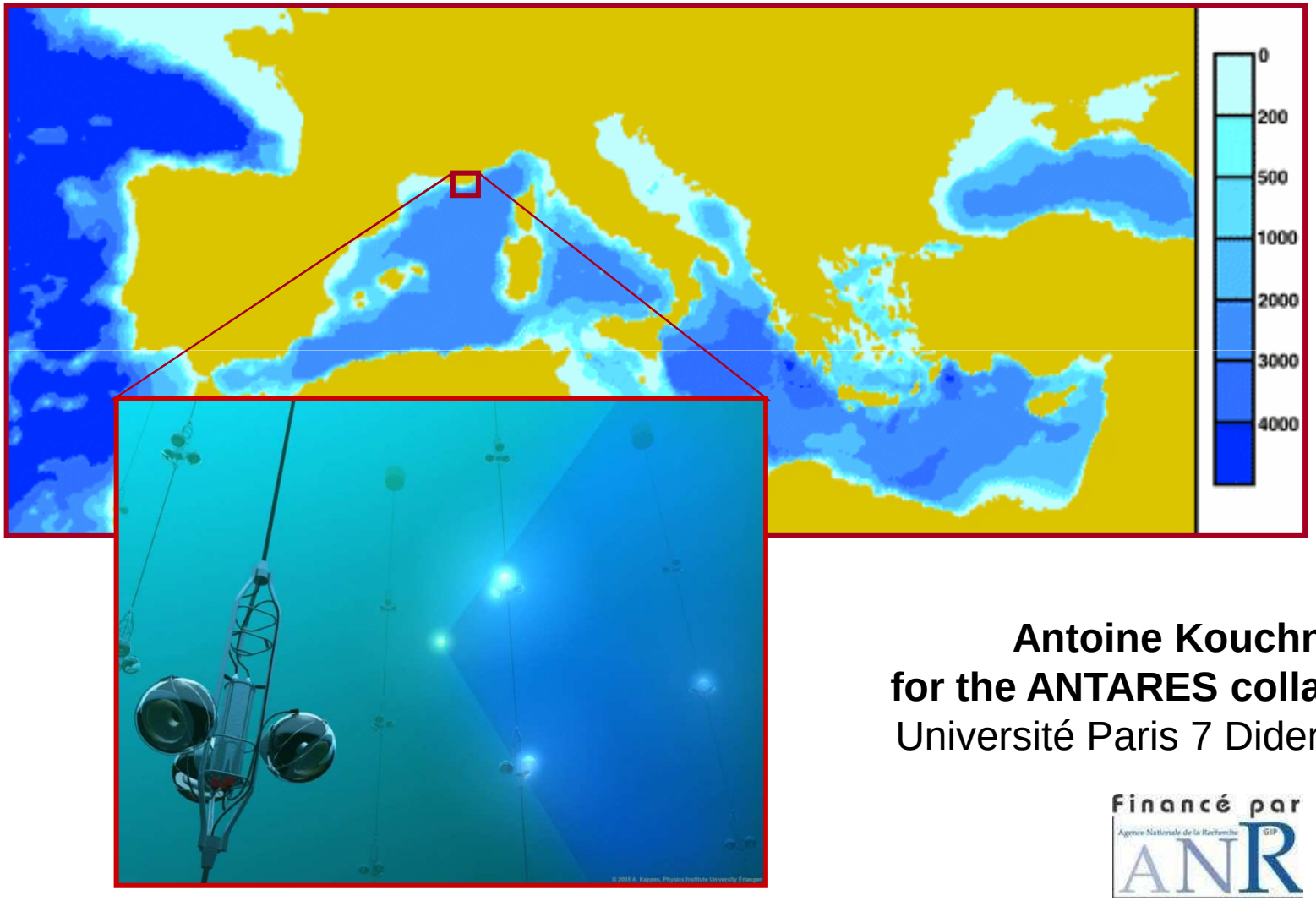
The first neutrino telescope in operation in the Mediterranean

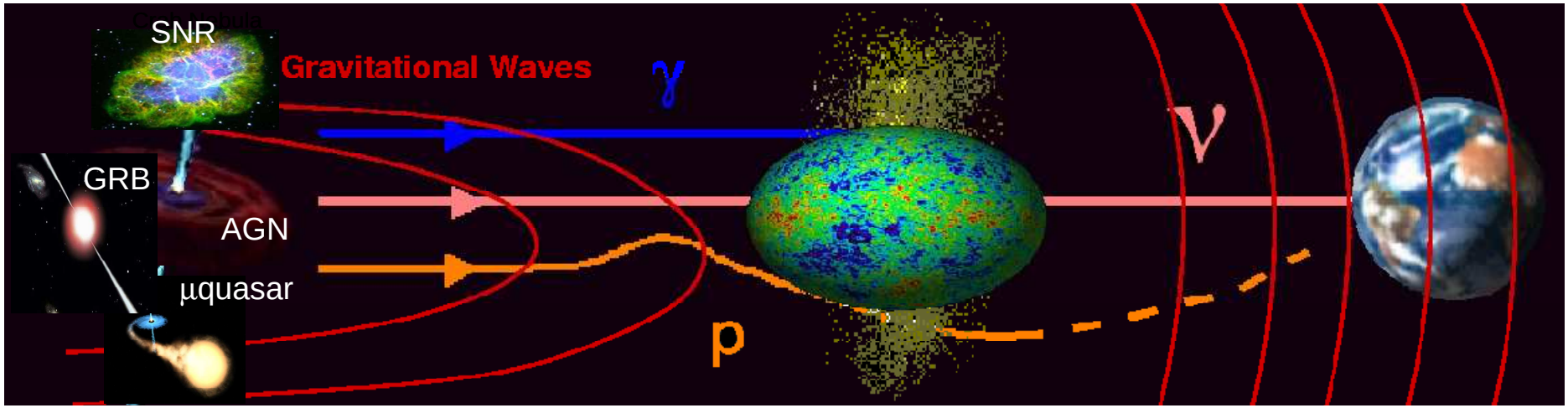
ANTARES : status report



Antoine Kouchner
for the ANTARES collaboration
Université Paris 7 Diderot – APC

Financé par ANR

Research goals



❖ Search for high-energy neutrinos as cosmic messengers :

➢ Production by cosmic ray interactions: $p+A/\gamma \rightarrow$ mesons $\rightarrow \nu, \gamma$

$\rightarrow$ trace hadronic processes

➢ Decay of heavy particle or DM (WIMP) annihilation: DM + DM $\rightarrow$ (…$\rightarrow$) ν, γ

➢ No absorption, Weakly interacting $\rightarrow$ cosmological distances & dense objects

➢ No deflection by B $\rightarrow$ pointing accuracy

In this talk

❖ Particle physic and exotic phenomena (oscillations, monopoles, nuclearites...)

❖ Interdisciplinary Deep Sea Studies (oceanography, sea biology, seismology...)

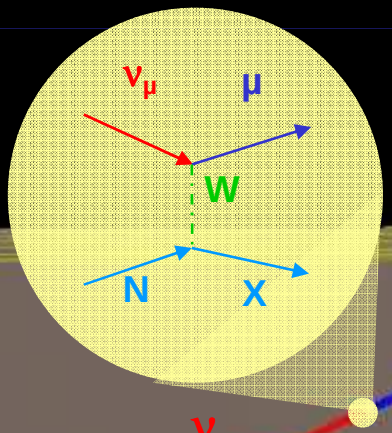
Detection principle

μ well suited for HE detection

Both range and cross-section increase with energy

☞ Large effective volume

Detection of Cherenkov light emitted by muons with a 3D lattice of PMT



Cherenkov cone

42°

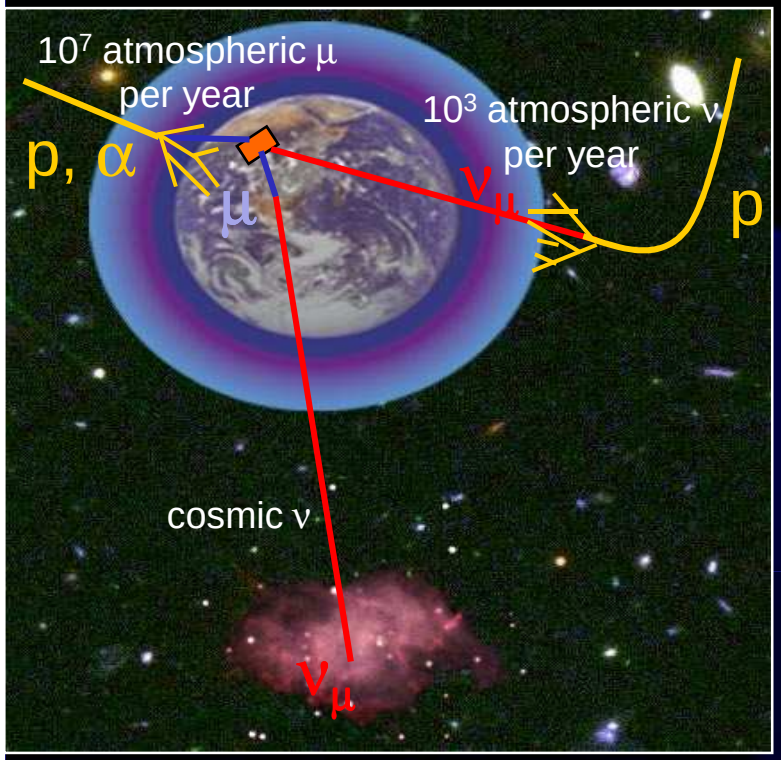
Detection lines

© François Montanet

Time, position, amplitude of PMT pulses ⇒ μ trajectory (~ ν < 0,5 °)

Requires a large dark transparent detection medium

Detection principle



Cherenkov cone

42°

Detection lines

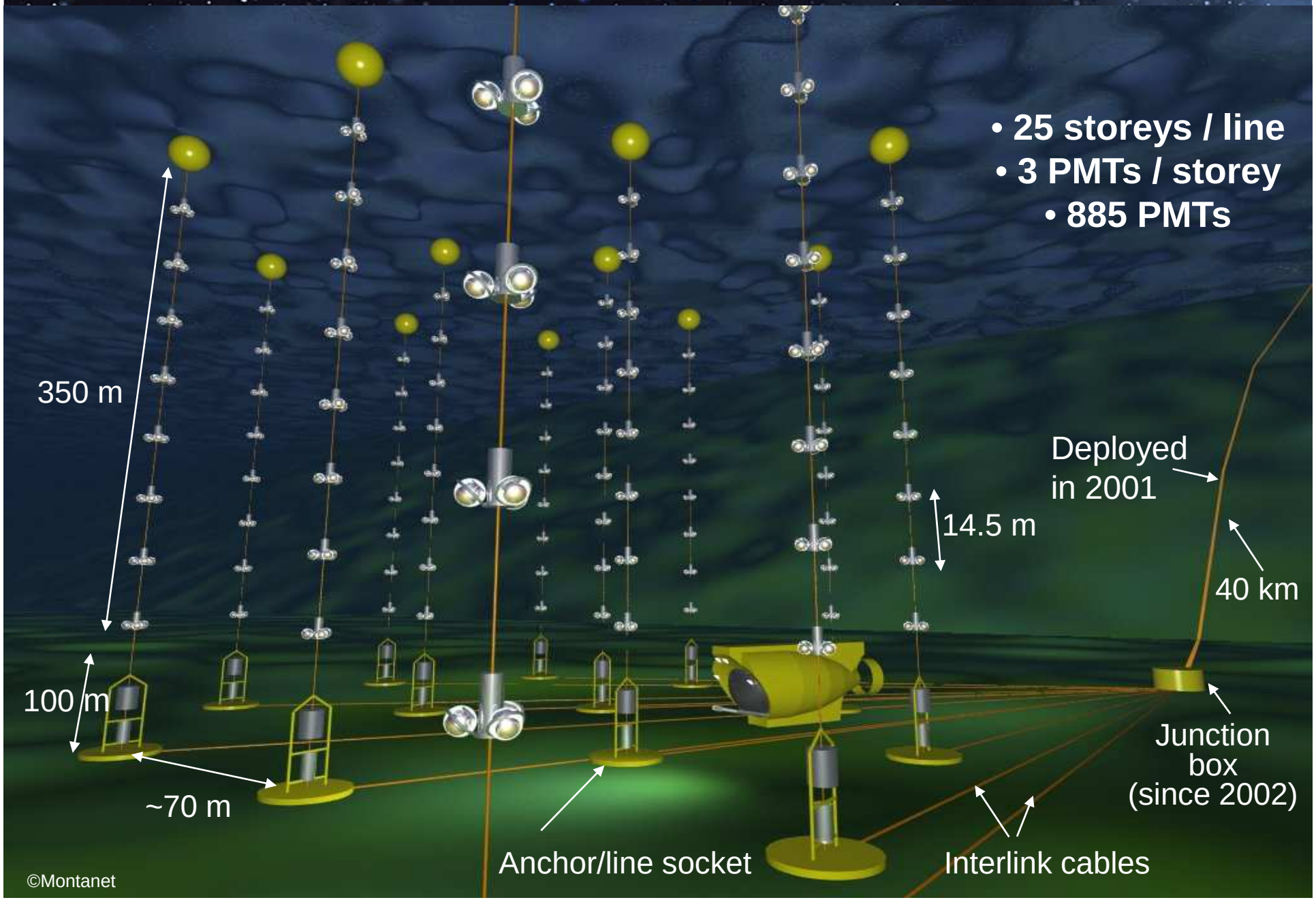
© François Montanet

ν_μ → μ

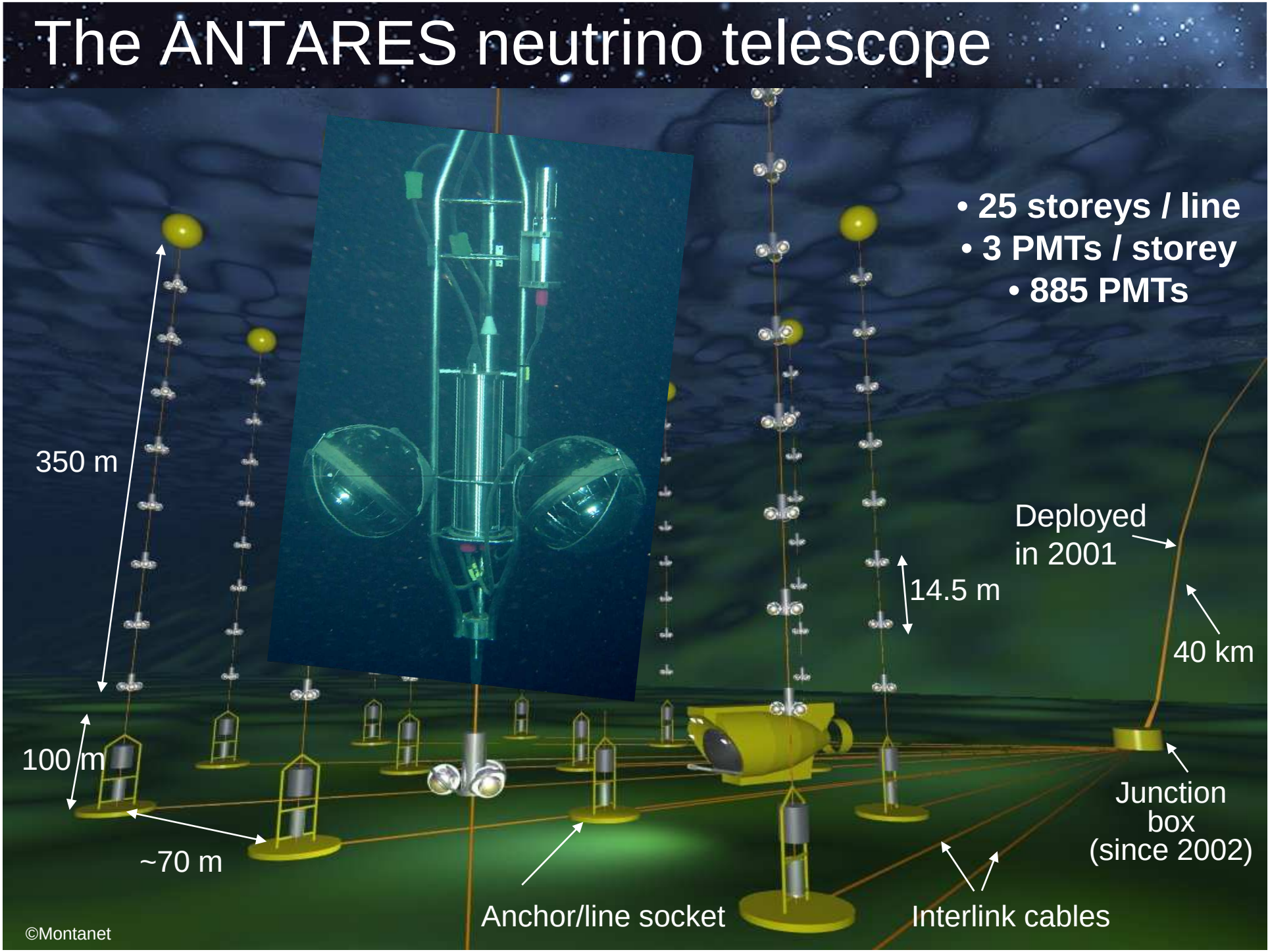
Intense background
→ deep ice/water shielding
Signal = upward going muon

Requires a large dark transparent detection medium

The ANTARES neutrino telescope

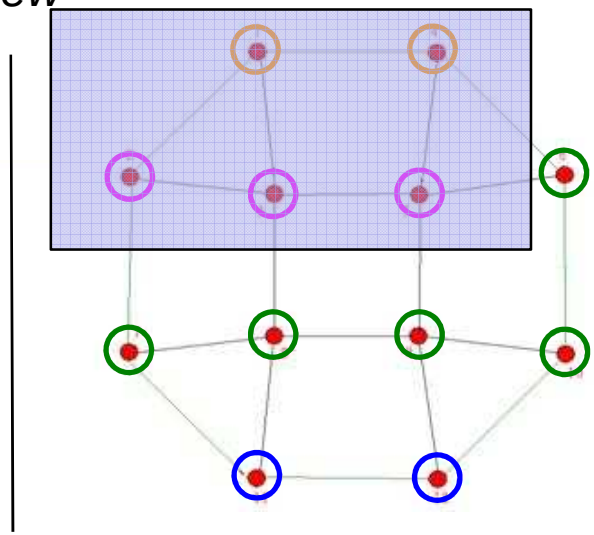


The ANTARES neutrino telescope



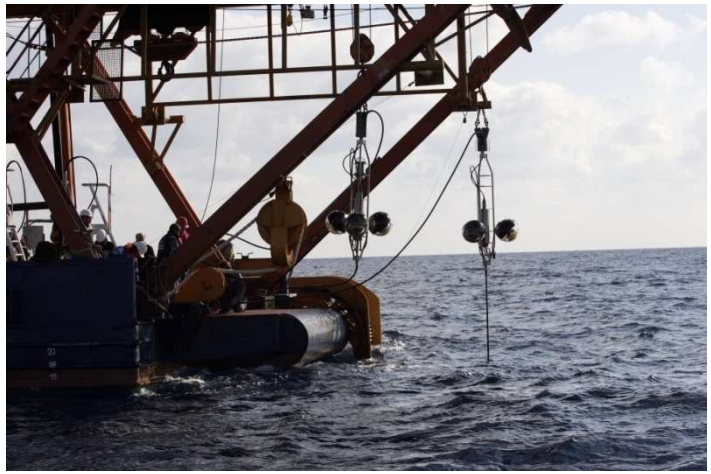
2006-2008: construction phases

Top view



2007 data taking 5 Line configuration

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



2006-2008: construction phases

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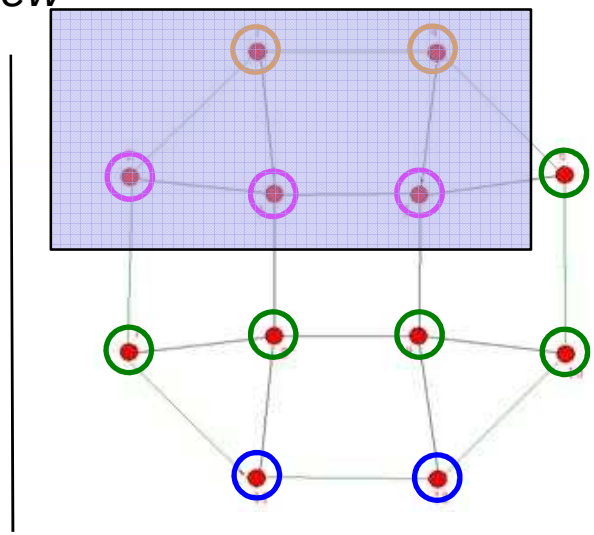
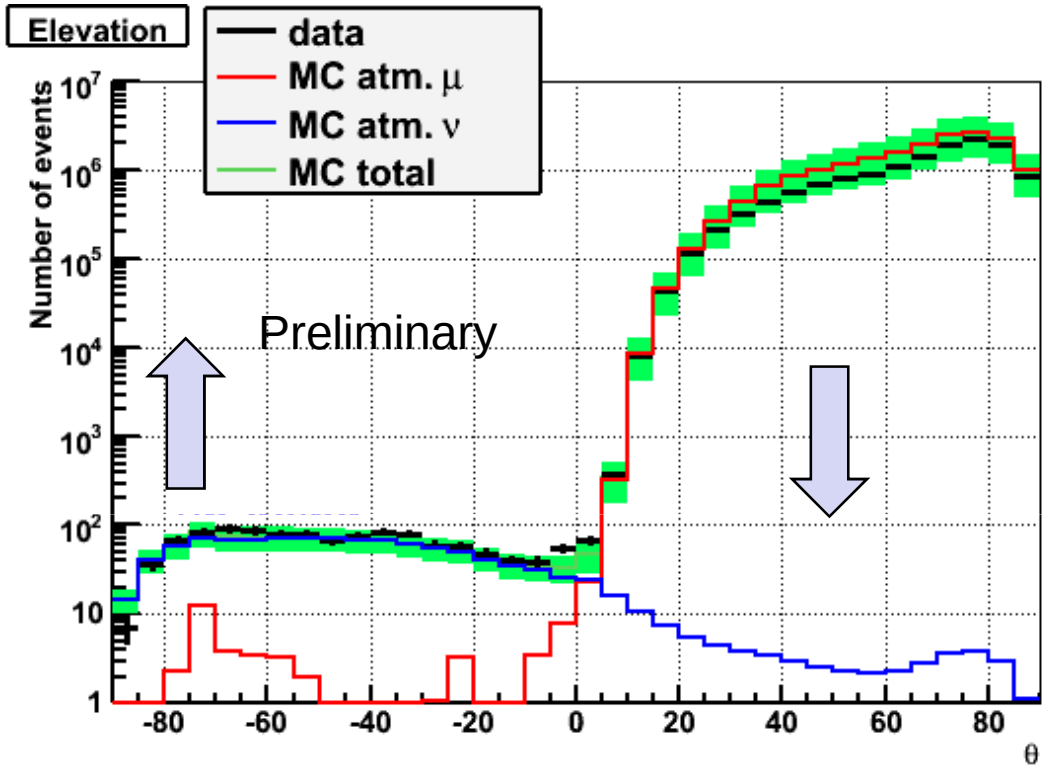


2007 data taking 5 Line configuration

- **Line 1, 2**: 2006
-
-
-
- **Line 11, 12**: 05 / 2008

Detector completed in May 2008

Atmospheric neutrinos



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

341 days detector live time

1062 neutrino candidates:
3.1 ν candidates/day

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

Search for cosmic neutrino sources are ongoing…

Indirect Search for Dark Matter

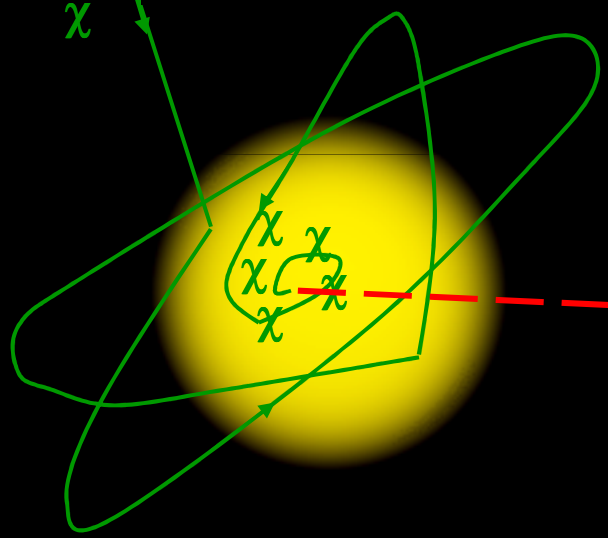
$$\Gamma_{ann} = \frac{\sigma_{ann} v \rho^2}{m^2}$$

Γ_{ann}: annihilation rate per unit volume
σ_{ann}: neutralino-neutralino cross-section
v: relative speed of the annihilating particles
ρ: neutralino mass density
m: neutralino mass

Relic WIMPs χ captured in celestial bodies

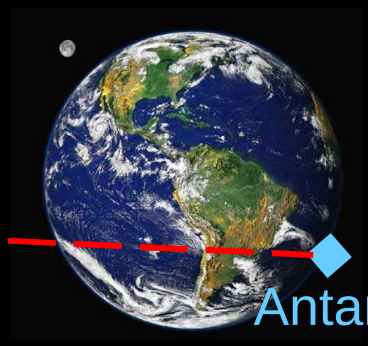
χ

WIMPs gravitationally trapped via elastic collisions in the sun



ν

Earth



Antares

$\langle E_\nu \rangle \sim M_\chi/3$

Potential $\chi\chi \rightarrow \nu$ sources are Sun, Earth & Galactic Centre

$\chi\chi$ self-annihilations can produce significant high-energy neutrino flux

"hard" annihilation : $\chi\chi$-> W+W-

"soft" annihilation : $\chi\chi$-> bb

Neutralino annihilations in the Sun in mSUGRA

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

Random walk scan within

mSUGRA parameter space :

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

$0 < m_0 < 8000$ GeV

$0 < \tan\beta < 60$

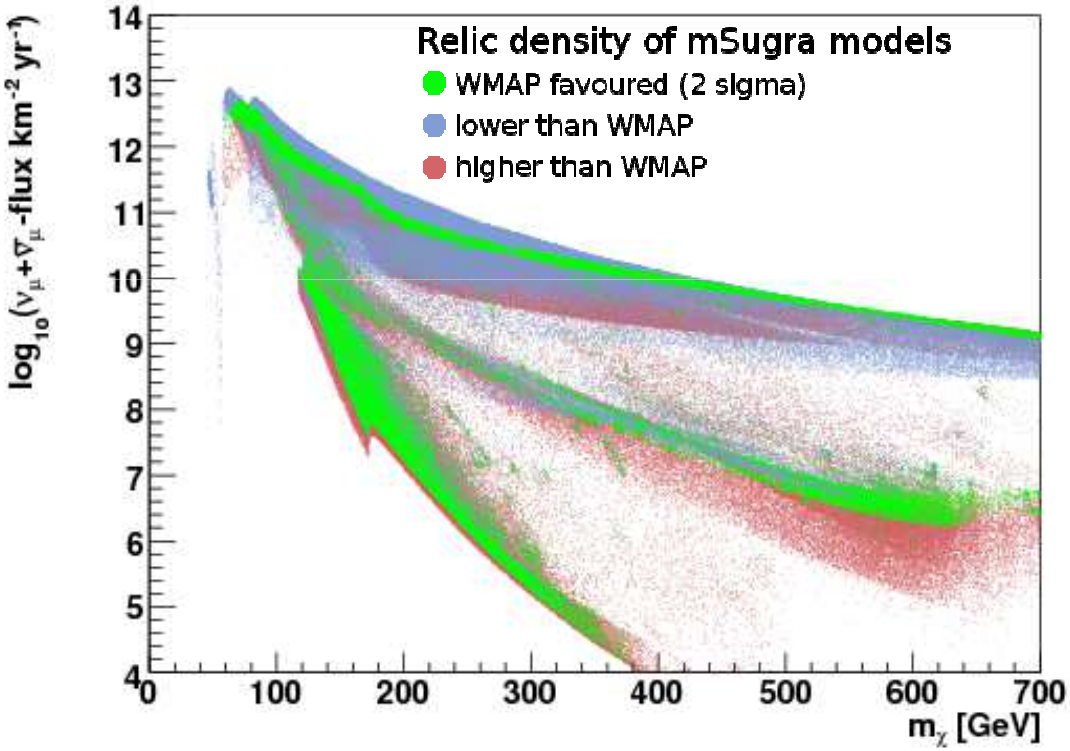
$-3\, m_0 < A_0 < 3\, m_0$

Calculated with DarkSUSY

and ISASUGRA (RGE code) with:

- $m_{top} = 172.5$ GeV
- Local halo density: 0.3 GeV/cm^3
- $<v_\chi> = 270$ km/s

Integrated neutrino flux for Eν > 10 GeV



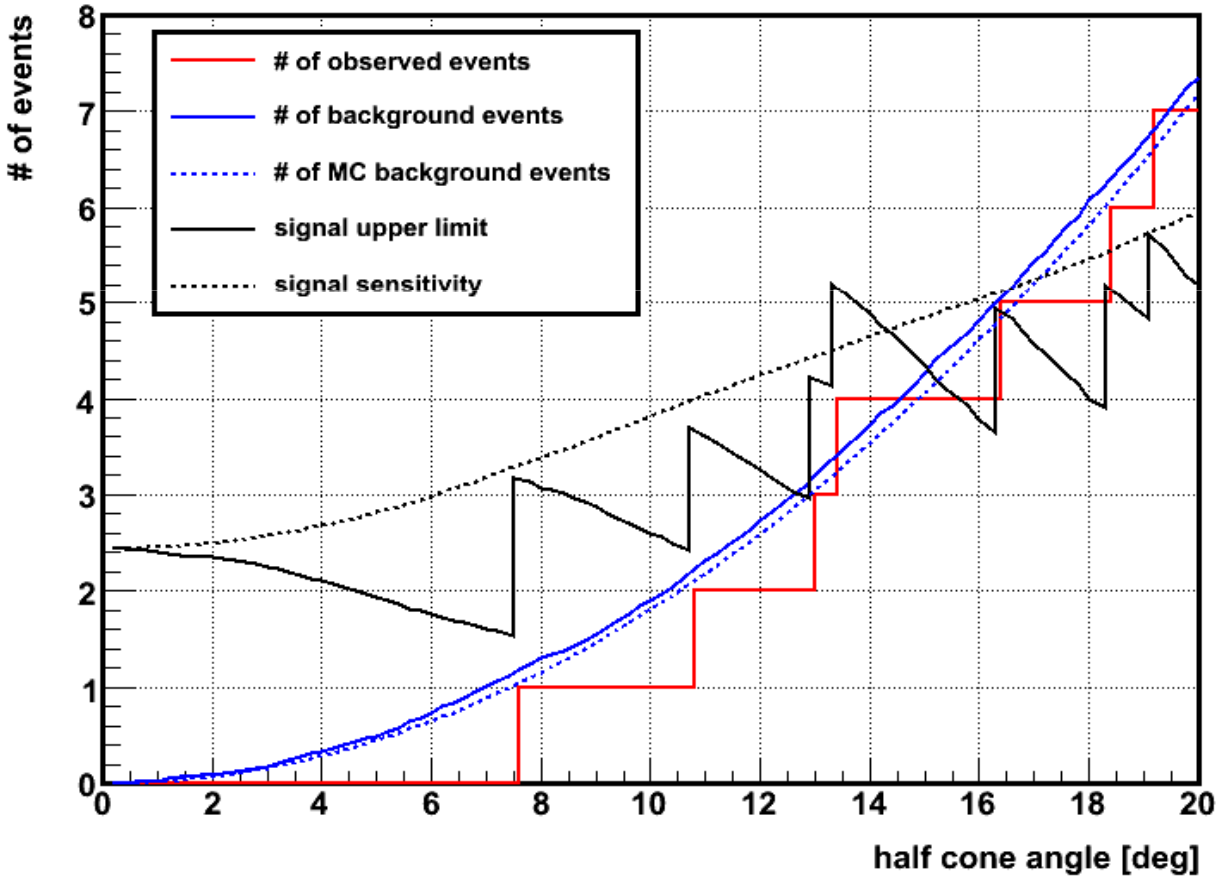
Includes ν oscillation effects in the Sun and in vacuum

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 (68 effective days)

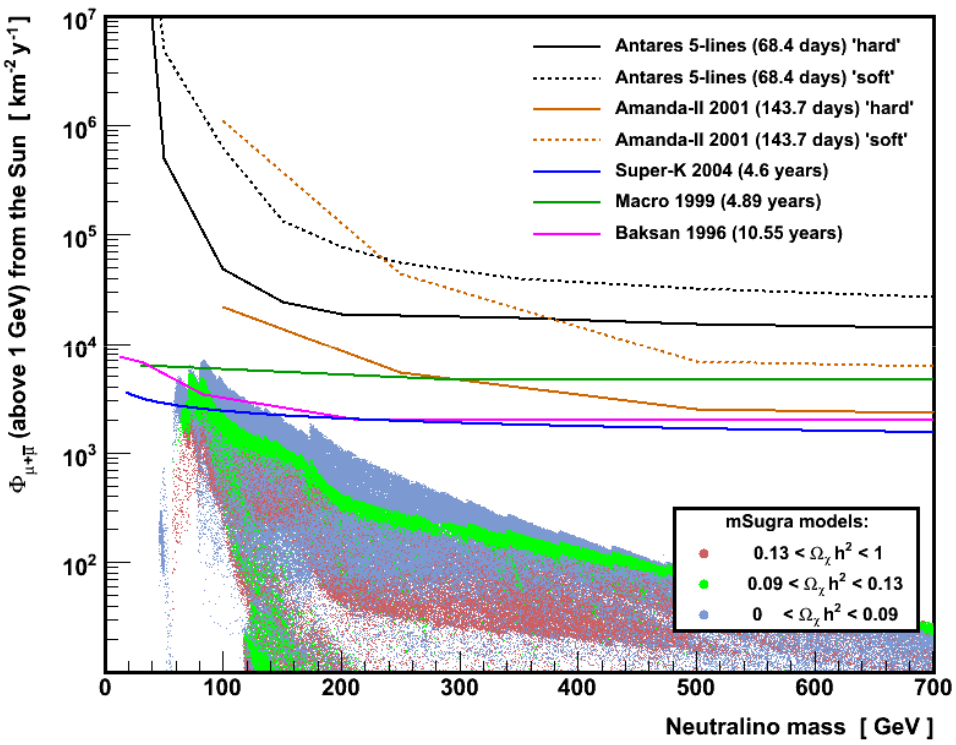
Good agreement for background estimation from MC and full sky data set

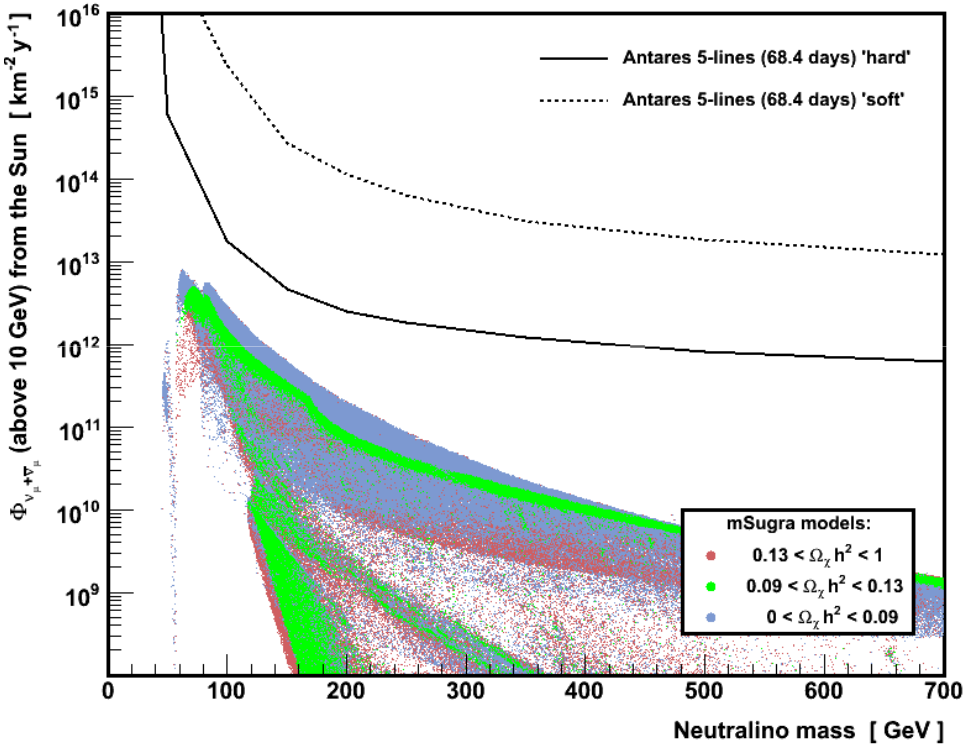
Size of search cone then optimized with MC depending on the Mχ and hard/soft spectrum



Limits from the 5-line period (2007)

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





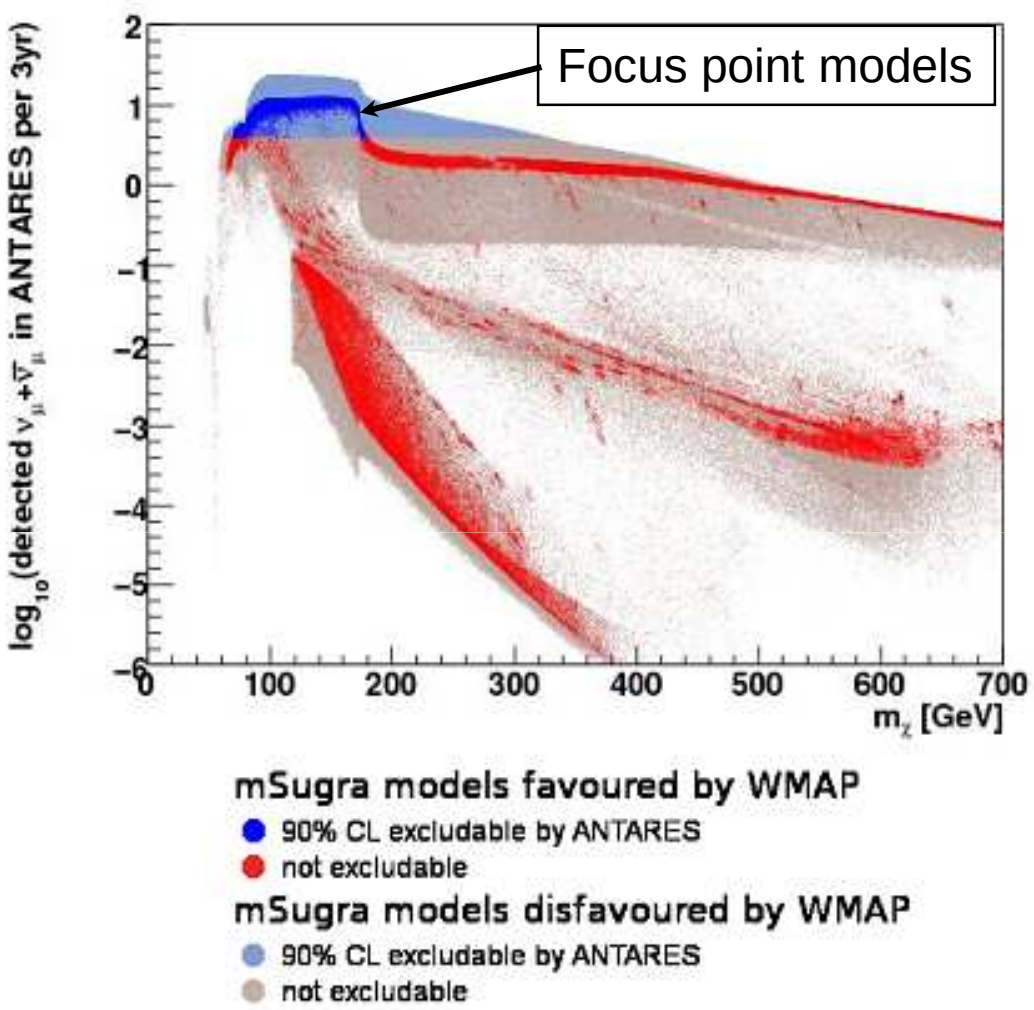
mSUGRA parameter space not reached yet but only 68.4 active days included in this analysis and only ~half of the detector

Sensitivity to mSUGRA models

Sensitivity calculated for 3 years of data taking (12 line detector)

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

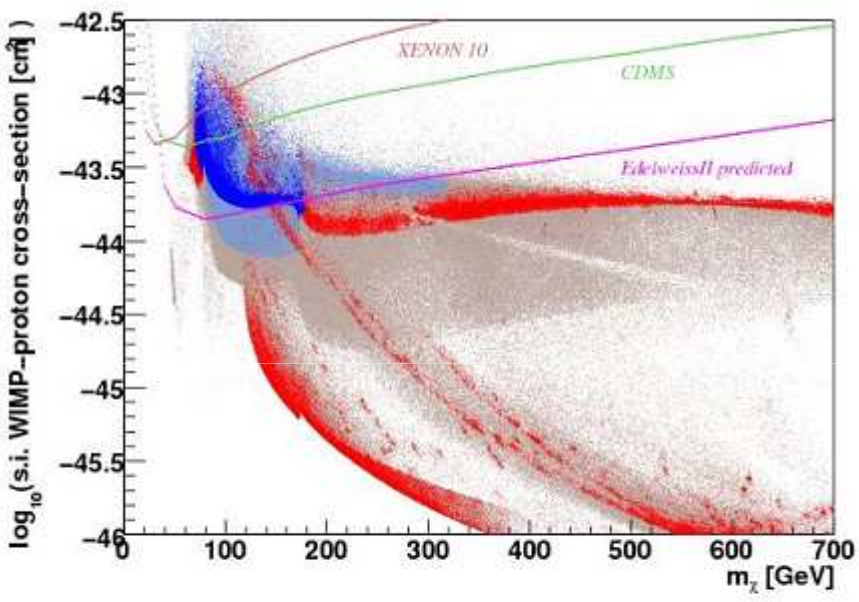
$(0.094 < \Omega\chi\ h^2 < 0.129)$



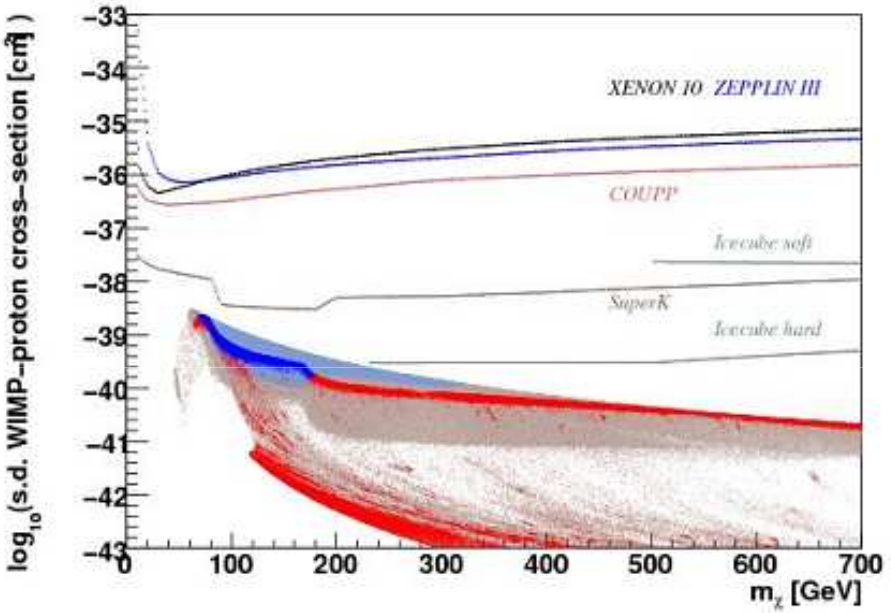
Exclusion capabilities of ANTARES for the mSUGRA parameter space : mainly Focus Point region (good complementarity to direct search at LHC)

Comparison with other experiments

Comparison to Spin-independent direct detection experiments



Comparison to Spin-dependent direct detection experiments



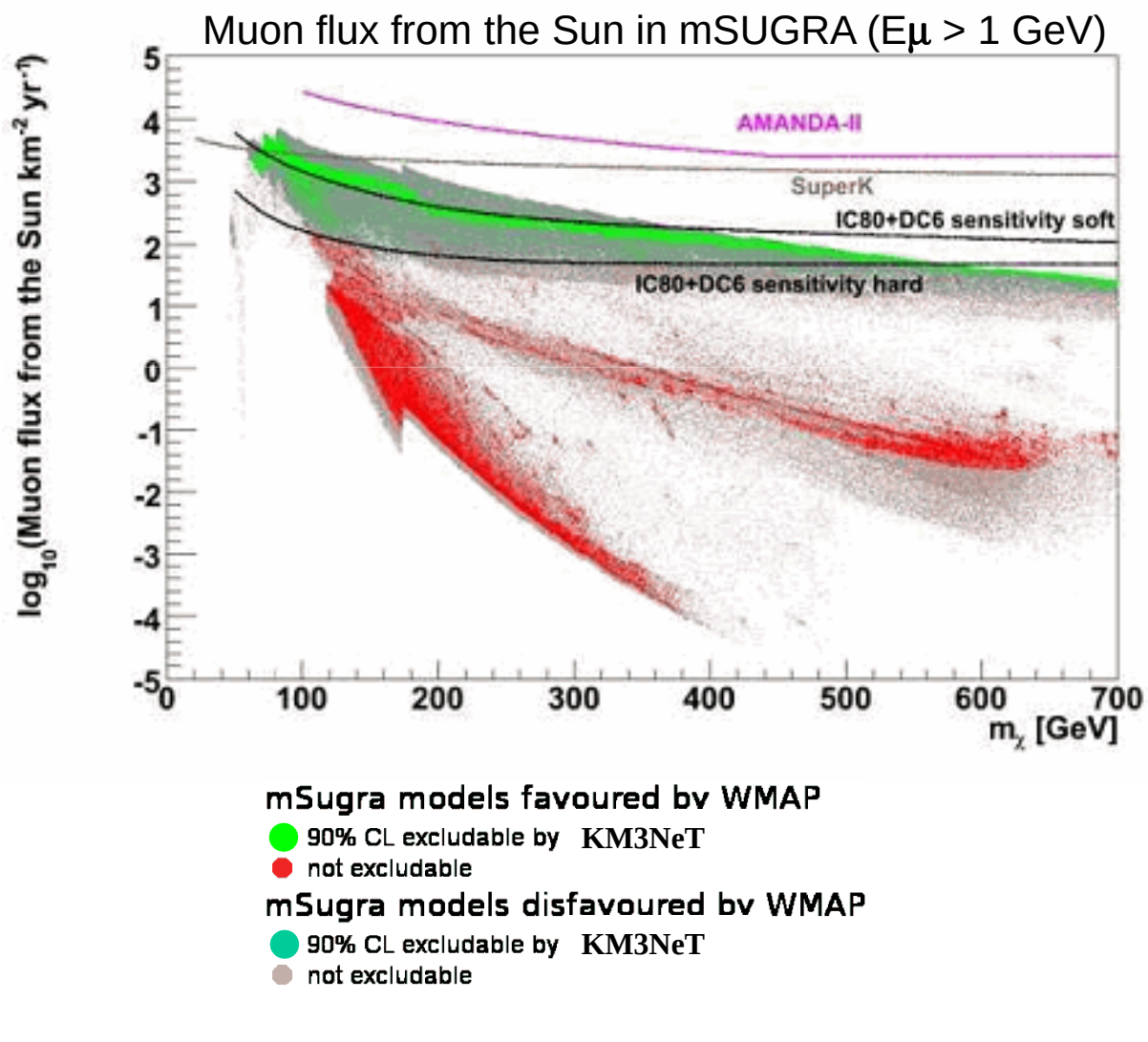
Almost direct relation since annihilation rate inside the Sun is tied to scattering cross section on H

XENON 10 : astro-ph/0706.0039
COUPP : Science 319 (2008)
IceCube : arXiv:0902.2460

CDMS : astro-ph/0802.3530
ZEPLIN III : arXiv:0901.4348

Future prospects

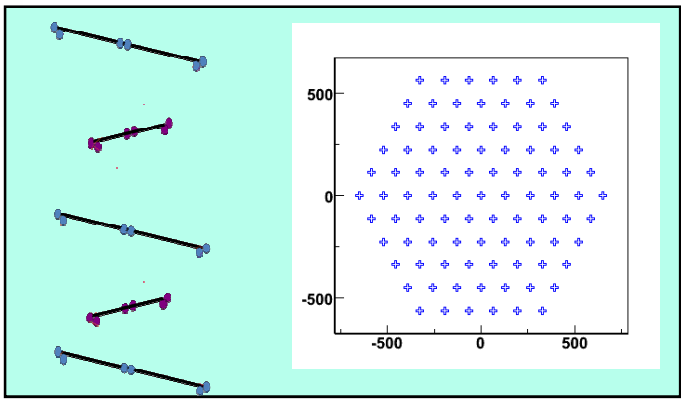
Prospective sensitivity of next generation km-scale neutrino telescopes (IceCube + DeepCore & KM3NeT) after 10 years of observation time.



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

KM3NeT detector:

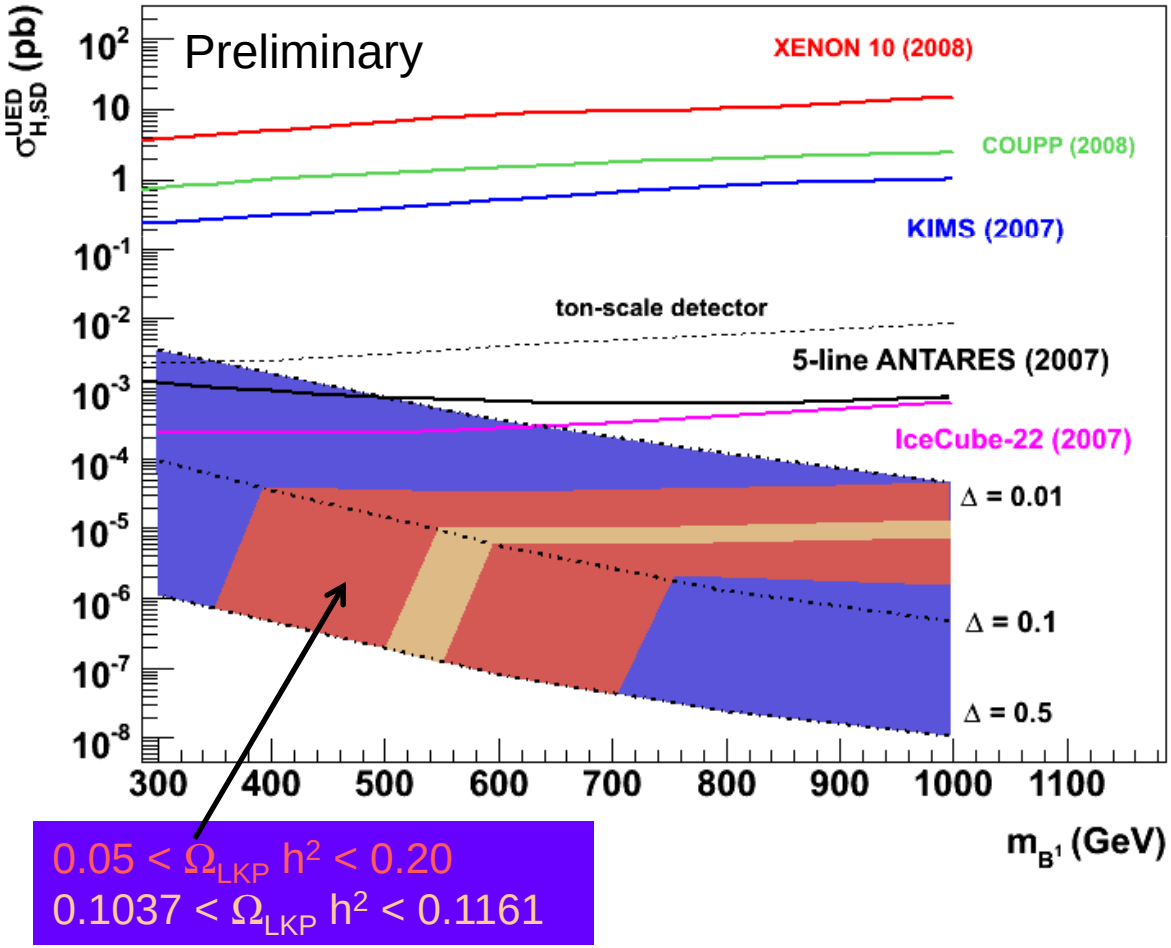
2x154 towers, 20 floors
Distance inter lines: ~180m
Distance inter floors: ~40m
3x2 PMTs (8", 35% QE) per floor
Volume ~5 km³



Sensitivity from 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

Self annihilation of LKPs directly into neutrinos (more favorable for detection)



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

Highly predictive phenomenological model due to very few free parameters

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

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

Search for magnetic monopoles

❖ **Direct emission above Cherenkov threshold $\beta_{M.M.} > 0.74$**

Very large number of emitted light compared to a muon with the same velocity (~8500 times more).

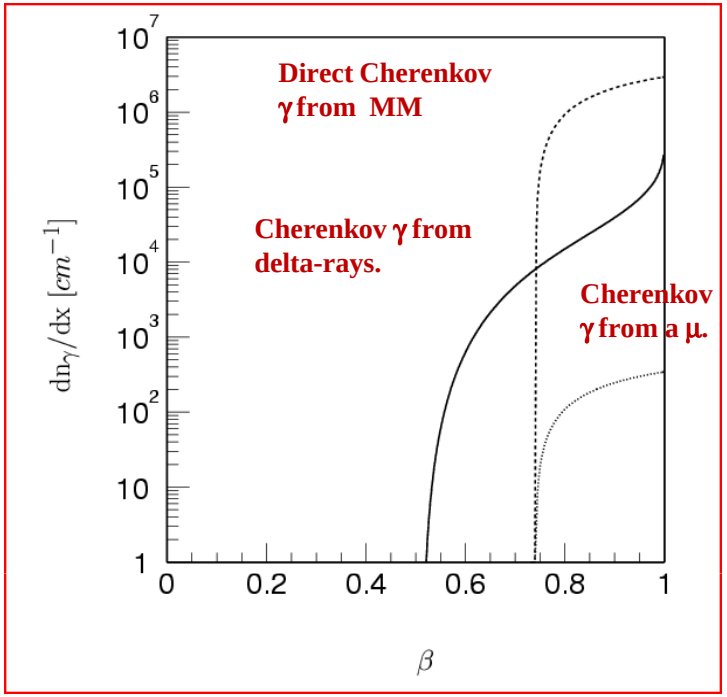
❖ **Indirect Cherenkov emission from δ-rays for $\beta_{M.M.} > 0.51$**

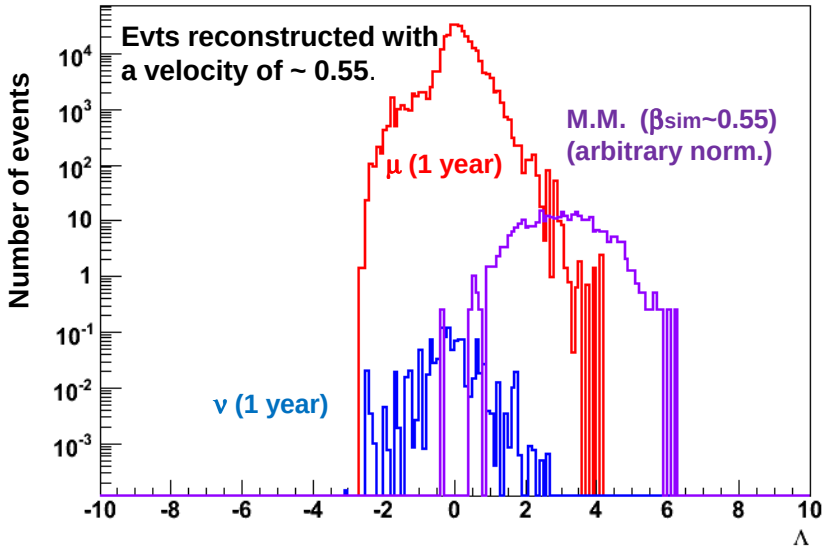
δ-rays provide detectable photons emitted within a large spread angle distribution.

❖ **Modification of the reconstruction algorithm to implement a fit on the velocity.**

$$\Lambda = \log\left(\frac{t\chi^2_{beta=1}}{t\chi^2_{beta\,var}}\right)$$

($\Lambda > 0$ for M.M. & $\Lambda \sim 0$ for ν,μ)

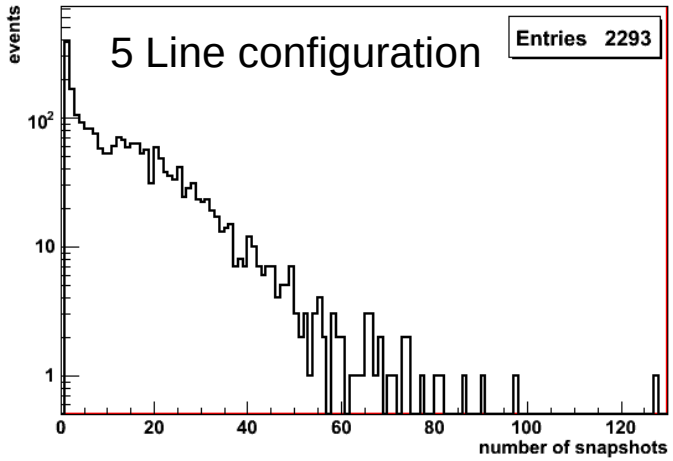




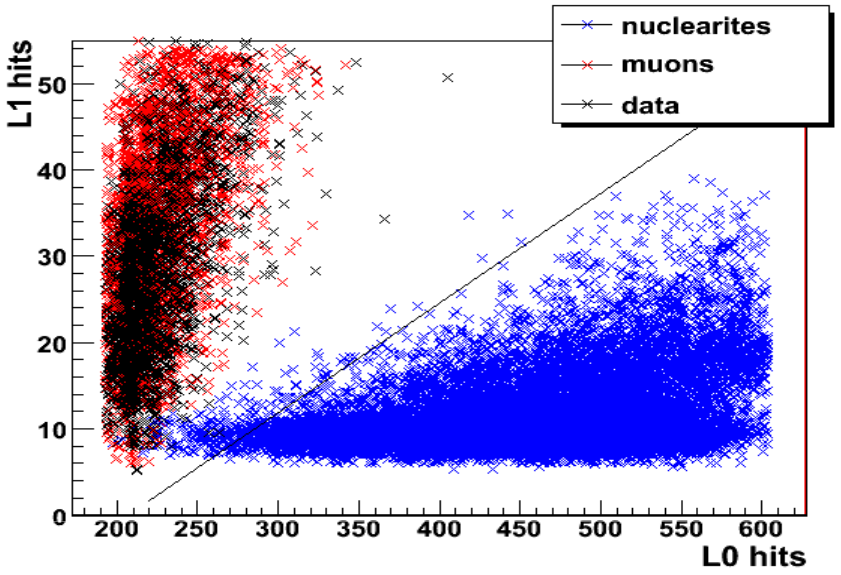
Search for Nuclearites (I)

- Massive lumps of strange quark matter originating in energetic astrophysical sources
- Origin: supernovae, collapsing binary strange stars, …
- Main interaction mechanism: elastic and quasi-elastic collisions
- Slow moving particles, with $\beta \sim 10^{-3}$
- Signal: black body radiation emitted at visible wavelengths by thermal shock waves
- A nuclearite would cross the full Antares detector in about 1ms
- Main background in ANTARES: down-going atmospheric muons
- Current available triggers select only a connected series of snapshots (2.2 μs) from down-going nuclearites with $M_{nucl} \geq 10^{15}$ GeV

Snapshot distribution for simulated nuclearite events



Search for nuclearites (II)

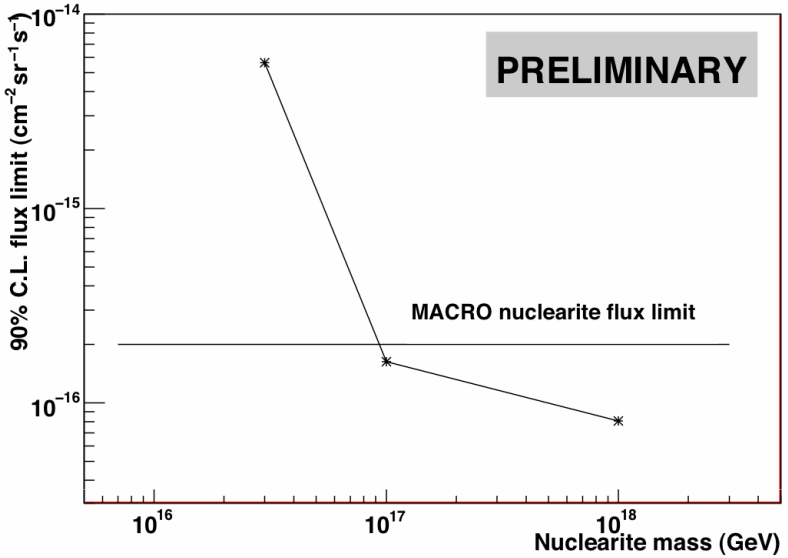


Analysis principles

► A linear cut is applied to separate the data (muon) and nuclearite distributions
►Additional cut on number of snapshots

►Preliminary analysis for nuclearites shows a sensitivity of the ANTARES detector in 5-line configuration competitive with the best existing limits.

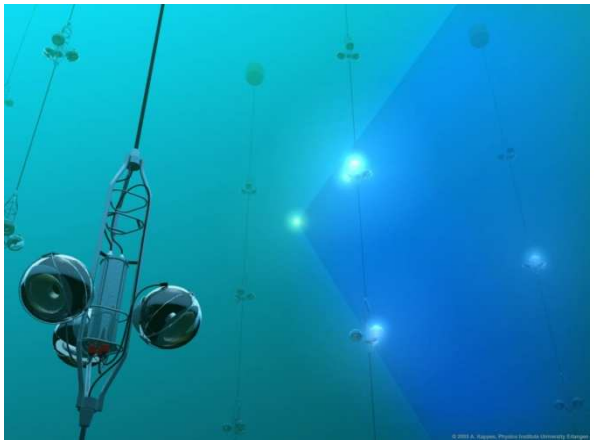
Sensitivity of the 5-line detector (84 days)



New proposal : Implementation of a dedicated **slow particle trigger** enabling to identify and reconstruct such exotic particles

- ➢Look for an increase in the count rate of PMTs along scan directions.
- ➢Eventually record all raw data for about 20 ms (as for GRBs, but much shorter)
- ➢Will increase the sensitivity

Conclusions



ANTARES detector completed in May 2008

- Detector operation and calibration under control
- Maintenance capability demonstrated

Exciting physics program ahead

- Over two thousand neutrino already reconstructed
- Astronomical sources, multi-messenger approach, other analysis in progress :
  - Dark matter signal in neutrino telescopes would be very clean.
  - Best prospects in “focus point region”.
  - Complementarity of neutrino telescopes with direct detection and LHC
  - Sensitivity to other SUSY models (pMSSM, AMSB,…) or Dark Matter candidates is being studied (KK excitations,…)
  - Search towards Galactic Centre and Earth in progress with 2008 data
- Other topics (magnetic monopoles, nuclearites, oscillations,) are also under the scope.
- New ideas are welcome !

Real-time readout

- A large program of synergetic multi-disciplinary activities: biology, oceanography……

A major step towards KM3NeT