3rd GNN Workshop on Indirect Dark Matter Searches with Neutrino Telescope

Granada, 31st March - 1st April 2022

Limits for Dark Matter annihilation in the Sun with ANTARES neutrino telescope

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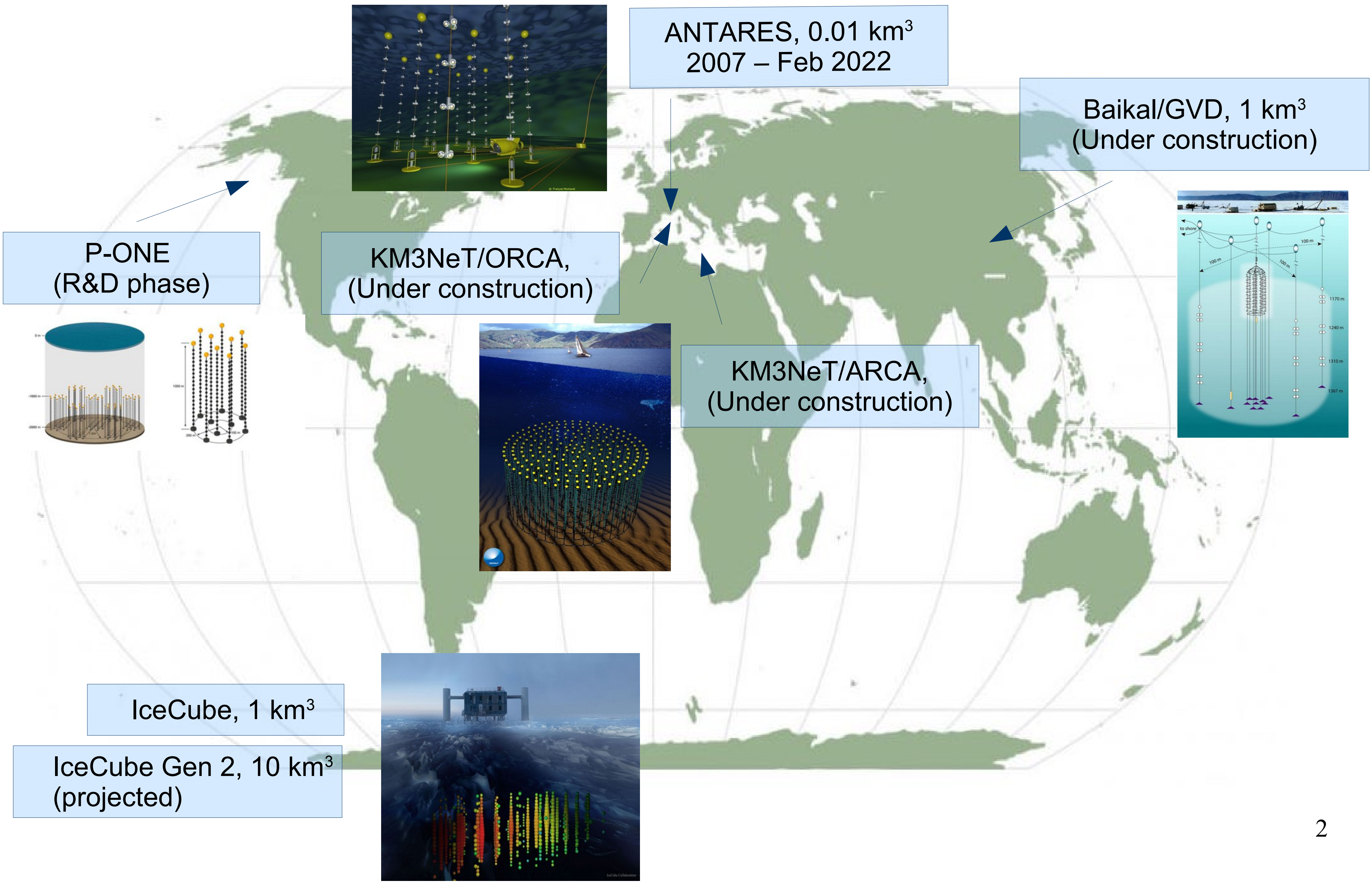
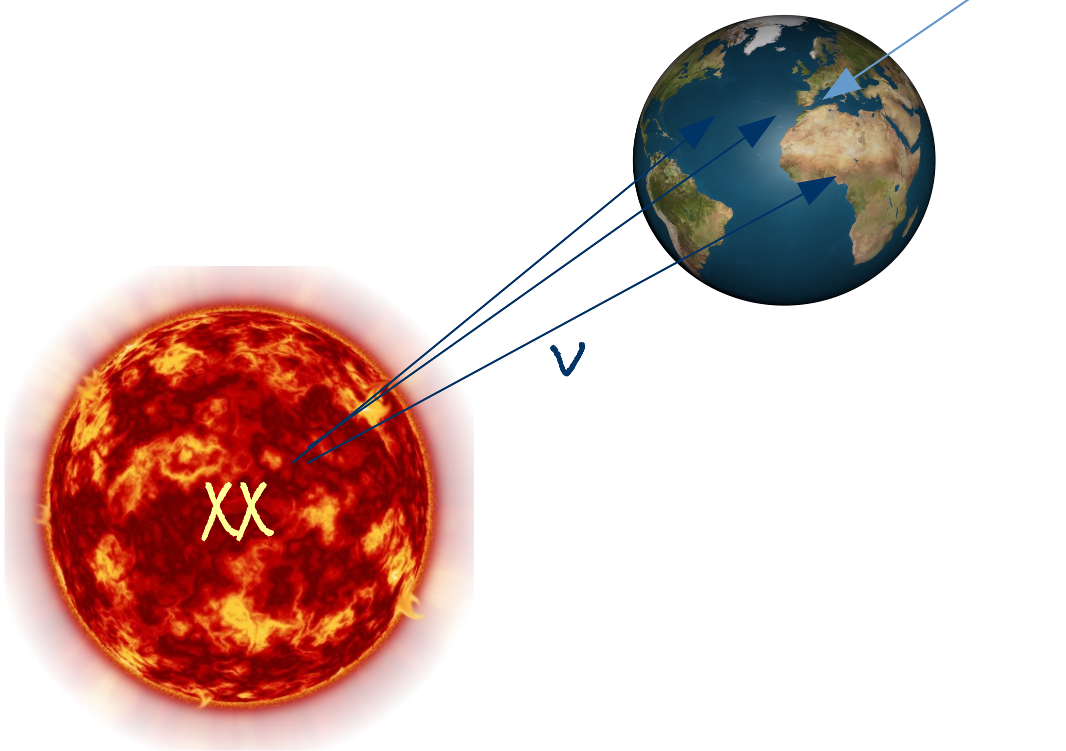
On behalf of the ANTARES Collaboration

Cherenkov Neutrino telescopes around the world

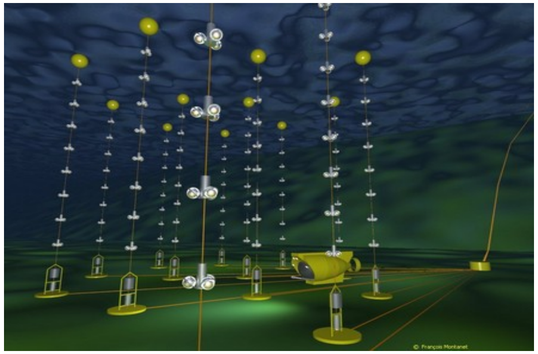


WIMP Dark Matter Indirect Detection

- DM can be captured by massive bodies, such as the Sun
- Inside these bodies, DM can annihilate into Standard Model particles
- These SM particles yield neutrinos

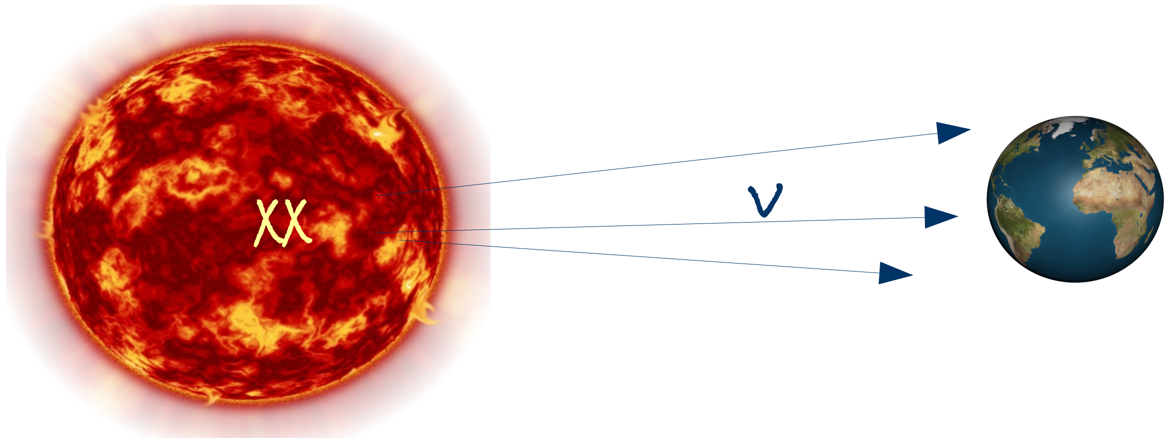


ANTARES Neutrino Telescope



- Neutrinos and anti-neutrinos, all flavours, with energy < 3TeV
- Neutrinos are detected through Cherenkov light emitted by the products (relativistic charged particles) of the neutrino interaction

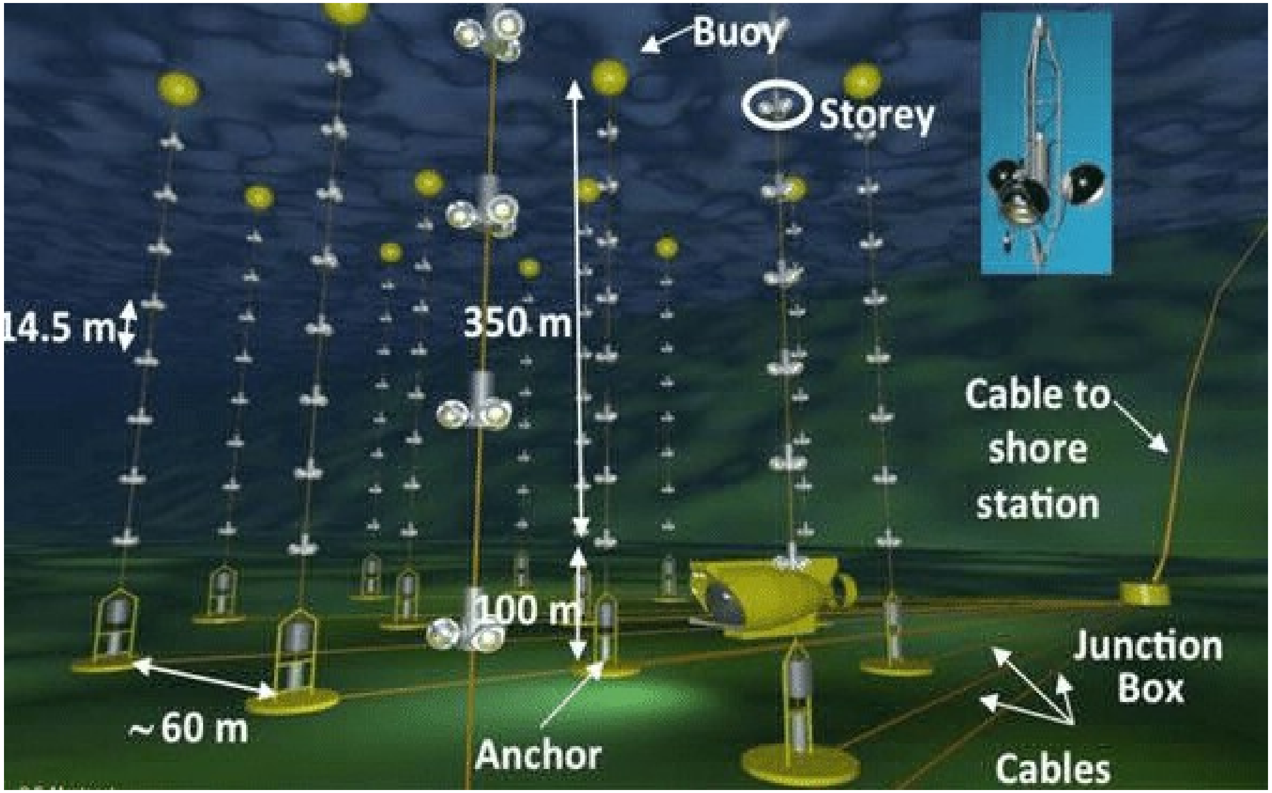
Dark Matter in the Sun



- Differential neutrino flux related to the annihilation rate $$\frac{d\Phi}{dE_\nu} = \frac{\Gamma}{4\pi d^2}\frac{dN_\nu}{dE_\nu}$$
- In equilibrium between capture and annihilation $\Gamma = C/2$ where C is the capture rate
- Neutrino flux is sensitive to DM-nucleon scattering cross-section, both spin-dependent and spin-independent
- Negligible Astrophysical background: Very clean signal $\longrightarrow$ DM interpretation [for neutrino background sensitivities see *Solar atmospheric neutrinos with ANTARES* by D. Lopez-Coto]

ANTARES Neutrino Telescope

- Toulon, France
- Data taking: 2007 → February 2022
- 2500 m depth



- 12 lines
- 25 storeys/line
- 3 PMT/storey (~ 900 PMTs)

This analysis

- This analysis is based on a ***binned method***
- Three channels are considered: $b\bar{b}, W^+W^-, \tau^+\tau^-$ (100% branching ratio)
- Three different *muon reconstruction strategies* have been considered
- The results presented are obtained after *unblinding* ANTARES data for ***2007-2019***

Reconstruction strategies

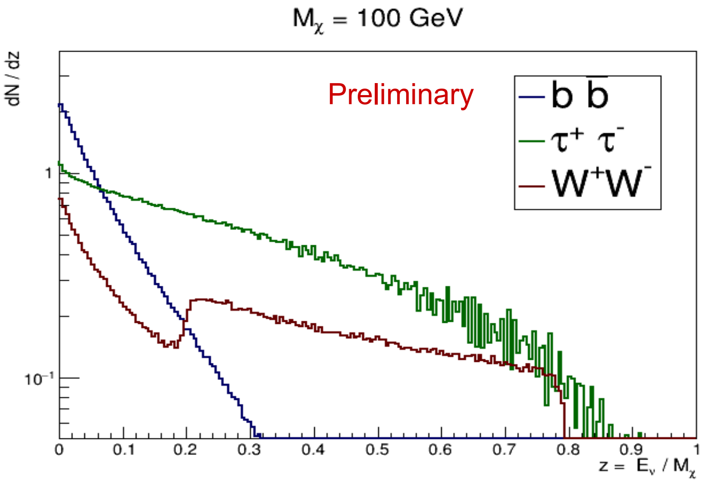
Three different reconstruction strategies have been considered:

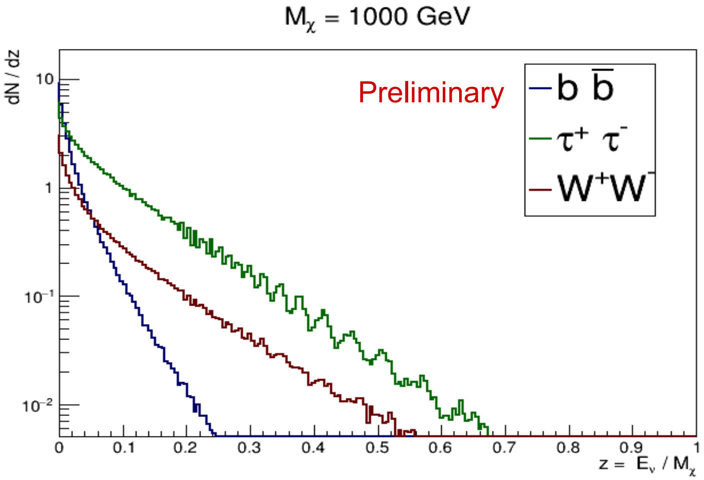
- **AAFit**: performs multiple consecutive reconstruction steps with a maximum likelihood fit as a final step
  $\longrightarrow$ more efficient for DM mass above 250 GeV/c^2
- **BBFit multiline**: performs a χ^2-like fit
  $\longrightarrow$ more efficient for low DM mass
- **BBFit singleline**: performs a χ^2-like fit (only zenith)
  $\longrightarrow$ more efficient for low DM mass

Acceptance

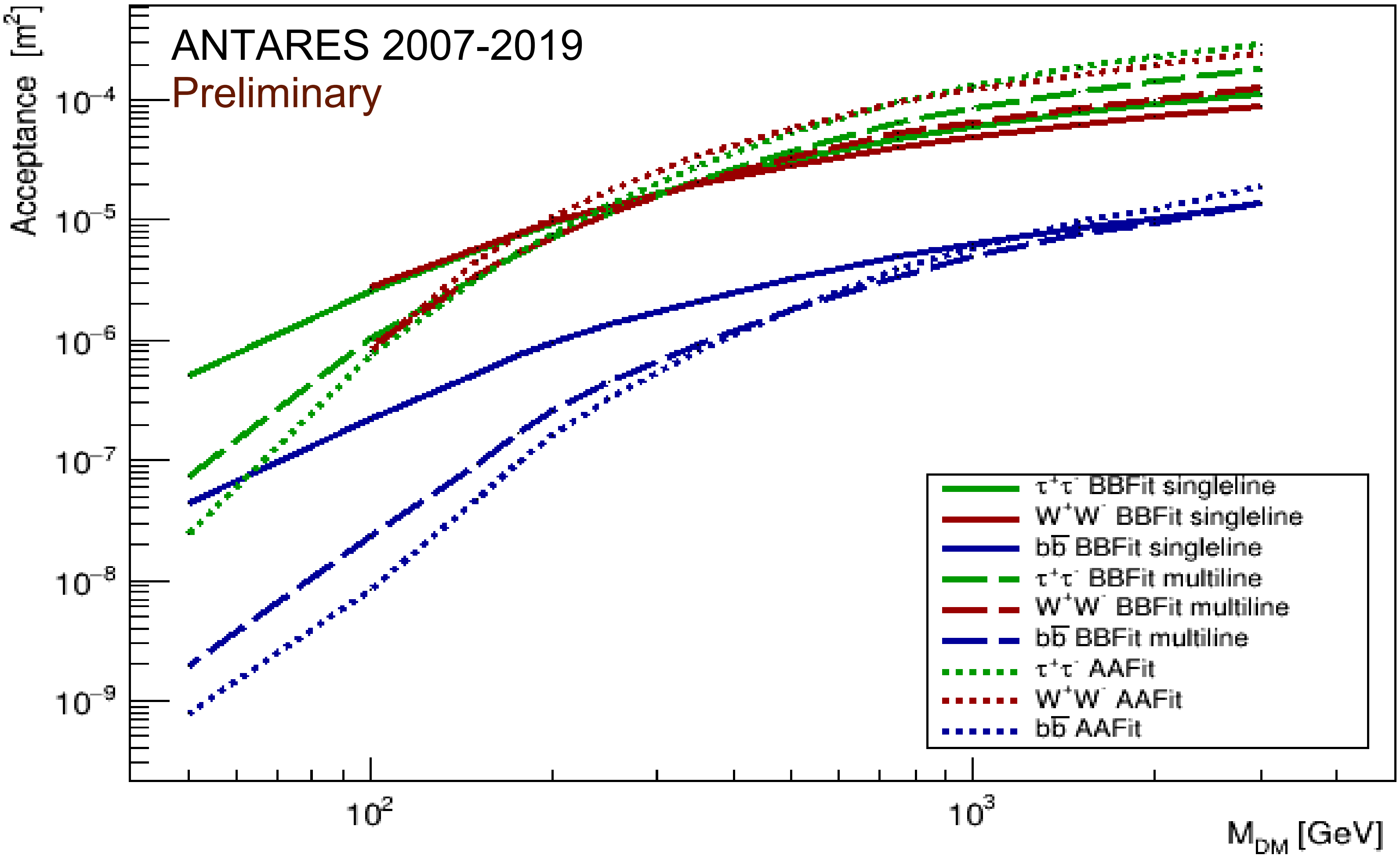
$$Acc(M_{WIMP}) = \bar{A}_{eff}(M_{WIMP}) = \frac{\sum_{j=\nu,\bar{\nu}}(\int_0^{M_{WIMP}} A^j_{eff}(E_j)\frac{dN_j}{dE_j}dE_j)}{\int_0^{M_{WIMP}} \frac{dN_\nu}{dE_\nu}dE_\nu + \frac{dN_{\bar{\nu}}}{dE_{\bar{\nu}}}dE_{\bar{\nu}}}$$

- Annihilation spectrum from WimpSim
- Channels: $b\bar{b}, W^+W^-, \tau^+\tau^-$
- Acceptances are computed for the different Effective Areas, obtained for the best combinations of quality cut parameters





Acceptance



ANTARES 2007-2019
Preliminary
Acceptance [m²]
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10²
10³
M_DM [GeV]
τ⁺τ⁻ BBFit singleline
W⁺W⁻ BBFit singleline
bb̄ BBFit singleline
τ⁺τ⁻ BBFit multiline
W⁺W⁻ BBFit multiline
bb̄ BBFit multiline
τ⁺τ⁻ AAFit
W⁺W⁻ AAFit
bb̄ AAFit

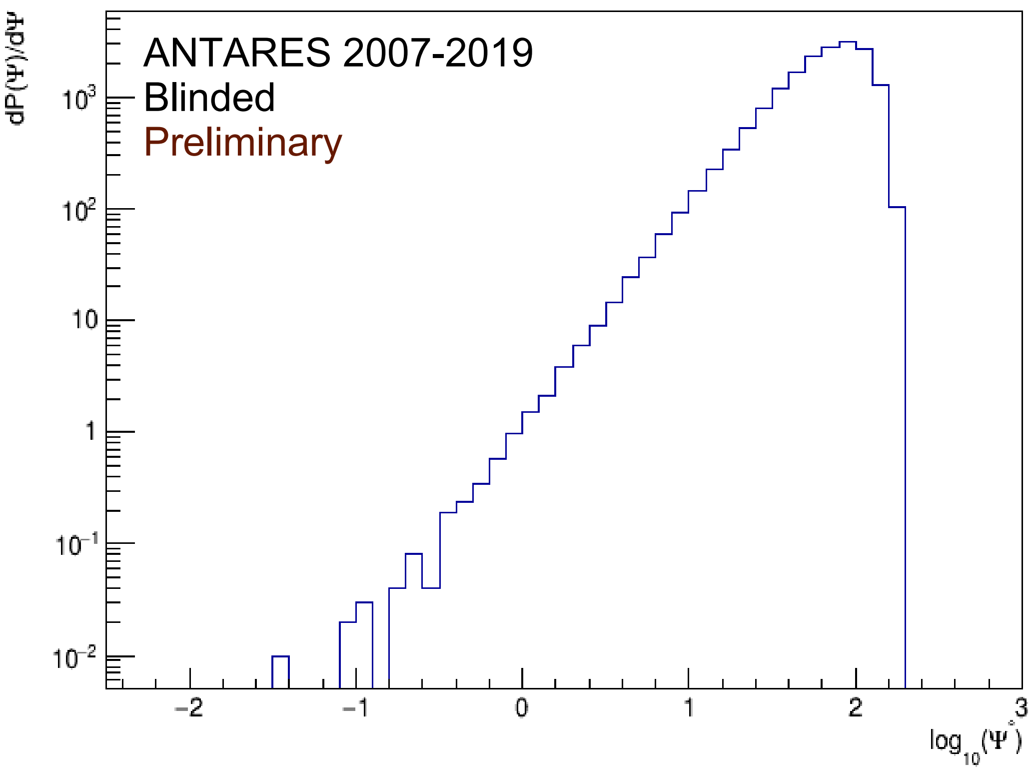
Sensitivity flux

$$\Phi_{\nu_\mu+\bar{\nu}_\mu,90\%} = \frac{\mu_{90\%}}{\bar{A}_{eff}(M_{WIMP}) \cdot T_{eff}}$$

- $\overline{\mu}^{90\%}$ is computed from the background estimation using Feldman&Cousin prescription
  - → The number of background events is estimated from *scrambled data*
- T_{eff} is the *livetime of ANTARES* (2007-2019) → 10.45 years
- Acceptance $\overline{A}_{eff}$

Background

- Scrambling data, generating 100 maps
- The angle ψ is the angular separation between the reconstructed track and the Sun's directions.
- Fit to estimate the number of events for a specific angular separation is done



Example for AAFit, Λ > -5.4

Sensitivity flux

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- $\overline{\mu}^{90\%}$ is computed from the background estimation using Feldman&Cousin prescription
  → The number of background events is estimated from *scrambled data*
- T_{eff} is the *livetime of ANTARES* (2007-2019) → 10.45 years
- Acceptance $\overline{A}_{eff}$
- Optimized using the quality cut parameter and cone angle/zenith band around the Sun

Unblinding results

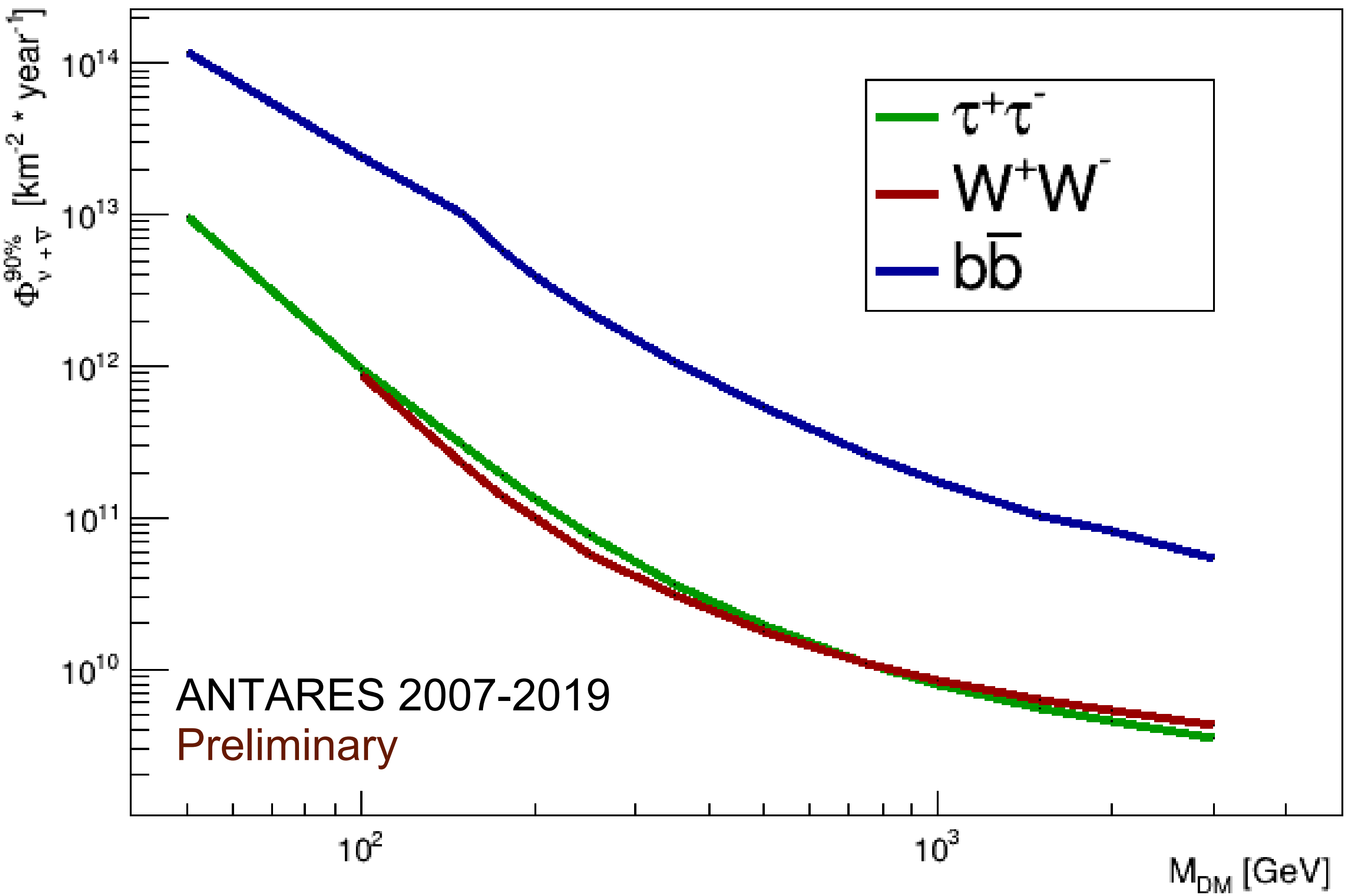
Strategy	Channel	Quality param.	Cone/Band (º)	Observed events	Expected events
AAFit	b,τ,W	Λ = -5.4	3	29	30.31
BBFit	b	$\chi2$ = 1.5	4	20	27.09
multiline	τ	$\chi2$ = 1.5	4	20	27.09
	W	$\chi2$ = 1.5	3	10	15.45
BBFit	b	$\chi2$ = 1.0	8	867	948
singleline	τ	$\chi2$ = 1.0	7	760	827
	W	$\chi2$ = 1.0	6	666	707

No excess of events observed above the expected background

→ upper limits are set to sensitivities

Upper limits

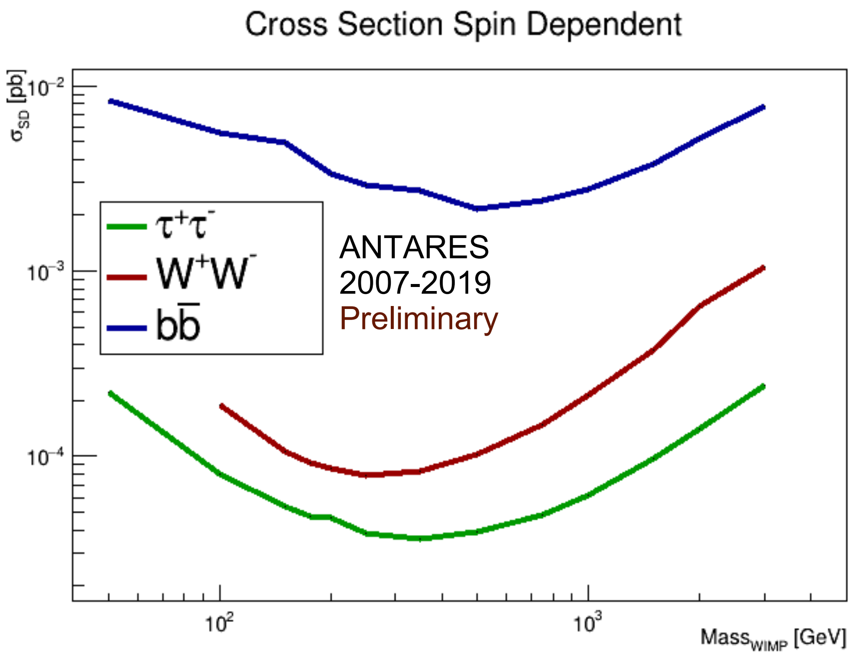
Flux upper limits for neutrinos+antineutrinos from DM in the Sun

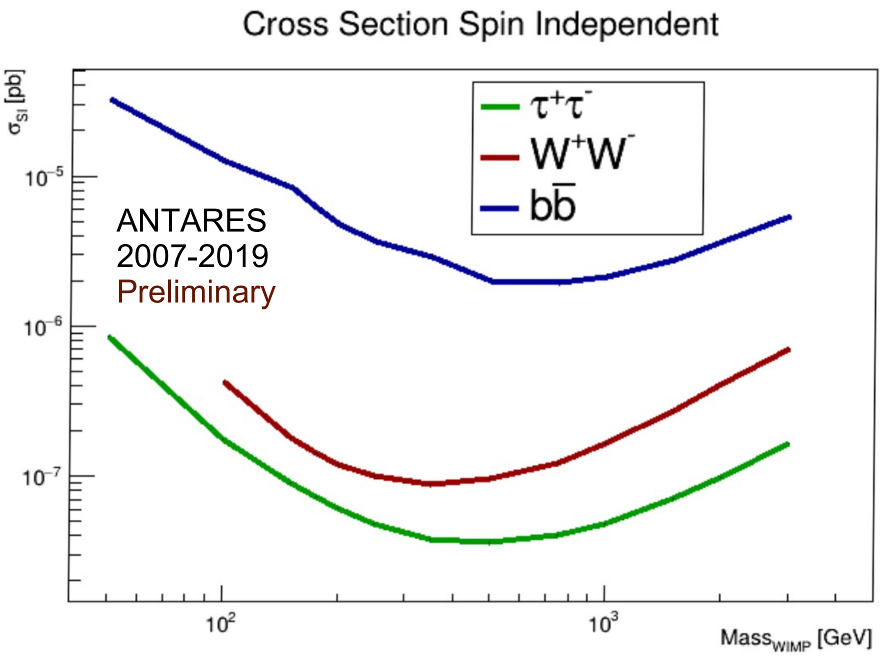


Cross Section

Conversion to limits on WIMP-nucleon SD and SI cross-section using WimpSim, assuming:
→ Equilibrium between capture and annihilation rates inside the Sun.
→ Local WIMP density = 0.4 GeV/cm^3.
→ Maxwellian velocity distribution of WIMPs with r.m.s. = 270 km/s.

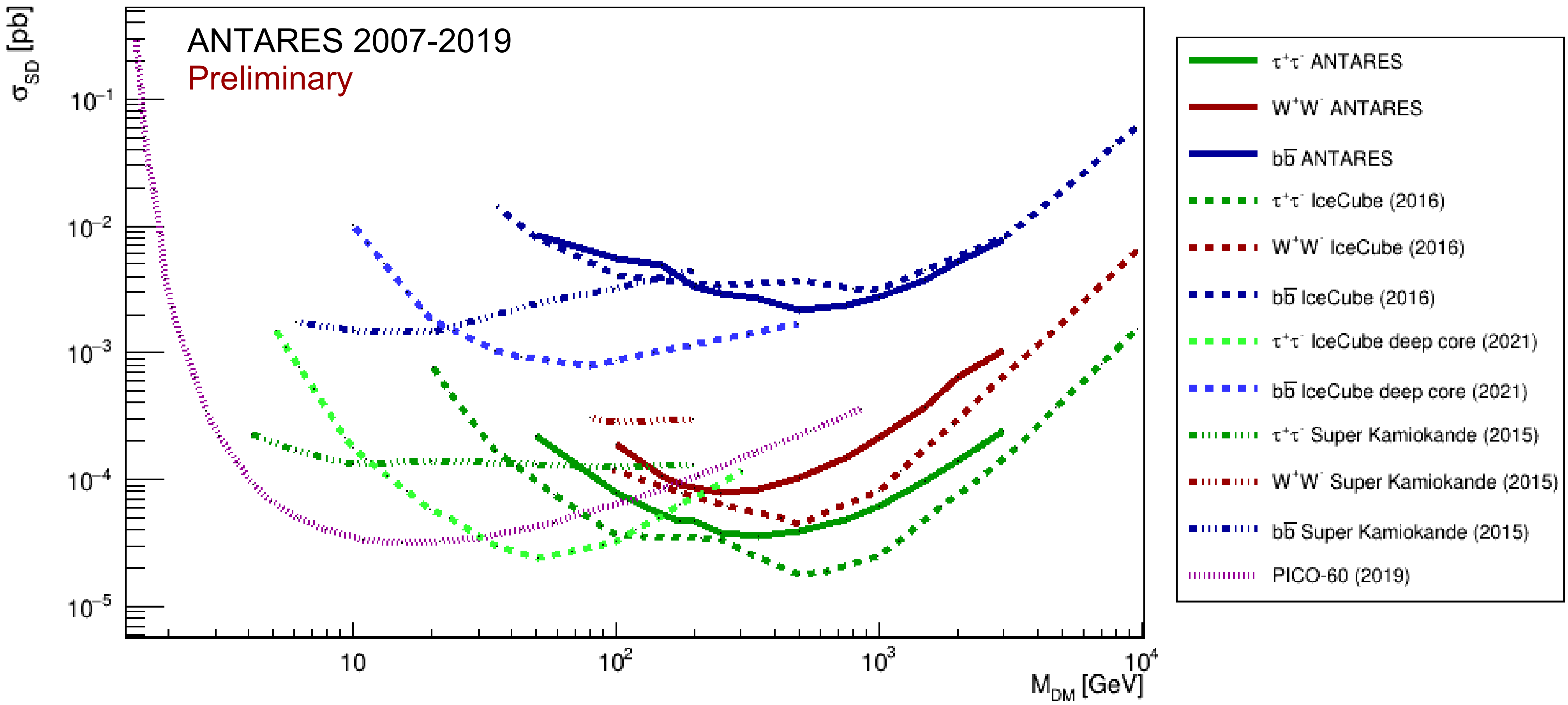
The results obtained in this work improved the last ANTARES publication by a factor of 2





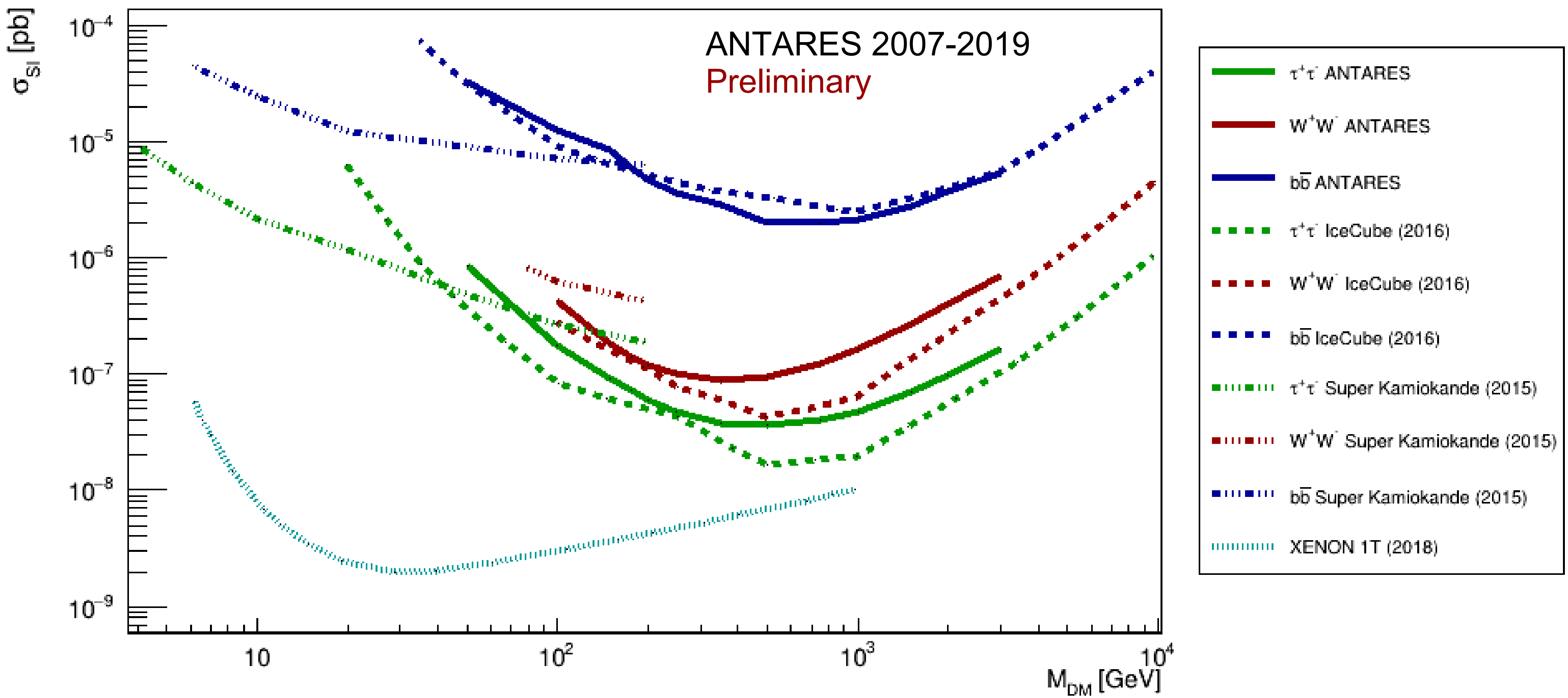
Cross Section Spin Dependent

Limits on the spin–dependent WIMP–nucleon scattering cross section as a function of WIMP mass. Limits given by other experiments are also shown: IceCube, PICO-60, SuperKamiokande.



Cross Section Spin Independent

Limits on the spin–independent WIMP–nucleon scattering cross section as a function of WIMP mass. Limits given by other experiments are also shown: IceCube, Xenon 1T, SuperKamiokande.



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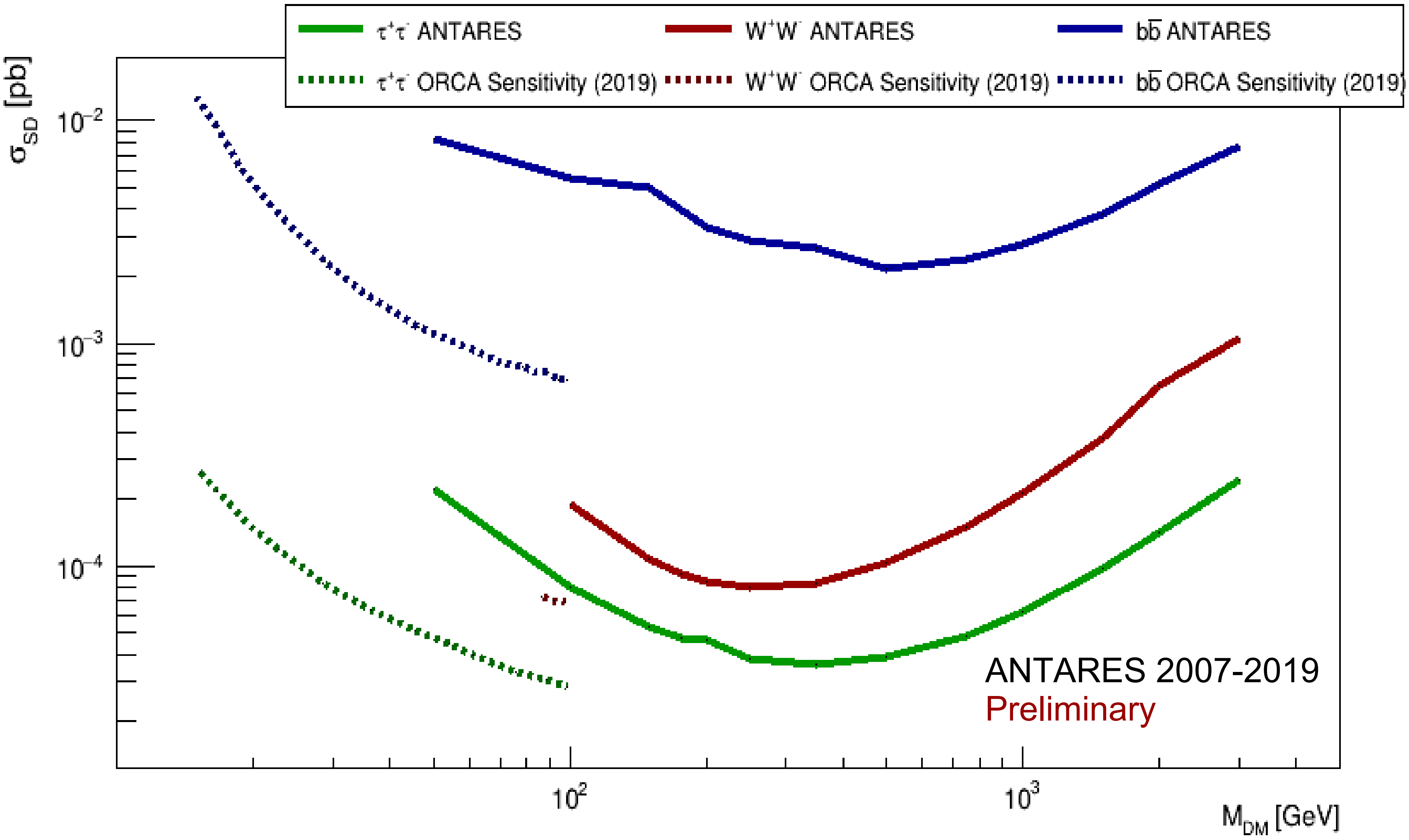
Limits on the spin–dependent WIMP–nucleon scattering cross section as a function of WIMP mass. Sensitivities of ORCA 5 years are also shown.



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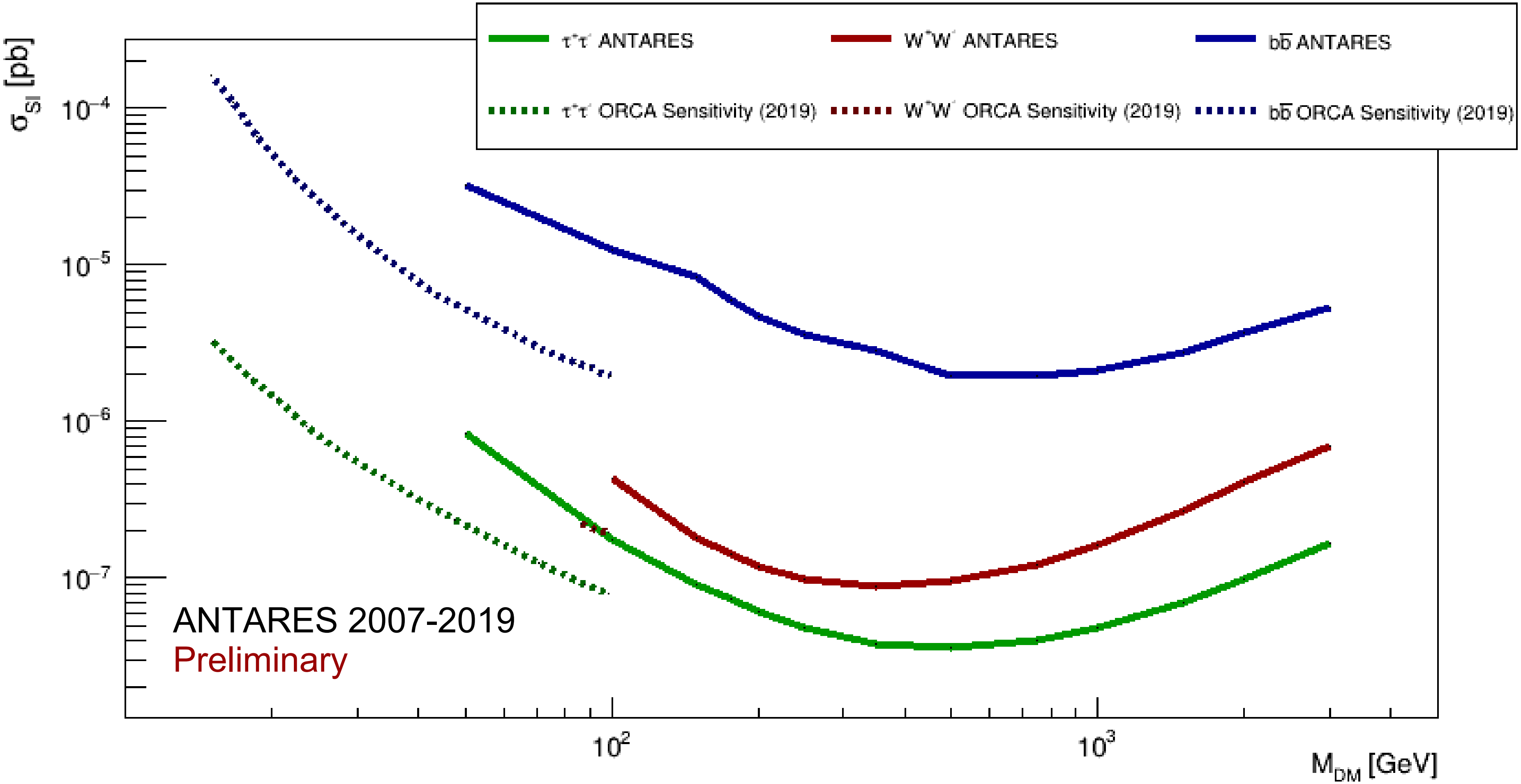


Conclusions

- Presented here are the upper limits related to indirect search of dark matter towards the Sun
- This analysis updates the last ANTARES publication (with the data from 2007 to 2012) up to the end of 2019, improved by a factor of 2

Next steps:

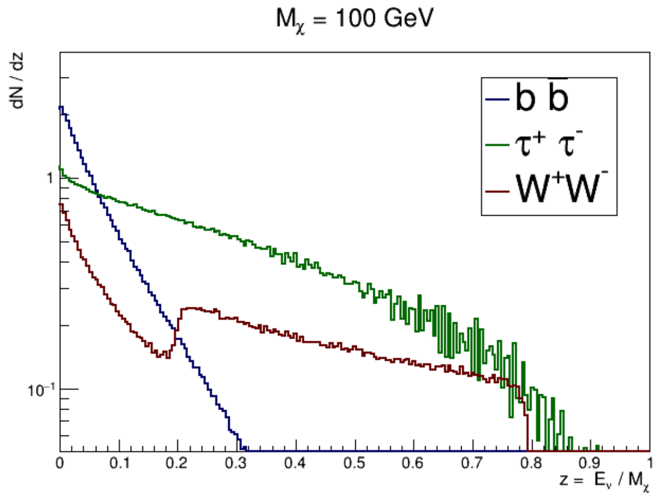
- Article in preparation
- Extend the analysis with the last two years of data taking of ANTARES and also include showers
- Use $\chi arov$ in the prediction of the neutrino spectra to evaluate the differences with WimpSim

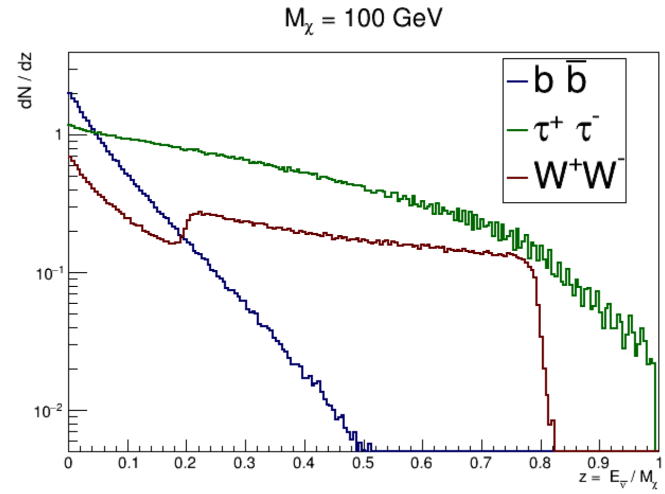
Back up

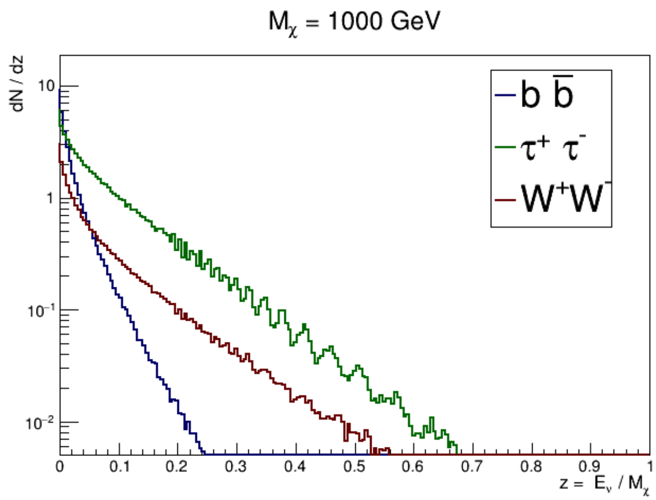
Best strategy for the final Upper limits

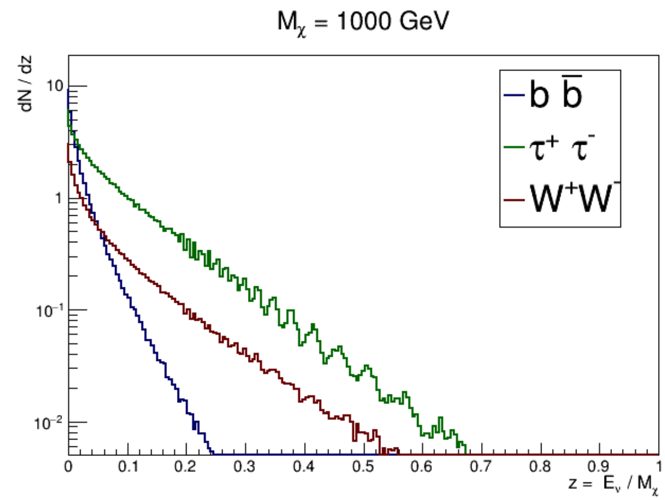
Channel	Strategy	Mass
$b\bar{b}$		
	BBFit singleline	Mass < 150 GeV
	BBFit multiline	150GeV ≤ Mass ≤ 500 GeV
	AAFit	Mass ≥ 750 GeV
$\tau^+\tau^-$		
	BBFit singleline	Mass = 50 GeV
	BBFit multiline	50 GeV < Mass ≤ 176 GeV
	AAFit	Mass ≥ 200 GeV
W^+W^-		
	BBFit singleline	NO
	BBFit multiline	100 GeV ≤ Mass ≤150 GeV
	AAFit	Mass ≥ 176 GeV

Spectra
Neutrinos vs. Anti-Neutrinos









Abstract

One of the most popular candidate of Dark Matter (DM) particle are the Weakly Interacting Massive Particles(WIMPs). These, once gravitationally captured in massive celestial objects and annihilating between them into Standard Model particles, can be indirectly detected. The centre of those massive objects is, therefore, a place where to look for a possible neutrino excess from DM annihilations using neutrino telescopes. The closest of such potential astrophysical DM sources is the Sun.

The ANTARES deep-sea neutrino telescope, located in the Mediterranean Sea, best performs in indirect searches for neutrino signals from DM annihilation in the 100 GeV to 1 TeV energy range.

In this work the results from the search for WIMPs towards the Sun direction, using 13 years of data collected by ANTARES telescope are presented.

Upper limits on the WIMP – nucleon cross section are obtained for DM mass in the range from 50 GeV/c^2 to 3 TeV/c^2 , improving the results of the last ANTARES publication by more than a factor of two.