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TITLE: SUMMARY - NEUTRINOS AND NONACCELERATOR PHYSICS

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SUMMARY - NEUTRINOS AND NONACCELERATOR PHYSICS

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INTRODUCTION

The parallel sessions on neutrinos and nonaccelerator physics were highlighted by a number of extremely exciting new results. These topics proved to be of great interest to the conference attendees; as a result, the attendance in the sessions overflowed the room.

The Standard Model[1] of electroweak and strong interactions has been with us a long time. It has been subjected to a large number of tests and has proven extremely successful in explaining the wealth of elementary particle and nuclear physics data. Since the formulation of the Standard Model, there have been only two major surprises in elementary particle physics:

1) The existence of the third generation of quarks and leptons.
2) The extreme heaviness of the top quark.

It is significant that these two surprises are related to the most glaring deficiencies of the Standard Model, namely the unexplained issues of the existence of generations and the masses of the fundamental fermions.

Many of the plenary talks at this conference concentrated on tests of the Standard Model.[2] In all cases, except those related to subjects covered by this parallel session, the Standard Model passed these tests with flying colors. It is important to recognize that several nonaccelerator results discussed in this session are <u>inconsistent with the Standard Model</u> and <u>will require its alteration or extension</u> if they prove correct. These results include:

1) The deficiency in the number of detected solar neutrinos compared with expectations.
2) The possible correlation of the detected number of solar neutrinos with sunspot number.
3) The nongamma-like signals observed at ultra high energies from the x-ray binaries Cygnus X-3 and Hercules X-1.
4) The possible existence of a 17-keV neutrino that mixes with ν_e.

It is striking that in nuclear and elementary particle physics, fields dominated by accelerator-based experiments, the results that point towards the need for changes in the accepted picture of the physics of these fields appear to be coming from nonaccelerator experiments.

The remainder of this paper contains brief synopses of the major topics discussed in the neutrino and nonaccelerator parallel sessions. Further details can be found in the contributed papers.

DARK MATTER

The subject of dark matter was discussed by Dave Caldwell and Kim Griest in the parallel sessions, and by Christopher Stubbs in the plenary session. Evidence from a number of sources indicates that luminous matter comprises only a small fraction of the total mass in the universe. Expressed in terms of the mass density needed to close the universe (Ω), the luminous matter comprises only about 0.007Ω. In order to account for nucleosynthesis, the density of baryons must be between 0.02-0.11Ω. Thus we see that there must be missing baryonic matter. Experiments, searching for evidence of gravitational microlensing, are beginning to look for MACHOS (massive astrophysical compact halo objects) such as brown dwarfs, "Jupiters," neutron stars, white dwarfs and massive black holes, to account for the missing baryonic matter.

Even if the missing baryonic matter is found, it cannot be nearly enough matter to close the universe. There are theoretical prejudices for $\Omega=1$, thus the rationale for searching for nonbaryonic dark matter. Possible candidates include massive (but light) neutrinos (hot dark matter), or a variety of possible cold dark matter particles including axions and weakly interacting massive particles (WIMPS). Note that if a 17-keV neutrino exists (see below), it cannot be dark matter as it is much too massive and would overclose the universe.

Most of the searches for cold dark matter involve searching for the existence of relic particles left over from the big bang. Some of these experiments have utilized detectors built to look for double beta decay, an example of the intersection between nuclear physics and both particle physics and astrophysics. Great progress has been made in ruling out a number of dark matter candidates although several possibilities remain. More sensitive, dedicated experiments are planned to improve the sensitivity of the searches.

NEUTRINO OSCILLATIONS AT ACCELERATORS AND REACTORS

Bill Metcalf reviewed the status of accelerator and reactor searches for neutrino oscillations. Neutrino oscillations require physics beyond the Standard Model, namely the existence of both massive neutrinos and mixing between the lepton generations. No terrestrial evidence for neutrino oscillations has been obtained although the limits (expressed in terms of the mixing angle and the mass difference between the neutrino species) have steadily improved. Several new experiments at CERN, Fermilab, Rutherford, LAMPF and a reactor in California, should lead to even more sensitive searches.

Richard Seto described a search for neutrino oscillations performed at Brookhaven. Steve Mintz described calculations for the scattering of neutrinos from ^{13}C.

VERY HIGH ENERGY AND ULTRA HIGH ENERGY GAMMA-RAY ASTRONOMY

Dick Lamb reviewed the status of Very High Energy (VHE, ~1 TeV) and Ultra High Energy (UHE, >100 TeV) gamma ray astronomy. Observations at these energies address some fundamental particle physics questions such as the origin of cosmic rays, the interactions of gamma rays at energies well above those available at terrestrial accelerators, and the possible existence of new particles. Observations over a decade ago indicated that Cygnus X-3, a gravitationally-bound binary system of a neutron star and a main sequence star, was the brightest UHE source in our galaxy and may well be the source of all high energy cosmic rays. There was also evidence that the interactions of the PeV photons from Cygnus X-3 with the earth's atmosphere were more hadron-like than photon-like. Unfortunately, all detections of Cygnus X-3 since 1985 are marginal at best; it appears as if Cygnus X-3 has "turned-off."

More recent (1986) observations of Hercules X-1, another x-ray binary system, also indicated anomalous photon interactions. However, since 1986, Hercules X-1 has not been convincingly detected at VHE or UHE. We must simply hope that new, more sensitive detectors, including the upgraded CYGNUS array in Los Alamos and the new, large CASA array in Utah, will find new evidence for emissions from sources.

On the other hand, the Crab nebula has been convincingly observed ($>20\sigma$) by an air-Cherenkov detector at the Whipple observatory (it is a "standard candle"). This observation utilizes imaging of the Cherenkov image; the photon interactions here (~1 TeV) appear photon-like.

Jim Musser described a search for underground muons from Cygnus X-3 using the MACRO detector, and Jeff Wilkes gave a progress report on DUMAND II.

The future of this field looks intriguing. The GRO satellite may well point the way to new potential sources. A second dish is being added to the Whipple air-Cherenkov detector that should lower its energy threshold and improve its sensitivity. New ideas include an array of air-Cherenkov mirrors (CASITA), a "lake" air-shower detector to extend the all-sky, 24-hour/day advantages of the air-shower technique to the VHE regime (MILAGRO), and the combining of the air-Cherenkov and air-shower techniques to sample each shower at two points in its development (AIROBIC). These new techniques should greatly improve on present sensitivities and, hopefully, develop the science and answer the outstanding questions.

DOUBLE BETA DECAY

The subject of double beta decay was reviewed by Frank Avignone. This is another area where the overlap between nuclear and particle physics is manifest. Two-neutrino double beta is an allowed, although strongly suppressed, process. Neutrinoless double beta decay is forbidden in the Standard Model: it would require the existence of massive Majorana neutrinos. It is impressive that two-neutrino double beta decay has been convincingly observed in three nuclei: ^{76}Ge, ^{82}Se, and ^{100} Mo. The observed rates are in good agreement with the expected rates calculated using the Quasiparticle Random Phase approximation.

There is no evidence for neutrinoless double beta decay, although the limits have improved significantly in the past few years. New, more sensitive experiments are being constructed. It is interesting to note that many of the best limits on the existence of cold dark matter come from detectors designed to search for double beta decay.

SOLAR NEUTRINOS

The subject of solar neutrinos was discussed in the plenary session by Gene Beier and in the parallel sessions by Gene Beier and Dave Wark. An illness in his family prevented Ken Lande from presenting results from the Homestake ^{37}Cl experiment: fortunately Gene Beier was briefed on the Homestake results and was able to present them at the conference.

There is overwhelming evidence from both the Homestake ^{37}Cl experiment and the Kamioka water Cherenkov experiment that there is a large deficit in the number of high-energy neutrinos coming from the sun. These experiments detect neutrinos primarily from the ^{8}B reaction: the flux of these neutrinos is extremely sensitive to the temperature of the core of the sun. The favored solution to this problem is matter-enhanced neutrino oscillations[3] in which the ν_e oscillates into some other type of neutrino on its way out of the center of the sun. As in vacuum neutrino oscillations, matter-enhanced neutrino oscillations require both neutrino mass and mixing, which are not present in the Standard Model. However, because of the strong dependence on the temperature of the solar core, it is impossible to rule out a small cooling of the solar core as the culprit.

Neutrino capture on ^{71}Ga has a much lower energy threshold than capture on ^{37}Cl. Thus the gallium experiments are sensitive to neutrinos from the pp reaction that provides most of the energy of the sun: the expected neutrino rate for gallium experiments, 132 SNU (solar neutrino units), is insensitive to the temperature of the solar core. Dave Wark described new results from the SAGE experiment being run at Baksan, USSR. The results from five months of running with 30 tons of gallium give a best fit result of 20 SNUs and a 90% CL upper limit of 72 SNUs, well below the expected Standard Model result. If this result holds up, the solution to the solar neutrino problem lies in neutrino properties, matter-enhanced oscillations being the probable solution.

The SAGE experiment has recently begun data-taking with 58 tons of gallium: new results should be available in several months. They are also planning to calibrate their entire system (neutrino capture, germanium extraction and counting) using a ^{51}Cr source inside a gallium tank within the next year. We were also happy to hear that the GALLEX experiment in Europe has just starting taking data. We expect definitive answers from the gallium experiments within a year.

The Homestake experiment has claimed evidence for a correlation between the ^{37}Cl neutrino capture rate with the number of sunspots. If this result is correct, and it is not universally accepted, it would probably require a neutrino magnetic moment far in excess of Standard Model expectations. There was a consensus that solar neutrino detectors with large counting rates are needed to study this phenomenon.

Other possible detection schemes for solar neutrinos were discussed by J. Engel and A. B. Balentekin.

POSSIBLE EXISTENCE OF A 17-keV NEUTRINO

Bhaskar Sur discussed evidence for the existence of a 17-keV neutrino that mixes with the electron neutrino. The first evidence for such a heavy neutrino was claimed by J. Simpson, from a study of the beta decay spectrum of ^{3}H.[4] Sur presented new evidence for a heavy neutrino from an experiment studying the beta decay of ^{14}C: a data set nearly twice as large as that described by a recent publication[5] was described here. The new result from this experiment is that the fit to the beta decay spectrum requires a neutrino of mass 17.1 ± 0.5 keV with a mixing coefficient of 1.3 ± 0.3%: this is a "4.5 σ" result. We also heard about other results that require a 17-keV neutrino including studies of ^{55}Fe, and ^{35}S. There is one recent result looking at the beta decay spectrum from ^{35}S using a magnetic spectrometer that claims to reject the 17-keV hypothesis.

The conclusion from this talk was that the need for a 17-keV neutrino is clearly not a statistical fluctuation, nor is it an atomic effect. It could be due to some subtle solid state detector effect or a 17-keV neutrino or other particle.

Petr Vogel provided a discussion of neutrino properties from a theoretical standpoint. A 17-keV neutrino has a hard time fitting into our standard picture. Big bang cosmology permits a 17-keV neutrino but it must decay with a lifetime of $< 10^6$ years. The only way to accommodate such a lifetime is for the neutrino to decay into a lighter neutrino plus a new, light weak singlet particle (such as a Majoron): thus one needs new physics here. If the 17-keV neutrino were a Majorana neutrino, it must have a partner of nearly the same mass to effectively cancel its contribution to neutrinoless double beta decay.

CONCLUSIONS

The neutrinos and nonaccelerator parallel sessions were extremely interesting, lively, and well-attended. We heard a number of results that may well shake the foundations of nuclear and particle physics. We look forward to expanded activities in this field in the coming years.

I would like to thank my co-coordinators for this session, Richard Imlay of Louisiana State University and Eric Norman of the Lawrence Berkeley Laboratory for their hard work in putting together such an important and provocative session. This work was supported by the U. S. Department of Energy.

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