Annual **Project Review** 2017

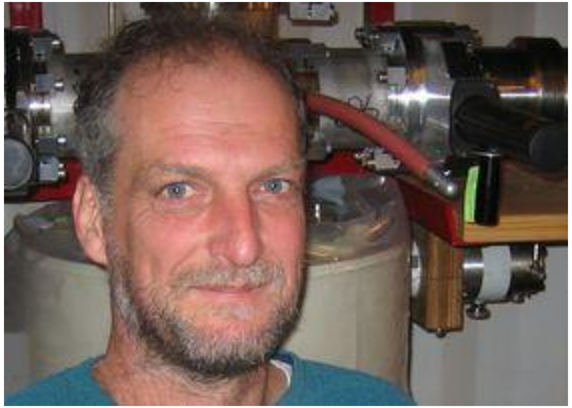
The CRESST experiment

Michele Mancuso

19 December 2017

Technische Universität München
University of Oxford
HEPHY Institute of High Energy Physics
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)
INFN Laboratori Nazionali del Gran Sasso
Eberhard Karls Universität Tübingen

In memory of Wolfgang Seidel



Our colleague Dr. Wolfgang Seidel passed away suddenly and much too soon on February 20, 2017. He had been a member of the scientific staff at the Max Planck Institute since 1991.

The CRESST experiment

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$\Delta p \cdot \Delta q \geq \frac{1}{2} \hbar$

TECHNISCHE UNIVERSITÄT MÜNCHEN
UNIVERSITY OF OXFORD
HEPHY INSTITUTE OF HIGH ENERGY PHYSICS
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Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- Overview
- Introduction
- CRESST-III detector
- CRESST-III first results
- CRESST perspective
- Not only DM

The CRESST collaboration

Led by the Max-Planck-Institut für Physik

6 institutions

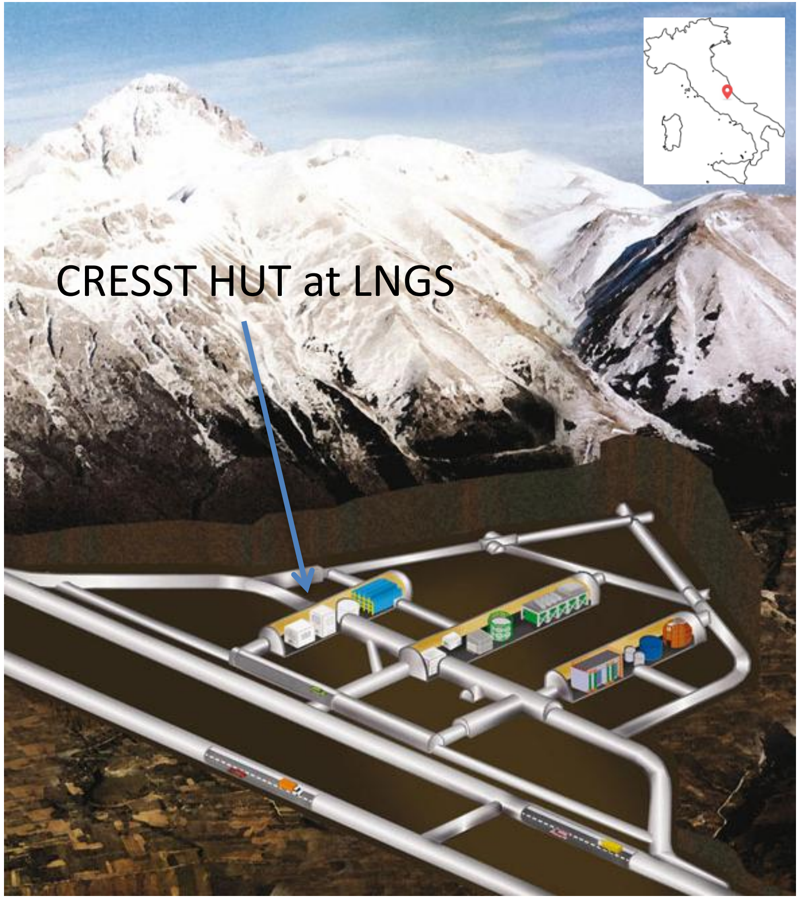
45 members:
- 16 senior scientists
- 2 guest scientists
- 11 Post Docs
- 16 PhDs

CRESST-III is collecting data at LNGS (Laboratori Nazionali del Gran Sasso) in Italy

- Cryogenic scintillating calorimeter
- Target material $CaWO_4$
- Read out channels: phonon
  scintillating light

Phase 1

- 10 detector modules
- 50 kg*day total exposure



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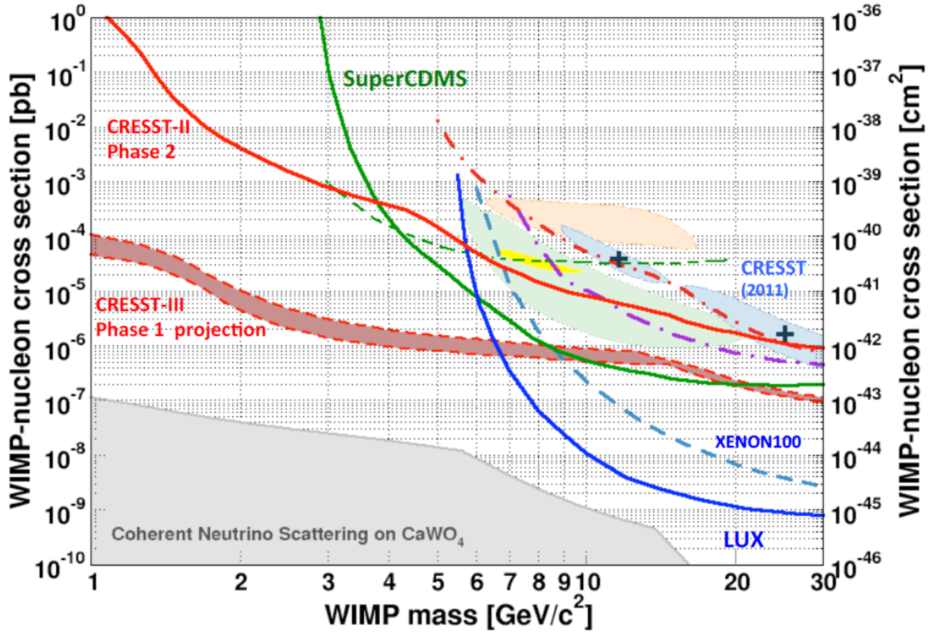
2015 projected sensitivity for CRESST-III phase 1

CRESST-III Phase 1

Assumptions:

- 24g $CaWO_4$ crystal
- **E_{th} = 100eV**
- Light detector improved by factor 2 (due to smaller volume)
- 2x more detected light: due to thin crystal
- **CRESST-II radiopurity**



See: CRESST collab. G. Angloher et al. arXiv:1503.08065

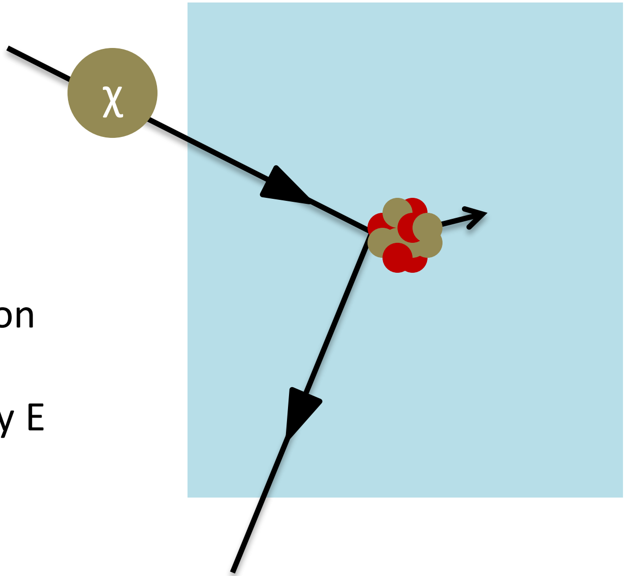
10 x 24g detectors operated for one year ≈ **50 kg-days** (net)

Raimund Strauss, Project Review 2015 29

The signature of dark matter in a direct detection experiment consists of a recoil spectrum of single scattering events.

$$\frac{dR}{dE}(E,t) = \frac{\sigma_0}{m_\chi} \cdot F^2 \cdot \frac{\rho_0}{2\mu_A^2} \int_{v_{min}}^{v_{esc}} \frac{f(\mathbf{v},t)}{v} d^3v$$

Target material



- ρ_0 : local DM density
- σ_0 : cross section at 0 momentum transfer
- m_χ : DM particle mass
- μ_A : reduced mass
- F : nuclear form factor
- $\int_{v_{min}}^{v_{esc}} \frac{f(\mathbf{v},t)}{v} d^3v$ Integral of the velocity distribution
- v_{min} : minimal velocity to produce a recoil of energy E

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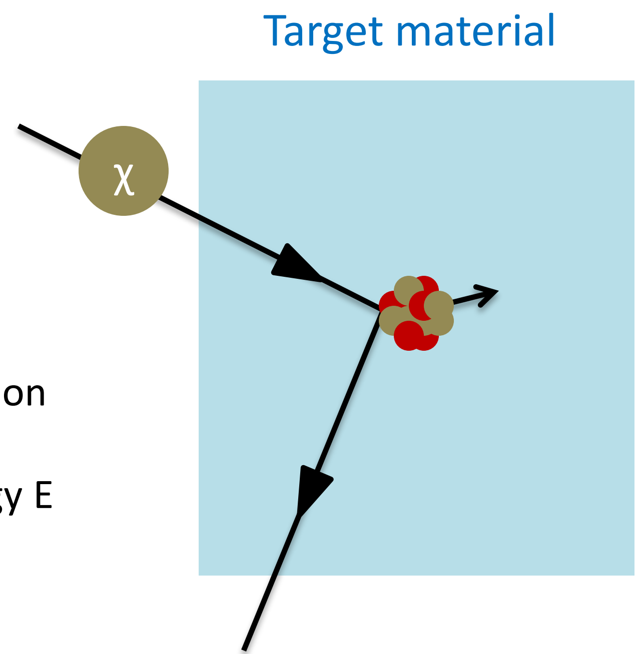
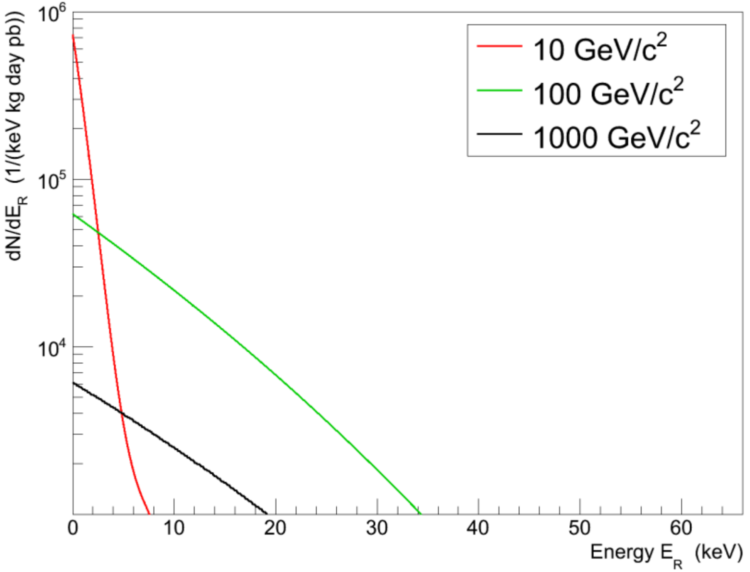


➢**The comparison between experiments is done using standard astrophysical assumptions**

Recoil spectrum for a given cross section



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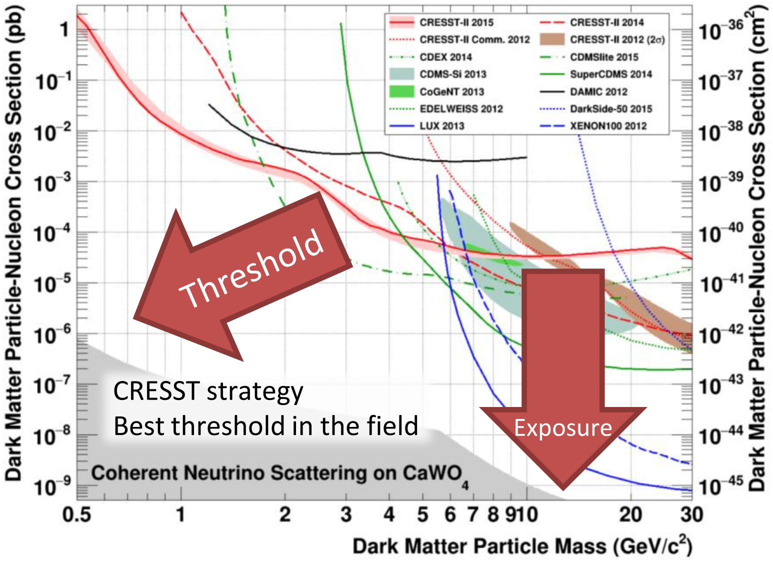
Dark matter particles scatter

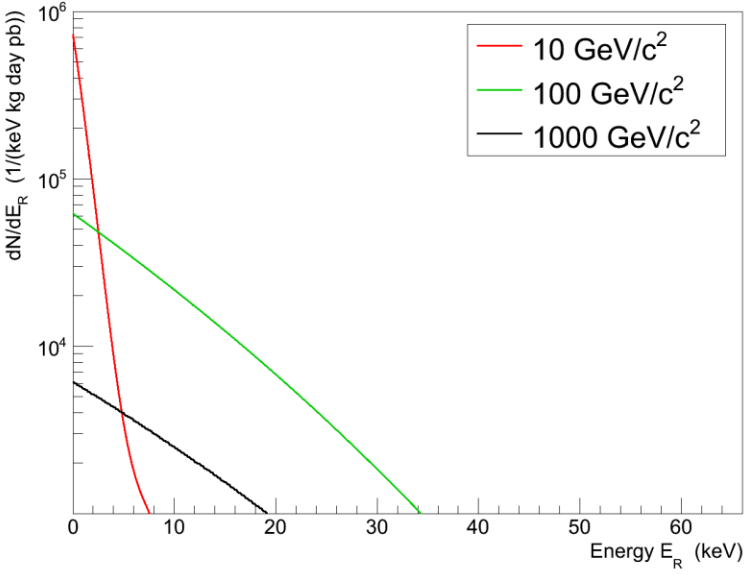
- off nuclei
- elastically
- coherently: ~A^2
- (spin-independent)

For a given cross section:

- The rate increases exponentially toward lower energy
- End point of the spectrum decreases for lower DM particle mass



Recoil spectrum for a given cross section



In case of a positive signal, **energy resolution** and **threshold** are crucial parameters to study structures in the spectrum.

In a modern view DM can scatter with different interactions

$$\mathcal{O}_1 = 1_\chi 1_N,$$
$$\mathcal{O}_2 = (v^\perp)^2,$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right),$$
$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N,$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right),$$
$$\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right),$$

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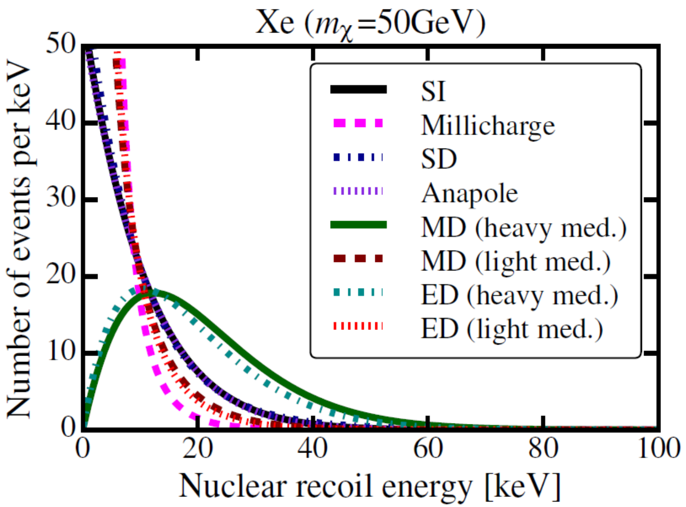
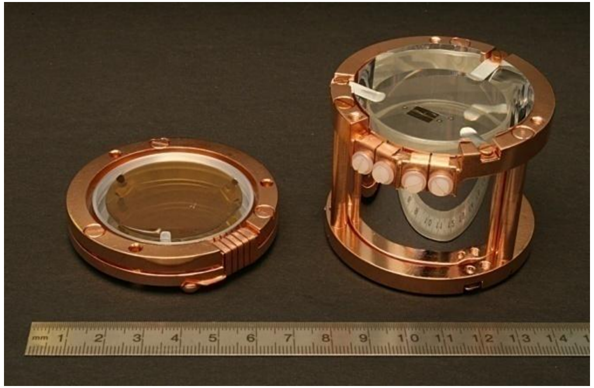


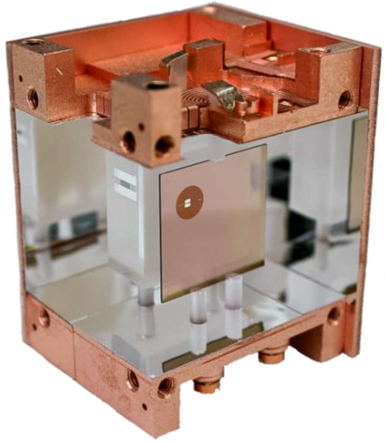
Vera Gluscevic et al. ArXiv:1506.04454

At Max-Planck-Institut für Physik new improved detectors have been developed to enhance the desired characteristics.

CRESST-II detector module



CRESST-III detector module



Target mass: 300g
Phonon threshold: Eth ≈ 300eV

Light detector res.: $\sigma \approx 10$ eV

Crystals: commercial/TUM

Target mass: ~25g
Phonon threshold: Eth ≲ 100 eV
improvement by at least a factor of 3
Light detector res.: $\sigma \approx 5$ eV
improvement by a factor of 2
Crystals: only TUM
improvement radiopurity

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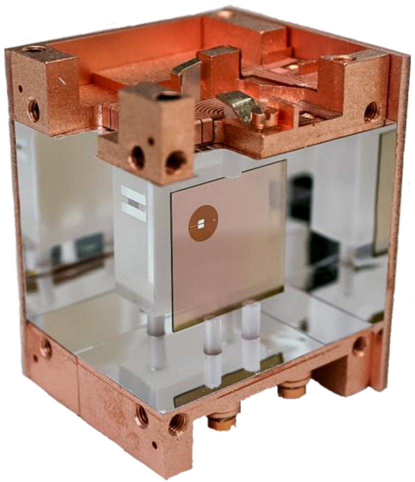
Energy resolution

Scintillating 24 g CaWO4 crystals as target

- Cryogenic detector $T_0 \approx 10$mK
- W-TES sensor for T read-out
- 100 eV threshold



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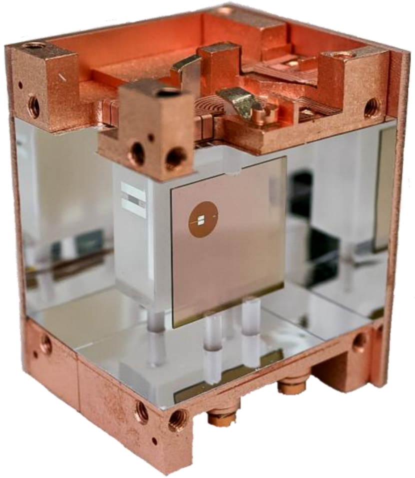
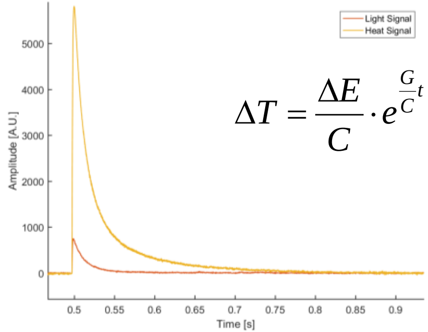


Particle discrimination

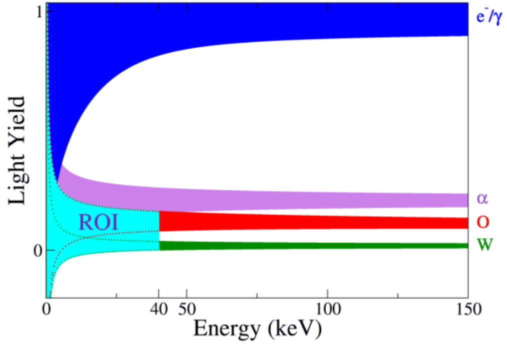
Light detector SOS

- Cryogenic detector $T_0 \approx 10mK$
- W-TES sensor for T read-out

Light yield characteristic of the type of particle →**Particle discrimination**



$$\Delta T = \frac{\Delta E}{C} \cdot e^{\frac{G}{C}t}$$



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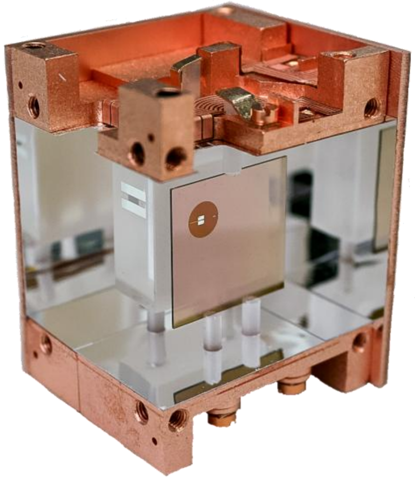
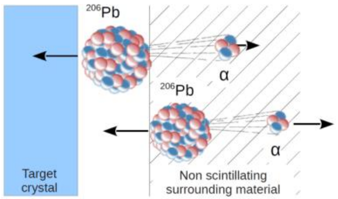


Background rejection

Veto surface related background

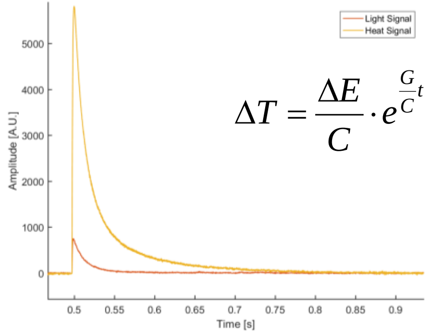
Housing

- Reflecting foil
- Fully scintillating



Instrumented holding system

- CaWO4 stick instrumented with W-TES



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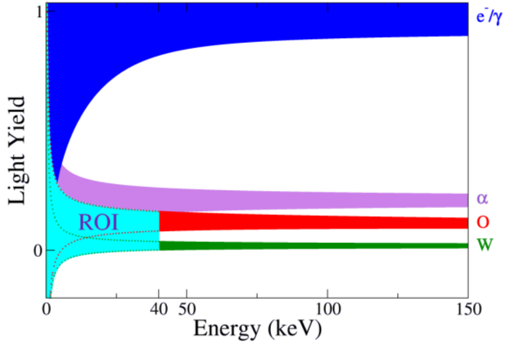

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Run commissioning

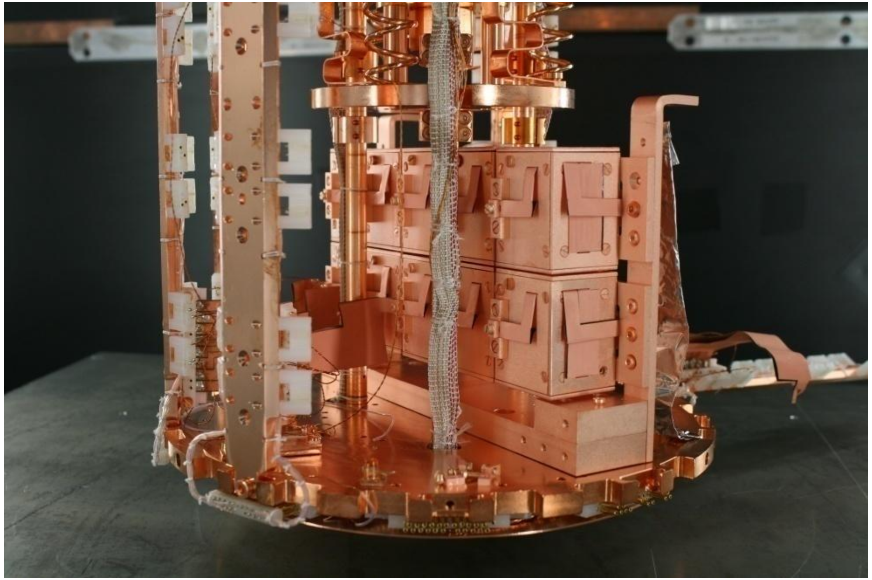
May 2016 ➢10 detector modules mounted

June 2016 ➢Cool down to mK temperature

Sept 2016 ➢Start physics run

Oct 2016 ➢Energy calibration

April 2017 ➢Neutron calibration



Today ➢Total background raw exposure collected as of 15.12.17: ~30 kg · day
➢**Unblinded 1 detector module above 100eV: 2.4 kg · day**

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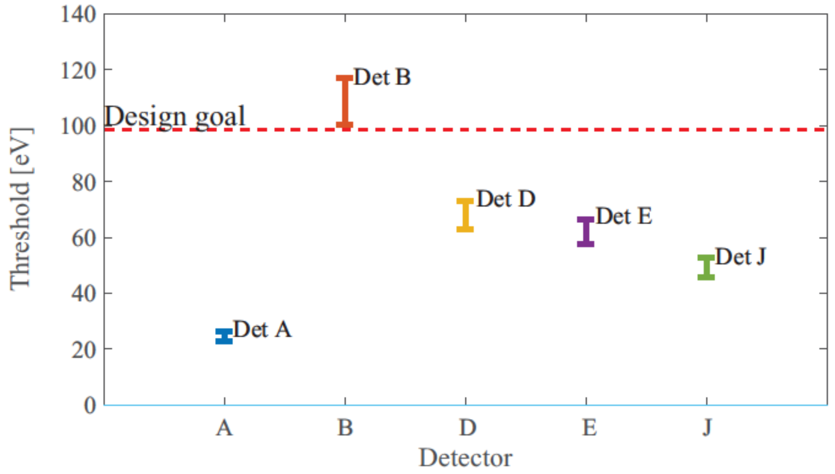
Optimum threshold

➢ In-depth study of energy calibration at low energy.

➢ Rigorous threshold analysis:

threshold determined by accepted noise trigger rate [M. Mancuso et al. (arxiv: 1711.11459)]



Noise-trigger rate	Det A	Det B	Det D	Det E	Det J
1 cts/(kg day)	6.69 mV	9.82 mV	6.65 mV	11.89 mV	5.57 mV
10 cts/(kg day)	6.26 mV	9.17 mV	6.21 mV	11.12 mV	5.21 mV
100 cts/(kg day)	5.80 mV	8.46 mV	5.73 mV	10.30 mV	4.82 mV
Energy range	22.6-26.1 eV	100.5-116.9 eV	63.0-73.2 eV	57.5-66.5 eV	45.5-52.6 eV

[M. Mancuso (CRESST collaboration) submitted to JLTP 2017]

5 detector modules already reached/exceeded the design goal

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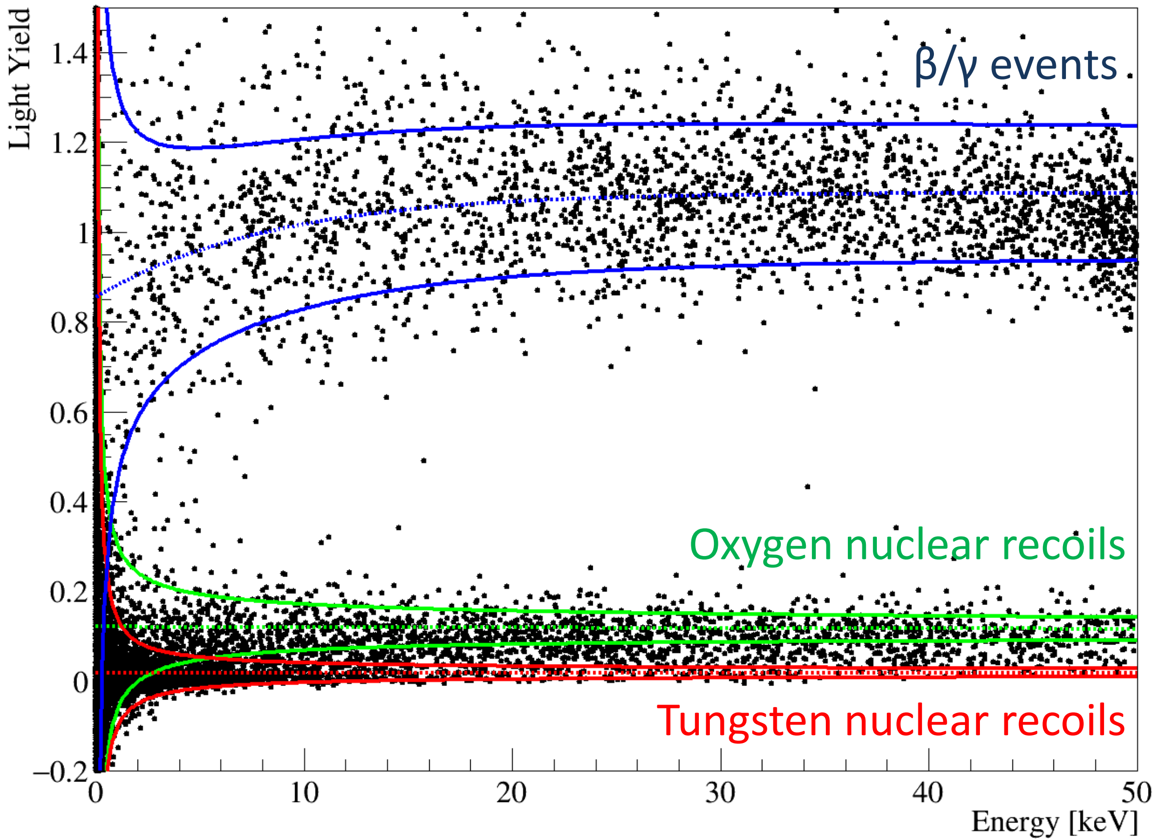
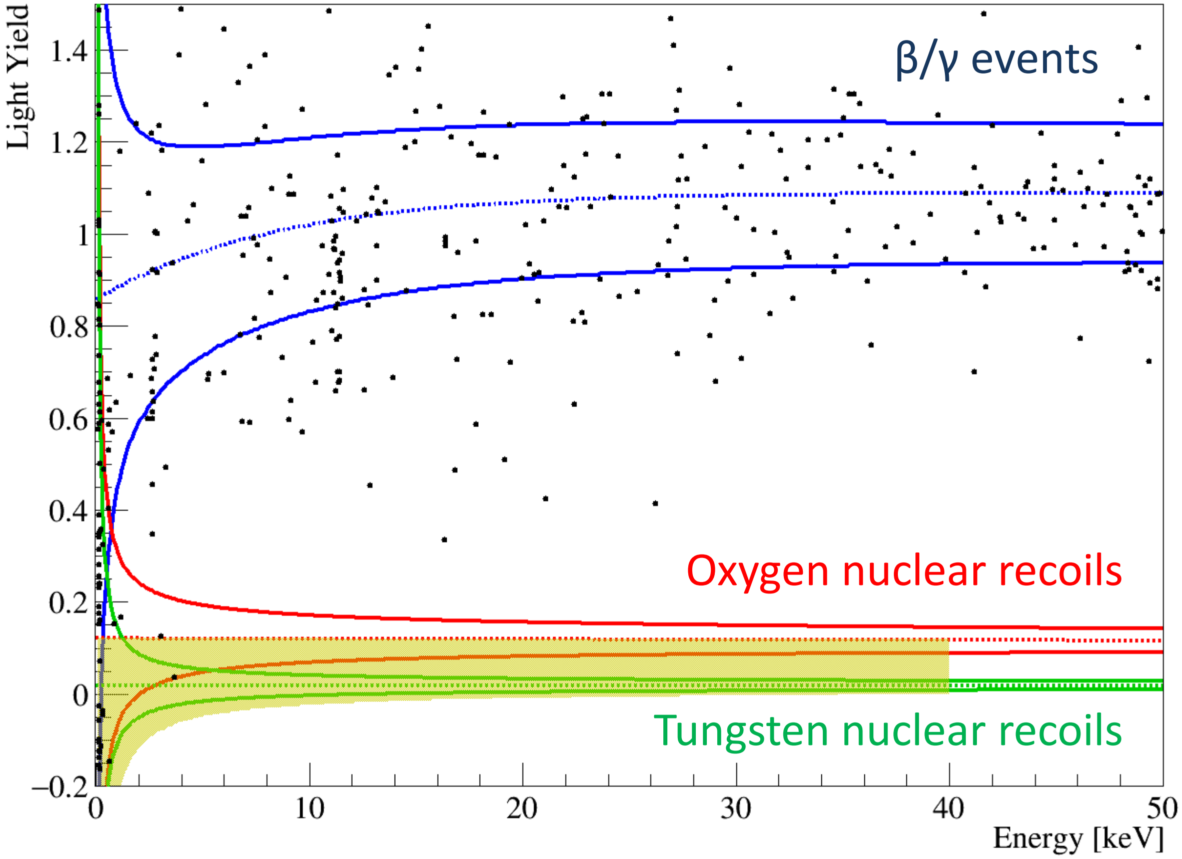
Neutron Calibration Det A



Background data Detector A ~2.4 kg · day



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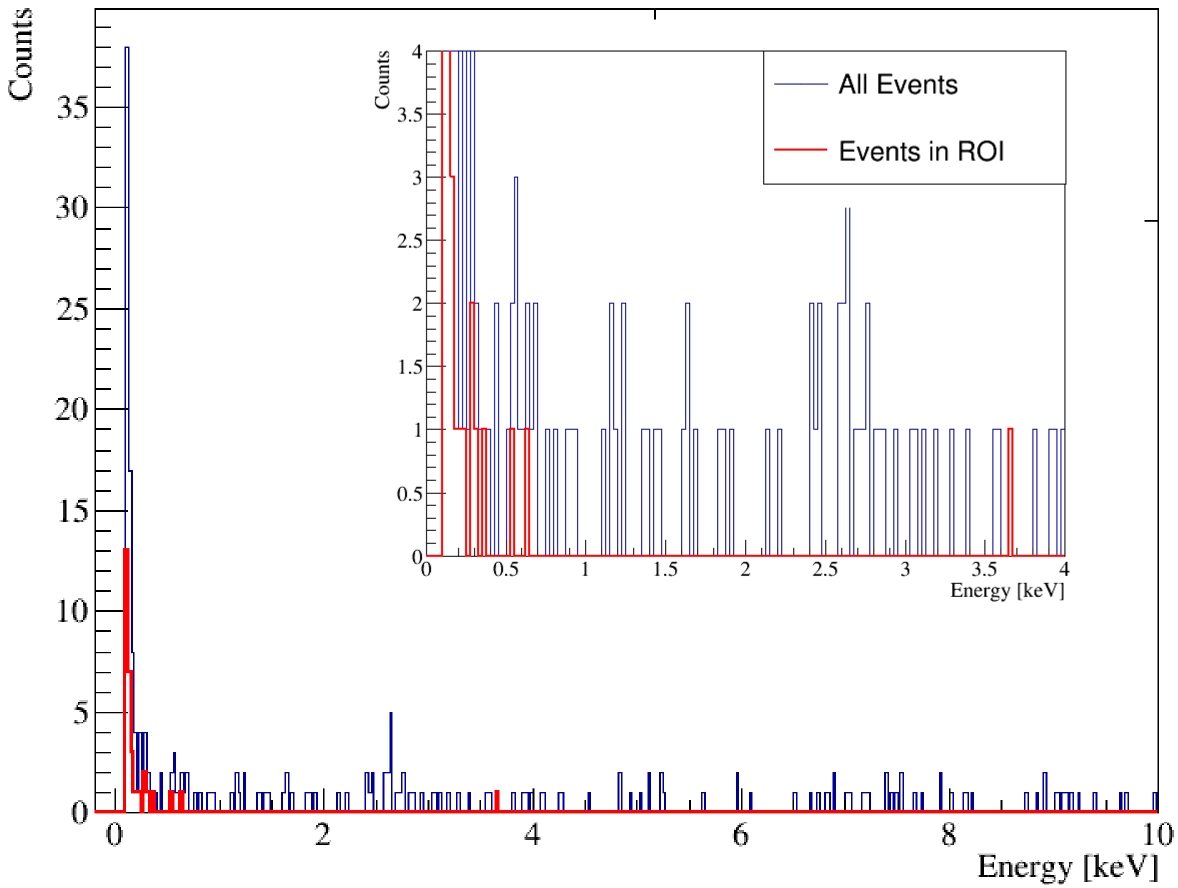
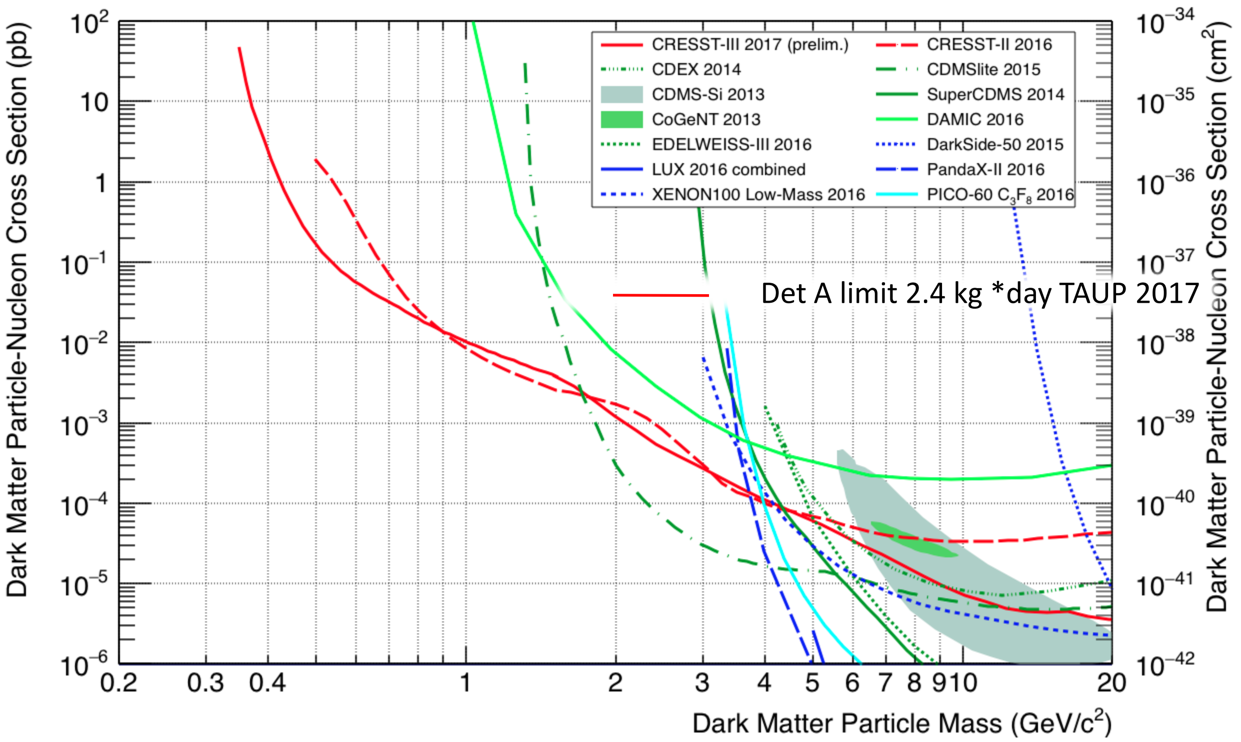


Limit with Det A 2.4 kg · day → ~8% of total exposure

Replicated and improved result from CRESST-II with only small fraction of the data set



Exponential background rising towards low energy limits the sensitivity al low DM masses

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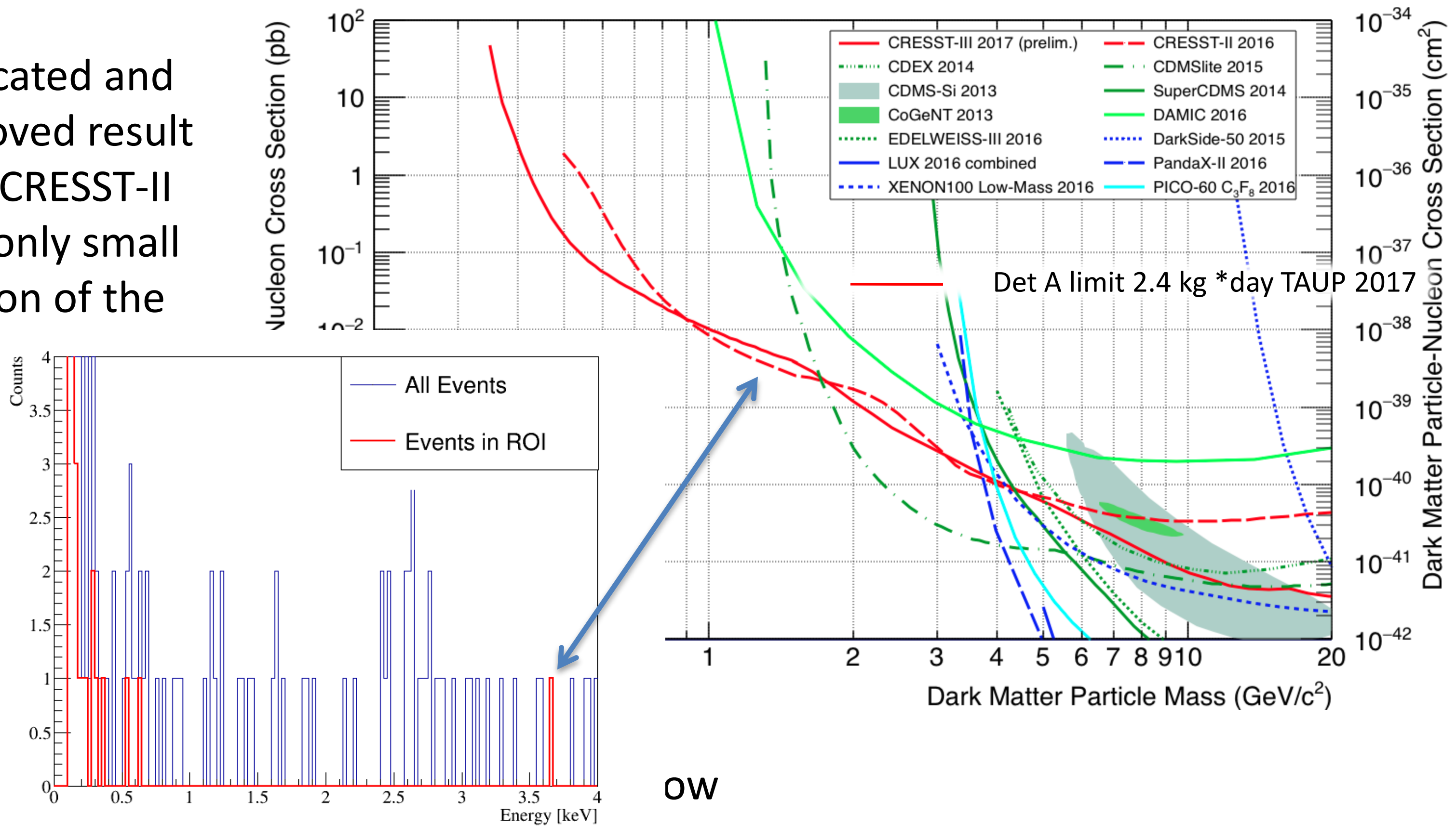
Limit with DET A 2.4 kg · day → ~4% of total exposure

Replicated and improved result from CRESST-II with only small fraction of the data



Expo... ow energy limits the sensitivity at low DM masses

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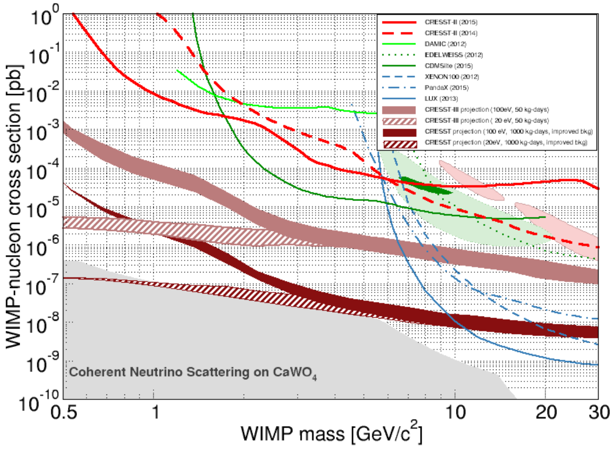
Outlook

Phase 1

- ➢Keep collecting data
- ➢Background investigation (in analysis) at low energy before the total unblinding
- ➢Detector development to exclude possible hardware background source (further detector upgrade in spring 2018)

Phase 2

- ➢Upgrade the setup from 10 to 100 detector modules



- Detector modules → MPP
- Upgrade of cryogenic facility → MPP
- 300 SQUID electronics channels and DAQ → Collaborative effort

Funding MPP:
Großgeräteantrag

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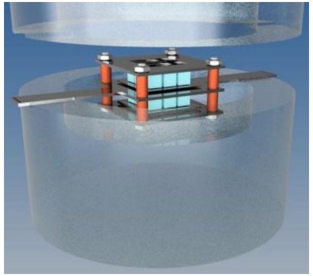
CRESST technology applications

ν-CLEUS

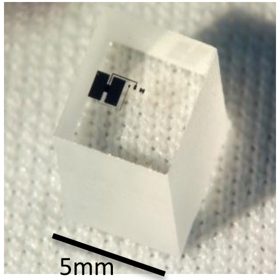
detection of coherent neutrino-nucleus scattering by probing nuclear-recoil energies down to the 10 eV-regime.

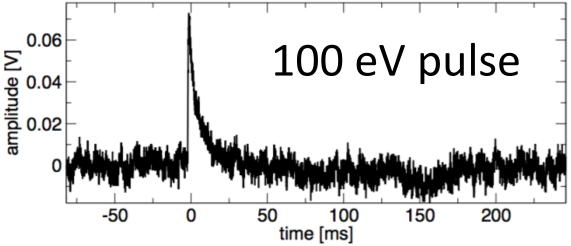
P.I.: Raimund Strauss

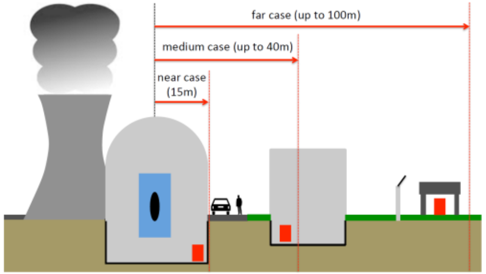


Array of small CRESST-like detectors in a cryogenic detector veto to be placed near nuclear power plant

First prototype tested @ MPP







Seed funding by Excellence Cluster Universe
Patent pending (Max Planck Innovations)

R. Strauss. et al. Eur. Phys. J. C (2017) 77: 506
R. Strauss et al. Phys. Rev. D **96**, 022009 – Published 28 July 2017

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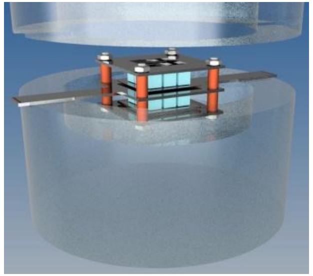

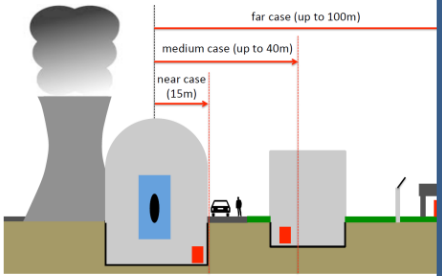

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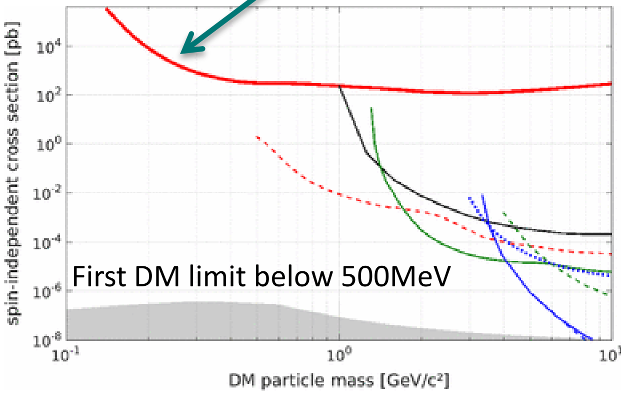
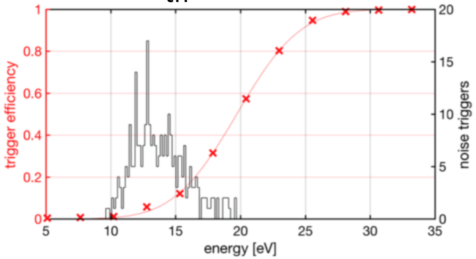
The European Physical Journal C
September 2017, 77:637 | Cite as

Results on MeV-scale dark matter from a gram-scale cryogenic calorimeter operated above ground

CRESST Collaboration

Energy threshold: E_{th} = (19.7 ±0.1) eV





Seed funding by Excellence Cluster Universe
Patent pending (Max Planck patent office)

R. Strauss. et al. Eur. Phys. J. C (2017) 77: 50
R. Strauss et al. Phys. Rev. D **96**, 022009 – Published 28 July 2017

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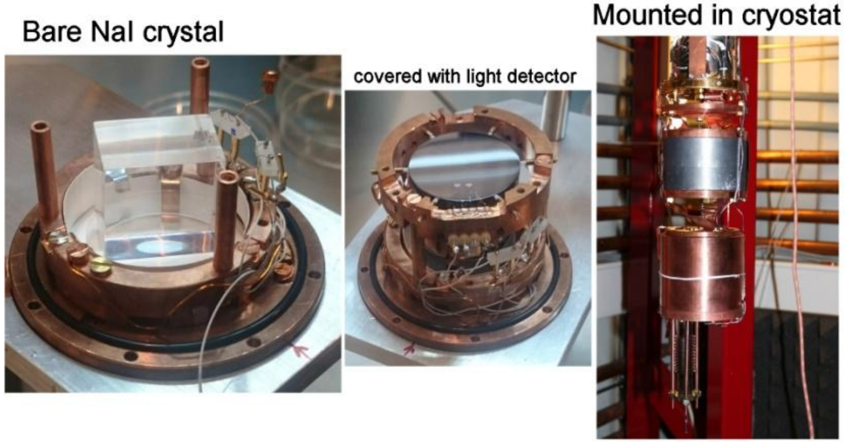
CRESST technology applications

COSINUS aims to develop a cryogenic scintillating calorimeter with sodium iodide (NaI) scintillating crystals as target for DM.
P.I.: Karoline Schaeffner



- direct comparability to DAMA/LIBRA
- significant lower nuclear recoil threshold
- particle discrimination

G. Angloher et al 2017 J. Phys.: Conf. Ser. 888 012207
G. Angloher et al. Journal of Instrumentation 12, P 11007 (2017)
COSINUS Collaboration (F. Reindl *et al.*). Nov 4, 2017 arXiv:1711.01482 (2017)

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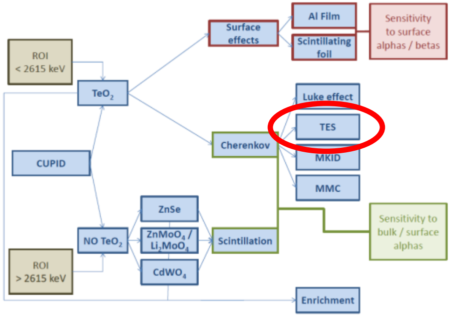
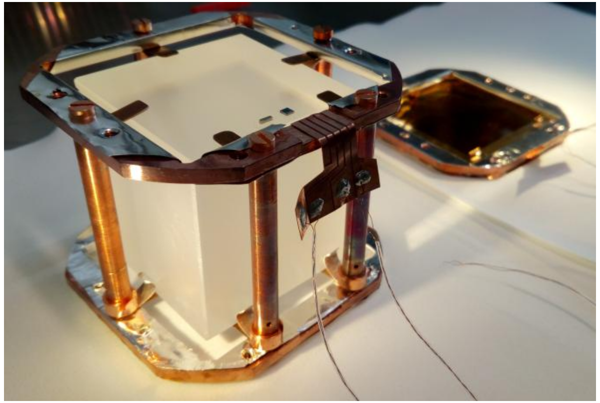
CRESST technology applications

CRESST light detectors are considered as possible upgrade for the next generation of $0\nu\beta\beta$ cryogenic experiment with TeO_2



CUPID

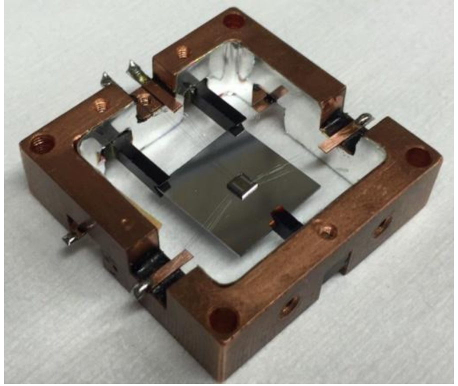
CUORE **U**pgrade with **P**article **ID**entification



SIDER (SIlicon detectors for Dark matter search through Electronic Recoils)

Silicon detector featuring single charge sensitivity at cryogenic temperature for detecting dark matter particle of mass lower than 1 MeV/c^2

P.I.: Xavier Defay



Seed funding by Excellence Cluster Universe

CRESST has an outstanding potential to explore the low mass region of the parameter space for DM nucleus scattering with unprecedented sensitivity

by courtesy of: Therese Desjardin