Solar and atmospheric neutrinos as background for direct dark matter searches

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Joined seminar on neutrinos and dark matter
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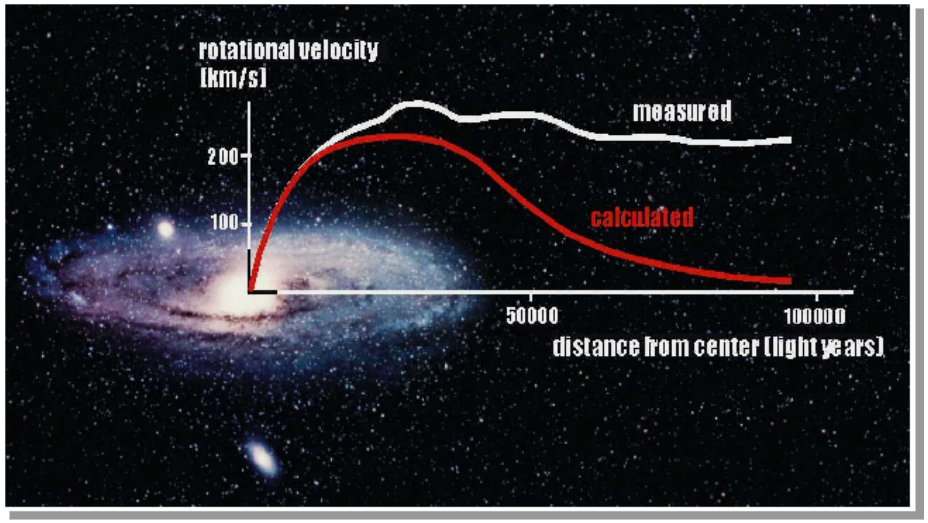
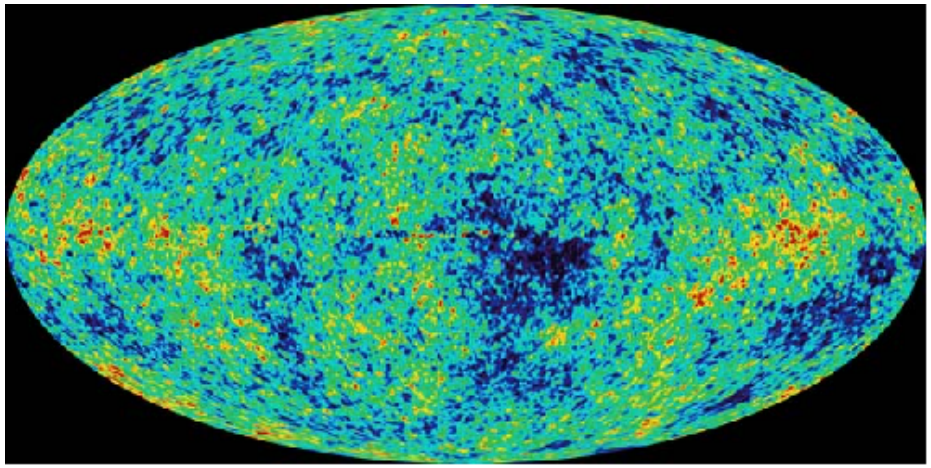
Outline

1. Direct Dark Matter Search
2. Neutrinos as background for direct dark matter searches
   - Coherent Neutrino Nucleus Scattering (CNNS)
   - Solar neutrinos
   - Solar neutrino count rates for different materials
   - Atmospheric neutrinos as background source
3. Limits for direct dark matter searches
4. Conclusions

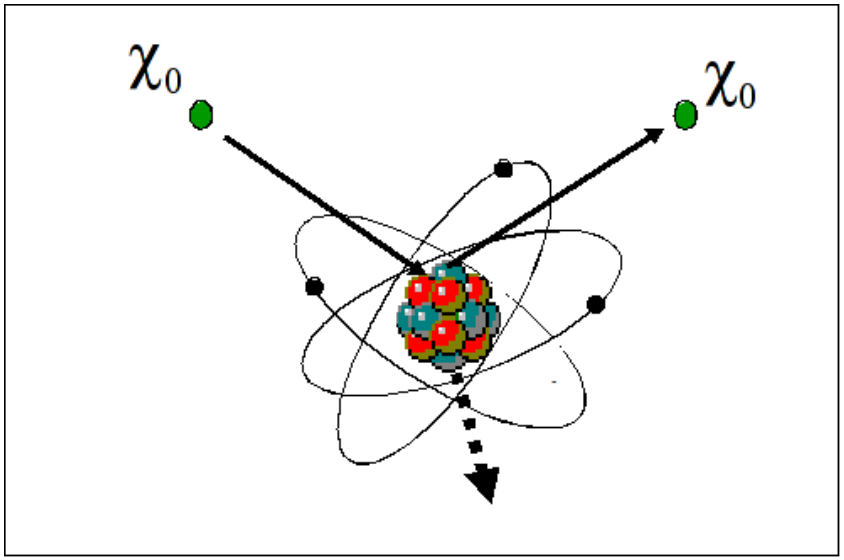
Hints for dark matter

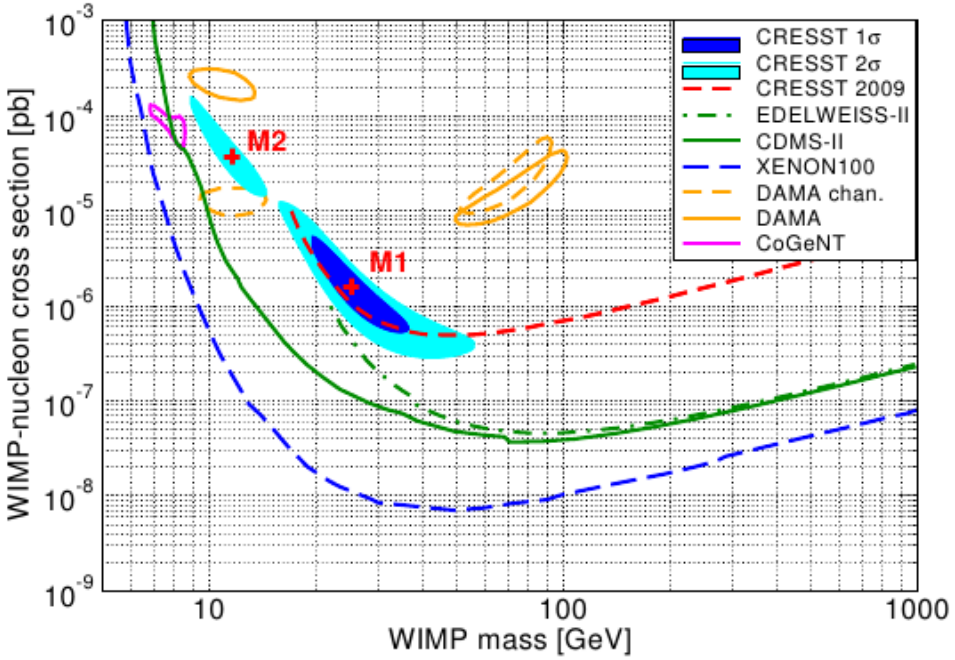




- Dynamics in galaxies and galaxy clusters
- Colliding galaxy clusters
- WMAP data

Direct dark matter search





- Dark matter candidate: WIMP (Weakly Interacting Massive Particle)
- Assumption: WIMP scatters coherently off target nucleus

→ Most direct dark matter search detectors can discriminate between electron (background) and nuclear recoils (signal)

WIMP model

- Spin independent interaction
- Elastic scattering
- WIMP scatters coherently off all nucleons
- Isothermal WIMP halo

$\Rightarrow$ Recoil spectrum of WIMPs:

$$\frac{dR(E_{rec})}{dE_{rec}} = \frac{c_1 N_A \rho_D}{2\sqrt{\pi}\mu_1^2} \sigma_{WN} \left|F(E_{rec})\right|^2 v_0 \frac{A^2}{E_0} e^{\frac{-c_2 E_{rec}}{E_0 r}}$$

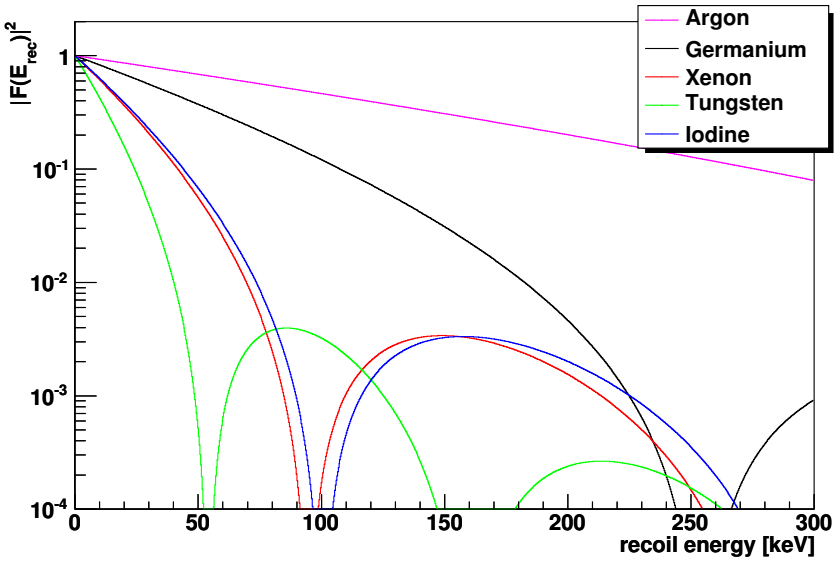
c_1, c_2: constants describing the annular modulation of the WIMP flux, N_A: Avogadro's number, ρ_D: local WIMP density, μ_1: reduced mass for A=1, σ_{WN}: WIMP-nucleon cross section, v_0: velocity of the earth relativ to the galaxy, A: mass number, E_0: kinetic energy of the WIMPs, E_{rec}: recoil energy, $r = 4\frac{M_D M_T}{(M_D+M_T)^2}$: kinematic factor, M_D: WIMP mass, M_T: mass of target nucleus

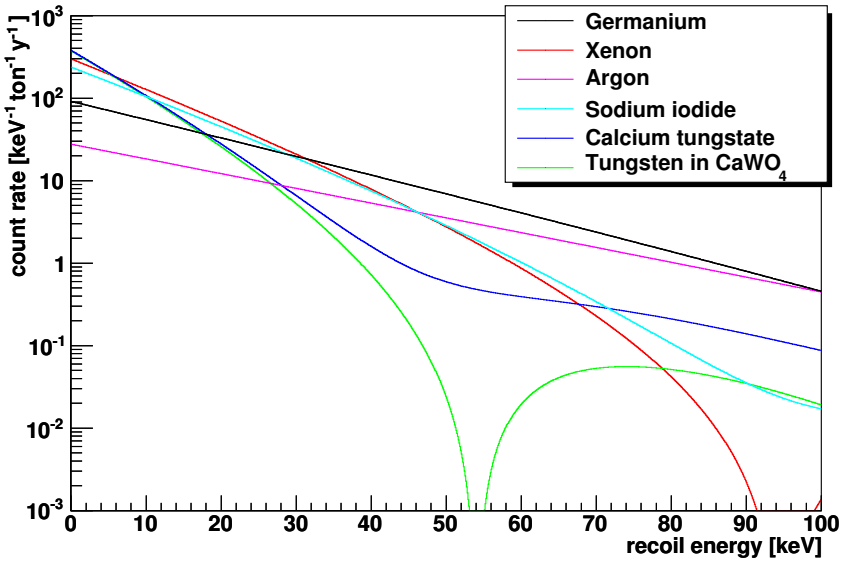
WIMP recoil spectrum

Helm form factor:

$$|F(q)|^2 = \left(\frac{3j_1(qR)}{qR}\right)^2 e^{-q^2 s^2}$$

q: transferred momentum, j_1: spherical Bessel function, R: effectiv nuclear radius, s: nuclear skin thickness

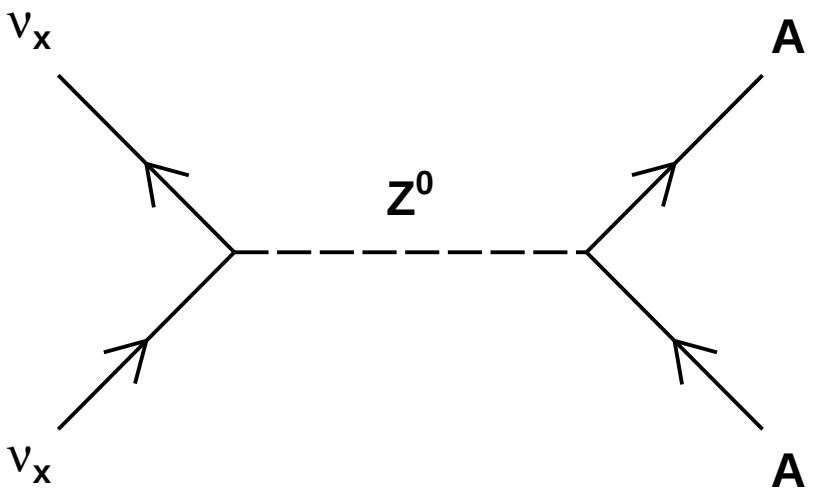




Recoil spectra for different materials:

- WIMP-nucleon cross section: $10^{-44}\,\mathrm{cm}^2 \hat{=} 10^{-8}\,\mathrm{pb}$
- WIMP-mass: 60 GeV

CNNS - A neutral current process



- Neutral current process $\Rightarrow$ CNNS independent of ν-flavor
- For low transferred momenta: Z^0 wave length comparable to radius of nuclei

$\Rightarrow$ ν scatters coherently off all nucleons

CNNS - Cross Section

$$\frac{d\sigma(E_\nu, E_{rec})}{dE_{rec}} = \frac{G_F^2}{8\pi}\left[Z\left(4\sin^2\theta_W - 1\right) + N\right]^2 M\left(2 - \frac{E_{rec}M}{E_\nu^2}\right)$$

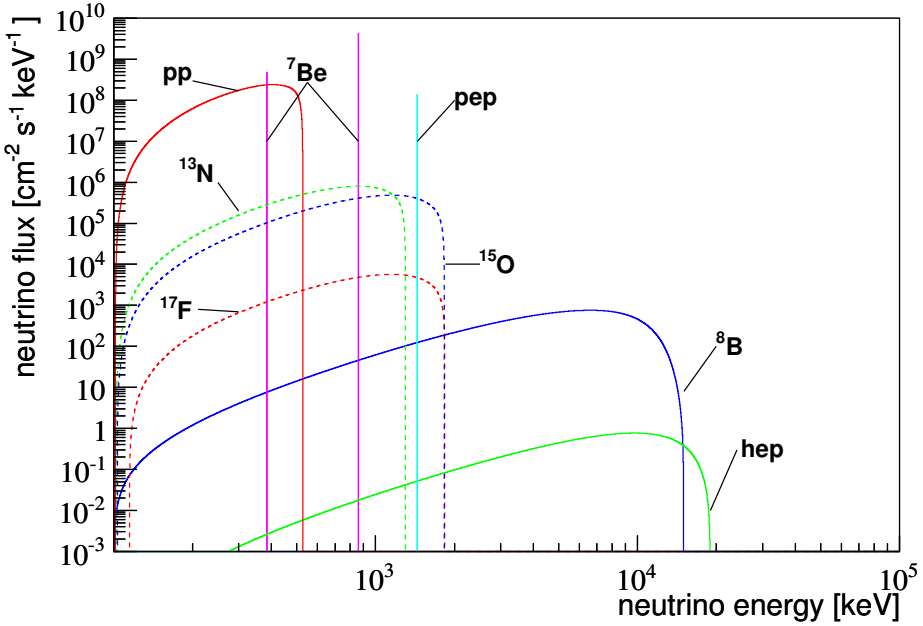
$$\sigma_{tot} = \frac{G_F^2}{4\pi}\left[Z\left(4\sin^2\theta_W - 1\right) + N\right]^2 E_\nu^2$$

with neutrino energy E_ν, recoil energy E_{rec}, Fermi constant G_F, Weinberg angle θ_W, mass of traget nucleus M, proton number Z and neutron number N.

$$\sin^2\theta_W = 0.23 \Rightarrow \sigma_{tot} \sim \frac{G_F^2}{4\pi} N^2 E_\nu^2$$

But recoil energy $E_{rec} \propto \frac{1}{N+Z}$.
$\rightarrow$ Higher neutron number $N \rightarrow$ higher cross section σ_{tot} but also lower recoil energy E_{rec}

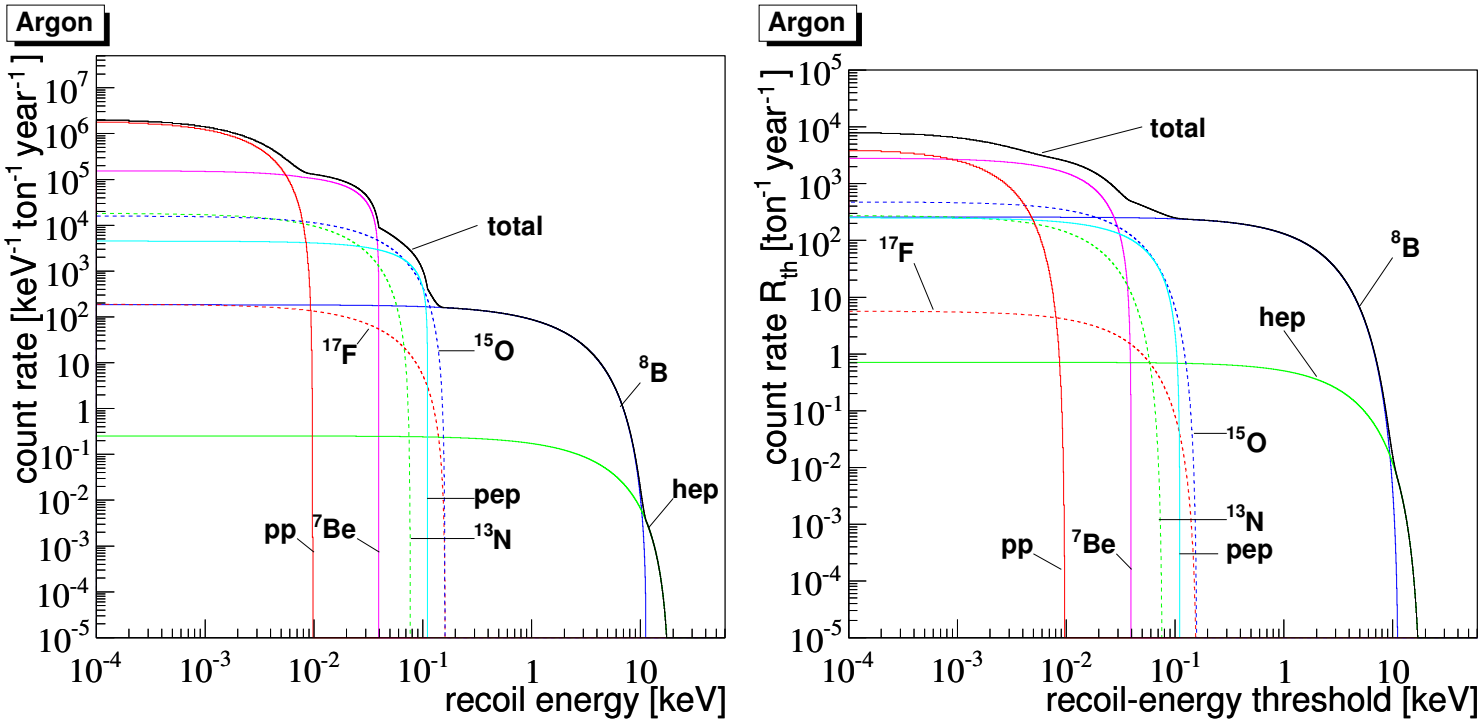
Solar neutrinos



- Neutrinos scattering coherently off a nucleus mimic a WIMP scattering event
- Strongest natural neutrino source: solar neutrinos
- Expected count rate for solar neutrinos is about 10^4 per ton-year

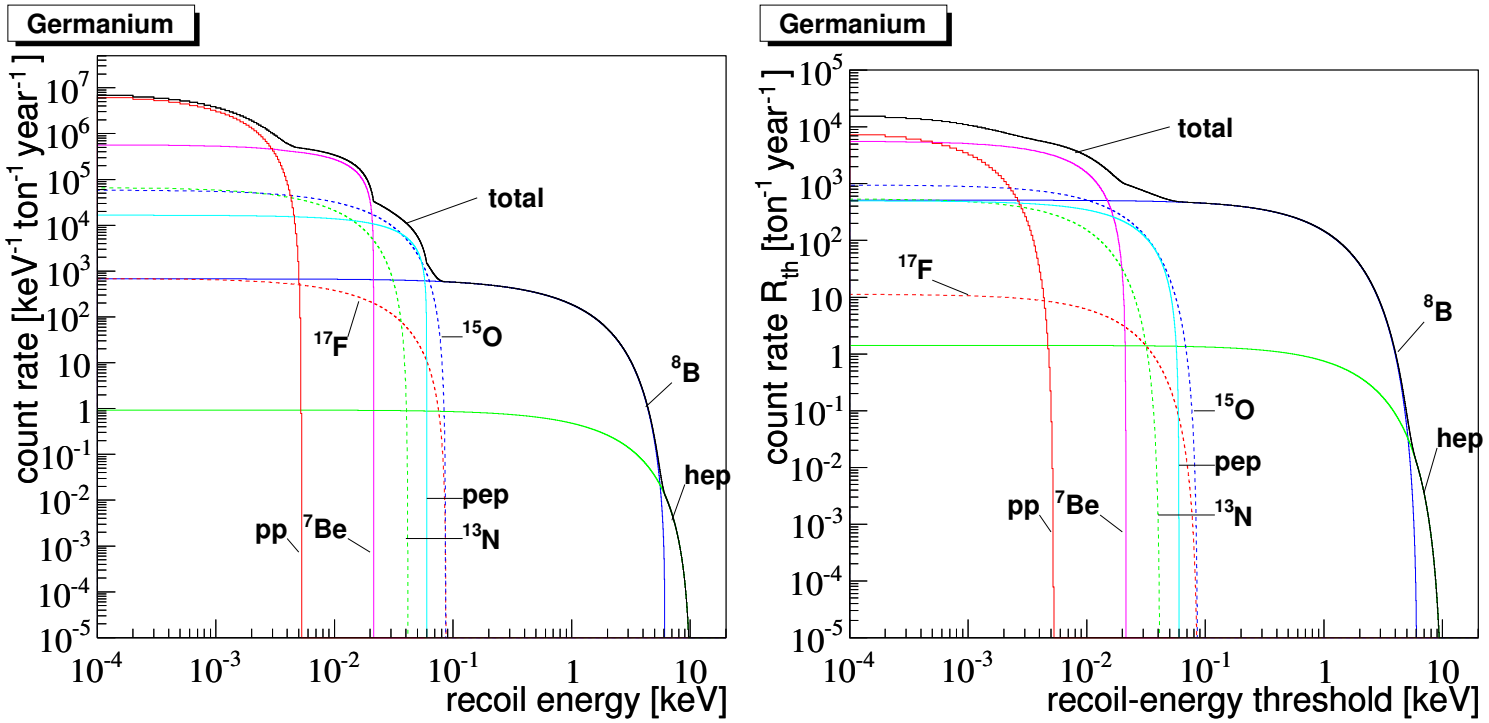
→ **Solar neutrinos can be a background source for direct dark matter searches**

Count rates for argon



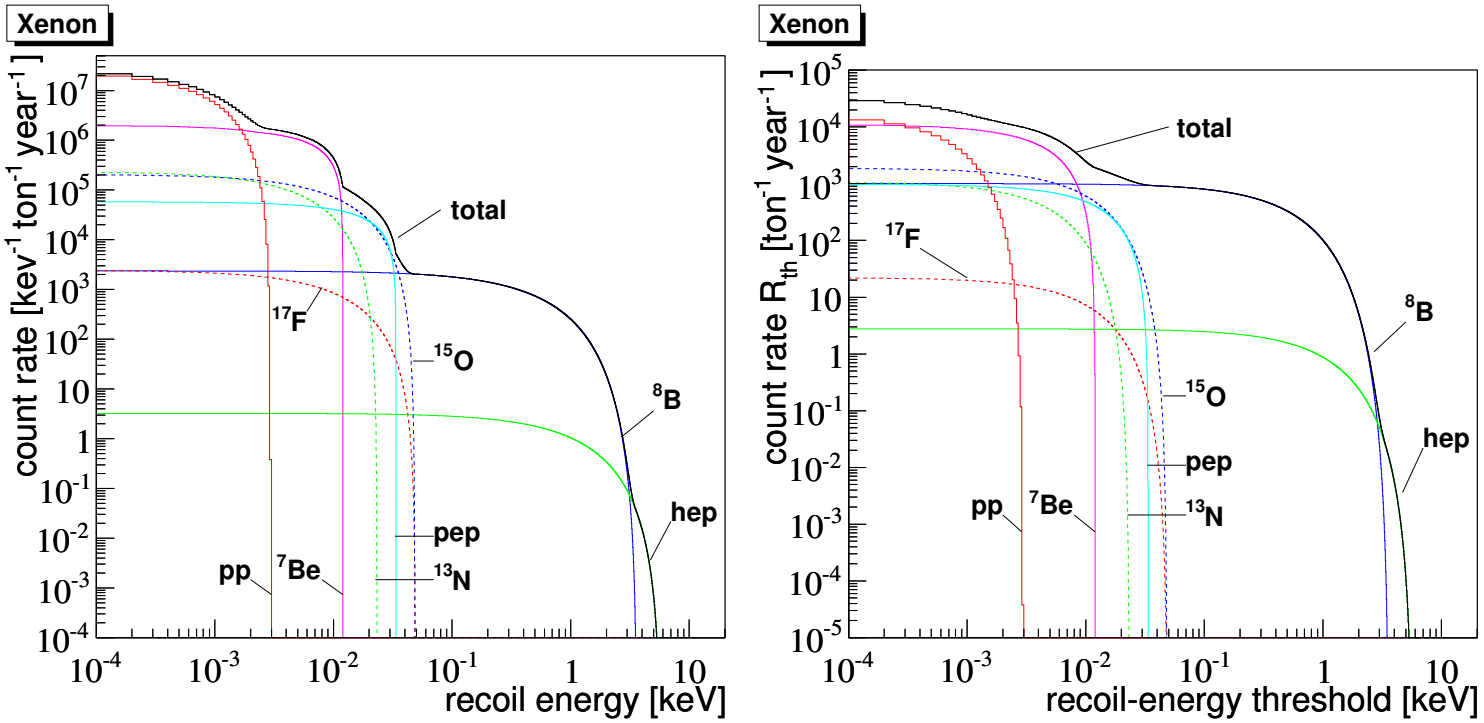
E_{th} [keV]	0	**8.66**	18.8
count rate per ton-year	$8.1 \cdot 10^3$	**0.1**	0.0

Count rates for germanium



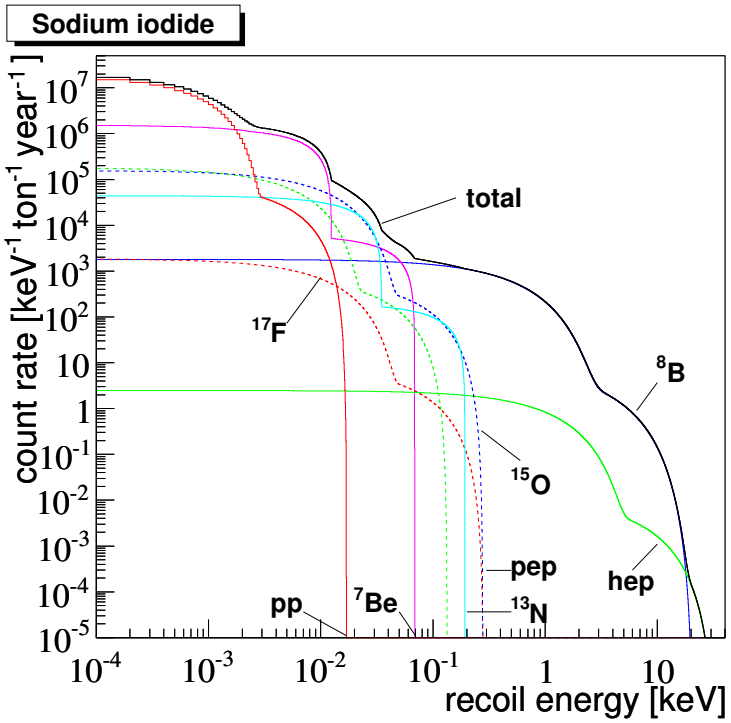
E_{th} [keV]	0	**4.95**	10.3
count rate per ton-year	$1.6 \cdot 10^4$	**0.1**	0.0

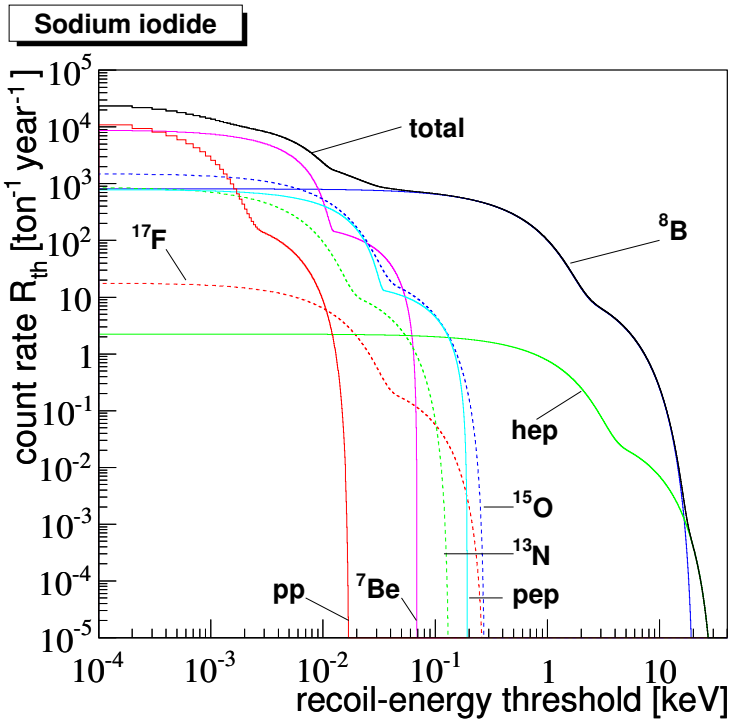
Count rates for xenon



E_{th} [keV]	0	**2.92**	5.7
count rate per ton-year	$3.0 \cdot 10^4$	**0.1**	0.0

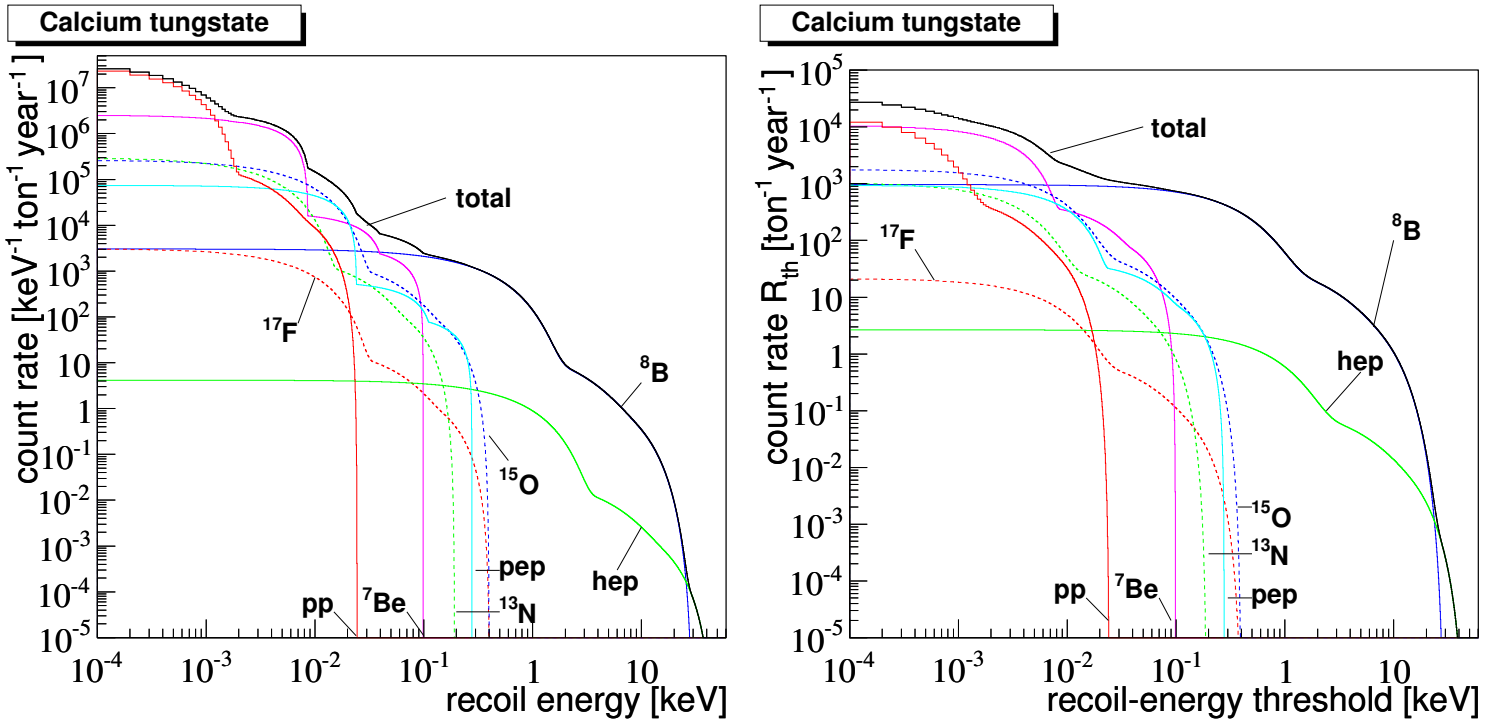
Count rates for sodium iodide





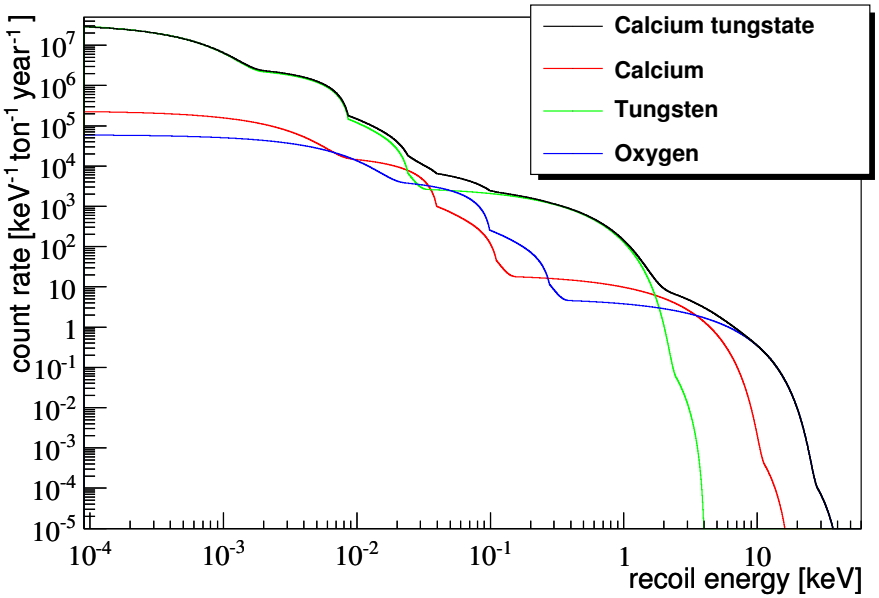
E_{th} [keV]	0	**11.55**	37.6
count rate per ton-year	$2.4 \cdot 10^4$	**0.1**	0.0

Count rates for calcium tungstate



E_{th} [keV]	0	**16.39**	7.0	47.1
count rate per ton-year	$2.8 \cdot 10^4$	**0.1**	2.7	0.0

Tungsten in calcium tungstate



- Counts for larger recoil energies (>2 keV) mainly due to scatterings off oxygen
- It is possible to discriminate between W recoils and Ca or O recoils

⇒ Solar neutrino events with recoil energies >2 keV can be rejected

Count rates for W in $CaWO_4$

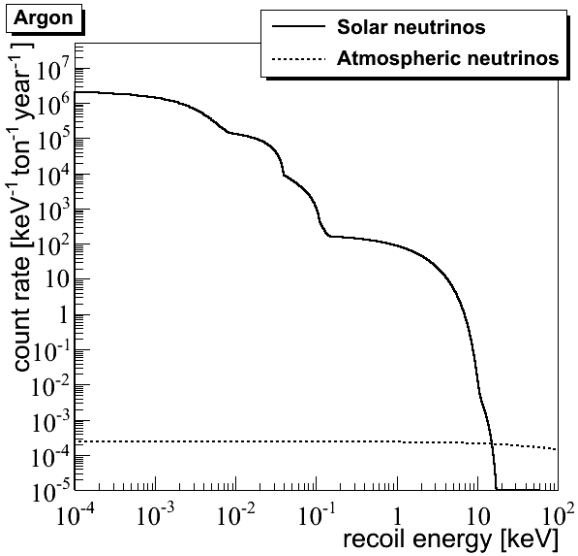
E_{th} [keV]	0	**2.08**	4.1
count rate per ton-year	$2.7 \cdot 10^4$	**0.1**	0.0

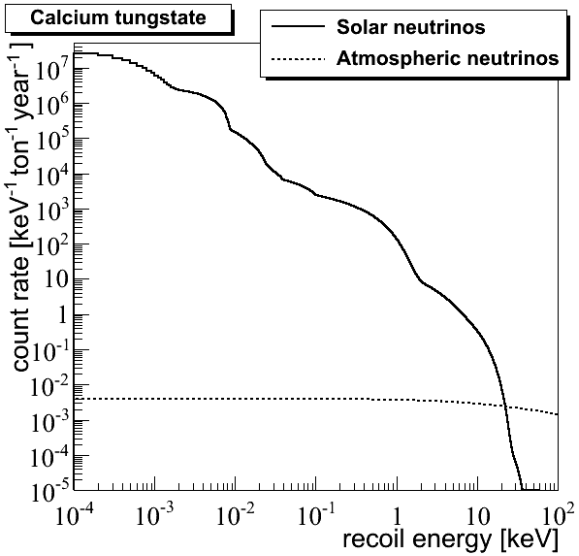
Energy thresholds for different target materials

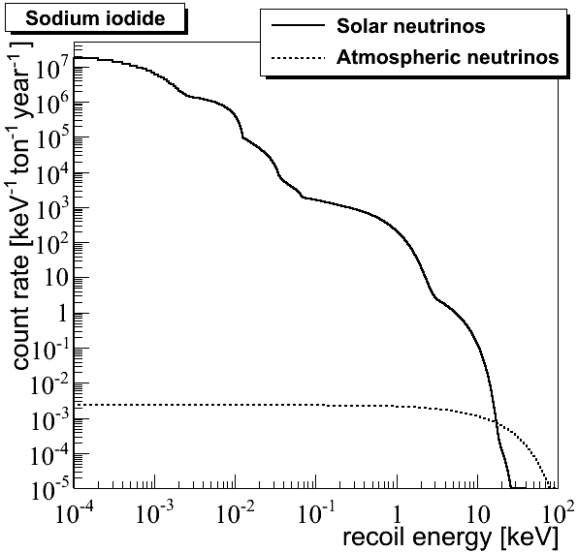
Material	0.1 counts	0 counts
Ar	8.66 keV	18.8 keV
Ge	4.95 keV	10.3 keV
Xe	2.92 keV	5.7 keV
NaJ	11.55 keV	37.6 keV
$CaWO_4$	16.39 keV	47.1 keV
W in $CaWO_4$	2.08 keV	4.1 keV

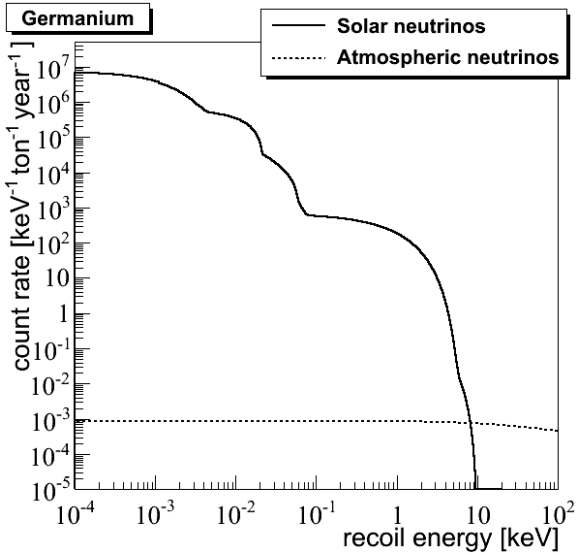
- Energy threshold for $CaWO_4$ is given without discrimination between W, Ca and O recoils
- Energy threshold for W in $CaWO_4$ is given with discrimination between W, Ca and O recoils applied

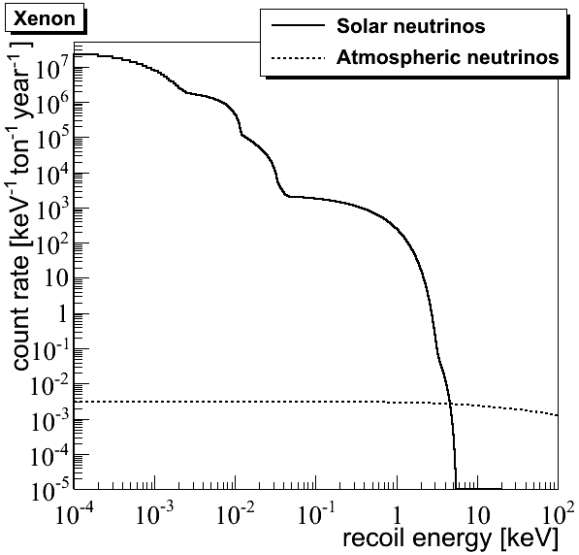
Recoil spectra of atmospheric neutrinos





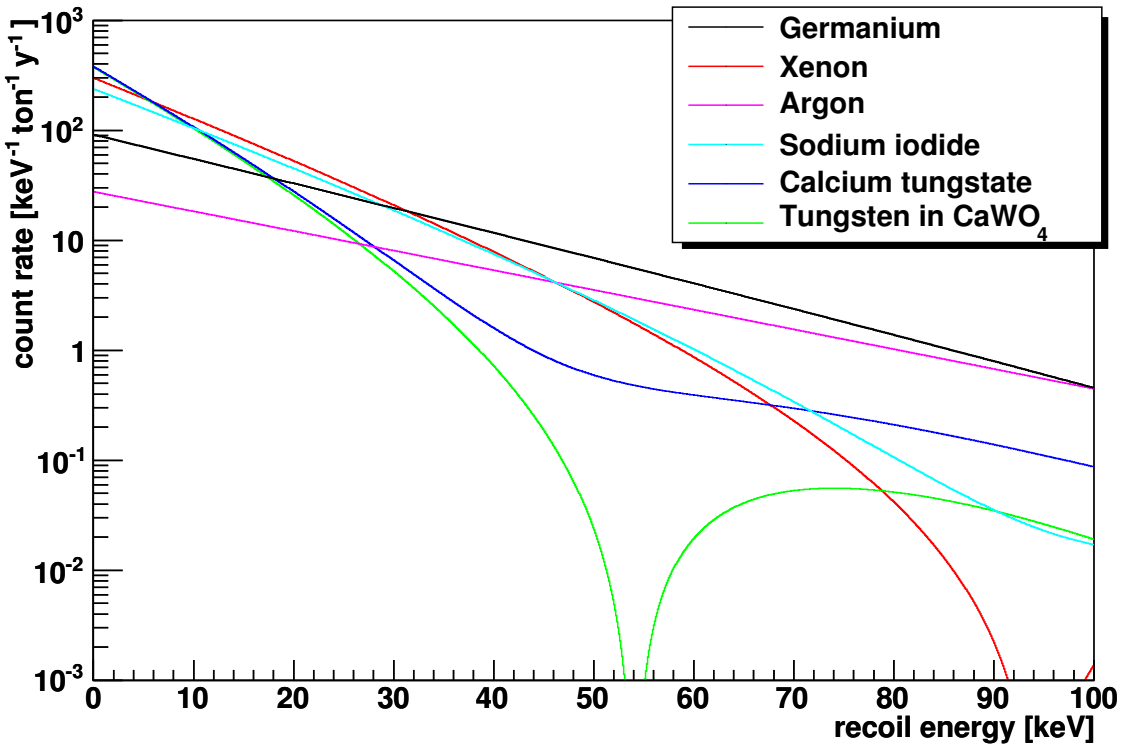






Count rates for solar neutrino thresholds are $\sim 10^{-2}$ per ton-year.
$\Rightarrow$ Atmospheric neutrinos limit the achievable sensitivity to $10^{-48}\,\mathrm{cm}^2$.

WIMP recoil spectrum



Recoil spectra for different materials:

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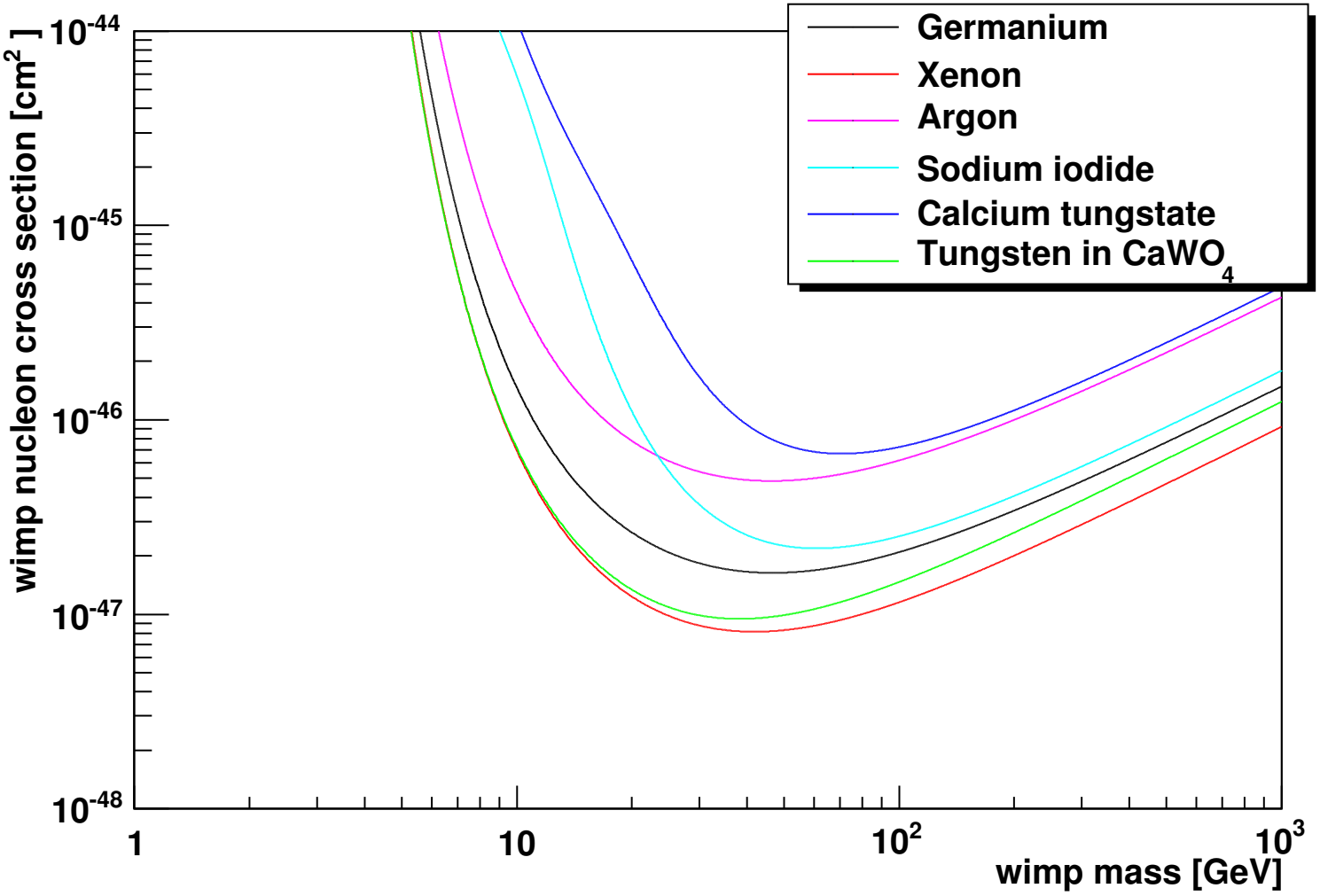
- WIMP-mass: 60 GeV

Exclusion plots for optimal WIMP search regions



→ Exposure 1 ton-year

Conclusions

- Solar neutrinos can be a background source for sensitivities below $10^{-46}\,\mathrm{cm}^2 \hat{=} 10^{-10}\,\mathrm{pb}$ for the WIMP-nucleon cross section
- However, solar neutrino background can be rejected by a proper choice of the WIMP search region
- W and Xe are the best target materials for the direct dark matter search, if WIMP masses are $\gtrsim 10\,\mathrm{GeV}$
- The discrimination between W, Ca and O recoils is very important for the use of $CaWO_4$ as target material
- Atmospheric neutrinos become a background source for the direct dark matter search for sensitivities below $10^{-48}\,\mathrm{cm}^2 \hat{=} 10^{-12}\,\mathrm{pb}$