DIRECT SEARCH FOR LIGHT DARK MATTER WITH THE CRESST-III EXPERIMENT

New Directions in the Search for Light Dark Matter Particles,
Fermilab, Chicago, 06/2019

Florian Reindl
HEPHY & TU Vienna

for the CRESST collaboration

THE CRESST COLLABORATION

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Max-Planck-Institut für Physik
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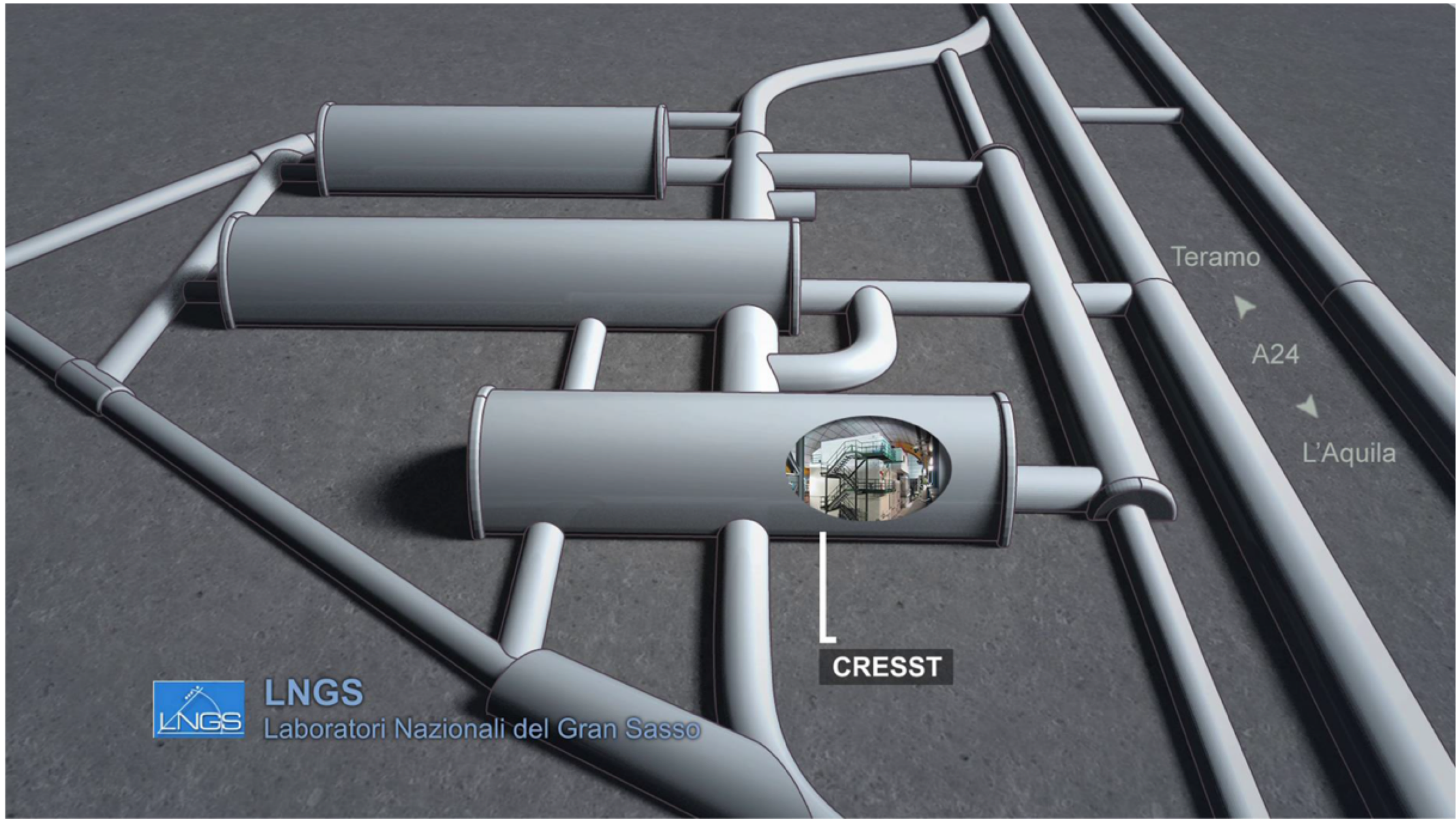
LABORATORI NAZIONALI DEL GRAN SASSO (LNGS)

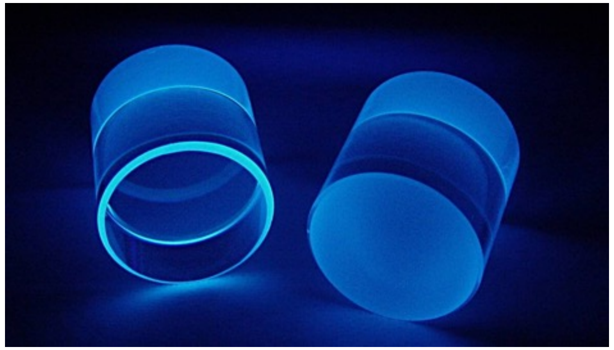


THE CRESST EXPERIMENT

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

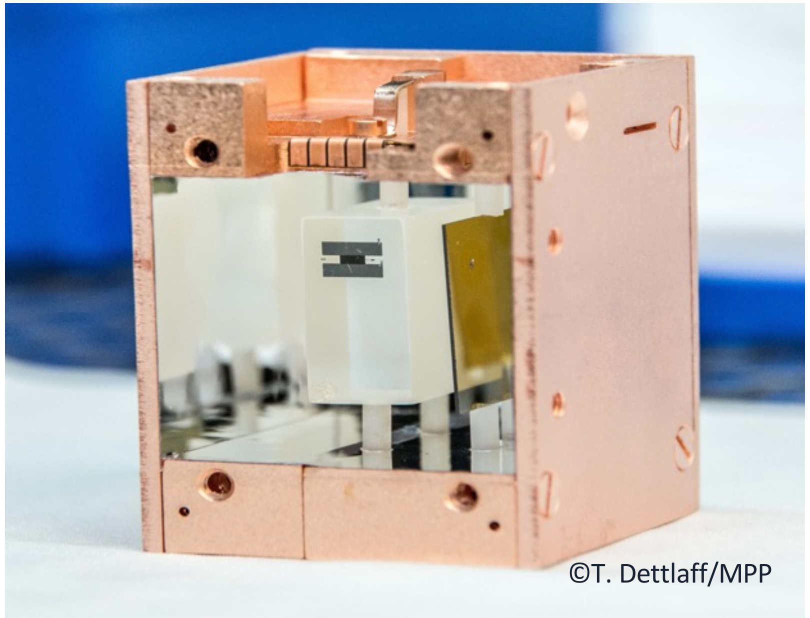
Direct detection of dark matter particles via their scattering off target nuclei

Scintillating $CaWO_4$ crystals as target

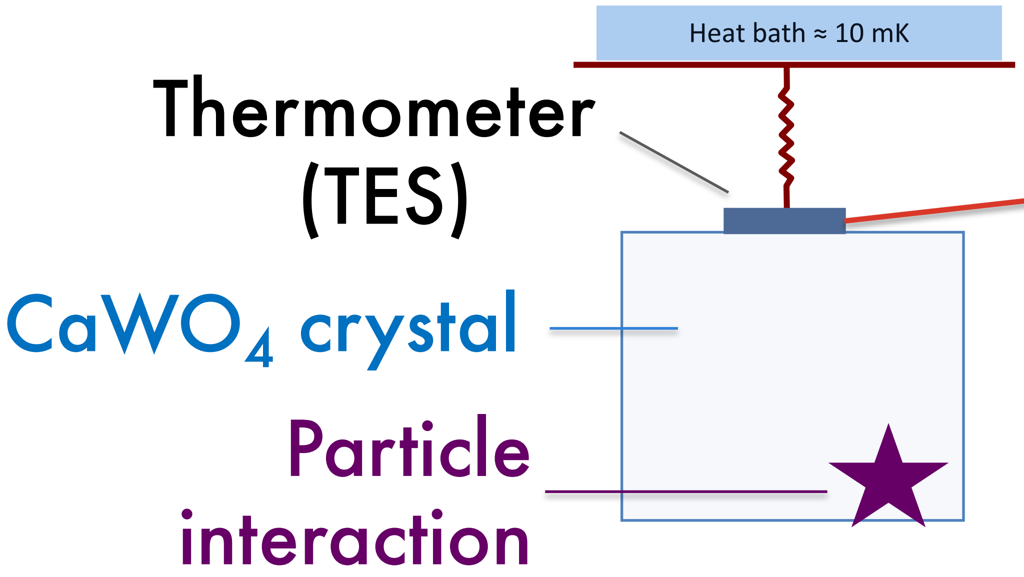


Target crystals operated as **cryogenic calorimeters** (~15mK)

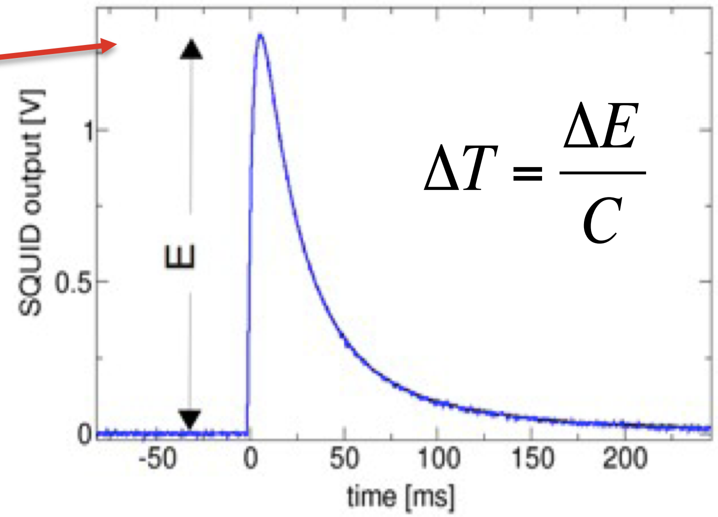
Separate **cryogenic light detector** to detect the scintillation light signal



CRYOGENIC DETECTOR



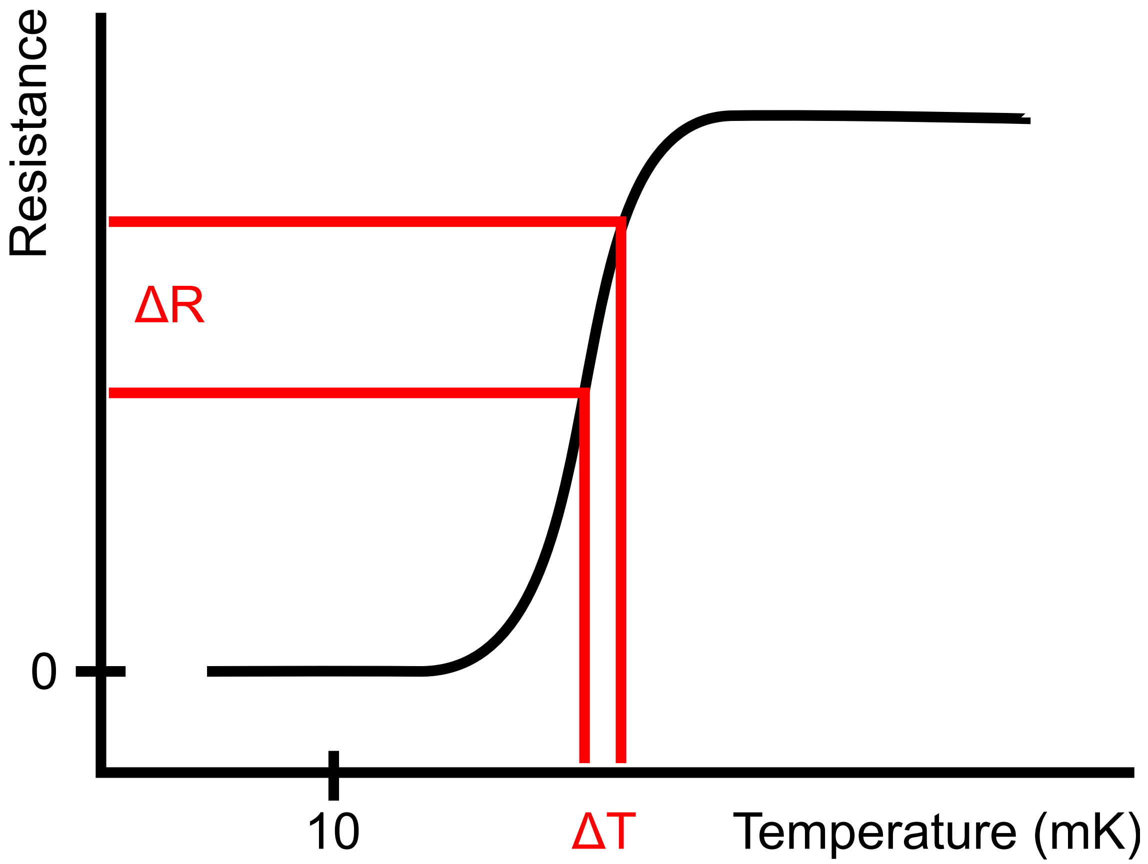
Temperature pulse



Low temperature
Low heat capacity } High sensitivity

TRANSITION EDGE SENSOR (TES)

WORKING PRINCIPLE



Energy deposition

~keV

↓

Temperature rise

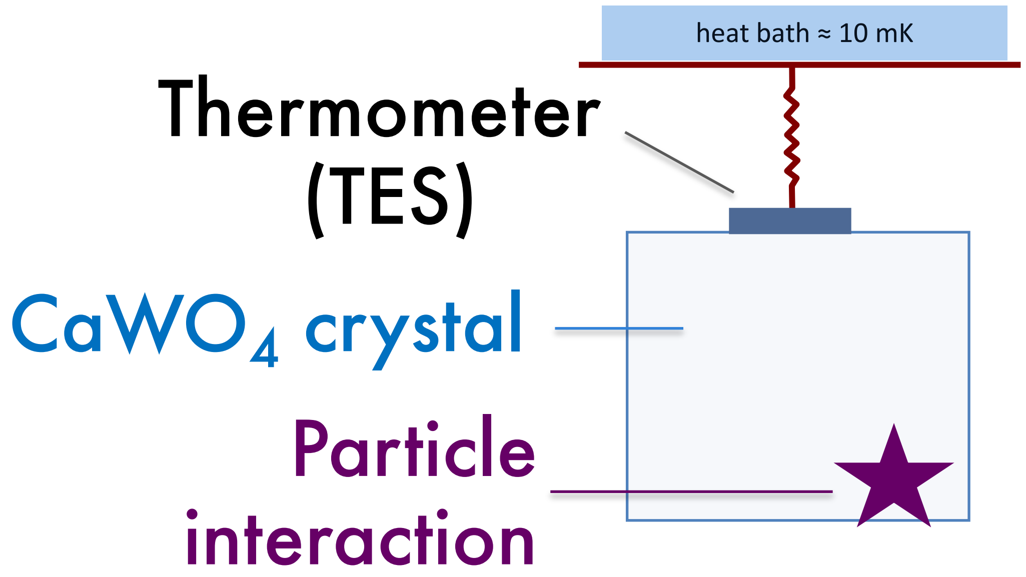
~μK

↓

Resistance change

~mΩ

CRYOGENIC DETECTOR

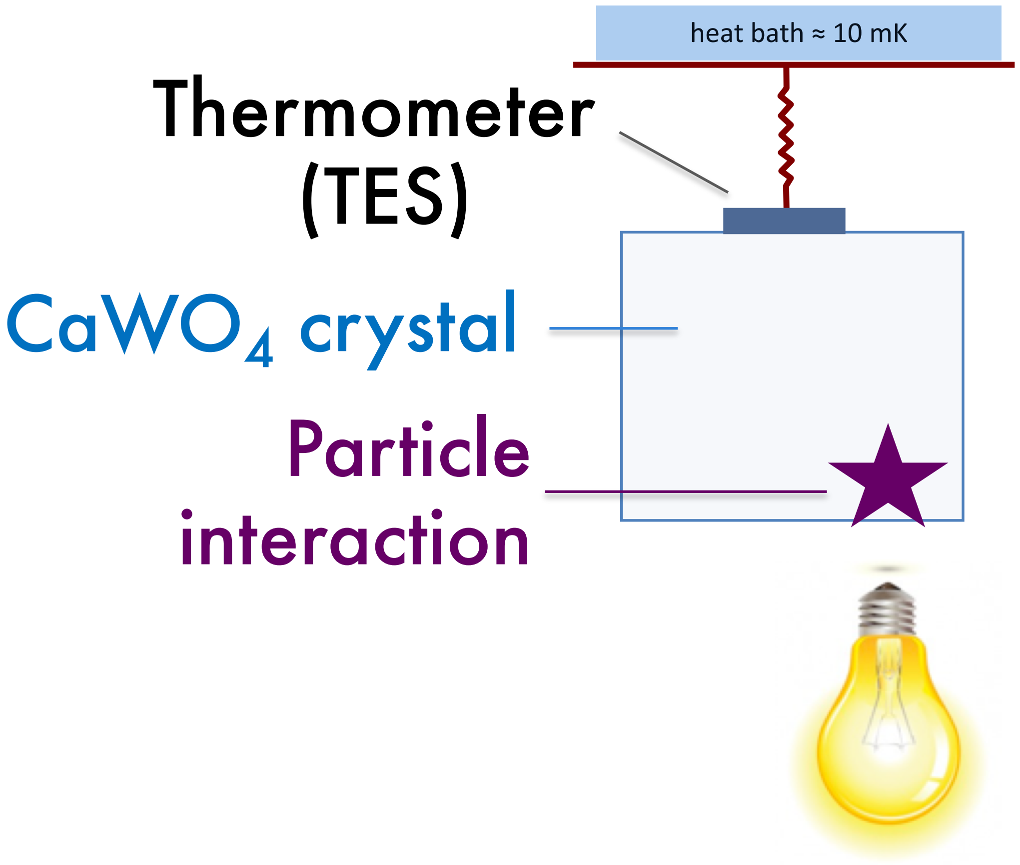


Phonon signal (≳90 %)

(almost) independent of particle type

Precise measurement of the deposited energy

SCINTILLATING CALORIMETER



Phonon signal (≳90 %)

(almost) independent of particle type

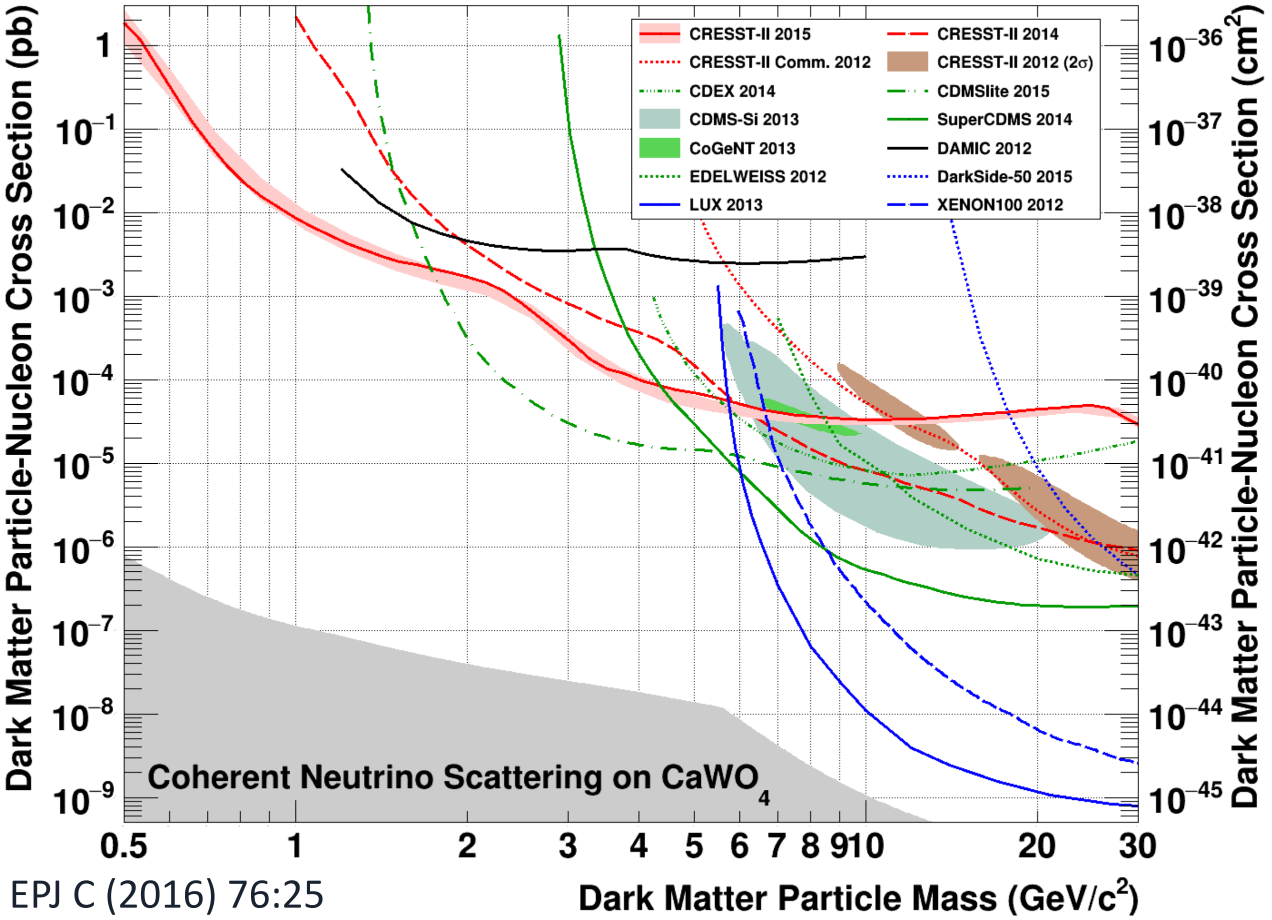
Precise measurement of the deposited energy

Scintillation light (few %)

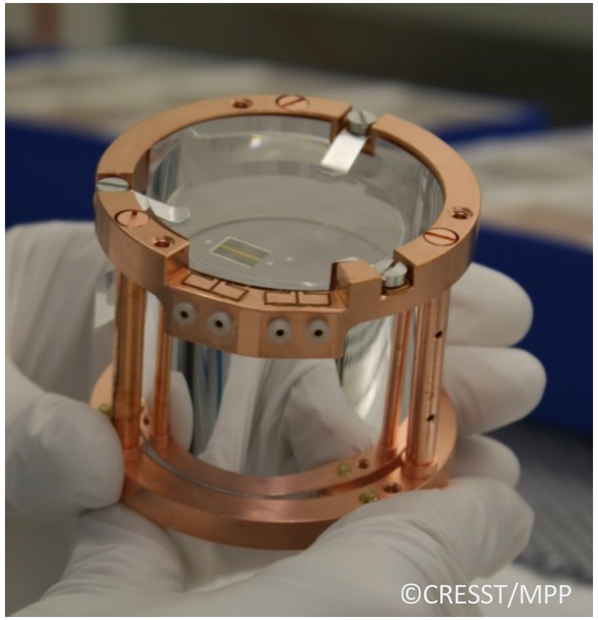
Particle-type dependent
→ LIGHT QUENCHING

CRESST-II RESULTS - 2015

Lise: Background level ≈8.5 counts/(keV kg day)
Threshold: 307eV



EPJ C (2016) 76:25

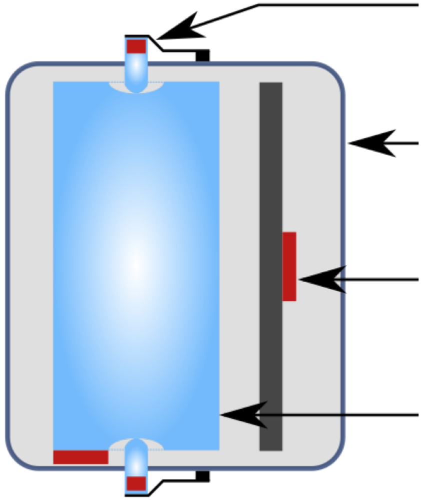


Until 2017 world-leading below $1.7 GeV/c^2$

Opened up sub-GeV/c^2 regime

Hunting light dark matter requires a low threshold!

CRESST-III LOW-THRESHOLD DETECTORS



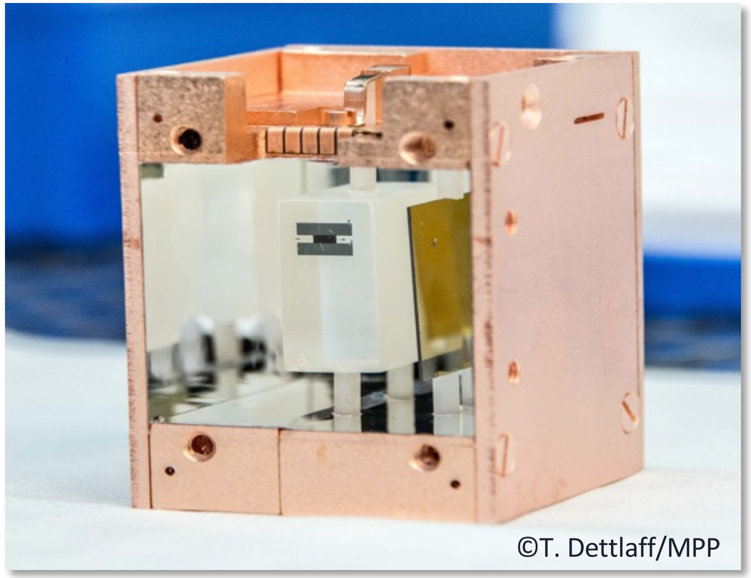
Detector layout optimized for low-mass dark matter

Radical reduction of dimension (250g → 24g)

- Cuboid crystals of $(20\times20\times10)mm^3$ (≈**24g**)
- Threshold design goal **100 eV threshold**

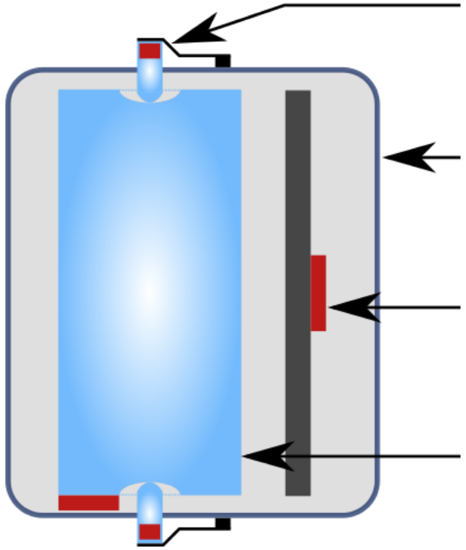
- Fully scintillating housing
- Instrumented sticks

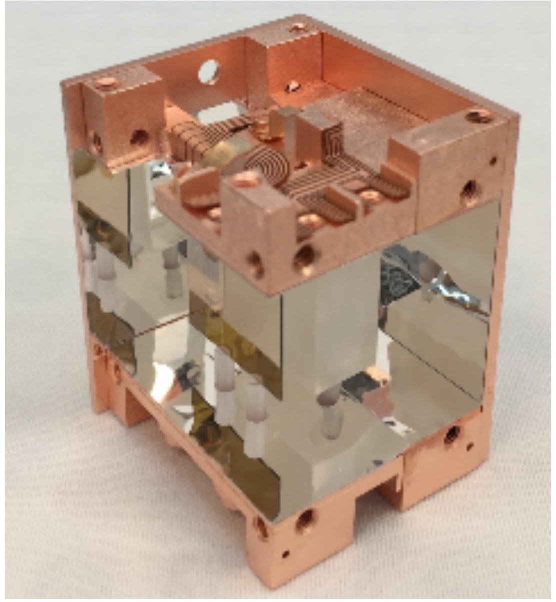
} Veto surface-related background



DETECTOR A

= LOWEST THRESHOLD IN CRESST-III PHASE 1

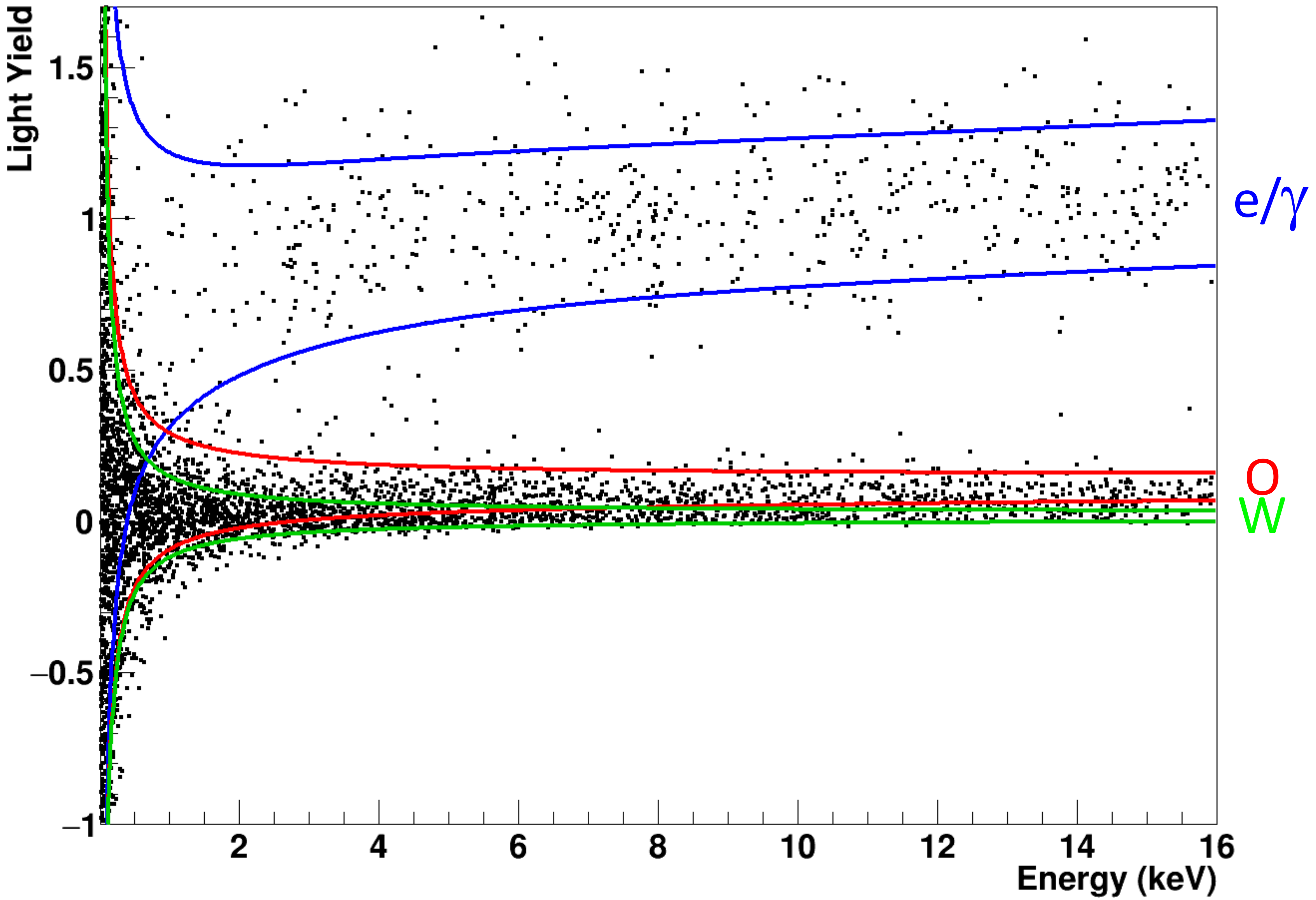




arXiv:1904.00498

Data taking period:	10/2016 – 01/2018
Non-blind data (dynamically growing):	20% randomly selected
Target crystal mass:	23.6g
Gross exposure (before cuts):	5.6 kg days
Nuclear recoil threshold:	30.1 eV

DETECTOR A – NEUTRON CALIBRATION



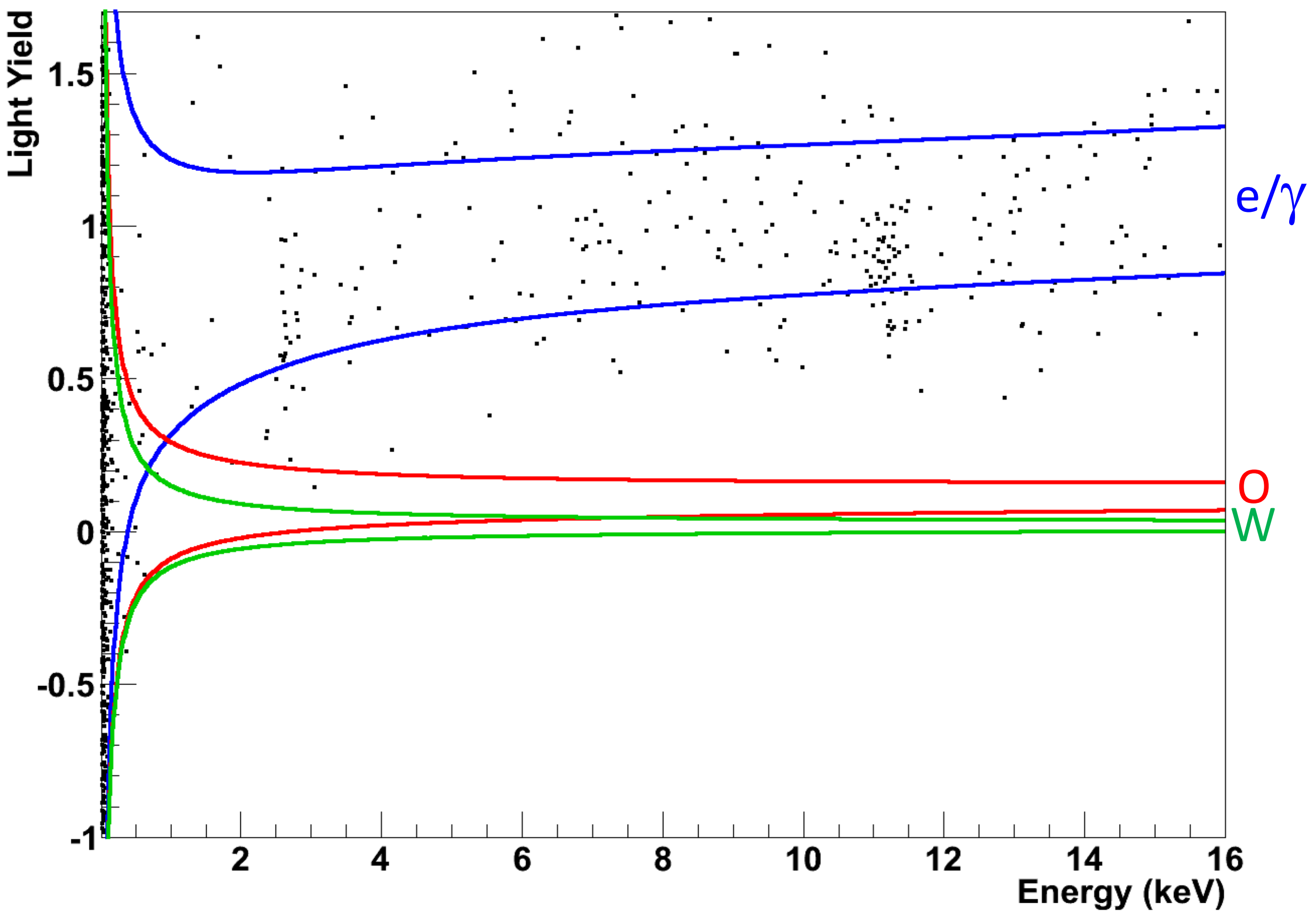
Unbinned maximum likelihood fit

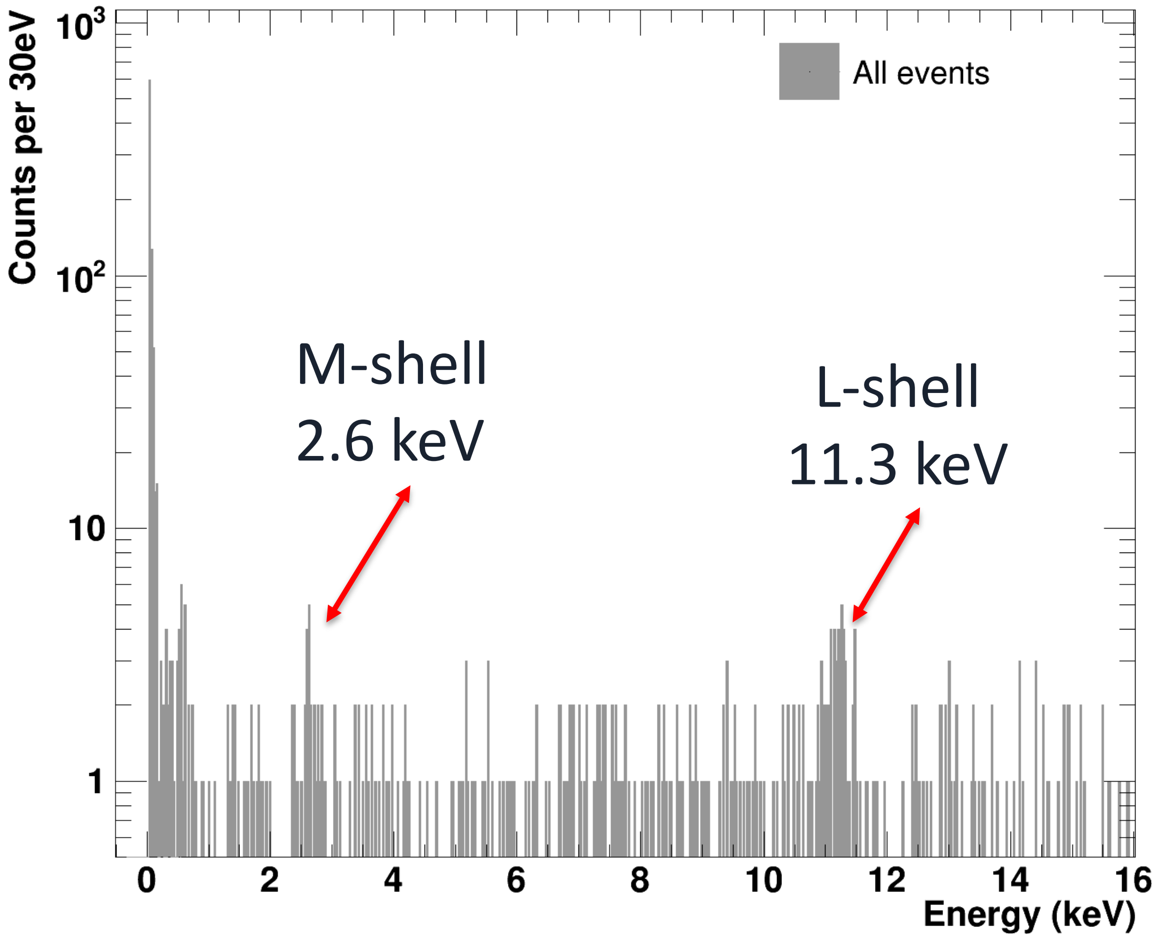
QFs from MLL neutron beam measurement

DARK MATTER DATA

Analysis optimized for very low energies: 30eV → 16keV

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

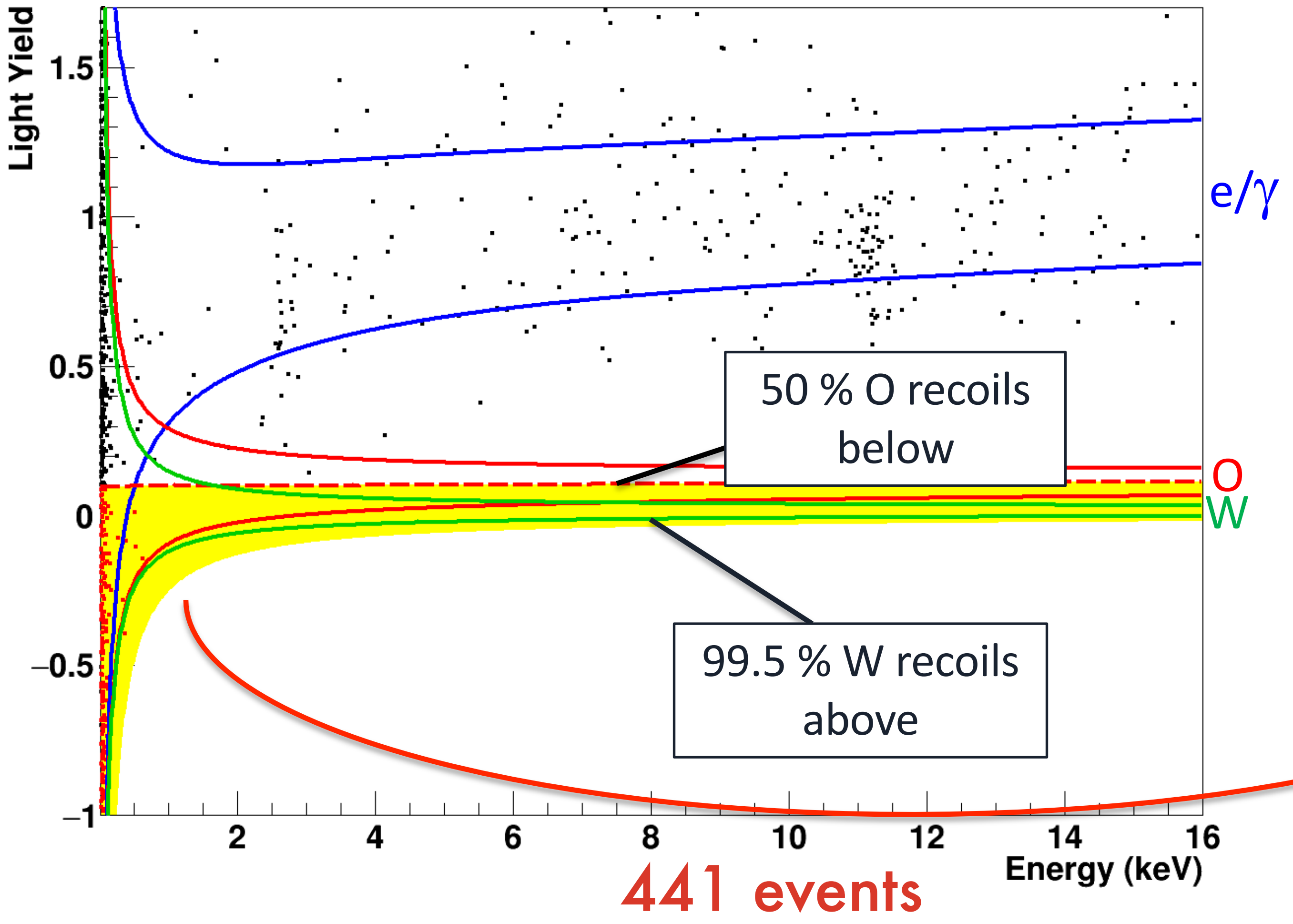


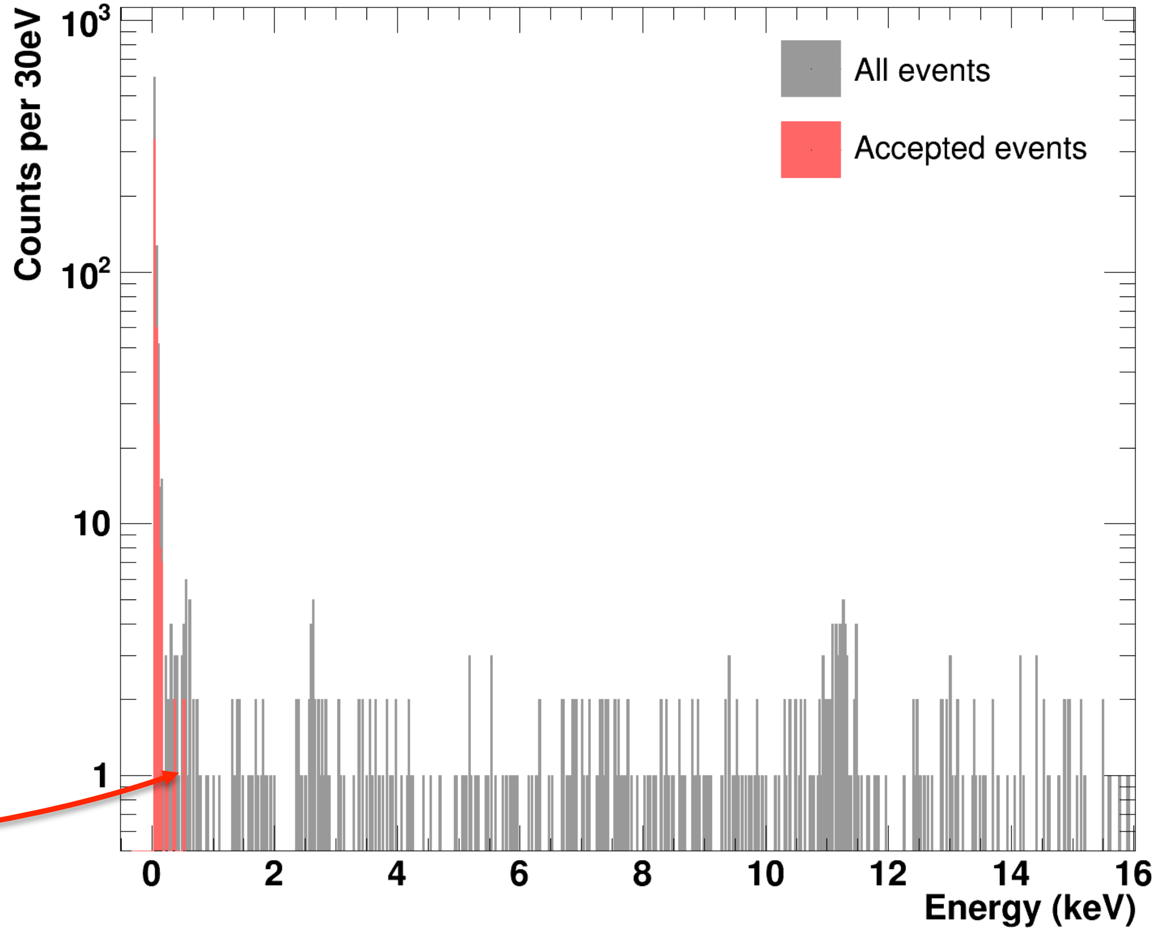


DARK MATTER DATA

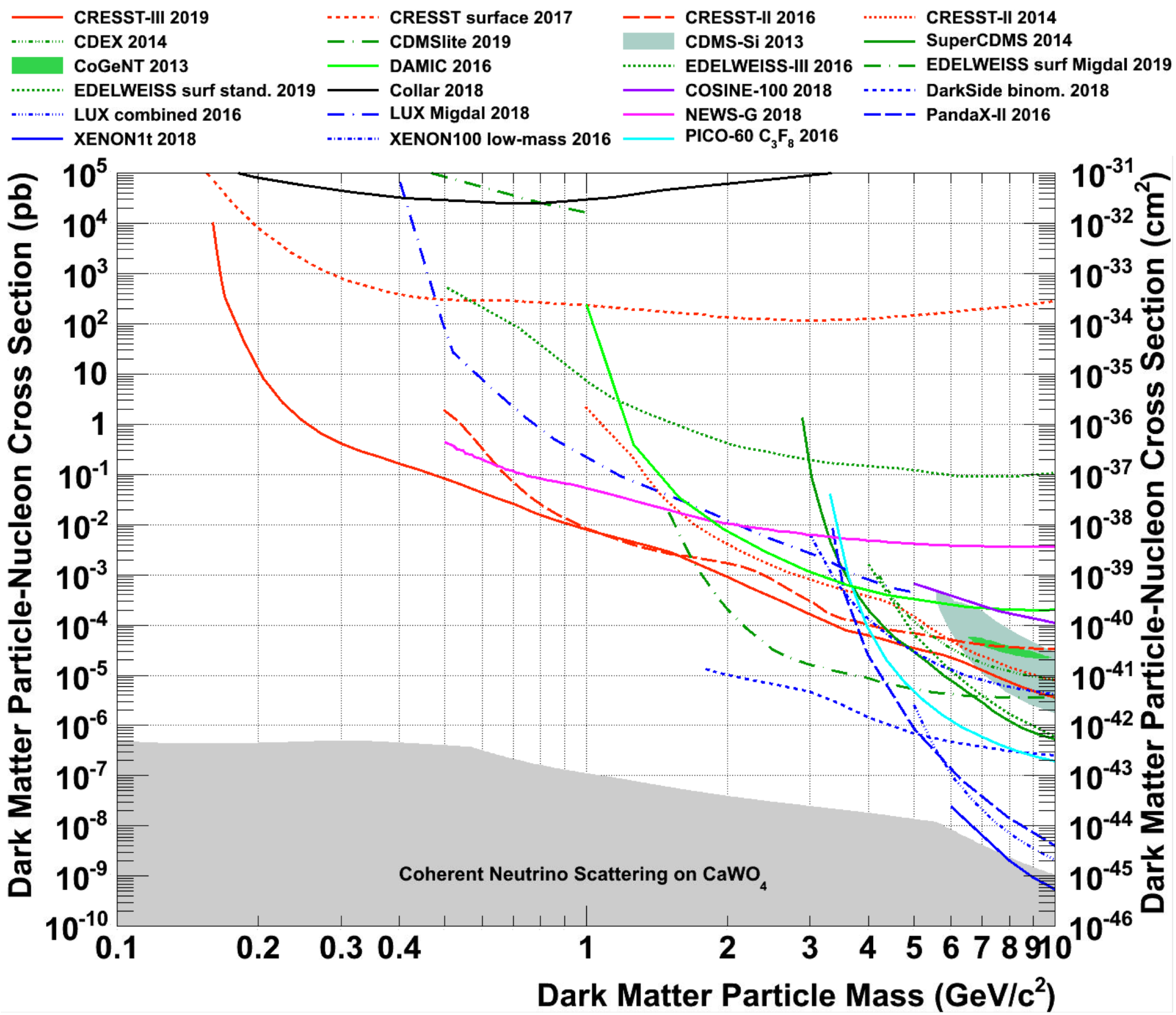
Analysis optimized for very low energies: 30eV → 16keV

Acceptance region fixed before unblinding





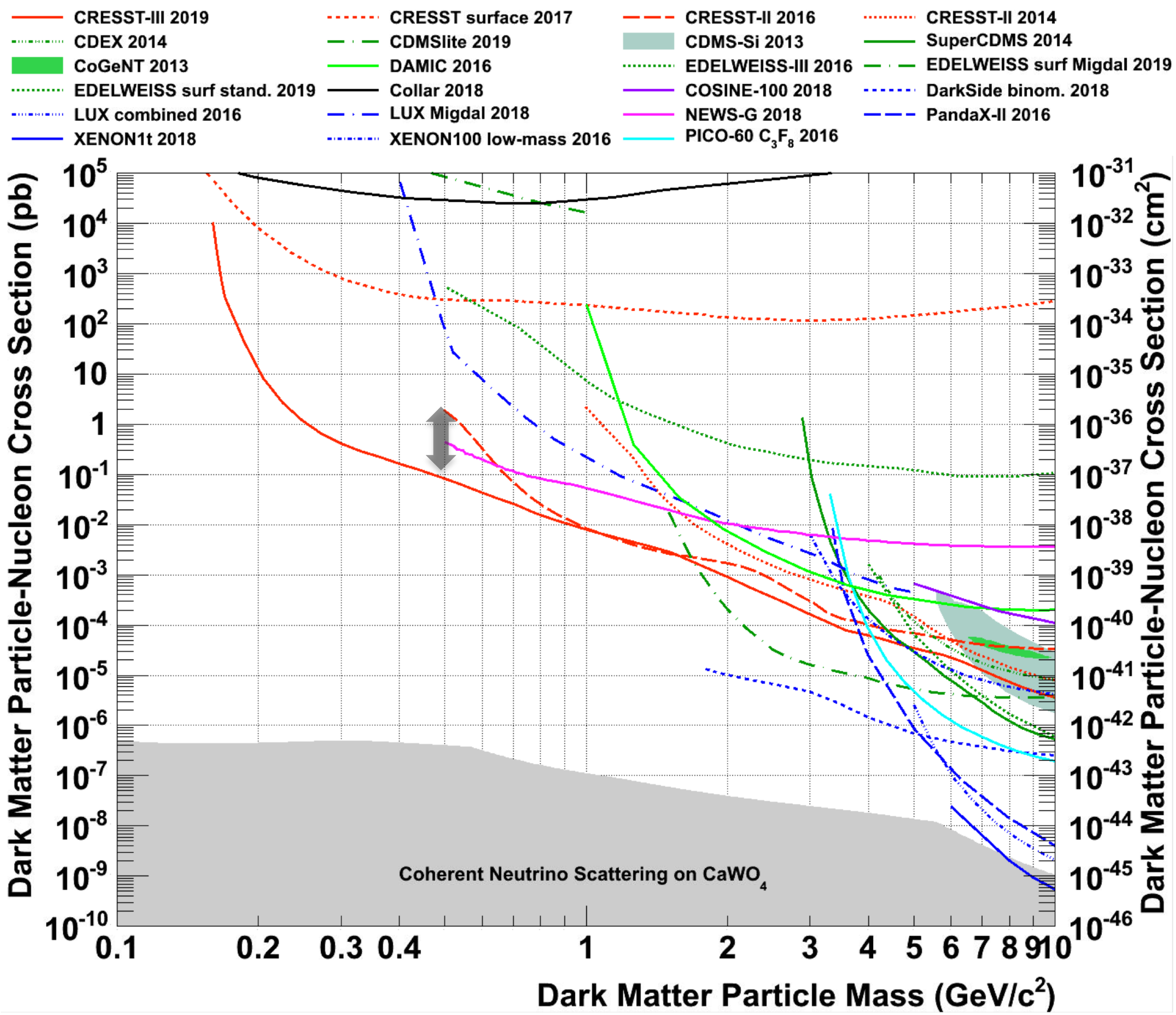
RESULTS



CRESST-III 2019
CRESST surface 2017
CRESST-II 2016
CRESST-II 2014
CDEX 2014
CDMSlite 2019
CDMS-Si 2013
SuperCDMS 2014
CoGeNT 2013
DAMIC 2016
EDELWEISS-III 2016
EDELWEISS surf Migdal 2019
EDELWEISS surf stand. 2019
Collar 2018
COSINE-100 2018
DarkSide binom. 2018
LUX combined 2016
LUX Migdal 2018
NEWS-G 2018
PandaX-II 2016
XENON1t 2018
XENON100 low-mass 2016
PICO-60 C_3F_8 2016
Coherent Neutrino Scattering on $CaWO_4$
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm^2)
Dark Matter Particle Mass (GeV/c^2)

RESULTS

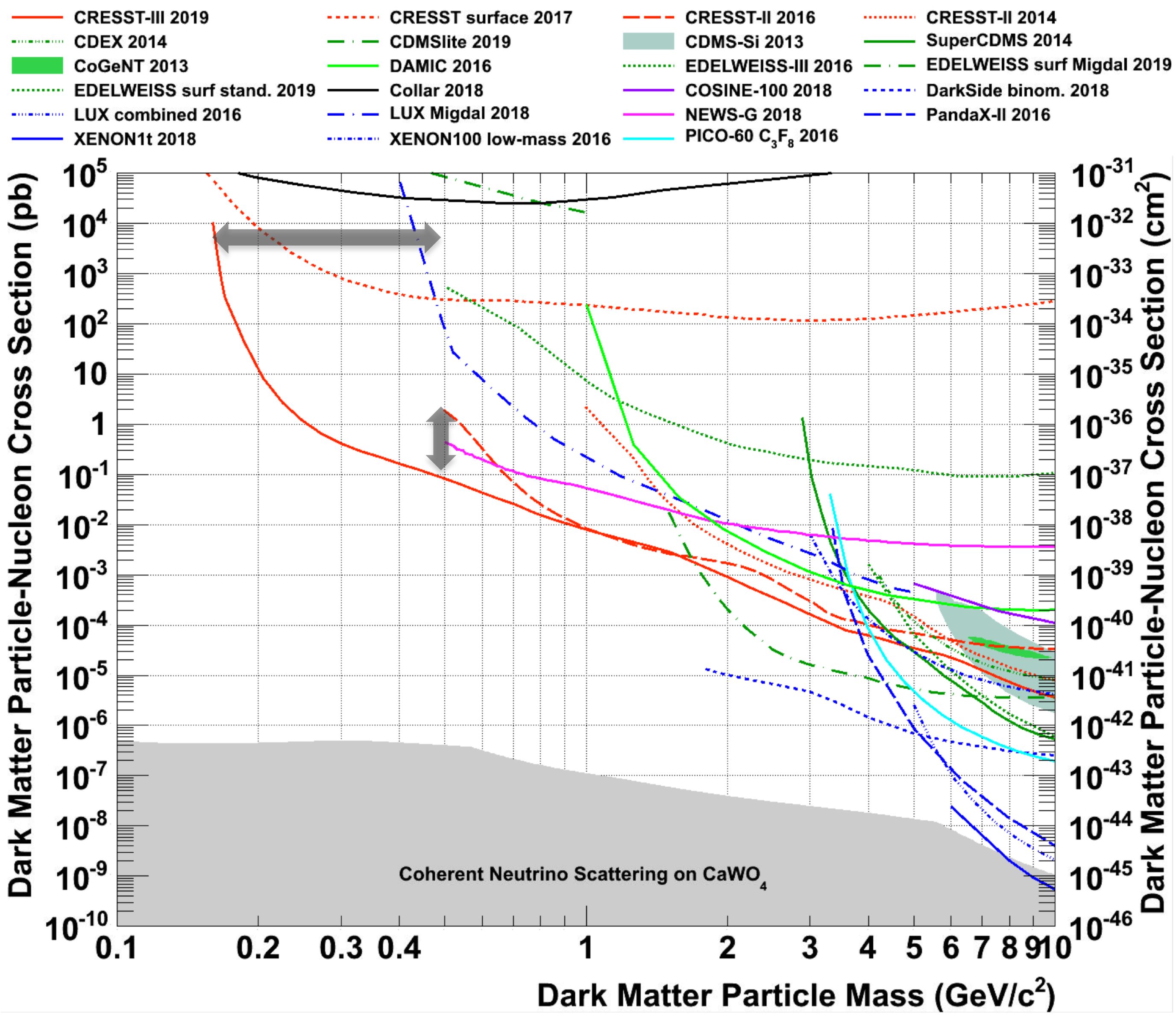
Improvement of one order of magnitude at $0.5 GeV/c^2$



RESULTS

Improvement of one order of magnitude at 0.5GeV/c²

Extended reach from 0.5GeV/c² to 0.16GeV/c²

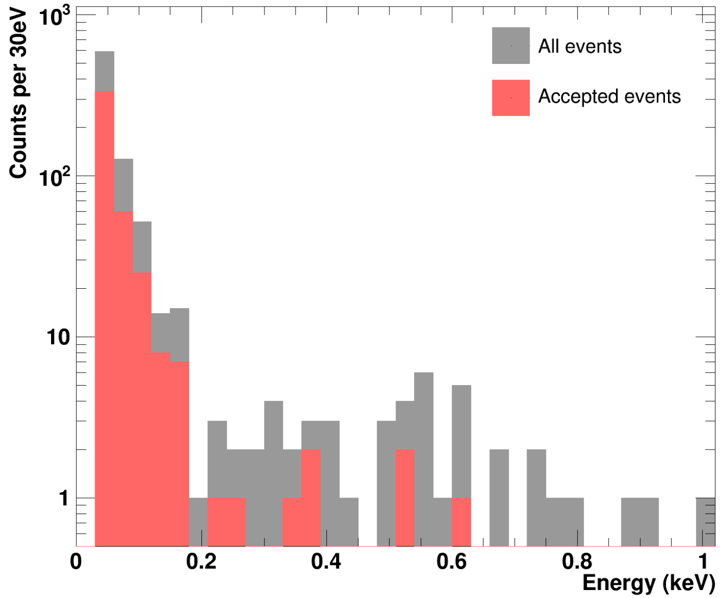


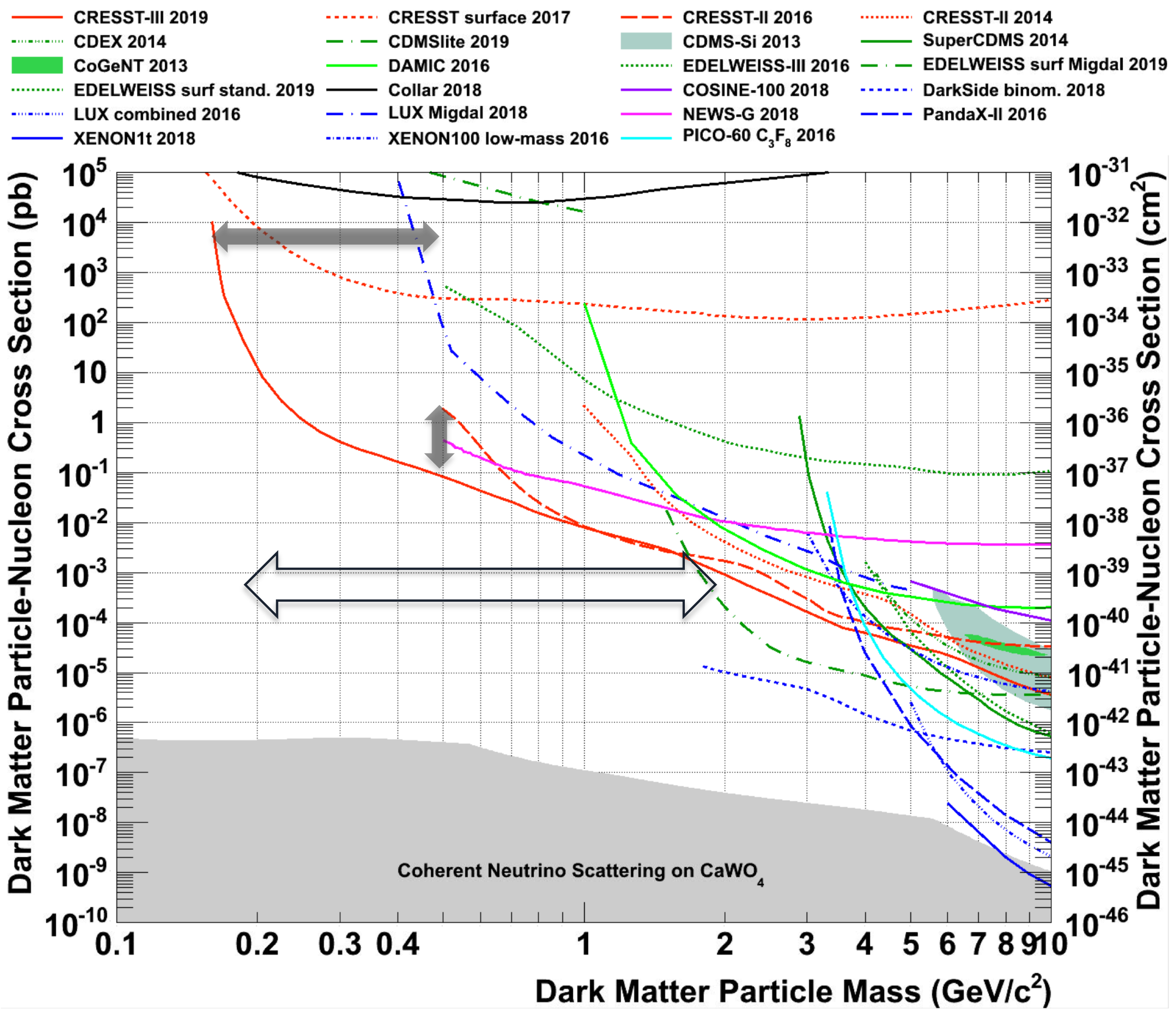
RESULTS

Improvement of one order of magnitude at 0.5GeV/c²

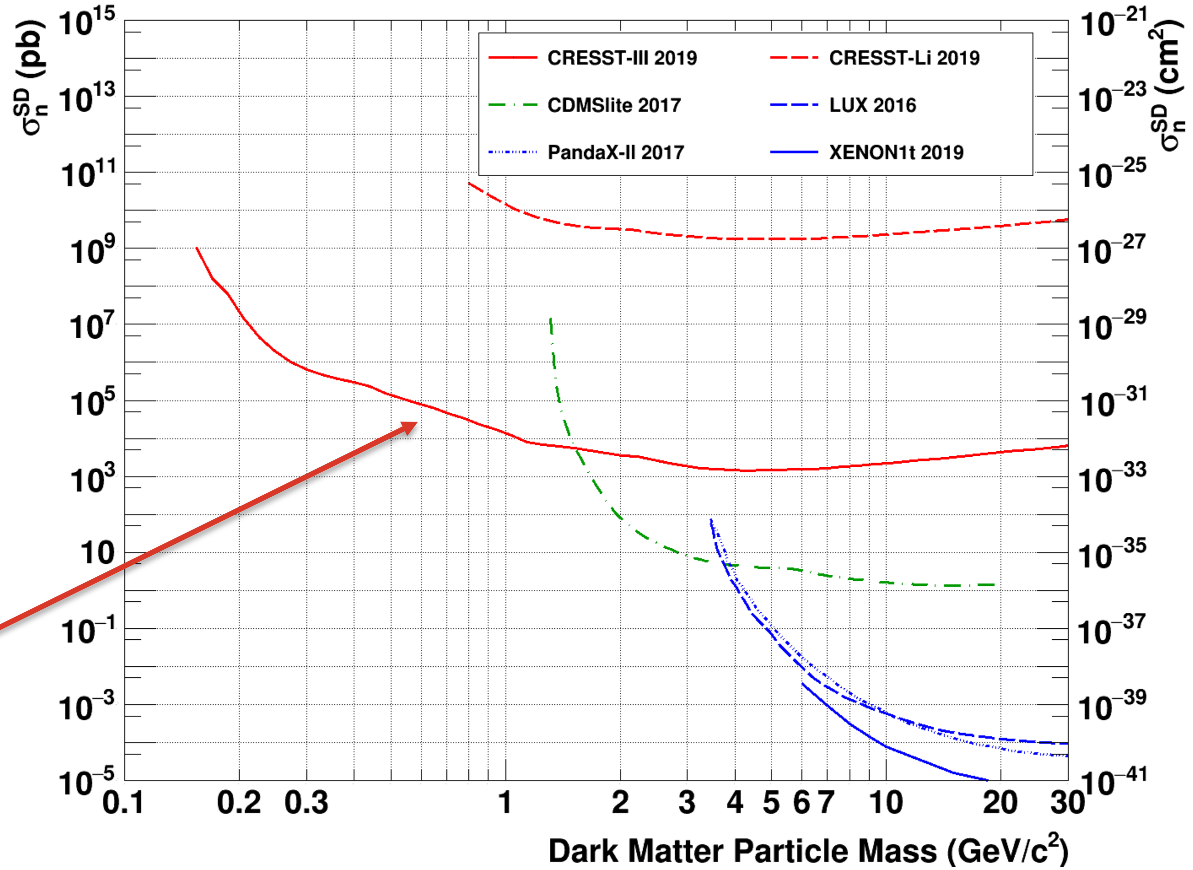
Extended reach from 0.5GeV/c² to 0.16GeV/c²

Unexpected rise of event rate <200eV





RESULTS – SPIN-DEPENDENT (NEUTRON ONLY)



Same data as shown before analyzed with spin-dependent signal expectation

^{17}O (natural abundance: 0.0367%)

→0.46g days of ^{17}O exposure

RESULTS – SPIN-DEPENDENT (NEUTRON ONLY)

Li_2MoO_4 above ground (arXiv:1902.07587)

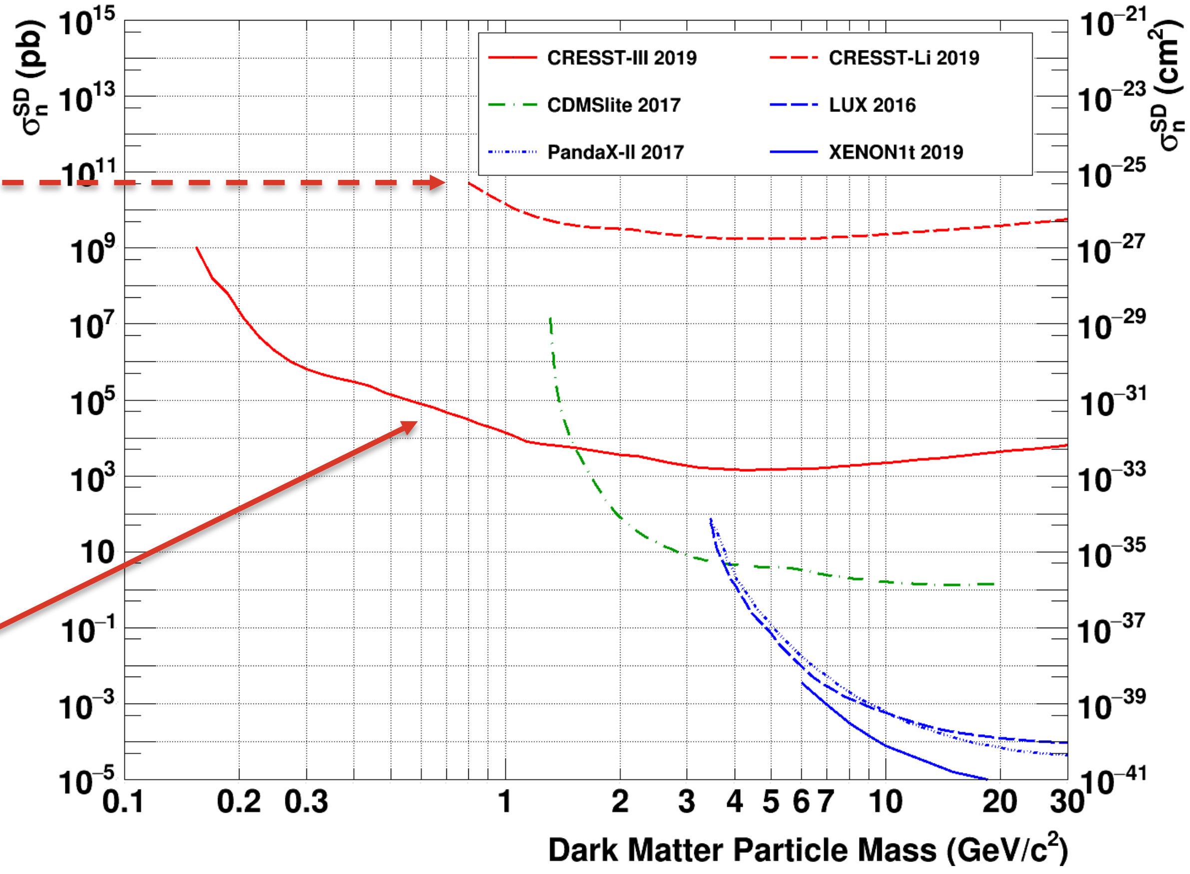
10h measurement

→ 7.91 $\times 10^{-5}$ kg days ^{7}Li "exposure"

Same data as shown before analyzed with spin-dependent signal expectation

^{17}O (natural abundance: 0.0367%)

→0.46g days of ^{17}O exposure



CONCLUSIONS

First CRESST-III run 07/2016 - 02/2018

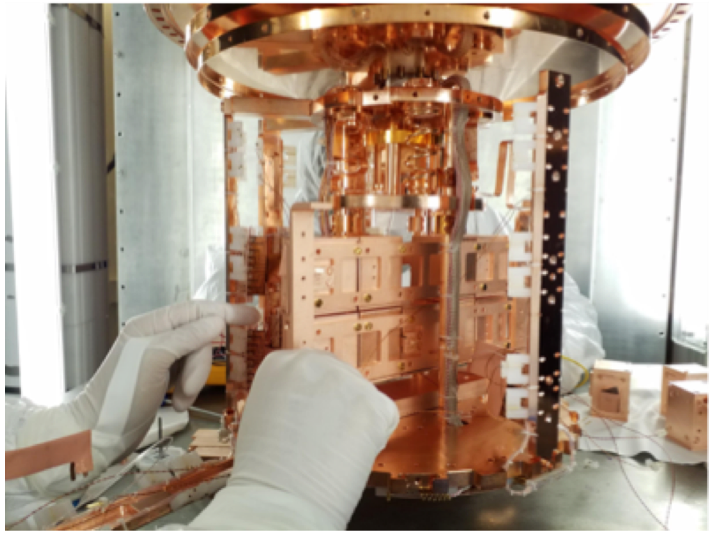
Unprecedented low nuclear recoil thresholds of 30eV

Leading sensitivity over one order of magnitude: 160MeV/c^2 → 1.8GeV/c^2

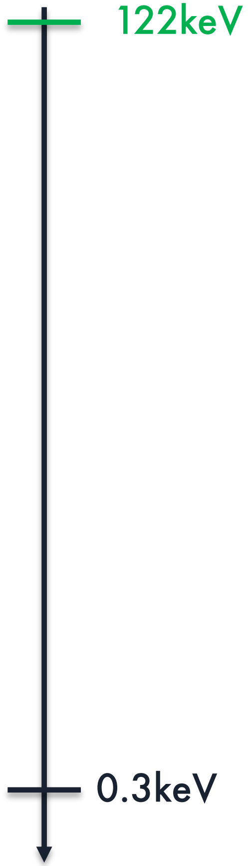
SECOND CRESST-III RUN: CURRENTLY ONGOING

Key innovation

Upgraded detector modules with dedicated hardware changes to understand backgrounds



CHALLENGE 1 – ENERGY CALIBRATION

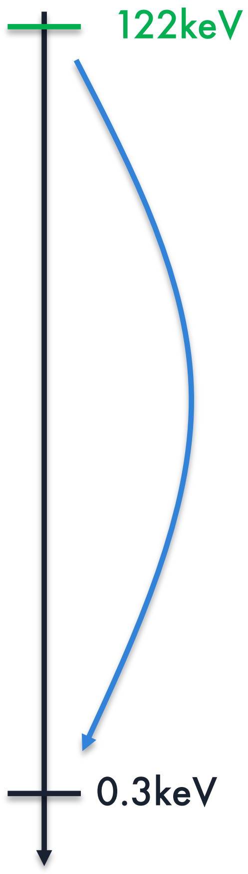


CRESST-II

(best threshold: 300eV)

Calibration with 122keV gammas from ^{57}Co

CHALLENGE 1 – ENERGY CALIBRATION



CRESST-II

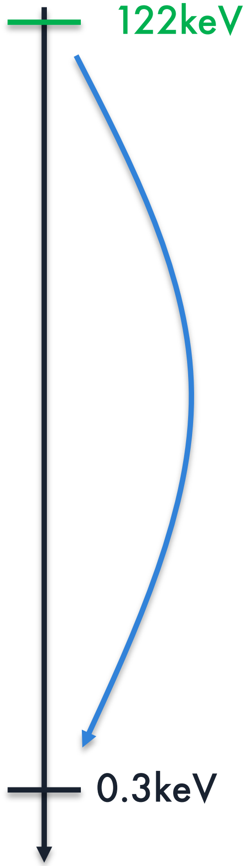
(best threshold: 300eV)

Calibration with 122keV gammas from ^{57}Co

Use electric pulses injected to heater for:

1. Monitoring of potential time-dependencies
2. Extrapolation to lower energies

CHALLENGE 1 – ENERGY CALIBRATION



CRESST-II

(best threshold: 300eV)

totally saturated for CRESST-III detectors

~~Calibration with 122keV gammas from ^{57}Co~~

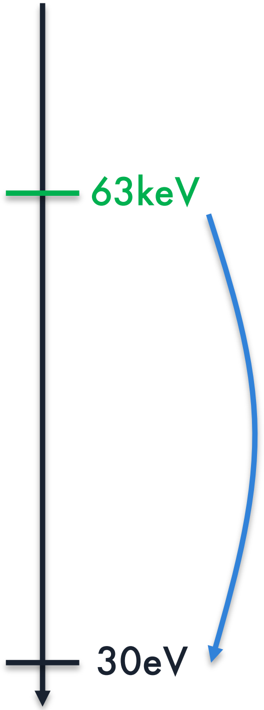
Use electric pulses injected to heater for:

1. Monitoring of potential time-dependencies
2. Extrapolation to lower energies

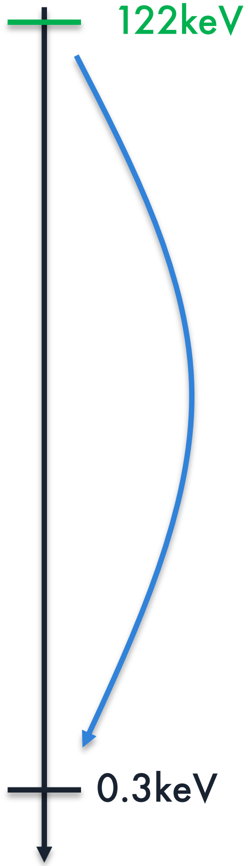
CRESST-III

(best threshold: 30eV)

1. Use122keV gammas from ^{57}Co to excite W-escape (63.2keV) → 10% accuracy of low-energy scale



CHALLENGE 1 – ENERGY CALIBRATION



CRESST-II

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~~Calibration with 122keV gammas from ^{57}Co~~

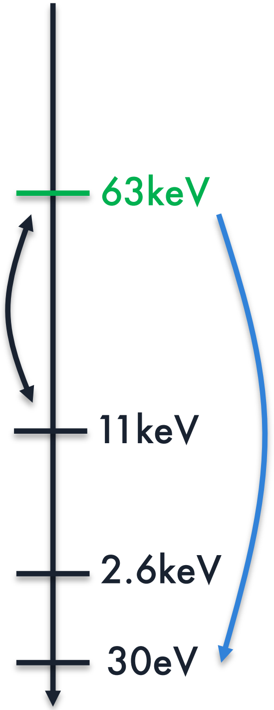
Use electric pulses injected to heater for:

1. Monitoring of potential time-dependencies
2. Extrapolation to lower energies

CRESST-III

(best threshold: 30eV)

1. Use122keV gammas from ^{57}Co to excite W-escape (63.2keV) → 10% accuracy of low-energy scale
2. Fine-adjust:11.3keV - Hf L-shell
3. Cross-check: 2.6keV - Hf M-shell (and 0.5keV -Hf N-shell)



CHALLENGE 1 – ENERGY CALIBRATION

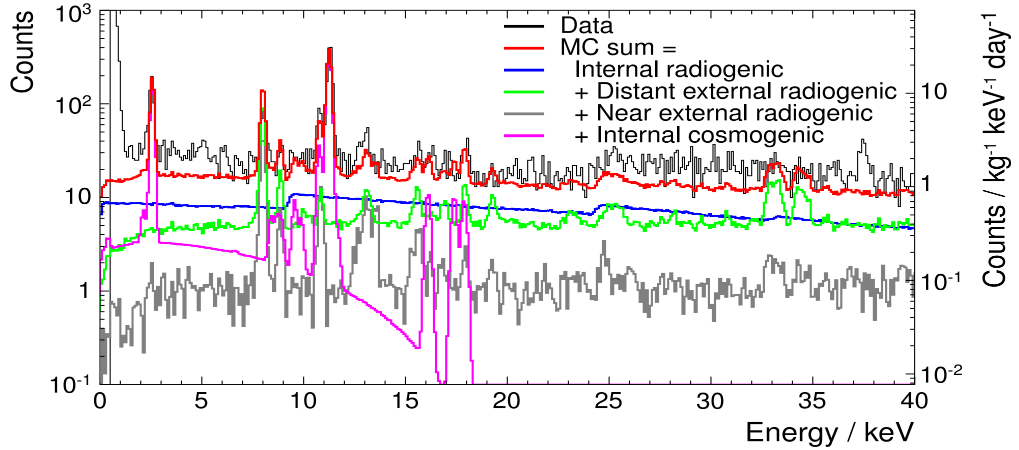
Summary: Current CRESST calibration relies on fine-adjustment with cosmogenic activation lines

Works with high precision

Cosmogenic activation
is not guaranteed for any material
and long measurement time (>1/2 year) needed

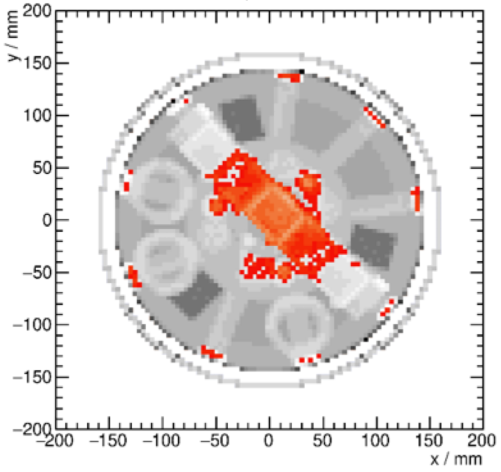
CHALLENGE 2: LOW-ENERGY MC SIMULATIONS

em bckg. model

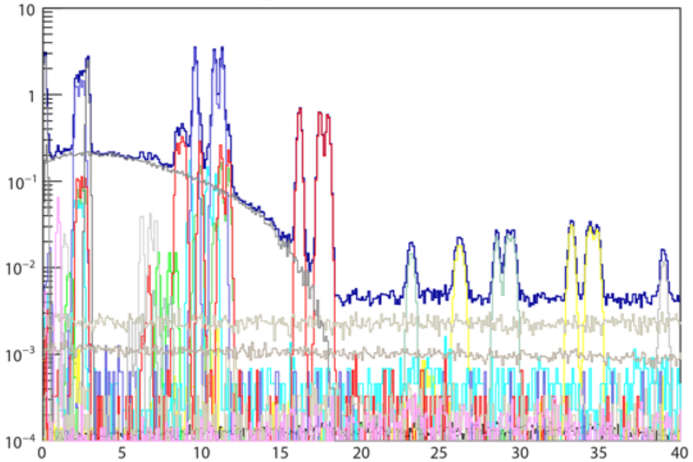


- Geant4 based electromagnetic background model for the CRESST experiment
- Simulation of neutron background
- Study of cosmogenic activation of $CaWO_4$ crystal scintillator
- Activity measurement of Cu with HPGe at LNGS
- Alpha spectrometry of Cu of bulk ^{210}Po ~20mBq/kg (ongoing)

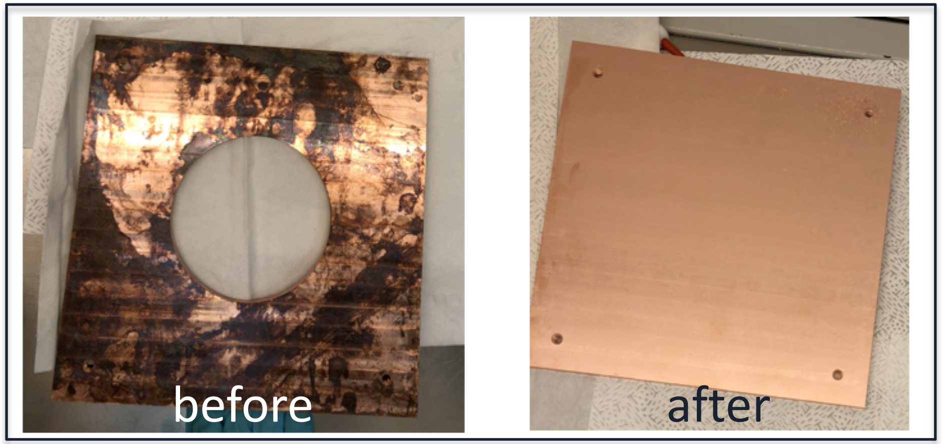
^{210}Pb E_γ=46keV



cosmogenic activation



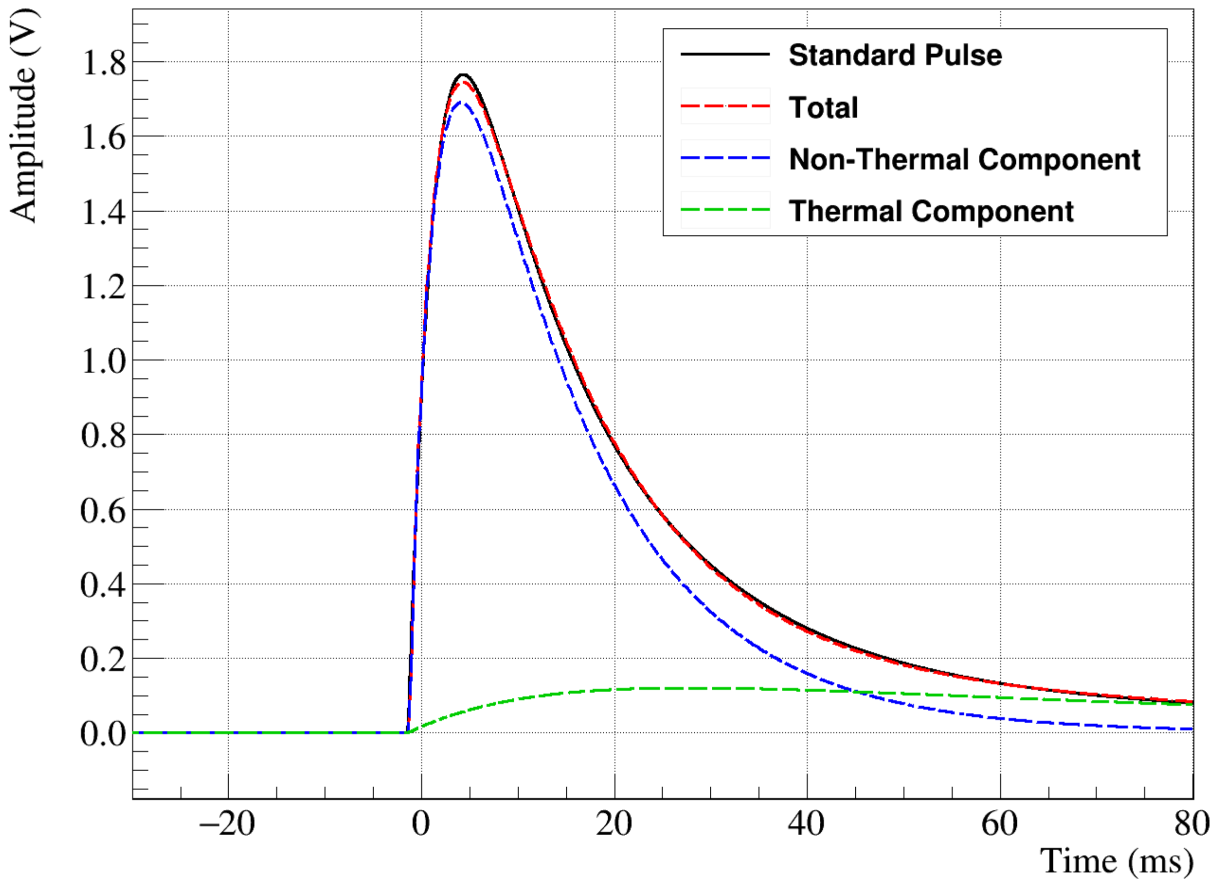
Cu cleaning




New frontiers ...
... new potentials ...
... new challenges!

BACKUP

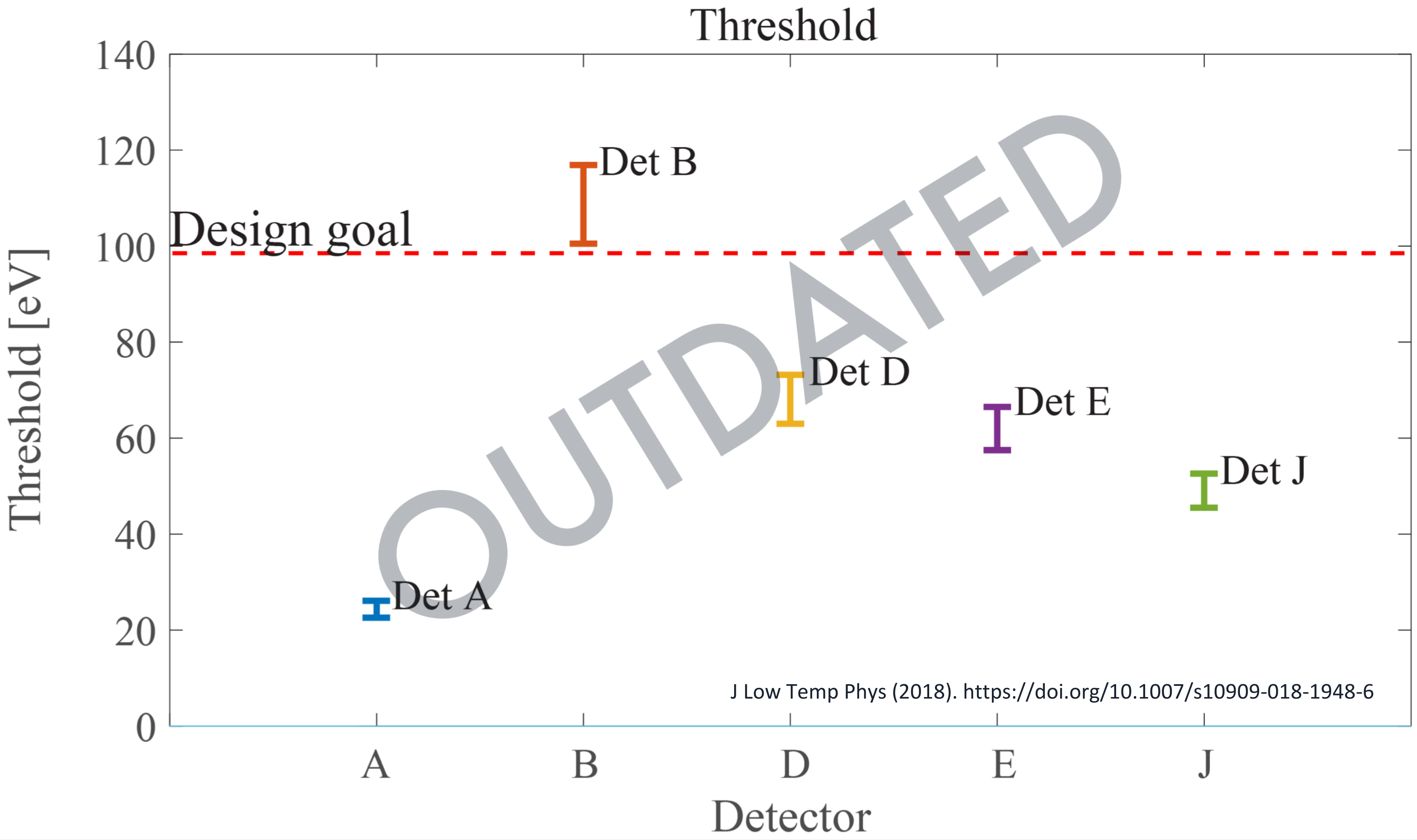
TYPICAL CRESST-II PULSE



Parameter	Fit Result
Baseline Level	1.6 mV ± 0.1 mV
t_0	-1.310 ms ± 0.001 ms
A_n	3.071 V ± 0.003 V
A_t	0.210 V ± 0.002 V
τ_{in}	2.628 ms ± 0.004 ms
τ_n	13.90 ms ± 0.02 ms
τ_t	78.2 ms ± 0.5 ms

OPTIMUM THRESHOLDS

SOFTWARE-TRIGGERED (OPTIMUM FILTER) ON CONTINUOUS DATA STREAM

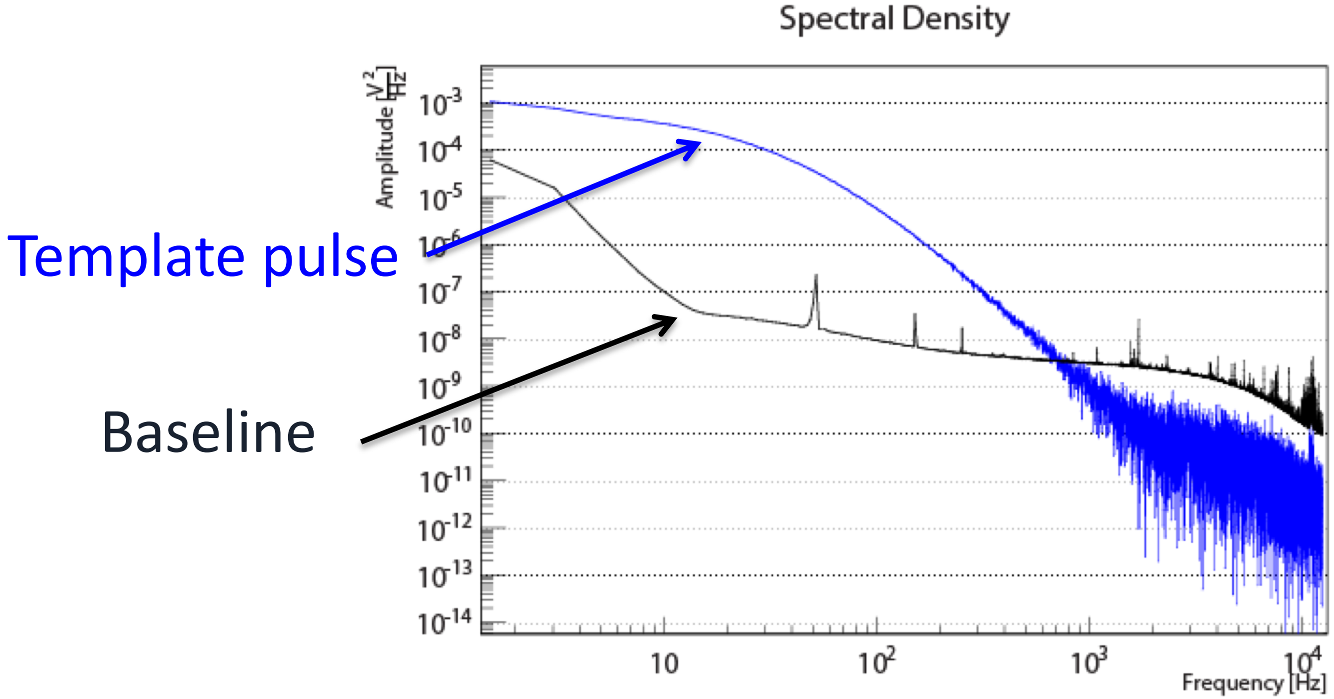


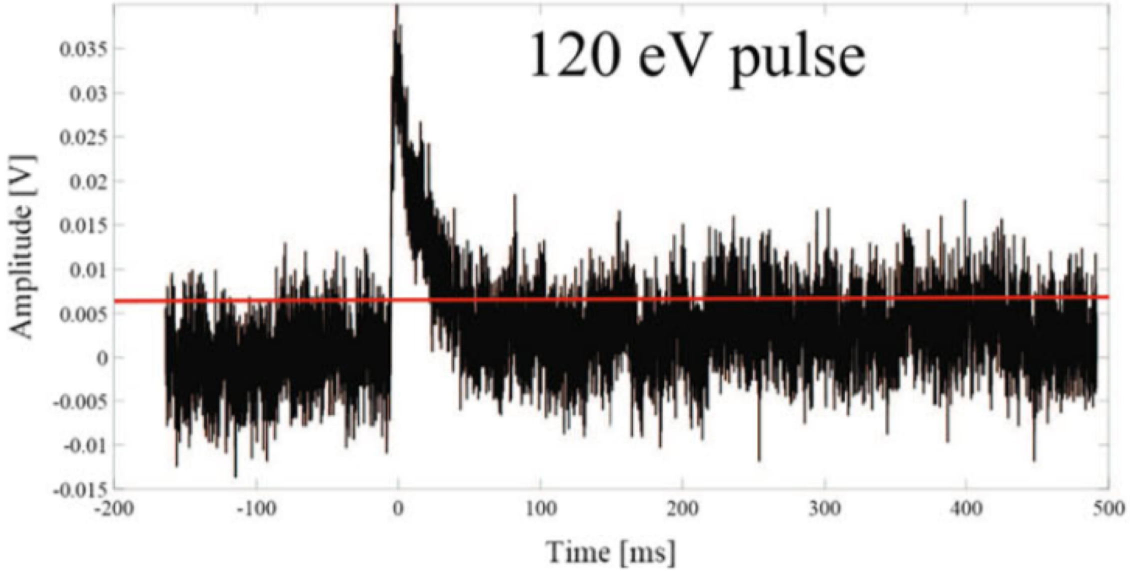
5 detectors reach/exceed the CRESST-III design goal

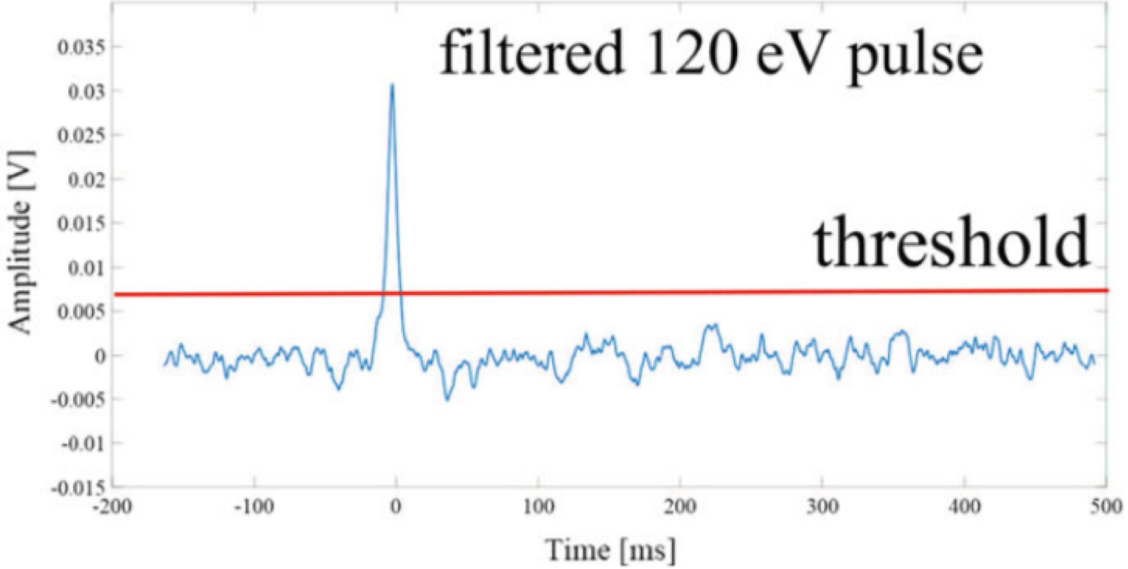
OPTIMUM FILTER

Maximizes signal-to-noise ratio (in frequency space)

Factor 2-3 typical improvement in resolution

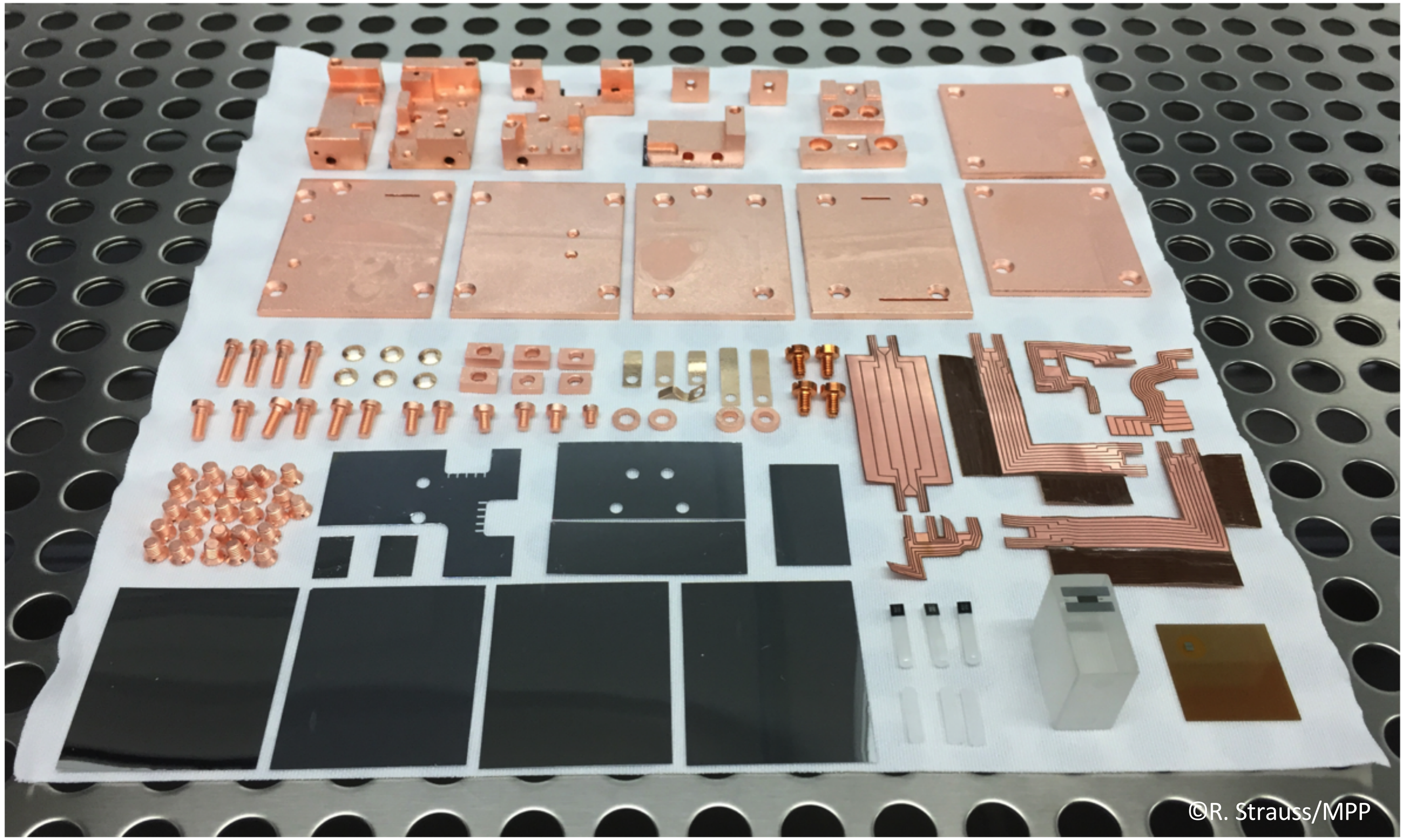


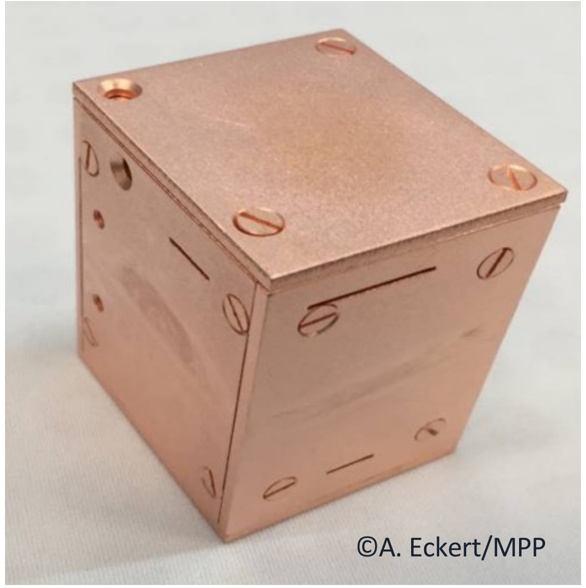


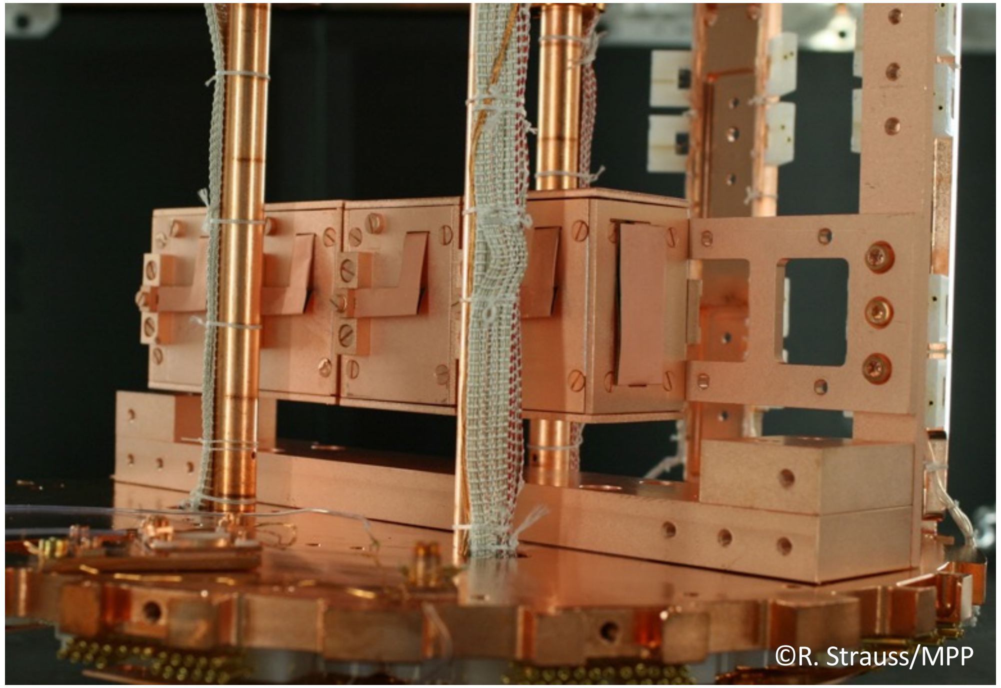


J Low Temp Phys (2019)
doi.org/10.1007/s10909-018-1948-6

CRESST-III DETECTOR

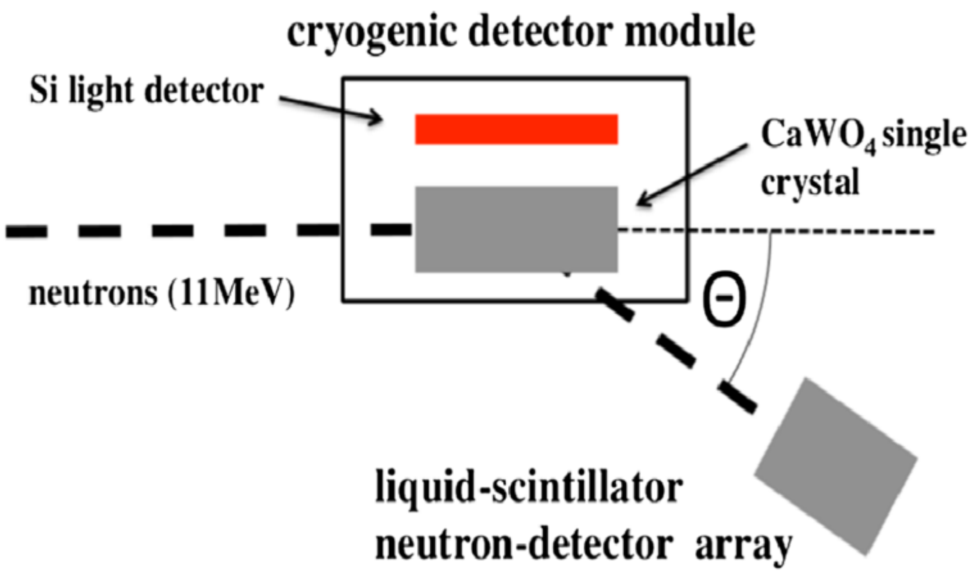


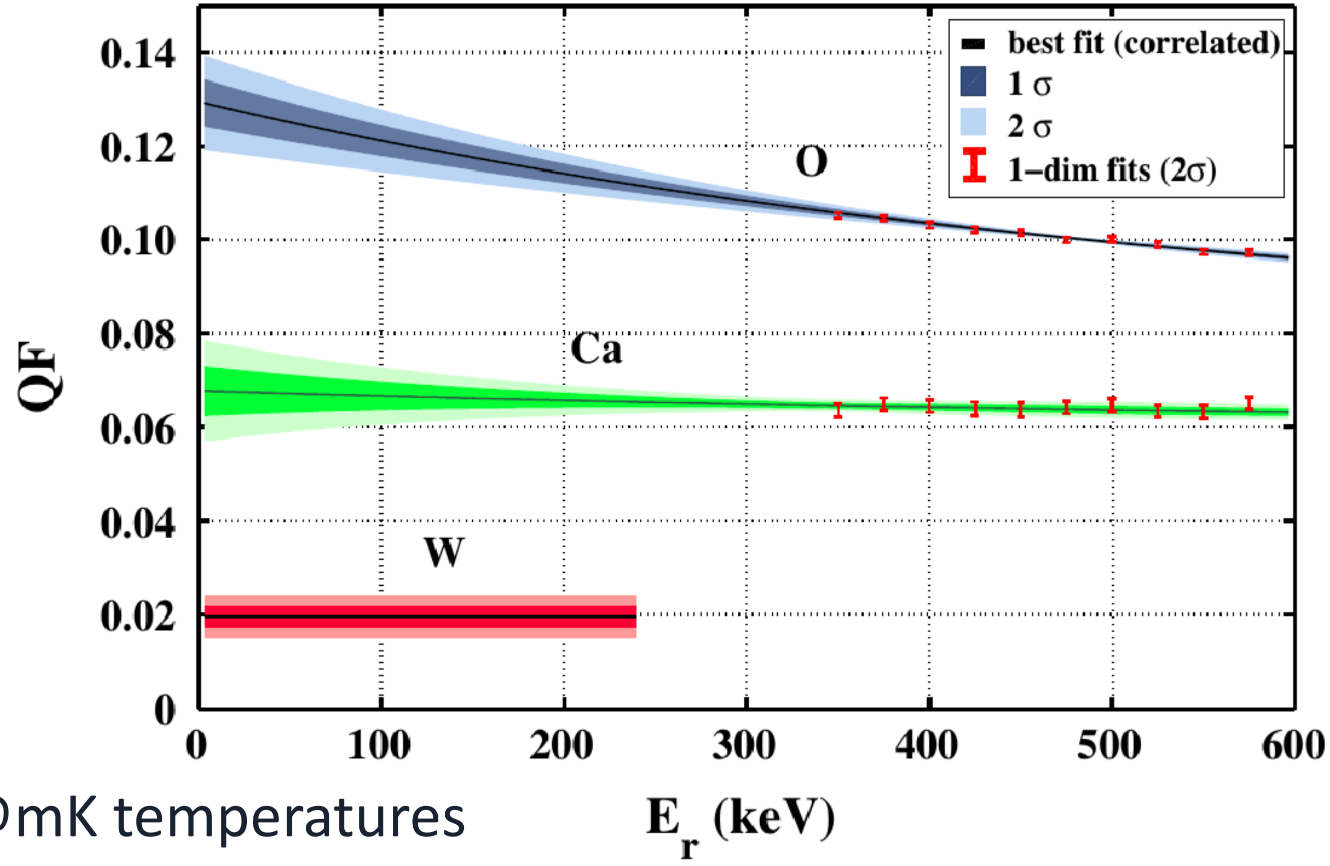




QUENCHING FACTOR MEASUREMENT

@ accelerator of Maier-Leibnitz-Laboratorium





Precise determination of QFs for O, Ca & W @mK temperatures

Values (in ROI)

- O: (11.2 ± 0.5)%
- Ca: (5.94 ± 0.49)%
- W: (1.72 ± 0.21)%

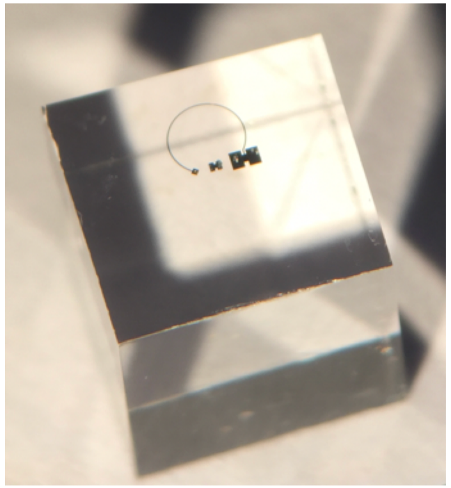
EPJ C (2014) 74:2957

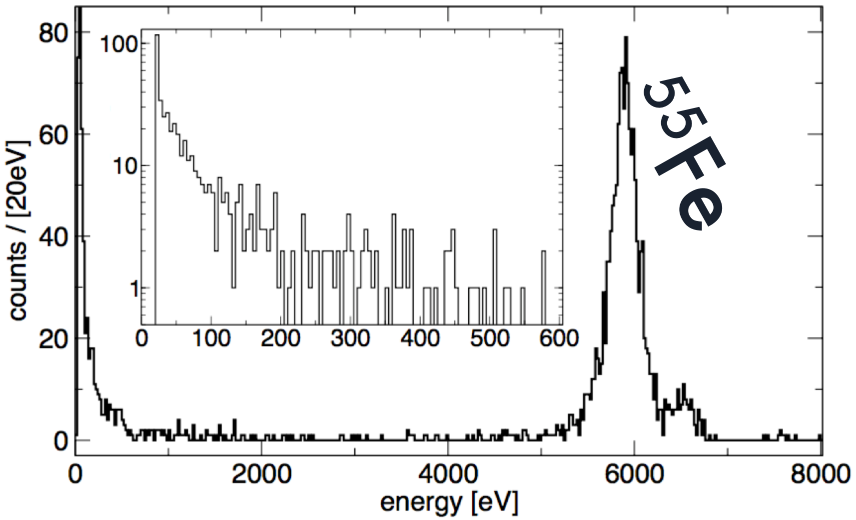
GRAM-SCALE DETECTOR

Al_2O_3 0.49g 5x5x5mm^3

E_{th} = (19.7 ± 0.9) eV

Measured above ground



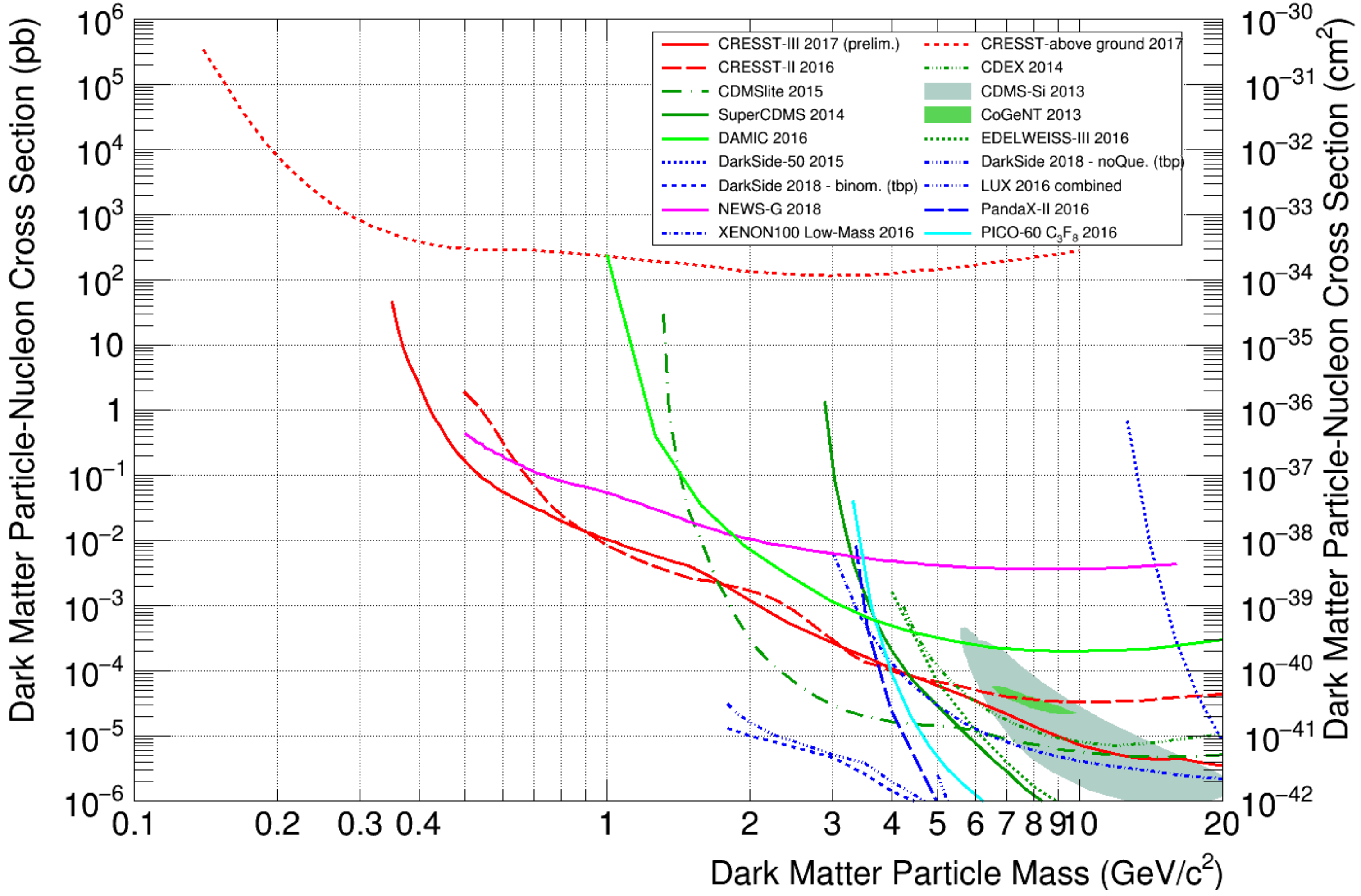


Measuring time 5.3h

No data quality cuts

EPJ C (2017) 77:637

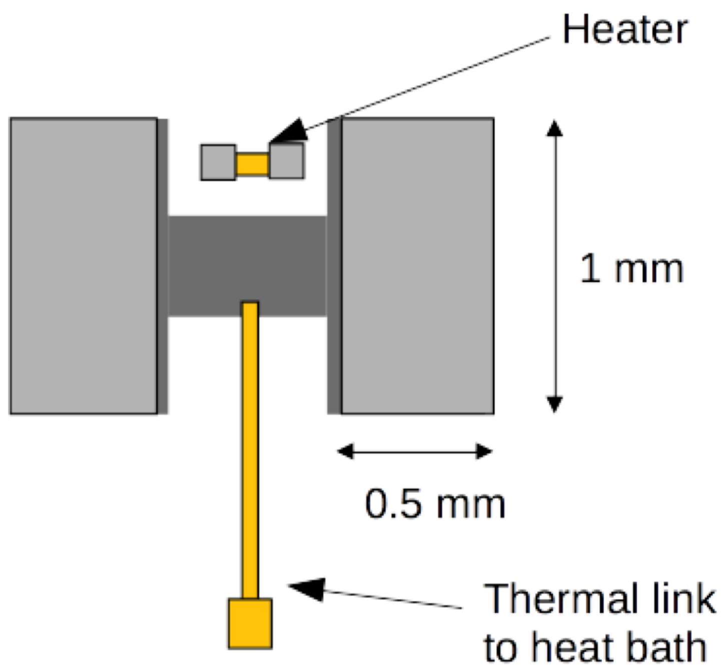
GRAM-SCALE DETECTOR

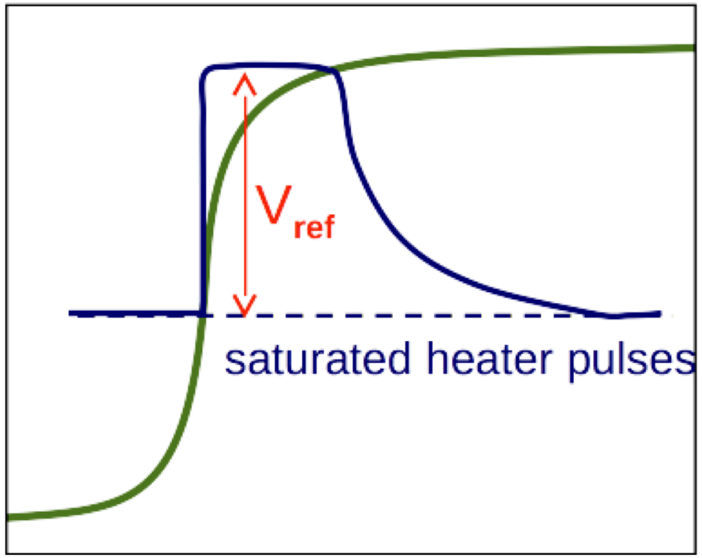


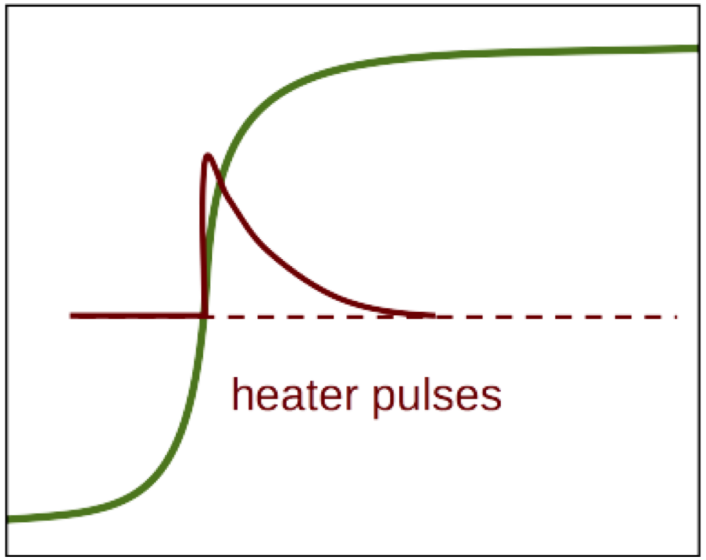
DETECTOR STABILITY

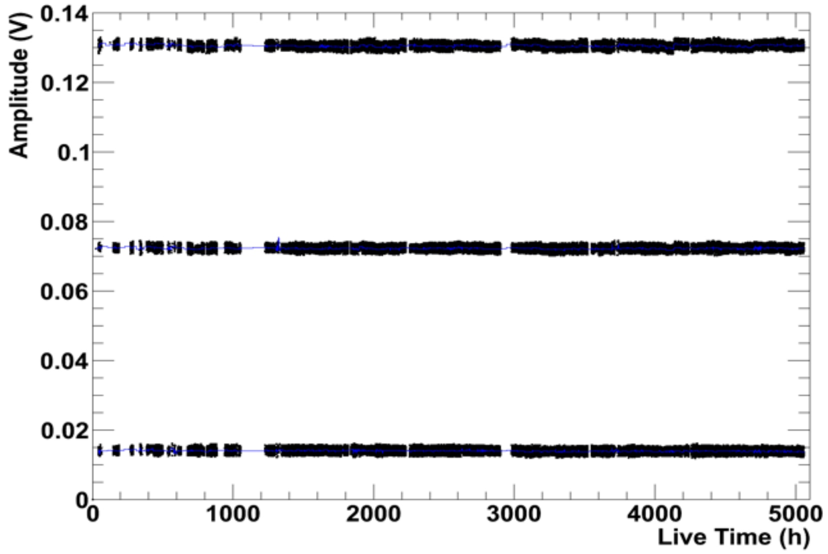
W-TES equipped with heaters

- Stabilization of detectors in the operating point
- Injection of heat pulses for calibration and determination of trigger threshold



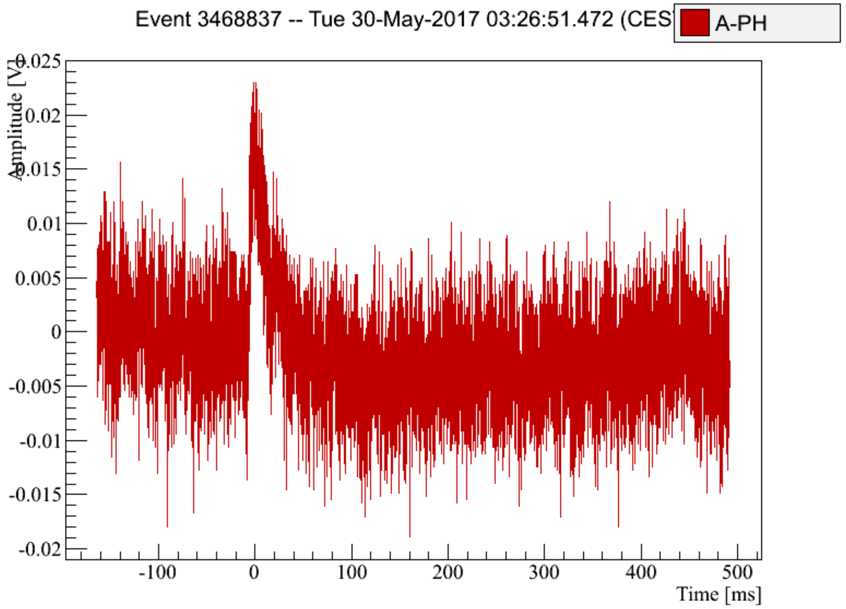


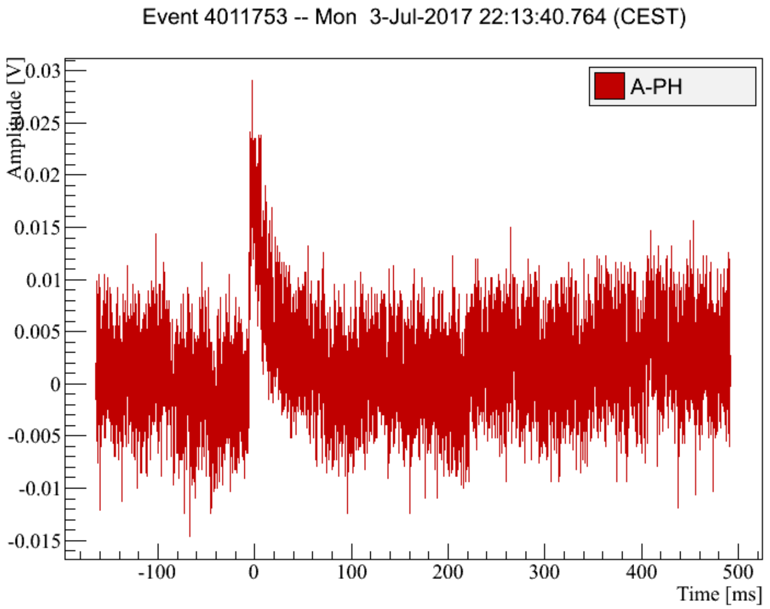




DET. A – 100eV EVENT EXAMPLES

Raw signals: no filtering, fitting etc.





100eV pulses are no challenge for amplitude determination