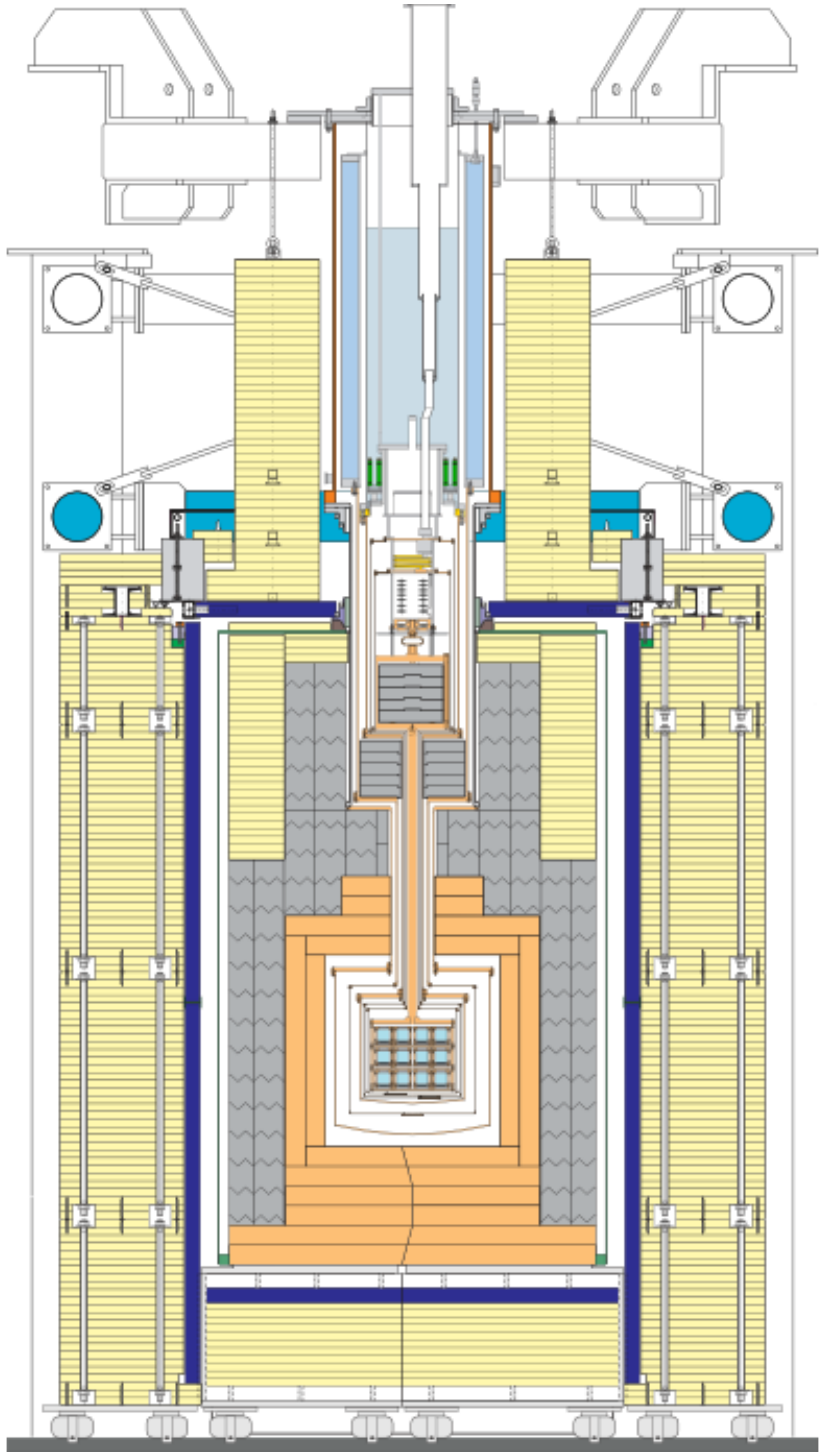
Direct search for light dark matter with the CRESST-III experiment

Paolo Gorla
Laboratori Nazionali del Gran Sasso - INFN

The CRESST Experiment

Cryogenic Rare Event Search with Superconducting Thermometers



Dilution Refrigerator

CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at ~15 mK

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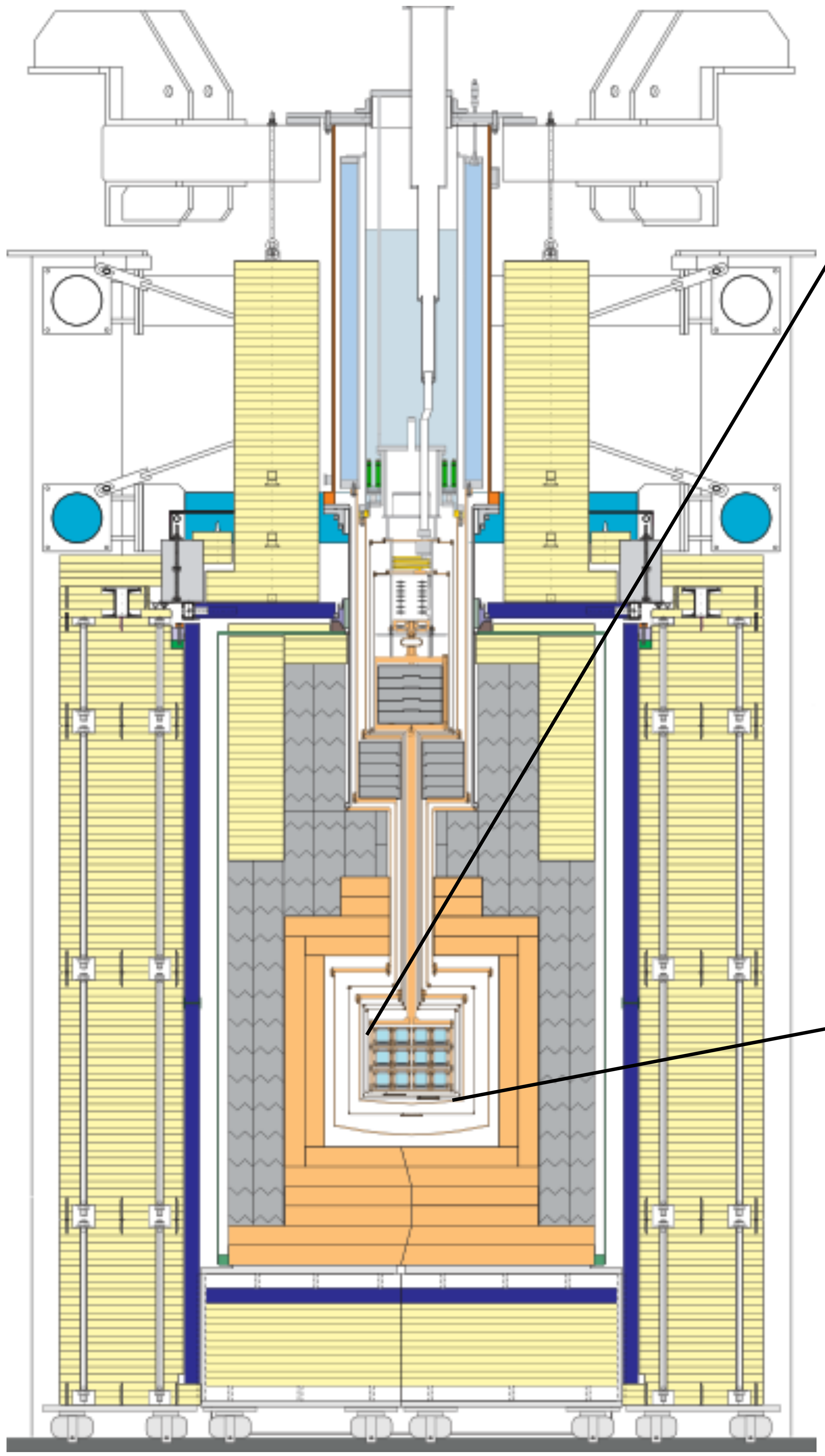
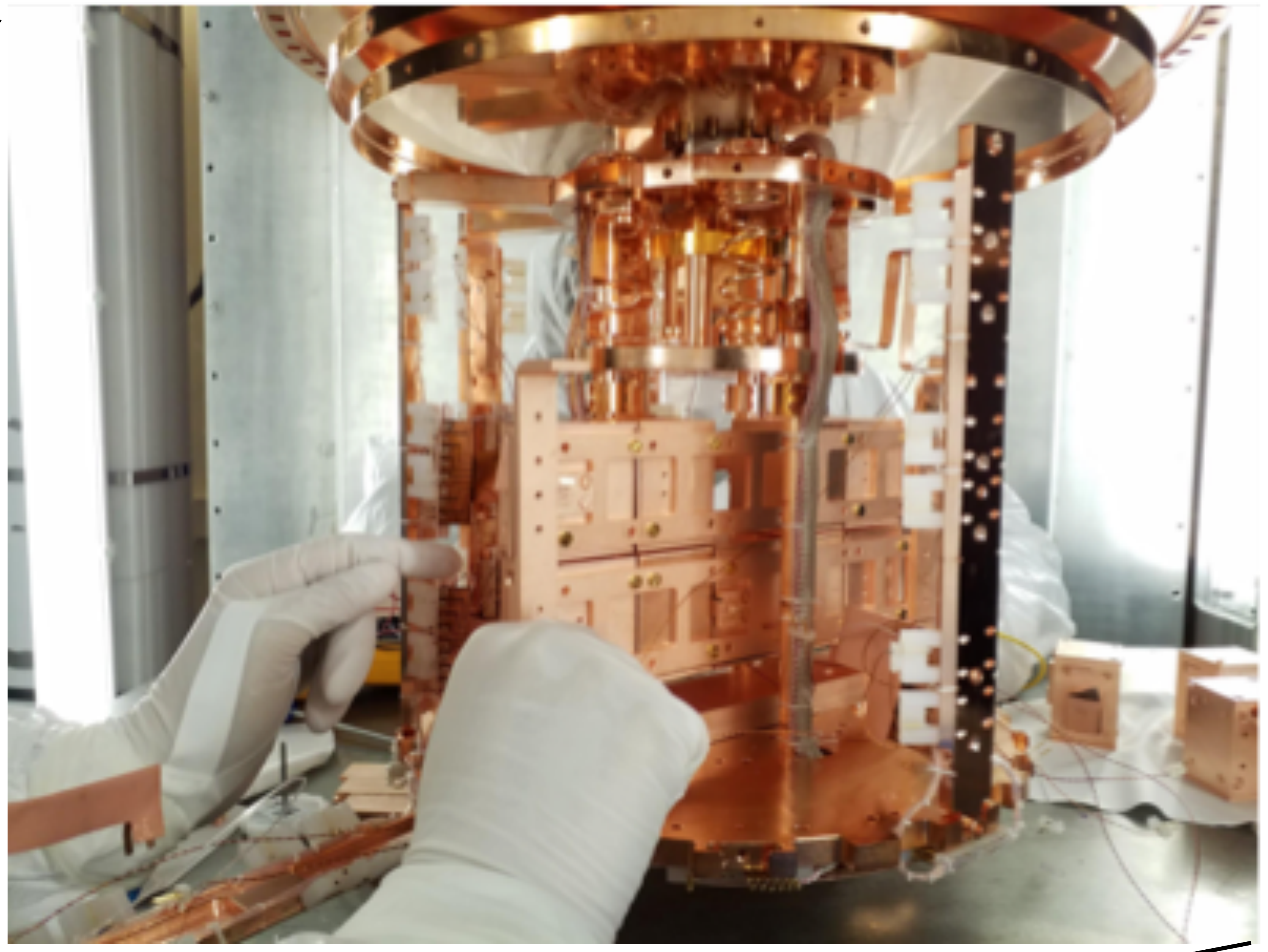


Dilution Refrigerator



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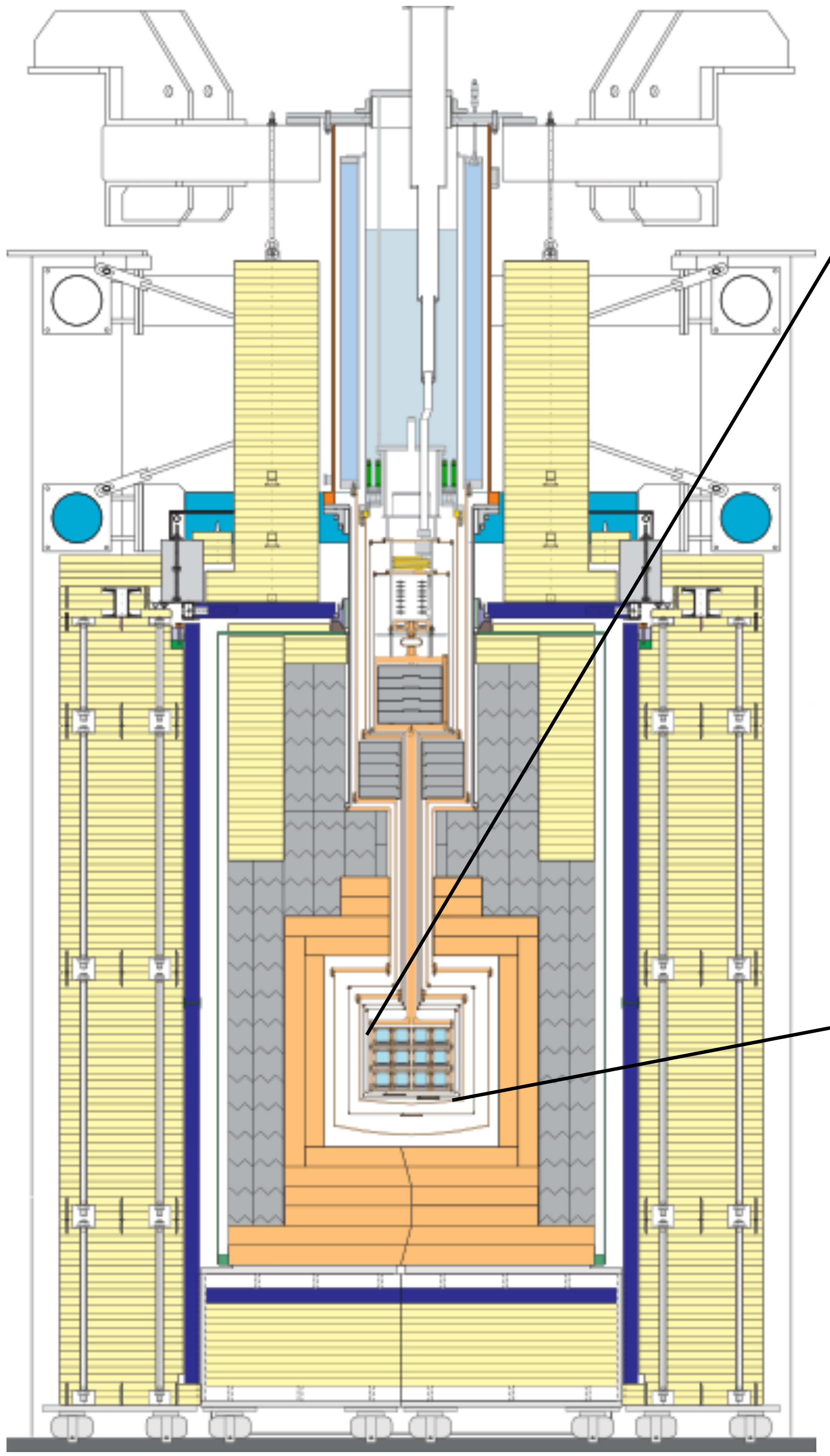

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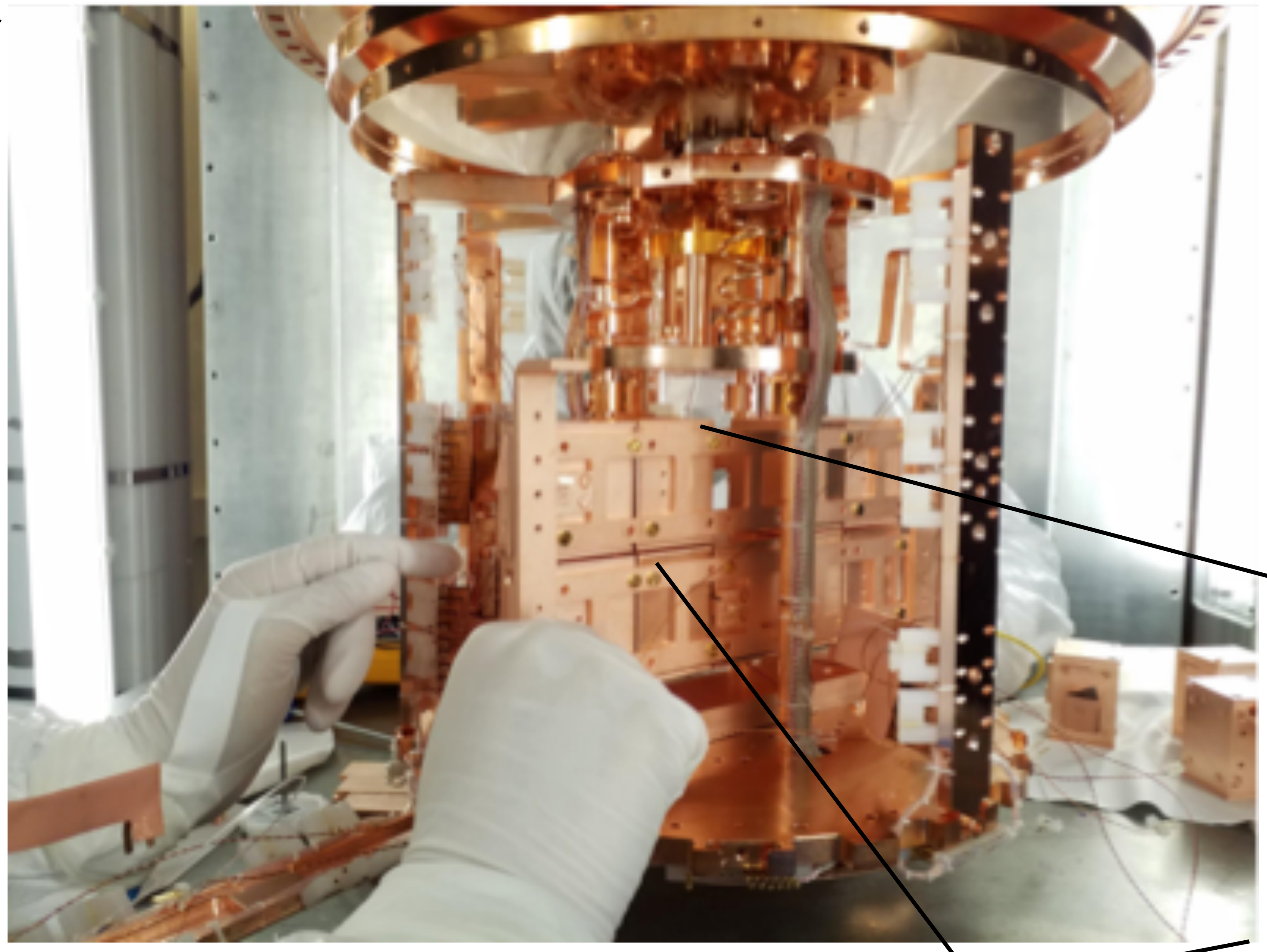
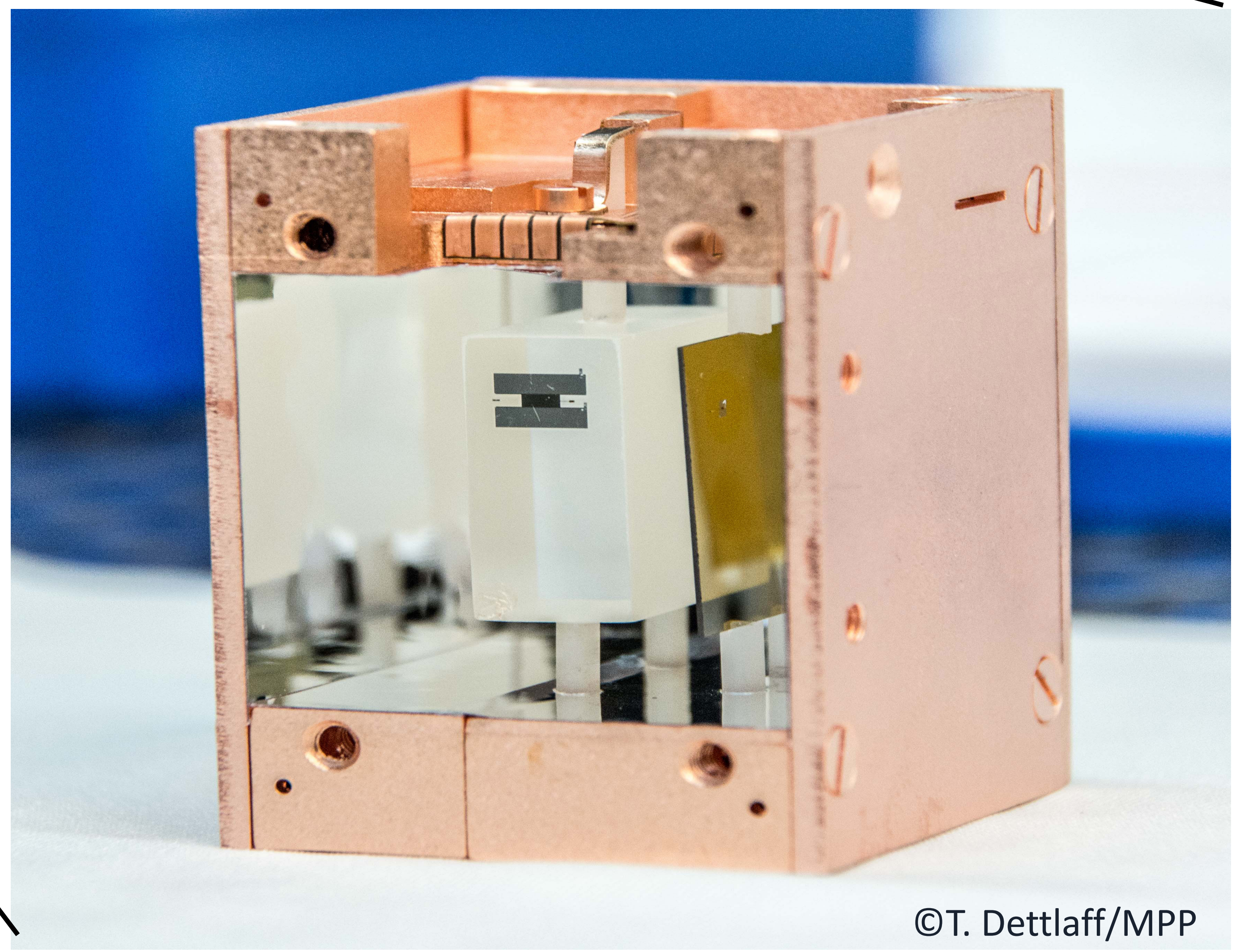


Scintillating $CaWO_4$ crystals as target

Separate **cryogenic light detector**



CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at ~15 mK

The CRESST Collaboration

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

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

TUM
TECHNISCHE UNIVERSITÄT MÜNCHEN

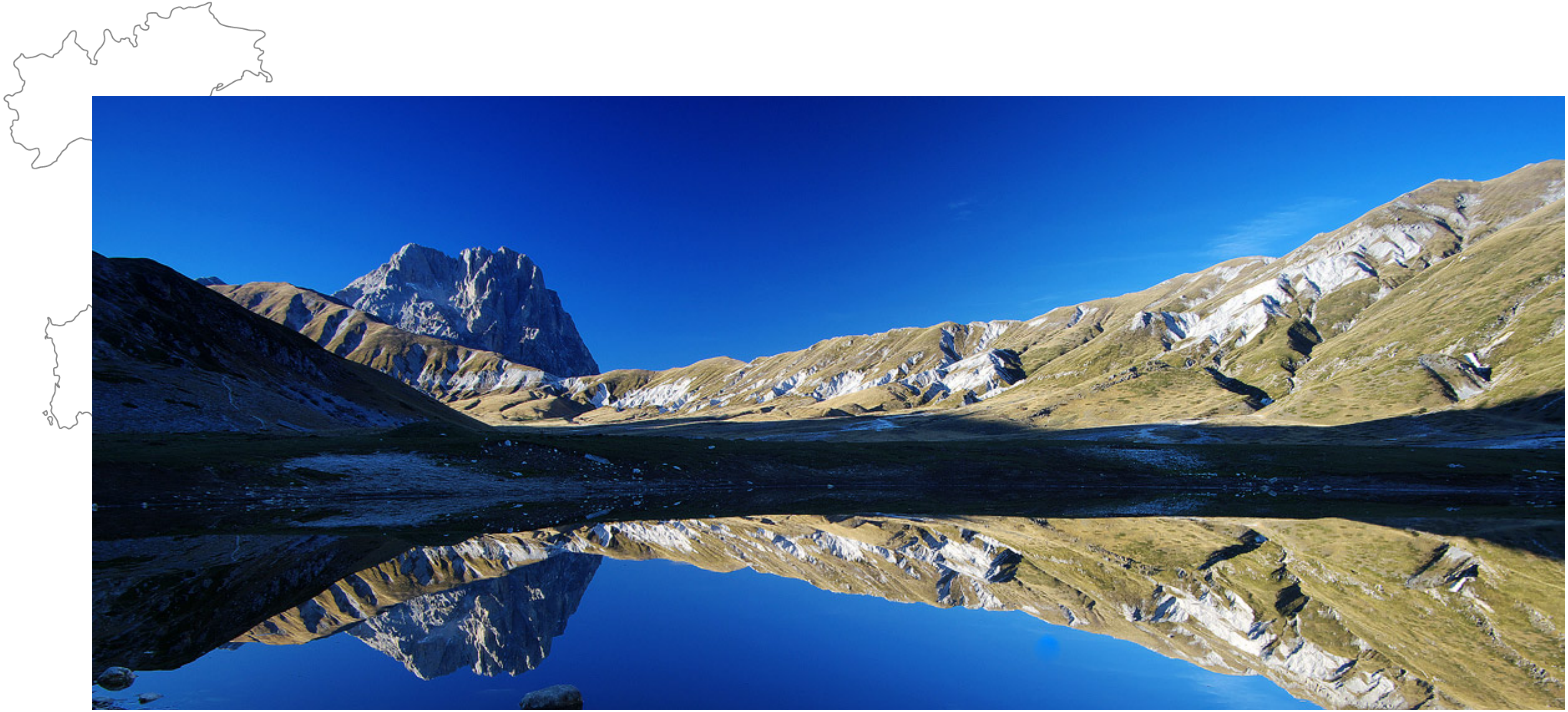
UNIVERSITY OF OXFORD

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

HEPHY
Institut für Hochenergiephysik

CRESST @ Gran Sasso

CRESST @ Gran Sasso

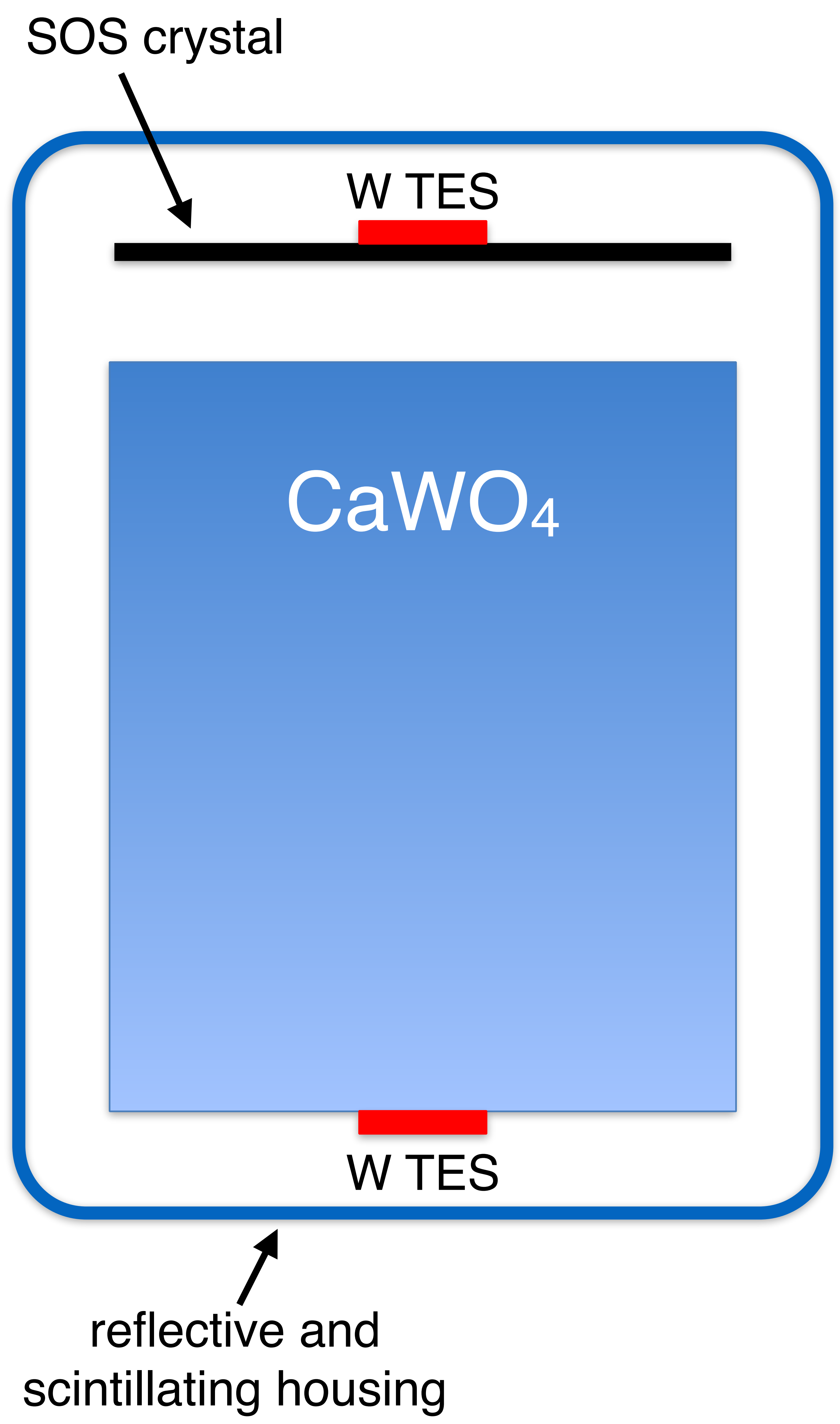


CRESST @ Gran Sasso

CRESST @ Gran Sasso

- ~3600 m.w.e. deep
- μs: ~3×10^{-8}/(s cm^2)
- γs: ~0.73/(s cm^2)
- neutrons: 4×10^{-6} n/(s cm^2)

CRESST Detectors



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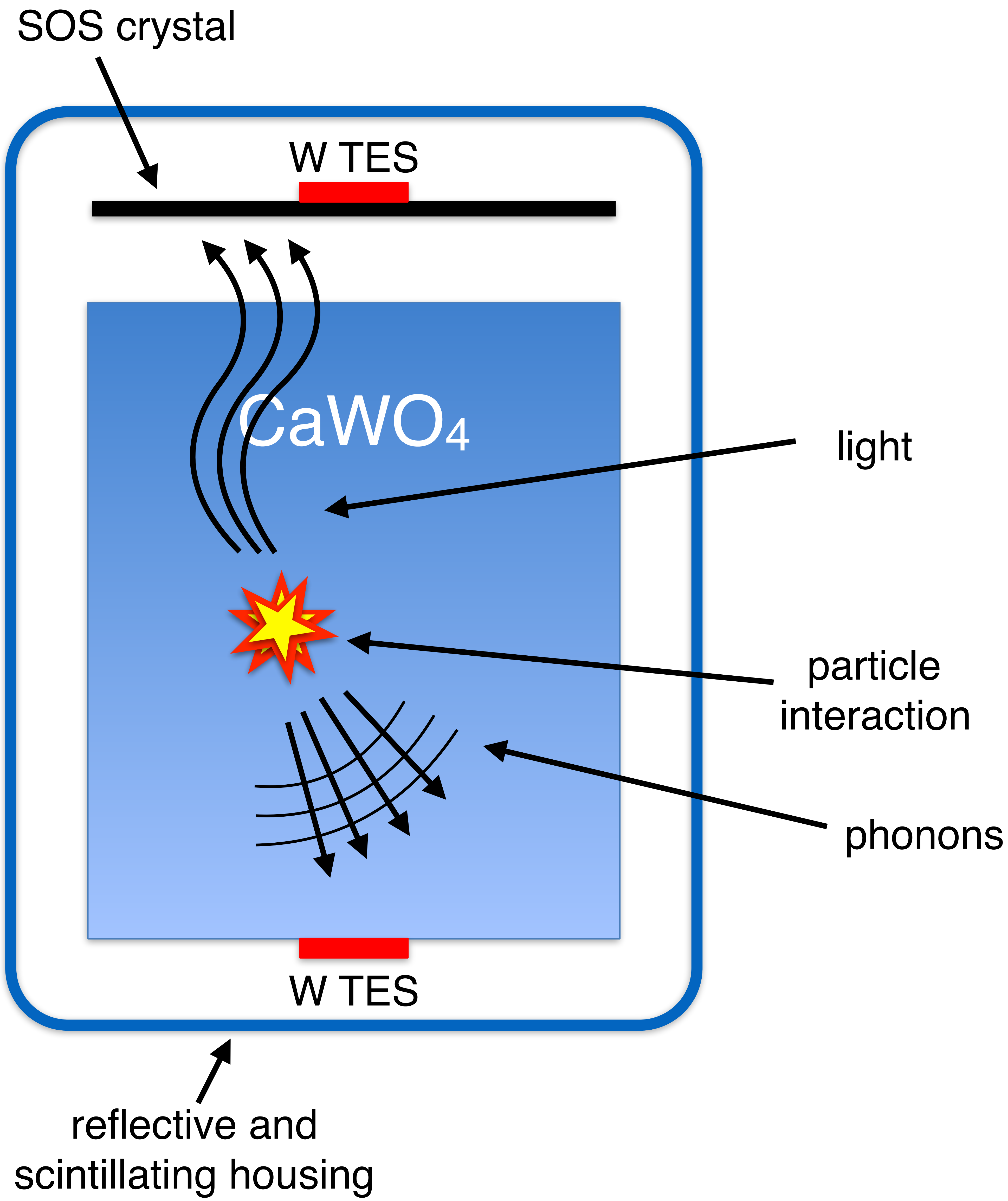

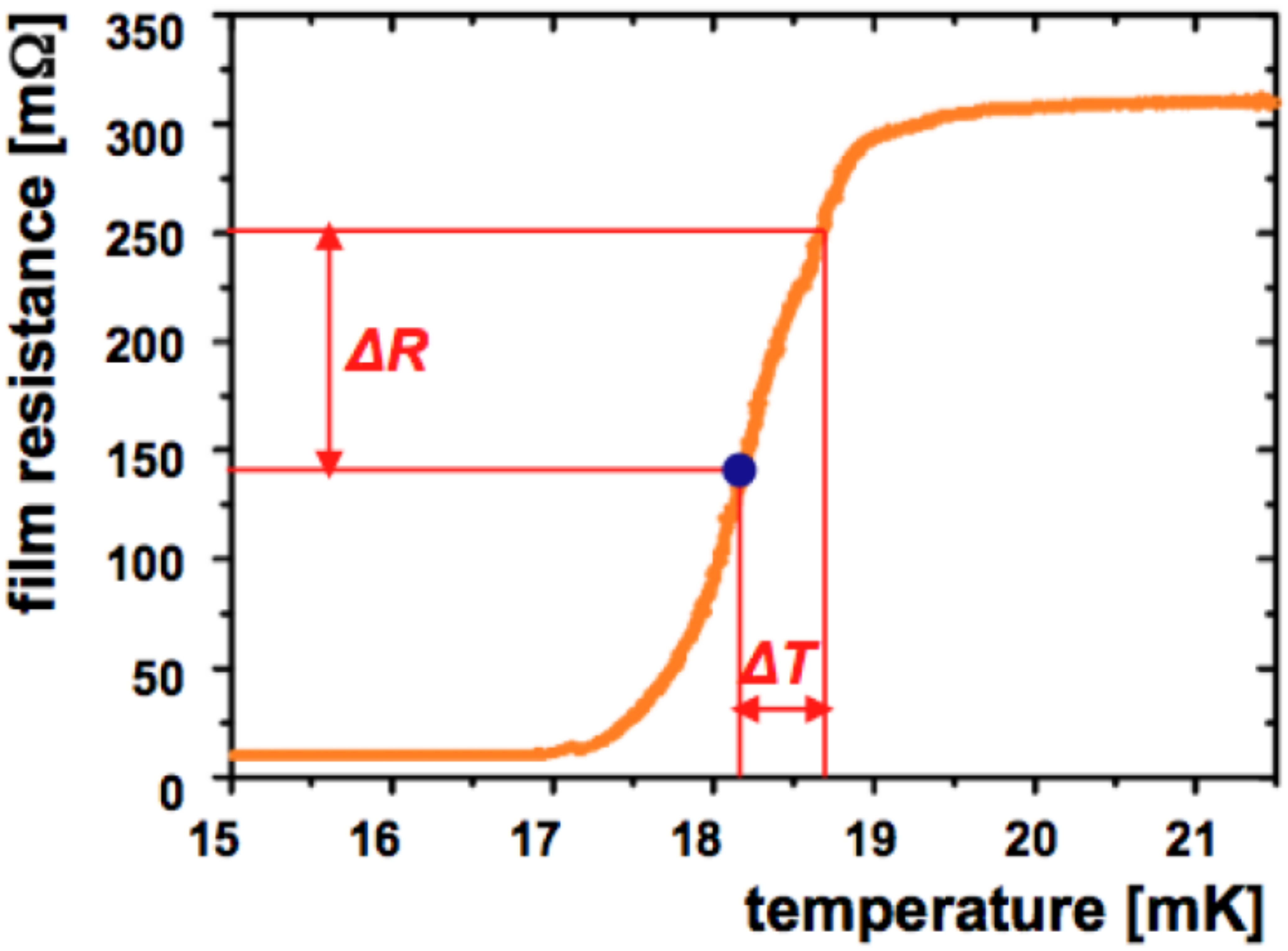

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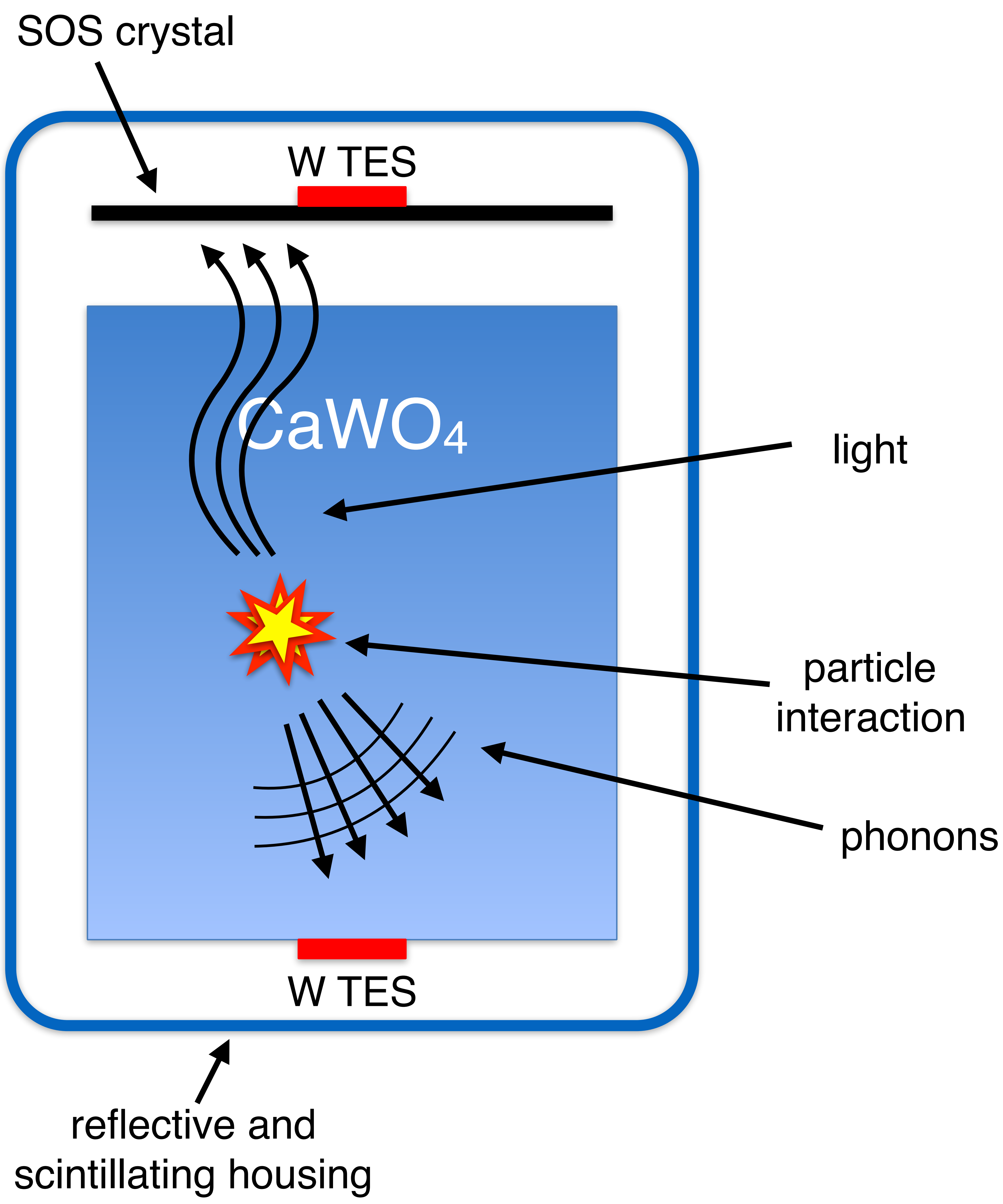
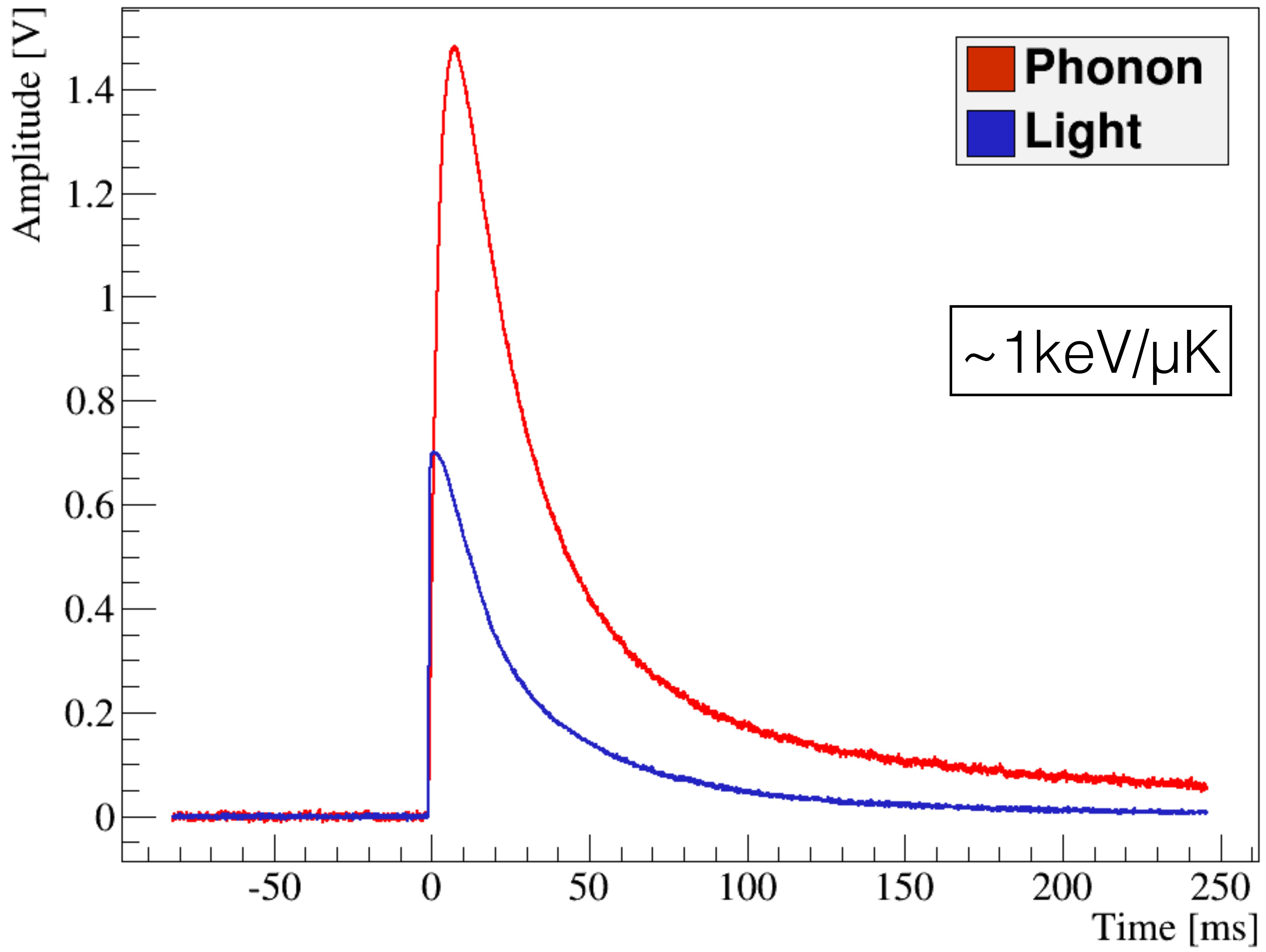
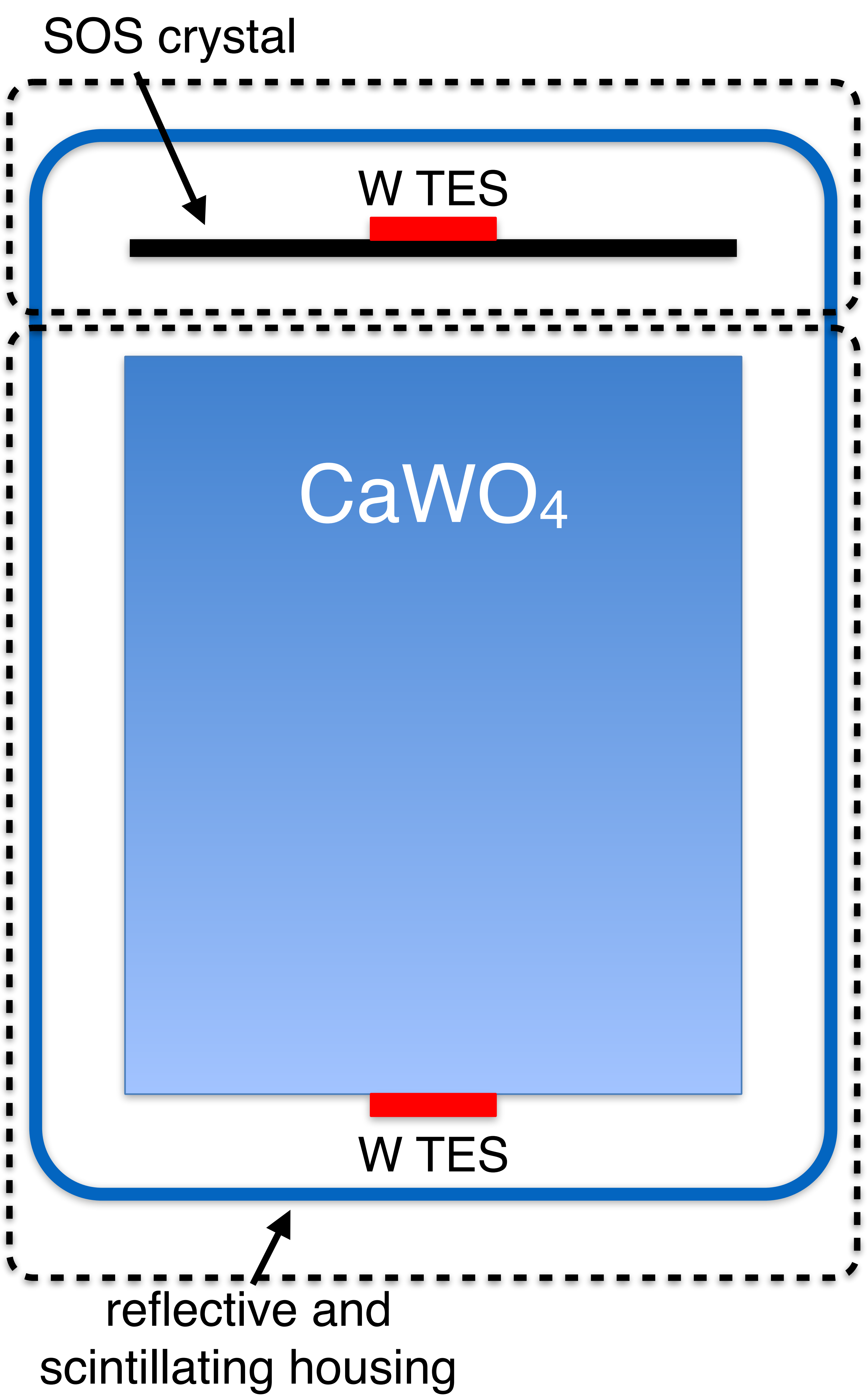




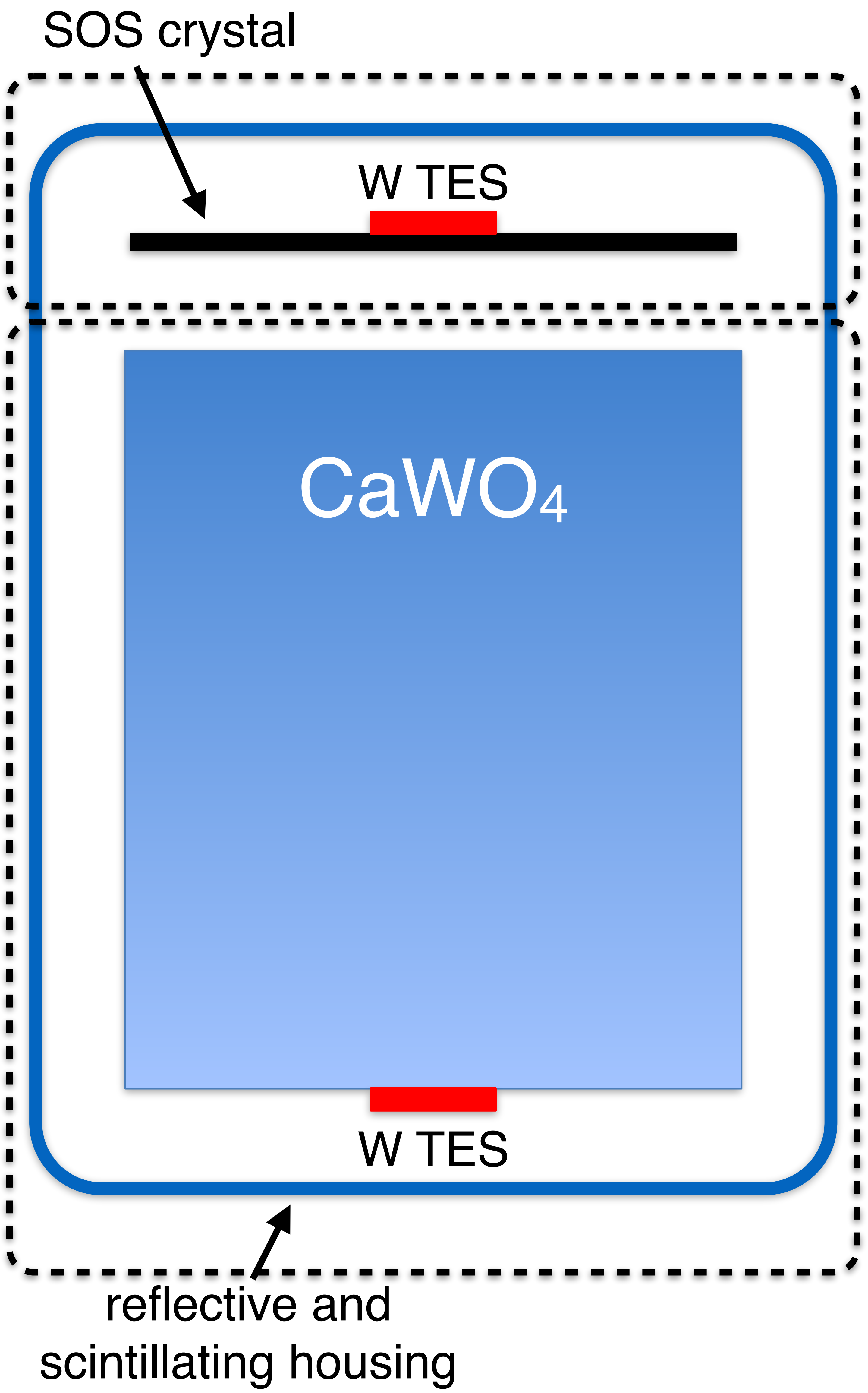
CRESST Detectors



Scintillating light:
particle discrimination

Phonon signal:
deposited energy

CRESST Detectors



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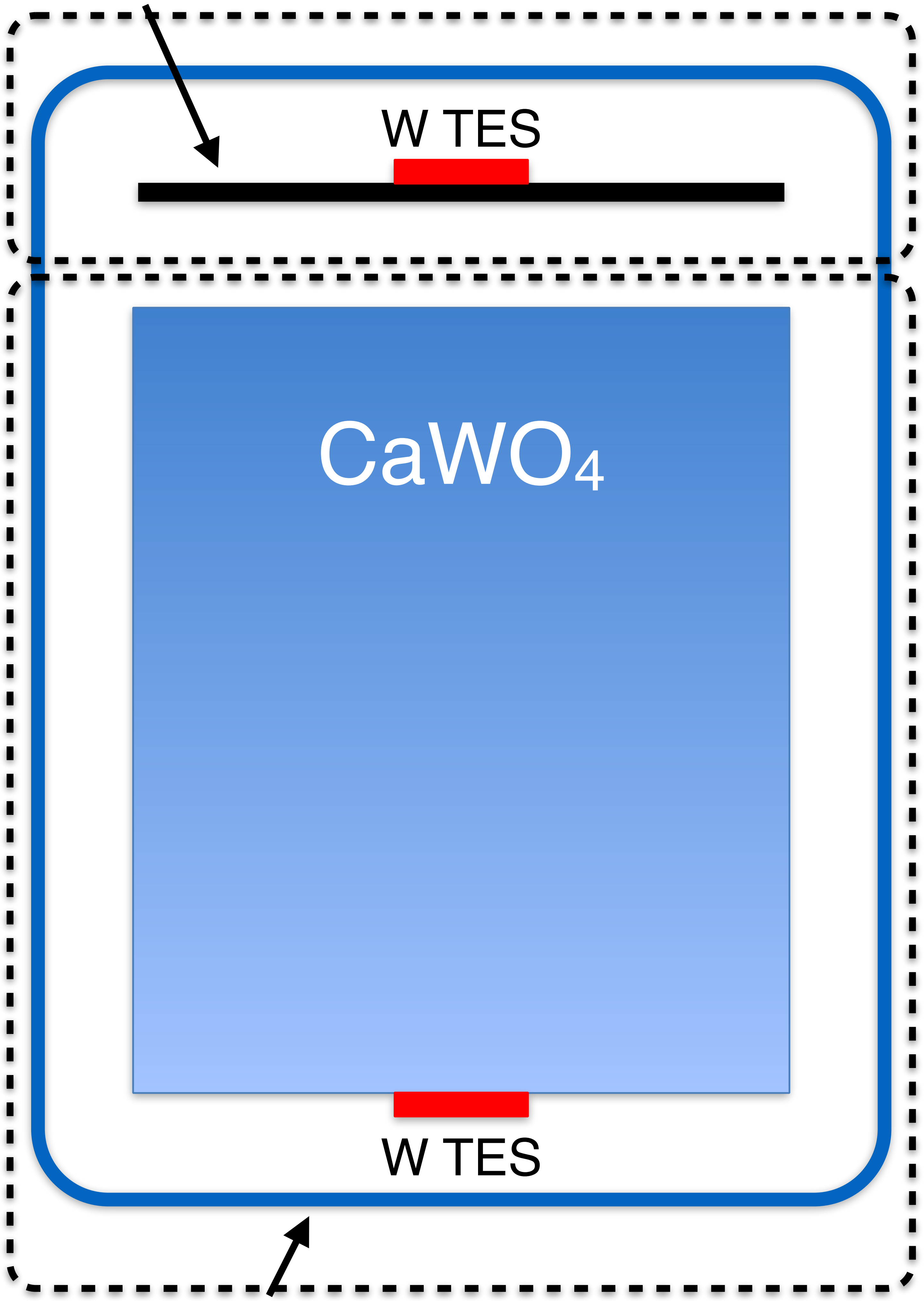
$$\text{light yield} = \frac{\text{energy detected in light channel}}{\text{energy detected in the phonon channel}}$$

CRESST Detectors



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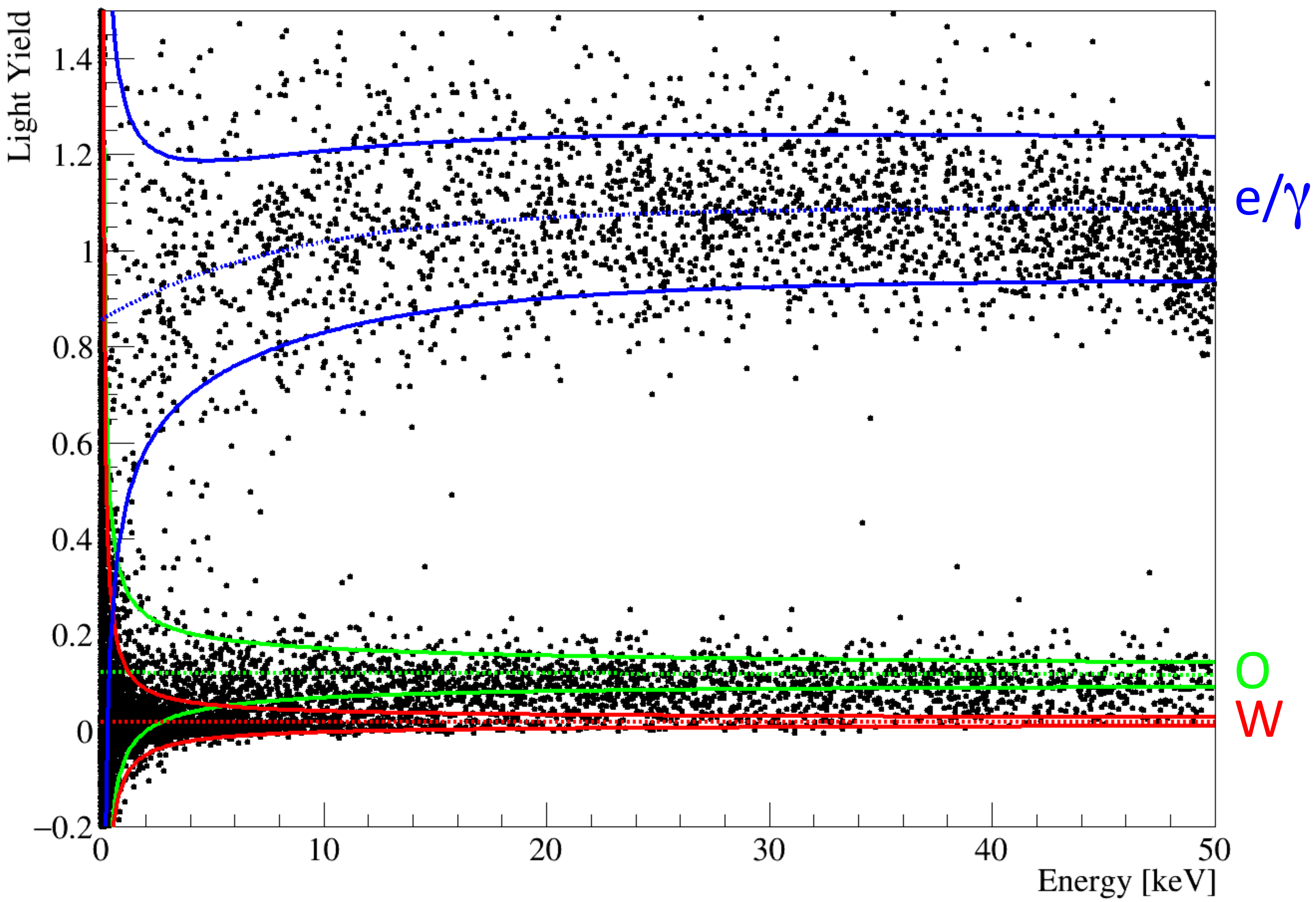
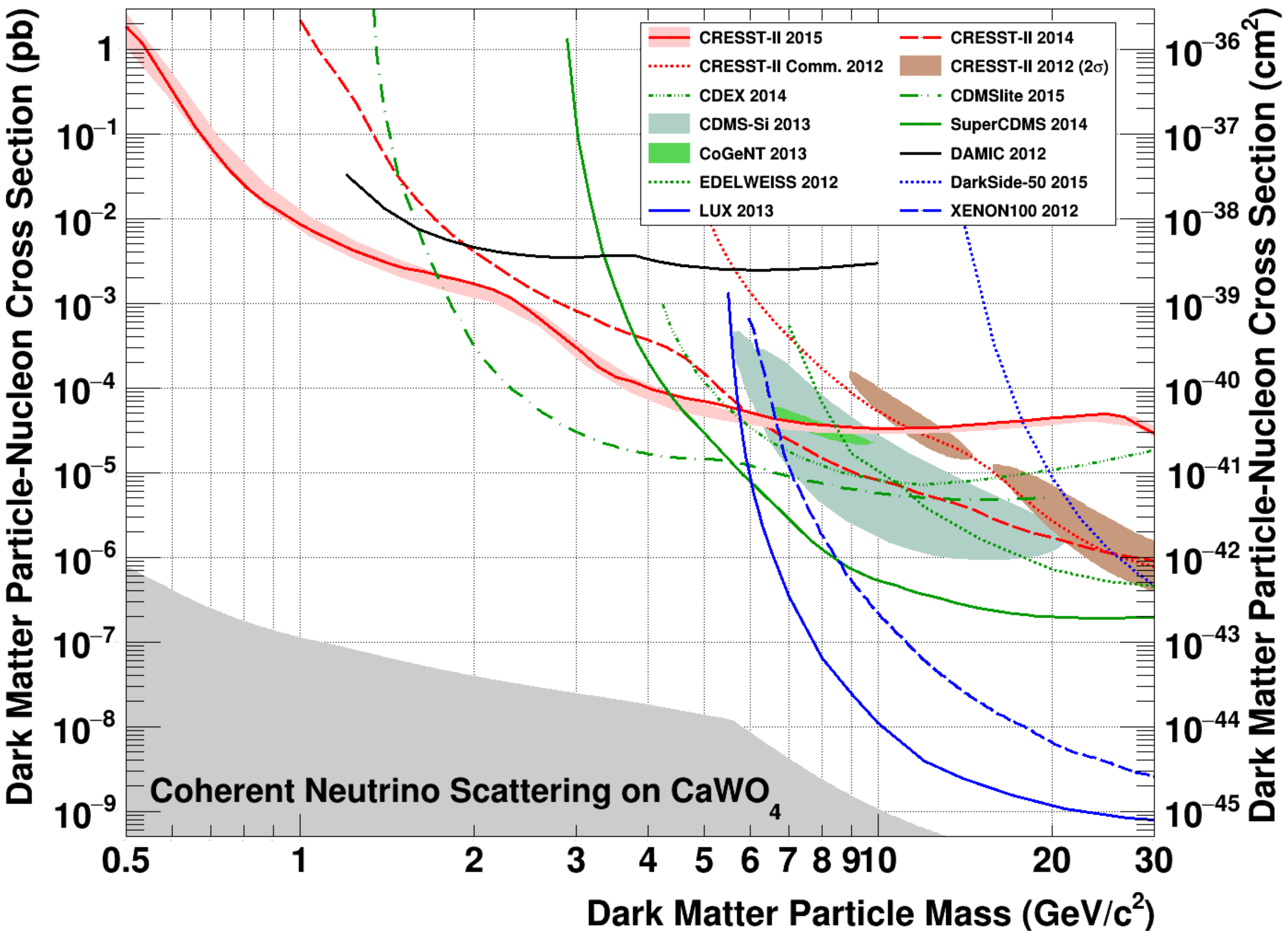
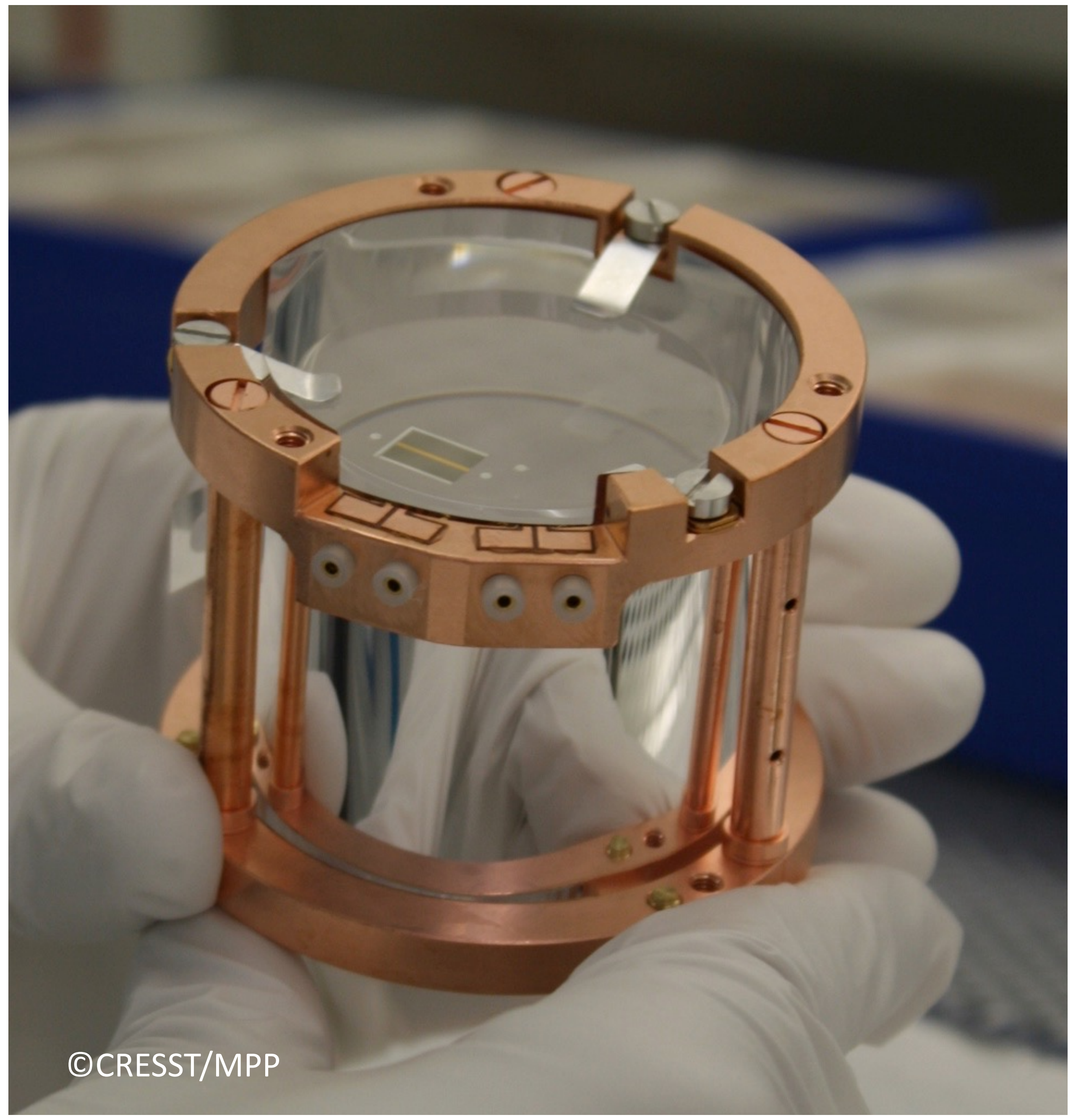


CRESST-II results (2015)

Crystal: Lise - background level ≈8.5 counts/(keV kg day)
Threshold: 307eV
Resolution: 62eV at zero energy



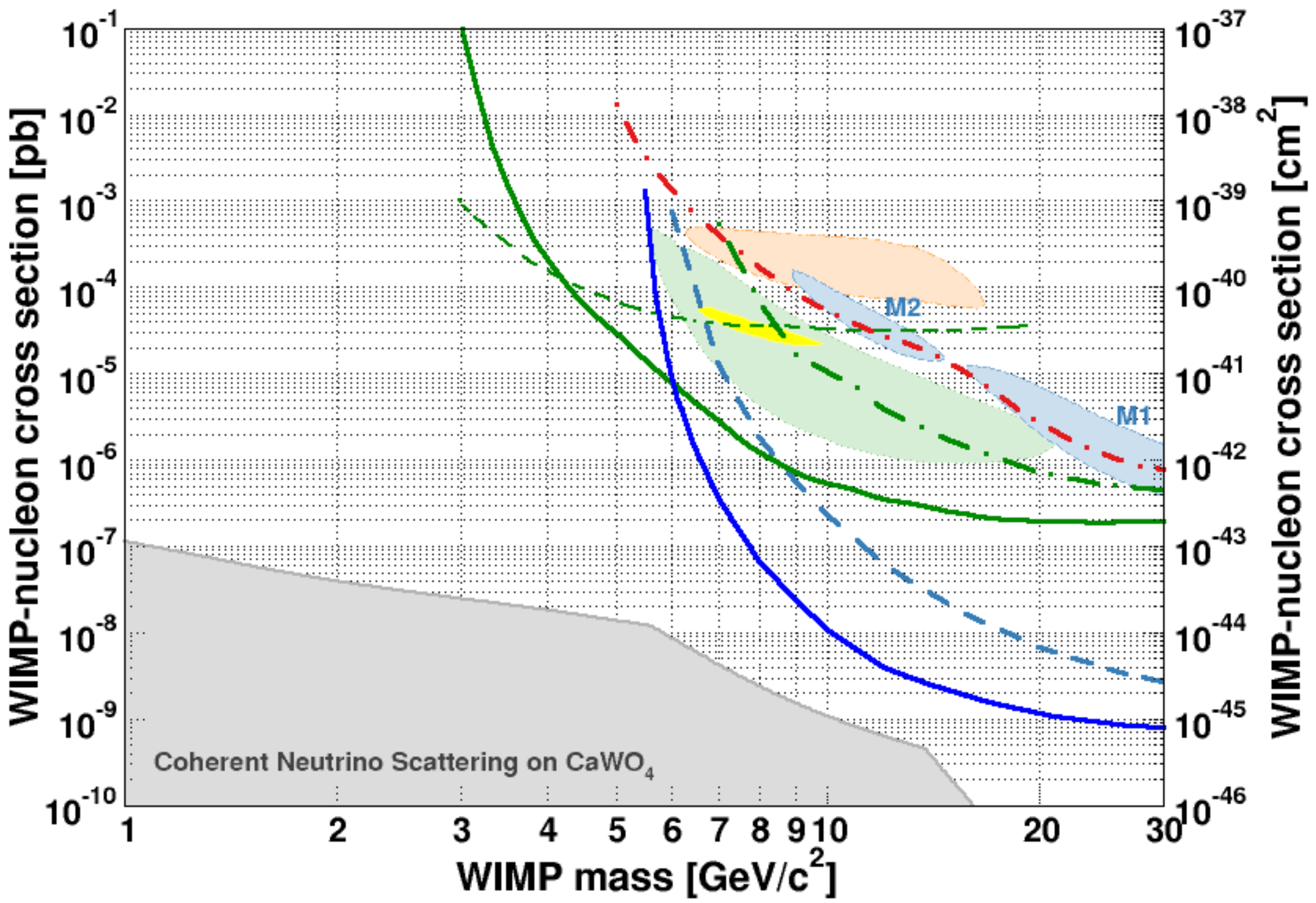


World-leading below 1.7GeV/c² (until 2017)
Exploring new parameter space down to 0.5GeV/c²

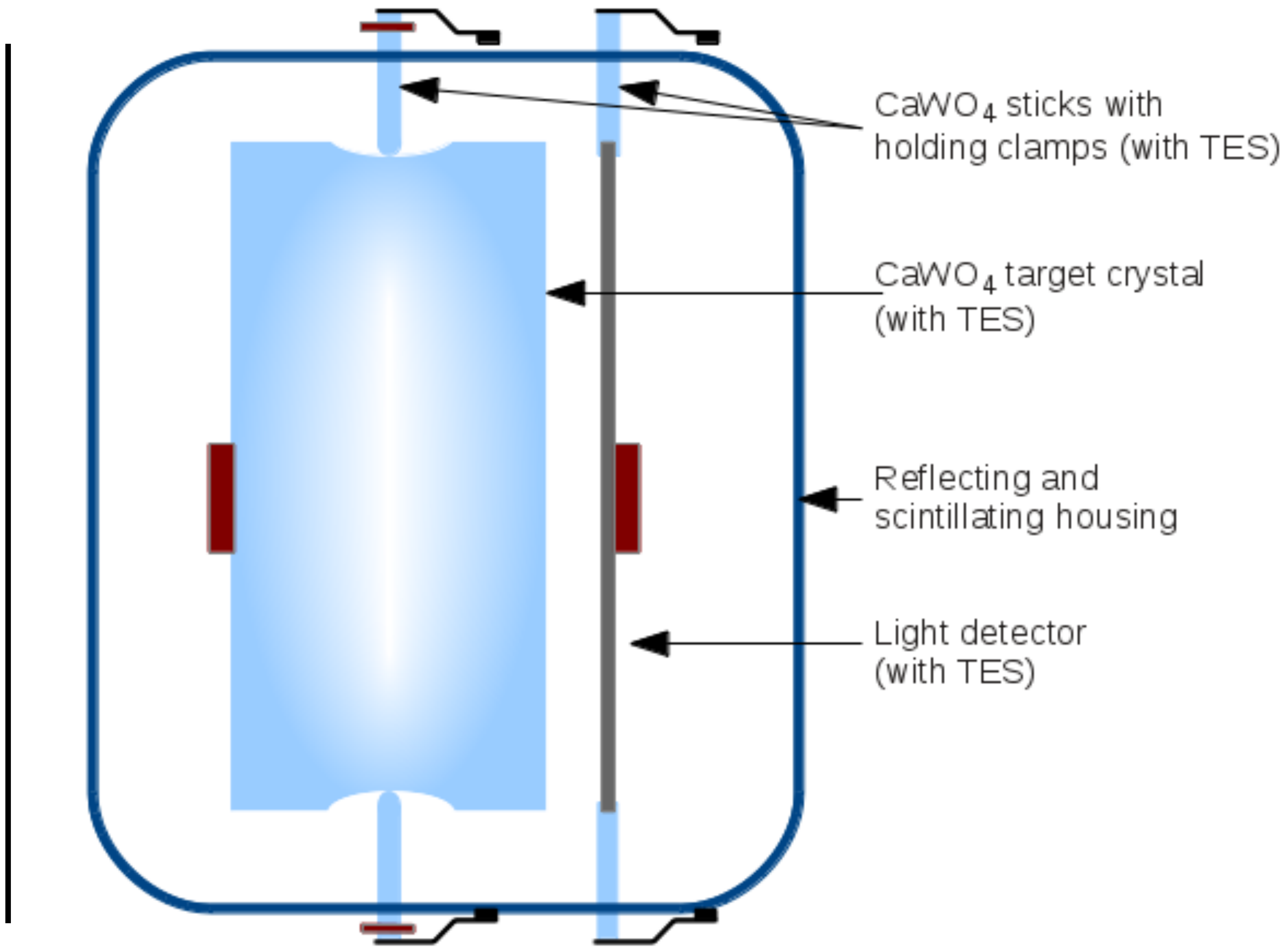
Hunting light dark matter requires a low threshold!

Eur.Phys.J. C76 (2016) 25

CRESST-III: go for the small



To improve sensitivity to low masses a radical change of strategy:



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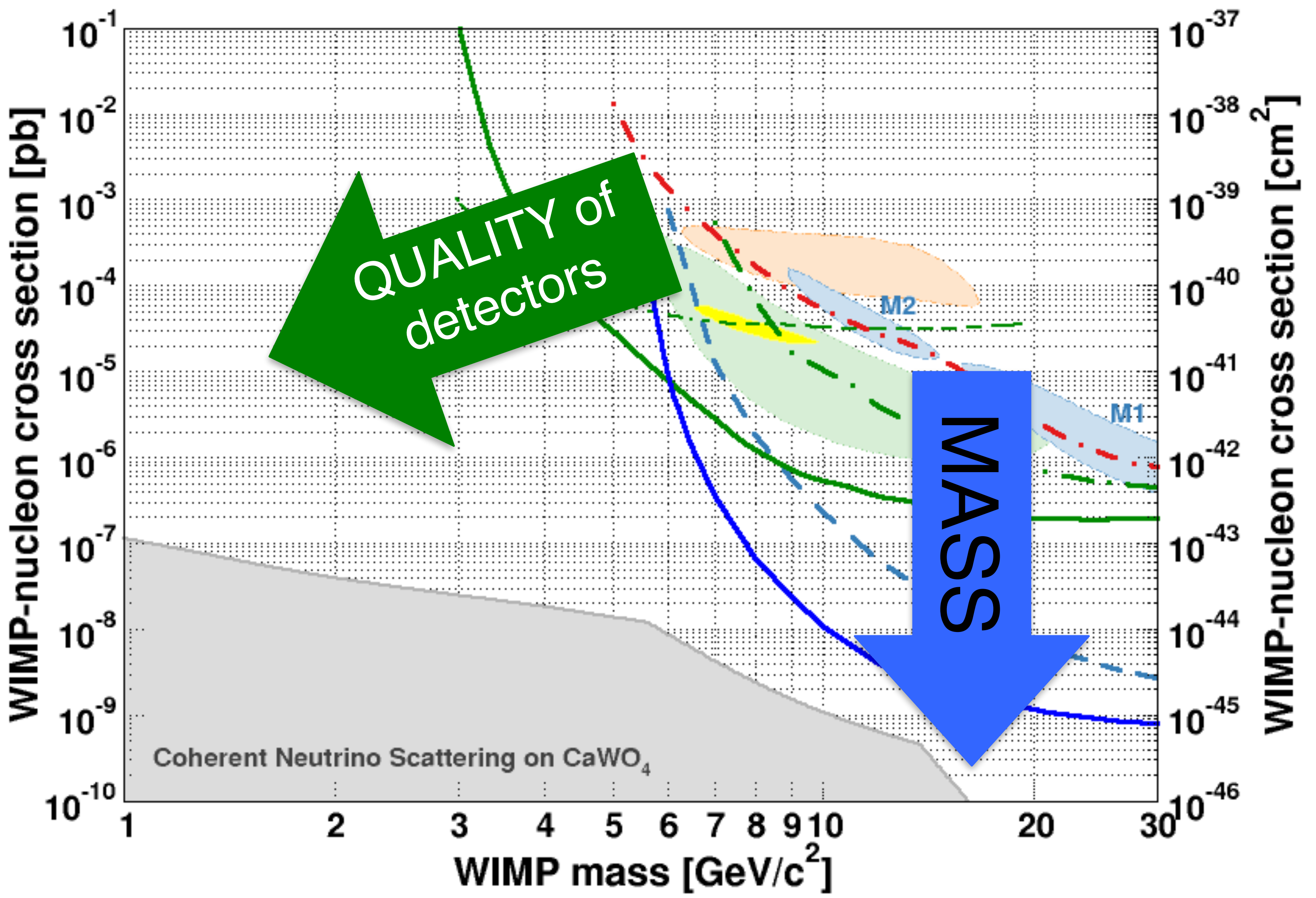

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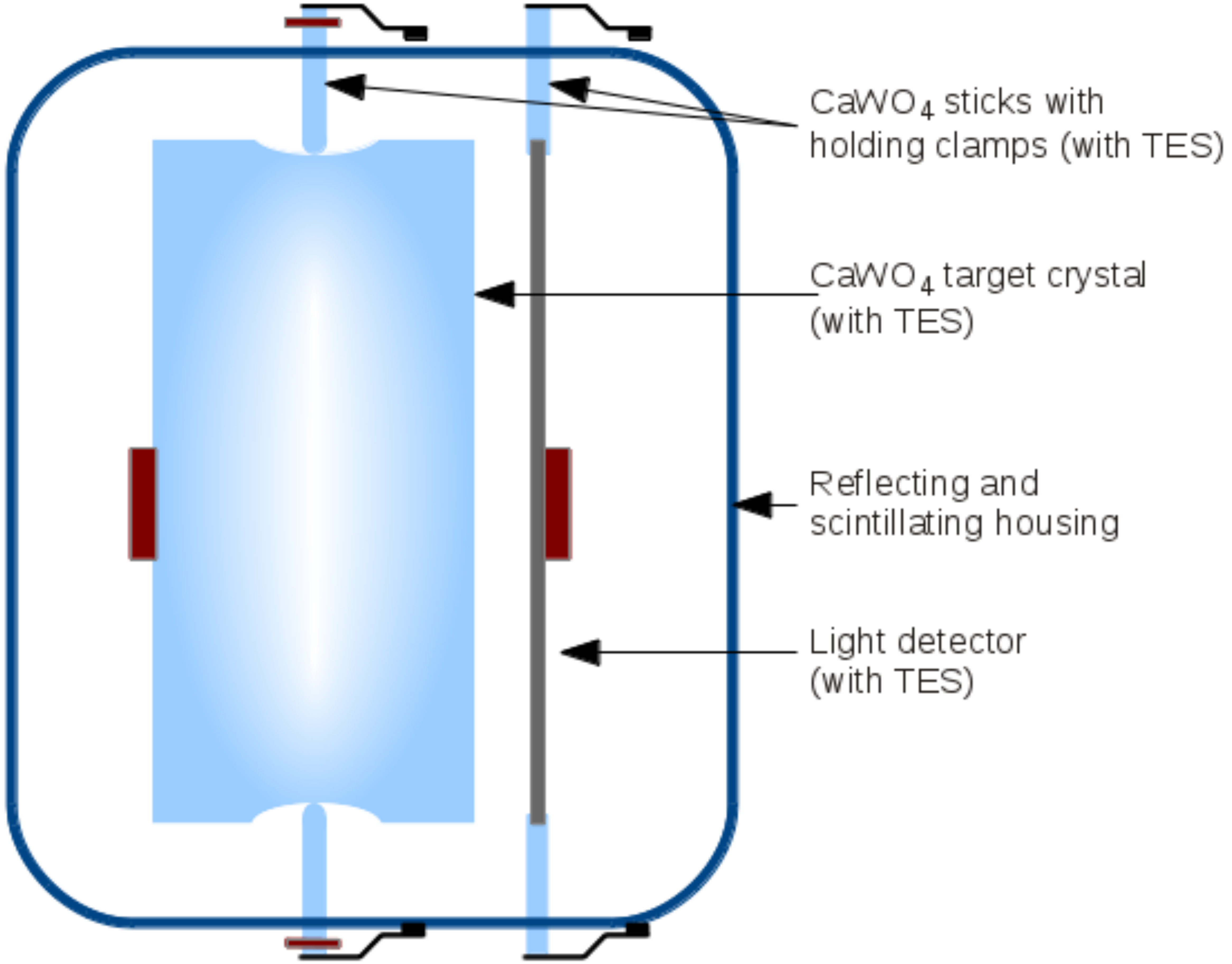

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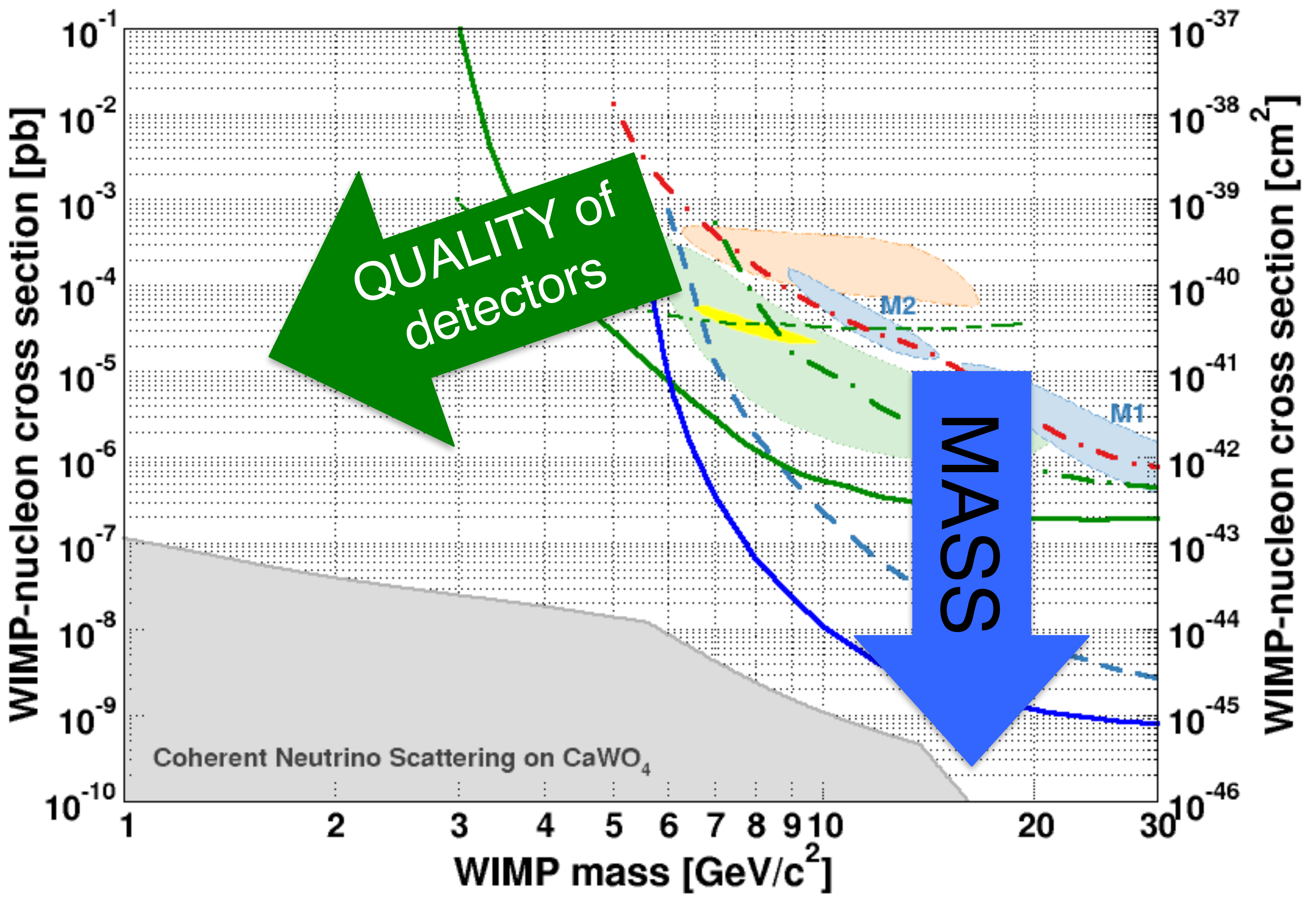
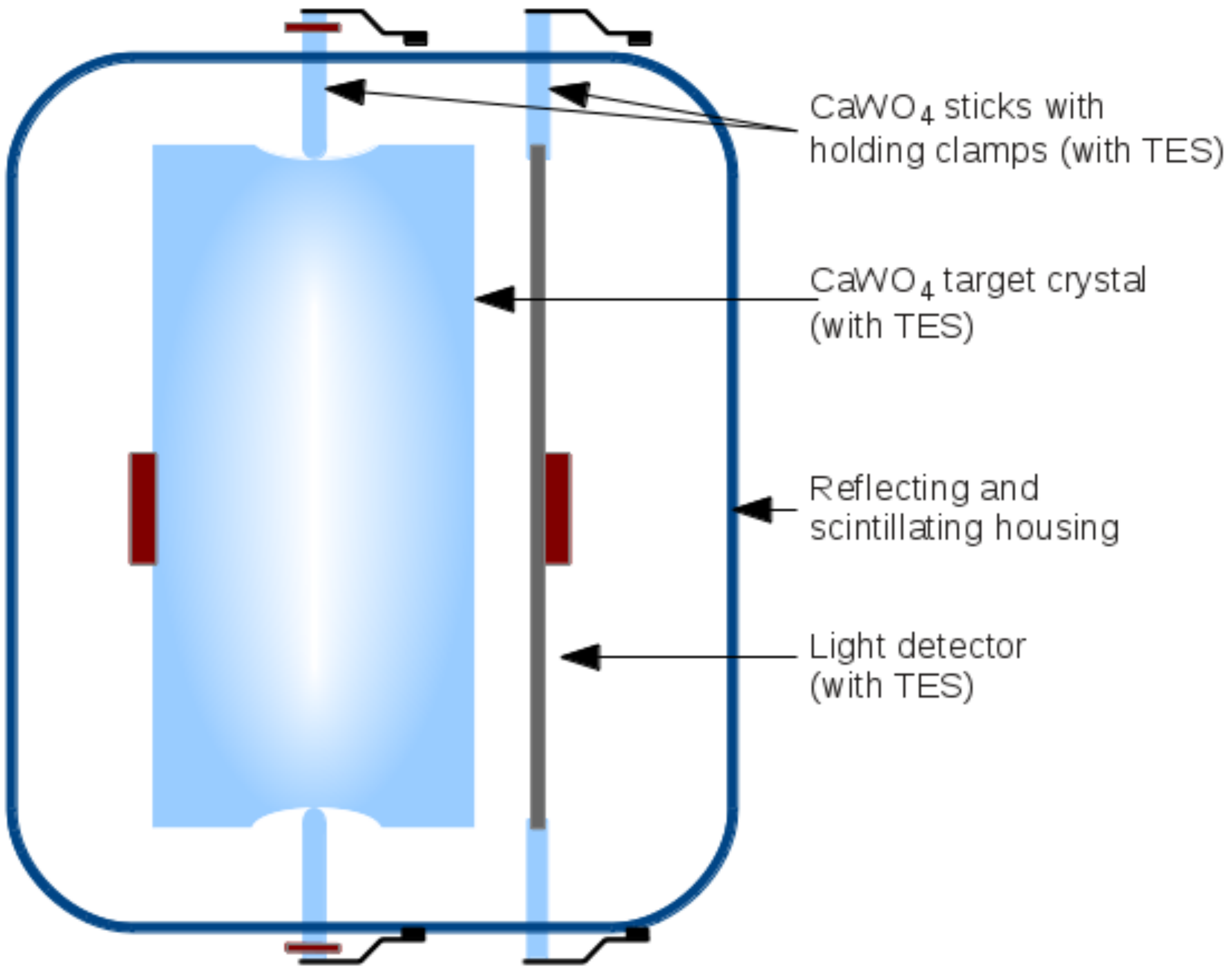




To improve sensitivity to low masses a radical change of strategy:

Smaller crystals: **250g → 24g**

Threshold: **300eV → 100eV**

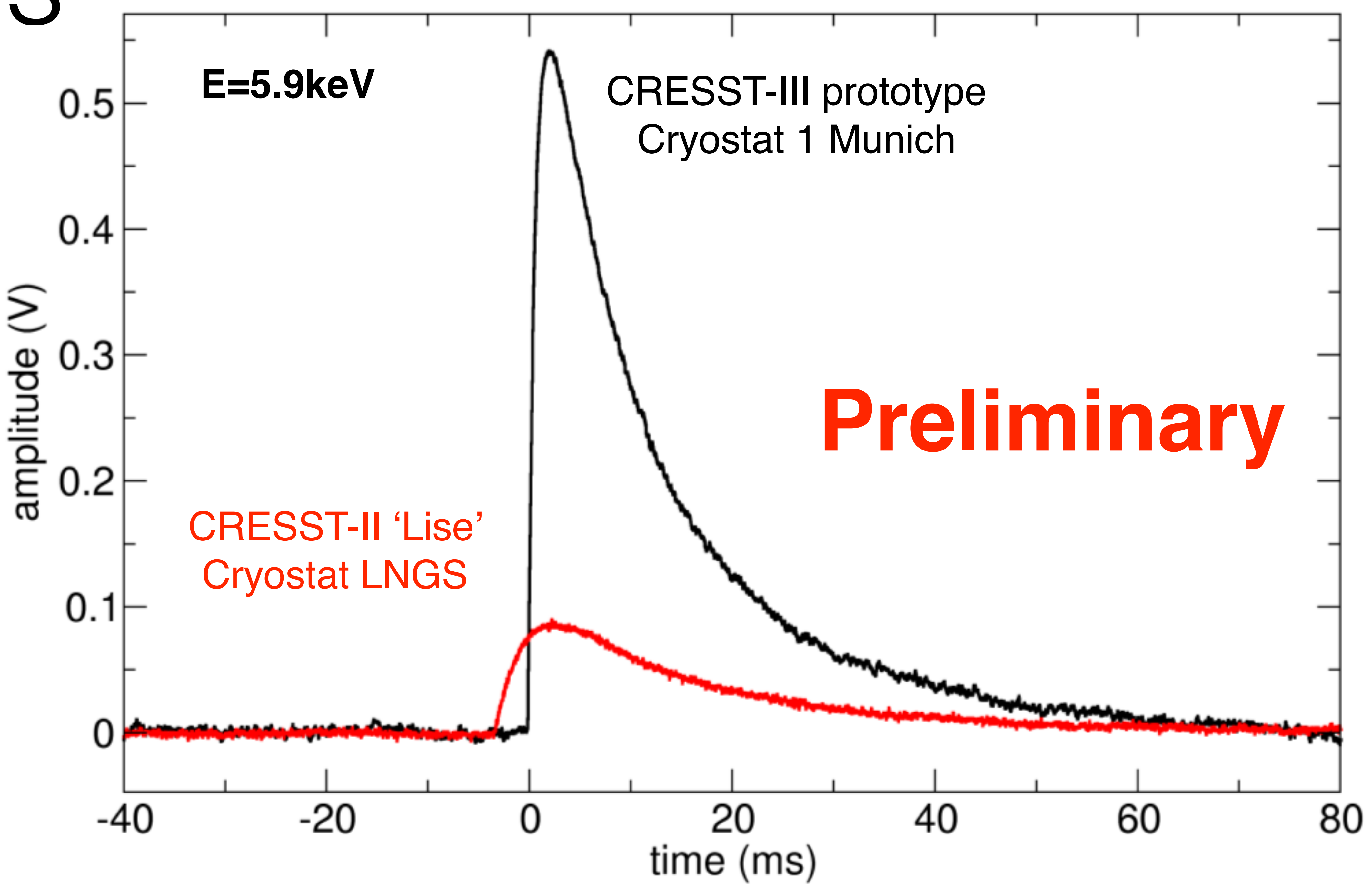
CRESST-III low threshold detectors

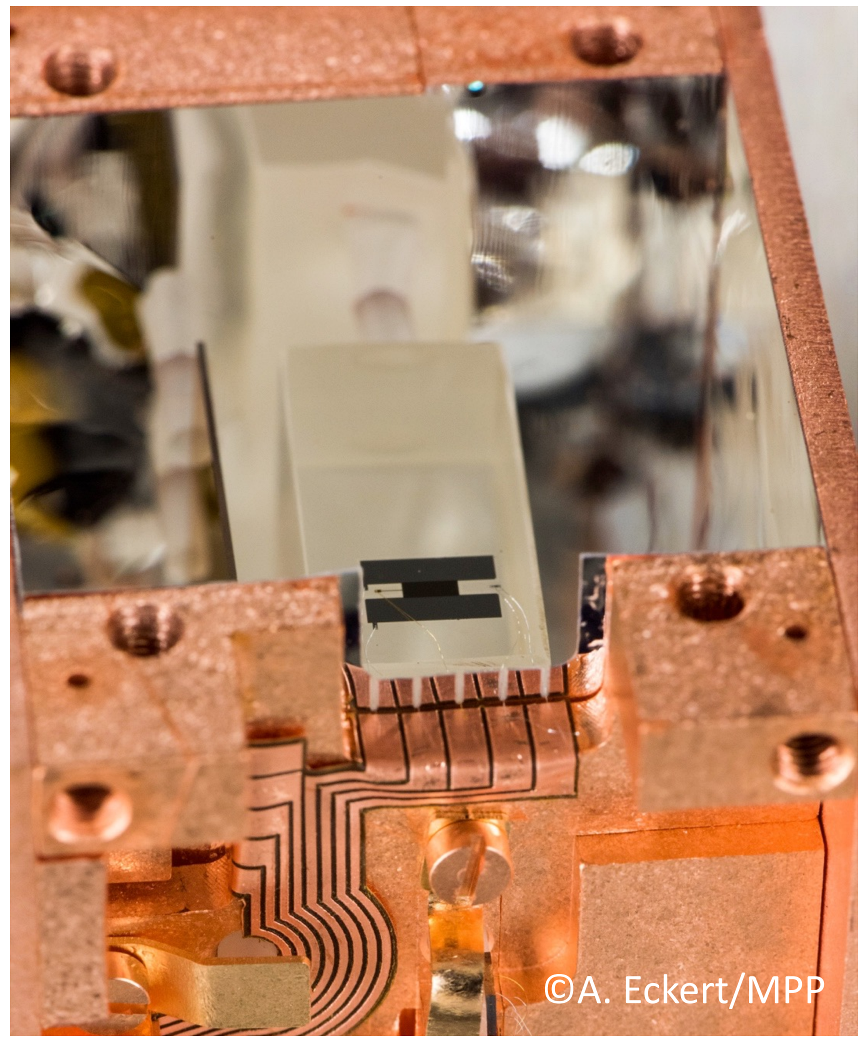
Detector layout optimized for low mass dark matter

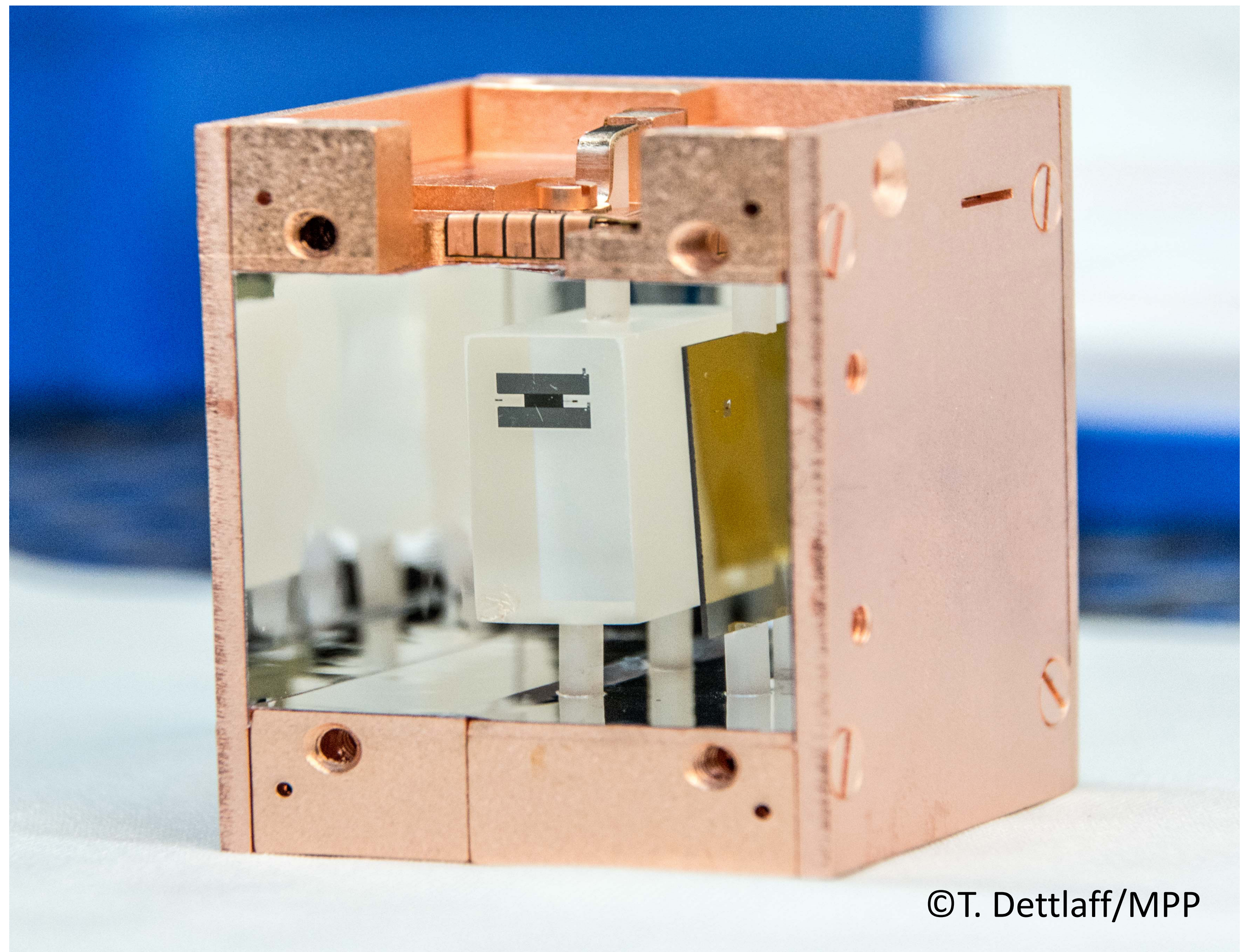
Radical reduction of dimension

- Absorber volume reduced of a factor ~10
- Cuboid crystals of (20×20×10)mm^3 (≈**24g**)
- Self grown crystals - background level **≈3 counts/(keV kg day)**
- **100 eV threshold**
- Light detector (20×20)mm^2
- Fully scintillating housing
- Instrumented sticks

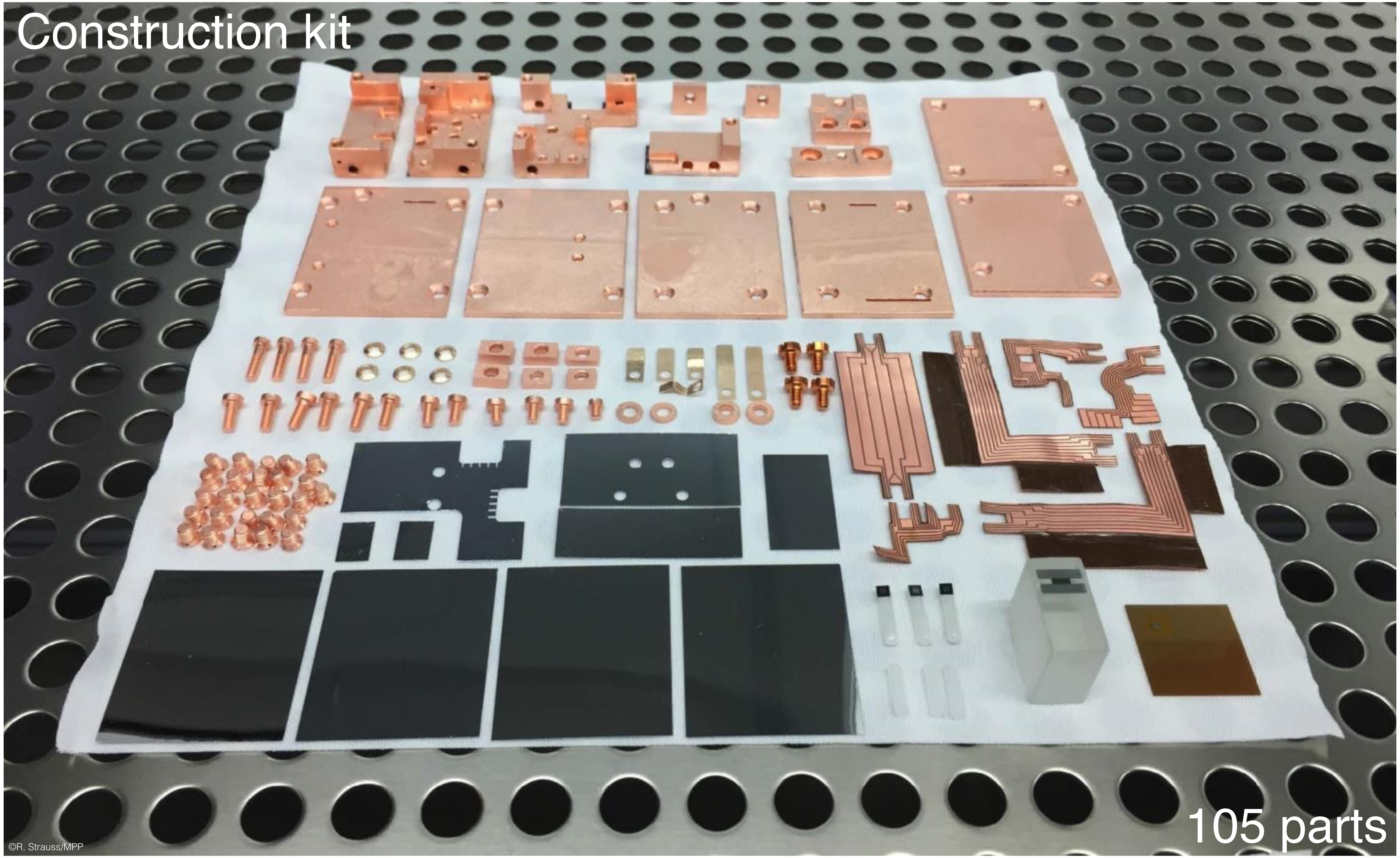
$\left.\begin{array}{l}\text{Fully scintillating housing}\\ \text{Instrumented sticks}\end{array}\right\}$ **Veto surface related background**

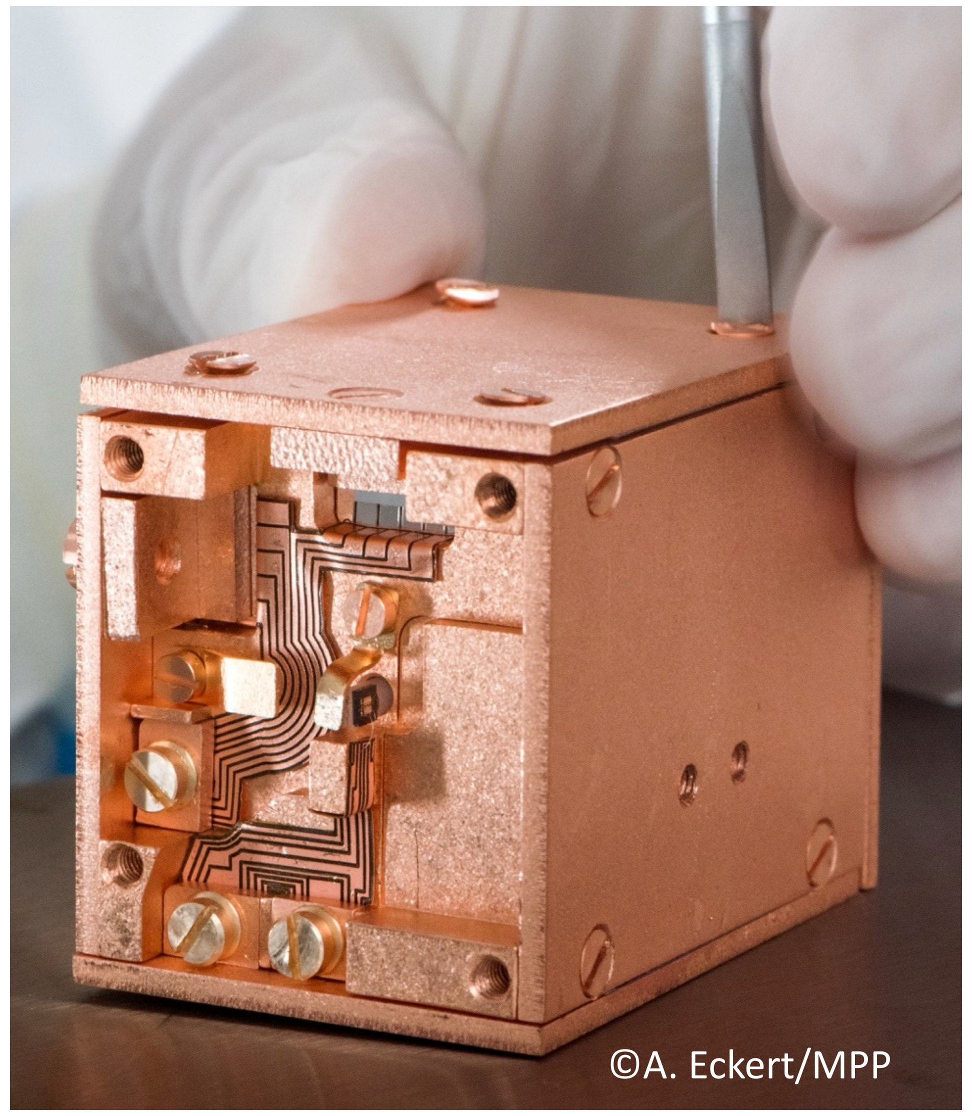


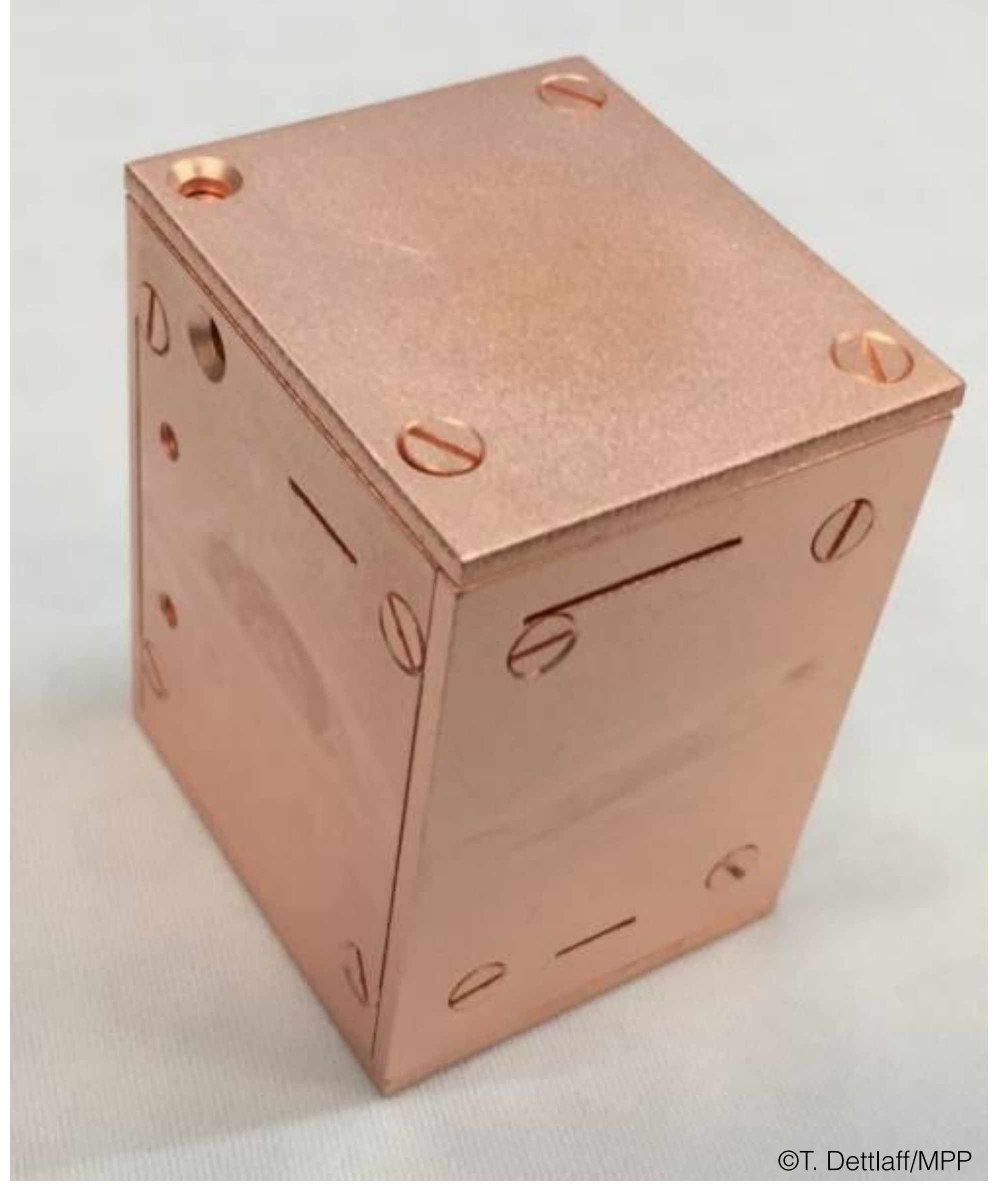




CRESST-III Phase I: Detector preparation





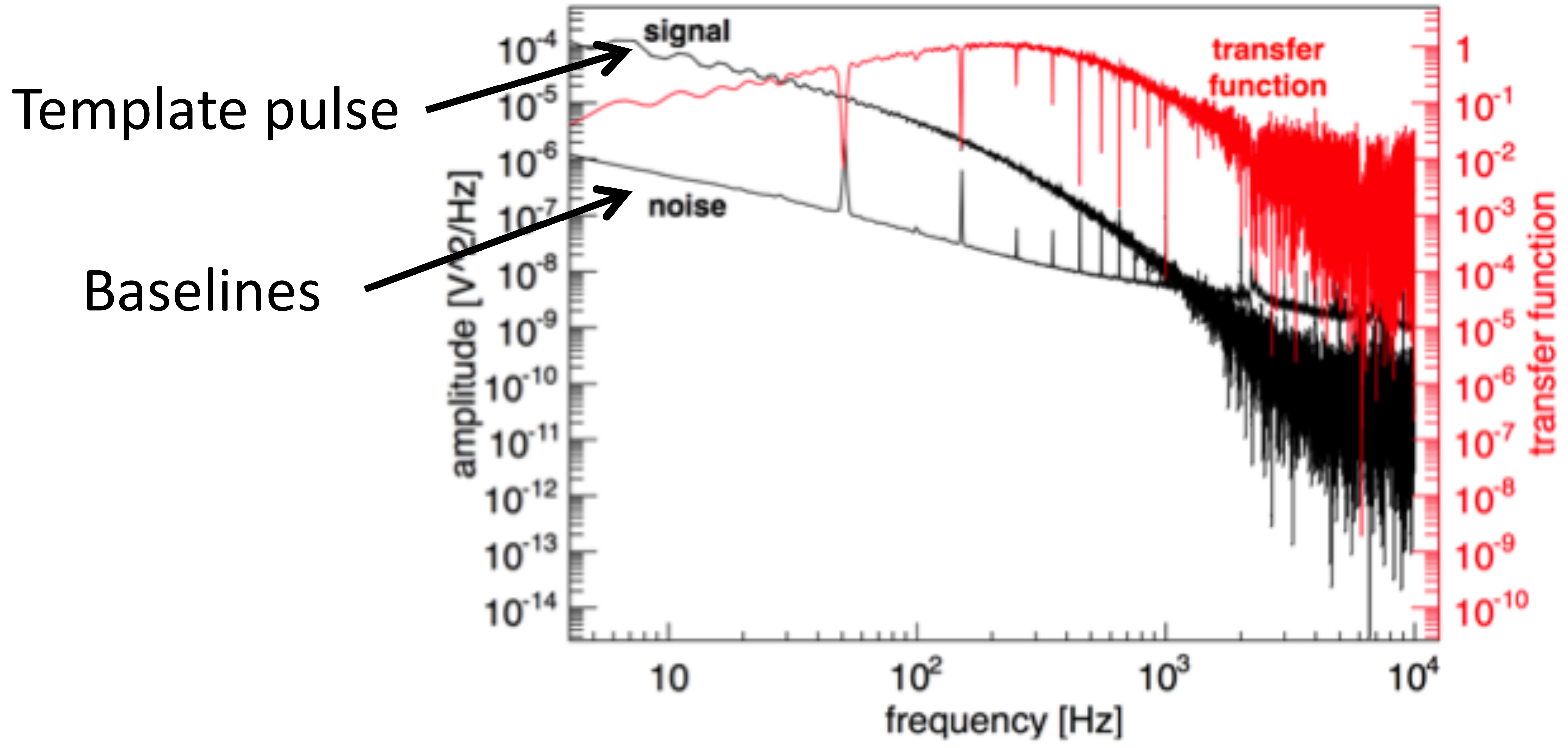


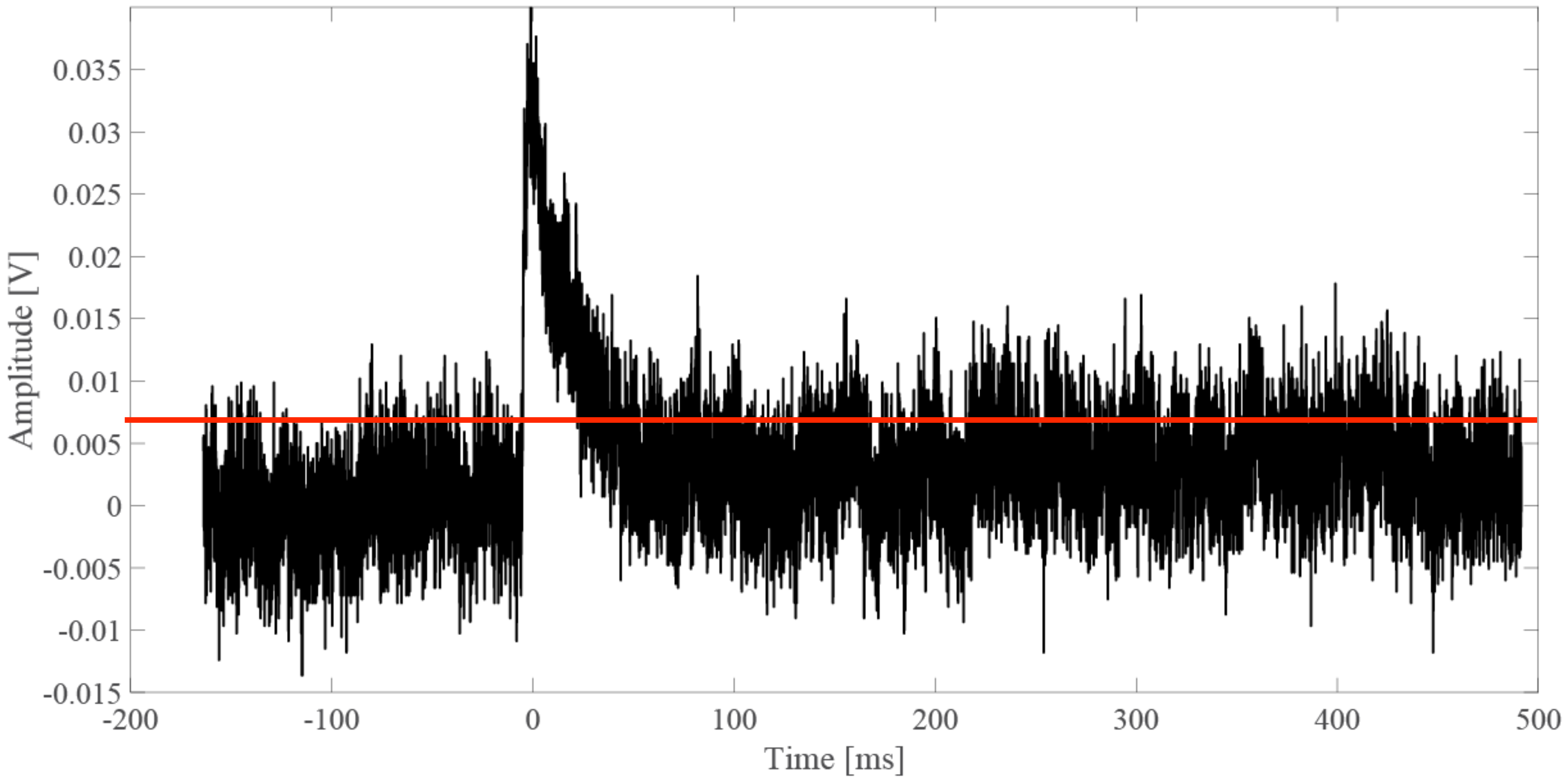
Optimum Filter

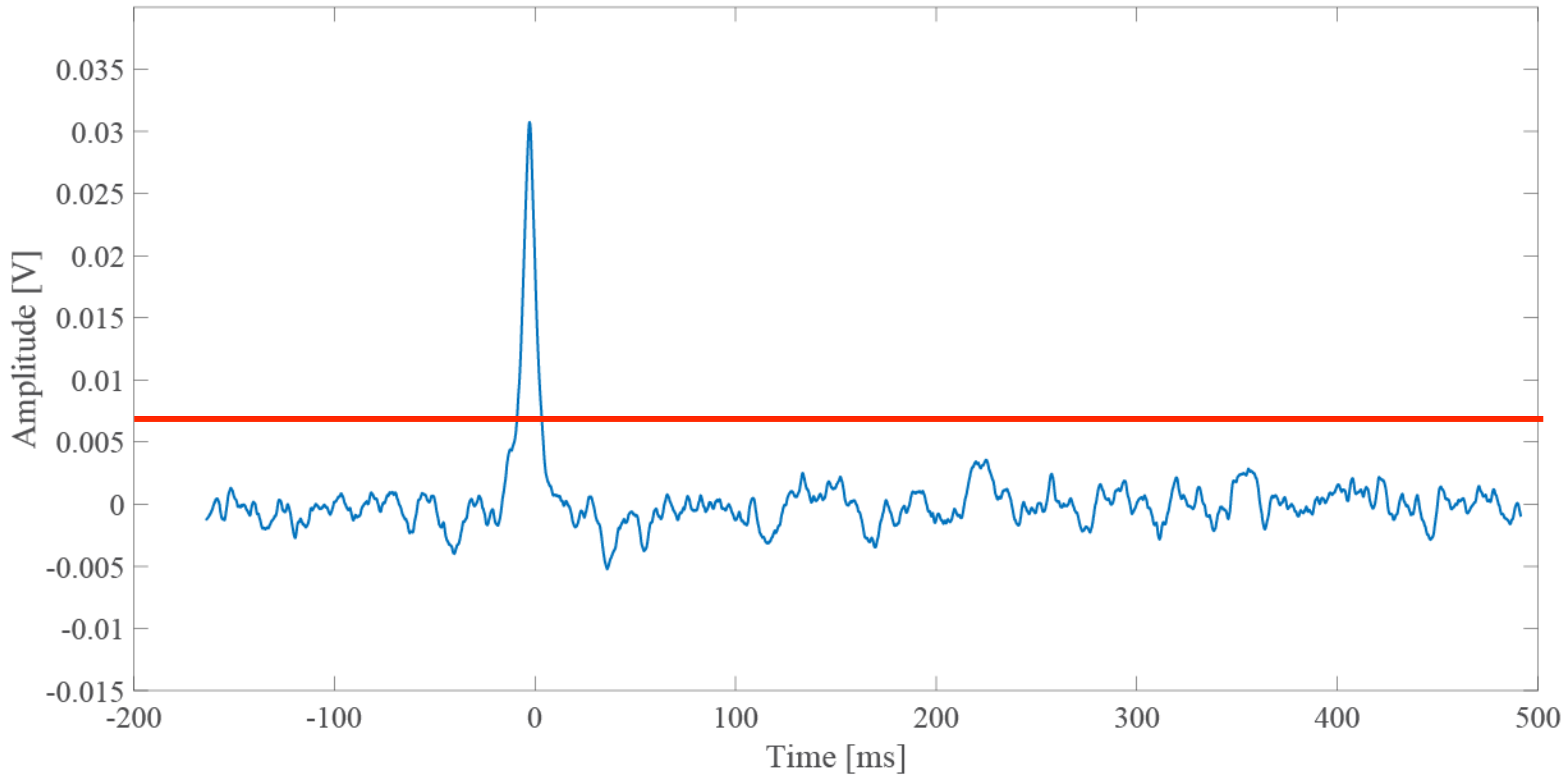
arXiv:1711.11459

Pulse-height evaluation with optimum filter

The **Gatti-Manfredi filter** is an optimum filter which maximize the ratio between the amplitude of the treated pulse and the noise RMS



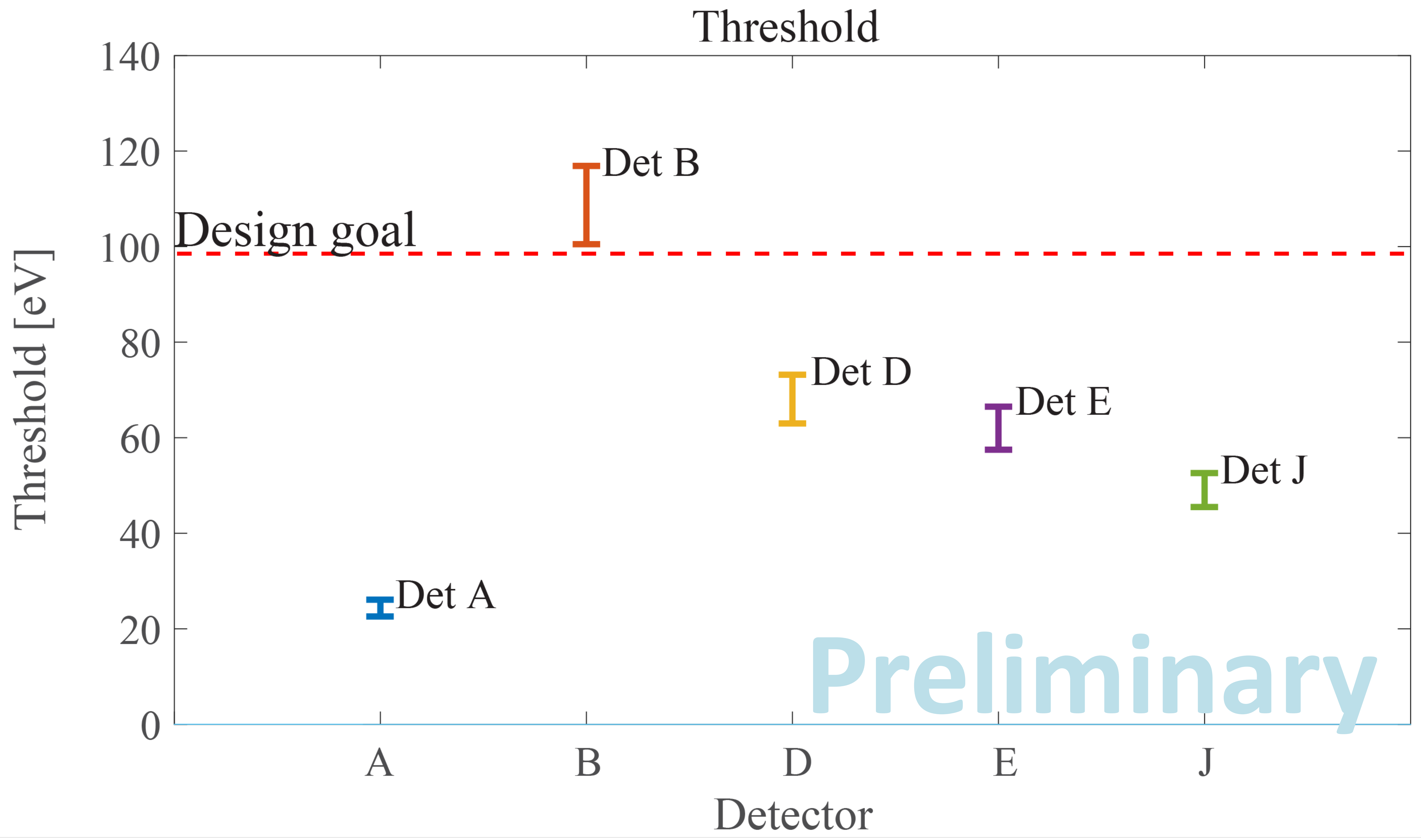




Typical improvement in resolution by using the optimum filter: factor 2-3

New frontier in direct dark Matter Detection

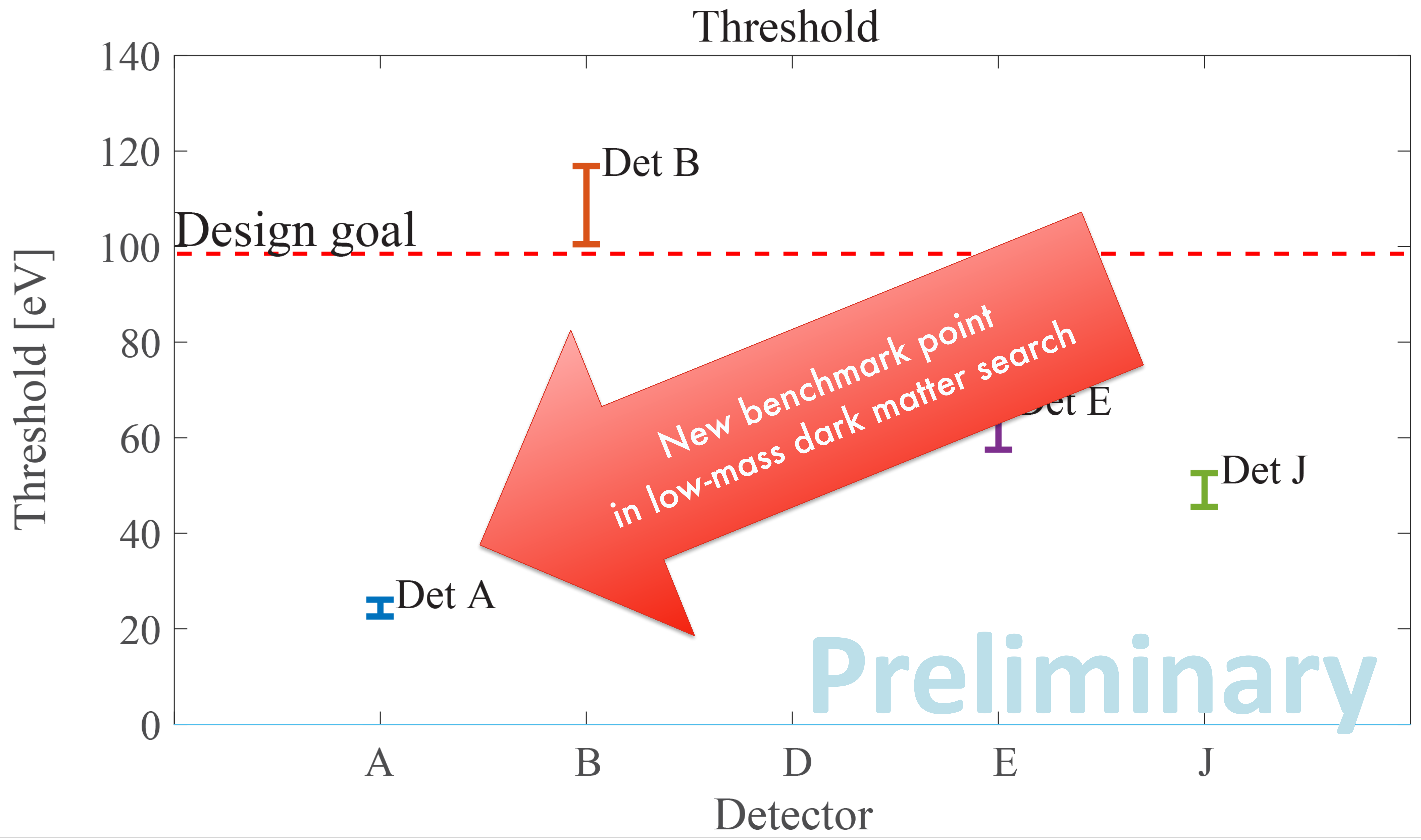
Optimum Threshold



5 detectors reach/exceed CRESST-III design goal

New frontier in direct dark Matter Detection

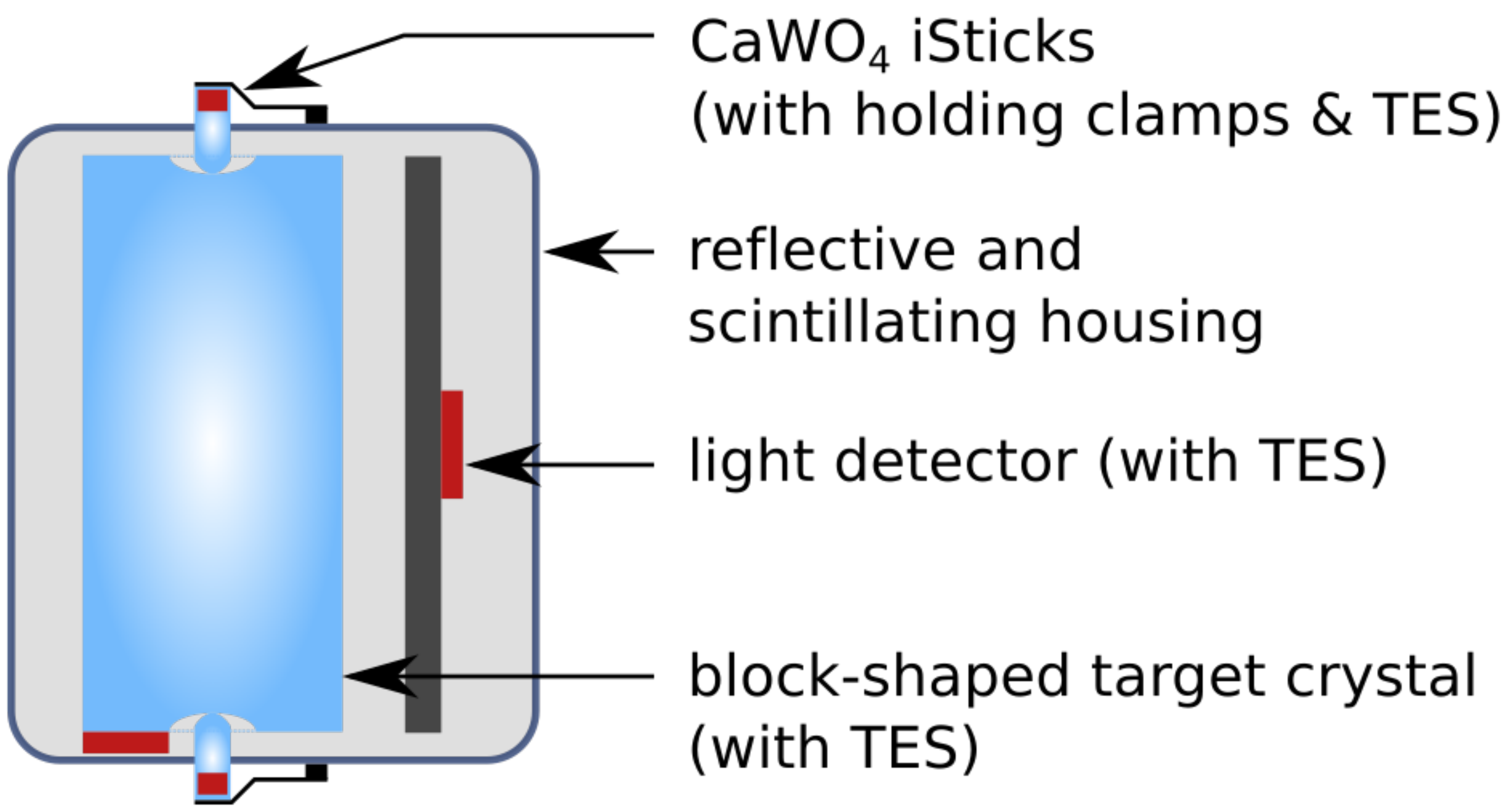
Optimum Threshold

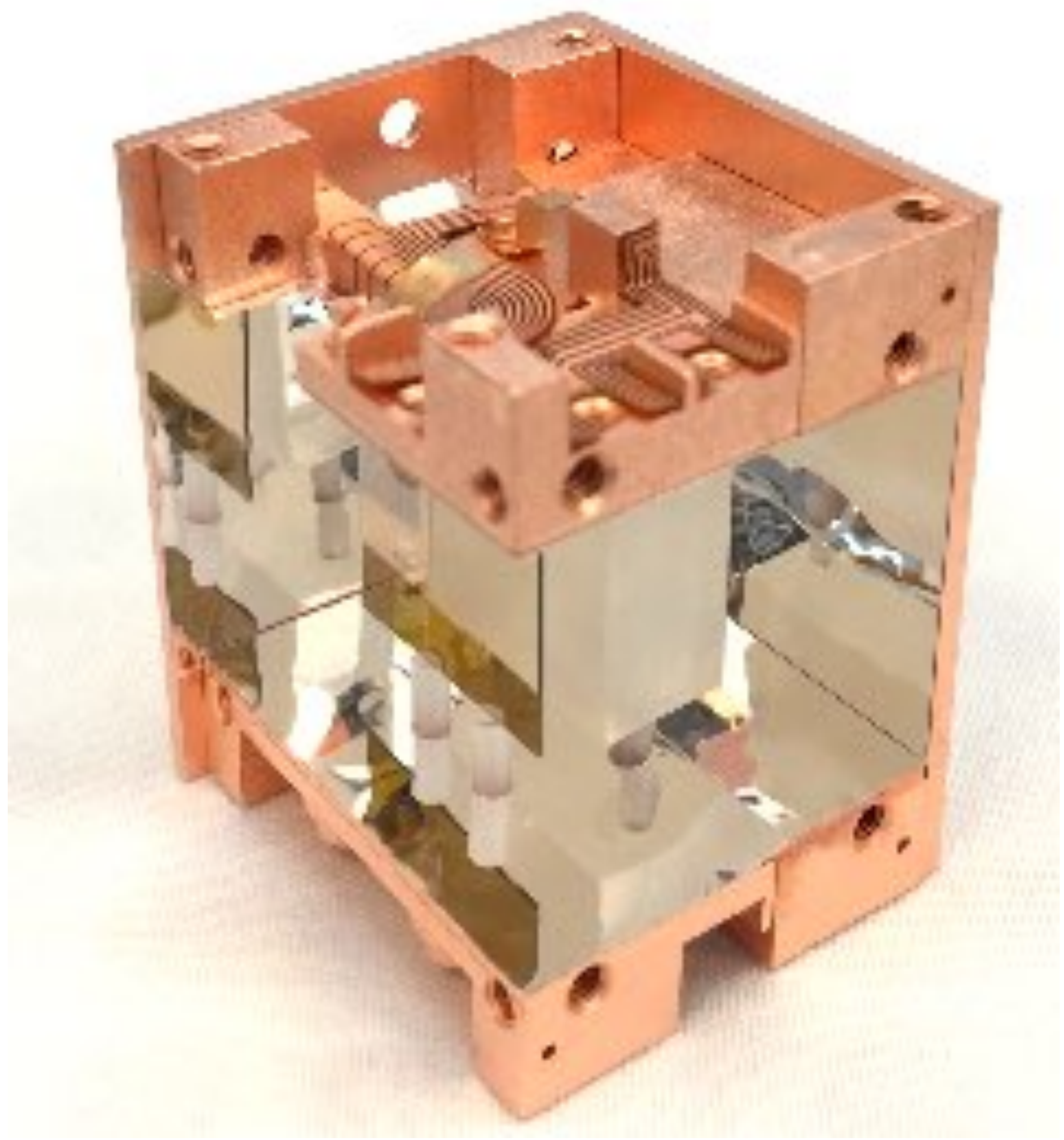


5 detectors reach/exceed CRESST-III design goal

Detector A

LOWEST THRESHOLD IN CRESST-III PHASE 1



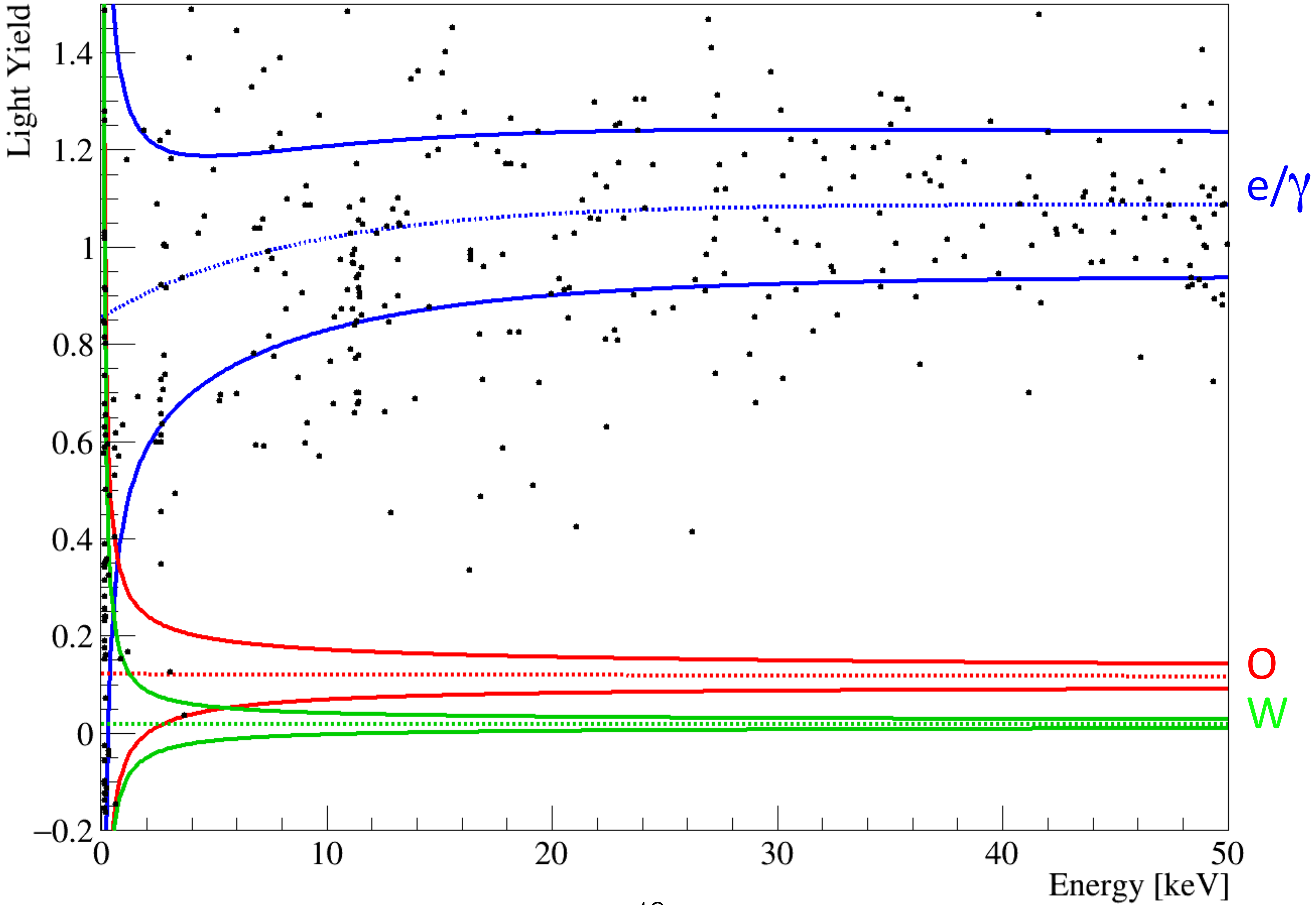


Data taking period:	10/2016 – 01/2018
Non-blind data (dynamically growing):	20% randomly selected
Target crystal mass:	23.6g
Gross exposure (before cuts):	5.7 kg days
Nuclear recoil threshold:	30.1 eV

Detector A: 100 eV threshold analysis

Blind data - LY vs. Energy

Unblinding for energies >100eV on July 10th



Selection criteria (aka “cuts”)

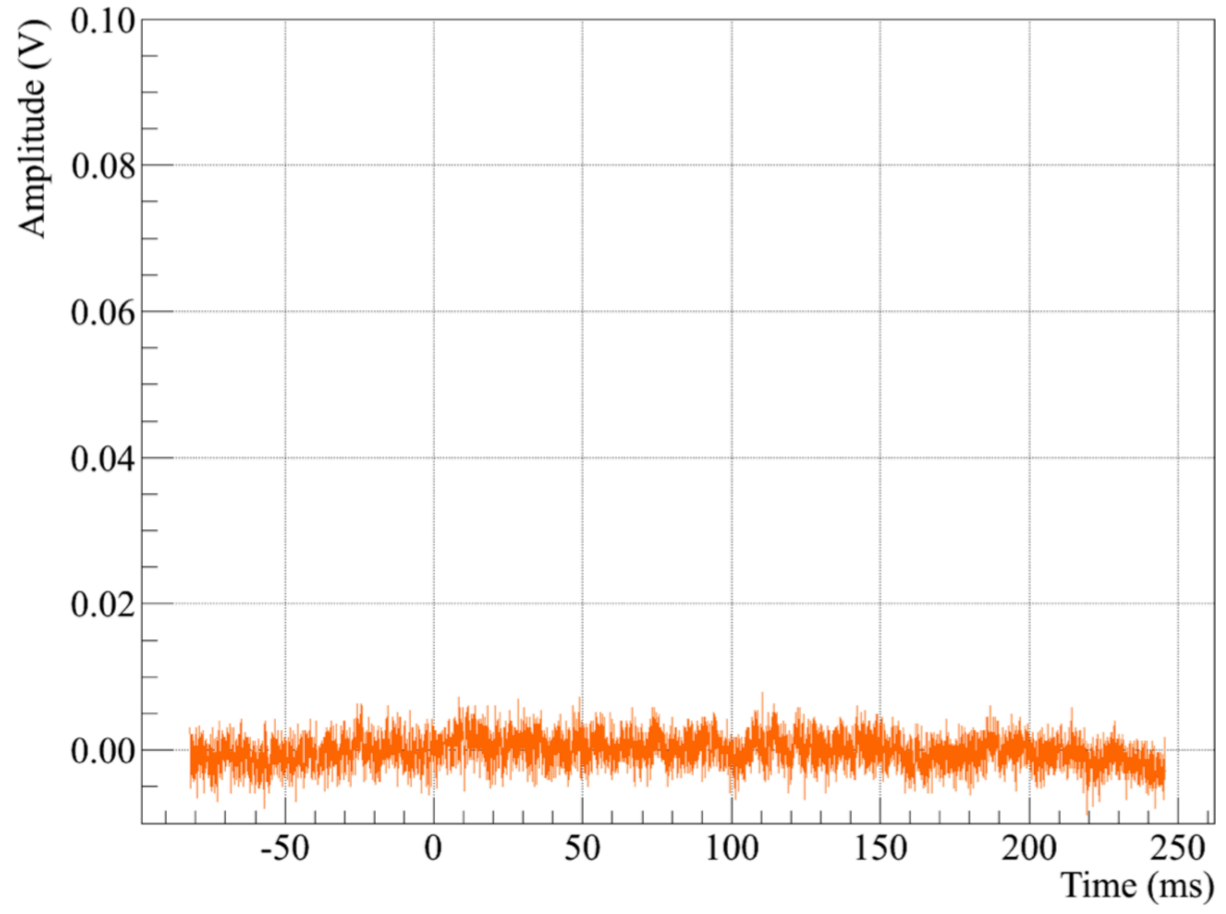
Objective

Keep only events where a correct determination of the amplitude (→energy) is guaranteed

Unbiased analysis

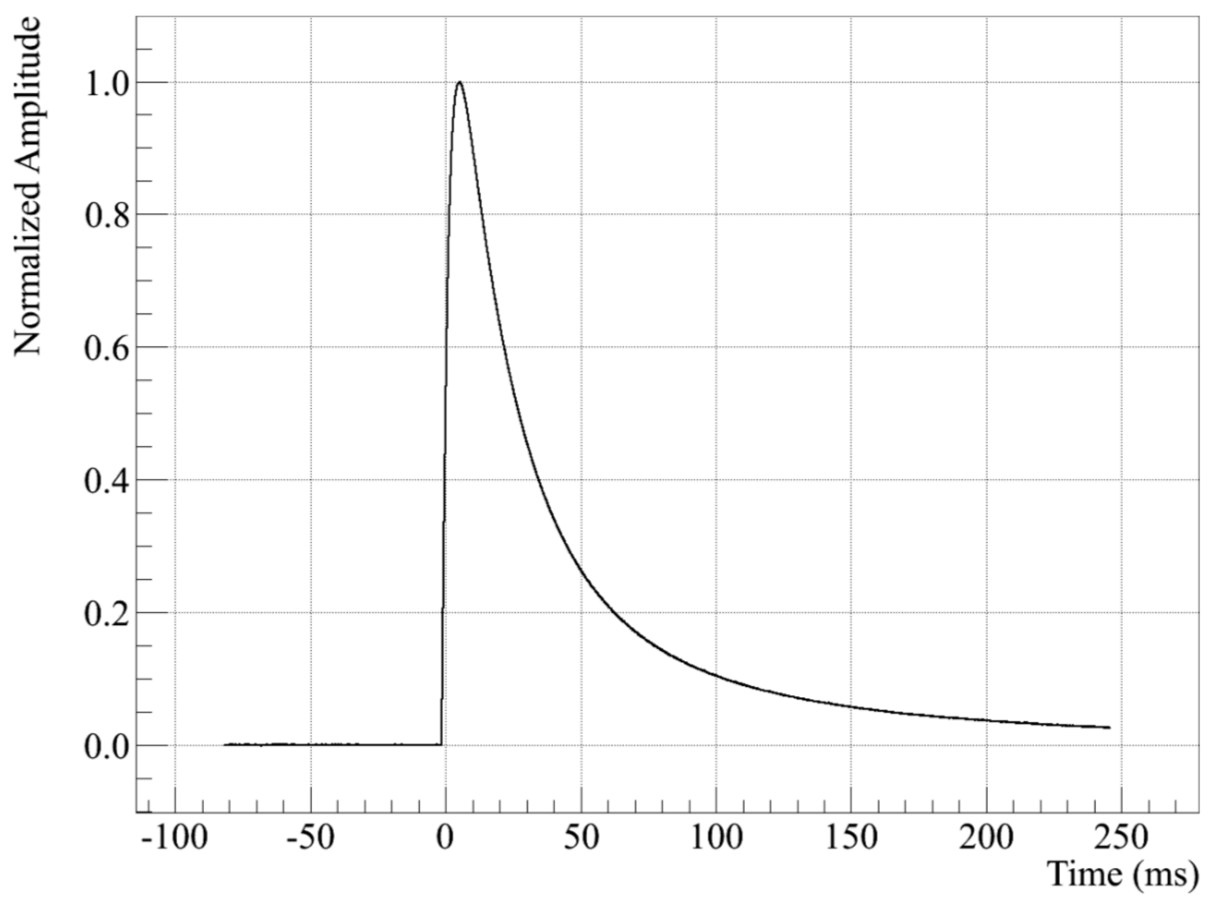
1. Design cuts on non-blind training set (≦20%, excluded from DM data set)
2. Apply without change to blind DM data set

Efficiency determination



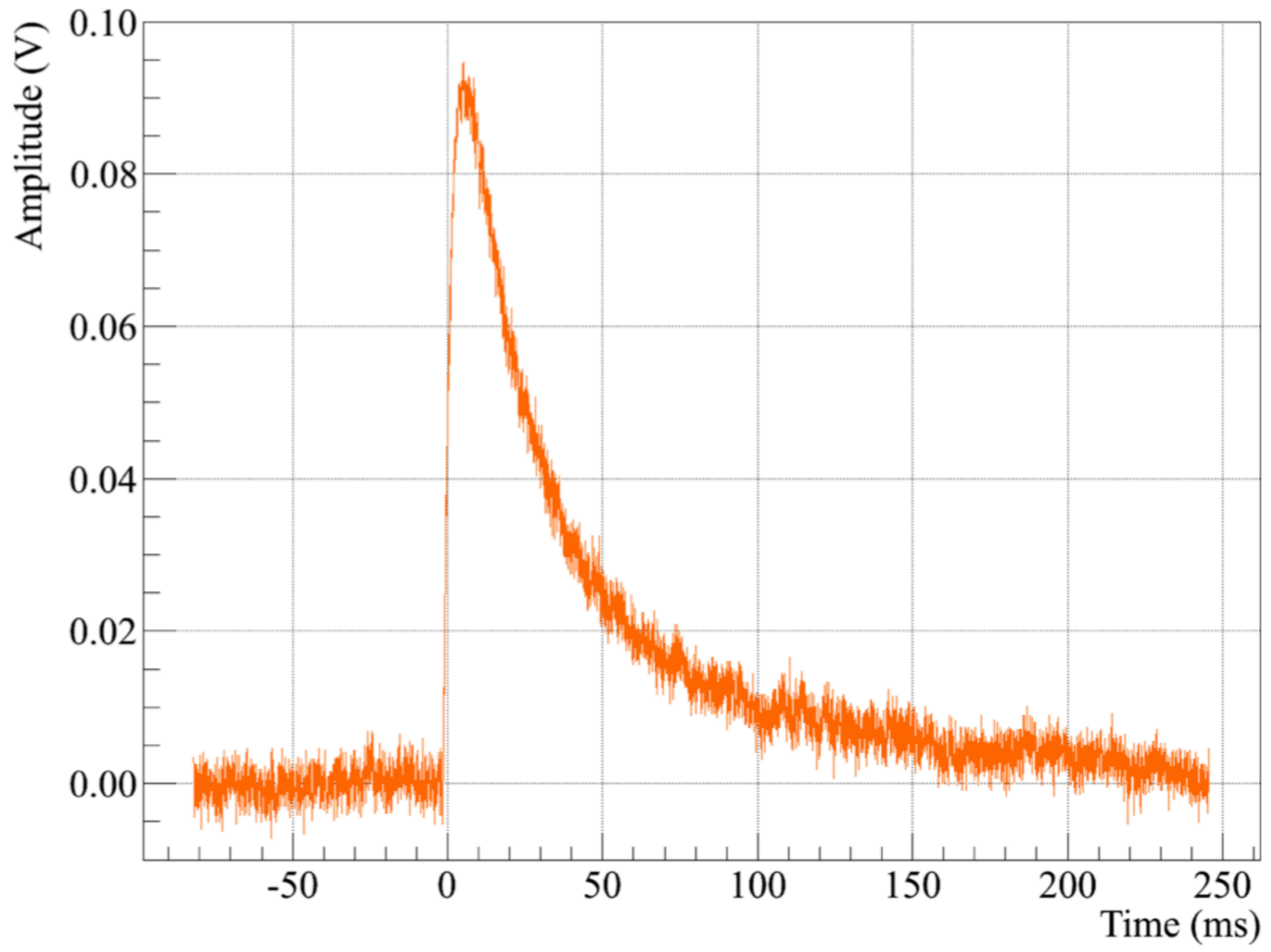
Empty baseline

+



Averaged pulse

=



Simulated pulse

Simulated pulses (of desired energies)
passed through analysis chain

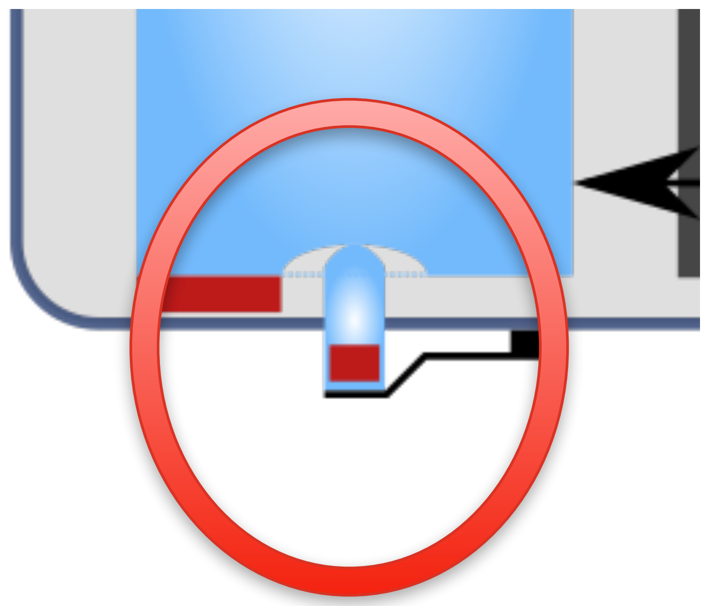
Selection criteria (aka “cuts”)

Rate: Noise conditions

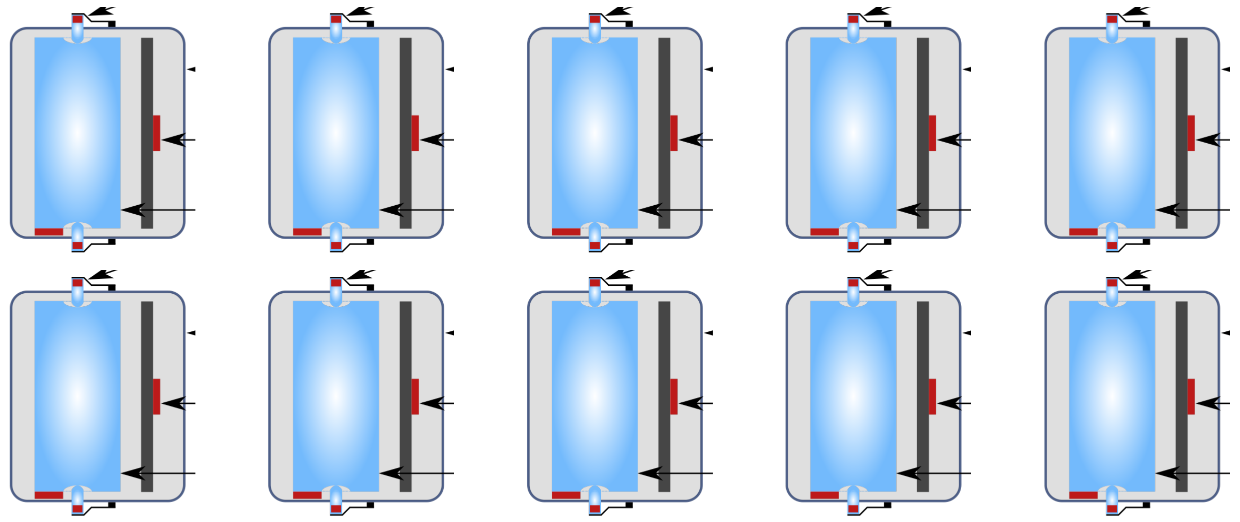
Stability: Detector(s) in operating point

Data quality: Non-standard pulse shapes (in particular iStick events and pileup)

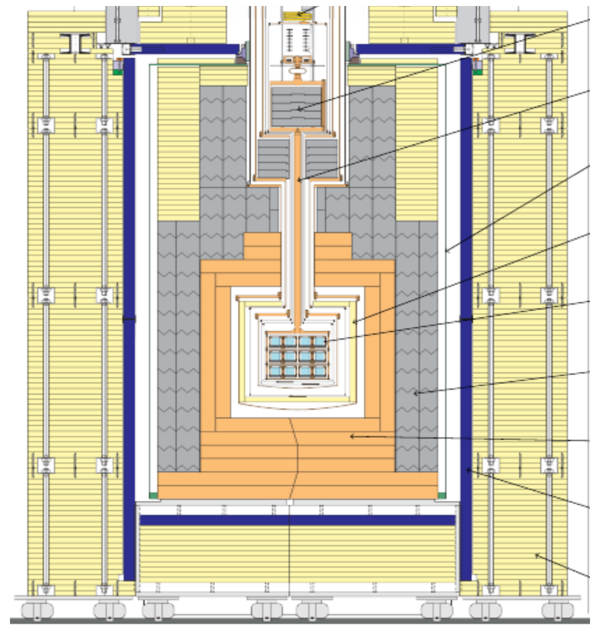
Coincidences: iSticks



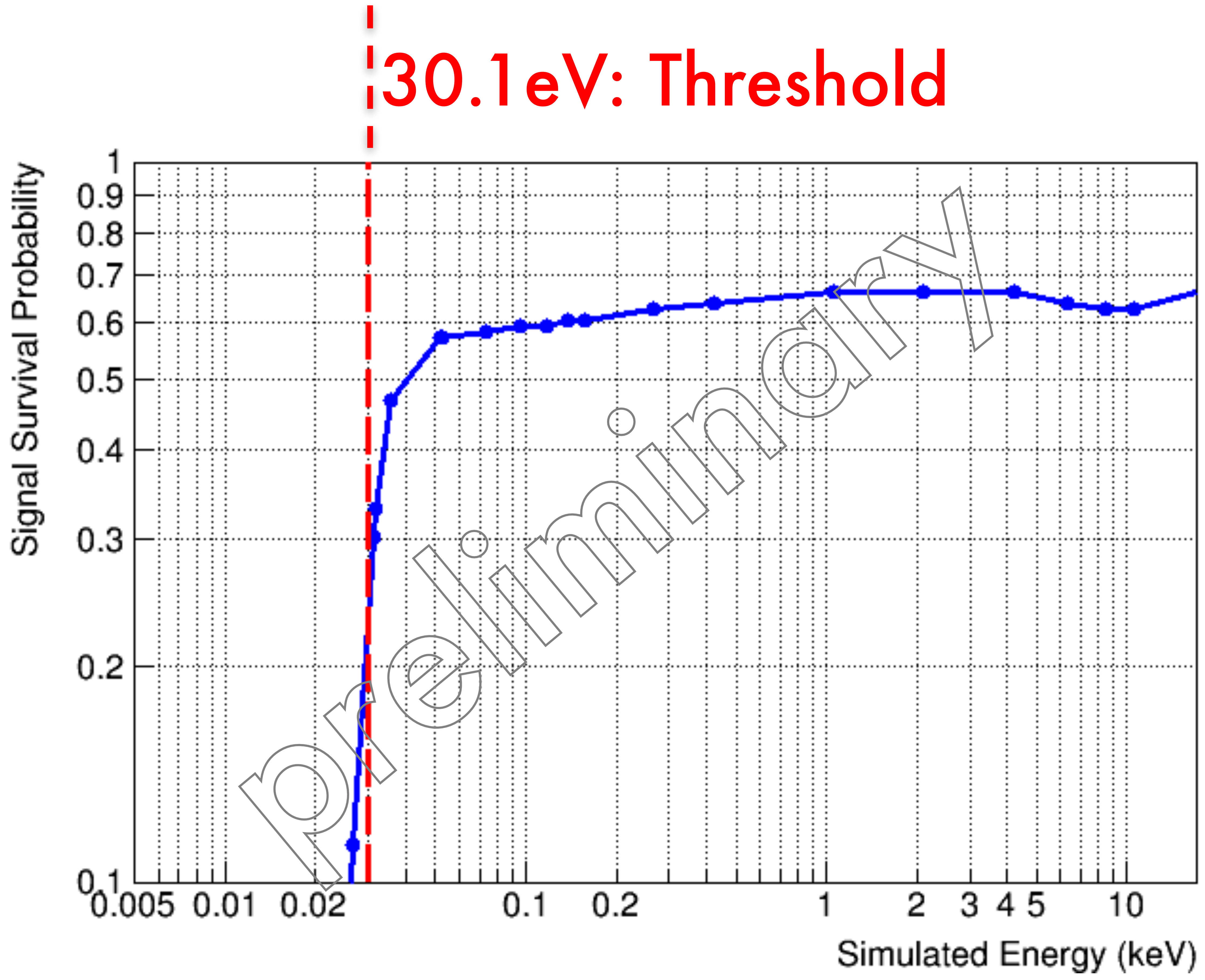
multi-hit events



muon veto



Efficiency

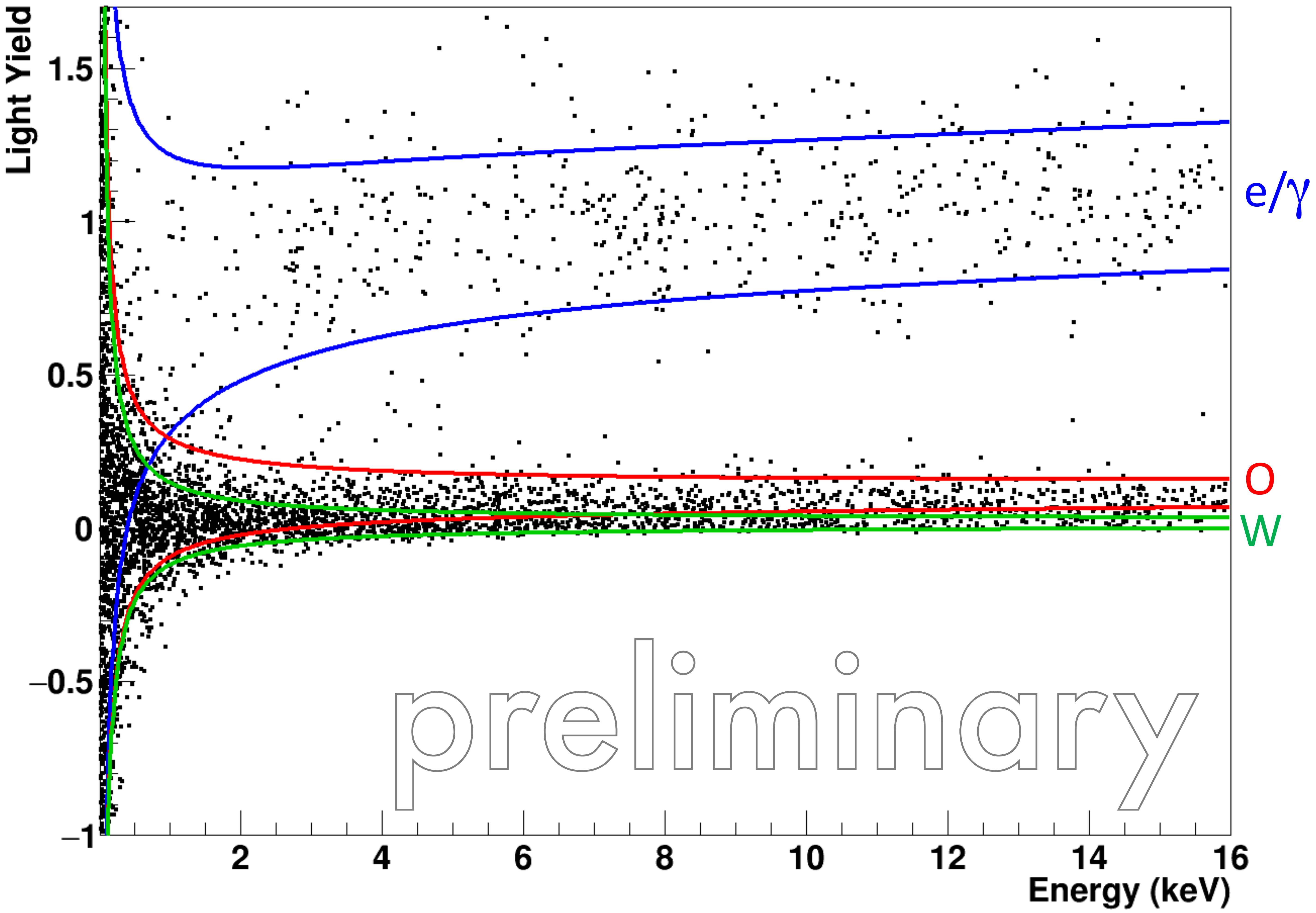


Simulated by artificial pulses placed at random positions in the data stream

Includes trigger and cuts

≳60% efficiency over broad energy range

Neutron calibration data

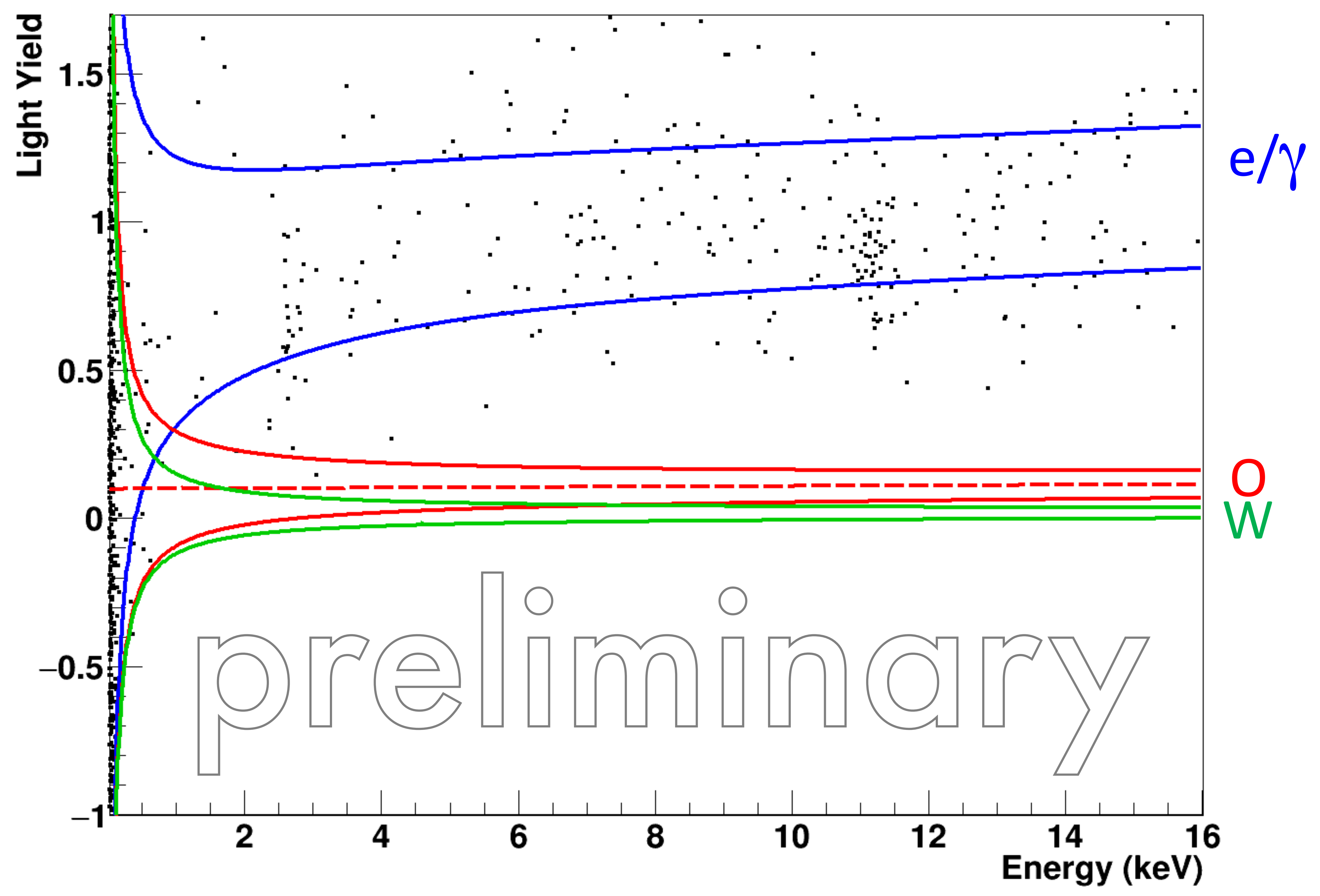


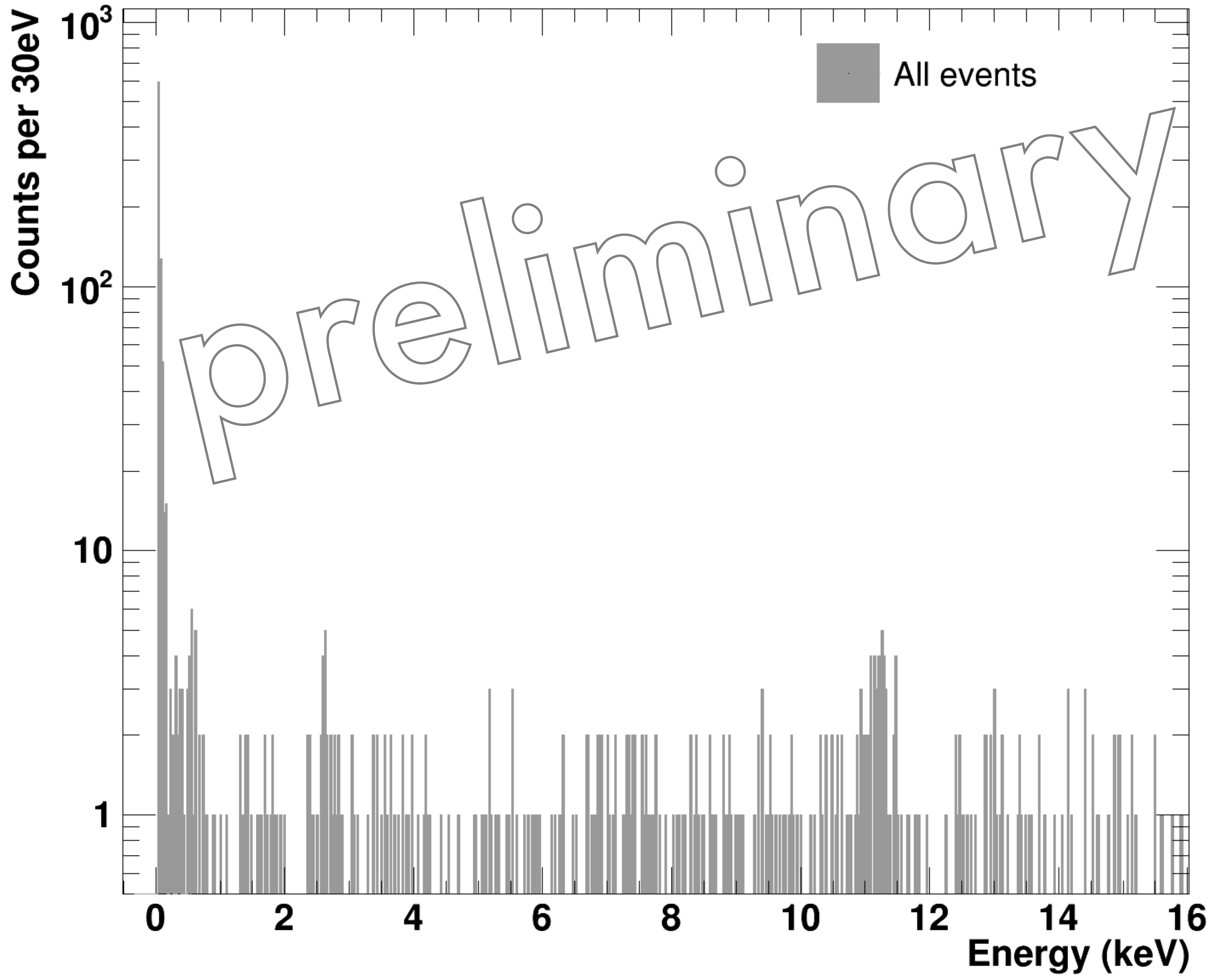
Unbinned maximum likelihood fit

Quenching factors measured with neutron beam

Dark matter data

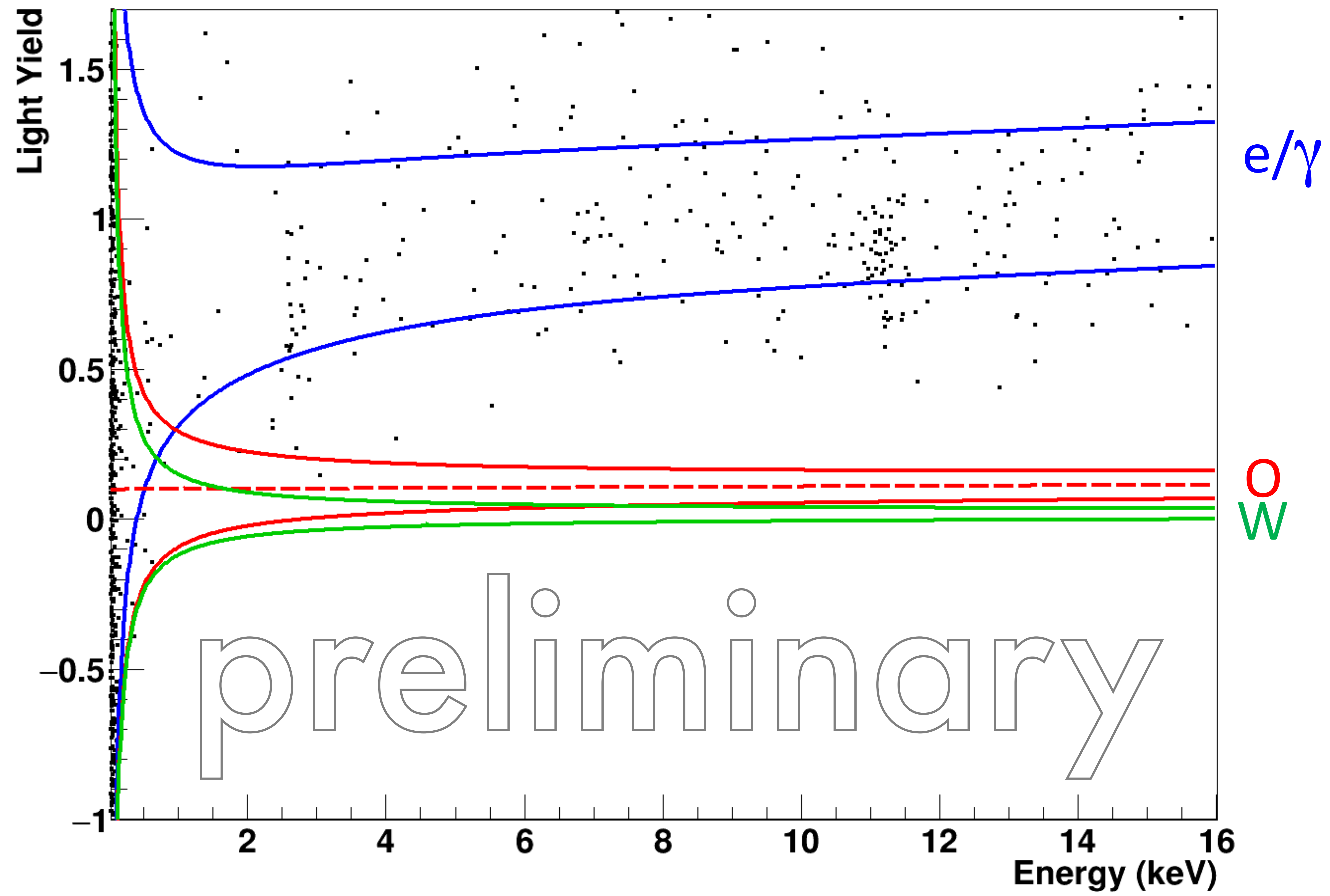
Analysis optimized for very low energies: 30eV → 16keV

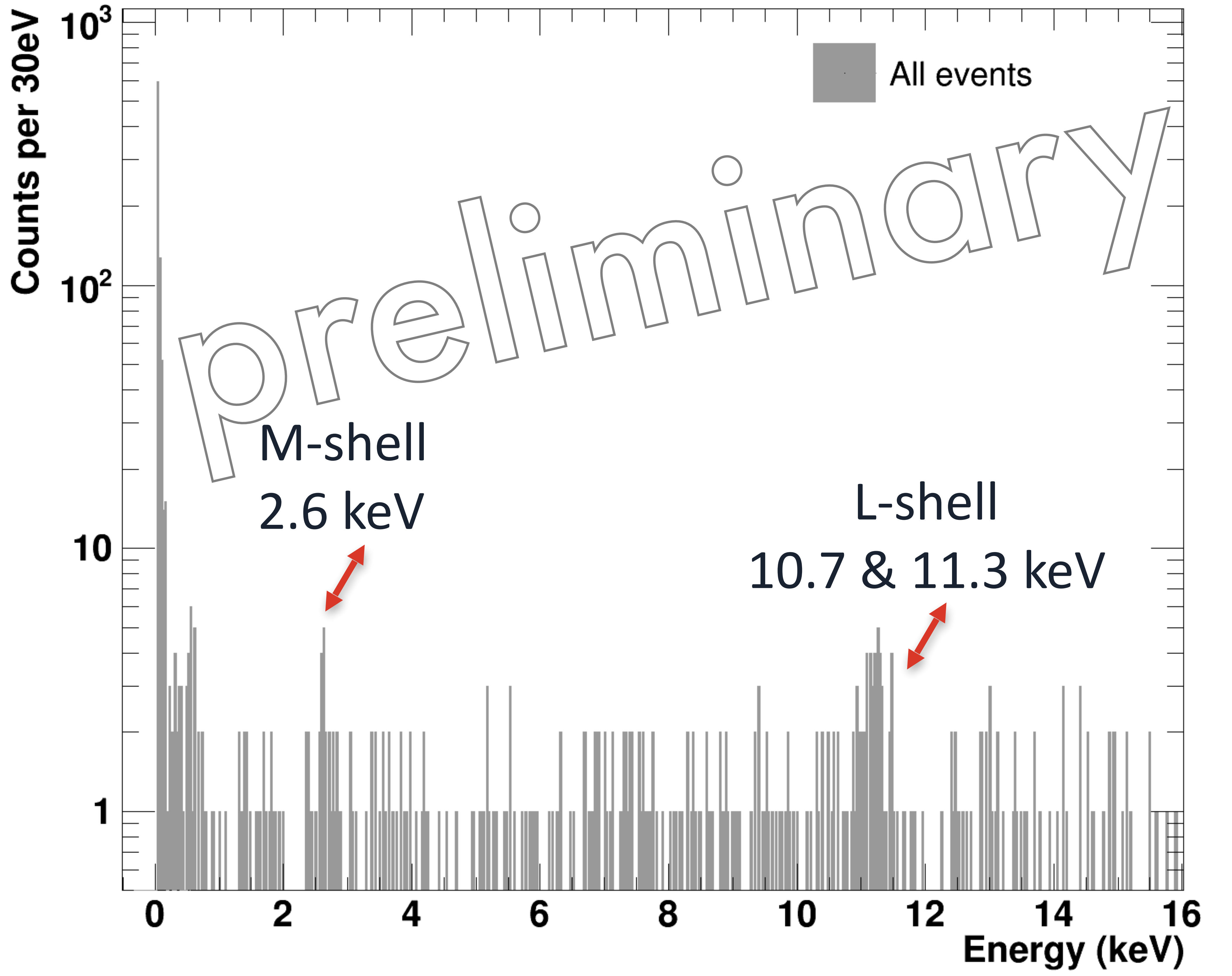




Dark matter data

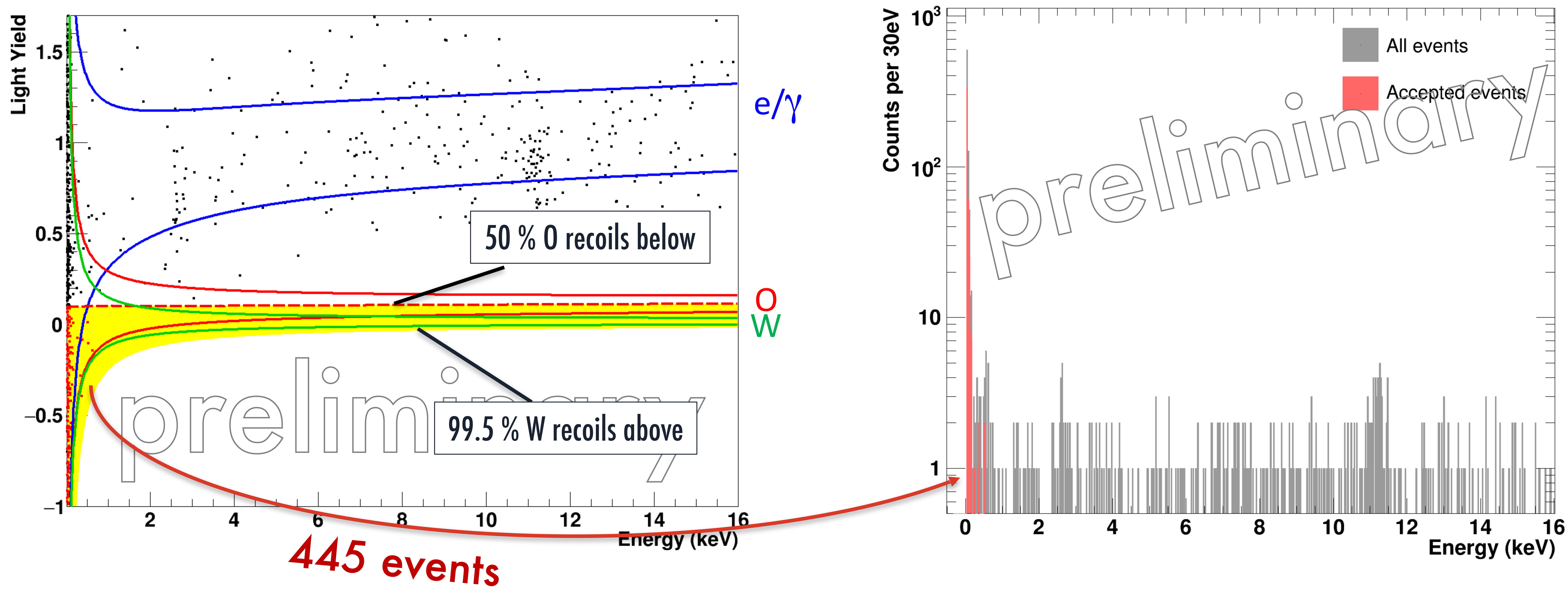
Cosmogenic activation → $^{179}Ta + e^- \rightarrow {}^{179}Hf + \nu_e$ (1.8y)





Dark matter data

Acceptance region fixed before unblinding

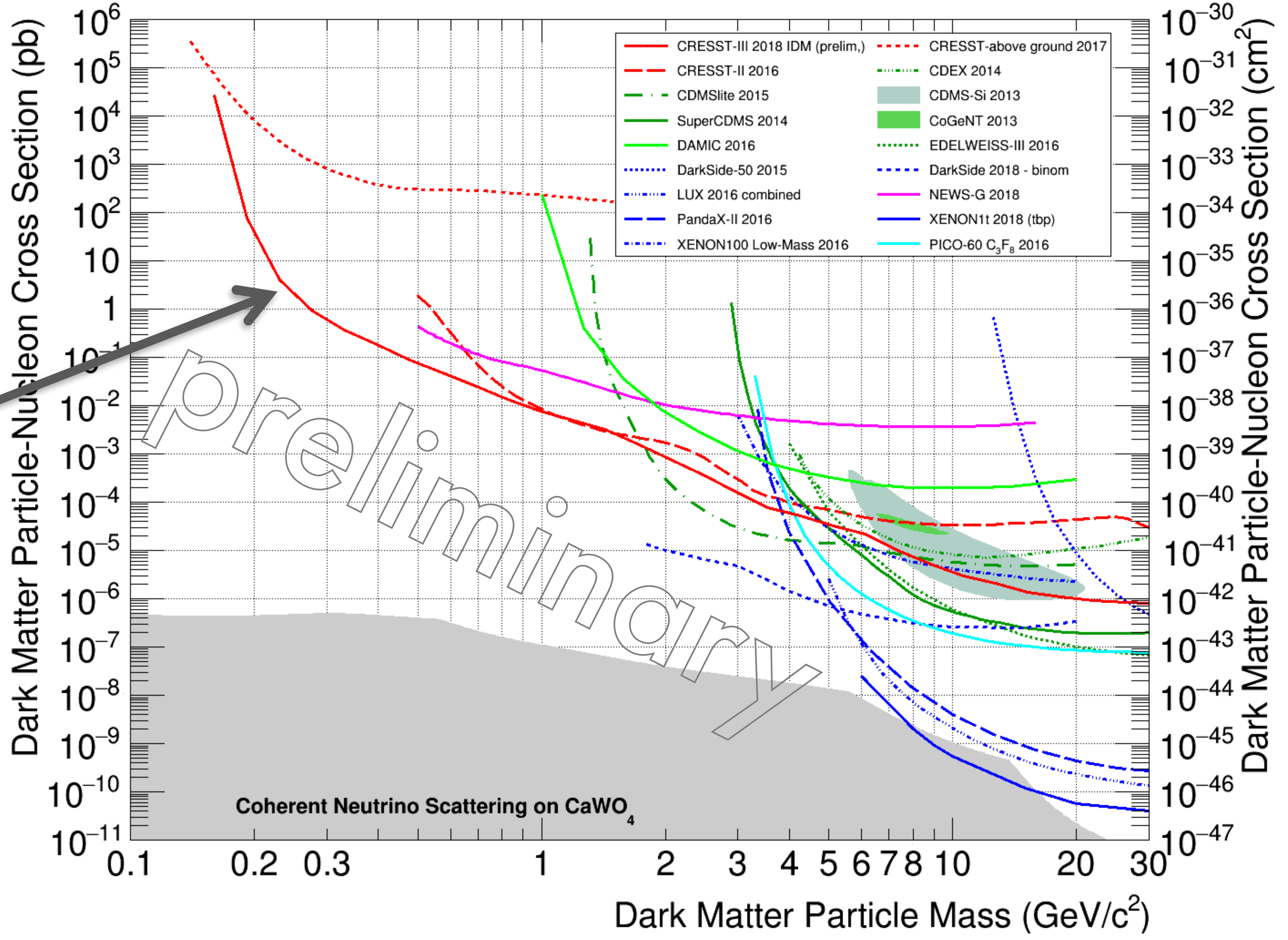


(Preliminary) result

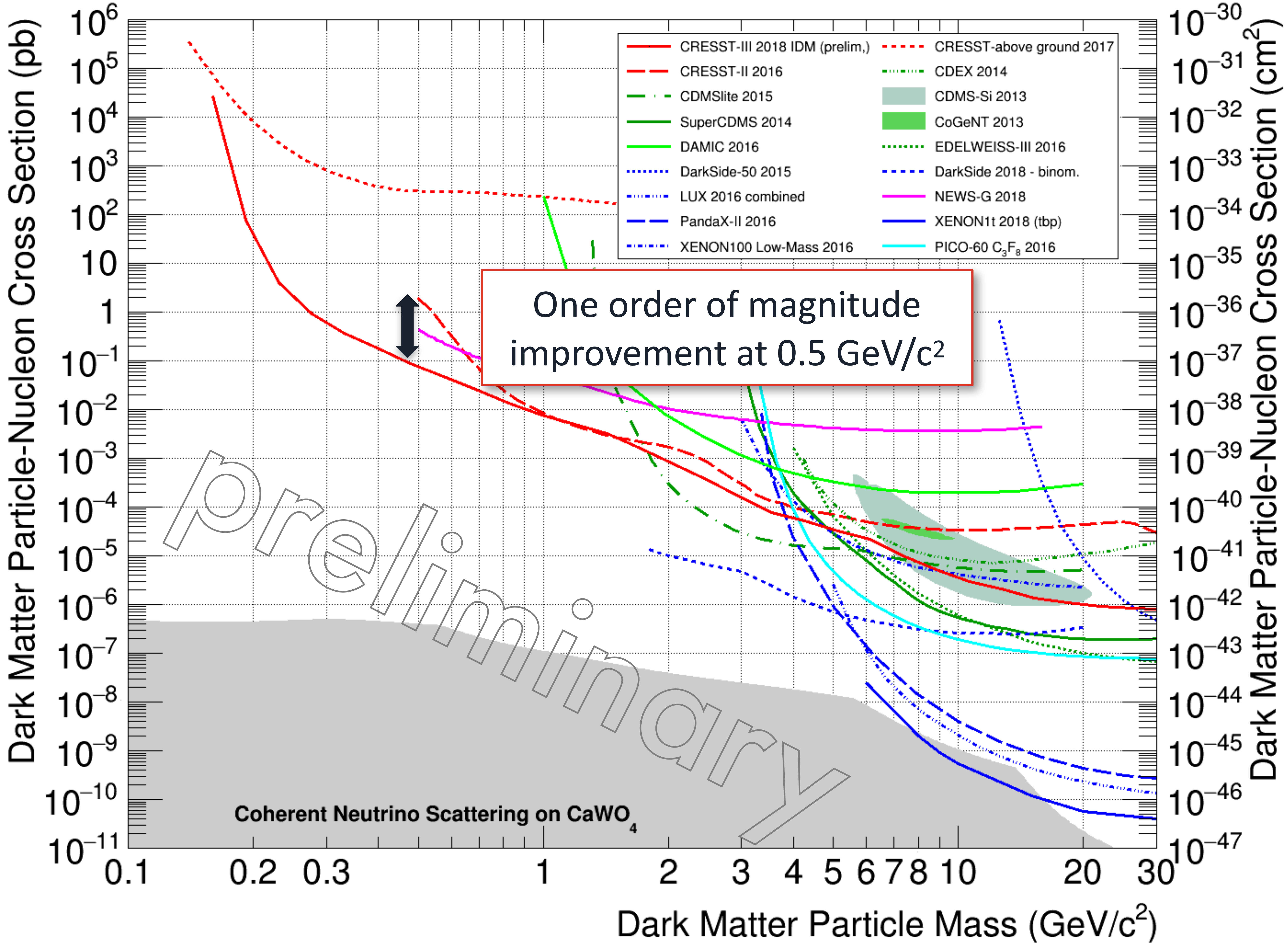
Energy spectrum of accepted events

Yellin 1D optimum interval method

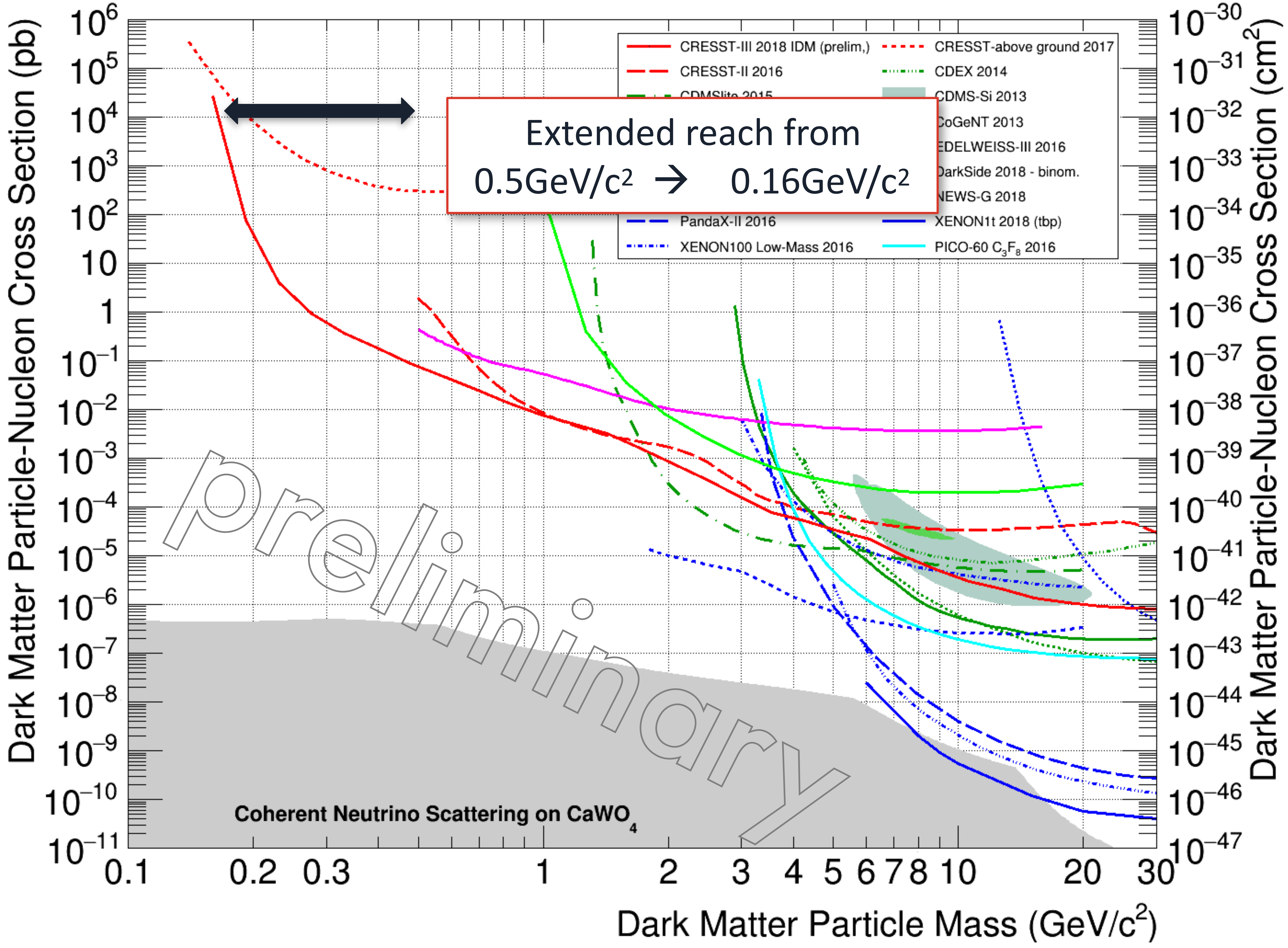
Energy spectrum expected for DM



(Preliminary) Result



(Preliminary) Result



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

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

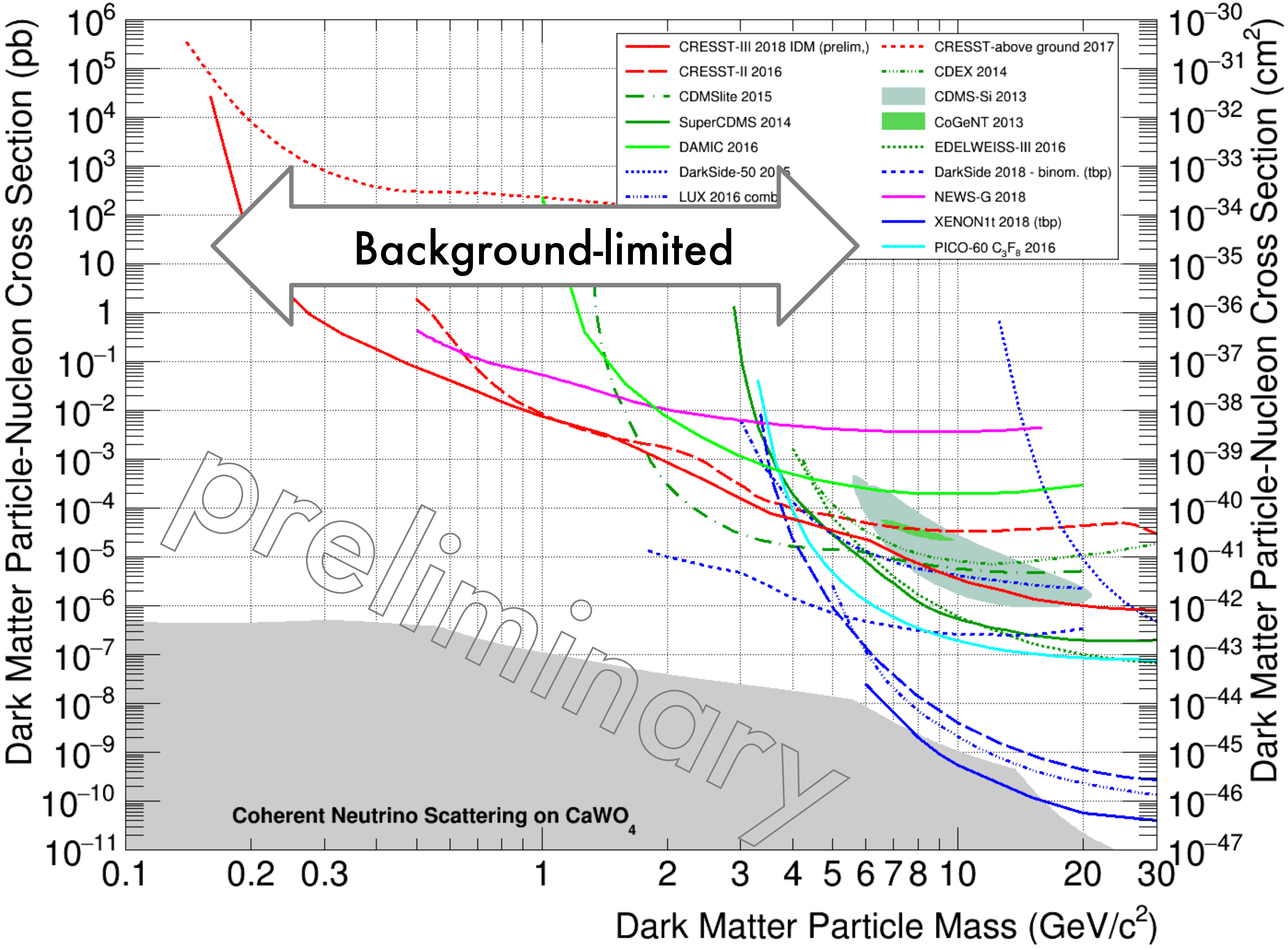
Unprecedented low nuclear recoil thresholds of 30eV

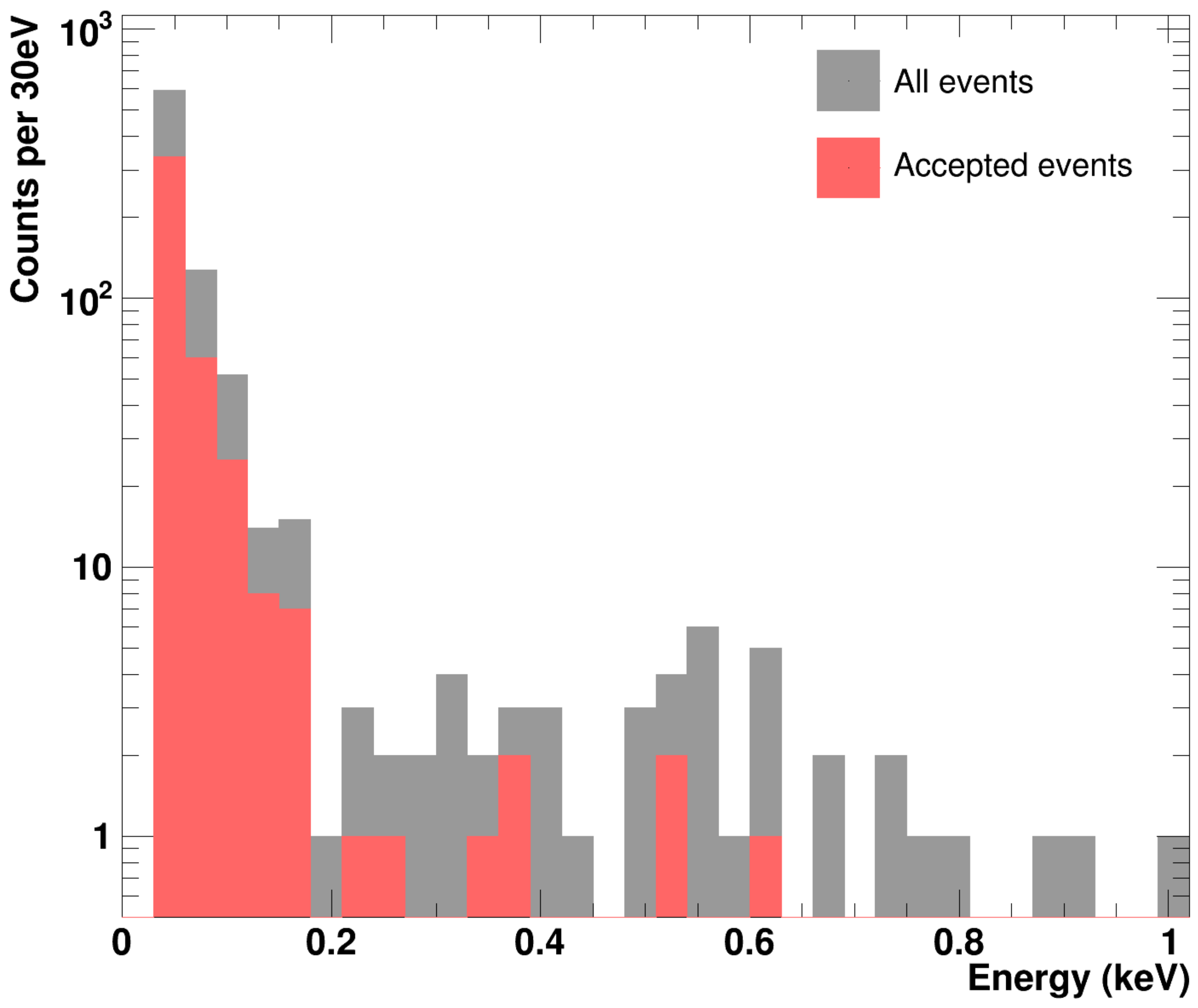
0.4GeV/c^2

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

LUX Migdal

(Preliminary) Result



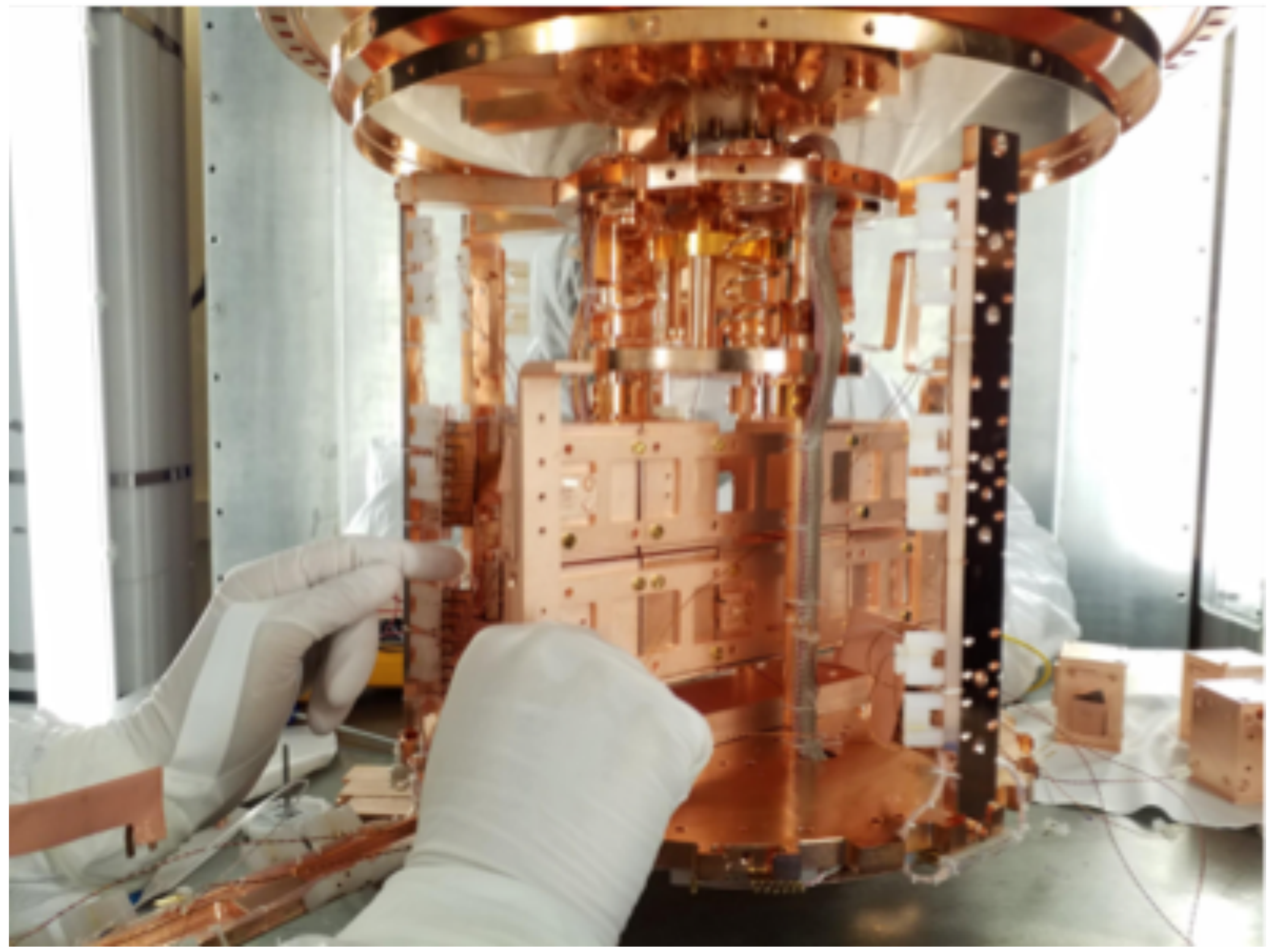


Unexpected rise of event rate < 200eV

Second CRESST-III run: Just starting

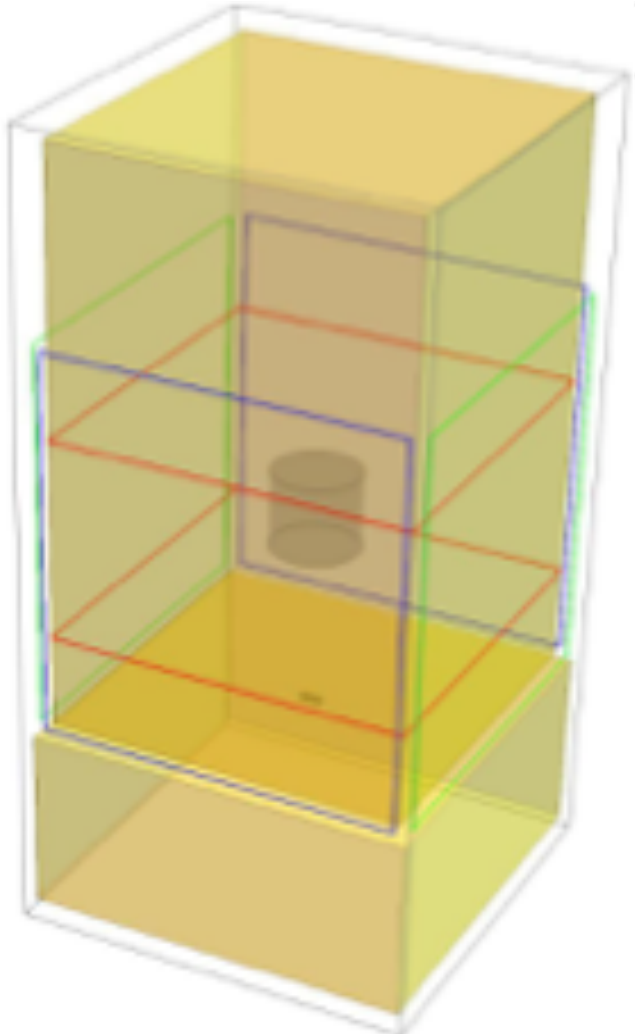
Key innovation

Upgraded detector modules
with dedicated hardware
changes to understand
backgrounds



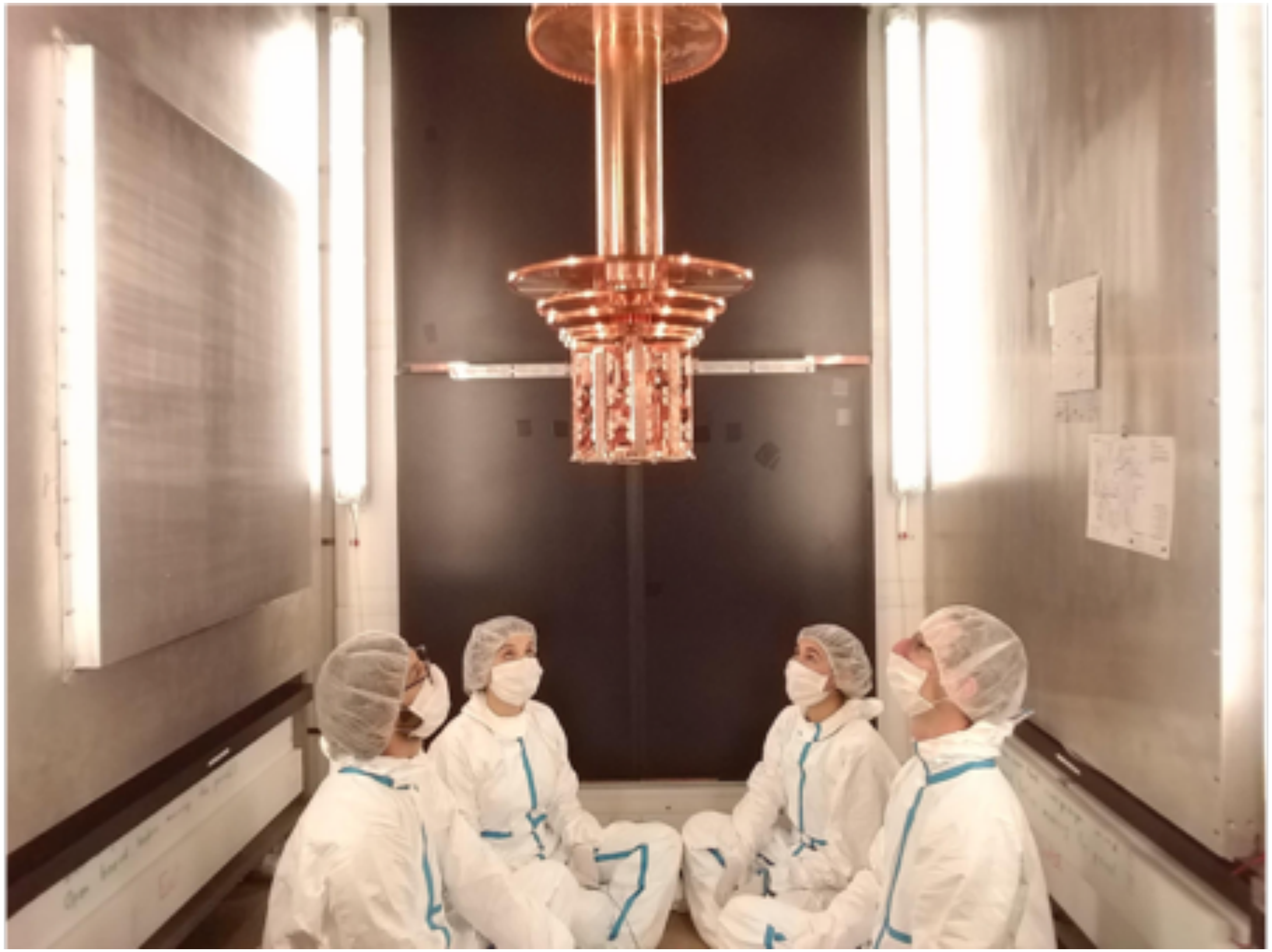
New feature

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



Waiting for dark matter

New Run in commissioning phase



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New frontiers. New potential. New challenges…