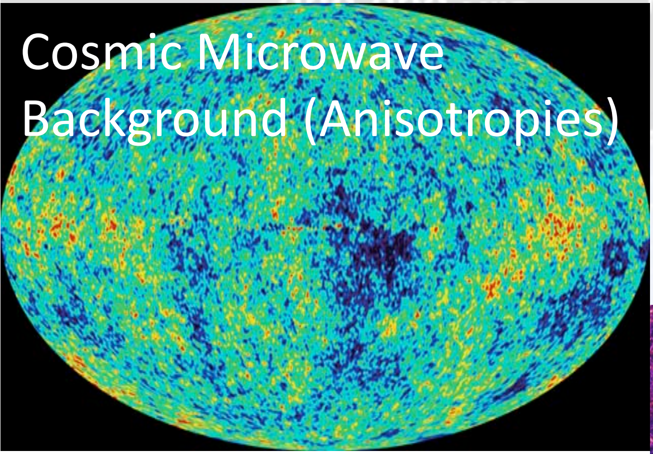
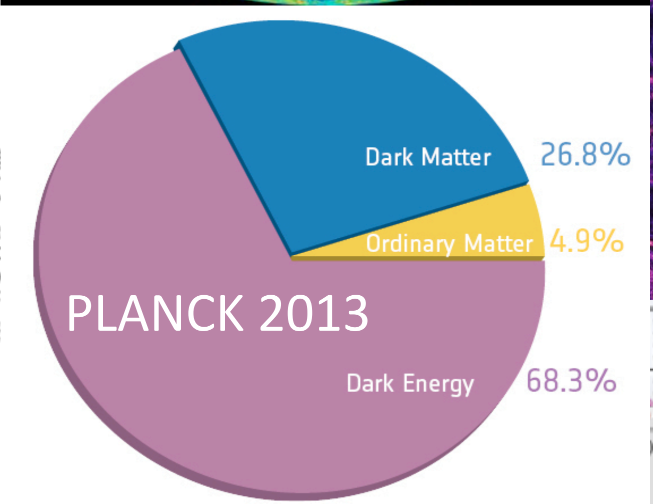
Dark Matter Search with CRESST

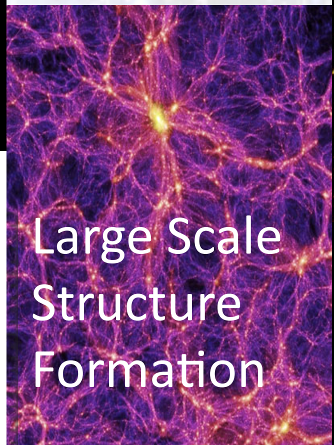
53rd International Winter Meeting on Nuclear Physics

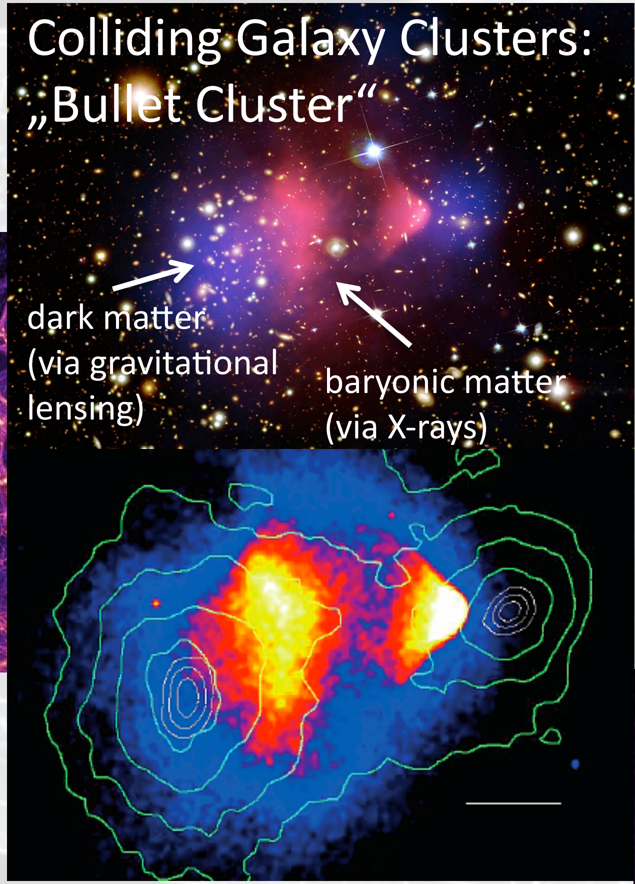
26-30 January 2015, Bormio, Italy

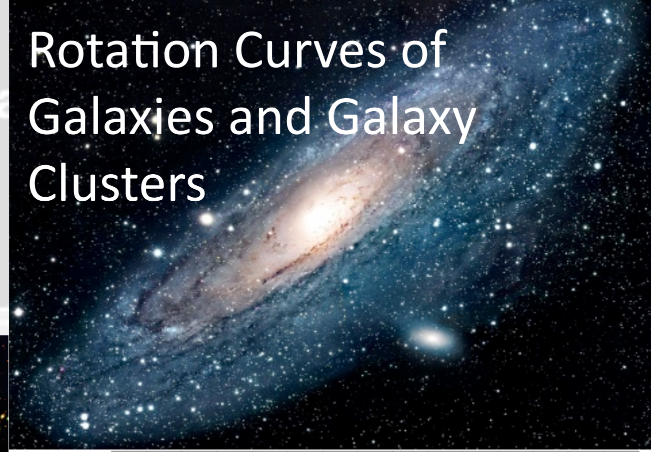
J.-C. Lanfranchi (TU München)

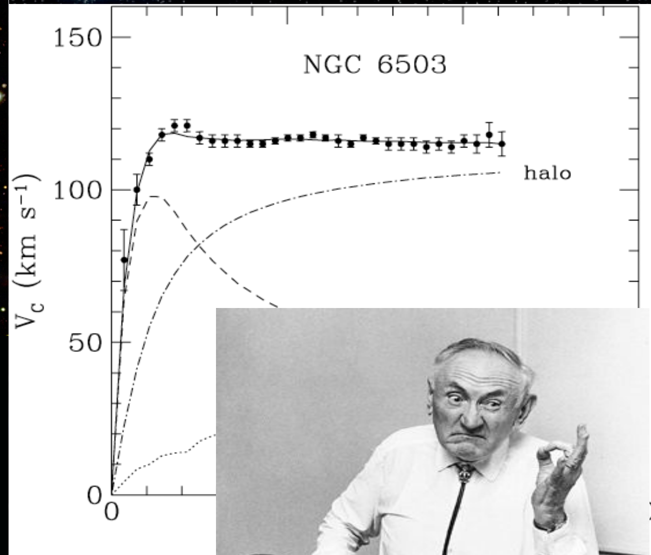


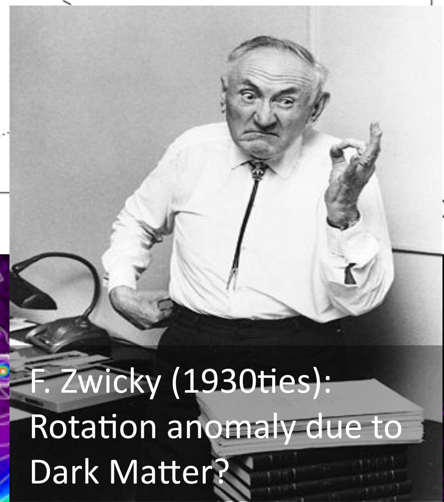


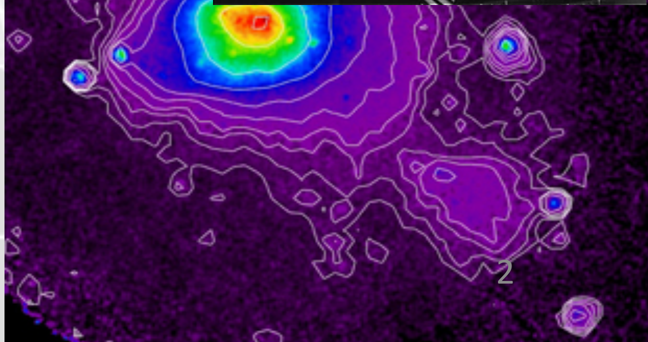






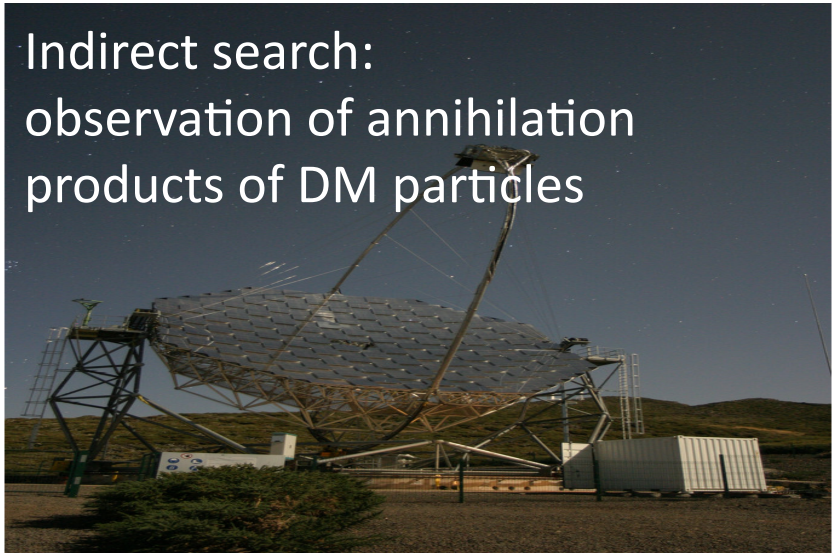


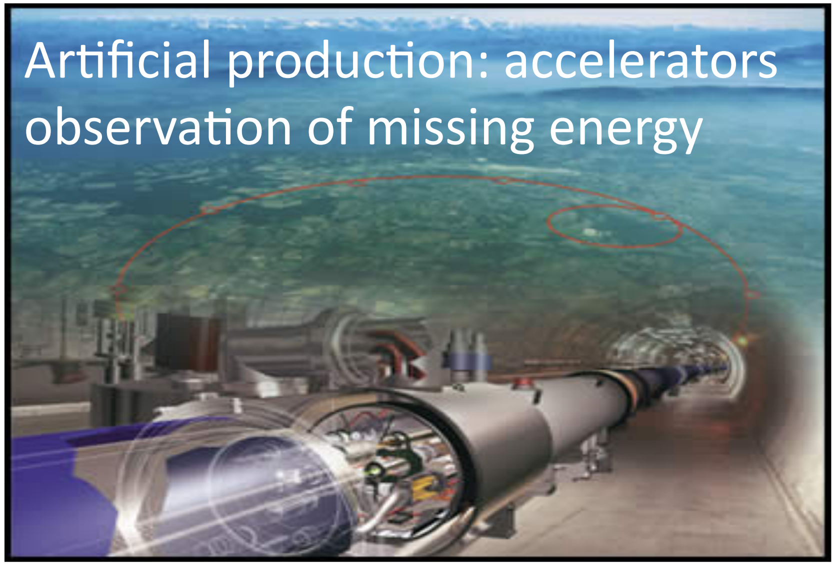




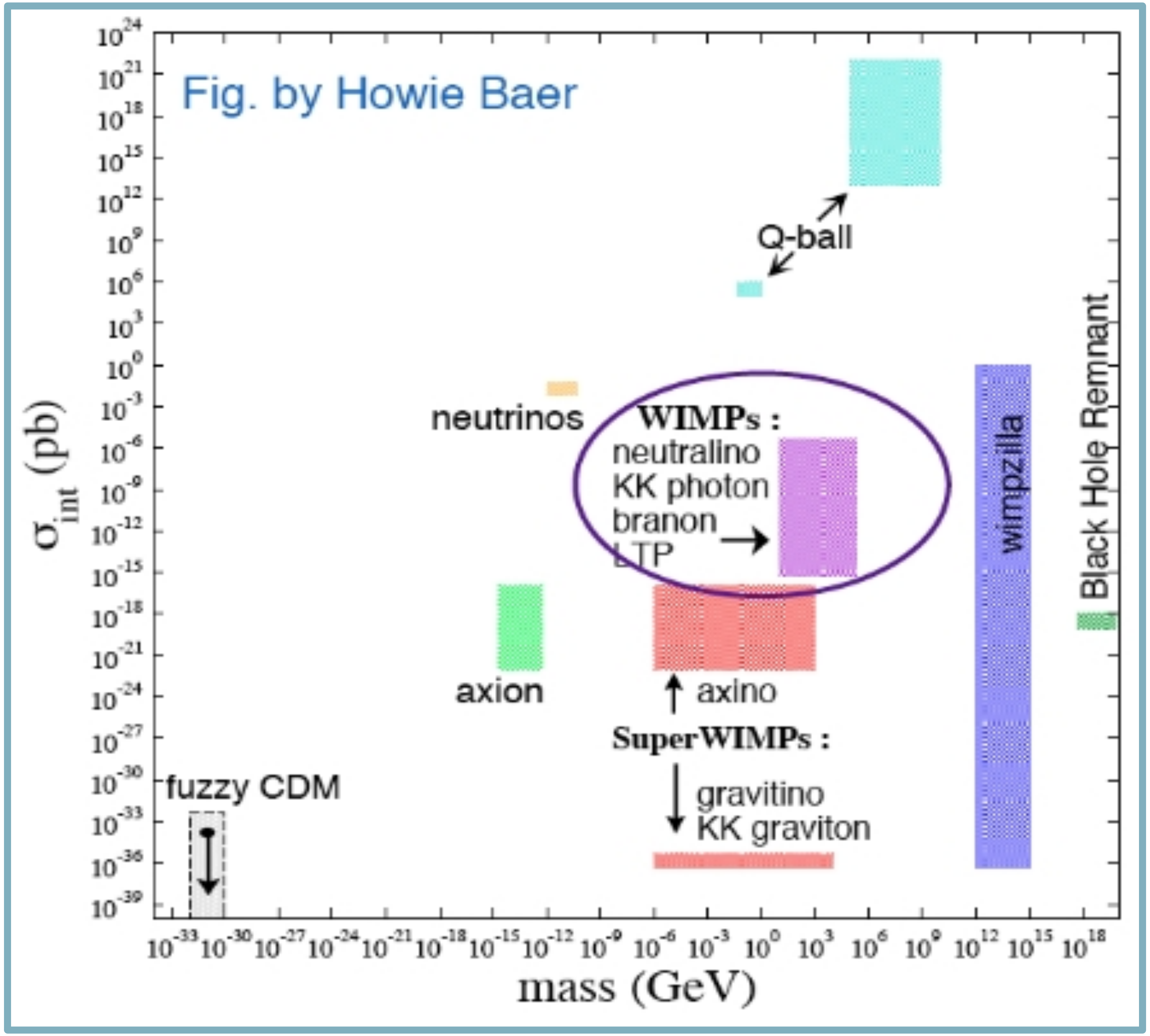
-> Evidence for Dark Matter on all scales in the Universe!

How can we learn about Dark Matter?





Dark Matter Particle Candidates



The universe could plausibly consist of particles ranging from 10^{-6} eV axions to 10^{15} GeV WIMPzillas

➢ **WIMP (Weakly Interacting Massive Particle)** is focused on by various detection experiments

• WIMP could be the lightest supersymmetric particle (LSP)
-> must be stable on cosmological timescales (R-parity conservation)

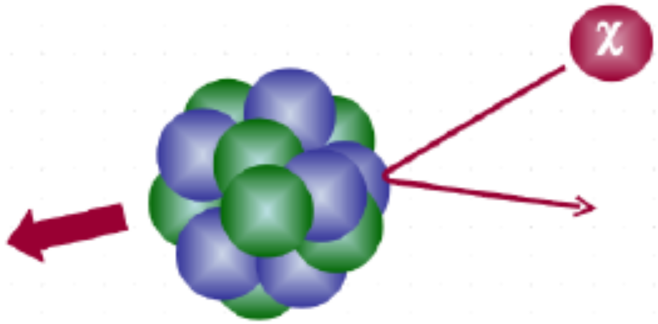
• The lightest neutralino, is a very attractive and thoroughly studied candidate for Dark Matter

Direct Detection Approach

Goal: Detect **WIMP-induced** nuclear recoil in an earth based target material

Standard assumptions:

- WIMP density (ρ_D) at the Earth: ~0.3 GeV/c^2/cm^3
- Spectral shape: exponential towards lower energies
- Wide range of WIMP masses: 1 – 1000 GeV/c^2
- Expected signature: nuclear recoil (of a few keV)
- Expected scattering behaviour (if spin independent): coherent, i.e. ~ A^2
- Single scatters distributed uniformly in target volume
- Extremely rare interaction rate with baryonic matter **(< 0.01 evts/kg/d)**



$$\frac{\partial R}{\partial E_R} \propto N F^2(\vec{q}) \frac{\rho_D}{M_D} \sigma_\chi e^{-\frac{E_R}{E_0}}$$

R	measured rate in detector	E_R	recoil energy of target nucleus
M_D	mass of WIMP	σ_χ	WIMP nucleus cross section
N	number of target nuclei	F^2	nuclear Form factor

→ suppress natural radioactivity and cosmic radiation by orders of magnitude:

- Deep **underground facilities**
- **Additional shielding** with selected materials
- Detectors with very **low energy threshold** and excellent **background discrimination** capability!

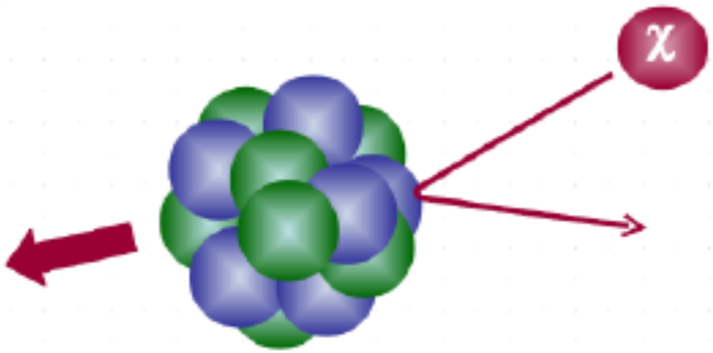
Direct Dark Matter (WIMP) Detection Approach

Expected WIMP „signature“ -> nuclear recoil of only a few keV

Phonons

SuperCDMS
EDELWEISS

CRESST



Ionization

Background is a big issue!

Scintillation

XENON

CRESST (Cryogenic Rare Event Search with Superconducting Thermometers)

CRESST experimental setup in Hall A at LNGS

Collaborating institutes

Spokesperson: F. Petricca, MPI

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

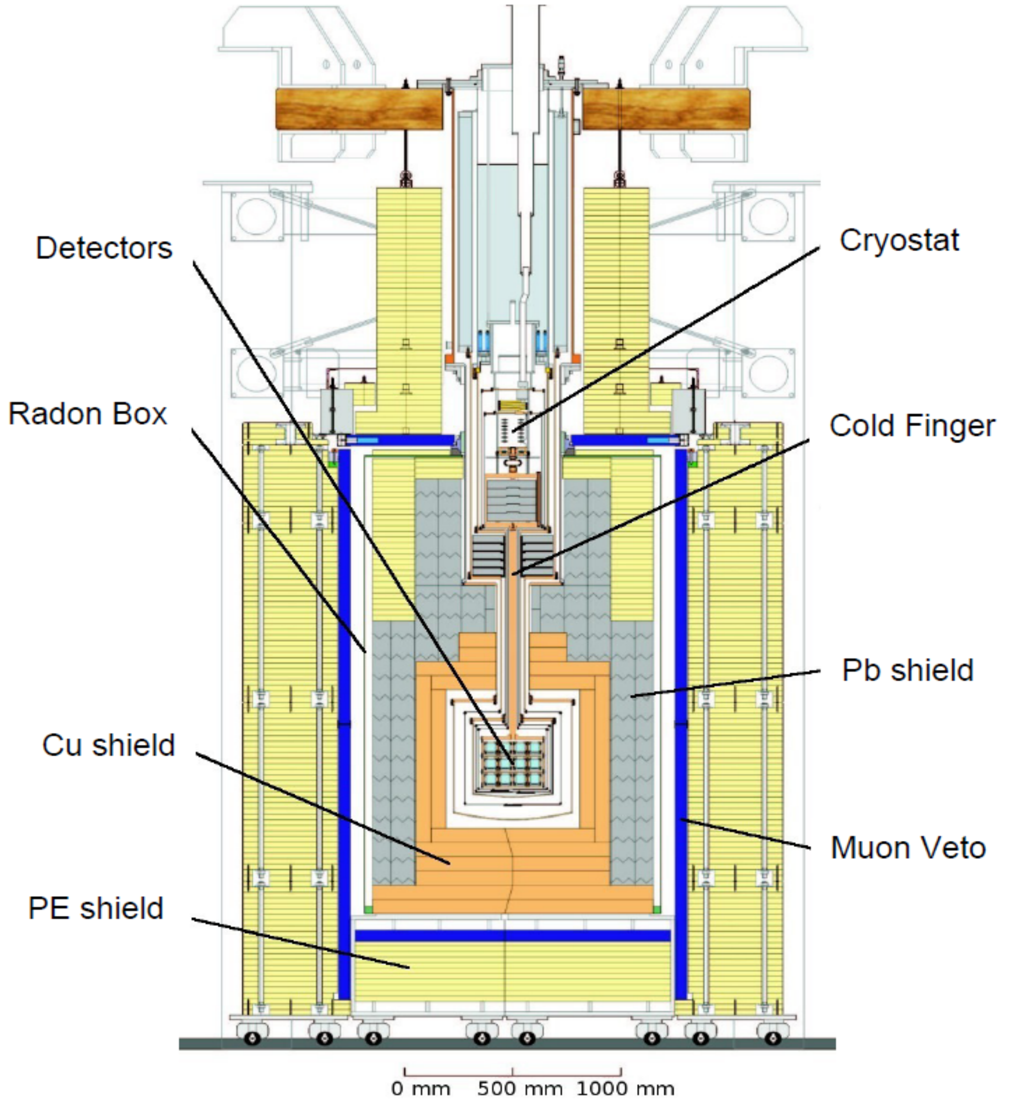
Technische Universität München

LNGS

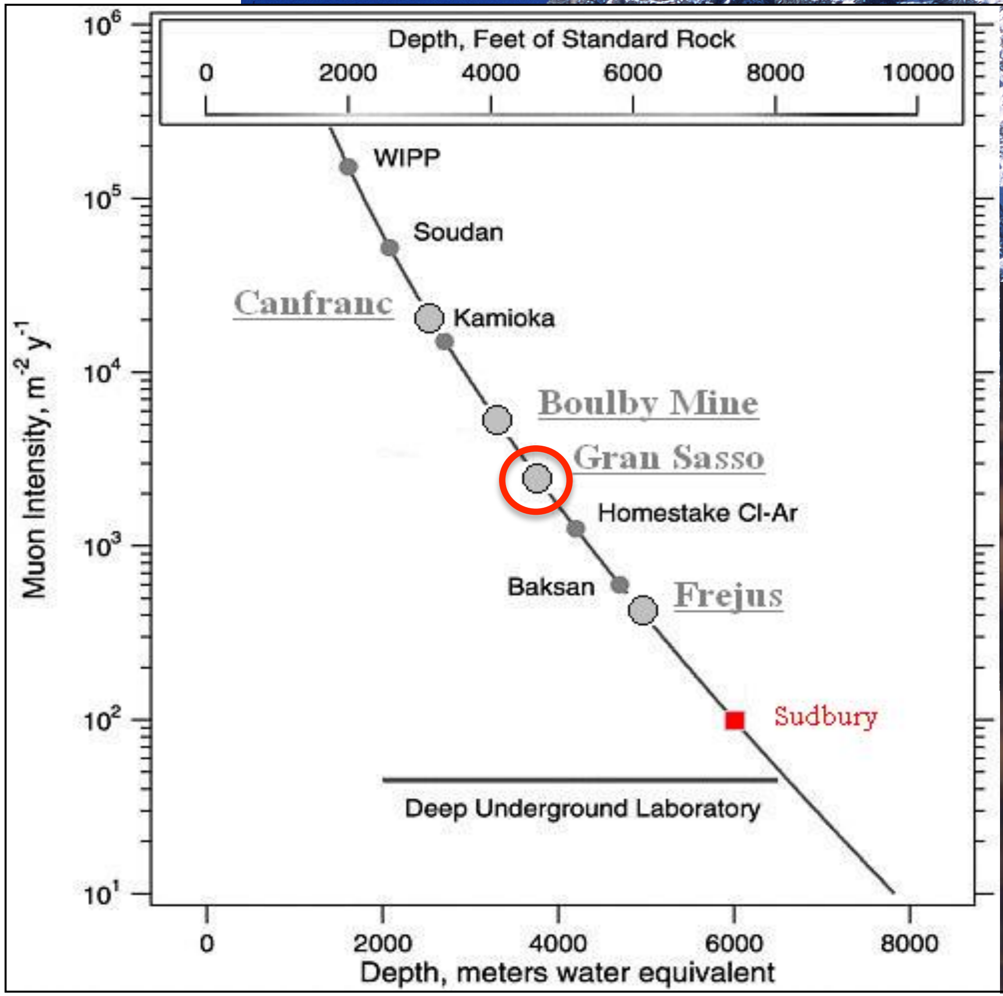
Eberhard Karls Universität Tübingen

University of Oxford

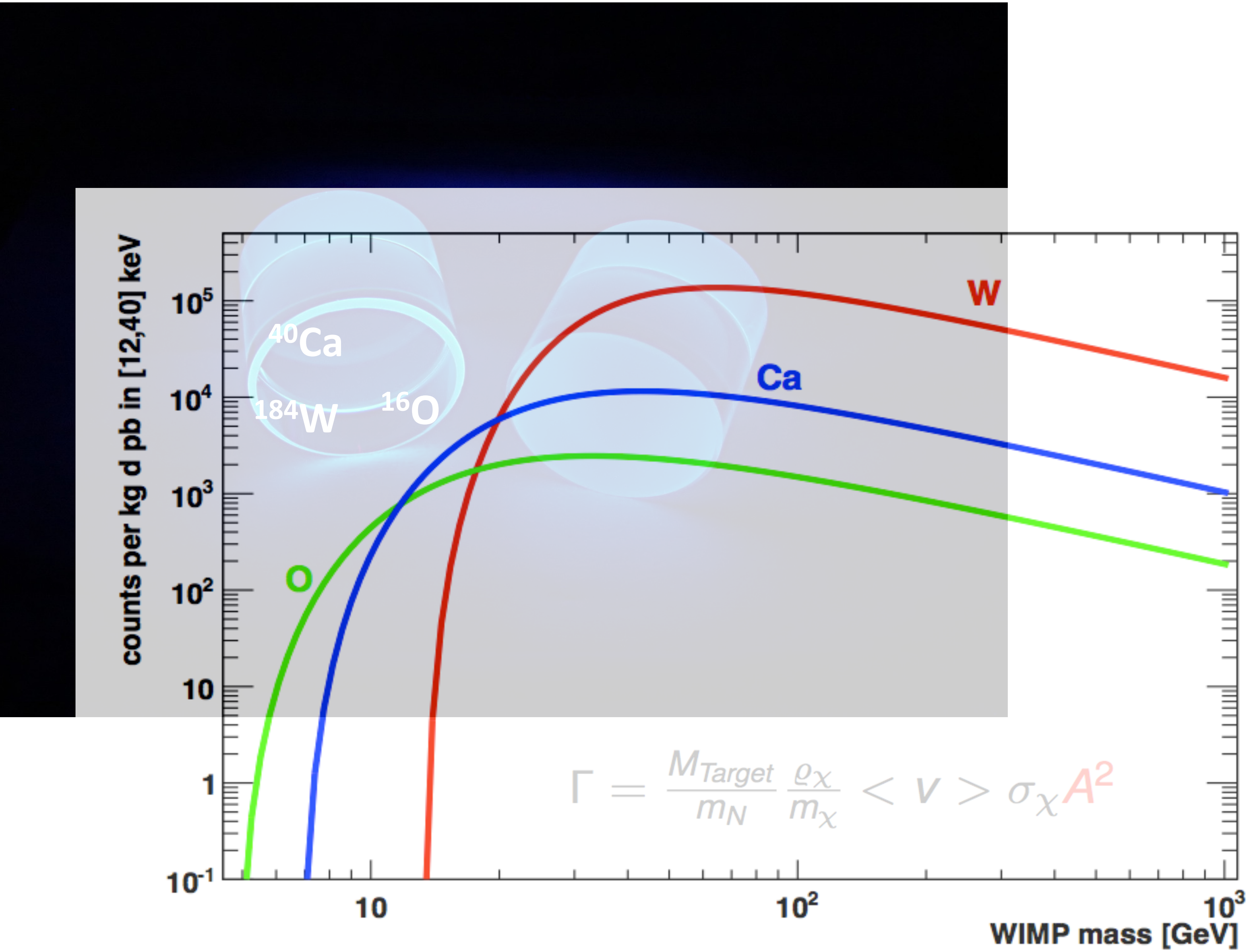
HEPHY Institut für Hochenergiephysik



CRESST at Gran Sasso Underground Laboratory



$CaWO_4$ Multi-Element WIMP Target



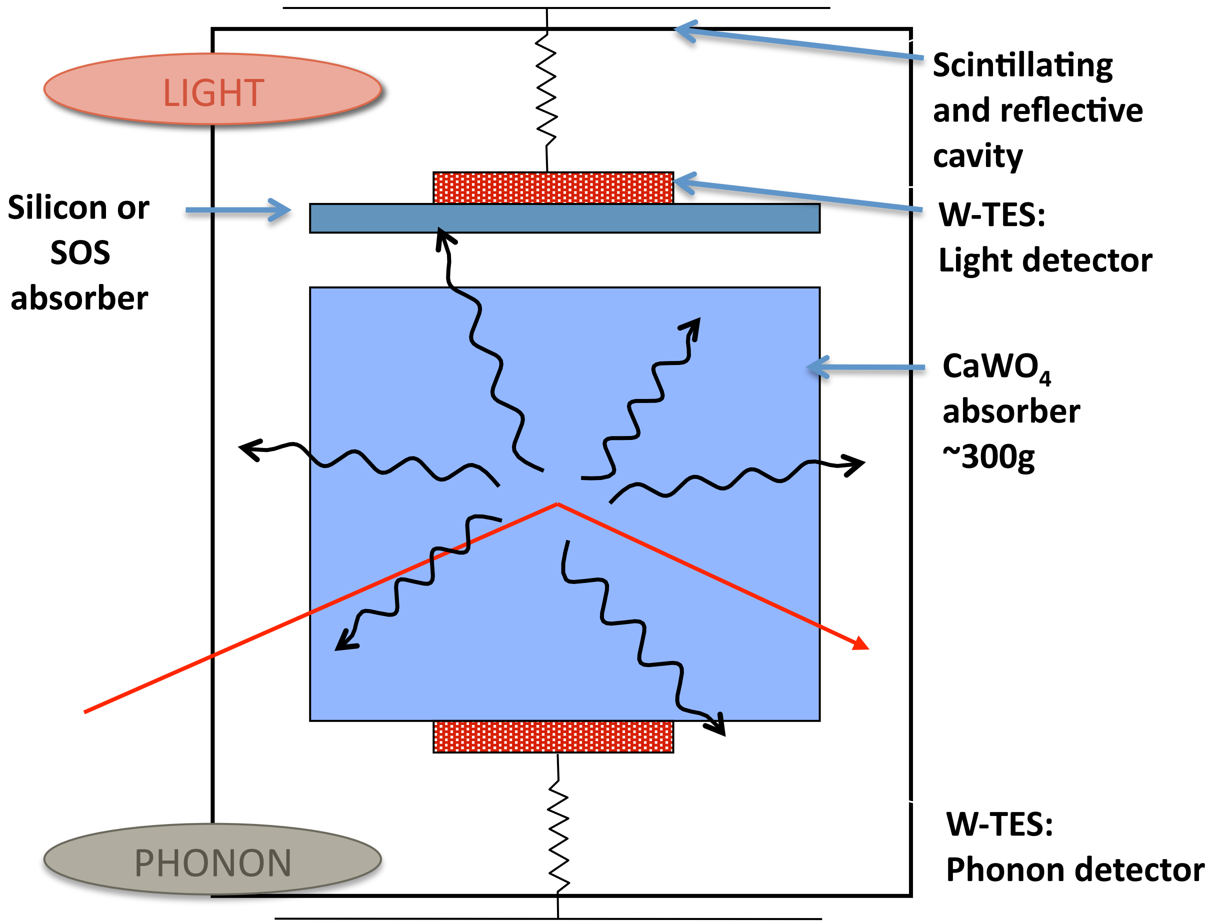
Assumption: coherent, spin-independent scattering

low WIMP masses
≤20GeV: only O, Ca recoils above detection threshold

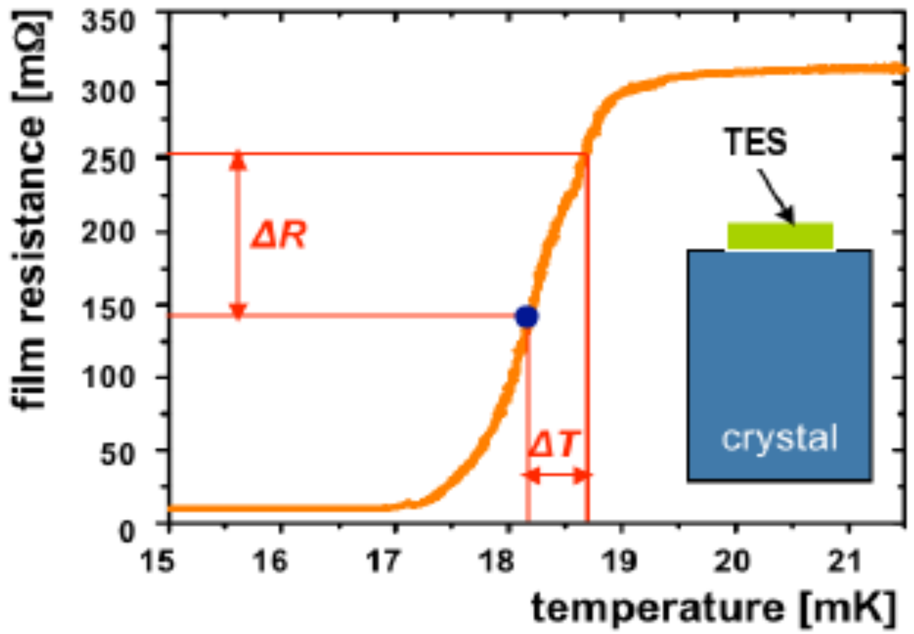
high WIMP masses
≥30GeV: dominated by W recoils

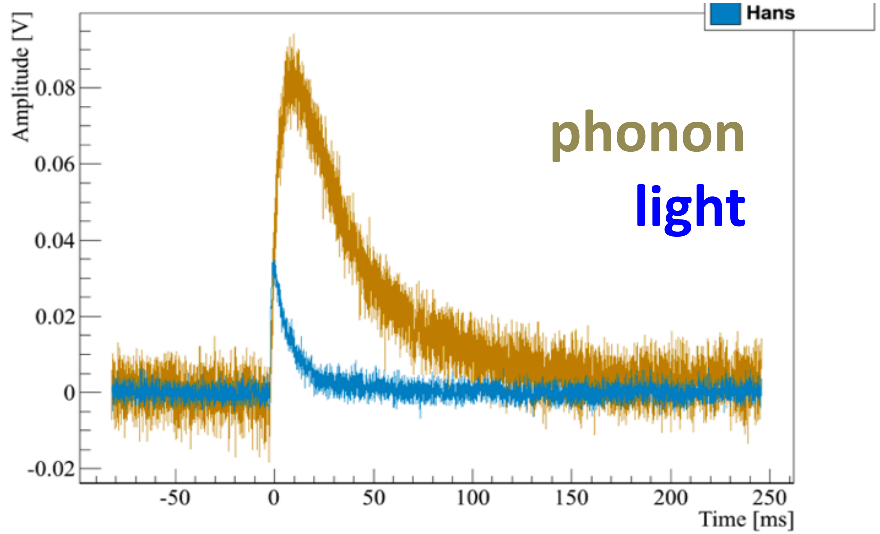
neutron background mainly O recoils above detection threshold

CRESST II Detector Modules

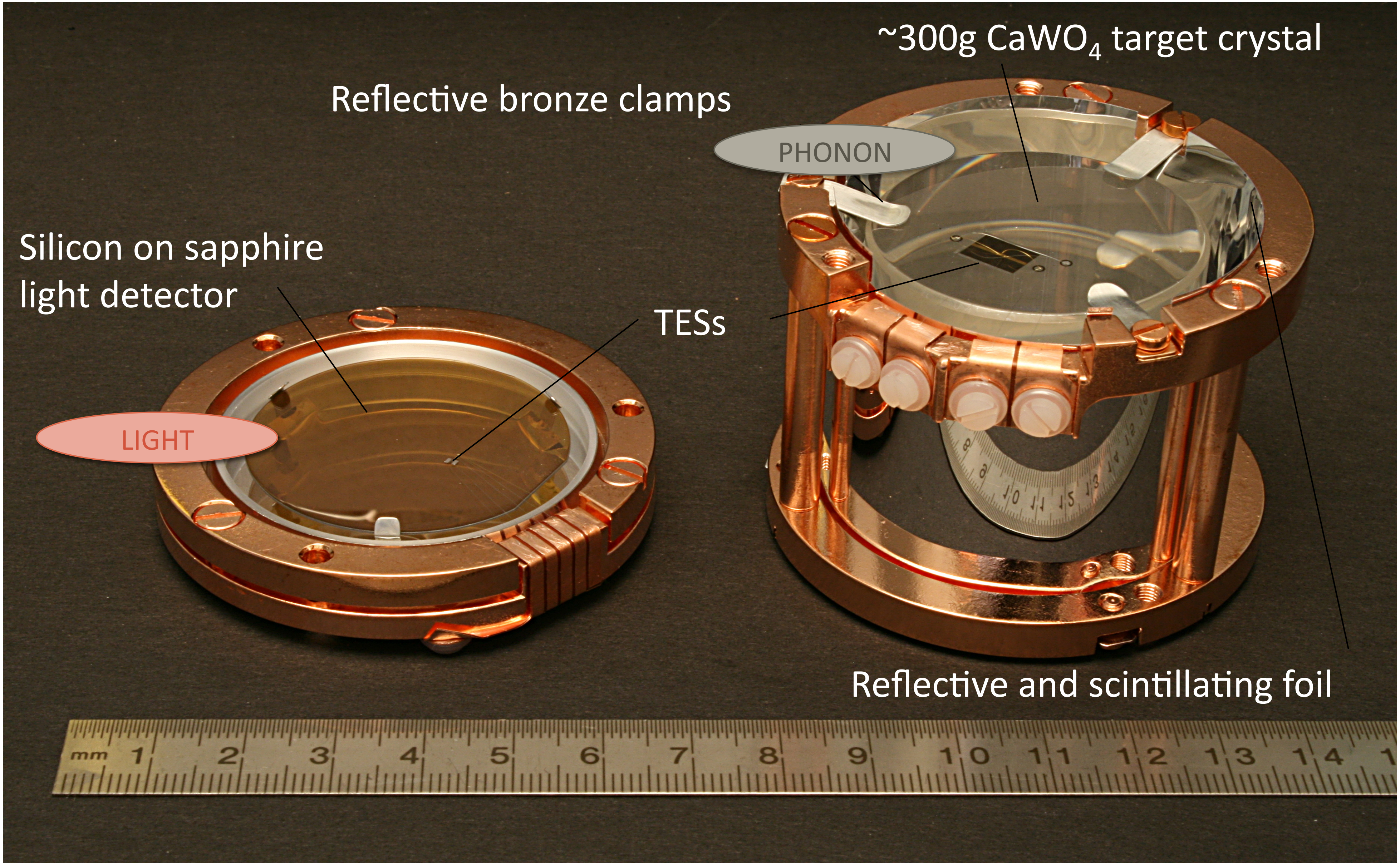


Transition Edge Sensor (TES)





CRESST II Detector Modules

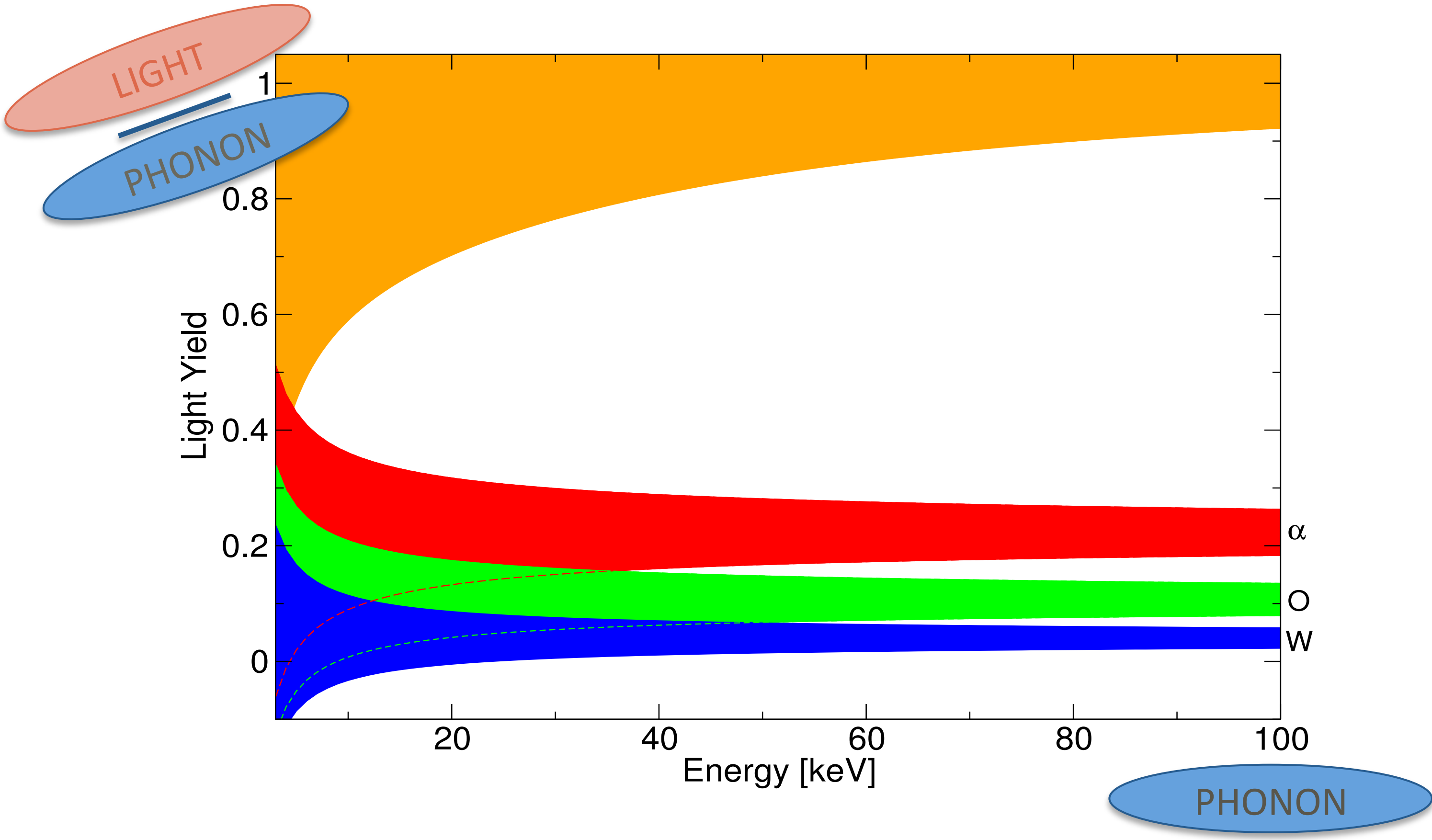


Identification of Event Type

- **Characteristic light yield (LY) for each type of event:**

e-recoil:	**1**	**(by def.)**
α:	**~ 0.22**	
O-recoil:	**~0.10**	
Ca-recoil:	**~0.06**	
W-recoil:	**~0.04**	

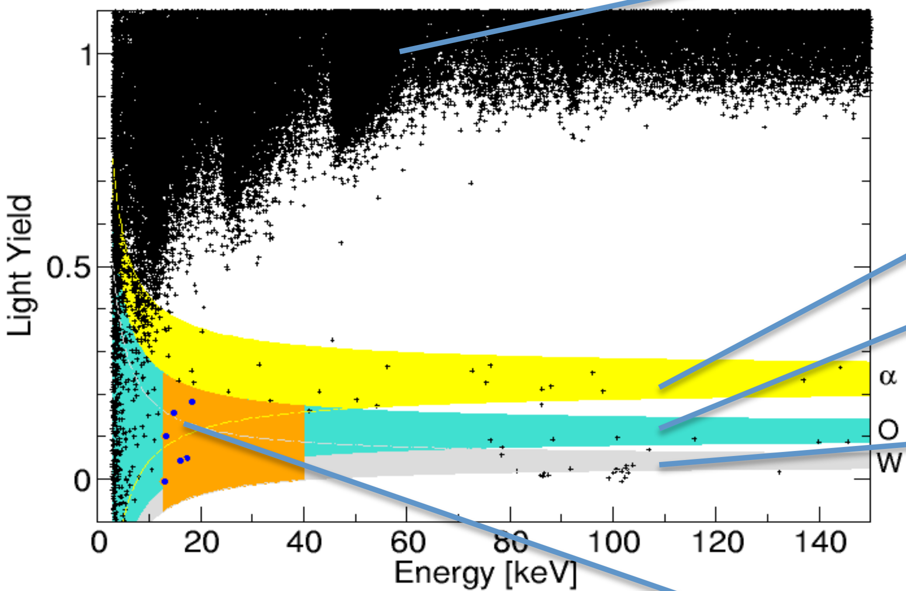
(„Quenching factors“)



- **Excellent discrimination:** electron recoils (induced by γ and β) and nuclear recoils
- Identification of recoiling nucleus possible (depends on achievable separation of Ca, W and O nuclear recoil bands)
- Possibility **to probe different WIMP mass scenarios in same target** (unique for CRESST)

Results of Run32 (2009-2011) – Exposure: 730kg-d

Data of one single 300g detector module in Run32:



Electron recoils: γ, β

α−events: from surfaces

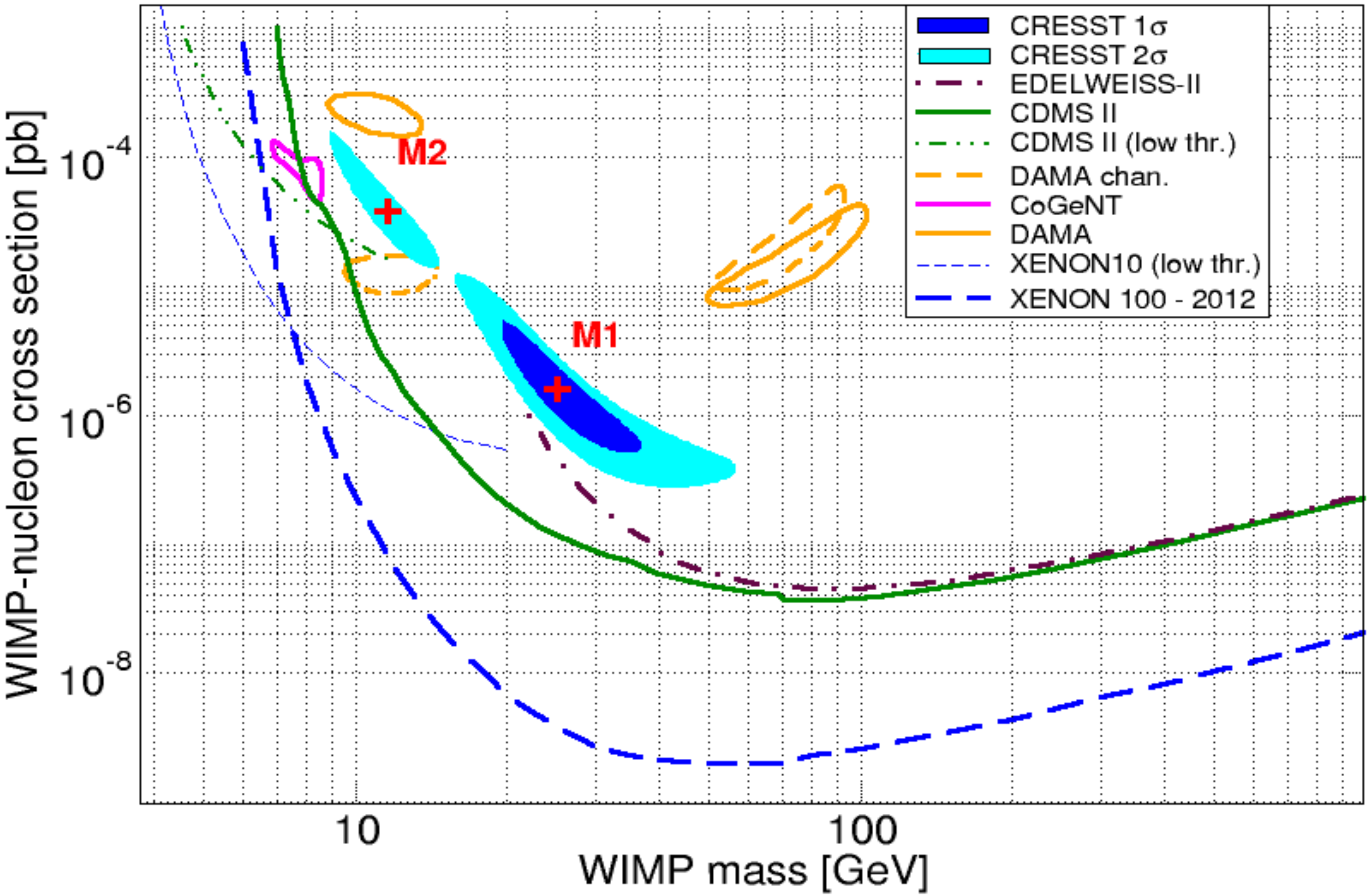
O-band: neutrons

W-band: expect „heavy"-WIMP interaction
-> contamination from ^{210}Po α-decays in clamps

67 events at low energy observed in O, Ca and W-bands in all detector modules (~730kg d)

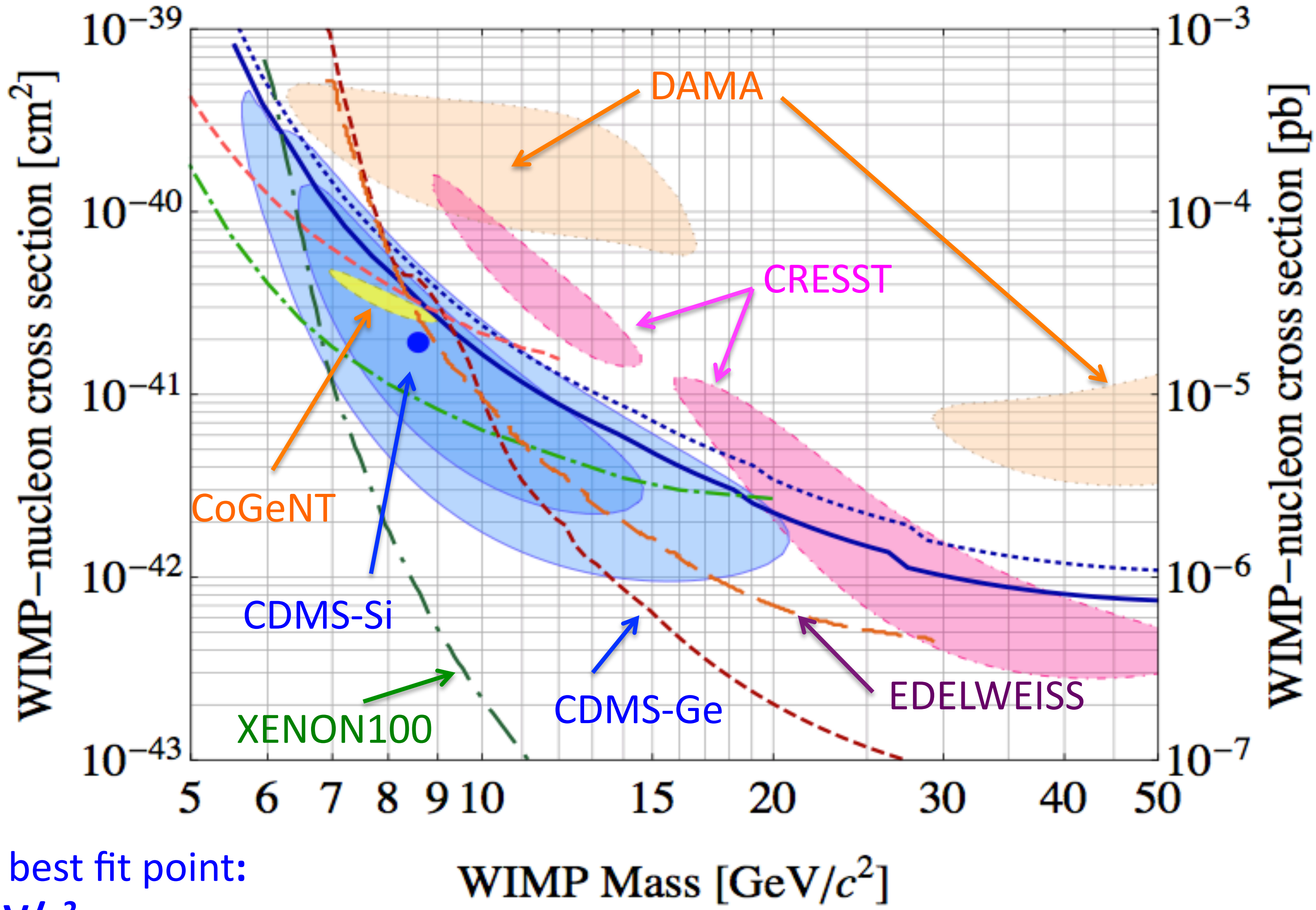
Eur. Phys. J. C (2012) 72:1971
DOI 10.1140/epjc/s10052-012-1971-8

Results of Run32 (2009-2011)



The Low WIMP Mass Region after CDMS-Si

arXiv **astro-ph.CO, arXiv:1304.4279 (2013)**

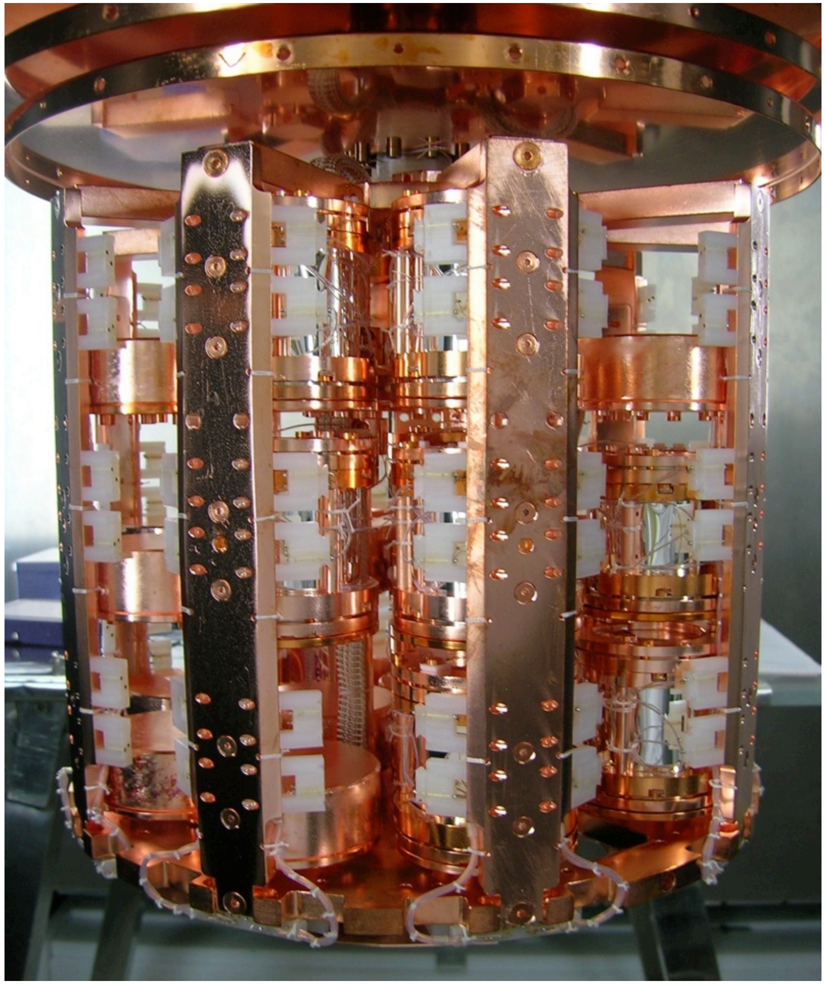


-> CDMS-Si best fit point:

m_χ = 8.6 GeV/c^2

σ_χ = 1.9 x 10^{-41}cm^2

CRESST-II Phase 2



Data-taking since July 2013

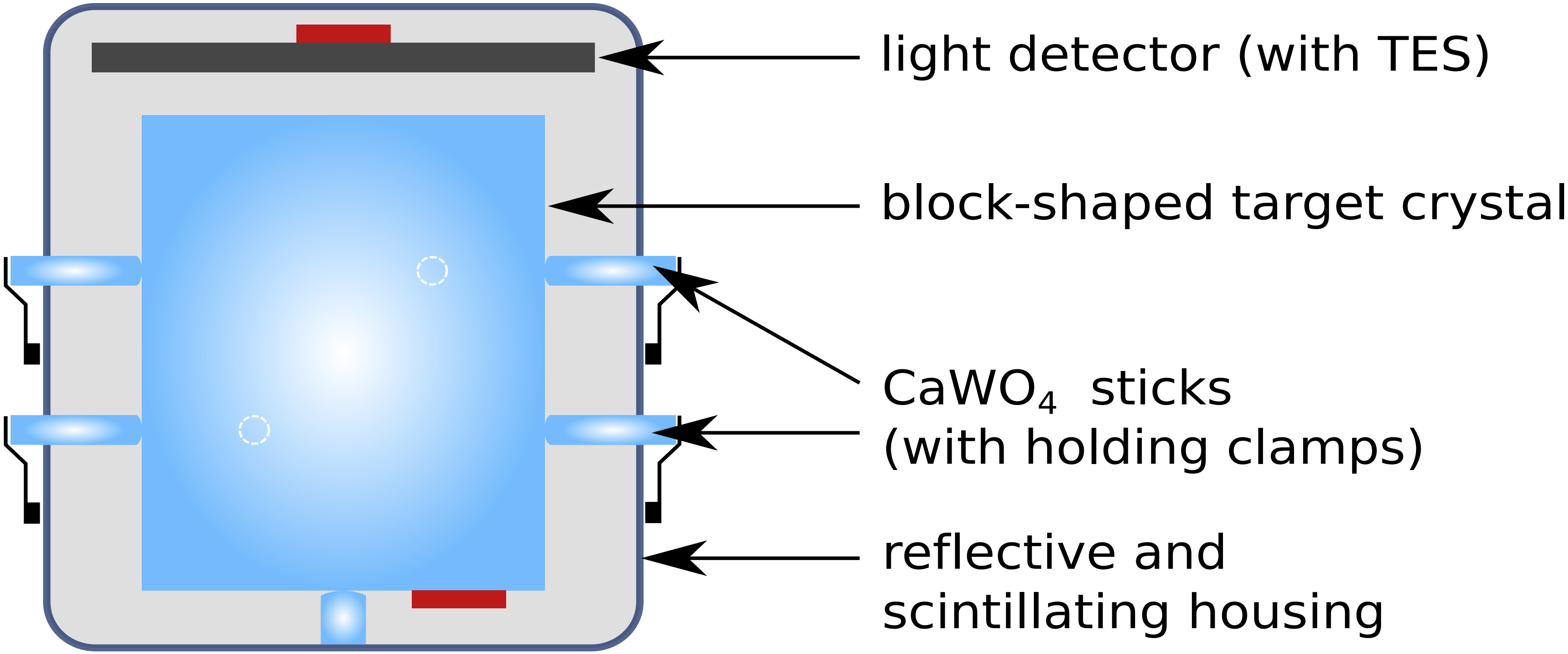
- 18 modules mounted (~ 5kg)
- Goal: clarify nature of excess observed in last run

Release of first data on low-mass WIMPs in July 2014

- 29 kg-days of exposure with a single detector module (TUM40)
- Novel detector design employed

CRESST-II Phase 2

Novel fully-scintillating detector design



→ Highly-efficient rejection of surface-alpha backgrounds!

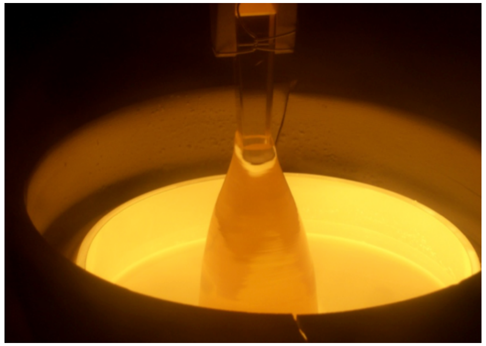
CRESST-II Phase 2

$CaWO_4$ crystal growth at TU Munich

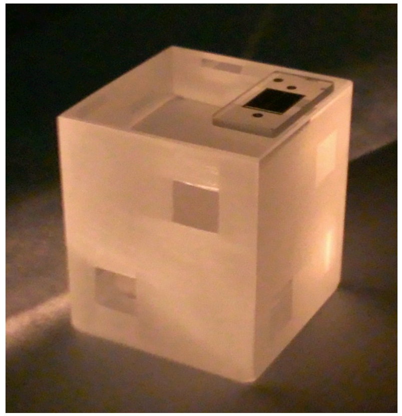
A. Erb and J.-C. Lanfranchi, *CrystEngComm*, 2013,**15**, 2301-2304
M. von Sivers, Opt. Mat. 34, 11 (2012) 1843-1848, arXiv:1206.1588

Goals :
- Increase radiopurity
- Increase light output
- Ensure supply (for ton scale)

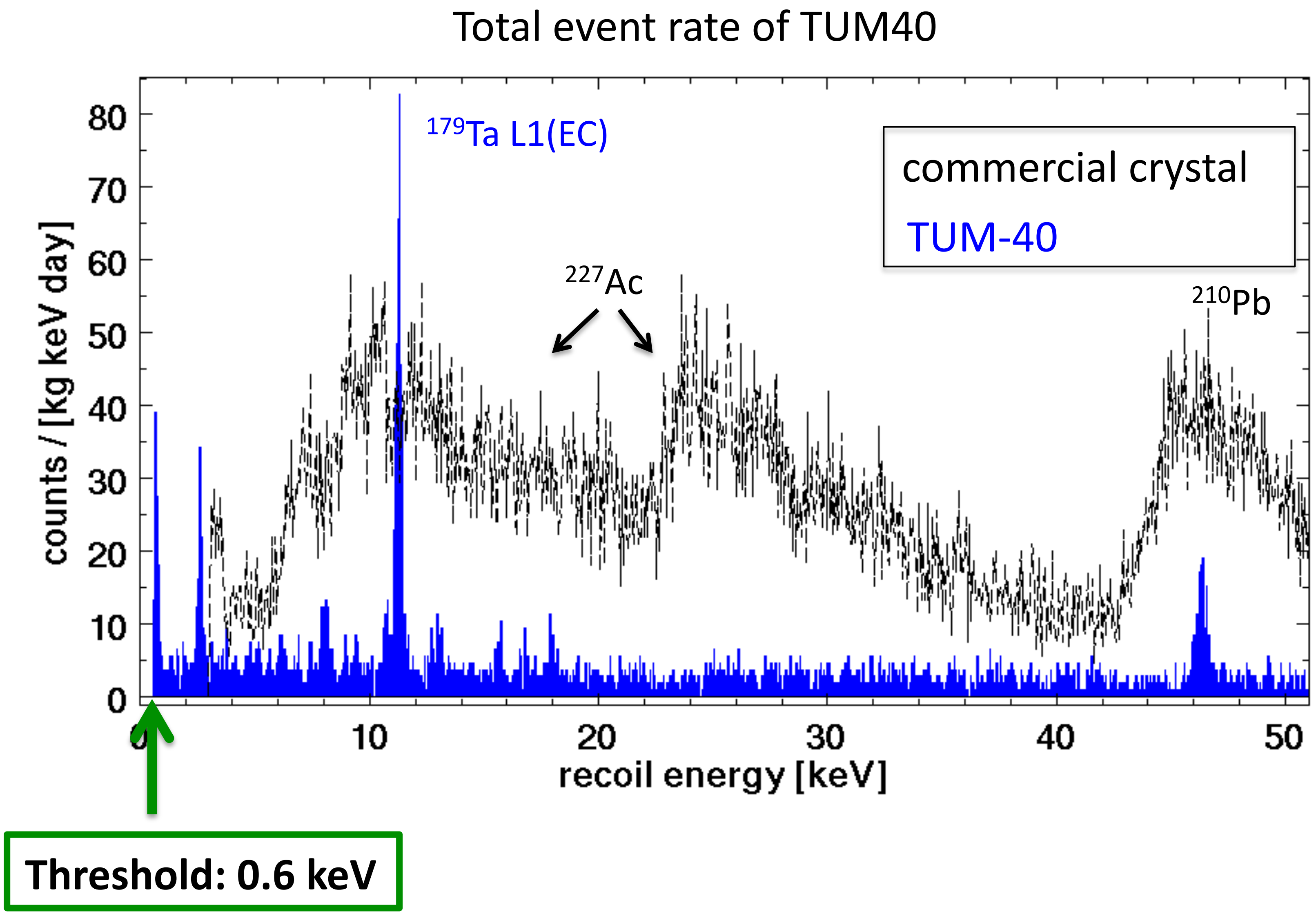
Major achievements:
- Reproducible growth of CRESST-size crystals
- Unprecedented intrinsic radiopurity



TUM-40
m=250g



CRESST-II Phase 2



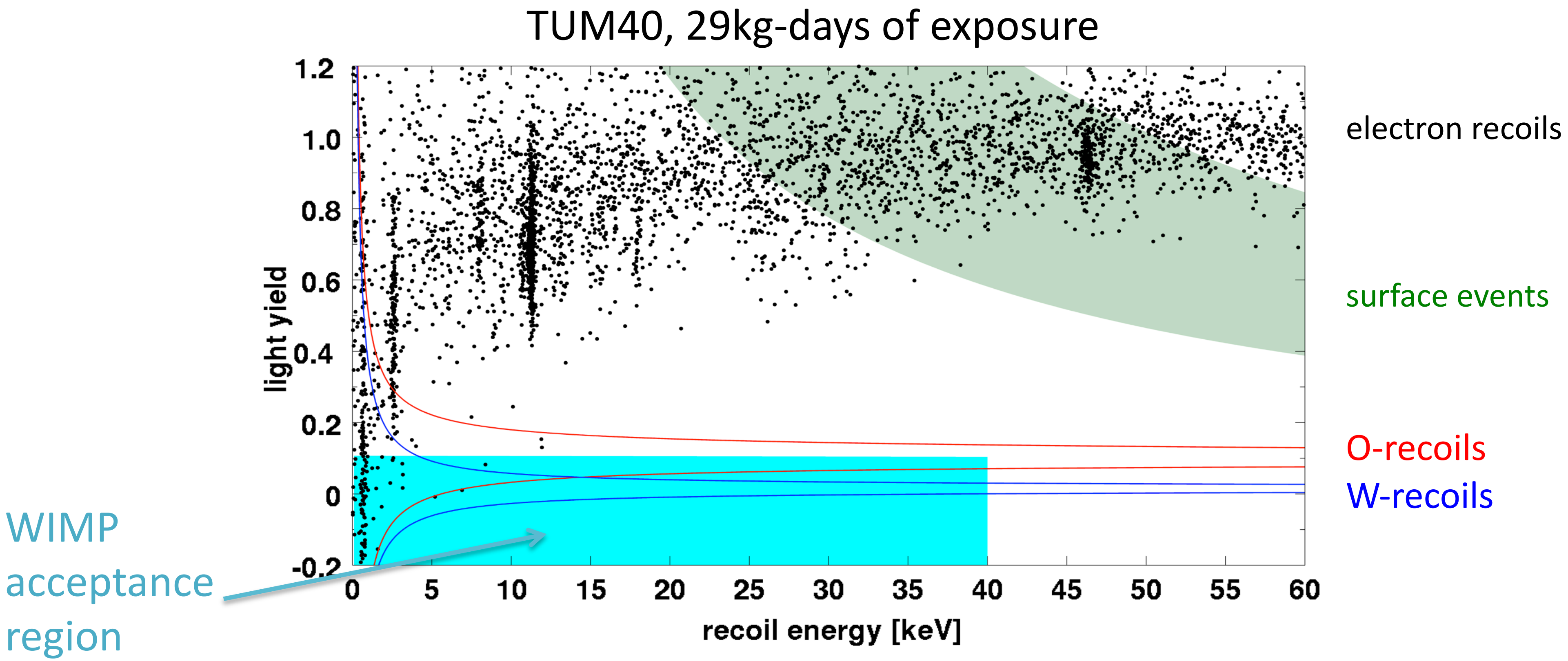
Unprecedented background rate: **~3.5 counts / [kg keV day]**

Gamma-lines from **cosmogenic activation**

Excellent energy resolution:

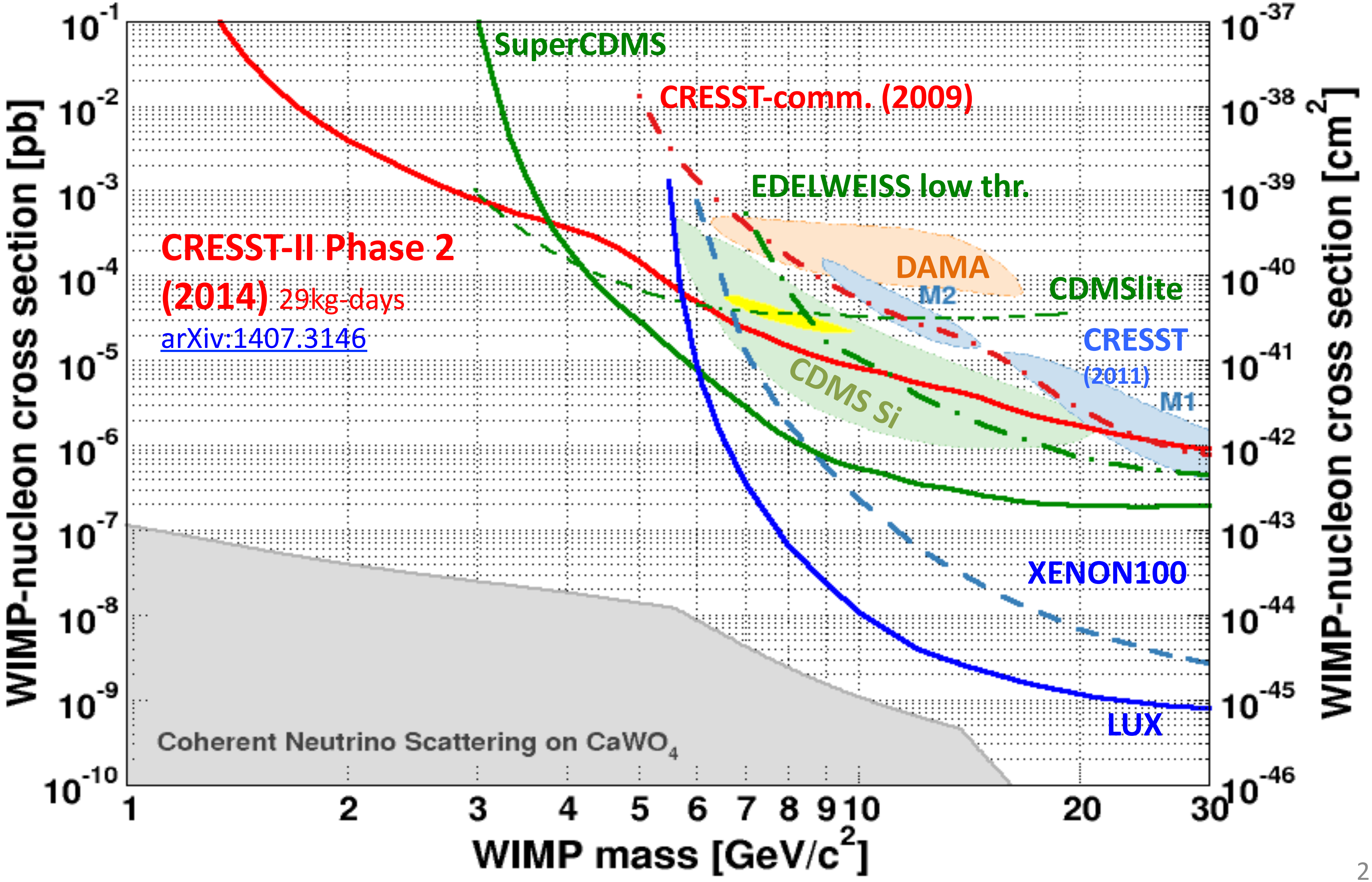
≈90 eV @2.6keV

CRESST-II Phase 2

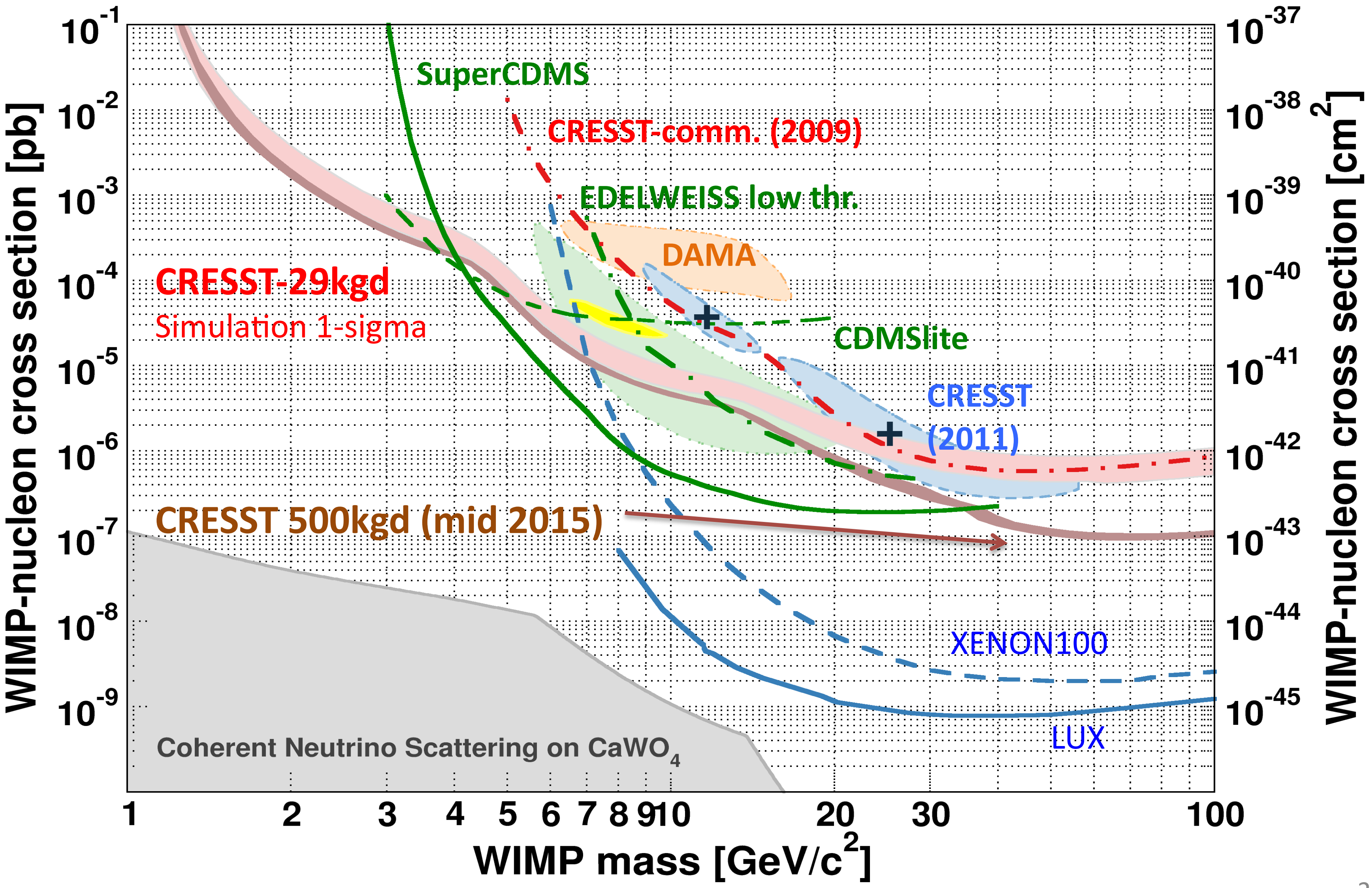


Phonon and Light channels fully-exploitable down to lowest energies!

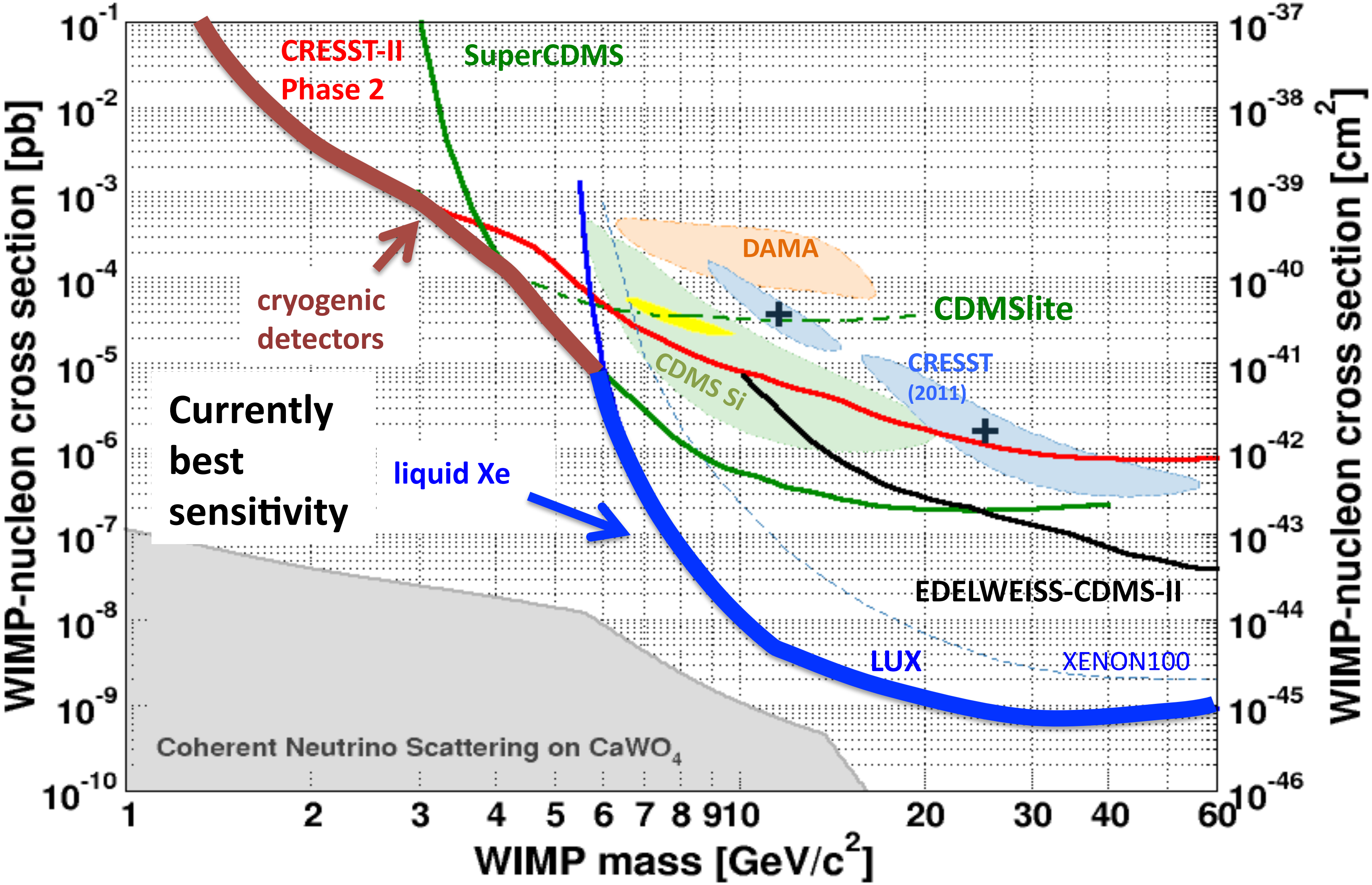
Results from 29kg-days of CRESST-II Phase 2



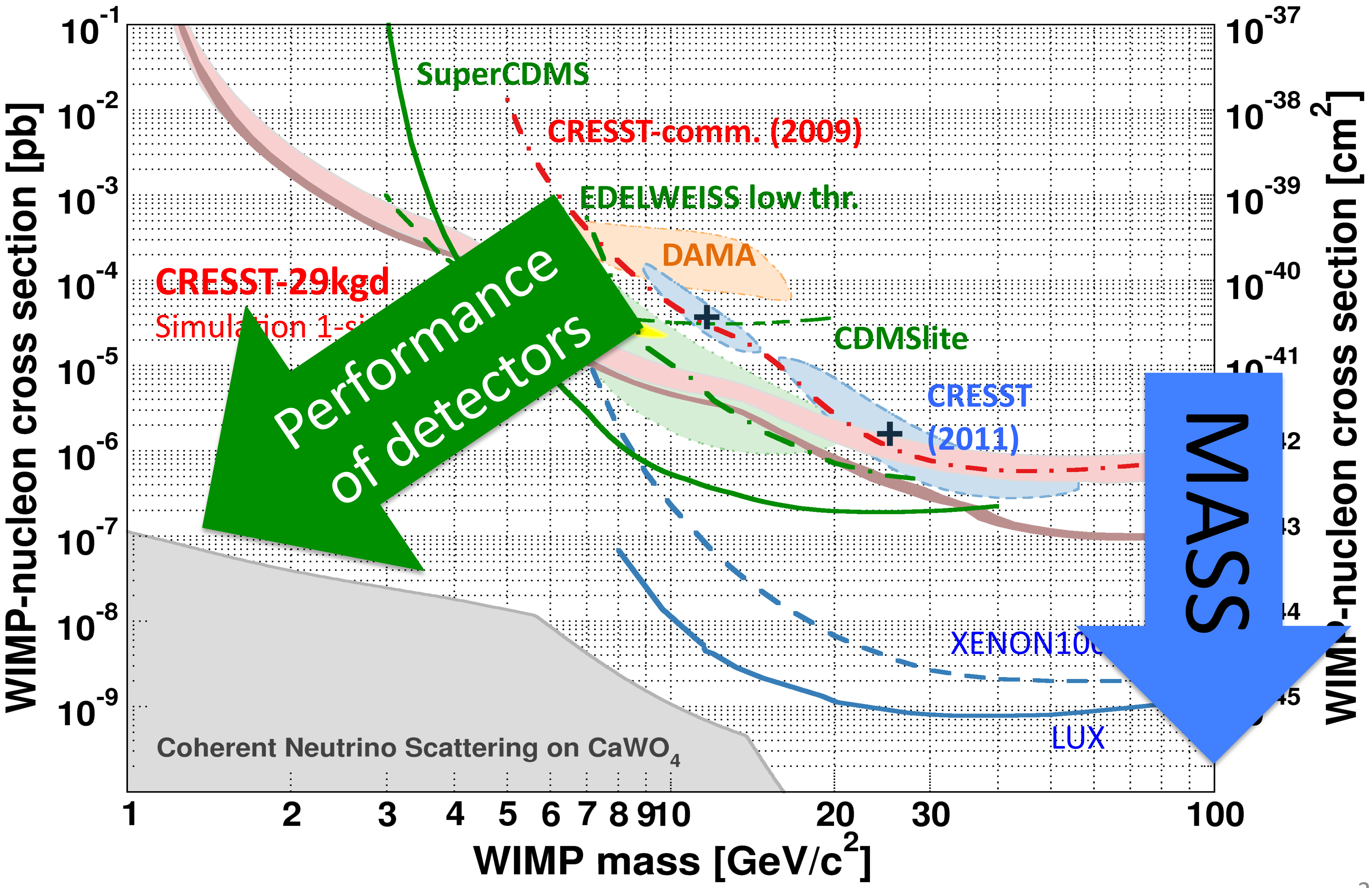
Projection for Final Exposure of CRESST-II Phase 2



Current Status of Direct Dark Matter Searches



Projection for Final Exposure of CRESST-II Phase 2



CRESST-III: Low-Mass WIMP Search

Straight-forward approach for near future: **CRESST-III Phase 1**

Status quo (TUM40)

m = 250g
V = 32x32x40 mm^3

Phonon threshold: $E_{th} \approx 0.4$ keV

Light-detector res.: [illegible] ≈ 5 eV

CRESST-III: Low-Mass WIMP Search

Straight-forward approach for near future: **CRESST-III Phase 1**

Status quo (TUM40)

m = 250g
V = 32x32x40 mm^3

Scale down size by factor 10

m=24g

+ use 2 light detectors

Phonon threshold: $E_{th} \approx 0.4$ keV **improvement by a factor of 5**

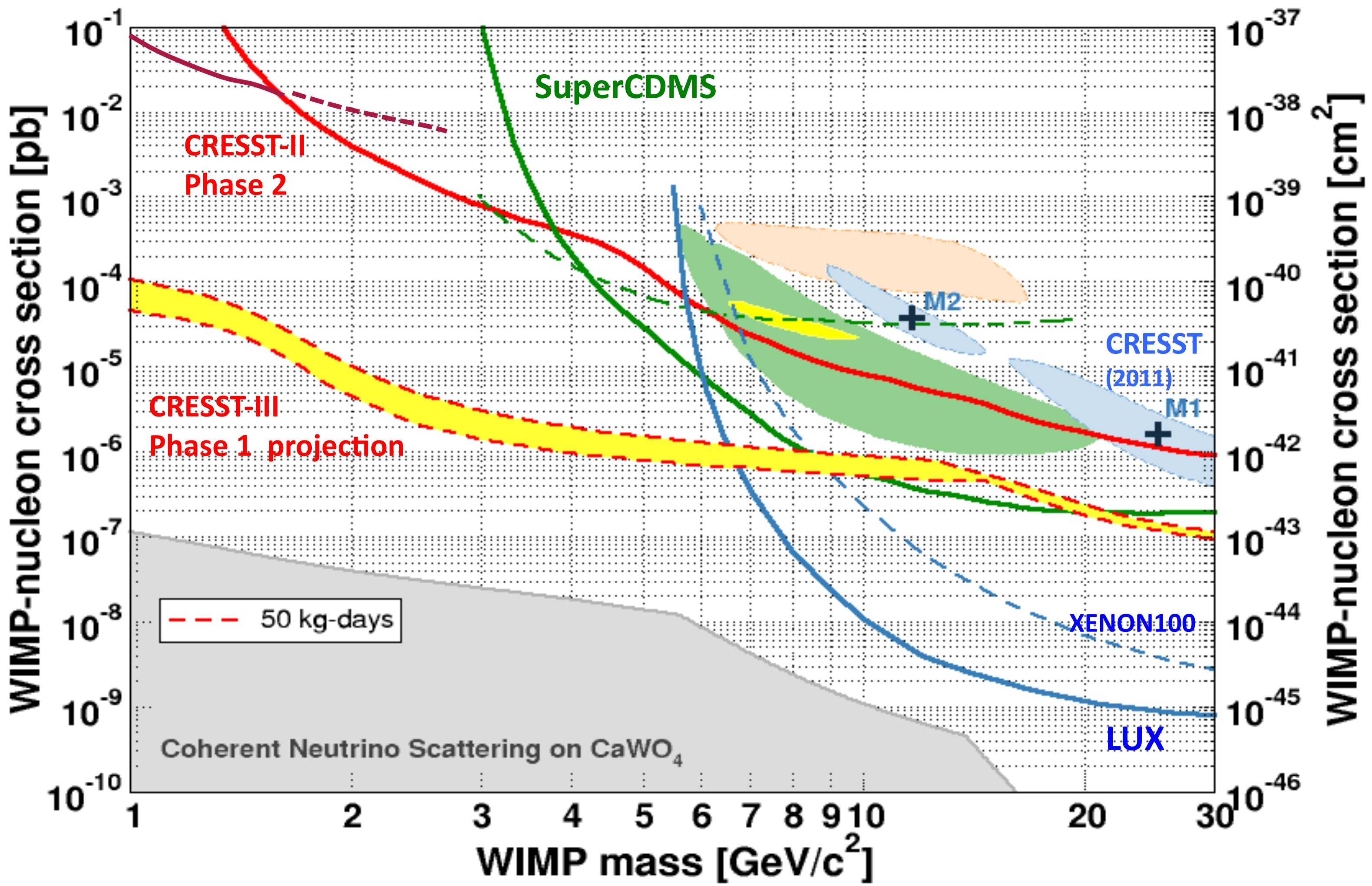
Light-detector res.: ≈ 5 eV **improvement by a factor of 2**

NO improvements assumed concerning radiopurity and optical quality of crystals!

CRESST-III Phase 1

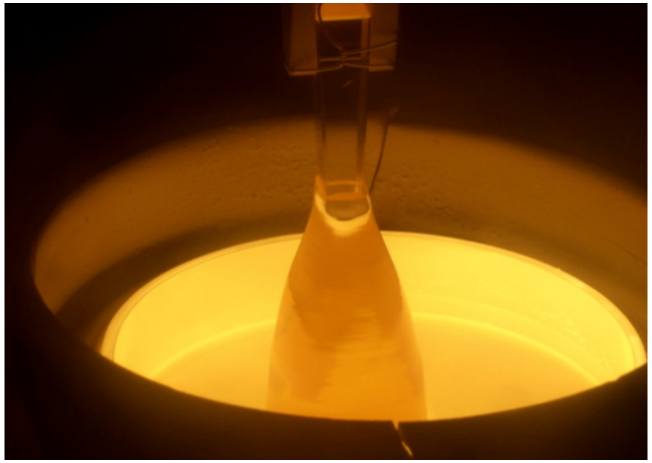
Assumptions:

- 24g $CaWO_4$ crystal
- E_{th} = 0.10 keV
- Light detector improved by factor 2 (due to smaller volume)
- 3x more detected light: due to thin crystal + 2nd light detector



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

CRESST-III Phase 2



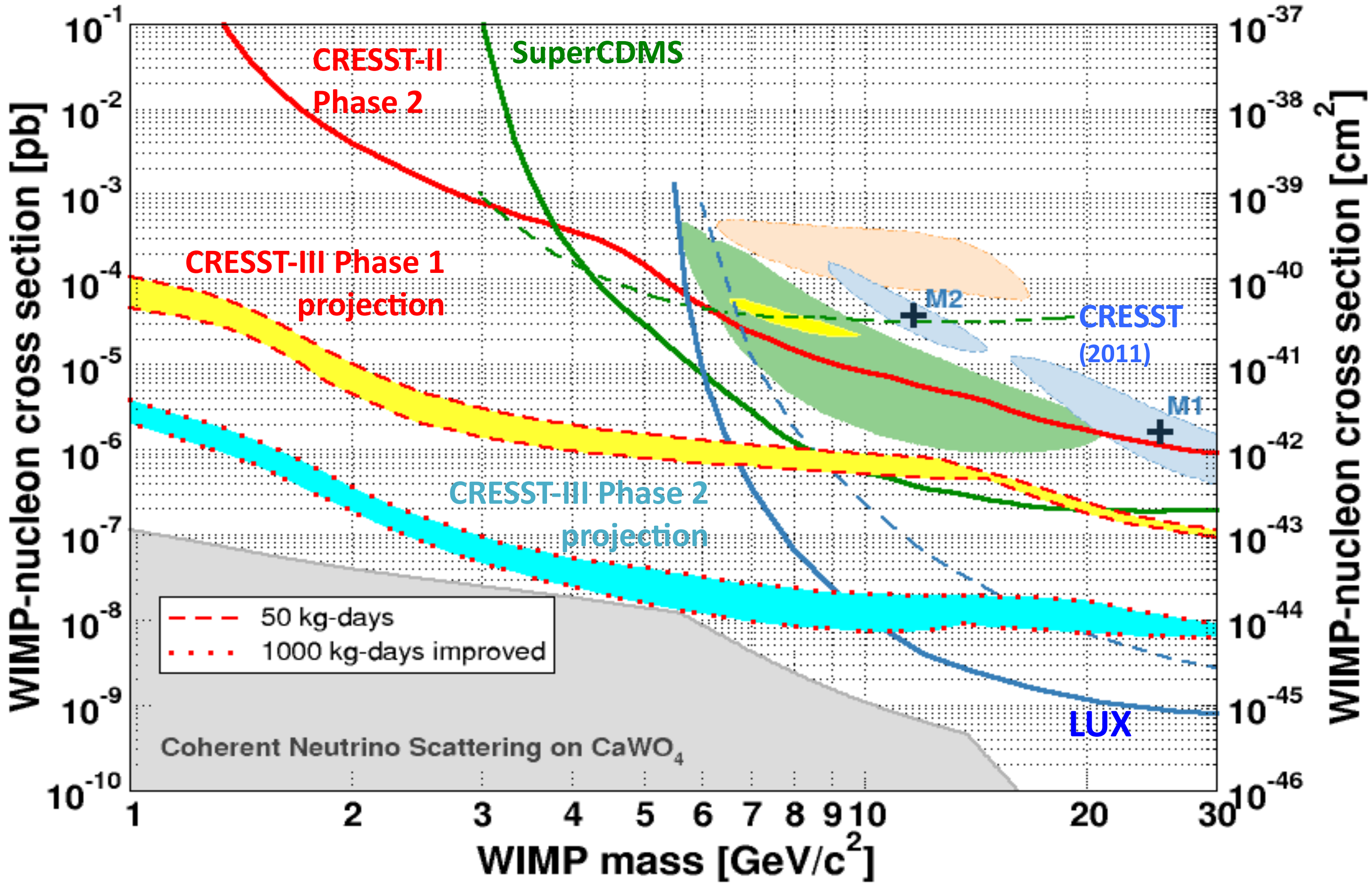
Reduce intrinsic background level of crystals!

- Growth of $CaWO_4$ crystals in-house (TUM)
- All production steps under control
- Improvement by factor 10 already achieved
- Cleaning procedure e.g. by re-crystallization

REALISTIC GOAL (in 2 years):

Reduction of background level to 10^{-2} counts /[kg keV day]
(2 orders of magnitude compared to present $CaWO_4$ crystals)

CRESST-III Phase 2



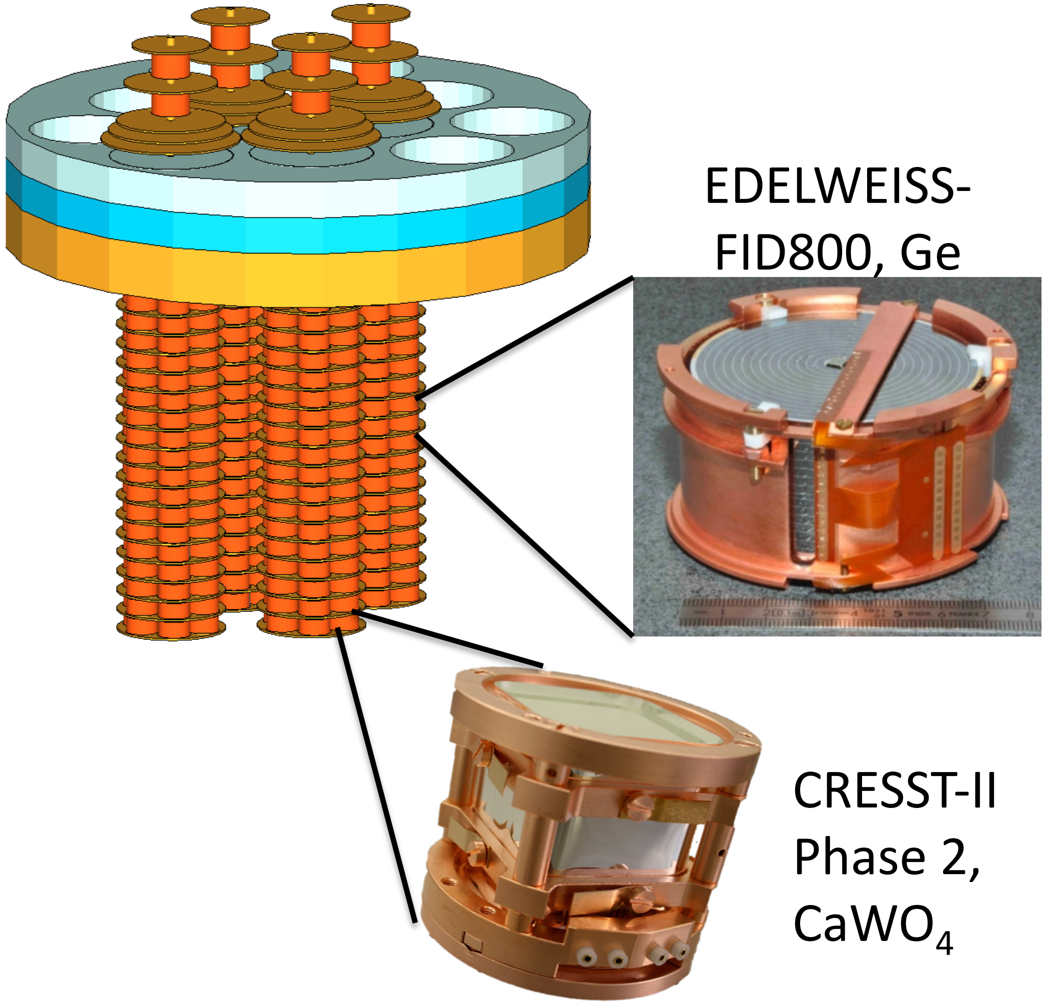
100 x 24g detectors of improved quality operated for 2 years ≈ 1000 kg-days (net)

Future European Cryogenic Dark Matter Experiment - EURECA

Project based on CRESST & EDELWEISS technologies

- Conceptual design report 2014
  G. Angloher et al., Physics of the Dark Universe **3** (2014) 41–74

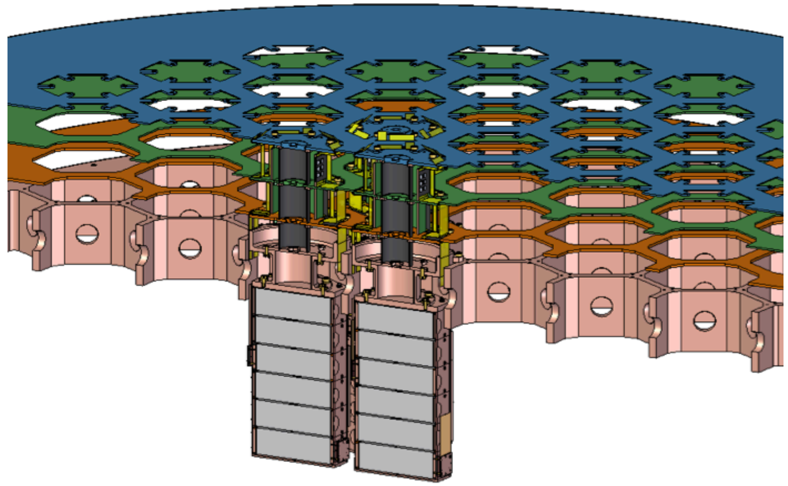
- modular towers in cryostat
- Water shield around cryostat
- ➢ **Phase 1:**
  - six 800g Ge or twelve 300g $CaWO_4$ per tower level
  - Option: 1.6kg Ge and 1kg $CaWO_4$ detectors
- ➢ **Phase 2:** up to 1ton of target mass



EUREKA & SuperCDMS

Based on earlier collaborative work between EDELWEISS and CDMS-II

- ➢ Common analysis of Ge detectors Phys. Rev. D 84, 011102(R) (2011)



Status SuperCDMS:

Supported experiment after G2-downselection

- Funding for large cryostat (up to 400kg of target mass)
- Funding of 50kg Ge detectors

Expected EURECA contribution:

- Detectors (Ge + $CaWO_4$)
- Cryogenics
- towers & readout
- optimisation of shielding

Close contact between EDELWEISS, CRESST and SuperCDMS collaborations!

Conclusions

- Tensions in the WIMP parameter space (direct detection)

- Present CRESST limit from **29kg-days** of exposure collected with only **one** new detector (~250g)

- **Best direct detection limit on low WIMP masses** (below 3GeV/c^2)

- Signal excess seen in run32 (2012) **not confirmed**

- Present run ongoing until mid 2015 (~500kg-d)

- Future:
  - explore low-mass WIMP parameter space with CRESST until solar neutrino background is reached
  - **EURECA-SCDMS as low-temperature ton-scale** experiment for **high and low** WIMP masses