The neutrino background to direct detection of Dark Matter

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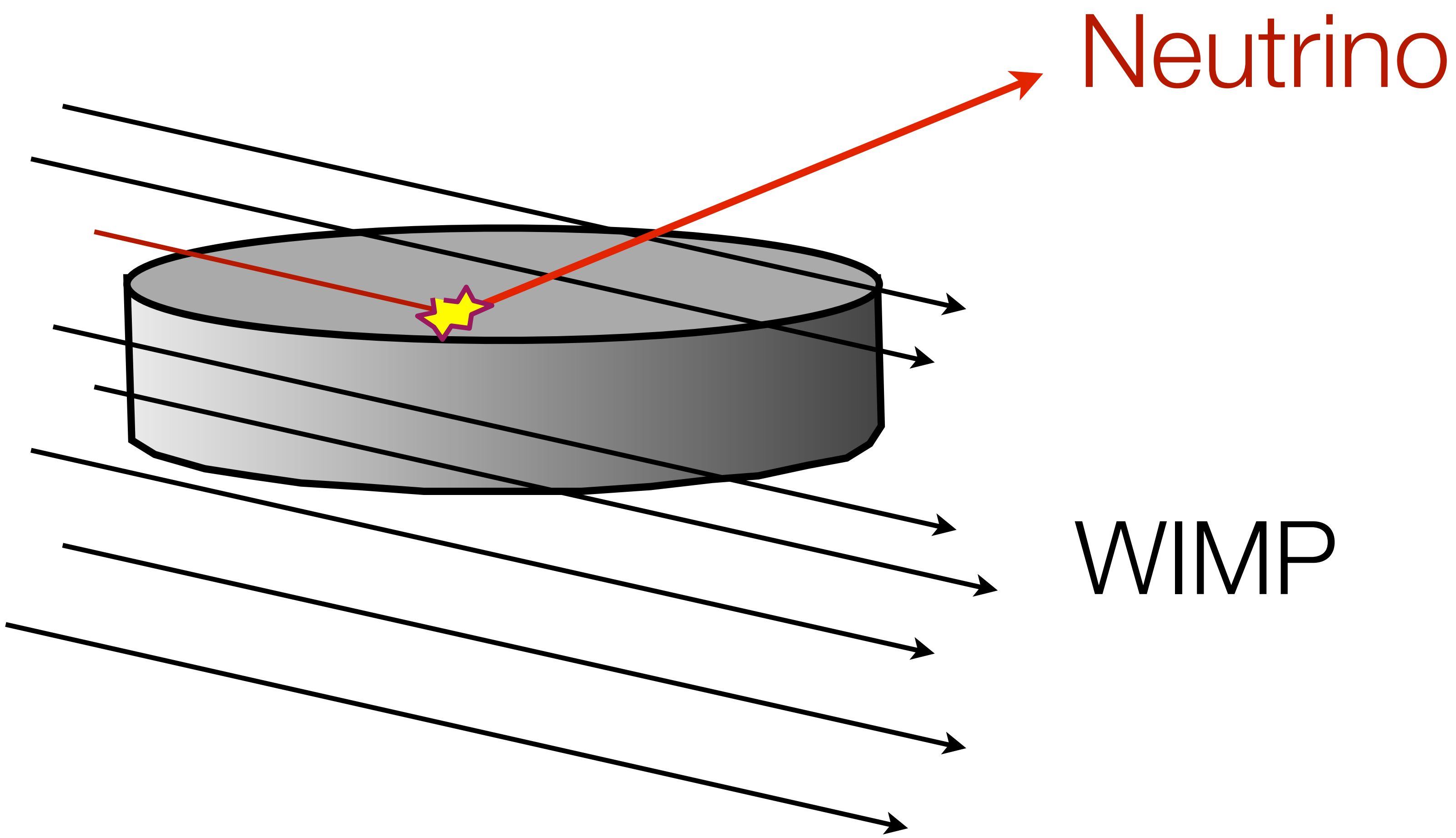
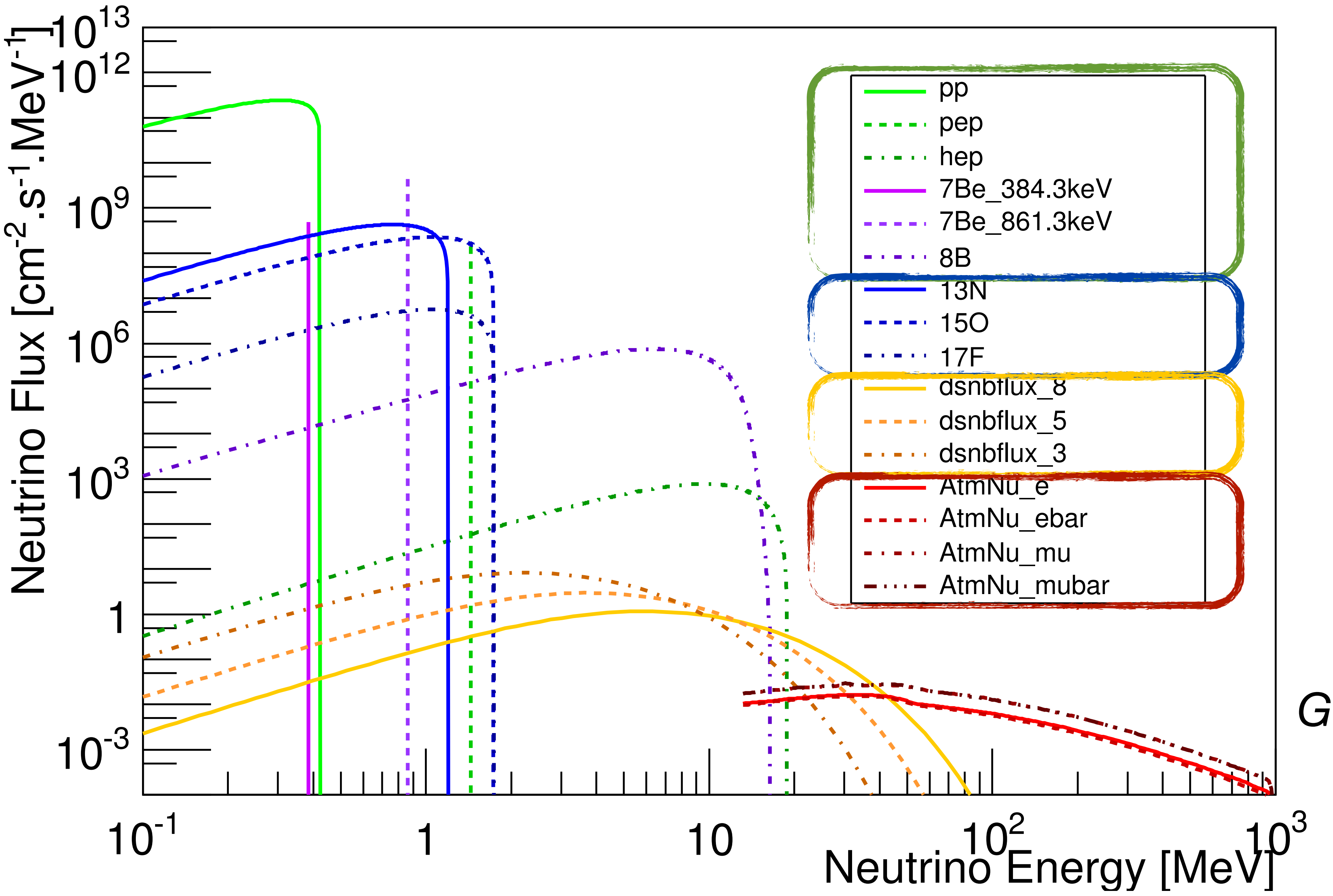
Introduction to the neutrino background

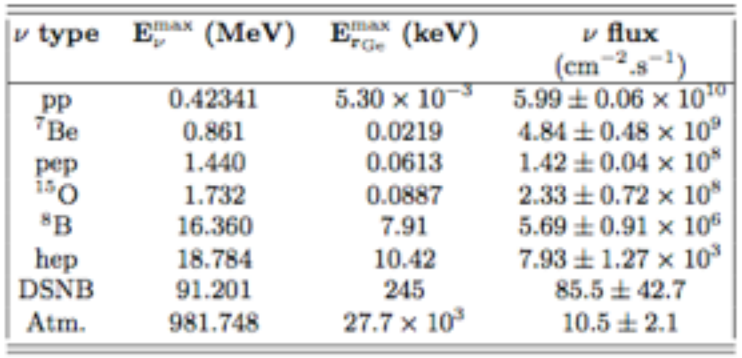


Based on:
- J. Billard, L. Strigari and E. Figueroa-Feliciano, PRD 89 (2014)
- F. Ruppin, J. Billard, L. Strigari and E. Figueroa-Feliciano, PRD 90 (2014)

Introduction to the neutrino background

The neutrino flux at an Earth based detector:





ν type	E_{ν}^{max} (MeV)	$E_{r_{Ge}}^{max}$ (keV)	ν flux (cm^{-2}.s^{-1})
pp	0.42341	5.30×10^{-3}	$5.99 \pm 0.06 \times 10^{10}$
^{7}Be	0.861	0.0219	$4.84 \pm 0.48 \times 10^{9}$
pep	1.440	0.0613	$1.42 \pm 0.04 \times 10^{8}$
^{15}O	1.732	0.0887	$2.33 \pm 0.72 \times 10^{8}$
^{8}B	16.360	7.91	$5.69 \pm 0.91 \times 10^{6}$
hep	18.784	10.42	$7.93 \pm 1.27 \times 10^{3}$
DSNB	91.201	245	85.5 ± 42.7
Atm.	981.748	27.7×10^{3}	10.5 ± 2.1

Solar neutrinos

CNO neutrinos

DSNB neutrinos

Atm. neutrinos

Geo neutrinos are negligible

Introduction to the neutrino background

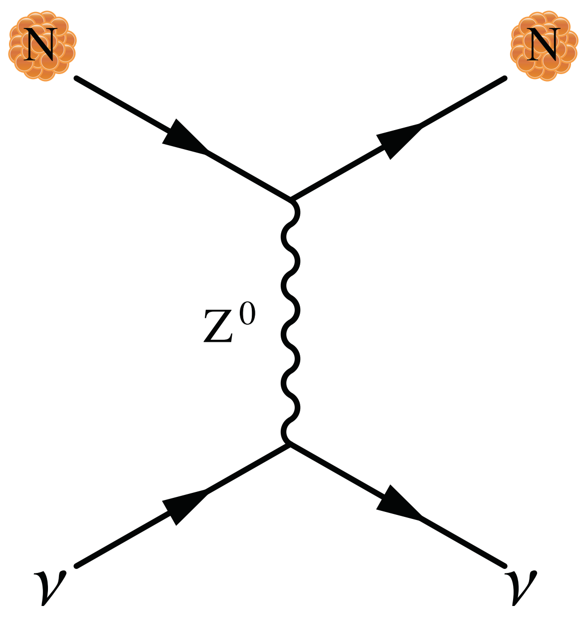
Neutrino interactions with Dark Matter experiment target material

- Coherent neutrino scattering (CNS):

$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)$$

- σ: Cross Section
- E_r: Recoil Energy
- E_ν: Neutrino Energy

- G_f: Fermi Constant
- Q_W: Weak Charge ~ **A**
- m_N: Atomic Mass



Neutral current

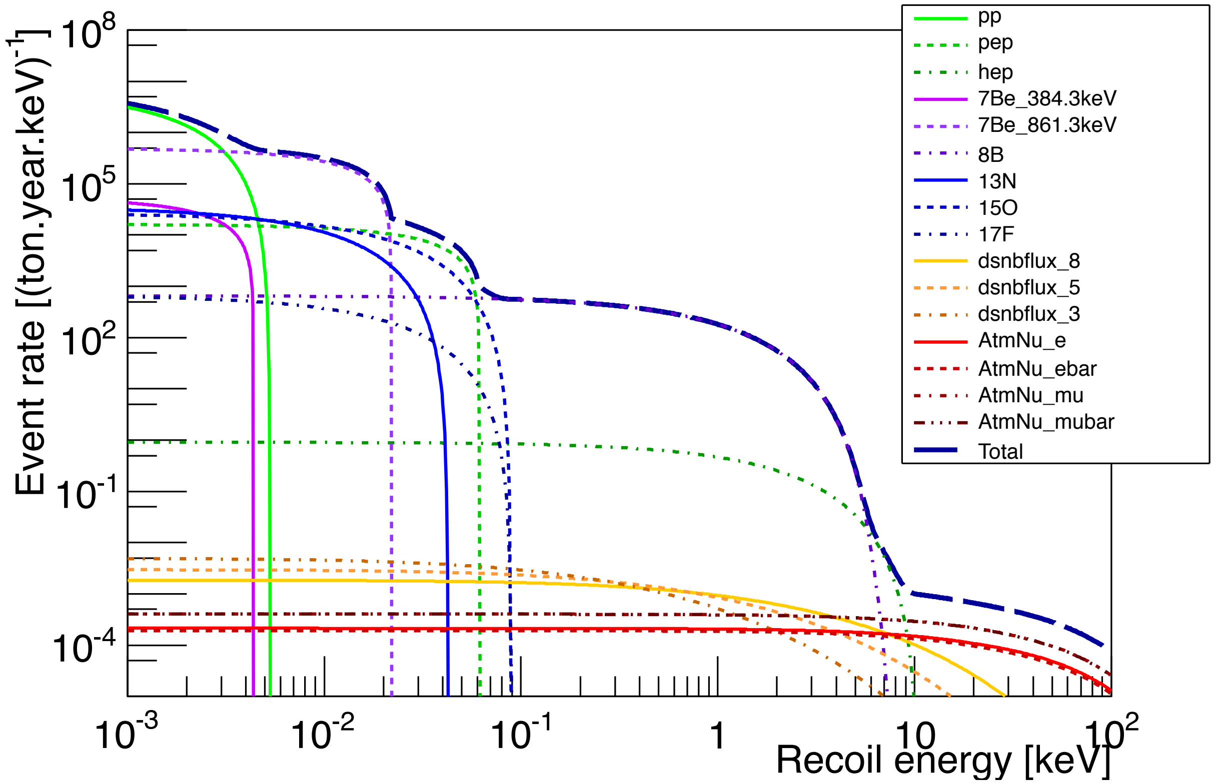
No flavor-specific terms!!!
Same rate for ν_e, ν_μ, and ν_τ

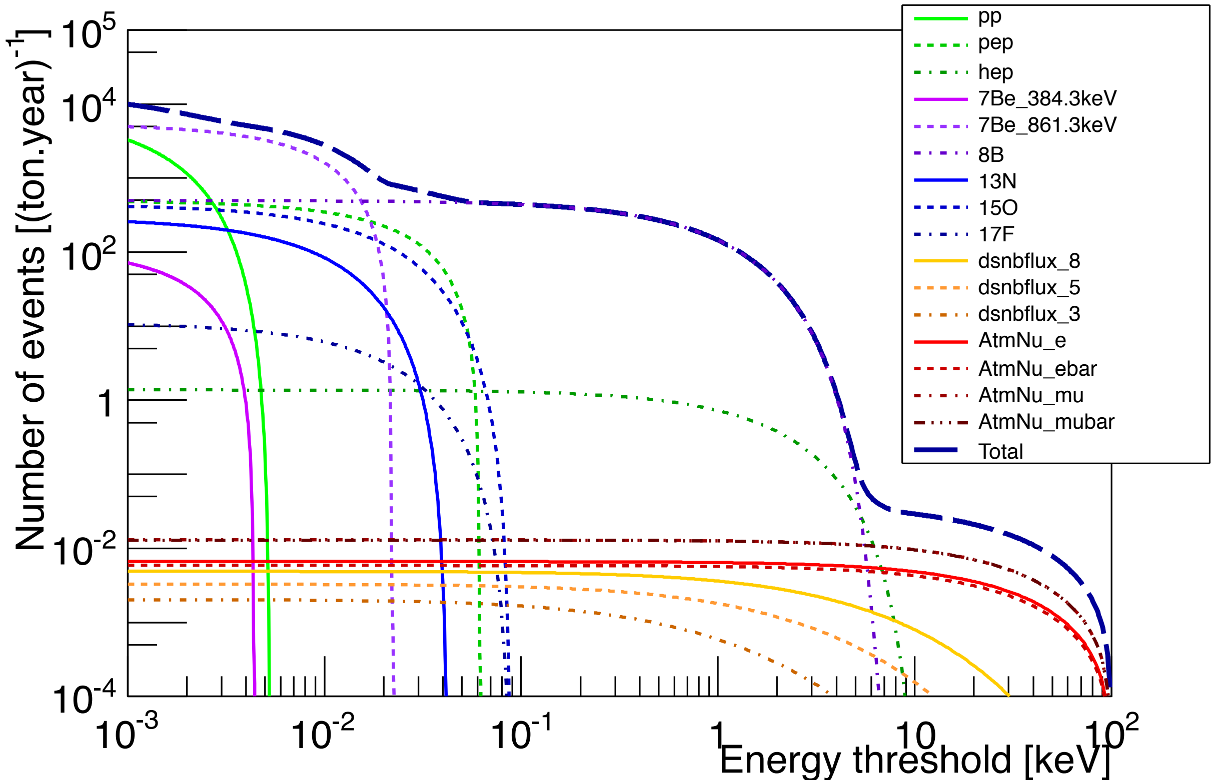
Ultimate background to direct detection

Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material

- Coherent neutrino scattering (CNS):



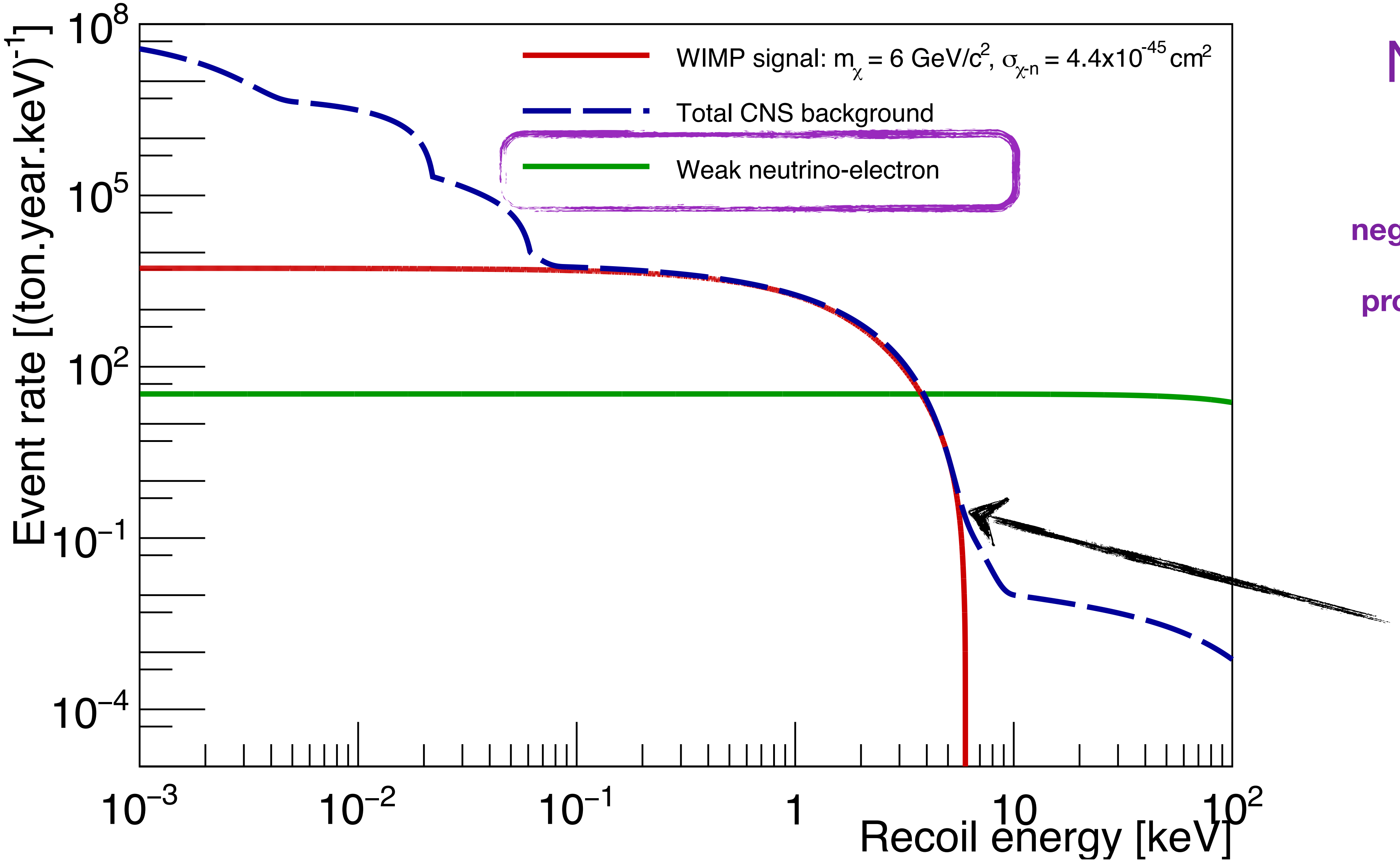


Depending on the Energy threshold, the CNS background can be very high!

- 1 keV threshold -> 100 evt/ton/year on Ge detector

Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material



Neutrino-electron background

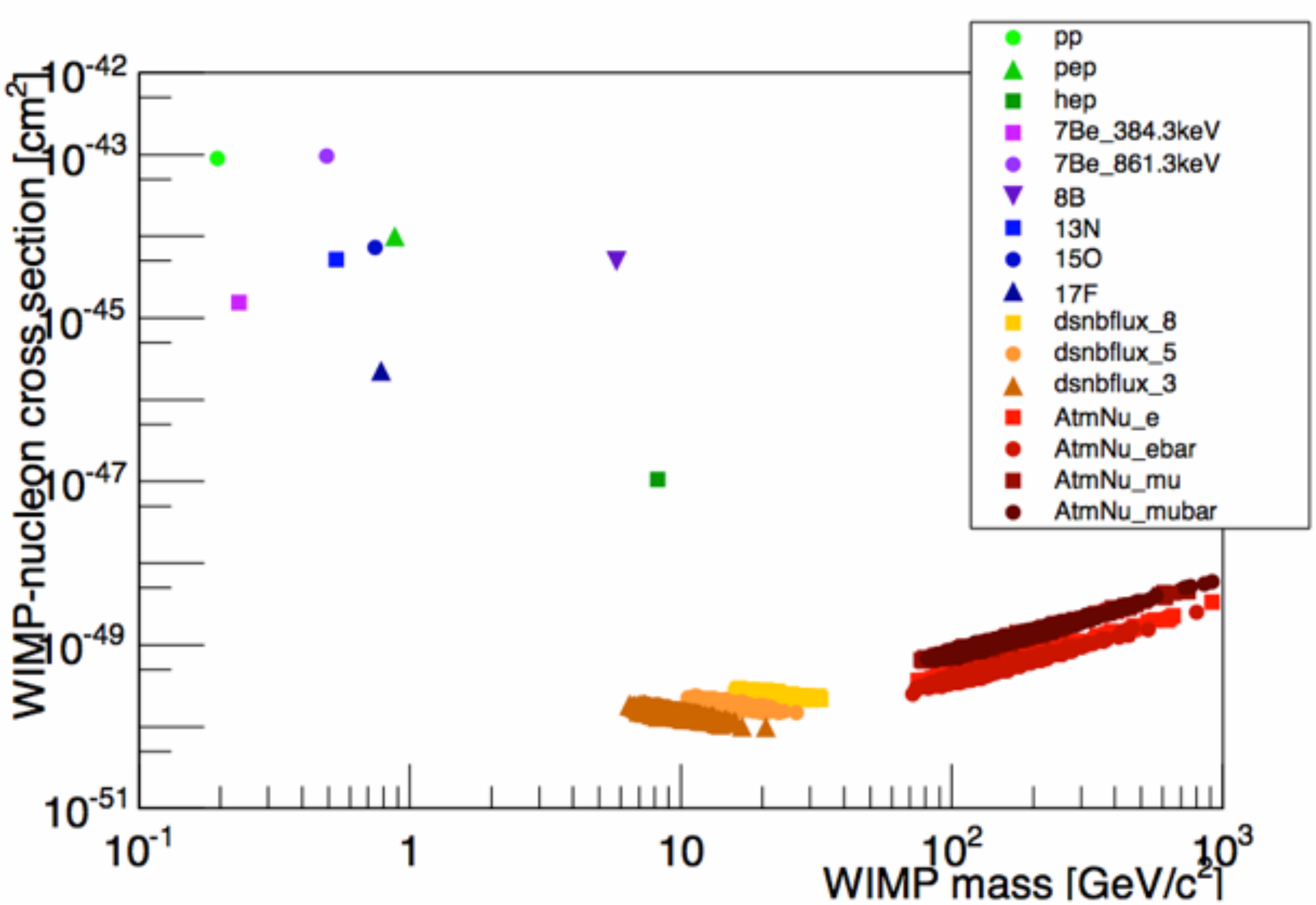
negligible for Ge cryogenic detectors
BUT
problematic for Xe based detectors

WIMP or neutrino??

Introduction to the neutrino background

WIMP and neutrino equivalence:

Using a maximum likelihood analysis where we fit a WIMP hypothesis to the different neutrino components we can determine the ***WIMP-neutrino equivalent models***



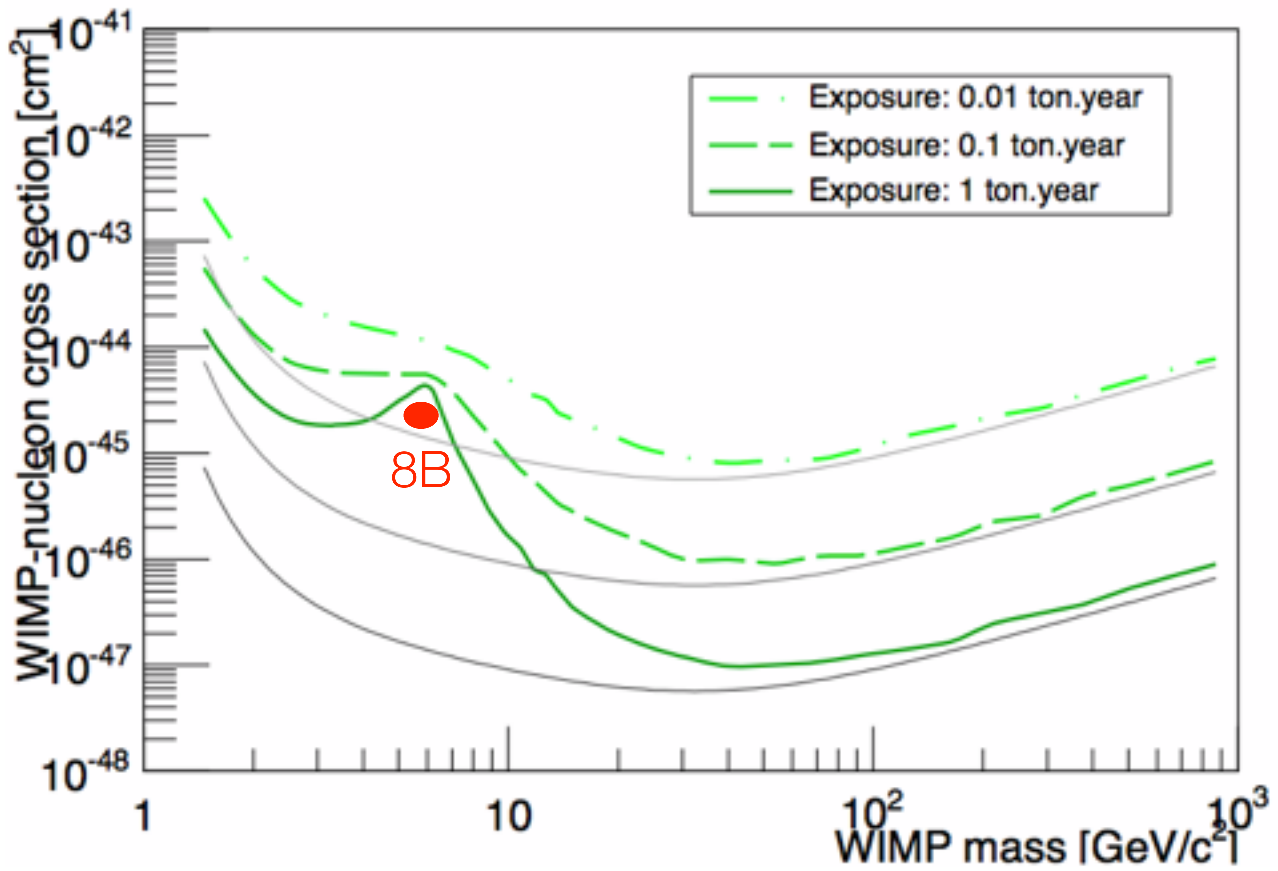
Considering a Xe target with no energy threshold

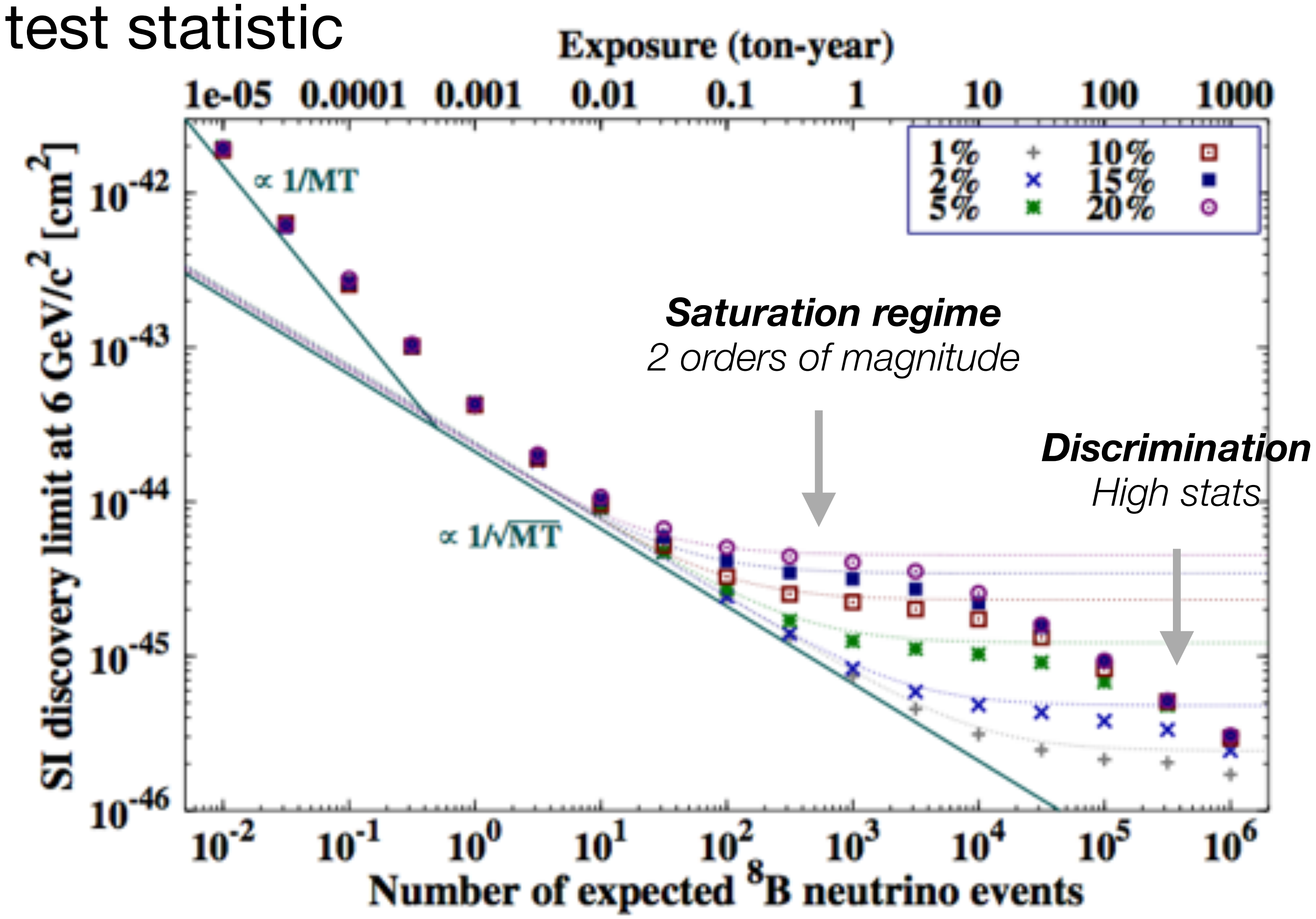
Impact on direct detection sensitivity

WIMP discovery potential:

(J. Billard, F. Mayet and D. Santos PRD 2012)

- 90% probability to get a 3 sigma or more WIMP discovery significance
- Computed using a profile likelihood ratio test statistic





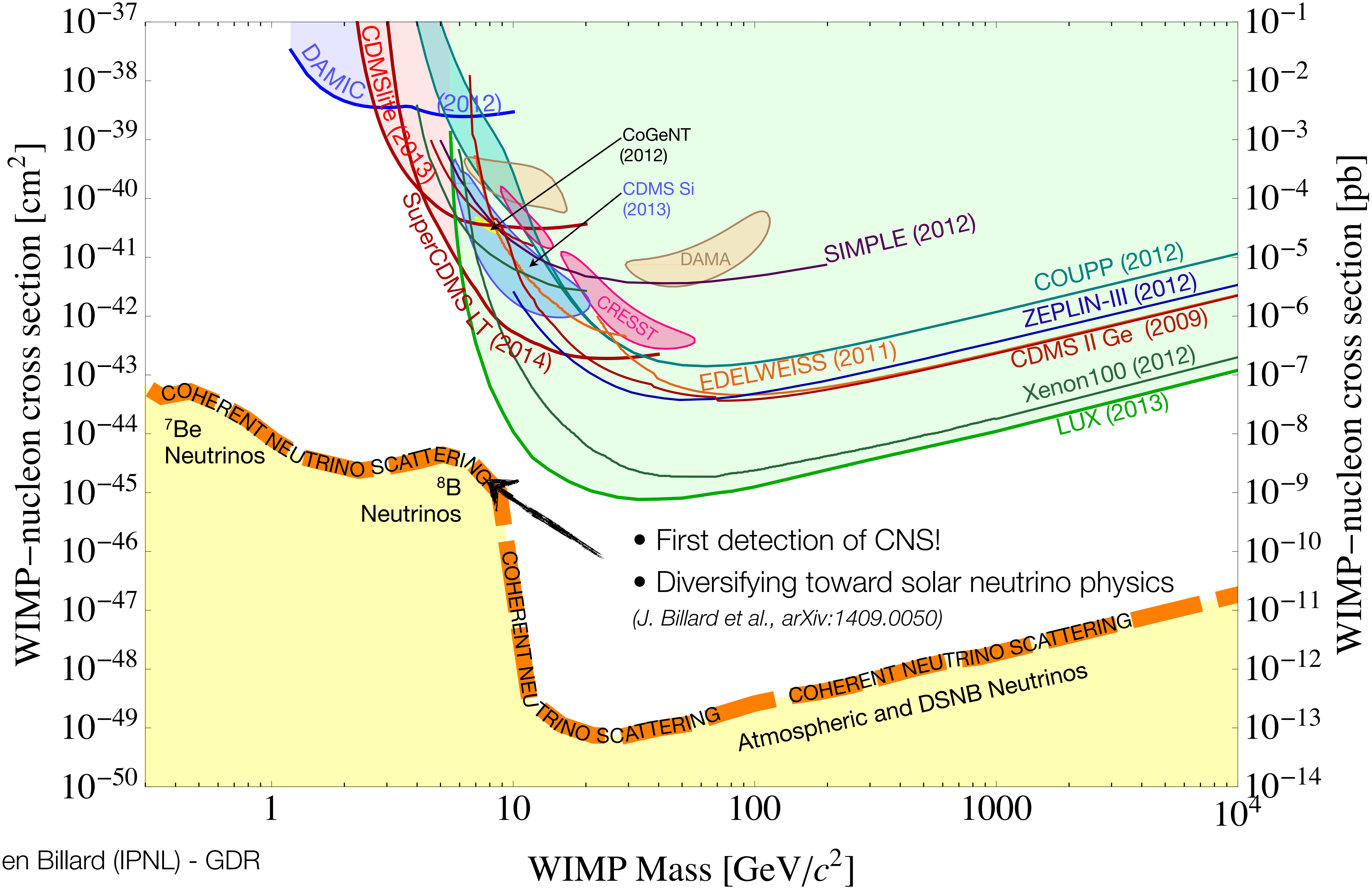
Saturation regime
2 orders of magnitude

Discrimination
High stats

In the case of a **perfect spectral matching**, we expect the sensitivity to scale as:

$$\sigma_{90\%} \propto \frac{\sqrt{N_\nu + \xi^2 (N_\nu)^2}}{N_\nu} = \sqrt{\frac{1 + \xi^2 N_\nu}{N_\nu}},$$

Impact on direct detection sensitivity



- First detection of CNS!
- Diversifying toward solar neutrino physics

(J. Billard et al., arXiv:1409.0050)

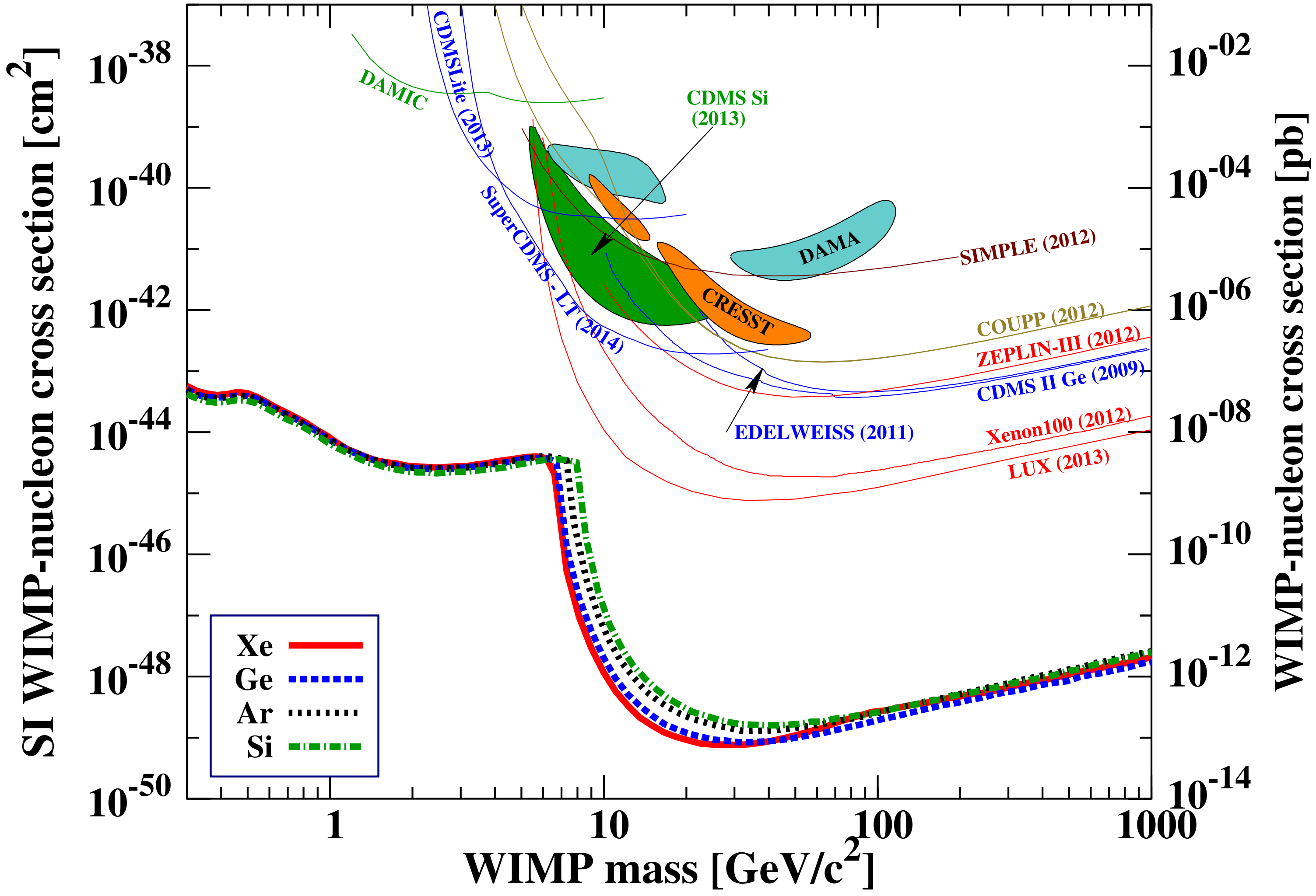
Target complementarity

How to bypass this neutrino-induced saturation of the sensitivity?

1. Diminution of the systematic errors will lower the saturation regime
2. Add directional information! Solar neutrinos and WIMPs have 2 very different angular distributions *(P. Grothaus et al, PRD 90 (2014))*
3. Annual modulation? seems possible! *(J. H. Davis arXiv:1412.1475)*
4. Target complementarity: combining data from several experiments.

Target complementarity

The neutrino bound (scalar interaction)



Bounds are very similar due to the nature of the CNS and the WIMP SI interaction

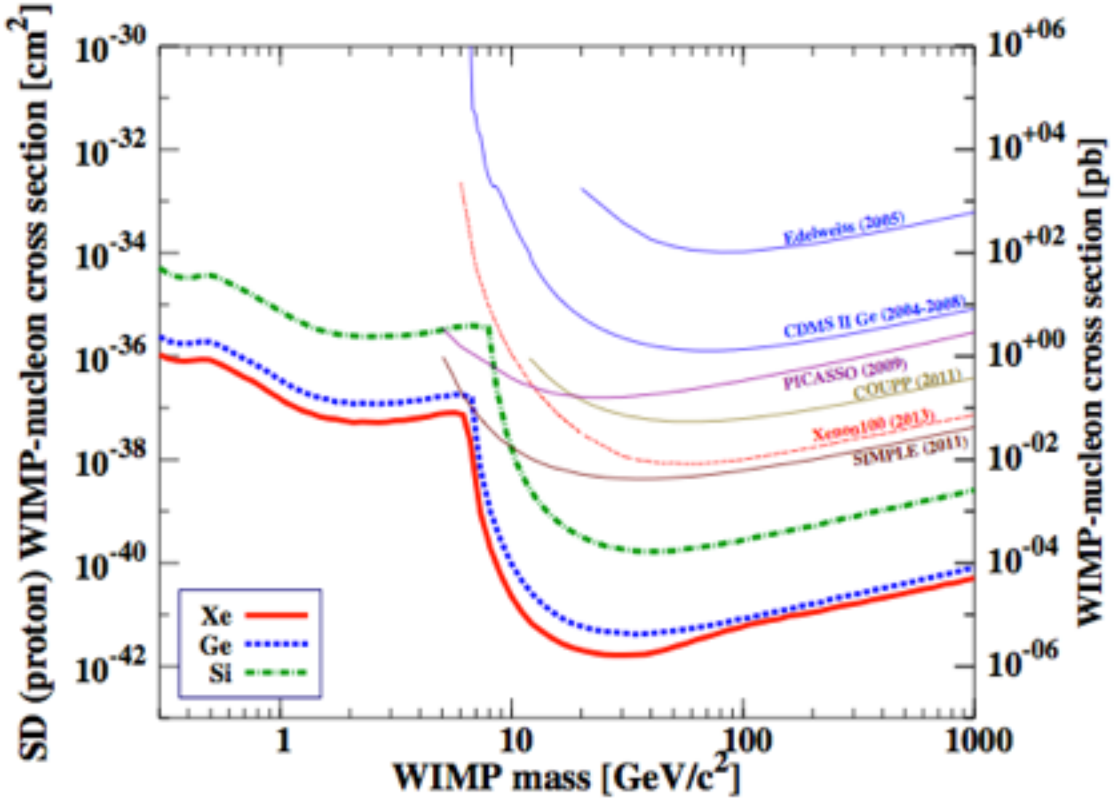
Target complementarity

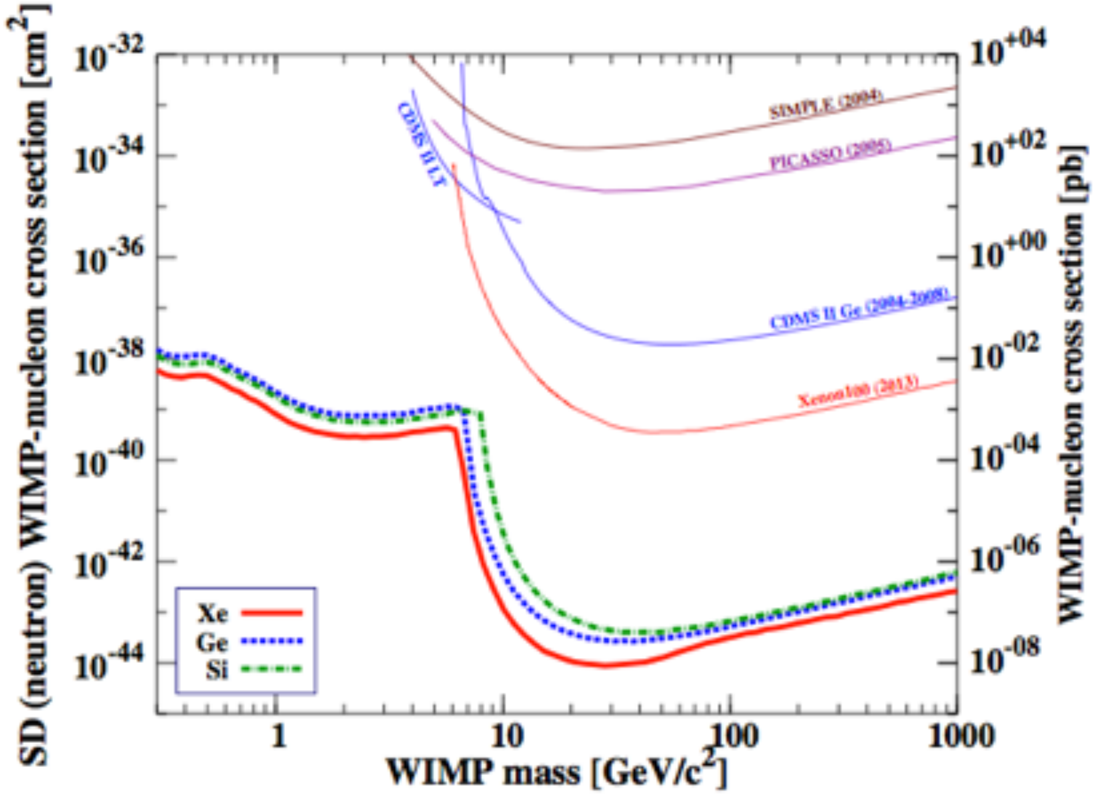
WIMP-nucleus Spin Dependent interaction $\sigma_{SD}^{p,n} = \frac{3}{4} \times \frac{\mu_p^2}{\mu_N^2} \times \frac{J}{J+1} \times \frac{1}{\langle S_{p,n} \rangle^2} \sigma_0^{SD}(^A X)$

The cross section is related to the mean spin contents which is different for all targets

	Nucleus	A	Z	Isotopic fraction	J	$\langle S_p \rangle$	$\langle S_n \rangle$
SD	Xe	131	54	0.2129	3/2	-0.009	-0.227
	Xe	129	54	0.264	1/2	0.028	0.359
	I	127	53	1.0	5/2	0.309	0.075
	Ge	73	32	0.0776	9/2	0.030	0.378
	Si	29	14	0.0468	1/2	-0.002	0.130
	F	19	9	1.0	1/2	0.477	-0.004

All targets are either preferentially sensitive to a WIMP-neutron or a WIMP-proton interaction

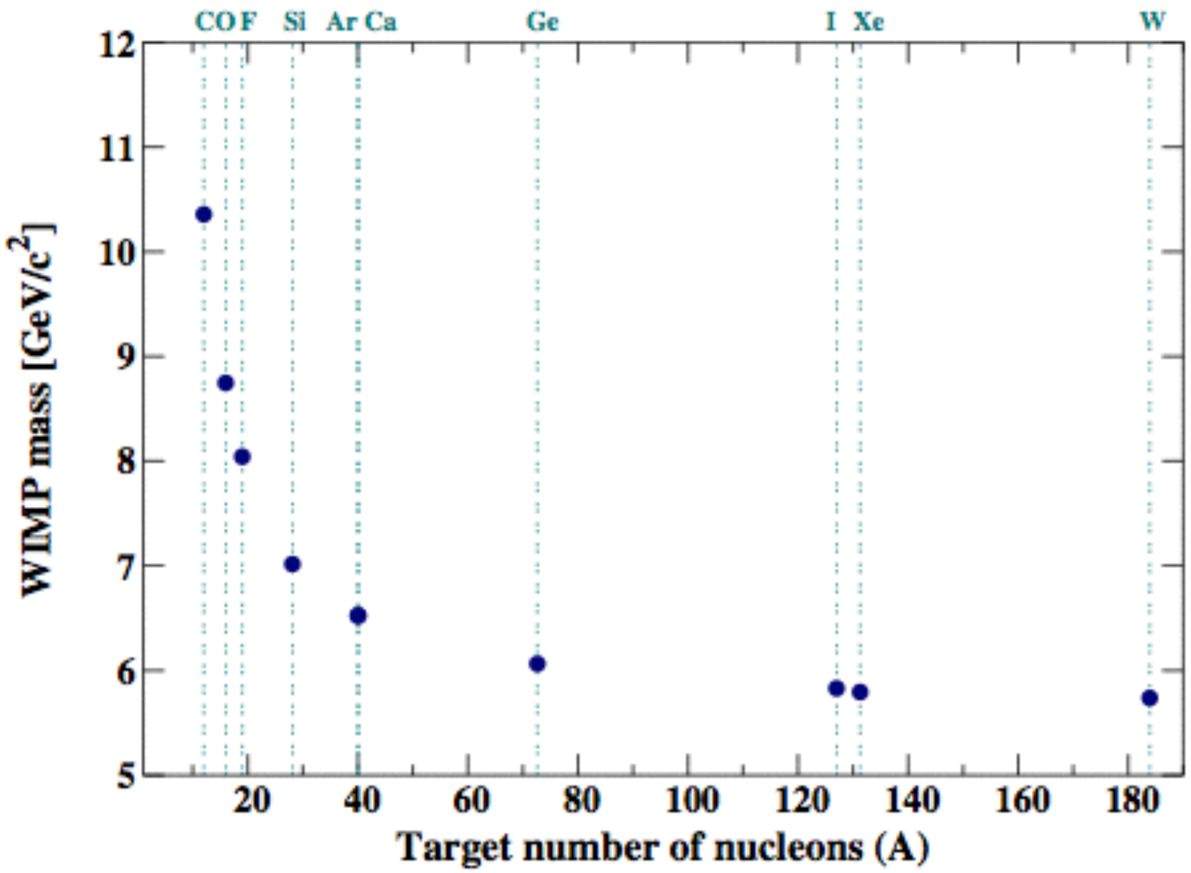


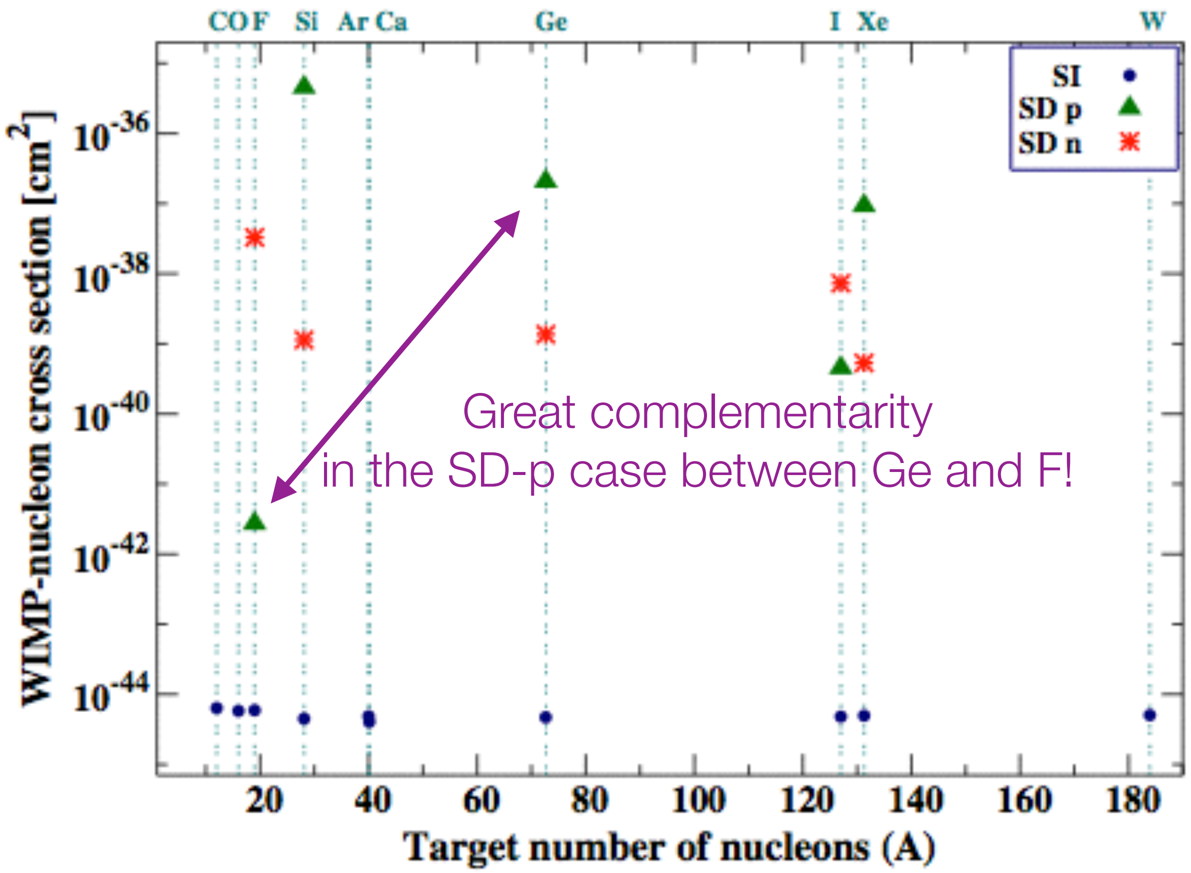


Target complementarity

How to estimate the « complementarity » of different targets?

The additional discrimination power brought by using different targets is related by how different are the WIMP-neutrino equivalent models





Great complementarity
in the SD-p case between Ge and F!

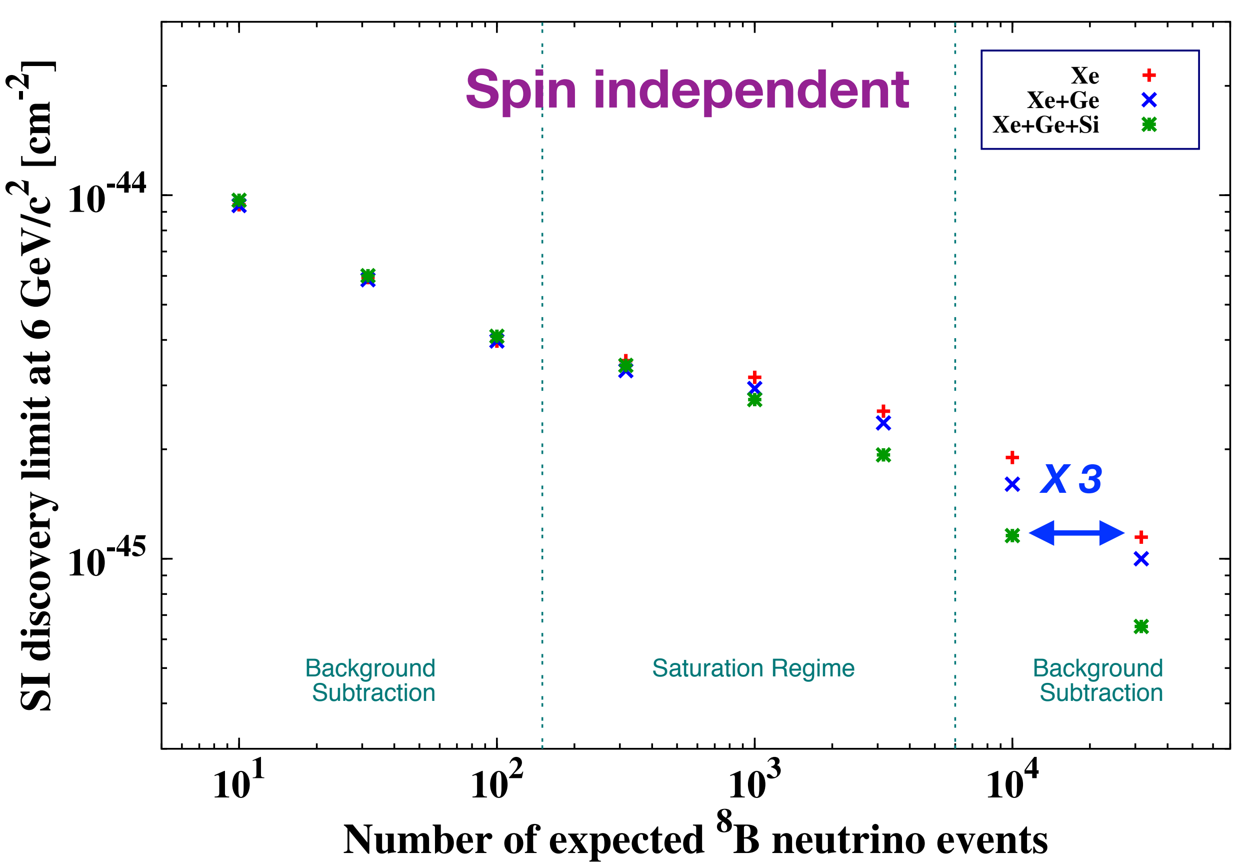
- Moderate differences in the WIMP mass and in the SI cross sections.
- Huge differences in the SD case -> ***WIMP hypothesis can't fit all experiments***

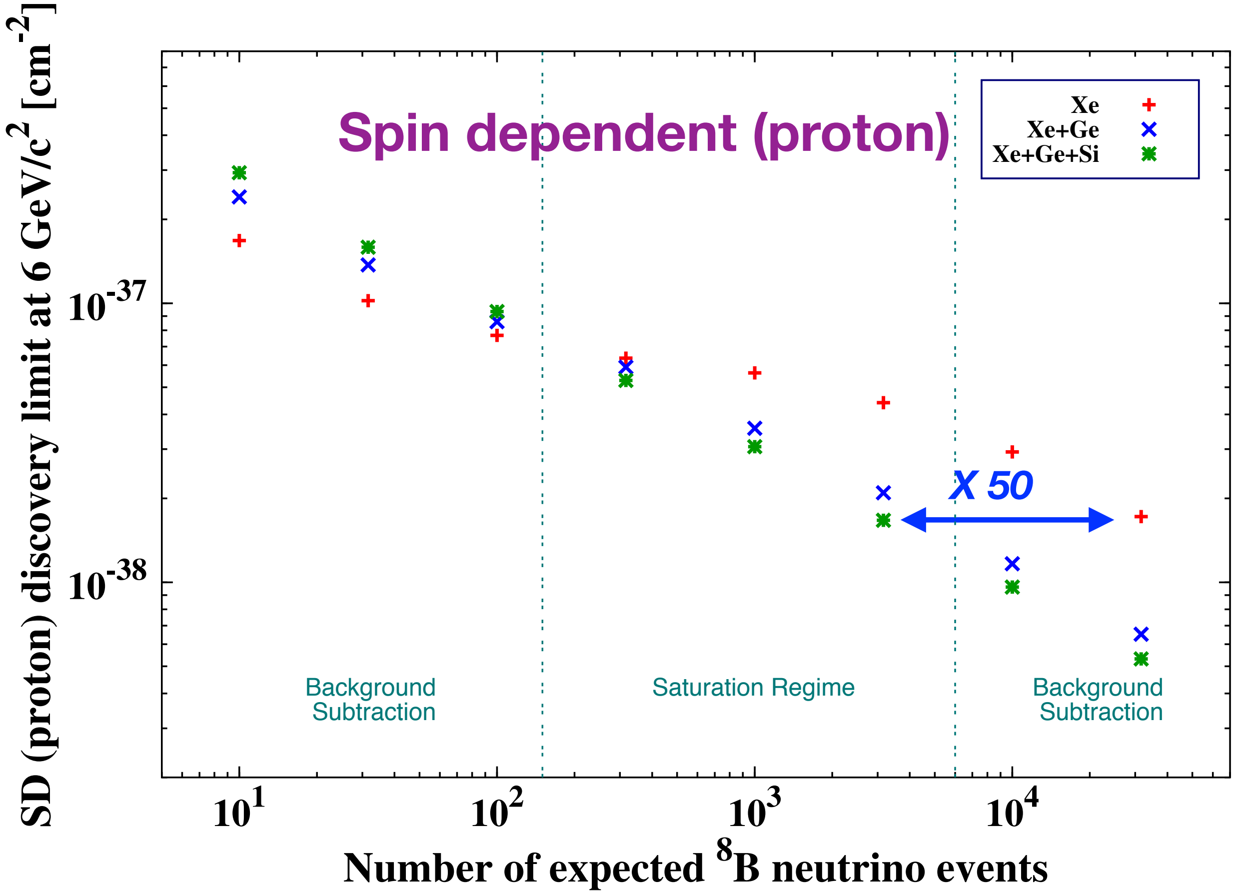
Target complementarity

Results from target complementarity

Considering a 6 GeV WIMP mass and a fixed systematic of 16% for 8B neutrinos

Total number of neutrinos equally distributed amongst each target nuclei





No more saturation regime in the SD-p case with Xe+Ge+Si -> ***no waste in exposure!***

Conclusions

Take away points:

- Solar, atmospheric and DSNB neutrinos are going to drastically affect the discovery potential of upcoming ton-scale experiments

- At some particular WIMP masses, they will imply a saturation of the discovery potential over about ***2 orders of magnitude in exposure***

- The easiest way to go around this, is by combining results from different experiments:
  - Moderate gain in the SI case with fp = fn, due to similarity in SI and CNS interactions
  - ***High gain in the SD case, depending on the considered target***