


# Searches for Dark Matter with the CRESST-III Experiment

Jochen Schieck
Institute of High Energy Physics
Austrian Academy of Sciences
http://www.hephy.at/jschieck

Technische Universität Wien
Atominstitut

**for the CRESST Collaboration** (www.cresst.de)

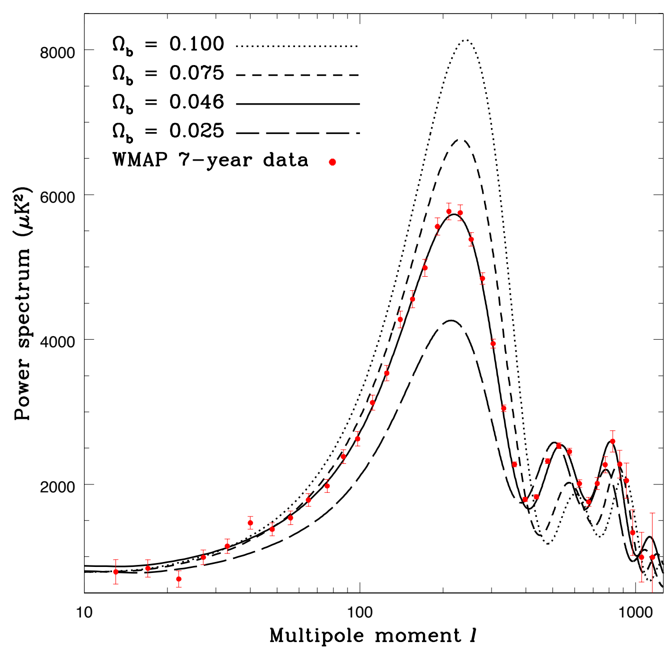
HEPHY
INSTITUT FÜR HOCHENERGIEPHYSIK

TU WIEN
TECHNISCHE UNIVERSITÄT WIEN

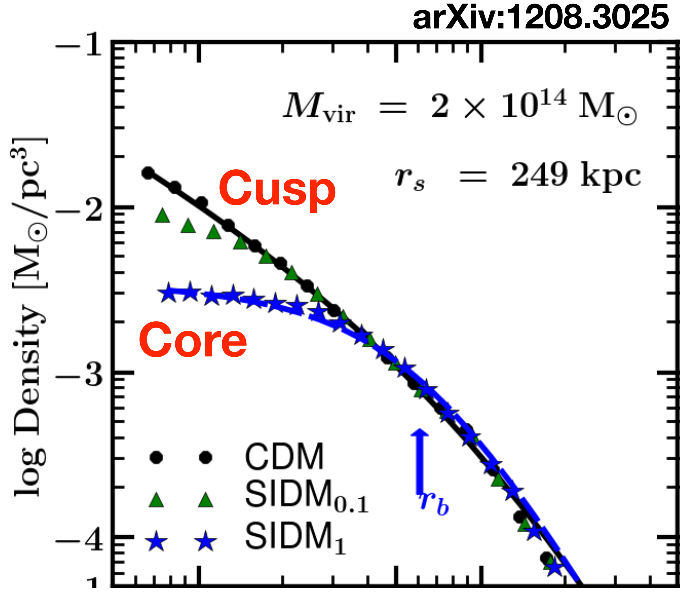
# Search for low mass dark matter

- observation of dark matter on different astrophysical scales
- microscopic character of dark matter unclear
  **→ search for particle dark matter**
- several models predict dark matter beyond the traditional WIMP mass window from ~2 GeV to ~120 TeV
  **→ search for low mass dark matter**

**CMB power spectrum**




**arXiv:1208.3025**




**SIDM**: self interacting Dark Matter

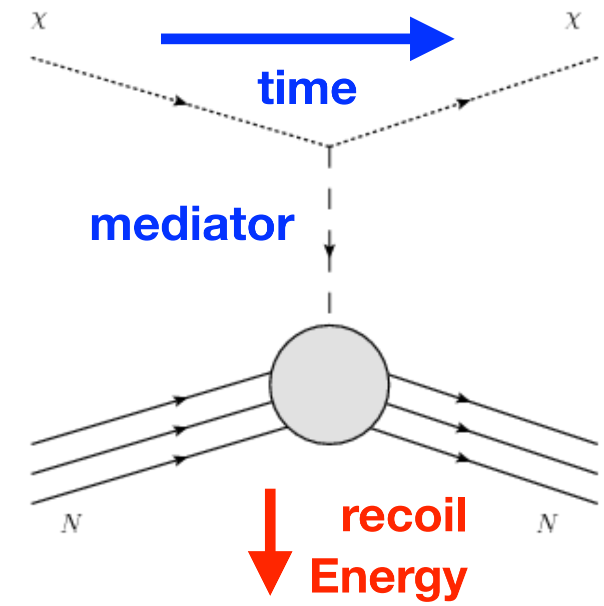
# Direct detection of dark matter - basic principle

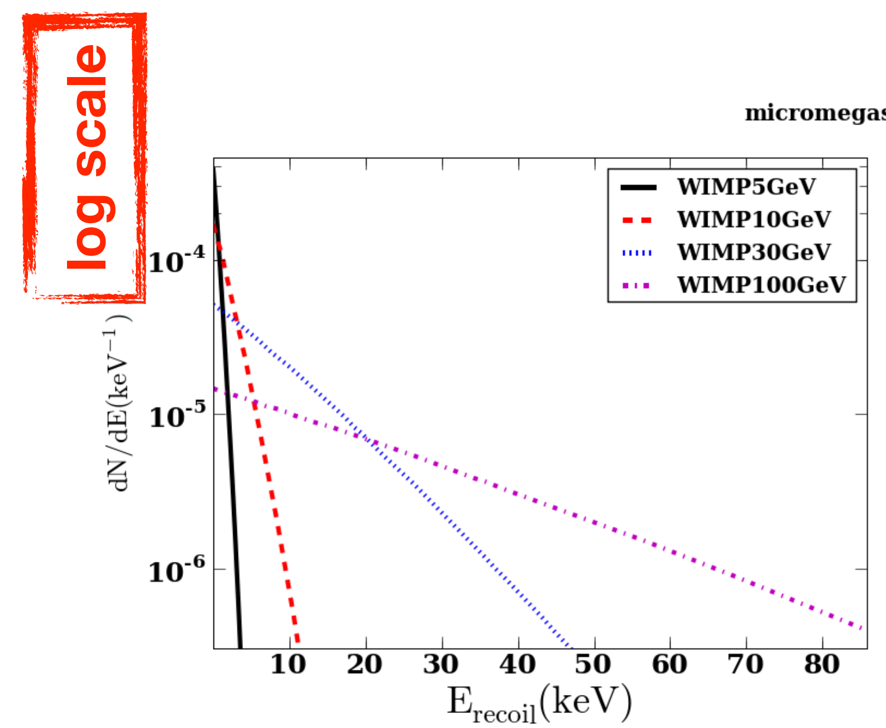
- weakly interacting massive particles scatter elastically with baryonic dark matter

  1. recoil of nucleus leads to
  2. deposition of energy followed by
  3. measurement of deposited energy

- exact interaction rate and size of deposited energy (=mass of Dark Matter particle) unknown

- **low mass dark matter requires sensitivity to low energy deposition ~ 100 eV**




**WIMP - $^{78}$Ge nucleon scattering**

# The CRESST Collaboration

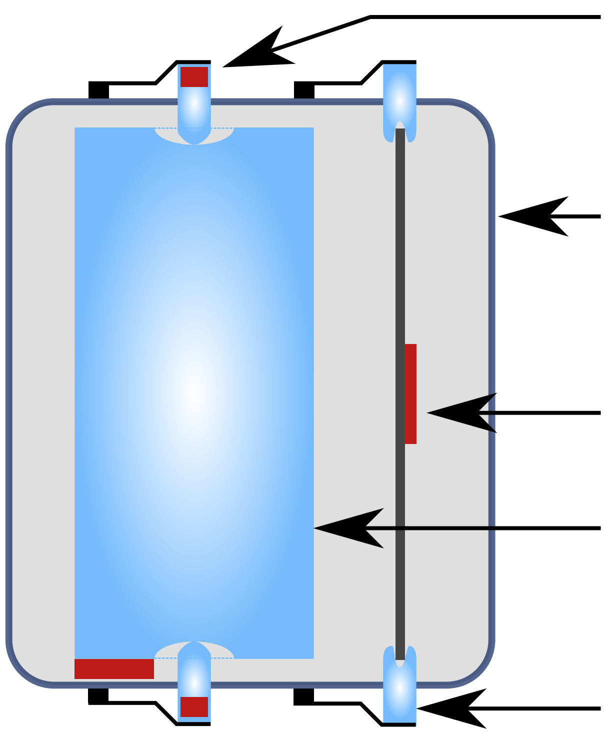
**About 40-50 scientists from 8 institutions and 5 countries**

# CRESST - detection principle I

simultaneous read-out of two signals

- **phonon channel:** particle independent measurement of deposited energy (= nuclear recoil energy)

- **(scintillation) light:** different response for signal and background events for background rejection ("quenching")



# CRESST - detection principle II

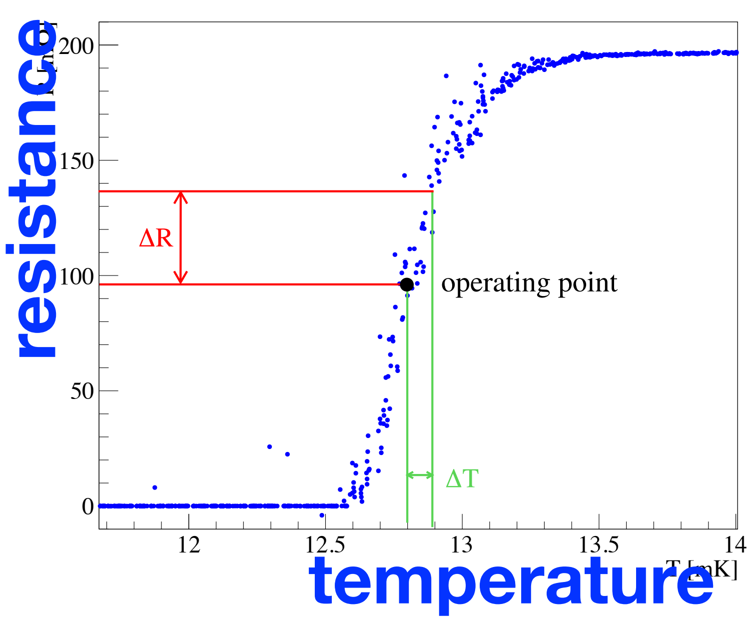
- experiment operated at cryogenic temperature (~15 mK)
- nuclear recoil will deposit energy in the crystal leading to a temperature rise proportional to energy

$$\Delta T \propto \frac{\Delta Q}{c \cdot m}$$

$$c \propto (T/\theta_D)^3$$

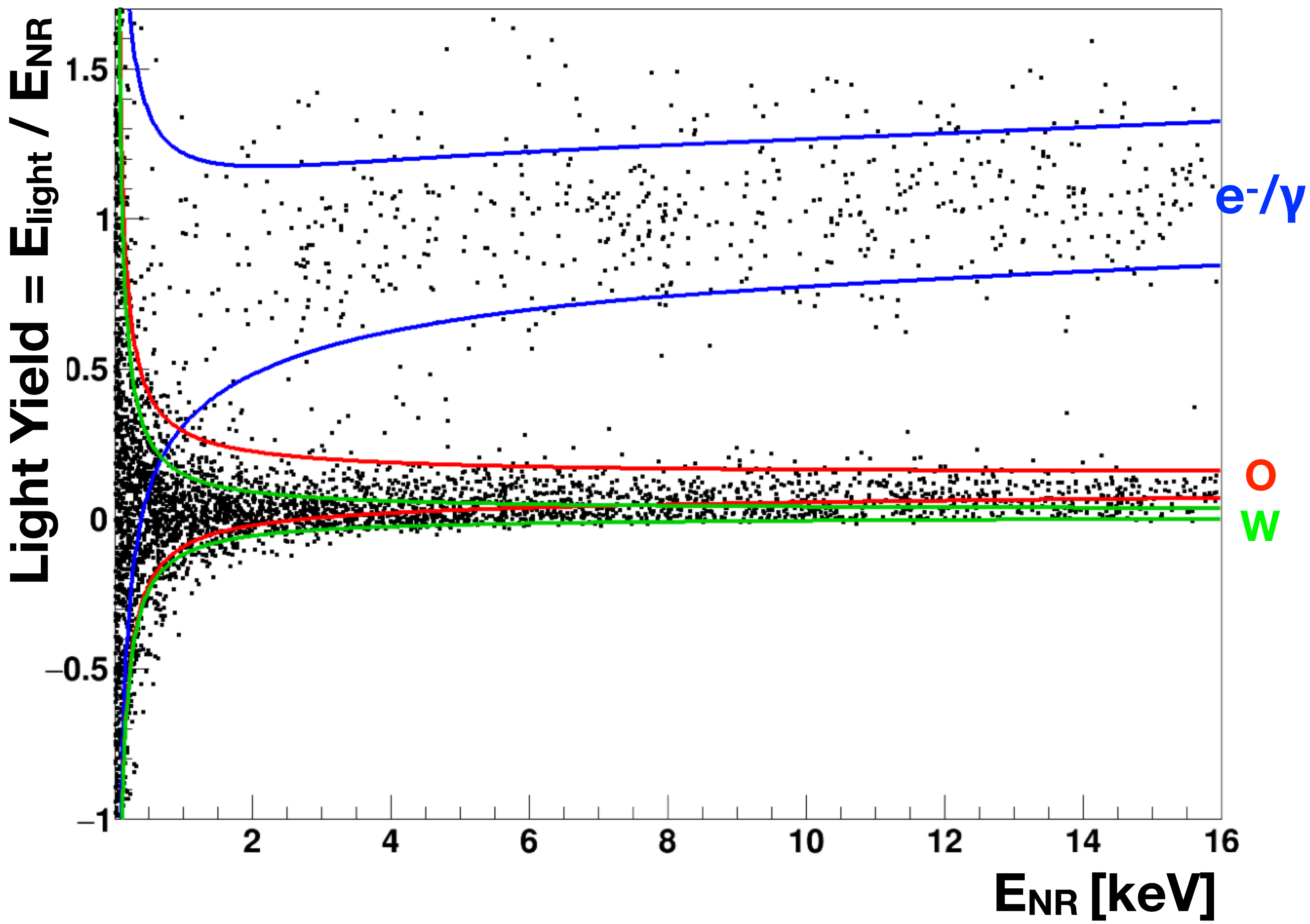
$\Theta_D$:Debye temperature

- detection of small energy depositions requires very small heat capacity C
- detection of temperature rise with superconductor operated at the phase transition from normal to superconducting



# Signal-background separation

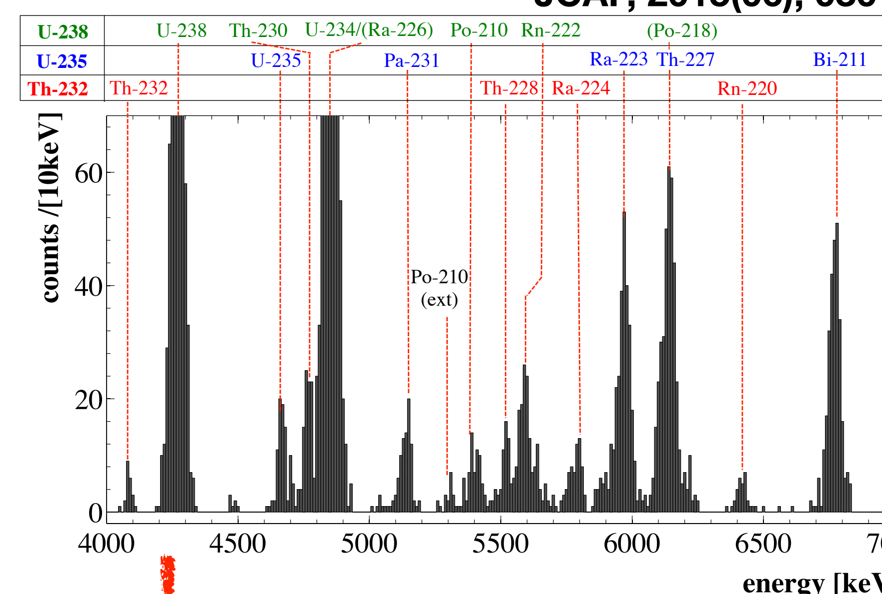
- simultaneous readout of light and phonon channel allows background reduction
- less scintillation light for nuclear recoils (“quenching”)
    - clear separation between signal and background at large $E_{NR}$
    - **significant overlap of bands at low energies (= low mass dark matter)**

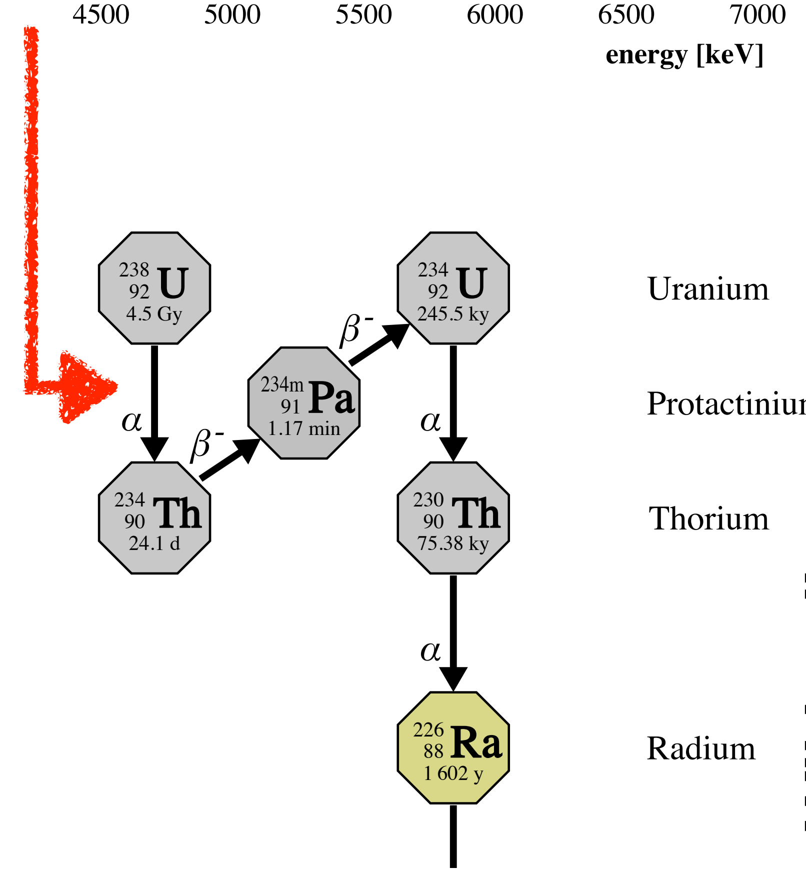


# Background simulation for CRESST - method I

- Geant4 based simulation to estimate intrinsic background
- use α-activity as input:
  - identification of decay / isotope
  - measured activity reflects size of contamination
- determine energy spectrum of isotope decay and scale it accordingly to the measured activity

JCAP, 2015(06), 030

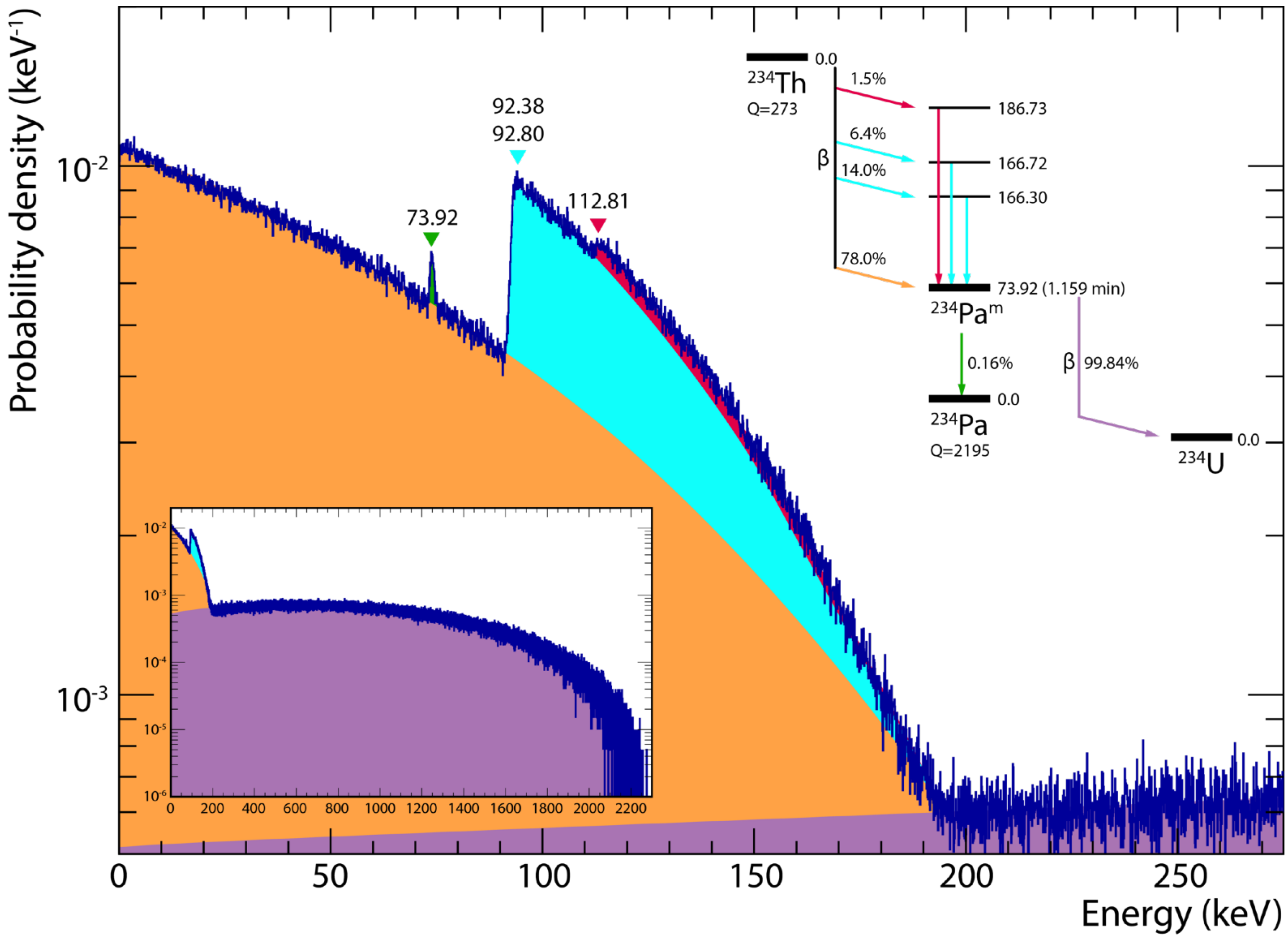



Wikipedia

# Background simulation for CRESST - method II

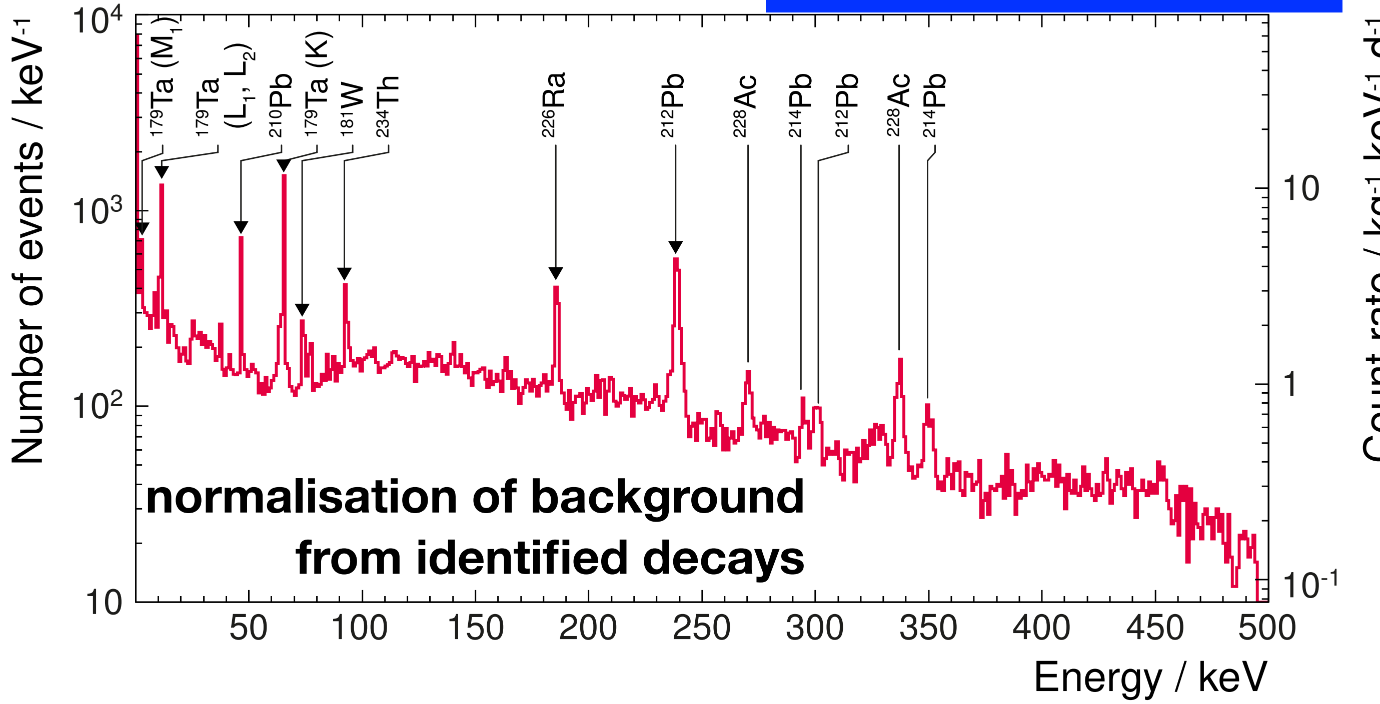
energy spectrum of simulated $^{234}$Th decay with Geant4

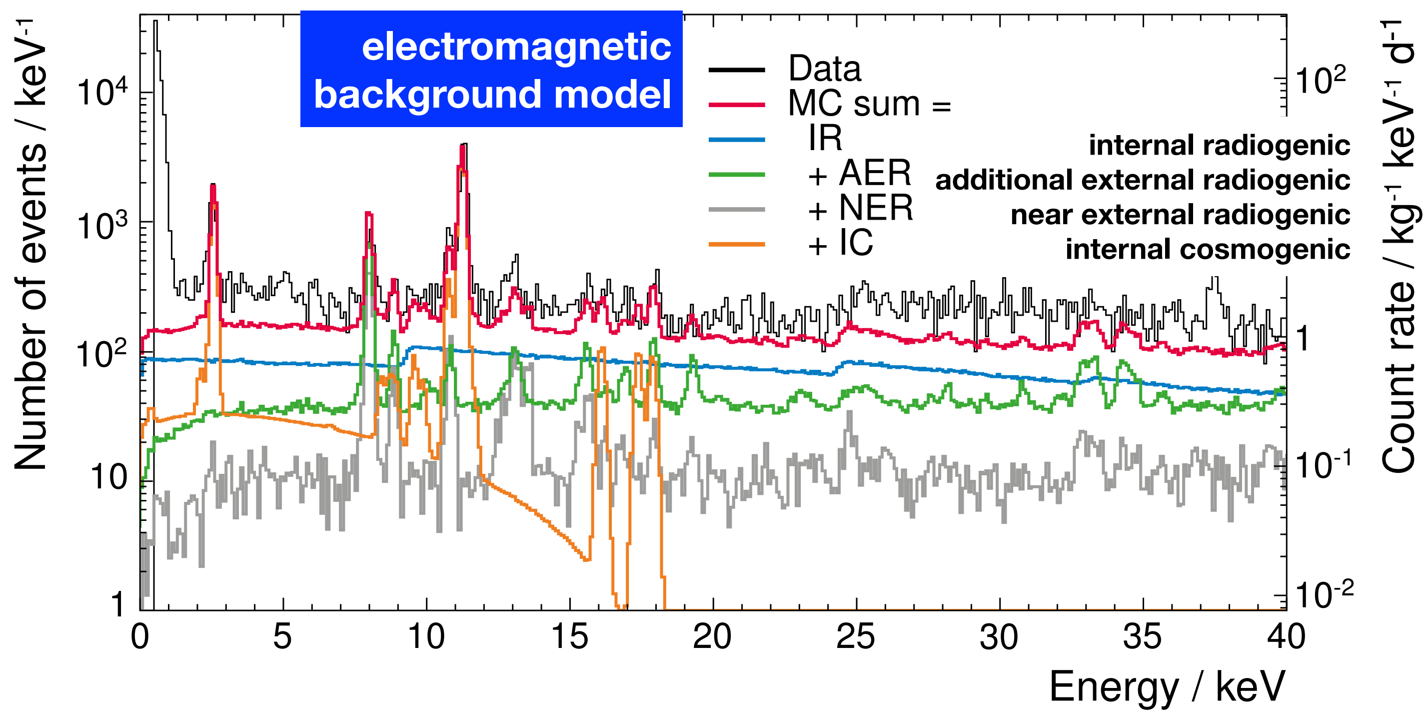


# Background simulation for CRESST - result

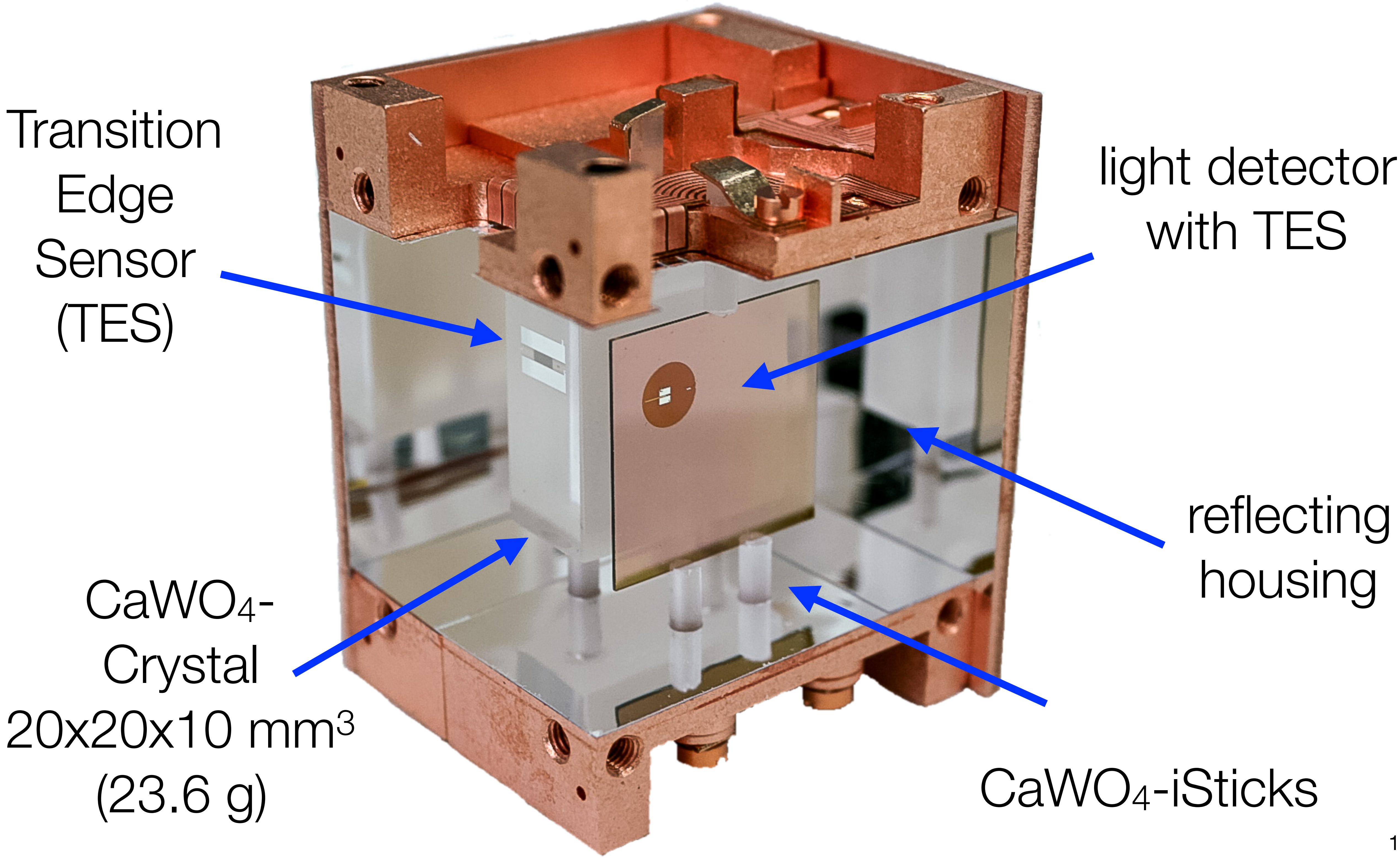
**PRELIMINARY**

- contribution of identified γ-peaks from external radiogenic background
- **electromagnetic background reproduces (69±16)% of the observed events**
- simulation of neutron background component and material screening ongoing



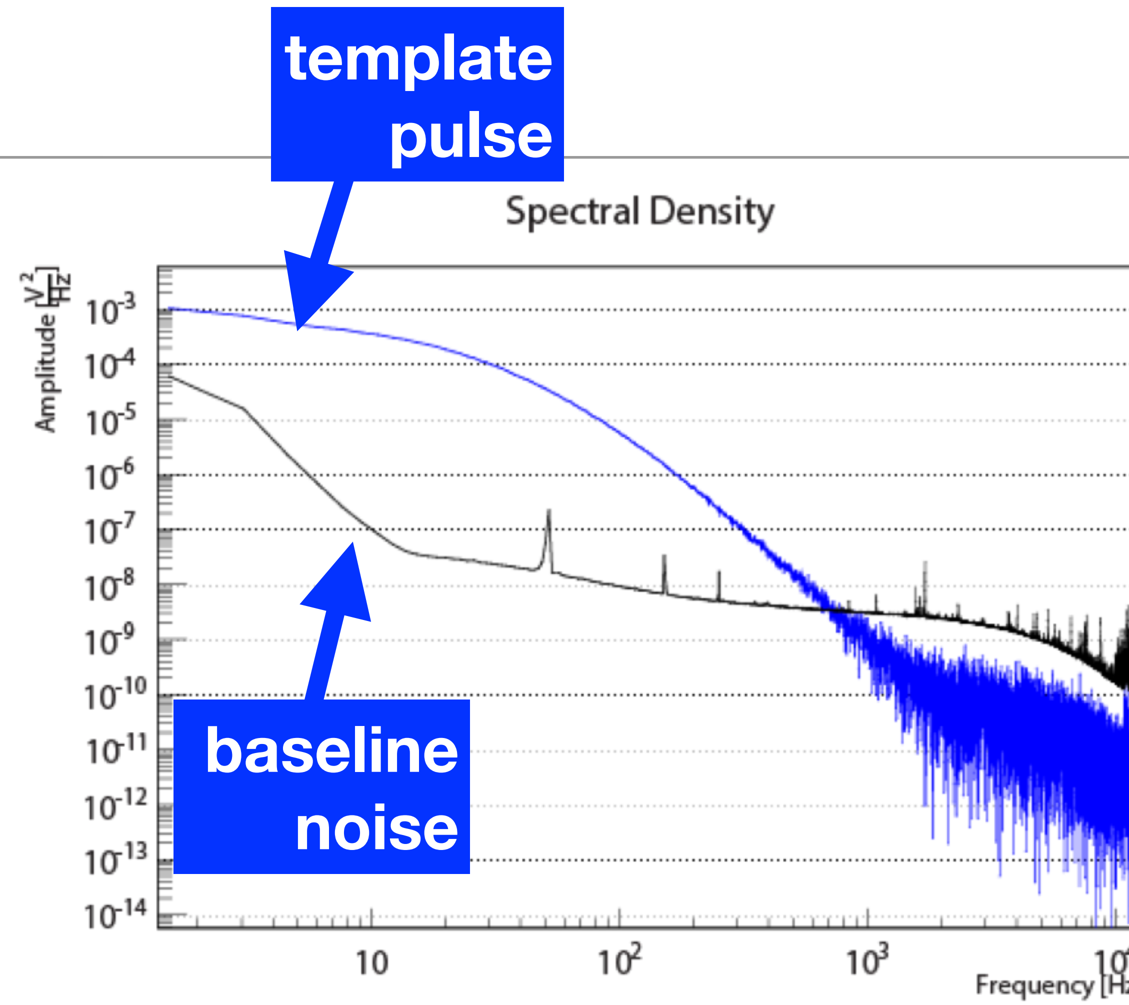
# CRESST III - detector module

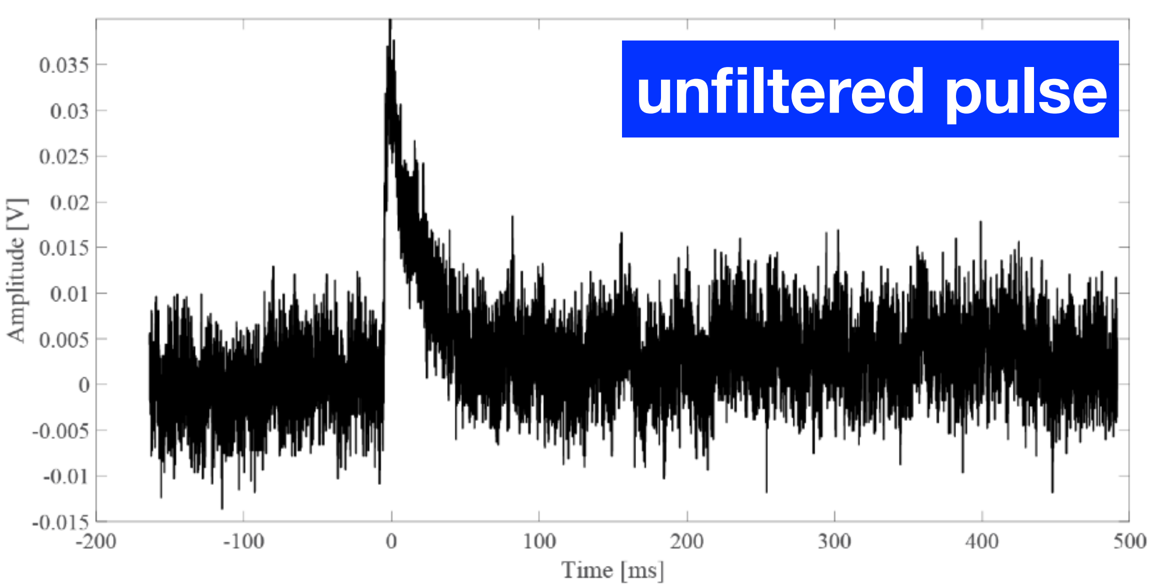


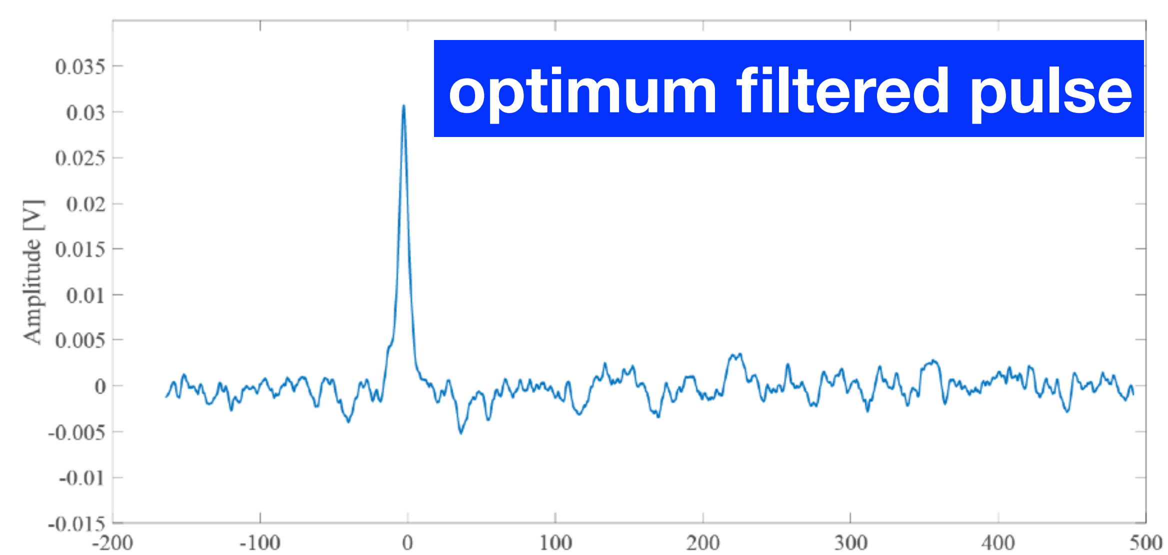
10.1016/j.nima.2019.06.030

# CRESST-III optimum filter

- implementation of the Gatti-Manfredi filter
- optimum filter maximizes signal-to-noise ratio
- typical improvement about factor 2-3
- new DAQ for CRESST-III with continuous data sampling
- threshold set after optimum filter

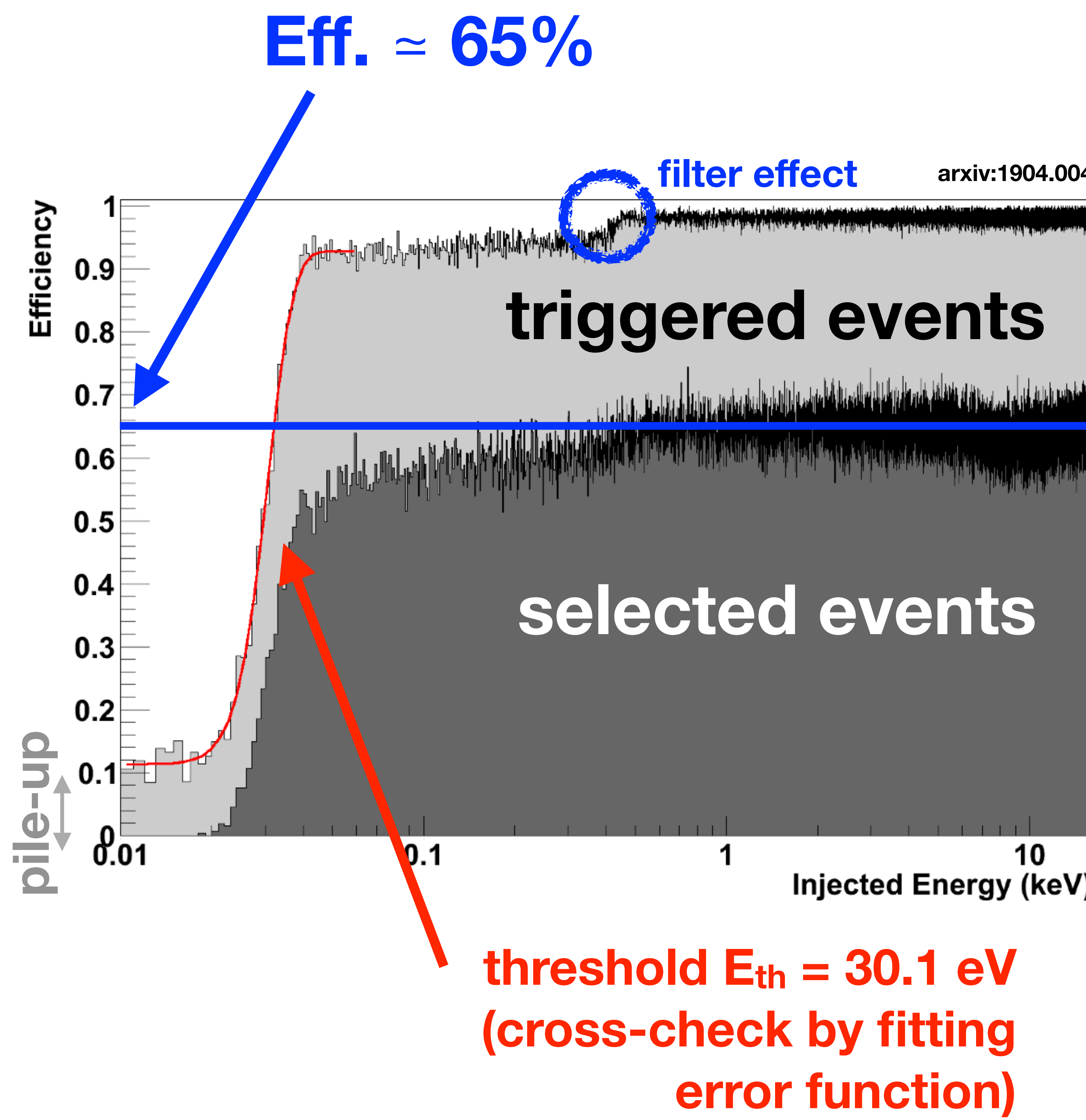


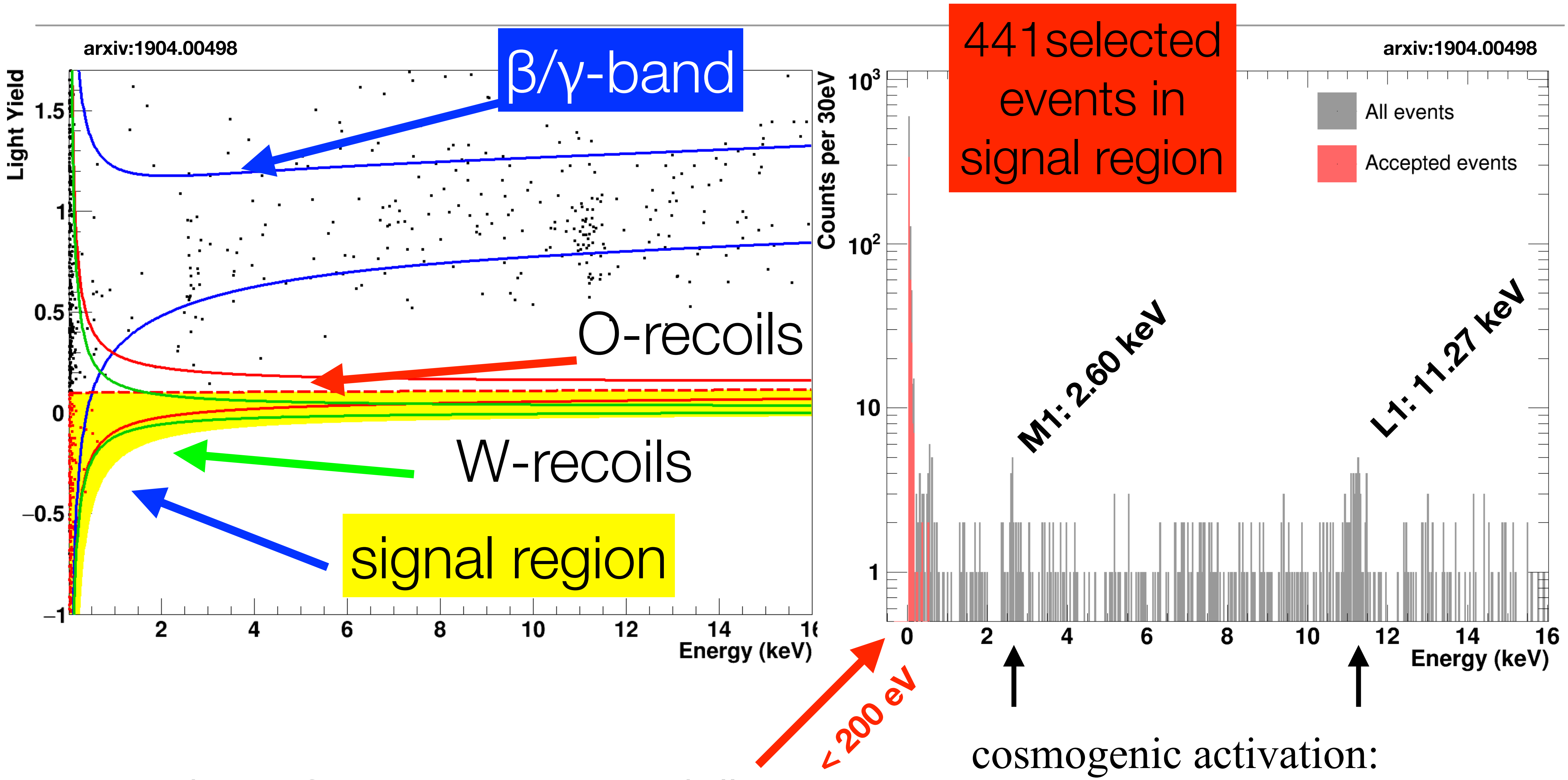



# Selection efficiency

- data taking period: 5/2016-02/2018
- 20% of data as non-blind training set randomly selected
- size of selected data set (after cuts): 3.64 kg·d
- efficiency (energy dependence not taken into account) ~65%



# CRESST III - selected data

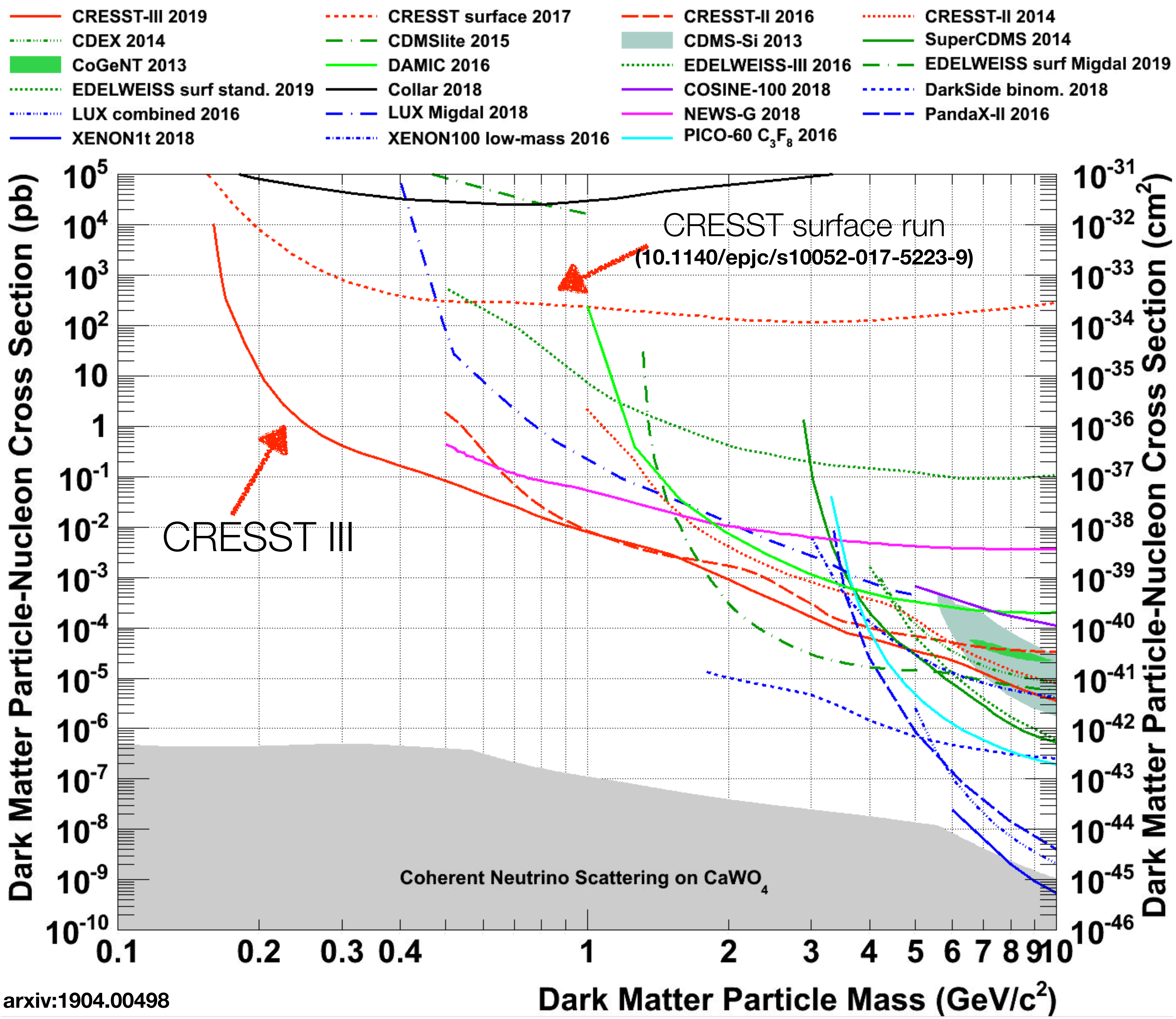



cosmogenic activation:

$$^{182}\mathrm{W} + \mathrm{p} \rightarrow {}^{179}\mathrm{Ta} + \alpha, \quad {}^{179}\mathrm{Ta} \xrightarrow{\mathrm{EC}} {}^{179}\mathrm{Hf} + \gamma.$$

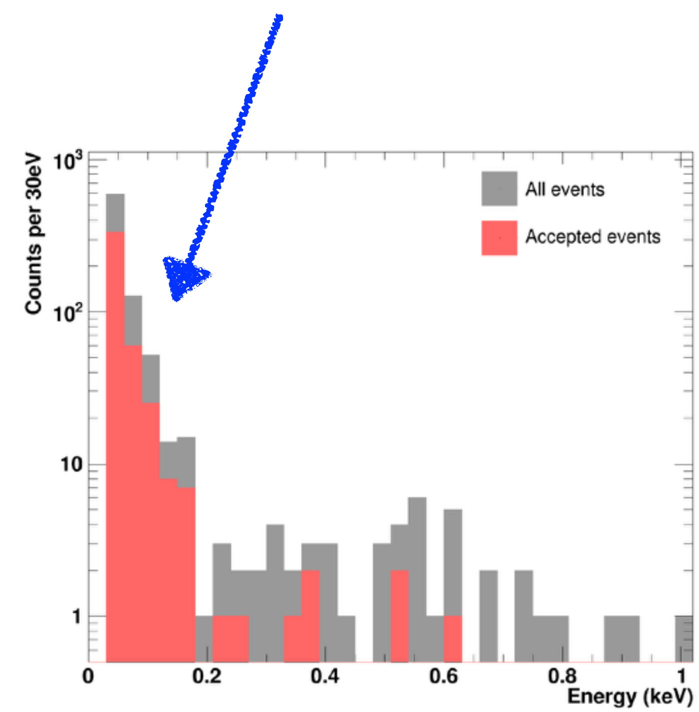
- number of events exponentially increasing for low energies

# Limit on spin-independent dark matter




arxiv:1904.00498

- extend sensitivity down to 160 MeV/$c^2$
- **unexpected rise of event rate below 200 eV**



# Limit on spin-dependent dark matter interaction

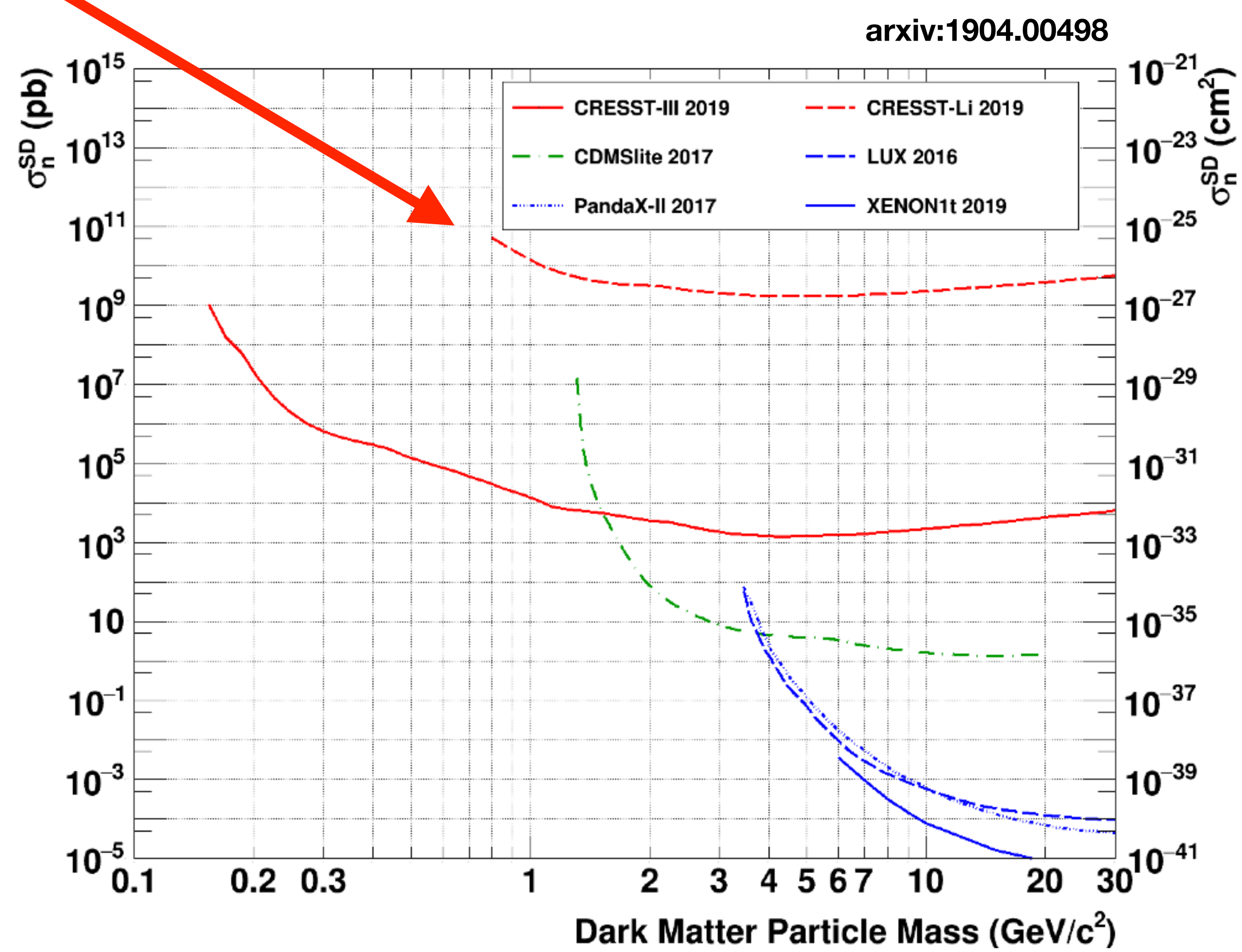
**$Li_2MoO_4$ above ground (10h)**
**→7.91x10$^{-5}$ kg·d $^7$Li exposure**
**(arxiv:1902.07587)**

- measurement of spin-dependent interaction via $^{17}$O (natural abundance 0.0367%)

**spin of the target**

$$\left(\frac{d\sigma_{WN}}{dE_R}\right)_{SD} = \frac{16 m_N}{\pi v^2}\Lambda^2 G_F^2 J(J+1)\frac{S(E_R)}{S(0)}$$

- exposure: 0.46 g·d



# Summary

- **CRESST-III** with **23.6 g** CaWO4 crystals from 05/2016-02/2018
- unprecedented low nuclear recoil **threshold of 30 eV**
- **best limit** for dark matter masses between **160 MeV/$c^2$ and 1.8 GeV/$c^2$**
- unexpected **rising background below 200 eV**

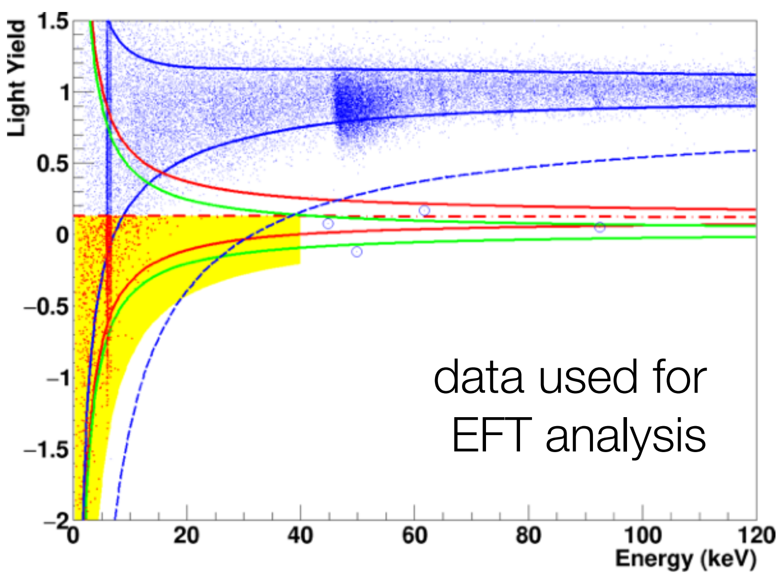
# Additional Information

# Result interpreted with Effective Field Operators

- develop cross section in terms of effective operators:

$$\mathscr{H}_{\chi T} = \sum_i \sum_j \left( c_j^0 \hat{\mathscr{O}}_j^i \mathbb{1}_{2\times 2}^i + c_j^1 \hat{\mathscr{O}}_j^i \tau_3^i \right)$$

**isoscalar** **isovector**




- nuclear matrix element required

✓ $\hat{\mathscr{O}}_1 = \mathbb{1}_\chi \mathbb{1}_N$ **spin independent**

✓ $\hat{\mathscr{O}}_3 = i\hat{\mathbf{S}}_N \cdot \left( \frac{\hat{\mathbf{q}}}{m_N} \times \hat{\mathbf{v}}^\perp \right) \mathbb{1}_\chi$

$\hat{\mathscr{O}}_4 = \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{S}}_N$ **spin dependent**

✓ $\hat{\mathscr{O}}_5 = i\hat{\mathbf{S}}_\chi \cdot \left( \frac{\hat{\mathbf{q}}}{m_N} \times \hat{\mathbf{v}}^\perp \right) \mathbb{1}_N$

$\hat{\mathscr{O}}_6 = \left( \hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N} \right) \left( \hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N} \right)$

$\hat{\mathscr{O}}_7 = \hat{\mathbf{S}}_N \cdot \hat{\mathbf{v}}^\perp \mathbb{1}_\chi$

✓ $\hat{\mathscr{O}}_8 = \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{v}}^\perp \mathbb{1}_N$

$\hat{\mathscr{O}}_9 = i\hat{\mathbf{S}}_\chi \cdot \left( \hat{\mathbf{S}}_N \times \frac{\hat{\mathbf{q}}}{m_N} \right)$

$\hat{\mathscr{O}}_{10} = i\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N} \mathbb{1}_\chi$

✓ $\hat{\mathscr{O}}_{11} = i\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N} \mathbb{1}_N$

✓ $\hat{\mathscr{O}}_{12} = \hat{\mathbf{S}}_\chi \cdot \left( \hat{\mathbf{S}}_N \times \hat{\mathbf{v}}^\perp \right)$

$\hat{\mathscr{O}}_{13} = i \left( \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{v}}^\perp \right) \left( \hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N} \right)$

$\hat{\mathscr{O}}_{14} = i \left( \hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N} \right) \left( \hat{\mathbf{S}}_N \cdot \hat{\mathbf{v}}^\perp \right)$

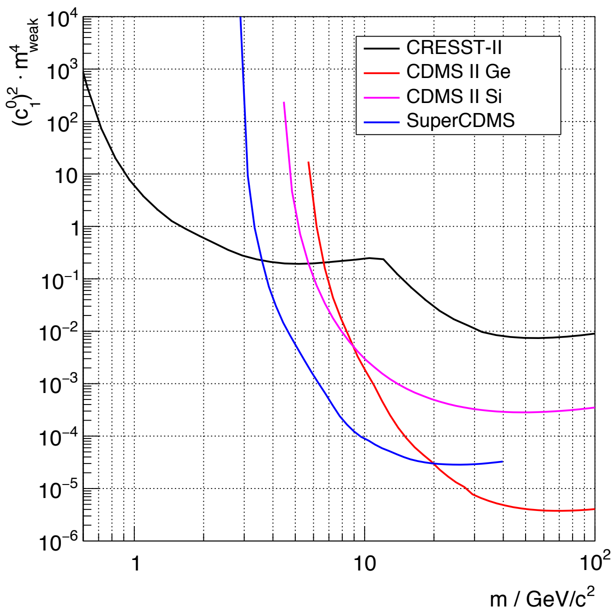
✓ $\hat{\mathscr{O}}_{15} = -\left( \hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N} \right) \left[ \left( \hat{\mathbf{S}}_N \times \hat{\mathbf{v}}^\perp \right) \cdot \frac{\hat{\mathbf{q}}}{m_N} \right]$

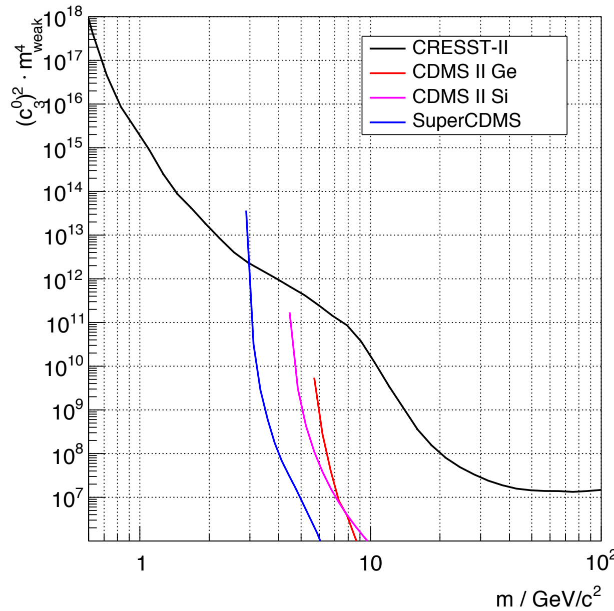
$\hat{\mathscr{O}}_{17} = i \frac{\hat{\mathbf{q}}}{m_N} \cdot \mathscr{S} \cdot \hat{\mathbf{v}}^\perp \mathbb{1}_N$

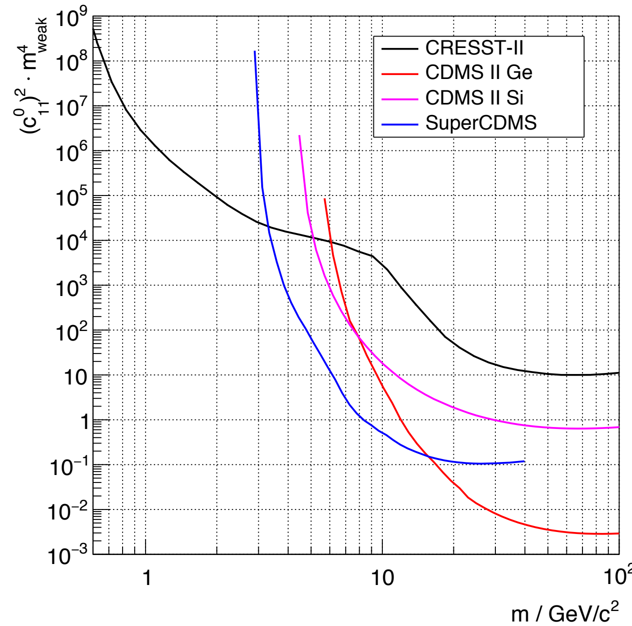
$\hat{\mathscr{O}}_{18} = i \frac{\hat{\mathbf{q}}}{m_N} \cdot \mathscr{S} \cdot \hat{\mathbf{S}}_N$

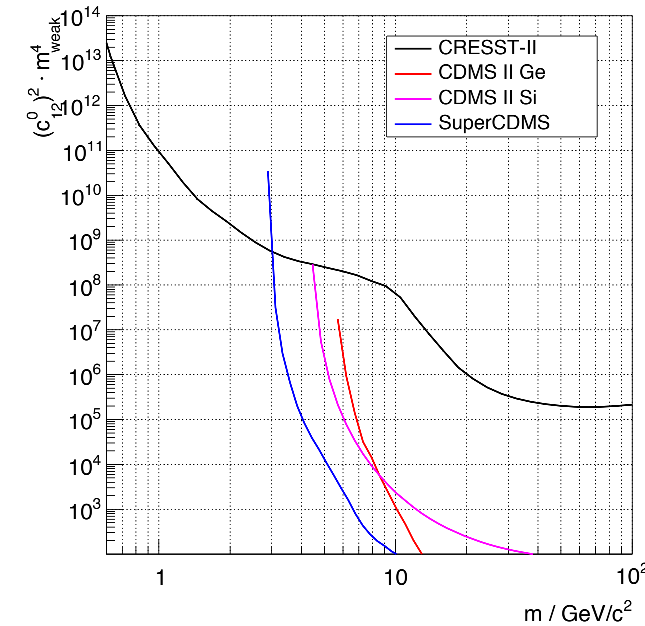
**O an Ca have Spin 0**

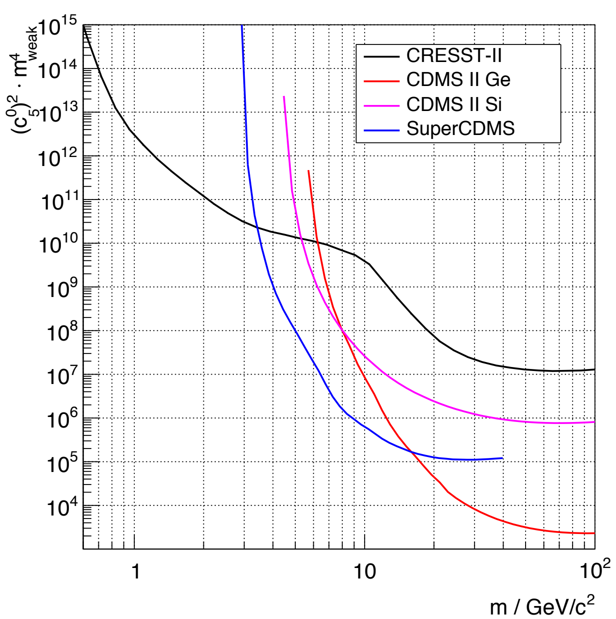
# Exclusion in terms of EFT couplings

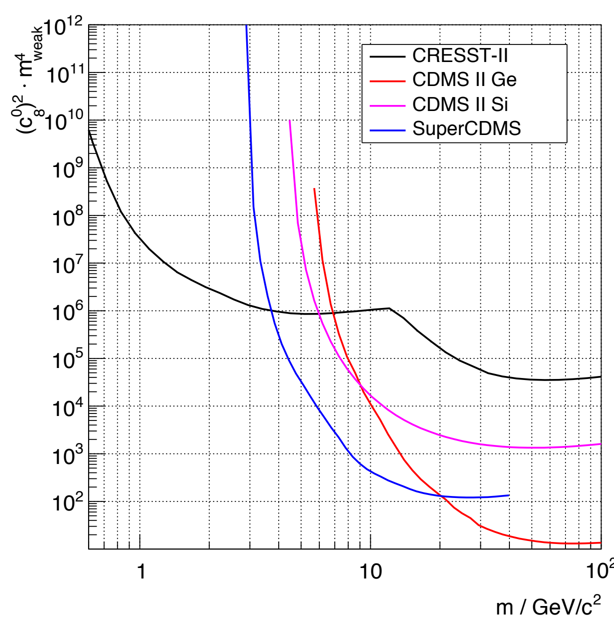


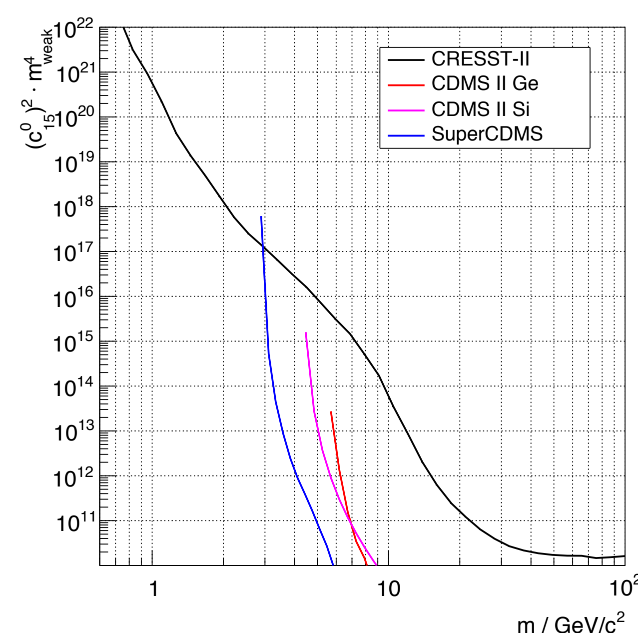



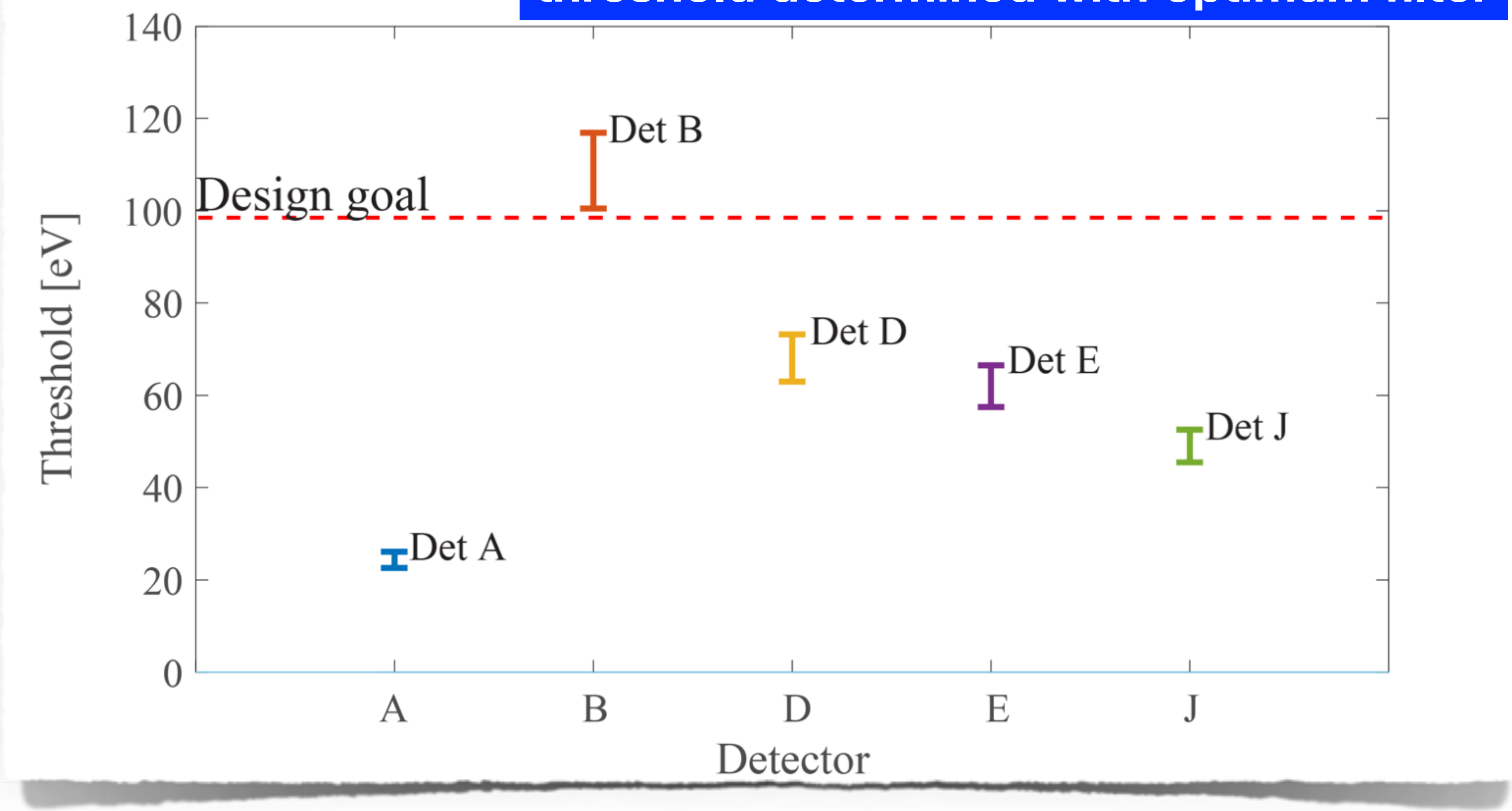



# CRESST-III Energy threshold

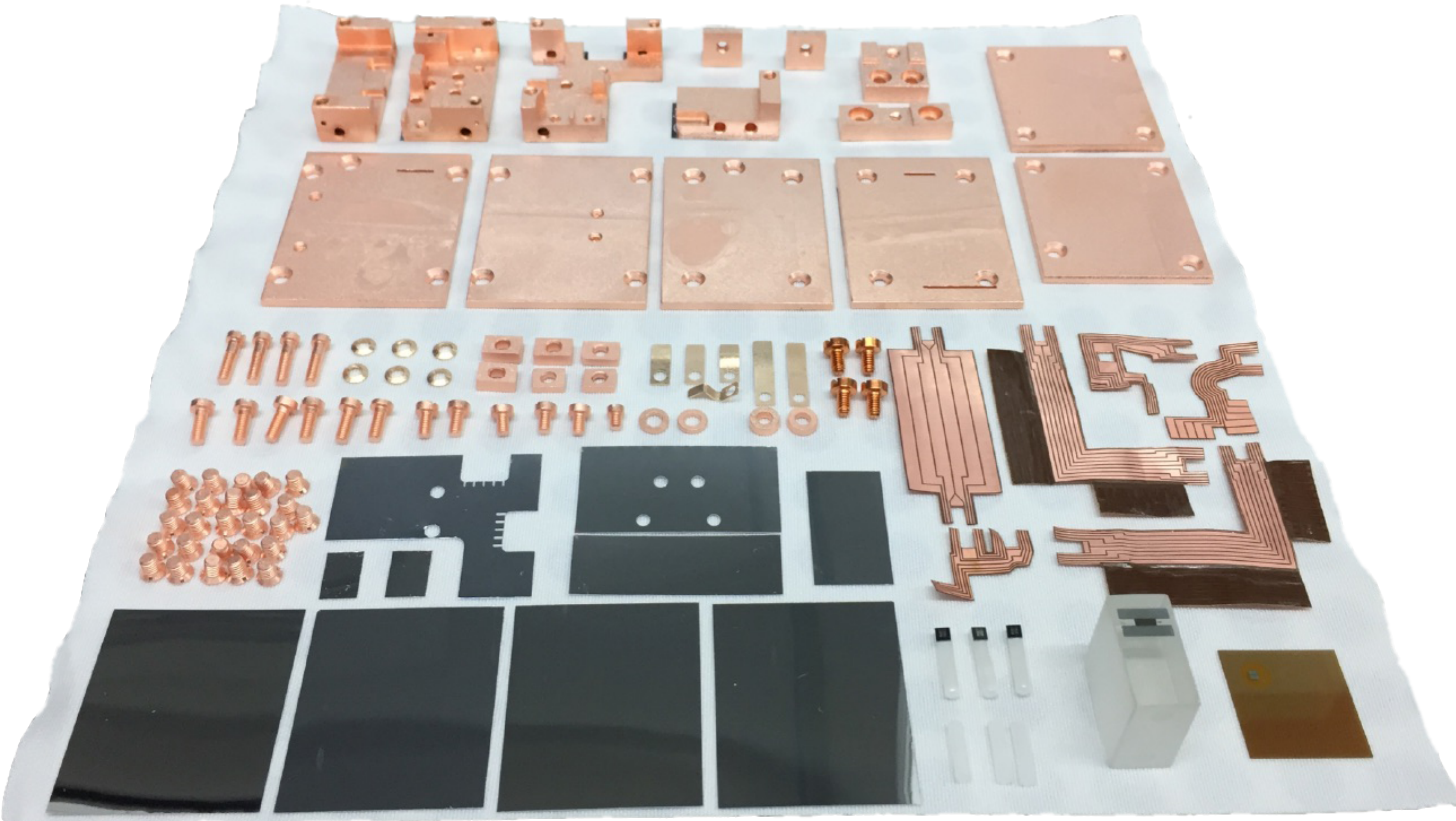
- ten detectors installed
- six of ten detectors can be operated
- four detectors have technical problems (no transition or noise)

**threshold determined with optimum filter**

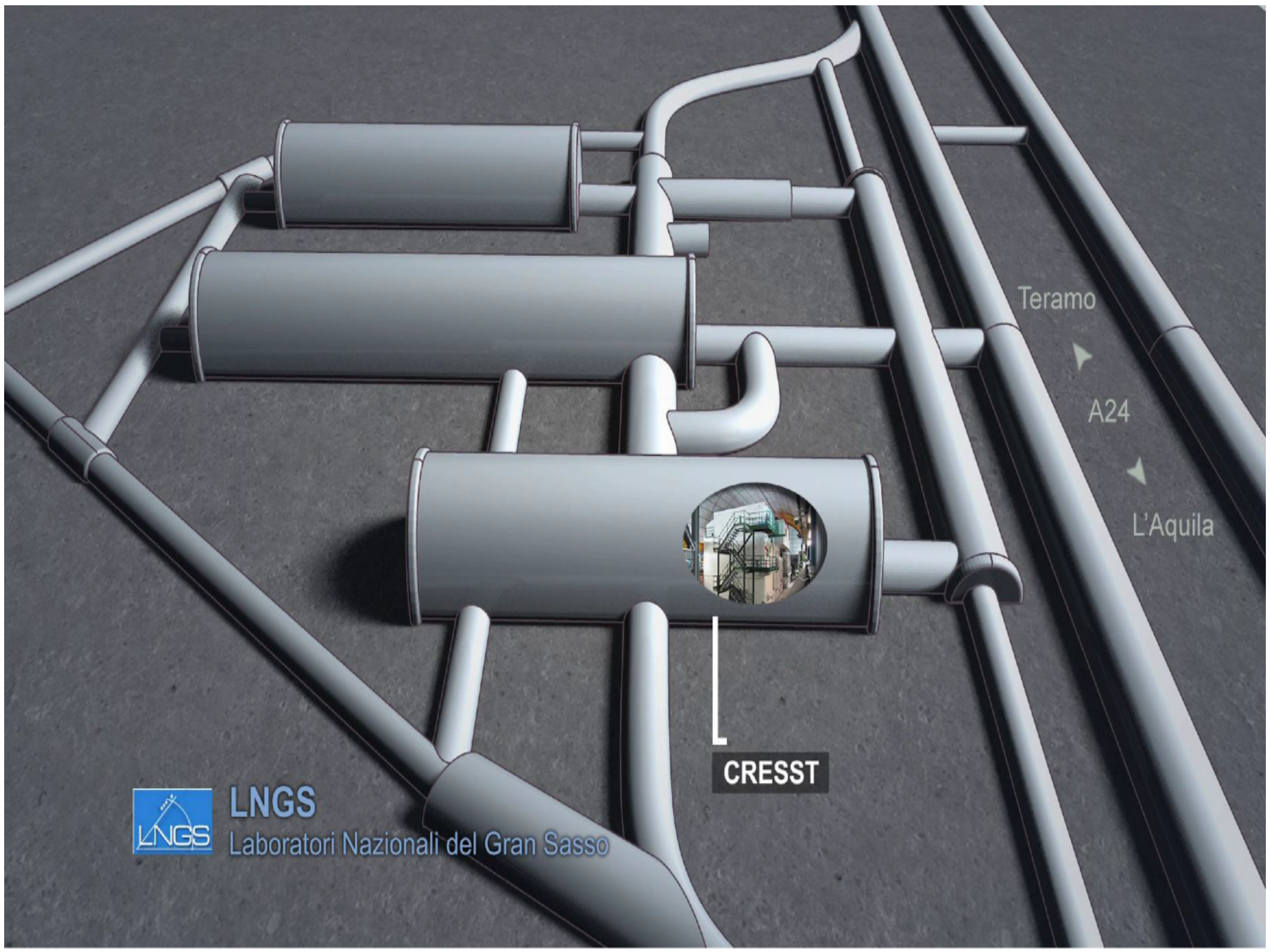


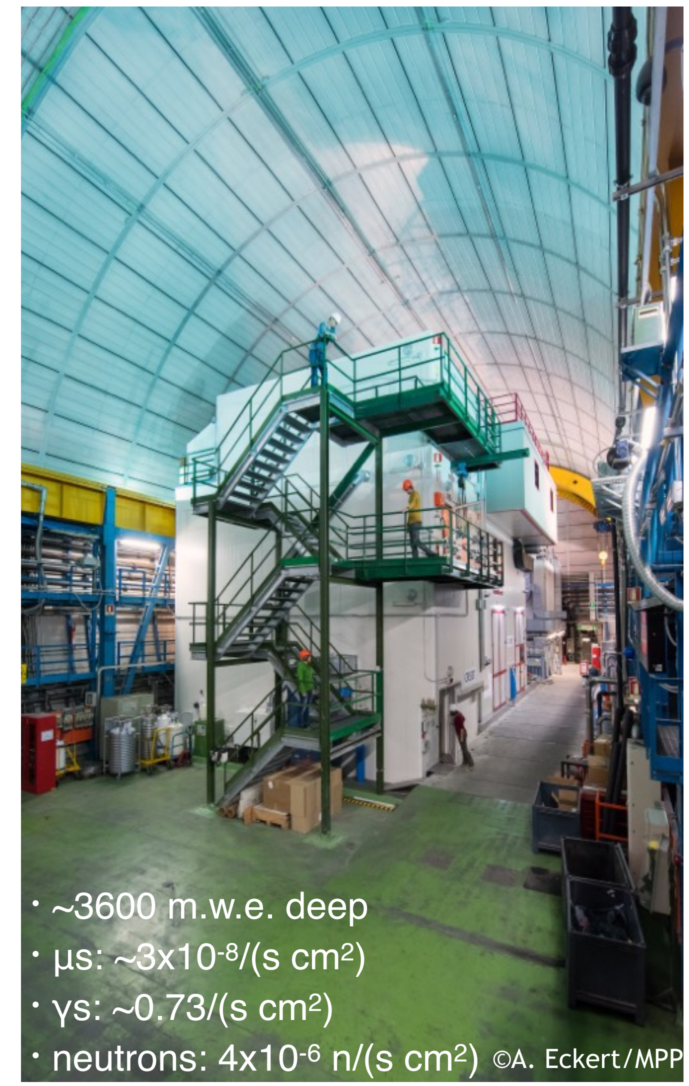

- **4 out of 5 detectors exceed design goal of 100 eV threshold**

# CRESST III Module Construction Kit



# CRESST @ LNGS


Teramo
A24
L'Aquila
CRESST
LNGS
Laboratori Nazionali del Gran Sasso


• ~3600 m.w.e. deep
• µs: ~3x10^-8/(s cm^2)
• γs: ~0.73/(s cm^2)
• neutrons: 4x10^-6 n/(s cm^2)
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