Indirect dark matter searches towards the Sun using the full ANTARES data set

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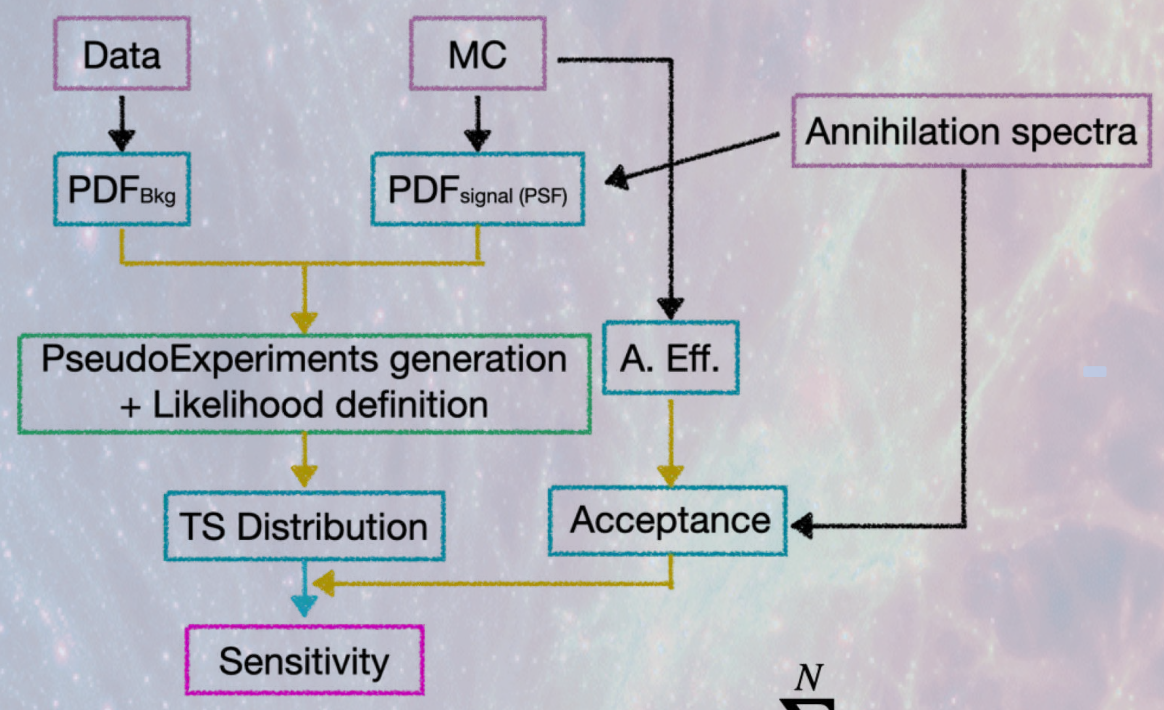
Summary

Weakly Interacting Massive Particles (WIMPs) are the most suitable particle dark matter candidates. These can be gravitationally captured into massive celestial objects, such as the Sun, where they can accumulate and then self-annihilate into Standard Model particles, also yielding neutrinos. In this work the data taken from 2007 to 2022 by ANTARES [1], a neutrino telescope located in the Mediterranean Sea, have been used to perform an indirect search for dark matter towards the direction of the Sun. ANTARES was an array of optical sensors in the deep sea distributed on 12 vertical lines.

Analysis ingredients

- ANTARES data set used: 2007 – 2022
- Track events for all neutrino flavours and interactions
- Only events producing signals on a single ANTARES line are considered (single-line events)
- A dedicated machine learning reconstruction (NNFit) [4] is used to reconstruct these events
- Single-line events provide the best sensitivity for low WIMP masses
- Neutrino spectra computed using WimpSim [3]
- Three different annihilation channels: bb, W^+W^-, $\tau^+\tau^-$ (100% branching ratio)
- Sun visibility included at different stages of the analysis

Analysis method



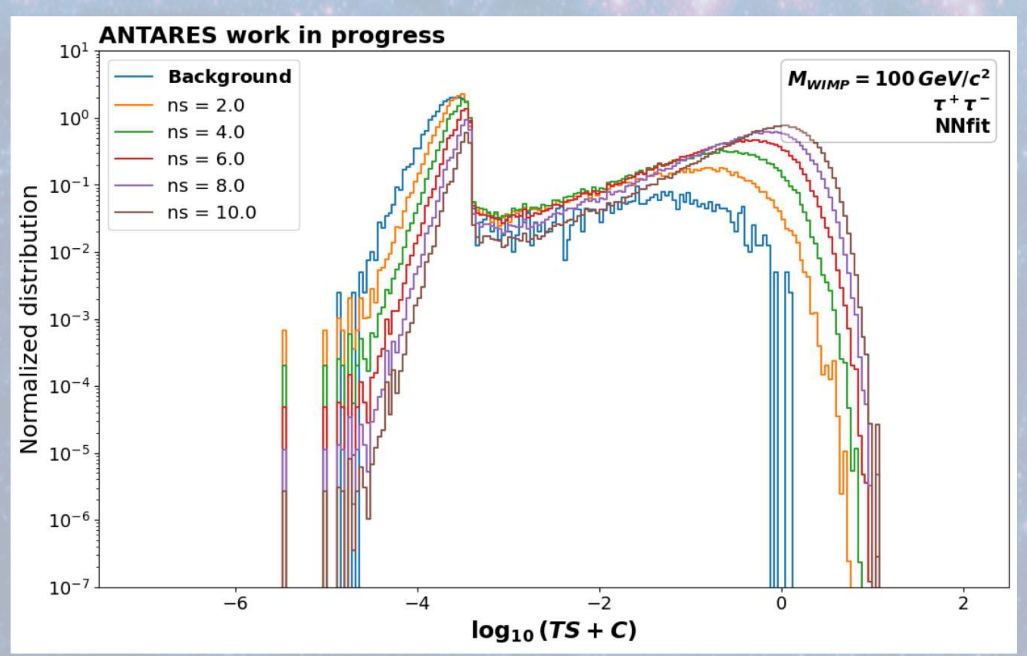
Unbinned Extended Maximum Likelihood

- $S(\Psi, \beta, N)$ Probability Density Function (PDF) for observing an event at an angular distance Ψ from the Sun, for a certain value of β and N_{hits}
- $B(\Psi, \beta, N)$ same but for background
- n_s and n_b are respectively the number of signal and background events
- 15% Gaussian smearing

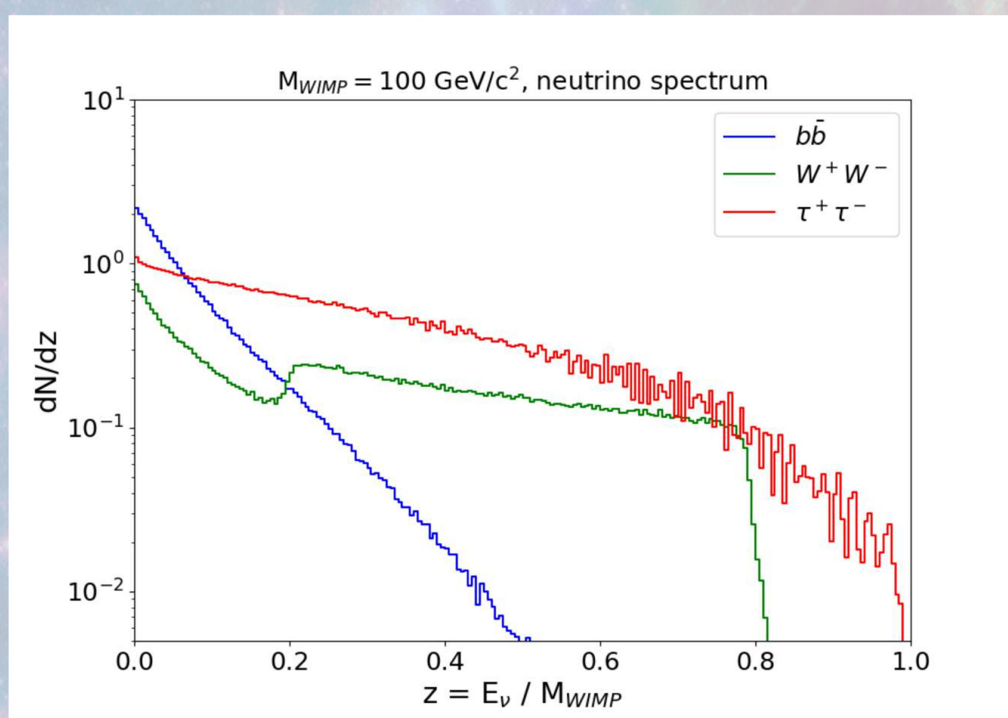
$$\ln L(n_s) = \sum_{i=1}^{N} \ln[n_s S(\Psi_{\odot,i}, \beta_i, N_{hits,i}) + n_b B(\Psi_{\odot,i}, \beta_i, N_{hits,i})] - (n_s + n_b)$$

TS distribution

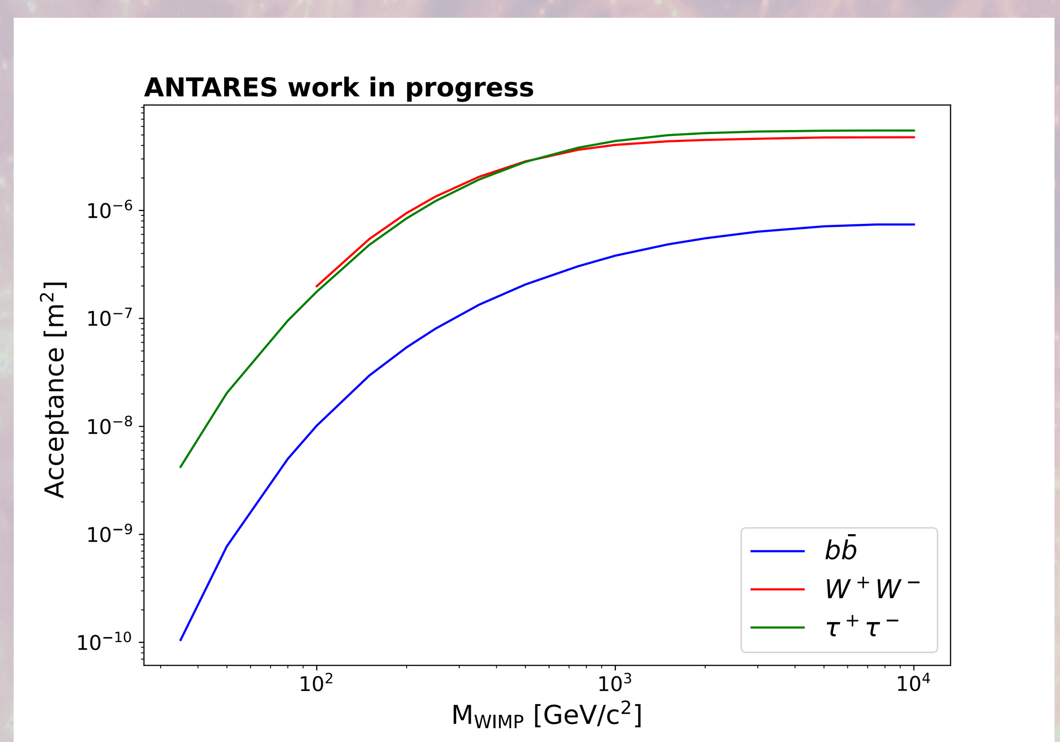
Test Statistics (TS) built to determine the significance of a signal against the background. Ratio of the fitted Likelihood for a certain number of signal events in the dataset over the Likelihood in background-only case (i.e. no signal events injected)



Neutrino Spectrum

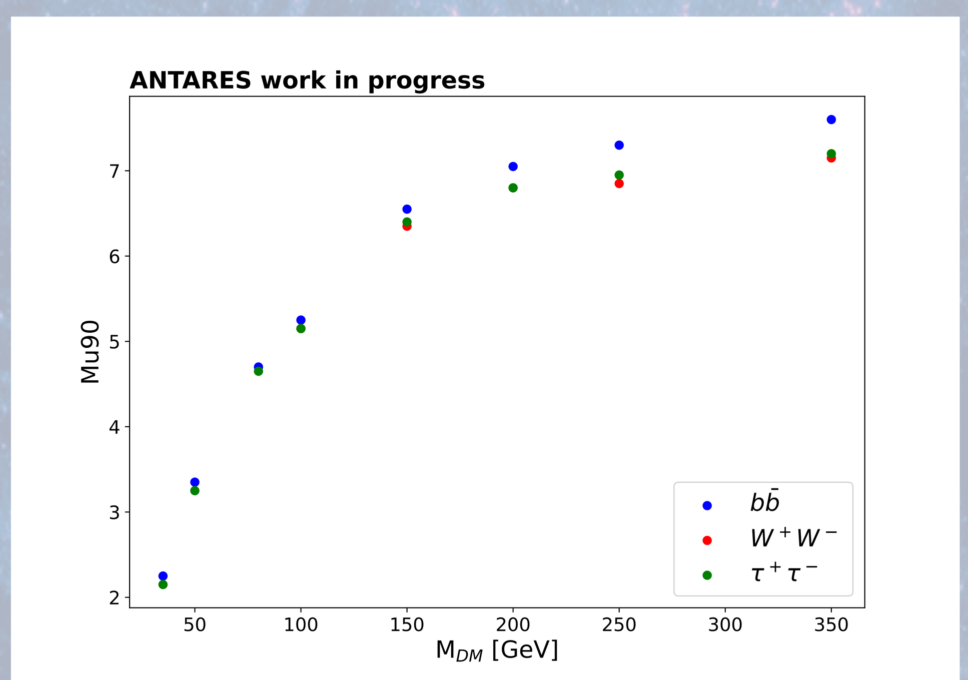


Acceptances



Sensitivity

The 90% upper limit on the number of signal events assuming the background-only hypothesis following the Neyman method.



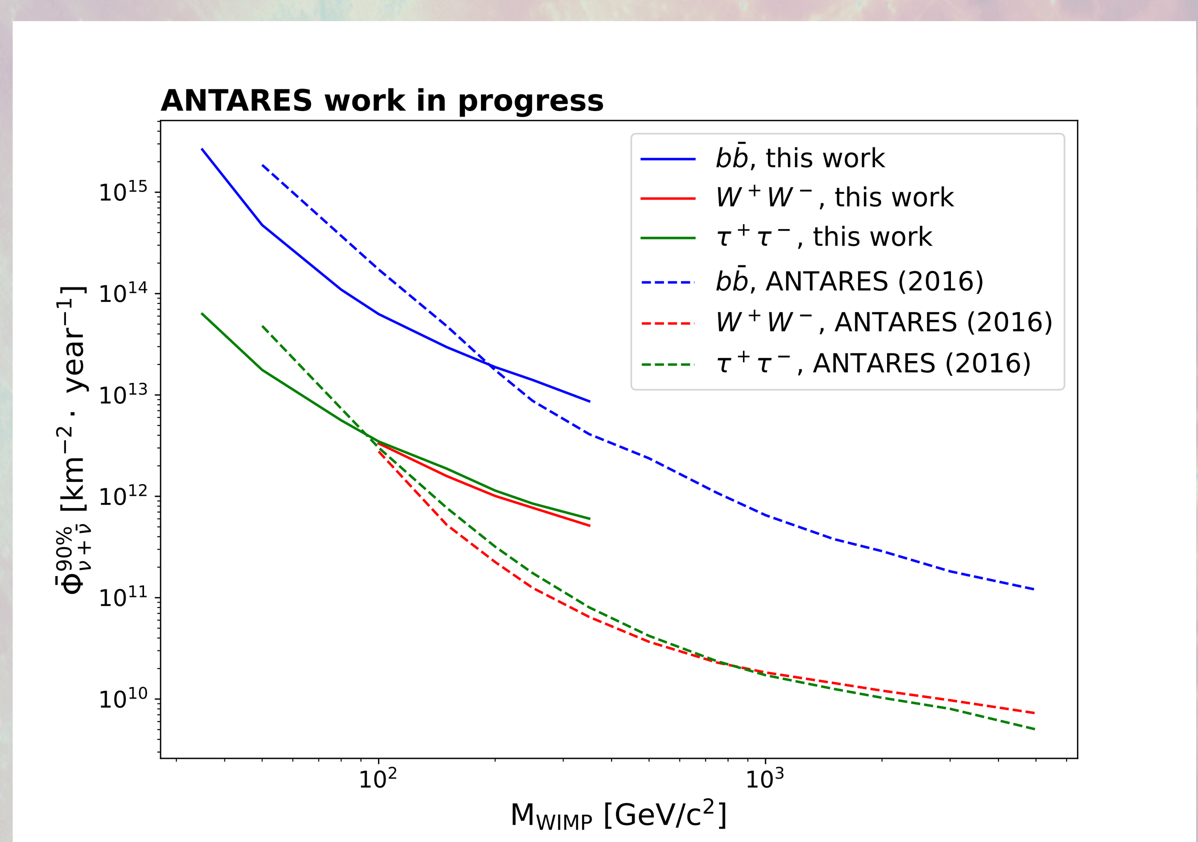
Flux Sensitivities

The flux sensitivities are computed as:

$$\bar{\Phi}^{90\%}_{\nu+\bar{\nu}} = \frac{Mu90}{Acceptance(M_{WIMP}) \cdot T_{eff}}$$

Where T_{eff} is 12.4 years of ANTARES livetime.

The flux sensitivities have been computed for low dark matter masses, ranging between 35 GeV/c² and 350 GeV/c². For these masses the machine learning method (NNFit) has been used. The Sun visibility has been included in the acceptances and in the TS distribution.



Conclusions

This work has obtained interesting results and a great improvement for low dark matter masses, with respect to the old results [2], also thanks to the application of a machine learning methodology (NNFit). Higher dark matter masses (> 350 GeV/c²) are currently under study. The analysis will be further expanded to include all ANTARES events, and the results will be used to test the WIMP-proton scattering cross sections.

[1] M. Ageron et al. [ANTARES], NIM.A 656 (2011). [2] S. Adrian-Martinez et al. [ANTARES], Phys. Lett. B 759 (2016), 69-74 . [3] J. Edsjö, J. Elevant and C. Niblaeus, "WimpSim Neutrino Monte Carlo," http://wimpsim.astroparticle.se. [4] PoS(ICRC2023)1443