Indirect search for Dark Matter with the ANTARES Neutrino Telescope

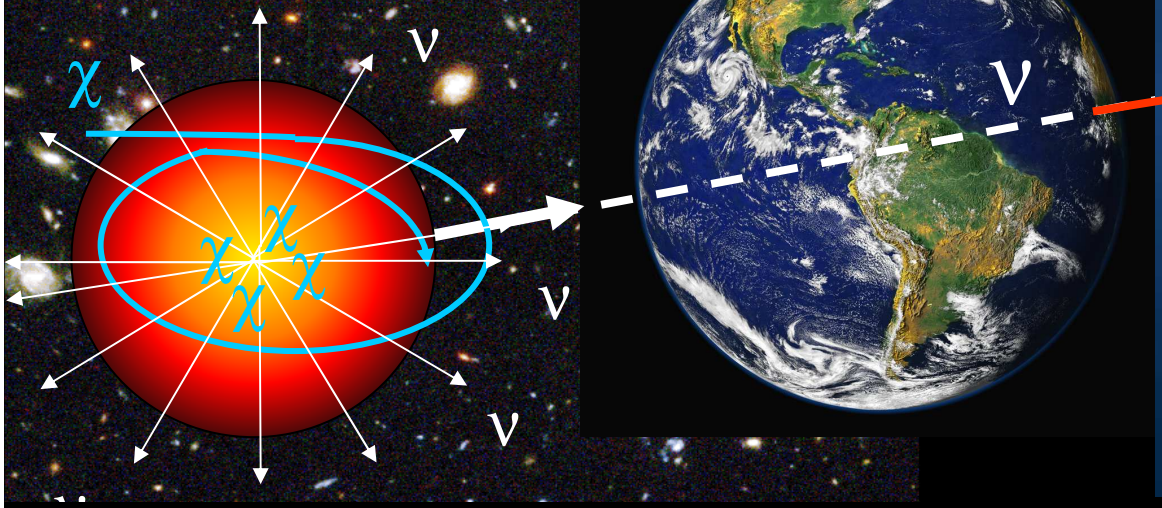
Vincent Bertin - CPPM-Marseille

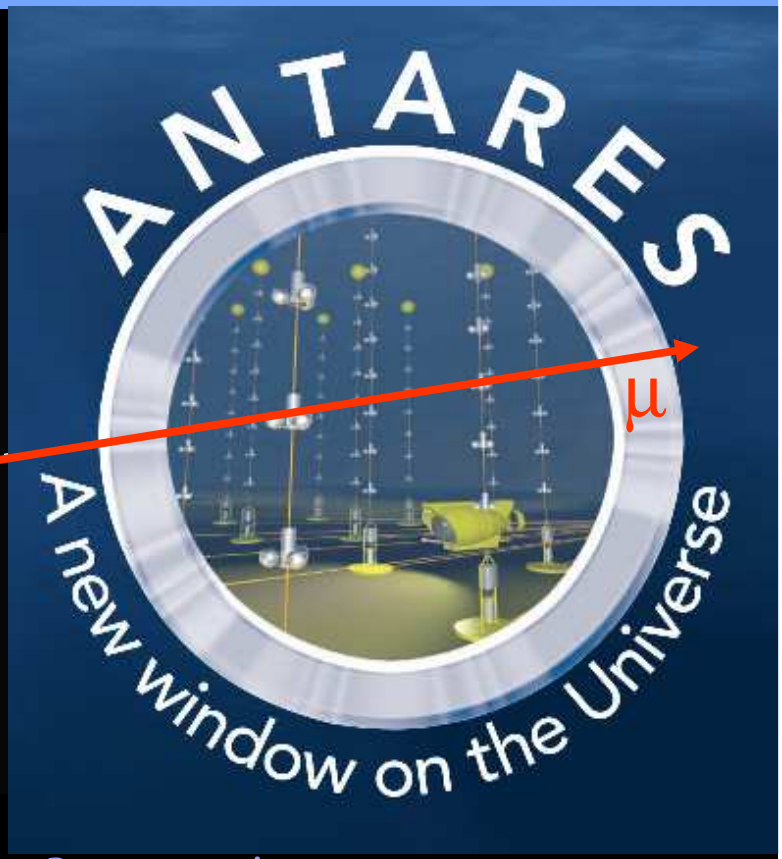
on behalf of the ANTARES Collaboration

Progress on Old and New Themes in cosmology – Avignon - April 2011

Indirect detection of WIMPs in a neutrino telescope

Relic WIMPs captured in celestial bodies

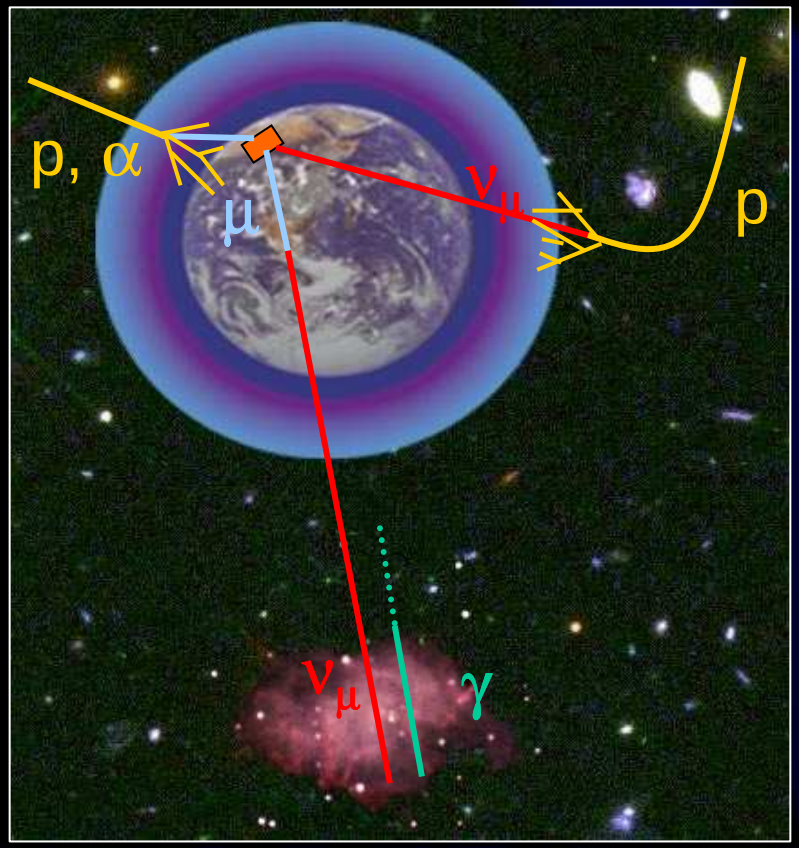




χχ self-annihilations into c,b,t quarks, τ leptons or W,Z,H bosons can produce significant high-energy neutrinos flux

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

$\gamma_č$

43°

3D PMT array

Sea floor

μ

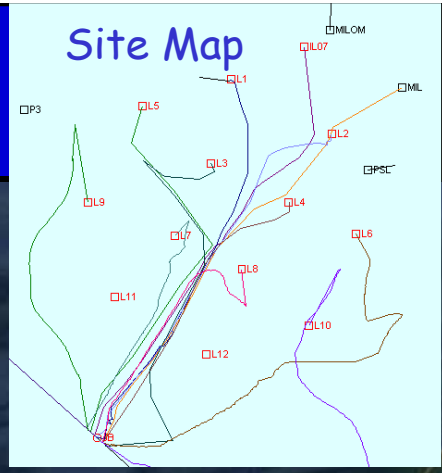
interaction

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



Buoy

Storey

14.5 m

350 m

100 m

Junction Box

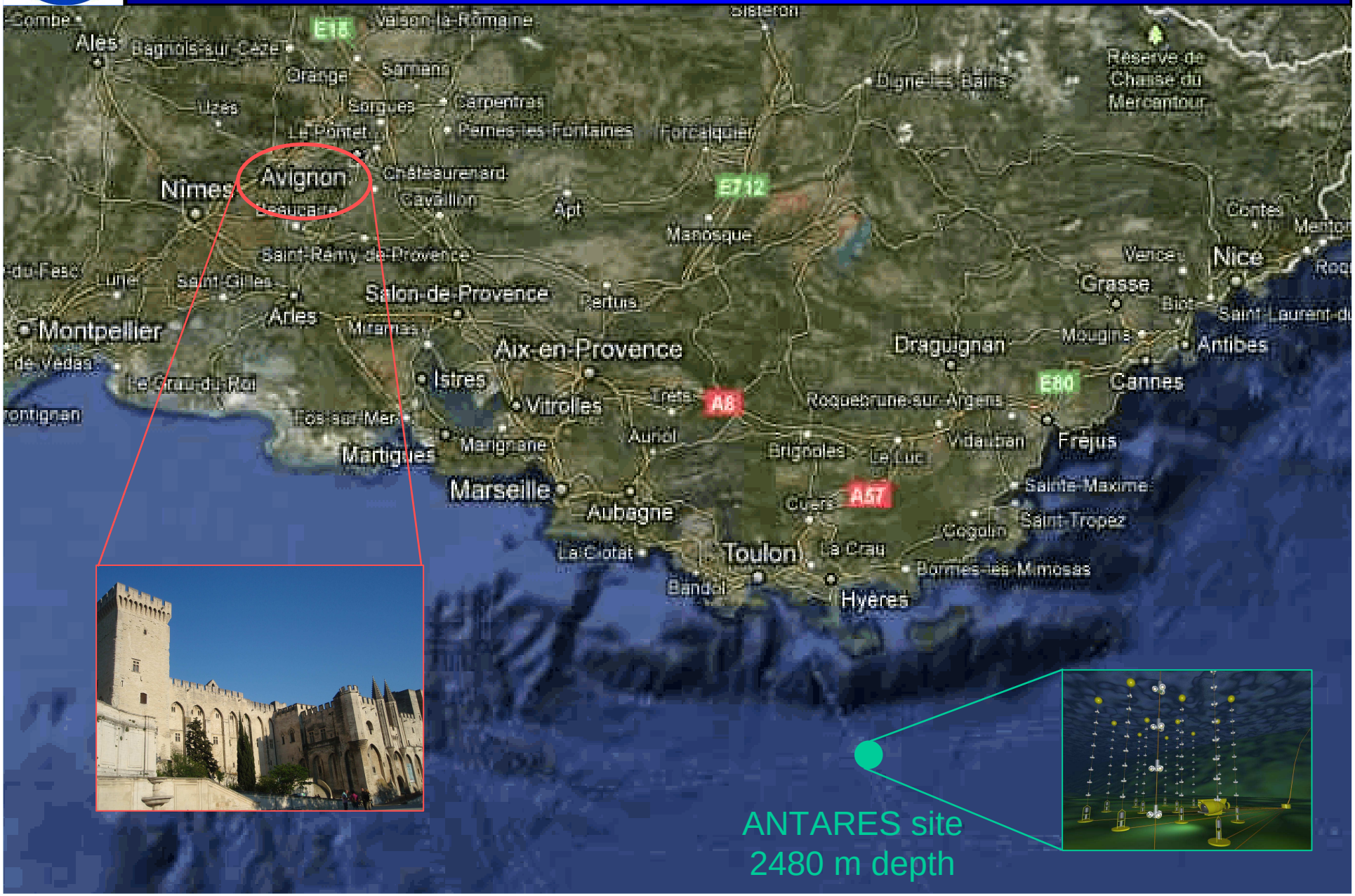
~60-75 m

Submarine links

Main Electro-optic Cable (~40 km)

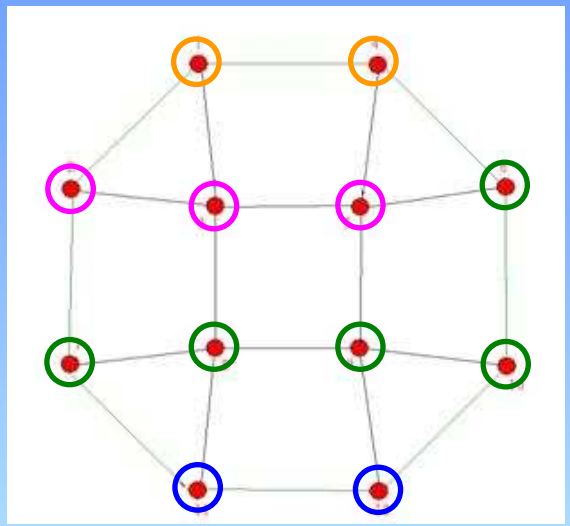
Depth : 2500m

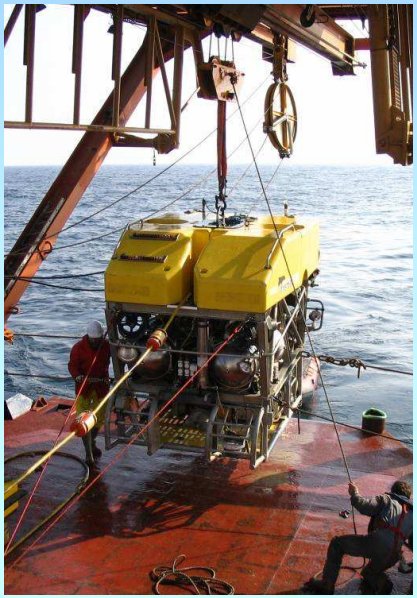
The ANTARES site

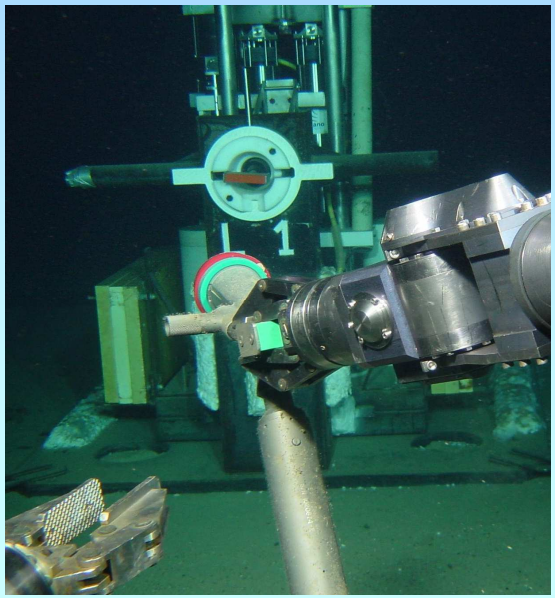


ANTARES site
2480 m depth

2006 – 2008: Building phase of the Detector







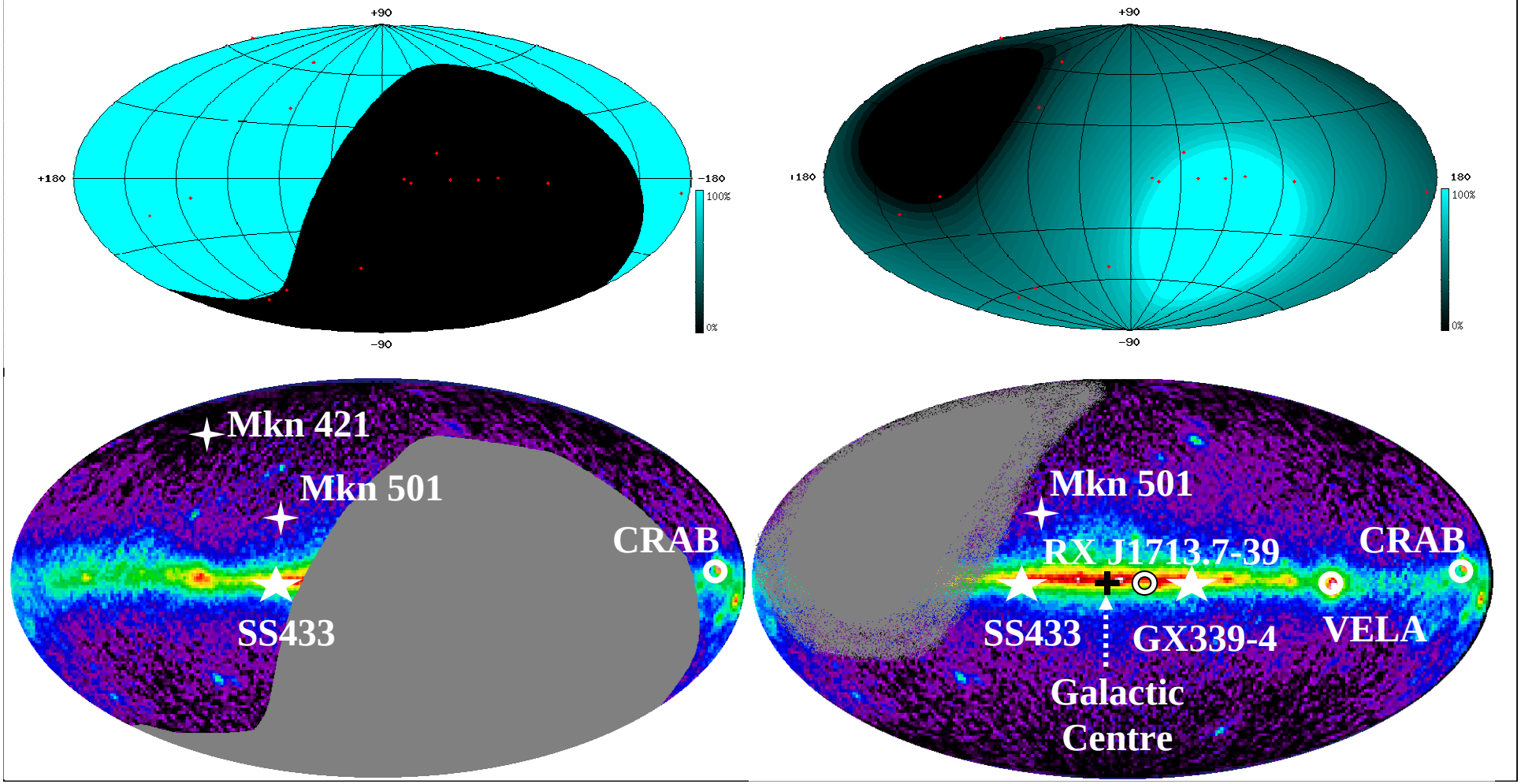
- **Line 1, 2**: 2006
- **Line 3, 4, 5**: 01 / 2007
- **Line 6, 7, 8, 9, 10**: 12 / 2007
- **Line 11, 12**: 05 / 2008

- **Detector maintenance** in 2009-2010:
  - **3 lines repaired and reconnected**
  - **Detector running again with full 12 lines config. since Nov 2010**

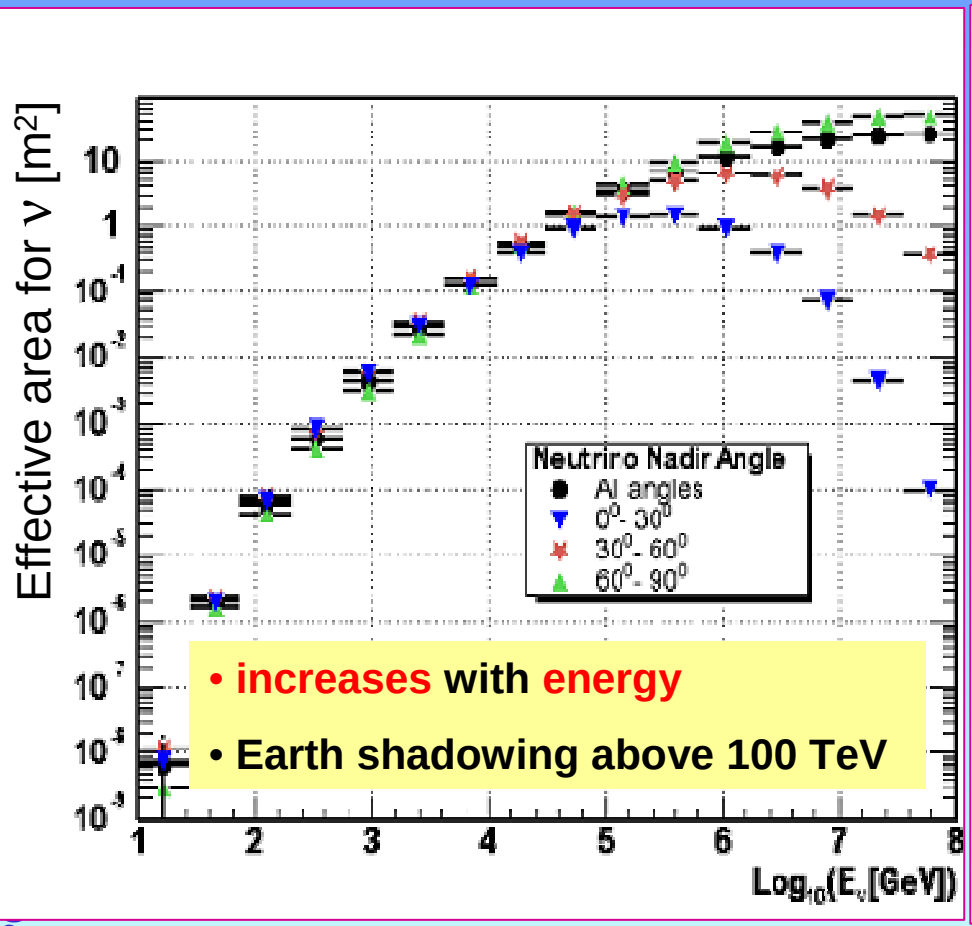
Region of Sky Observable by Neutrino Telescopes

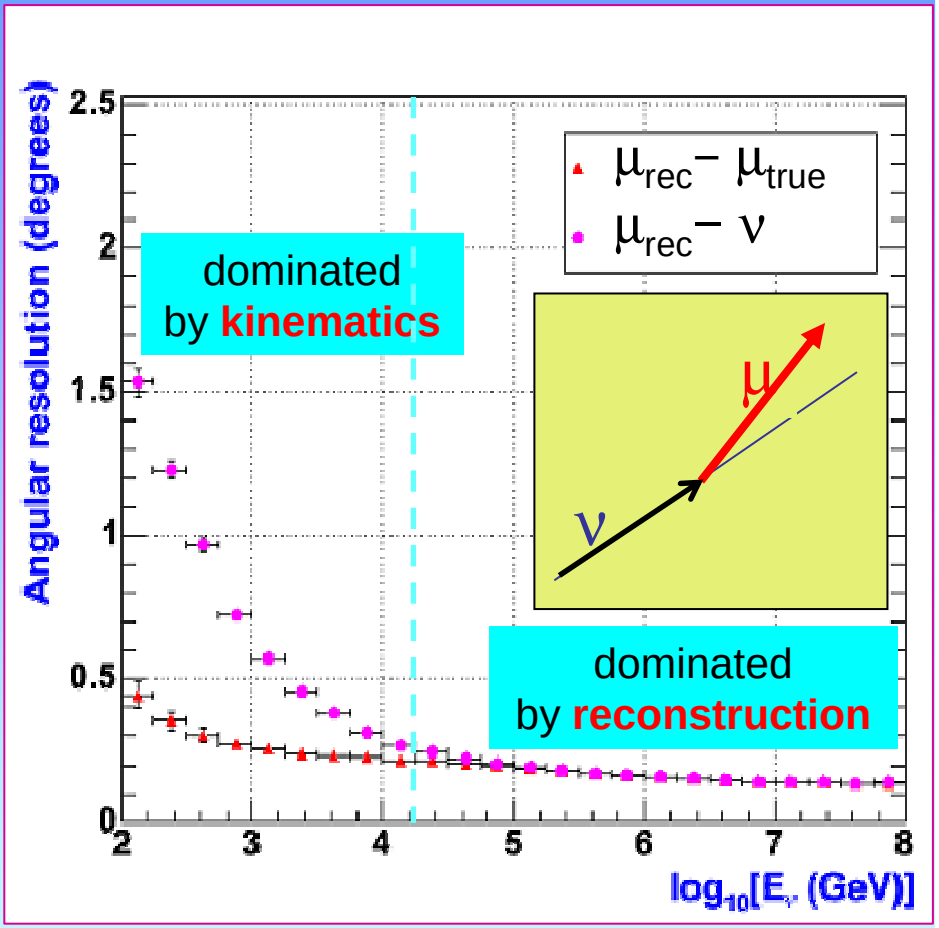
AMANDA/IceCube (South Pole) **ANTARES/KM3 (43° North)**

(ice: ~2°/0.6°) Angular resolution (water: ~0.3°/0.2°)



Expected performance (MC Studies)





Angular resolution better than 0.3° above a few TeV, limited by:

- Light scattering + chromatic dispersion in sea water: σ ~ 1.0 ns
- TTS in photomultipliers: σ ~ 1.3 ns
- Electronics + time calibration: σ < 0.5 ns
- OM position reconstruction: σ < 10 cm (↔ σ < 0.5 ns)

Neutralino annihilations in the Sun in CMSSM

Study of **neutralino Dark Matter** sensitivity within SUSY CMSSM framework

Random walk scan within CMSSM parameter space :

$0 < m_{1/2} < 2000$ GeV

$0 < m_0 < 8000$ GeV

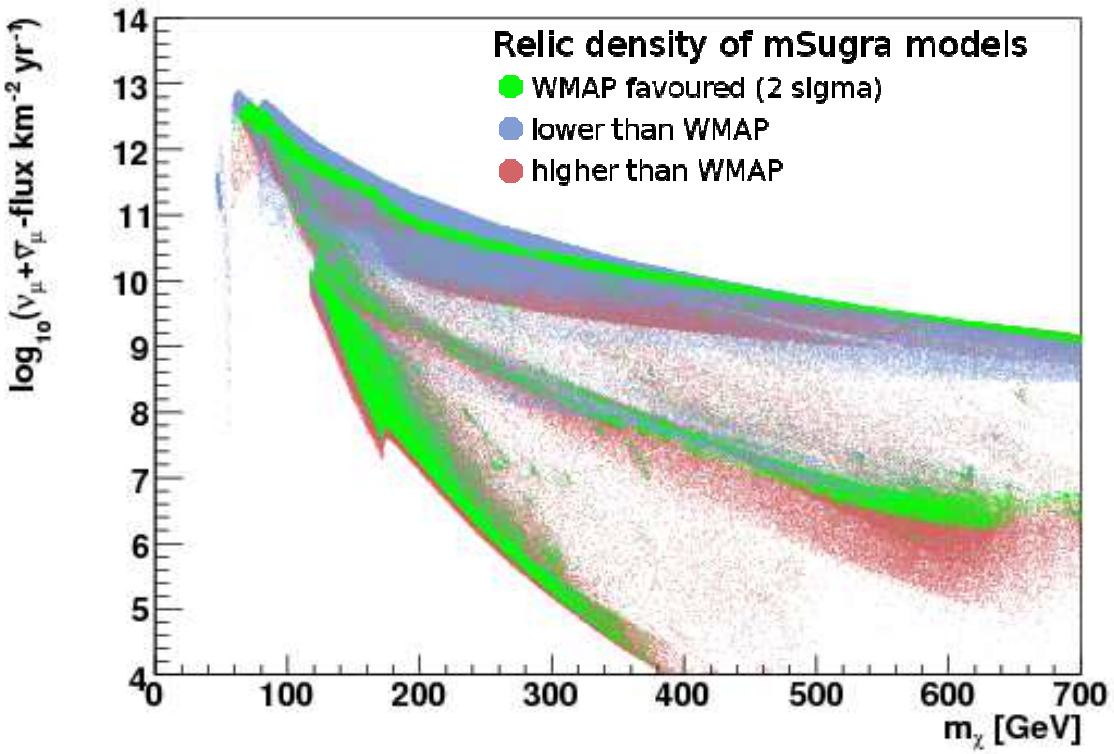
$0 < \tan\beta < 60$

$-3\, m_0 < A_0 < 3\, m_0$

Calculated with DarkSUSY and ISASUGRA (RGE code) with $m_{top} = 172.5$ GeV

Includes ν oscillation effects in the Sun and in vacuum

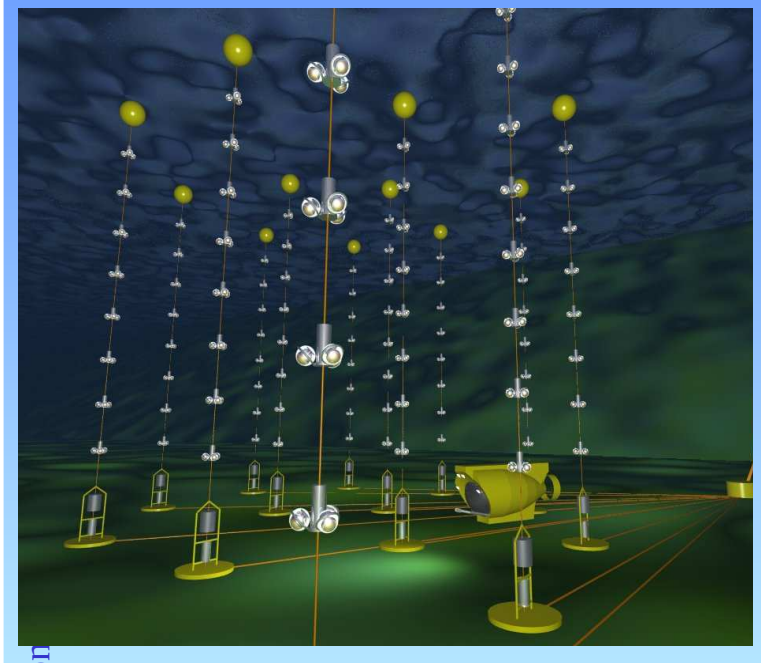
Integrated neutrino flux for Eν > 10 GeV



Local ρ_χ : 0.3 GeV/cm3

Dispersion velocity : v_χ = 270 km/s

Low energy performance of the ANTARES detector

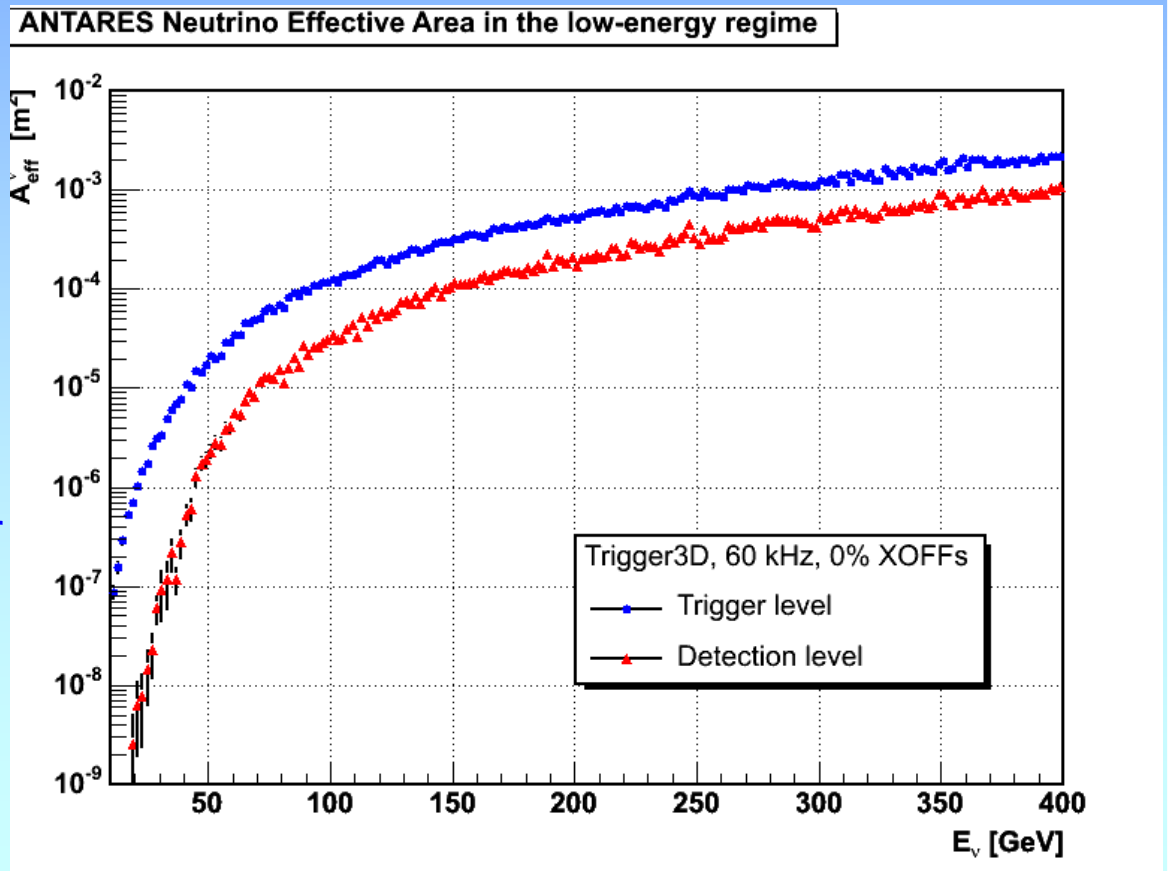


Trigger : Events with hits on at least 5 storeys in whole detector

Detection : Selected after 3D reconstruction with quality cuts

ANTARES Low-Energy Effective Area

Assume 60 kHz of optical background mean rate



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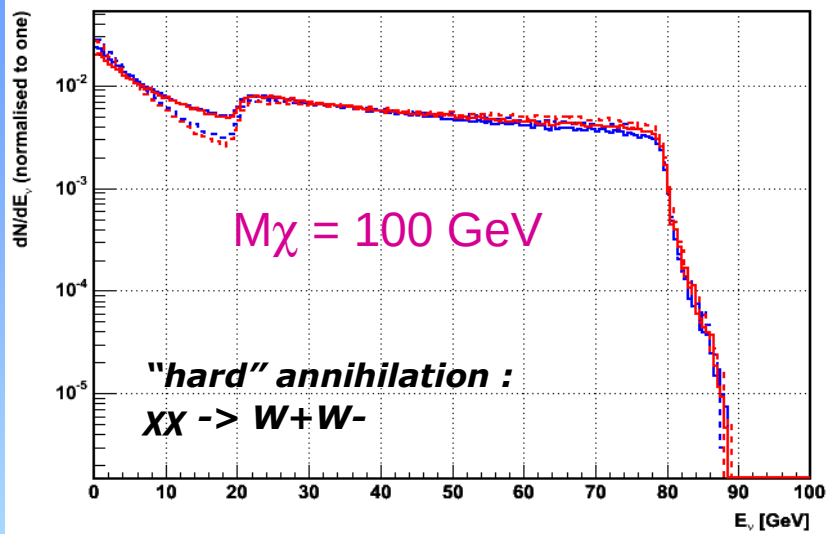
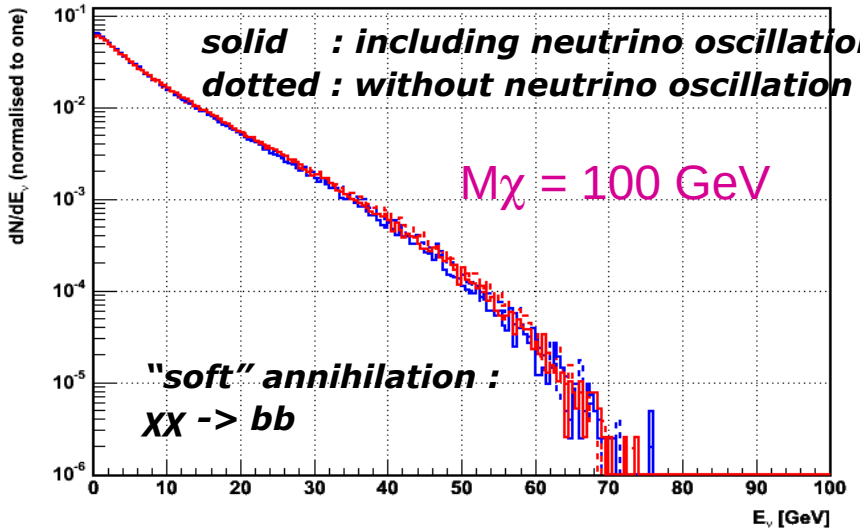
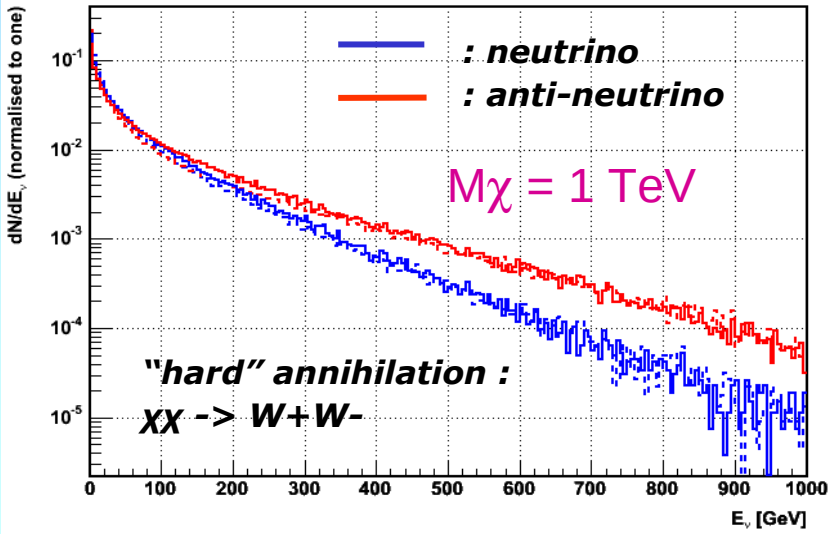
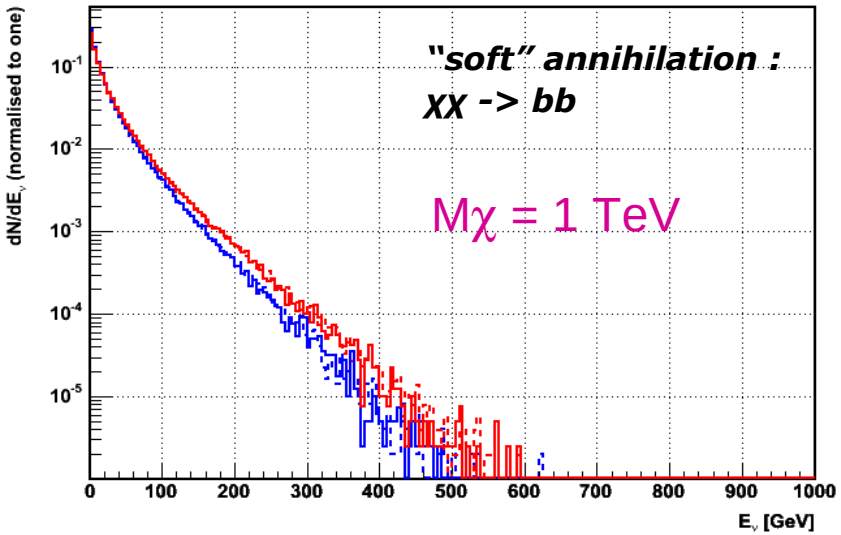
Neutrino spectra from neutralino annihilations





Neutrinos from $\chi\chi \rightarrow$ WW (hard spectrum) are more energetic and easier to detect





Neutralino annihilations in the Sun in CMSSM

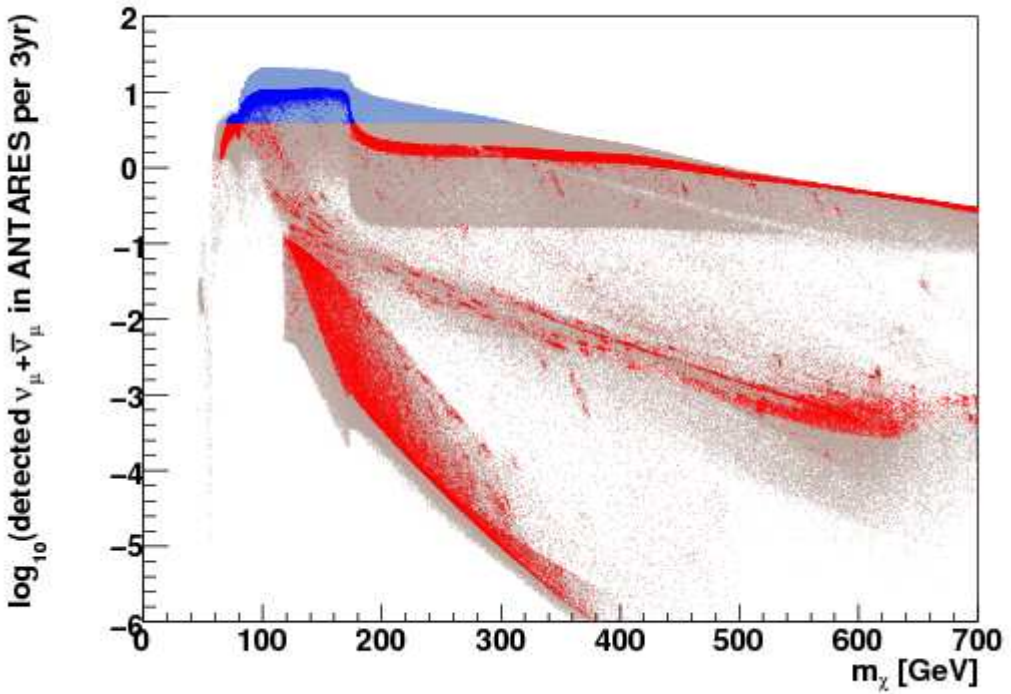
Sensitivity calculated for
3 years of data taking

Background from atmospheric neutrinos and misreconstructed atmospheric muons within 3° radius search cone around the Sun

Model with relic density **within 2σ** of WMAP constraint are **highlighted**

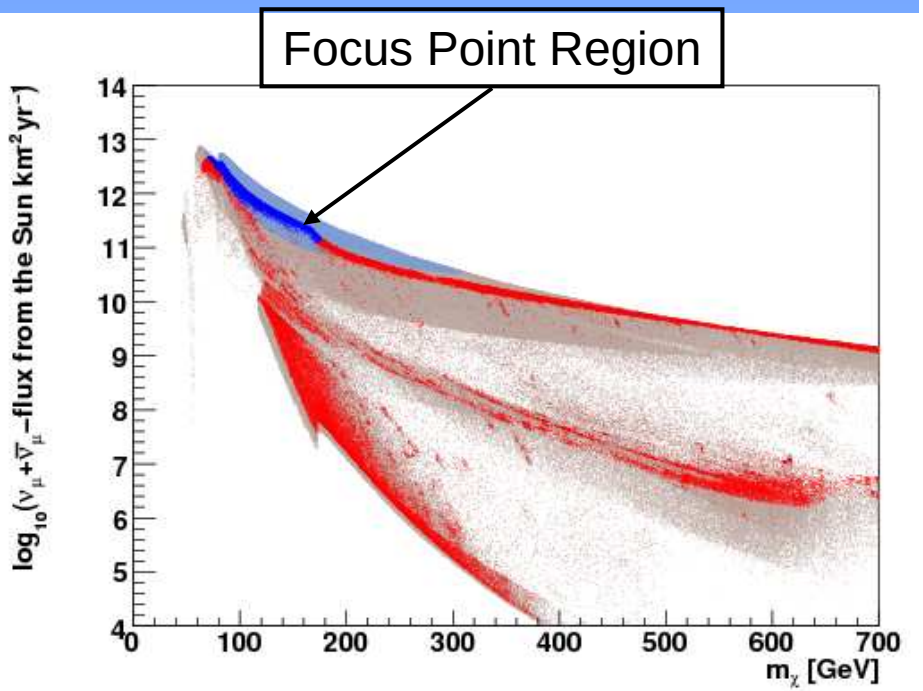
$(0.094 < \Omega\chi h^2 < 0.129)$

Detection rate with ANTARES in 3 years



Neutralino annihilations in the Sun in CMSSM

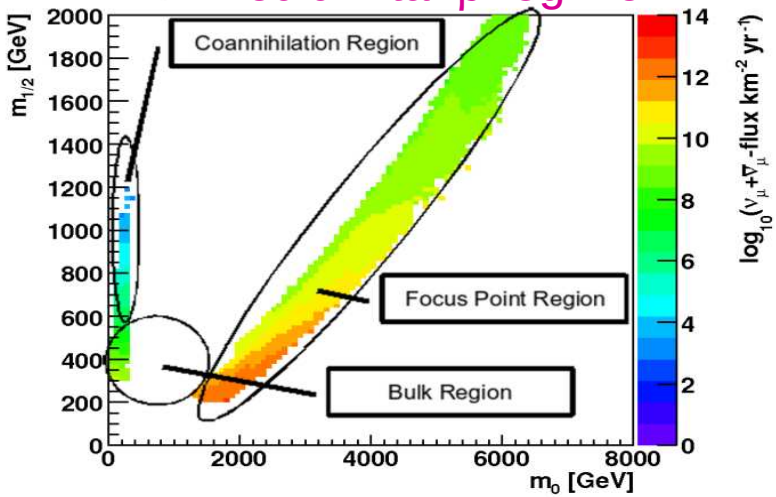
CMSSM Parameter Space



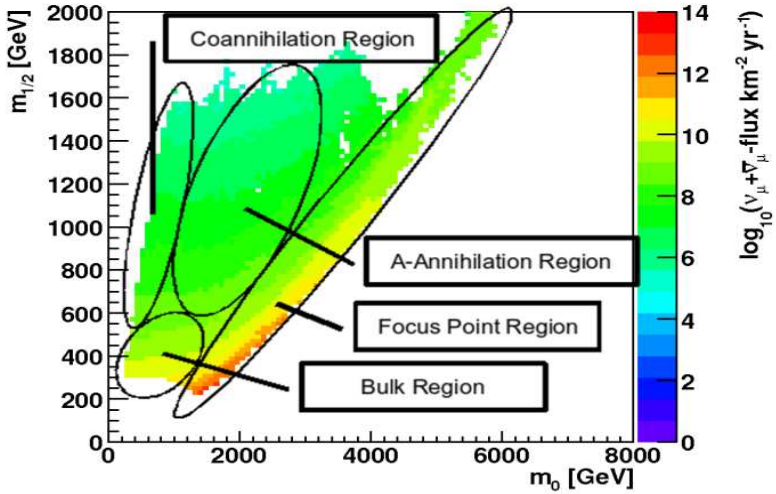
mSugra models favoured by WMAP
- 90% CL excludable by ANTARES
- not excludable

mSugra models disfavoured by WMAP
- 90% CL excludable by ANTARES
- not excludable

10<tanβ<20 — Medium tanβ regime

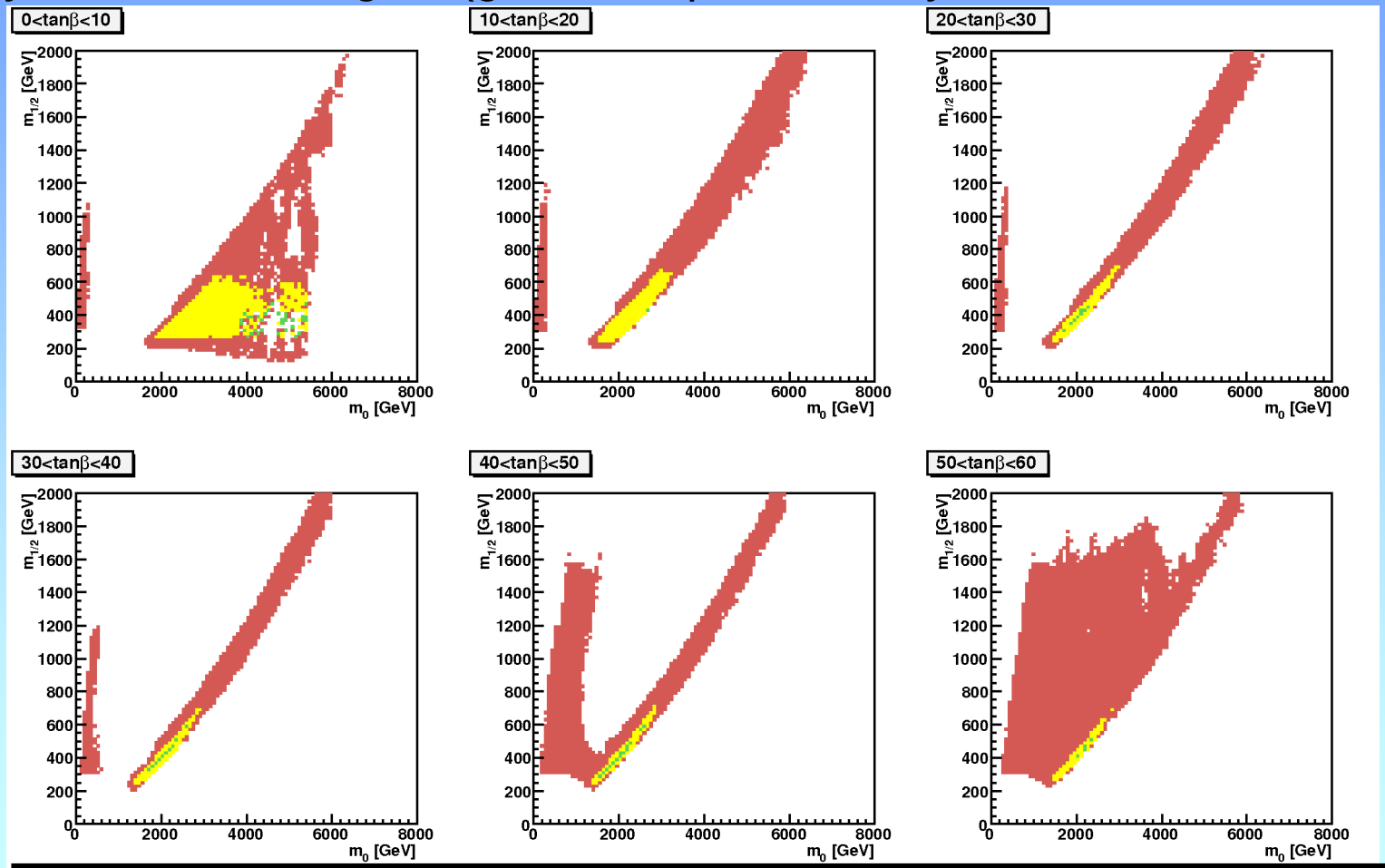


50<tanβ<60 — High tanβ regime



Search for neutralino annihilations in the Sun

Exclusion capabilities of ANTARES for the CMSSM parameter space :
mainly Focus Point region (good complementarity to direct search at LHC)



Excludable in 3 years at 90% CL: all some none
(A_0 varied between $-3m_0$ and $+3m_0$ and tan(β) within indicated slice)

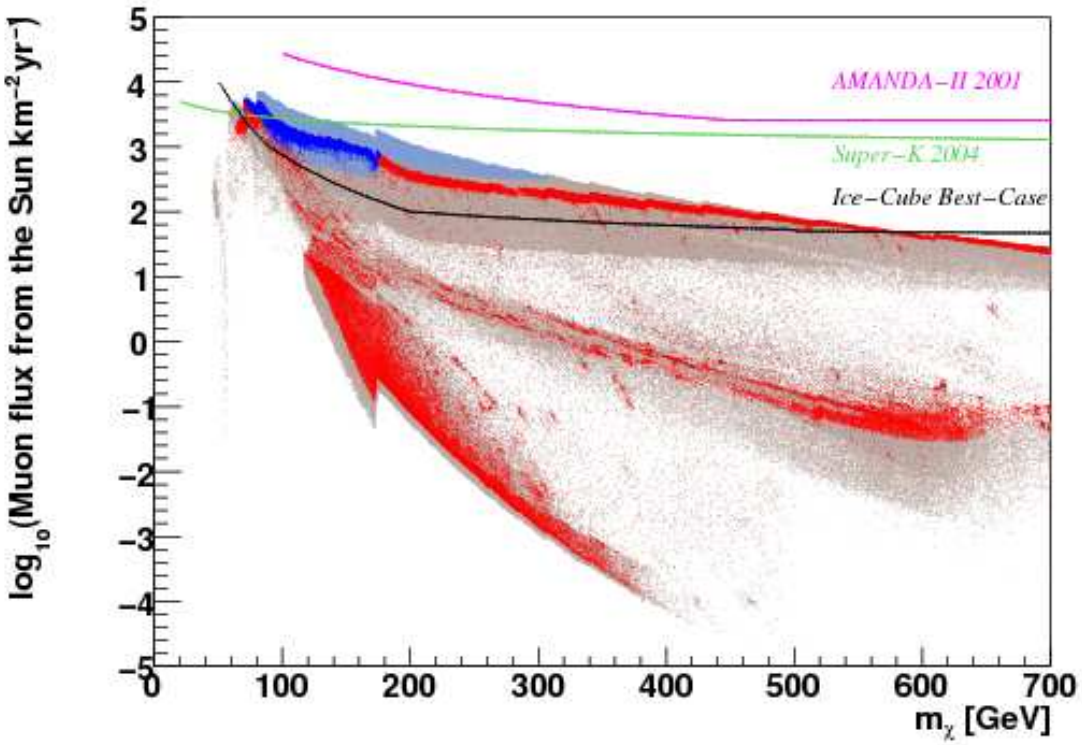
Muon flux from neutralino annihilations in the Sun

Used for comparison to other neutrino experiments

Site dependent quantity (ν propagation through Earth, target density at detector…)

Derived from neutrino flux through ν → μ conversion rate extracted from DarkSUSY for different m_χ

Muon flux from the Sun in CMSSM (Eμ > 1 GeV)



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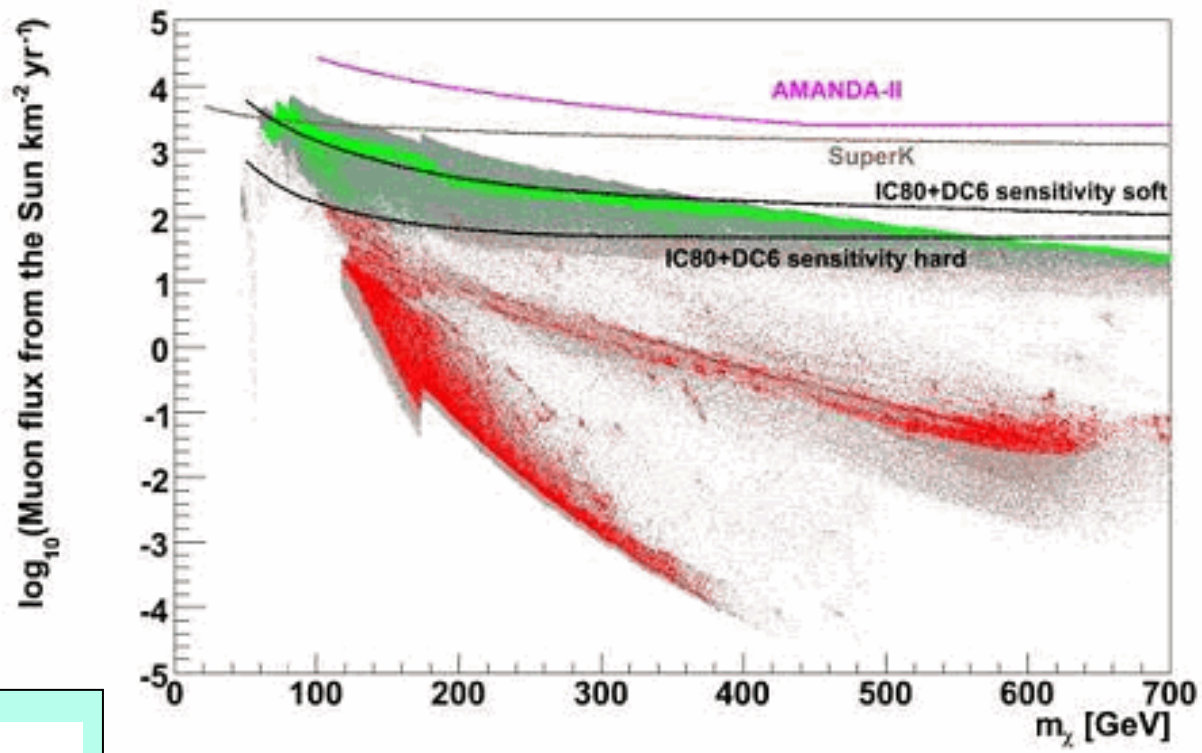
AMANDA-II : astro-ph/0810.4513
Super-K : hep-ph/0106024
IceCube :astro-ph/0805.3546

Muon flux from neutralino annihilations in the Sun

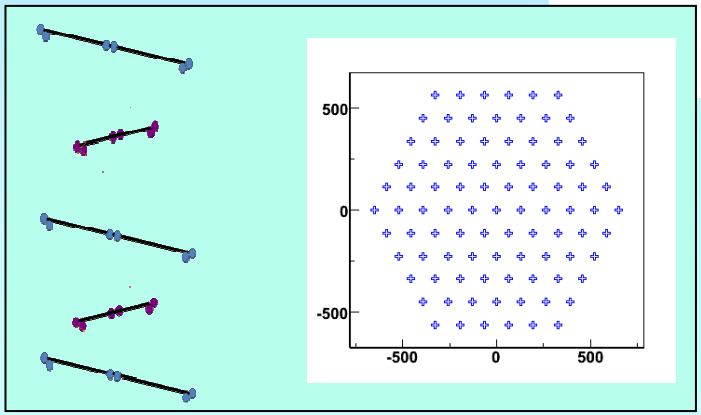
Prospective sensitivity of 2nd generation km-scale neutrino telescopes (IceCube+DeepCore & KM3NeT) with10 years of observation time

Muon flux from the Sun in CMSSM ($E\mu > 1$ GeV)



KM3NeT detector:

2x154 towers, 20 floors
Distance inter lines: ~180m
Distance inter floors: ~40m
3x2 PMTs (8'', 35% QE) per floor
Volume ~5 km³



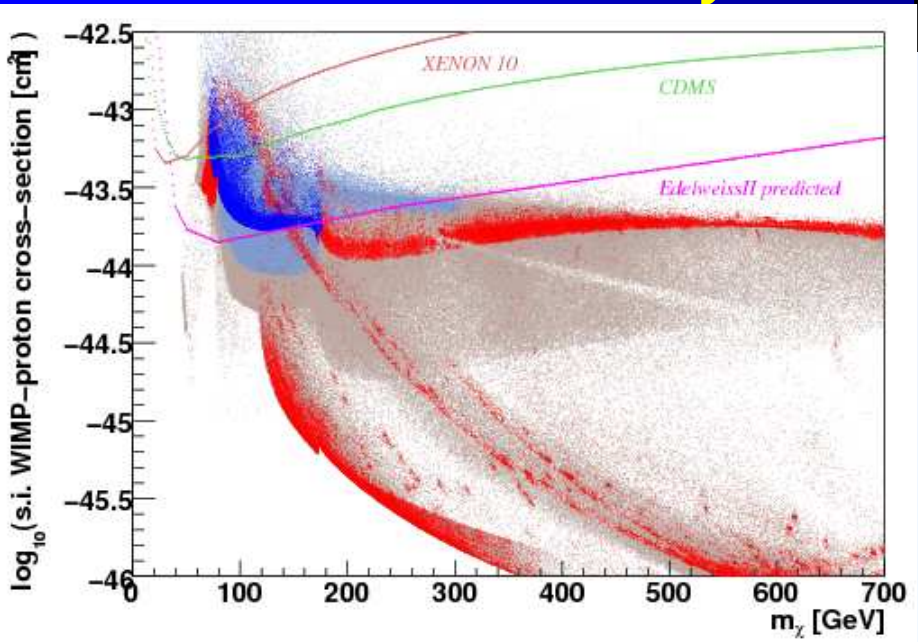
mSugra models favoured by WMAP
- 90% CL excludable by KM3NeT
- not excludable

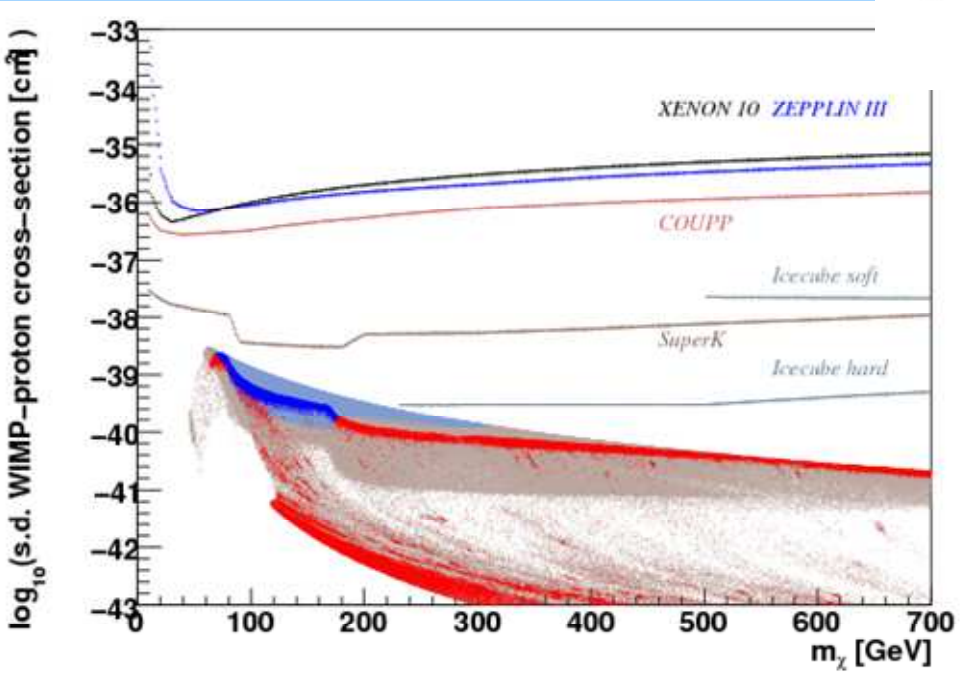
mSugra models disfavoured by WMAP
- 90% CL excludable by KM3NeT
- not excludable

AMANDA-II : astro-ph/0810.4513
Super-K : hep-ph/0106024
IceCube+DC : arXiv:0902.2460

Comparison to Direct Detection sensitivity

Comparison to Direct Detection
on Spin-Dependant cross-section:
Almost direct relation since
annihilation rate inside the Sun is
tied to scattering cross section on H





Comparison to Direct Detection on Spin-Independant cross-section

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- not excludable

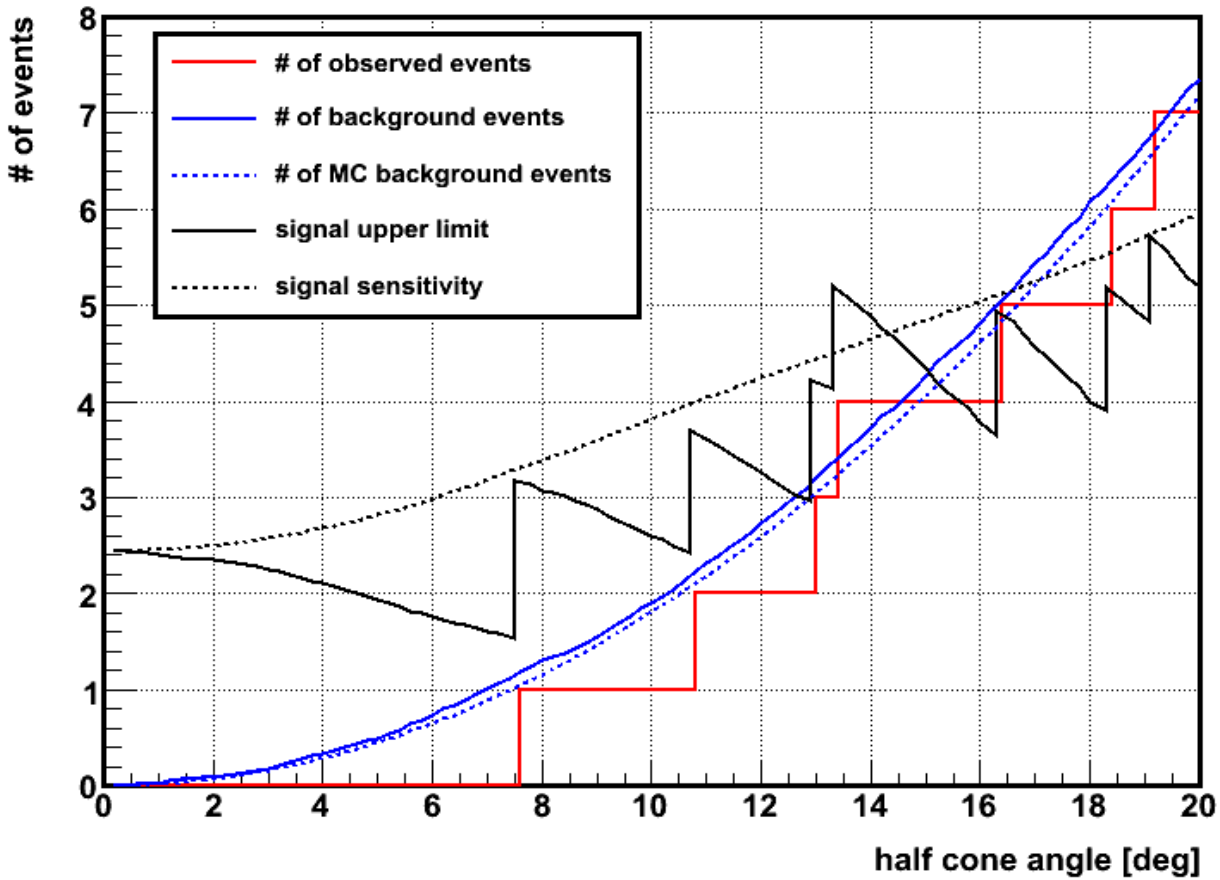
XENON 10 : astro-ph/0706.0039
CDMS : astro-ph/0802.3530
COUPP : Science 319 (2008)
ZEPLIN III : arXiv:0901.4348
IceCube : arXiv:0902.2460

Search for neutrino events coming from the Sun

Expected sensitivity (90% CL) and background in a cone around the Sun for the ANTARES 5-line upgoing neutrino sample (2007 data)

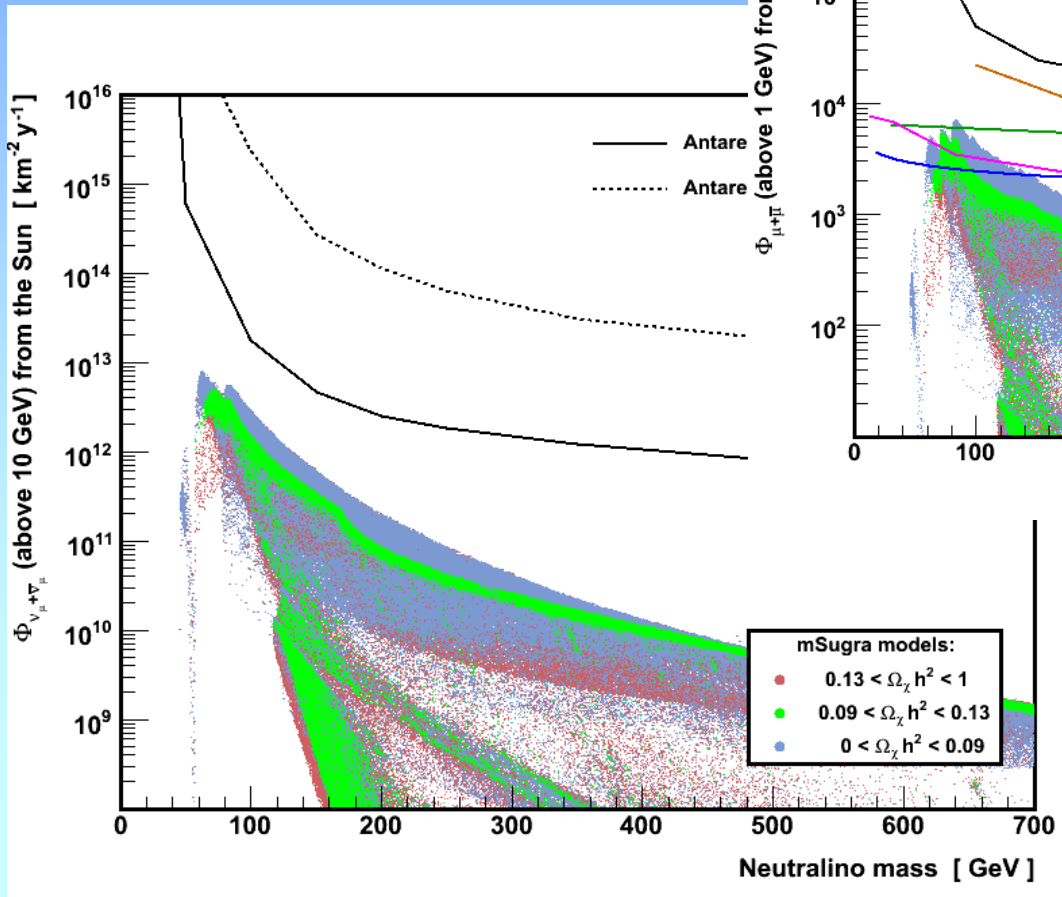
Good agreement for background estimation from MC and full sky data set

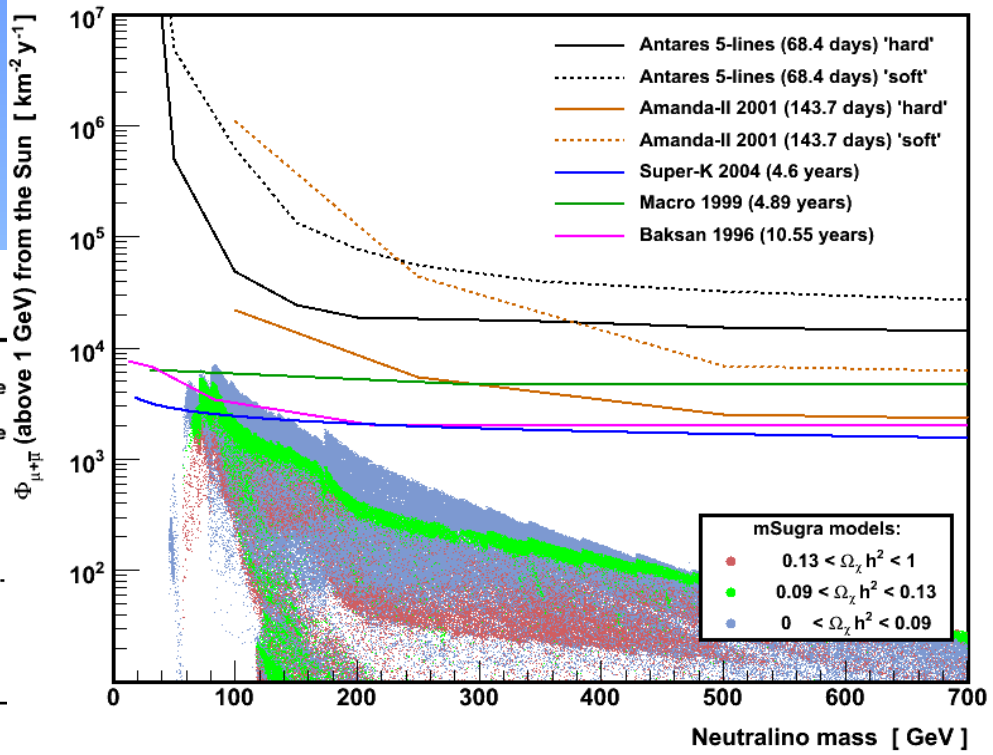
Size of search cone optimized on MC as a function of Mχ and hard/soft spectrum



First ANTARES limit on ν/μ flux from the Sun

Promising limit based on data with ~ ½ of ANTARES detector within 6 months

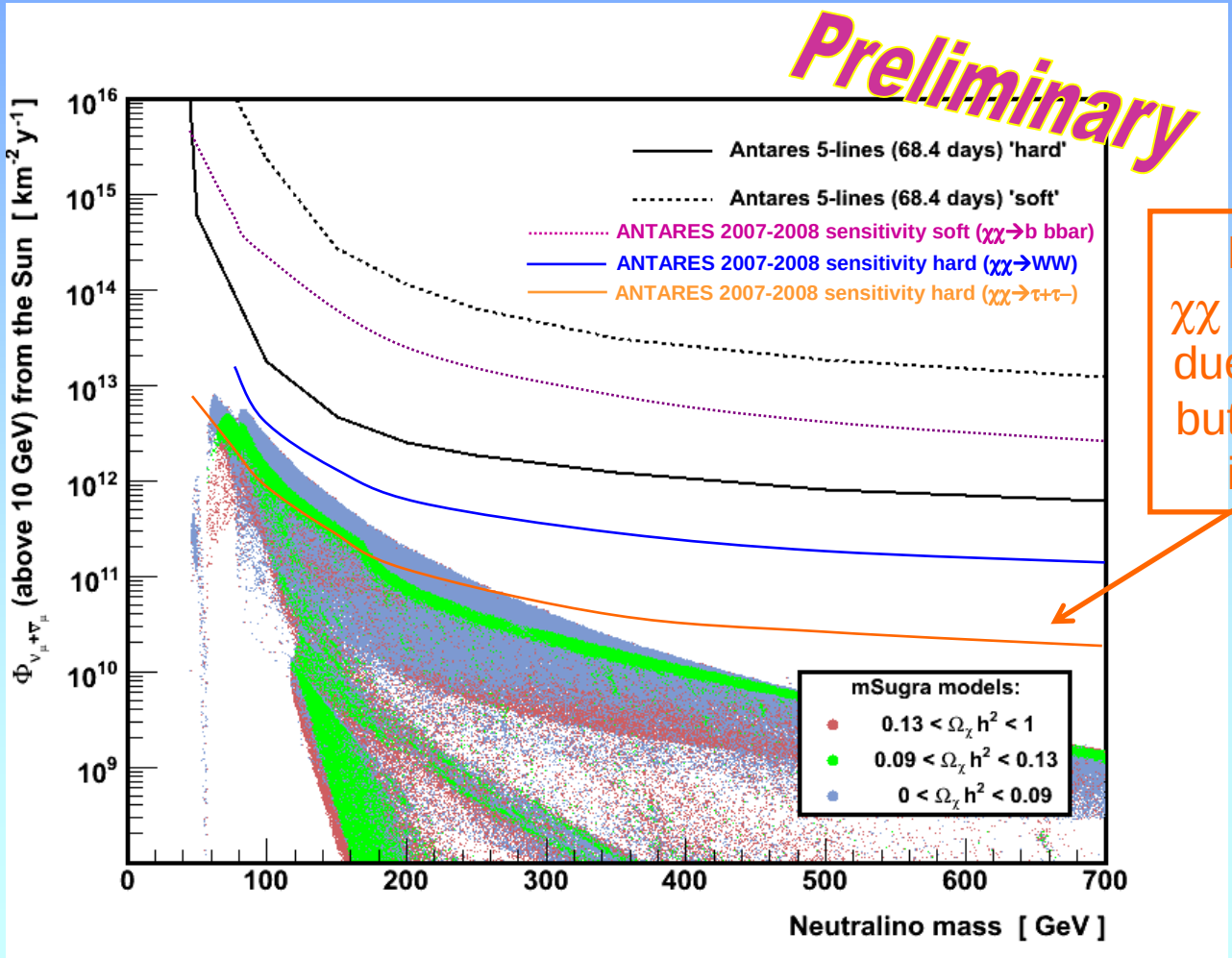




Limit with b-quark (soft) or W-boson (hard) annihilation channel

Sensitivity of 2008 data analysis towards Sun

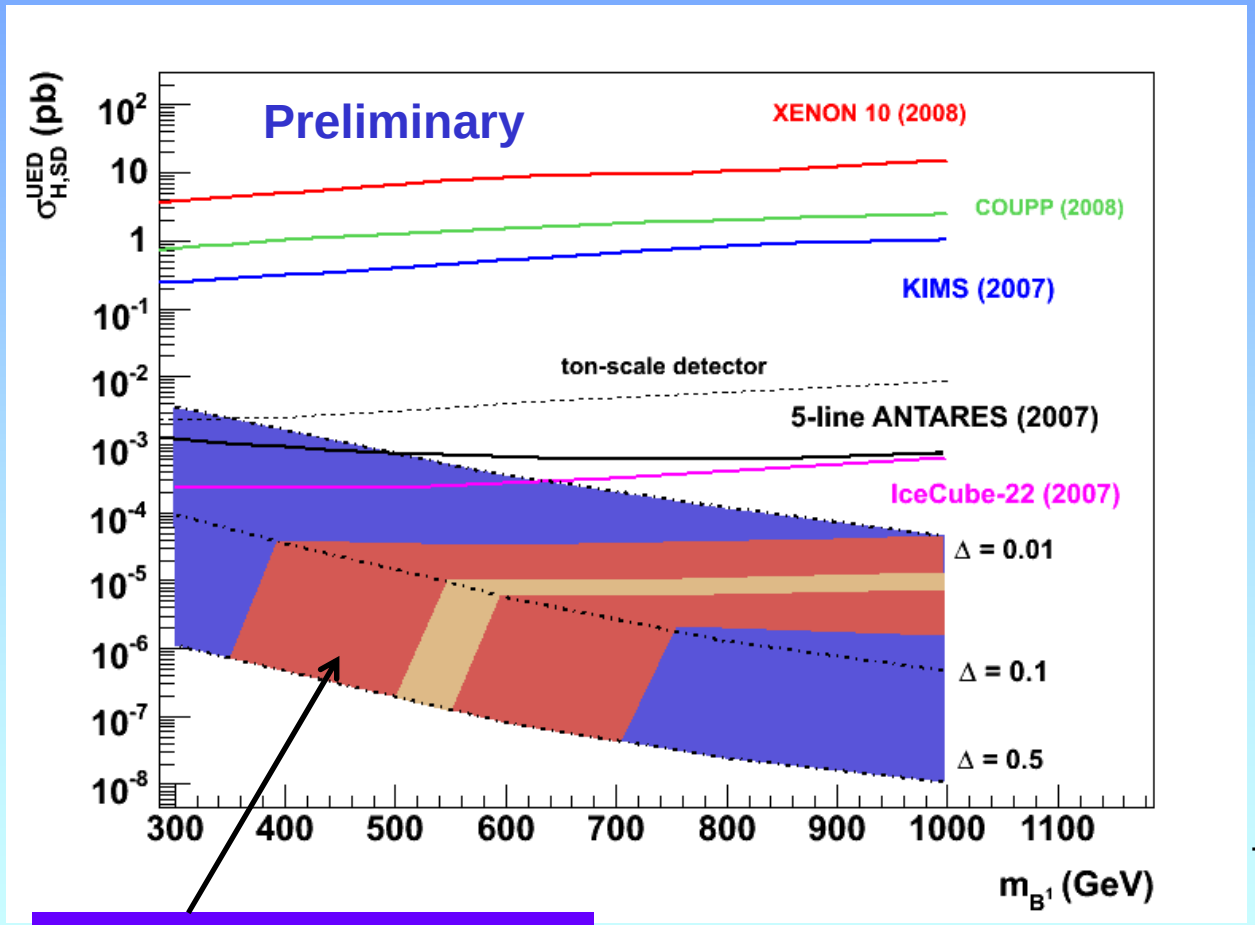
Analysis combinig 2007+2008 ANTARES data (~300 days of lifetime)
currently under completion → to be unblinded soon
Premilinary sensitivity just above CMSSM domain for $\chi\chi \rightarrow$ b bbar decays



Best sensitivity to
$\chi\chi \rightarrow \tau^+\tau^-$ annihilations
due to harder spectrum
but usually disfavoured
in CMSSM models

Limit on LKP annihilations in the Sun in mUED model

Interpretation in Minimal Universal Extra Dimension model (1 extra dim)
with $B^{(1)}$ (first KK excitation of photon) as LKP and DM candidate



$0.05 < \Omega_{LKP}\, h^2 < 0.20$
$0.1037 < \Omega_{LKP}\, h^2 < 0.1161$

XENON 10 : astro-ph/0805.2939
KIMS : astro-ph/0704.0423
COUPP : Science 319, 933 (2008)
IceCube : arXiv:0910.4480

Highly predictive phenomenological model due to very few free parameters

Direct LKP annihilations into neutrinos allowed

Limit on LKP-proton cross-section as a function of $B^{(1)}$ mass and $\Delta = (M_{Q(1)} - M_{LKP}) / M_{LKP}$

Summary and Outlook

- ANTARES detector is working well : first search on Dark Matter annihilation in the Sun performed on 5-line data (2007)
- Interesting signal of SUSY Dark Matter for neutrino telescopes :
  - Part of CMSSM parameter space accessible to ANTARES in 3 years (Focus Point Region)
  - Most of Focus Point Region can be explored by KM3-scale detectors
  - Complementarity of neutrino telescopes with Direct Detection experiments and LHC
- Sensitivity to other SUSY models (pMSSM, AMSB,…) or Dark Matter candidates is being studied (KK excitations,…)
- Search towards Sun, Galactic Centre and Earth are in progress with 2008 data (+2009-2010 data soon)
- More than 3000 neutrinos already collected today !

Stay tuned for the BIG DARK DISCOVERY !!