Indirect search for Dark Matter with the ANTARES Neutrino Telescope

Vincent Bertin

CPPM-Marseille

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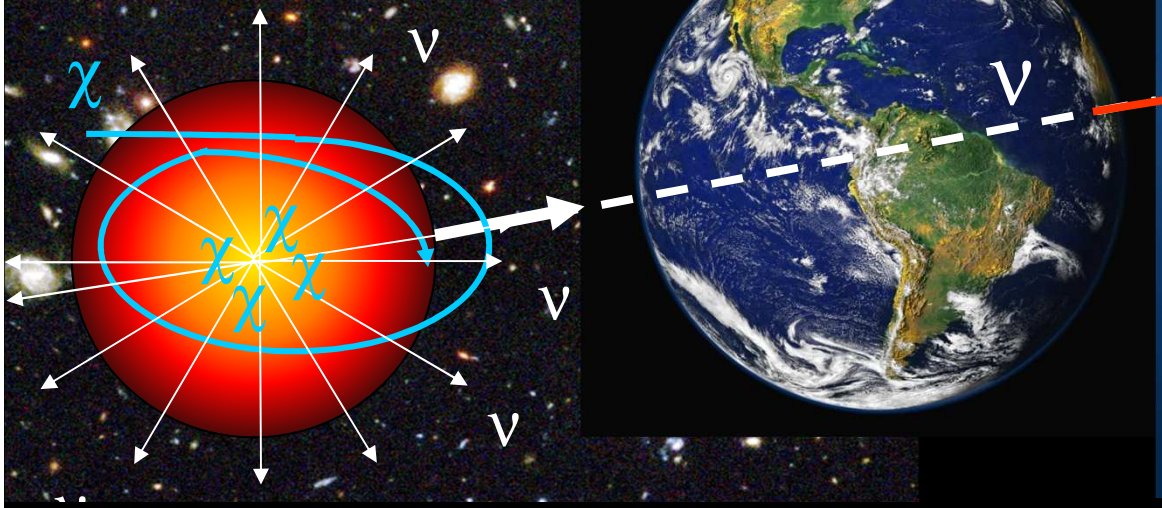
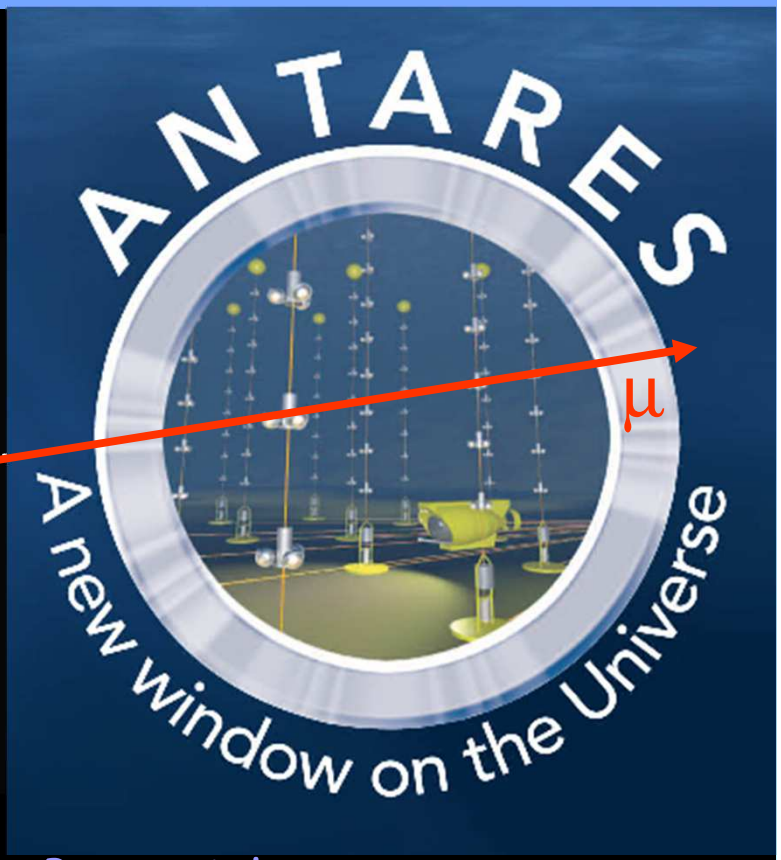
Indirect detection of WIMPs in a neutrino telescope

Relic WIMPs captured in celestial bodies

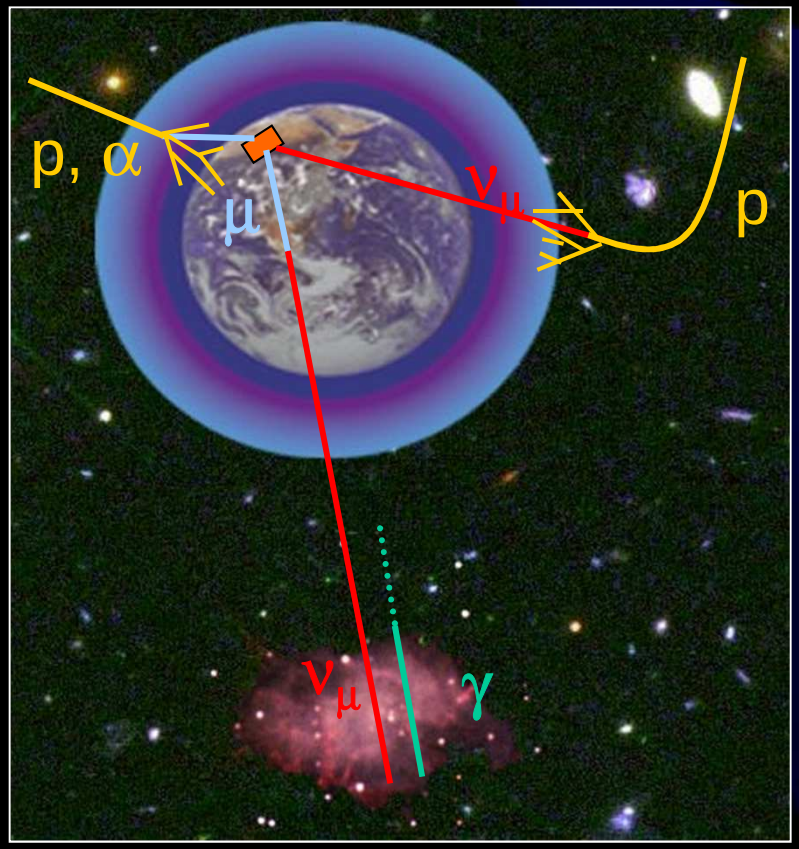




χχ self-annihilations into c,b,t quarks, τ leptons or W,Z,H bosons can produce significant high-energy neutrinos flux

Potential χχ→ν sources are Sun, Earth & Galactic Centre
Signal less affected by astrophysical uncertainties than γ-ray indirect detection

Neutrino telescope: Detection principle



Cherenkov light from μ

3D PMT array

γ

43°

Sea floor

μ

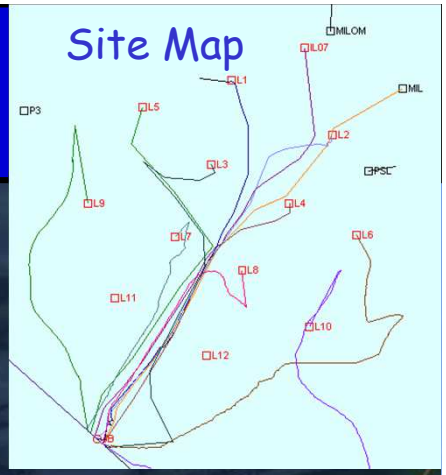
interaction

ν

Reconstruction of μ trajectory (~ ν) from timing and position of PMT hits

The ANTARES detector

- 12 lines
- 25 storeys / line
- 3 PMs / storey
- ~900 PMs



Indirect search towards the Sun with ANTARES

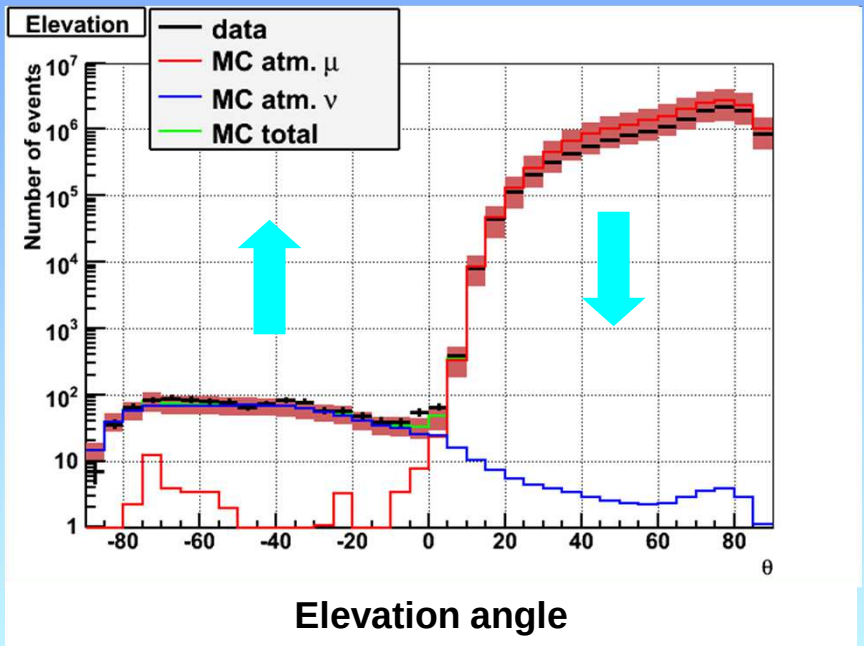
- **Detector** building started in 2006, completed in May 2008
- **Analysis** based on data collected between 2007 and 2012
  → **> 7000 upgoing neutrino** candidates (in **~1321 effective days**)

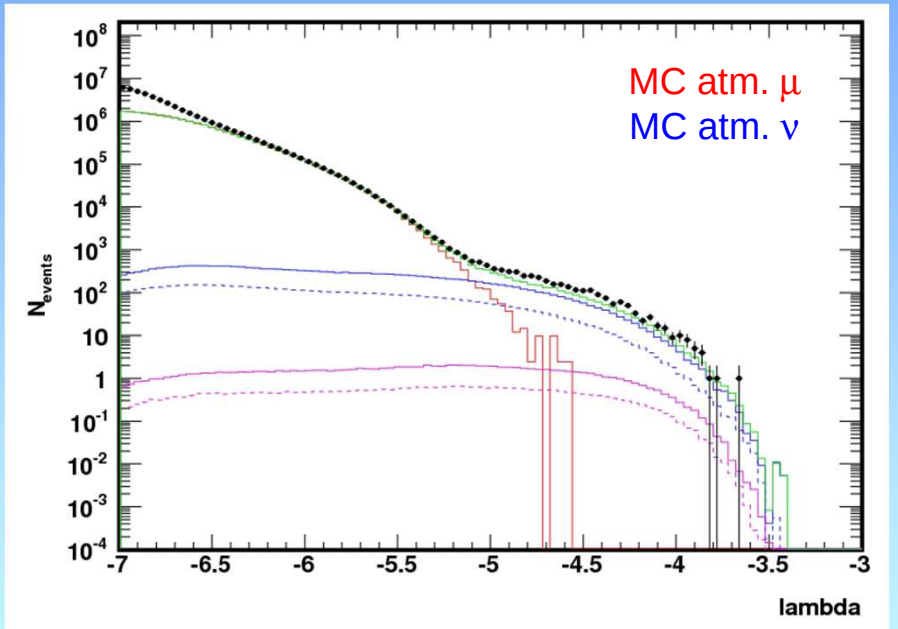
- **Reconstruction strategies:**
  - BBFit (χ^2 based) → optimal for low energies/masses (<250 GeV)
    - **Single line events** : reconstruction of **zenith angle only** → very low energies
    - **Multiline events**: reconstruction of **zenith & azimuth angles**
  - AAFit (likelihood based) → high energies/masses (>250 GeV)
    - **lambda** (**quality parameter**, basically the likelihood value)
    - **beta**: **angular error** estimation

- **Selection parameters:**
  - **tchi2**: ~χ^2 (BBFit)
  - **lambda**: Quality reconstruction parameter ~ likelihood (AAFit)
  - **beta**: angular error estimate (AAFit)
  - **Cone opening angle** around the Sun (or **zenith band** for single line events)

Event selection : background rejection

- Selection of neutrinos and rejection of atmospheric muons by selecting up-going tracks and cutting on track fit quality



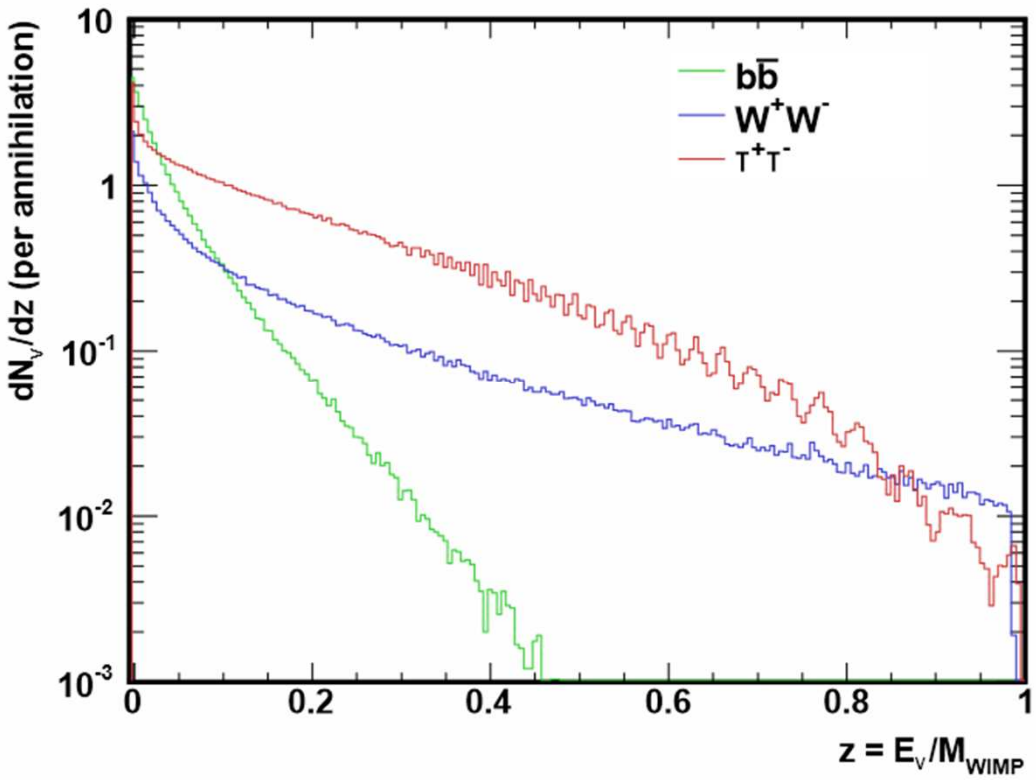


- Rejection of atmospheric neutrinos by looking into a cone towards the Sun direction (or zenith band for single line events)

- Remaining **background** estimated from **scrambled data**

Neutrino signal from WIMP annihilations

- WIMPSIM package (Blennow, Edsjö, Ohlsson, 03/2008) used to generate events in the Sun in a **model independent way**
- Annihilations into b quarks (soft spectrum) and τ leptons, WW/ZZ bosons (hard spectrum) **used as benchmarks**
- Take into account ν **interactions** in the Sun medium, **regeneration of** ν_τ in the Sun and ν **oscillations**

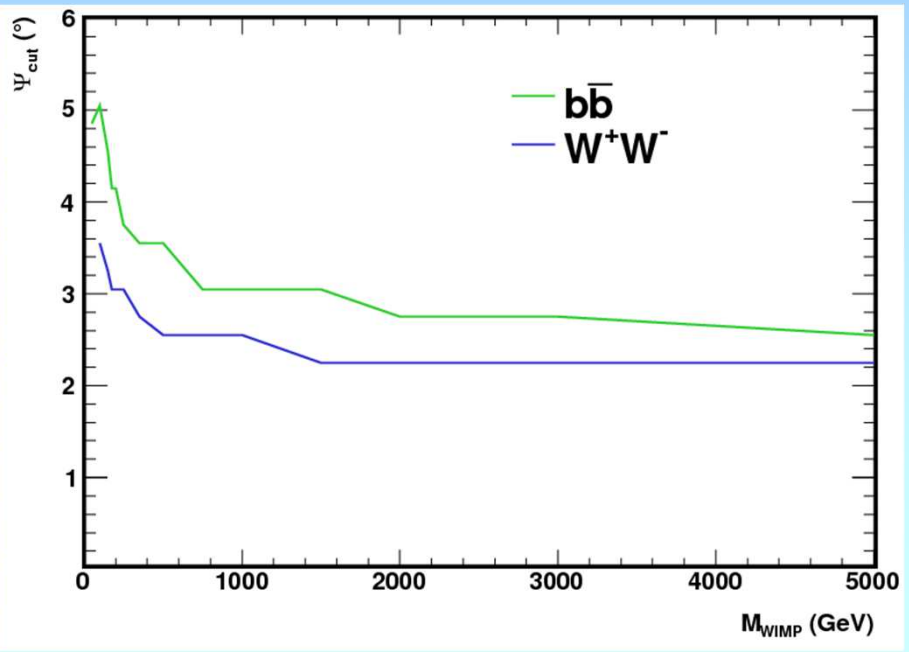


Selection optimization and observed events

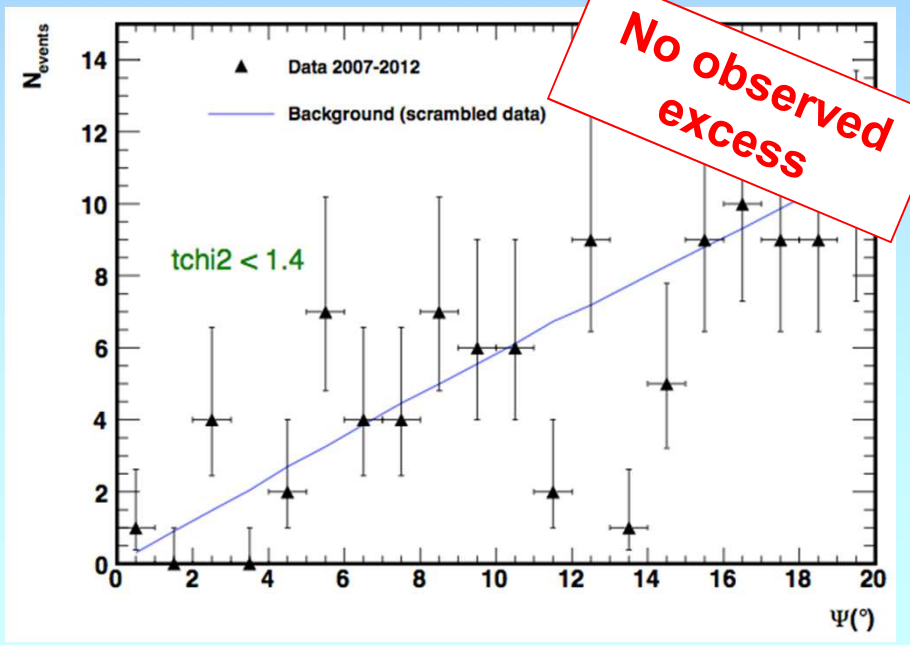
- **Neutrino fluxes** at the Earth produced by Dark Matter coannihilation are **convoluated** with the **detector efficiency** for given selection parameter sets (track fit quality, cone size)
- **Neutrino background** given by **scrambled data in the Sun direction** is evaluated for the same selection set
- **Optimization of sensitivity** performed by minimizing

$$Sensitivity = \frac{\bar{\mu}_{90}}{Aeff\,(Mwimp) \times Teff}$$

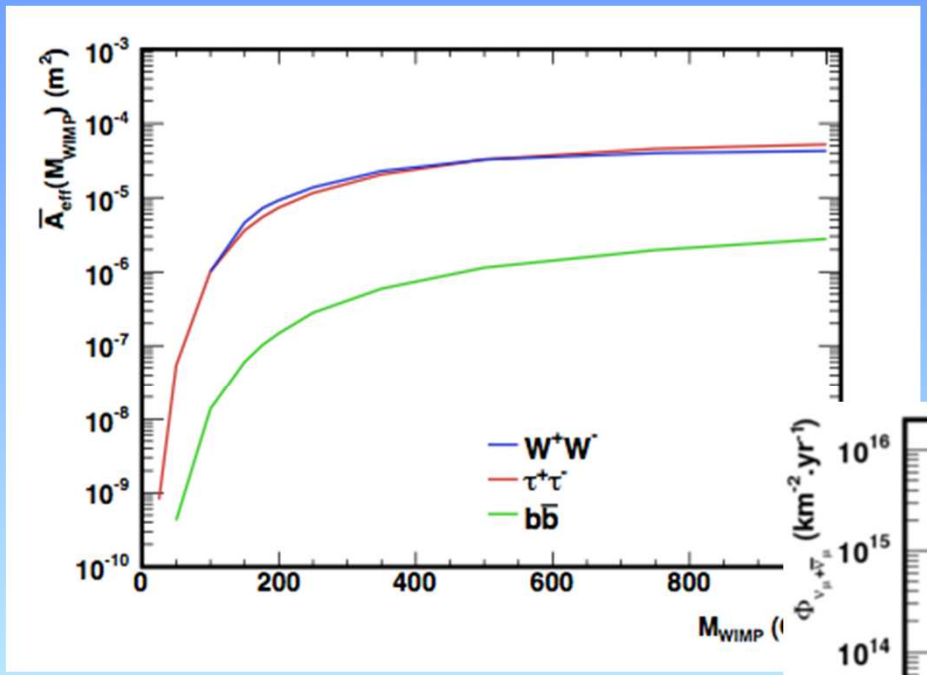
Optimal half-opening angle
of the search cone around the Sun



Observed events in the Sun direction
vs. scrambled data in 2007-2012

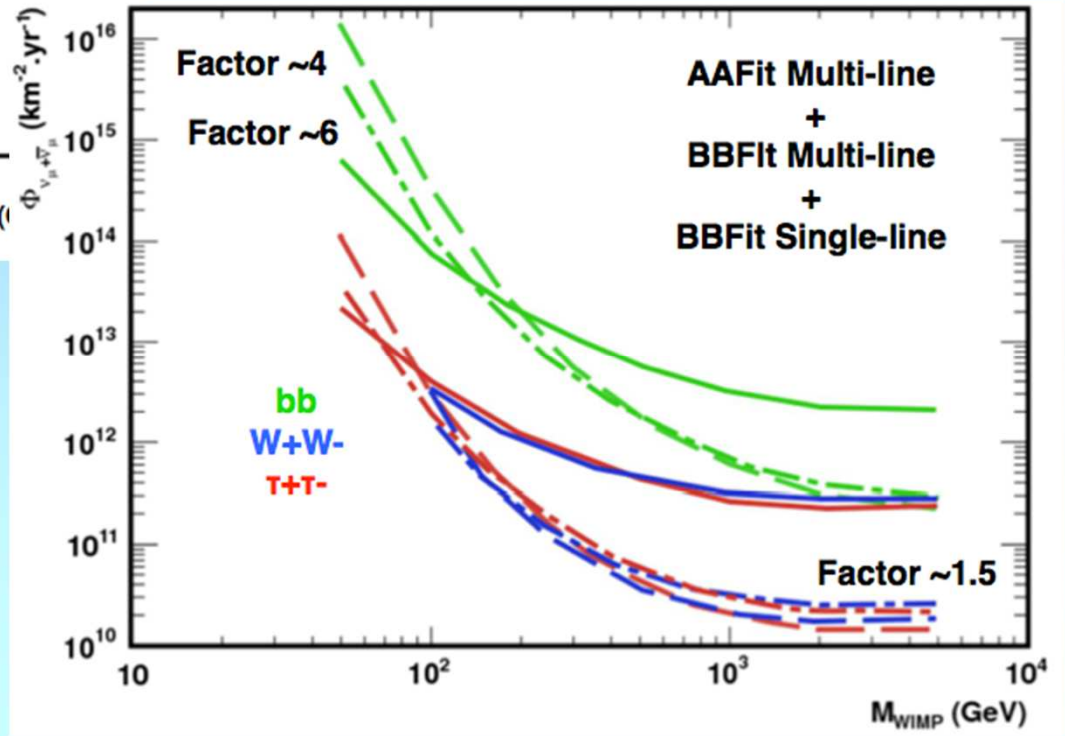


Limit on neutrino flux coming from the Sun



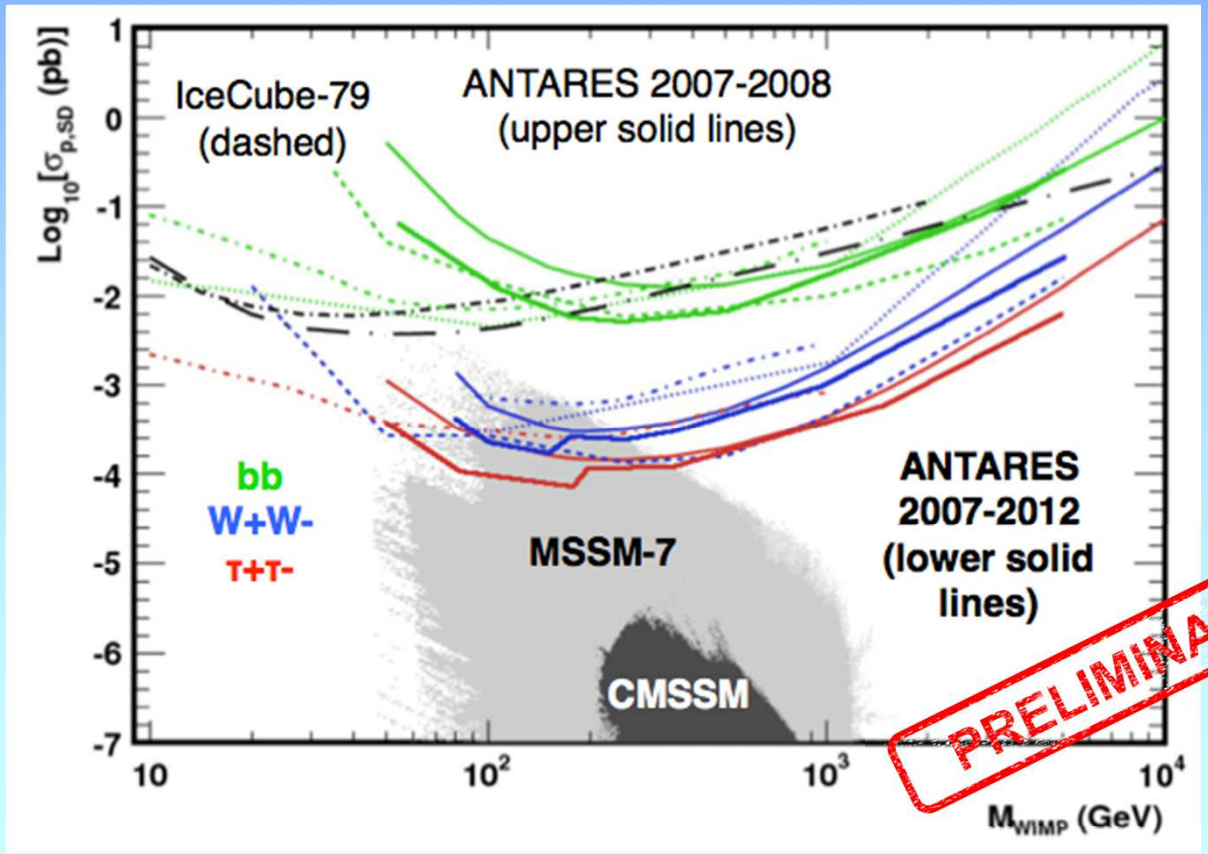
Effective area of signal
as function of WIMP mass
→ **low threshold**
at M_{WIMP} ~ 50 GeV

Limits on neutrino flux assuming
100% Branching Ratio of WIMP
annihilations into benchmark channel



Limits on Spin Dependent cross sections

Conversion to **limits on WIMP-proton Spin Dependent cross sections** assuming equilibrium between capture and annihilation rates inside the Sun
→ **much better sensitivity of neutrino telescopes on SD cross-section** w.r.t. direct detection due to capture on Hydrogene inside the Sun



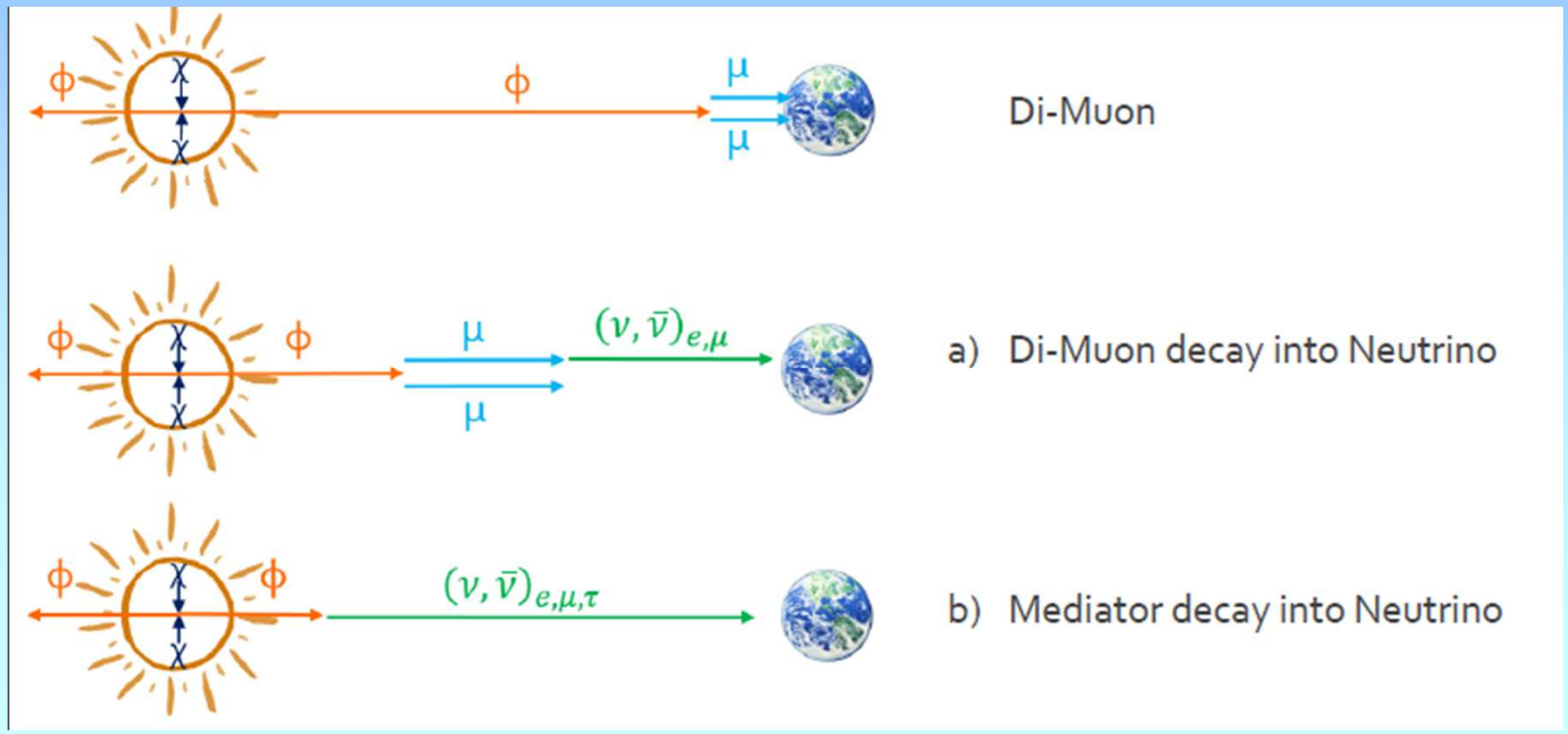
Comparison to predictions of CMSSM and MSSM-7 models taking into account recent experimental constraints (Higgs mass,…)

First limits with ANTARES 2007-2008 data published in JCAP11 (2013) 032

Search for secluded DM inside the Sun

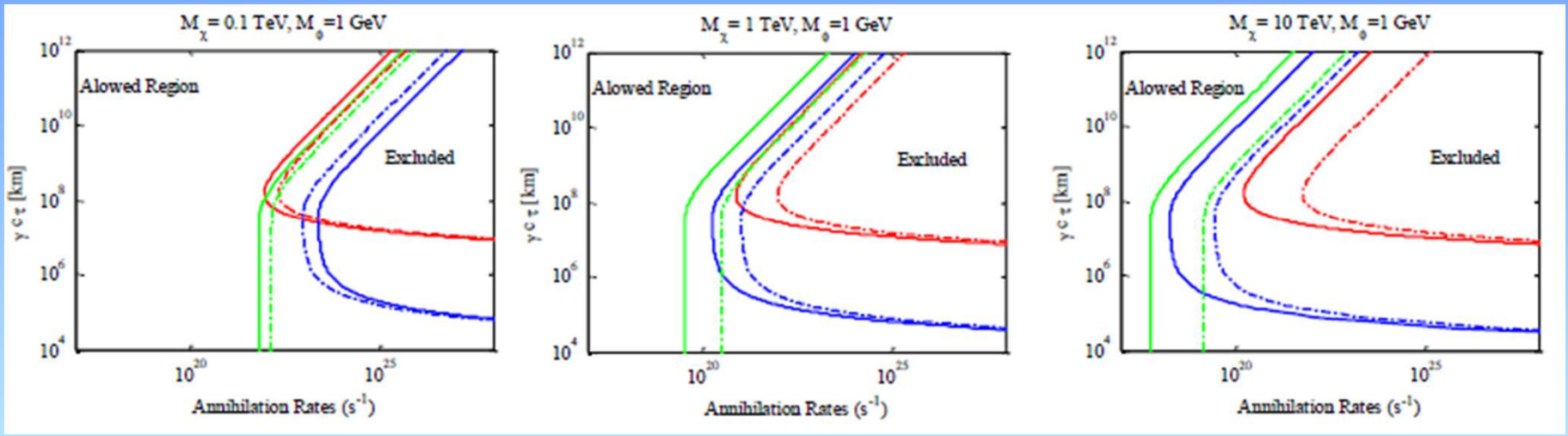
- In **Secluded DM models**, the DM particle and the Standard Model sectors are **secluded** from each other and communicate only via a **metastable mediator** ϕ (new gauge boson, dark photon,…)
- Signal depends on the **mediator lifetime and decay channel**

- Analysis of ANTARES 2007-2012 data performed for 3 different cases :



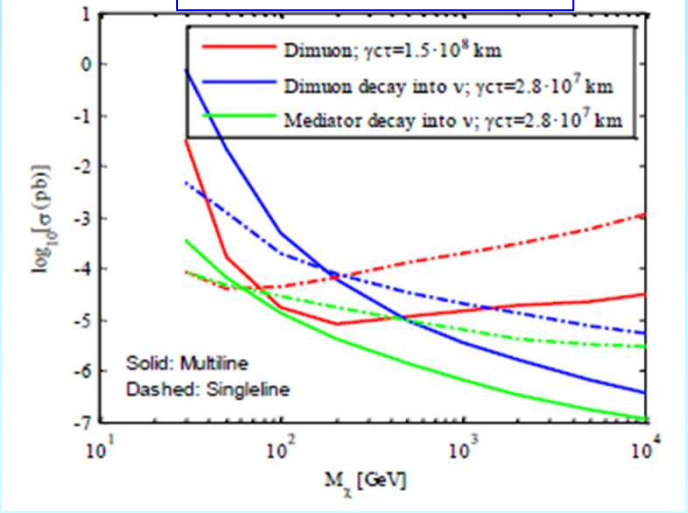
Limit on secluded DM models

Limit on DM annihilation rate as function of mediator lifetime for:
Dimuon decay, Dimuon decay to neutrinos, Mediator decays to neutrinos

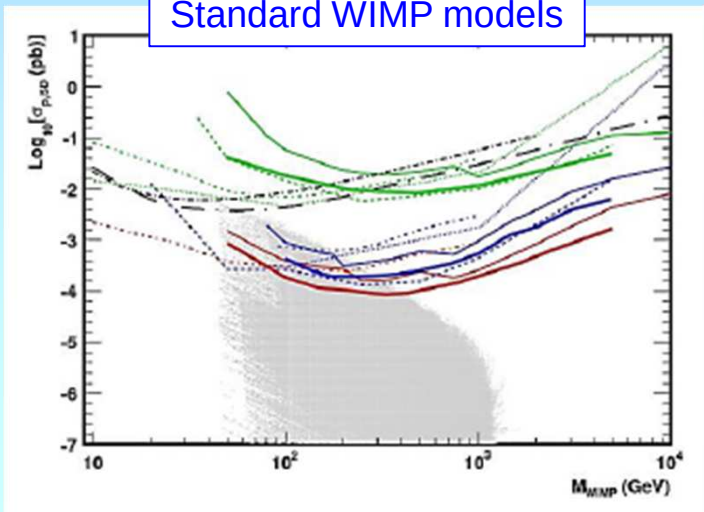


Limit on SD DM-proton cross-section for most favourable mediator lifetime

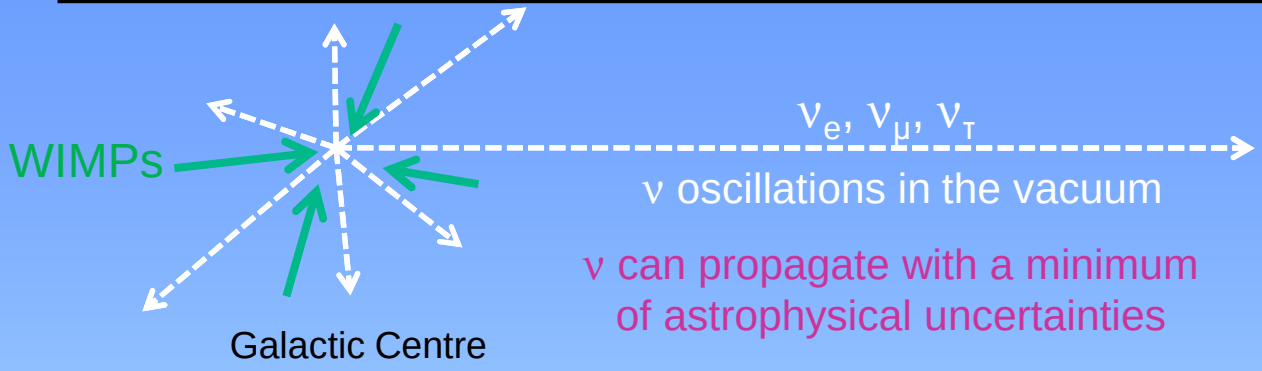
Secluded DM models



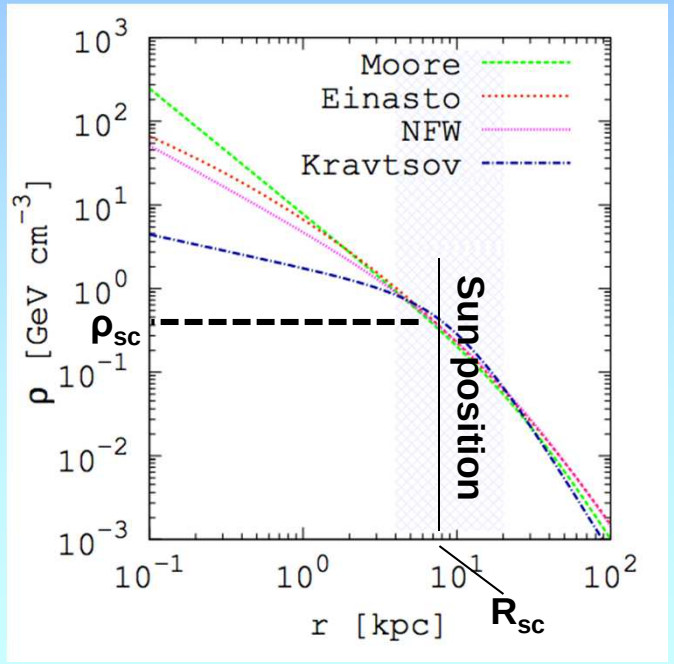
Standard WIMP models



Search for Dark Matter towards the Galactic Centre



WIMPs self-annihilate according to $\langle\sigma_A v\rangle$ (halo model-dependent)



$$\frac{d\Phi_\nu}{dE_\nu}(E_\nu, \Delta\Psi) = \Phi^{PP}(E_\nu) \times J(\Delta\Psi)$$

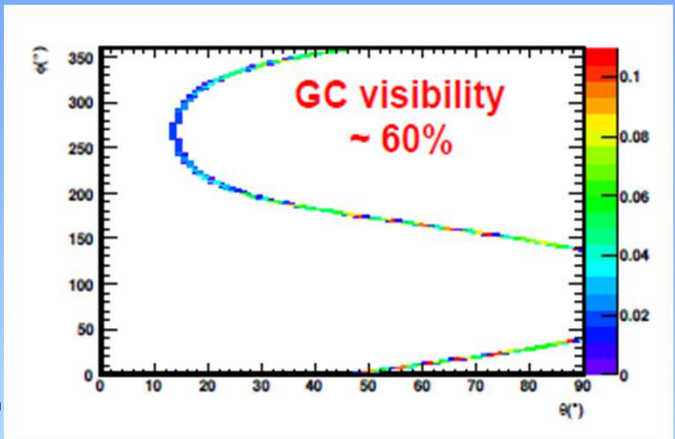
where

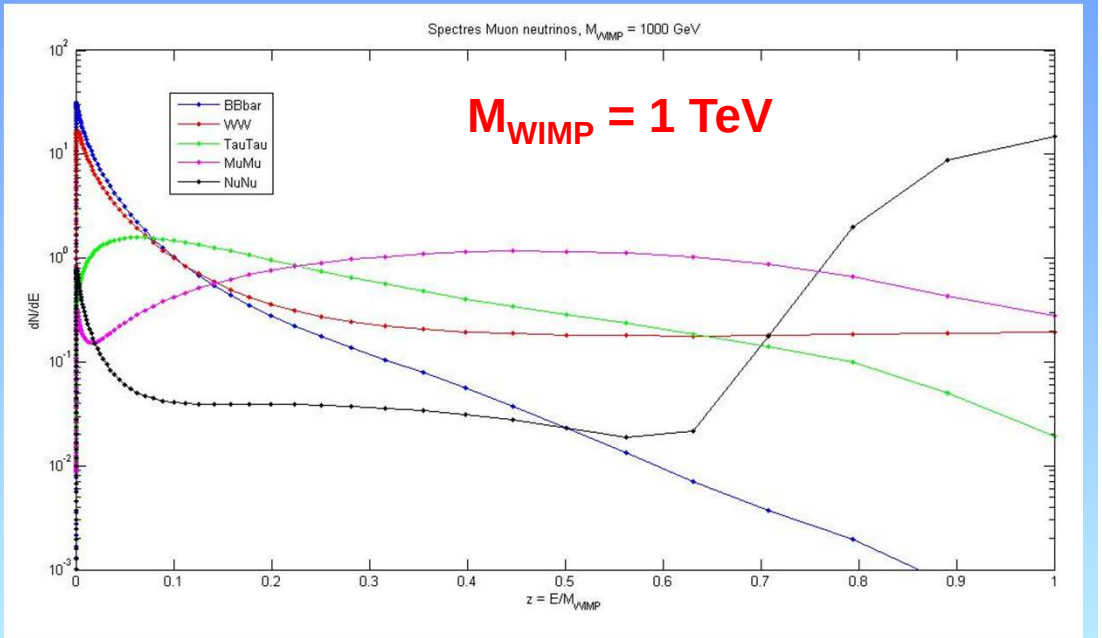
$$\Phi^{PP} \equiv \frac{1}{4\pi} \frac{\langle\sigma v\rangle}{2M^2_{WIMP}} \frac{dN_\nu}{dE_\nu}$$

$$J(\Delta\Psi) = \int_{\Delta\Psi} \int \rho^2_{DM}(l, \Psi) dl d\Psi$$

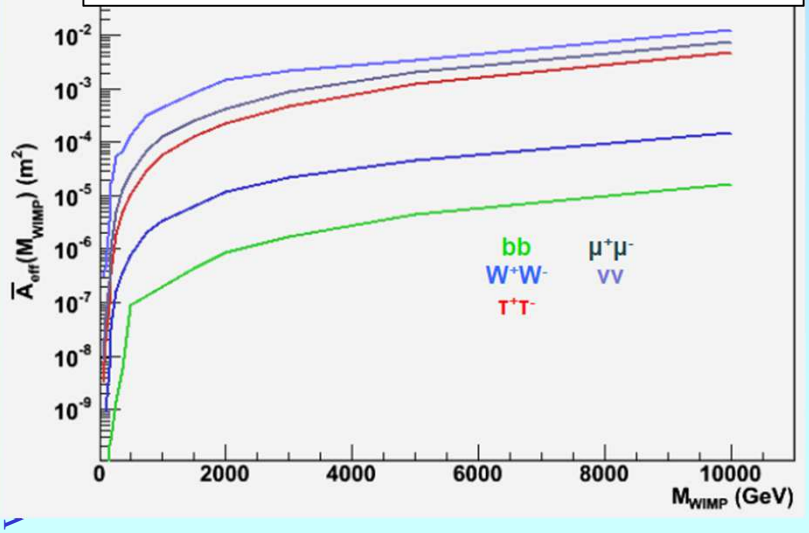
Search for Dark Matter towards the Galactic Centre

ANTARES **visibility** of the **Galactic Centre**





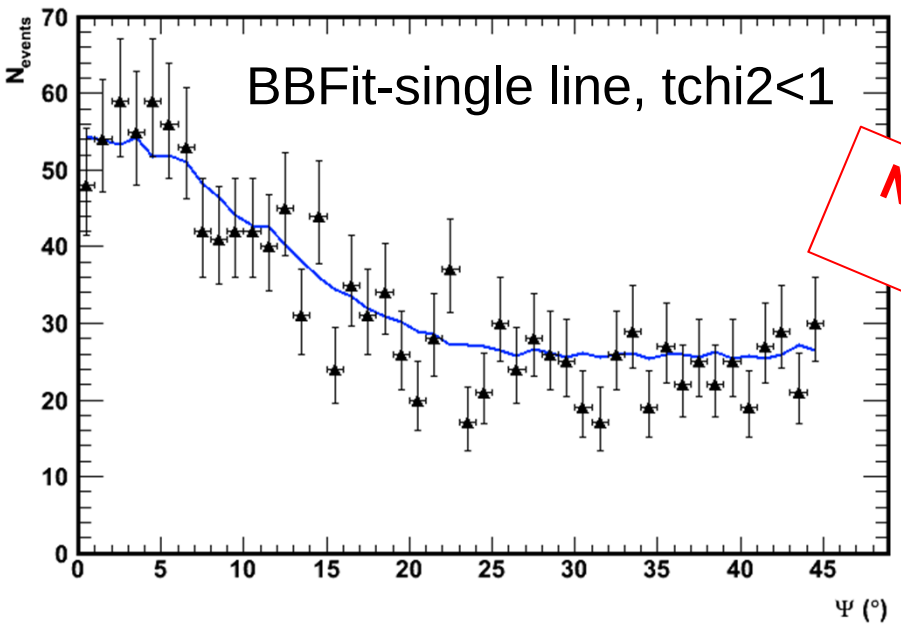
Effective area for Aafit analysis



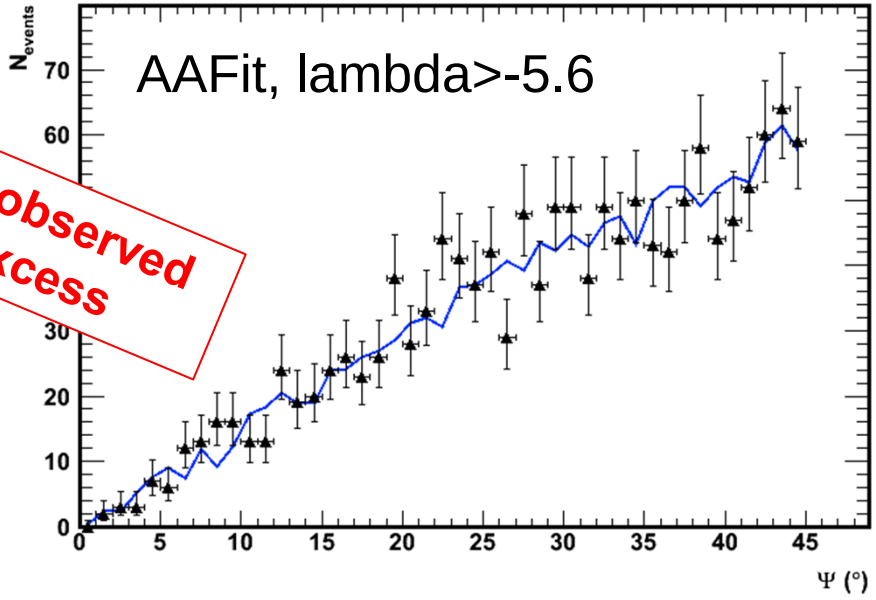
Spectra from Dark Matter annihilations in vacuum including EW corrections for 5 main benchmark channels
from M. Cirelli et al., JCAP 1103 (2011) 051
(www.marcocirelli.net/PPPC4DMID.html)

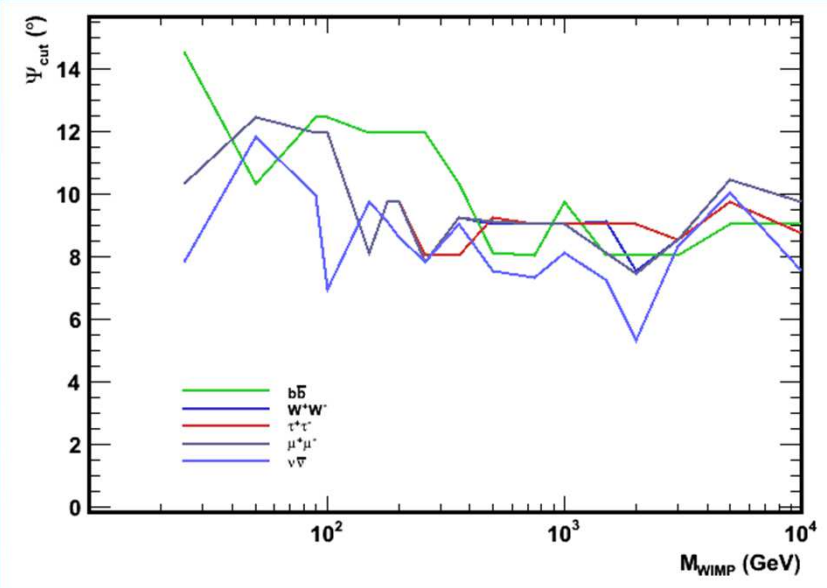
Astroparticle- Jan'15

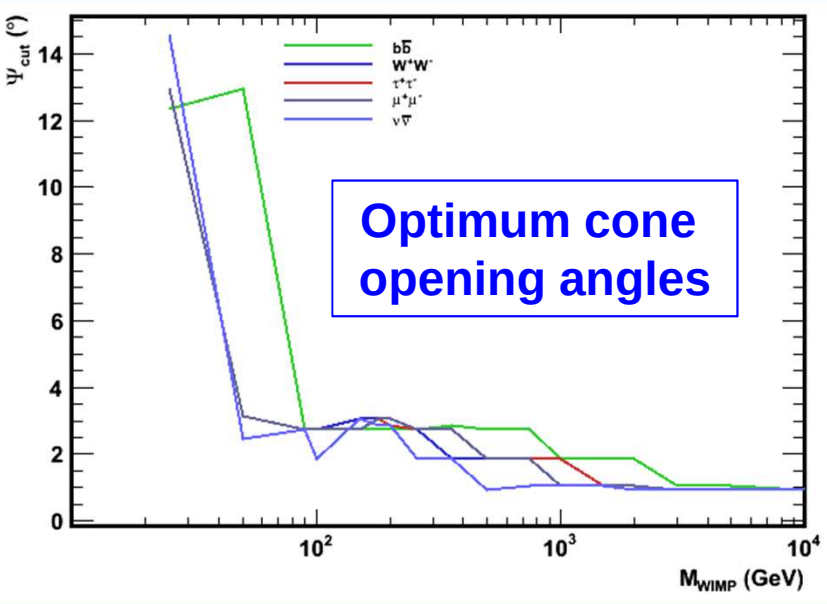
ANTARES observation of the Galactic Centre with 2007-2012 data



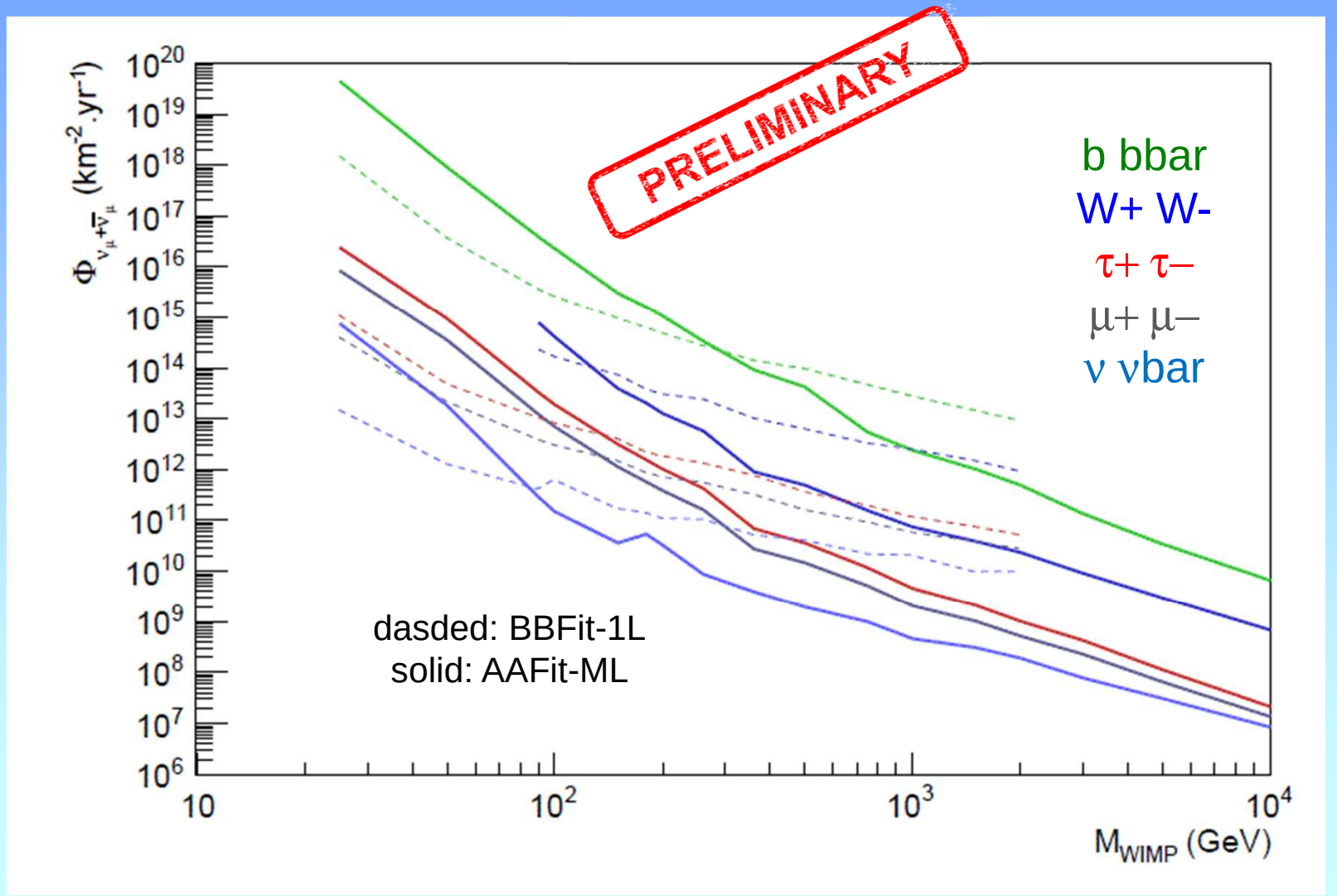
No observed excess





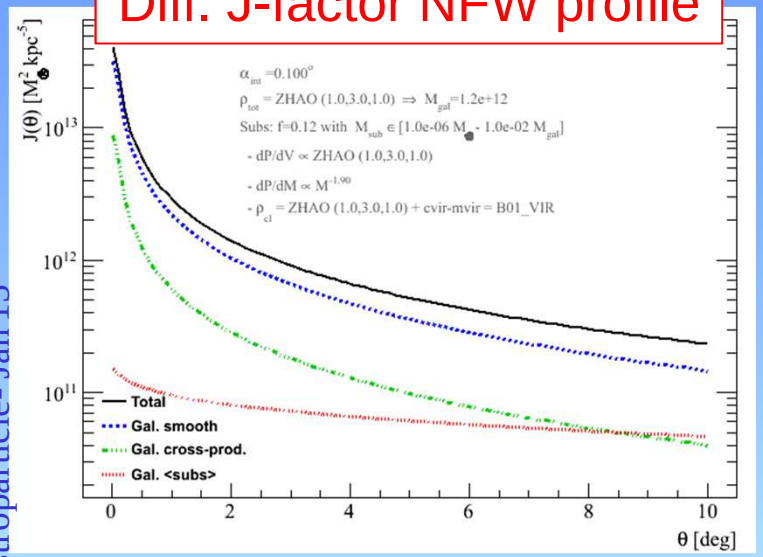


Limits on neutrino flux from Galactic Centre

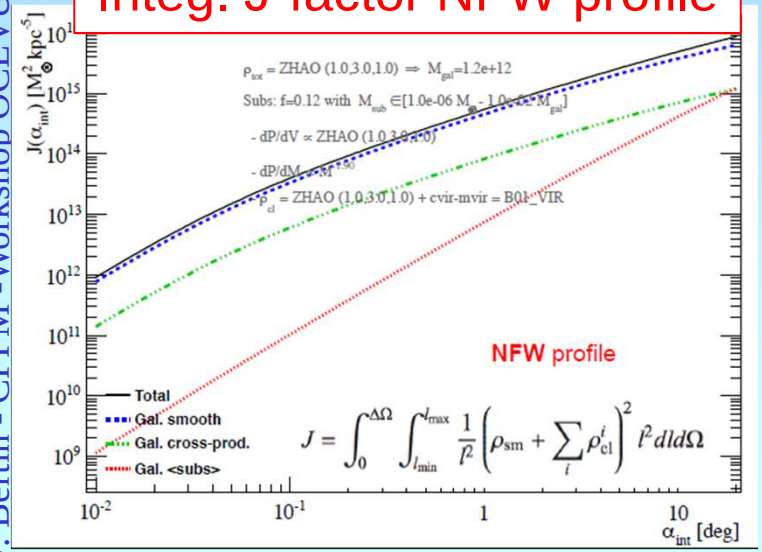


Limits on <σ v> from Galactic Centre

Diff. J-factor NFW profile



Integ. J-factor NFW profile

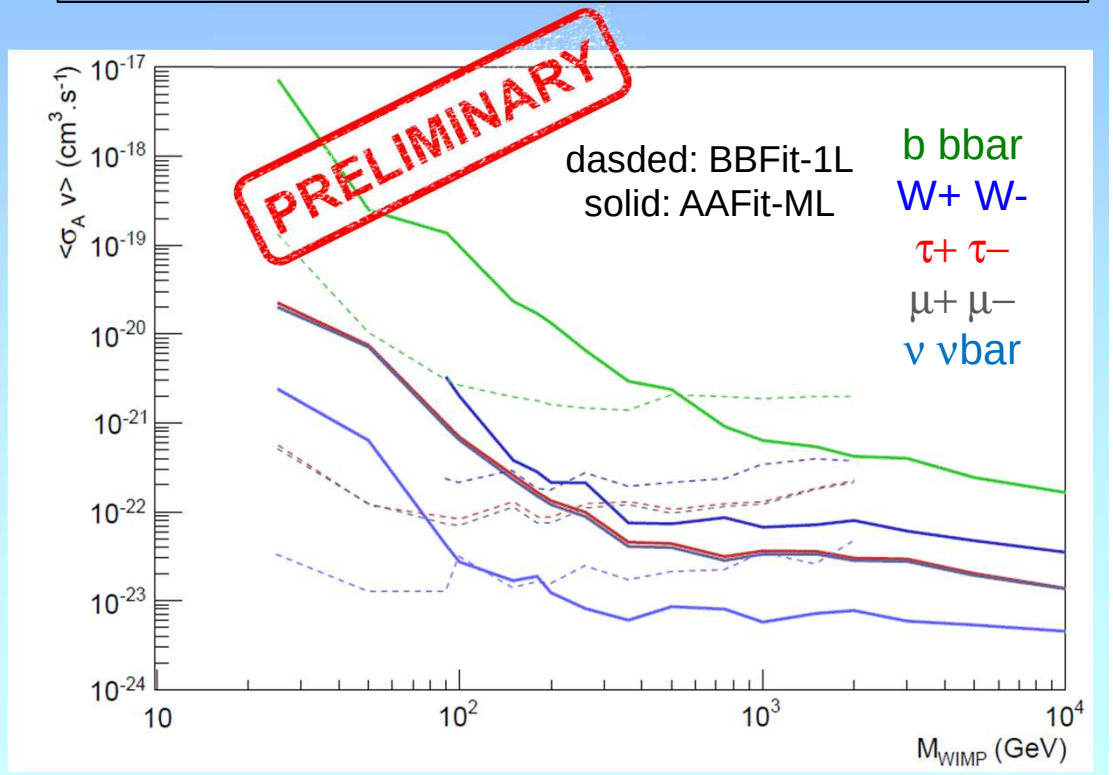


$$J(\Delta\Psi) = \int_{\Delta\Psi}\int \rho^2_{DM}(l,\Psi)\,dl\,d\Psi$$

J factor for DM profiles computed using CLUMPY version 2011.09_corr2

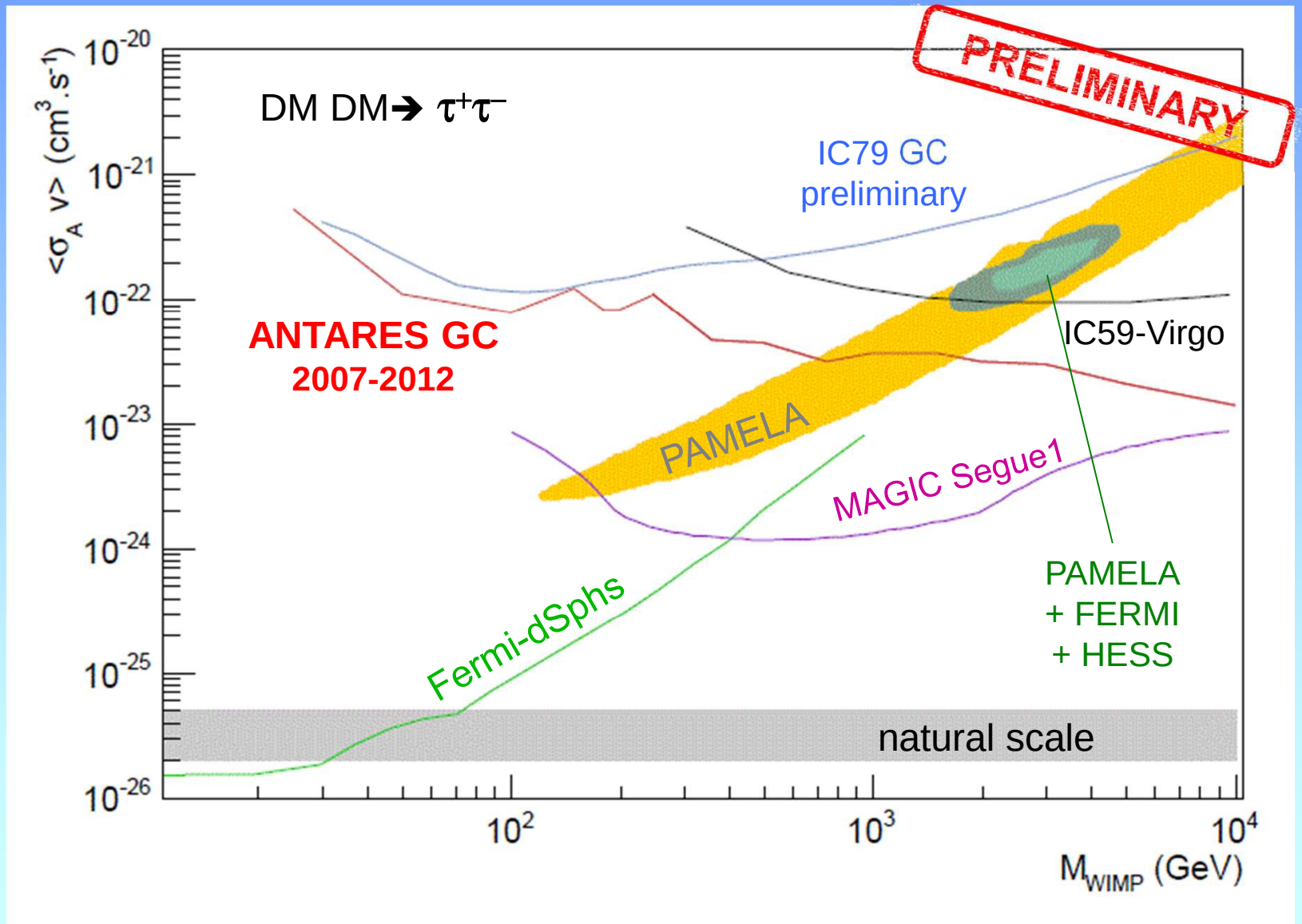
A. Chardonnier et al., Comp. Phys. Comm. 183, 656 (2012)

(http://lpsc.in2p3.fr/clumpy)

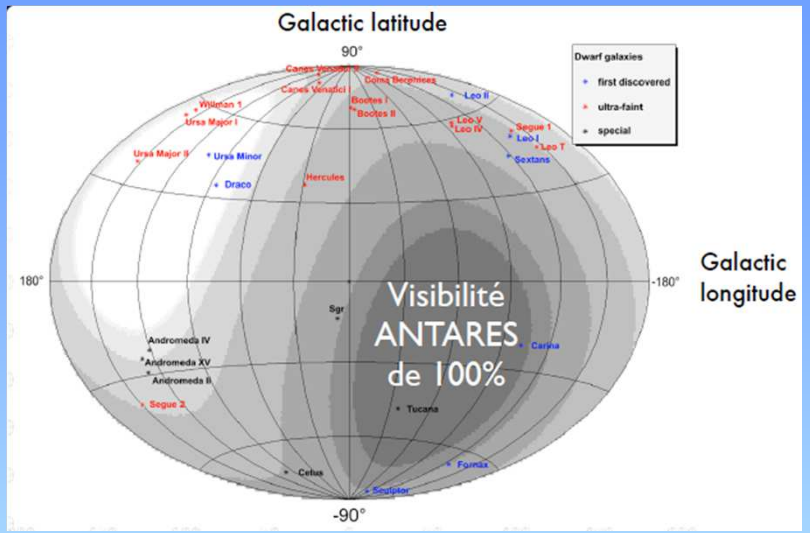


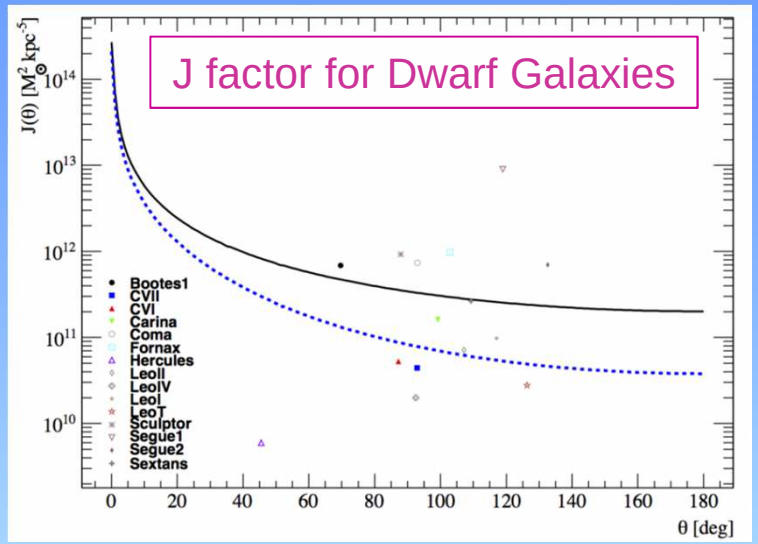
NFW profile: Navarro, Frenk, White ApJ 490 (1997) 493.

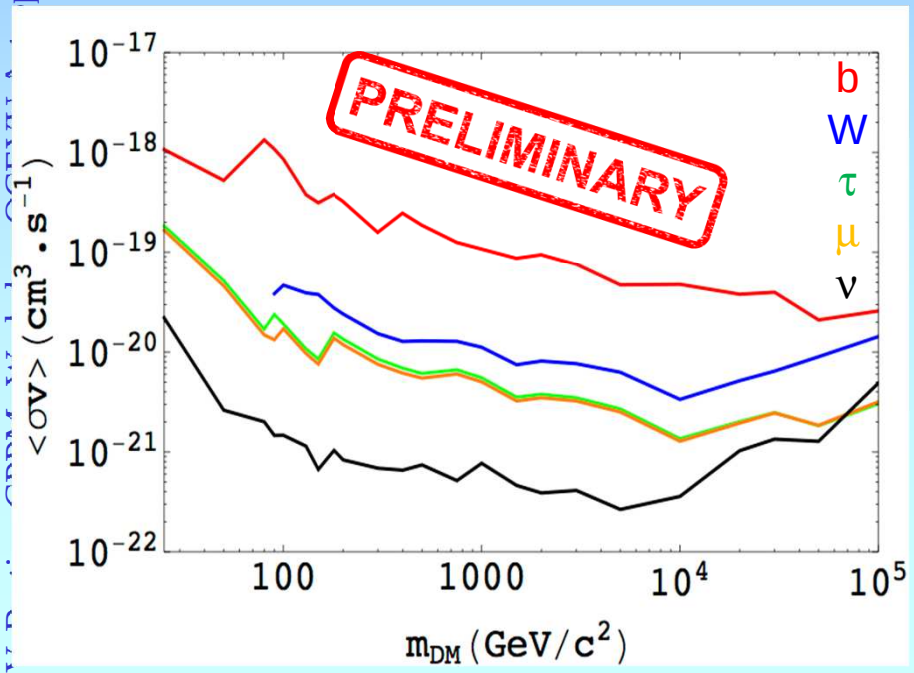
Comparison to other experiments

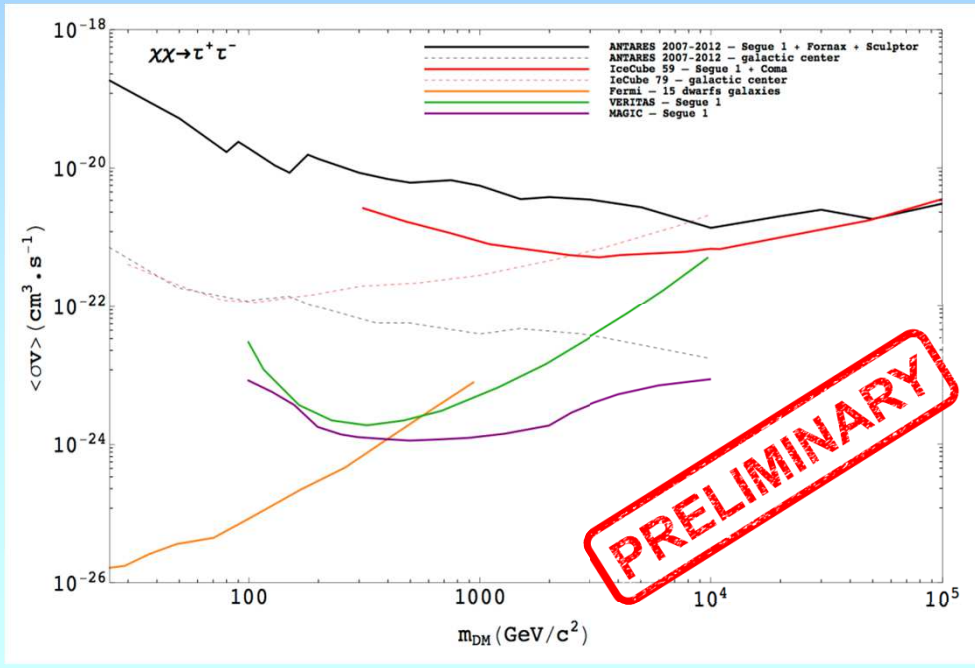


Search for DM towards **Dwarf Galaxies**



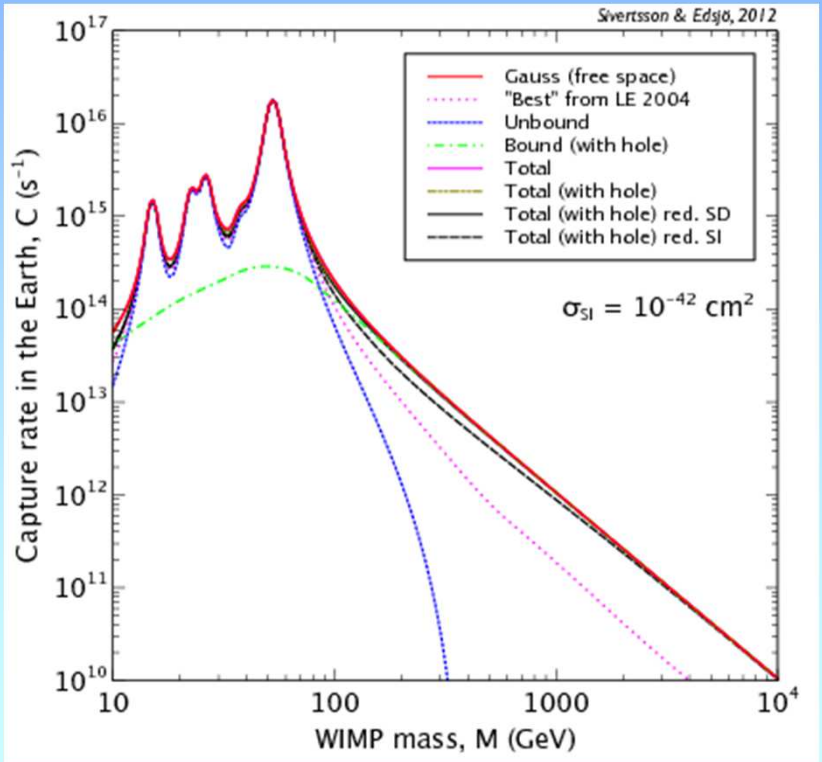






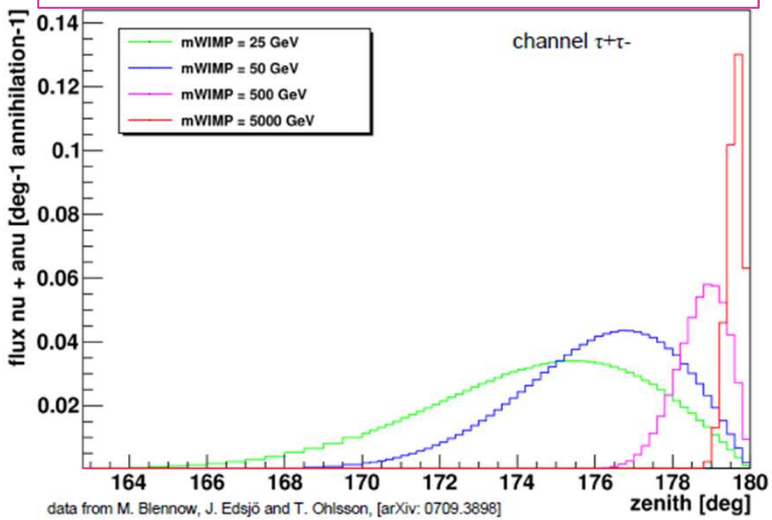
Indirect Search for Dark Matter in the Earth

Capture rate of WIMPs in the Earth
dominated by SI cross-section
Resonnant enhancement
on dominant nuclei (Fe, Ni, Si,…)

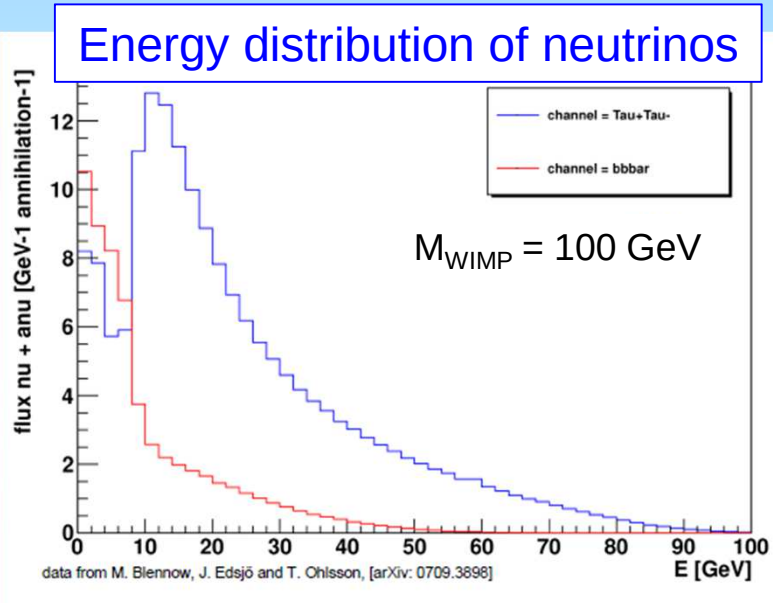


from M. Blennow, J. Edsjo and T. Ohlsson, arXiv:0709.389

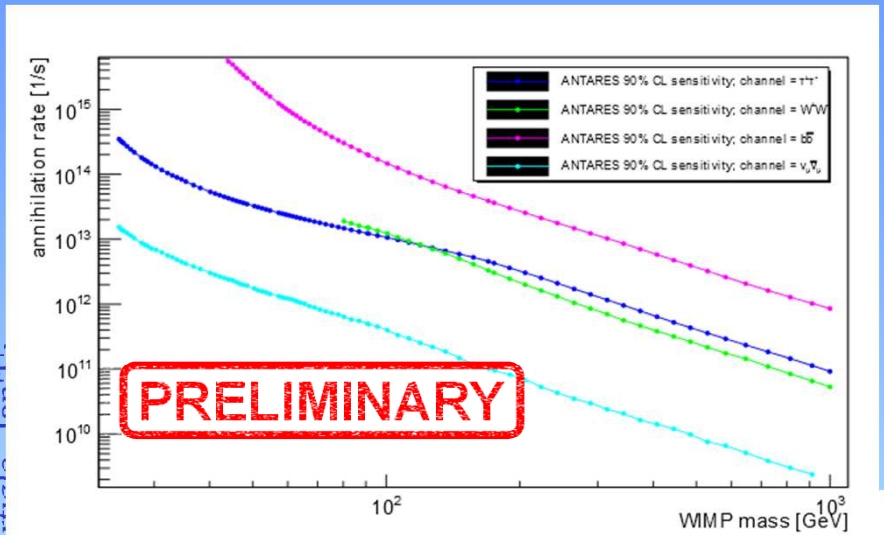
Angular distribution of neutrinos



Energy distribution of neutrinos



Sensitivity to DM annihilations in the Earth

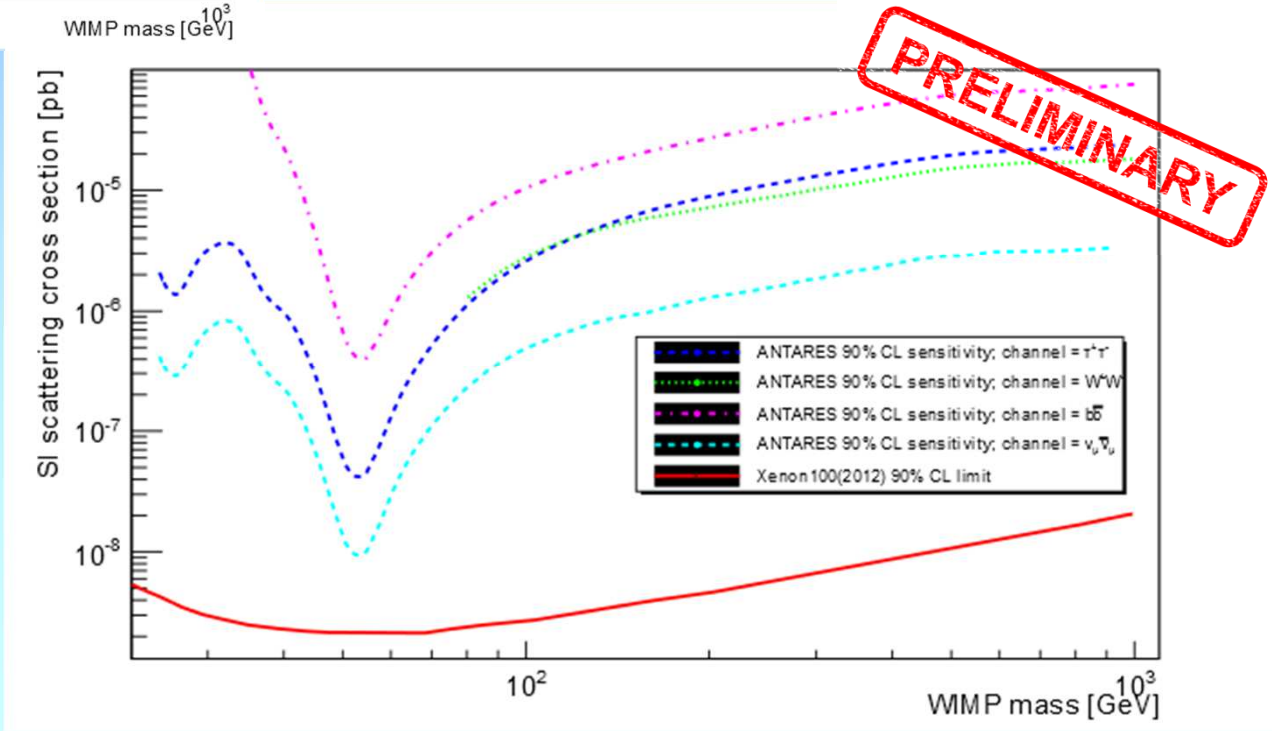


Dark Matter density usually not at equilibirum

due to low capture rates by the Earth

Assume **annihilation rate**

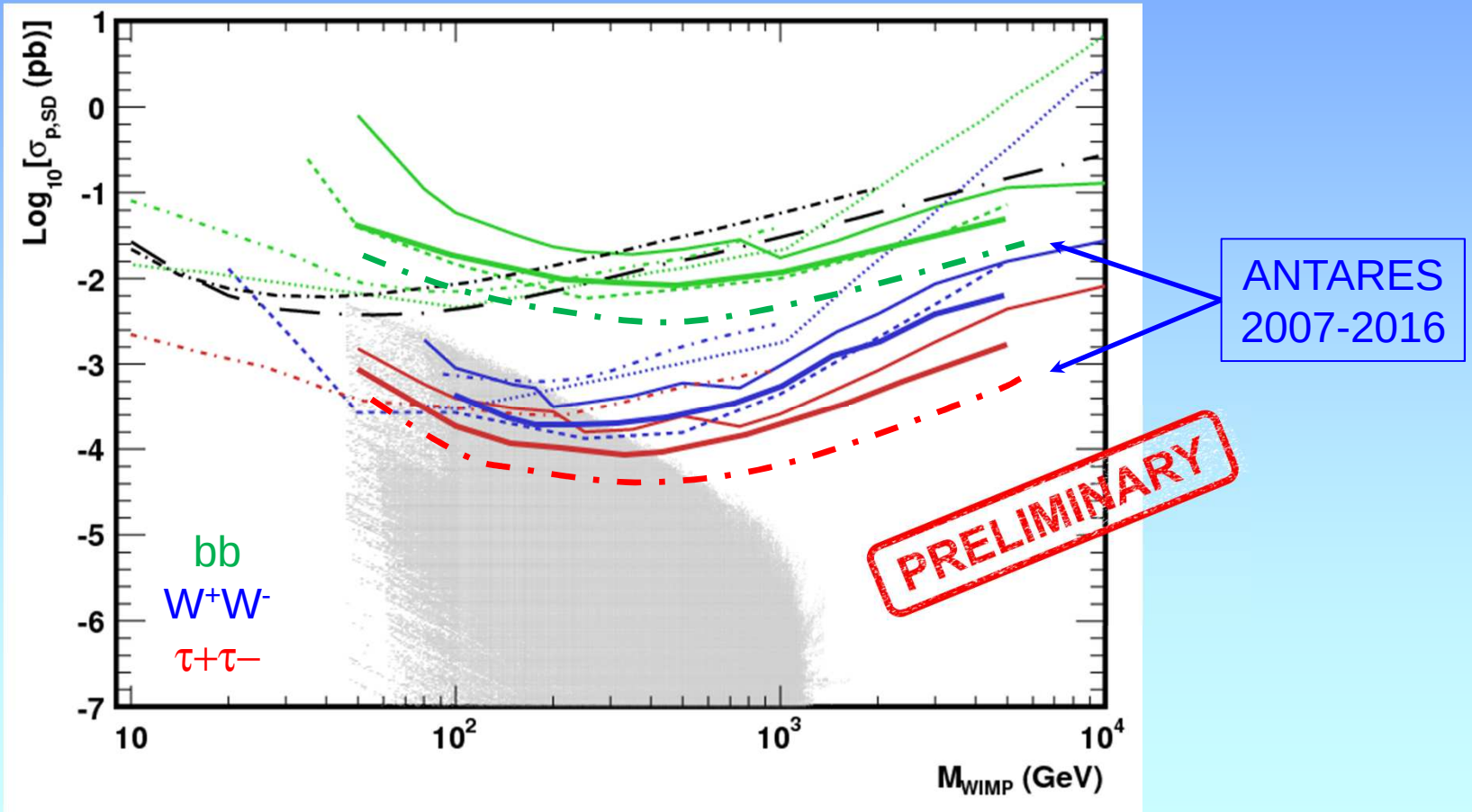
$\langle \sigma v \rangle = 3\ 10^{-26}\ cm^3\ s^{-1}$



Future Sensitivity of ANTARES to Sun DM search

ANTARES is scheduled to take data until ~ end of 2016

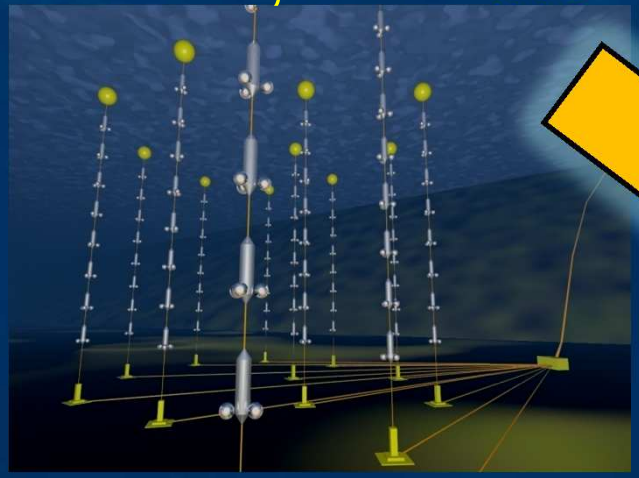
→ Expect **improvement factor ~2 on sensitivity to Sun analysis**
due to statistic + improvement of analysis under progress



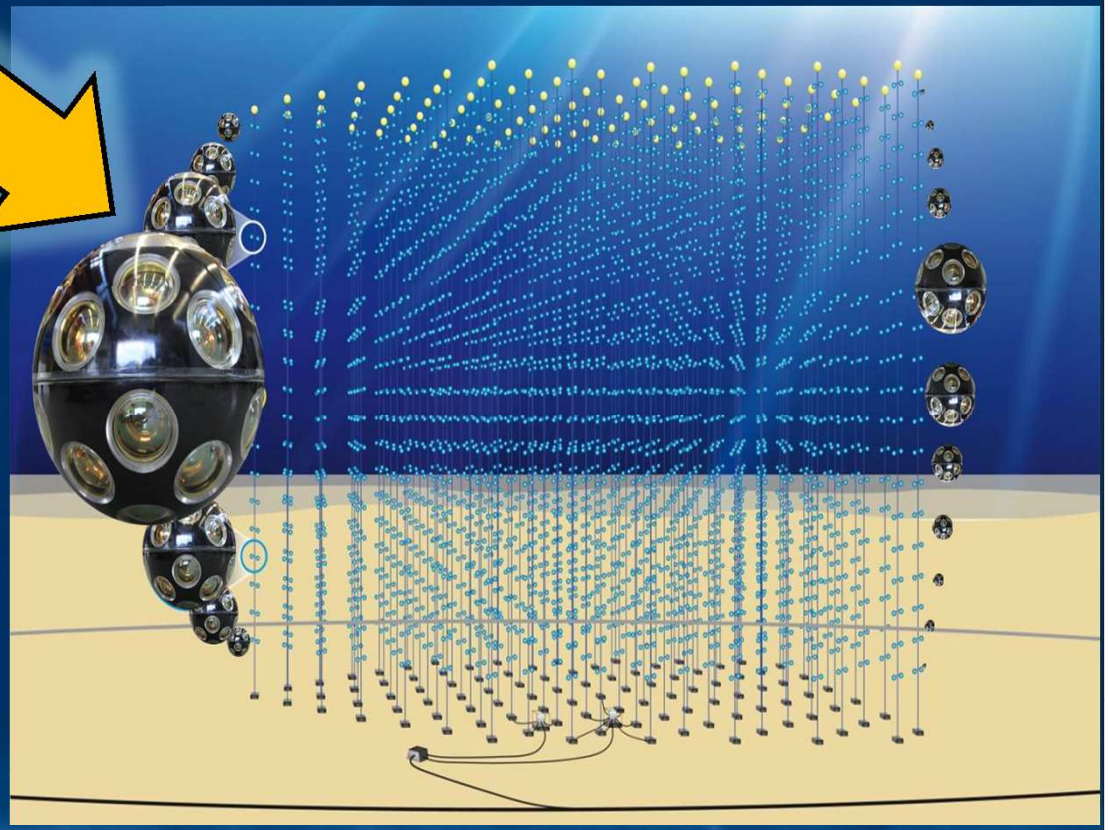
→ Additional improvement possible by using shower events : to be studied

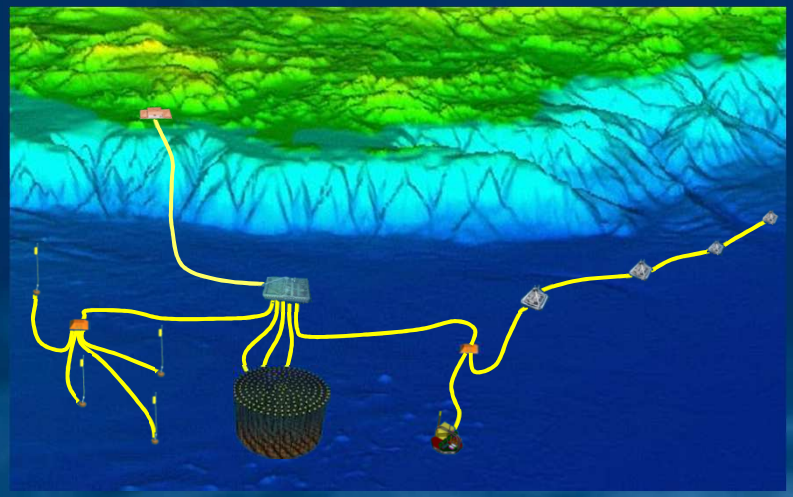
Beyond **ANTARES** : the **KM3NeT** Neutrino Telescope

12 lines, 900 PMTs



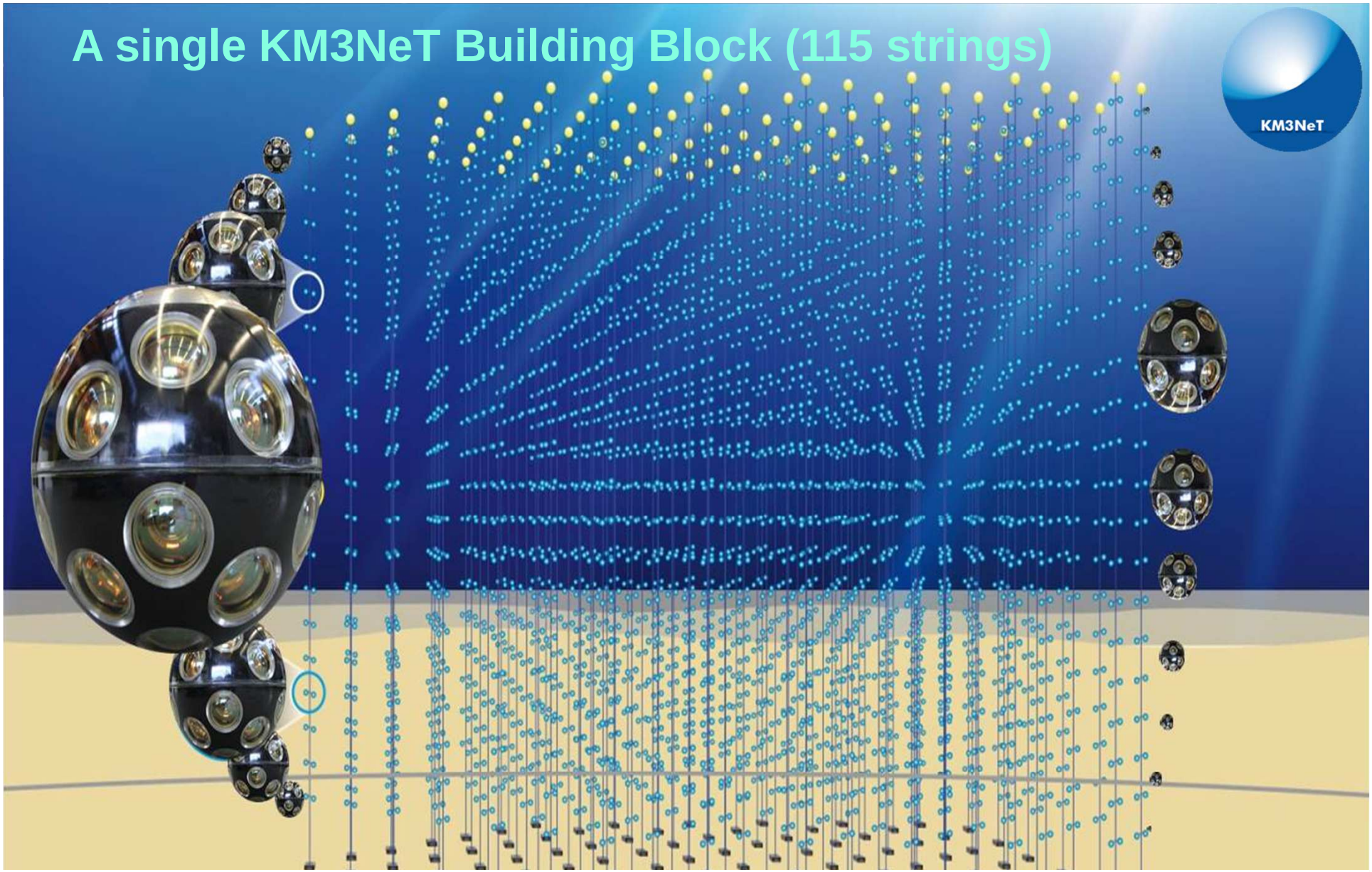
~600 lines, ~12 000 OMs





Permanent multidisciplinary observatory in the deep sea

Detector split on 3 deep sites in Mediterranean Sea offshore Toulon (France), Sicily and Greece



Phase 1 (funded) : 2 sites (Toulon, Capo Passero), 31 lines total (~2016)

Phase 1.5 (LoI) : 2 sites with 1 building block each (~2020)

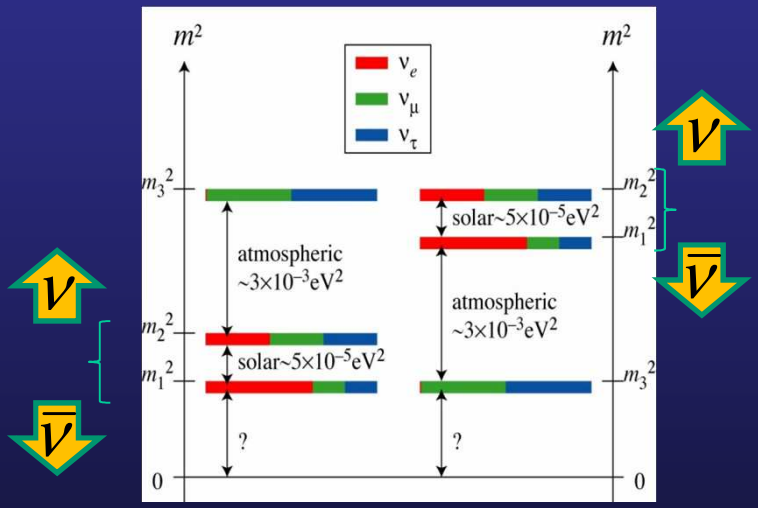
Phase 2 (ESFRI) : 2 (or 3 Greece?) sites with 6 blocks total (> 2020)

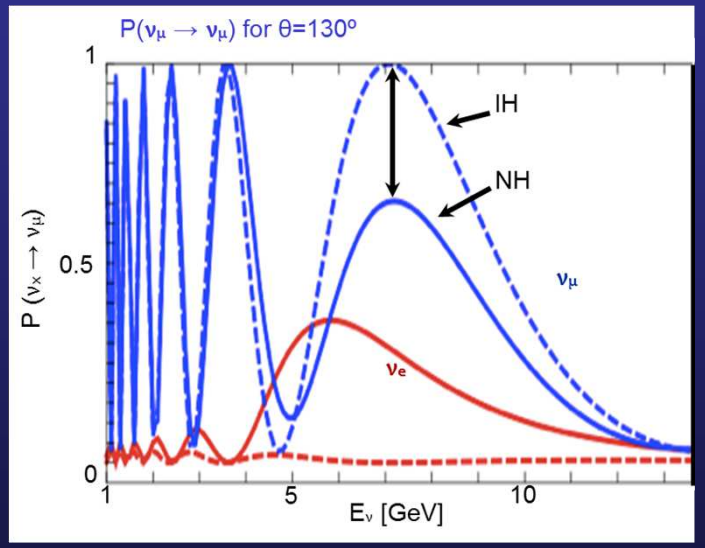
KM3NeT Collaboration

ORCA: measurement of the neutrino mass hierarchy with a dense undersea neutrino telescope

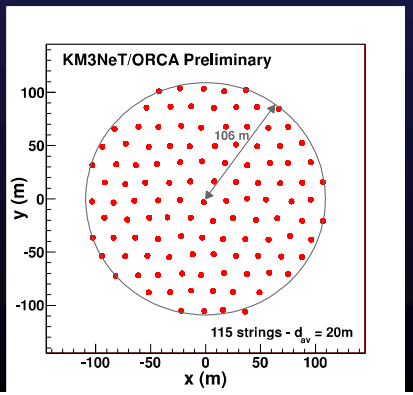
Measurement of the Daya Bay experiment in Spring 2012: $\sin^2 2\theta_{13} = 0.109 \pm 0.03 \pm 0.025$

→ Sensitivity to neutrino mass hierarchy (Normal vs Inverse) with oscillations of atmospheric neutrinos of few GeV interacting with the Earth

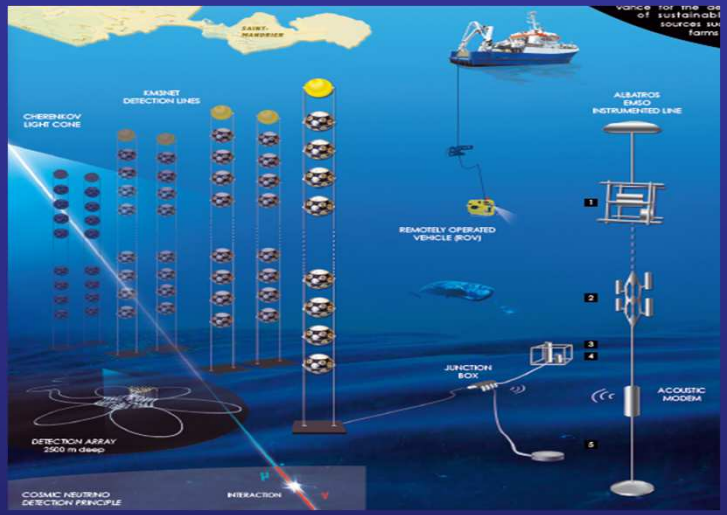


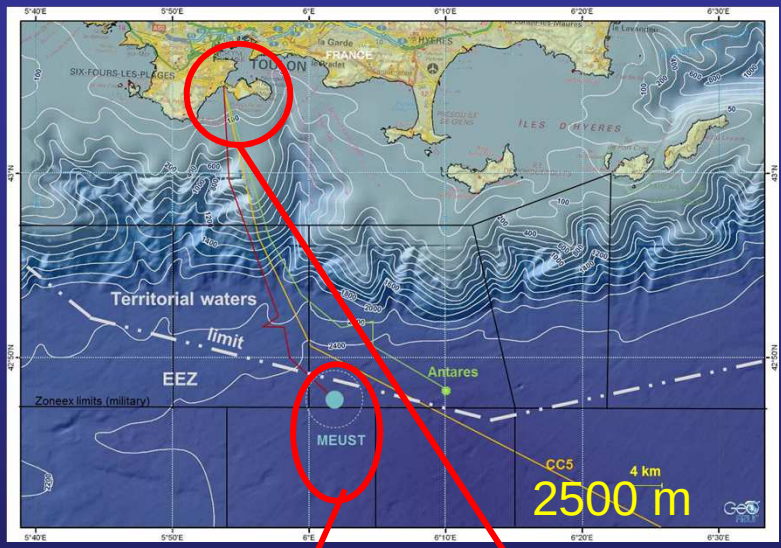


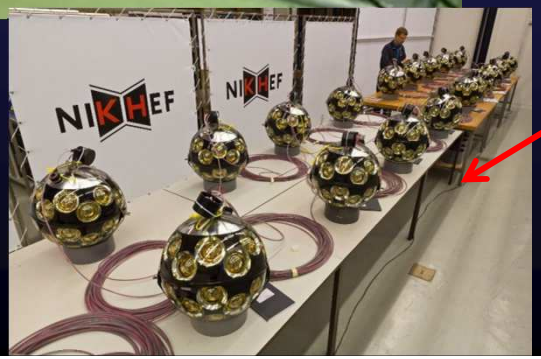
→ On-going faisability study of such measurement with a dense undersea neutrino telescope **(ORCA)**

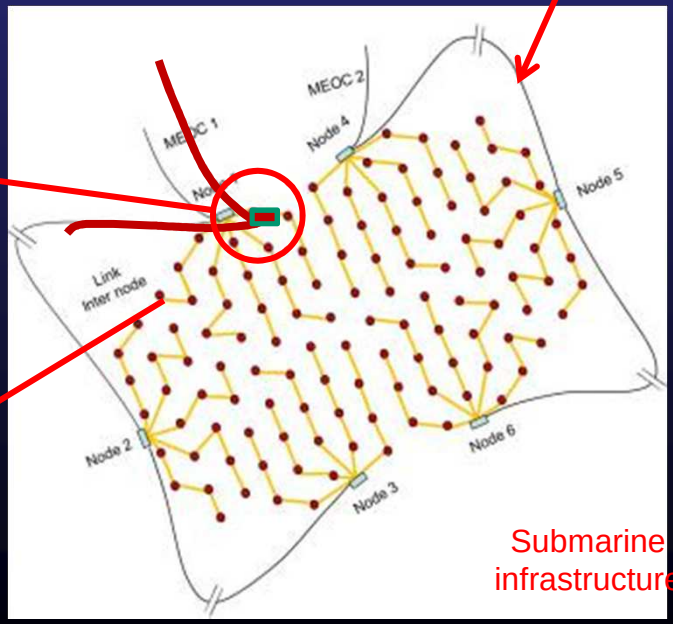


MEUST : a multi-disciplinary Deep Sea Observatory off Toulon for KM3NeT/ORCA and EMSO





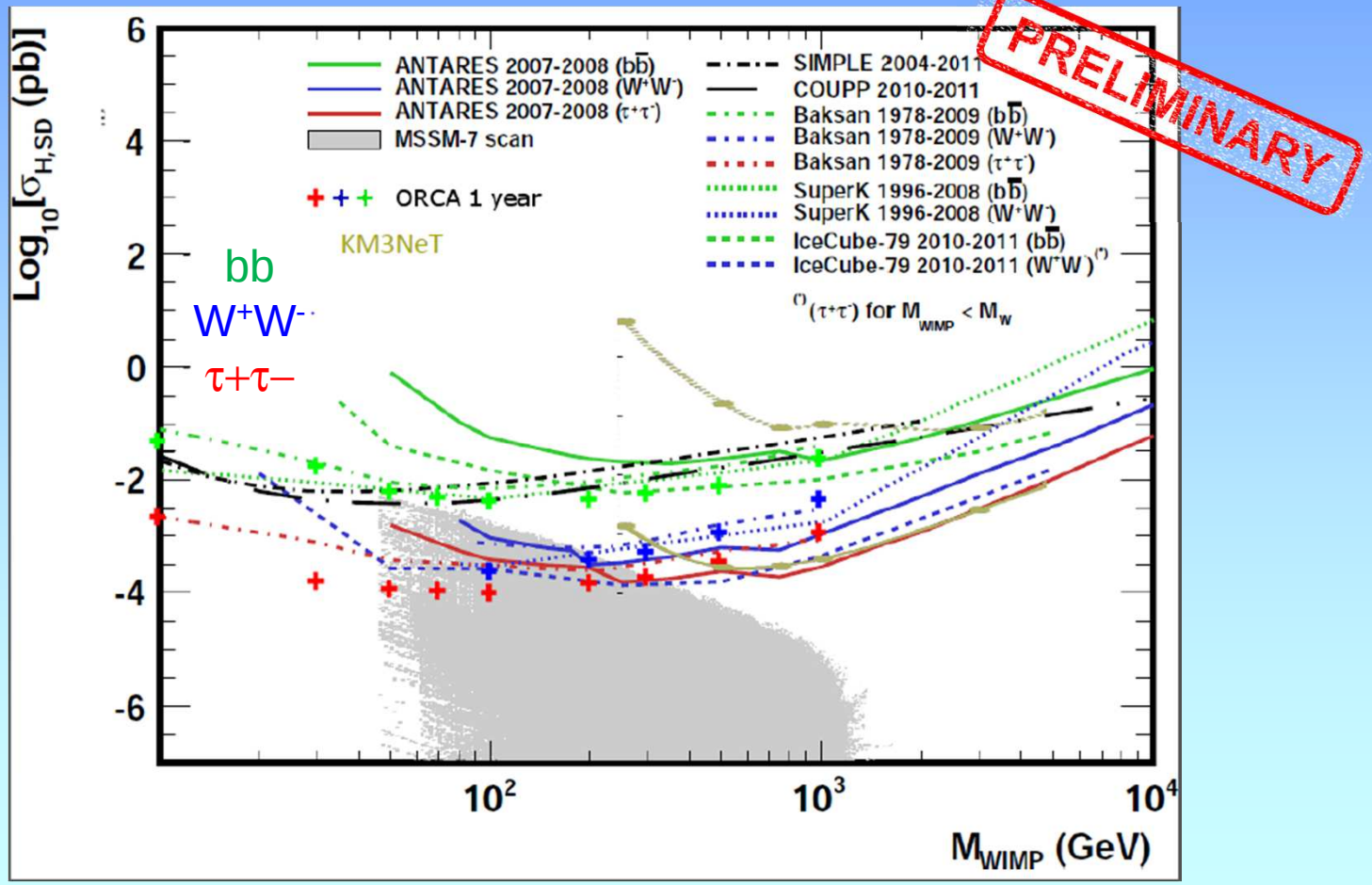




Submarine infrastructure

Preliminary sensitivity of ORCA to Sun DM search

→ **Promissing sensitivity to low DM mass region**
due to low energy threshold



→ Additional improvement possible by using shower events : under study

Summary and Outlook

- **Indirect search for Dark Matter** is a **major goal** for neutrino telescopes (**important complementarity** to direct detection experiments)
- **Indirect search** towards the **Sun** performed by **ANTARES** with data recorded in 2007-2012
  → **competitve limits** derived especially for low DM masses
- **First ANTARES limits towards the Galactic Centre**
  →**best current limits** using neutrinos
  →important complementary **constraints** on leptophilic Dark Matter models
- **Study of other potential signal sources** (Earth, dwarf galaxies, galaxy clusters…) **done** or in **progress**
- **Exciting improvement of sensitivity** expected for DM search towards the Sun with ANTARES and KM3NeT/ORCA