Status and Results of the ANTARES Neutrino Telescope

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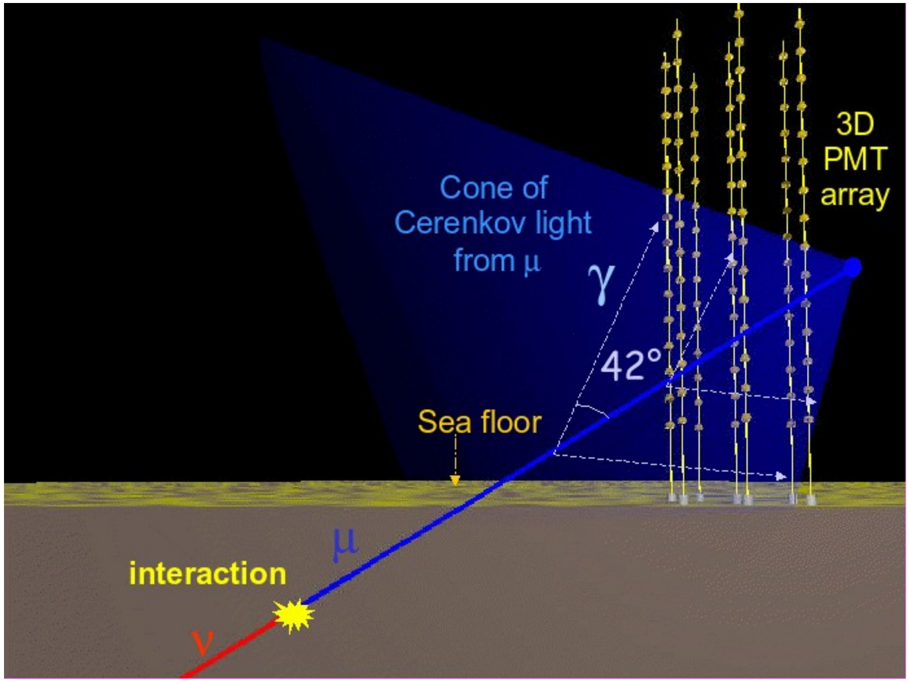
University of Erlangen-Nuremberg
COSMO/CosPa2010, Tokyo

Neutrino Telescope: Detection Principle

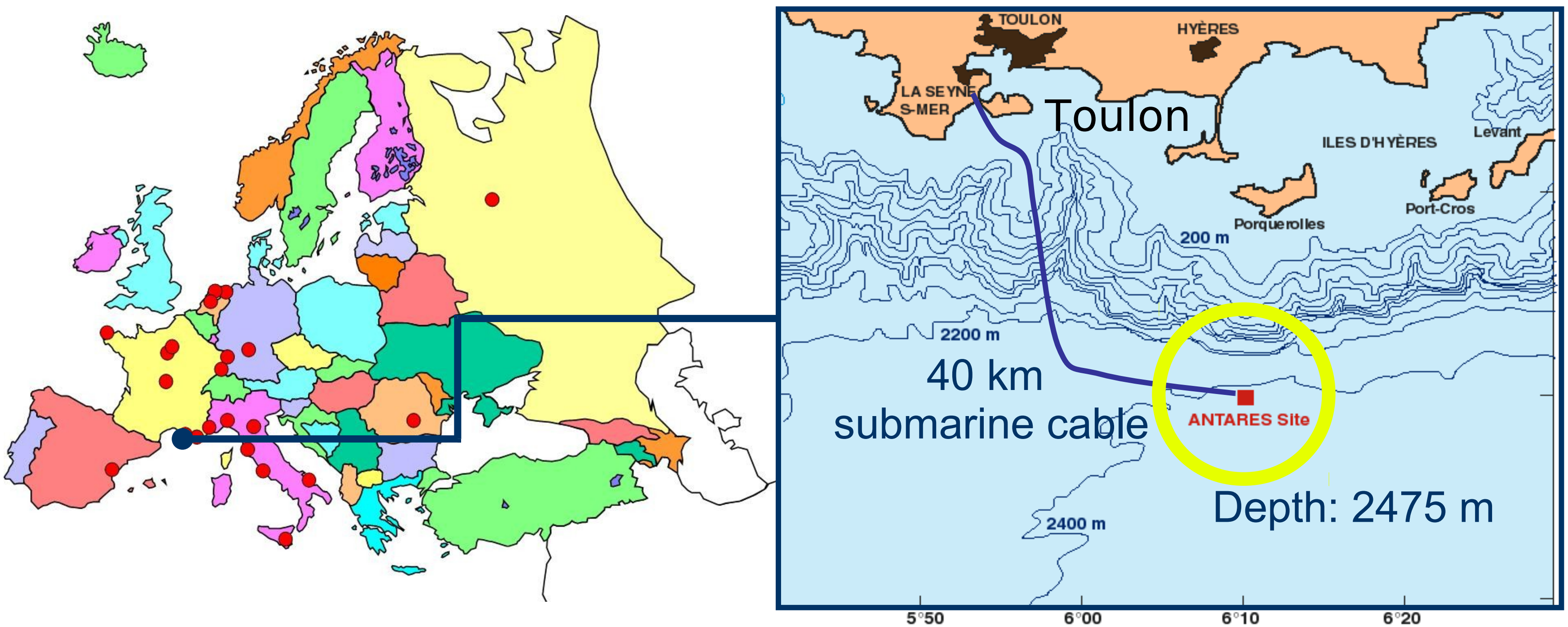


- Neutrinos can penetrate Earth
- CC interaction in the vicinity of the detector → muon with (almost) same trajectory
- Muon emits Cerenkov light when traversing water
- Reconstruction of muon track from position and time of Cerenkov photons detected

The ANTARES Collaboration and Site

24 Institutes from 7 Countries

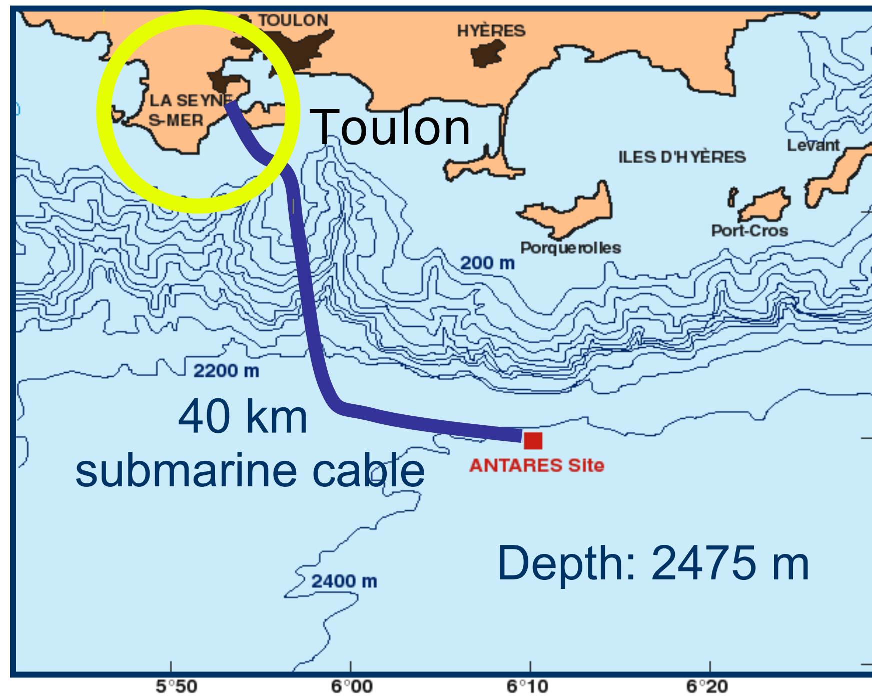
Detector located in Mediterranean near Toulon at 2475 m depth (to shield from atmospheric muons)



The ANTARES Collaboration and Site

Shore Station “Michel Pacha” in La Seyne sur Mer

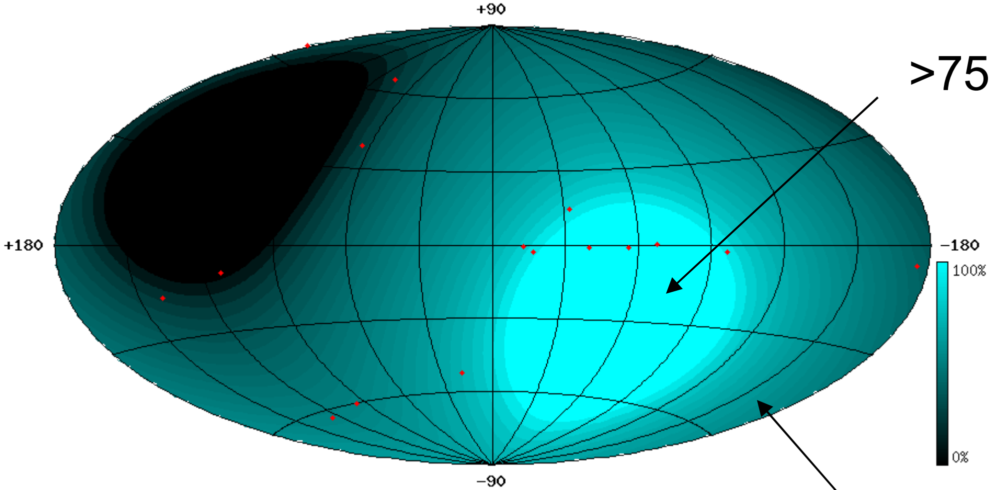
40km electro-optical cable for power and data transmission



Sky Coverage

ANTARES: 3.5 π sr

Position: 42°50’ N, 6°10’ E → Mediterranean Sea



>75% Visibility

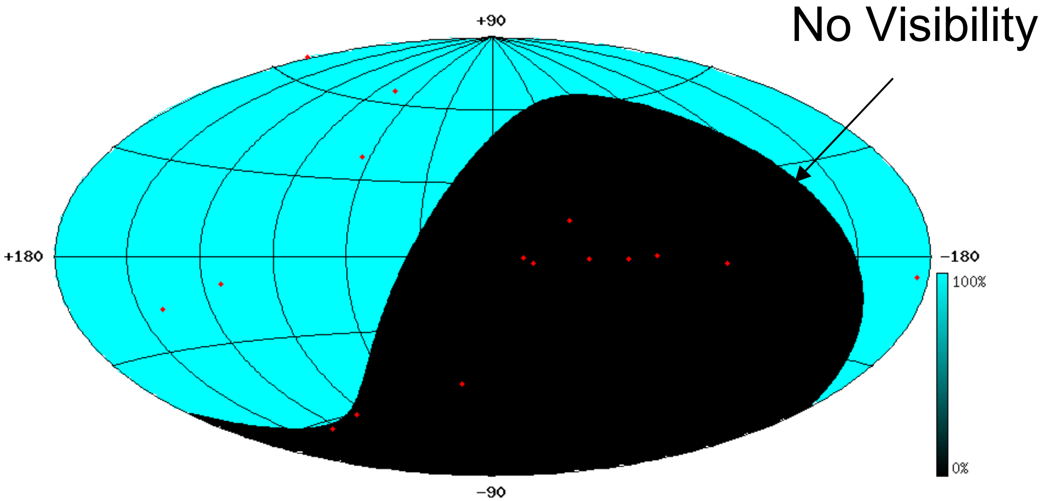
>25% Visibility

Galactic Coordinates

Assumption: only sensitive to upgoing neutrinos

Sky Coverage

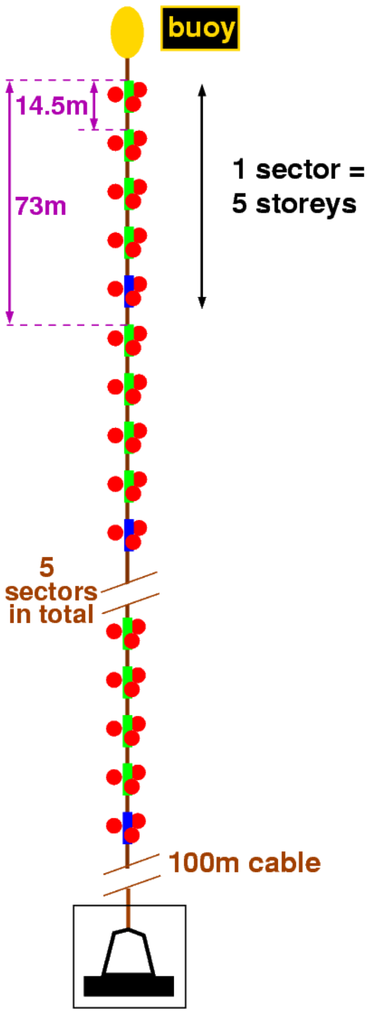
IceCube, AMANDA: 2 π sr
Position: Southpole



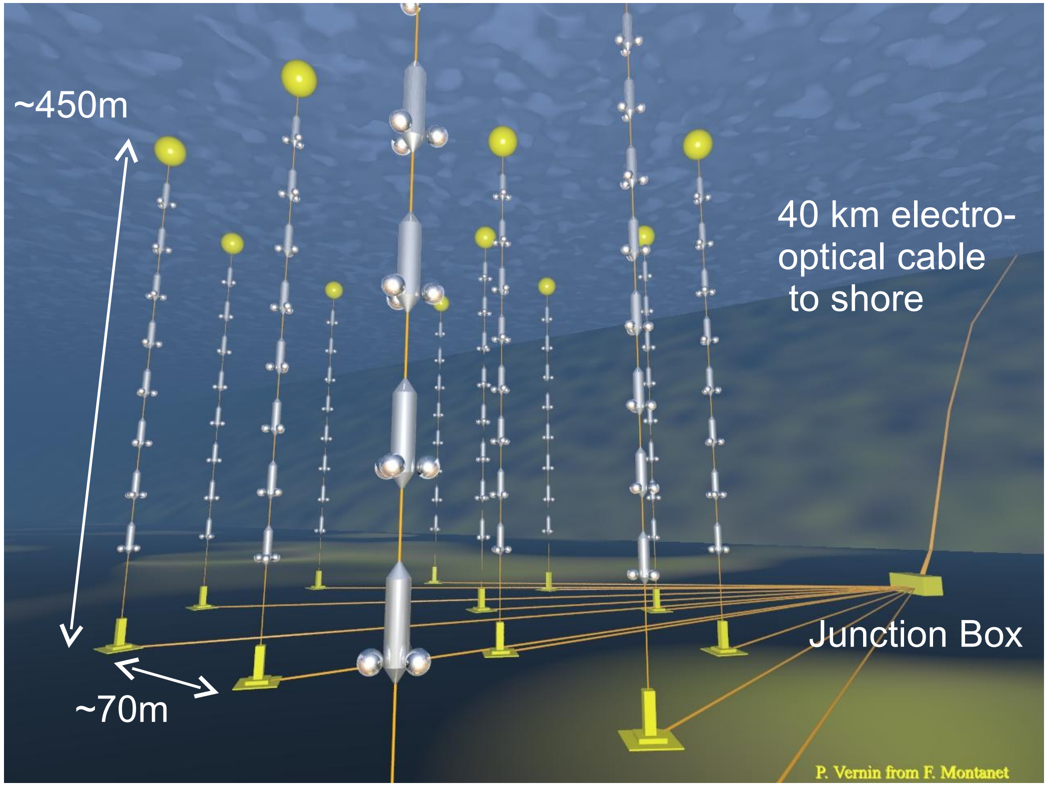
Galactic Coordinates

Assumption: only sensitive to upgoing neutrinos

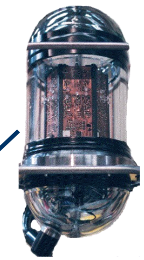
The ANTARES Detector



- 12 Lines + IL, ~0.1km² geometric area
- Each line: 25 storeys with 3 PMTs per storey
- 885 PMTs total (one sector acoustic particle detection)

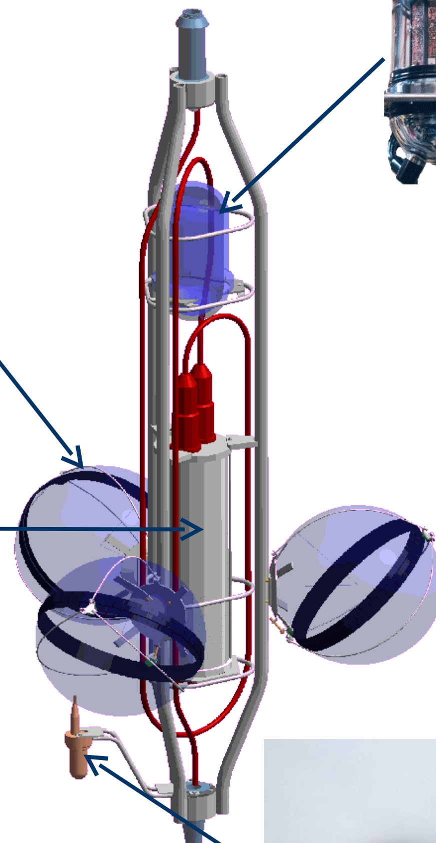


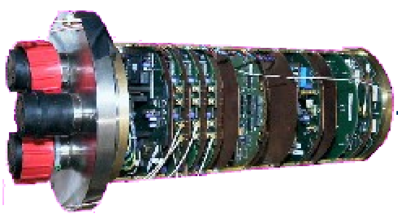
Detection and Calibration Elements



Optical Beacon
with blue LEDs
Timing calibration
(4 per line)

Optical Module
(10” PMT in 17” glass sphere)
photon detection

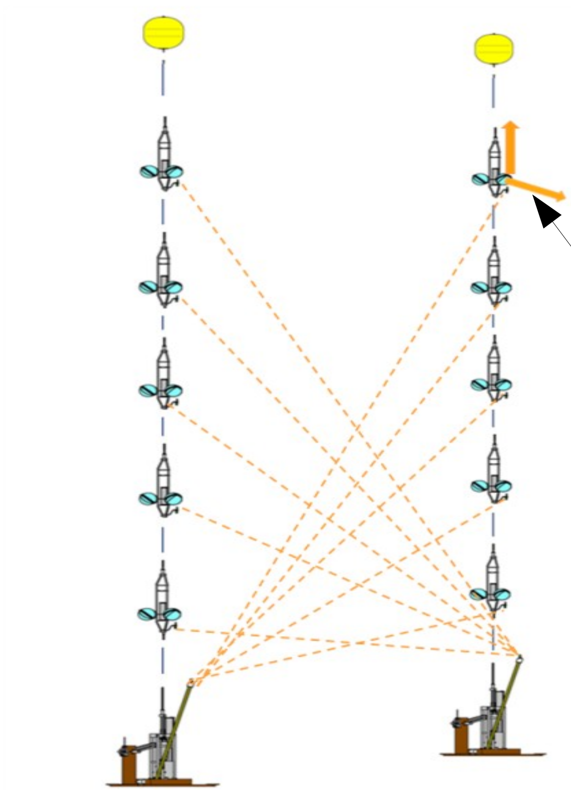




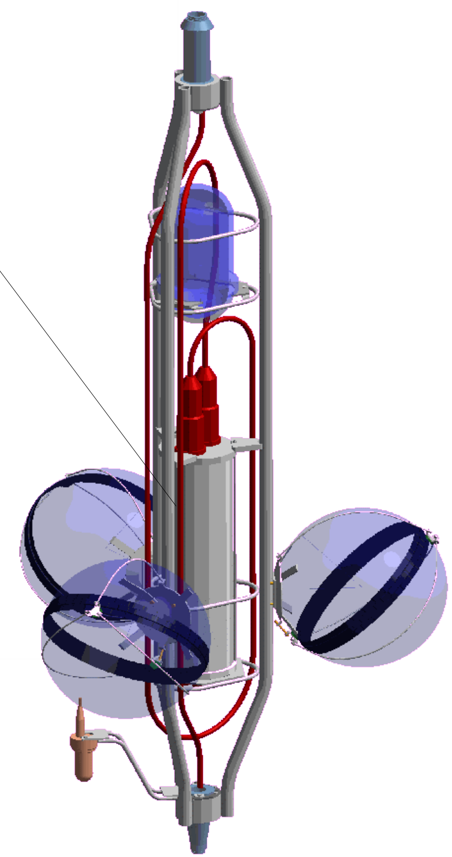
Local Control Module
(in Titanium container)
Front-end ASIC, Clock, DAQ/SC,
Compass and Tiltmeter for
measuring storey orientation

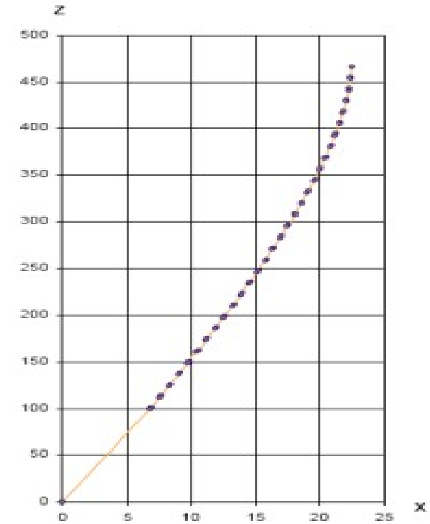
Hydrophone
Storey position by
acoustic triangulation
(5 per line)

Position Calibration



Orientation of each Storey by Compass and Tiltmeters

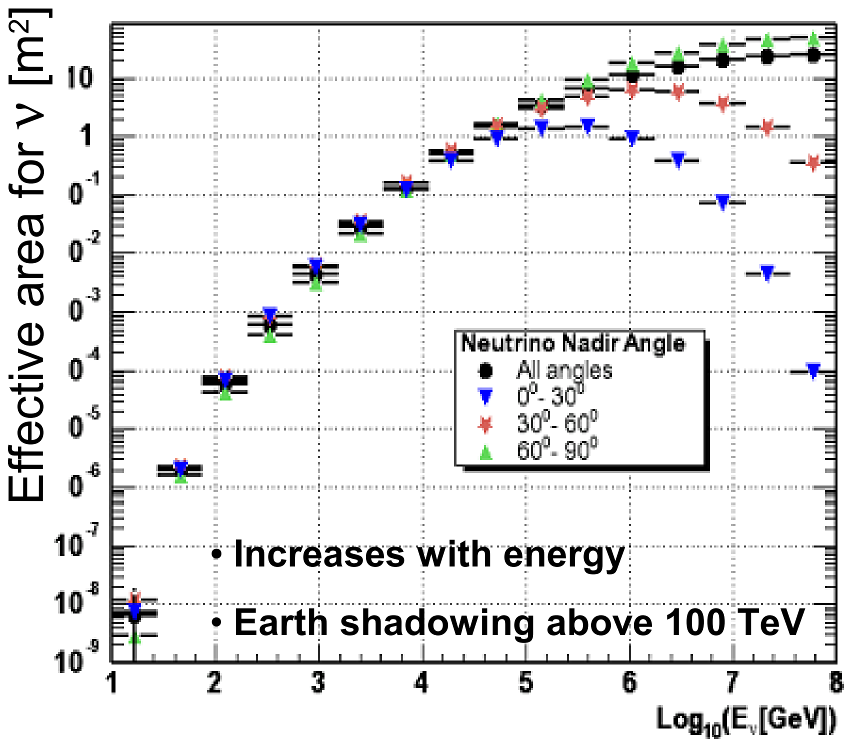


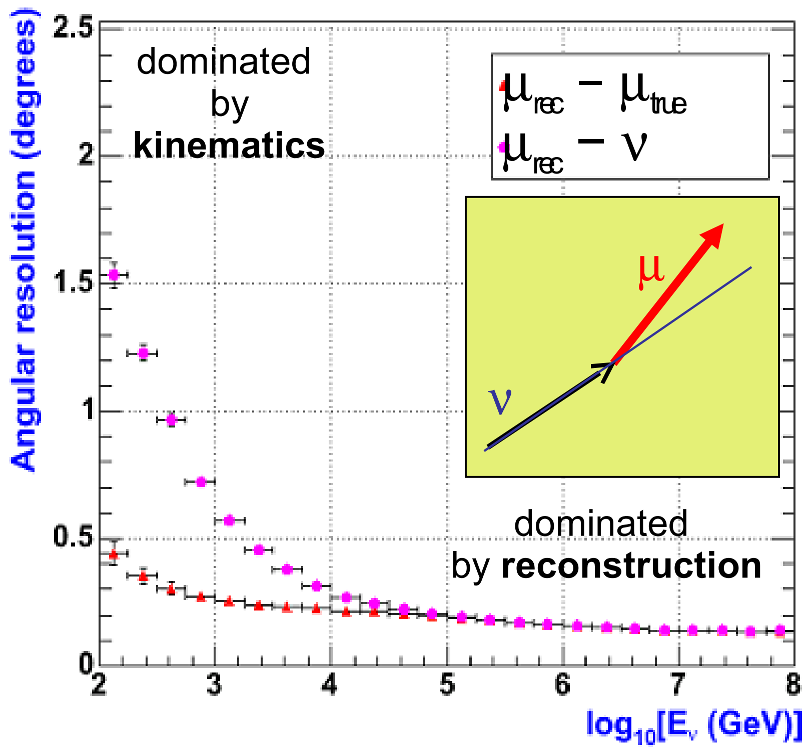


Lineshape formula fitted to data.
→ Position and Orientation of all Optical Modules at ~cm precision

Triangulation of the position for five hydrophones per line with Signal from Emitters at Bottom String Socket (BSS)

Effective Area and Angular Resolution



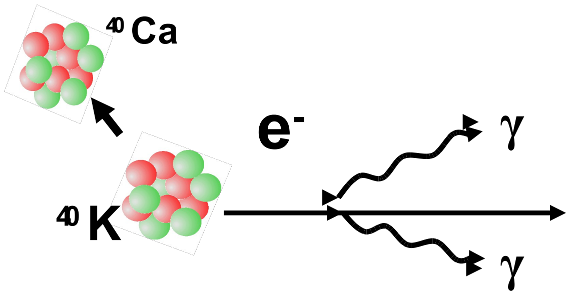


Angular resolution better than 0.3° above a few TeV, limited by:

- Light scattering and chromatic dispersion in sea water: $\sigma \sim 1.0$ ns
- TTS 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)

Optical Background

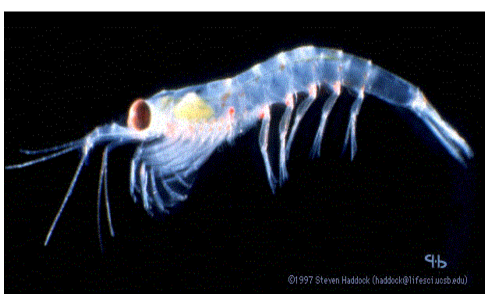
Dominated by two effects:



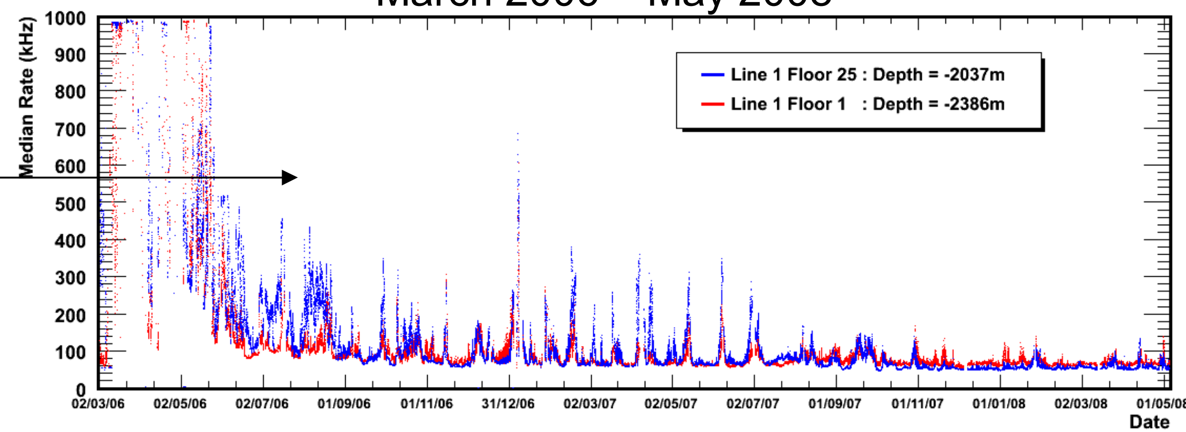
1. β – decay of ^{40}K

2. Bioluminescent organisms:

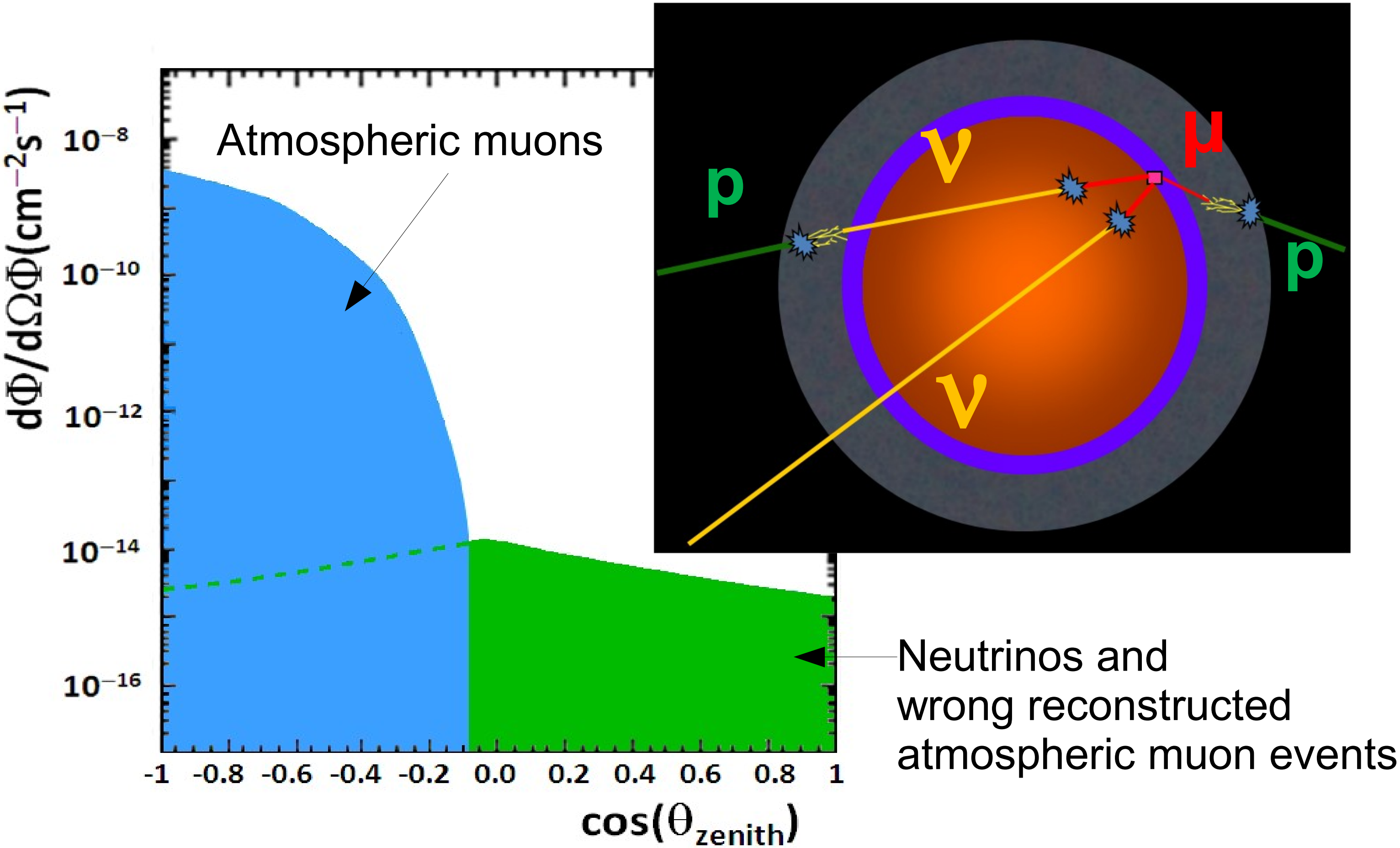
e.g.



March 2006 – May 2008

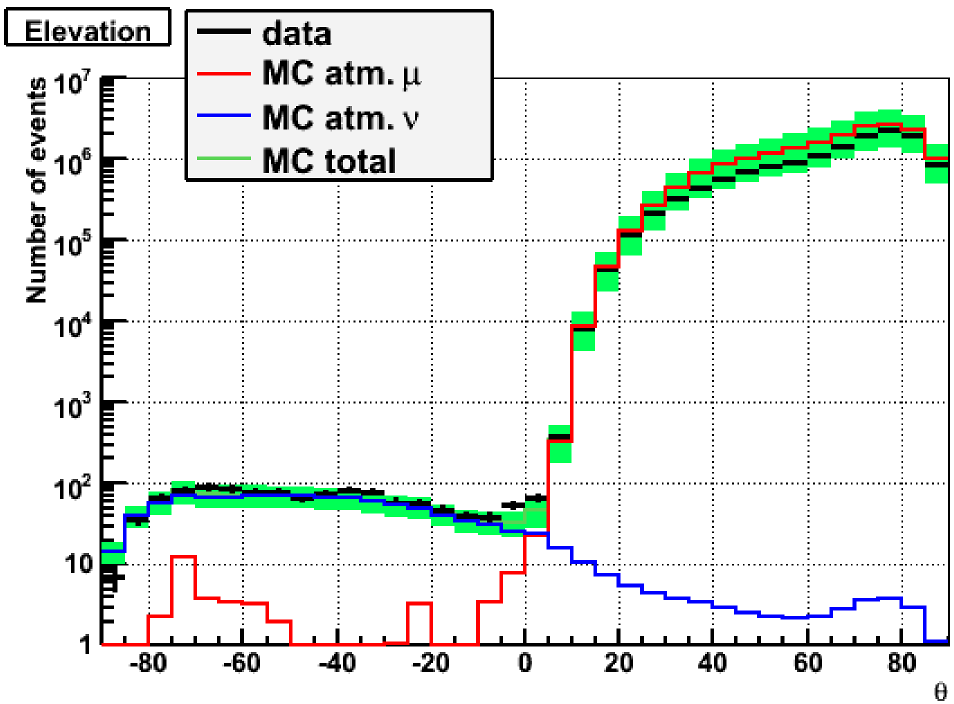


Background from Cosmic Radiation



Quality cuts required to remove atmospheric muon background

Atmospheric Neutrinos and Muons



- 341 days of lifetime
- Data (upgoing events):

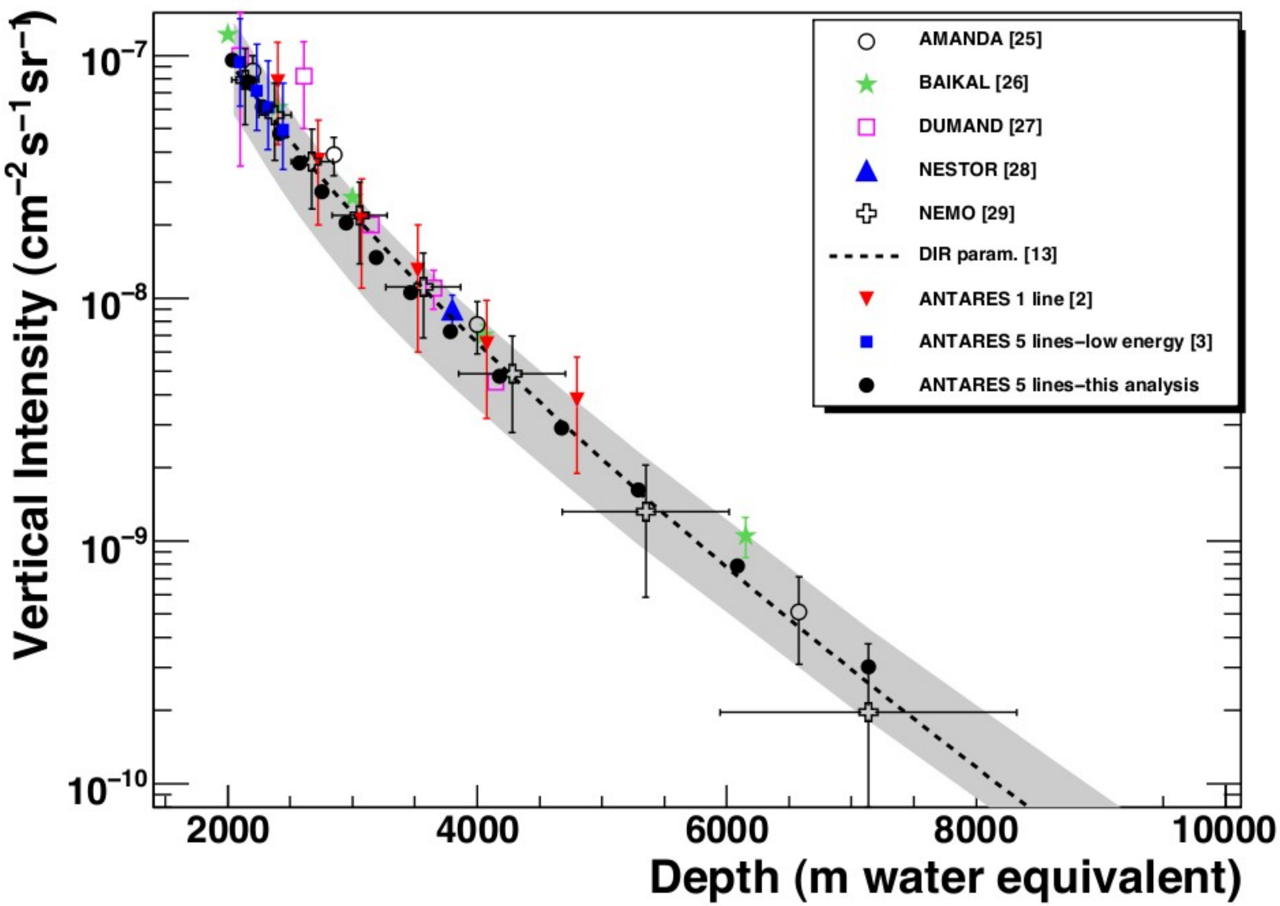
1062 neutrino candidates = 3,1 per day

- Expectation from Monte Carlo:

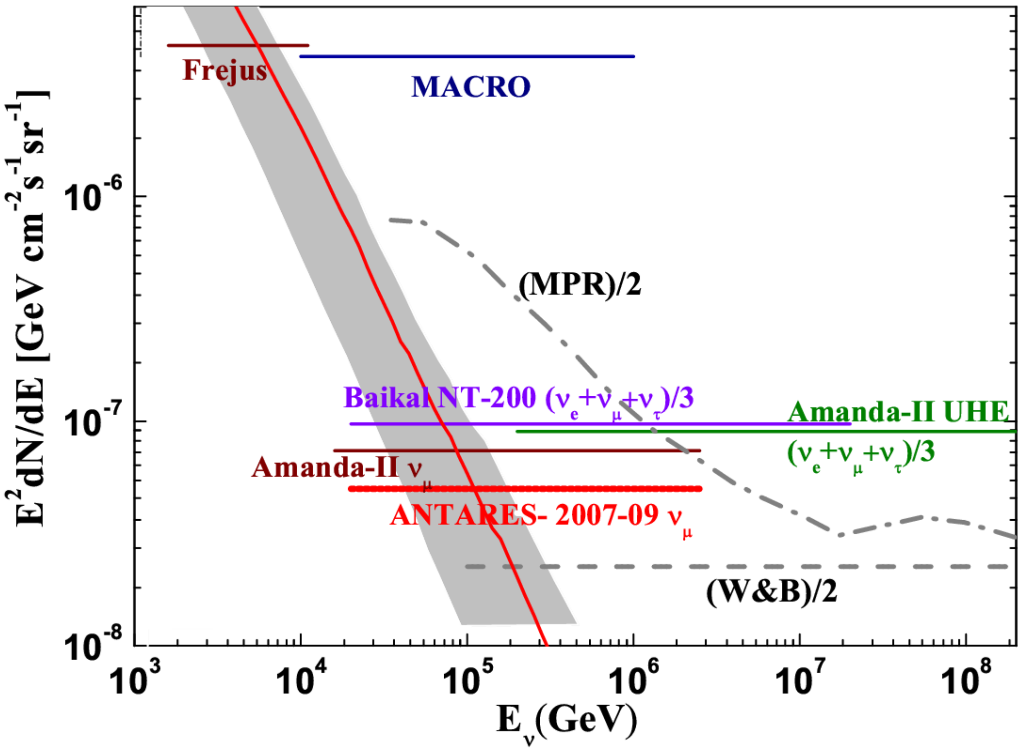
916 atmospheric neutrinos (30% systematic error)

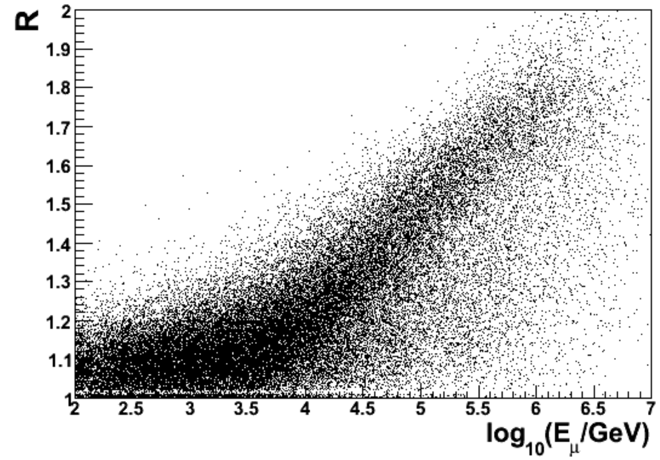
40 wrong reconstructed muons (50% systematic error)

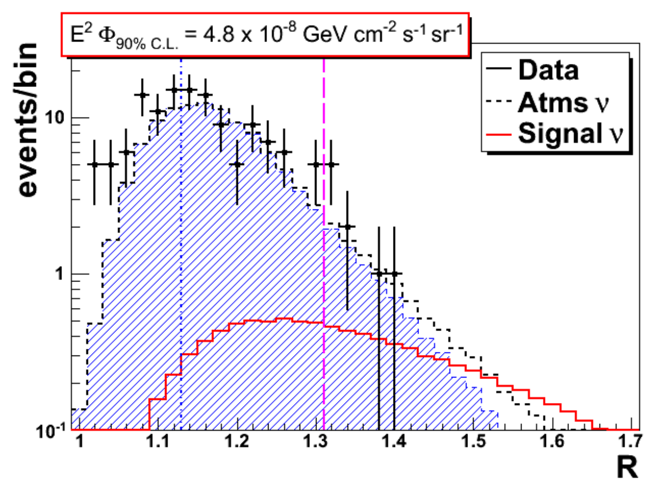
Atmospheric Muons – Intensity vs Depth



Diffuse Flux Limit







Energy Estimator R:
Fraction of PMTs which see light arriving late
(from EM-showers along the muon track)

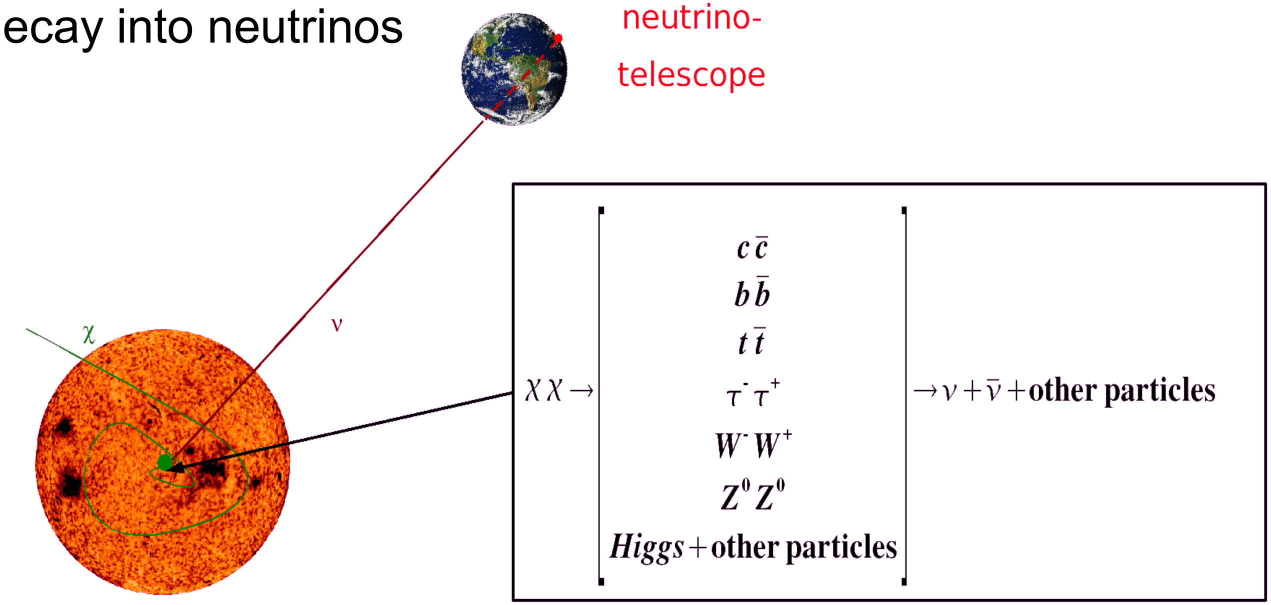
Indirect Search for Dark Matter

Cold Dark Matter Candidates:

- LSP from SUSY (here: mSugra - minimal Supergravity)
- LKP from Kaluza Klein (here: mUED - minimal univ. extra dim.)

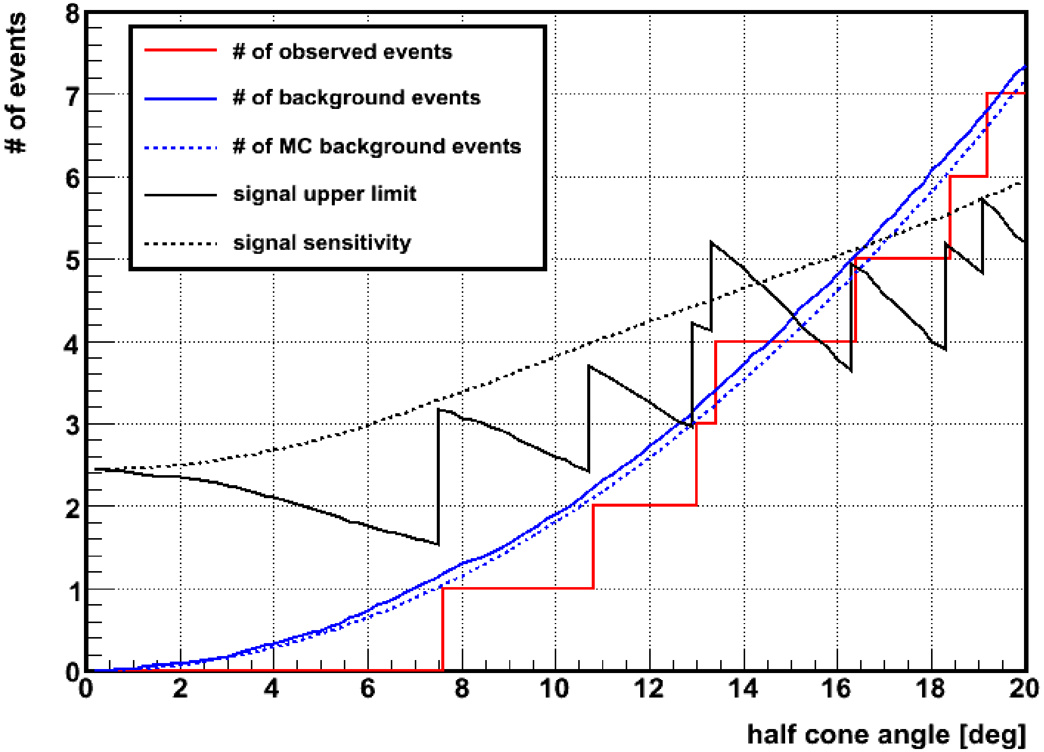
Elastic scattering → bound to massive stellar objects (Sun/Earth)

- Increase of Neutralino density → Annihilation rate enhanced
- Primary annihilation products (quarks, gauge bosons, leptons) decay into neutrinos

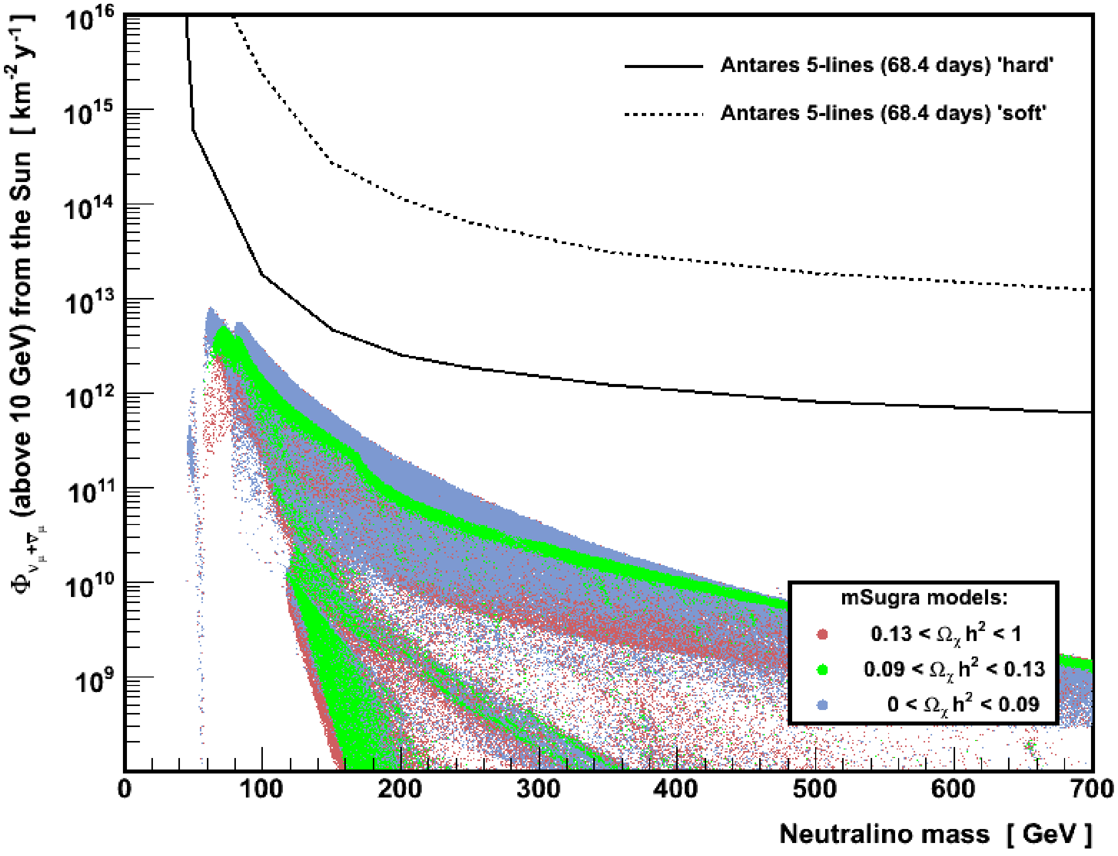


Dark Matter: Limit

- Reconstructed neutrinos from an effective lifetime of 68.4 days as a function of angular distance from Sun's direction
- Consistent with background estimation from both full sky measurement and MC
- Search cone for actual limit optimized from MC prior to analysis for different neutralino masses and hard/soft neutrino energy spectrum

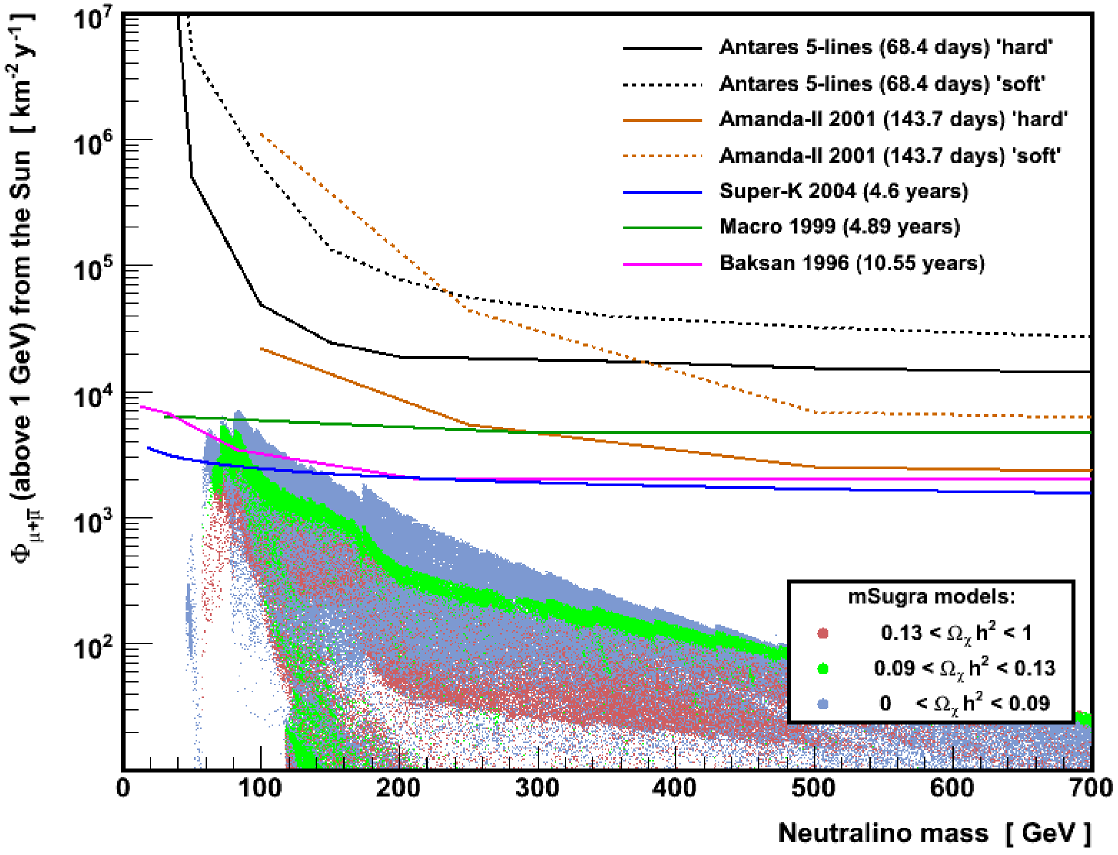


Dark Matter: Limit on Neutrino Flux



- Limits for soft (b-quark) and hard (W-boson) annihilation channel
- mSugra parameter space not yet reached

Dark Matter: Limit on Muon Flux



- Competitive limit given the short time of measurement
- Only 5 lines out of the total 12 of the final detector deployed at that time
- Analysis for full detector still going on

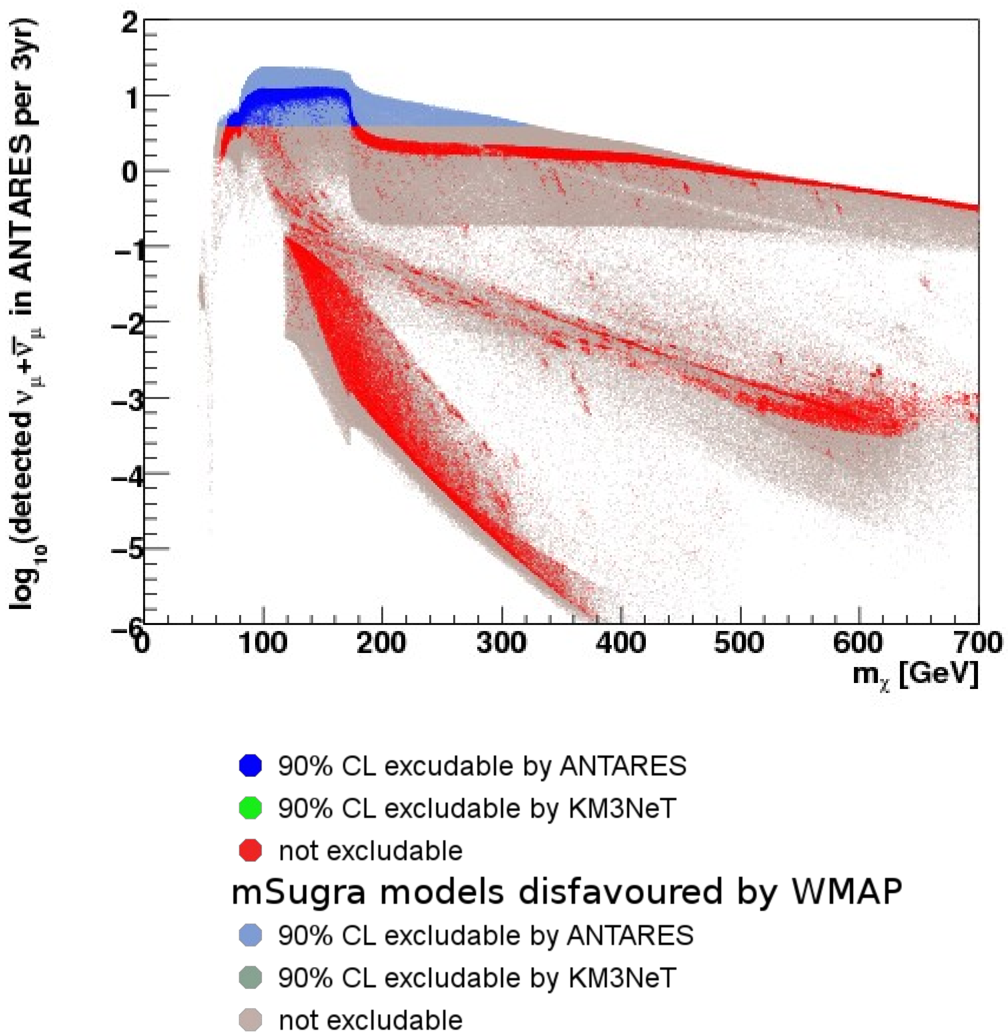
Sensitivity: Detection Rate

• Sensitivity calculated for three years of taking data

• Random walk scan of mSugra parameter space

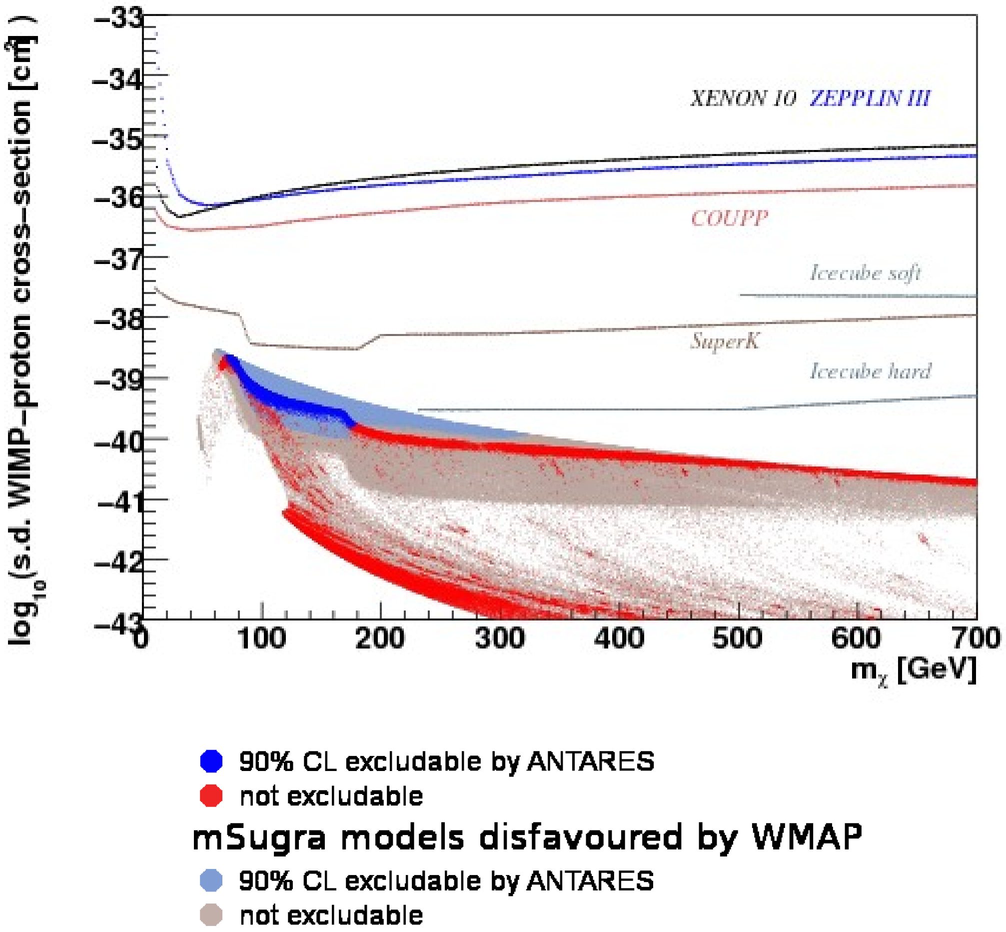
• Background from atmospheric neutrinos and wrong reconstructed atmospheric muons

• 3° radius search cone

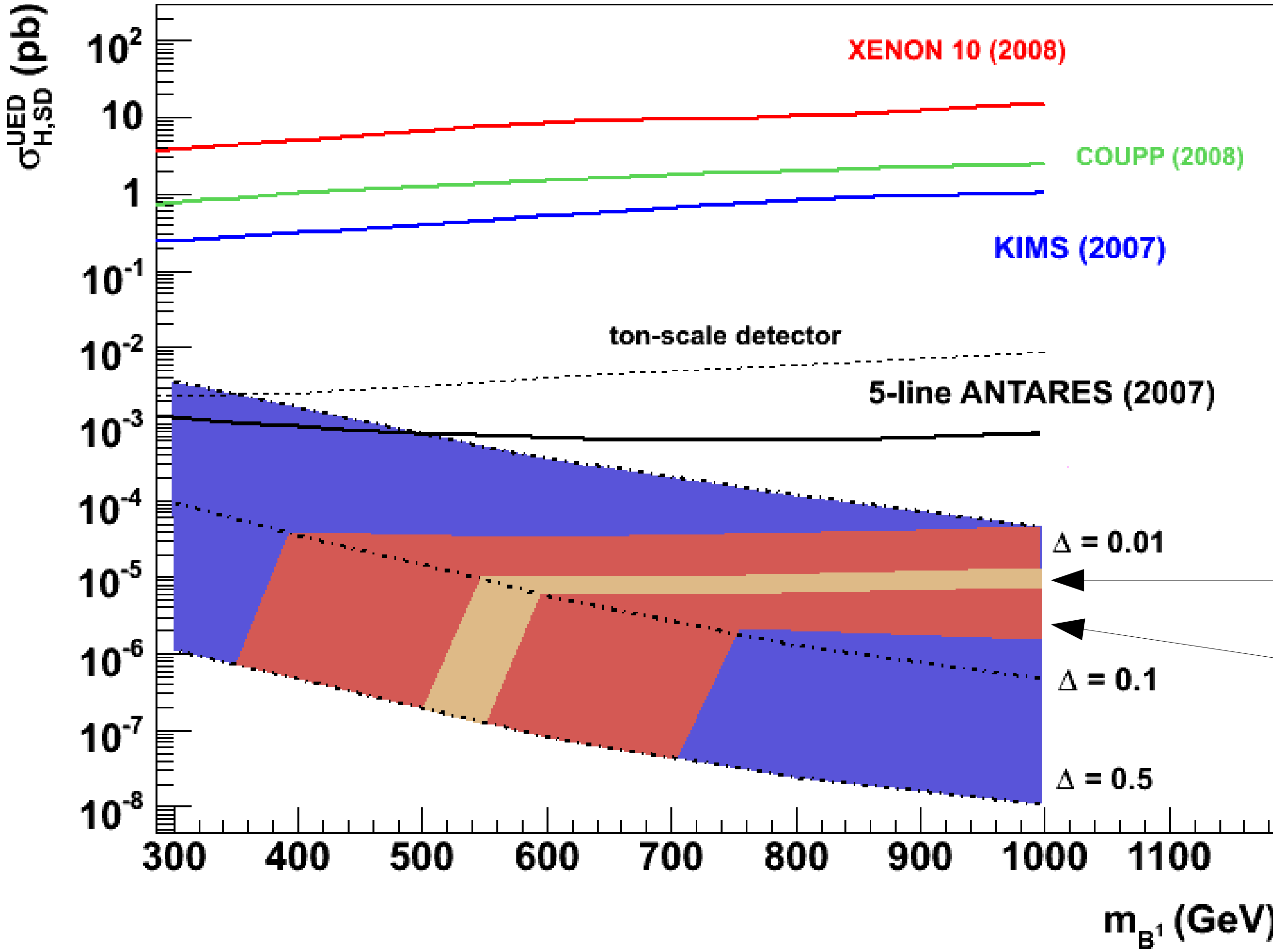


Sensitivity: Spin Dependent X-section

- ANTARES sensitivity vs other experiments limits
- Sun consists mostly of Hydrogen – spin dependent scattering
- Annihilation in equilibrium with capture rate



Kaluza Klein Dark Matter (SD-X-section)



mUED:
1 extra dimension

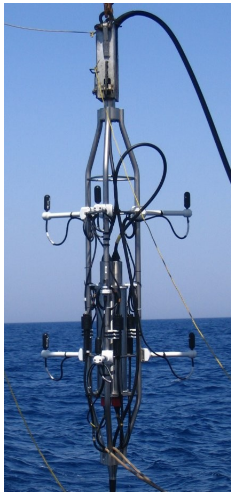
$0.1037<\Omega h^2<0.1161$

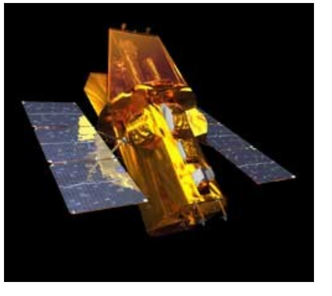
$0.05<\Omega h^2<0.20$

$\Delta = (m_{Q(1)} - m_{B^1})/m_{B^1}$

More than just Neutrinos

- Triggers for Signatures of Magnetic Monopoles and relic Strangelets
- Acoustic Neutrino Detection project AMADEUS also monitors anthropogenic and biogenic sound
- Trigger for optical follow up with automatic telescopes Tarot and ROTSE
- Receiving GRB alerts from satellites (triggers a period of storing all data for later analysis)
- Infrared biocams on IL look for sea creatures
- Seismometer for study of earthquakes and integrated in Tsunami warning network





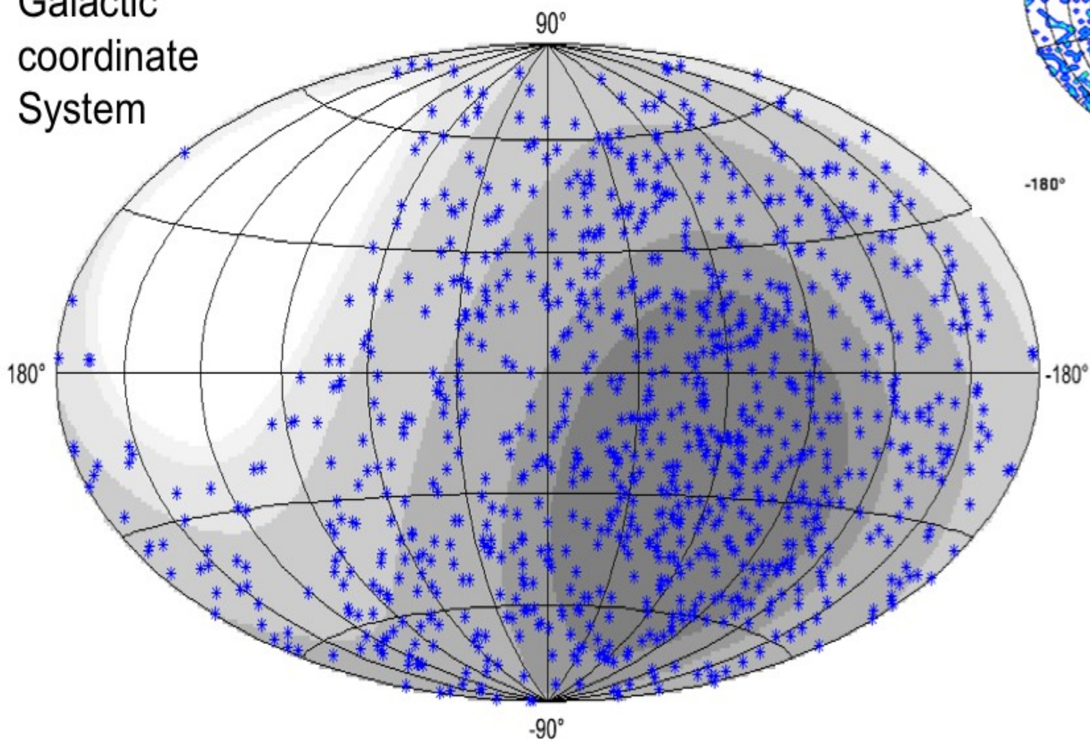
Summary - ANTARES

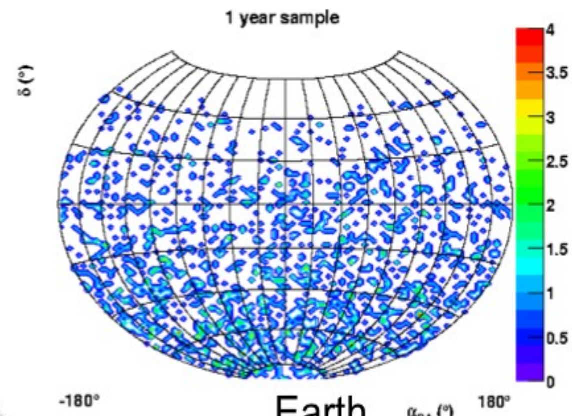
- continuously takes data for several years now
- complements the sky coverage of IceCube
- has put limits on observables for astrophysical neutrino sources, directly and on diffuse flux
- is a valuable tool for indirect Dark Matter search
- has many analyses with recent data going on at the moment for improved results

Backup Slides

Neutrino Skymap (scrambled)

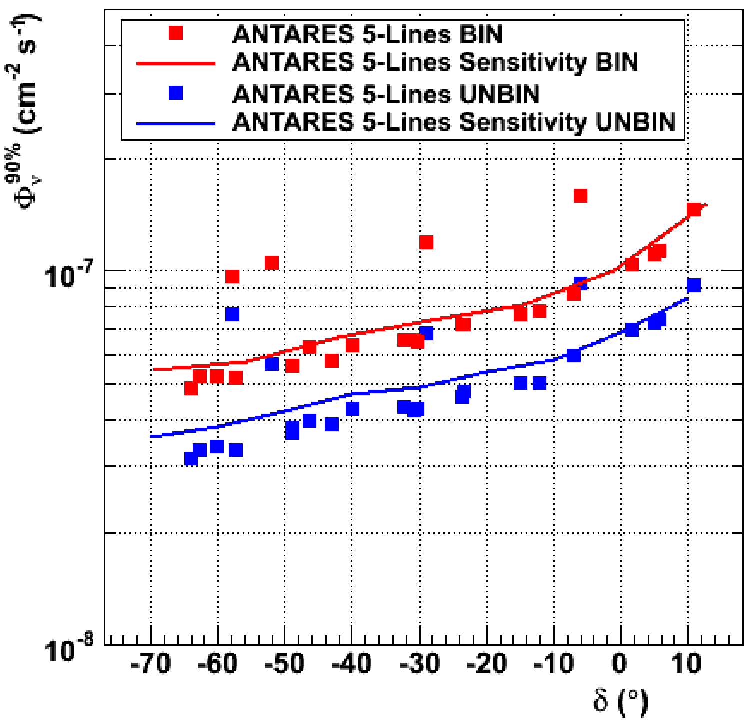
Galactic coordinate System

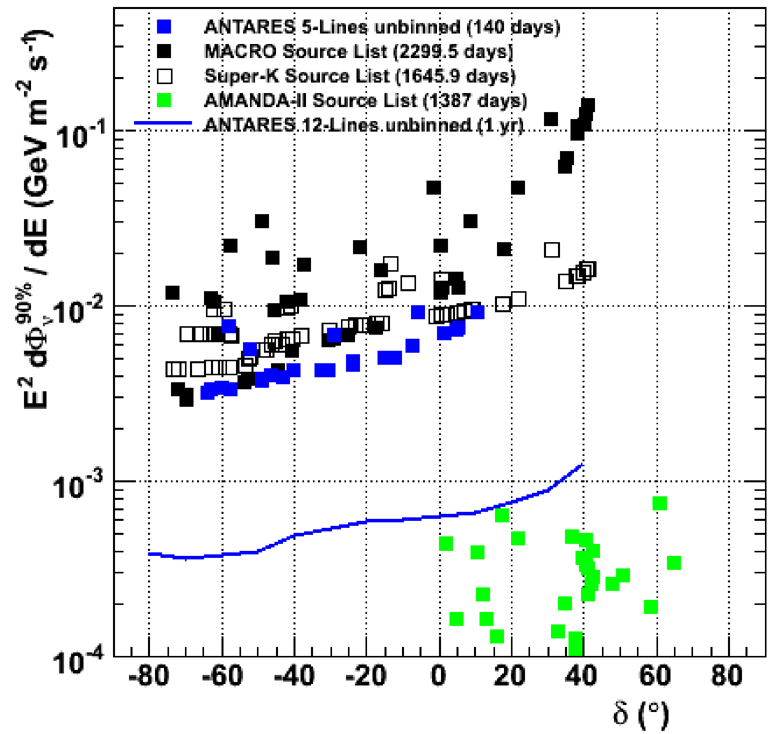




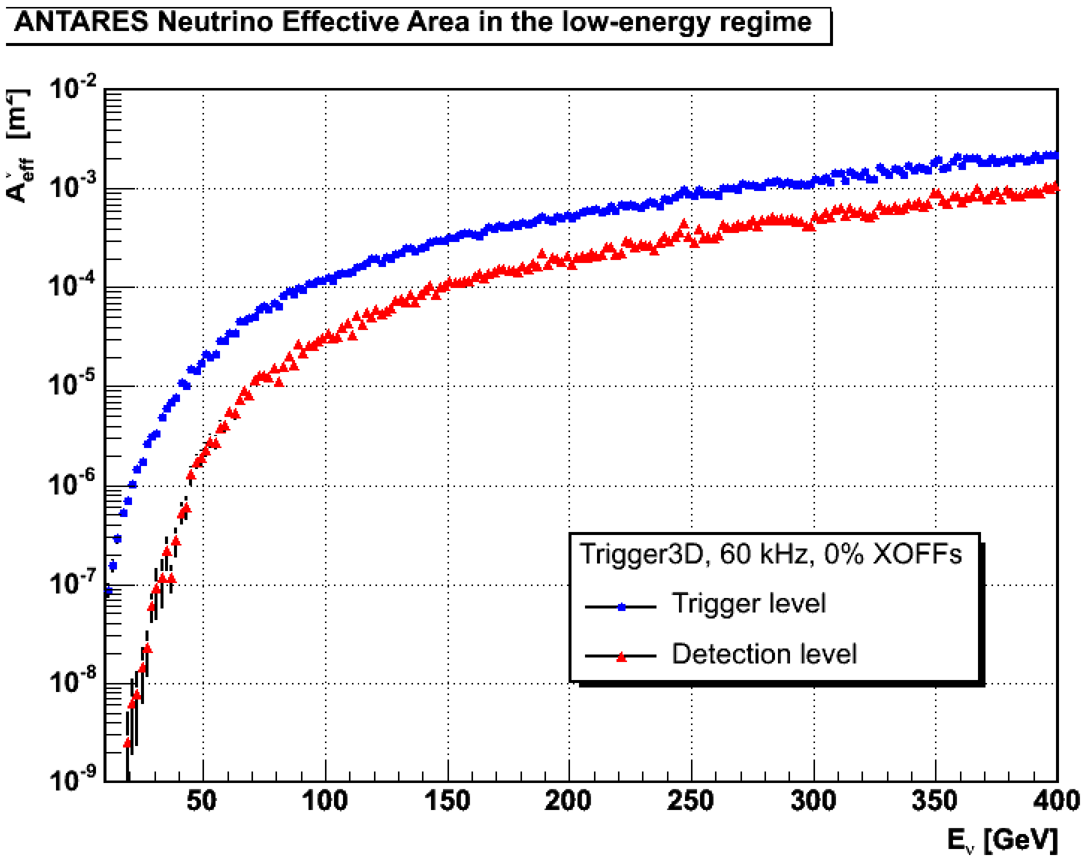
Earth coordinate System

Point Source Limits





No excess above background detected in any direction nor close towards possible source directions

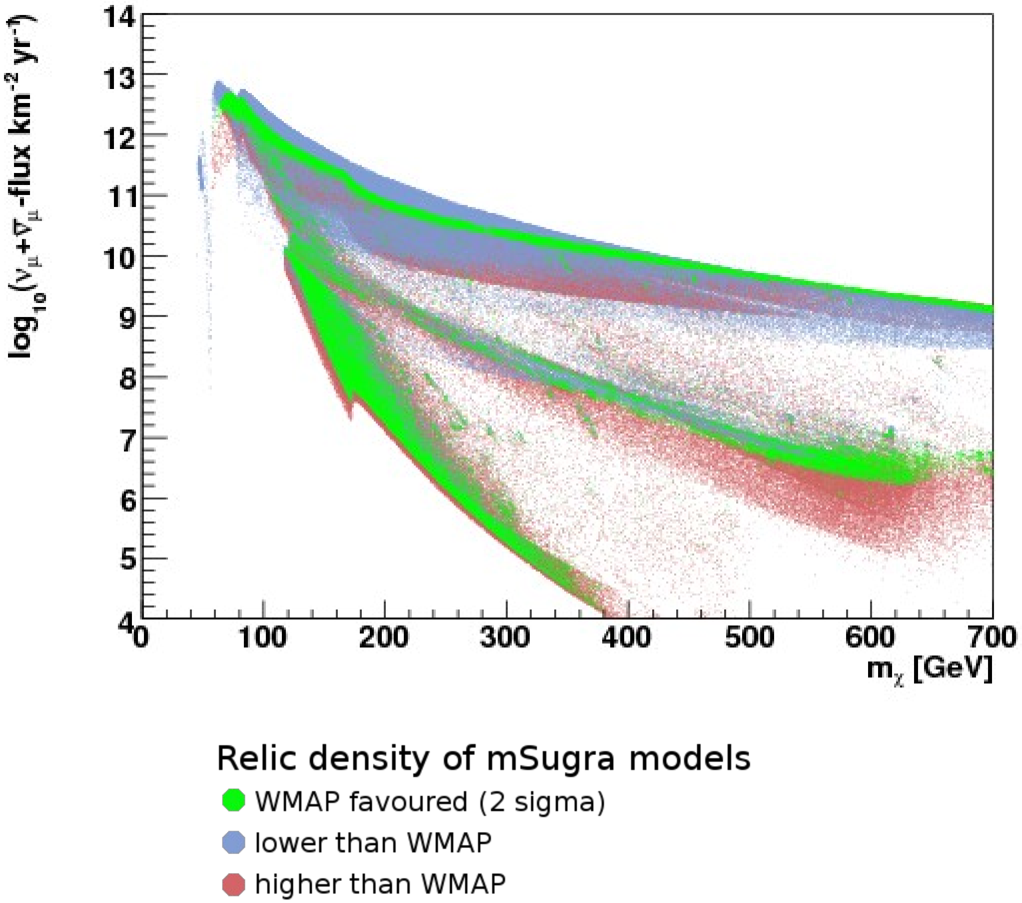


ANTARES Low-Energy Effective Area

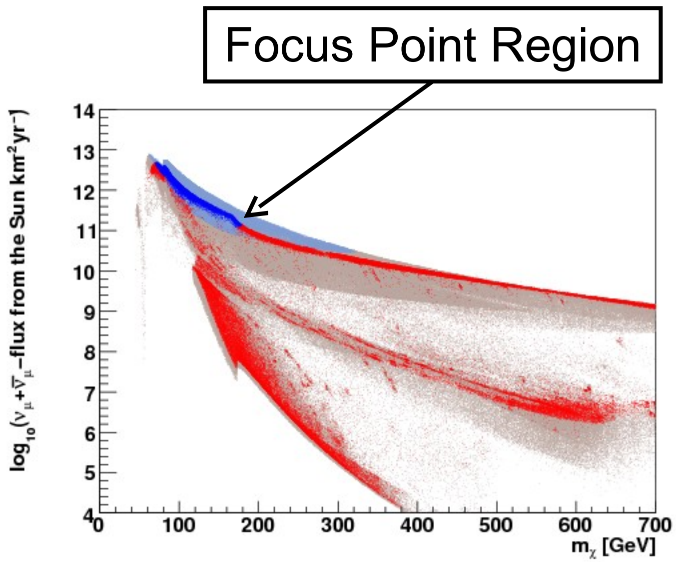
60 kHz background rate from K-40 decay and bioluminescence

Neutrino Flux from mSugra Dark Matter Annihilation in the Sun

- Integrated ν_μ and $\bar{\nu}_\mu$ flux above 10 GeV threshold energy plotted against m_χ
- From random walk scan of mSugra Parameter Space
- Calculated with DarkSUSY
- Includes oscillation effects
- RGE-code: ISASUGRA
- Halo-model: NFW
- m_{top} = 172.5 GeV



mSugra Parameter Space Regions

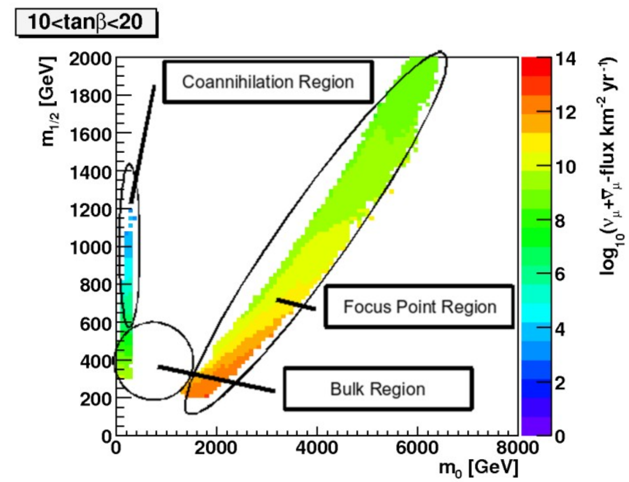


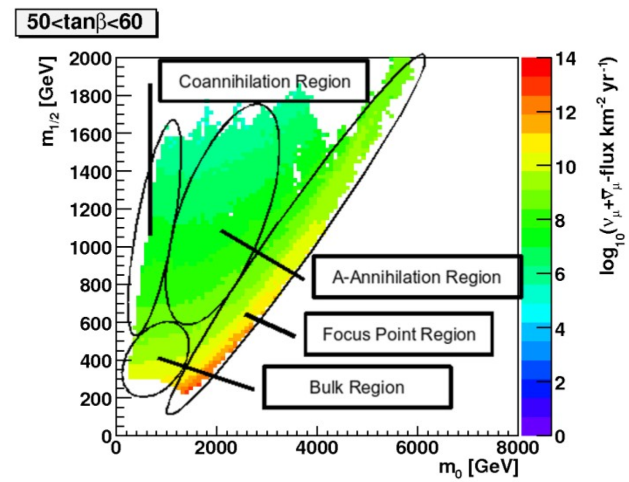
mSugra models favoured by WMAP

- 90% CL excludable by ANTARES
- not excludable

mSugra models disfavoured by WMAP

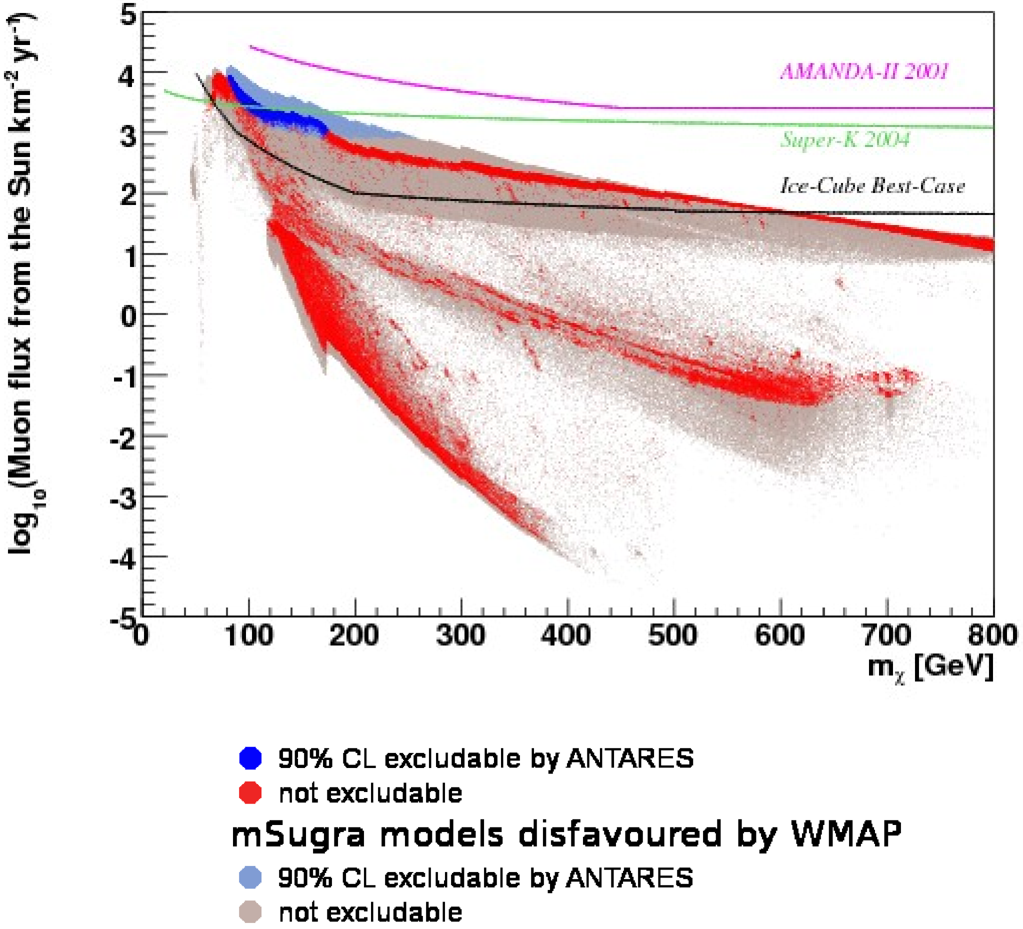
- 90% CL excludable by ANTARES
- not excludable





Muon Flux from mSugra Dark Matter Annihilation in the Sun

- Comparison to other neutrino experiments
- Site dependent quantity
- Derived from neutrino flux through ν to μ conversion rate extracted from DarkSUSY for different m_χ (approximation)

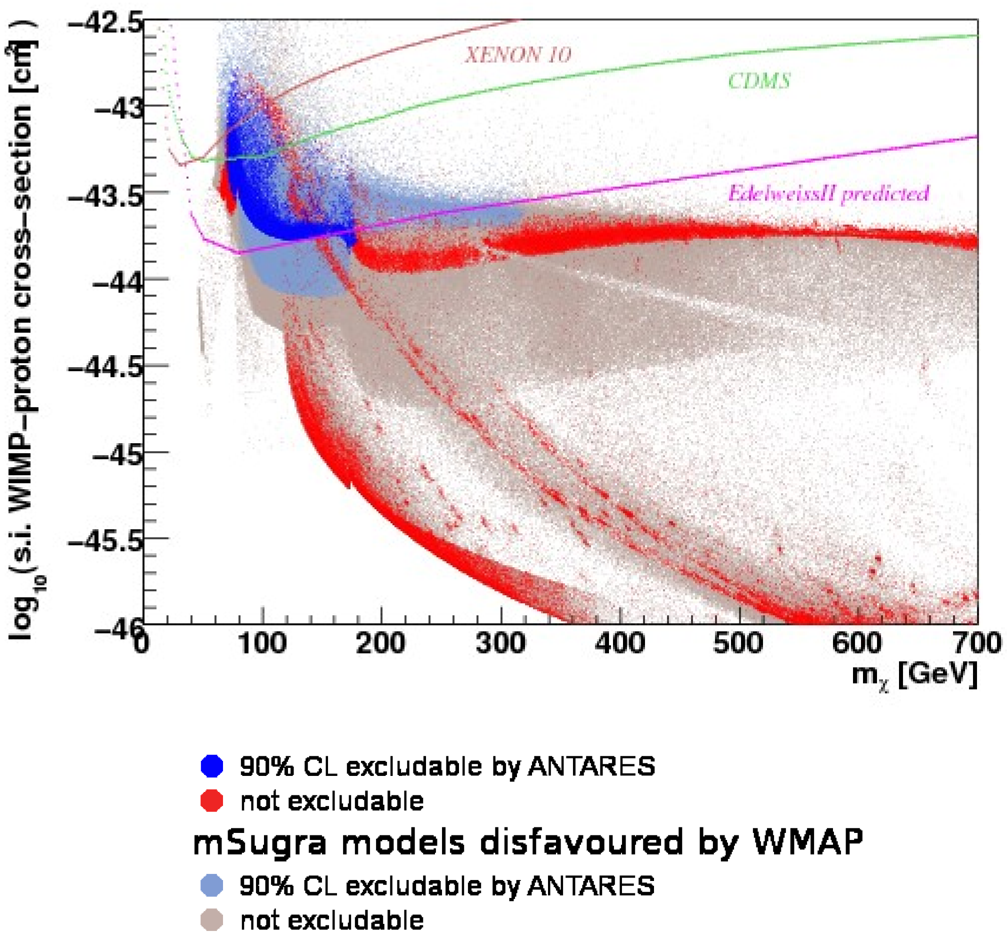


Direct Detection (Spin Independent)

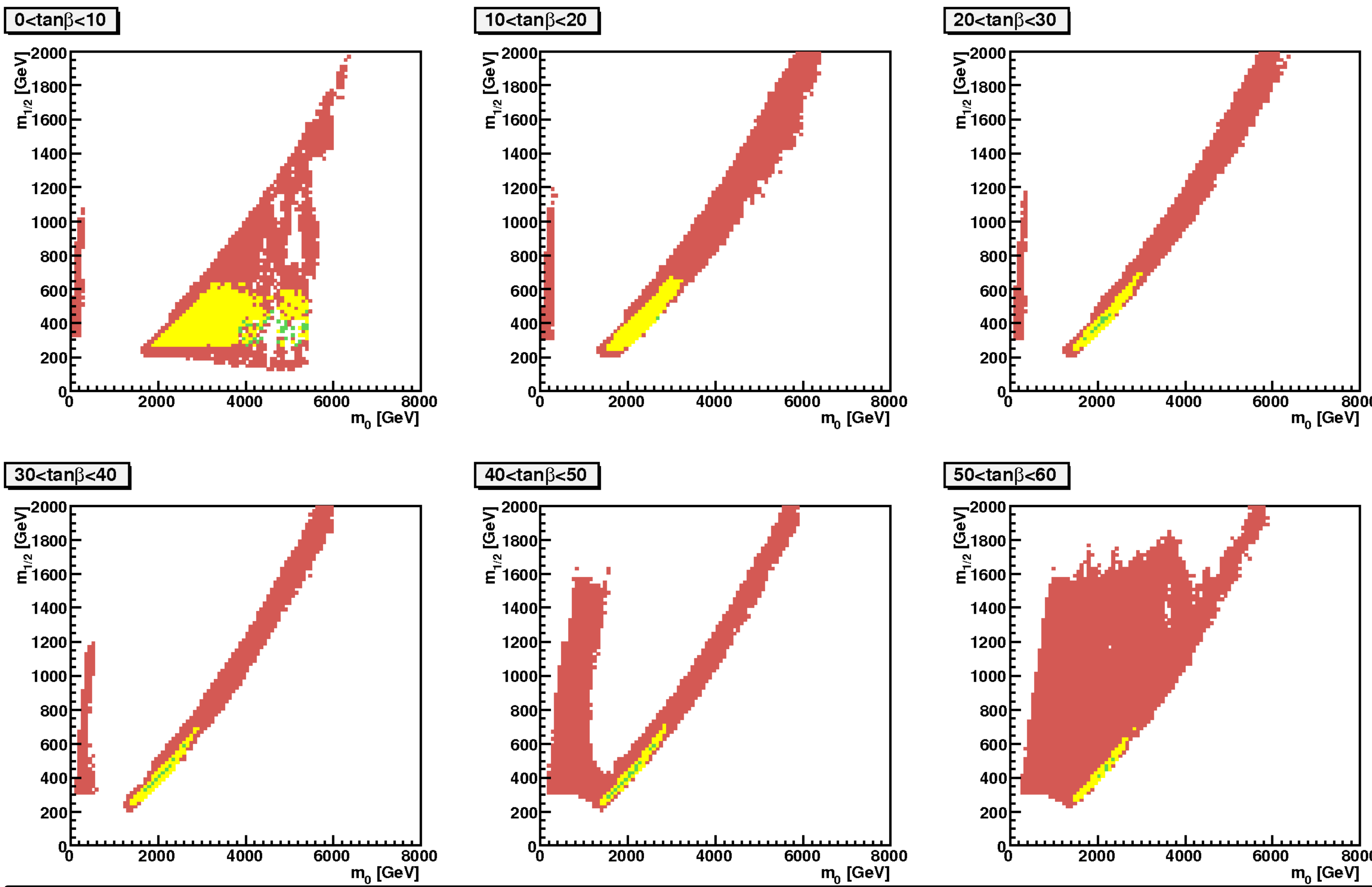
•Comparison to direct detection experiments sensitive to spin independent WIMP-nucleon crossection

CDMS: arXiv:0802.3530

XENON: arXiv:0706.0039



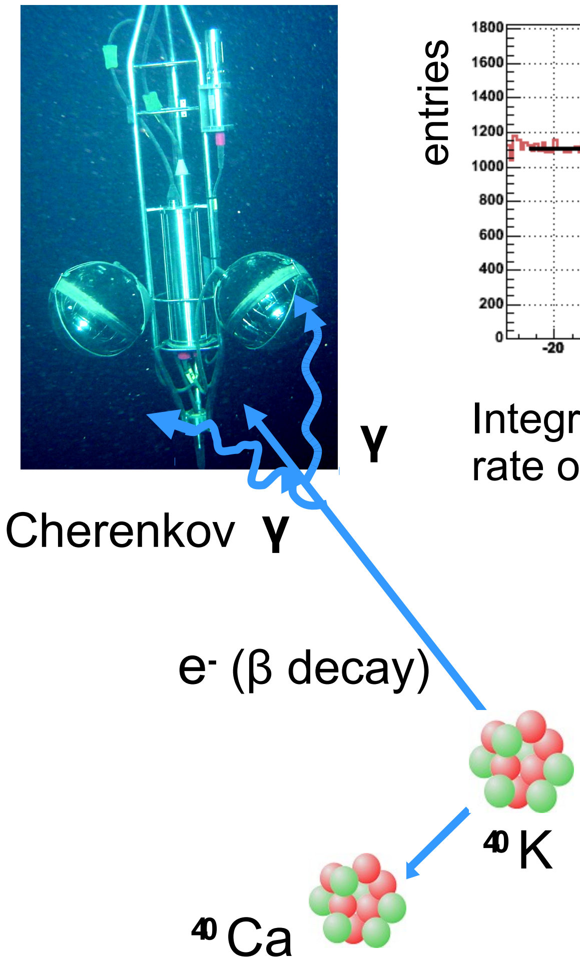
Exclusion Capabilities of ANTARES for the mSugra Parameter Space



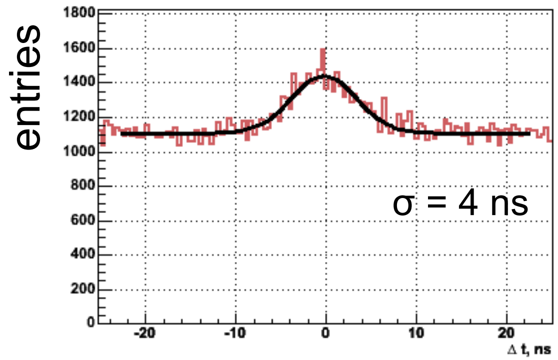
Excludable in 3 years at 90% CL: all some none

(A_0 varied between $-3m_0$ and $+3m_0$ and tan(β) within indicated slice)

In Situ Calibration with Potassium-40



Time difference between hits in two OMs



Pedestal = random coincidences (from ^{40}K and bioluminescence)

Gaussian peak = genuine coincidences from ^{40}K

MC prediction (18 ± 4 Hz)

Integral under Gaussian fit curve = rate of correlated coincidences

→ High precision (~5%) monitoring of OM efficiencies

Peak offset ?

→ Cross-check of time calibration ("0" = ideal calibration)