Search for dark matter particles with CRESST-III

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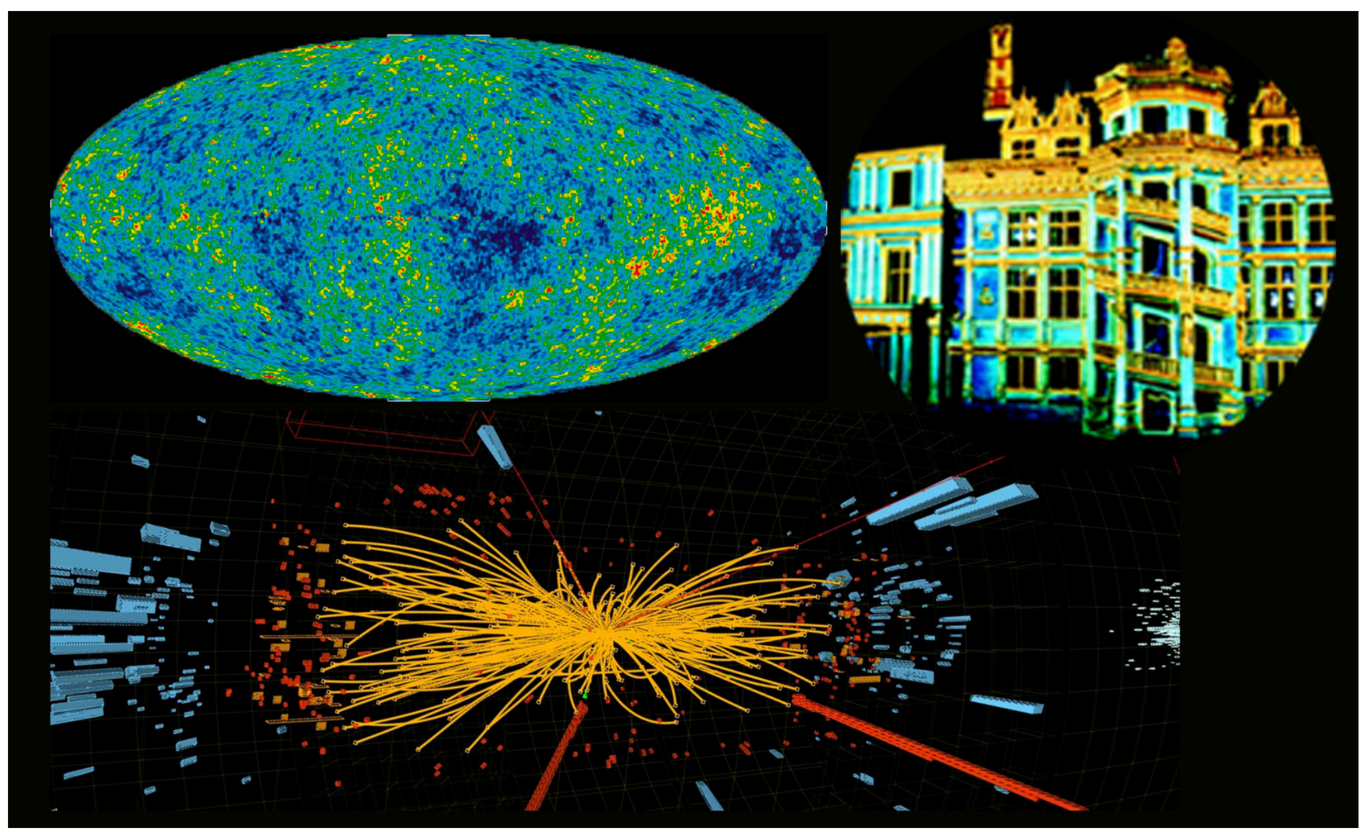
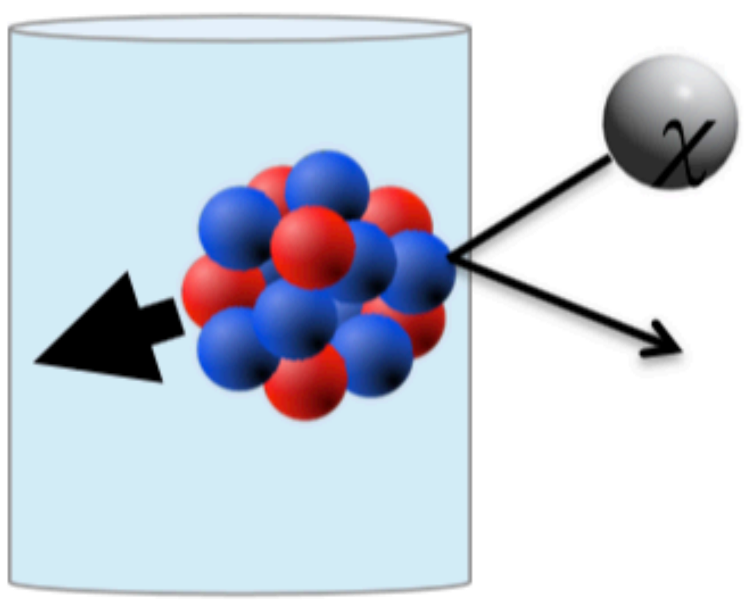


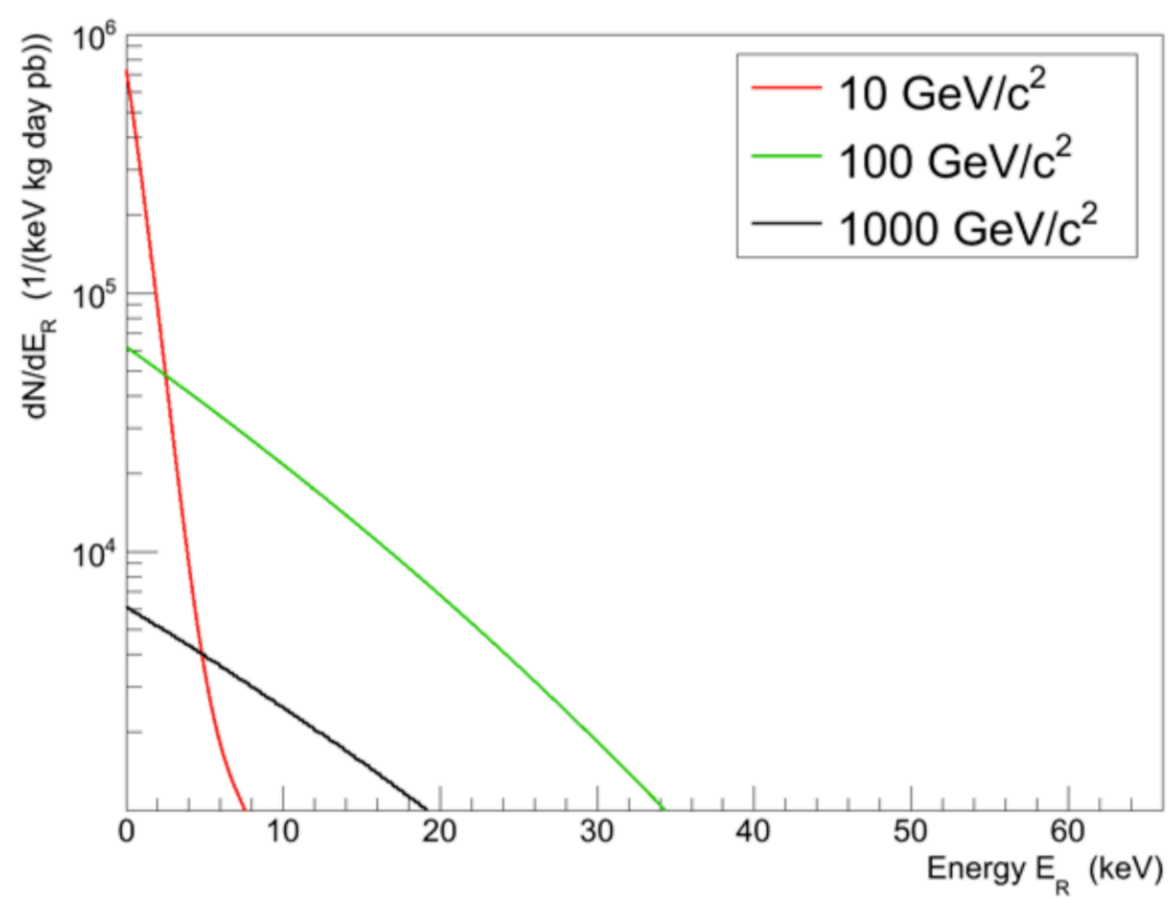
30th Rencontres de Blois
June 03 - 08, 2018
Château de Blois, Blois

Direct Dark Matter detection

- Most common scenario for the DM interaction:
  - Scattering off nuclei
  - Elastically and coherently
  - Spin independently



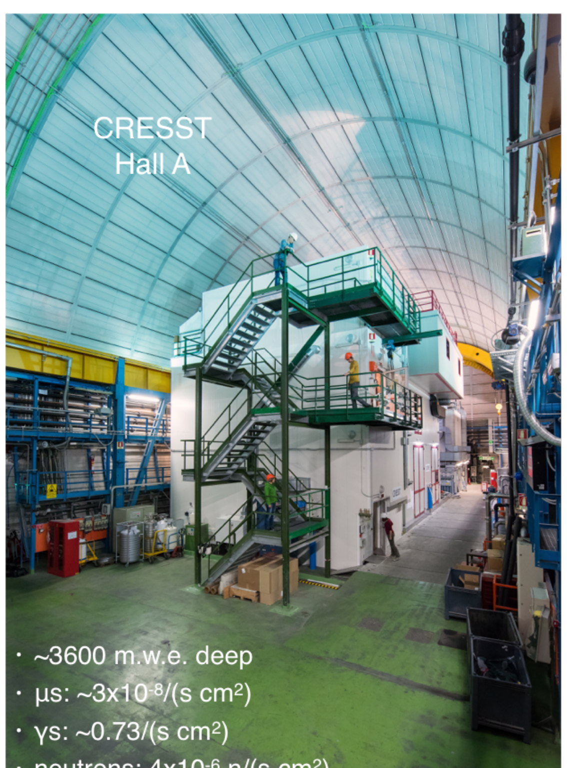
- Detection challenges:
  - Small recoil energies
  - Low interaction rate



The CRESST experiment

Cryogenic Rare Event Search with Superconducting Thermometers

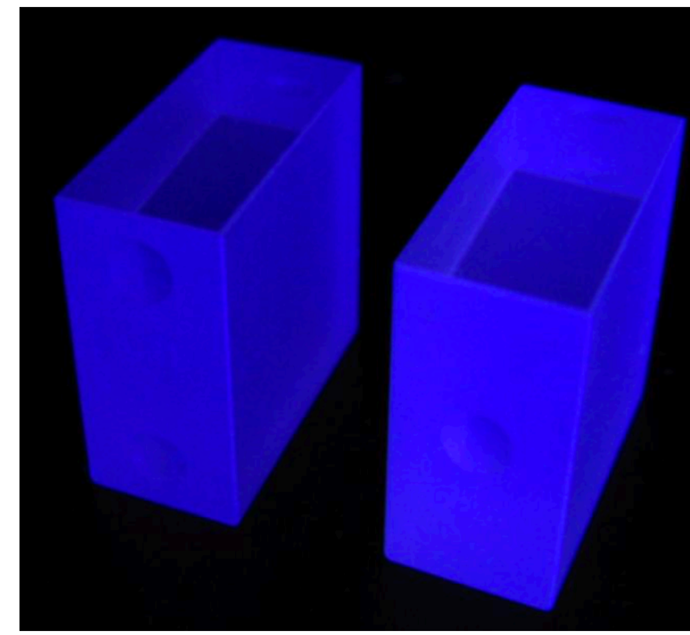
Eberhard Karls Universität Tübingen
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)
INFN LNGS
ÖAW Österreichische Akademie der Wissenschaften
Technische Universität München
University of Oxford

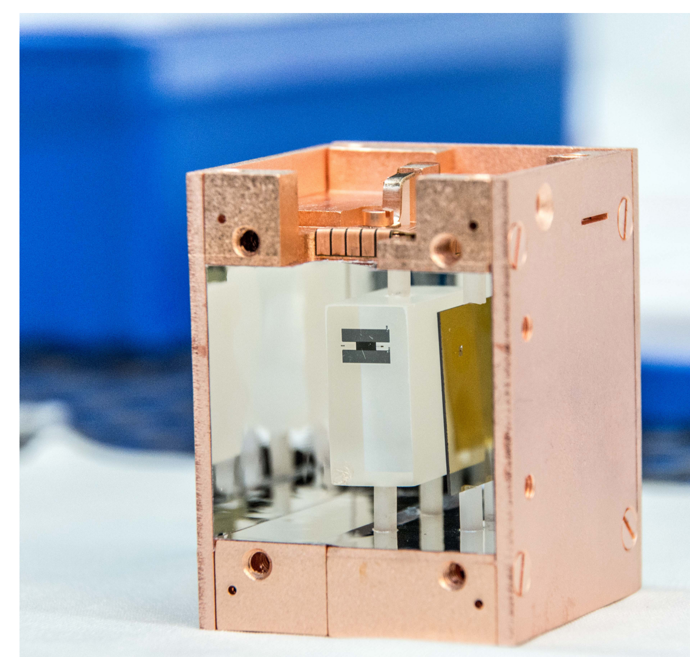


The CRESST experiment

Cryogenic Rare Event Search with Superconducting Thermometers

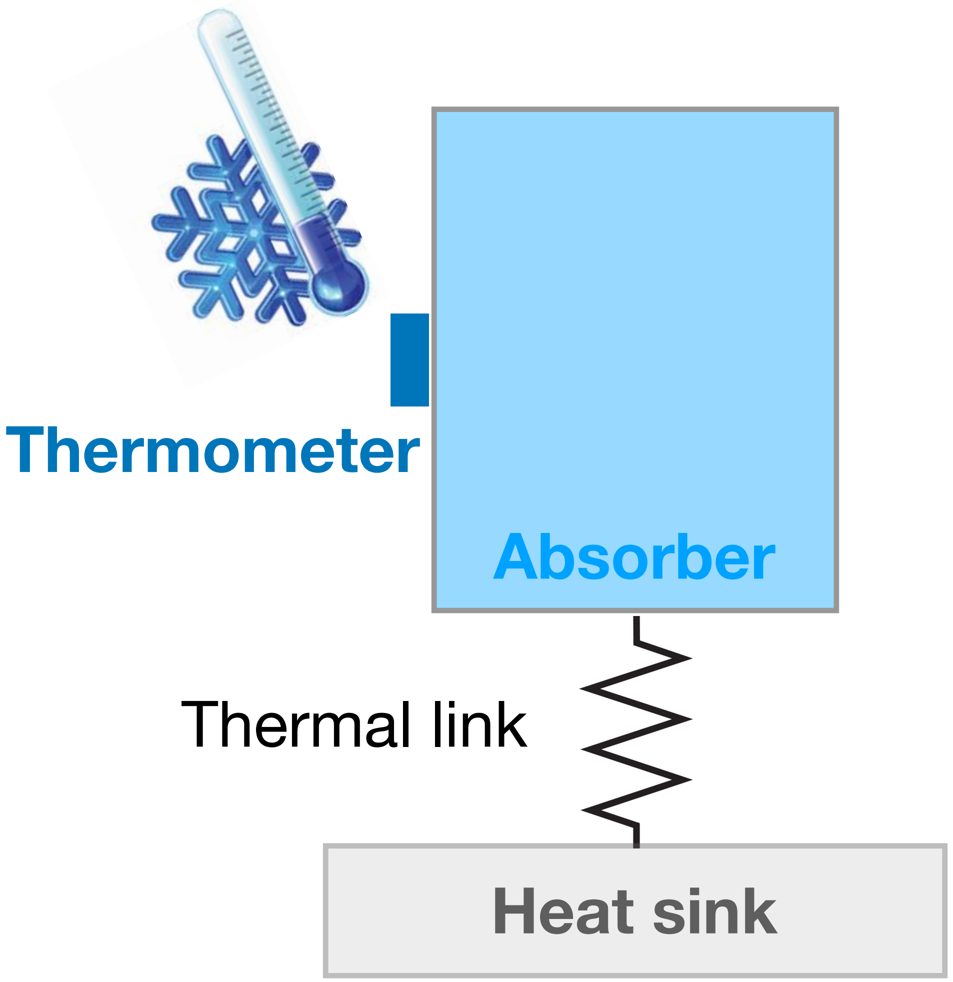
- Direct detection of Dark Matter particles via their scattering off target nuclei
- Target: Scintillating $CaWO_4$ crystals
- Operated as cryogenic calorimeters (~15mK)
- Separate cryogenic light detector to detect the scintillation light signal.
- Transition Edge Sensor (TES) for read out



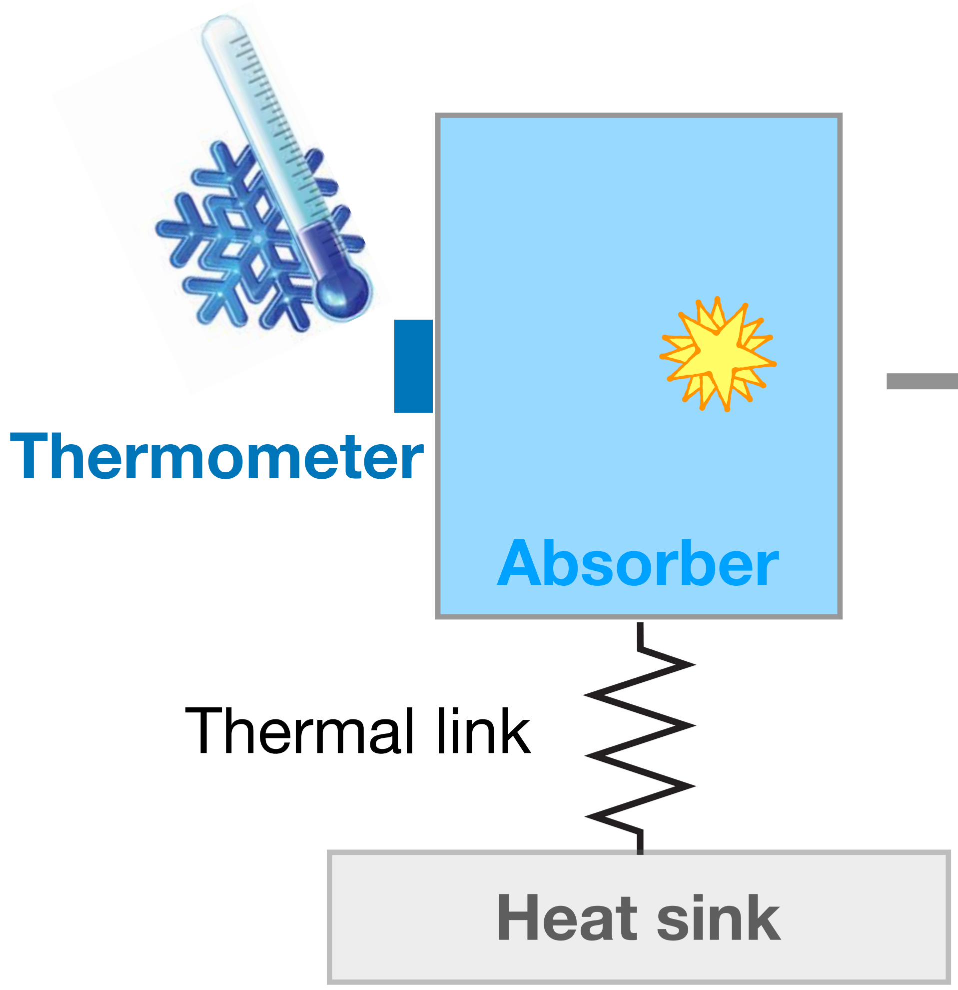


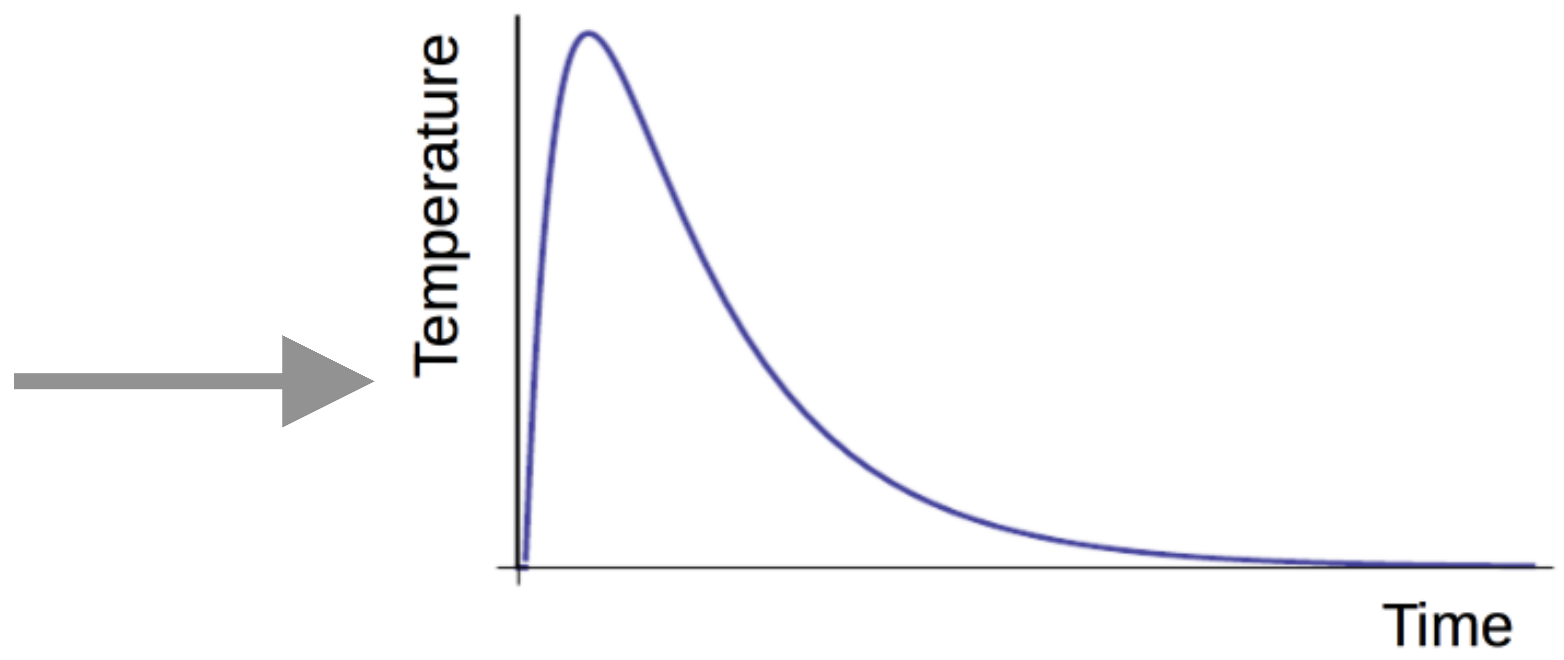
Credit: MPP/T.Dettlaff

Cryogenic calorimeter



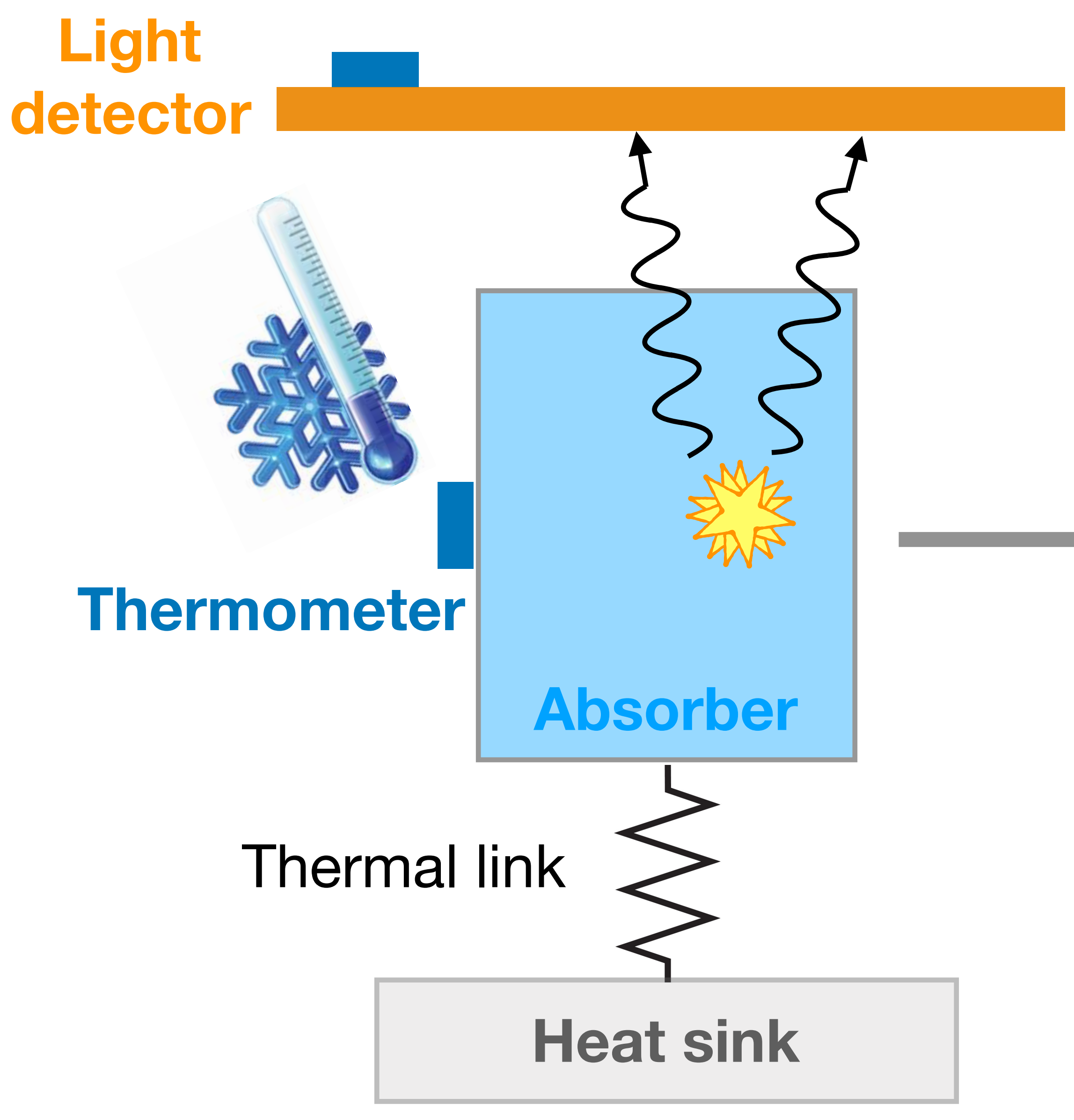
Cryogenic calorimeter

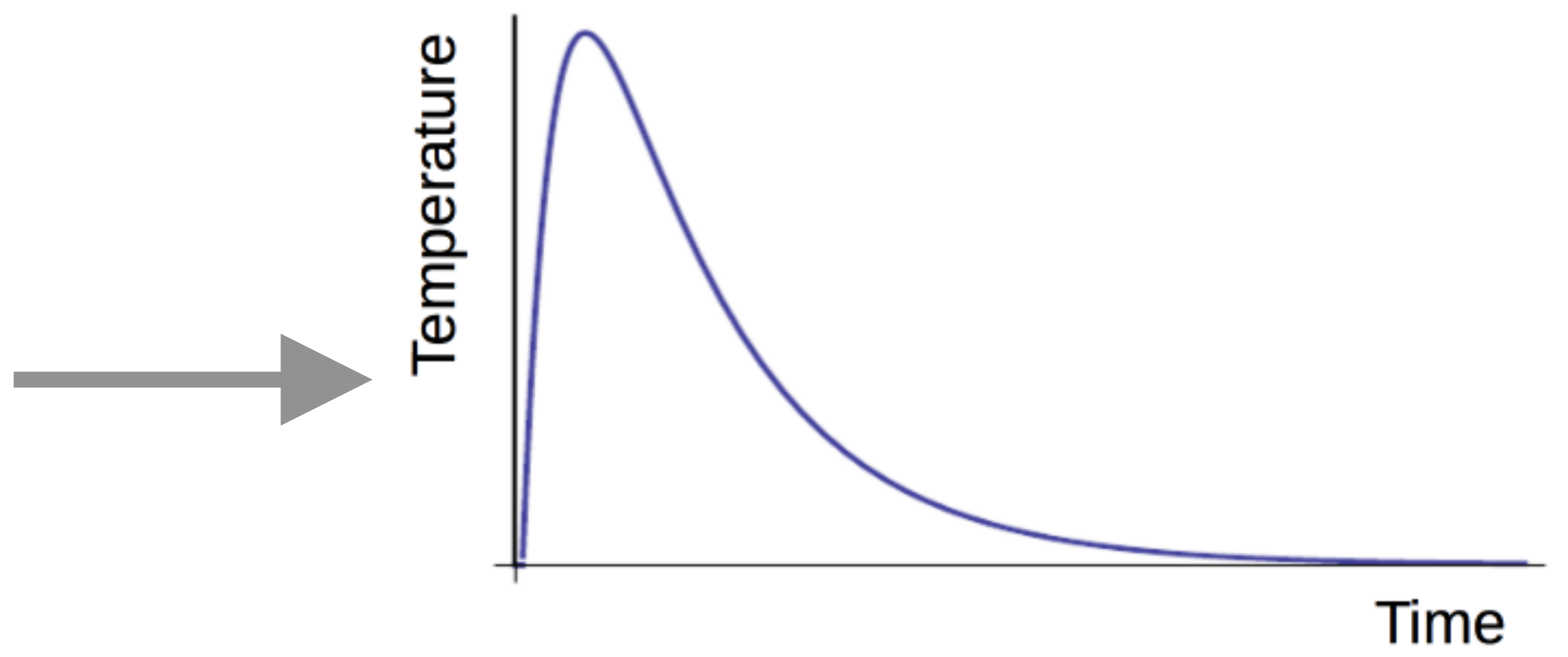




- Measurement of total deposited **energy** (particle independent)

Cryogenic calorimeter

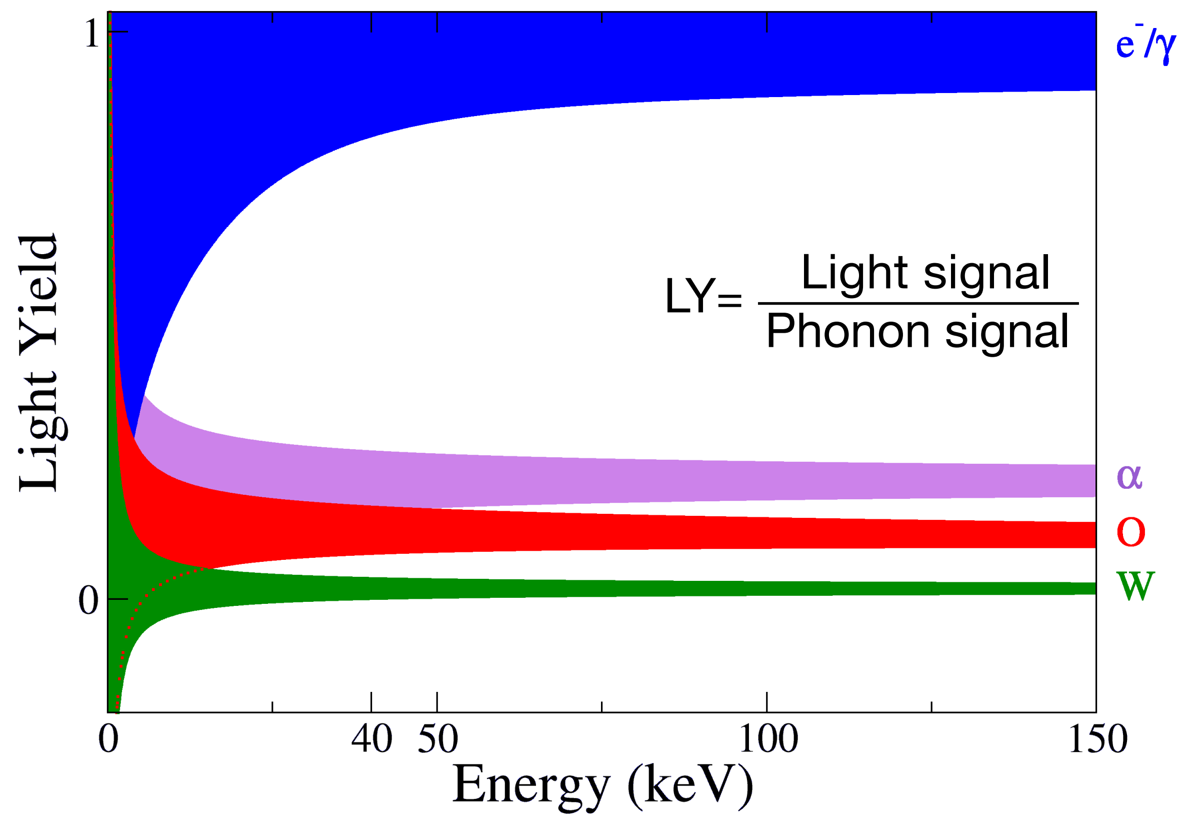


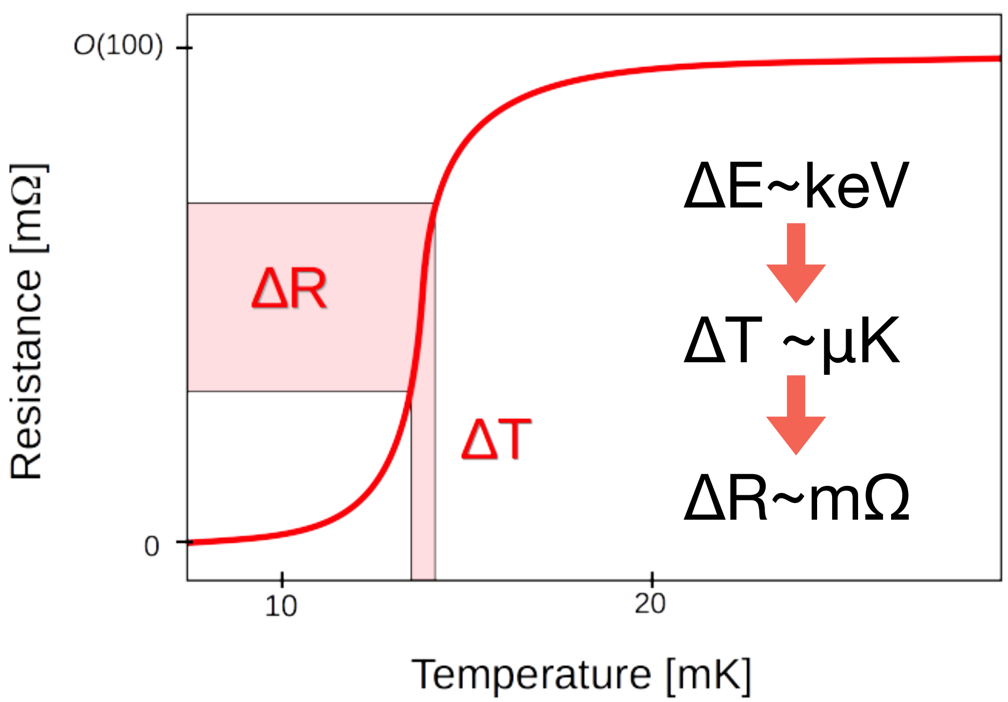


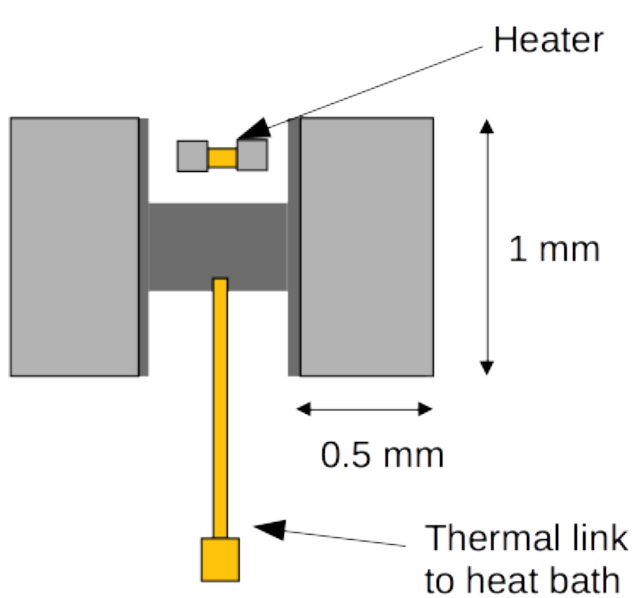
- Measurement of total deposited **energy** (particle independent).
- **Particle identification** given by the measurement of the scintillation light (Light yield).

Particle ID and thermal sensor

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







Detection of temperature rise with superconductor sensor operated at the phase transition from normal to superconducting

Particle ID and thermal sensor

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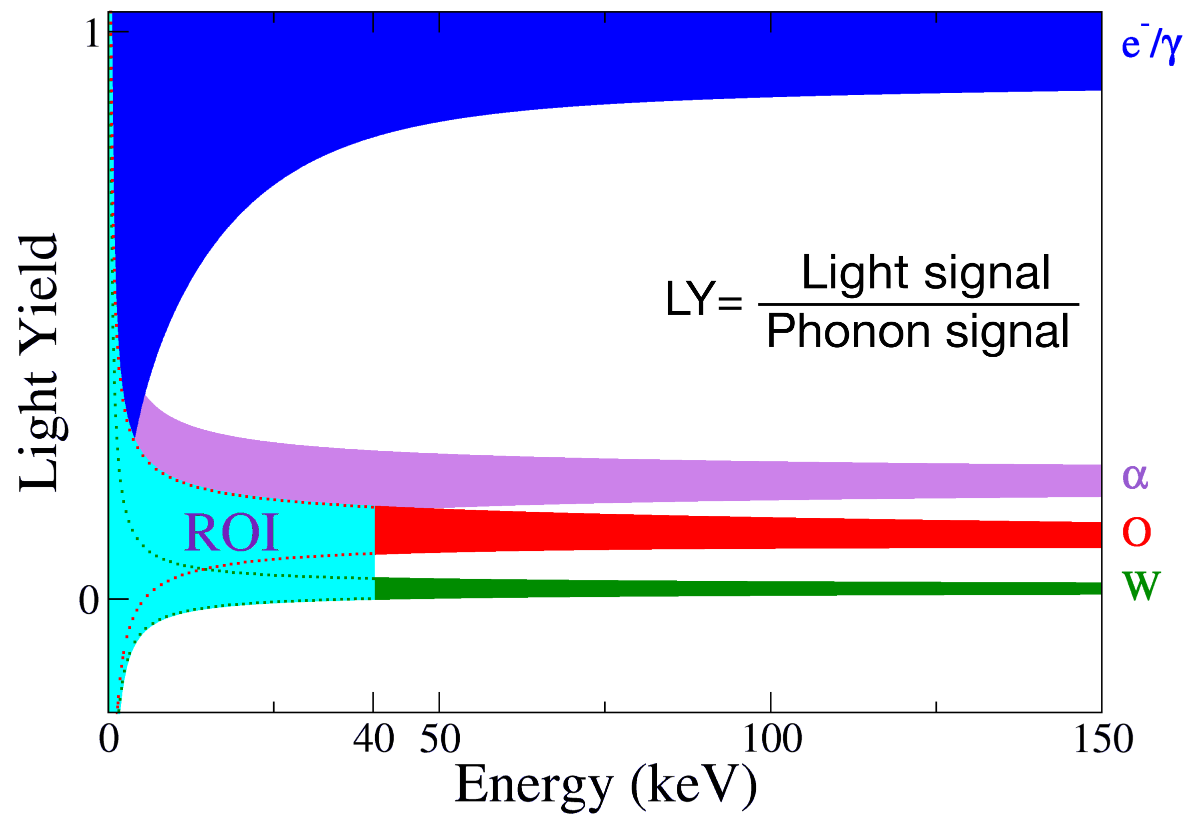
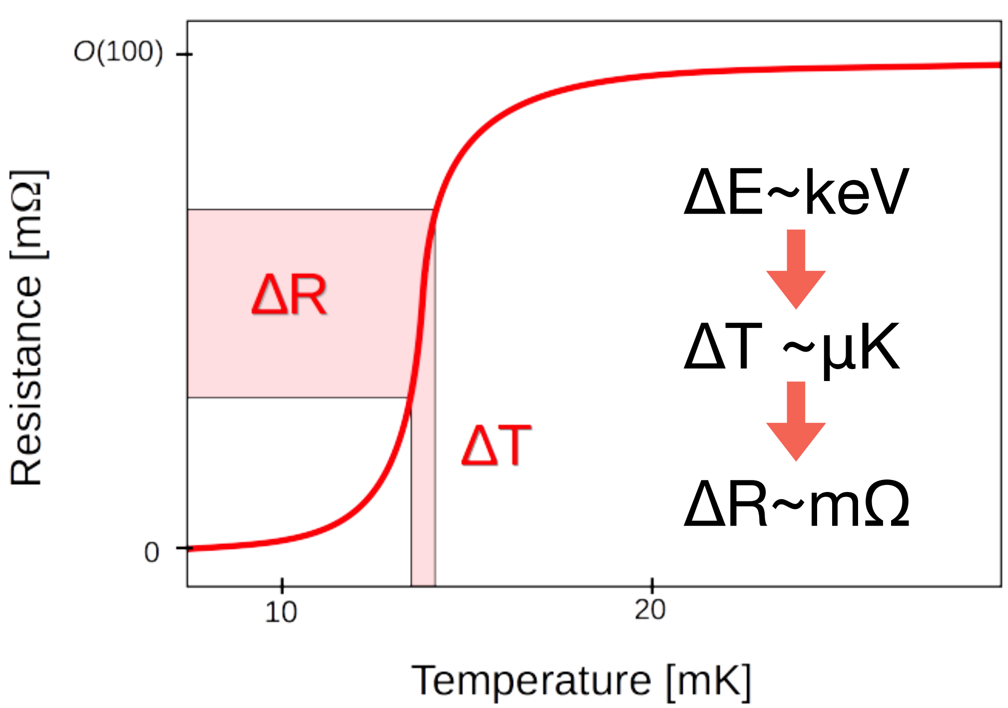
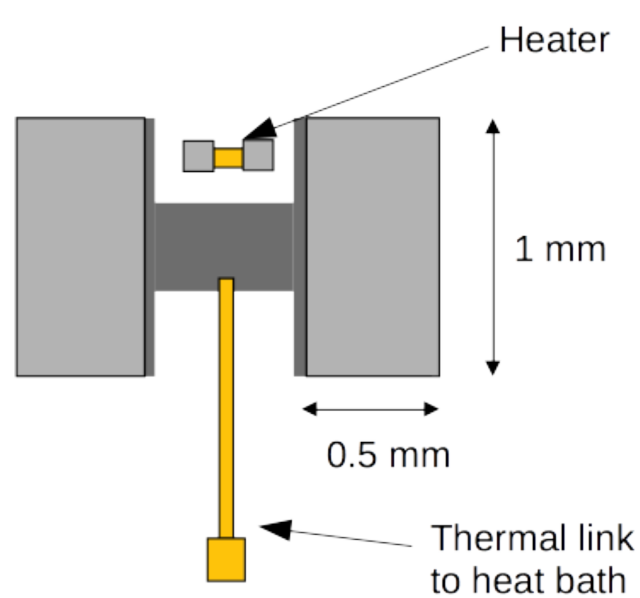
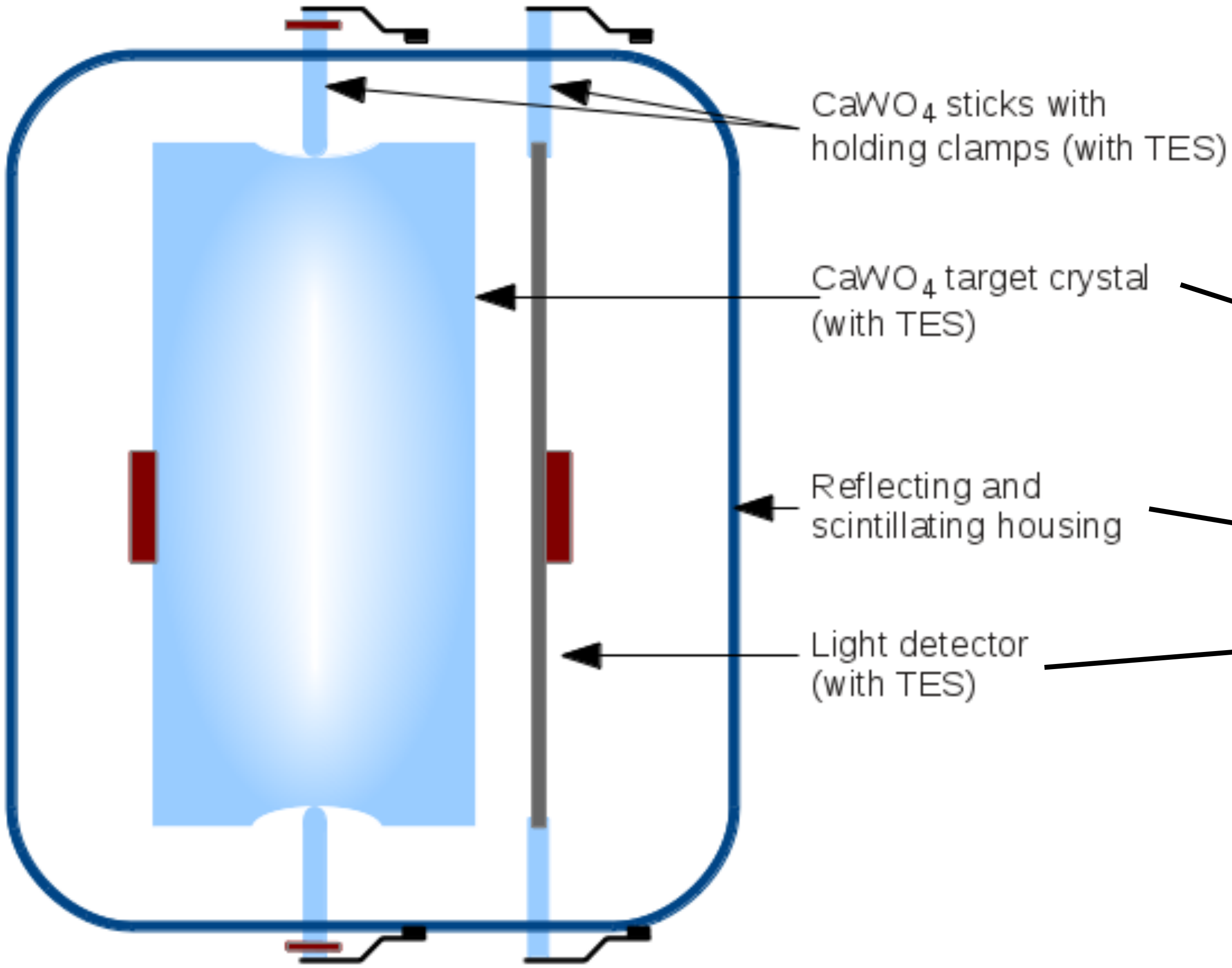


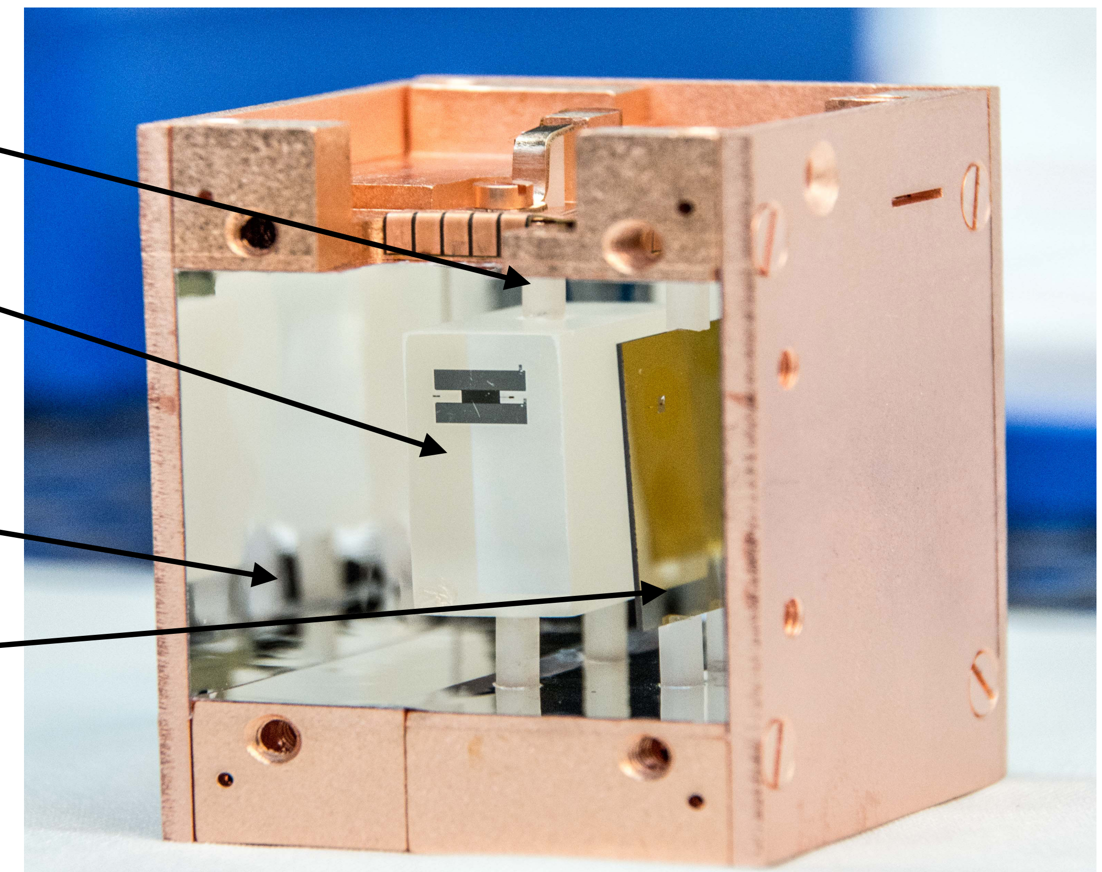




Detection of temperature rise with superconductor sensor operated at the phase transition from normal to superconducting

CRESST III detector module



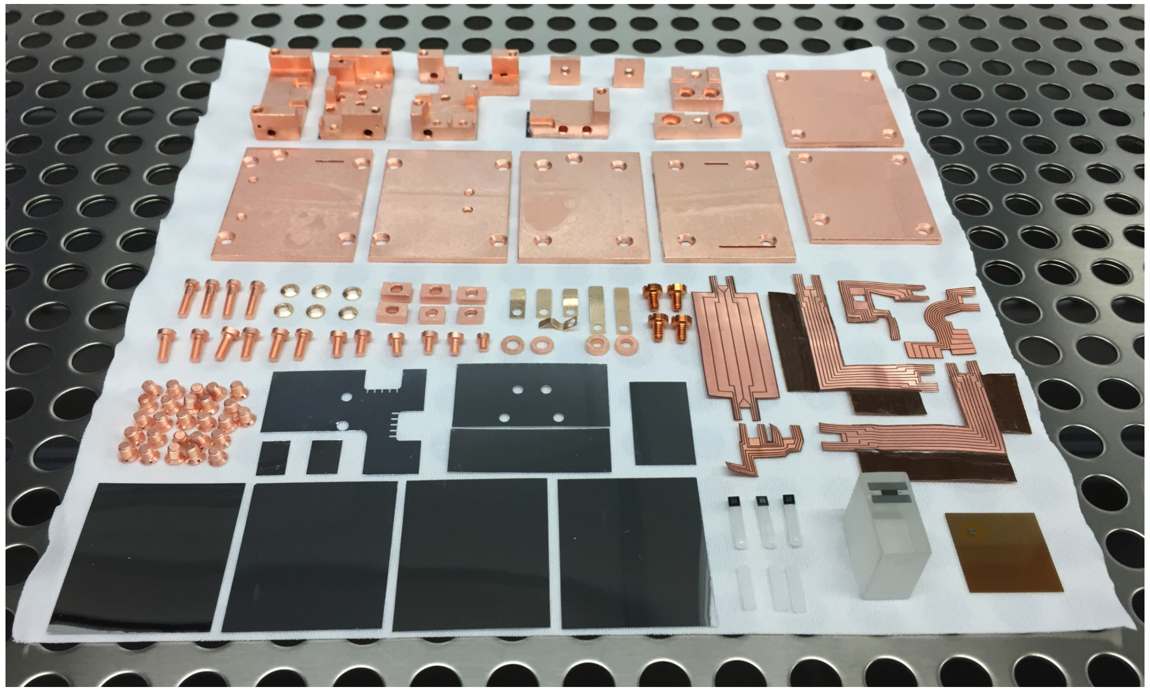


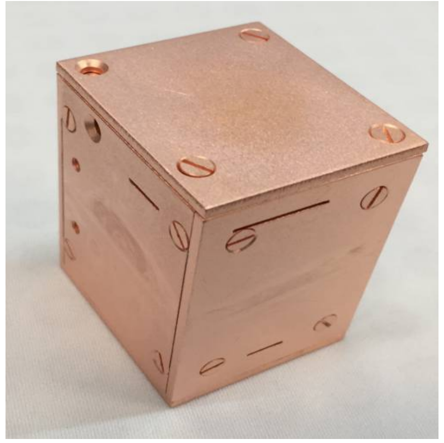
$CaWO_4$ crystals of (20x20x10)mm^3 (≈24g)

- Detector layout optimized for low-mass dark matter
- Cuboid fully scintillating housing
- Instrumented holders

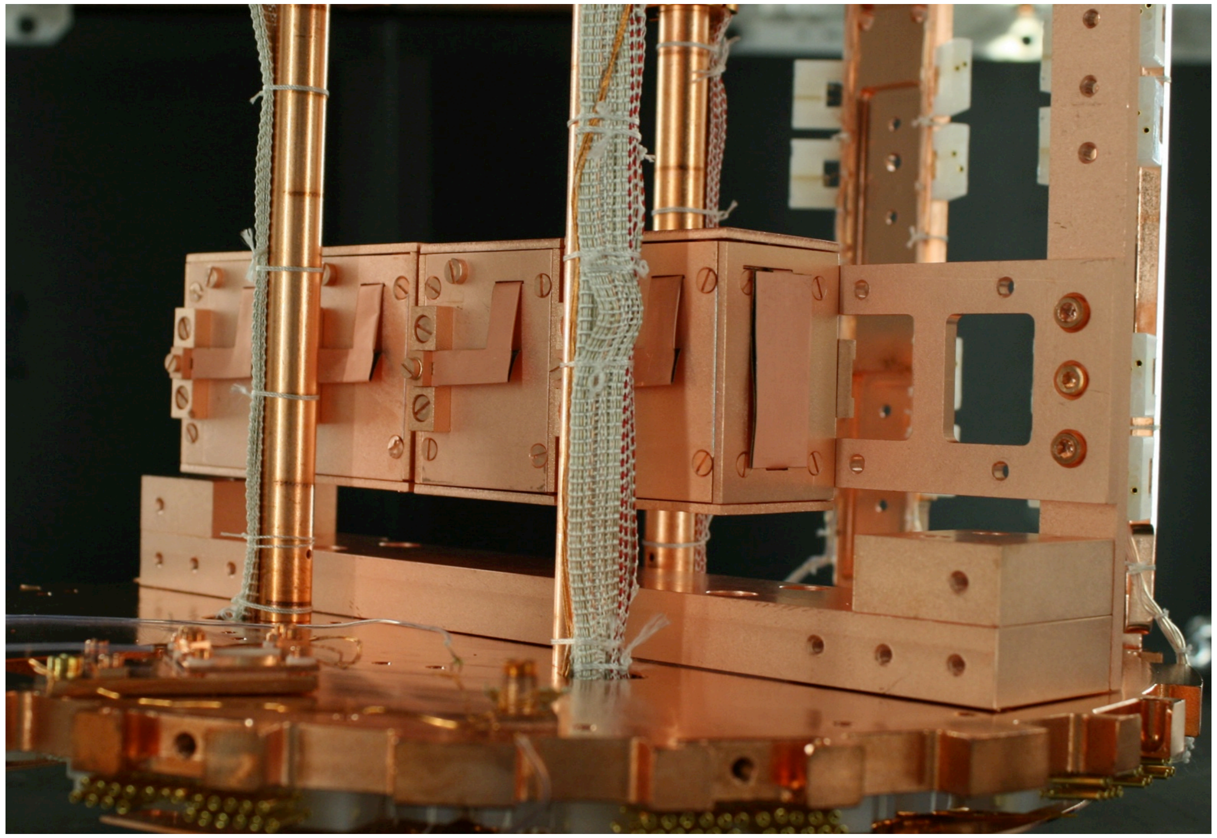
Threshold design goal:
100 eV threshold

CRESST III





Total of 10 detector modules

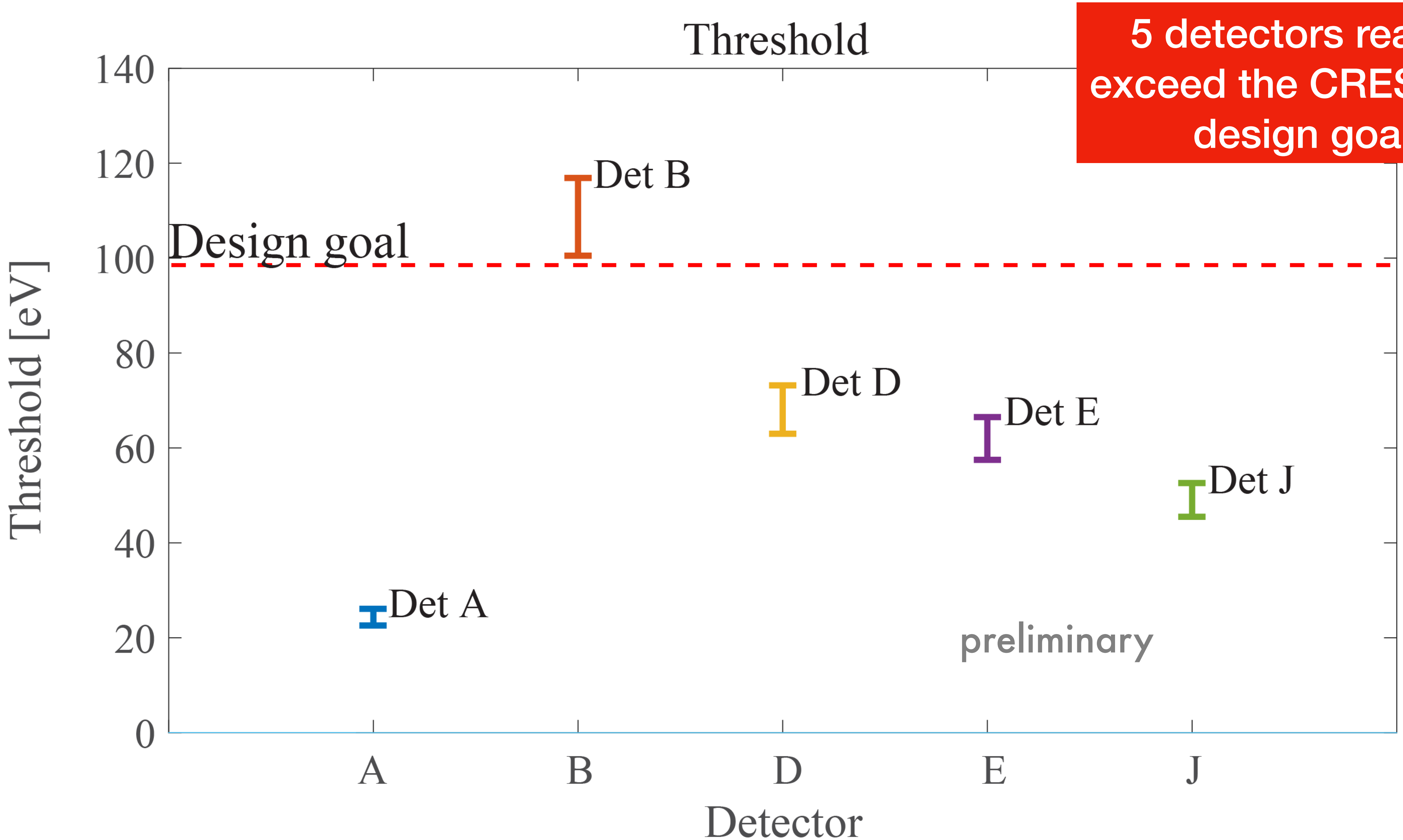


Data taking: July 2016 - February 2018

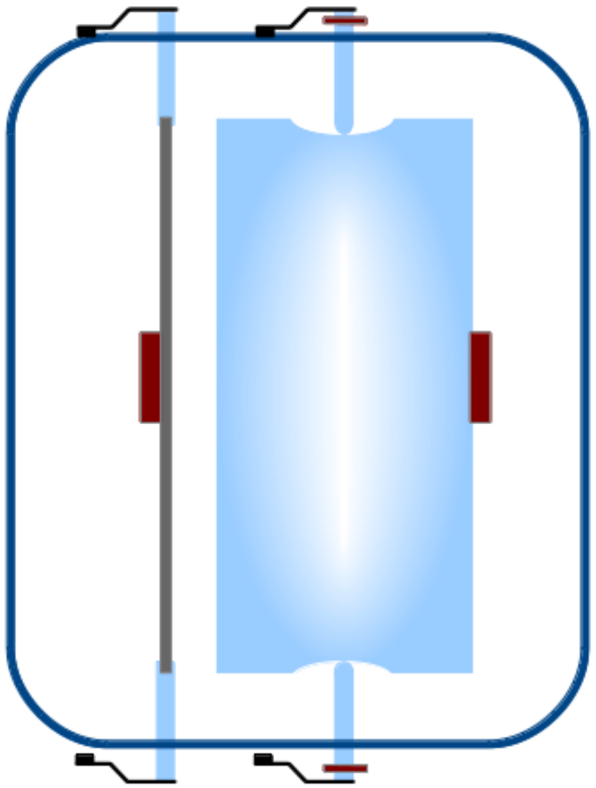
- high statistics gamma calibration (350 h)
- high statistics neutron calibration (840 h)
- 20 % of DM data as training set

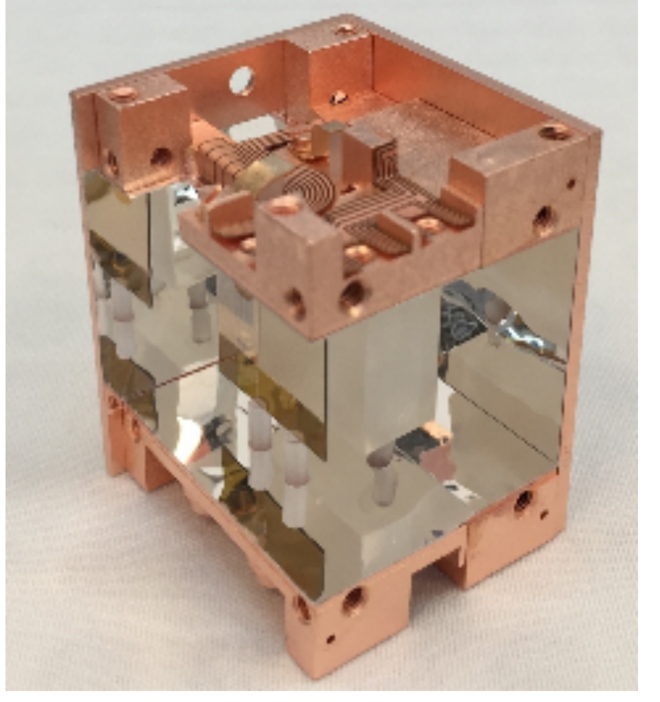
Detector thresholds

5 detectors reach/ exceed the CRESST-III design goal



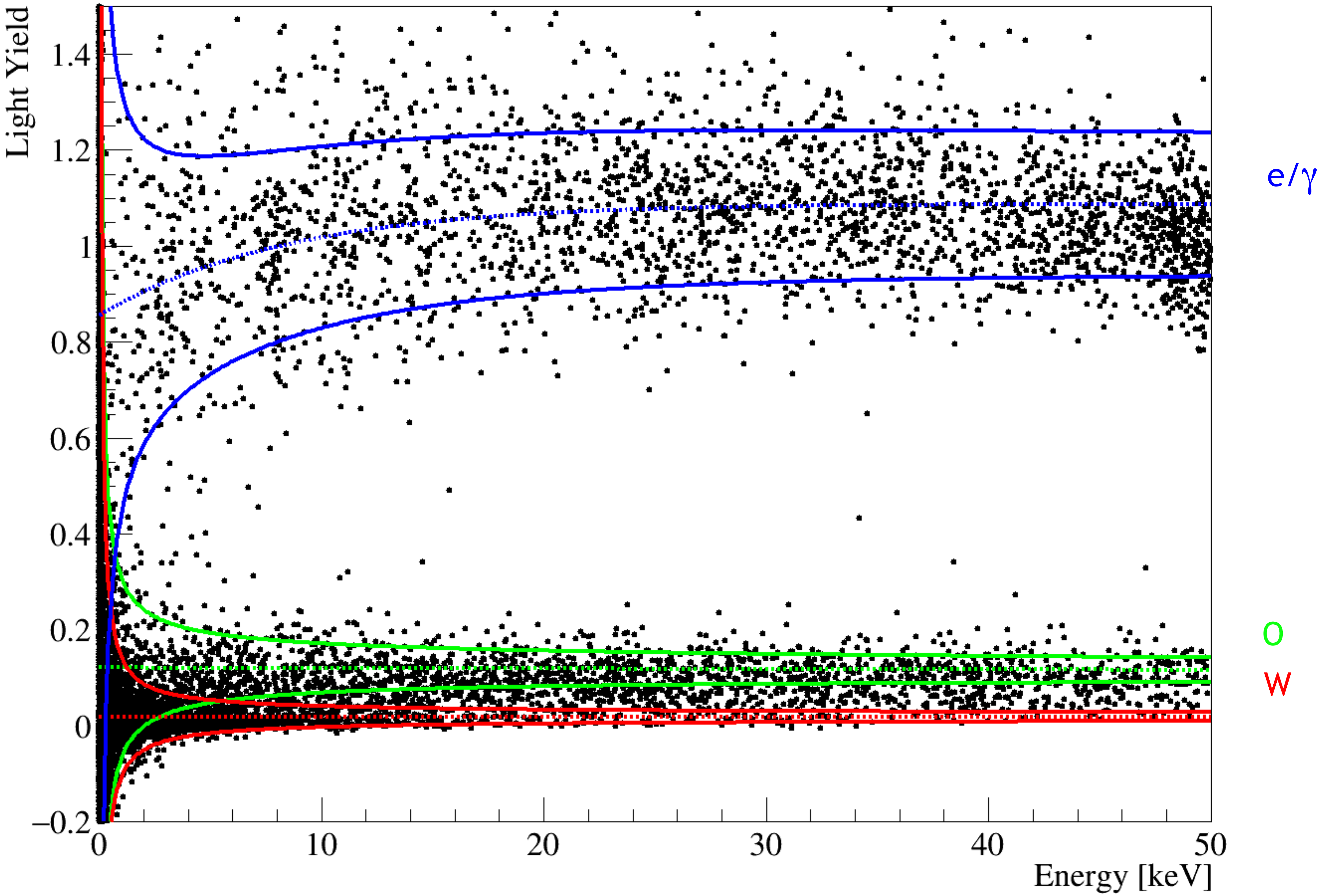
Detector A



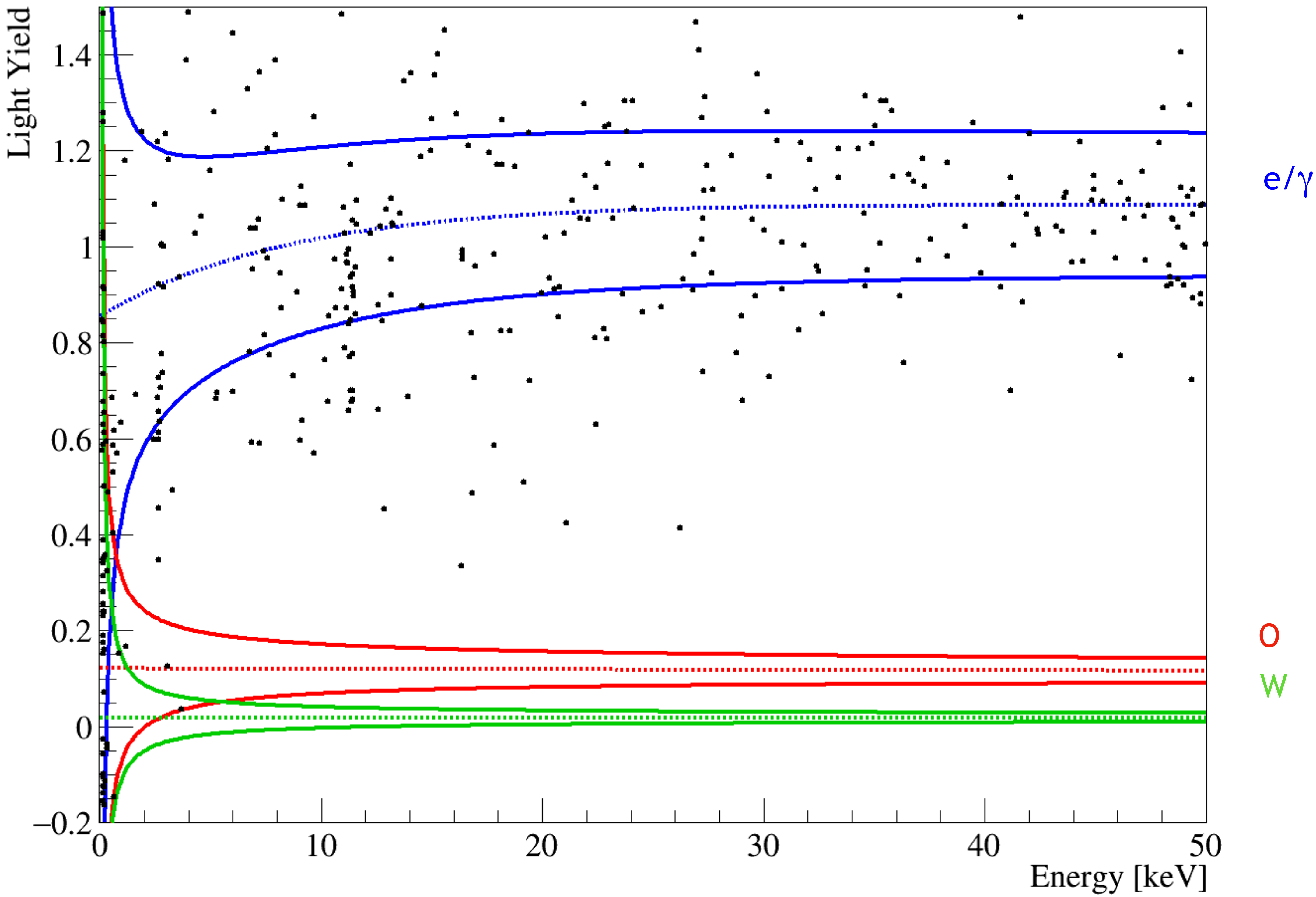


Data taking period for this analysis:	10/2016 – 05/2017
Non-blind data (dynamically growing):	20% randomly selected
Target crystal mass:	24g
Gross exposure (before cuts):	2.39 kg days
Analysis threshold:	100 eV

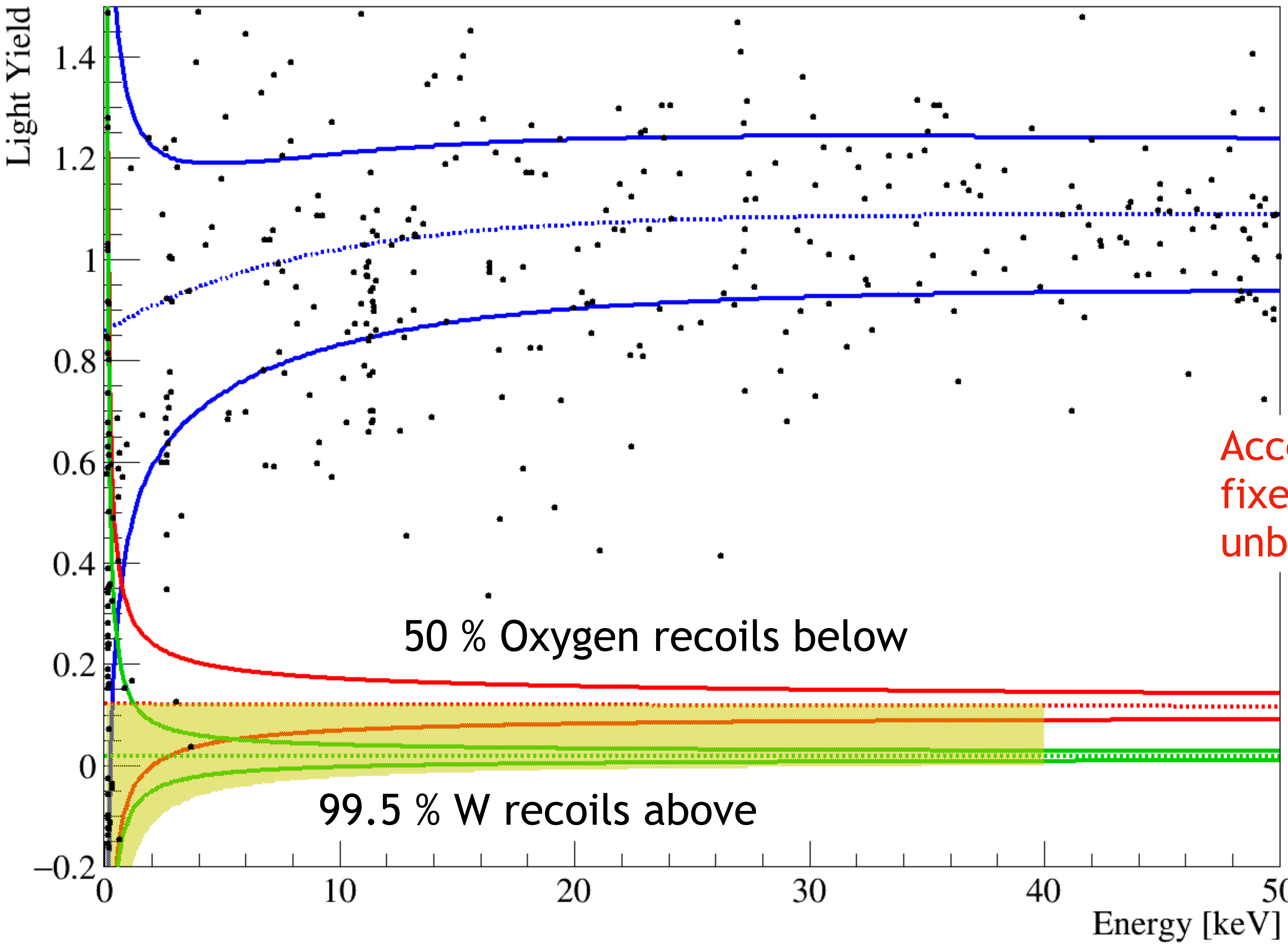
Detector A: neutron calibration



Detector A: Dark Matter data



Detector A: Region Of Interest



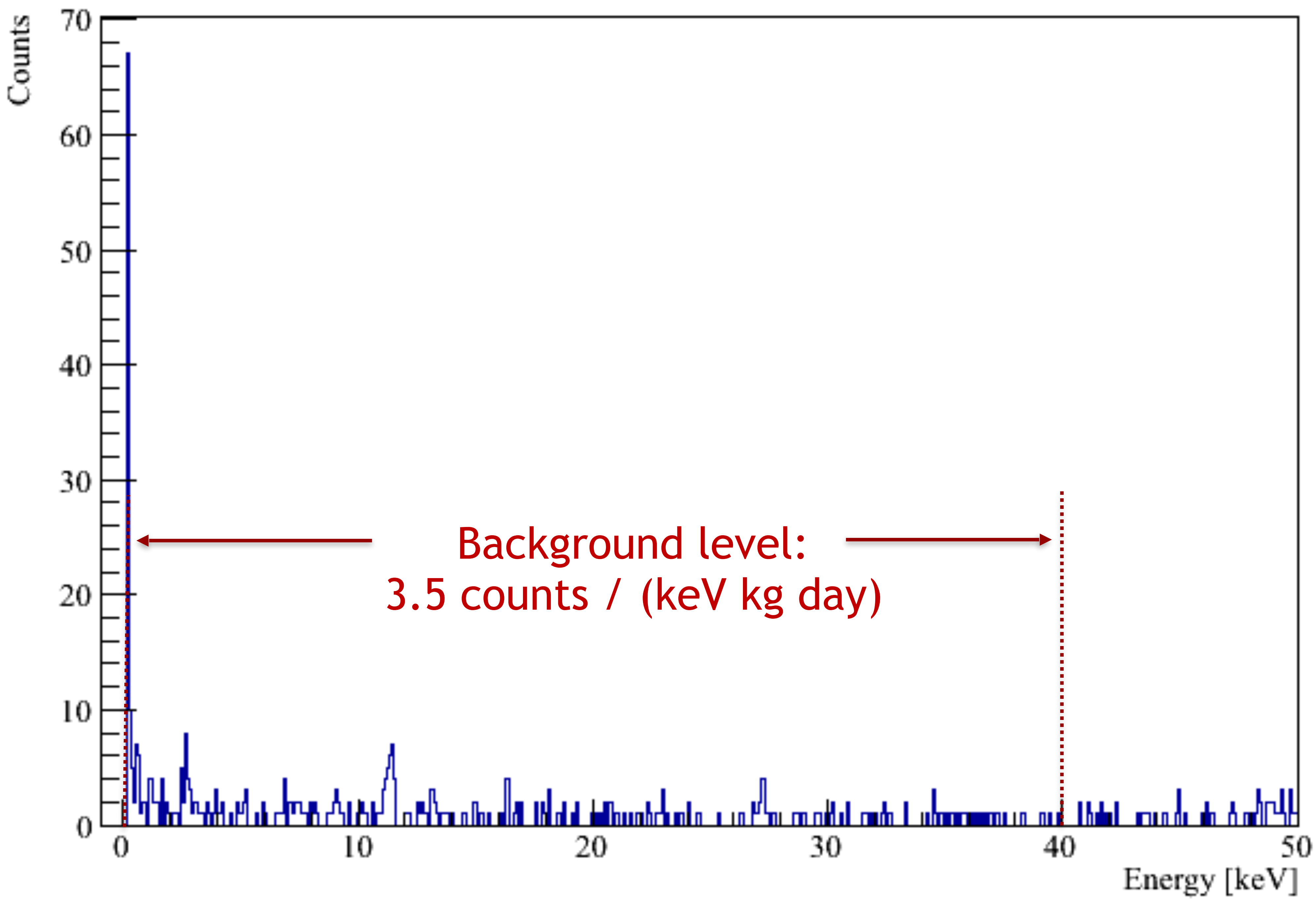
e/γ

Acceptance region fixed before unblinding

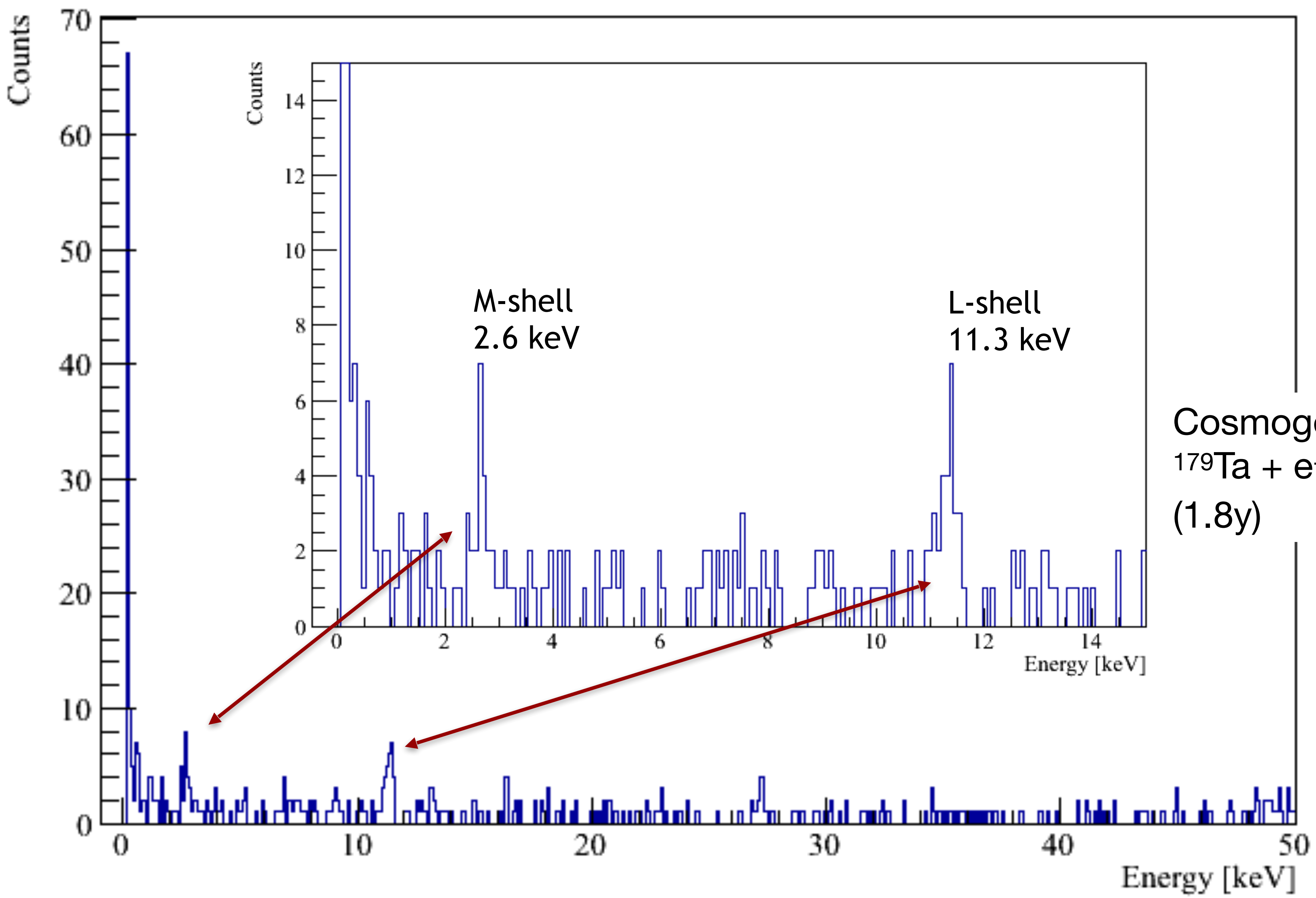
O

W

Detector A: Energy spectrum

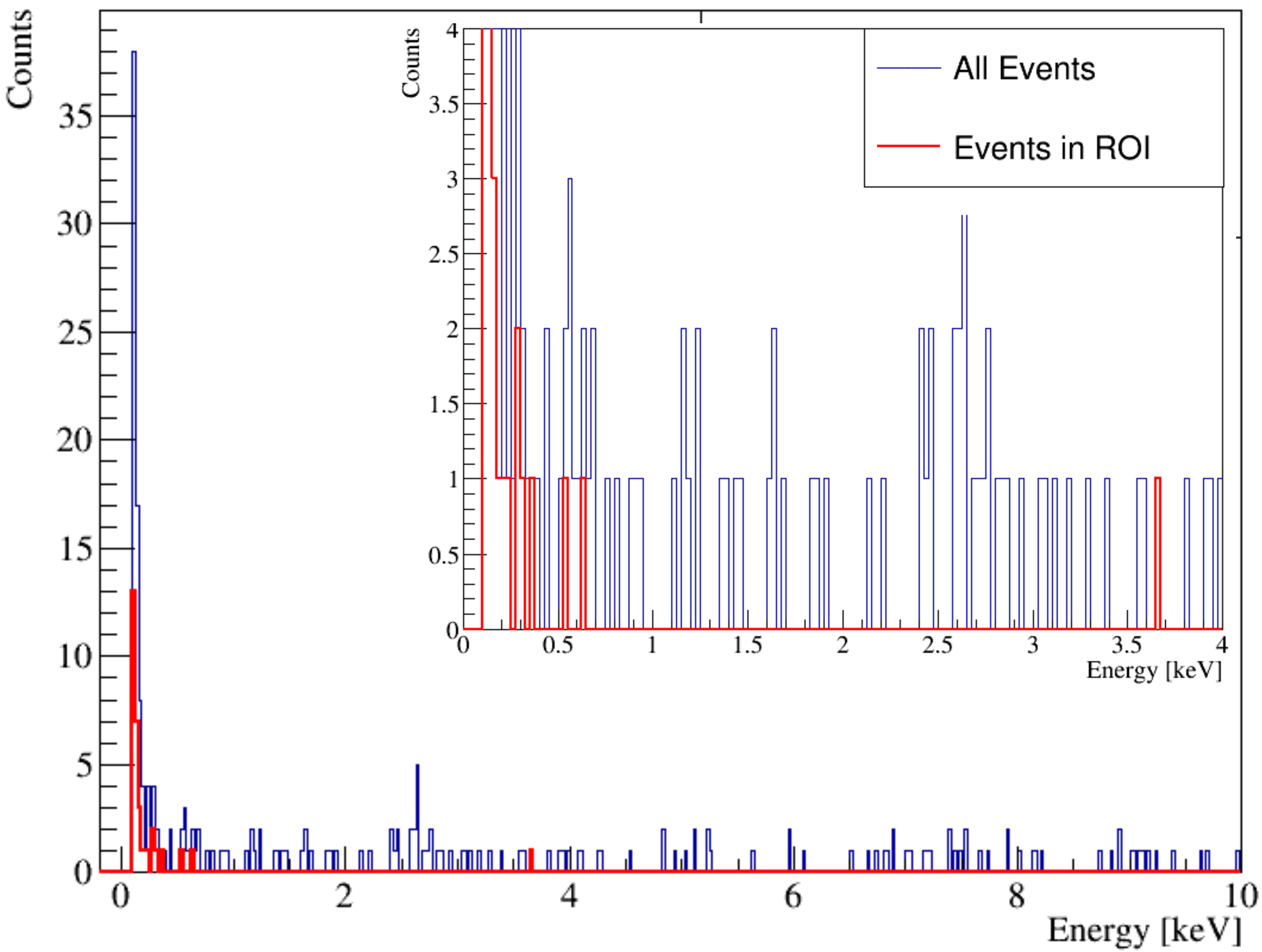


Detector A: Energy spectrum



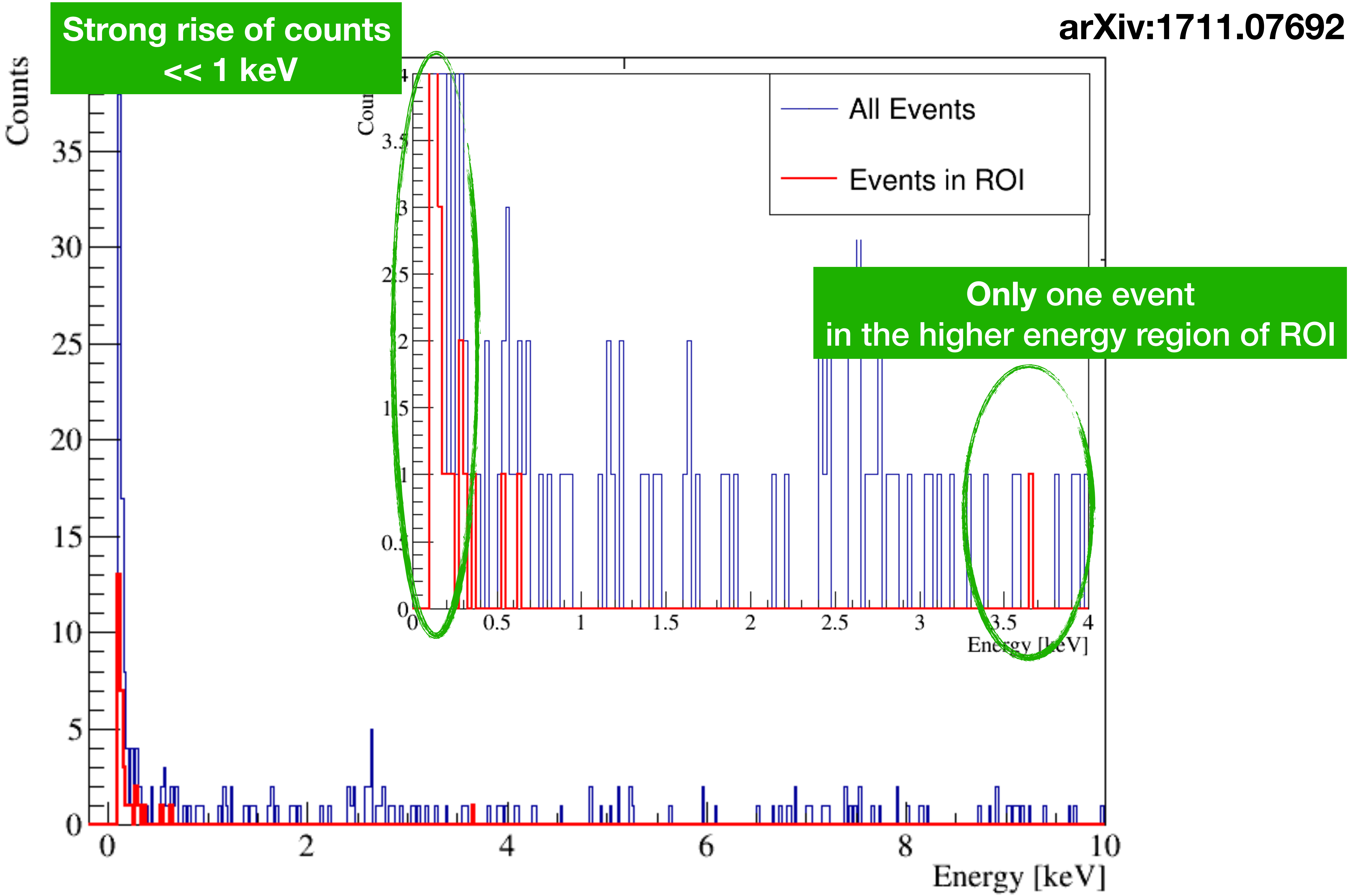
Cosmogenic activation
$^{179}Ta + e^{-} \rightarrow ^{179}Hf + \nu_e$
(1.8y)

Detector A: ROI energy spectrum

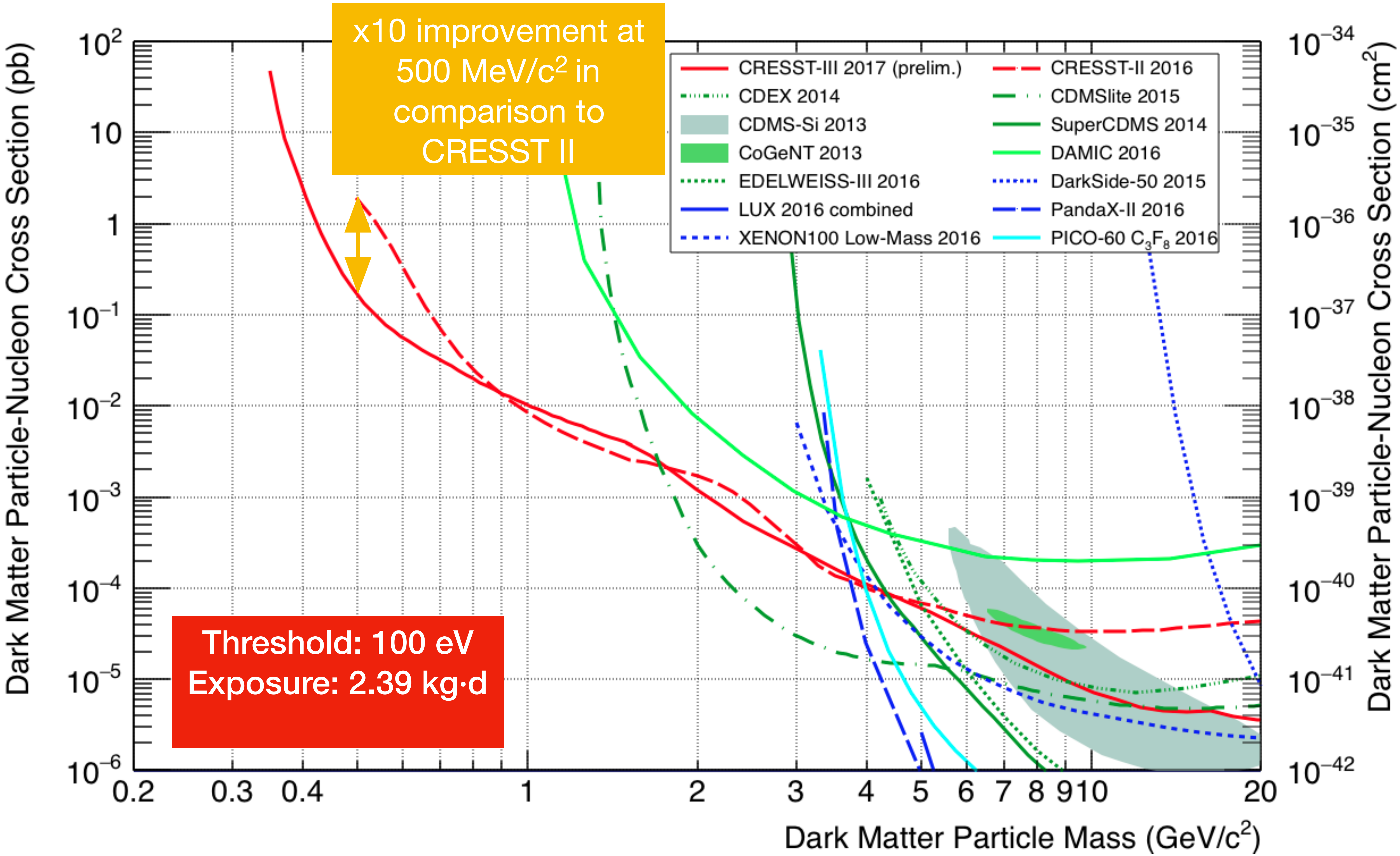


Detector A: ROI energy spectrum

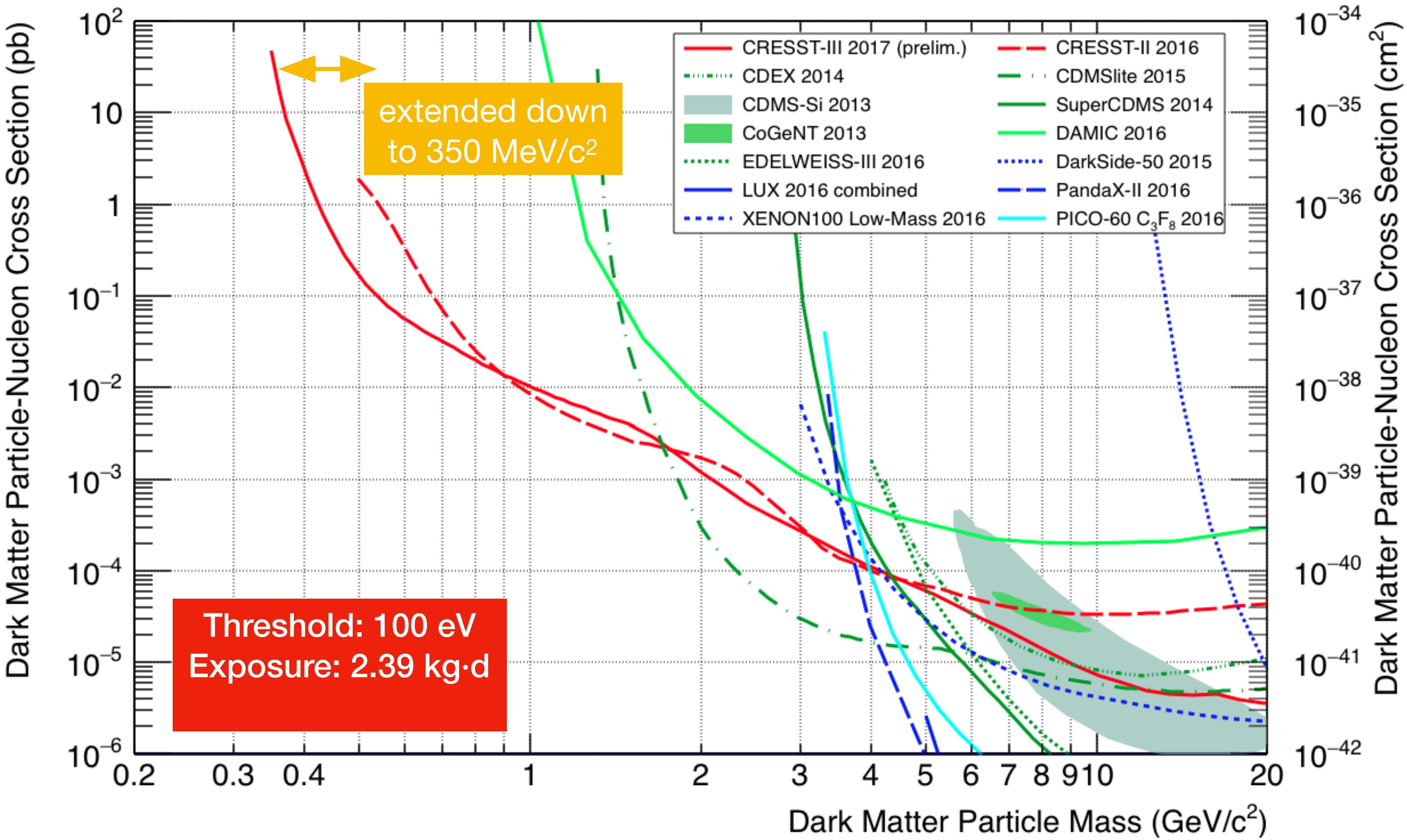
arXiv:1711.07692



Dark matter limit



Dark matter limit

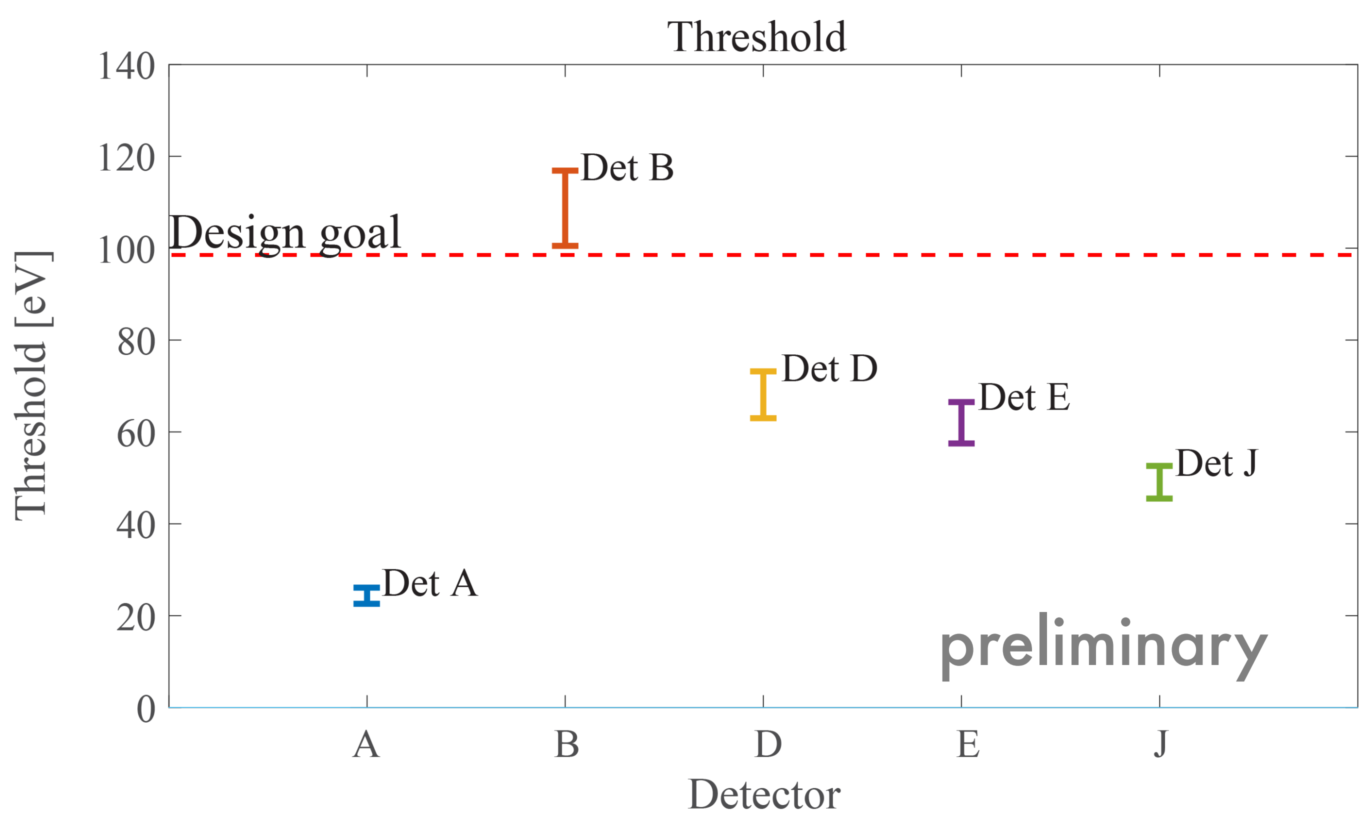


Current status

- The full statistic results of det A will be released in summer, with energy threshold extended below 100eV.

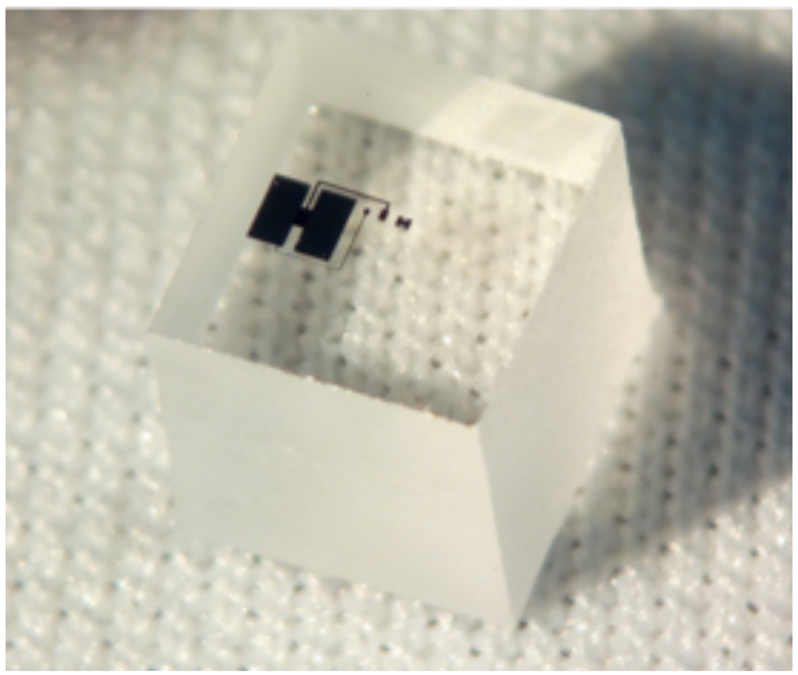
- More results to come from other modules

Stay tuned!



Gram-scale detector prototype

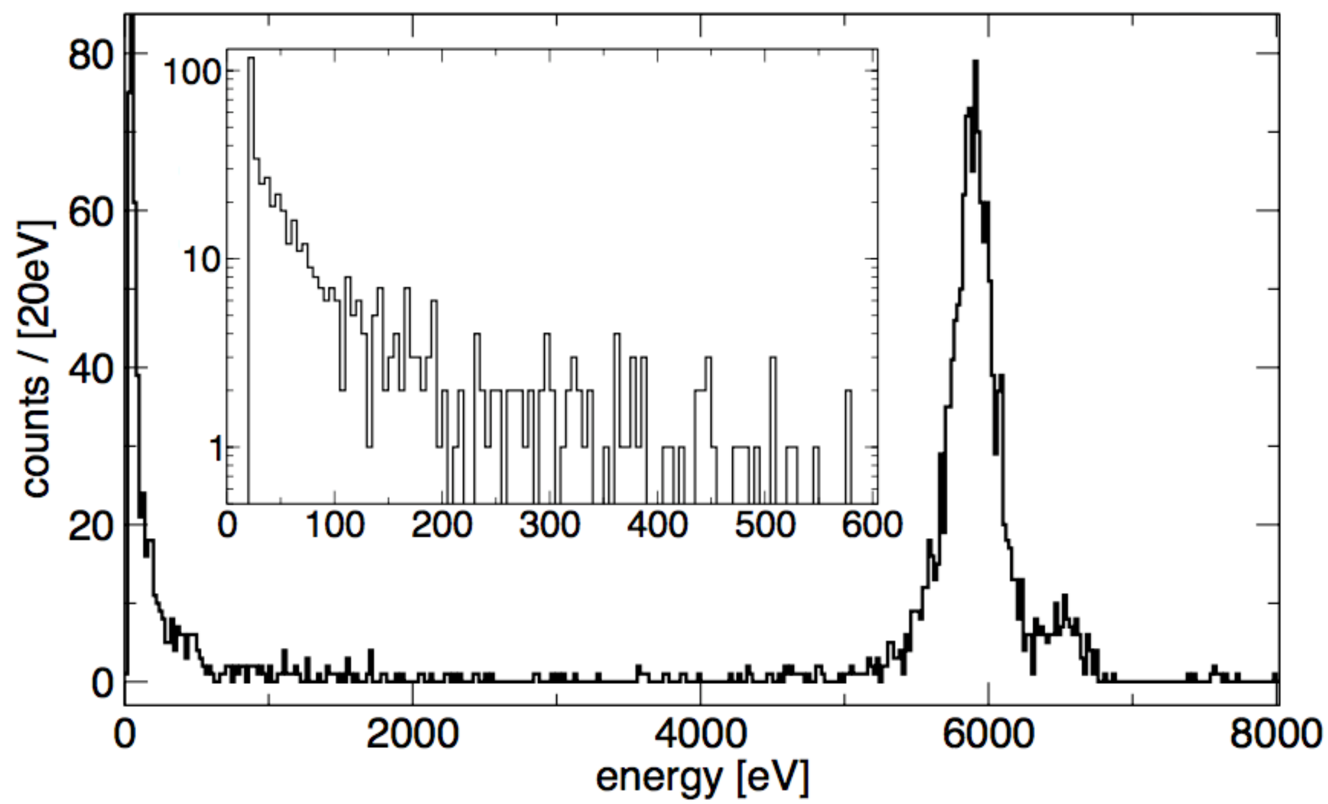
Al_2O_3 crystal 0.5g
E_{th} = (19.7 ± 0.9) eV



First prototype detector successfully tested:

- operated above ground
- setup without shielding

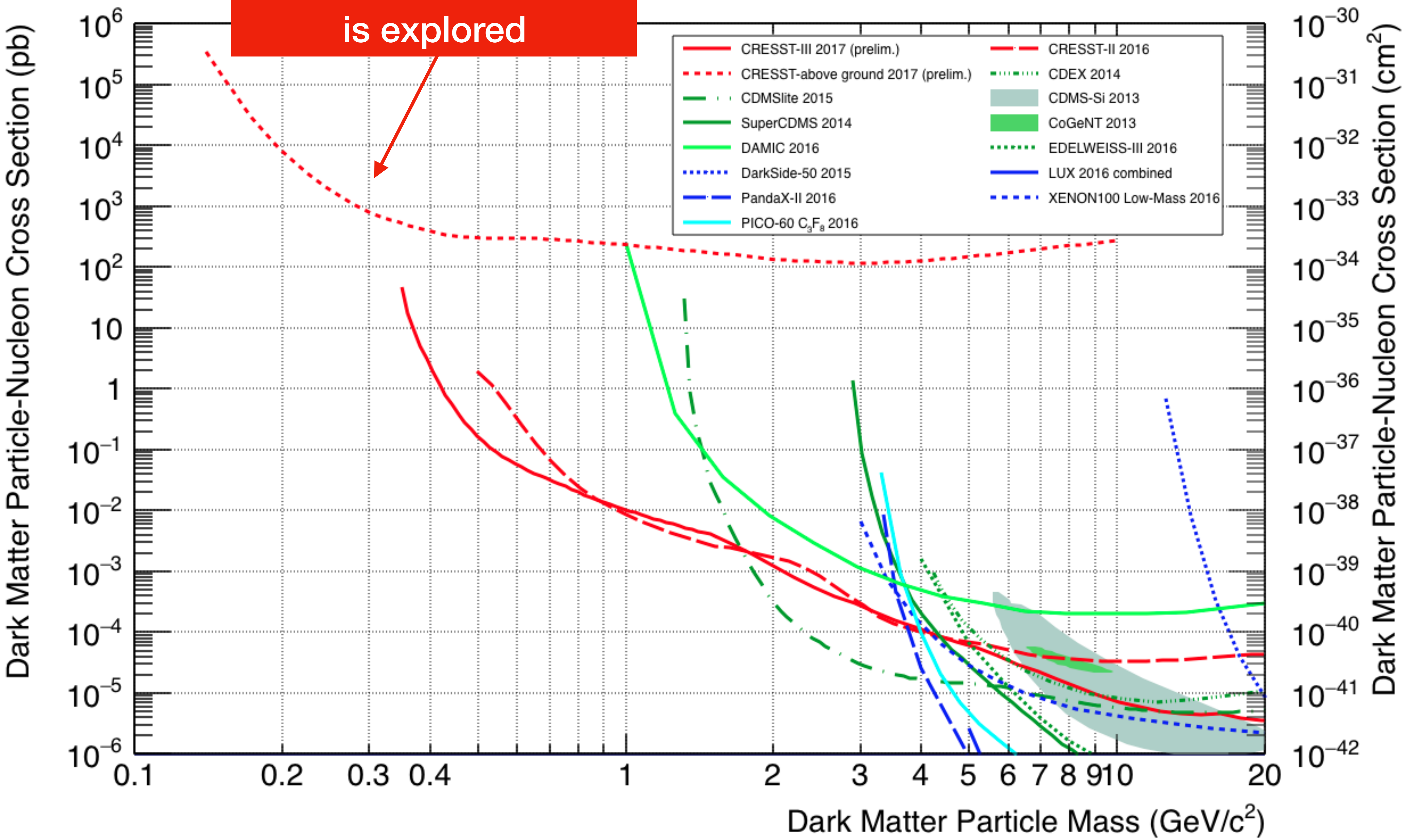
Measuring time 5.3h
No data quality cuts



EPJ C (2017) 77:637

Gram-scale exclusion limit

New mass region between 140 and 350 MeV/c^2 for dark matter is explored



Conclusions

- CRESST III, using cryogenic detectors, has set new benchmark point in low-mass dark matter search.
- First data from CRESST-III showed:
  - design goal of 100 eV threshold successfully reached
  - excellent sensitivity to low energy nuclear recoils provide the best sensitivity for dark matter particles < 1.7 GeV/c^2
- Gram-scale detector extends limit down to 140 MeV/c^2.

Conclusions

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- First data from CRESST-III showed:
    - design goal of 100 eV threshold successfully reached
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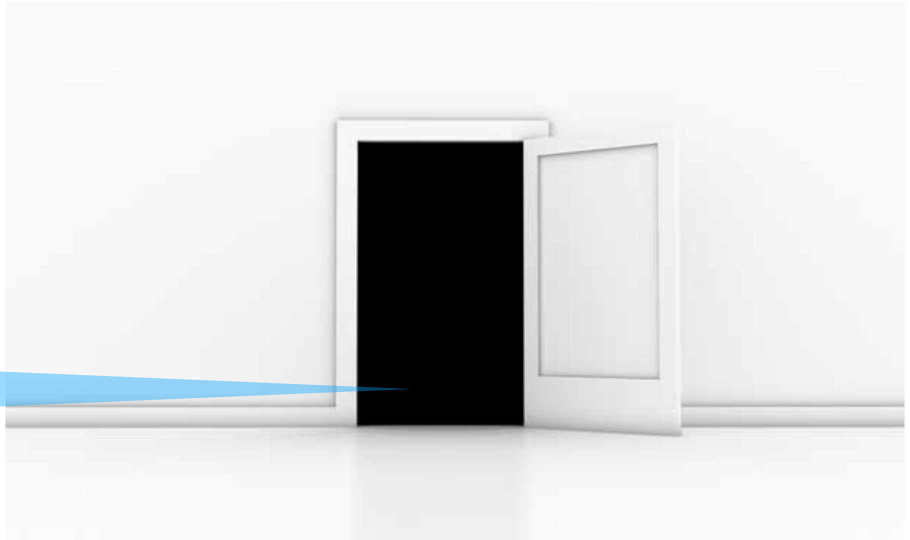
- Gram-scale detector extends limit down to 140 MeV/c^2.

New challenges,
new potentials,
new discoveries….

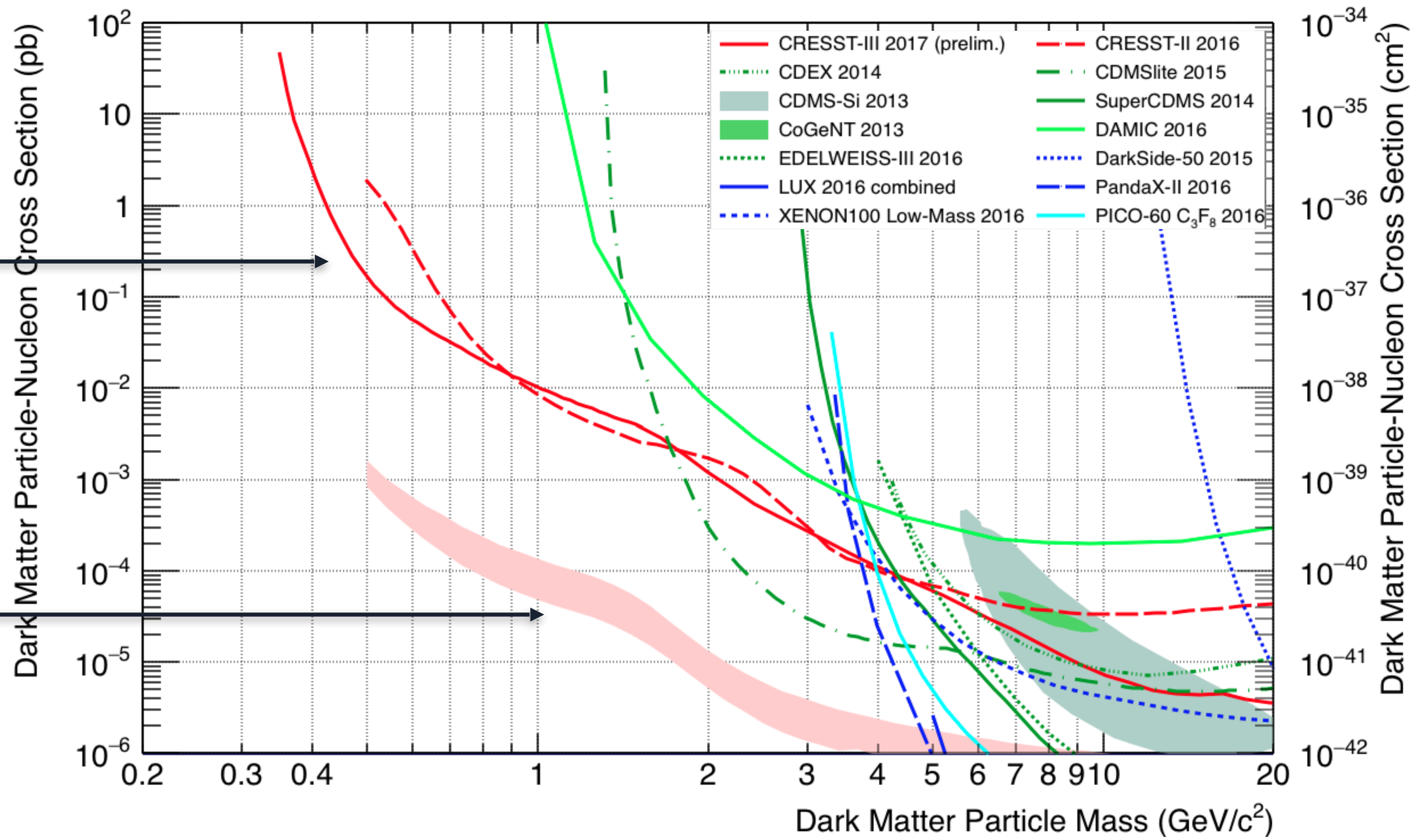


Backup slides

Sensitivity projections

2.39 kg days
From detA

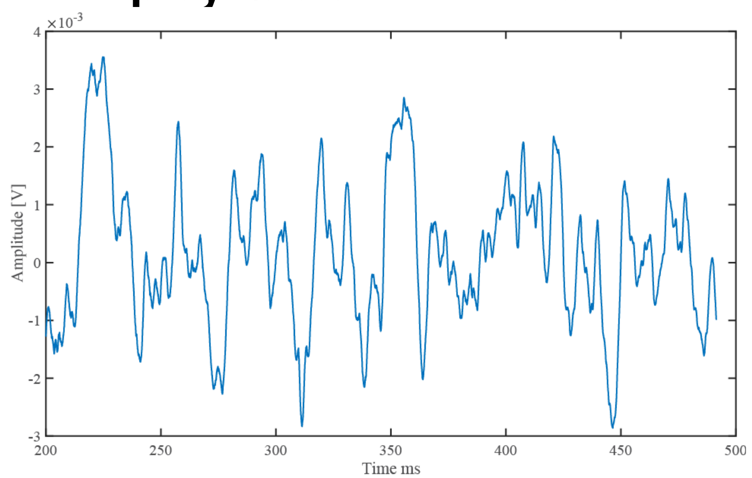
50kg days
Projection

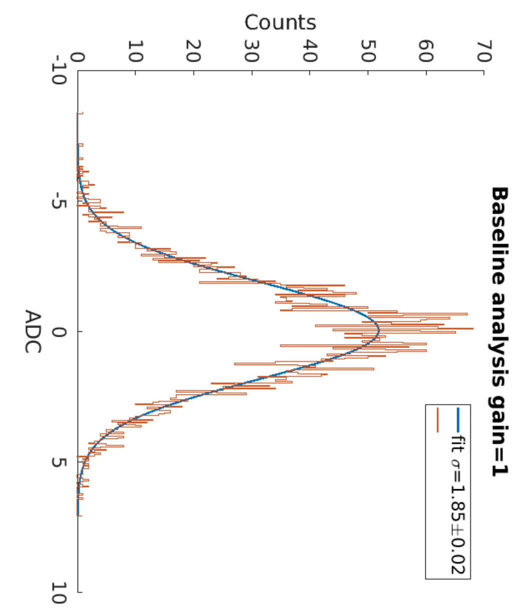


Optimum trigger – Detector A

Optimum filter for threshold analysis

Empty base line trace

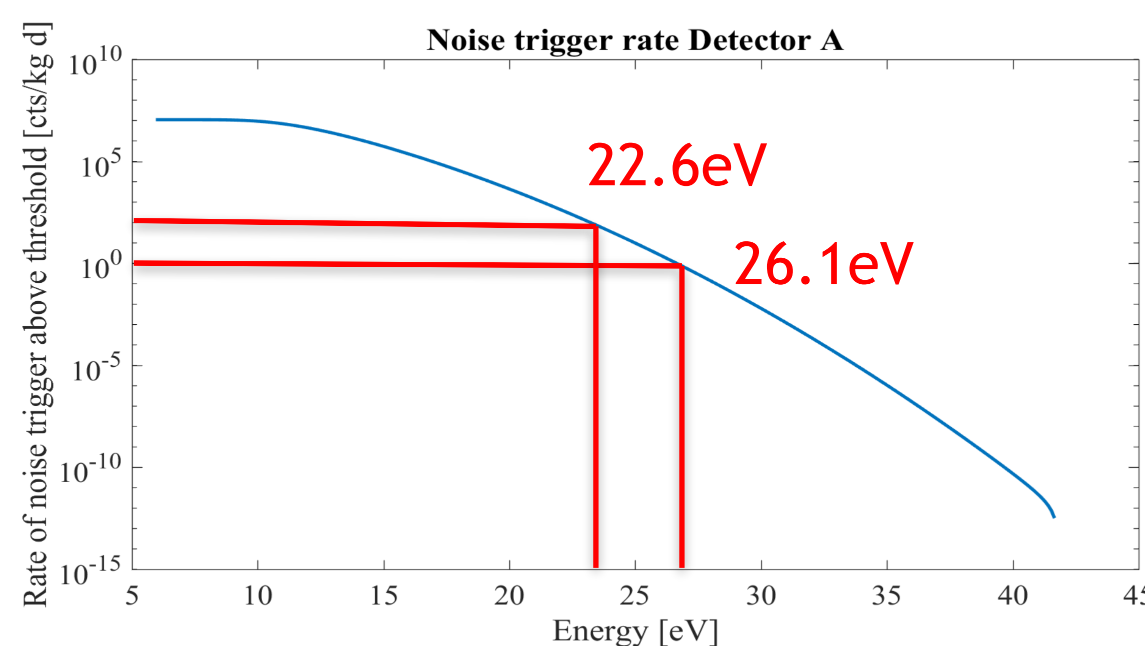




Histogram of a typical baseline trace

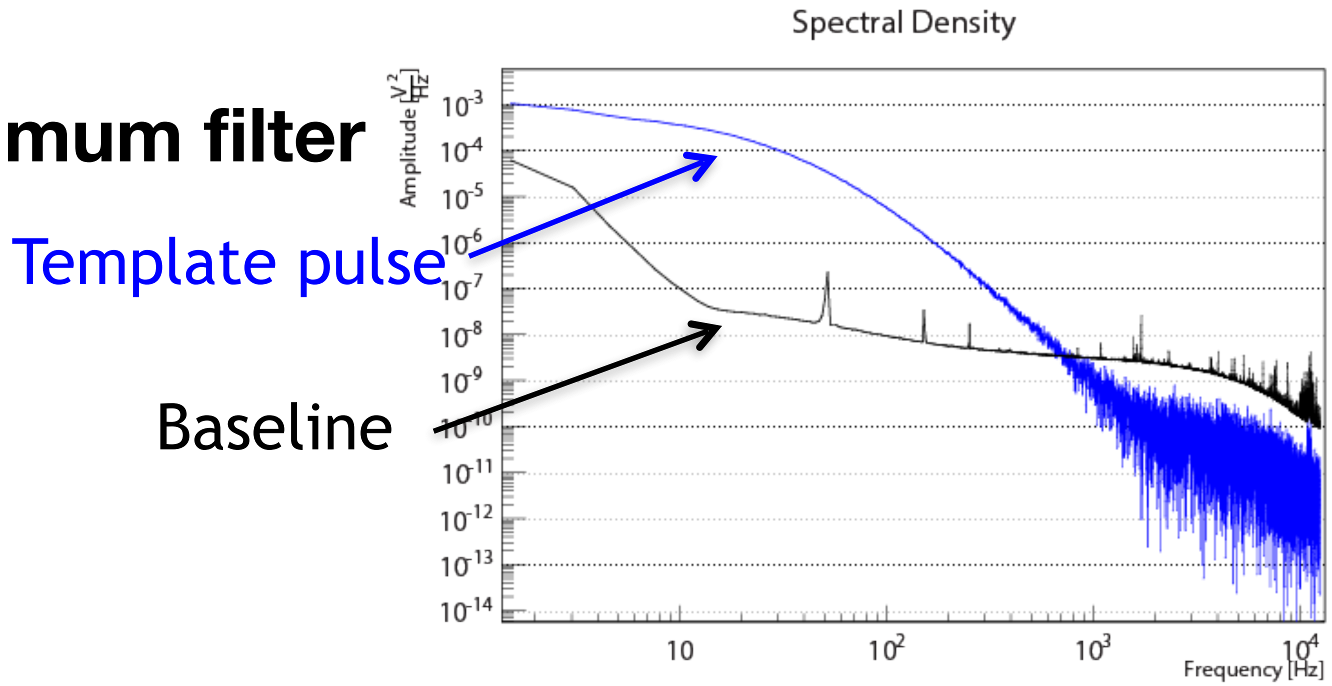
- Continuous sampling of raw data
- Study the noise distribution after optimum filter in order to set the threshold

Analytical description of amplitude distribution in empty baselines

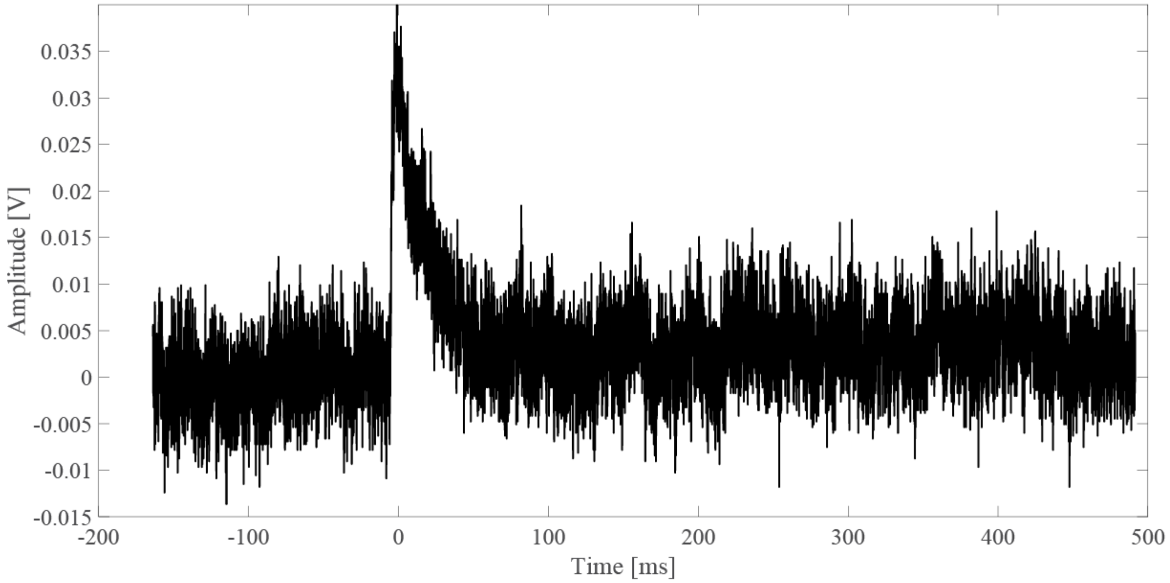


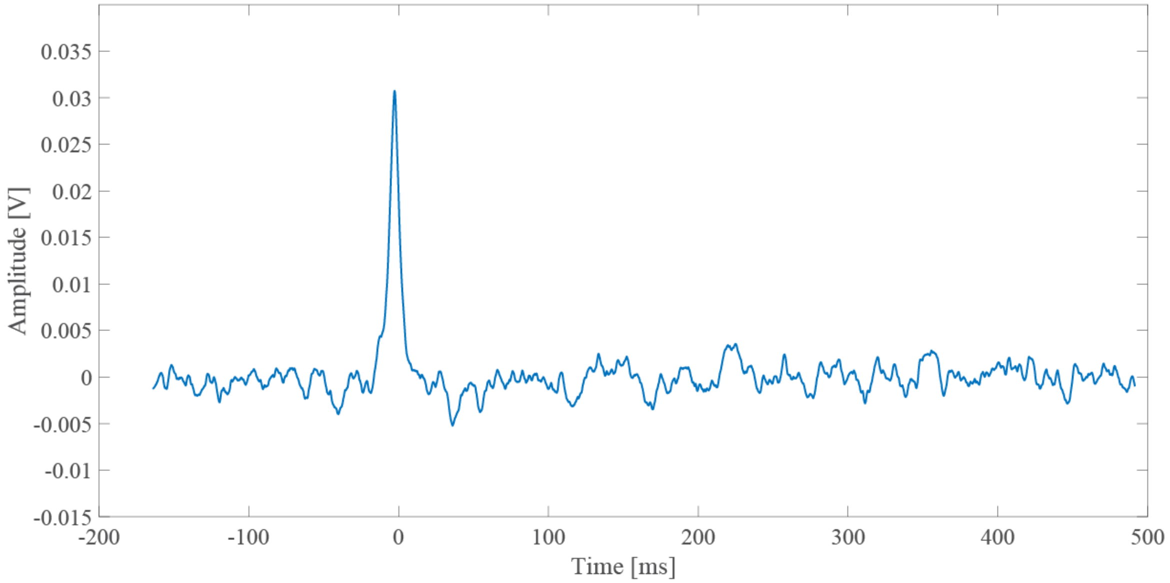
Optimum filter

Pulse-height evaluation with optimum filter



The **Gatti-Manfredi filter** is an optimum filter which maximises 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

Differential interaction rate

$$\frac{dR}{dE_r} = \frac{\sigma_0}{m_\chi} \frac{F^2(E_r)}{\mu^2} \frac{\rho_\odot T(E_r)}{v_\odot \sqrt{\pi}}$$

counts per kg, day and keV recoil energy Er

σ_0	interaction cross section at zero momentum transfer
m_χ	dark matter particle mass
$F(E_r)$	nuclear form factor
$\mu = \frac{m_\chi m_N}{m_\chi + m_N}$	reduced mass
$T(E_r) = \frac{\sqrt{\pi}}{2} v_\odot \int_{v_{min}}^{v_{esc}} \frac{f_1(v)}{v} dv$	integral over local dark matter velocity distribution
$v_{min} = \sqrt{\frac{E_r m_N}{2\mu^2}}$	minimal velocity to produce a recoil of given energy E_r