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"EXPERIMENTAL WINDOWS TO POST-COLLIDER ENERGIES"

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EXPERIMENTAL WINDOWS TO POST-COLLIDER ENERGIES*

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1. Introduction
2. Review of some current experiments
   2.1 Nucleon decay
   2.2 Monopole searches
   2.3 The solar neutrino problem
   2.4 The Fly's Eye experiment
   2.5 The DUMAND project
3. The MACRO and ICARUS experiments
   3.1 The MACRO experiment
   3.2 Neutrino astronomy
   3.3 The ICARUS experiment
4. Acknowledgements

Abstract

We discuss some of the experiments designed to probe the energy regime beyond the reach of existing or proposed accelerators. We attempt to classify the diverse efforts presently underway and give a brief update of the results in the major areas of interest to particle physics. We then describe two detectors presently under construction in the Gran Sasso laboratory, as examples of the next generation of experiments.

1. Introduction

The era of particle accelerators, born with the invention of the cyclotron, continues to dominate particle physics as large machines such as LEP or the SSC are being built and being planned. Beyond the c.m. energies that these large colliders will provide lies a vast uncharted territory, which we show graphically in Fig. 1. What makes this "post-collider" energy regime particularly interesting at this time is that there are specific theoretical predictions about phenomena occuring at these energies.

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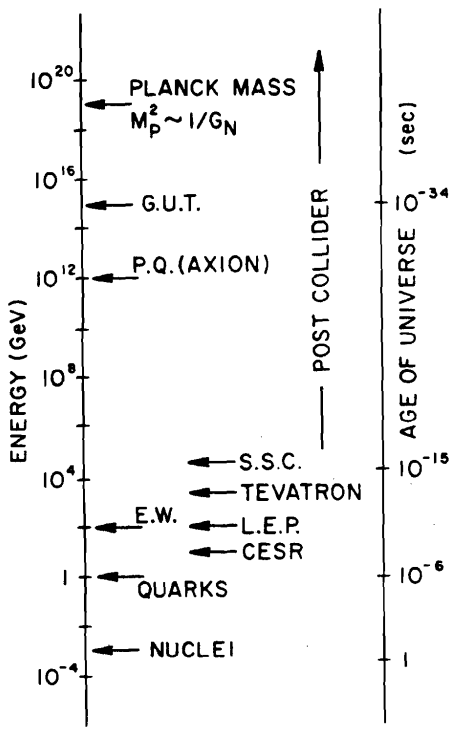
These phenomena and the particles they generate could be observed as "relics" from the big-bang era when, for a brief interval, very high energies prevailed in the universe. Alternately phenomena governed by physics at very high energy could manifest themselves at low energies in the realm of nuclear or atomic physics. Astrophysical and cosmological considerations often set limits on the expected effects or can suggest the specific experimental window. This has led to a close interconnection between particle physics, the study of cosmic radiations and theories of the early universe. We attempt to indicate this relationship by the triangle of Fig. 2. Still, the major source of new information about the universe comes from observational astronomy which has made rapid progress at all wavelengths.

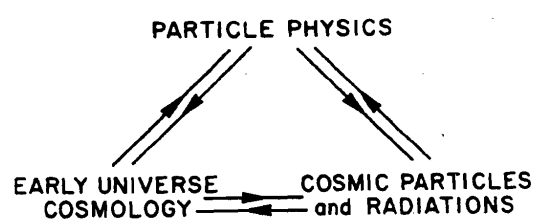
Fig. 1



The energy scale of the post-collider regime.

Fig. 2

Particle physics and its connections in the post-collider regime.



Current experiments that attempt to probe the post-collider energy regime without the explicit use of particle accelerators could be loosely classified into four groupings:

I. <u>Particle properties and searches for proposed particles</u>

a. Nucleon decay.

b. Search for magnetic monopoles.

c. Detection of neutrinos:

Low energy ν_e from sun, stellar collapse

High energy ν_μ, ν_e from point sources

d. Searches for seculative particles such as axions, SUSY partners, WIMPS.

A positive discovery by any of these experiments would have obvious implications for physics at very high energies. It would also alter our views of the very early universe and provide us with a snapshot of the universe at the time that the corresponding particles decoupled.

II. Cosmic Rays and Their Properties

a. Study of very high energy primaries: up to EeV = 10^{18}eV energies.

b. Study of extensive air showers.

c. Search for point sources of very high energy γ's. This is based on the detection of the Cerenkov light emitted during the development of the shower in the atmosphere.

d. Study of the spectrum, composition and interactions of primary cosmic rays.

The relevance of these experiments is more toward the understanding of the acceleration mechanisms that can impart such high energies to single particles and how these particles propagate through the interstellar medium.

III. Laboratory Experiments

a. Search for neutrino mass (almost exclusively from the endpoint of the tritium β-decay spectrum $^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$).

b. Search for neutrinoless double beta decay.

c. Reactor experiments such as neutron oscillations, e.d.m. of the neutron.

These experiments are searching for manifestations at low energy of phenomena that would crucially alter our views of the post-collider energy regime.

IV. Classical and Other Astronomical Observations

a. Study of the 3°K microwave background radiation: spectrum, anisotropy.

b. Space-based observations in the visible, infrared, X-ray and γ-ray bands.

c. High resolution radio-astronomy with large arrays of telescopes.

d. Search for gravitational effects such as waves, lenses and their manifestation on close binary systems.

e. Direct tests of general relativistic effects and deviations from Newtonian gravity.

This last category is very broad and encompasses several communities of researchers using very different tools and with different traditions. However it is the collective information from such experiments that allows us to form an image of the present and early universe; in turn this image permits us to speculate about the physics that governed the universe at those early times of exceptionally high energies.

I listed these groupings of experiments to give a feeling for the broad and varied range of activities that are being pursued. In some respects this differs from collider experiments where all detectors are, at least generically, identical. Particle physicists are mainly involved in experiments in groups I, II. They have brought with them techniques and analysis methods from research using accelerators and the new experiments are becoming large, highly sophisticated and of appreciable cost. Furthermore the size of the experimental groups is reaching towards fifty or more scientists which brings with it many of the organizational and sociological problems of "big science".

It is worth noting that the experiments in group I have so far yielded negative results and thus could only set upper limits. This was particularly valuable in the case of proton decay where theory had made explicit predictions. In contract a positive result would have a momentus impact on our understanding of nature, but the experiments are "high risk" in that there is little other information to be obtained if the primary search is negative. The technical spin-off can be substantial if the experiment is carried out with "state of the art" technology.

The detectors in most cases, must be of large size since the event rate is directly proportional to the area or volume. To address the question of nucleon decay with detectors of very large volume the water Cerenkov detector was introduced, whereas for very high spatial resolution, fine-grained calorimeters of considerable size have been constructed. In the search for magnetic monopoles and for rare cosmic ray events it becomes essential to use very large planar arrays; a device combining many of these properties is the recently proposed cryogenic liquid imaging detector. The problems that can be addressed by various types of detectors are shown

schematically in Fig. 3; the heavy arrows are my own, rather subjective view, of the experiment for which each detector is best suited. In many cases the detectors are located deep underground to avoid the large flux of low energy atmospheric muons and other backgrounds. One can say that in order to explore the post-collider regime one has to be either under the earth's surface or above its atmosphere.

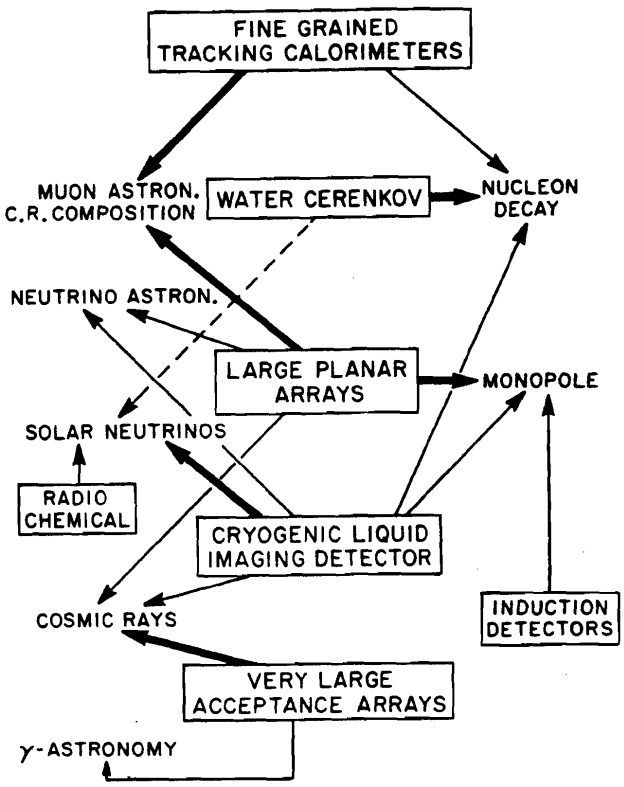


Fig. 3

Detector classes and physics goals

In the following section I will briefly review some of the recent major experiments. Results from these experiments have been published and have been reported on several occasions. In the third section I discuss two experiments that are being prepared for installation in the Gran Sasso Laboratory in Italy. These are typical of the new large underground detectors and their description should give the reader a general idea of the techniques and aims of such efforts. I do not discuss the detection of WIMPS (weakly interacting massive particles) which are covered in part elsewhere in the proceedings.[1] Similarly the current status of double beta decay was reviewed by F. Avignone.[2] A discussion of the dark matter in the universe and of neutrino oscillations in the sun can be found in the presentations of M. Turner[3] and A. DeRujula[4].

During the meeting I had time to describe the general features of the Rochester-BNL-Fermilab cosmic axion search experiment[5]. Because of the limited space this topic is not included in the proceedings.

2. Review of Some Current Experiments

In this section I give a brief update on nucleon decay, monopole searches and the solar neutrino problem. I also mention the principal characteristics of the Fly's Eye experiment and of the DUMAND project.

2.1 Nucleon Decay: The most significant results on nucleon decay have been published by the IMB (Irvine-Michigan-Brookhaven) collaboration.[6] This group has operated a water Cerenkov detector since 1983. The signature is a contained event with energy and momentum balance. Neutrino interactions in the detector can mimic this signature and are the primary source of background.

The detector located in a salt mine near Cleveland has a total volume of 6,800 m^3 of which the fiducial volulme is 3,300 m^3. The depth is 1,700 m.w.e. and the rate of muons traversing the detector is 200,000/day. The present limits are obtained from 417 live days of data taking during which 401 contained events were observed. The total visible energy spectrum for these events is shown in Fig. 4 and it is consistent with atmospheric neutrino interactions. Eventhough one can identify candidate events the limit on the proton lifetime as obtained from this sample is at the 90% confidence level

$$\tau/B\ (p \rightarrow e^+\pi^0) > 2.5 \times 10^{32} \text{ years}$$

$$\tau/B\ (\text{other modes}) \gtrsim 10^{21} \text{ years}$$

In conclusion, if proton decay takes place in the IMB detector it must be at the level of 1% of the neutrino interaction rate. We recall that the prediction from SU(5) symmetry is that $\tau \sim 10^{30}$ years with $p \rightarrow e^+\pi^0$ as one of the dominant modes. It is expected that this experiment will continue to run for another 2 to 3 years in order to improve on the above limits.

The other nucleon decay experiment in the U.S. is located at the Soudan mine in Minnesota and is currently under construction.[7] When completed, in late 1988, it will consist of 1100 tons of fine grained tracking calorimeter. The detector is fabricated in 5-ton modules so that operating experience and preliminary results on muon angular distributions can be obtained at an earlier date.

Similar detectors are in operation around the world and some of them are listed in Table 2.1. Many of these experiments have reported at one time or another candidates for nucleon decay. These reports have not been substantiated by the IMB results.

Table 2.1 Some Nucleon Decay Experiments

Experiment	Detector	Fiducial Mass	Operating Time
IMB	Water Cerenkov	3,300 Tons	400 days
Kamioka[8]	Water Cerenkov	900 Tons	300 days
Soudan II	Track Calorimeter	1,100 Tons	Late 1988
Frejus	Track Calorimeter	800 Tons	200 days
Mont Blanc[9]	Track Chambers	100 Tons	>800 days
K. G. F.[10]	Track Chambers	140 Tons	>3 years

2.2 Monopole Searches: The possibility of existence of magnetic monopoles originated with Dirac's 1931 paper and is reexamined whenever tentative observations are announced, or as new theories demand the existence of monopoles. This is the case presently, when GUT theories[12] imply the existence of very massive monopoles with the usual Dirac charge $g=\hbar c/2e$. The search can proceed with ionization detectors akin to those used for the detection of charged particles or with superconducting induction detectors. Ionization detectors are somehow dependent on the details of the interaction of monopoles with matter and are limited to $\beta>10^{-4}$; but they can be made to cover large areas at a moderate cost. Induction detectors on the other hand respond to monopoles of any velocity and the observed signal must correspond to a change of flux through the coil exactly equal to $2\Phi_0 = 2\pi(\hbar c/e)$; however it is difficult and expensive to construct induction detectors of large dimensions.

Another technique used to search for magnetic monopoles is by etching plastic materials, such as "Lexan", CR39 or mica, which maintain the defects (discolorations) produced by the passage of a monopole for a long time (millions of years). When suitably etched these materials reveal pits along the track which can then be easily recognized under a microscope. This technique can be applied to geological samples which, of course, had a very long time of exposure. The sensitivity does however depend crucially on the velocity of the monopole.

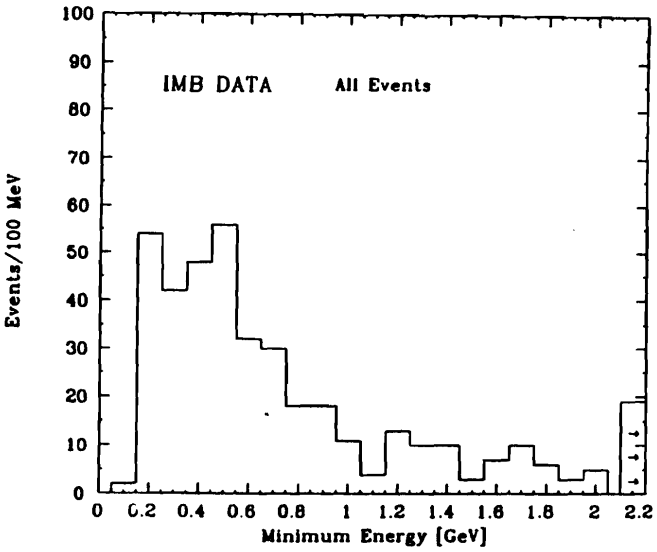


Fig. 4

Minimum energy of 401 contained events from the IMB experiment (ref. 6).

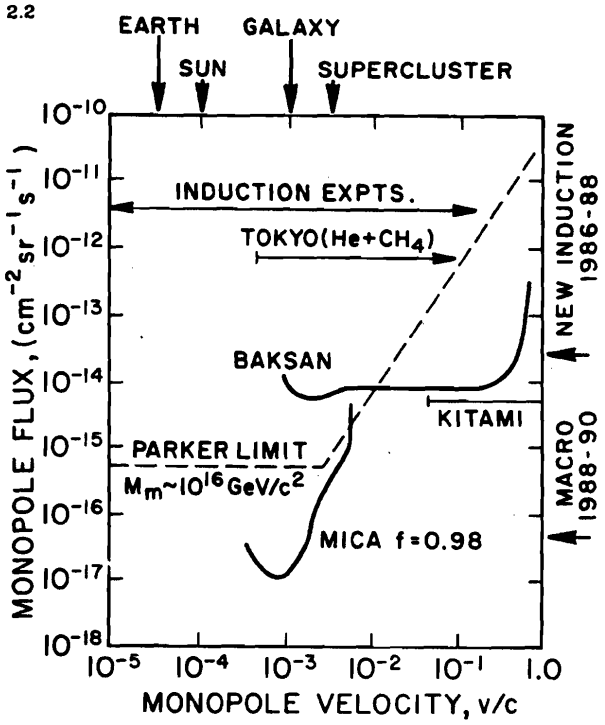


Fig. 5

Present limits on the flux of magnetic monopoles including the sensitivity level of future experiments.

Ionization detectors have been operated by many groups: Texas A&M, UC San Diego, Pennsylvania, Baksan in the USSR, etc. They have, typically, areas of 10-100 m^2 and no new data have been reported.(13) Induction detectors are operated by Stanford, IBM, Chicago-Fermilab-Michigan collaboration, Imperial College in the UK, and others.(14) These detectors are already multiloop, have typically an effective area of 1 m^2 and rely on a coincidence in two planes of the detector. In spite of an occasional signal no events have been reported so far. At the present time, most of these groups are upgrading their detectors to areas ~10 m^2.

The limits on monopole flux set by the various experiments are shown in Fig. 5 as a function of velocity. The "yardstick" in such monopole

searches is the Parker bound which is established by the existence of the intergalactic magnetic field of 3×10^{-6} Gauss over distances $\ell\sim10^{23}$cm. A monopole flux higher than

$$F_{PB} = 10^{-15}\ \mathrm{cm}^{-2}\ \mathrm{sr}^{-1}\ \mathrm{sec}^{-1}$$

would short out the intergalactic field.[15] This result depends on the velocity as shown in the figure. The results of the geological technique mentioned earlier are included in the figure and are the only ones below the bound.[16] The limits expected by the new induction experiments[17] and by a new large area ionization detector[18] are also shown.

2.3 The Solar Neutrino Problem Neutrinos are copiously produced in any star and for the sun one can make reasonably accurate predictions of the neutrino flux from various nuclear reactions. Some of these reactions produce neutrinos with a continuous spectrum while for others the neutrinos are monoenergetic. The expected solar neutrino flux[19] at the earth is shown in Fig. 6. The highest energy neutrinos come from

$$^{8}B \rightarrow {}^{8}Be + e^{+} + \nu_e \qquad 14.1\ \text{MeV end-point}$$

whereas the most copious flux arises from

$$p + p \rightarrow d + e^{+} + \nu_e \qquad 0.42\ \text{MeV end-point}$$

R. Davis and his collaborators[20] have for many years studied solar neutrinos by the capture reaction

$$\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^{-}$$

where the ^{37}Ar is detected by radiochemical methods. The Q-value (threshold) for this reaction is 0.814 MeV and therefore it is sensitive almost exclusively to the neutrinos from ^{8}B decay. These experimenters find a flux

$$2.1 \pm 0.3 \quad \text{SNU}$$

to be compared with the flux predicted from theory

$$5.8 \pm \ ? \quad \text{SNU.}$$

[One SNU (solar neutrino unit) is defined as 10^{-36} captures/atom-sec]. The theoretical rate depends on the ninth power of the sun's interior temperature and thus is quite sensitive to the models of the sun and to our input assumptions. Another explanation of the discrepancy is the presence of resonant neutrino oscillations[21] which could transform the ν_e to ν_μ, ν_τ, leading to reduced flux.

To address this problem a new experiment using gallium is being prepared. In this case the capture reaction

$$\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^{-}$$

has a Q-value of 0.236 MeV and therefore it will proceed with the ν_e from the pp reaction. The solar neutrino flux for this reaction is calculated to be 107 SNU so that with a 30 Ton detector one expects 1000 events/yr against a background of 70 events/yr. The experiment has been approved for the Gran Sasso laboratory and the necessary tonnage of gallium could be assembled in 2-3 years.

An alternate approach to the radiochemical experiments is to attempt to detect directly the elastic scattering of ν_e from electrons.

$$\nu_e + e^- \rightarrow \nu_e + e^-$$

Since both Z° and W exchange contribute to this process, the cross section is larger than for the purely neutral current reactions. Furthermore the e^- follows the incident neutrino direction and the electron spectrum can be measured. The recoil electron spectrum per detector atom is shown in Fig. 7 for neutrinos from the various solar reactions. Clearly the difficulty of these measurements is the detection of such low energy electrons in the presence of background.

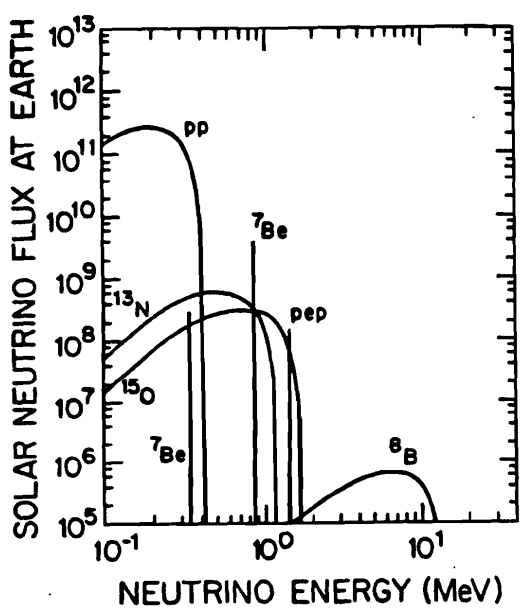


Fig. 6 The flux of solar neutrinos at the earth (cm^{-2}-sec^{-1}); for continuous spectra the differential flux is per MeV.

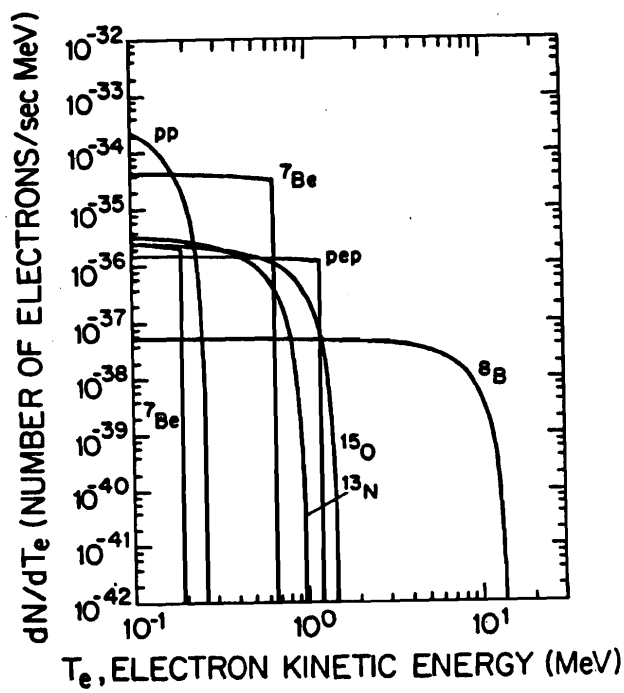


Fig. 7 The recoil electron spectrum from solar neutrinos interacting with one electron $\nu_e + e^- \rightarrow \nu_e + e^-$.

One proposal is to use the Kamioka detector[8,22], or its upgraded version with a threshold of $E_e > 5$ MeV and a concentrated effort is being made to reduce the background in this energy region. Another proposal involves the liquid argon imaging detector ICARUS[23] which is discussed in the next section. A third proposal is to use heavy water so as to exploit the charged current reaction

$$\nu_e + d \rightarrow p + p + e^-$$

which has a Q-value of 1.44 MeV. It may even be possible to detect the neutrons from the neutral current reaction

$$\nu + d \rightarrow p + n + \nu$$

followed by neutron capture on a deuteron with the emission of 6.25 MeV γ, ($n+d \rightarrow {}^3H+\gamma$). A large volume of D_2O would be used as a Cerenkov detector to be installed in Sudbury in Canada.[24]

2.4 <u>The Fly's Eye Experiment</u>: This experiment is designed to detect very high energy primary cosmic rays by observing the fluorescence induced in the atmosphere by the air shower. The path of the air shower is detected by an array of sixty-seven 62-inch mirrors. The mirrors are housed in motorized mounts, each mirror being viewed by a cluster of 14 photomultipliers with appropriate light collectors. A schematic view of the experiment including a second array which is currently being installed is shown in Fig. 8. The mirrors are oriented so as to cover a large portion of the sky - as a fly's eye - and since showers can be detected at large distance the effective acceptance of the detector is 10^7 m^2-sr for $E \sim 10^{17}$ eV.

The detector can operate only on moonless and cloudless nights but has logged in excess of 10^7 sec of data taking. Primaries with energy of 20 EeV

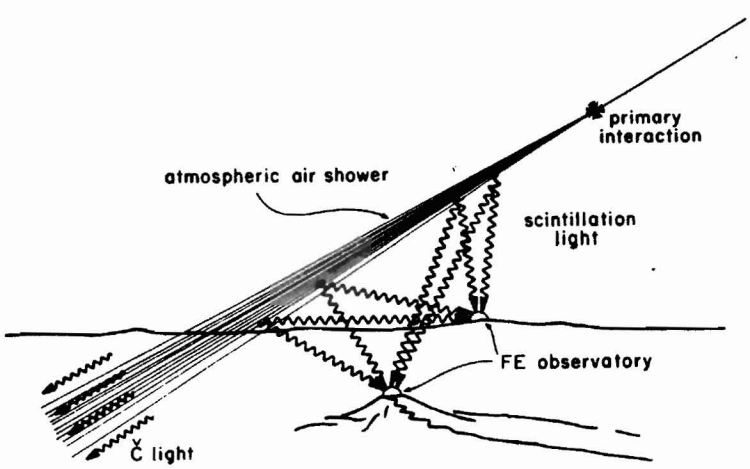


Fig. 8

Schematic sketch of the Fly's Eye experiment (ref. 25).

(2×10^{19} eV) have been detected. It has been predicted that primaries with energies E > 70 EeV will be degraded because they are above the threshold for pion production when scattering from the 2.7°K background radiation

$$p + \gamma \rightarrow p + \pi^{o}$$

Thus a sharp cut-off may exist in the cosmic ray spectrum, consistent with the data from Fly's Eye. However the rate of such high energy primaries is so low that the data are not as yet conclusive.

Fly's Eye does also detect the direct Cerenkov light generated by electron-rich showers, but with much reduced acceptance; such showers could originate from very high energy γ-rays. Groups from the University of Michigan and the University of Chicago plan to add an 1100 m^2 muon and charged particle detection system to the present setup.[26] The purpose of this instrumentation is to correlate the Cerenkov pulses with shower activity and composition. It may even be possible to detect neutrino interactions by observing an upward going electron shower.

2.5 <u>The DUMAND Project</u>: The acronym (<u>D</u>eep <u>U</u>nderwater <u>M</u>uon <u>A</u>nd <u>N</u>eutrino <u>D</u>etector) correctly describes this project.[27] The idea is to locate an array of large photomultiplier tubes deep in the ocean off the island of Hawaii. At a depth of 4.7 km the water is clear and there is little biological or other luminous activity. Thus the Cerenkov light from high energy muons would reveal their direction, and with less precision - through δ-rays - their energy. Down-going muons could originate from atmospheric sources but upward (zenith angle >70°) muons come only from neutrino interactions. Thus the basic goal of the detector is neutrino astronomy.

The full complement of the proposed detector is shown in Fig. 9. The 16" photomultipliers are mounted on strings; there are 21 tubes spaced 25 m apart for a 500 m long string. Six strings are moored to each cable and are spaced at 50 m from one another. Finally six rows of cables are deployed with a lateral separation of 50 m. Thus the total volume of the array will be

$$V = 3.1 \times 10^{7} \ m^{3}$$

The effective volume is considered to be about ten times larger.

At present the DUMAND group is developing instrumentation and is studying the effects of the deep sea environment on the photomultipliers. The main thrust is to operate a prototype of the string and gain experience from its response. Following that step a triad of full strings will be

installed leading to the eventual deployment of the entire array.

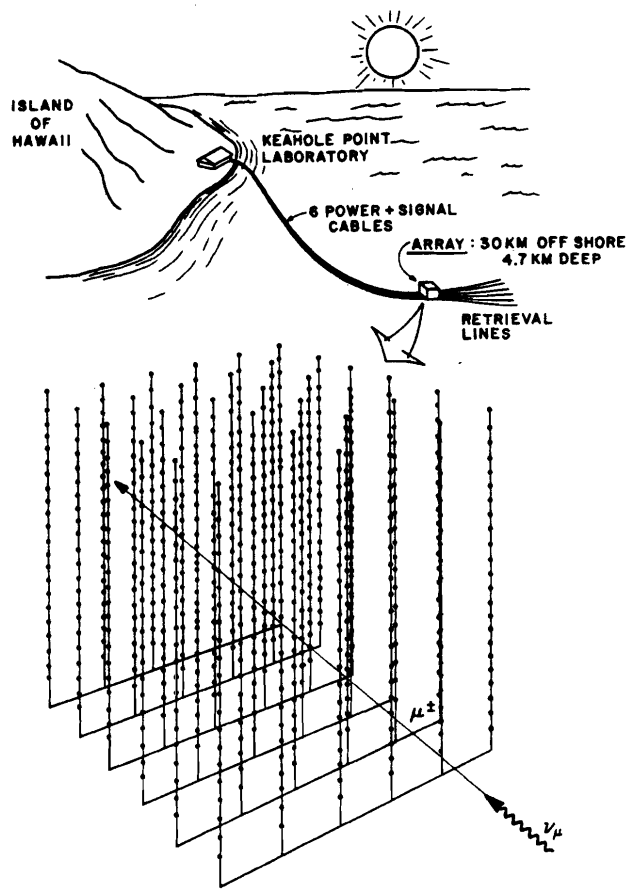


Fig. 9

Schematic sketch of the DUMAND project (ref. 27).

3. <u>The MACRO and ICARUS Experiments</u>

These recently proposed experiments are good examples of large detectors that would have the capability of exploring the post-collider regime. The detectors will be installed in the Gran Sasso underground laboratory which is now being completed in central Italy. The laboratory is part of the construction of a new vehicular tunnel east of Rome; the location and layout of the lab are shown in Fig. 10. There are three experimental halls typically 100 m long by 20 m wide each. The overburden is in excess of 4,000 m.w.e. The easy access - as compared to mine shafts - and the logistic and support structure should make Gran Sasso one of the best laboratories for large underground experiments.

At the G.S. depth, atmospheric muons loose about 1 TeV of energy; the integral spectrum above this range is roughly given by

$$F_{\mu}(E>E_0) \simeq 10^{-4}\left(\frac{E_0}{\mathrm{TeV}}\right)^{-2} \qquad m^{-2}sr^{-1}sec^{-1}$$

The reduction in penetrating muons as compared to the flux at sea level is

of the order of 10^6. This is essential for these experiments which have a large area, and by necessity must have a loose trigger and long time gates. For instance, a monopole with $\beta=10^{-3}$ takes 15 μsec to traverse 5 meters which is a typical dimension of the apparatus; the drift time in 2 m of liquid argon is of the order of 1 msec. Yet, evenat this depth the singles rate at the experimental location is 3 m^{-2} sec^{-1} indicating some of the difficulties encountered by very low rate experiments.

3.1 The MACRO Experiment: The acronym for this experiment stands for Monopole And Cosmic Ray Observatory; it is being carried out by a collaboration of some 40 Italian and 40 U.S. physicists. The basic features of the experiment are:

a) large surface area

b) good spatial and energy resolution

c) very good timing resolution.

It consists of liquid scintillator counters which are sensitive to 1/10 of minimum ionization and have a time resolution of 2 nsec. The scintillator arrays are separated by ~ 6 m as can be seen in the schematic drawing of the apparatus (Fig. 11). The space between the scintillators is filled with concrete absorber to filter out strongly interacting particles. Sets of limited streamer tubes are placed in layers between the concrete to provide tracking information. It is expected to achieve $\Delta x \sim 1$ cm and $\Delta\theta \sim 0.2$. Finally sheets of Lexan and C39 will be interspersed in the absorber; these detectors integrate the monopole flux and it is planned to develop them after several years of operation.

The detector consists of nine 12 m wide by 5.7 m high and 12.4 m long for a total length of 111.6 m. This yields a top and bottom surface of ~ 1,400 m^2. To evaluate the overall acceptance we note that a simply connected surface of total area A_T has the same acceptance as a plane surface $A_P = (1/2)\ A_T$. The acceptance for isotropic flux of a plane surface A_P is,

$$\epsilon = 2\pi A_P = 4\pi\left(\frac{1}{4}\ A_T\right) = 4\pi A_E$$

where we have defined an effective area $A_E = (1/4)\ A_T$. For the MACRO detector

$$A_T = 4{,}100\ m^2$$

$$\epsilon = 4\pi\ (1/4)\ A_T \simeq 13{,}000 \quad m^2\text{-sr}$$

Thus, 1 event in 1 year of operation corresponds to a flux $F = 0.25 \times 10^{-15}$ $cm^{-2}sr^{-1}sec^{-1}$, namely four events/year at the Parker bound. In contrast, the rate of atmospheric muons crossing the detector is 1 Hz so that in one year a sample in excess of 10^7 will be available. This could be useful in studying the composition of showers with several muons. Of course, should reports of muon clustering at particular celestial orientations persist until MACRO becomes operational, it will be possible to check such effects with great accuracy.

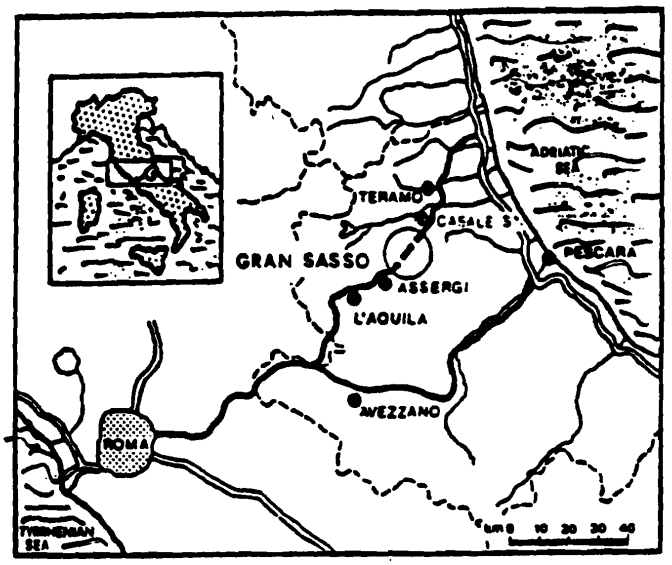


Fig. 10
Location of the Gran Sasso laboratory in Italy

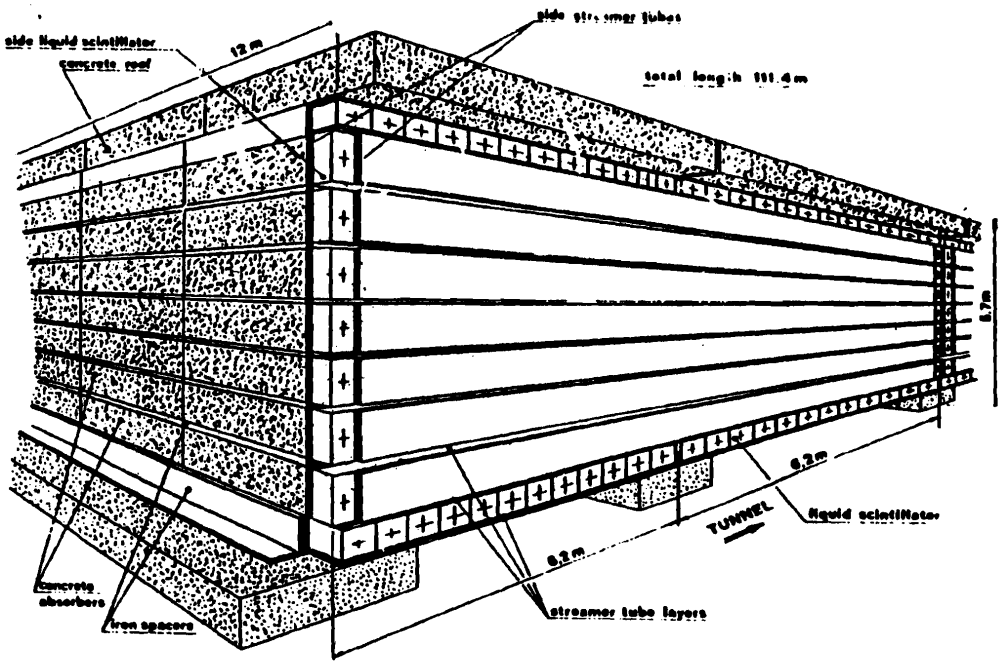


Fig. 11
Schematic of one module of the MACRO experiment (ref.18).

Another important goal of MACRO is to search for and identify point sources of high energy neutrinos; it could also check for neutrino oscillations by exploiting the difference in path length of atmospheric neutrinos that traverse the earth when coming from below the horizon. The experiment is also sensitive to exotic particles that are penetrating enough to reach the detector.

3.2 Neutrino Astronomy: Since the detection of high energy neutrinos in 1962 it became clear that it would be possible to detect neutrinos from astronomical sources if a large enough detector were available. The neutrinos interact in the rock under the detector

$$\bar{\nu}_\mu + p \rightarrow n + \mu^+$$

$$\bar{\nu}_\mu + n \rightarrow p + \mu^-$$

and the produced muons are observed in the detector. The difficulty is in identifying the neutrino induced muons in the large flux of atmospheric muons. However, muons observed below the horizon cannot be atmospheric and thus must come from neutrino interactions; the directionality of the muons reflects the neutrino direction and should be a sufficient constraint to separate point-sources from the remaining isotropic background of atmospheric neutrinos.

The rate of neutrino induced muons crossing the detector is almost independent of the energy. We write

$$R_\mu = F_\nu \cdot \sigma \cdot \ell \cdot \rho$$

$F_\nu \sim 10^2 [E_\nu/\mathrm{GeV}]^{-2}$	$m^{-2}sr^{-1}sec^{-1}$
$\sigma \sim 10^{-38} [E_\nu/\mathrm{GeV}[$	cm^2
$\rho \sim 6 \times 10^{23}$	nucleons/g
$\ell \sim 500\ [E_\nu/\mathrm{GeV}]$	g/cm^2

Here ℓ is the maximal length of rock that a muon of energy E_ν could traverse, and therefore represents the effective target length. Combining these expressions we find a muon rate of order

$$R_\mu \simeq 3 \times 10^{-10} \quad m^{-2}sr^{-1}sec^{-1}$$

Given the acceptance of MACRO one then expects ~100 events/year. This is to be contrasted with the yield from certain astronomical sources which are estimated to yield 10-30 counts/year.

The preferred candidates for intense neutrino point sources are X-ray binaries; as already mentioned, they must be located in the sourthern

hemisphere in order to be below the horizon at Gran Sasso. The expected neutrino flux is calculated on the basis of the observed high energy γ-rays[28] from sources such as LMCX-4 (in the large Magelanic cloud), VELA X-1, or CYG X-3. Yet the γ-ray flux from these sources is not known with great certainty and this is reflected in the differing estimates on the feasi-bility of neutrino astronomy.

3.3 The ICARUS Experiment: As the acronym indicates "Imaging Cosmic And Rare Underground Signals"[23] the detector for this experiment will have very high spatial resolution. It will consist of a liquid argon volume in which the tracks of charged particles are established with resolution of 2 mm or better. The primary ionization electrons along the track are drifted in a 1 KV/cm field toward three readout planes. There is readout along X, along U and along V to provide a point in the plane and the Z coordinate is obtained from timing (TPC). The drifting electrons pass through the wire planes and induce a charge on the wires. The FET amplifiers are sensitive enough to detect the induced charge eventhough no amplification has taken place in the argon.

A schematic of one readout unit is shown in Fig. 12b. The maximum drift distance is 2.3 m requiring an anode potential of 250 KV. The detector is continuously active, the contents of each wire being stored in memory; if a trigger occurs then the contents of the memory are recorded while otherwise the memory is overwritten. Since there is no amplification in the argon the sense wires are relatively thick (100 μm) which is necessary in order to support a 30 m span. There will be approximately 200,000 channels and the maximum drift time is 1.2 msec. To achieve such long drift distances it is important to maintain very high purity in the argon. It has also been proposed to use an argon-methane mixture in order to increase the free proton content of the detector.

The layout of the detector in the gallery is sketched in Fig. 12a. The liquid argon cylinder is 30 m long and 14 m in diameter; this provides a volume of 4,600 m^3 or 6,500 Tons of argon. The surface area is 1,600 m^2 and therefore the acceptance is 5,000 m^2-sr. An important feature of the detector is the presence of a magnetic field; this will be axial and of strength 0.5T. An external muon detector using resistive plate counters will surround the coil in order to provide timing and certain triggers. The principal trigger is based on pattern recognition of the information collected by the readout planes.

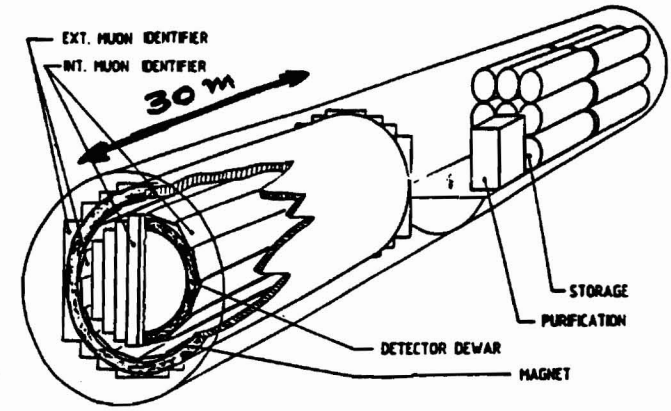
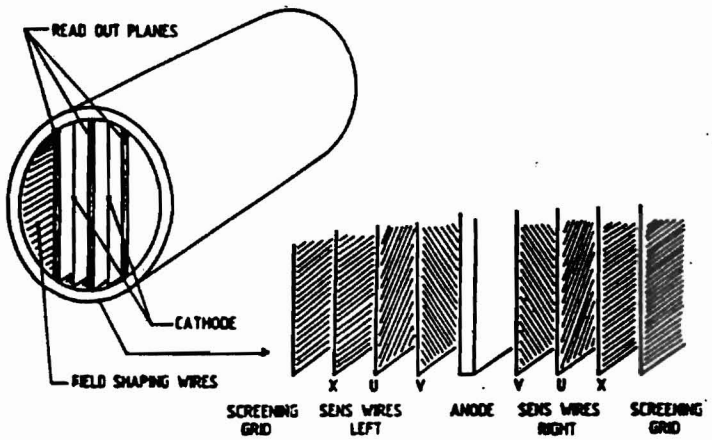


Fig. 12
Schematic of the ICARUS experiment (ref. 23).

(a) Layout in the tunnel



(b) Details of the electron TPC read out planes.

A detector such as ICARUS will have excellent calorimetric properties, with energy resolution $\Delta E/E \sim 1.7\%/\sqrt{E}$. It should also have a low energy threshold and it has been proposed that the threshold could be lowered below 10 MeV. This depends, among other factors, on natural and delayed radioactivity and on electronics noise. It is however clear that ICARUS is representative of a new generation of detectors with multiple capabilities; these could be decisive for the detection of new phenomena of which we are presently unaware.

In the more conventional arena ICARUS could search for nucleon decay with complex topologies and, in view of its excellent resolution, the background from neutrino interactions could be greatly reduced. On the other hand its volume is not much larger than that of IMB and even with a methane-argon fill the number of free protons is limited. The detector should be able to detect solar neutrinos from the ^8B decay through their scattering off electrons. If the recoil electron threshold is $E_e \gtrsim 4$ MeV then 9 events/day are expected while for $E_e \gtrsim 7$ MeV there are 3 events/day.

ICARUS is well suited for the detection of low energy $\nu_e, \bar{\nu}_e$; the presence of significant fluxes of such neutrinos could be expected from supernovae explosions and even from terrestrial reactors. Of course atmospheric neutrinos and high energy neutrinos can be detected in the usual way. If monopoles catalyze proton decay in the sun (Rubakov effect)[29] there should be a significant flux of 100 MeV neutrinos which would be detectable providing indirect evidence for magnetic monopoles.

The large volume, the cryogenic load and the ambitious readout scheme make the construction of ICARUS a real challenge. On the other hand such a detector could address many of the current questions concerning cosmic radiations, and one could reasonably hope that it would uncover new physics as well.

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