The ANTARES Deep-Sea Neutrino Telescope: Status and First Results

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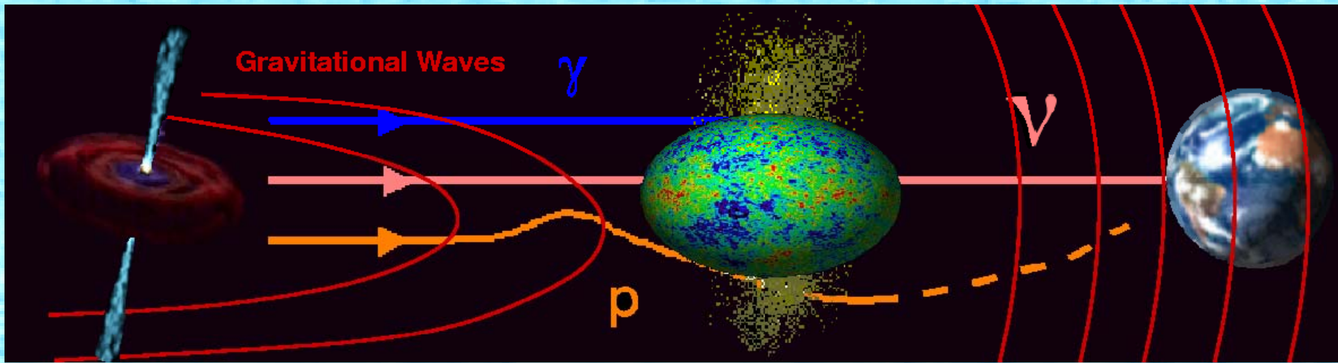
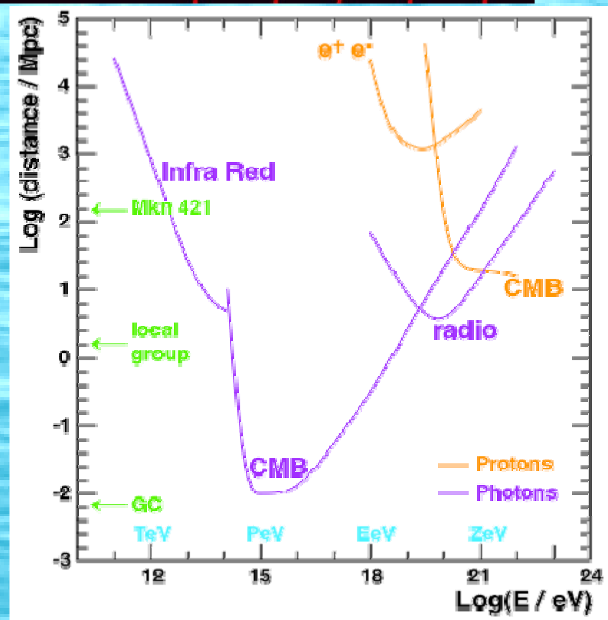
CPPM, Marseille
Les Rencontres de Physique
de la Vallée d'Aoste.

28 Feb.- 06 March 2010

Multimessenger Astronomy

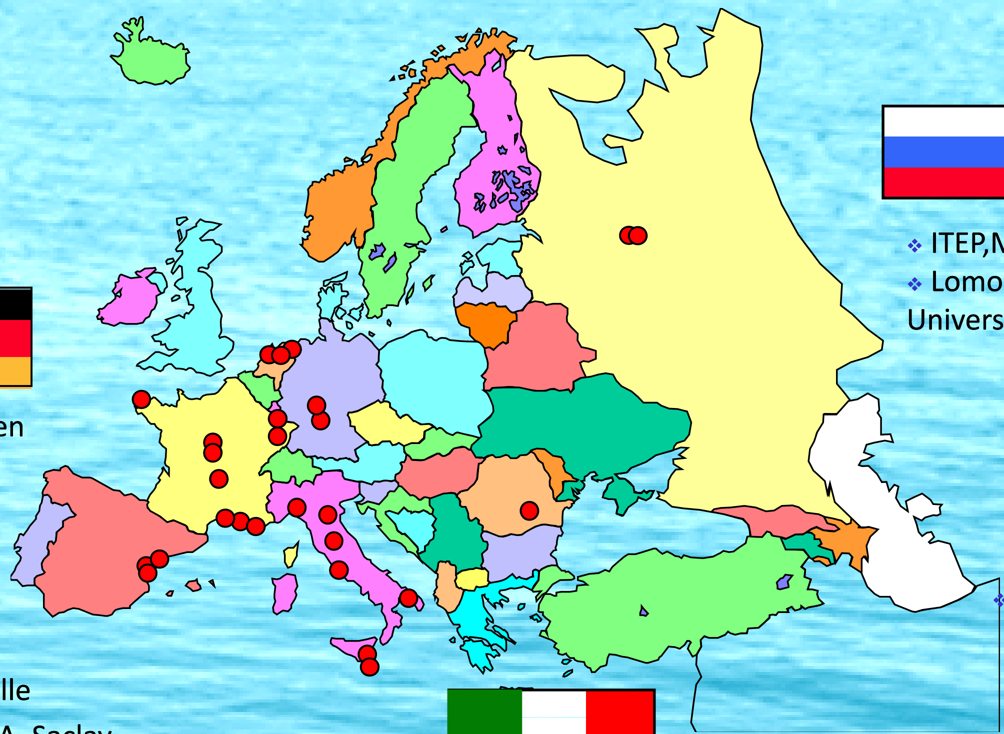


γ	Interaction with: Interstellar medium, IR, CMB, radio.
p	Deflected by B fields. Useful above 10^{20}eV, but GZK effect.
ν	Not deflected by B fields, Not absorbed by dust, Unambiguous probe of hadronic processes.



absorption		cut-off	mean free path
γ-rays:	$\gamma + \gamma_{2.7k}$	$>10^{14}$eV	10 Mpc
proton:	$p + \gamma_{2.7k} \rightarrow \pi^0 + X$	$>5.10^{19}$eV	50 Mpc
neutrinos:	$\nu + \nu_{1.95K} \rightarrow Z+X$	$>4.10^{22}$eV	(40 Gpc)

The ANTARES Collaboration



- NIKHEF, Amsterdam
- KVI Groningen
- NIOZ Texel

- ECAP, Erlangen
- Bamberg

- IFIC, Valencia
- UPV, Valencia
- Technical Univ. Catalonia, Barcelona

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

- ITEP,Moscow
- Lomonosov State University, Moscow

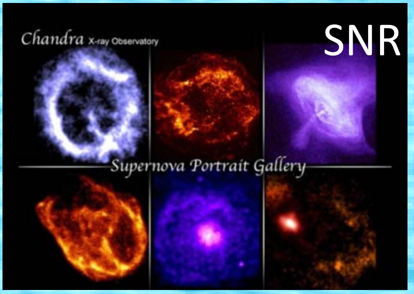
- ISS, Bucarest

- 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

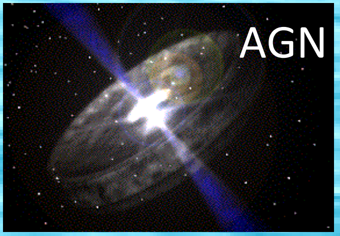
ANTARES science goals

Understanding production mechanisms of HE cosmic rays.

<u>Study very energetic objects</u>:
_ Galactic: SN, SNR, Microquasars, …
_ Extra-Galactic: AGN, GRB, …

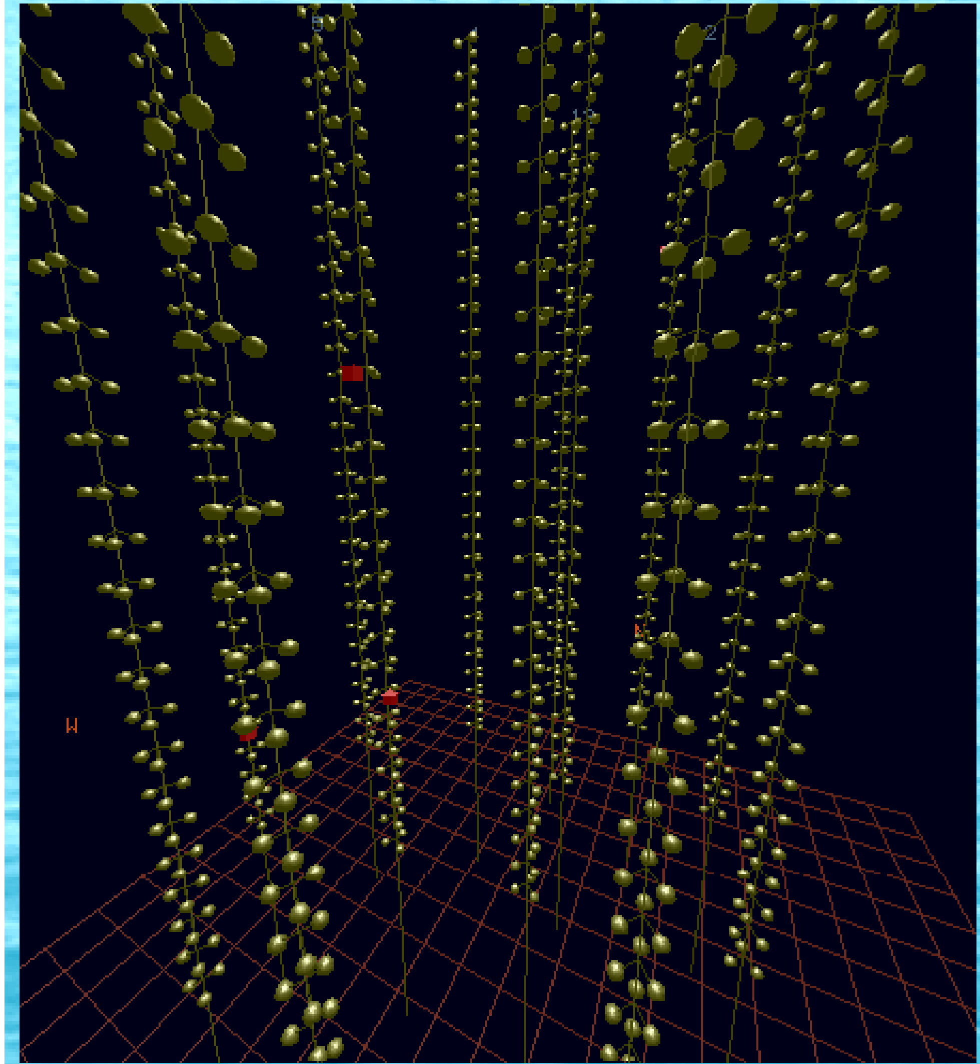


<u>Search for new physics</u>:
Dark matter (Sun, GC), Monopoles, Nuclearites, …

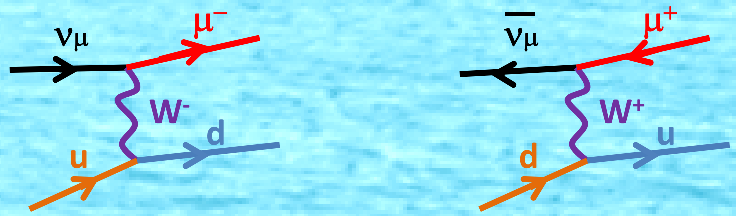


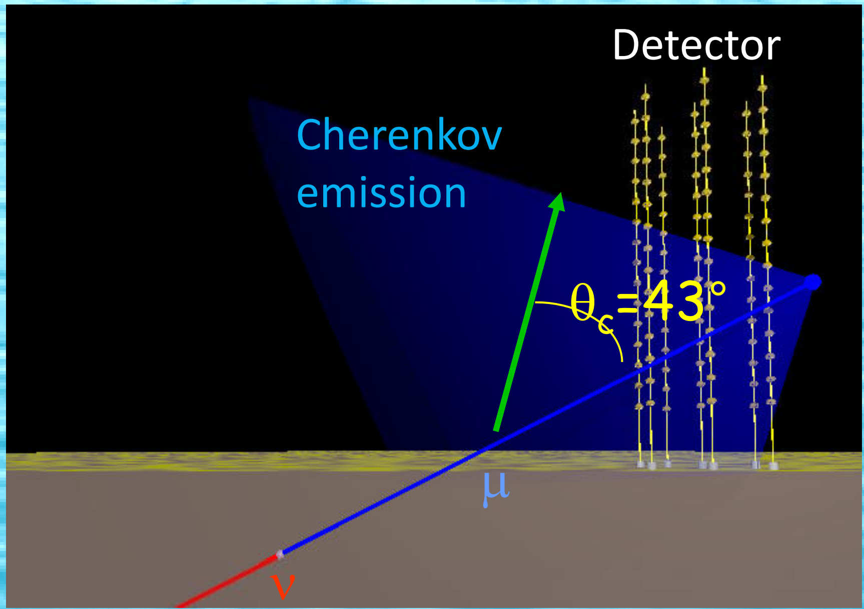
<u>Multidisciplinary science</u>:
Oceanography, Sea biology, Seismology, Environment monitoring, …

Detection Principle



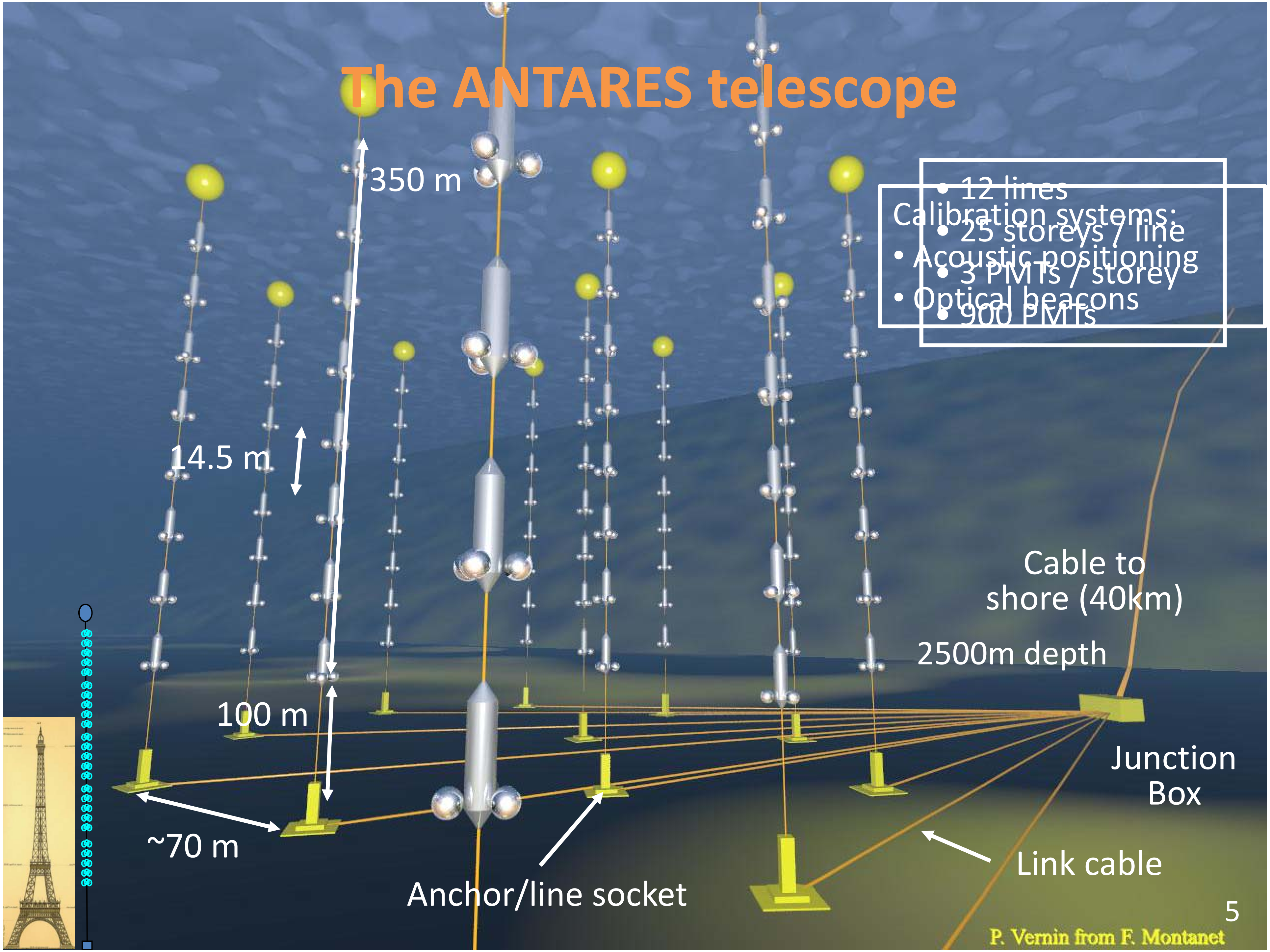
MC TeV muon traversing the apparatus





Time-position correlation
➡ muon direction.

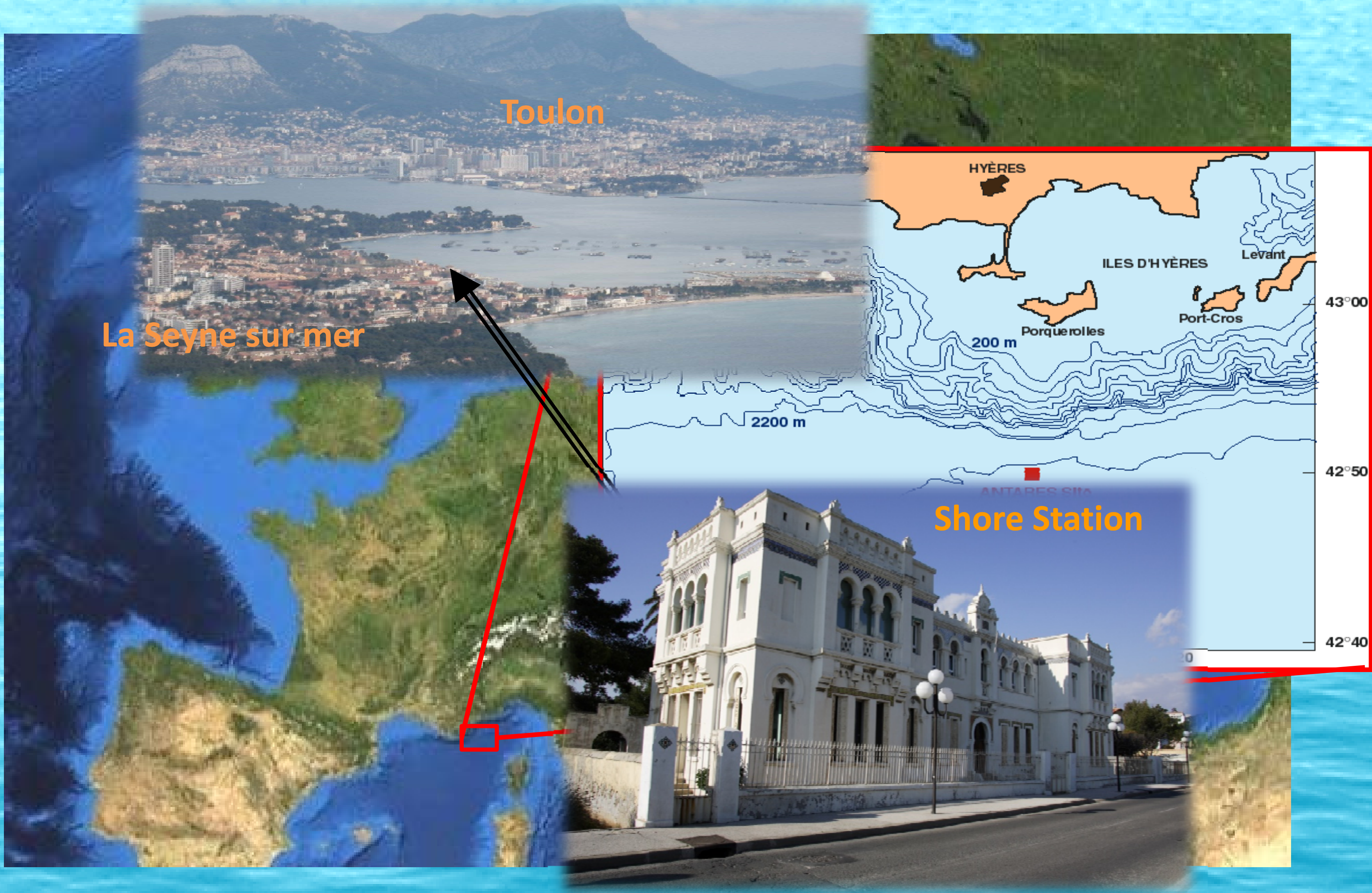
The ANTARES telescope



- 12 lines
- 25 storeys / line
- 3 PMTs / storey
- 900 PMTs

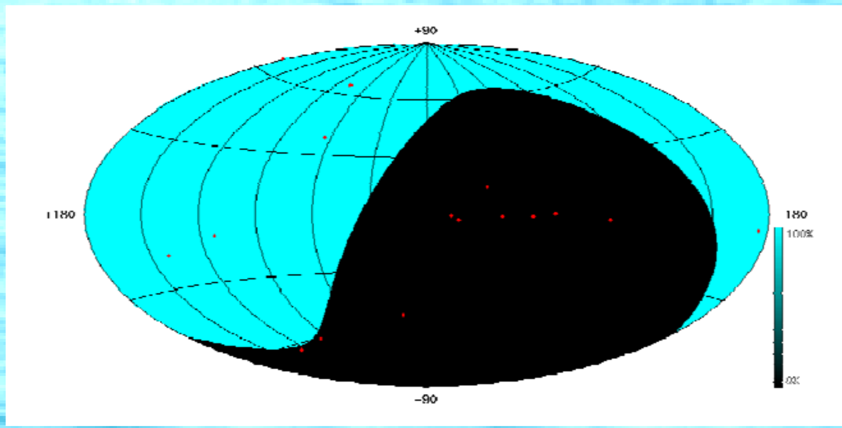
Calibration systems:
- Acoustic positioning
- Optical beacons

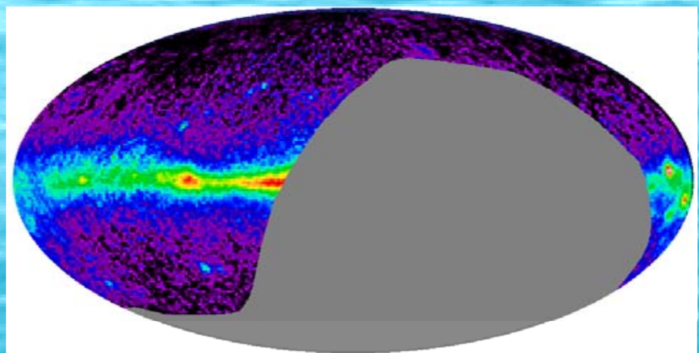
The ANTARES site



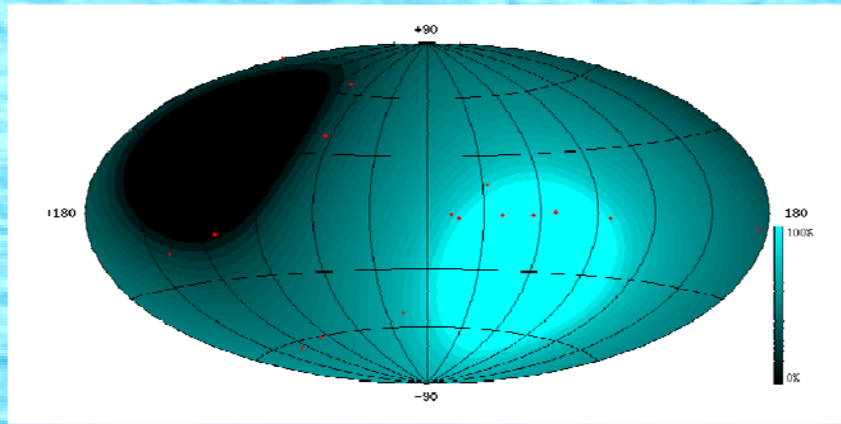
Sky coverage

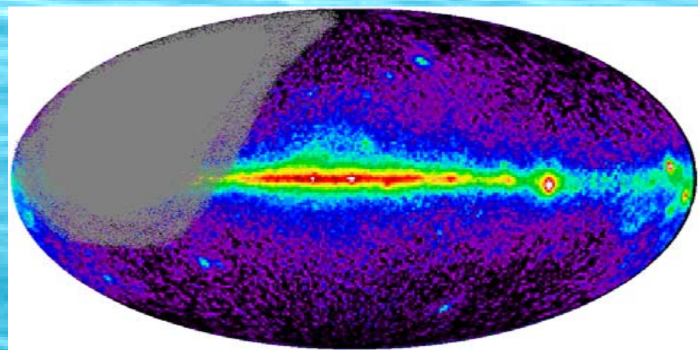
AMANDA/IceCube (South Pole)
(resolution in ice: ~2°/0.8°)





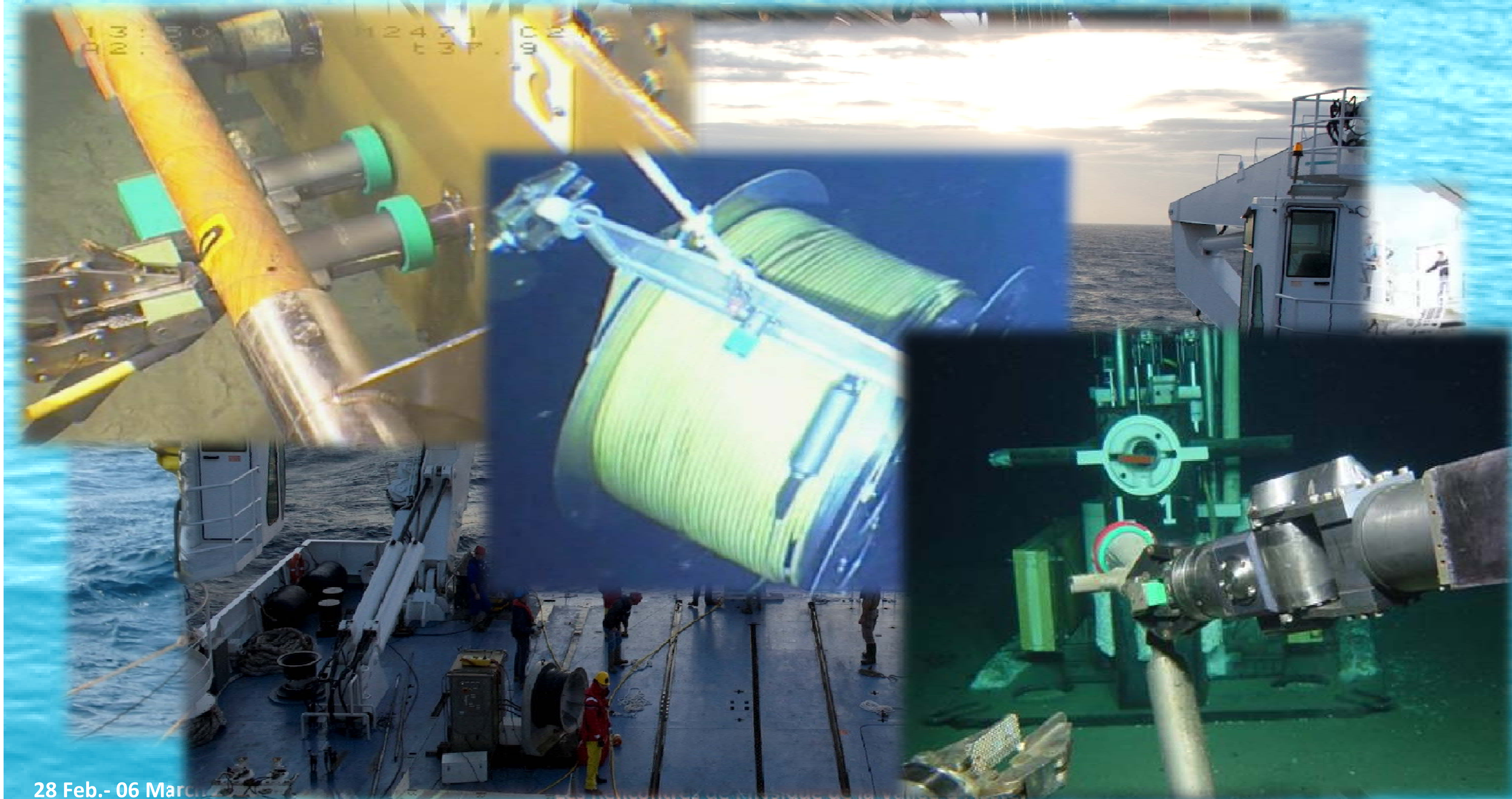
ANTARES (43° North)
(resolution in water: 0.3°)



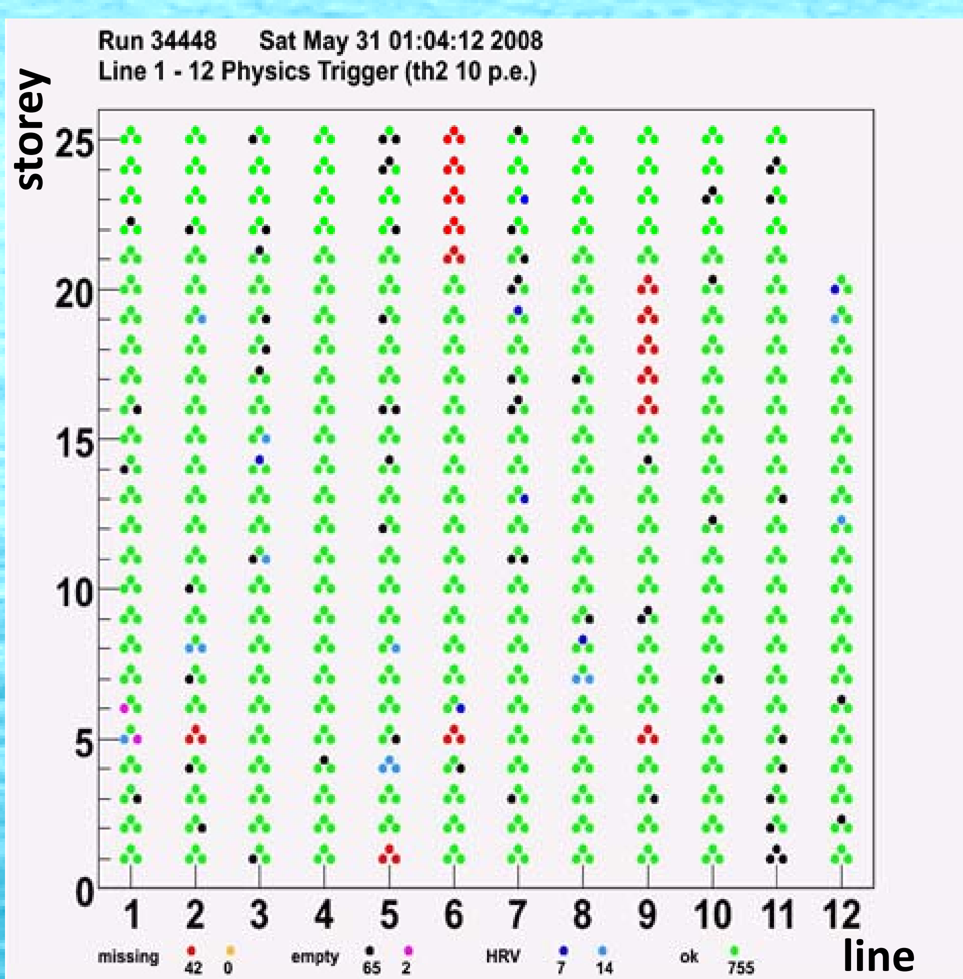


Line connections

- **2006** **Lines 1, Line 2**
- **2007** **Lines 3 - 5, Lines 6 -10**
- **2008** **Lines 11-12**



Detector status after completion



Detector completed 30 May 2008.

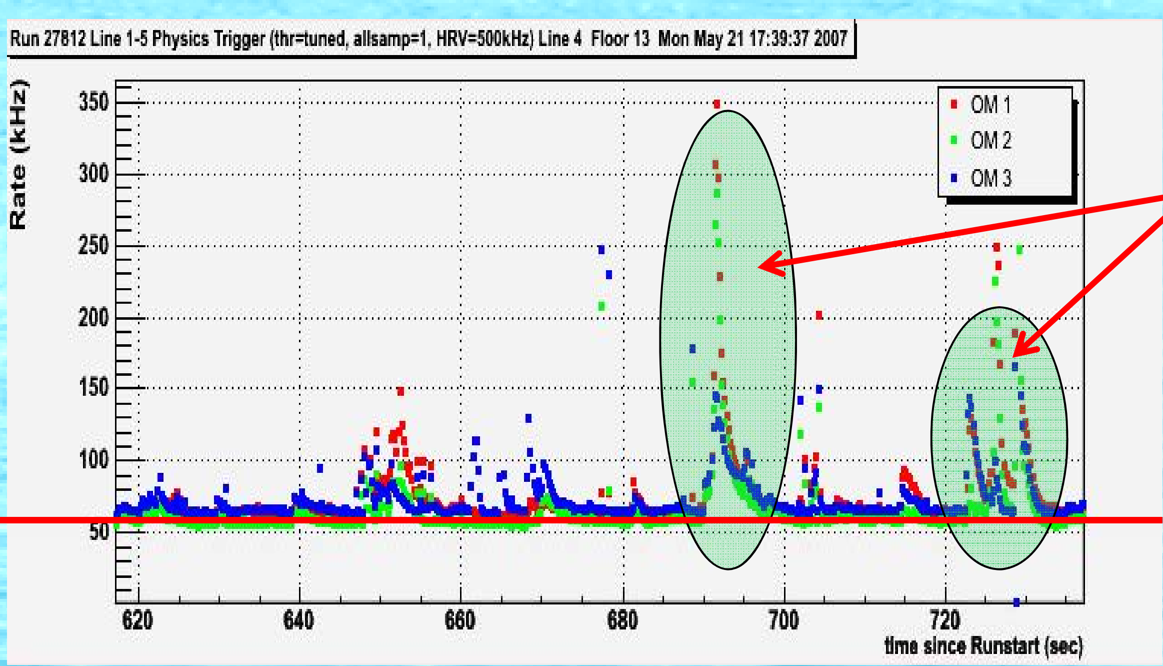
Regular maintenance of the infrastructure foreseen.

Line 12: Successful recuperation+repair, and then redeployment in November 2009.

Line 6: Currently in reparation.

Line 9: Planned to be recovered this week.

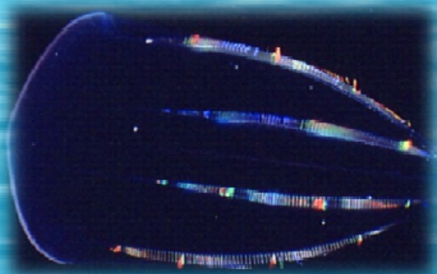
Optical Background

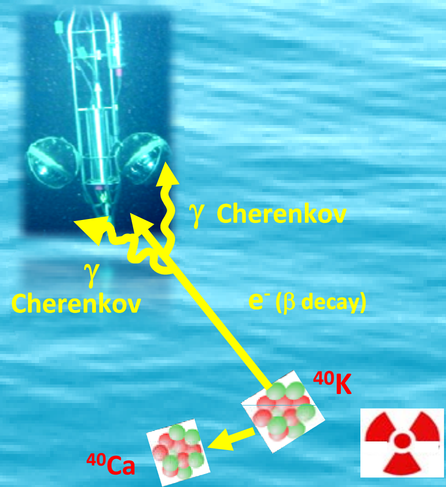


Bursts from macroorganisms (strongly affected by sea currents)

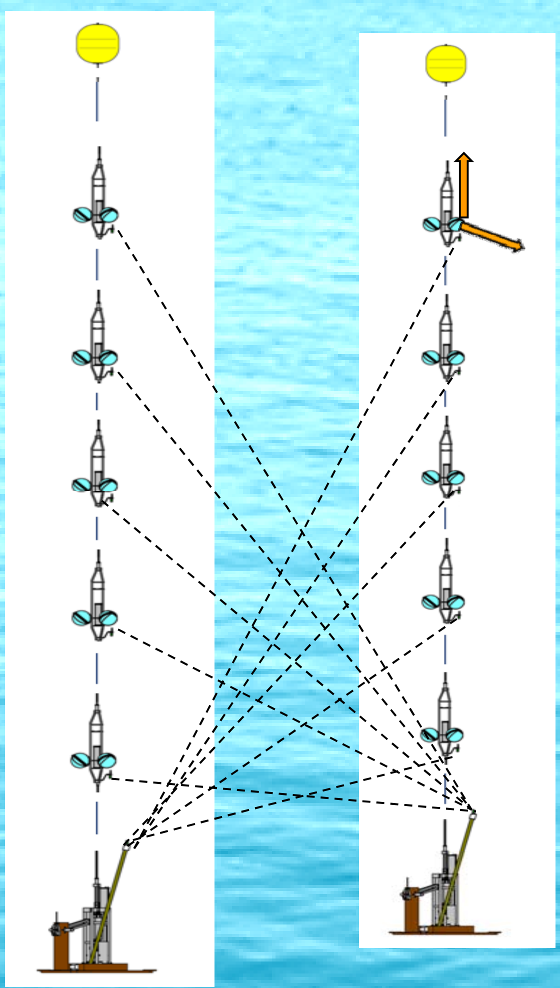
Baseline

~ 60kHz from K^{40} + microorganisms.

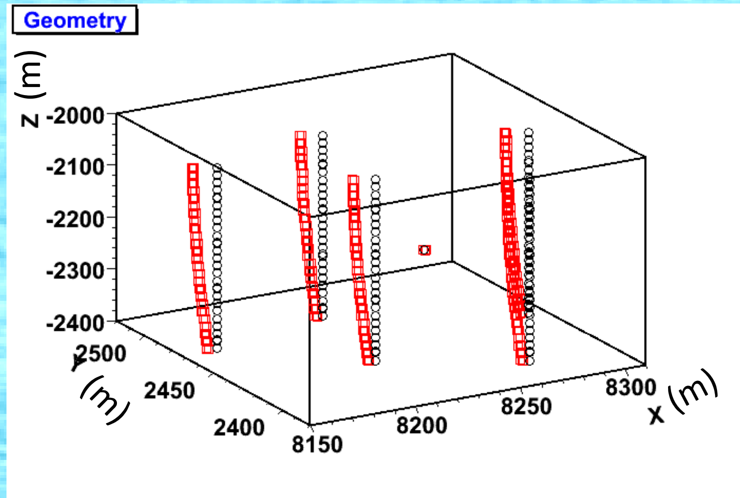


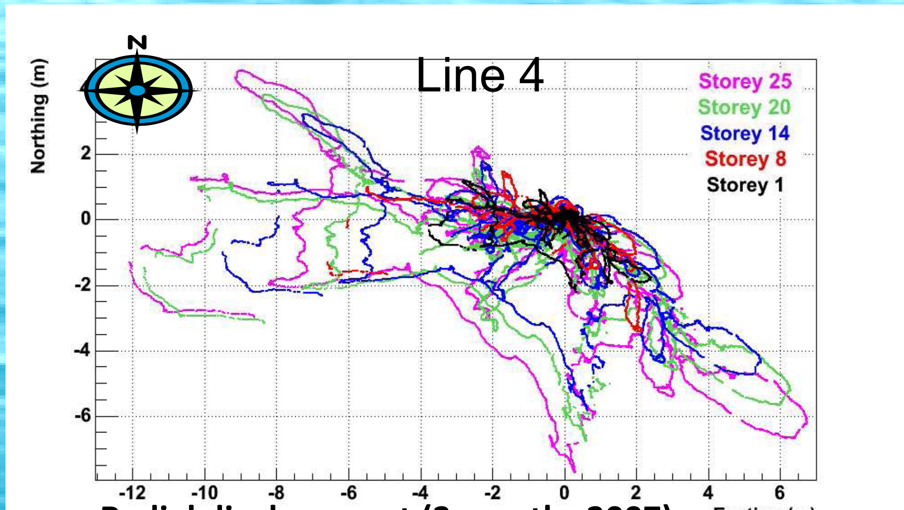


Position Alignment



Distances and rotations measured every 2 min.



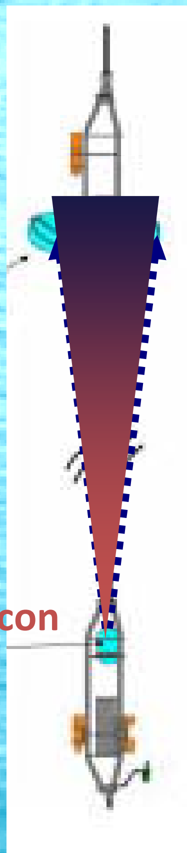


Radial displacement (2 months 2007)

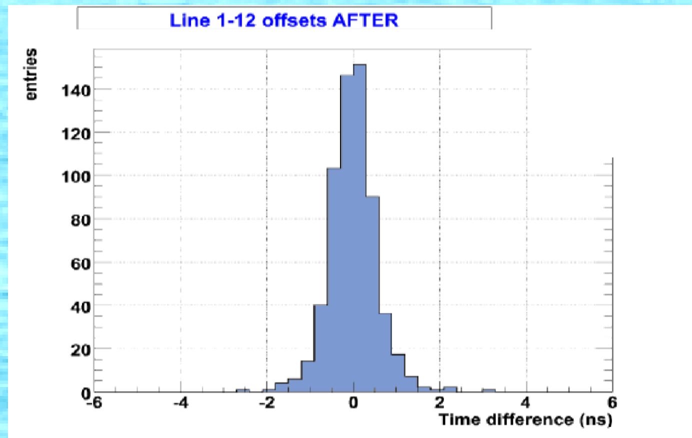
Position resolution better than ~ 10 cm.

In situ Calibration

Computation of time differences between pairs of OMs.



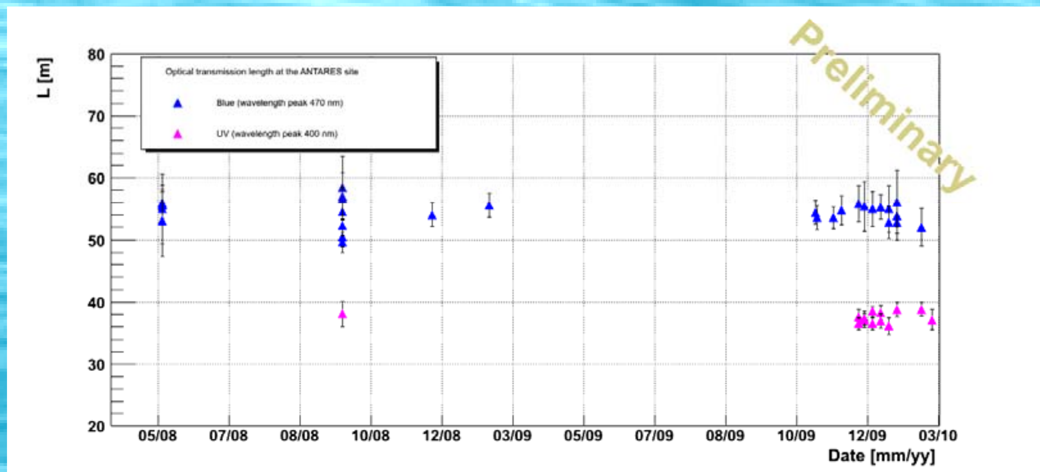
LED beacon



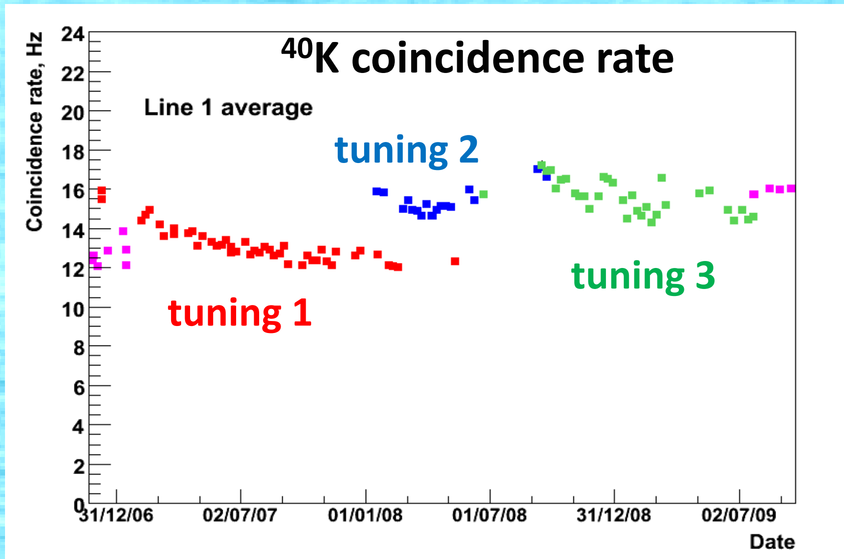
➡ Time resolution of ~ 0.5 ns.

Detector efficiency:

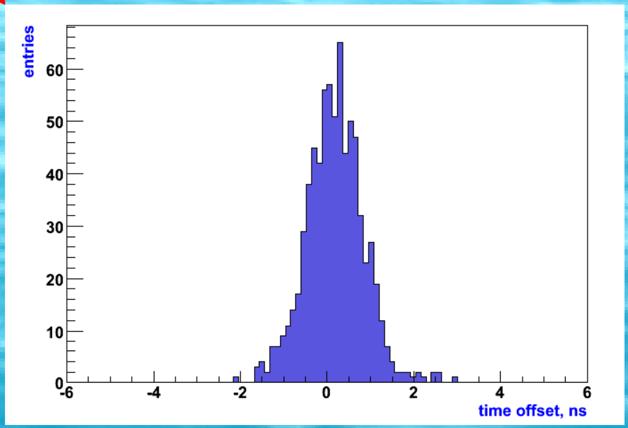
Absorption length at ANTARES site.



In situ Calibration with K^{40}

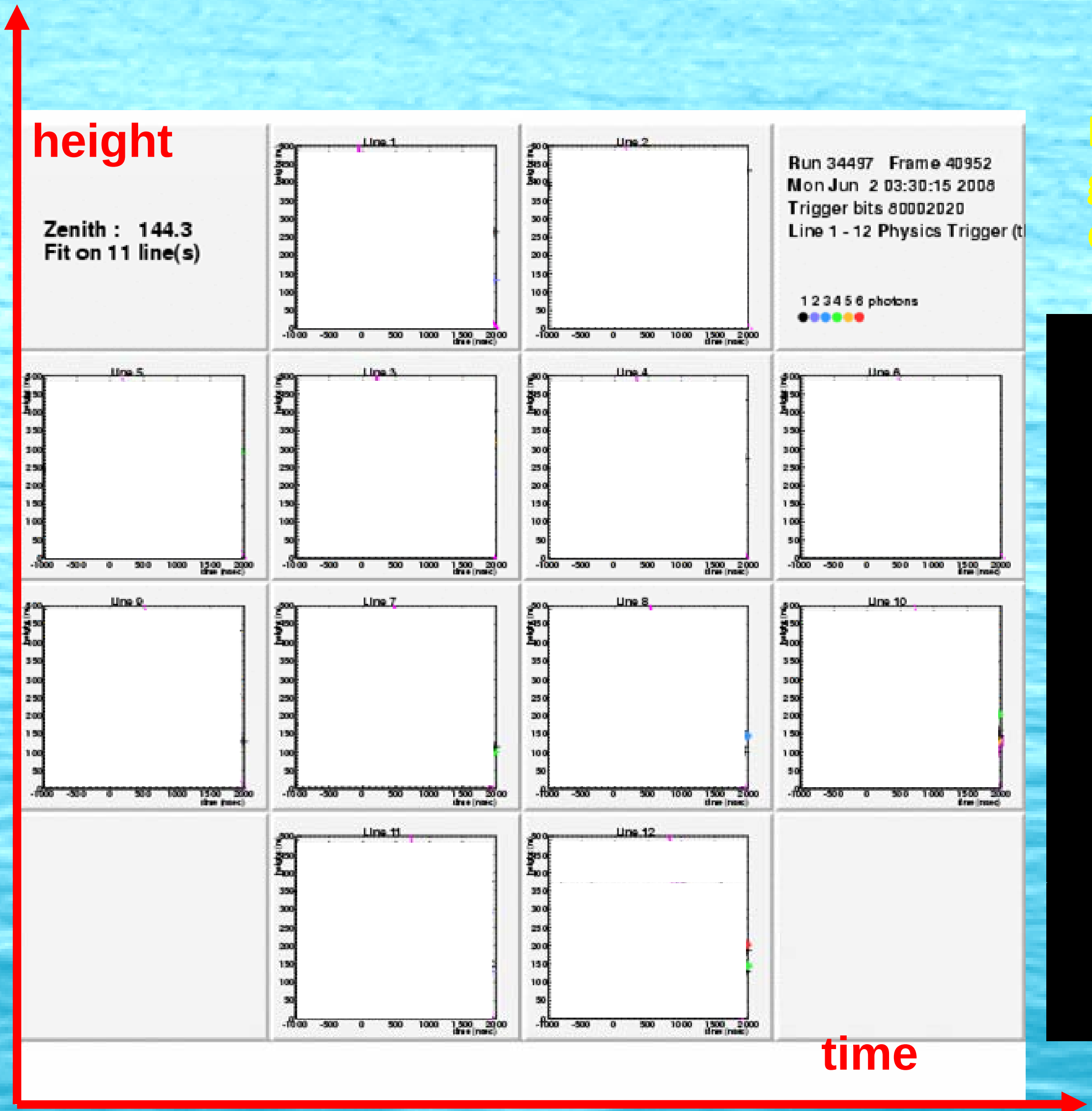


Time offsets for all OMs

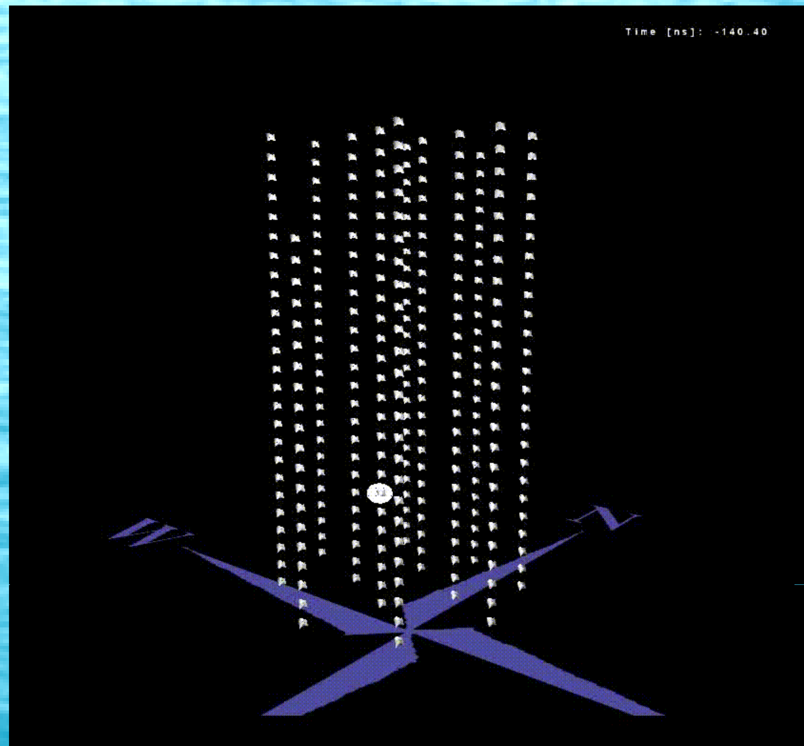


Crosscheck of time calibrations.

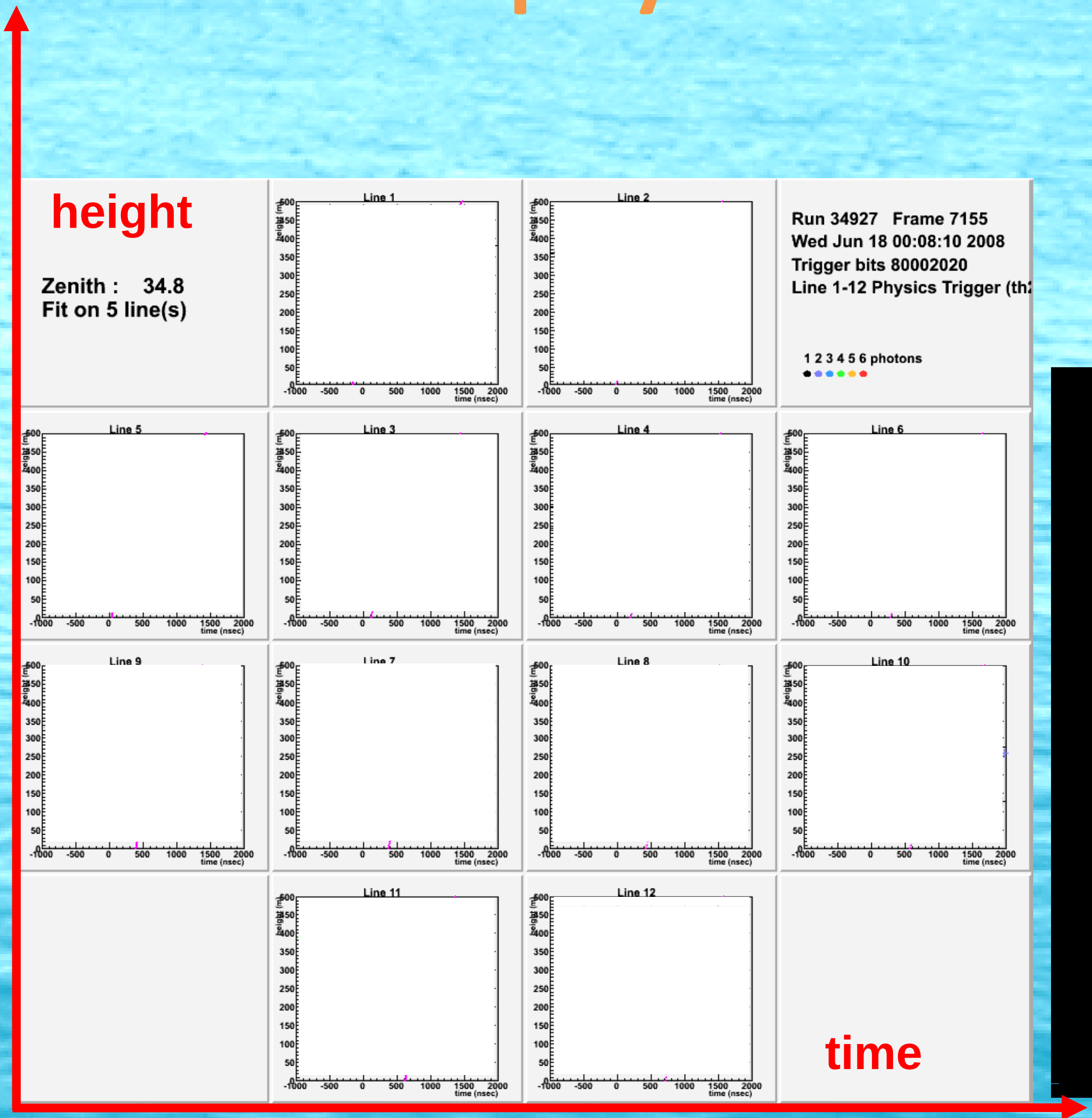
Event display: Atmospheric muon



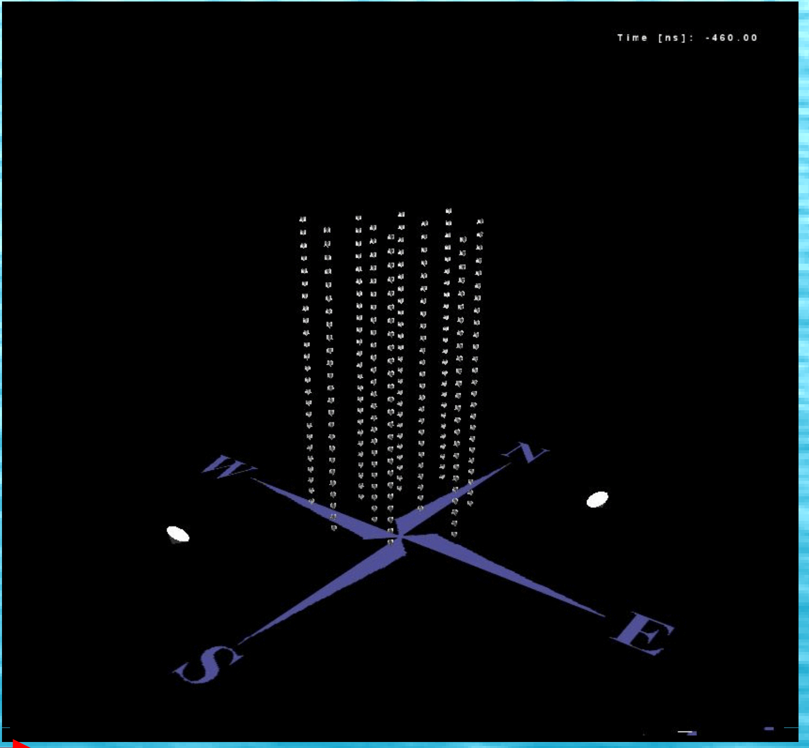
Example of a reconstructed down-going muon, detected in all 12 detector lines.



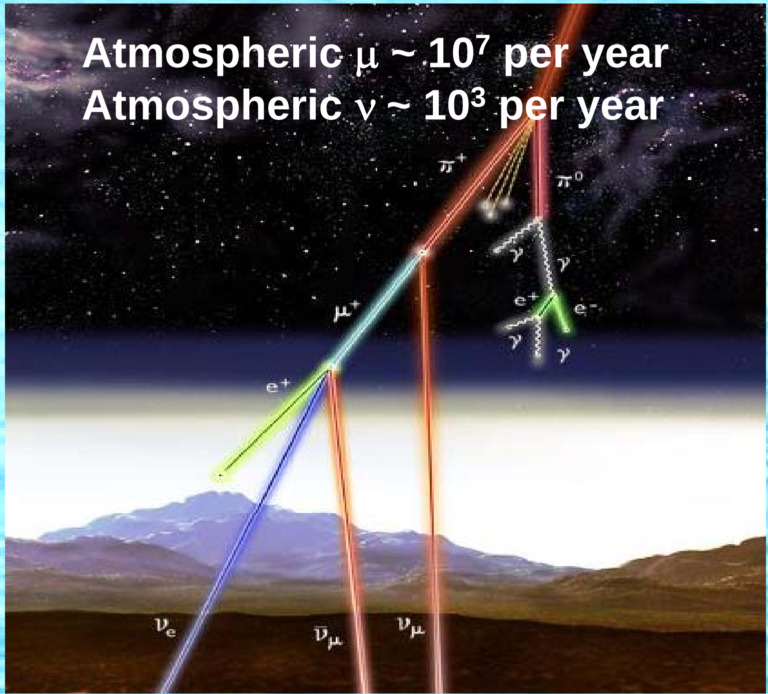
Event display: Neutrino-induced muon

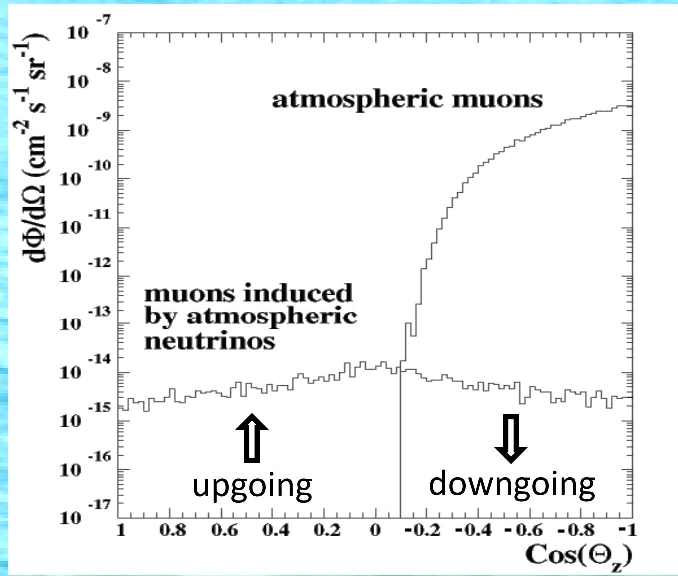


Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6 detector lines.

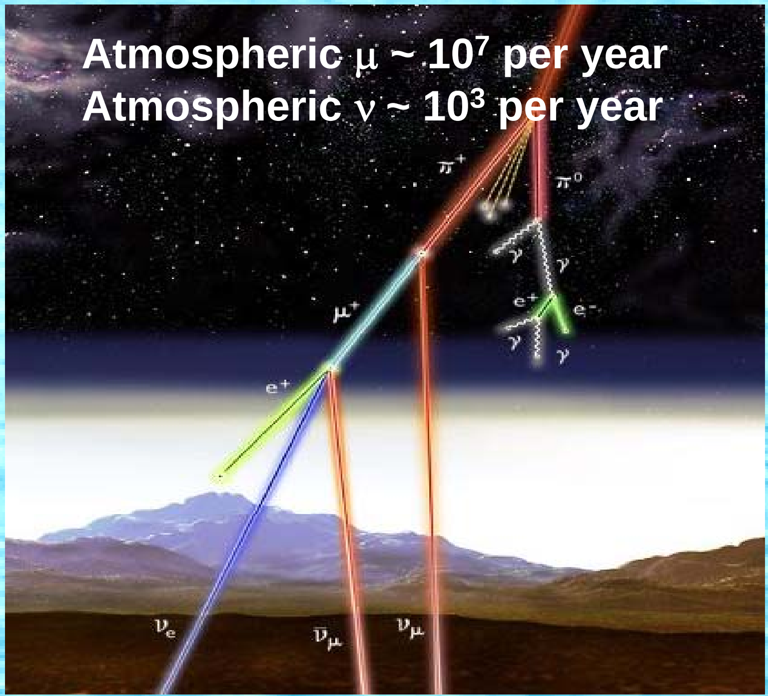


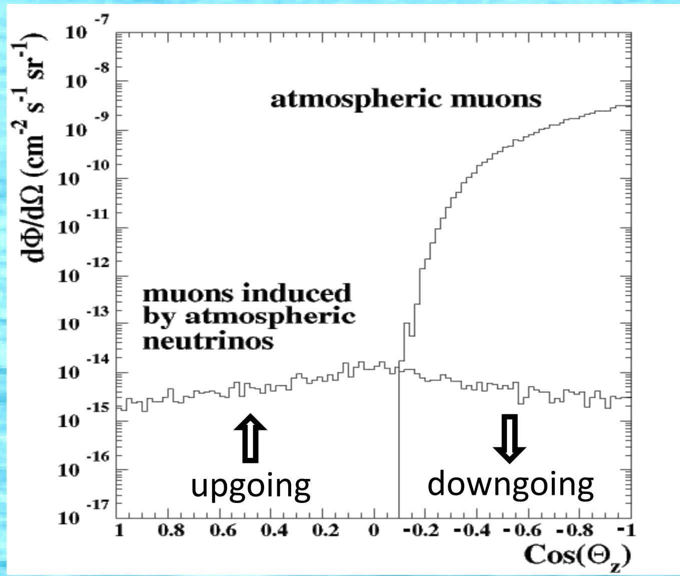
Atmospheric Background





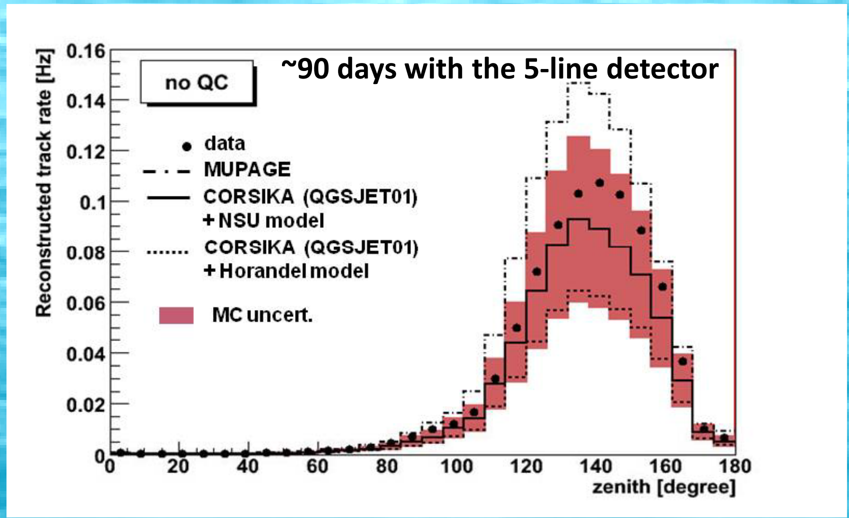
Atmospheric Background





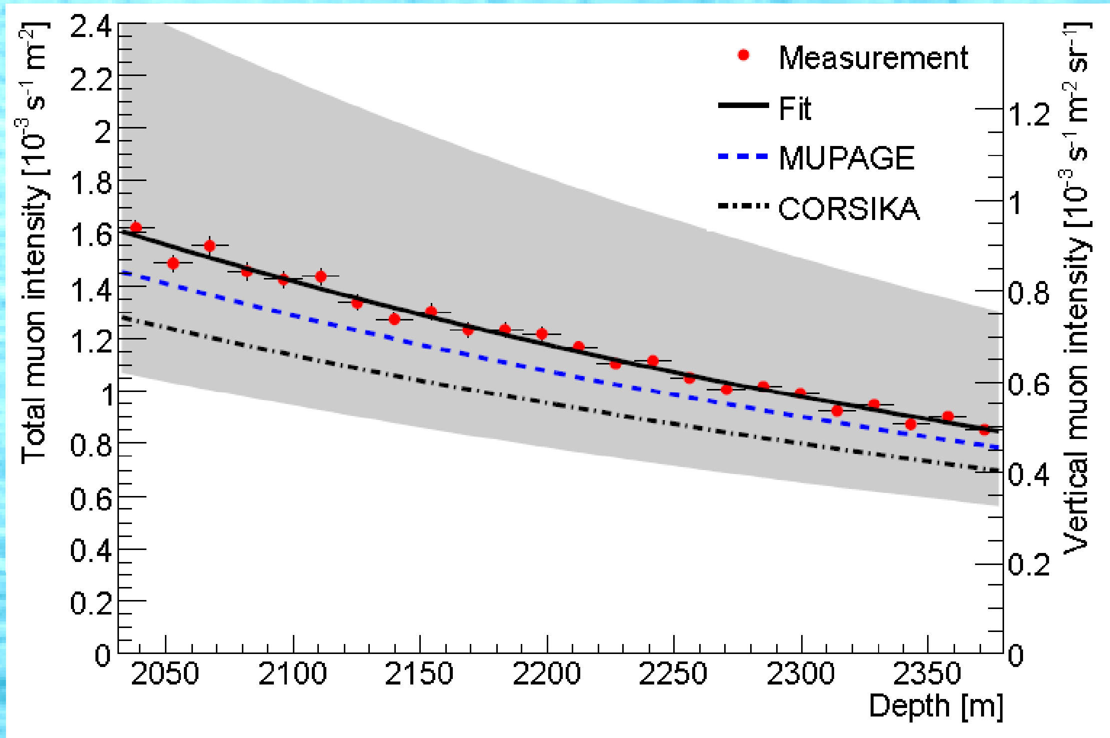
Main sources of simulation uncertainties:

- Angular dependance of OM efficiency.
- Absorption length of light in sea water.



Measurements agree with MC within systematics, and cannot distinguish between this various models.

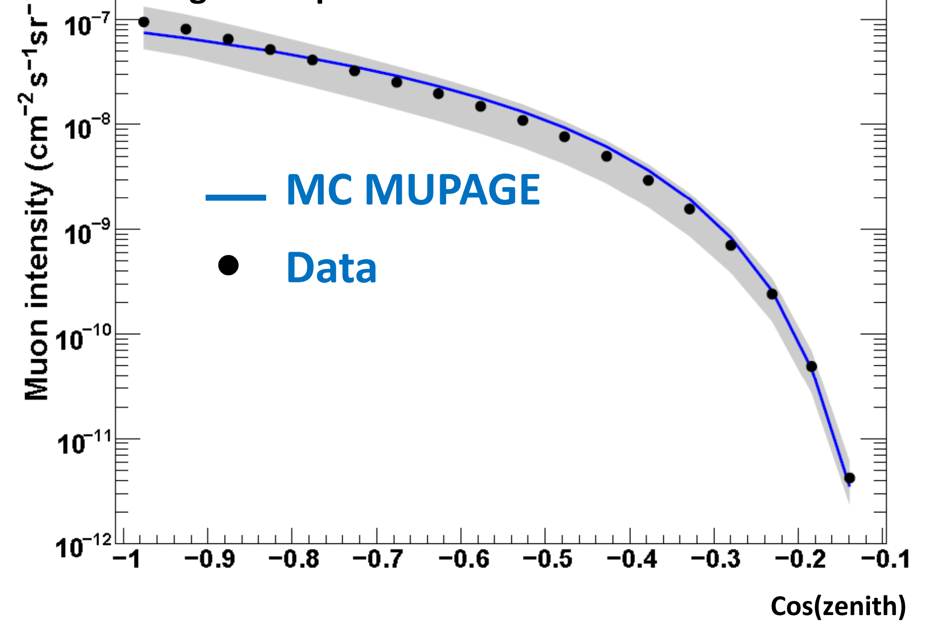
Muon depth-intensity relation from coincidence rates



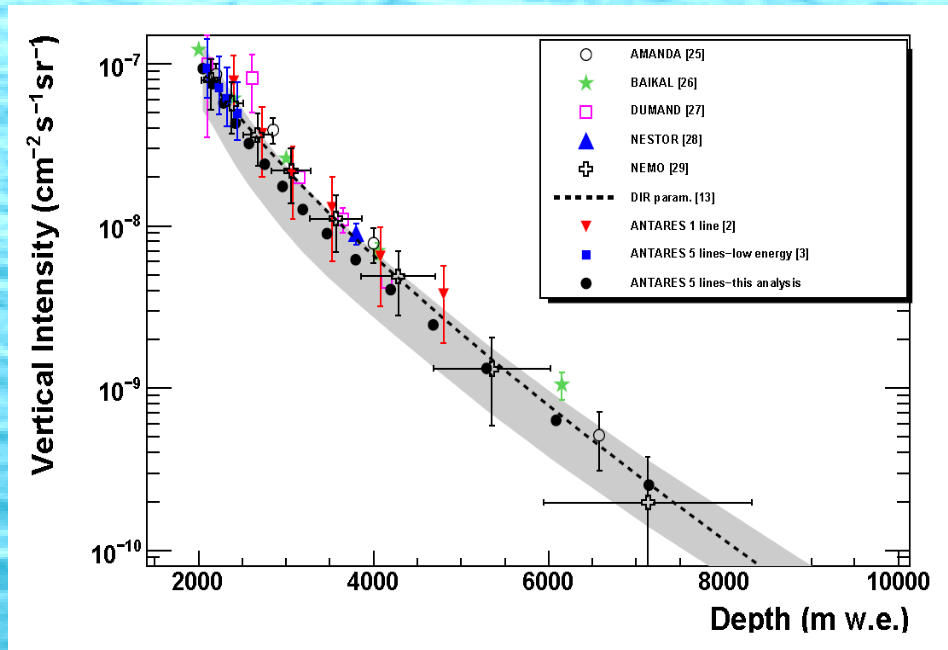
Low-energy threshold compared to full reconstruction.
Muon flux attenuation with depth directly measured.
Paper accepted for publication in Astroparticle Physics.
(Astroparticle Physics 33 (2010) pp. 86-90)

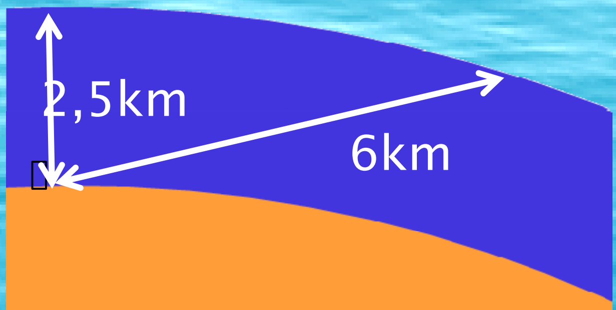
Depth-intensity relation for atmospheric muons

Angular dependance of the muon flux at 2000m.



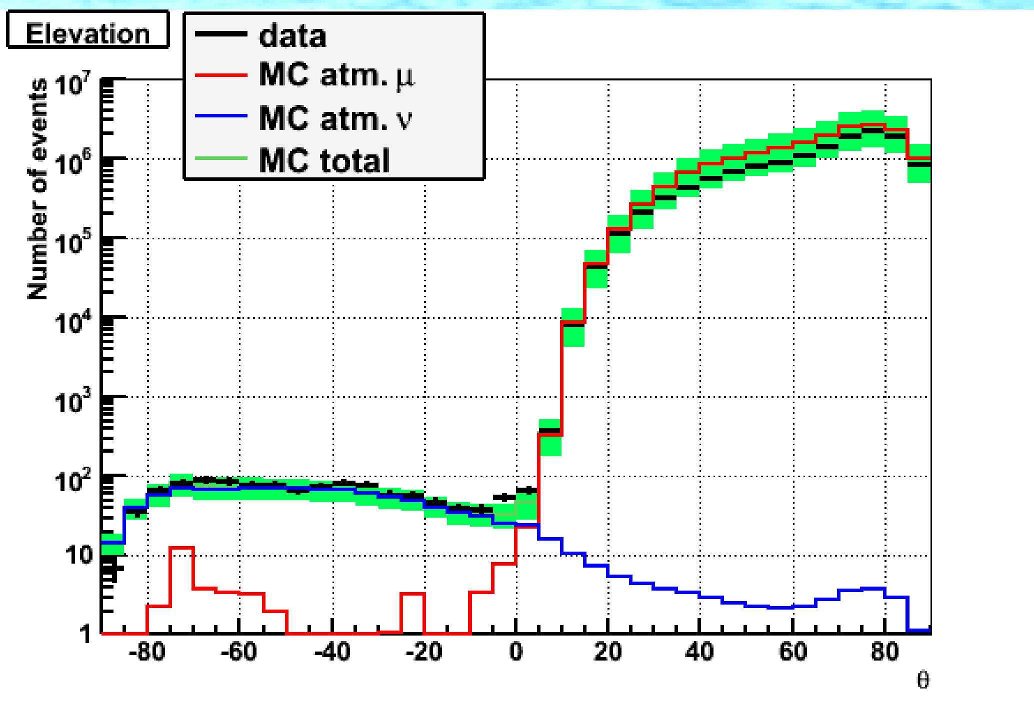
~ 90 days with the 5-line detector





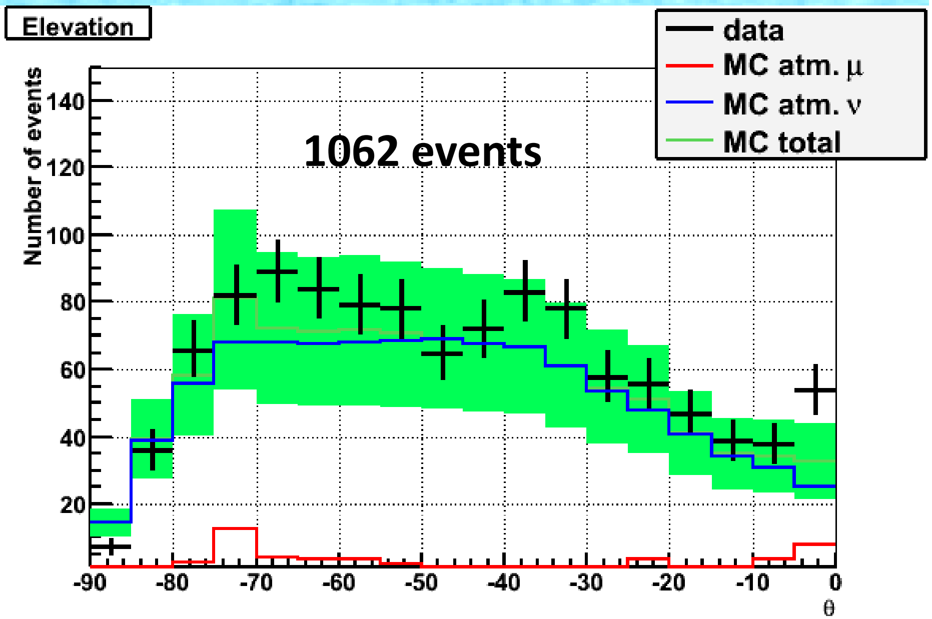
Submitted to Astroparticle Physics.

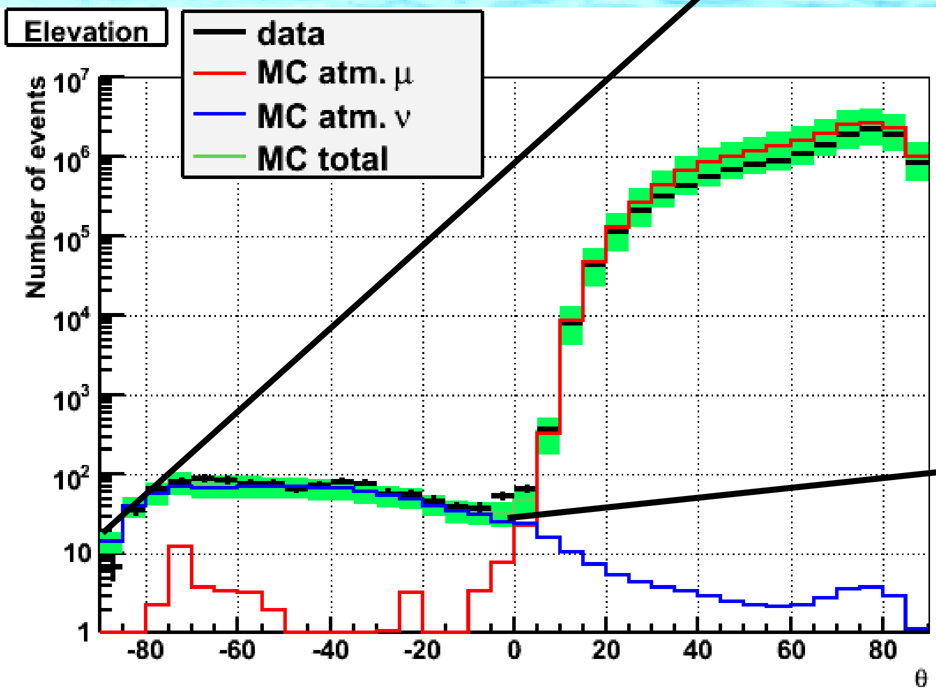
Neutrinos



2007+ 2008 fit events (341 days of effective livetime)

Neutrinos

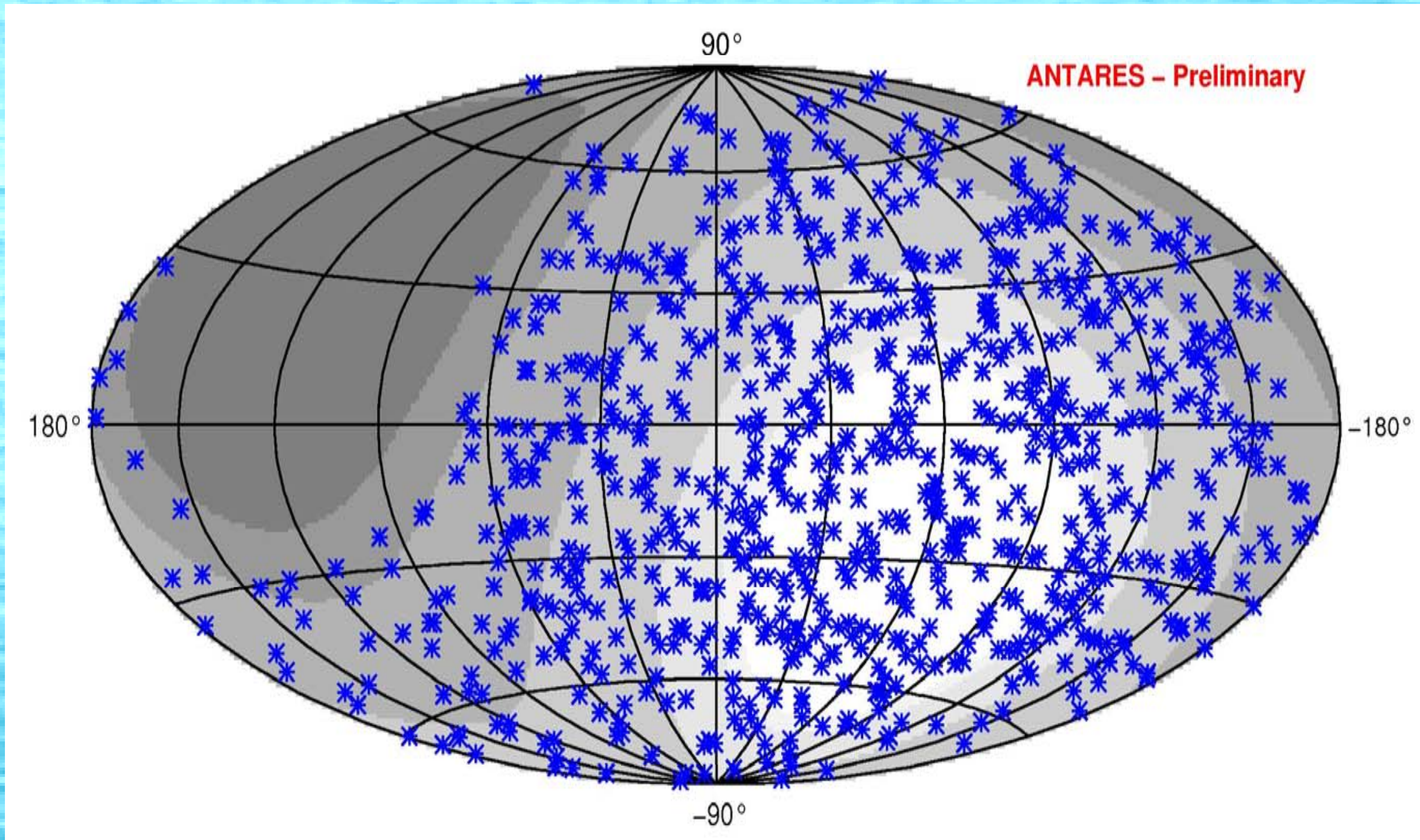




Neutrino-induced muon purity of ~ 96%

2007+ 2008 fit events (341 days of effective livetime)

Scrambled neutrino sky map 2007-2008



750 upgoing neutrinos (multi-line) in 341 days of effective livetime.

Real sky map will be shown next summer conferences.

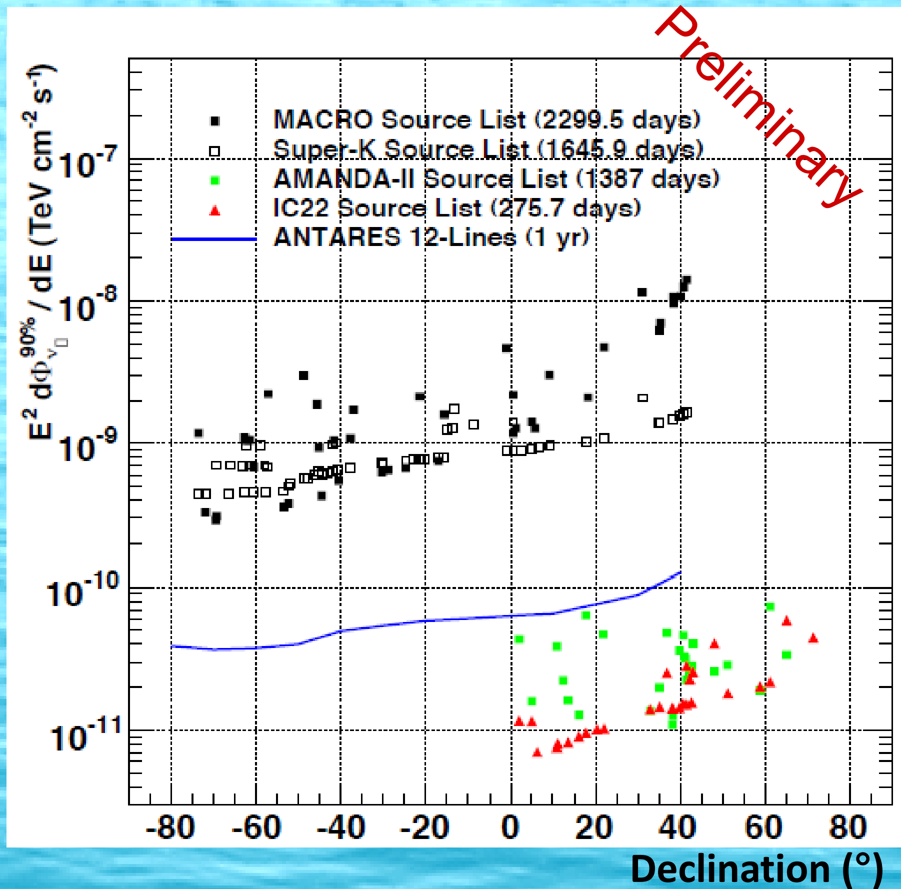
Point Source Search

•Definition of a list of potential sources (SNR, BL Lac objects, etc …)

•Analysis based on simulations, following a blinding procedure.

Expected sensitivity competitive with previous multi-year experiments.

Analysis for 2007 and 2008 data period presented soon.



Magnetic monopole search

1931: Dirac introduced:

Magnetic field: $\overrightarrow{B} = g\frac{\overrightarrow{r}}{r^3}$

Magnetic charge: $g = \frac{k\hbar c}{2e}$

1974: 't Hooft and Polyakov:

Any unified gauge theory in which U(1)$_{E.M.}$ is embedded in a spontaneously broken semi-simple gauge group necessarily contains M.Ms.

Signal in sea water:

- **Direct Cherenkov emission $\beta_{MM} > 0.74$:**

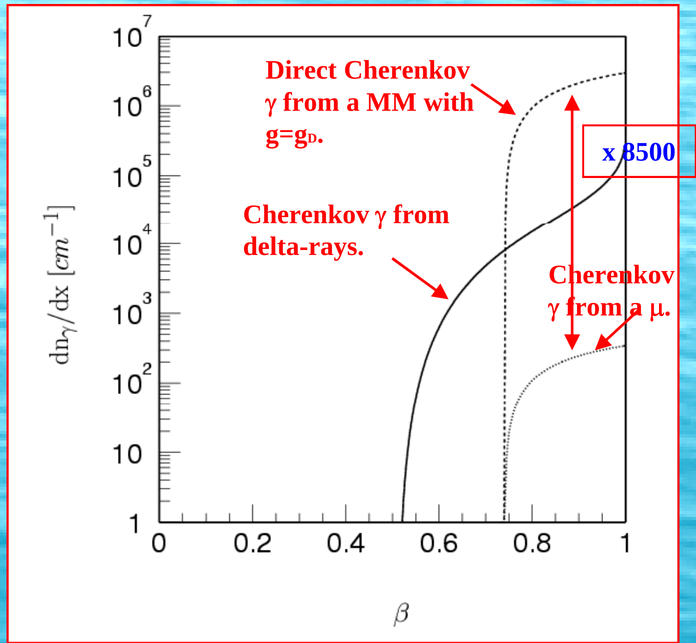
$$\frac{d^2N_\gamma}{dx d\lambda} = \frac{2\pi\alpha}{\lambda^2}\left(\frac{gn}{e}\right)^2\left(1 - \frac{1}{\beta^2 n^2}\right)$$

Number of photons emitted by a MM with the minimal charge g_D ~ 68.5 e, is ~ 8500 times more than that of a muon.

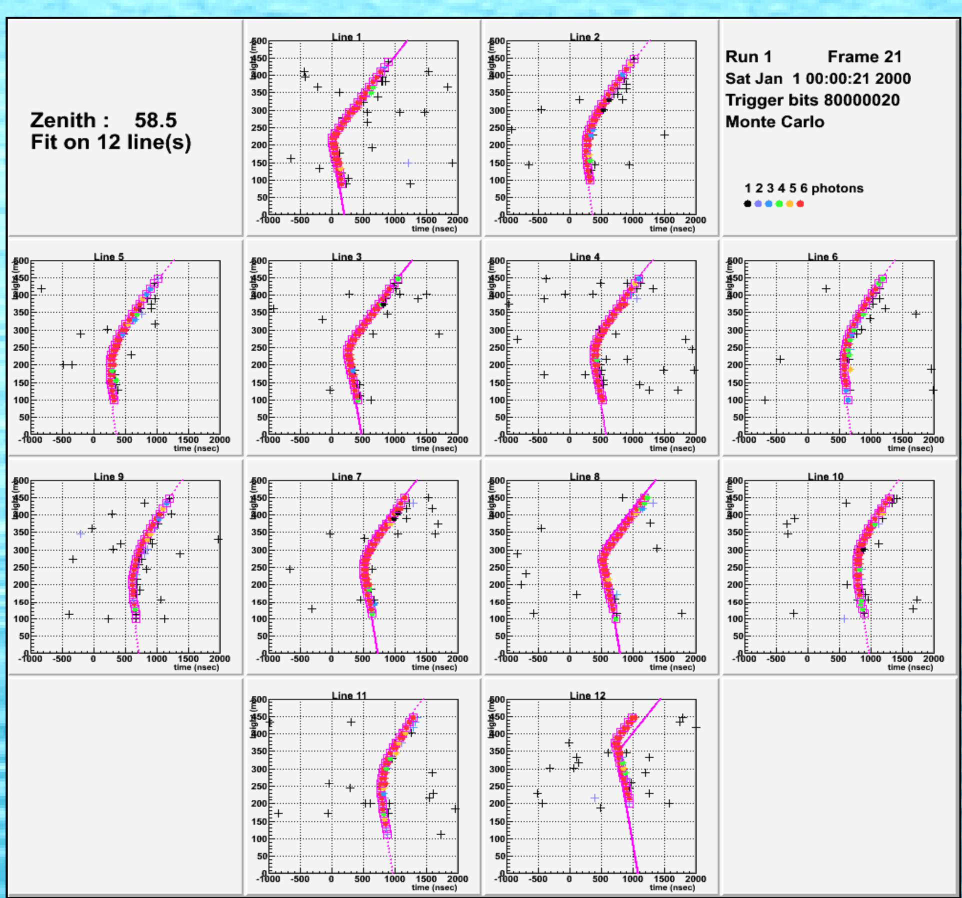
- **Indirect Cherenkov emission $\beta_{MM} > 0.51$:**

The energy transferred to electrons allows to pull out electrons (δ-rays), which can emit Cherenkov light.

Number of emitted photons in sea water



Magnetic monopole search



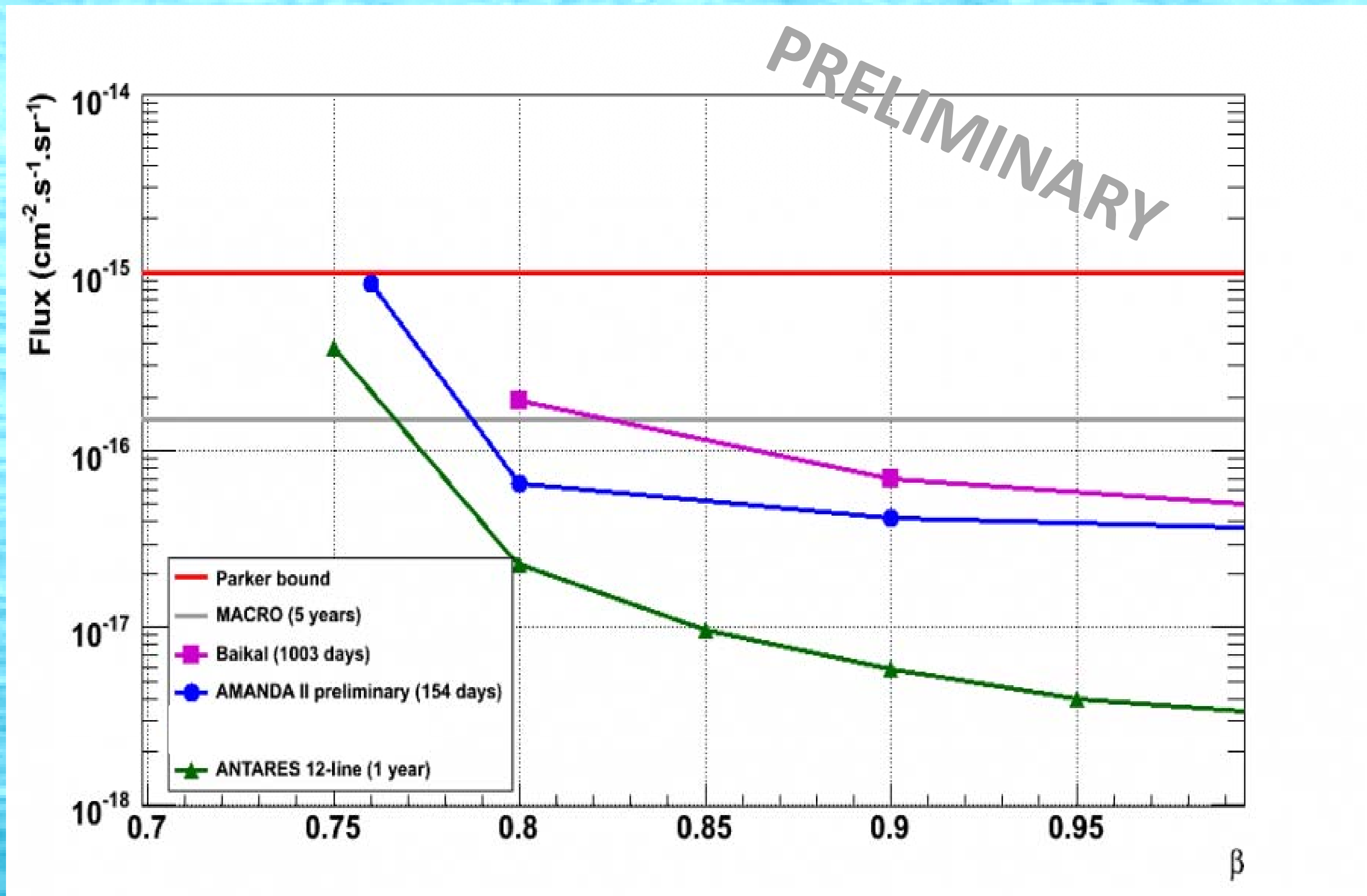
Extremly high energy deposition.

Analysis using the large number of hits in ANTARES OMs.

Upgoing magnetic monopole event with β ~ 0.99.

Magnetic monopole search

Expected sensitivity 90% C.L. after one year of data taking with the 12-line detector.



~1.1 expected background events after one year of 12-line ANTARES data taking.

Conclusion and Outlook

ANTARES is the largest neutrino telescope in the northern hemisphere.

First neutrino telescope under sea completed and taking data.

Mediterranean site complementary to South Pole.

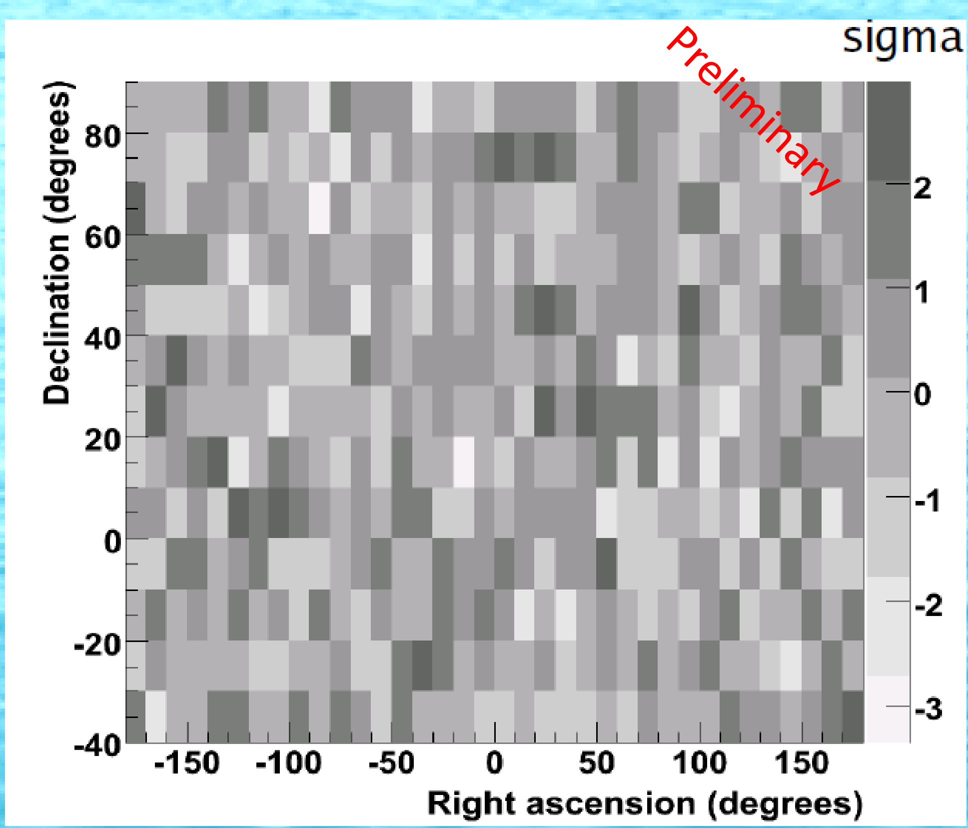
Physics analysis are on the track.

Multidisplinary platform.

First step towards a km^3 scale detector.

BACKUP

Search for Large Scale Asymetry in Downgoing Muons



5 line data (2007)

Selection:

Elevation >10°.

At least 2 lines.

>20 hits.

⇨ **660000 downgoing muons.**

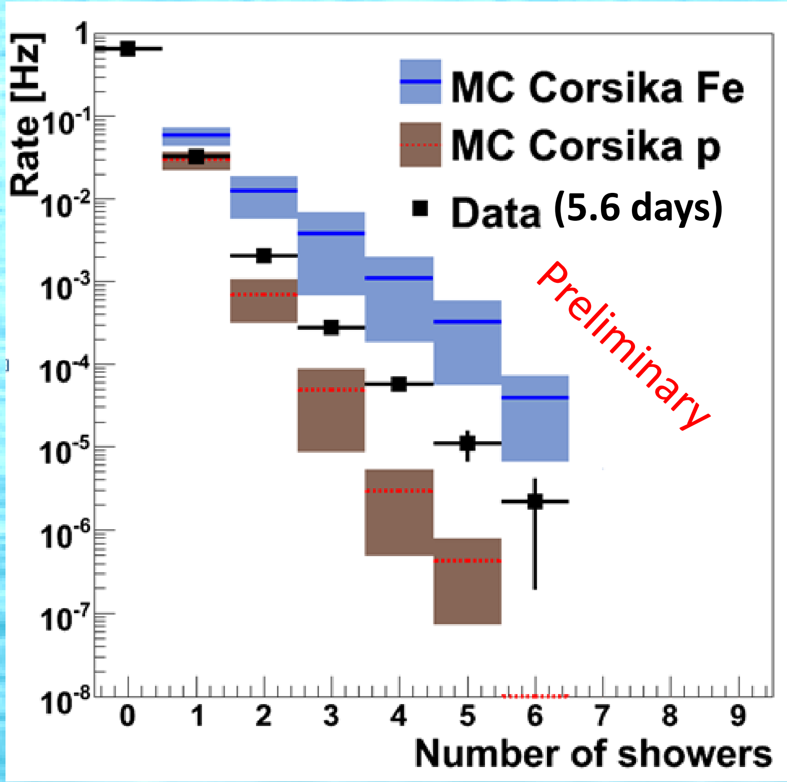
Ang. Resolution < 5°.

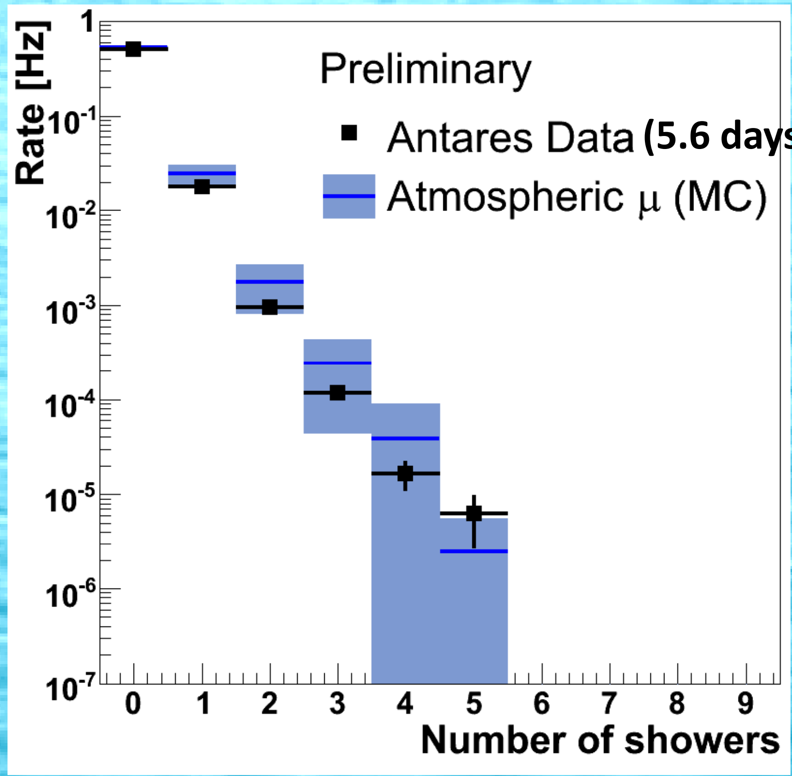
10*10 degree bins.

No asymmetry observed with current statistics.

EM showers from atm. muons

→ **Link to the cosmic ray composition.**

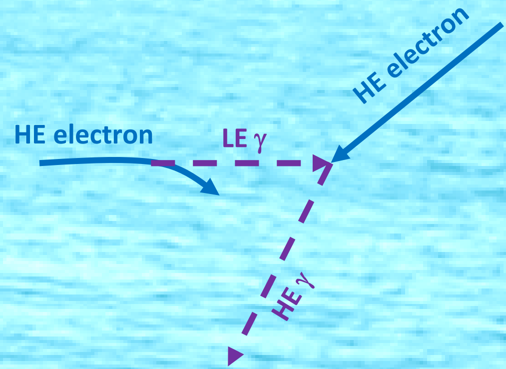




Compatible with a mixed composition (Horandel model)

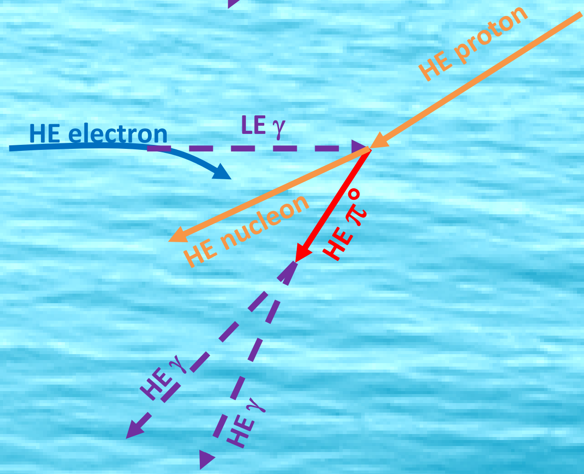
Mechanisms

Leptonic process:



Synchrotron radiation followed by inverse Compton scattering.

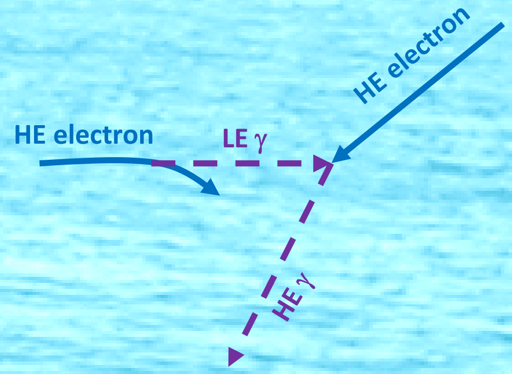
Hadronic process:



Synchrotron radiation followed by π° photo-production.

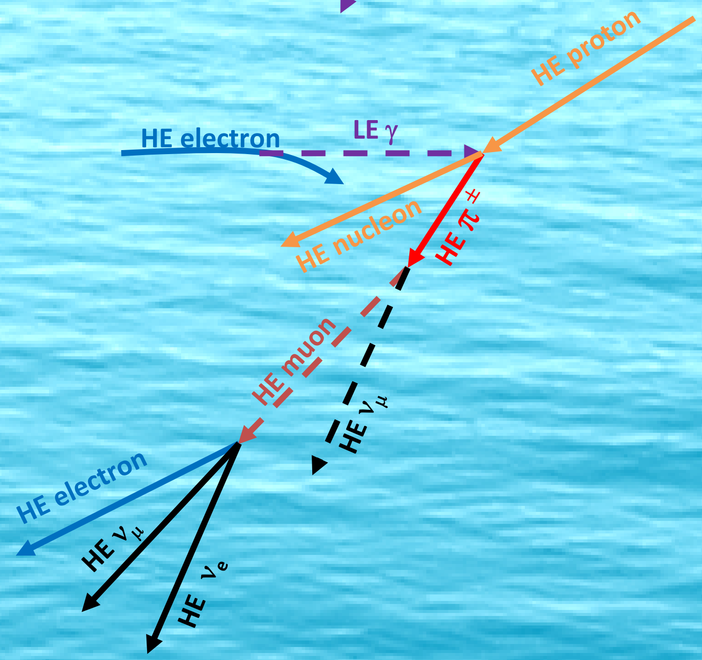
Mechanisms

Leptonic process:



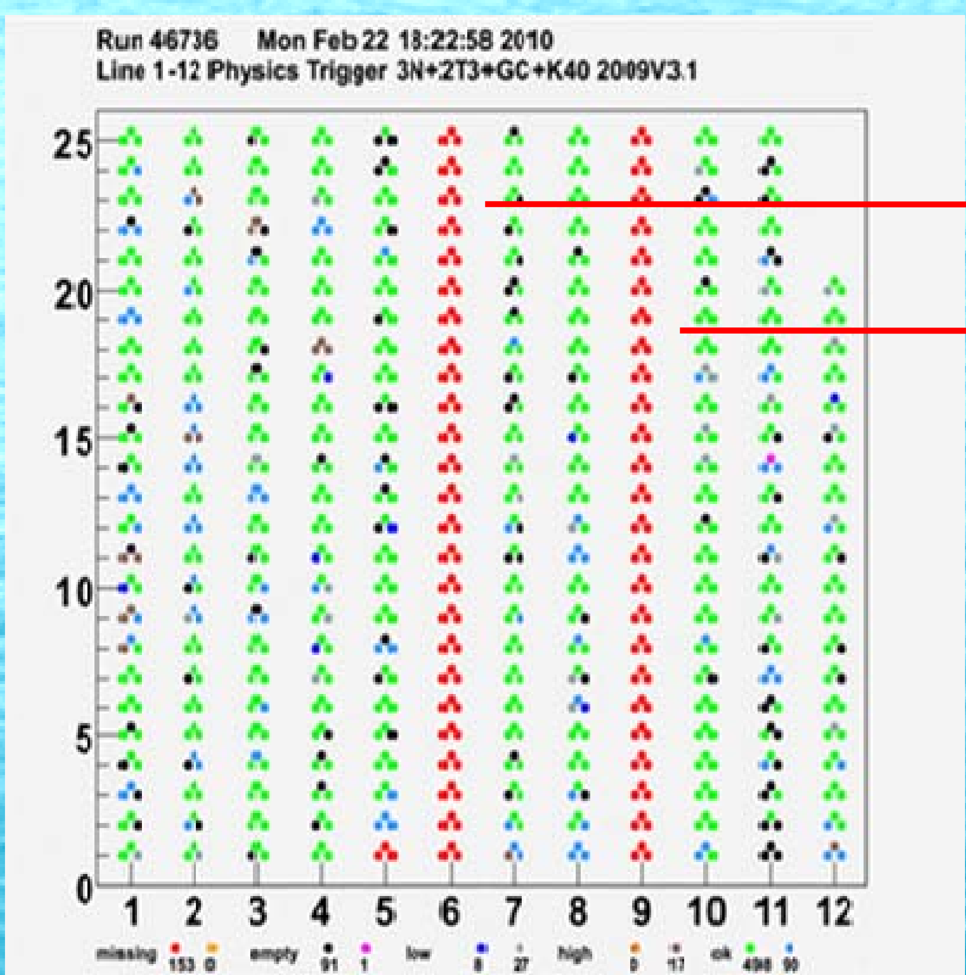
Synchrotron radiation followed by inverse Compton scattering.

Hadronic process:



Synchrotron radiation followed by $\pi^{\pm}$ photo-production.

Detector present status

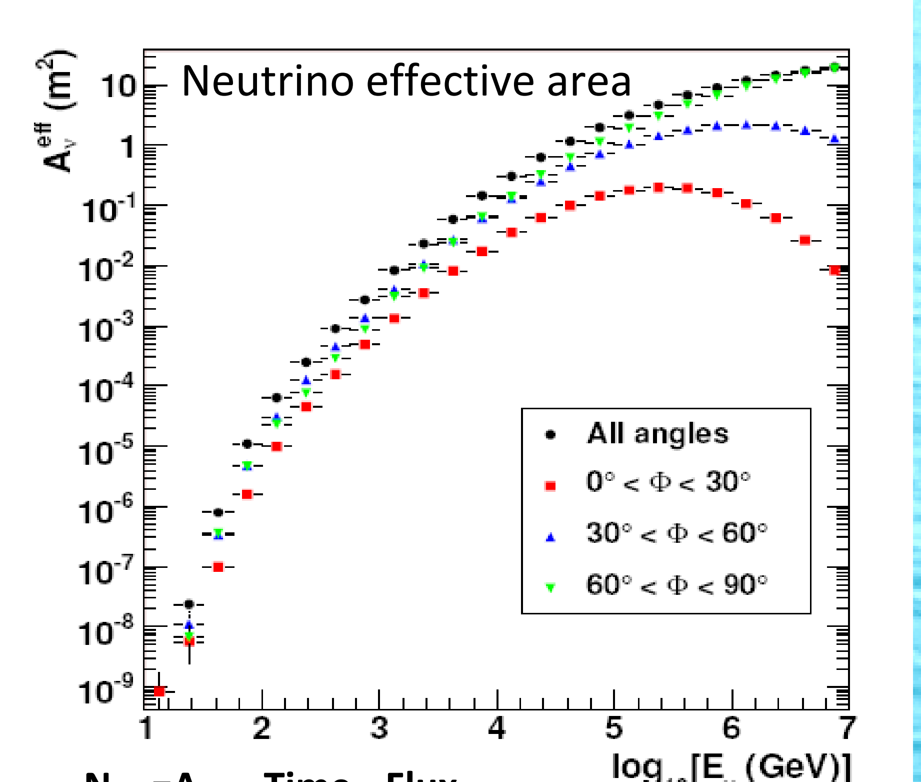


Line 6: Recovered in October 2009.

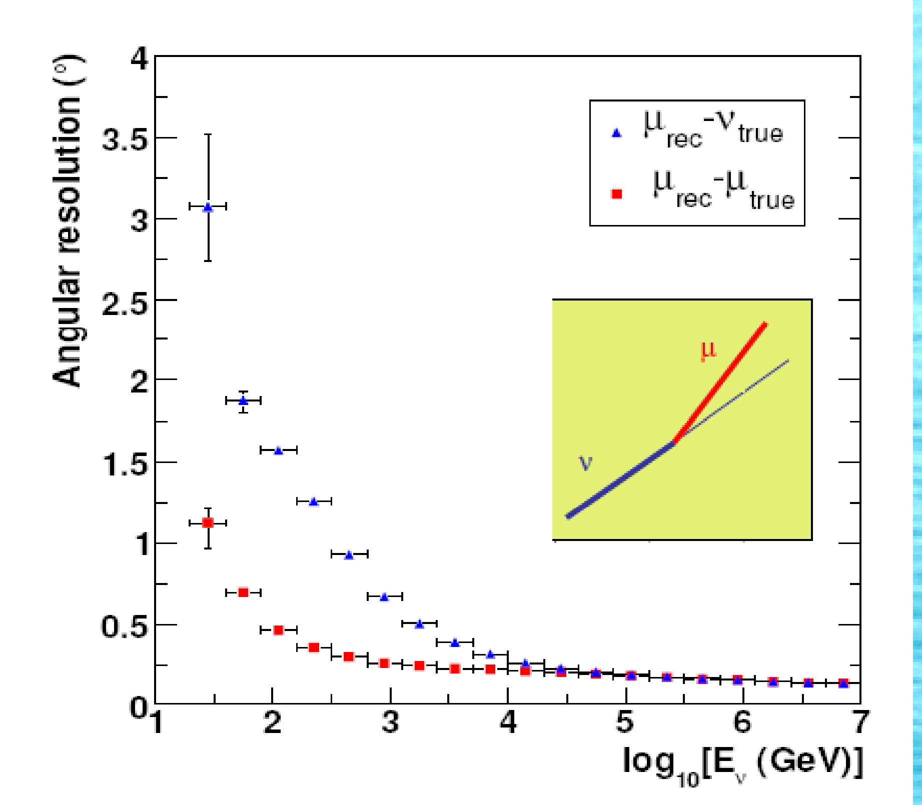
Line 9: Planned to be recovered this week.

Line 12: First example of successfull recuperation+repair+redeployment.

Expected performances



$N_{det}=A_{eff} \times$ Time $\times$ Flux



For E_ν<100 TeV, A_{eff} grows with energy due to the increase of the interaction cross section and the muon range.

For E_ν>100 TeV the Earth becomes opaque to neutrinos.

For E_ν<10 TeV, the angular resolution is dominated by the ν–μ angle.

For E_ν>10 TeV, the resolution is limited by track reconstruction uncertainties.

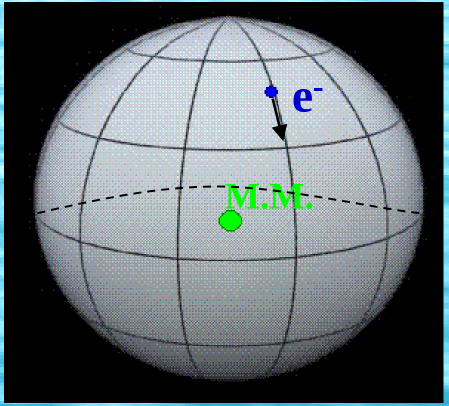
Introduction of magnetic monopoles

- **Initially introduced by Dirac in 1931:**

$$\overrightarrow{B} = g\frac{\overrightarrow{r}}{r^3}$$

  - **Make symmetric Maxwell's equations.**
  - **Imply the quantization of the electric charge.**
  - **Magnetic charge is given by** $g = \frac{k\hbar c}{2e}$

The smallest magnetic charge is the Dirac charge g_D, where k=1.



Introduction of magnetic monopoles

- **’t Hooft and Polyakov in 1974:**

Any unified gauge theory in which $U(1)_{E.M.}$ is embedded in a spontaneously broken semi-simple gauge group necessarily contains M.Ms.

Transition example with the minimal GUT group:

$$SU(5) \rightarrow \{SU(3)_C \times [SU(2)_L \times U(1)_Y]\}/Z_6 \rightarrow \{SU(3)_C \times U(1)_{E.M.}\}/Z_3$$

MM appear with charge $g=g_D$ at the first transition.

In this typical case the monopole mass is about ~ 10^{16} GeV with a radius of the order ~ 10^{-28} cm.

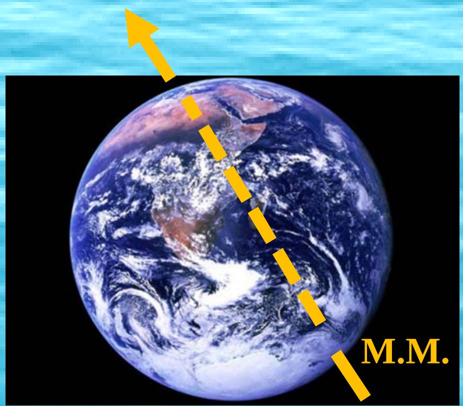
Predicted magnetic monopole’s masses : 10^8 to 10^{17} GeV (depending on the unified gauge group).

Acceleration of magnetic monopoles in the Universe

Energy gain in a magnetic coherent field: $E_K = gB\xi$

	B/μG	ξ/Mpc	$gB\xi$/eV
normal galaxies	3 to 10	10^{-2}	$(0.3 \text{ to } 1) \times 10^{21}$
starburst galaxies	10 to 50	10^{-3}	$(1.7 \text{ to } 8) \times 10^{20}$
AGN jets	~ 100	10^{-4} to 10^{-2}	$1.7 \times (10^{20} \text{ to } 10^{22})$
galaxy clusters	5 to 30	10^{-4} to 1	3×10^{18} to 5×10^{23}
Extragal. sheets	0.1 to 1.0	1 to 30	1.7×10^{22} to 5×10^{23}

→ Magnetic monopoles with masses below 10^{14} GeV could be relativistic (with extragalactic sheets expecting to dominate the spectrum).



Estimated energy loss when crossing the Earth is $\sim 10^{11}$ GeV.

→ M.M. with masses up to about 10^{14} GeV are expected to cross the Earth and be relativistic.

Magnetic monopole's signal in ANTARES

- **Direct Cherenkov emission β > 0.74 :**

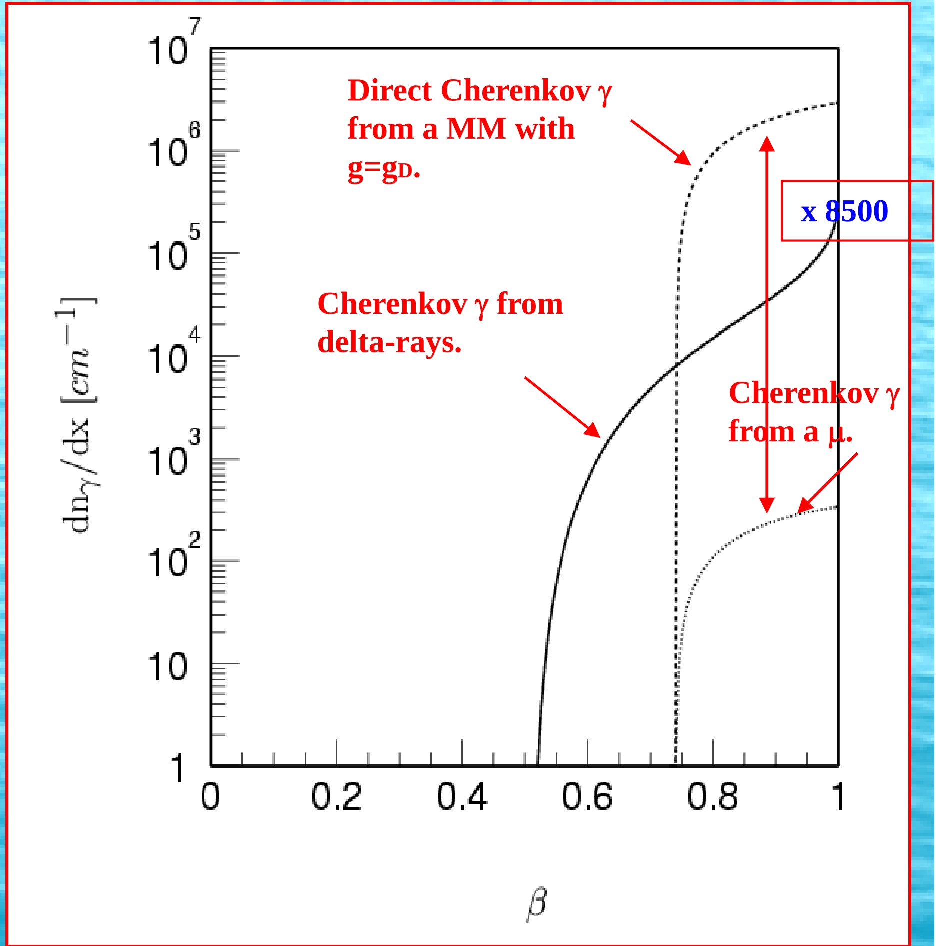
$n_{\text{sea water}} \sim 1.35$

$$\frac{d^2N_\gamma}{dxd\lambda} = \frac{2\pi\alpha}{\lambda^2}\left(\frac{gn}{e}\right)^2\left(1 - \frac{1}{\beta^2 n^2}\right)$$

Number of photons emitted by a MM with the minimal charge $g_D \sim 68.5\ e$, compared to a muon of same velocity is about ~ 8500 more!

- **Indirect Cherenkov emission β > 0.51 :**

The energy transferred to electrons allows to pull out electrons (δ-rays), which can emit Cherenkov light.

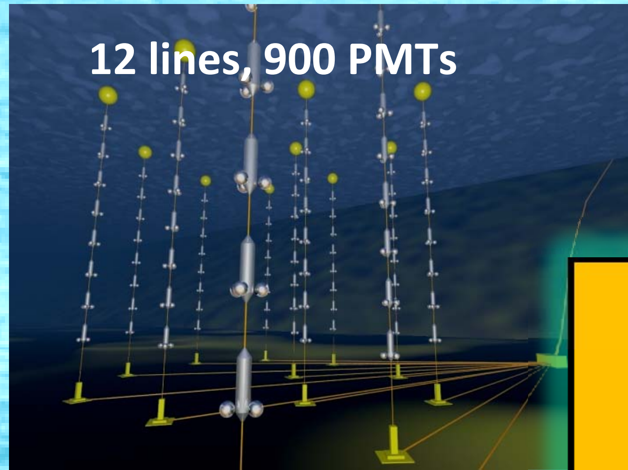


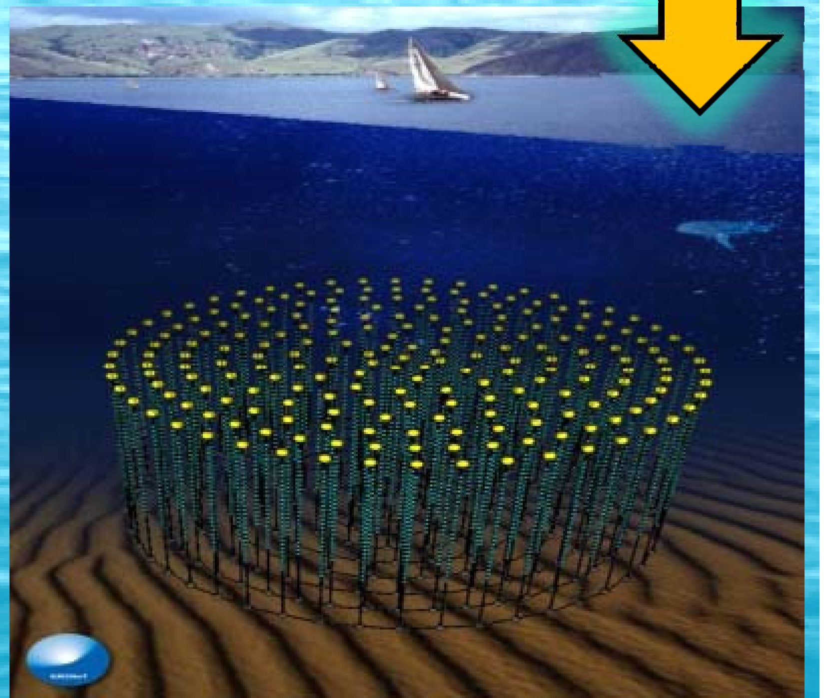
KM3NeT

– Design Study and Preparatory Phase
  • Consortium ANTARES/NEMO/NESTOR
– Maximise physics potential
  • Instrumented volume >1km^3
  • Angular resolution ~0.1 degrees (E>10 TeV)

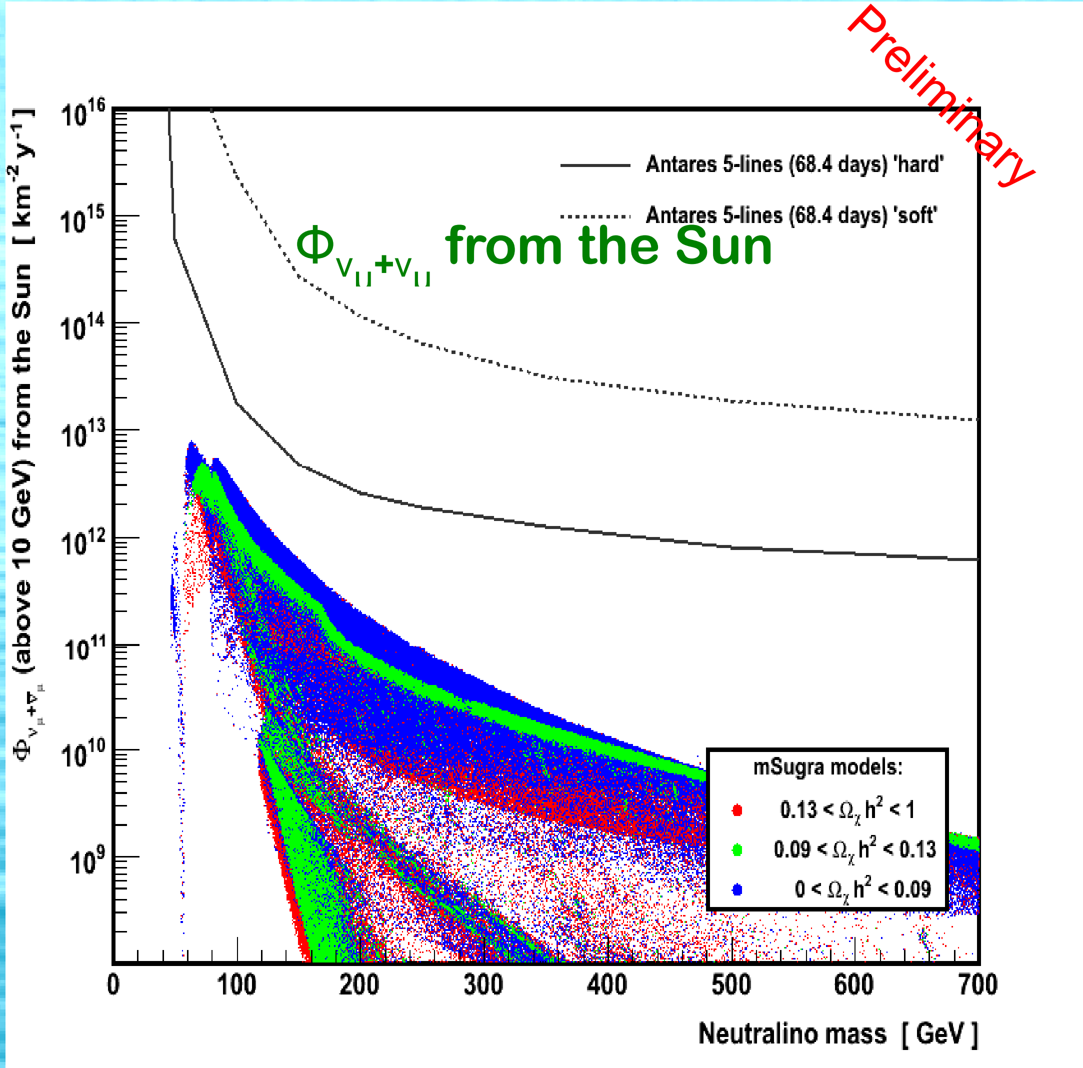
– Build in a reasonable time ~4 years
  • Multi-line deployment techniques
  • Speed-up integration time
  • Sub contract part of the production

– At a reduced cost
  • Factor 2 reduction cf ANTARES
  • Simplified architecture
  • Reduced maintenance





Dark matter search: Neutrino limits



- 5-line data, 68.4 days
- No excess observed (90% C.L. limits)