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NUCLEAR TRANSPARENCY, B PHYSICS, AND DOUBLE BETA DECAY

Annual Progress Report
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ABSTRACT

A Physical Review paper with the final results of a search for neutrinoless double- β decay of molybdenum 100 with collaborators from the Lawrence Berkeley Laboratory, the University of New Mexico, and the Idaho National Engineering Laboratory has been accepted for publication in Physical Review C and a NEMO collaboration paper on the two neutrino double beta decay of ^{116}Cd has been accepted for publication in *Zeitschrift Physics*. A paper outlining a statistical procedure for treating small data samples with background co-authored by Professor Nicholson and Dr. Margaret Garnjost was submitted to NIM and subsequently withdrawn when a previously published paper covering similar material was discovered. This paper is being reworked and extended and will hopefully be resubmitted for publication this fall.

Professor Nicholson, who was on sabbatical during the 1995-96 academic year, has had the principal responsibility for overseeing the rebuilding of the EVA superconducting magnet whose cryostat failed catastrophically during the January to June High Energy Physics run to study color transparency at Brookhaven National Laboratory. At present, the magnet has been redesigned and rebuilt and is currently being installed on the flux return steel. The cryogenic system is also nearing completion and the entire system is expected to be ready to test within the next two months.

Professor Nicholson is also involved in the calorimeter development effort of the SLAC BaBar experiment. He took part in the beamtest of an array of 25 full sized CsI(Tl) crystals at PSI during the fall of 1995, and has been involved in some of the data reduction of this test along with involvement in a study of source calibration options and some electronics and photodiode testing. Professor Nicholson along with Professor Kofler and his group at UMass expect to help in the testing of preamps and shaping amplifiers and have principal responsibility for testing complete CsI(Tl) modules before final assembly in the calorimeter barrel next year.

Professor Sutton continues to spend the majority of his research time working on the NEMO 3 double beta decay experiment involving molybdenum 100 and other isotopes. During the past year he has continued to be involved in organizing international meetings in which progress in purification techniques for molybdenum is discussed and the direction of future efforts are planned. Professor Sutton has also been involved in hiring efforts

for NEMO-3, and, along with Mount Holyoke Students, in analyzing data from a Soudan detector, in studying cathode wires and epoxies for use in the detector, and in purifying molybdenum.

NARRATIVE

During his sabbatical, Professor Nicholson has divided his time among three projects. He has taken on the primary responsibility for overseeing the redesign and rebuild of the EVA superconducting magnet which failed catastrophically during the spring 1995 high energy physics run at the Brookhaven AGS. He has also become involved in the design and construction of the CsI(Tl) calorimeter for the SLAC BaBar detector and expect to share with collaborators at the University of Massachusetts a major responsibility in testing preamp and shaping amplifier electronics and completed CsI module testing during the coming year. Finally, Professor Nicholson, working with Dr. Margaret Garnjost and Dr. Robert Kenney, both retired staff of LBNL, completed the final Physical Review Paper on the LBNL, Mt. Holyoke, University of New Mexico, INEL molybdenum double beta decay experiment which has just recently been accepted for publication in Phys. Rev. C and he is working on a paper on confidence limits for experiments with small data samples governed by Poisson statistics.

During the summer of 1995, Professor Nicholson and Brookhaven physicists Don Barton and Alan Carroll along with members of the Brookhaven engineering and cryogenic staff began to meet on a regular basis to identify and correct a variety of design problems with the superconducting magnet obtained from Cornell (the old CLEO I superconducting solenoid) used in the Brookhaven EVA detector to study color transparency. During this time it was determined that the four point coil suspension system and the nitrogen heat shield were inadequate for this application and that the g-10 tubes used to constrain the coil against the 32 tons of upstream force due to the asymmetric steel flux return were creating a number of problems, one of which was an increasing cryostat vacuum leak with increasing magnetic field. By September 1995, the design work had been completed and Mike Green of LBNL carried out an overall design review. During the fall and winter mechanical modification were made to the cryostat, a new heat shield was designed and installed, and the parts needed for the rebuild were manufactured. (The majority of the manufacturing was carried out at a machine shop near Mount Holyoke.) Late this spring the coil was inserted in the cryostat and the coil-cryostat assembly was then vacuum checked. At present, the coil-cryostat assembly has been satisfactorily leak checked and surveyed and it is being reinstalled on the flux return steel.

A considerable amount of work has also gone on in parallel with the work on the coil-cryostat assembly. A new liquid helium control dewar has been added to the cryogenic system and a new valve box has been designed and constructed. New current leads have been designed, build and tested. A control system similar to but considerably simpler than the one used in the Brookhaven g-2 experiment has been designed and is being built. It is hoped that a week long test of the final complete system will be possible in September or early October. There are a variety of modifications to the original design which ought to make it possible to identify and fix problems if they should arise in the new design. To date no serious problems have been encountered in the new design and there is cautious optimism that the magnet will work reliably after this rebuild.

During the past year, Professor Nicholson and the physicists and staff of Brookhaven laboratory have met formally 29 times and had numerous additional informal meetings and conversations related to the magnet rebuild effort. There is considerably more information available about this project than is appropriate for or is being included in this report. It is likely that a summary paper will be written and published in an appropriate journal if the overall design proves to be successful in this application.

Along with his work on the Brookhaven magnet, Professor Nicholson has also been involved in a variety of projects related to the design and fabrication of the CsI(Tl) calorimeter for the SLAC BaBar detector. Professor Nicholson's activities in this area include studying ways of optically coupling readout silicon photodiodes to the ends of the CsI(Tl) crystals, looking at the possibility of using the 2.6 MeV gammas from the thallium 208 decay daughter in uranium 232 source decays to calibrate CsI(Tl) detectors in the calorimeter (which became part of a formal SLAC source study report), and doing noise and shaping time studies.

During the fall of 1995, Professor Nicholson spent two weeks at PSI in a beamtest of 25 full sized CsI(Tl) crystals and a few subsequent months analyzing some of the data. The principal motivation of this beamtest was to determine the energy resolution of the array and to compare it against the performance target of

$$\frac{\sigma_E}{E} = \frac{1\%}{\sqrt[4]{E(GeV)}} \oplus 1.2\%$$

which was given in the BaBar Technical Design Report. Although a con-

siderable amount of effort ultimately was required to determine satisfactory calibration parameters for the crystals in the beamtest and problems arose because the peak sensing electronics used had rate effects which will not be a problem for the waveform digitizing electronics used in the final BaBar detector, results at this time look very encouraging. A BaBar note should be completed with a few months and a NIM paper is being considered.

Next year Professor Nicholson expects to take on a major responsibility, in collaboration with Dr. Richard Kofler and members of his group at UMass, for the testing of preamps and shaping amplifiers to be used in the final detector and for testing completed modules of 21 CsI(Tl) crystals before final insertion in the barrel section of the BaBar calorimeter. Preliminary SLAC preamp-shaper amplifiers are in hand and studies of their characteristics are underway.

Professor Sutton has spent the majority of his research time working with NEMO collaborators to measure two neutrino and to search for zero neutrino double beta decays of molybdenum 100 and other isotopes. The NEMO-2 experiment on double-beta decay continued to operate well throughout the year and measurements made of a ^{116}Cd source foil generated a two-neutrino decay mode half-life with high statistics of $3.7 + 0.35(\text{stat}) + 0.20(\text{syst}) \times 10^{19}$ years. A half-life limit on the zero-neutrino decay mode was also determined to be 6.2×10^{21} years. These results have been accepted for publication in *Zeitschrift Physics*. In addition, the NEMO-2 collaboration has recently produced some preliminary results on ^{82}Se and ^{96}Zr source foils which have been presented in contributed papers at the VIII-th Rencontres de Blois and the XVII International Conference on Neutrino Physics.

The schedule to start running NEMO-3 has slipped a little but there is good progress on a number of fronts. A tender for the photomultiplier tubes was made which resulted in a contract for tubes which are less radioactive and capable of greater energy resolution than the design standards established in the experiment's proposal. The first of the experiments 20 sectors is nearly complete and many of the mechanical components have been machined. Prototypes of the electronics function well. Chemical purification of molybdenum currently appears to provide the required upper limits on the radioactive contamination due to the uranium and thorium decay chains. Aging of the 20 micron cathode wires in the open Geiger cell tracking volume has proven to be a problem and 50 micron wires may be required. Copper coated nylon wires are being researched as a possible solution.

Professor Sutton's specific involvement in the NEMO project range over a variety of activities. In the summer and fall of 1995, a Post-doc from the United States was sought to work in France and help with the development of software. In the end two candidates were selected and interviewed at Mount Holyoke and in France at the Laboratoire de L'Accelérateur Lineaire (LAL) in Orsay. Either candidate would have had a significant impact on the program in Orsay, but both eventually declined and accepted higher paying jobs in the public sector. Problems in getting US Post-docs to go to France include a three month period for clearance from the French government, which gives the candidate three months to find another job having one in hand already, low salaries coupled with a high cost of living, and concern about difficulty in reentry into the U.S. high energy physics community. Now that a clear understanding of the problems has been obtained, a more targeted search will be carried out again this fall.

In December of last year the Third Purification Meeting for molybdenum source material was organized by Professor Sutton and carried out at Soudan, Minnesota and the Idaho National Engineering Lab (INEL), Idaho. Nine scientists from three different countries (France, Russia and the United States) from seven different institutions meet and prepared a ^{100}Mo excited state decay experiment in Soudan. In addition, chemical purification results on natural Mo that was purified in the previous summer by Mount Holyoke students at INEL under the guidance of John Baker and by a slightly different method by Jean-Louis Reyss of the Centre des Faibles Radioactivités was presented. High purity germanium (HPGe) detector measurements on the purified samples were also presented and the new extraction technique involving barium to remove radium seems to be effective at achieving the necessary levels of purity for the uranium chain extraction. Also, of the 130 grams of purified natural Mo, 30 grams were tested with the Emanation technique at ITEP-Moscow, which confirmed the HPGe results. The ability to check the sought levels of the Th chain contamination is impractical with HPGe detectors but if the reduction factor in contamination can be maintained at lower initial levels in the chemical purification then it will be possible to achieve the appropriate levels for the Th chain. To test this further a neutron activation test arranged in the low level counting facility of the Lawrence Berkeley National Laboratory is being pursued and will most likely be carried out early this fall with Russian ^{100}Mo so as to complete the preliminary tests.

After the Third Purification Meeting, software programs were written at Mount Holyoke to interpret the binary files of data from the Soudan detector whose source code was lost and which program is currently of little use for modern multi-site analysis. Mount Holyoke therefore became the site where the data was first inspected, and, after a detector problem was discovered, the task of characterizing it using the intermittently changing data was begun.

Professor Sutton was also involved in a series of studies which are important to the NEMO-3 detector construction. Spectrophotometry measurements on epoxies to study yellowing with age characteristics were carried out at Mount Holyoke as part of the search with collaborators from the University Louis Pasteur, Strasbourg to identify a stable epoxy to use in calorimeter construction. Similarly, because a couple of possible sources for the Geiger cells wire are companies based in the United States, Professor Sutton has constructed a prototype Geiger cell at Mount Holyoke to study wire aging which will mature into a parallel study, with the collaborators from the LAL, of different gases and the their effects of aging on the cathode wires.

Mount Holyoke students are also involved in these activities. During the 1996 summer, two students have been working on straw tubes at Brookhaven, supported by the Mount Holyoke DOE grant and two more students are working at INEL purifying a kilogram of natural Mo so as to get better limits on the purification technique before committing large quantities of ^{100}Mo to the process.

APPENDIX

Title pages from publications and reports

Experimental Search for Double- β Decay of ^{100}Mo

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J. D. Baker and A. J. Caffrey

Idaho National Engineering Laboratory, Idaho Falls, Idaho 83415

(December 15, 1995)

Abstract

No evidence for the neutrinoless double- β decay of ^{100}Mo has been found in a search using a segmented Si(Li) detector with source foils enriched to 97% ^{100}Mo . After 0.2664 mole-years of exposure, we report a Bayesian 68% lower limit on the half-life for the $J^p = 0^+ \rightarrow 0^+$ transition of 0.22×10^{23} years, the best published value to date for ^{100}Mo . The measured half-life of the two neutrino double- β decay is $0.76^{+0.22}_{-0.14} \times 10^{19}$ years.

PACS numbers: 23.40.Bw, 14.60.Gh, 27.60.+j

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Double- β decay of ^{116}Cd

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NEMO Collaboration

Abstract

The NEMO-2 tracking detector located in the Fréjus Underground Laboratory was designed as a prototype of the detector NEMO-3 to study 0ν and 2ν double-beta decay ($\beta\beta$) physics. After ten months of nearly continuous running with an enriched cadmium source (0.92 mol-y of ^{116}Cd) a $\beta\beta 2\nu$ half-life of $T_{1/2} = (3.75 \pm 0.35(\text{stat}) \pm 0.20(\text{syst})) \cdot 10^{19}$ y was measured. Limits on half-lives of $6.2 \cdot 10^{21}$ y (CL=90%) and $1.2 \cdot 10^{21}$ y (CL=90%) for $\beta\beta 0\nu$ and $\beta\beta 0\nu \gamma^0$ decays of ^{116}Cd were obtained. Theoretical predictions for 0ν and 2ν decays of ^{116}Cd are also presented.

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Use of Radioactive Photon Sources with the BABAR Electromagnetic Calorimeters

An Interim Report

The Calorimeter Calibration Task Force:

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D.G. Hitlin, R.R. Kofler, H. Marsiske, H. Nicholson, S. Playfer,
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May 3, 1996