Combined WIMP search from the Galactic Centre with ANTARES and IceCube

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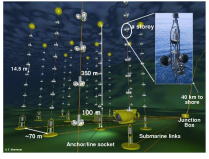
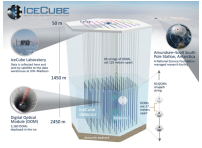
Analysis idea

Relic WIMPs accumulate in massive celestial bodies like the GC (dec = -29°, Southern Hem.)

- below horizon for ANTARES = ✓Earth is muon filter
- above horizon for IceCube: event selection is based on DeepCore data + IceCube veto



12 lines between 2 and 2.4 km underwater



86 strings between 1.5 and 2.5 km in ice

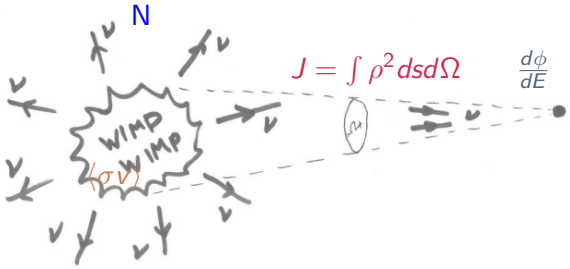
Data sets

Exchange of following data sets between the collaborations was approved

- ANTARES
  - Lifetime: 2101.6 days from 2007 to 2015
  - Split into low-energy and high-energy sets according to two reconstruction algorithms
- IceCube:
  - Lifetime: 1006 days from May 2012 to May 2015
  - Official IC86 GC WIMP search data set

ANTARES PDFs $\rightarrow$ IceCube, ANTARES acceptances to pre-agreed spectra $\rightarrow$ IceCube $\rightarrow$ sensitivity estimate $\rightarrow$ revision in both collaborations $\rightarrow$ actual data exchange $\rightarrow$ limits

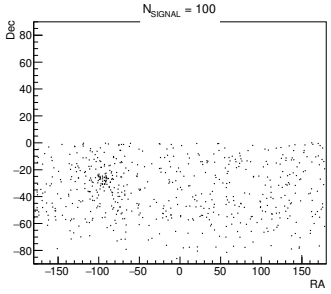
Signal: neutrinos from WIMP pair collision



$$\frac{d\Phi}{dE} = \frac{\langle\sigma v\rangle}{2} \frac{dN}{dE} \frac{J}{4\pi} \frac{1}{M_\chi^2} \qquad \mu_{90} = \int_0^M \frac{d\Phi}{dE} \mathcal{A}cc(M_\chi)\, t\, dE$$

flux at Earth = annihilation rate * number of ν per collision * source geometry

Signal: neutrinos from WIMP pair collision: find cluster



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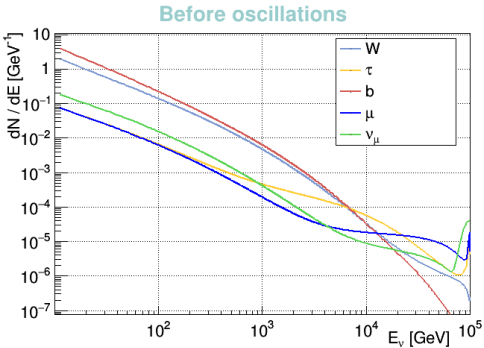
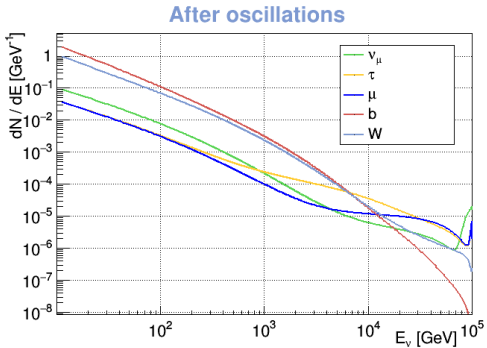
flux at Earth = annihilation rate * number of ν per collision * source geometry

WIMP annihilation spectra

Both collaborations have converged on the use of PPPC4 [arXiv:1012.4515] + long-baseline oscillation. Previous IceCube analysis were based on PYTHIA.

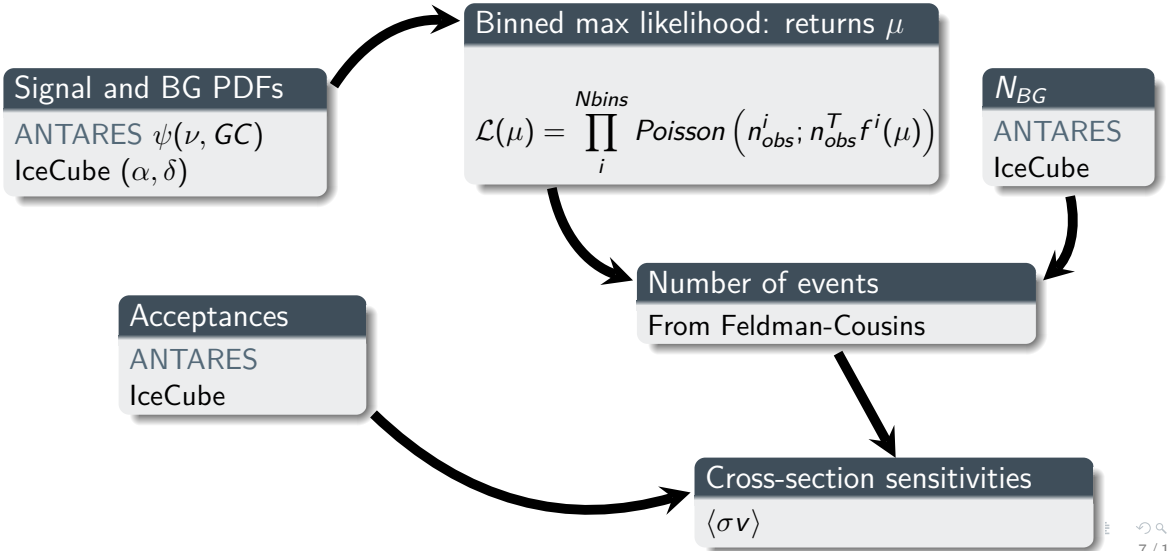


Source

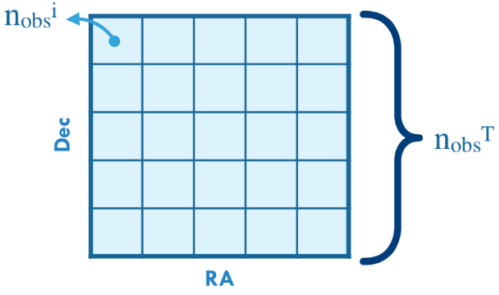


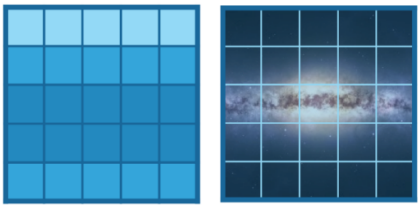
Earth (oscillated)

Analysis workflow



Binned likelihood method





Minimise $-\log \mathcal{L}(\mu)$

$$\mathcal{L}(\mu) = \prod_{i}^{Nbins} Poisson\left(n^i_{obs}; n^T_{obs} f^i(\mu)\right)$$

n^i_{obs} = oberved events in bin i
n^T_{obs} = total expected events
$f^i(\mu) = \mu f^i_s + (1-\mu) f^i_{bg}$

Free parameter $\mu = \frac{n_{sig}}{n^T_{obs}}$ in [0,1]

f_s, f_{bg} probability density functions for signal and background

[Main analyser: N. Iovine, UL Brussels]

Combined likelihood

Two-component mixture model to combine the sensitivities of IceCube and ANTARES

$$\mathcal{L}_{comb}(\mu) = \prod_{k=A,I} \mathcal{L}_k(\mu_k)$$

maximisation variable μ is the ratio of the number of signal events over the total number of background events in the sample n_{obs}^{T}. Differences

- Standard ANTARES analysis: unbinned; here: binned
- Standard ANTARES analysis: Neyman, here: Feldman-Cousins

Combined likelihood

$$-\log \mathcal{L}_{comb}(\mu) = -\log \mathcal{L}_A(\mu_A) - \log \mathcal{L}_I(\mu_I)$$

Minimize a single parameter $\mu = \frac{n_s}{n_T} = \frac{n_s^A + n_s^I}{n_T^A + n_T^I} = \frac{n_s(f_s^A + f_s^I)}{n_T(f^A + f^I)}$

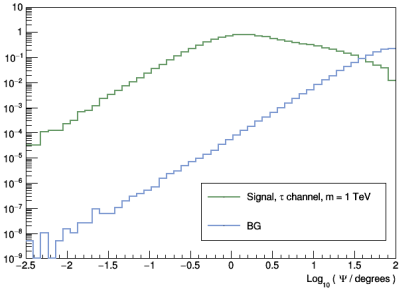
$$\mu_i = \frac{n_s^i}{n_T^i} = \frac{f_s^i n_s}{f^i n_T} = \frac{f_s^i}{f_i}\mu$$

IceCube: $$n_{sig}^{ICE} = \sum \frac{1}{4\pi m_{WIMP}^2} \frac{\langle \sigma v \rangle}{2} \frac{w_{OW}}{N_{gen}} \frac{dN}{dE} \int \rho^2 ds$$

ANTARES: $$n_{sig}^{ANT} = \frac{1}{4\pi m_{WIMP}^2} \frac{\langle \sigma v \rangle}{2} t \langle \mathcal{A}_{eff} \rangle \Phi^{INT} J$$

PDFs ANTARES → IceCube

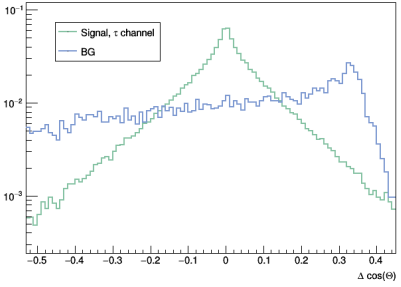
For binned analysis, same variable for signal and BG.



AAFit

$\log_{10}(acos(v_{track} \cdot v_{GC}))$

v is direction versor

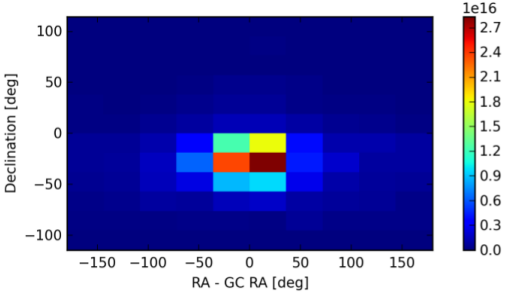


BBFit single line

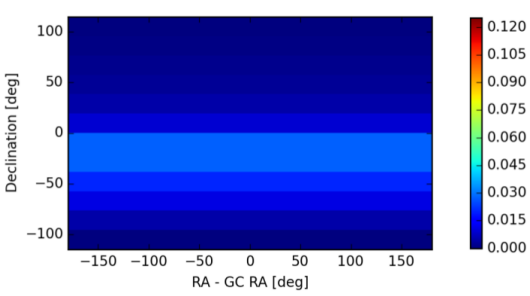
$\cos(\theta_{track}) - \cos(\theta_{GC})$

θ is zenith

PDFs IceCube



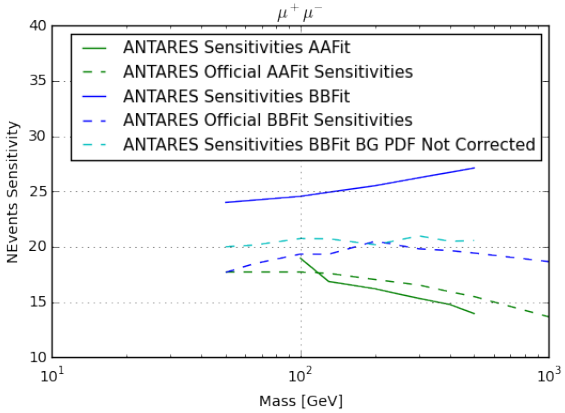
Signal

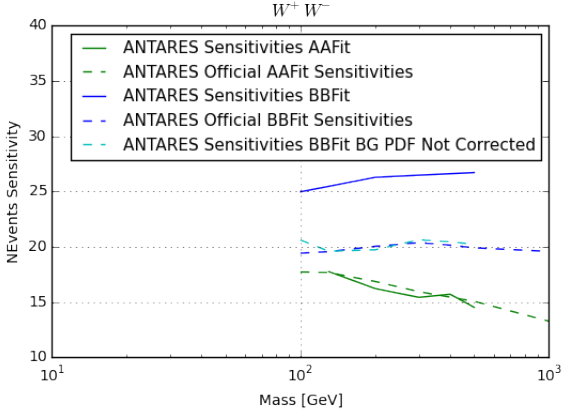


BG

ANTARES Sensitivity: number of events

ANTARES sensitivity is succesfully reproduced with IceCube method, both in number of events and in annihilation cross-section.





ANTARES Sensitivity: cross-section

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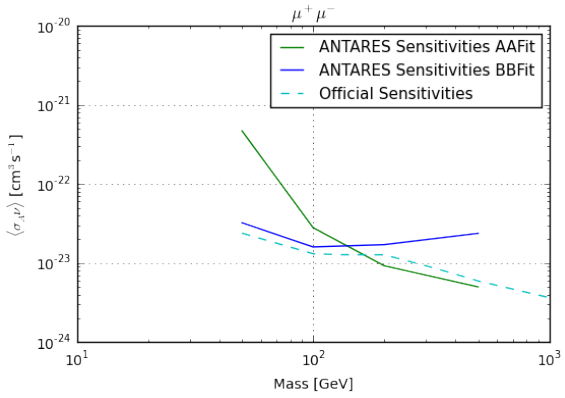
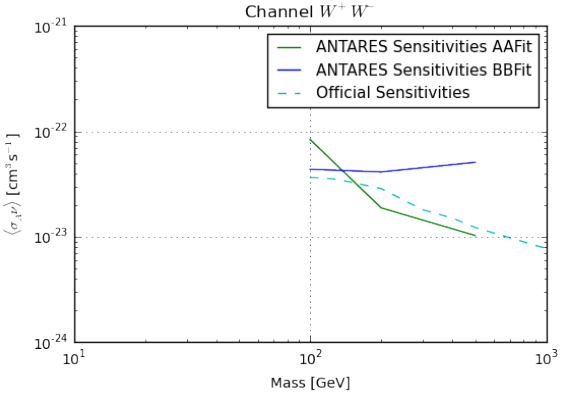
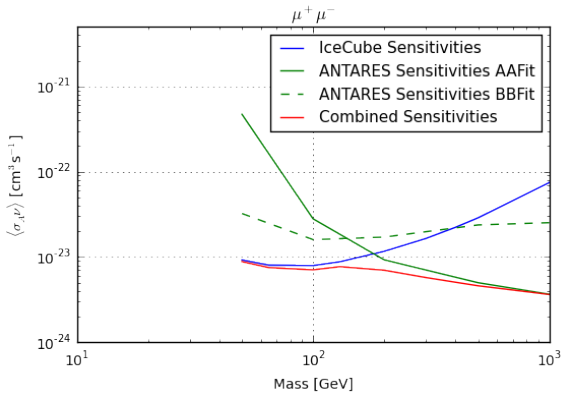
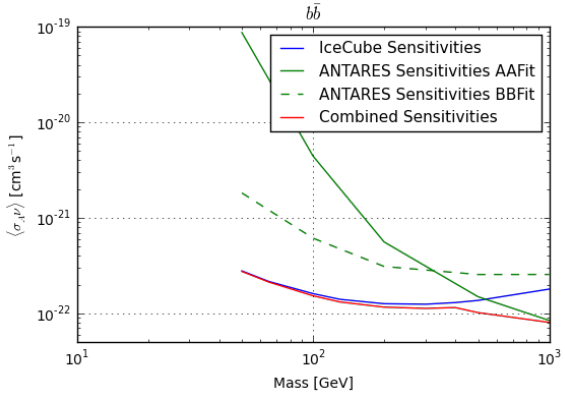




Combined Sensitivity ANTARES + IceCube





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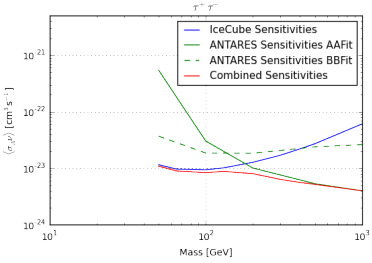

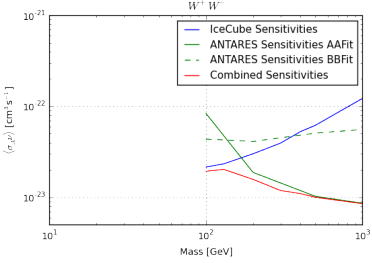

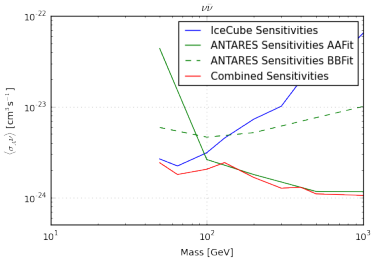

Status / Conclusions

Combination of different experimental datasets reaches down to **better sensitivity**, but also allows for **unification of analysis procedure** and **better control of analysis details**

- Between 65 GeV and 1 TeV an improvement was achieved with respect to the sensitivities of ANTARES and IceCube
- Results are in review within IceCube and unblinding outcome will be presented at ICRC

A powerful way to maximally exploit existing data! Strategy to follow for future analyses.

Atlas of neutrino telescopes