Direct Dark Matter Search with CRESST

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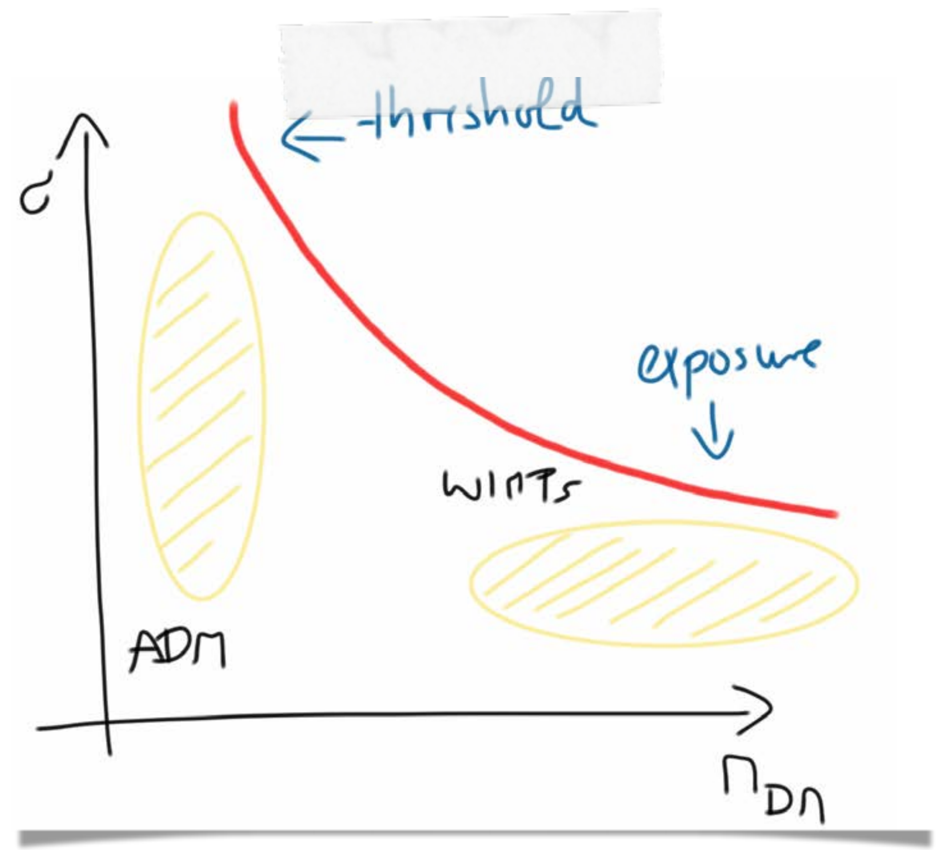
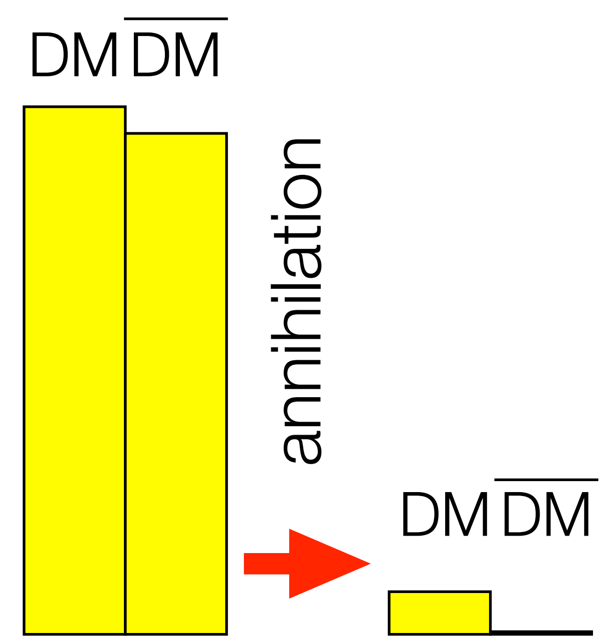
Search for low mass Dark Matter candidates

- WIMPs as Dark Matter candidate predicted above ~10 GeV
- DM density ρ_{DM} ~ 5 x baryon density ρ_B
  - DM density coupled to freeze out mechanism
  - baryon density related to CP violation and baryon number violation

no relation!

- asymmetric Dark Matter models predict **M_{DM}** ~ 5 M_B ~ 5 M_{proton} **~ 5 GeV**
- **orthogonal approach to DM problem**



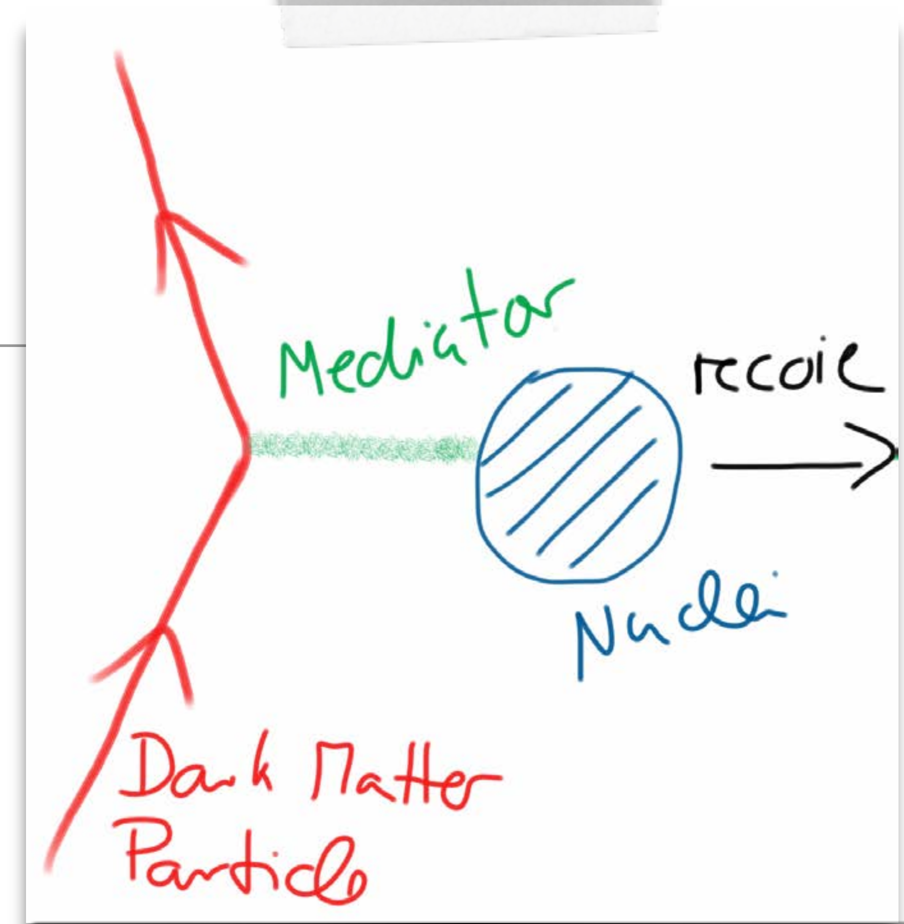


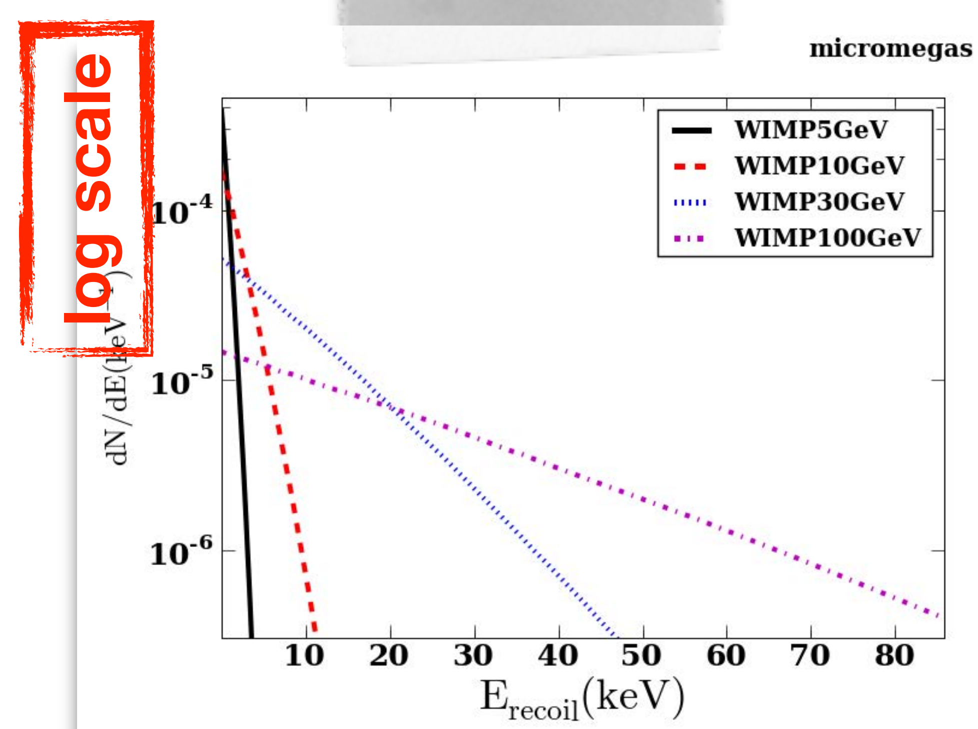
DM direct detection - expected event rate

- differential event rate decreases exponentially with recoil energy

$$\frac{dR}{dE_R} = \left(\frac{dR_0}{dE_R}\right)_0 F^2(E_R)\,\exp(-E_R/E_c)$$

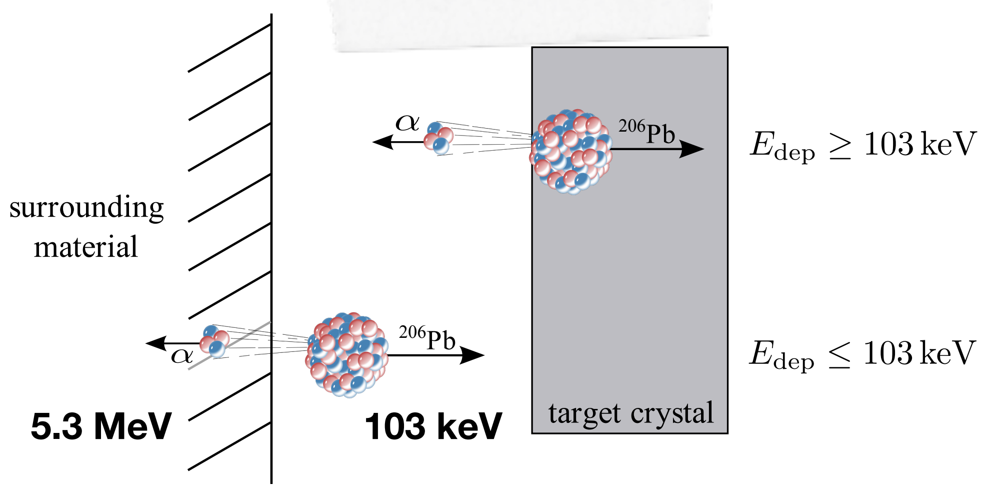
- low detection threshold for low mass DM-nucleus scattering crucial





DM - ^{78}Ge nucleon scattering

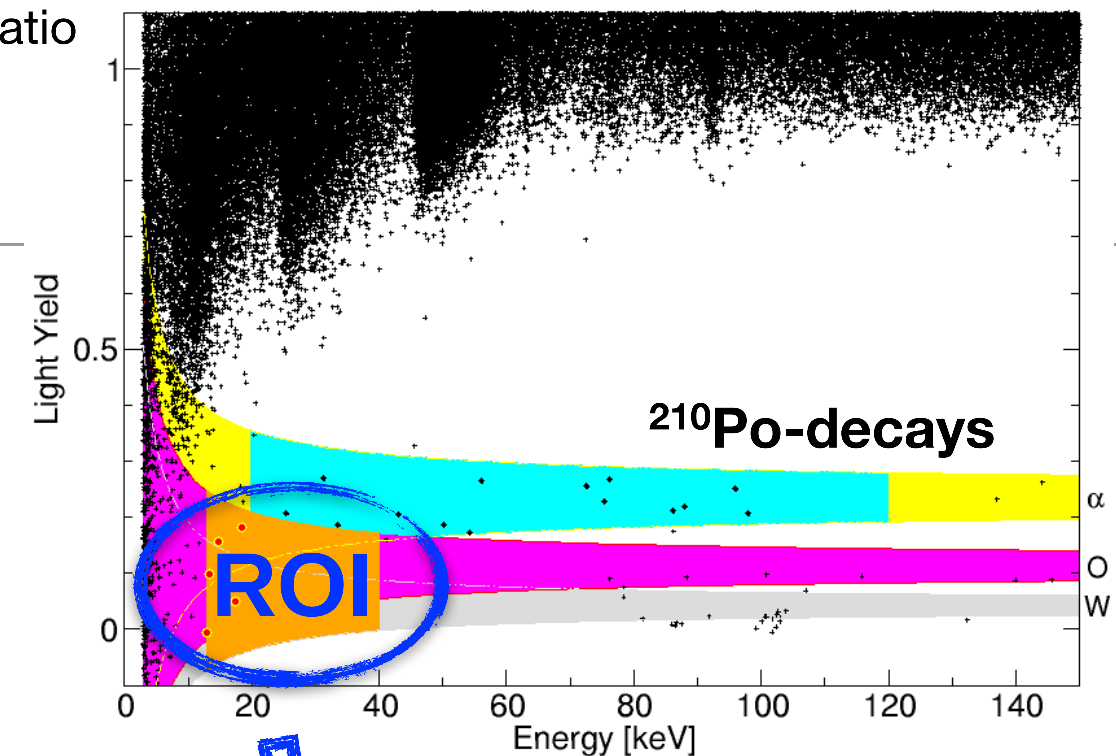
CRESST Result 2011



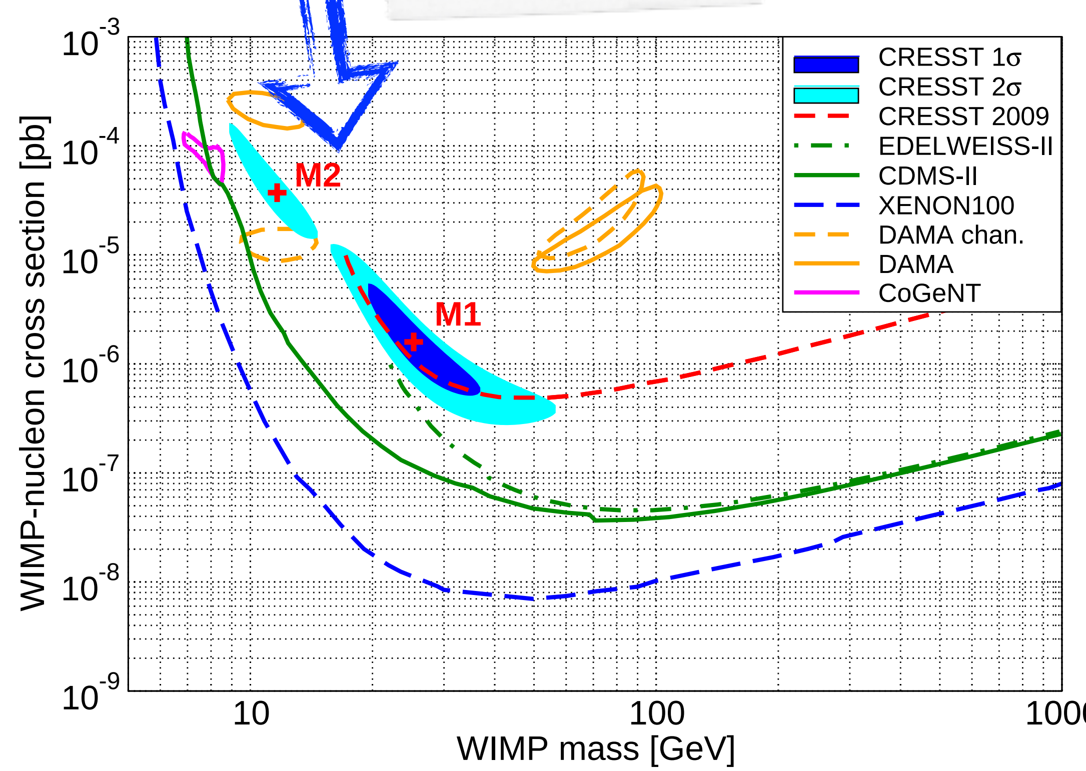
- main background source: surface α-decays of Polonium
- number of observed events exceeds expected number of background events
- WIMPs as a possible interpretation lead to signal > 4σ
- **reduction of background from ^{210}Po-decays**

Eur. Phys. J C72 (2012) 1971
arxiv 1109.0702

light yield: normalised photon-phonon energy ratio

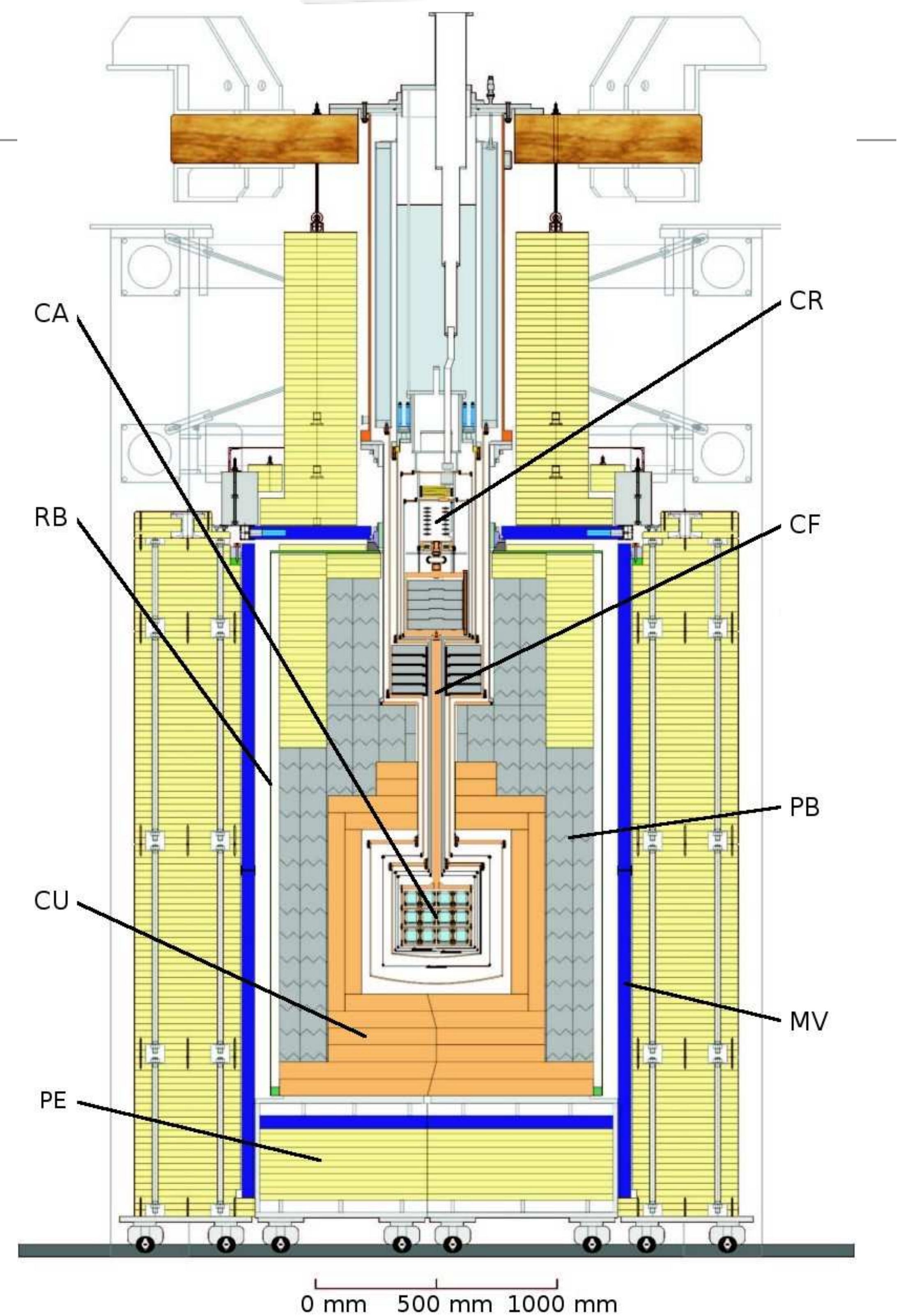


total energy



The CRESST II-Experiment

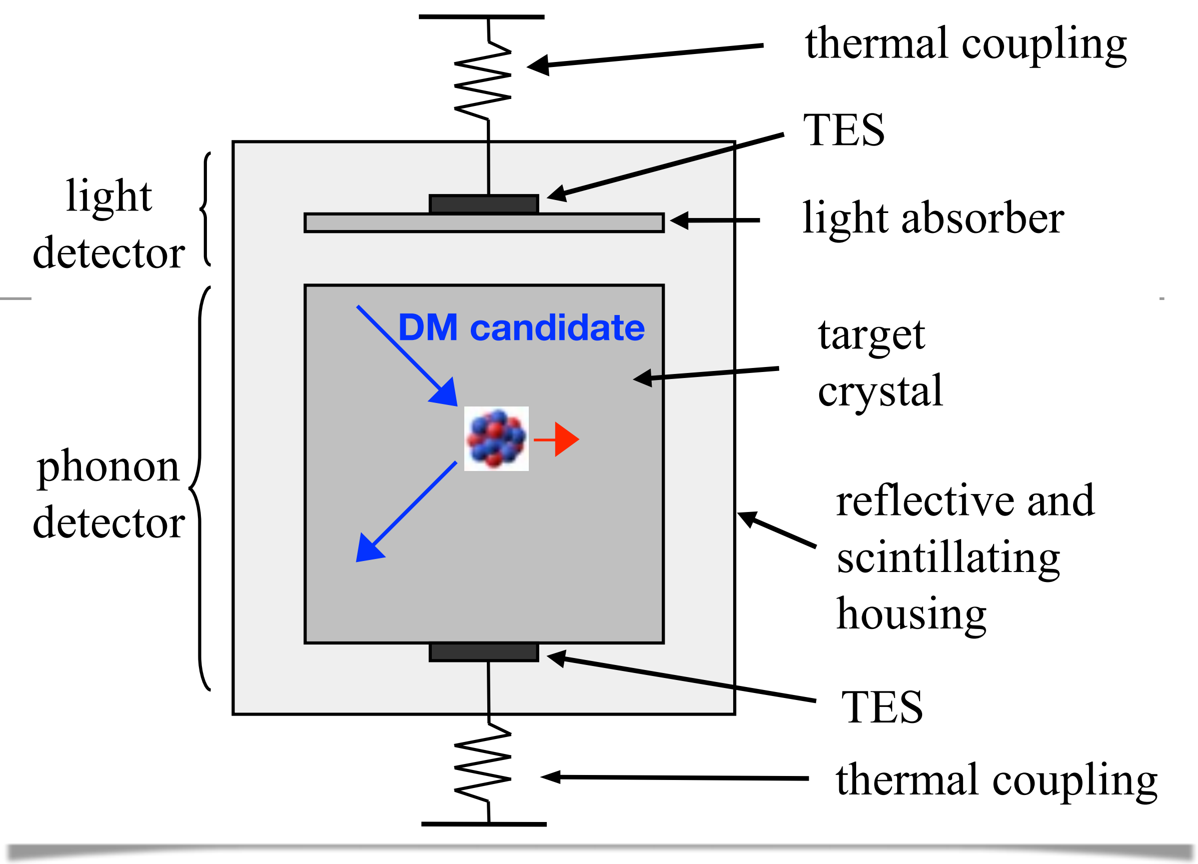
The CRESST II Experiment



- CRESST II is operated at Gran Sasso laboratory in Italy
- active and passive shielding against background events

CRESST Dark Matter detection principle

- incoming Dark Matter particle scatters with target leading to a recoiling nucleus
  → **energy deposition O(keV)**



- CRESST II simultaneously reads out two different signals

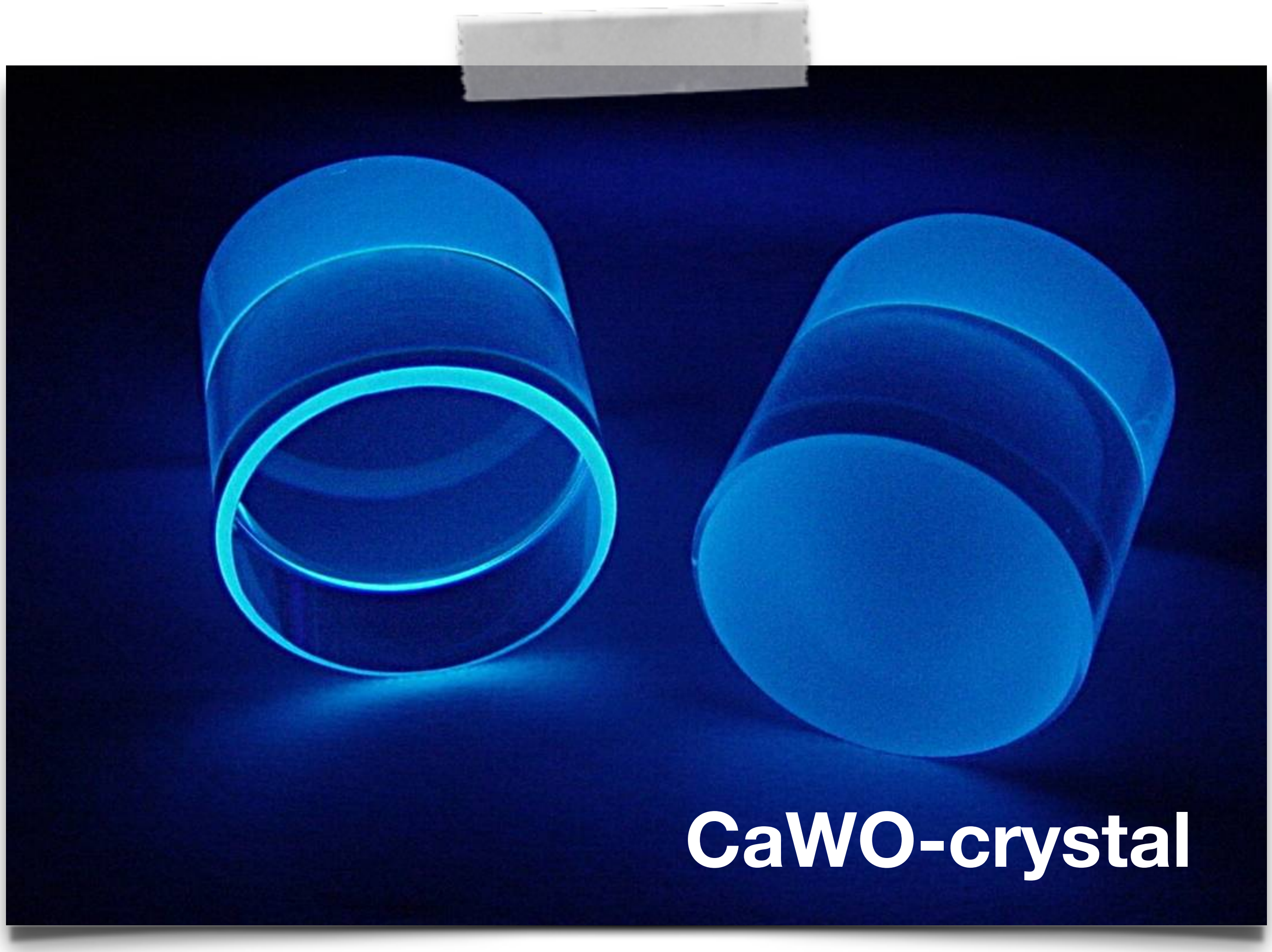
  (a) phonos - excitation of crystal lattice - ~100% of energy

  (b) scintillation light - ~small fraction of deposited energy

- combination of both allows discrimination between nucleus from from electron recoil events

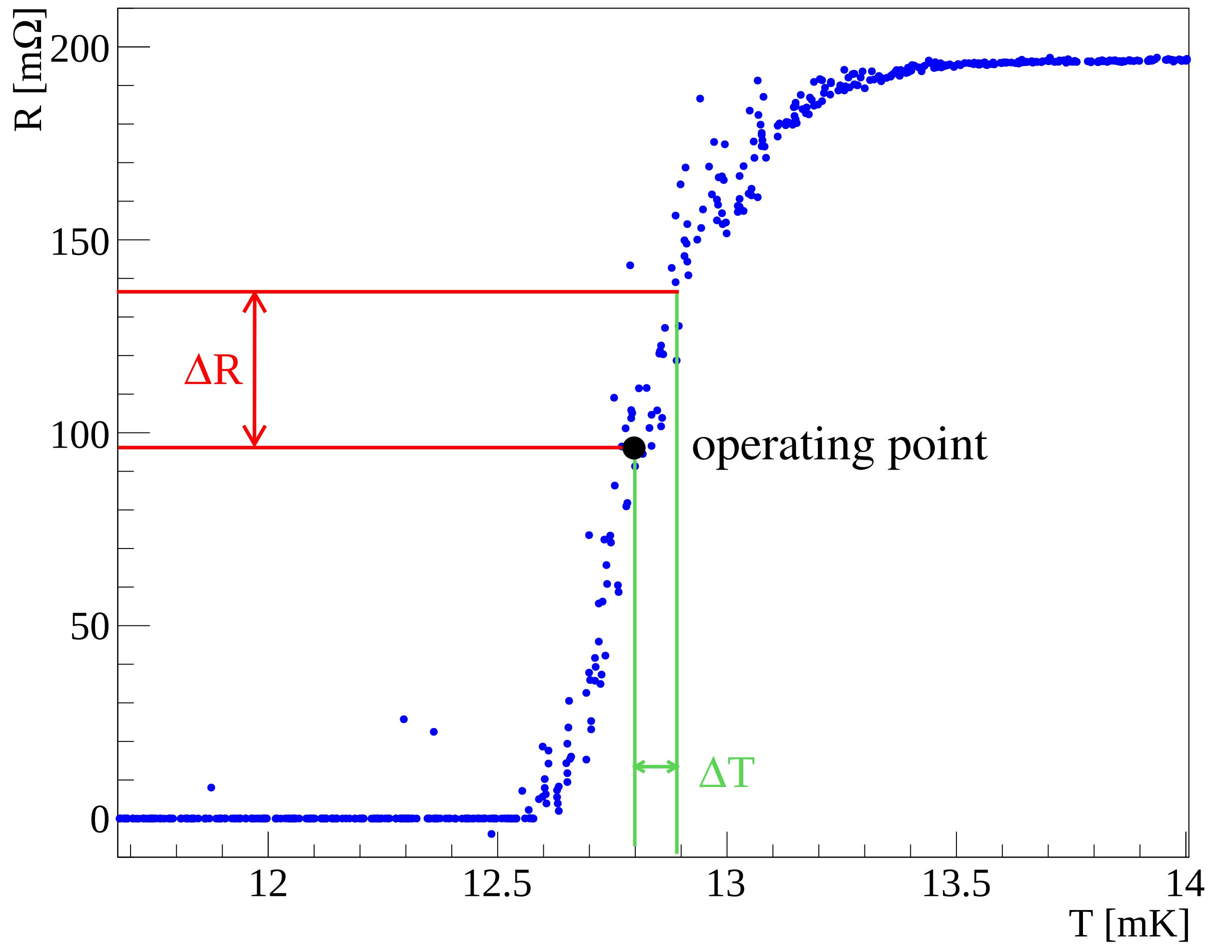
Cryogenic Approach: Phonon Detection I

- CRESST II uses $CaWO_4$ crystals operated at ~ 15 mK
- ΔE~10 keV recoil energy leads to ΔT~10 μK temperature rise
- detect temperature change with transition edge sensor (TES)



Cryogenic Approach: Phonon Detection II

- TES: tungsten film stabilised in the transition from normal to superconducting state
- μK temperature change leads to measurable resistance change
- current (=B-field) change detected by SQUID
- direct measurement of totally deposited energy
- **threshold: 600 eV**

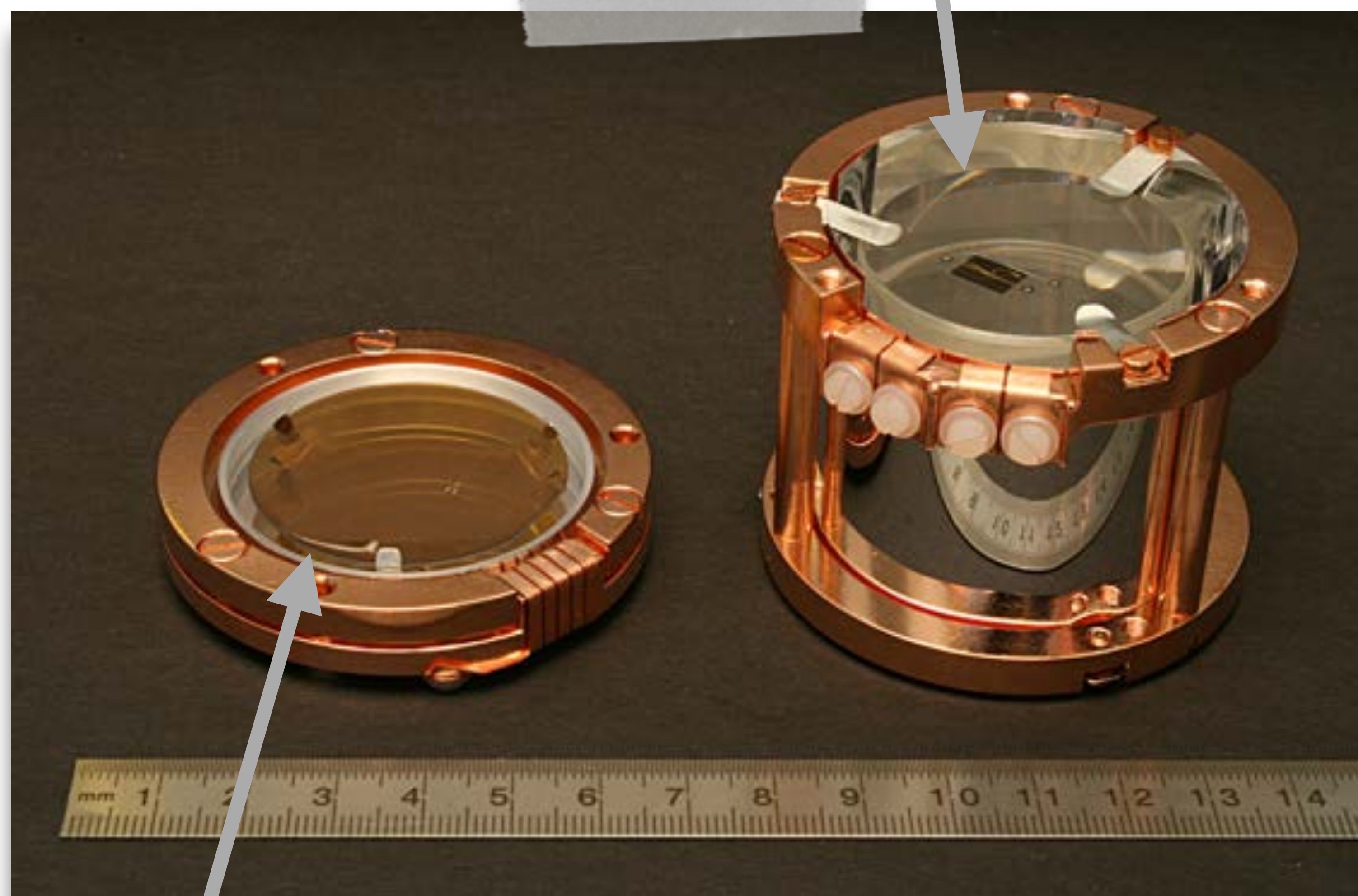


SQUID: superconducting quantum interference device

Scintillation Light

- few percent of deposited energy is converted to scintillation light
- amount of scintillation light differs between nucleus and electron recoils
- absorption of scintillation light by silicon-on-sapphire (SOS) detector
- SOS read out by transition edge sensor

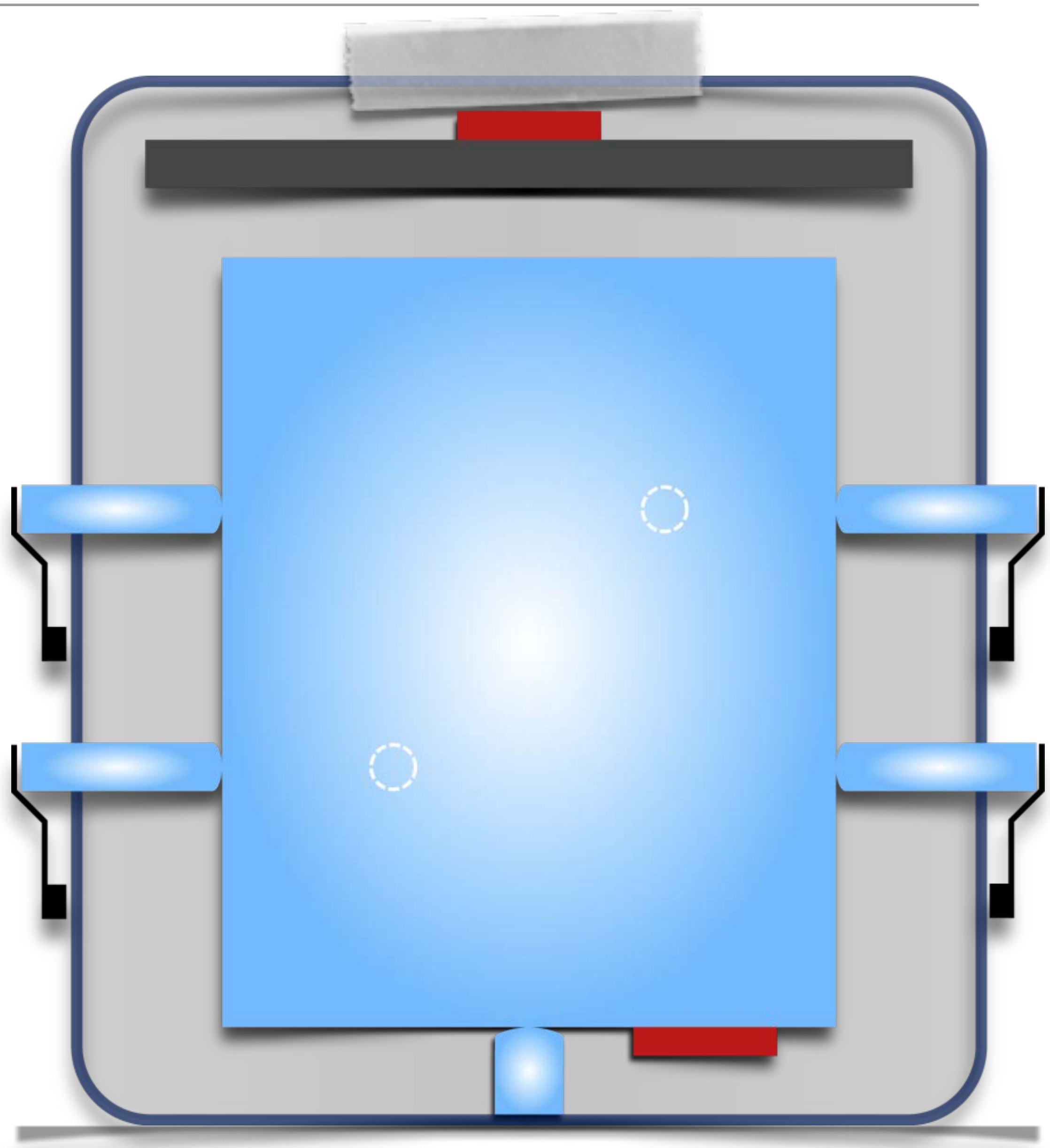
phonon detector



light detector

Search for Dark Matter with CRESST II Phase 2

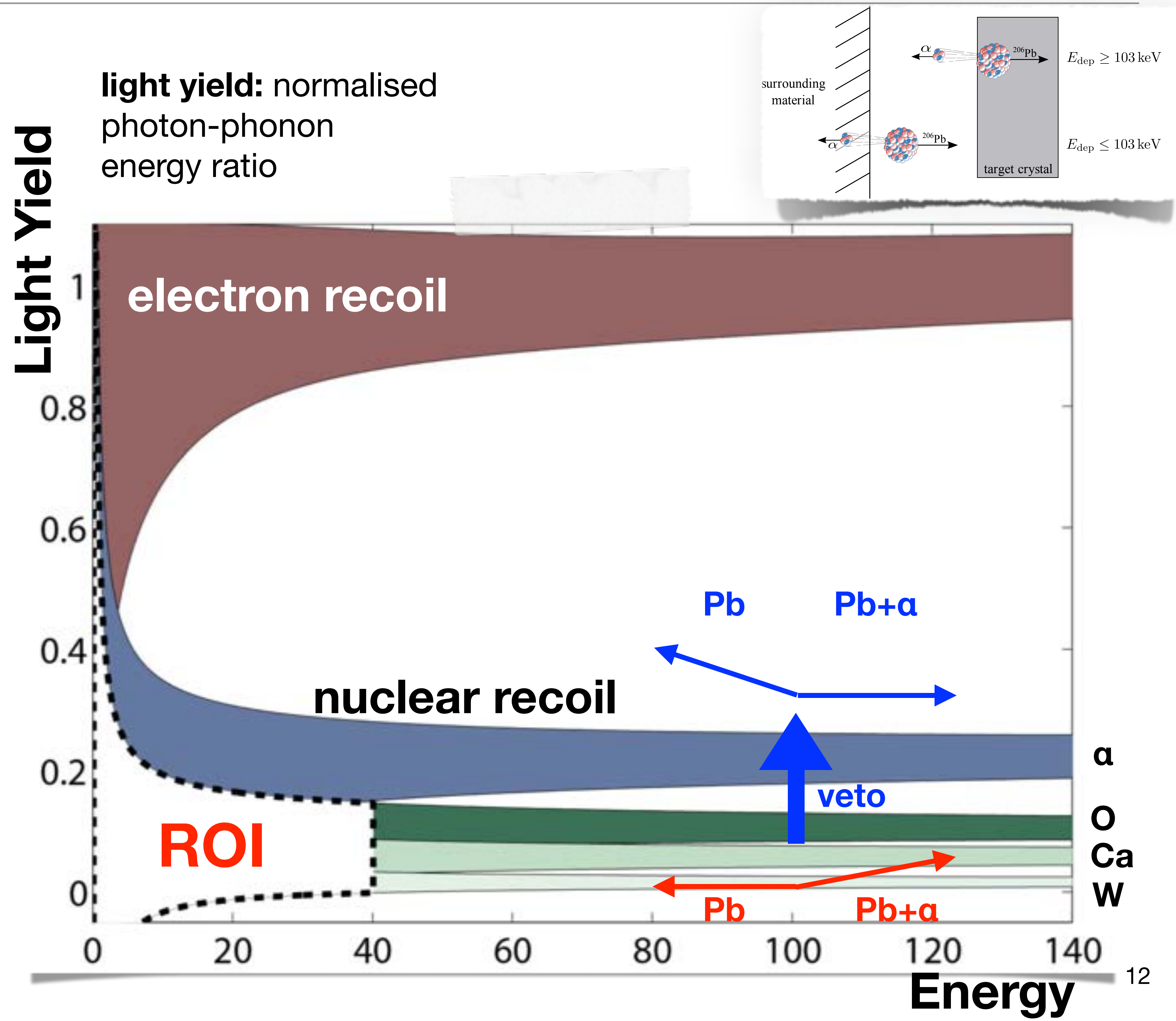
- excess of signal events or background events?
- improved handling to avoid contribution from Po-decays
  - detector mounting in radon clean environment
  - fully scintillating housing; hold crystal with $CaWO_4$-sticks



detector module “TUM40” with improved background treatment

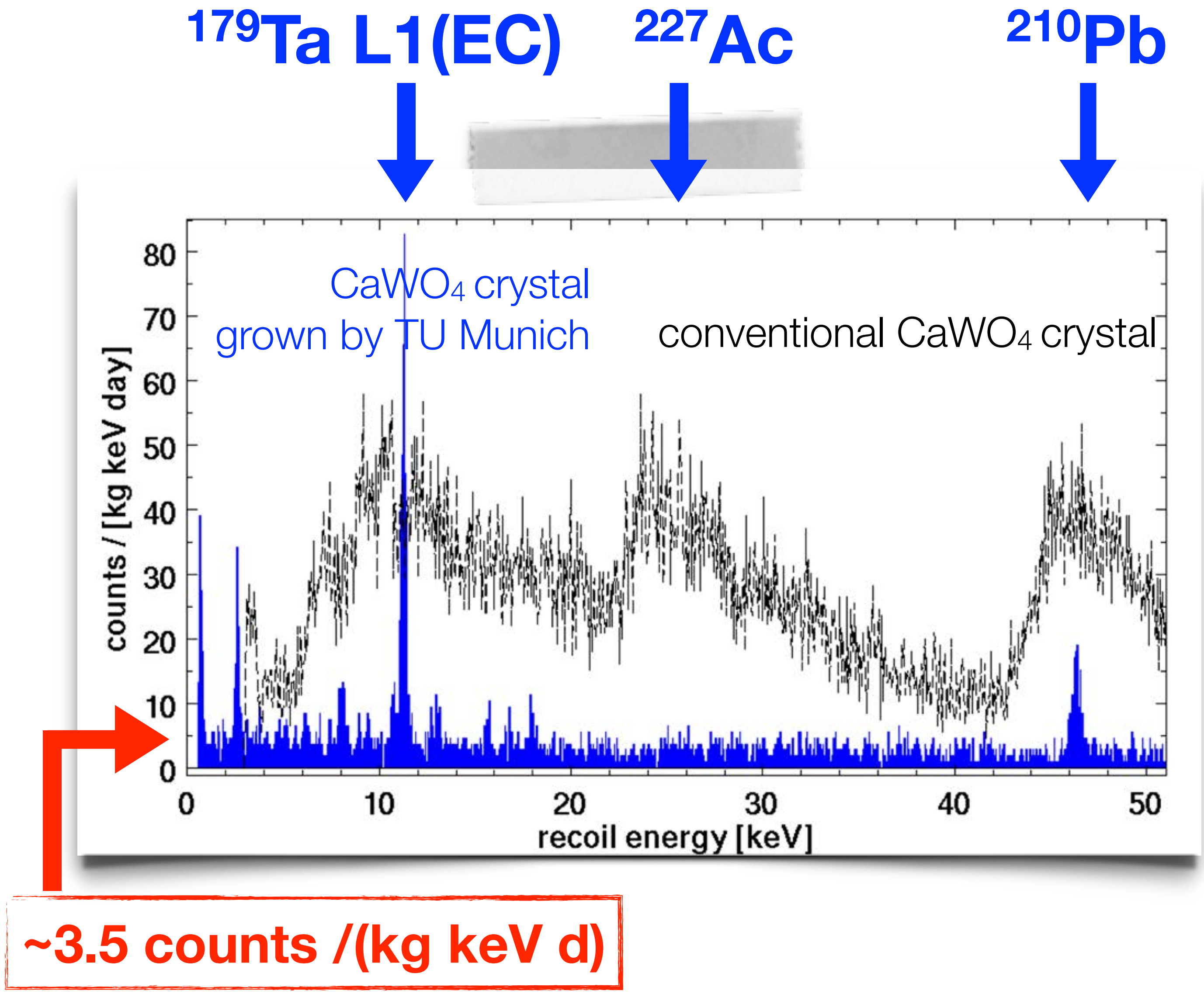
Search for Dark Matter with CRESST II Phase 2

- full scintillating housing crucial for veto
- remove background events from ROI



Search for Dark Matter with CRESST II Phase 2

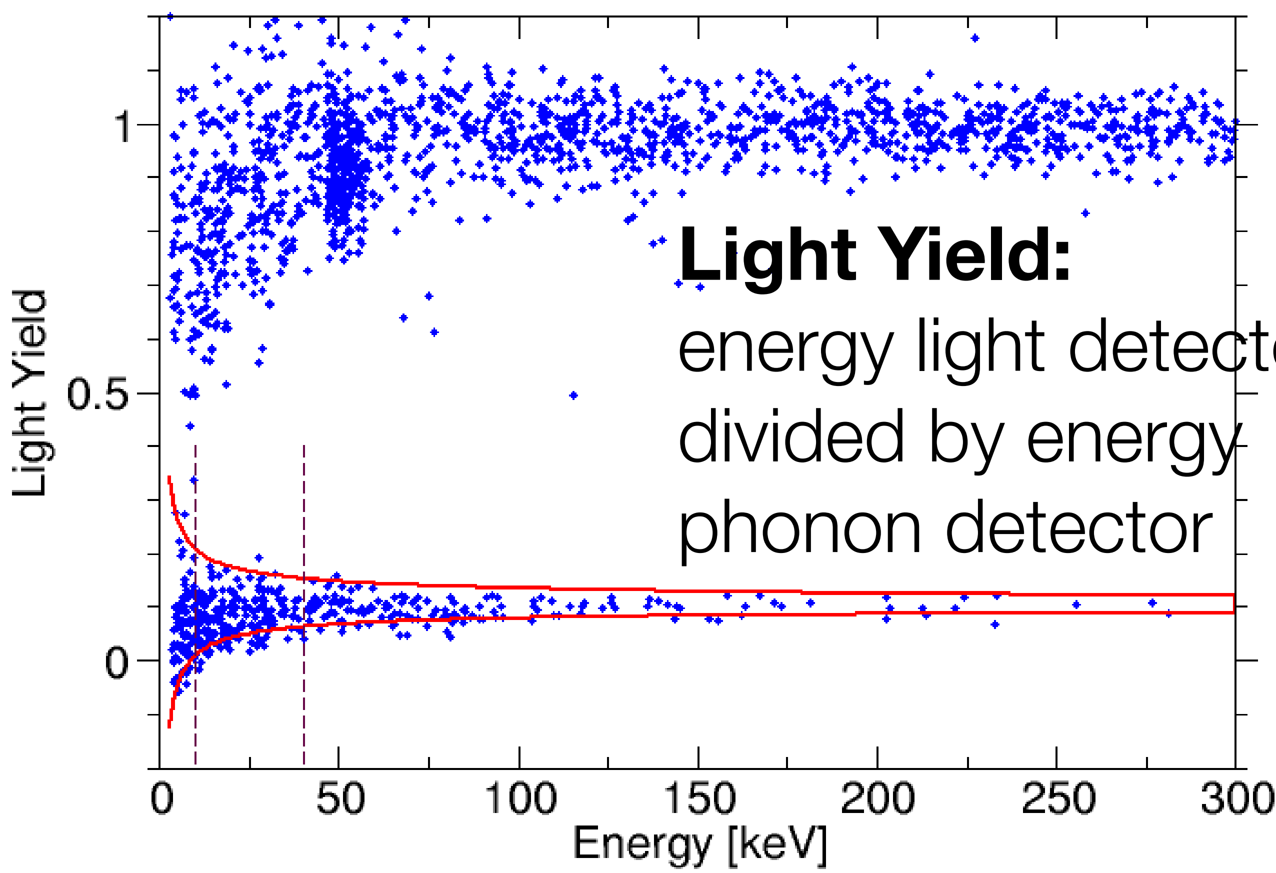
- external background suppression using scintillating sticks significantly improved
- leakage from internal e^-/γ-background sources in signal region dominant background contribution
- in-house production of $CaWO_4$-crystals with significantly improved background (TU Munich)



Dark Matter searches with CRESST II Phase 2

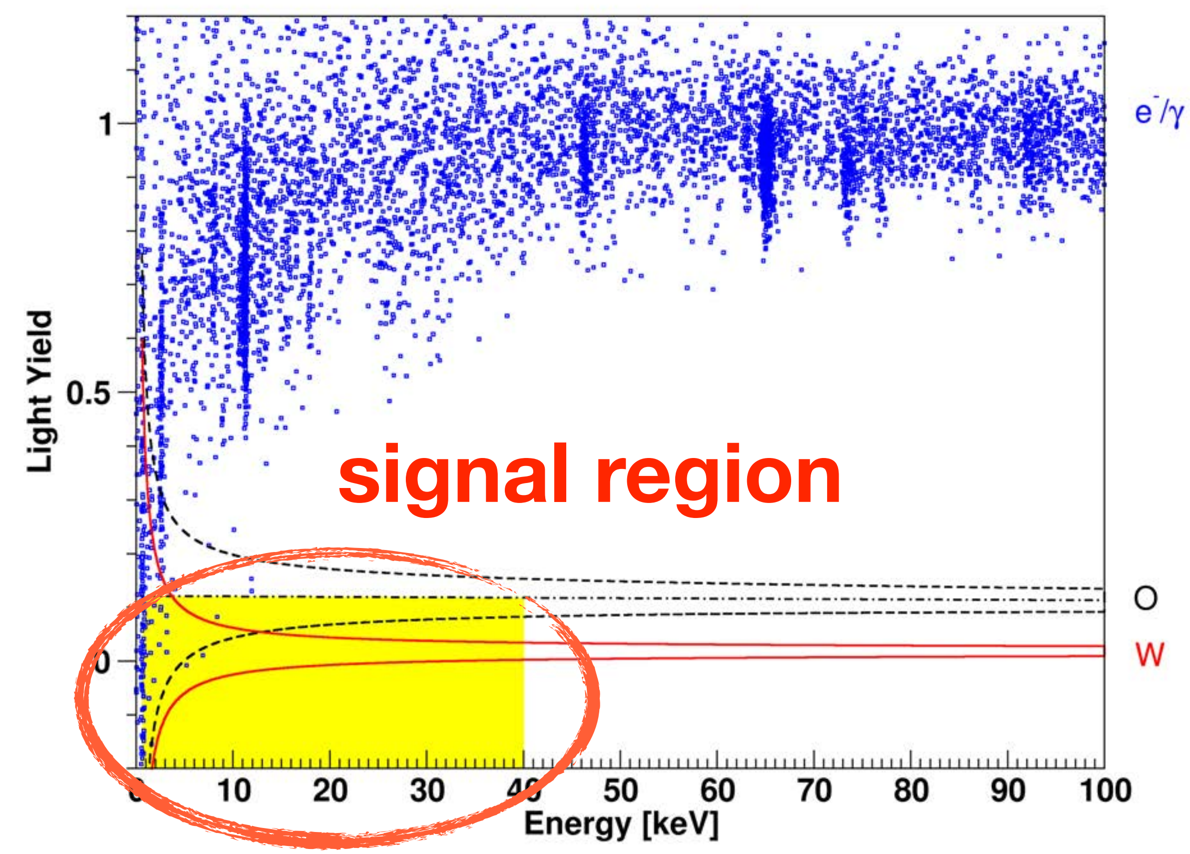
Eur.Phys.J. C74 (2014) 12, 3184
arxiv 1407.3146

neutron calibration



Light Yield:
energy light detector
divided by energy
phonon detector

measurement



- clear separation between signal and background events
- identify signal region in Light Yield / Energy space

the Result

Search for Dark Matter with CRESST II Phase 2

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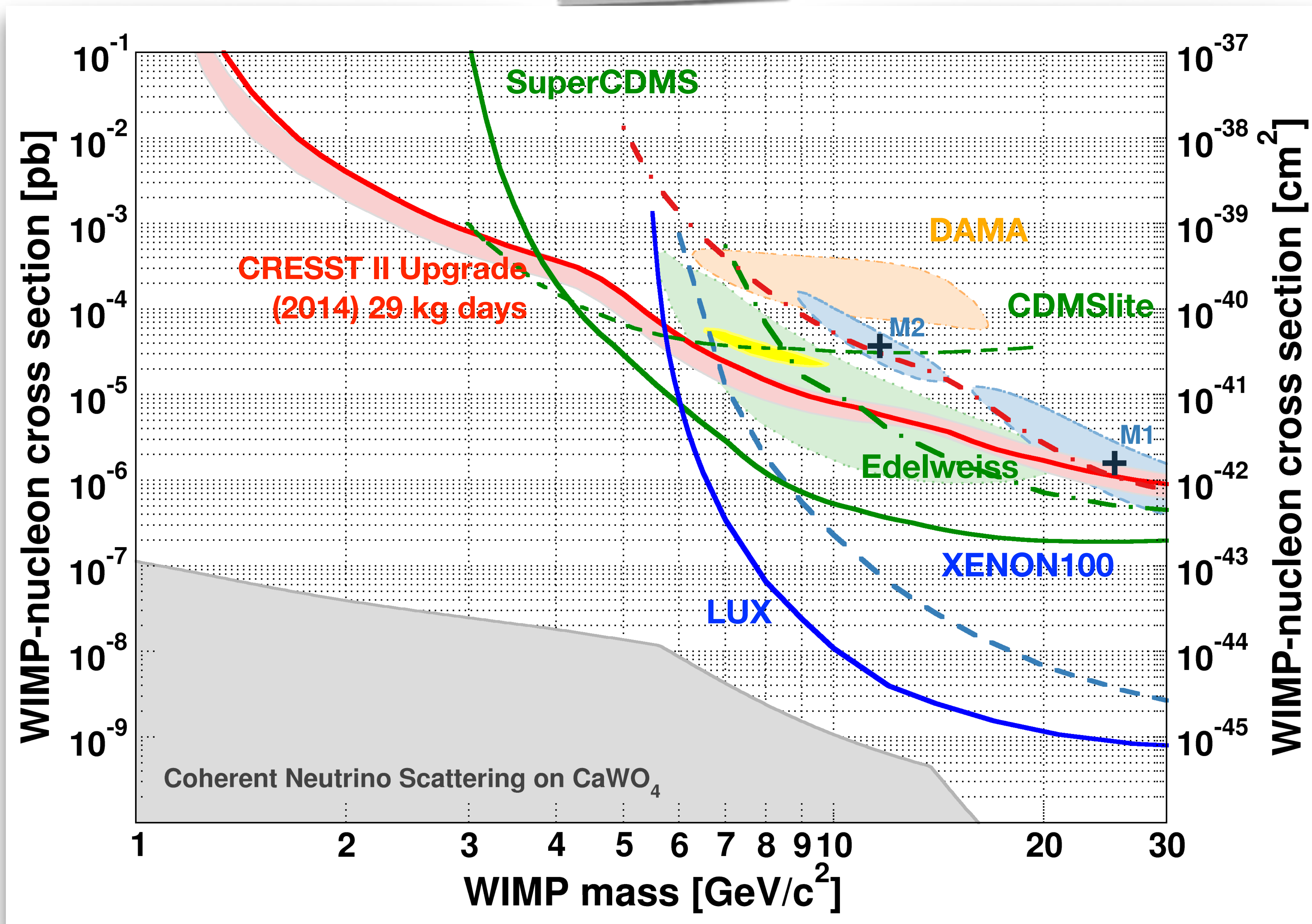
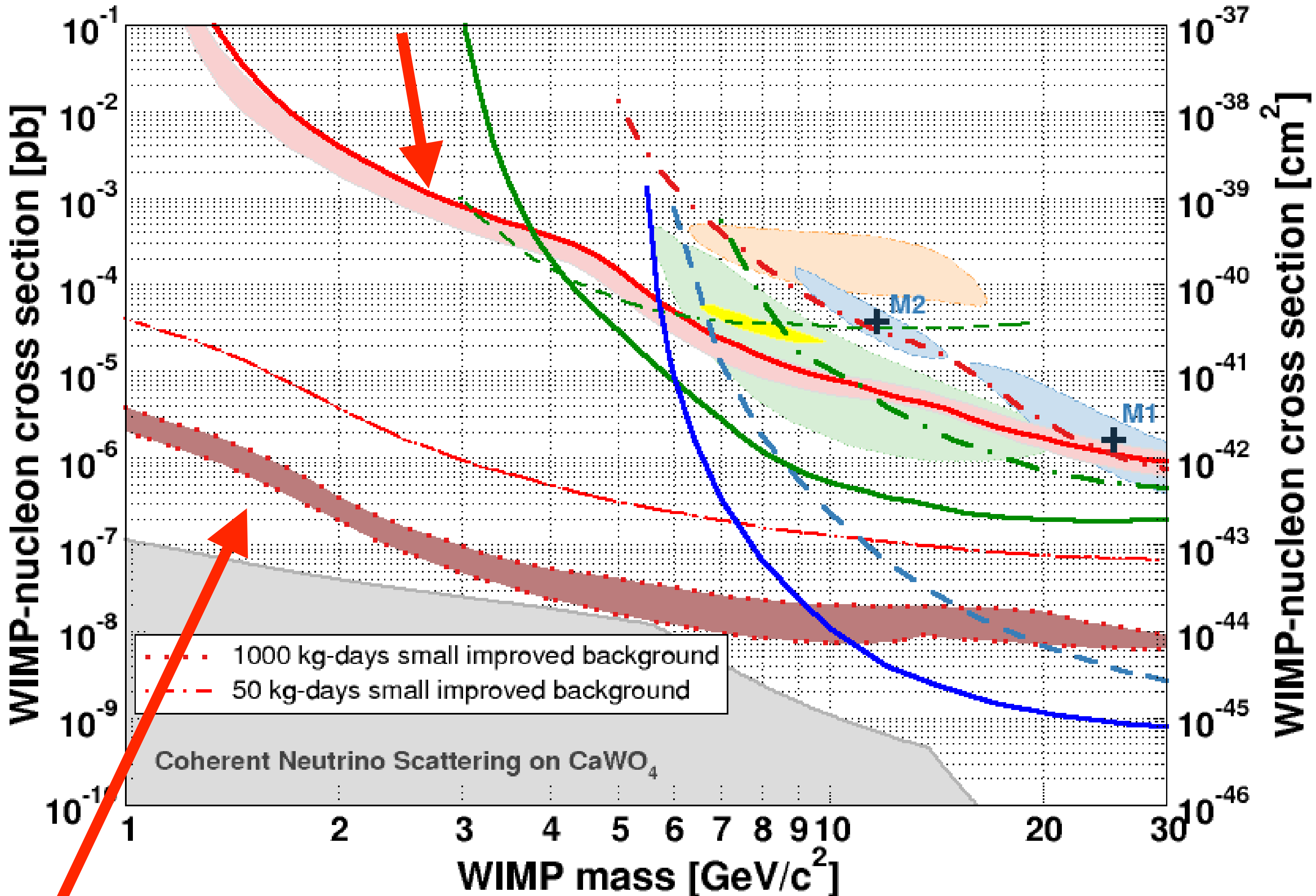


Expected Sensitivity with CRESST III

- decreasing crystal size (24g) increases phonon density
- reduction of crystal radiopurity

➡ **increased sensitivity**

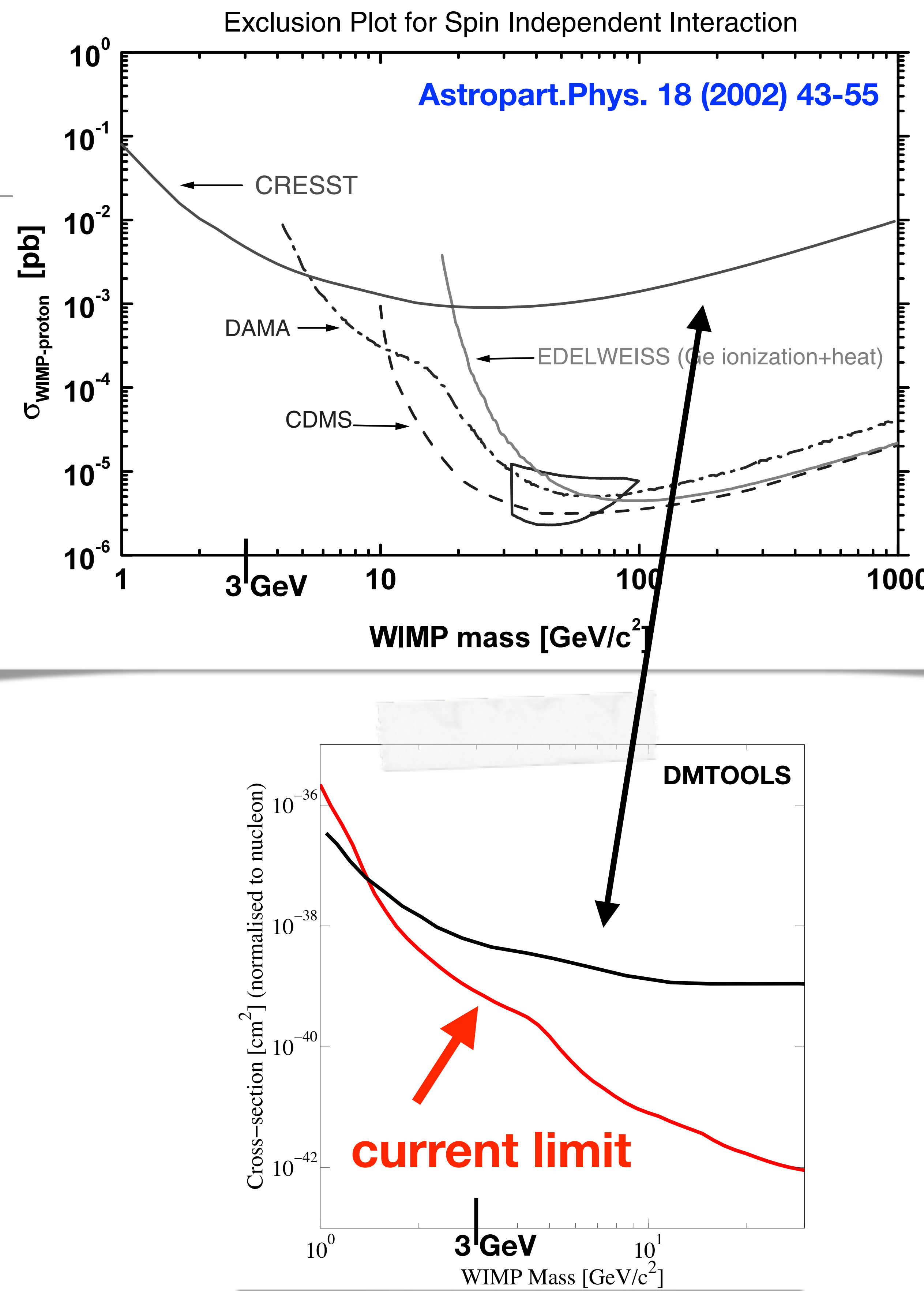
current limit



expected limit with improved design and reduced background

Historical Interlude

- result based on non-scintillating Al_2O_3 crystals showed similar sensitivity in low mass region
- Al_2O_3 crystals non-scintillating
  ⇒ no e/γ-background rejection possible
- less sensitivity in mass region above 5 GeV



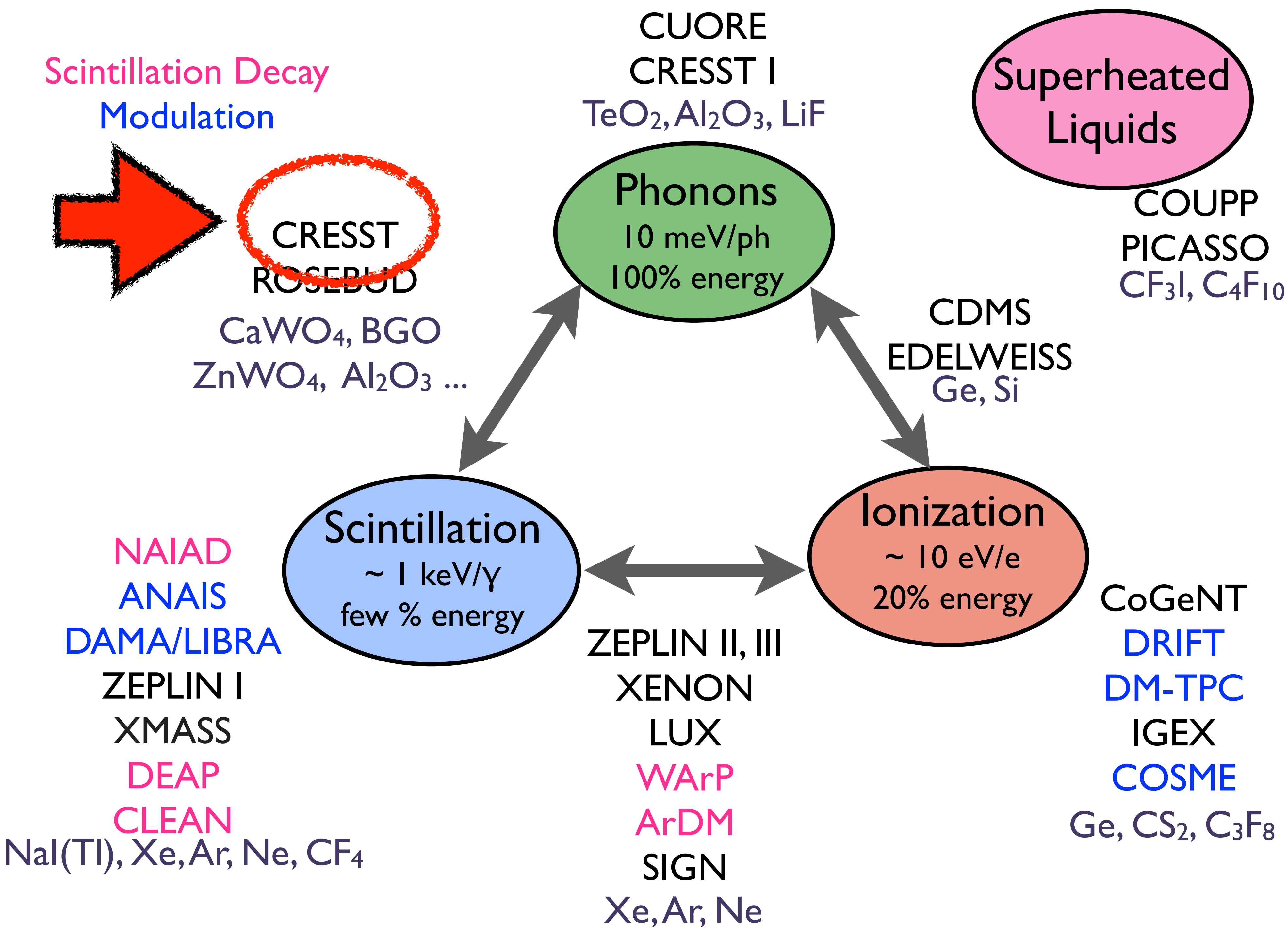
Summary and Conclusion

- CRESST II: combined phonon-light measurement of DM-nuclear recoils in almost background free environment
- improved module design and radiopurity did not confirm signal like excess of previous data taking period
- phonon threshold of 600 eV significantly improves sensitivity in low-mass DM region ⇒ among the best limits
- further reduction of threshold and background will improve limit in low-mass region by 3-4 orders of magnitude

The CRESST Collaboration

About 40-50 scientists from 7 institutions and 4 countries

Measurement of Recoil Energy deposited by WIMPs



Cryogenic Approach: Phonon Detection

- (almost) Complete energy is deposited as phonons
- Energy deposition in the crystal will lead to a temperature rise proportional to energy
- Detection of temperature with transition edge detectors

$$\Delta T \propto \frac{\Delta E}{C}$$

C: heat capacity of the crystal

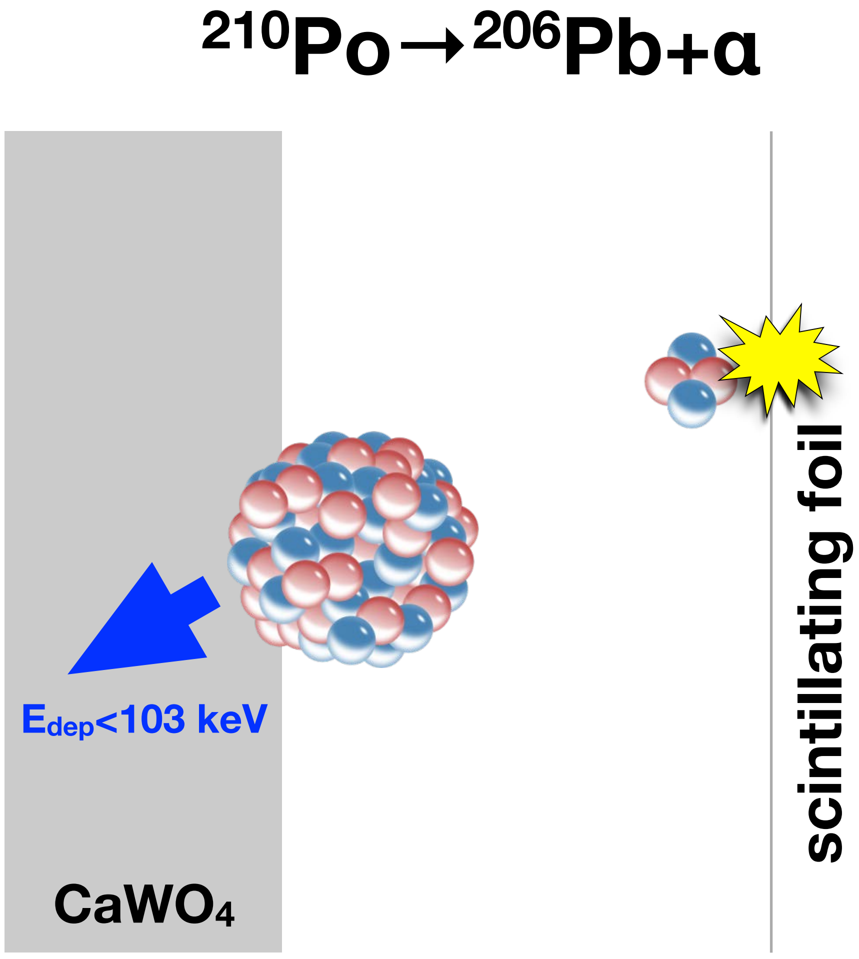
$$C \propto (T/\theta_D)^3$$

Θ_D:Debye temperature

- Very small energy deposition (O(10 keV)) requires very small heat capacity C
- Small C requires very low temperature

Dark Matter searches with CRESST II Phase I- Background

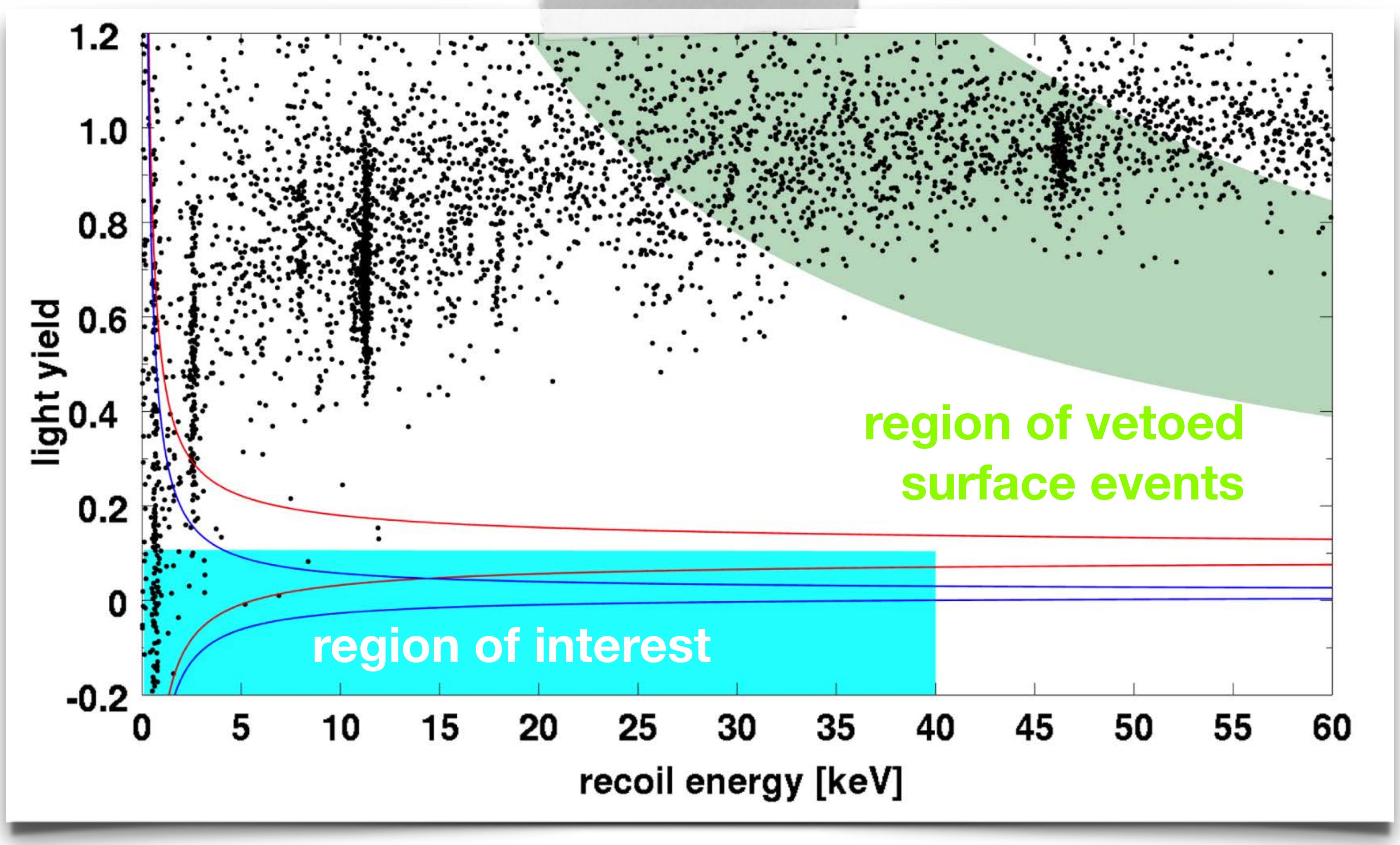
- Decay of polonium close to the crystal surface can mimic WIMP event
- Interaction of α-particle with surrounding scintillating foil will enhance light yield
  - Move event out of the region of interest
- **Problem: clamps holding the crystal do not scintillate**



significant contribution to overall background

Search for Dark Matter with CRESST II Phase 2

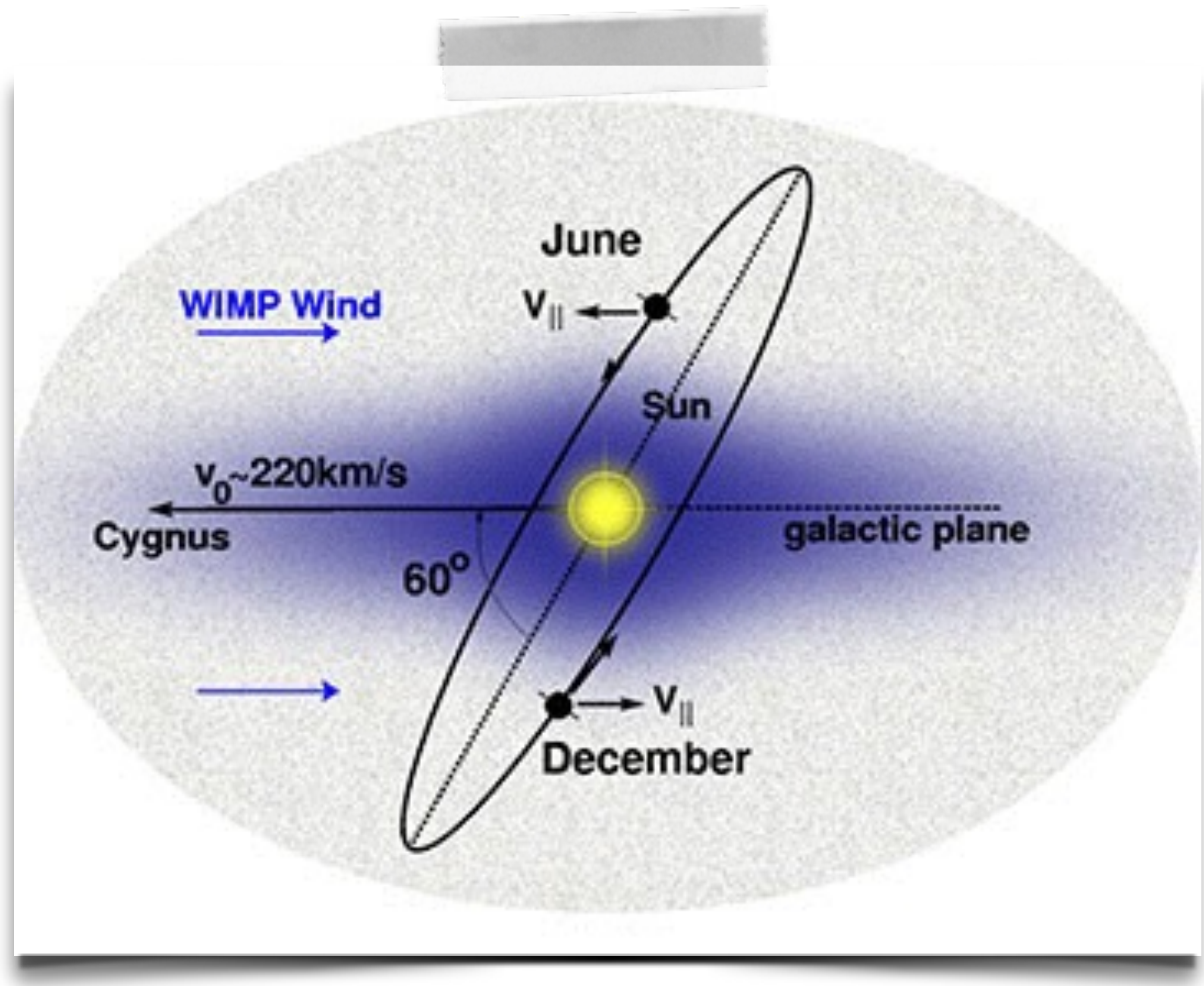
- Threshold for nuclear recoils at 600 eV with 100 eV resolution
- Sensitivity for low-mass WIMPs improved significantly
- **Strategy change: focus on low-mass WIMPs**
- **Low-mass WIMP region preferred region for asymmetric Dark Matter models**



events recorded with TUM40 crystal (29.4 kg d)

Astrophysical Parameters - Distribution of WIMPs

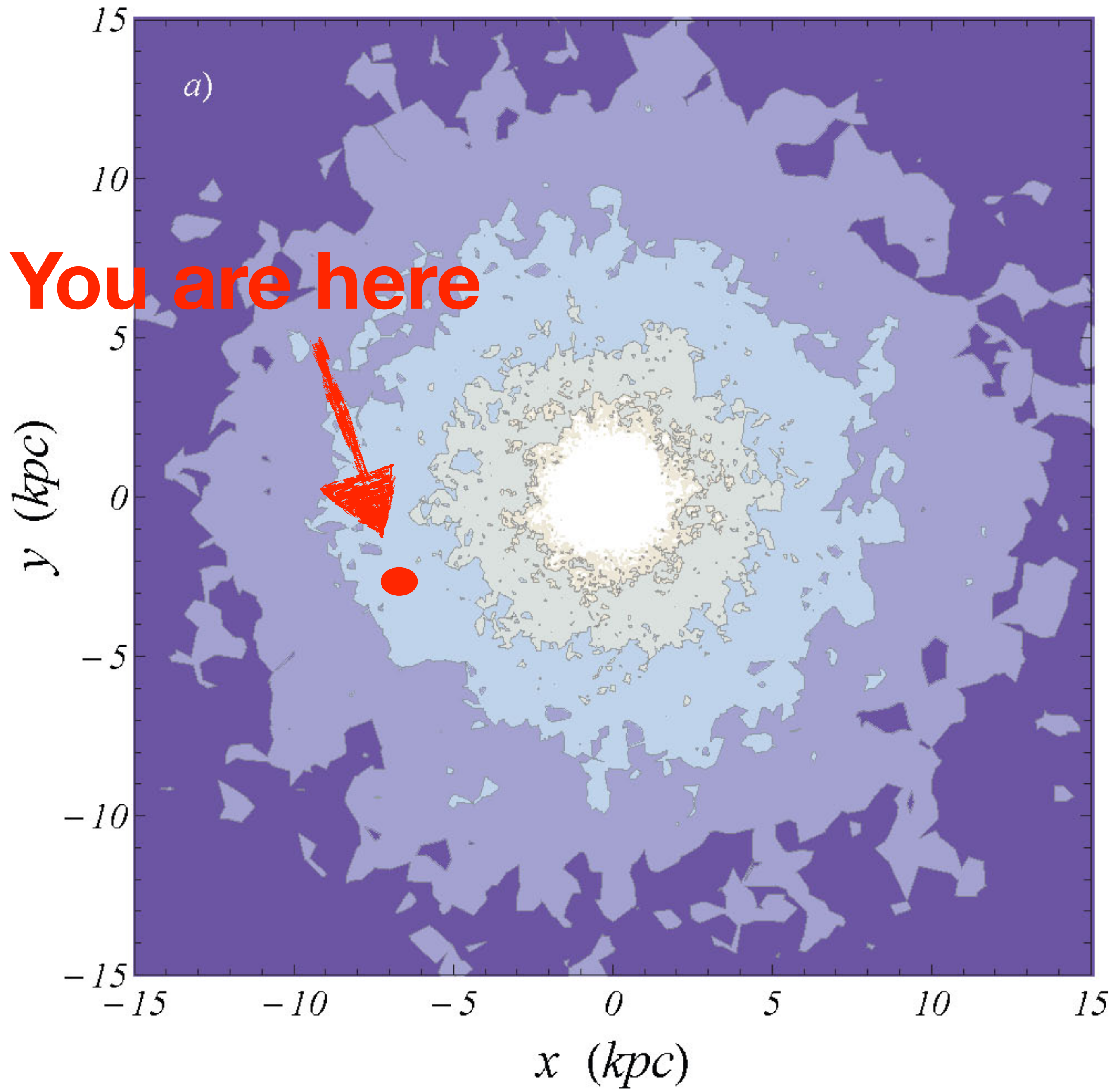
- Velocity of dark matter in the halo follows Maxwell-Boltzmann distribution
  - Most probable WIMP velocity ~220 km/s
  - Escape velocity for WIMP to escape halo about 540 km/s
- Sun travel through halo with a speed of ~230 km/s
  - ~5% variation originating from path of earth around sun



Astrophysical Parameters - Distribution of WIMPs

- Dark Matter distribution in Milky Way from simulation
- Local Dark Matter density ~0.3 GeV/cm^3
- WIMP flux on earth ~10^6 /cm^2 s for M_{WIMP} = 10 GeV

arxiv 0909.2028



contours correspond to {0,1,0.3.,1.0,3.0} GeV/cm^3

arxiv 1002.1912

Direct Detection - Event Rate

- Differential event rate for WIMP nucleon scattering

ρ_0: WIMP density in the Milky Way

f(v): WIMP speed distribution

$d\sigma/dE_R$: WIMP-nucleus elastic scattering

$$\frac{dR}{dE_R} = \frac{\rho_0}{m_N\, m_\chi} \int_{v_{min}}^{\infty} v\, f(v)\, \frac{d\sigma_{W\,N}}{dE_R}(v, E_R)\, dv$$

m_N : nucleon mass

m_χ: WIMP mass

- Recoil energy between keV and tens of keV

Direct Detection - Particle Physics Input

- WIMP nucleon differential cross section

$$\frac{d\sigma_{WN}}{dE_R} = \frac{m_N}{2\mu_N^2 v^2}\left(\sigma_0^{SD} F_{SD}^2(E_R) + \sigma_0^{SI} F_{SI}^2(E_R)\right)$$

- Cross section can be divided in spin-dependent and spin-independent cross-section

$$\left(\frac{d\sigma_{WN}}{dE_R}\right)_{SD} = \frac{16 m_N}{\pi v^2}\Lambda^2 G_F^2 J(J+1)\frac{S(E_R)}{S(0)}$$

$$\left(\frac{d\sigma_{WN}}{dE_R}\right)_{SI} = \frac{16 m_N}{\pi v^2}\left[[Z f^p + (A-Z) f^n]^2 + \frac{B_N^2}{256}\right] F^2(E_R)$$

- WIMP-nucleon elastic scattering effective theory has six components (arxiv 1203.3542)