

The neutrino background to direct detection of Dark Matter

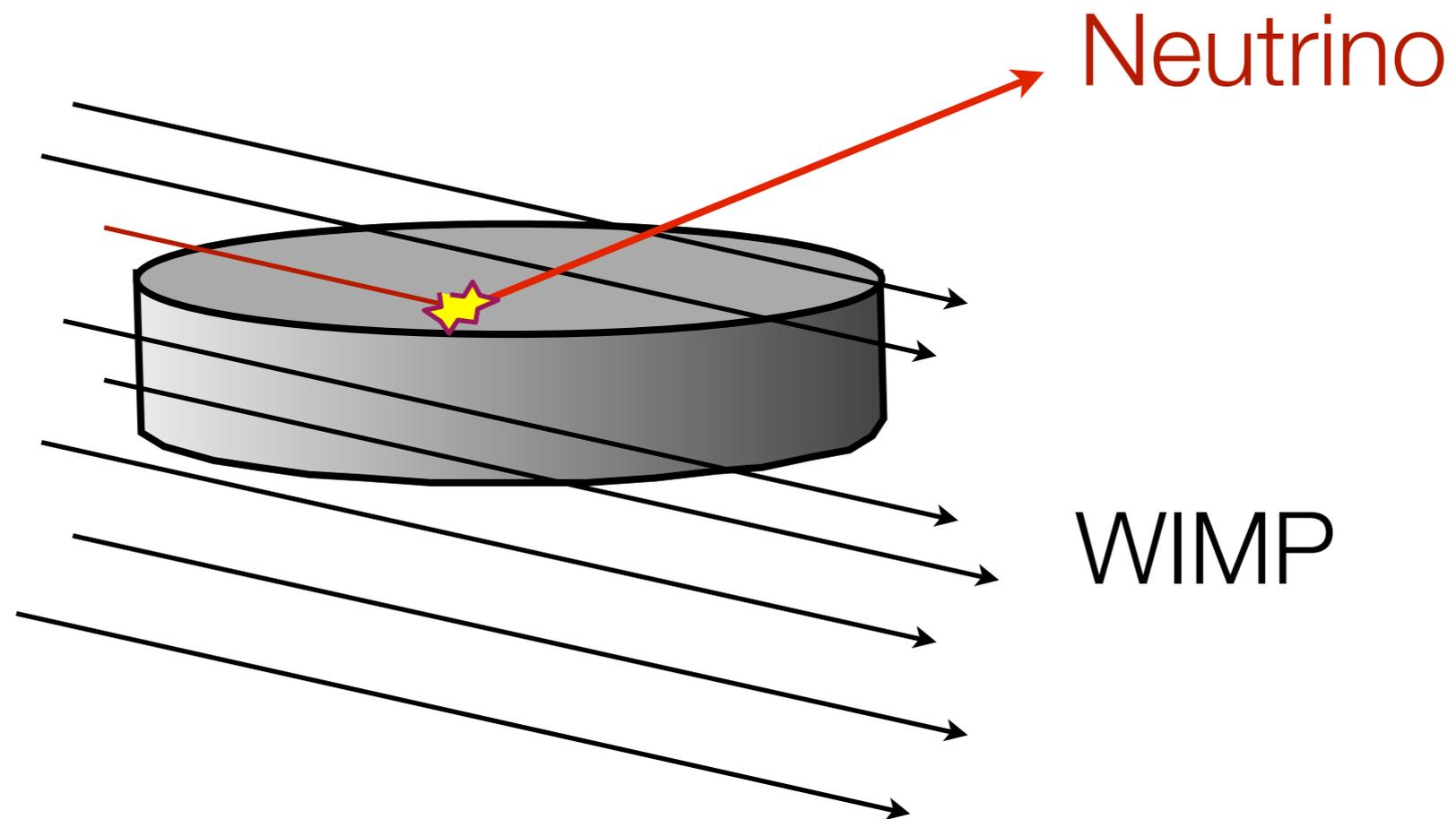
Julien Billard

Institut de Physique Nucléaire de Lyon
Massachusetts Institute of Technology

Moriond Electro-Weak
March 16th, 2015



Introduction to the neutrino background

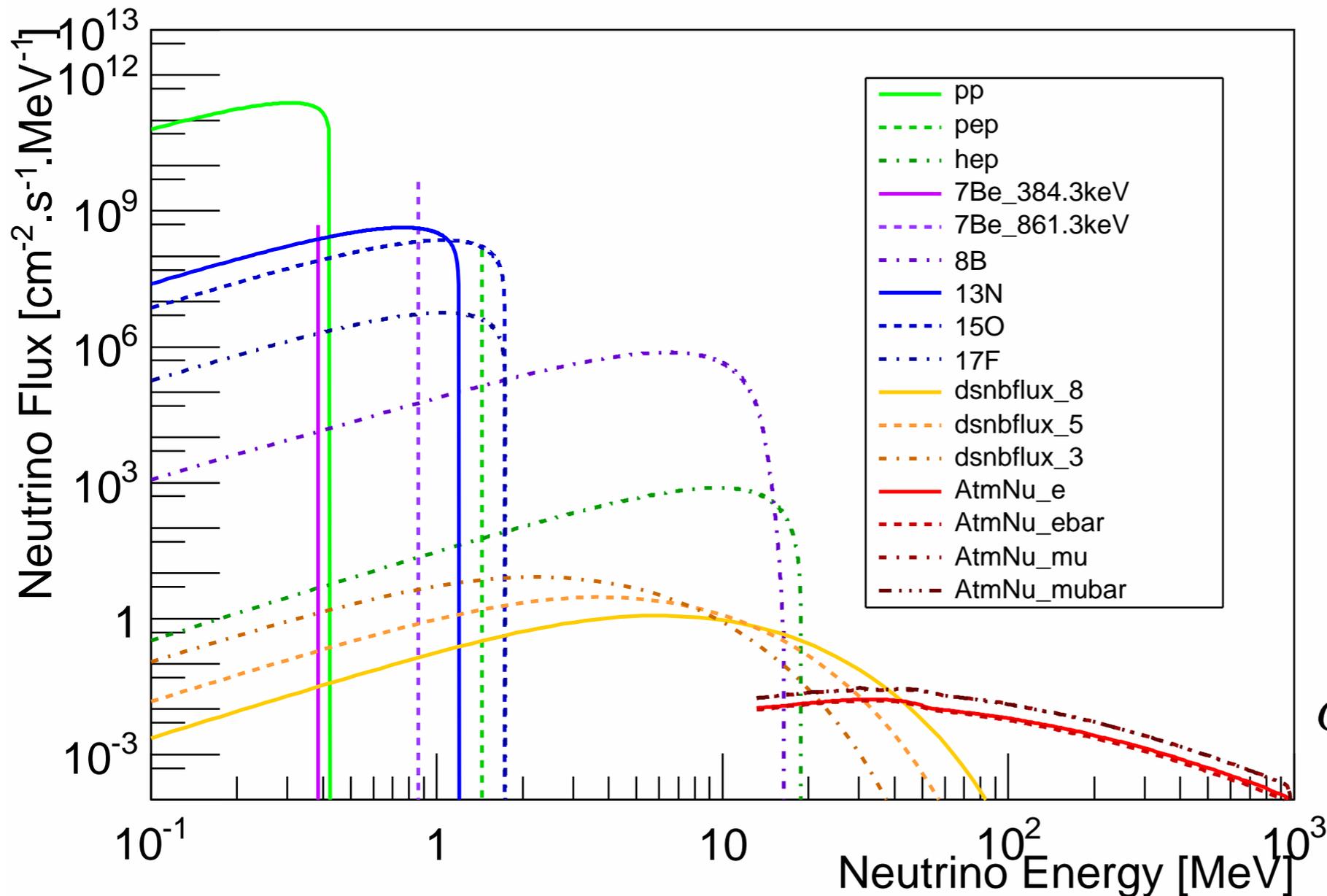


- Based on:
- J. Billard, L. Strigari and E. Figueroa-Feliciano, PRD 89 (2014)
 - F. Ruppin, J. Billard, L. Strigari and E. Figueroa-Feliciano, PRD 90 (2014)
 - C. O'Hare, J. Billard, E. Figueroa-Feliciano, A. Green and L. Strigari (*in preparation*)

Introduction to the neutrino background

The neutrino flux at an Earth based detector:

ν type	E_{ν}^{\max} (MeV)	E_{Geo}^{\max} (keV)	ν flux ($\text{cm}^{-2} \cdot \text{s}^{-1}$)
pp	0.42341	5.30×10^{-3}	$5.99 \pm 0.06 \times 10^{10}$
${}^7\text{Be}$	0.861	0.0219	$4.84 \pm 0.48 \times 10^9$
pep	1.440	0.0613	$1.42 \pm 0.04 \times 10^8$
${}^{15}\text{O}$	1.732	0.0887	$2.33 \pm 0.72 \times 10^8$
${}^8\text{B}$	16.360	7.91	$5.69 \pm 0.91 \times 10^6$
hep	18.784	10.42	$7.93 \pm 1.27 \times 10^5$
DSNB	91.201	245	85.5 ± 42.7
Atm.	981.748	27.7×10^3	10.5 ± 2.1

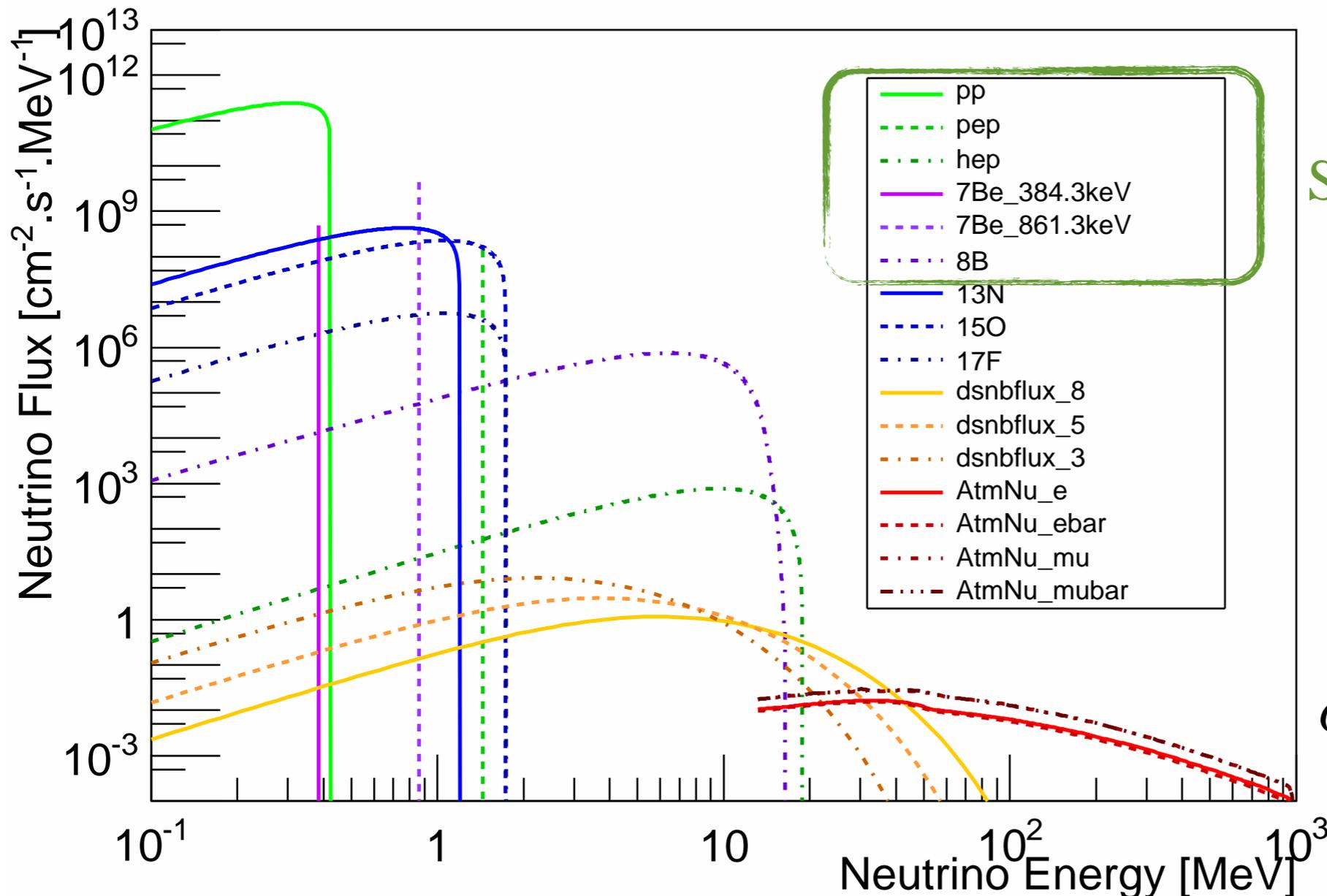


Geo neutrinos are negligible

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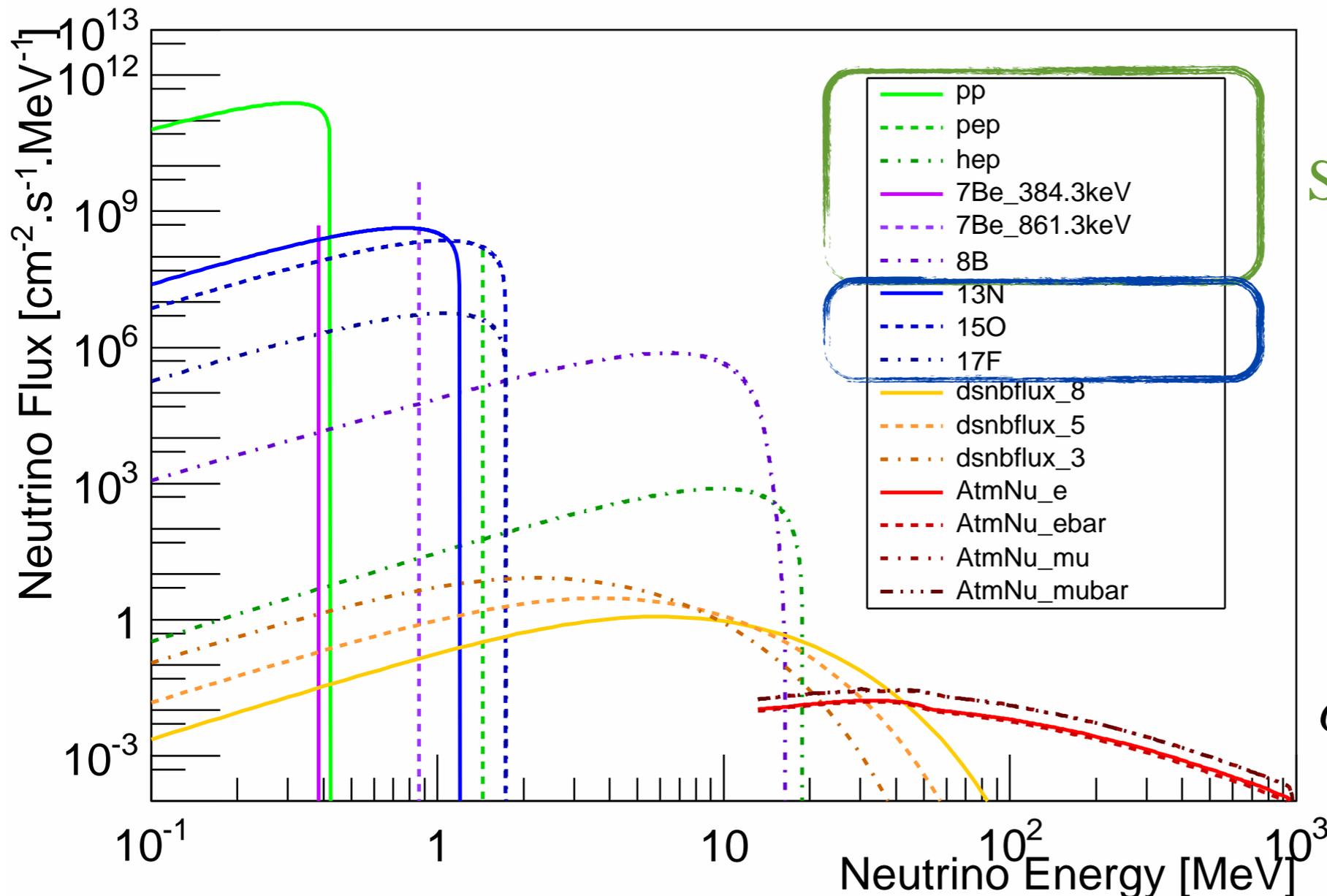
Solar neutrinos: pp-chain

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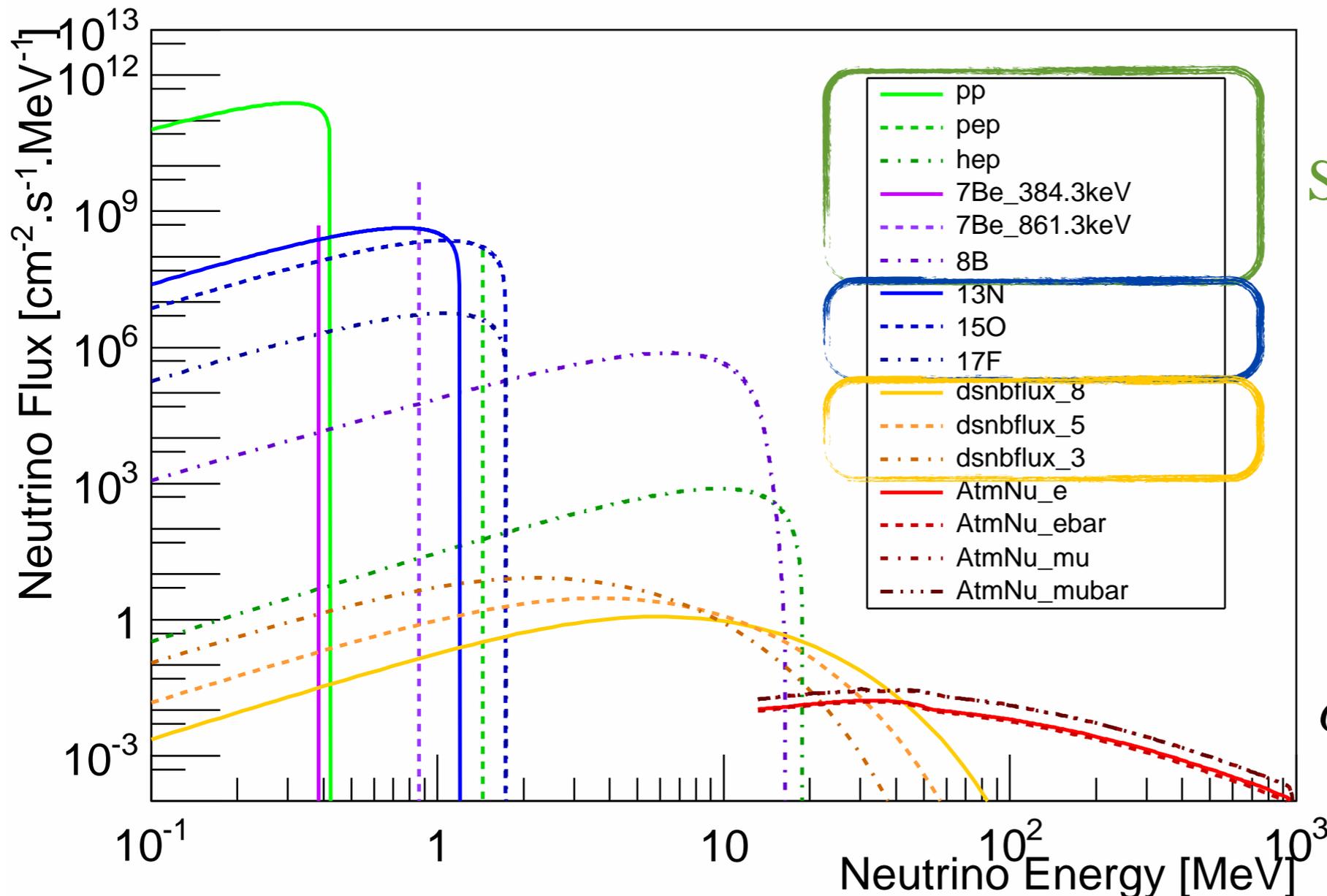
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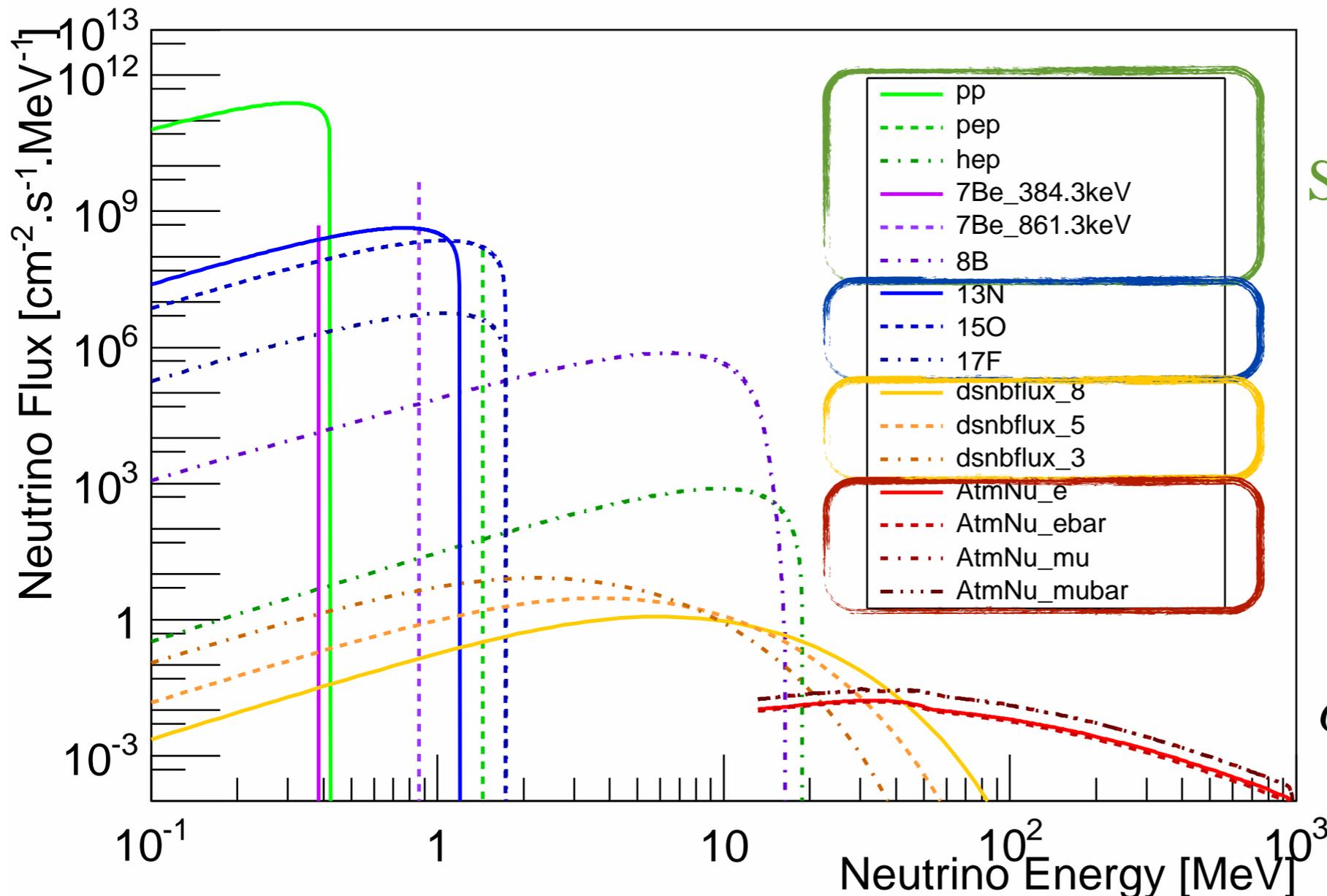
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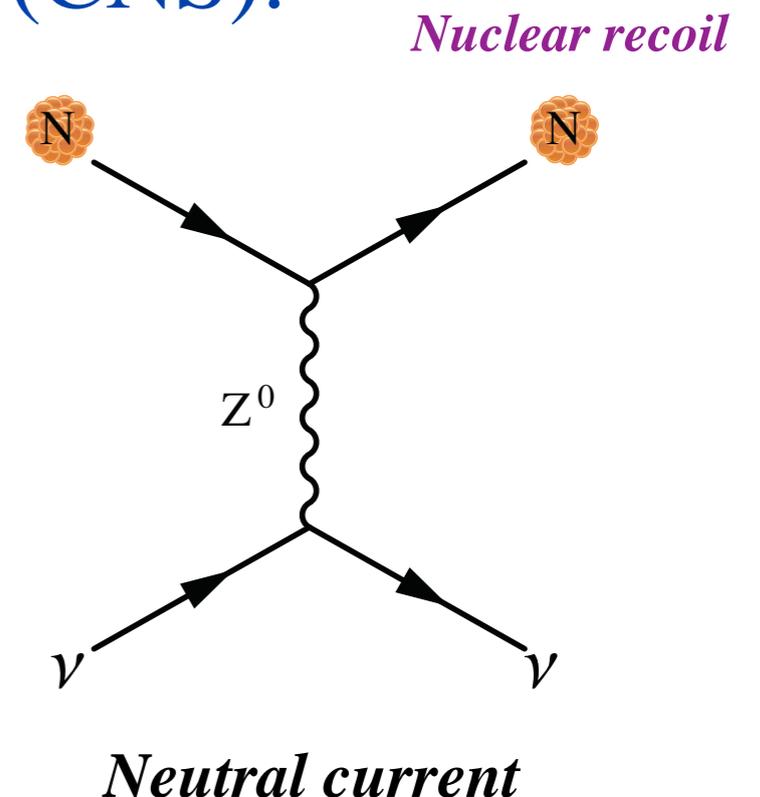
Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material

- Coherent neutrino-nucleus elastic 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 $\sim A$
- m_N : Atomic Mass



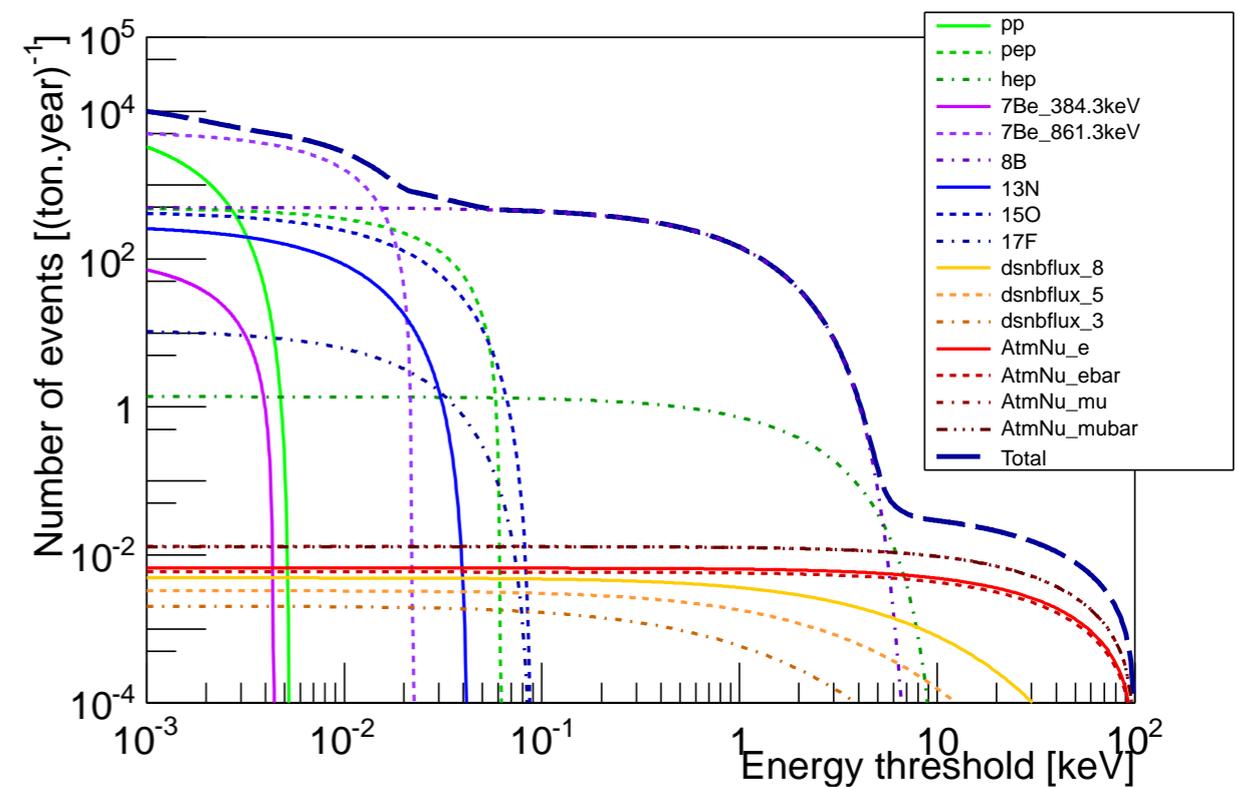
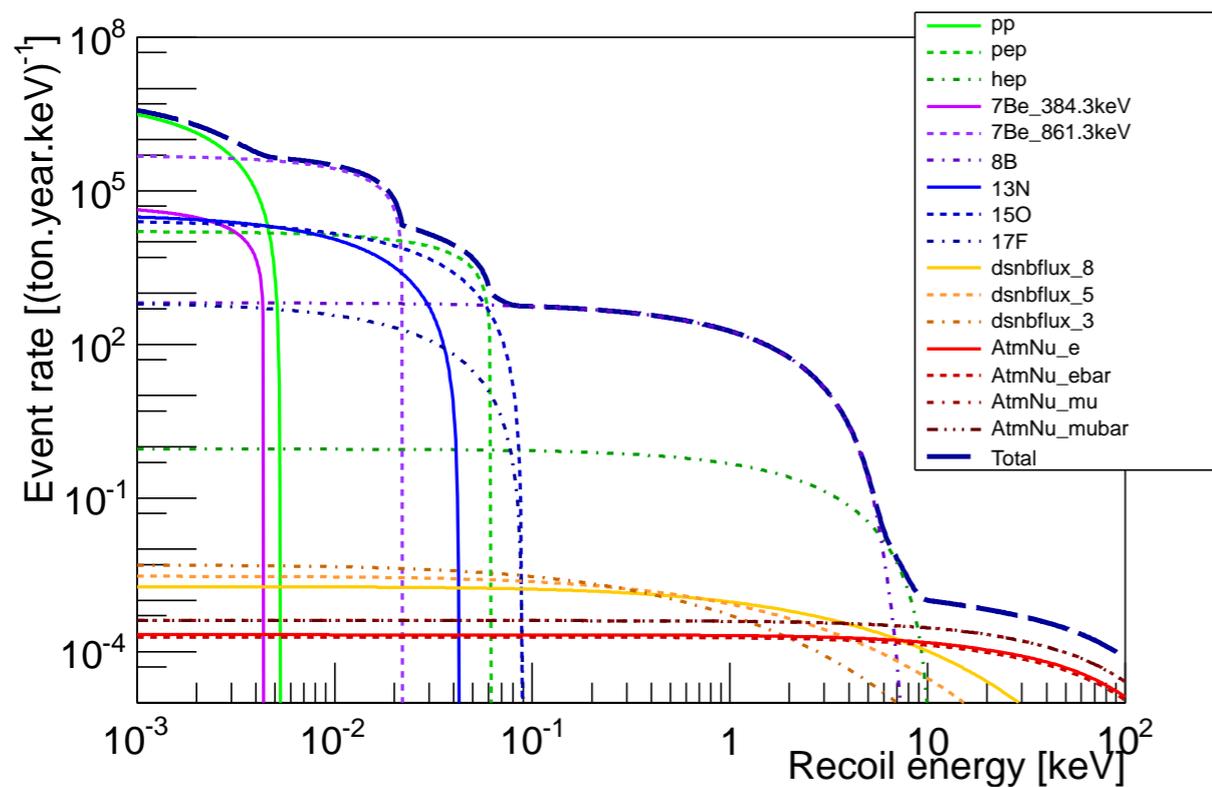
No flavor-specific terms!!!
Same rate for ν_e , ν_μ , and ν_τ

Ultimate background to direct detection

Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material

- Coherent neutrino-nucleus elastic scattering (CNS):

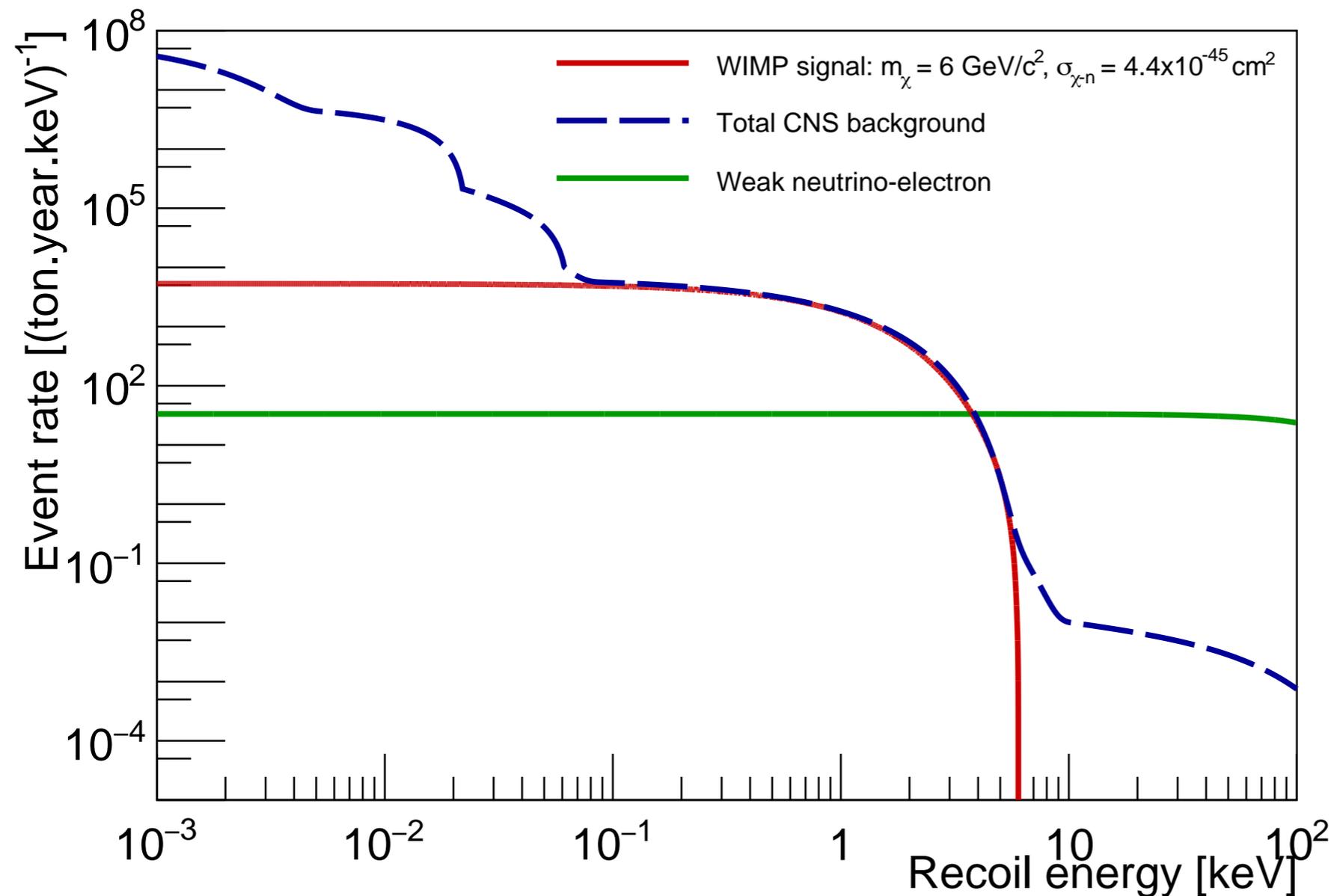


Depending on the Energy threshold, the CNS background can be very high!

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

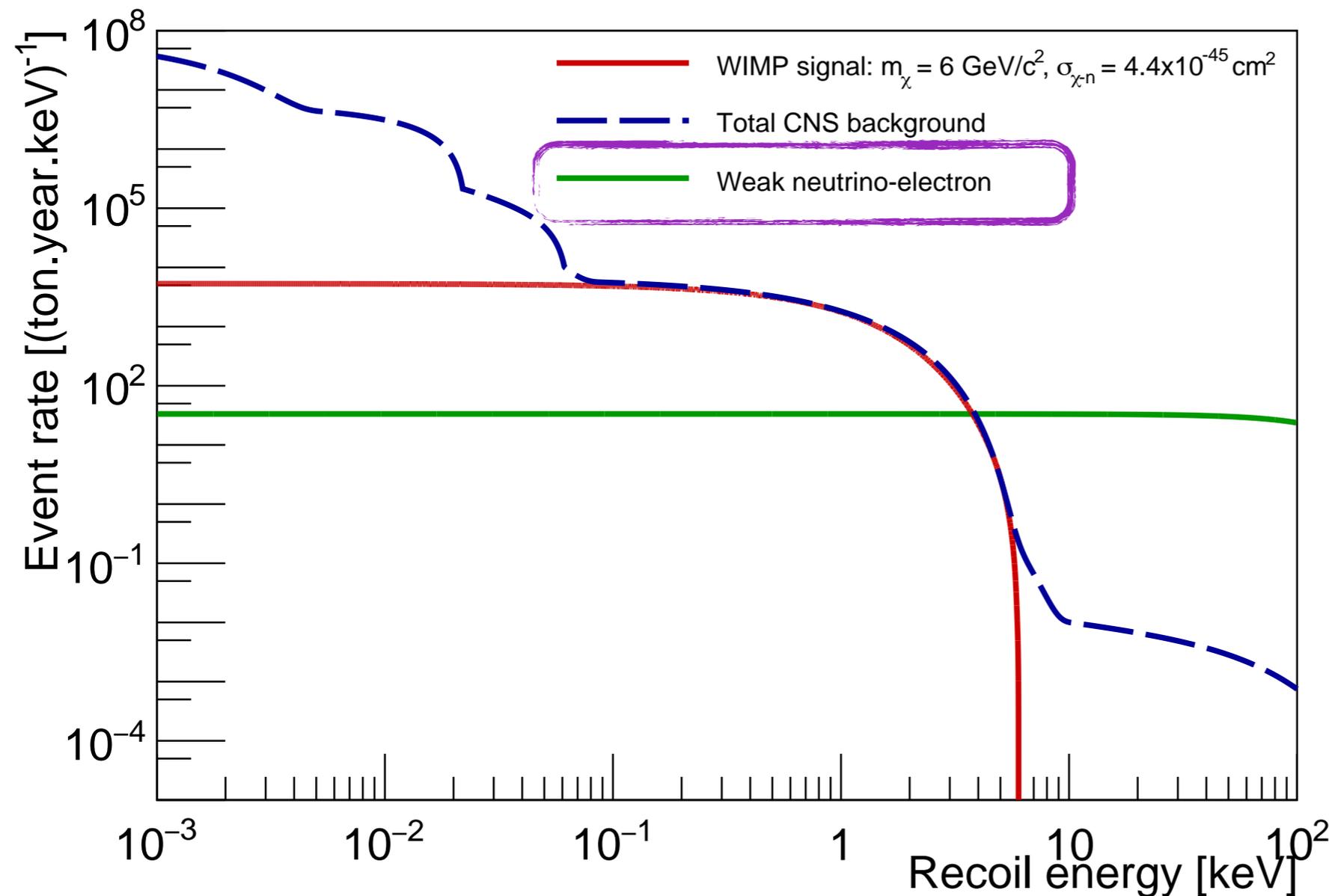
Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material



Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material

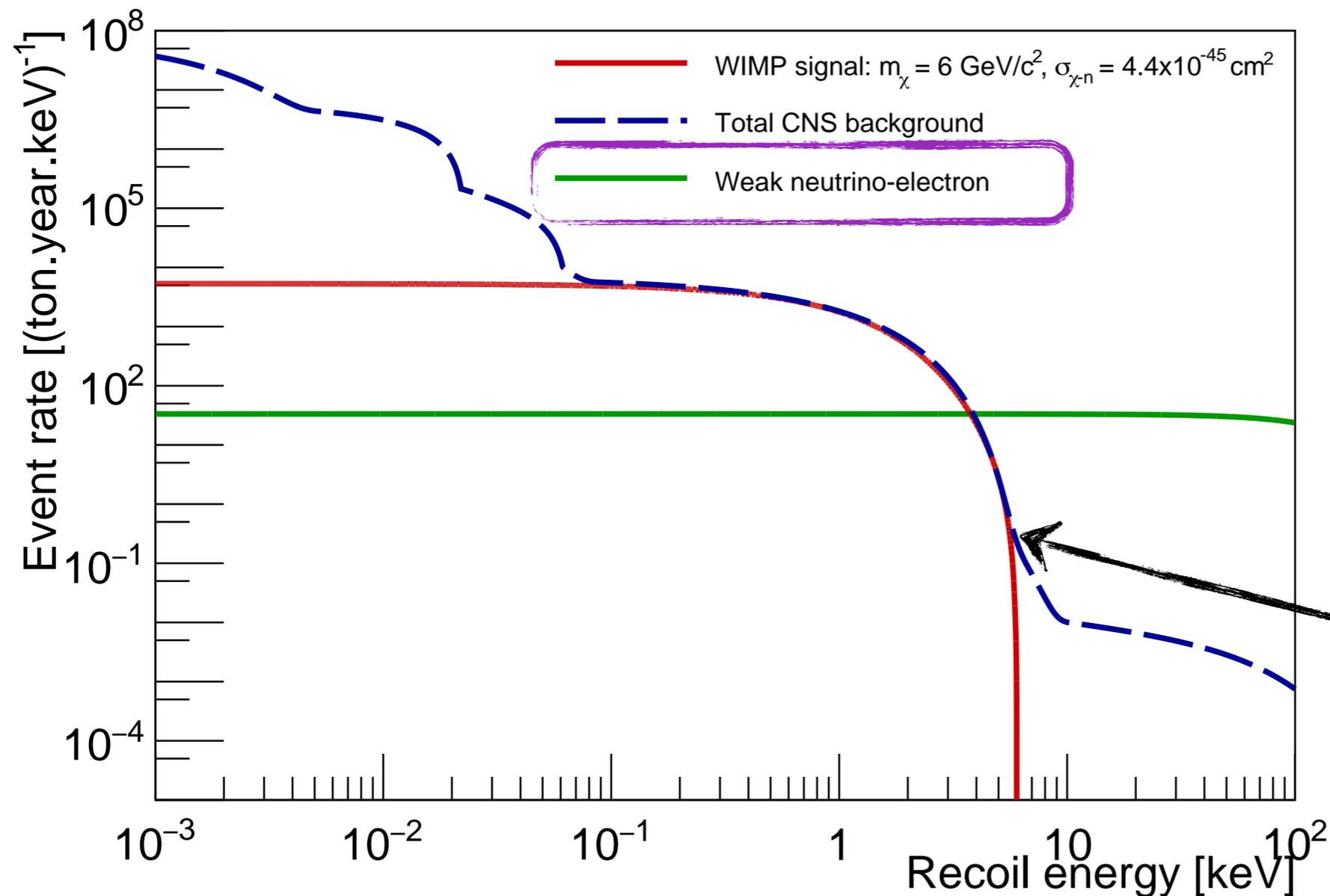


Neutrino-electron
background

negligible for Ge cryogenic detectors
BUT
problematic for Xe based detectors

Introduction to the neutrino background

Neutrino interactions with Dark Matter experiment target material



Neutrino-electron
background

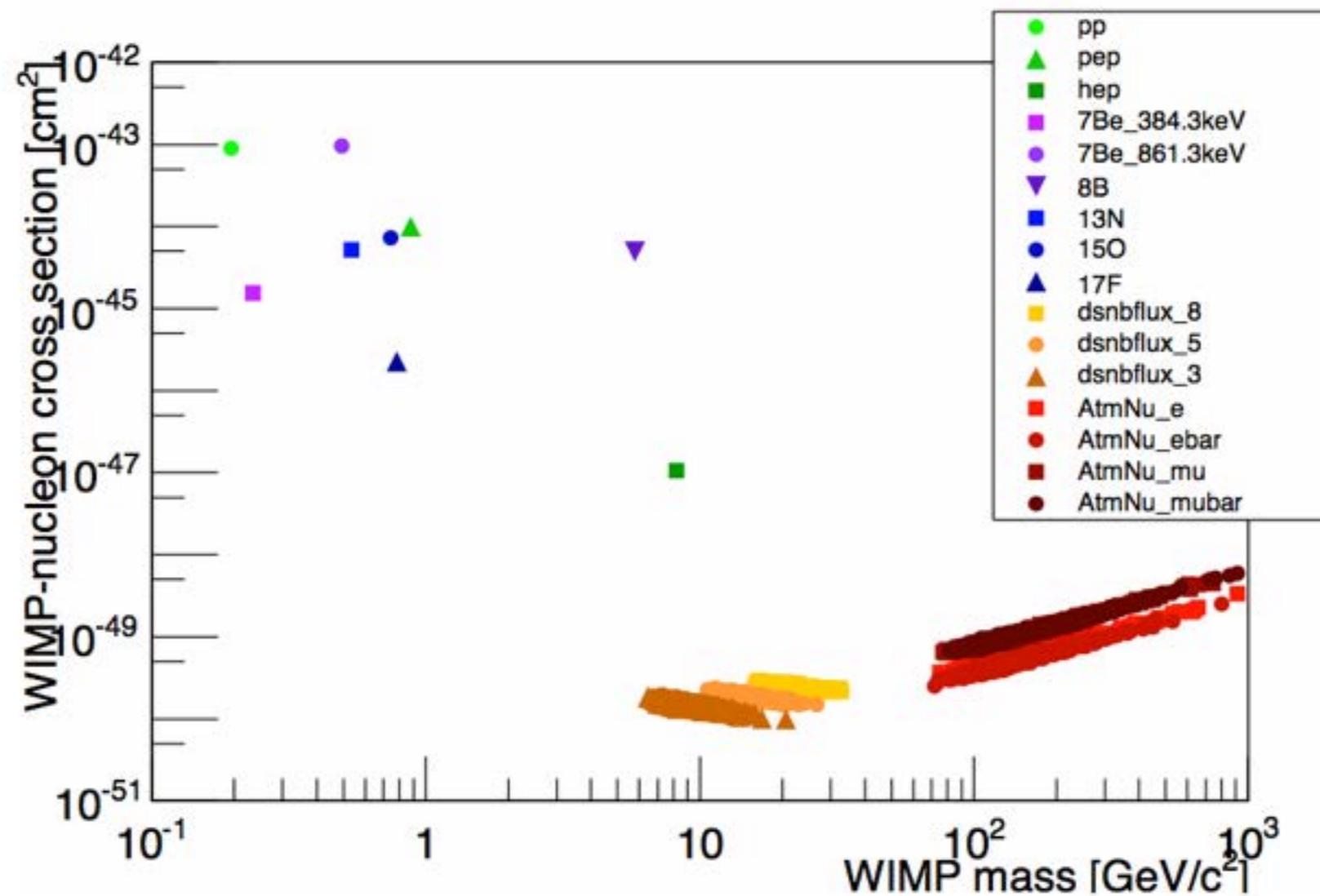
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WIMP or neutrino (^8B)??

Introduction to the neutrino background

WIMP and neutrino equivalence:

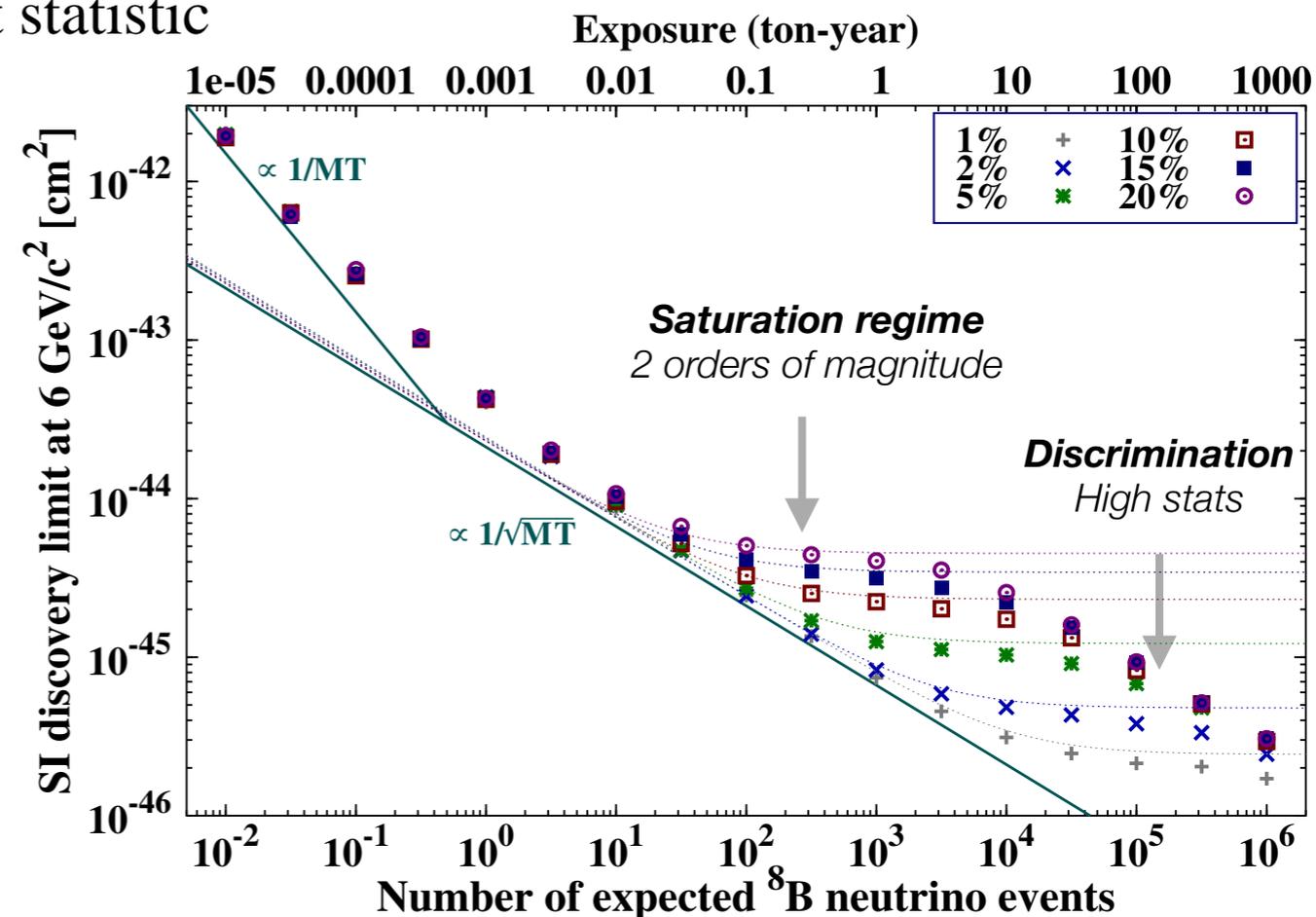
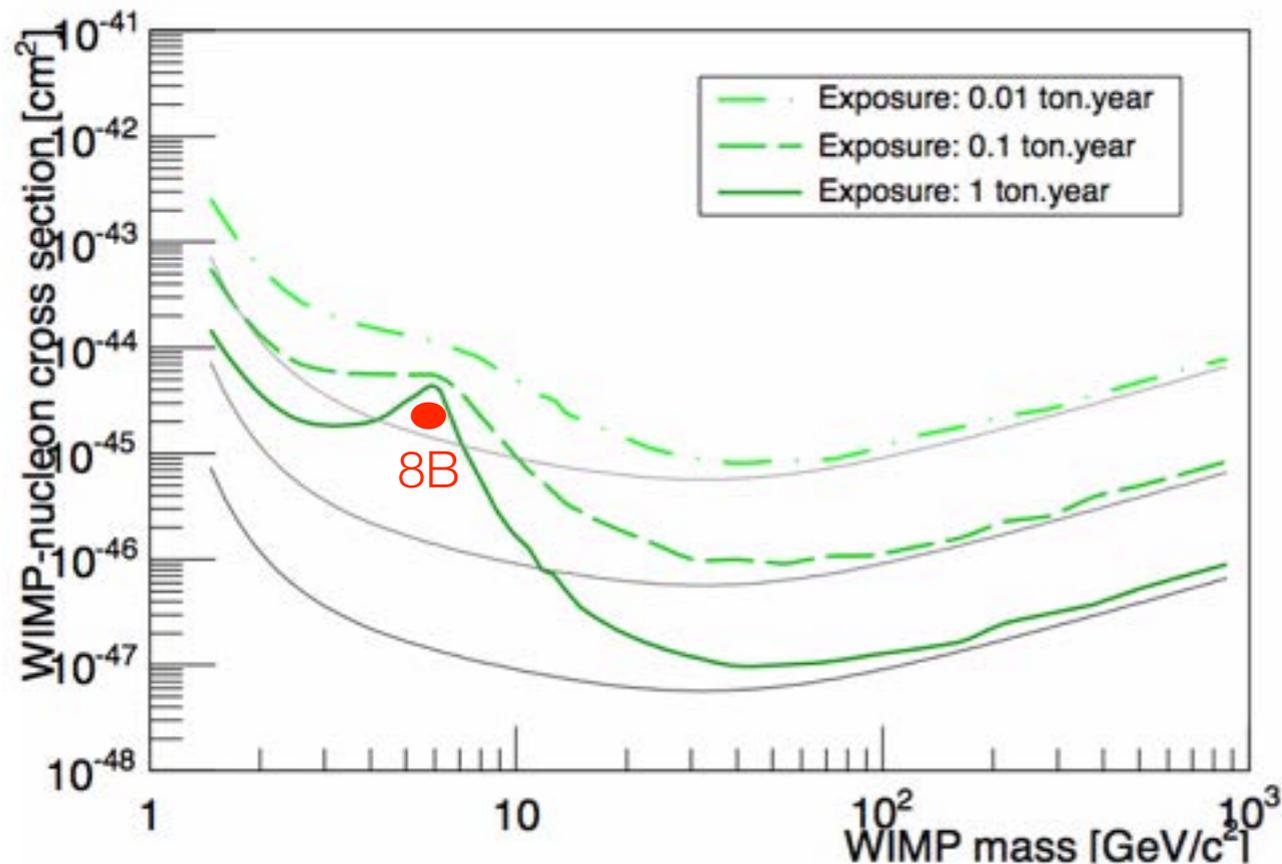
- ➔ Using a maximum likelihood analysis where we fit a WIMP hypothesis to the different neutrino components we can determine the *WIMP-neutrino equivalent models*



Impact on direct detection sensitivity

WIMP discovery potential:

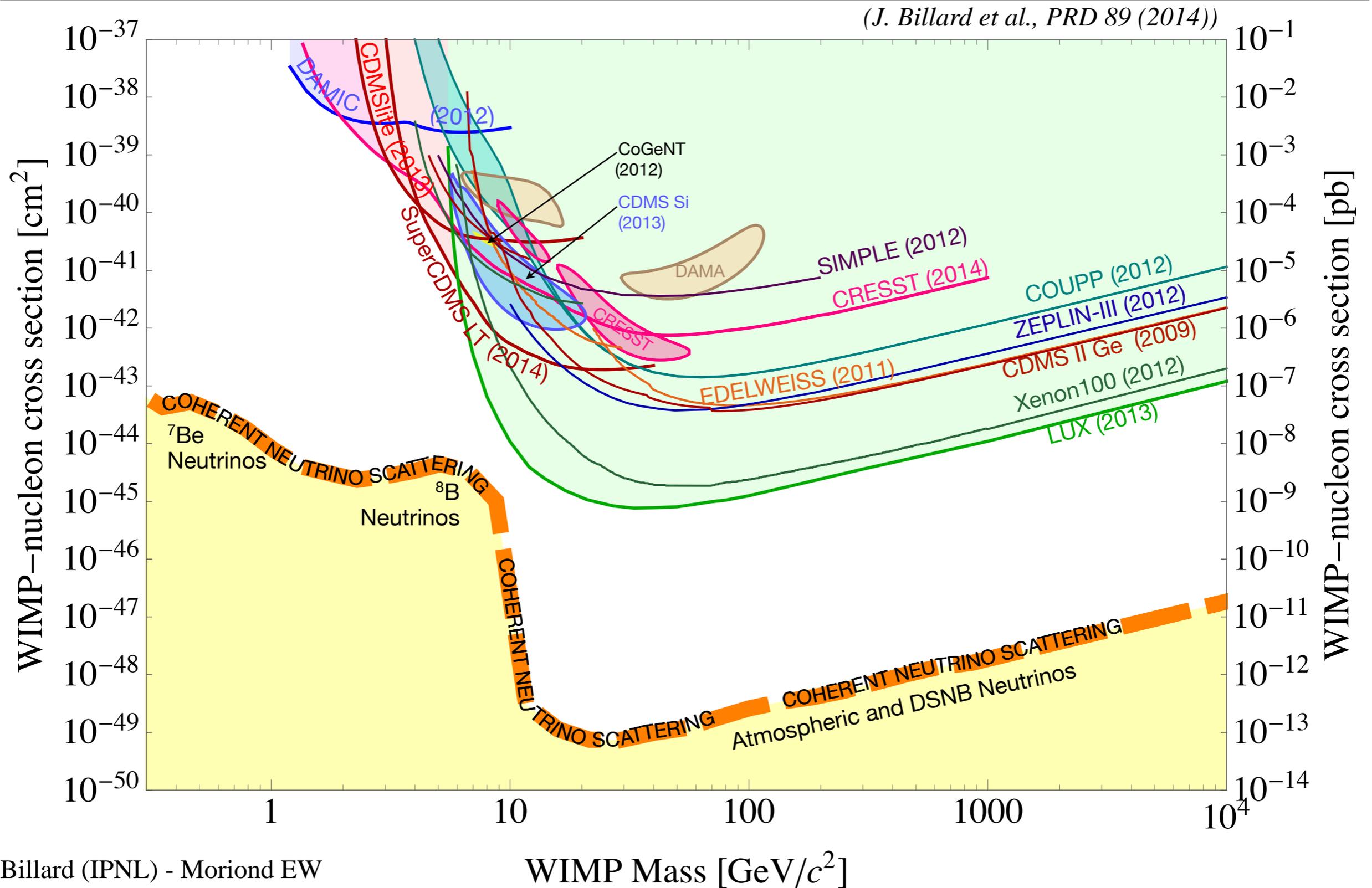
- 90% probability to get a 3 sigma or more WIMP discovery significance
- Computed using a profile likelihood ratio test statistic



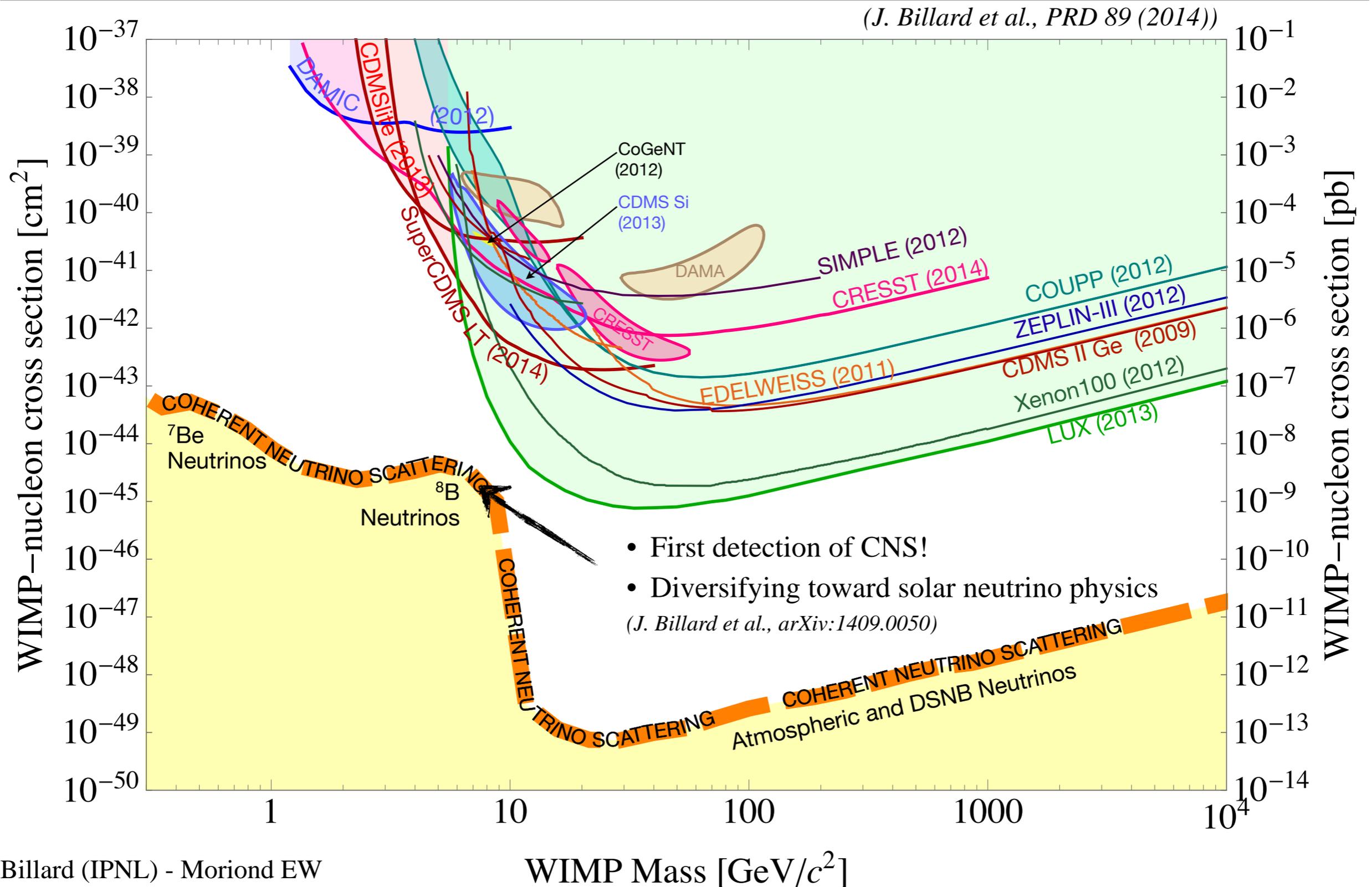
In the case of a **perfect spectral matching**, we expect the sensitivity to scale as:

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

Impact on direct detection sensitivity



Impact on direct detection sensitivity



Impact on direct detection sensitivity

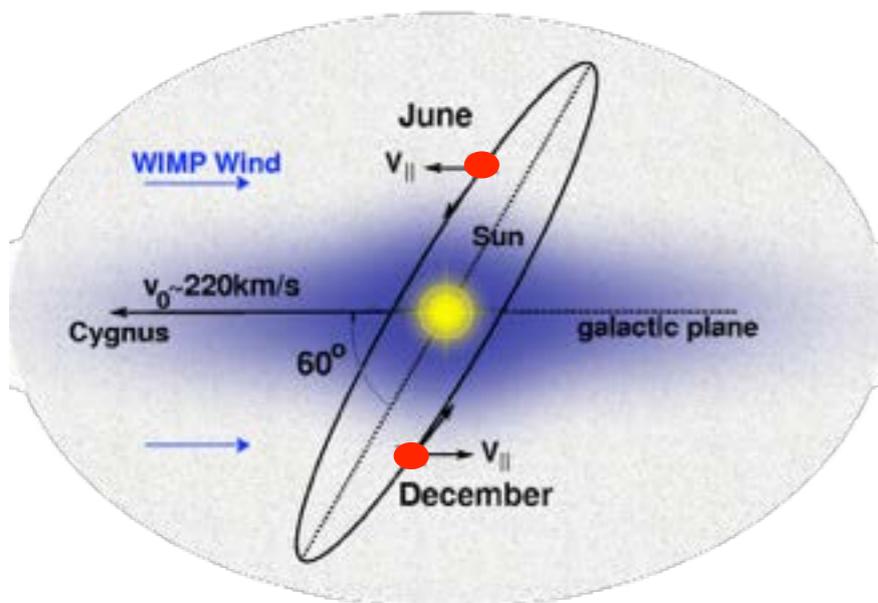
How to bypass this neutrino-induced saturation of the sensitivity?

1. **Reducing the systematic uncertainties on neutrino fluxes** $\sigma_{90\%} \propto \frac{\sqrt{N_\nu + \xi^2(N_\nu)^2}}{N_\nu} = \sqrt{\frac{1 + \xi^2 N_\nu}{N_\nu}},$
2. **Annual modulation** (first studied in J. H. Davis, JCAP 2015)
3. **Directional detection** (first studied in P. Grothaus et al., PRD 2014)
4. **Target complementarity:** combining data from several experiments, (F. Ruppin et al., PRD 2014)

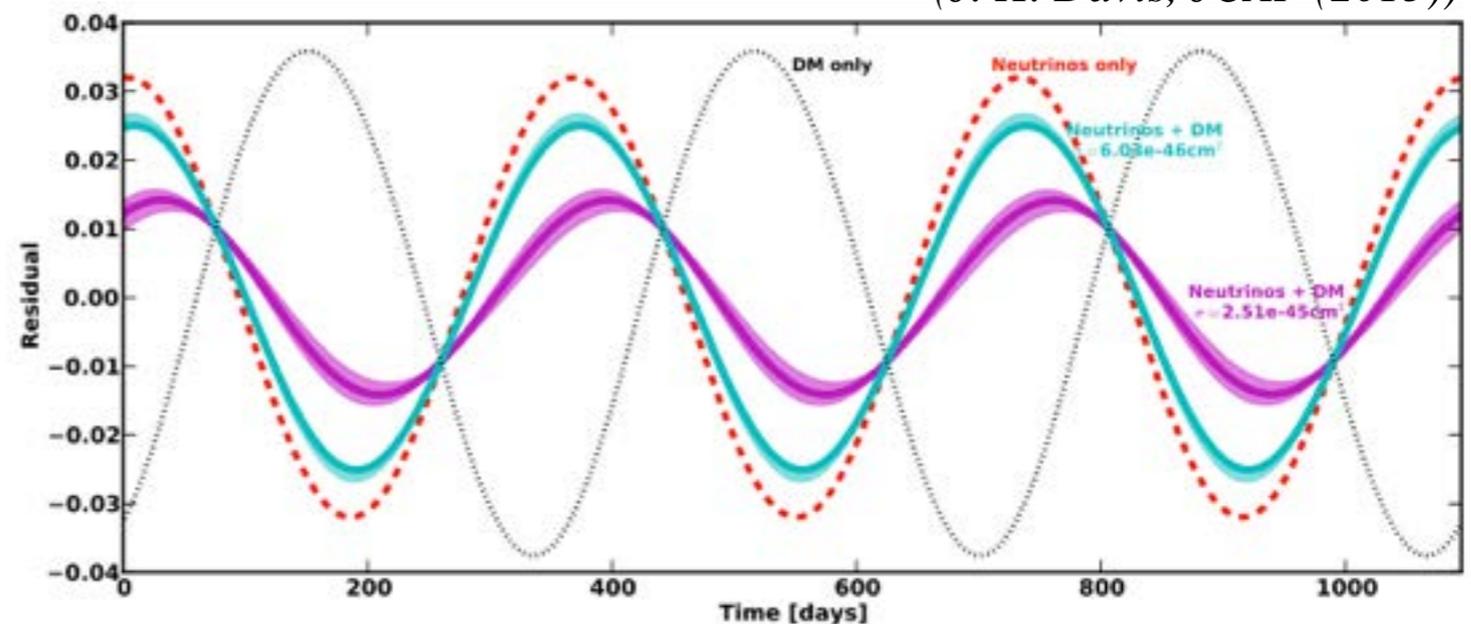
Going beyond the neutrino bound

Considering annual modulation

- WIMP event rate modulates thanks to the rotation of Earth around the Sun: **max. in June**
- Solar neutrino event rate modulates thanks to the eccentricity of the Earth's orbit: **max. in January**



(J. H. Davis, JCAP (2015))



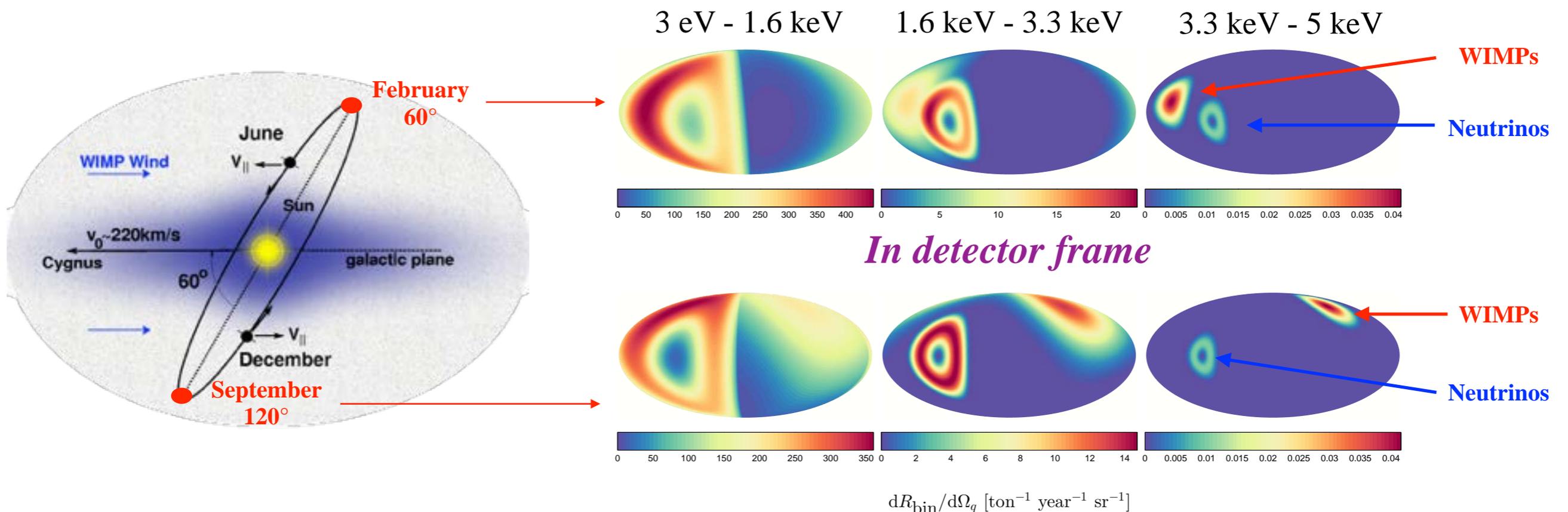
- WIMPs and solar neutrino have a modulation of about 3% which are shifted by about 180 days
- Still requires about a 1000 of neutrino events to help going beyond the neutrino bound...
- Additionally, modulation signals in direct dark matter searches have always been controversial

Going beyond the neutrino bound

Considering directional detection

- Thanks to the rotation of Solar System around Galactic Center, WIMPs are coming from **Cygnus**
- Solar neutrinos are coming from ... the **Sun**

(C. O'Hare et al., in preparation)

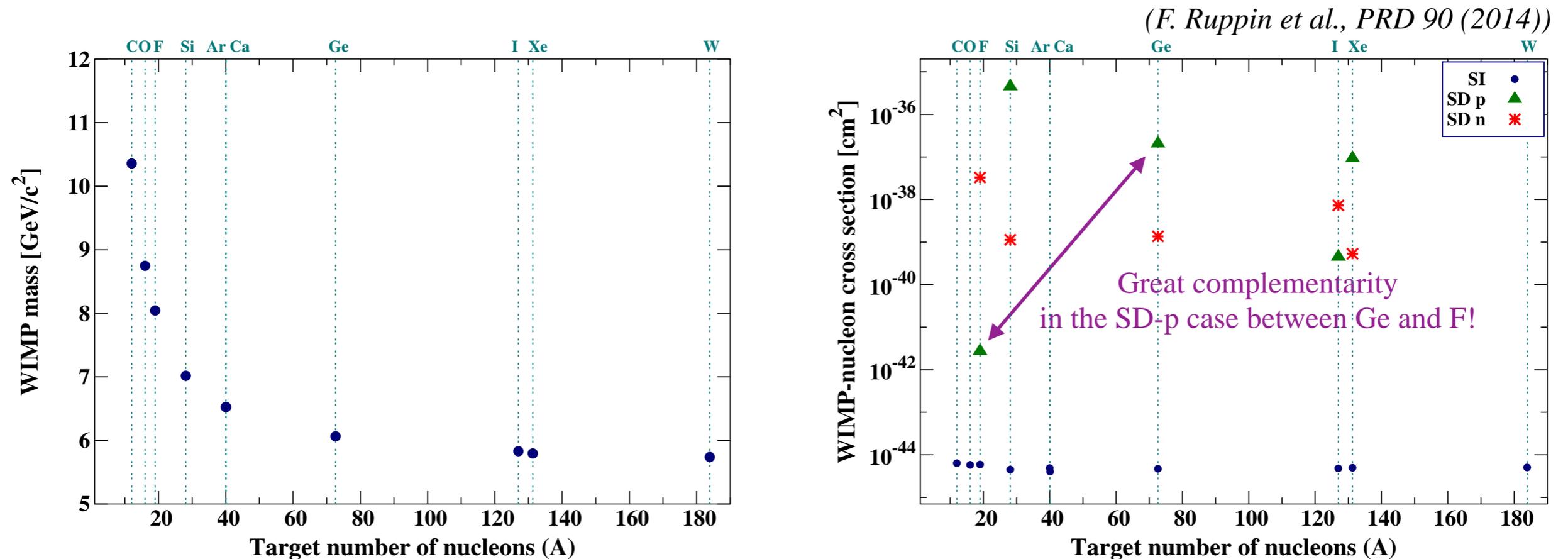


- Depending on angular resolution, the irreducible neutrino background could be largely subtracted
- But of course, we first need massive directional experiments... but this could be a great motivation!!

Going beyond the neutrino bound

Considering target complementarity from different experiments

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



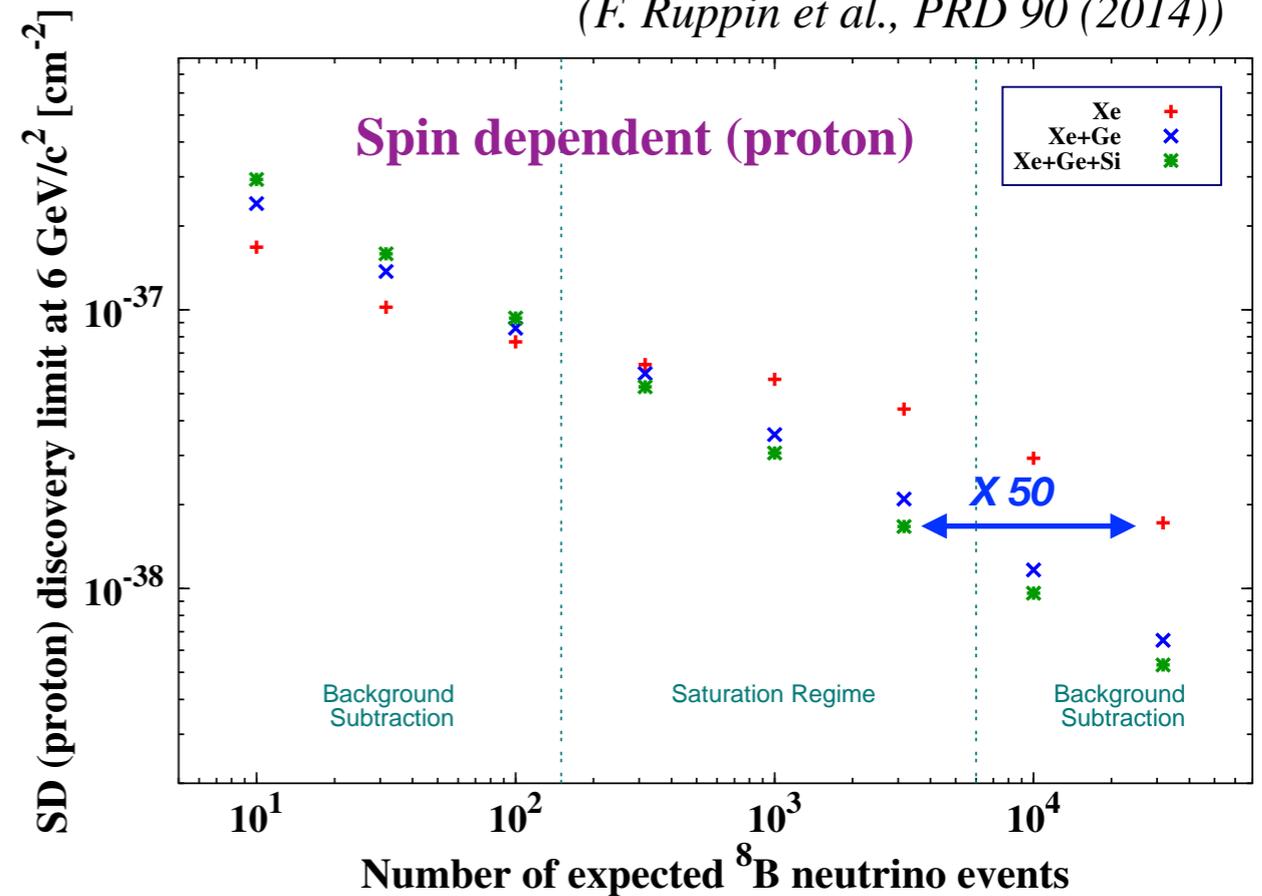
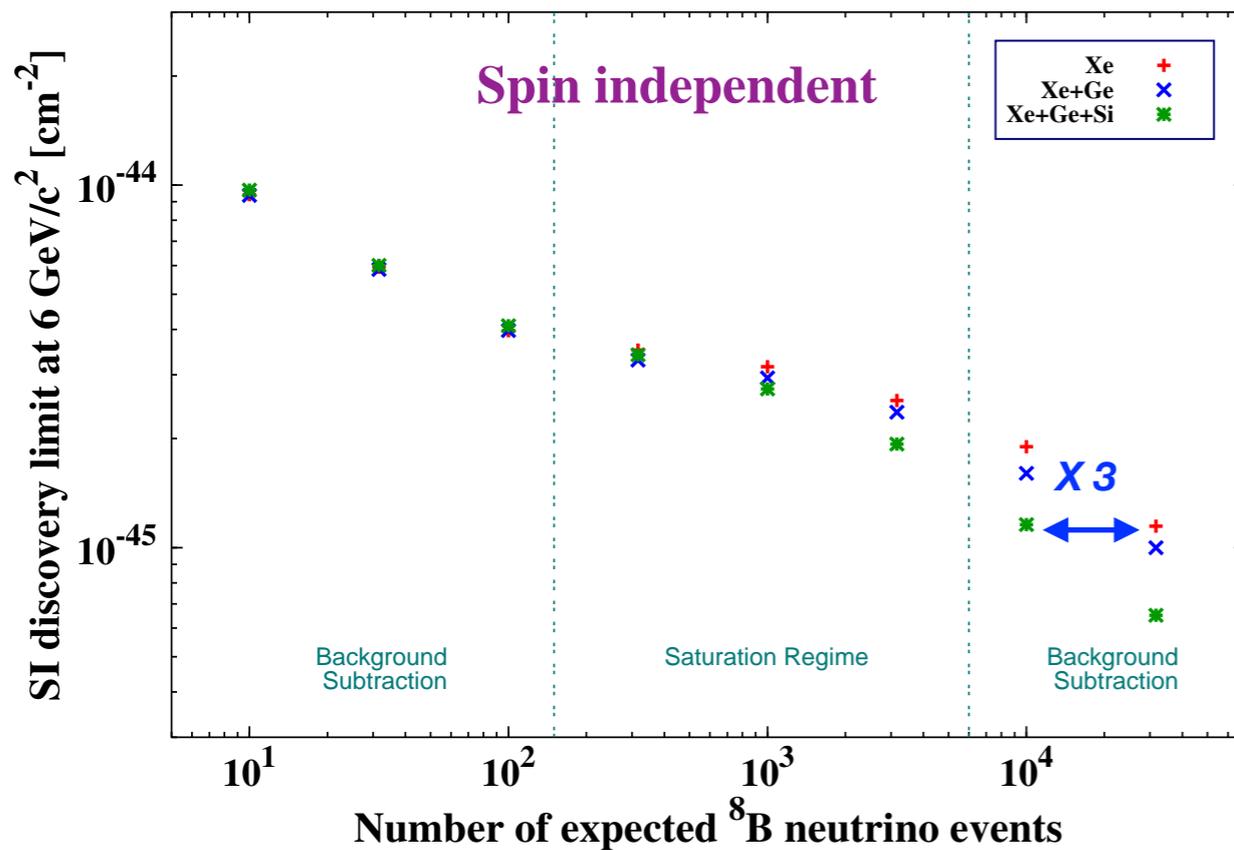
- Moderate differences in the WIMP mass and in the SI cross sections (SI and CNS are coherent)
- Huge differences in the SD case -> **WIMP hypothesis can't fit all experiments**

Going beyond the neutrino bound

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

(F. Ruppin et al., PRD 90 (2014))



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

Upcoming experiments should combine their data

Conclusions

Take away points:

- Solar, atmospheric and DSNB neutrinos are going to drastically affect the discovery potential of upcoming ton-scale dark matter experiments via CNS interaction
- 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 $f_p = f_n$, due to similarity in SI and CNS interactions
 - ***High gain in the SD case, depending on the considered target***
- The only hope for significant improvement in the SI case requires directional sensitivity