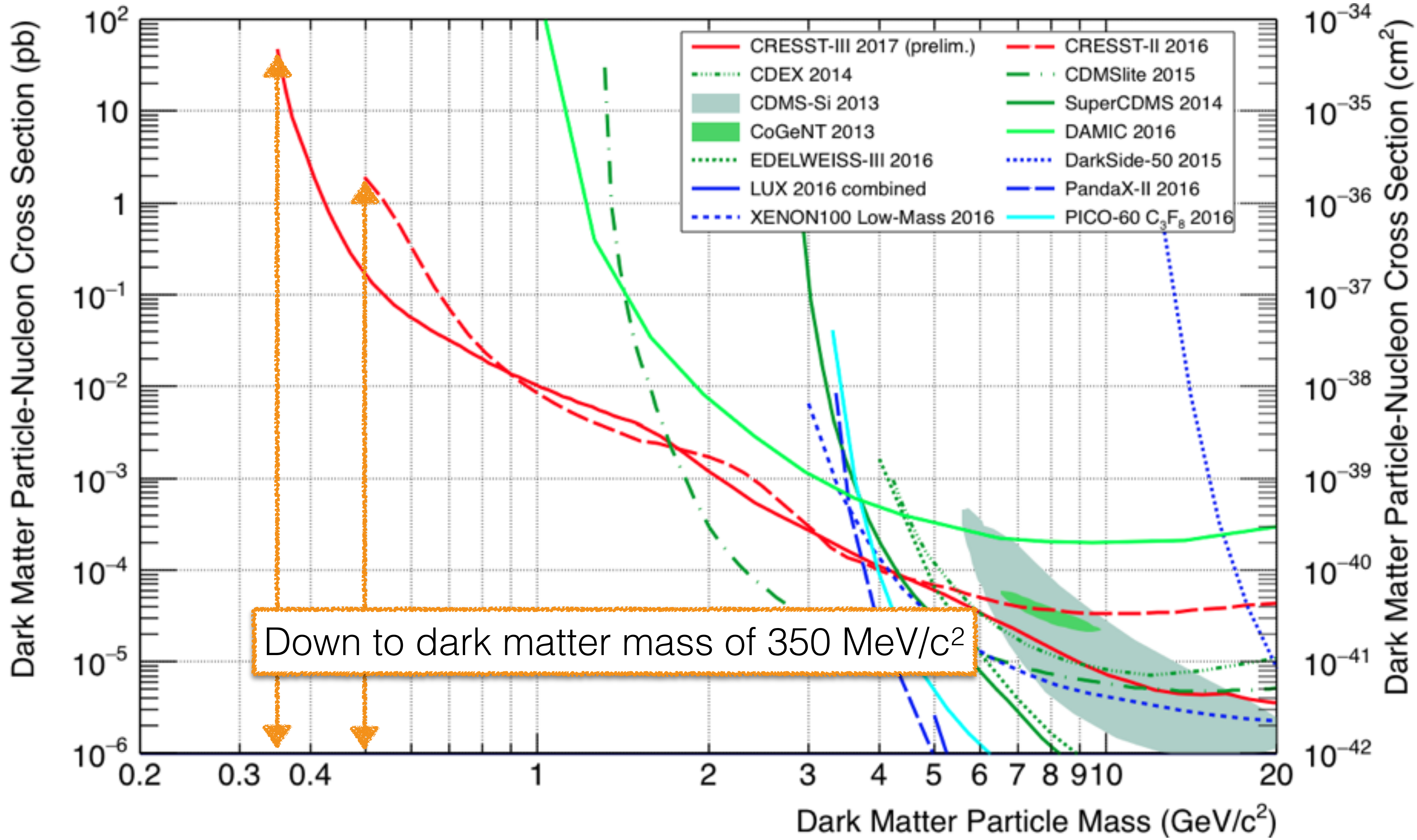
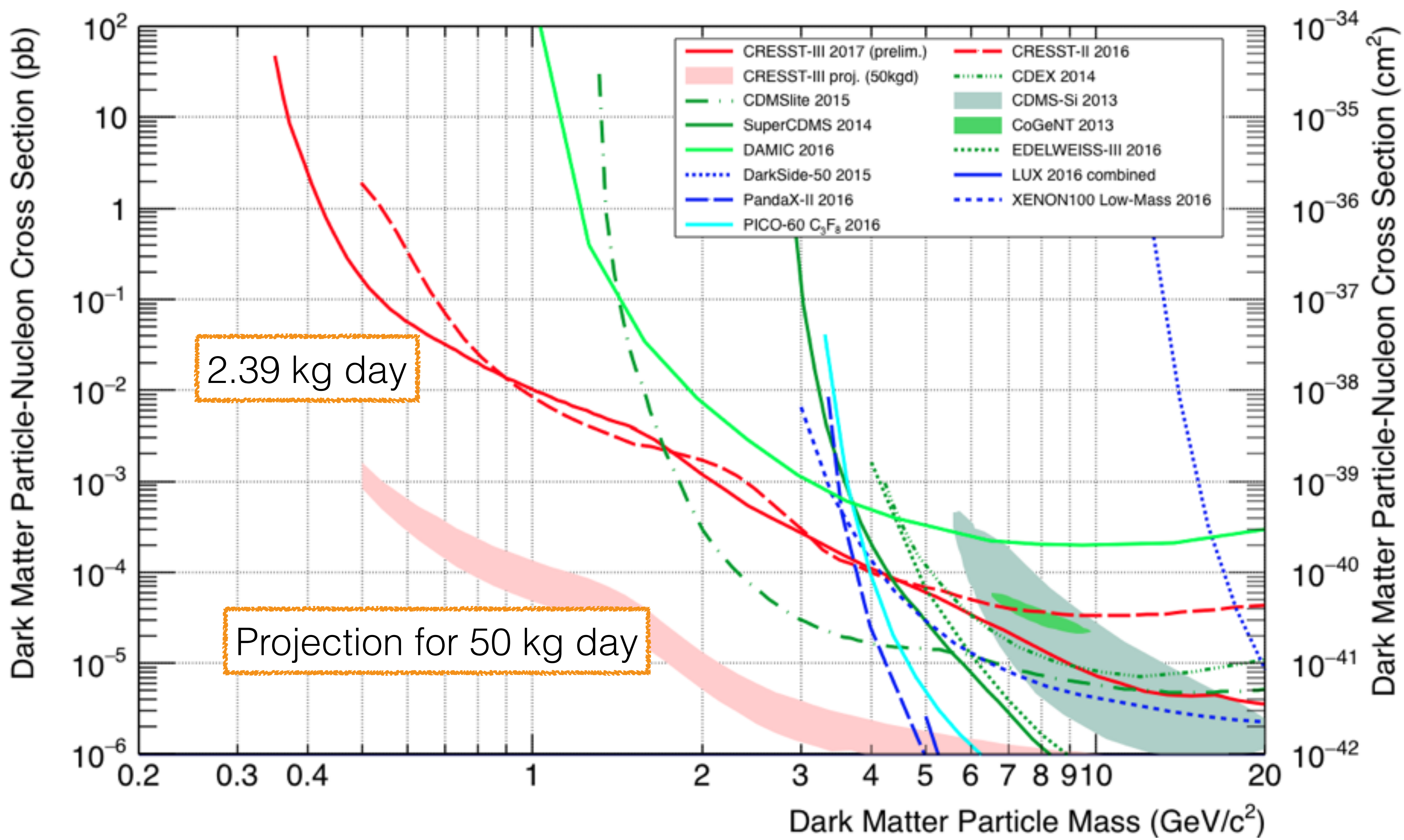
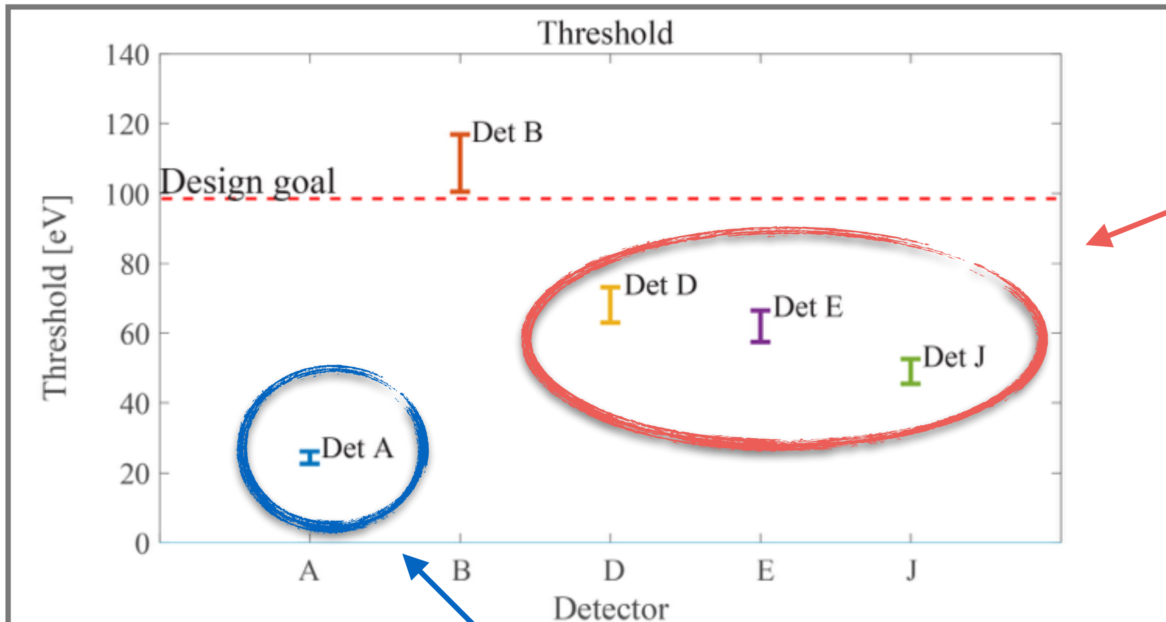


CRESST-III Projections



What's next: Very-Near Future



Full analysis in preparation:
- 3 more detectors
- 3 times more exposure

—> understanding of background

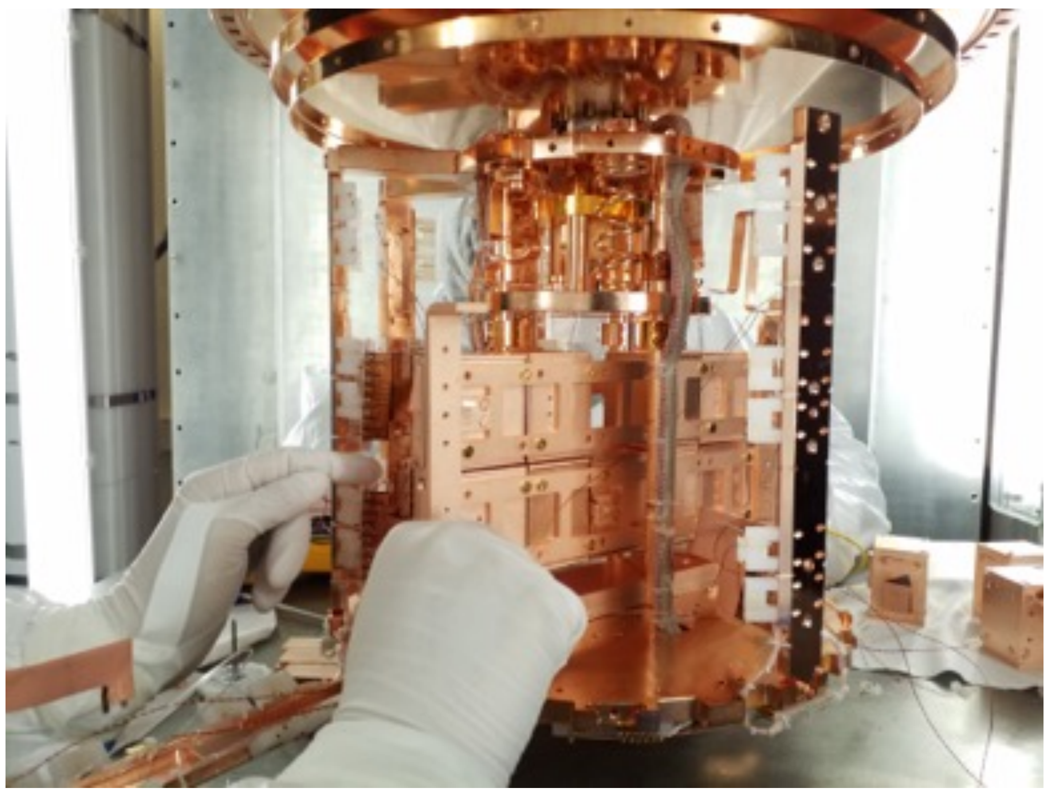
Low-threshold analysis of Detector A ready:
- lowest threshold: 26eV
- 3 times more exposure

—> new low-mass limit
—> publication in preparation

Stay tuned for this summer!

What's next: Near Future

Explorative Run Ongoing
GOAL: understand the origin of the low-energy excess
APPROACH: various modifications on detector modules
(e.g. different holding, targets)



14 new modules mounted in May 2018

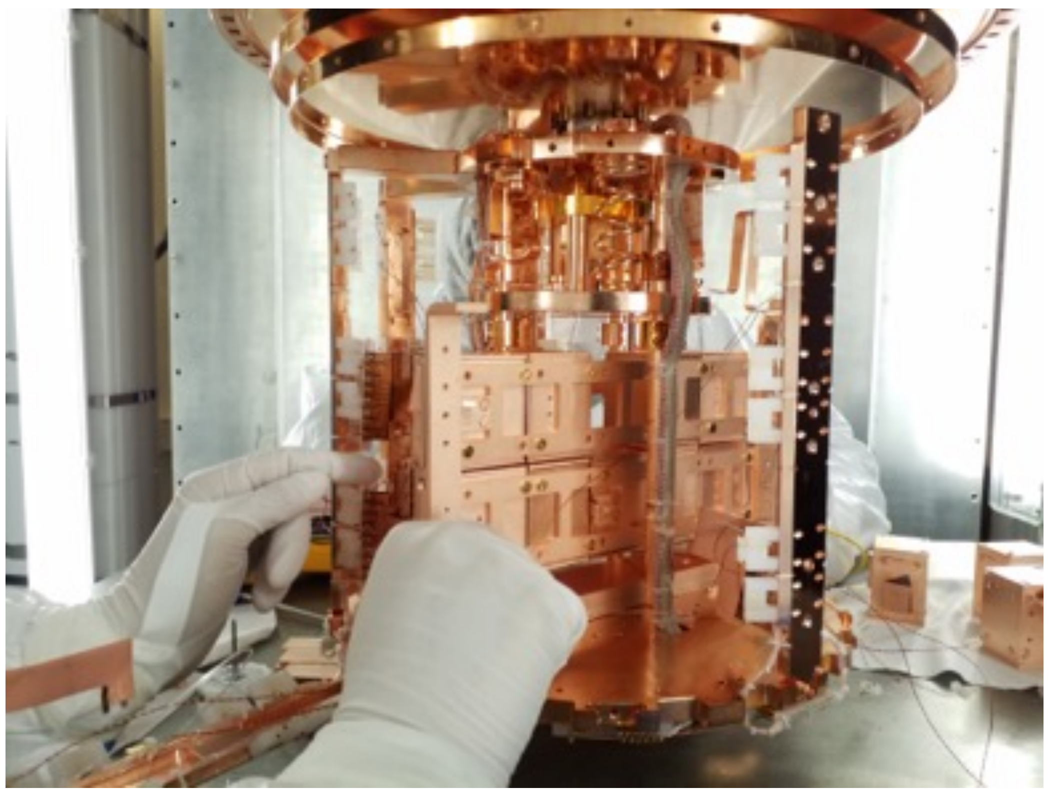
Cryostat closed and cooling down!

Stay tuned for the next year!

What's next: Near Future

Explorative Run Ongoing
GOAL: understand the origin of the low-energy excess
APPROACH: various modifications on detector modules
(e.g. different holding, targets)

Mid-term to long-term:
- major upgrade funded
- 300 channel system
- 3kg of larger mass



10 new modules mounted in May 2018

Cryostat closed and cooling down!

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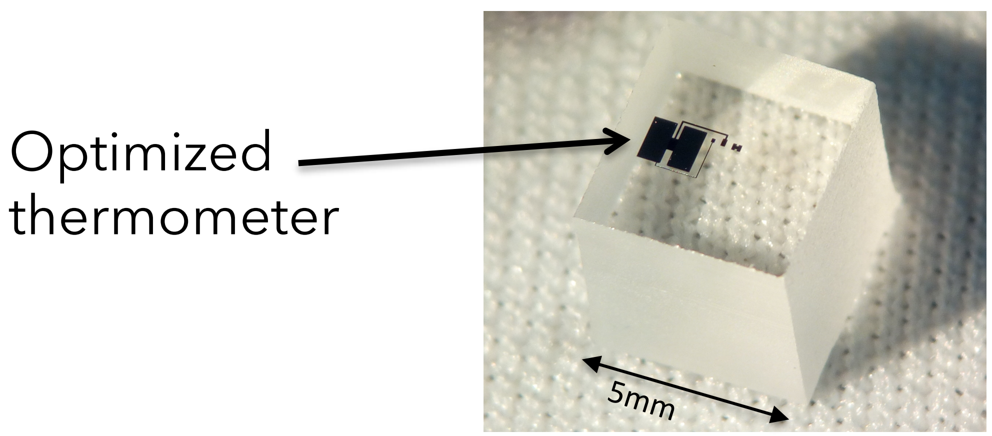
CRESST Spin-Off: The NU-CLEUS Experiment

Gram-scale cryogenic calorimeters

Technology demonstrated

0.5g sapphire prototype



Lowest energy threshold for nuclear recoils: 19.7eV

- operated in high-background environment
- precise knowledge of energy scale (no quenching)

R. Strauss et al., *Phys. Rev. D* **96**, 022009 (2017)

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Technology demonstrated

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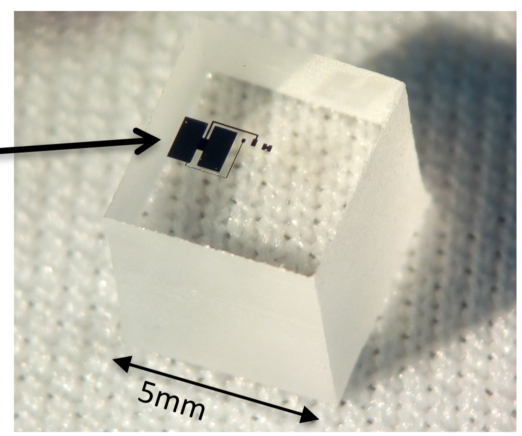
Optimized thermometer



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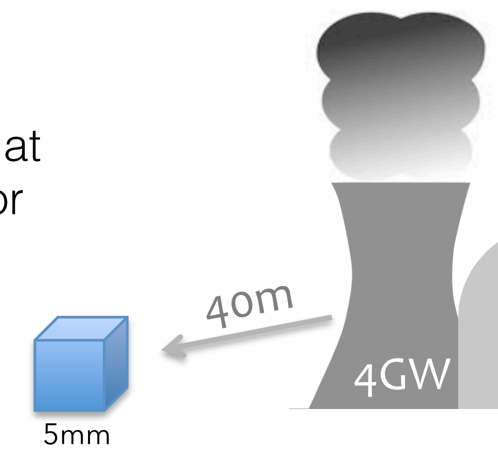
R. Strauss et al., *Phys. Rev. D* **96**, 022009 (2017)

NU-CLEUS

gram-sized detectors at nuclear power reactor



Coherent neutrino-nucleus scattering at the **low-energy frontier**

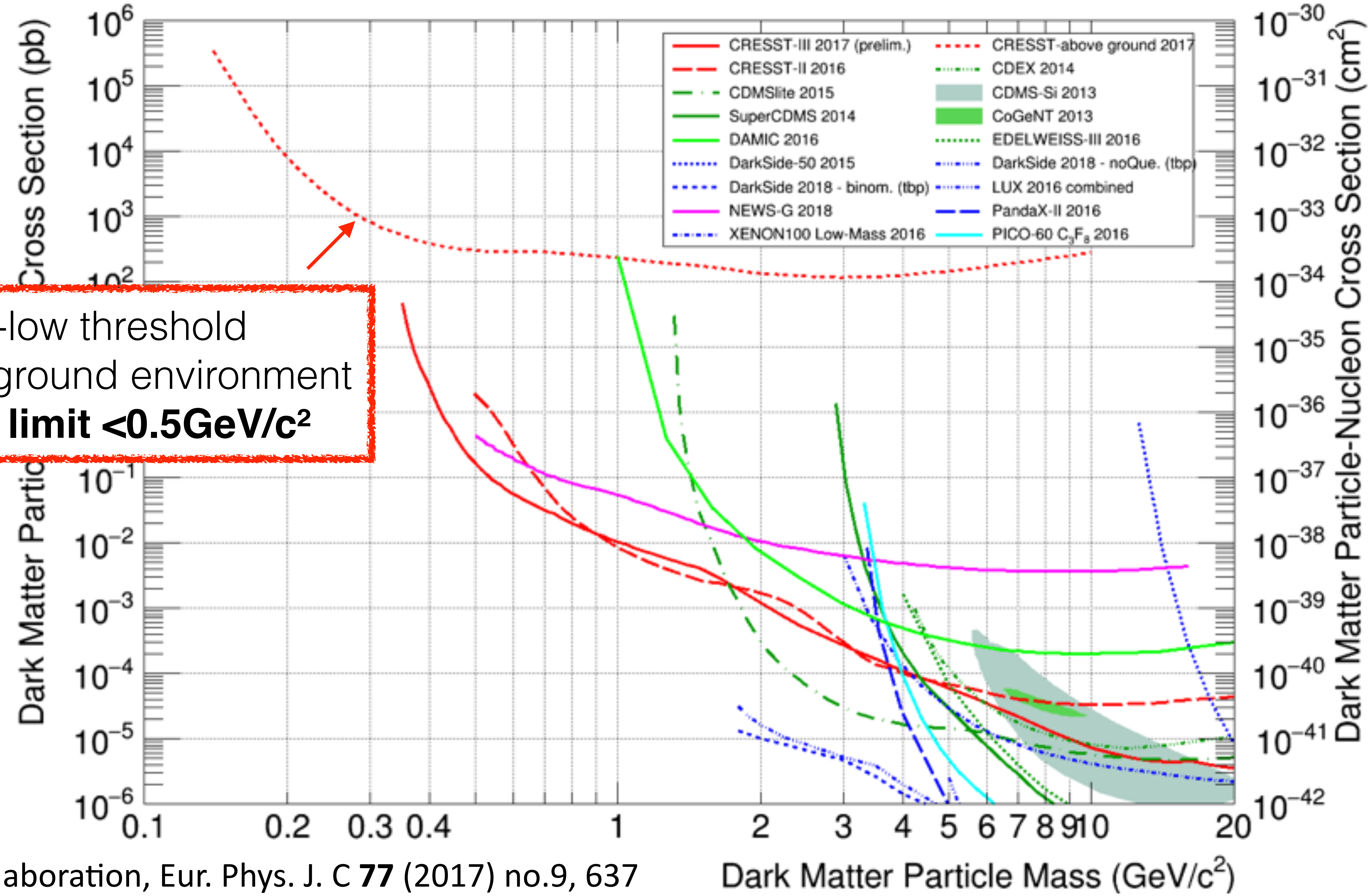
- New fundamental physics
- Miniaturization of neutrino detectors

NDM 2018

Talk: Tuesday 3pm

Results on MeV-Scale Dark Matter

Side product of NU-CLEUS program: **Dark Matter search above ground**



Ultra-low threshold
High background environment
—> first limit <0.5GeV/c²

CRESST Collaboration, Eur. Phys. J. C **77** (2017) no.9, 637
+ Results on **SIMPs**: Phys. Rev. Lett. **119**, 211302 (2017)

CRESST Spin-Off: The COSINUS Experiment

COSINUS

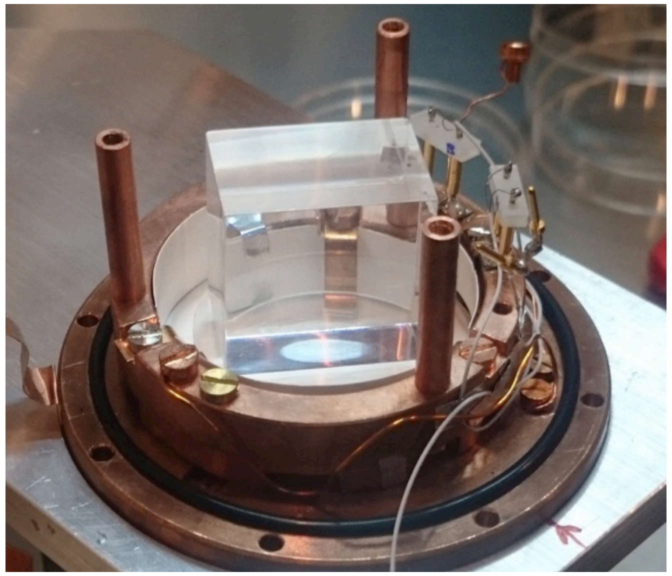
NaI cryogenic detectors to probe DAMA signal

arXiv:1603.02214, Eur. Phys. J. C 76 441

PI: Karoline Schaeffner

NEWS from yesterday:
Experiment fully funded

Promising demonstrator



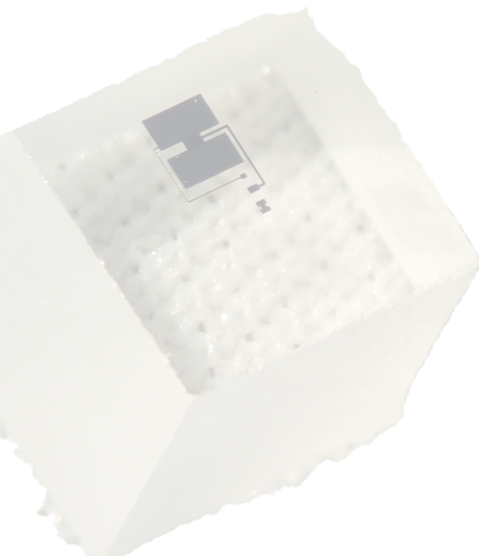
CONCLUSIONS

CRESST-III has high potential for low-mass Dark Matter Search

CRESST achieves lowest thresholds in the field

Full data release this summer

New CRESST-III run started



Promising results and prospects for MeV-scale Dark Matter

New data release and results within next months