Coherent Neutrino-Nucleus Scattering with the CRESST experiment

Lucia Canonica
INFN - LNGS

Bologna, 9-10 November 2015

Outline

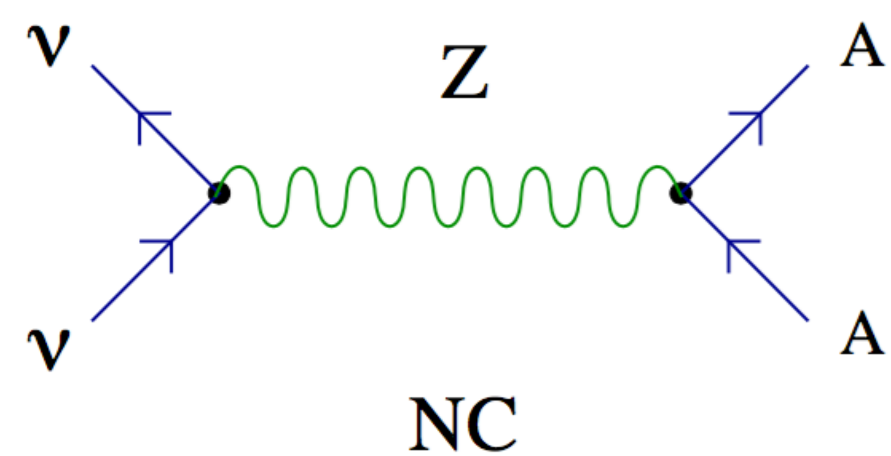
- Coherent Neutrino - Nucleus Scattering (CNNS)
- The CRESST experiment
- CRESST-II results
- Perspective for CRESST-III
- In reach of CNNS with CRESST

Outline

- Coherent Neutrino - Nucleus Scattering (CNNS)
- The CRESST experiment
- CRESST-II results
- Perspective for CRESST-III
- In reach of CNNS with CRESST

Coherent Neutrino-Nucleus Scattering

- Neutrino interacts with nucleus through neutral current



- CNNS has never been observed.
  - Largest σ in Supernovae dynamics.
  - Ideal for studying active sterile transformation.
  - Irreducible background for WIMP searches.

CNNS detection

- Neutrino (E<50 MeV) scatters coherently off all nucleons —> cross section enhancement.
- Signature: low-energy nuclear recoil (sub-keV to keV)

- Detector requirements are extremely challenging:
  - Low backgrounds: $<10^{-2}$ c/(keV kg d)
  - Large mass: 1kg – 1ton
  - Extremely low threshold

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{M_A T}{2E_\nu^2}\right) F(q^2)^2$$

- σ: Cross Section
- T: Recoil Energy
- E_ν: Neutrino Energy
- G_F: Fermi Constant
- Q_W: Weak Charge
- M_A: Atomic Mass

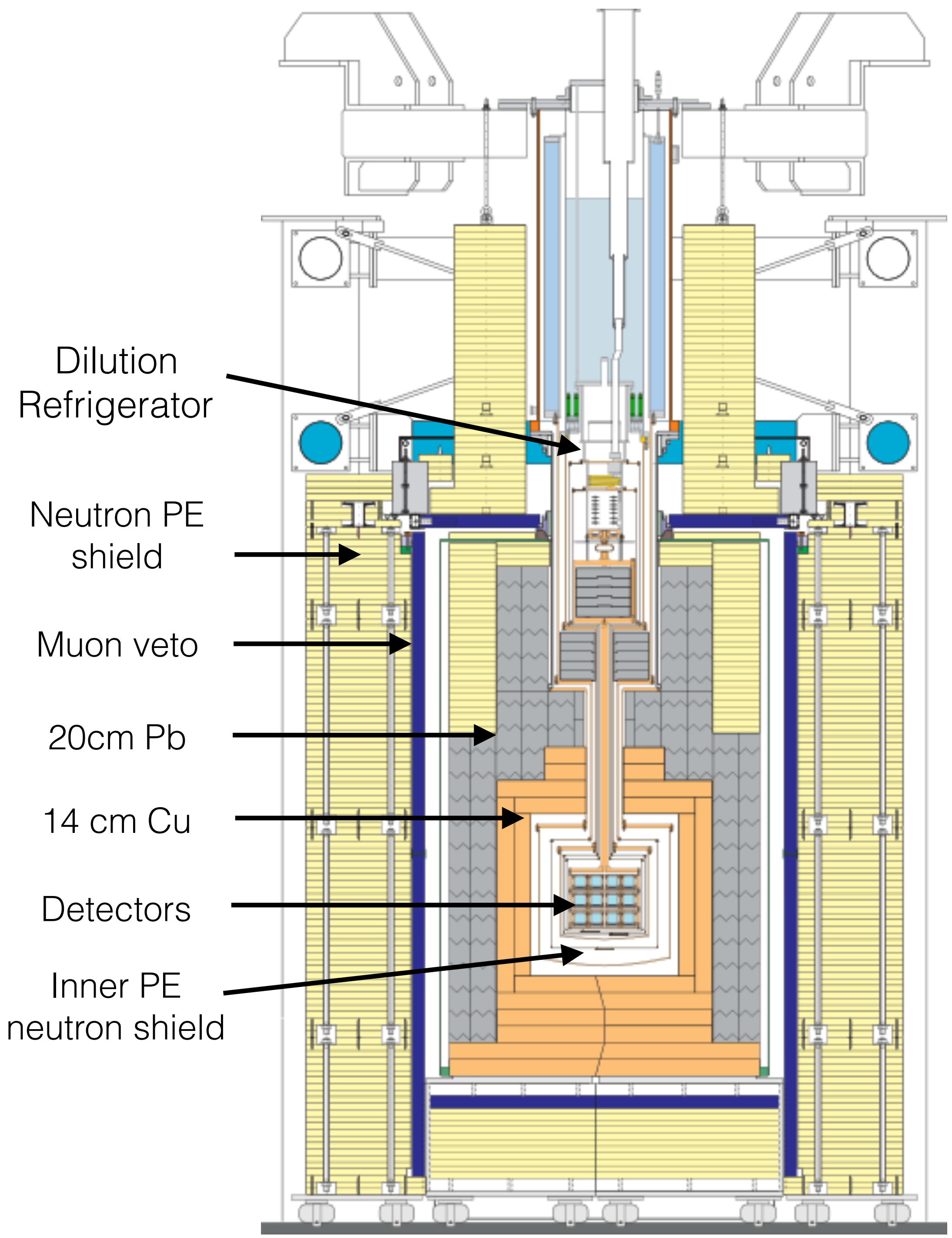
Similar signature as nuclear recoil from WIMP interaction

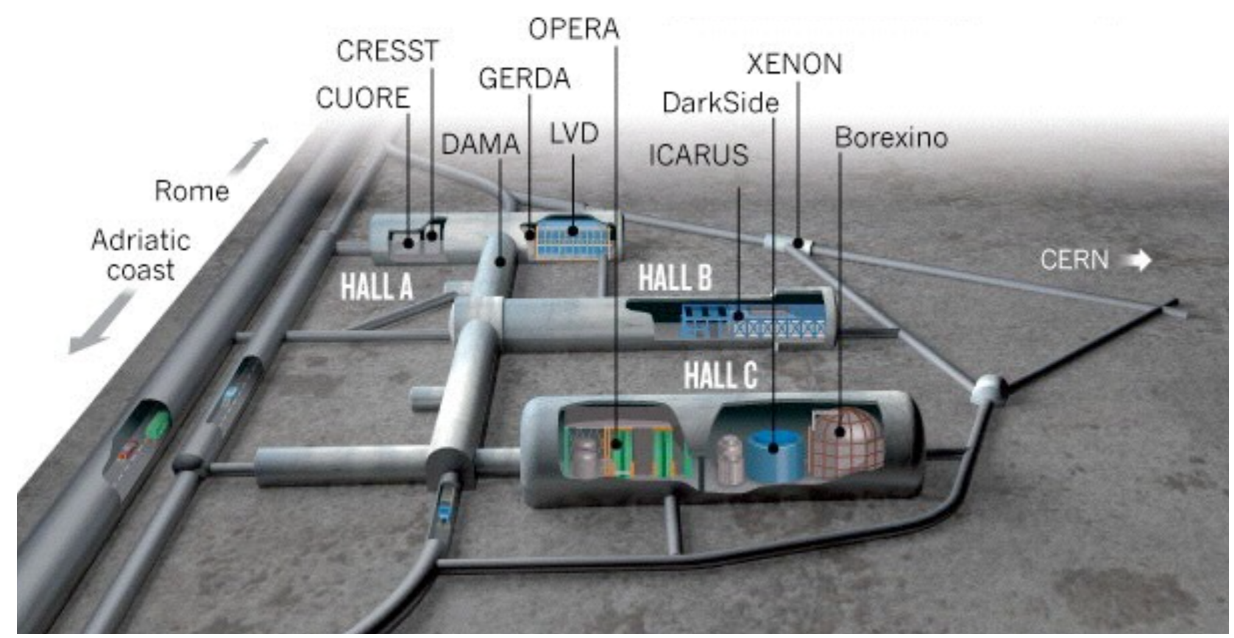
Outline

- Coherent Neutrino - Nucleus Scattering (CNNS)
- The CRESST experiment
- CRESST-II results
- Perspective for CRESST-III
- In reach of CNNS with CRESST

The CRESST experiment

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

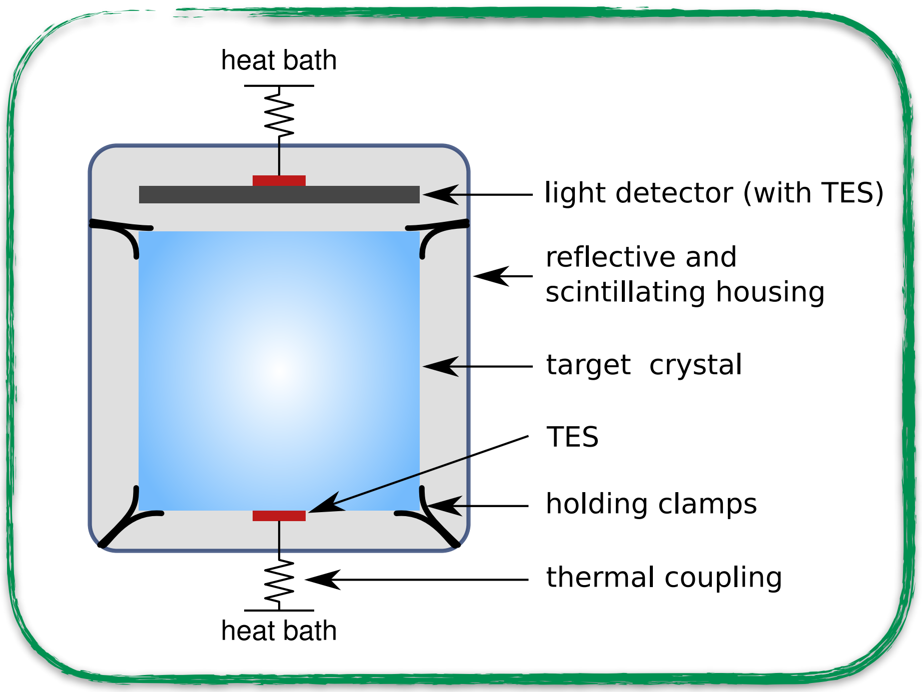


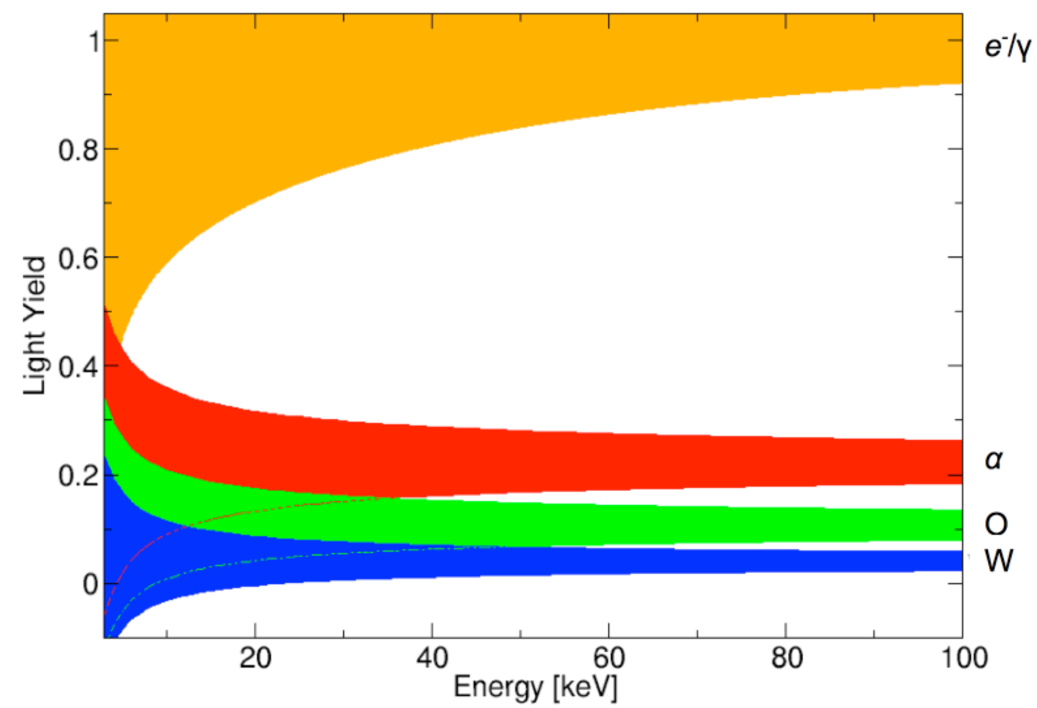


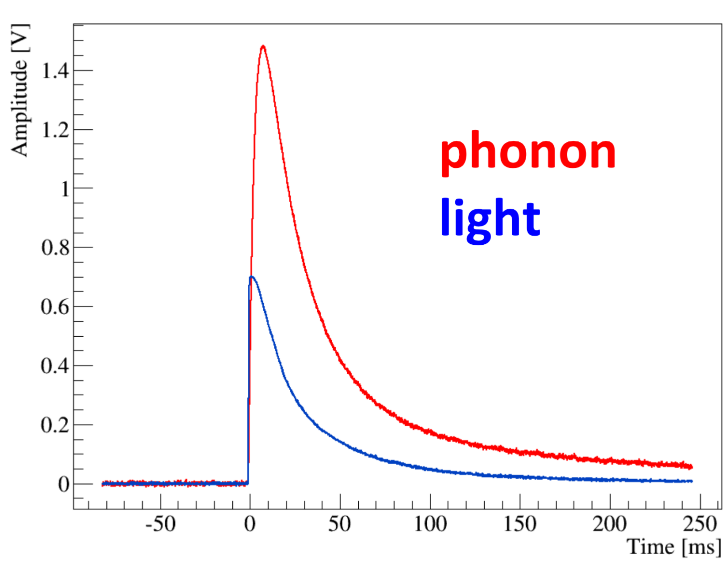
- Underground installation
- Ultra-low background environment
- Cryogenic detectors (10-15mK)

CRESST detectors

- When a bolometer is an efficient scintillator at low temperature, part of the energy deposited in the absorber is converted into light, the remaining in phonons.



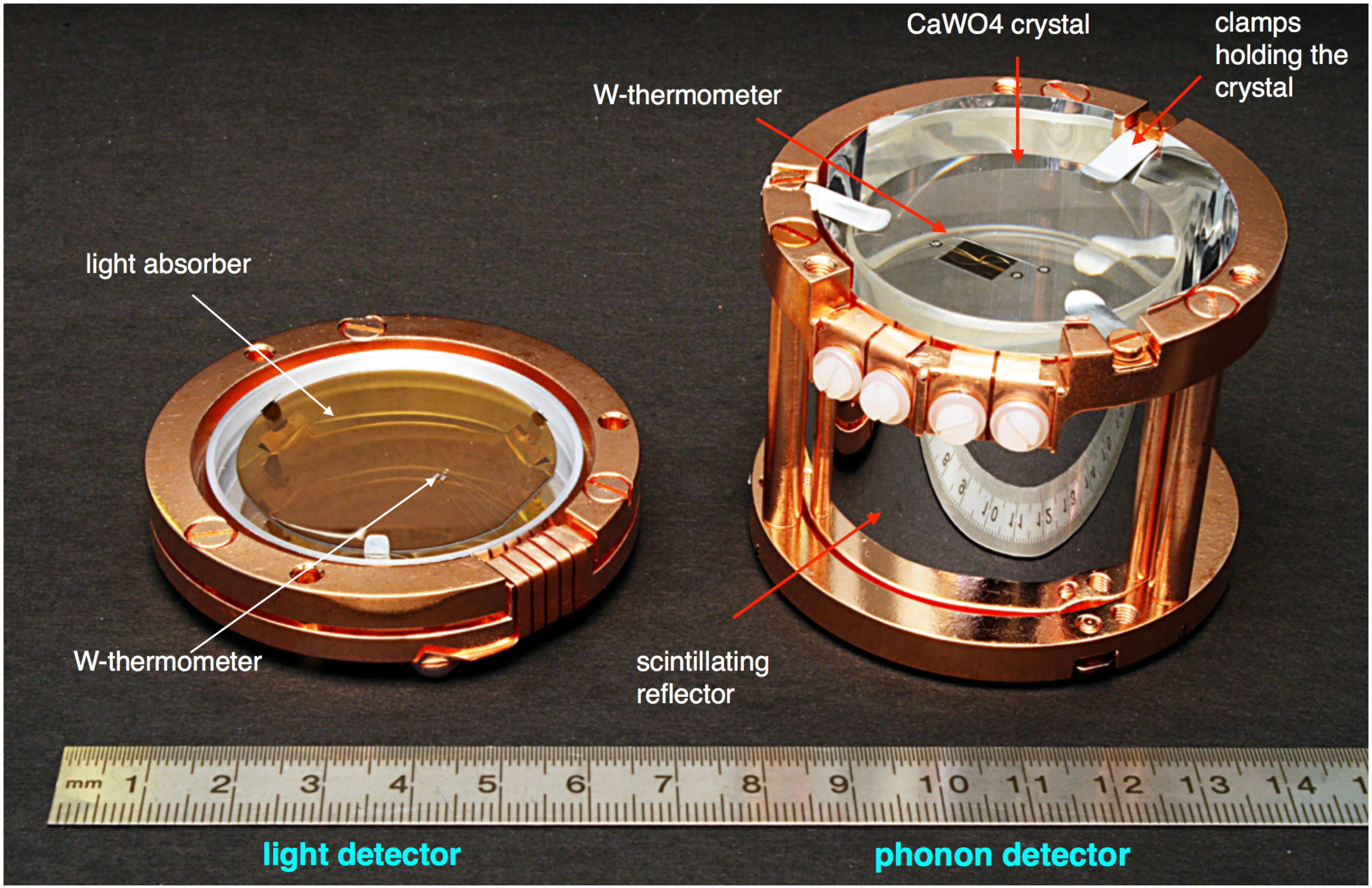




Event type discriminated by different light yield.

$$LY = \frac{Light\ Signal}{Heat\ Signal}$$

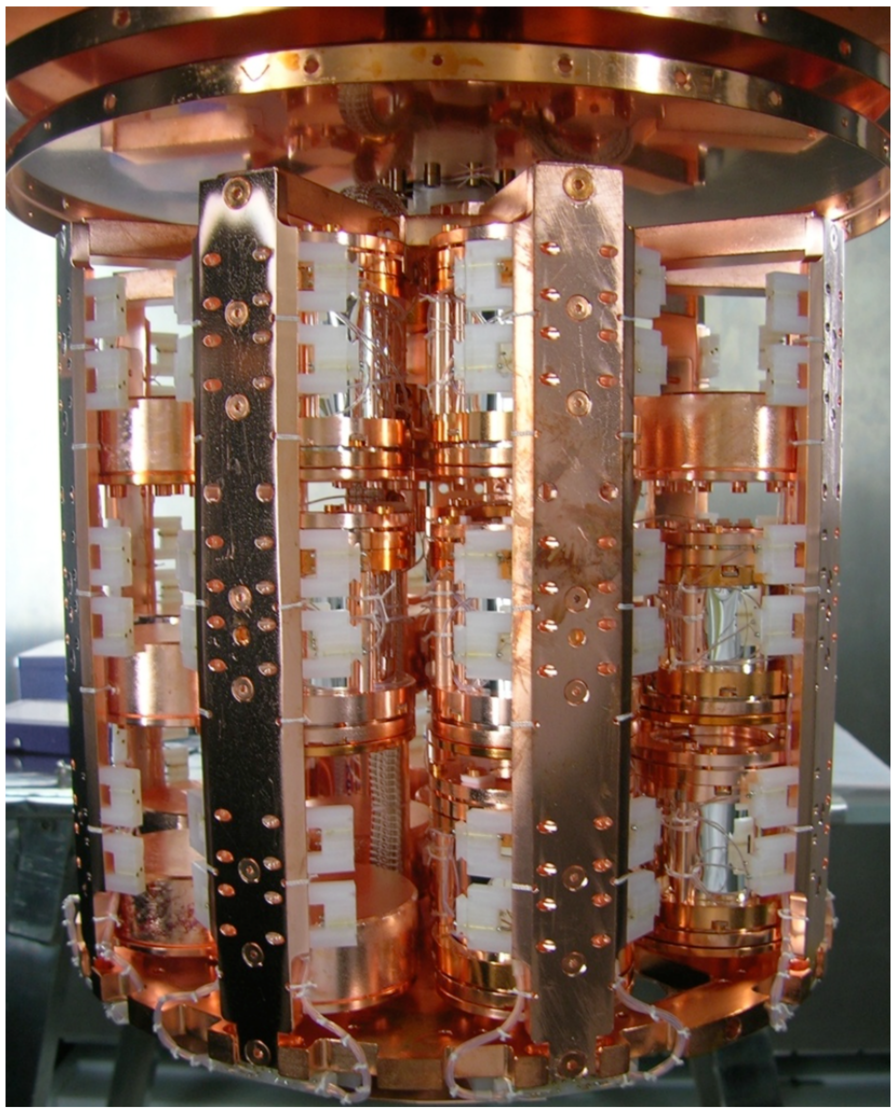
CRESST module



Outline

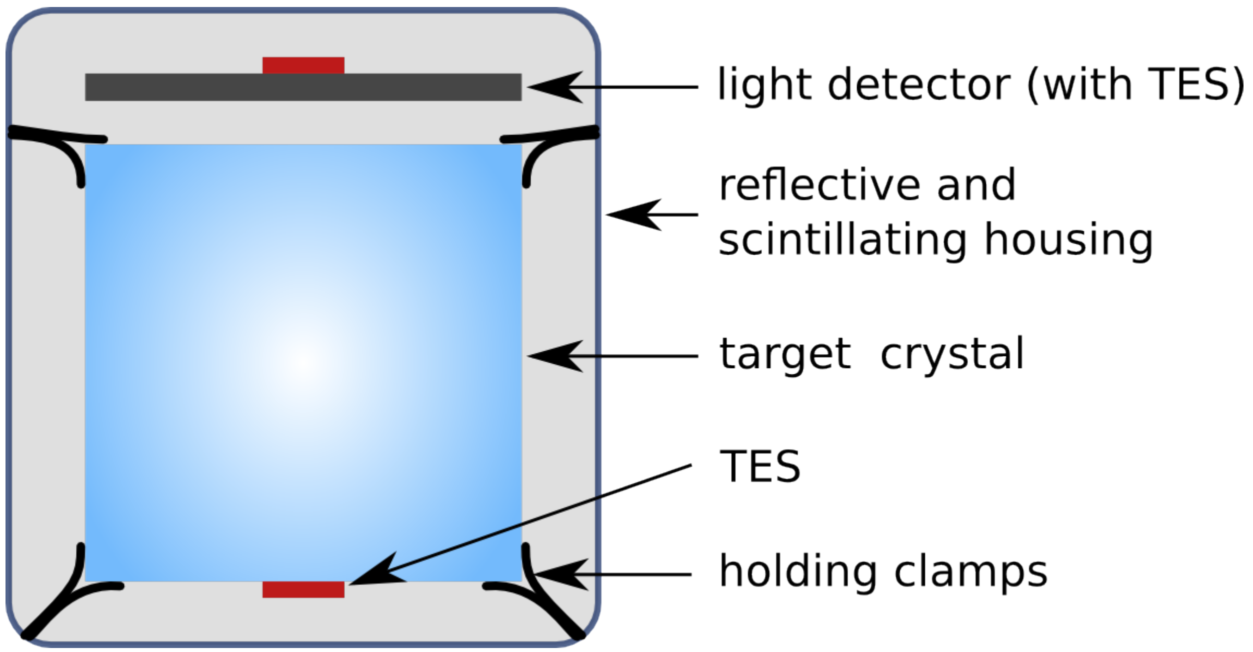
- Coherent Neutrino - Nucleus Scattering (CNNS)
- The CRESST experiment
- CRESST-II results
- Perspective for CRESST-III
- In reach of CNNS with CRESST

CRESST-II results

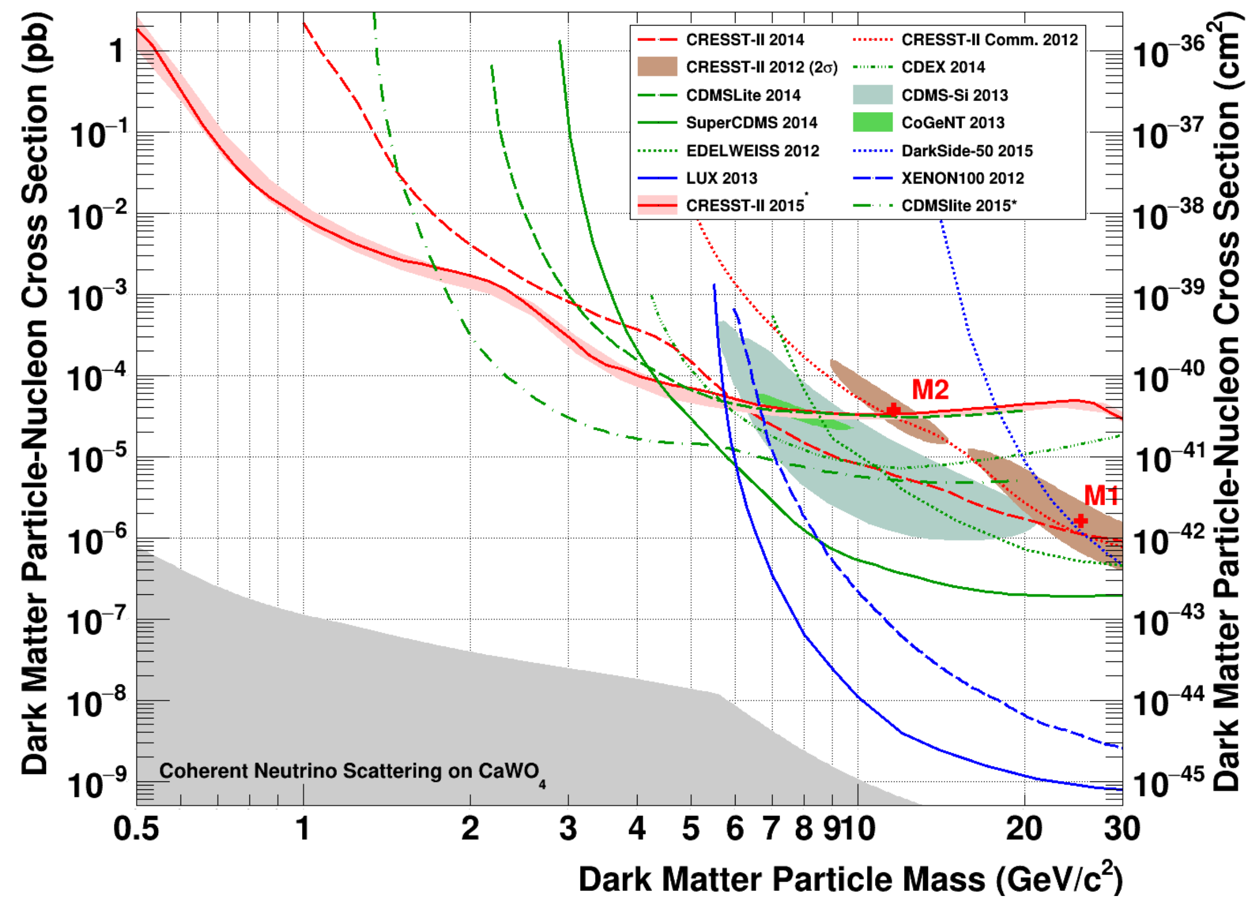


- Data taking from July 2013 to August 2015 with 18 modules
- 2015 result: “Lise”
- 2014 result: “TUM40”

Lise result



G. Angloher et al. arXiv:1509.01515

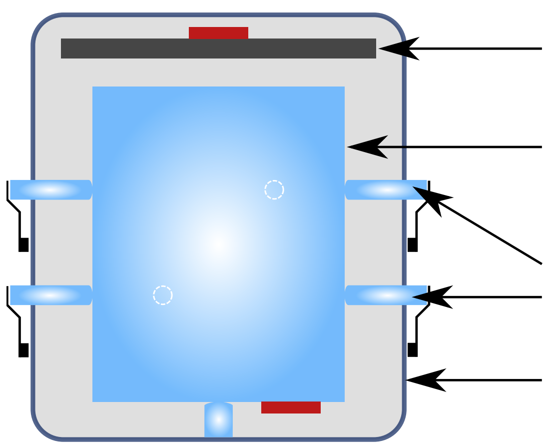


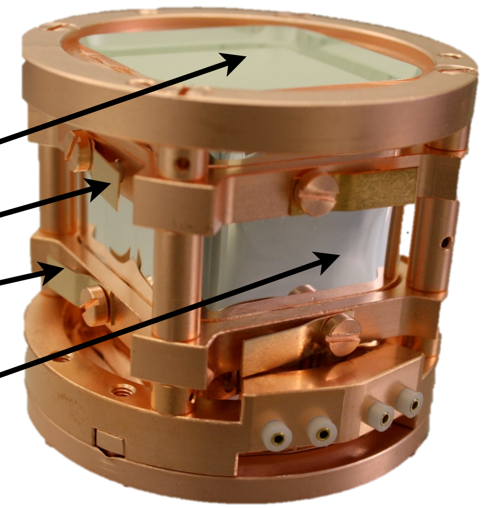
Module with **lowest threshold**:

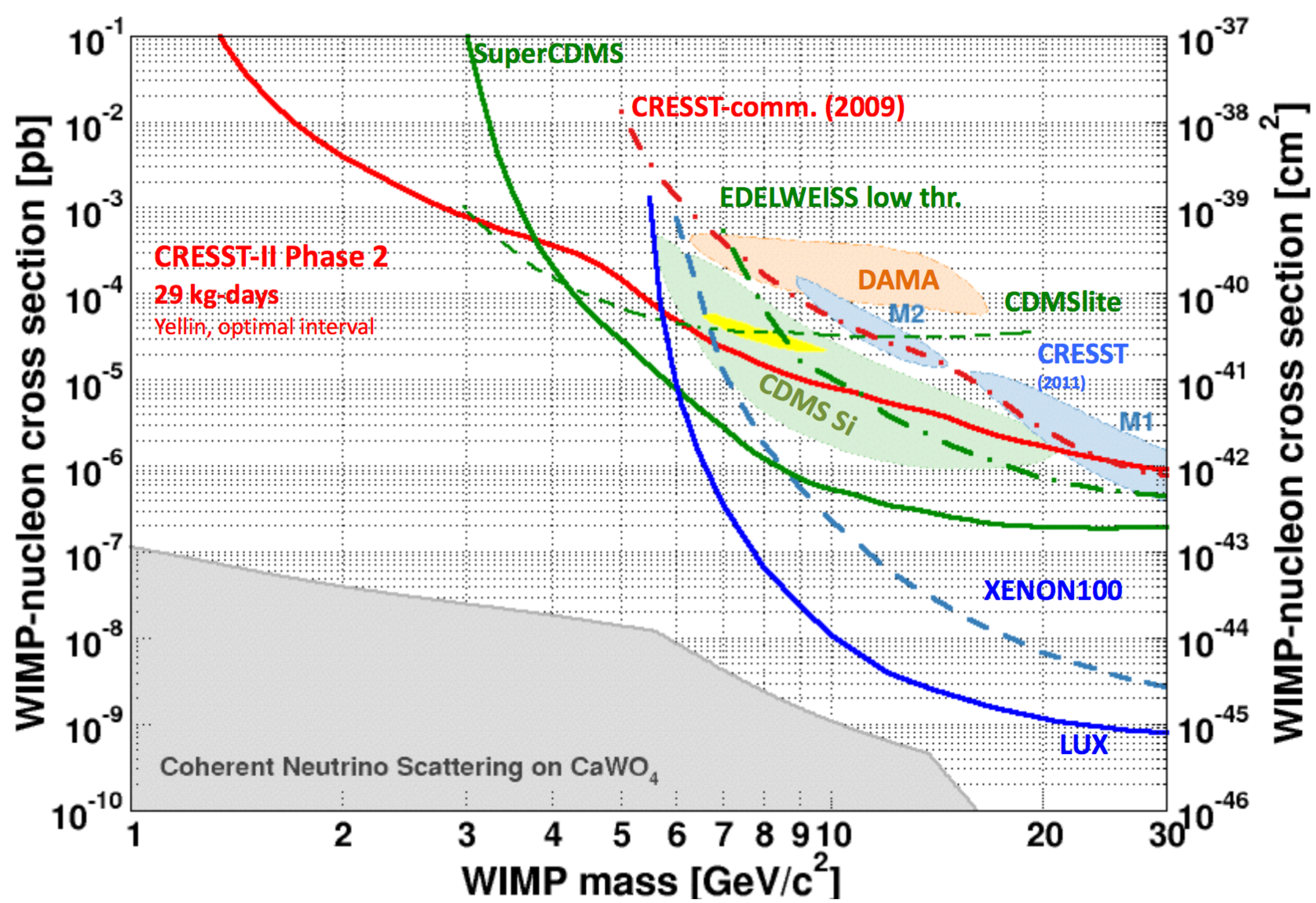
- radiopurity: ~ **8.5 c/(keV kg day)**
- excellent resolution (σ ~**60eV**)
- threshold: **307 eV**
- **52 kg days** of exposure

Currently best limit for low - mass WIMPs

TUM 40 result







Fully scintillating housing.
Module with best overall performance:

- excellent radiopurity **~ 3.5 c/(keV kg day)**
- excellent resolution (σ ~**100 eV**)
- Threshold: **600 eV**
- **29 kg days** of exposure

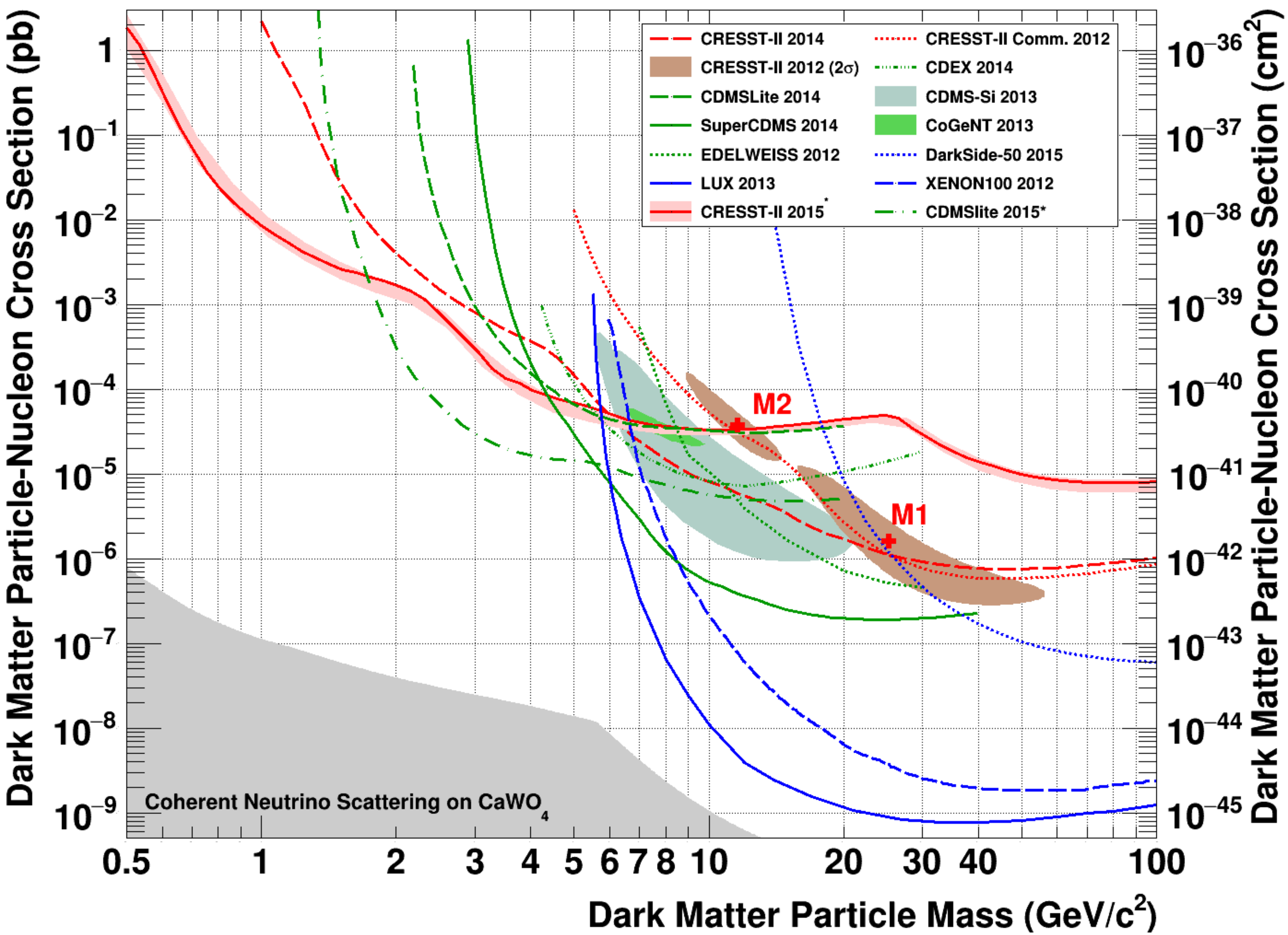
Explored new parameter space for WIMP masses < 3 GeV/c^2 with single detector module.

Angloher et al., EPJ C 74:3184 (2014)

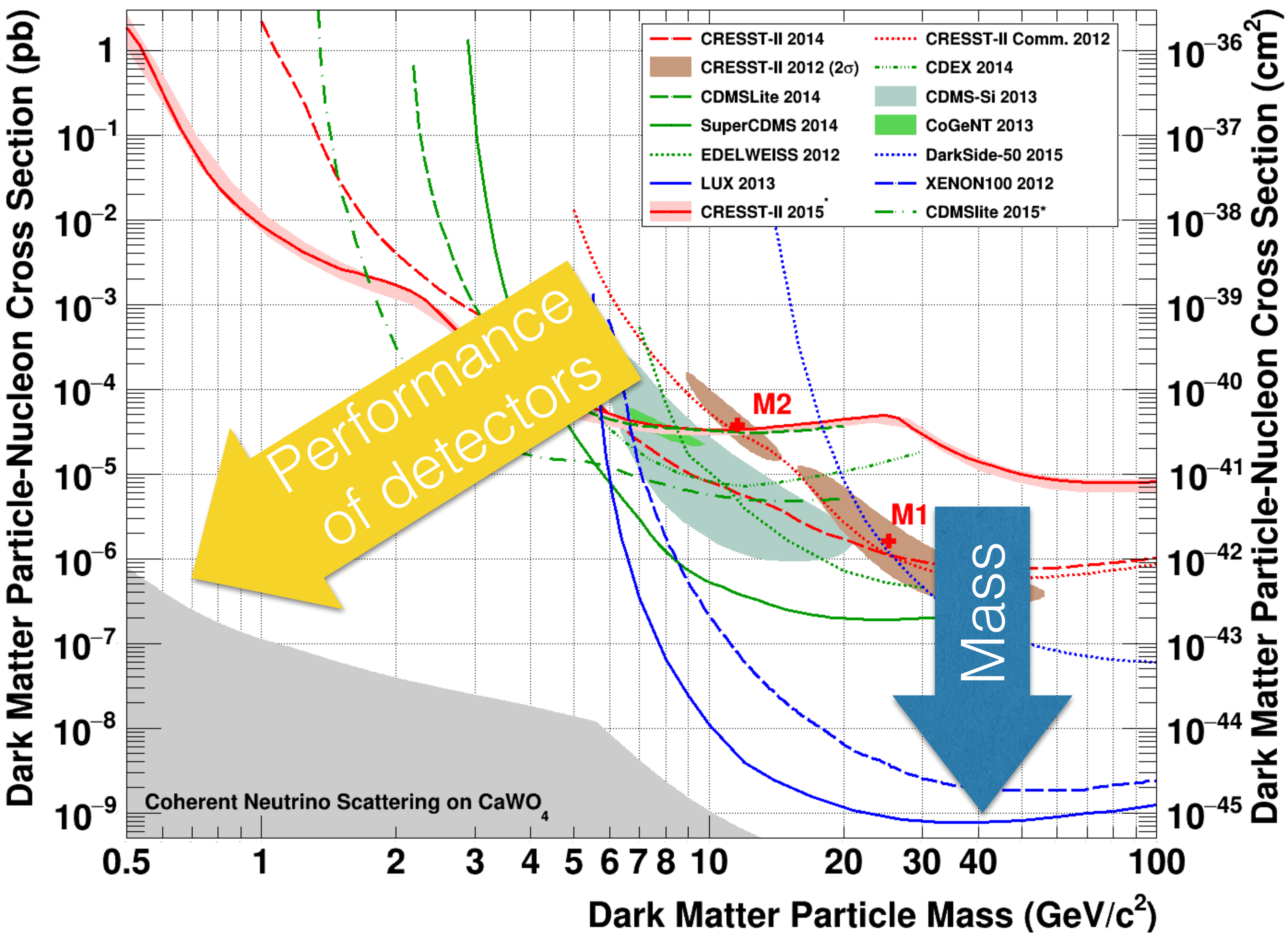
Outline

- Coherent Neutrino - Nucleus Scattering (CNNS)
- The CRESST experiment
- CRESST-II results
- Perspective for CRESST-III
- In reach of CNNS with CRESST

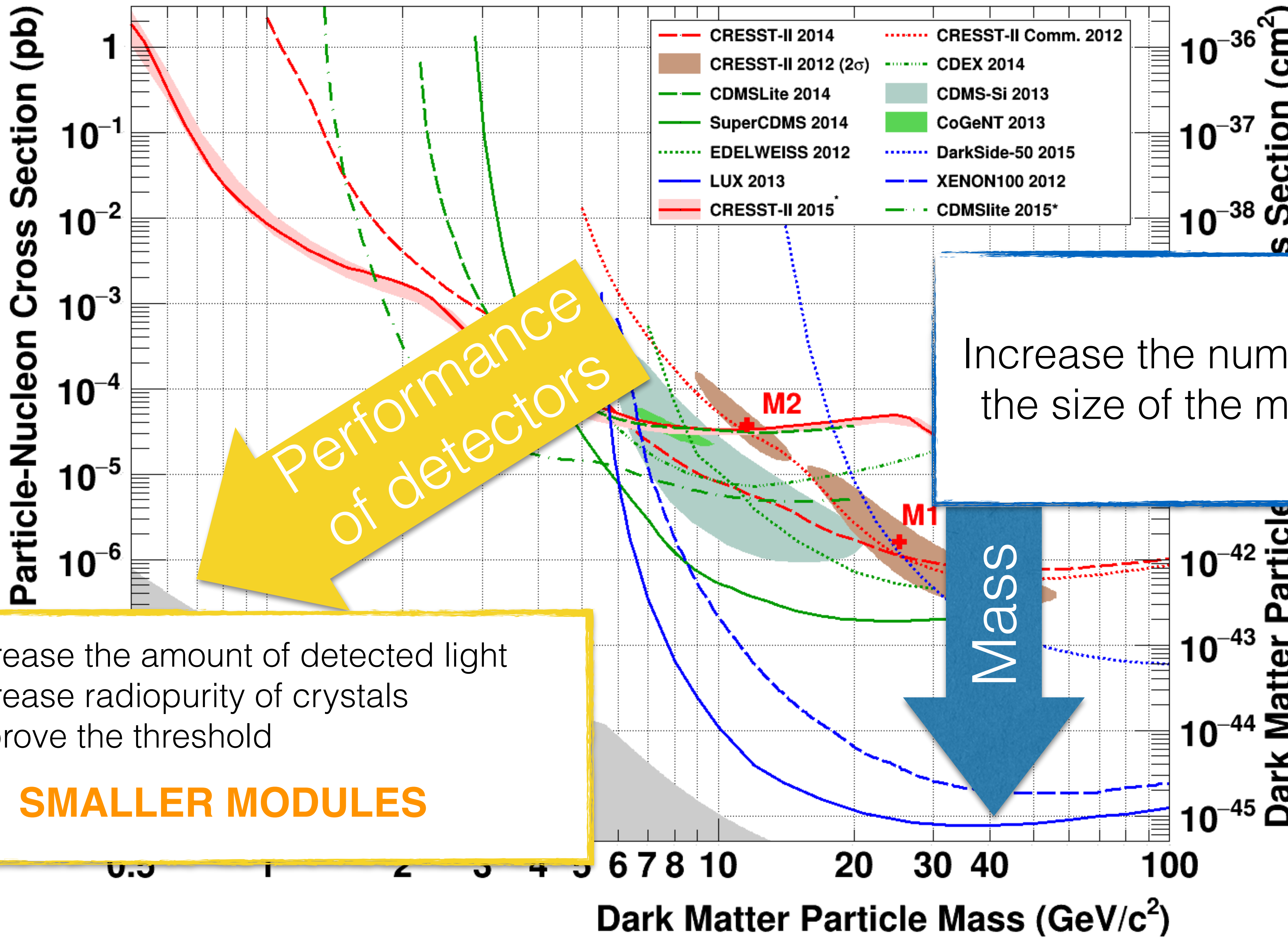
CRESST: What's next?



CRESST: What's next?



CRESST: What's next?



Increase the number and the size of the modules

- Increase the amount of detected light
- Increase radiopurity of crystals
- Improve the threshold

SMALLER MODULES

CRESST-III

m=250g

Phonon threshold: $E_{th} \lesssim 600$eV

Light-detector res.: $\sigma \approx 5$ eV

Scale down size by factor 10

m=25g

Performance goal

Phonon threshold: $E_{th} \lesssim 100$eV

Light-detector res.: $\sigma \approx 2.5$ eV

CRESST-III

m=250g

Phonon threshold: $E_{th} \lesssim 600eV$

Light-detector res.: $\sigma \approx 5$ eV

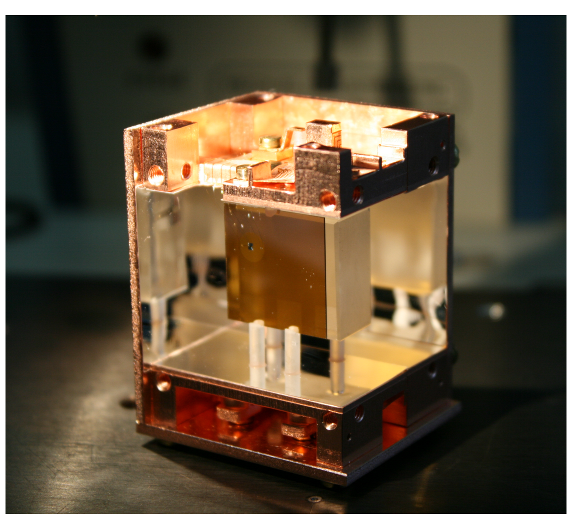
Scale down size by factor 10

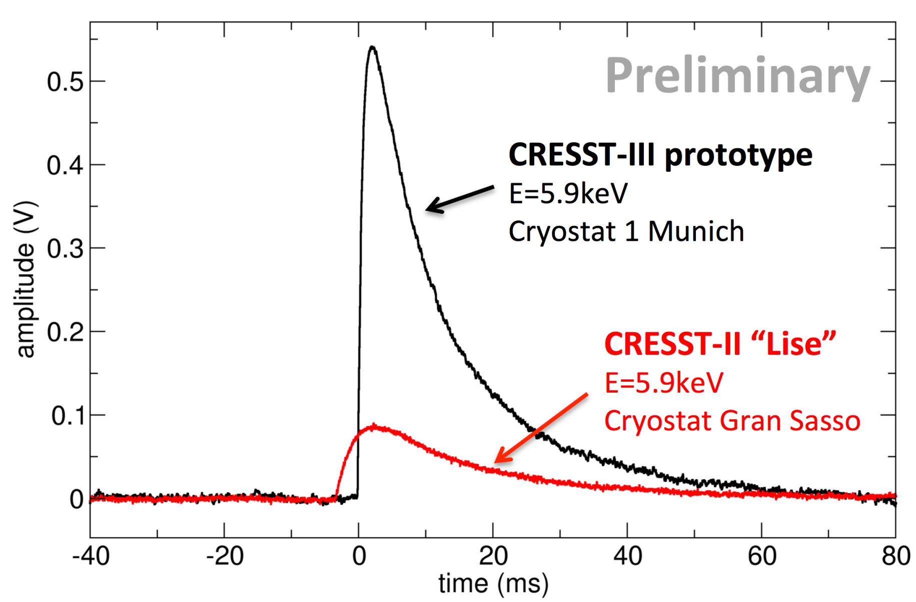
m=25g

Performance goal

Phonon threshold: $E_{th} \lesssim 100eV$

Light-detector res.: $\sigma \approx 2.5$ eV

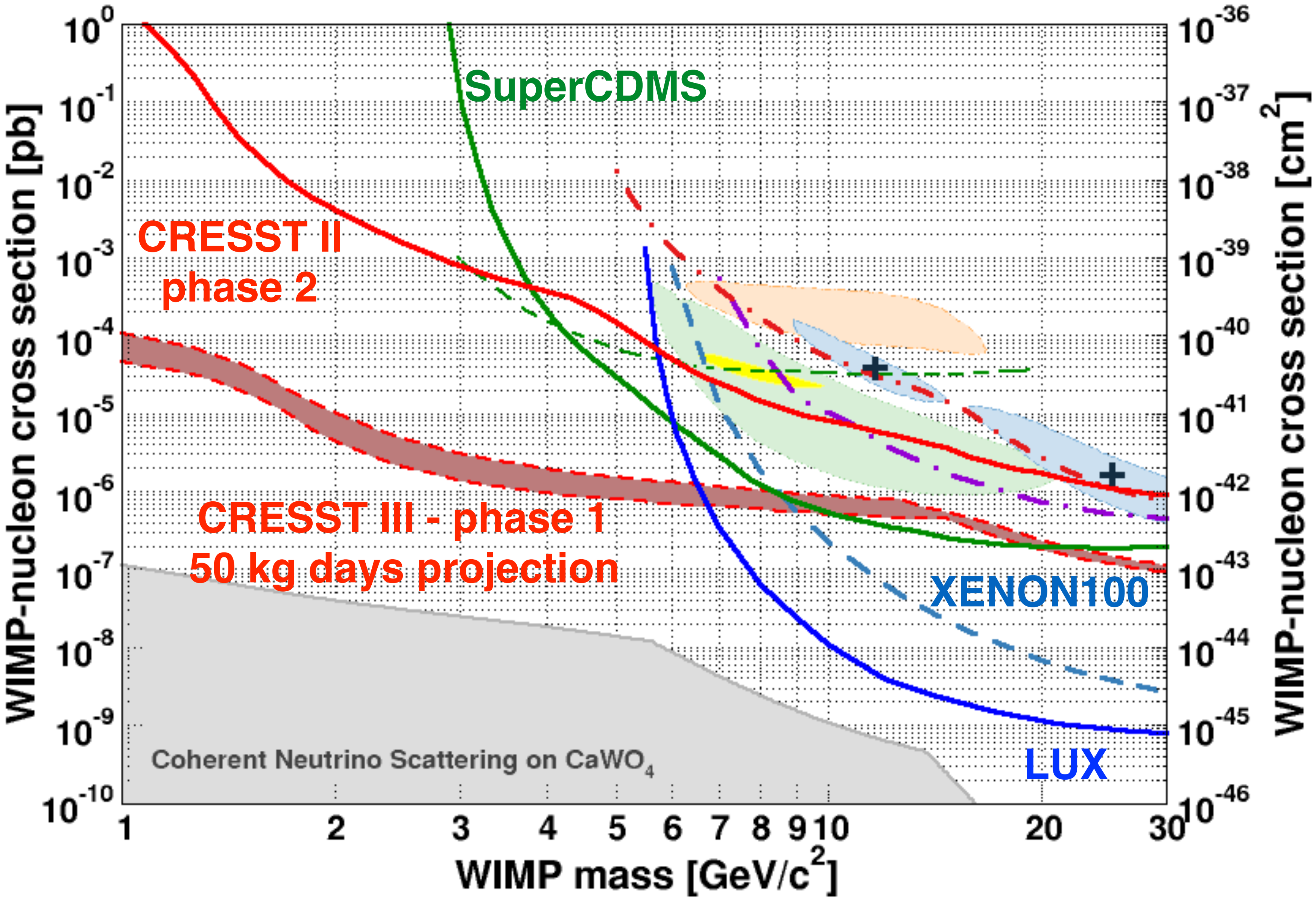




- Threshold achieved: **E_{th}= 45-60 eV**
- Improvement by factor ~6 compared to best CRESST-II detector (E_{th} ~300eV).

Threshold design goal (<100eV) reached with prototype detector

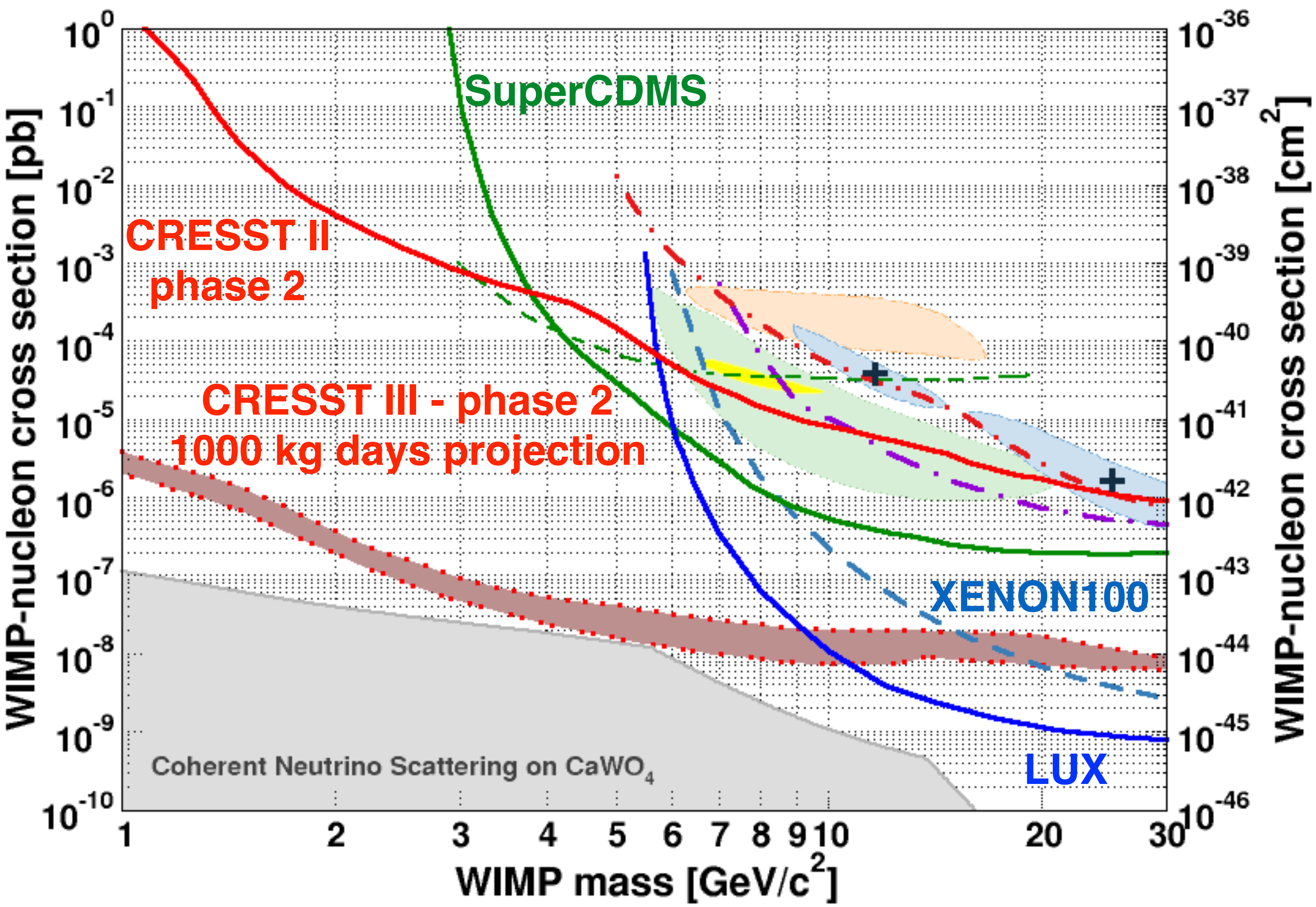
CRESST-III (Phase 1)



ASSUMPTIONS:

- 10 modules of 25g $CaWO_4$
- E_{th} = 100eV
- Light detector improved by factor 2 (due to smaller volume)
- 2x more detected light: due to thin crystal
- TUM40 radiopurity

CRESST-III (Phase 2)



ASSUMPTIONS:

- ~~10~~ 100 modules of 25g $CaWO_4$
- E_{th} = 100eV
- Light detector improved by factor 2 (due to smaller volume)
- 2x more detected light: due to thin crystal
- ~~TUM40 radiopurity~~ factor of 100 in β/γ background

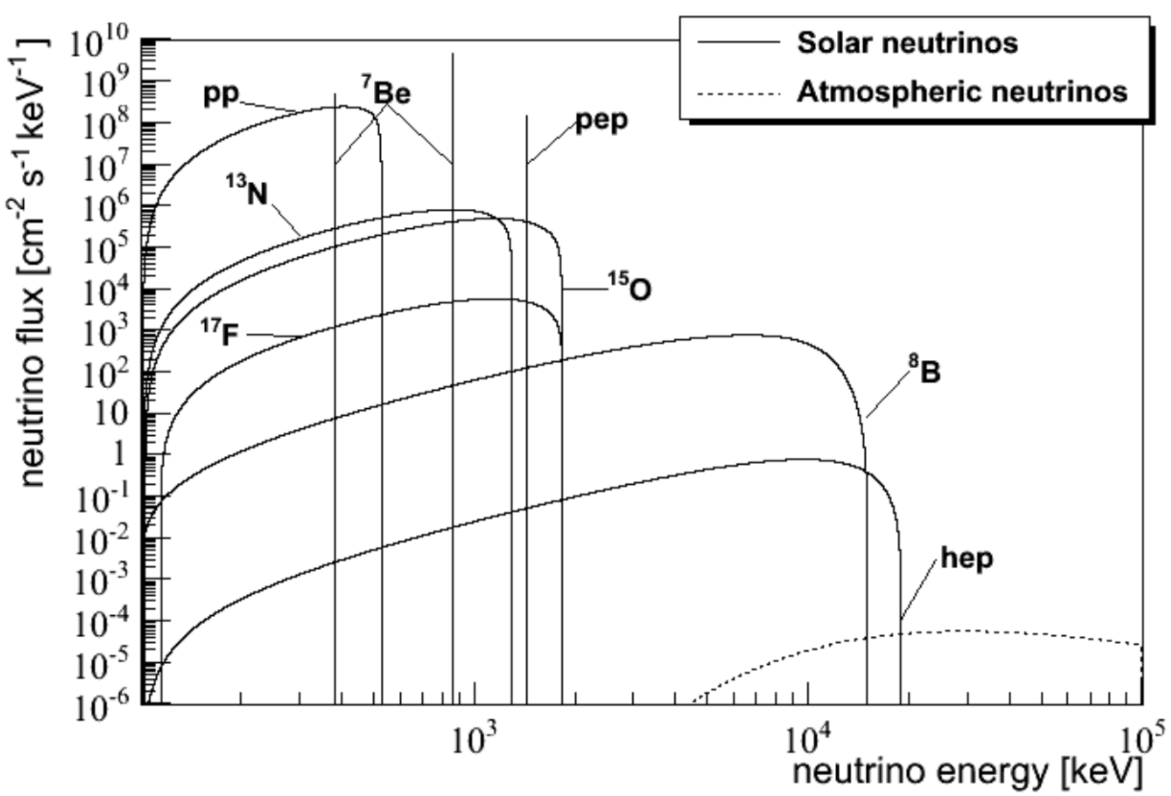
Approaching the neutrino floor in the next ~5y

Outline

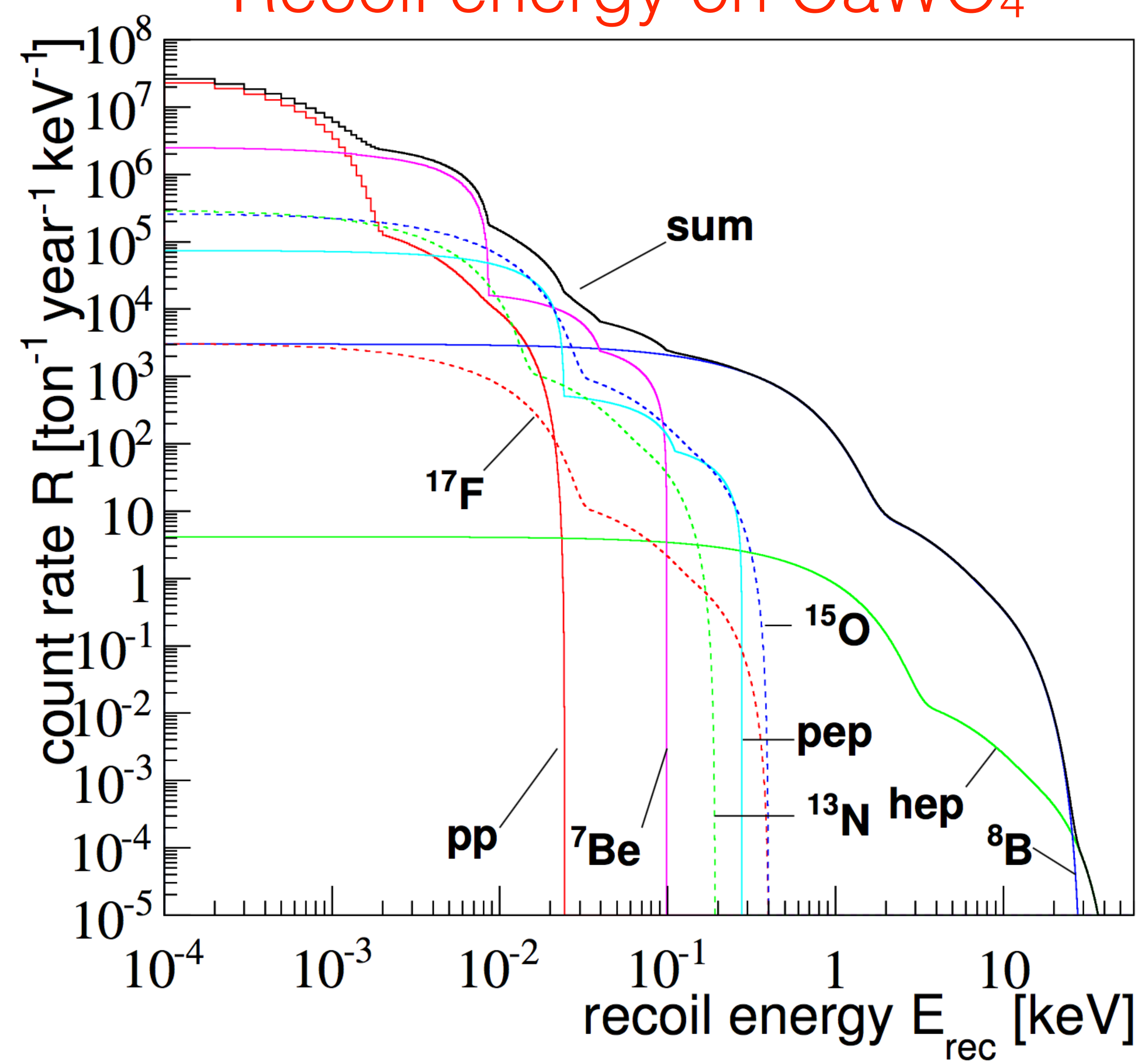
- Coherent Neutrino - Nucleus Scattering (CNNS)
- The CRESST experiment
- CRESST-II results
- Perspective for CRESST-III
- In reach of CNNS with CRESST

In reach of neutrino floor

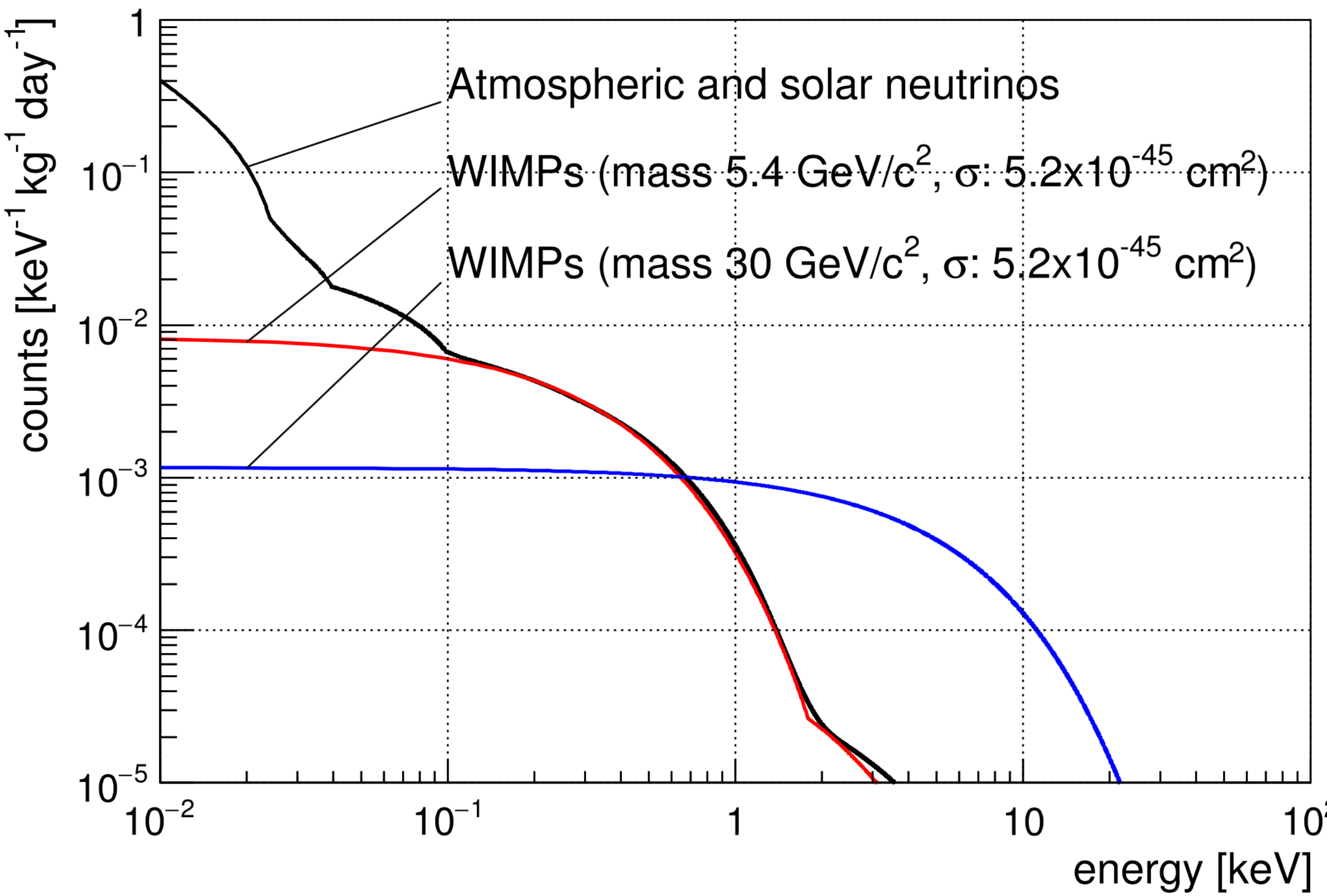
Relevant neutrino fluxes which are backgrounds to direct DM detection experiments are mainly solar and atmospheric



Recoil energy on $CaWO_4$



CNNS as background for DM searches

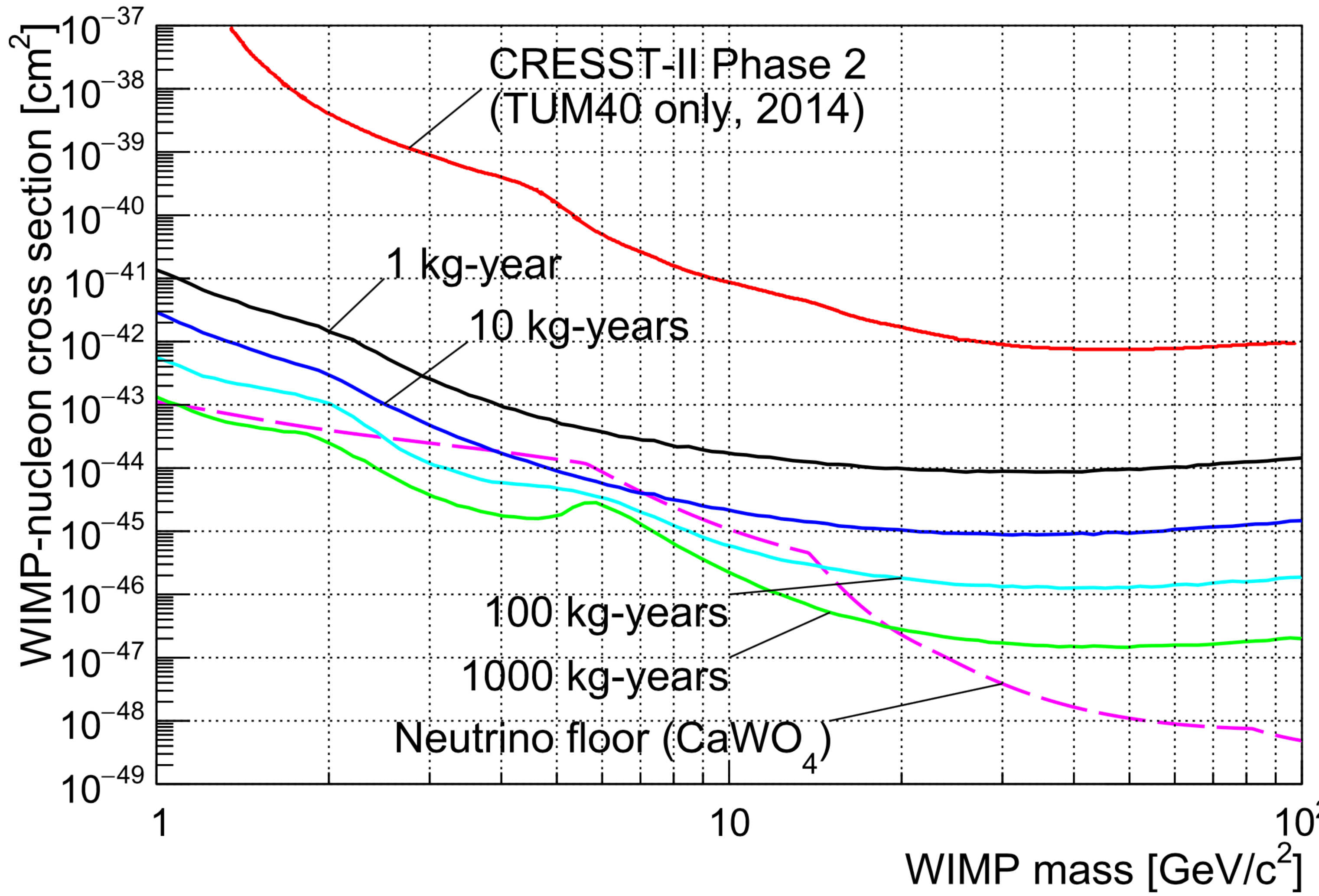


Exclusion limits

Detection of CNNS from atmospheric and solar neutrinos

A. Gütlein et al, Astr. Phys. 69 (2015) 44–49

- Realistic and reasonably improved detector performance w.r.t. TUM40:
    - factor of 2 in energy resolution and threshold
    - factor of 3 in light output
    - factor of 100 in β/γ background



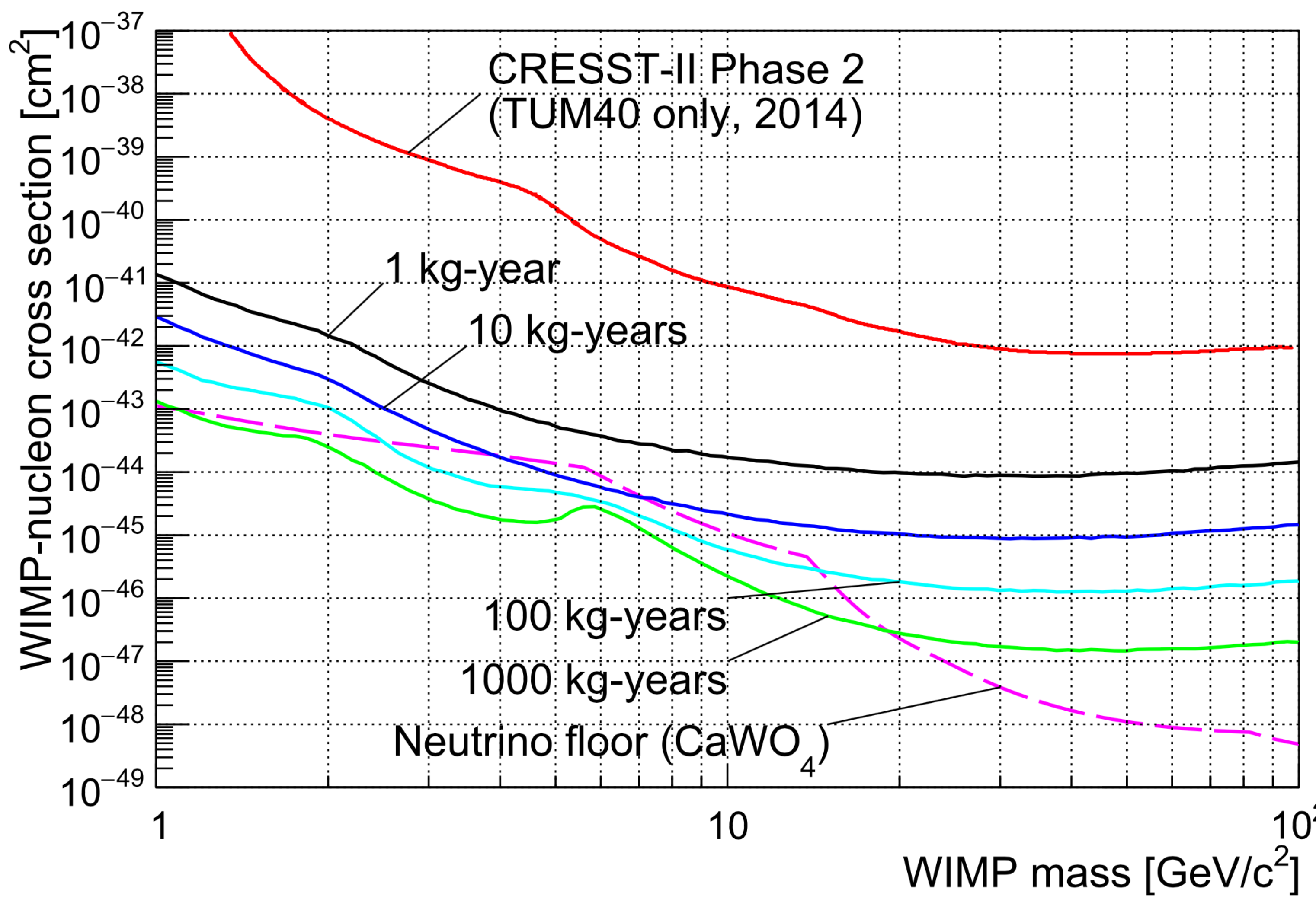
- 50 kg-years: high performance detectors, 2 years of running with ~1000 modules

Exclusion limits

Detection of CNNS from atmospheric and solar neutrinos

A. Gütlein et al, Astr. Phys. 69 (2015) 44–49

- Realistic and reasonably improved detector performance w.r.t. TUM40:
  - factor of 2 in energy resolution and threshold
  - factor of 3 in light output
  - factor of 100 in β/γ background



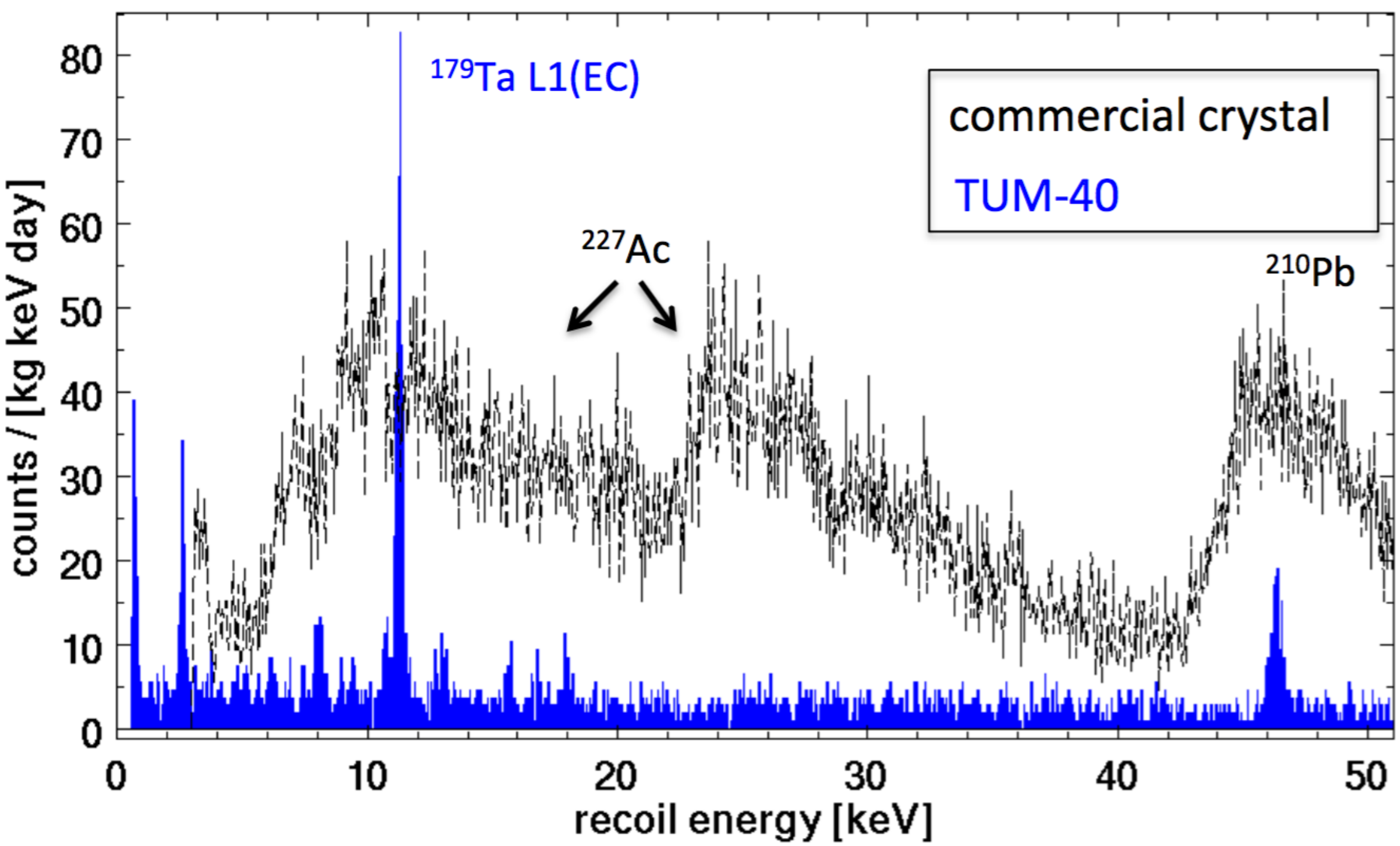
- 50 kg-years: high performance detectors, ~~2~~ 4 years of running with ~ ~~1000~~ 500 modules

Conclusions

- CRESST has a leading role in the field of dark matter searches.
- The excellent detector performance (energy threshold and energy resolution) are giving the opportunity to study the solar neutrino coherent scattering.
- Reasonable improved CRESST-II like detectors can approach the neutrino floor (100 modules x 25g, 2 years of data taking).
- Detection of CNNS is in reach for a setup with ~500 modules x 25g.

TUM 40 radiopurity

- $CaWO_4$-crystal **production at TU Munich**
- Unprecedented radiopurity (by factor 2-10)
- Room for further improvements



Average rate:
~3.5 counts / [kg keV day]

Gamma-lines from **cosmogenic activation**

Excellent resolution:
$\sigma \approx 100\text{eV}$

SOX-like source

- Artificial neutrino source ^{144}Ce - ^{144}Pr (^{144}Ce $T_{1/2}$ = 285 days)
    - Activity 100kCi
    - Exposure: 1 year with 100 small modules
    - Threshold: 100eV