Indirect dark matter searches with neutrinos from the Galactic Centre region with the ANTARES and KM3NeT telescopes

Sara Rebecca Gozzini

on behalf of the ANTARES and KM3NeT Collaborations

Instituto de Física Corpuscular (IFIC), University of Valencia and CSIC

ICRC 2021
21 July 2021

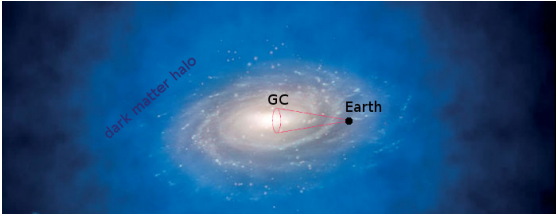
Theory (1) - WIMPs

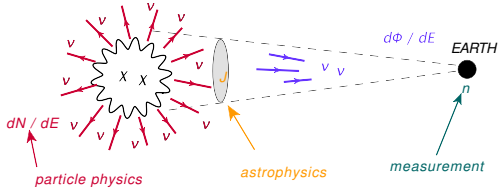
Hints for dark matter are only of macroscopic nature: from cosmology and gravitation.

> It comes natural to theorise a dark matter **particle** candidate. For instance WIMPs.

WIMP miracle: required interaction strength is of the same size as the known weak interaction. **Universality**: despite numerous models with differences in the details.→

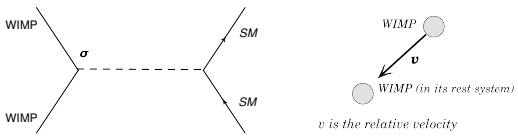
It is possible to predict fluxes of SM products from WIMPs decay or pair-annihilation.





Theory (2) - Process

The process that we would like to observe is a pair annihilation of WIMPs producing final fluxes of high-energy ν (directly or through an intermediate channel, still inside the source)



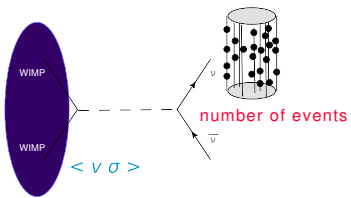
Measurement = number of outcoming events $\rightarrow$ translates into number of processes.
The probability for **one** process to happen is $\propto$ velocity of projectile $\times \sigma$.

Generally: rate outcoming particles $\propto$ velocity incident particle $\times \sigma \times$ number of targets

WIMPs are cold, non-relativistic $\rightarrow v \ll c$, we cannot extract c, we only know a velocity distribution $\Rightarrow$ measurement (limit) of velocity-averaged cross-section $\langle \sigma v \rangle$.

Theory (3) - Which measurement?

We measure (limit) the v-averaged cross-section through the number of ν-induced events



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

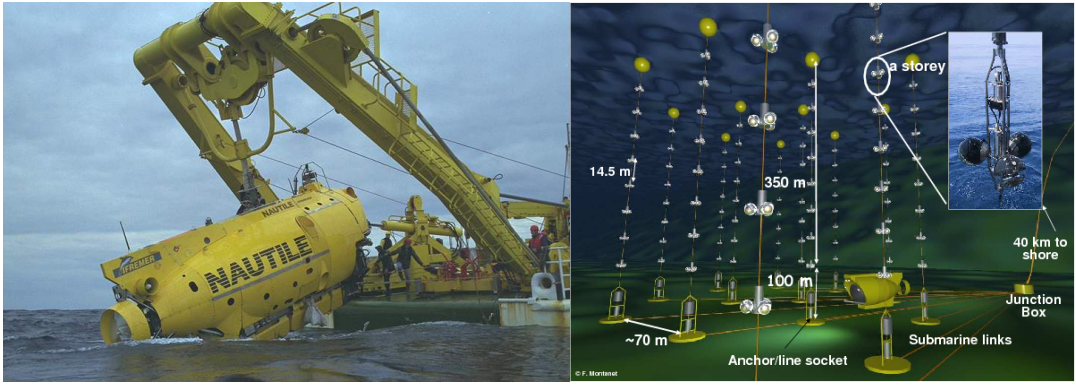
The detector acceptance is described through the effective area (geometry, efficiency, analysis cuts) modulated by the energy distribution of the single WIMP WIMP collision.

✚ PPPC4 [hep-ph: 1012.4515] provides the energy distribution per collision $\frac{dN}{dE}$

✚ We sit inside the source. The J-factor (here obtained using [https://clumpy.gitlab.io/CLUMPY]) provides number of WIMPs in a cone around the source identified by our detector's FoV. We can test different dark matter halo profiles: NFW, Burkert, MacMillan, Einasto.

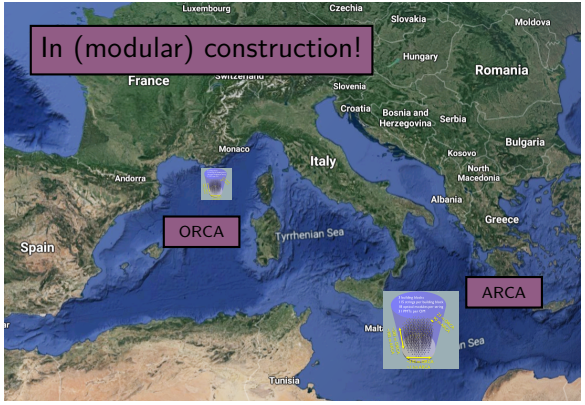
Instrument (1) ANTARES

In continuous, smooth operation for more than 13 years with very little off-duty time.

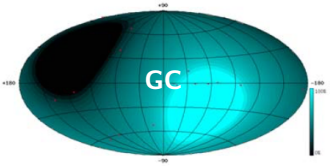


Layout: 40 km offshore Toulon, 12 lines, 885 PMTs, 2500 m depth. Designed for ν astronomy, pointing accuracy from $\sim 1^\circ$ to 0.3° for the energy range of DM analyses [50 GeV - 100 TeV].

Instrument (2) The multi-site KM3NeT infrastructure



- ORCA: 1 dense block (7 Mton, 115 lines) for measuring atmospheric ν properties with high statistics. **As of today: 6 lines, some in operation for more than 1 year**
- ARCA: 2 very-large volume blocks (1 Gton, 230 lines) to catch astrophysical fluxes. **As of today: 6 lines**



Good visibility of the Southern sky for upgoing events from Mediterranean Sea, including the best dark matter source: the centre of the Milky Way - close source $\rightarrow$ high J-factor
Sea water has good optical properties for excellent pointing accuracy (low scattering)

Search with ANTARES

Data set: January 2007 to February 2020, lifetime: 3845 days, all-flavour

- 11174 track candidates, coming from CC interaction of ν_μ
- 225 shower candidates, coming from NC interaction of ν or CC interaction of ν_e, ν_τ

The search for a signal of dark-matter induced neutrinos is conducted with a hypothesis test.

- H_0 background obtained from blind data
- H_1 signal is reproduced with simulated data, space-distributed as NFW halo profile[1] (realised with CLUMPY[2]), and energy-weighted with PPPC4[3] according to 5 channels

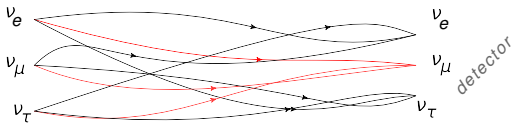
$$\text{WIMP WIMP} \rightarrow \tau^+\tau^-,\ \mu^+\mu^-,\ W^+W^-,\ b\overline{b},\ \nu\overline{\nu}$$

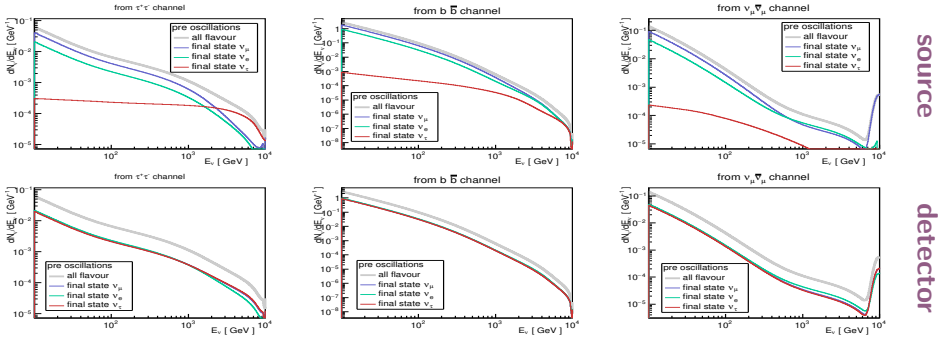
[1] http://www.marcocirelli.net/PPPC4DMID.html]
[2] [Navarro, Frenk & White, Astrophys.J. 462 (1996) 563-575]
[3] [https://clumpy.gitlab.io/CLUMPY/physics.html]

Dark matter signal at ANTARES

The signal is reproduced weighting simulated events with PPPC4

- **tracks** $\times \frac{dN}{dE}|_{\mathrm{final-state}-\nu_\mu} \times$ oscillations
- **showers** $\times \left[\frac{dN}{dE}|_{\mathrm{final-state}-\nu_e/\nu_\tau}\right] \times$ oscillations





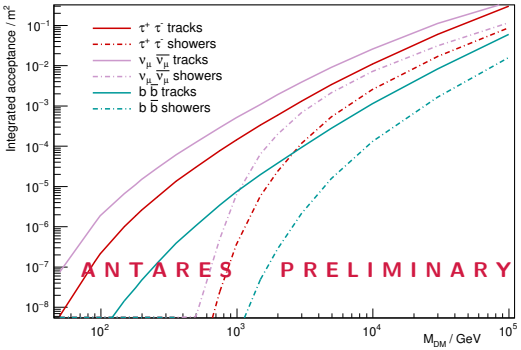
Detector acceptance to dark matter events

Cuts are optimised for best sensitivity. The acceptance ratio of tracks (showers) to total is later used to simulate the correct fraction for each topology, mass and channel considered.

Selection criteria independently optimised for tracks and showers

- direction: upgoing events
- likelihood of geometrical fit
- quality indicators: angular error
- minimum nr. of light hit N_{HIT}

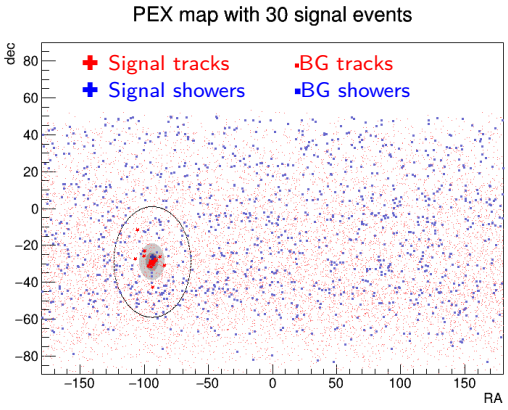
$$\mathcal{A} = \int A_{\mathrm{EFF}}(E) \frac{dN}{dE} dE$$



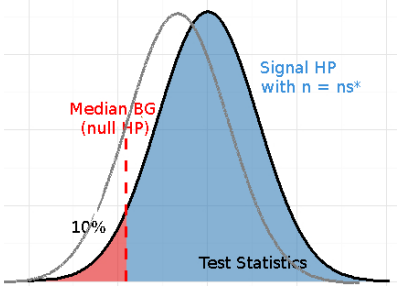
Analysis method for hypothesis test

Unbinned maximum likelihood is used to obtain the most likely number of signal events n_s^*

$$\mathcal{L} = \prod_i^{n_{TOT}} \left[n_s \cdot P_s(\text{angle}, N_{\text{HIT}}, \beta) + n_b \cdot P_b(\text{angle}, N_{\text{HIT}}, \beta) \right]$$

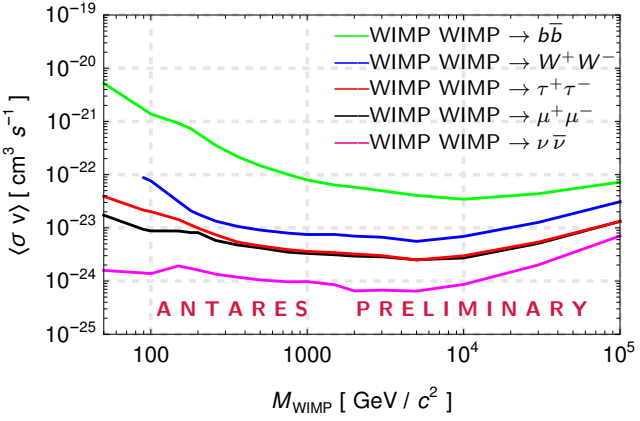


$$TS = \log \left[\frac{\mathcal{L}(n_s^*)}{\mathcal{L}_{\text{BG}}} \right]$$



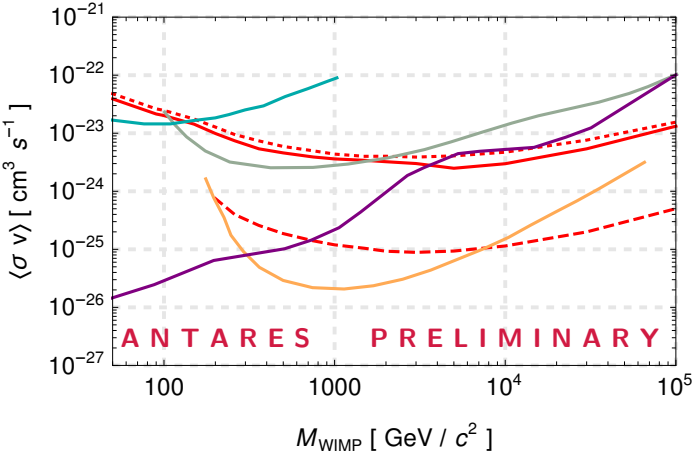
All-flavour limits on pair annihilation cross-section

In the search for νs from WIMP annihilations in the Galactic Centre, ANTARES all-flavour data Jan. 2007 - Feb. 2020 is compatible with background.



Overview and follow-up with KM3NeT

The sensitivity of KM3NeT (1 year) is shown below alongside with the results from other experiments. As of today, 6 lines of ORCA are recording data (some for $\sim$ 1 year), and 6 lines of ARCA are in operation. Search for dark matter in first KM3NeT data will begin soon.



WIMP WIMP $\rightarrow \tau^+\tau^-$

- ANTARES 14 years (NFW)
- ANTARES 11 years (NFW)
- KM3NeT 1 year (NFW)
- HESS 10 years (Einasto)
- Fermi-MAGIC (Dwarf Sph.)
- VERITAS (Dwarf Sph.)
- IceCube 3 years (NFW)

Summary of results

Indirect dark matter searches need triangulation with different measurement techniques!

- In the search for νs from WIMP annihilations in the Galactic Centre, ANTARES all-flavour data Jan. 2007 - Feb. 2020 is compatible with background.
- Sensitivity estimated for KM3NeT-ARCA is very competitive in the high WIMP mass.
- The search will continue in KM3NeT data, soon ready to be analysed. 6 detection lines both for ORCA and ARCA will deliver first KM3NeT limits soon.