Ultra High Energy Neutrinos in the Mediterranean: detecting ν_τ and ν_μ with a km^3 telescope

Gennaro Miele
Università degli studi di Napoli "*Federico II*"
miele@na.infn.it

XII International Workshop on "Neutrino Telescopes"

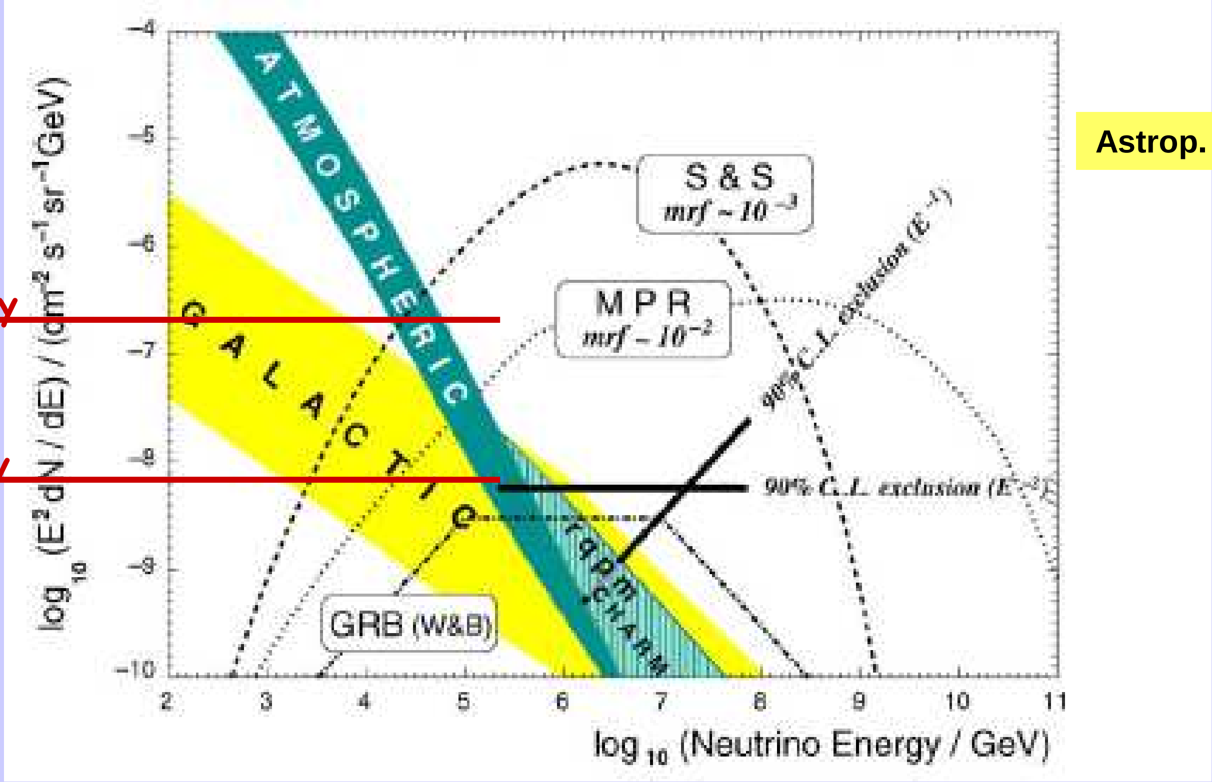
Reference: JCAP02(2007)007

Why to detect UHEν at a Km^3 Neutrino Telescope?

At ultra high energy extragalactic ν-flux dominates

AMANDA Sensitivity

ICECUBE Sensitivity



Astrop. Phys. 20 (2004) 507

Two Main reasons for UHE

- The extragalactic contribution dominates: extragalactic astronomy
- It is possible to measure simultaneously the neutrino flux and the ν-Nucleon cross section, at energies and kinematical regions never tested. Events ν_τ and ν_μ induced.

Final results:

The sensitivity increases for proper km^3-NT shape and orientation

UHE Neutrinos are produced via

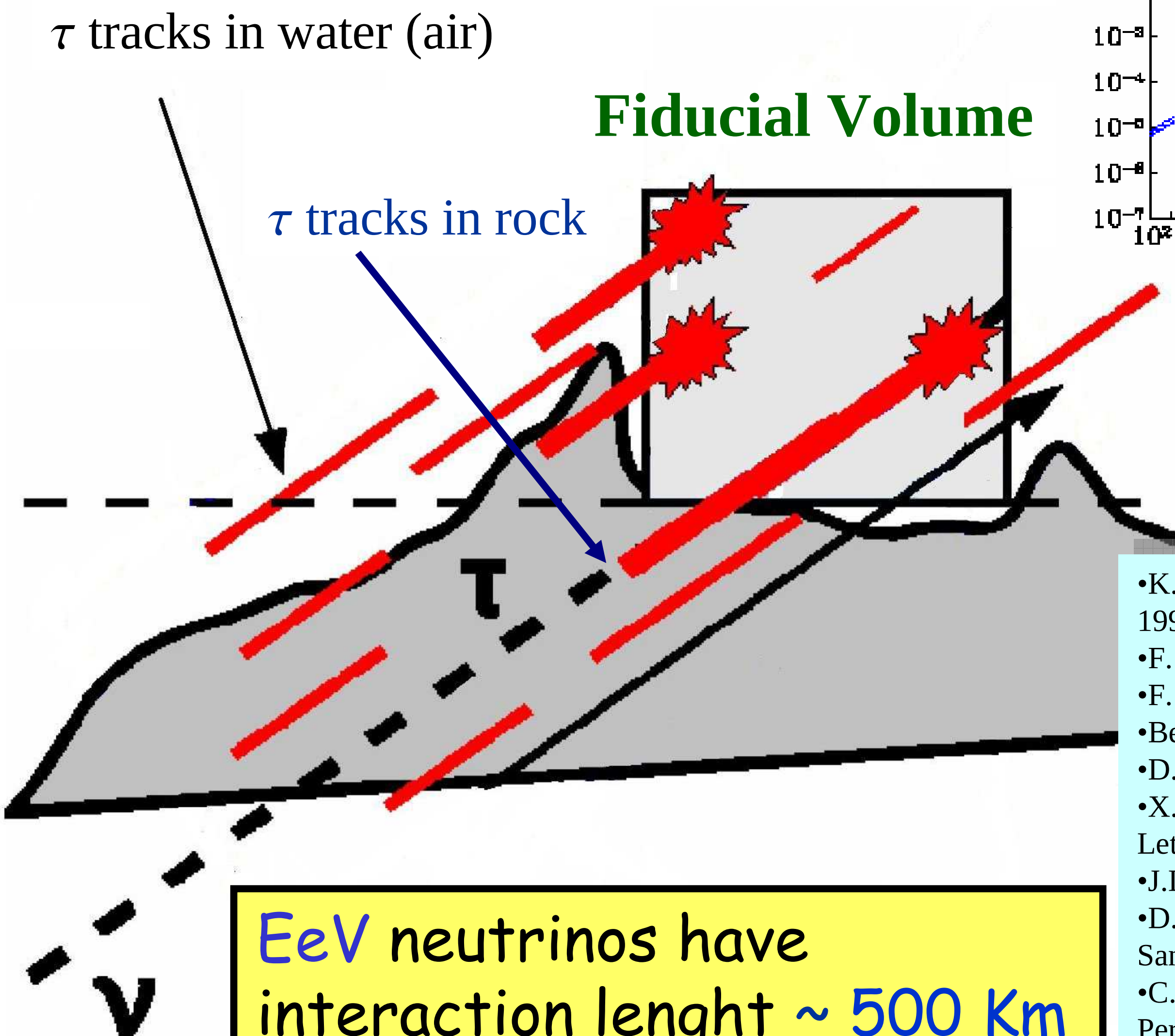
- The Acceleration mechanisms of UHE charged particles
- The Propagation in the cosmo of UHE particles

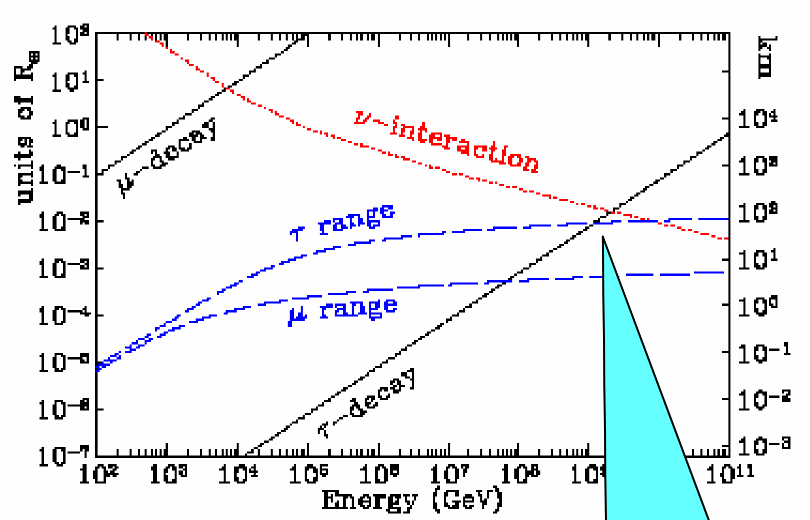
- $p + \gamma_b \longrightarrow p + e^- + e^+$ proton pair production
- $N + \gamma_b \longrightarrow N + n\,\pi$ photo-production of single or multiple pions
- $n \longrightarrow p + e^- + \overline{\nu_e}$ neutron decay

Due to neutrino oscillation and UHECR we expect almost the same UHE fluxes for ν_e , ν_μ ,ν_τ. **But the fluxes are still unknown!**

The ν_τ chances: two kinds of tracks

Earth-skimming ν_τ a real chance





τ interaction range larger or similar to the decay length

EeV neutrinos have interaction lenght ~ 500 Km water equivalent in rock

•K.S. Capelle, J.W. Cronin, G. Parente and E. Zas, 1998.
•F. Halzen and D. Saltzberg, 1998.
•F. Becattini and S. Bottai, 2001
•Beacom, Crotty, Kolb, 2001
•D. Fargion, 1999, 2002, 2005
•X. Bertou, P. Billoir, O. Deligny, C. Lachaud, A. Letessier-Selvon., 2002
•J.L. Feng, P. Fisher, F. Wilczek and T.M. Yu, 2002
•D. Fargion, P.G. De Sanctis Lucentini and M. De Santis, 2004
•C. Aramo, A. Insolia, A. Leonardi, G. Miele, L. Perrone, O Pisanti, D.V. Semikoz, 2005
•Z. Cao, M.A. Huang, P. Sokolsky and Y. Hu, 2005
•M.M. Guzzo and C.A. Moura, 2005
•G. Miele, S. Pastor and O. Pisanti, 2006

Let us consider a Km^3 in all the three sites proposed in the Mediterranean

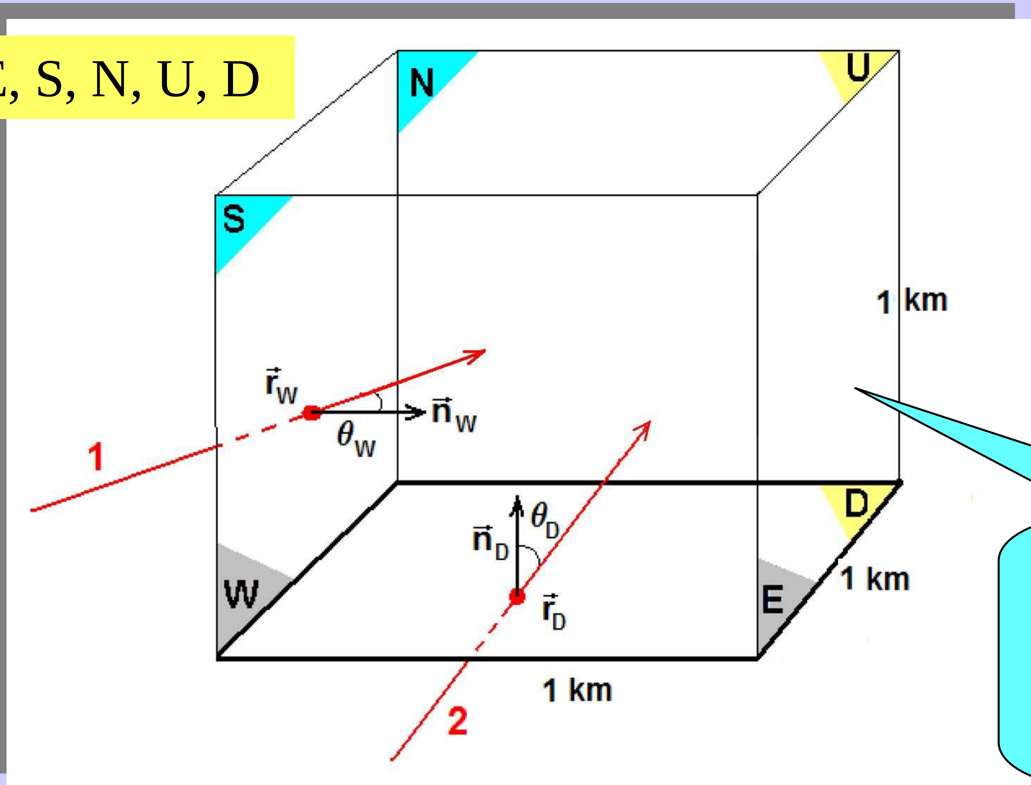
- Just a cube as *fiducial volume*
- No experimental details (Simplicity ansatz: each charged leptons crossing the fiducial volume is detected)
- Underwater surface profile

We generate possible neutrino tracks which account for the characteristics of Earth surface profile.

The rate of τ events in 1 Km^3

$$\frac{dN_\tau}{dt} = D \sum_a \int d\Omega_a \int dS_a \int dE_\nu \frac{d\Phi_\nu(E_\nu)}{dE_\nu d\Omega_a} \int dE_\tau \, \varepsilon(E_\tau) \cos(\theta_a) \, k_a\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right)$$

a = W, E, S, N, U, D



Same calculation for Auger FD in PLB634:137-142,2006

Fiducial volume, no experiment characteristics, just able to recognize a τ

For ν_τ crossing the rock (Earth-skimming) or water.

$$k_a\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right) = k_a{}^r\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right) + k_a{}^w\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right)$$

is the probability that an incoming neutrino crossing the Earth (rock "r" events) with energy E_ν and direction Ω_a, produces a lepton emerging with energy E_τ, which enters the fiducial volume through the lateral surface dS_a at the position $\vec{r}_a$. Similar definition for (water "w" events)

$$k_a^r\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right)$$

Takes three contributions, the main one is:

$$k_a^r\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right) = \int_0^{z_{\max}} dz \int_0^{f\,E_\nu} dE_\tau^{'}\; P_1\; P_2\; P_3\; P_4 + \ldots.$$

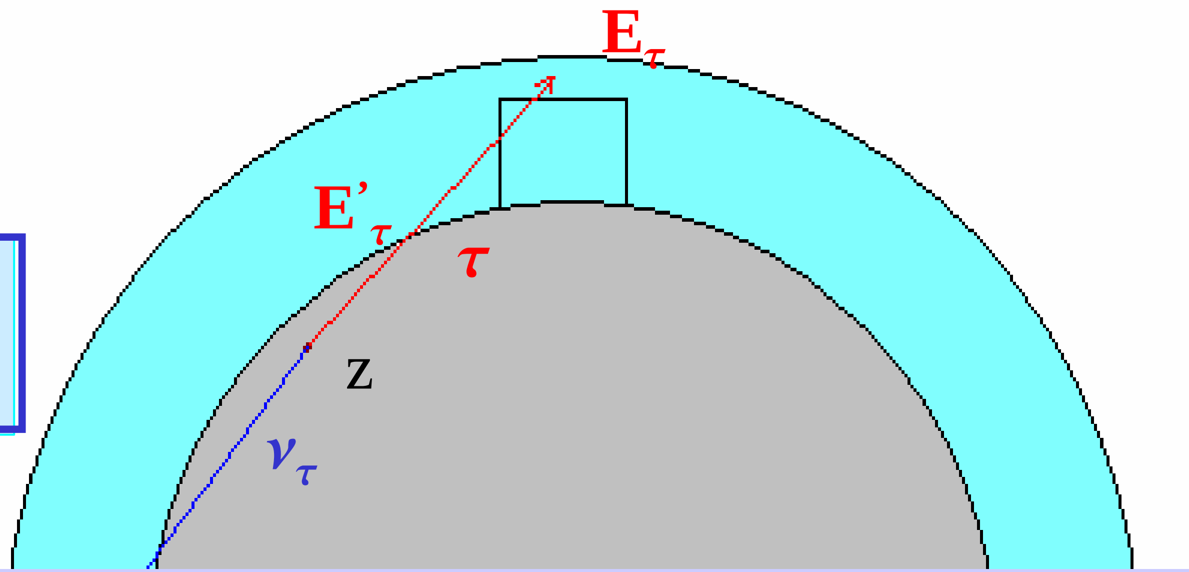
This process occurs if

1. **the ν_τ survives for some distance z in the Earth (P_1)**
2. **$\nu_\tau \longrightarrow \tau$ in z, $z+dz$ (P_2)**
3. **the τ comes out from the Earth before decaying (P_3)**
4. **the τ is able to reach the fiducial volume (P_4)**

$$P_1 = Exp\left[-\frac{z}{\lambda_{CC}^{\nu}(E_\nu)}\right]$$

$$\lambda_{CC}^{\nu}(E_\nu) = \frac{1}{\sigma_{CC}^{\nu}(E_\nu)\,\rho_s\, N_A}$$

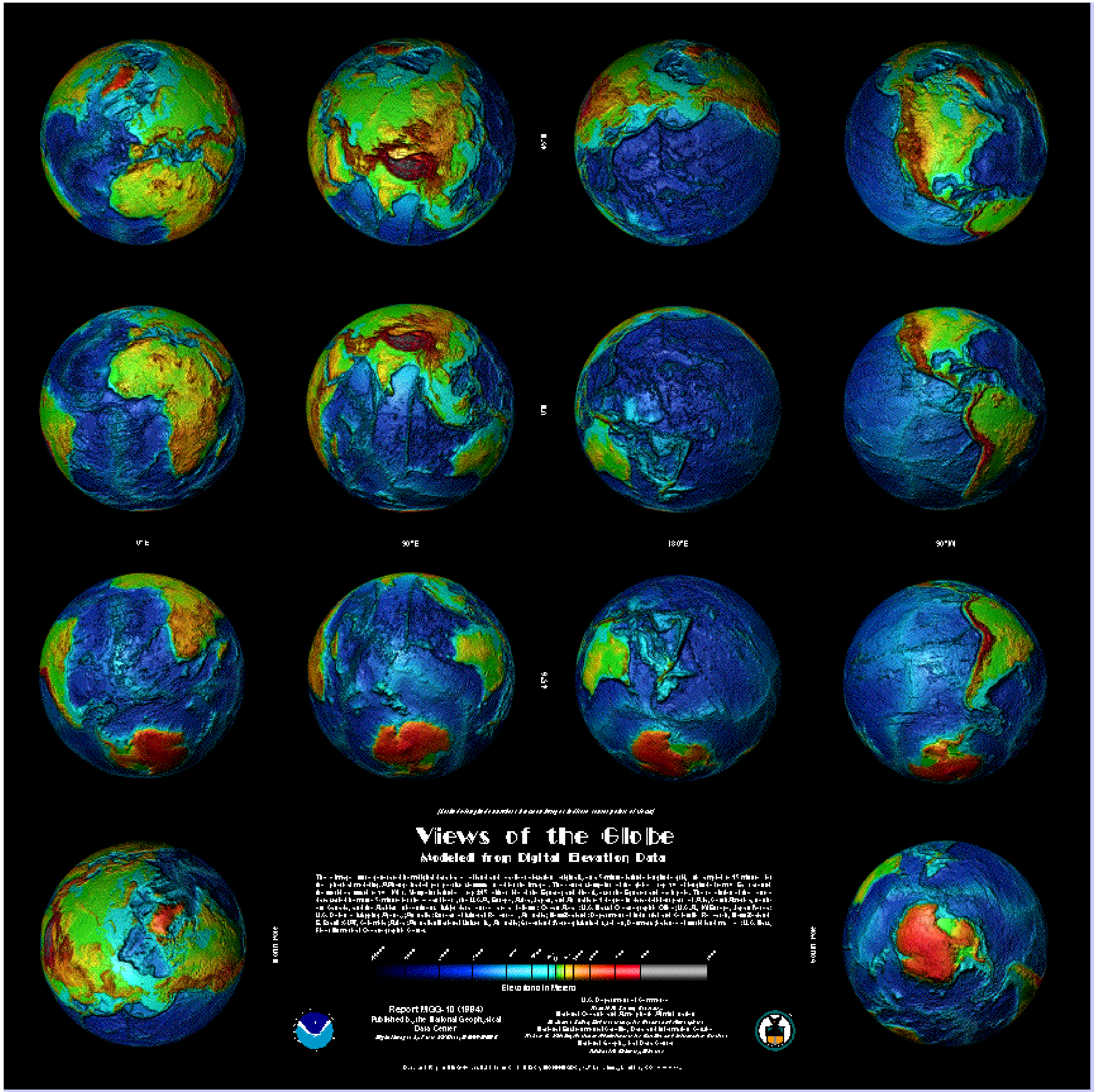
$$P_2 = \frac{dz}{\lambda_{CC}^{\nu}(E_\nu)}$$



$$P_3 = Exp\left[-\frac{m_\tau}{c\,\tau_\tau\,\beta_\tau\,\rho_s}\left(\frac{1}{E_\tau^{'}} - \frac{1}{f\,E_\nu}\right)\right]\delta\left(E_\tau^{'} - f\,E_\nu\,e^{-\beta_\tau \rho_s \left(z_s^{\max} - z\right)}\right)$$

$$P_4 = Exp\left[-\frac{m_\tau}{c\,\tau_\tau\,\beta_\tau\,\rho_a}\left(\frac{1}{E_\tau} - \frac{1}{E_\tau^{'}}\right)\right]\delta\left(E_\tau - E_\tau^{'} e^{-\beta_\tau \rho_a z_a^{\max}}\right)$$

$\mathbf{z_a^{max}}$ and $\mathbf{z_s^{max}}$ are the total lengths in water and rock for a given track. It depends on the real surface profile.

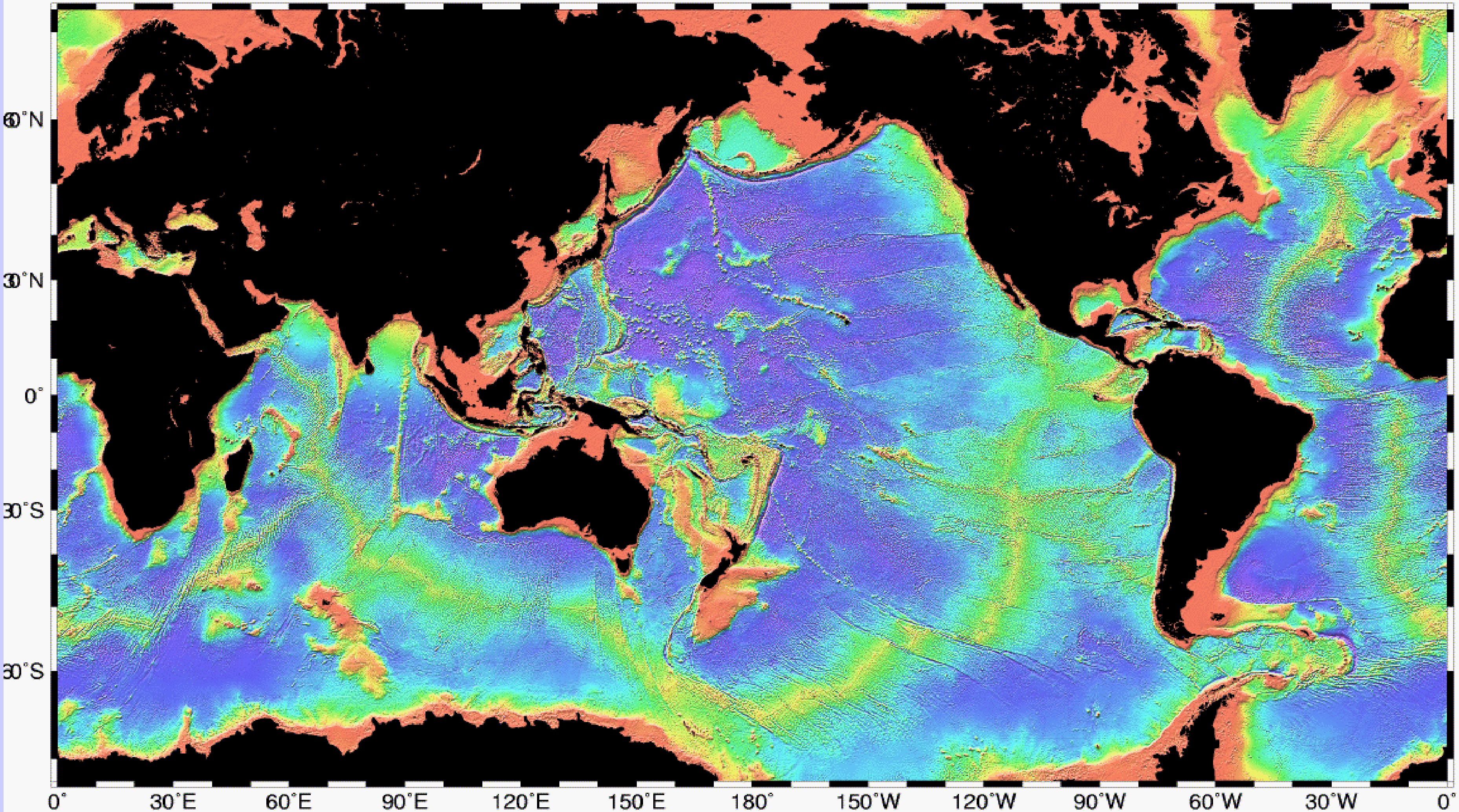


ETOPO2

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center, 2001. 2-minute Gridded Global Relief Data (ETOPO2)

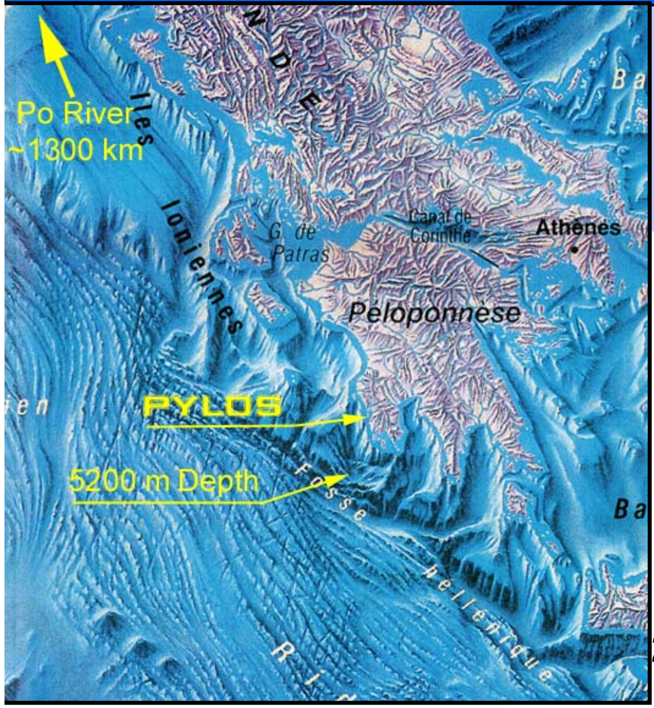
The horizontal resolution is 2-minutes of latitude and longitude (1 minute of latitude = 1.853 km at the Equator). The vertical resolution is 1 meter.

Satellite Radar Bathymetry: The surface of the ocean bulges outward and inward mimicking the topography of the ocean floor. The bumps, too small to be seen, can be measured by a radar altimeter aboard a satellite. Over the past year, data collected by the European Space Agency ERS-1 altimeter along with recently declassified data from the US Navy Geosat altimeter have provided detailed measurements of sea surface height over the oceans. These data provide the first view of the ocean floor structures in many remote areas of the Earth.



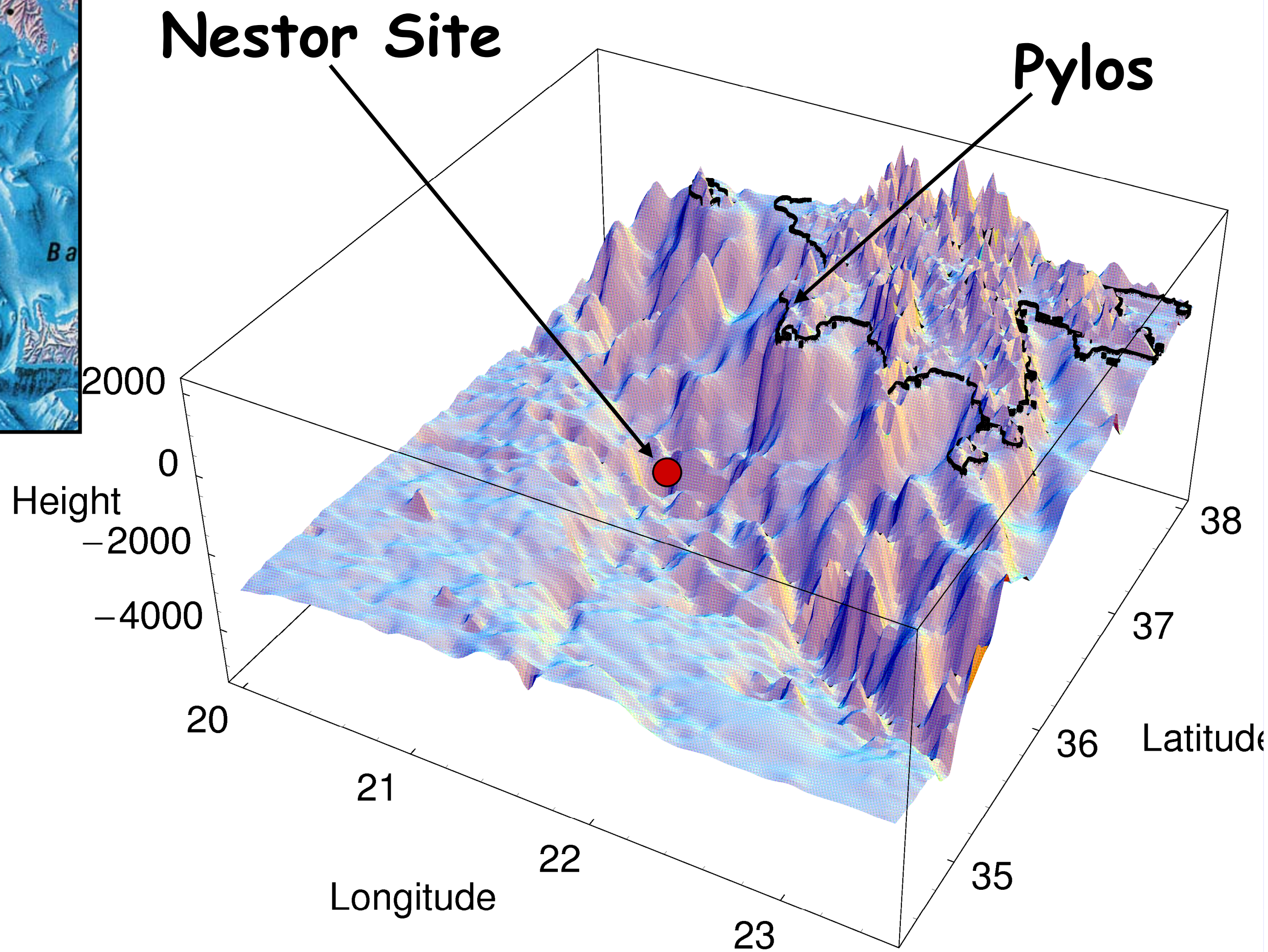
Walter H. F. Smith and David T. Sandwell, Seafloor Topography Version 4.0, SIO, September 26, 1996

NESTOR Site

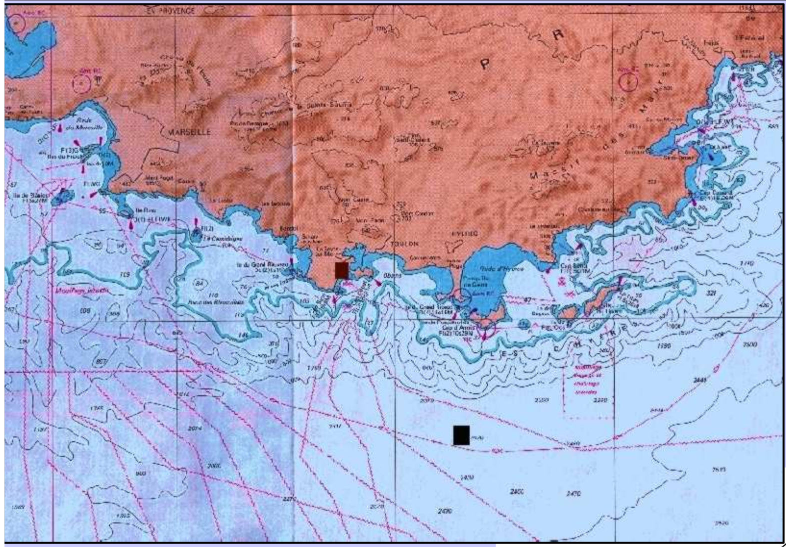


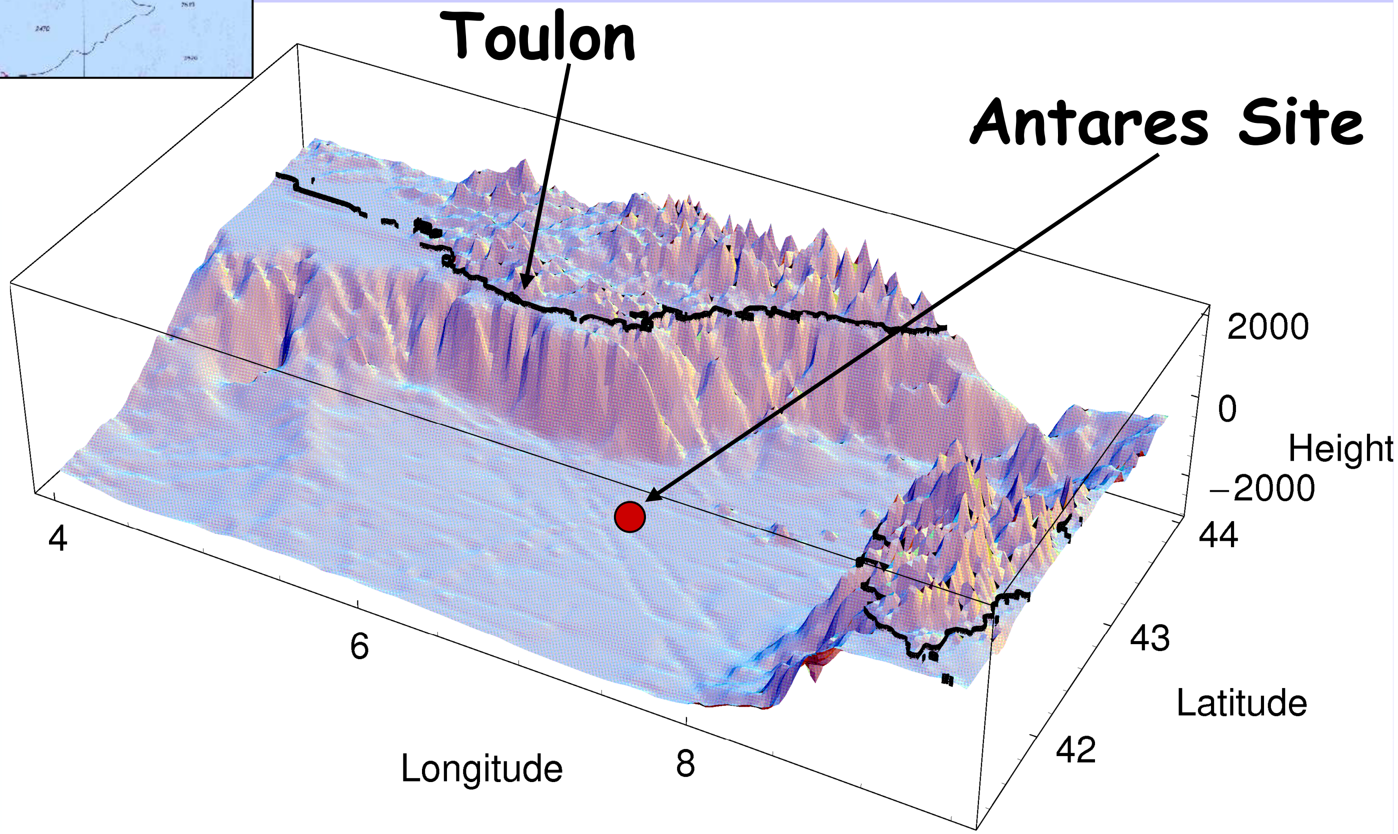
- **Site Location**
  36°21′ N, 21°21′ E

- **Average Deep**
  ~4000 m
  (4166 in our simulation)



Antares Site

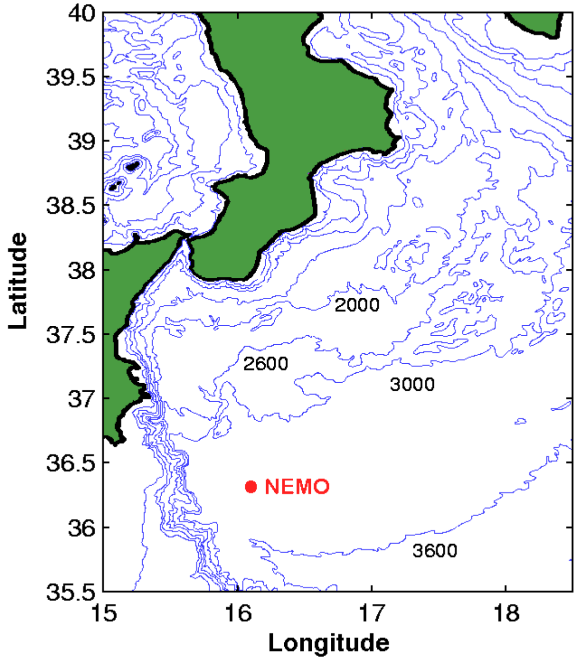




Site Location
42°30' N, 07°00' E

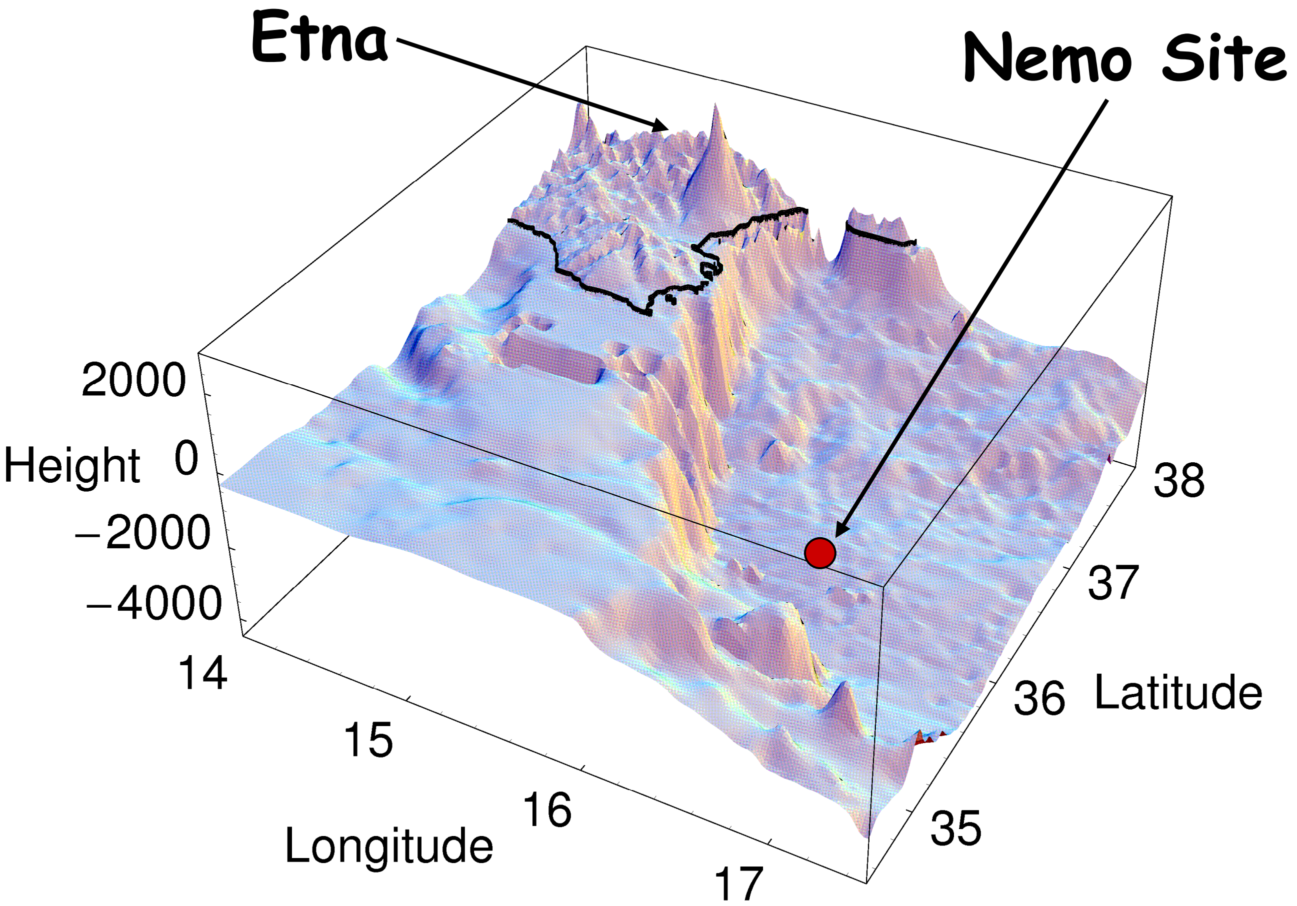
Average Deep
~2600 m
(2685 m in our simulation)

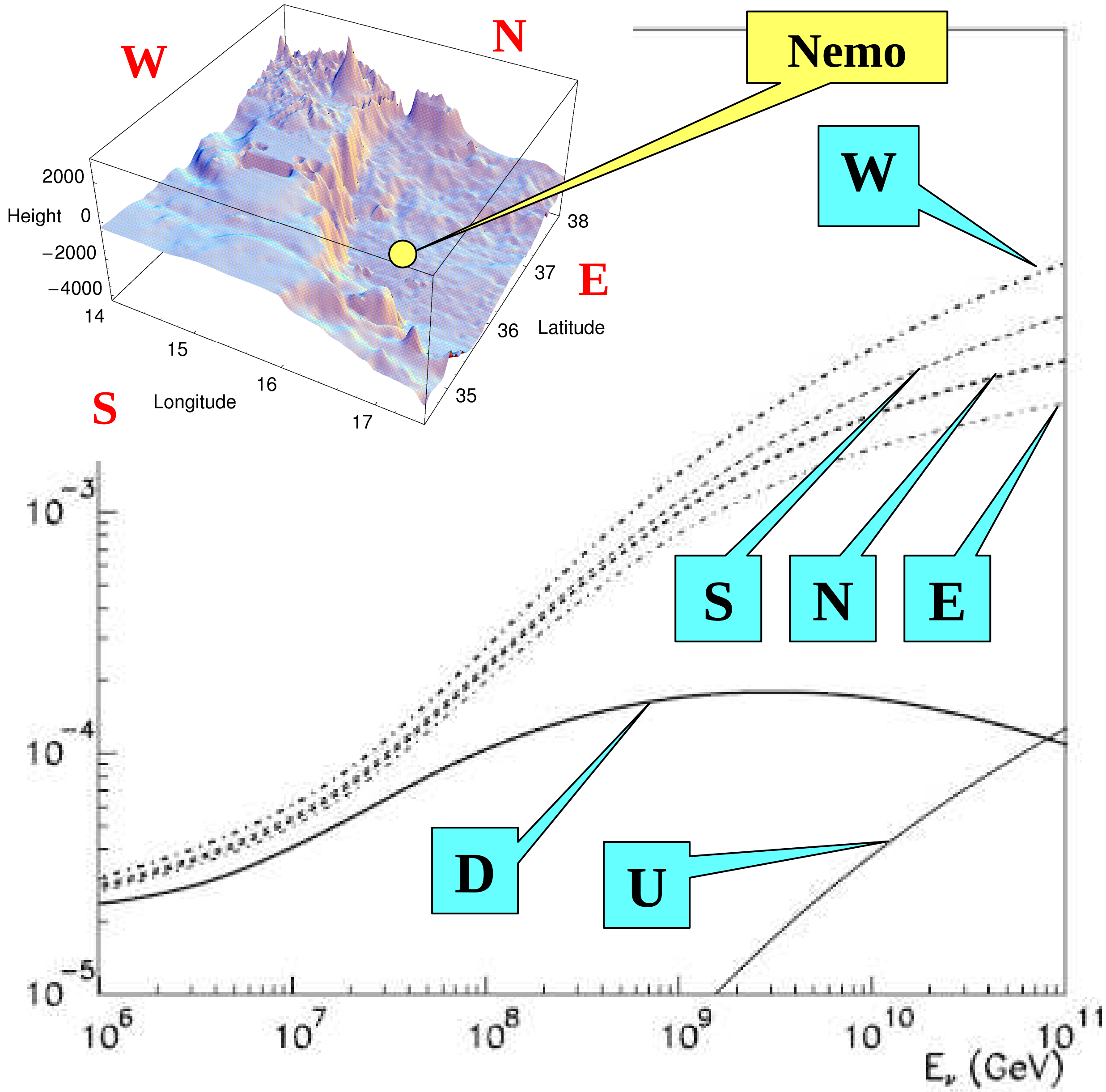
NEMO Site



- Site Location
  36°21' N, 16°10' E

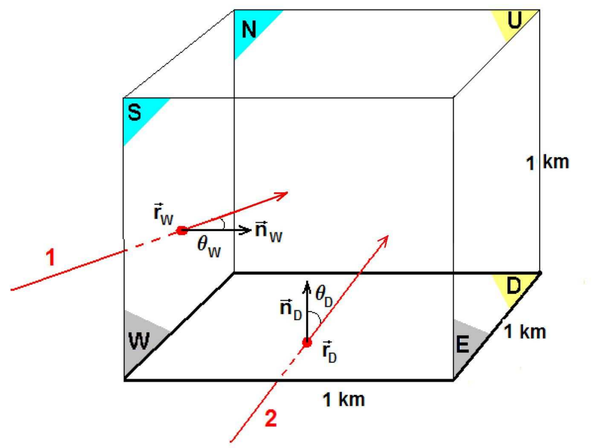
- Average Deep
  ~3500 m
  (3424 in our simulation)

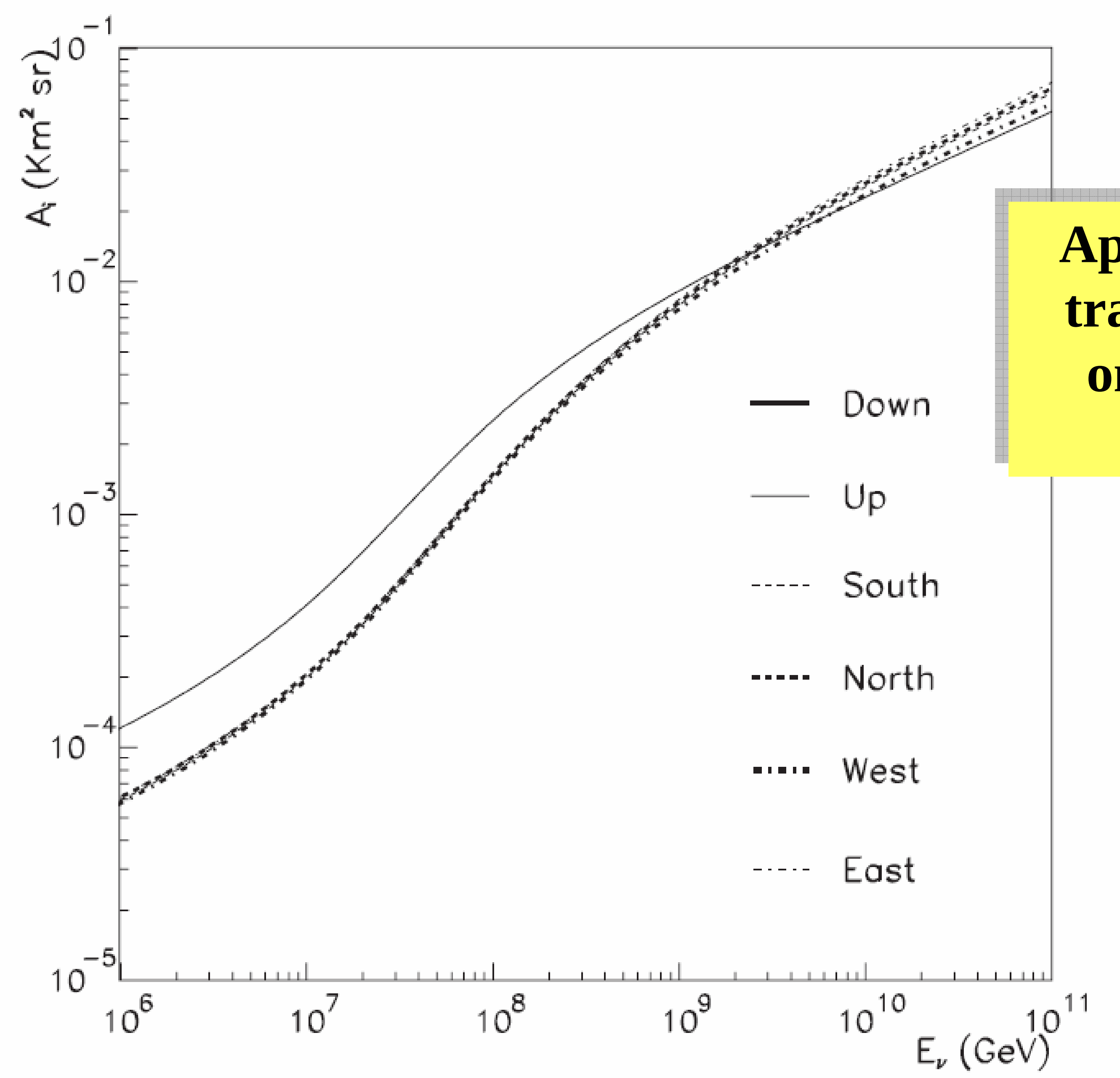




Apertures for τ tracks crossing the rock in Nemo

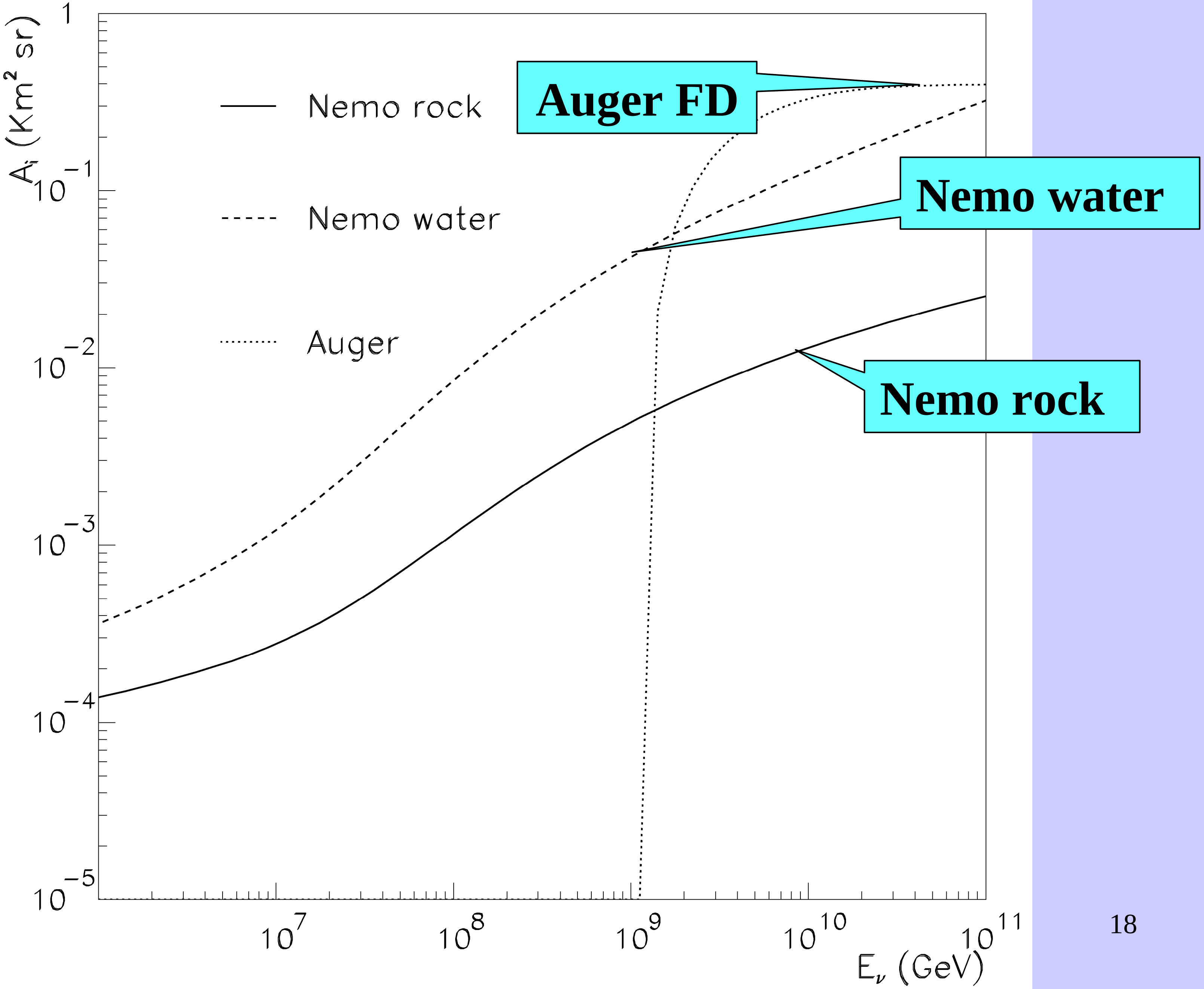
Matter Effect!





Apertures for τ tracks crossing only water in Nemo

Comparison of Apertures



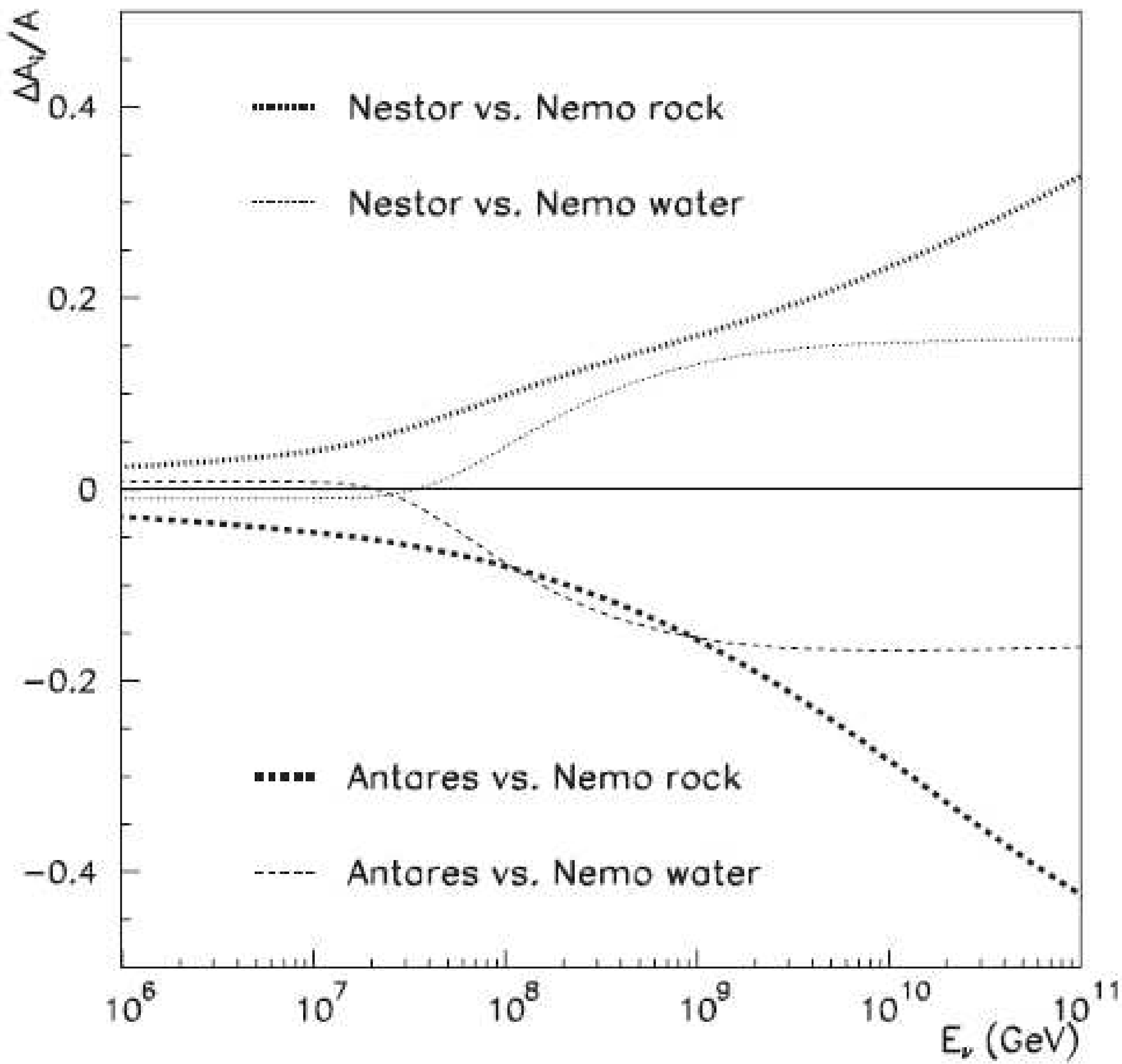
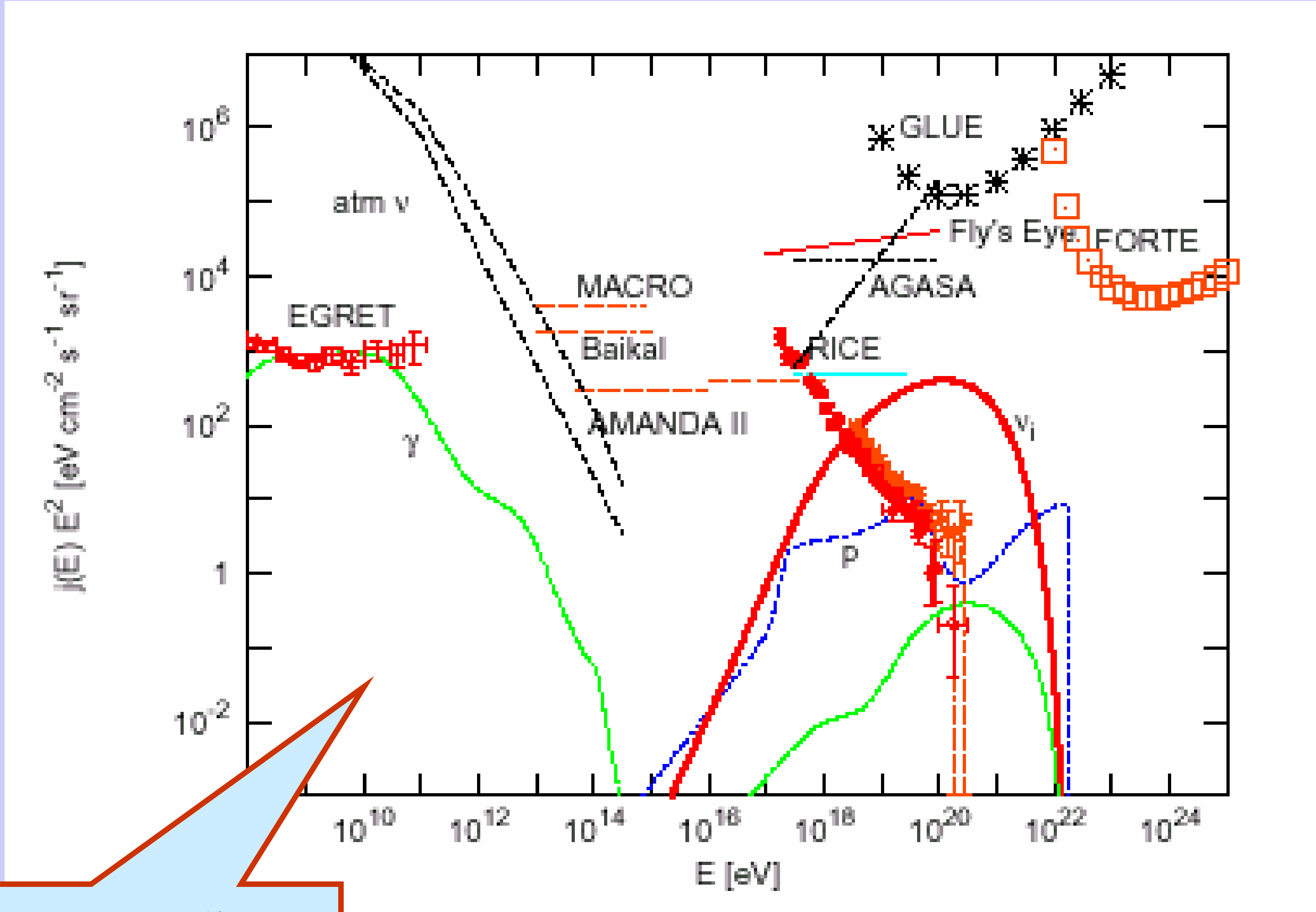


Figure 8. A comparison of the effective apertures $A^{\tau((r,w))}(E_\nu)$ for the three NT sites. We plot the ratios $[A^{\tau((r,w))}(\texttt{NESTOR}) - A^{\tau((r,w))}(\texttt{NEMO})]/A^{\tau((r,w))}(\texttt{NEMO})$ and $[A^{\tau((r,w))}(\texttt{ANTARES}) - A^{\tau((r,w))}(\texttt{NEMO})]/A^{\tau((r,w))}(\texttt{NEMO})$ versus the neutrino energy.

Perfoming the exercise for some neutrino fluxes



Cosmogenic neutrino flux per flavour

Kalashev et al. 01, 02, Semikoz & Sigl, 03

Table 2. Yearly rate of *rock/water* τ events at the three km^3 NT sites for different UHE neutrino fluxes. GZK-H is for an initial proton flux $\propto 1/E$, assuming that the EGRET flux is entirely due to π photoproduction. GZK-L shows the neutrino flux when the associated photons contribute only up to 20% in the EGRET flux. GZK-WB stands for an initial proton flux $\propto 1/E^2$ [59]–[63]. The other two neutrino fluxes correspond to more exotic UHECR models. NH represents the neutrino flux prediction in a model with new hadrons [64], whereas TD is the neutrino flux for a topological defect model [65]. In the last column we report the corresponding prediction for Earth-skimming ν_τ at Auger FD.

ν fluxes	ANTARES	NEMO	NESTOR	Auger FD [39]
GZK-WB	0.090/0.799	0.107/0.929	0.123/1.039	0.074
GZK-L	0.099/1.076	0.130/1.282	0.157/1.465	0.213
GZK-H	0.225/2.744	0.313/3.280	0.386/3.766	0.560
NH	0.891/8.696	1.102/10.19	1.295/11.47	1.245
TD	0.701/5.072	0.817/5.799	0.921/6.424	0.548

~10-20% of difference among the three sites

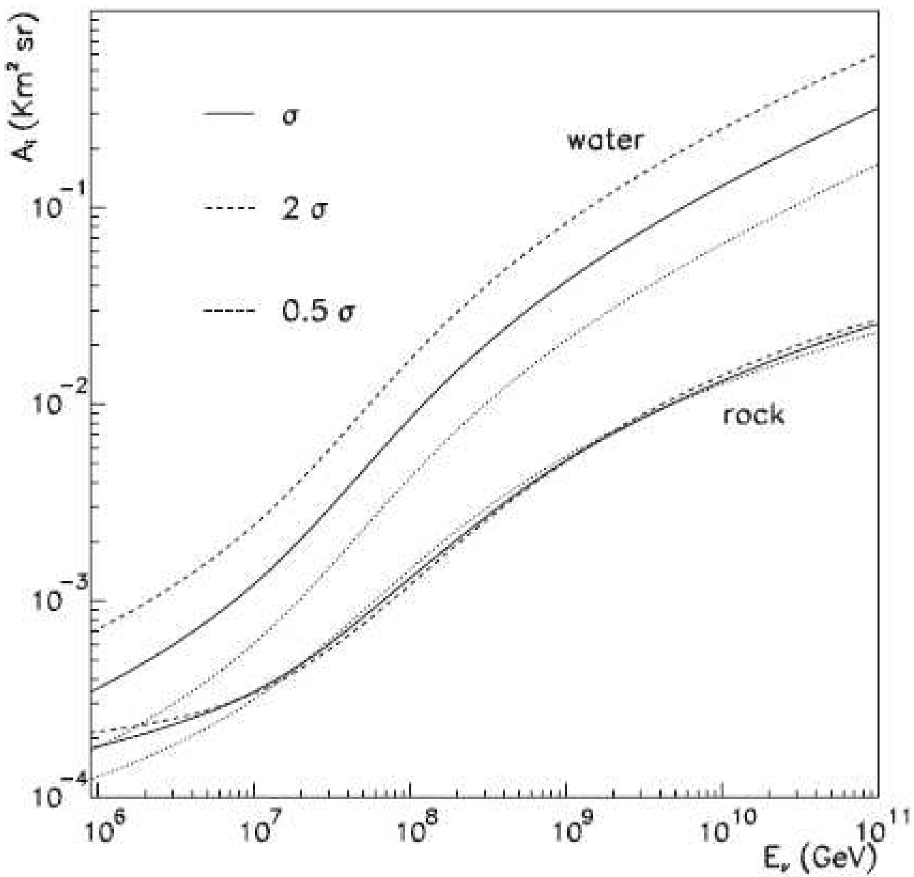
# of yearly τ events crossing the rock and the water for a WB flux at Nemo. The same for other sites.

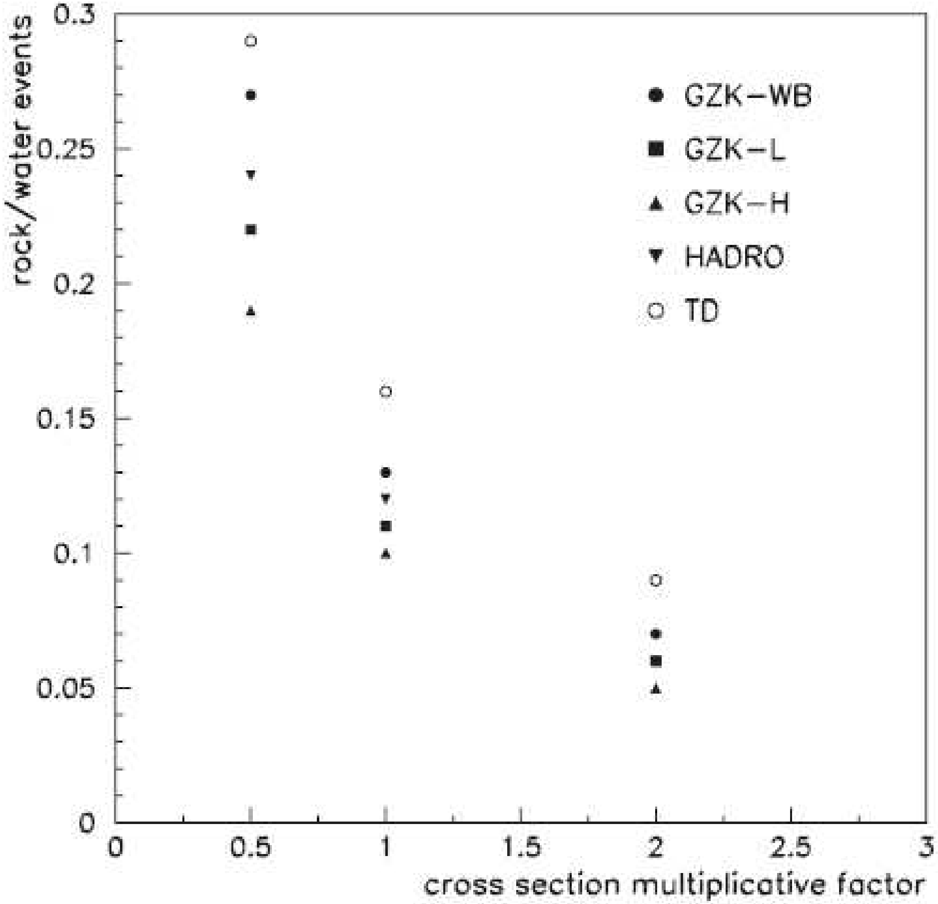
Surface	Nemo-r	Nemo-w
D	0.006	0.000
U	0.000	0.213
S	0.026	0.177
N	0.023	0.182
W	0.034	0.169
E	0.019	0.188
Total	**0.11**	**0.93**

Even a factor 10 for more copious fluxes!

Mainly a shadowing effect!

Rock/water events is a good estimator of ν-Nucleon cross section

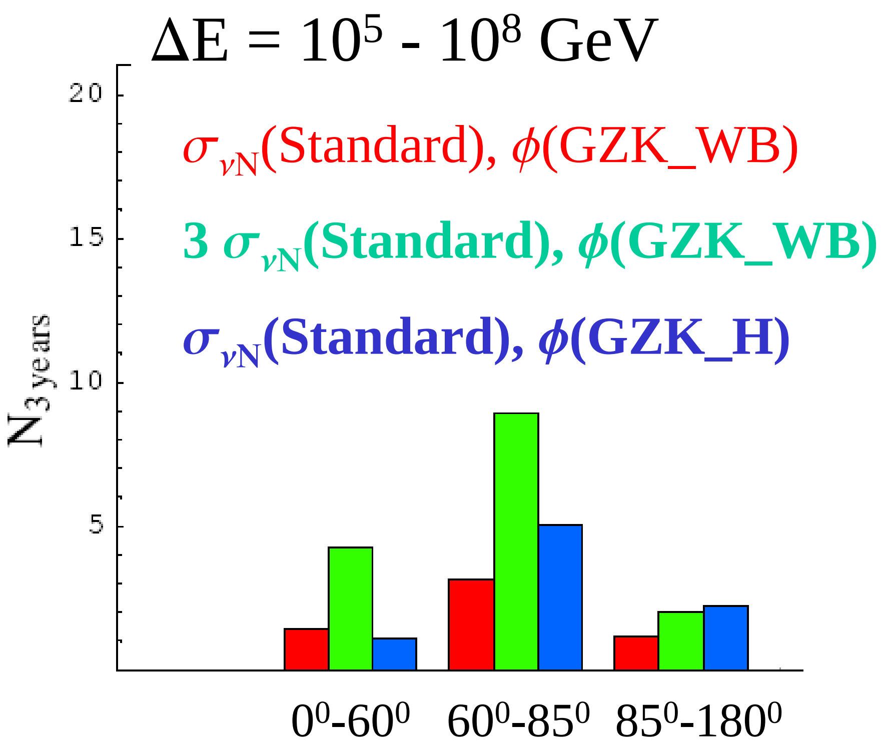


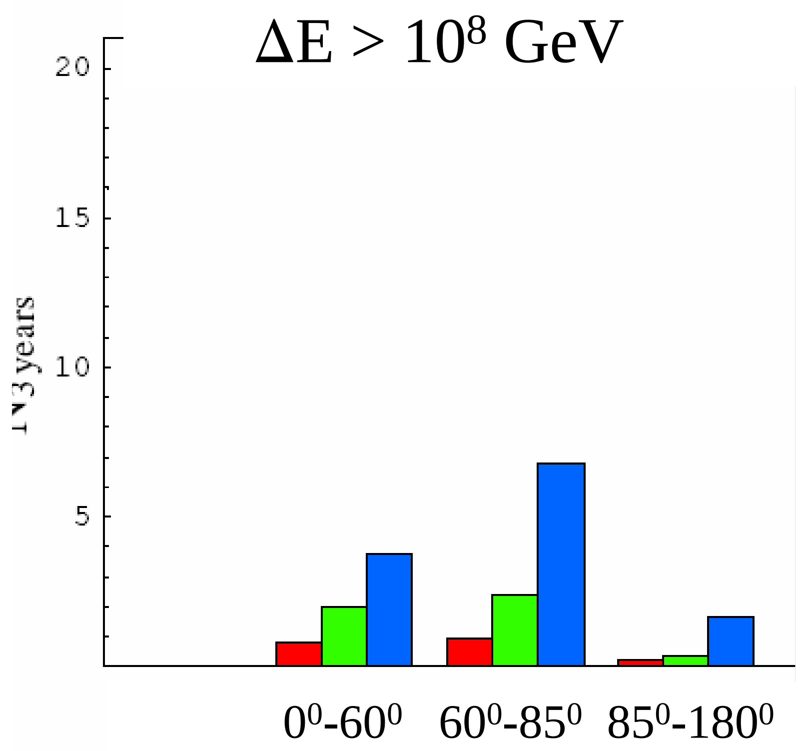


<u>Unless τ does not decay in the NT it cannot easily disentangled from μ</u>

Work in Progress!

The real observable is the energy lost (ΔE) in the detector summing muons and tau's contribution. An appropriate binning in arrival direction and energy deposited provides a way to disentangle neutrino flux from neutrino-Nucleon cross section,





Distribution in arrival direction/energy loss rate for ν_τ & ν_μ

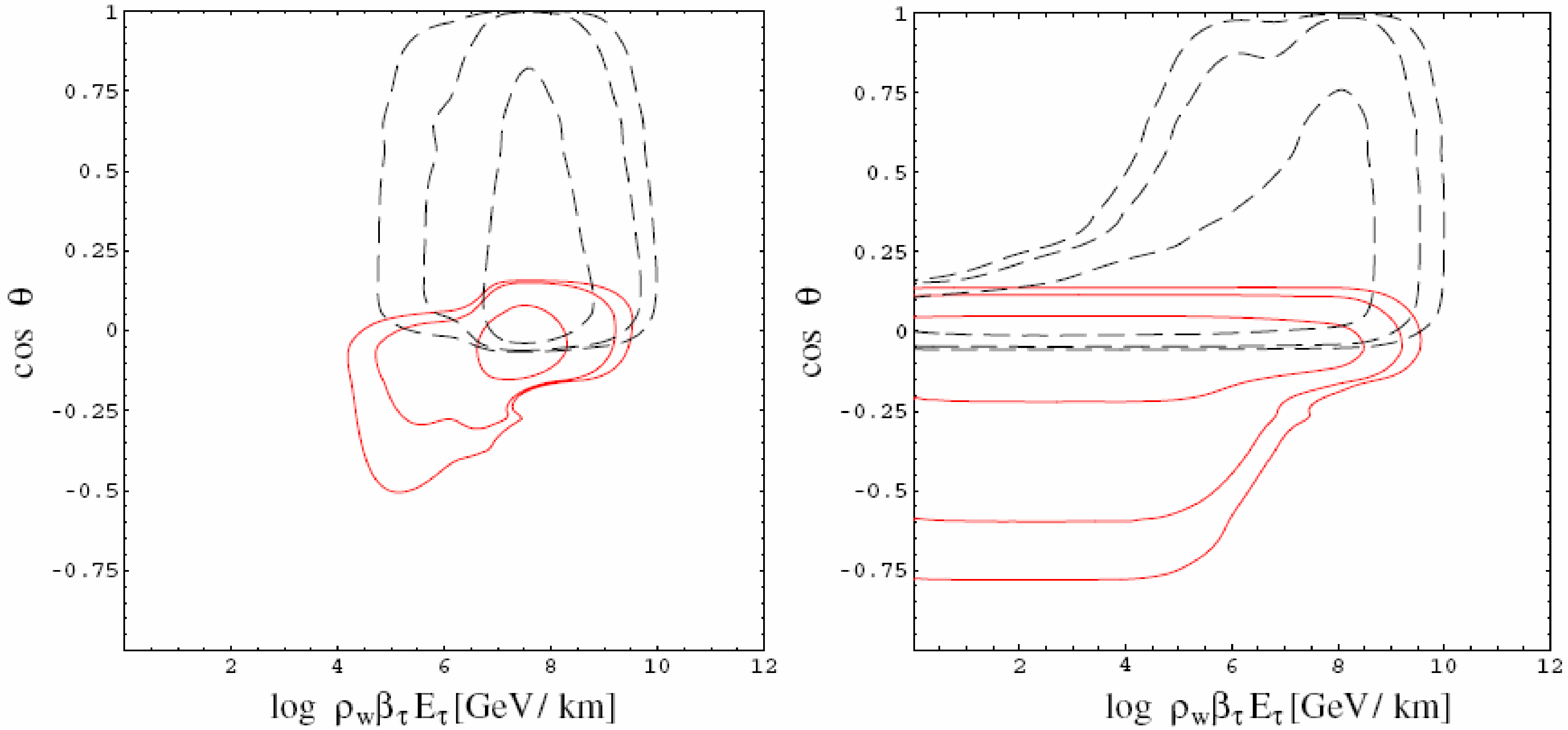


Figure 13. Contour plots of the number of *rock* events (red full lines) and *water* events (black dashed lines) at the NEMO site in the zenith angle–dE/dx plane for τ (left panel) and μ (right panel) assuming a GZK-WB neutrino flux. The contours enclose 65, 95 and 99% of the total number of events.

Dependence of the event rate upon the shape of the NT detector for a fixed total volume of 1 km3.

CUBE ⟶ PARALLELEPIPED

Consider the E and W surfaces enlarged by a factor 3 in the horizontal dimension, and the N and S surfaces being reduced by the same factor, keeping the height of towers still 1 km.

rock **events per year is enhanced by almost a factor 2, from 0.11 to 0.18 for the GZK-WB flux (enhancement enlarges for more energetic neutrino fluxes). Moreover, the expected rate of** ***water*** **events increases by a factor of the order of 50%, from 0.93 up to 1.40 per year.**

Conclusions

• UHE neutrino detection allows for extragalactic ν-astronomy, and makes possible the simultaneous measurements of the νN cross, section at energy ranges never explored before (New Physics?), and the value of neutrino flux. This depends on the different behavior of the rock and water events on these quantities (work in progress).

• To performe the measurement one has to enlarge the number of rock and water events already too small. This can be done by working on the shape of NT, in correlation with the position of the coast line (shadowing effect).