Impact of neutrinos on direct dark matter searches

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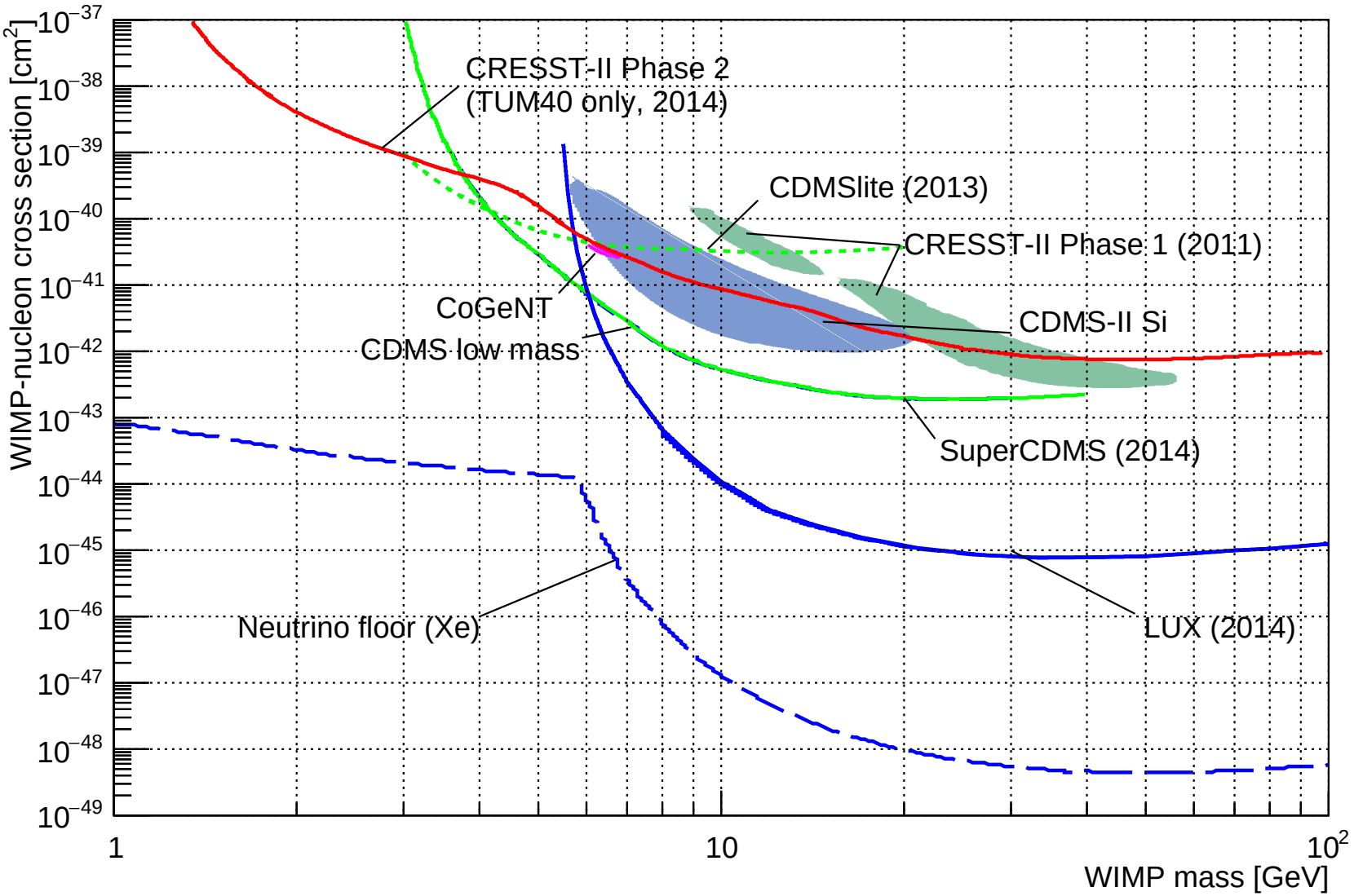
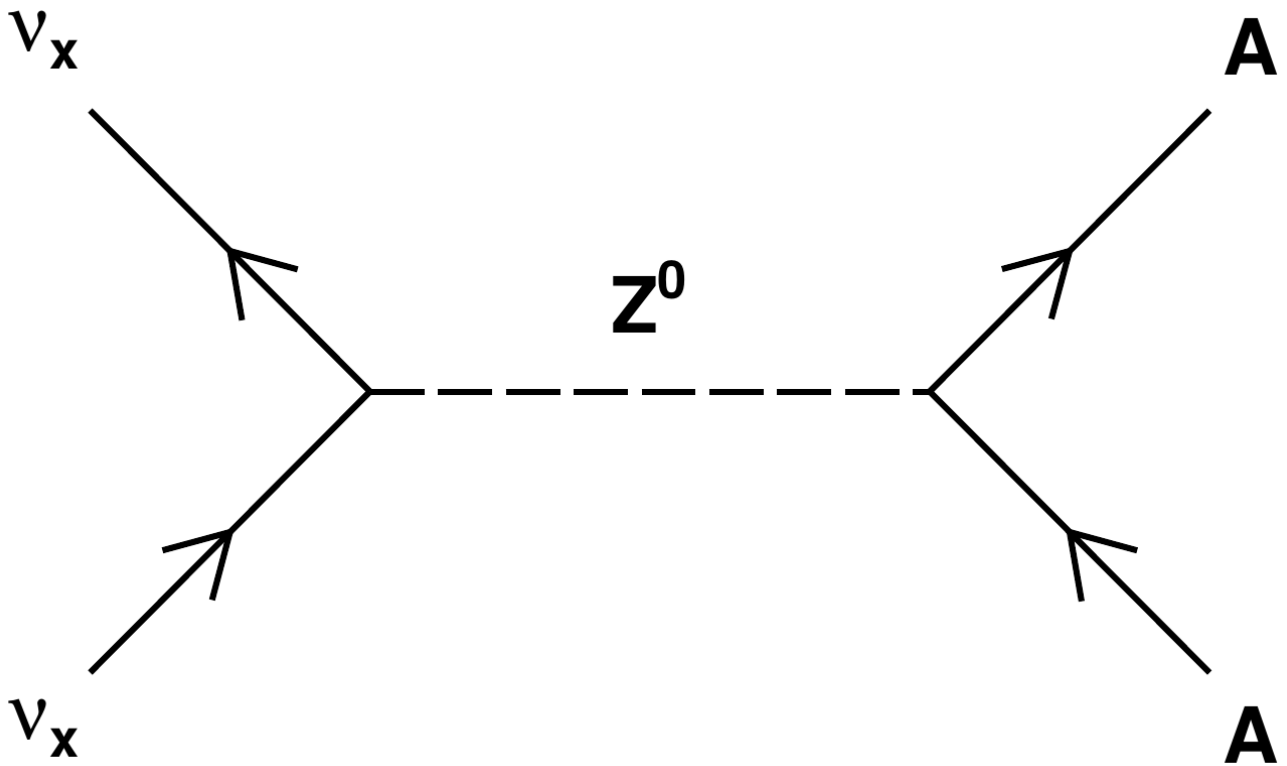
Current exclusion-limits



Outline

1. Introduction
   - Coherent Neutrino Nucleus Scattering (CNNS)
   - Atmospheric and solar neutrinos
2. Calculation of the neutrino floor
3. Neutrino background for $CaWO_4$ based searches
   - CRESST-II like detectors
   - Expected limits for future experiments
4. Detection of CNNS

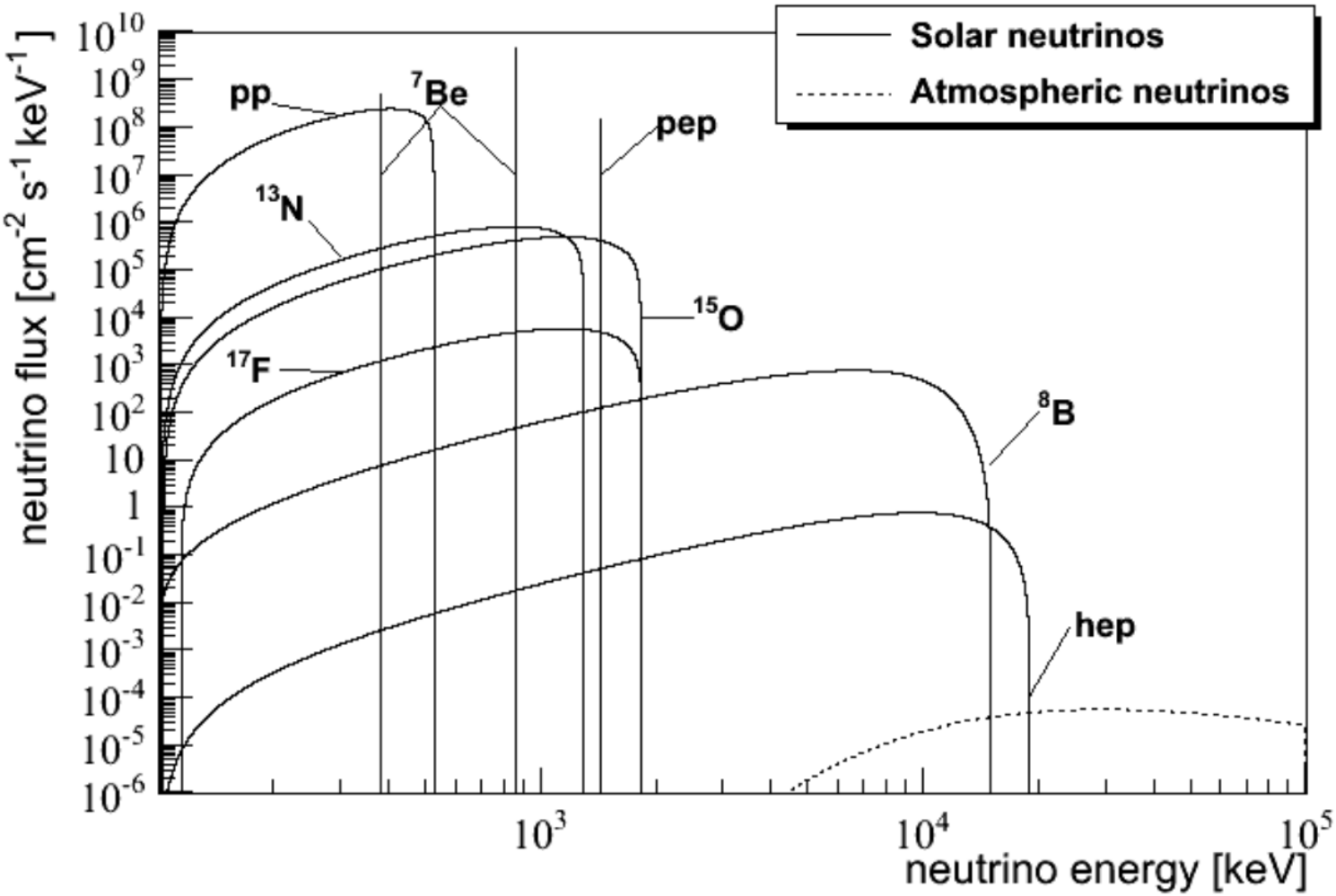
Coherent Neutrino Nucleus Scattering (CNNS)



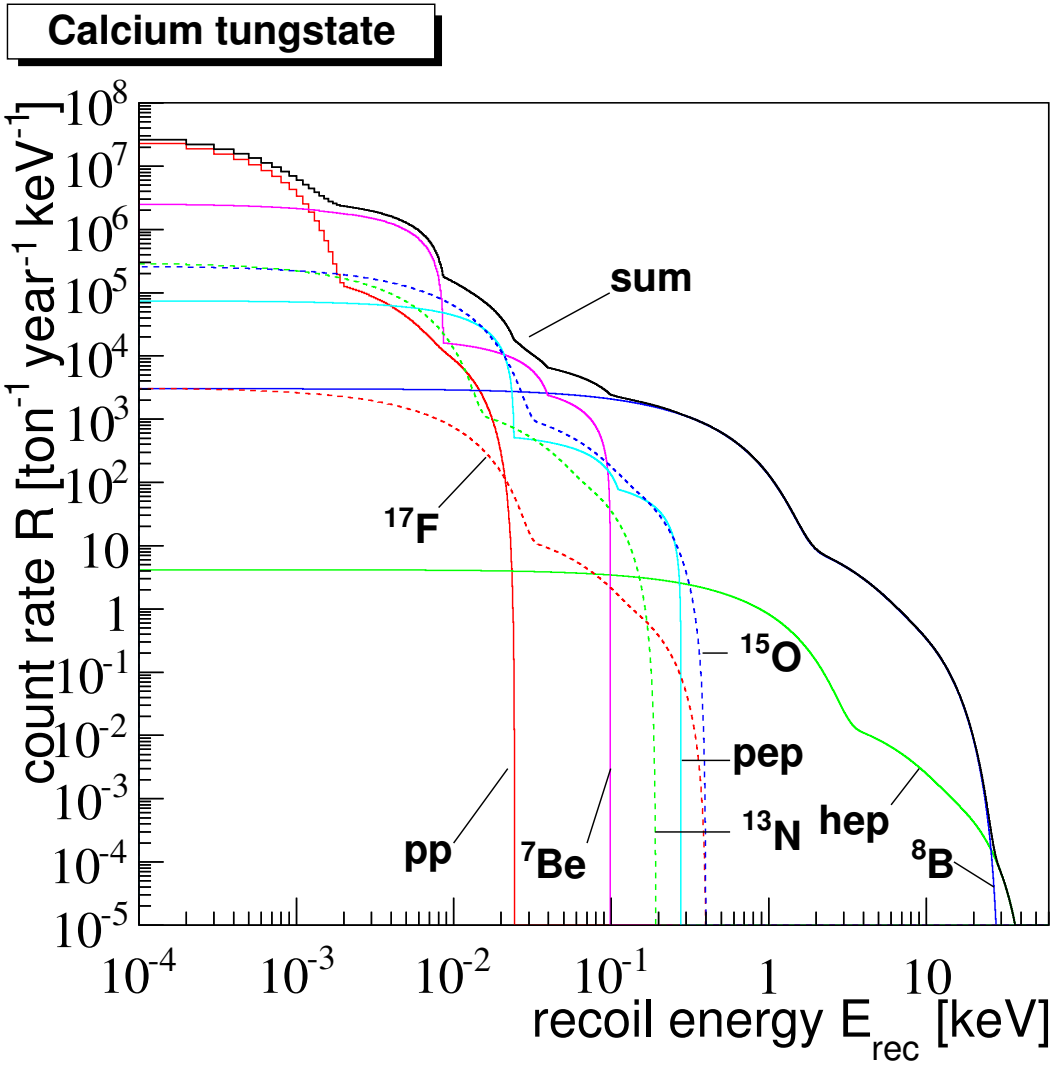
- Neutral current process
- For low transferred momenta: coherent scattering

$\Rightarrow$ Enhanced cross section

Neutrino spectra



Expected recoil energies for $CaWO_4$



Outline

What is a neutrino floor?

- Direct dark matter searches look for WIMPs scattering off target nuclei inside detectors
- Most backgrounds: β/γ events
- Suppression of β/γ backgrounds on an event-by-event basis

$\rightarrow$ Background-free experiments: $\mathcal{O}(1)$ events are a very large signal!

- Neutrinos scattering off target nuclei mimic WIMP scatterings

$\Rightarrow$ Atmospheric and solar neutrinos are background source for direct dark matter searches

- What sensitivity can be reached?
- Decouple that question from detector specific limitations (threshold, resolution, efficiency, background suppression, ...)

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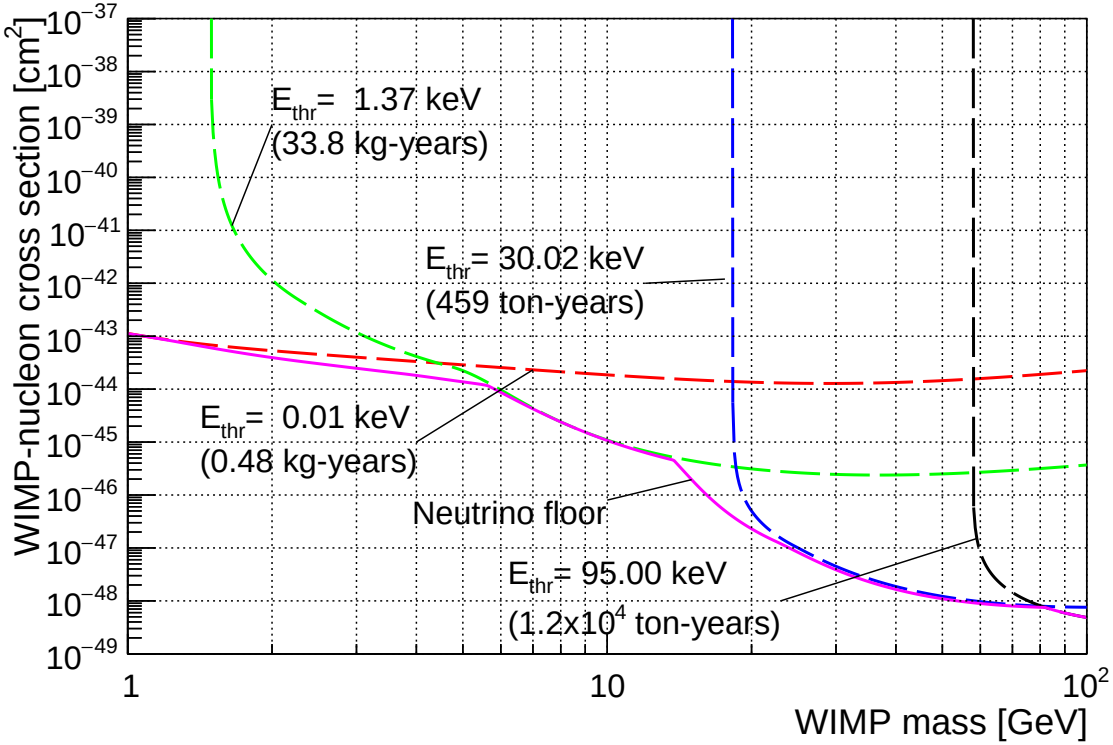
Calculation of neutrino floors

1. Choose (analysis) threshold
2. Integrate expected recoil spectra for neutrinos ($\int_{E_{thr}}^{\infty} \frac{dR}{dE_r}$)
3. Adjust exposure so that $N_{\nu,exp} = 1$ for neutrinos
4. Assume that no events are observe ($p_{\lambda=1}(0) \approx 37\%$)
5. Calculate exclusion limit for WIMP-nucleon cross section (90% limit for $N_{WIMP,exp} = 2.3$)

- Repeat steps 1-5 for different (analysis) thresholds

$\Rightarrow$ For each WIMP mass: neutrino floor is minimum of all exclusion limits for all thresholds

Neutrino floor for $CaWO_4$



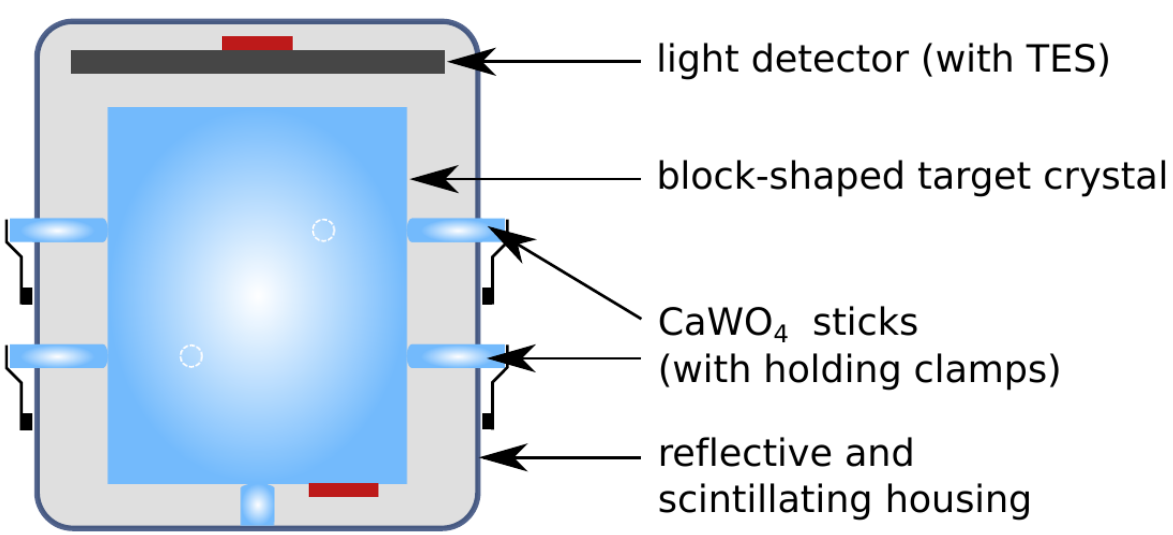
- Small WIMP masses: Very low thresholds

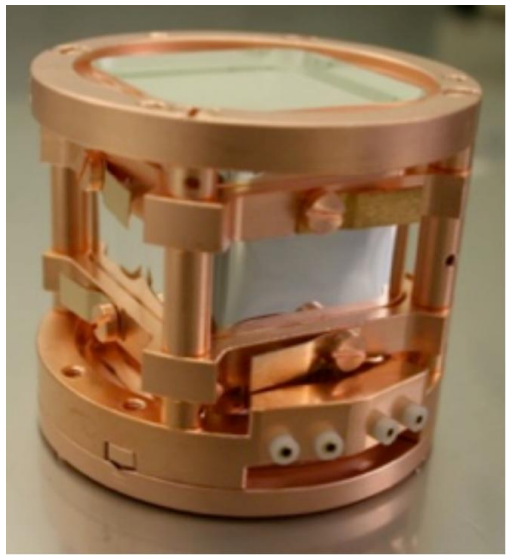
→ Background-free experiments?

- High WIMP masses: Very high exposures
- Most relevant for $CaWO_4$ based detectors: 3 - 15 GeV

Outline

Phonon-light technique





- Particle interaction in $CaWO_4$ crystal ($\rightarrow$ energy deposition)

$\Rightarrow$ Phonons (=heat) and scintillation light is generated

- Phonon signal is read out by sensitive thermometer (TES)
- Scintillation light is detected by separate light detector
- Different amount of scintillation light for different particles

$\Rightarrow$ Particle identification by light yield (scintillation signal/phonon signal)

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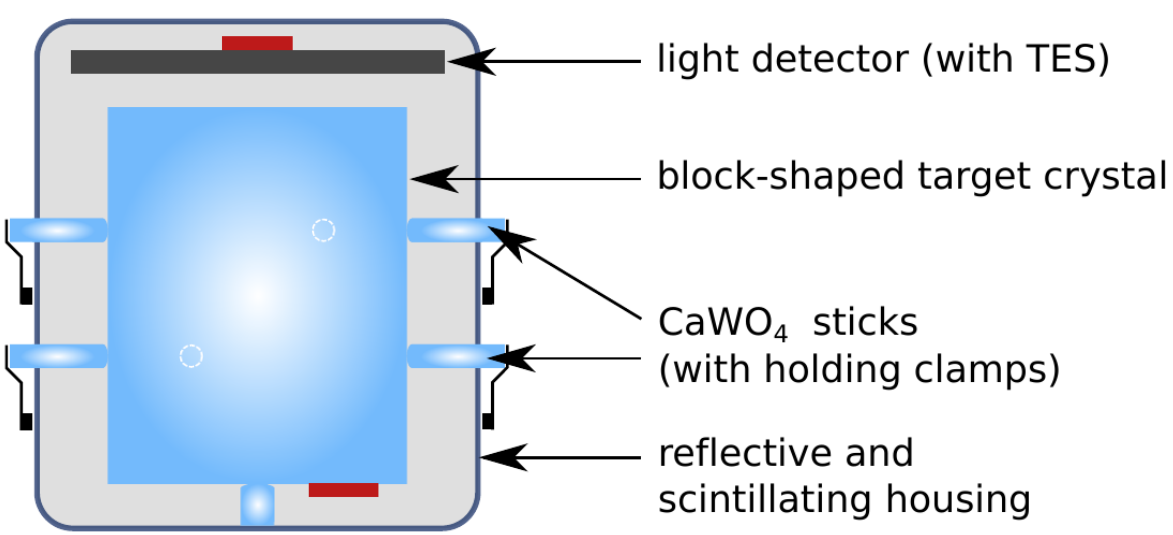

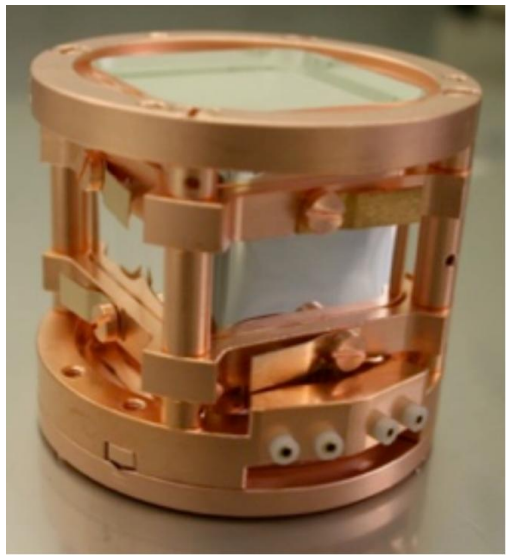

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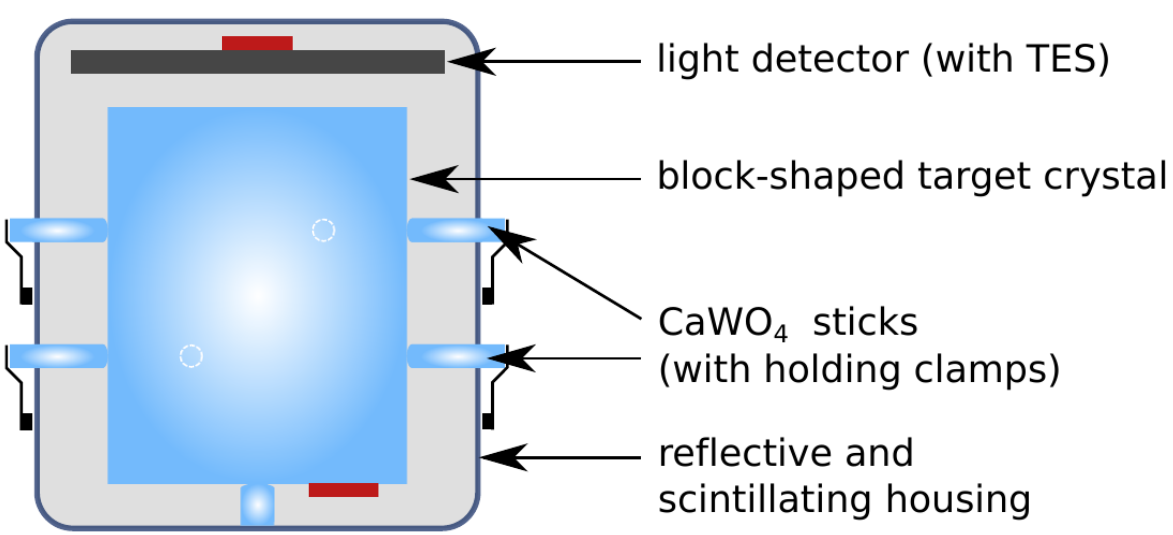

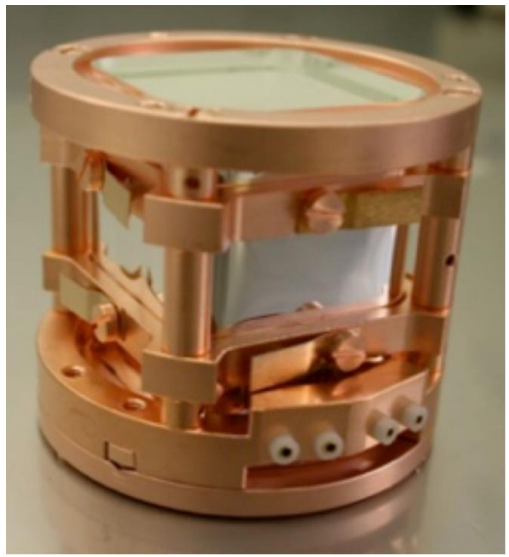

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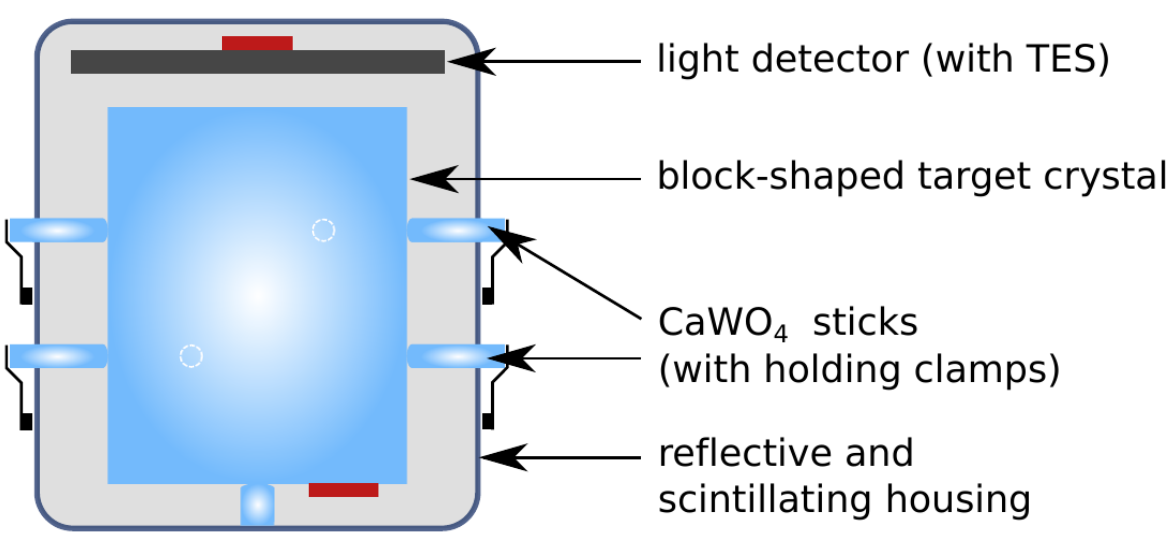

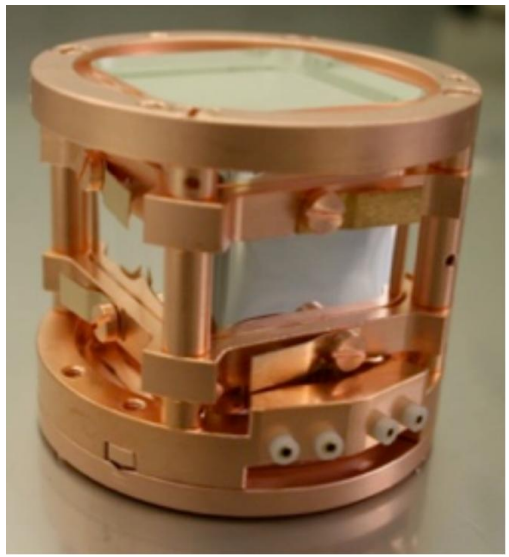

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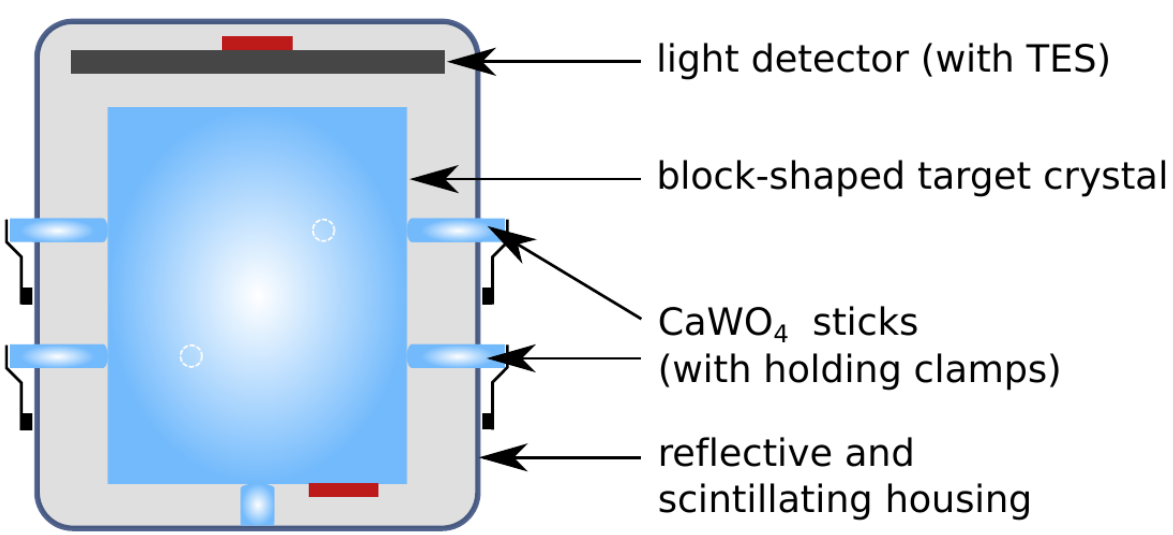

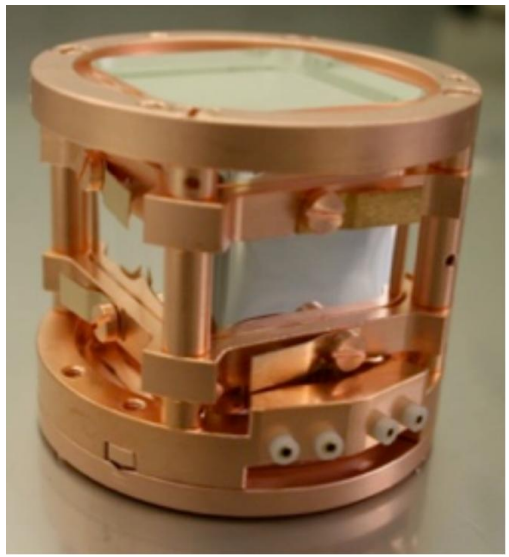

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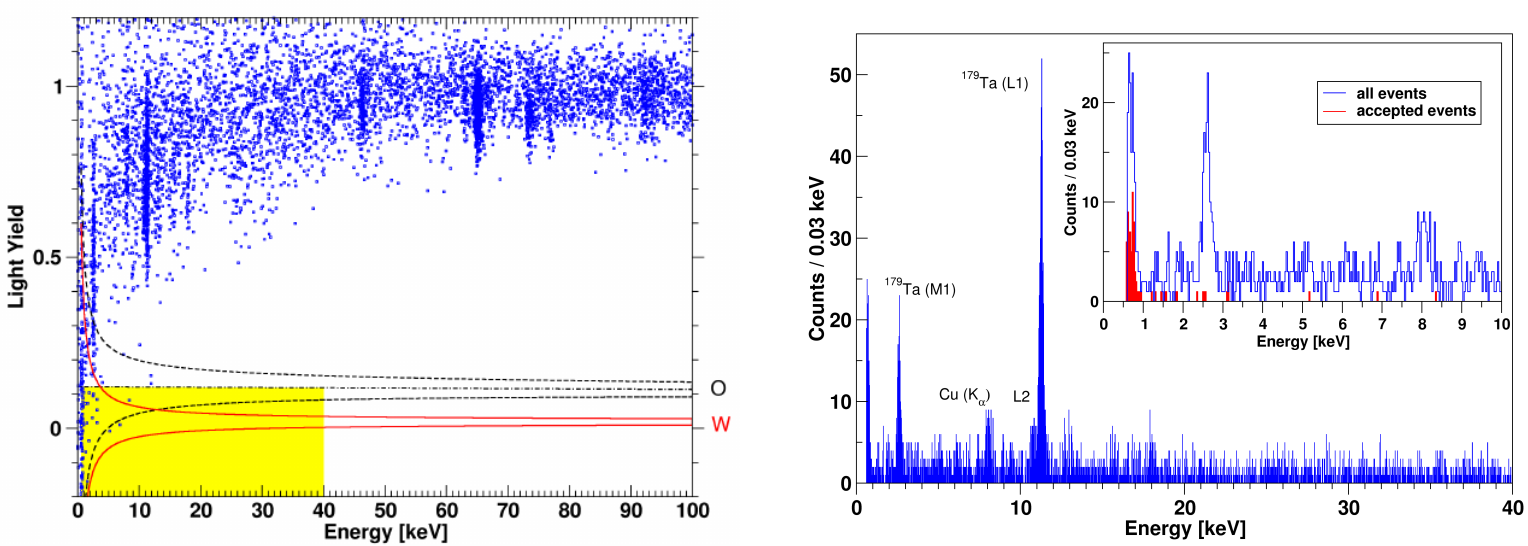
Particle separation by Light yield



(Eur. Phys. J. C (2014) 74 , arXiv:1407.3146)

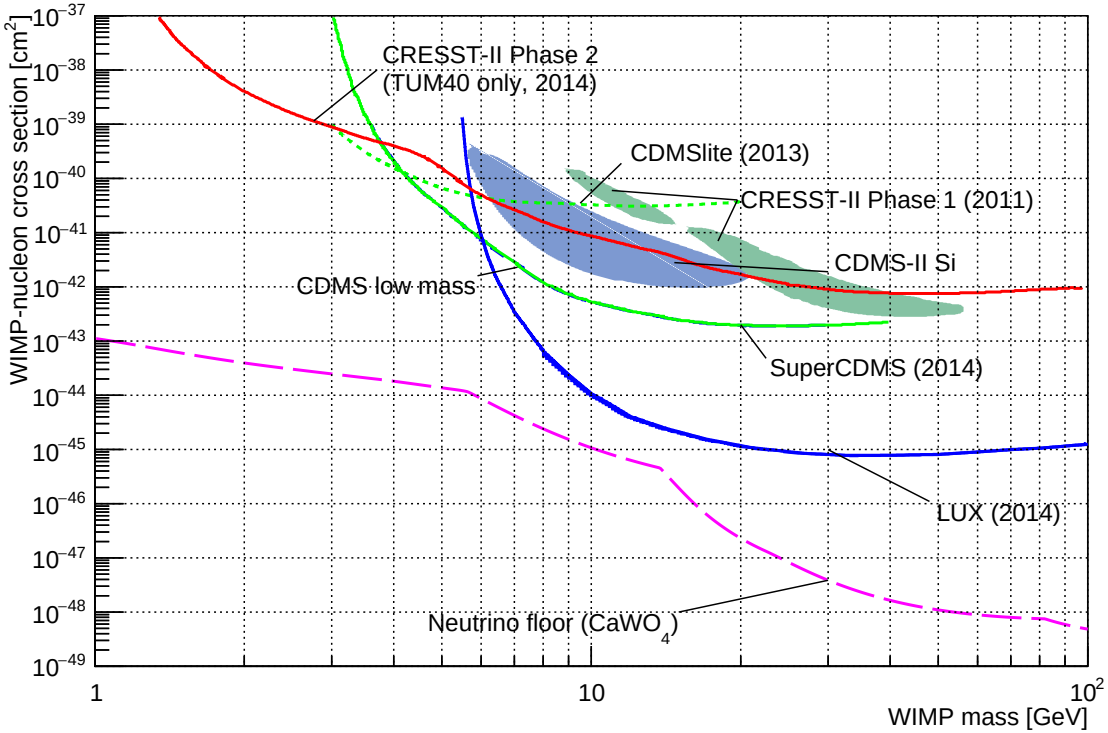
- Latest results from ~ 29 kg-days with one detector module
- WIMP-nucleon scatterings should appear in yellow box

$\rightarrow$ Background free for energies $\gtrsim 10$ keV

- Leakage of β/γ background at smaller energies

$\rightarrow$ Limit for low WIMP masses: Take background into account

Current exclusion limits



- Current exclusion limit from CRESST-II 4-6 orders of magnitude above neutrino floor
- Already now background/performance limited at small WIMP masses

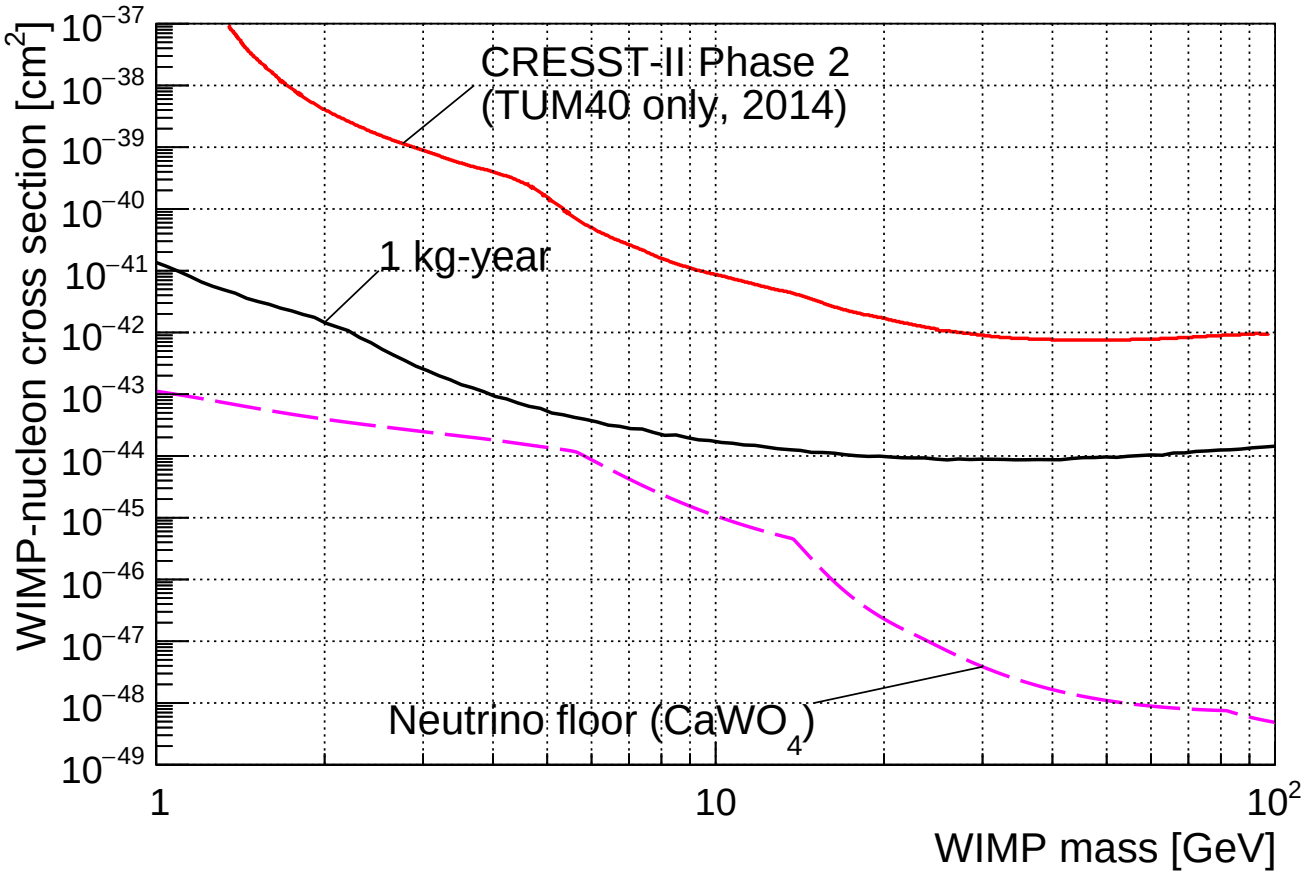
$\rightarrow$ What can be expected for future experiments?

Study of sensitivities of future detectors

- Reasonably improved performance:
  - Factor of 2 in energy resolution and threshold
  - Factor of 3 in light output
  - Factor of 100 in β/γ background
- Simulation of mock-data sets: β/γ background + atmospheric and solar neutrino signal
- Unbinned Likelihood fits β/γ background + atmospheric and solar neutrino signal + WIMP signal to light yield vs energy plane.

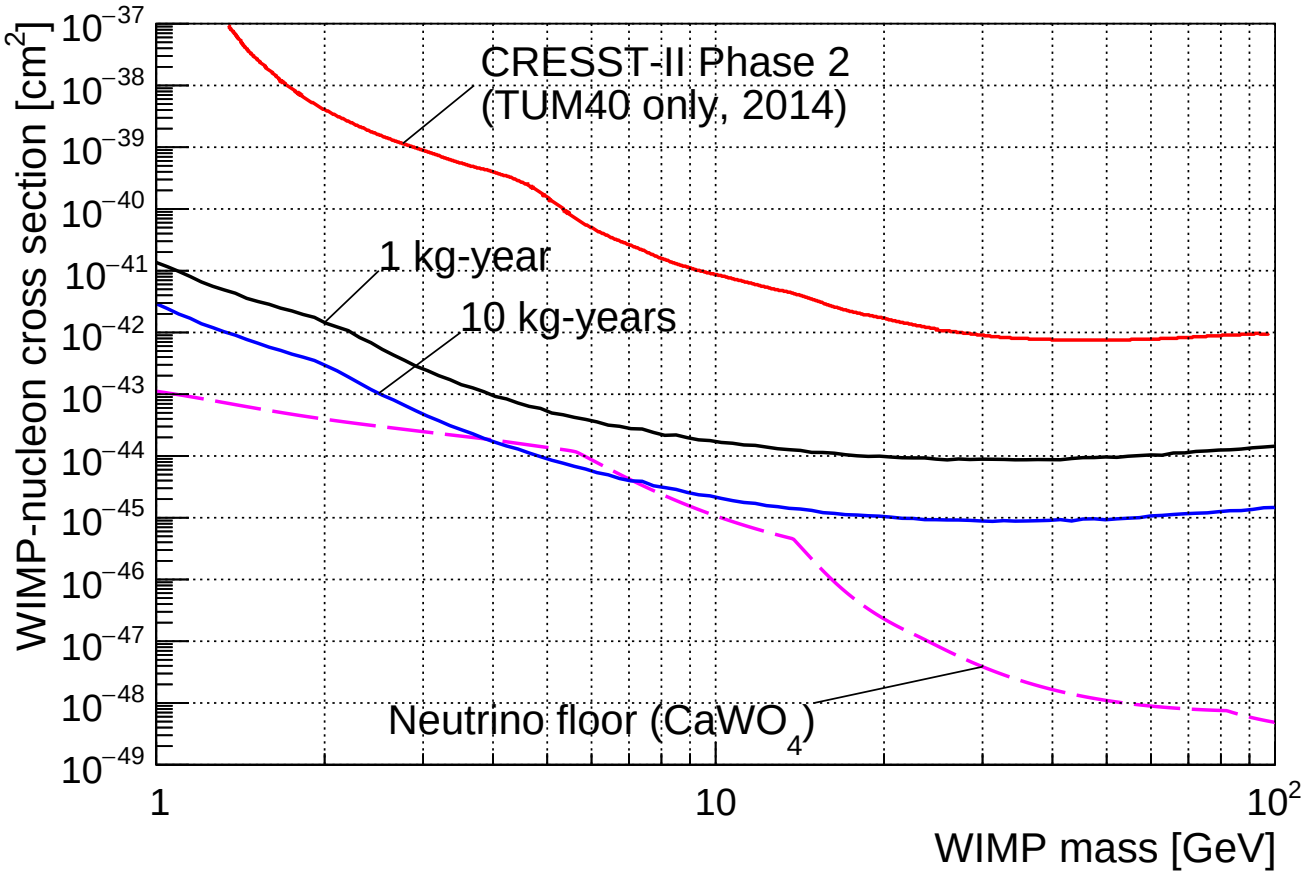
$\Rightarrow$ 90% exclusion limits of WIMP-nucleon cross section

Future exclusion limits (exposure 1 kg-year)



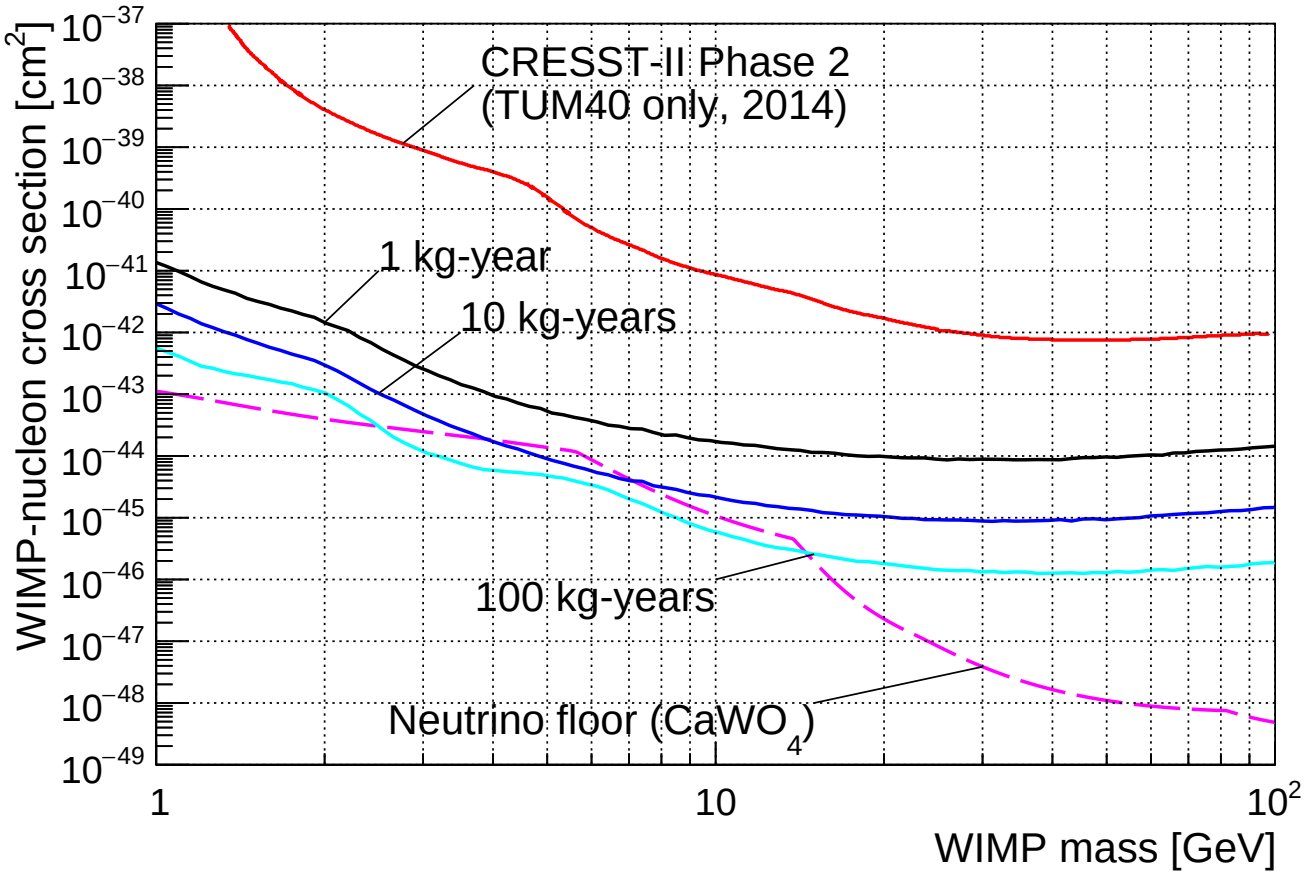
→ 20 x 25 g for 2 years

Future exclusion limits (exposure 10 kg-year)



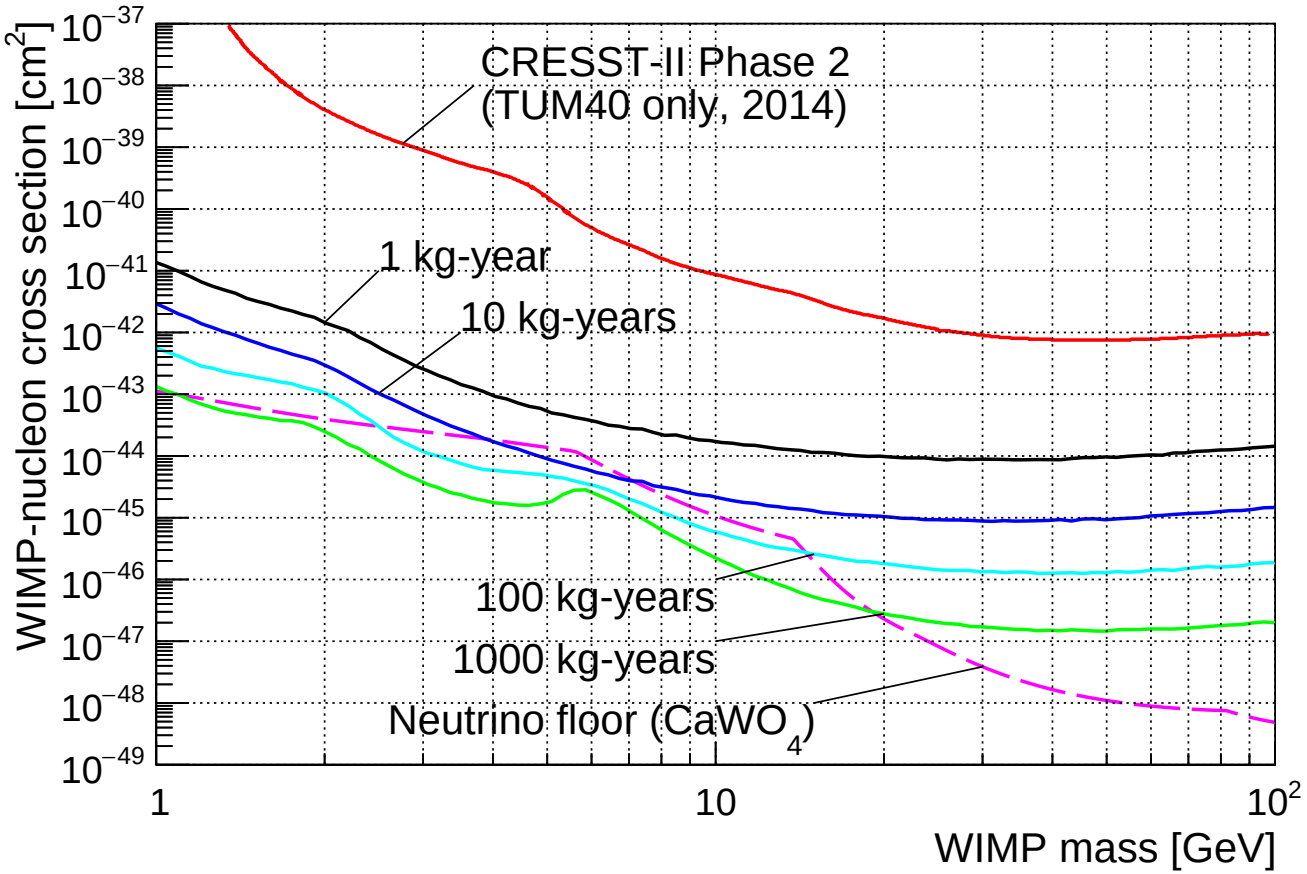
$\rightarrow$ 200 x 25 g for 2 years

Future exclusion limits (exposure 100 kg-year)



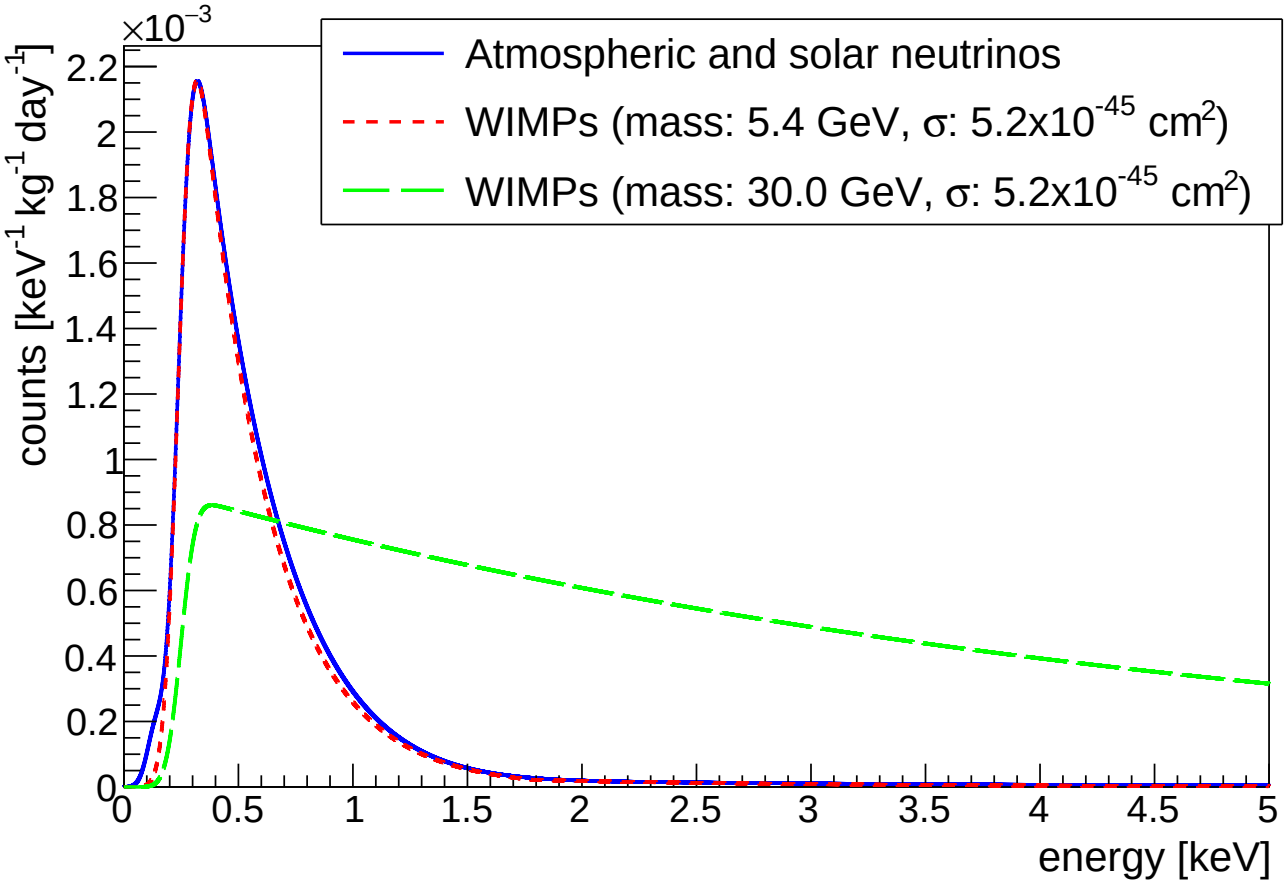
→ 1000 x 25 g for 4 years

Future exclusion limits (exposure 1000 kg-year)



→ 10000 x 25 g for 4 years

Spectral information for high statistics



- Neutrino spectrum and WIMP spectrum very similar for WIMP masses of $\sim 5.4\,\text{GeV}$.

$\rightarrow$ Neutrinos are serious background source for low WIMP masses

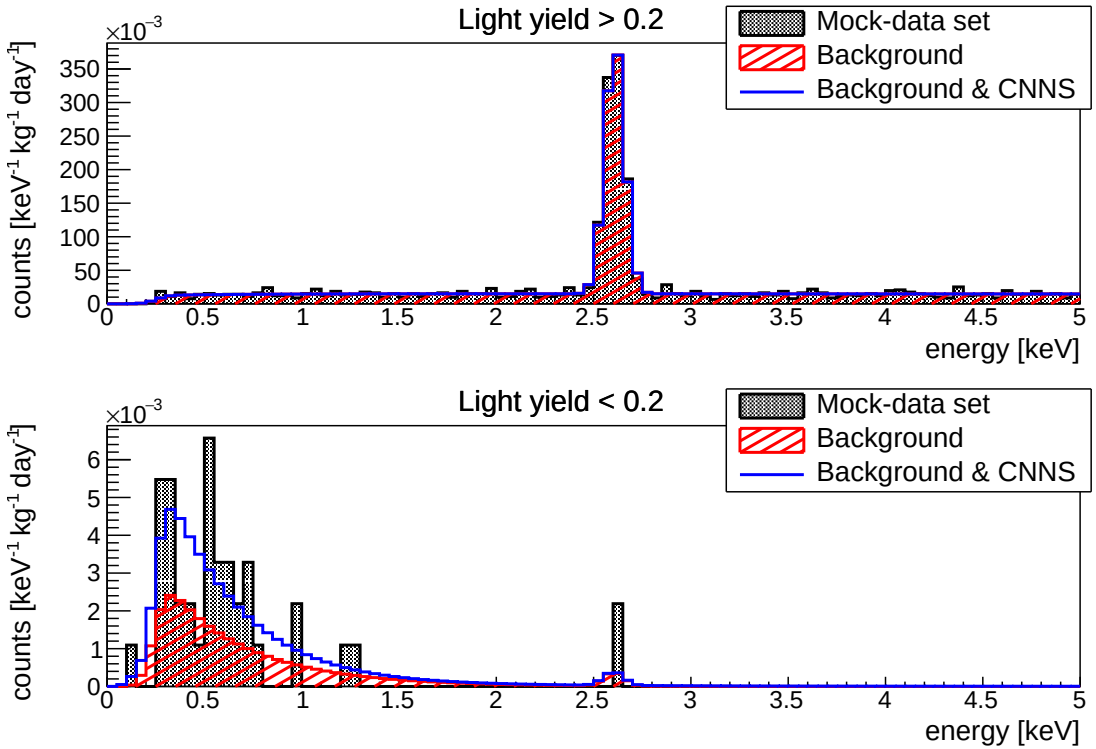
Outline

First observation of CNNS

- Detectors with improved performance
- Simulation of mock-data sets: β/γ background + atmospheric and solar neutrino signal
- Hypothesis testing:
  - H_0: Unbinned Likelihood fits β/γ background to light yield vs energy plane.
  - H_1: Unbinned Likelihood fits β/γ background + atmospheric and solar neutrino signal to light yield vs energy plane.

$\rightarrow$ Maximum likelihood ratio test to reject background-only hypotheses H_0

One example mock-data set



- Exposure 50 kg-years
- $P(Data|Background - only) = 3.2 \cdot 10^{-6}$

$\Rightarrow$ Observation of CNNS at confidence level of 99.9997%

$\rightarrow$ Just luck with simulated data set?

Detection potential

Exposure	Detection potential
30 kg-years	9.3 %
40 kg-years	15.4 %
50 kg-years	46.8 %
60 kg-years	58.7 %
70 kg-years	73.4 %
80 kg-years	78.8 %
90 kg-years	86.1 %
100 kg-years	88.4 %

- Simulation of 1000 mock-data sets for each exposure
- Detection potential = fraction of mock-data sets with detection of CNNS at confidence level $\geq 99.99\%$

$\Rightarrow$ Detection of CNNS in reach for setup with 1000x25 g detectors with improved performance

Conclusions and outlook

Conclusions

- Neutrino floor marks the region where neutrino backgrounds have to be taken into account
- But: Exploration of cross sections below neutrino floor is possible
- Reasonable improved CRESST-II like detectors can reach neutrino floor (2 years with 100x25 g)
- Detection of CNNS in reach for setup with 1000x25 g (2-4 years)

Outlook

- Redo these studies for actual performance of next-generation detectors
- Create detailed model for β/γ backgrounds
- Include detailed background models as well as uncertainties of neutrino fluxes