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

CRESST
Cryogenic **Rare Event Search**
with Superconducting Thermometers

The **CRESST** experiment

L. Canonica

for the MPP CRESST group

MPP project review

December 13th, 2021

The CRESST Group at MPP

- Staff
  - F. Petricca (Group Leader)
- Scientific service
  - D. Hauff (retired in Feb. 2021)
  - M. Mancuso (replaced D. Hauff)
- Postdocs
  - L. Canonica
  - N. Ferreiro
  - A. Garai
  - A. Nilima

ORIGINS Excellence Cluster

- PhD students
  - J. Rothe (finished 01.2021)
  - E. Bertoldo (finished 01.2021)
  - A. Abdelhameed (finished 03.2021)
  - D. Fuchs
  - A. Bertolini (started 01.2021)
  - F. Pucci (started 01.2021)
- Others
  - F. Pröbst
  - A. Bento (guest)
  - F. Mang (HiWi)
  - F. Dominisky (Internship)

The CRESST Collaboration

Collaboration meeting at Ringberg Castle, September 2021

Special thank to D. Werner and to the Human Resources Department, to provide valuable support to young families.

MAX PLANCK INSTITUTE FOR PHYSICS

INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

TU WIEN

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

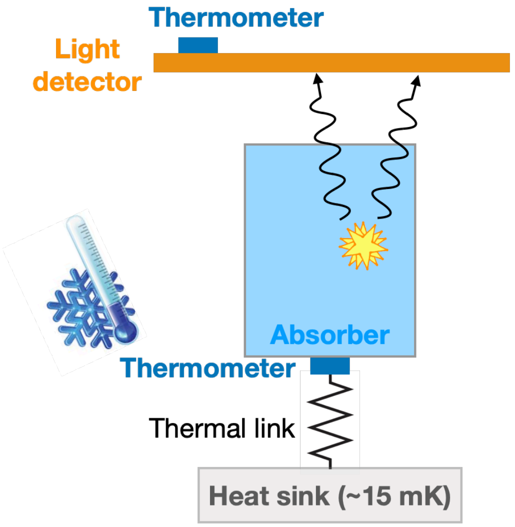
UNIVERSITAS COMENIANA BRATISLAVENSIS MCMXIX

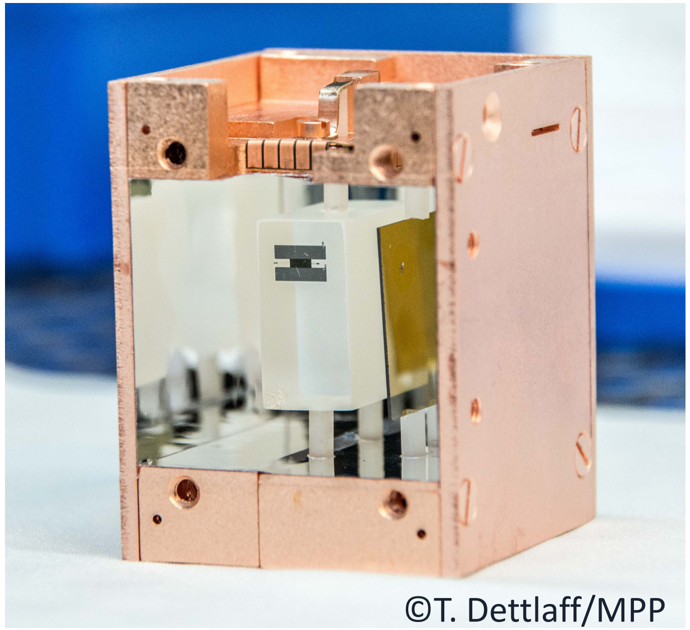
TUM

UNIVERSITY OF OXFORD

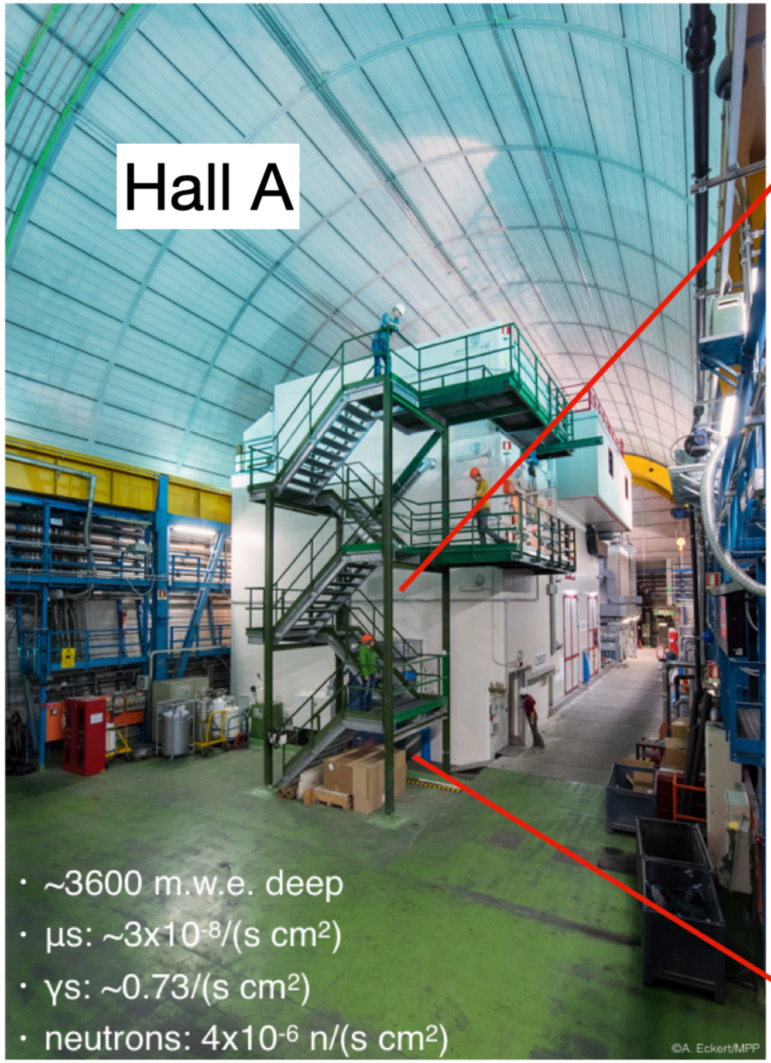
The CRESST experiment

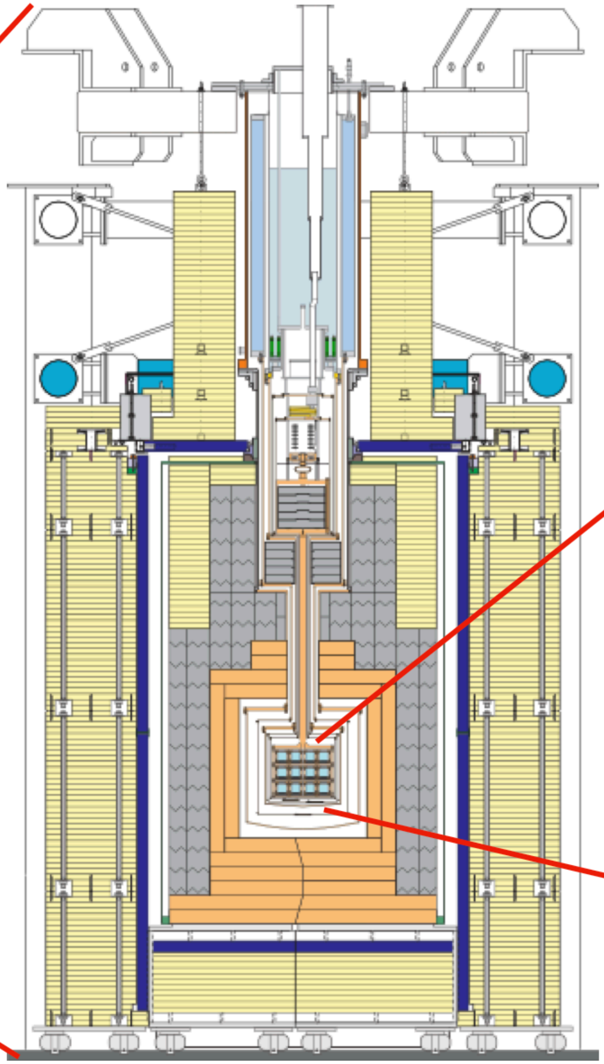
- Direct detection of dark matter particles via their scattering off target nuclei
- Scintillating $CaWO_4$ crystals operated as cryogenic calorimeters
- Simultaneous read-out of heat and light signals allow for background discrimination on an event-by-event base
- Transition Edge Sensor (TES) for temperature read-out



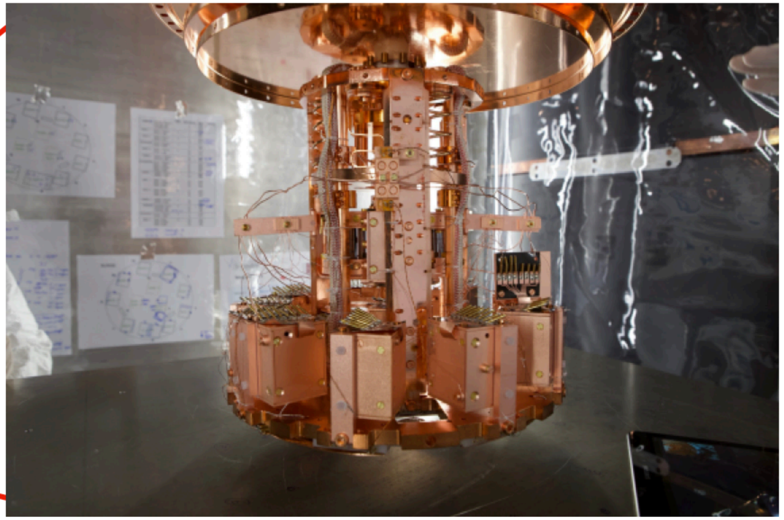


CRESST @ LNGS





Gran Sasso National Laboratory, Italy



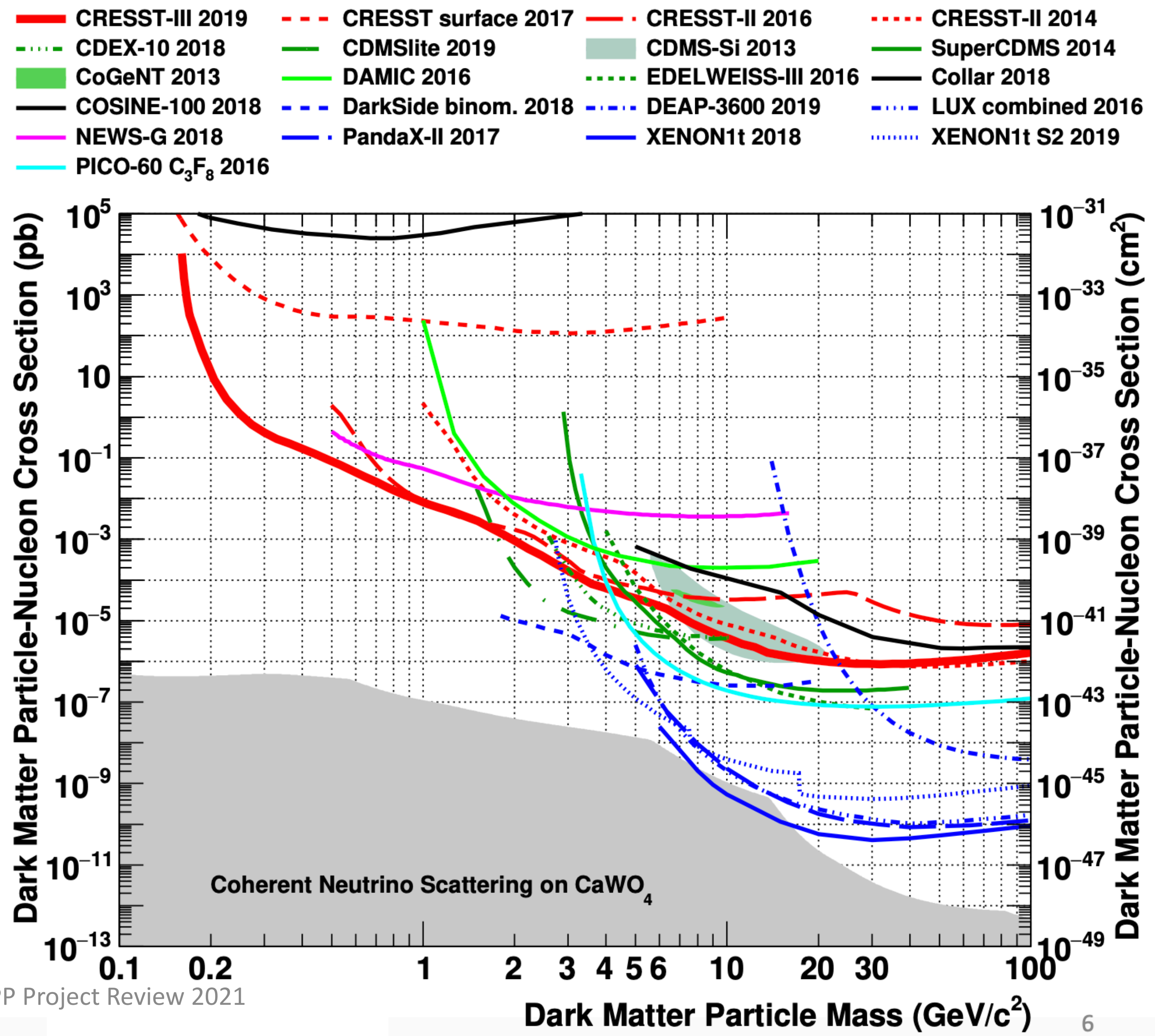
CRESST-III: Results

adapted from: Phys. Rev. D 100, 102002 (2019)

Since 2019, CRESST is the leading experiment in the low-mass DM field.

Key features:

- **Low threshold** for nuclear recoil detection (*30 eV*)
- **Low background** in the region of interest



CRESST-III: Results

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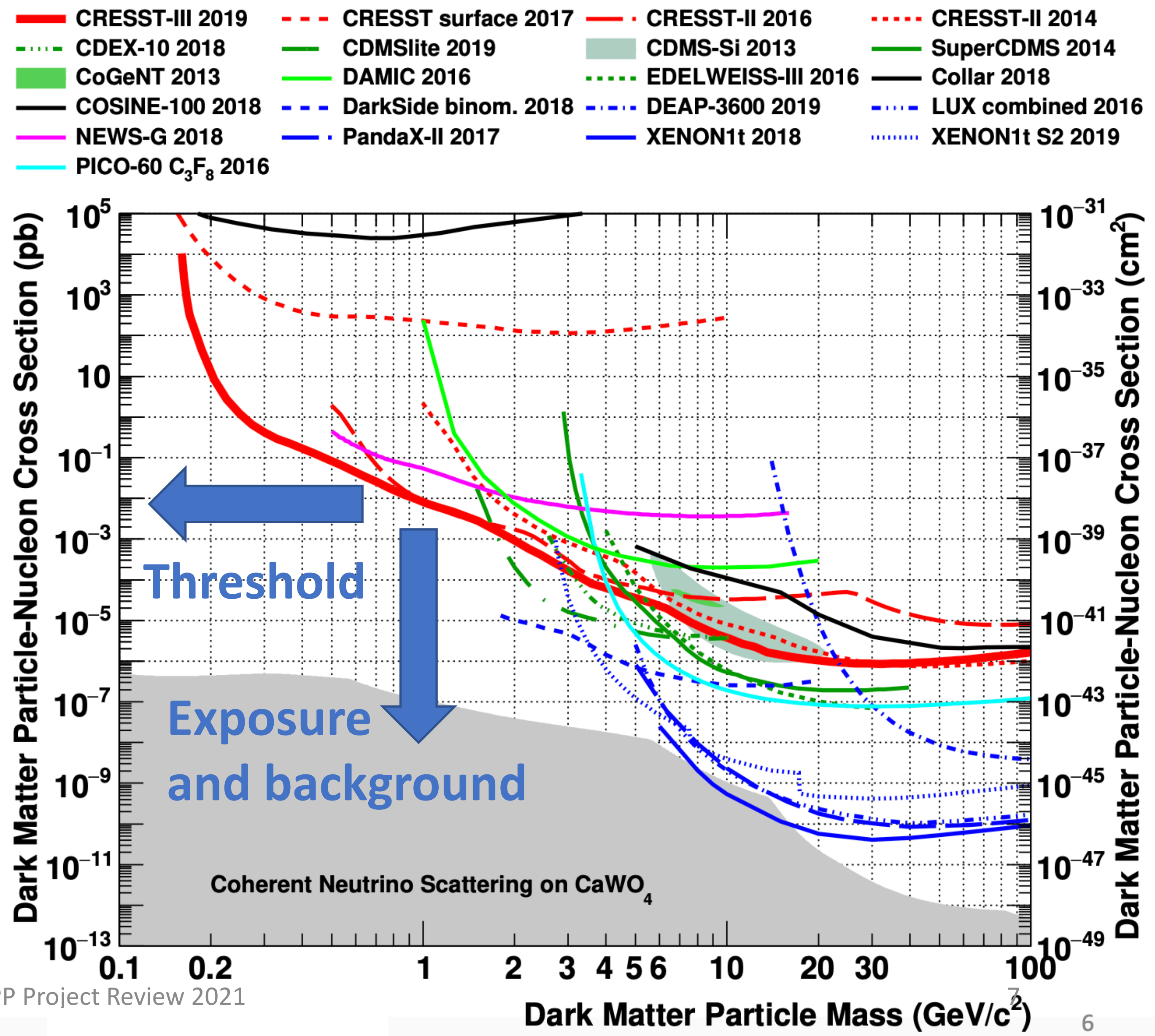

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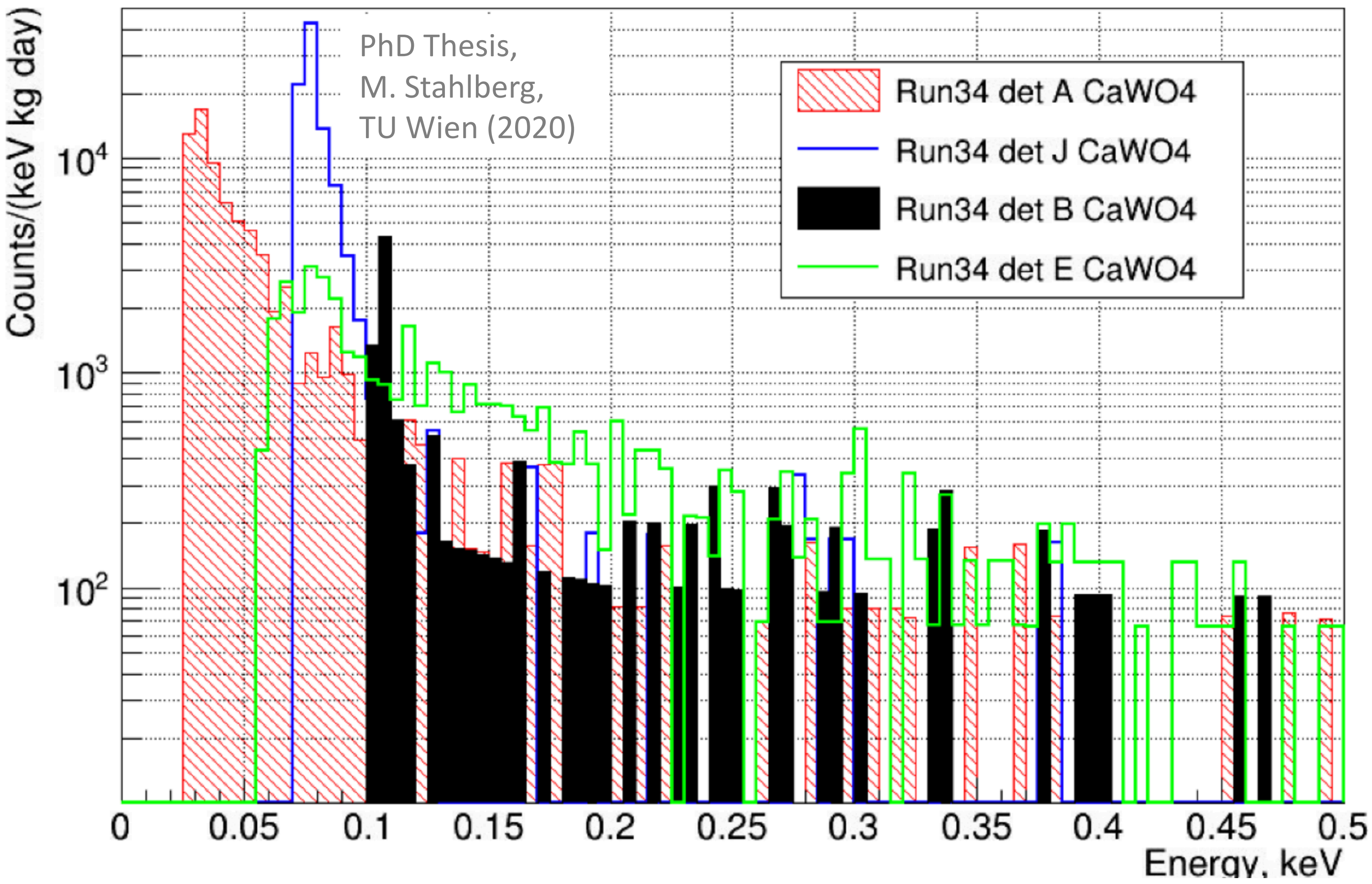
Low-energy excess

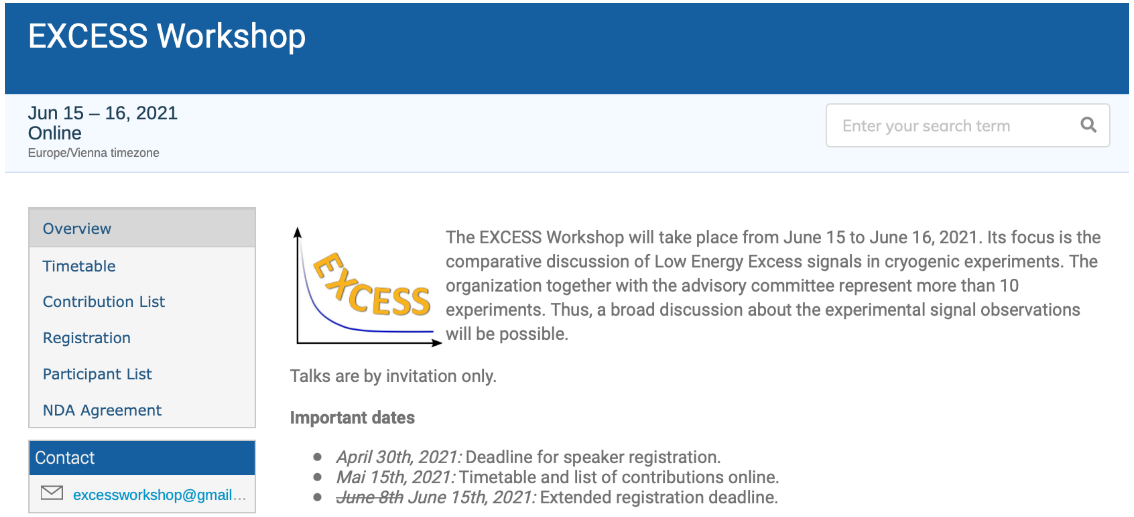


- Low-energy excess with different shape observed also in:
  - detectors of the very same type

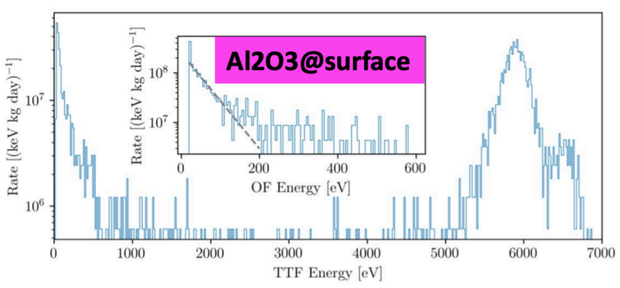
→ not compatible with one single common origin

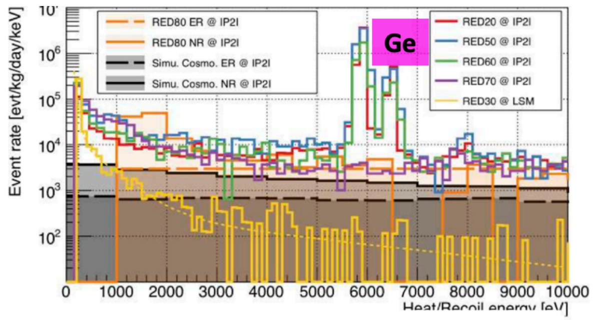
Excess workshop

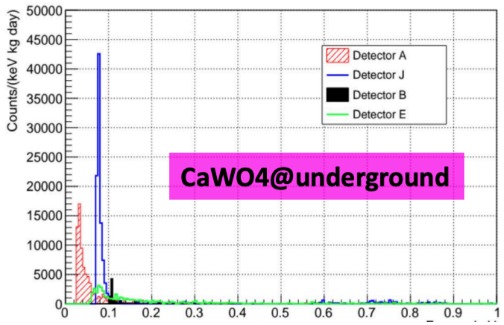
https://indico.cern.ch/event/1013203/

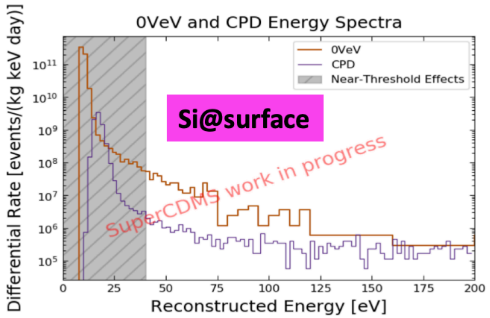


- Organized by CRESST Collaborators in Wien
- Multiple experiments observe an unexplained low energy excess background.
- This background is the main limiting factor for low energy experiments.
- Intensive discussions ongoing within the DM and low-energy neutrino communities.









Margarita Kaznacheeva

Current data taking campaign @LNGS: Run36

- In the current run (Run 36) we operate detectors with different target materials and dedicated modifications to the housing to learn more about the origin of the low-energy excess
  - Crystal material ($CaWO_4$, Al_2O_3, Si, $LiAlO_2$)
  - Holding
- DM data taking campaign (blind exposure collected): Nov 2020 – Nov 2021
- Current status: data taken ready to be unblinded.

Data Type	Period	Statistics
Training set		711h
Blind data		5812h
Gamma calibration	11.09.2020-02.11.2020	980h
Neutron calibration	06.08.2021-21.09.2021	950h

Preliminary results from Run36: thresholds

detA (2019):
30 eV

Excellent performance allows for physics results and detailed study of the low-energy excess

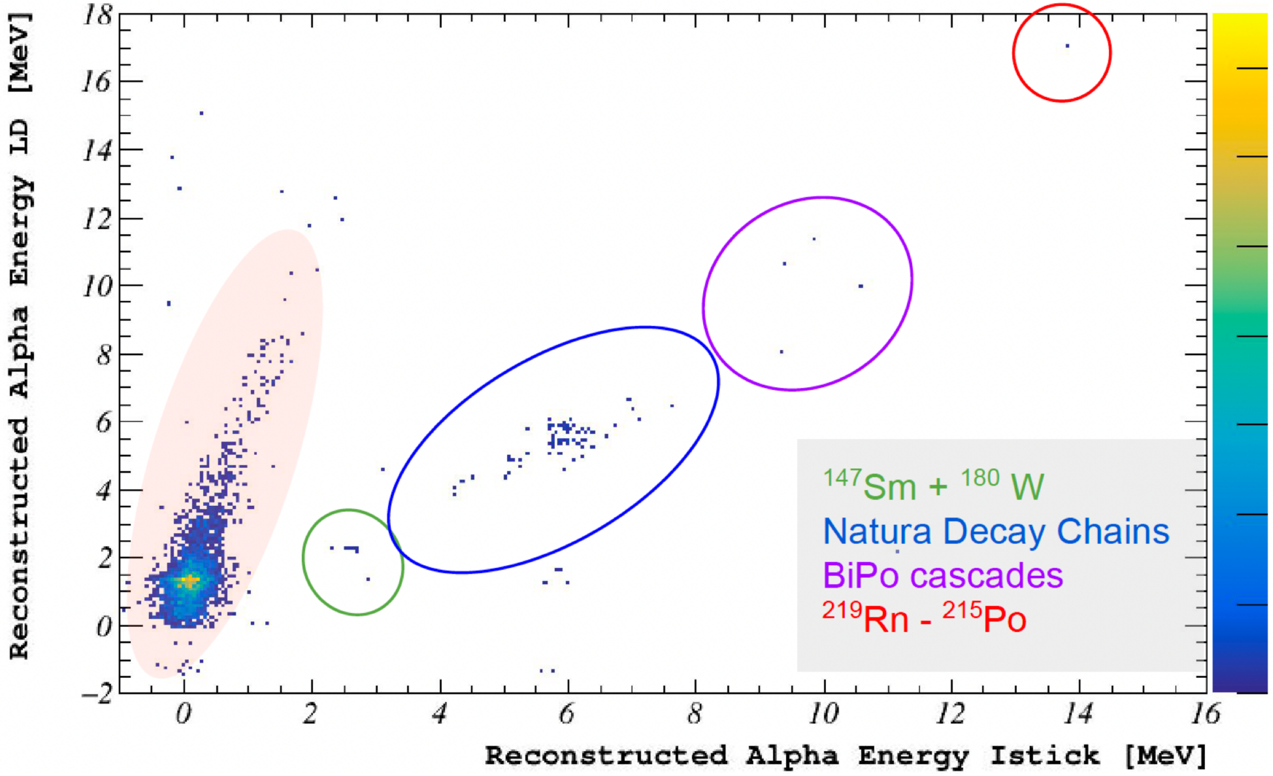
Energy spectra and time dependence

- Low-energy excess present in all the detectors, with different shapes and rates.
- Decay of low energy excess seen with all absorber materials.
- Data from training set only, more information from the full dataset of unblinded data.

Preliminary results: radiopurity

- Chemically purified powder
- Stress optimized growth process at E15 TUM department.
- Analysis of the alpha region (non-blind):
  - Improvement in radiopurity by a factor of ~6 in the alpha region
  - Full dataset needed to assess improvement in the ROI

Poster presented @ LTD19



The CRESST-III programme

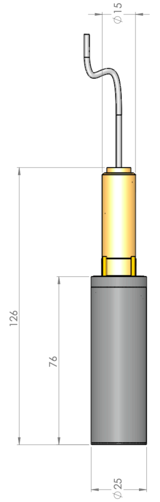
Short term plan: Understanding of the origin of the low energy excess

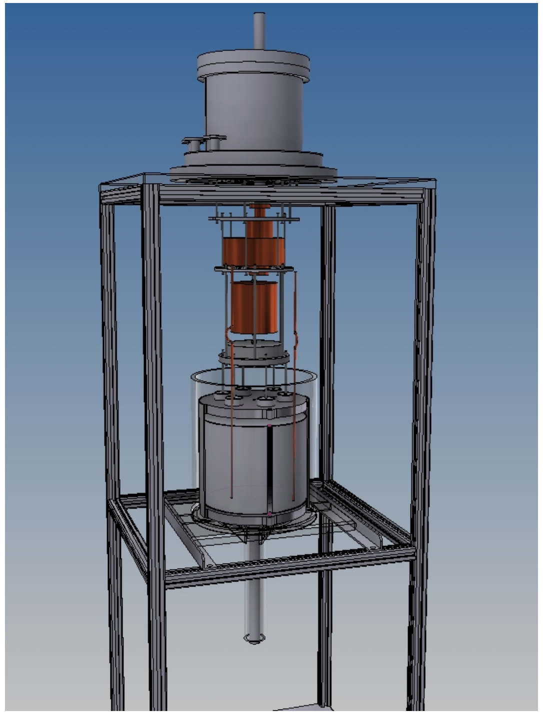
Long term plan: Upgrade of the LNGS experimental infrastructure to scale the number of read-out channels to ~300

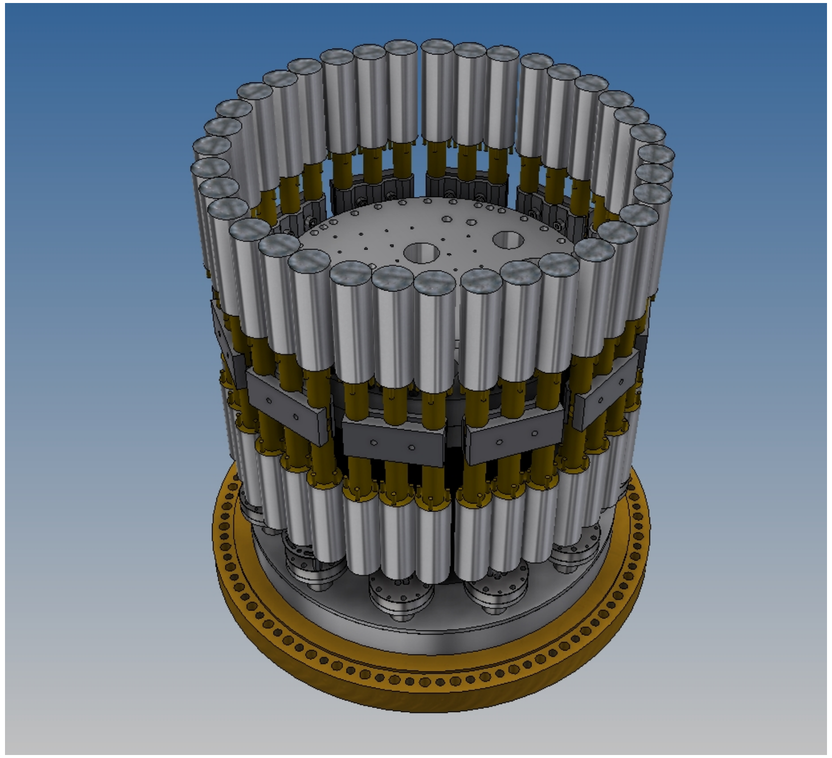
- MPP work packages for the upgrade:
  - Readout chain: scale up from 66 to 300 readout lines
  - Detectors and TES: developments ongoing to lower threshold.

Readout chain (1)

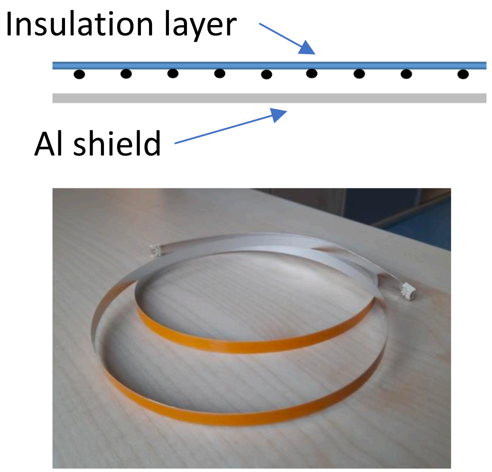
- 288 SQUID channels have been delivered to MPP in October 2021.
- Testing and validation of the chips under development.
- Mechanical construction workshop is working to make the 288 channels fit on the existing cryostat (currently hosting 66 channels).
- **Strong support of MPP mechanical construction workshop.**
    - **Special thanks to G.Finenko**

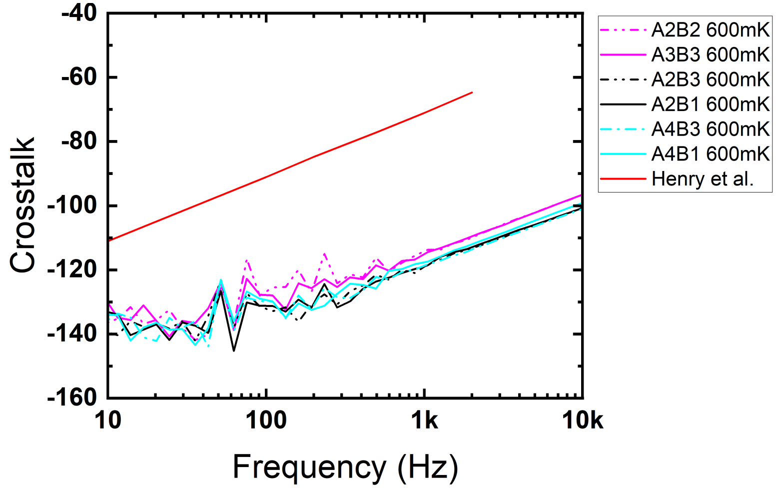


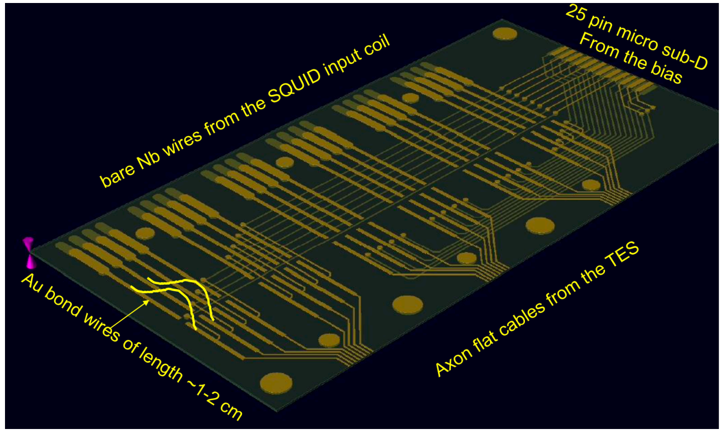




Readout chain (2)



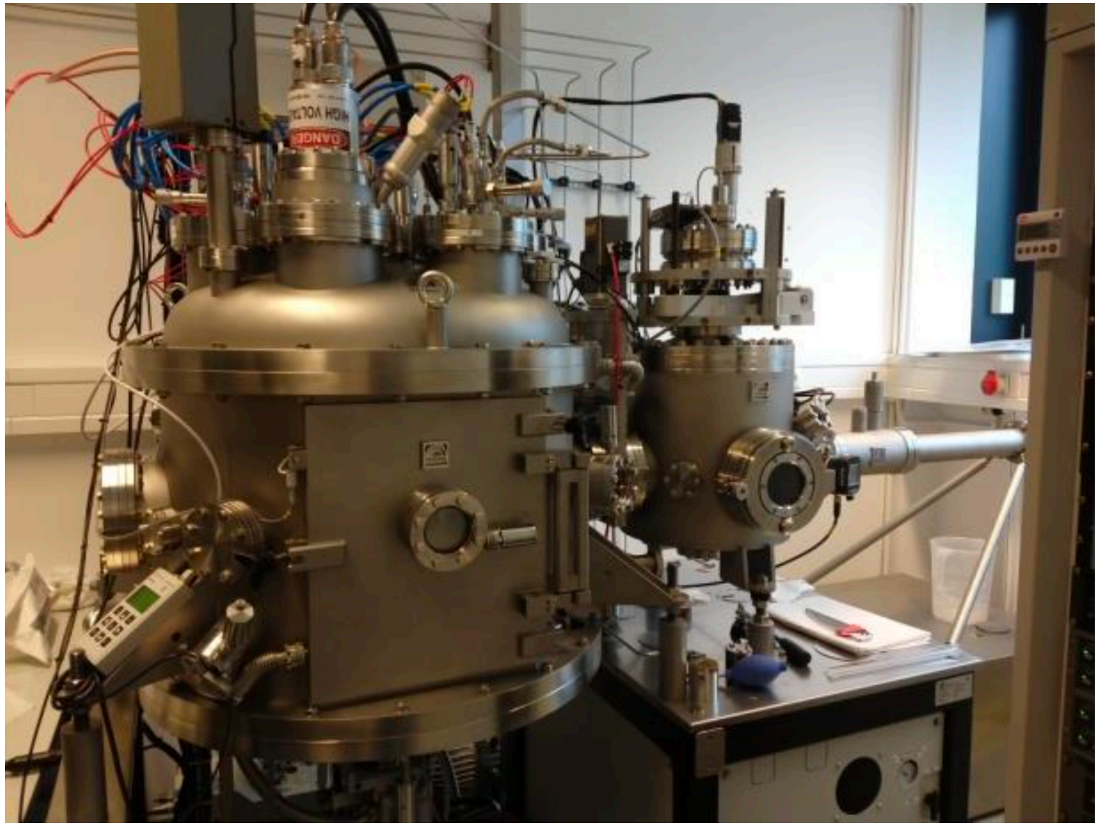




- Flat superconducting cables produced in collaboration with an external company (AXON cables).
- Good performance at cryogenic temperature. Patent creation under evaluation.
- Design of the superconducting boards for the interface of detectors with redaout chain
- **Strong support of MPP hybrid workshop (Elektronik Produktion Aufbau und Verbindungstechnik).**
  - **Special thanks to M. Hertrich and Q. Fischl.**

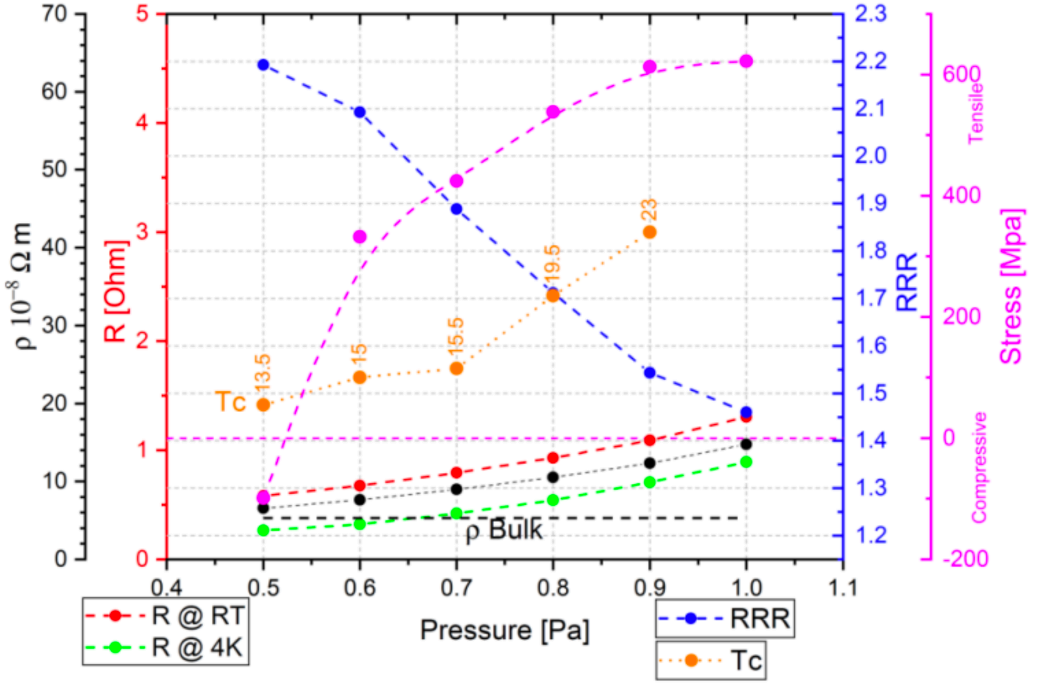
Sensor production

Reproducibility in sensor performance is a key issue when operating *O*(100) detectors.



Sputtering system at MPP

PhD thesis of
Ahmed Abdelhameed



Full characterization of the sensor transition temperature as a function of production parameters:

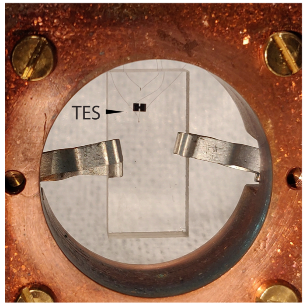
- Reproducible detector performance
- Tunable transition temperature

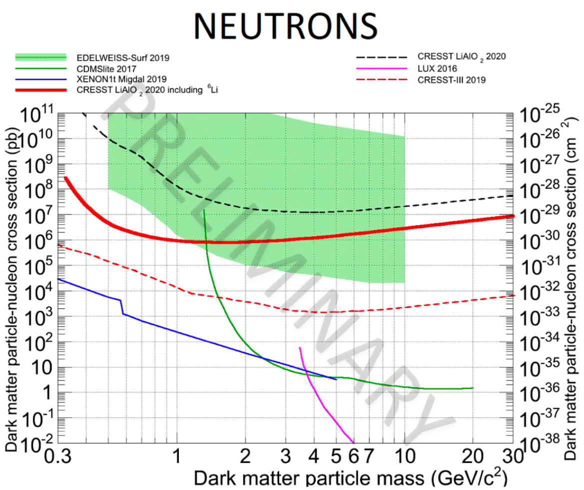
Complementary target materials

Leading limits obtained with proof of principle detectors operated at MPP

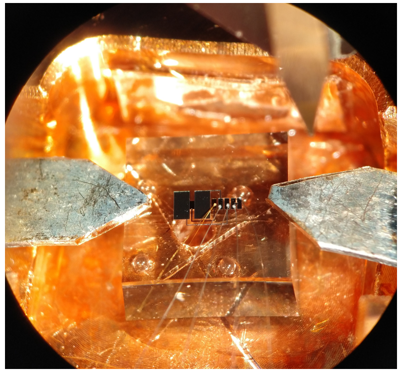
$LiAlO_2$ – light elements, sensitive to spin dependent DM interaction (with Li7 and Li6 isotopes), in situ neutron monitor.

Submitted to Eur. Phys. J.





Diamond – samples purchased thanks to ORIGINS Excellence Cluster Seed Money. Light target for sub-GeV dark matter searches.



Physics reach

- The understanding of the origin of the low-energy excess is of paramount importance.
- With improved performance (threshold and background) the upgraded setup will allow to access unexplored region of parameters (sub-GeV DM masses).
- Approaching the “neutrino floor”.

Future of CRESST

Direct Detection of Dark Matter – APPEC Committee Report

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https://arxiv.org/abs/2104.07634

Over the last thirty years or so a tremendous and sustained increase in detection sensitivity – on average of nearly three orders of magnitude per decade, possibly the biggest in science and maybe also industry – has been achieved by direct detection experiments searching for WIMPs, due to many technological advances, availability of underground laboratory infrastructure and scientific effort. The biggest advances were made by mature technologies aiming at measuring nuclear recoils at time projection chambers (TPCs) using liquid noble gas in probing the WIMP mass range from $\sim \mathrm{GeV}/c^2$ up to $\sim \mathrm{TeV}/c^2$, and by bolometers (both scintillators and semiconductors) in exploring the low mass range down to the MeV/c^2 regime.

TPC detectors using the liquefied noble gases argon or xenon as target are very successful in exploring WIMPs – within the ranges specified above – via detecting their nuclear recoils and have played the leading role over the last several years by placing the strongest limits. In fact, the liquid xenon experiments XENONnT (mainly Europe-USA-Japan), LZ (mainly USA-UK) and PandaX-4T (mainly China) – currently all preparing for data taking in 2020 – are expected to improve the current best limits of their predecessors in WIMP-nucleon elastic scattering cross section by more than a factor of ten in the next years. A similar sensitivity will be reached by the liquid argon TPC DarkSide-20k (mainly Europe-USA-Canada) – at present under construction. Due to the different masses of the target nuclei and experimental thresholds xenon and argon detectors are more sensitive to lower and higher side of this mass range, respectively.

The noble-gas TPC detector technology is highly promising as, by the virtue of being scalable to very large target masses, as it allows acquiring high exposures. At low mass, below a few GeV/c^2, the sensitivity becomes much poorer, although electron recoil and other recently used detection channels allowed one to improve sensitivity to lighter DM candidates, such as low-mass WIMPs or other DM candidates, e.g., ALPs or hidden photons. Complementary technologies with a better sensitivity are thus crucial to explore the few to sub–GeV/c^2 region and that is where cryogenic detectors (bolometers) are best suited to take a leading position.

European leadership in highest-sensitivity experiments is very strong, and providing key contributions, including innovative technologies, extensive research and development (R&D) effort, and also significant funding for LXe (XENONnT), LAr (DarkSide) and two out of three most sensitive bolometer-type experiments (CRESST, EDELWEISS).

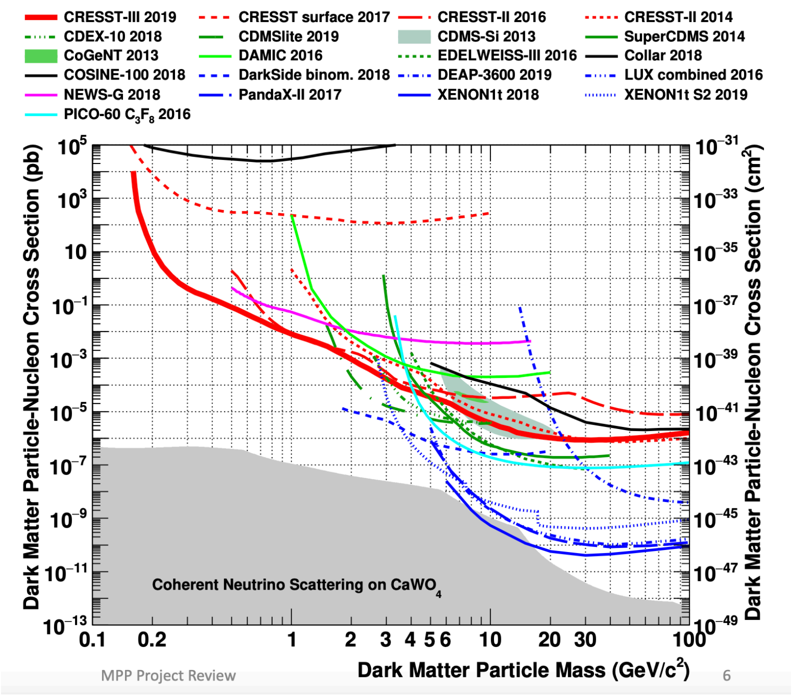
Liquid noble gas detectors and bolometers will face another challenge – that will be both an obstacle and opportunity – of the irreducible background due to the so-called neutrino floor of coherent neutrino interactions with target nuclei. Initial detection is likely to be achieved by XENONnT, LZ and PandaX-4T, around the $6\,\mathrm{GeV}/c^2$ WIMP mass range, just before the solar branch of the neutrino floor turns abruptly down into the atmospheric branch with the drop of some five orders in magnitude. Reaching down to within an order of magnitude from the solar neutrino floor is the main goal of DarkSide-LM on the LAr side, the LXe-based projects XENONnT, LZ and PandaX-4t, and of the bolometer experiments CRESST-III, EDELWEISS-subGeV, as well as SuperCDMS. This is expected to be achieved within the next decade.

Taking the ten-year perspective and beyond, on the bolometer side, the technology to access low mass DM is already mature enough to start the planning on a tonne-scale experiment to reach down to the solar neutrino floor. Above some $10\,\mathrm{GeV}/c^2$, an improvement of some three orders of magnitude in sensitivity will be needed to reach down to the atmospheric neutrino floor, which would be the ultimate goal of future liquid noble gas experiments, and for which a substantial amount of innovative R&D of both LAr and LXe programmes will be needed. The LAr groups from ArDM, DarkSide-50, DEAP-3600 and MiniCLEAN have recently formed the Global Argon DM Collaboration (GADMC) to build DarkSide-20k and its successor, the $300\,\mathrm{t}$ detector ARGO. On the xenon side, R&D is ongoing to build the next generation detector DARWIN with a $40\,\mathrm{t}$ active target and a comparable reach, and towards multi-tonne liquid xenon detectors in general. It is evident that the outcome of these searches will likely have tremendous implications not only for the field of DM itself – by opening up a new window on the Universe – but actually on all particle physics, and beyond. For instance, a discovery of a massive, $10\,\mathrm{GeV}/c^2$–scale or heavier, DM particle in underground experiments in the next decade would provide arguably a very strong rationale to boost construction of a new-generation particle collider capable of opening up a new era of discoveries in the dark sector of physics.

Recommendation 3. The experimental underground programmes with the best sensitivity to detect signals induced by dark matter WIMPs scattering off the target should receive enhanced support to continue efforts to reach down to the so-called neutrino floor on the shortest possible timescale.

Summary and acknowledgments

- Cryogenic detectors developed at MPP ensure the best sensitivity in the field of low-mass DM searches.
- CRESST is preparing a major upgrade of the Gran Sasso experimental setup.
    - Strong involvement of MPP group



Many thanks to the technical departments, to the administration and to Diana that continuosly and efficiently support us and our work!