

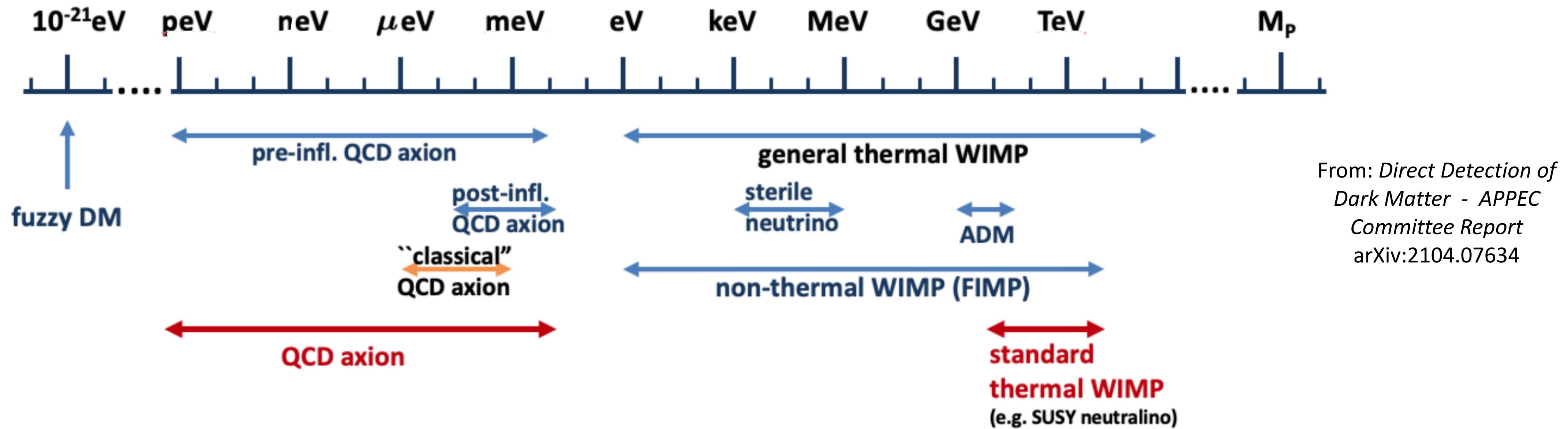
Sub-GeV Dark Matter search with CRESST-III

Luca Pattavina

Technical University of Munich
INFN - Gran Sasso Laboratories

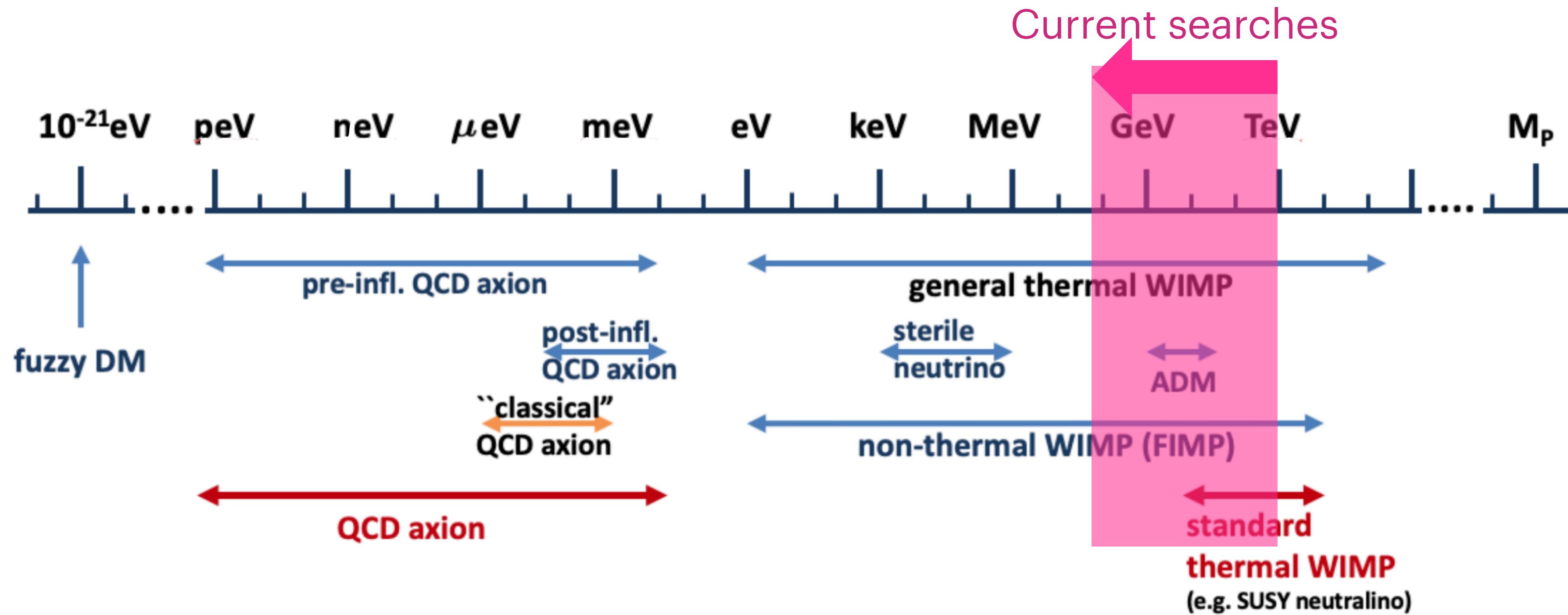


Dark Matter



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

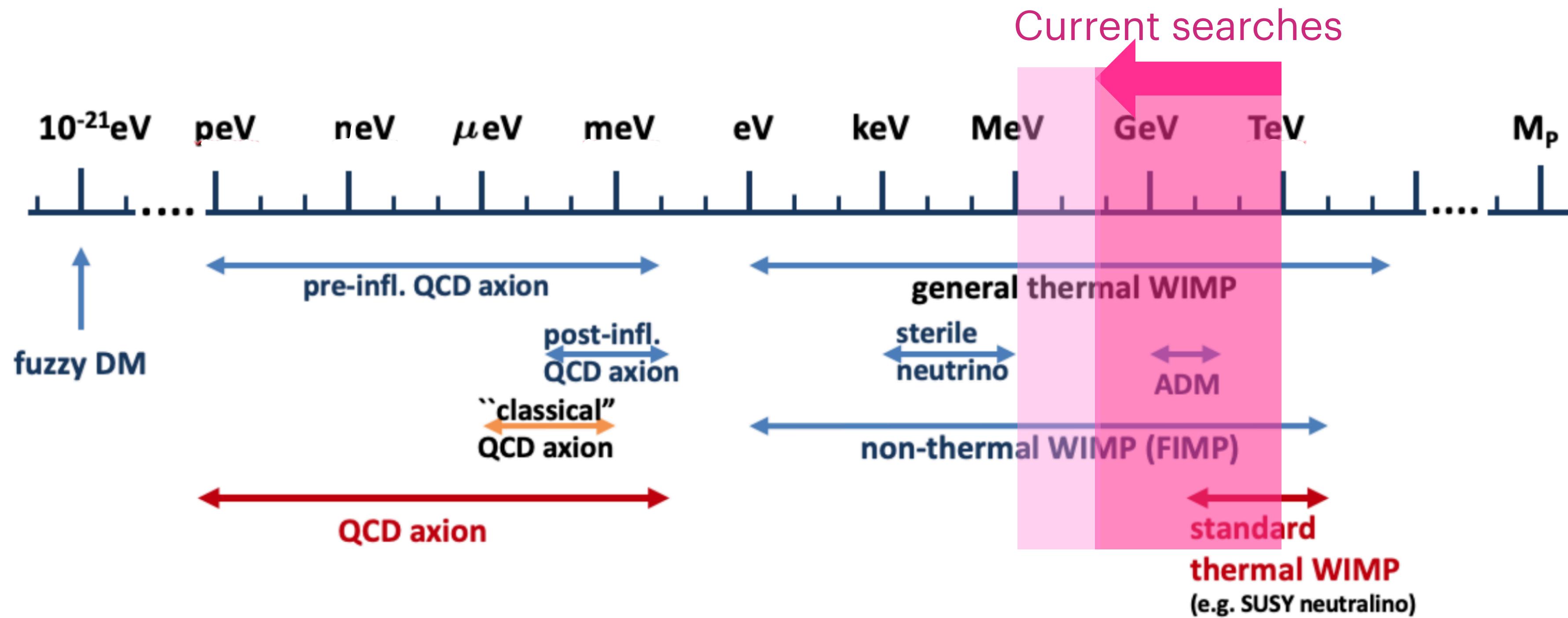
Dark Matter



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

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Dark Matter

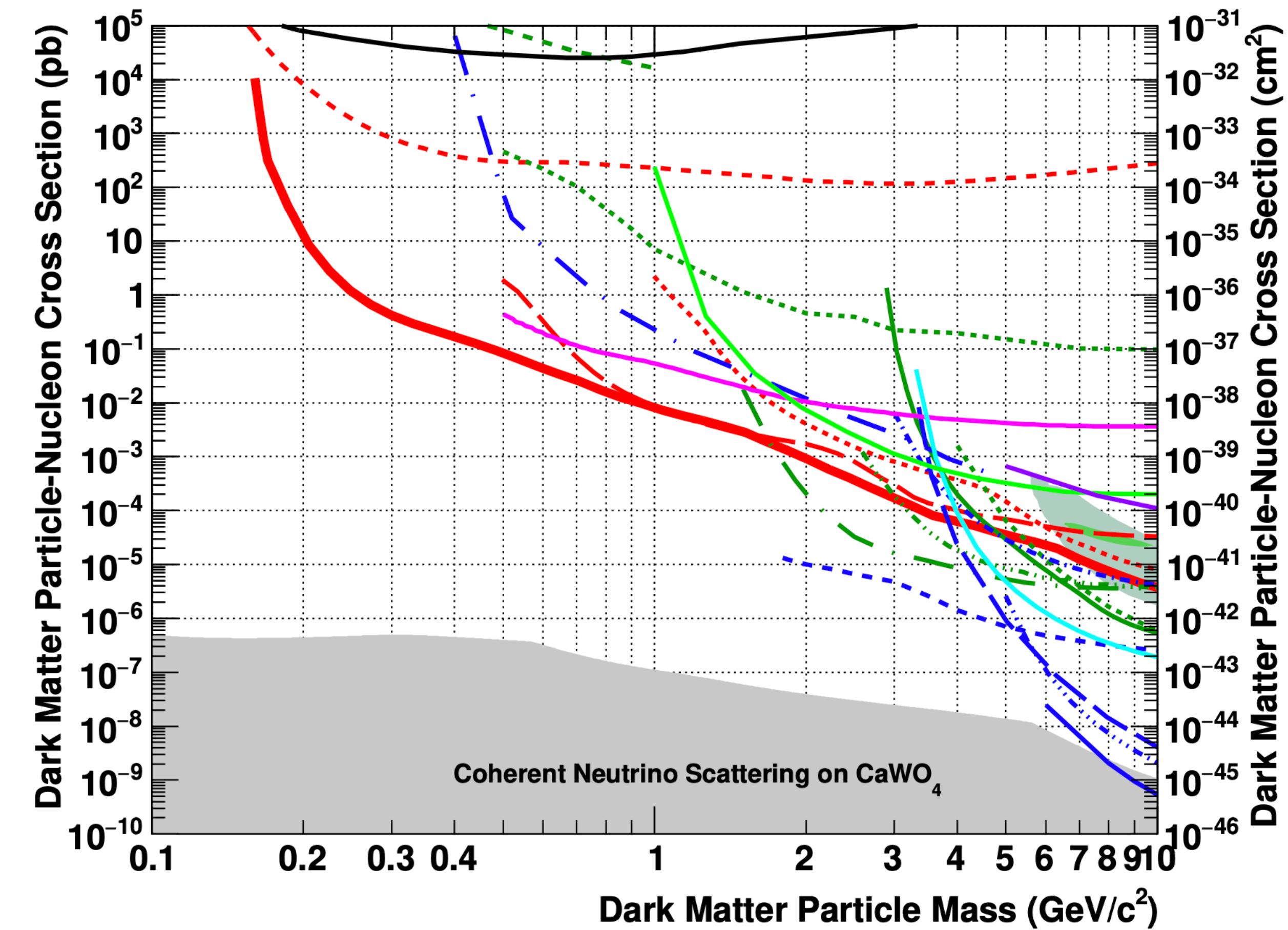
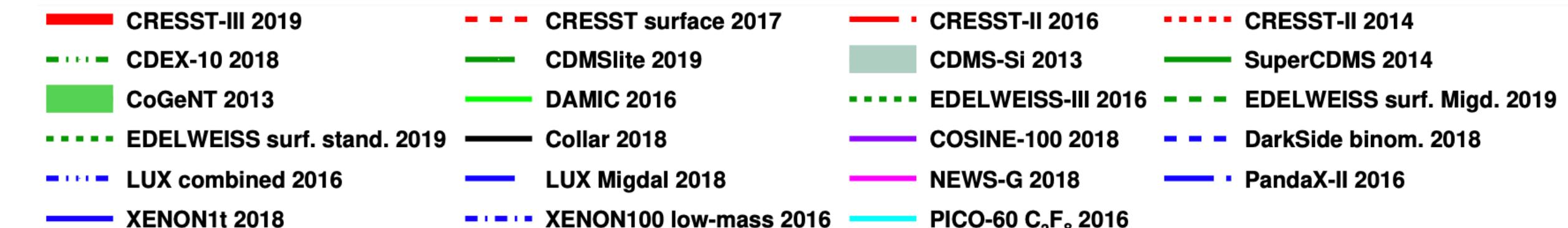


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Great variety of theoretical motivated dark matter particle candidates with a wide range of mass and cross section.

Direct Dark Matter searches

Several different experiments
with different technologies



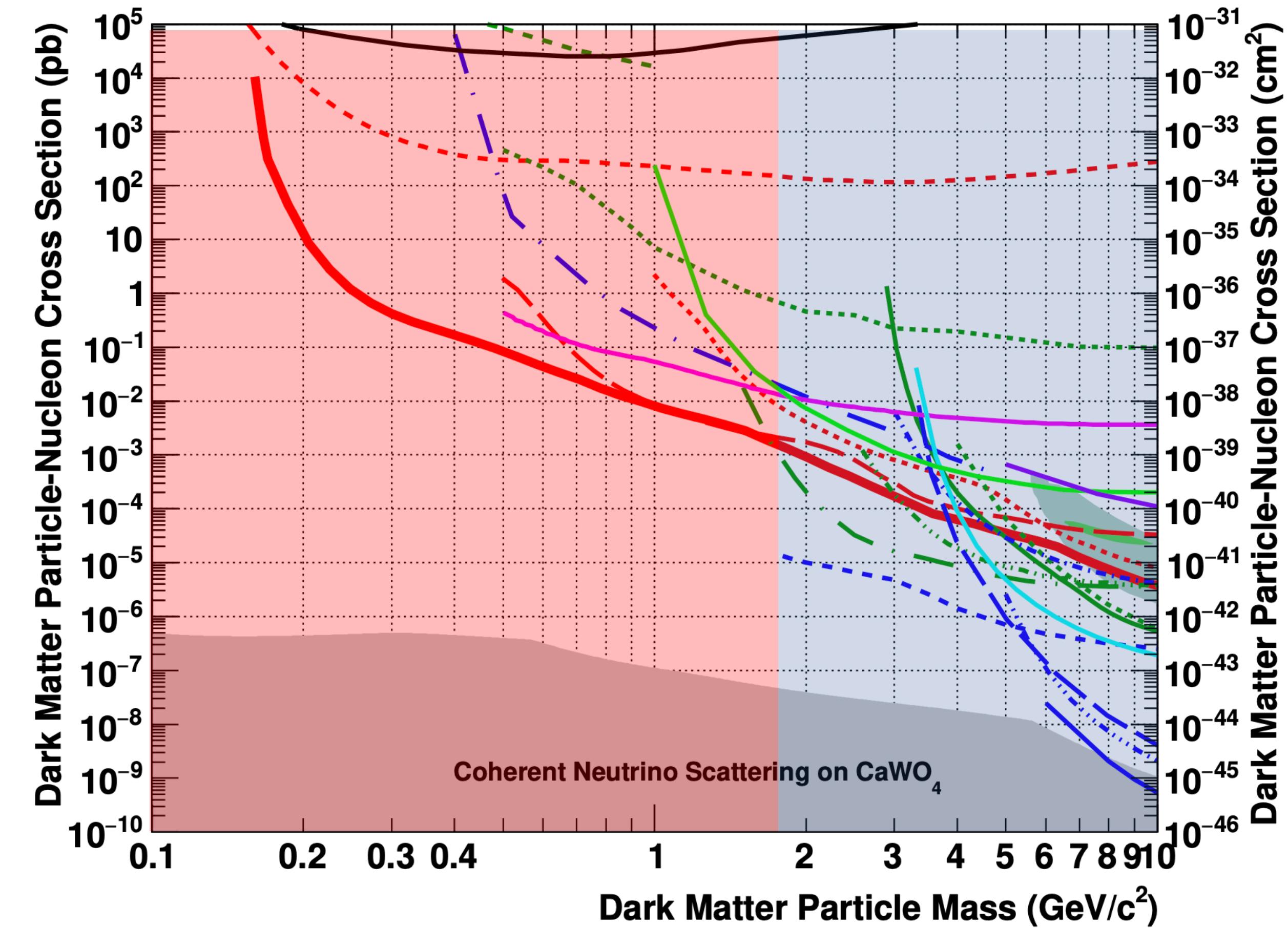
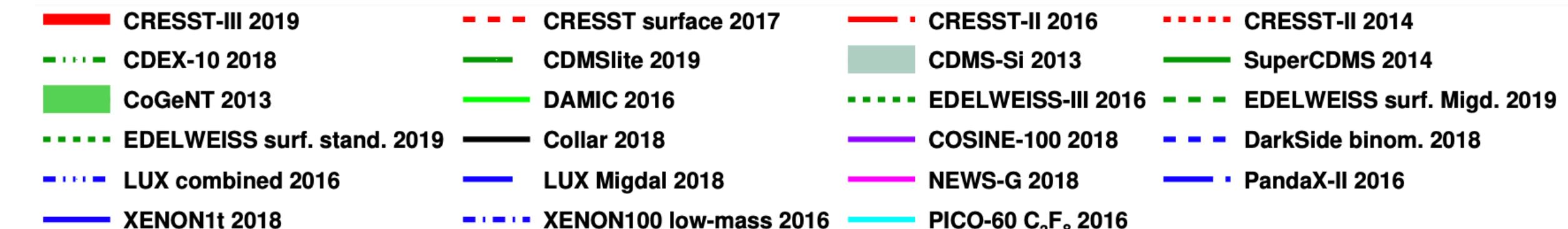
Direct Dark Matter searches

Several different experiments
with different technologies

The sensitivity is dominated by:

Noble liquids TPCs:
 $M_{DM} > \text{few GeV}$

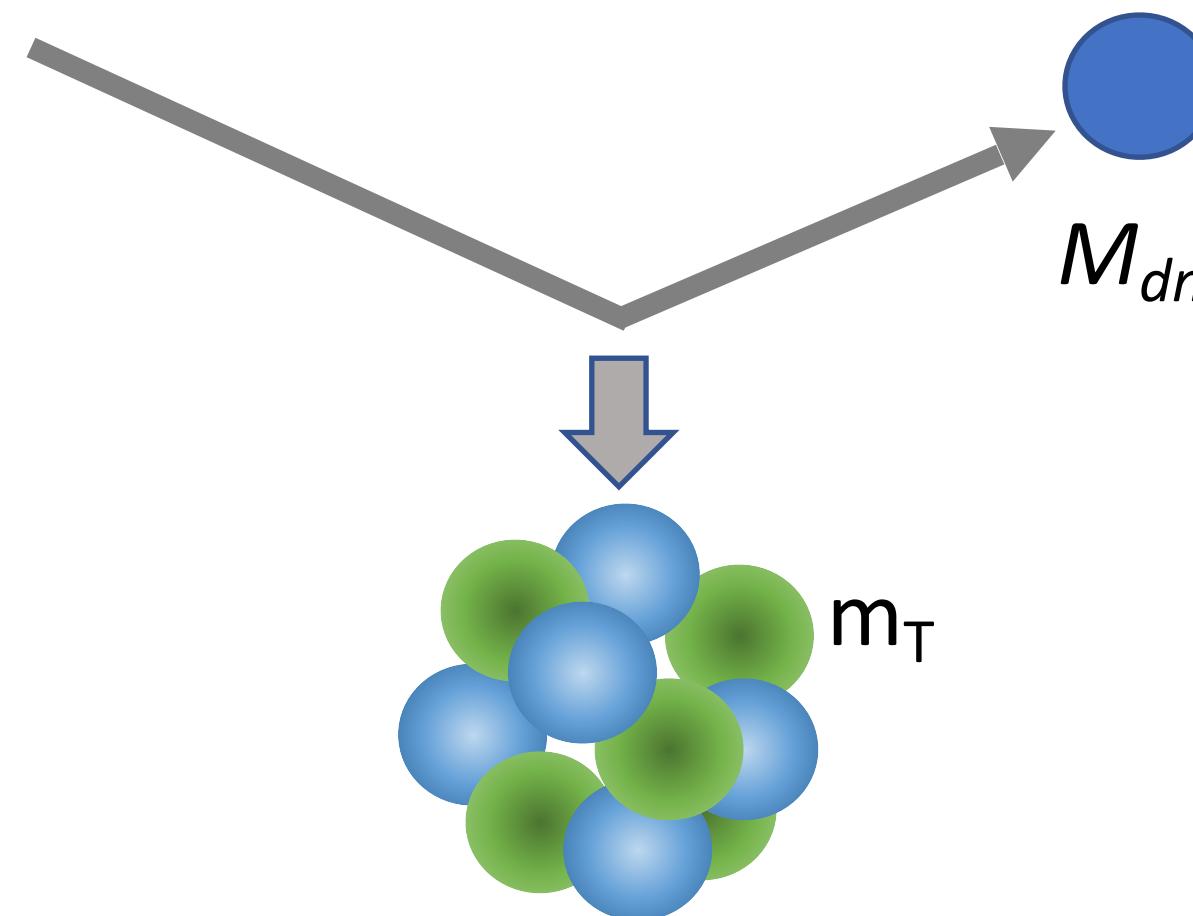
Cryogenic detectors:
 $M_{DM} < \text{few GeV}$



Direct DM detection on Earth

Assumptions on DM interaction:

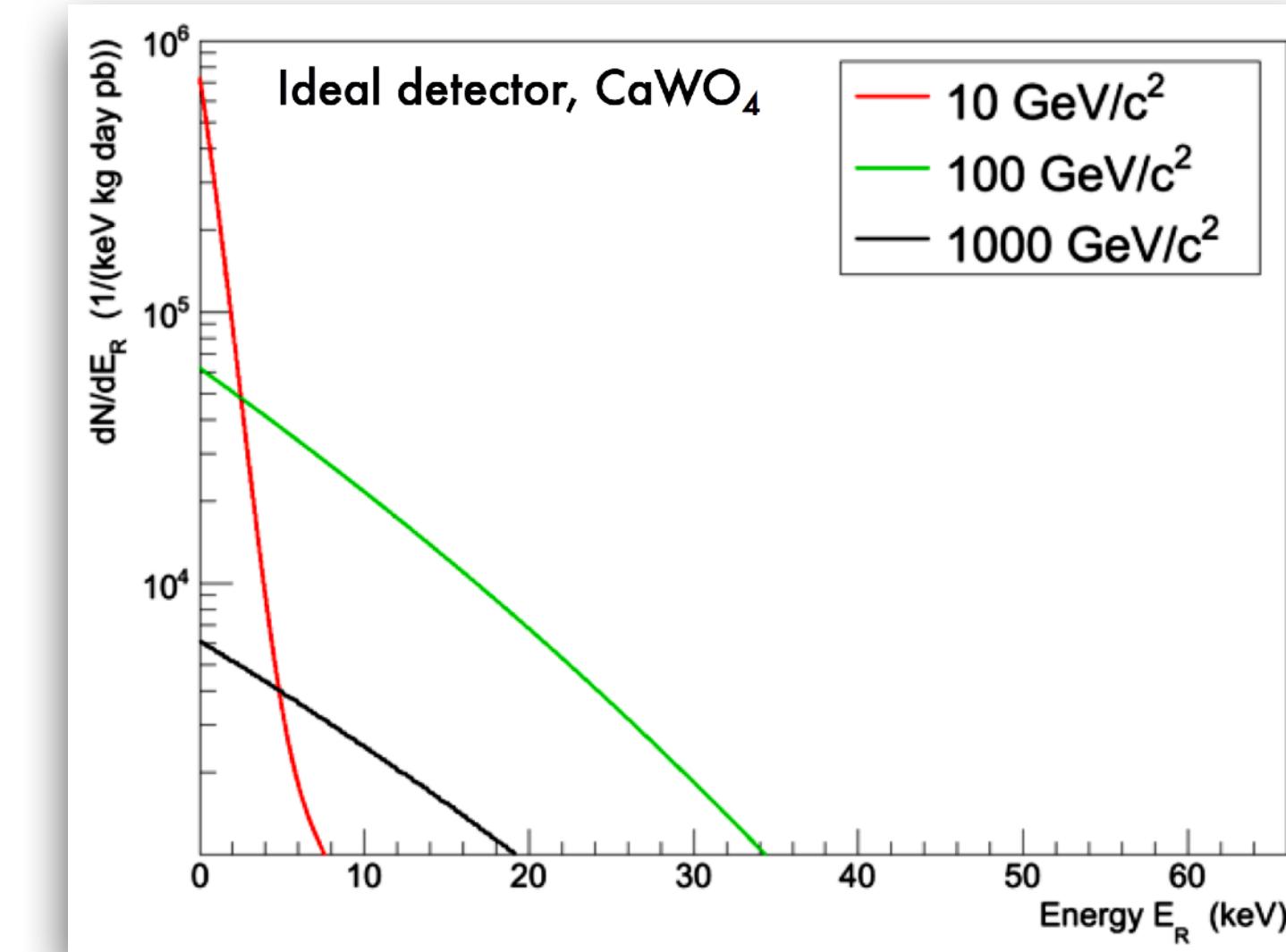
- Scattering off nuclei
- Elastically and coherently
- Spin independently



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

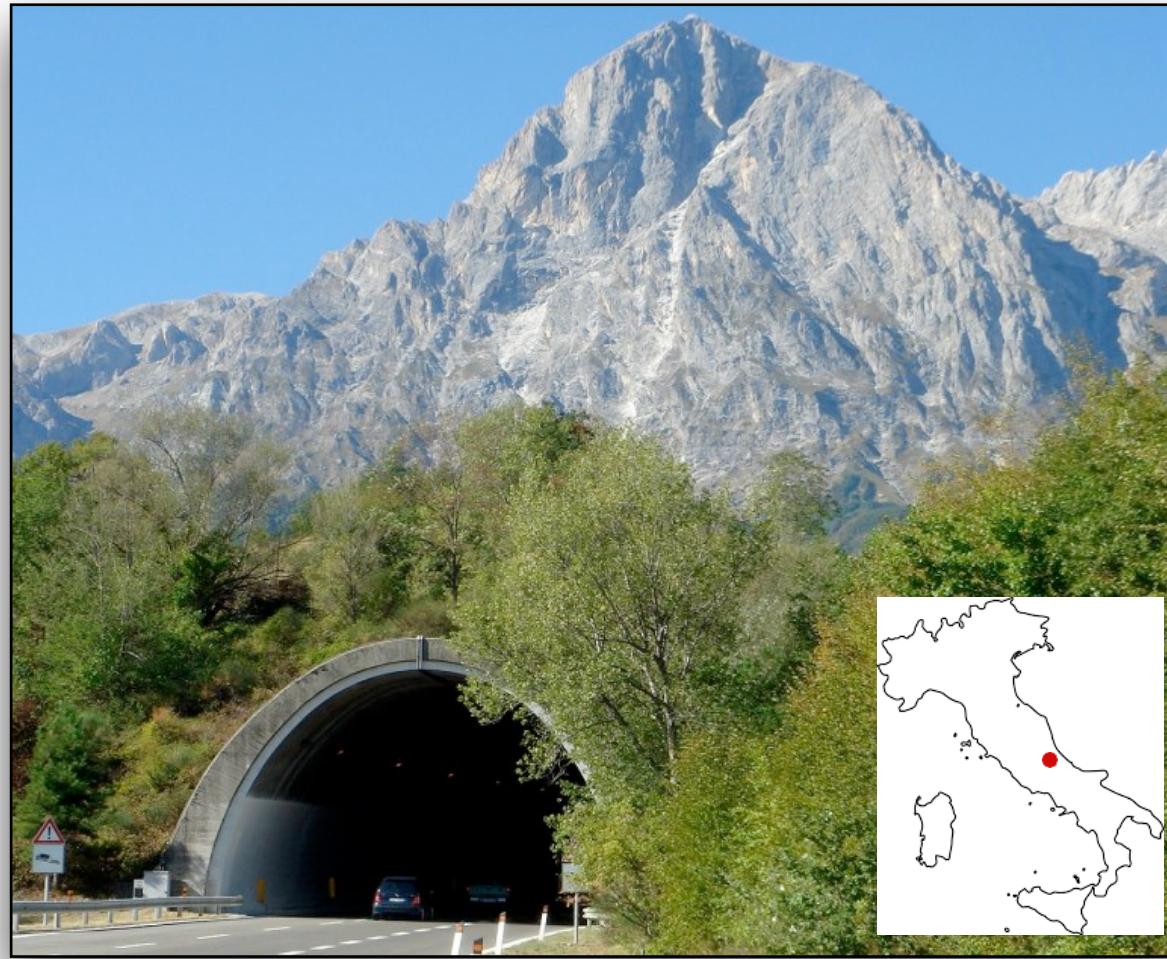


Signal + bkg feature :

- 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 ~ $2.6 \times 10^{-8} \mu/\text{s}/\text{cm}^2$

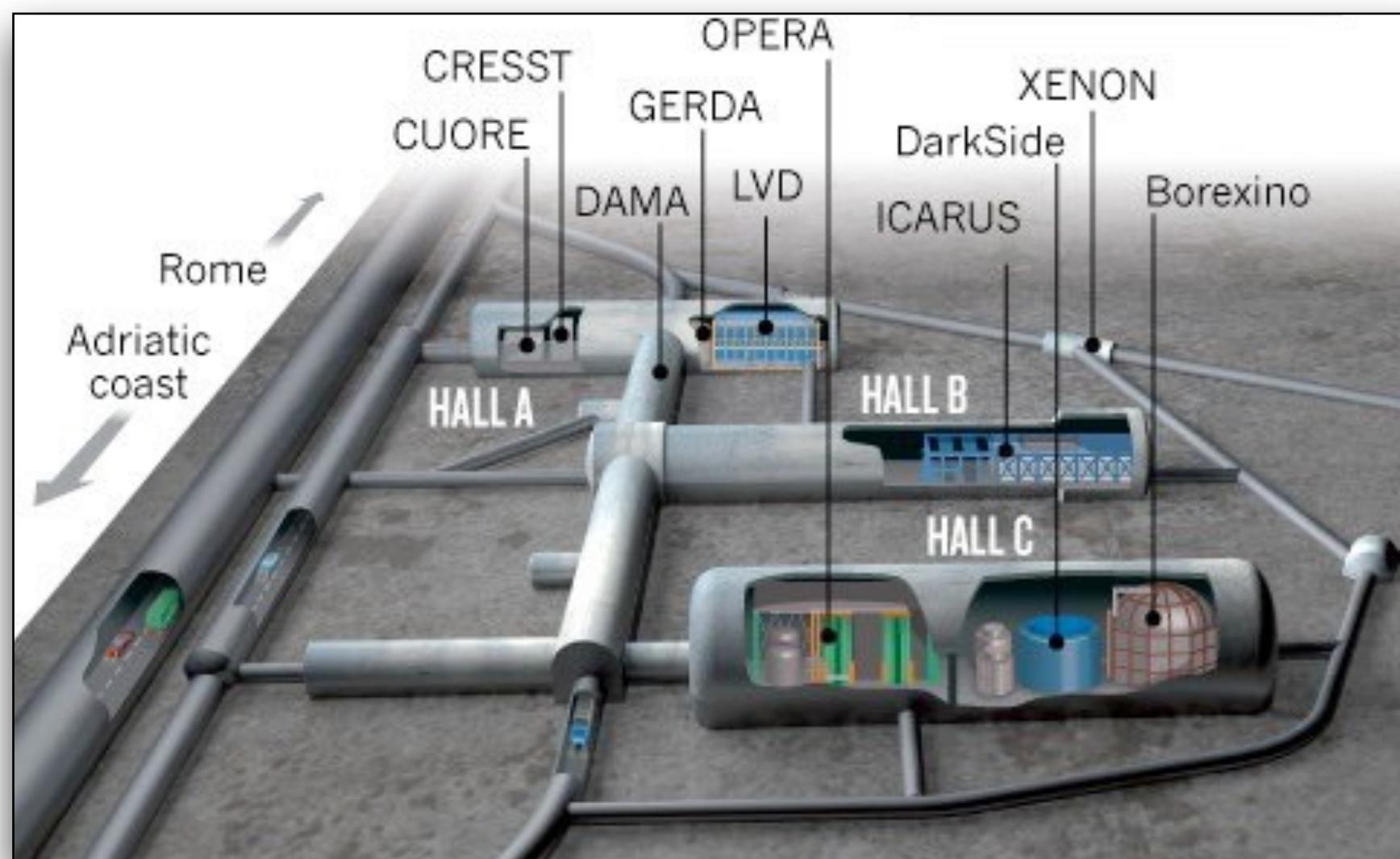
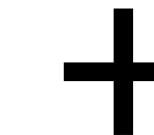
Neutrons < 10 MeV: $< 10^{-6} \text{n}/\text{s}/\text{cm}^2$

Detector shieldings :

Muon-veto

Gamma shields: Pb + Cu

Neutron moderator: PE (45 + 5) cm



CRESST detectors

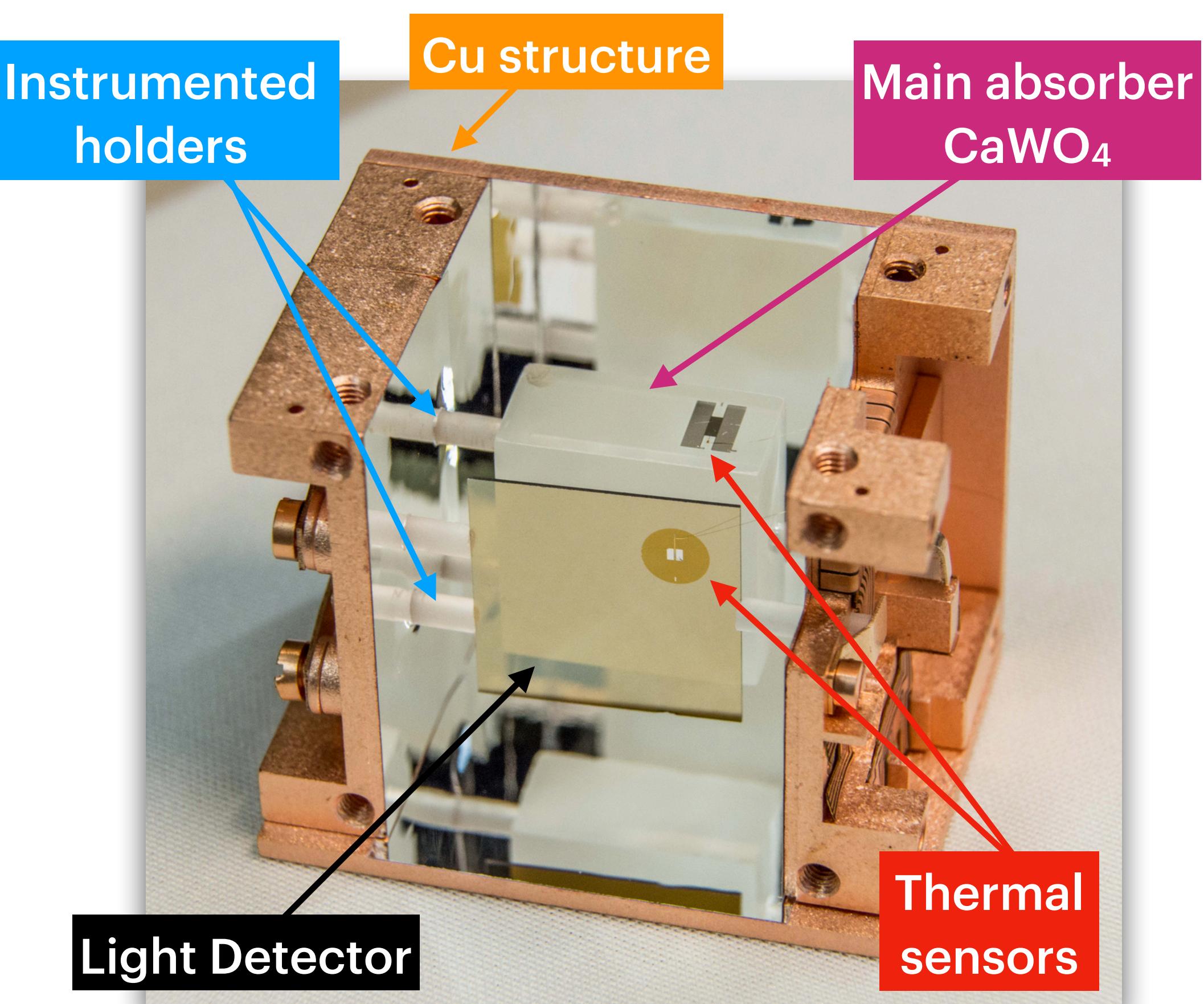
Cryogenic Rare Event Search with Superconducting Thermometers

CaWO₄ target crystals (24 g each)

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

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

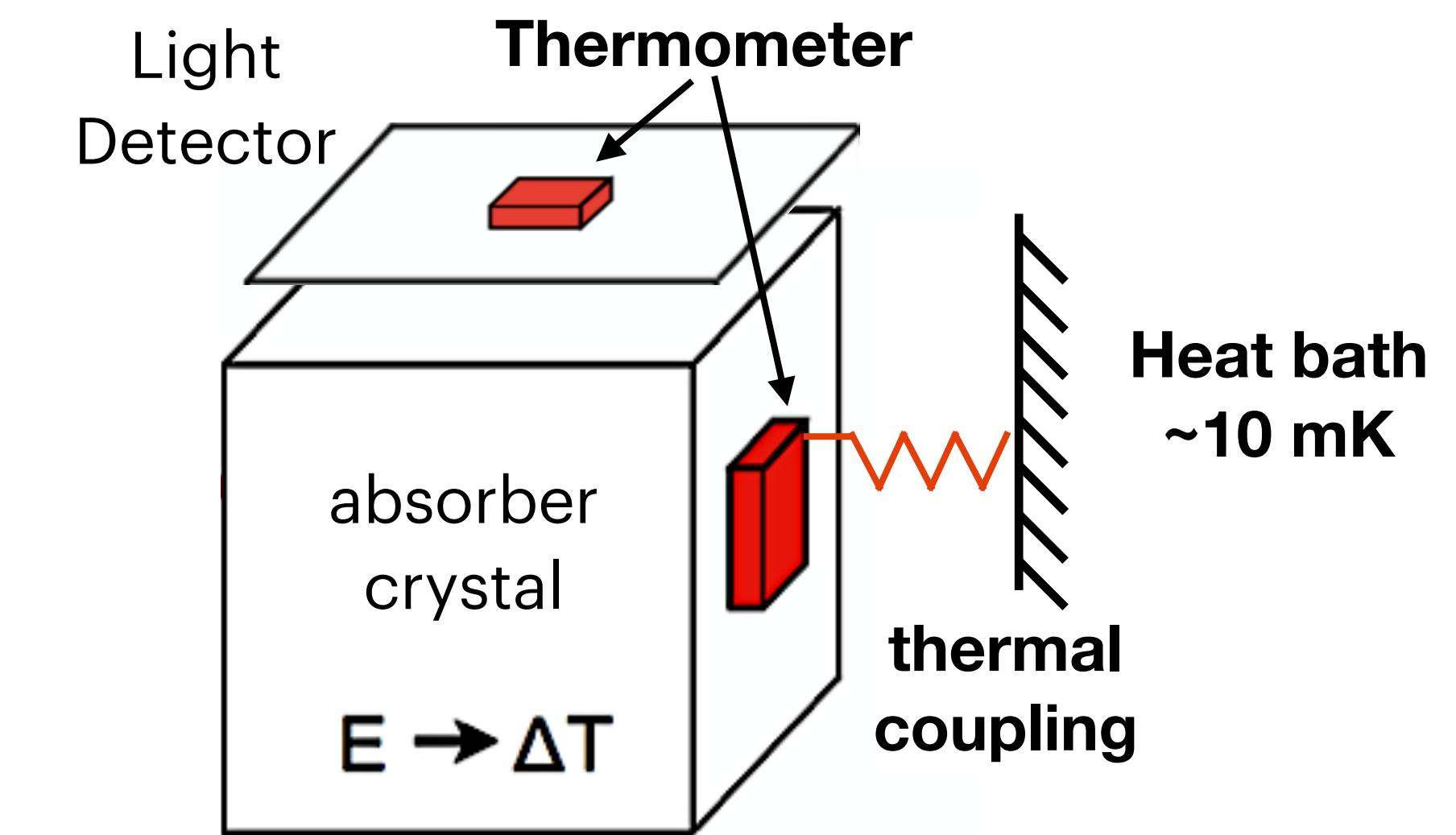
Double read-out cryogenic detector:
heat (CaWO₄) and **light** (LD - Light Detector)



Detector working principle

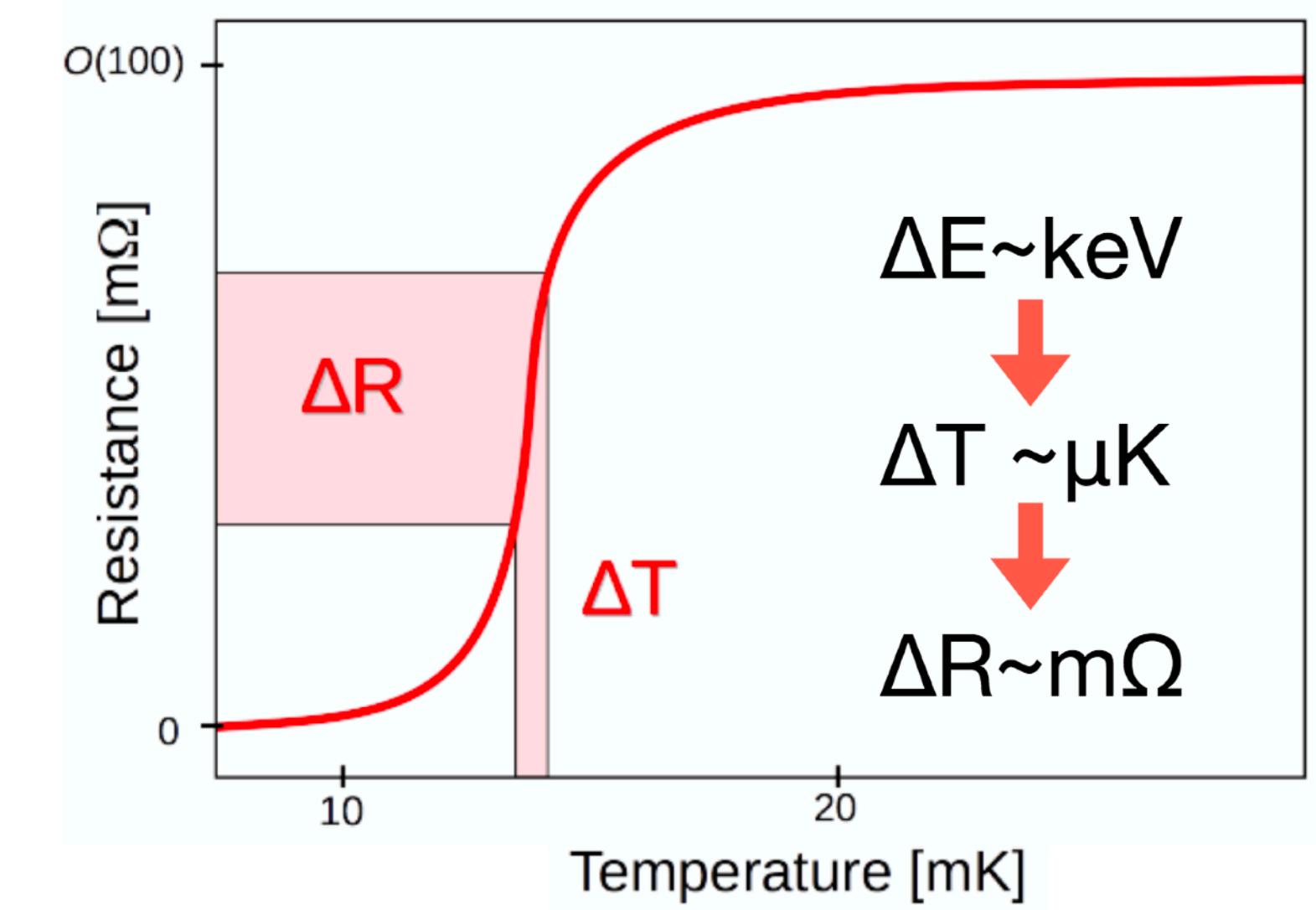
CRESST detectors are highly sensitive calorimeters operated @ cryogenic temperature

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



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

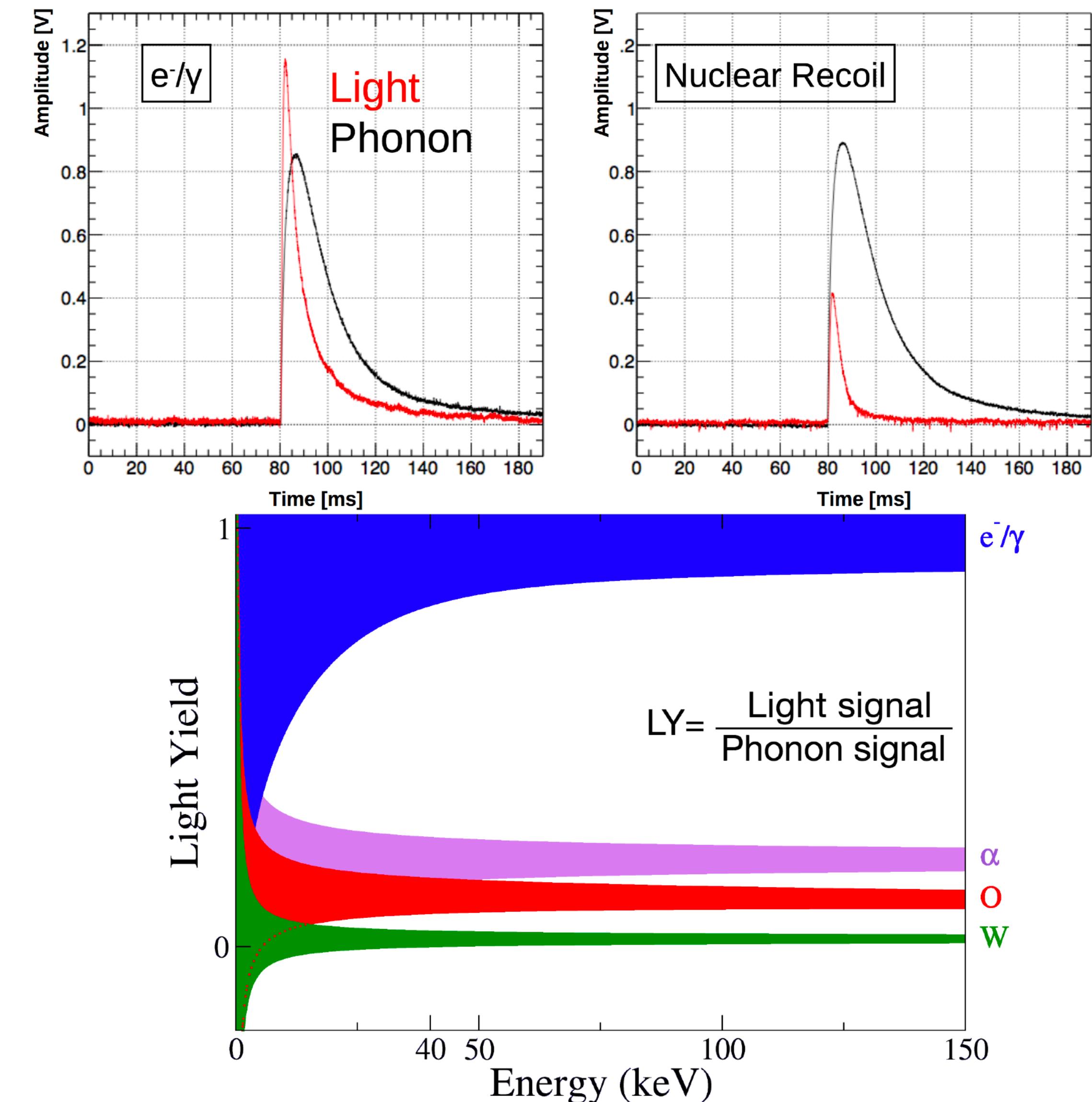
Ideal for reading out
extremely small ΔT O(μ K)



Signal identification technique

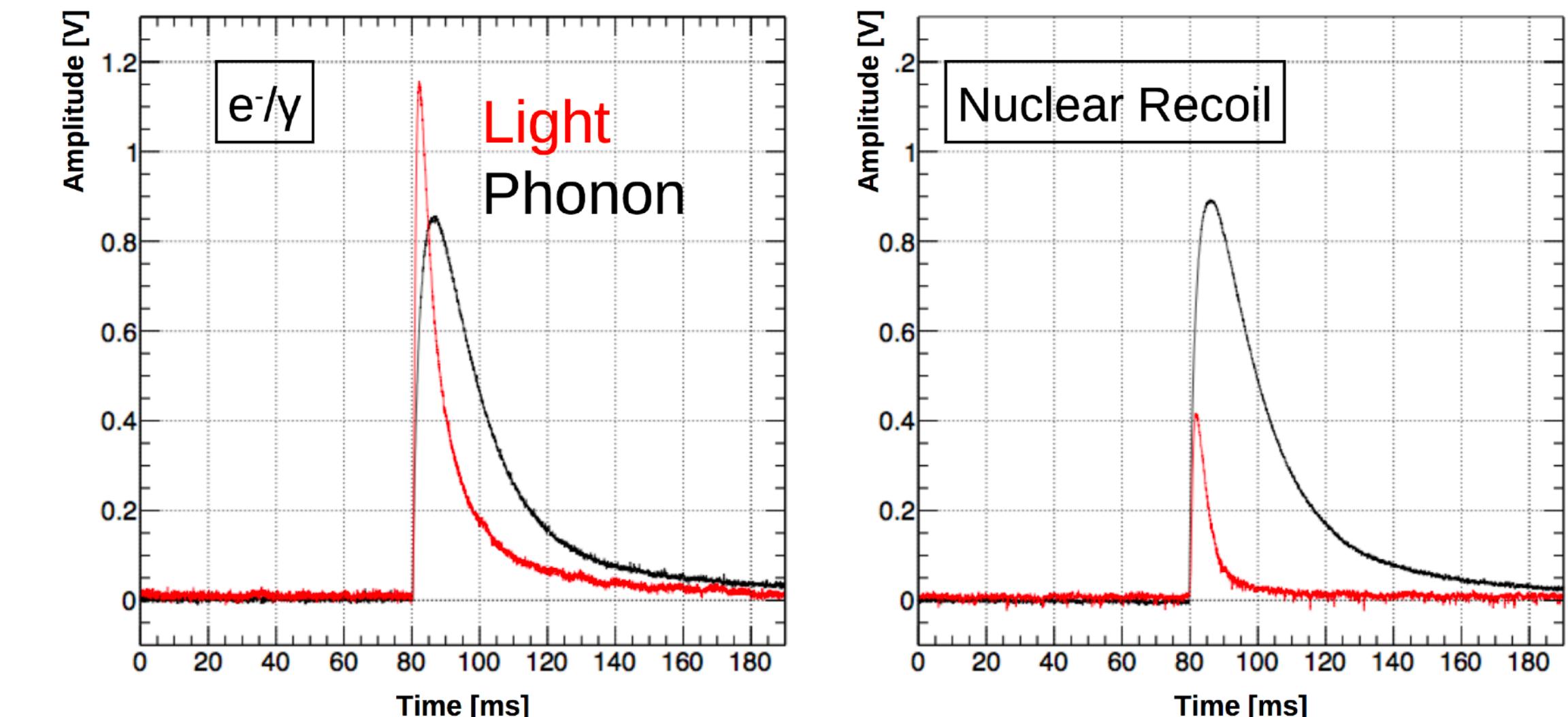
If the absorber is also an efficient scintillator the energy is converted into **heat + light**

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



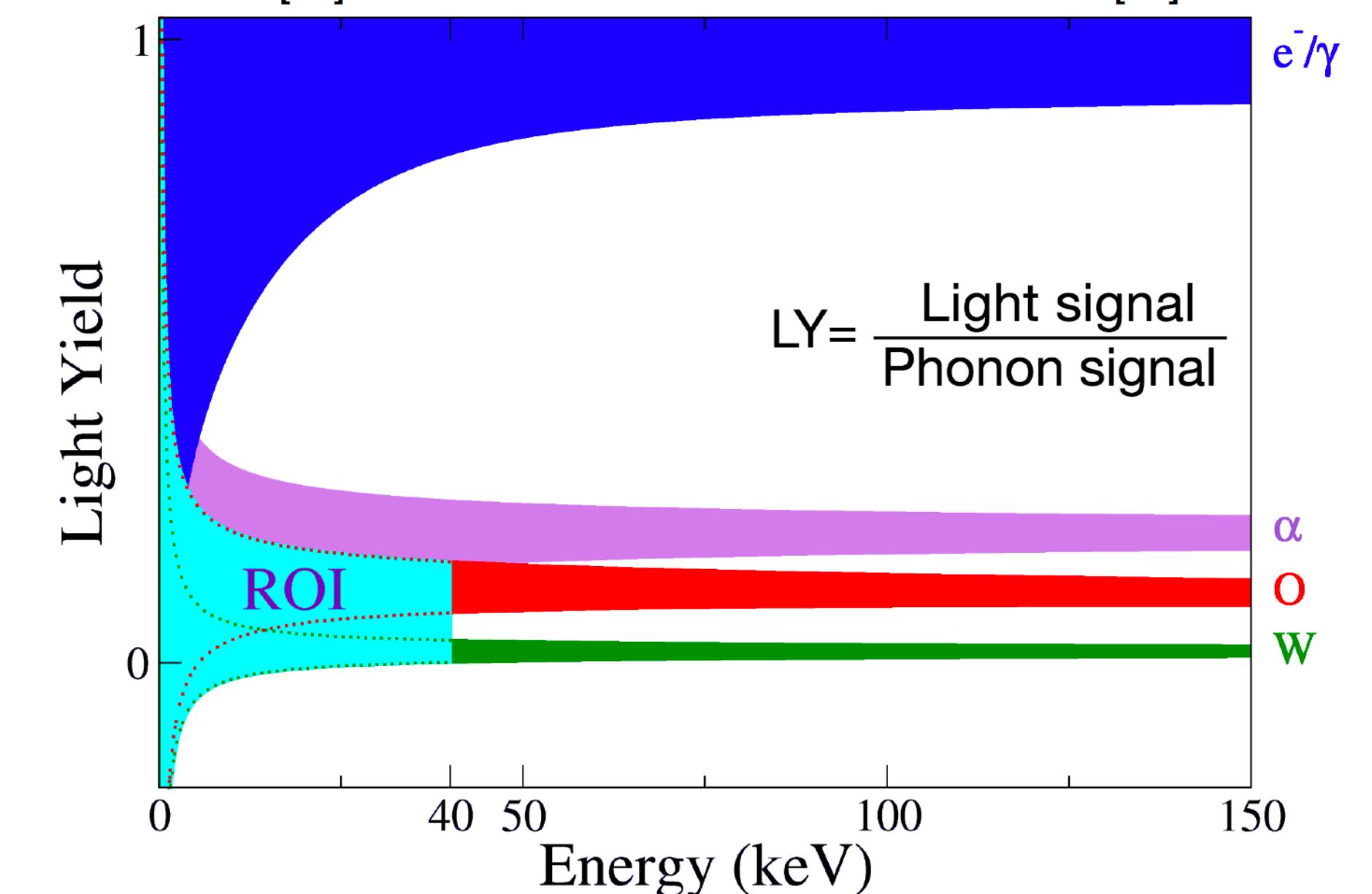
Signal identification technique

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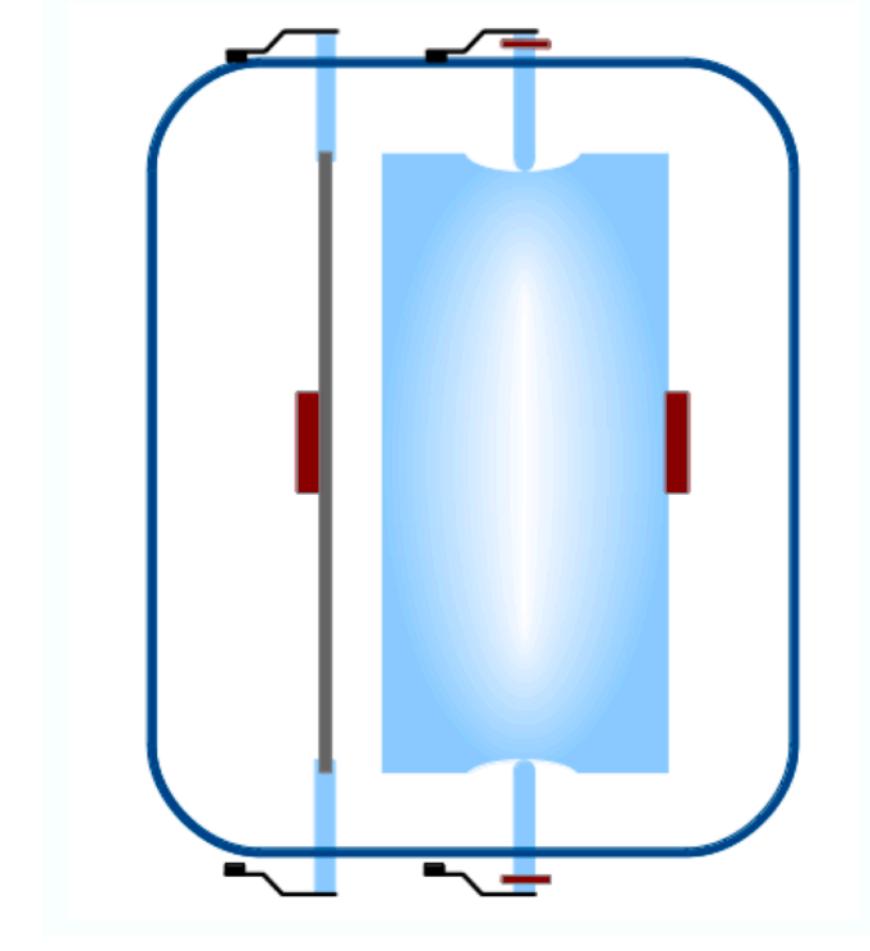
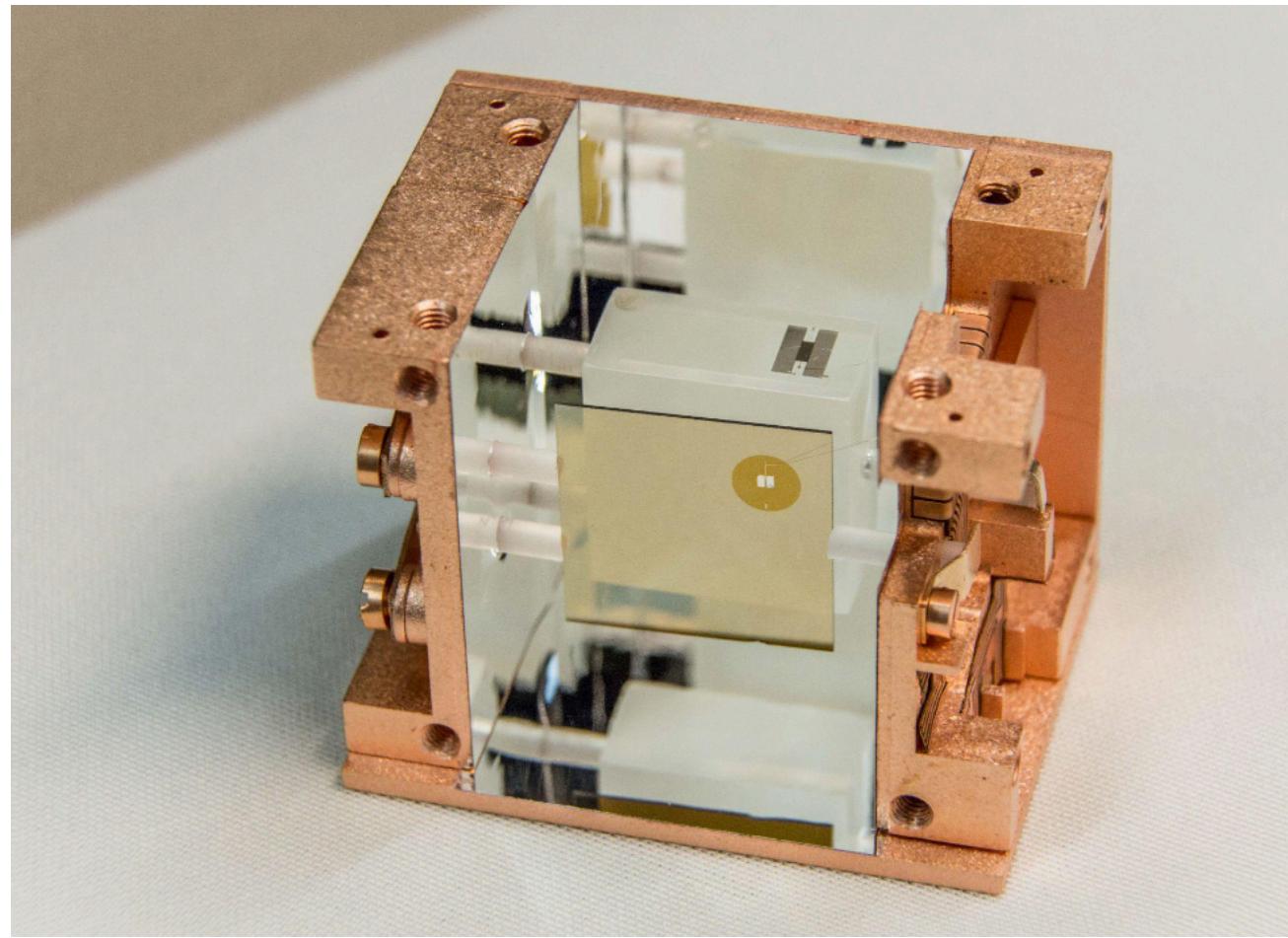


Excellent discrimination between potential signal events (**nuclear recoils**) and dominant radioactive background (**electron recoils**)

DM signal expected in the nuclear recoil band



CRESST-III



Gross exposure (before cuts): **5.7 kg days**

Target crystal mass: **23.6 g**

Baseline resolution: **4.6 eV**

Analysis threshold: **30.1 eV**

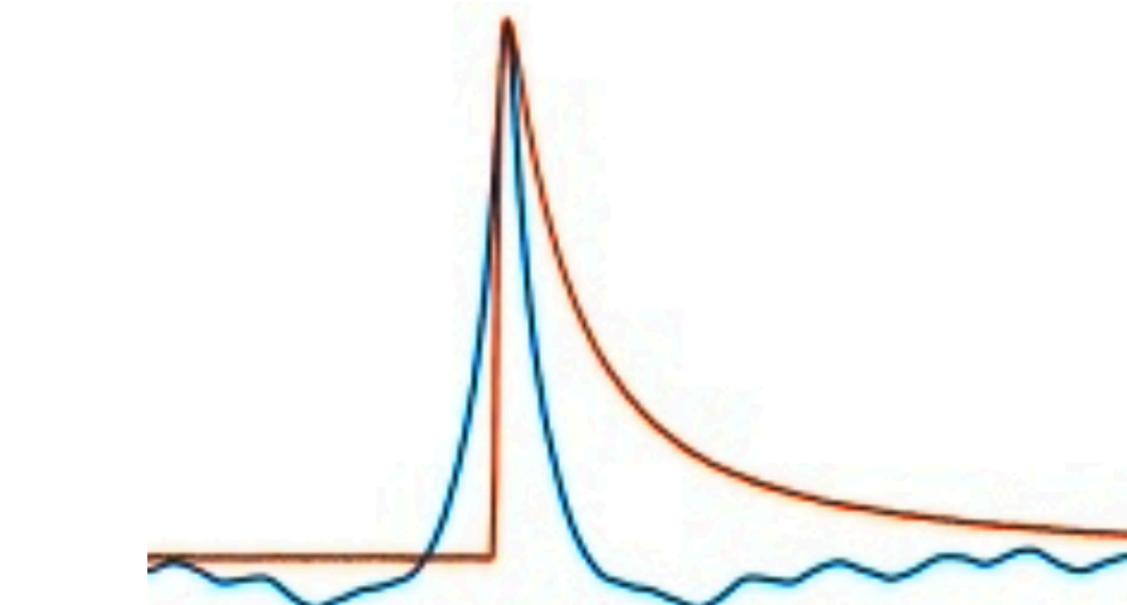
ROI: **up to 16 keV**

Data processing & selection

We record the continuous stream of data:



Data goes through an Optimum Filter/Trigger algorithm:



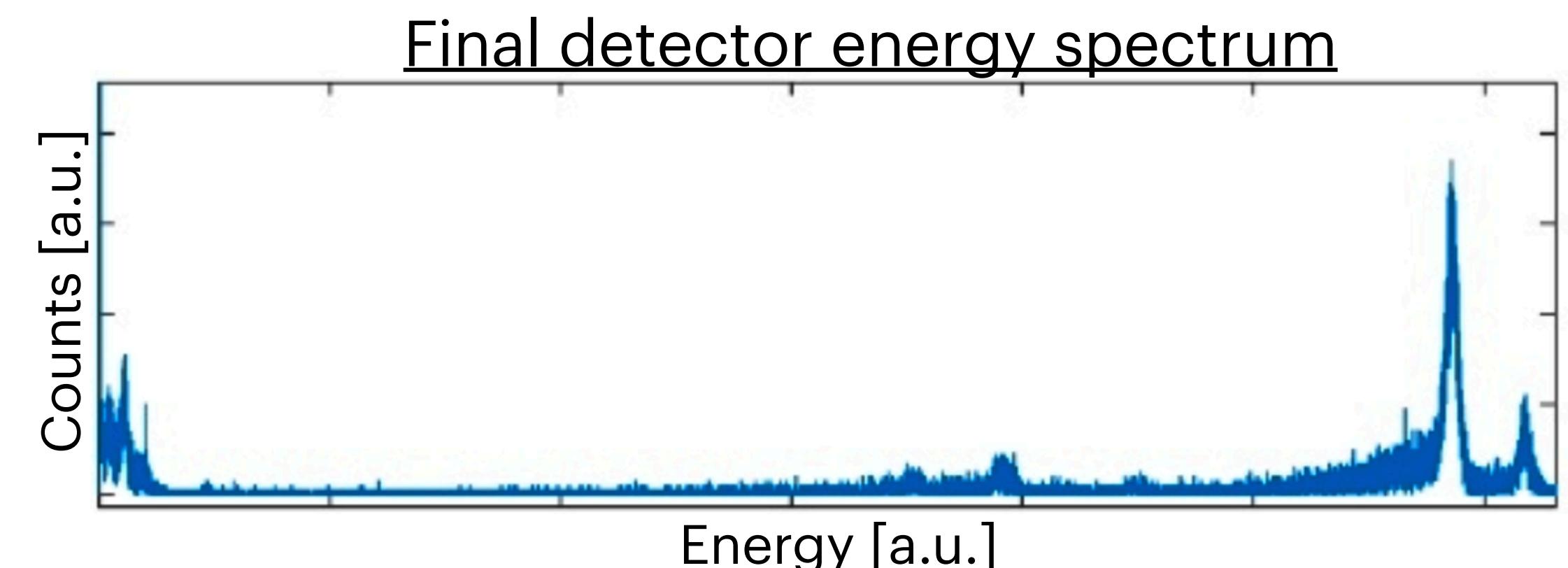
Data selection training done on different parameters (<20% of acquired data, the rest is blinded):

Rate: noise conditions

Stability: Detector(s) in operating point

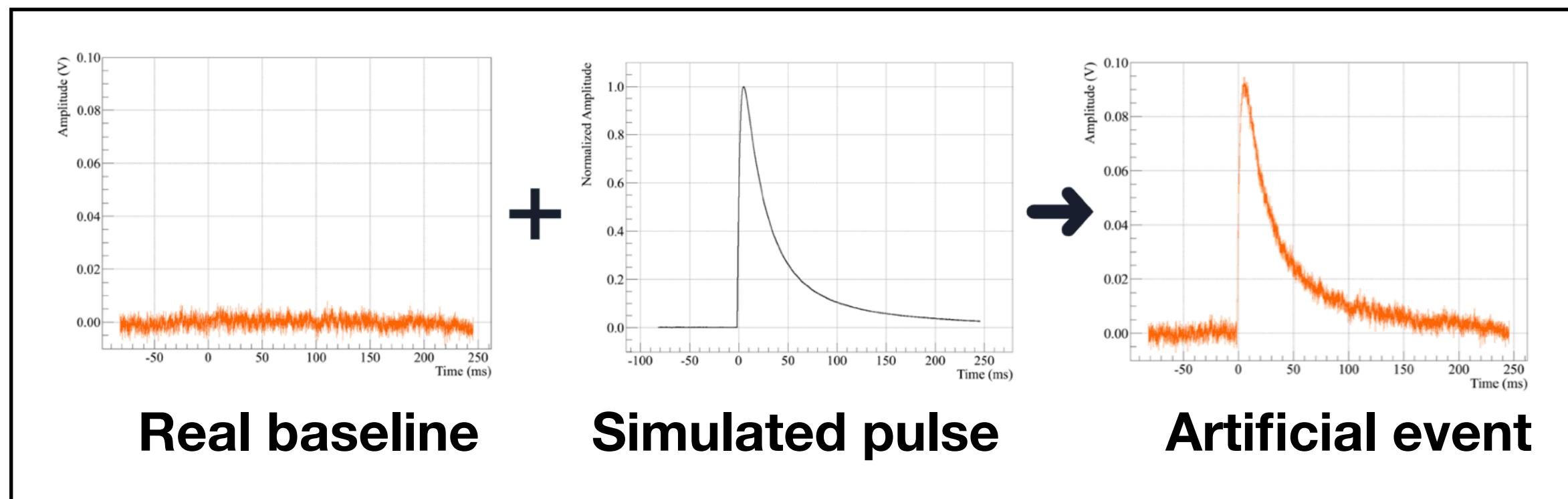
Data quality: Non-standard pulse shapes (e.g. pileup)

Coincidences: with μ -veto, i-Sticks, other detectors



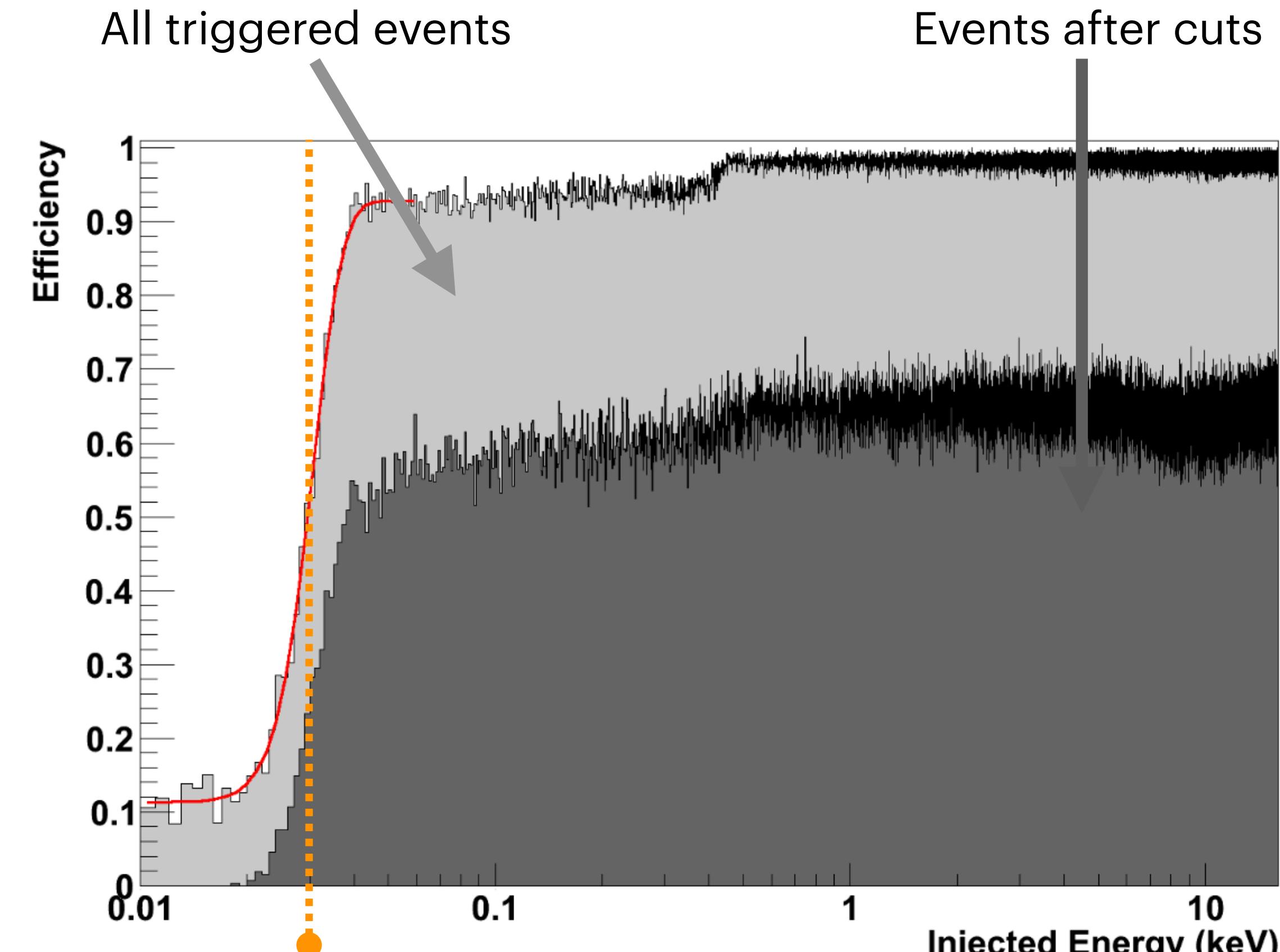
Signal survival probability

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



→ Trigger and cuts efficiency

$\epsilon \geq 60\%$ efficiency over a wide energy range

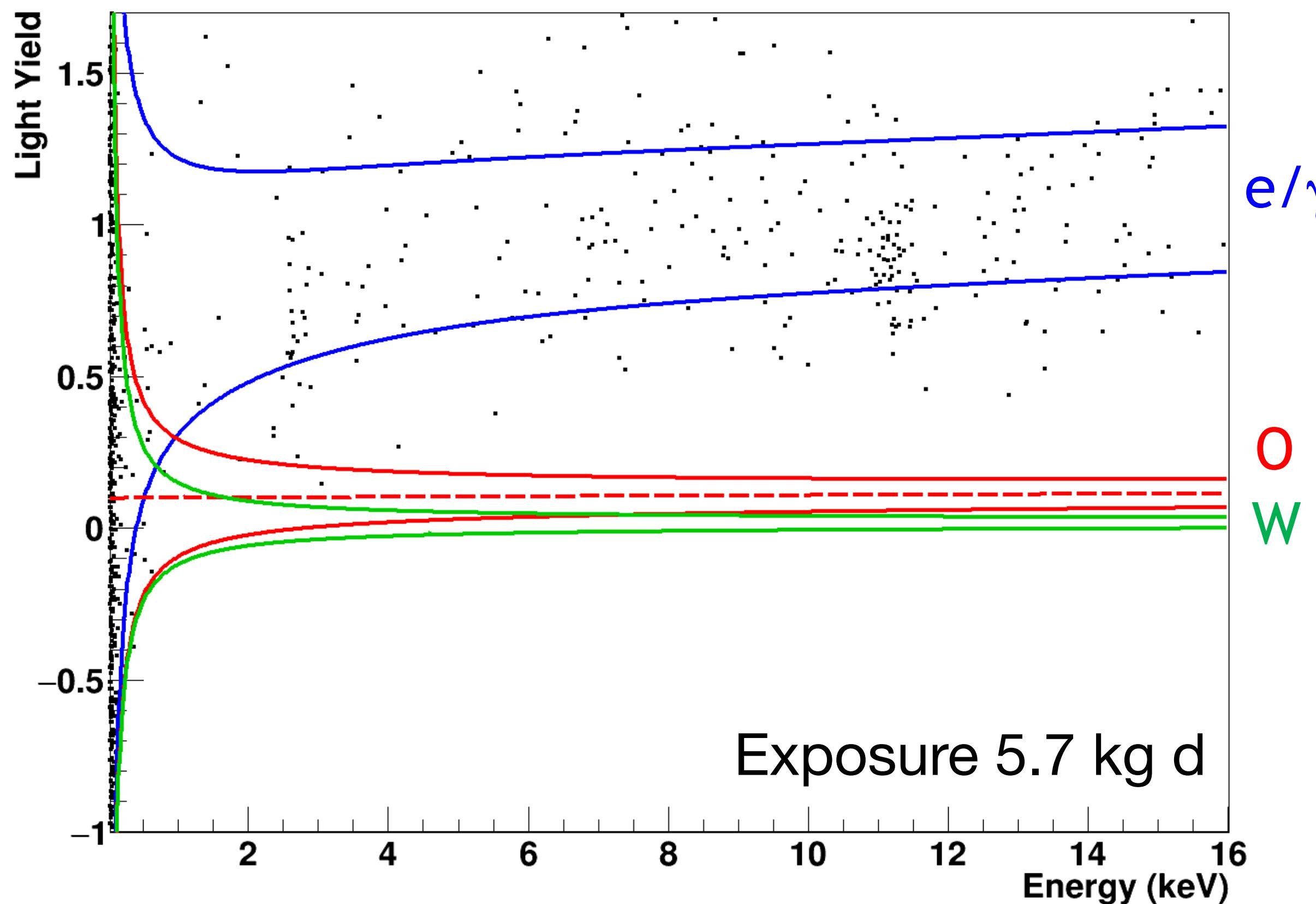


Best performing detector:
Energy Threshold: 30 eV
(= 1 noise event triggered 1 c/kg/d)

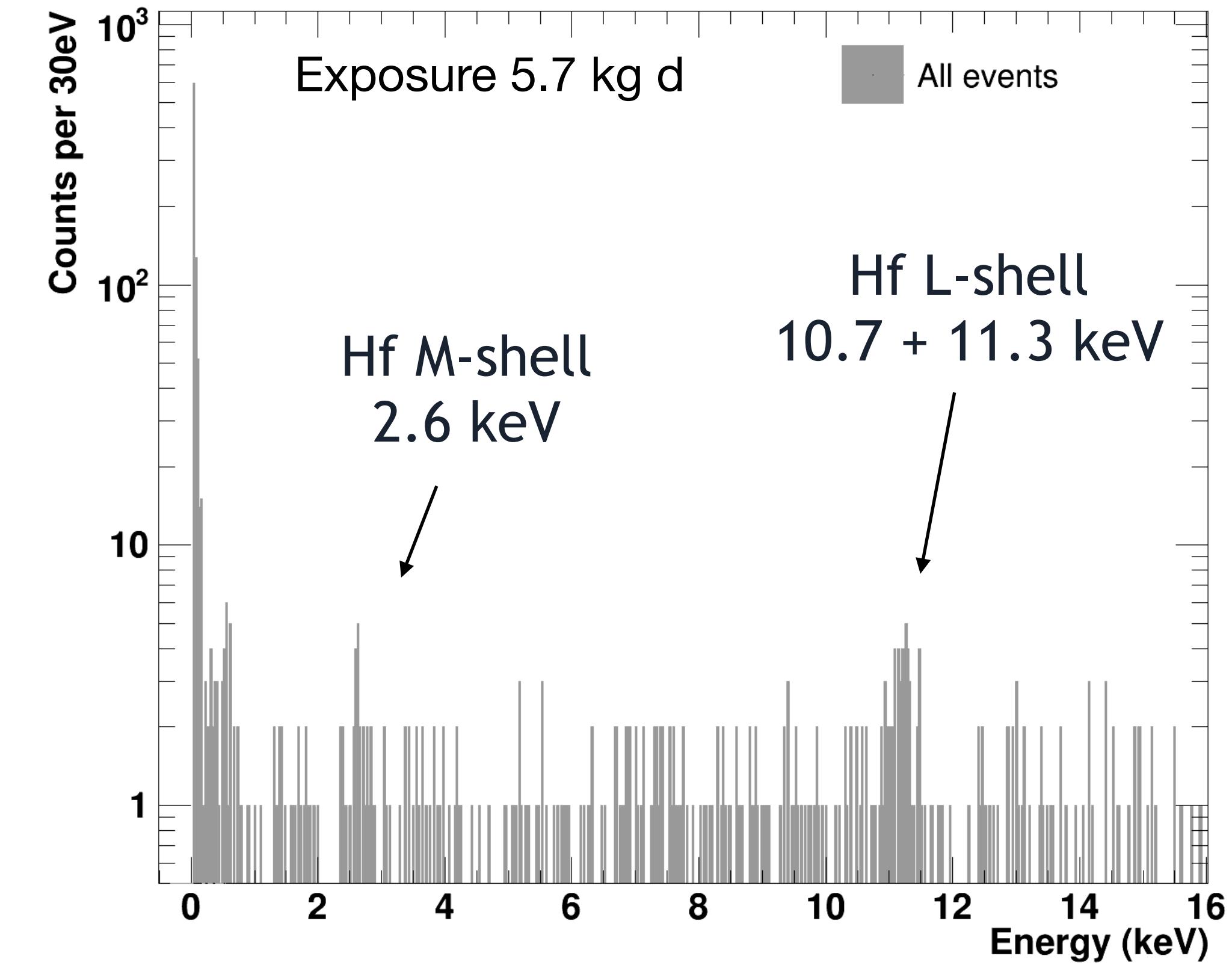
Det-A

Final energy spectra of Det-A

Background Light Yield scatter plot



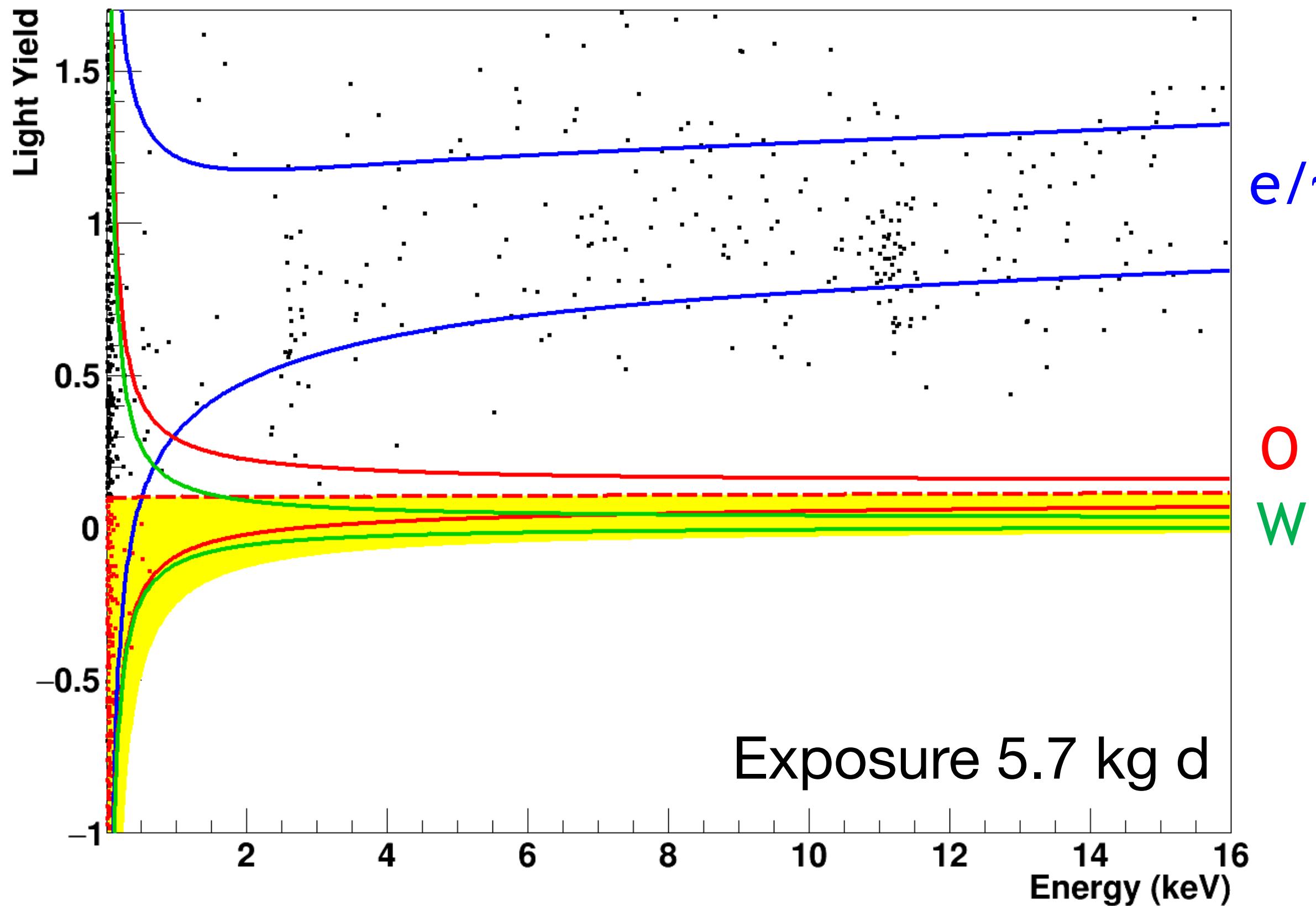
Total energy spectrum (e/g + NR)



cosmogenic activation { $^{182}\text{W} + \text{p} \rightarrow ^{179}\text{Ta} + \text{a}$
 $^{179}\text{Ta} + \text{e}^- \rightarrow ^{179}\text{Hf} + \nu_e$

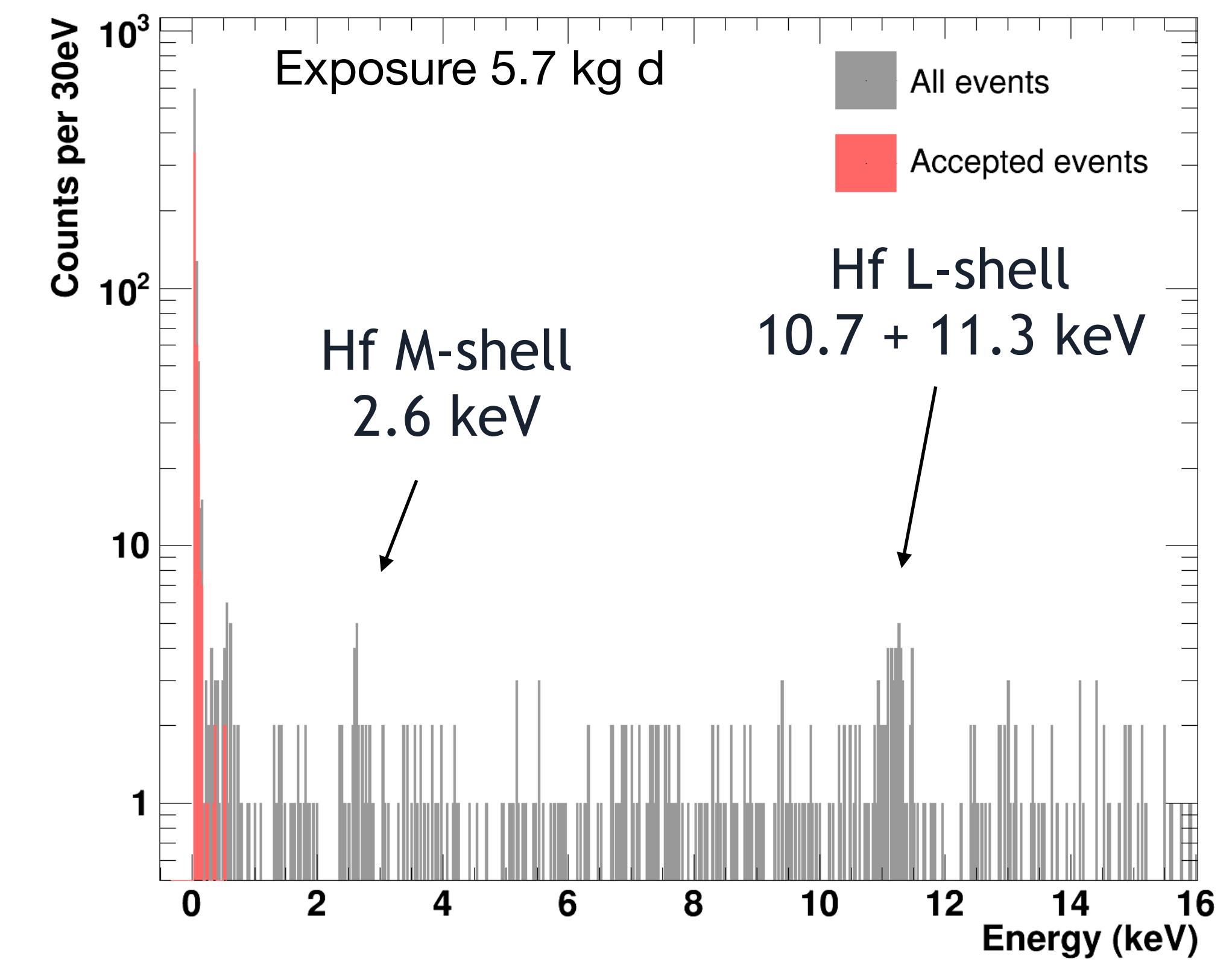
Final energy spectra of Det-A

Background Light Yield scatter plot



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

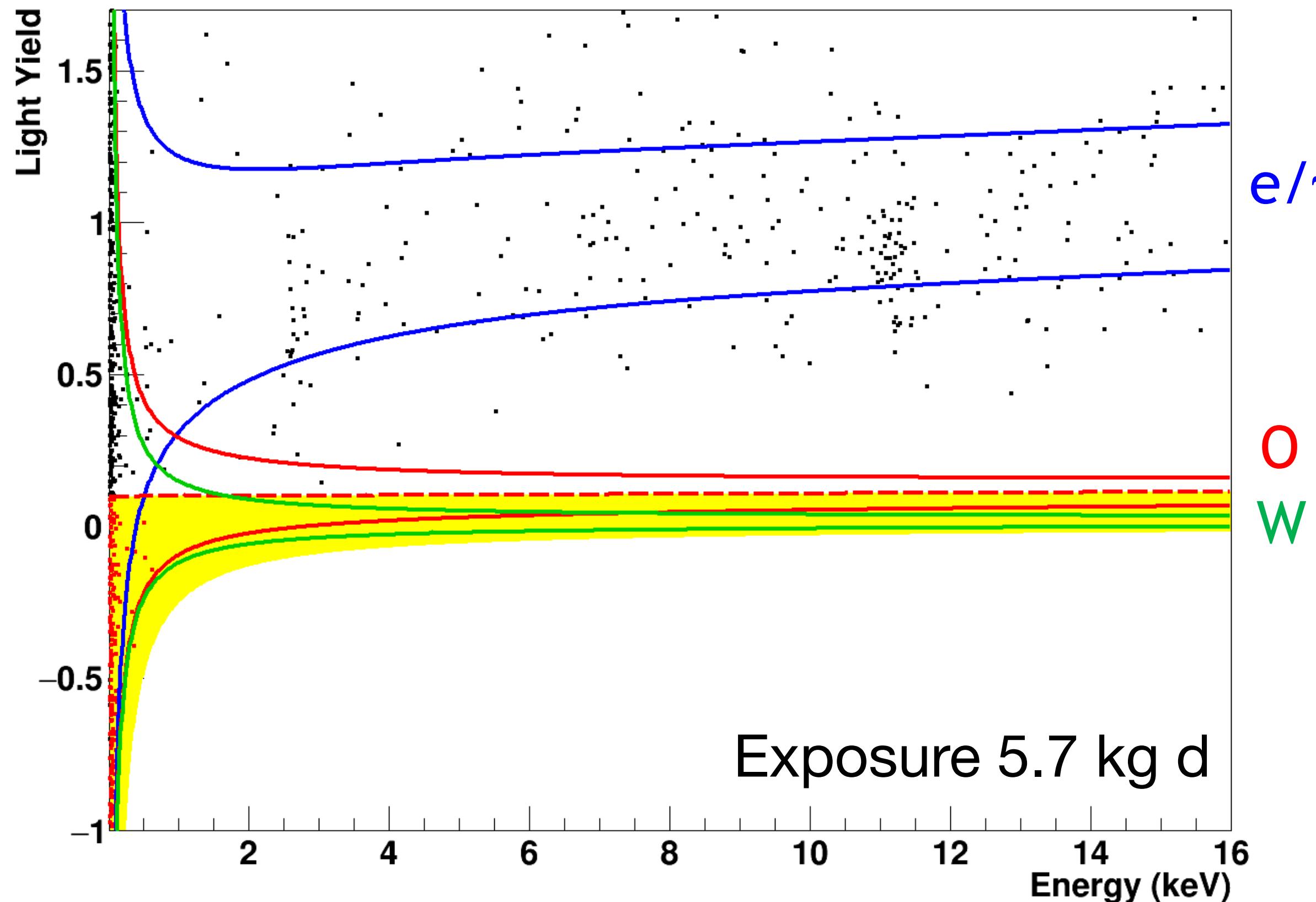
Total energy spectrum (e/g + **NR**)



Cosmogenic activation $\left\{ \begin{array}{l} ^{182}\text{W} + \text{p} \rightarrow ^{179}\text{Ta} + \text{a} \\ ^{179}\text{Ta} + \text{e}^- \rightarrow ^{179}\text{Hf} + \nu_e \end{array} \right.$

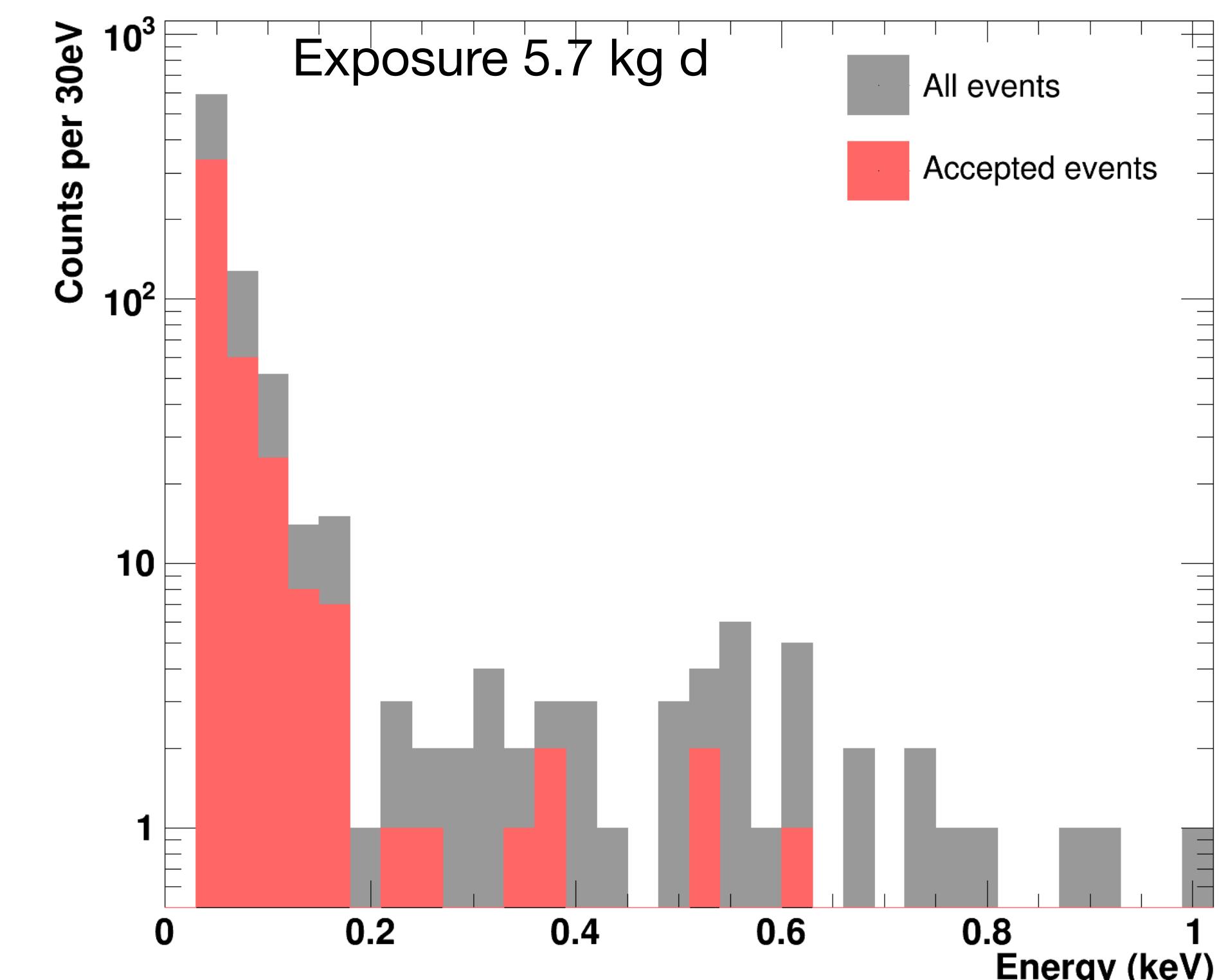
Final energy spectra of Det-A

Background Light Yield scatter plot

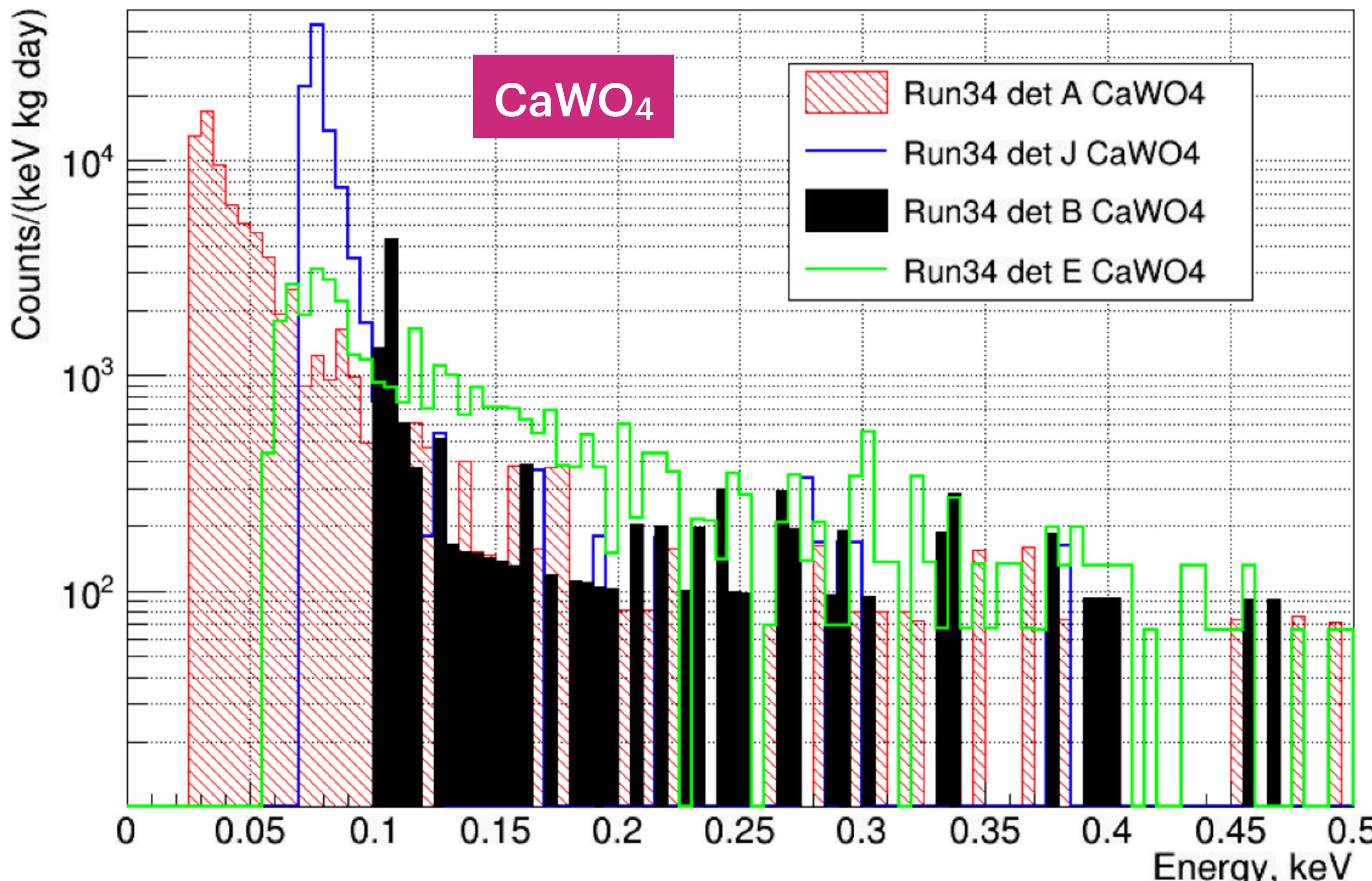


ROI: upper limit 50 % O recoils
lower limit 99.5 % W recoils

Zoom in
Total energy spectrum (e/g + NR)



Sanity checks (1)

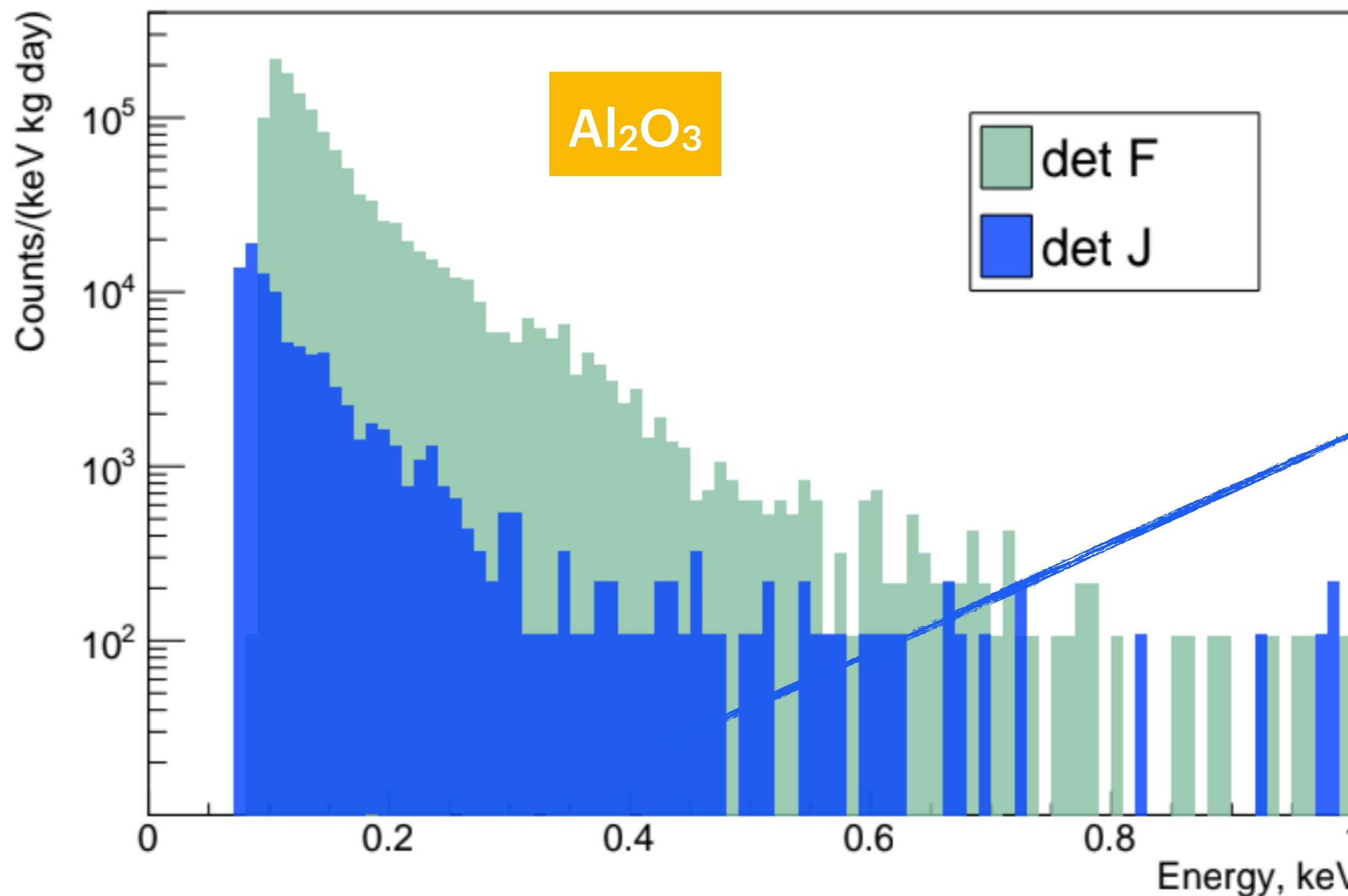


- Limiting low-mass DM sensitivity
- Strongly rising event rate below ~ 200 eV
- Rate and shape varies between detectors

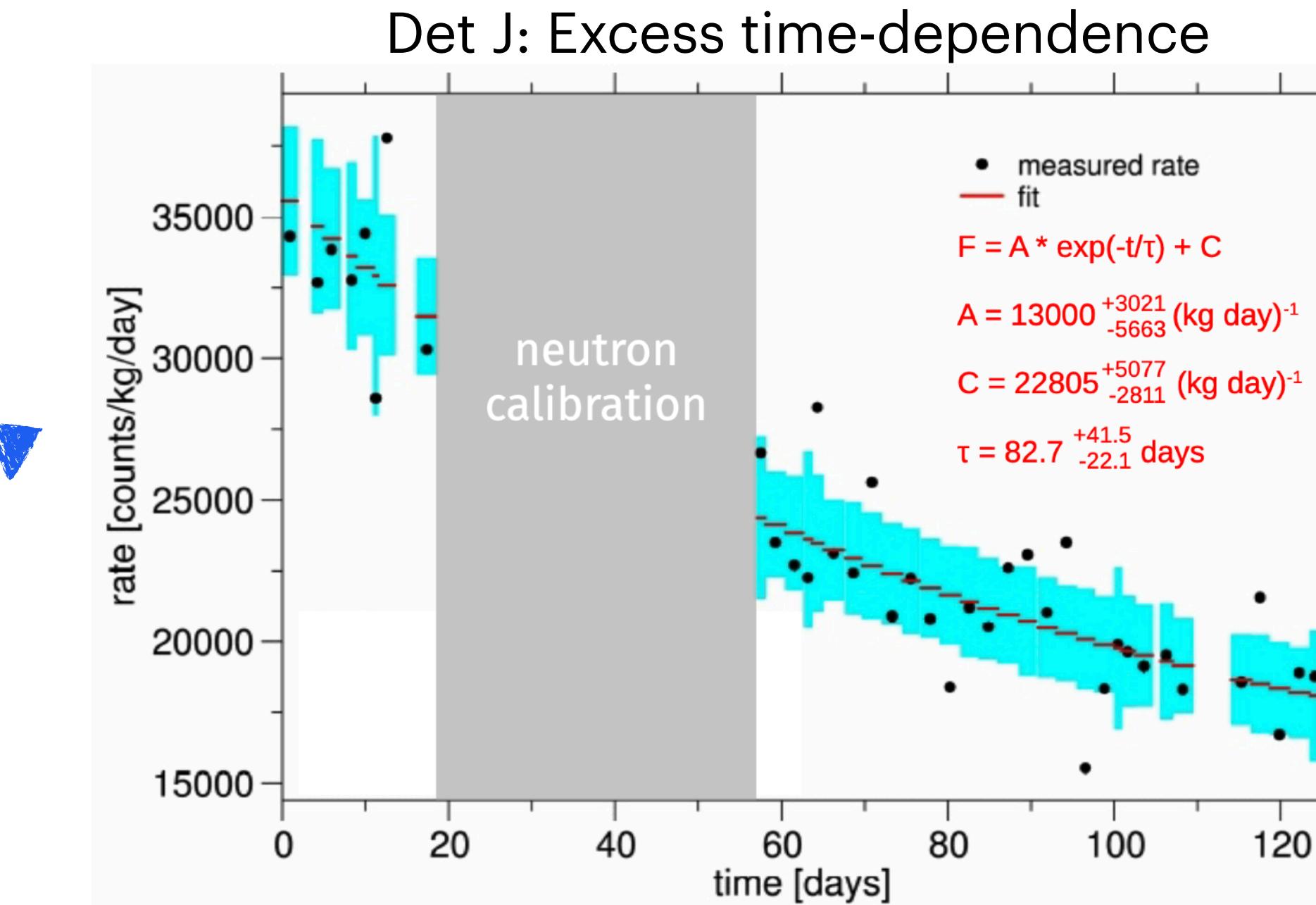
Broad community effort in understanding the excess observed in many others DM and CEvNS experiments



Sanity checks (2)



Gross (net) Exposure: 1.14 (0.99) kg d
 Detector mass: mass 15.92 g
 Det J threshold: 66 eV
 Det F threshold 77 eV



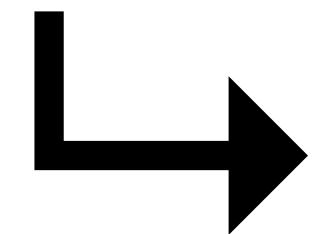
Preliminary hints

- ✓ Radioactivity origin: unlike
- ✓ Neutron background: unlike
- ✓ Noise trigger: unlike
- Non-particle origin: under-investigation

Final results Det-A

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

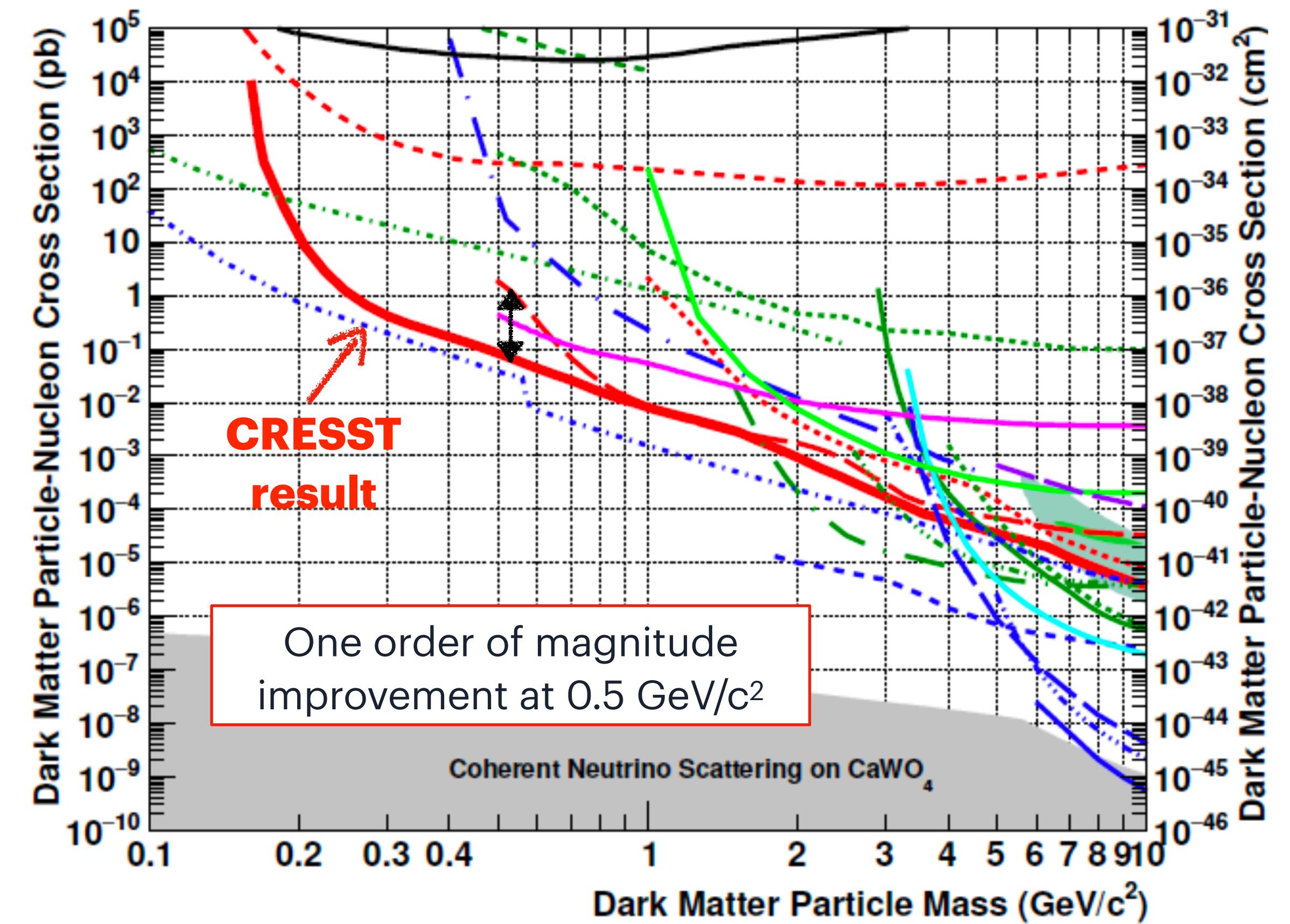
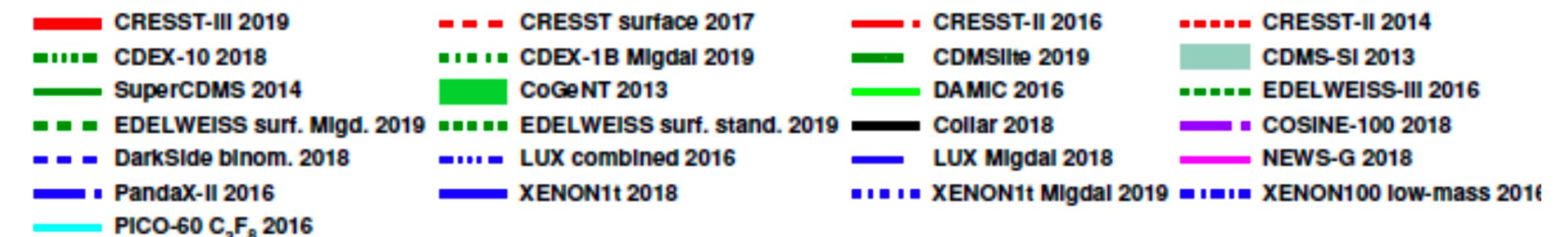
Energy spectrum of accepted
events (no bkg subtraction)



* Leading limit at low-
mass $< 1.7 \text{ GeV}/c^2$

↪ Background limited

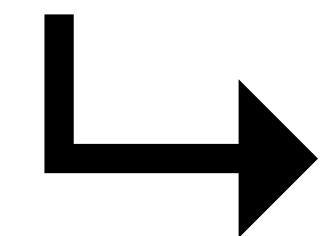
* until the existence of the Midgal effect is confirmed



Final results Det-A

1D Yellin optimum interval method
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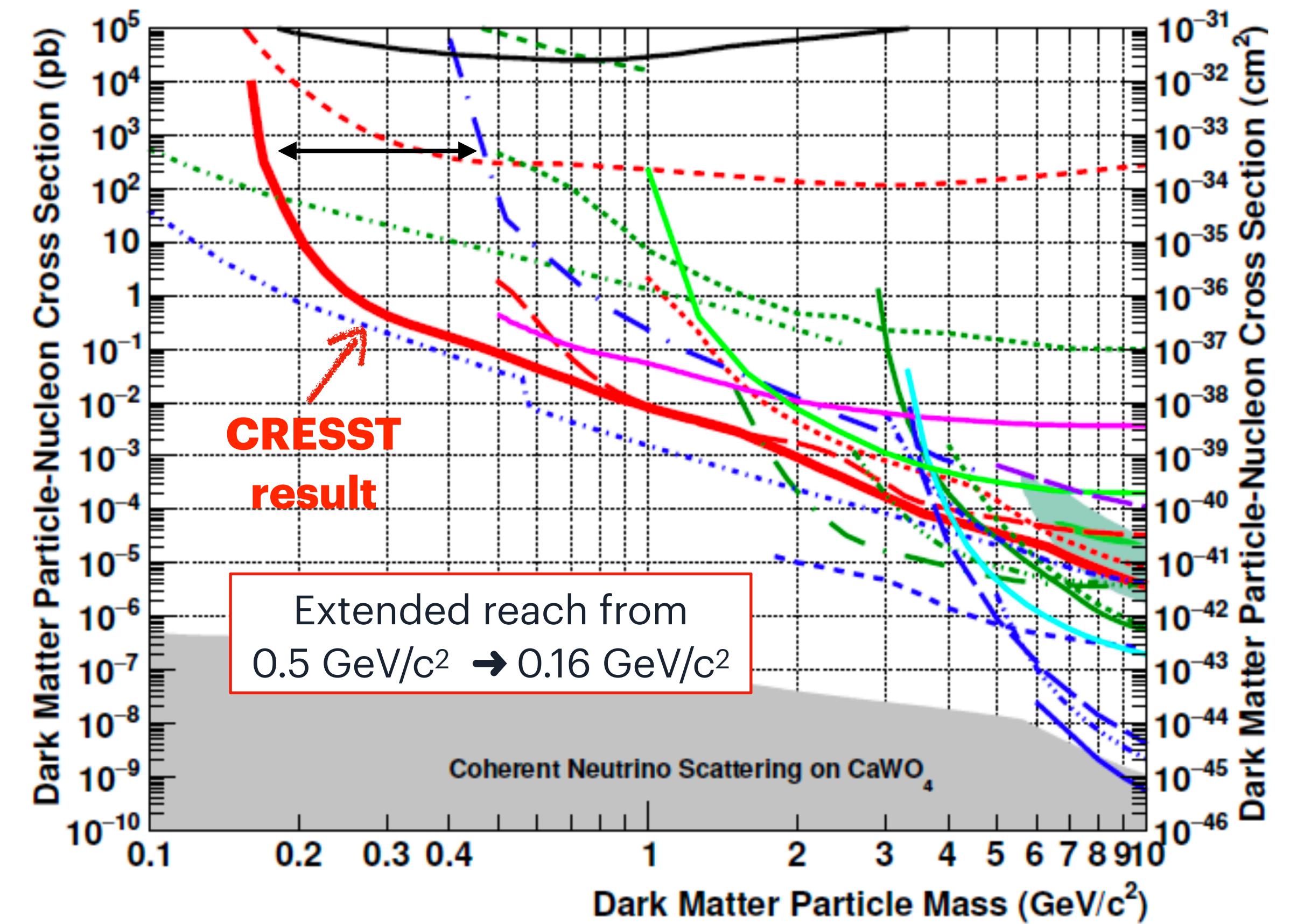
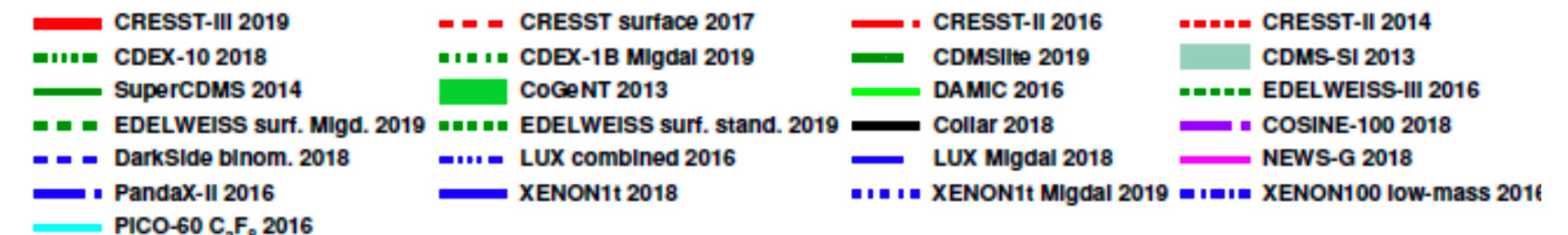
Energy spectrum of accepted
events (no bkg subtraction)



* Lowest mass investigation
 $>0.16 \text{ GeV}/c^2$

↳ Performance "limited"

* until the existence of the Midgal effect is confirmed

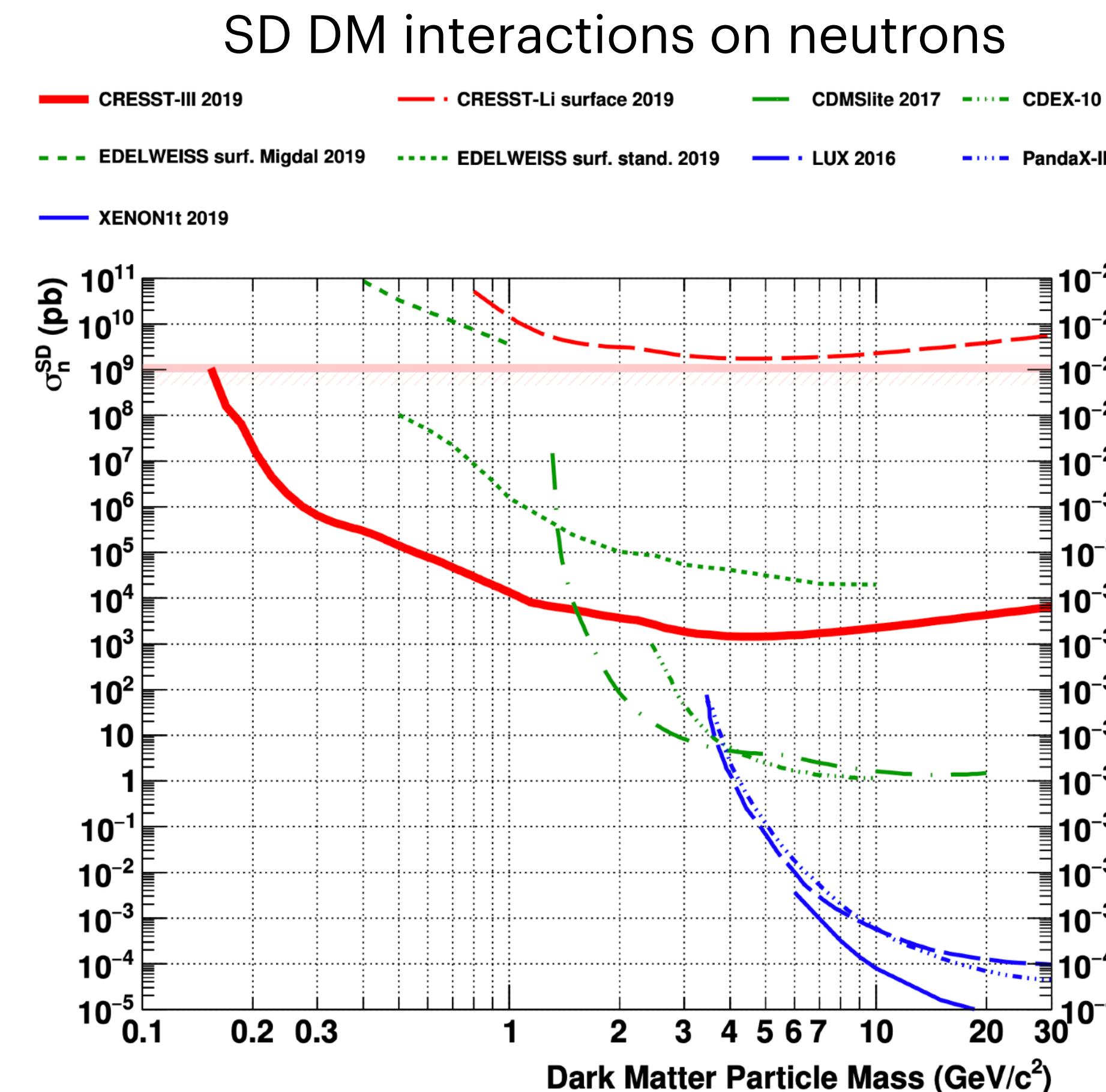


Other target materials

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

Operation of a LiAlO₂ scintillating cryogenic detector

Results on spin-dependent (⁷Li and ²⁷Al) DM interactions with *neutron* and *protons*



Conclusions

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

- ultra-low energy threshold
- versatility of target material

Leading results in the field of Light DM:

- spin-independent
- spin-dependent

The DM community is currently facing a challenge:

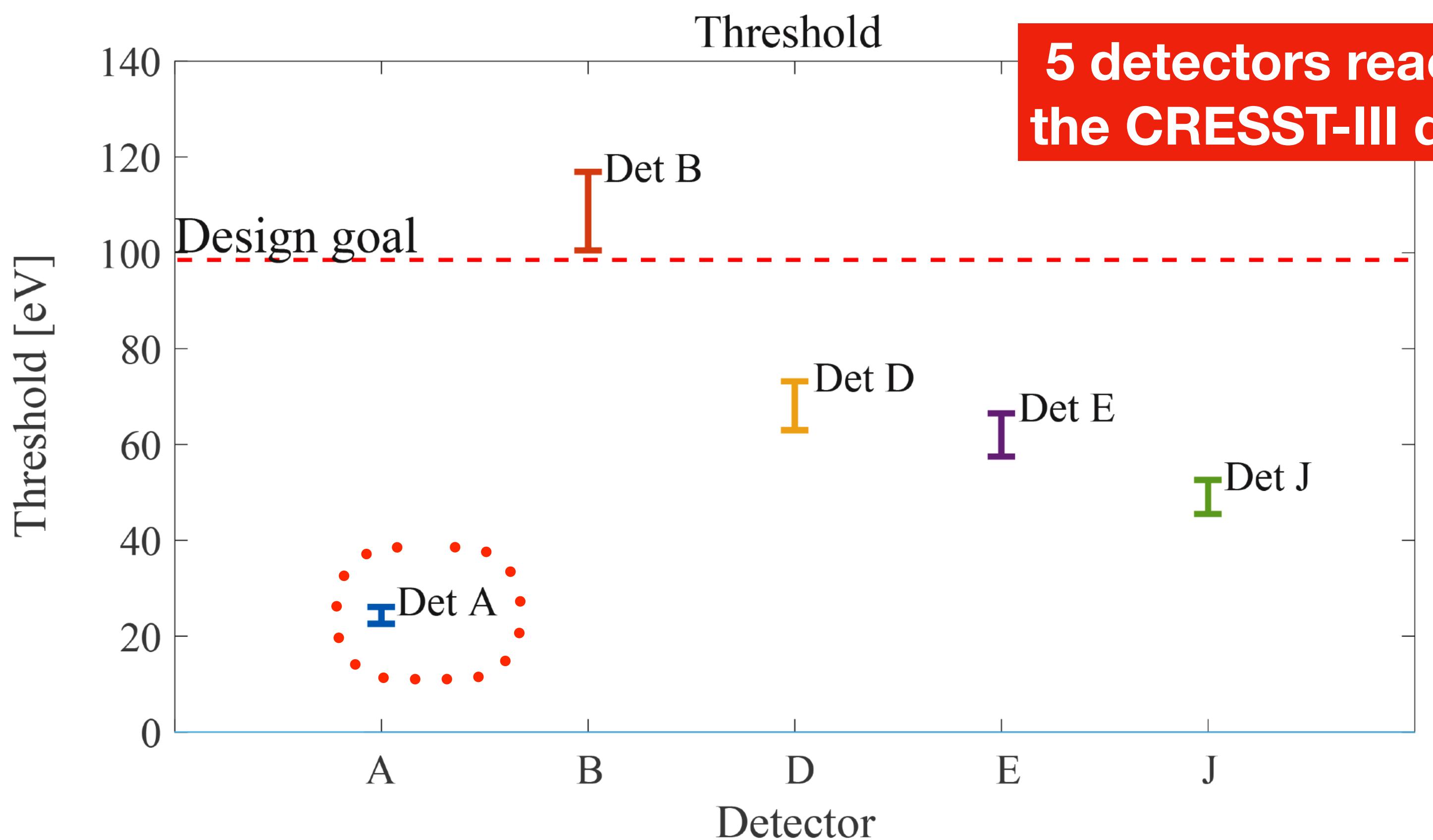
- low energy excess

positive hints on possible mitigation strategies are already available

- Latest data release at IDM2022 Vienna

Detector performance

Low energy analysis performed by means of the Optimum Trigger technique



5 detectors reach/exceed
the CRESST-III design goal

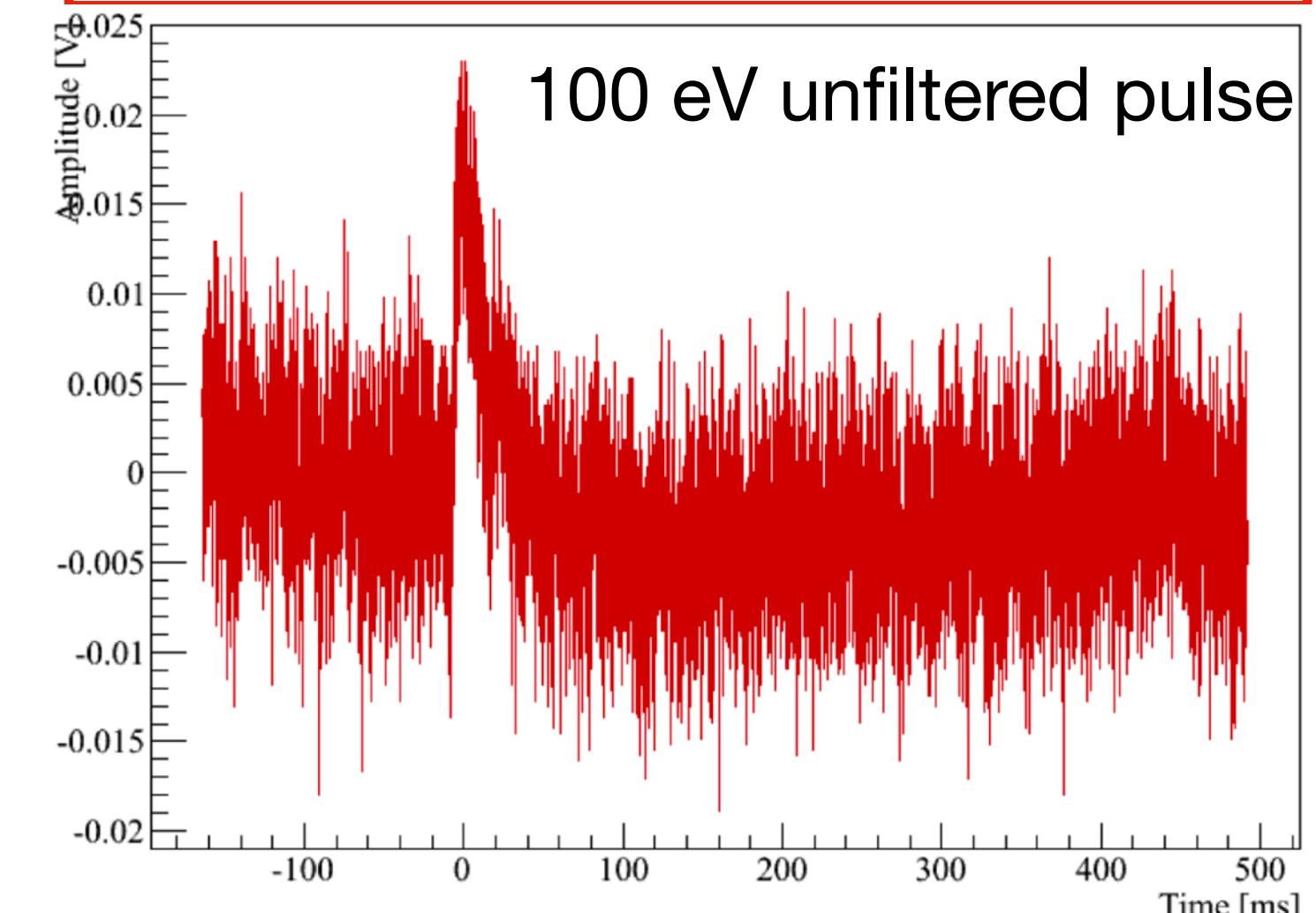
CRESST-II

Xtal mass: **300 g**
Energy res. @ 0keV: **63 eV**



CRESST-III

Xtal mass: **24 g**
Energy res. @ 0keV: **4.6 eV**



* error bars are not uncertainties (<20%), but energy threshold set as the noise-trigger rate acceptance