Search for dark matter annihilation in the center of the Earth with 8 years of IceCube data

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References

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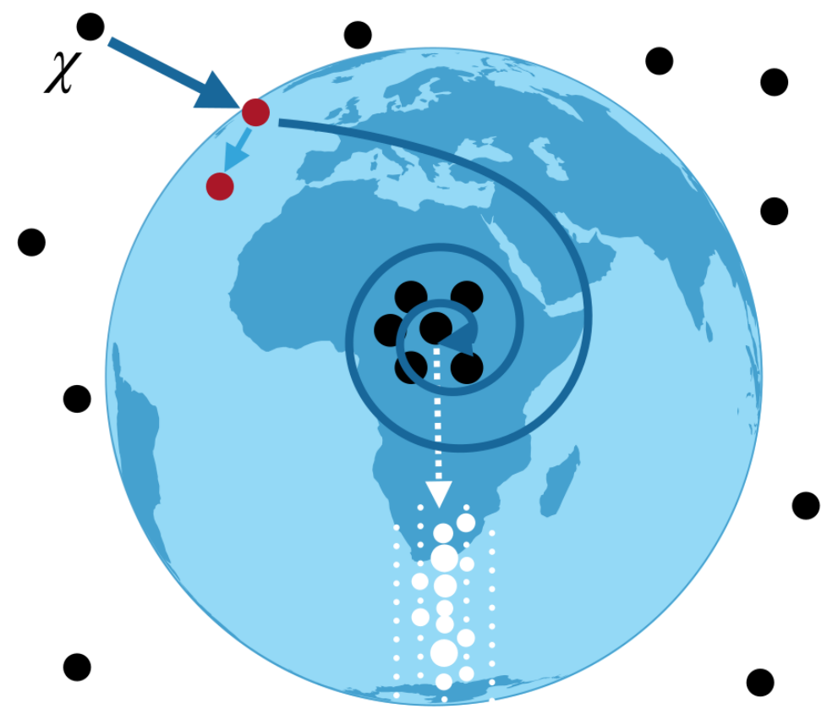
Dark matter from the center of the Earth

$$\frac{\mathrm{d}N}{\mathrm{d}t} = C_C - C_A N^2$$



C_c = **capture rate**. Dark matter particles can **scatter** off nuclei in the vicinity of the Earth with cross-section , lose velocity and be σ_{SI} **gravitationally captured** in the **center** of the planet.

$\Gamma_A = \frac{1}{2} C_A N^2$ = **annihilation rate**. Accumulated dark matter can **self-annihilate** into Standard Model particles with cross-section $\langle \sigma_A v \rangle$.

Neutrinos are among the final products. They are a **signature** of the presence of dark matter

The process is **not in equilibrium** for the Earth case

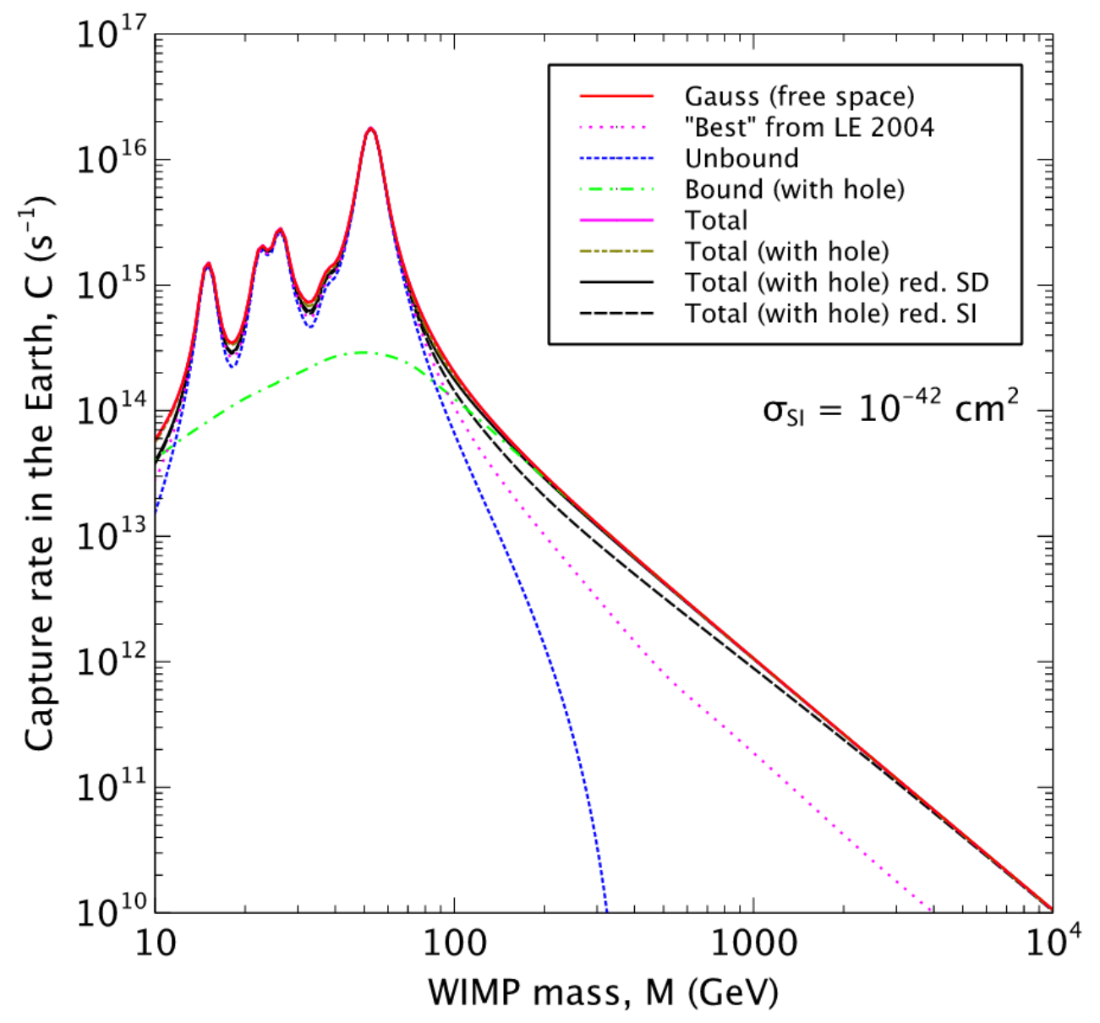
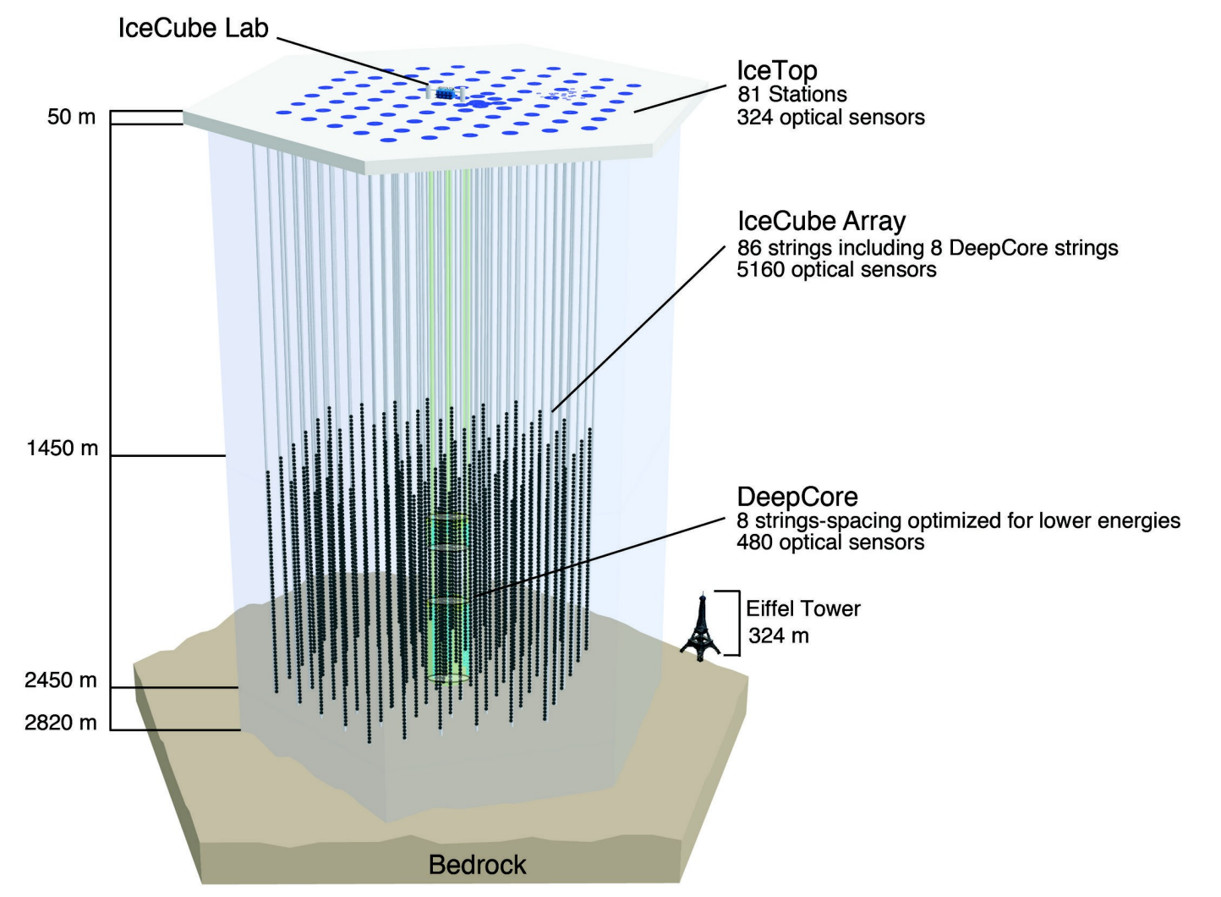


Fig. 1. Capture rate value vs. DM mass. The peaks are due to resonance with the most abundant elements on Earth. From [1]

The IceCube Neutrino Telescope

IceCube is a cubic kilometer neutrino detector located at the geographical South Pole.

An array of optical modules detects the **Cherenkov** light emitted along the path of relativistic charged particles produced by neutrino interactions in the ice or bedrock.



Time Direction
N. of photo-electrons

Reconstruction of particles **direction** and **energy**

Event selection

A dedicated event selection has been developed.

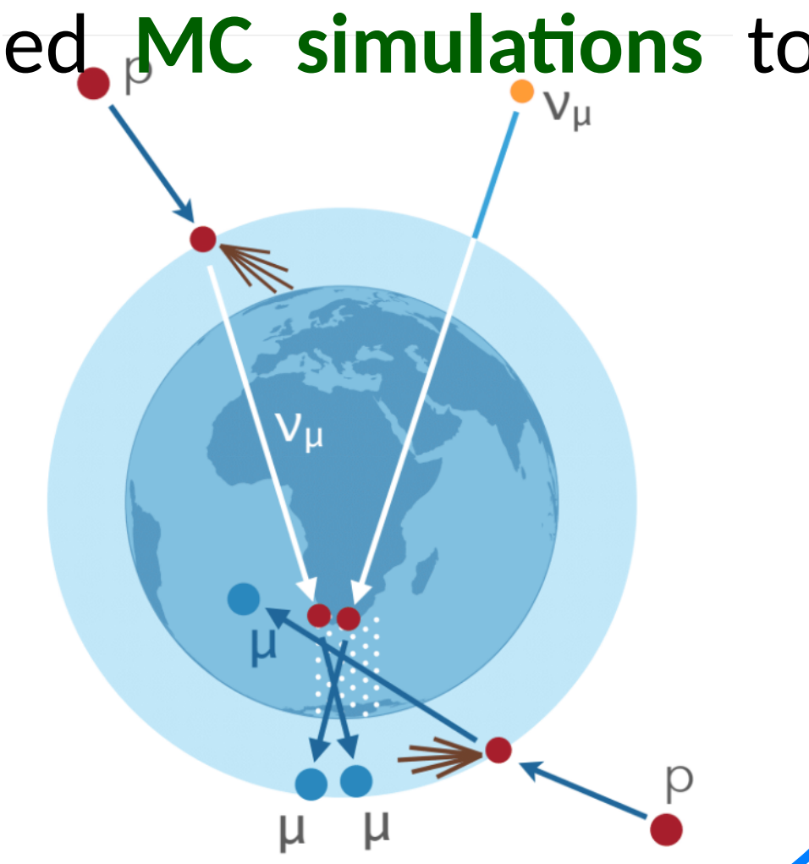
Signal: up-going neutrinos. **Zenith** angle close to **180°**.

Background produced in cosmic ray air **showers**:

- down-going *atmospheric* **muons** mis-reconstructed as up-going
- up-going *atmospheric* **neutrinos**

Peculiar observation point: need **MC simulations** to estimate background

Selection is **split** in **low energy** (LE) and **high energy** (HE) to optimize the results on a wider range of dark matter masses



Signal and background expectation

The final selection **2D reconstructed zenith-energy** binned distributions are the **PDFs** used to compute sensitivities.

Fig. 2 shows atmospheric background distributions and one reference WIMP hypothesis for LE and HE selections respectively.

The bin size is chosen to optimize the sensitivity.

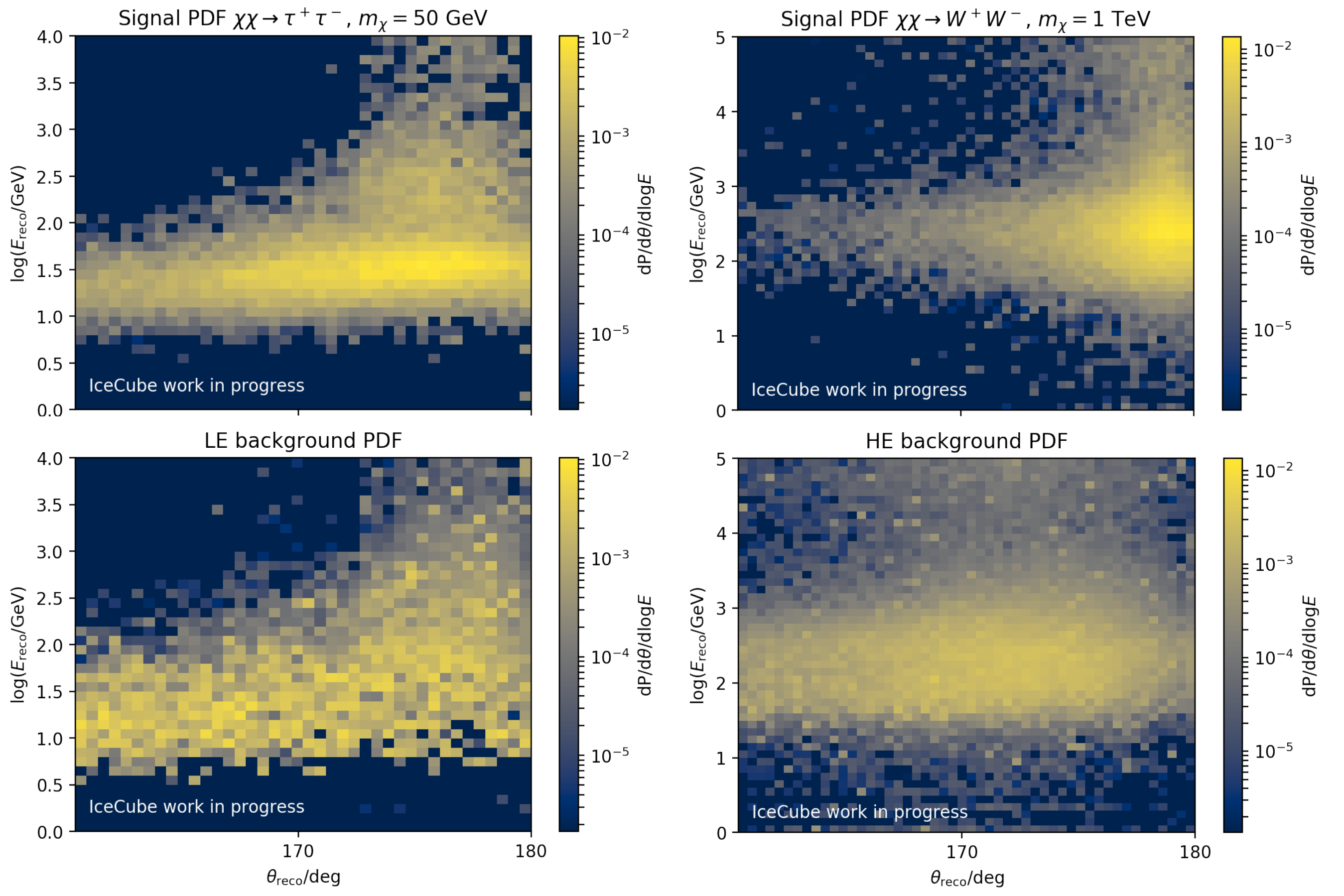


Fig. 2. PDFs for LE and HE reference signal (top) and atmospheric background (bottom).

Sensitivity

A **binned likelihood test** is performed, where the likelihood is defined [4] as

$$\mathcal{L}_{\text{Eff}}(\xi, \overrightarrow{f_{bkg}}|k) = \frac{\beta^\alpha \Gamma(k+\alpha)}{k!(1+\beta)^{k+\alpha}\Gamma(\alpha)}$$

where $\alpha = \frac{\mu^2}{\sigma^2}$ $\beta = \frac{\mu}{\sigma^2}$

with

$$\mu_{\text{bin}_\text{i}}(\xi, \overrightarrow{\eta}) = \xi S_{\text{bin}_\text{i}}(\theta, E) + \sum_i \eta_\text{i} B_{\text{i,bin}_\text{i}}(\theta, E)$$

and σ the corresponding uncertainties function.

S_{bin_i} and B_{i,bin_i} are the bins of the signal and background PDFs.

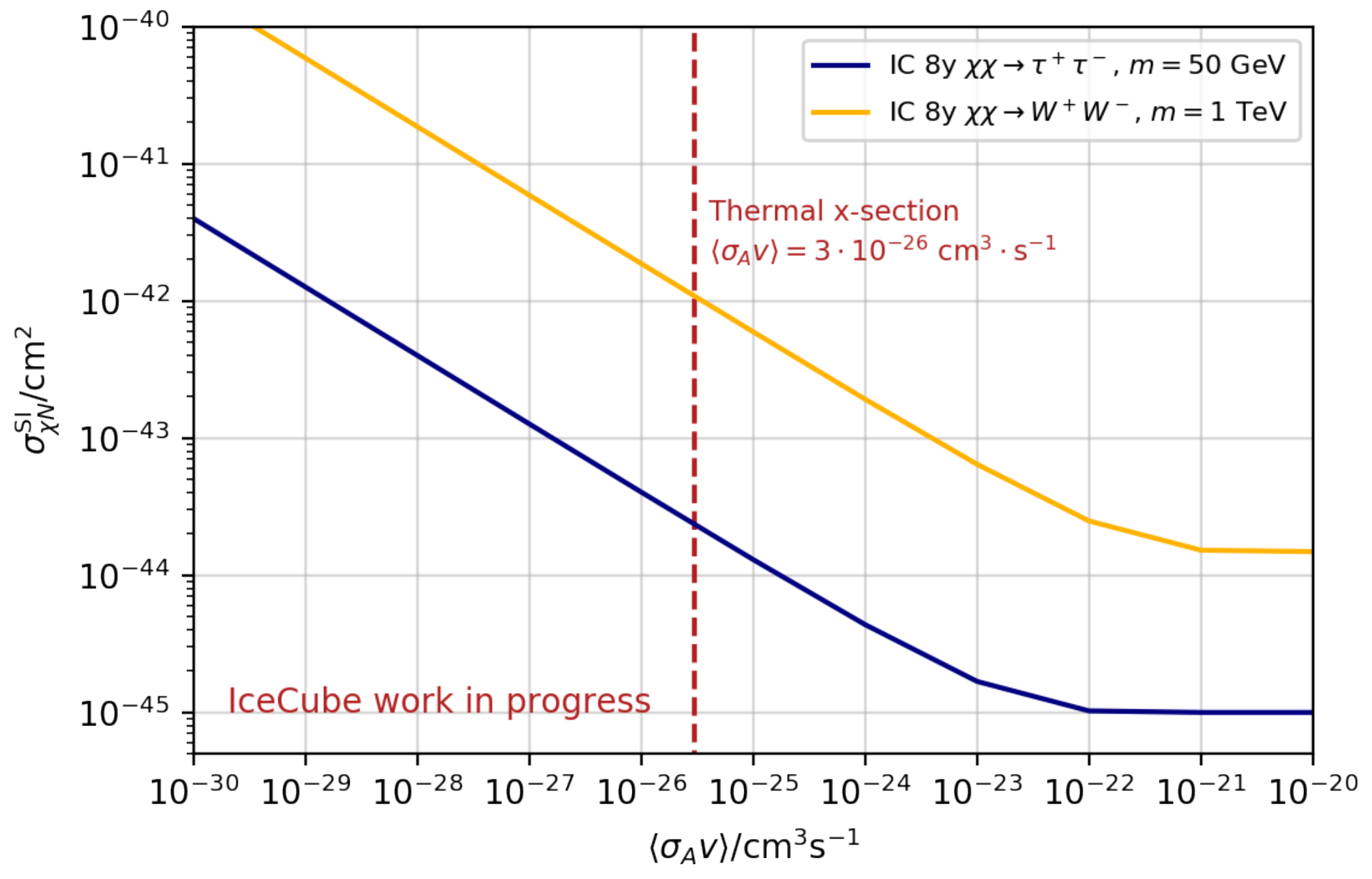
To estimate 90% sensitivities a **TS** is defined

$$TS = 2 \ln \frac{\mathcal{L}(\hat{\xi}, \overrightarrow{\eta})}{\mathcal{L}(\xi = 0, \overrightarrow{\eta})}$$

This likelihood has been chosen because it includes uncertainties in the calculation, to deal with low MC statistics. Limits on the number of events are then converted to σ_{SI} results

Given the **non-equilibrium** condition, to calculate the sensitivities on σ_{SI} , an **assumption** on $\langle \sigma_A v \rangle$ must be made. Fig. 3 shows the sensitivity on σ_{SI} as a function of the $\langle \sigma_A v \rangle$ value assumed for the two reference masses and channels .

Fig. 3. Cross-section sensitivity scan for the two reference signal channel-mass combinations.



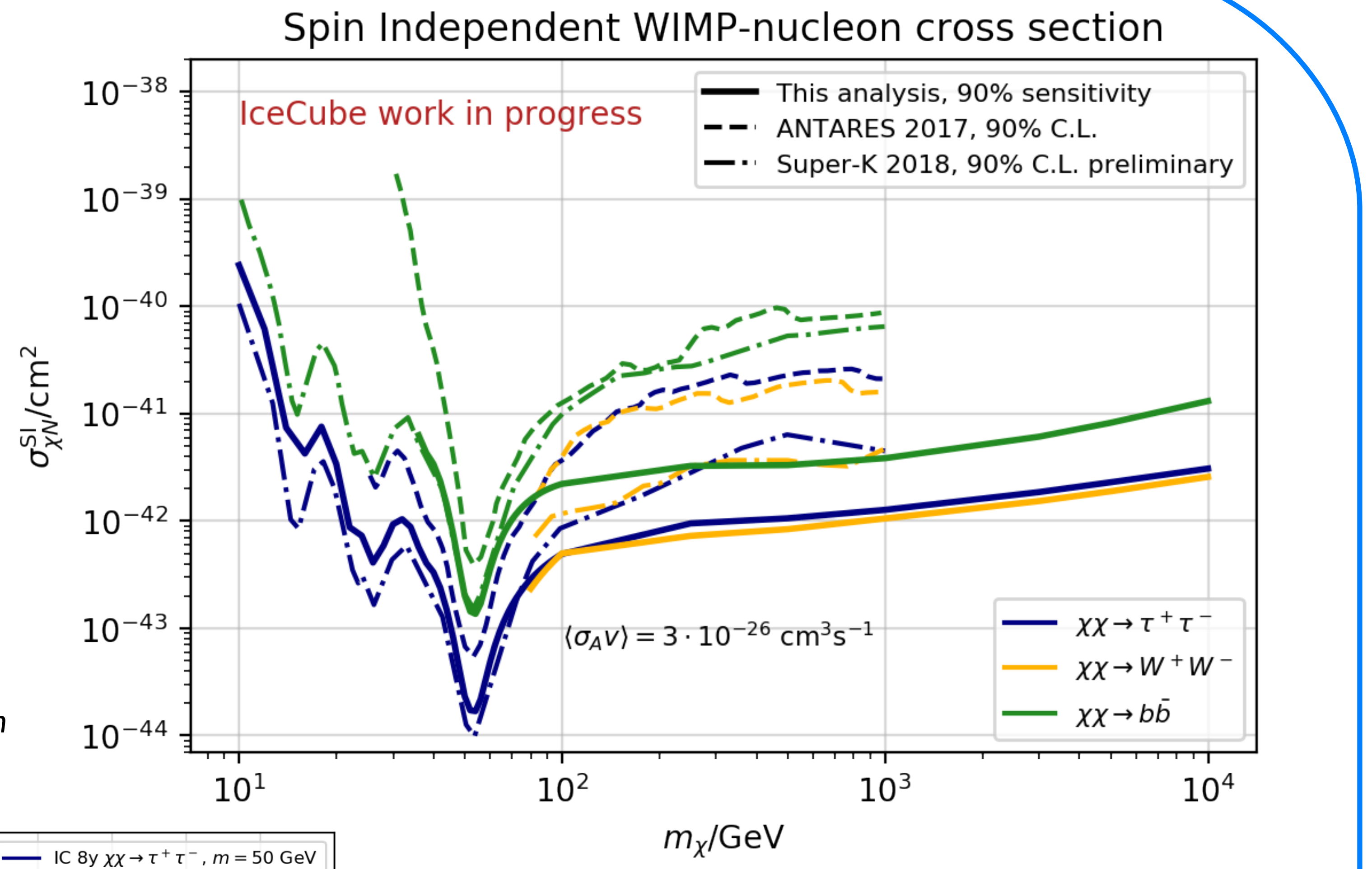


Fig. 4. Sensitivities at 90% C.L. for the spin-independent scattering cross-section σ_{SI}.

The **sensitivities** at the 90% C.L. on σ_{SI} are presented in Fig. 4. The results are compared to the current limits from Super-Kamiokande [5] and ANTARES [6].

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