Results on Light Dark Matter investigation with CRESST-III

Luca Pattavina
Technical University of Munich
INFN - Gran Sasso Laboratories

luca.pattavina@lngs.infn.it

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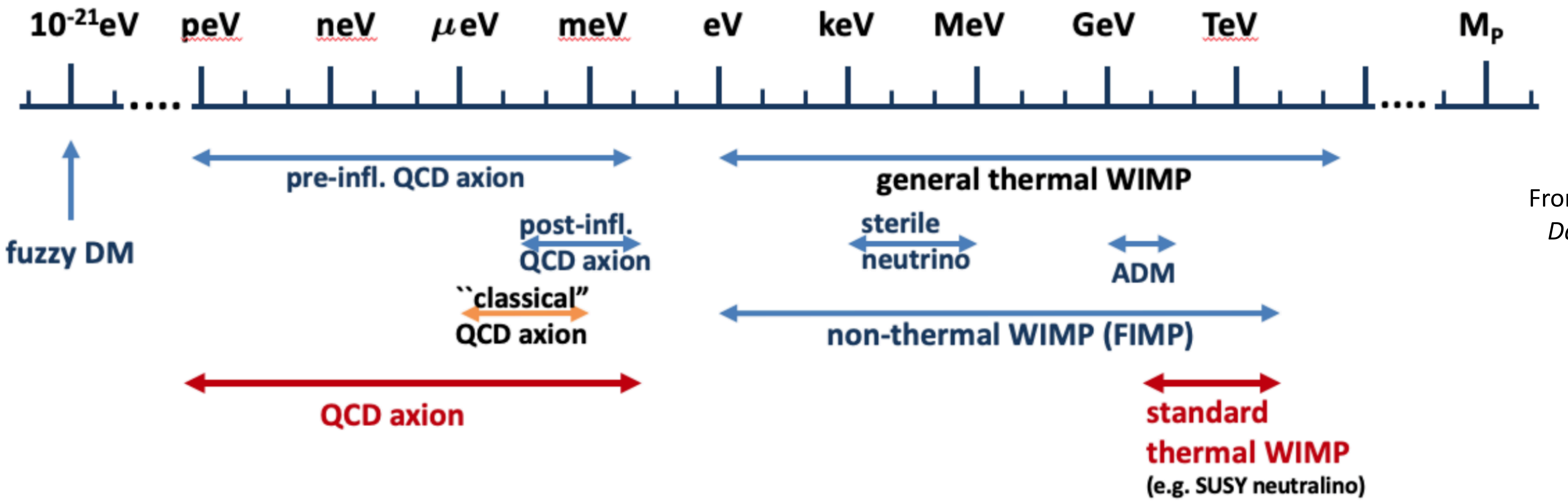
VIRTUAL EDITION

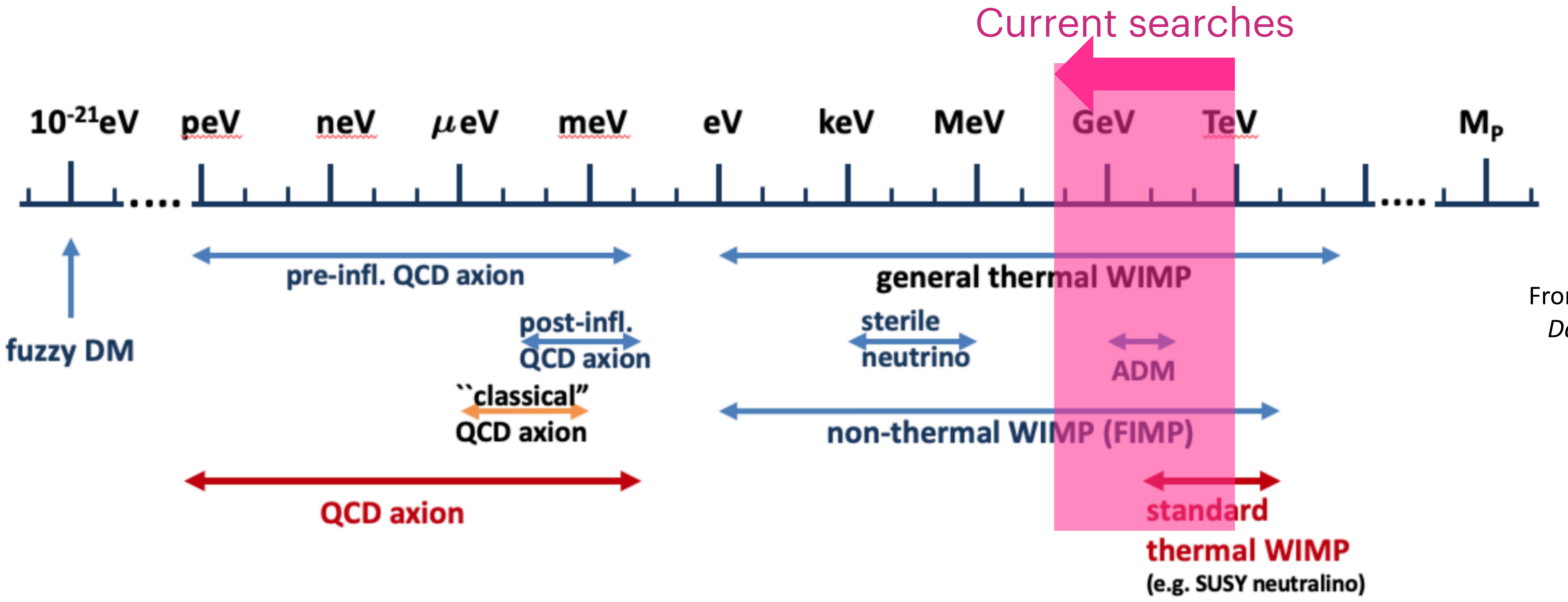
Dark Matter



From: *Direct Detection of Dark Matter - APPEC Committee Report* arXiv:2104.07634

Great variety of theoretical motivated dark matter particle candidates with a wide range of mass and cross section.

Dark Matter



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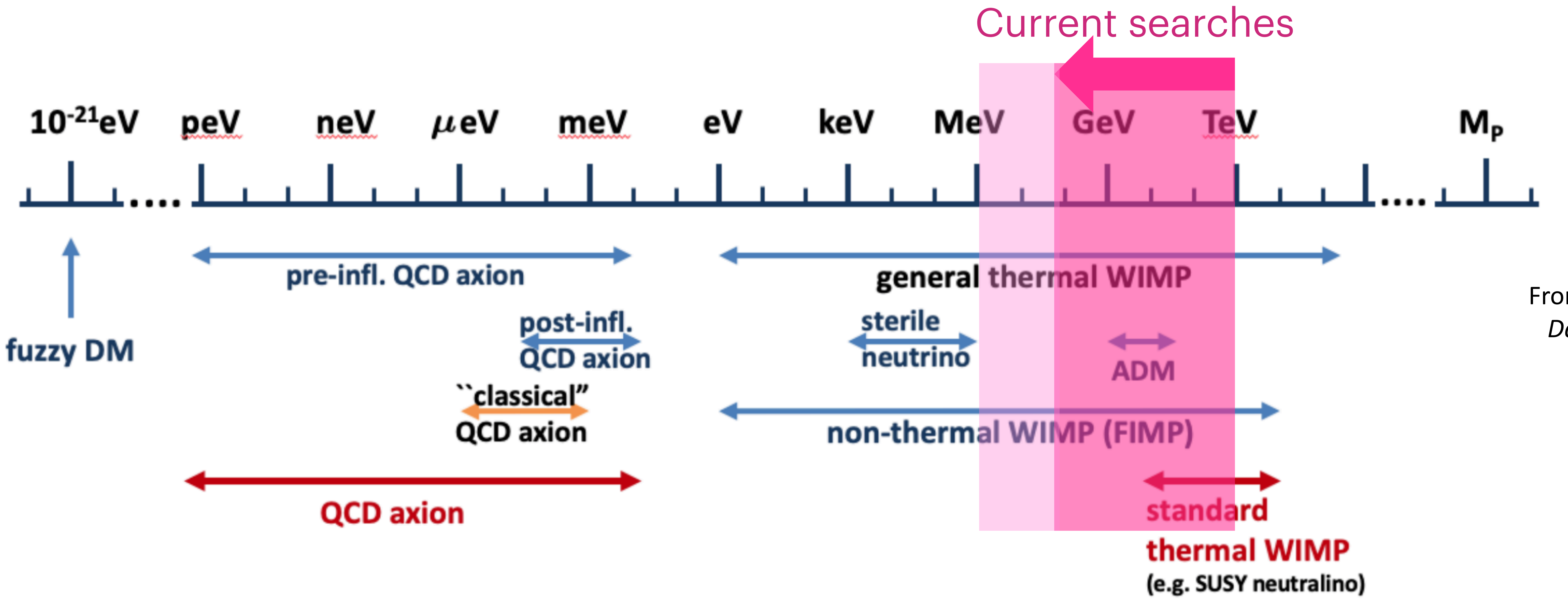

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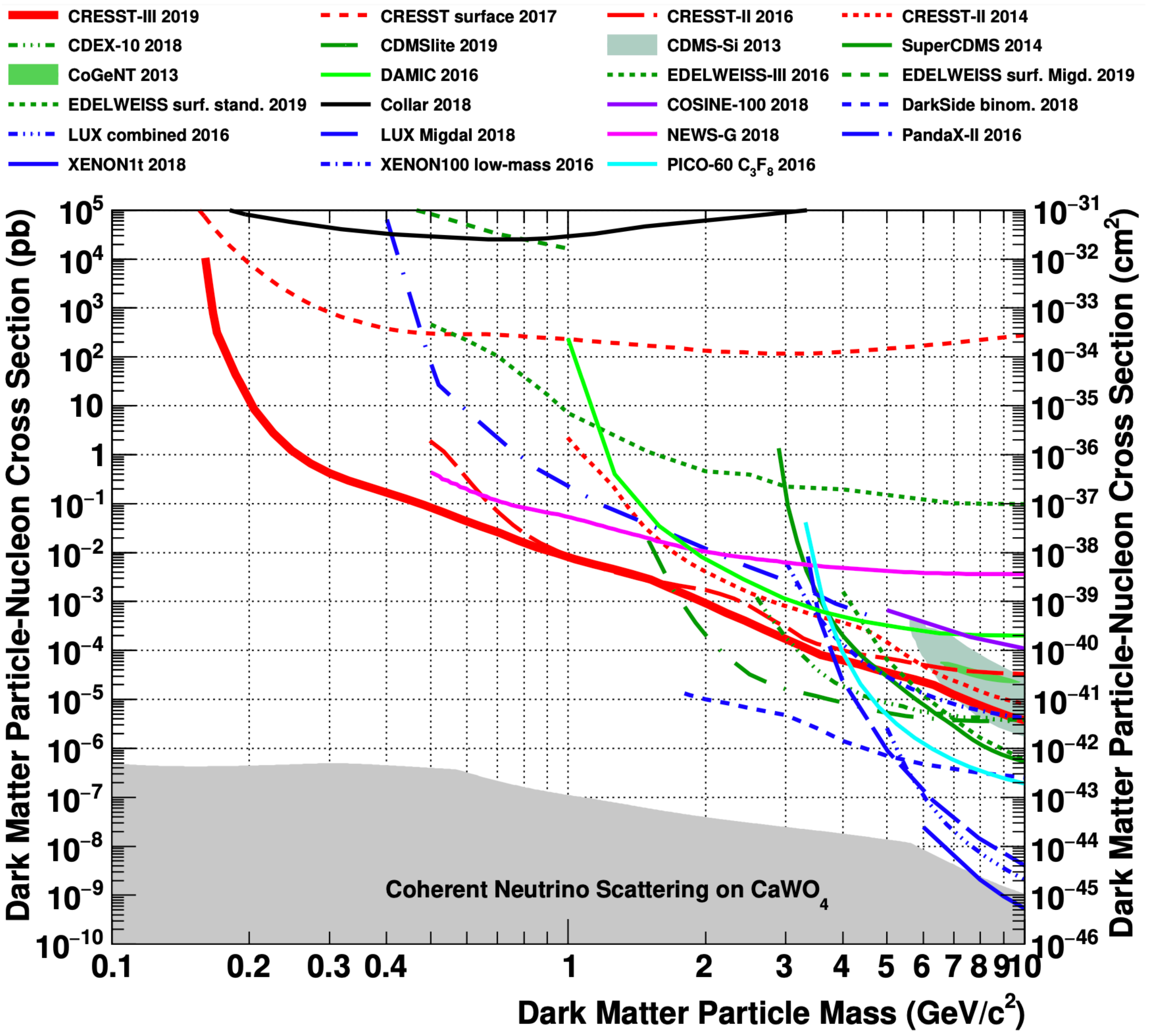
Great variety of theoretical motivated dark matter particle candidates with a wide range of mass and cross section.

Direct Dark Matter searches

Several different experiments with different technologies



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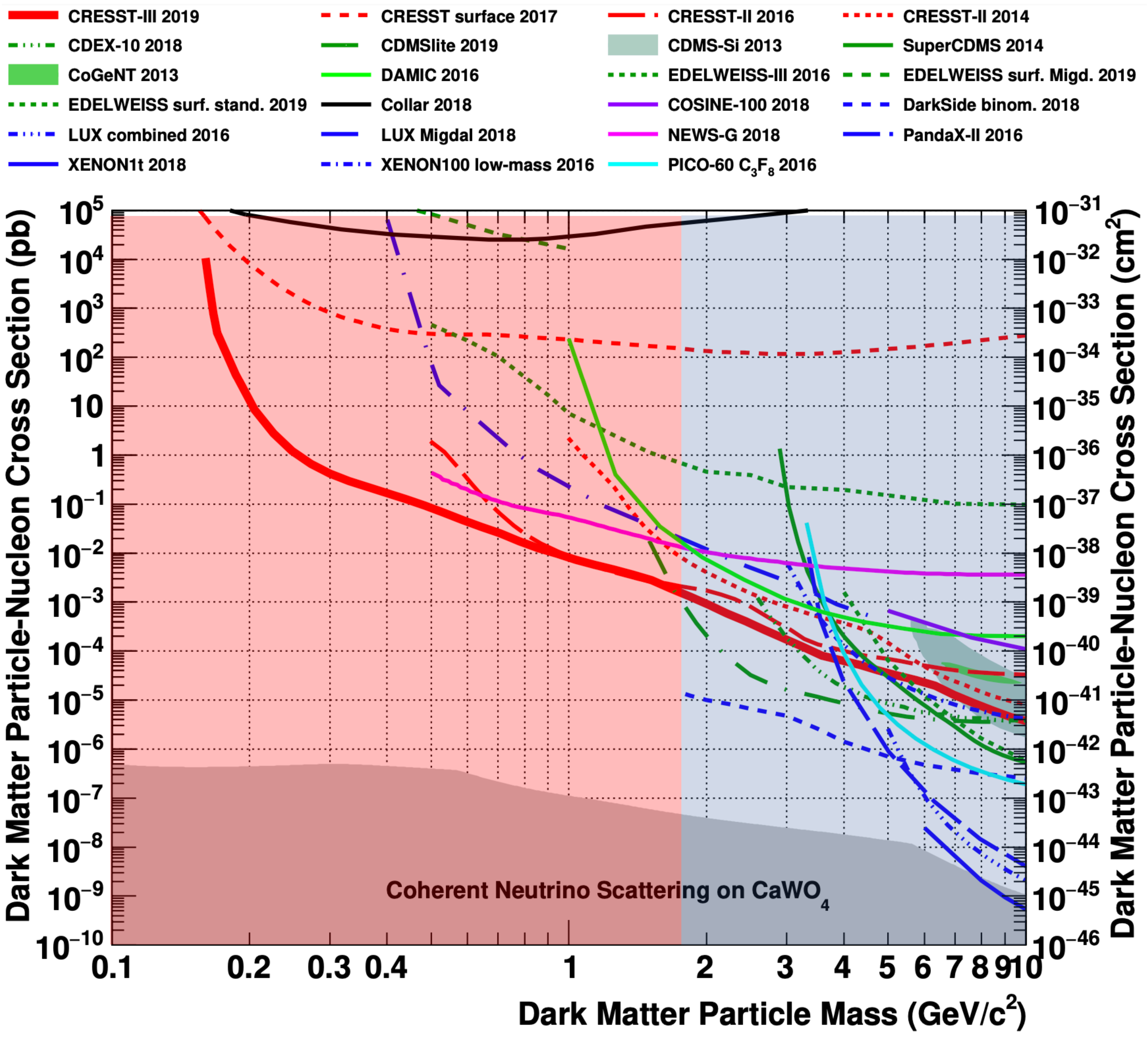
Direct Dark Matter searches

Several different experiments with different technologies

The sensitivity is dominated by:

Noble liquids TPCs:
M_{DM} > few GeV

Cryogenic detectors:
M_{DM} < few GeV



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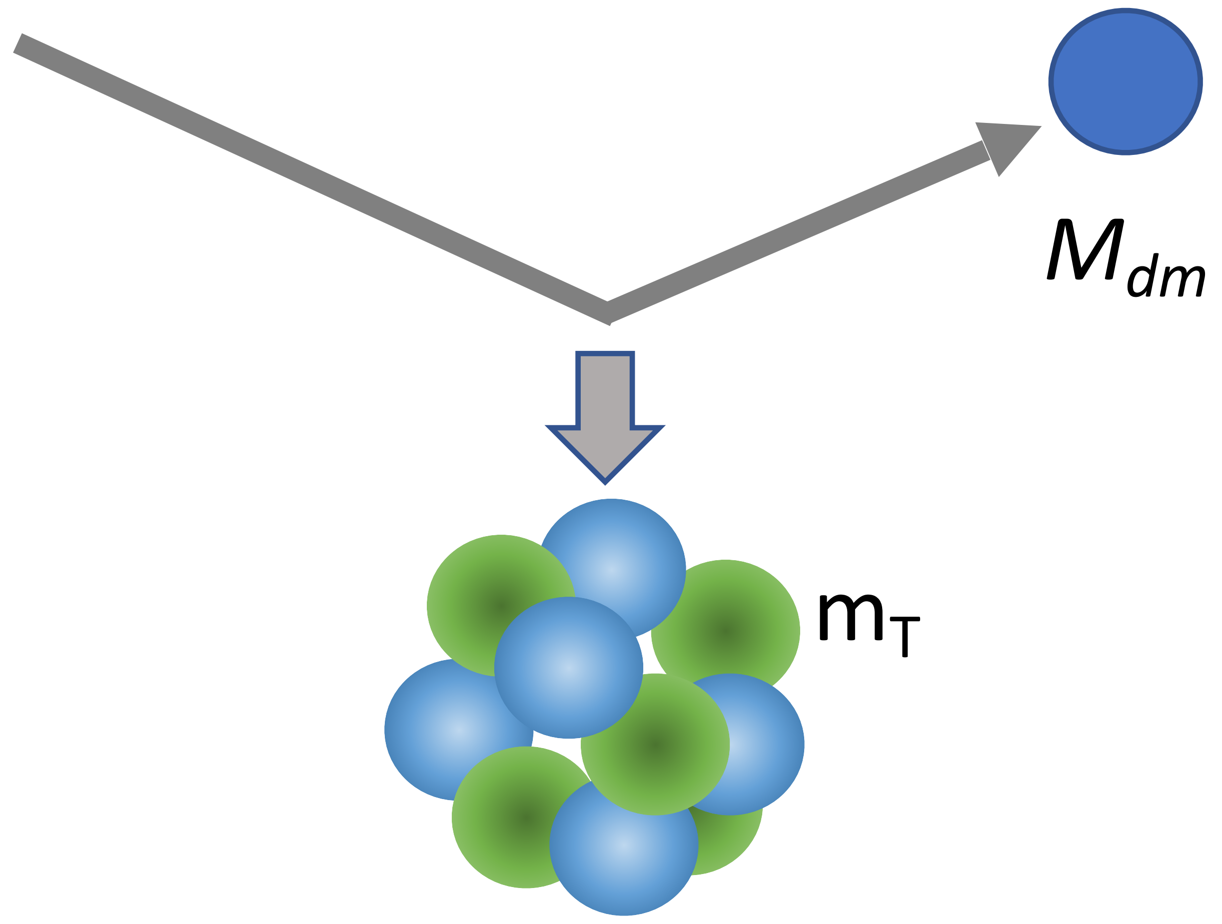
Direct DM detection on Earth

Assumptions on DM interaction:

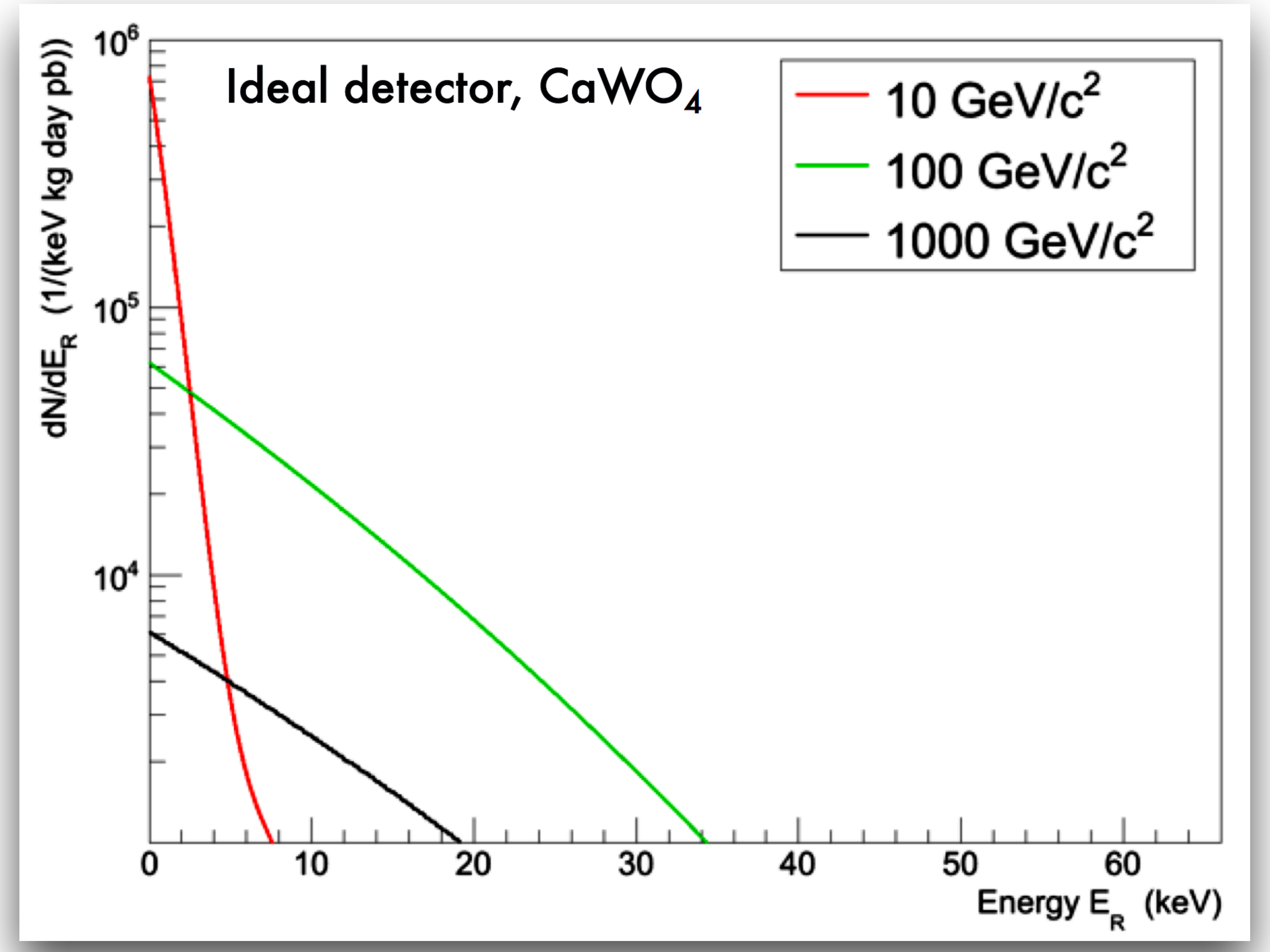
- Scattering off nuclei
- Elastically and coherently
- Spin independently



Expected signal (nuclear recoil rate) :

$$\frac{dR}{dE_R} = N_T \cdot \frac{\rho_{dm}}{M_{dm}} \int dv \, v \frac{d\sigma}{dE_R}(v, E_R)$$

σ	DM-nucleus cross section
ρ_{dm}	DM density
N_T	Number of target nuclei
M_{dm}	Mass of the DM particle
v	Velocity of the DM particle
E_R	Nuclear recoil energy

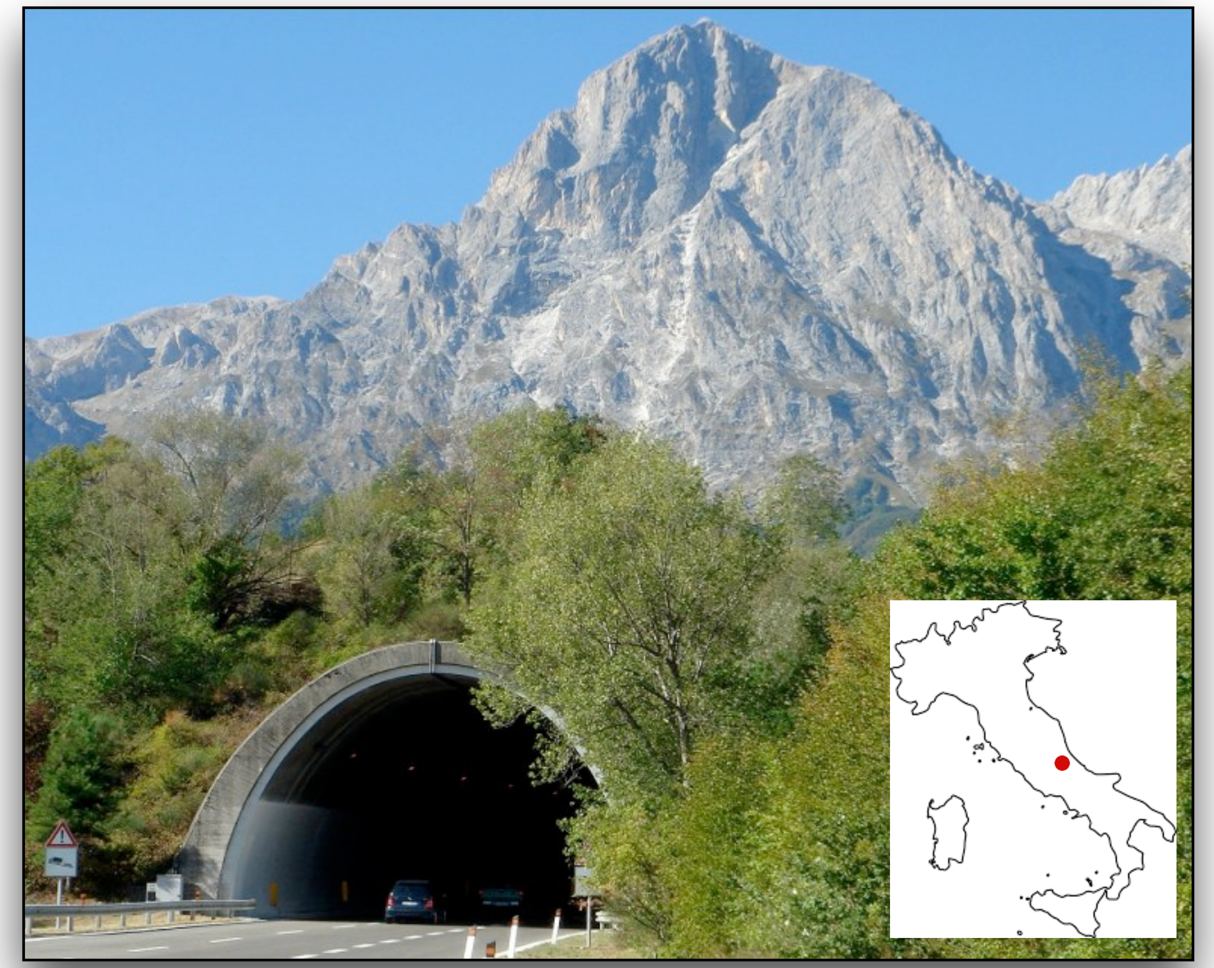


Signal features :

- Low energy nuclear recoil
- Low interaction rate
- Overwhelming background (natural radioactivity & cosmic rays)

CRESST underground

Deep underground laboratories of Gran Sasso



Mountain coverage :

Average depth ~ 3600 m w.e.

Muon flux ~ 2.6×10^{-8} μ/s/cm^2

Neutrons < 10 MeV: $<10^{-6}$ n/s/cm^2

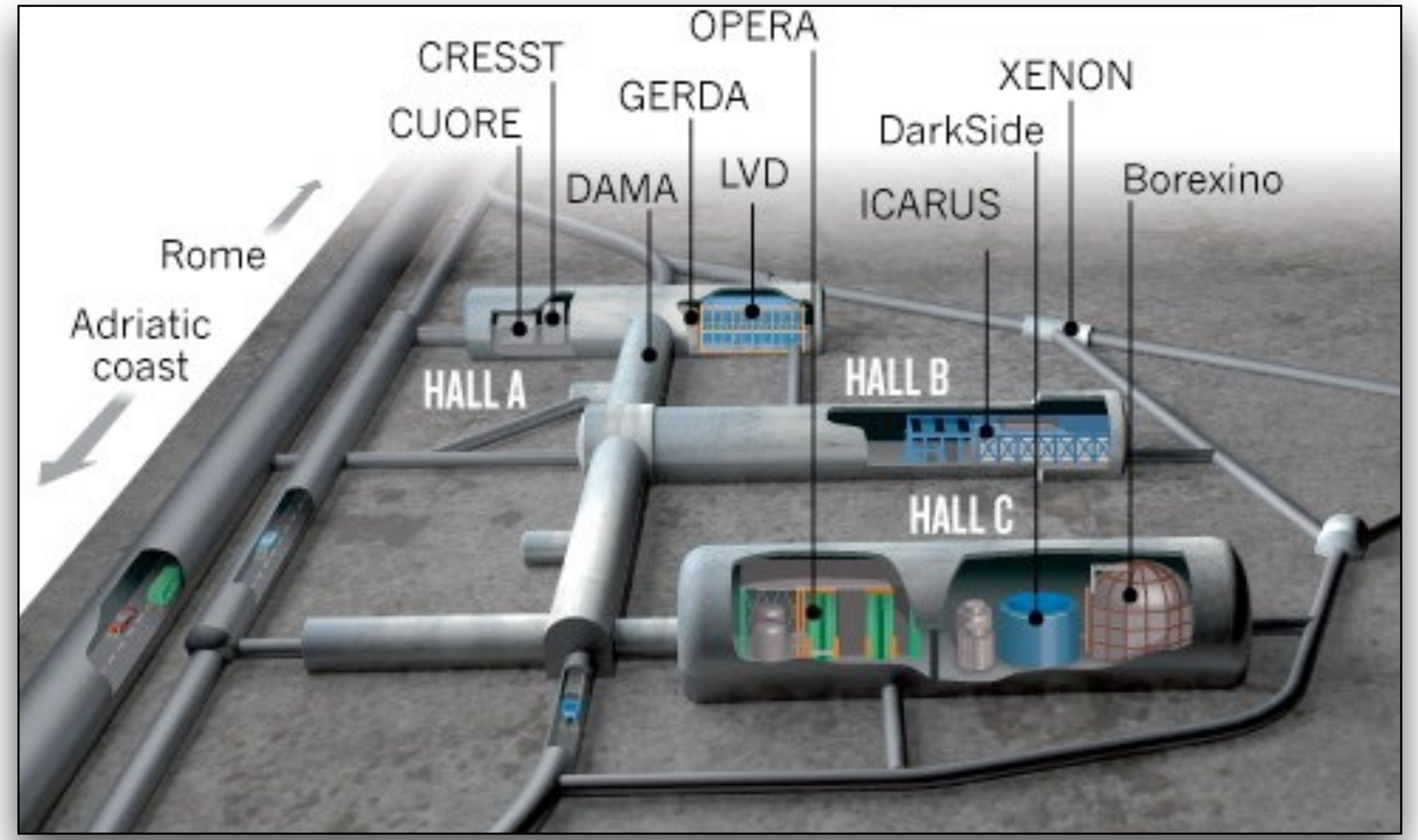
+

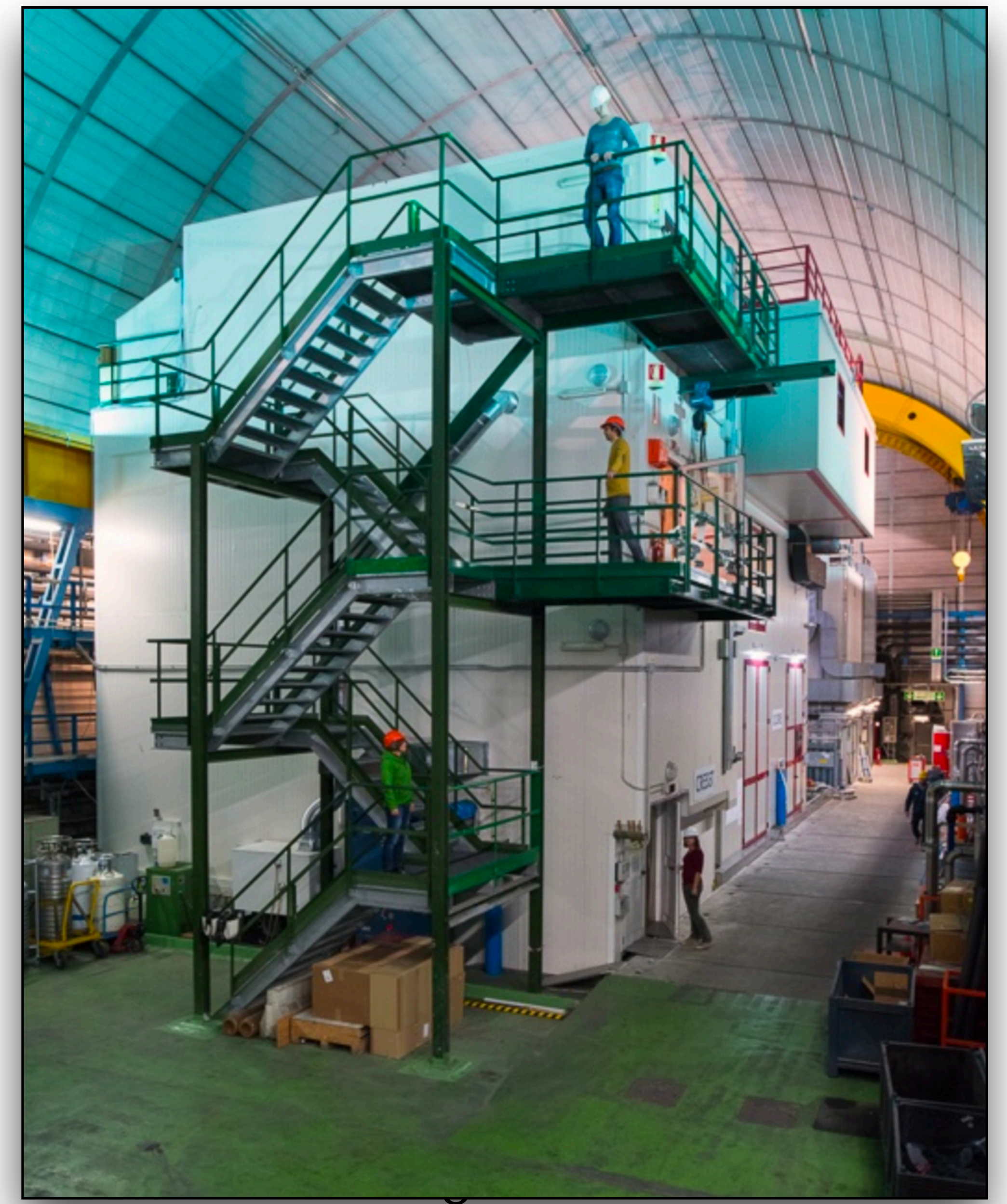
Detector shieldings :

Muon-veto

Gamma shields: Pb + Cu

Neutron moderator: PE (45 + 5) cm





CRESST detectors

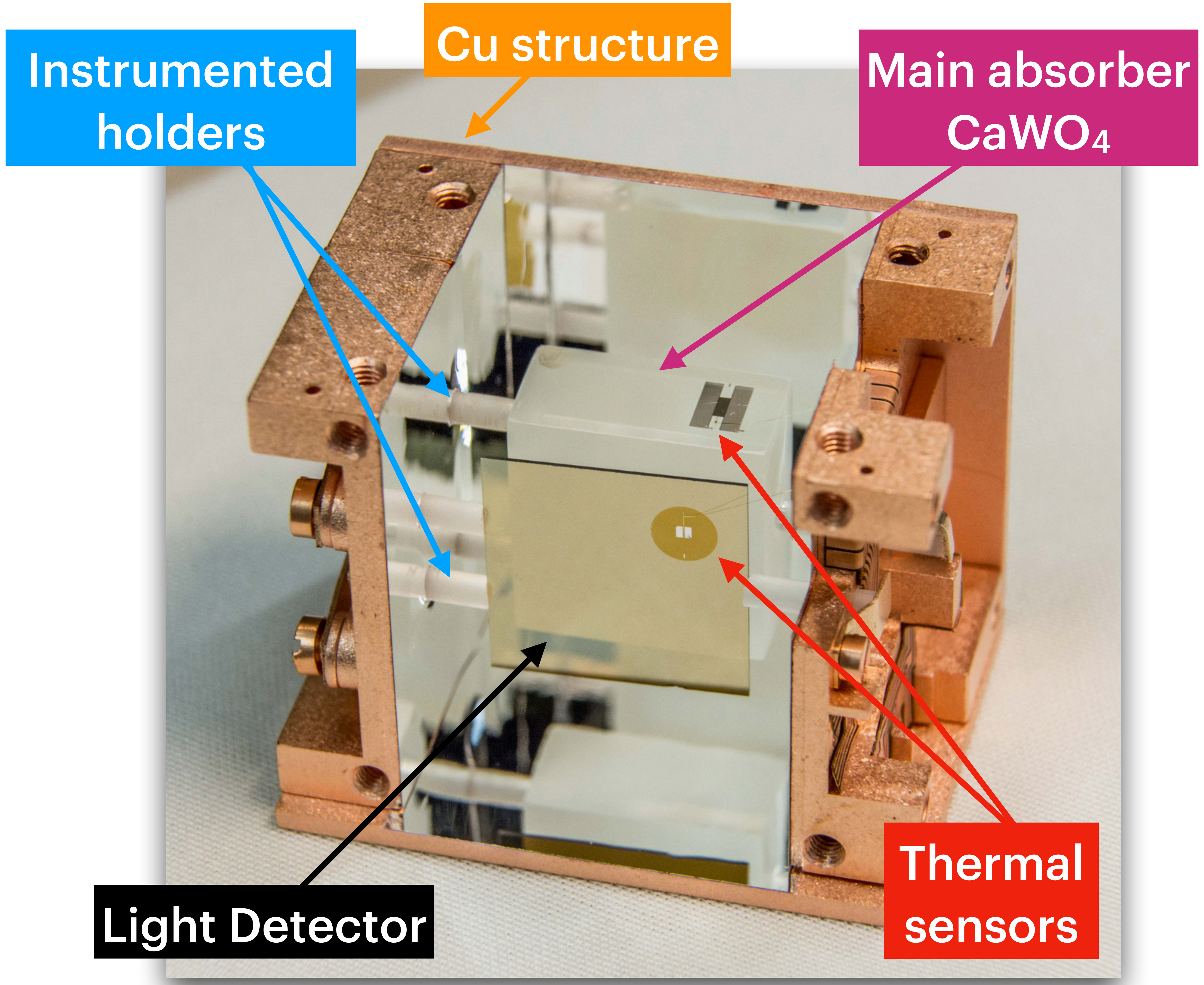
Cryogenic Rare Event Search with Superconducting Thermometers

$CaWO_4$ target crystals (24 g each)

Detector operated as: **cryogenic calorimeters @** 10 mK

Double read-out cryogenic detector:
heat ($CaWO_4$) and **light** (LD - Light Detector)

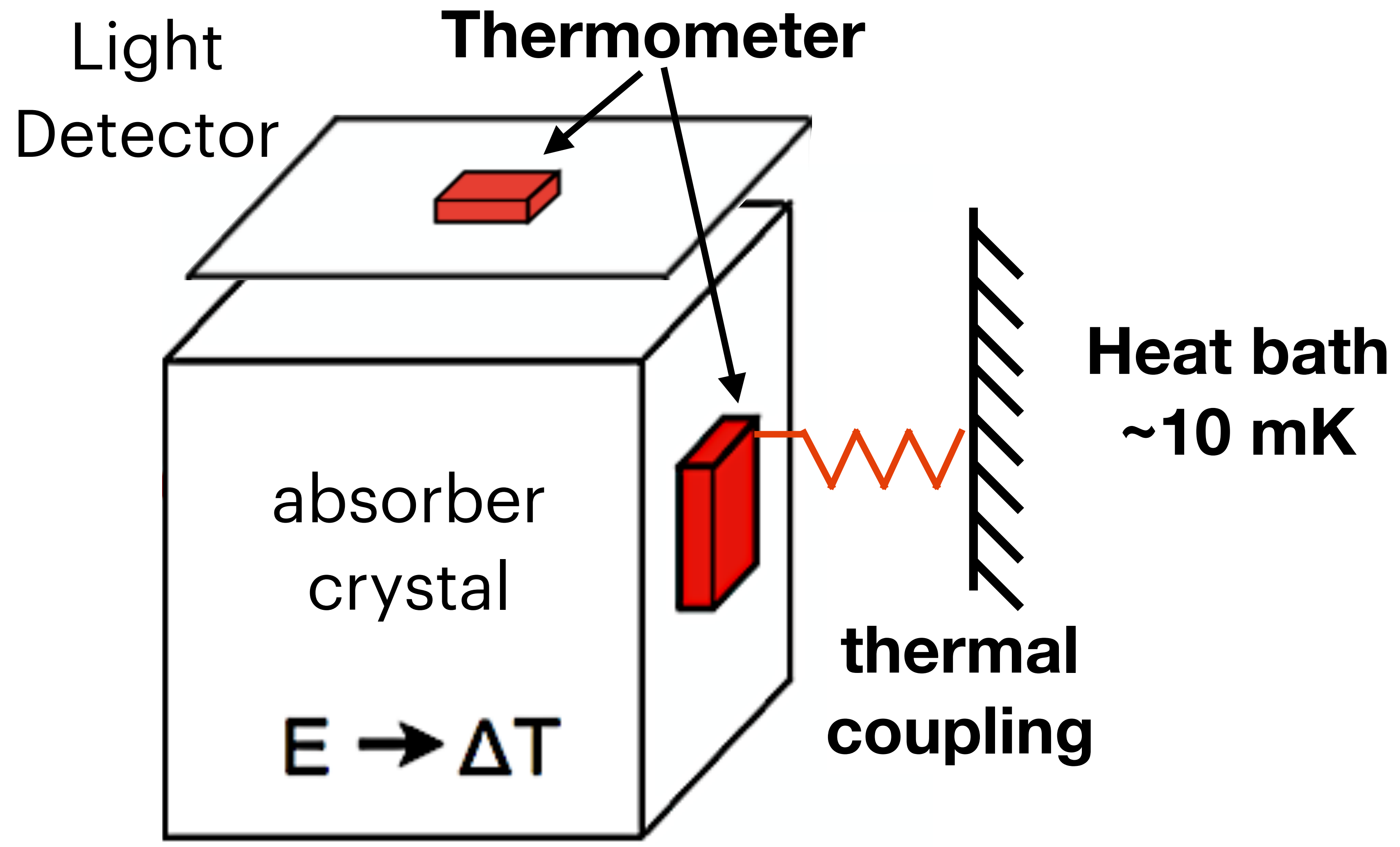
Temperature read-out with **Transition Edge Sensor**



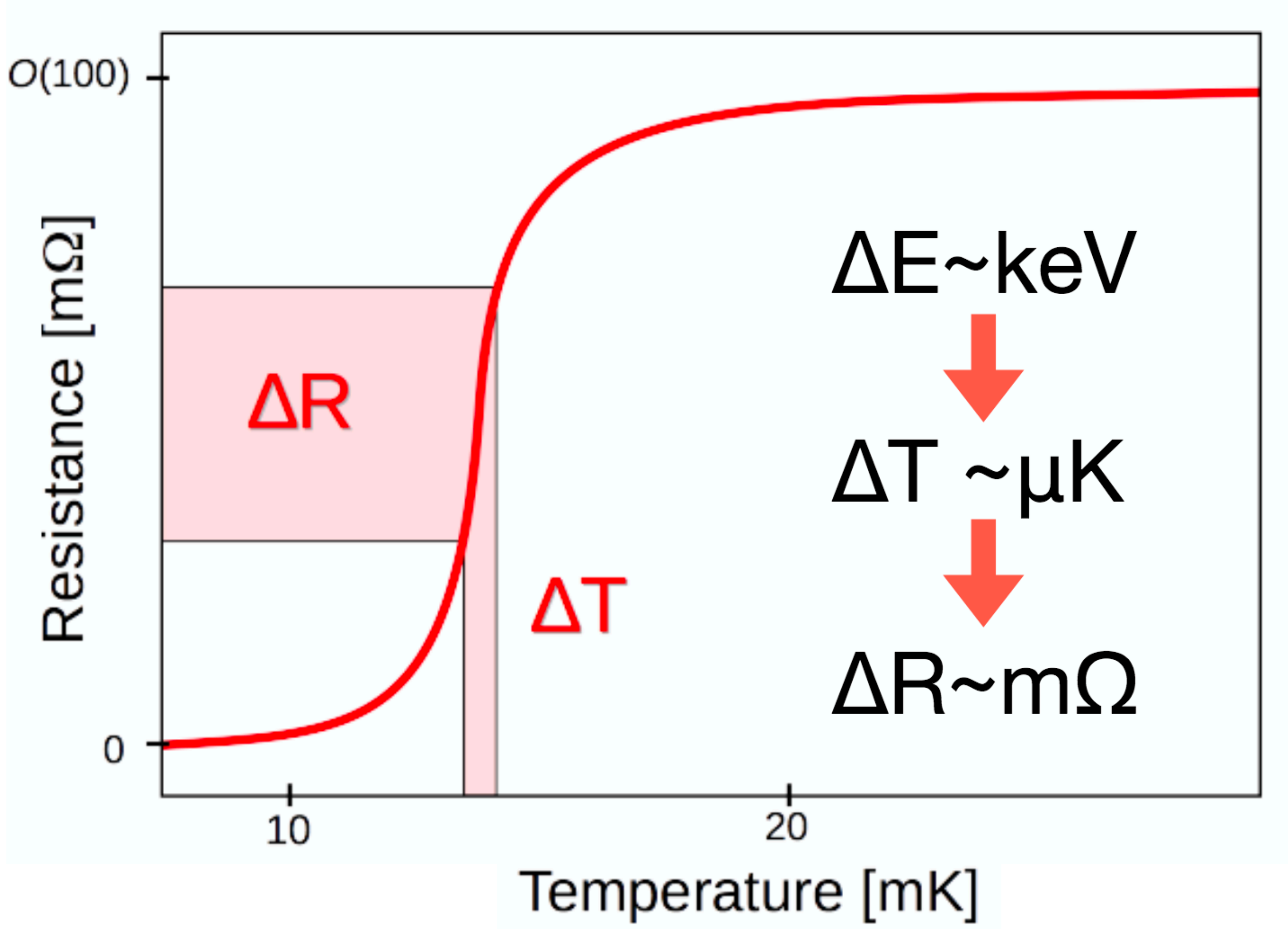
Detector working principle

CRESST detectors are highly sensitive calorimeters operated @ cryogenic temperature

➜ **Energy** deposits are measured as **temperature variations**



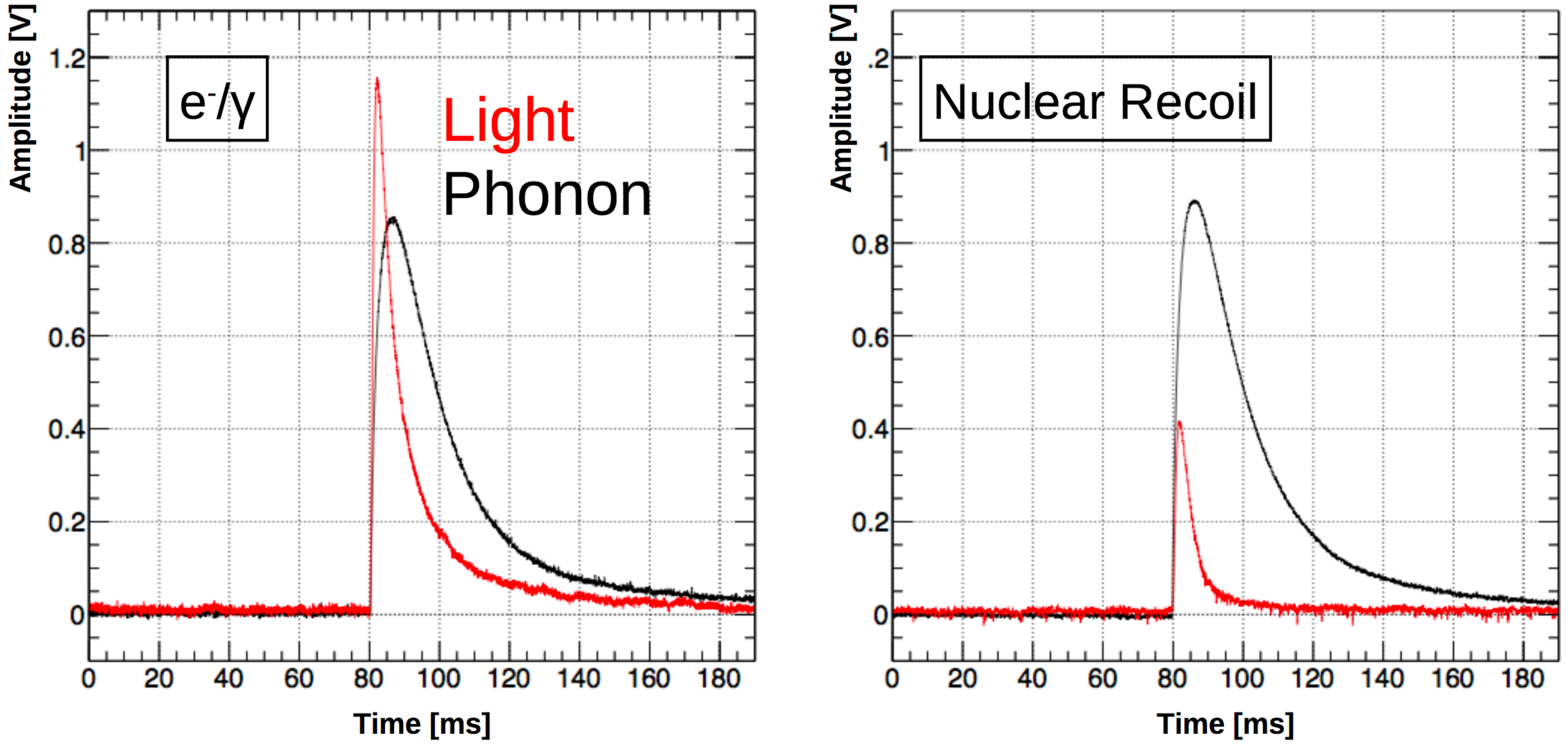
Detection of temperature rise with TES sensors operated at the phase transition from normal to superconducting



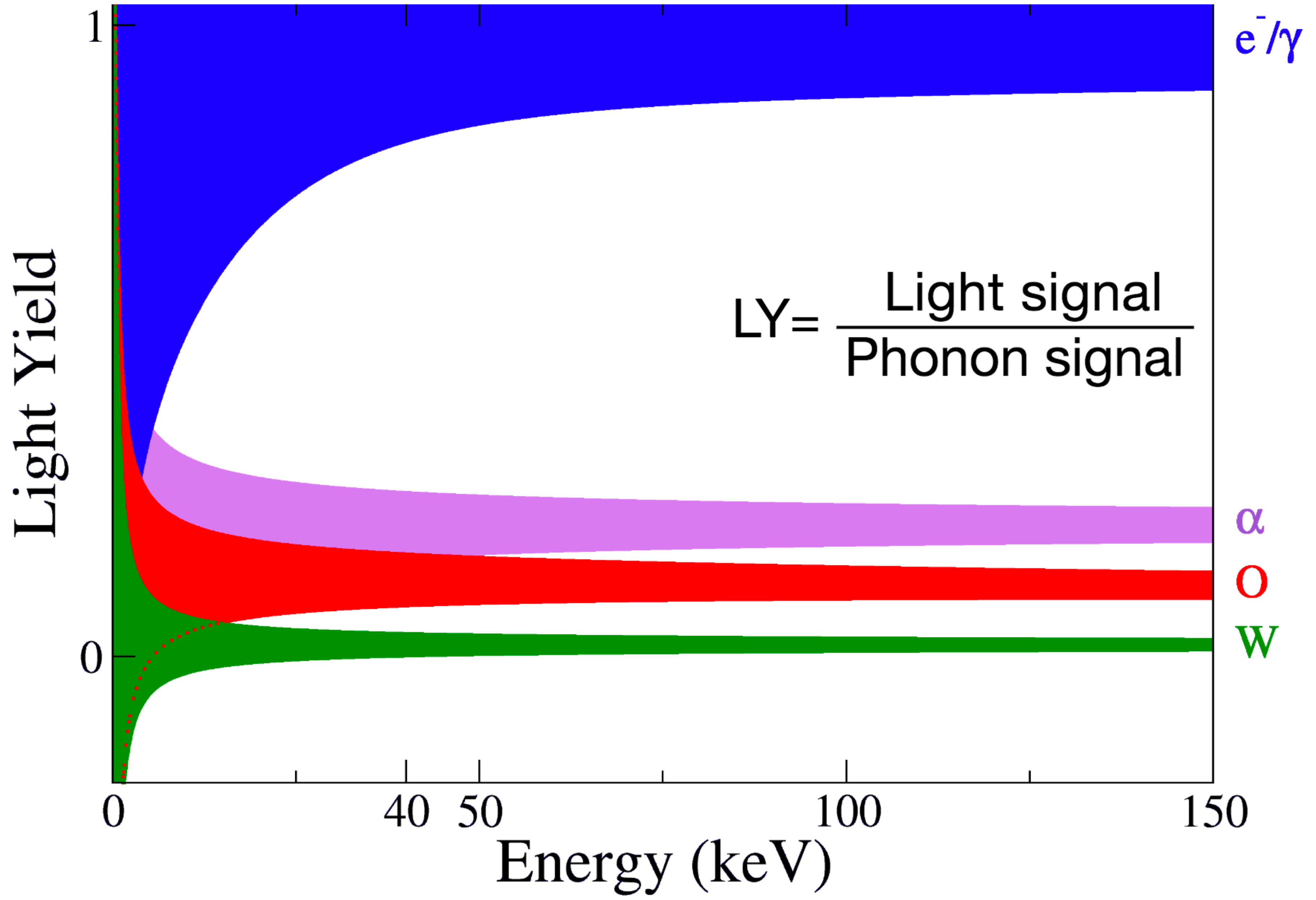
Ideal for reading out extremely small ΔT O(uK)

Signal identification technique

If the absorber is also an efficient scintillator the energy is converted into **heat** + **light**



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



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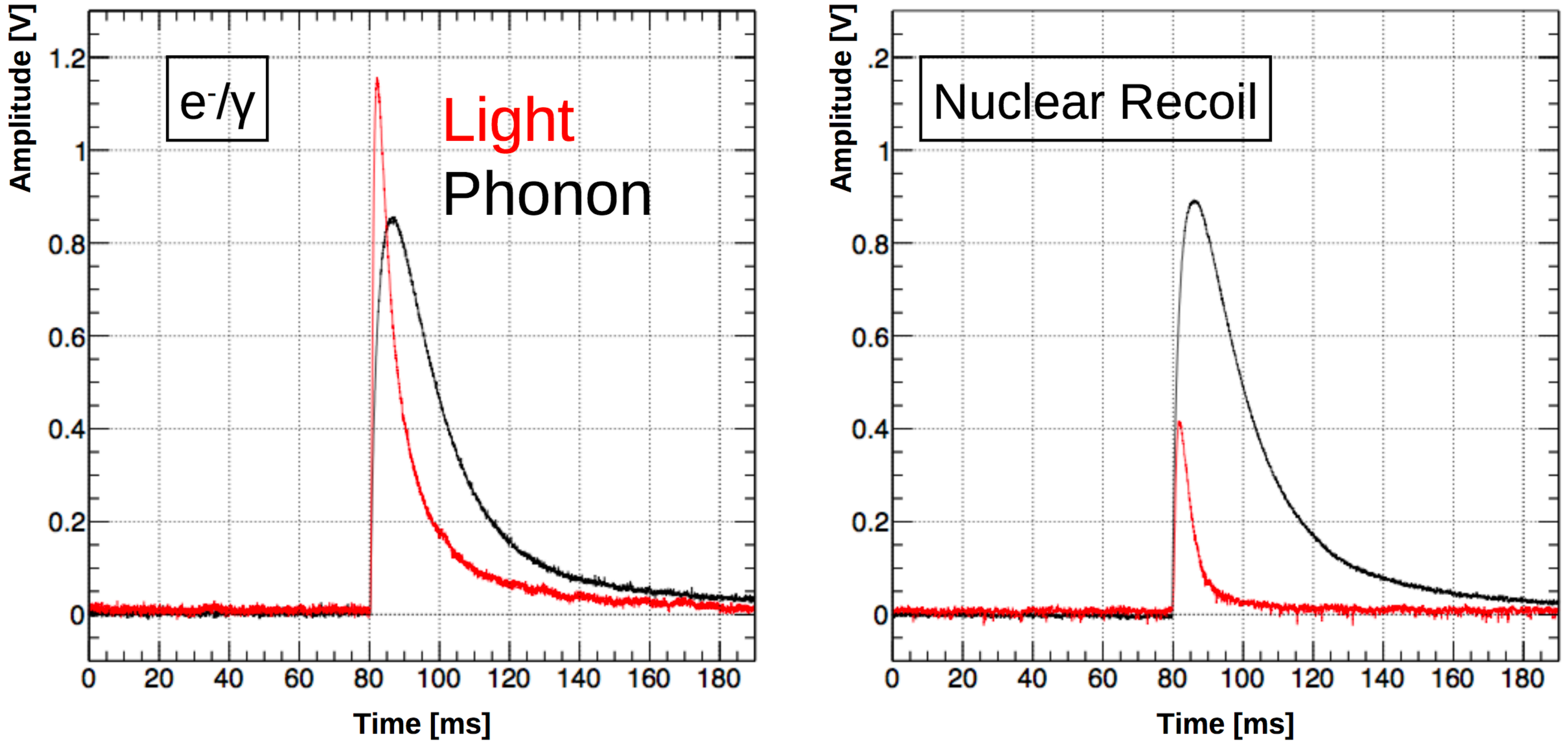

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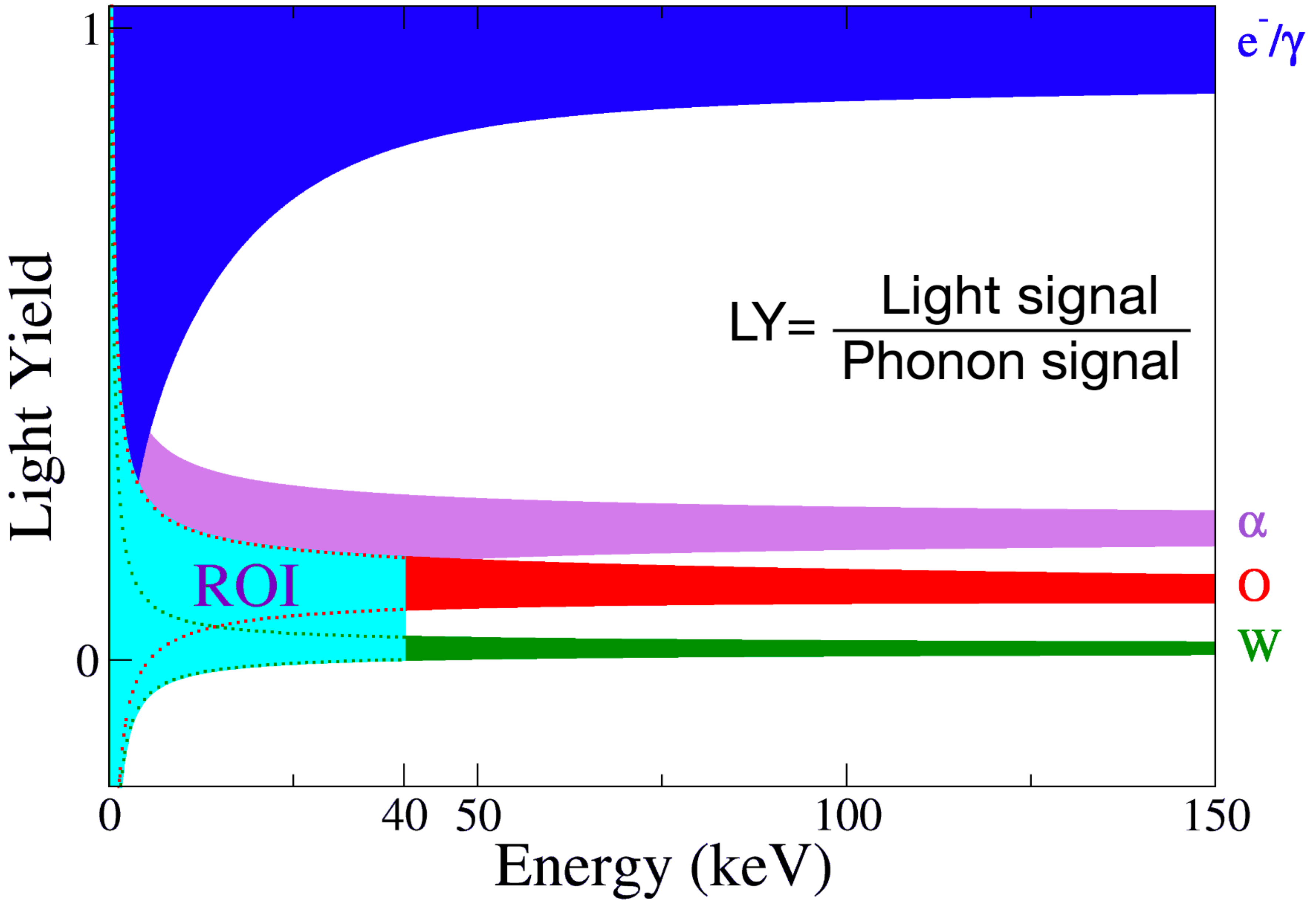
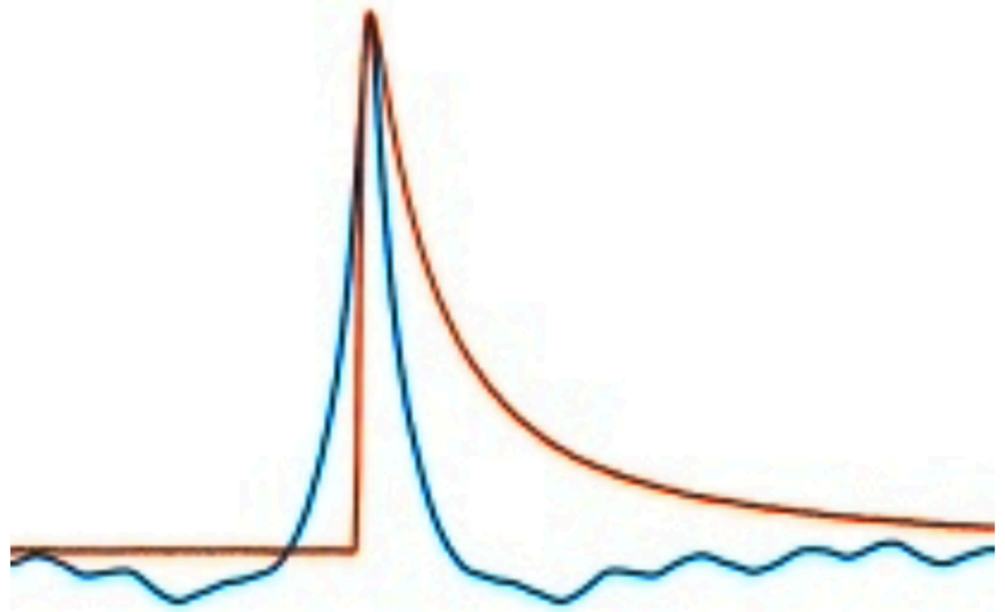


DM signal expected in the nuclear recoil band

Data processing & selection

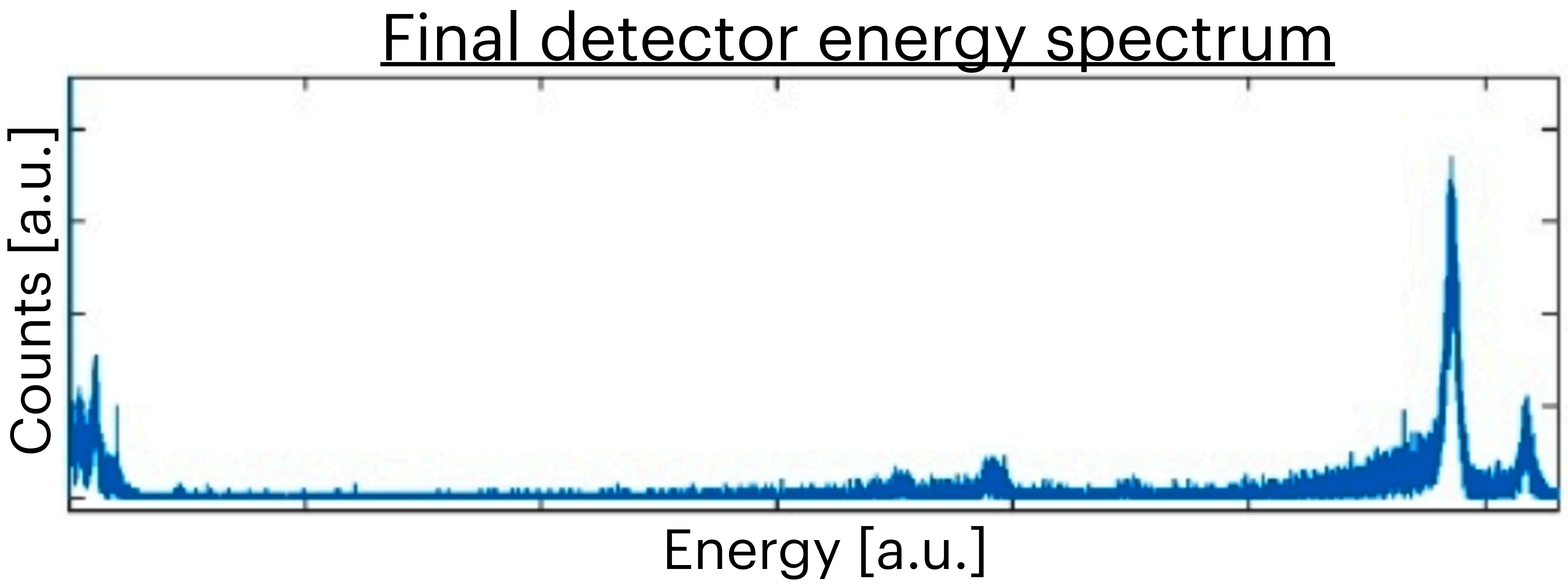
We record the continuous stream of data:

Data goes through an Optimum Filter/Trigger algorithm:



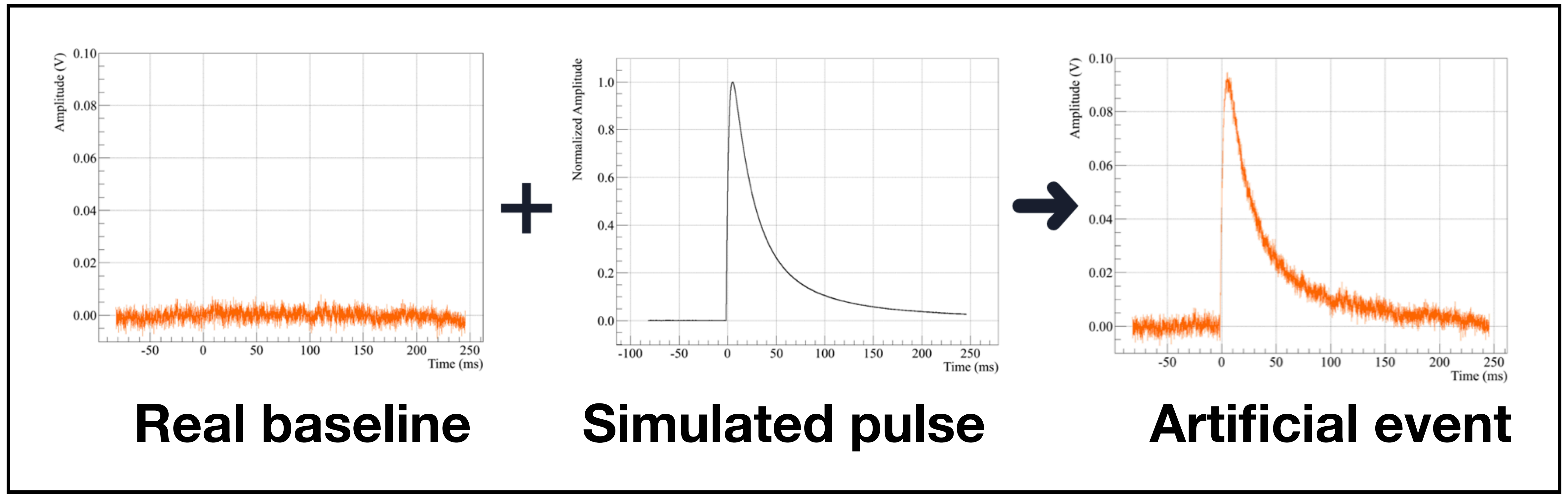
Data selection training done on different parameters (<20% of acquired data, the rest is blinded):

Rate: noise conditions
Stability: Detector(s) in operating point
Data quality: Non-standard pulse shapes (e.g. pileup)
Coincidences: with μ-veto, i-Sticks, other detectors



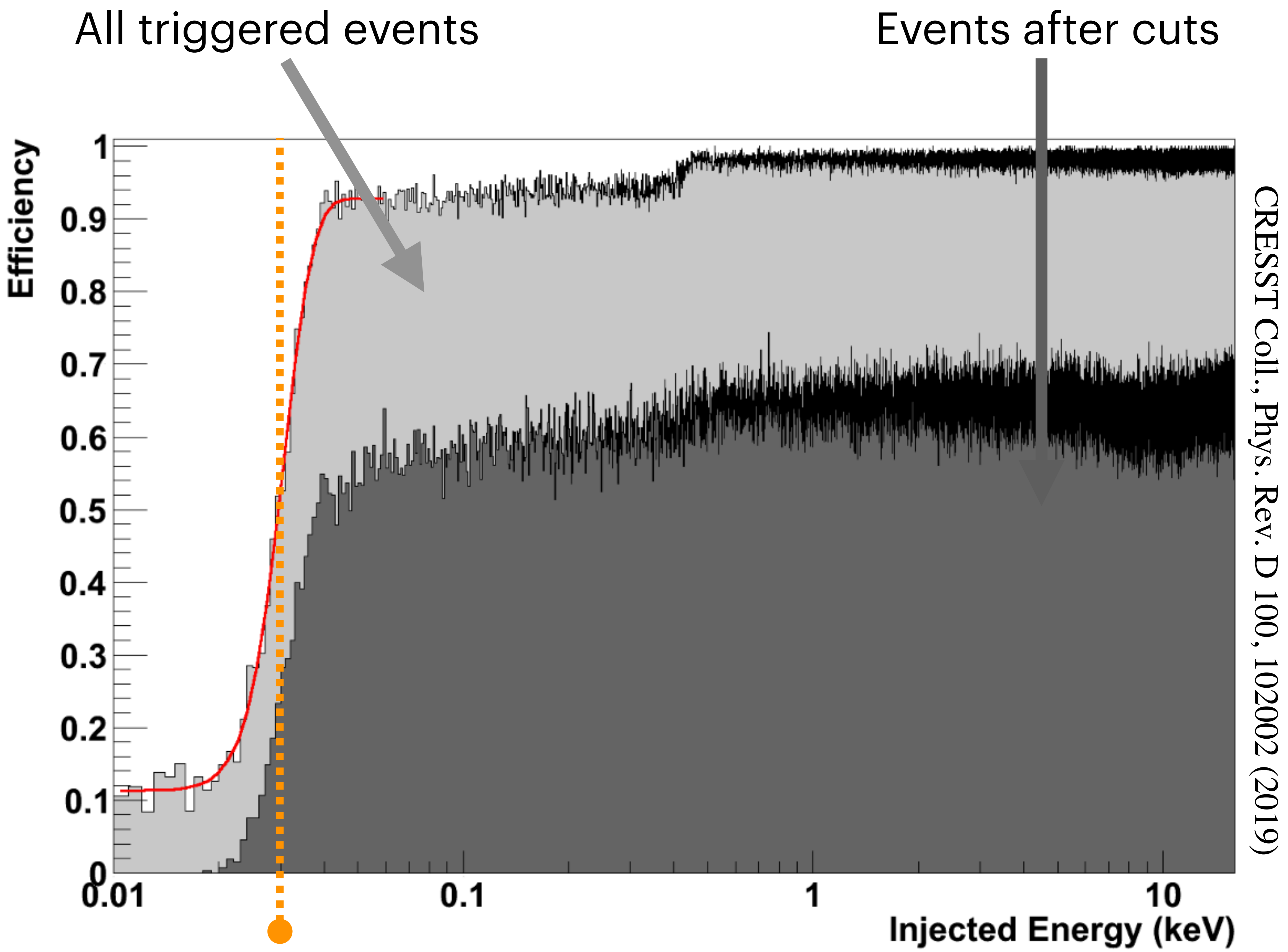
Signal survival probability

Simulated by randomly superimposing artificial pulses on the continuous stream of data



➜ Trigger and cuts efficiency

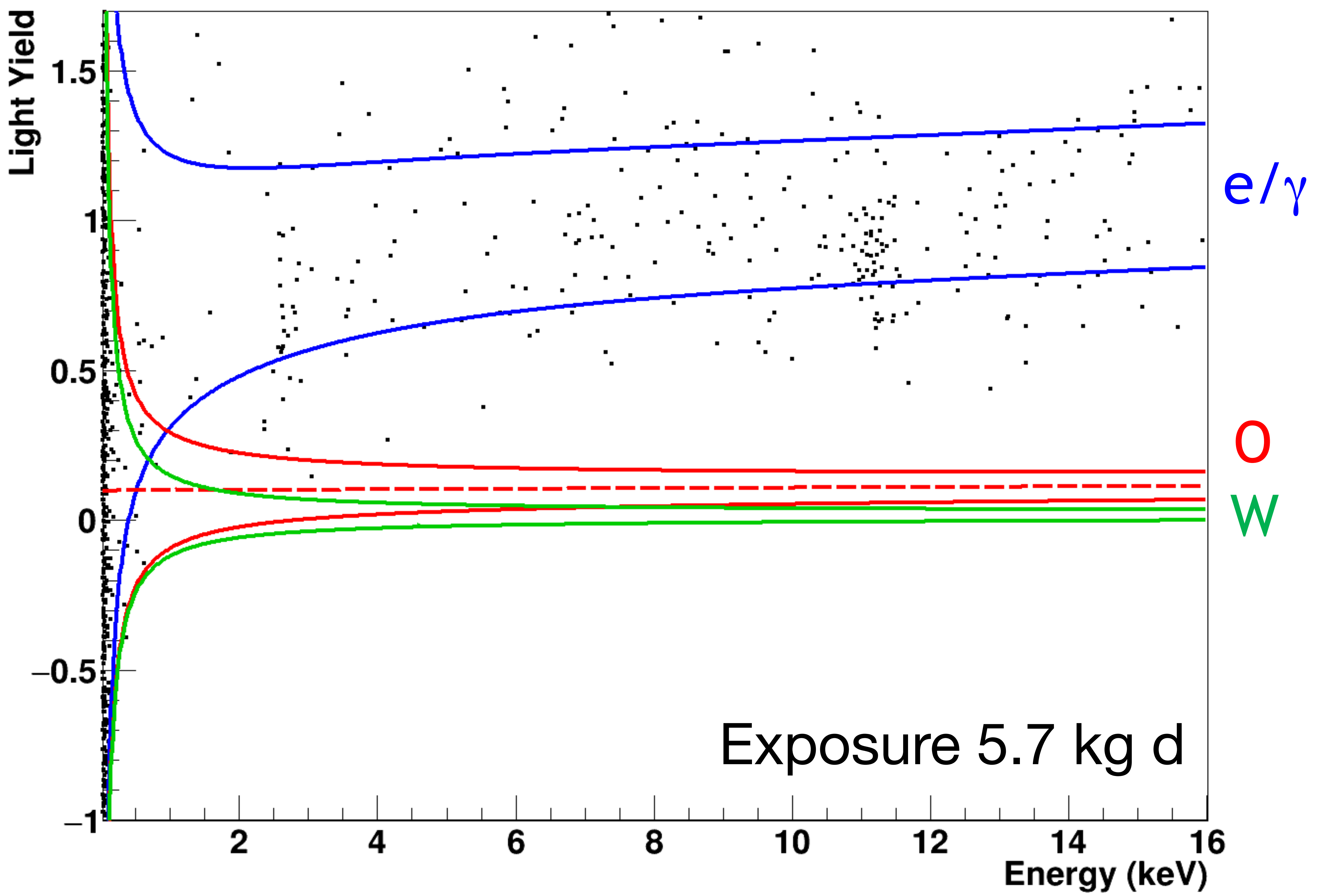
ε ≳60% efficiency over a wide energy range



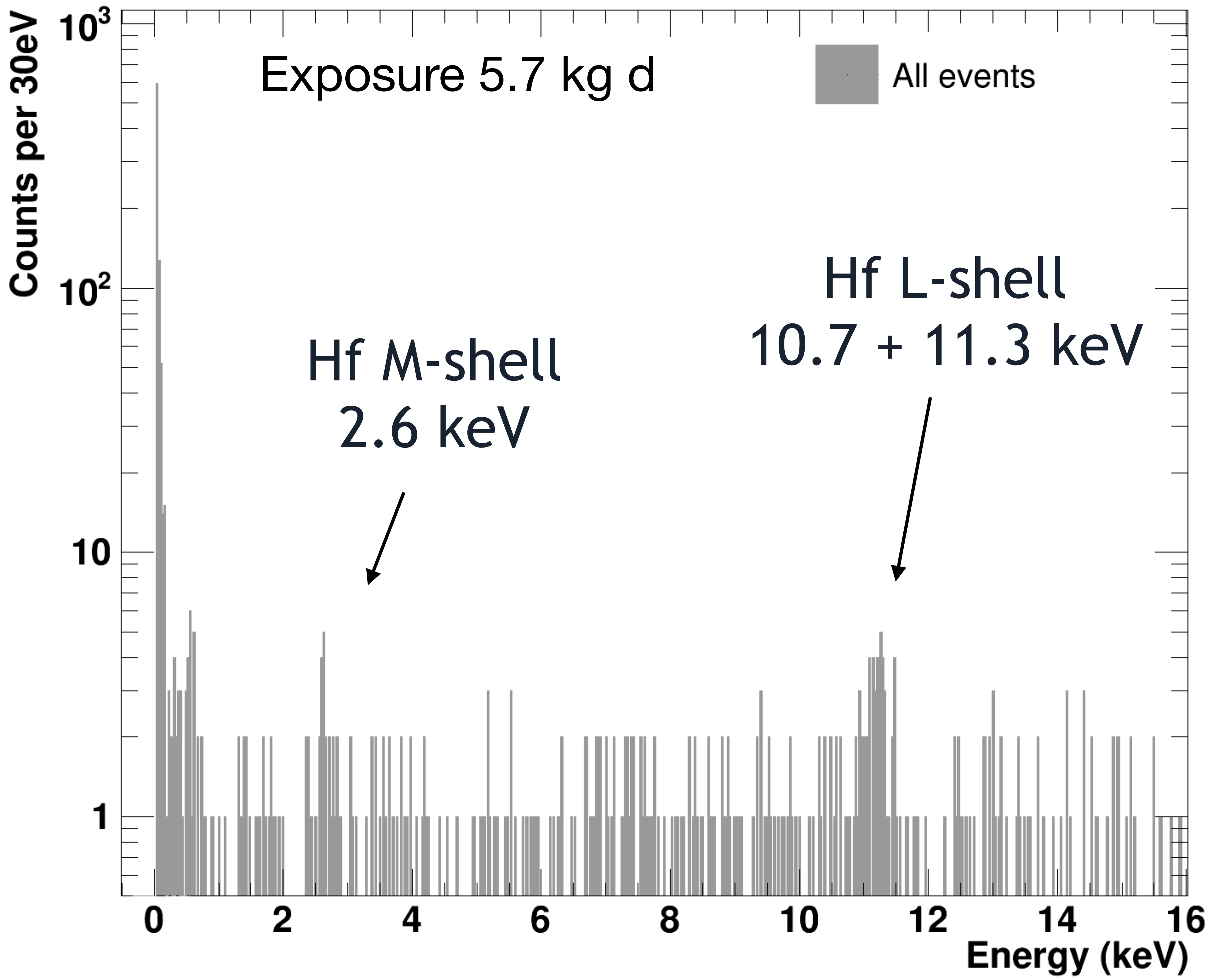
Best performing detector:
Energy Threshold: 30 eV → Det-A
(= 1 noise event triggered 1 c/kg/d)

Final energy spectra Det-A

Background Light Yield scatter plot



Total energy spectrum (e/g + NR)



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cosmogenic activation

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

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

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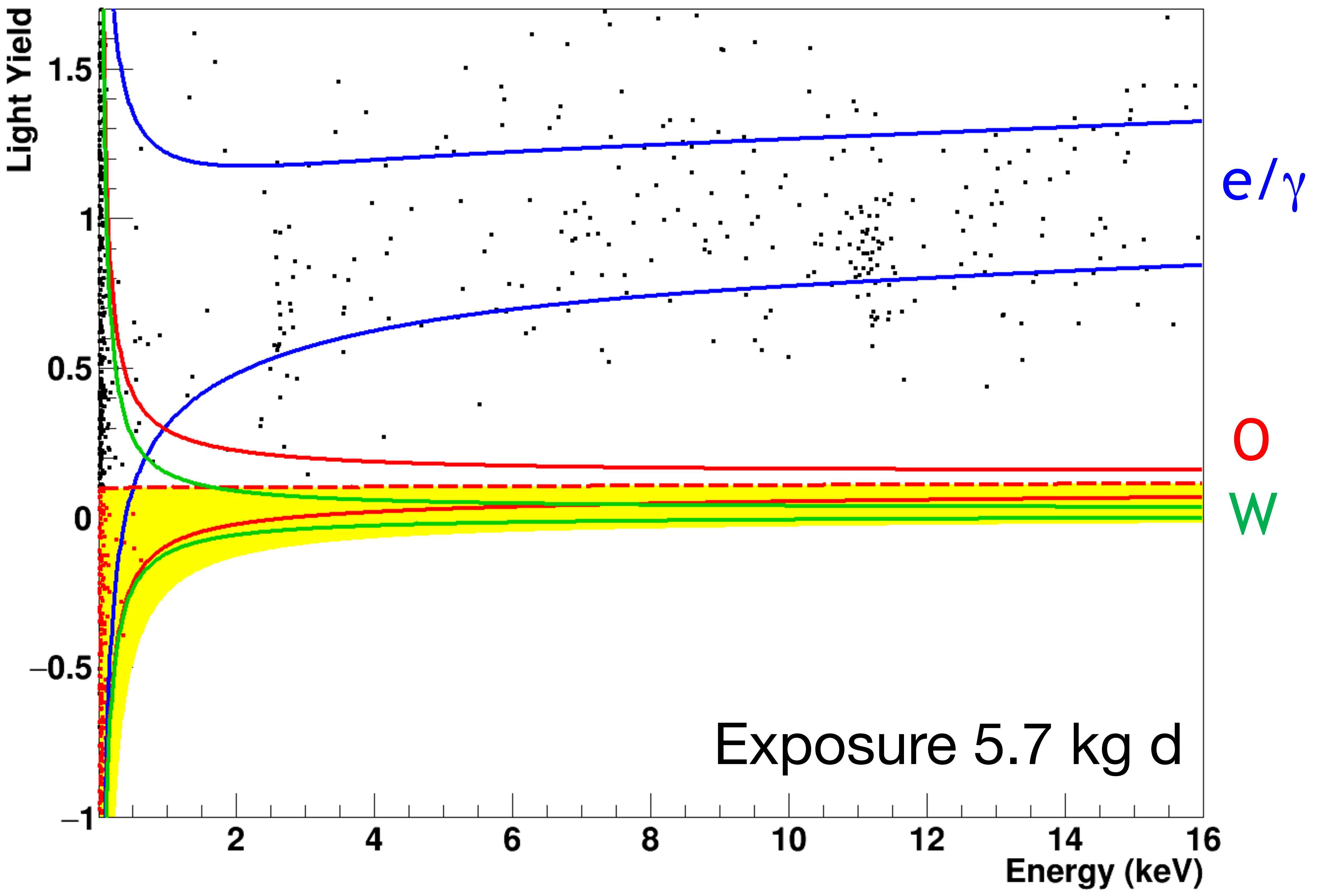
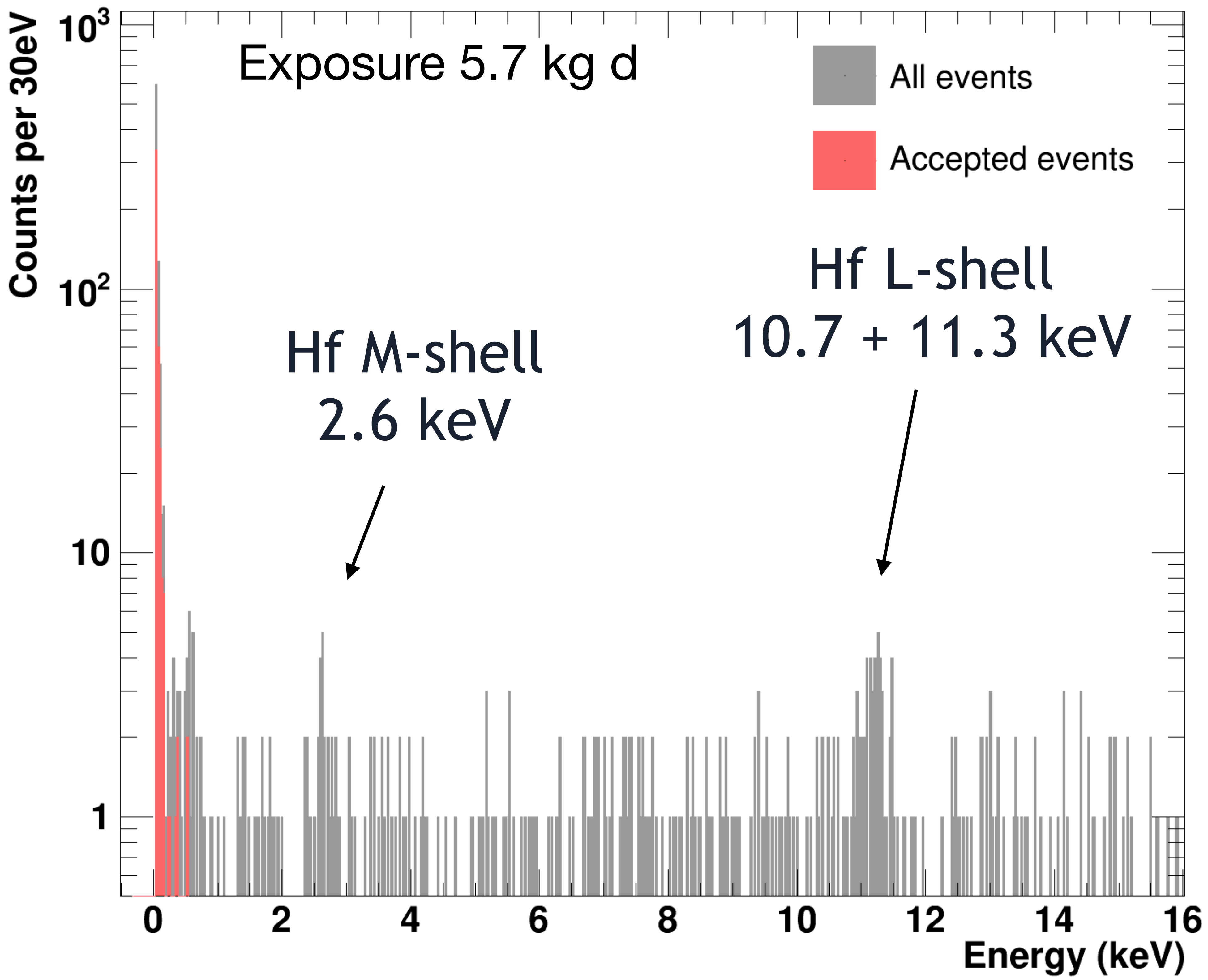


ROI: upper limit 50 % O recoils
lower limit 99.5 % W recoils

Total energy spectrum (**NR**)



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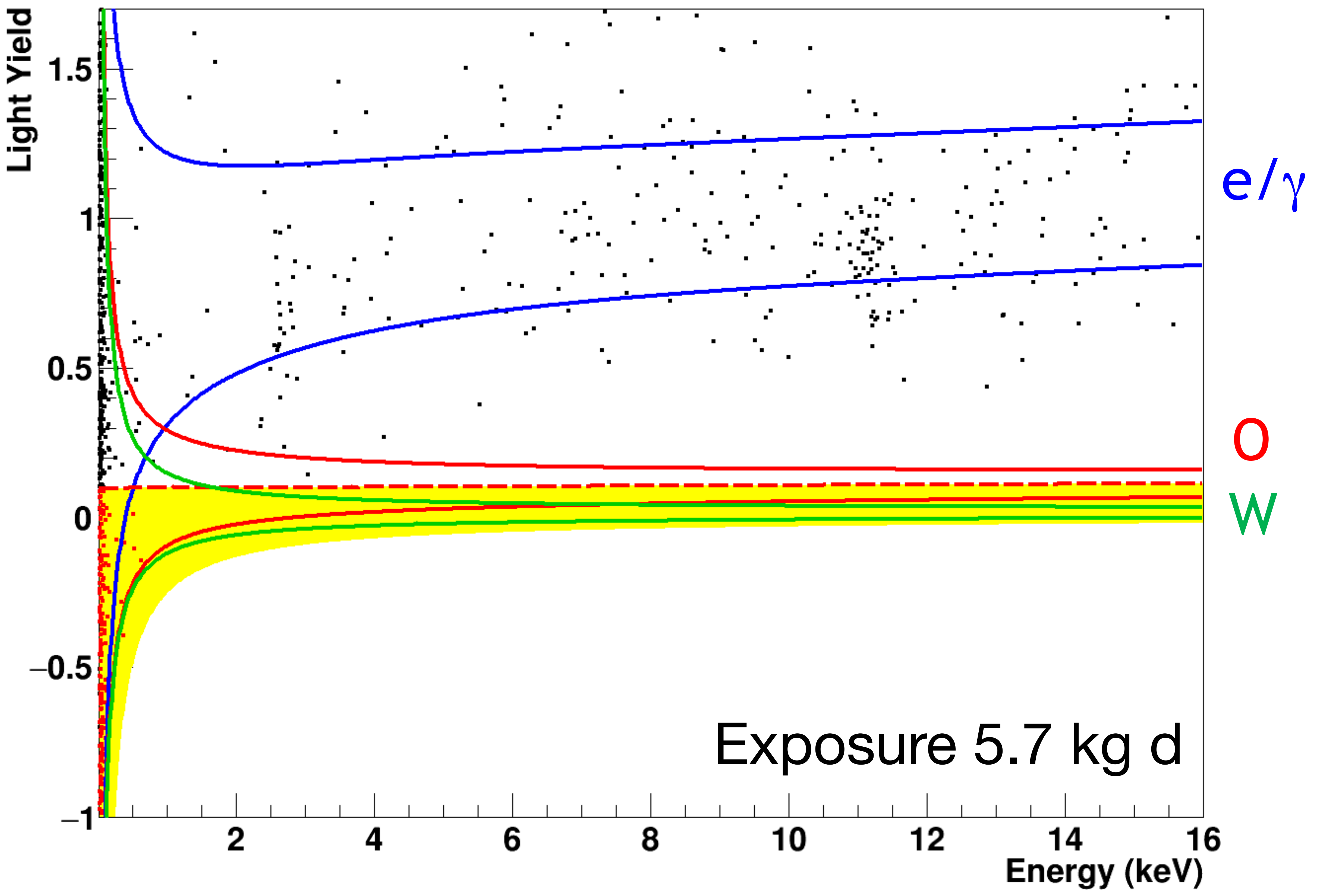

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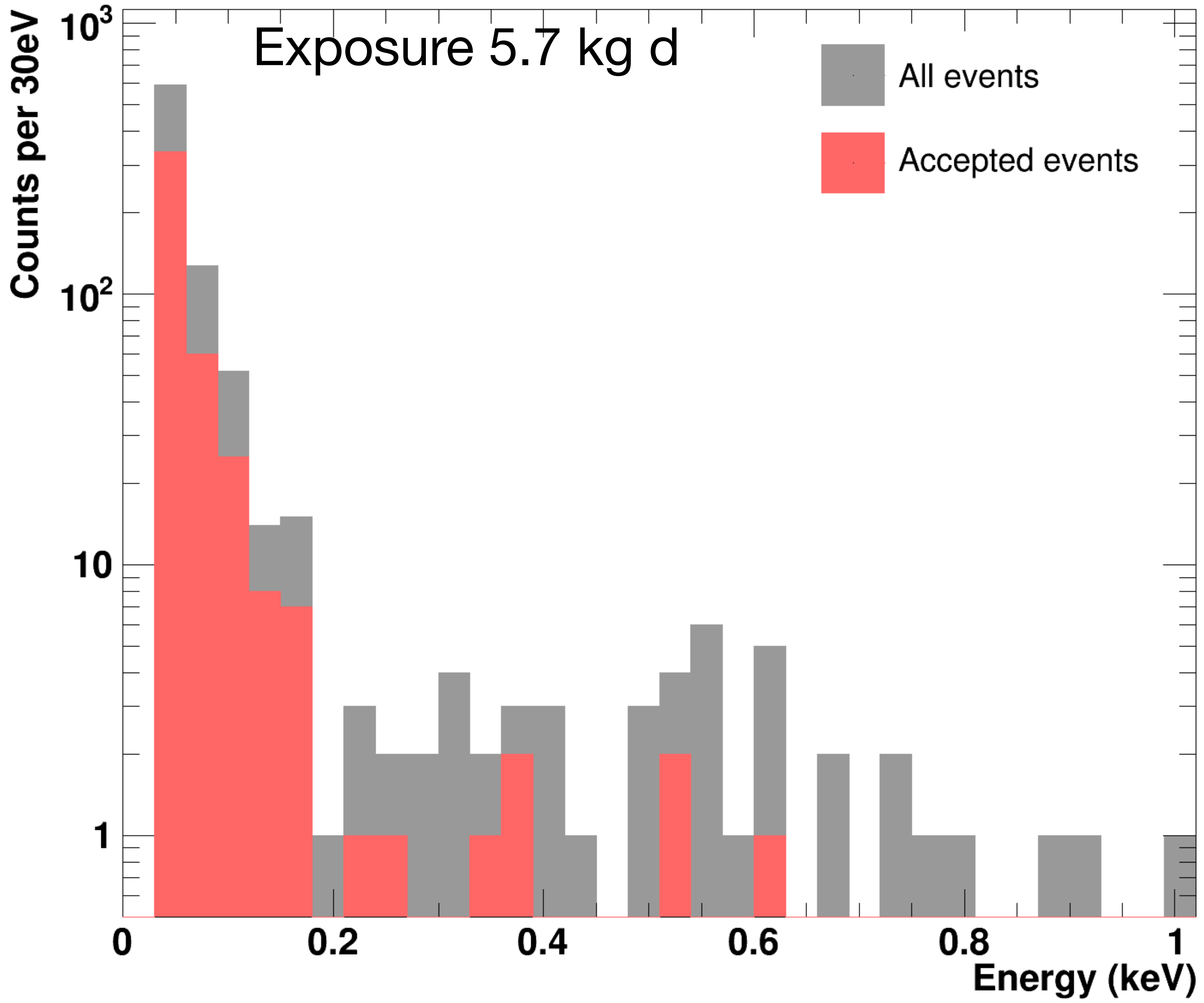
Zoom in

Total energy spectrum (**NR**)



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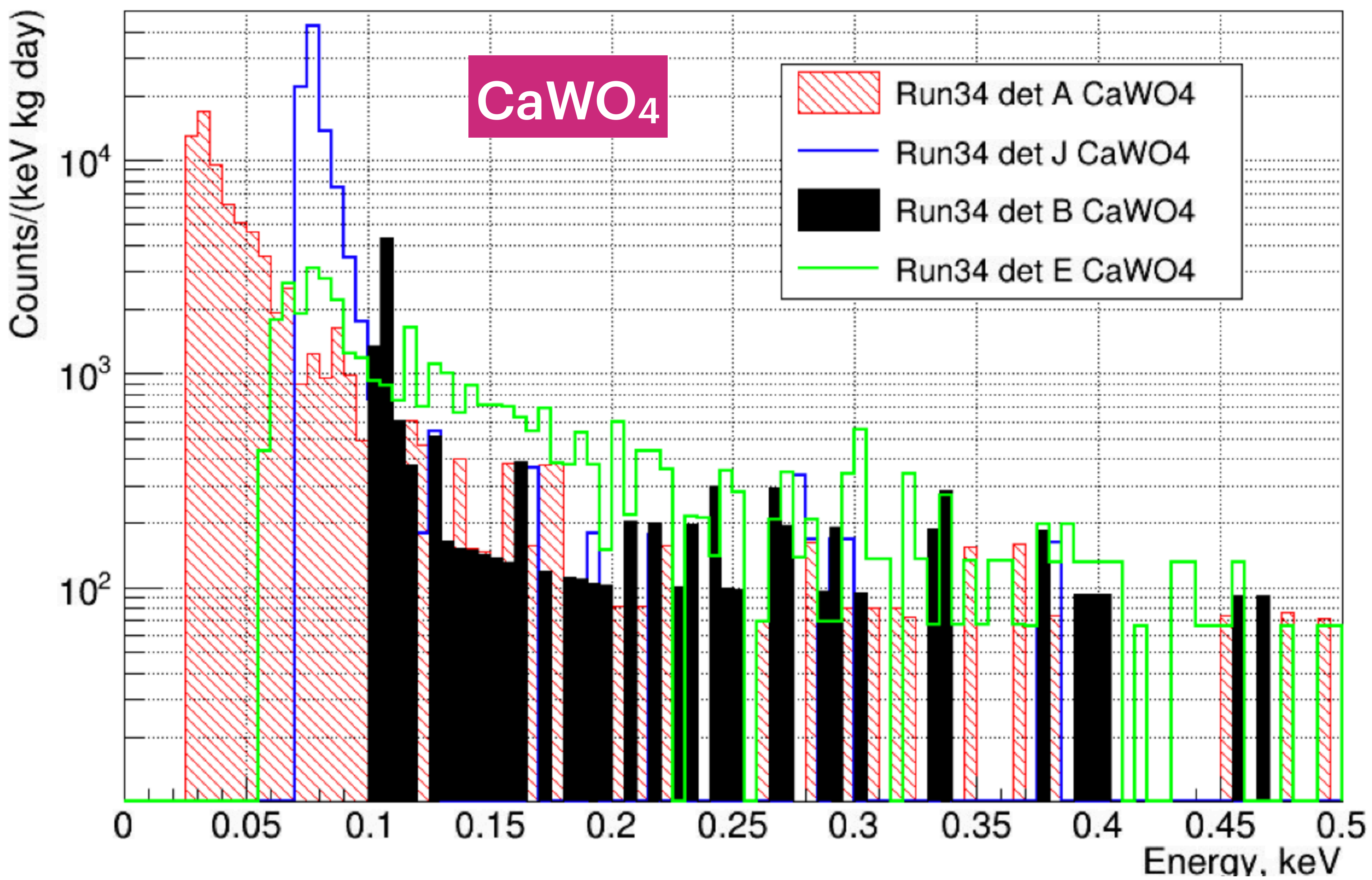
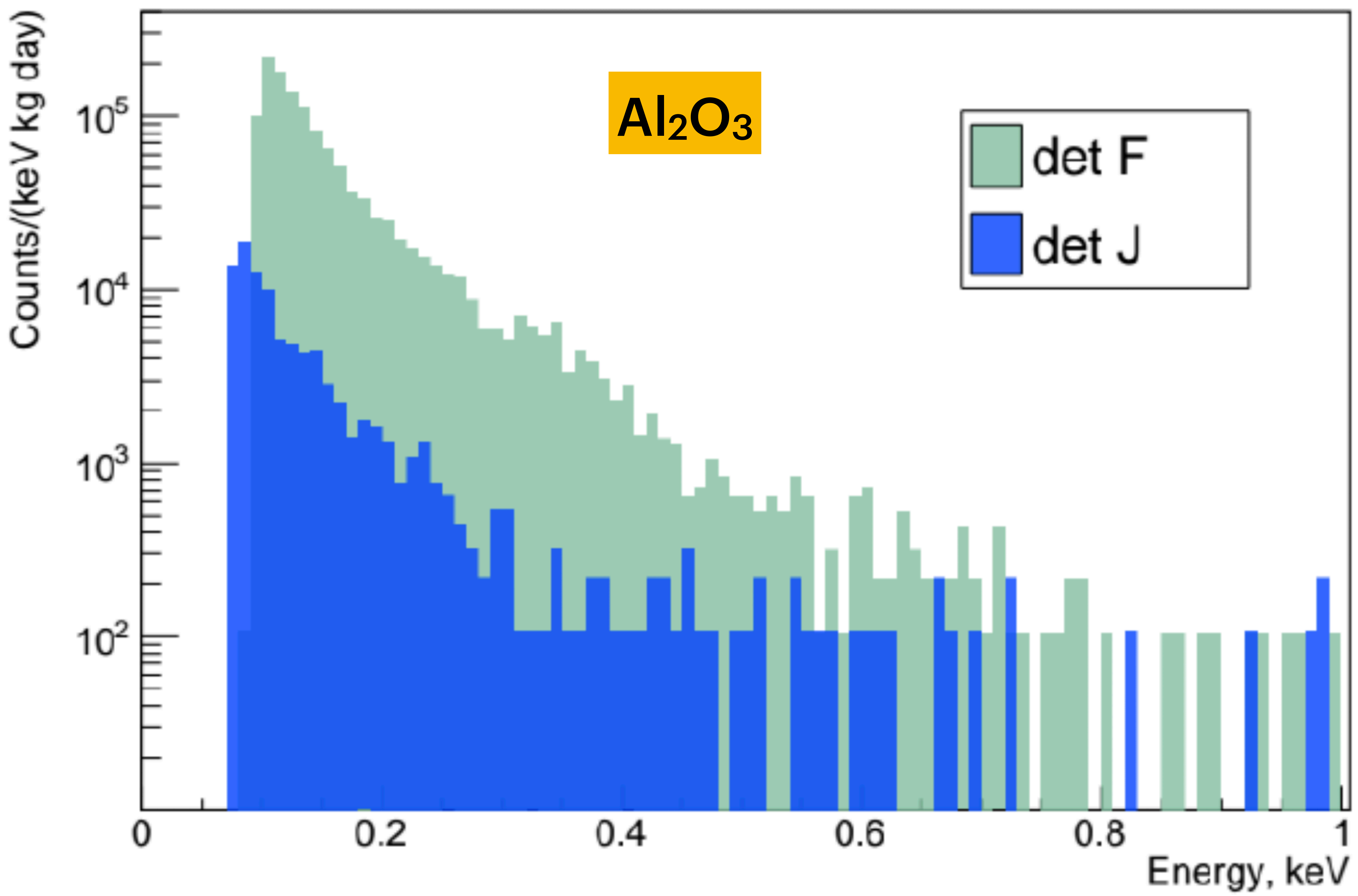
Sanity checks





Excess with different shape in detectors of the same type (see $CaWO_4$)

Excess with different intensity in detectors of the same type (see Al_2O_3)

Broad community effort in understanding the excess observed in many others DM and CEvNS experiments

PhD Thesis, M. Stahlberg, TU Wien (2020)

https://indico.cern.ch/event/1013203/

EXCESS

Final results Det-A

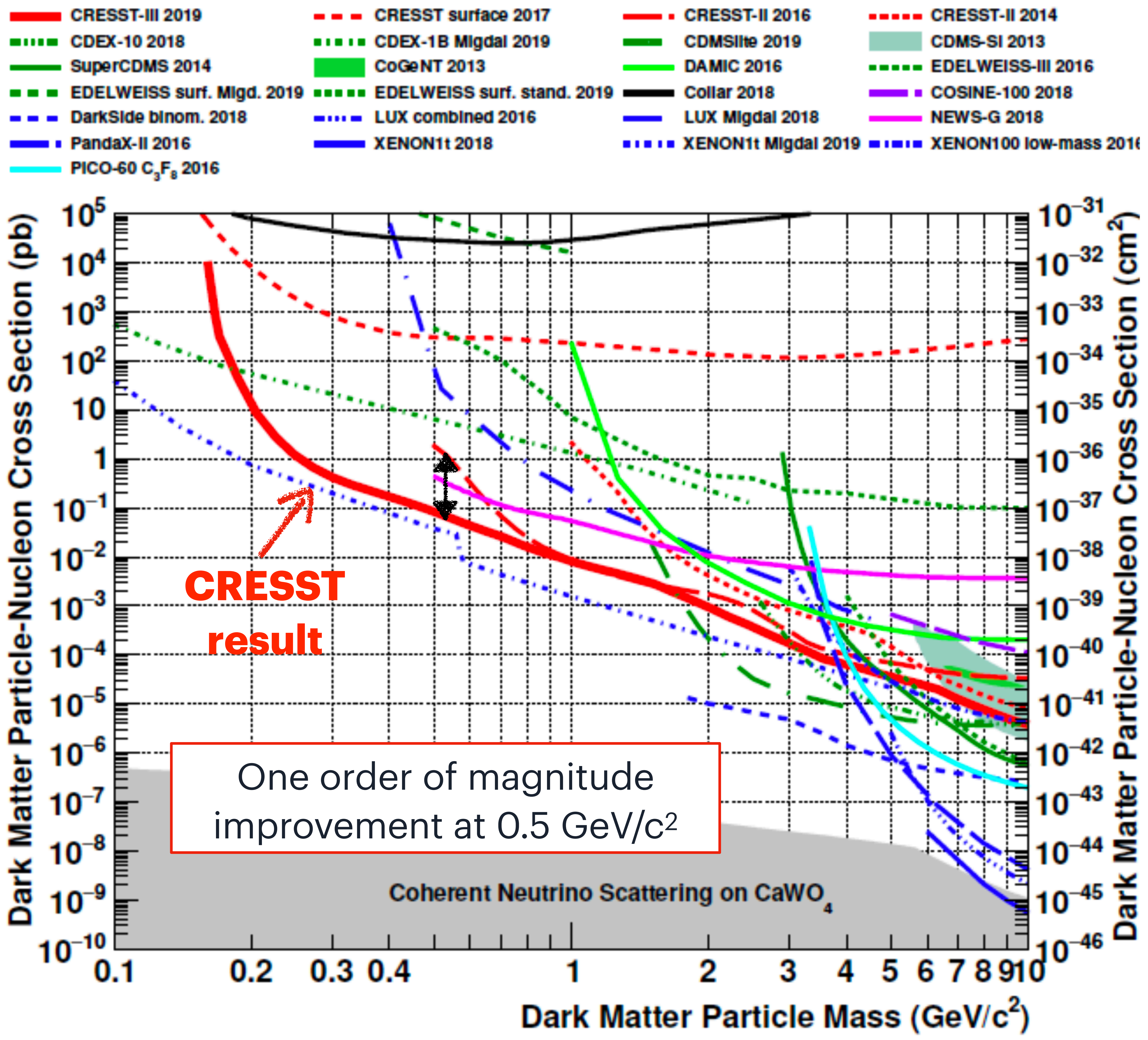
1D Yellin optimum interval method to compute the exclusion limit:

Energy spectrum of accepted events (no bkg subtraction)

↳

*Leading limit at low-mass <1.7 GeV/c²

↳ Background limited



* until the existence of the Midgal effect is confirmed

Final results Det-A

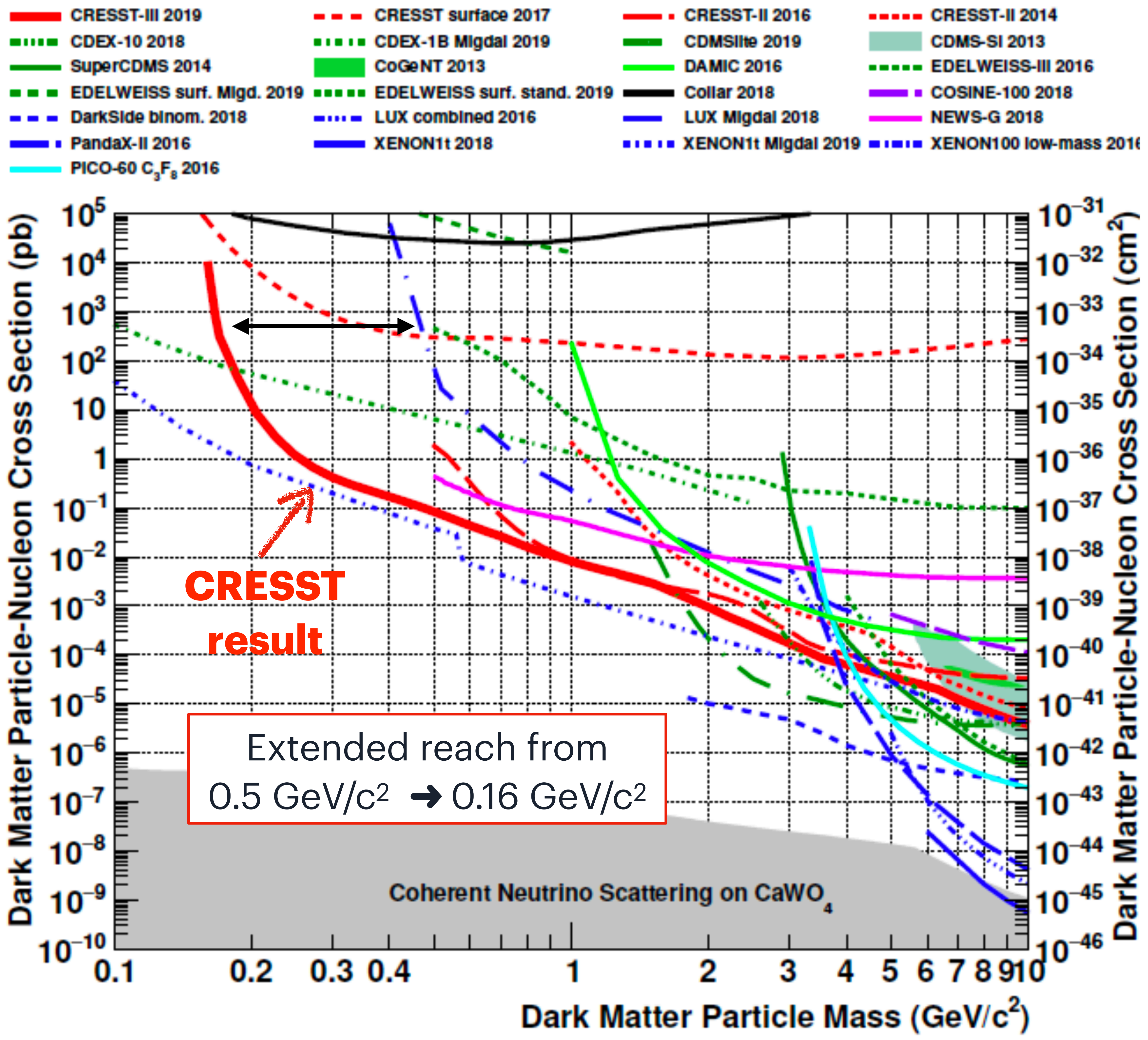
1D Yellin optimum interval method to compute the exclusion limit:

Energy spectrum of accepted events (no bkg subtraction)

↳

*Lowest mass investigation >0.16 GeV/c²

↳ Performance "limited"



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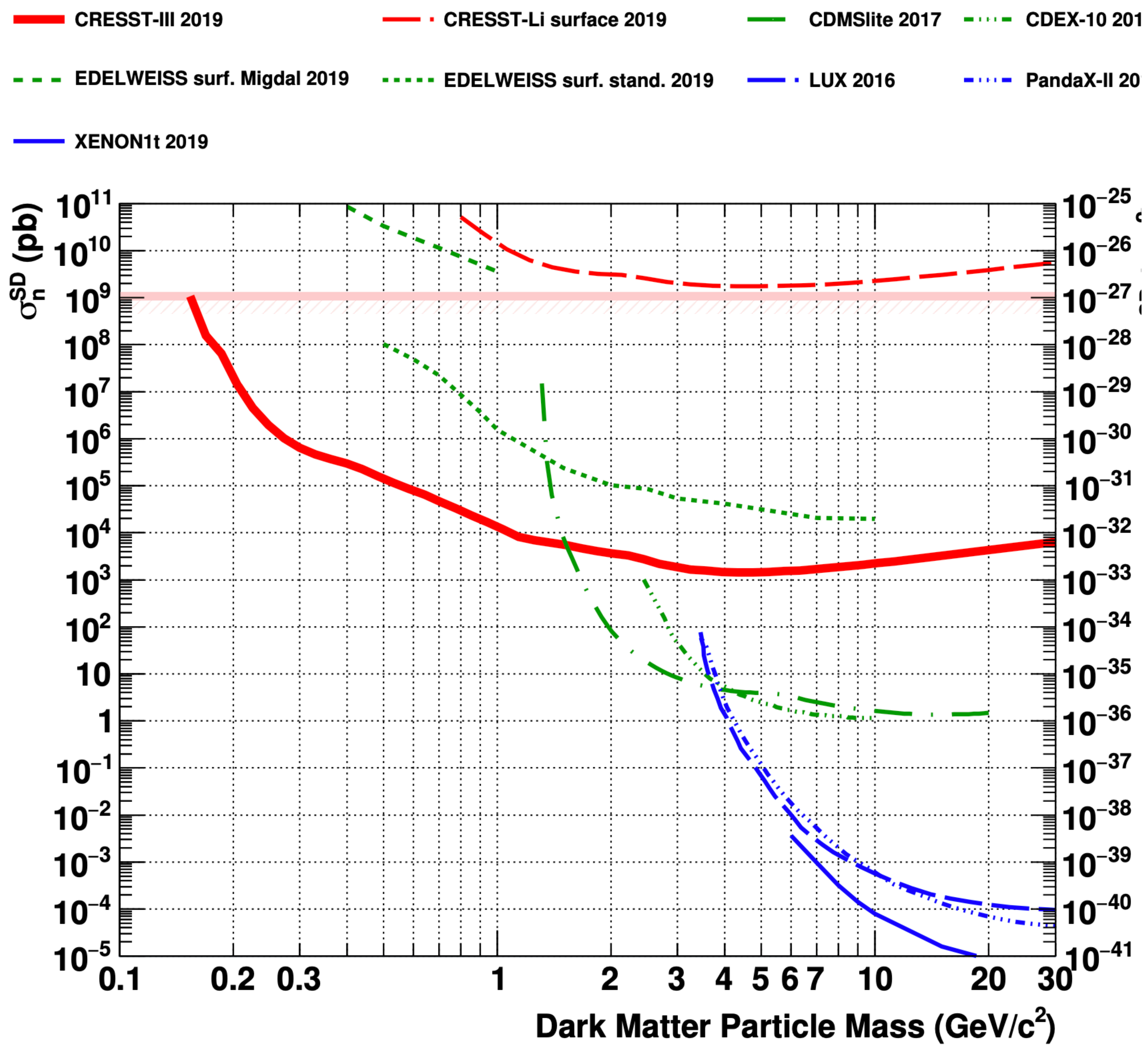
Other target materials

Cryogenic detector *à la CRESST* enable the operation of different target materials

Operation of a $LiAlO_2$ scintillating cryogenic detector
Results on spin-dependent (^{7}Li and ^{27}Al) DM interactions with *neutron* and *protons*

SD DM interactions on neutrons



Conclusions

CRESST cryogenic detector technique enables to achieve outstanding results in direct DM searches:

➜ ultra-low energy threshold
➜ versatility of target material
➜ active background suppression techniques

Leading results in the field of Light DM:

➜ spin-independent
➜ spin-dependent

The DM community is currently facing a challenge:
➜ low energy excess
positive hints on possible mitigation strategies are already available