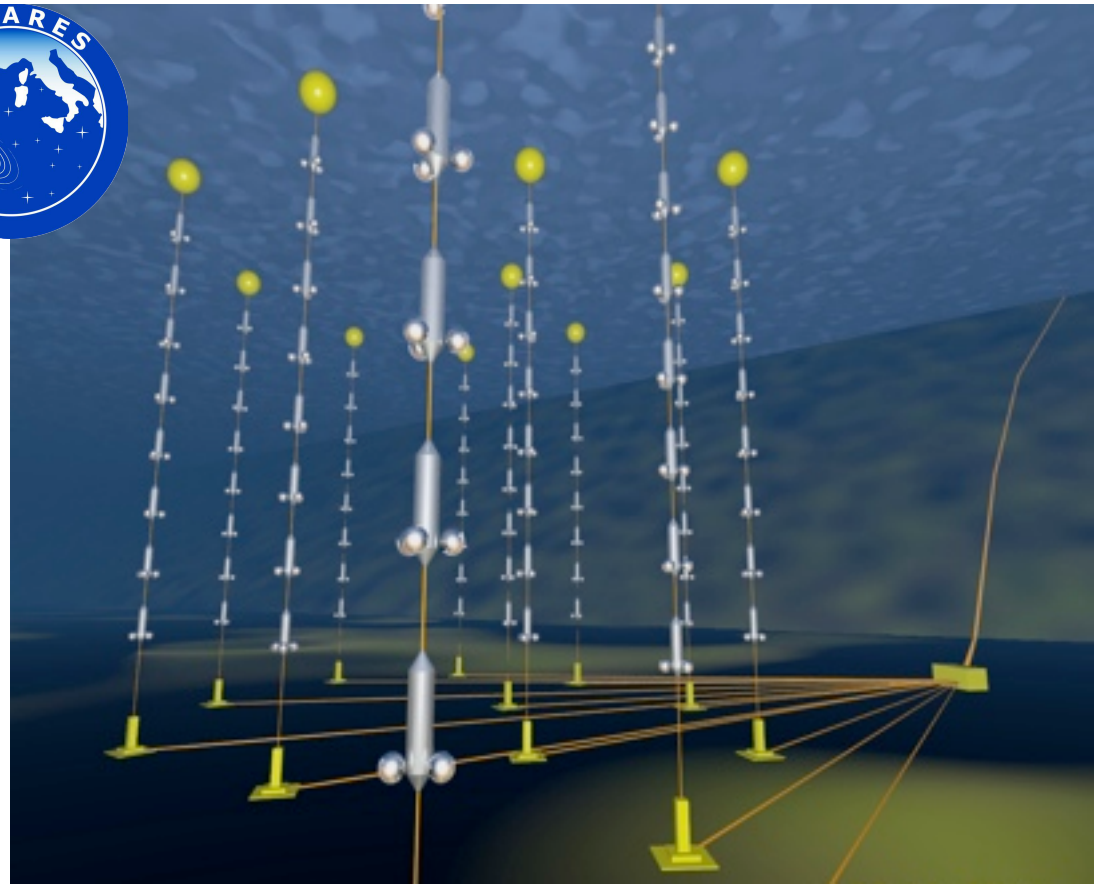
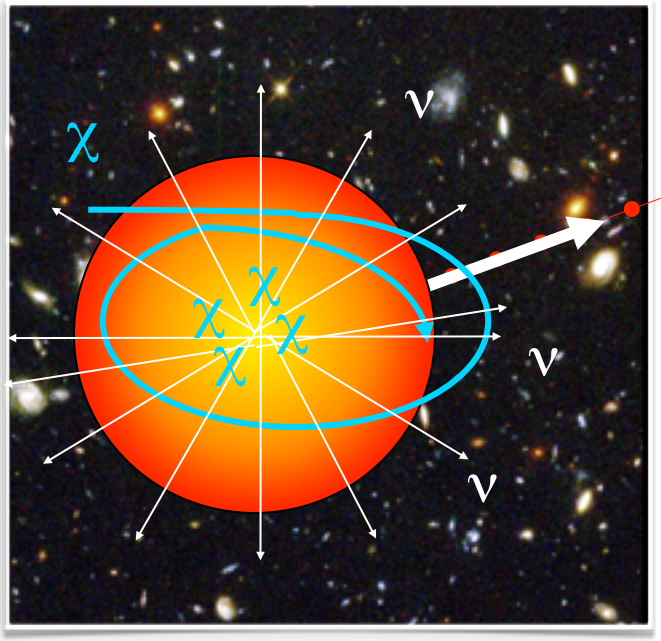
Indirect Searches of Dark Matter with the ANTARES Neutrino Telescope



Pascal Gay
LPC Clermont
Université Blaise Pascal IN2P3-CNRS

Indirect detection of WIMPs in a neutrino telescope

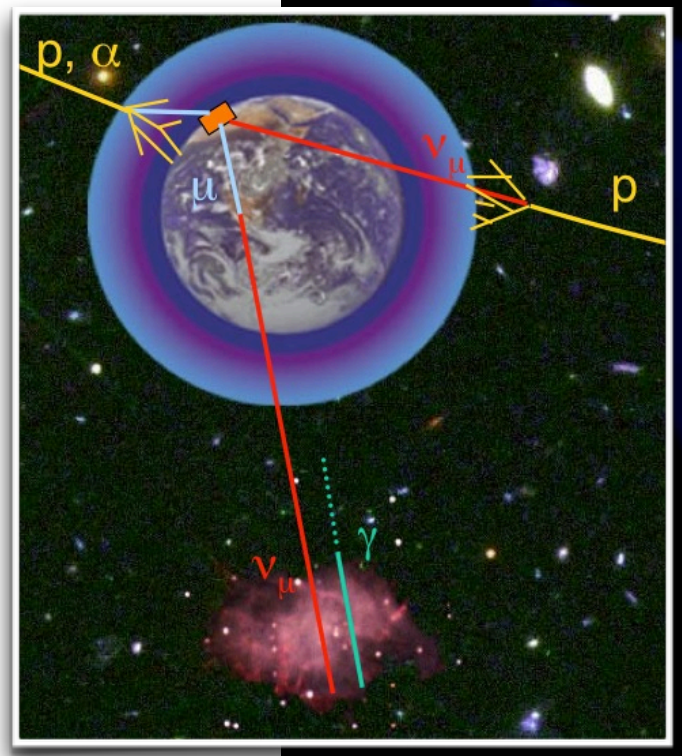
Relic WIMPs captured in celestial bodies



Potential $\chi\chi \rightarrow \nu$ sources : Sun, Earth, Galactic Centre & Dwarf Sph Galaxies

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

Neutrino telescope : detection principle



3D PMT array

$\gamma_č$

Cherenkov light from μ

43°

Sea floor

μ

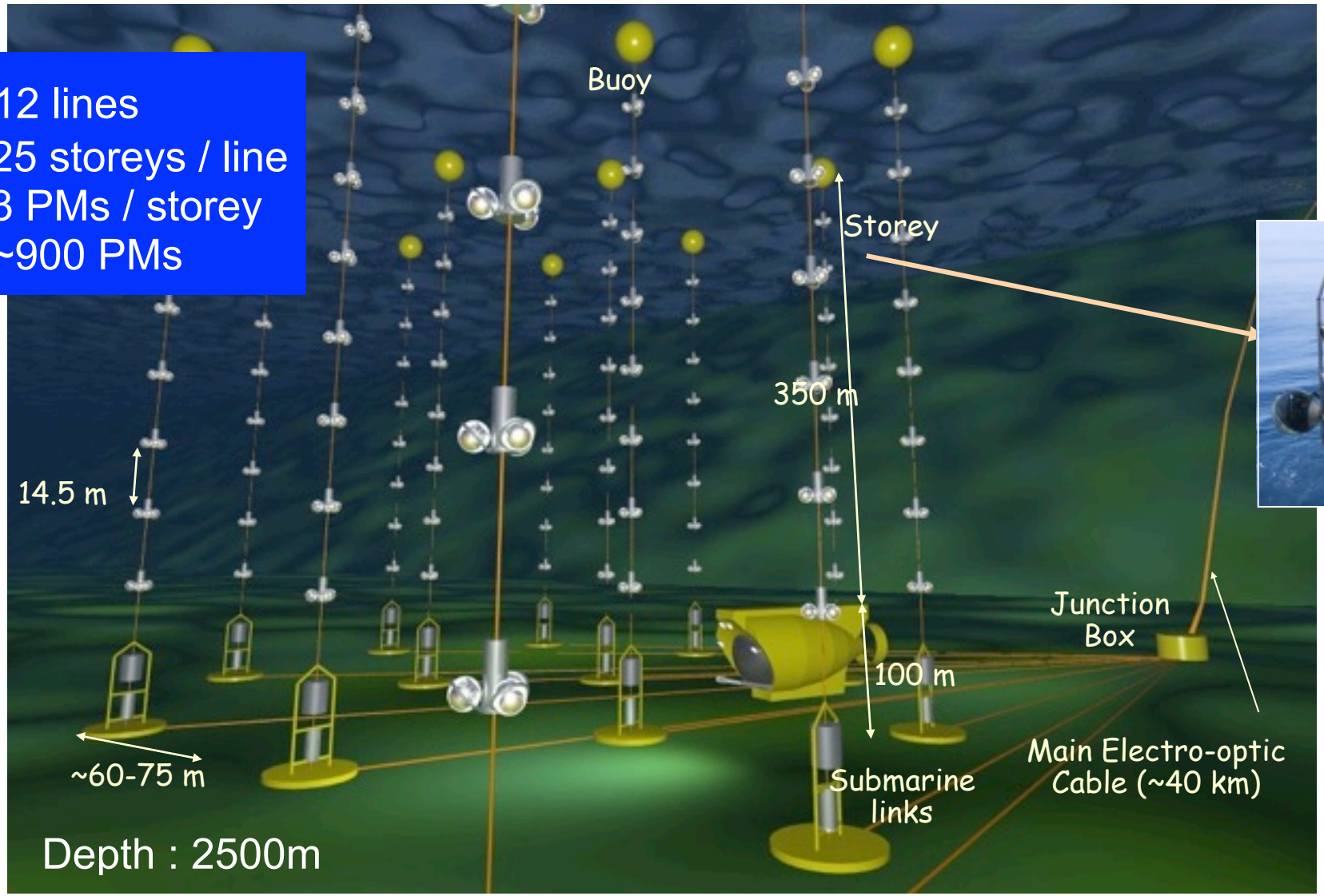
interaction

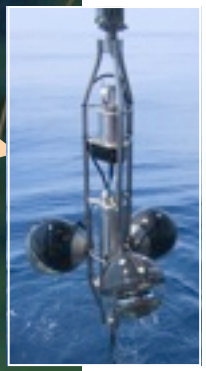
ν

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

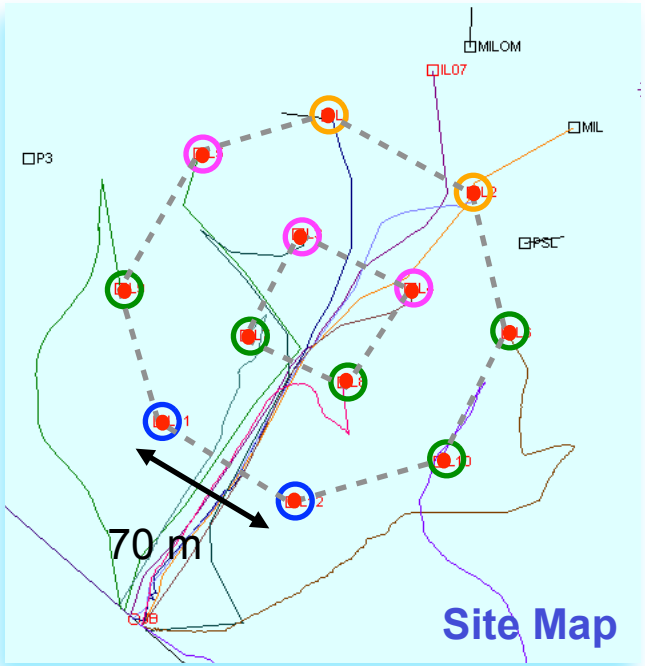
ANTARES Detector

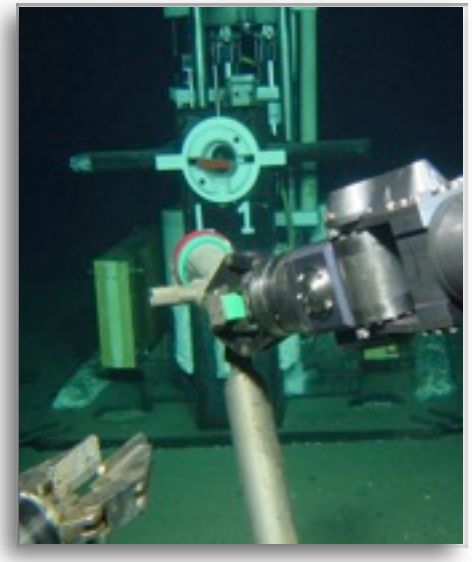
- 12 lines
- 25 storeys / line
- 3 PMs / storey
- ~900 PMs





Bulding phase 2006-08





2006 **Line 1, 2** data under
01 / 2007 **Line 3, 4, 5** scope here

12 / 2007 **Line 6, 7, 8, 9, 10**

05 / 2008 **Line 11, 12**

2009-10 **Detector maintenance**

L12 repaired and reconnected

L6 repaired and redeployed

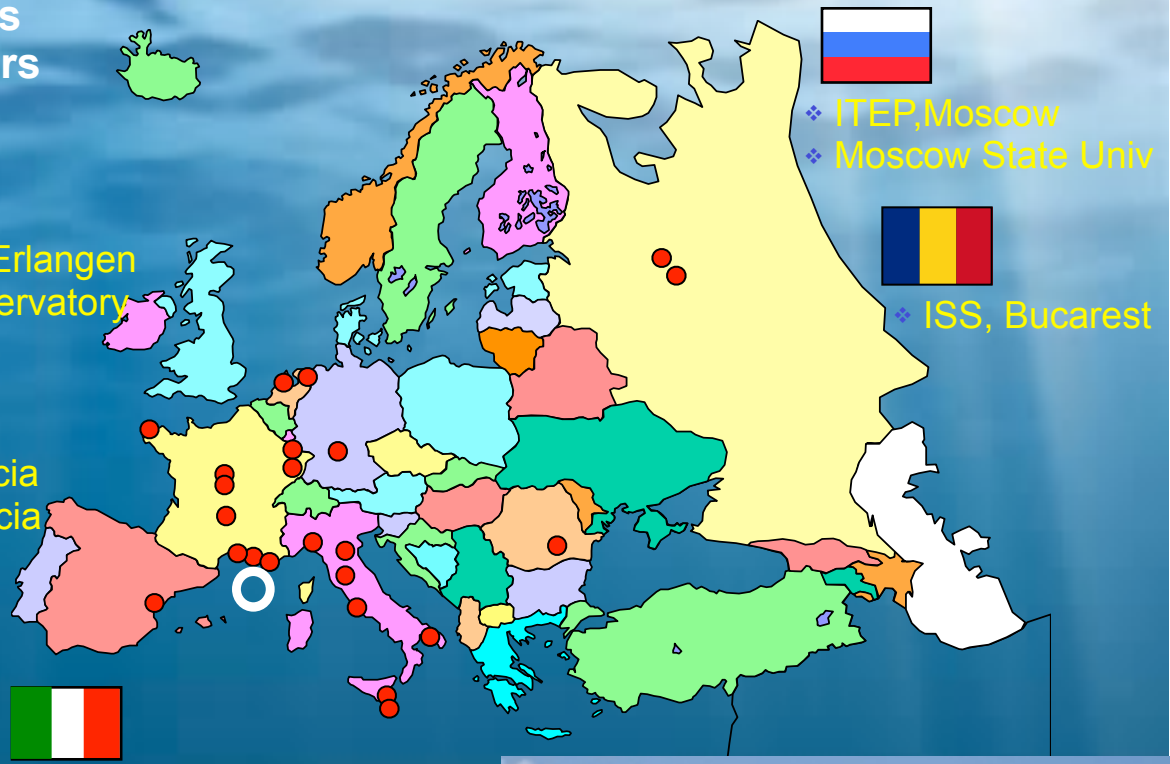
L9 recovered and under repair

L6 & L9 in water nov'10 connected dec. '10

2011-xx **12 lines**

The ANTARES collaboration

7 countries 29 institutes
~150 scientists+engineers



- NIKHEF, Amsterdam
- Utrecht
- KVI Groningen
- NIOZ Texel

- University of Erlangen
- Bamberg Observatory

- IFIC, Valencia
- UPV, Valencia

- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC, Paris
- LPC, Clermont-Ferrand
- IPHC (IReS), Strasbourg
- Univ. de H.-A., Mulhouse
- IFREMER, Toulon/Brest
- C.O.M. Marseille
- LAM, Marseille
- GeoAzur Villefranche

- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS – Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

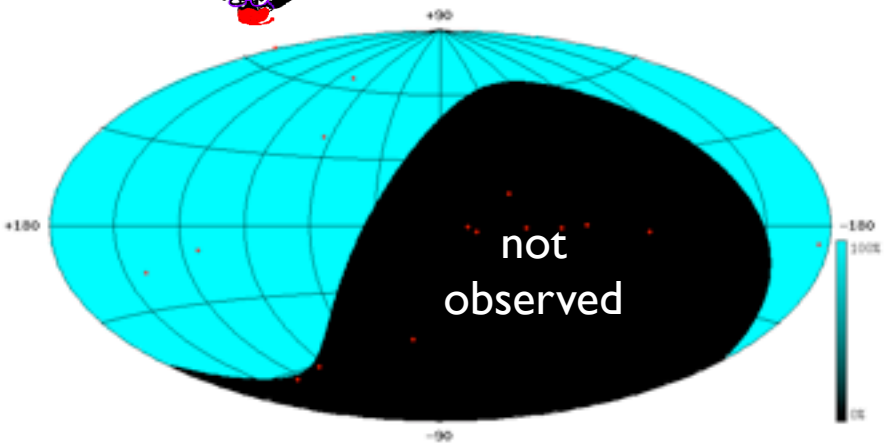
- ITEP,Moscow
- Moscow State Univ

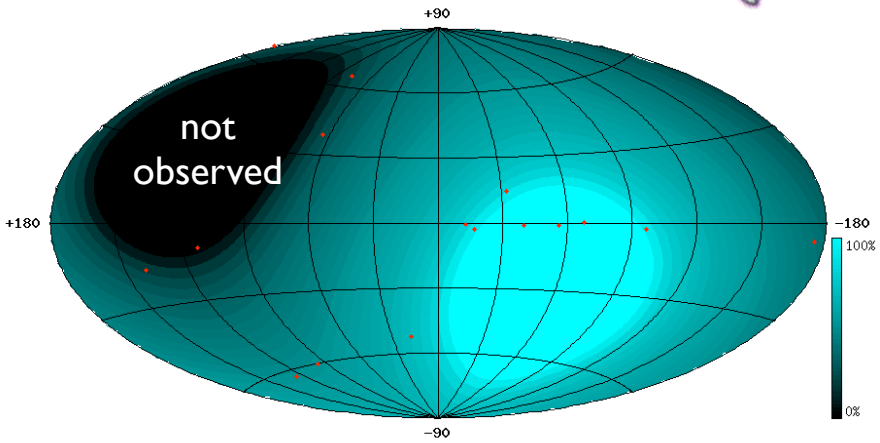
- ISS, Bucarest

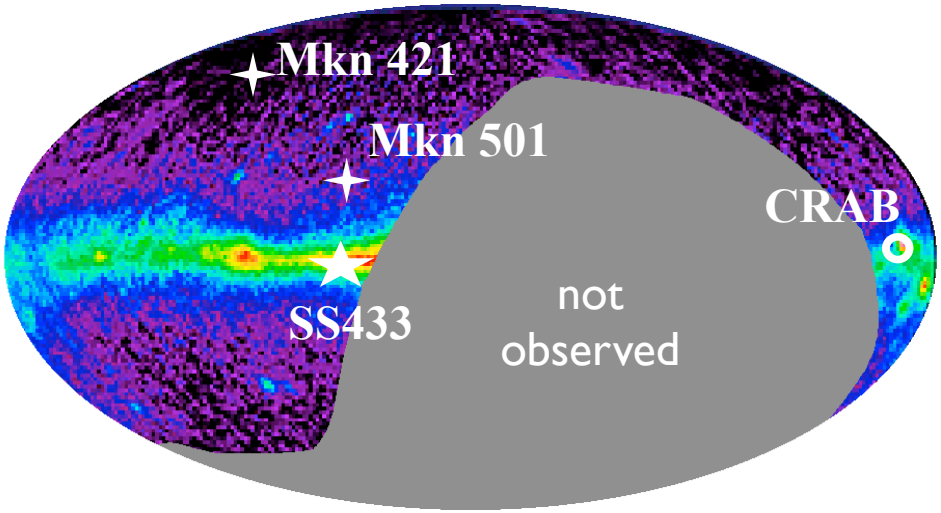
Region of Sky Observable by Neutrino Telescopes

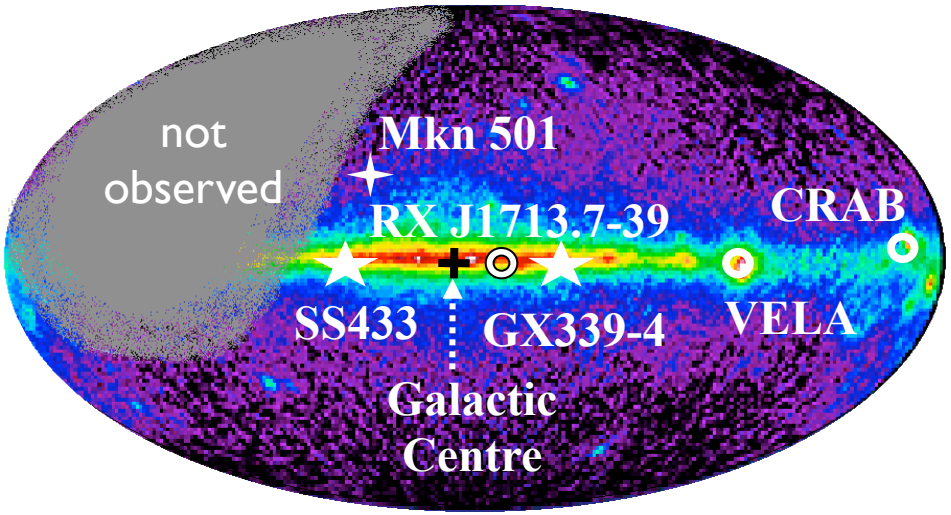
AMANDA/IceCube (South Pole) **ANTARES/KM3** (43° North)

(Ice: ~2°/0.6°) Angular resolution (water: ~0.2°/0.1°)







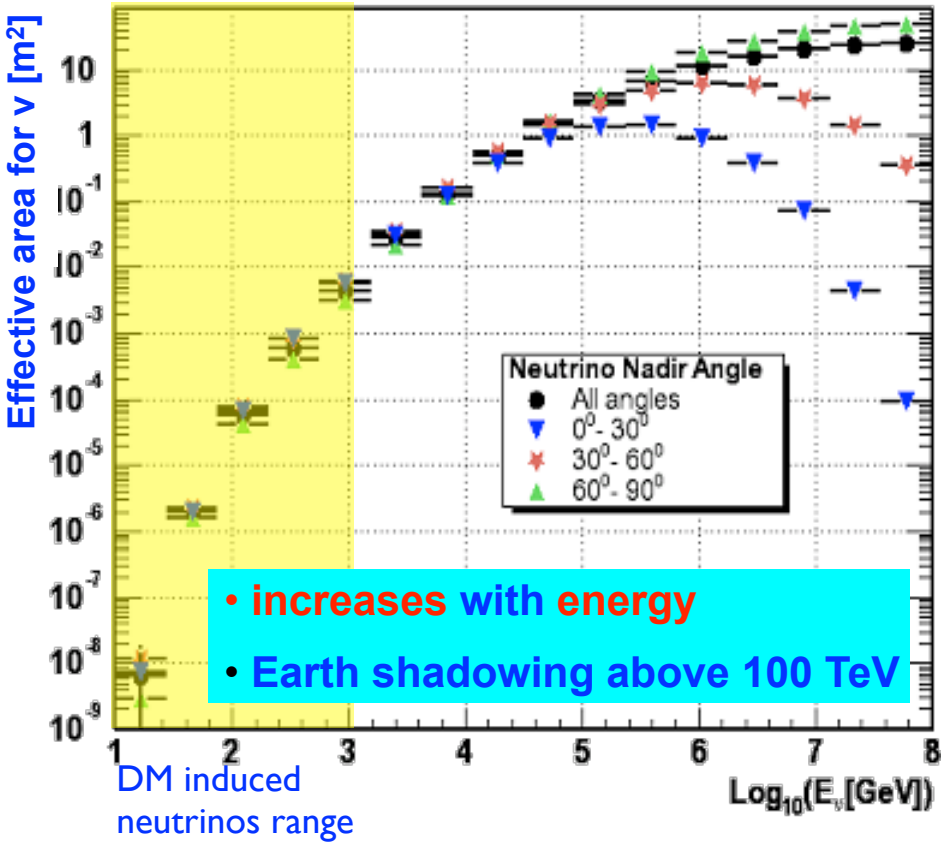


Galactic centre: not seen

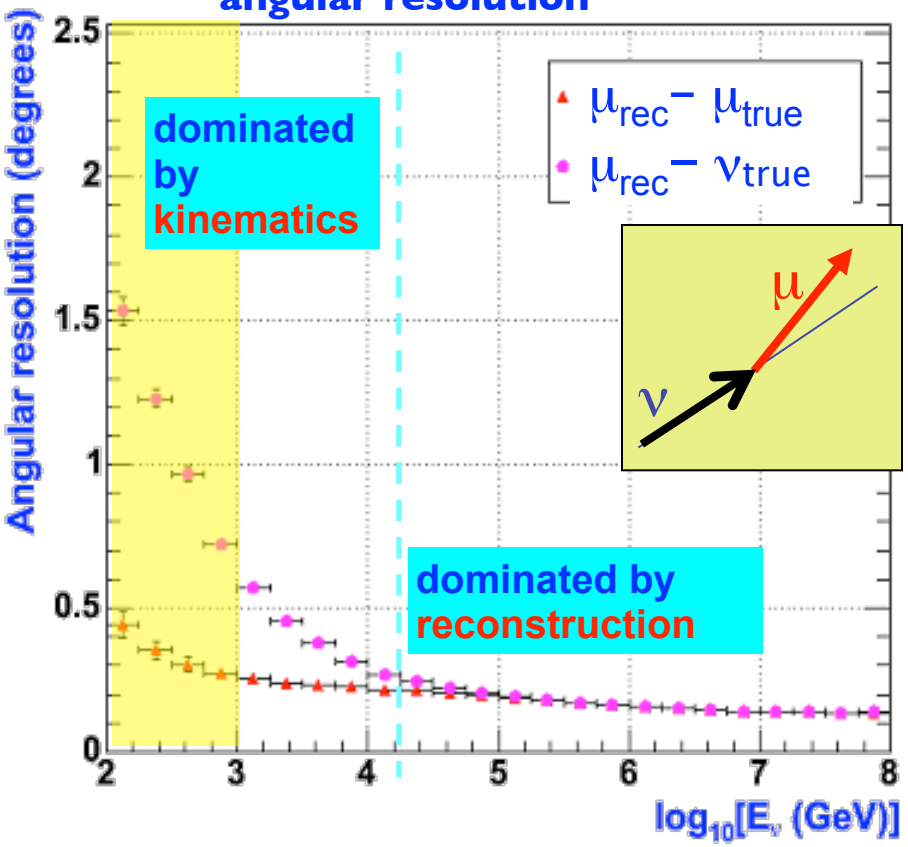
galactic centre: 2/3 of the time

Expected performance (MC Studies)

neutrino effective area



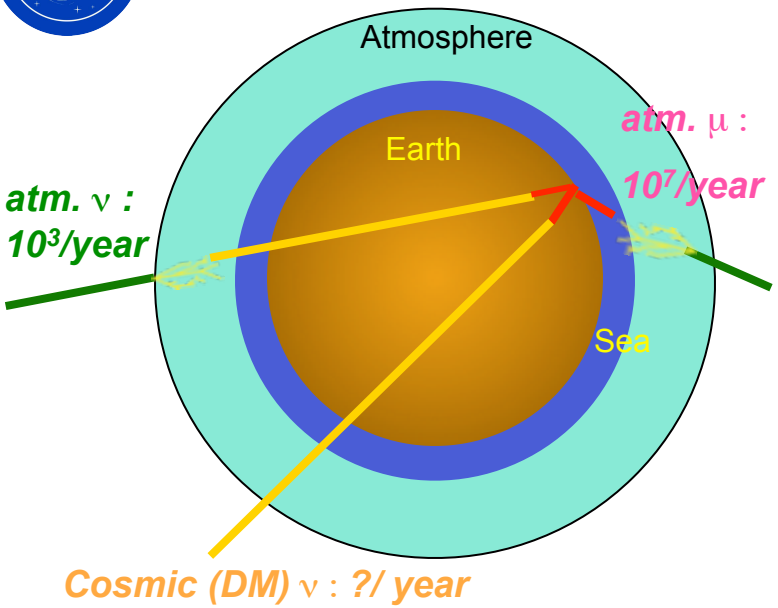
angular resolution

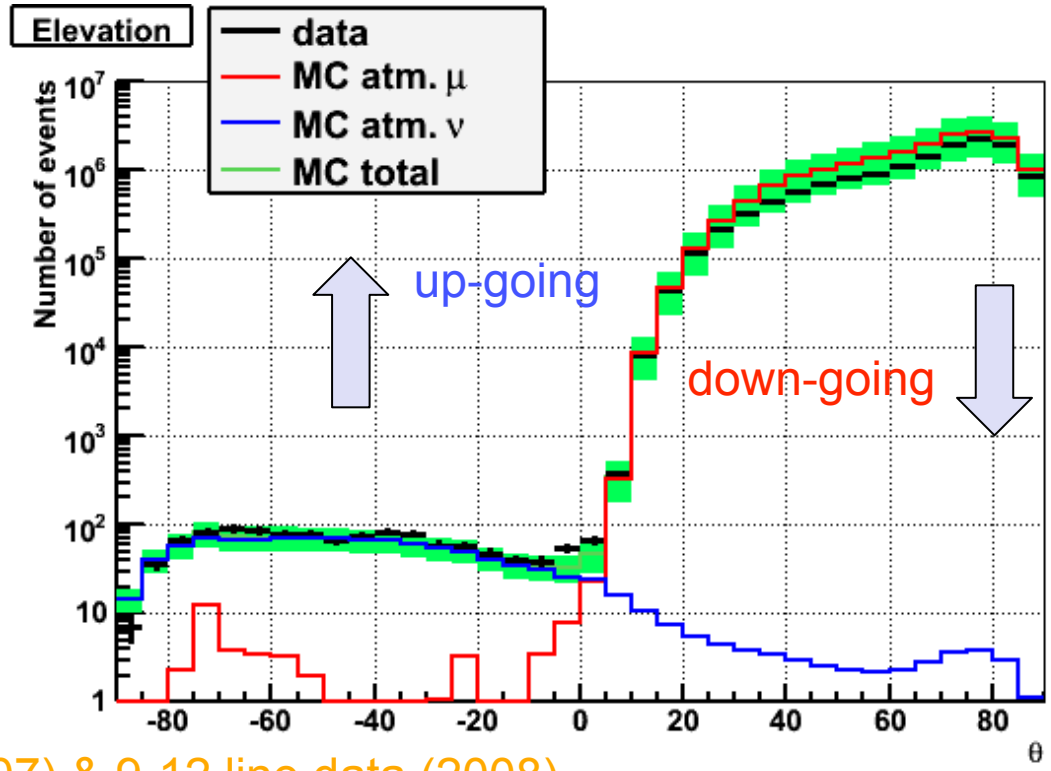


Angular resolution better than 0.3° above a few TeV, limited by:

- ✤ Light scattering + chromatic dispersion in sea water: $\sigma \sim 1.0$ ns
- ✤ Transit Timing Spread in photomultipliers: $\sigma \sim 1.3$ ns
- ✤ Electronics + time calibration: $\sigma < 0.5$ ns
- ✤ OM position reconstruction: $\sigma < 10$ cm ($\leftrightarrow \sigma < 0.5$ ns)

Atmospheric neutrinos with ANTARES





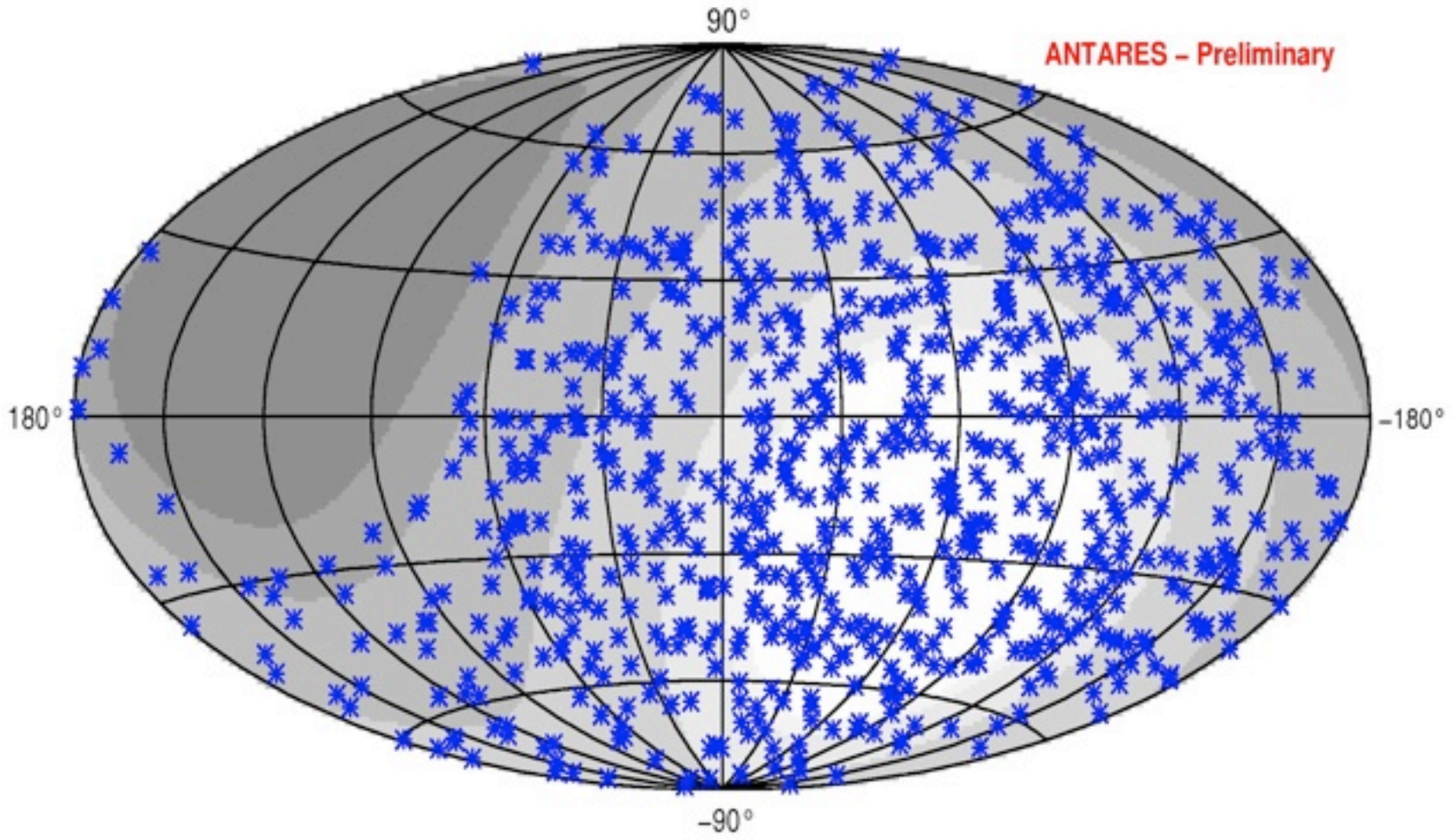
1062 ν candidates: 3.1ν cand./day

5-line data (May-Dec. 2007) & 9-12 line data (2008)

341 days detector live time, single- and multi-line fit:

good agreement with **Monte Carlo**:
atmospheric neutrinos: 916 (30% syst. error)
atmospheric muons:40 (50% syst. error)

Sky map of neutrinos events (blinded)



750 (multiline) upgoing neutrinos: scrambled 2007+2008 data

Neutralino annihilations in the Sun in CMSSM

Study of **neutralino DM** sensitivity within SUSY CMSSM framework

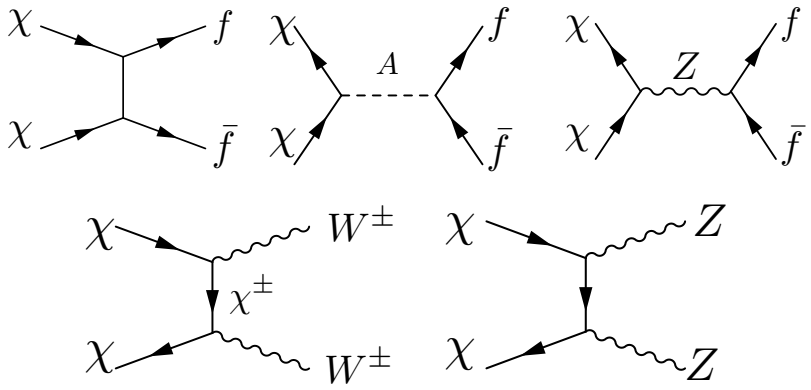
Random scan within CMSSM parameter space

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

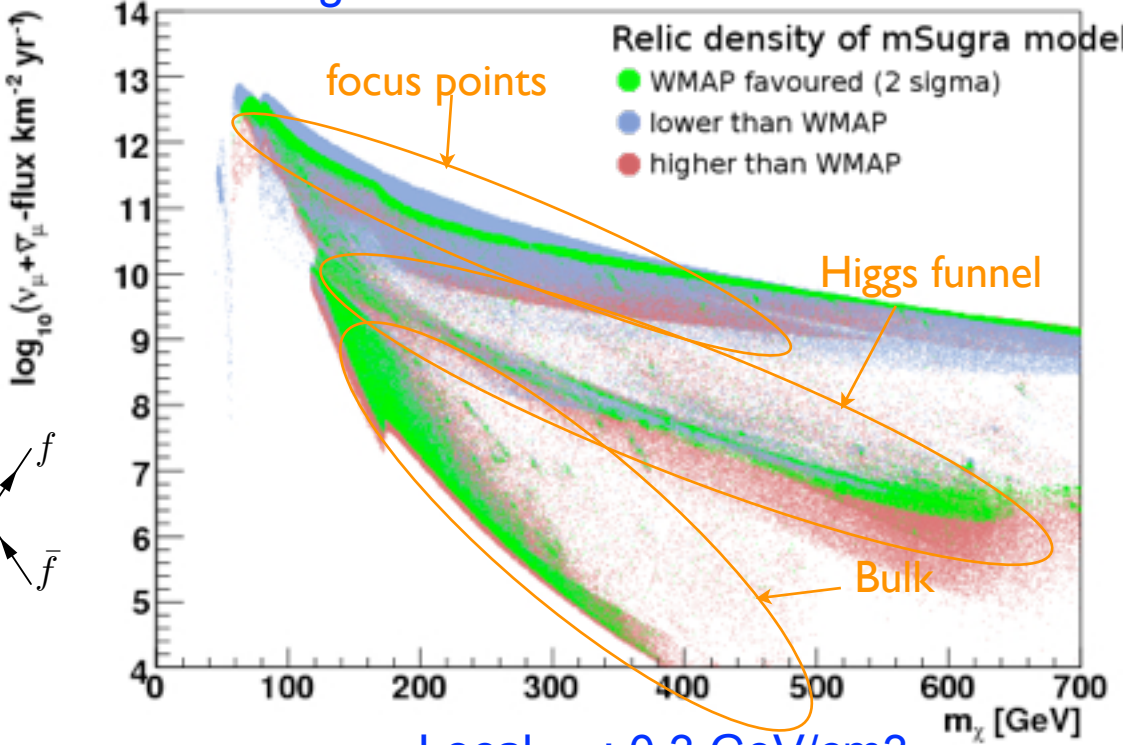
$0 < m_0 < 8000$ GeV

$0 < \tan\beta < 60$

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



Integrated neutrino flux for Eν > 10 GeV



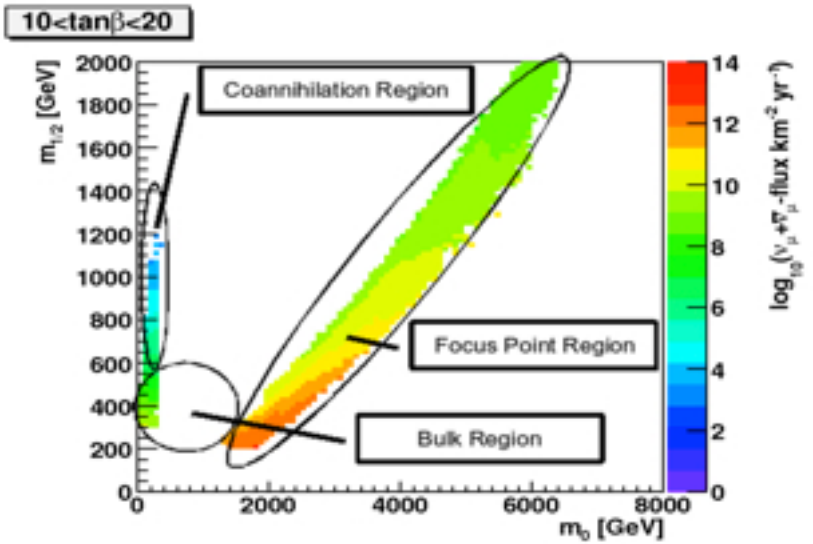
Local ρ_χ : 0.3 GeV/cm3

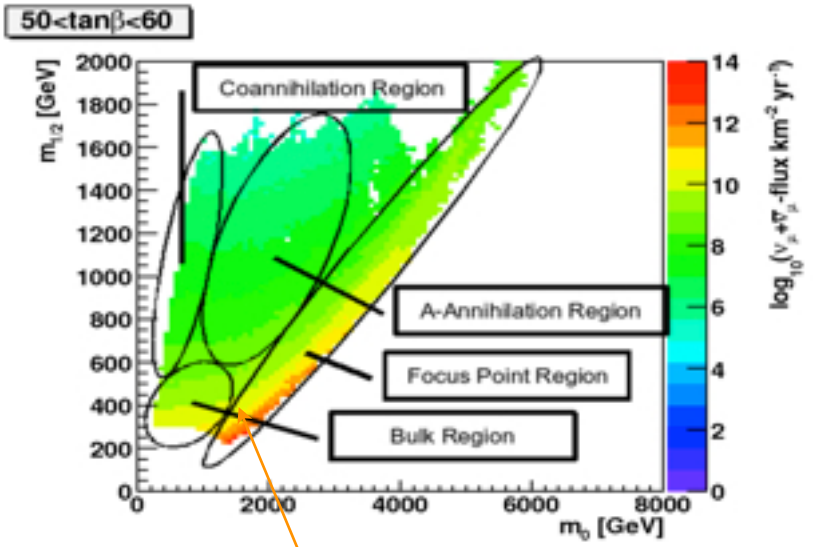
$\langle v_\chi \rangle$ = 220 km/s

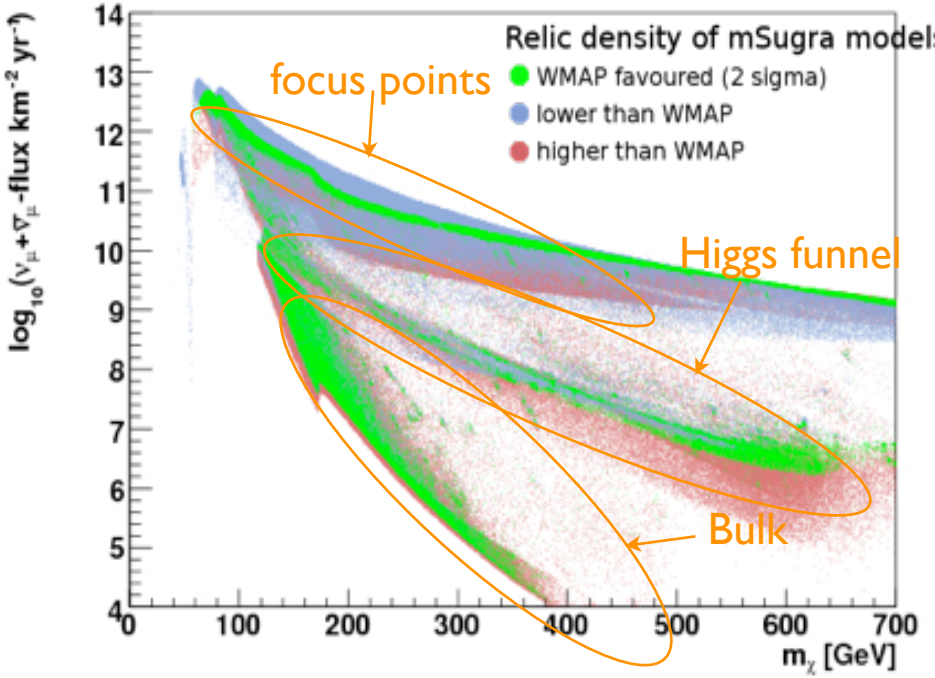
DarkSUSY & ISASUGRA (RGE code)

w/ m_{top} = 172.5 GeV/c² Including ν oscillation effects in the Sun and in vacuum

Neutralino annihilations in the Sun in CMSSM







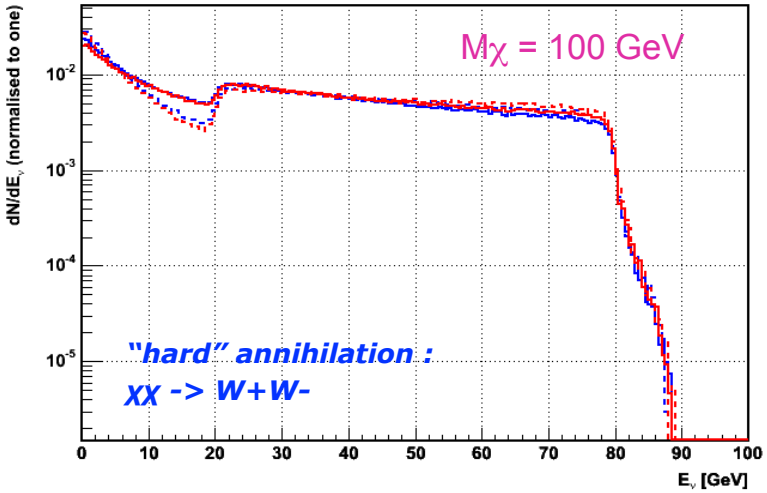
Higgsino fraction of χ is relatively large then χχ-> ***WW/ZZ*** dominates

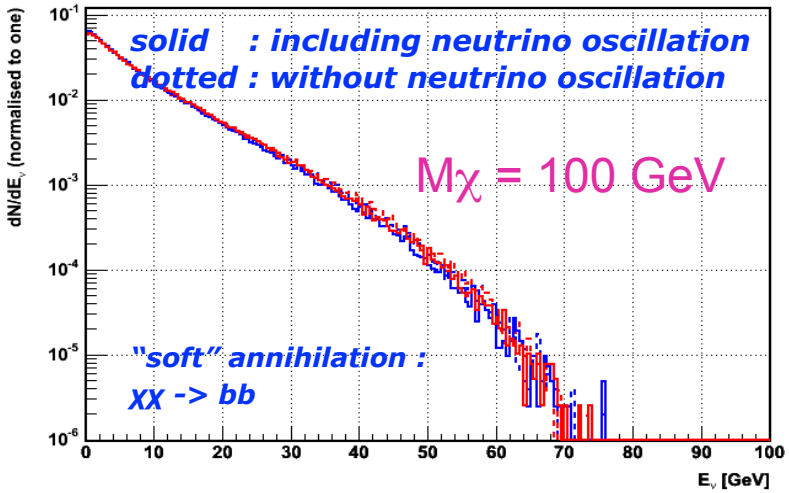
Neutrino spectra from neutralino annihilations

"hard" annihilation : χχ -> W+W-

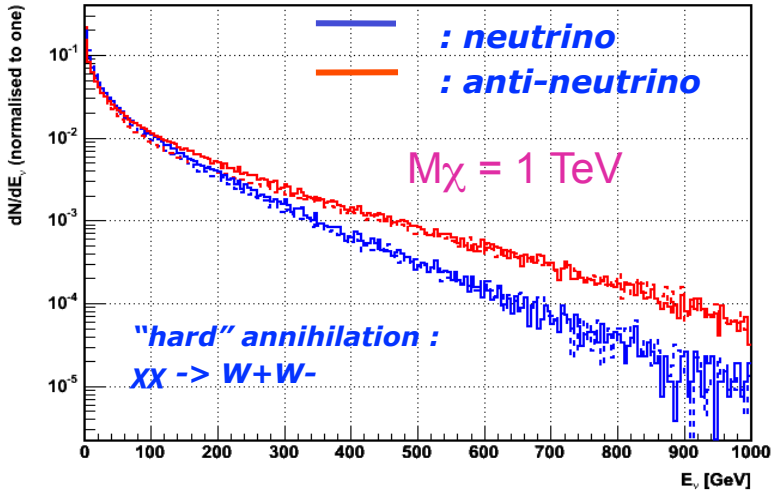
"soft" annihilation : χχ -> bb

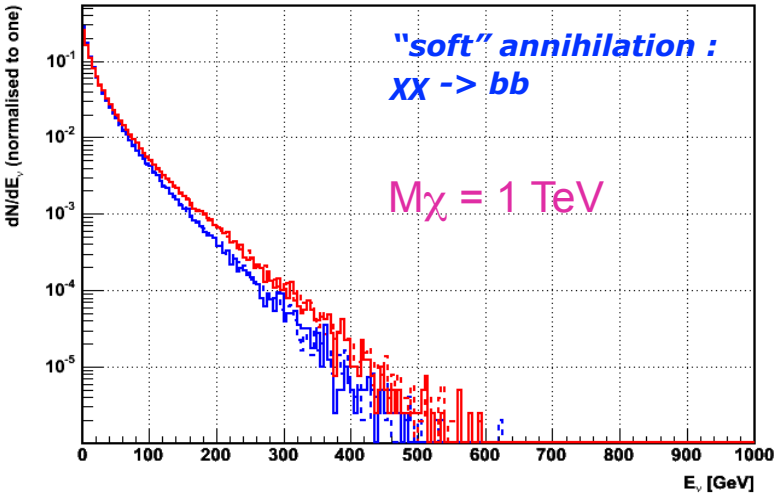
Mχ = 100 GeV





Mχ = 1 TeV





Neutrinos from χχ → WW (hard spectrum) are more energetic and easier to detect

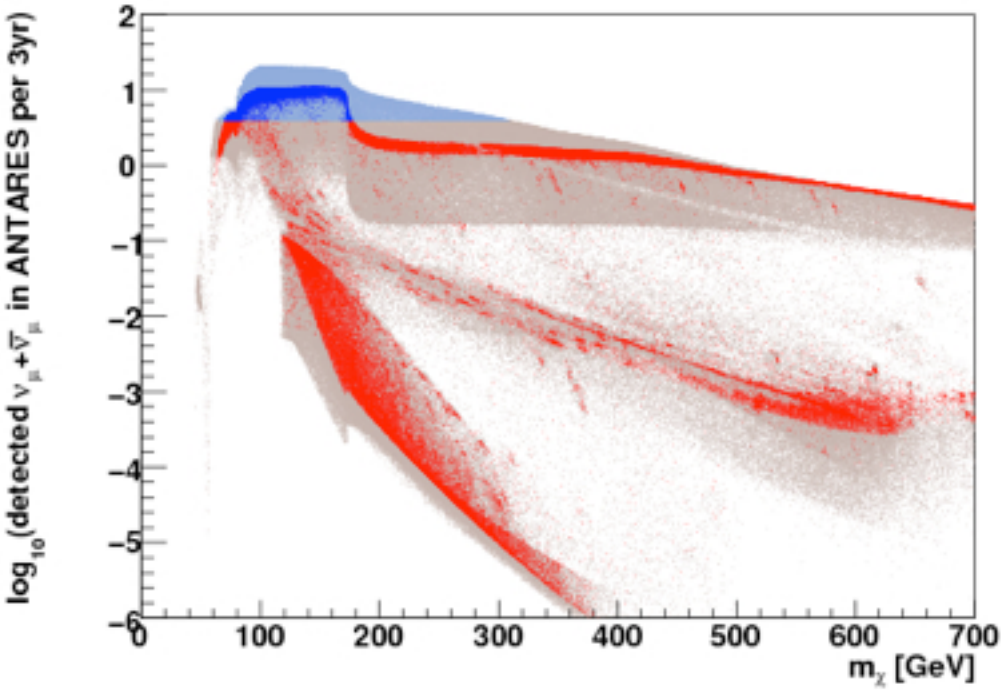
Neutralino annihilations in the Sun in CMSSM

Detection rate with ANTARES in 3 years

Detection rate (t) =
$\nu_\mu + \bar{\nu}_\mu$ flux (E_ν, θ_ν, t) ·
Effective Area (E_ν, θ_ν) ·
Sun's θ_ν distribution

Sensitivity calculated for 3 years of data taking

"Excludable" =
Signal is distinguishable from the background at 90% C.L. (Feldman-Cousins scheme)

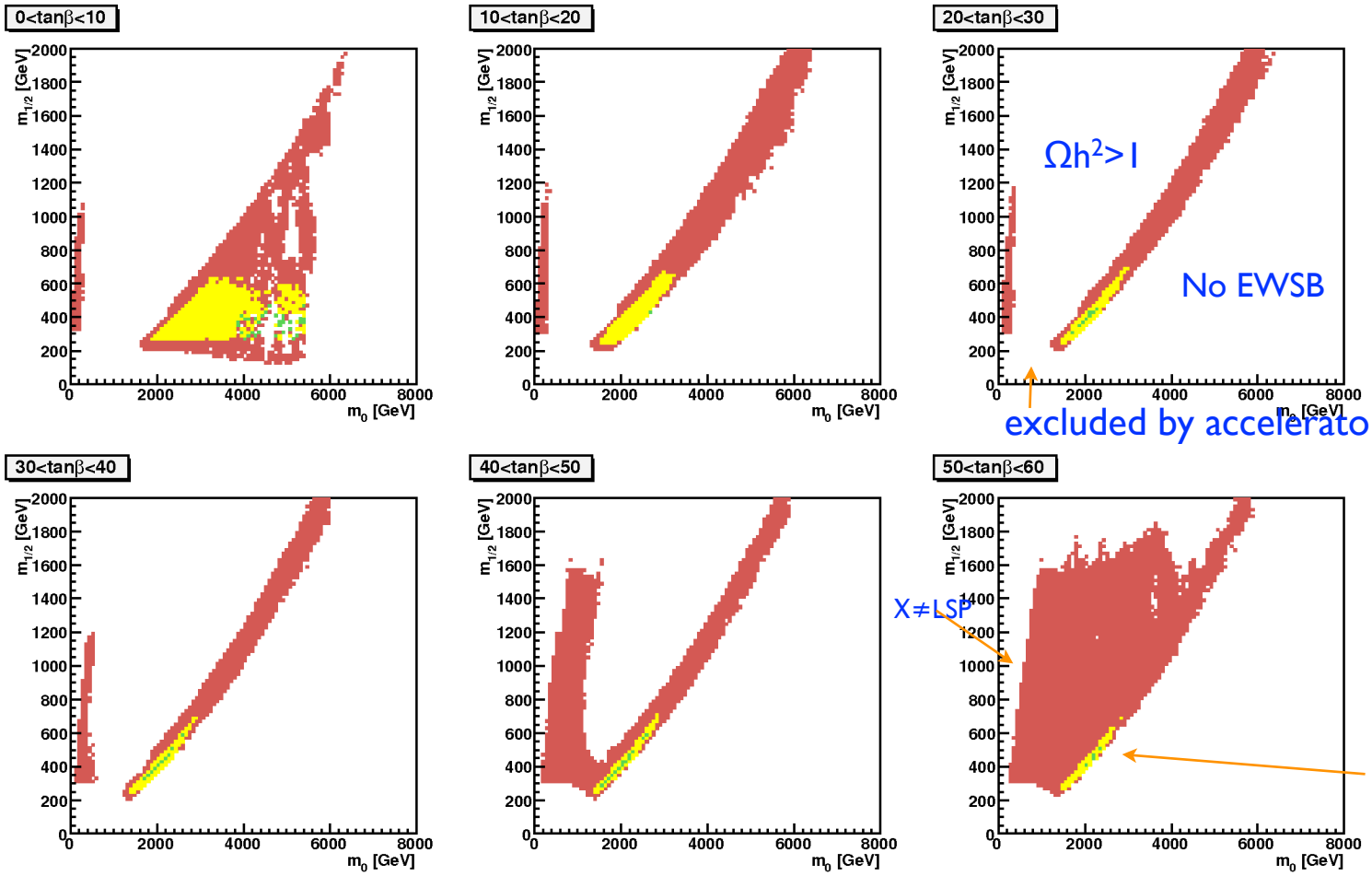


Background from atmospheric neutrinos and misreconstructed atmospheric muons within 3° radius search cone around the Sun

Model with relic density **within 2σ** of WMAP constraint are **highlighted** ($0.094 < \Omega_\chi h^2 < 0.129$)

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)

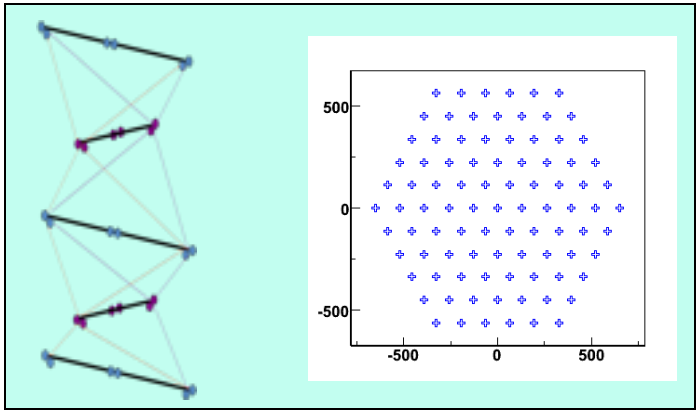
Muon flux from Neutralino annihilations in the Sun

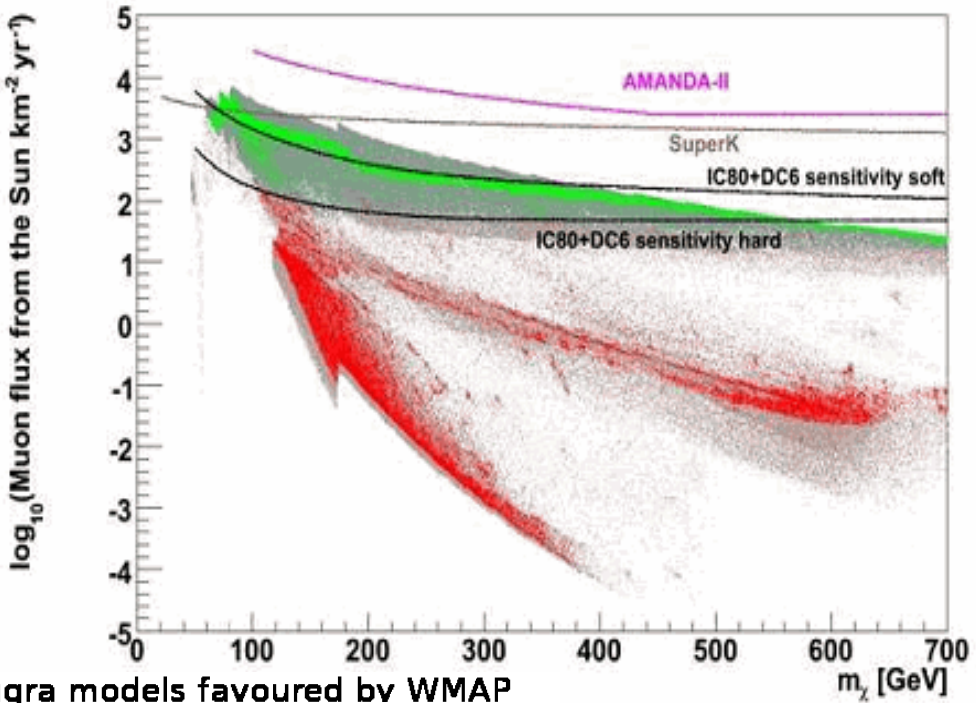
Muon flux from the Sun in CMSSM (E_μ > 1 GeV)

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

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

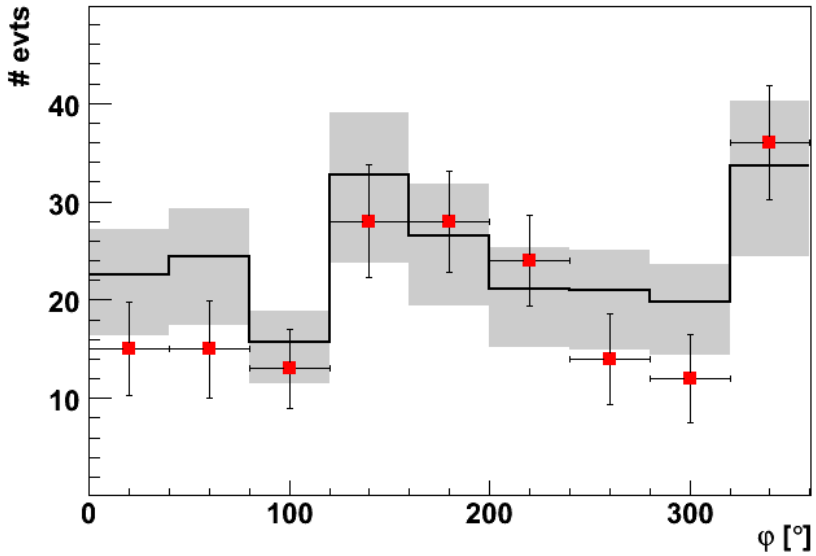
TDR KM3Net optimized for High Energy ν
➙New Studies are on the way.

Analysis of the ANTARES 5-line data sample

~200 reconstructed neutrinos events
in 167 days of effective lifetime

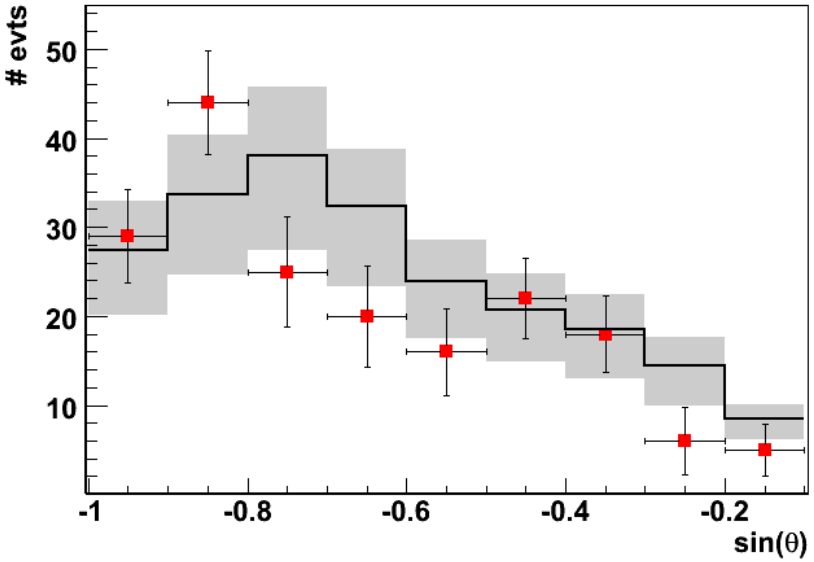
Azimuth Angle Distribution

Detector acceptance not uniform
due to line distribution on sea floor



Zenith Angle Distribution

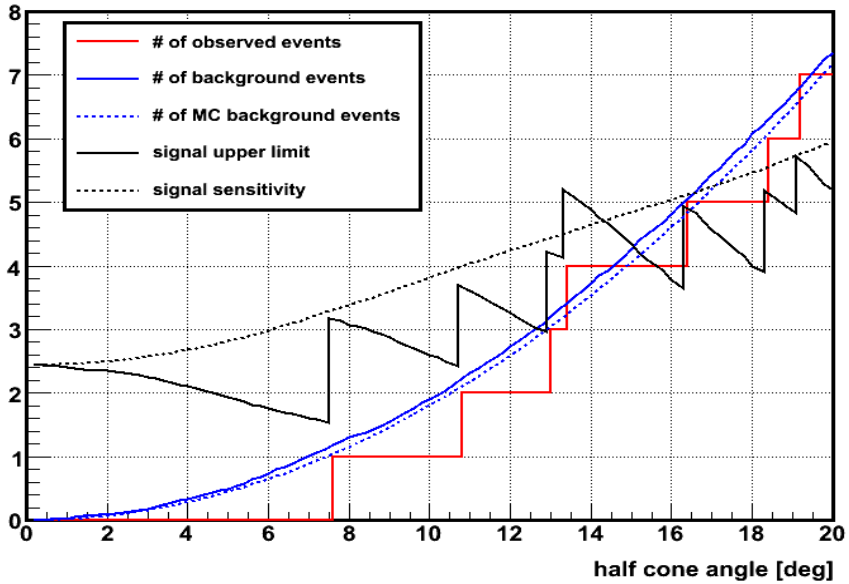
upgoing events only



- Data — MC possible MC systematic errors from alignment resolution, uncertainty of PMT angular acceptance and efficiency, charge calibration

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



RED # of observed events inside the search cone around the Sun

BLUE SOLID # of background events. background estimated by scrambling the direction and the time of all observed events

BLUE DASHED # of background event corresponding to the total atmosph. $\nu_\mu + \bar{\nu}_\mu$ flux (Honda parameterisation) during data taking

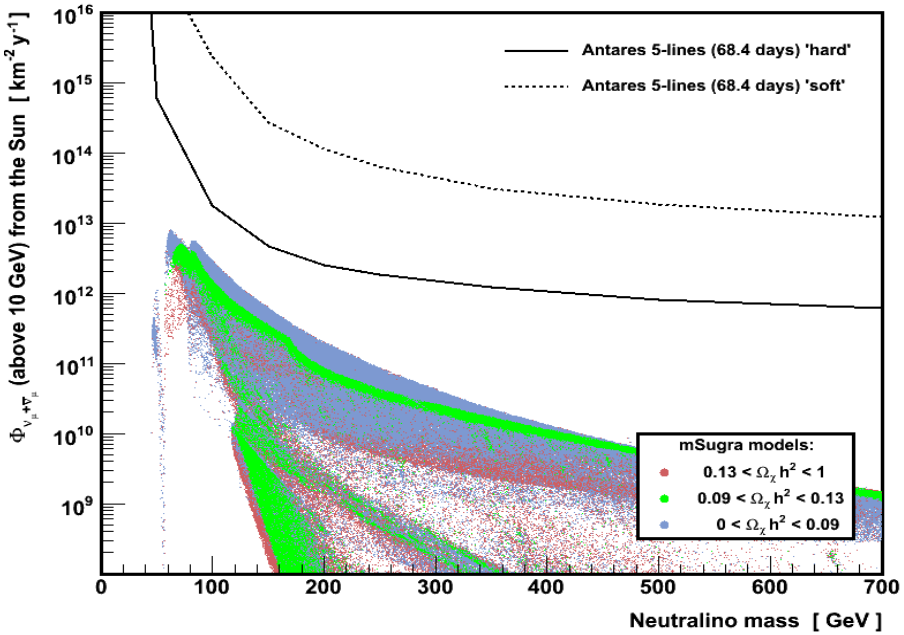
BLACK SOLID Upper limit @ 90% C.L. on the # of signal events inside the search cone around the Sun, assuming Poissonian statistics according to the Feldman-Cousins unified approach

BLACK DASHED "Expected" upper limit (or "sensitivity") @ 90% C.L. on the # of signal events inside the search cone around the Sun, assuming Poissonian statistics according to the Feldman-Cousins unified approach

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

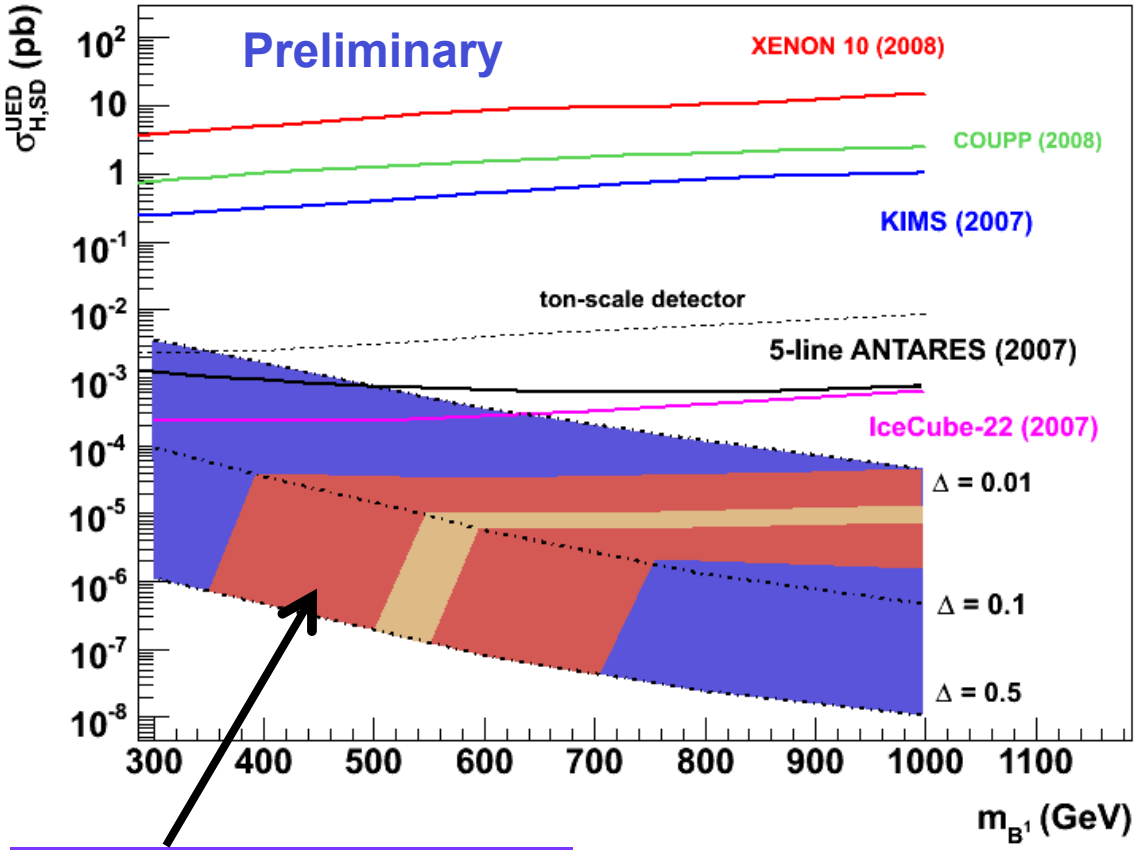
first limit: based on data with ~ ½ of ANTARES detector within 6 months

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



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 Lightest Kaluza-Klein Particule 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

$\Delta = (M_{NLKP} - M_{LKP}) / M_{LKP}$

Summary

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
- Sensitivity to other SUSY models (pMSSM, AMSB,…) or DM candidates is being studied (KK excitations,…)
- Search towards Sun, Galactic Centre and Earth are in progress with 2008 data
- More than 2000 neutrinos already collected !

Stay tuned


ANTARES

$$\frac{dN_{\text{observed}}}{dt} = \iint A^{\nu}_{eff}(E_\nu, \Omega) \frac{d\Phi(E_\nu, \Omega)}{dE_\nu \, d\Omega} \, dE_\nu \, d\Omega$$

what we are measuring

what we are looking for

$$A^{\nu}_{eff}(E_\nu, \Omega) = V_{eff}(E_\nu, \Omega) \, \sigma(E_\nu) \, \rho N_A \, P_{\text{Earth}}(E_\nu, \Omega)$$

where

$\sigma(E_\nu)$: the neutrino interaction cross-section

ρN_A : the nucleon density in/near ANTARES

$P_{\text{Earth}}(E_\nu, \Omega)$: the neutrino transmission probability through the Earth

$V_{eff}(E_\nu, \Omega)$: ***the Effective Volume***, a detector dependent quantity that represents the sensitive volume of ANTARES

intrumental characteristics
detector geometry
trigger efficiency
reconstruction efficiency
event selection efficiency