Looking for High Energy Neutrinos from Space: the ANTARES experiment

Vincenzo Flaminio for the ANTARES Collaboration

(Physics Dept. & INFN-Pisa)

νs from space: the long march

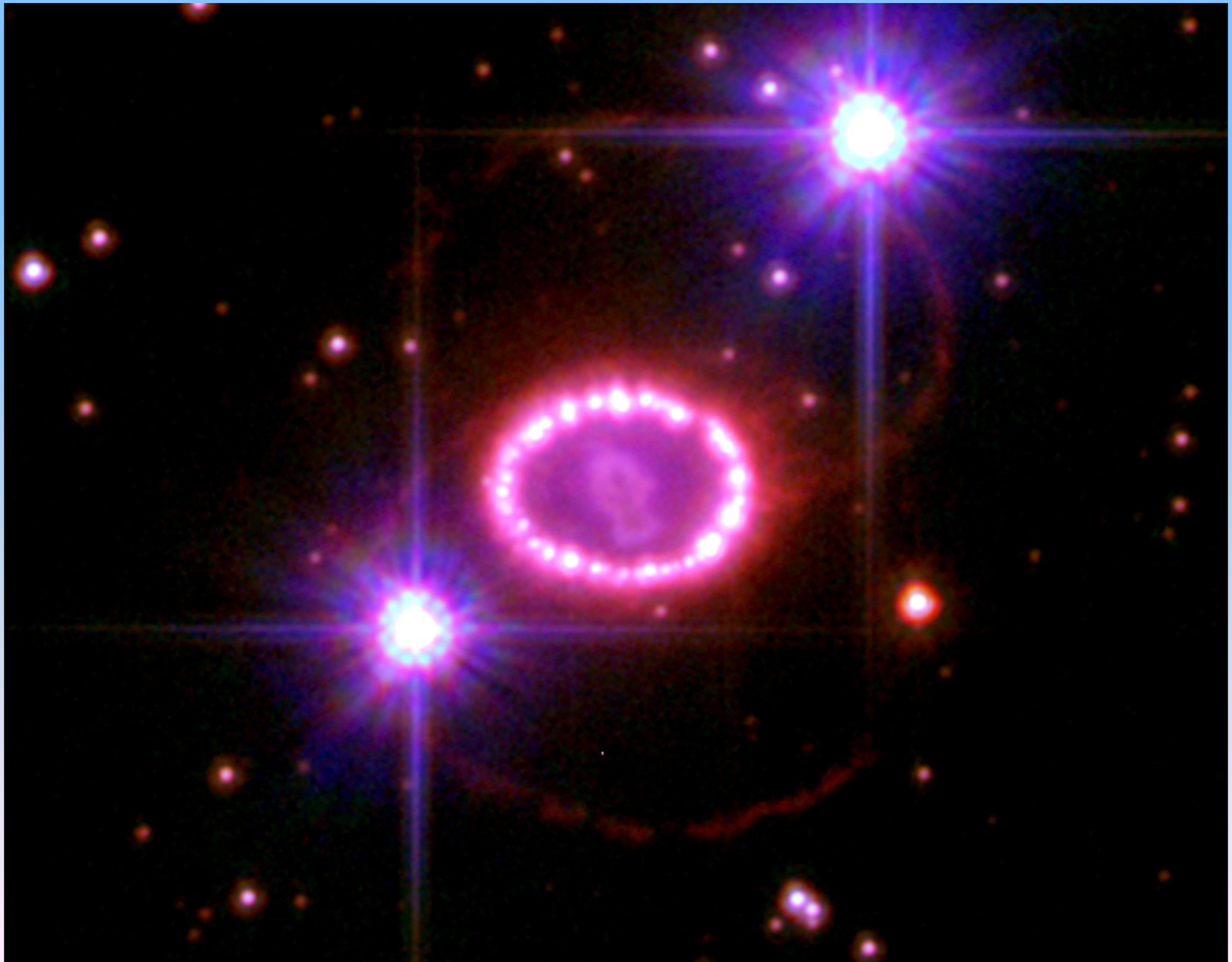
Solar neutrinos (MeV energies)

→ Davis et al. 1955 – 1978 Koshiba et al., 1987-1988

Riccardo Giacconi,
Masatoshi Koshiba
Raymond Davis Jr.
Stockholm, 12 December 2002.

ν^s from space: the long march

Later → observation of ν^s from SN1987a → help clarify mechanism of SNs (Energies around 10 MeV)



From MeV νs to PeV νs

Detectors of High Energy (GeV→ PeV Energy) Cosmic νs

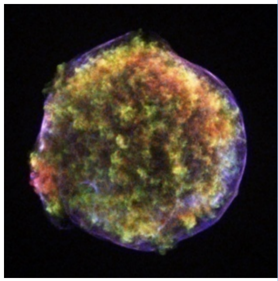
Why ?

- Understand production mechanism of HE cosmic rays
- Disentangle Synchrotron-Inverse Compton from Hadronic production in SNRs
- Study Binary systems, μQuasars
- Investigate the very high energy processes occurring in GRBs
- Search for Dark matter
- New probe → new observations

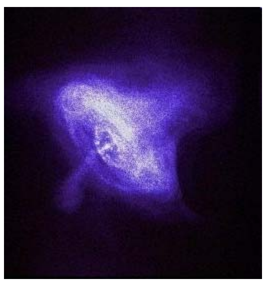
See also talk by Felix Aharonian at this Conference

Potential sources

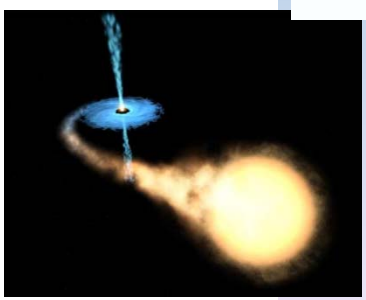
GALACTIC



Supernova remnant

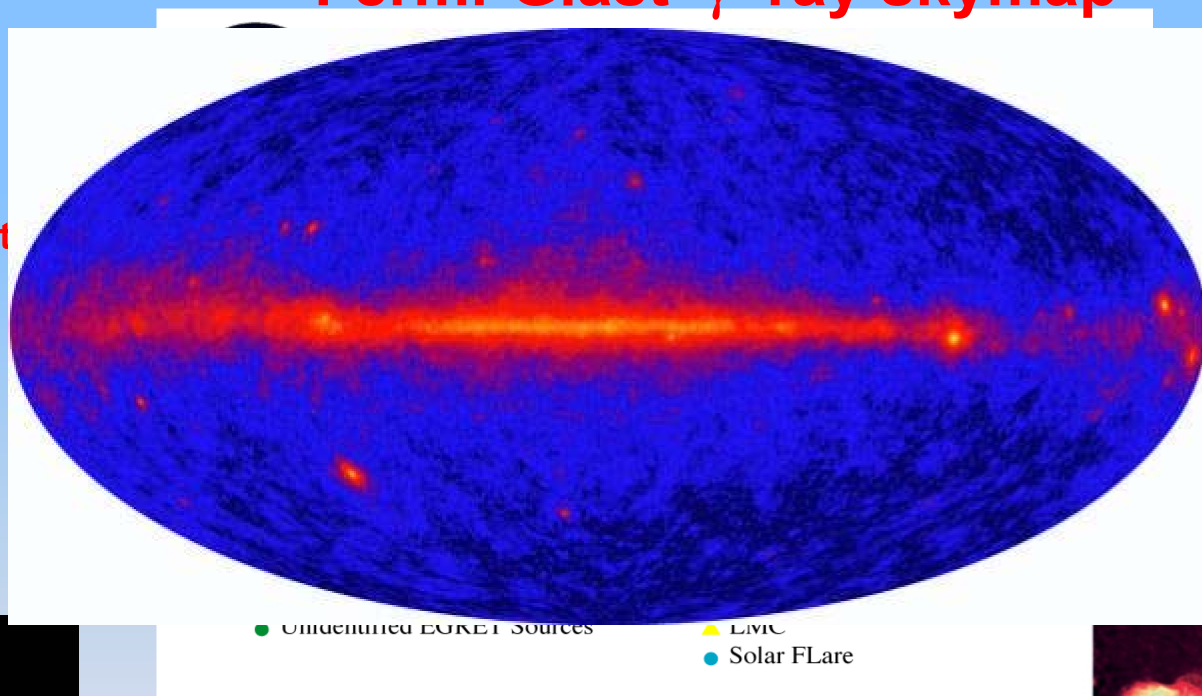


Pulsars

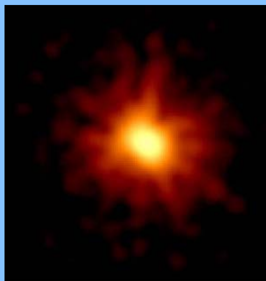


Microquasars

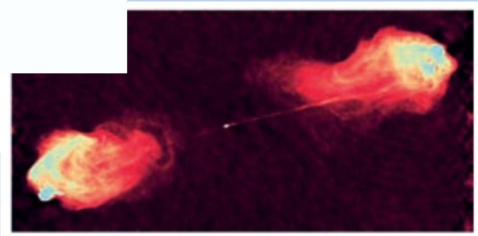
Fermi-Glast γ–ray skymap



EXTRAGALACTIC



GRBs



AGNs

Cross Sections & Interaction Lengths

Particle	σ (mb)	σ (cm^2)	Interaction length λ (m of H_2O)
H.E. Proton	50	5×10^{-26}	0.3
H.E. γ	0.4	4×10^{-28}	42.0
H.E. ν	$0.7 \times 10^{-11} \times E_\nu$ (GeV)	0.7×10^{-35} (at 1 TeV)	2×10^9
“ “	$0.7 \times 10^{-11} \times E_\nu$ (GeV)	0.7×10^{-32} (at 1 PeV)	2×10^6

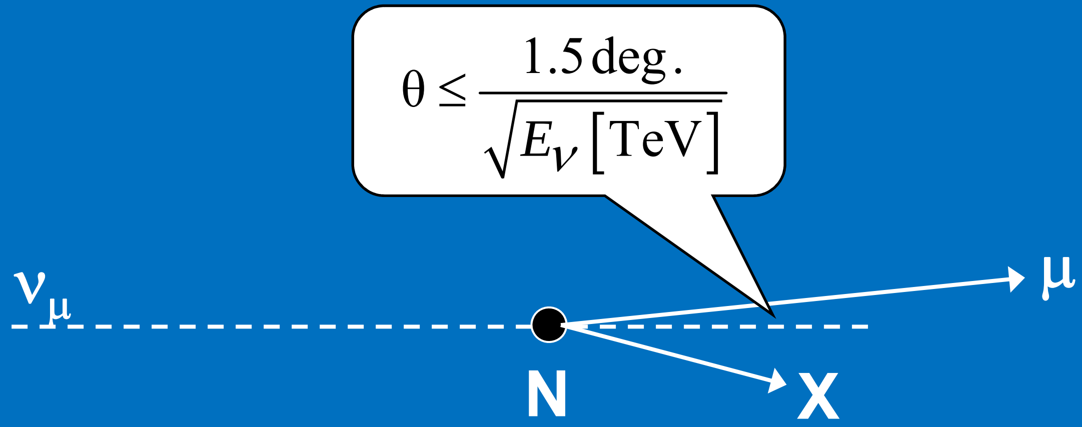
$$D_{Earth} = 12.8 \times 10^6 \text{ m} \rightarrow \lambda = D_{Earth} \text{ at } E_\nu = 190 \text{ TeV}$$

Neutrino Telescopes

- Neutral particle → points back to source (undeflected by B fields)
- Weak interaction → negligible absorption

Tiny cross section
→ need huge detector

ν_μ + N → μ + hadrons
μ measures ν direction



A little bit of history

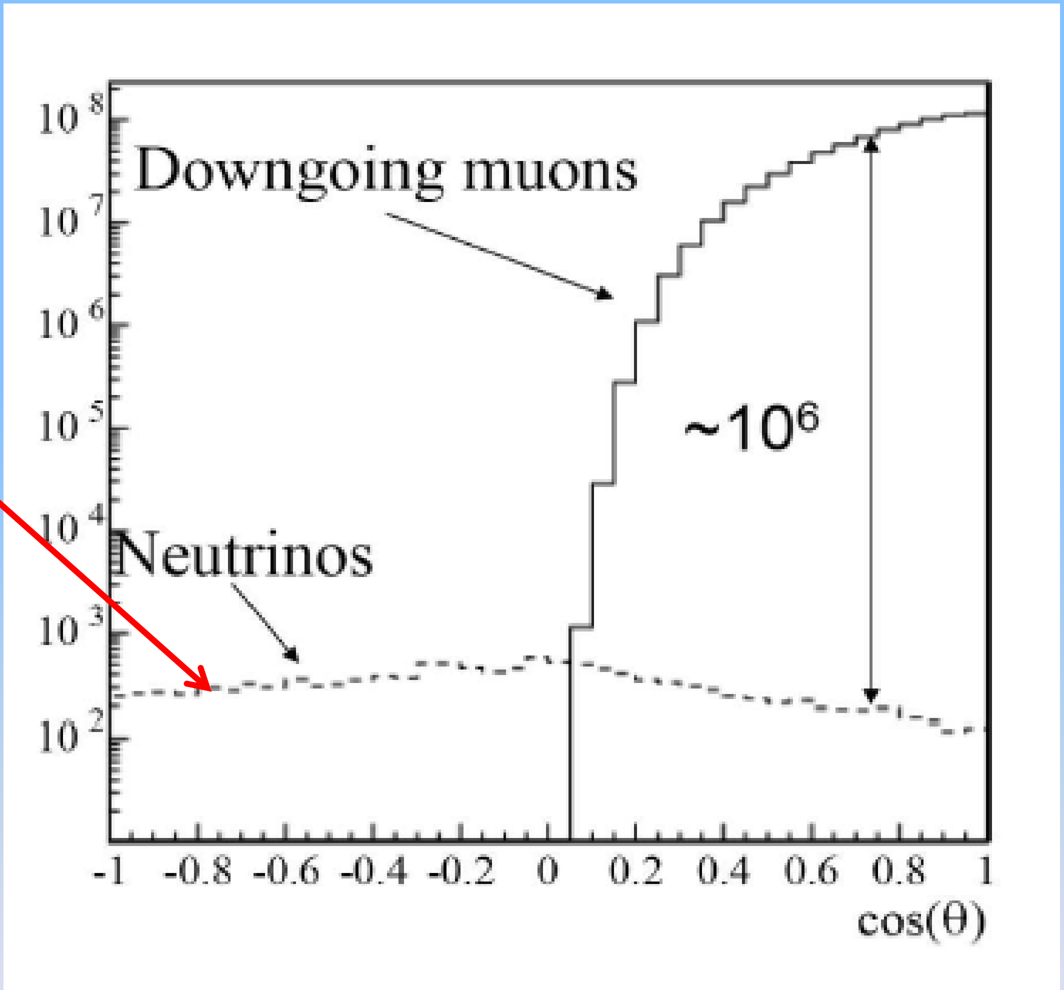
Detection technique

M.Markov, **1960**:

We propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation

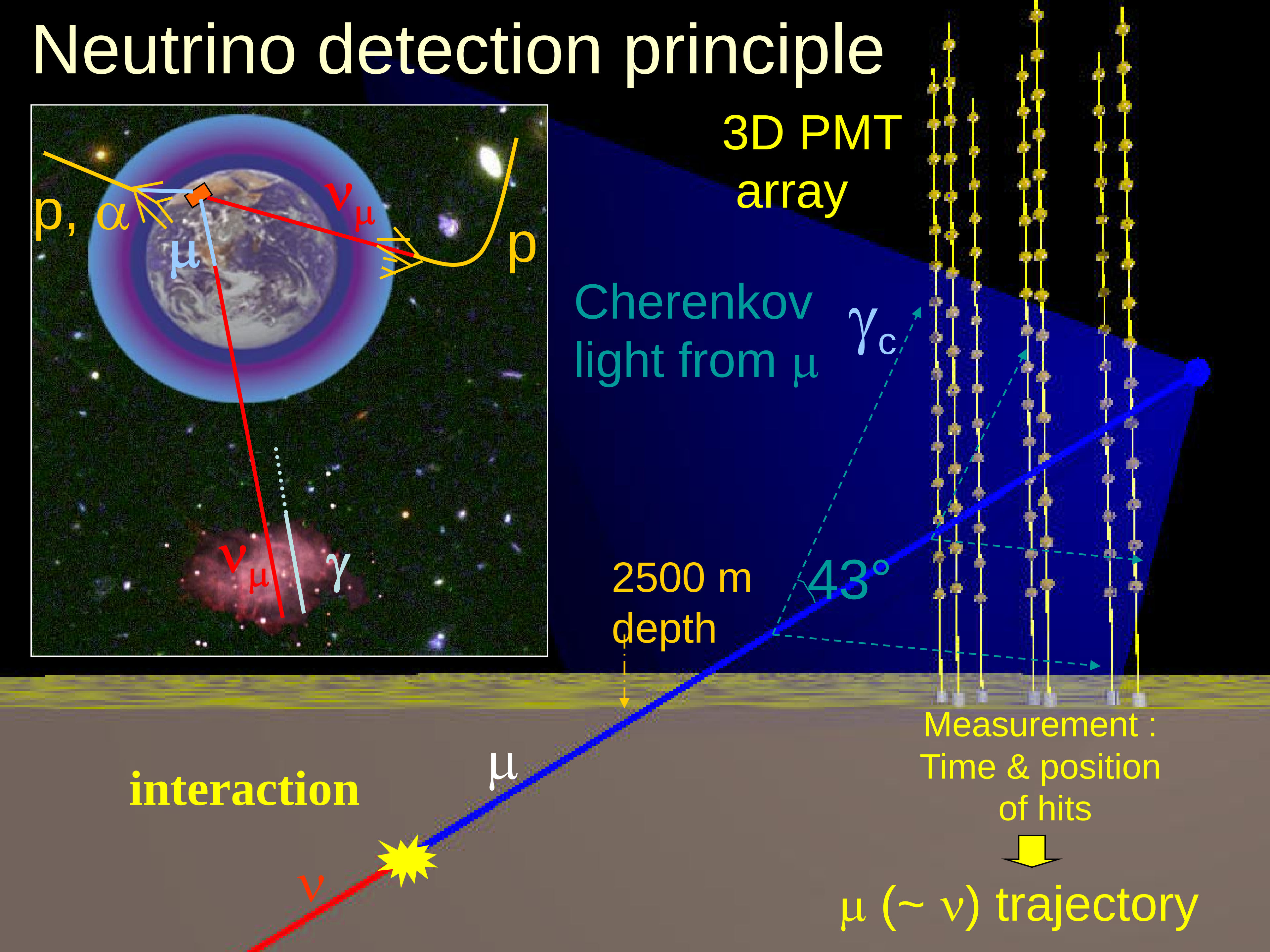
Atmospheric muon background at 2500 m

Reduced background if only events from the other side of the Earth selected



Price to pay → cutoff due to absorption by the Earth

Neutrino detection principle



Pioneering developments

Dumand experiment **(Hawaii 1978-1992), depth 4500 m phased out**
Roberts, RMP 64, 1, 1992

Later experiments in lakes or sea

Baikal **(Baikal lake, Russia, 1983 → present) depth 1100 m** ***running***
I.A. Belolaptikov et al., Astr. Ph. 7, 263, 1997

Nestor **(Pylos, Greece → 1996 - 2003) depth 4000 m** ***prototype operated in 2003***
G. Aggouras et al., Astr. Ph. 23, 377, 2005

NEMO **(Capo Passero, Sicily 2001→ present) depth 3500 m** ***prototype operated in 2007***
Capone et al., N.I.M. A 602, 47, 2009 ***new one under construction***

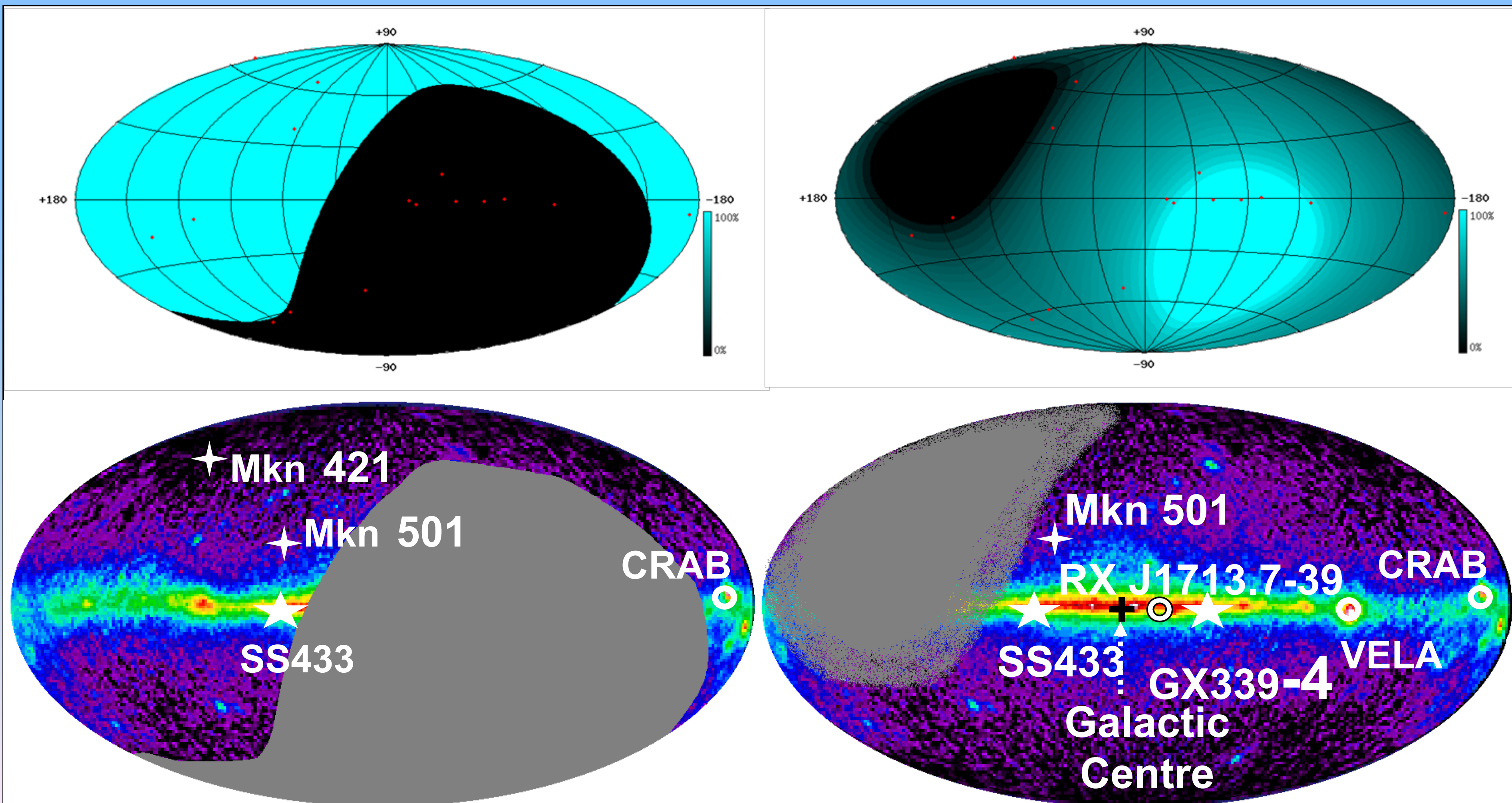
ANTARES **(Toulon, France → 2001 → present) depth 2500 m** ***running since 2006***
V. Flaminio, XIII Int. Works. on ν Telescopes, Venice, 2009

KM3NET **(European Project: Antares+Nemo+Nestor)** ***FP6 → Design Study***
http://www.km3net.org ***FP7 → Prep. Phase***
(Mediterranean: site to be decided)

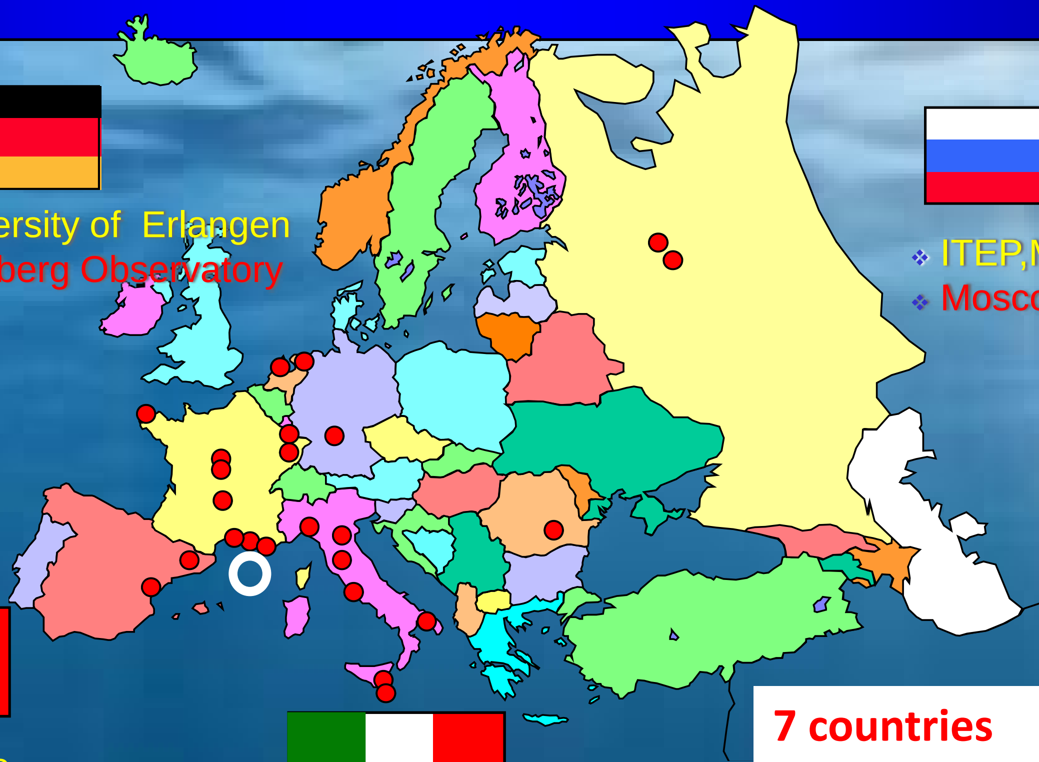
Mediterranean Sea ν Telescopes → Complementary to South Pole

AMANDA/IceCube (South Pole)
(Ice: ~2°/0.6°)

ANTARES/KM3 (43° North)
(water: ~0.2°/0.1°)



The ANTARES Collaboration



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

- University of Erlangen
- Bamberg Observatory

- ITEP,Moscow
- Moscow State Univ

- ISS, Bucarest

- IFIC, Valencia
- UPV, Valencia
- UPC, Barcelona

- 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

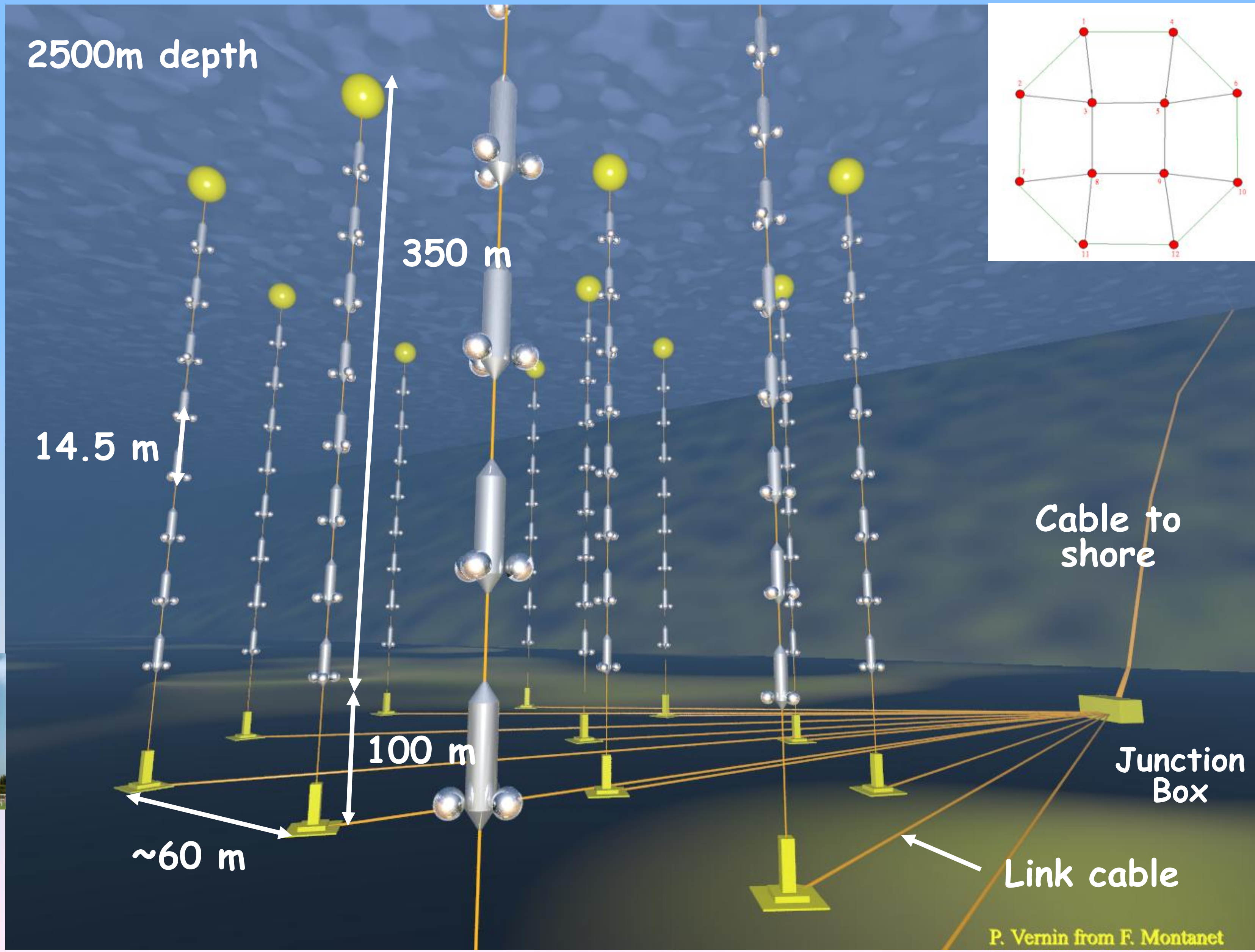
- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS – Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

7 countries
29 institutes
~150 scientists+engineers

The Michel Pacha Building

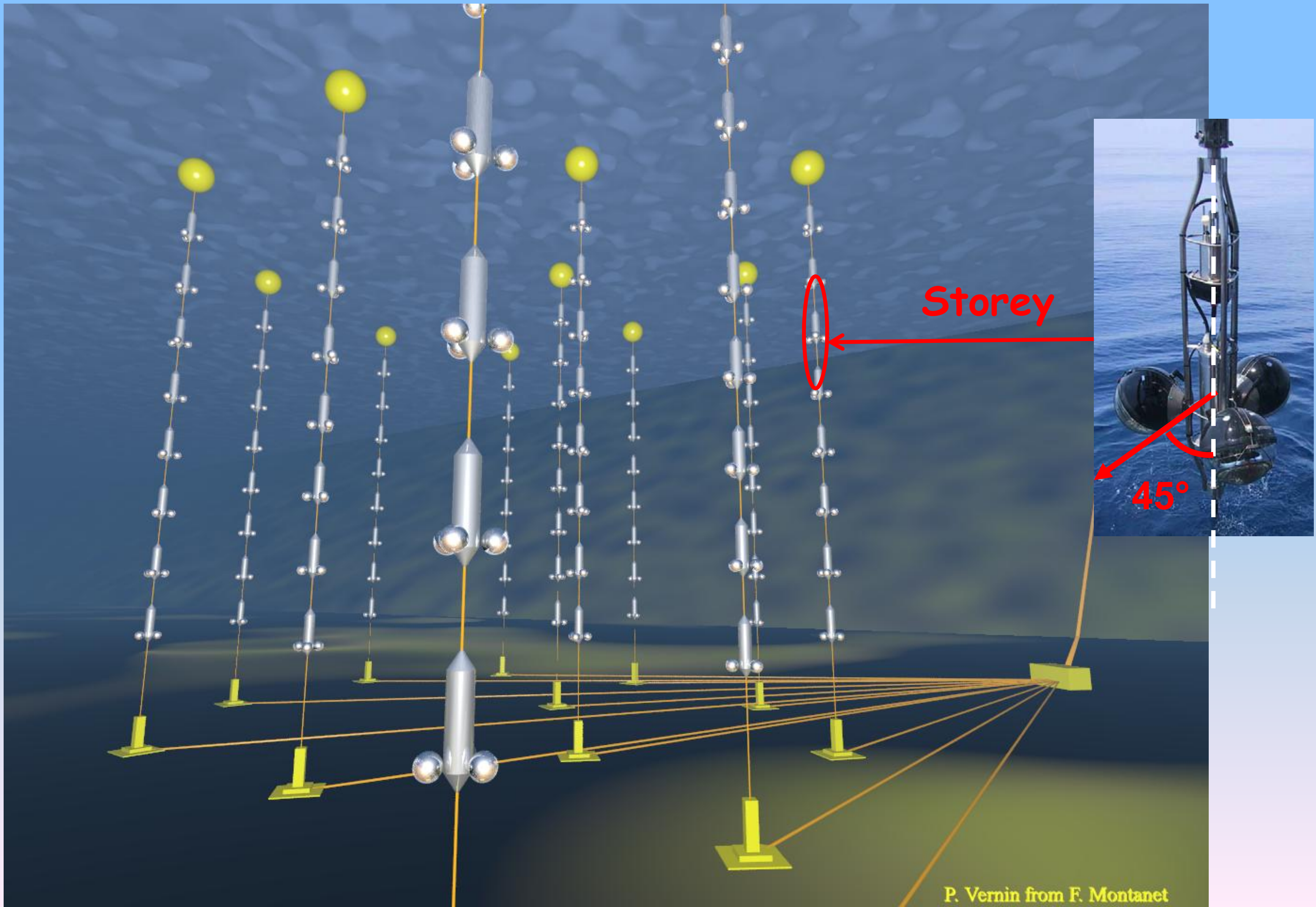
(Marius Michel)

The ANTARES detector



57 m

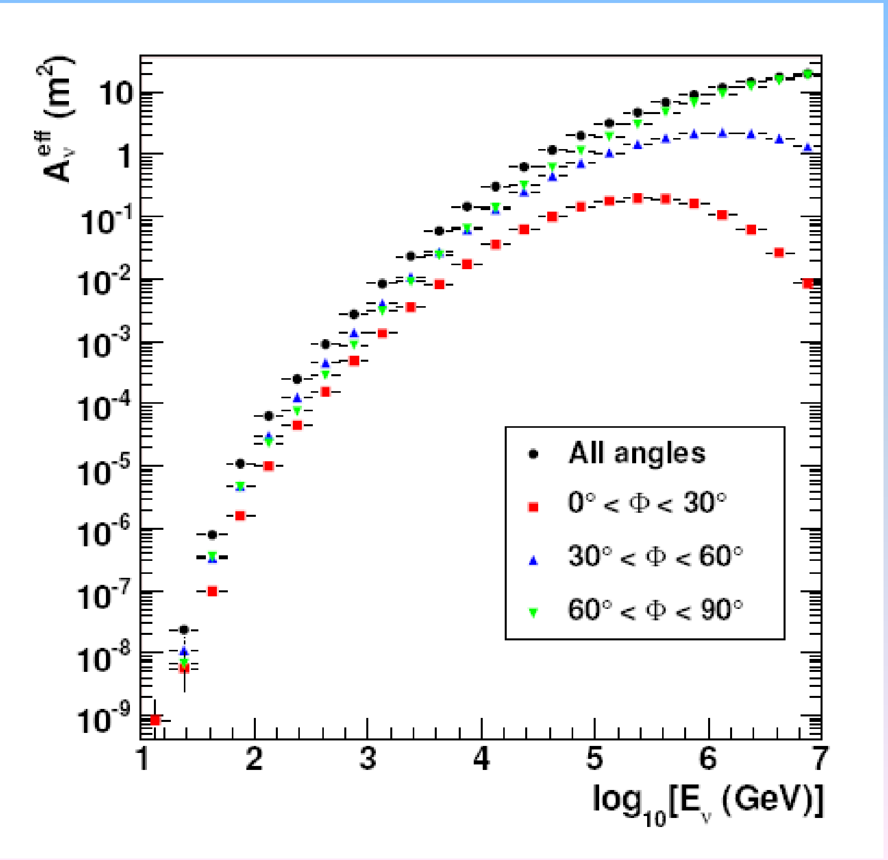
The ANTARES detector



Expected Performance (12 lines detector)

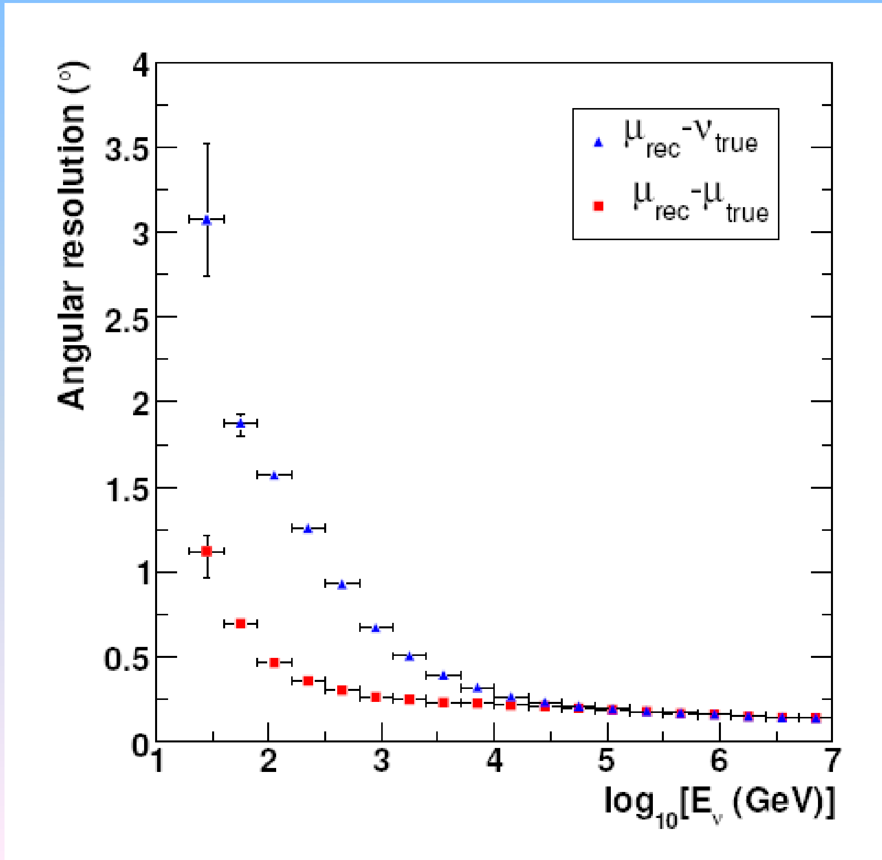
Neutrino effective area

For E_ν<10 PeV, A_{eff} grows with energy due to the increase of σ_ν and the muon range.
For E_ν>10 PeV the Earth becomes opaque to neutrinos.

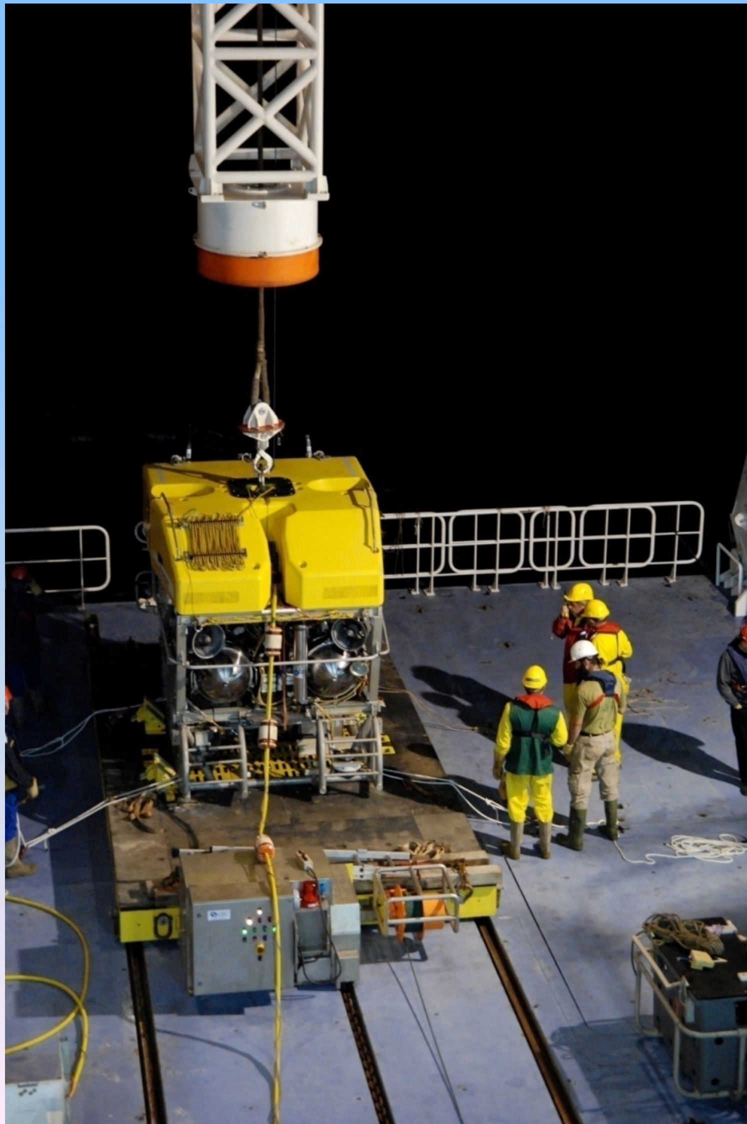


Angular resolution

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 errors.

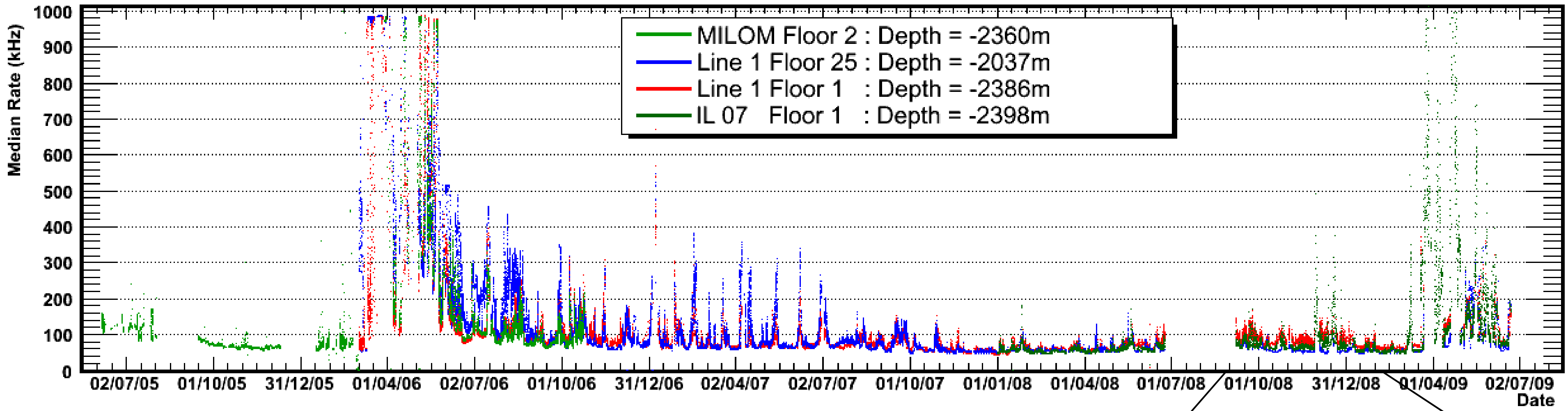


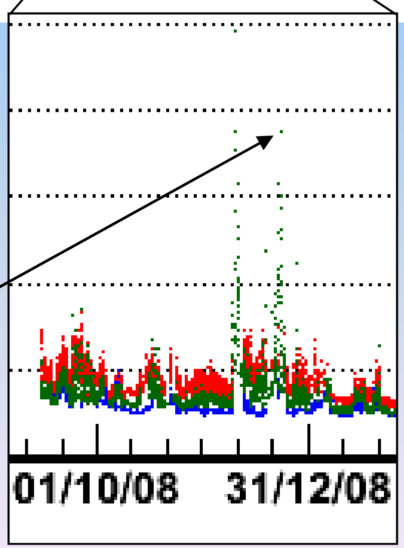
Detector operations



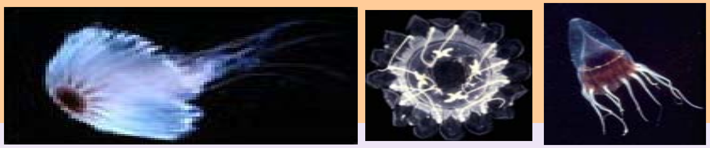
Data rate

- Muon (Cherenkov) → 2 µs crossing time
- Bioluminescence

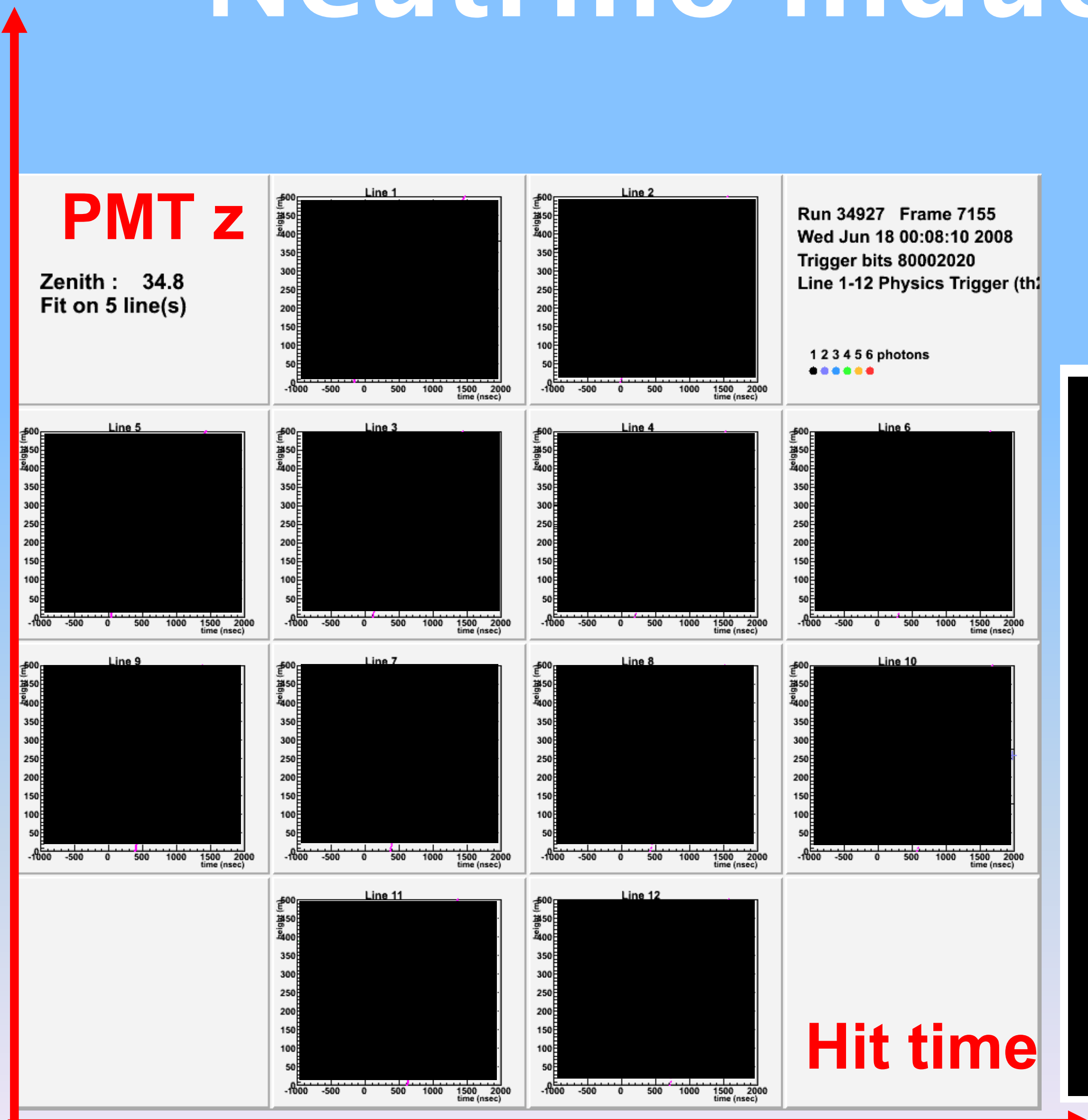




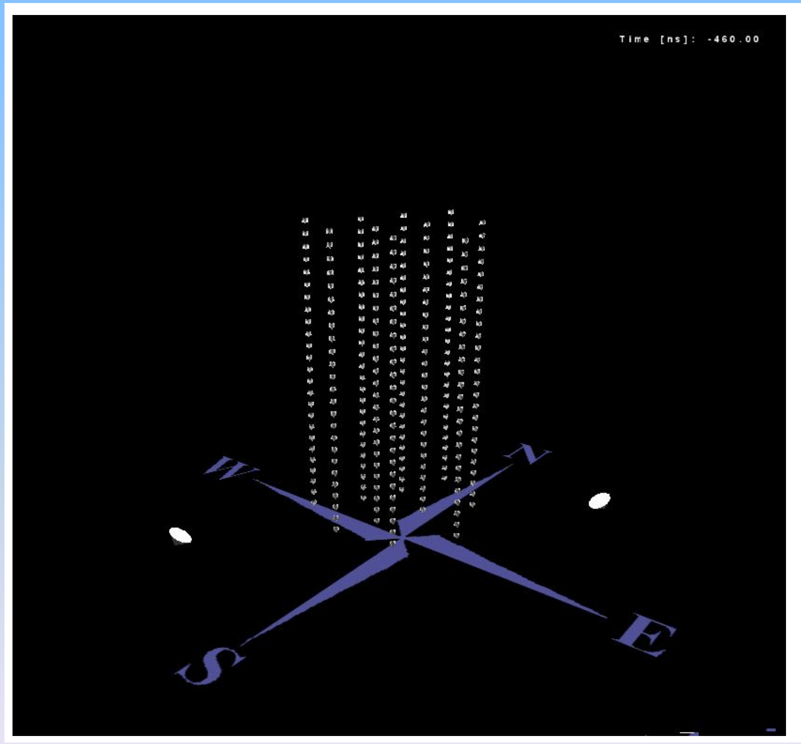
Median rate
of measured single photon counts: typ. 60 – 80 kHz caused by
bioluminescence (~ 30 kHz) and ^{40}K decay (~ 40 kHz)
with occasional bursts of extreme high rates (~ MHz) caused by macro-organisms (depends on sea current):
multidisciplinary research, oceanographic studies



Neutrino-induced muon

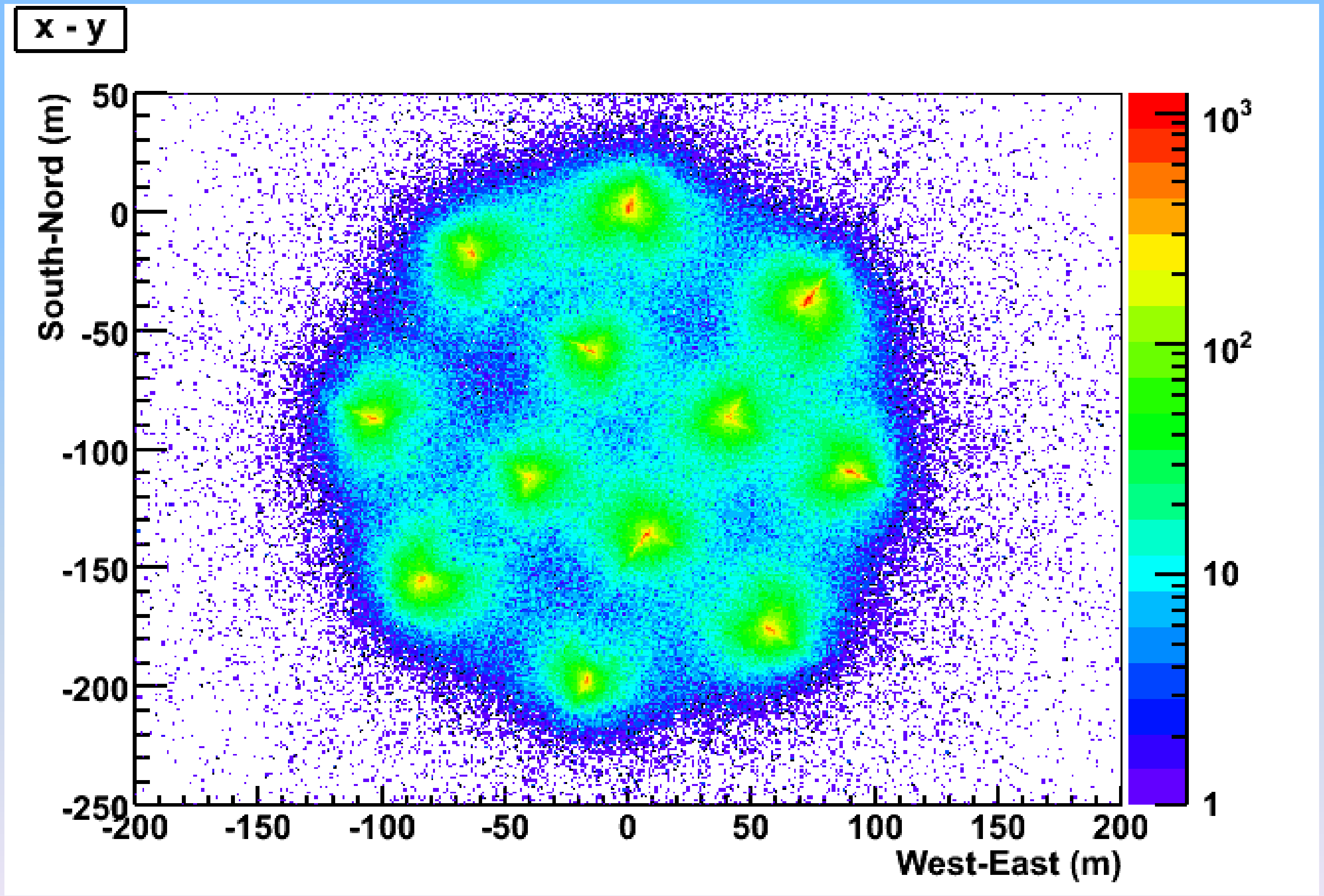


Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:

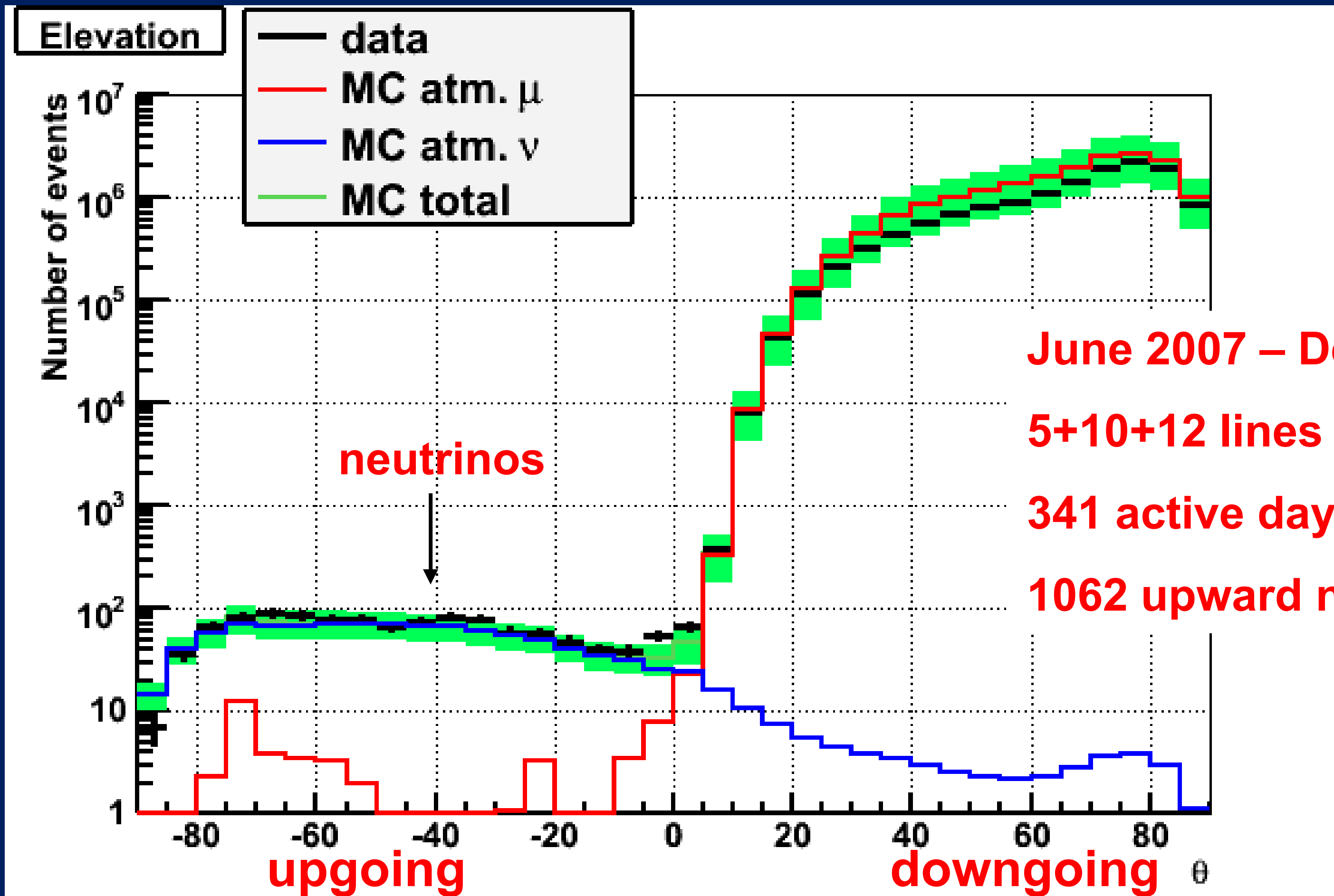


Detector footprint

Detector as seen by atmospheric muons: reconstructed position of the muon at the time of the first triggered hit



Zenith angle distribution



June 2007 – Dec 2008

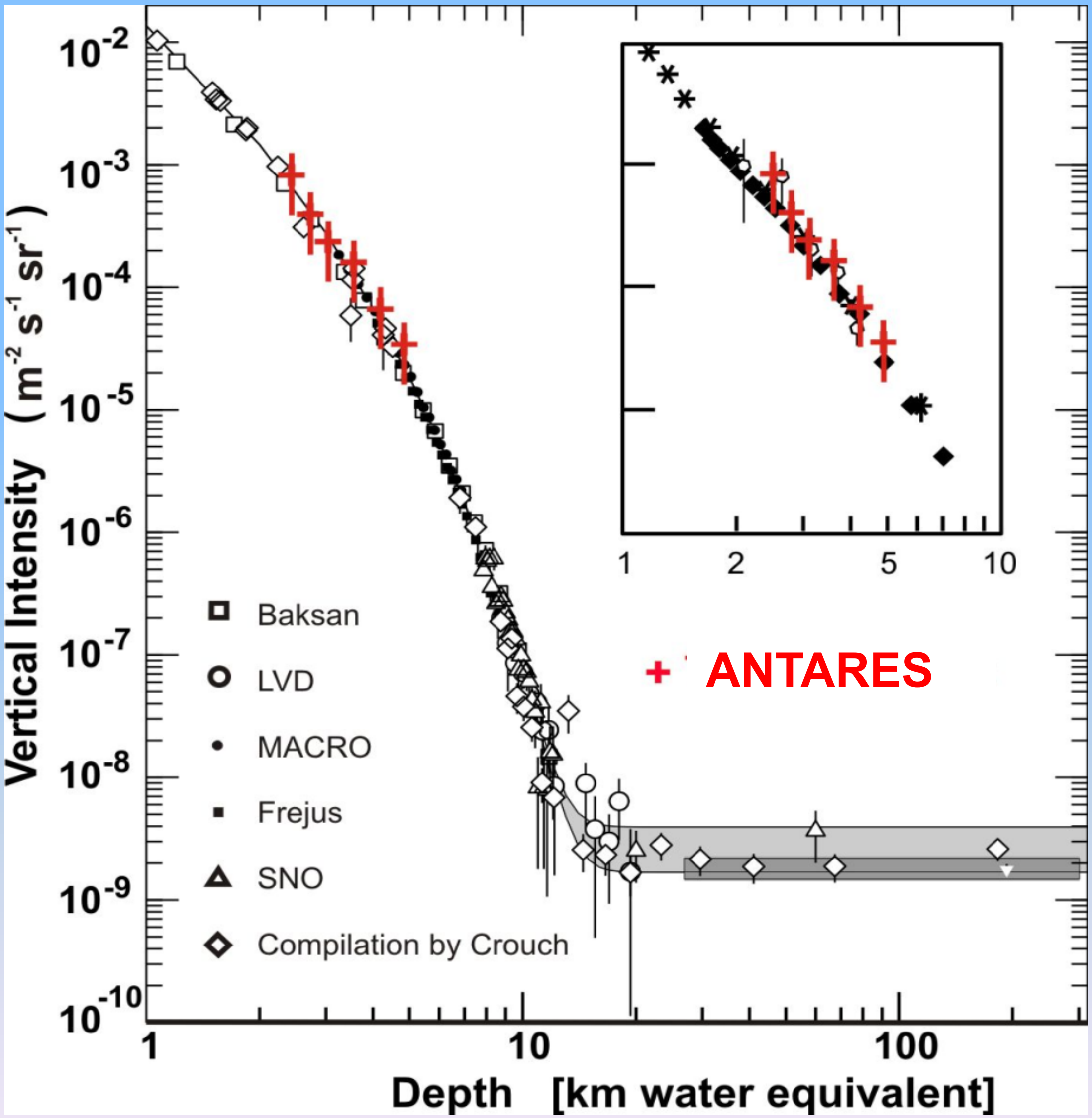
5+10+12 lines

341 active day

1062 upward neutrino candidates

Good agreement with "standard" neutrino oscillations: $\sin^2 2\theta = 1$; $\Delta m^2 = 2.4 \cdot 10^{-3}$ eV^2

vertical muon intensity



derived from zenith distribution for down-going muons in line 1:

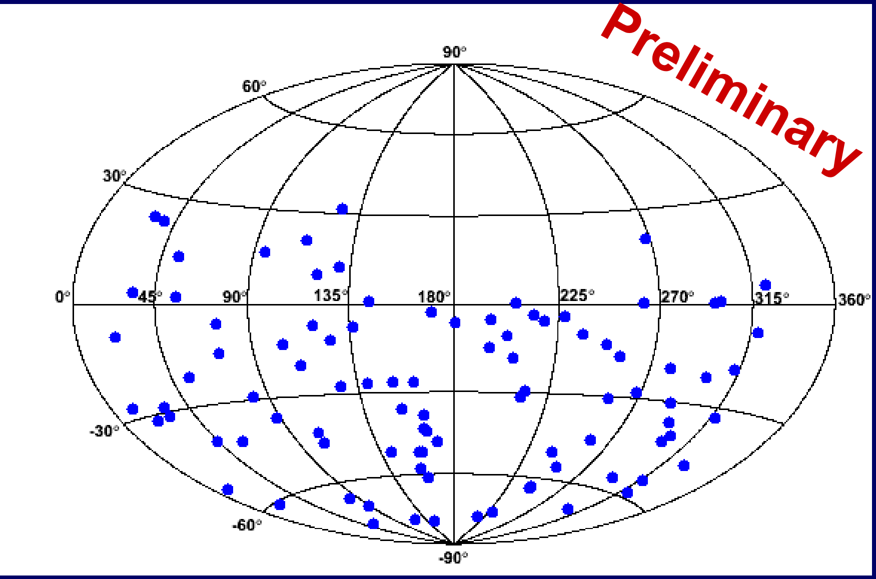
📖 APP 31(4): 277-283 (2009)

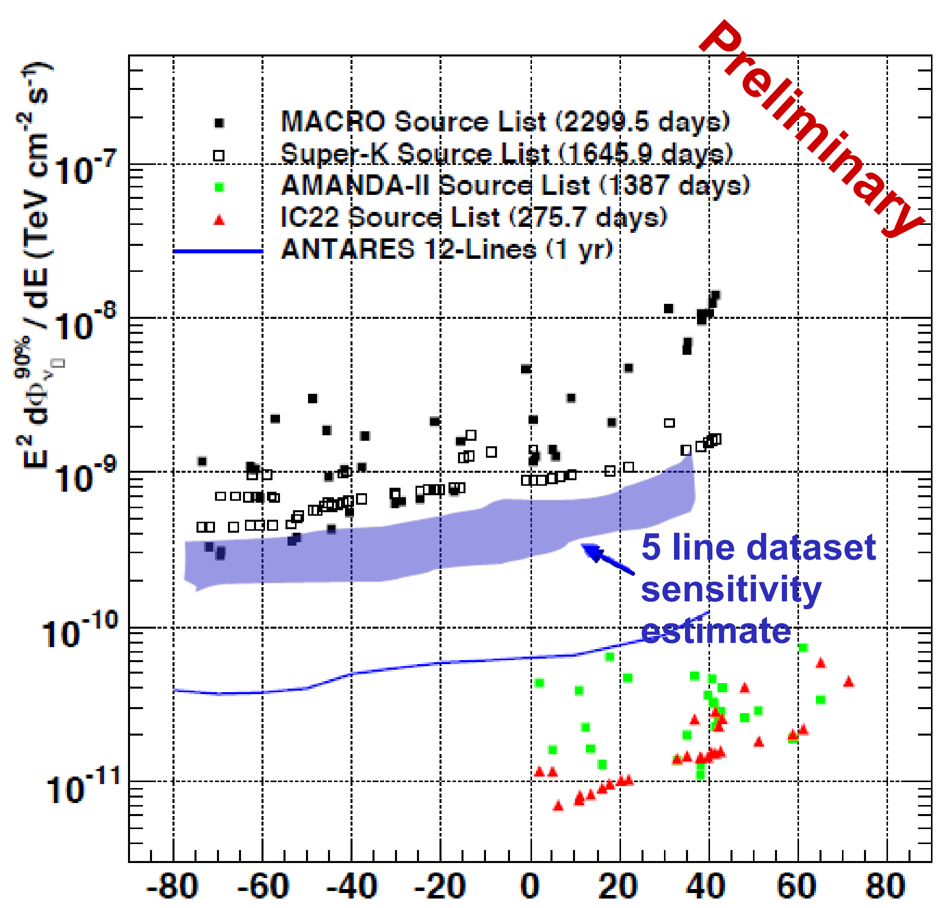
ANTARES data in good agreement with published data from Baksan, LVD, MACRO, Frejus, SNO and underwater/ice neutrino telescopes: BAIKAL, AMANDA, NESTOR

2007 data → neutrino sky map (all sky search)

Effective live time 140 days . Stringent selections: low backgroun & high reconstruction quality (ang. resolution < 0.5°)

binned, unbinned searches on data with scrambled coordinates of 94 events (equatorial coordinates):



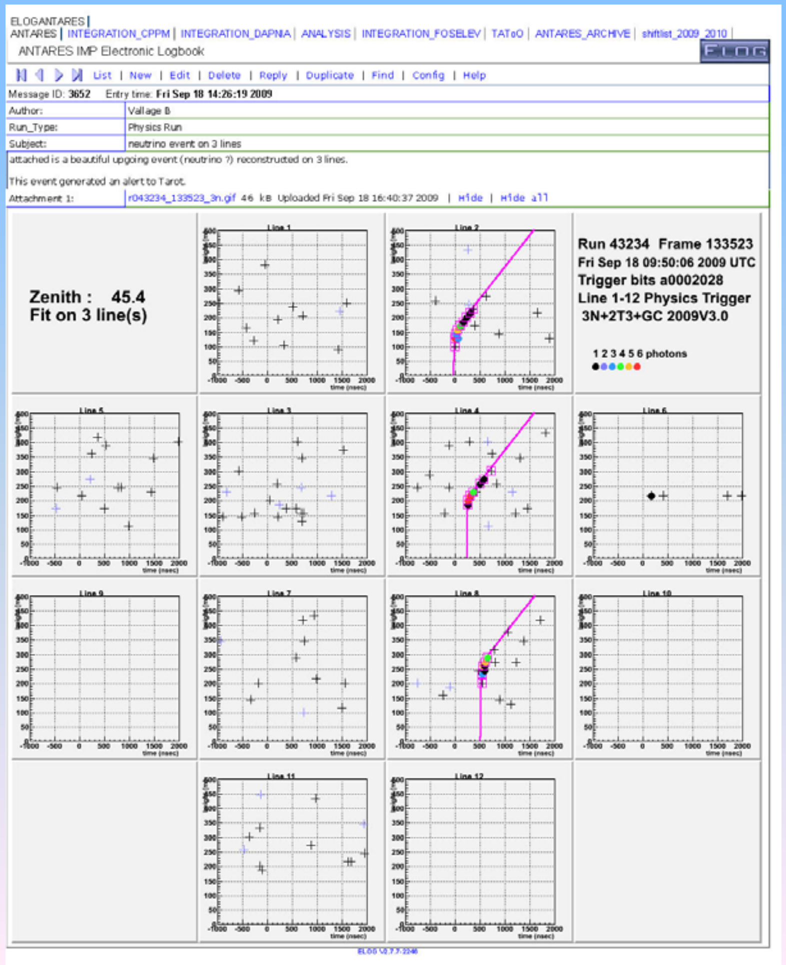


no correlation with 25 potential ν sources;
no excess (± 1σ) in all-sky search;
sensitivity competitive with multi-year exposures of previous experiments

Additional initiatives in ANTARES

a) Antares-Virgo-Ligo agreeement (common trigger)
b) Antares Alerts to Optical Tescopes (Tarot)

September 18, 2009
observed neutrino and alert sent to TAROT



KM3NeT Consortium

42 institutes from:

Cyprus, France, Germany, Greece, Ireland, Italy, Netherlands, Romania, Spain, UK

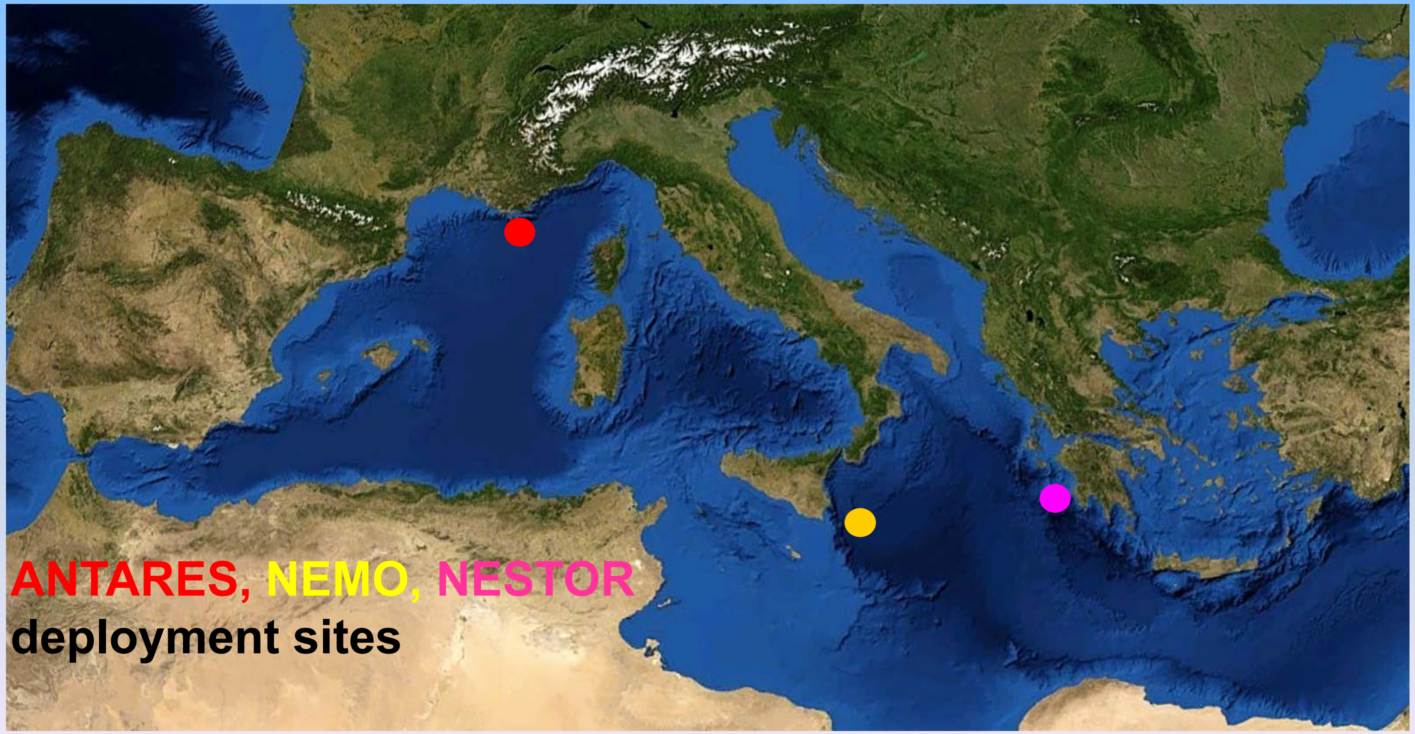
pilot projects:

+ + +..

funded by FP6 for Design Study, by FP7 for Preparatory Phase, on the ASPERA roadmap

Conceptual Design Report: public since April 2008,
Technical Design Report being finalised now ,
Start Construction Phase → 2011-2012

candidate deployment sites



criteria:

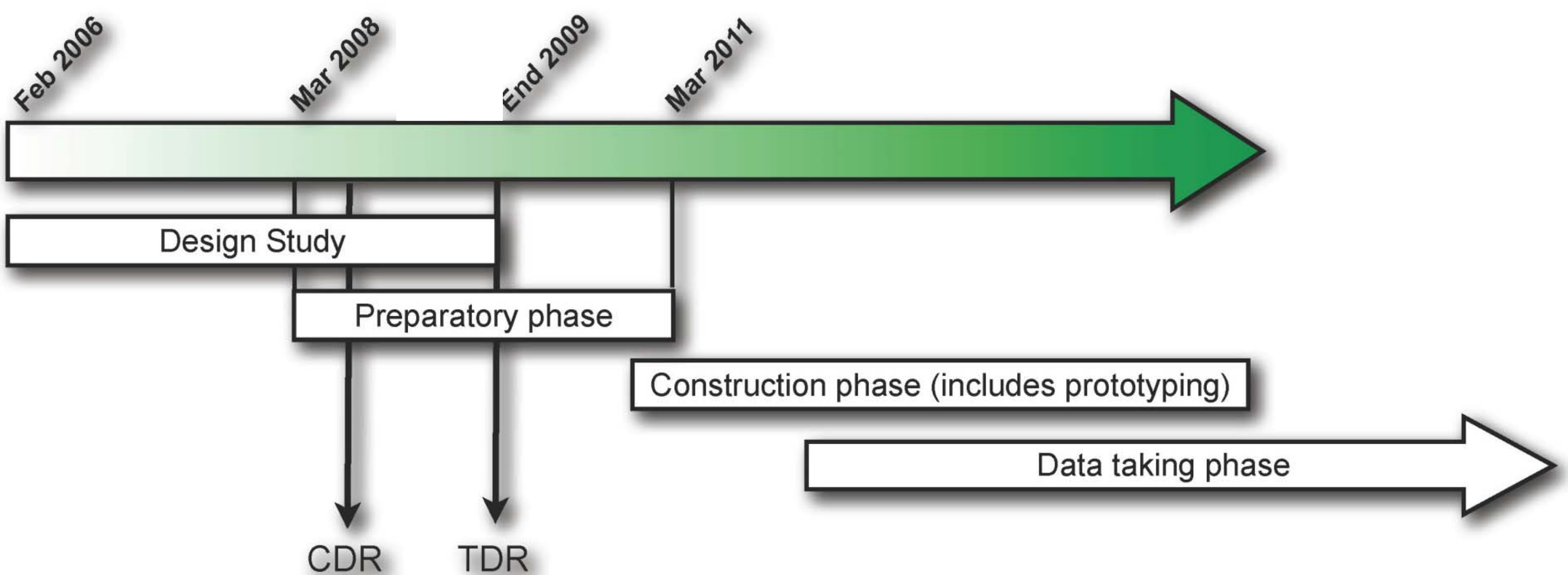
bioluminescence,
optical background,
currents,
water transparency.

Km3Net Preparatory Phase

Funded by the EU FP7 framework in March 2008

Primary objective → pave the path to political and scientific convergence on the legal, governance, financial engineering and siting aspects of the infrastructure…..

Km3net timeline



Conclusions

- Long march towards underwater cosmic neutrino detection has undergone an acceleration

- Nestor → first serious attempt in the Mediterranean → results published from prototype

- NEMO → big effort towards Capo Passero site (3500 m)
  Construction of detector for NEMO PhaseI completed. Results being published.
  The 100 km electro-optical cable for NEMO PhaseII installed and shore-station building ready

- ANTARES made a major step forward during 2006-2007 and the 12-lines detector with 900 OMs was completed in 2008. Data taking going on steadily.

- Joint European effort towards a km3 detector in the Mediterranean well advanced (Km3NeT DS+PP)

The End

Background Material

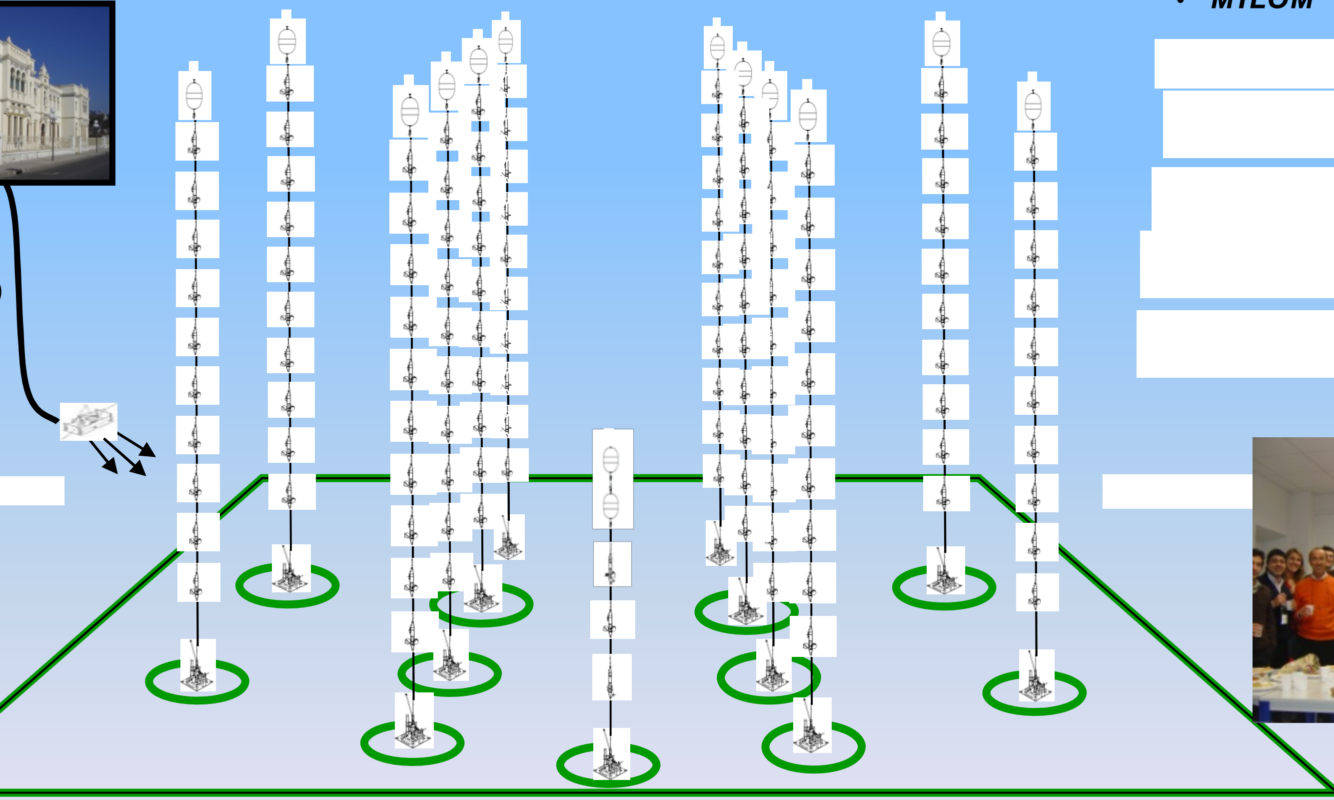
Deployment

Data taking periods:

- ***MILOM : Mar '05 – Mar '06***

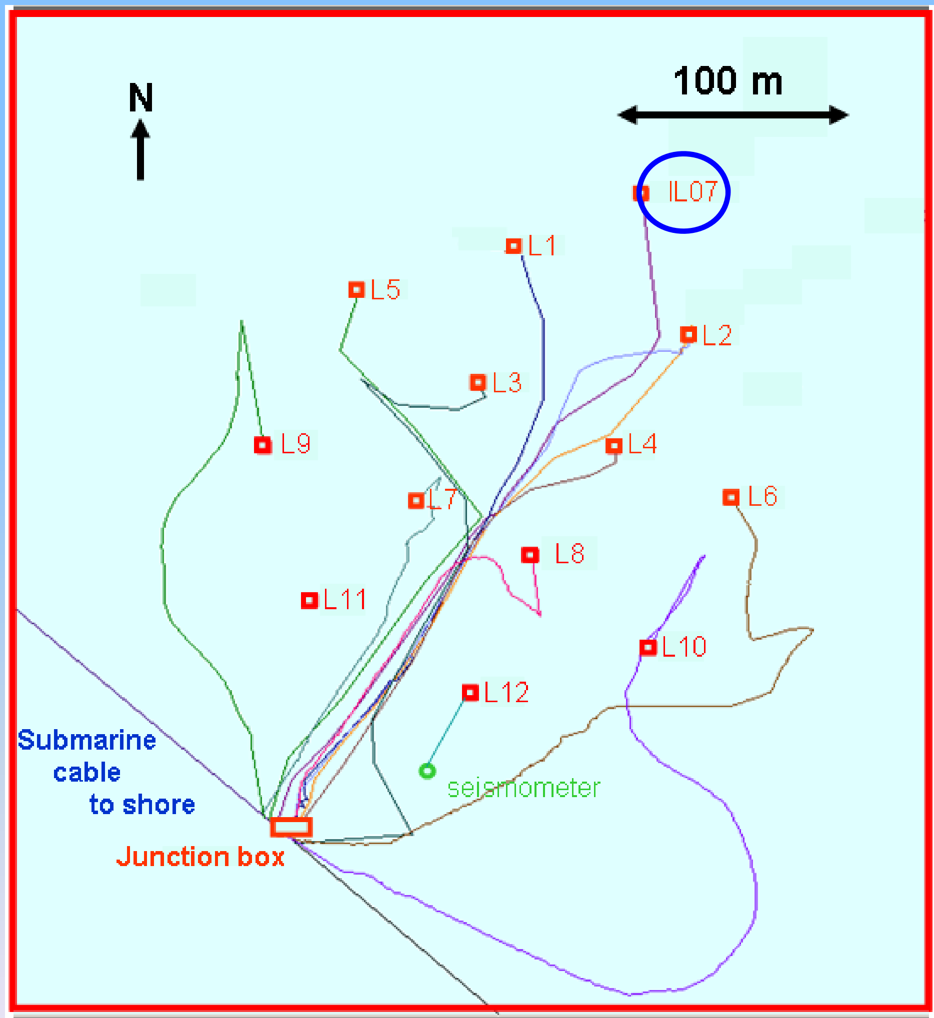
La Seyne-sur-Mer

(40 km)



(2.5 km depth)

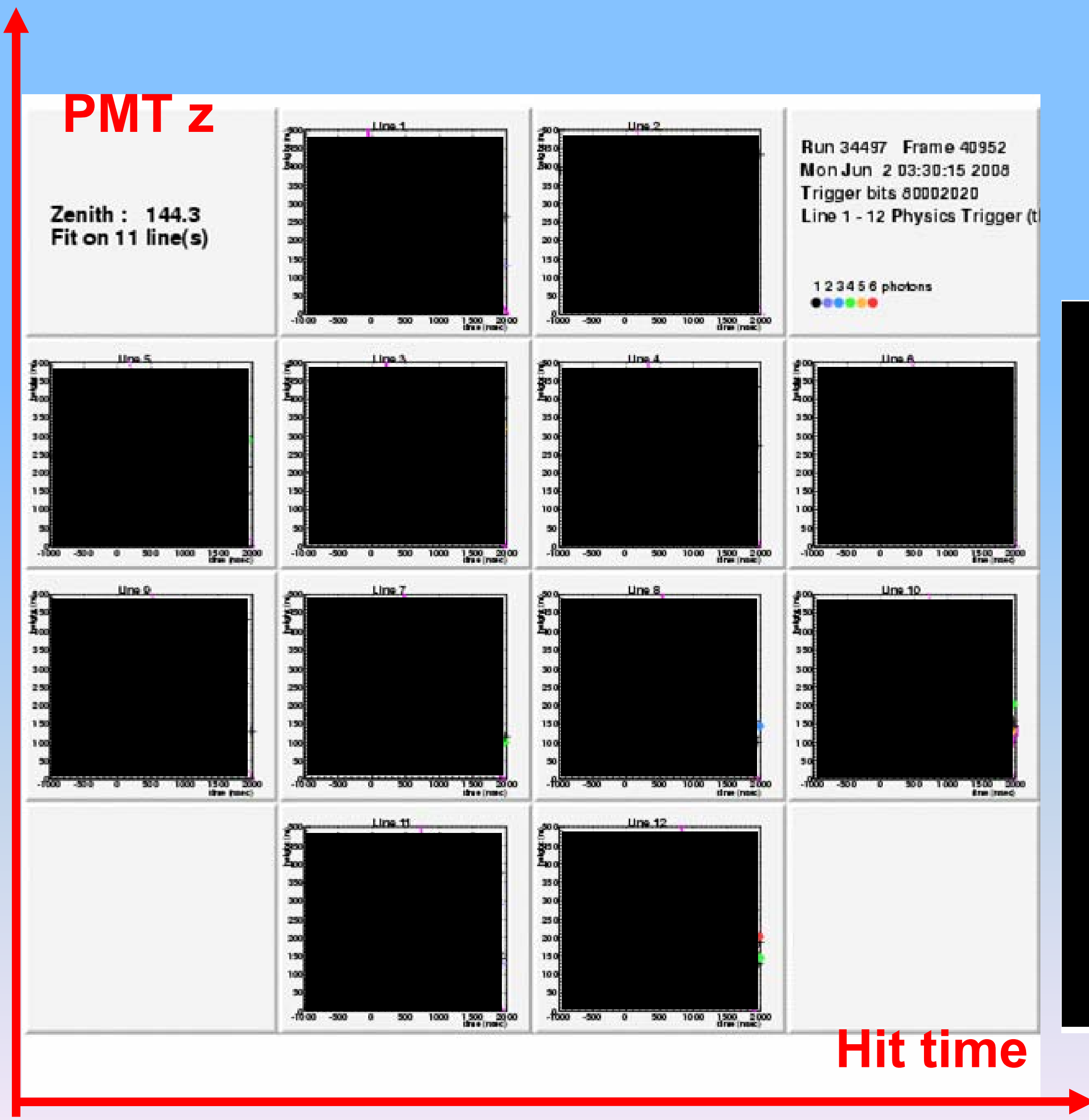
Detector layout



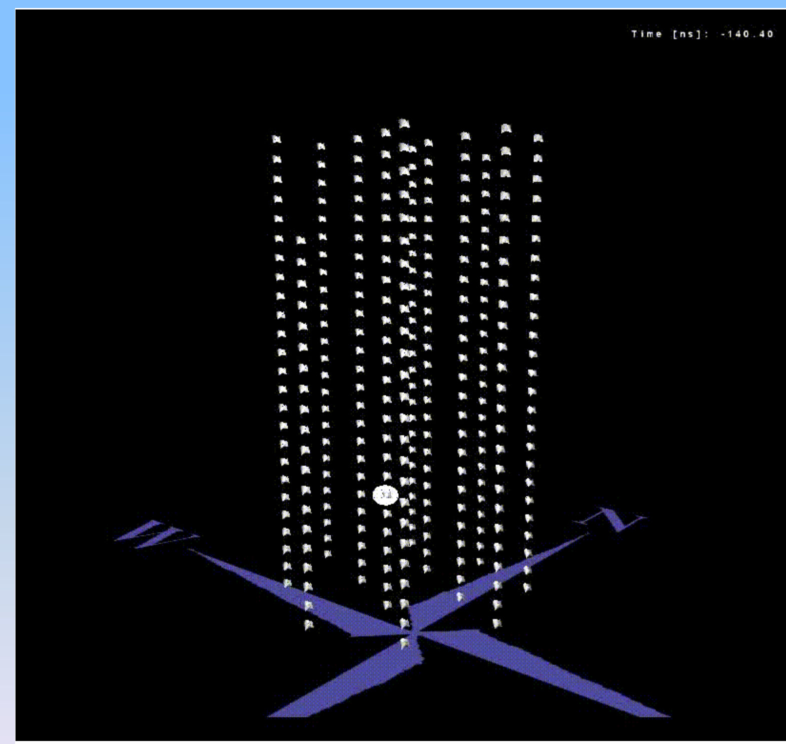
Acoustic storey

… and several instruments for environment studies with the ANTARES infrastructure

Atmospheric muons



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

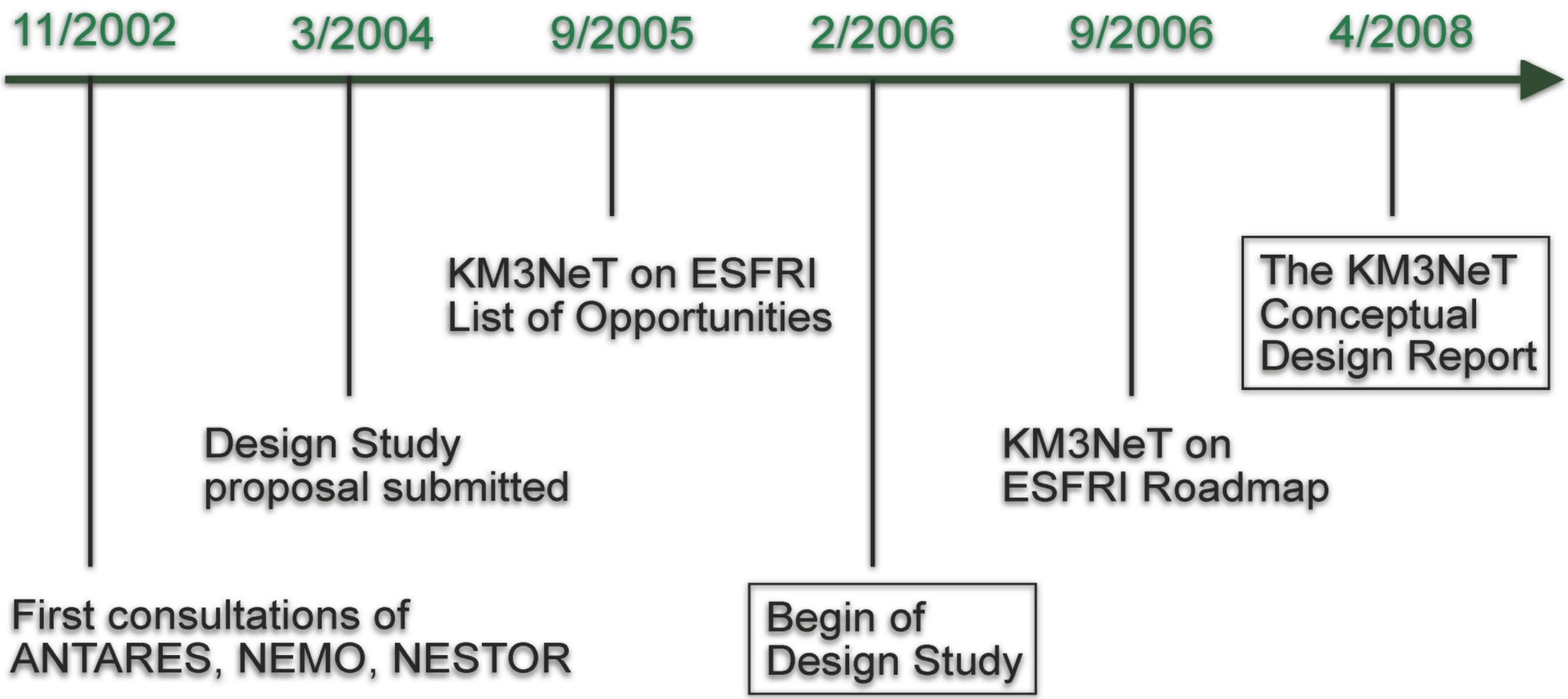


Design goals

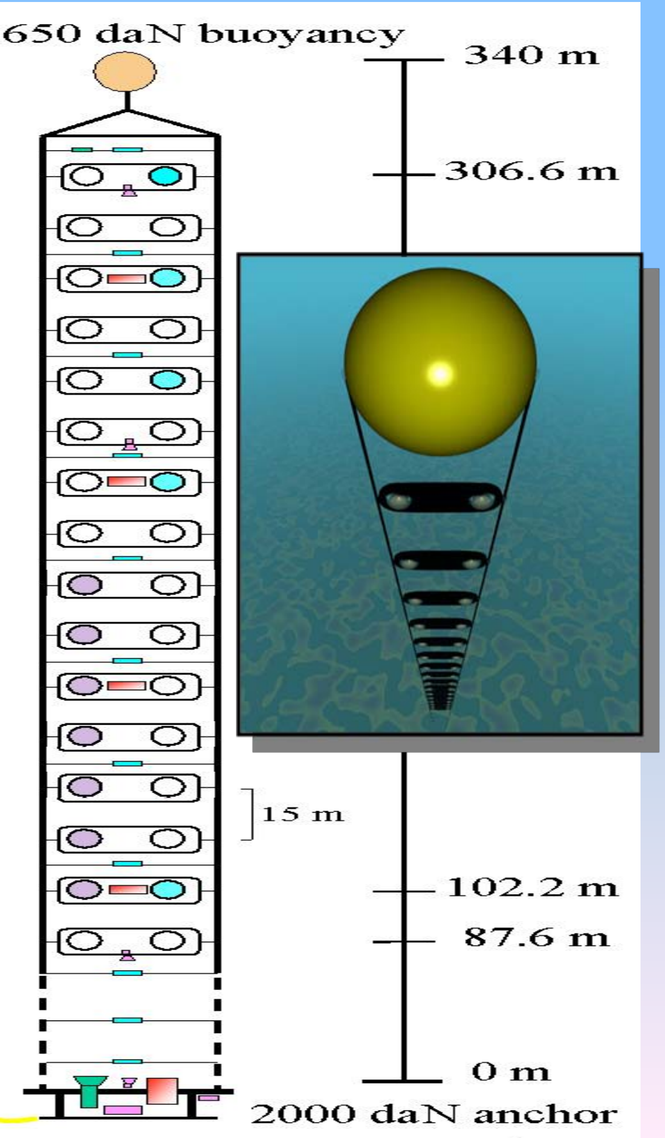
- Substantially better sensitivity than IceCube
- Volume > 1 km^3
- Core process: $\nu_\mu + N \rightarrow \mu + X$ above 100 GeV
- Construction and deployment < 4 years
- Data taking period > 10 year
- Optimized for energy range 1 TeV – 1 PeV
- Angular resolution < 0.1^o
- Zenith angle:
  - Full acceptance for neutrinos originating from directions up to at least 10° above the horizon
  - For energies > 100 TeV angular acceptance limited only by the absorption of the Earth

Km3Net Design Study

KM3NeT: from the idea to a concept

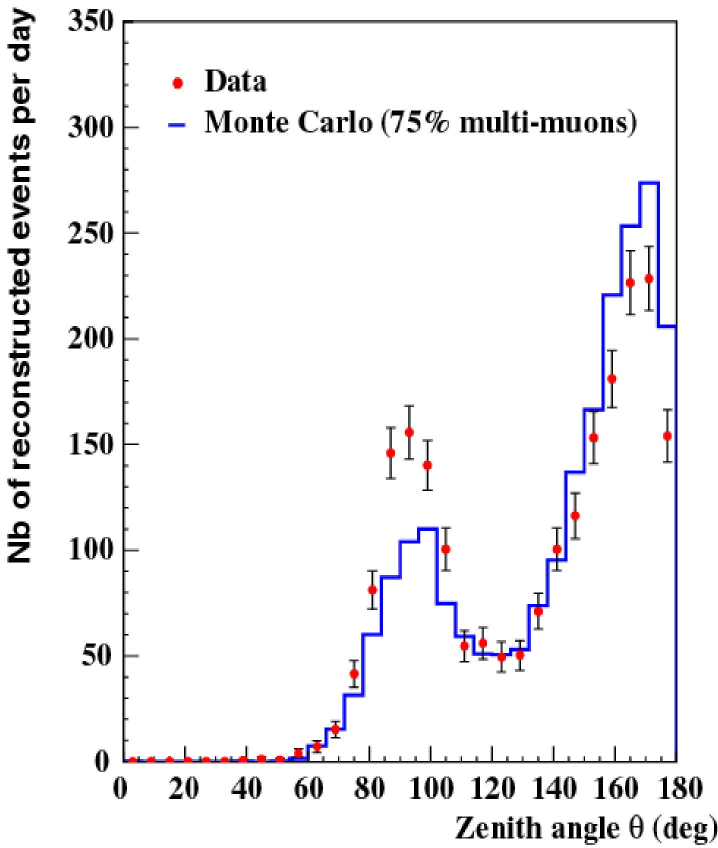


Antares « Demonstrator » deployed end 1999 (1100 m depth)



A. Kouchner PhD Thesis

Atm. μs angular distribution compared to MC



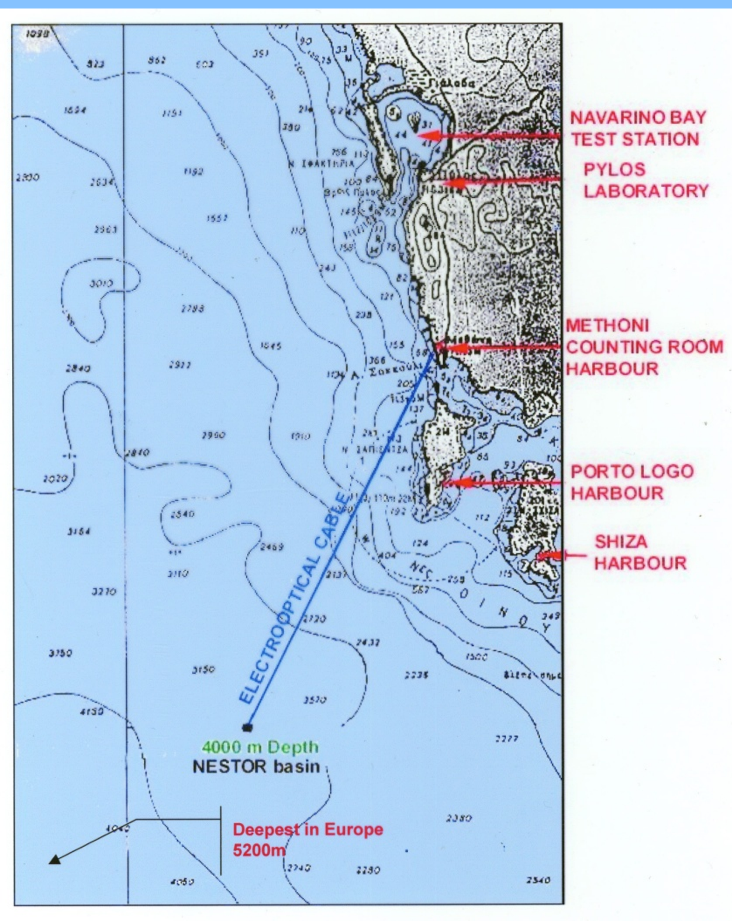
NESTOR→ Prototype deployed in the Mediterranean (2003)

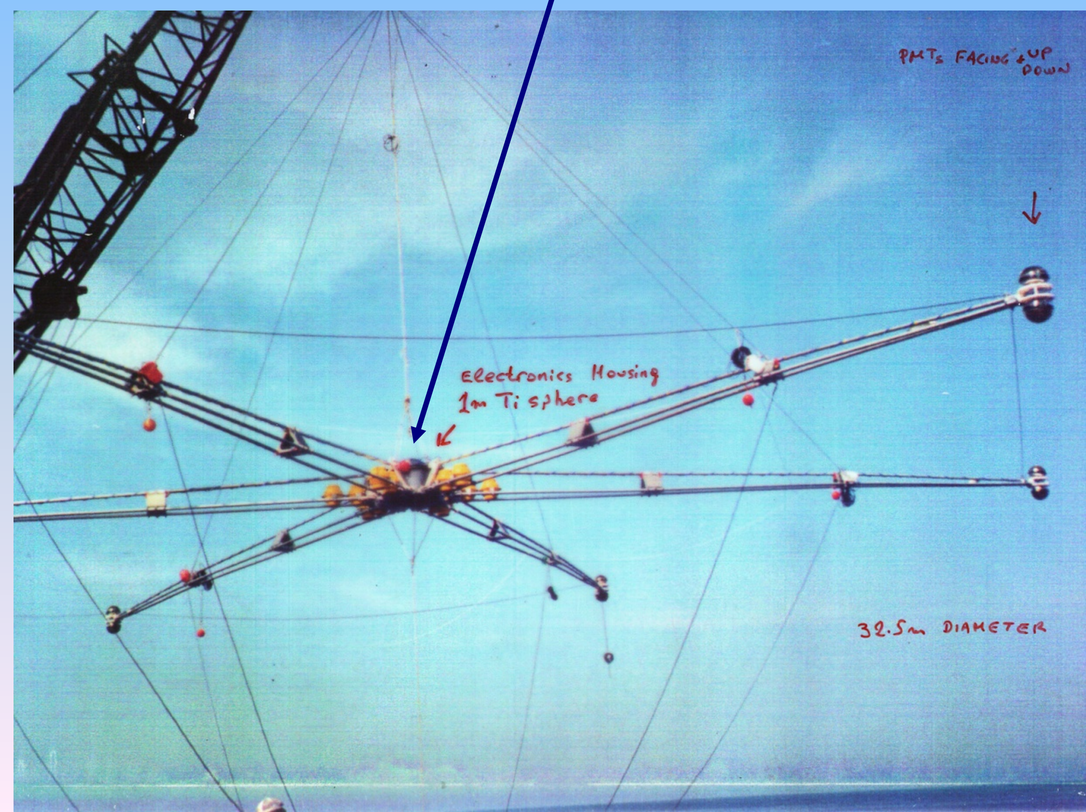
Avoid underwater connections → no use of ROV

Implications: have to recover entire detector in case of repairs
(not recommended after DUMAND experience)

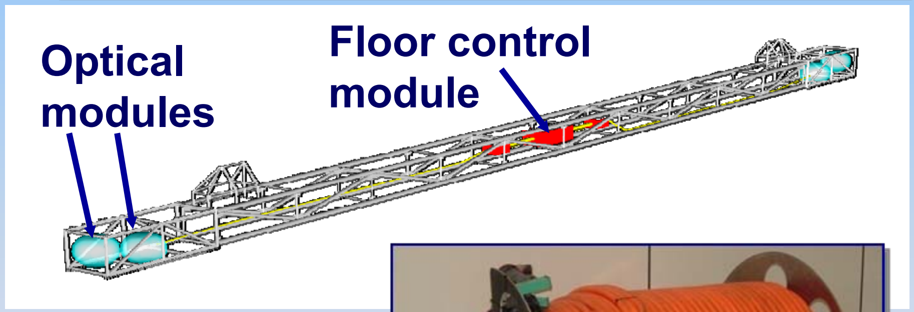
32 m diameter floor (6 floors)
30 m between floors
144 15” PMTs

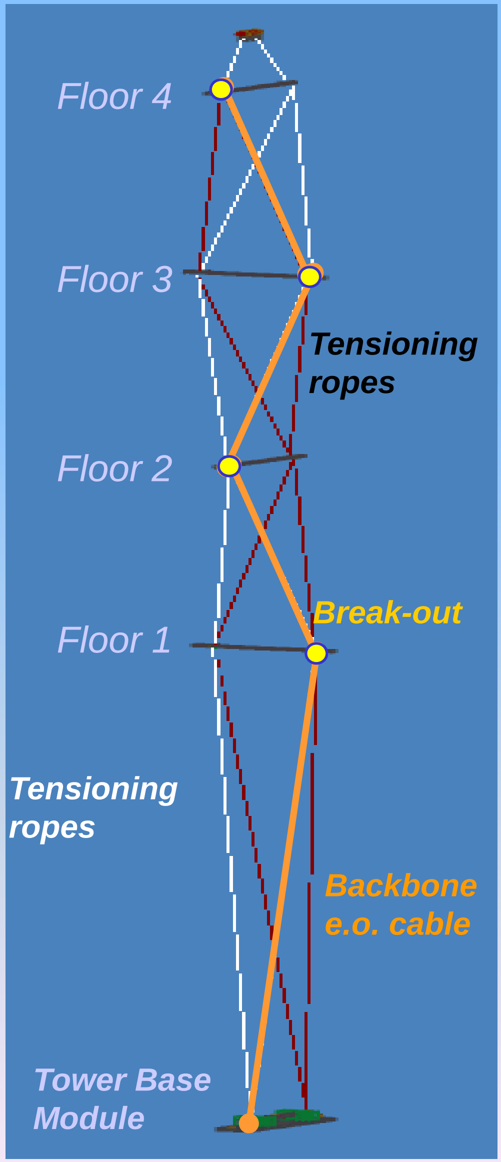
At the center of each floor a Ti sphere
Houses the floor electronics





The Mini Tower for NEMO Phase-1





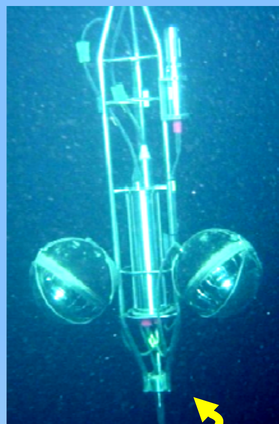
Mechanical stresses are applied only to the tensioning ropes

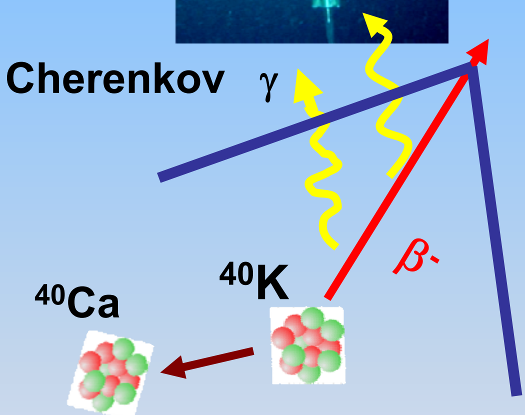
Cross Sections & Interaction Lengths

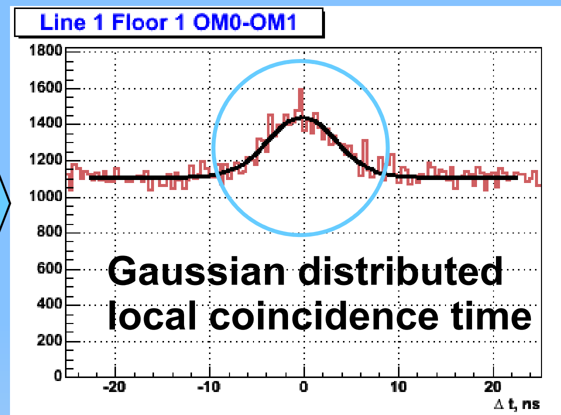
D_{Galaxy} = 10^{19} m => nr of Galaxies which could fit in one λ

Particle	Galactic Interaction length λ_G (m)	Nr Galaxies
Proton **(if no neflection)**	2×10^{23}	2×10^{4}
γ	3×10^{25}	10^{7}
ν (1 TeV)	1.5×10^{33}	10^{14}
ν (1 PeV)	1.5×10^{30}	10^{11}

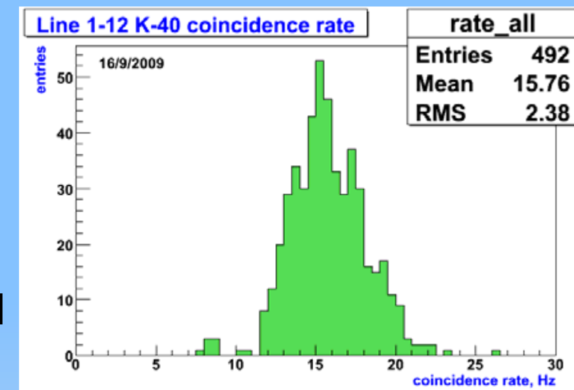
Local coincidences from ^{40}K decay





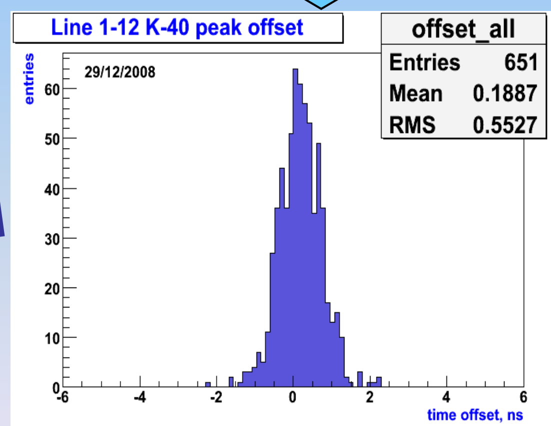


Peak integral



average coincidence rate 16 ± 2 Hz

Peak offset



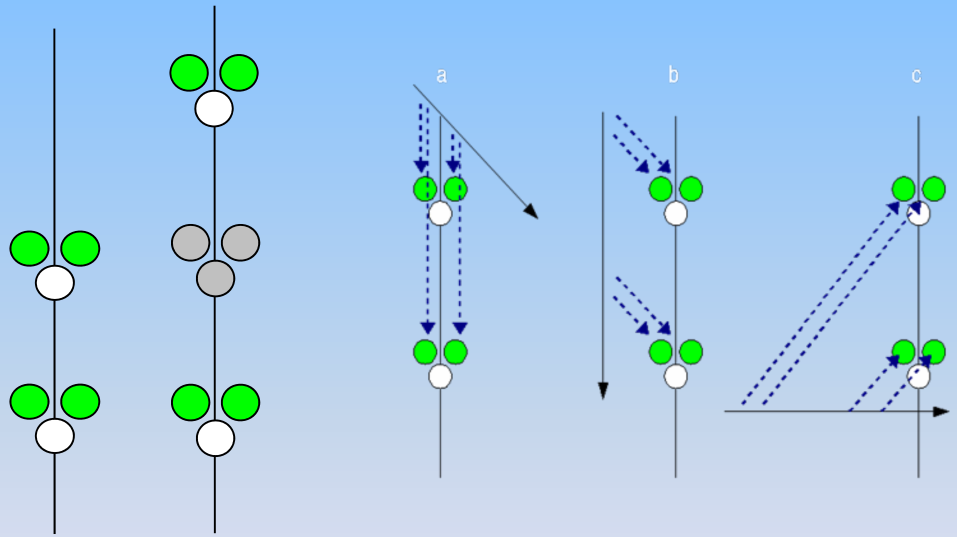
- **Efficiency of Optical Modules (~8%)**
- **Accuracy of time calibration (~0.5 ns)**

Storey coincidences

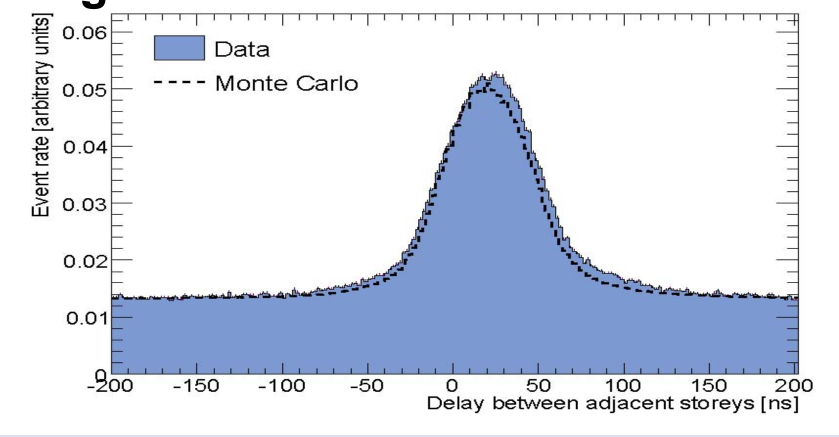
derive depth dependence of muon flux
from coincidence-time distributions of
(next-to) adjacent storeys, each with a local coincidence (± 20 ns):

low threshold of 4 GeV

(minimum track length between adjacent storeys)



distribution of measured
time differences
agrees with MUPAGE MonteCarlo

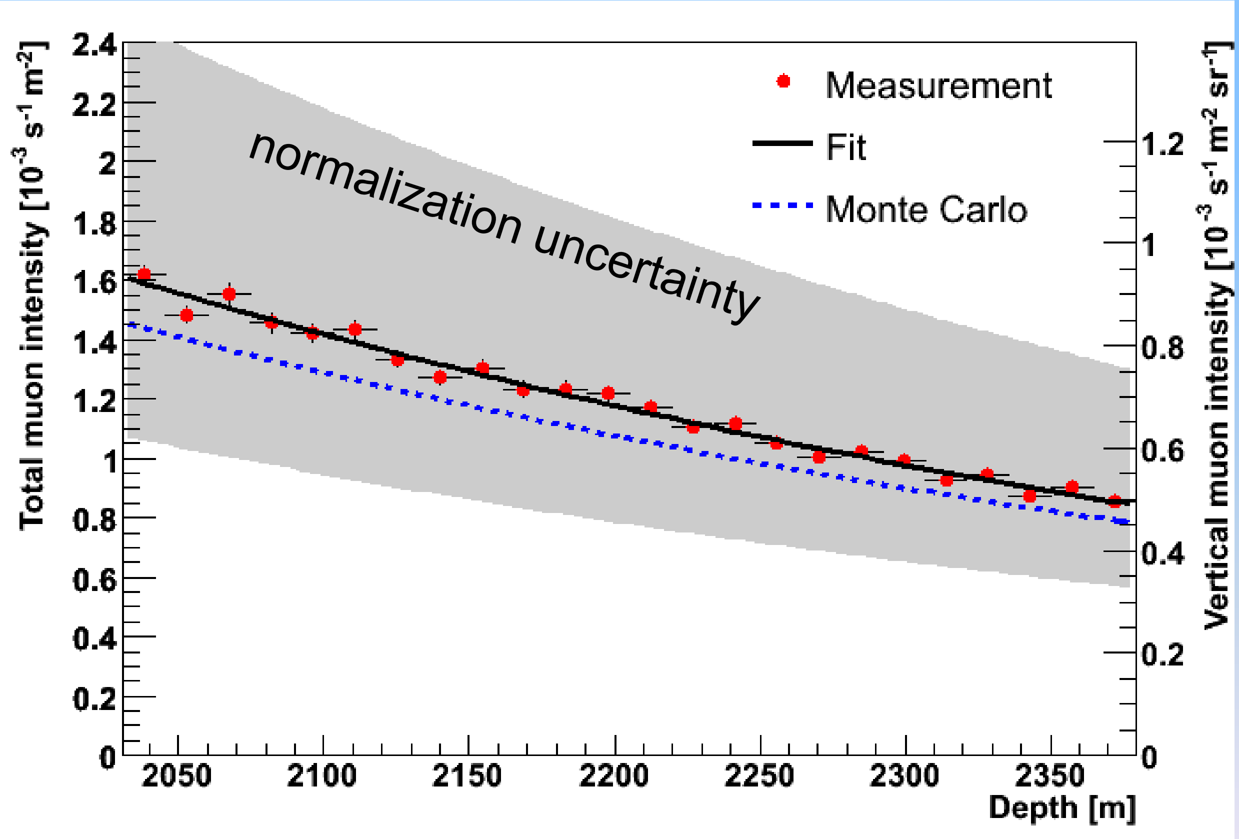


mostly down-going muons: delay ~ + 20 ns)

Muon Flux

depth (h) dependence of muon flux $\Phi(h)$ is directly measured from adjacent storey coincidences:
(📖 accepted for publ. in APP)

$$\Phi(h) = \Phi_0 \cdot \exp\left(\frac{h - h_0}{\lambda}\right)$$



slope λ not affected by normalization uncertainty:

λ = 540 ± 25 m

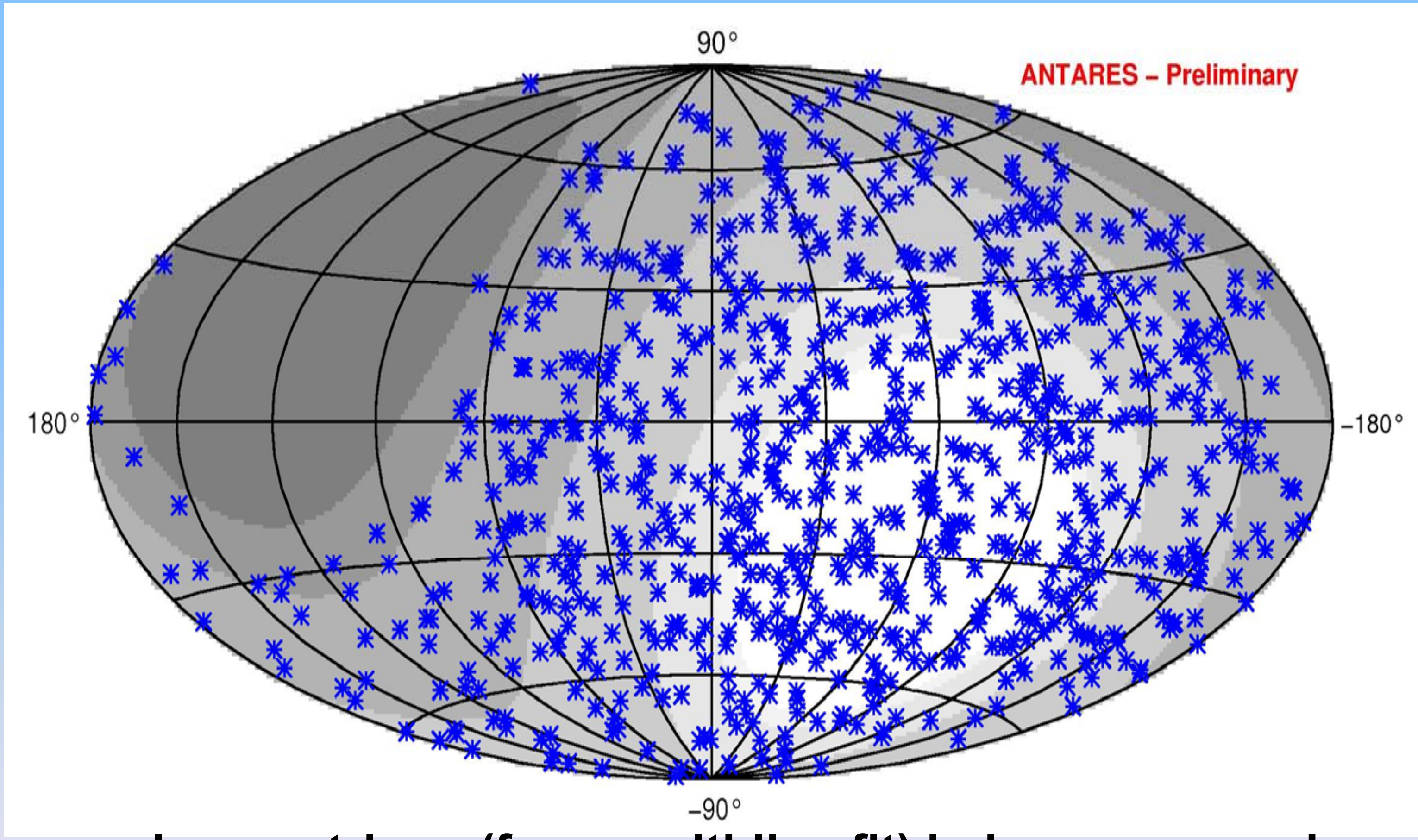
in agreement with Monte Carlo:
λ^{MUPAGE} = 560 m

$\lambda^{CORSIKA}$ = 570 m

current work: reducing the systematic uncertainties

Improved sky map data

Scrambled data from 2007+2008 analysis: galactic coordinates



750 up-going neutrinos (from multi-line fit) being processed

Km3Net Design Study

Design study → ***funded by EU FP6 in February 2006***

Development of a cost-effective design for a cubic km sized deep-sea infrastructure housing a neutrino telescope….

Conceptual Design Report released in April 2008
(www.km3net.org)

Includes:

- **Science case**
- **Site studies**
- **Design goals**
- **Technical implementation**