UNIVERSITAT POLITÈCNICA DE VALÈNCIA

MultiDark
Multimessenger Approach for Dark Matter Detection

ANTARES

Indirect detection of Dark Matter with the ANTARES Neutrino Telescope

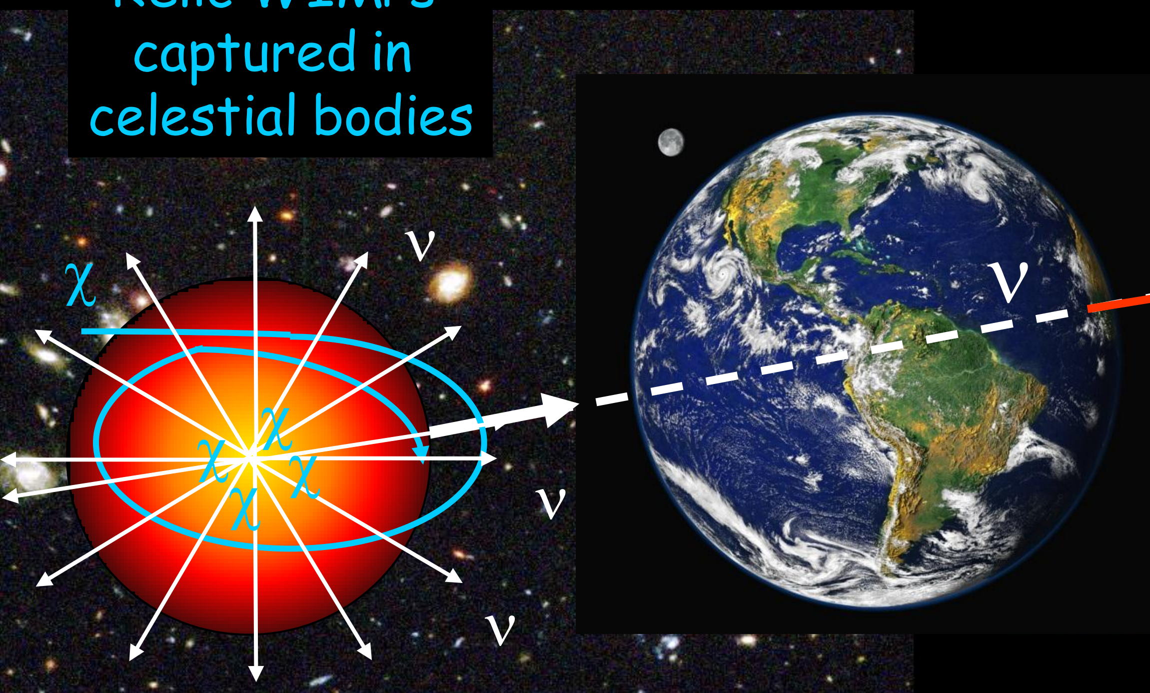
Miguel Ardid
on behalf of the ANTARES Collaboration

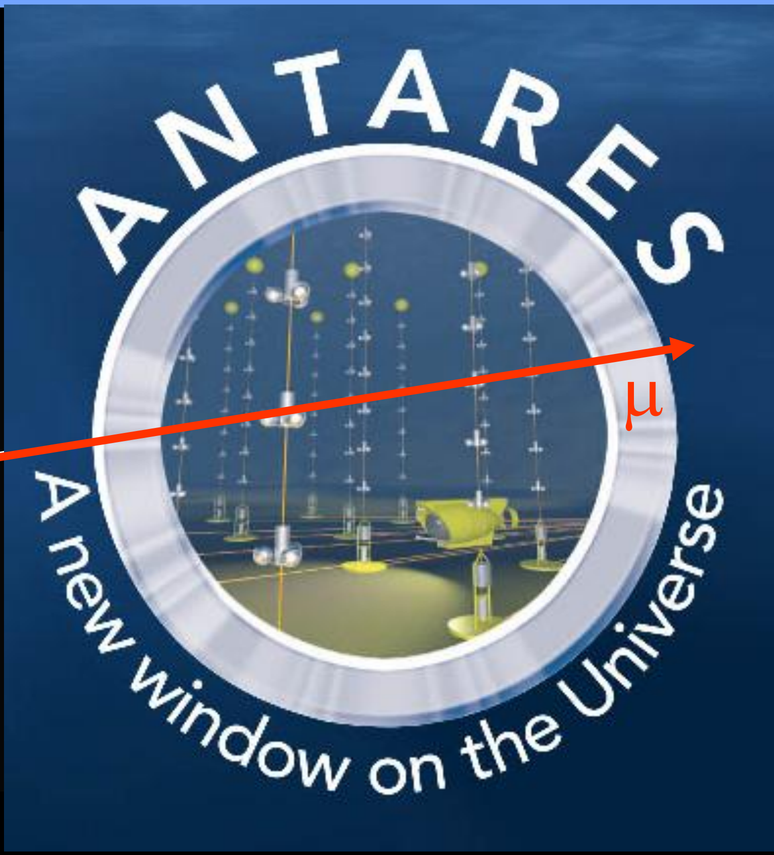
Very Large Volume Neutrino Telescope
VLVνT workshop

Rome – September 2015

Indirect detection of WIMPs in a neutrino telescope

Relic WIMPs captured in celestial bodies



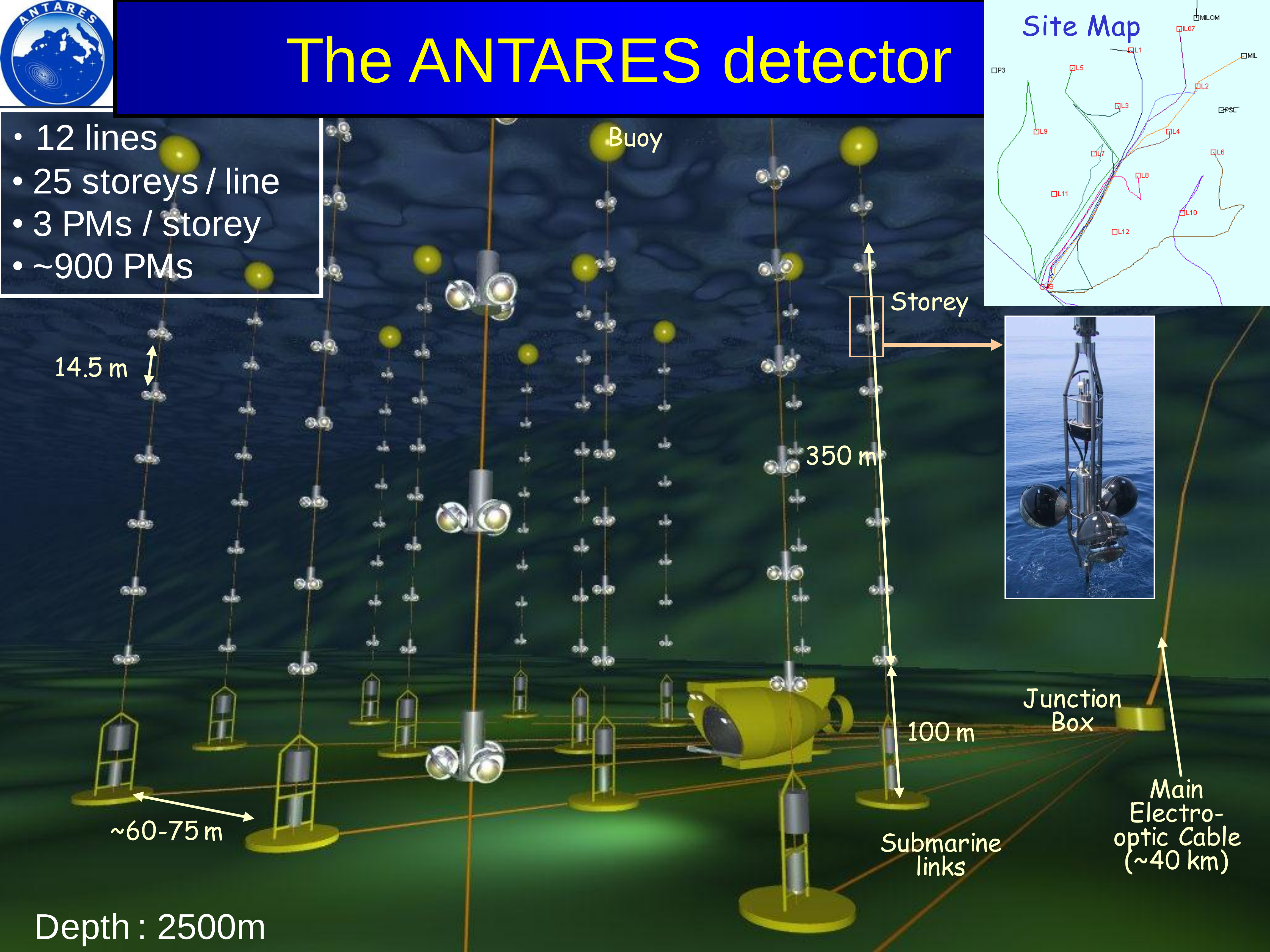


$\chi\chi$ self-annihilations into
c,b,t quarks, τ leptons or W,Z,H bosons
can produce significant
high-energy neutrinos flux

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

The ANTARES detector

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



Depth : 2500m

Data and reconstruction strategies

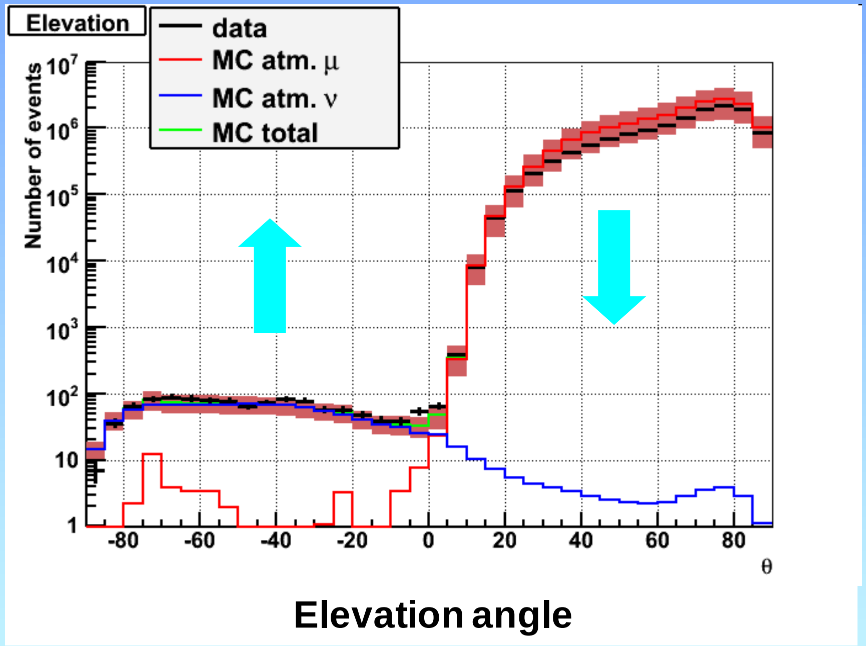
- **Detector** building started in 2006, completed in May 2008
- Most of the analyses presented are based on data collected between 2007 and 2012 → **7000** upgoing neutrino candidates (in ~1321 eff. days)

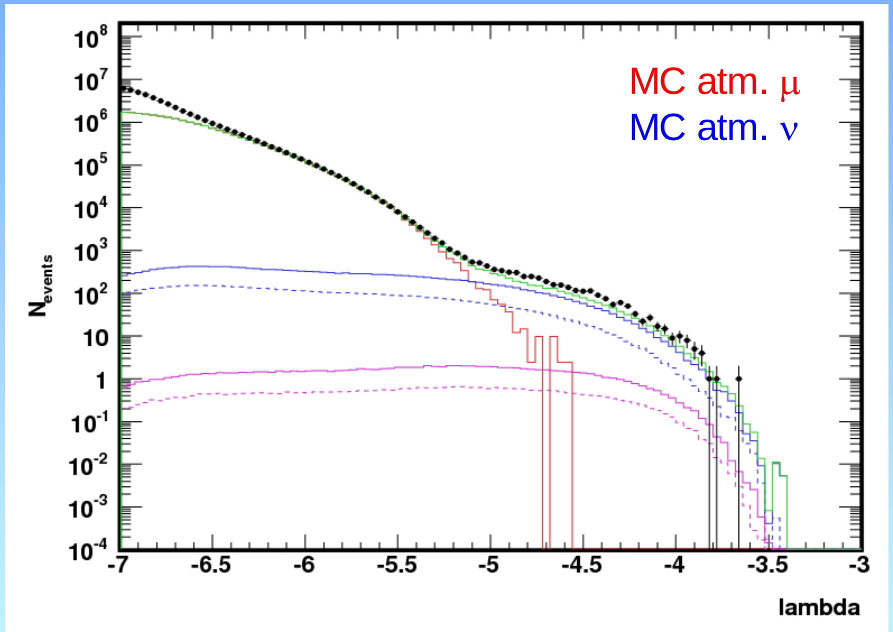
- **Reconstruction strategies:**
  - BBFit (χ^2 based) → optimal for low energies/masses (<250 GeV)
    - **Single line events** : reconstruction of **zenith angle only** → very low energies
    - **Multiline events**: reconstruction of **zenith & azimuth angles**
  - AAFit (likelihood based) → high 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



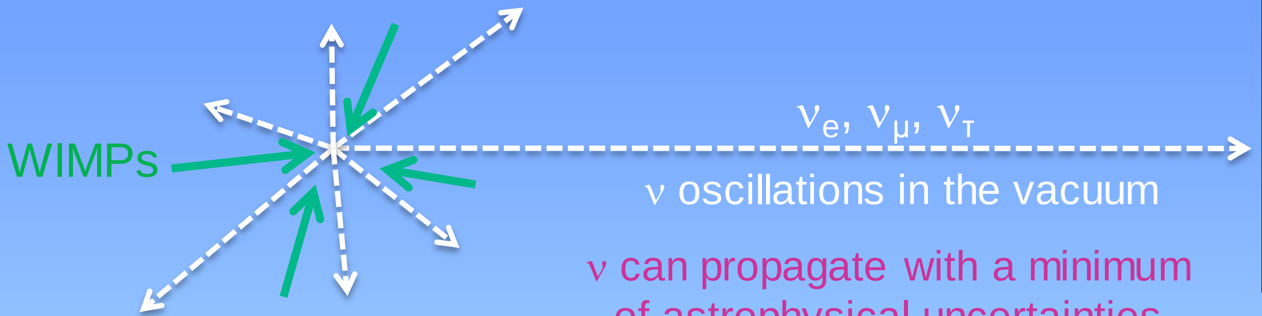


- Rejection of atmospheric neutrinos by looking into a cone towards the Sun direction (or zenith band for single line events)

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

Search for Dark Matter towards the Galactic Centre

Analysis and results in **arXiv:1505.04866**

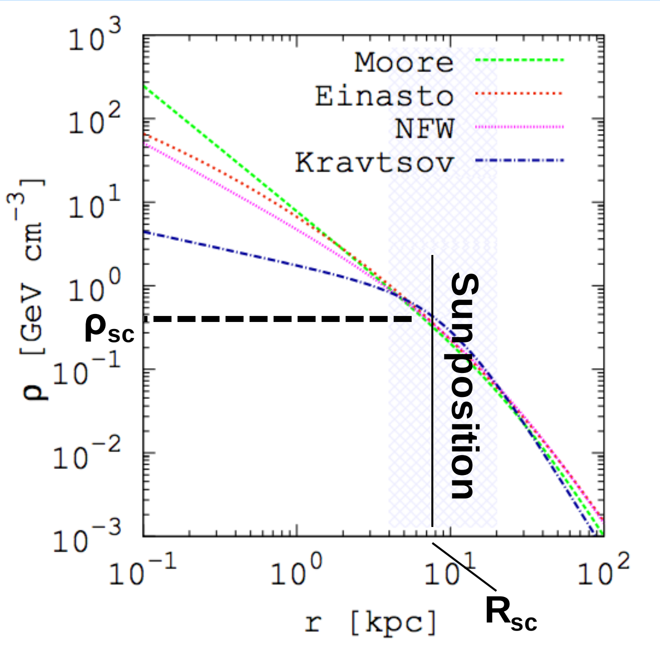


ν oscillations in the vacuum

ν can propagate with a minimum of astrophysical uncertainties

Earth

WIMPs self-annihilate according to <$\sigma_A v$> (halo model-dependent)



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

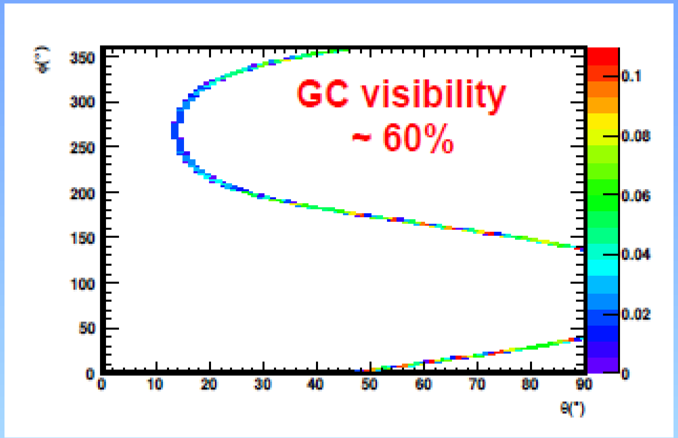
where

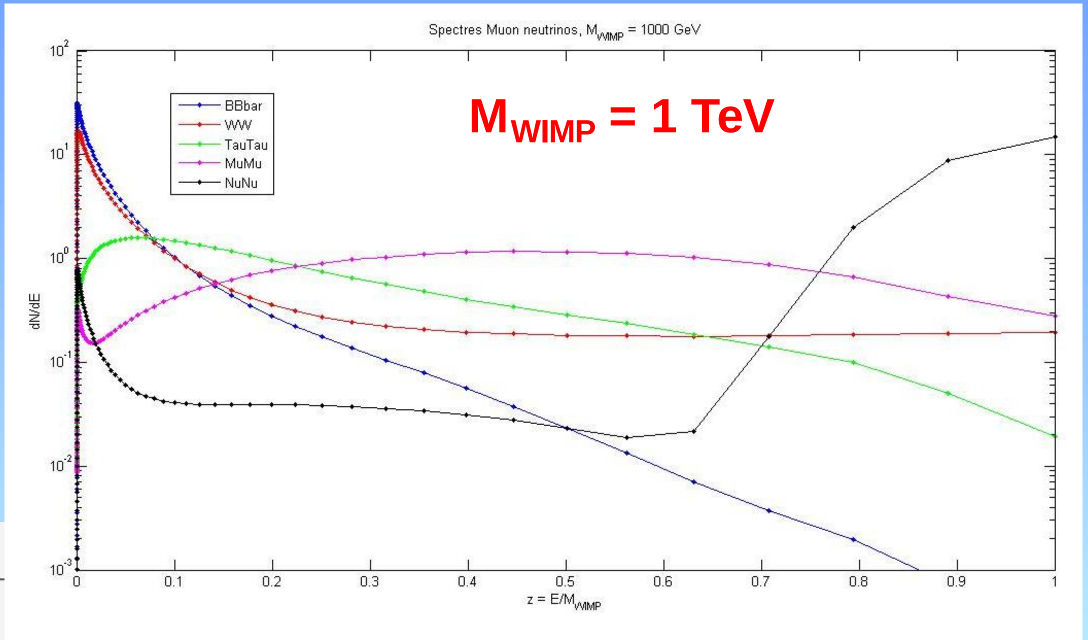
$$\Phi^{PP} \equiv \frac{1}{4\pi} \frac{<\sigma v>}{2M^2_{WIMP}} \frac{dN_\nu}{dE_\nu}$$

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

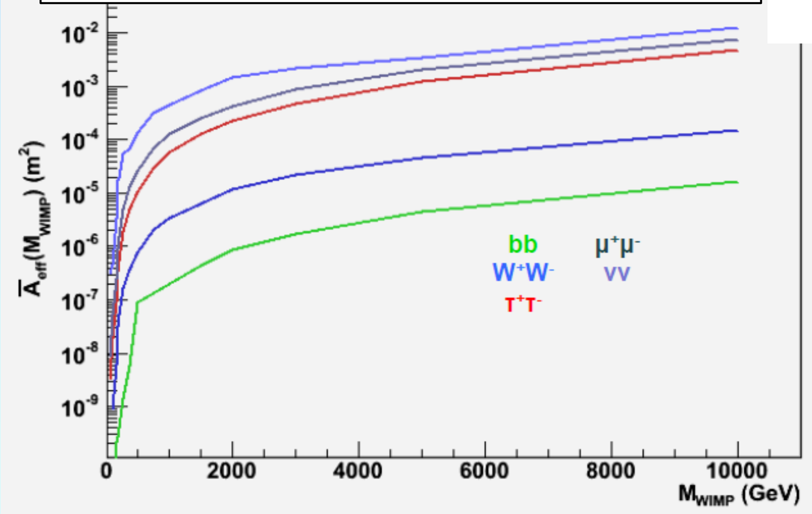
Search for Dark Matter towards the Galactic Centre

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





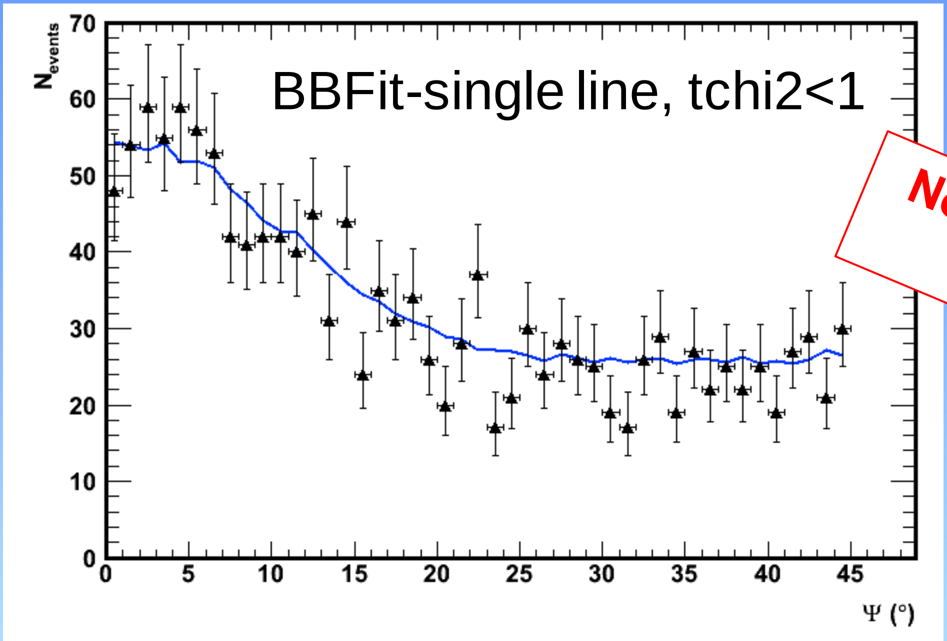
Effective area for Aafit analysis

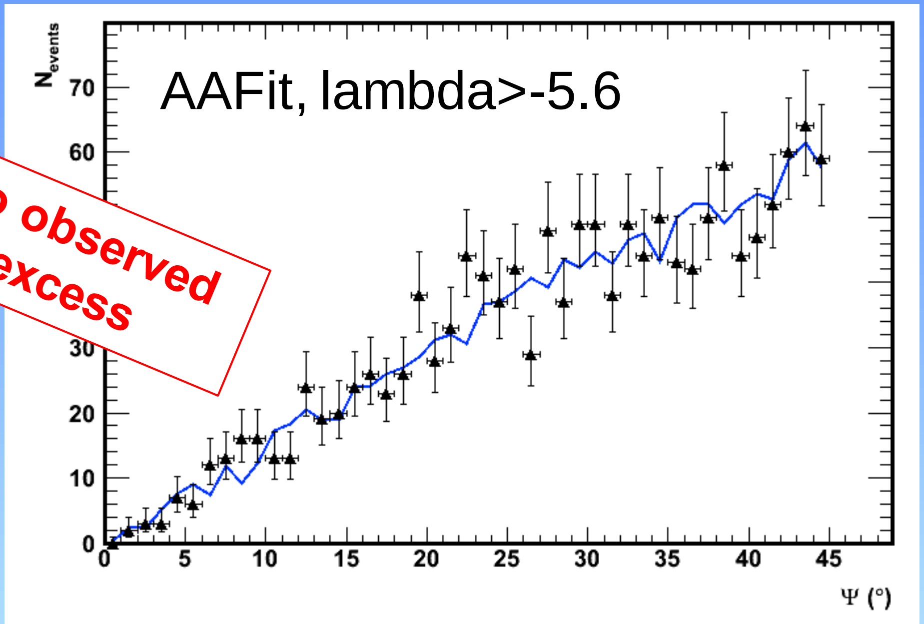


Spectra from Dark Matter annihilations in vacuum including EW corrections for 5 main benchmark channels

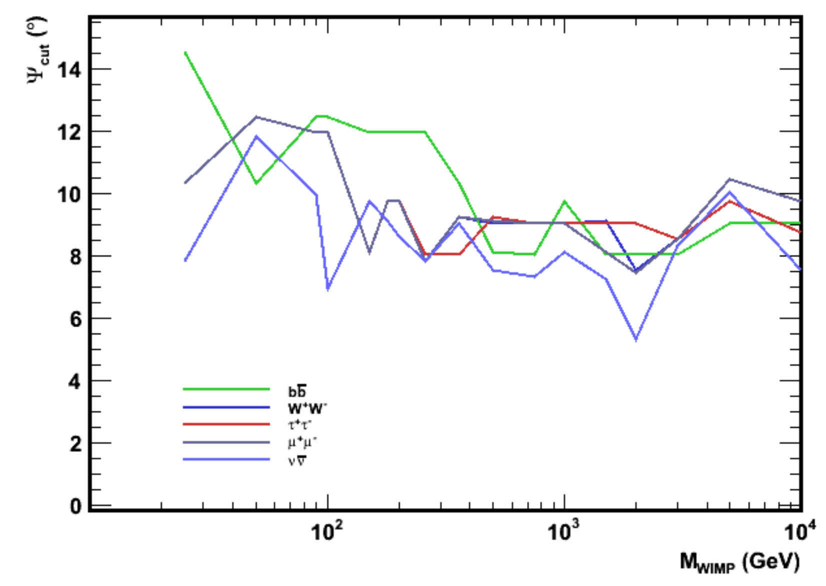
from M. Cirelli et al., JCAP 1103 (2011) 051 (www.marcocirelli.net/PPPC4DMID.html)

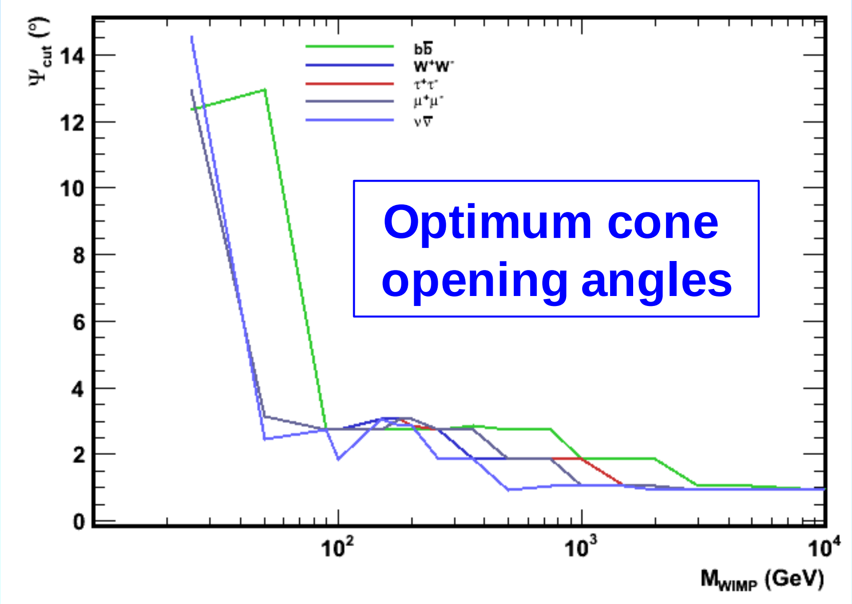
ANTARES observation of the Galactic Centre with 2007-2012 data





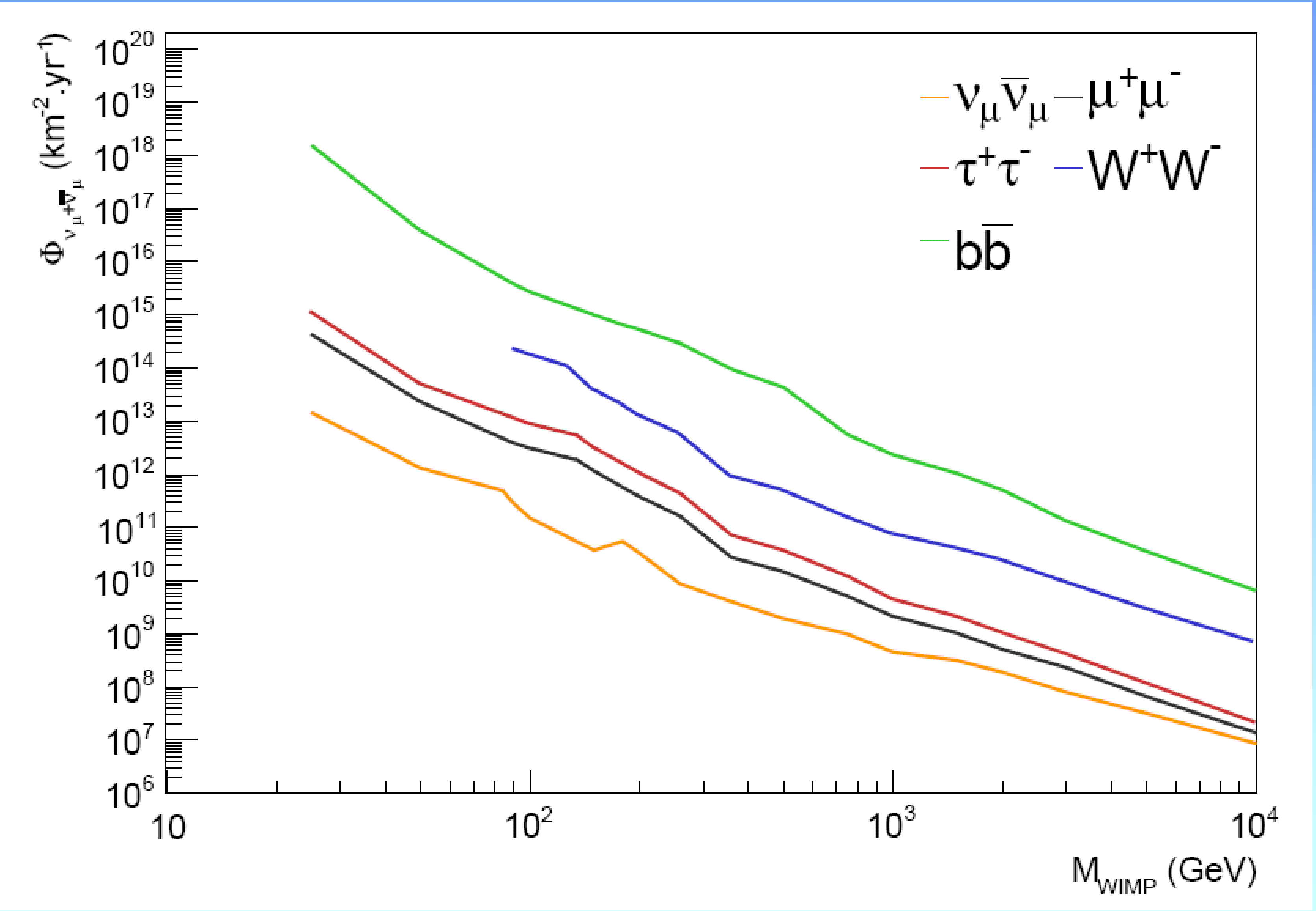
No observed excess





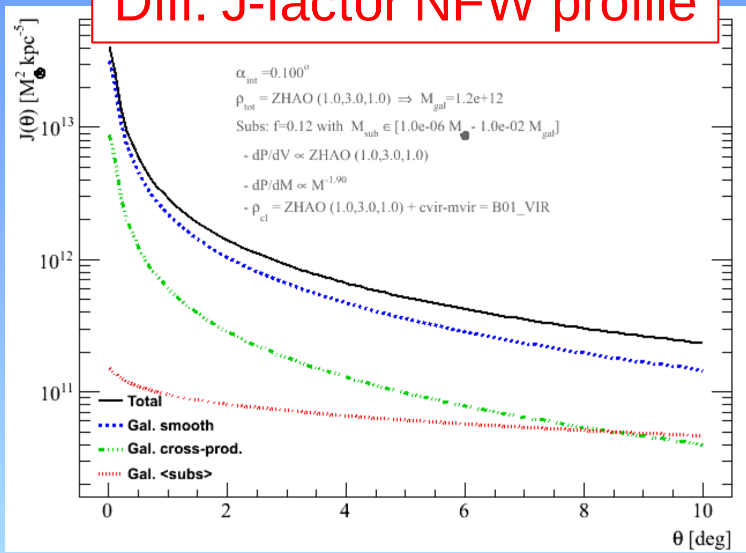
Optimum cone opening angles

Limits on neutrino flux from Galactic Centre

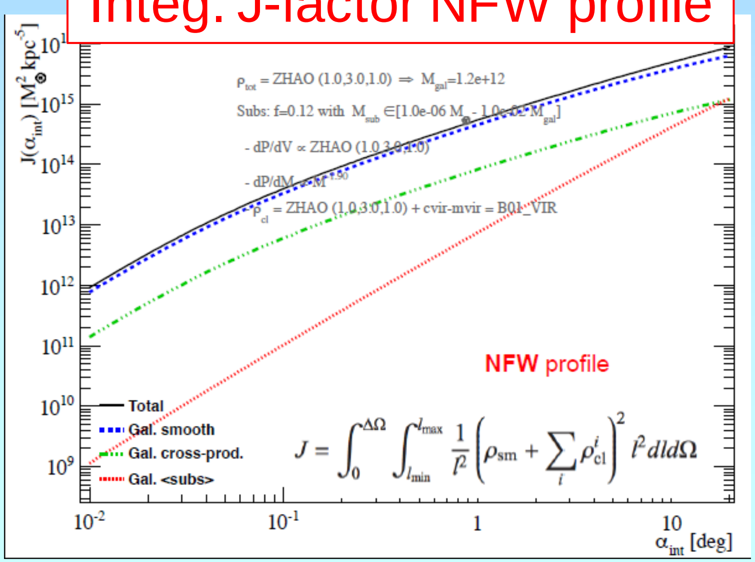


Limits on <σ v> from Galactic Centre

Diff. J-factor NFW profile



Integ. J-factor NFW profile

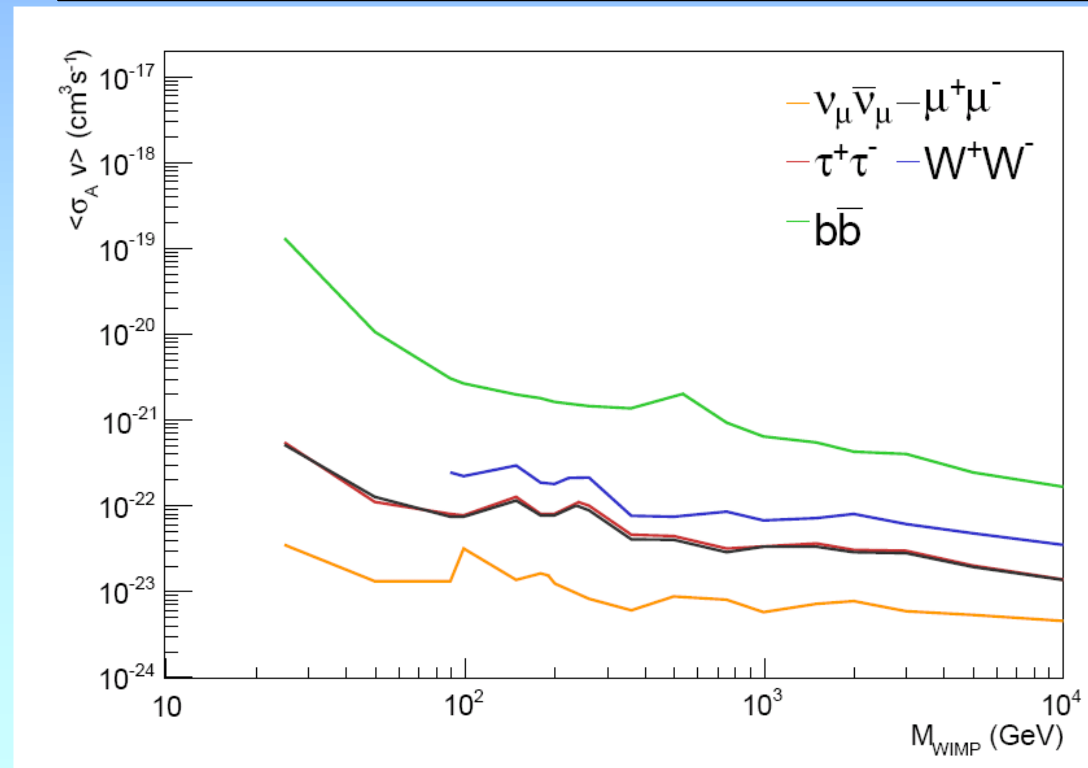


$$J(\Delta\Psi) = \int_{\Delta\Psi} \int \rho_{DM}^2 (l, \Psi) dl d\Psi$$

J factor for DM profiles computed using CLUMPY version 2011.09_corr2

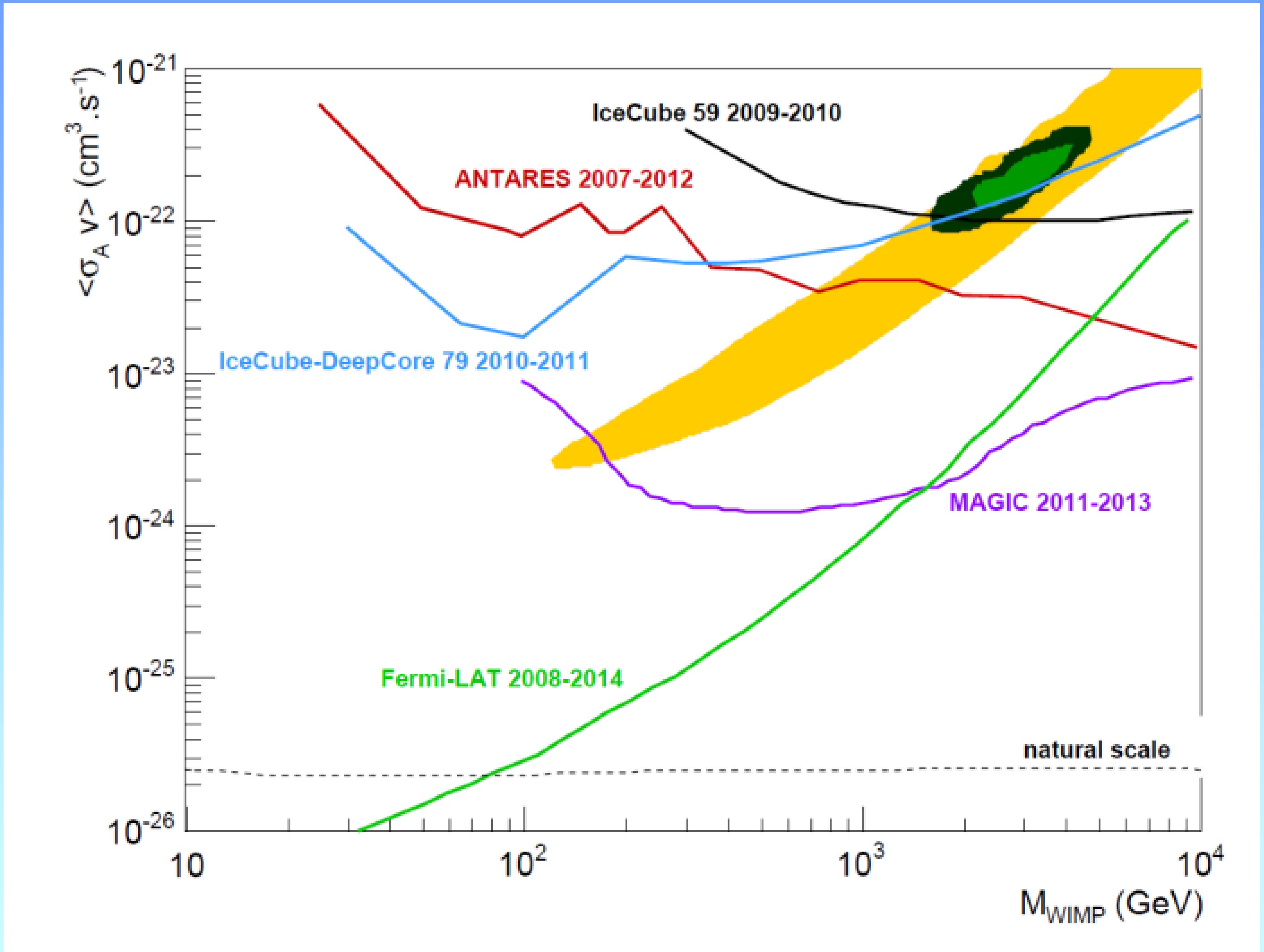
A. Chardonnier et al., Comp. Phys. Comm. 183, 656 (2012)

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



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

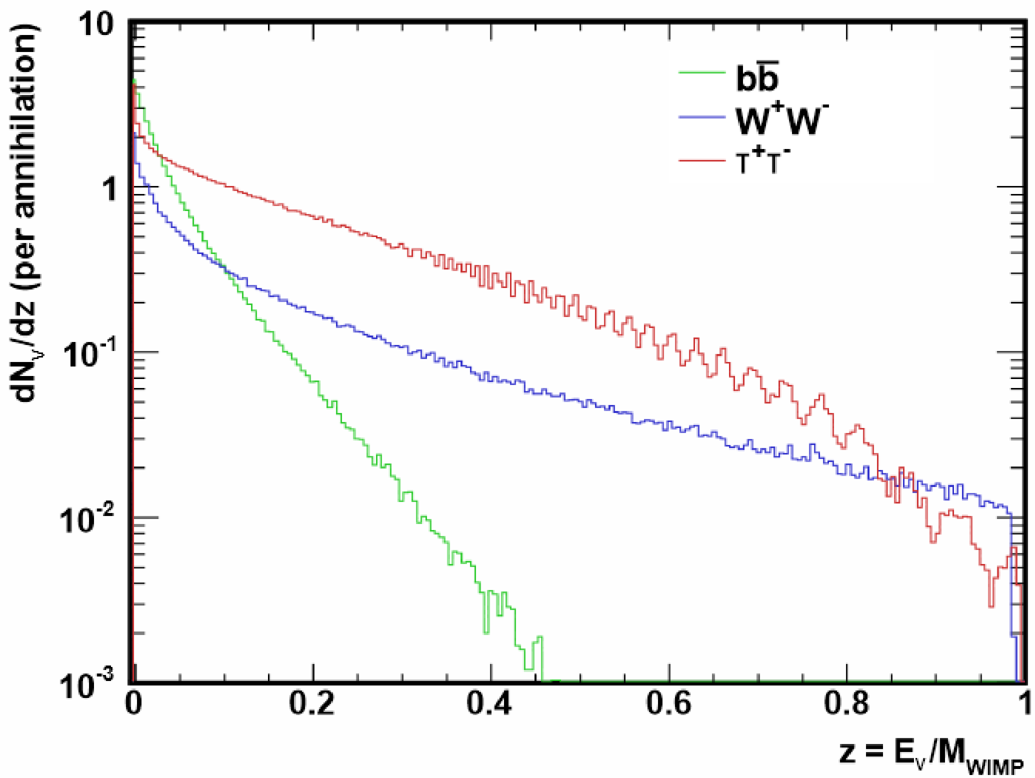
Search for Dark Matter towards the Galactic Centre Comparison to other experiments



An analysis of the data using the unbinned method is ongoing

Search for Dark Matter towards the Sun

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**

Method

Unbinned method

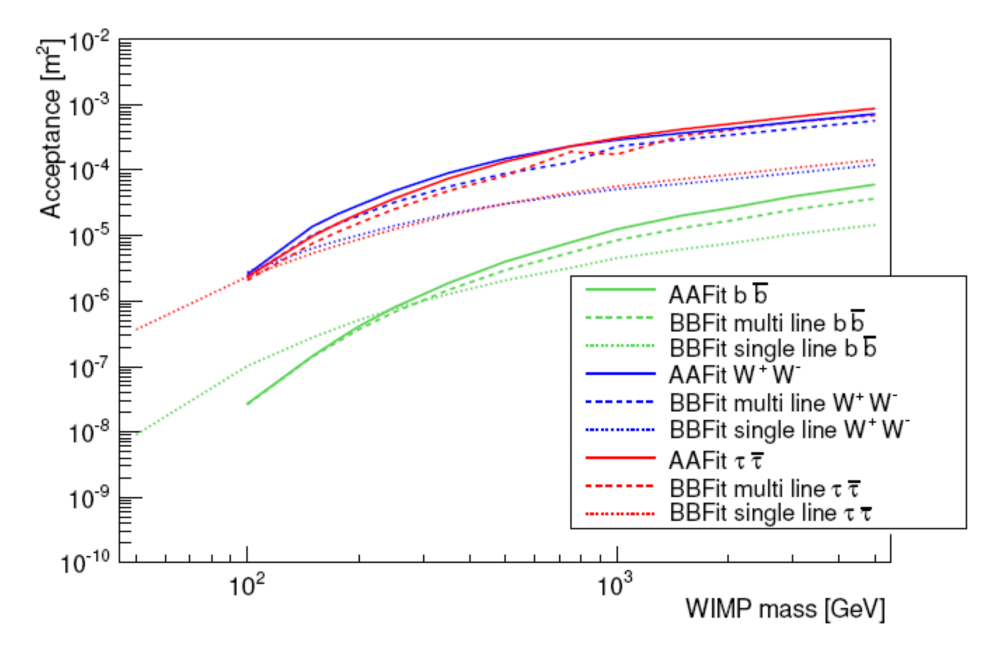
- The used likelihood function is:

$$\log(L) = \sum_i \log\left(\frac{n_s}{N} S_i(\alpha, N_{hits}, \beta) + \left(1 - \frac{n_s}{N}\right) B_i(dec, N_{hits}, \beta)\right)$$

- N_{hits} is the number of selected hits in the event, β the angular error estimate (χ^2 is used for BBFit)
- The test statistics are generated by:

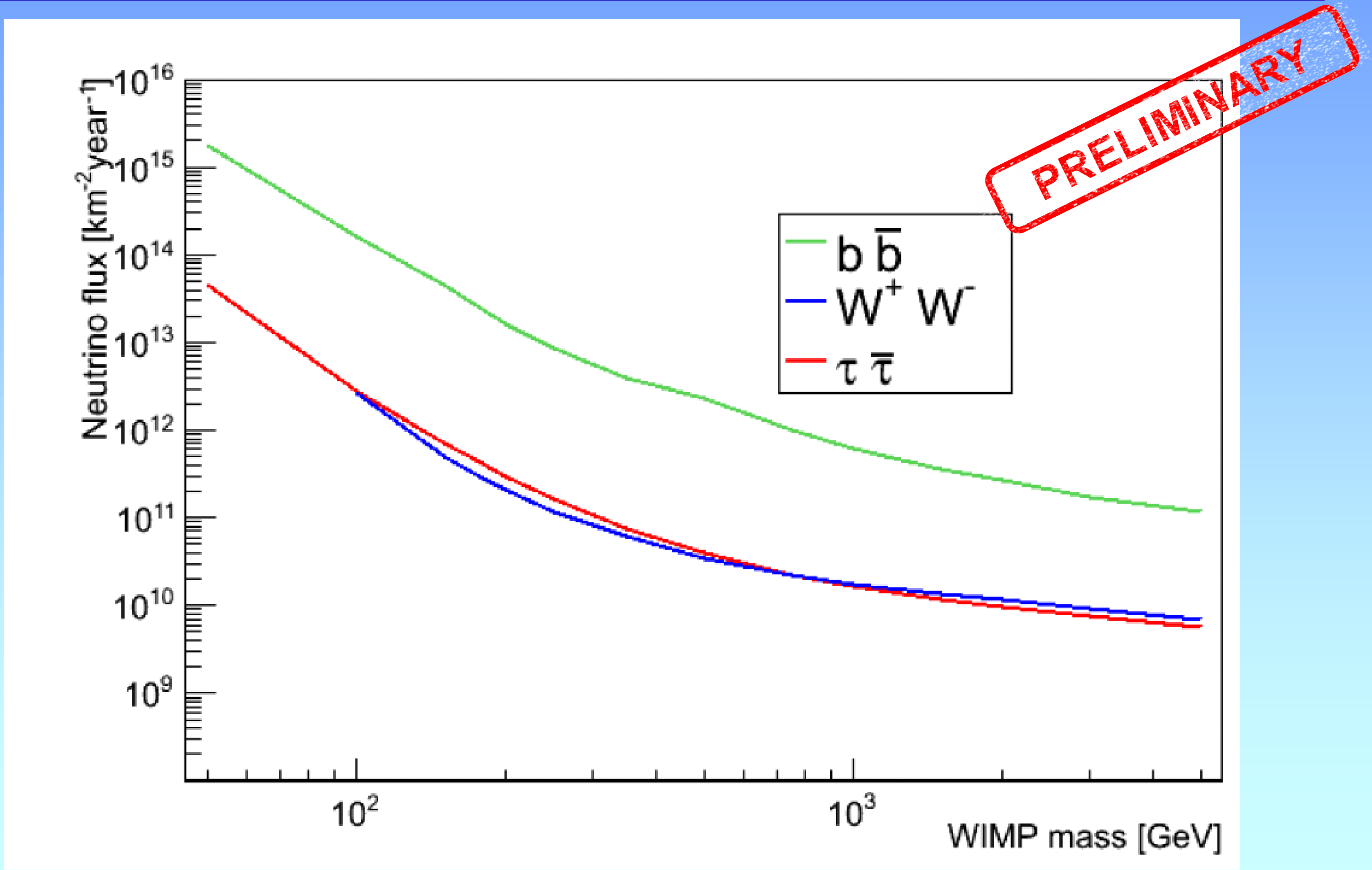
$$\log[TS] = \log[L^{max}] - \log[L(n_s = 0)]$$

Acceptance



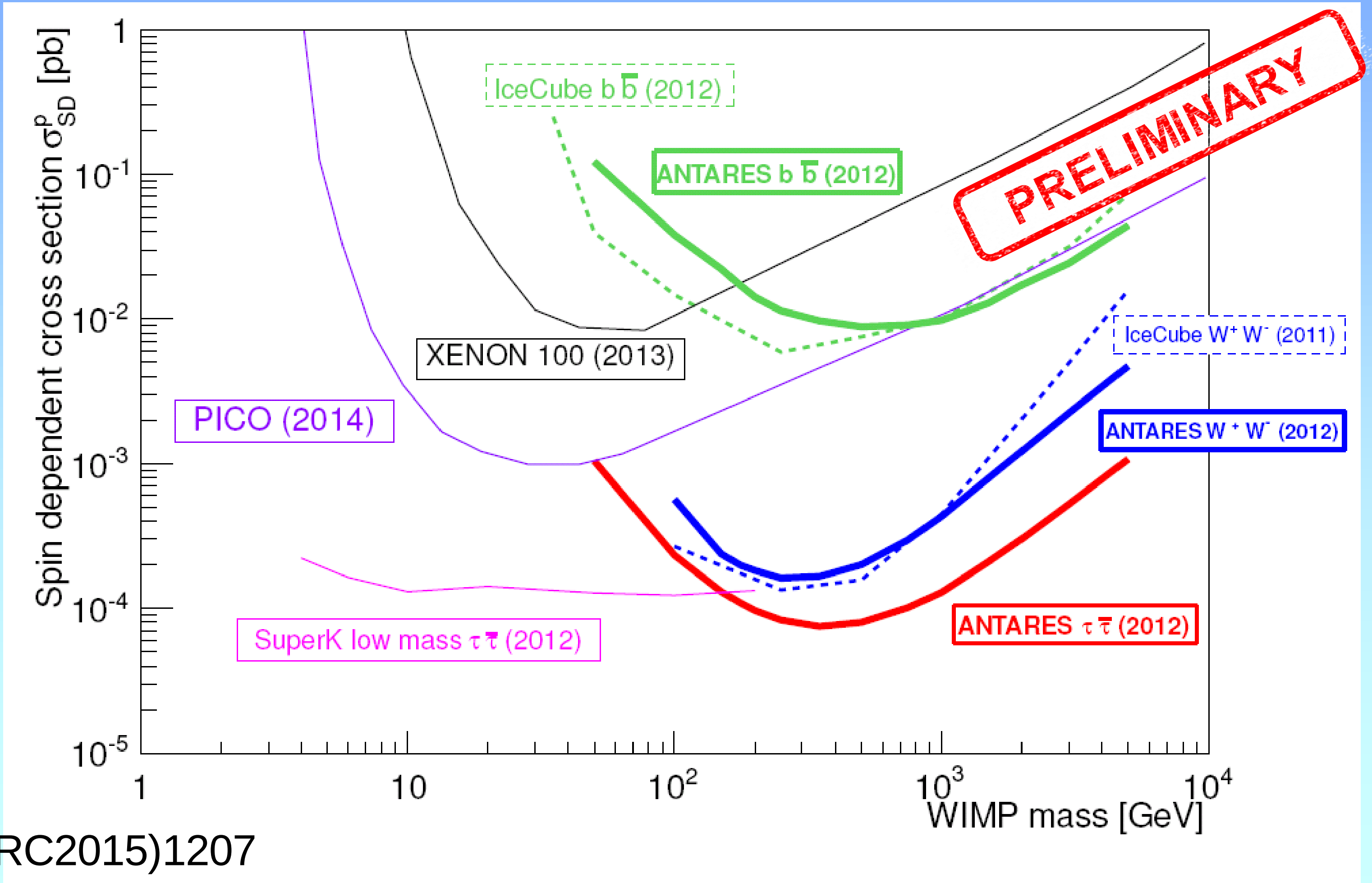
Limit on neutrino flux coming from the Sun

No excess in data observed -> 90% Upper limits derived



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



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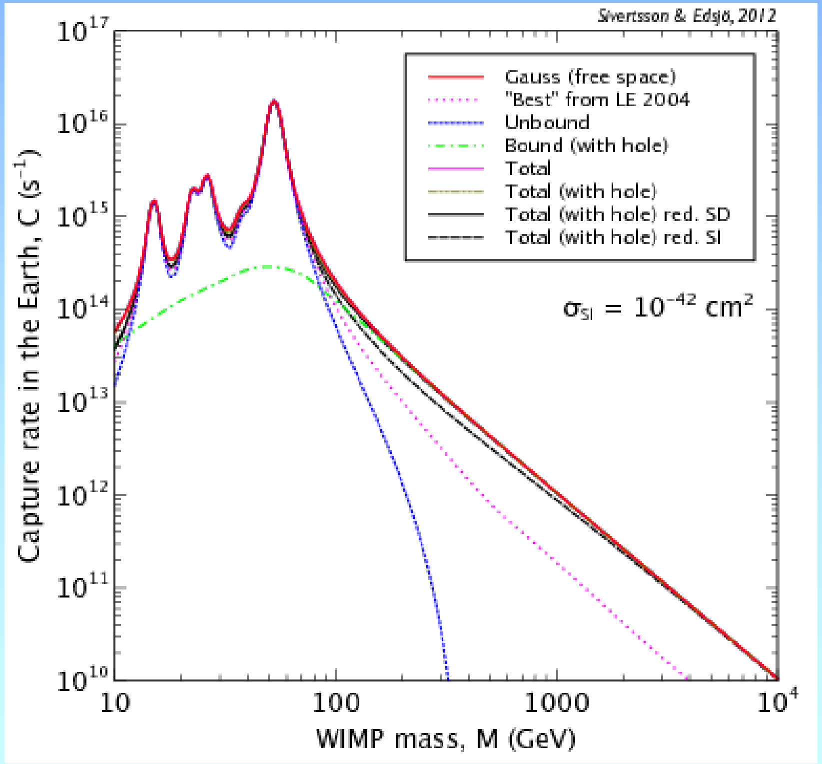
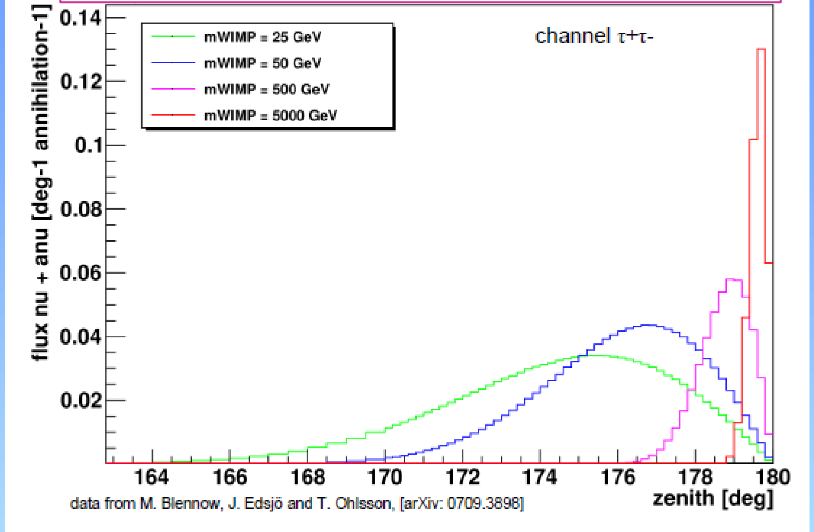
Indirect Search for Dark Matter in the Earth

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

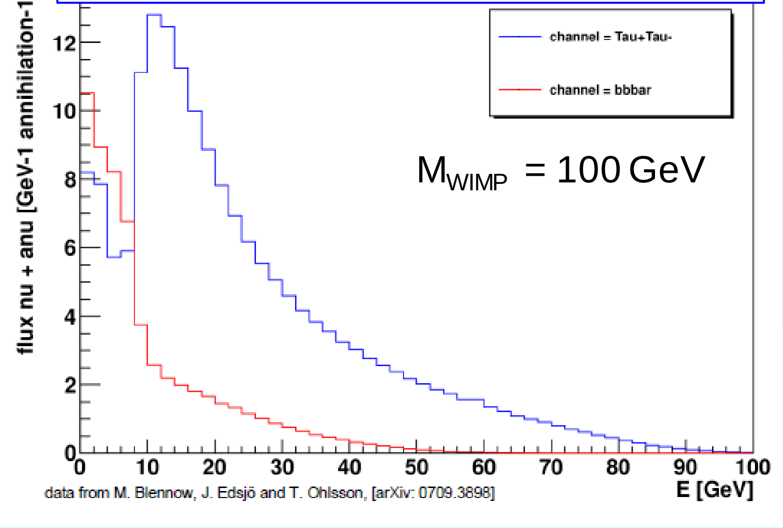


from M. Blennow, J. Edsjo and T. Ohlsson, arXiv:0709.389

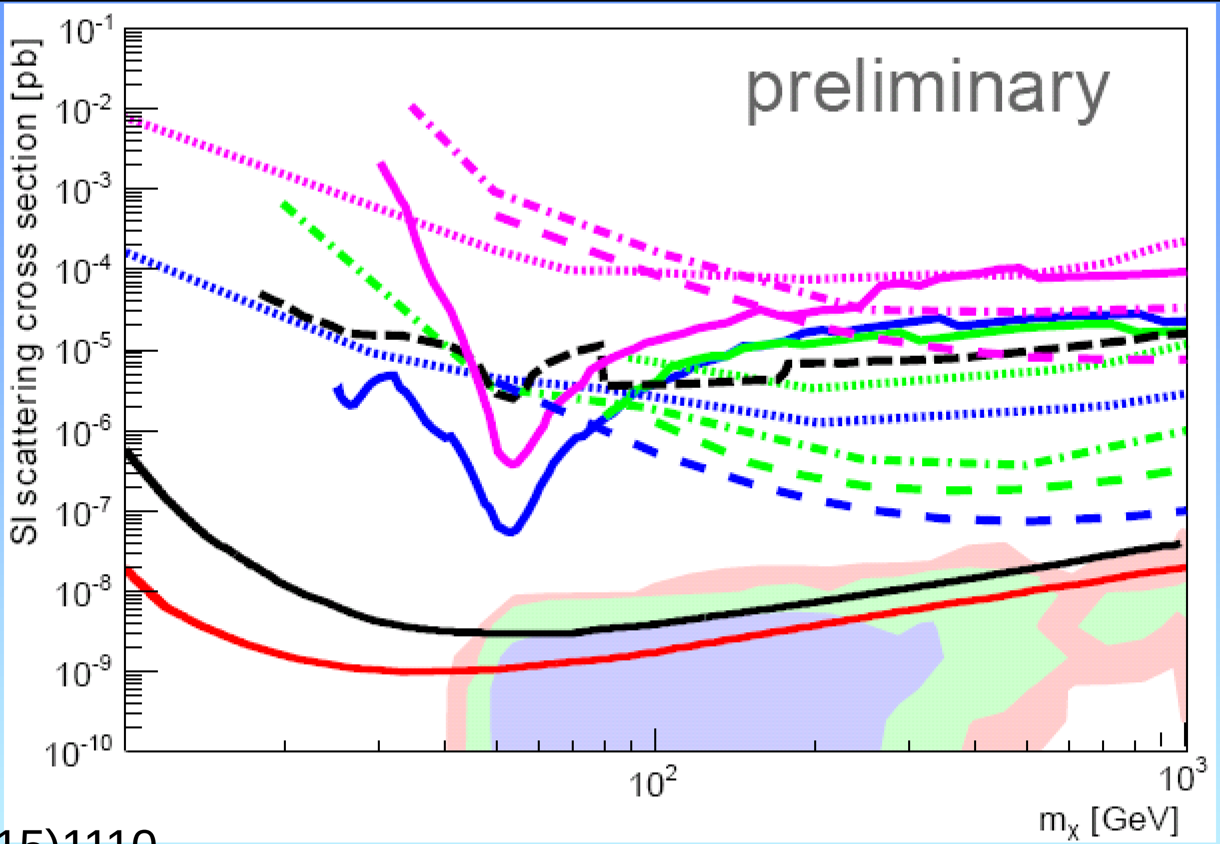
Angular distribution of neutrinos



Energy distribution of neutrinos



Limits to SI scattering cross-section

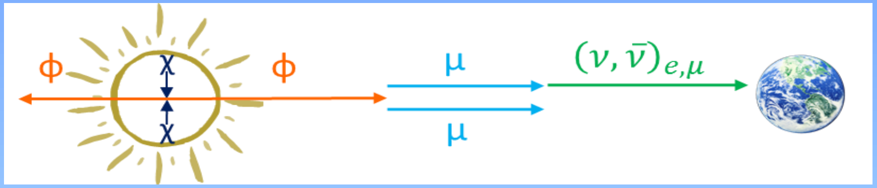


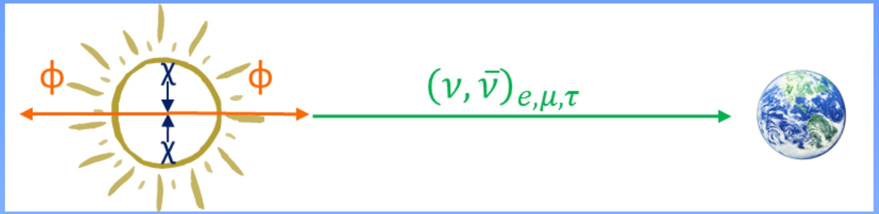
PoS(ICRC2015)1110

ANTARES 2007–2012 90% C.L. upper limit (W^+W^- channel; $\langle\sigma v\rangle$=3E-26 $cm^3\ s^{-1}$)
ANTARES 2007–2012 90% C.L. upper limit ($\tau^+\tau^-$ channel; $\langle\sigma v\rangle$=3E-26 $cm^3\ s^{-1}$)
ANTARES 2007–2012 90% C.L. upper limit (bb channel; $\langle\sigma v\rangle$=3E-26 $cm^3\ s^{-1}$)
Baksan 1978–2009 90% C.L. upper limits (W^+W^- channel, sun)
Baksan 1978–2009 90% C.L. upper limits ($\tau^+\tau^-$ channel, sun)
Baksan 1978–2009 90% C.L. upper limits ($b\bar{b}$ channel, sun)
IceCube-79 2010–2011 90% C.L. upper limits (W^+W^- ($\tau^+\tau^-$ for WIMP mass <80.4 GeV/c^2) channel, sun)
IceCube-79 2010–2011 90% C.L. upper limits (bb channel, sun)

ANTARES 2007-2008 90% C.L. upper limits (W^+W^- channel, sun)
ANTARES 2007-2008 90% C.L. upper limits ($\tau^+\tau^-$ channel, sun)
ANTARES 2007-2008 90% C.L. upper limits (bb channel, sun)
Super–Kamiokande 1996- 2001 90% C.L. upper limits
XENON 100 (2012), 90% C.L. upper limit
LUX (2013), 90% C.L. upper limit
Strege et. al. 15-dimensional MSSM (2014); SI, 68% C.L.
Strege et. al. 15-dimensional MSSM (2014); SI, 95% C.L.
Strege et. al. 15-dimensional MSSM (2014); SI, 99% C.L.

Search for **Secluded DM** in the Sun





Testing models from:

- Meade et al., JHEP06(2010)29
- Bell and Petraki, JCAP04(2011)003

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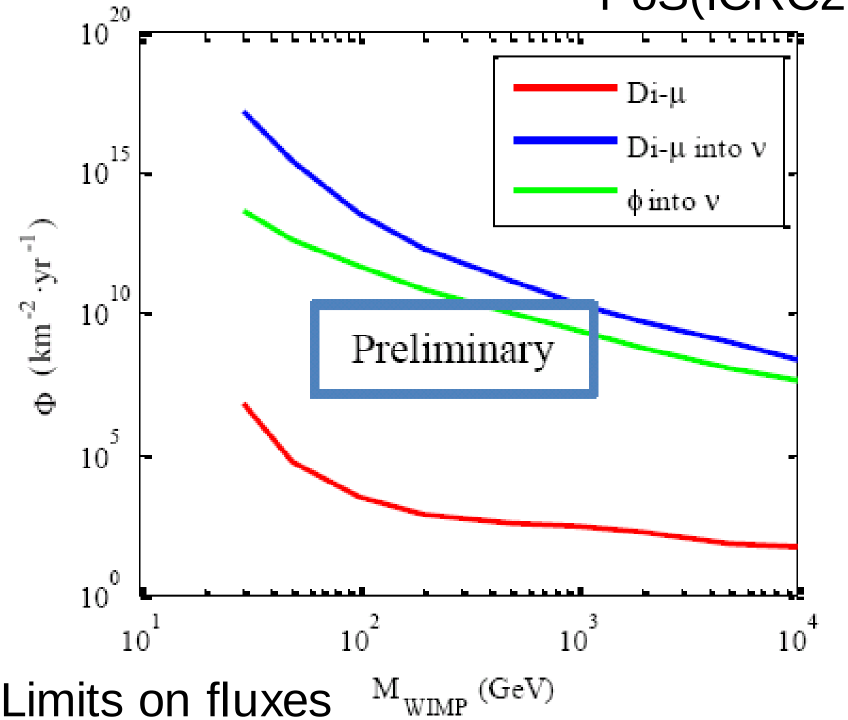
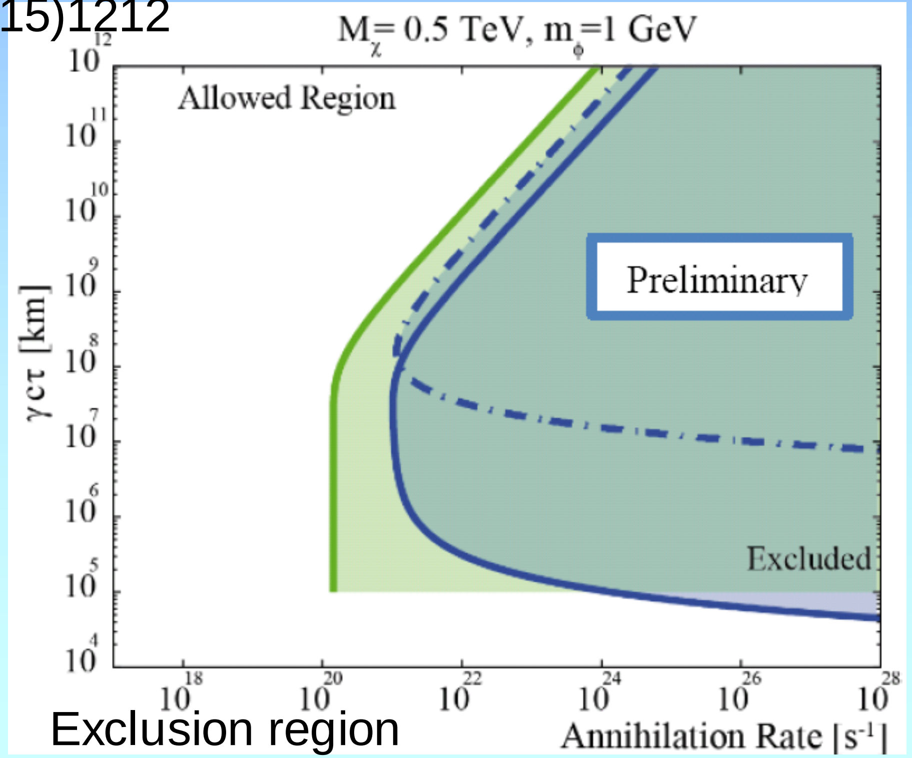
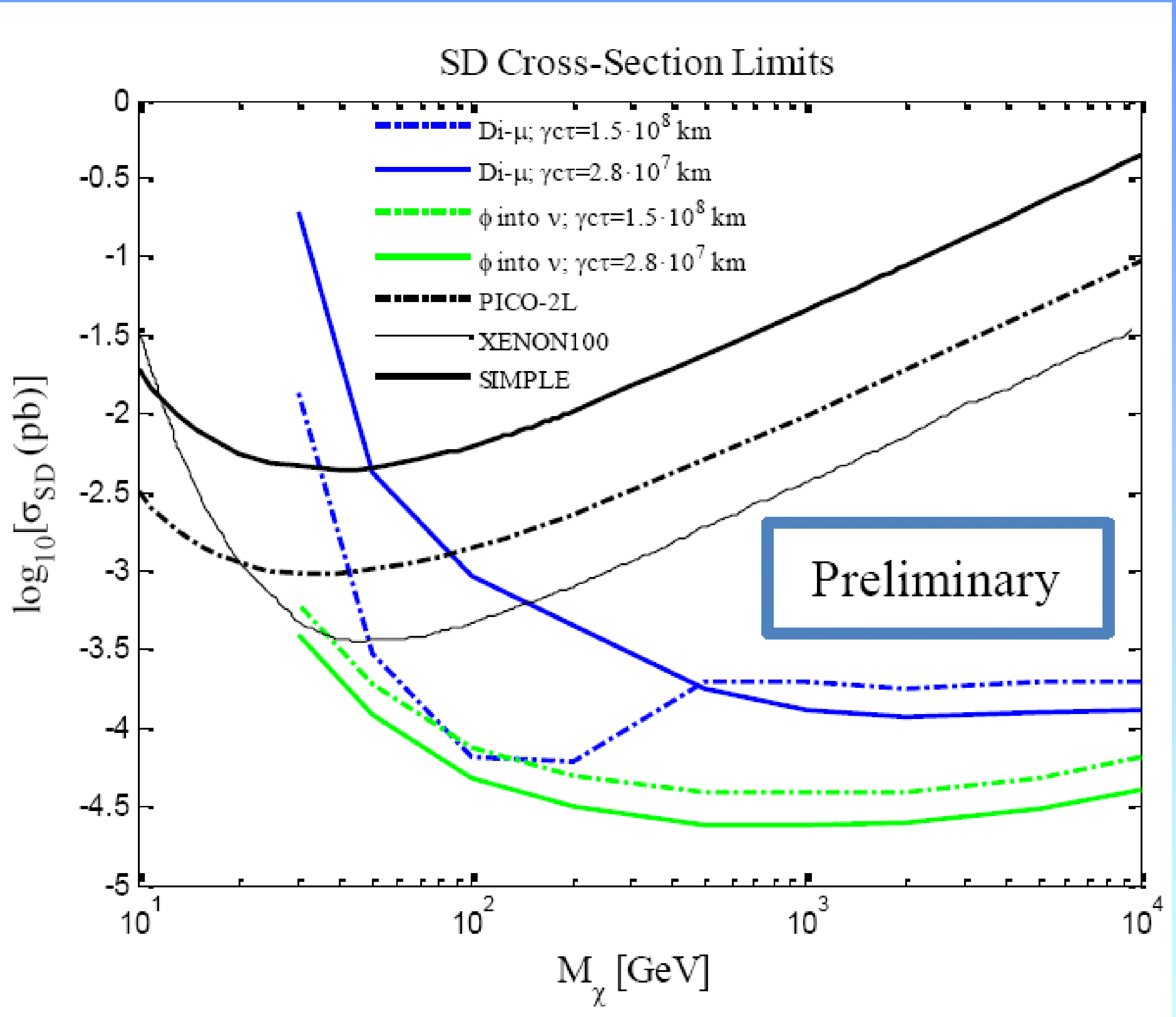


Limits on fluxes



Exclusion region

Search for **Secluded DM** in the Sun



First constrains to these models from neutrino telescopes

Restrictive limits for Spin Dependent proton-WIMP cross-section in secluded models for sufficiently long-live but unstable mediators

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Summary and Outlook

- **Indirect search for Dark Matter** is a **major goal** for neutrino telescopes (**important complementarity** to direct detection experiments)
- **First ANTARES limits towards the Galactic Centre**
  →**best current limits** using neutrinos
  →important complementary **constraints** on leptophilic DM models
- **Indirect search** towards the **Sun** performed by **ANTARES** with data recorded in 2007-2012 using unbinned method
  → **competitive limits** derived especially for large DM masses
- **First constrains to secluded DM models** in neutrino telescopes
- **Study of other potential signal sources** (dwarf galaxies, galaxy clusters, …) and improvements and updates of these analysis are in **progress, stay tuned**

Thank you

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Acknowledgements

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