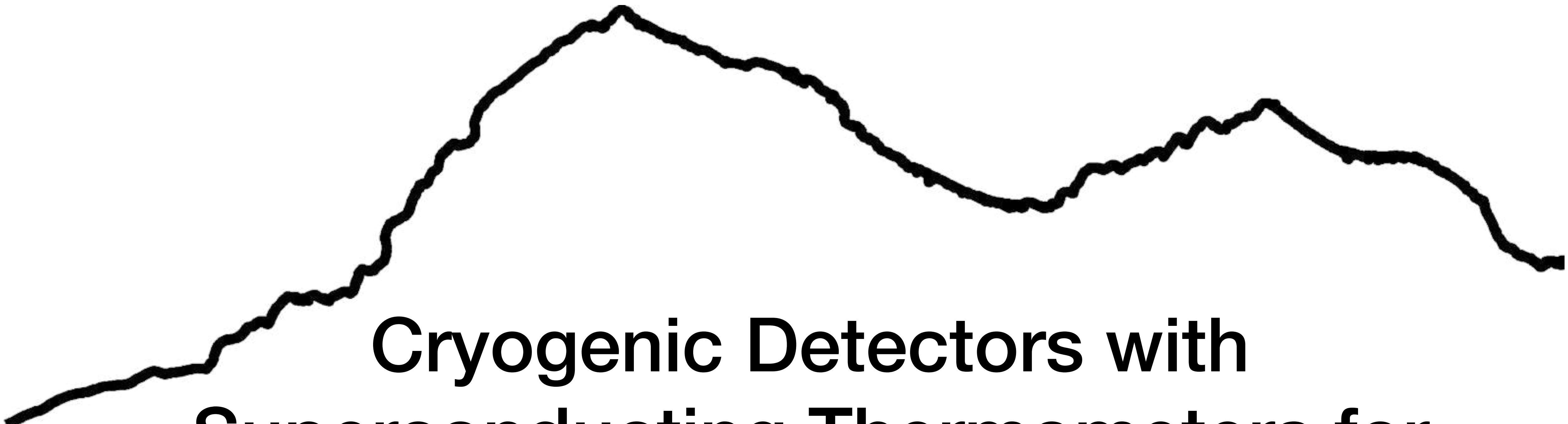
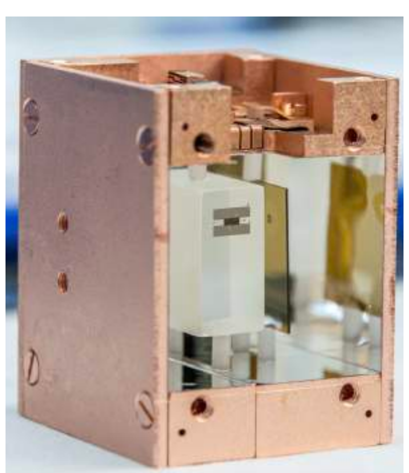
IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), February 2019.
Invited presentation 5EOr1B-02 given at ASC 2018, October 28-November 02, 2018, Seattle, (USA).



Cryogenic Detectors with Superconducting Thermometers for Low-Mass Dark Matter Searches



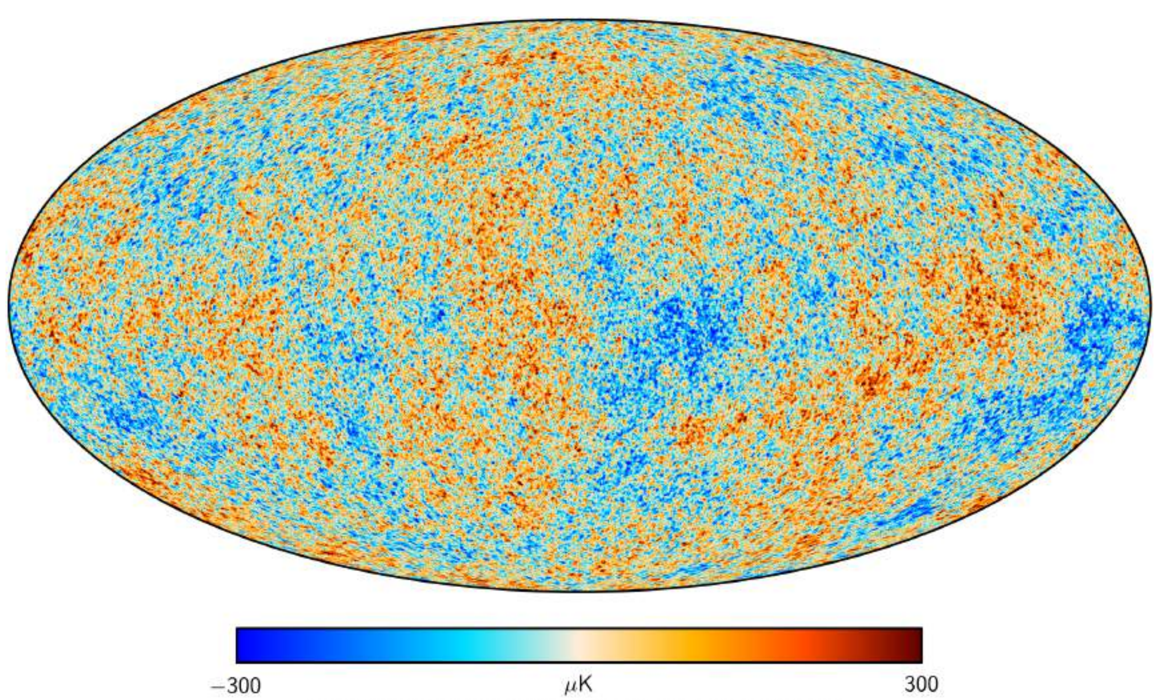
Lucia Canonica
Max Planck Institut für Physik, München

ASC 2018
Seattle, WA, November 2nd 2018

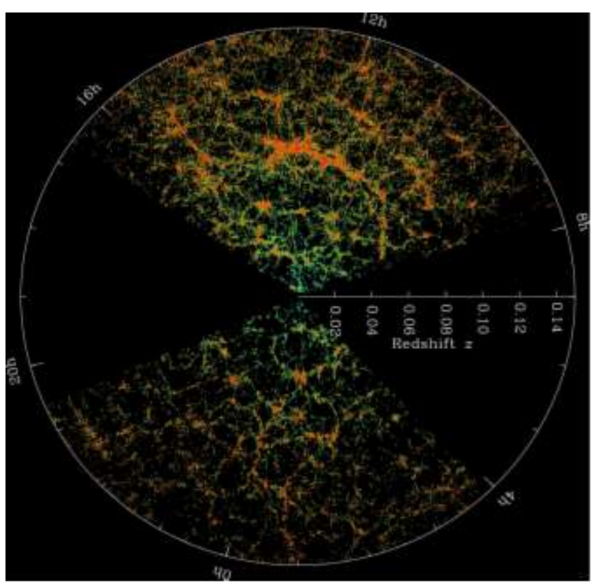
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The Standard Model of Cosmology

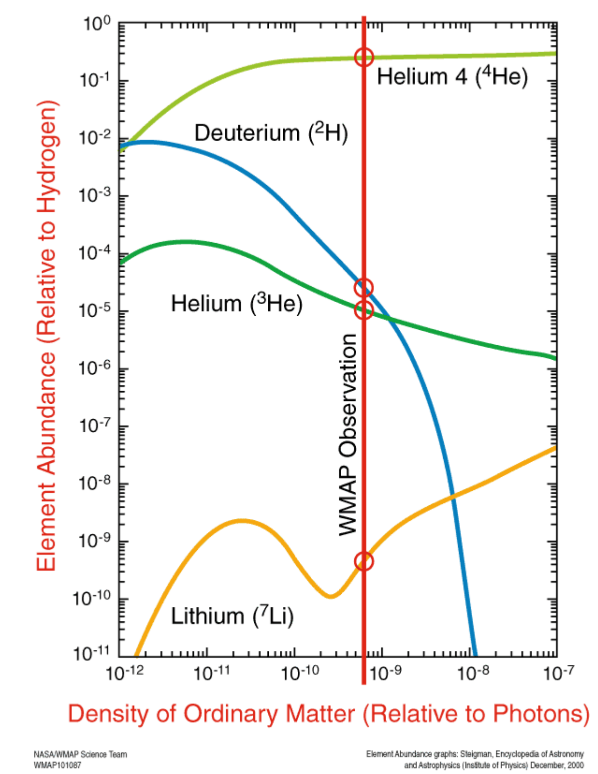
The standard model of Big Bang cosmology explains many properties of our universe (CMB, LSS, BBN)



Source: © European Space Agency / Planck

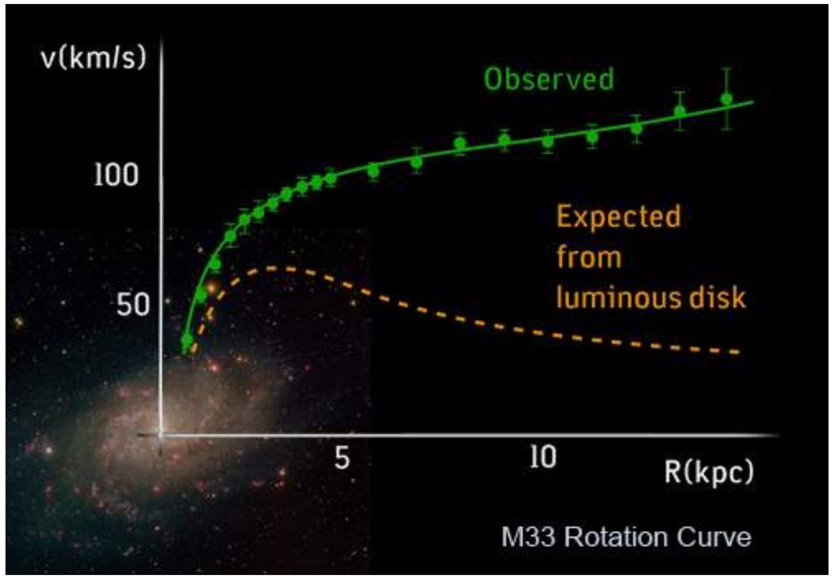


Source: © SDSS

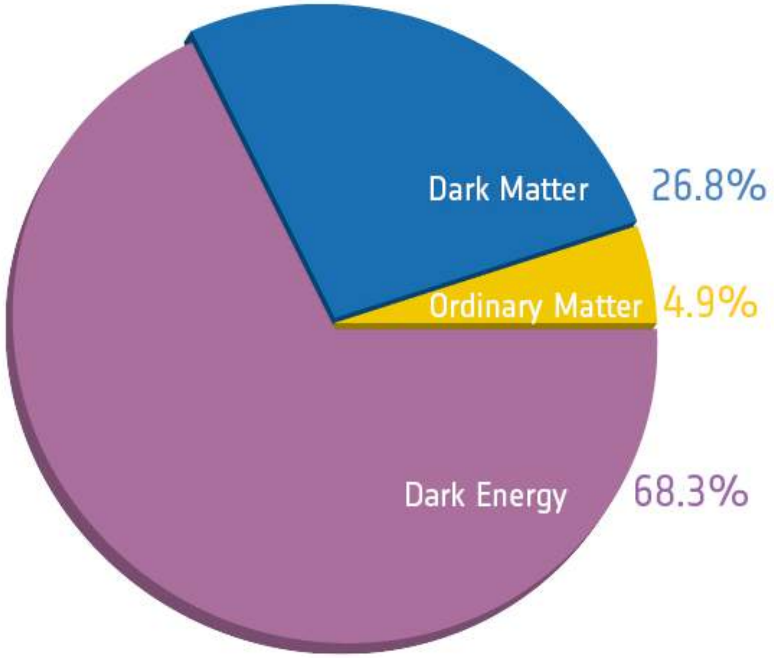


The Dark Matter problem

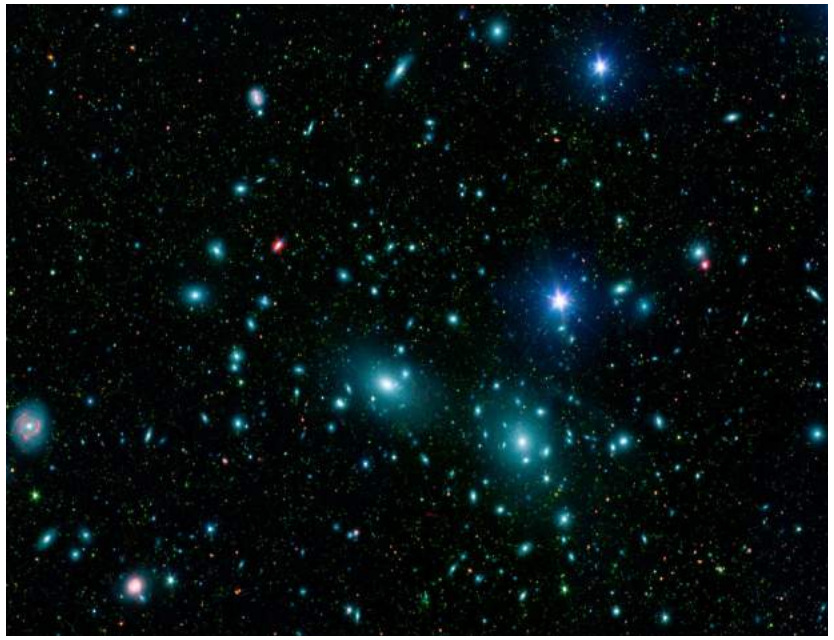
- The model implies also the existence of Dark Matter
- Compelling evidence for Dark Matter on various cosmological scales (galaxies rotation curves, gravitational lensing…)



Source: NOAO, AURA, NSF, T.A.Rector.



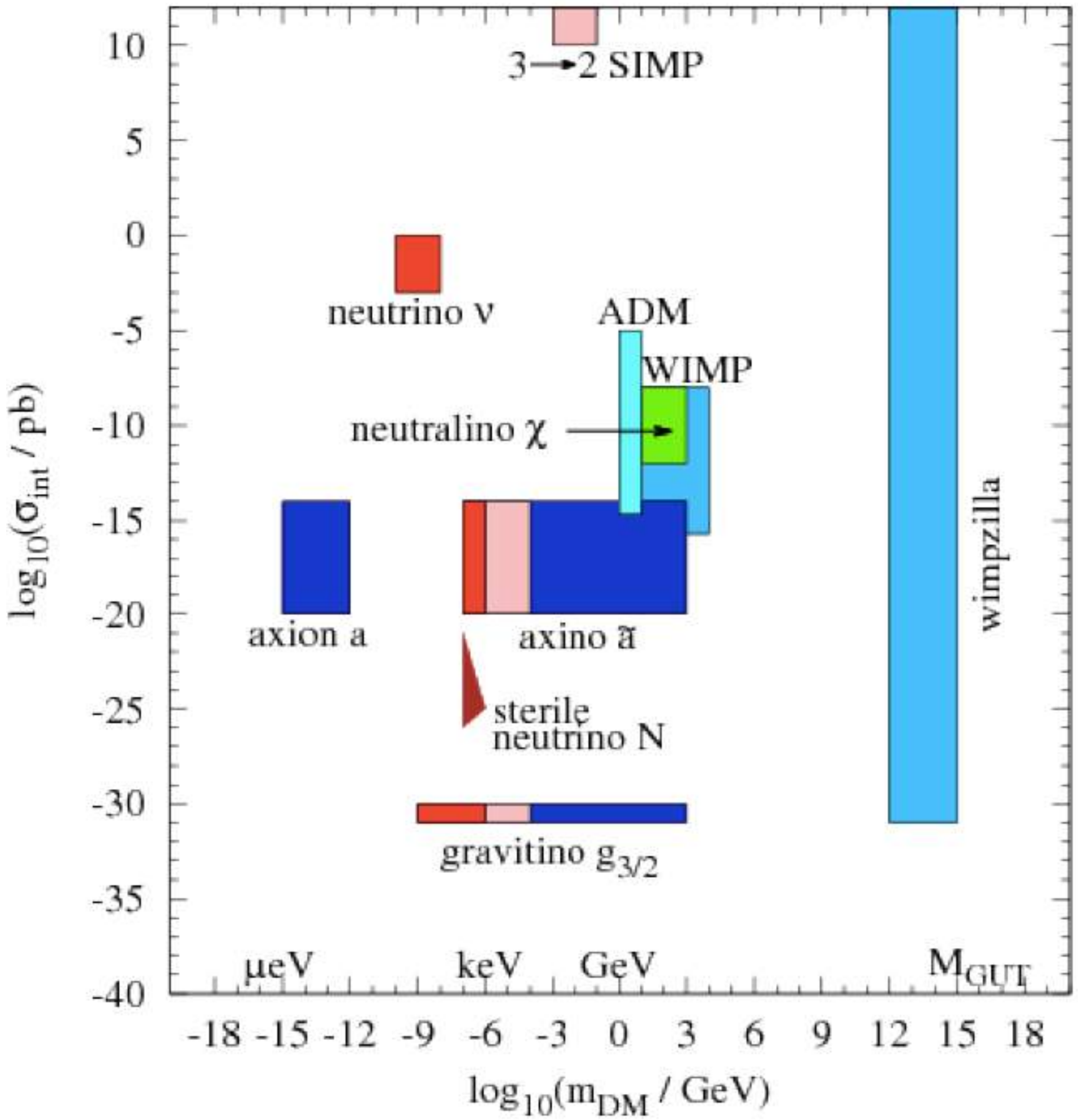
Source: ESA and the Planck Collaboration



Source: NASA, JPL-Caltech, SDSS, Leigh Jenkins, Ann Hornschemeier (Goddard Space Flight Center) et al.

What do we know about Dark Matter?

- It has mass
- It is non relativistic (structure formation)
- It is dark: does not interact e.m.
- Non baryonic
- Stable (or extremely long-lived)

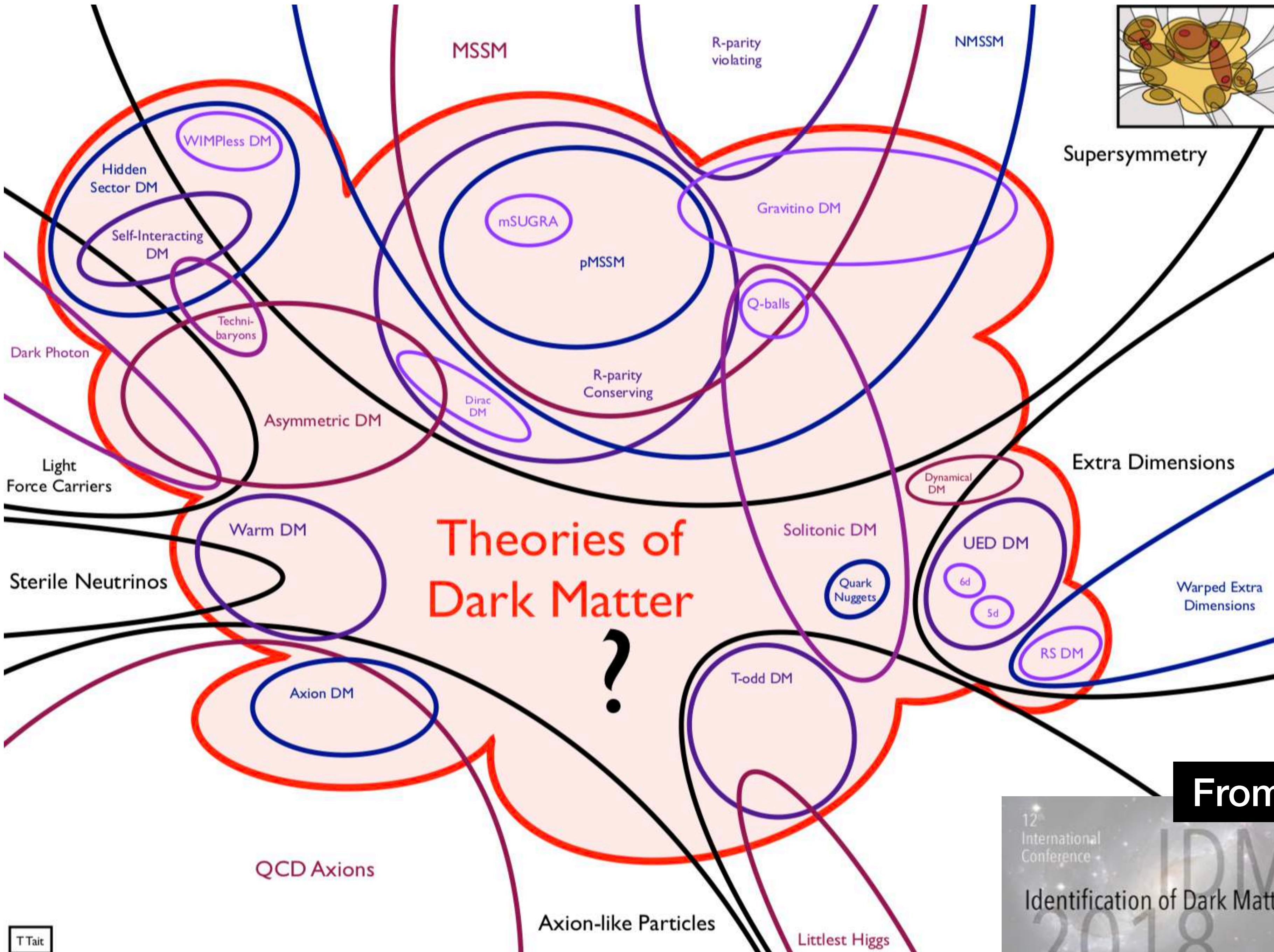


Phys. Rep. 555 (2015) 1

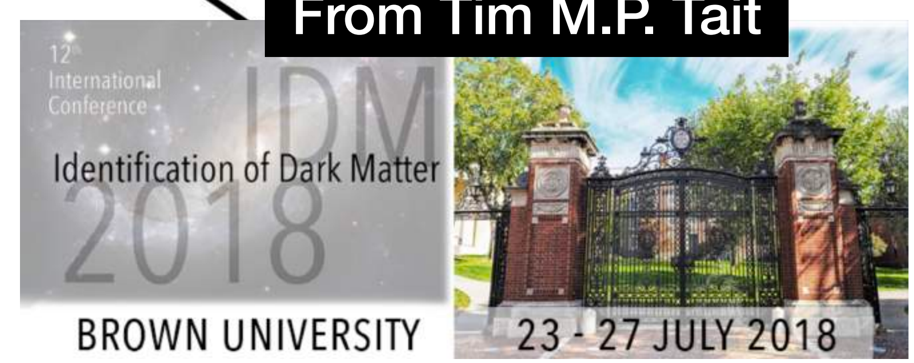
Great variety of theoretical motivated dark matter particle candidates with a wide range of mass and cross section.

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), February 2019.
Invited presentation 5EOr1B-02 given at ASC 2018, October 28-November 02, 2018, Seattle, (USA).

In a picture



From Tim M.P. Tait



Complementary approaches

Production at accelerators

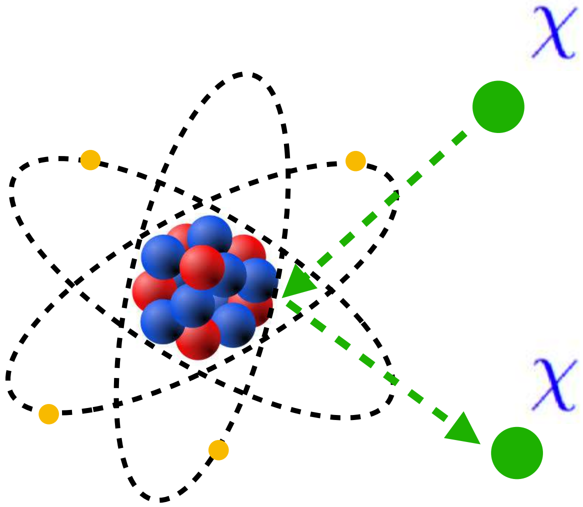
$$p + p \rightarrow \chi\bar{\chi} + \text{a lot}$$

Indirect detection

$$\chi\chi \rightarrow \gamma\gamma, q\bar{q}, \ldots$$

Direct detection

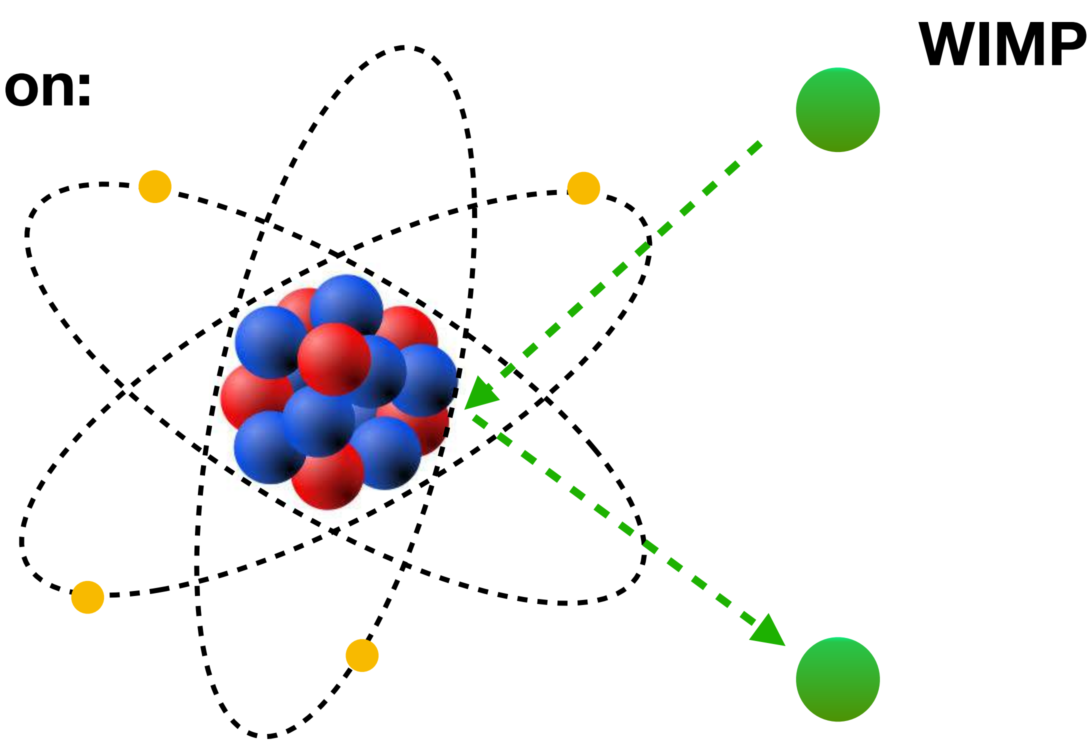
$$\chi\, N \rightarrow \chi\, N$$



Direct Dark Matter detection

Most common scenario for the DM interaction:

- WIMP in the galactic halo
- Scattering off nuclei
- Elastically and coherently
- Spin independently



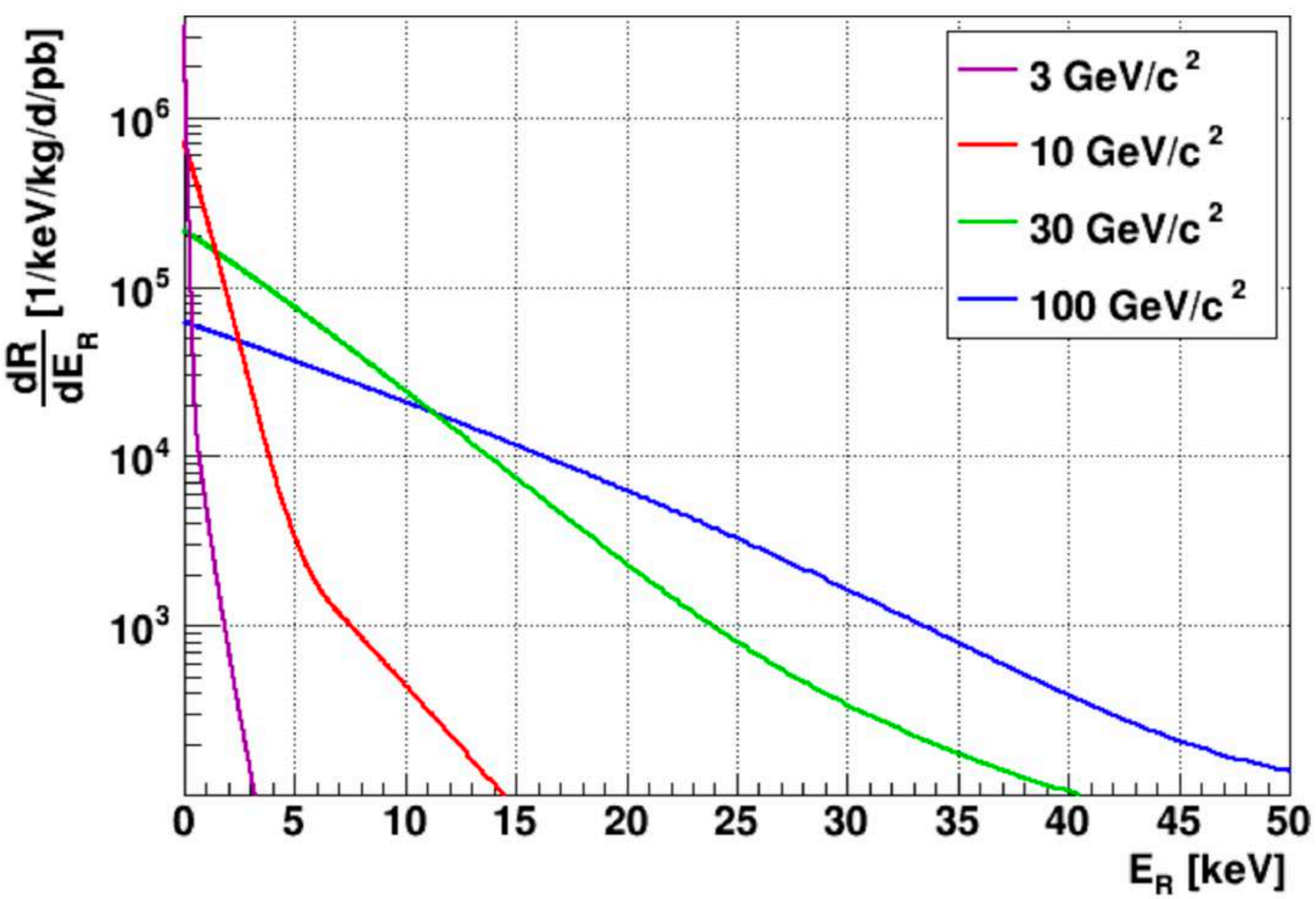
Expected nuclear recoil rate

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

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

Nuclear recoil energy spectra

$$R \sim \frac{events}{kg\, year}\left[\frac{A}{100}\cdot\frac{\sigma}{10^{-38}cm^2}\cdot\frac{v}{220km\, sec^{-1}}\cdot\frac{\rho}{0.3\, GeV\, cm^{-3}}\right]$$



Detection challenges

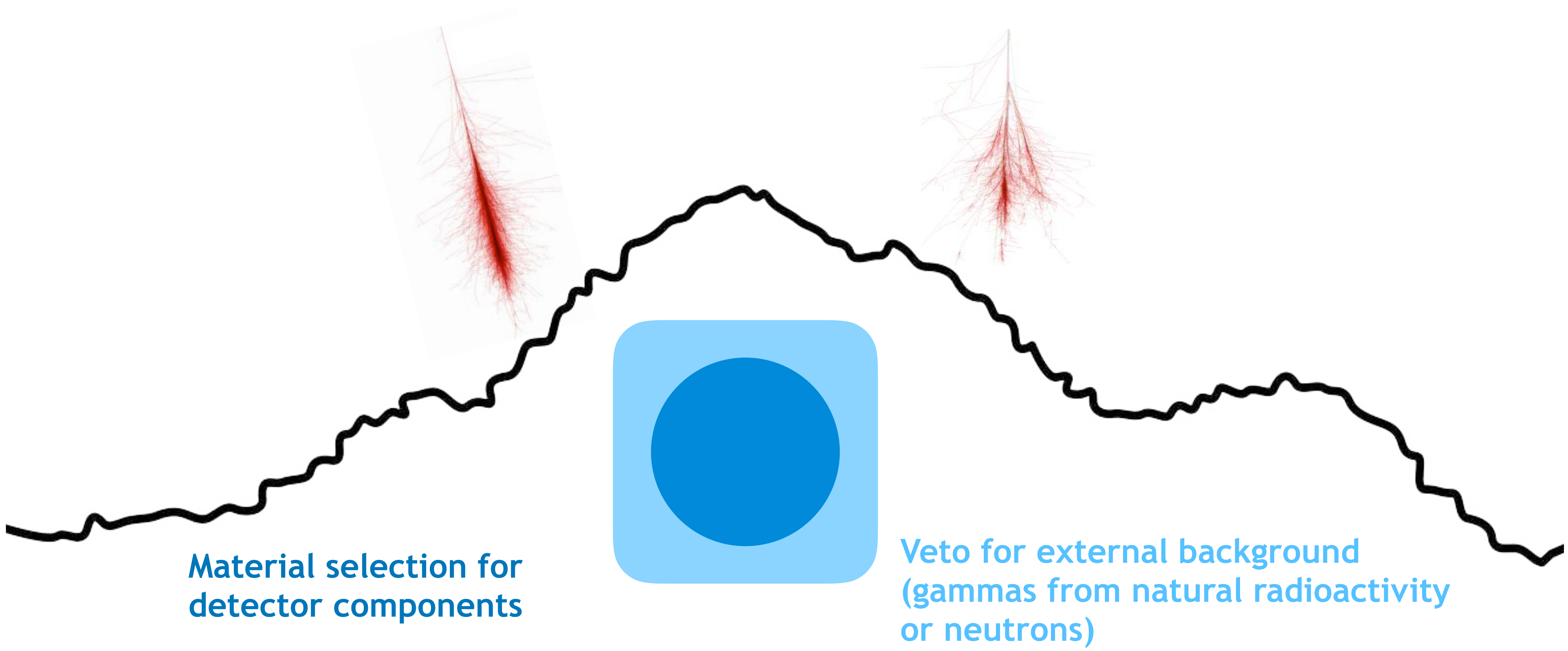
- Detection challenges:
  - Small recoil energies (~eV to ~keV, depending on the cinematic)
  - Low interaction rate. (Current best limit from XENON experiment, *Phys. Rev. Lett. 121, 111302, 2018* $\sigma < 4.1 \cdot 10^{-47} cm^2$ for M_{dm} ~25GeV)

- Requirements for a DM detector:
  - Low energy threshold
  - Large detector mass
  - Low background —> Underground Location

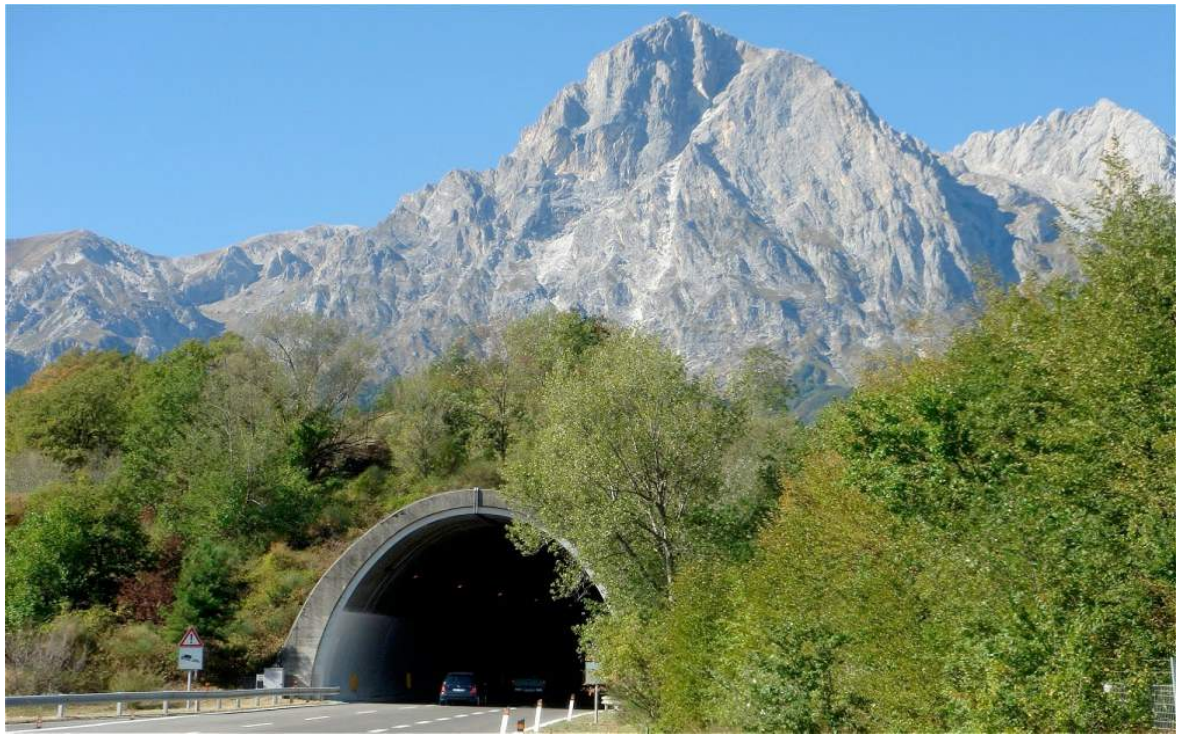
Detection challenges

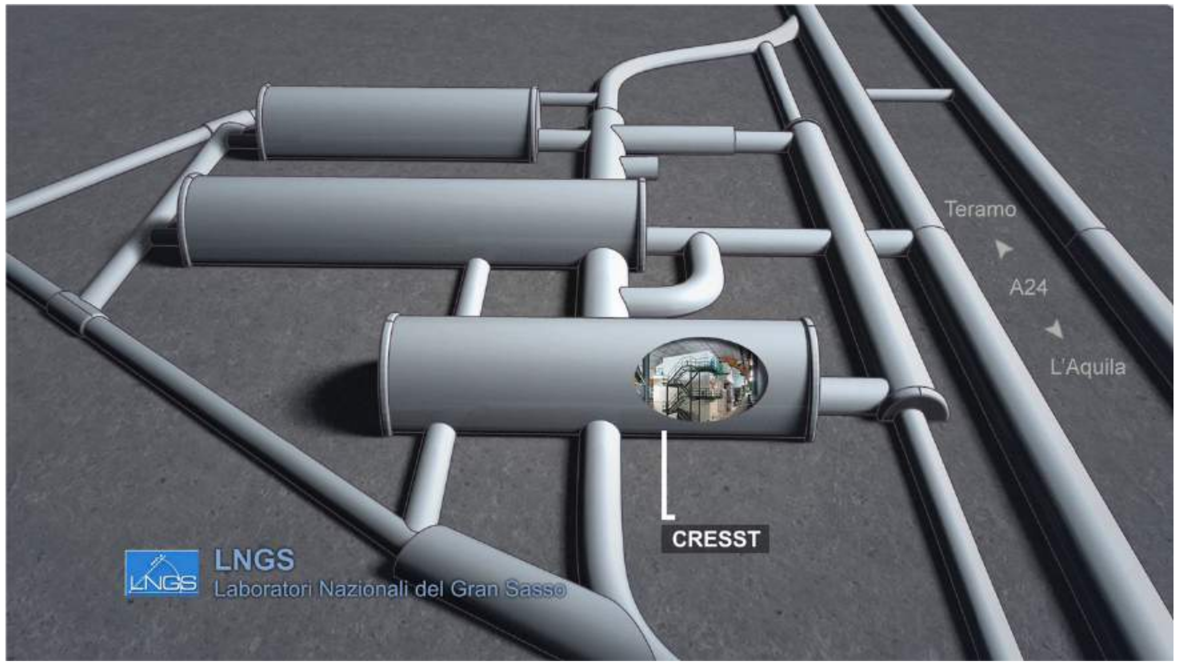
- Detection challenges:
  - Small recoil energies (~eV to ~keV, depending on the cinematic)
  - Low interaction rate. (Current best limit from XENON experiment, *Phys. Rev. Lett. 121, 111302, 2018*
    $\sigma < 4.1 \cdot 10^{-47} cm^2$ for M_{dm} ~25GeV)

- Requirements for a DM detector:
  - Low energy threshold
  - Large detector mass
  - Low background —> Underground Location



Experimental site





Laboratori Nazionali del Gran Sasso (Italy)

Experimental location:

Average depth ~ 3600 m w.e.

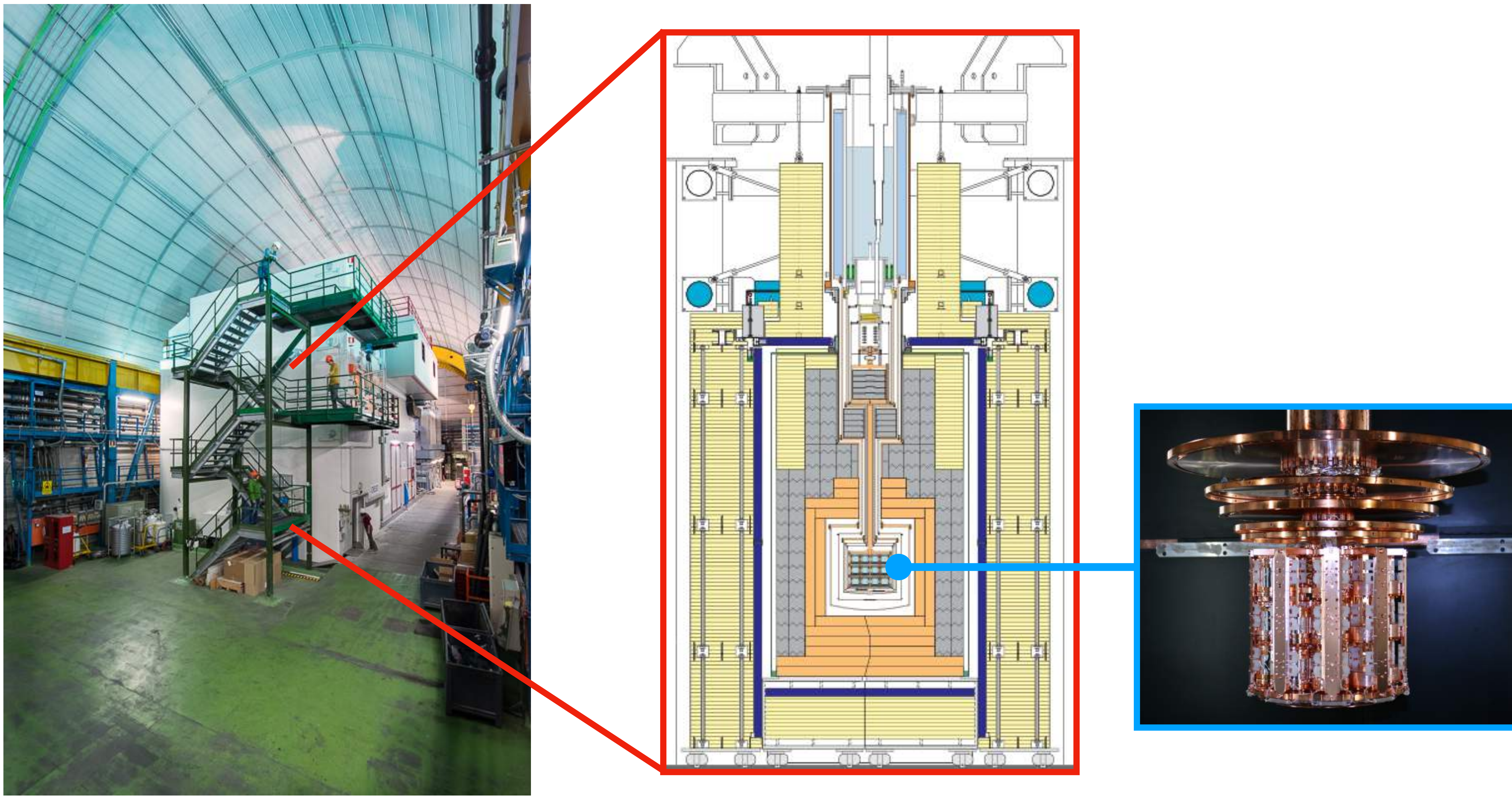
Muon flux ~ 2.6×10^{-8} μ/s/cm^2

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

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), February 2019.
Invited presentation 5EOr1B-02 given at ASC 2018, October 28-November 02, 2018, Seattle, (USA).

CRESST @ LNGS

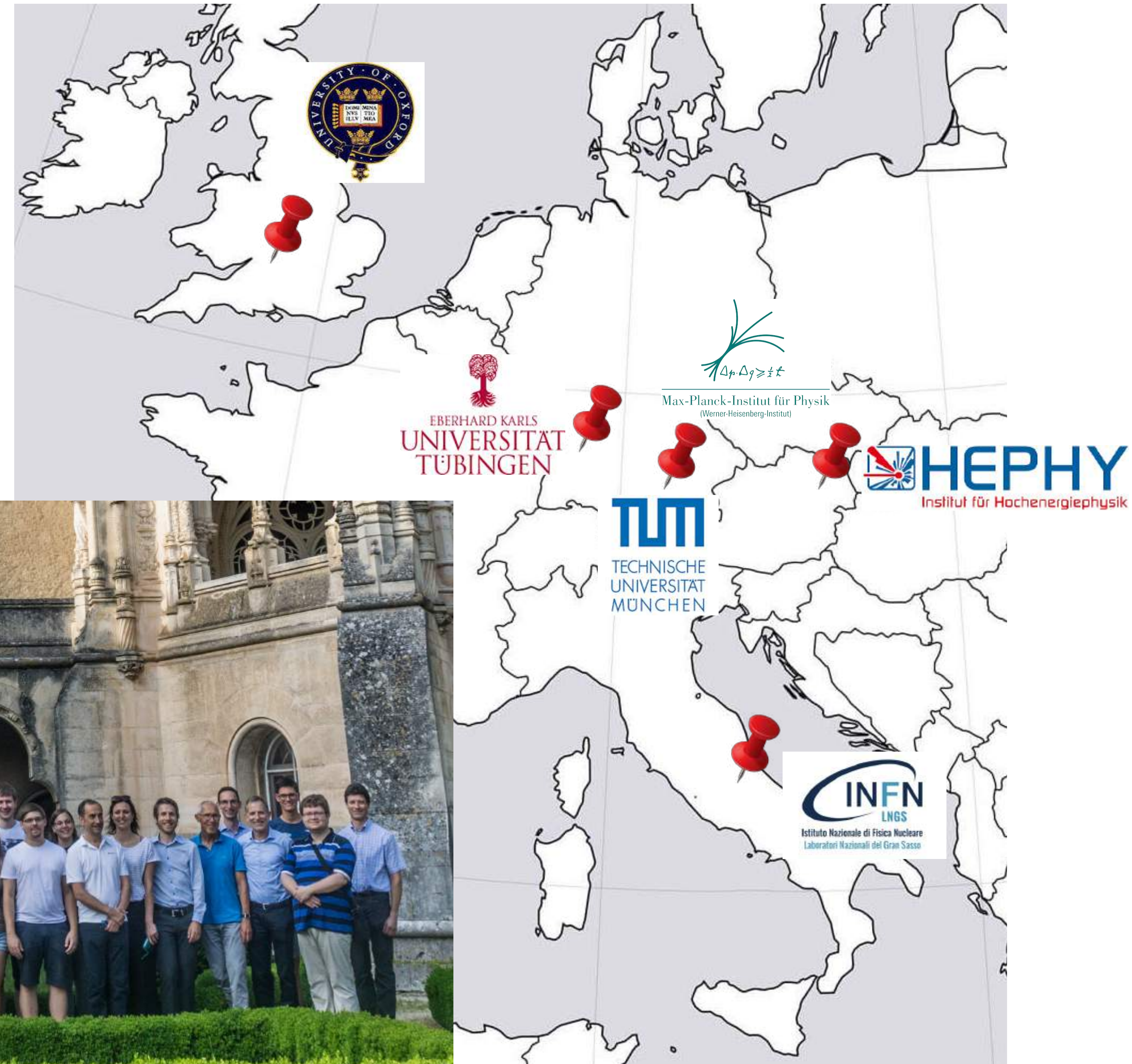
Cryogenic Rare Event Search with Superconducting Thermometers



The CRESST Collaboration

~50 Collaborators:

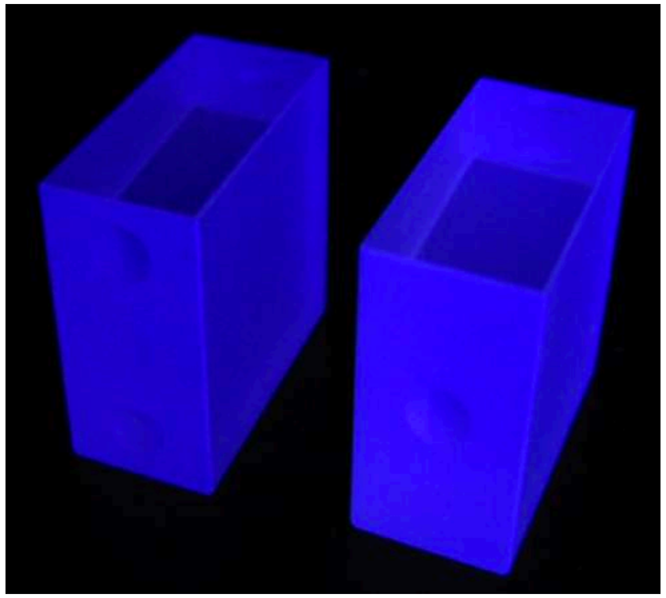
- 16 MPP, DE
- 14 TUM, DE
- 4 Tubingen, DE
- 8 HEPHY, AT
- 8 LNGS, IT
- 1 Oxford, UK

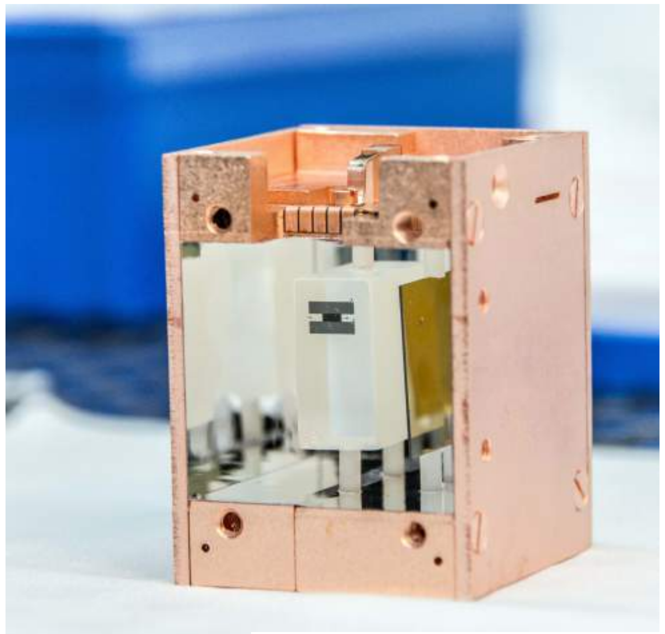


The CRESST detector

Cryogenic Rare Event Search with Superconducting Thermometers

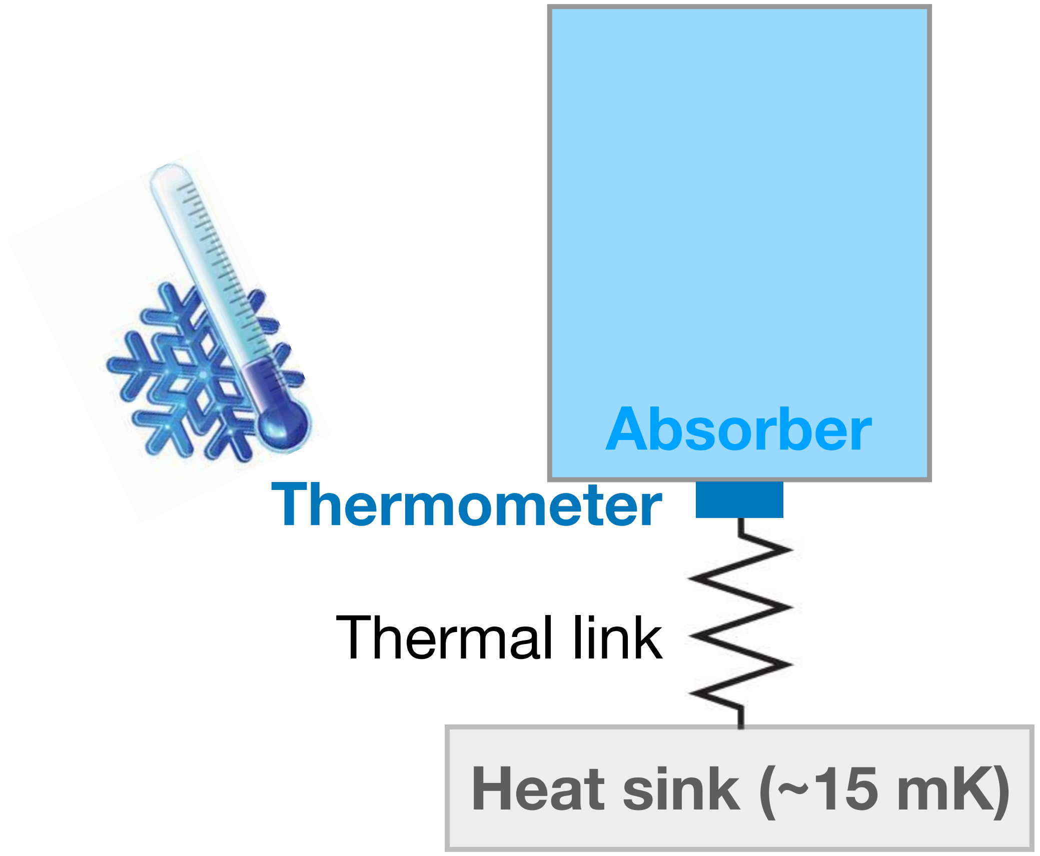
- Direct detection of Dark Matter particles via their scattering off target nuclei
- Target: Scintillating $CaWO_4$ crystals
- Operated as cryogenic calorimeters (~15mK)
- Double read-out cryogenic detector: heat ($CaWO_4$) and light (Light detector)
- Transition Edge Sensor (TES) for read out



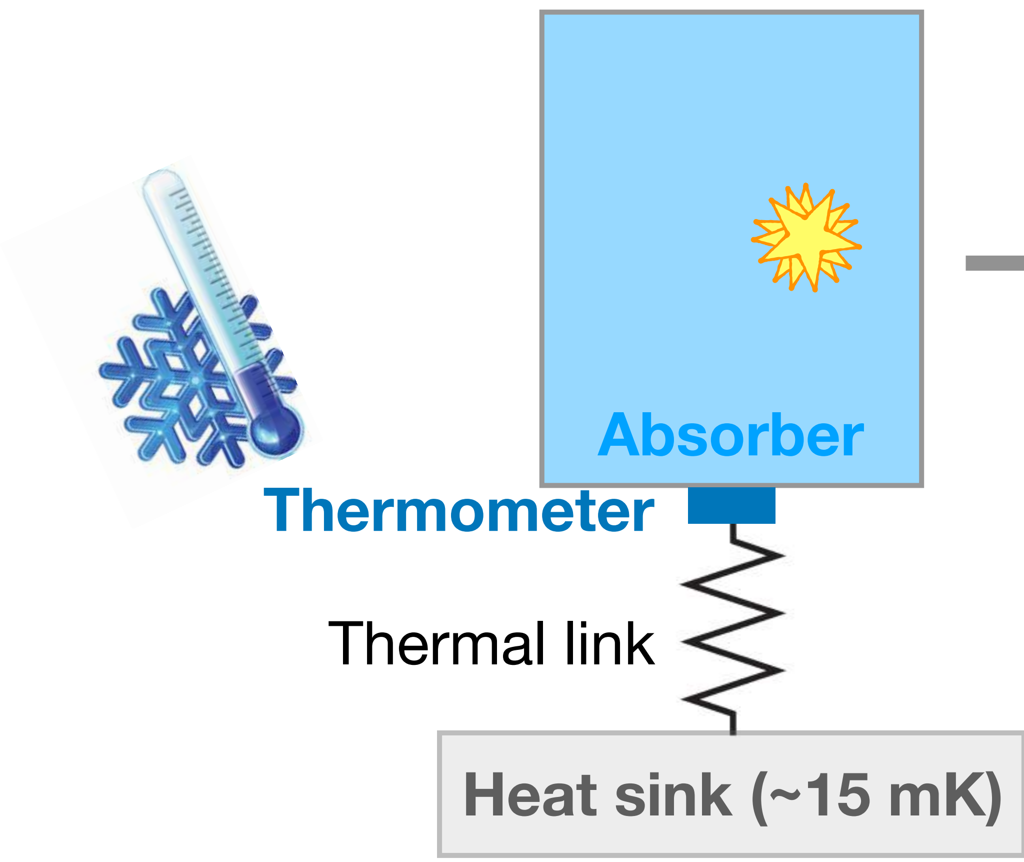


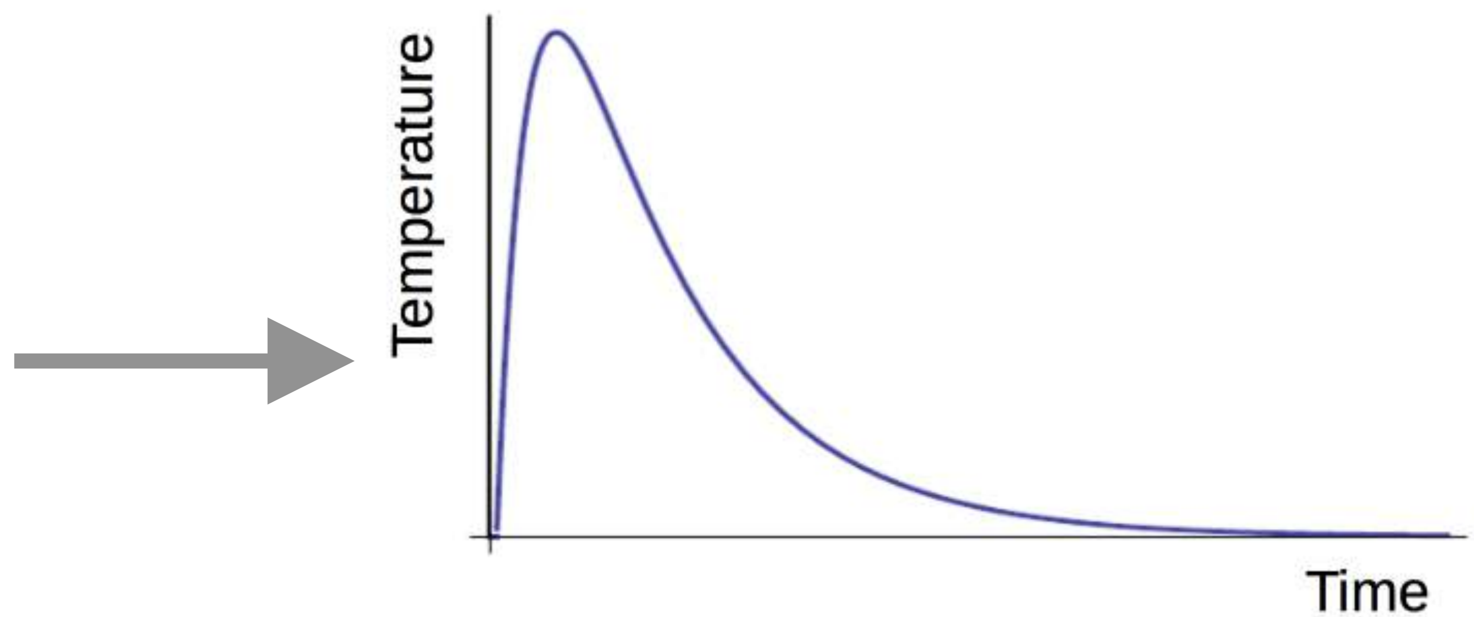
Credit: MPP/T.Dettlaff

Cryogenic calorimeter



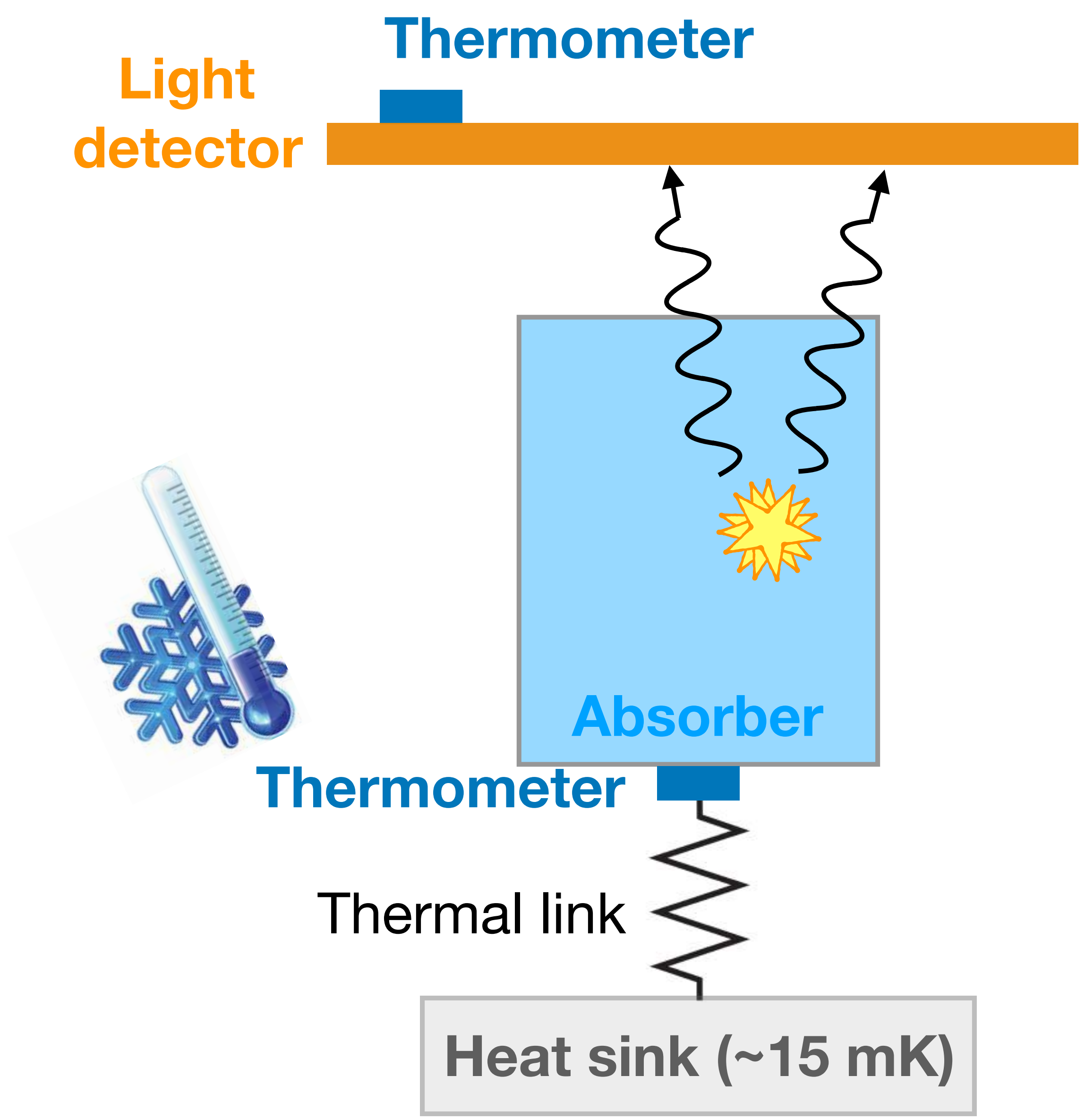
Cryogenic calorimeter





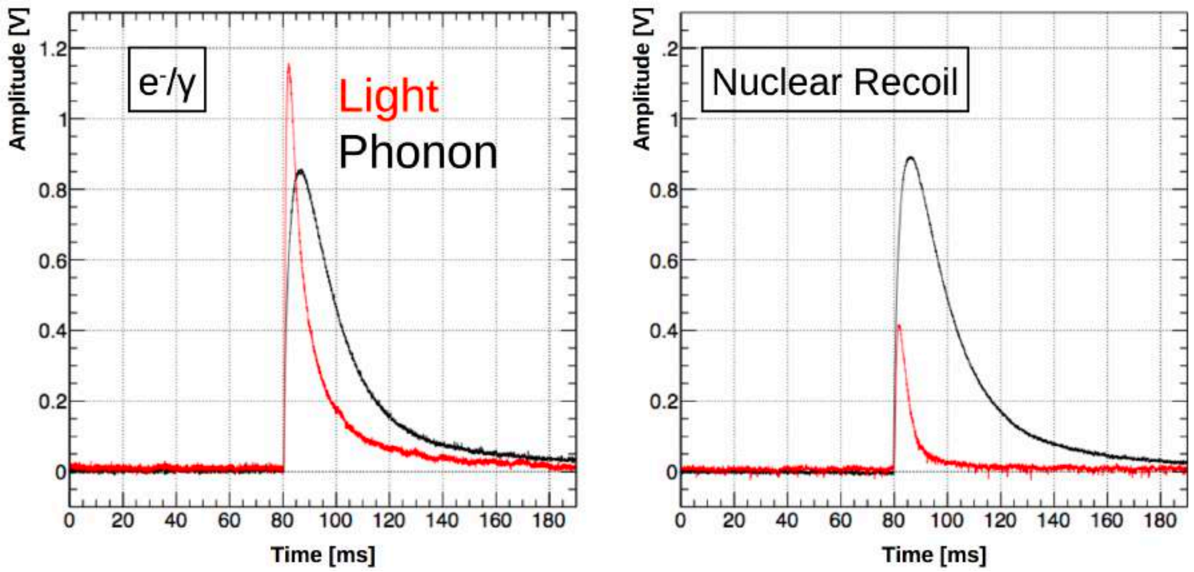
- Measurement of total deposited **energy** (particle independent)

Cryogenic calorimeter



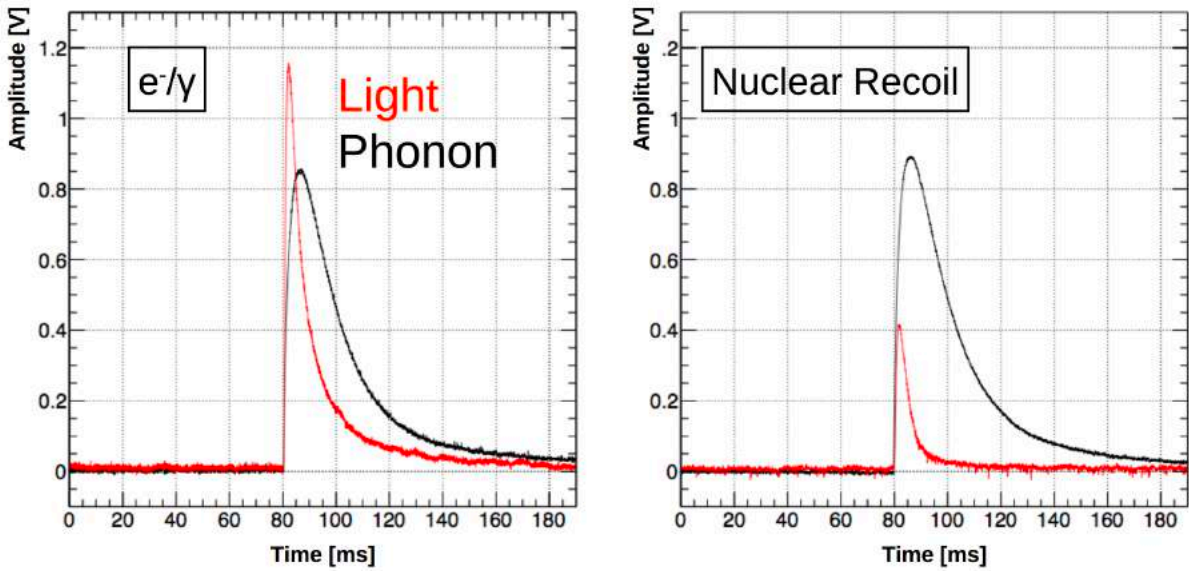
Particle Identification

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

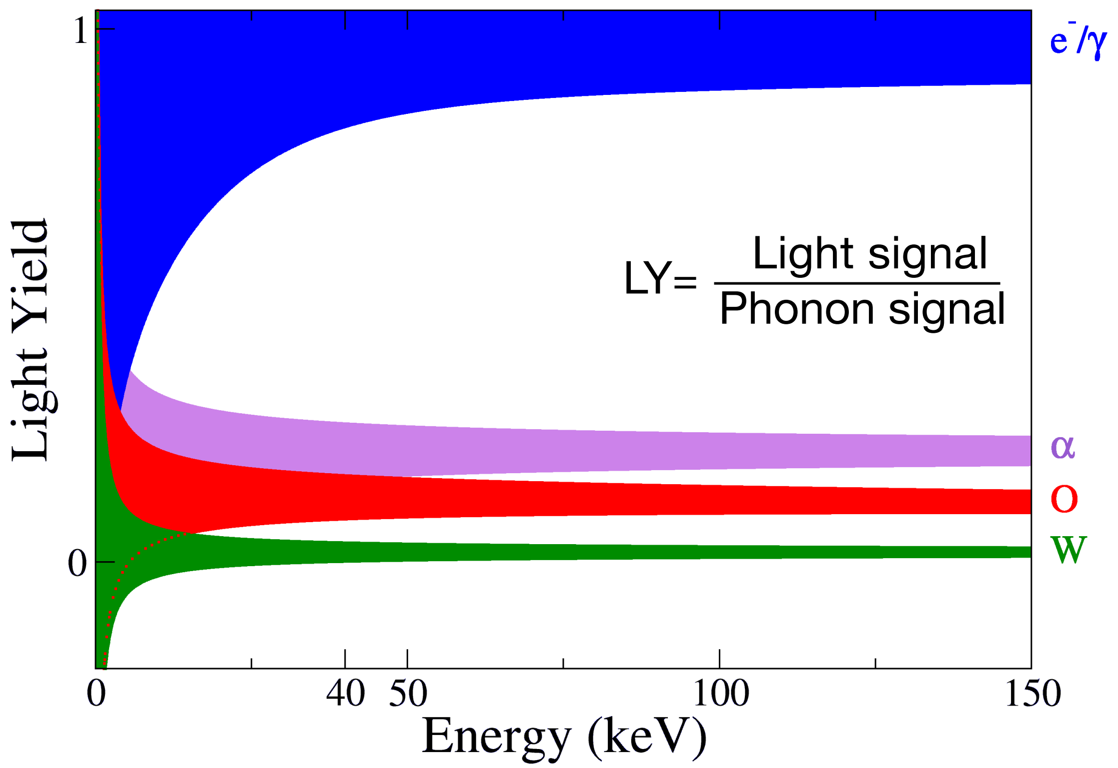


Particle Identification

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

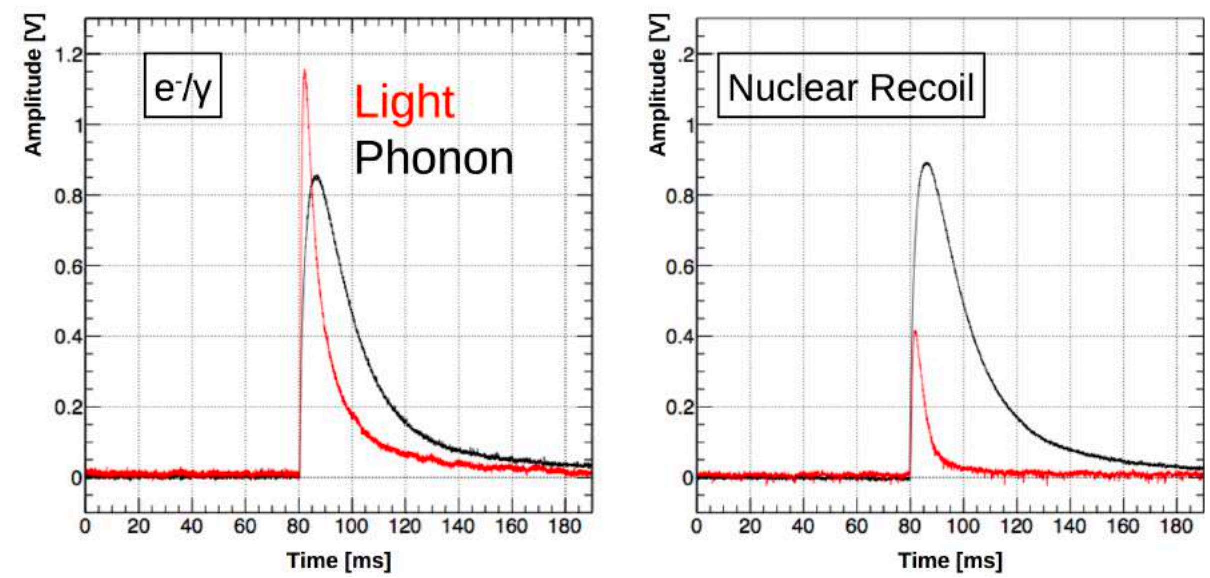


Excellent discrimination between potential signal events (**nuclear recoils**) and dominant radioactive background (**electron recoils**)

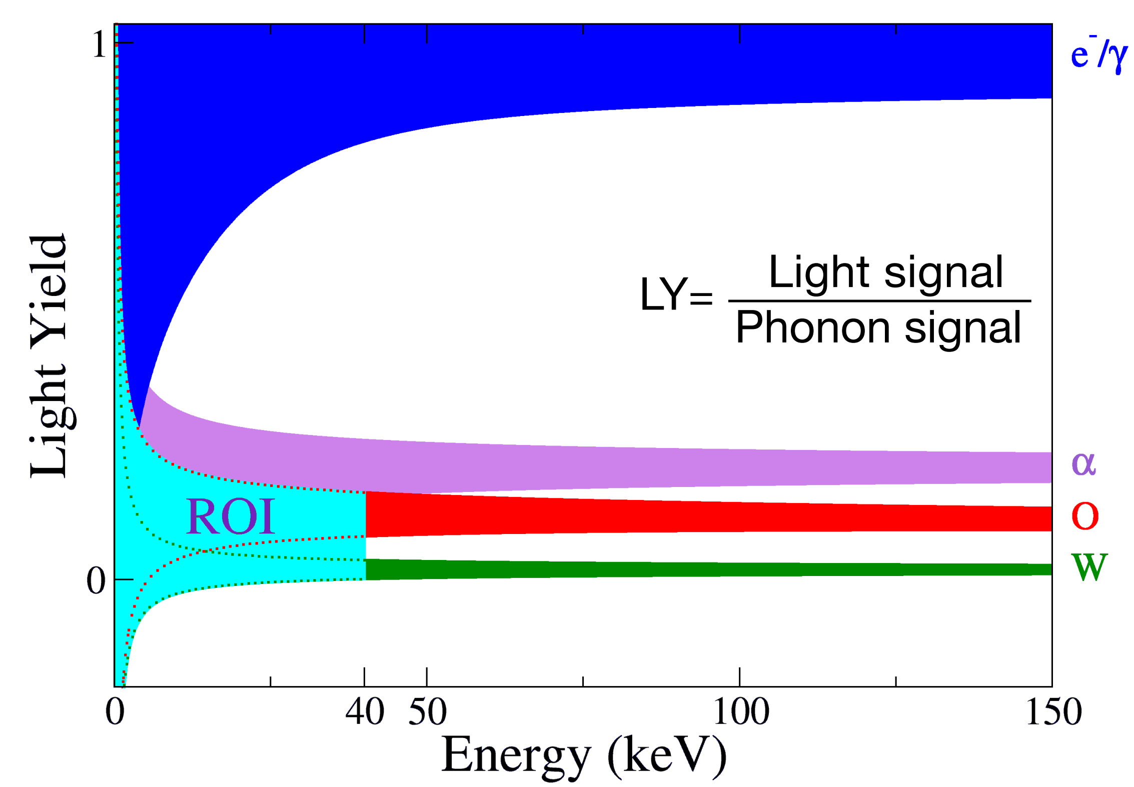


Particle Identification

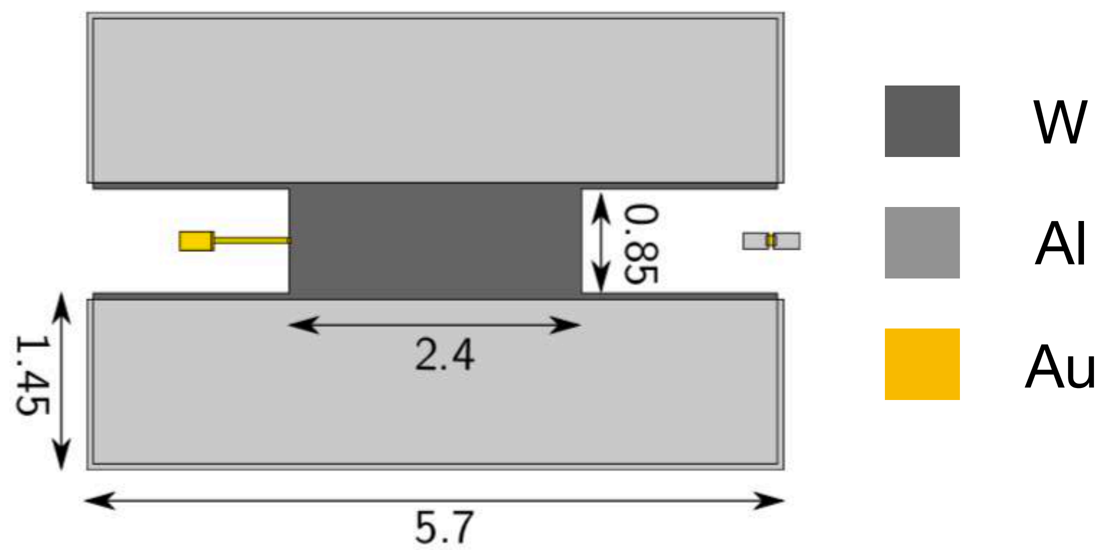
If the absorber is also an efficient scintillator the energy is converted into **heat + light**

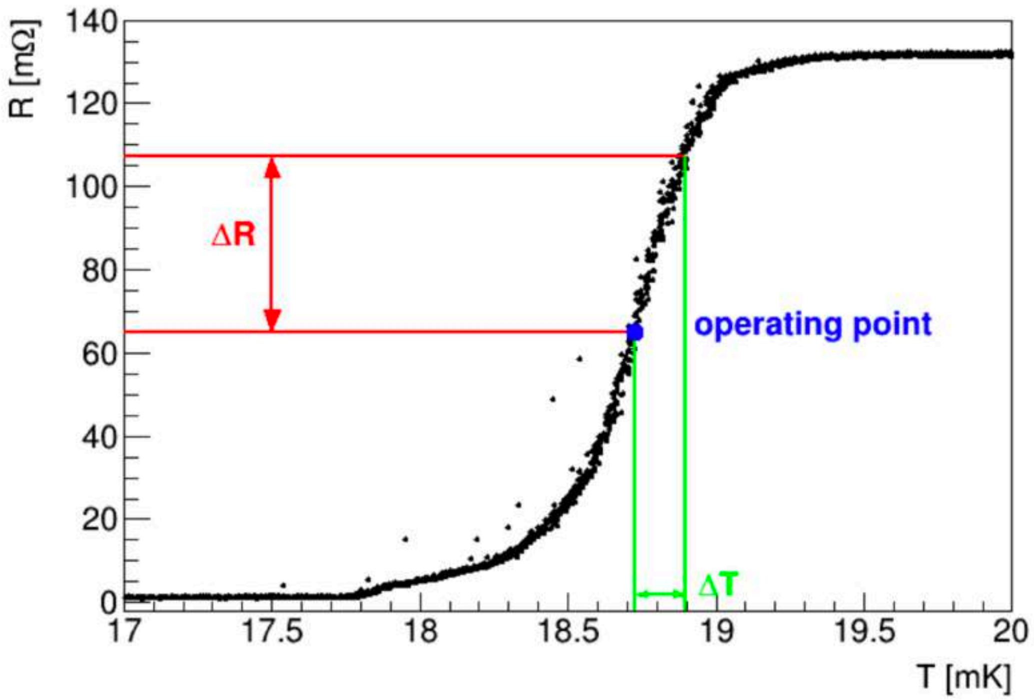


Excellent discrimination between potential signal events (**nuclear recoils**) and dominant radioactive background (**electron recoils**)

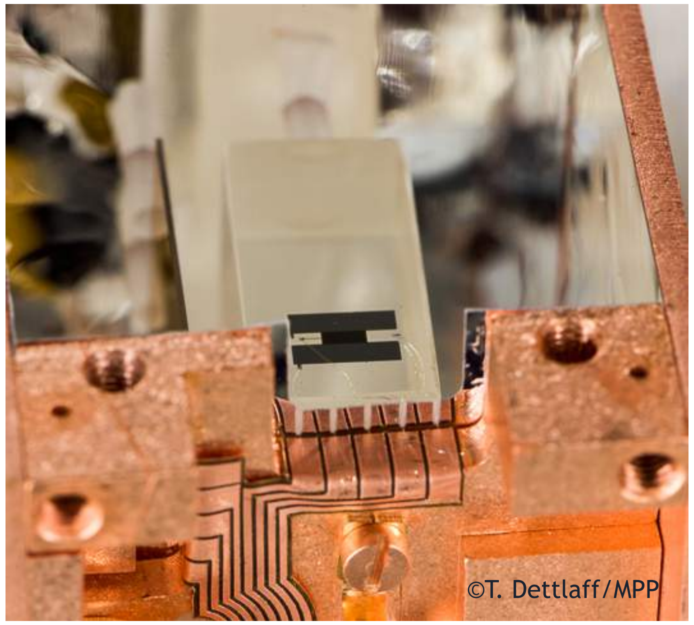


Transition Edge Sensors

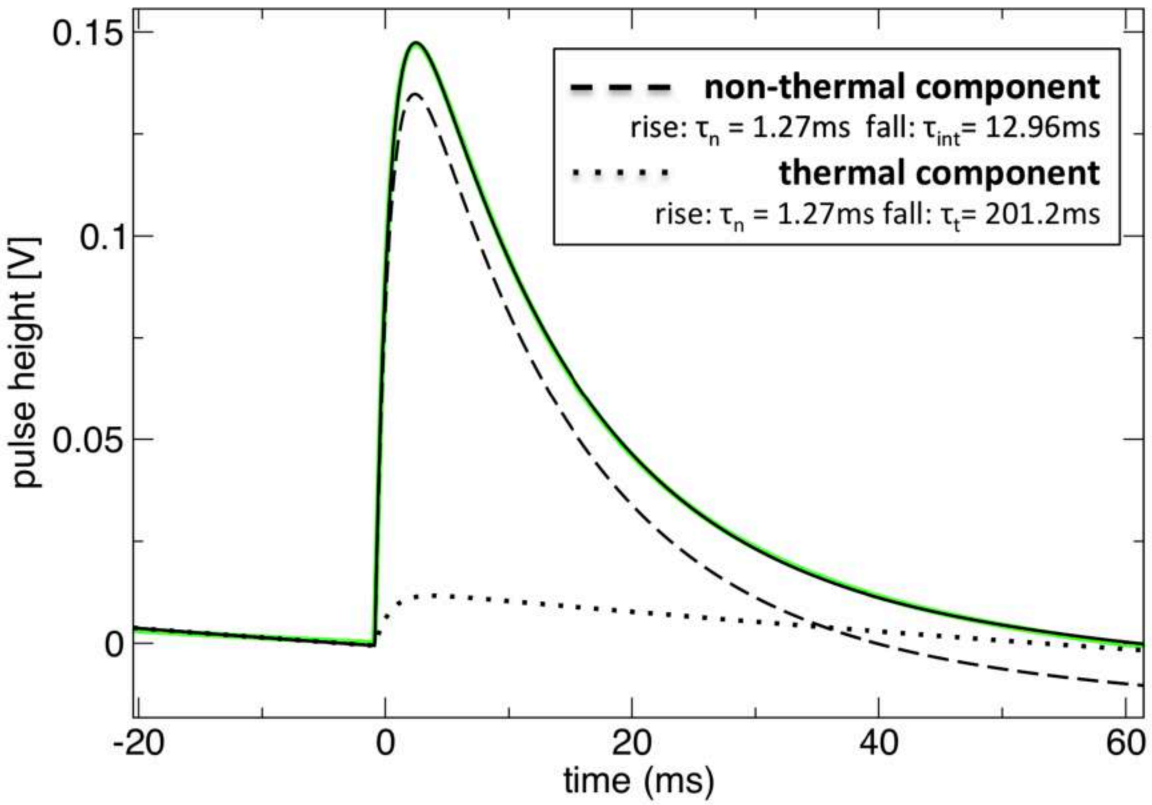




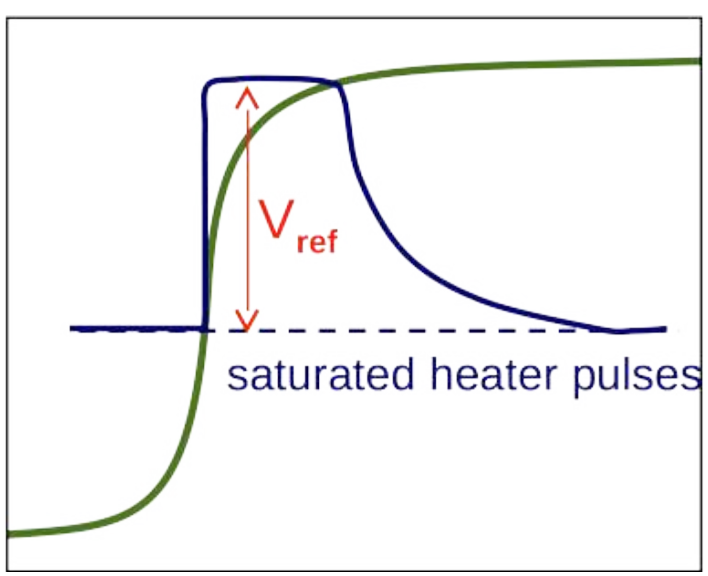
- 2.4x0.85 mm^2 W film, 200 nm thick, directly evaporated on the absorber
- Al film for phonon collection and electrical read out
- Sputtered Au film for thermal connection to the heat bath (~100pW/K at 10mK)
- Separated heater used to stabilize the TES at its operating point.
- Transition temperature ~ [10 - 20] mK

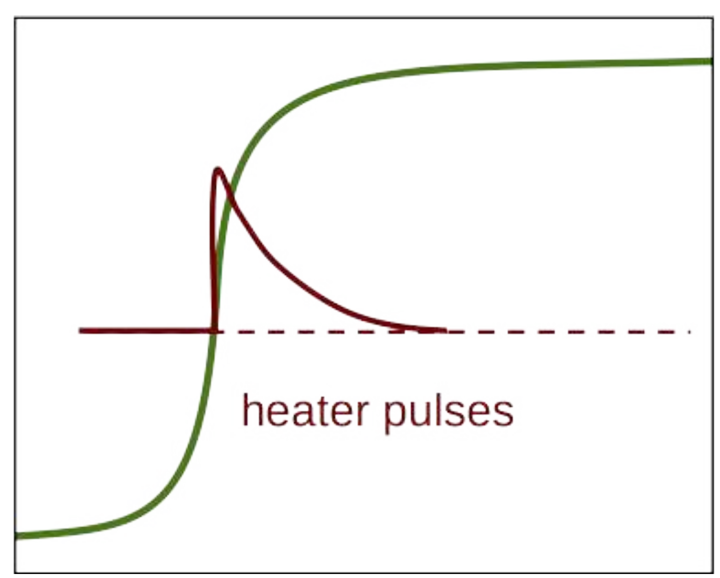


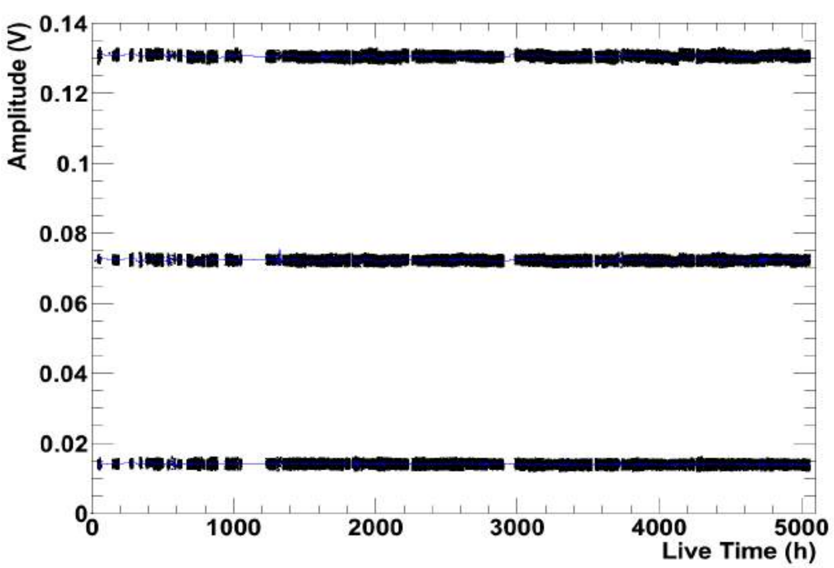
Detector operation



- W-TES equipped with heaters
- Stabilization of detectors in the operating point with an almost constant current
- Injection of heat pulses for calibration and determination of trigger threshold
- Stabilization of the TES in an operating point within a few μK.







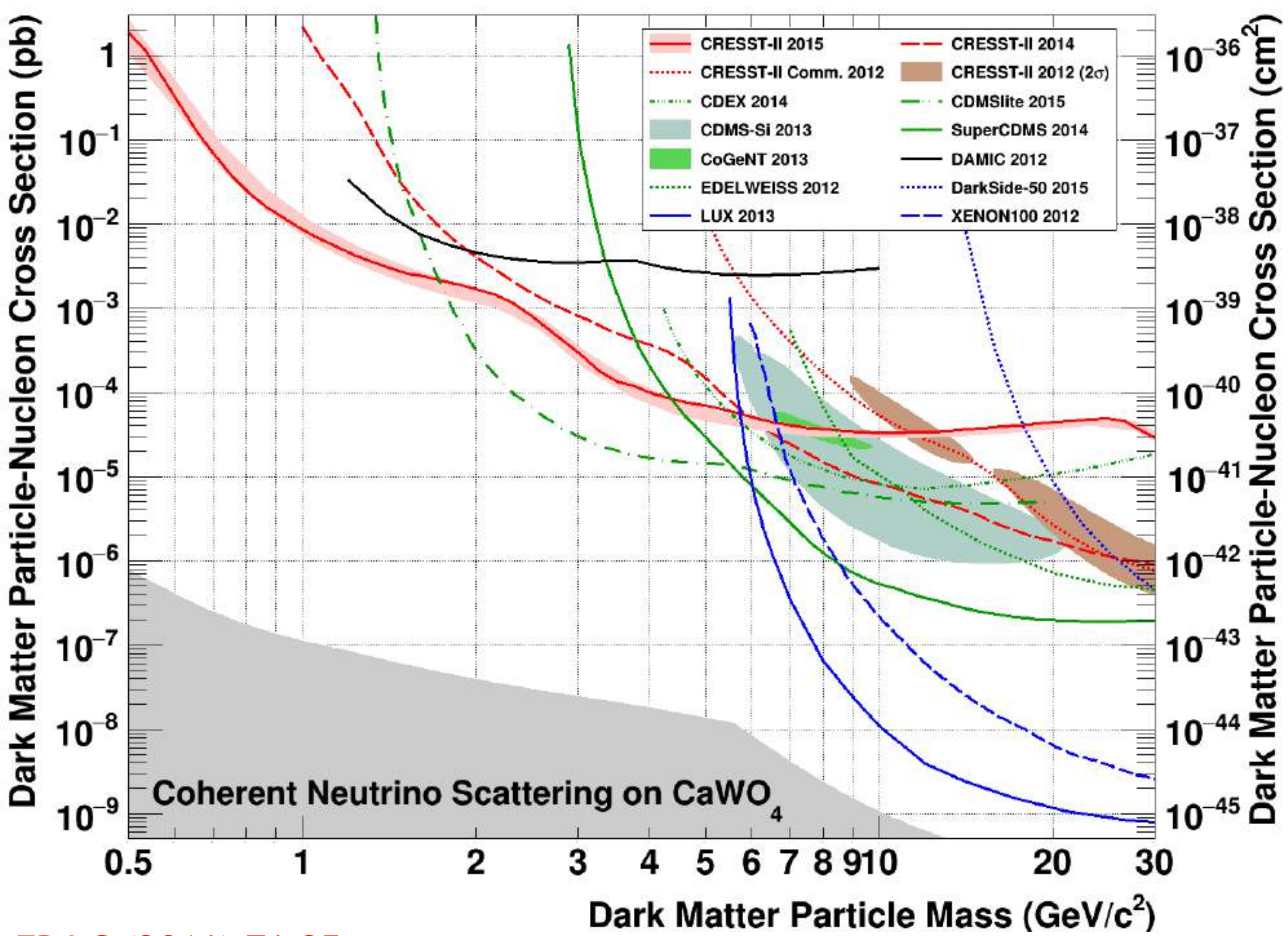
CRESST-II results - 2015

Crystal: Lise (mass ~300 g)

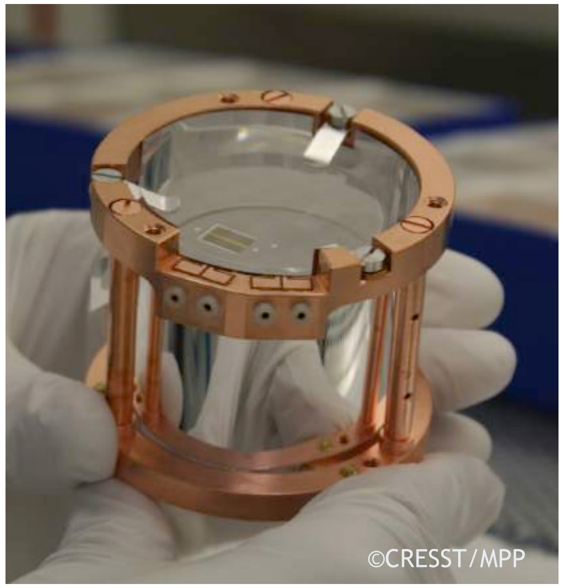
Exposure: 52 kg day

Background level ≈ 8.5 counts/(keV kg day)

Threshold: 307eV



EPJ C (2016) 76:25



Until 2017 world-leading below 1.7GeV/c^2

Opened up sub-GeV/c^2 regime

Hunting light dark matter requires low threshold and low background!

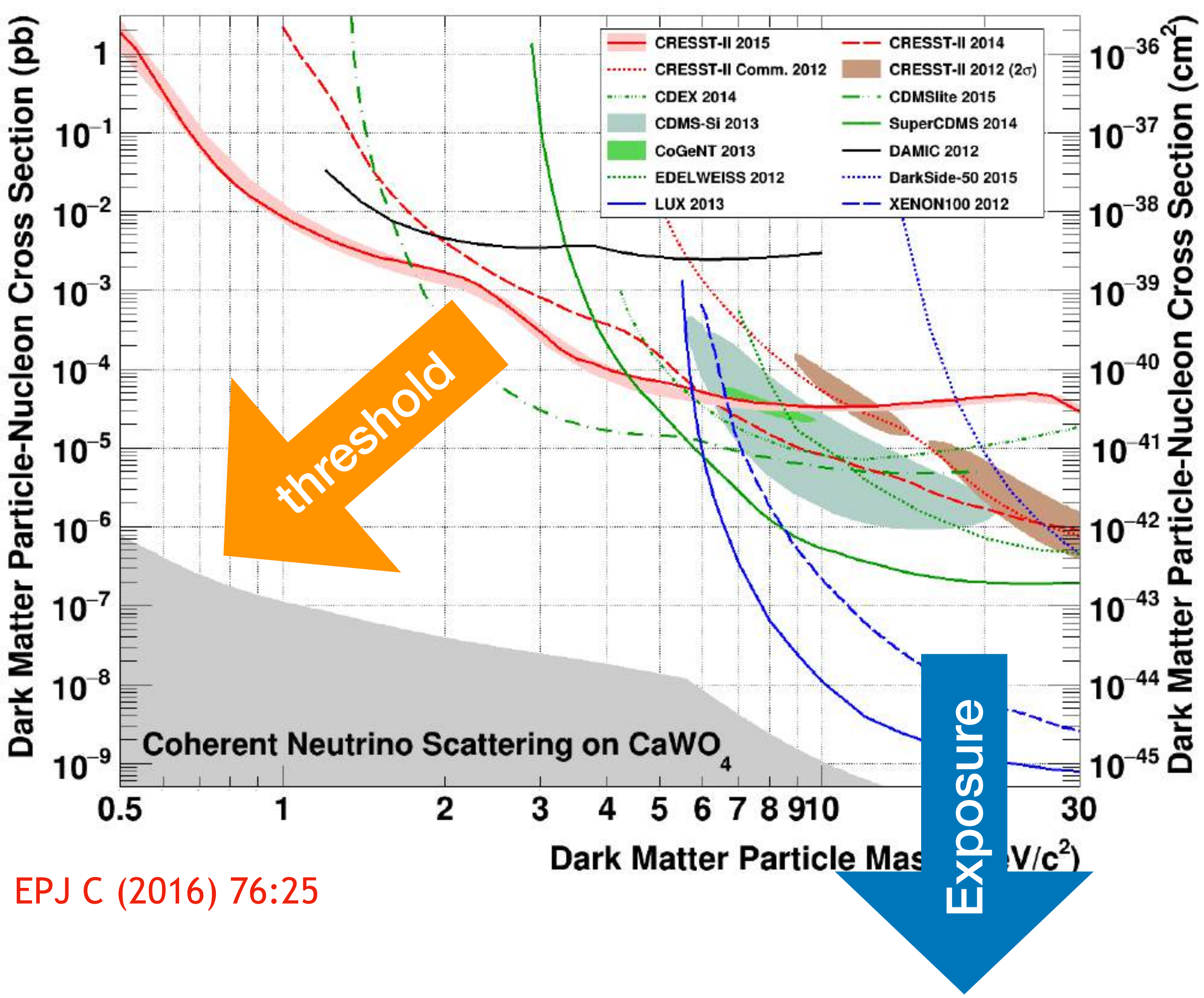
CRESST-II results - 2015

Crystal: Lise (mass ~300 g)

Exposure: 52 kg day

Background level ≈ 8.5 counts/(keV kg day)

Threshold: 307eV



EPJ C (2016) 76:25

Until 2017 world-leading below 1.7GeV/c^2

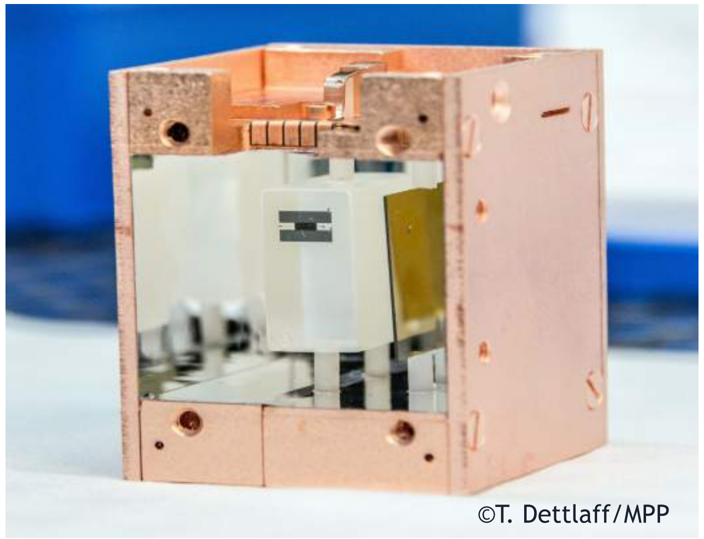
Opened up sub-GeV/c^2 regime

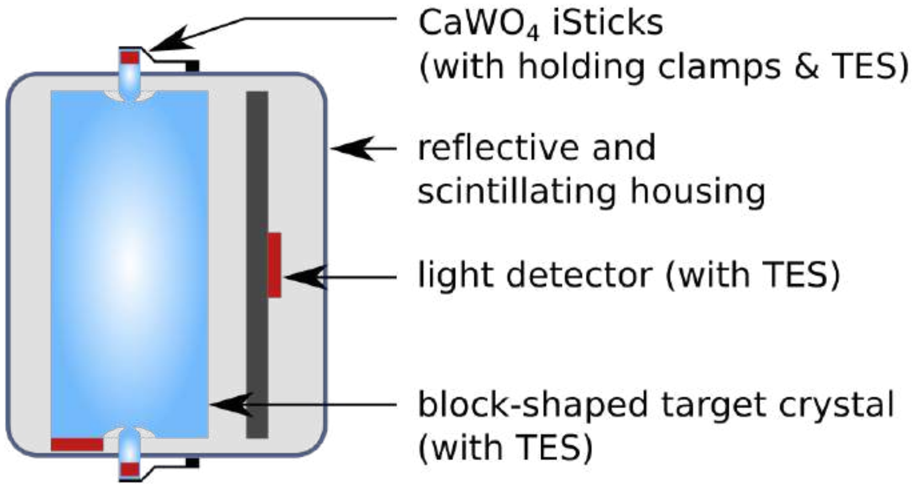
Hunting light dark matter requires low threshold and low background!

Towards low thresholds

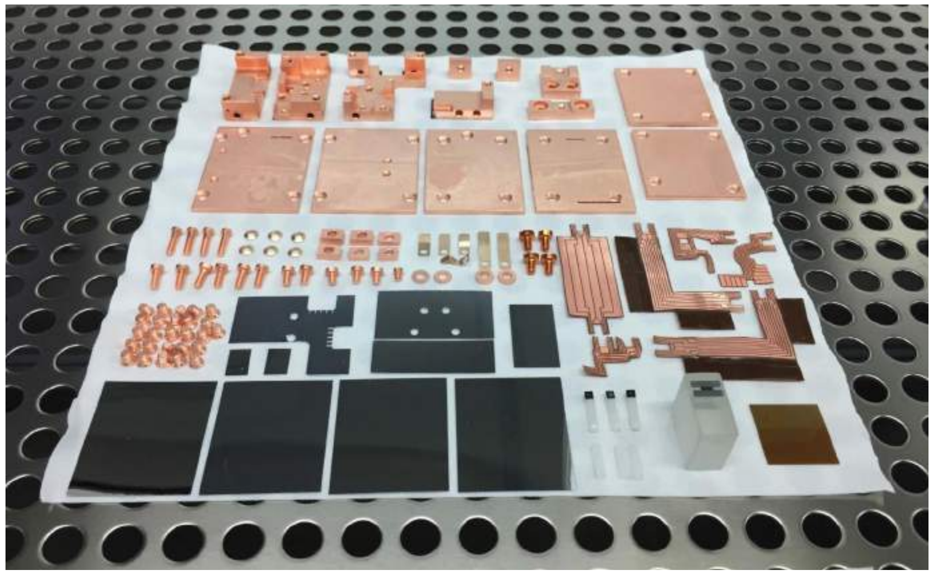
- Detector layout optimized for low-mass dark matter: reduction of crystal dimension (from 300g to 24g, 20x20x10 mm^3)
- TES design optimisation
- Cuboid fully scintillating housing
- Instrumented holders

Threshold design goal: 100 eV threshold

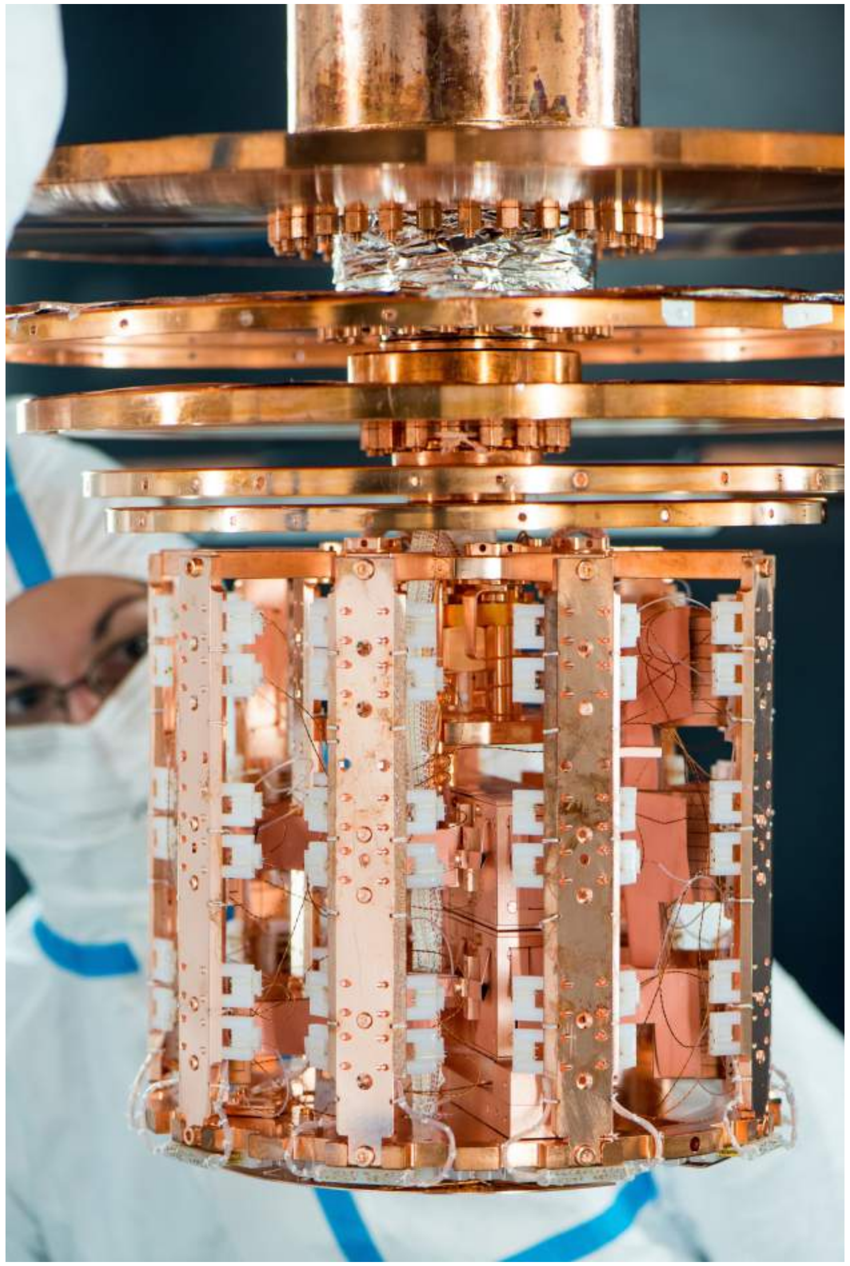


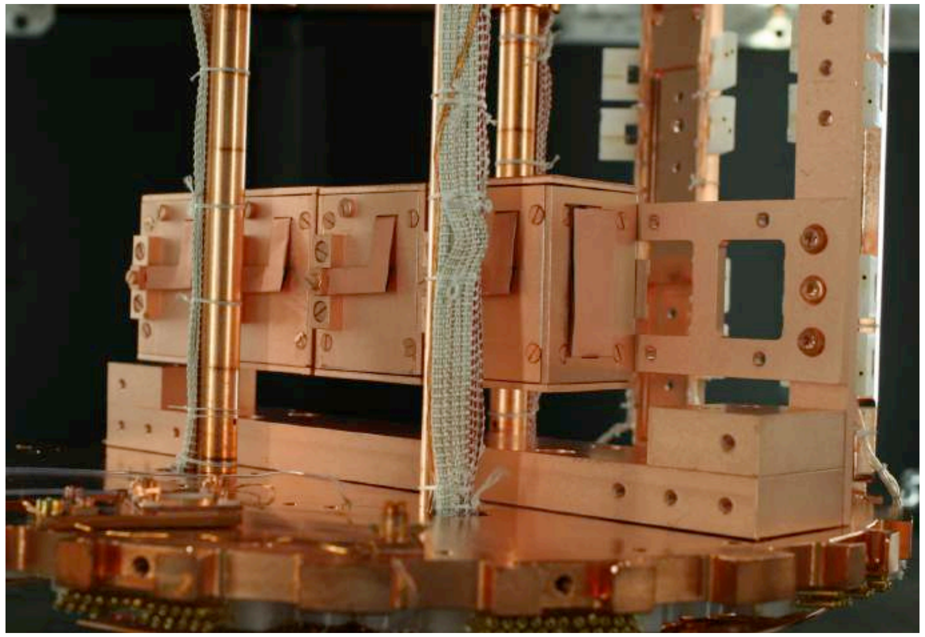


CRESST-III detectors




©A. Eckert/MPP

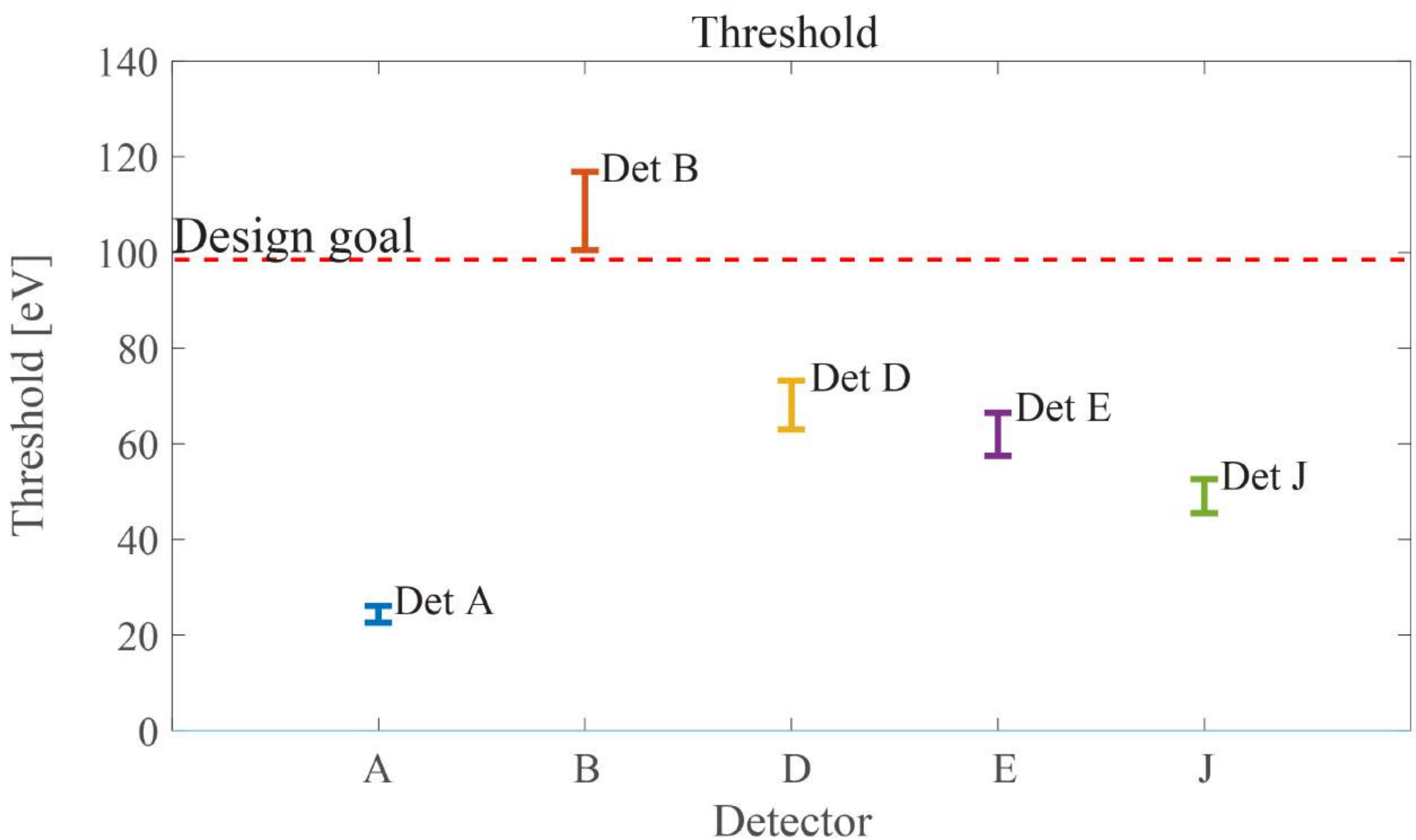





©T. Dettlaff/MPP

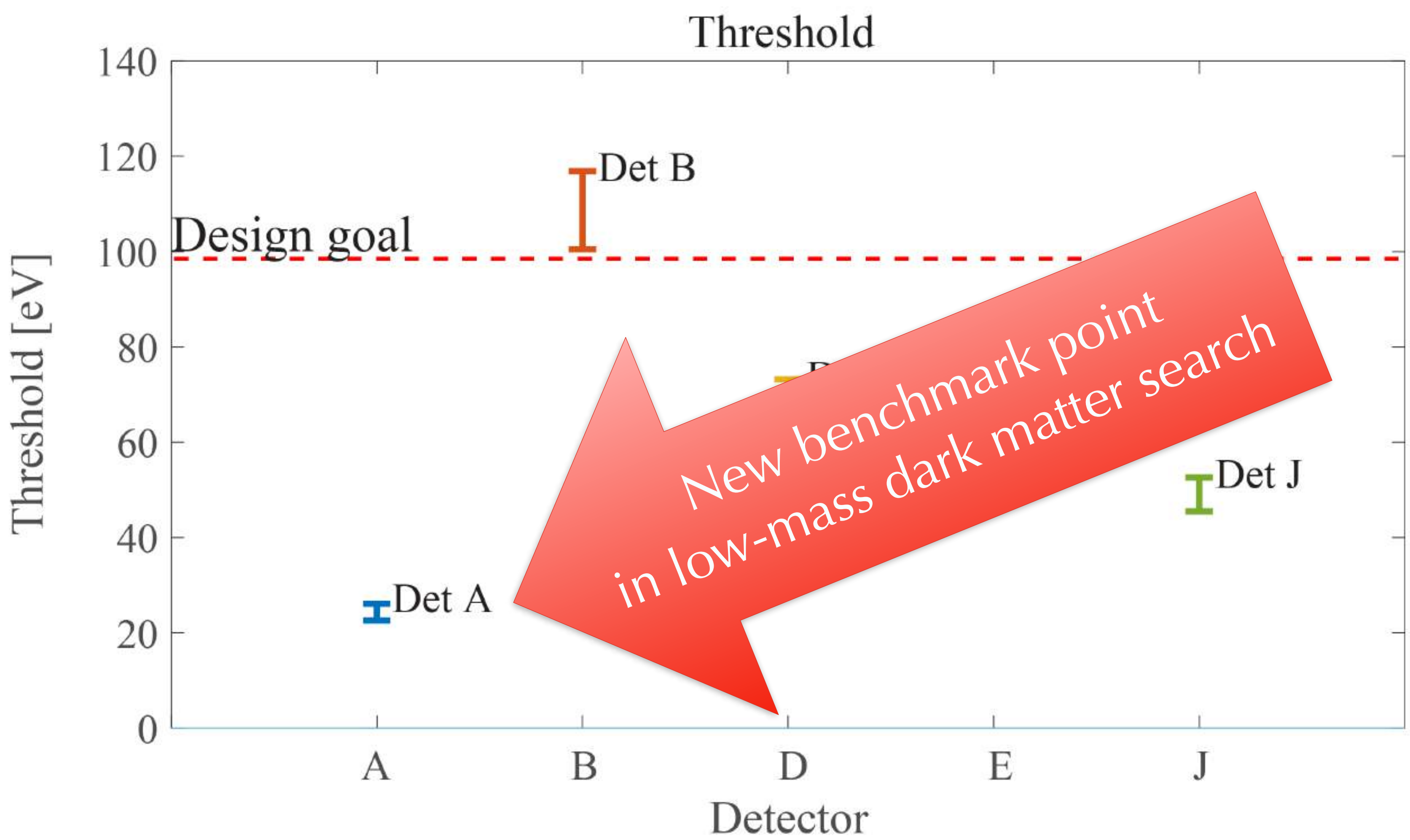
10 detectors operating in Gran Sasso from July 2016 to February 2018

Optimum thresholds



5 detectors reach/exceed the CRESST-III design goal

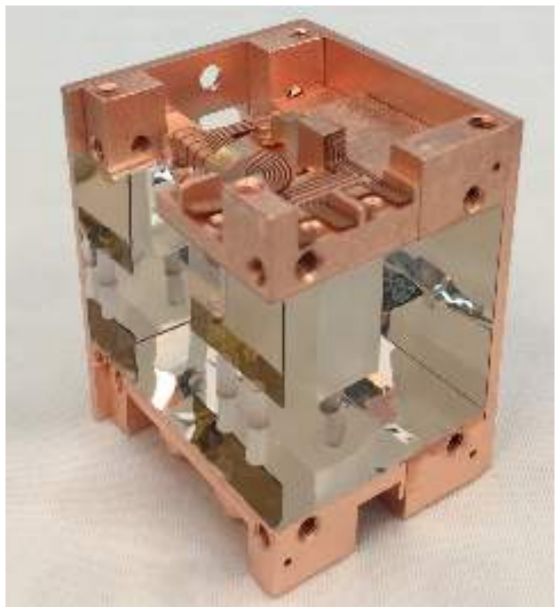
Optimum thresholds



5 detectors reach/exceed the CRESST-III design goal

NEW FRONTIER IN DIRECT DM DETECTION

Detector A



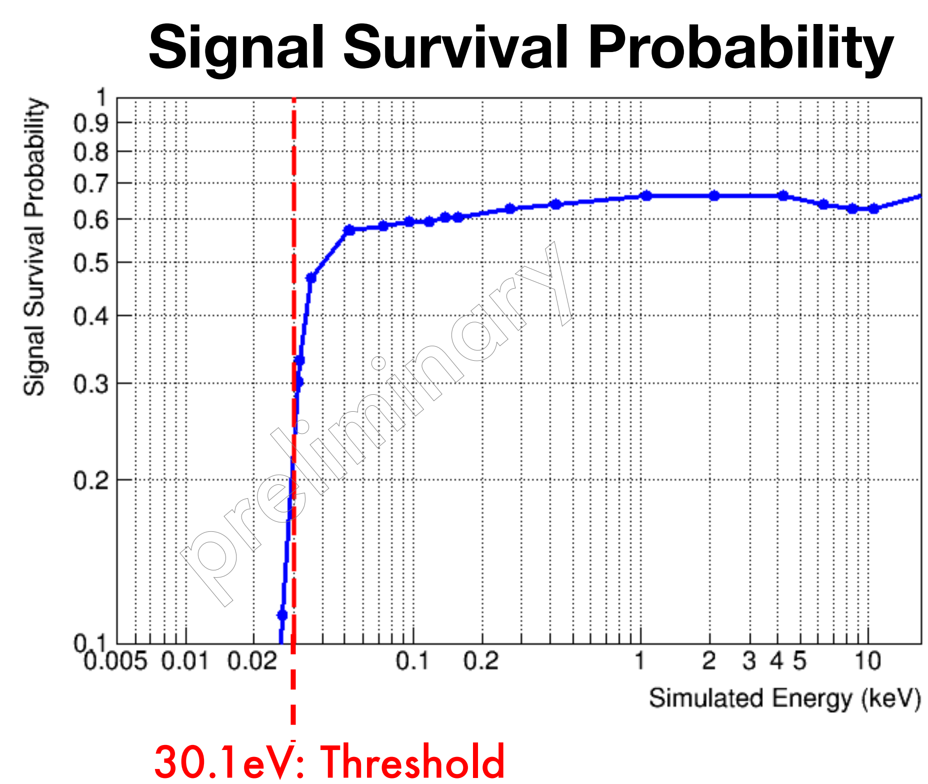
Data taking period: 10/2016 – 01/2018

Target crystal mass: 23.6 g

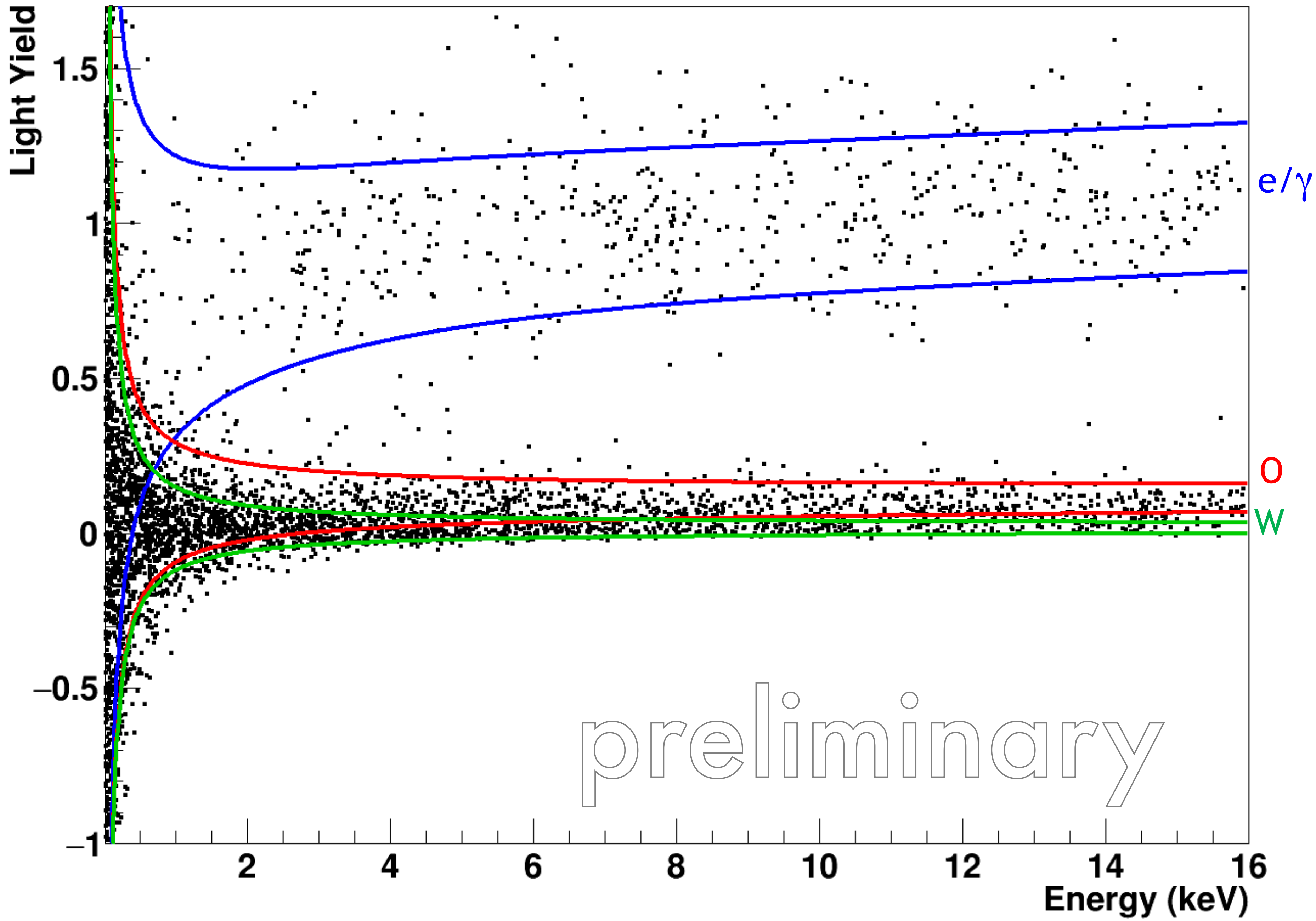
Gross exposure (before cuts): 5.7 kg days

Energy threshold: 30.1 eV

- Analysis chain includes selections on:
  - *Rate*: to select stable noise conditions
  - *Stability*: to select detector(s) in operating point
  - *Data quality*: Non-standard pulse shapes are discarded
  - *Coincidences*: rejected events in coincidence with iSticks, with other detectors and with muon veto

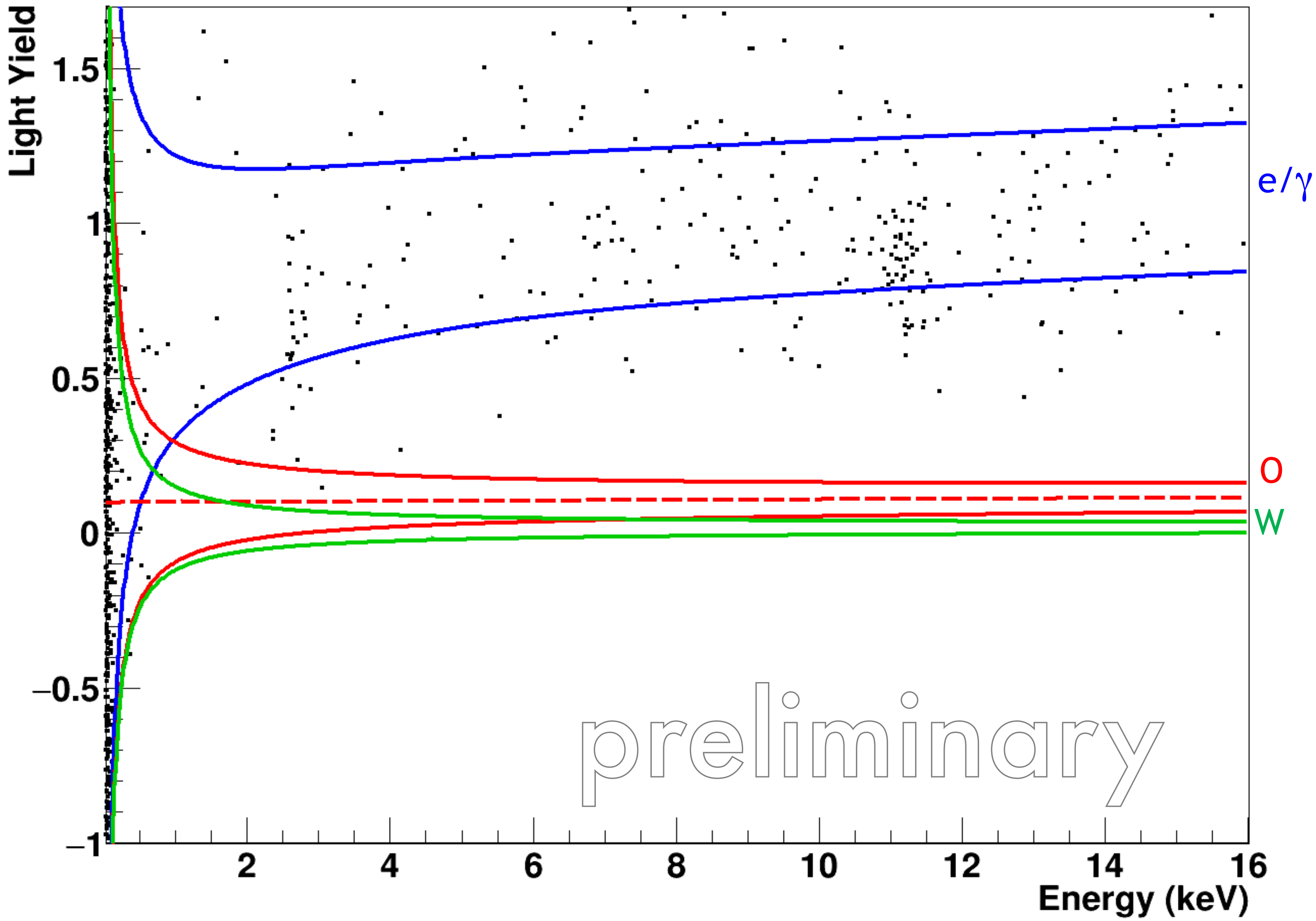


Neutron calibration data

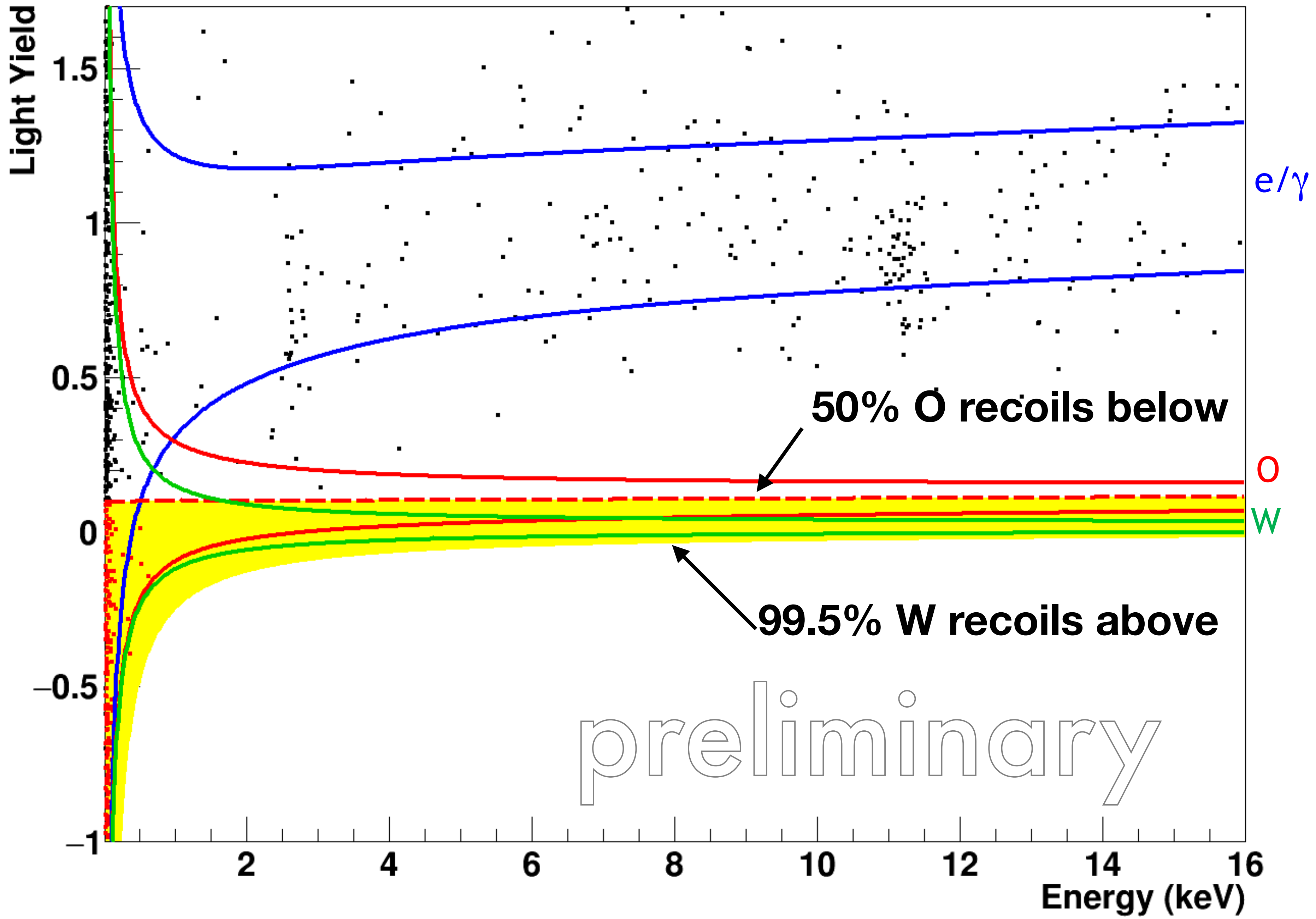


Quenching factors measured with neutron beam
Unbinned maximum likelihood fit

Dark matter data

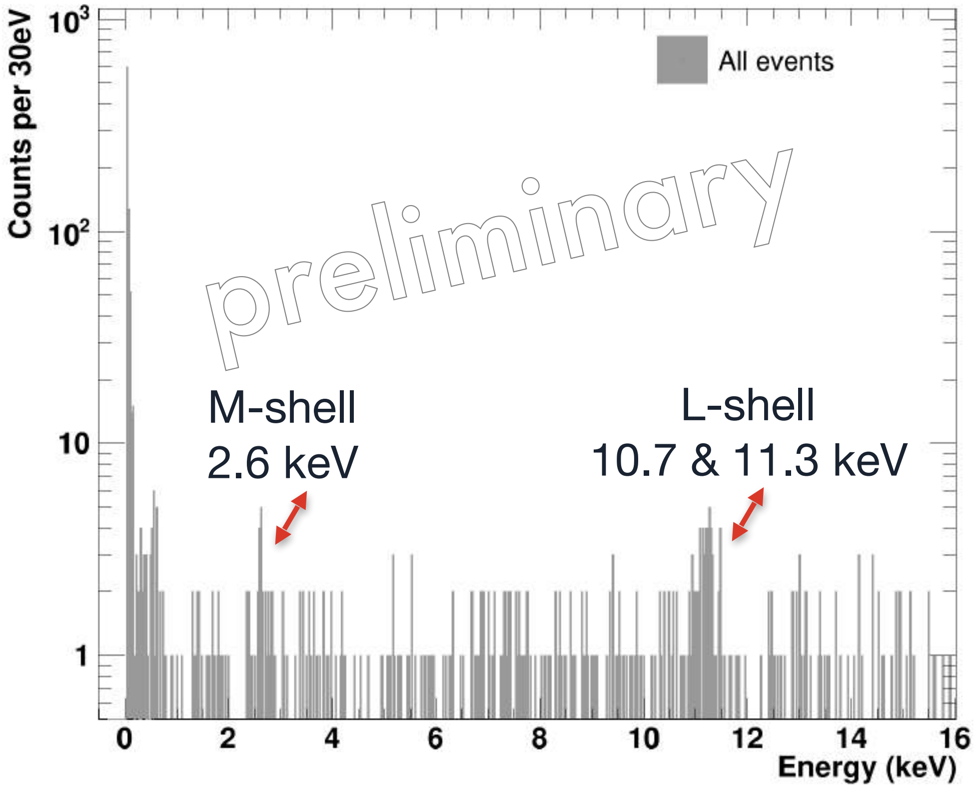


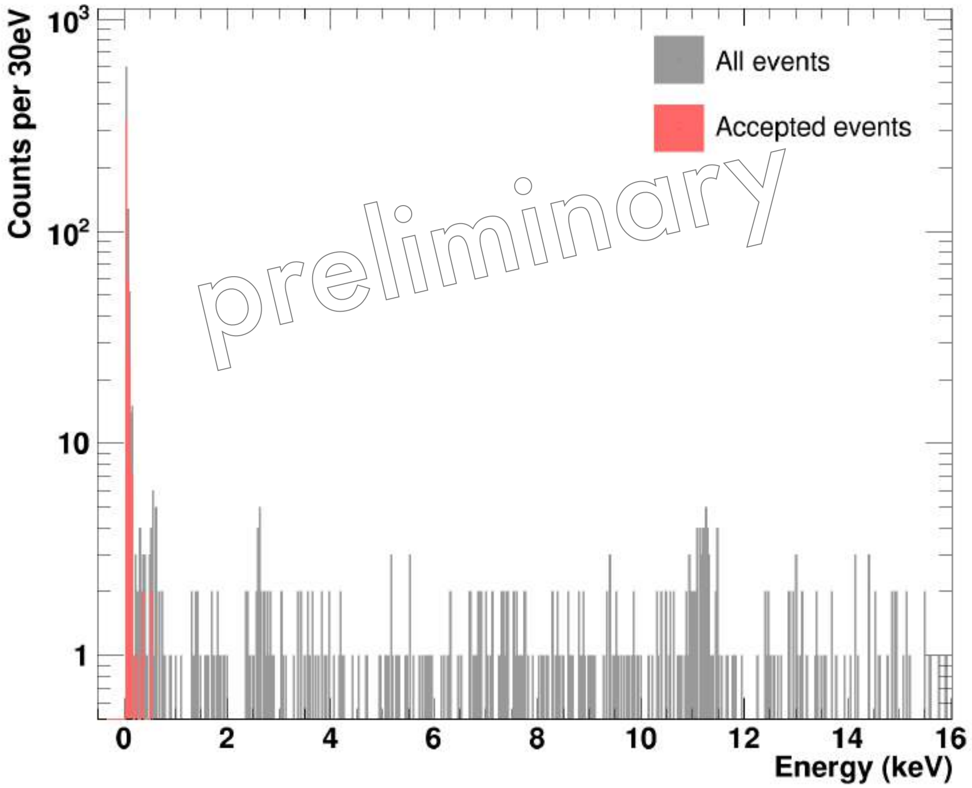
Dark matter acceptance region



Acceptance region defined before unblinding

Energy spectra





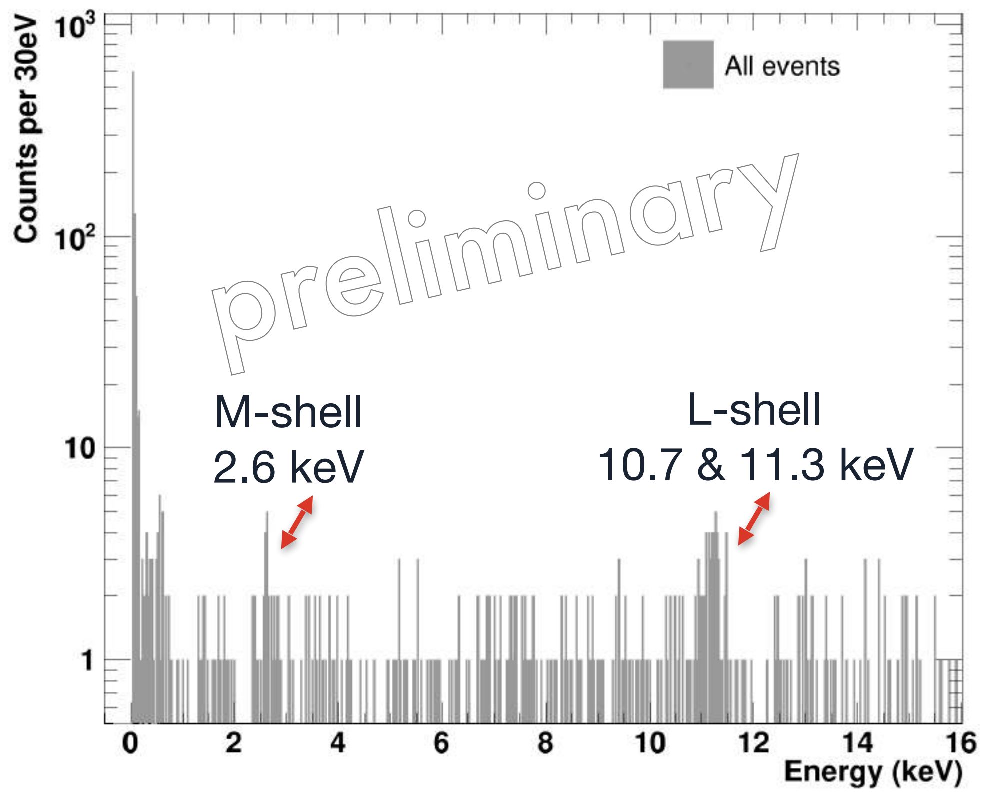
Cosmogenic activation

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

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

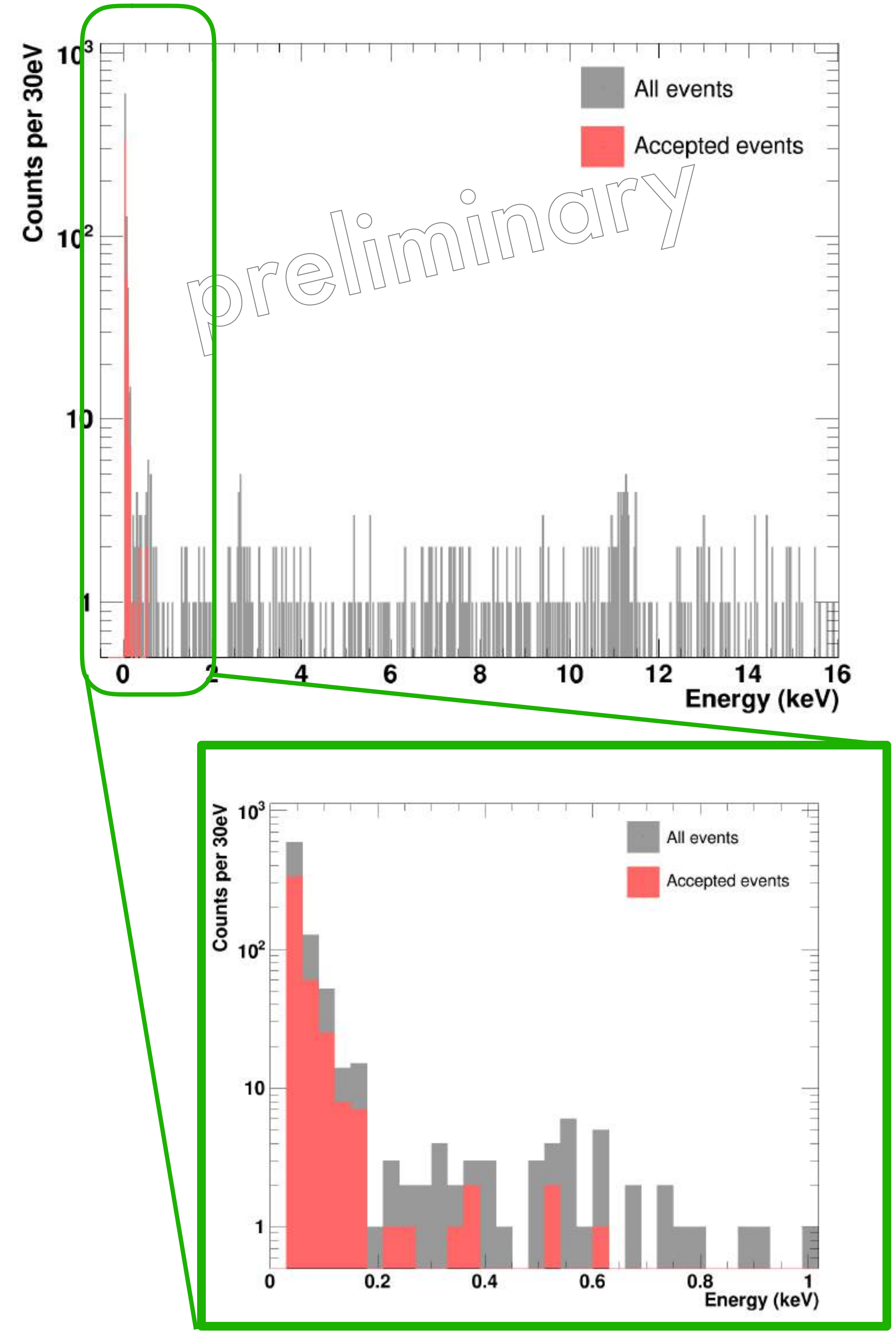
- 445 events in the acceptance region

Energy spectra



Cosmogenic activation
$^{182}W + p \rightarrow {}^{179}Ta + \alpha$
$^{179}Ta + e^- \rightarrow {}^{179}Hf + \nu_e$ (1.8y)

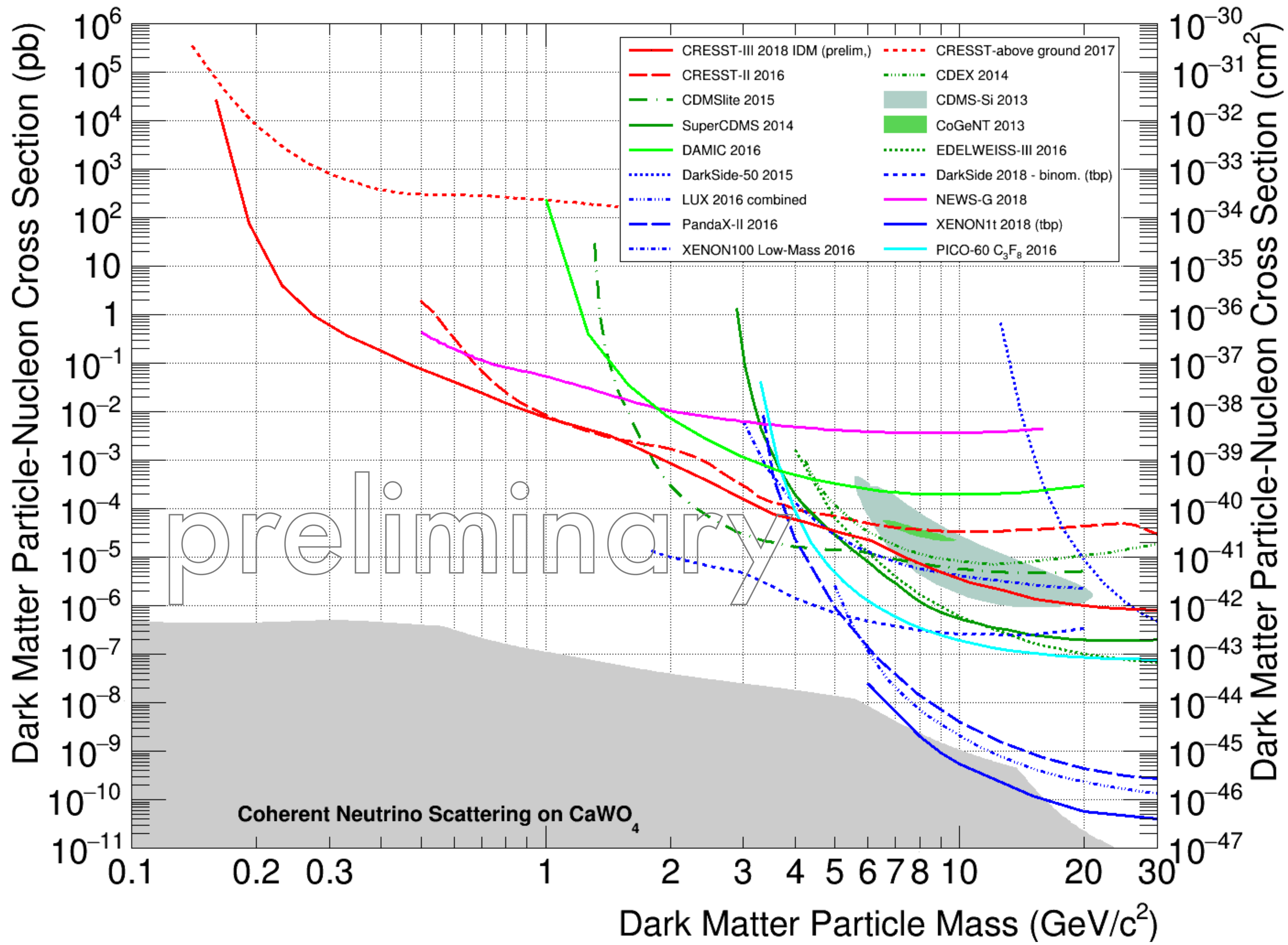
- 445 events in the acceptance region
- Unexpected rise of event rate <200 eV



Result

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

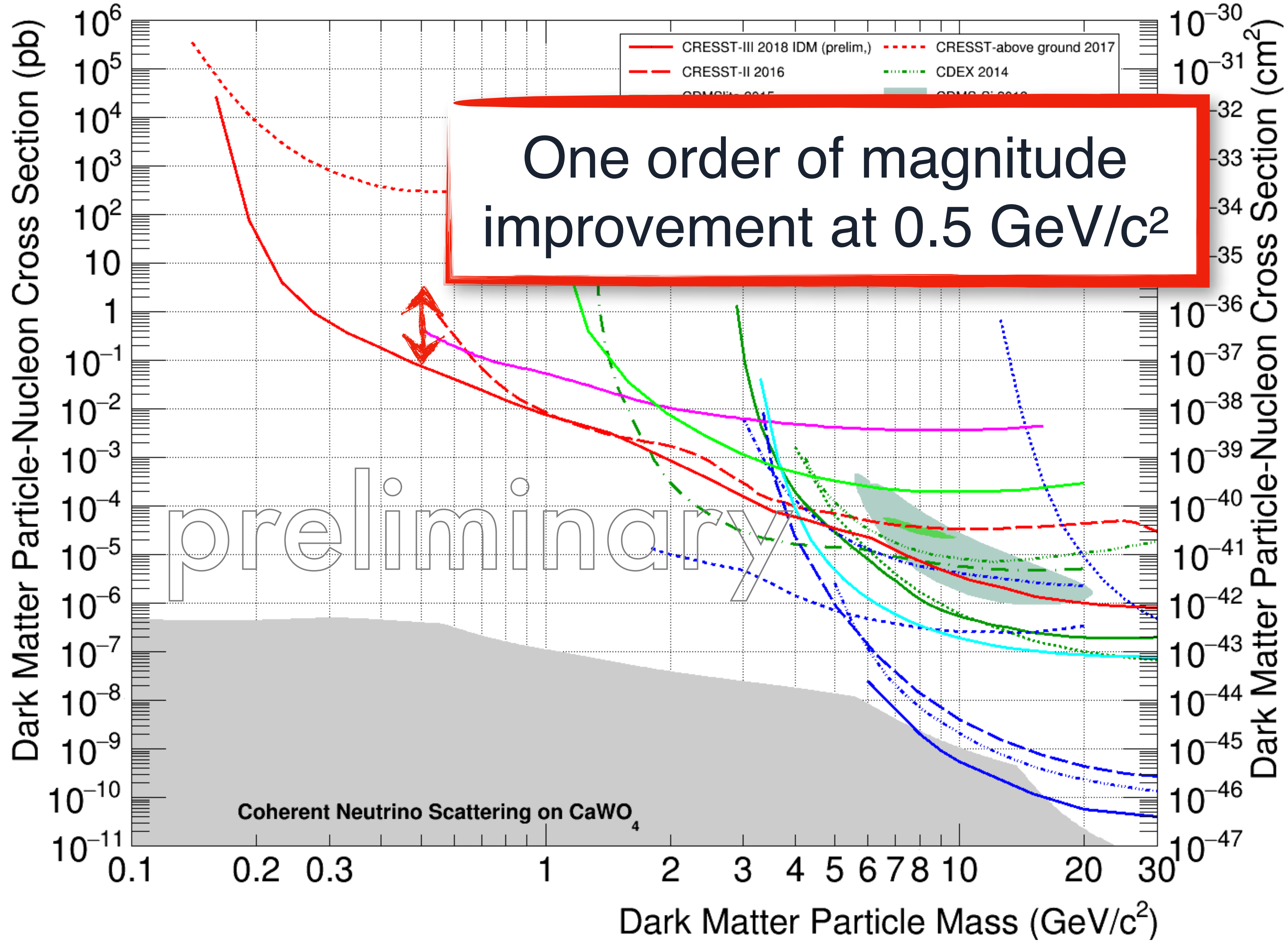
Energy spectrum of accepted events
+
Expected DM energy spectrum



Result

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

Energy spectrum of accepted events
+
Expected DM energy spectrum



One order of magnitude improvement at 0.5 GeV/c²

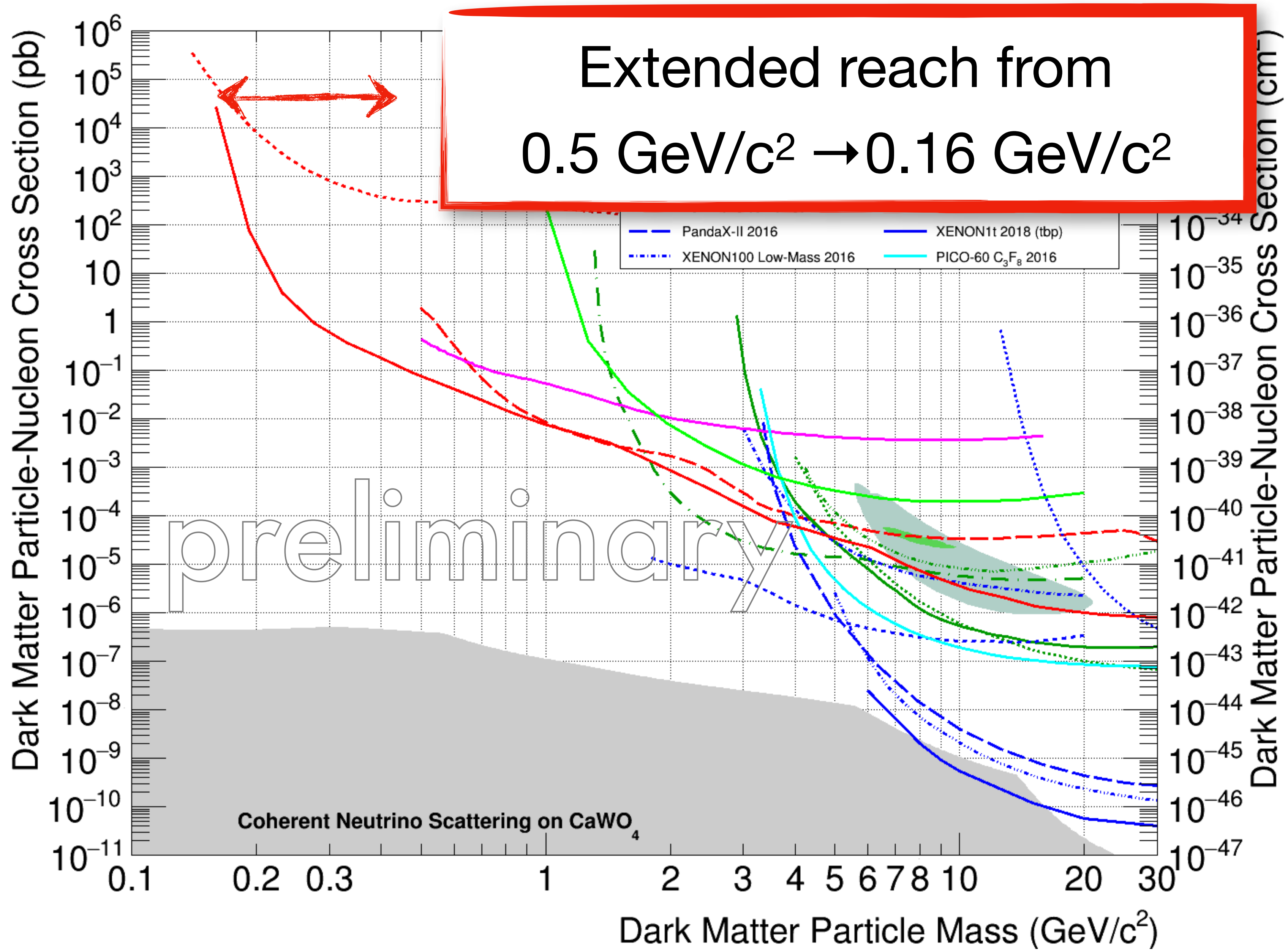
World leading limit at low-mass <1.7 GeV/c²

↳ Background limited

Result

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

Energy spectrum of accepted events
+
Expected DM energy spectrum

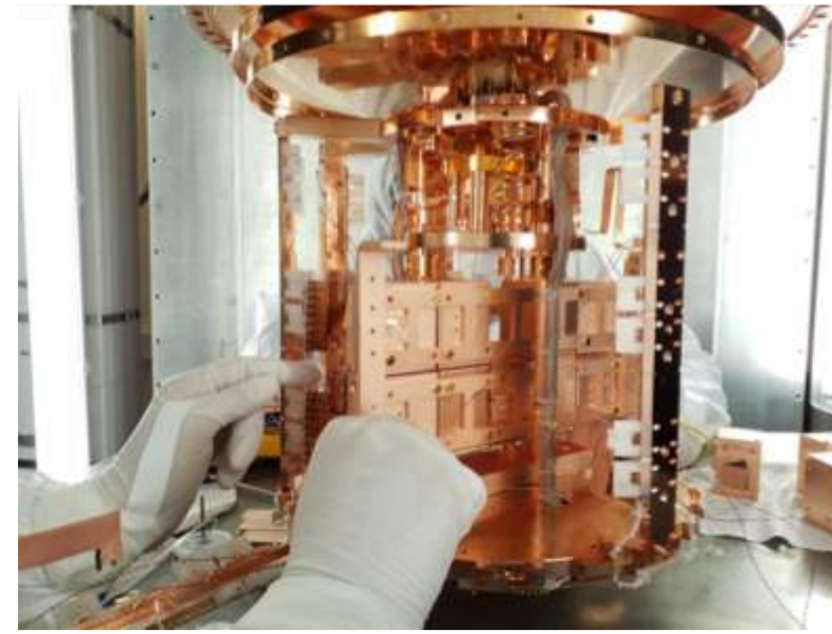


Lowest limit
>0.16 GeV/c²

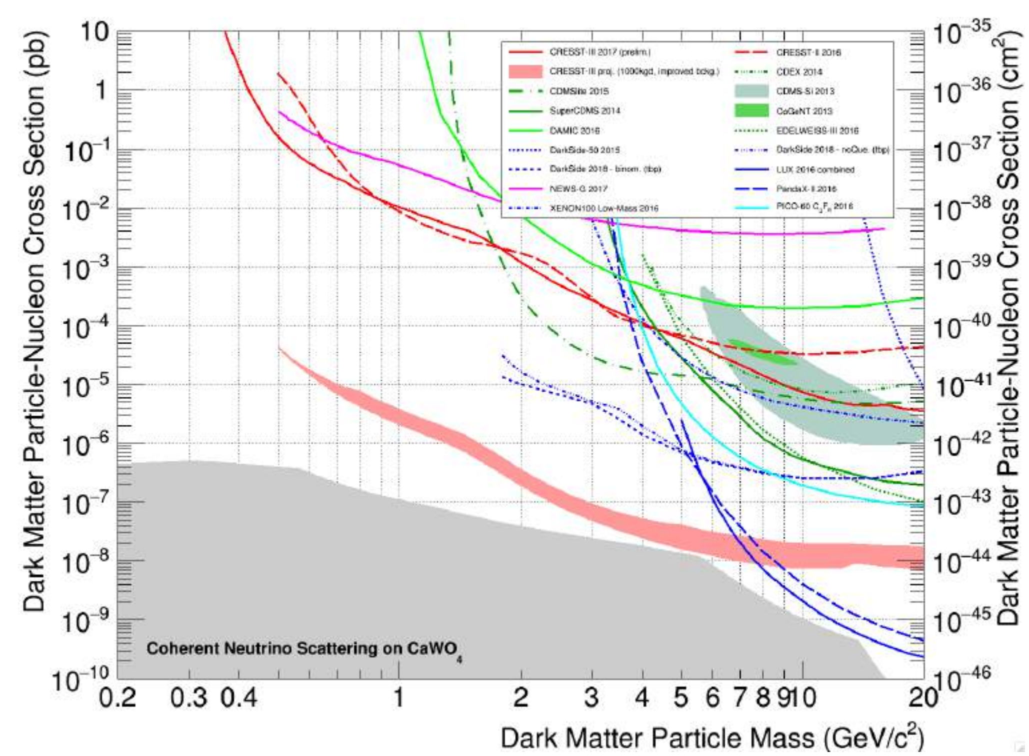
↳ Performance "limited"

What's next?

Short term: Upgraded detector modules with dedicated hardware changes to understand source of excess events (different crystal absorbers, different detector holders)



Long term: Major upgrade of the experiment is foreseen to start next year. Goals: increase the number of channels to 100 and further improve threshold and background



Conclusions

- Cryogenic calorimeters represent a well established technology for the investigation of dark matter and other rare event searches.
- **CRESST** has reached an unprecedented low nuclear recoil thresholds of 30eV, and is leading sensitivity over one order of magnitude in the region at 160MeV/c^2.
- Cryogenic calorimeters are complementary to noble liquids for the investigation of dark matter properties.
- New explorative run is ongoing to investigate the source of excess events.

Conclusions

- Cryogenic calorimeters represent a well established technology for the investigation of dark matter and other rare event searches.
- **CRESST** has reached an unprecedented low nuclear recoil thresholds of 30eV, and is leading sensitivity over one order of magnitude in the region at 160MeV/c^2.
- Cryogenic calorimeters are complementary to noble liquids for the investigation of dark matter properties.
- New explorative run is ongoing to investigate the source of excess events.

New challenges,
new potentials,
new discoveries….