Determining WIMP properties with neutrino detectors

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1 – Outline

- Dark matter: direct and indirect detection
- Neutrino flux from dark matter annihilation
- Reconstructing WIMP properties with LBL neutrino oscillation detectors
- Conclusions

Strong evidence in favour of the existence of dark matter has been found from cosmological and astrophysical observations.

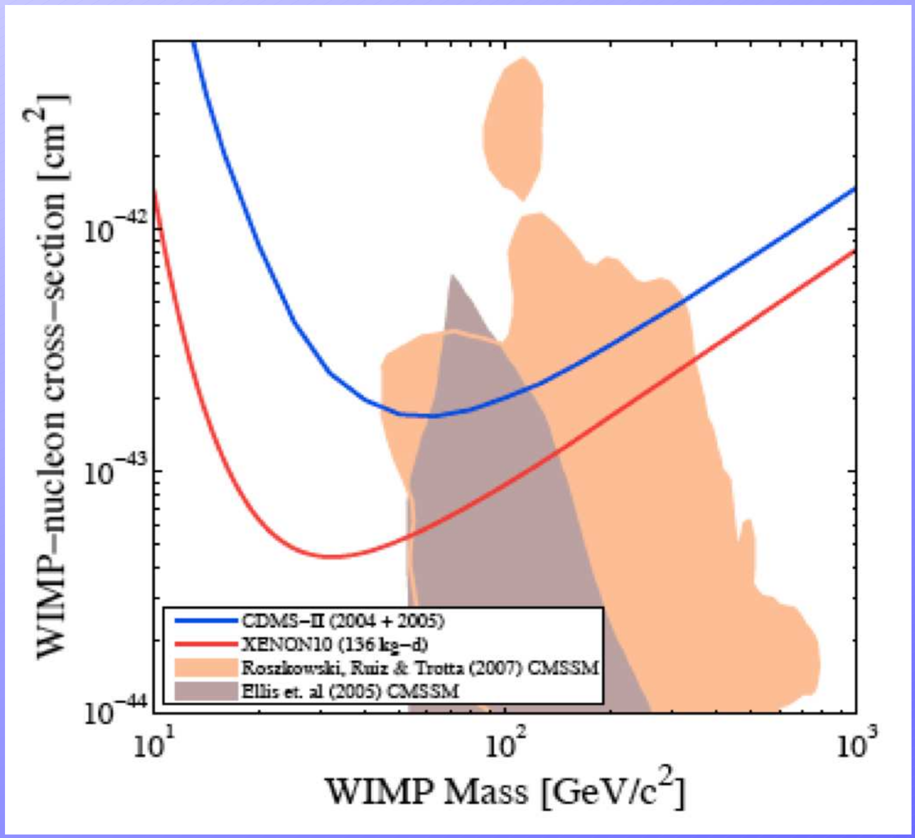
Its nature is still unknown but various candidates have been proposed, e.g.:

- Weakly interacting massive particles (WIMP)
- KeV sterile neutrinos
- MeV particles (scalars or fermions)
- superheavy relics

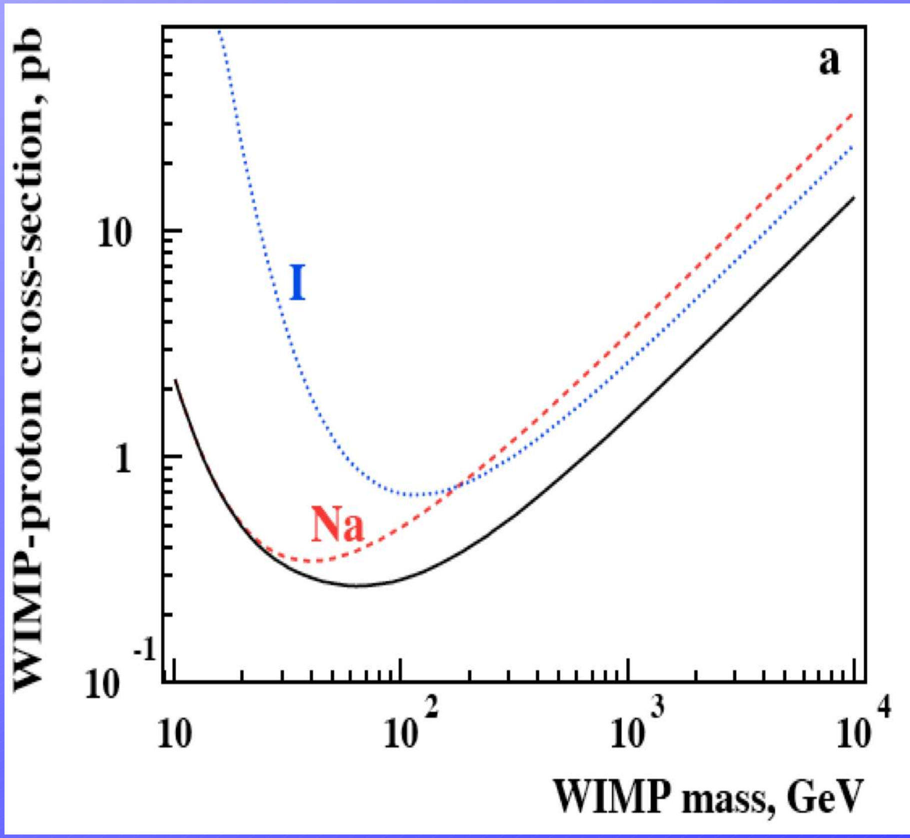
Here, I focus on WIMPs and their properties. They can naturally be embedded in extensions of the SM (SUSY, extra-D, Little Higgs models).

2 – Detecting WIMPs

● Direct detection: a DM WIMP collides elastically with a nucleus in the detector, which recoils. Sensitivity to the spin-dependent and spin-independent cross section.



[Angle et al., 2007]



[Alner et al., PLB 616]

• Indirect detection observing the annihilation products (gamma rays, anti-matter, neutrinos).

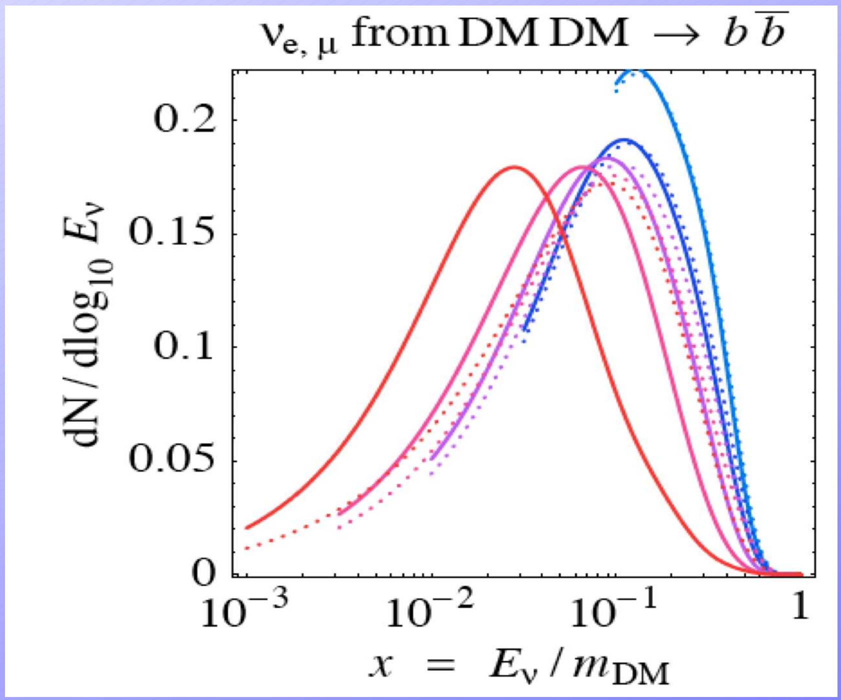
When a WIMP goes through a celestial body, it has a non-negligible probability of being scattered off to a velocity smaller than the escape one. The WIMP gets trapped and an isothermal distribution forms.

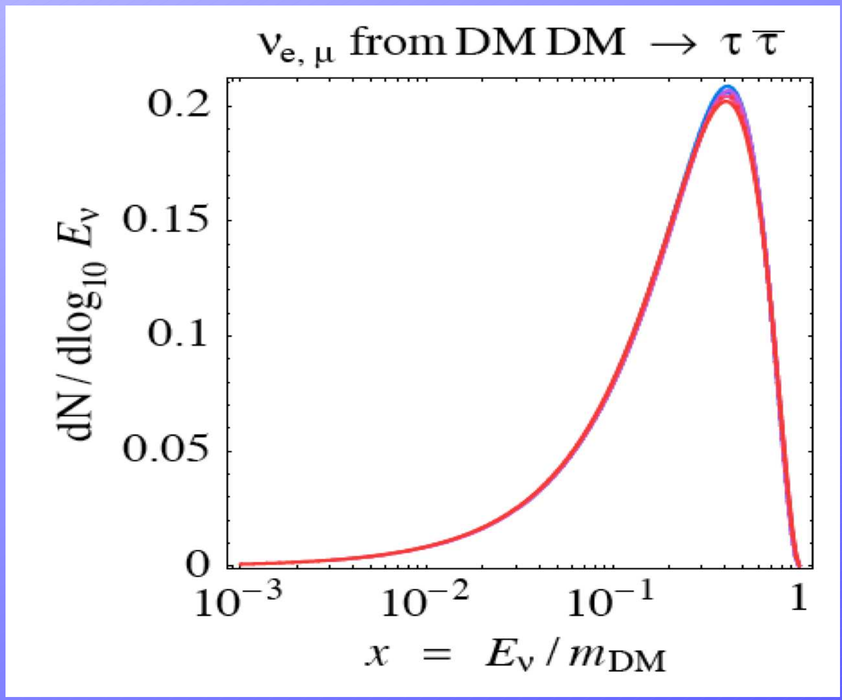
$$C_\odot \simeq 9 \times 10^{24} s^{-1} \left(\frac{\rho_{local}}{0.3\mathrm{GeV/cm^3}}\right)\left(\frac{\sigma}{10^{-2}\mathrm{pb}}\right)\left(\frac{50\mathrm{GeV}}{m_{DM}}\right)^2$$

Two WIMPs can then annihilate each other into SM particles. In the Sun, annihilation and capture rates equilibrate.

$$\Gamma_{ann} = \frac{1}{2} C_\odot$$

Neutrinos are produced directly in the annihilation ($\chi\chi \to \nu\nu$) but also in the subsequent decay of other SM particles (quarks, leptons, bosons).





[Cirelli et al., NP B727]

Once the neutrinos are produced, they travel from the interior of the Sun to the detector. Oscillation, energy loss and absorption effects need to be included.

The ν spectrum depends on the models considered. For ex.:

- LSP in SUSY models: typically the branching ratio is $\propto m_f$. The BR into neutrinos is negligible. Dominant decay modes for light LSP: $b\bar{b}$ and $\tau\bar{\tau}$.
- Kaluza-Klein modes in extra-D models: BR$_{\nu\nu}$ can be as high as few %. Spectrum typically dominated by the $\tau\bar{\tau}$ channel.

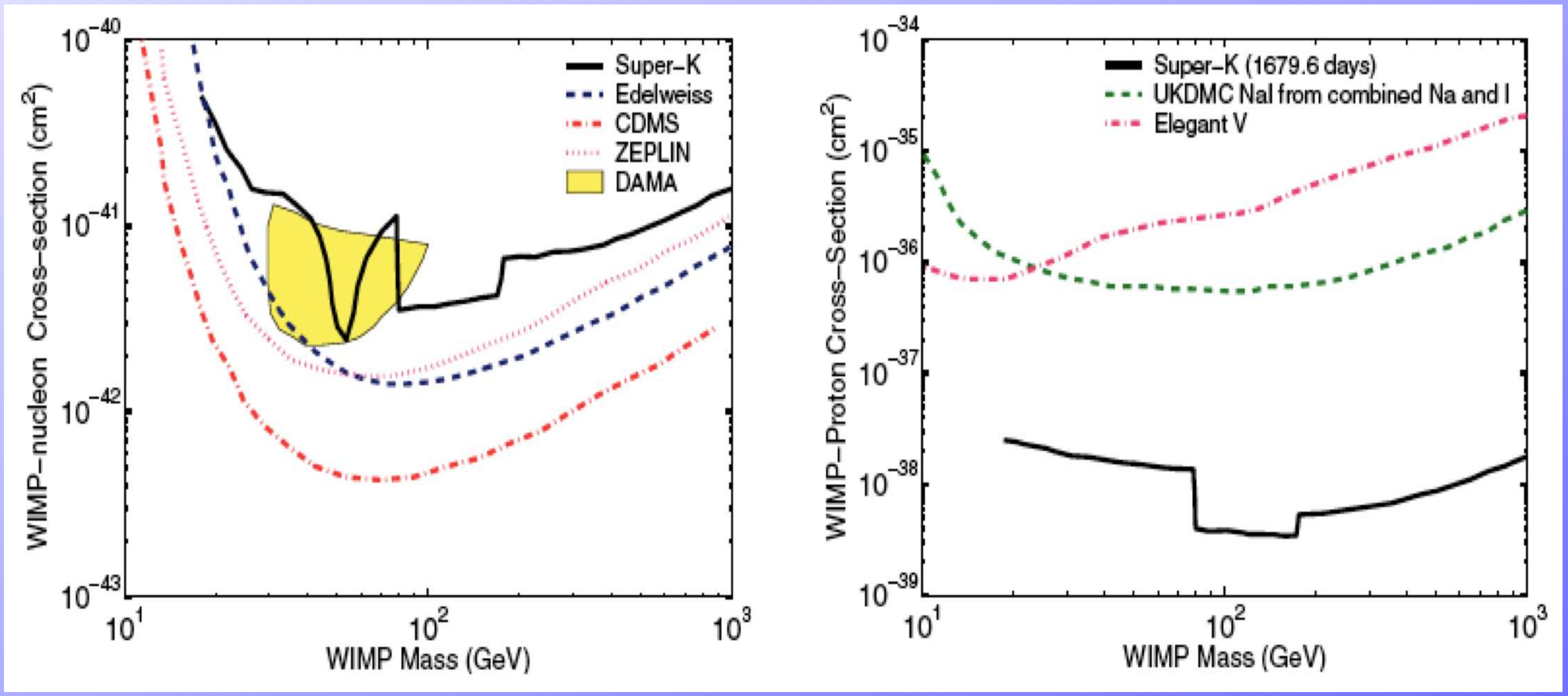
Determining BR$_{\nu\nu}$ together with their other properties (mass, elastic cross section...) will play an important role in establishing the nature of the WIMP.

3 – Detection of DM neutrinos

The neutrinos produced can be observed with neutrino detectors and neutrino telescopes.

- Super-Kamiokande (IMB, Kamiokande, MACRO) looked at through-going muons produced in the rock and put a strong bound on the flux of these neutrinos. Very limited information is obtained on the neutrino energy as these events are not contained.

- Neutrino telescopes (IceCube, Antares...) have a very large size and therefore can be used to detect these neutrinos.

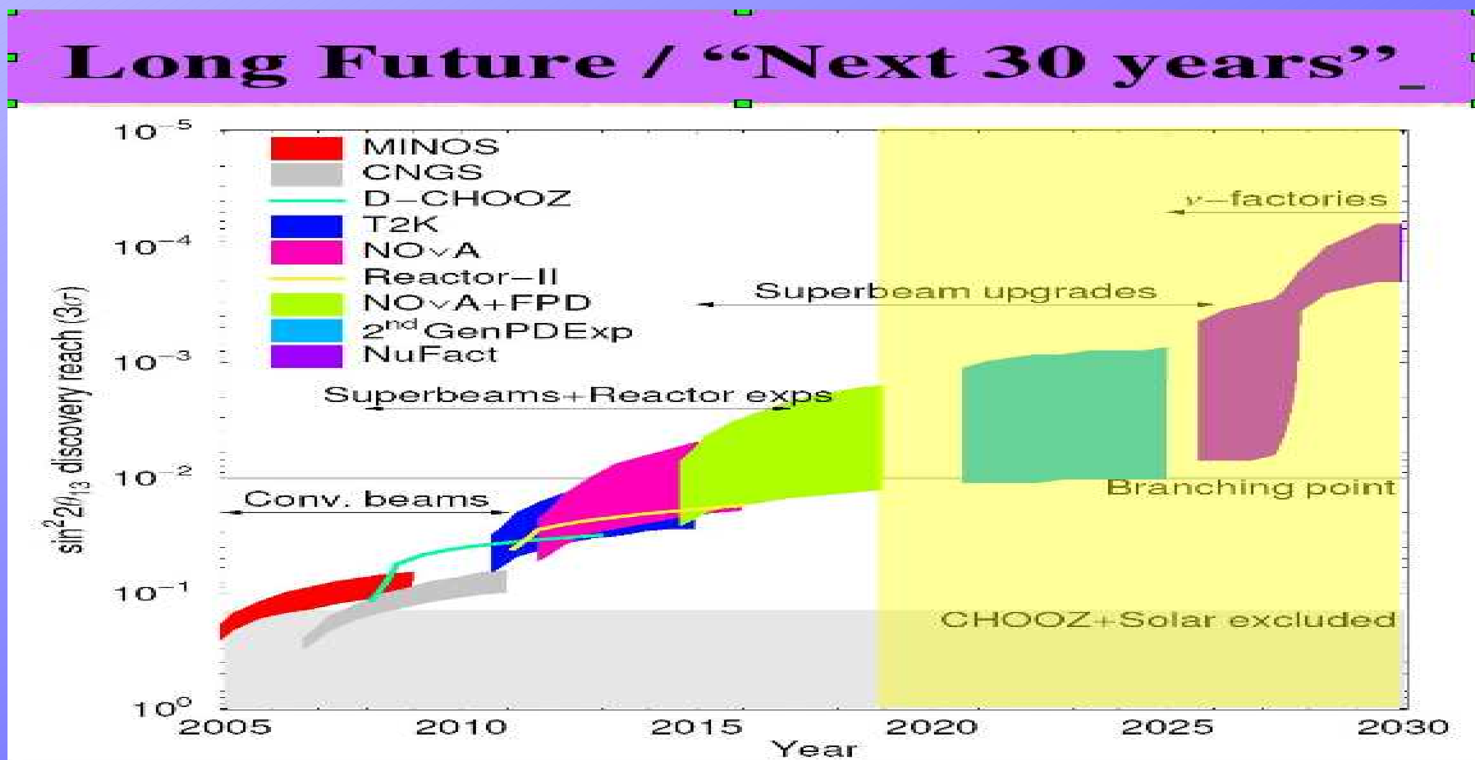


[Desai et al., PRD 70]

These experiments can only count the rates. Limited information is obtained on WIMP properties as the same rate can be obtained by trading off the annihilation channel with the cross section (BR-σ degeneracy).

In the coming future, LBL neutrino oscillation experiments will search for θ_{13}, the type of neutrino mass hierarchy and CP-violation. They require very intense neutrino beams and very large detectors.

1. **Superbeams**.
2. **Neutrino factories**.
3. **Beta-beams**.



The discussed detectors are

- Water Cherenkov (SK and HyperK, MEMPHYS): they perform well below 1 GeV. They have poor energy resolution at $E > 10$ GeV. Not suitable for our purposes.

- Iron magnetised calorimeters (MINOS, MIND, INO): muons of tens of GeV can be contained in a sufficiently large detectors. With the additional reconstruction of the hadronic energy, an energy resolution of ~ 10% can be achieved for muons with tens of GeV energy. [A. Cervera, private communication]

- Liquid Argon TPC (GLACIER, Flare): the tracks of leptons can be reconstructed and the initial neutrino energy well measured.

- Totally active scintillator detectors: they could achieve good energy resolution for ν_e in the tens of GeV energy range.

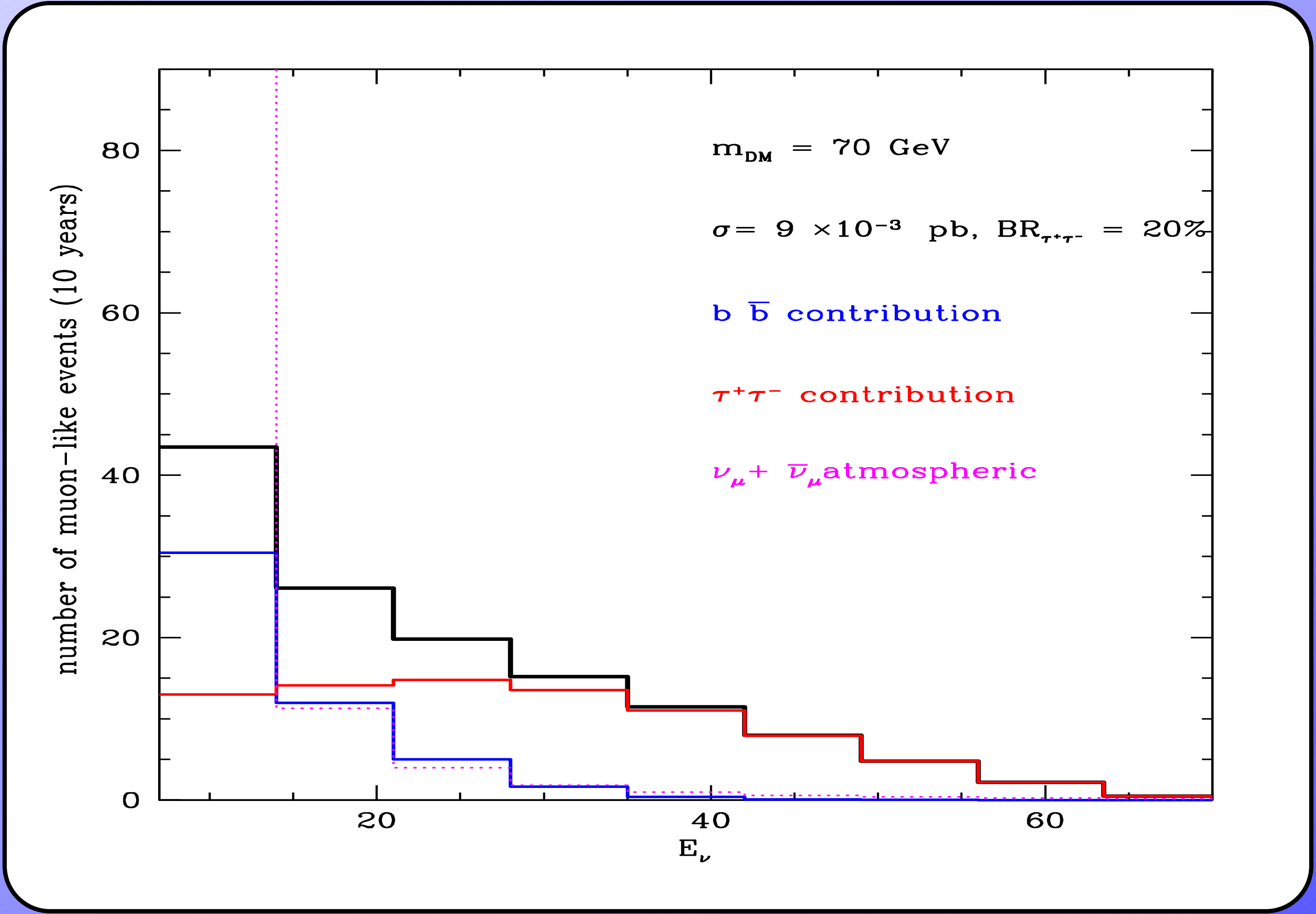
We exploit the angular and energy resolution of future LBL neutrino detectors (LiAr, TASD, MIND):

- 5 GeV (7 GeV) binning in neutrino energy
- in order to evaluate the atmospheric neutrino background, we use the rms spread in the direction between the neutrino and the lepton:

$\theta_{rms} \sim \sqrt{\frac{GeV}{E_\nu}}$.

We simulate the data in an iron magnetised detector and evaluate the performance in reconstructing the neutrino spectrum.

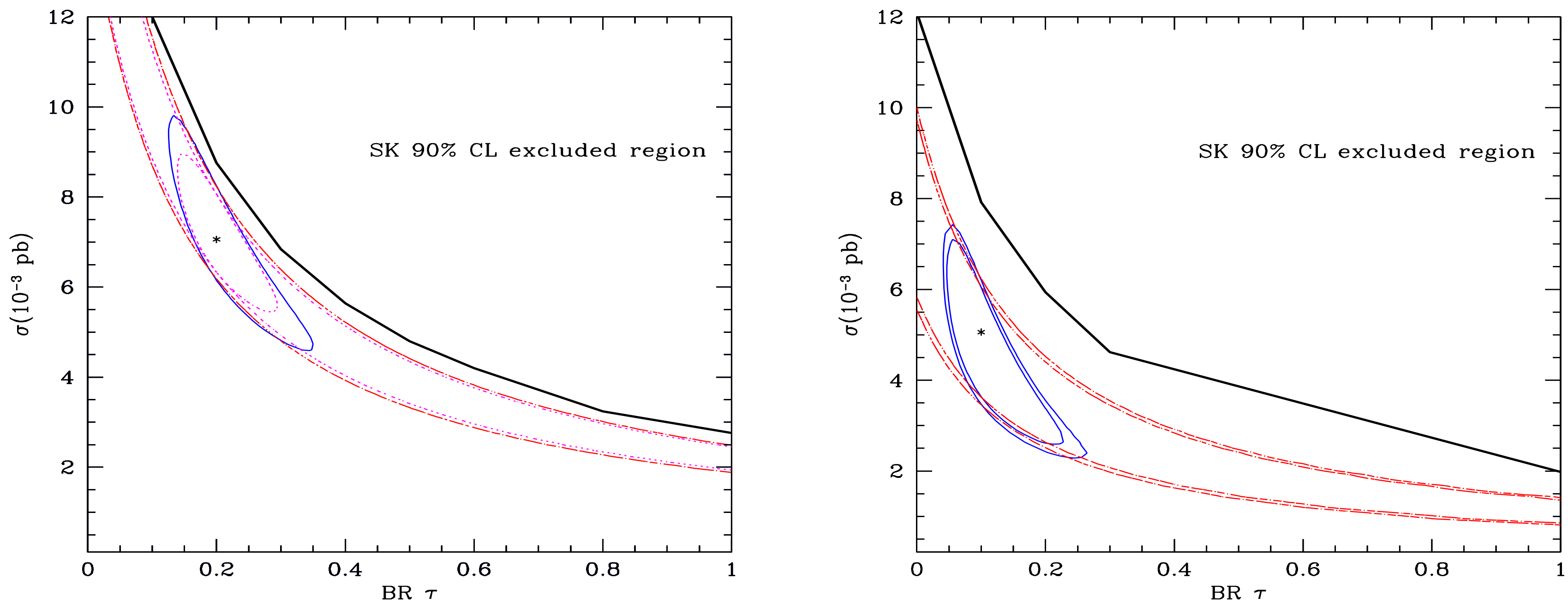
We study the number of neutrino events ($m_{DM} = 70$ GeV):



The shape of the spectrum gives information on the BR of annihilation.

The endpoint would allow to determine the WIMP mass.

Reconstruction of the BR:



[O. Mena, S. Palomares-Ruiz, SP]

4 – Conclusions

- Establishing the nature and properties of Dark Matter is of crucial importance.

- Indirect DM searches look for neutrinos from WIMP annihilation. WC detectors can only determine the total neutrino flux. IMD, TASD, LiAr detectors can reconstruct the spectrum of DM neutrinos from the Sun.

Future LBL neutrino detectors could constrain the BR of the SM annihilation channels.

They would play a crucial role in reconstructing WIMP properties, in synergy with collider experiments and direct DM searches.