SFB 1258 Neutrinos Dark Matter Messengers

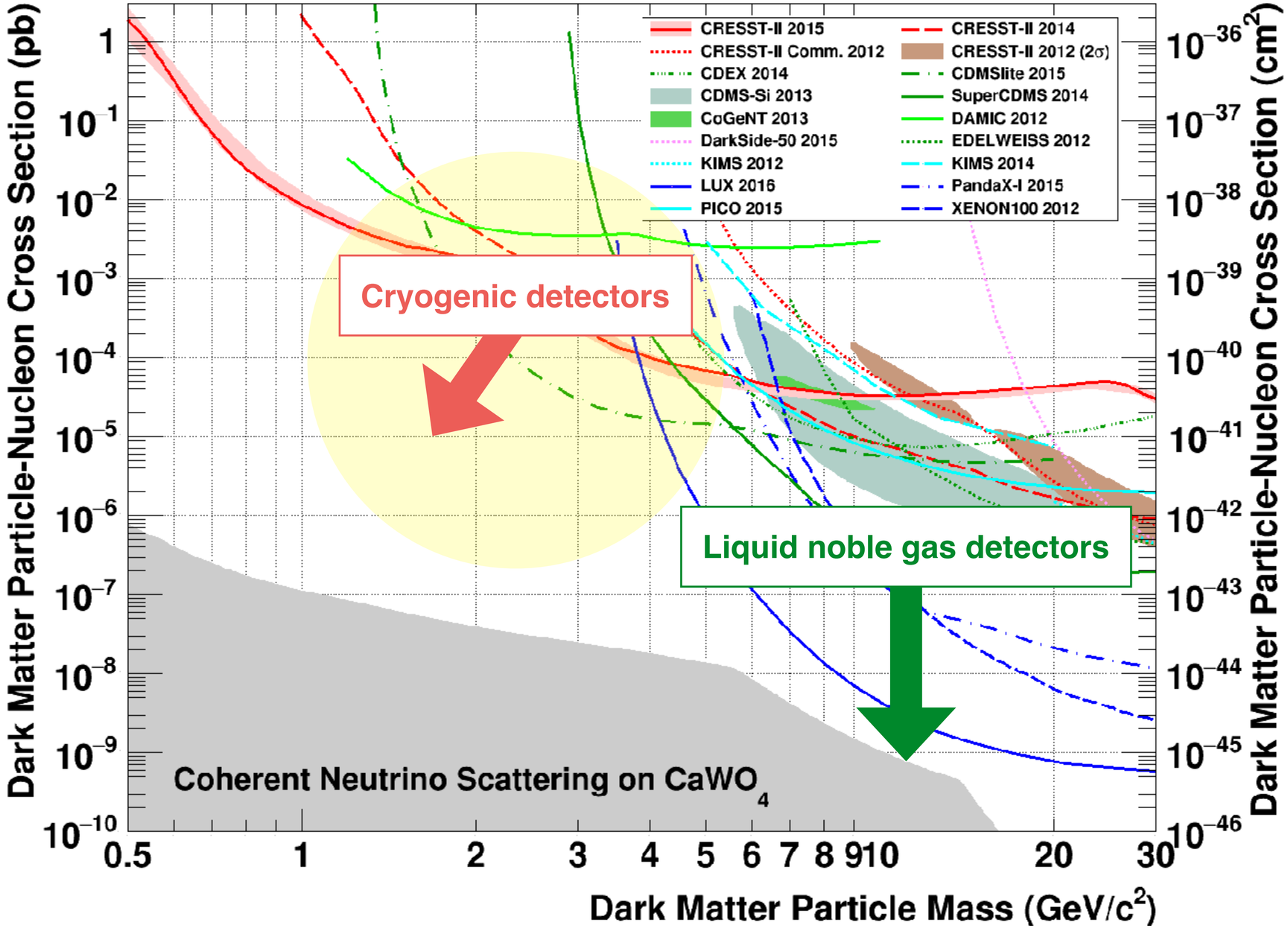
Excellence Cluster Universe

Search for low-mass Dark Matter with CRESST-III

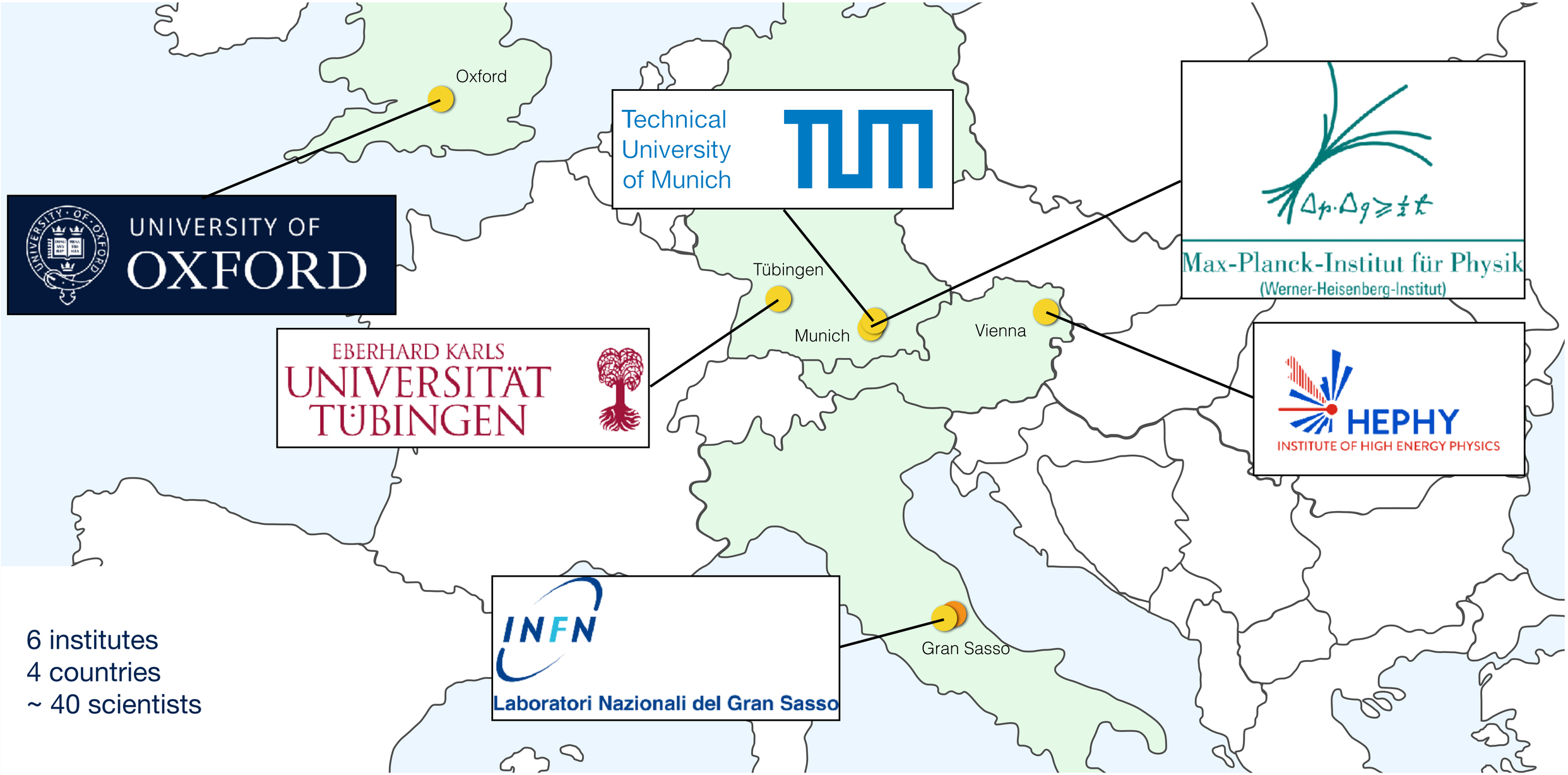
WIN 2017 - 23. June 2017

Michael Willers
Technical University of Munich

Direct DM search: the current landscape



The CRESST Collaboration



6 institutes
4 countries
~ 40 scientists

The CRESST Collaboration

The CRESST Experiment - Cryogenic Rare Event Search with Superconducting Thermometers

- Direct DM search using cryogenic detectors
- Located @ LNGS (central Italy)

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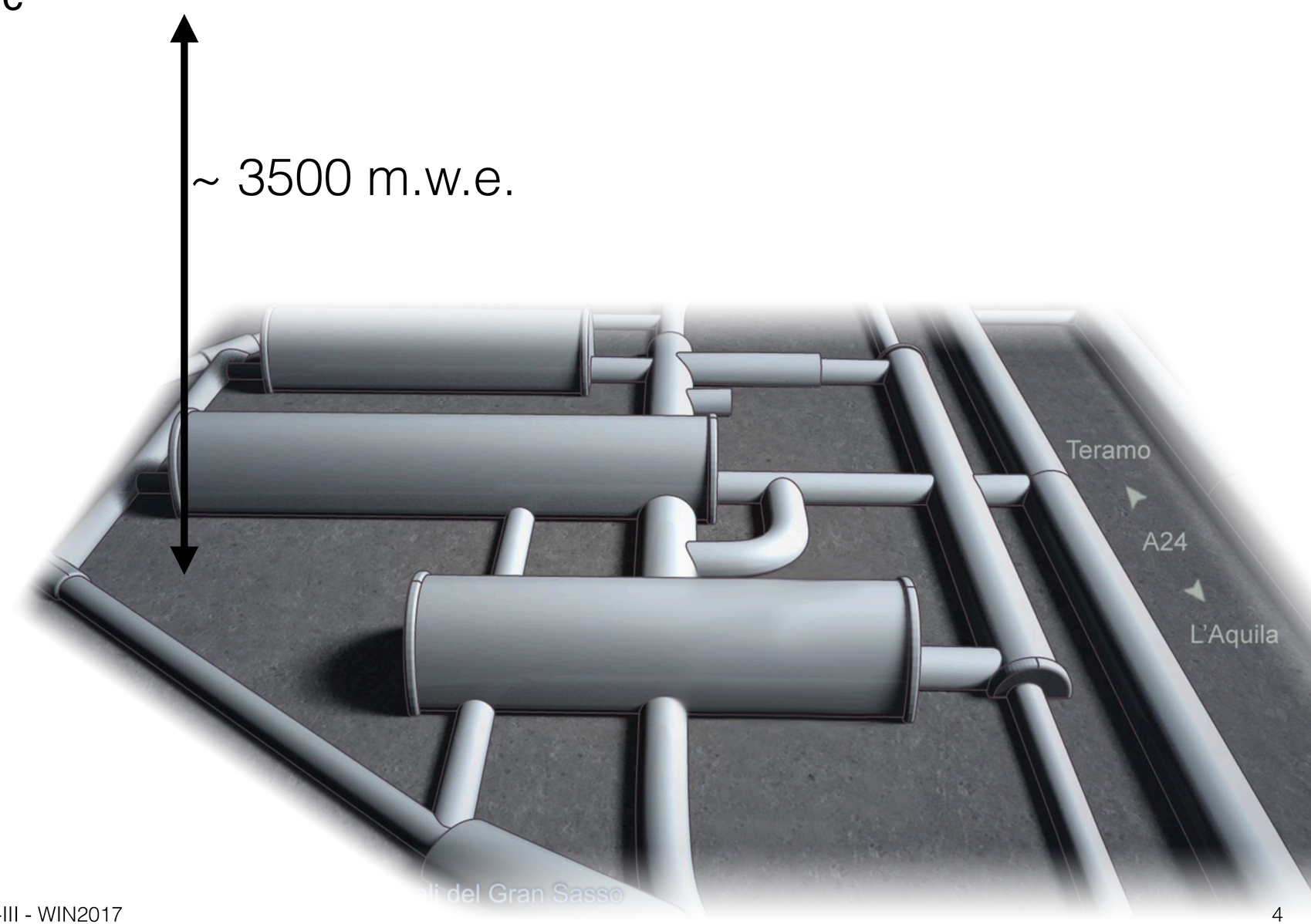

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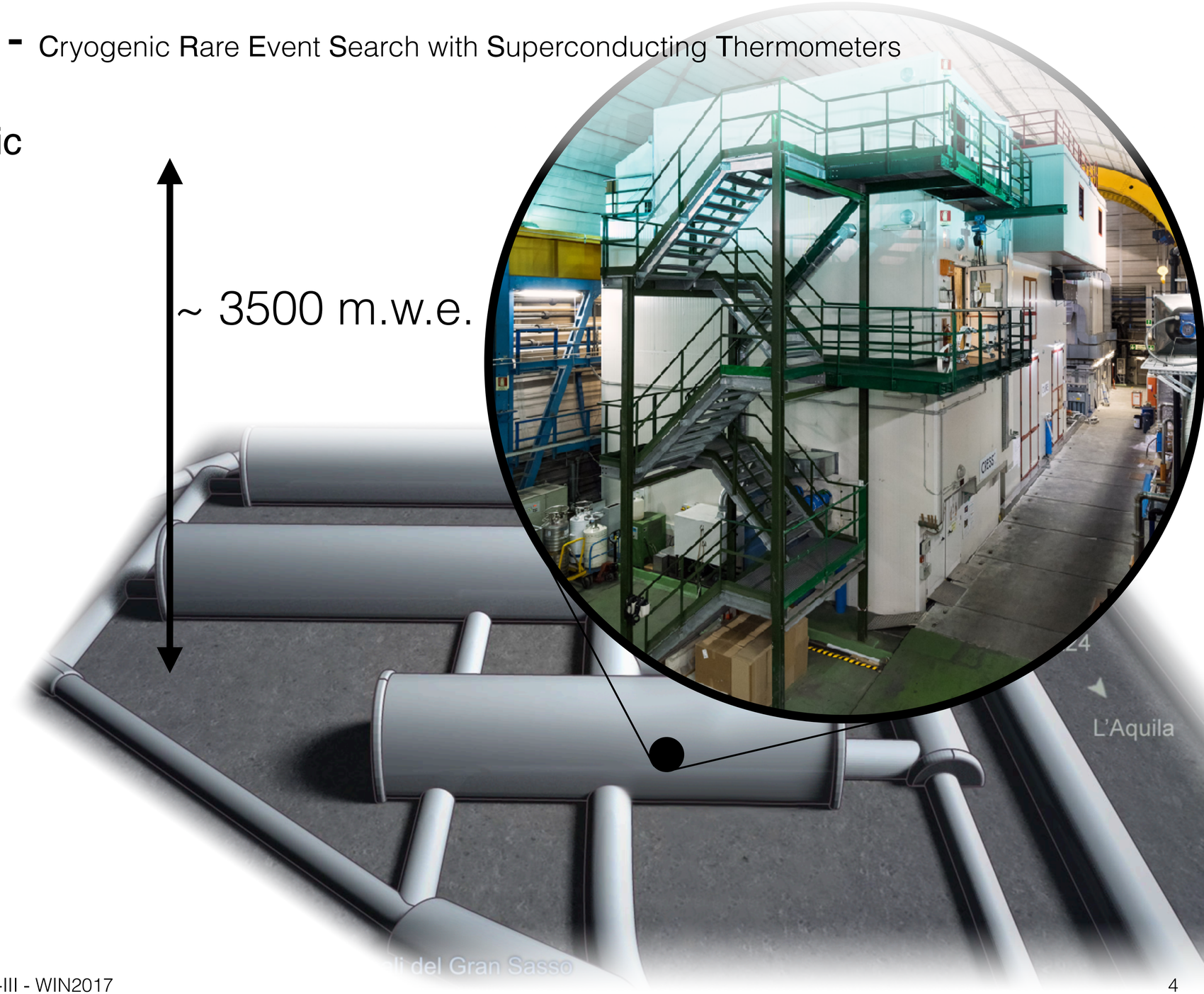
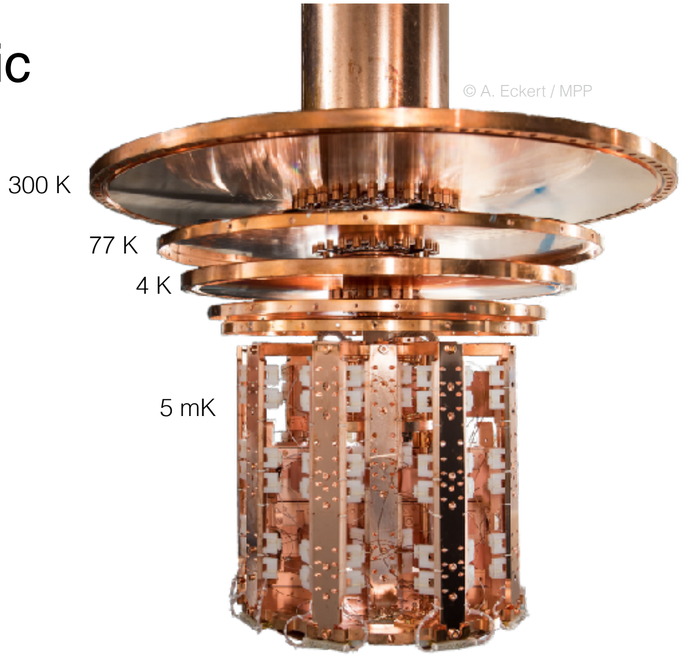
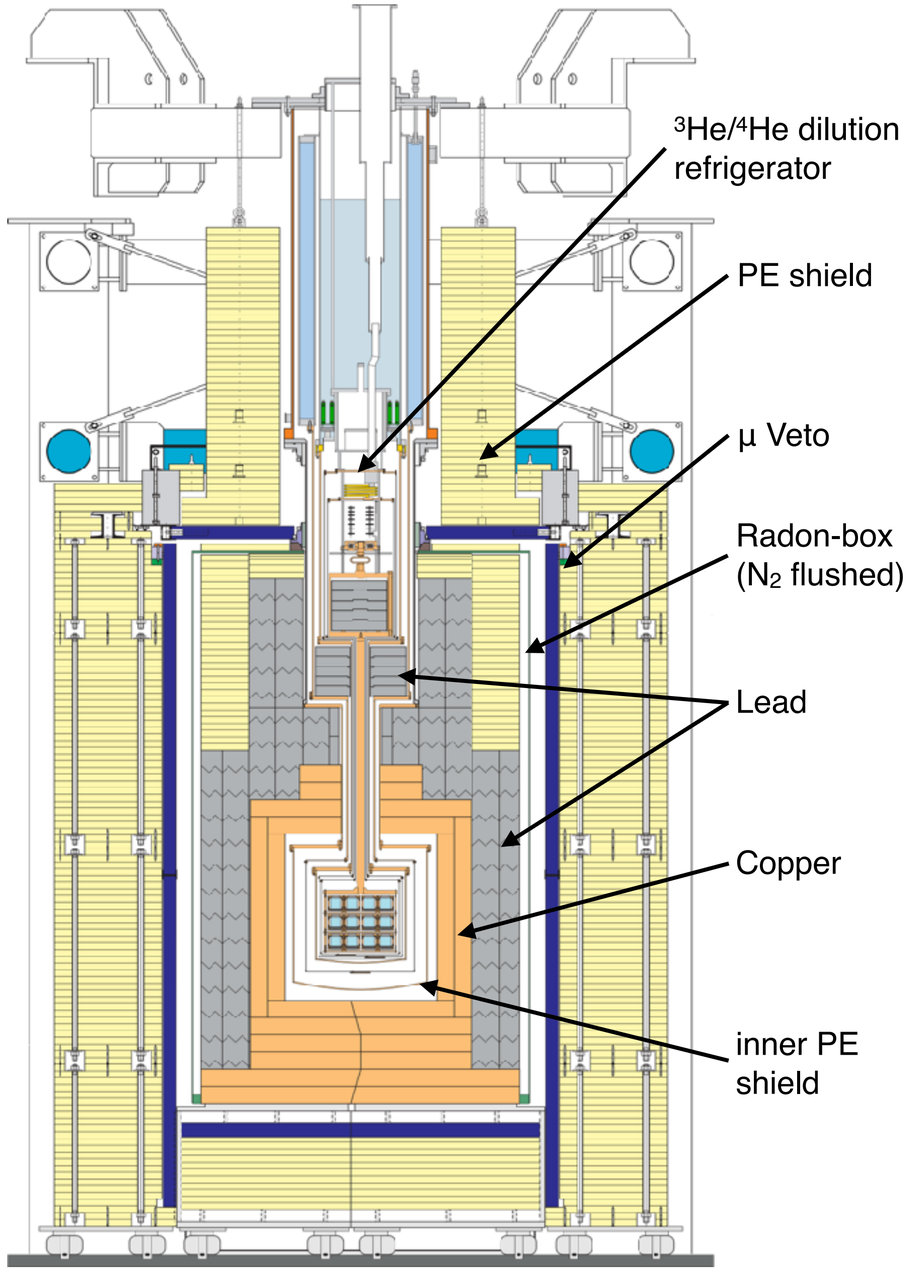


The CRESST Experiment - Cryogenic Rare Event Search with Superconducting Thermometers

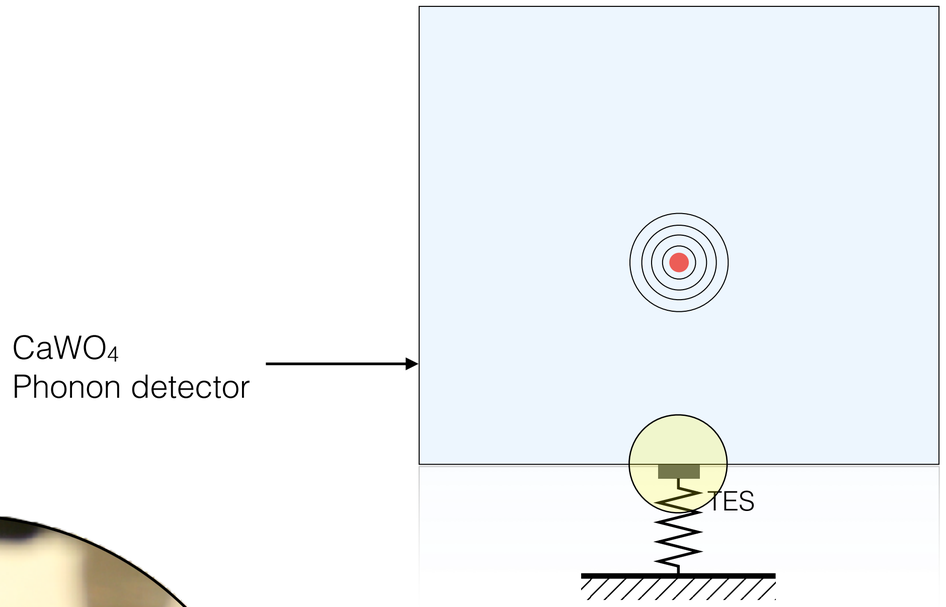
- Direct DM search using cryogenic detectors
- Located @ LNGS (central Italy)
- Rock overburden ~ 3500 m.w.e.
- Shielding:
  - Lead, copper, PE, internal PE
  - Active muon veto
  - N_2 flushed radon box
- Cryostat:
  - Base temperature: 5mK
  - SQUID based detector readout
- Cryogenic detectors:
  - Scintillating $CaWO_4$ target crystals
  - Multi-element target (Ca, O, W)
  - Precise nuclear recoil energy measurement using W-TES

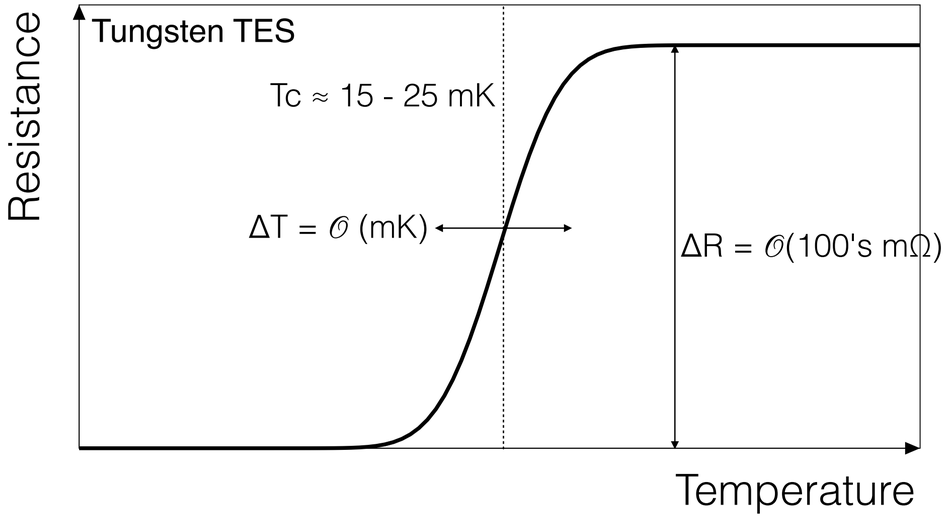


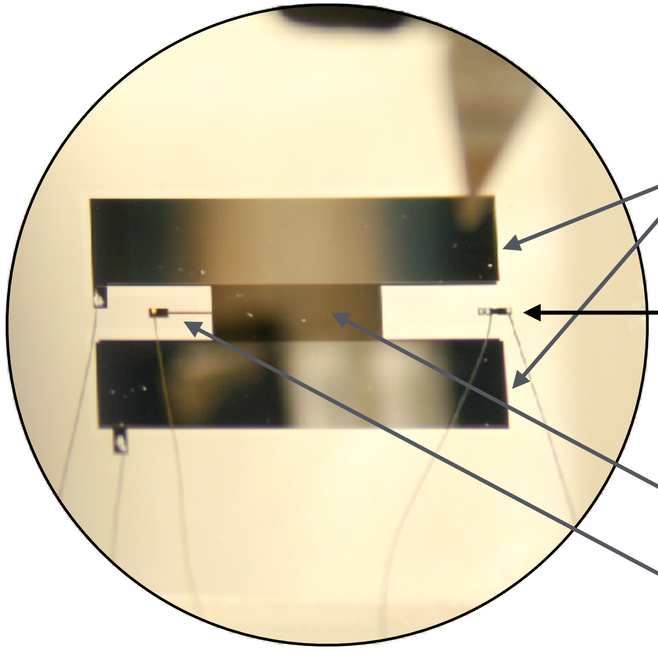


CRESST Detector Module

- Scintillating $CaWO_4$ target crystals as cryogenic detectors → high sensitivity to nuclear recoils
- Precise energy measurement using Tungsten Transition Edge Sensors (W TES)







Aluminum phonon collectors (& readout contacts)

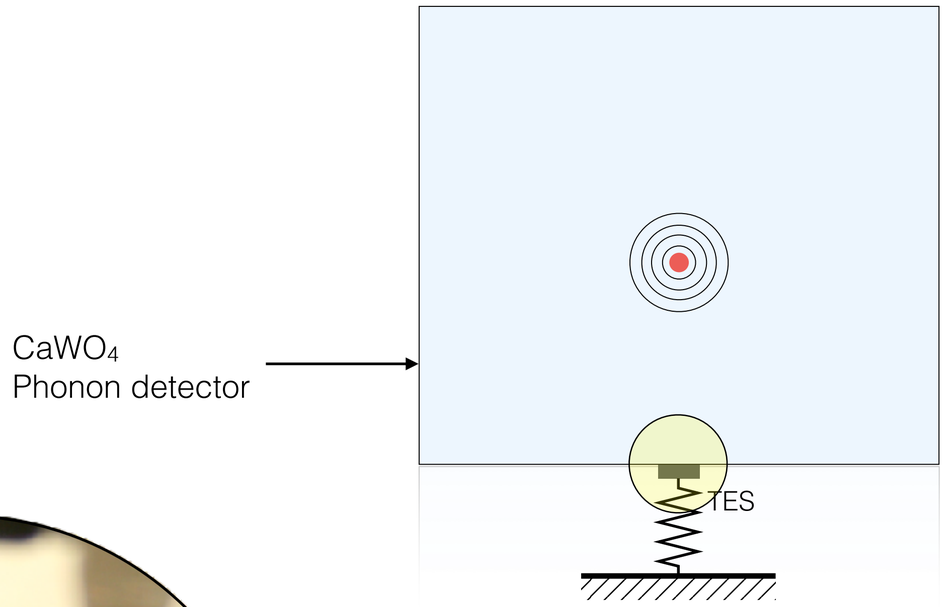
Resistive heater (Gold) used for active temperature stabilisation

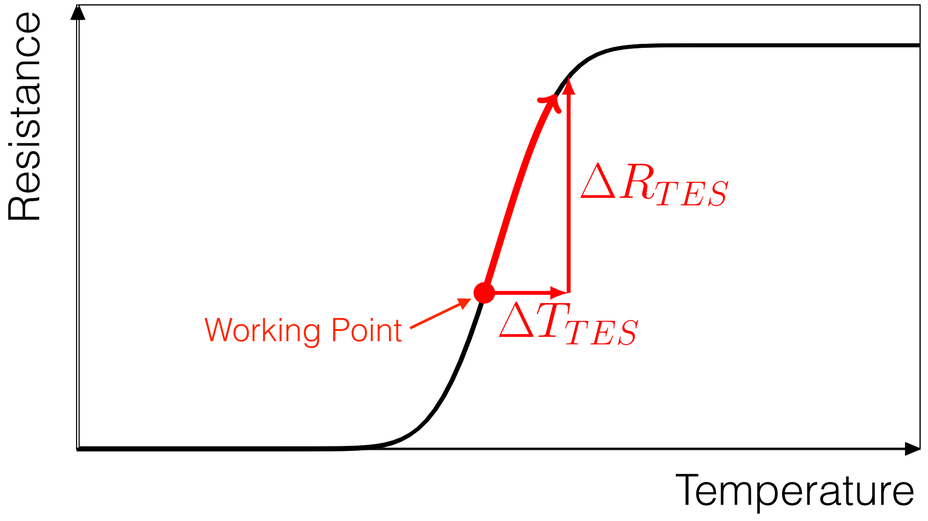
Tungsten TES

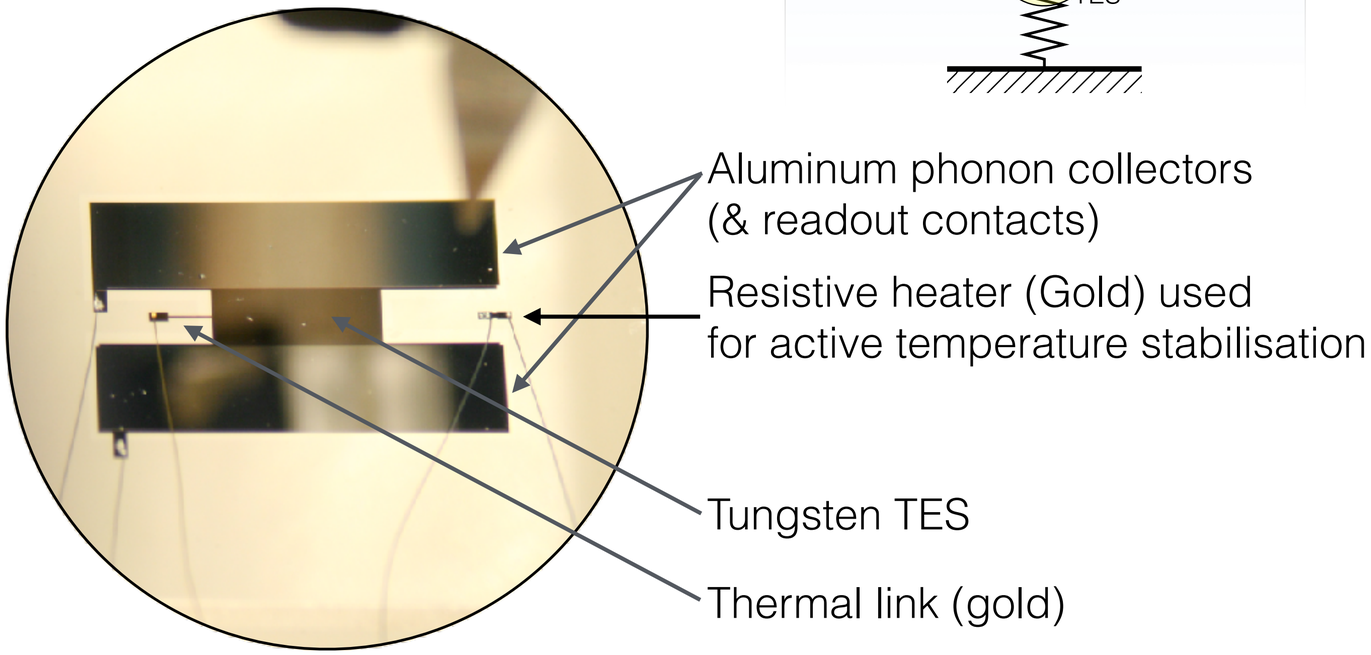
Thermal link (gold)

CRESST Detector Module

- Scintillating $CaWO_4$ target crystals as cryogenic detectors → high sensitivity to nuclear recoils
- Precise energy measurement using Tungsten Transition Edge Sensors (W TES)
- Active stabilisation: long-term stability and energy calibration / detector linearisation

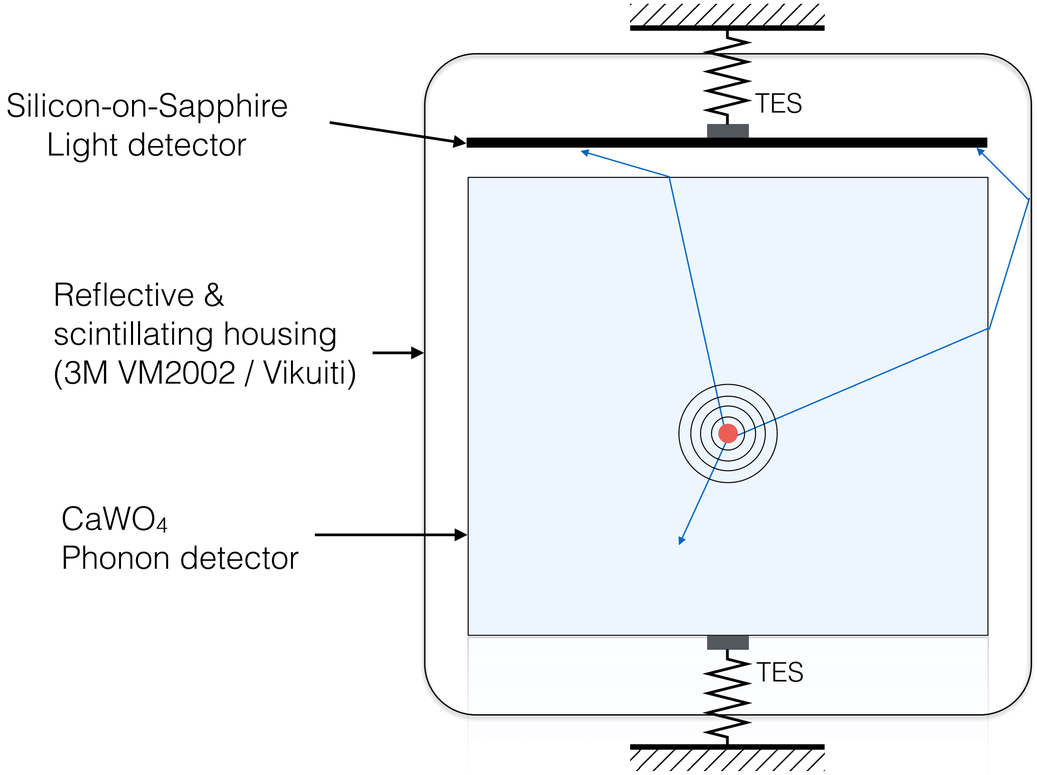


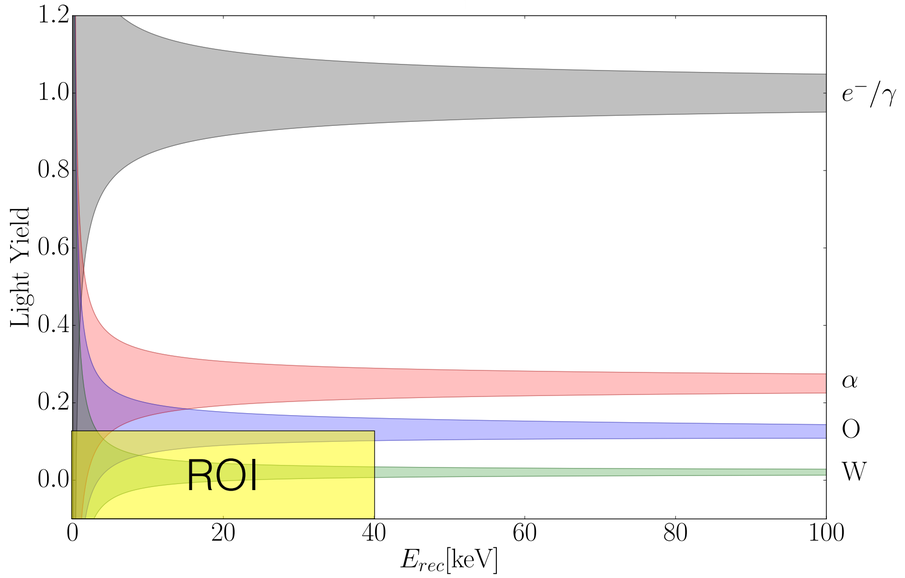




CRESST Detector Module

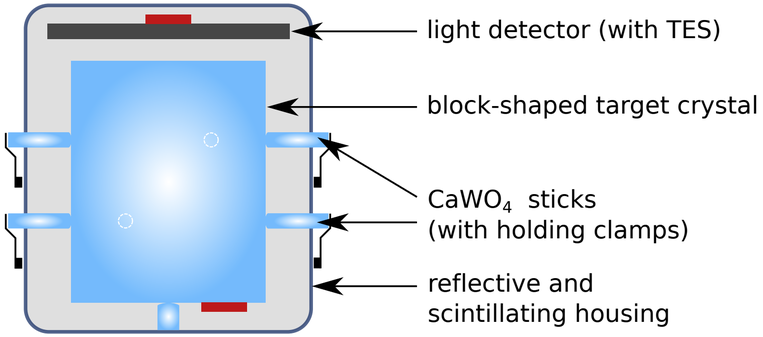
- Scintillating $CaWO_4$ target crystals as cryogenic detectors → high sensitivity to nuclear recoils
- Precise energy measurement using Tungsten Transition Edge Sensors (W TES)
- Active stabilisation: long-term stability and energy calibration / detector linearisation
- Measurement of scintillation light with separate cryogenic light detector (Silicon-on-Sapphire)
- Reflective & scintillating housing: increased light collection + veto against surface backgrounds
- Simultaneous measurement of heat (phonon) and light signal enables highly efficient discrimination between e^- / γ and nuclear recoils





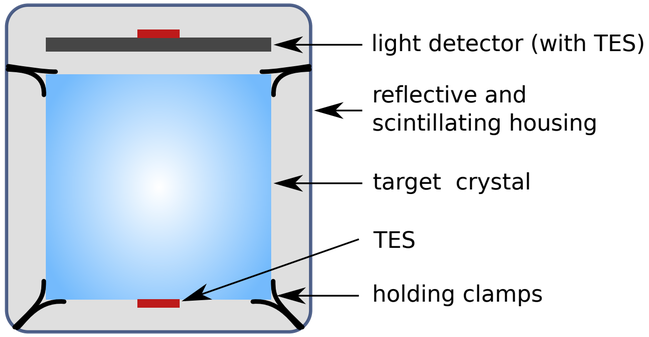
The road from CRESST-II to CRESST-III

TUM40 (2014)



- 250g $CaWO_4$ crystal (block shaped), **TUM grown**
- **fully scintillating inner detector housing**
- Energy threshold (phonon detector): E_{thres} = 603 ± 2 eV
- Published exposure: 29.35 kg days (before cuts)
  Eur.Phys.J. C74 (2014) 3184
- Non-blind analysis

Lise (2015)

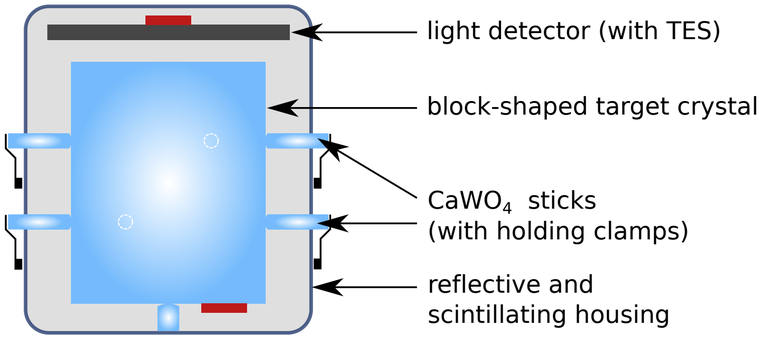


- 300g $CaWO_4$ crystal (cylindrical), **commercial supplier**
- crystal mounted using bronze clamps
- Energy threshold (phonon detector): E_{thres} = 307 ± 4 eV
- Published exposure: 52 kg days (before cuts)
  Eur.Phys.J. C76 (2016) 25
- Blind analysis

→ **World leading limit for M_{DM} < 1.7 GeV/c²**

The road from CRESST-II to CRESST-III

TUM40 (2014)



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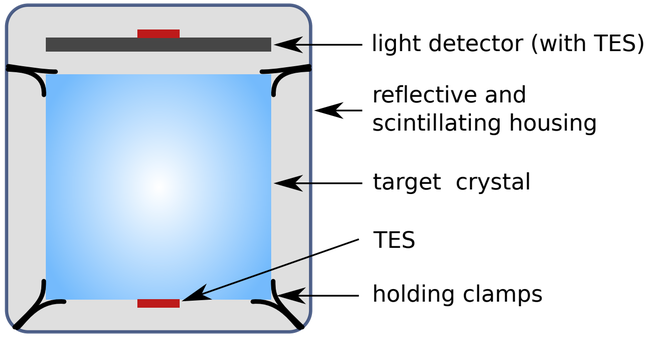
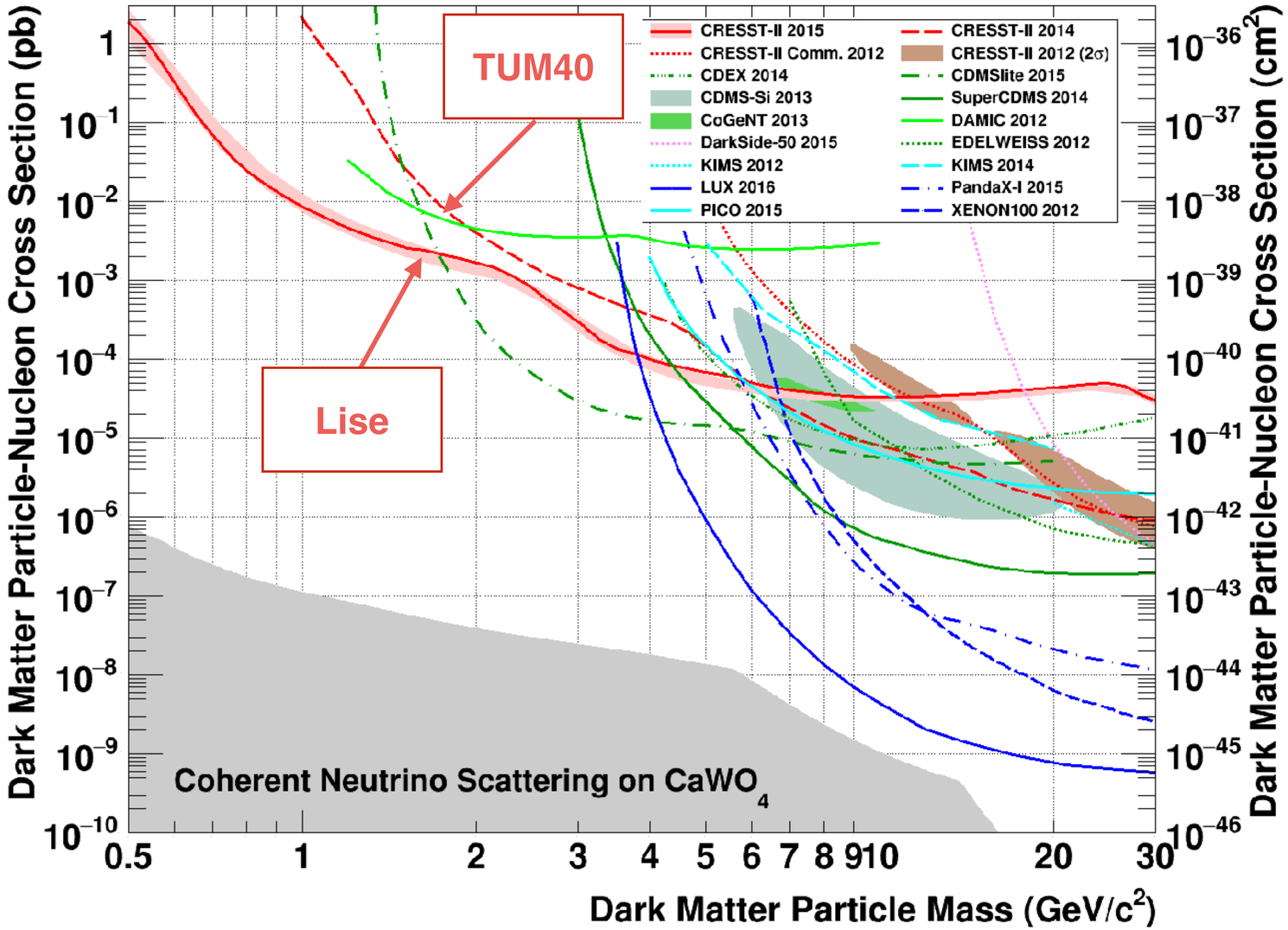




CRESST-III

→ Dedicated to search for low mass dark matter
→ Focus on detector performance & crystal radiopurity

Design goals for the CRESST-III detector module:

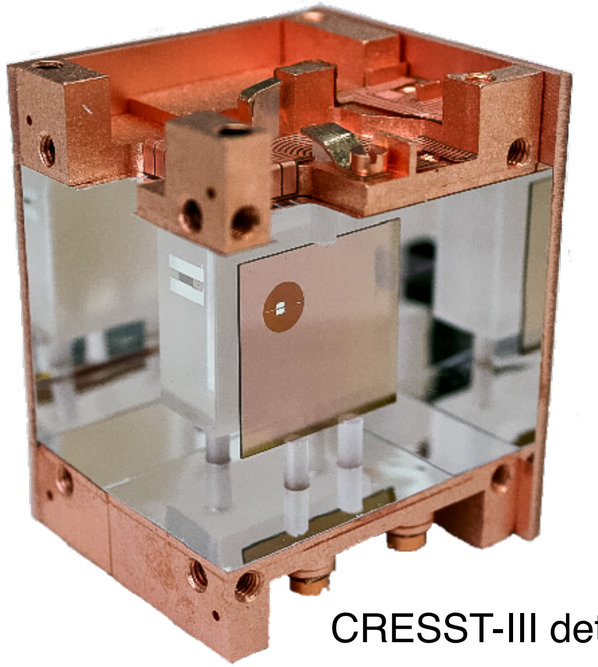
- control intrinsic contaminations in $CaWO_4$ crystals
- Improve phonon detector sensitivity: $\mathbf{E_{thr} \lesssim 100\ eV}$
- fully scintillating detector housing

→ in-house (TUM) grown $CaWO_4$ crystals
→ Reduce crystal mass by factor of 10
→ Detectors held using $CaWO_4$ sticks

Phased approach: (arXiv:1503.08065)

→ Probe low mass DM parameter space to ν-floor

- Phase 1: 10 detectors, maintain crystal radiopurity
- Phase 2: increase # of detectors, improve crystal radiopurity

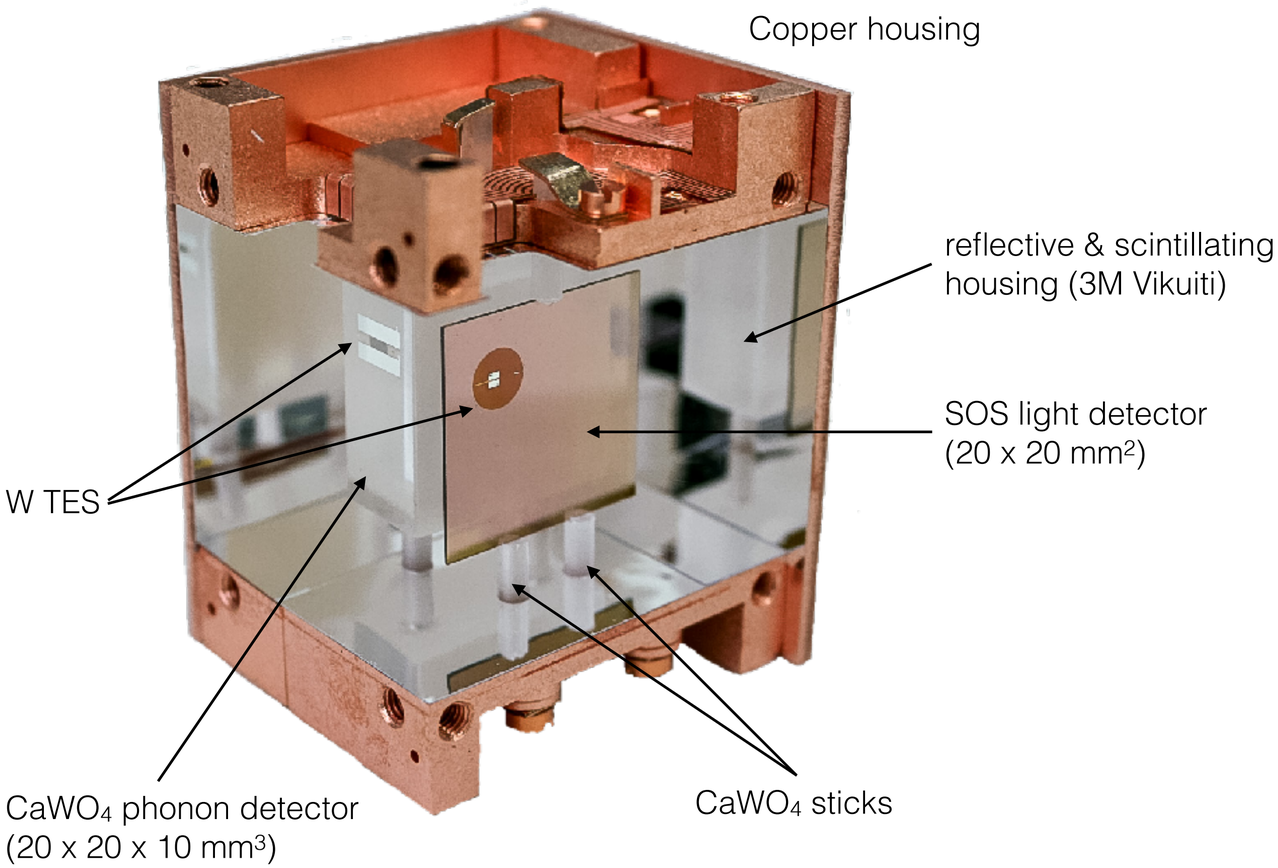


CRESST-III detector module

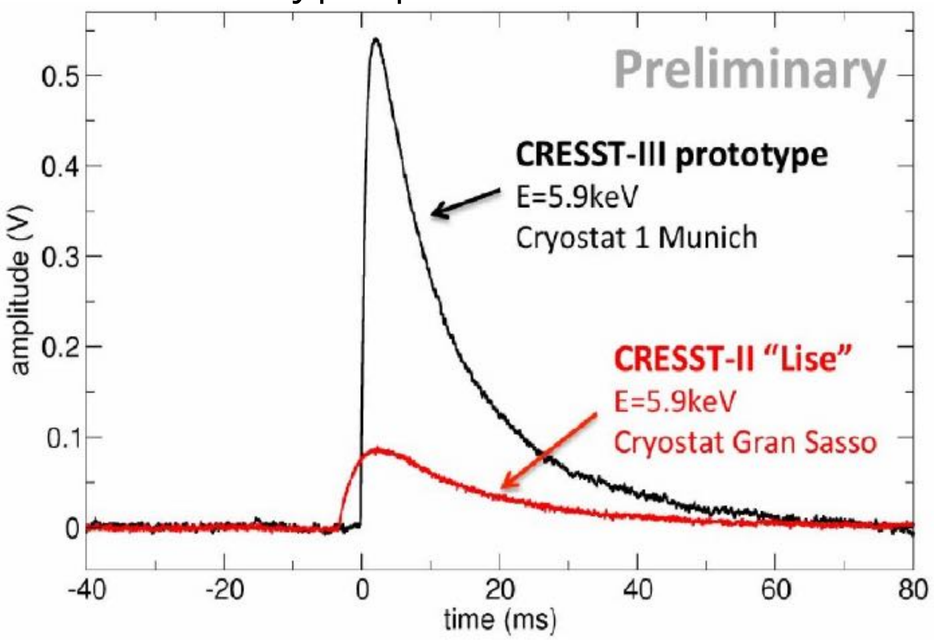
TUM40
- mass ~ 250 g
- E_{thr} ~ 600 eV

CRESST III
- mass ~ 25 g
- $E_{thr} \lesssim 100$ eV

CRESST-III — Detector Module



Prototype phonon detector

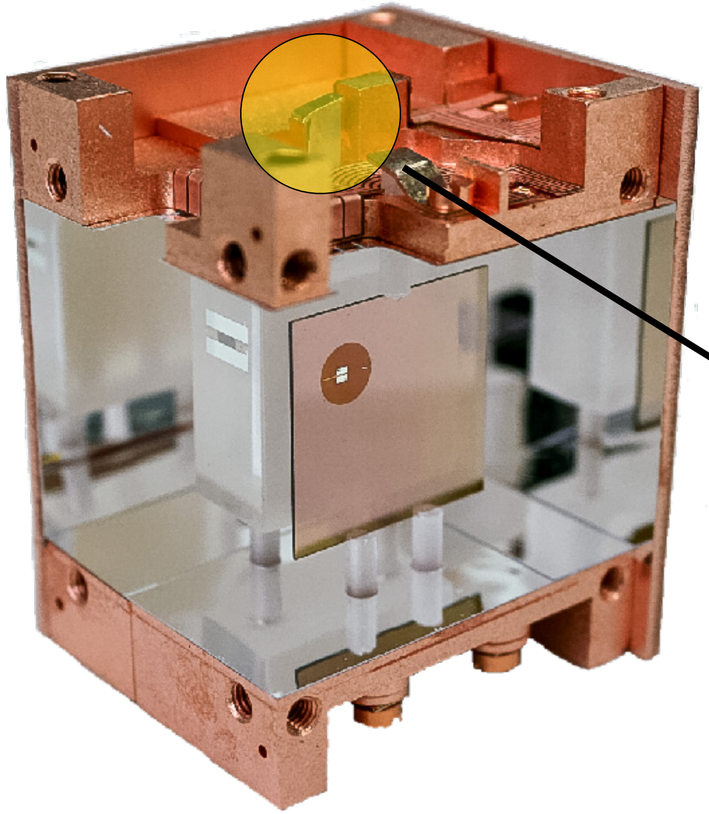


Based on design of detector module TUM40

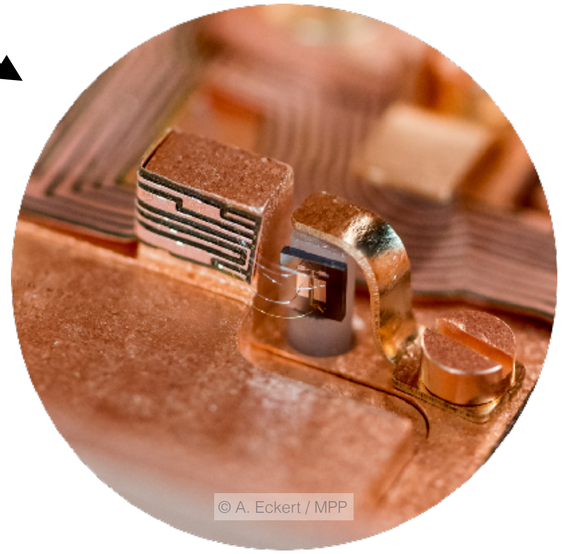
- block shaped crystal, reduced mass (m=24 g)
- TES adapted to new crystal size
- fully scintillating housing → rejection of surface backgrounds
- Smaller housing & crystal → improved light collection

- $E_{thr} \lesssim 100$ eV & Significant improvement in Signal / Noise
- Threshold-goal confirmed by ongoing measurement at LNGS

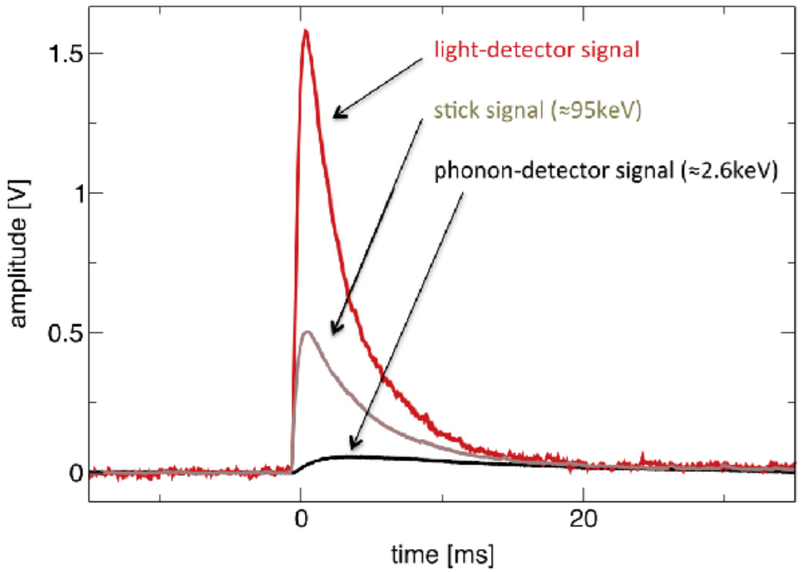
CRESST-III — iStick System

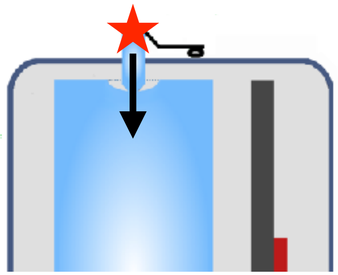


- → instrumentation of $CaWO_4$ sticks with W-TES
- → veto for "stick-events"
- → 3 iStick TES / module, readout in parallel with one SQUID channel



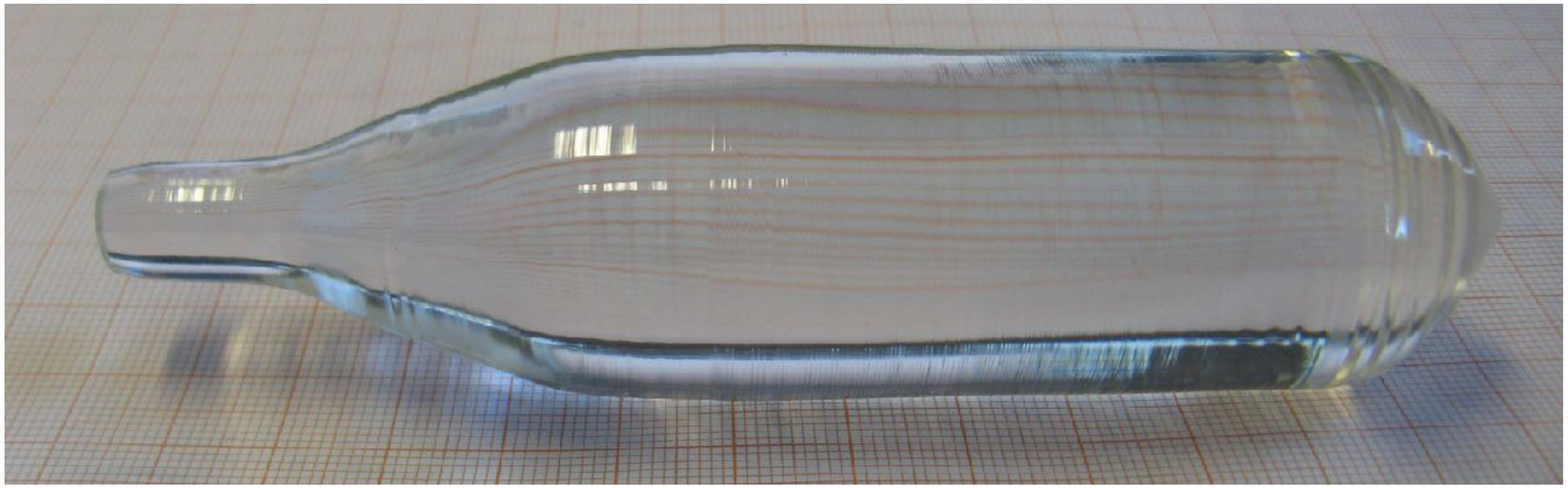
iStick system tested @ MPP Munich

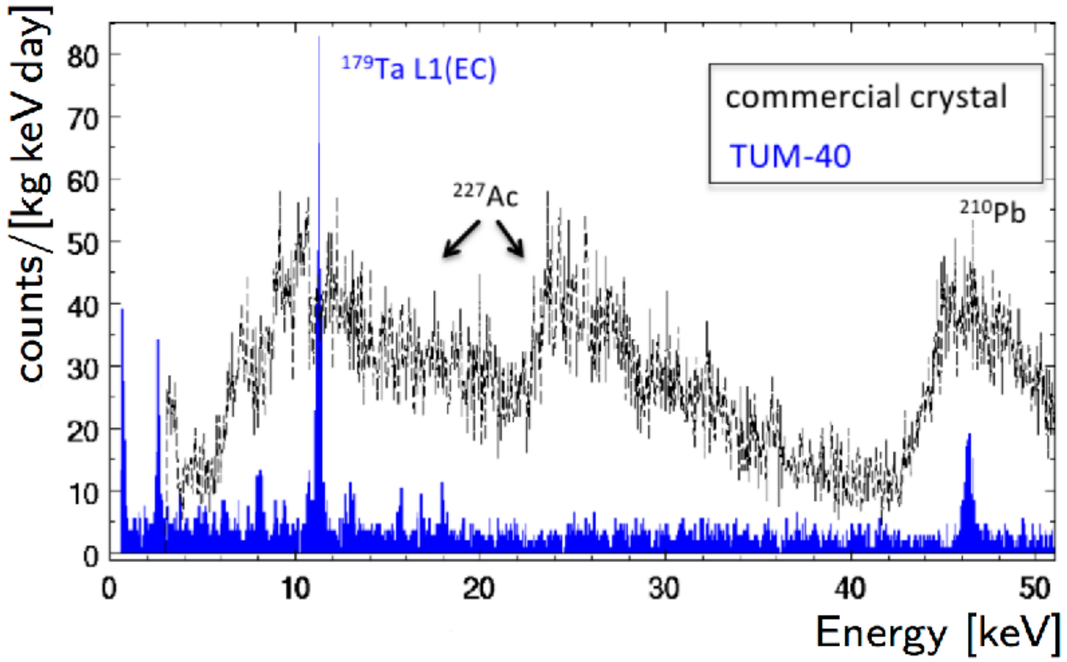




Events in $CaWO_4$ sticks can lead to energy degraded events in main $CaWO_4$ target crystal
→ potential background for DM search

$CaWO_4$ crystals for CRESST-III





TUM40: 3.51 / (keV kg day)
commercial crystals:
6 - 30 / (keV kg day)

JCAP06(2015)030

$CaWO_4$ crystal growth at TUM

- → prior to CRESST II Phase 2 (2013): only commercial crystals (Russia / Ukraine) installed
  - → difficult to control growth process

- → since ~ 2011 in-house crystal growth with dedicated **Czochralski** furnace
  - → full control of growth process and materials

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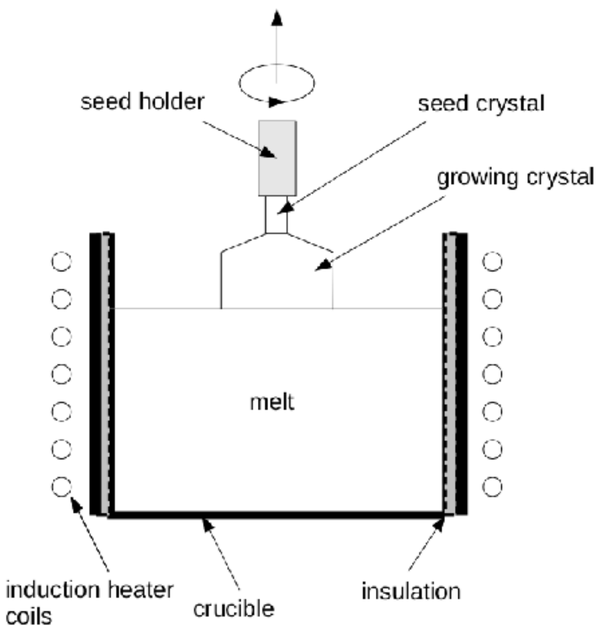

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  → full control of growth process and materials

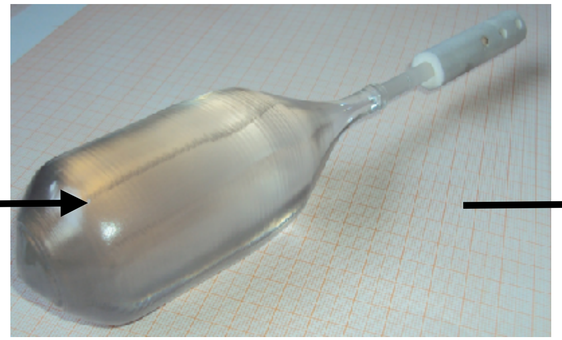
Complete in-house production process:

- Production of raw powder: **$CaCO_3 + WO_3 \rightarrow CaWO_4 + CO_2$**
- Crystal growth in **Rh crucible**
  growth atmosphere: 99%Ar / 1% O_2
- Post growth treatment (**annealing**) to improve optical quality (100% O_2 @ 1400°C for 20h)
- Cutting & polishing of crystals

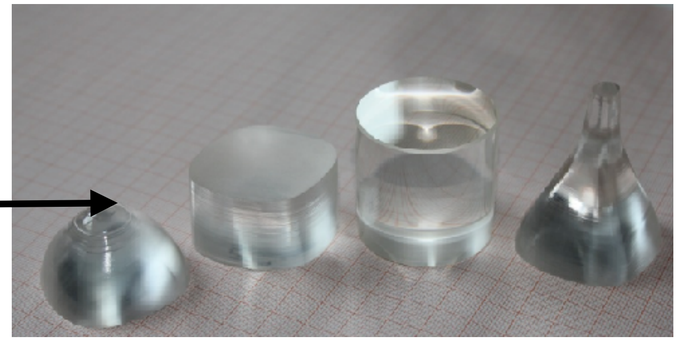
CrystEngComm 15 (2013) 2301–2304

CaCO3 + WO3

CaWO4

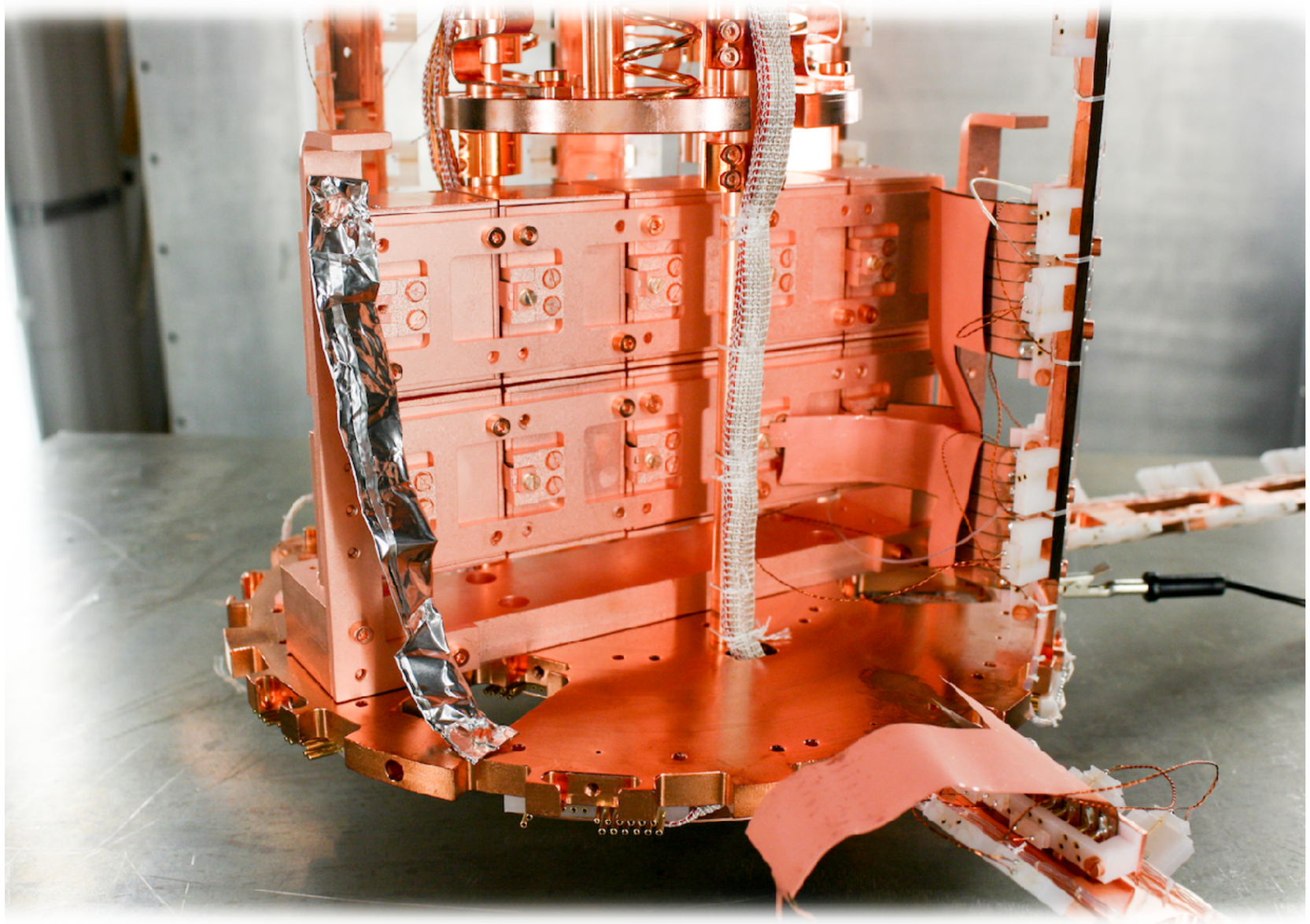


Crystal growth & annealing



Cutting & Polishing

CRESST-III — Status



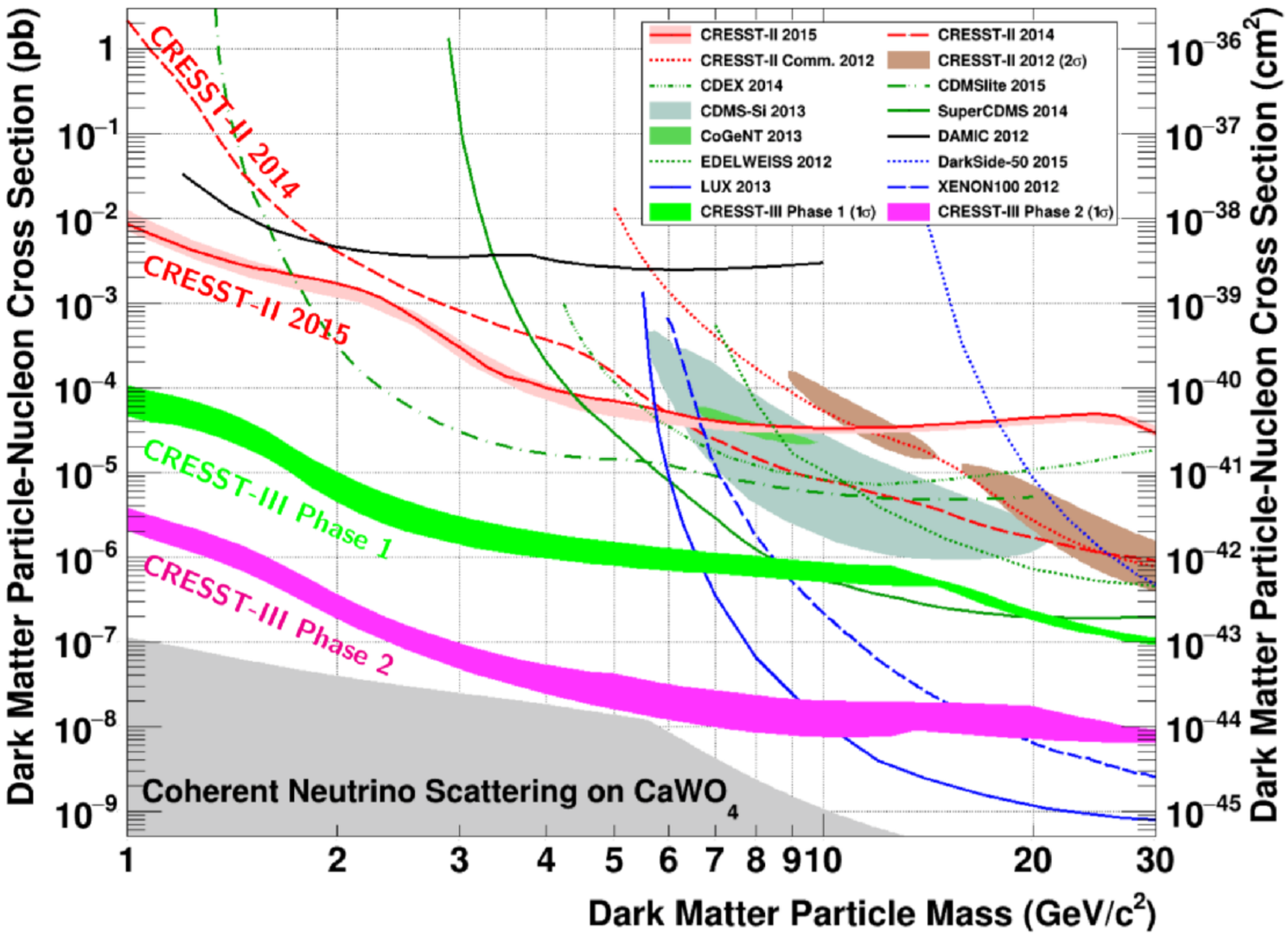
CRESST III Phase 1
currently ongoing!

→ 10 detector modules assembled & installed at LNGS
→ Installed $CaWO_4$ crystals:
- 5 self-grown crystals (TUM40 quality)
- 3 self-grown crystals (from additionally cleaned raw materials)
- 2 commercial crystals

→ Detector mounting finished **May 2016**
→ cool down of cryostat **June 2016**
→ Setup of detectors: **July - September 2016**
→ Calibration:
γ - calibration: **Oct. 2016**
n - calibration: **April 2017**

→ First results expected July / August 2017

CRESST-III — Projections



CRESST III Phase 1

- 10x 25g detectors
- operated for ~ 1 year

→ 50 kg days

- E_{thr} = 100 eV
- Maintain crystal radiopurity

CRESST III Phase 2

- exposure: **1000 kg days**
- intrinsic background: reduction by **100x**
- same detector performance as phase 1 (E_{thr} = 100 eV)

→ **Major upgrade of experimental infrastructure:** increase number of detectors to ~ 100 (300 SQUID channels)

arXiv:1503.08065 & Journal of Physics: Conference Series **718** (2016) 042048

Summary & Conclusion

CRESST → World leading DM limit below ~ 1.7 GeV / c^2

CRESST-III detector technology:

- Precise measurement of low-energetic nuclear recoils
- Very low threshold: E_{thr} < 100 eV
- Fully scintillating detector housing & rejection of holding structure related backgrounds
- TUM-grown crystals provide improved radiopurity

→ CRESST III has high potential to explore low-mass dark matter parameter space below ~ 3 GeV / c^2

Stay tuned!

Thank you for your attention!