Search for dark matter with the ANTARES and KM3NeT neutrino telescopes

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on behalf of the ANTARES and KM3NeT Collaborations

36th ICRC

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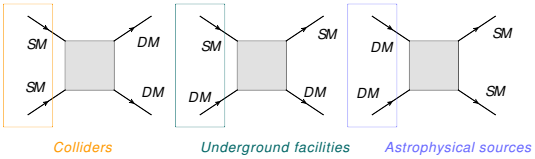
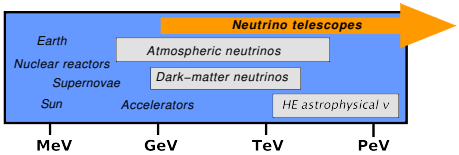
Dark-matter signals at neutrino telescopes

Dark-matter candidate particle is searched with complementary methods





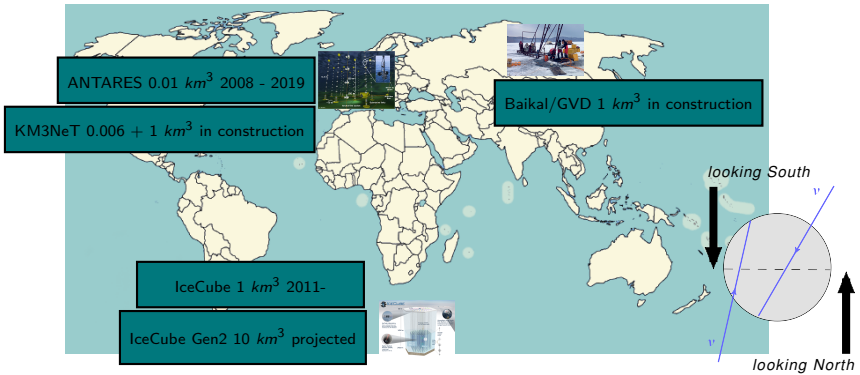
Indirect searches

1. look into potential dark-matter sources in astrophysical environment: typically Dwarf Spheroidal Galaxies, Galaxy Clusters, Galactic Centre, Sun, Earth
2. aim at measuring Standard Model products of annihilation or decay
3. contain large uncertainties and many parameters

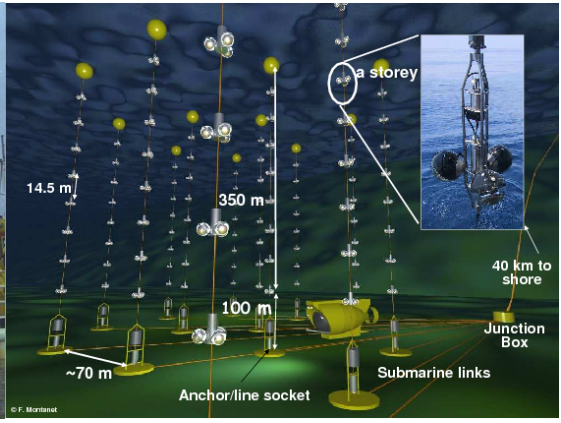
Signal is elusive! Cross-analysis is required to go for an **unambiguous identification**.
Combined efforts necessary to push **limits** to new regions of the parameters space

Neutrinos as dark-matter messengers

1. Reduce the problem of *source confusion* in regions like the Centre of the Milky Way
2. Need no dedicated data set!



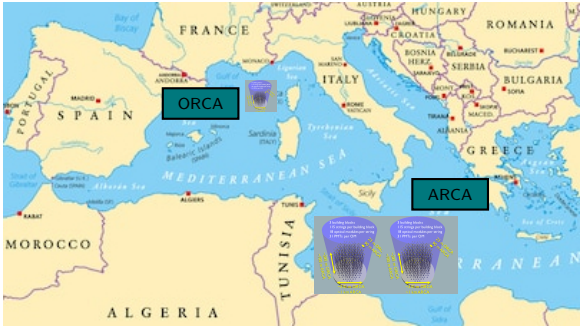
The ANTARES neutrino detector

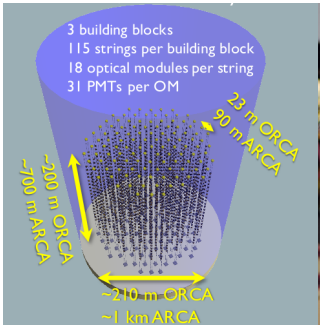


40 km offshore Toulon, 12 lines, 885 PMTs, 2500 m depth, more than 12 years of operations

The KM3NeT neutrino detector

Currently being deployed in French and Italian sites with phased installation scheme



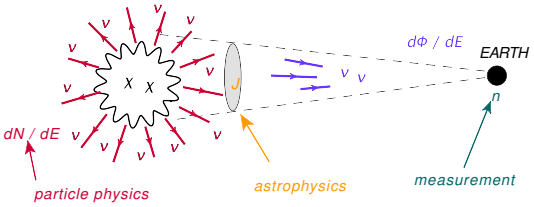


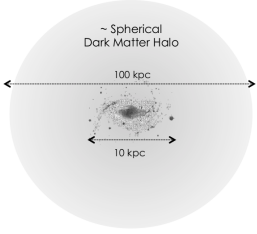
1. ORCA: 1 small, dense block for oscillations and mass hierarchy with atmospheric ν
2. ARCA: 2 large, sparse blocks for astrophysics

Both suitable for dark-matter searches (being candidate particle mass fairly unconstrained)

ANTARES: Galactic Centre

Favourable source: (1) largest dark-matter density and (2) in the Southern Hemisphere





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

flux = number of events observed / acceptance * lifetime = annihilation rate[1] * average number of particles per collision * source geometry

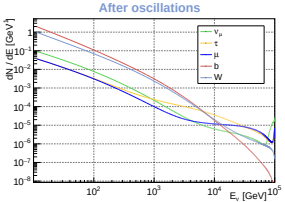
[1] in the above formula: for Majorana self-conjugated WIMPs

Search input and setup

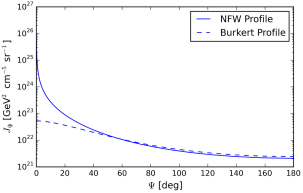
Data set: 11 years (3170 days lifetime), two algorithms for track (ν_μ CC) reconstruction.

Dark-matter signal is reproduced with PPPC4[1] and different models for J-Factor[2] as a cluster of events around the source position, searched for with *unbinned likelihood method*.

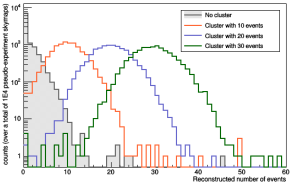
$$\log \mathcal{L}(n_s) = \sum_{i=1}^{N} \log \left[n_s \, \mathrm{S}(\psi_i, N^i_{\mathrm{HITS}}) + n_{bg} \, \mathrm{B}(\delta_i, N^i_{\mathrm{HITS}}) \right] - n_{bg} - n_s$$



Energy distribution



Morphology



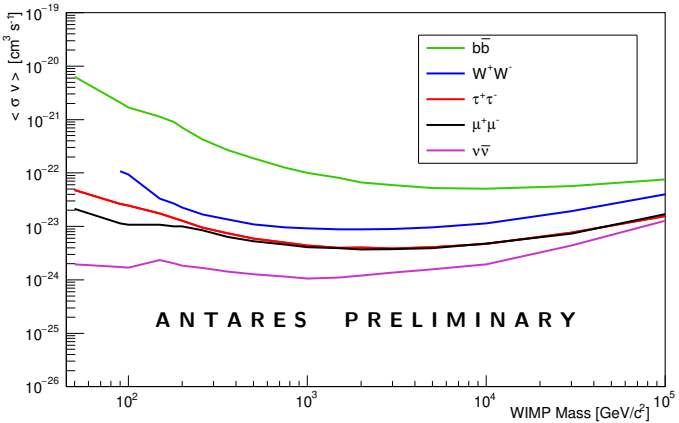
Pseudo-experiments

Background is described with right-ascension shuffled (*blind*) data

[1] http://www.marcocirelli.net/PPPC4DMID.html [2] Burkert [ApJ 1995], NFW [ApJ 1996], McMillan [MNRAS 2017]

Unblinding results

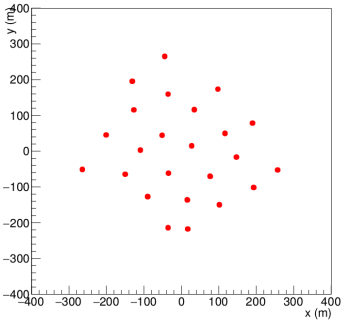
The test statistic for 11 years of ANTARES data is compatible with background

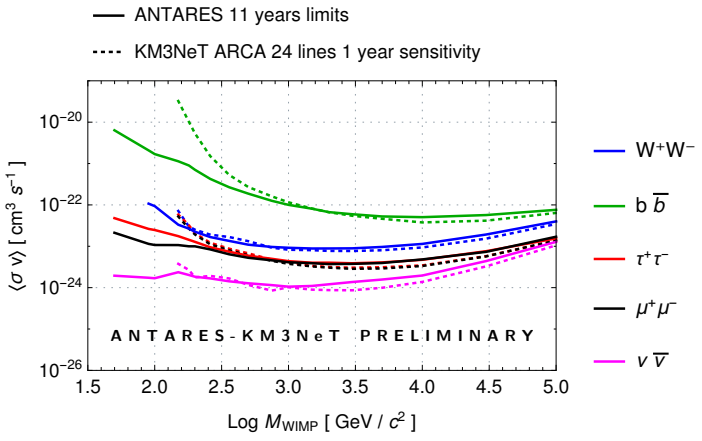


Upper limits on $\nu_\mu + \bar{\nu}_\mu$ flux at 90% CL are converted into limits on the thermally averaged annihilation cross section for WIMP pair annihilation $\langle \sigma v \rangle$, for five channels inspected.

Sensitivities of KM3NeT-ARCA for the Galactic Centre

Preliminary study done with a first installation phase of ARCA (24 lines). With 1 year of lifetime, similar level to current ANTARES limits can be reached.





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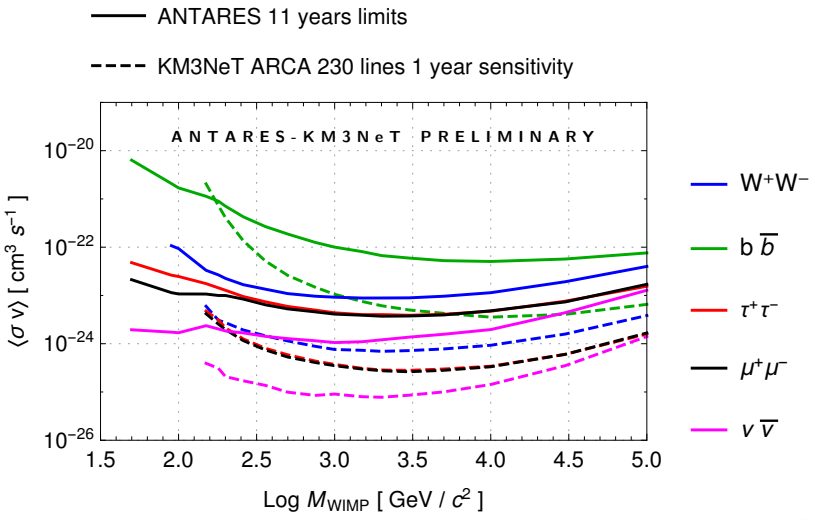
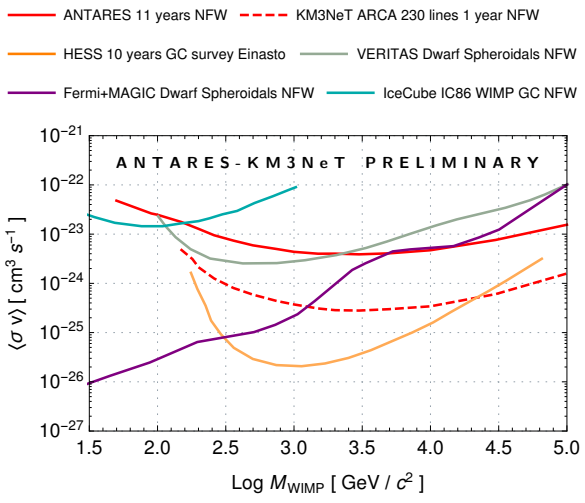


Summary of Galactic Centre results

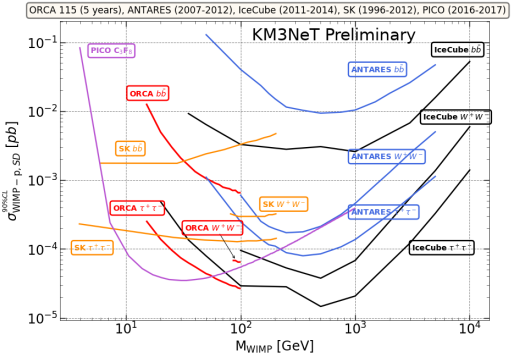


Searches towards the Sun

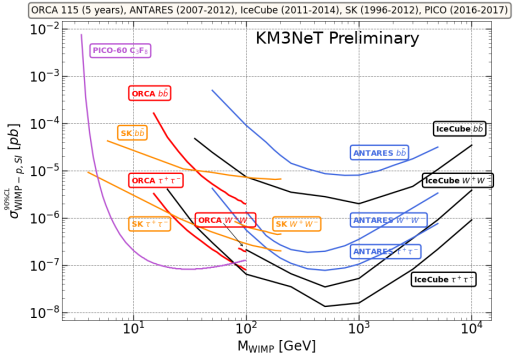
- Sensitive to DM-nucleon scattering cross-section, spin-dependent and spin-independent
- Differential neutrino flux is related with the annihilation rate $\frac{d\Phi}{dE_\nu} = \frac{\Gamma}{4\pi d^2}\frac{dN_\nu}{dE_\nu}$
- In equilibrium between capture and annihilation $\Gamma = C/2$ with C capture rate
- Very clean: if signal $\rightarrow$ direct interpretation (astrophysical background well known)
- Less affected by halo uncertainties (point-like extension)
- Signal from moving source: bias-free
- Searches with neutrino telescopes are sensitive at low velocities (= easier capture)

Searches towards the Sun with KM3NeT-ORCA: sensitivities

WIMP-proton scattering cross-section. Red lines are 5 years of ORCA simulated data.
For analysis details see PoS(ICRC2019)536 and poster by D. Lopez-Coto and S. Navas



Spin-dependent



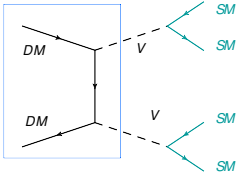
Spin-Independent

Other dark-matter analyses

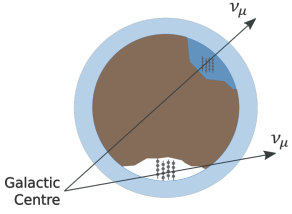
Heavy sectors can provide DM candidates beyond the TeV scale. Extension to high-energy searches with *secluded* DM scenarios:

- evade unitarity bound ($\Rightarrow$ limits on DM mass) with a modified cosmology implying a change of freeze-out point [3]
- DM is secluded from SM particles by new on-shell mediator

For details see PoS(ICRC2019)519 and poster by S.R. Gozzini, F. Sala, C. Lagunas and J. Zornoza



[3] M. Cirelli, Y. Gouttenoire, K. Petraki, F. Sala, JCAP, 2019



Combined DM search with ANTARES and IceCube, in a range between 50 GeV and 1 TeV where sensitivities are comparable. For details see PoS(ICRC2019)552 and talk by N. Iovine.

Summary of ANTARES and KM3NeT dark-matter searches

Results with ANTARES and KM3NeT on WIMP pair annihilation

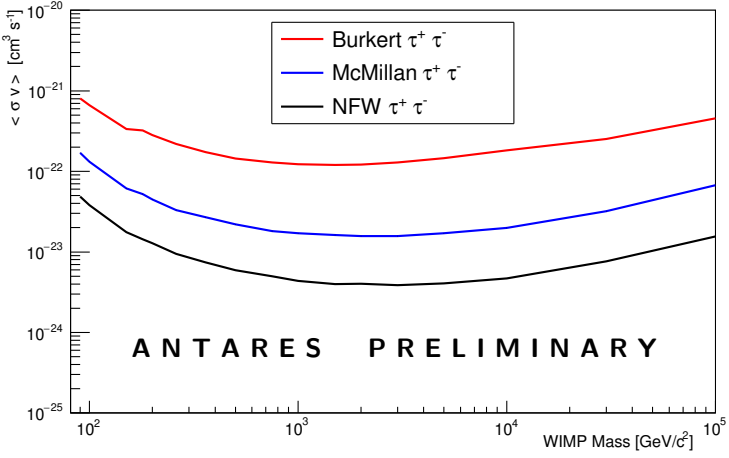
- **Galactic Centre: 11 years of ANTARES data unblinded**, compatible with background.
- **KM3NeT-ARCA 24 lines** will reach down to current ANTARES limits for the GC with 1 year of operation. Noticeable improvement with **KM3NeT-ARCA 230 lines**.
- Sensitivities for **KM3NeT-ORCA for WIMP pair annihilation in the Sun**
  [see PoS(ICRC2019)536] by D. Lopez-Coto and S. Navas.

Other analyses involving ANTARES and KM3NeT

- Test of new scenarios: ***secluded* dark matter** in heavy WIMP models with ANTARES
  [see PoS(ICRC2019)519] by F. Sala, S.R. Gozzini, C. Lagunas and J. Zornoza.
- **Combined searches** involving ANTARES and IceCube joint analysis
  [see PoS(ICRC2019)552] by N. Iovine, S.R. Gozzini, J.A. Aguilar, S. Baur and J. Zornoza.

Additional backup material

ANTARES limits for different halo models



Workflow of unbinned analysis

PDFs

Signal: $\psi(\nu, GC)$

BG: $\sin\delta$

in equal solid angle bins

Maximum likelihood: returns n_s

$$\mathcal{L}(n_s) = \prod_{i}^{Nbins} [n_s \mathcal{S}(\psi_i, E_i, q_i) + n_{bg} \mathcal{B}]$$

Poisson

$\mathcal{P}(n_s, \mu)$

Number of events

Neyman statistics

Acceptances

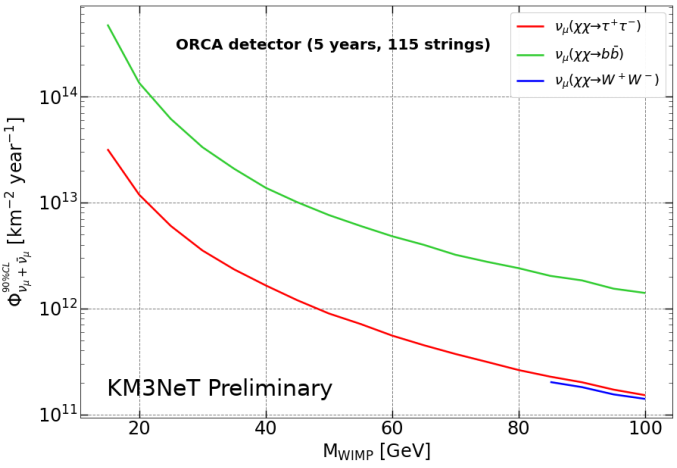
From PPPC

Integrated

Cross-section sensitivities

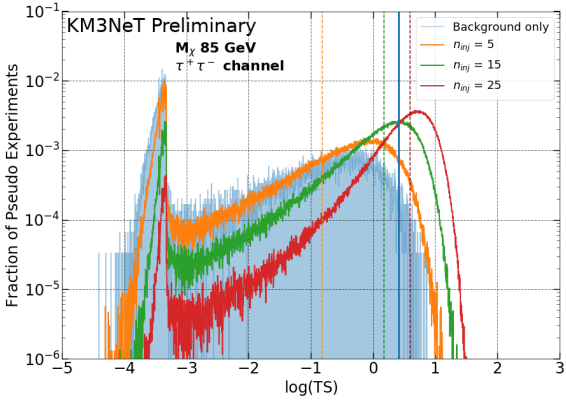
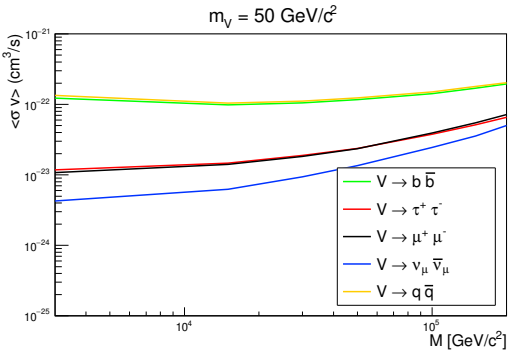
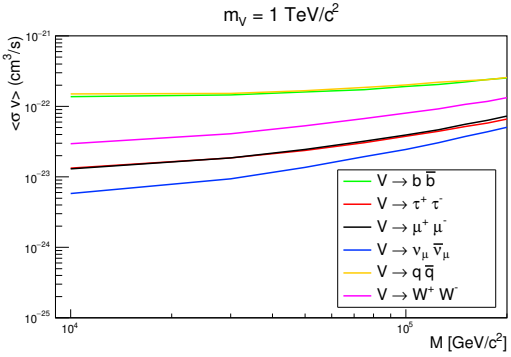
Limits on $\langle \sigma v \rangle$

Sensitivities on ν flux from WIMP annihilations in the Sun



Test statistic and 90% CL upper limits

Test statistic distribution from pseudoexperiments with variable injected signal:



Sensitivities of ANTARES to secluded dark-matter signal