Dark matter detection vs. the neutrino background

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Based on arXiv:1505.08061

Lunch talk January 2016

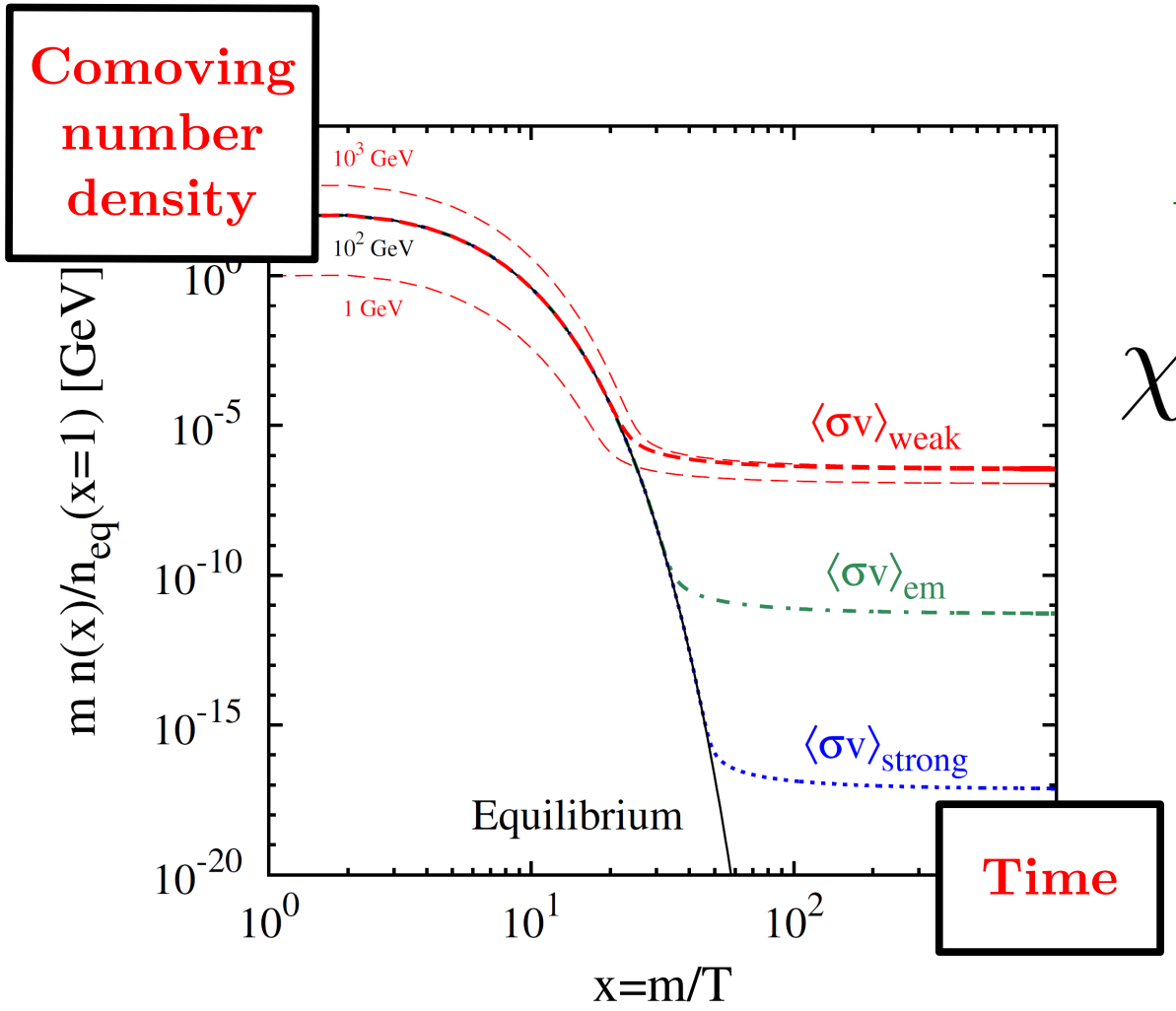
The University of Nottingham

Outline

- **Direct detection of dark matter**
    - WIMPs
    - Experiments
- **Neutrino backgrounds**
    - Solar
    - Supernovae
    - Atmospheric
- **Solving the neutrino floor problem**

Weakly interacting massive particles (WIMPs)

- Self-annihilating particles with weak scale interactions
- Predicted by extensions to standard model (supersymmetry)



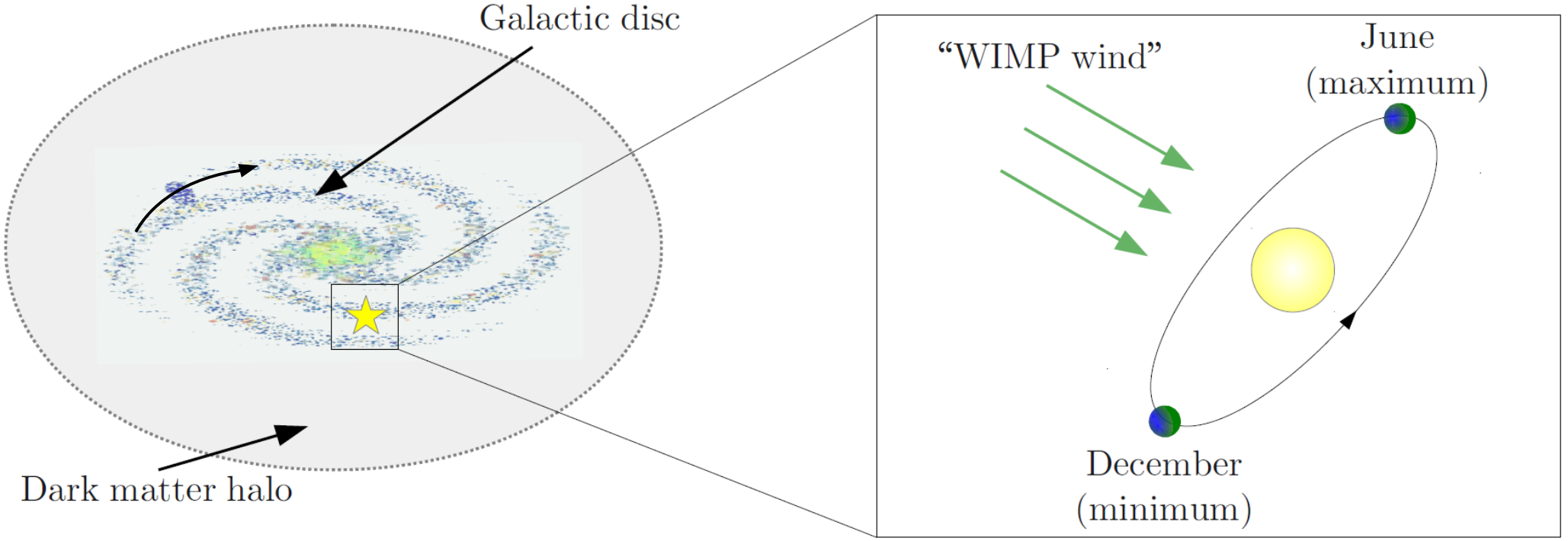
WIMPs **Standard model particles**

$$\chi + \chi \longleftrightarrow X + \bar{X}$$

$$\Omega_{\rm dm} h^2 \sim \langle \sigma v \rangle^{-1}$$

Direct detection

- Rotating Galactic disc embedded in non-rotating DM halo

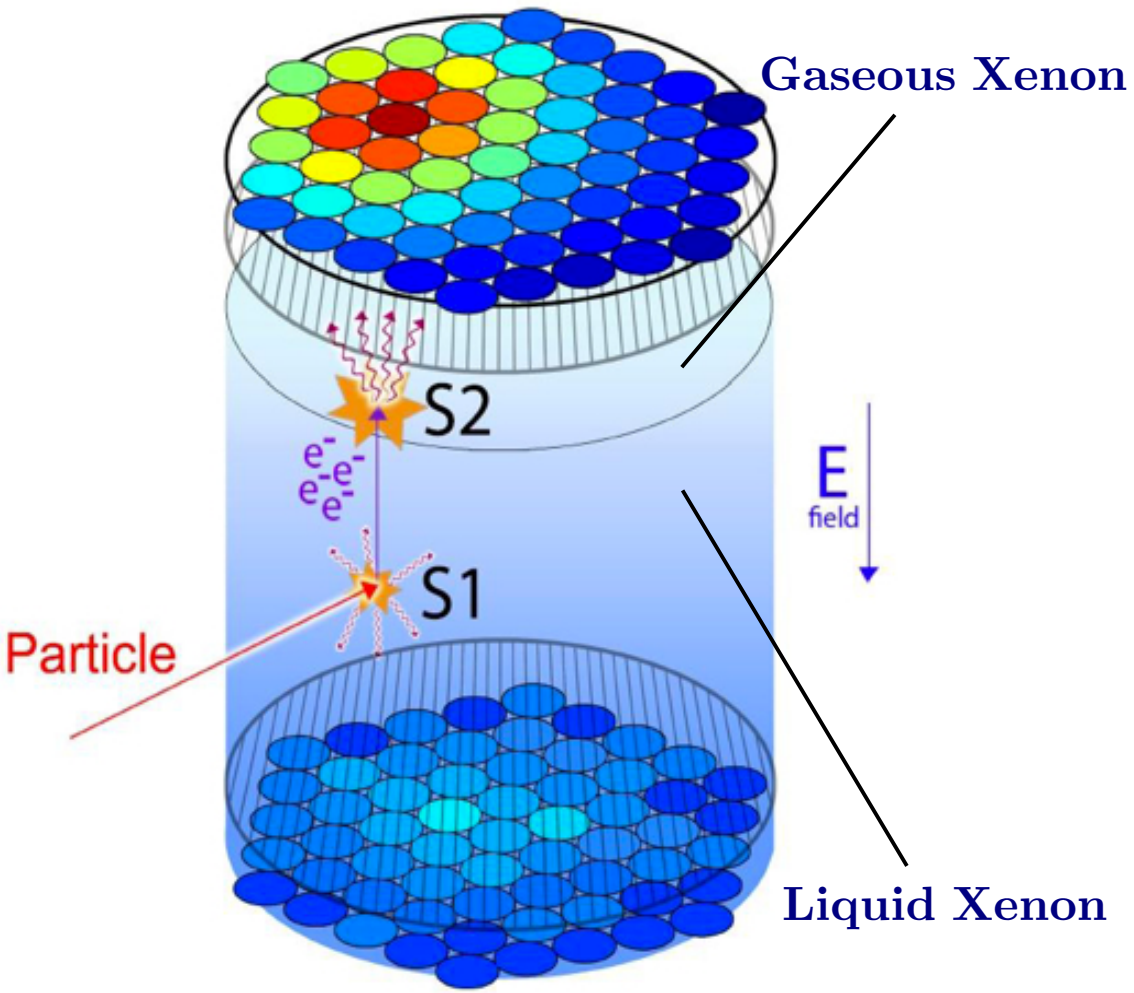


WIMP signal:

- $\sim$ keV interactions with nuclei
- incoming direction towards Cygnus
- annual modulation of event rate

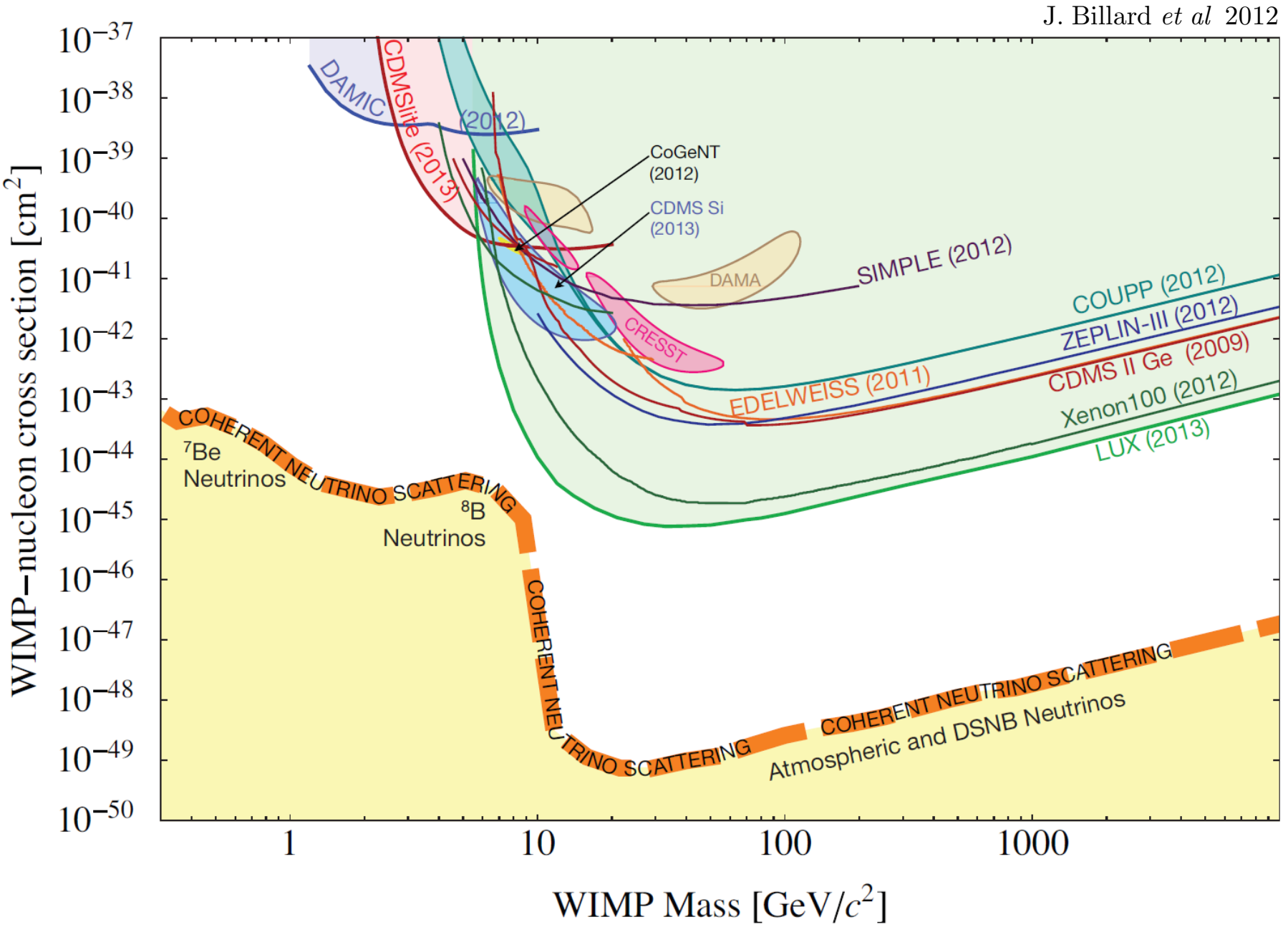
Dual-phase Xenon detector

- e.g. LUX experiment (Homestake mine, South Dakota)



LUX collaboration, 2013

Exclusion limits



Coherent neutrino-nucleus scattering (CNS)

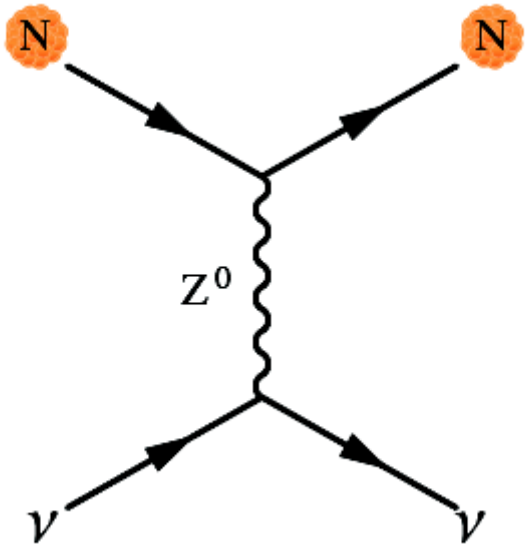
$$\frac{\mathrm{d}R}{\mathrm{d}E_r} = \int_{E_\nu^{\min}}^{\infty} \frac{\mathrm{d}\sigma}{\mathrm{d}E_r} \times \frac{\mathrm{d}\phi}{\mathrm{d}E_\nu} \mathrm{d}E_\nu$$

Differential event rate

Cross-section

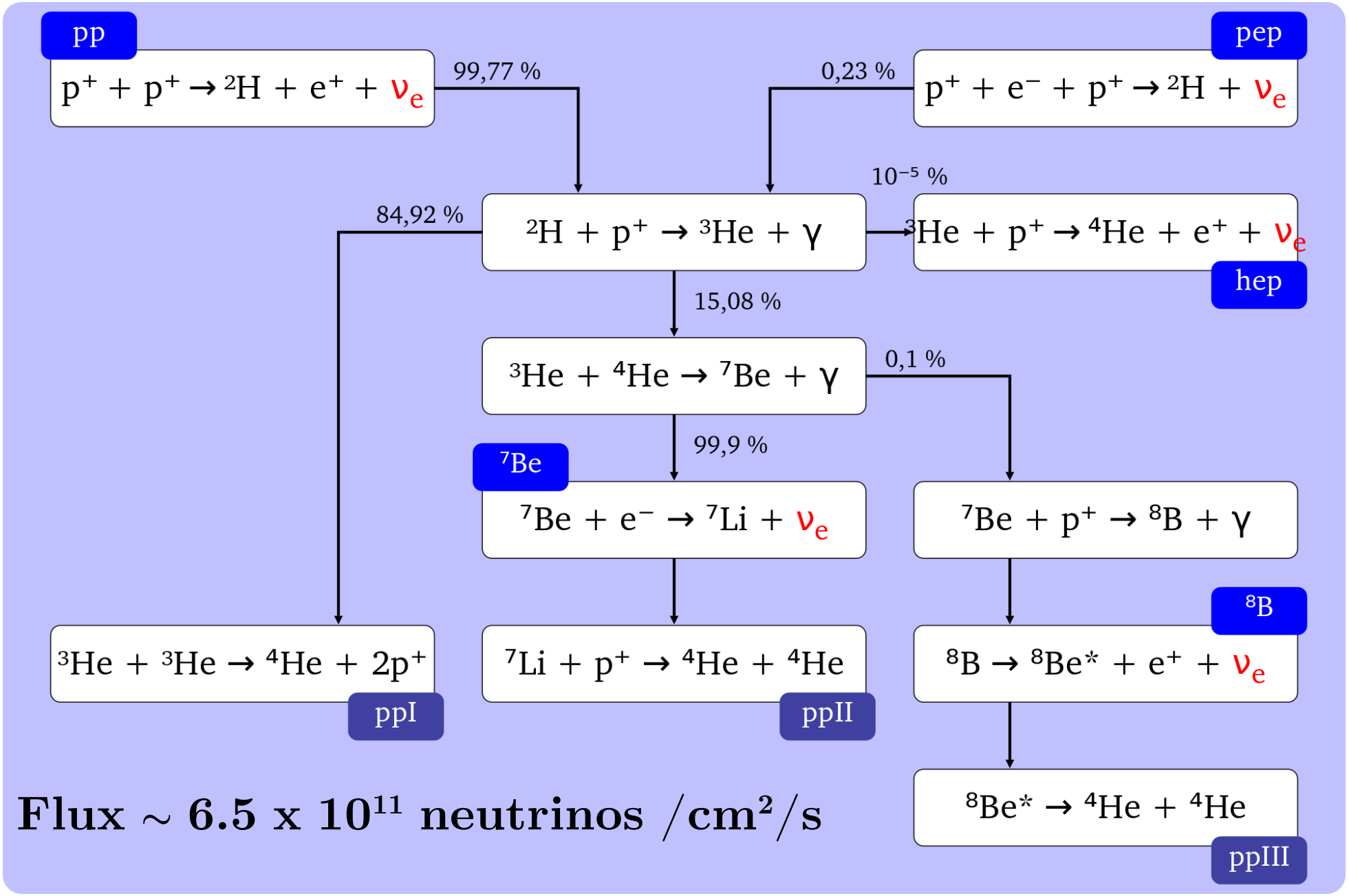
- Flavour-blind neutral current
- Well explained by standard model

Neutrino flux



CNS is still yet to be detected!

Solar neutrinos



Flux ~ 6.5 x 10^{11} neutrinos /cm²/s

Diffuse supernova neutrino background

$$\frac{\mathrm{d}\phi}{\mathrm{d}E_\nu} = \int_0^\infty [(1+z)\psi(E_\nu(1+z))][R_{\mathrm{SN}}(z)]\left[c\left|\frac{dt}{dz}\right|dz\right]$$

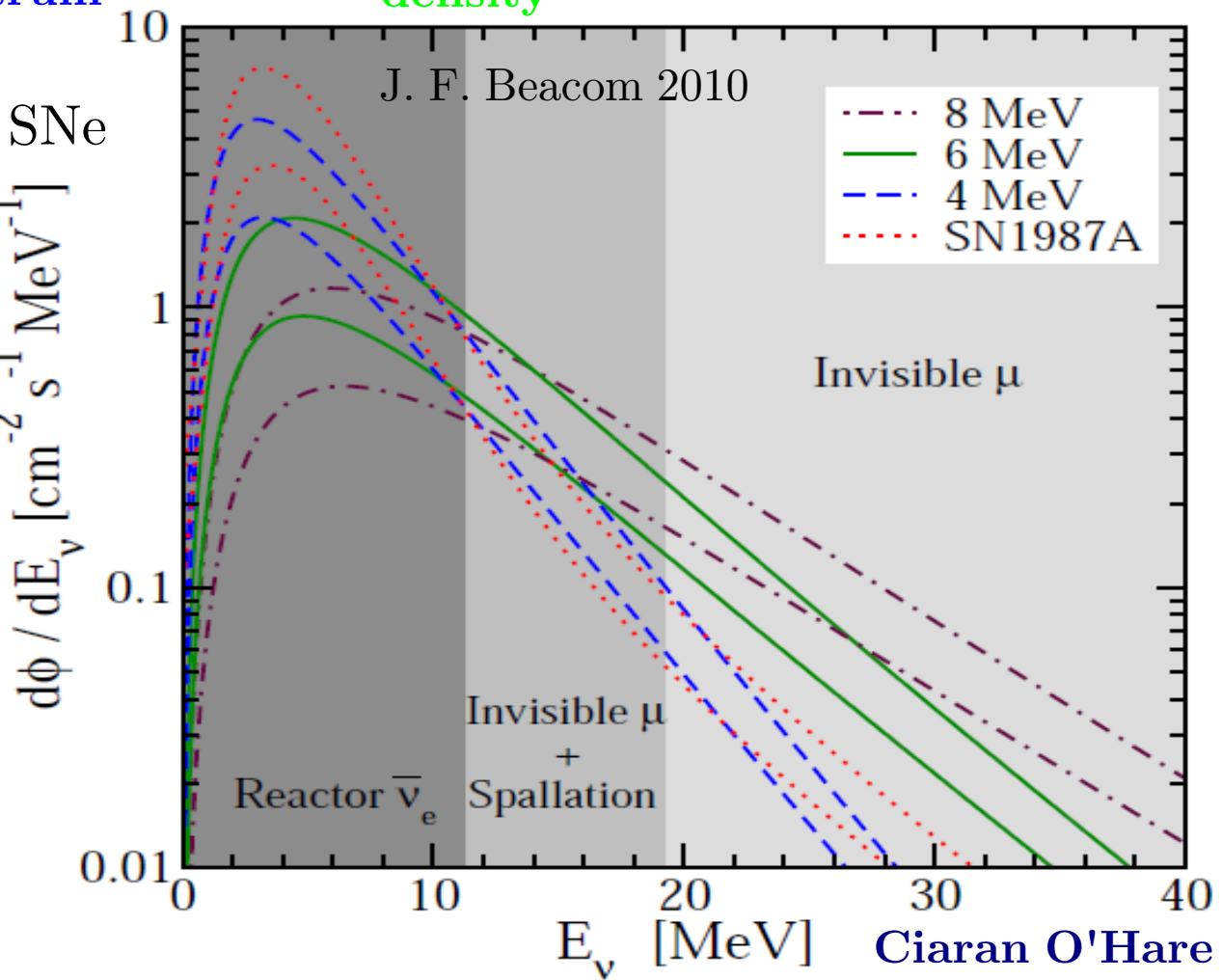
Diffuse supernova neutrino flux

Supernova emission spectrum

Supernova rate density

Line of sight integral

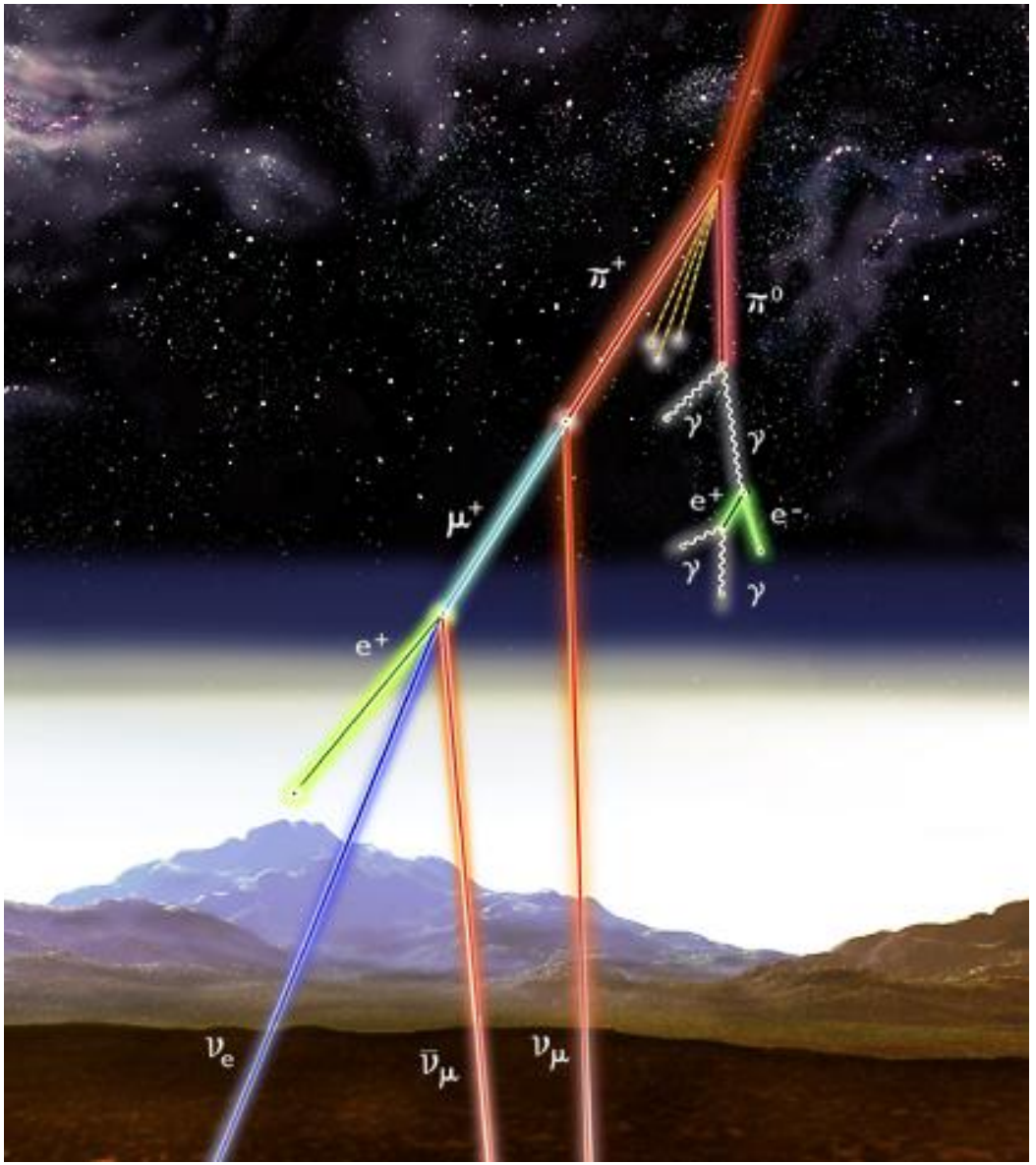
- Cumulative emission from all SNe over history of the Universe
- **Flux ~ 86 /cm²/s**
- Around 20% uncertainty on flux



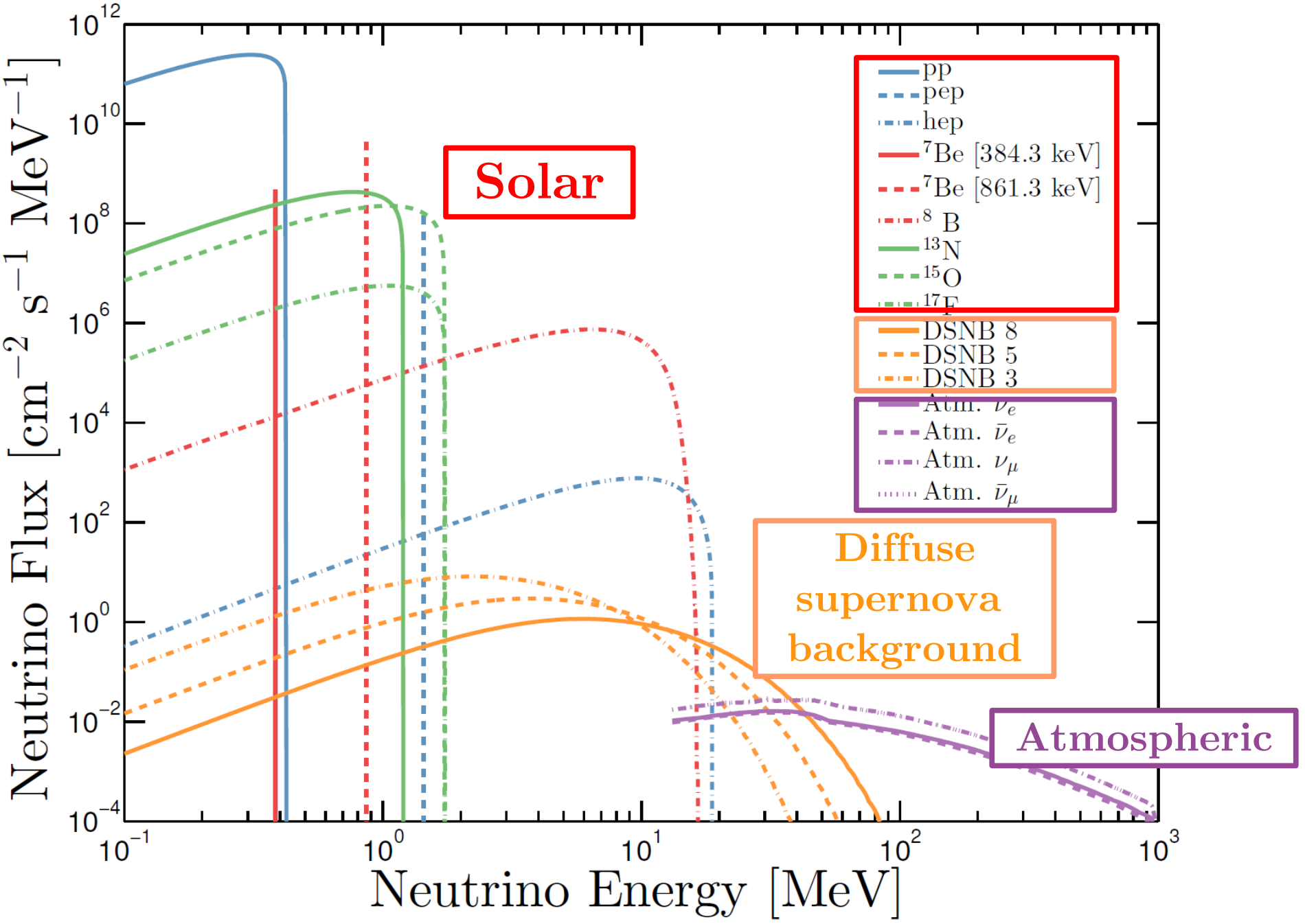
Atmospheric neutrinos

- Cosmic ray collisions in upper atmosphere produce neutrinos via pion decays
- Already detected by experiments such as IceCube, SNO and Super-Kamiokande
- **Flux $\sim$ 11 /cm^2/s**
- 50% uncertainty at direct detection energies

Super-Kamiokande, 2010

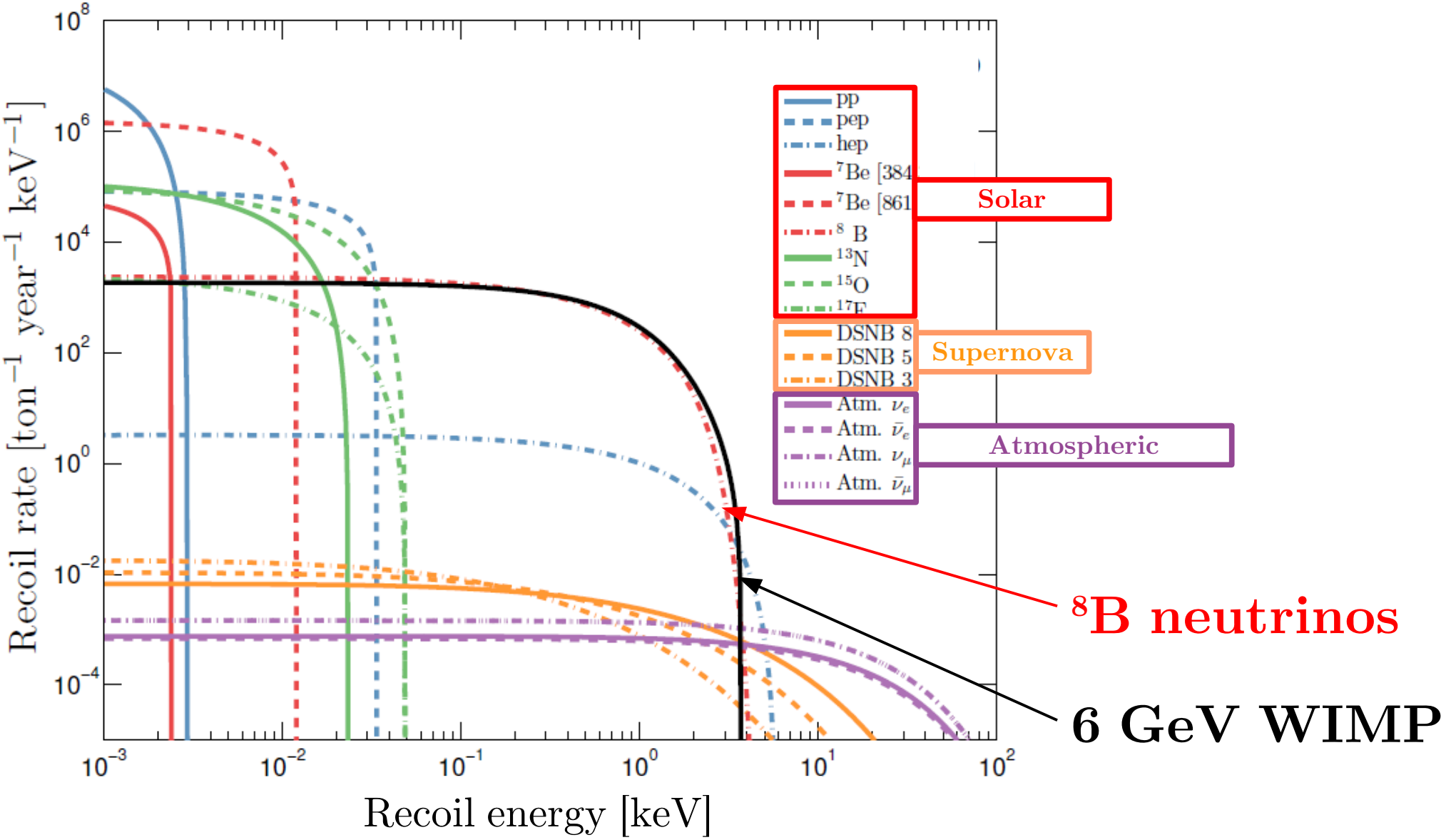


Neutrino backgrounds

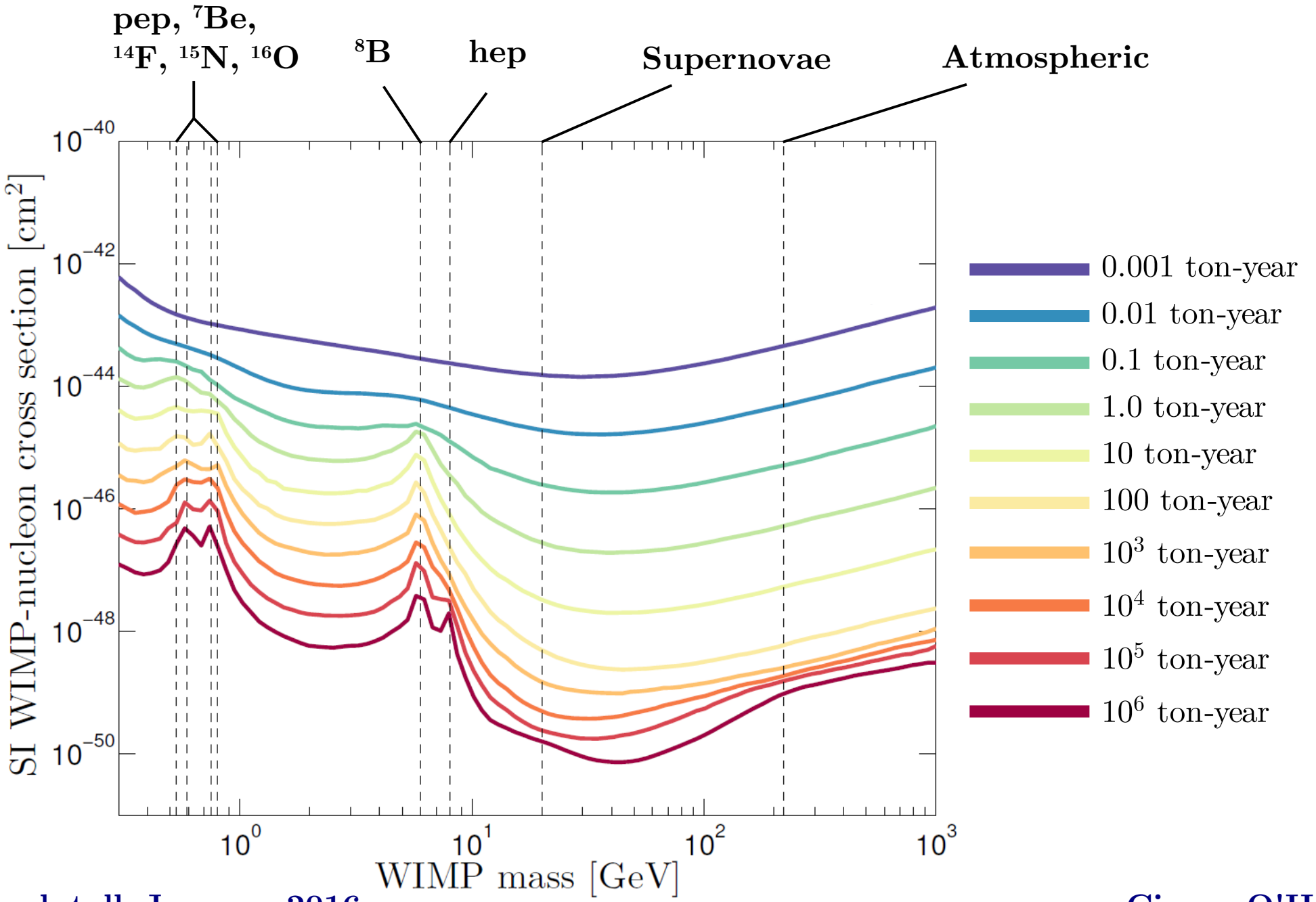


Neutrino backgrounds

- Coherent neutrino-nucleus scattering (CNS) rates on a Xenon target:

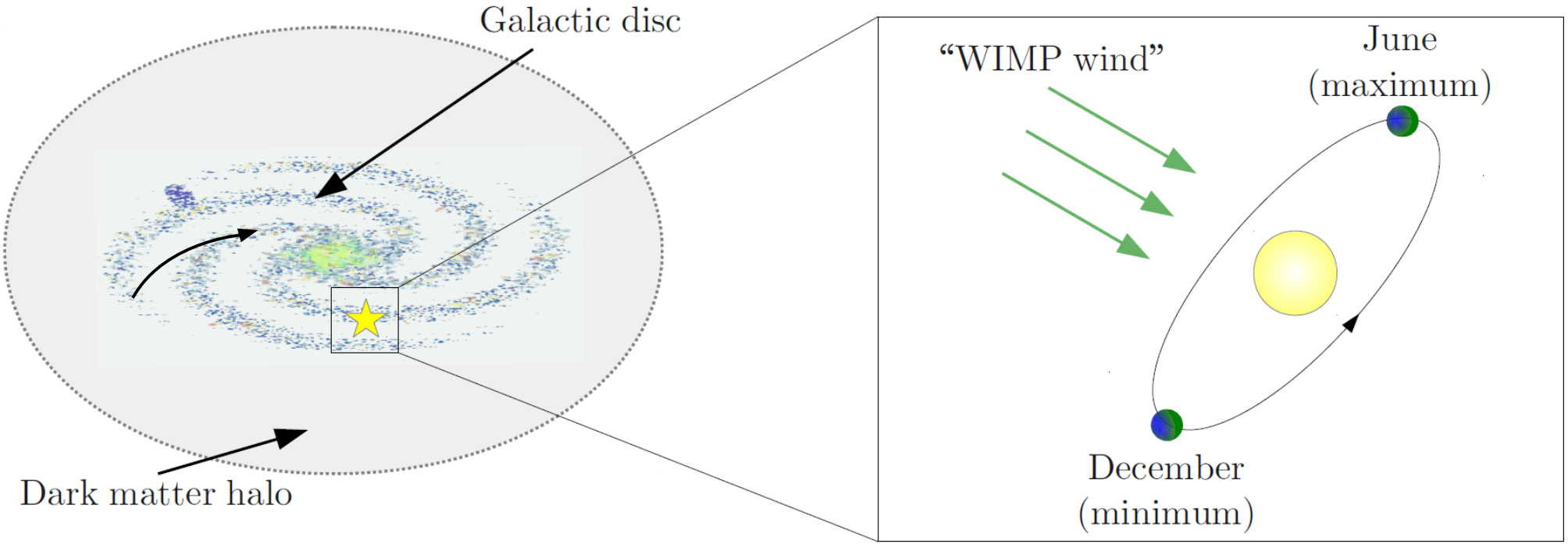


Neutrino floor



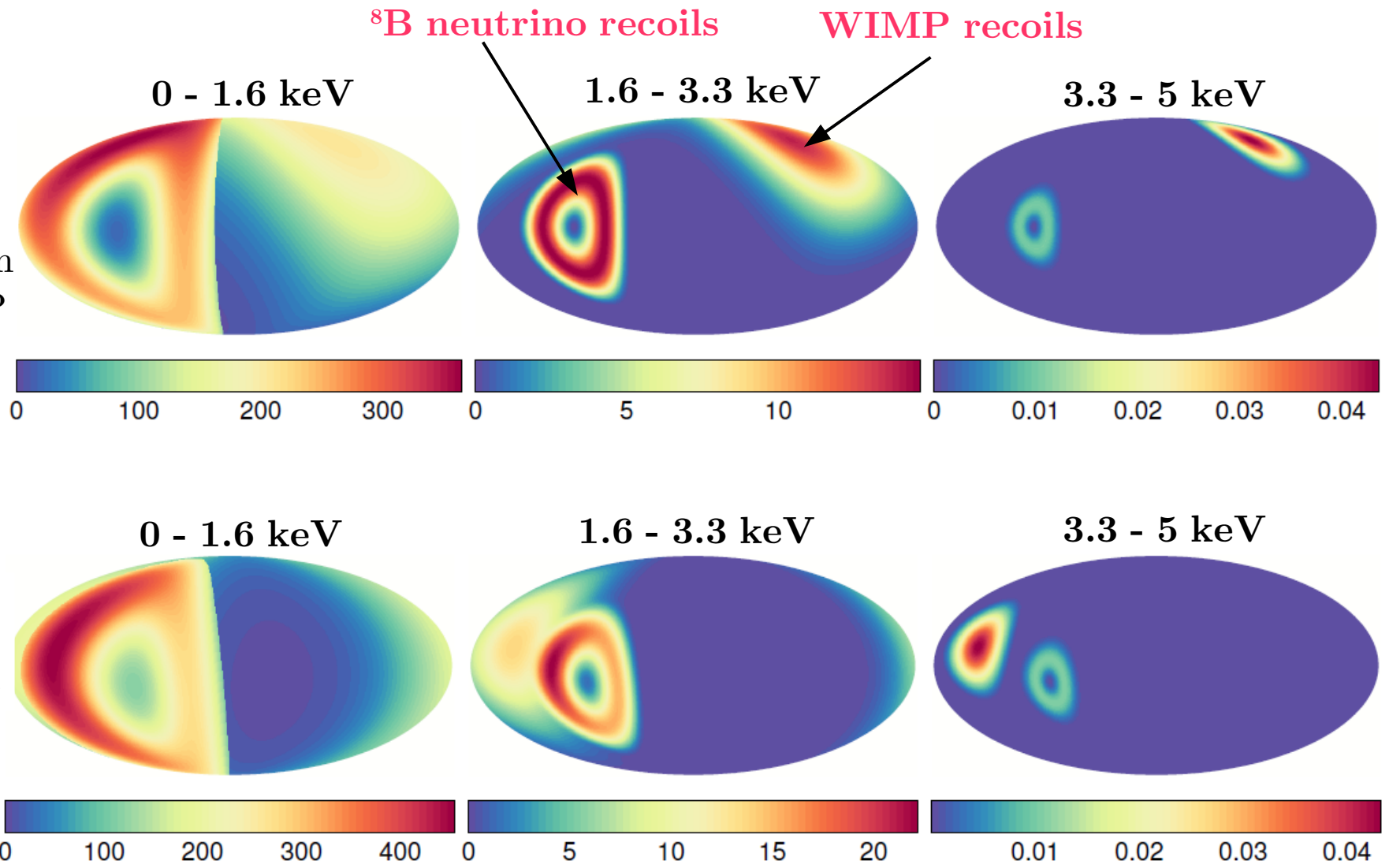
Solution to the neutrino floor problem

- **Use distinguishing features of dark matter signal:**
  - Annual modulation
  - Direction dependence



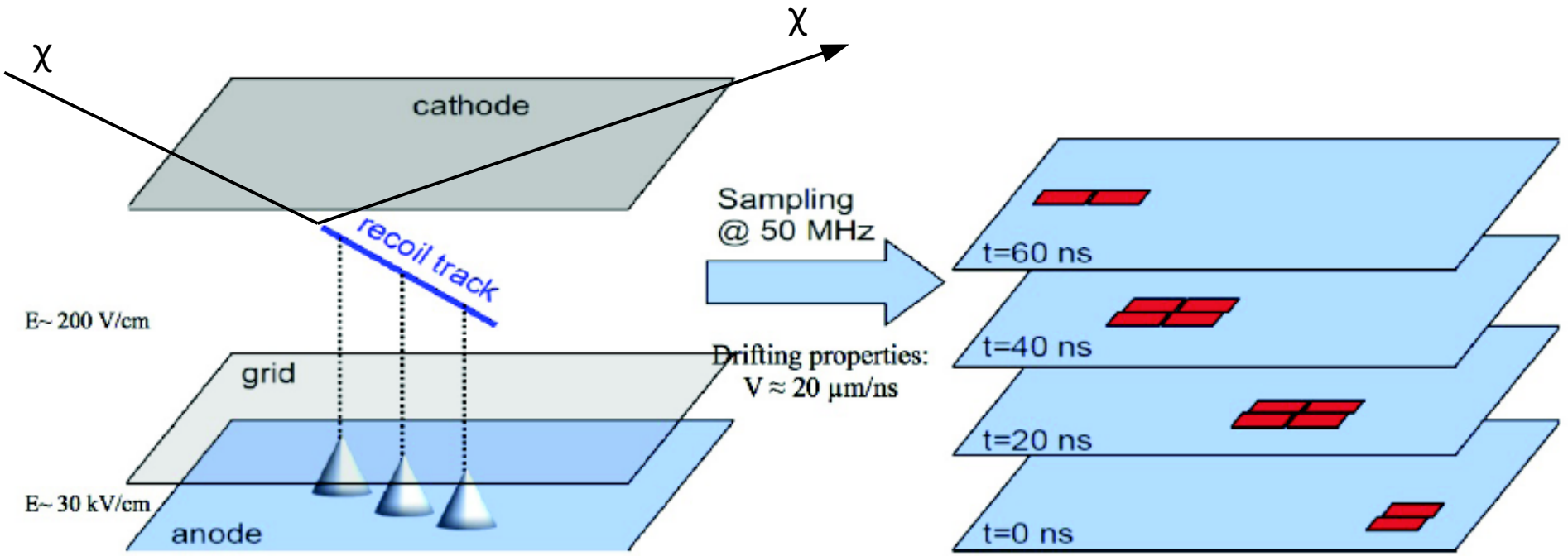
Directional signatures

- Sun does not coincide with peak WIMP direction at any time
- It should be possible to distinguish the two signals with direction:



Directional detection

- Time Projection Chamber (TPC)

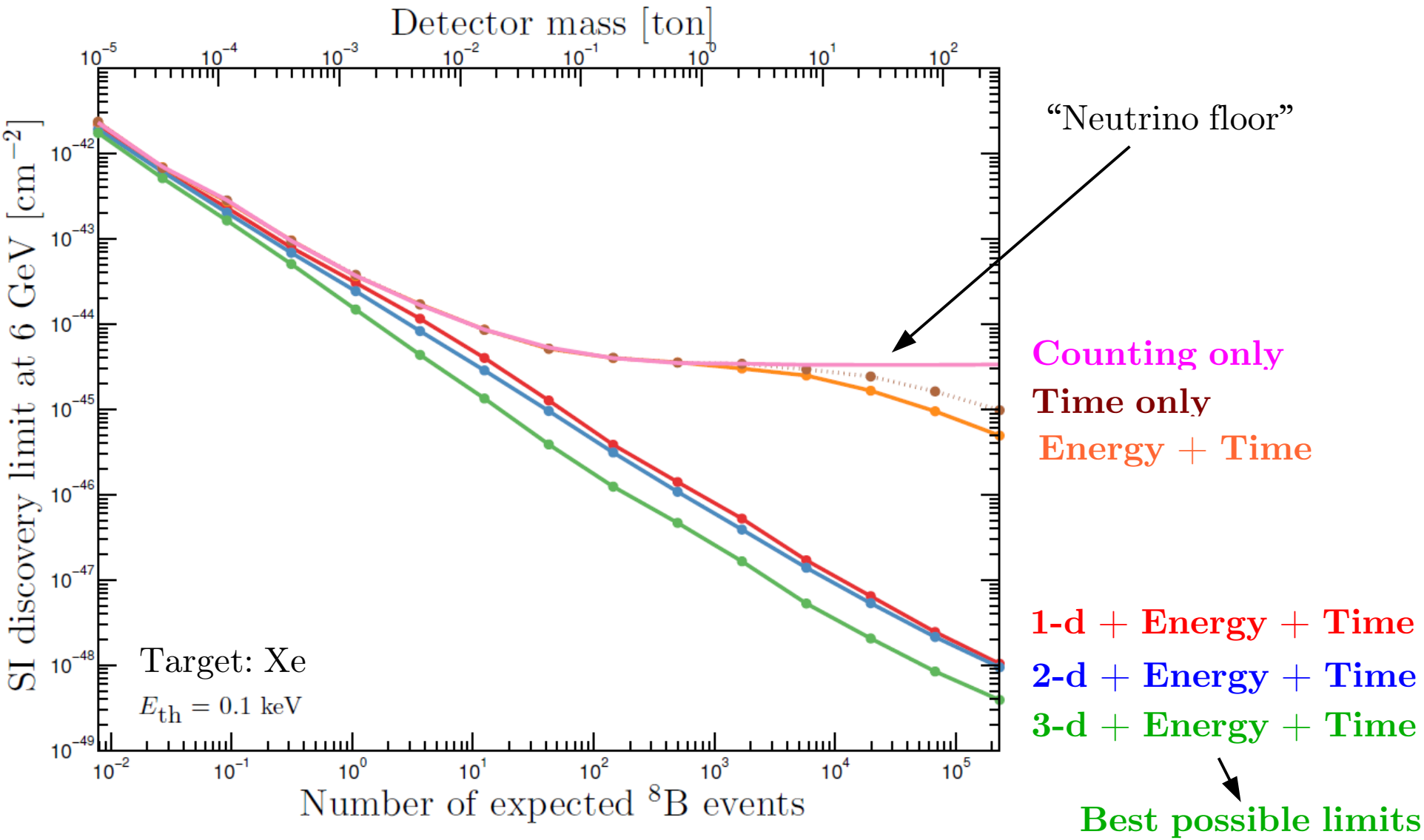


MIMAC Collaboration (2013)

- **3-d readout:** full recoil track
- **2-d readout:** projection onto anode
- **1-d readout:** projection along drift direction

Discovery limits

- Discovery limit = **minimum discoverable cross-section** (3σ in 90% of expts)
- Evolution of discovery limit for 6 GeV WIMP as a function of detector mass:



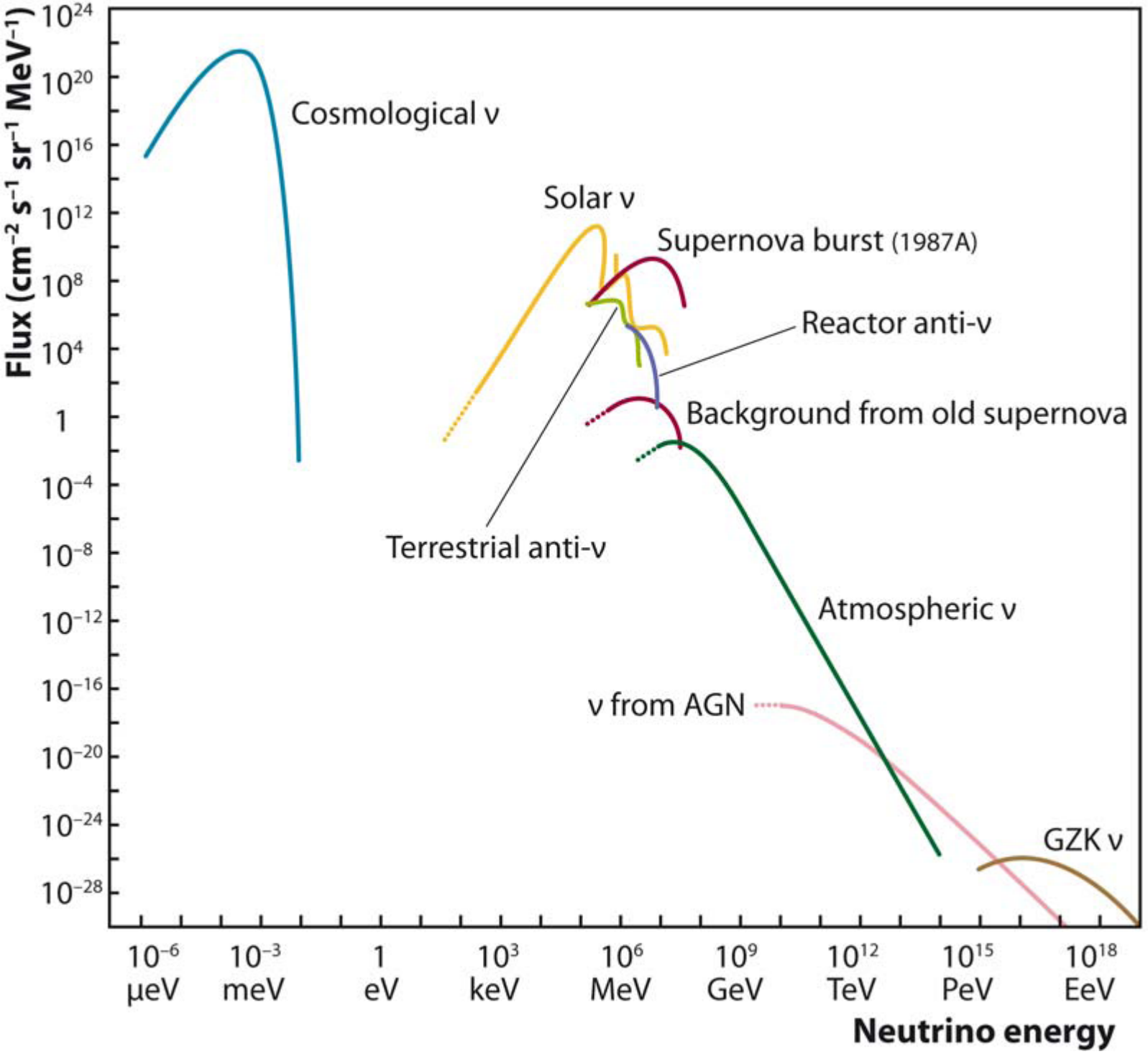
Summary

Directionality is a powerful tool for subtracting neutrino backgrounds

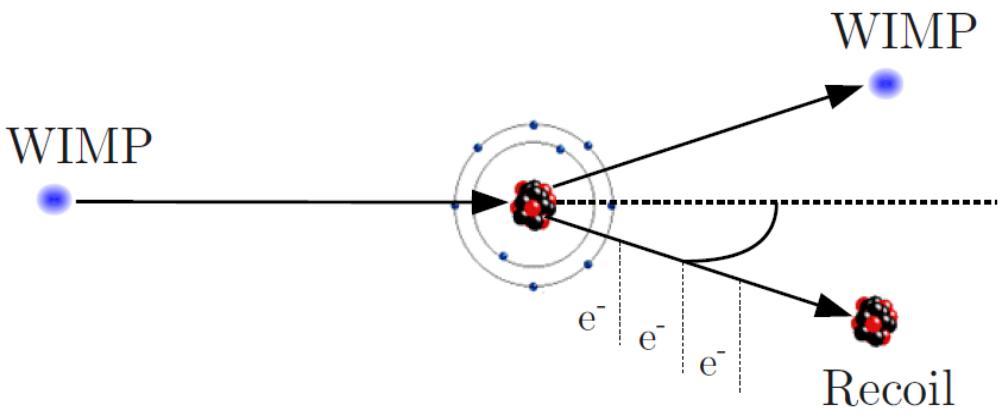
- Neutrinos are an important background for future experiments
- Neutrinos create a "floor" to dark matter discovery
- Including direction dependence can eliminate the floor
- Even when only partial directional information is available

Extra slides

C. Spiering 2012



WIMP-nucleus elastic scattering



Differential event rate

$$\frac{\mathrm{d}R}{\mathrm{d}E_r} = \frac{A^2 F^2(E_r)}{2\mu_p^2} \times \frac{\sigma_p}{m_\chi} \times \rho_0 \int_{v_{\rm min}}^{\infty} \frac{f(\mathbf{v}+\mathbf{v}_{\rm lab})}{v} \mathrm{d}^3 v$$

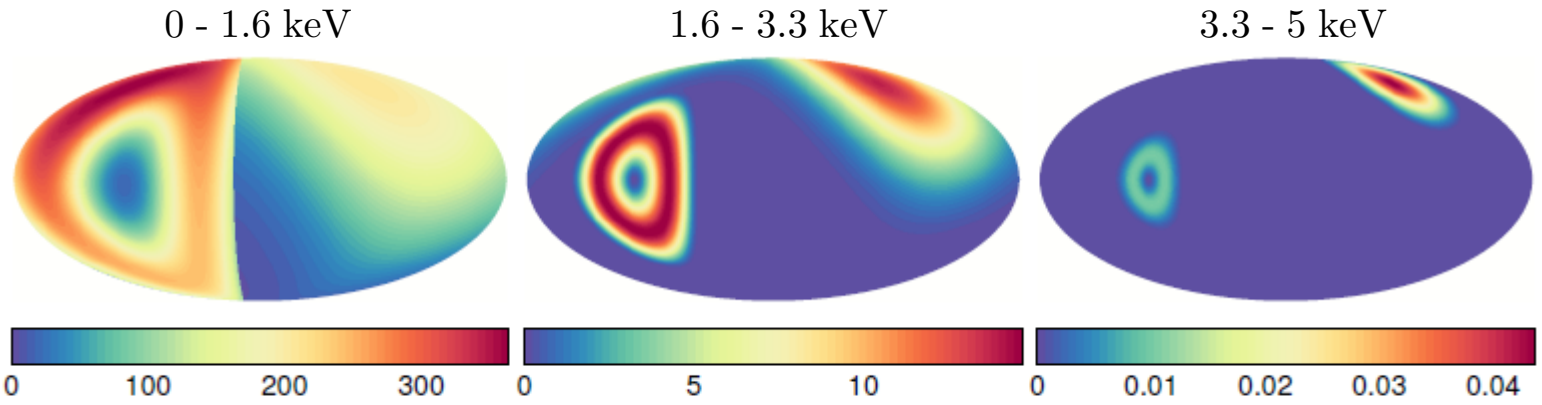
Nuclear physics
- Mass number
- Nucleus mass
- Nuclear form factor

WIMP properties
- WIMP mass
- WIMP-nucleon cross-section

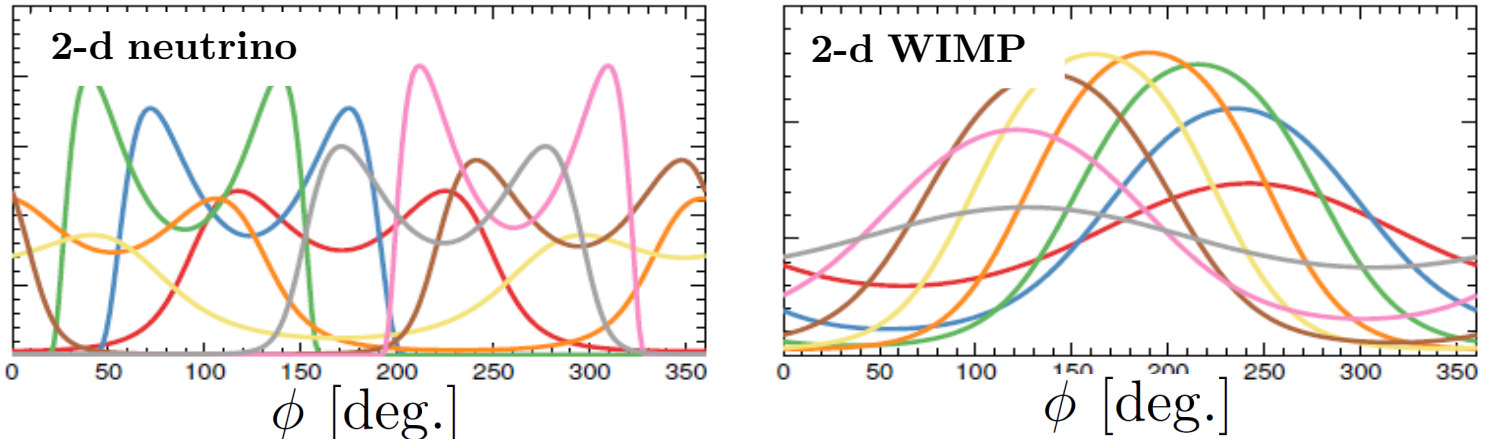
Astrophysics
- Galactic DM density
- Velocity distribution
- Laboratory frame velocity

Projected angular pdfs

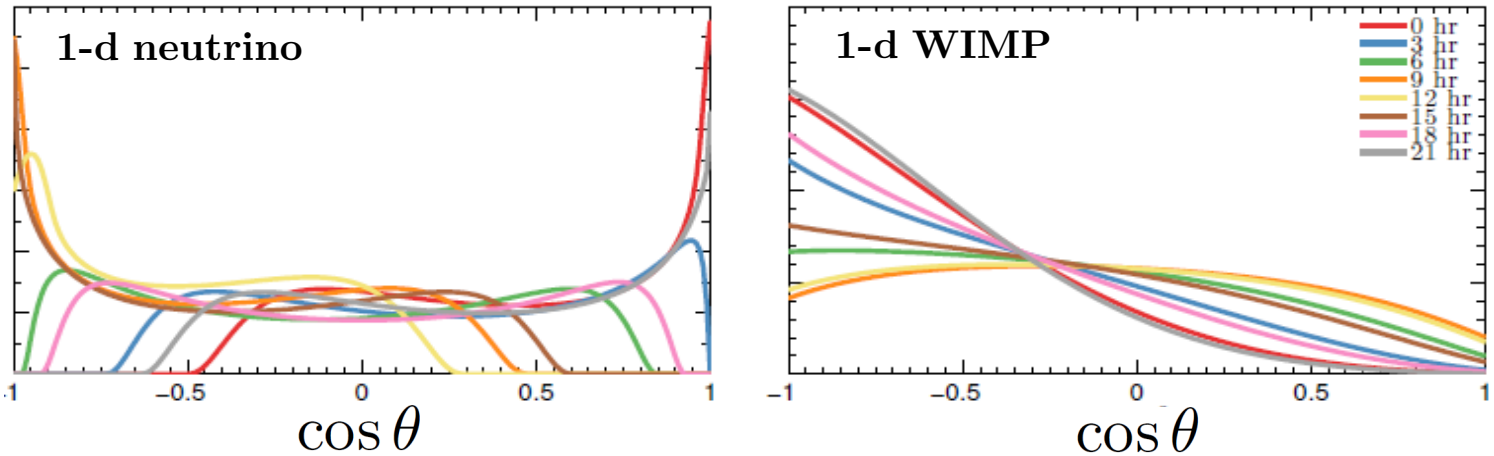
3-d readout:



2-d readout:

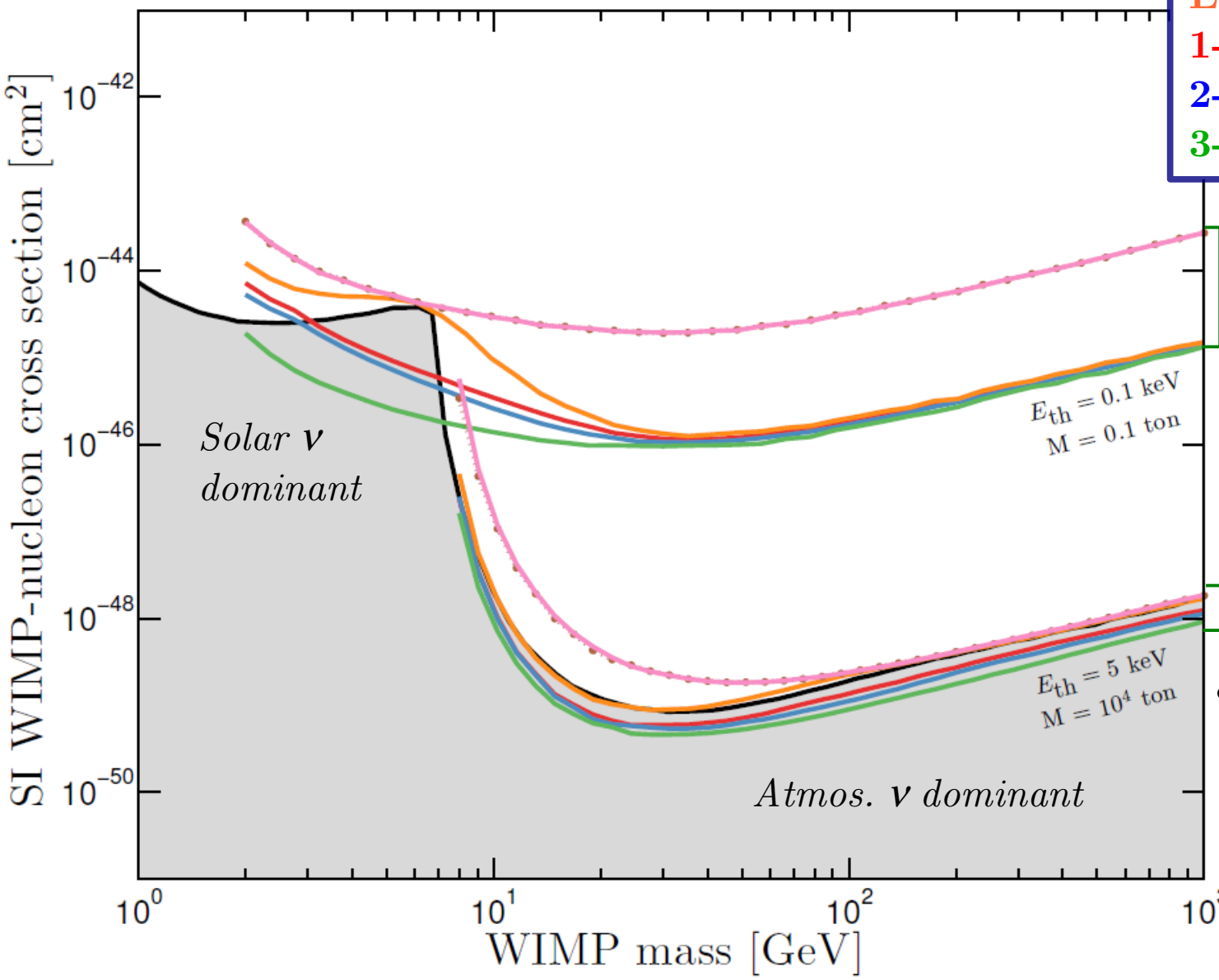


1-d readout:

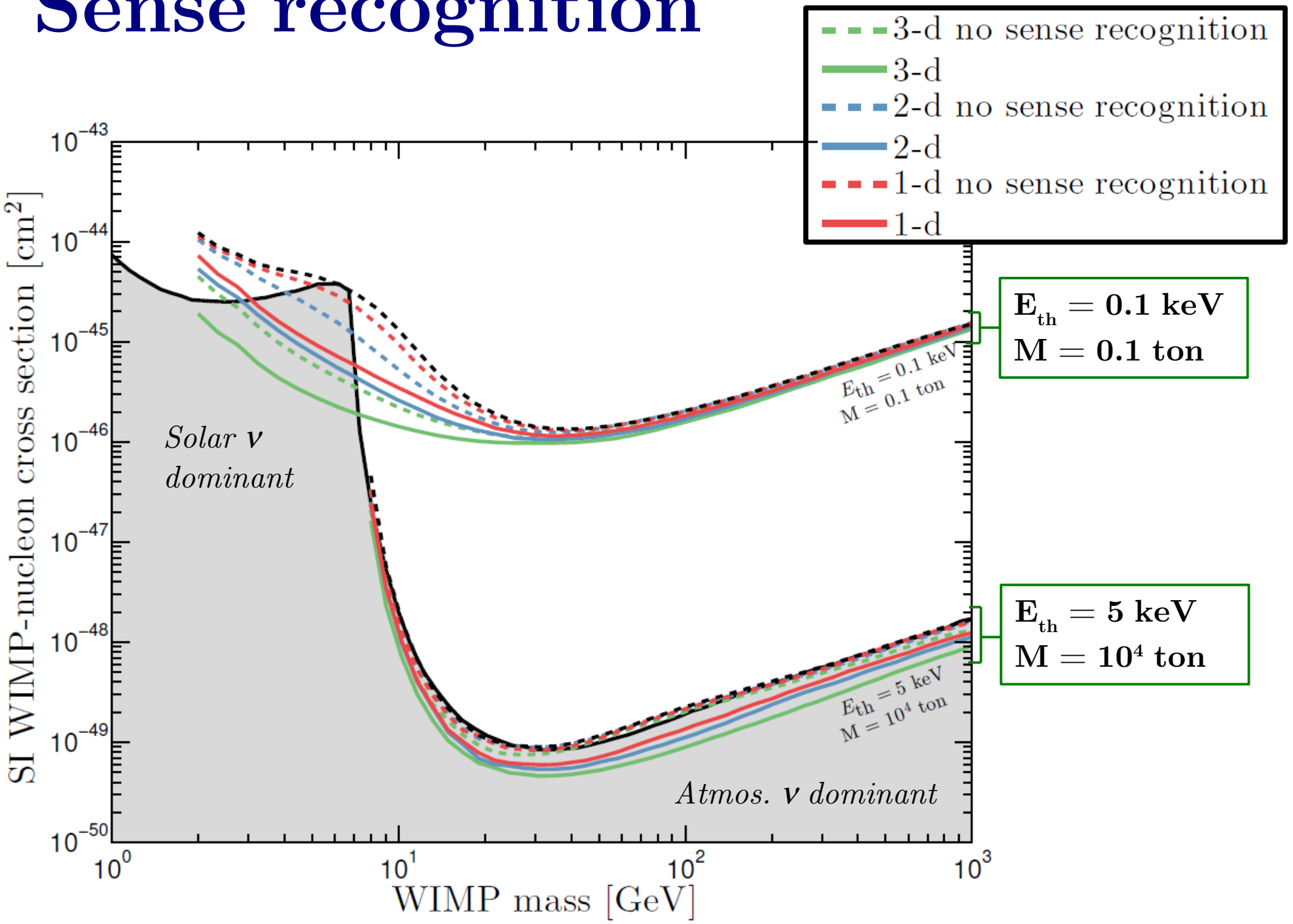


Discovery limits

- Discovery limit as a function of WIMP mass



Sense recognition



Angular resolution