The Relevance of Mediterranean Neutrino Telescope Sites on Earth-skimming ν_τ detection

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Previous related refs. Astrop. Phys. 23:65-77,2005; Phys. Lett. B634:137-142,2006

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

The proton energy threshold for this reaction is $E_{\pm} = 10^3/E_{\gamma}(eV)GeV$. For CMB $E_{\gamma}(eV) \sim 10^{-3}$ eV $\Longrightarrow E_{\pm} = 0.01$ EeV

- $N + \gamma_b \longrightarrow N + n\,\pi$ photo-production of single or multiple pions

The nucleon threshold energy for single pion production on the CMB photon is $E_{th} = m_{\pi}(m_N + m_{\pi}/2)/\,E_{\gamma} \Longrightarrow E_{th} \cong 50$ EeV

- $n \longrightarrow p + e^- + \overline{\nu_e}$ neutron decay

No threshold. A 1 EeV neutron travels 30 Kpc before decaying

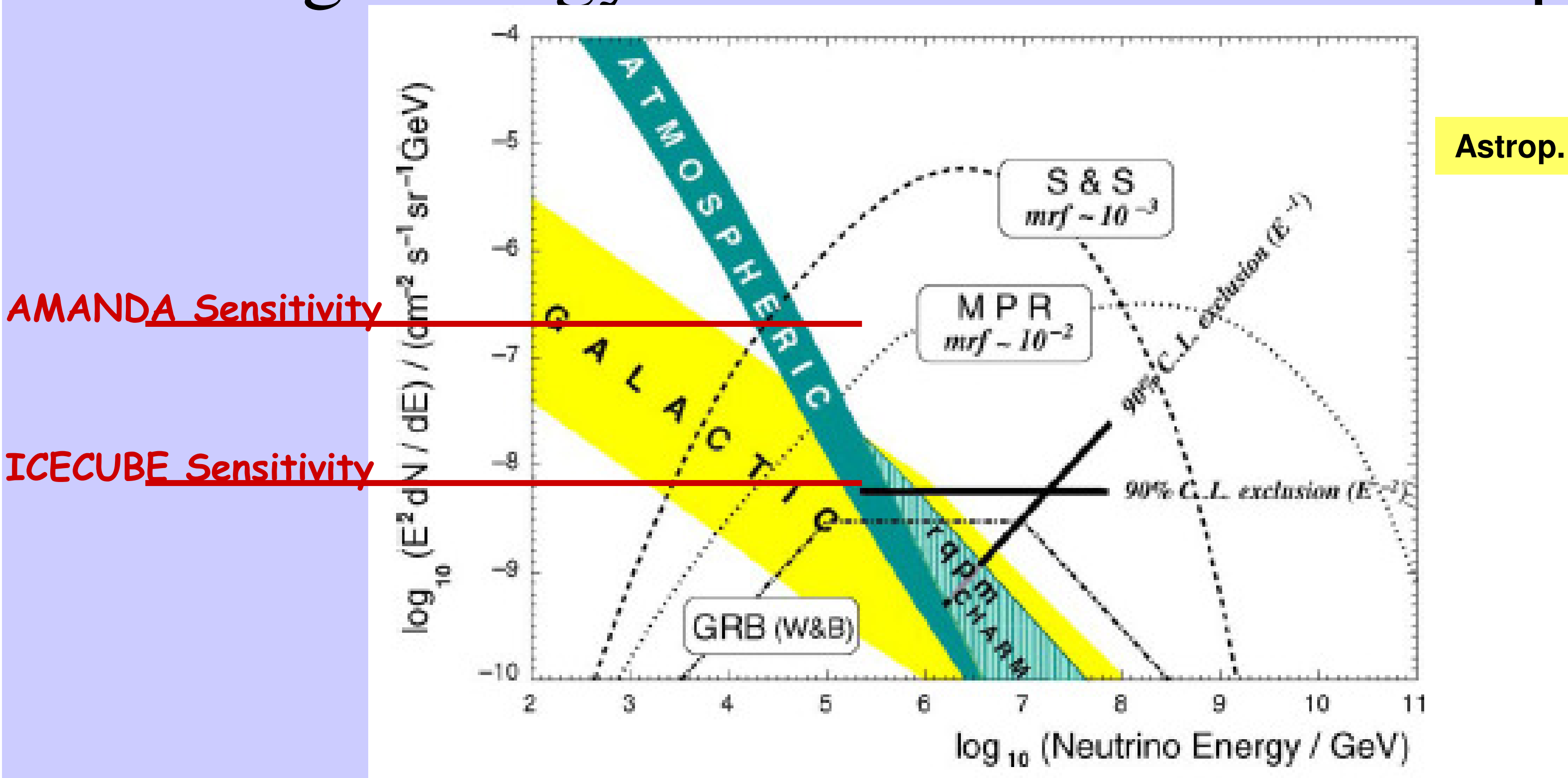
Earth-skimming ν_τ could represent a real chance to use the large Cosmic Rays Experiments as Neutrino Telescopes

very few events, but a safe way to disentagle neutrinos from other primaries

•K.S. Capelle, J.W. Cronin, G. Parente and E. Zas, 1998.
•F. Halzen and D. Saltzberg, 1998.
•F. Becattini and S. Bottai, 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

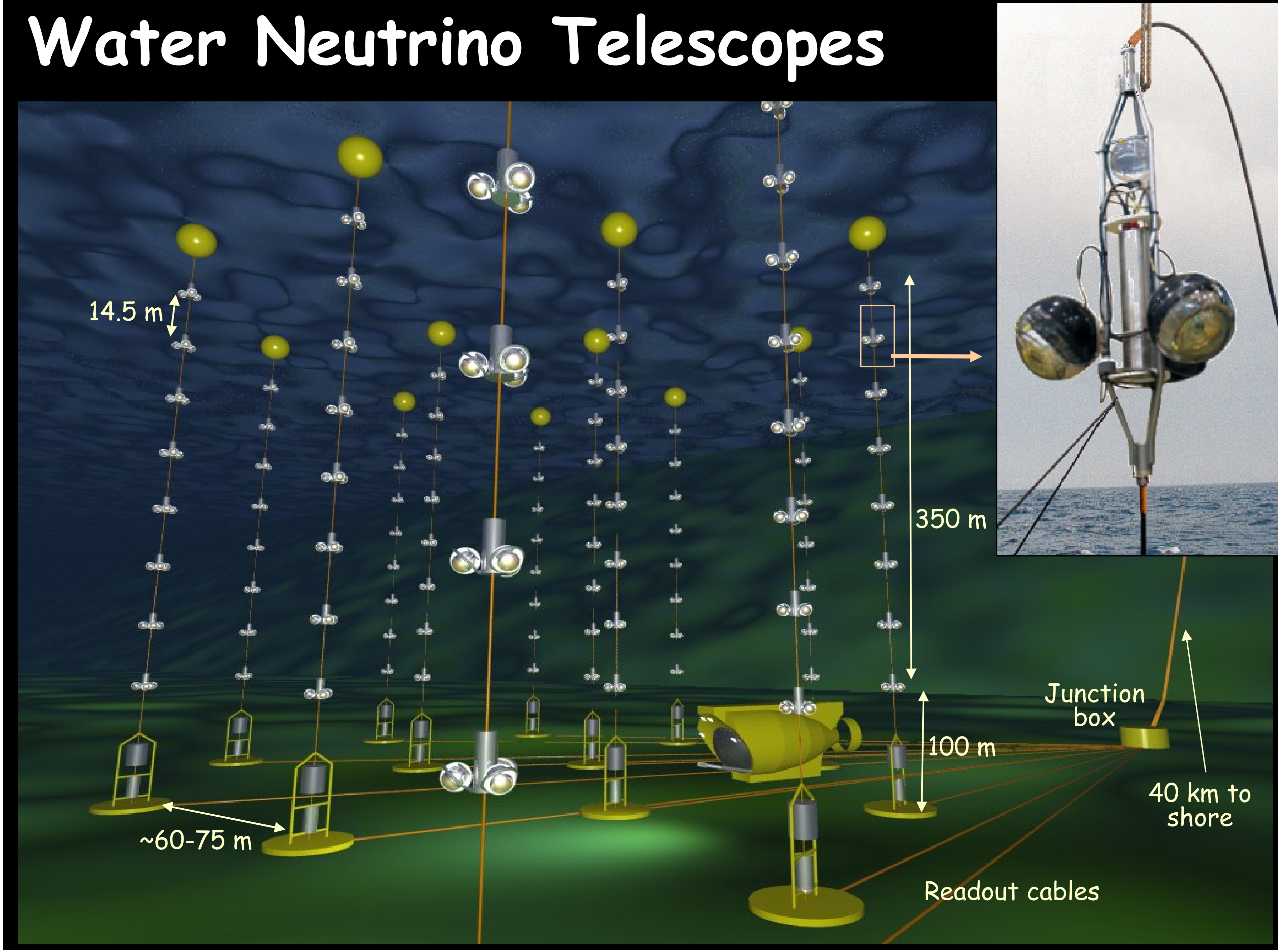
What about a 1 Km^3 Neutrino Telescope for Earth-skimming ν_τ?

- Earth-skimming ν_τ could also be seen in the high energy tail of a Neutrino Telescope

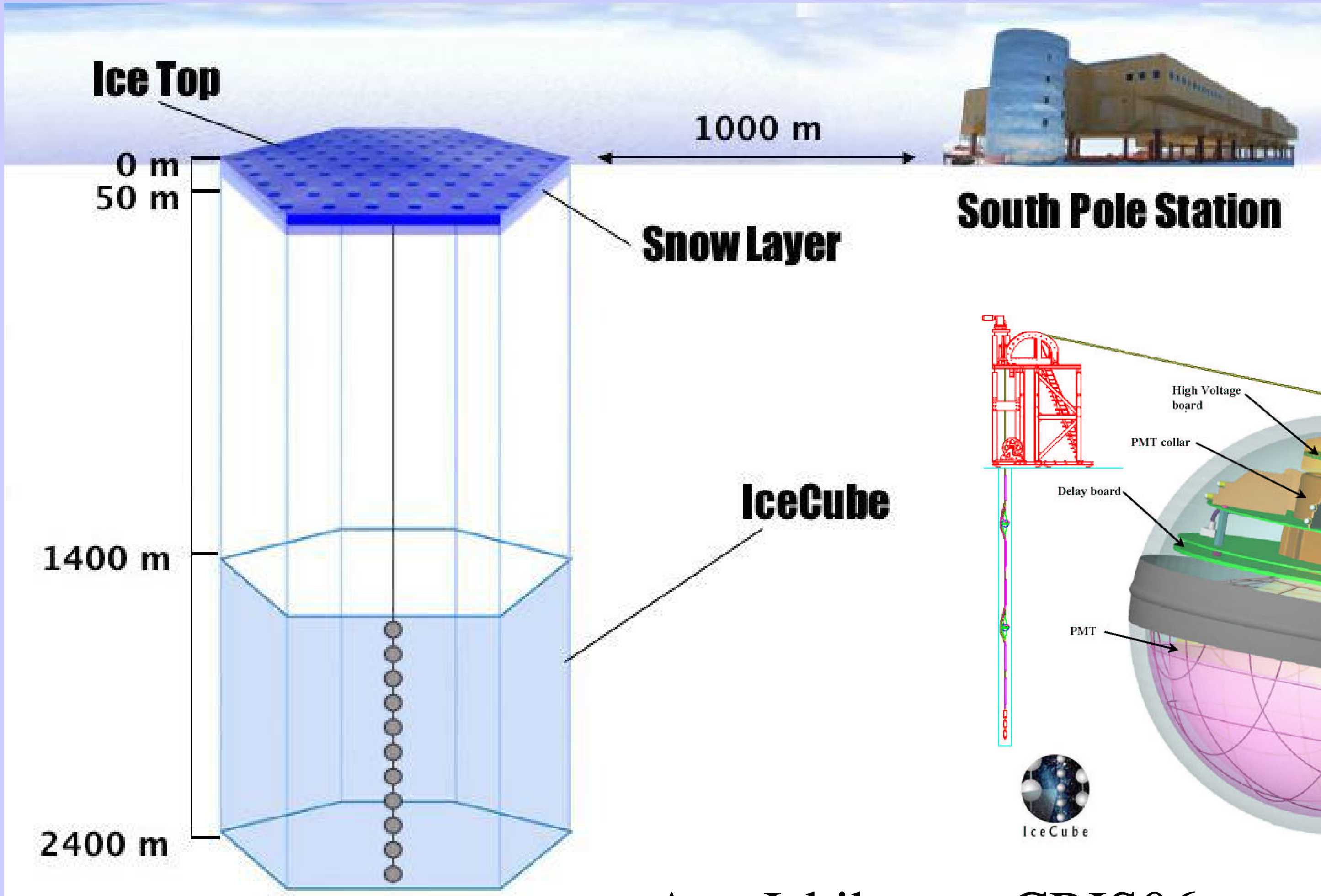


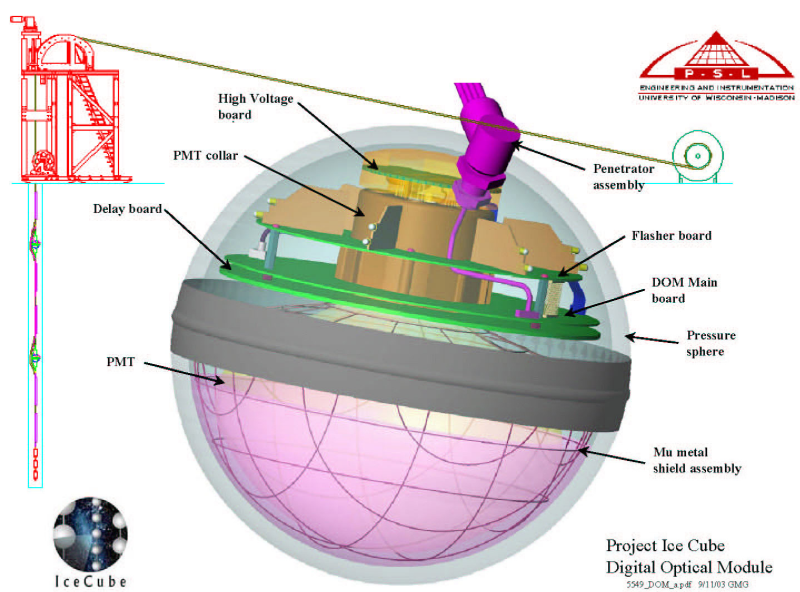
Astrop. Phys. 20 (2004) 507

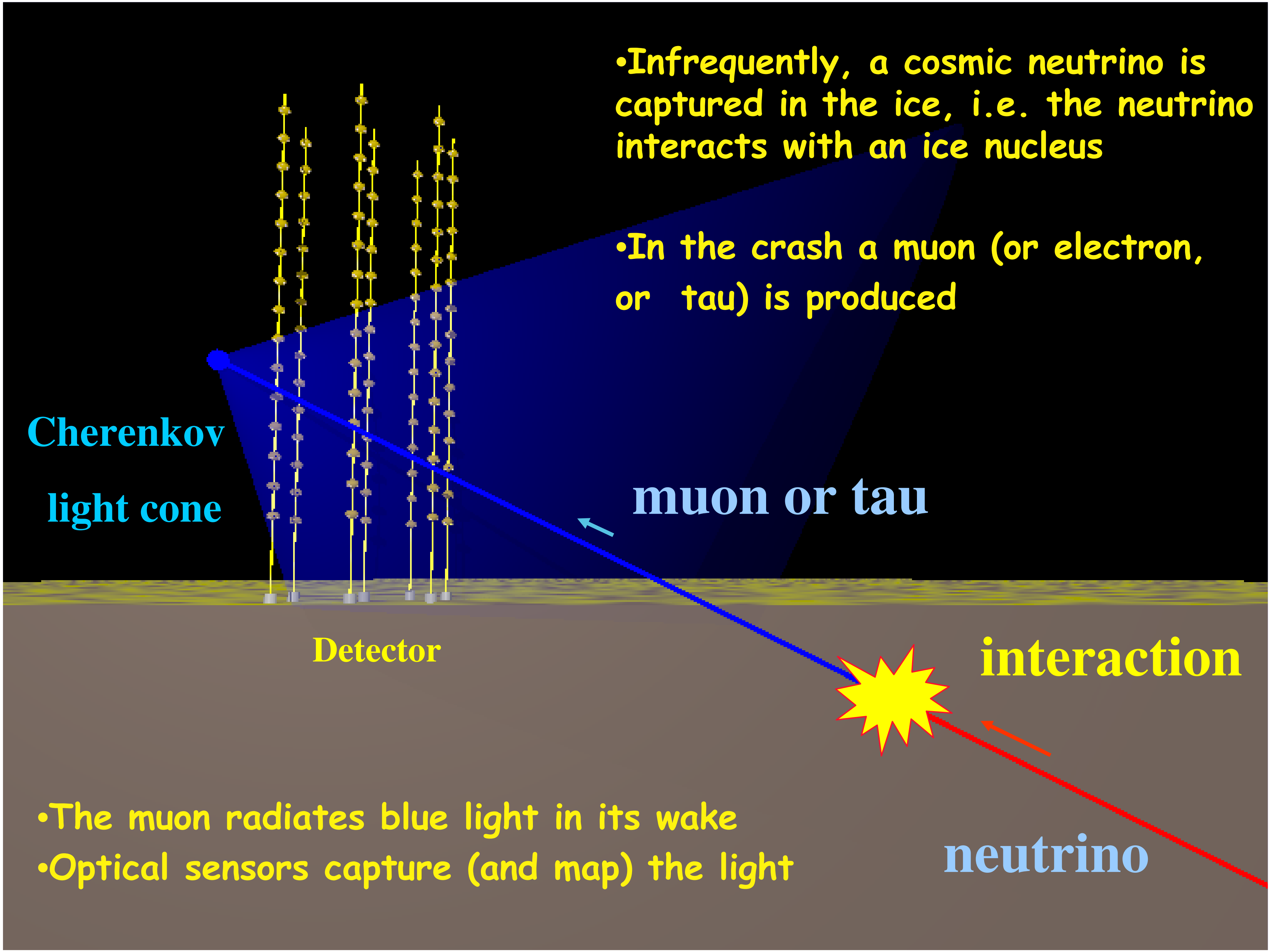
Water Neutrino Telescopes



The IceCube Detector



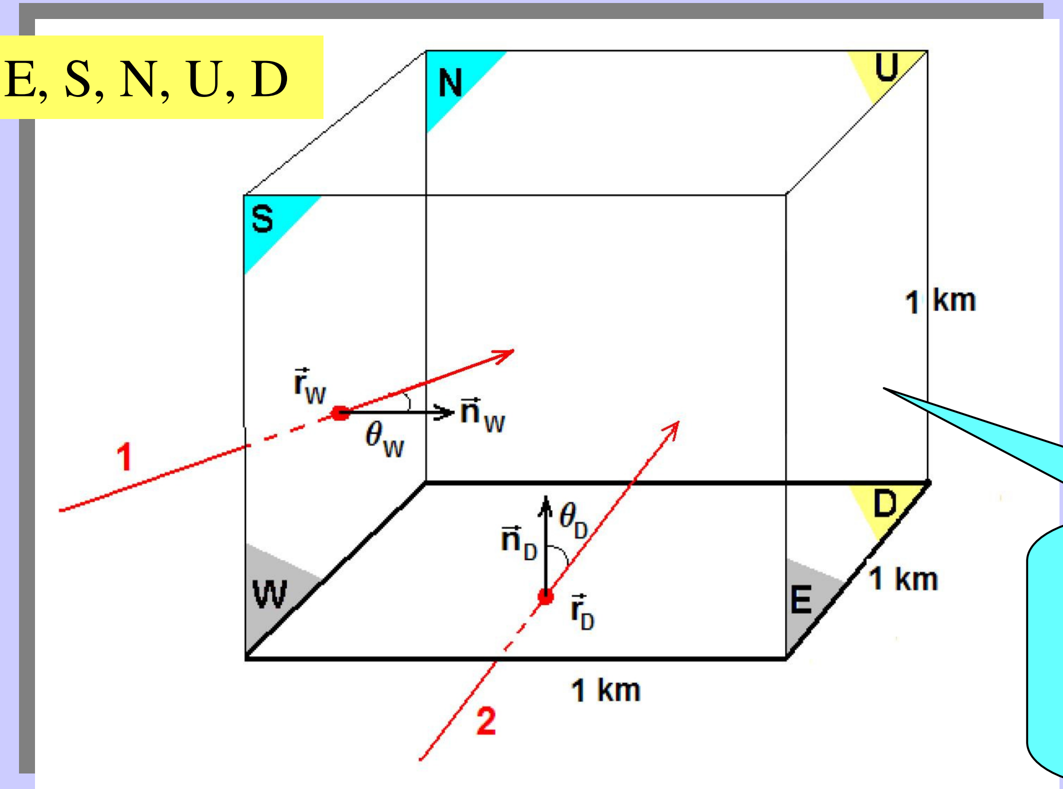



•Infrequently, a cosmic neutrino is captured in the ice, i.e. the neutrino interacts with an ice nucleus
•In the crash a muon (or electron, or tau) is produced
Cherenkov light cone
muon or tau
Detector
interaction
neutrino
•The muon radiates blue light in its wake
•Optical sensors capture (and map) the light

The rate of τ events in 1 Km^3

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

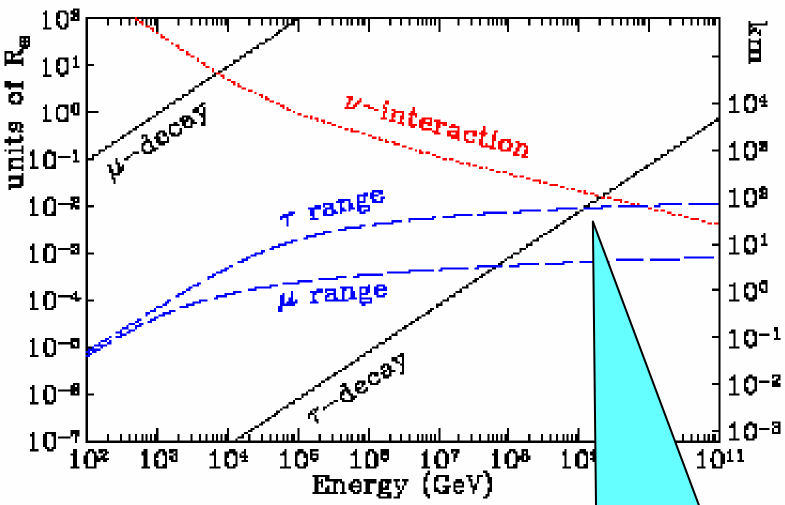
a = W, E, S, N, U, D

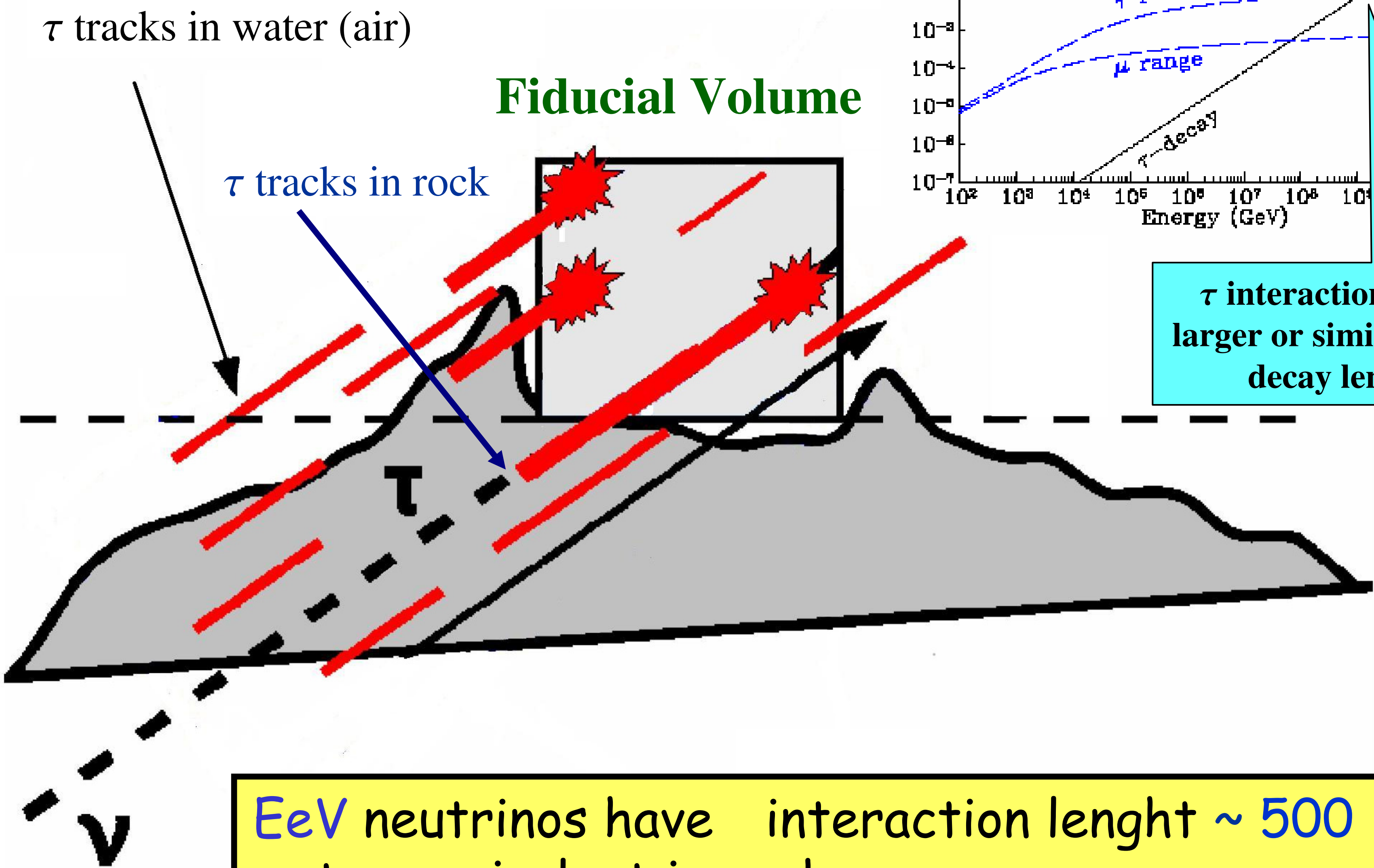


Same calculation for Auger in PLB634:137-142,2006

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

The ν_τ chances: two kinds of tracks





τ interaction range larger or similar to the decay length

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

For ν_τ crossing the rock (Earth-skimming)

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

is the probability that an incoming neutrino crossing the Earth 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 $\vec{r}_a$

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)**

$$\frac{dN_\tau}{dt} = D \int dE_\nu \, \frac{d\Phi_\nu(E_\nu)}{dE_\nu d\Omega_a} \, A(E_\nu)$$

where the total aperture ***A*** of the experiment is defined as:

$$A(E_\nu) = \sum_a A_a(E_\nu) = \sum_a \int dE_\tau \; K_a\left(E_\nu, E_\tau\right)$$

where the integrated kernel is

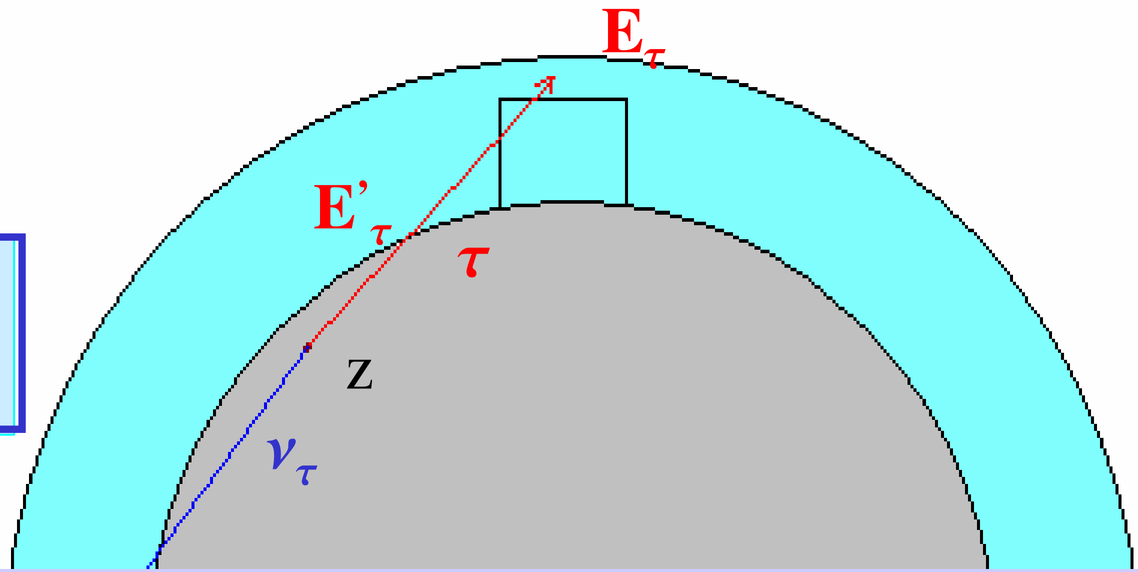
$$K_a\left(E_\nu, E_\tau\right) = \int d\Omega_a \int dS_a \varepsilon(E_\tau) \cos\left(\theta_a\right) k_a\left(E_\nu, E_\tau; \vec{r}_a, \Omega_a\right)$$

$$= \int d\Omega_a \int dS_a \varepsilon(E_\tau) \cos\left(\theta_a\right) \int_0^{z_{\max}} dz \int_0^{f\,E_\nu} dE_\tau^{'} \; P_1 \; P_2 \; P_3 \; P_4$$

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

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

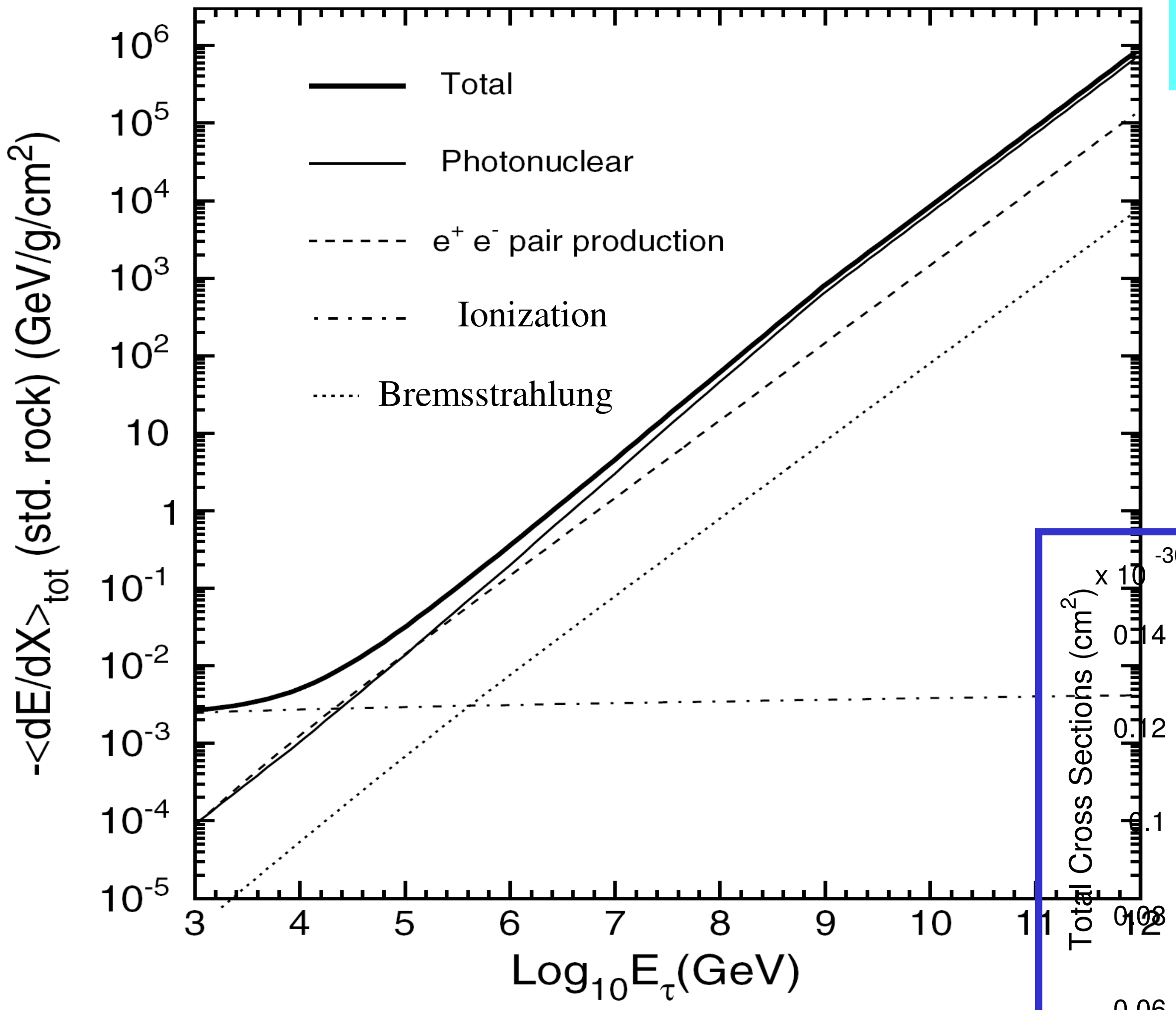
$$P_2 = \frac{dz}{\lambda_{CC}^{\nu}(E_\nu)}$$



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

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

$\mathbf{z_a^{max}}$ and $\mathbf{z_s^{max}}$ are the total lengths in water and rock for a given track. It depends on the real surface profile. **There is an additional term, properly taken into account!**

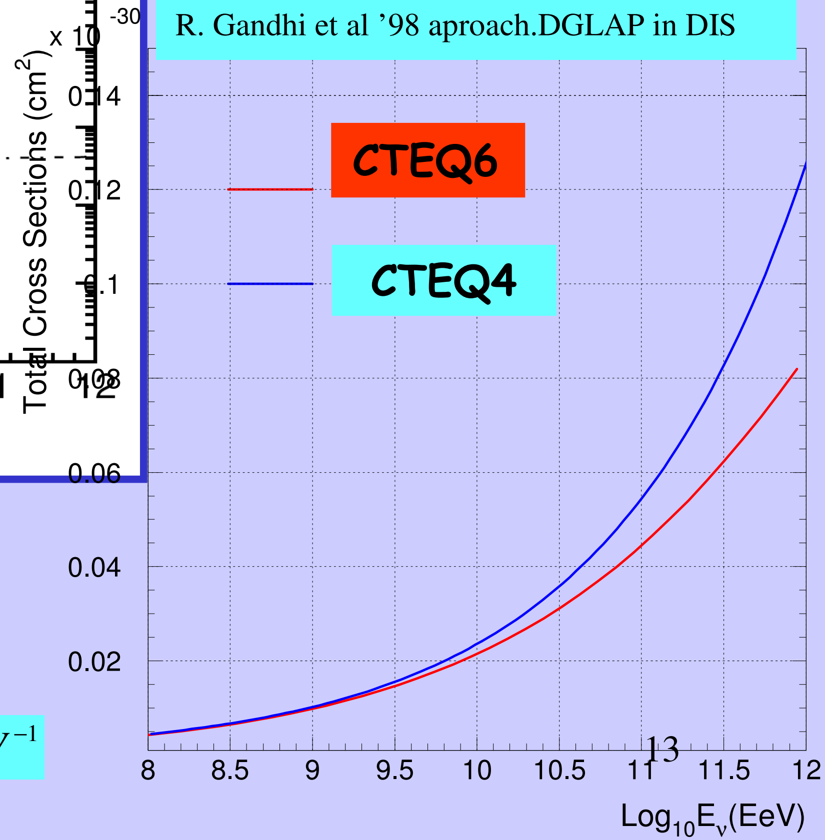


τ Energy loss

C. Aramo, A. Insolia, A. Leonardi, G. Miele, L. Perrone, O Pisanti, D.V. Semikoz, **Astrop, Phys. 23:65-77,2005**

νN cross section

R. Gandhi et al '98 aproach.DGLAP in DIS



$$\frac{d E_\tau}{d z} = -\left(\alpha_\tau + \beta_\tau E_\tau + \gamma_\tau E_\tau^2\right)\rho_s$$

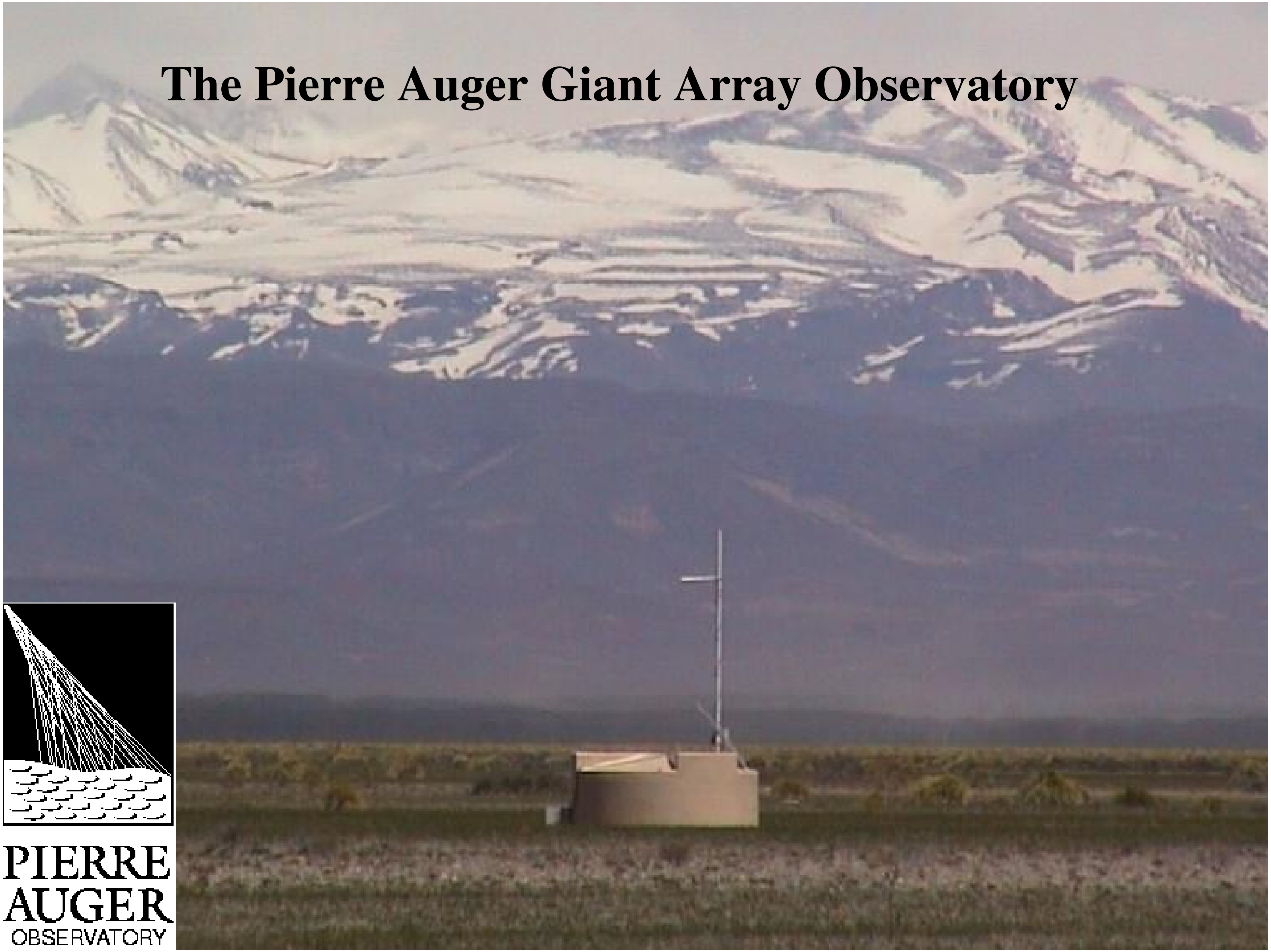
$\alpha_\tau \cong 0$ $\beta_\tau = 0.71 \cdot 10^{-6}\ cm^2\ g^{-1}$ $\gamma_\tau = 0.35 \cdot 10^{-18}\ cm^2\ g^{-1} GeV^{-1}$

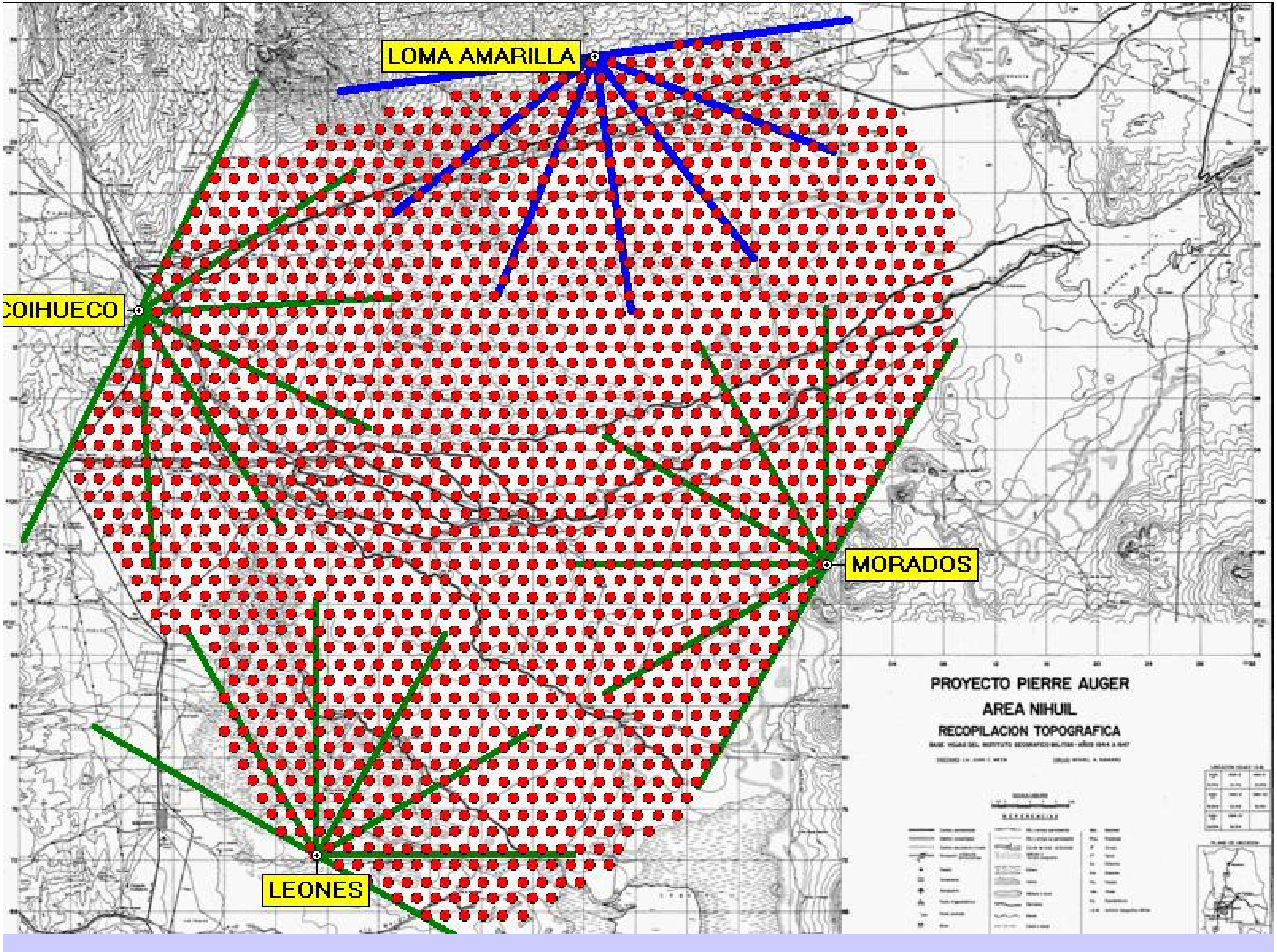
To get the kernel expression we use the available DEM of Neutrino Telescope sites to isotropically generate a large number of oriented tracks (let us say N) which cross the fiducial volume. If we denote with N_a the subset of the N tracks which enter through the surface Σ_a then the kernel is well approximated by the expression

$$K_a(E_\nu, E_\tau) = 2\pi\, \varepsilon(E_\tau)\, \frac{S_a}{N_a} \sum_{i_a=1}^{N_a} \cos(\theta_{i_a})\, k_a\left(E_\nu, E_\tau; \vec{r}_{i_a}, \Omega_{i_a}\right)$$

The exercise already performed for Auger FD

The Pierre Auger Giant Array Observatory




LOMA AMARILLA
COIHUECO
MORADOS
LEONES
PROYECTO PIERRE AUGER
AREA NIHUIL
RECOPILACION TOPOGRAFICA

Auger numbers

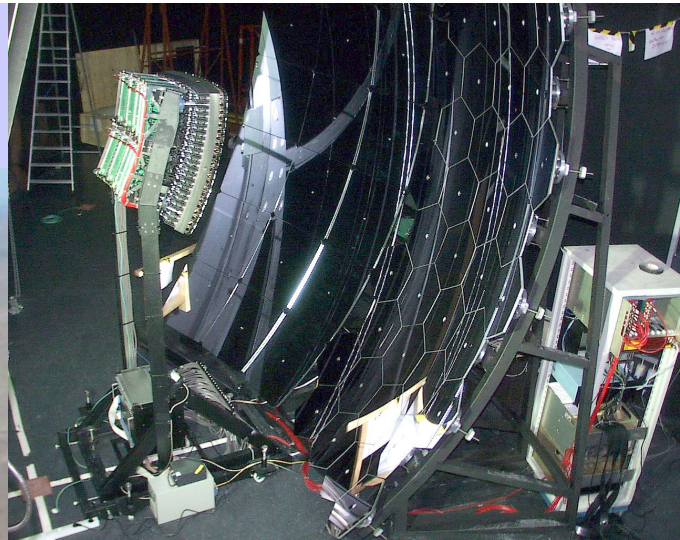
PIERRE AUGER OBSERVATORY

- 3000 km^2 area at an altitude of ” 1300 m a.s.l (Mendoza, Argentina);
- SD detector: 1600 Čerenkov light detectors with a 1.5 km spacing – (more than 400 already operating);
- FD detector: 13000 photomultipliers for 24 fluorescence telescopes located in 4 sites (duty cycle of 10%) – 12 already operating ;
- 3000 events yr^{-1} expected with energies above 10^{19} eV and 30 events yr^{-1} above 10^{20} eV;

http://www.auger.org

Fluorescence Detector

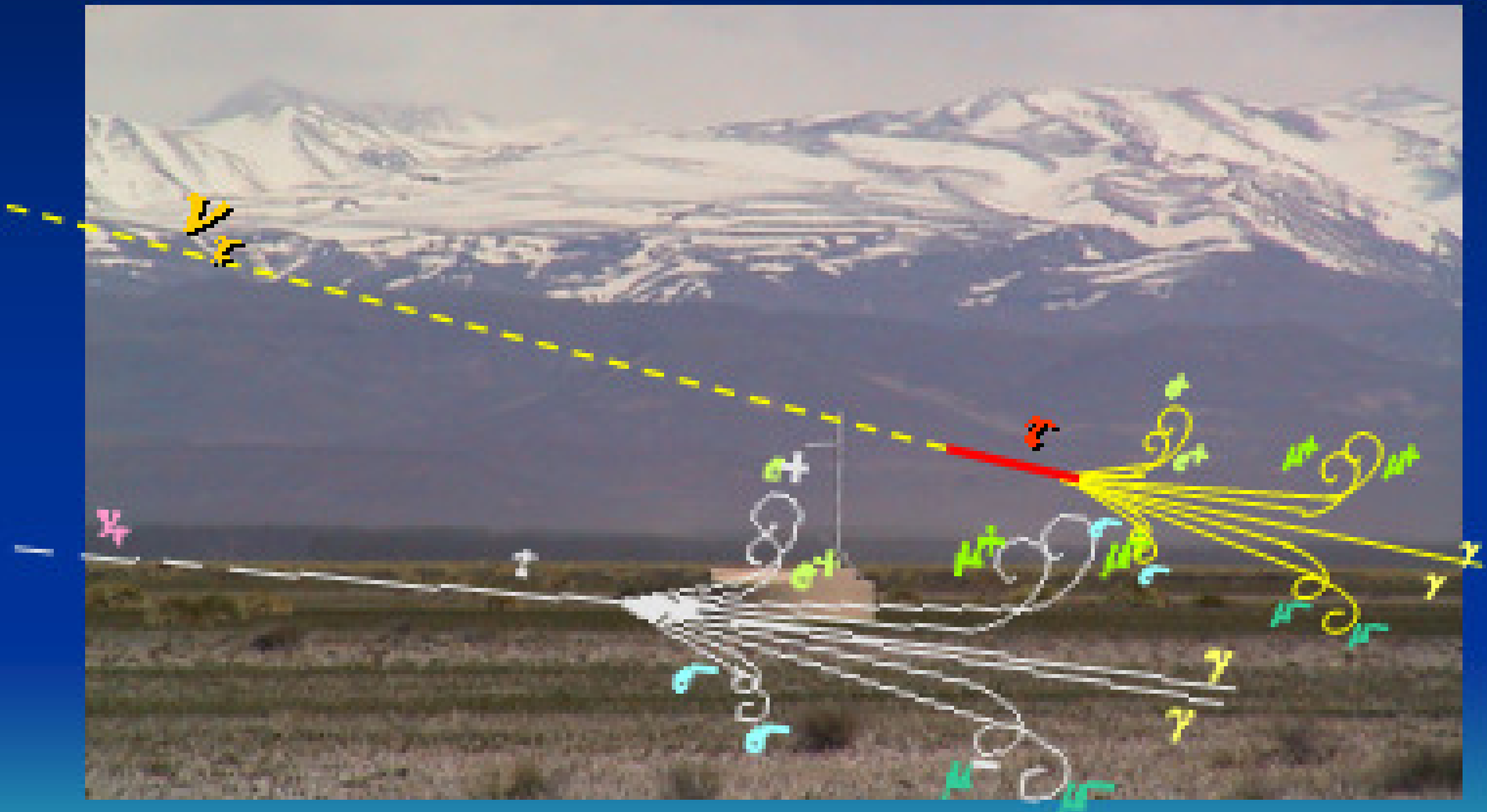
Los Leones



Upgoing τ shower (seen by Los Leones telescope)

The Ande Mountains as a target for detecting UHE neutrino tau by Horizontal Air-Showers at AUGER:

ANDE SHADOWs on GZK Cosmic Rays from West and Young Horizontal Tau Air-Showers at EeVs



D.Fargion The Astrophysical Journal,570,p.909. 2002

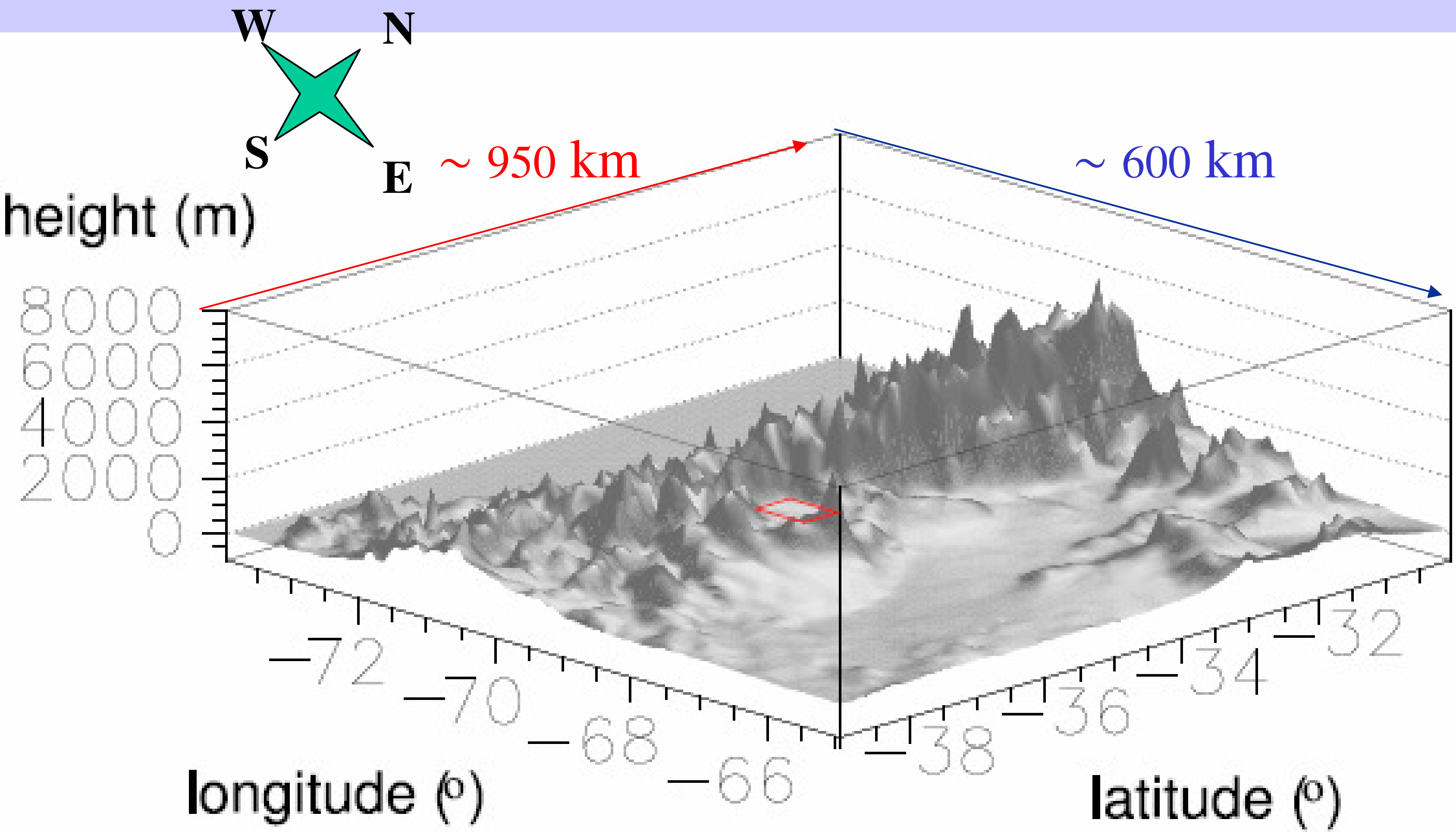
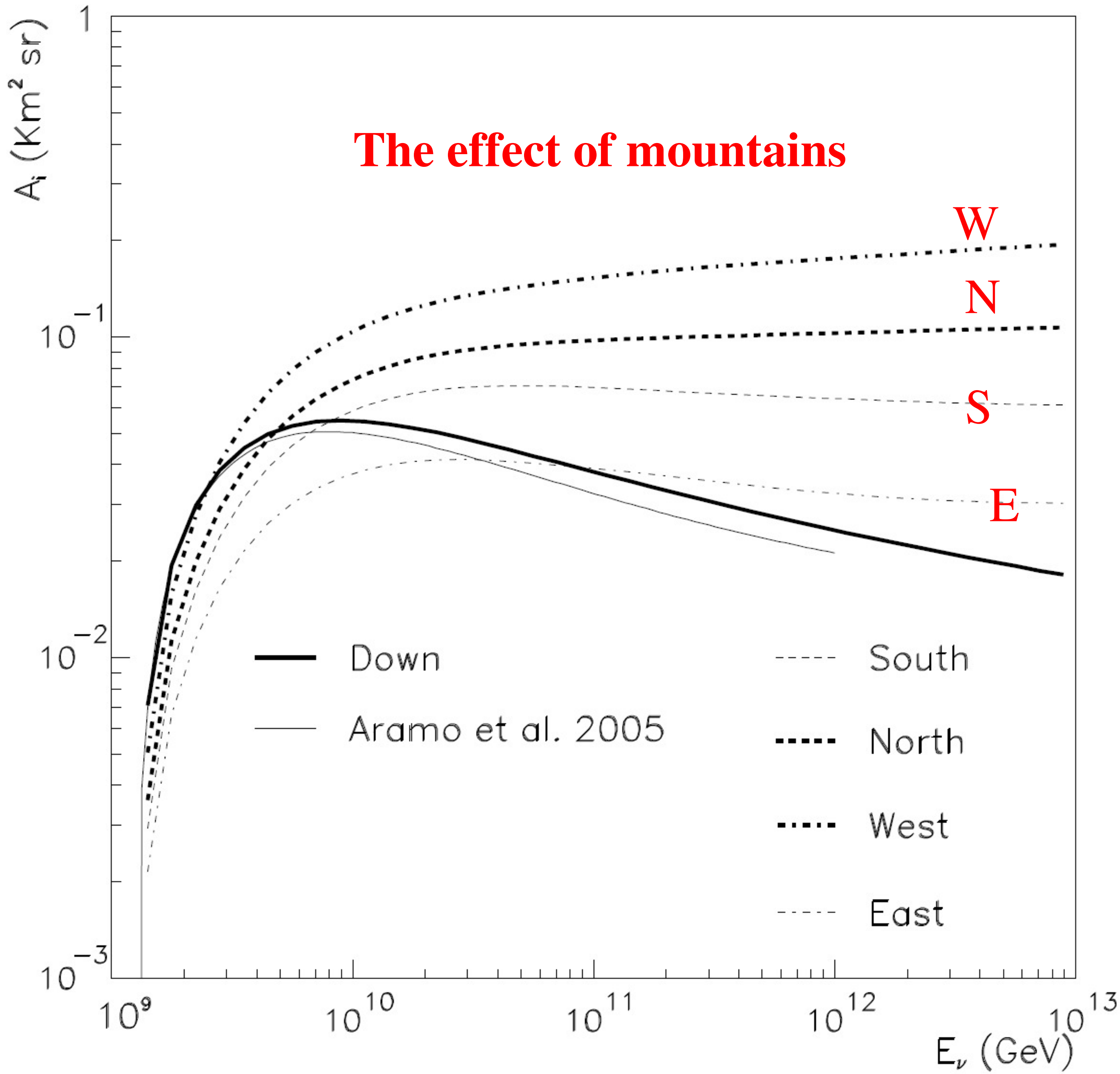


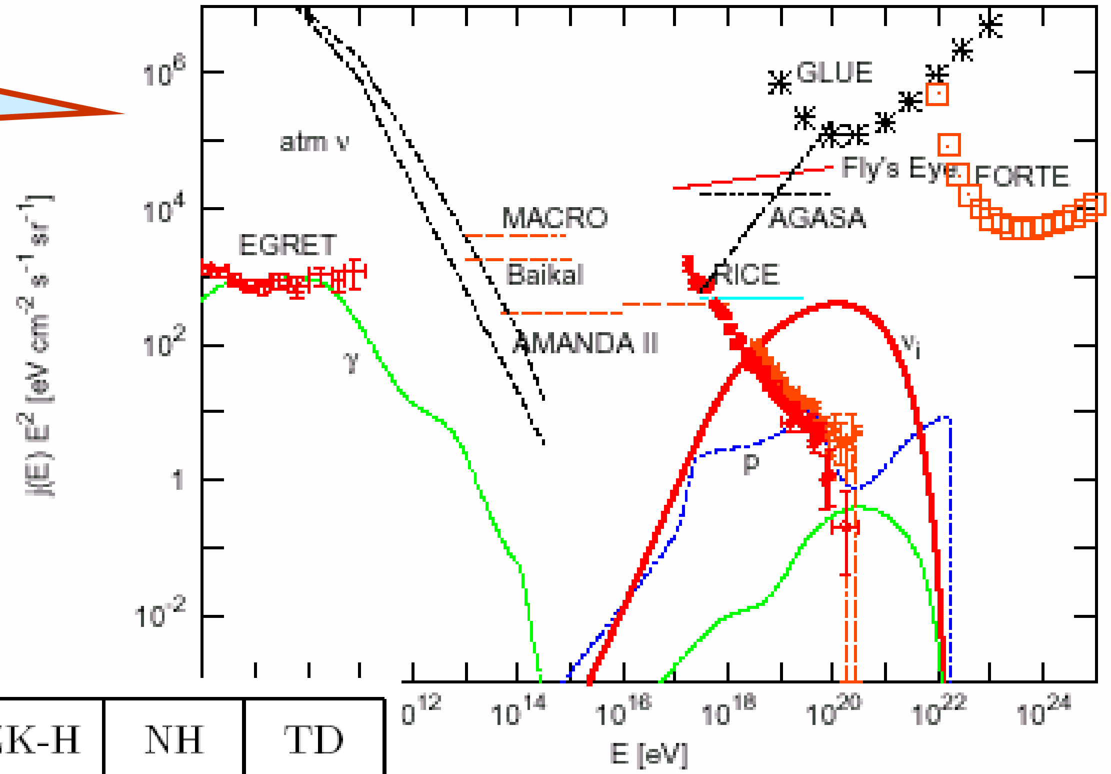
Fig. 1. A 3D map in longitude and latitude of the area around Auger with the elevation (not to scale) expressed in meters. The Auger position and surface, approximated to a rectangle, is indicated in red.


The effect of mountains
W
N
S
E
Down
Aramo et al. 2005
South
North
West
East
A_i (Km² sr)
E_ν (GeV)
1
10^{-1}
10^{-2}
10^{-3}
10^9
10^{10}
10^{11}
10^{12}
10^{13}

Perfoming the exercise for some neutrino fluxes

Cosmogenic neutrino flux per flavour

Matter enhancement effect ~ 20%



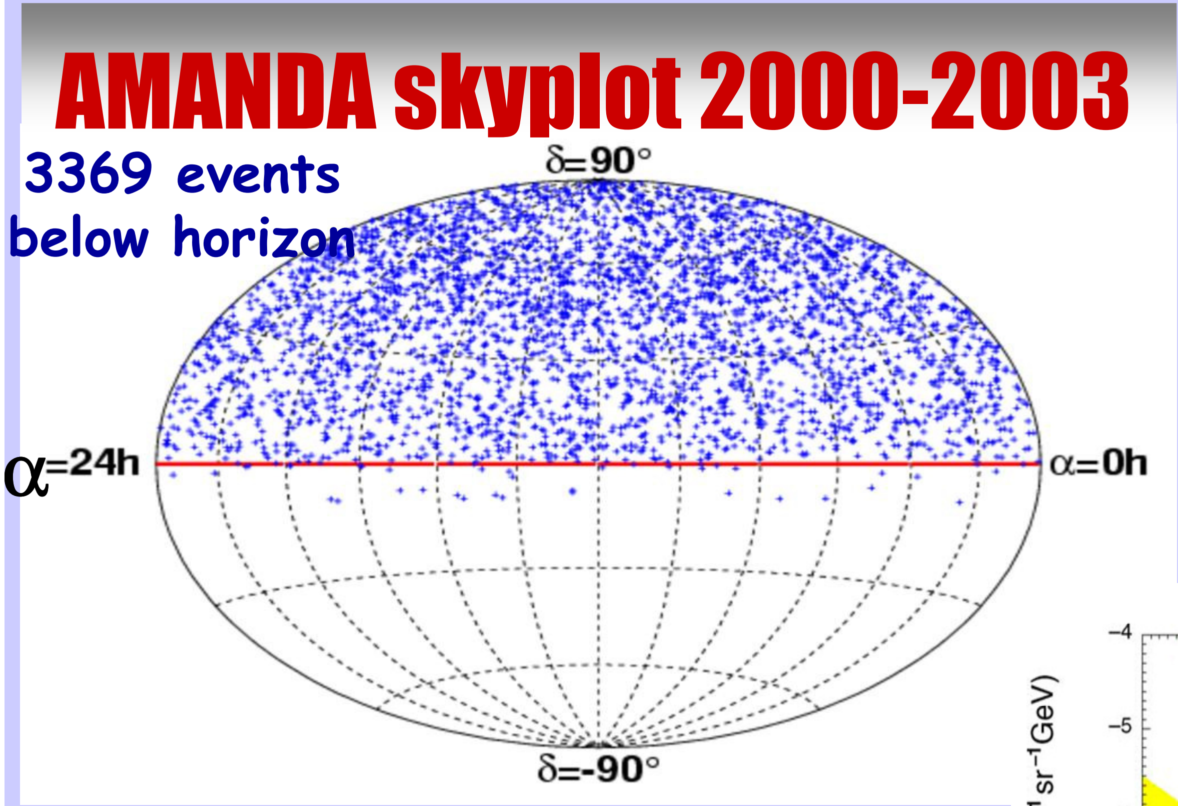
Kalashev et al. 01, 02, Semikoz & Sigl, 03

	GZK-WB	GZK-L	GZK-H	NH	TD
Surface D	0.016	0.040	0.095	0.246	0.100
Surface S	0.012	0.037	0.098	0.214	0.094
Surface N	0.015	0.046	0.125	0.267	0.120
Surface W	0.022	0.066	0.181	0.380	0.174
Surface E	0.008	0.024	0.061	0.139	0.060
Total	0.074	0.213	0.560	1.245	0.548

Preliminary!

What about Neutrino Telescopes ?

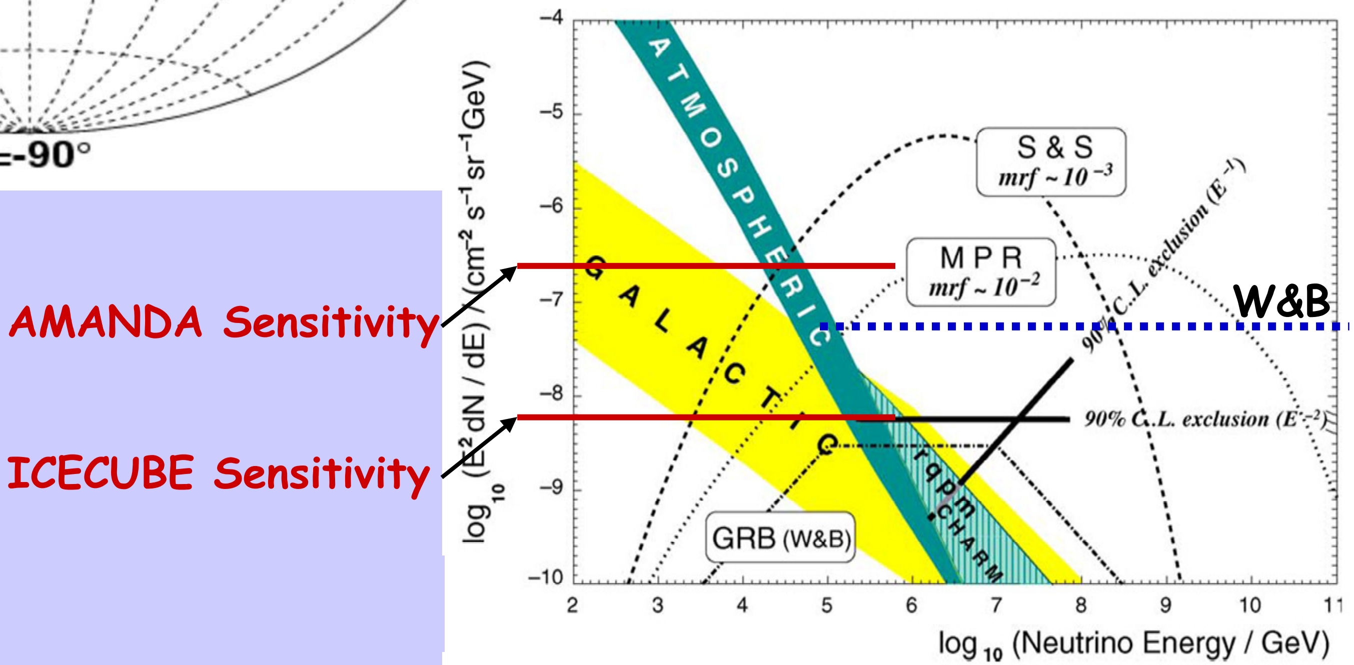
Neutrino Astronomy

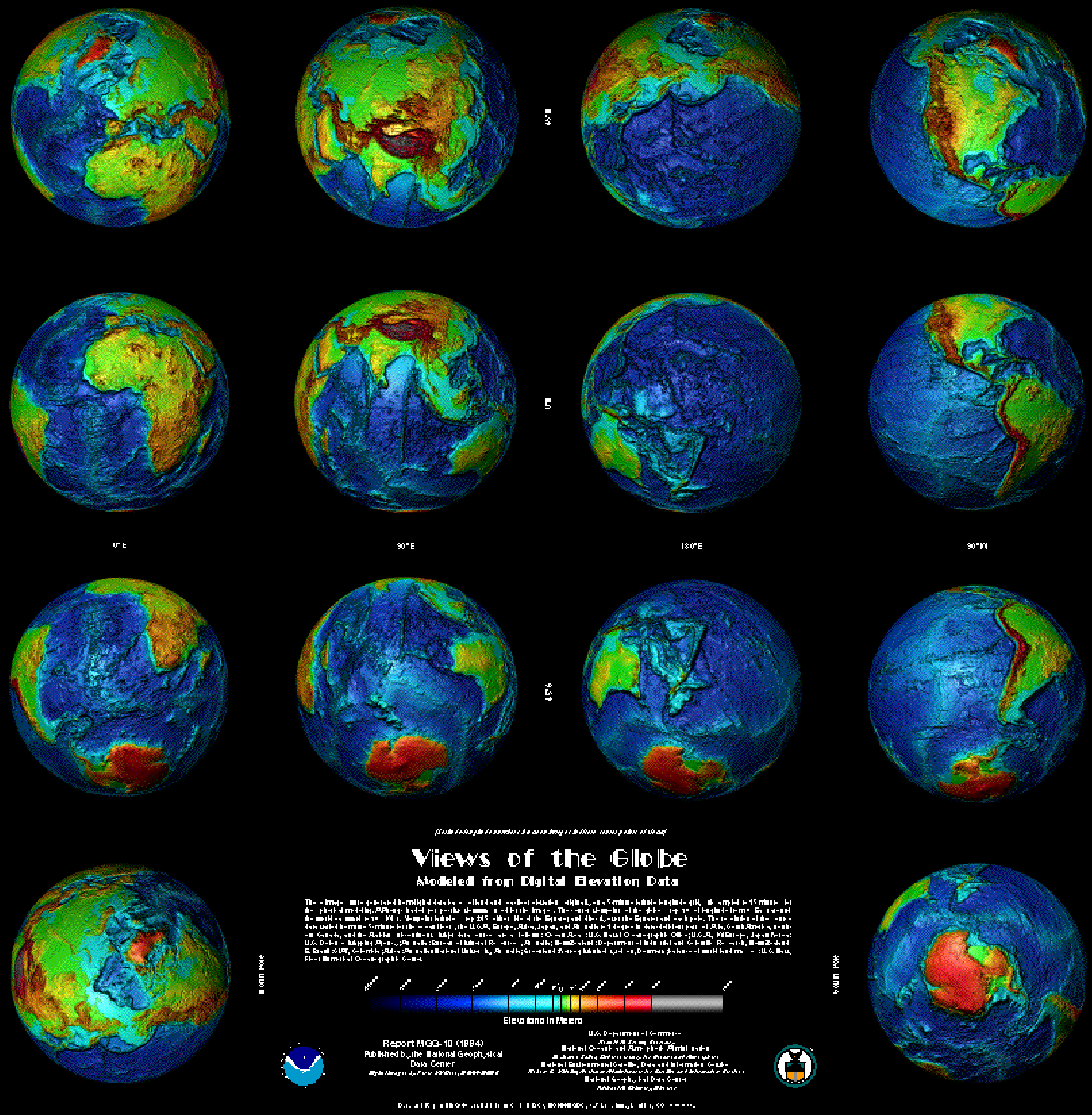


Present AMANDA neutrino events are likely all atmospheric

Sensitivity to at least 100 TeV events required to overcome atmospheric backgroud: IceCube, Nemo

τ Channel very promising: no atmospheric background but sensitivity only at 7 < LogE(GeV) < 9



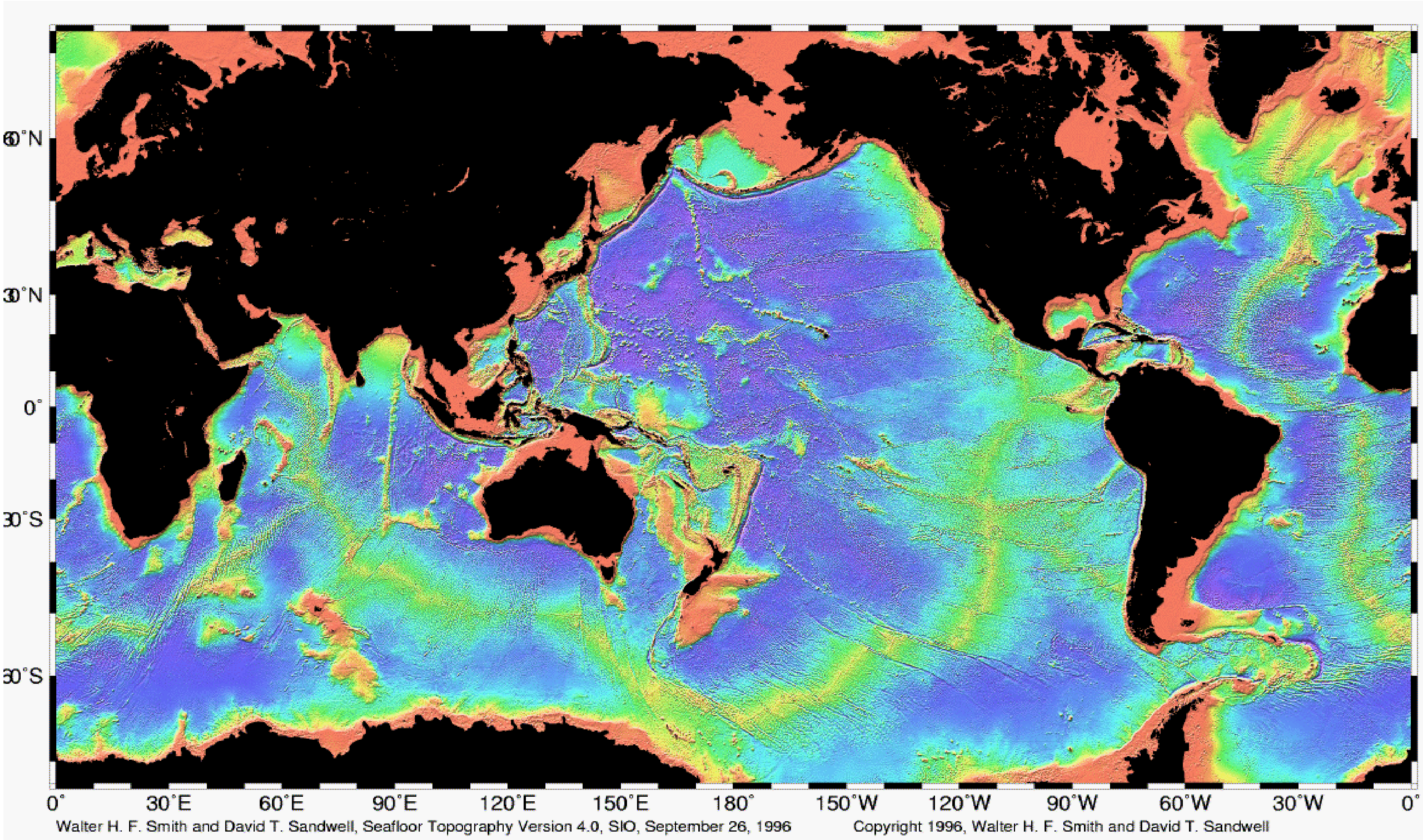


ETOPO2

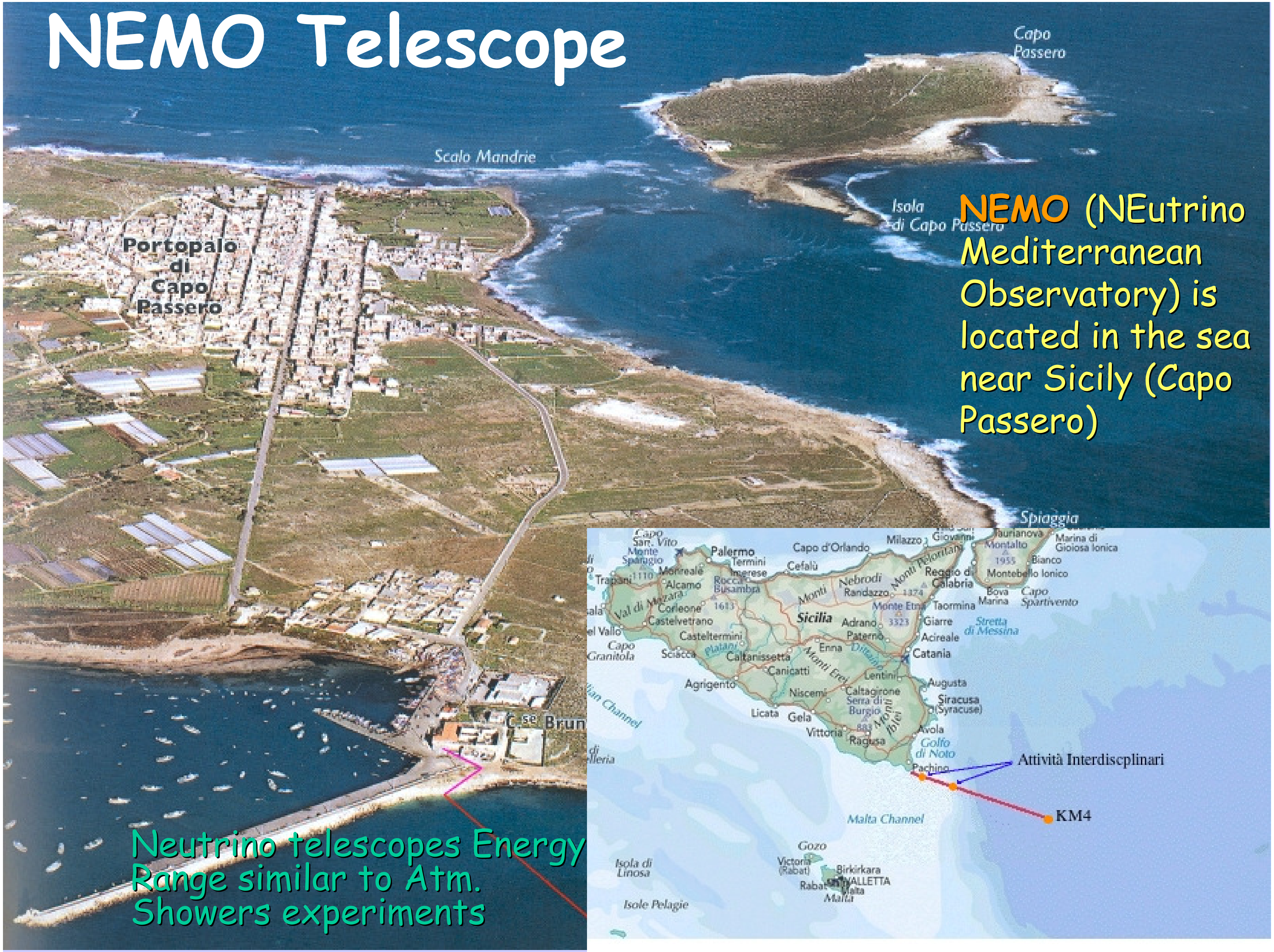
U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center, 2001. 2-minute Gridded Global Relief Data (ETOPO2)

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.



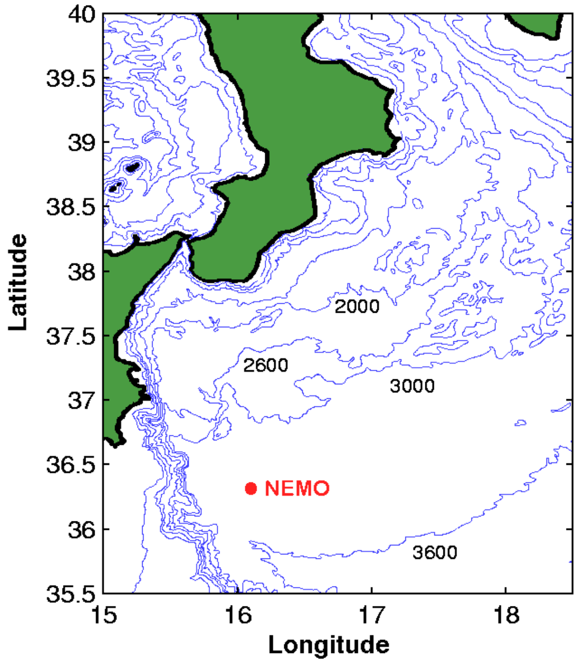
NEMO Telescope



NEMO (NEutrino Mediterranean Observatory) is located in the sea near Sicily (Capo Passero)

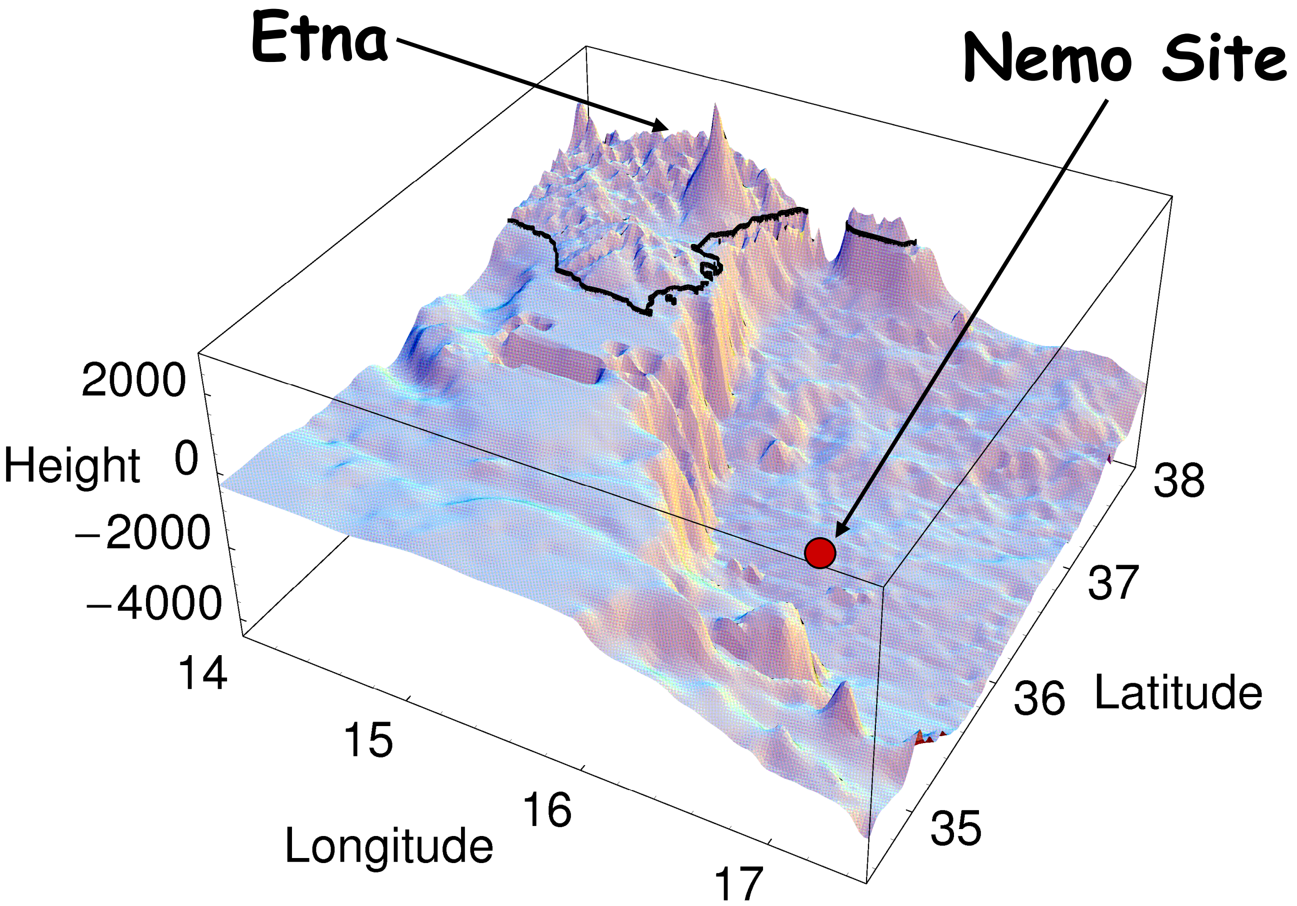
Neutrino telescopes Energy Range similar to Atm. Showers experiments

NEMO Site



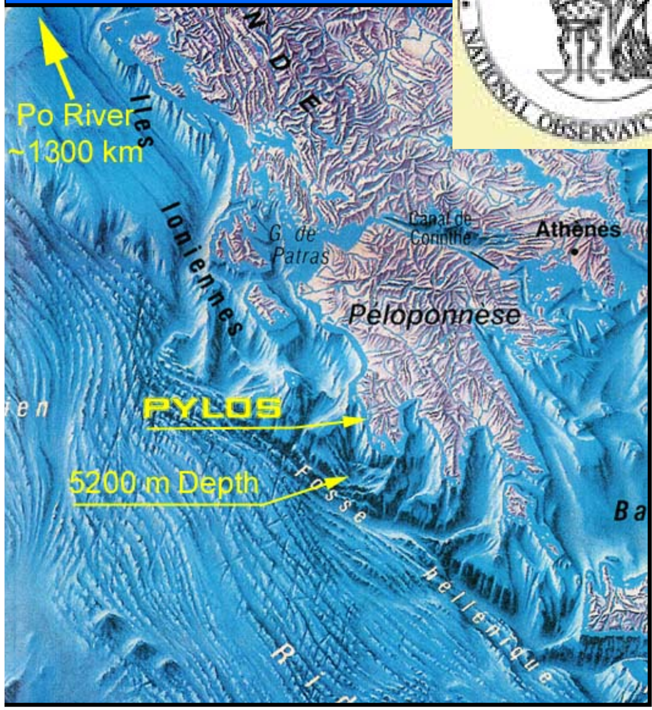
- Site Location
  36°21′ N, 16°10′ E

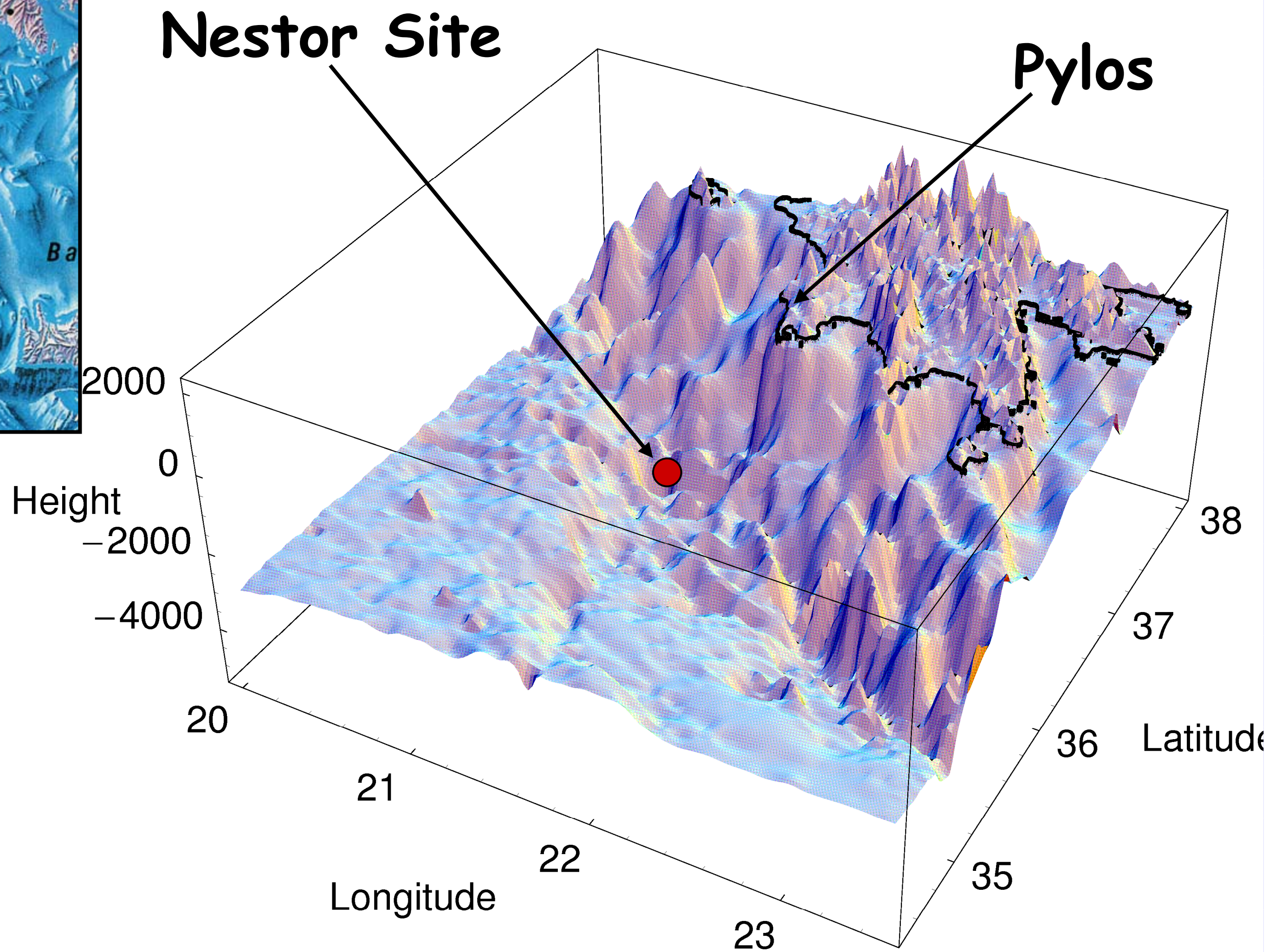
- Average Deep
  ~3500 m
  (3424 in our simulation)



National Observatory of Athens

NESTOR Institute for Astroparticle Physics

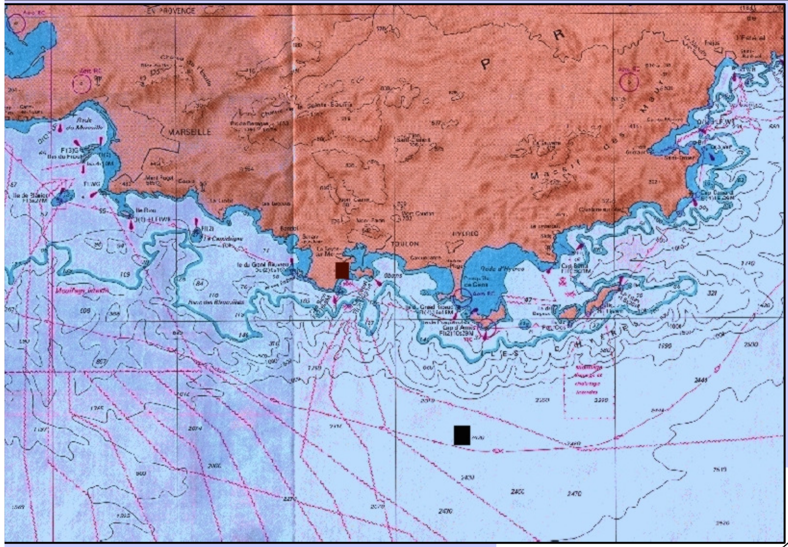


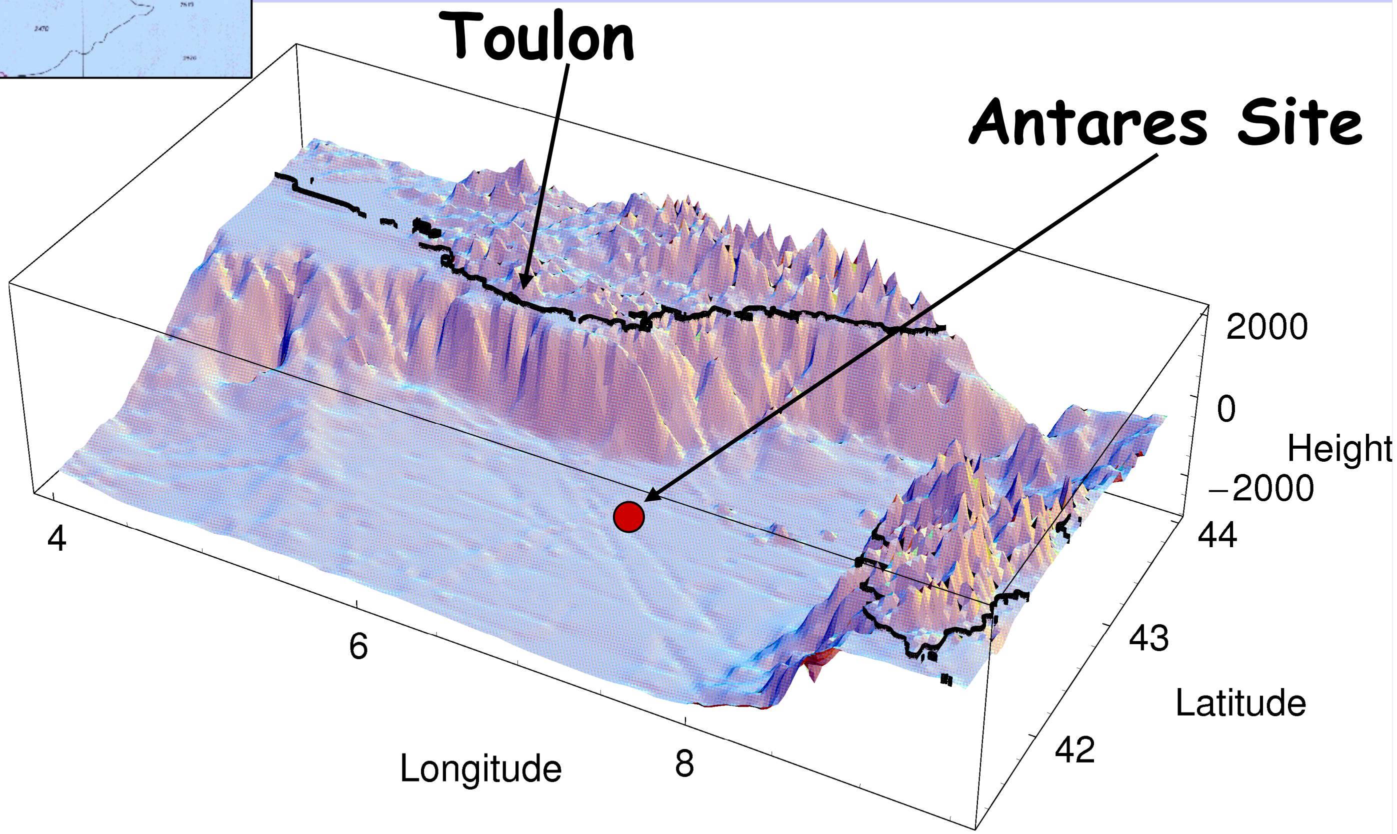


- Site Location
  36°21′ N, 21°21′ E

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

Antares Site



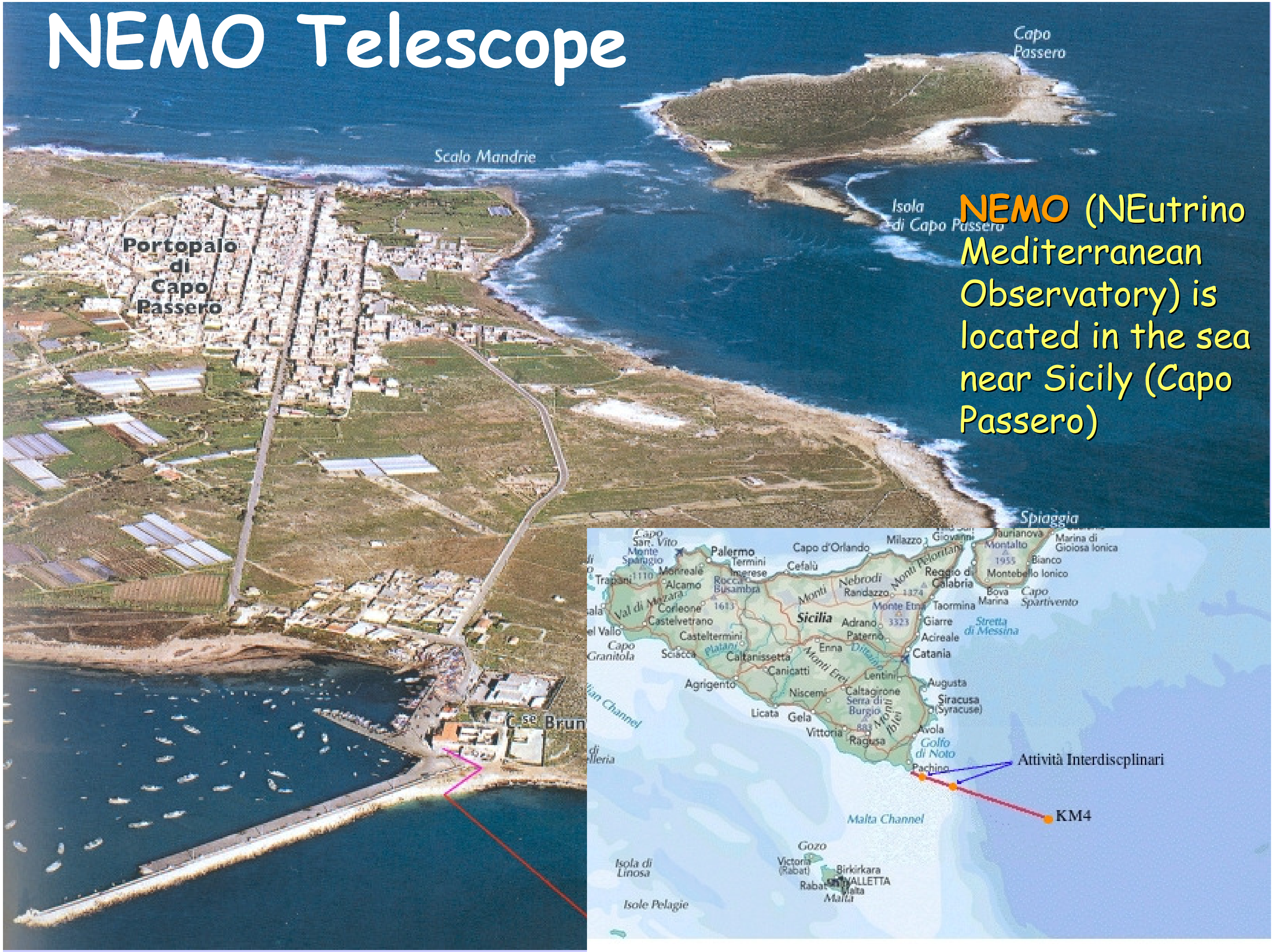


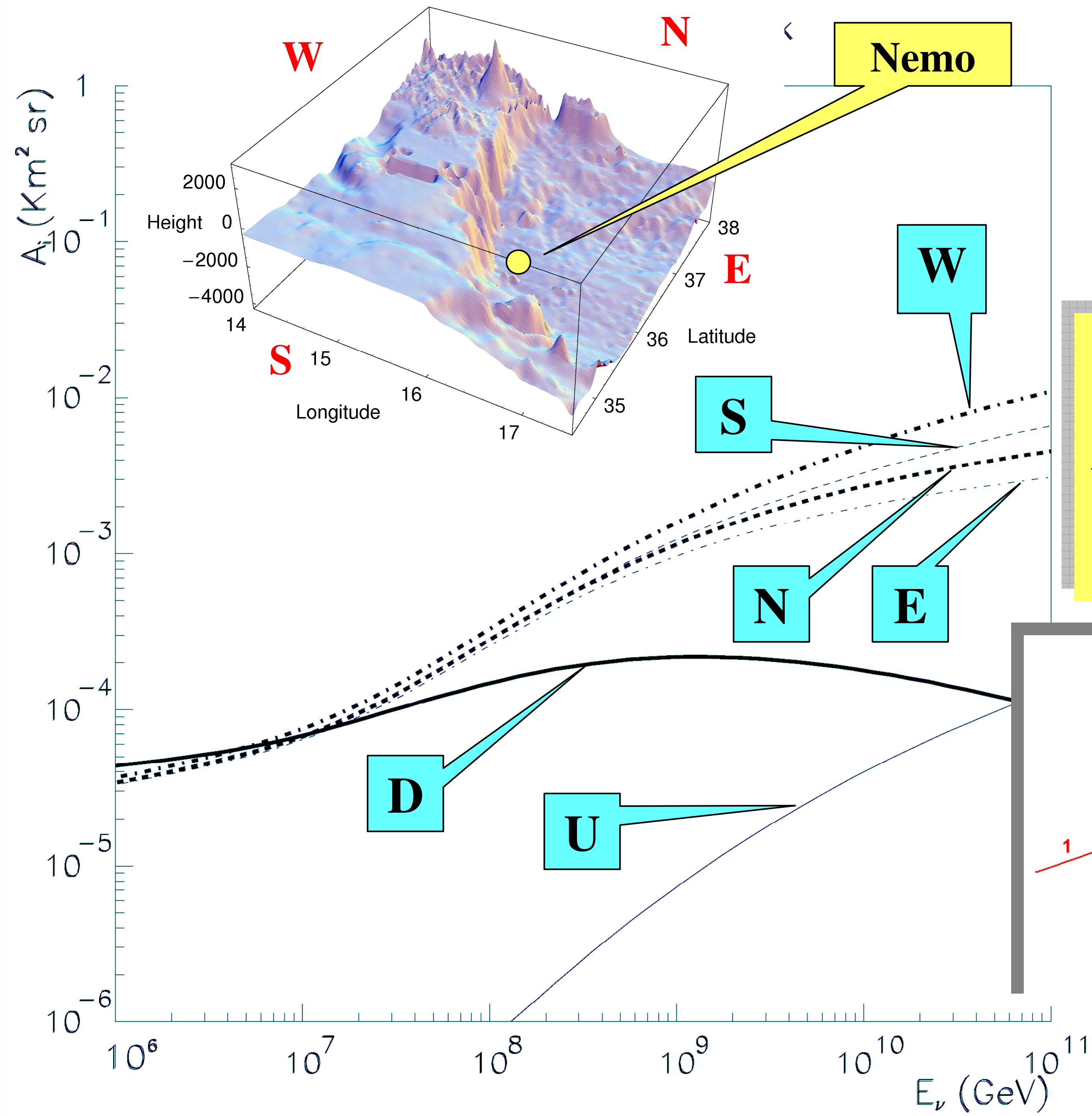
Site Location
42°30′ N, 07°00′ E

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

NEMO Telescope

NEMO (NEutrino Mediterranean Observatory) is located in the sea near Sicily (Capo Passero)

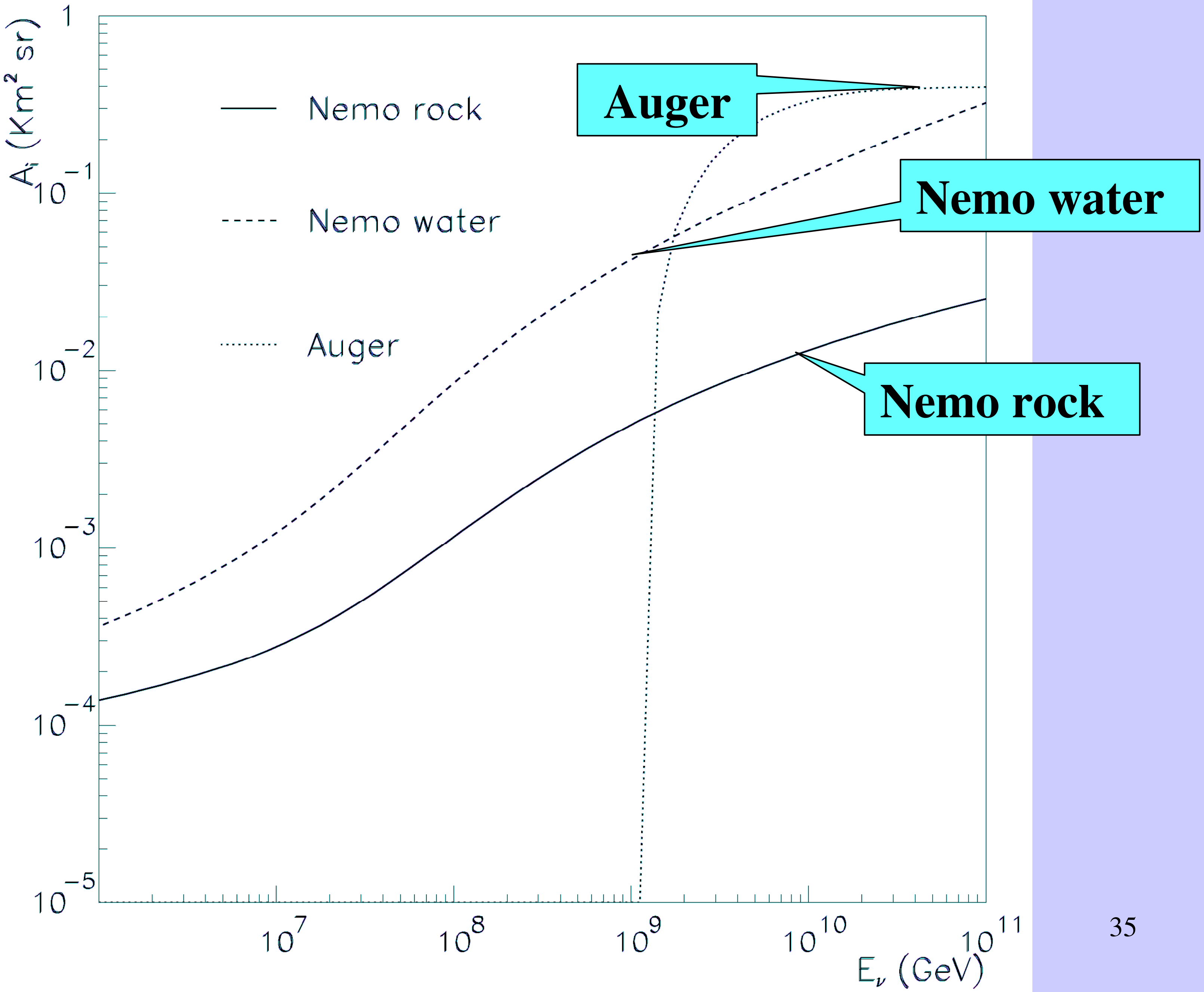


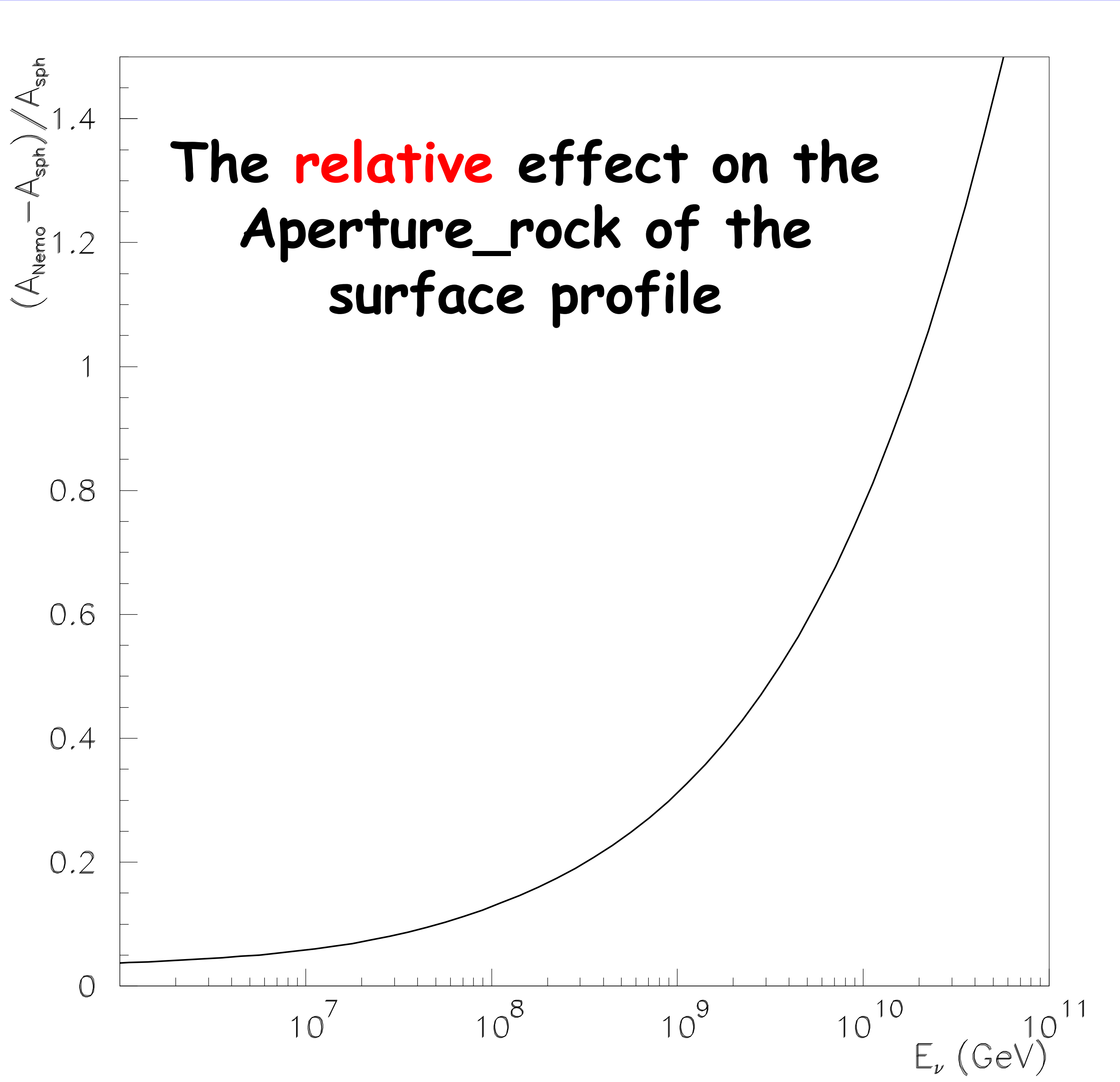


Apertures for τ **tracks crossing the rock in Nemo**

Matter Effect!

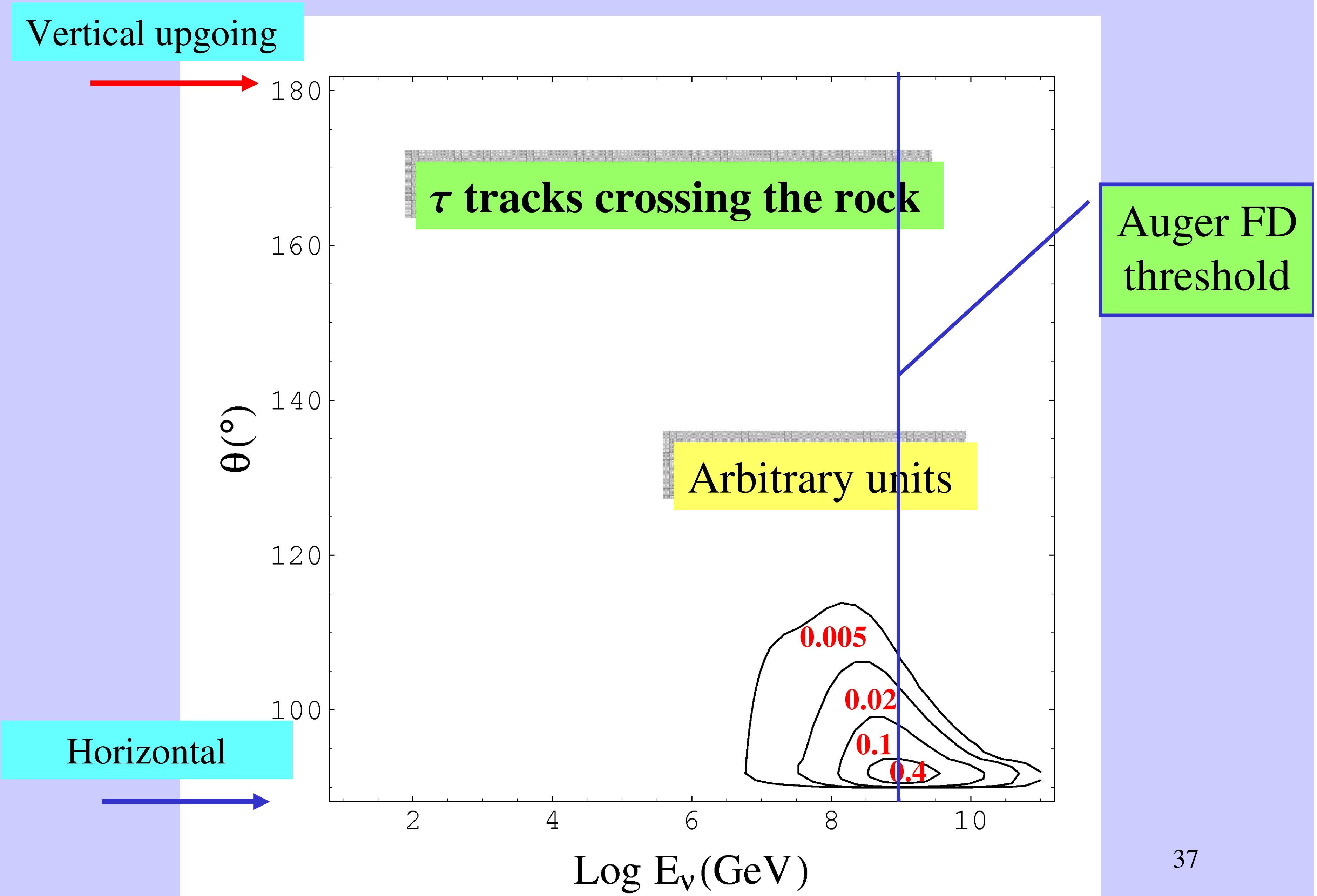
Comparison of Apertures



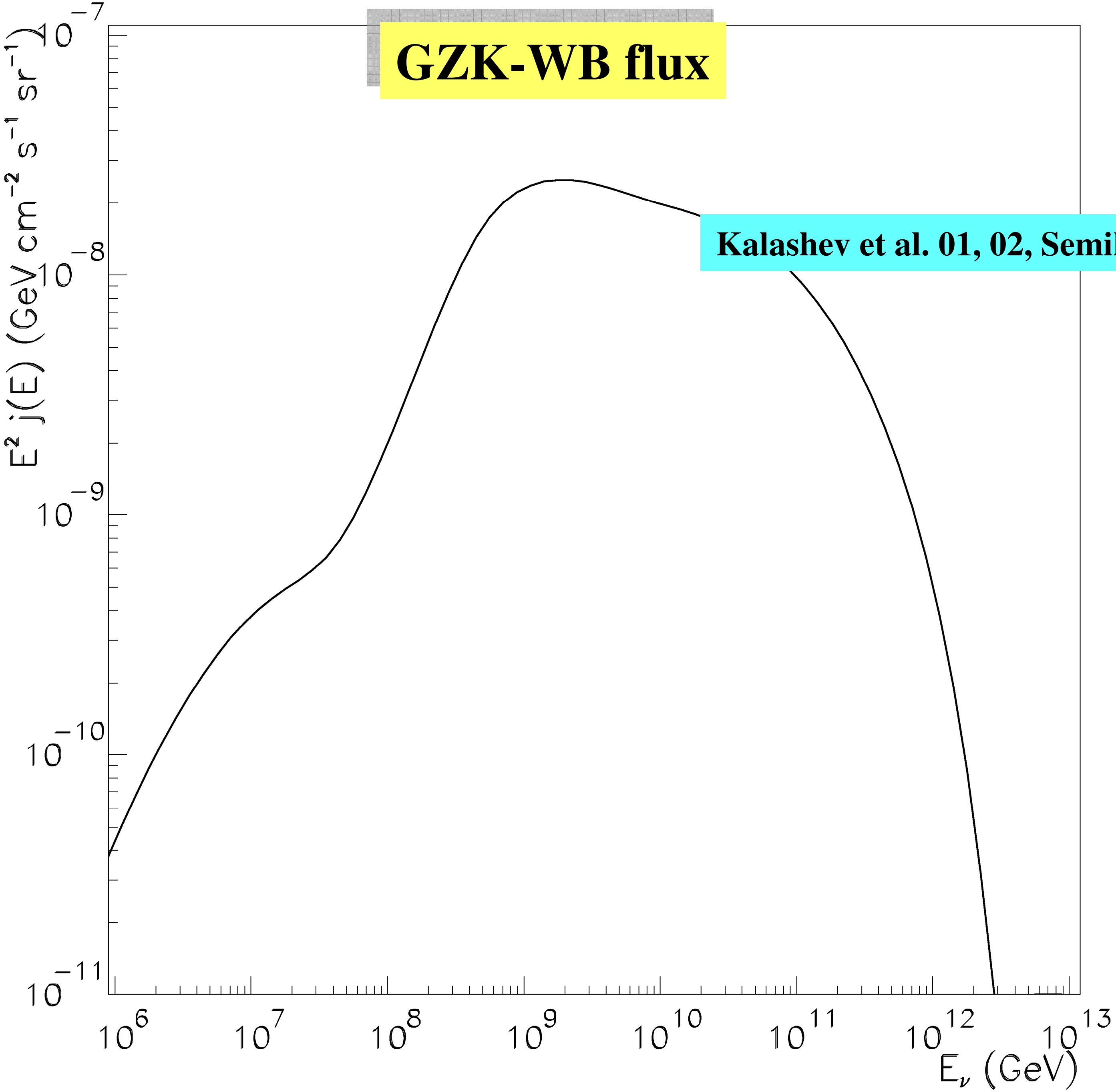


The relative effect on the Aperture_rock of the surface profile
$(A_{Nemo} - A_{sph})/A_{sph}$
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^7
10^8
10^9
10^{10}
10^{11}
E_ν (GeV)

GZK-WB flux & no surface profile

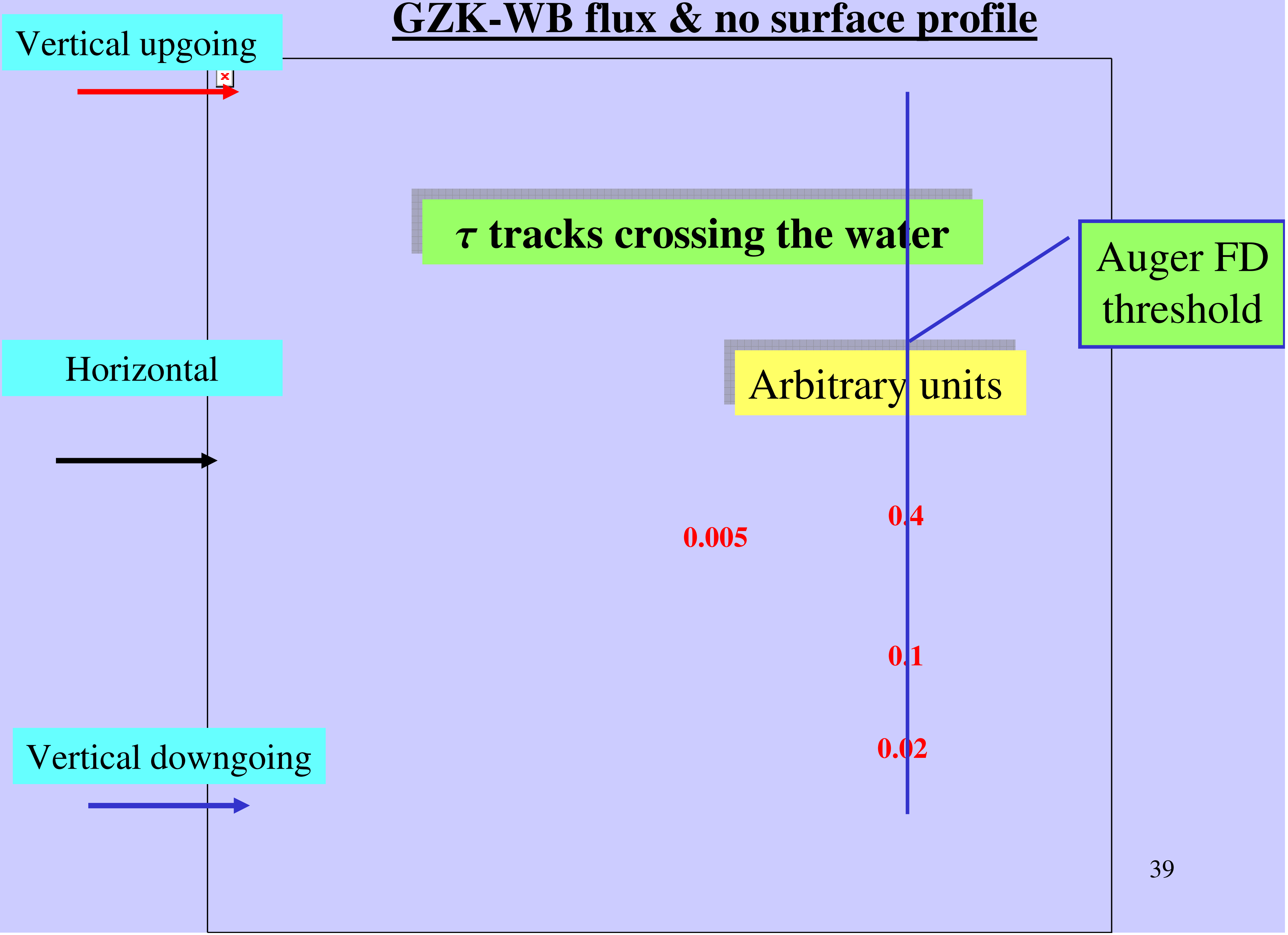


GZK-WB flux

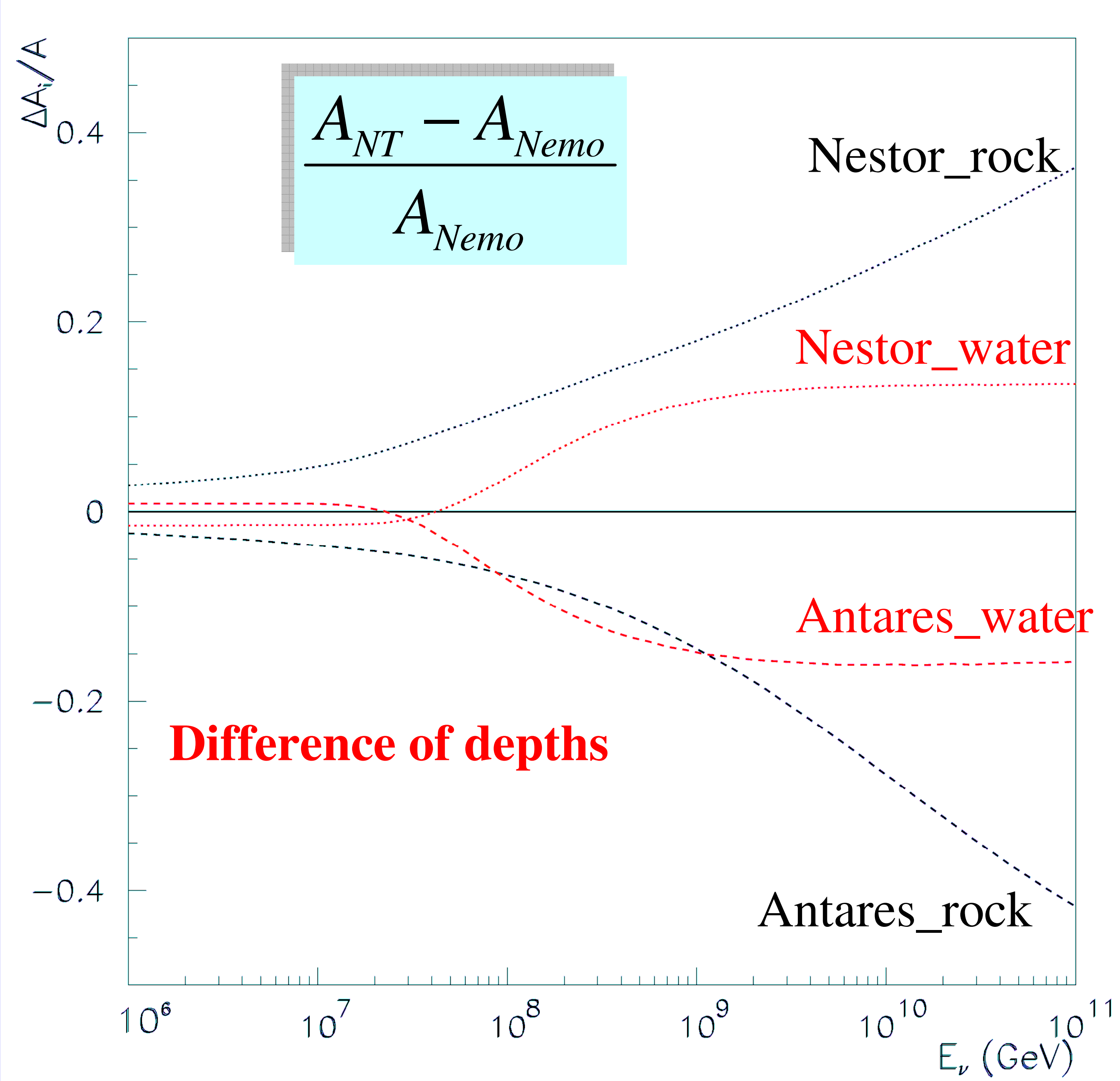


Kalashev et al. 01, 02, Semikoz & Sigl, 03

GZK-WB flux & no surface profile



Comparison between the different Neutrino Telescope sites



$\frac{A_{NT} - A_{Nemo}}{A_{Nemo}}$
Nestor_rock
Nestor_water
Antares_water
Antares_rock
Difference of depths
$\Delta A_i/A$
0.4
0.2
0
−0.2
−0.4
10^6
10^7
10^8
10^9
10^{10}
10^{11}
E_ν (GeV)

# of yearly τ events crossing the rock and the water for GZK_WB flux

Surface	Nemo	Nestor	Antares
D	0.0086	0.0085	0.0086
U	0.0002	0.0003	0
S	0.0290	0.0287	0.0219
N	0.0268	0.0359	0.0275
W	0.0371	0.0303	0.0247
E	0.0228	0.0414	0.0240
Total_R	**0.124**	**0.145**	**0.107**
Total_W	**0.945**	**1.043**	**0.819**

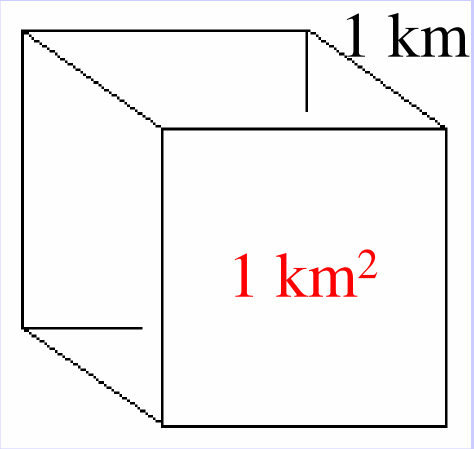
But we could have more copious fluxes!

Matter enhancement effect ~ 20% as for Auger

Predictions for different fluxes

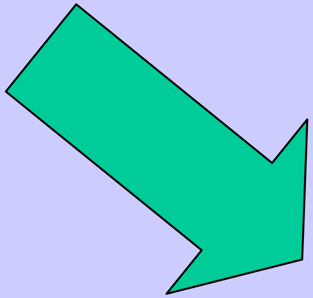
ν-fluxes	Nemo	Nestor	Antares
GZK_WB	0.124/0.945	0.145/1.045	0.107/0.819
GZK_L	0.141/1.308	0.175/1.471	0.110/1.106
GZK_H	0.335/3.348	0.423/3.777	0.245/2.824
NH	1.248/10.37	1.488/11.51	1.029/8.920
TD	0.957/5.888	1.087/6.436	0.837/5.181

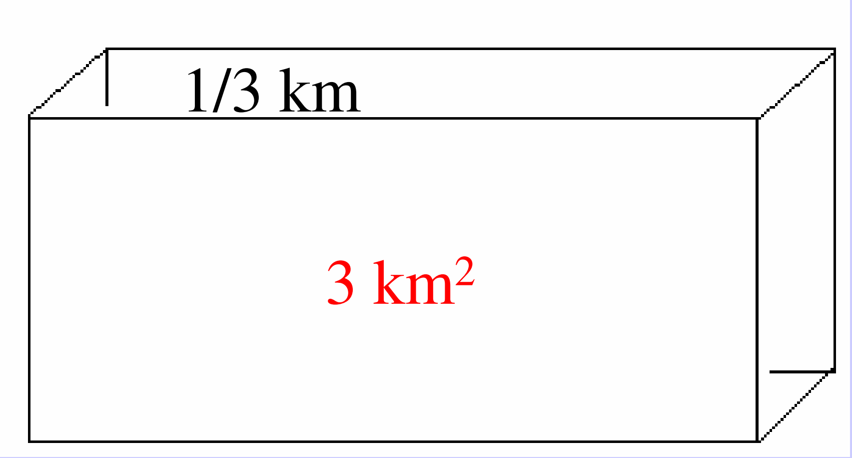
τ-Events per year in Rock **τ-Events per year in Water**

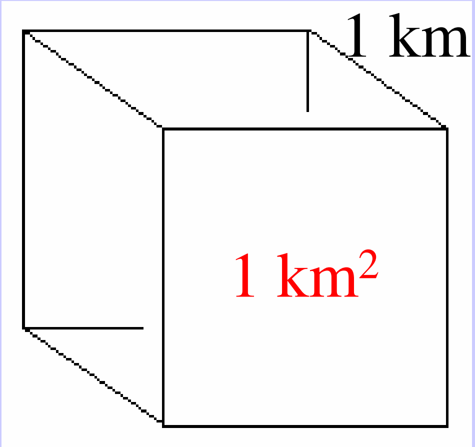


Enlarging the surfaces W and E from 1 km² to 3 km² but keeping the same volume

The total events in rock Double

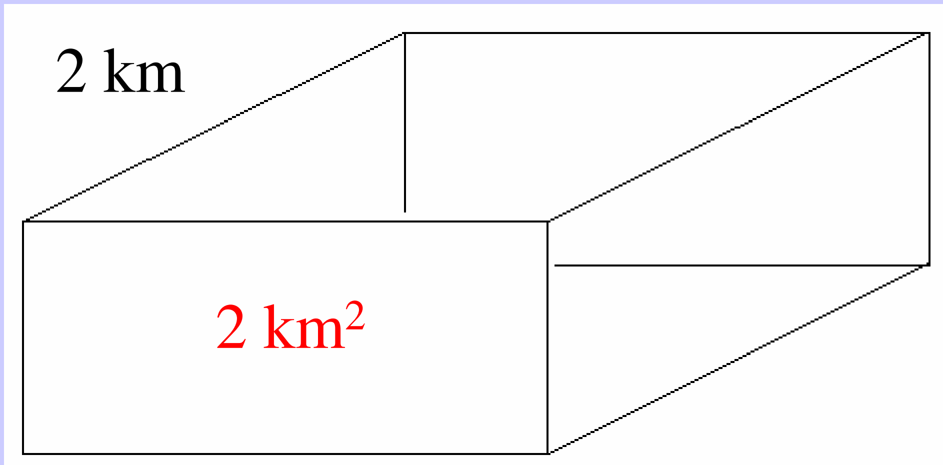






Enlarging the volume by factor 4 and surfaces W and E from $1\ km^2$ to $2\ km^2$ but keeping the same numbers of towers

The total events in rock Double



This could be done in Nemo!

Conclusions

- The prediction for the # of yearly ν_τ events is strongly dependent on the ν-flux. Unavoidable! Our predictions were conservative.
- The available DEM of a large area around different sites of Neutrino Telescopes allows for a realistic estimate of ν_τ Earth-skimming events.The matter enhancement effect is about 20% as obtained for Auger.
- The number of yearly ν_τ Earth-skimming is comparable with Auger_FD but at a lower energy scale. The events are almost horizontal and their yearly number depends on the geometry of the apparatus.

Perspectives

- The ν_μ induced and ν_τ regenereted events should also be included
- The ratio of rock/water events is a way to measure $\sigma_{\nu N}$ at high energies