GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

Dark Matter Particle Search with the CRESST-III Experiment

Vanessa Zema on behalf of the CRESST Collaboration

CHALMERS UNIVERSITY OF TECHNOLOGY

PREPARING FOR DARK MATTER PARTICLE DISCOVERY
11-15 June 2018, Göteborg, Sweden

THE COLLABORATION

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

TECHNISCHE UNIVERSITÄT MÜNCHEN

ÖAW
ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

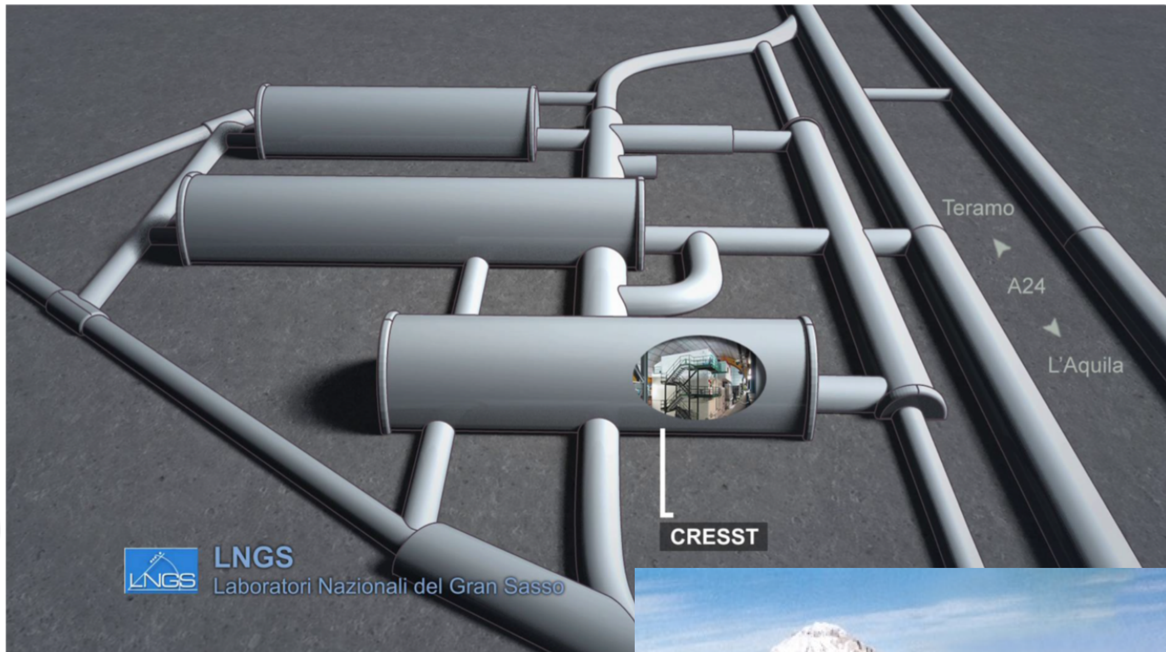
INFN
Istituto Nazionale di Fisica Nucleare

UNIVERSITY OF OXFORD

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

Laboratori Nazionali del Gran Sasso



INFN
LNGS
Istituto Nazionale di Fisica Nucleare
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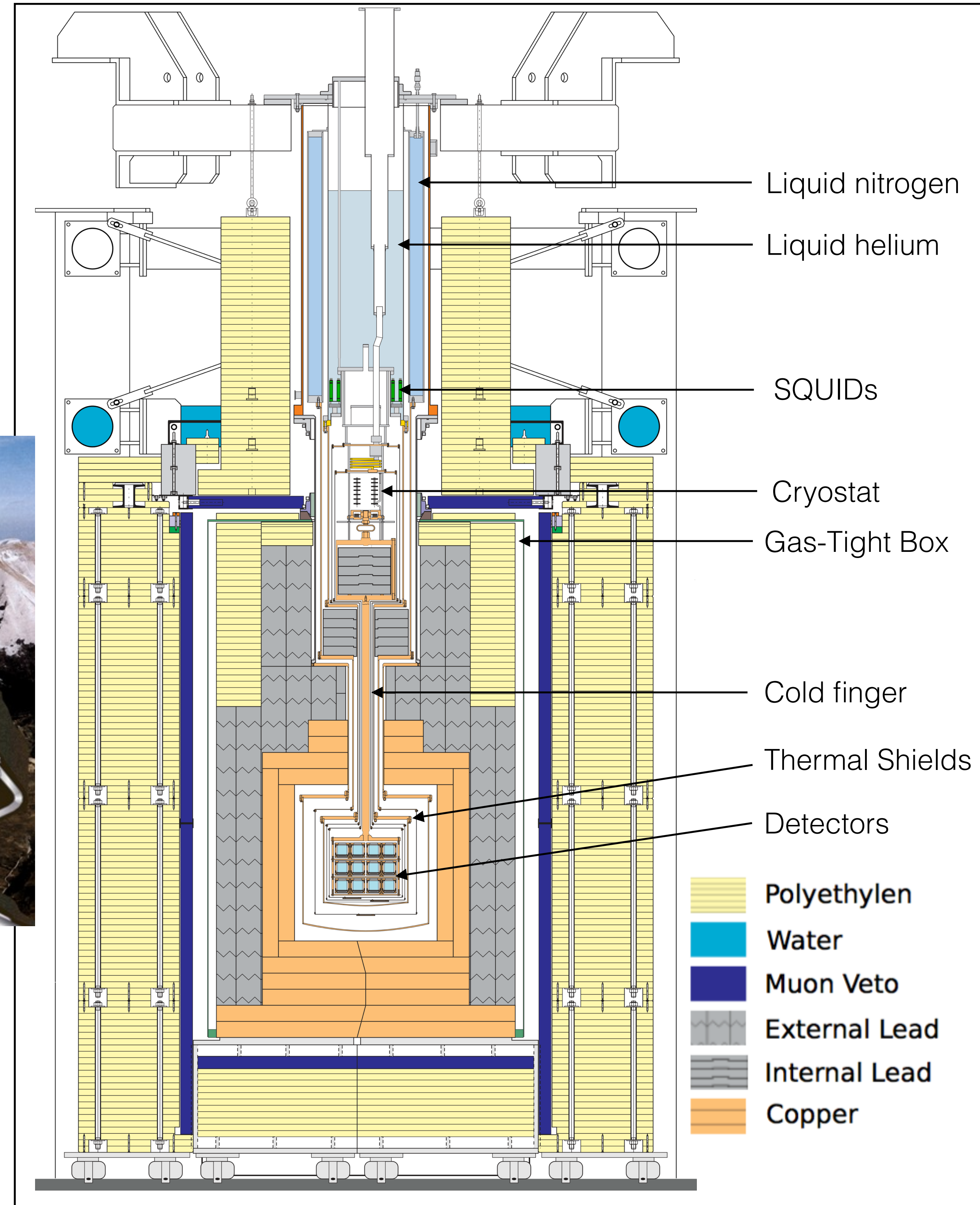
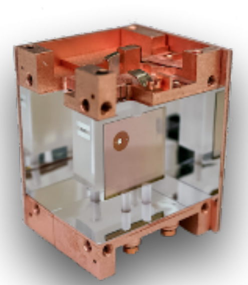
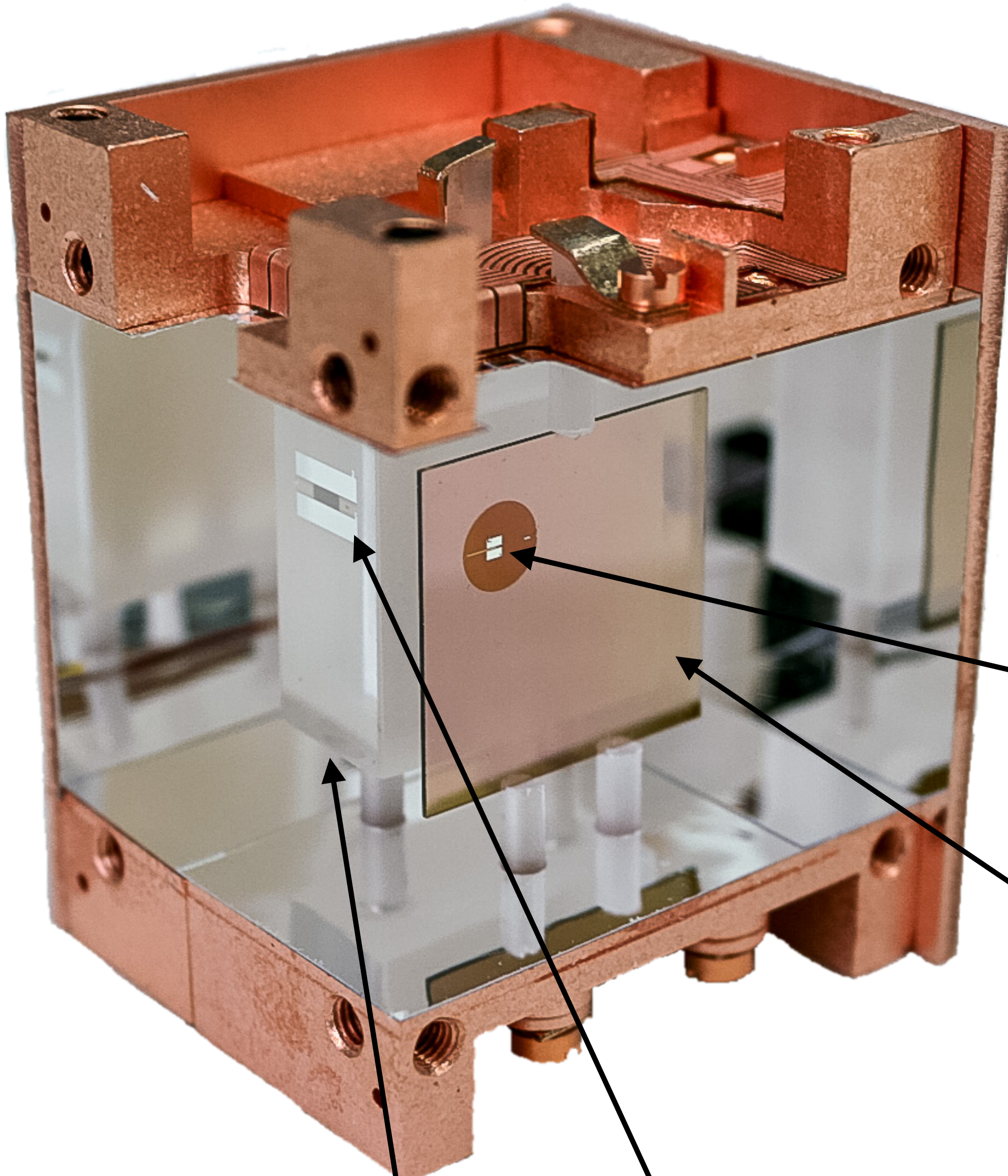


Located under Gran Sasso mountain:
~ 3600 wme (water meter equivalent)



THE DETECTOR



$CaWO_4$ scintillating crystal

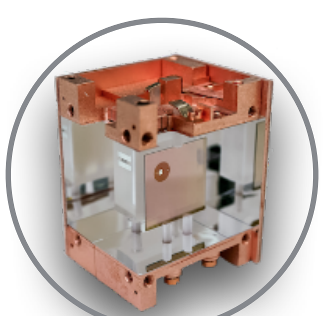
Cryogenic temperature ~ **10 mK**

Operated as **<u>calorimeter</u>**

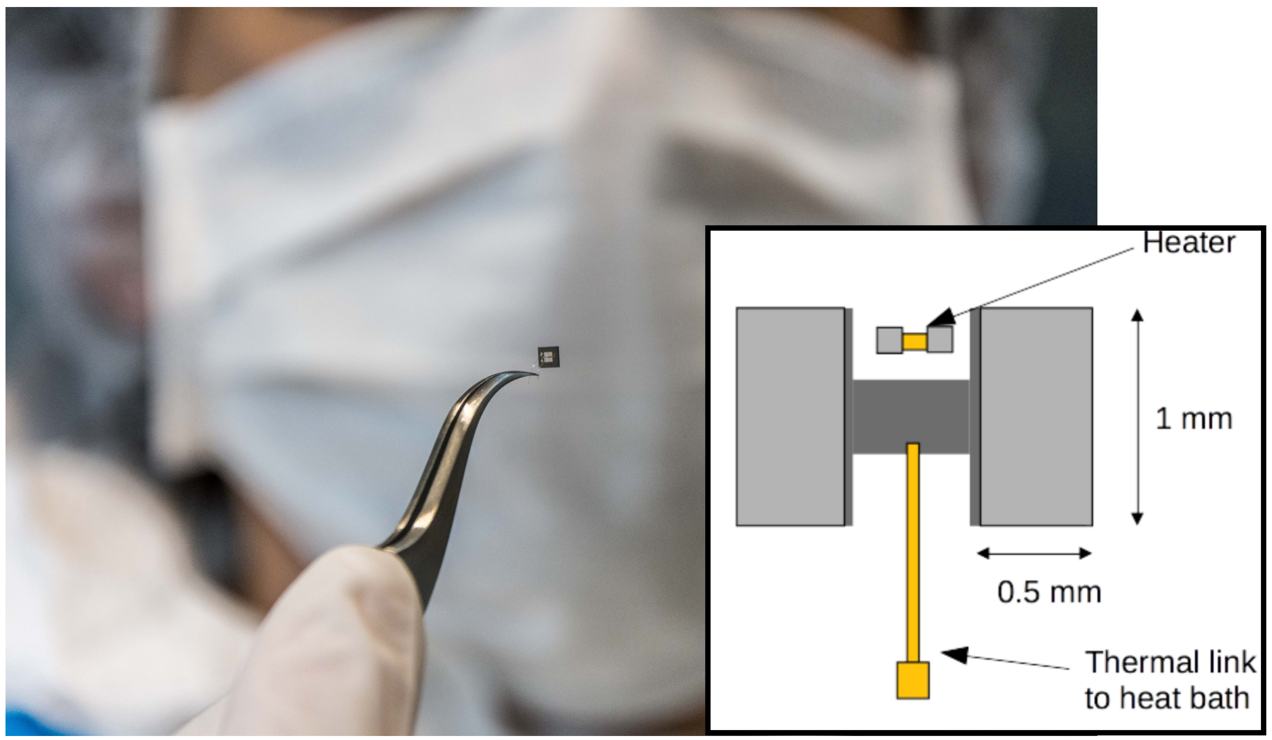
Both the energy converted in **heat** (phonons) and the energy converted in **scintillation light** are detected

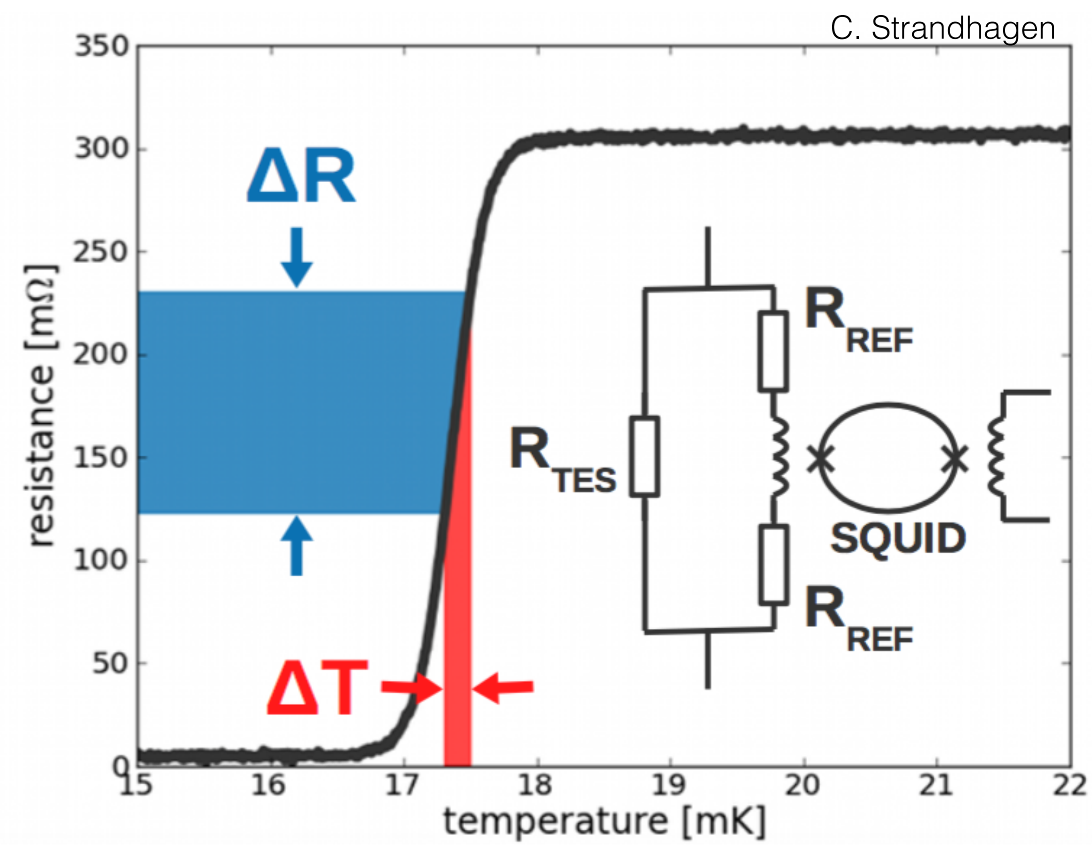
Silicon on Sapphire (SOS)+TES is the **light detector**

$CaWO_4$+TES is the **phonon detector**

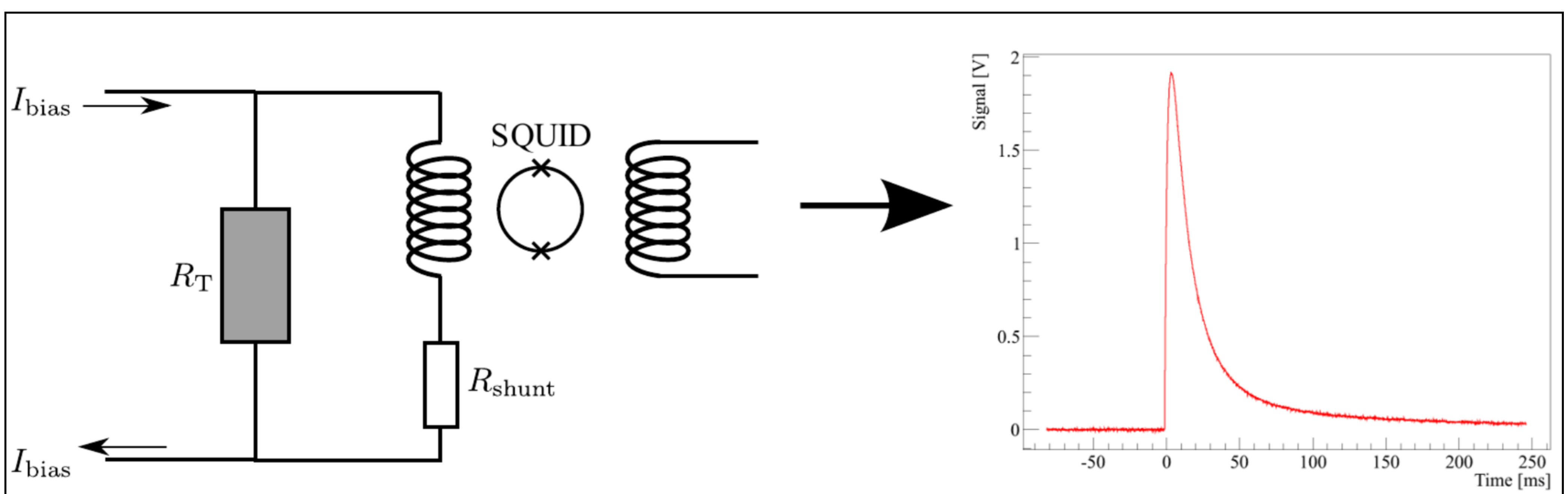


TES: Transition-Edge-Sensor

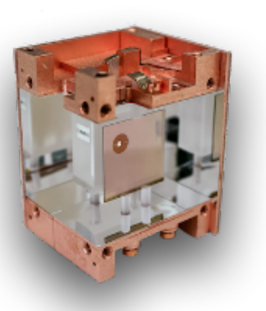




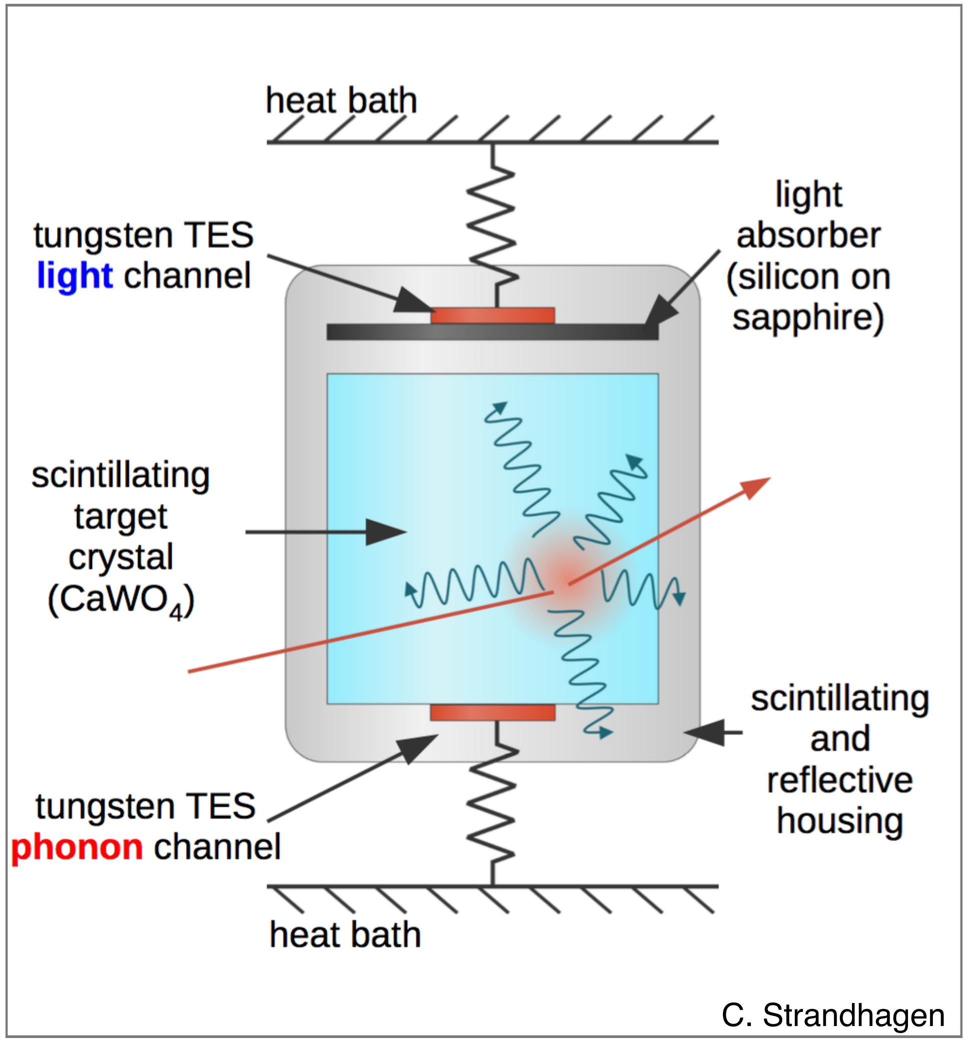
Energy Deposition (keV) → Temperature Increase (μK) → Superconducting Transition of the Resistance (mΩ)



J. M. Schmaler

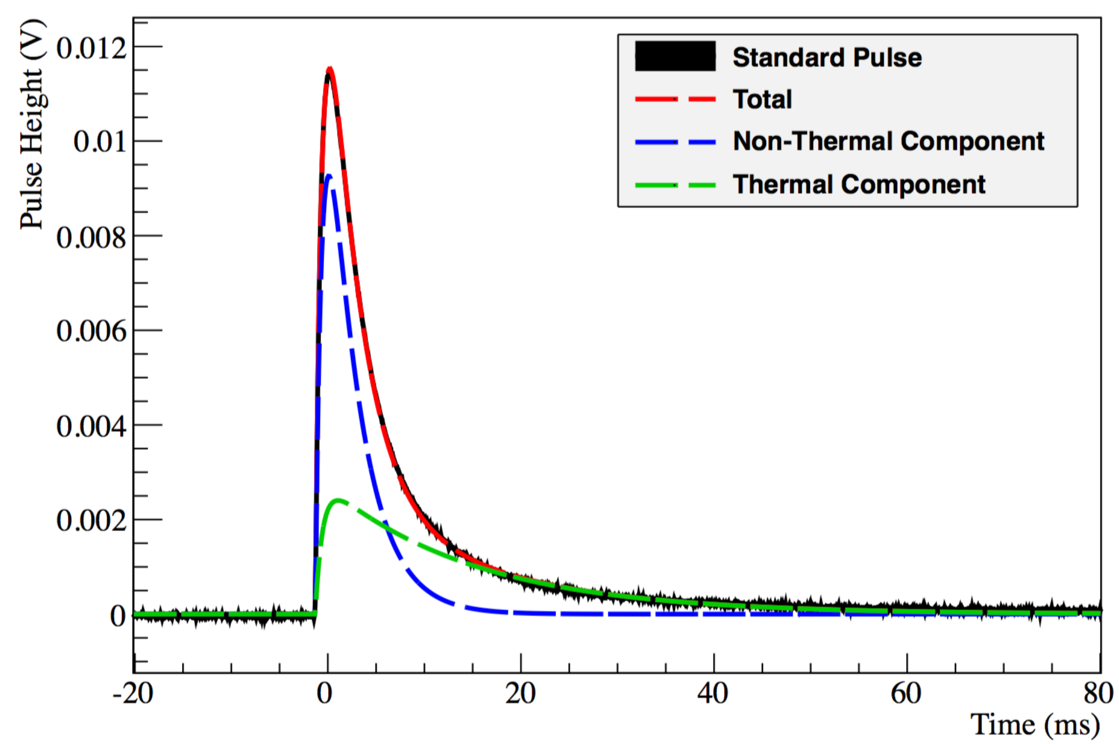


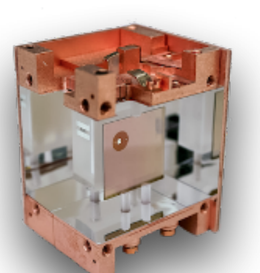
Working Principle



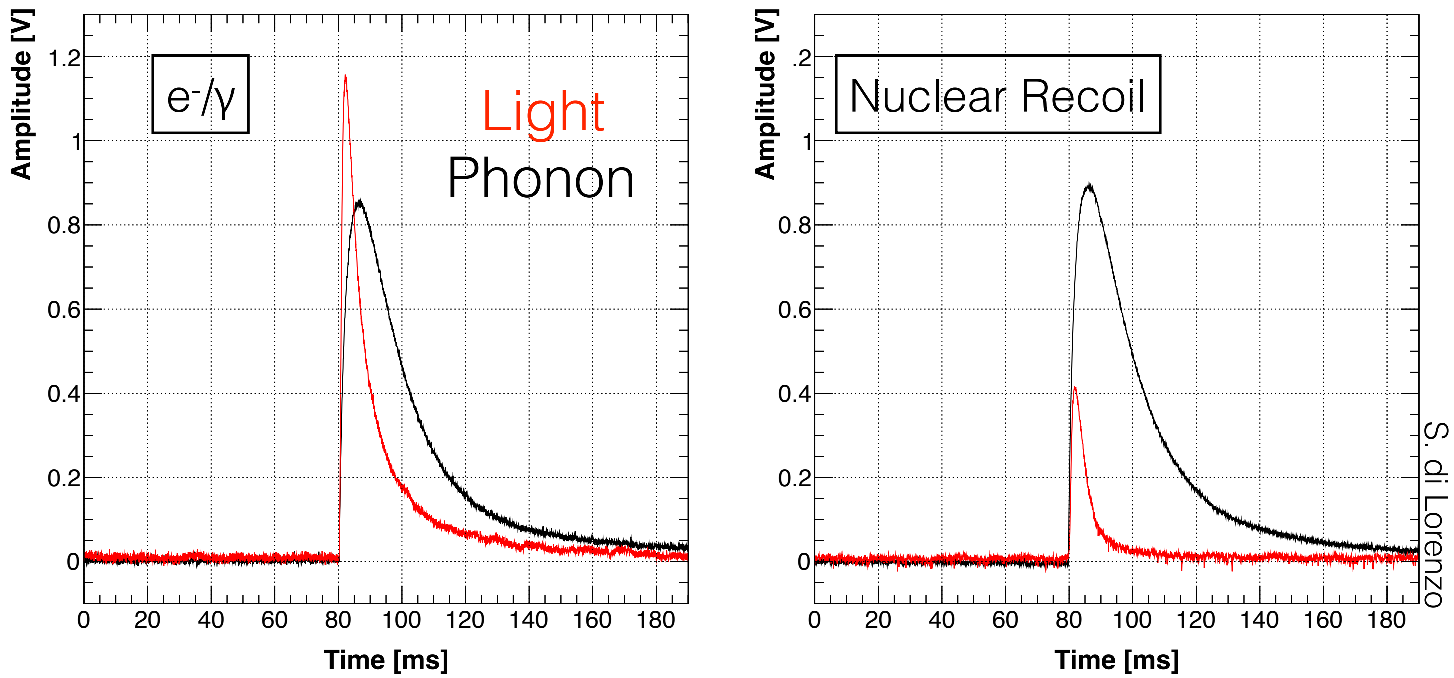
F. Pröbst et al, J. Low Temp. Phys. 100,69 (1995)

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





Particle Discrimination

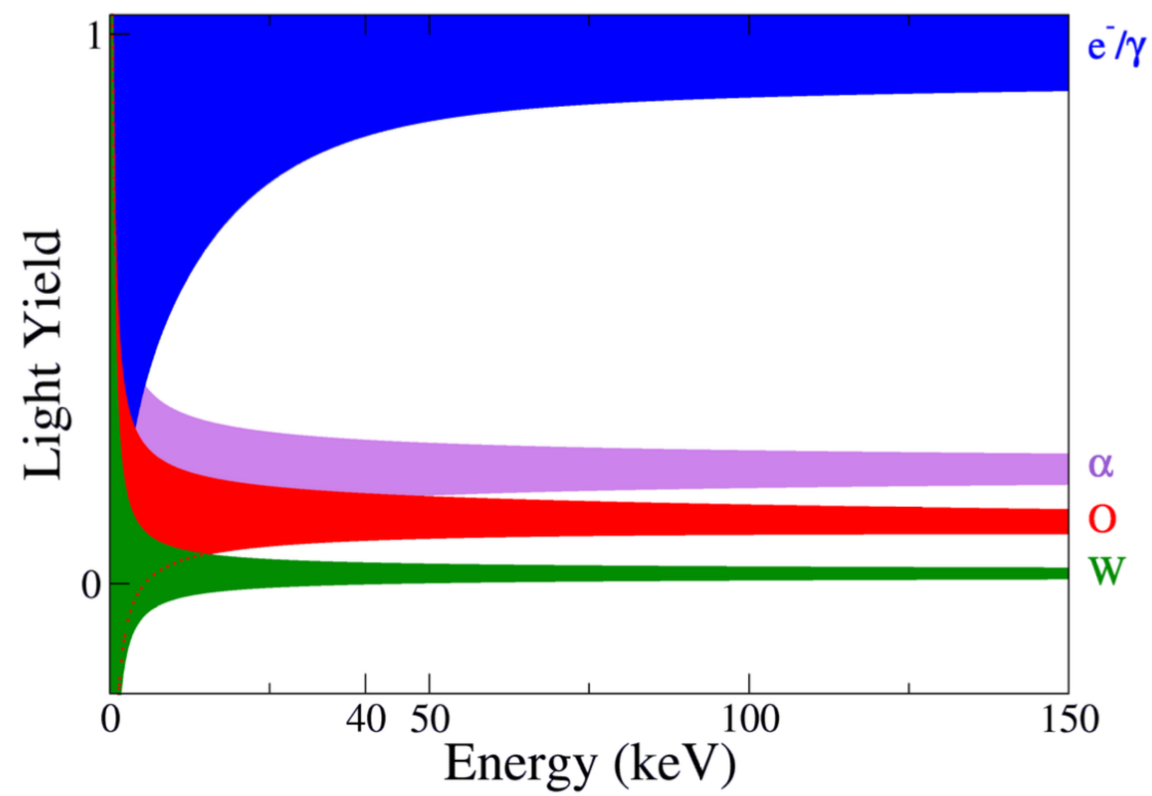


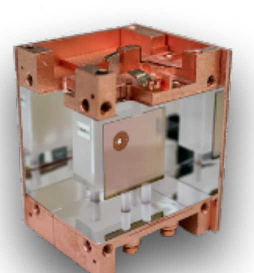
$$\text{Light Yield} = \frac{\text{Light Pulse Energy}}{\text{Phonon Pulse Energy}}$$

This difference in the light yield is called **Quenching Factor (QF).**

QF in CRESST is roughly proportional to the **atomic mass A**.

A multi-target crystal of spin 0 nuclei (as O, Ca and W) could be a Dark Matter mass spectrometer

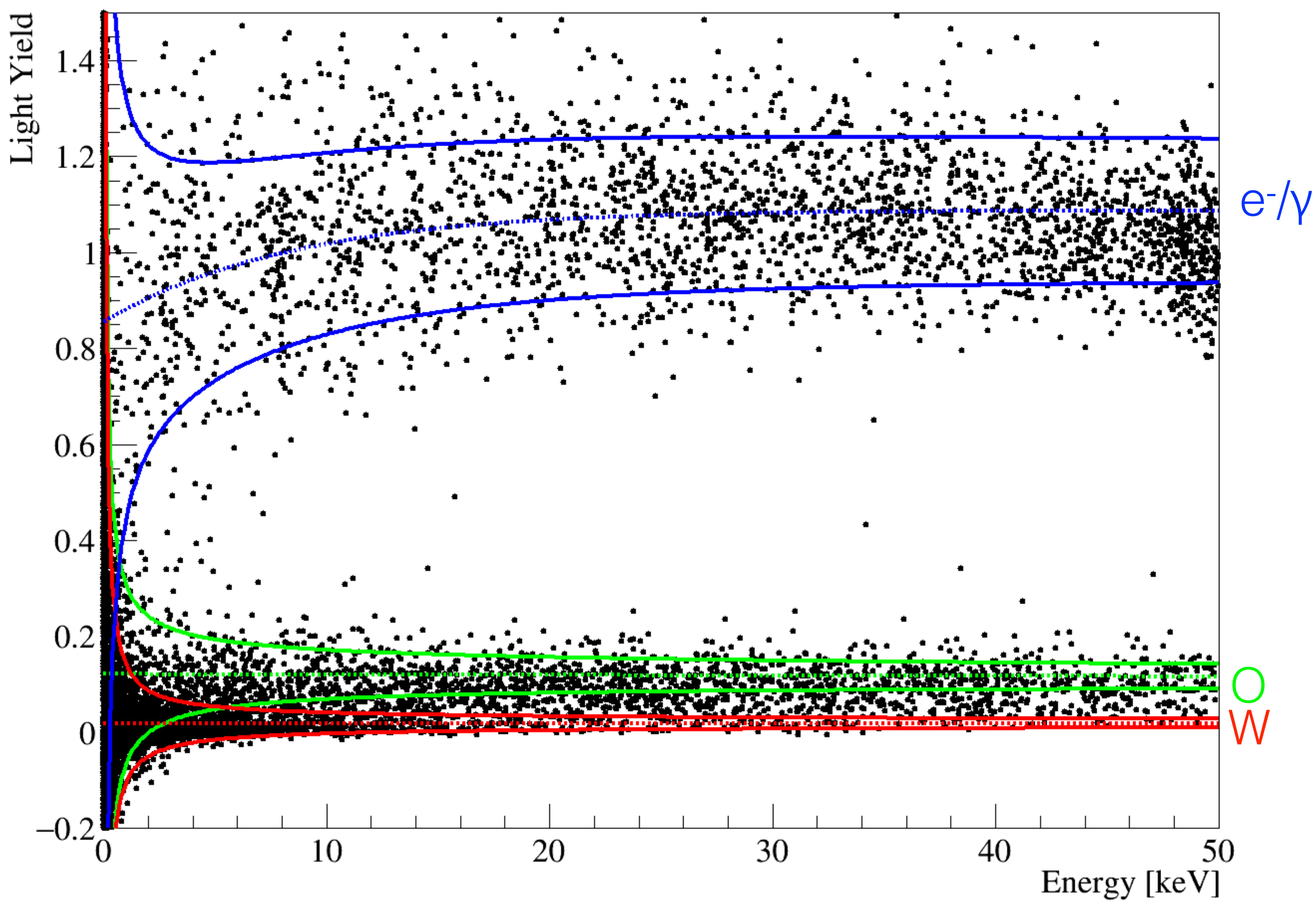


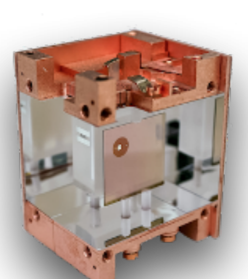


Neutron Calibration

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

Strauss, R., Angloher, G., Bento, A. et al. Eur. Phys. J. C (2014) 74: 2957.



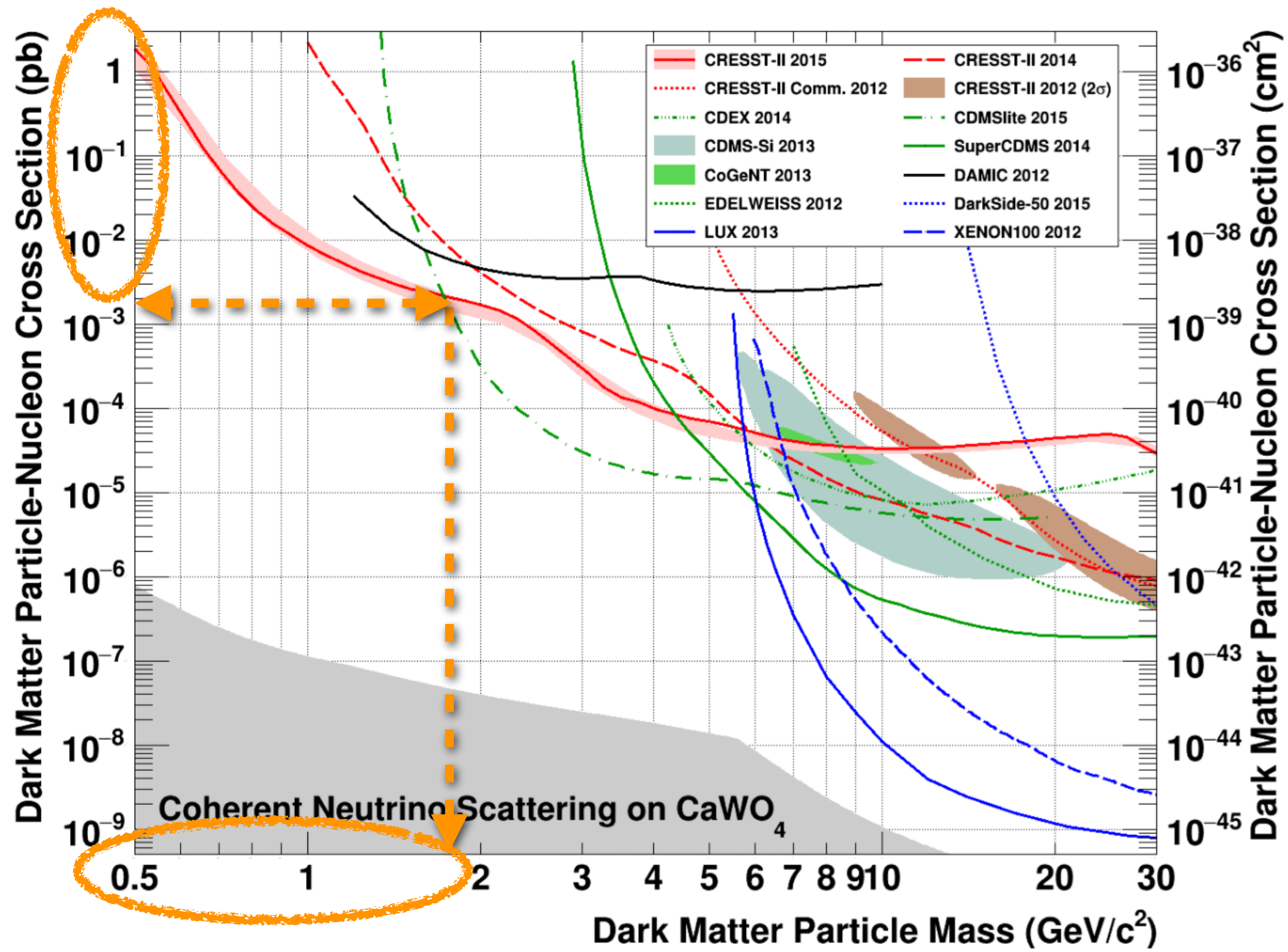


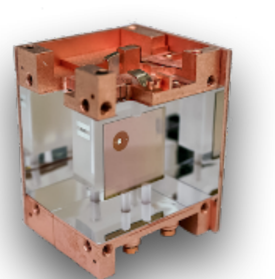
CRESST-II (2015)

- 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 Module
This sensitivity plot was obtained using the detector which showed the lowest threshold achieved in CRESST-II Phase2 (307 eV)

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



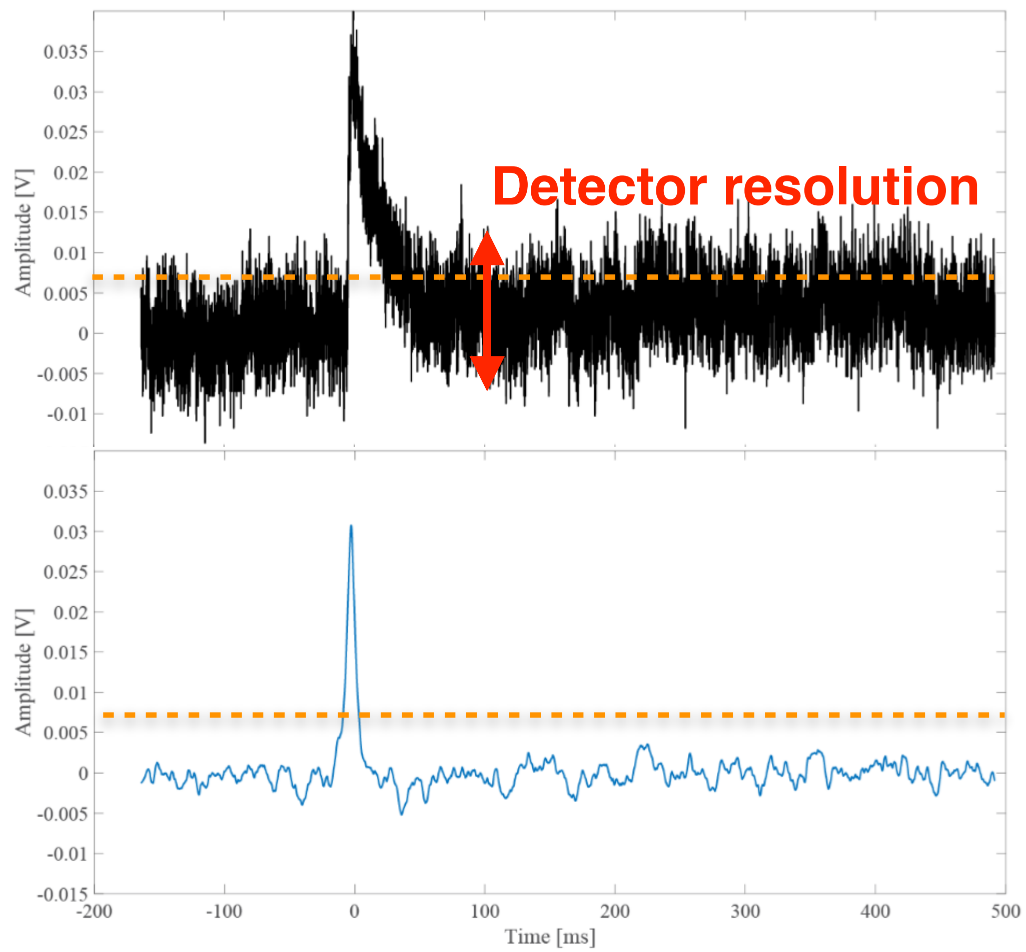


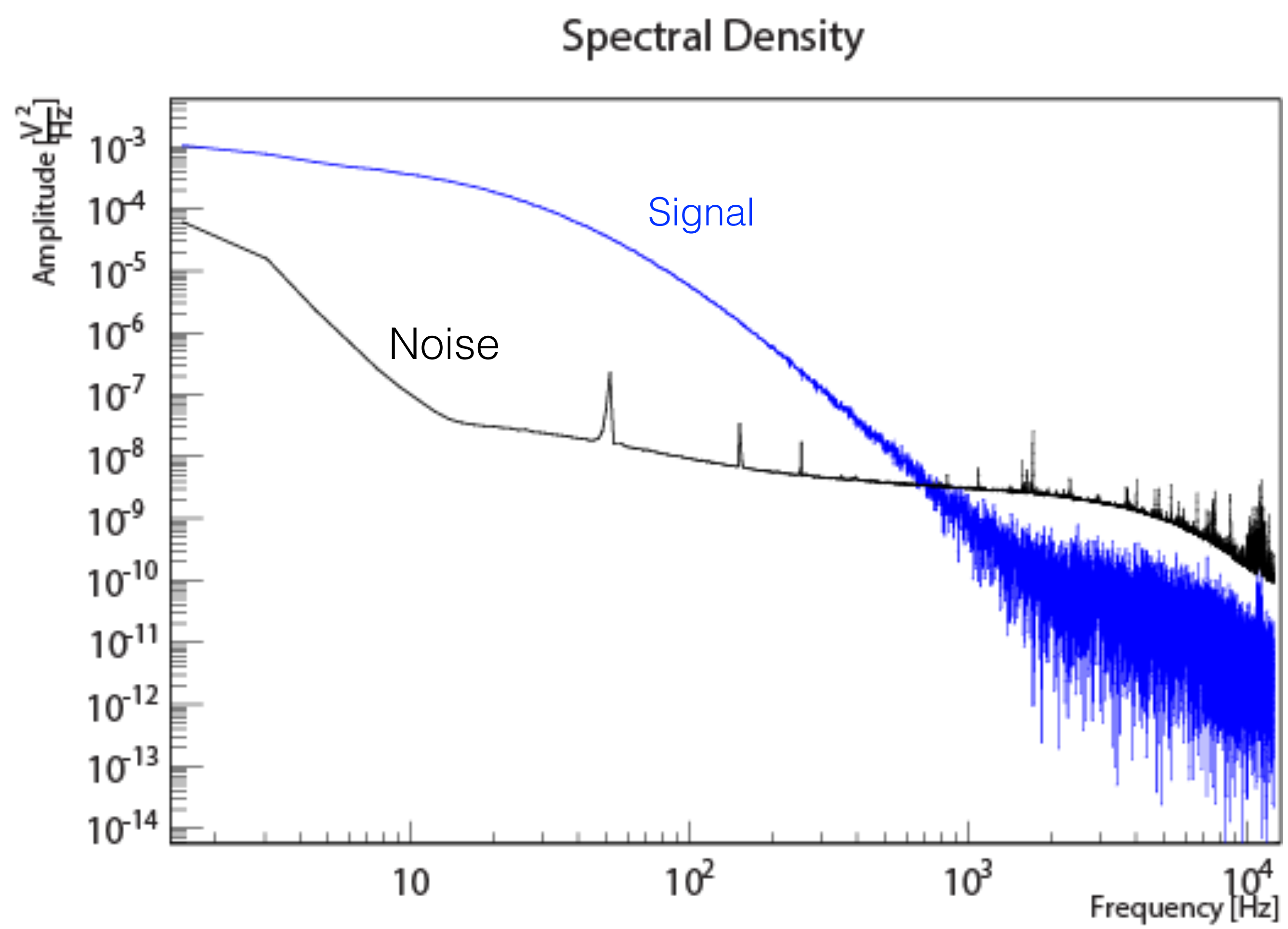
What's next?

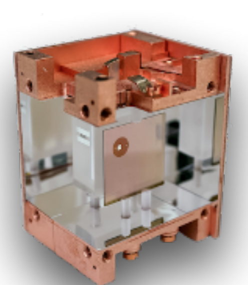
From CRESST-II to CRESST-III

Optimisation for low-mass dark matter search

- Mass reduction by a factor ~ 10: from 300 g to 24 g crystals
- Fully scintillating housing (surface-alpha event discrimination, e.g. $^{210}Po \rightarrow {}^{206}Pb+\alpha$)
- Optimum Filter: Maximisation of the signal-to-noise ratio (**Mancuso, M., Angloher, G., Bauer, P. et al. J Low Temp Phys (2018). https://doi.org/10.1007/s10909-018-1948-6**)



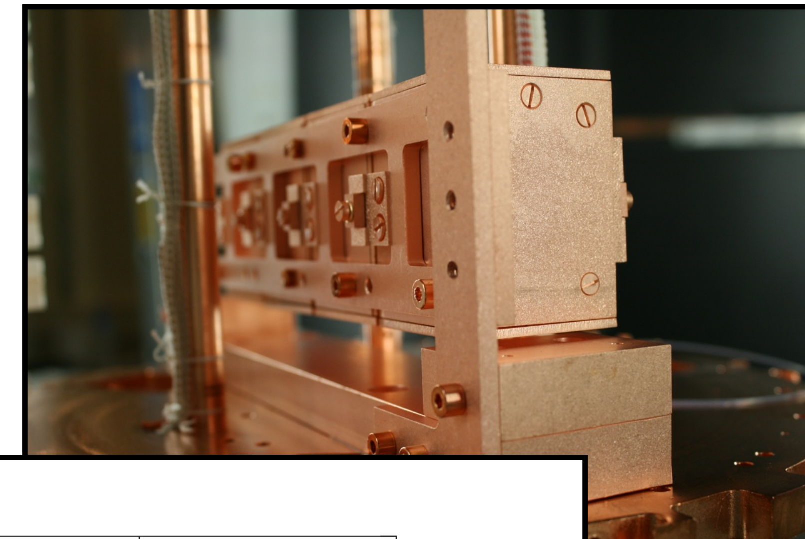


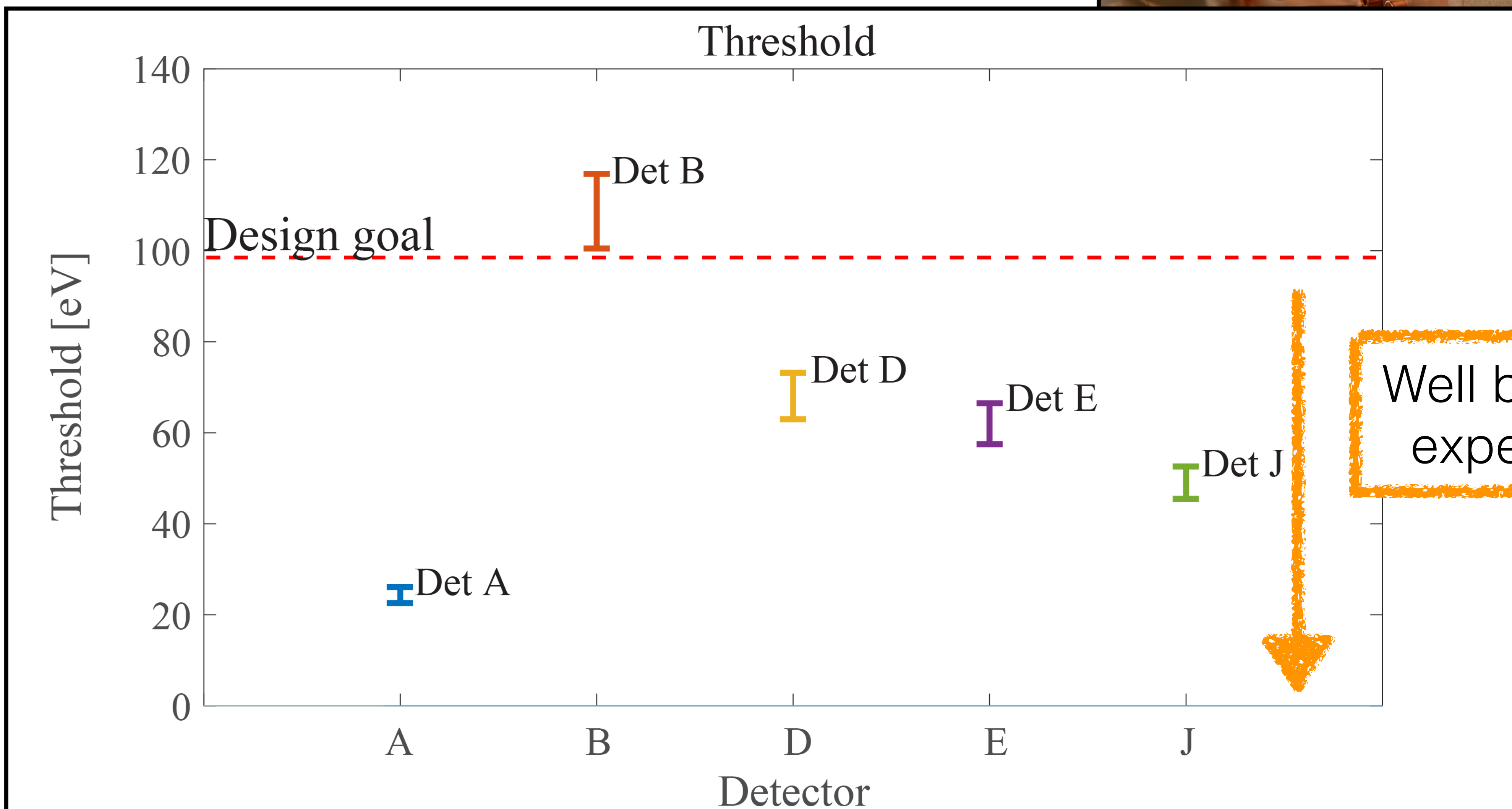


The goal is to push the threshold <u>down to 100 eV</u>

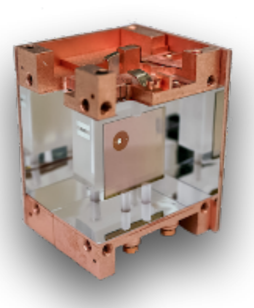
CRESST-III: Threshold Results

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

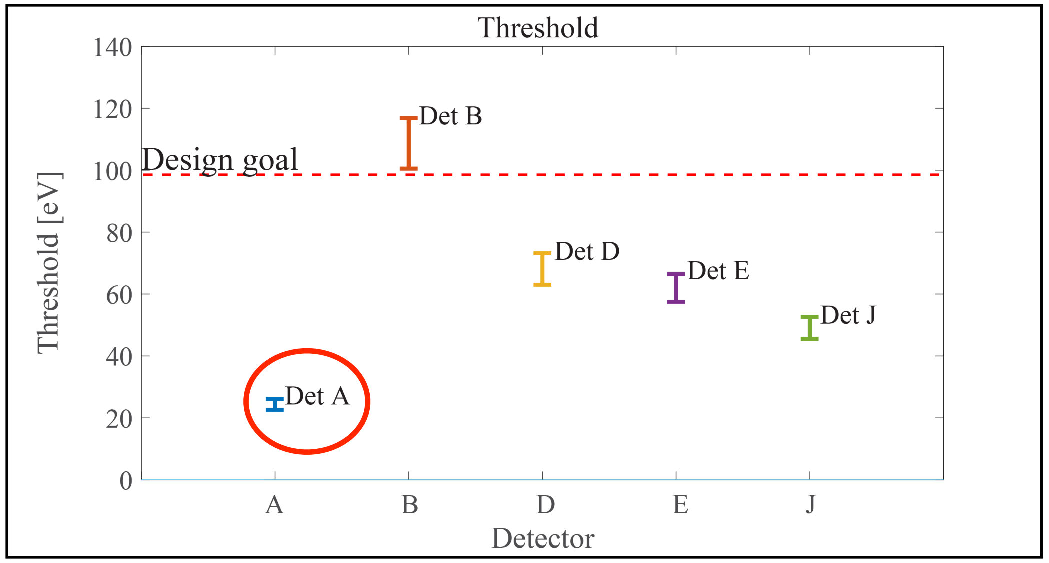




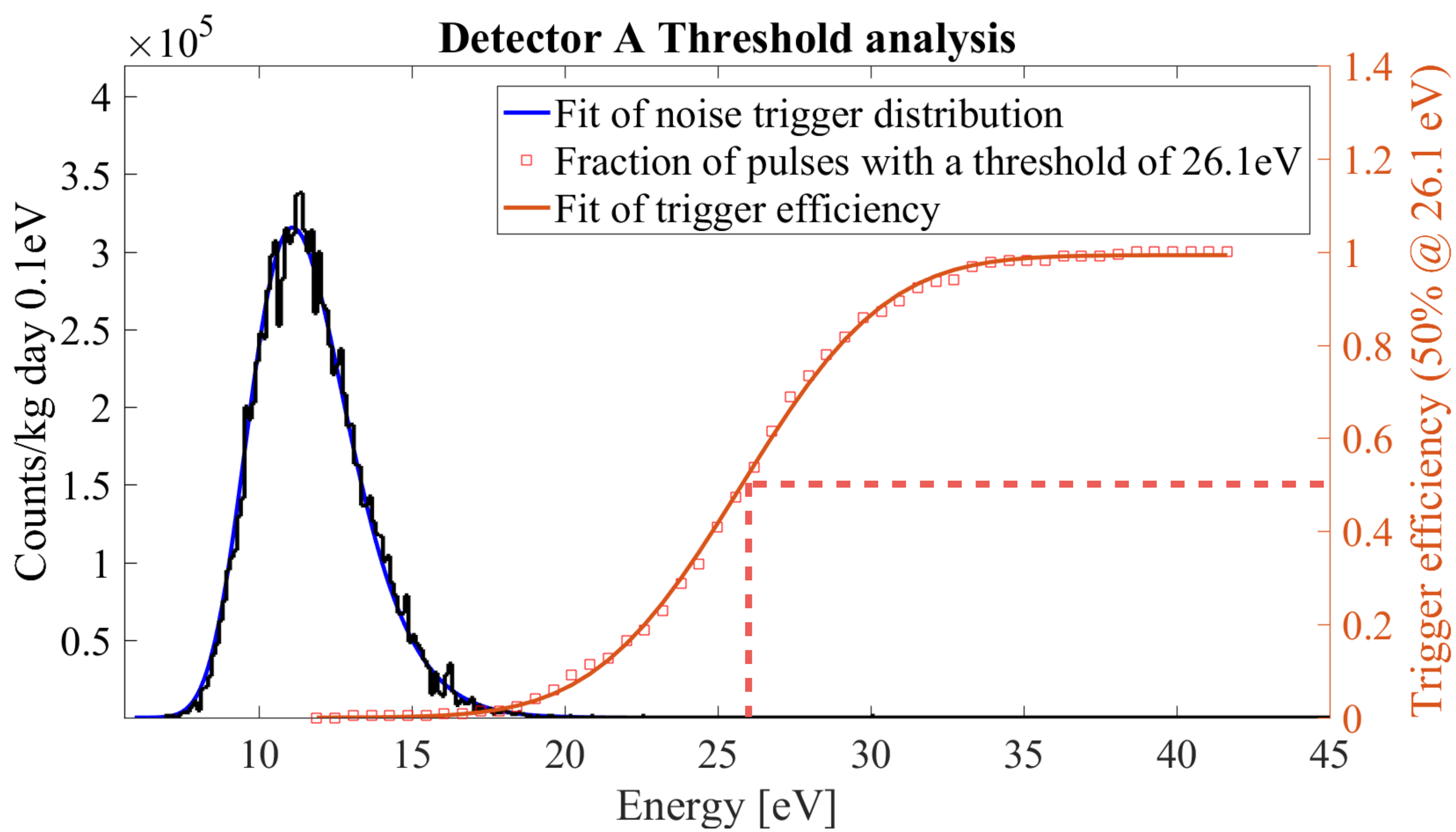
Well beyond the expectations!

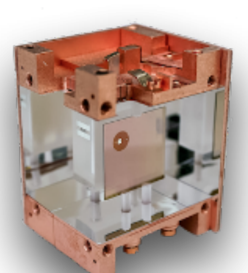


DETECTOR A

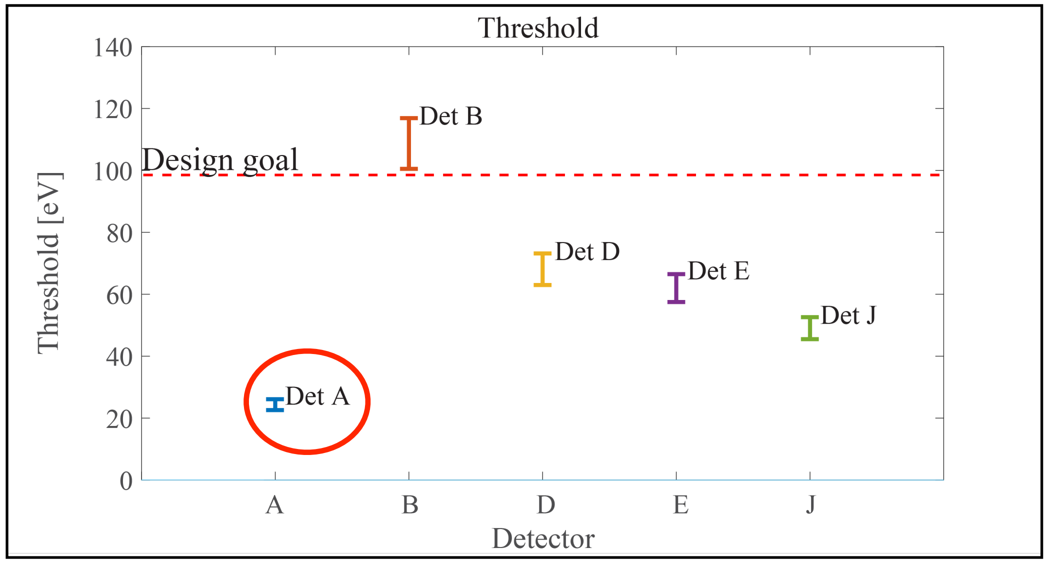


Threshold = 26.1 eV
Corresponds to 50% of trigger efficiency





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
- Net exposure (after cuts): 2.21 kg days
- Analysis Threshold: 100 eV

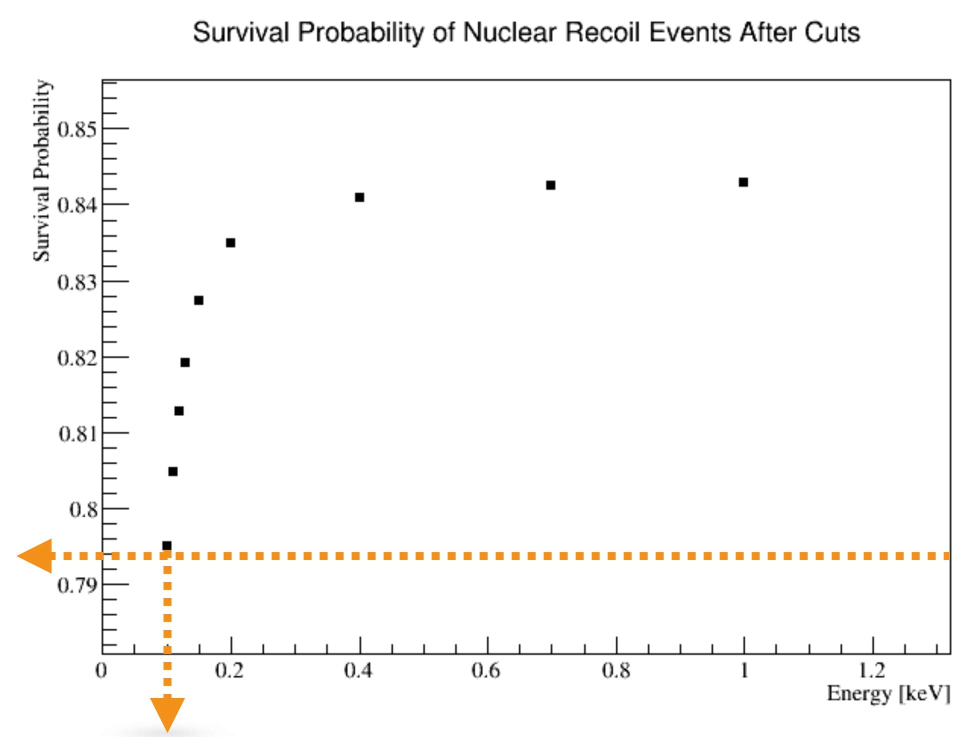
Cut selection and efficiency

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

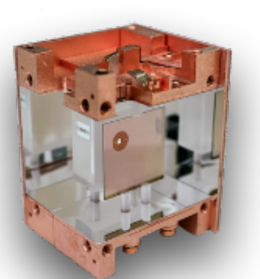
Are removed as the correctness of the energy reconstruction cannot be guaranteed for those events.

After cuts, efficiency 79.4% at 100 eV

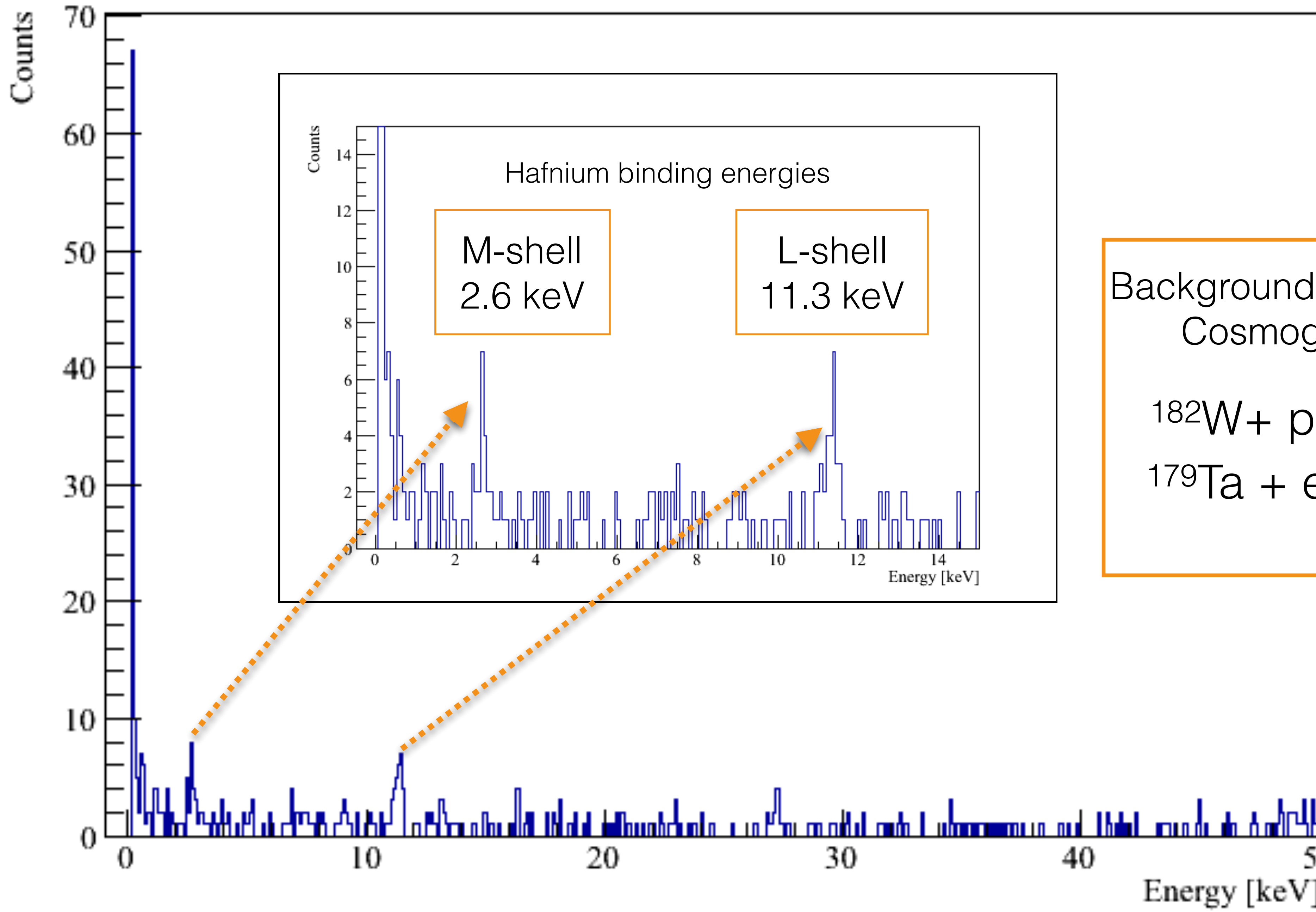
79.4 %



100 eV



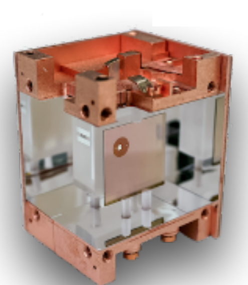
DETECTOR A: EVENT RATE



Background events recognised
Cosmogenic activation

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

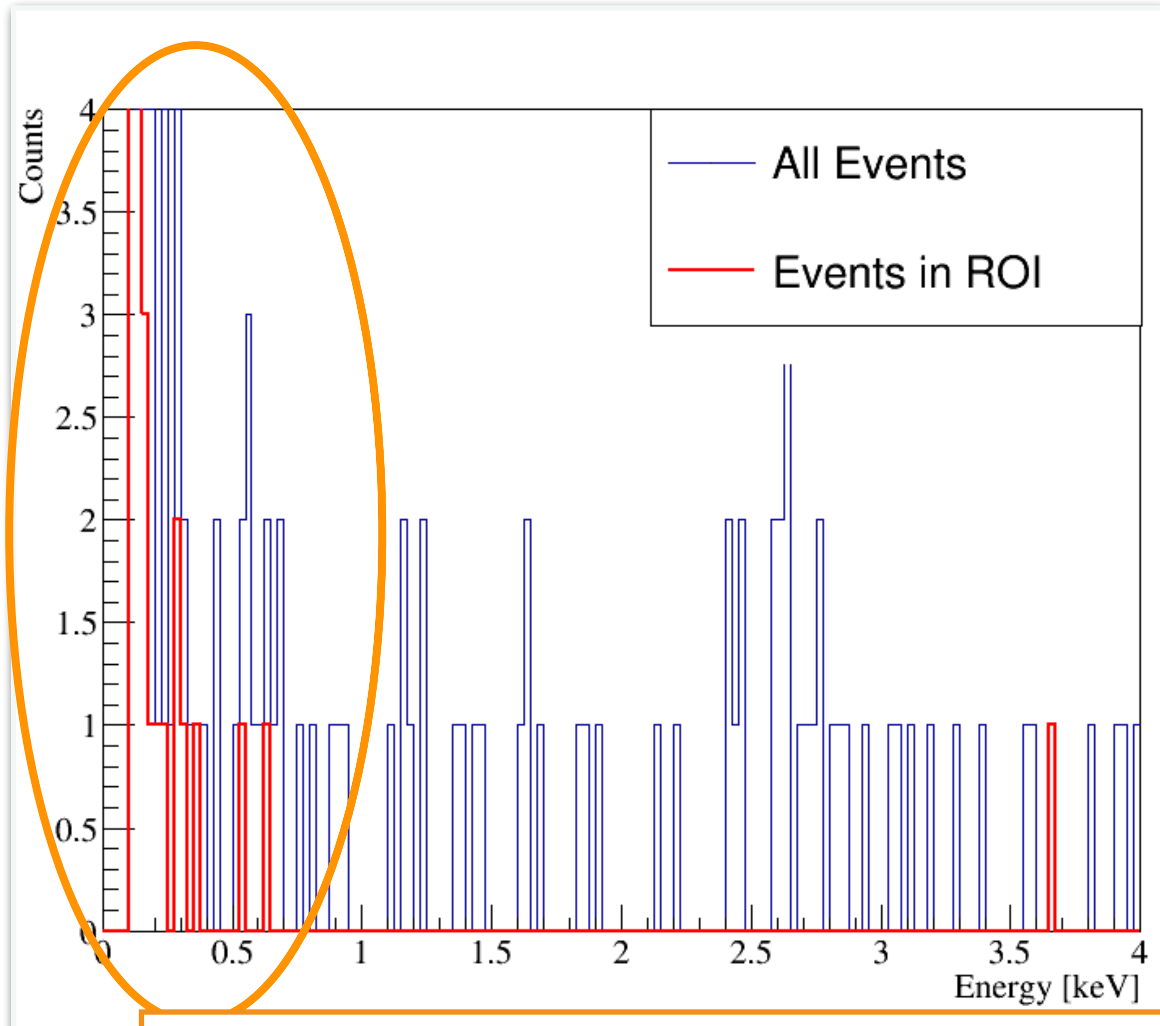
$^{179}Ta + e^- \longrightarrow {}^{179}Hf + \nu_e$

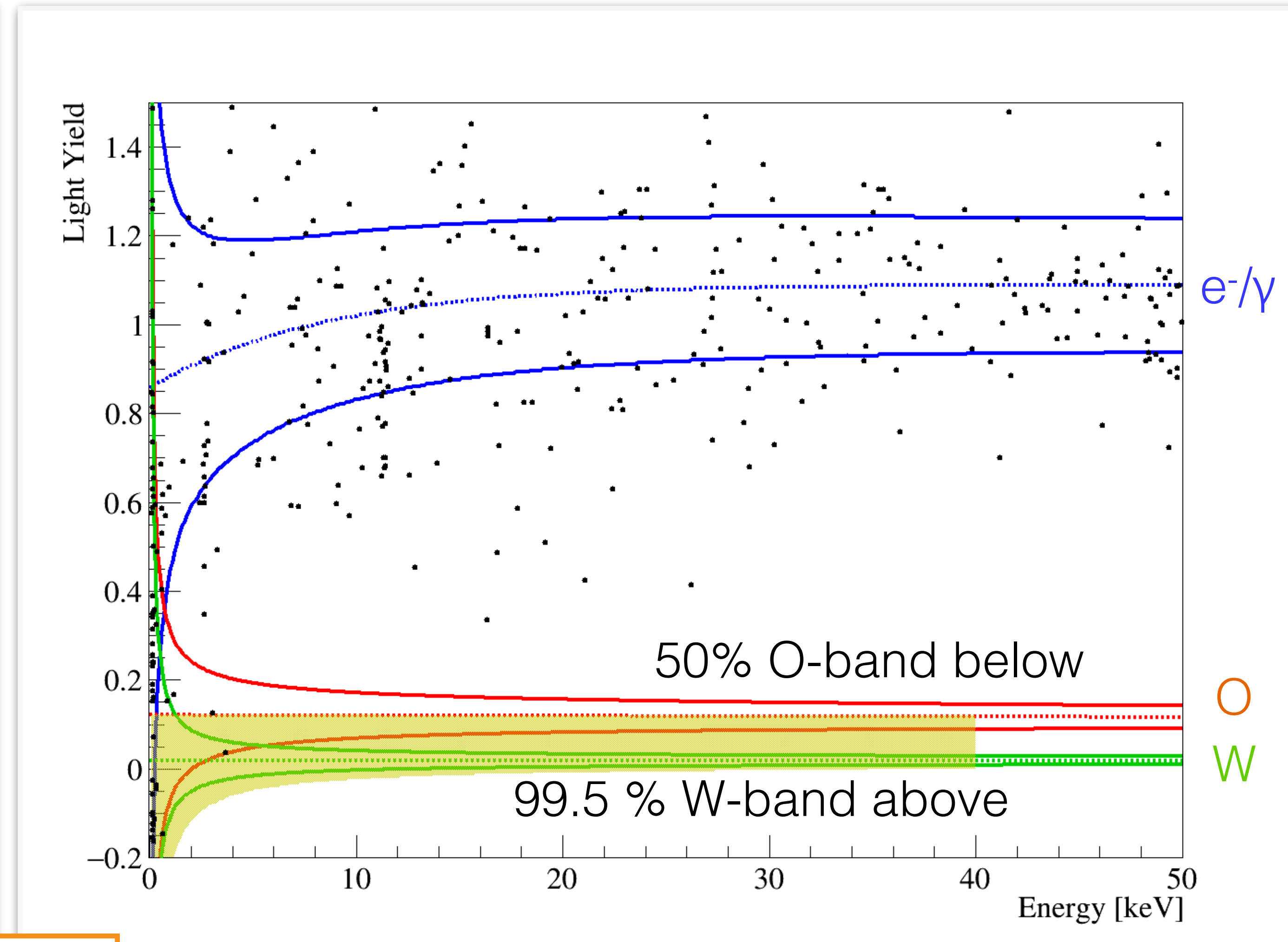


DETECTOR A

Event Rate in the Region of Interest (ROI)

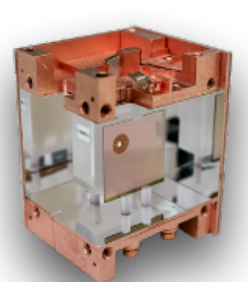
Acceptance regions decided before unblinding



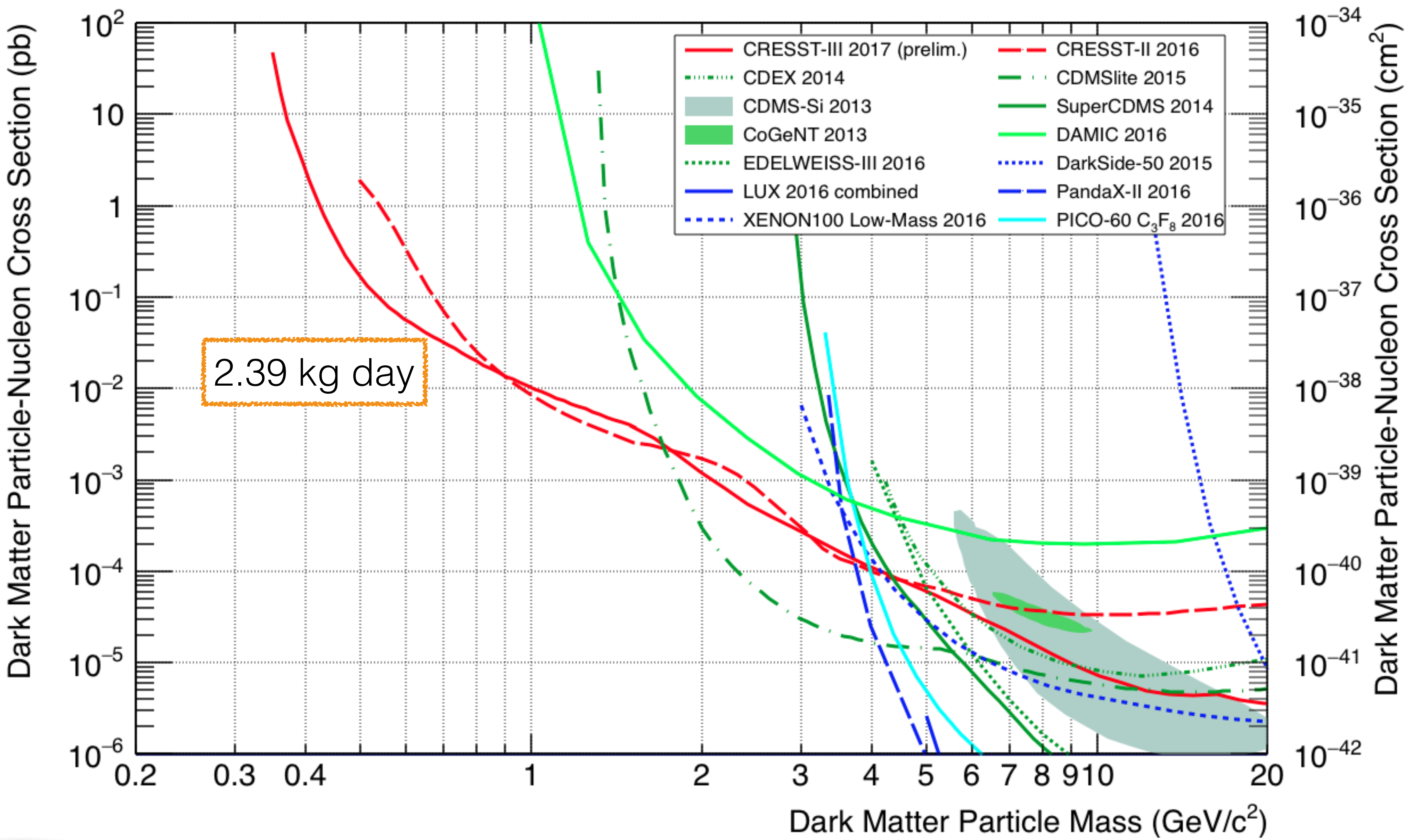


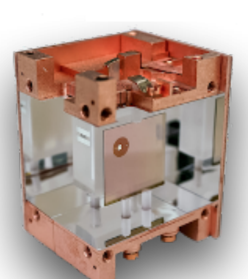
Excess of events below 0.5 keV

New run has been planned for better understanding the background in this region

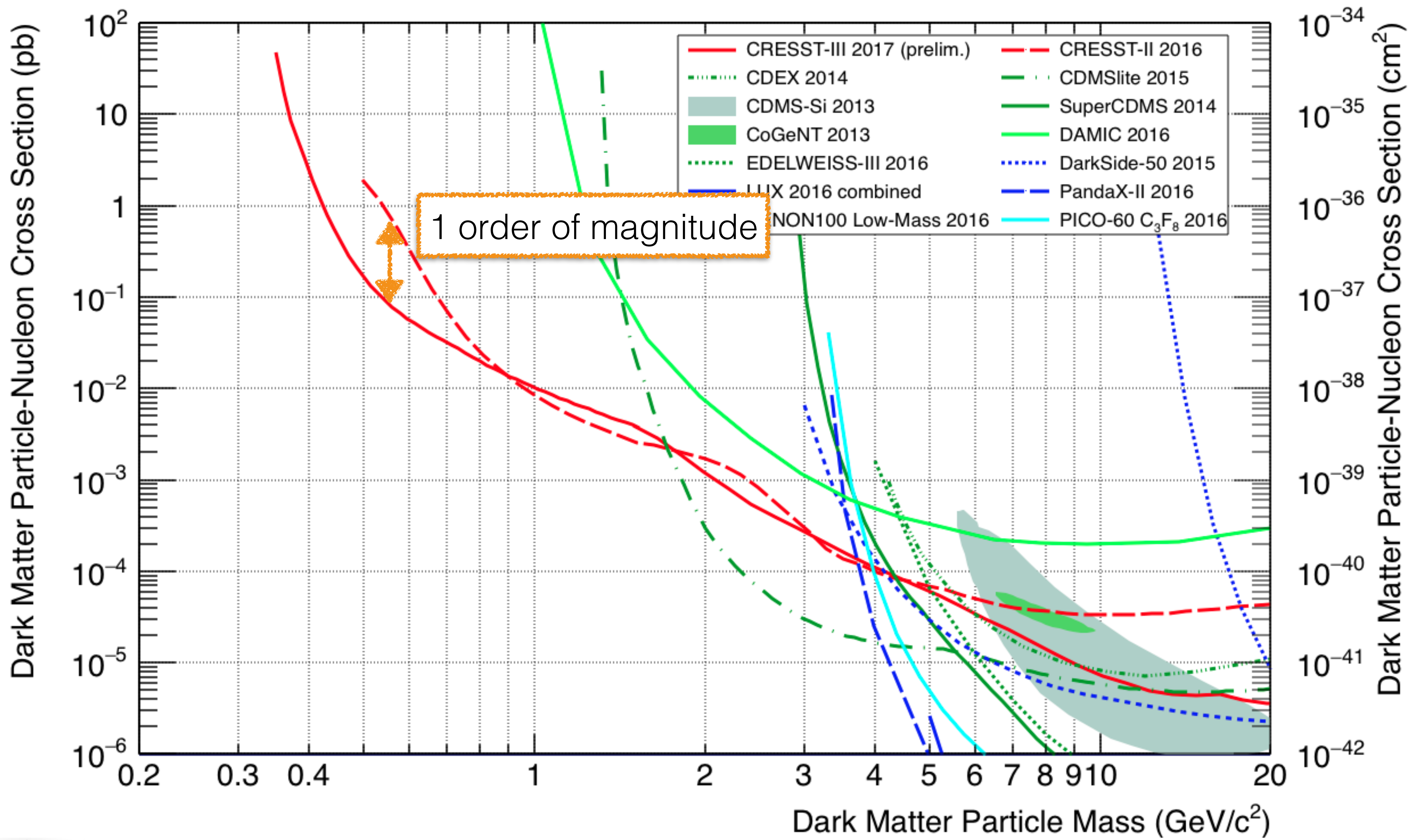


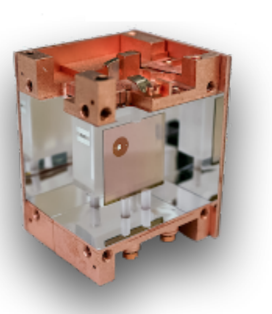
Sensitivity Plot



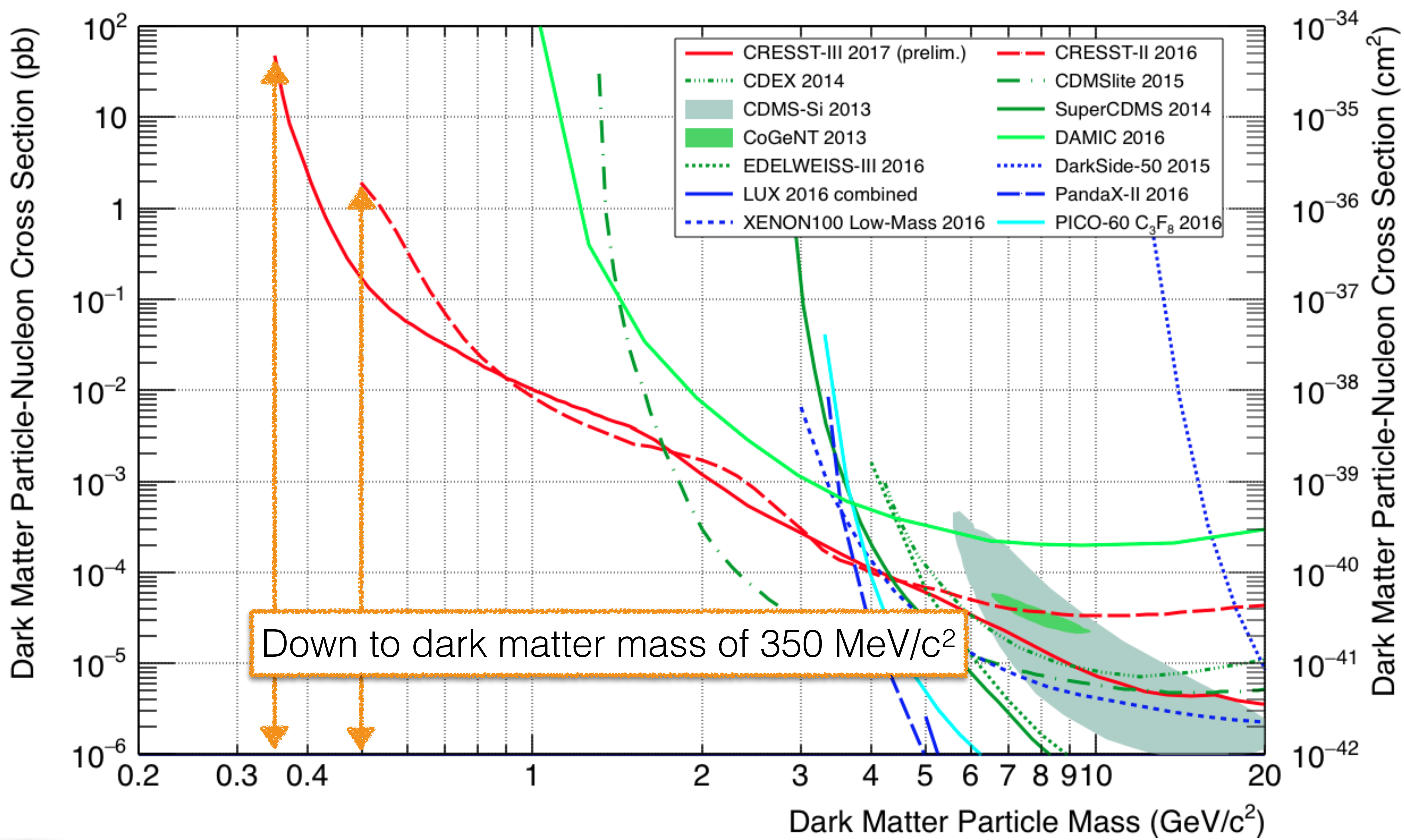


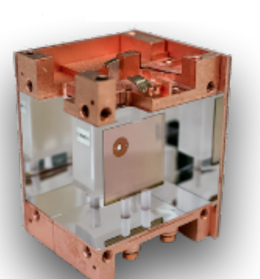
Sensitivity Plot



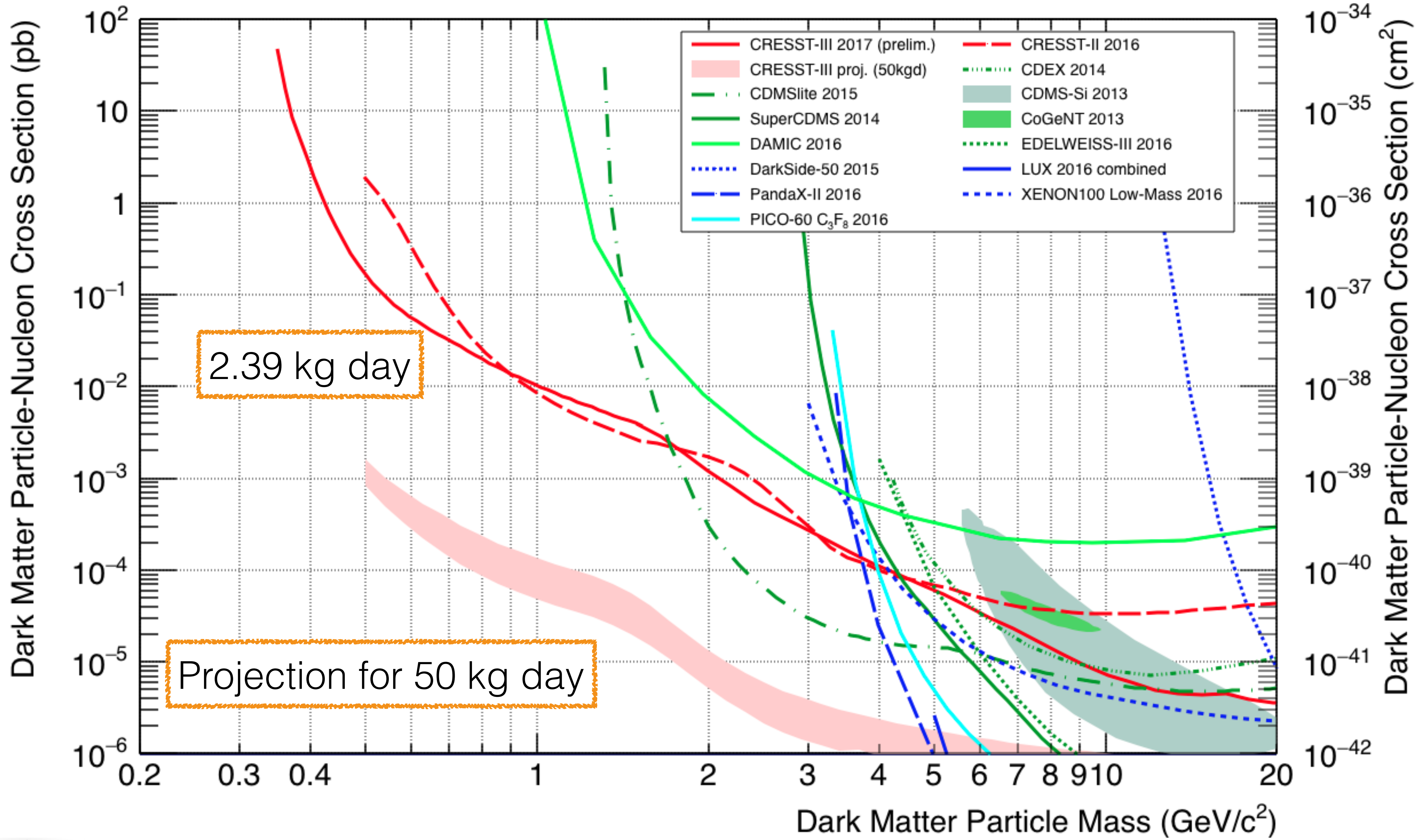


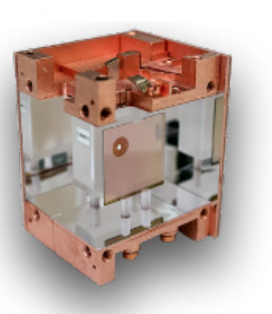
Sensitivity Plot





Sensitivity Plot





CRESST and Effective Field Theory

$$\boxed{\mathbb{1}, v^{\perp}, q, S_{\chi}, S_N}$$

Galilean invariants

$\hat{\mathcal{O}}_1 = \mathbb{1}_{\chi} \cdot \mathbb{1}_N \rightarrow$ (standard SI)

$\hat{\mathcal{O}}_2 = (\vec{v}^{\perp})^2$

$\hat{\mathcal{O}}_3 = i\vec{S}_N \cdot \left(\vec{q}/m_N \times \vec{v}^{\perp}\right)$

$\hat{\mathcal{O}}_4 = \vec{S}_{\chi} \cdot \vec{S}_N \rightarrow$ (standard SD)

$\hat{\mathcal{O}}_5 = i\vec{S}_{\chi} \cdot \left(\vec{q}/m_N \times \vec{v}^{\perp}\right)$

$\hat{\mathcal{O}}_6 = (\vec{S}_{\chi} \cdot \vec{q}/m_N)(\vec{S}_N \cdot \vec{q}/m_N)$

$\hat{\mathcal{O}}_7 = \vec{S}_N \cdot \vec{v}^{\perp}$

$\hat{\mathcal{O}}_8 = \vec{S}_{\chi} \cdot \vec{v}^{\perp}$

$\hat{\mathcal{O}}_9 = i\vec{S}_{\chi} \cdot \left(\vec{S}_N \times \vec{q}/m_N\right)$

$\hat{\mathcal{O}}_{10} = i\vec{S}_N \cdot \vec{q}/m_N$

...

Anand et al. arXiv:1308.6288 [hep-ph]

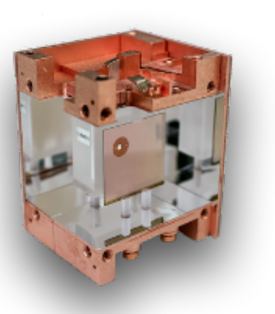
→

$$\frac{\mathrm{d}\sigma}{\mathrm{d}q^2} = \frac{1}{(2J+1)v^2} \sum_{\tau,\tau'} \Bigg[\sum_{\ell=M,\Sigma',\Sigma''} R_{\ell}^{\tau\tau'}\left(v_T^{\perp 2}, \frac{q^2}{m_N^2}\right) W_{\ell}^{\tau\tau'}(q^2) + \frac{q^2}{m_N^2} \sum_{m=\Phi'',\Phi''M,\tilde{\Phi}',\Delta,\Delta\Sigma'} R_m^{\tau\tau'}\left(v_T^{\perp 2}, \frac{q^2}{m_N^2}\right) W_m^{\tau\tau'}(q^2)\Bigg]$$

D. Gazda, R. Catena, and C. Forssén arXiv:1612.09165 [hep-ph]

$R_{\ell}^{\tau\tau'}$ contains the dark matter - nucleon interaction terms

$W_{\ell}^{\tau\tau'}$ is the nuclear response to the non relativistic interaction



CONCLUSIONS

In 2017 CRESST explored a new parameter space in the low-mass region

CRESST-III first campaign has been completed in March 2018

New campaign will start in summer

Full exposure and <100 eV analysis is still ongoing

New data release and results will come soon

Stay tuned!