HDC-10-85

THE CURRENT STATUS OF

D U M A N D

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Invited Lecture Presented at the
1st Symposium on Underground Physics
St. Vincent, Italy, April 25 - 28, 1985

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ABSTRACT

We give a brief description of the scientific aims of the DUMAND project, of the system layout and its capabilities, together with some technical details of the detector modules. Subsequently we present the anticipated project schedule and construction strategy, followed by an account of the present project status.

1. INTRODUCTION.

To most cosmic ray, particle and astrophysicists the name DUMAND, which stands for Deep Underwater Muon and Neutrino Detector, has become more or less familiar in recent years. It is now about ten years that serious thinking and planning began on a deep ocean muon and neutrino detector after years of loose discussions in the sixties and early seventies on what some peoples thought to be science fiction-like brain storming. Evidently an idea as revolutionary as DUMAND required an adequate period of evolution and familiarization even among intuition-rich physicists. Today, DUMAND is probably one of the most thoroughly studied and most carefully planned and prepared experiments.

DUMAND is a completely new concept. It employs the water masses of the ocean simultaneously in many ways: As cosmic ray shield, dark room, absorber, as target for muon and neutrino interactions and as detection medium producing Cerenkov light. In principle, such a detector system is almost freely expandable and allows the construction of a truly giant experiment. It is not confined to the size of an underground cavity and does not need access tunnels or shafts; nor will the interpretation of its data ever be troubled by the uncertainties of the density of the surrounding rock or the complexity of the surface topography, both problems which are typical for most underground experiments.

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However, the central problem with this new concept was that completely new technologies had to be employed in an unusual, for this kind of work more or less unknown and "hostile" environment. Consequently an enormous amount of exploratory and pioneering work had to be done in the course of the detailed feasibility study and system development phase which began early in 1980 and had been completed some time ago.

The major technical problem, of course, was the development of a suitable detector module which met all the requirements. But also the optimization of the overall response of the detector matrix, of its sensitivity, efficiency and track reconstruction capability as well as the questions related to background presented serious problems and required great efforts.

This work together with extensive theoretical studies lead to the present scope of scientific activities for DUMAND, as discussed below, and to today's system configuration. It also was the basis for the 1982 DUMAND proposal (1) which had been submitted by the American collaborators to the U.S. Department of Energy in April of 1983 and, subsequently, by the foreign members of the collaboration to their respective funding agencies.

In the following we will present a brief overview of the project without giving a detailed account of the scientific motivations for carrying out the experiment. Subsequently we will summarize the project schedule and give a brief account of the current status.

2. BRIEF REVIEW OF THE DUMAND PROJECT

2.1 The DUMAND Scenario and its Phenomenology.

The DUMAND detector system is a giant three-dimensional matrix consisting of 756 highly sophisticated optical detector modules that are distributed within a parallelepiped measuring 250 • 250 • 500 meters, planned to be submerged and operated at a depth of almost 5 km in the Pacific ocean, approximately 30 km off-shore, west of Keahole Point on the "Big Island" of Hawaii. Figure 1 is an artist's view of the array after installation on the sea floor.

The system will be capable of detecting penetrating cosmic rays, in particular ULTRA HIGH ENERGY MUONS originating from even more energetic interactions of primary cosmic rays at the top of the atmosphere with nuclei of air constituents, and VERY HIGH ENERGY MUON NEUTRINOS and their antiparticles of TERRESTRIAL and EXTRATERRESTRIAL ORIGIN that interact within the detector or its immediate vicinity, producing a detectable and reconstructable muon trajectory within the detector matrix. In either case detection is based on Cerenkov radiation produced by the relativistic muons in the ocean. The phenomenology of the kind of events that are expected to occur and will be studied is illustrated in figure 2.

2.2 Basic Scientific Goals.

The basic scientific goals of the DUMAND project are threefold:

i) To search for and, hopefully, find sources of energetic muon neutrinos and antineutrinos in astrophysical objects and to determine the neutrino spectrum, in order to identify locations of high energy hadronic processes in space and to learn more about possible acceleration mechanisms of cosmic rays as well as other astrophysical aspects.

ii) To study the properties of cosmic ray muons of energy ≥ 3 TeV, their production, propagation, interaction and spectral properties as well as their multiplicity (multi muons), decoherence and lateral distribution, in order to deduce spectral features, interaction properties, chemical composition, isotropy and other aspects of the parent primary cosmic ray particles and their interaction in the atmosphere in the energy range from about 10 TeV to over 10^5 TeV, which covers the region of changing primary spectral index. There will also be a search for events of high transverse momenta.

iii) To investigate neutrino interactions at energies far beyond the range of present and planned accelerators and to search for new effects, including the production of heavy flavor particles.

It is evident that DUMAND and its support system make it possible to carry out a variety of research projects in other fields such as oceanography, ocean biology, geophysics, environmental sciences, climatology as well as deep ocean technology, provided that they do not interfere with the top priority objectives of DUMAND.

Figure 3 illustrates the energy scenario of cosmic ray physics and astrophysics between 1 and 10^{12} GeV. The central line shows the energy scale in GeV. The double-lined arrow across the figure on top pointing to the right represents the range of the primary cosmic ray spectrum. A similar parallel double line below which tapers off and ends towards the center of the figure represents symbolically our diminishing knowledge of the chemical composition of the primary radiation with increasing energy. The large field labelled DUMAND - μ identifies the energy range where cosmic ray muon physics and related fields will be studied with DUMAND. The smaller field to the left below which shows the DUMAND symbol with the Greek letter ν indicates the energy region where most of the neutrino detection and work will take place.

For comparison we have also marked the operating energies of some of the major accelerators of the past and present. Below the energy scale we show cosmic ray and astrophysical landmarks for orientation.

2.3 System Layout.

The array layout is illustrated in figure 4 with the major dimensions indicated. The detector matrix consists of 6 by 6 or a total of 36 so-called strings which have orthogonal separations of 50 meters between neighbors. Each string holds 21 optical detector modules, labelled DM, that have a separation of 25 meters. On top, at the bottom and in the middle of each string will be an instrumentation or environmental module, labelled EM. They are used to record all significant environmental parameters and to house sonar devices (hydrophones, pingers) for accurate determination of the string positions, needed for event reconstruction. These modules may also hold small additional experiments from other fields that may not be part of DUMAND itself.

To avoid problems with bioluminescent animals on the sea floor or murky water for extended periods after deployment due to stirring up silt and mud, the matrix will be installed with its bottom plane of modules located 150 meters above the sea floor.

A so-called string bottom controller (SBC) at the end of each string on the sea floor handles the data and command flow from the modules via transceiver to shore, and vice versa. A fast optical data link will be used between modules, SBC and transceiver. A different ultra fast optical link will be used between each plane of the detector matrix (six strings) and the shore station. Consequently only six special electro - optic cables will be needed to operate all of DUMAND, including the individual power links for each detector plane. Each module can be addressed and controlled individually by a slow command link from shore.

2.4 System Capabilities and Expected Counting Rates.

DUMAND will have an enclosed mass of 33 megatons which is 3000 times more than that of the largest now existing underground detector. Its effective mass for detecting neutrinos of energy $\geq$ 2 TeV is nearly 0.5 gigatons which represents a volume of 0.5 km^3. This includes events that originate outside the array and produce a reconstructable muon trajectory in the array. The angular resolution varies from 15 to 45 milliradians, depending on the angle of incidence.

The minimum detectable flux for extraterrestrial muon neutrinos of energy $\geq$ 1 TeV originating from discrete sources, defined as a 4.5 σ effect over the general cosmic ray induced neutrino background, will be $2 \cdot 10^{-10}$ cm^{-2} sec^{-1}. This value is based on the assumption that the integral neutrino spectrum has a slope of -1.5. The dependence of the minimum detectable flux as defined above on neutrino energy and spectral slope is shown in figure 5. The rate of atmospheric muon neutrino induced events of energy $\geq$ 1 TeV is estimated at about 10^4 per year. The yearly counting rate for cosmic ray muons of energy $\geq$ 1 TeV at the detector level is expected to be about 10^7 for singles; it will be about a factor of 40 lower for doubles and is expected to be about $3 \cdot 10^3$ or more for groups of five simultaneous muons.

The directional response of DUMAND in galactic coordinates with respect to cosmic ray muons and neutrinos is shown in figures 6 and 7, respectively. The muon distribution looks similar to that of an air shower array, whereas the neutrino distribution is complete but not uniform, i. e., it covers the entire celestial sphere but not at all times. This is because of the event rejection near the zenith, imposed by the cosmic ray background, obscuring temporarily those areas of the sky for neutrino observations that record cosmic ray muons, as shown in figure 6.

3. CURRENT PROJECT STATUS

3.1 The International DUMAND Collaboration and its Organization.

DUMAND has been planned and will be constructed within the frame of the International DUMAND Collaboration which includes scientists from the following institutions (The names of the respective representatives that form the "International DUMAND Council" are listed in parenthesis):

University of Hawaii (V. Peterson, V. Stenger, J. Learned)
University of California, Irvine (W. Kropp)
California Institute of Technology (B. Barish)
Purdue University (J. Gaidos)
University of Wisconsin (R. March)
Vanderbilt University (C. Roos)
University of Tokyo (T. Kitamura)
University of Bern (P. Grieder)

Coordination of the project is being directed by the Hawaii DUMAND Center (HDC), located at the University of Hawaii at Manoa under the leadership of Prof. V. Z. Peterson.

3.2 Project Schedule.

The feasibility study for DUMAND had been completed towards the end of 1982 together with the proposal for the full project. Simultaneously much of the development and design work for the detector modules has been well under way at that time and is now completed. The entire project has been subdivided into five stages as listed below. The estimated target dates are given in parenthesis.

Stage 1). Construction of a short prototype string (SPS) with 7 modules, including one string bottom controller (SBC) for data handling and one environmental module (EM) for recording environmental parameters, to test the final design. Initially, the SPS will be operated at variable depth from a special ship, the SSP Kaimalino, a stable, semi submersible platform. Later on it will be placed on the sea floor at the final site, linked to shore and operated for a period of some months to study system performance and environmental effects, including sedimentation and biofouling (1985).

Stage 2). Construction and deployment at the final DUMAND site of a full prototype string (FPS), consisting of 21 detector modules and 3 environmental modules. (Later on provisions will be made that some of the environmental modules can house small ocean and earth science experiments). Some of the environmental modules will house pingers to locate the string, and later on the array and its modules accurately by means of sonar techniques. The string will be linked to shore and operated during the construction phase of stage 3 (1986).

Stage 3). Construction and deployment of the first plane of detectors, consisting of 6 full strings of the type used for the FPS of stage 2, at the final site. The plane will be linked to shore and put into full operation (1986/87).

Stage 4). Construction, deployment and linking to shore of the remaining 5 detector planes (1987).

Stage 5). Running-in and operation of the full array (1988).

All five stages listed above will be used for scientific work and even the early stages are expected to yield valuable new data. The transition from one stage to the next is expected to proceed more and more continuous as the project advances. At present stage 1 is funded by American and Japanese agencies. It must be completed successfully to obtain the go-ahead for stage 2.

3.3 Current Funding Situation.

As mentioned above, the collaboration has prepared a common proposal (1982 DUMAND proposal (1)) which all participants have submitted to their respective funding agencies. In May 1983 the project had been recommended by the scientific review panel of the U.S. Department of Energy (D.O.E.) and subsequently by Japanese authorities. Stage one of the project is now being funded by D.O.E., N.S.F and Japanese agencies. A proposal submitted by the author to the Swiss National Science Foundation, which has supported his contributions to the feasibility study of the DUMAND project since 1980 is pending.

3.4 Existing Hardware.

Development of the detector module has been completed some time ago. A cross sectional view of it is given in figure 8, which shows the 16 inch phototube with the electronics and optronics boards around the tube neck, inside a pressure resistant Benthos glass housing. Note that the DUMAND phototube does not have the usual metallization on its backside. It can accept light from almost all directions. The photocathode is connected by means of a few very narrow metal coatings to the tube base to avoid light absorption.

A number of detector modules are now being assembled for the ship tethered test of the short prototype string, mentioned above, later on this summer at the future DUMAND site and depth.

Furthermore, an instrumentation module, two optical calibration modules with their own light source to check and calibrate the detector modules and to carry out absorption measurements of the surrounding water, power supplies and the optical data link for the SPS tests this summer approach completion.

3.5 The DUMAND Site, Environmental Problems and Background.

The site where the detector matrix will be installed has been surveied several times in the past jointly by scientists from different institutions, including the Hawaii Institute of Geophysics, Scripps Institute of Oceanography and members of the DUMAND collaboration. As a result most of the significant ocean parameters are known around a depth of 4500 meters where the array will be installed, such as the deep ocean currents ($\lesssim$ 5 cm sec^{-1}), the water temperature around (+1.5 °C) and the optical attenuation in the visible range (approx. 30 to 50 meters). Composition and topography of the sea floor are known to some extent. However, some more surveying will be needed prior to the deployment of the final matrix. Figure 9 shows the location of the DUMAND site on the map of the Hawaiian islands.

The optical background problem has also been investigated carefully. It is chiefly due to bioluminescence and Cerenkov light from potassium 40 radioactivity. The latter causes a counting rate of approximately 10^5 counts per second at the one photo electron level in a submerged module, which is no problem to handle.

Bioluminescence is another problem. The high light levels observed during ship tethered measurements which showed typical bioluminescence characteristics were mostly due to stimulated bioluminescence. This was caused primarily by the ship's motion that was transmitted via suspension cable to the detector module which stirred the surrounding water masses. Subsequently the local turbulence caused the bacteria in the water to release light flashes, thus producing the high background.

New measurements which included ship as well as bottom tethered detectors have shown that the latter records a bioluminescence level which is at least one order of magnitude or more lower than a ship tethered detector. Thus, the bioluminescence level seen by a bottom tethered detector working under conditions similar to those of the final DUMAND array is of the same order as that caused by potassium 40.

Sedimentation is not expected to be a problem, it is known to be very small in this area. The frequent volcanic eruptions do not cause dust fall-out, only very local lava flows that cannot interfere with the array.

Biofouling is another topic that could cause problems. However, it is known from studies carried out in other parts of the world that biofouling seems to cease at depth inferior to 800 meters (2).

3.6 Short Prototype String Test and Operation.

The layout of the short prototype string (SPS) is illustrated in figure 10. It consists of 7 optical detector modules (DM), one environmental module (EM), two calibration modules (CM) and a power and control unit (PCU). The purpose of the SPS is to give the prototype system a thorough "in situo" engineering test. This implies in particular testing the performance of the following components and subsystems: The optical sensors, the data handling and command software of the module processor, the electro - optical data link including the control, communication and power systems, module calibration, and all aspects of the environmental module. Furthermore it is intended to demonstrate muon counting in the deep ocean, check background and determine a number of environmental parameters.

The separation of the modules is 5 meters as compared to the 25 meters in the final array. This much shorter module separation was chosen for a number of reasons. In particular to subtend a larger solid angle for muon detection and to facilitate module calibration and water transparency measurements.

For the ship tethered tests the SPS will be suspended from a special ship, a so-called semi submersible or stable platform. This will greatly reduce the hazards at sea to the equipment and simplify operations during deployment and while carrying out the measurements. It will also strongly reduce stimulated bioluminescence background, as mentioned above.

ACKNOWLEDGEMENTS.

The author is grateful to his colleagues of the DUMAND collaboration for supplying advanced information and supporting his efforts for this presentation. He is indebted to the Swiss National Science Foundation for supporting part of his work.

REFERENCES.

1) The DUMAND Collaboration, 1982 DUMAND Proposal, University of Hawaii at Manoa, Honolulu, HI., U.S.A. (1982).

2) J. Piccard, private communication.

Figure 1: DUMAND site with array implanted. The figure shows the location of the array on the sea floor, the shore laboratory at Keahole Point on the "Big Island" together with the interconnecting electrical power and data cables. The latter consist of glass fibers. The retrieval lines on the right of the array serve to recover parts or all of the array in case of a major failure.

Figure 2: Muon and neutrino phenomenology. Shown are sources of terrestrial (atmospheric) (1) and extraterrestrial high energy neutrinos (2), (3), and of muons (5). Neutrinos of origin (1) produce an omnidirectional background in DUMAND (4); (2) and (3) show up as point and diffuse sources, respectively. Neutrinos from all directions are detectable (4), atmospheric muons (5) only within 70° of the zenith. DUMAND responds to muon and not electron neutrinos.

Figure 3: DUMAND energy scenario. The figure shows the range of the established cosmic ray energy spectrum. The primary composition is known with diminishing accuracy out to about 10^5 GeV. The field marked DUMAND μ represents the region over which the array will record mostly single and multiple cosmic ray muons; the field marked with the DUMAND symbol and ν identifies the energy region where the neutrino work will be carried out. The array's peak sensitivity for extraterrestrial neutrinos centers around 1 TeV. Cosmic ray and astrophysical landmarks are indicated below the energy scale.

Figure 4: The DUMAND array. Shown is the three-dimensional matrix with its 6•6•21 (756) Cerenkov detector modules (DM), the 108 environmental modules (EM) (36 each on top, at the lower end of the array and one horizontal plane in the center) that record all of the relevant environmental parameters and serve to located the position of the detector modules accurately using sonar techniques. Also shown are the string bottom controllers (SBC) at the end of each string on the sea floor. The latter are special custom made computers for data and command handling and transmission.

Figure 5: Minimum detectable flux (MDF) for both discrete (solid curves) and diffuse (dashed curves) sources of extraterrestrial muon neutrinos as a function of a) threshold energy E_t and b) integral spectral index γ. For the diffuse source a region of 20° by 70° was assumed. In b) the value of E_t is the optimum in each case.

Figure 6: The DUMAND cosmic ray response. Shown is the distribution in galactic coordinates of the source directions of 1000 randomly generated cosmic ray events of energy 10^8 GeV. Such events can be seen only within 70° of the zenith.

Figure 7: The DUMAND neutrino response. Shown is the distribution in galactic coordinates of 1000 randomly simulated atmospheric neutrino events. The distribution is complete but not uniform because of the temporary obscuration of areas near the zenith by cosmic ray muons.

Figure 8: Cross sectional view of detector module. Shown is the photomultiplier with its photocathode coating, multiplier system and socket, mounted inside the 17 inch Benthos glass pressure housing. The printboards which hold power converter, high voltage supply, discriminator, electro-optical signal converter, modem, a/d and d/a converters as well as processor and memory are placed around the tube neck.

Figure 9: The Hawaiian islands. The DUMAND site is located about 30 km off-shore, west of Keahole Point on the "Big Island", as indicated. The Hawaii DUMAND Center located at the University of Hawaii at Manoa in Honolulu on Oahu is also shown.

Figure 10: The short prototype string (SPS) with its detector modules (DM), two calibration modules (CM) with L the light source and S the scatterer, an environmental module (EM) and the power and control unit (PCU). Command and data handling hard and software permit full flexibility for individual and joint operation of all subsystems.

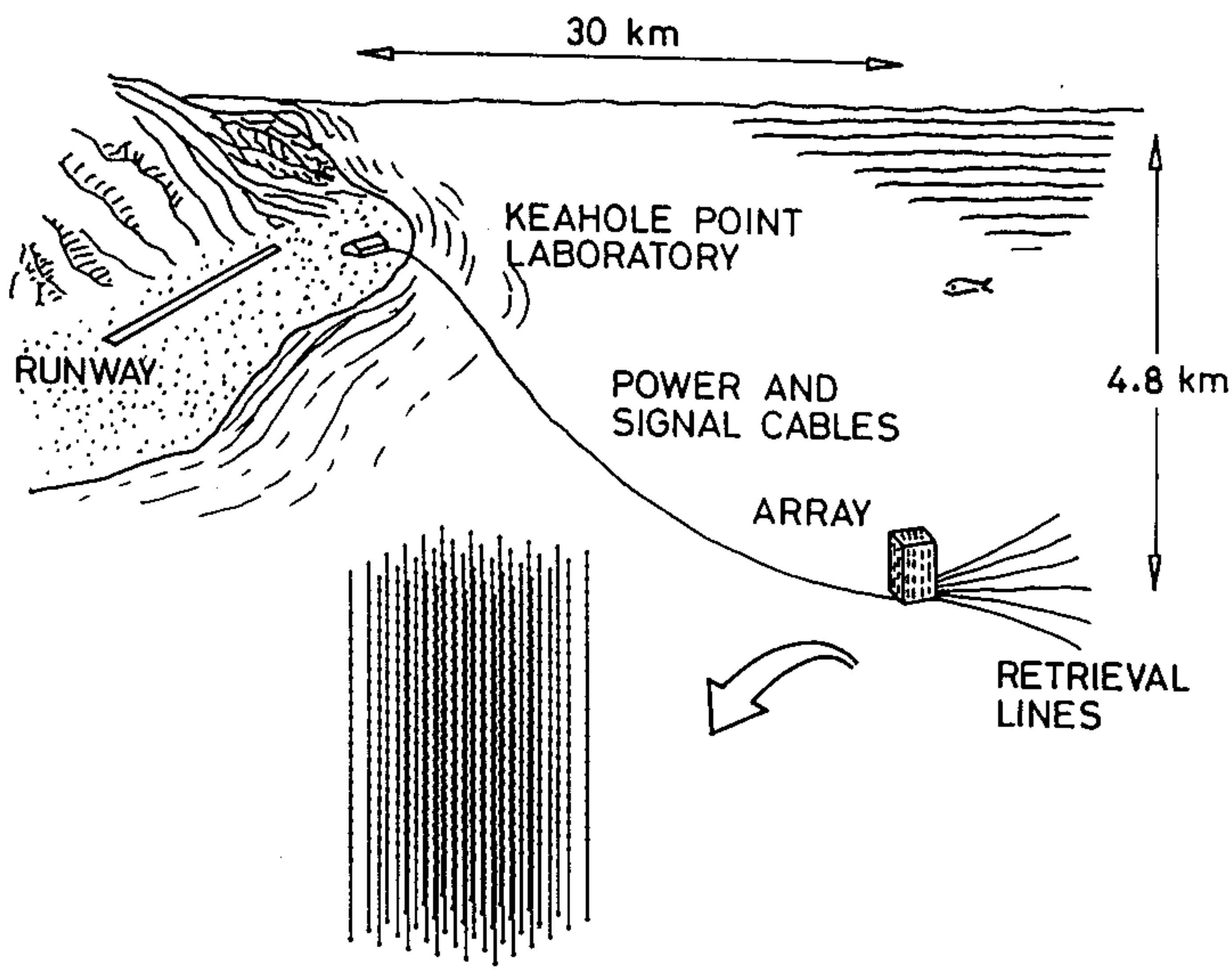

30 km
KEAHOLE POINT
LABORATORY
RUNWAY
POWER AND
SIGNAL CABLES
4.8 km
ARRAY
RETRIEVAL
LINES

Fig. 1

PHENOMENOLOGY

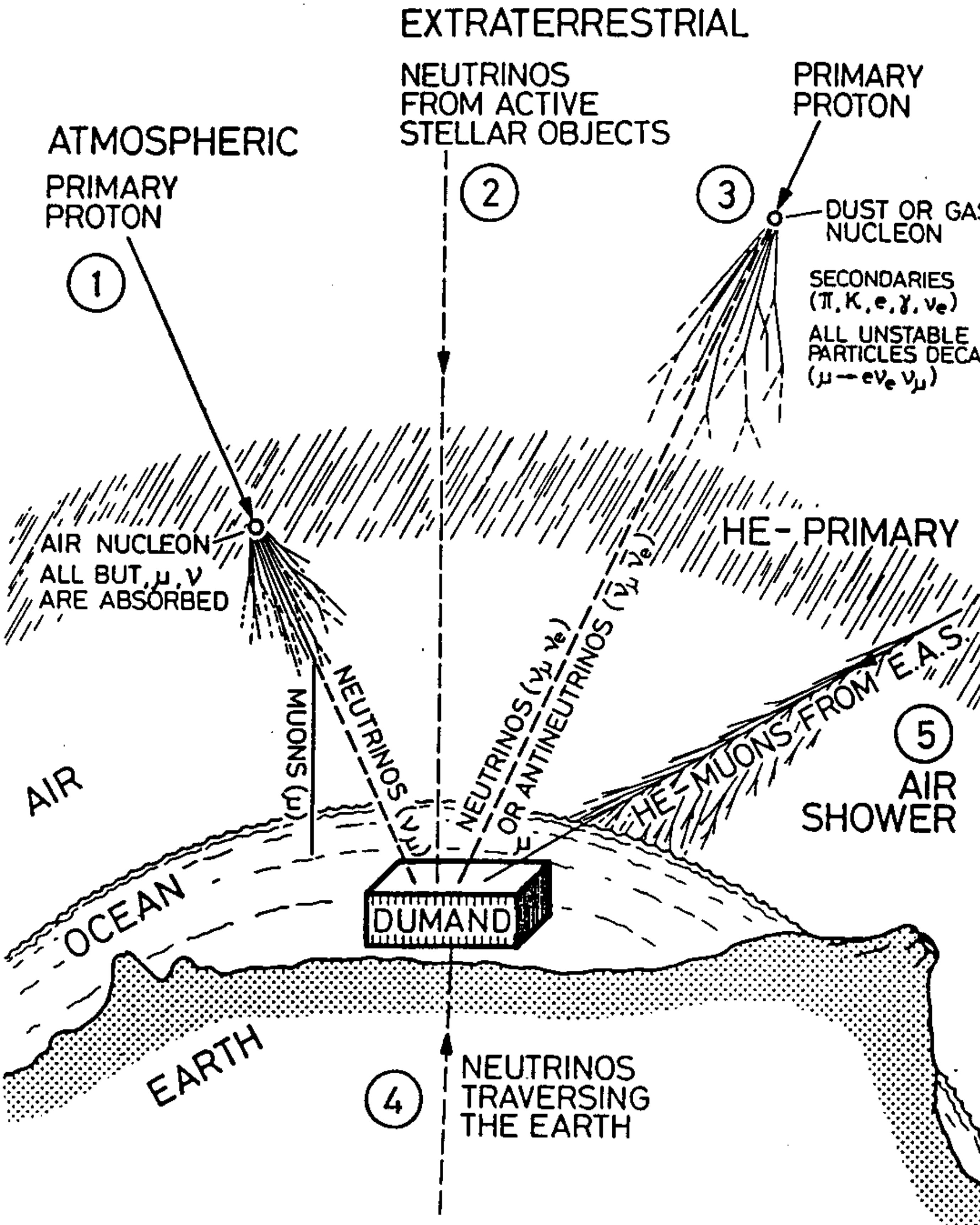
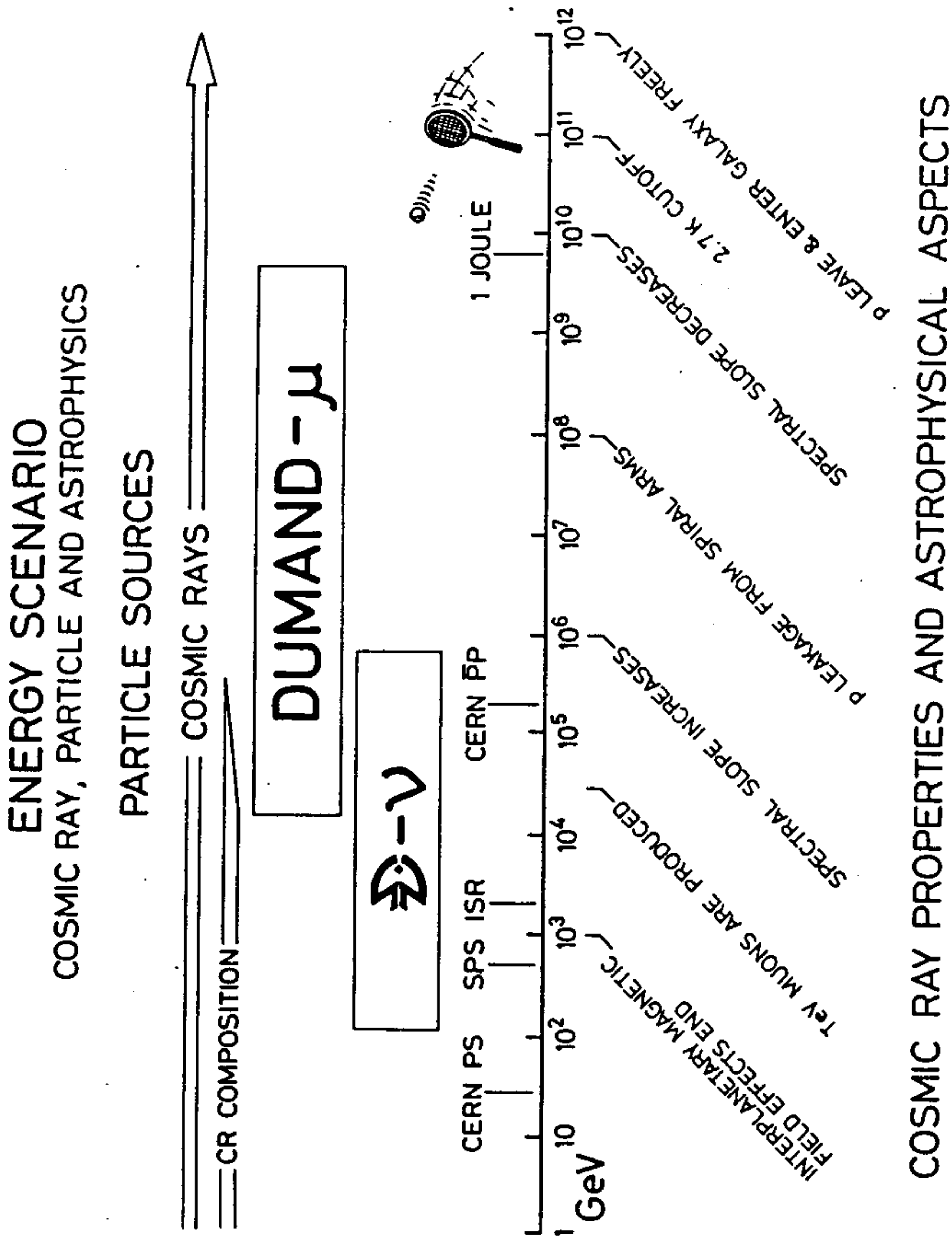


Fig. 2


ENERGY SCENARIO
COSMIC RAY, PARTICLE AND ASTROPHYSICS
PARTICLE SOURCES
COSMIC RAYS
CR COMPOSITION
DUMAND-μ
-ν
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SPS
ISR
CERN p̄p
1 JOULE
1 GeV
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10^8
10^9
10^{10}
10^{11}
10^{12}
INTERPLANETARY MAGNETIC FIELD EFFECTS END
TeV MUONS ARE PRODUCED
SPECTRAL SLOPE INCREASES
p LEAKAGE FROM SPIRAL ARMS
SPECTRAL SLOPE DECREASES
2.7 K CUTOFF
p LEAVE & ENTER GALAXY FREELY
COSMIC RAY PROPERTIES AND ASTROPHYSICAL ASPECTS

Fig. 3

DUMAND DETECTOR SYSTEM

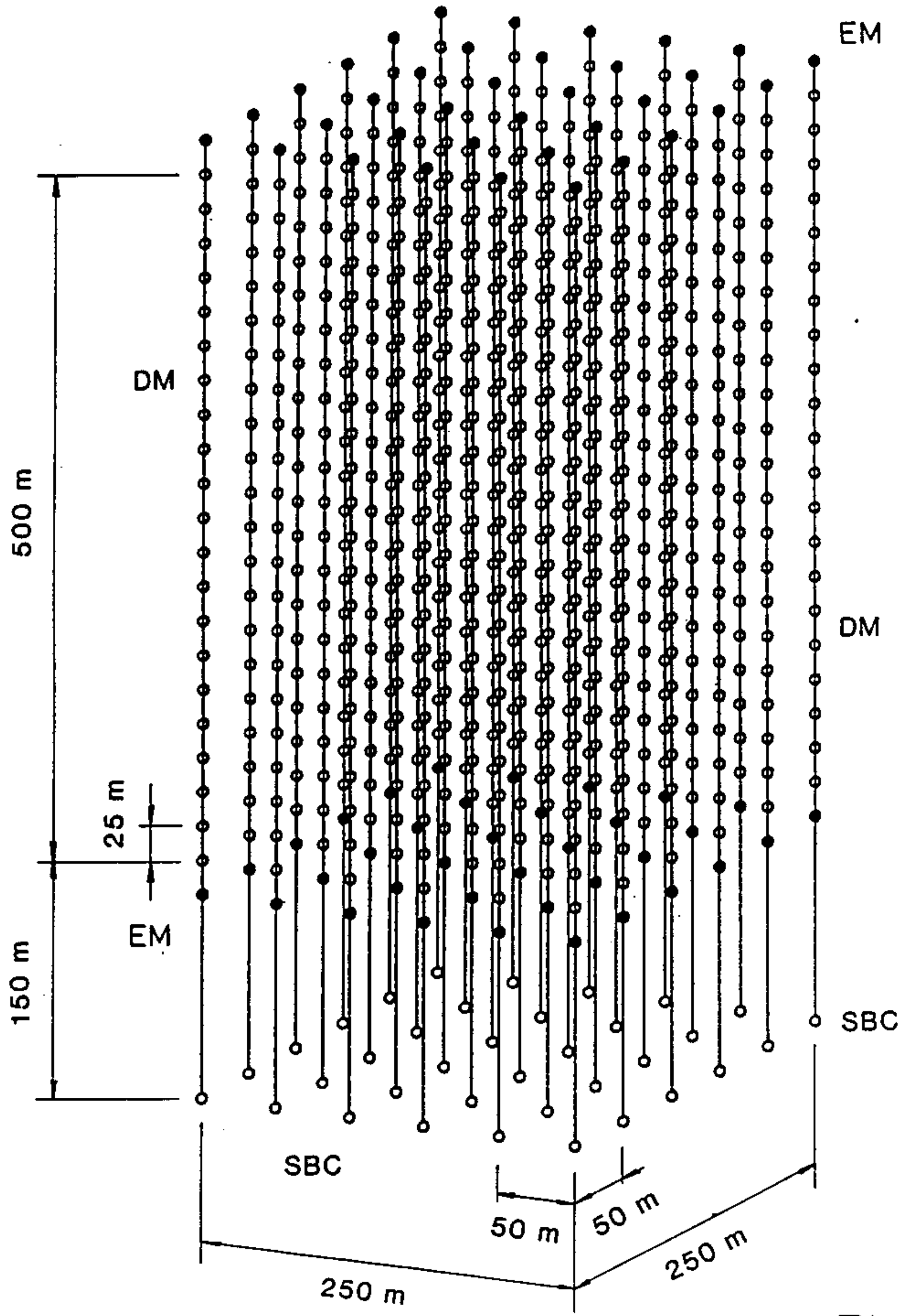


Fig. 4

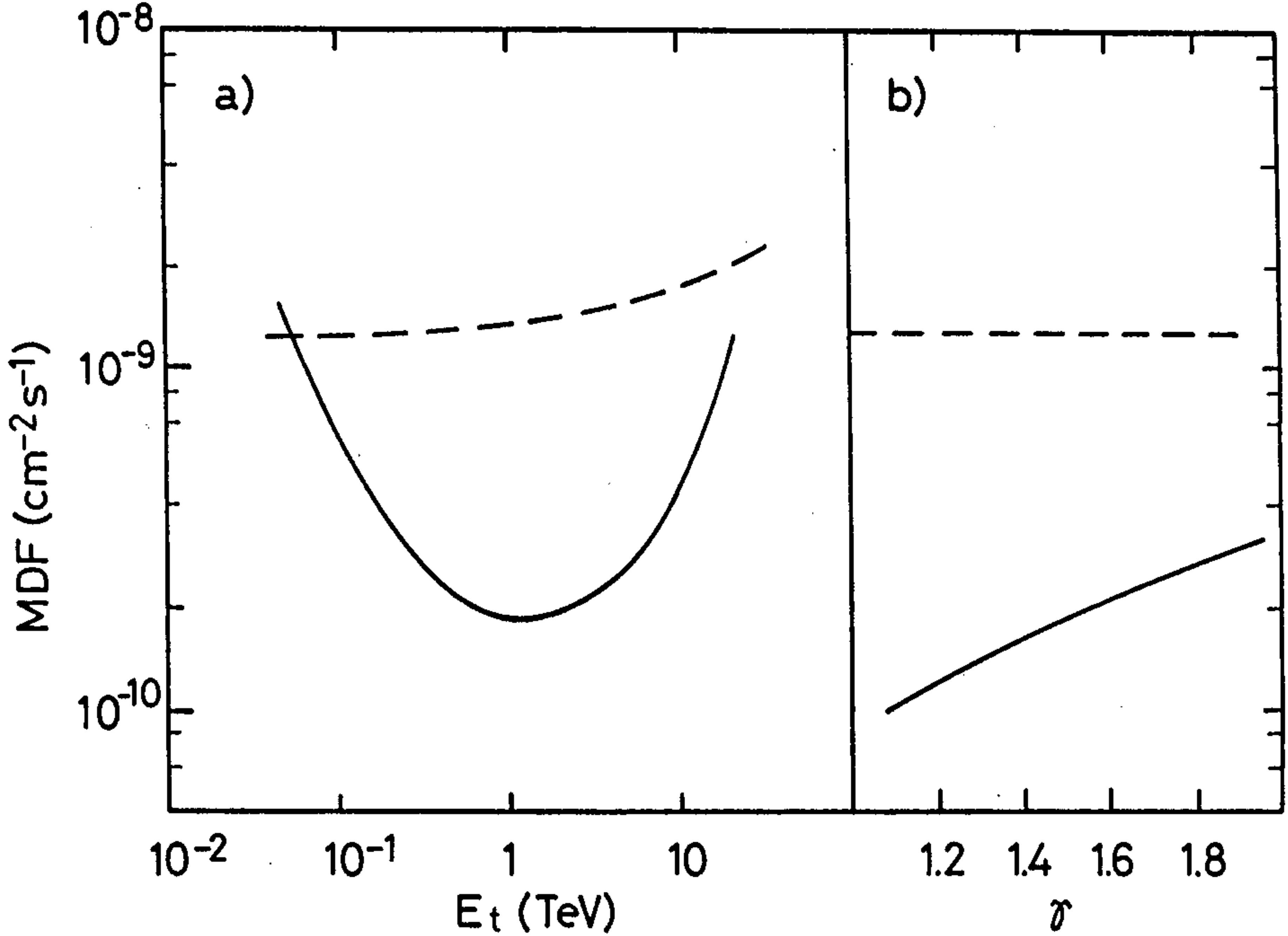


Fig. 5

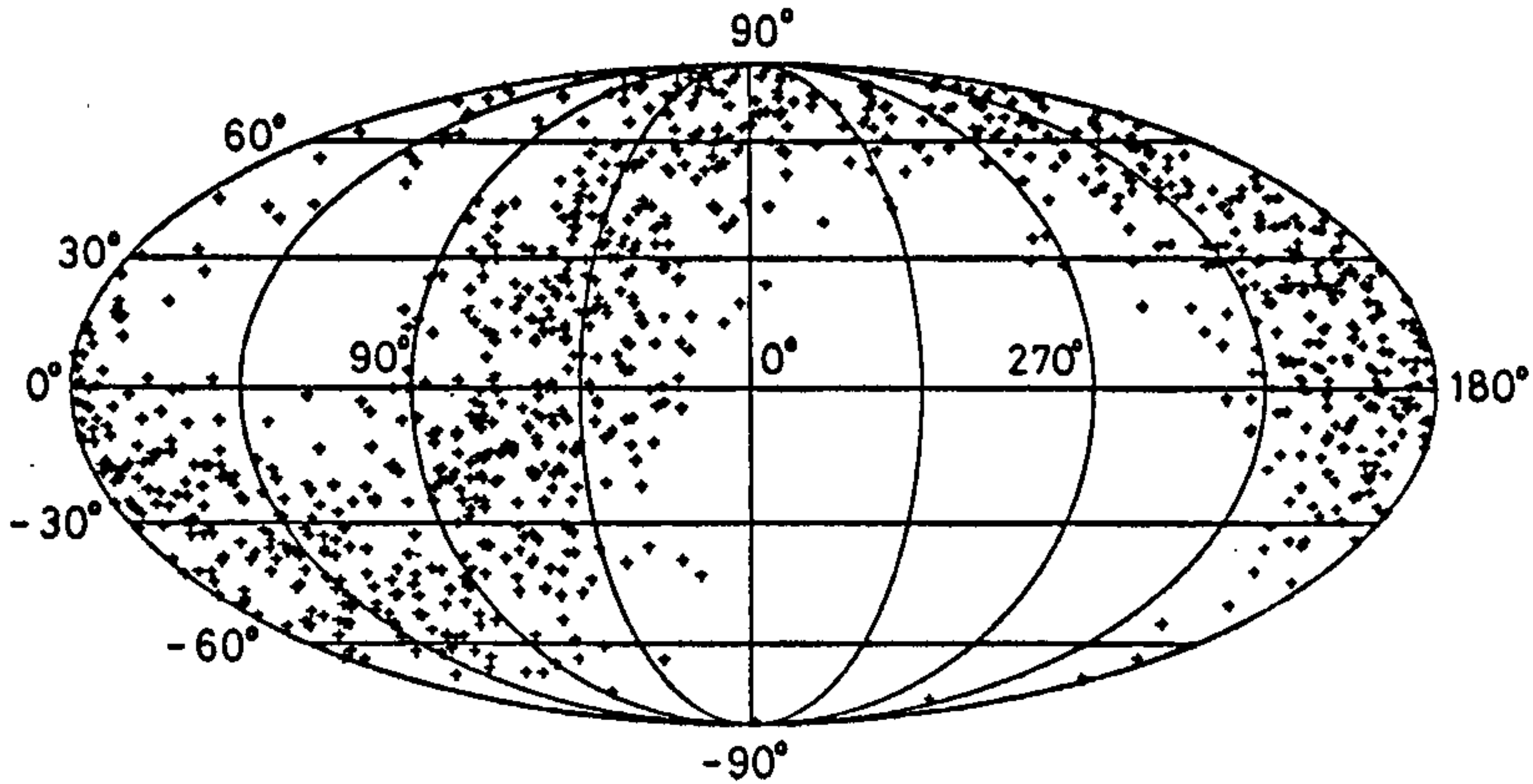


Fig. 6

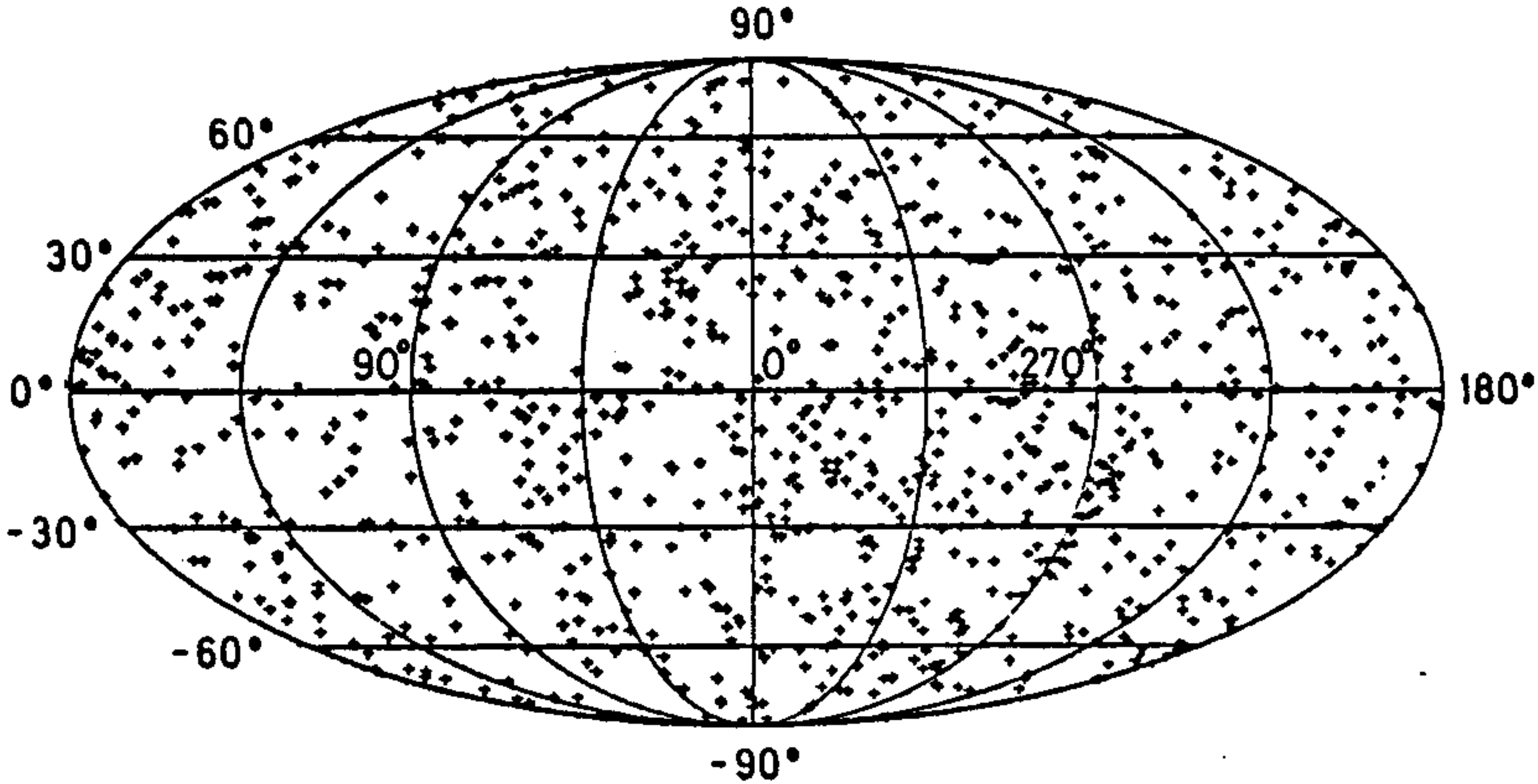


Fig. 7

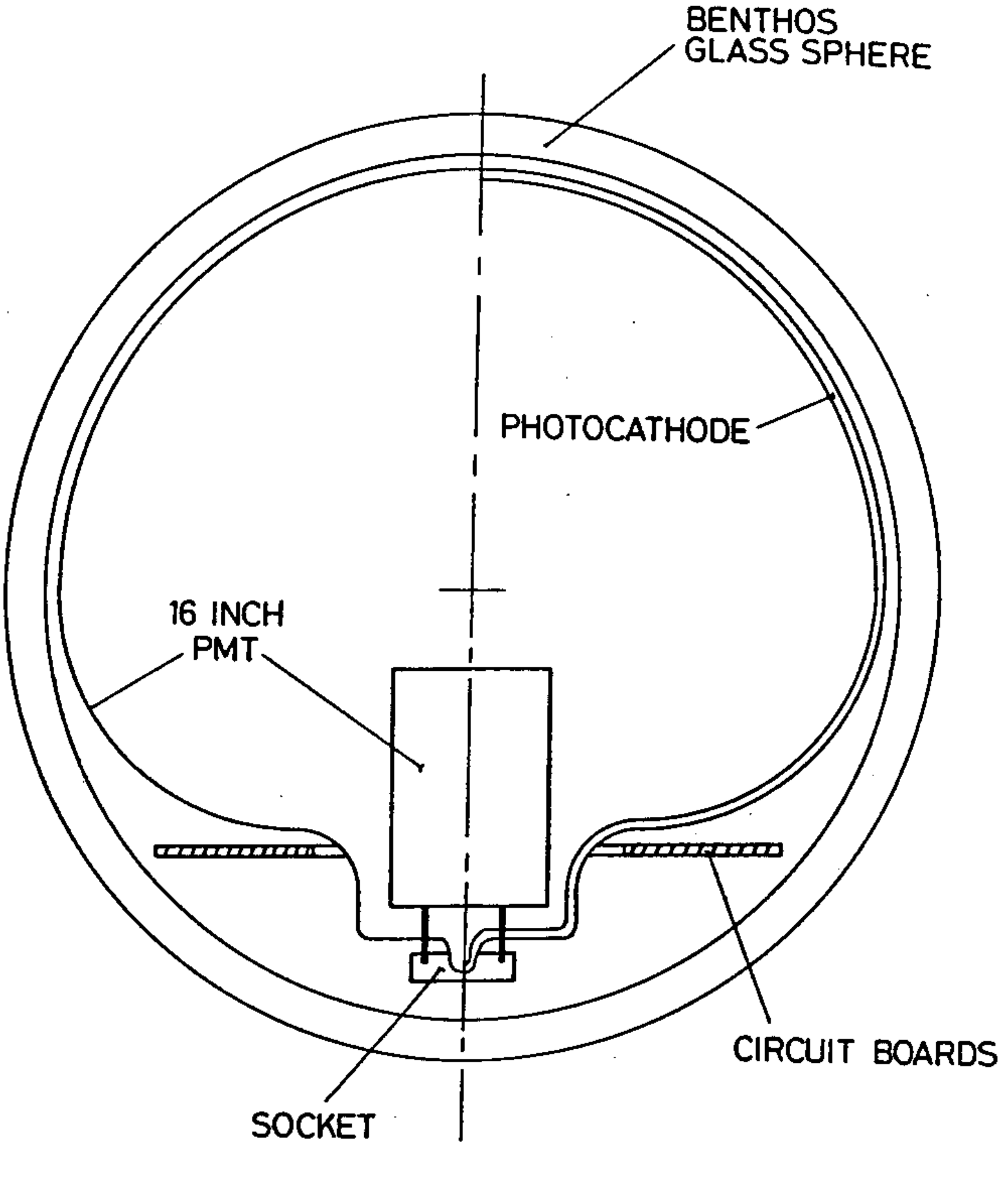
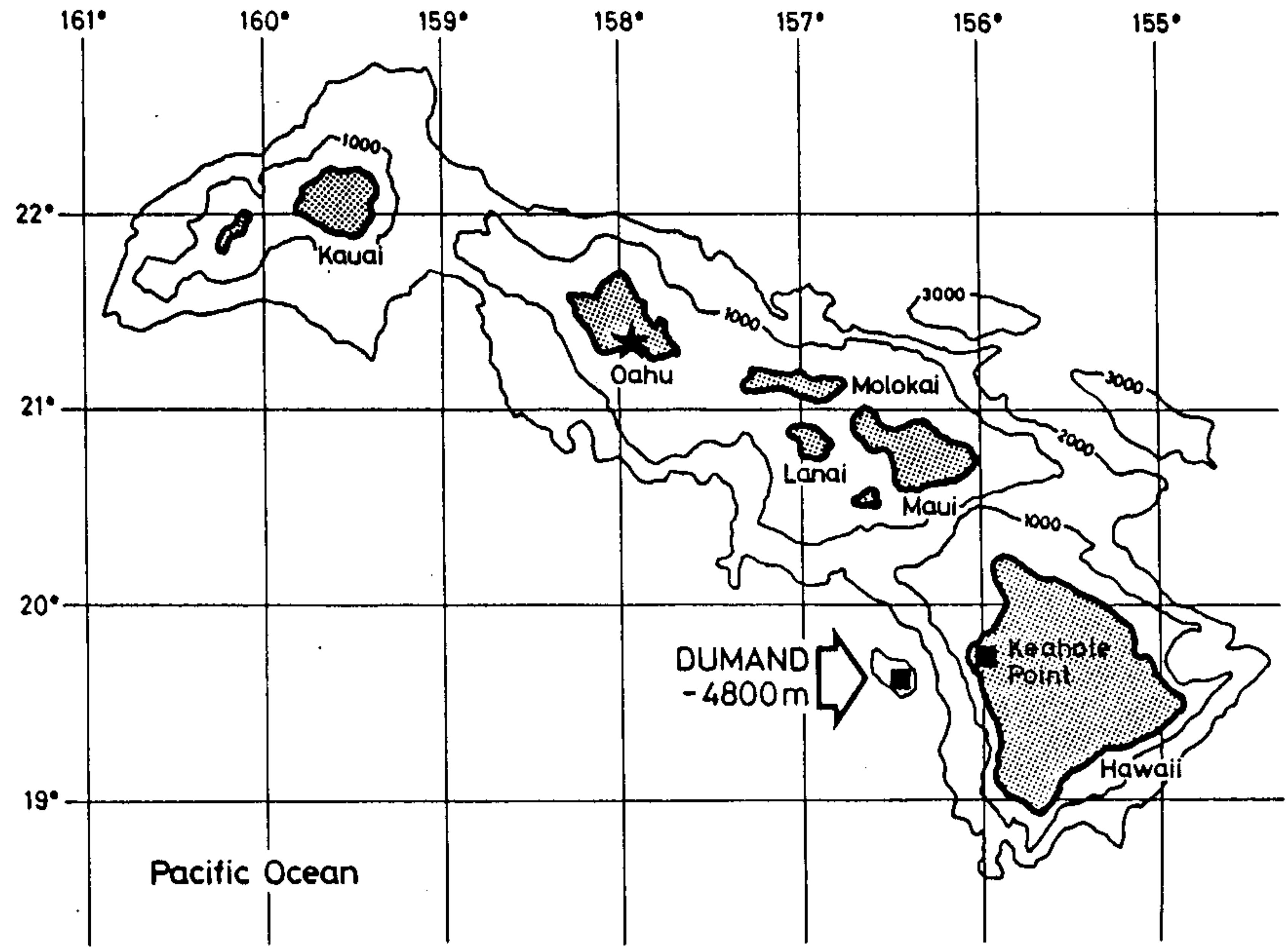

BENTHOS
GLASS SPHERE
PHOTOCATHODE
16 INCH
PMT
CIRCUIT BOARDS
SOCKET

Fig. 8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Maui
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DUMAND
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Point
Hawaii
Pacific Ocean

Fig. 9

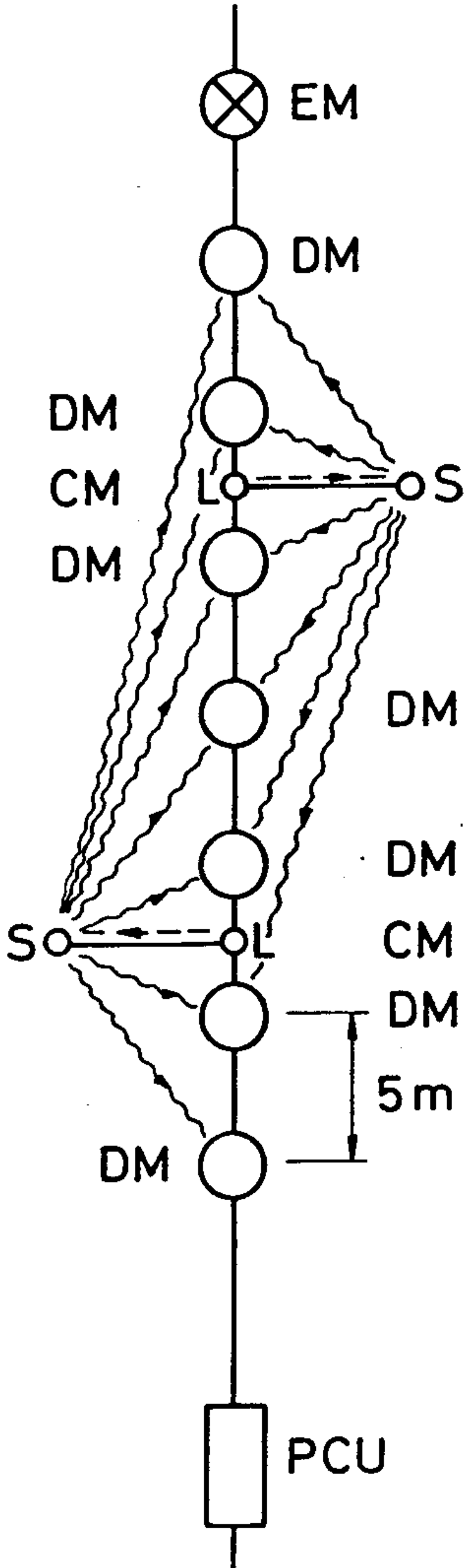

Fig. 10