

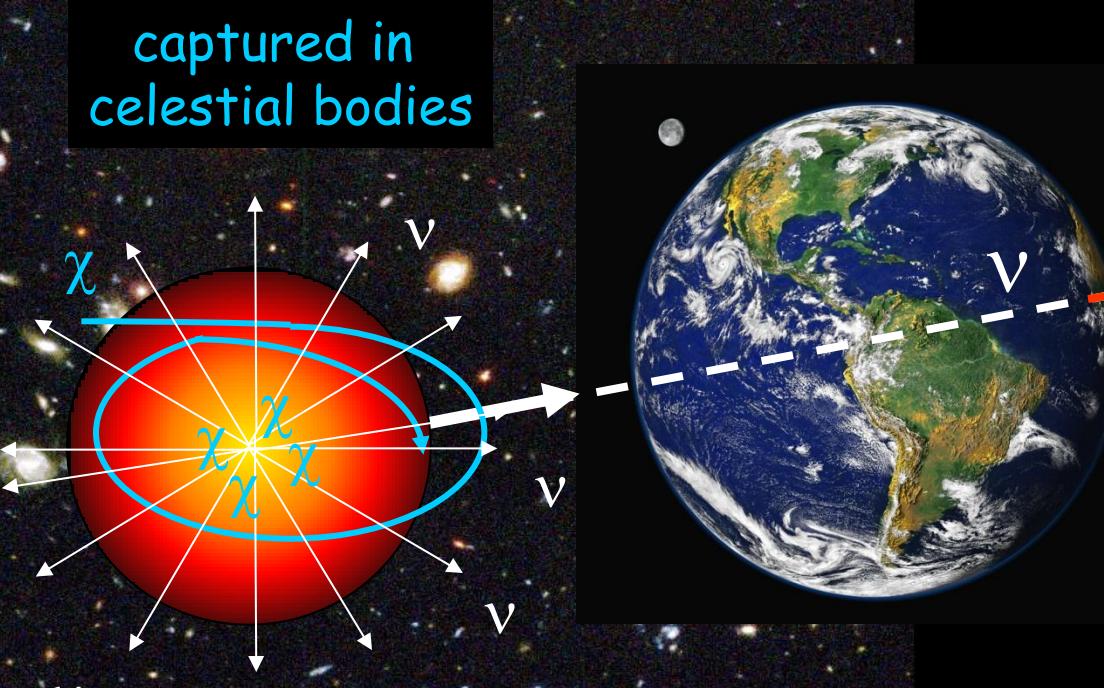
Indirect search for Dark Matter with the ANTARES Neutrino Telescope

Vincent Bertin - CPPM-Marseille
on behalf of the ANTARES Collaboration

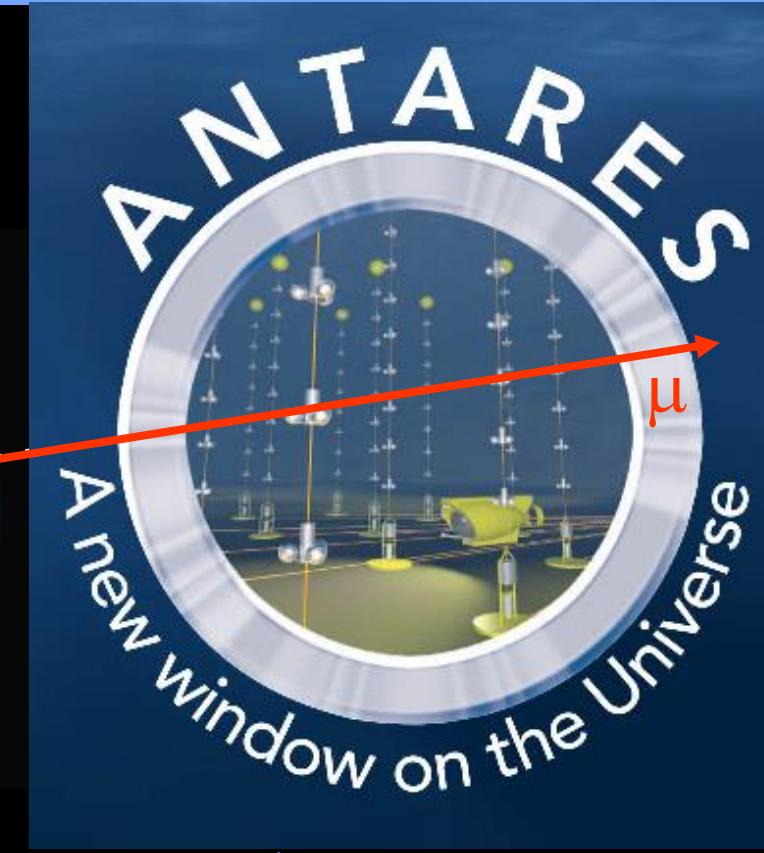


Indirect detection of WIMPs in a neutrino telescope

Relic WIMPs
captured in
celestial bodies

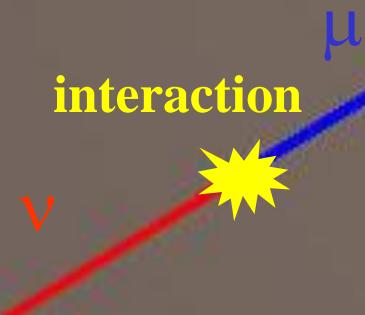
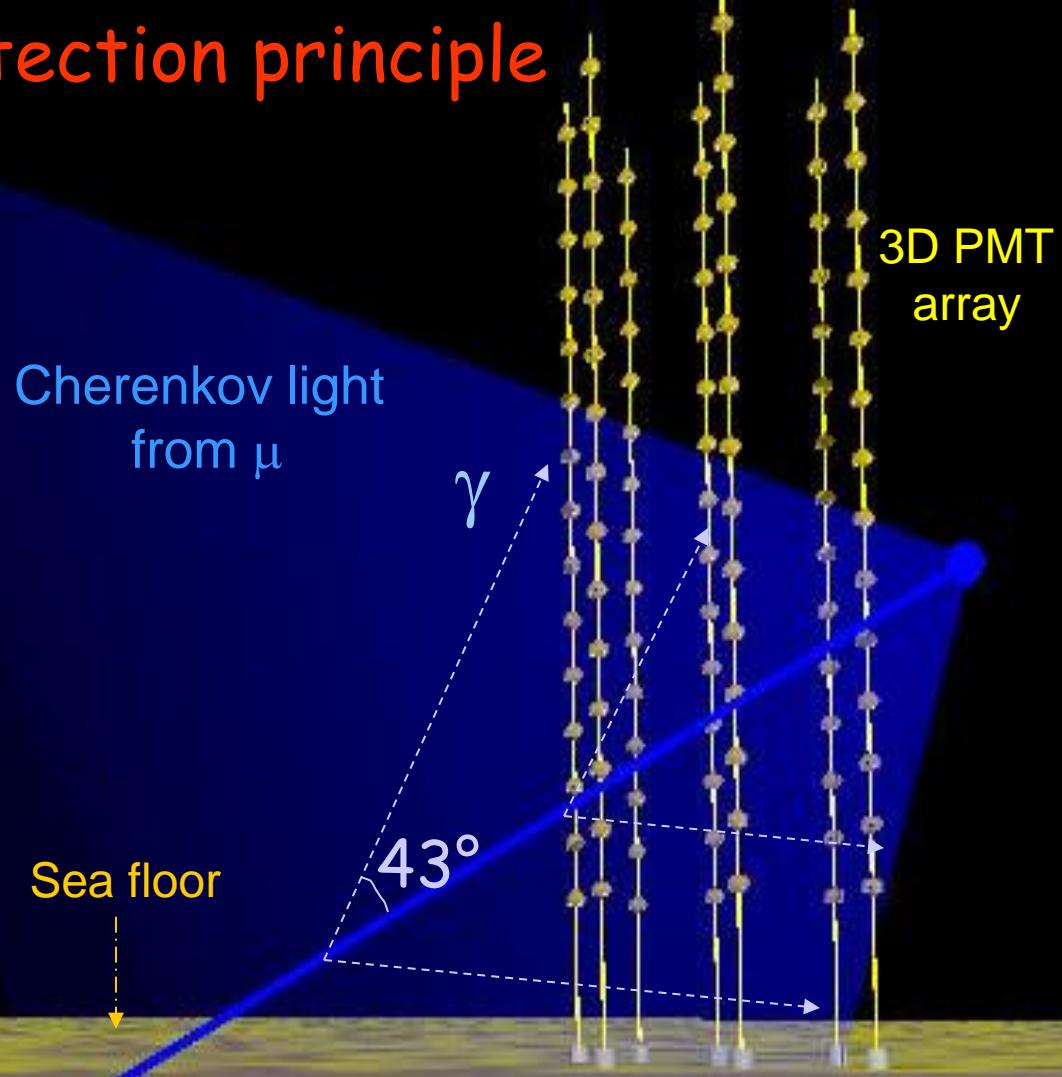
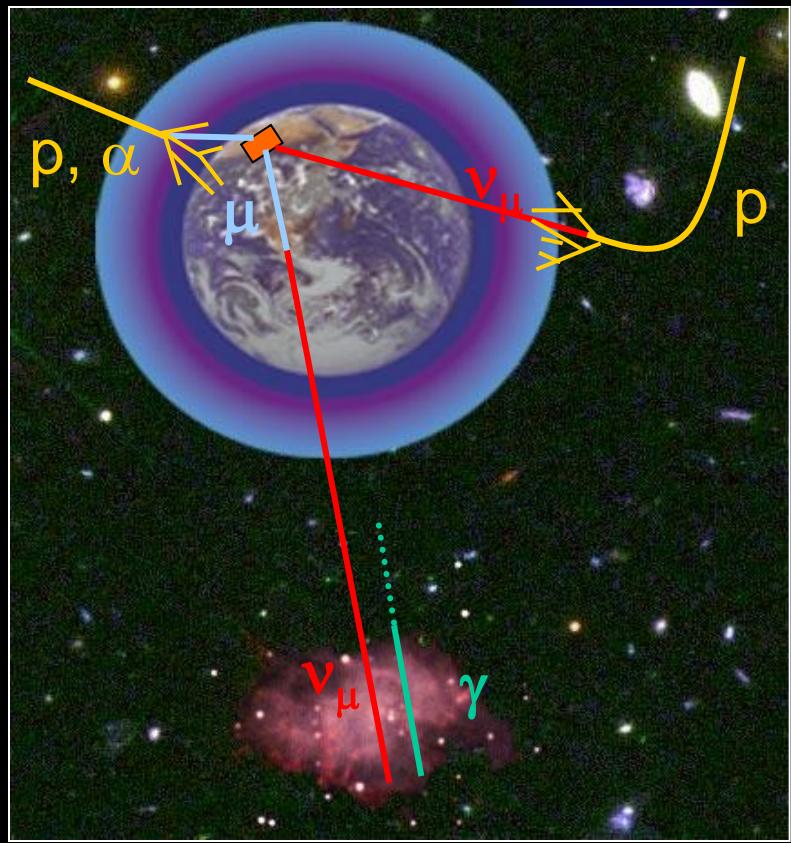


$\chi\chi \rightarrow \nu\nu$ self-annihilations into
c,b,t quarks, τ leptons or W,Z,H bosons
can produce significant
high-energy neutrinos flux



Potential $\chi\chi \rightarrow \nu\nu$ sources are
Sun, Earth & Galactic Centre
Signal less affected by
astrophysical uncertainties
than γ -ray indirect detection

Neutrino telescope: Detection principle

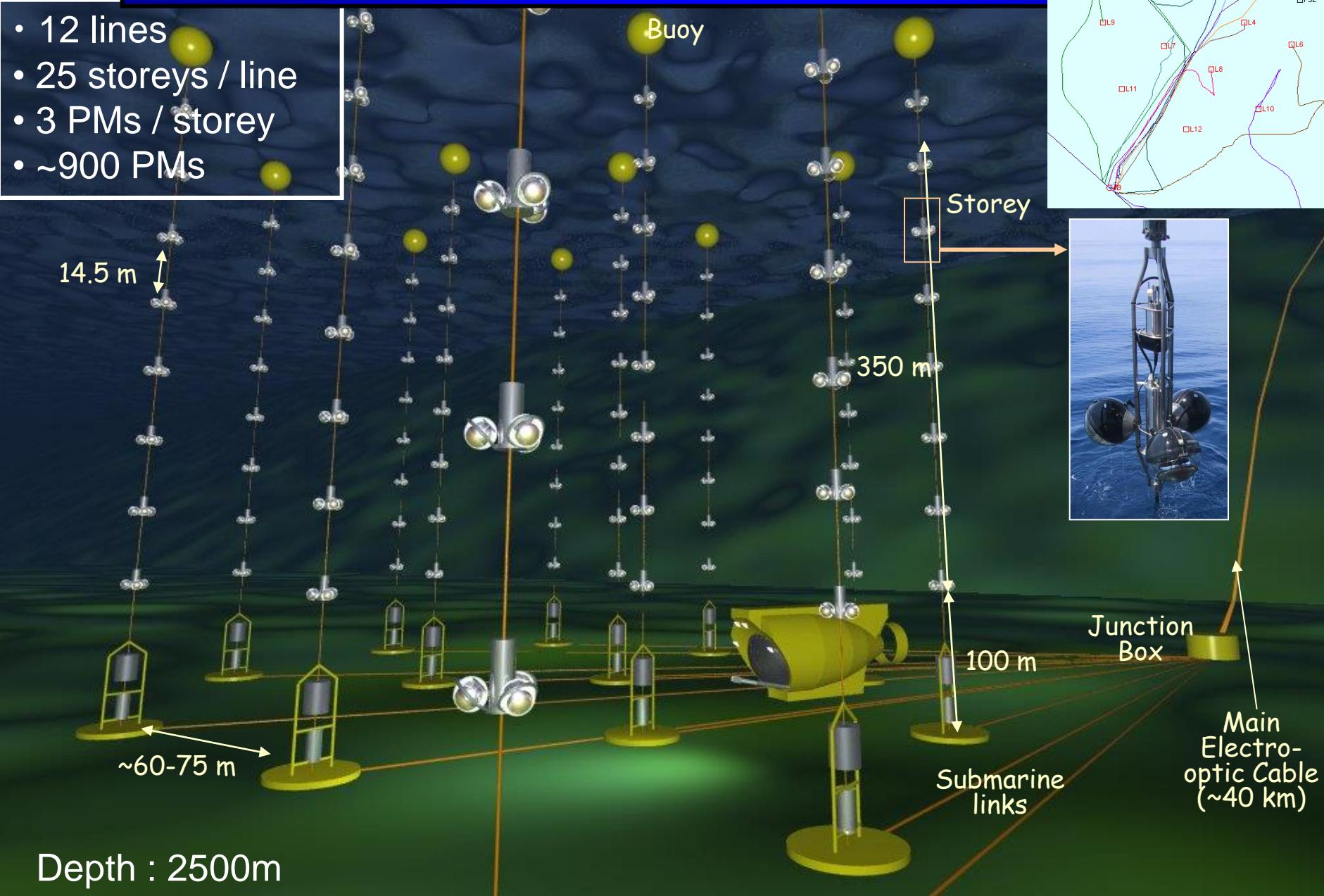


Reconstruction of μ trajectory ($\sim \nu$)
from timing and position of PMT hits



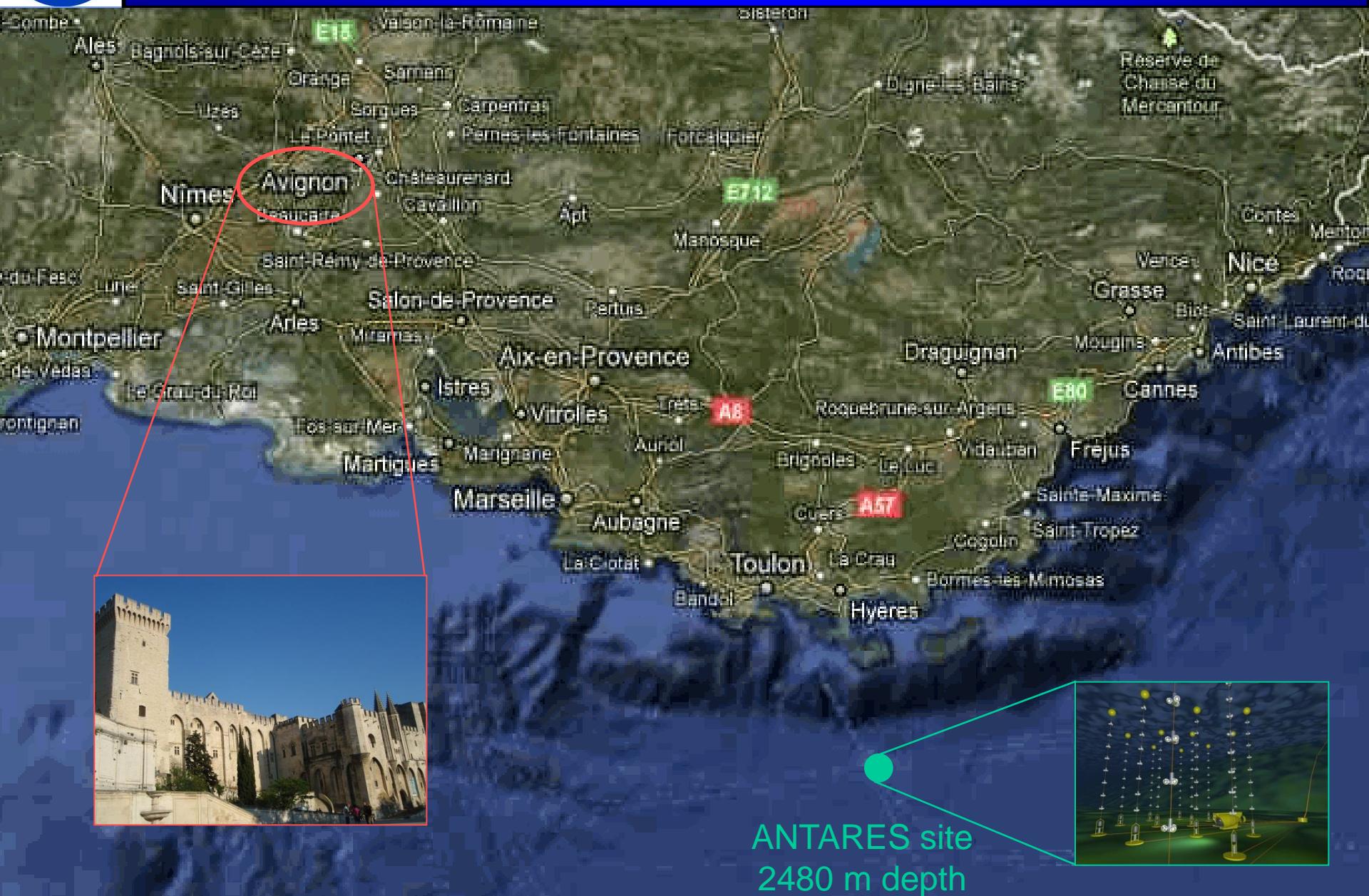
The ANTARES detector

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





The ANTARES site



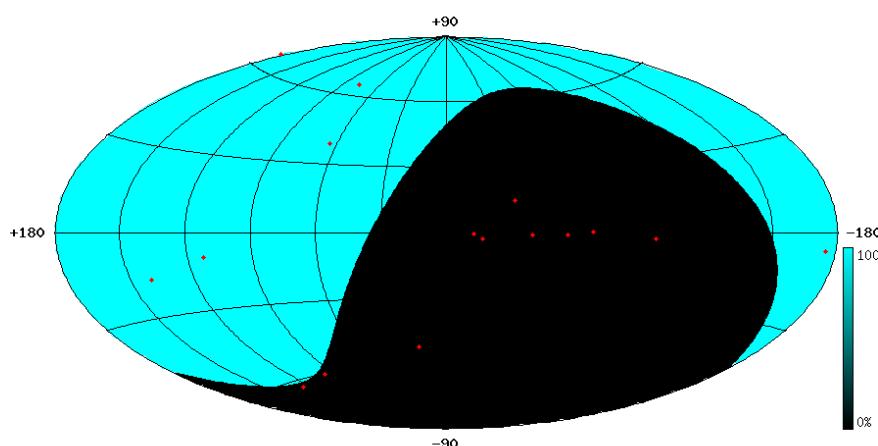


Region of Sky Observable by Neutrino Telescopes



IceCube (South Pole)

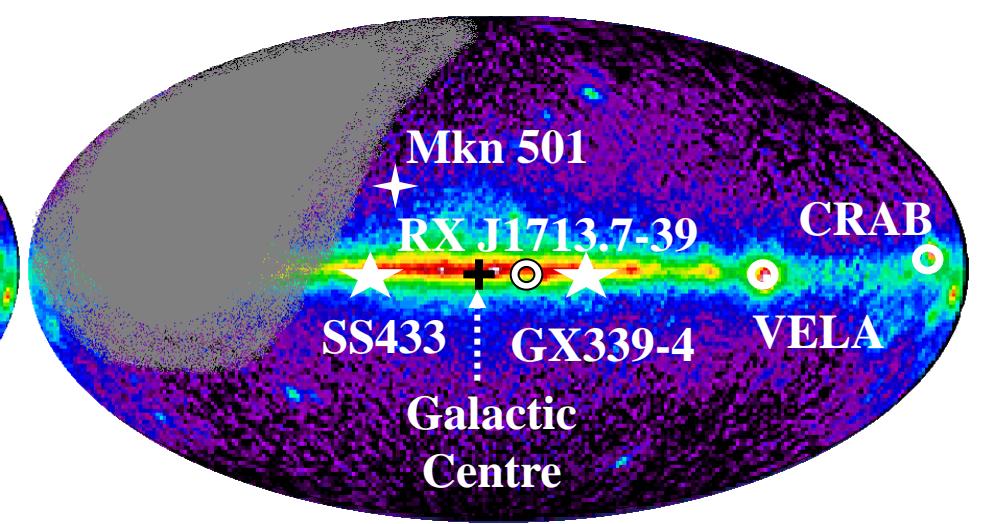
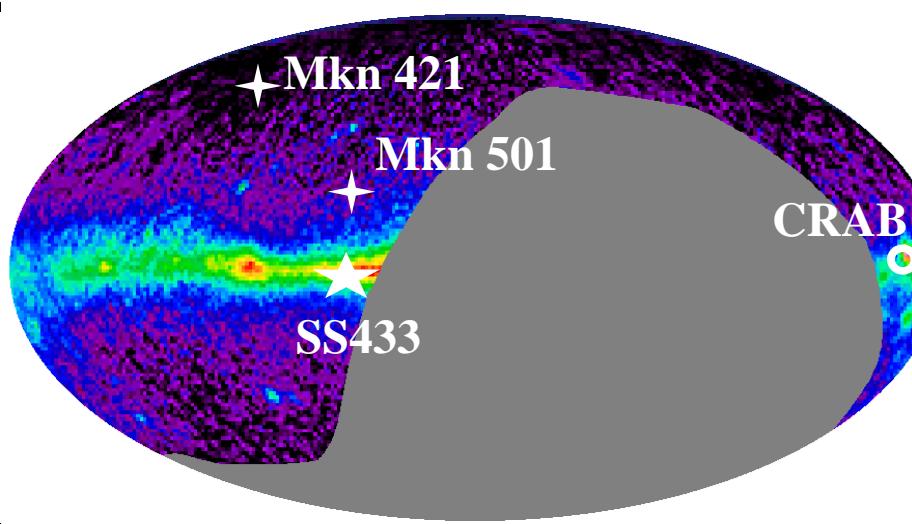
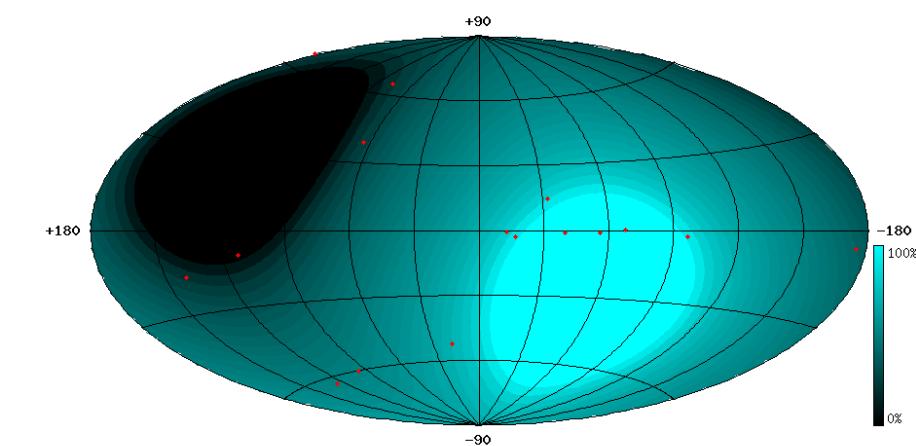
(ice: $\sim 0.6^\circ$)



ANTARES (43° North)

Angular resolution

(water: $\sim 0.3^\circ$)



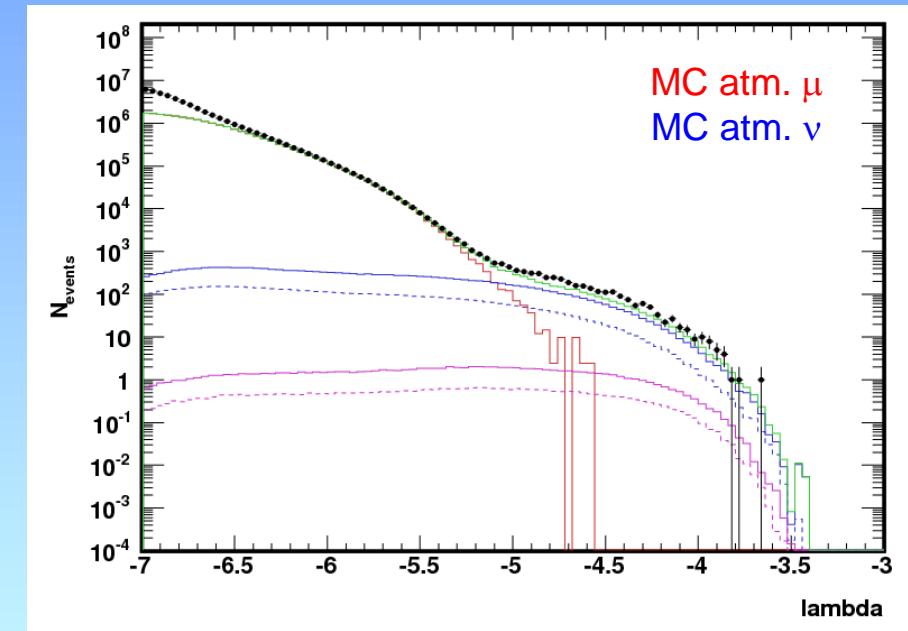
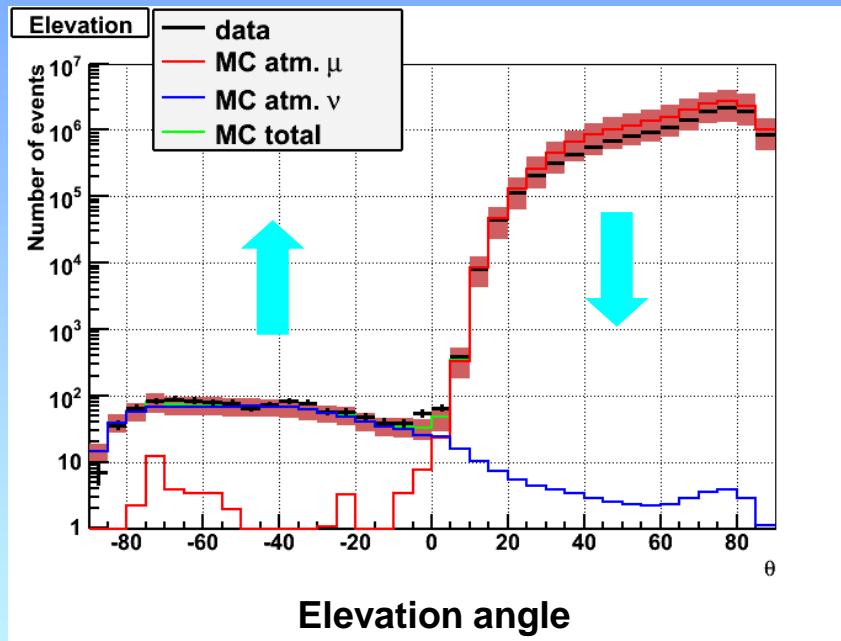


Indirect search towards the Sun with ANTARES

- **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**
 - AAFFit (likelihood based) → high energies/masses (>250 GeV)
 - **lambda** (**quality parameter**, basically the likelihood value)
 - **beta**: **angular error** estimation
- **Selection parameters:**
 - **tchi2**: $\sim\chi^2$ (BBFit)
 - **lambda**: Quality reconstruction parameter \sim likelihood (AAFFit)
 - **beta**: angular error estimate (AAFFit)
 - **Cone opening angle** around the Sun (or **zenith band** for single line events)

Event selection : background rejection

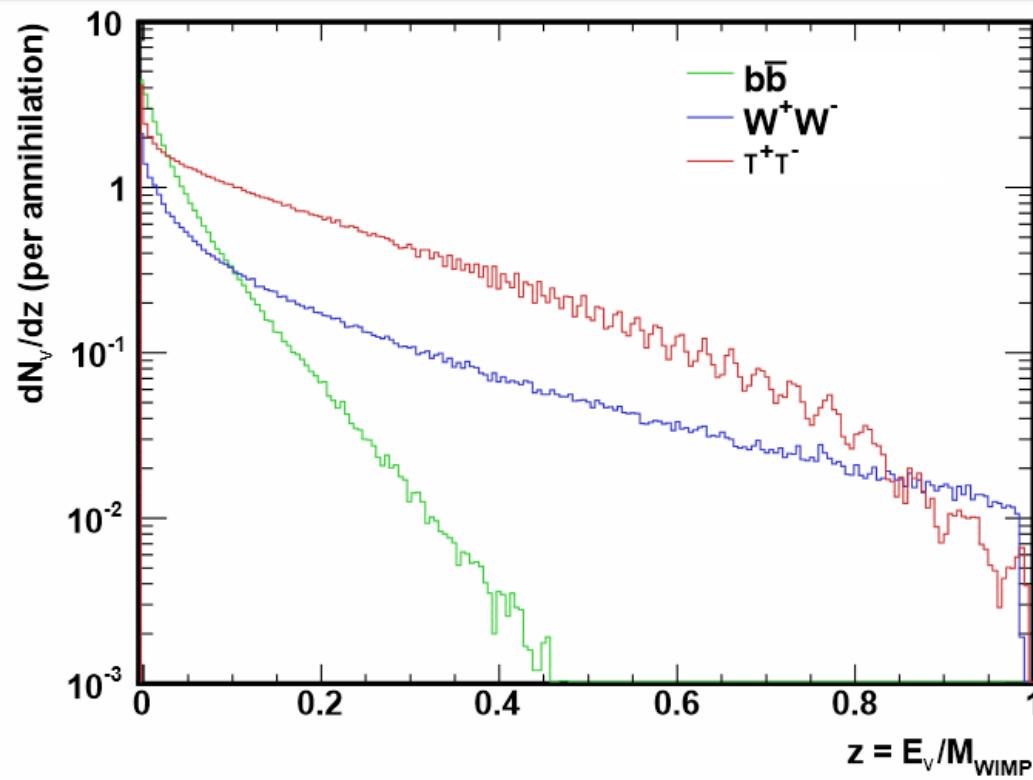
- Selection of neutrinos and rejection of atmospheric muons by **selecting up-going tracks** and **cutting on track fit quality**



- 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**



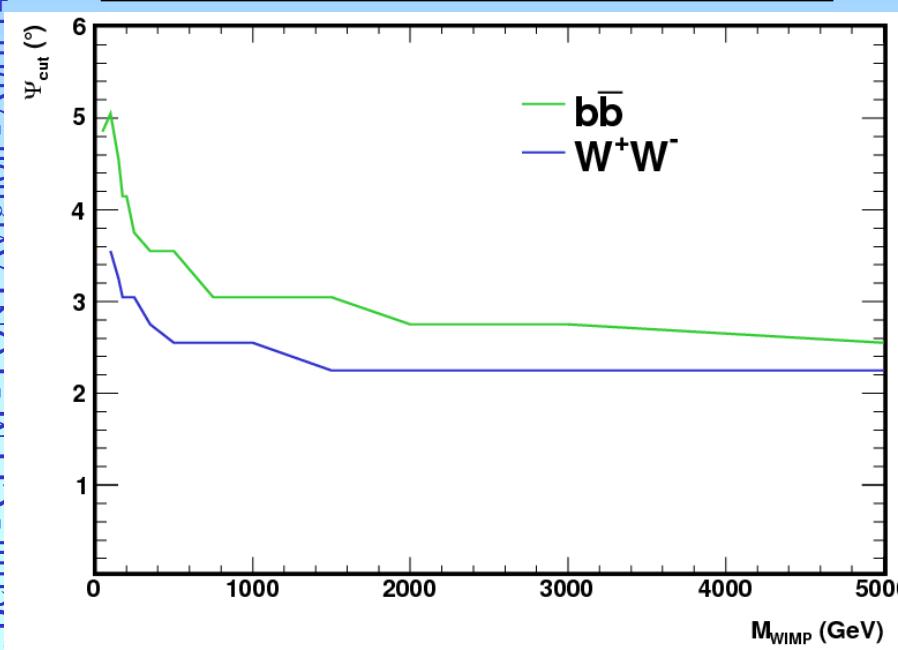


Selection optimization and observed events

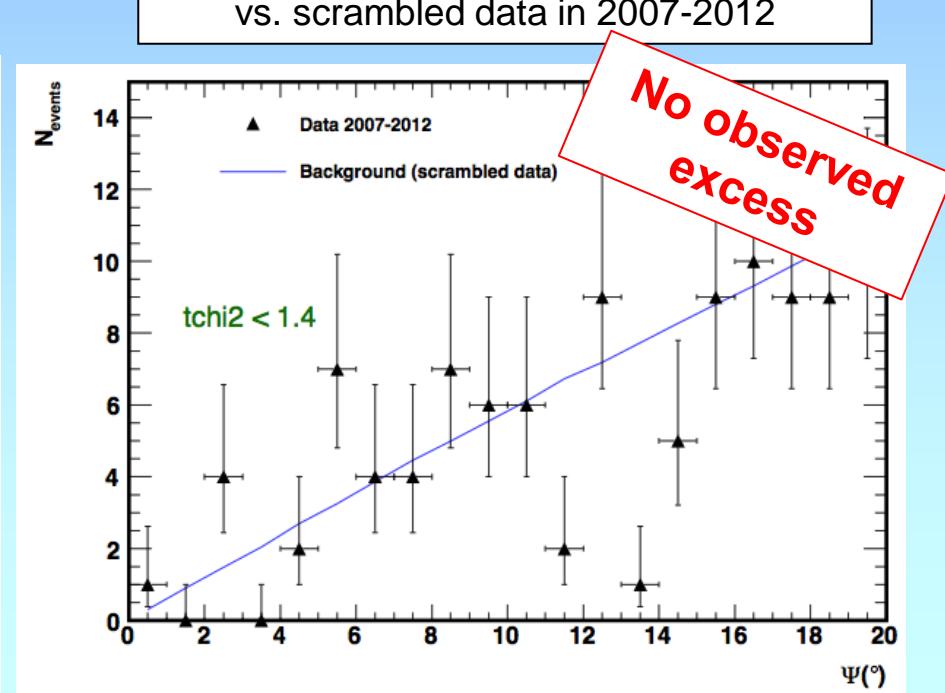
- Neutrino fluxes at the Earth produced by Dark Matter coannihilation are **convoluted** with the detector efficiency for given selection parameter sets (track fit quality, cone size)
- Neutrino **background** given by **scrambled data in the Sun direction** is evaluated for the same selection set
-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

$$Sensitivity = \frac{\bar{m}_{90}}{A_{eff}(M_{wimp}) \cdot T_{eff}}$$

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

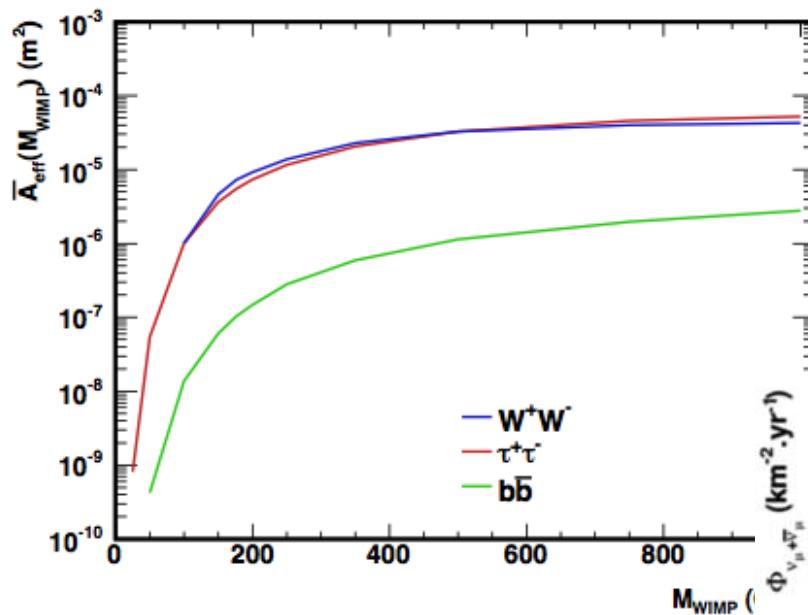


Observed events in the Sun direction
vs. scrambled data in 2007-2012



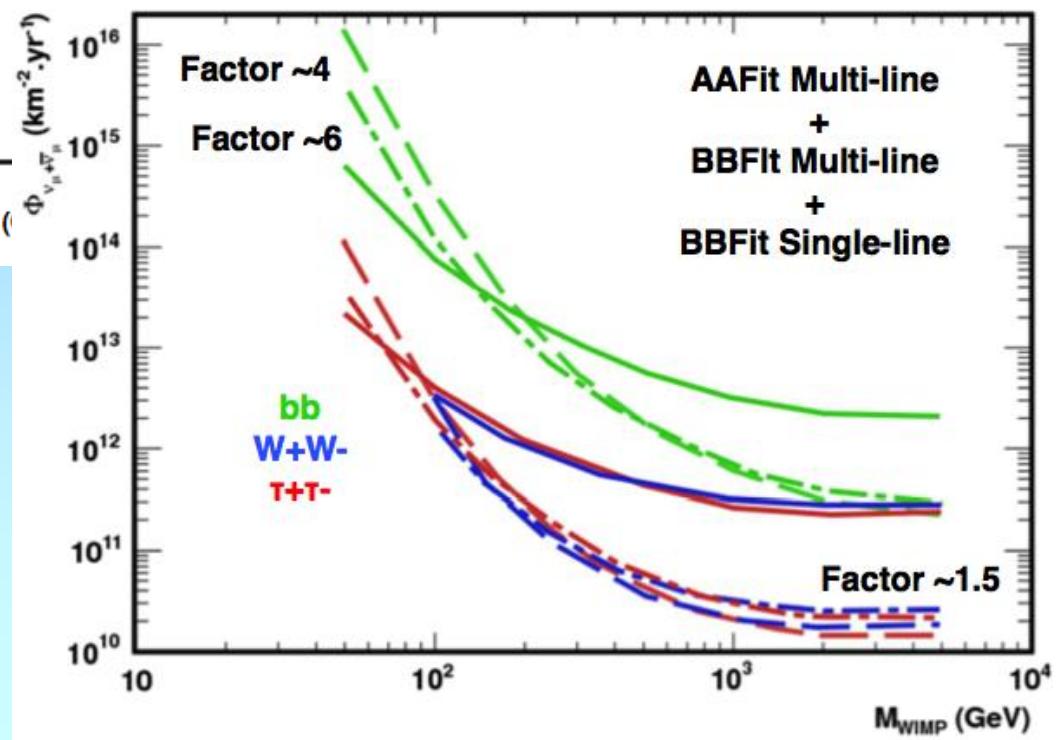


Limit on neutrino flux coming from the Sun



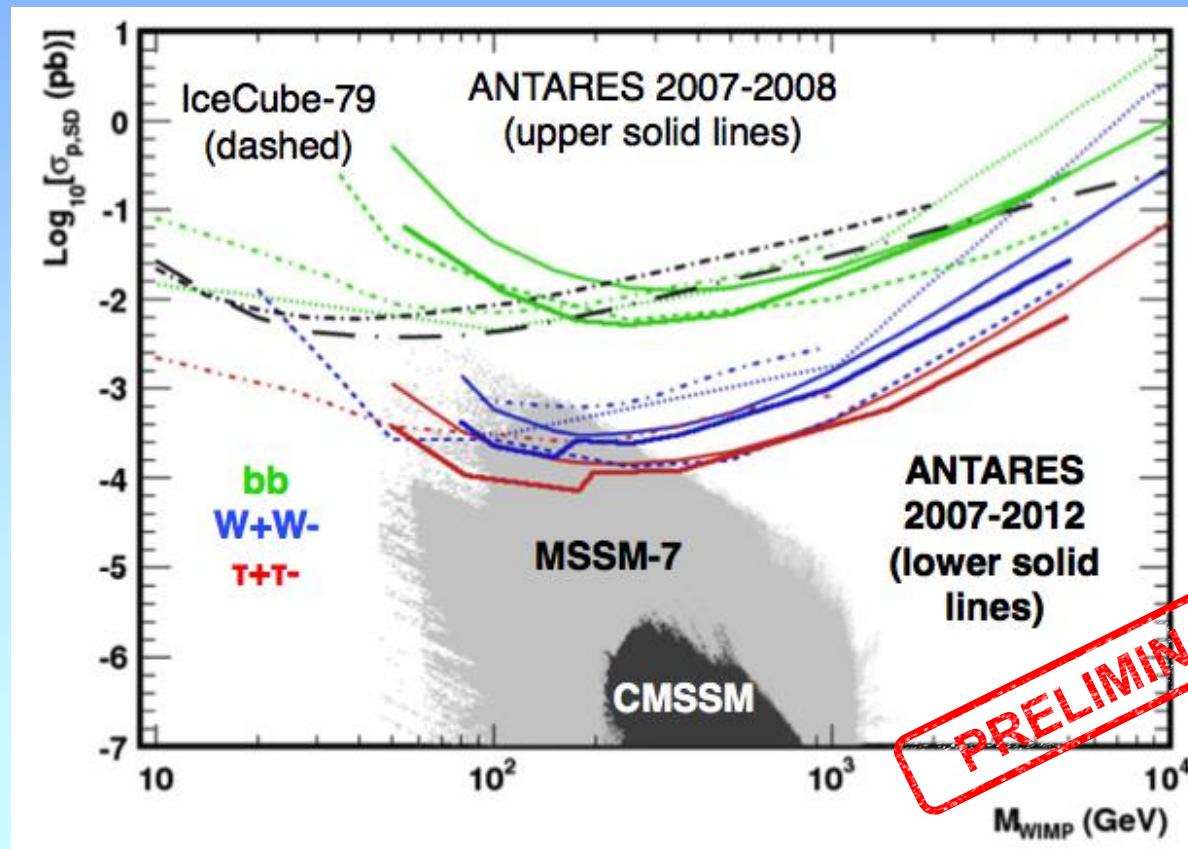
Effective area of signal
as function of WIMP mass
→ low threshold
at $M_{\text{WIMP}} \sim 50 \text{ GeV}$

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



Limits on Spin Dependent cross sections

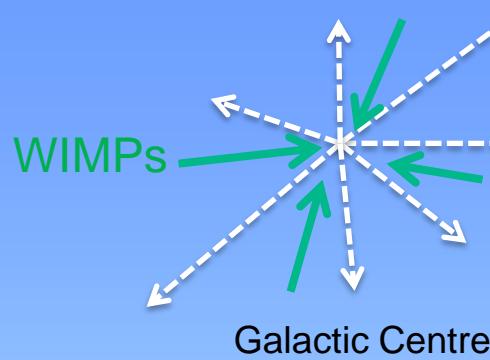
Conversion to limits on WIMP-proton Spin Dependent cross sections
 assuming equilibrium between capture and annihilation rates inside the Sun
 → much better sensitivity of neutrino telescopes on SD cross-section
 w.r.t. direct detection due to capture on Hydrogen inside the Sun



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



Search for Dark Matter towards the Galactic Centre

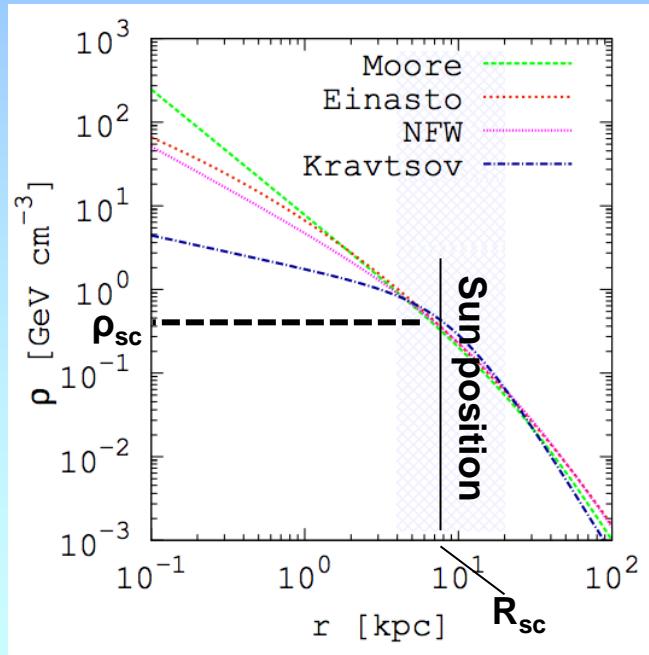


ν_e, ν_μ, ν_τ
 ν oscillations in the vacuum
 ν can propagate with a minimum of astrophysical uncertainties



Earth

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

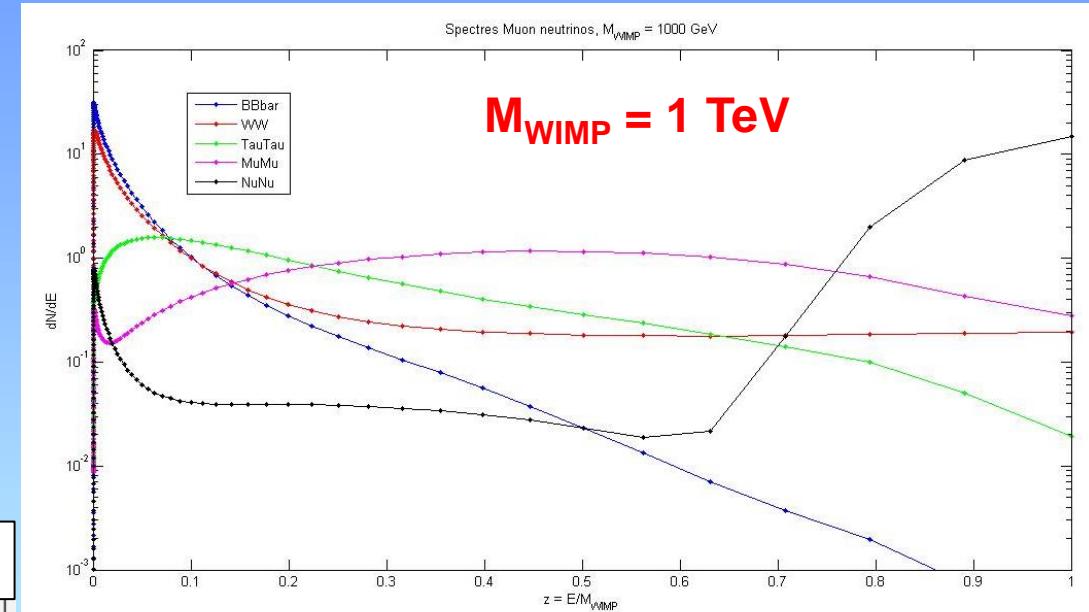
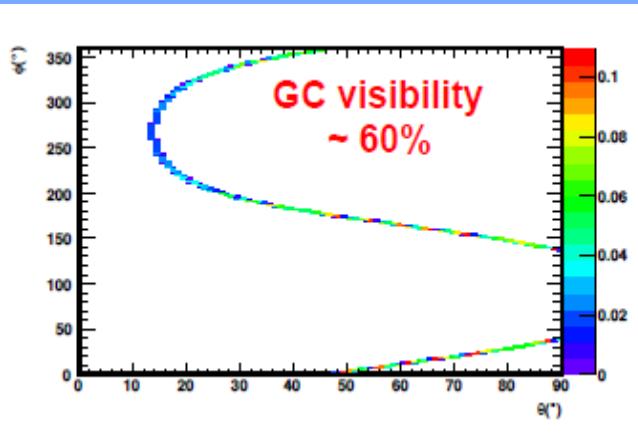
$$\Phi^{PP} \equiv \frac{1}{4\pi} \frac{\langle\sigma v\rangle}{2M_{WIMP}^2} \frac{dN_\nu}{dE_\nu}$$

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

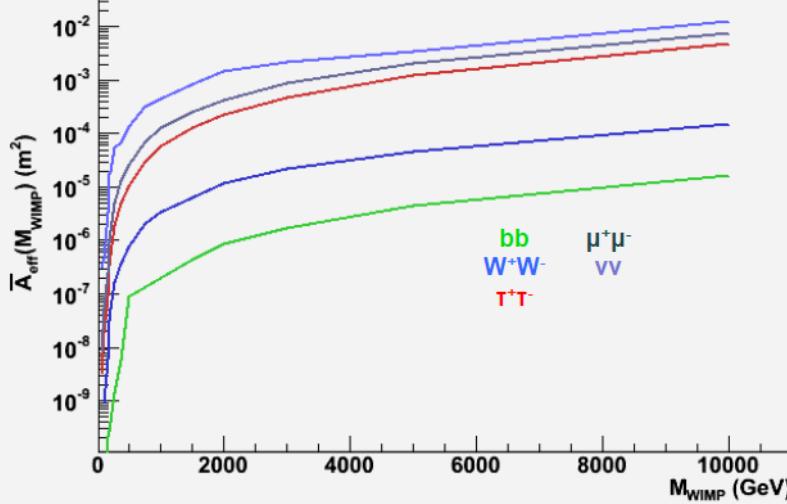


Search for Dark Matter towards the Galactic Centre

ANTARES visibility of the Galactic Centre



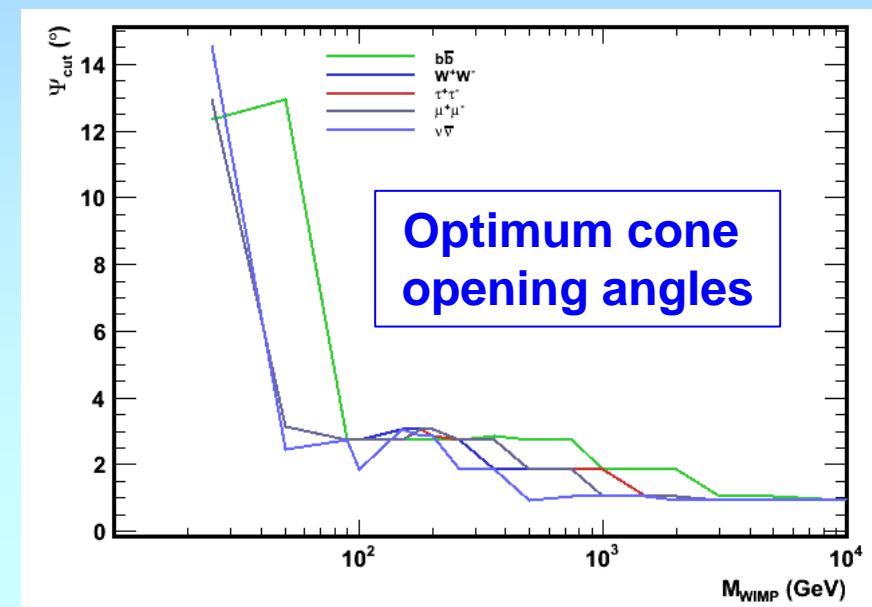
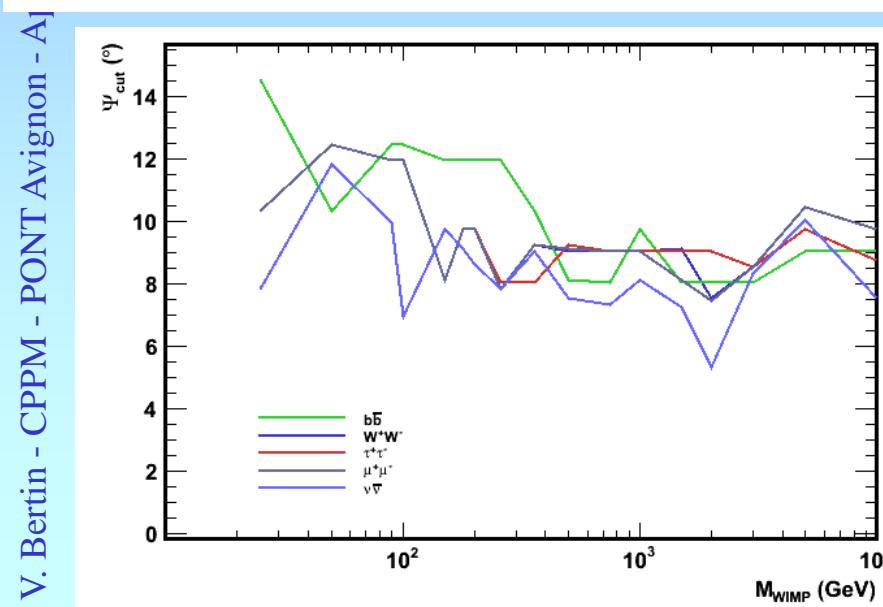
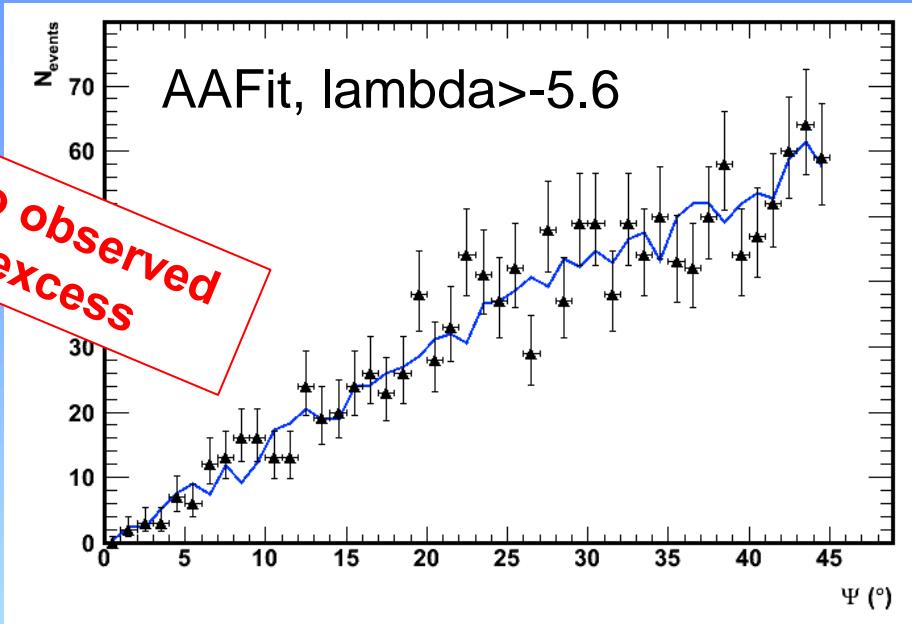
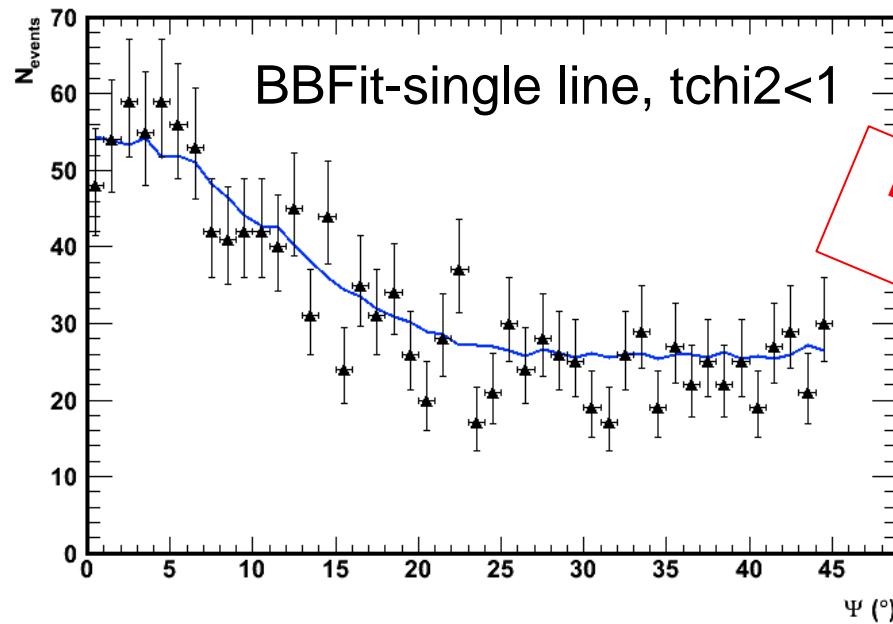
Effective area for Aafit analysis



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)

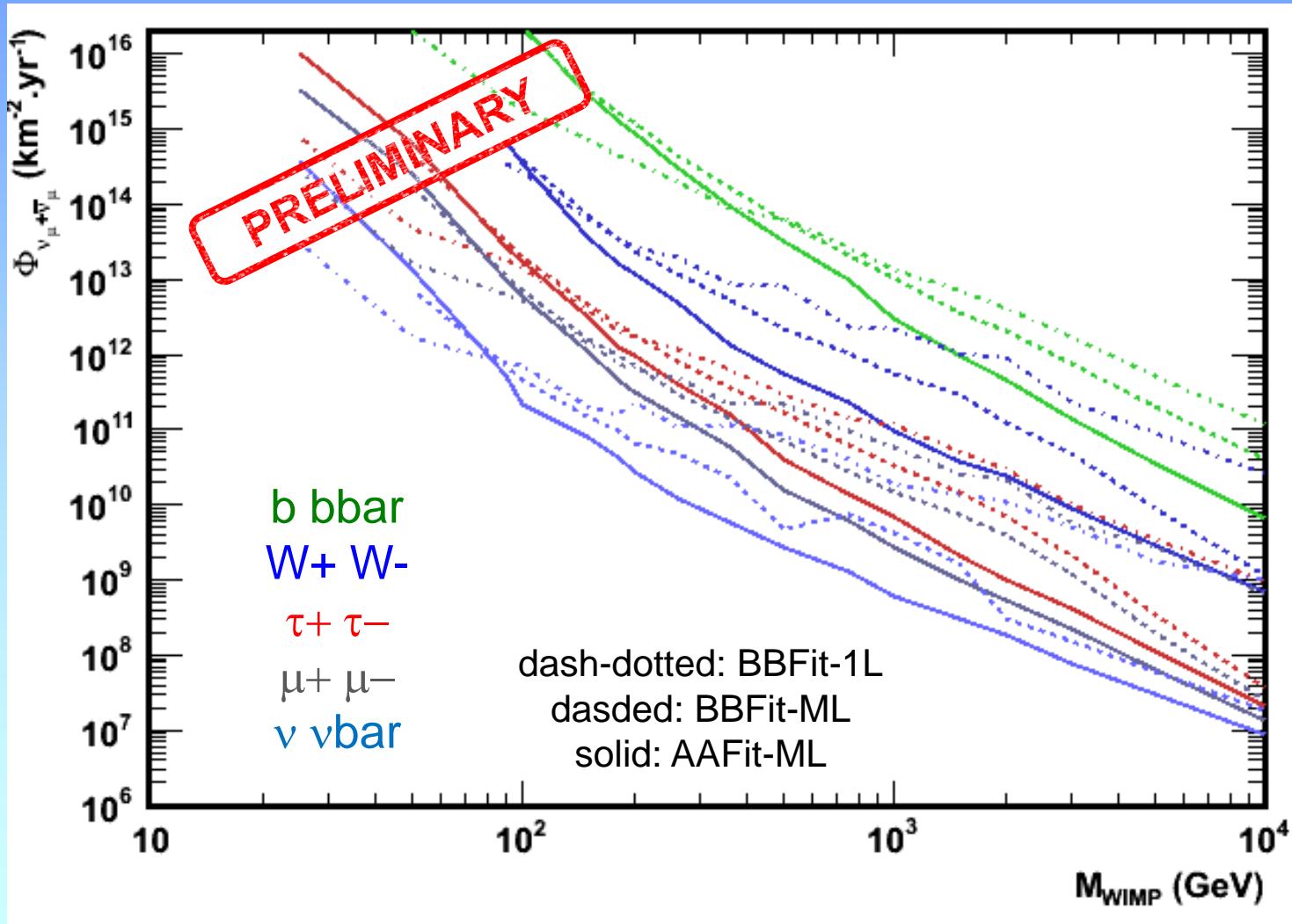


ANTARES observation of the Galactic Centre with 2007-2012 data





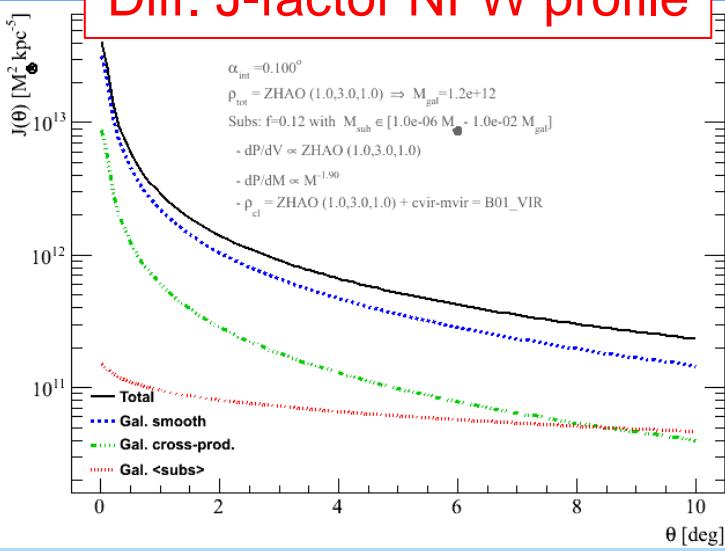
Limits on neutrino flux from Galactic Centre



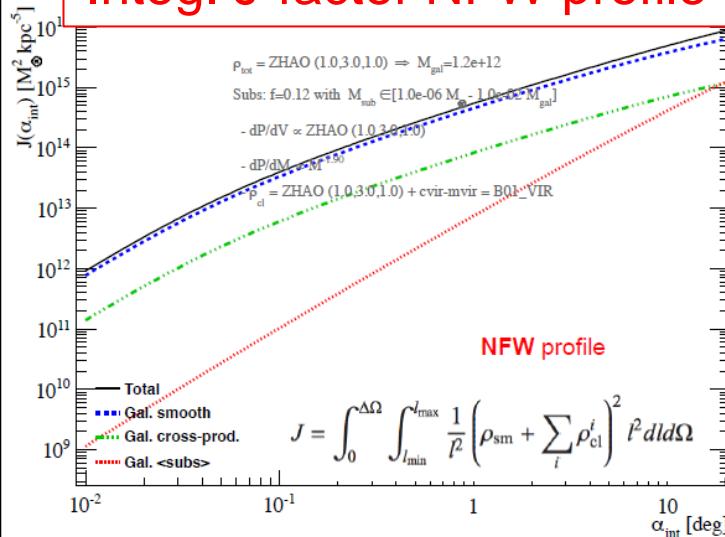


Limits on $\langle\sigma v\rangle$ from Galactic Centre

Diff. J-factor NFW profile



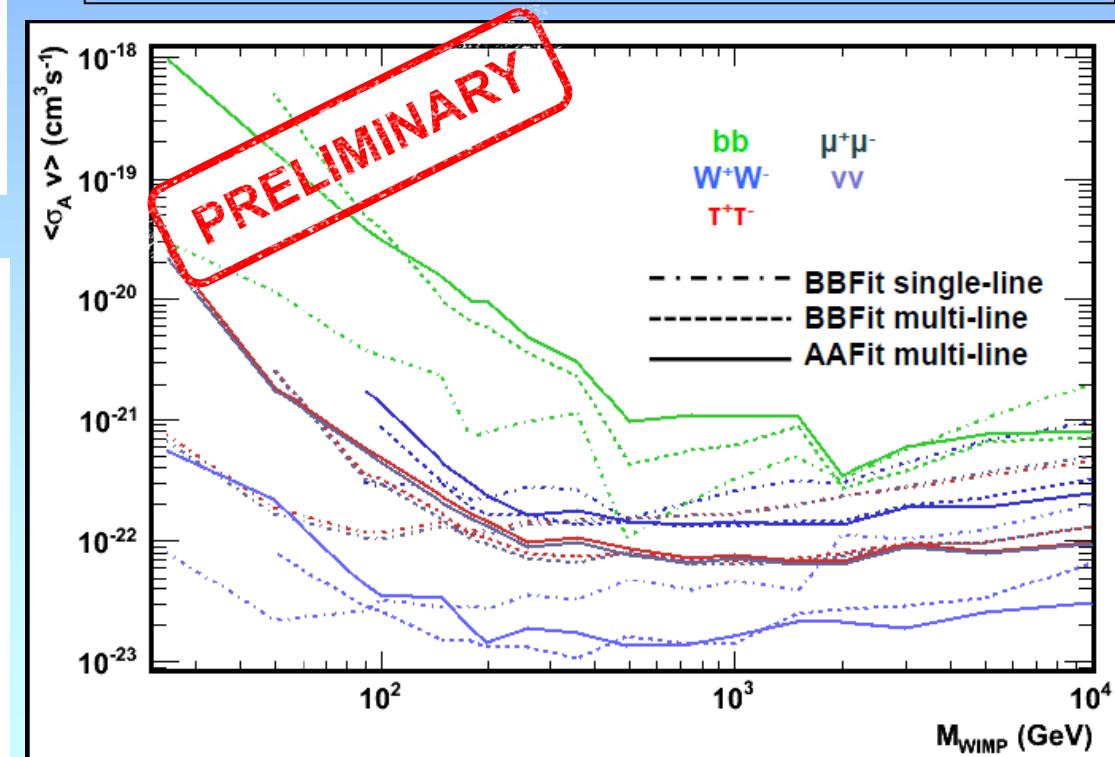
Integ. J-factor NFW profile



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

J factor for DM profiles computed using CLUMPY version 2011.09_corr2

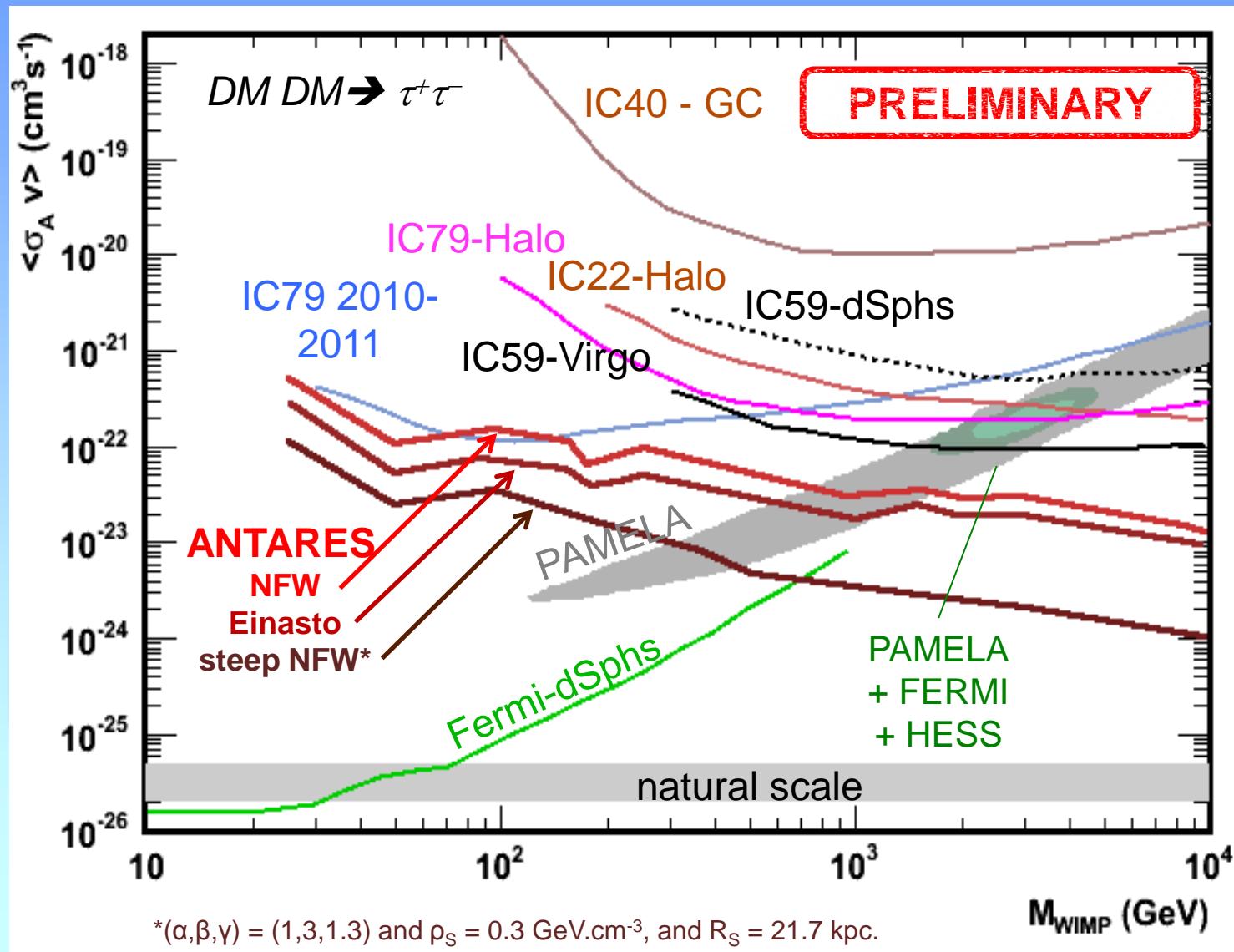
A. Chardonner et al., Comp. Phys. Comm. 183, 656 (2012)
<http://lpsc.in2p3.fr/clumpy>



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

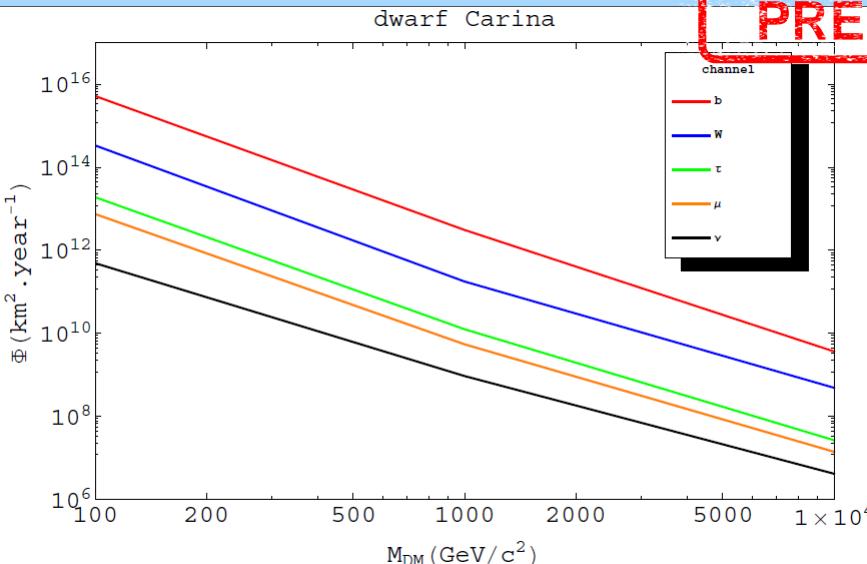
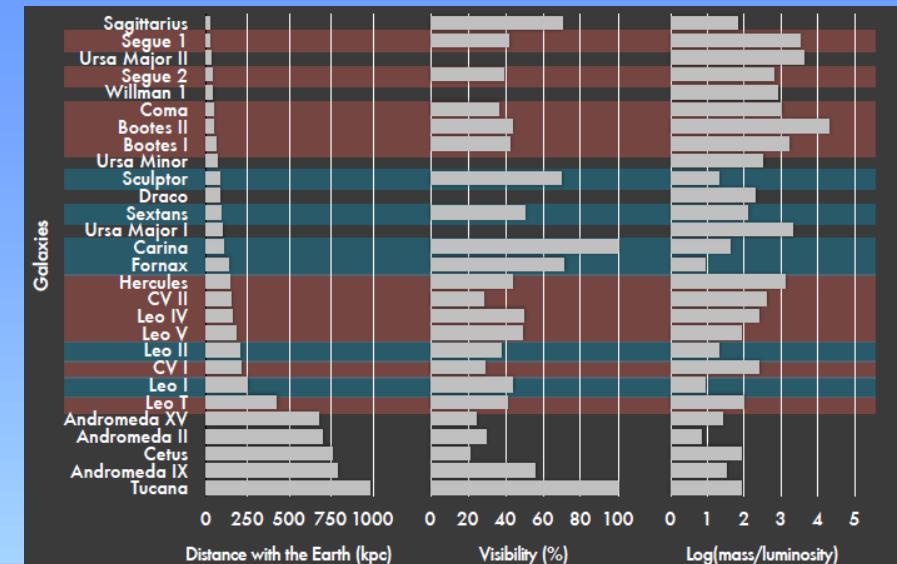
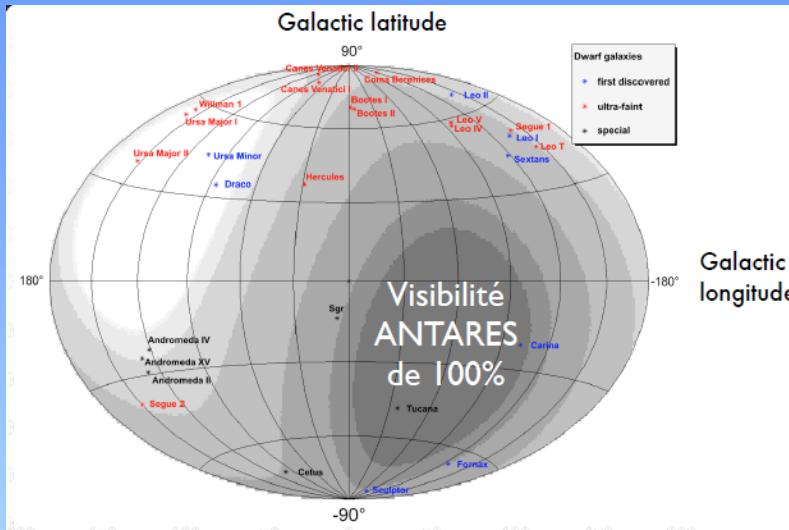


Comparison to other experiments

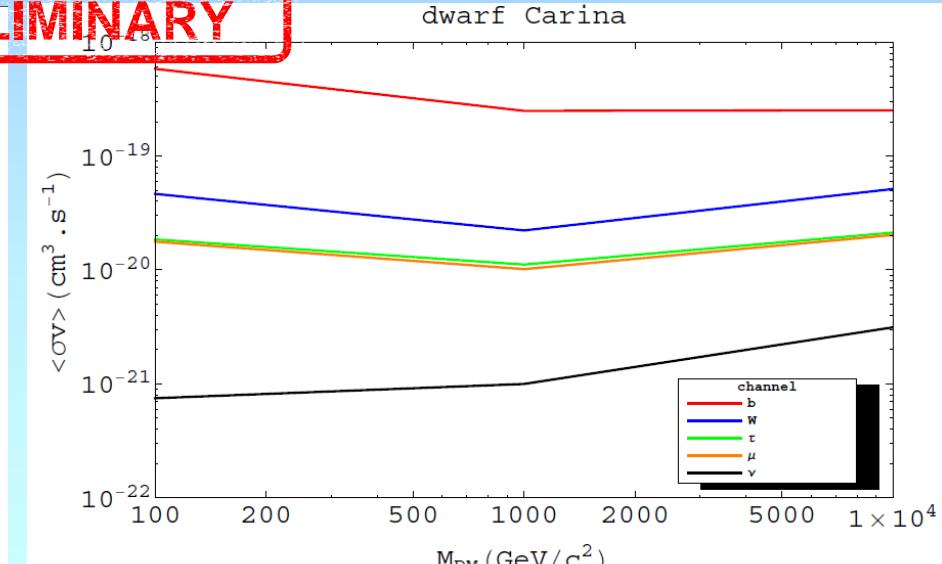




Search for DM towards Dwarf Galaxies: sensitivity



PRELIMINARY

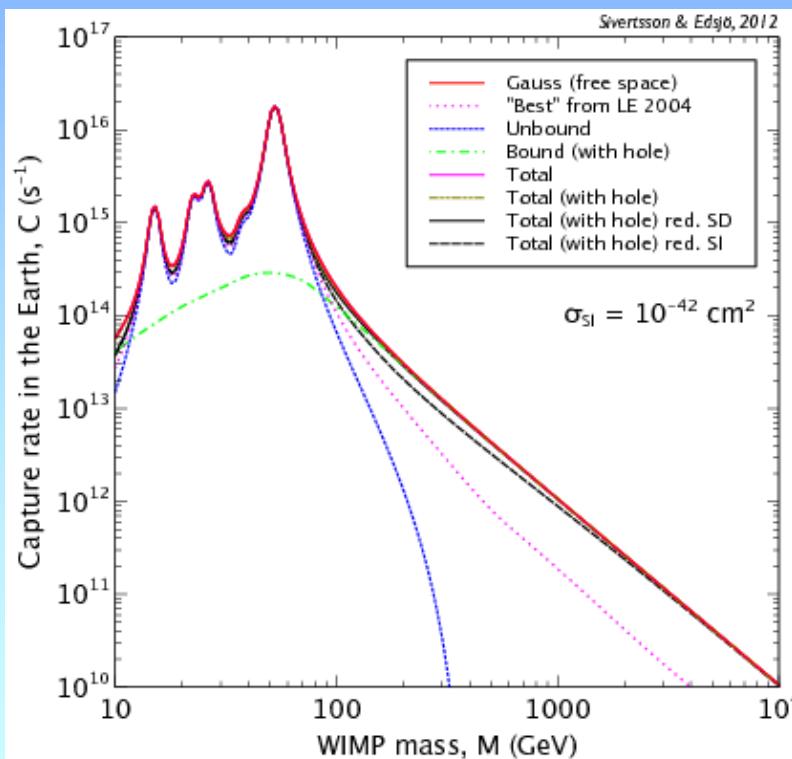


Stacking analysis of visible Dwarfs in progress...



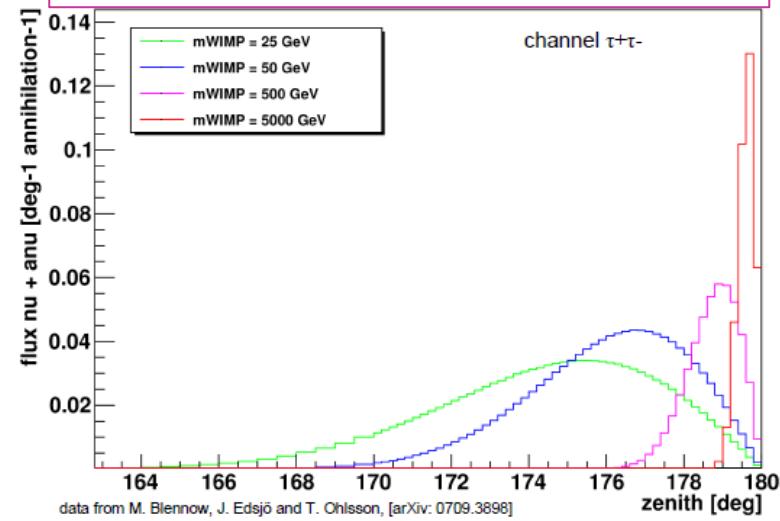
Indirect Search for Dark Matter in the Earth

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

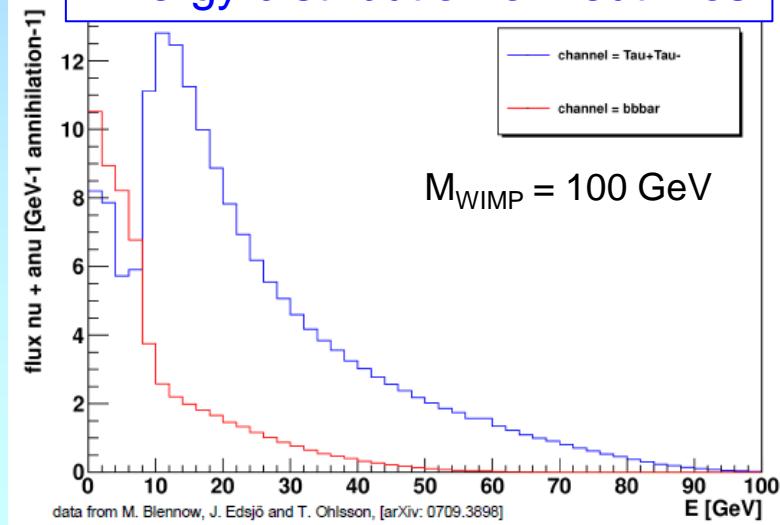


from M. Blennow, J. Edsjo and T. Ohlsson, arXiv:0709.389

Angular distribution of neutrinos



Energy distribution of neutrinos



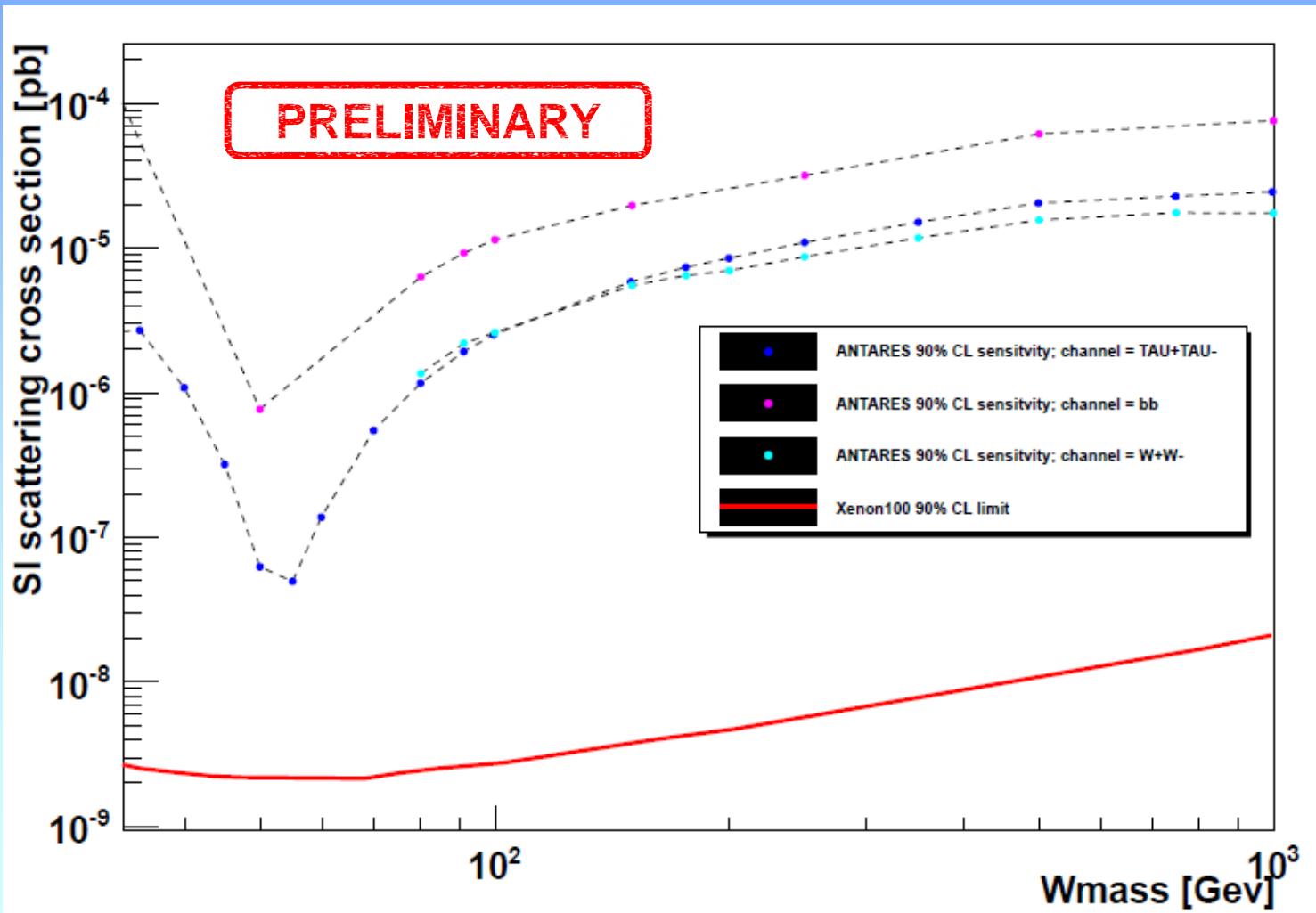


Sensitivity to DM annihilations in the Earth

Dark Matter density usually not at equilibrium

due to low capture rates by the Earth

Assume annihilation rate $\langle\sigma v\rangle = 3 \cdot 10^{-26} \text{ cm}^3 \text{ s}^{-1}$





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
→ **competitive 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...) are in **progress**

Stay tuned for the BIG DARK DISCOVERY !!