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

Dark Matter (DM) particles can scatter off nuclei in celestial bodies like Earth, lose energy, be gravitationally captured and accumulate in the center of the Earth.

This process of capture happens at a rate \( C_C \) that depends on the DM-nucleon spin-independent scattering cross-section \( \sigma_{SI} \) and the Earth chemical abundances.

Accumulated DM particles can then self-annihilate into Standard Model particles.

The rate of the competing processes are related by:

\[
\frac{dN}{dt} = C_C - C_A N^2
\]

where \( C_C \) is the capture rate. The second term describes annihilation, where the annihilation rate is defined as \( \Gamma = \frac{1}{2} C_A N^2 \) and is proportional to the annihilation cross-section \( \langle \sigma v \rangle \).

Given the Earth age, this process has not reached equilibrium yet.

The IceCube Neutrino Telescope

IceCube is a cubic kilometer neutrino detector located at the geographical South Pole and installed below 1450 m of ice.

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

Signal and background expectation

A DM annihilation signal will manifest as an excess of neutrinos coming from the center of the Earth at zenith angles close to 180°.

The background for this analysis consists of down-going mis-reconstructed muons and up-going neutrinos produced in cosmic rays air showers.

A dedicated event selection has been developed to discriminate signal from background. The event selection is split in low energy (LE) and high energy (HE) selections. This allows us to optimize the results on a wider range of masses.

The PDFs, shown in Fig. 2, are binned normalized distributions of reconstructed zenith angle vs. energy. The bin size is chosen in order to optimize the sensitivity results.

Sensitivity

A binned likelihood test is performed, where the likelihood is defined as

\[
\mathcal{L}(\mu) = \prod_i \text{Poisson}(N_{\text{obs,bin}_i}(\mu) | N_{\text{true,bin}_i}/f(\text{bin}_i | \mu))
\]

The function \( f(\text{bin}_i | \mu) \) describes the probability function for a bin:

\[
f(\text{bin}_i | \mu) = \mu S(\text{bin}_i) + (1 - \mu) B(\text{bin}_i)
\]

where \( S(\text{bin}_i) \) and \( B(\text{bin}_i) \) are the PDFs for signal and background respectively (see Fig. 2) and \( \mu \) is the fraction of signal.

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

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

References


Fig. 1. Capture rate value vs. DM mass. From [2]

Fig. 2. PDFs for LE and HE reference signal and background.

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 \( \sigma_{SI} \).

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