Comments on Ultrahigh Energy Neutrino Beams

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Neutrino and Arms Control Workshop

U Hawaii, February 5, 2004

A global array of Gigaton Neutrino Detectors would benefit from a common, controllable calibration source
= Steerable high-energy neutrino beam.

Such a beam would have other applications to Arms Control.

Would this beam cost more or less than the Gigaton Detector array? Is it buildable at all?

Destruction of Nuclear Bombs Using Ultra-High Energy Neutrino Beam

— dedicated to Professor Masatoshi Koshiba —

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Abstract

We discuss the possibility of utilizing the ultra-high energy neutrino beam ($\simeq$ 1000 TeV) to detect and destroy the nuclear bombs wherever they are and whoever possess them.

Our basic idea is to use an extremely high energy neutrino beam which penetrates the earth and interacts just a few meters away from a potentially concealed nuclear weapon. The appropriate energy turns out to be about 1000 TeV. This is the energy where the neutrino mean free path becomes approximately equal to the diameter of the earth. The neutrino beam produces a hadron shower and the shower hits the plutonium or the uranium in the bomb and causes fission reactions. These reactions will heat up the bomb and either melt it down or ignite the nuclear reactions if the explosives already surround the plutonium. We will calculate the intensity of the neutrino beam required and the duration of time which the whole process will take place for a given intensity.

We emphasize that the whole technology is futuristic and the reason should be clear to all the accelerator experts. Actually, even the simplest prototype of our proposal, i.e. the neutrino factory of GeV range needs substantial R & D work. We also note that a 1000 TeV machine requires the accelerator circumference of the order of 1000 km with the magnets of $\simeq$ 10 Tesla which is totally ridiculous. Only if we can invent a magnet which can reach almost one order of magnitude higher field than the currently available magnet, the proposal can approach the reality. Even if it becomes the reality, the cost of the construction is of the order of or more than 100 billion US$. Also we note that the power required for the operation of the machine may exceed 50 GW taking the efficiency into account. This is above the total power of Great Britain. This implies that no single country will be able to afford the construction of this machine and also the operation time must be strictly restricted. We believe the only way this machine may be built is when all the countries on earth agree to do it by creating an organization which may be called the "World Government" for which this device becomes the means of enforcement.

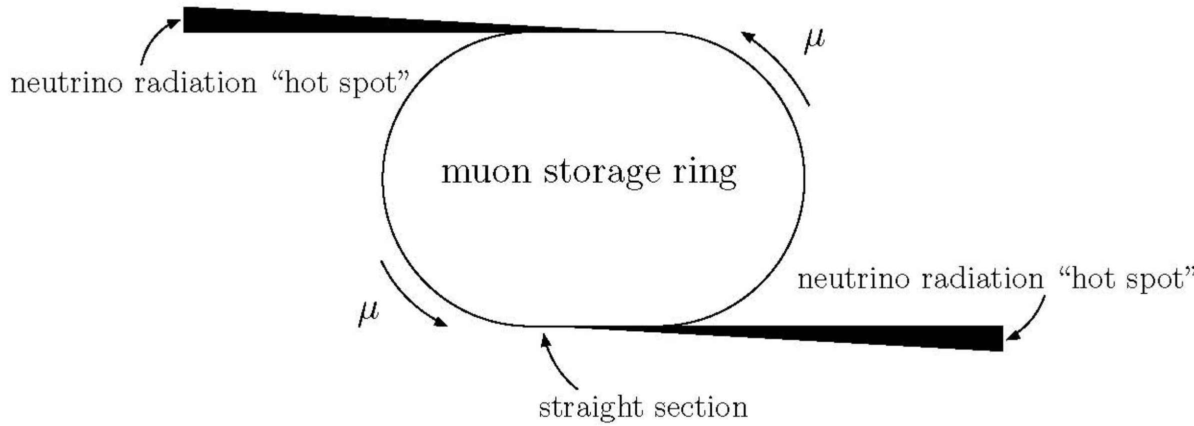

Figure 1: *Neutrino radiation from a race track shaped muon storage ring. The decay of muons will produce the neutrino radiation emanating out tangentially everywhere from the ring. In particular, the straight sections in the ring will cause radiation "hot spots" where all of the decays line up into a pencil beam.*

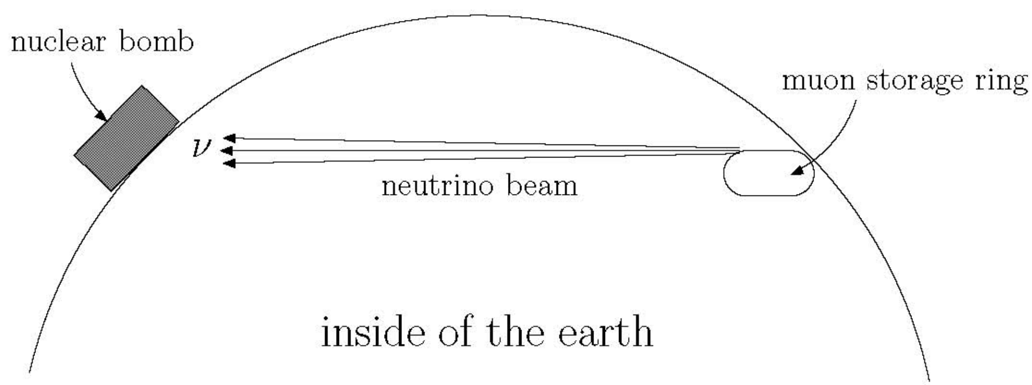

Figure 2: *Neutrino beam is aimed at the nuclear bomb that is placed on the opposite side of the earth. The beam is emitted downstream from one of the straight sections of the muon storage ring (see fig. 1), and reaches the bomb after passing through the inside of the earth.*

Recent progress in neutrino factory and muon collider research within the Muon Collaboration

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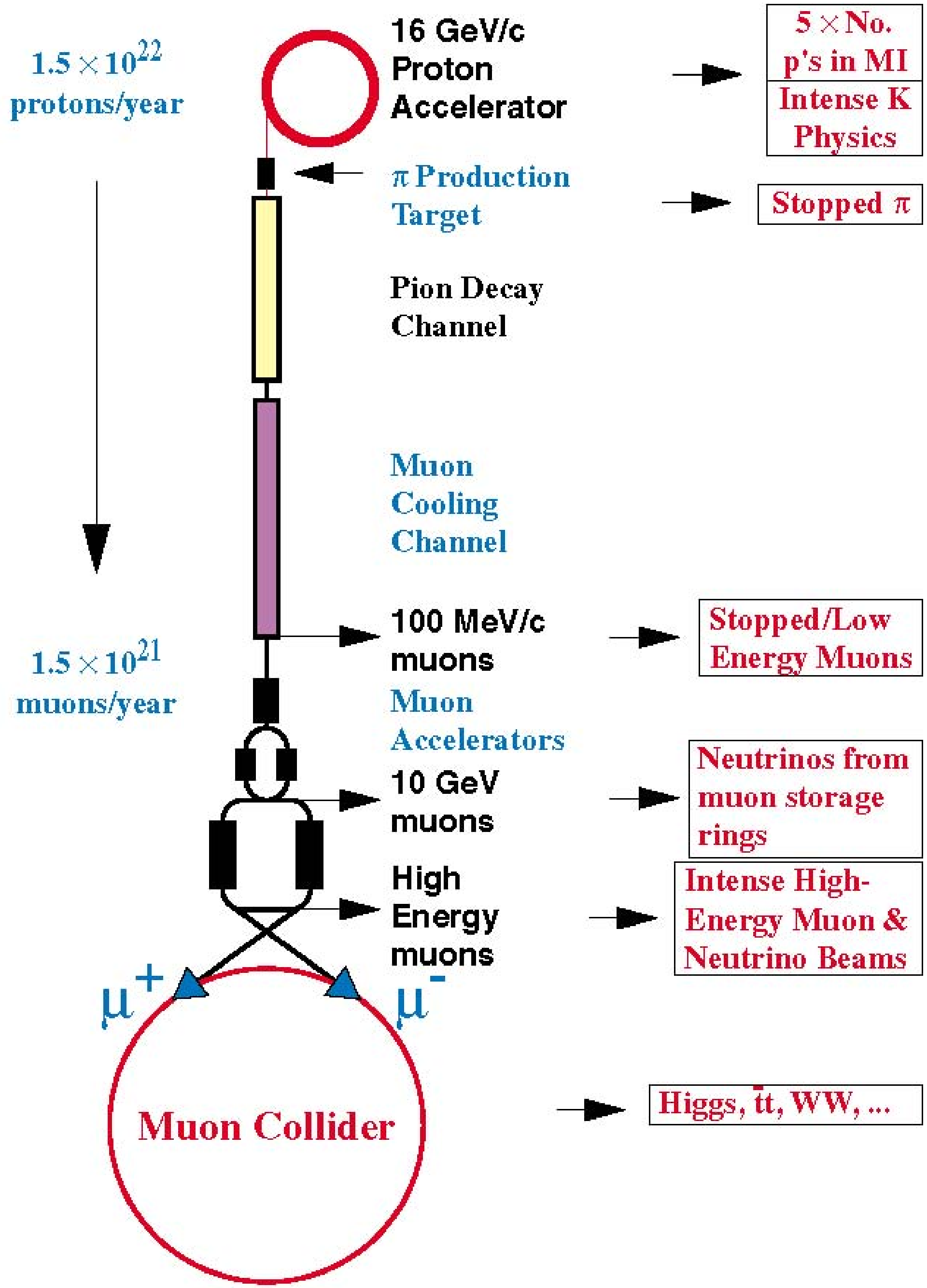

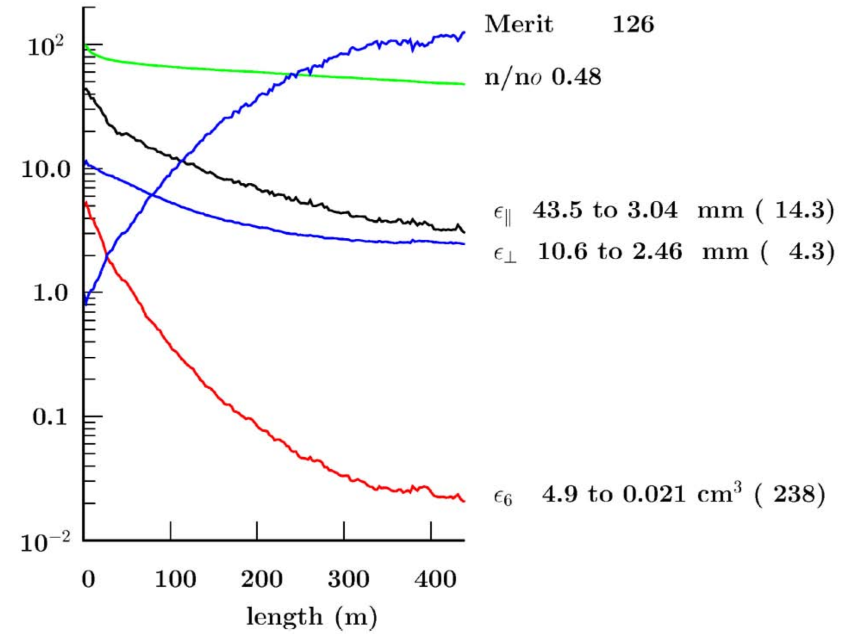

FIG. 39. (Color) Transmission, normalized transverse emittance, normalized longitudinal emittance, normalized 6-dimensional emittance, and the merit factor, as a function of distance.

A 3 TeV muon collider might cost $10B.

1 PeV ν's require 3 PeV μ's.

⇒Need factor of 100 cost reduction to stay at $10B.

⇒Well matched to the spirit of the Gigaton Project!

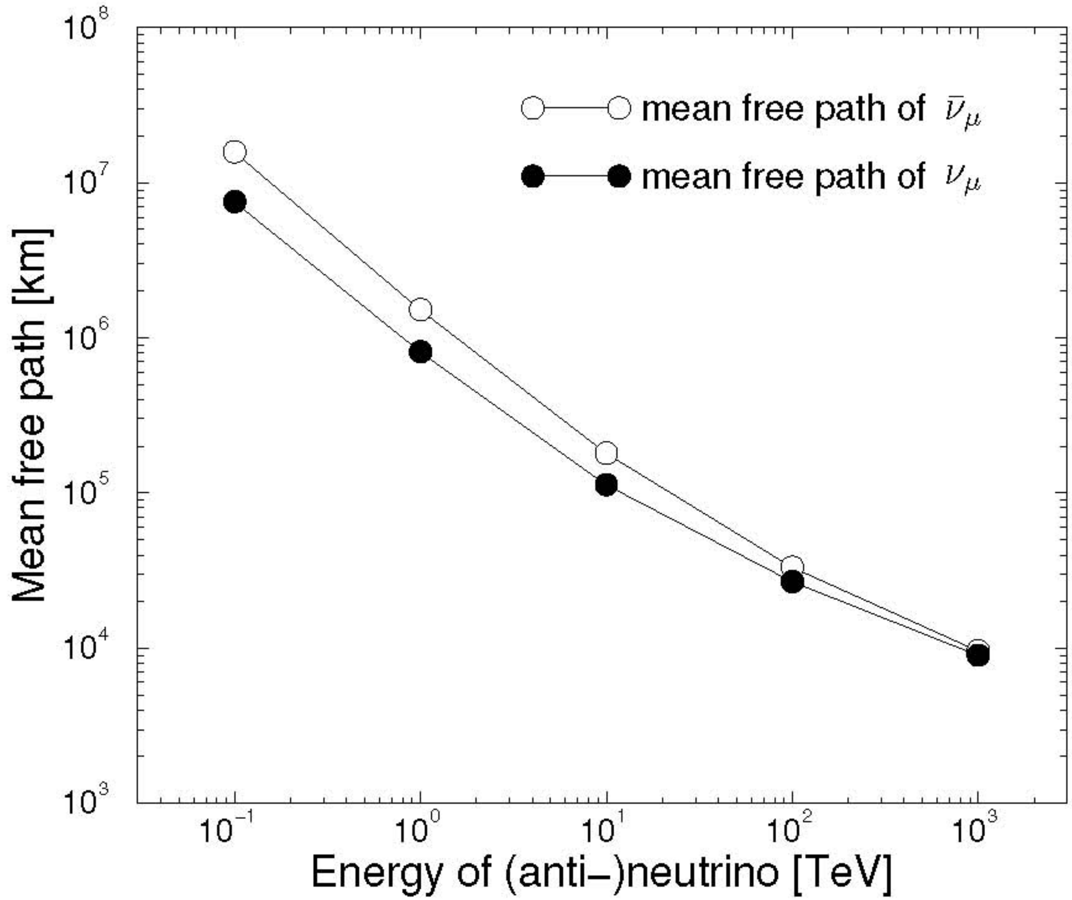

Figure 3: *Mean free path of (anti-)neutrino vs. its energy. This is calculated under the assumption that in this energy region the deep inelastic cross sections dominate. For the detail of the calculation, see Appendix A.*

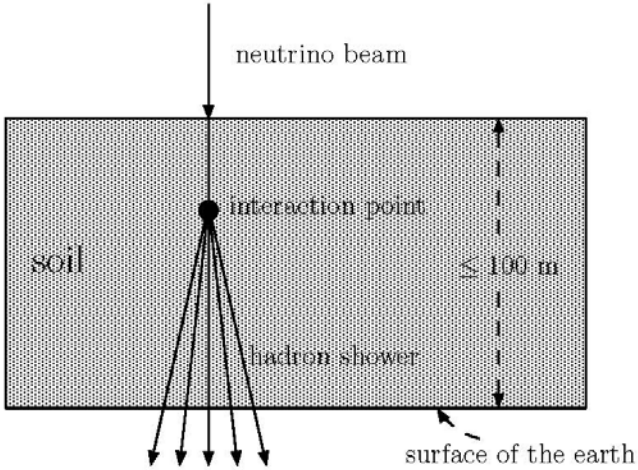

Figure 5: *Hadron shower arising near the target bomb. The neutrino beam passing through the soil interacts with nuclei near the surface of the earth, resulting in a hadron shower in a place a few meters close to the bomb.*

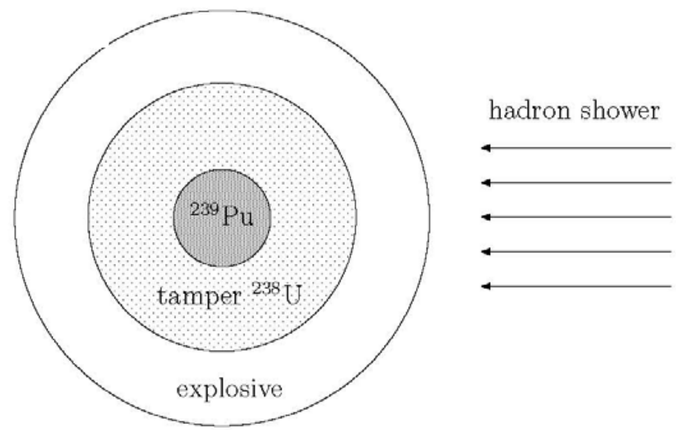

Figure 6: *A hadron shower going into the plutonium bomb. It will induce the fission reactions inside the plutonium system and cause the temperature increase as a result.*

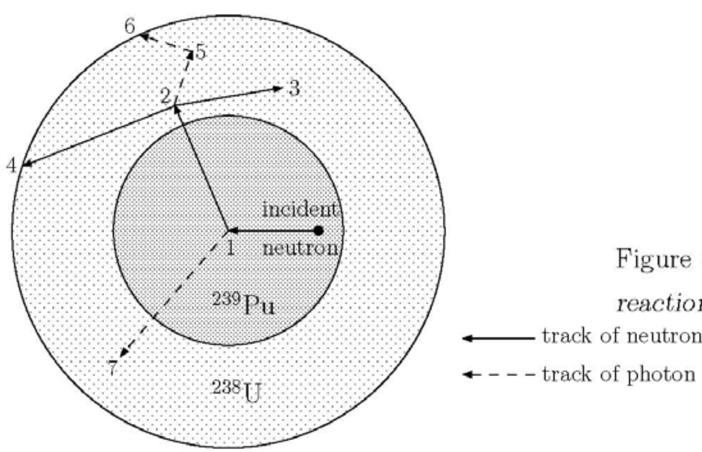

Figure 7: *A history of a neutron incident on the* ^{239}Pu *core that can undergo nuclear fission. 1. Neutron scattering and photon production in the core. 2. Fission and photon production in the* ^{238}U *tamper. 3. Neutron capture in the tamper. 4. Neutron leakage out of the tamper. 5. Photon scattering in the tamper. 6. Photon leakage out of the tamper. 7. Photon capture in the tamper.*

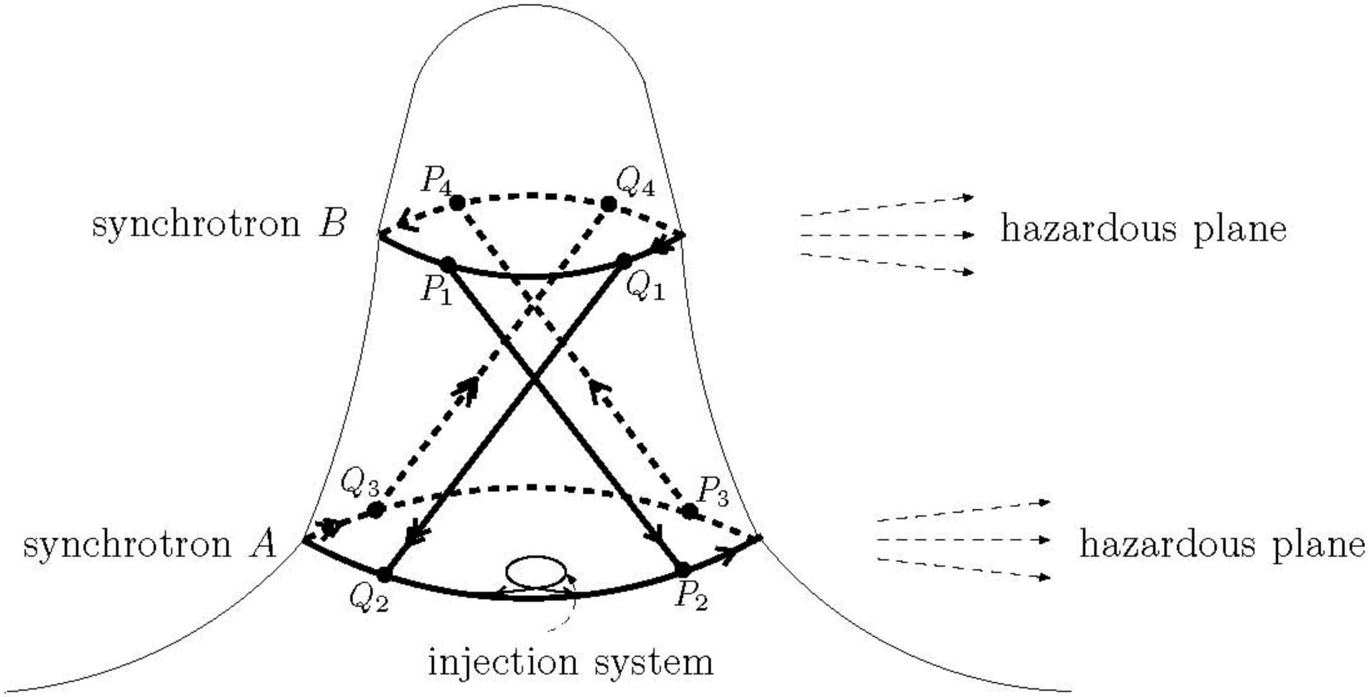

Figure 8: *Accelerator scheme.*

The size of the beam at the point of the bomb is given by

$$r = \frac{m_\mu c^2}{E_\nu} d \simeq \frac{0.1\ (\text{GeV}) \times 10^7\ (\text{m})}{10^6\ (\text{GeV})} = 1\ (\text{m}) \ ,$$

When we rotate A or B the chambers must follow until we steer the straight section to a given target.The next question is how precisely we can steer it. From the discussion given in the text the required accuracy is 10^{-7}. This is 1/10 micron per meter.

Must rotate a 1000-km-long object to 10^{-7} accuracy in arbitrary directions, $\Rightarrow$? Site in space?

Why not use a Space Elevator to a geosynchronous orbit?

Carbon nanotubes might be strong enough.

Of course, still must provide the (large) energy differential of the orbiting objects.

And, must give the objects the (large) transverse momentum of orbiting objects.

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TERRESTRIAL NEUTRINOS

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Received 11 October 1965

bstract: Arguments are given for a remarkable abundance of radioactive elements within the earth. Methods are discussed in order to measure this abundance by neutrino experiments.

1. Introduction

The chemical composition of the interior of the earth is still quite unsure. There-re it would be an advancement if one could measure the abundance of selected hemical elements by their neutrino emission. In this connection, potassium, thorium ad uranium are of interest. Generally it is assumed that these elements are confined ainly to the earth's crust, if only for that reason that the material obtainable from e earth's mantle shows a small portion of the mentioned substances. On the other and the exchange of material between the earth's crust and the upper mantle can ve rise to a reduction of radioactive elements in this region. Further there are ar-

GEOPHYSICS BY NEUTRINOS*)

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A review of the possibilities for the chemical exploration of the central regions of the Earth is given, making use of the antineutrino flux produced by natural radioactive isotopes.

1. INTRODUCTION

It was suggested many years ago that the neutrino and antineutrino luminosity of different celestial bodies might provide means of exploring the internal structure of these objects (see e.g. [1]). Due to the enormous mean free path the neutrinos and antineutrinos provide valuable direct information, which is not available with other methods. Searching the Sun with a neutrino telescope is well under way [2]. The present paper is concentrated on the second important task of neutrino physics: the Earth. The idea of observing terrestrial antineutrinos is not a new one [1, 3, 4, 5]. Here a review of different experimental possibilities will be given.

Antineutrino astronomy and geophysics

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Radioactive decays inside the Earth produce antineutrinos that may be detectable at the surface. Their flux and spectrum contain important geophysical information. New detectors need to be developed, discriminating between sources of antineutrinos, including the cosmic-background. The latter can be related to the frequency of supernovas.

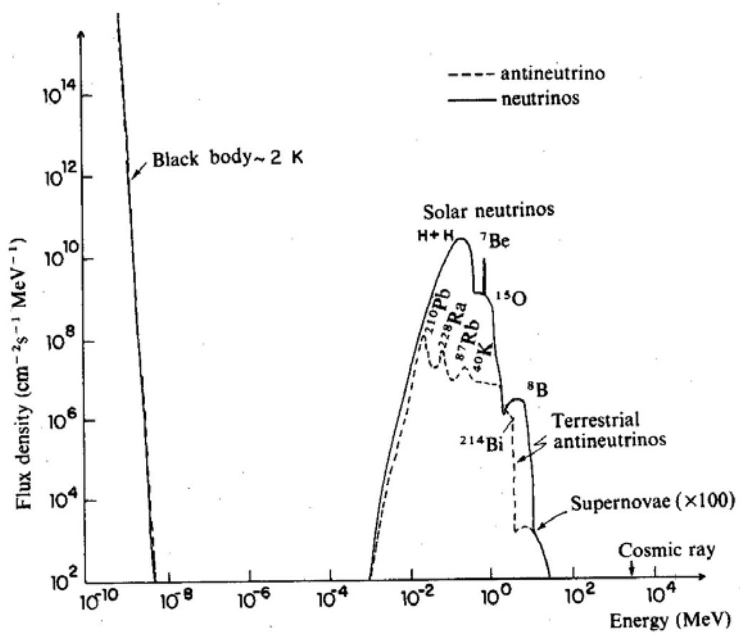

Fig. 2 Spectrum of neutrinos and antineutrinos at the Earth's surface (continuous sources in $cm^{-2} s^{-1} MeV^{-1}$, line sources in $cm^{-2} s^{-1}$. Supernovae peak is enhanced by a factor of ~100).

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NEUTRINO EXPLORATION OF THE EARTH*

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Contents:

1. Introduction 343
2. Accelerator design 346
   - 2.1. The Geotron 346
   - 2.2. A Tevatron-like Geotron 346
   - 2.3. A more up-to-date Geotron 347
   - 2.4. Buried pipes and robots 348
   - 2.5. More about magnets 348
   - 2.6. Injector system 350
   - 2.7. Costs 350
   - 2.8. A seaborne Geotron 350
   - 2.9. The external proton beam: The snout 352
   - 2.10. A prototype 352
3. Neutrino beams 353
4. Sound generation by particles interacting with matter 358
   - 4.1. Possible mechanisms 358
   - 4.2. The thermoacoustic model 359
   - 4.3. Experimental tests of the thermoacoustic model 361
   - 4.4. The sonic neutrino antenna 363
5. Background seismic noise 367
6. GENIUS vs. other methods of seismic research 372
7. GEMINI: Geological Exploration with Muons Induced by Neutrino Interactions 376
8. GEOSCAN: The density profile of the Earth 384
9. Directions of future research and development 390
10. Conclusion 393

References 395

the machines. High-technology pump priming can induce the rebirth and revitalization of our industrial society. Nonetheless, the *raison d'être* for the construction of high-energy accelerators has always been the pursuit of science for science's sake.

We believe that future accelerators can be of direct commercial and technological importance. We envisage the construction of one (or more) large proton synchrotrons for purposes which may loosely be termed "WHOLE EARTH TOMOGRAPHY". It is the purpose of this paper to explore the nature and feasibility of such a project.

We shall refer to the accelerator dedicated to geological exploration as the GEOTRON, presumably a proton synchrotron with a beam energy $\sim$10 TeV. Some considerations on the construction of the GEOTRON are given in section 2. The high-energy protons must be aimed towards a distant site of geological interest. Immediately after extraction, the protons collide with a target, producing an intense and highly collimated beam of mesons. These mesons pass through a long decay tunnel, wherein they generate a neutrino beam. The complex system of proton beam transport, target, and decay tunnel must be capable of being redirected with great precision towards remote sites. We refer to this novel construction as the SNOUT of the GEOTRON. The nature of the neutrino beam which is produced at the GEOTRON complex is discussed in section 3.

The collimated neutrino beam, when it reaches the remote site to be explored, undergoes secondary interactions with the underground medium. This leads to the production of a detectable signal whose interpretation can provide useful information.

The neutrino beam can be used in at least three different ways to reveal information about the subsurface. Project GENIUS stands for Geological Exploration by Neutrino Induced Underground Sound. In this scenario, the neutrino beam is deployed at a shallow angle of declination so as to emerge from the Earth at a distant site. For example, at a declination angle of 4.5°, the point of emergence of the beam is 1000 km distant from the accelerator and its maximum depth is 20 km. As the neutrinos pass through the Earth they undergo occasional interactions wherein their energy is converted into

2.7. Costs

Costs, seemingly so prosaic, are in reality utterly romantic, and in every sense of the word. We have seen that the idiot's delight we started with might cost two billion dollars. With a better design, the Geotron as just described might cost about one billion dollars. By more ingenious people, it might cost less; but it might cost very much more if built under the loving supervision of present day bureaucrats. The construction could well be drawn out in a jobs-for-all Nirvana, for years and years as the costs double and then double again. This sobering pitfall for projects is not, experience informs us, the exception. But let us take the optimistic view; the cost will be of the order of one billion dollars, and it will be built in three years after funding. This does assume that we do have a few very committed physicists on board.

2.8. A seaborne Geotron

Can we really put an accelerator out to sea or is this just another technical chimera? The first part is easy. We will just float the pipe containing the magnets and robots, etc. at a depth of about five fathoms where the wave motion will be very small most of the time. During large storms, the accelerator would be shut down. The robots with their magnets in hand will gain entry to the pipe through snorkels and air locks in a manner already rather well worked out in the last century. But the ocean currents, what can stand up to them? Cables. Stainless steel cables fastened to the bottom might hold the pipe in position – perhaps to within several centimeters of where it should be. The cables would be most effective if the water were not too deep. This suggests that the Geotron be located over a submerged coral reef of the kind that is found encircling a desert island. The booster ring in that case might be placed in a sheltered lagoon within the reef. The linac and control center could be placed on the island itself.

But we must face up to the main reason for skepticism about floating the accelerator in the sea. Here-to-fore much has been made of the necessity of extremely solid and stable supports for a

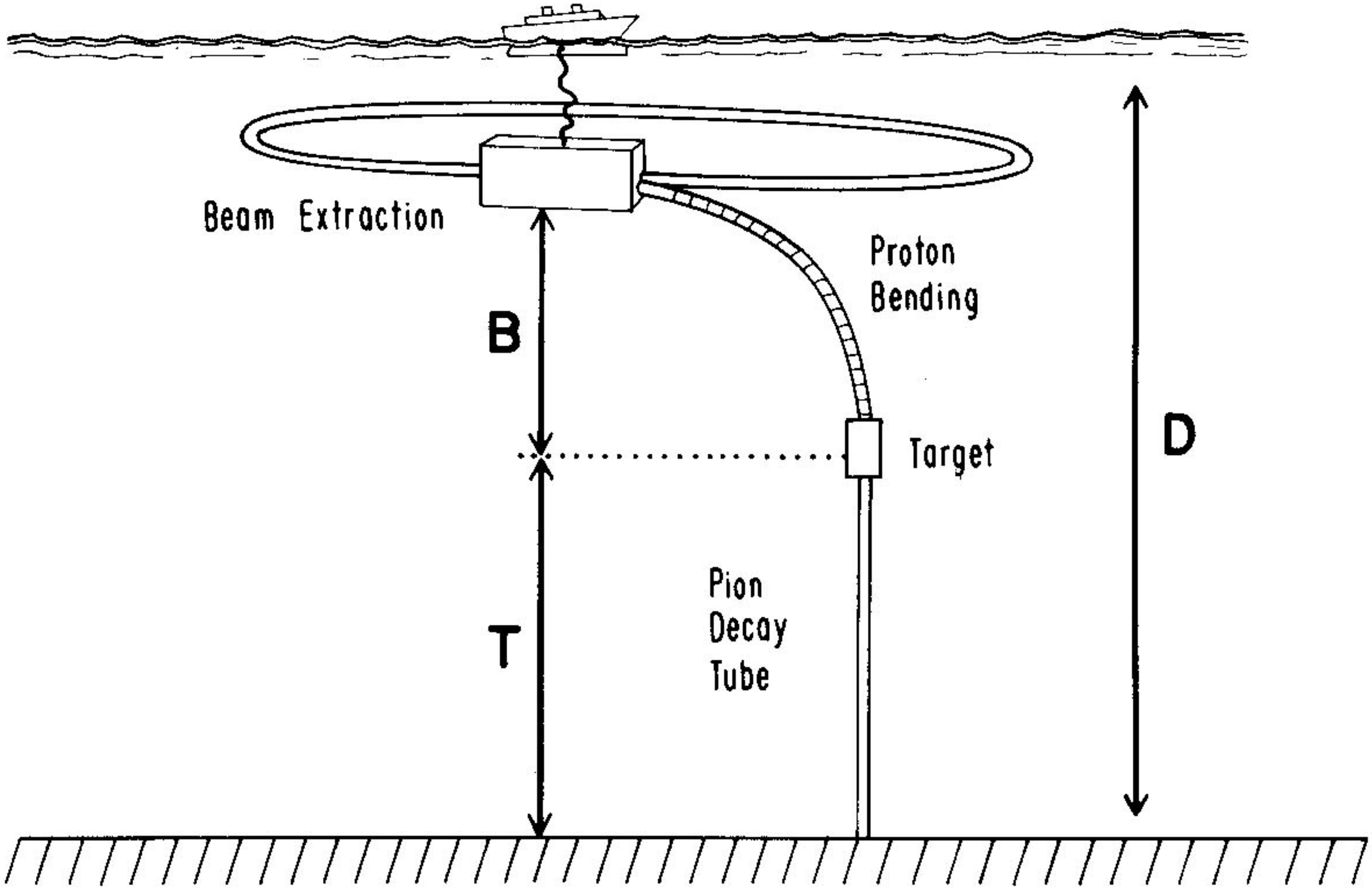

Fig. 8.3. Accelerator and beam deployment at sea, a possibility that suggests itself in a GEOSCAN Project.

(3) This is a self-normalizing procedure in which muon energies need not be measured. It is the procedure we believe can be implemented with Project GEOSCAN, and we proceed to consider it in detail. It involves the simultaneous use of two or more seaborne detectors, as shown in fig. 8.4. One of the detectors is placed at the central axis of the neutrino beam where the mean neutrino energy is greatest, and is given by $4\langle E_\nu \rangle$ in the limit of ideal pion focusing. The second detector is placed at a fixed angle α off-axis, where the neutrino flux is both less intense and less energetic. The off-axis flux, being less energetic, is less affected by neutrino attenuation in the Earth, than is the on-axis flux. The ratio of the off-axis flux N_{off} to the on-axis flux N_{on} must be measured as a function of the neutrino-direction θ at which the neutrino beam traverses the Earth. This ratio is given by

$$P(\theta, \alpha) = N_{\text{off}}/N_{\text{on}} = f(\alpha)\,[1 + 6p(\alpha)\,a(\theta)\,\langle E_\nu \rangle]\,, \tag{8.7}$$

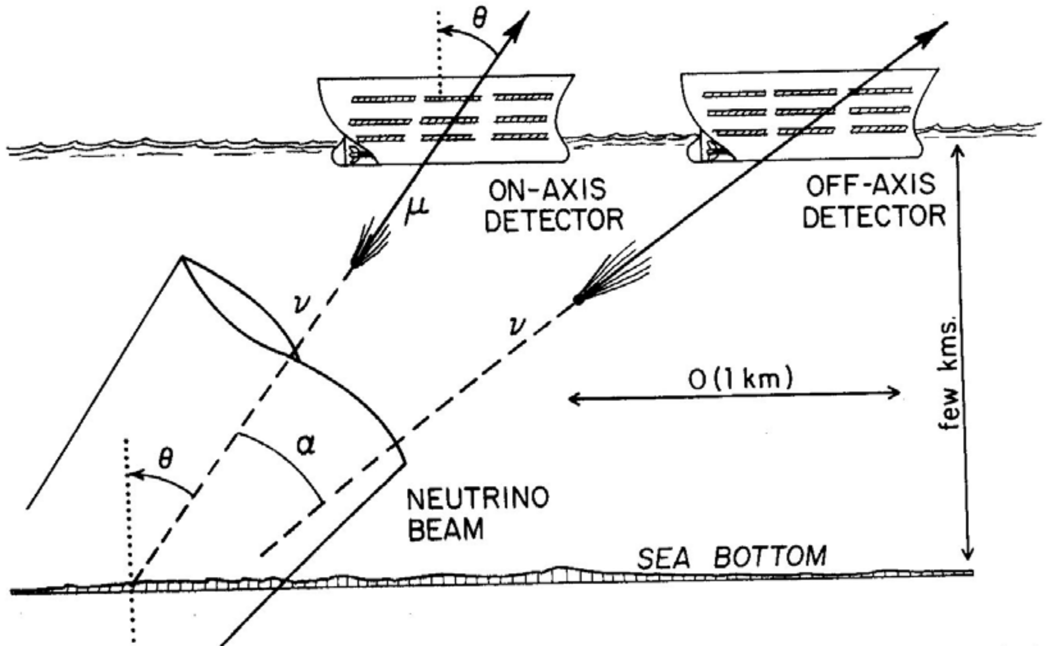

Fig. 8.4. Deployment of GEOSCAN detectors. The angle θ is that of emergence of the neutrino beam axis. The angle α is that of on-axis to off-axis neutrinos.

Did our heroes appreciate the merits of off-axis neutrino beams in providing a more monochromatic spectrum (due to Jacobian peak in 2-body decay kinematics)? NO!

Synchrotron radiation by the protons has already been mentioned. Were the proton intensity high and were the radiation not intercepted on warm fingers protruding into the donut, the radiation would add significantly to the refrigeration load. Indeed, the power radiated by N protons moving in an orbit of radius of curvature R is

$$P \cong 6 \times 10^{-14} N E^4 / R^2 \tag{2.1}$$

where P is in watts, E in TeV, and R in km. As an example, with $R = 6$ km, $E = 10$ TeV, and $N = 10^{15}$ protons, the radiated power is 16 kilowatts. The same proton intensity in a 20 TeV accelerator of twice the radius produces 64 kilowatts of synchotron radiation, which in this case is about three times the static heat load.

E/R is fixed for a given strength of bend magnets.

So $P \sim N E^2/m^2$ for a circular ring storing particles of mass *m*.

1000 TeV rings are power hogs.

So, what about 100 TeV? 10 TeV? 1 TeV?

The Challenges of a 100 TeV Muon Collider

- all the challenges of muon colliders at lower energies (beam cooling!)

substantial!

- neutrino radiation. ave. dose in plane > U.S. Fed. Limit => isolated site
- huge demagnification at final focus. Feasible ? $\frac{\sigma_{x,y}^{\max}}{\sigma_{x,y}^{\min}} \approx 100000 \approx 2.5 \text{ times NLC}$
- power consumption. Beam power ~ 100 MW, synch. rad. power ~ 100 MW
- cost: it won't be cheap ! 100 km of collider ring + acceleration etc.

A long way off but already ~1 decade above the potential mass reach for e+e-, pp colliders. **The crucial decade ??**

A 1000 TeV Linear Accelerator?

No synchrotron radiation.

But, must have full energy (1000 TeV!) of rf acceleration.

⇒ Linear accelerators typically more expensive than circular accelerators of same energy.

? Save on real estate costs by siting on the Moon (J. Learned).

100 PeV positrons via 100 km of 100 GeV/m acceleration.
Collide with e's to make Z's.
$Z \to \nu\nu$ yields a 5 PeV neutrino beam.
Angular spread ~ 50 GeV / 5 PeV ~ 10^{-5}.
⇒ 5 km beam spot at the Earth.