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NON-ACCELERATOR EXPERIMENTS

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I. INTRODUCTION

The title of my talk, "Non-accelerator Experiments" sounds more like a budget item than a coherent field of physics. The aims pursued in these experiments overlap often with aims pursued in accelerator experiments. Clearly, we are dealing with a lot of good questions, sometimes disguised as theories.

Table I gives a partial list of non-accelerator experiments. Most of these experiments have been discussed at this Conference. Since some have been covered by other rapporteurs, I shall confine myself to a subset.

TABLE I

SOME NON-ACCELERATOR EXPERIMENTS

Proton decay
$n - \bar{n}$ oscillations
Cygnus X-3
ν masses
$\beta\beta$ decay (with and without 2ν)
ν oscillations
Axions
WIMPS
Atmospheric ν's
Solar ν's
Extra solar ν's
  a. Supernovae
  b. H.E. ν's
New particles (KGF)
Dark matter
Gravitational waves
Neutral current effects in atoms
Fifth force
Electric dipole (n,e, atoms)
Free quarks
Magnetic monopole

Much physics done in the eighties, especially in the non-accelerator field, can be characterized as the "physics of pushing limits". Some of these limits (masses, mixing angles, abundances, etc.) may be too small to be detected with present day techniques. They may even be zero, a number that experiment can approach, but not reach; it can only be a theoretical prediction. Experimenters, therefore, must beware of "false positives"!

I belong to the old school that was brought up to talk of experiments in the past tense. However, as rapporteur for non-accelerator experiments, I cannot avoid talking of experiments in progress or planned, though I shall try to minimize this.

II. PROTON DECAY SEARCHES AND THE ATMOSPHERIC NEUTRINO BACKGROUND

Of the few definitive results in the non-accelerator field I shall concentrate on two in particular: (1) Proton decay searches, where the results contradict the minimal SU(5) theory, thus forcing theory into new directions; (2) the observation of atmospheric neutrinos resulting from interactions of primary cosmic-ray protons in the atmosphere, found in agreement with expectations from π,K, and μ decays.

1. The University of California, Irvine; 2. The University of Michigan; 3. Brookhaven National Laboratory; 4. California Institute of Technology; 5. Cleveland State University; 6. The University of Hawaii; 7. University College, London; 8. Warsaw University; 9. Case Western Reserve; 10. The University of Illinois; 11. Lawrence Berkeley Laboratory; 12. Lawrence Livermore National Laboratory; 13. Notre Dame University; 14. Boston University; 15. Fermi National Accelerator Laboratory; and 16. A.T.T. Bell Laboratory.

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Fig. 1 shows the known particle states into which a proton could decay. This could happen in many ways. In fact, if you count all individual members of the singlets, doublets, triplets and quadruplets shown in Fig. 1 you find about 30 different potential two-body-decay modes. I always use "proton decay" as a kind of code word meant to include bound neutron decay, because the term "neutron decay" is ambiguous since it is already used for the beta-decay of a free neutron to a proton. The masses of the particles shown are all well known except for the masses of the neutrinos, for which we only know upper limits.

Table II gives the expected branching ratios for the minimal SU(5) theory, as compiled by W. Lucha from many theoretical estimates with a variety of models used for the nucleon.

To look for proton decay you might like to build a detector that is sensitive to all possible decay modes. But it is nearly impossible to build a detector that is equally sensitive to all modes, and so you have to make a decision which mode you would like to emphasize. The strongest branch in Table II is $e^+\pi^0$, and this is the mode which the IMB experiment was designed to emphasize. It is not widely appreciated, however, that our detector is also sensitive to most other potential modes, though usually less so.

When you build a proton decay detector you have to make a number of compromises: How deep are you going to go; how large is it going to be; what is it going to be made of; how good an energy resolution you should aim at; how well you can recontruct the vertex, and so on. Different researchers have made different compromises. There is a great variation in the depth chosen for the ongoing and proposed experiments. The advantage of going deeper lies in the fact that the flux of cosmic ray muons decreases very rapidly with depth. The IMB detector is located deep enough for us to be able to handle the number of muons, and to distinguish them from a potential proton decay, because of their large energy deposition.

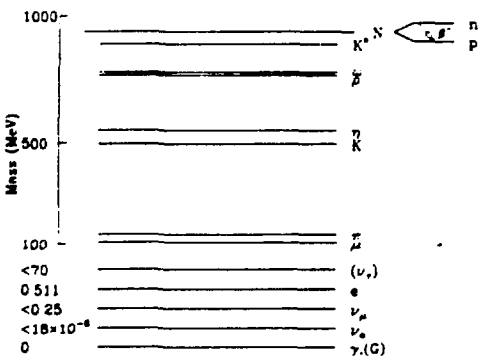

Fig. 1 Masses of particles (in MeV) into which a proton might decay. The hypothetical graviton (G) is included.

TABLE II

Theoretical Branching Ratios for Proton Decay

DECAY MODE	BRANCHING RATIO (%)
$p \to e^+\pi^0$	31 - 43
$p \to e^+\eta$	0 - 8
$p \to e^+\rho^0$	2 - 18
$p \to e^+\omega$	15 - 29
$p \to \bar{\nu}_e\pi^+$	11 - 17
$p \to \bar{\nu}_e\rho^+$	1 - 7
$p \to \mu^+K^0$	1 - 20
$p \to \bar{\nu}_\mu K^+$	0 - 1

At this conference T.J. Haines of our group reported on new a priori calculations of the background due to atmospheric neutrinos, the one background that cannot be reduced, no matter how deep you go. He has calculated the expected event distribution for neutrinos interacting with the water of our detector, yielding a visible energy E_c, which is what we measure. I shall not go into the details of his calculations, as they appear in these proceedings.

Starting from the predictions of Gaisser, Stanev, and others for the flux of atmospheric neutrinos, ν_e and ν_μ, as a function of energy he considers all important interactions due to either charged or neutral currents. For single pions he uses the Fogli and Nardulli model and for multiple pions the parton model. This gives a systematic error of about 30%. Since the agreement *for energies beyond the proton mass is quite* good, we can have confidence in the calculations also below that. Independent calculations on a different model by T.W. Jones and by other members of our group using calculations based on Gargamelle and other bubble chamber data also agree with Haines' calculations; he therefore has the courage to subtract neutrino backgrounds from the observed proton candidate events, thus obtaining somewhat better lifetime limits for most decay

ranches. The important branch $p \to e^+\pi^0$ is ot improved, because it had no candidate.

G. Blewitt, and previously also the Kamiokande collaboration, as well as . Seidel of our collaboration, studied invariant masses for two-body nucleon decay andidates and in this way some ambiguous andidates are removed. From minimal SU(5) theory W. Marciano predicts $4.5 \times 10^{29} \pm 1.7$ years for the partial lifetime of the proton decay branch $e^+\pi^0$. Our experiment, however, gives a lower limit of 2.5×10^{32} years, and if you add the results of the Kamiokande detector you can get a combined lower limit of 3.3×10^{32} years. (See Fig. 2.) H. Meier (Heidelberg Conference, July 1986) adds also the Fréjus result and gets a lower limit of 4×10^{32} years. The experimental limits thus contradict the minimal SU(5) theory. If we believe in the general idea of grand unification, we would expect the proton decay to be governed by a grand unification mass not larger than the Planck mass. This would lead to a lifetime of around 10^{47} years, which would yield of the order of a few decays per hour for the whole earth!

A number of proton decay detectors have recently been improved and a number of new detectors are being proposed. (See Tables III and IV, bases on a compilation by H. Meier.)

As the resolution improves, proton decay candidates can be better resolved from neutrino background. Of the presently active detectors, Fréjus has the best resolution and reports the lowest number of candidates per ton-year of observation.

III. NEUTRINOS

R. Svoboda reported on the search for energetic neutrinos that come through the earth and produce muons that traverse our detector. He sees no indication of point sources in the sky; the upward going muons

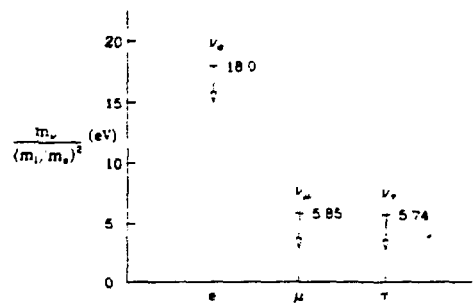

Fig. 2 Limits for partial lifetime $p \to e^+\pi^0$.

TABLE III

RECENTLY IMPROVED DETECTORS

Kolar II	10 mm → 6 mm
	130 ton → 260 ton
IMB II	All 5" PMT → 8"↕
	wavelength shifter plates on all PMT's
	factor 4 gain in light collection
Kamiokande II	Time digitizer on all PMT's
	4π veto shield (H_2O active)
	Factor 4-6 of vertex reconstruction

observed are compatible with the rates expected from atmospheric neutrinos.

Neutrinos were discussed in general by Prof. Altarelli. Let me just add a few remarks.

One can make some "reasonable" conjectures about neutrino masses:

1. Either all three masses are zero, or they are all finite.

2. If the masses are finite, no two are equal, i.e., all mass differences are finite.

TABLE IV

Future Projects

Soudan II	1200 ton, 2 mm Fe
under construction	Drift tube sampling
	$\frac{dE}{dx}$
Super Kamiokande	46,000 m^3 H_2O
proposal	11,000 PMT's
	15 x Kamiokande II!
ICARUS	4500 m^3 liquid Ar, CH_4
proposal	Cryogenic Imaging Chamber
	0.5T magnetic field

3. All mixing angles are either zero, or they are all finite.

GUTS which have right-handed heavy neutrinos, e.g., SO(10), lead to the Gell-Mann - Ramond - Slansky - Yanagida "see-saw" relation:

$$m_{\nu_e} : m_{\nu_\mu} : m_{\nu_\tau} \approx m_e^2 : m_\mu^2 : m_\tau^2$$

If we make use of this relation, we can obtain from the experimentally established upper limits for the neutrino masses a "figure of merit" for each neutrino: $m_\nu/(m_i/m_e)^2$ (see Fig. 3). If this relation is correct, an improvement in the measurement of the mass of the electron-neutrino to ~ 5 eV, the best that could be expected from the ongoing tritium experiments, would make the three figures of merit approximately equal.

The solar neutrino problem is still with us. There are some new ideas: The Mikheev-Smirnov-Wolfenstein matter oscillations have been invoked to explain the signal obtained in the chlorine experiment by Davis, Rowley, and Cleveland, who find about one-third the amount of ^{37}A expected from the standard solar model. Since there are several possible solutions for the neutrino oscillation case, the proposed gallium experiment, which is now getting underway in the Gran Sasso Laboratory, may or may not be able to decide whether the amount of ^{8}B produced in the sun is compatible with the standard model. If neutrinos oscillate into "infertile" ones, they may oscillate back into fertile ones, as they traverse the earth, according to A. Baltz and J. Weneser (Phys. Rev. D15, to be published). A number of "on-line" solar neutrino searches have been proposed; the Kamiokande detector is ready for such a search, and it will be interesting to see whether a signal above background will be obtained.

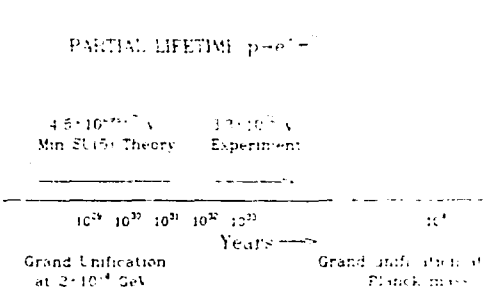

Fig. 3. "Figure of merit" for neutrinos, according to the see-saw relation.

IV. CYGNUS X-3

Cygnus X-3, a double-star with a period of 4.8 hr., that "accelerator in the sky" which just now is a "non-accelerator", has been studied with many detectors, with only Soudan I consistently claiming that muons from the direction of Cygnus X-3 can be detected underground at the "correct" phase. M. Marshak gave a detailed account of the present status of these observations and emphasized that the results of different observers cannot be reconciled. This may partly be due to the great variability of the source, and we must await further observations, when Cygnus X-3 "switches on" again.

V. DOUBLE-BETA-DECAY

In double-beta-decay experiments, reported by D.O. Caldwell, no evidence for no-neutrino double-beta-decay has yet been found. Should it be found, lepton conservation would have to be given up. From the limits obtained, one can deduce limits for the masses and interactions of some hypothetical intermediary particles which would make neutrinoless double-beta-decay possible. But Caldwell emphasized that considerable uncertainties remain, because those limits depend on uncertain estimates of the nuclear matrix elements involved.

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