Dark matter identification with CRESST-III

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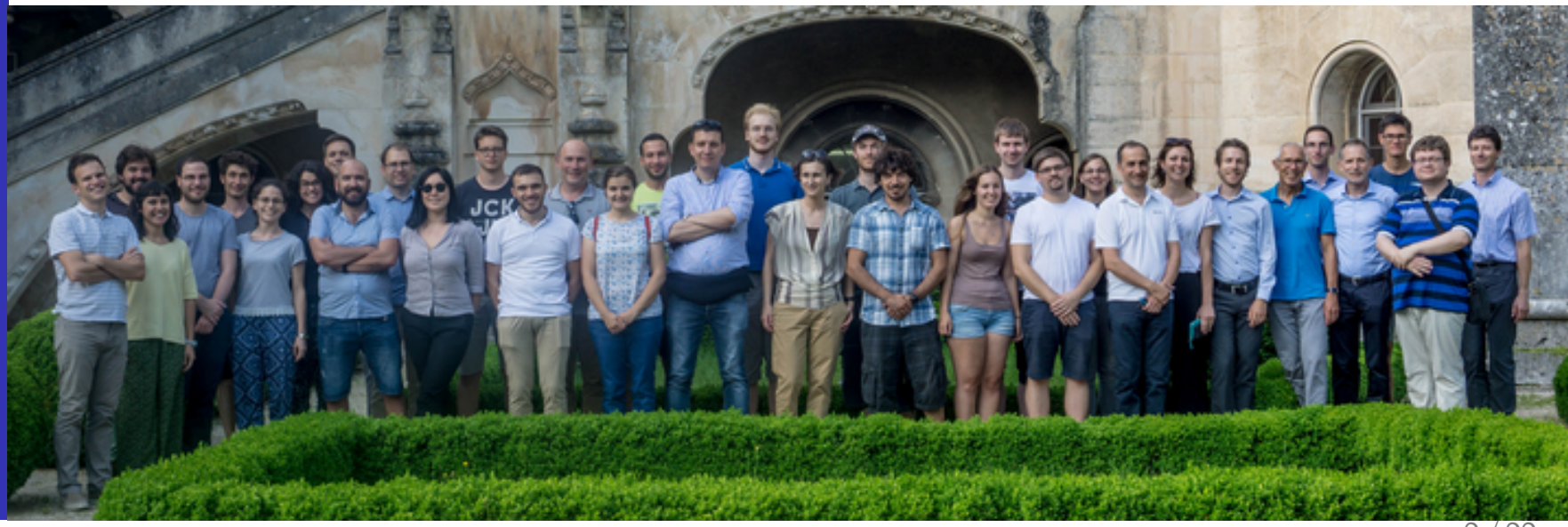
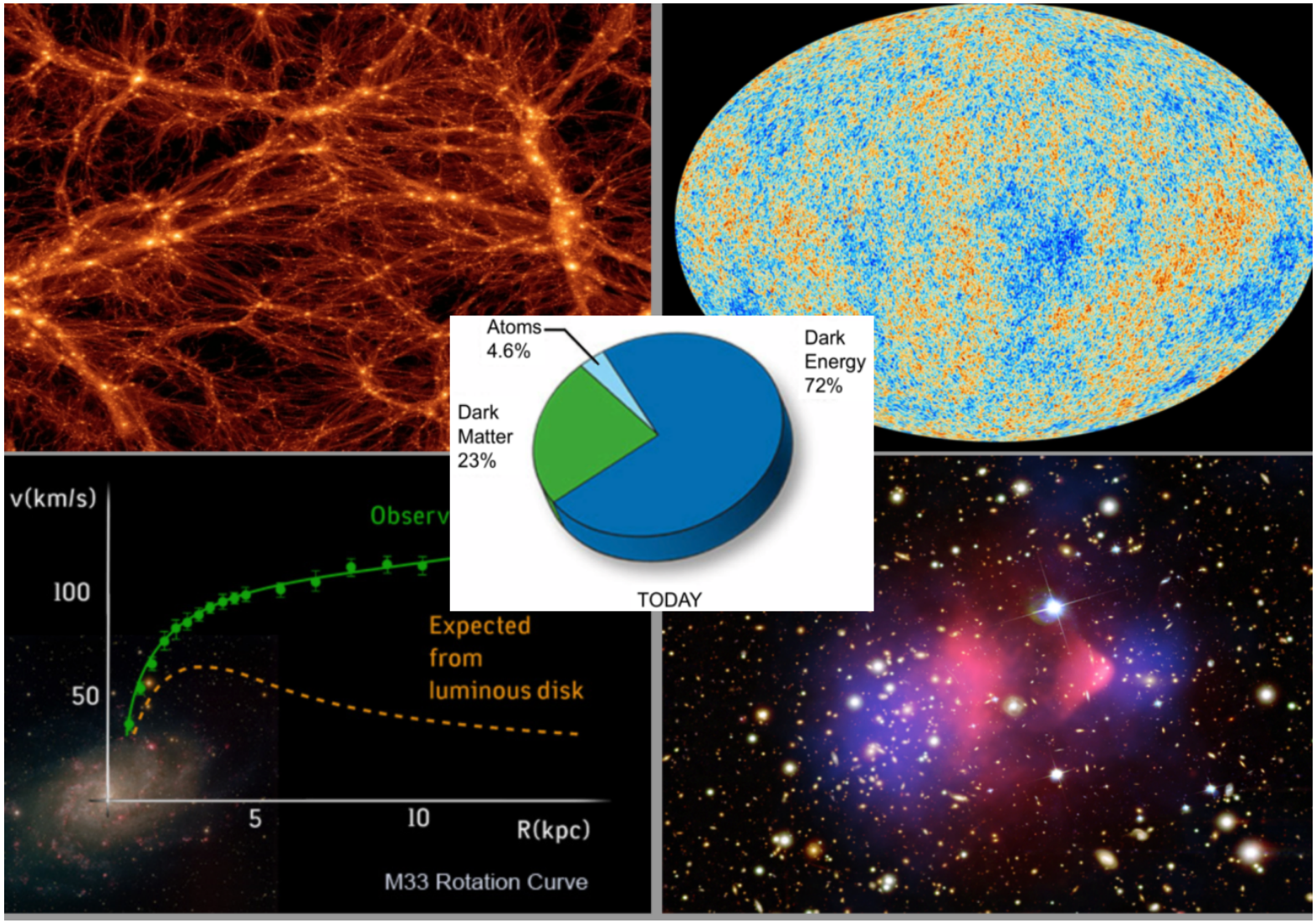
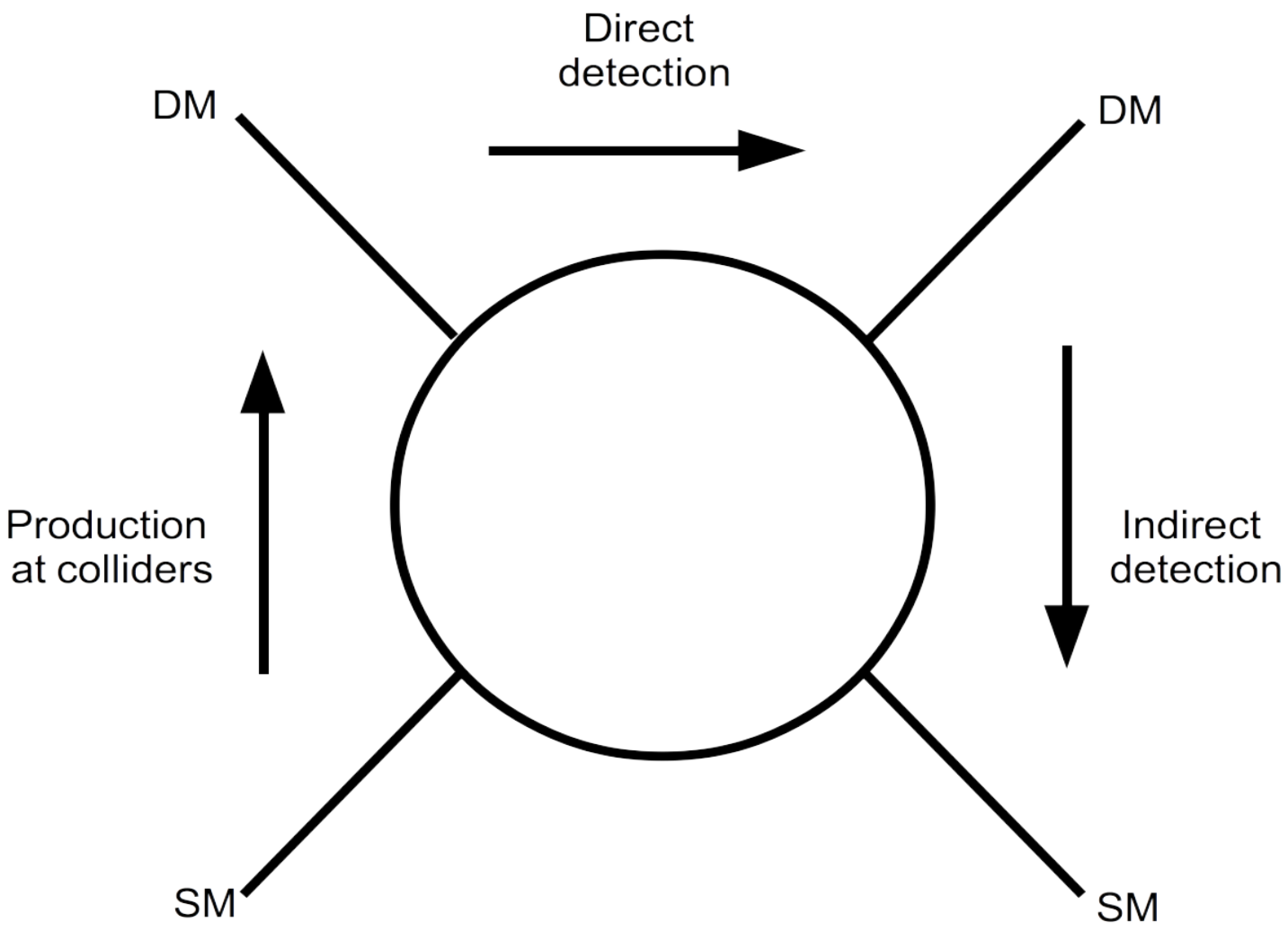
Overview



Dark matter evidence



Complementarity in searches for dark matter



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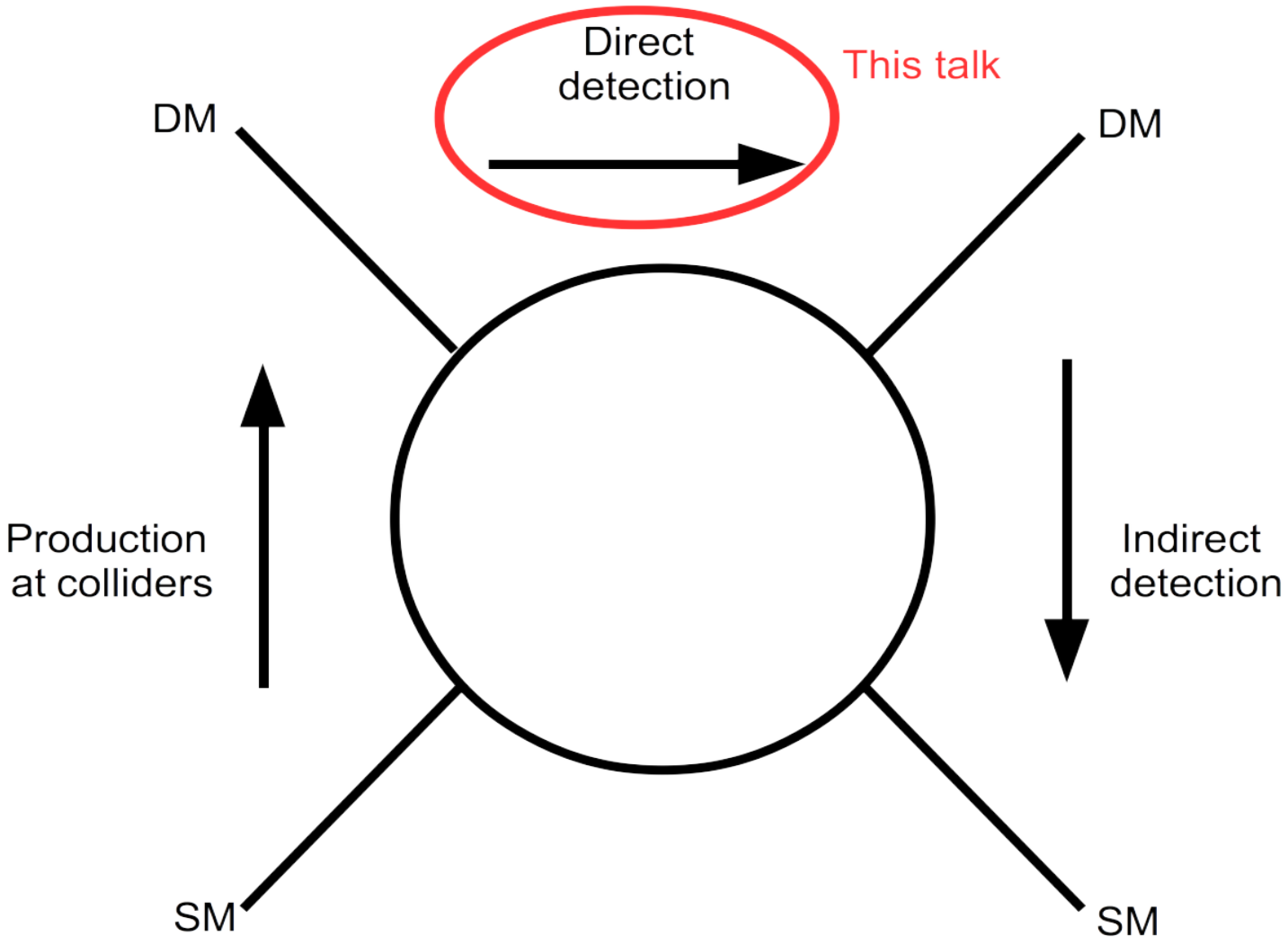
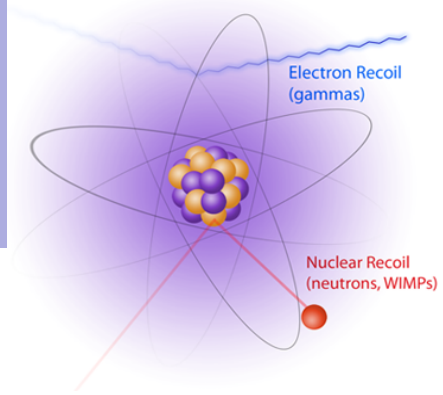


Direct detection

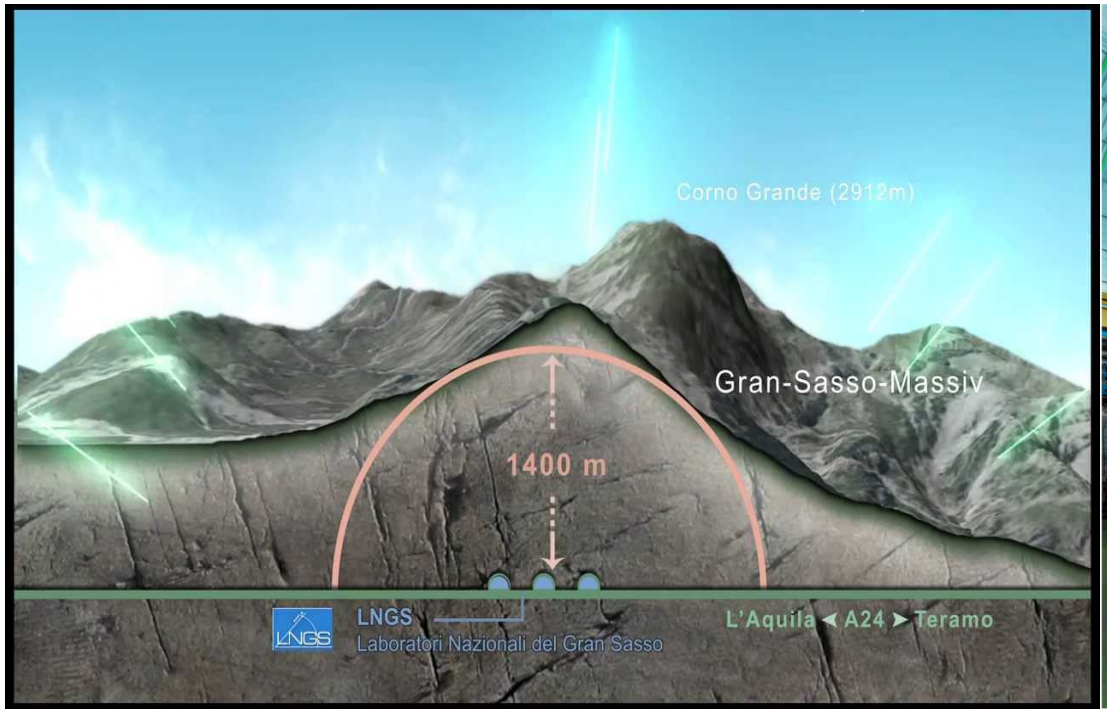


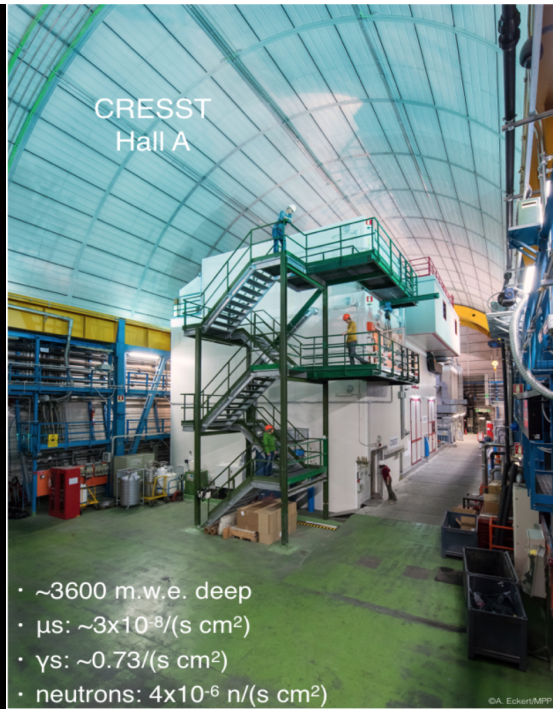
Expected signatures of the elastic scattering of dark matter particles off target nuclei:

- Single scatter nuclear recoils at low energy (a few tens of keV max)
- Low interaction rate
- ~Exponential shape of the energy spectrum
- Dependance on the target material ($\sim A^2$)
- Earth's velocity relative to the galactic rest frame is largest in summer (WIMP flux has annual modulation (~3% effect)

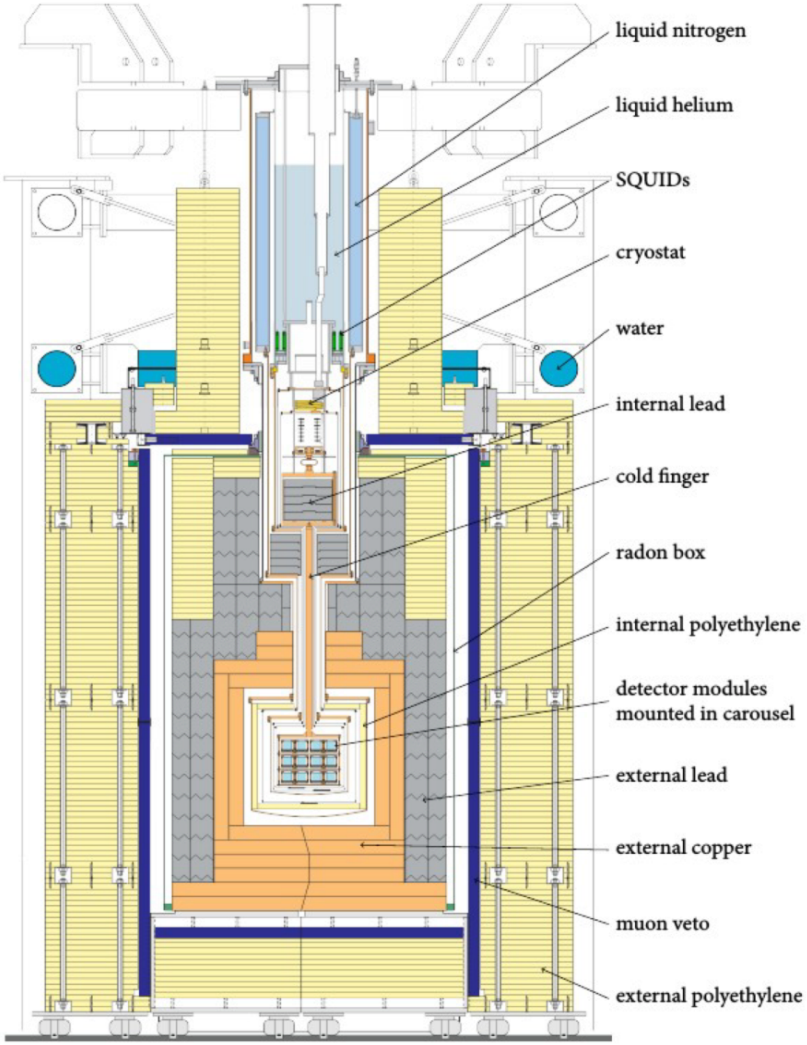
Background mitigation

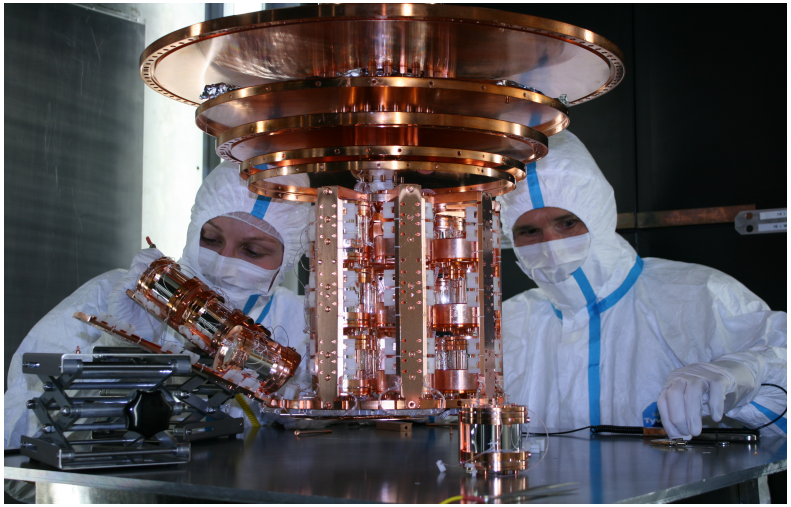
- Underground facility in Laboratori Nazionali del Gran Sasso
- Radioactive shielding / Muon veto / Radon mitigation
- High purity materials
- Event discrimination





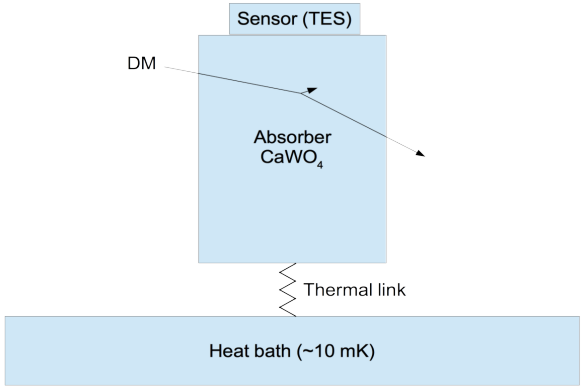
The CRESST setup

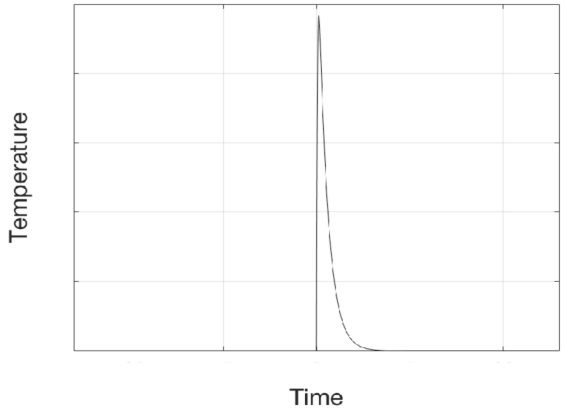




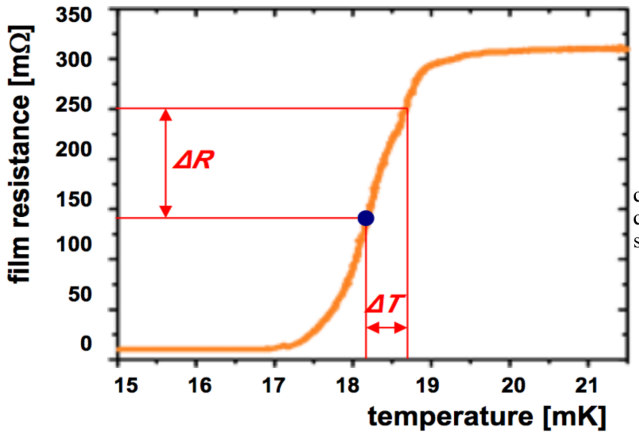
Cryogenic calorimeters

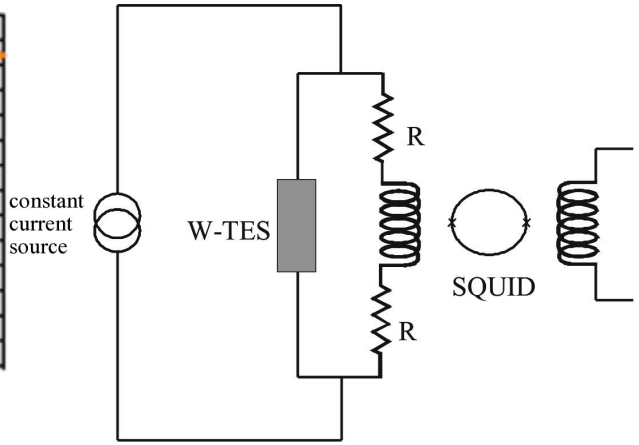
- Phonon signal measures the recoil energy $\Delta E/C = \Delta T$



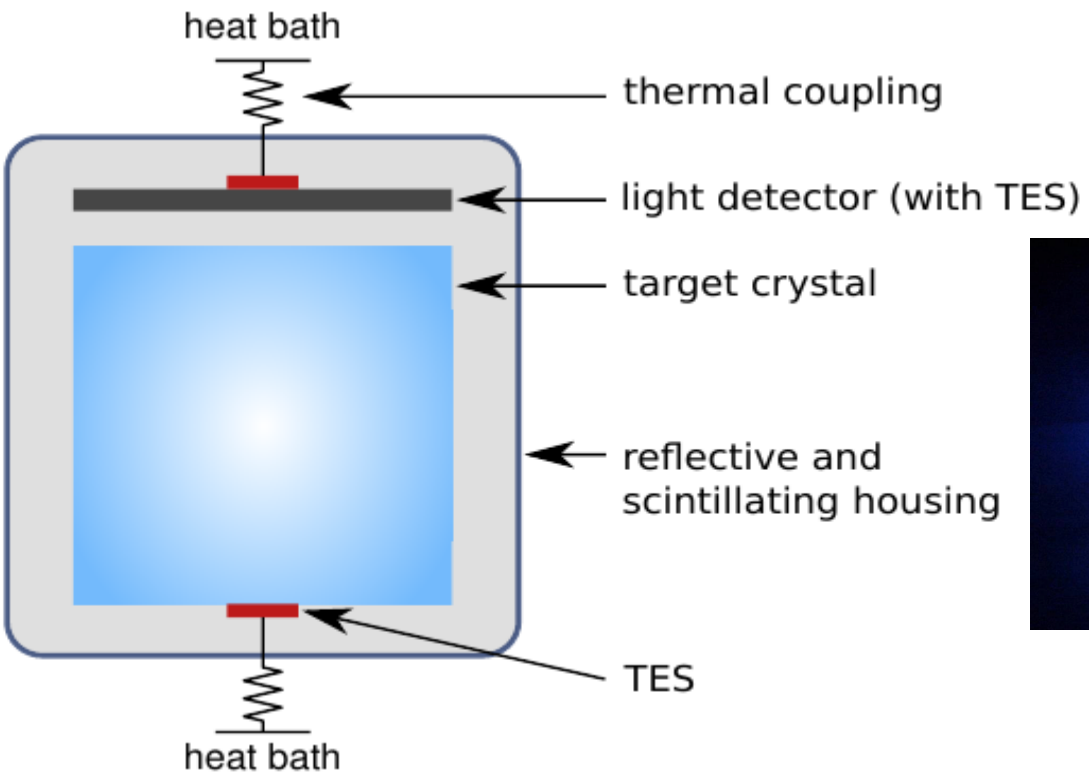


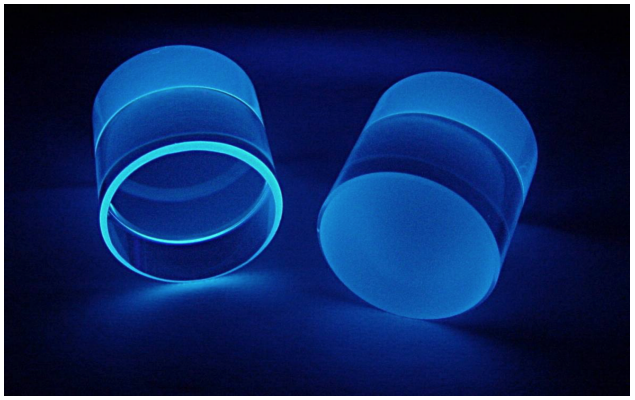
- Read out by a Tungsten Transition Edge Sensor (TES)





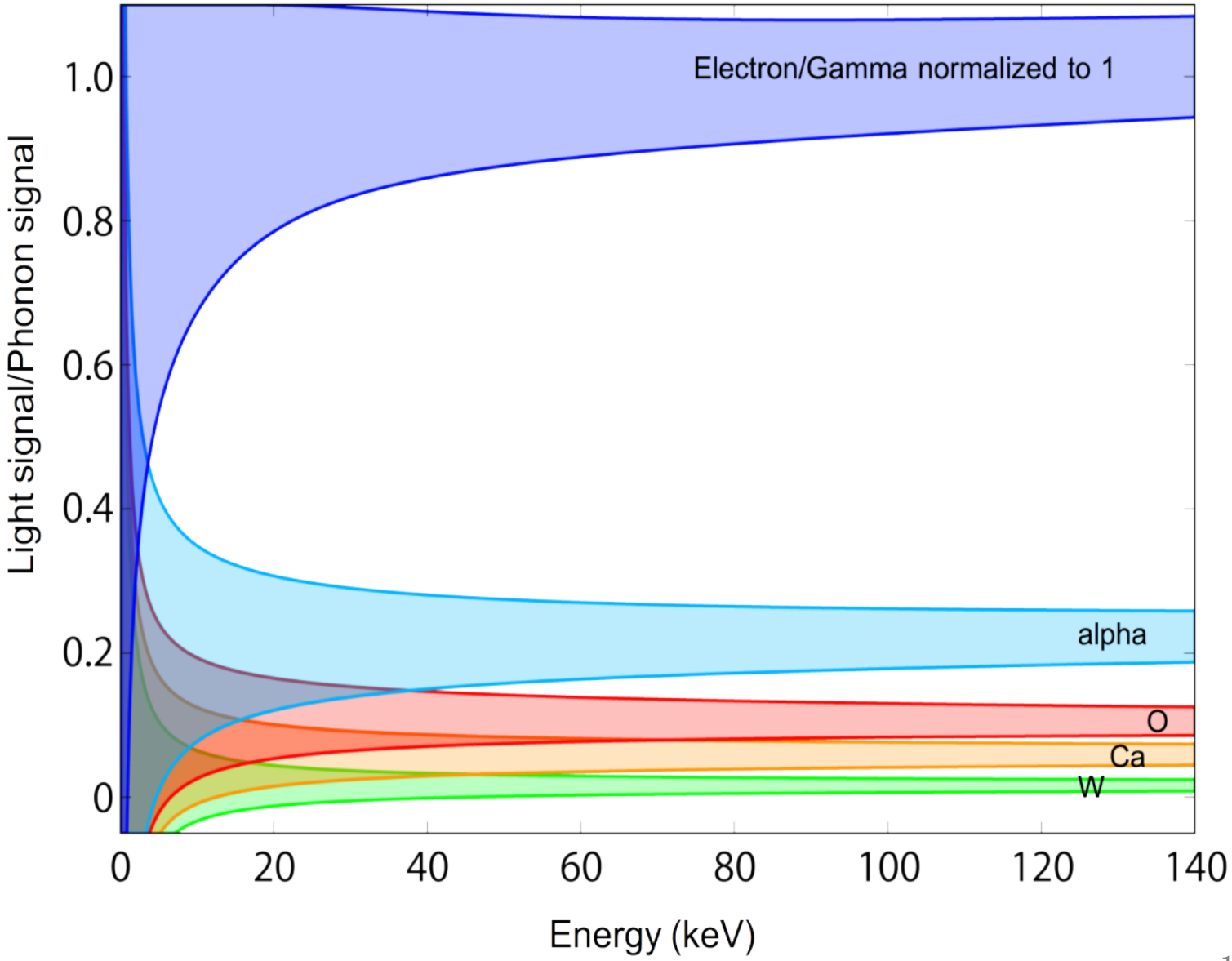
Particle identification



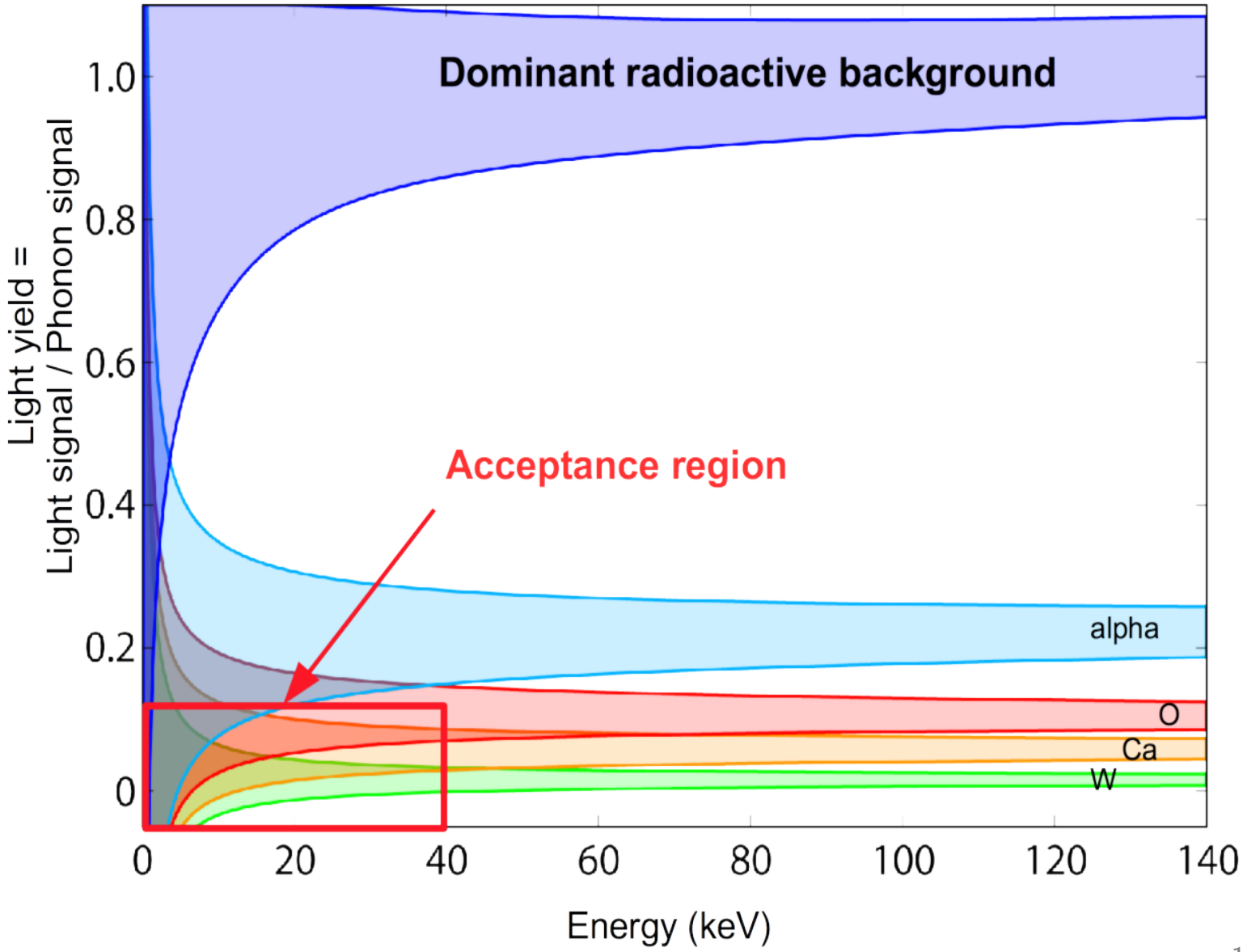


- $CaWO_4$ Crystals operated at ∼10mK
- Simultaneous measurement of heat and scintillation signals for particle identification

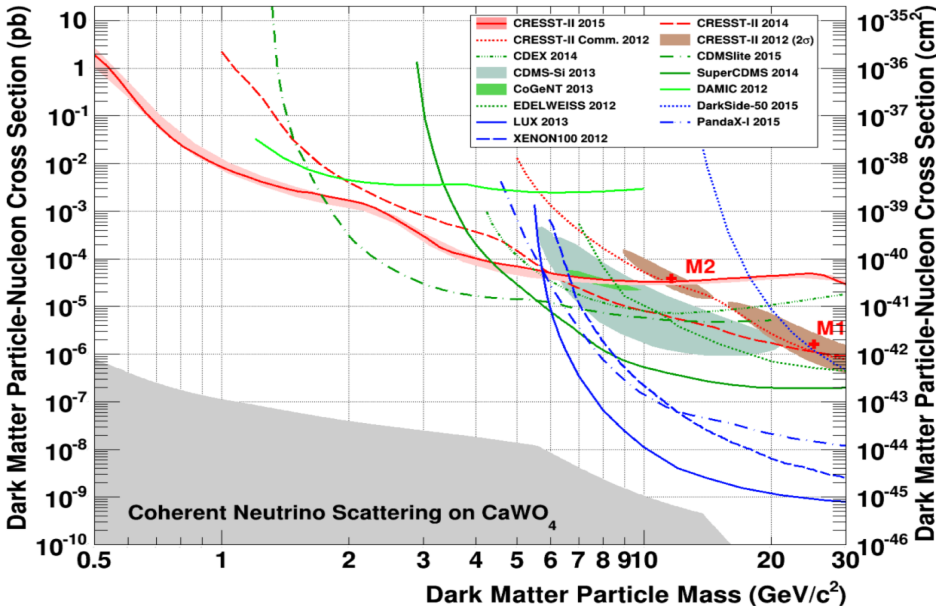
Particle identification 2

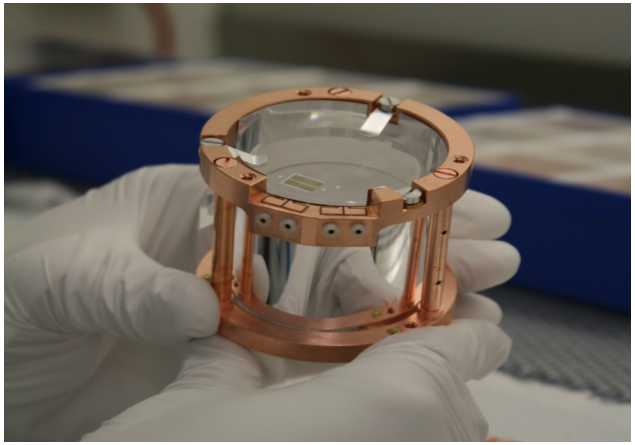


Particle identification 2



Previous results: CRESST-II phase 2

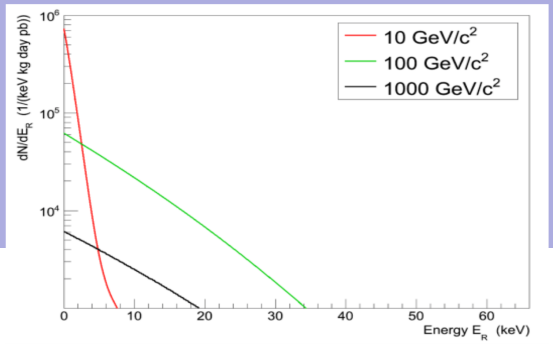


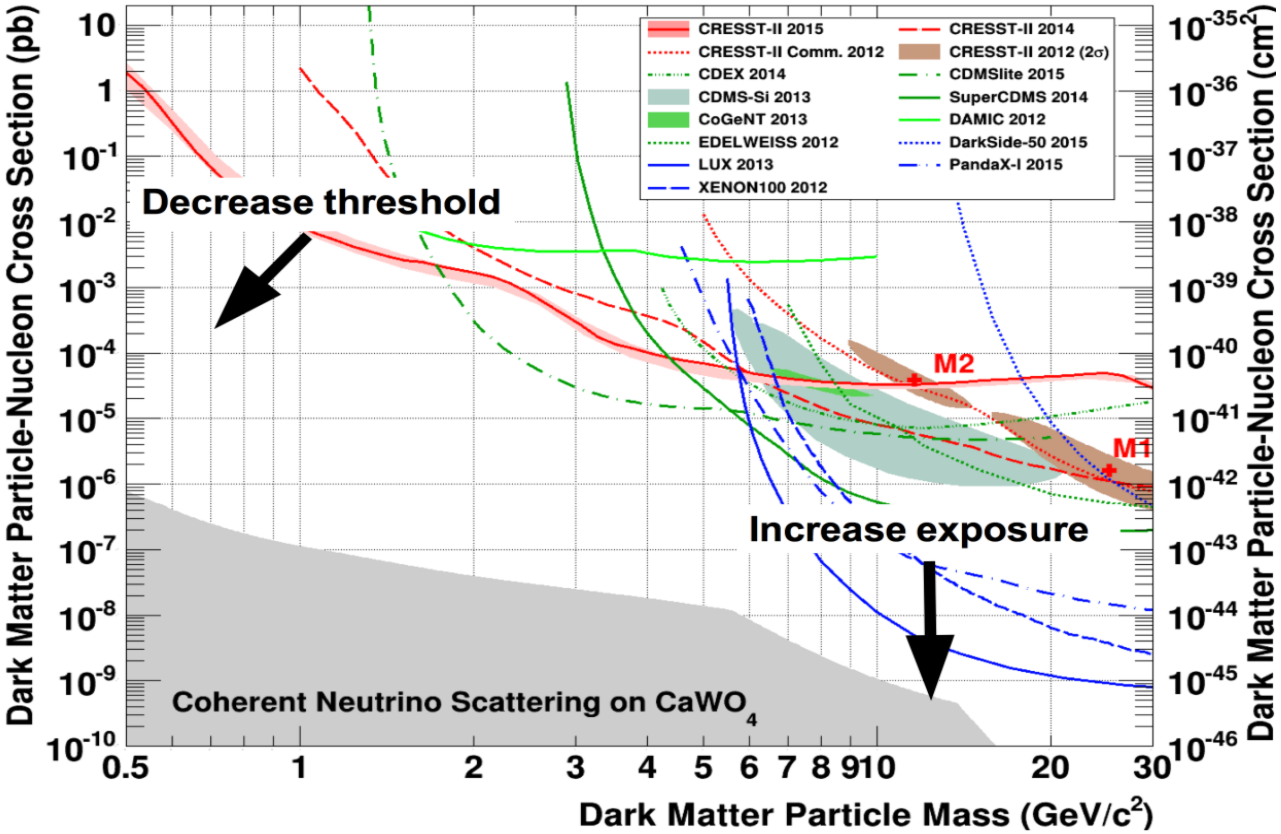


- Low threshold : 307eV (with 300g crystal)
- In-house production of crystal with higher radiopurity

$\rightarrow$ World leading experiment below 1.7 GeV.c^{-2}
(CRESST-II phase 2 (2015), Eur.Phys.J. C76 (2016)25)

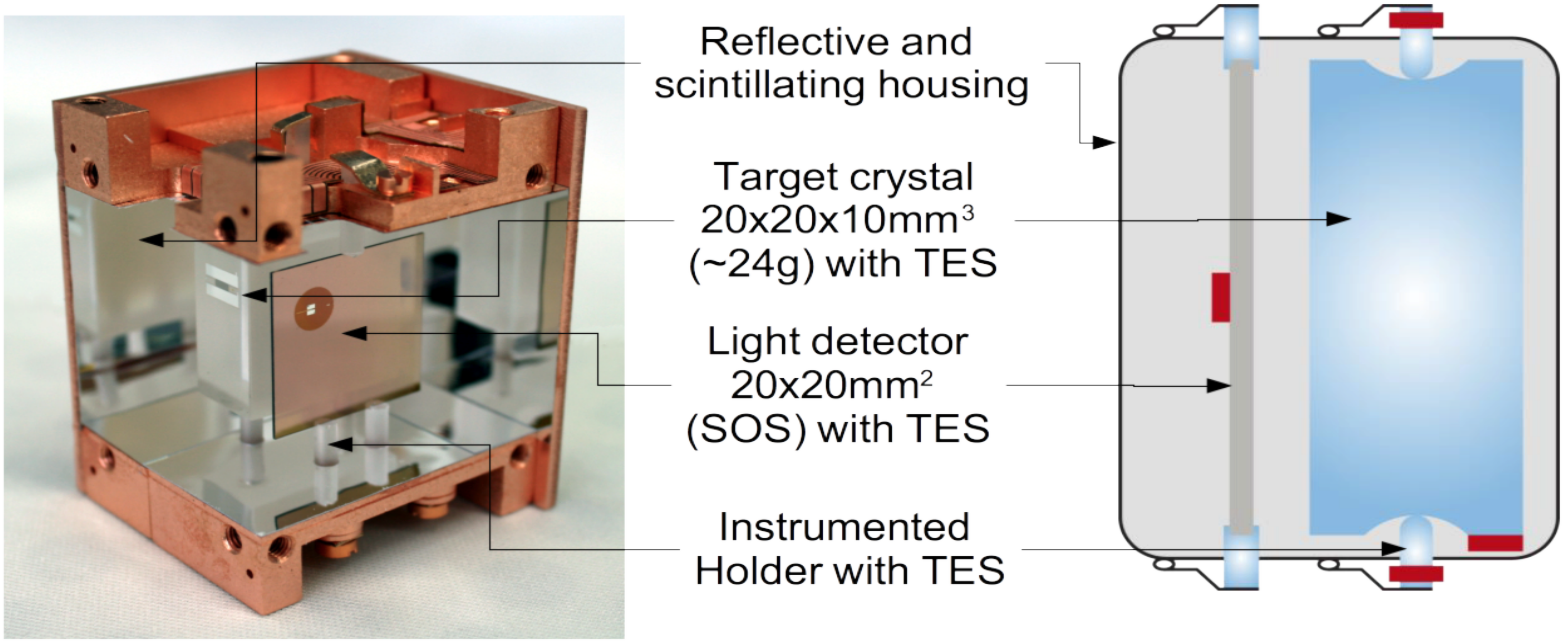
Low-mass dark matter search





→ Aim of CRESST-III: lower the threshold for low-mass DM search

CRESST-III, phase 1: Optimization of the detector design for low-mass search



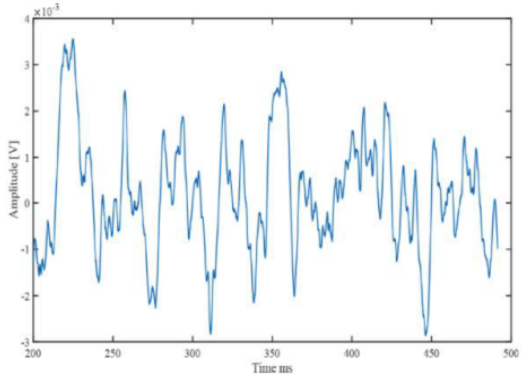
- Goal : threshold of 100eV (Decrease detector mass: from ∼300g to ∼24g, optimized thermal link)
- High purity crystals grown at TUM
- Veto surface related background : scintillating housing
- Veto holder related background : instrumented holder

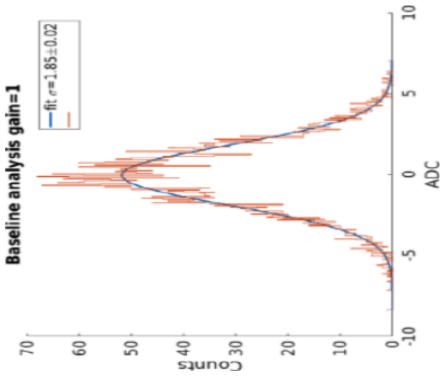
Data analysis

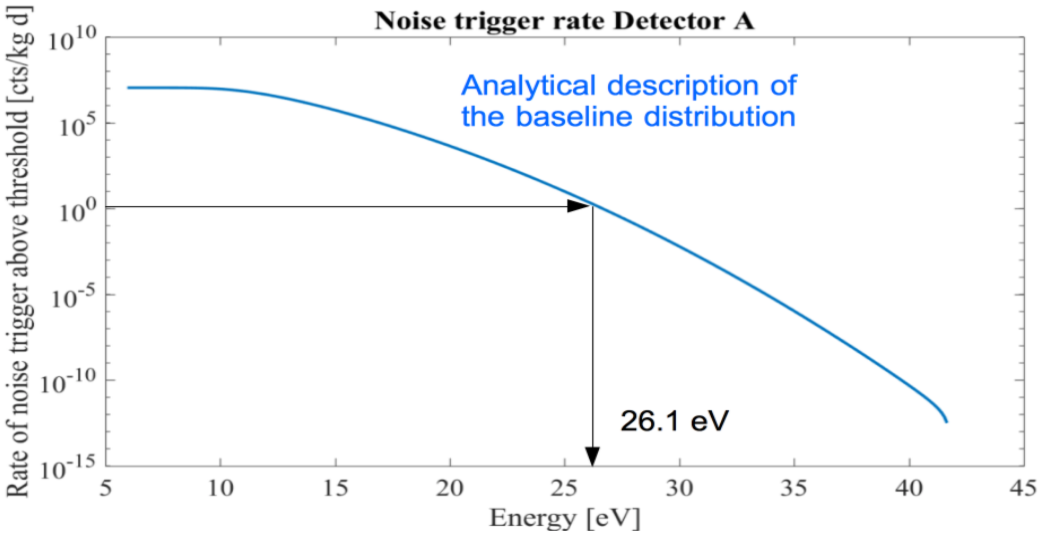
- Selection of events where the energy is measured properly. The selection criteria:
  - Rate : noise conditions
  - Stability : the detector is at the operating point
  - Non-standard pulse shapes (e.g. pileup)
  - Remove coincidental events : with muon-veto, holder related, or with other detector modules
- Optimum filter trigger implemented in the software
- Unbiased analysis : 20% of the data is randomly selected as a non-blind training set to determine cuts, these cuts are applied to the blind data set (80%)

Determination of the thresholds

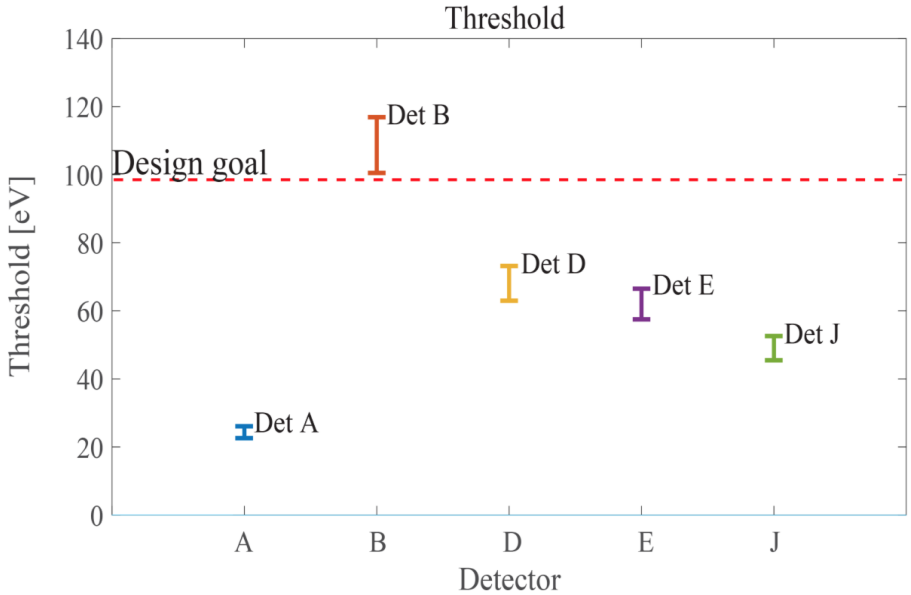
- New DAQ with continuous sampling
- Threshold set according to the empty baseline distribution (after optimal filtering)







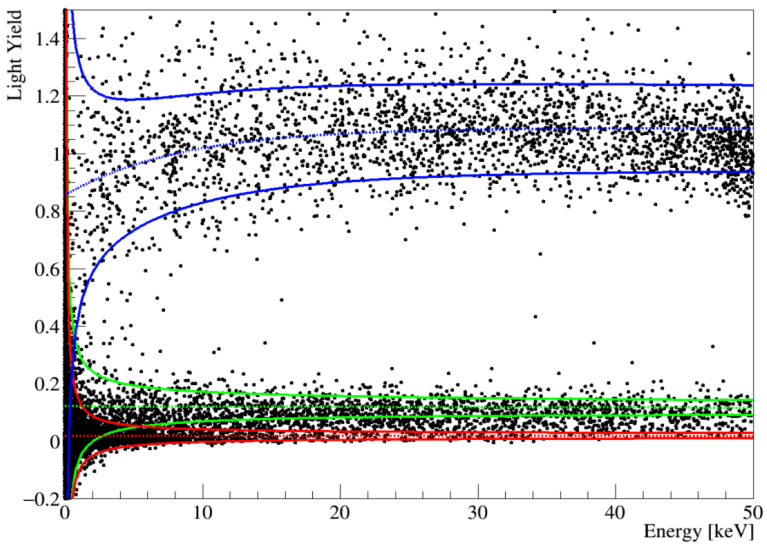
Experimental thresholds

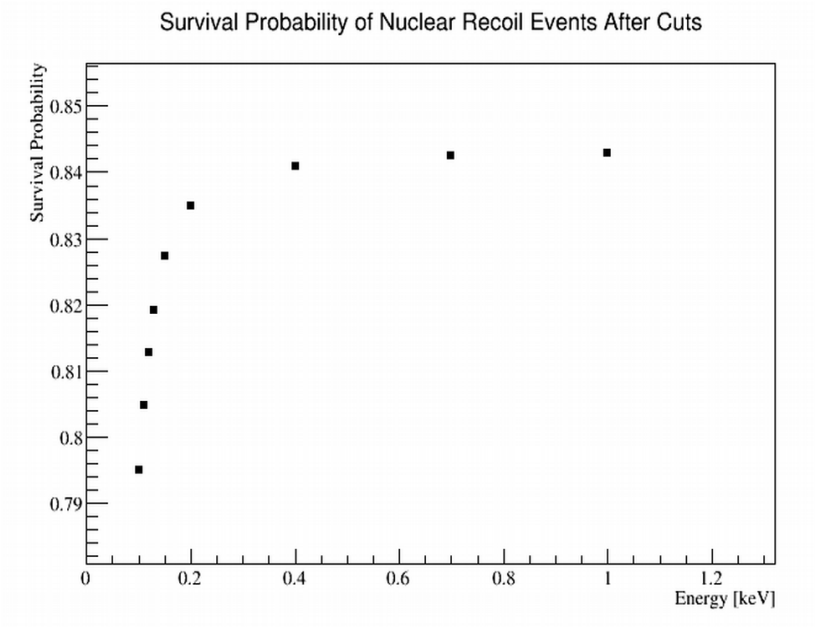


Detector A :

- Lowest threshold: 26.1 eV
- Preliminary results with a net exposure of 2.21 kg.day (total : 2.39 kg.day)
- Analysis threshold : 100 eV

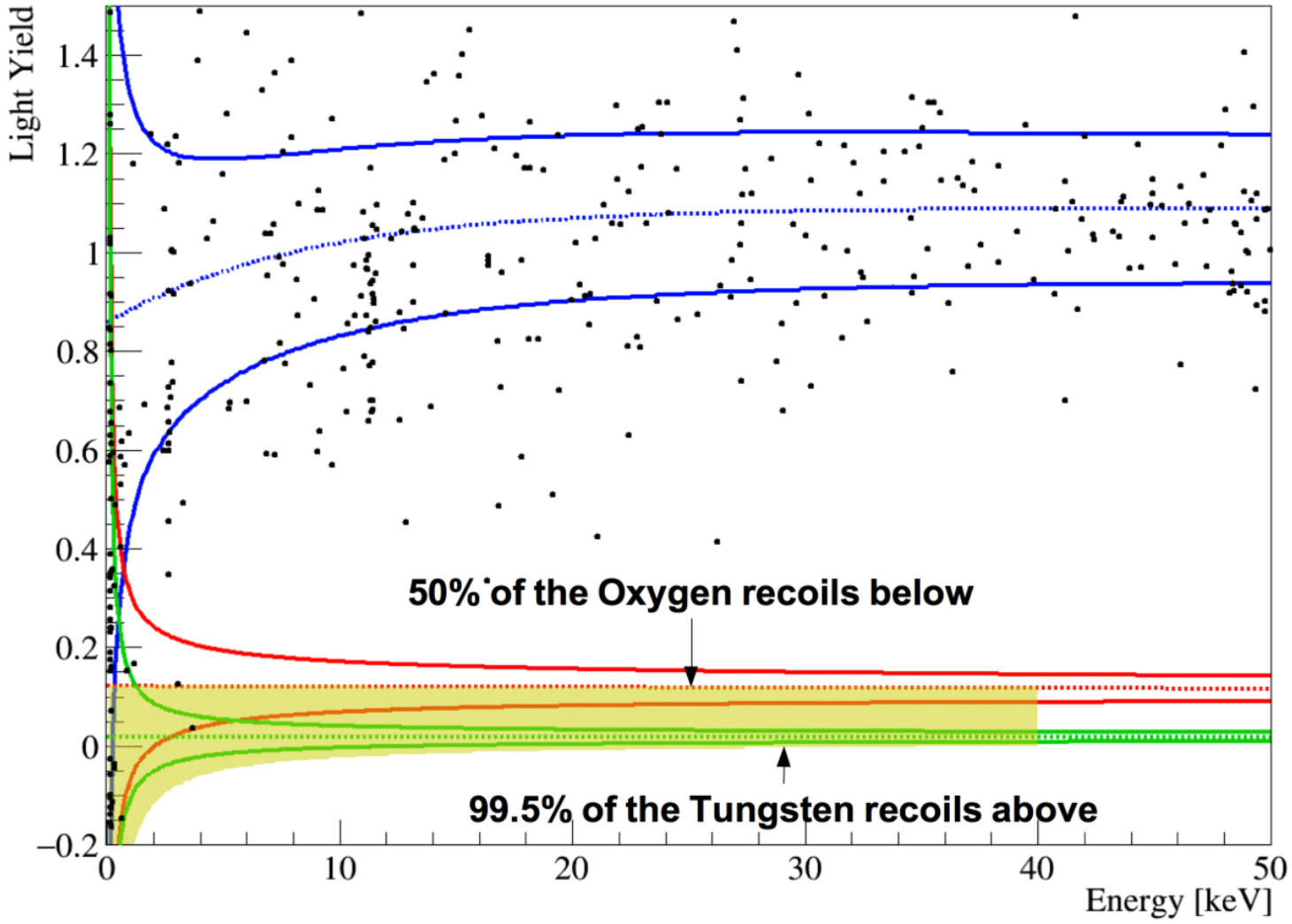
Neutron calibration, detector A





- 79.4 % of survival probability for nuclear recoil events after cuts (at 100 eV)

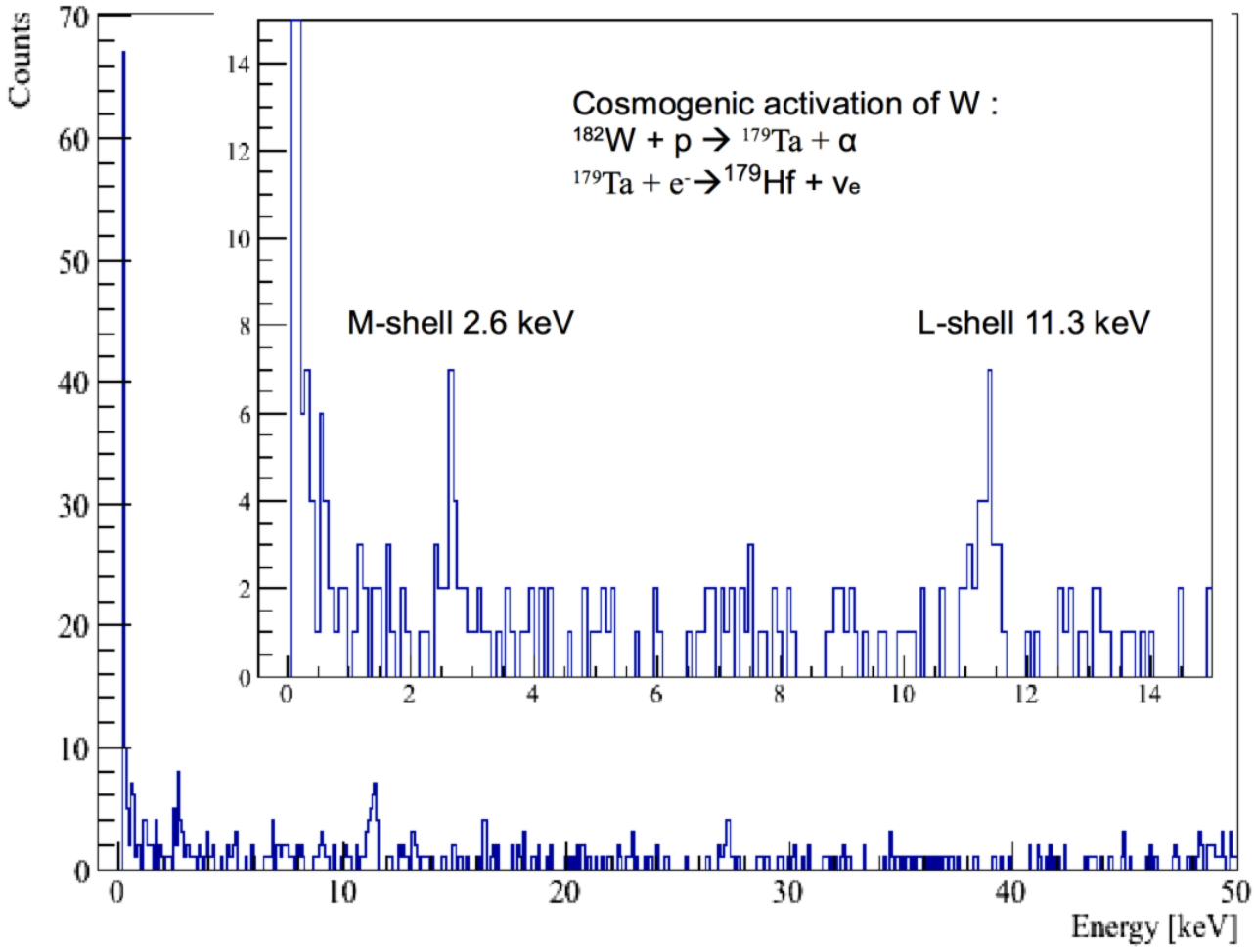
Unblinding of detector A (E>100eV)



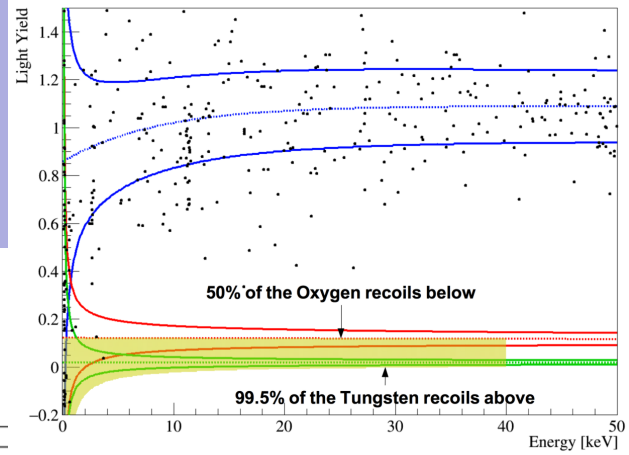
Net exposure = 2.21 kg.day

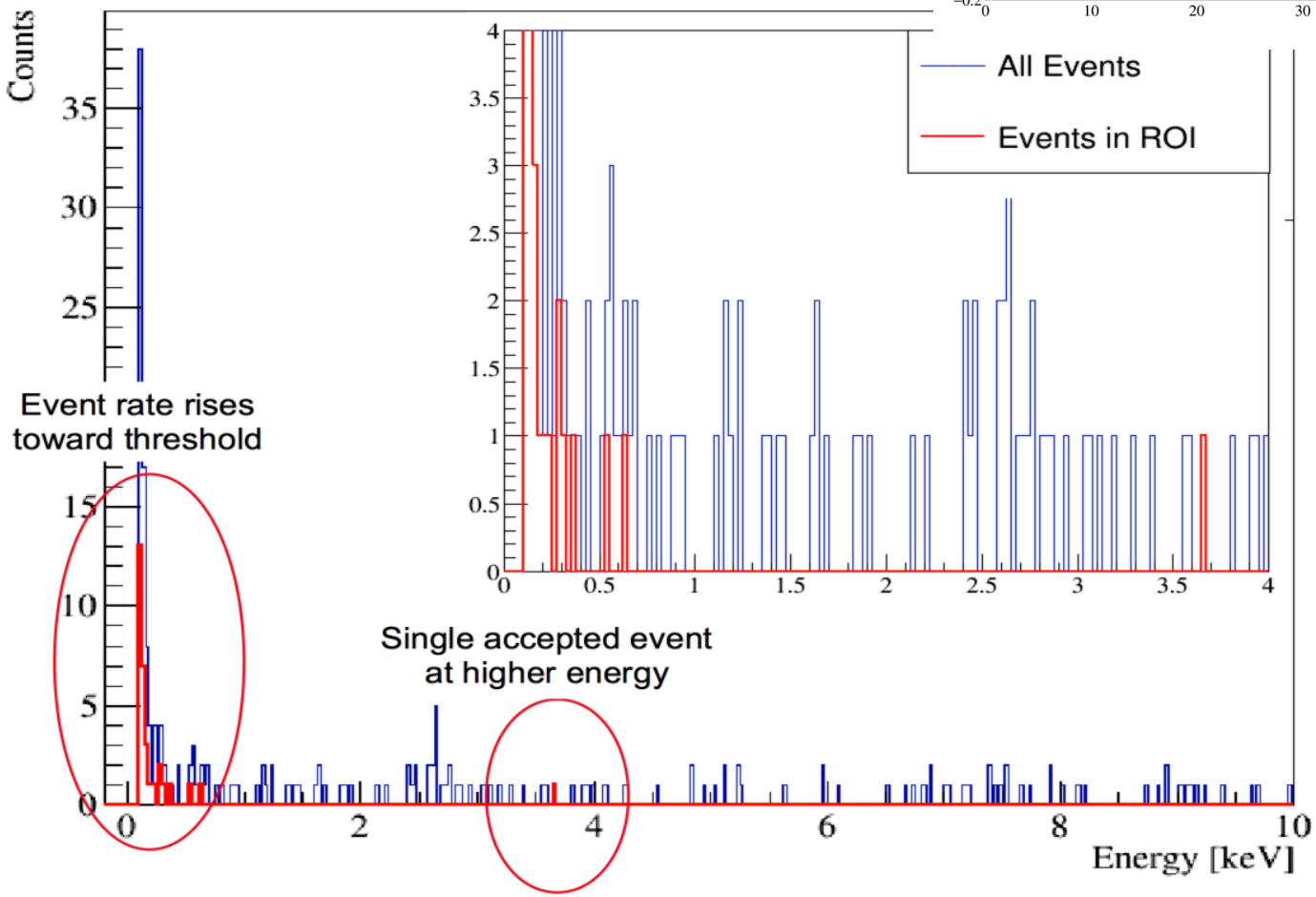
Spectrum of the background

Background level : 3.5 counts/(keV.kg.day)



Accepted events





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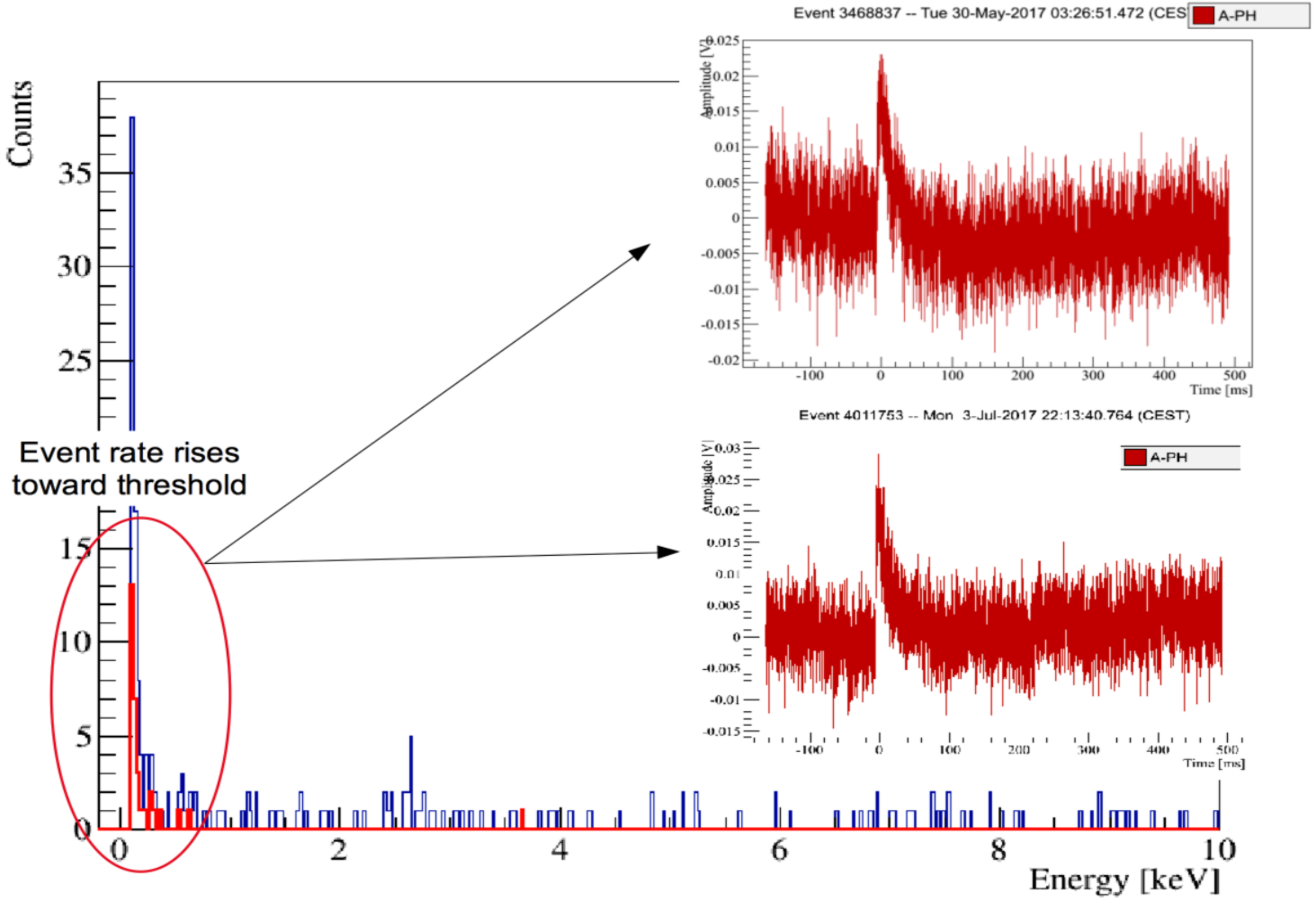
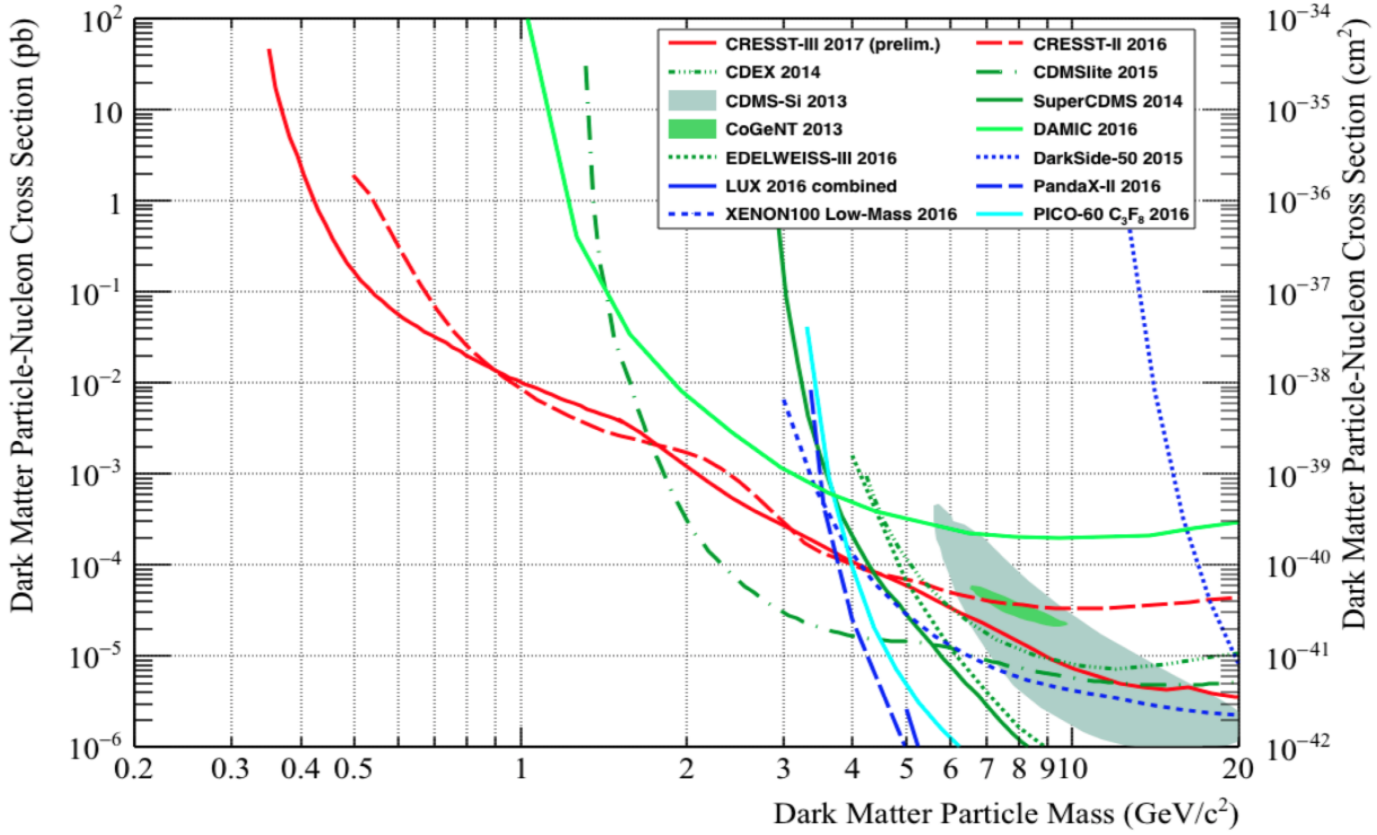


Preliminary exclusion plot, detector A

Limit obtained with Yellin's optimal interval method (using the spectrum of accepted events and the expected spectrum for DM)



(arXiv:1711:07692)

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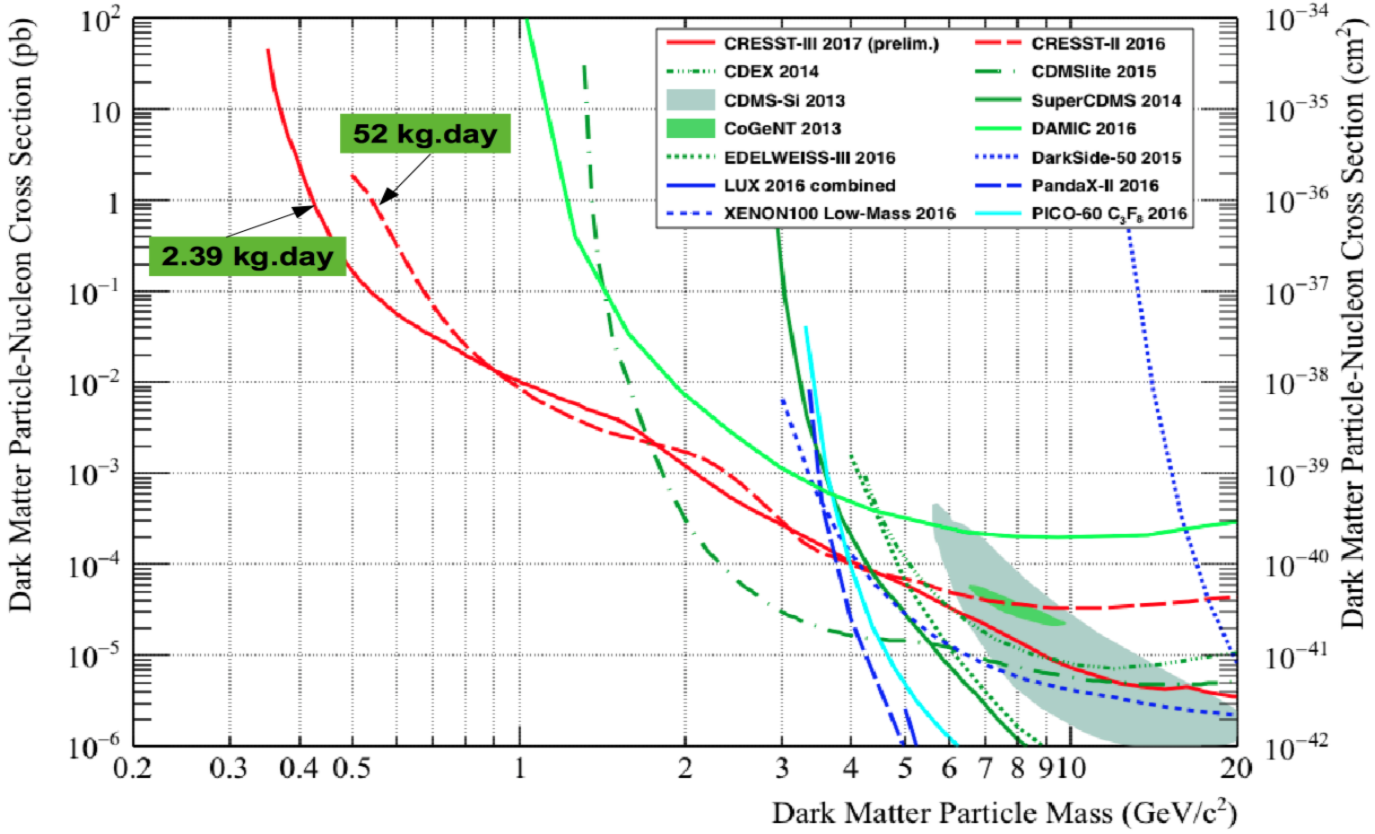

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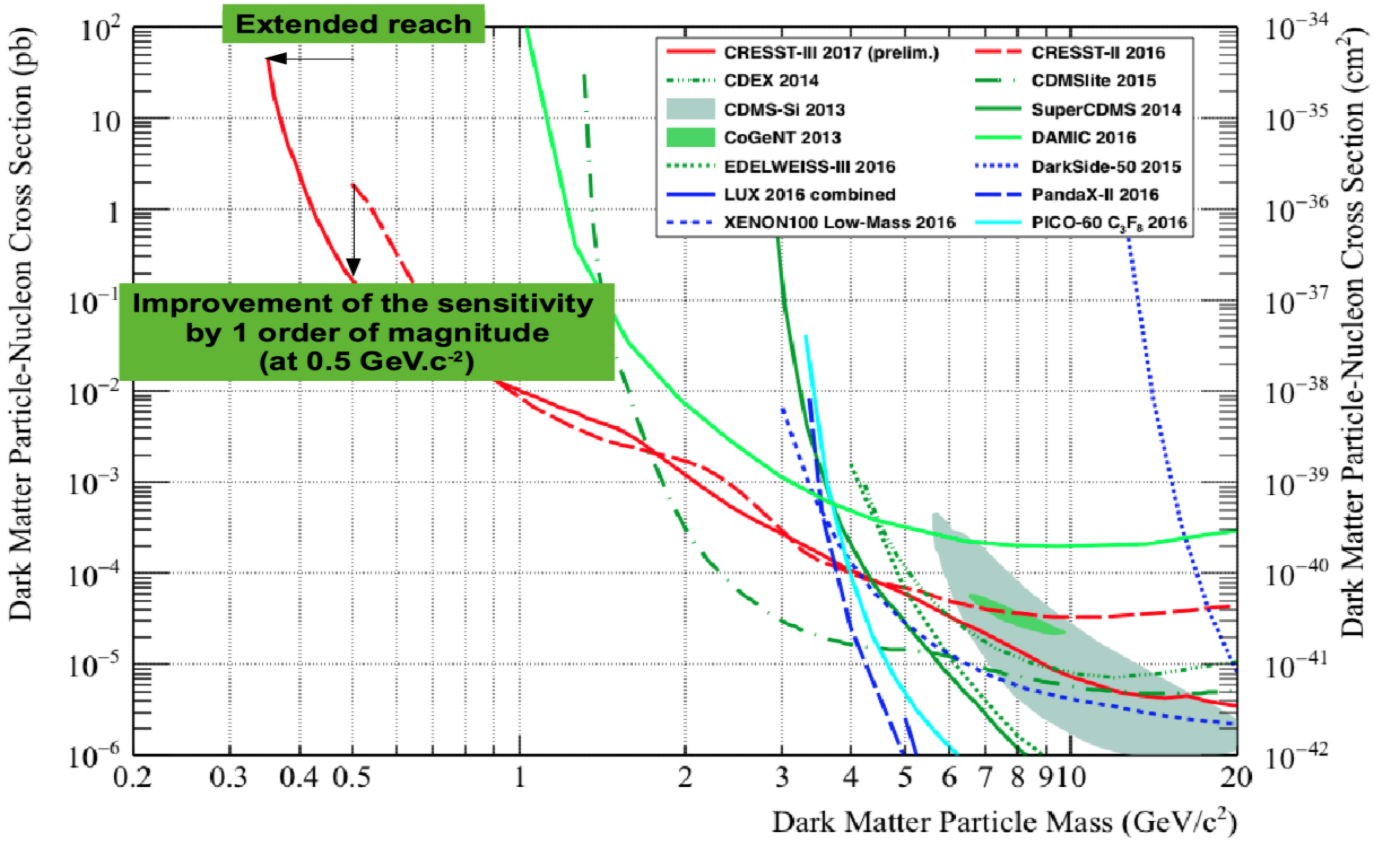

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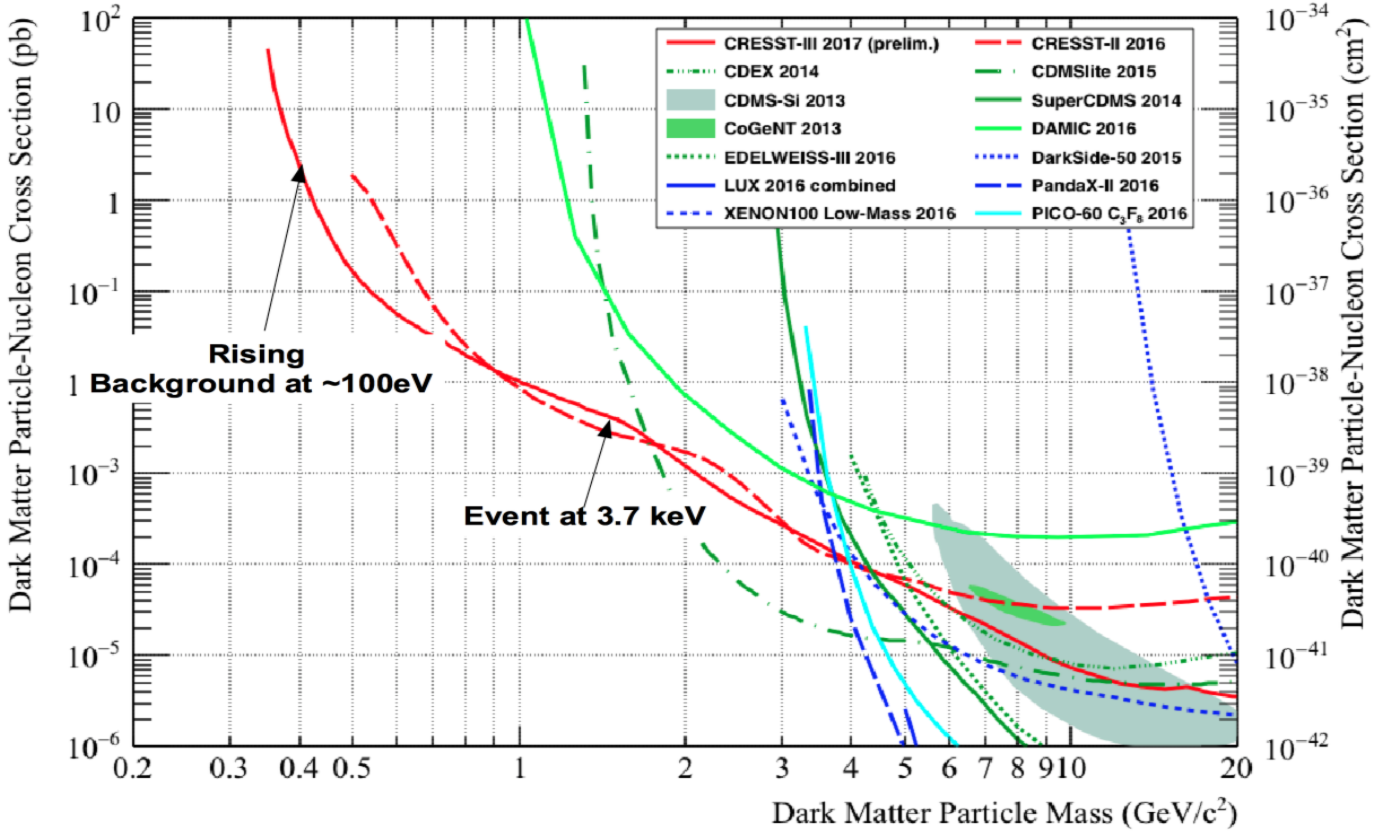


(arXiv:1711:07692)

Outlook

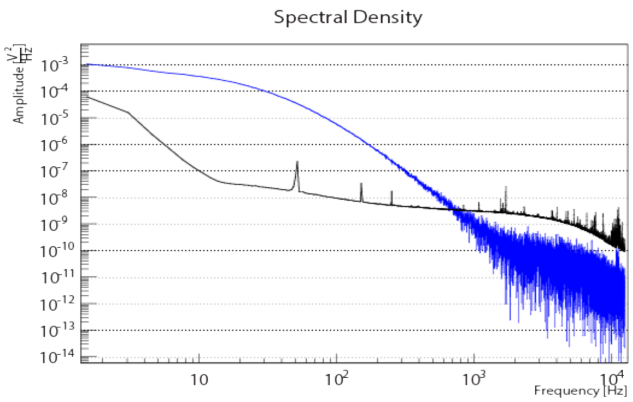
- Preliminary results of CRESST-III :
  - 100 eV analysis threshold reached
    $\rightarrow$ Leading sensitivity for low-mass dark matter
  - Extension of DM search down to 350 MeV.c^{-2}
- Analysis ongoing with :
  - a much lower threshold
  - 3 times more statistics
  - 3 more detectors
- Run ongoing dedicated to the understanding of the rise of the event rate at low energies by implementing hardware modifications

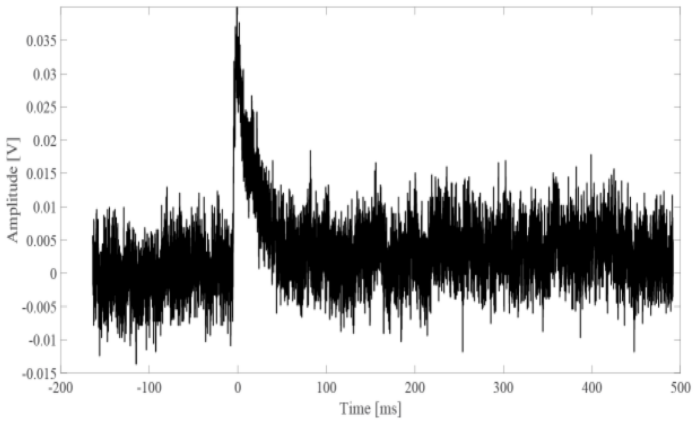
Thank you for your attention

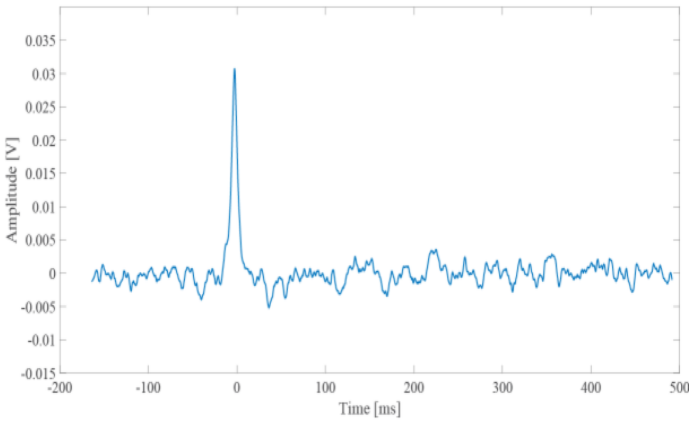
Backup slides

Optimal filter

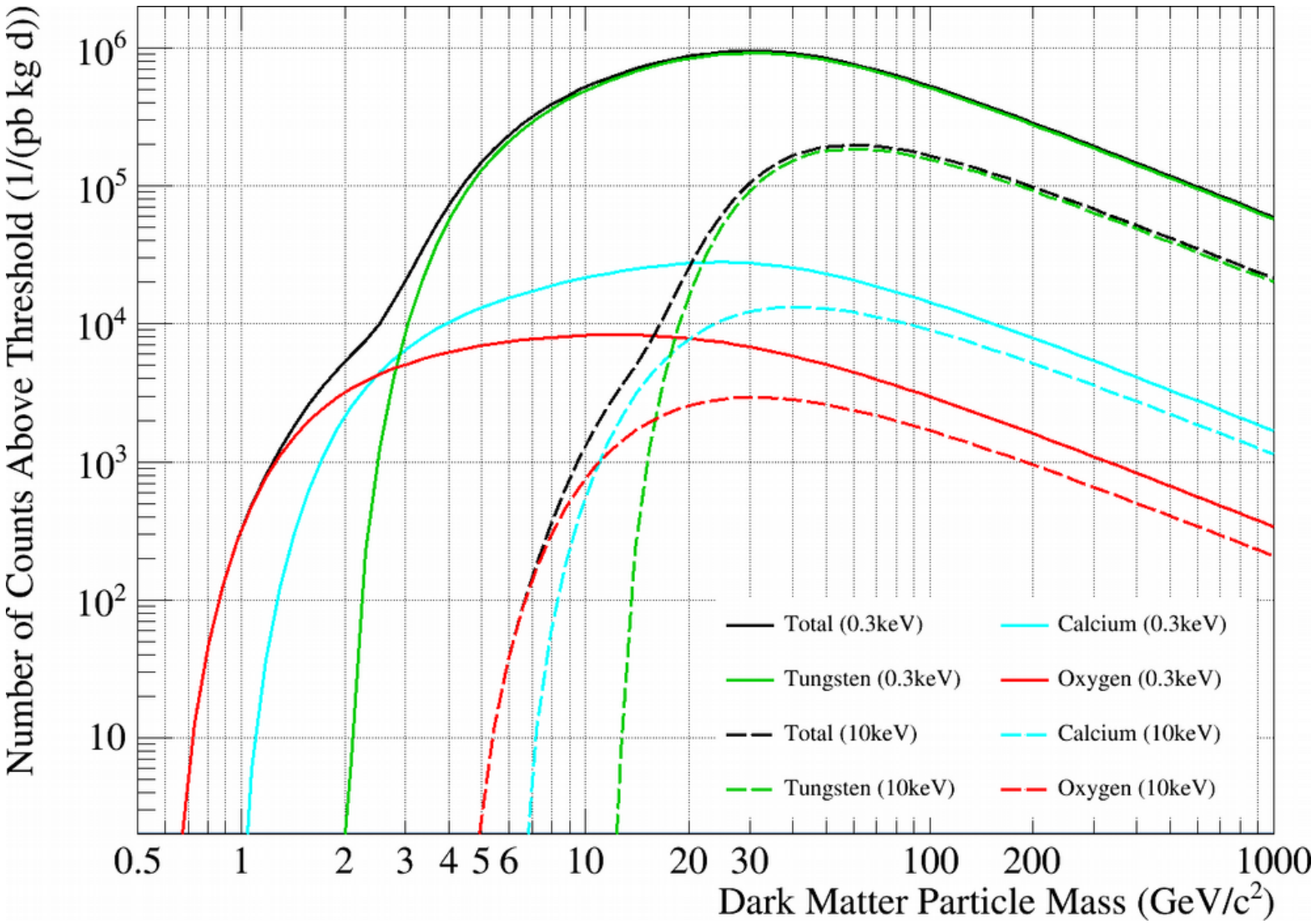
- Implemented in the software
- Maximisation of the signal/noise in frequency space
- typical improvement of the resolution: factor 2-3



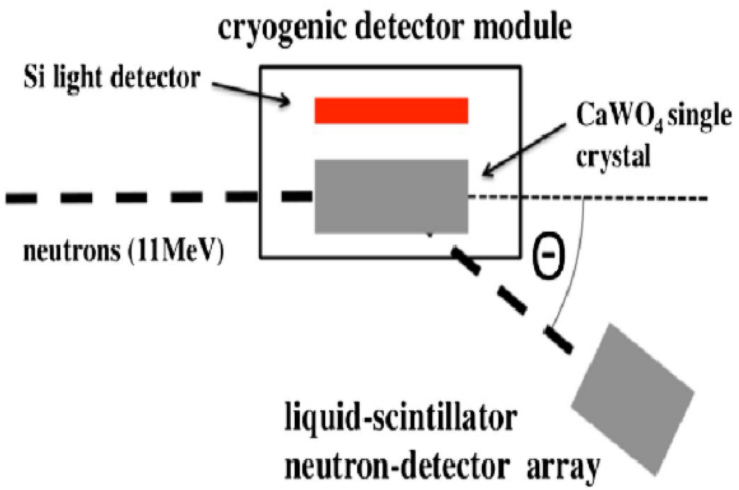


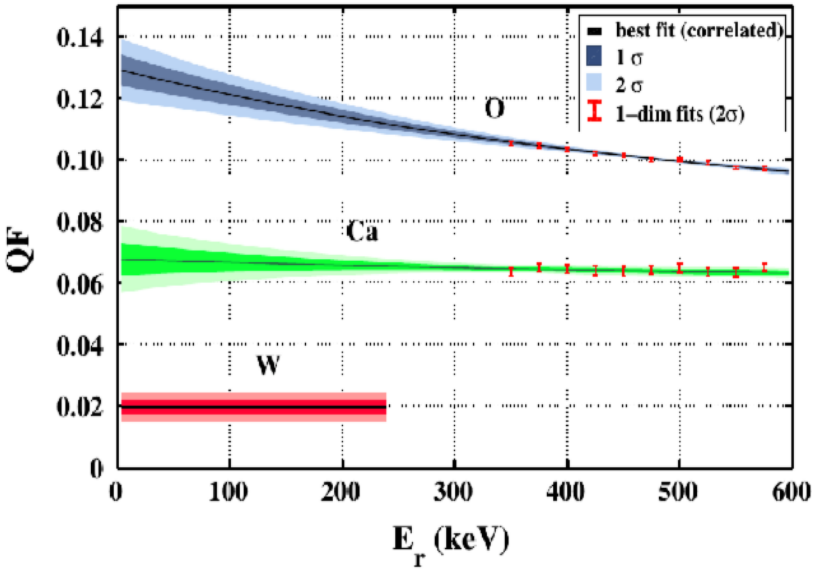


Threshold and target mass



Determination of the quenching factors





Neutron beam form Maier-Leibnitz-Lab.

Quenching factors determined at low temperature for each elements of the $CaWO_4$:
O: $(11.2 \pm 0.5)\%$ Ca: $(5.94 \pm 0.49)\%$ W: $(1.72 \pm 0.21)\%$

Exclusion limit with a gram-scale detector prototype

- Al_2O_3 crystal of 0.5g
- Operated above ground, without shielding
- Measuring time 5.3h, no quality cut
- Threshold $= 19.7 \pm 0.9$ eV