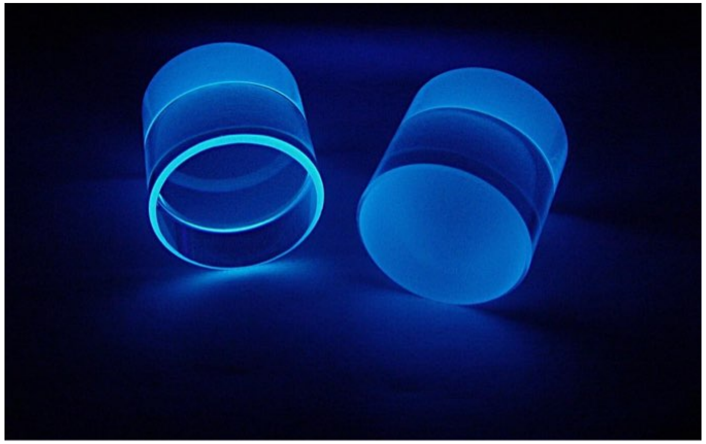

Direct Dark Matter Search with the CRESST Experiment

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HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

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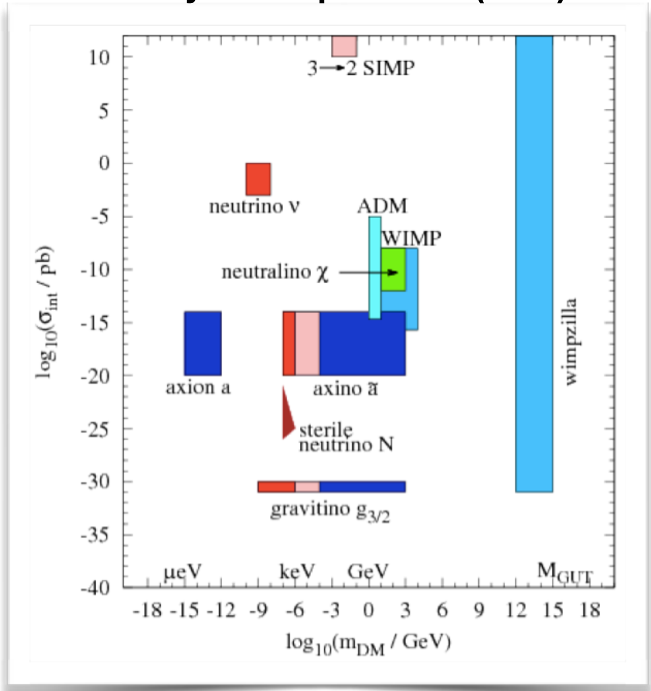
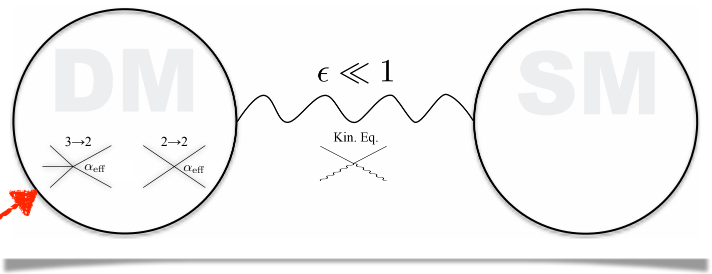
Unraveling the Particle Character of Dark Matter

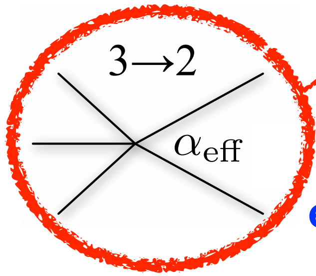
- clear evidence for dark matter on different scales
    - observation of dark matter based on gravitational pull only
- undiscovered new particles well motivated candidate for dark matter
- mass region below the WIMP mass scale (“**low mass dark matter**”) recently gained a lot of theoretical interest

Physics Reports 555 (2015) 1–60



Physical Review Letters 113 (2014) 171301

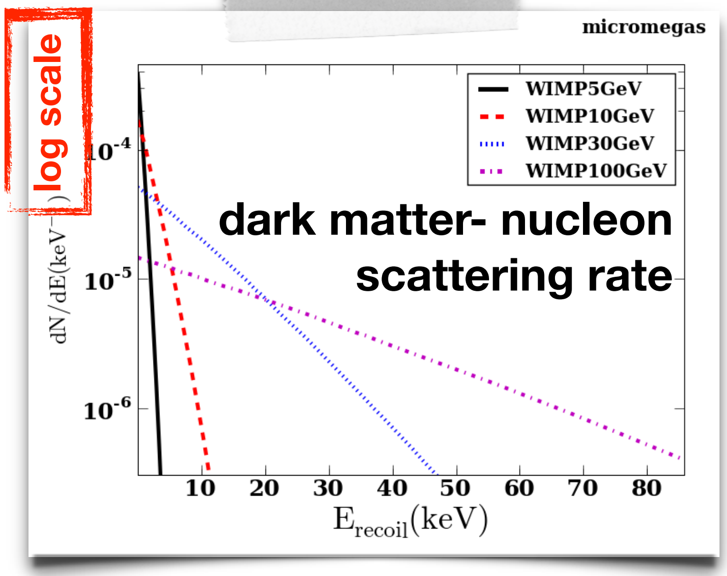


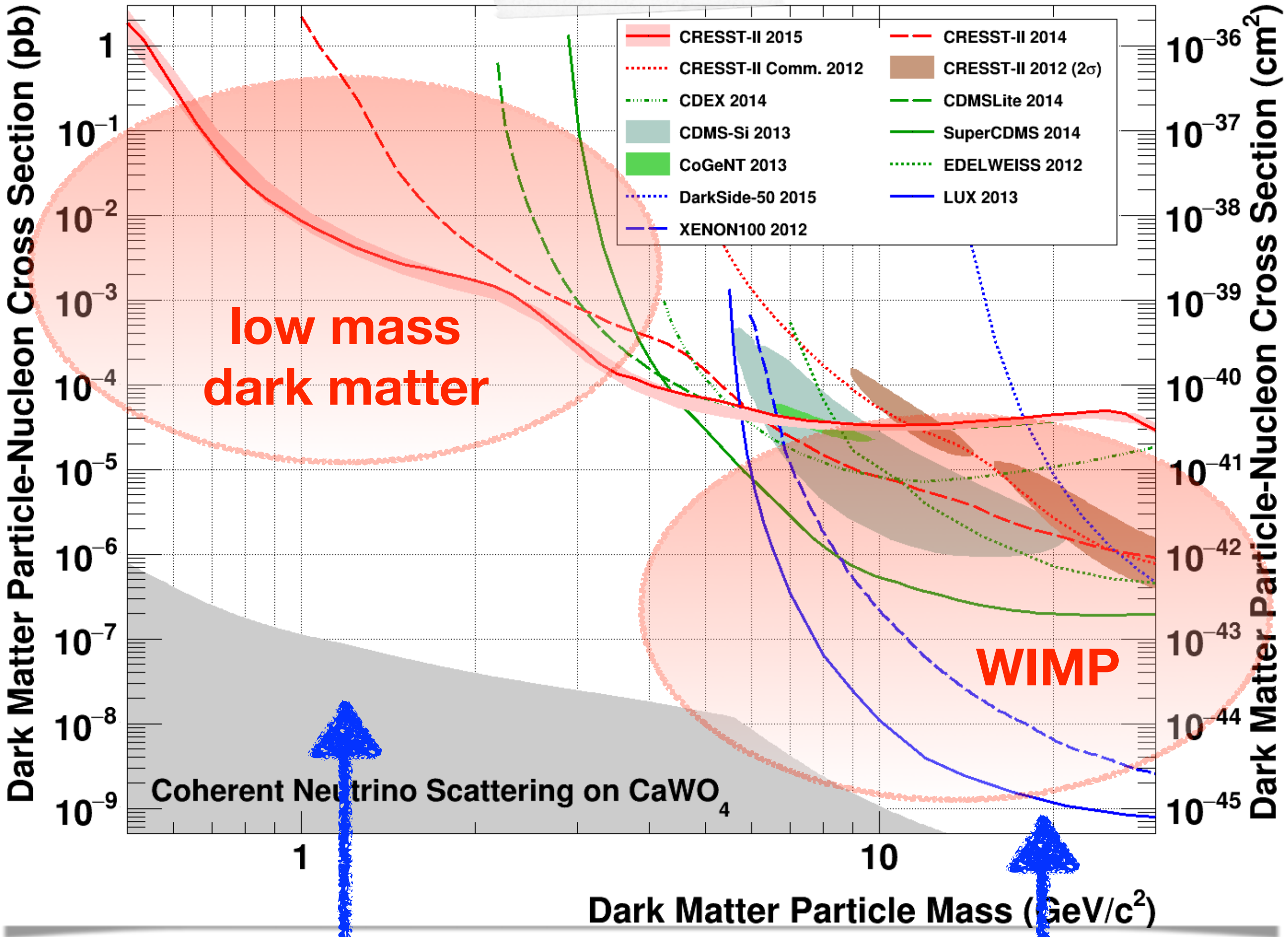


strongly interacting dark matter- expected mass scale ~ 100 MeV/c²

The Dark Matter Landscape - Detector Challenge

- different mass regions have different requirements on the detector technology
- low mass dark matter requires low detection threshold





detection threshold

exposure

The CRESST Experiment

The CRESST Collaboration

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

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

TECHNISCHE UNIVERSITÄT MÜNCHEN

LNGS

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

TU WIEN

UNIVERSITY OF OXFORD

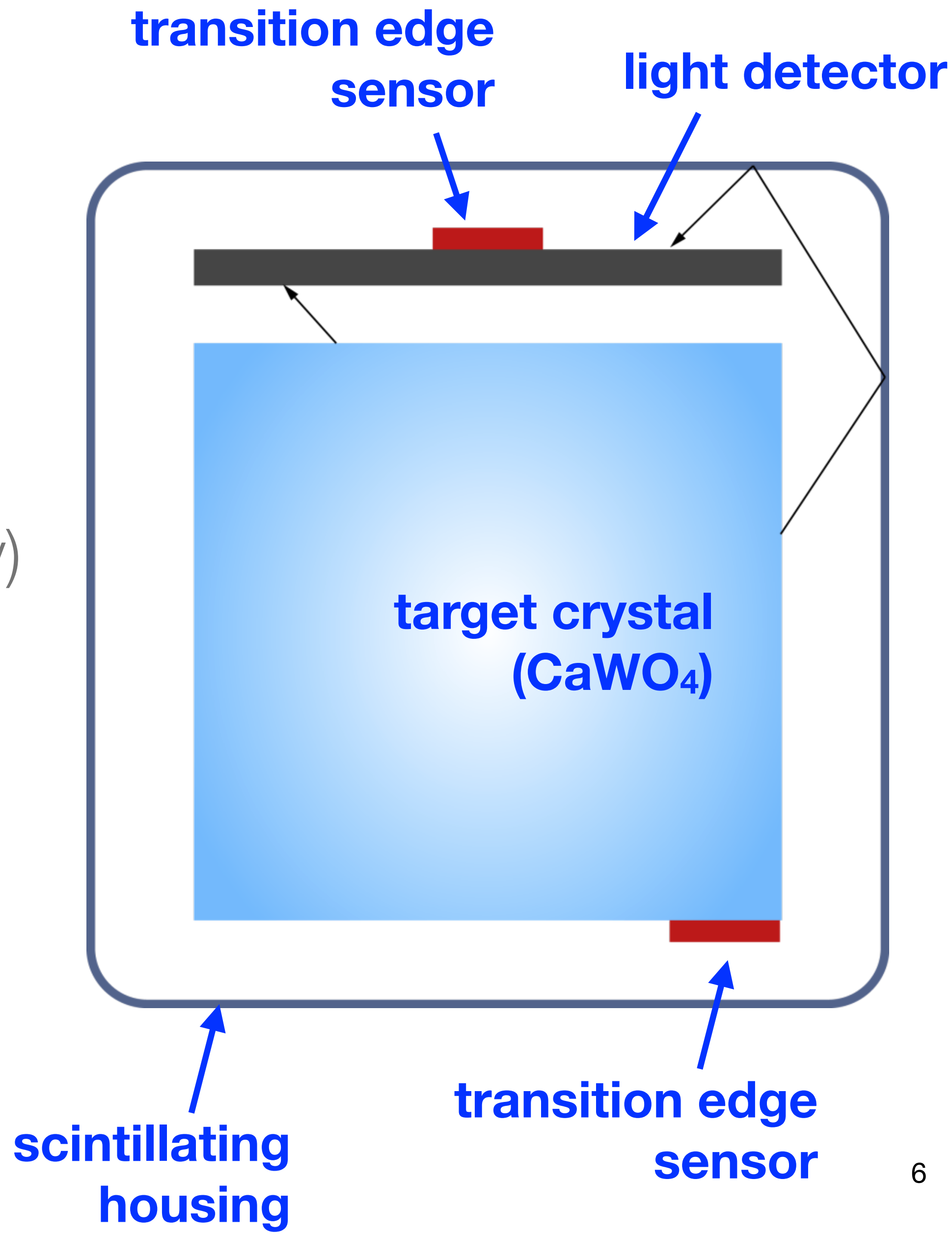
About 40-50 scientists from 6 institutions and 4 countries

CRESST - Detection Principle I

simultaneous read-out of two signals

- **phonon channel:**
  particle independent measurement of deposited energy (= nuclear recoil energy)

- **(scintillation) light:**
  different response for signal and background events for background rejection ("quenching")



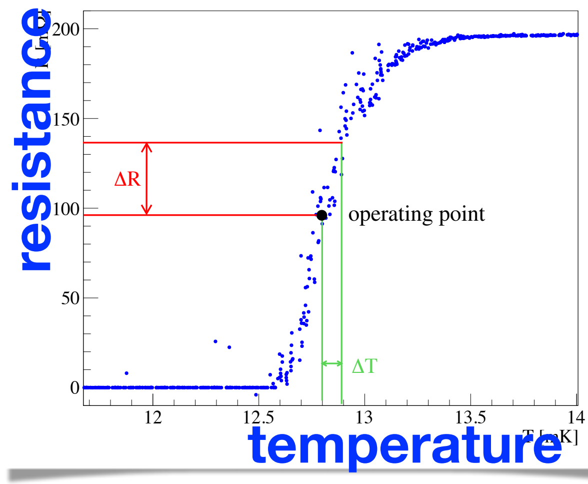
CRESST - Detection Principle II

- experiment operated at cryogenic temperature (~15 mK)
- nuclear recoil will deposit energy in the crystal leading to a temperature rise proportional to energy

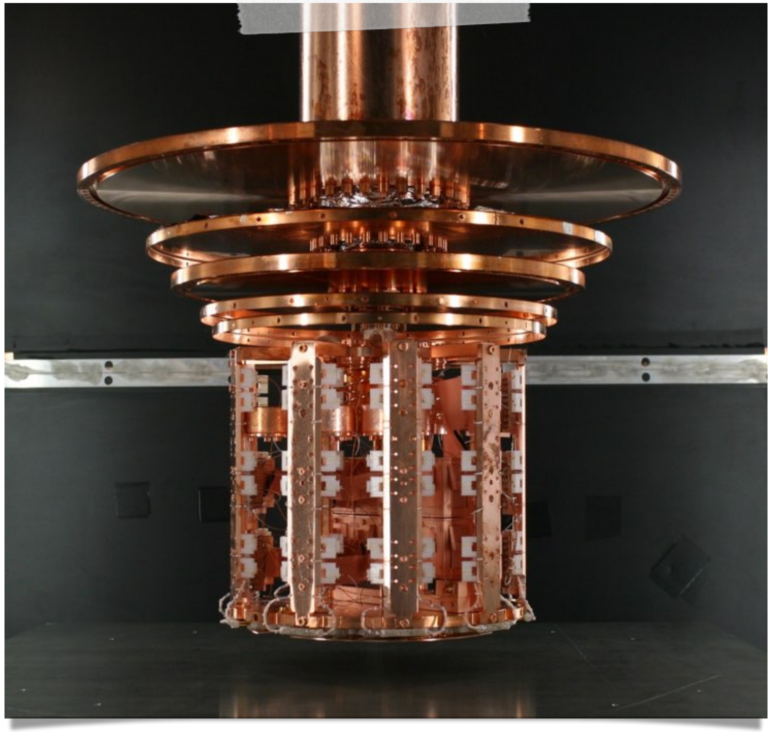
$$\Delta T \propto \frac{\Delta Q}{c \cdot m} \qquad c \propto (T/\theta_D)^3$$

Θ_D:Debye temperature

- detection of small energy depositions requires very small heat capacity C
- detection of temperature rise with superconductor operated at the phase transition from normal to superconducting



CRESST - Detector Module

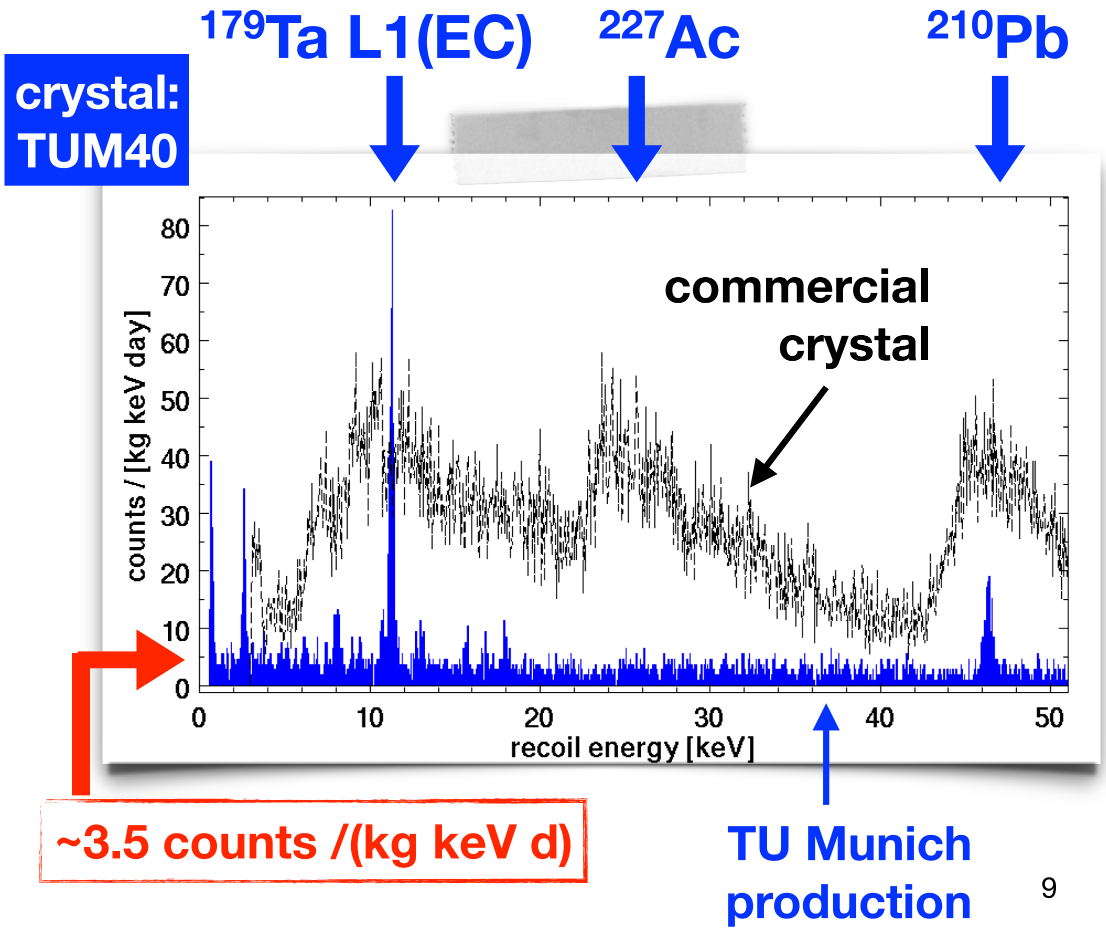


- $CaWO_4$ crystal placed inside fully scintillating and reflective housing
- modules operated in shielded cryostat in the Laboratori Nazionali del Gran Sasso (Italy) at 3600 mwe

Crystal Intrinsic Background

crystal production at TU Munich

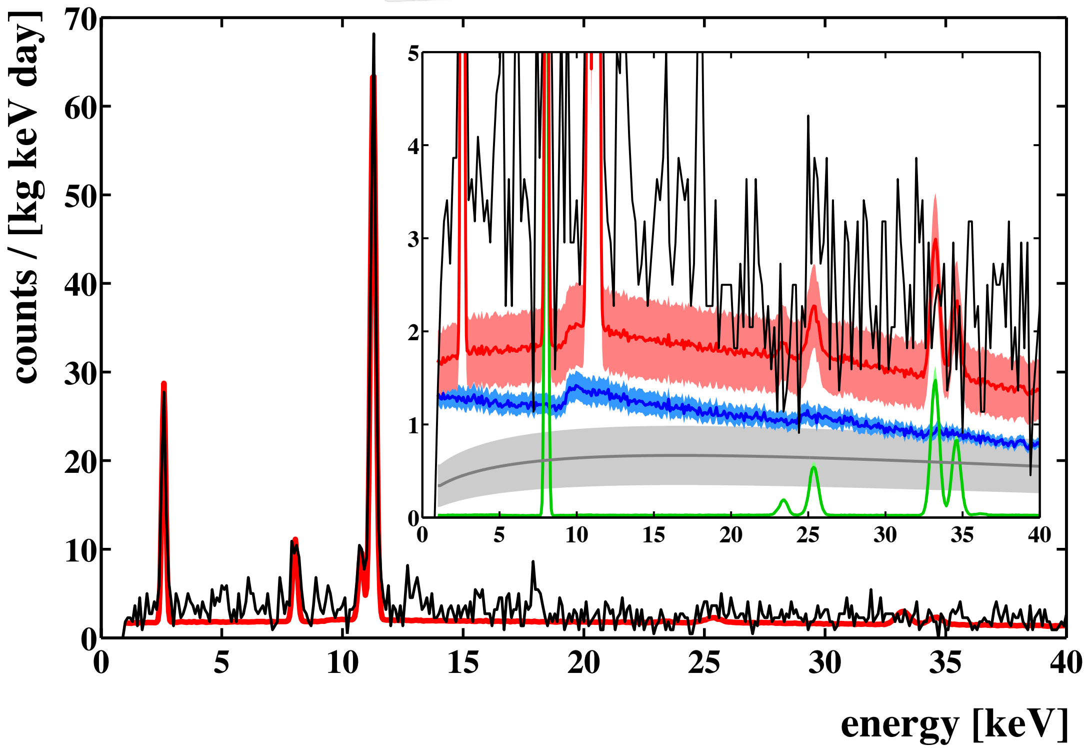
- experimental sensitivity limited by background
  - CRESST dominated by crystal-intrinsic radioactive contaminations
- in-house production of $CaWO_4$ crystals improves radio purity significantly



Background Simulation of CRESST Data

- understanding of background crucial
- Geant4 based simulation to estimate intrinsic background
- use measured α-activity as input for Geant4 to determine intrinsic β/γ radiation

JCAP, 2015(06), 030

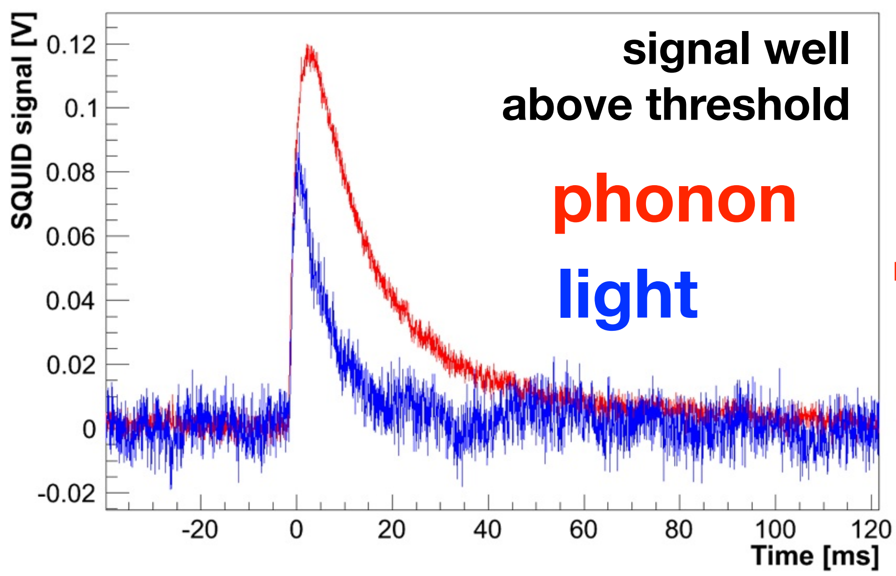


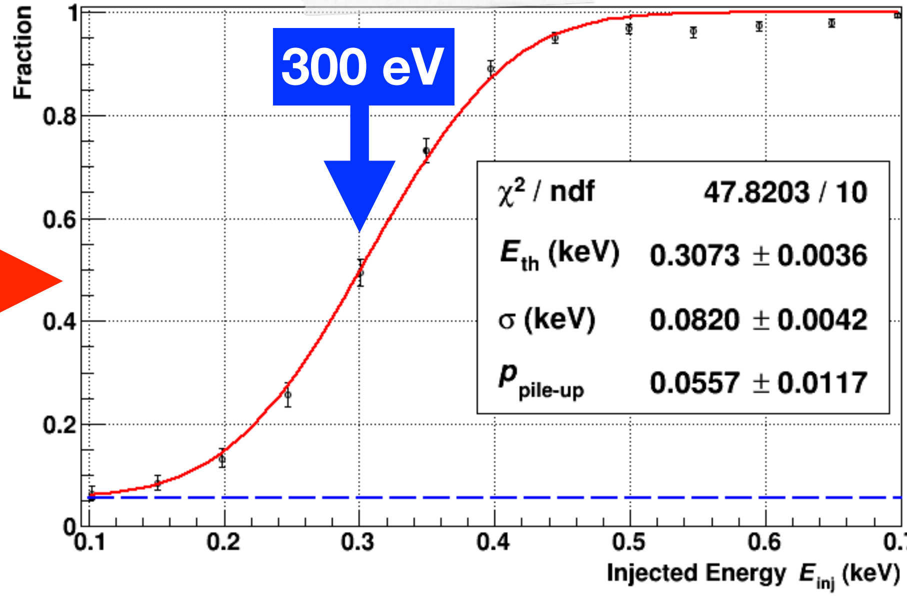
green: external gamma radiation
gray: external betas
blue: intrinsic β/γ radiation from natural decay chains
red: sum + cosmogenic activation

crystal: TUM40

Data collected with CRESST II

Detection Threshold



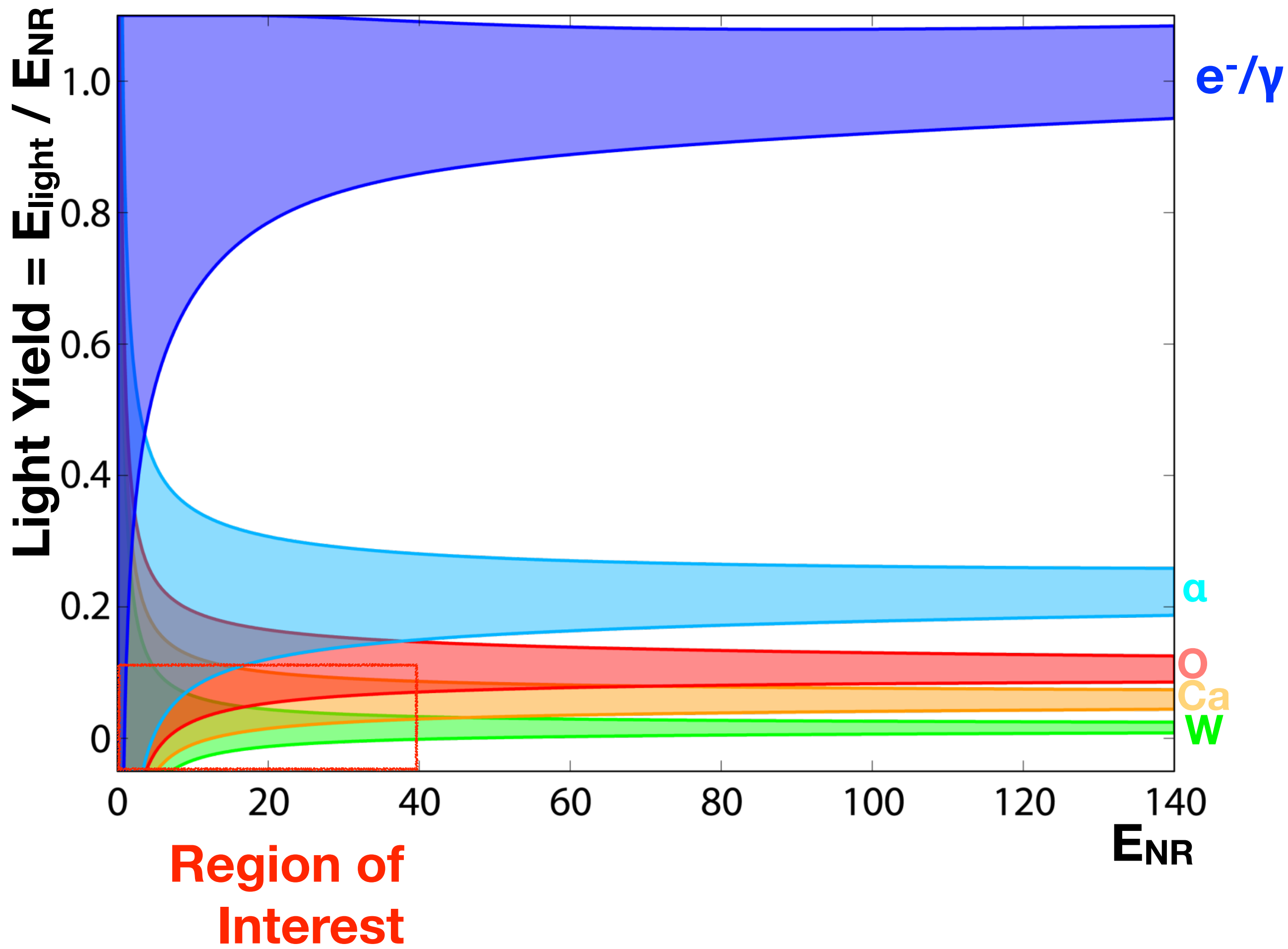


- simultaneous read out of phonon and light channel
- signal height proportional to deposited energy in the corresponding channel

- detection threshold determined with low-energy heater pulses
- energy threshold at ~300 eV for nuclear recoil

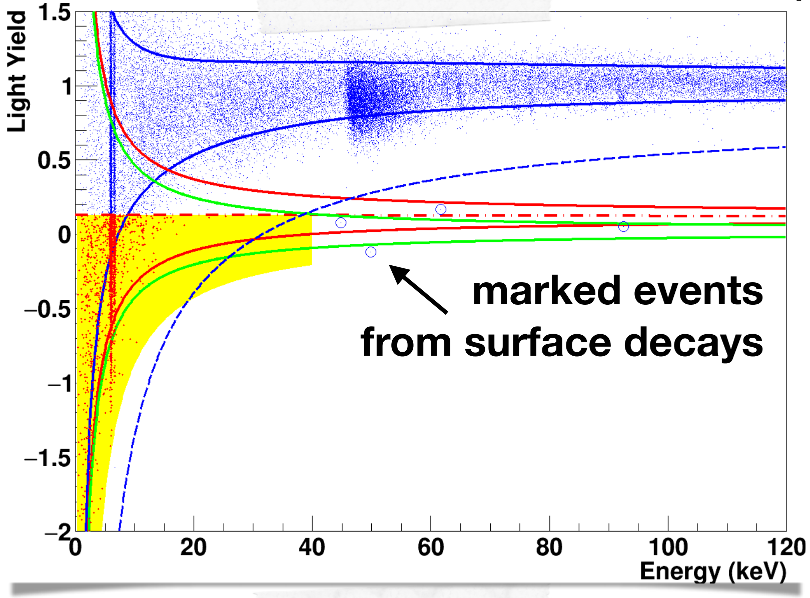
Signal-Background Separation

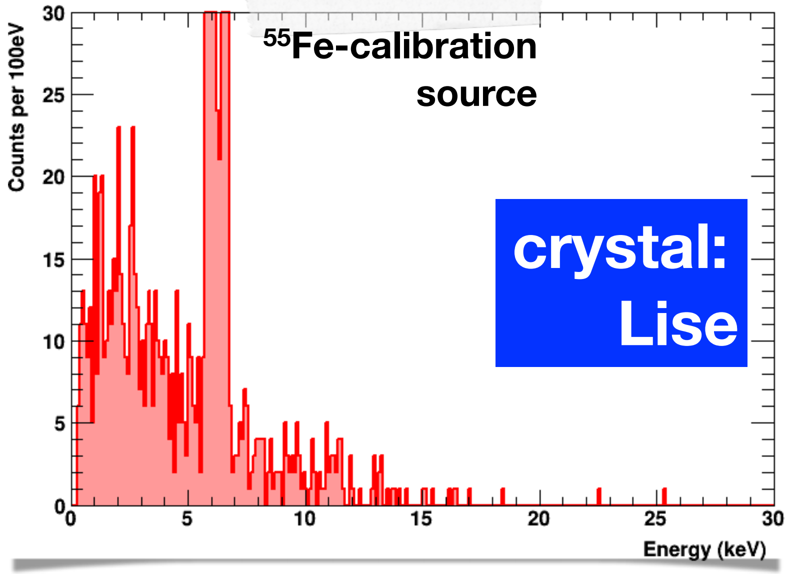
- simultaneous readout of light and phonon channel allows background reduction
- less scintillation light from dark matter-nucleon scattering
  - clear separation between signal and background at large E_{NR}
  - significant overlap of bands at low energies (= low mass dark matter)



Data Sample

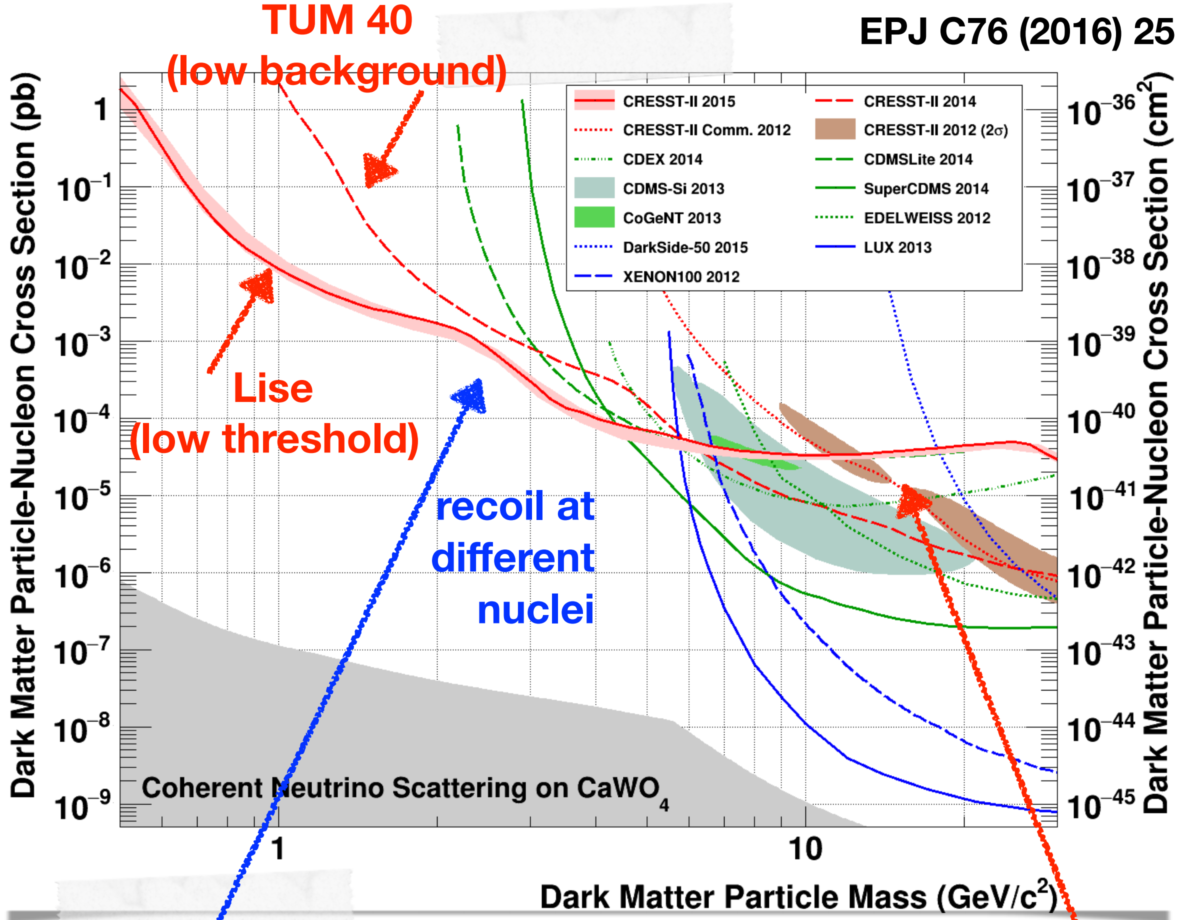
EPJ C76 (2016) 25

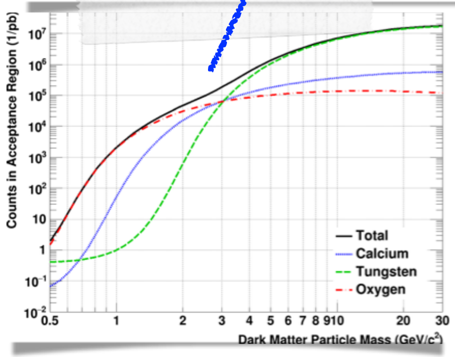




- data collected with a single detector module
  - commercial crystal with higher intrinsic e-/γ-background
  - trigger threshold of 300 eV
- interpretation of data using standard astrophysical assumptions
- limit set with Yellin's optimum interval method (conservative limit)

CRESST II limit for low mass dark matter





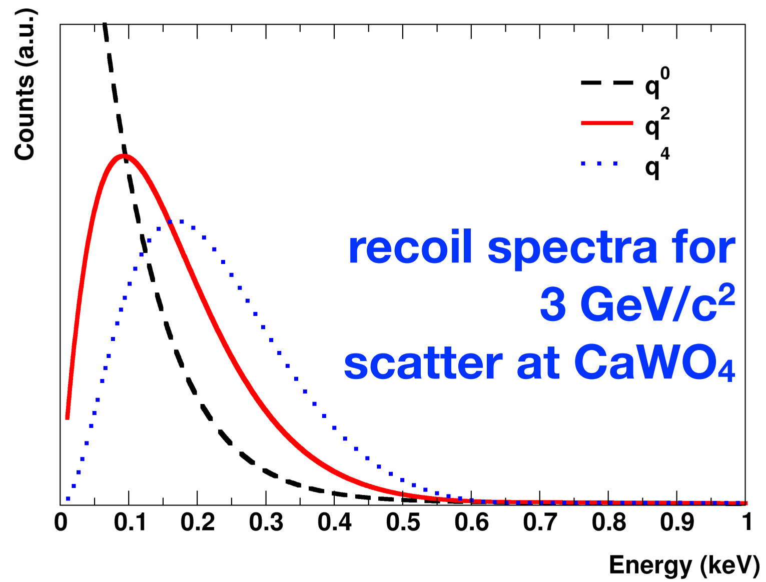
expected number of counts for $\sigma_{\chi\text{-}n}$=1pb in the acceptance region

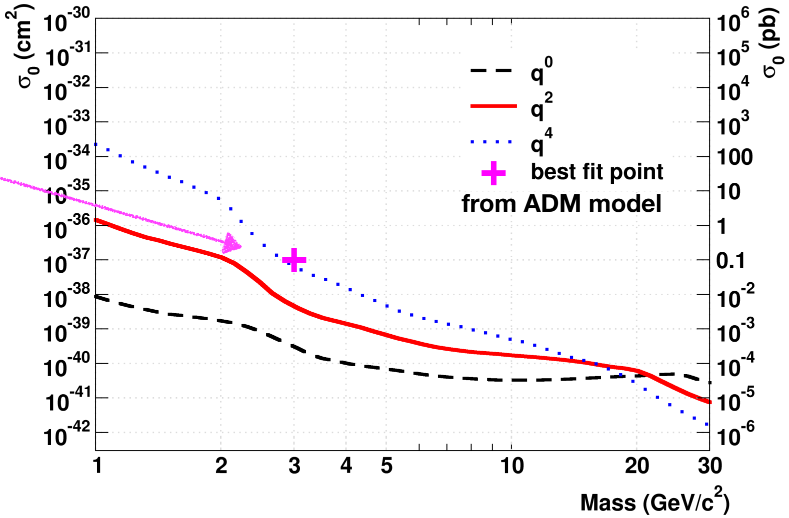
reduced sensitivity due to surface ^{55}Fe

- energy threshold and background conditions have impact to different mass regions
- CRESST technology offers high potential towards scattering of low mass Dark Matter

Momentum Dependent Cross-Section

- disagreement between helio-seismological data and solar models (Phys. Rev. Lett. 114, (2015) 081302)
- momentum dependent asymmetric dark matter (ADM) can resolve problem
  - preferred dark matter mass of 3 GeV/c^2 and $\sigma_{X\text{-}n}=10^{-37}$ cm^2
- reinterpretation of CRESST data assuming momentum dependent cross-section (Angloher et al., PRL 117 (2016) 021303) rules out the proposed best fit point

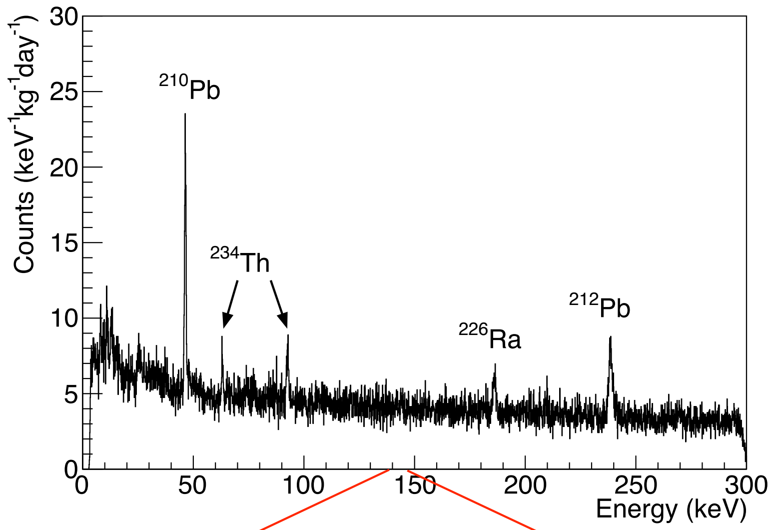


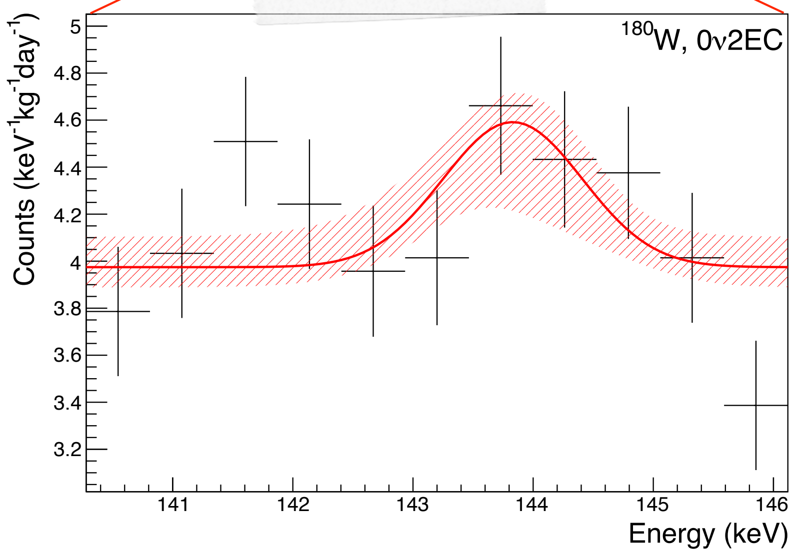


arXiv 1604.08493
accepted for publication

Limits on Double Electron Capture of ^{40}Ca and ^{180}W

- observation of zero neutrino double electron capture (0ν2EC) would prove Majorana ν
- $T_{1/2}$ longer compared to 0ν2β decays
- released energy fully absorbed in the detector →**signal peak**





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Limits on Double Electron Capture of ^{40}Ca and ^{180}W

exp. limit before this work

Isotope	Abundance (%)	Process	Observable Energy (keV)	$T^{exp}_{1/2}$ (y) (90% CL)	$T^{th}_{1/2}$ (y)
^{40}Ca	96.94(16) [17]	$0\nu 2EC$	193.51(2) [18]	$> 3.0 \times 10^{21}$ [19]	-
		$2\nu 2K$	6.4 [20]	$> 7.3 \times 10^{21}$ [19][a]	1.2×10^{33} [21]
^{180}W	0.12(1) [17]	$0\nu 2EC$	143.27(20) [22]	$> 1.3 \times 10^{18}$ [13]	$(1.3 - 1.8) \times 10^{31}$ [6][b]
		$2\nu 2K$	130.7 [20]	$> 1.0 \times 10^{18}$ [13]	$\sim 2.5 \times 10^{28}$ [23]

double electron capture processes studied

- 730 kg.d exposure from data taken between 2009 and 2011
- no signal for 2v2K and 0v2EC observed
- upper limit on lifetime improves by a factor of ~30 compared to previous measurements

Isotope	Process	$T_{1/2}$ [y] CRESST
^{40}Ca	0v2EC	$> 1.4 \times 10^{22}$
	2v2K	$> 9.92 \times 10^{21}$
^{180}W	0v2EC	$> 9.39 \times 10^{18}$
	2v2K	$> 3.13 \times 10^{18}$

Outlook - CRESST III

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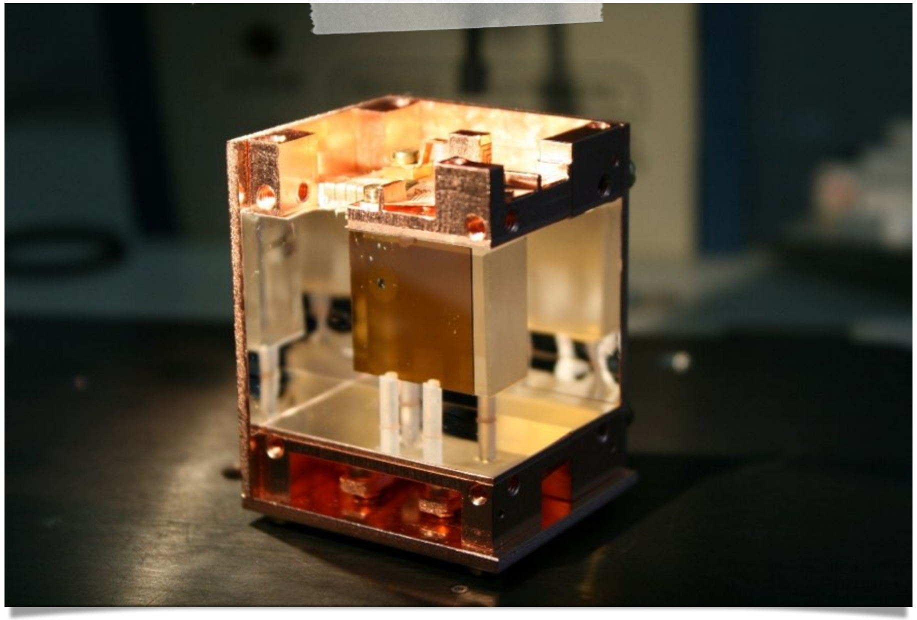
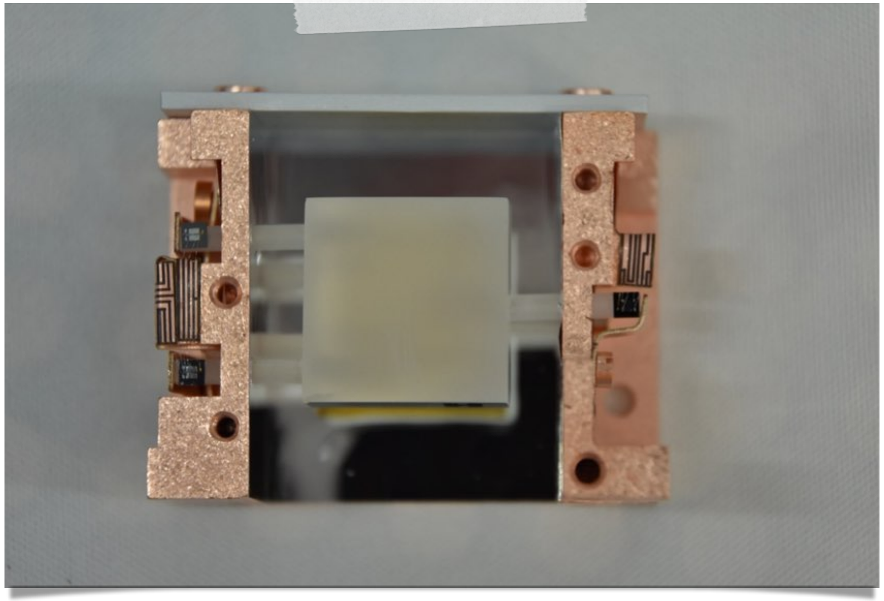
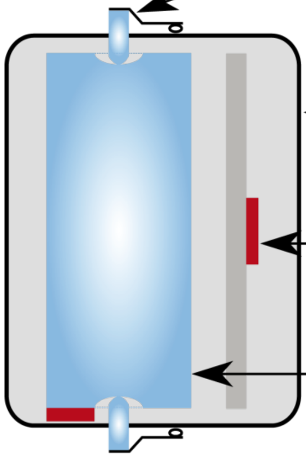


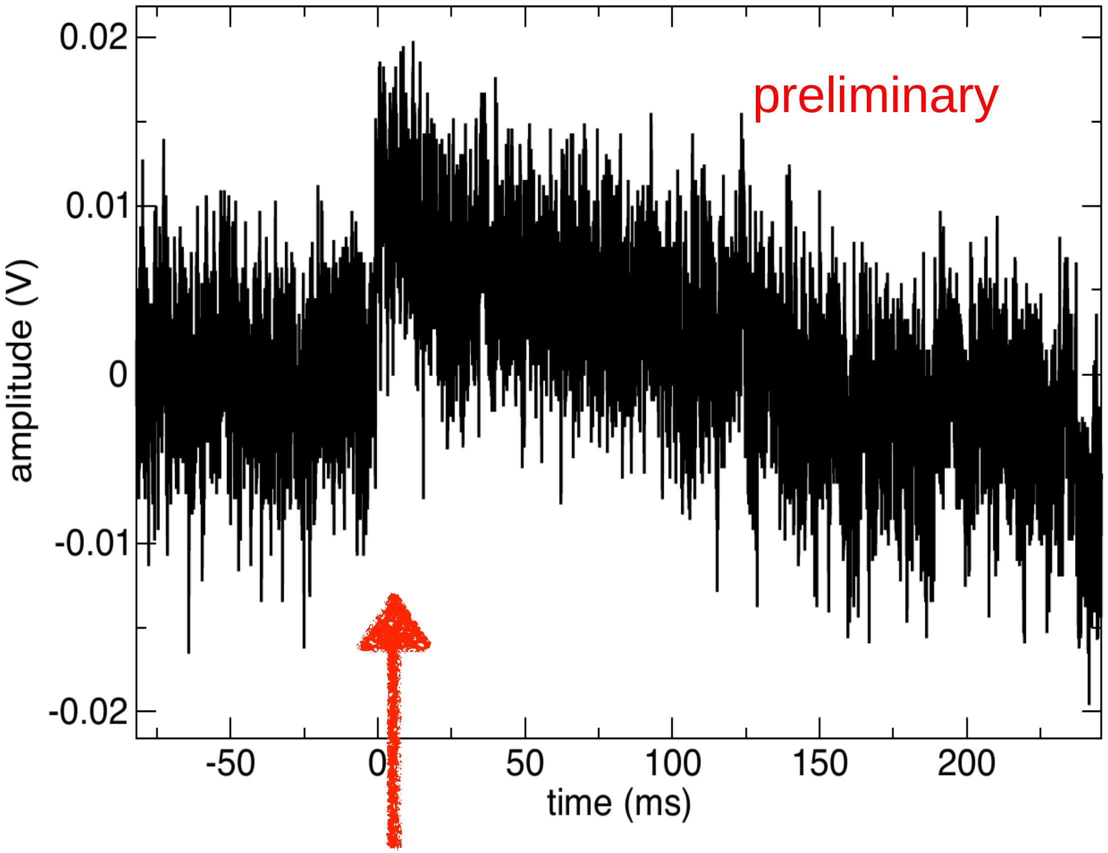




- optimised detector layout with improved detection of scintillation light
- instrumented detector holder (iSticks)
- reduced crystal size (24 g) with reduced heat capacity
- **design goal for threshold: 100 eV**
- intrinsic background level similar to TUM40 crystal

Outlook - CRESST III

- 10 modules installed in cryostat at LNGS
- cryostat reached operation temperature
- extensive calibration campaign started
- start of physics run expected for August 2016

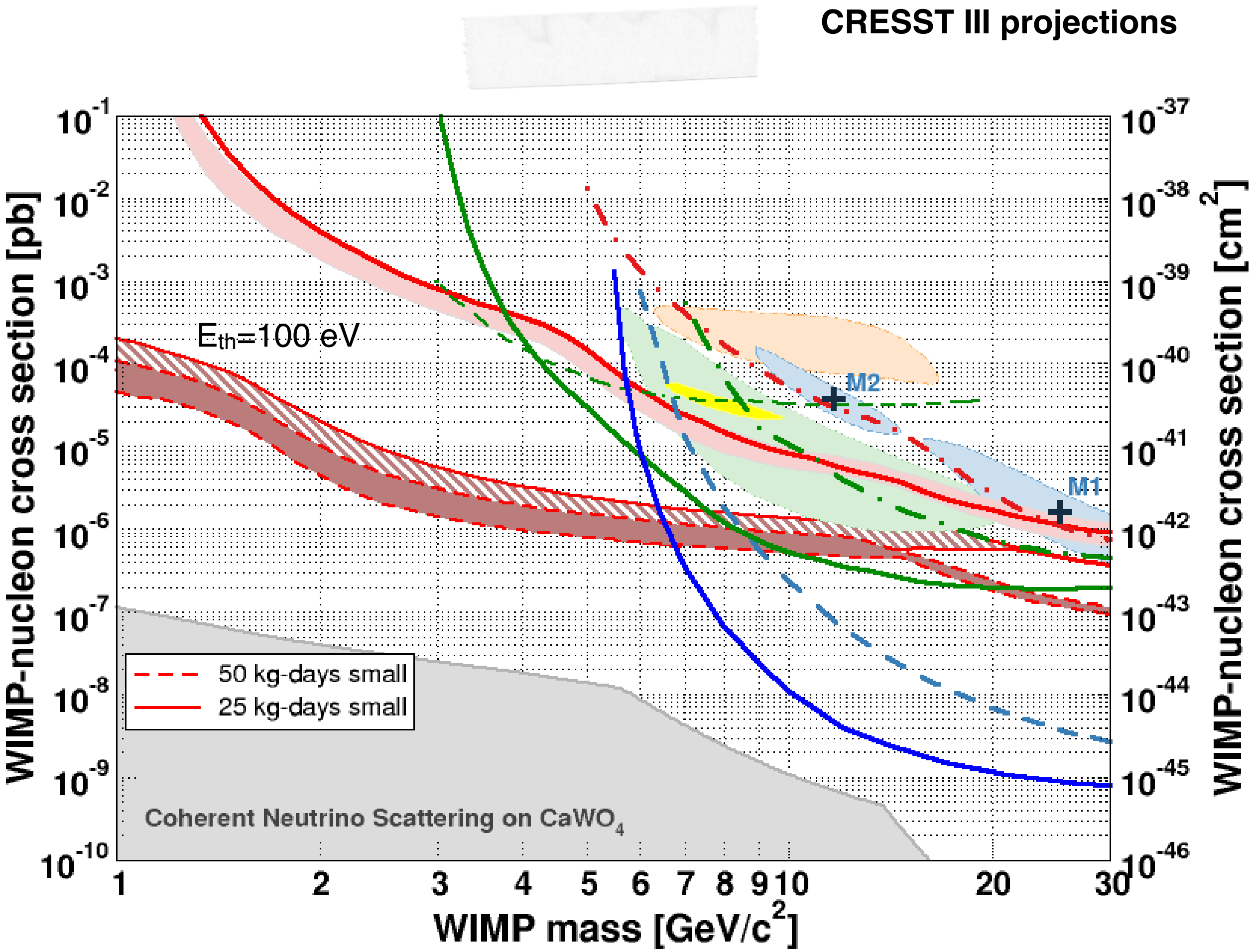


phonon signal of a ~100 eV pulse
➔signal pulse clearly visible

CRESST III - expected sensitivity

- expect to reach $\sigma_{\chi\text{-}n} \sim 10^{-40}$ cm^2 for 1 GeV/c^2 dark matter particles
- detector R&D program for improved radio purity ongoing
- to increase exposure upgrade of read out system planned

arXiv 1503.08065



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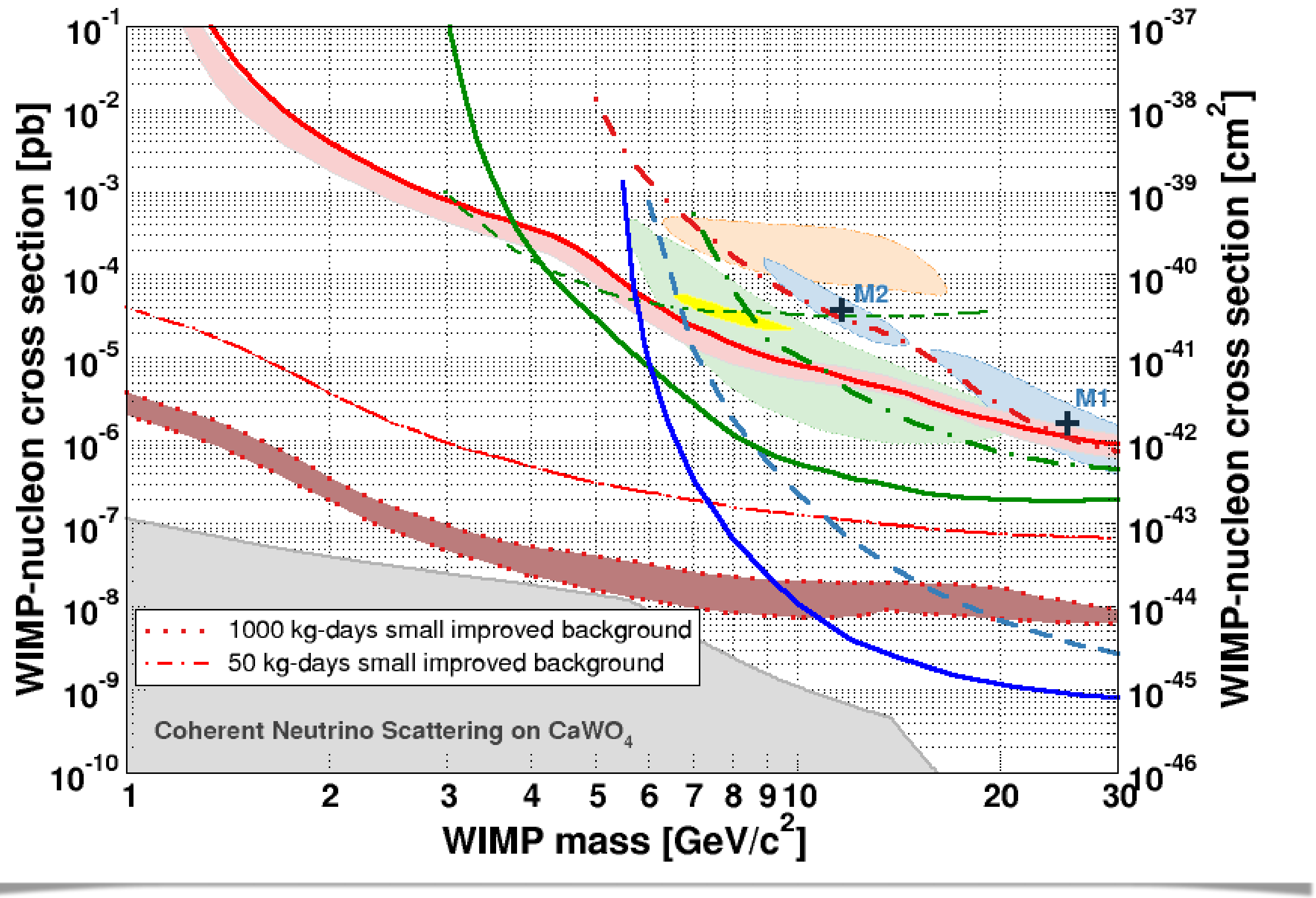

Conclusion and Outlook

- CRESST operates $CaWO_4$ crystals at cryogenic temperatures to search for low mass dark matter particles

- excellent sensitivity to low energy nuclear recoils provide the best sensitivity for dark matter particles < 1.7 GeV/c^2

- new data taking campaign with improved detector modules will start soon

    - expect increase of two orders of magnitude in sensitivity