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NESTOR
A NEUTRINO PARTICLE ASTROPHYSICS UNDERWATER LABORATORY FOR THE MEDITERRANEAN

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A new program for an underwater neutrino astrophysics laboratory to be located in the international waters off the Southwest of Greece, near the town of Pylos has now been funded for the initial stage. In the last 2 years a group of physicists from Greece and Russia have carried out two demonstration experiments in 4km deep water, counting muons and verifying the adequacy of the deep sea site. Plans are presented for a 100,000 m^2 high energy neutrino detector composed of a hexagon of hexagonal towers, with 1176 optical detector units. A progress report is given and the physics potential of a single tower with 168 phototubes (currently under construction) is described.

I hope that everyone here is a believer that neutrino astrophysics will soon become an important part of both Elementary Particle Physics and Astrophysics. Clearly the field was born with the detection of neutrinos from supernova 1987A by IMB and Kamiokande. Very soon, with the deployment of DUMAND off the coast of Hawaii the detection of high energy neutrinos will become a reality also. The laboratory of Gran Sasso is a real proof of the importance that the European Physics community gives to extraterrestrial neutrino physics, but

$1000m^2$ is the maximum sensitive area that an underground detector can have. Most of us believe that in order to get into the point astronomy with neutrinos a sensitive area of $100,000m^2$ or more is needed, the only way that one can get to these huge areas is to go deep into the water. One has to go deep (usually around 4000m deep) in order to reduce the huge cosmic ray background (noise to signal on the earth's surface of $\sim 10^{11}$) to a level that is both manageable by fast electronics and efficient reconstruction. The water is a beautiful Cerenkov medium, with a Cerenkov angle of ~43° and a water transmission length that can be as good as 60 meters. So the sea water, acts as I) an absorber that filters out cosmic rays, II) a target with which the neutrinos interact and III) an active detector medium which with the Cerenkov effect illuminates large areas quite a distance away from the passage of the particles (mainly the muon) that are produced in neutrino interactions.

We believe that Europe needs its own dedicated underwater neutrino laboratory that will extend the sensitive reach of Gran Sasso to more than a million square meters. The Baltic Sea, the Black Sea and the North Sea are relatively shallow and the required depths of 4000m are found only in the Mediterranean and the Atlantic. The deep Atlantic sites are far away from shores and good harbours, a fact that gives nightmares to many of us especially when we worry about deployment and is compounded by the high waves and the big swells that are always present, to contrast this, the placid (most of the time) waters of the Mediterranean offer a haven. In fact there are two underwater plateaus in the Mediterranean with depths of 4000m or more, one off the South East coast of Rhodos and the other 7.5 miles South West of Sapienza near Pylos (fig.1), where a little further away one finds the deepest part of the Mediterranean 5200m. This is the location we have chosen to deploy our neutrino telescope. Further, the Bay of Navarino (Pylos) is a perfect testing station for underwater hardware and a good assembling area before going out a few miles away to deploy the telescope towers.

We call our project[1] NESTOR because we want to honour the most famous man of the land of Pylos, Nestor was the wise king of Pylos who counselled the Greeks during the Trojan war. To us now the name underlies the scientific goals of our laboratory to engage in the detection of both low energy and high energy neutrinos, so it is an acronym, NEutrinos from Supernovae and Tevsources Ocean Range. Although our finances right now are such that we cannot afford to built an extragalactic supernova detector we have designed a high energy neutrino detector that is also an efficient low energy neutrino detector (in order to do atmospheric neutrino oscillations) and still is a competitive galactic supernova detector.

Site

As you can see from the chart of isobaths (fig.2) we have located at a depth of 3,750m a rectangular plateau with sides of 8km · 9km (at a distance of 7.5 nautical miles from the lighthouse of Sapienza (where our counting room will be located), then the processed data will be transferred from Sapienza to Pylos by either microwave link or optical fiber. It is worth

emphasise that the slope of the plateau is indeed flat and horizontal, its depth changes only by 100m over 9 kilometers, it is also interesting to note that on a two dimensional projection our site lies on the extrapolation of a straight line from CERN to Gran Sasso.

Water Transmissivity

The water transmissivity at the depth of 3800m is the most important environmental parameter. This is why we have spent a lot of effort to measure it. Basically there are three ways of measuring it.

1) taking a large number of samples (47 in our case) from different depths at various locations in the vicinity of the deployment site and measuring the attenuation coefficient aboard the oceanographic ship with a highly collimated monochromator spectrophotometer[2]. This technique yielded an attenuation coefficient ranging from .025 to .045 (fig.3) at 4600 Angstroms. But the scattering of the light does not take light away from a water Cerenkov experiment[3], we therefore have to correct the attenuation coefficient for scattering. Oceanographers differ in this correction[2],[3] and their estimates range from 20% to 50%. If you believe the first number, then the absorption length (i.e. the inverse of the attenuation coefficient corrected for scattering) is somewhere between 28m and 50m. If you believe the 50% correction then the transmission length is between 35m and 60m. In either case the water transparency is very good.

2) Taking an autonomous module[2], e.g. a photometer and deploying it in situ. Three such deployments were made down to depths of 4000m. Since there was no reference cell one gets relative numbers only. The shape we get is consistent with the results of method 1, which means that we understand the systematics. For more details see reference 2.

3) A high energy physicist's way of doing the measurements i.e. measuring in situ the light detected as a function of the distance between the light source and the detector. Indeed such a device was designed and built by Hugh Bradner was used for the DUMAND measurements. The advantage of this technique is that the light beam is not highly collimated so one does not have to correct for the scattered light. The same device[4] was deployed four times in the NESTOR location and measurements gave a transmission length of 54±10m (fig.4). This result is clearly consistent with the one described in 1 above. If one considers that the cost of the detector drops inversely with the third power of the transmission length, I can only say that we are very fortunate to have such great water transmission length.

Underwater Currents

The underwater currents in the proposed NESTOR site were measured in October 1989, July/August 1991 and October/November 92. Their values are a few cm/sec, truly minimal. There is a detailed presentation in a paper by Demidova[5]. We will soon embark on a long term program of continuous measurement of the underwater currents in order to accumulate long term

statistics.

Sedimentology

A large number of photographs of the sea bottom around the proposed site were taken. Nine core samples (almost 2 meters long) and 3 core grabs were taken also and careful sedimentology studies were made. The result is nice firm clay, good anchoring ground. The detailed sedimentology study is presented in a paper by Trimonis et. al[6].

Deep Water Cosmic Ray Measurements In The Nestor Site

During July 1991, a collaboration of the Institute for Nuclear Research and the Institute of Oceanology of the Russian Academy of Sciences and the University of Athens carried out a successful cruise using the R/V VITYAZ off the coast of Pylos. We deployed[1] a Russian built hexagonal structure fig. 5a,5b,5c,5d (7m radius) built out of titanium using 10 phototubes (15 inch photocathodes) facing upwards, down to a depth of 4100m. Six of the phototubes were located at the corners of the hexagon and four 3.5 meters below the center. We successfully measured the vertical muon intensity and the angular distribution of downcoming muons. As one can see from figures 6-7 our results at 3300m, 3700m, and 4100m agree very well with DUMAND I, the deep mine measurements, and Miyake's formula.

In November 1992 we deployed[7] a linear string of five 15 inch phototubes (again the photocathodes were facing upwards). This time the deployment was made from the Russian research vessel "Ac. Mstislav Keldysh". The string was deployed in depths from 3700m to 3900m, the vertical intensity of cosmic ray muons and their dependence of the muon flux as a function of the zenith angle was obtained. The results are in good agreement with the previous measurements and calculations.

To summarise, at depths between 3700m and 3900m the vertical flux $(9.8\pm4.0)\cdot 10^{-9}$ $cm^{-2}s^{-1}sr^{-1}$. The background due to radioactive K^{40} and water bioluminescence is 597 ± 150 photons/$cm^2\cdot s$. We note that this is an upper limit because since the phototubes were suspended from the ship the vertical motion excites the various organisms giving very high values for the bioluminescence compared to anchored phototubes

Basic Detector Element: Omni Directional Module

Instead of using one 15 inch phototube facing down (like DUMAND), we will use two 15 inch phototubes (each in its own protective glass 17 inch Benthosphere), tested to 600 Atmospheres of pressure one looking up and the other looking down (fig.8, detail). This way we get a detector element with an isotropic (4π) response.

Two Dimensional Array Element: A 16m Hexagon

Six Omni-Directional Modules will be placed at the corners of a horizontal hexagon and a

seventh one in its center. The radius of the hexagon is planned for 16m, and the arms made out of titanium piping. This design is a straightforward extension of the hexagonal autonomous module we used during the tests off Pylos in the summer of 91, and the increase of the hexagon radius from 7m to 16m may easily be achieved. We are investigating the feasibility of constructing titanium hexagons with 20m radius, in order to increase the active detection area.

Three Dimensional Element: 330m Tower

By stacking hexagons we can built "towers", figure 8. The vertical distance between these hexagonal floors will be around 30m, this spacing matches well the light transmission length of 55m±10m (at 460nm) we have measured in these waters. With 30m inter-hexagonal floor spacing and 7 phototubes from a lower hexagon looking up and 7 phototubes from a higher hexagon looking down, the active volume between hexagonal floors will be monitored efficiently. A total of 12 such hexagonal floors is planned for one tower. At this moment, the number of floors is constrained to 12 by the number of optical fibers in currently commercially available electro-optical cables for the data transmission to the shore and for the supply of electrical power to the tower. Each floor will be electrically and electronically independent from the other floors and will have its own optical fiber for data transmission.

Single Tower Sensitivity

The beauty of the water Cerenkov technique is that the detector sensitive area reaches out quite a bit further away than the actual geometrical area of the detector. Clearly the effective area is a function of the energy of the muon. In fig.9 we see that for 10° reconstruction accuracy of the direction of a 10TeV muon the effective area is 20,000m^2 and 50,000m^2 for 10^3TeV muons and 40° reconstruction accuracy(compare this to 400m^2 for IMB and 1000m^2 for MACRO). The angular resolution along the horizontal for a single tower is, of course, not as good as needed for point source astronomy simply due to the restricted lever arm. Note however that the predictions for the flux of UHE neutrinos for Active Galactic Nuclei is for a diffuse background of neutrinos with energies up to 10^{16}eV, so very good pointing is not needed in order to get started.

Full Detector Array: e.g. A Hexagon Of Hexagonal Towers

The need for a full 10^5m^2 array can be satisfied with a hexagonal configuration of another six towers deployed on the apexes of an 100m or 150m radius hexagon centered around the original tower fig.10. Such an arrangement would provide an overall angular resolution of better than 1°, excellent for point astronomy, and sensitive area bigger than 10^5m^2 for neutrinos of 1TeV. The total cost of such an array is less than 15M$. Such a detector would have a sensitive area of > 100,000m^2, angular resolution of < 1°, enclosed mass > 20 Megatons and would almost certainly be able to begin the field of high energy neutrino point source astronomy.

Off course the possibilities do not stop at $10^5 m^2$.The beaty of the deep approach is the potential for following the physics as one gains experience and first looks at the data.A bigger detector is obviously possible,as are configurations that maximise low energy sensitivity, or tune on any particular facet of the science that may prove worth pursuing.

The Physics Potential Of Nestor With Only One Tower

There is a multitude of existing physics that we can do with one NESTOR tower,while waiting for the events of extraterrestrial origin to come in. These include atmospheric neutrino oscillations, long baseline oscillations with CERN, (perhaps in conjuction with a detector at Grand Sasso).

Atmospheric neutrino oscillations

The subject of neutrino oscillations first suggested by Pontecorvo, has been a topic of intense interest for more than 15 years. For some recent reviews see [8]. If neutrino oscillations occur in their simplest form, assuming a two flavor oscillation, the probability of oscillation is :

$$P(\delta m^2, \sin^2 2\theta) = \sin^2 2\theta \sin^2(\frac{1.27\delta m^2 L}{E_\nu}) \quad (1)$$

where $\delta m^2 = m_1^2 - m_2^2$ is the difference of the mass eigenvalues in eV^2 , θ is the two flavor mixing angle , L is the ν propagation length in Kilometers and E_ν is the neutrino energy in GeV.

Recent results by the KAMIOKA, IMB and SUDAN2 collaborations suggest that perhaps as much as 40 % of the atmospheric $\nu_\mu$events in the energy range from 0.2-1.5 GeV have oscillated to some other type of neutrino [9],[10],[11]. Other less sensitive experiments did not record any effect [12] NESTOR will be able to test by studying atmospheric neutrino oscillations at a higher energy regime (above 5 GeV). The higher energy regime diminishes the dependence of the study on geomagnetic effects and on the uncertainties of the Oxygen cross section and other nuclear effects.The NESTOR design is such that the top floors can be used to "veto" downcoming cosmic rays.Therefore we can be sensitive to neutrinos arriving from all zenith angles.This way our L dependence varies from 10km to 13000km giving NESTOR an unprecedented sensitivity in δm^2 spanning four orders of magnitude. Further, since we intend to study the oscillations as a disappearence experiment, that is by measuring the ratio of muons coming from different zenith angles, we will be independent from theoretical flux predictions which currently are the source of considerable systematic uncertainties in KAMIOKA, IMB and SUDAN2.Our experiment will be internally normalisable i.e. comparing the expected number of neutrinos coming from all directions to anyone we choose to use as the "control" direction, this way modulo solid angle effects the number of muonlike neutrinos should be constant as a function of zenith, if there is a decrease it would be caused uniquely by neutrino oscillations i.e. muonlike neutrino oscillations to another

species. Figure 11 shows the distance that the neutrinos have transversed from their point of production as a function of zenith angle.

Further our sensitivity will profit from the matter enhancement of the $\nu_\mu$to $\nu_e$oscillations. We took the density profile of the earth from reference [13]. For the purpose of this study we estimated the incoming neutrino flux by using 3 different calculations, those of Butkevitch et al [14], Mitsui et al [15] and Volkova [16] and a fourth one using the low energy spectra of [17] together with the Volkova spectrum. For our energies the flux predictions differ by 10-15 %. See fig. 12.and table 1

E_ν Spectrum	Events	Mean E in GeV
Butkevitch et al	1043	6.877
Mitsui et al	880	6.901
Volkova et al	956	6.365
Gaisser+ Volkova	862	6.690

Table 1: Fluxes and Energy comparison

The downcoming cosmic ray muons are usually a major obstacle to downward detection of contained neutrino events in shallow water detectors, but in our case present a difficult but manageable background. Figure 13 shows the flux of downcoming muons per year compared to the number of contained neutrino atmospheric events as a function of the zenith angle. The ratio of signal to background from 0 to 60 degrees is of the order of 10^4. Preliminary studies have shown that we can reject the downcoming cosmic ray muons at this level, by using veto techniques.

Our efficiency to reconstruct a muon, with 20 degrees pointing reolution is shown in figure 14. We are sensitive down to 5 GeVneutrino energy.

Finally, figure 15 shows the sensitivity we should have. The systematic errors due to the separation between $\nu_\mu$and $\nu_e$interactions are not included, but they are estimated to be less than 10 %, therefore comparable to our statistical errors. See the discussion of the same systematics in the next section and reference [18]. Note that our sensitivity includes the KAMIOKA solution.

Long baseline oscillations with CERN

As we have demonstrated in the preceding section, a 2 π zenith fit to the expected number of atmospheric neutrinos gives us an unprecedented sensitivity in δm^2, on the other hand accelerator experiments provide an extremely useful tool for systematic control (pulsed beam, selectivity of ν or $\bar{\nu}$) and by selecting the neutrino energy one can study in detail selected regions of δm^2 . A complementary study to the atmospheric neutrino oscillation can be conducted with a long baseline experiment with a CERN beam (see [19] for reviews of the

long baseline techniques). As part of the work of the LHC project injection transfer lines are being designed to bring the fast extracted beams from SPS to the new collider. The primary proton beam for a neutrino production target to feed Gran Sasso with only minor modifications can be derived from the one, TI48, which links SPS/LSS4 to LHC/P8. See reference [20] for more details.

On a two dimensional projection CERN, Gran Sasso and Nestor, are lined up. Calculations from M.Mayoud (the head of the CERN surveyors) are reported in table 2. One sees that a neutrino beam pointing to Nestor would need to be diverted by only 1 degree to the west in azimuth (easily acommoded), and 5 degrees or 7.5 % downwards in declination, from the one pointing to Gran Sasso.

Place	λ	ϕ	A_z	α	Distance
CERN	6.0732	46.2442	-	-	-
Gran Sasso	13.5744	42.4525	122.502	3.283	731 Km
NESTOR	21.3500	36.3500	124.1775	8.526	1676 Km

Table 2: Coordinates absolute (λ, ϕ) and relative w.r.t TI48 CERN beam (A_z, α) of Gran Sasso and NESTOR (angles are in degrees)

For demonstration purposes we have run the beam MC, with the horns used for CHORUS and NOMAD (in other words not optimized for our energies) and we have found, that for 10^{19} protons on target, (which is equivalent to an optimistic year of running, but noting the fact that the horn has not been optimized for our configuration), we should have 27000 events in one tower (without including our efficiency),for a proton beam of 450 GeV, and one order of magnitude fewer events, for a proton beam of 160 GeV. The flux energy spectra are shown in fig. 16. The beam diverges at the NESTOR location by about 1.5 km, matching well the detector dimensions ($\sim$ 300 m for one tower).Clearly such an experiment will require more than one tower appropriately configured to enhance e/μ separation.

We shall detect the oscillation as a change of the ratio of neutral (NC) to charged current (CC) interactions, since all charged current $\nu_e$events will apear as NC, or "muonless" events. In the case of oscillation to ν_τ, all CC events will appear muonless, except the fraction where the τ decays to a μ (this fraction is B_μ=17 %), there will also be a kinematical suppression η ($\sim$ 25 %) due to the high mass of the τ.Therefore the sensitivity to $\nu_\tau$oscillations will be less than the one to ν_e. If P is the oscillation probability shown in (1), the change of the ratio for the $\nu_\mu$to $\nu_\tau$is oscillation is shown below. The case of $\nu_\mu$to $\nu_e$is obtained by setting η=1. and B_μ=0.

$$R_\nu^{obs} = \frac{R_\nu^{true} + \eta P - \eta B_\mu P}{1 - P + \eta B_\mu P} \tag{2}$$

We have applied the detection efficiency shown in figure 14.

The separation of μ from e and hadrons in the detector is under study. Preliminary MC results indicate that we will be able to distinguish between "muonless" ("NC") and "muon-full" ("CC") events, by using the time distribution of the events (Cerenkov light from muons comes earlier than the one from the hadronic or electromagnetic showers) and/or the longitudinal shower development of the event (the muons distribute their light evenly while electrons emmit their light according to the development of the electromagnetic shower). The systematic effect due to this statistical separation is estimated to be of the order of 10%. We are currently installing our code in GEANT, to assess in more detail the above method. In the case of $\nu_\mu$to $\nu_e$matter effects could enhance the oscillation but as seen in figures 17 and 18, 1676 Km is not enough distance to produce a significant difference from the matter effects. Further as we see in figures 19 and 20 the statistics due to the larger beam divergence, disfavour the 160 GeVproton beam option. This can only improve with an optimized beam design. We are currently studying it together with A.Ball. The 450 GeVbaseline oscillation with CERN, as one can see from figure 18 will cover better the area of small mixing angles, due to better statistics, provided that we will be able to control our systematics.

Sensitivity to Active Galactic Nuclei

We have estimated the expected AGN neutrino events in NESTOR by using the neutrino fluxes as they were calculated for various AGN types and parametrized by V.Stenger [21], [22]. The final number of events is given by the formula:

$$R = \rho \int F(E_\nu) A(E_\nu) dE_\nu \int V(E_\mu) dy \int \sigma(x, y, E_\nu) dx \tag{3}$$

where $F(E_\nu)$ is the differential flux of neutrinos as it is given by V.Stenger's routine, $A(E_\nu)$ is the attenuation of the neutrinos due to interaction with the Earth and $\sigma(x,y,E_\nu)$ is the νN differential cross section and where x and y are the conventional scaling variables. E_μ is the muon energy depending from y and the neutrino energy via the type $E_\mu=(1-y)*E_\nu$. We integrated over a mean solid angle of 2π . The total cross section is a parametrization of the plots shown at the DUMAND Proposal [23] where cross sections are ploted versus neutrino energy. The parametrized cross sections are multiplied with a term involving the structure functions giving us the differential cross section in terms of x and y. The mean fraction of the energy of the neutrino taken from the produced muon is 51% for the case of the neutrino and 66% in the case of the antineutrino.

The second integration in our formula involves the integration over the y scaling parameter, and the effective volume has to be taken into account. The effective volume was calculated as the product of the effective area times the muon range.The calculation of the muon range is based on the formula:

$$R_\mu = \frac{1}{b} ln \frac{a + bE_\mu}{a + bE_{\mu 0}} \tag{4}$$

In conclusion it will be extremely difficult to see individual sources with one year of running (an average of 1 event is expected from most luminous sources) while we should detect $\sim$ 80 events of diffused AGNs above the atmospheric neutrino background, (above $\sim$ 150 TeV, figure 21).

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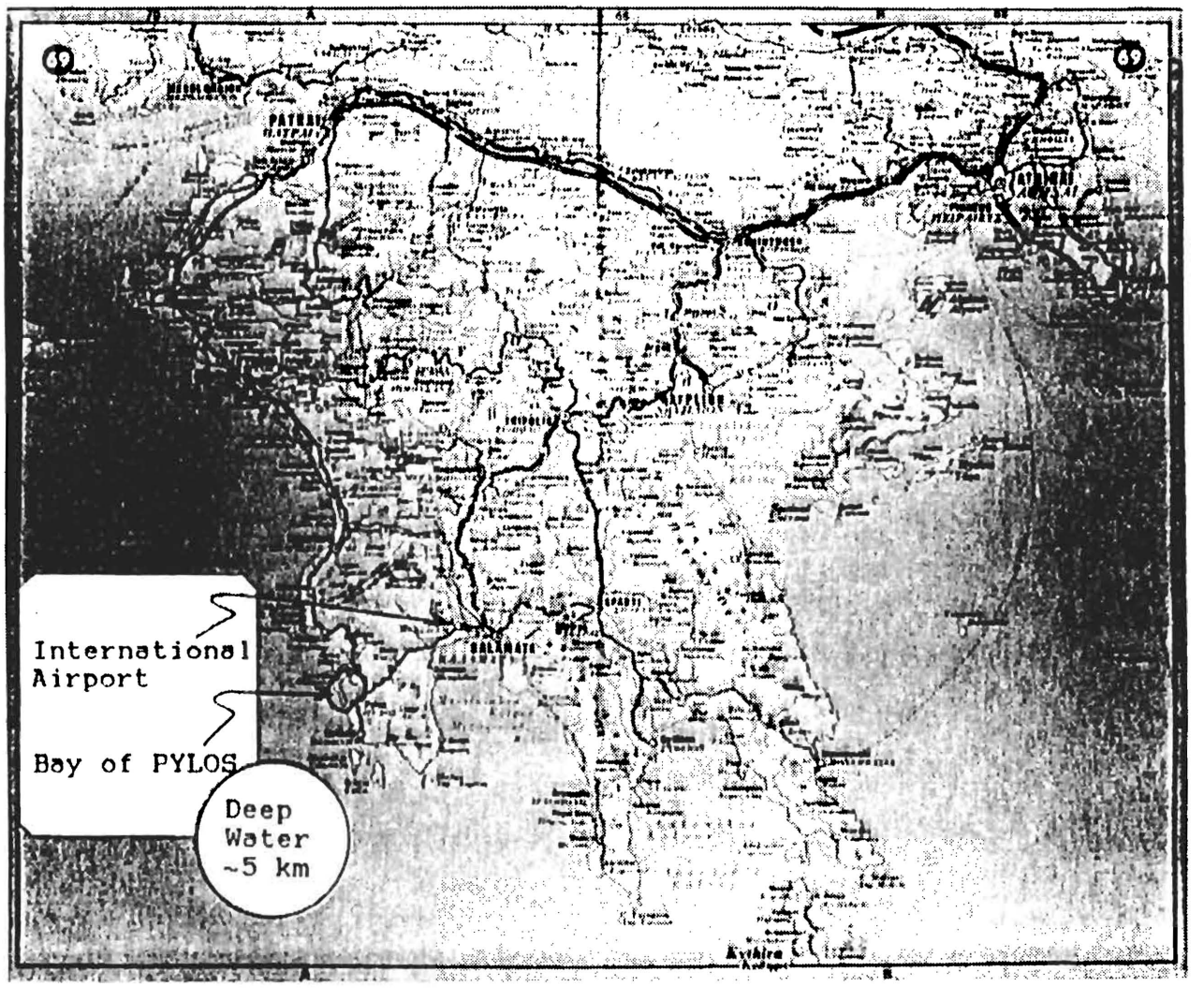
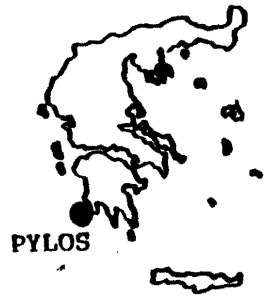


Figure 1

ISOBATHS
CONTOURS OF EQUAL DEPTH

The lighthouse of Sapientza will be the counting room. Then the data will be transmitted to PYLOS by cable or microwave link.



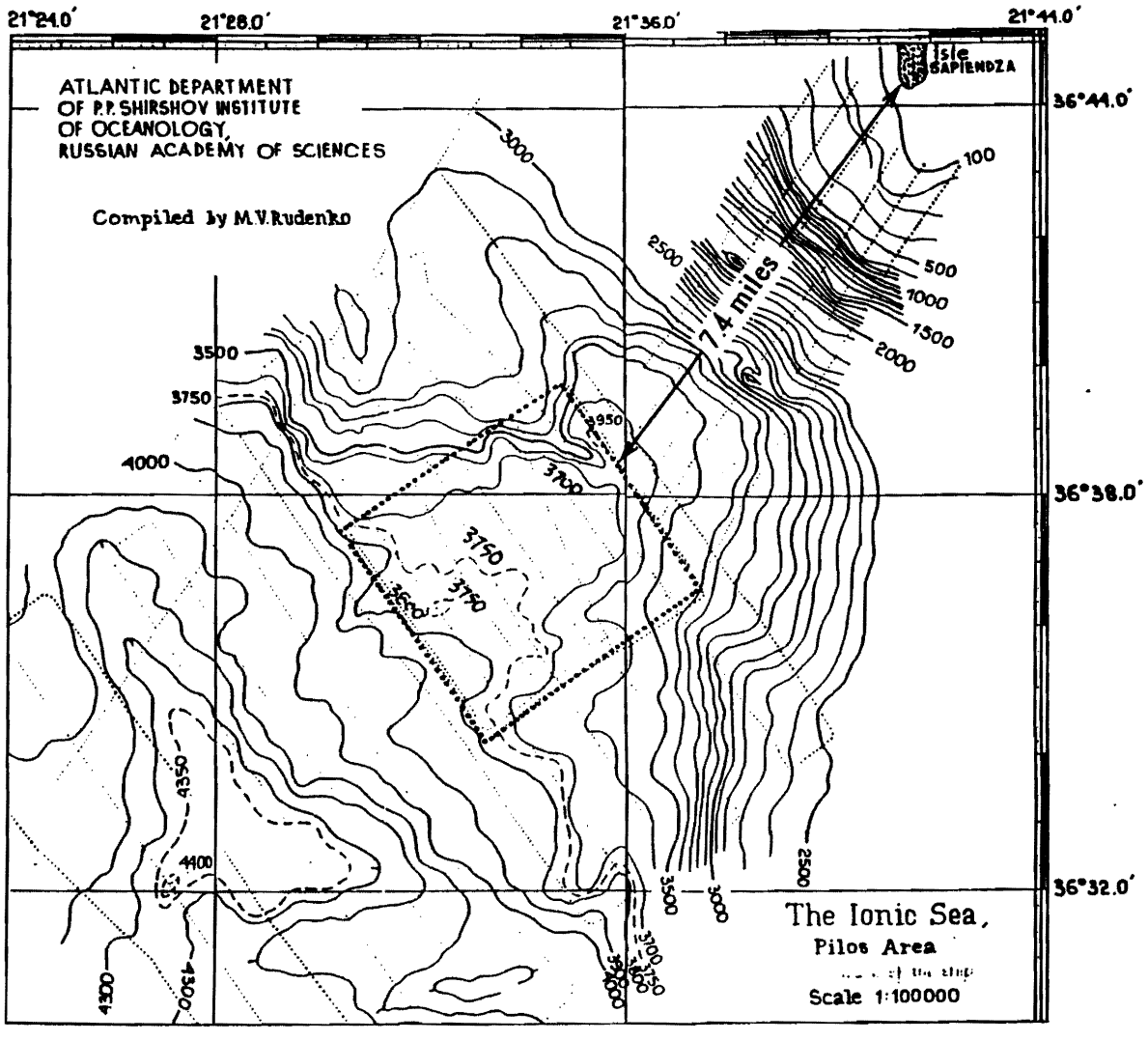


Figure 2

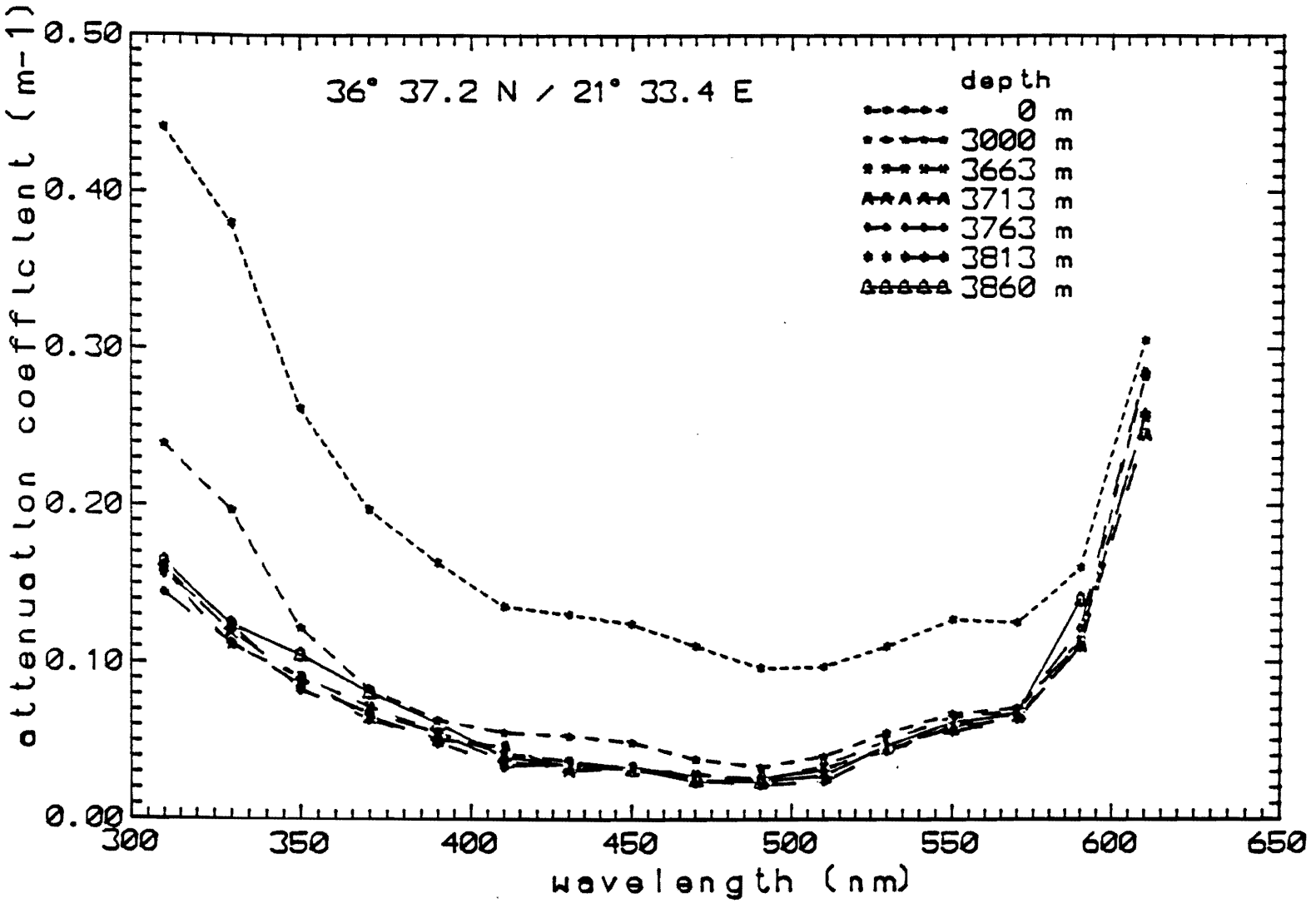

36° 37.2 N / 21° 33.4 E
depth
0 m
3000 m
3663 m
3713 m
3763 m
3813 m
3860 m
attenuation coefficient (m-1)
0.50
0.40
0.30
0.20
0.10
0.00
300
350
400
450
500
550
600
650
wavelength (nm)

Figure 3

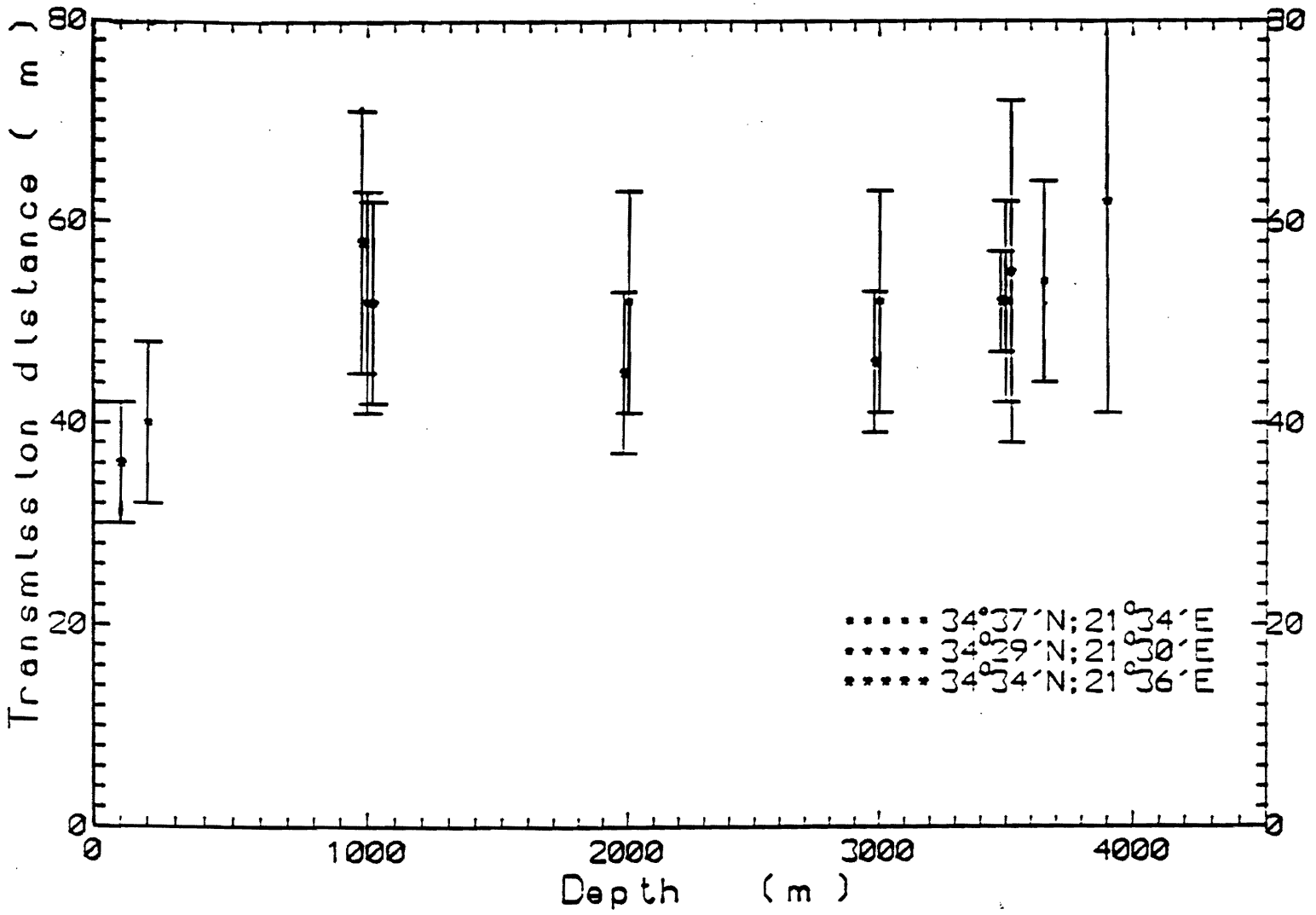


Figure 4 Transmission distance vs depth at three locations near the future NESTOR site

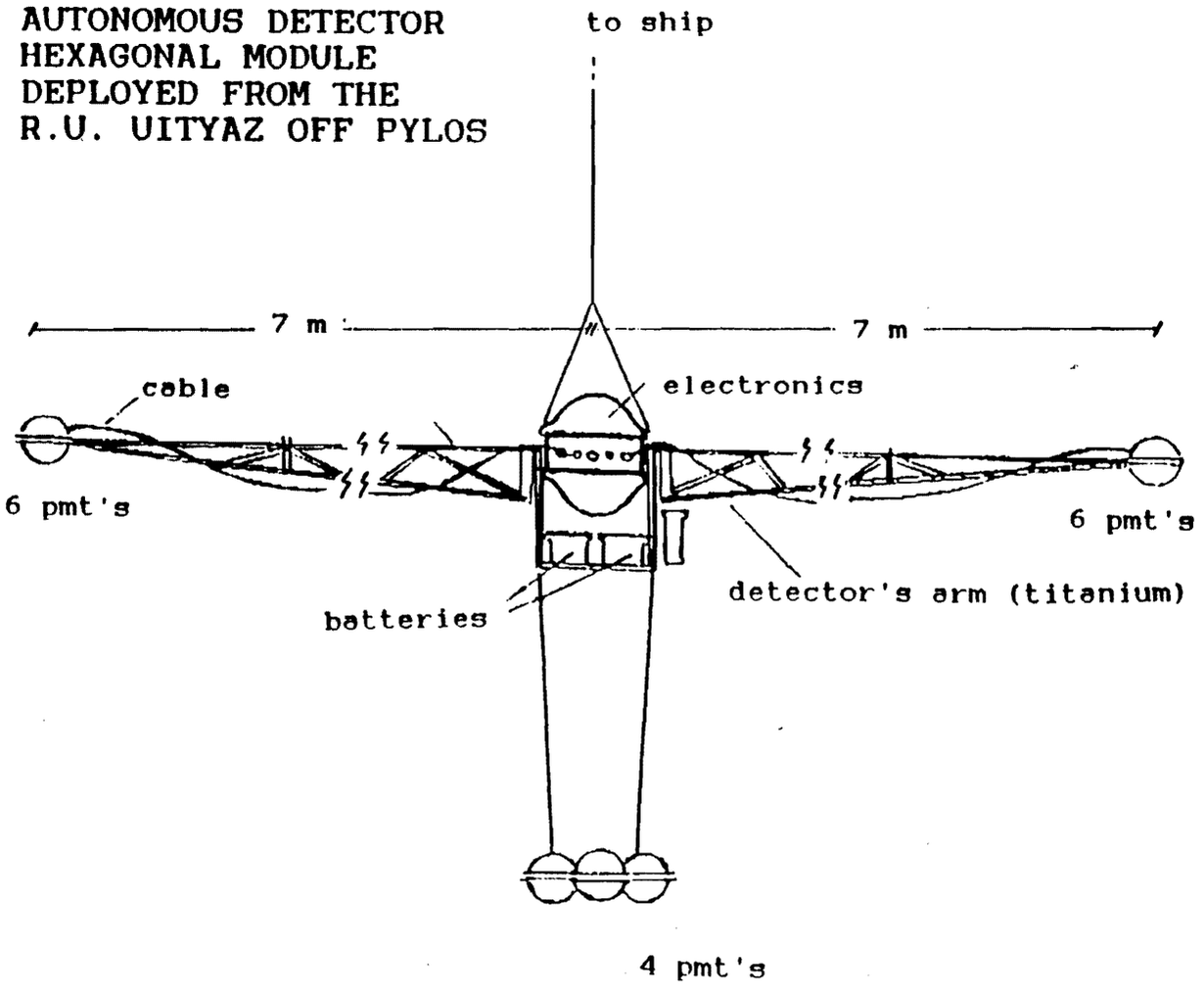

AUTONOMOUS DETECTOR
HEXAGONAL MODULE
DEPLOYED FROM THE
R.U. UITYAZ OFF PYLOS
to ship
7 m
7 m
cable
electronics
6 pmt's
6 pmt's
detector's arm (titanium)
batteries
4 pmt's

Figure 5a

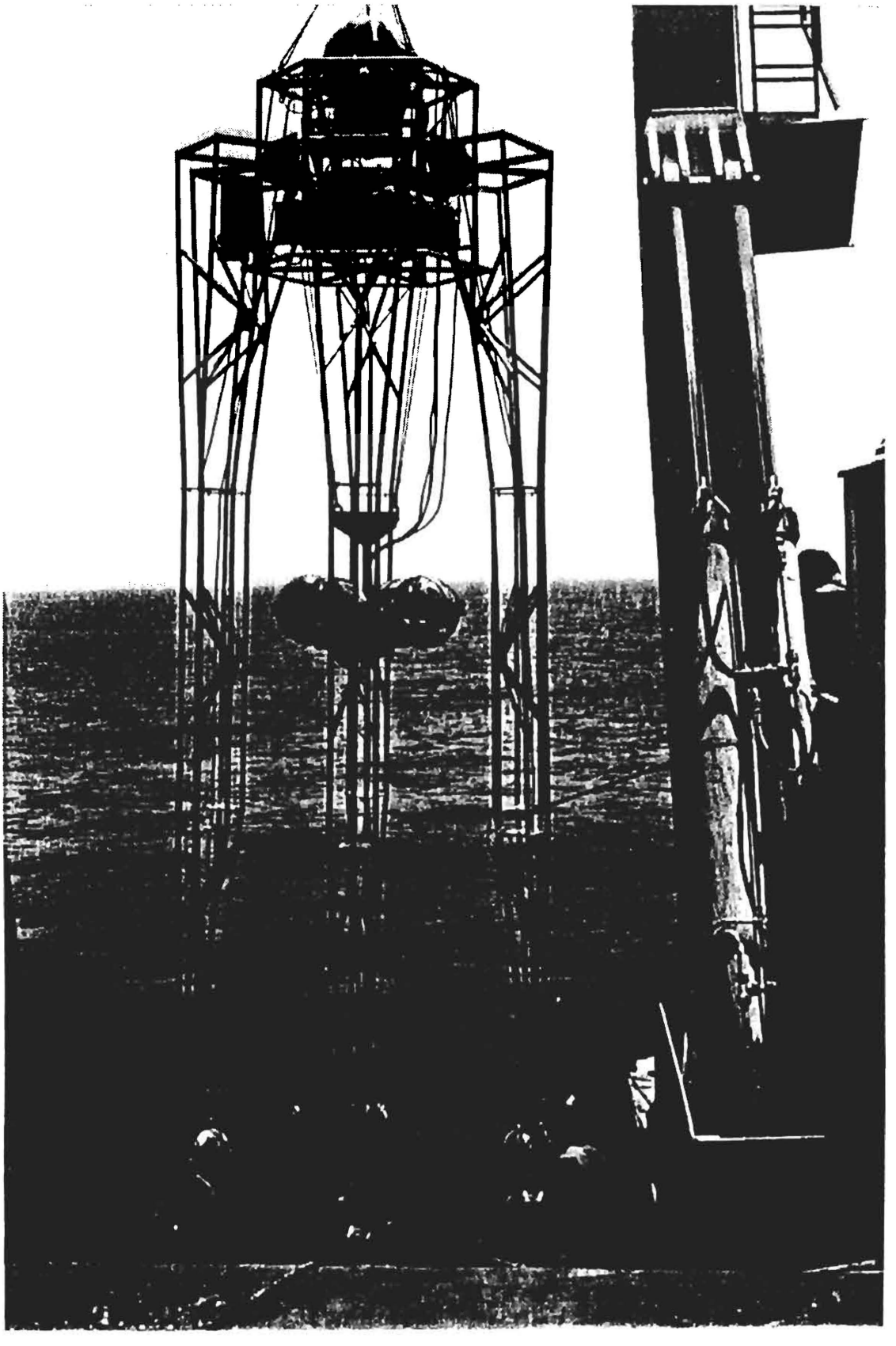


Figure 5b

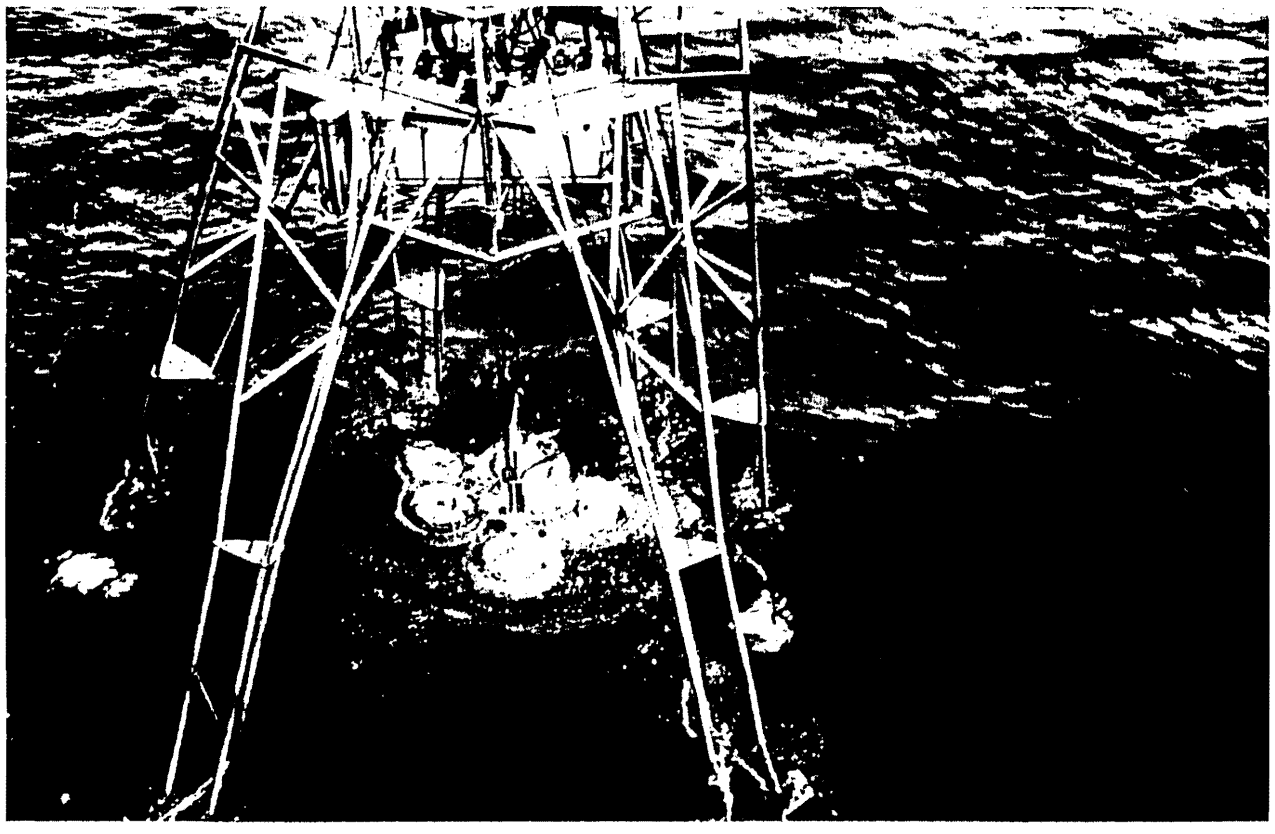


Figure 5c

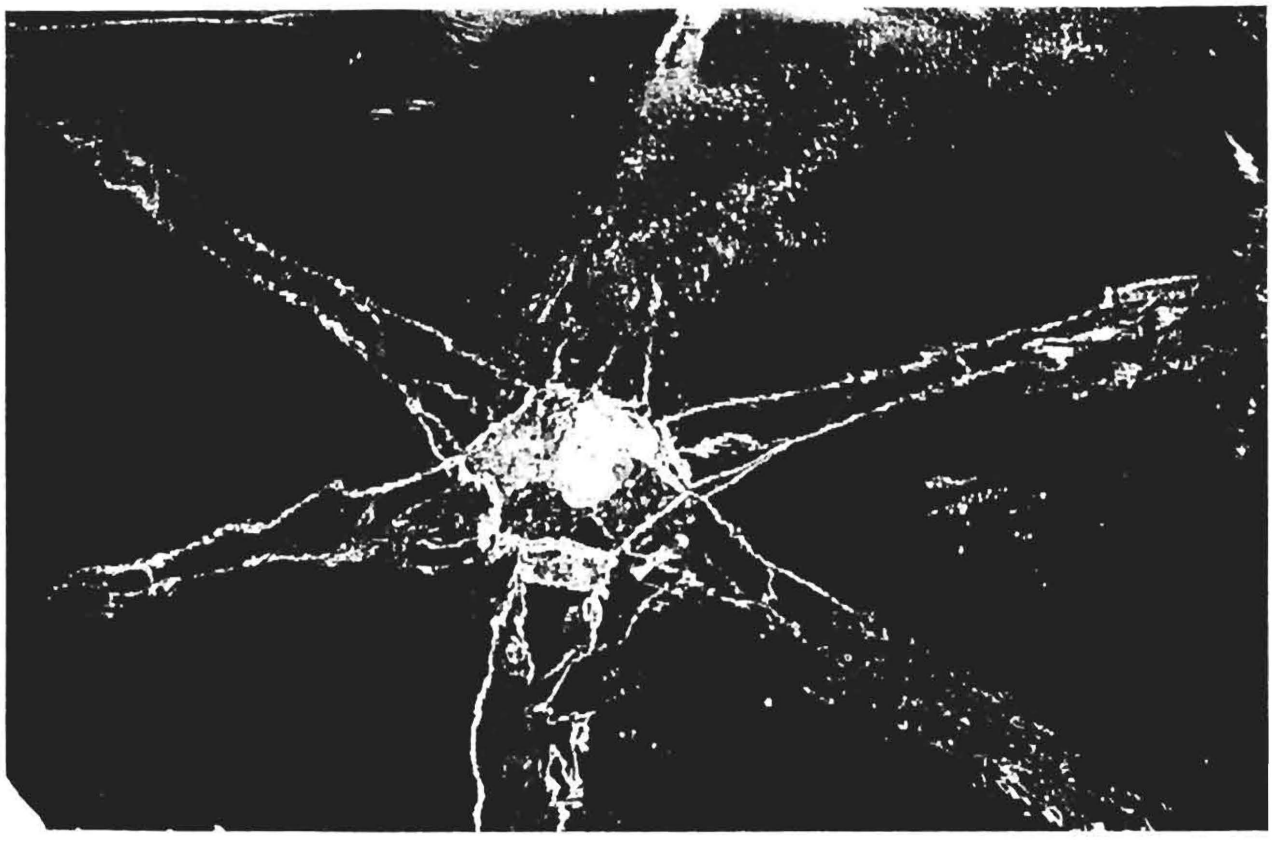


Figure 5d

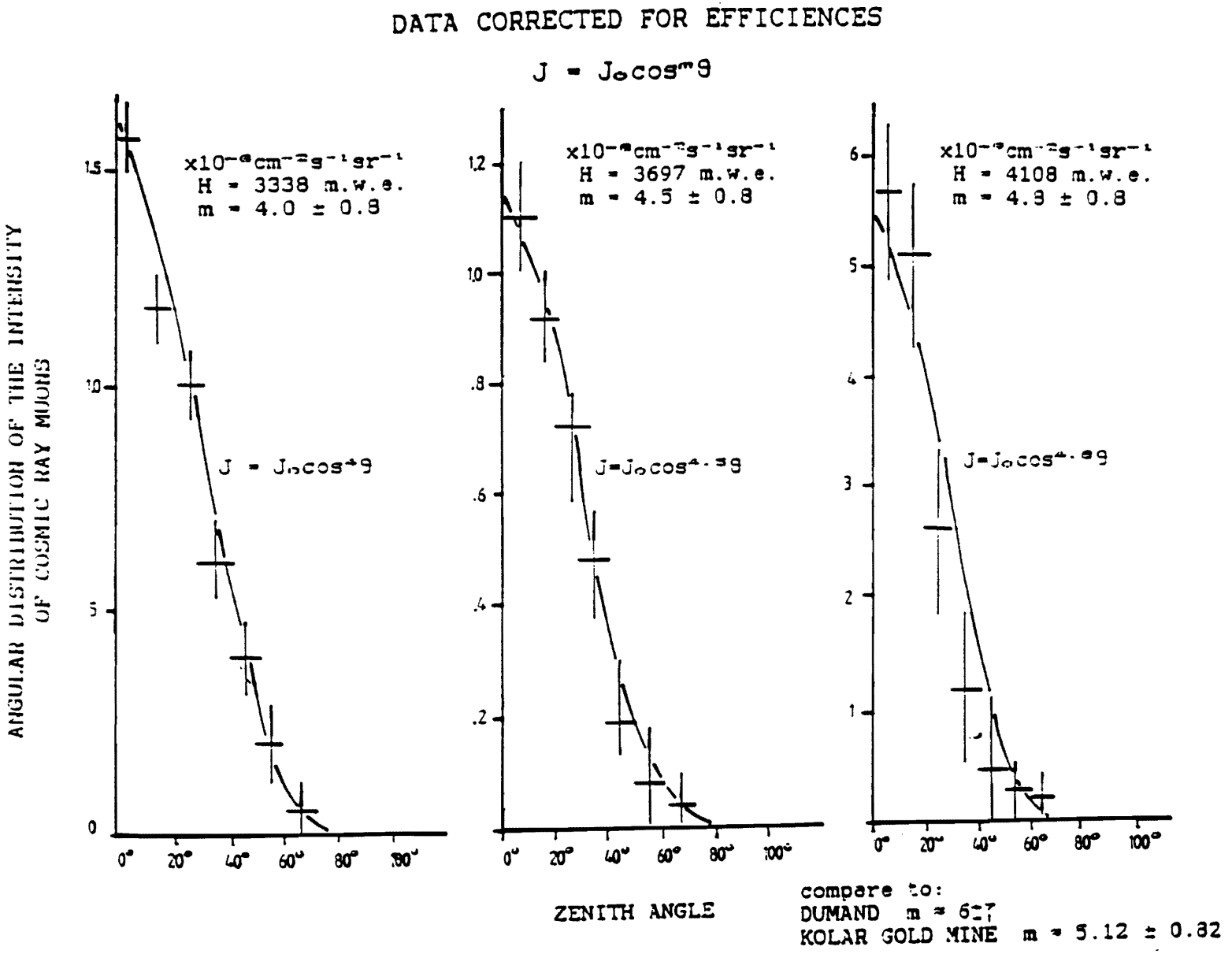

DATA CORRECTED FOR EFFICIENCIES
J = J₀cos^m θ
ANGULAR DISTRIBUTION OF THE INTENSITY OF COSMIC RAY MUONS
x10⁻⁸cm⁻²s⁻¹sr⁻¹
H = 3338 m.w.e.
m = 4.0 ± 0.8
J = J₀cos⁴θ
x10⁻⁸cm⁻²s⁻¹sr⁻¹
H = 3697 m.w.e.
m = 4.5 ± 0.8
J=J₀cos^4.5θ
x10⁻⁸cm⁻²s⁻¹sr⁻¹
H = 4108 m.w.e.
m = 4.8 ± 0.8
J=J₀cos^4.8θ
ZENITH ANGLE
compare to:
DUMAND m = 6±7
KOLAR GOLD MINE m = 5.12 ± 0.82

Figure 6

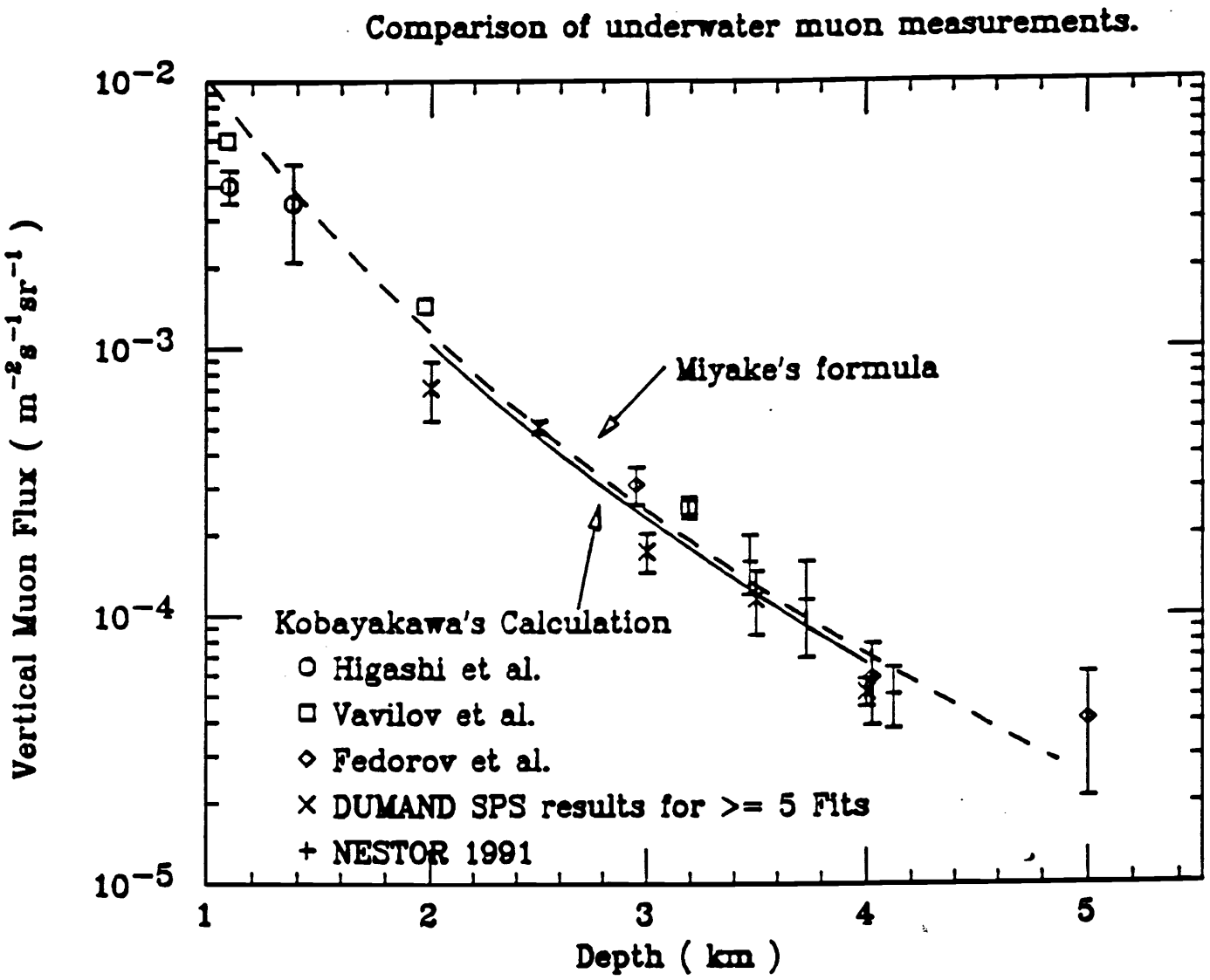

Comparison of underwater muon measurements.
Vertical Muon Flux (m^{-2}s^{-1}sr^{-1})
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
2
3
4
5
Depth (km)
Miyake's formula
Kobayakawa's Calculation
Higashi et al.
Vavilov et al.
Fedorov et al.
DUMAND SPS results for >= 5 Fits
NESTOR 1991

Figure 7

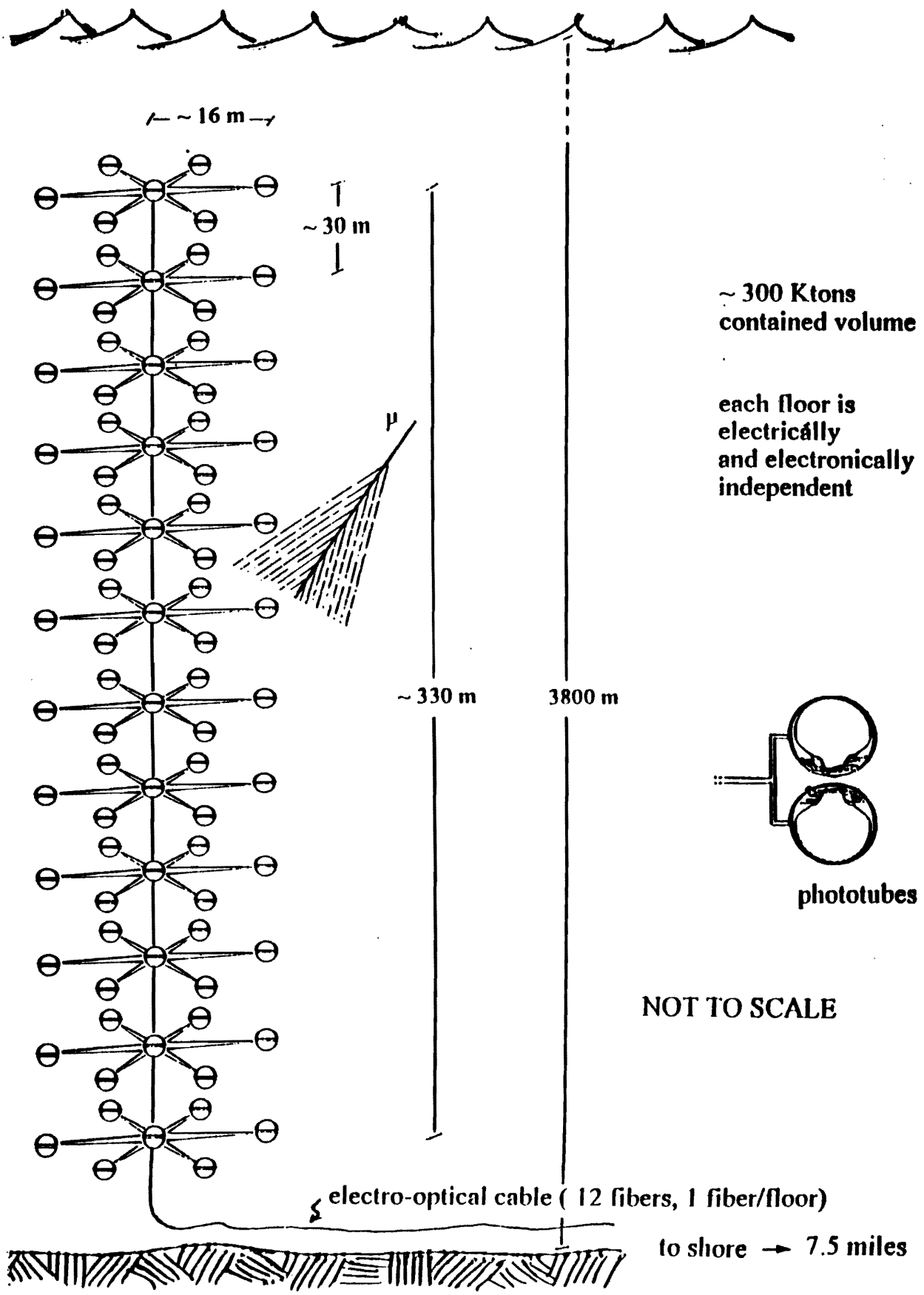

~ 16 m
~ 30 m
μ
~ 330 m
3800 m
~ 300 Ktons
contained volume
each floor is
electrically
and electronically
independent
phototubes
NOT TO SCALE
electro-optical cable (12 fibers, 1 fiber/floor)
to shore → 7.5 miles

Figure 8

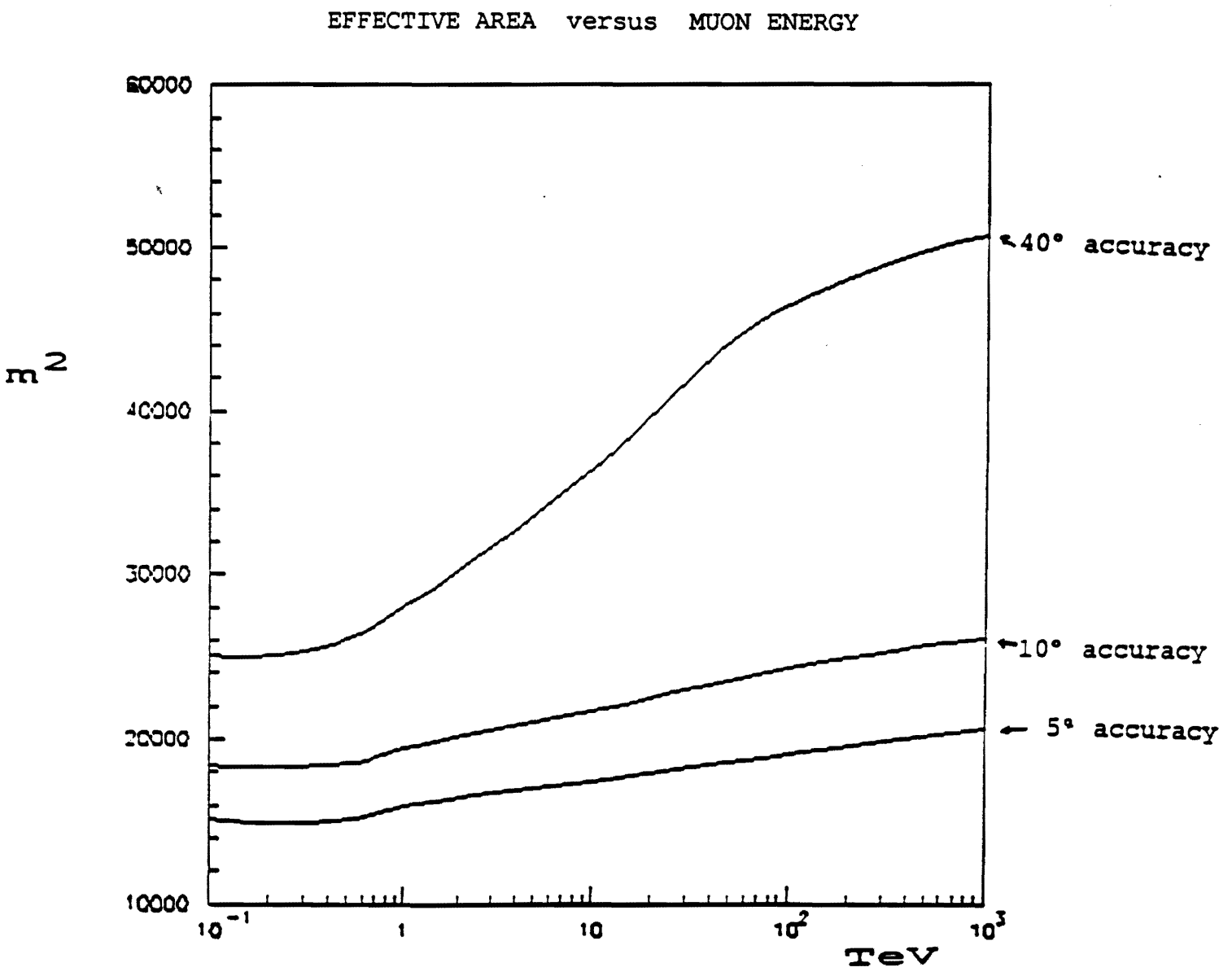
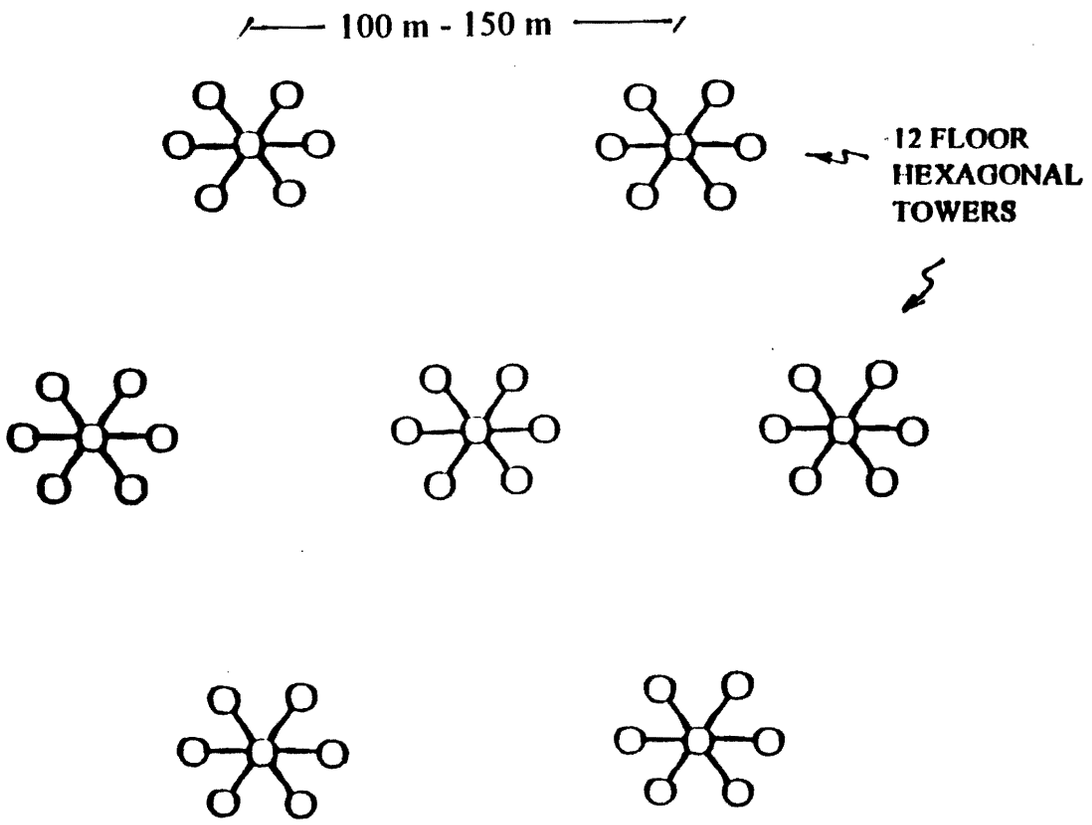

EFFECTIVE AREA versus MUON ENERGY
60000
50000
40000
30000
20000
10000
m2
10-1
1
10
102
103
TeV
40° accuracy
10° accuracy
5° accuracy

Figure 9

FULL NESTOR ARRAY

A HEXAGONAL ASSEMBLY OF 7 TOWERS
VIEW FROM ABOVE

each tower has 12 floors
the towers are mechanically and electrically independent



sensitive area > 100,000 m^2
angular resolution ~ 1°
enclosed volume > 20 megatons
total number of phototubes 1176

THIS CONFIGURATION SHOULD BE BIG ENOUGH TO BEGIN THE FIELD OF HIGH ENERGY NEUTRINO POINT SOURCE ASTRONOMY

Figure 10

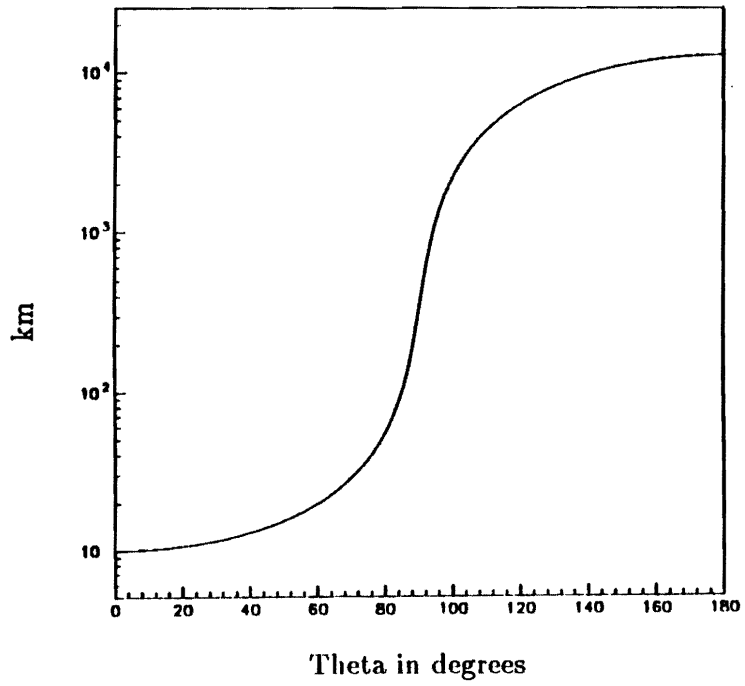


Figure 11: Variation of oscillation length with zenith angle

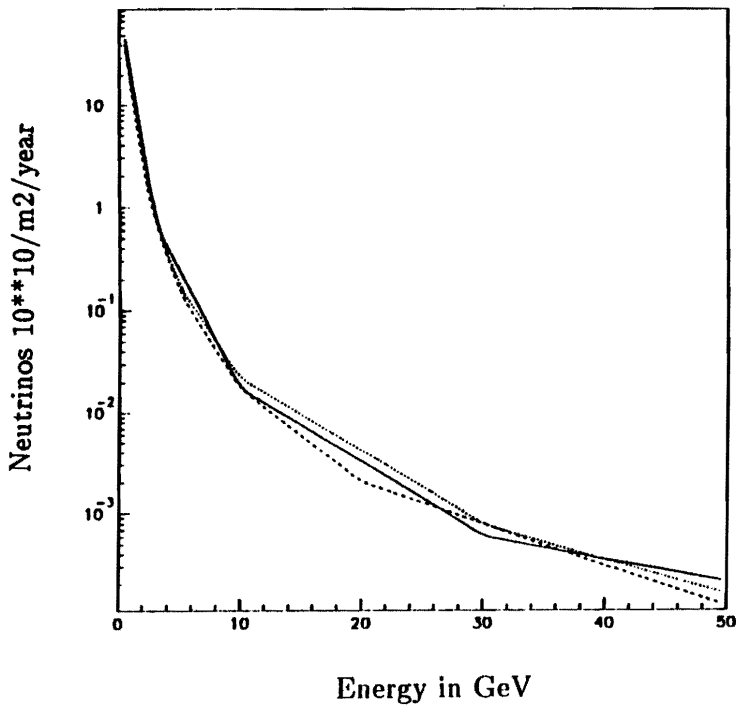


Figure 12: Atmospheric neutrino fluxes, Solid line is from Volkova, Dashed line is Mitsui et al, and Dotted line is Butkevitch et al

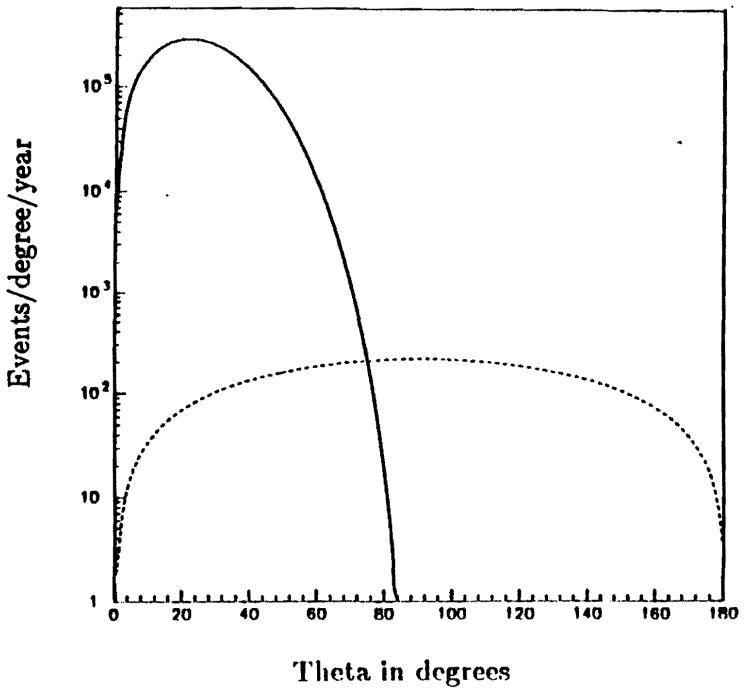


Figure 13: Comparison of downcoming cosmic ray per annus muons with contained atmospheric neutrino events (no efficiency applied)

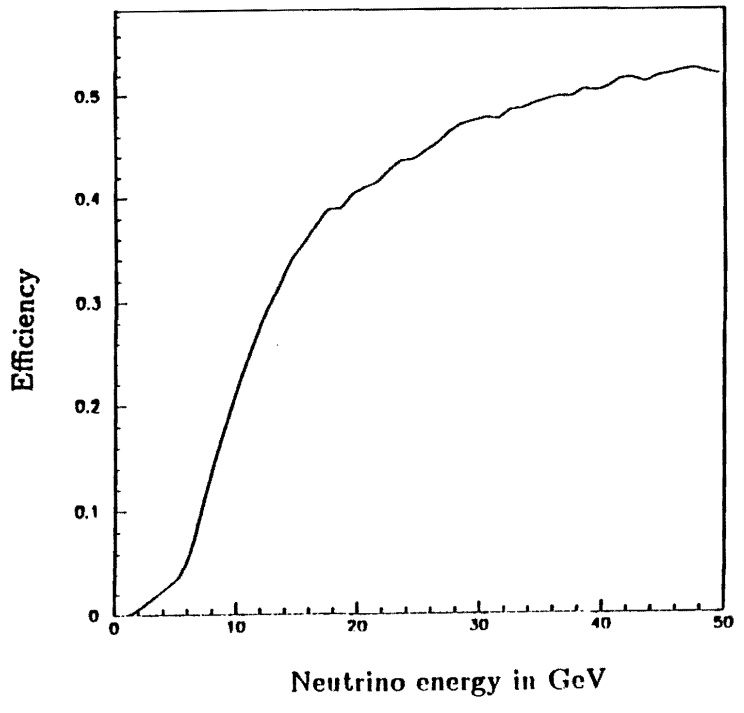


Figure 14: Reconstruction efficiency, for 20 degrees pointing resolution

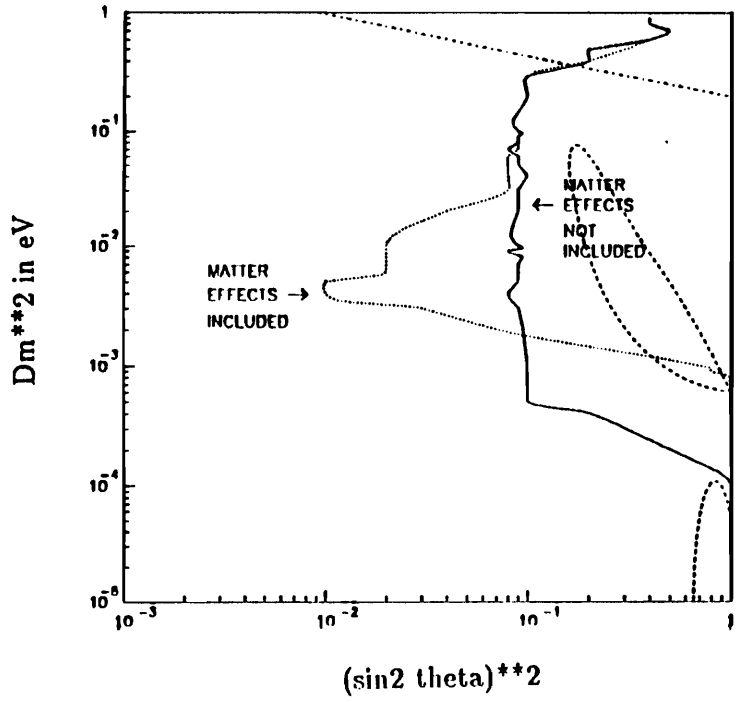


Figure 15: Atmospheric Oscillation limits. The upper straight line is the CHORUS/NOMAD sensitivity. The dotted curves are respectively the KAMIOKA signal and one solution to the solar oscillation

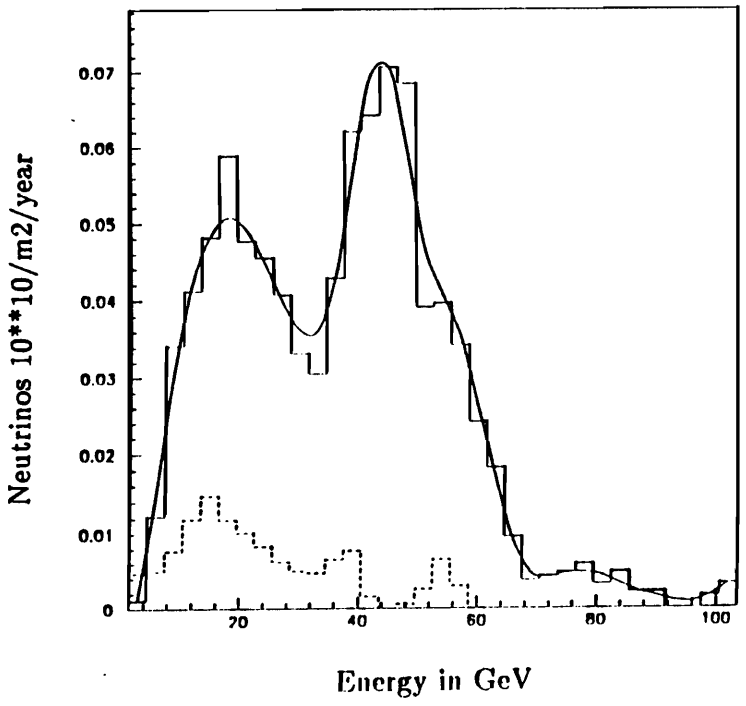


Figure 16: Estimated neutrino fluxes from CERN for two proton beams

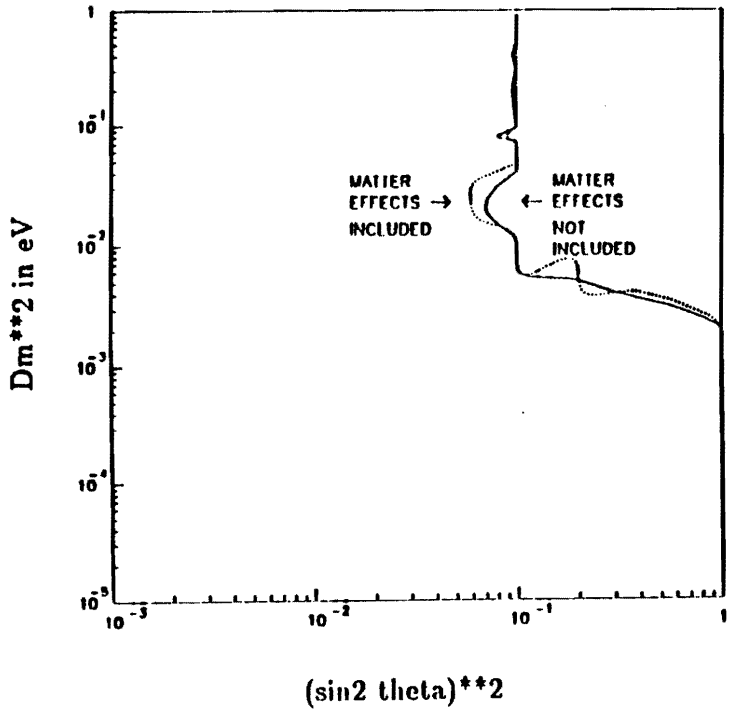


Figure 17: Long Baseline Oscillation ν_μ to ν_e for 160 GeV

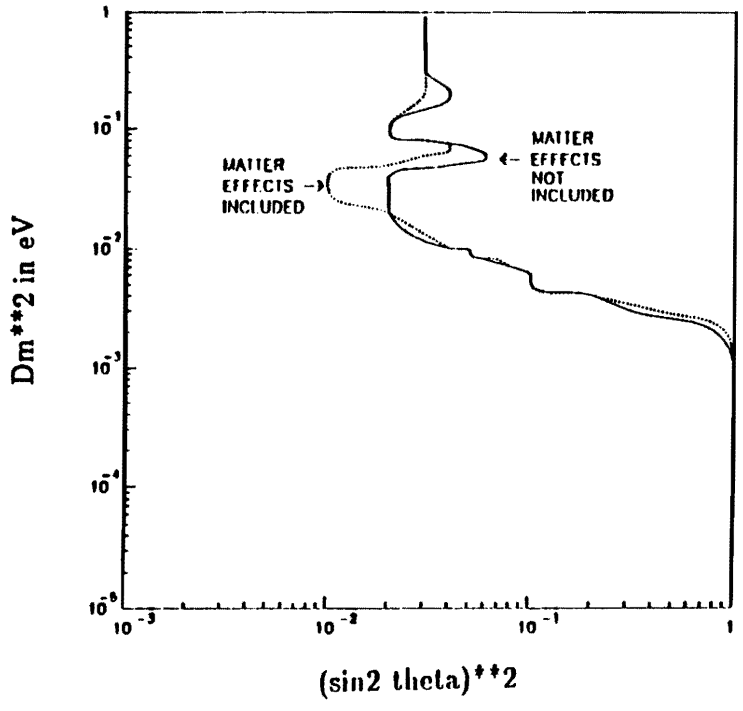


Figure 18: Long Baseline Oscillation ν_μ to ν_e for 450 GeV

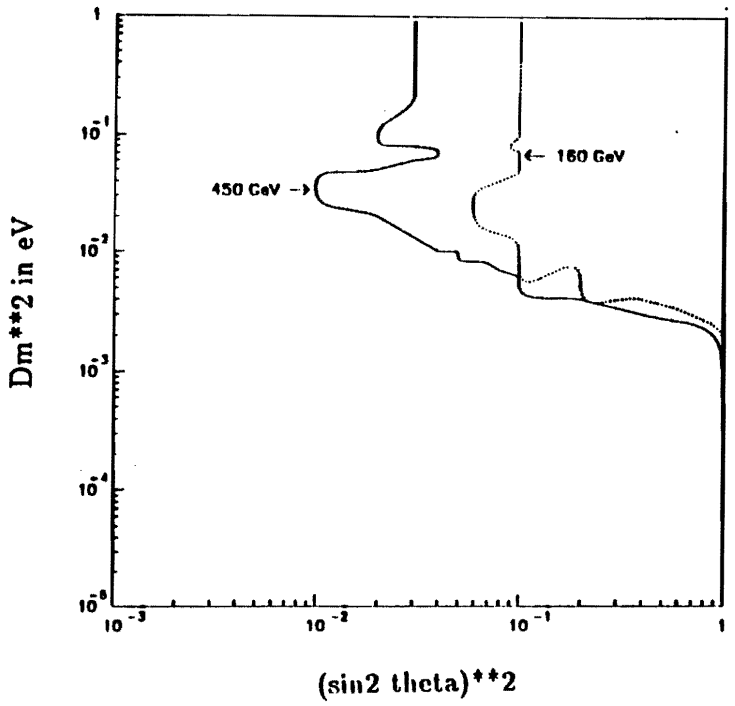


Figure 19: Long Baseline Oscillation ν_μ to ν_e for 160 and 450 GeV

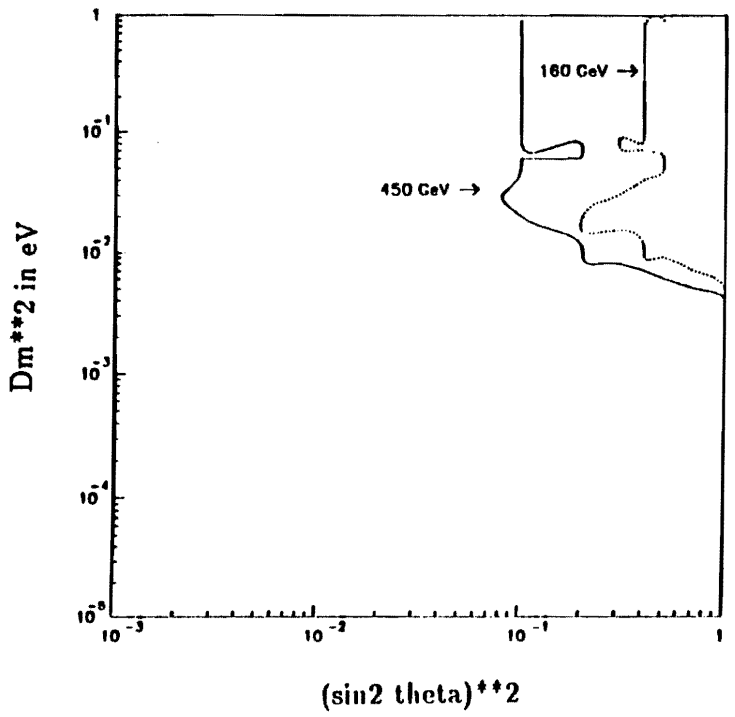


Figure 20: Long Baseline Oscillation ν_μ to ν_τ for 160 and 450 GeV

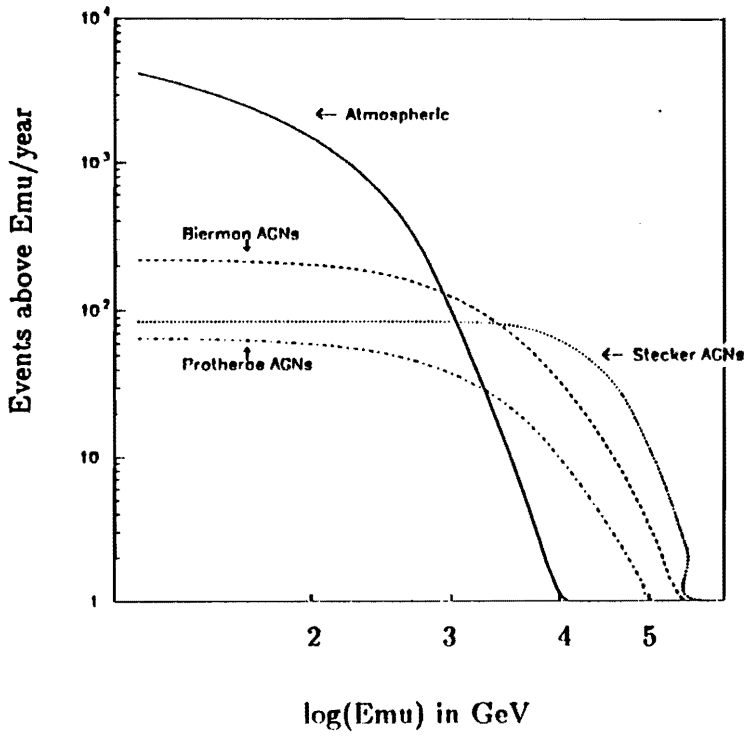


Figure 21: Diffuse AGNs