DOE/ER/40553--3

DE92 019519

NUCLEAR TRANSPARENCY AND
DOUBLE BETA DECAY OF MOLYBDENUM 100

Annual Progress Report
for Period March 1, 1992 - January 31, 1993

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August 1992

Prepared for

The U.S. Department of Energy under Grant No. DE-FG02-90ER40553

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ABSTRACT

Data taking is now complete on a double beta decay experiment which has been carried out with collaborators from the Lawrence Berkeley Laboratory, the University of New Mexico, and the Idaho National Engineering Laboratory, and work is continuing on a second collaborative experiment, AGS experiment 850 at the Brookhaven National Laboratory with collaborators from Brookhaven Laboratory, Pennsylvania State University, the University of Massachusetts at Dartmouth, and the University of Minnesota to study nuclear color transparency.

In March, the experimental apparatus used to search for double beta decay in molybdenum 100 in the Consil silver mine in Osburn, Idaho was dismantled, and the data analysis is in its final stages. No evidence has been seen for the $0^+ \rightarrow 0^+$ mode of zero neutrino double beta decay collaborators with a 1σ lifetime limit of 3×10^{22} years. This limit is 7.5 times greater than the limit we published previously in Physical Review Letters in 1989.¹ Backgrounds have been simulated and fits are currently underway to a simulated $0^+ \rightarrow 2^+$ mode of zero neutrino double beta decay to improve on a very preliminary 1σ lifetime limit of 2.3×10^{21} years presented at the April, 1992 meeting of the APS in Washington. We are preparing a Physical Review Letter and a longer Physical Review article to publish the final results of this experiment.

A scintillating fiber detector with three Hamamatsu, H4140, 256 channel multianode phototubes has been built, instrumented, and tested in the May - July 1992 run in the EVA detector at Brookhaven Laboratory's AGS. Preliminary results from this detector have been disappointing. It is likely that the detector will have to be substantially redesigned before the 1993 AGS run.

¹ M. Alston-Garnjost et al., Phys. Rev. Lett. 63, 1671 (1989)

NARRATIVE

During the last year, Professors Nicholson and Sutton have continued working with experimenters from the Lawrence Berkeley Laboratory (LBL), the University of New Mexico, and the Idaho National Engineering Laboratory (INEL) in a search for the neutrinoless double beta decay of molybdenum 100. Since January, 1991 Moun- Holyoke has had the primary responsibility for all aspects of the operation of this experiment. Detailed descriptions of the experimental apparatus are given in the papers "A New Detector System for Double Beta Decays", M. Alston-Garnjost et al., Nucl. Instr. and Meth. A271 475 (1988) and Professor Sutton's contributed paper to the Neutrino '90 Conference entitled "The Second Generation of the ^{100}Mo Double Beta Decay Modes in the Consil Mine". Results from the apparatus before the upgrade from 40 to 145 detectors were published in October, 1989 in the paper "Search for Neutrinoless Double- β Decay of ^{100}Mo ", M. Alston-Garnjost et al., Phys. Rev. Lett. 63, 1671 (1989).

In March, 1992 the experiment was shut down in order to reclaim the molybdenum 100, which was on lease from Oak Ridge, and to avoid paying the very substantial price increase required to continue the lease. After eliminating the first and the last experimental data runs which had observable radioactive contamination, we obtained five usable runs. These corresponded to 3849.5 hours of live-time with 60.63 grams of ^{100}Mo located in one of two detector stacks giving an total exposure of .2664 mole-years.

Raw data from these experiments is shown in Figure 1a, and data after all cuts is shown in Figure 1b. (Cuts are described in M. Alston-Garnjost et al., Phys. Rev. Lett. 63, 1691 (1989)). Monte Carlo simulations for the $0^+ \rightarrow 0^+$ and $0^+ \rightarrow 2^+$ zero neutrino double beta decays are shown in Figures 2a and 2b respectively. Events are considered $0^+ \rightarrow 0^+$ zero neutrino double beta

decay event candidates if they lie in the energy region between 2.7 and 3.0 MeV, an energy region above backgrounds from the 2.6 MeV gamma from thallium 208 in the thorium decay chain and below the 3.033 MeV maximum energy release detectable in $0^+ \rightarrow 0^+$ zero neutrino double beta decay in Molybdenum 100. It can be seen in Figure 1b that only 1 event survives all the cuts and lies in this energy range. A preliminary maximum likelihood fit to the data using a linear background and a fit to the Monte Carlo generated data rejects this event as a real double beta decay and strongly favors it as background. Given this single event as an lower limit to the $0^+ \rightarrow 0^+$ zero neutrino double beta decay lifetime, we obtain the 1σ lifetime limit of 3×10^{22} years.

Because of the substantial backgrounds between 2.2 and 2.5 MeV, the analysis of the $0^+ \rightarrow 2^+$ zero neutrino double beta decay is substantially more complicated. At present, we have completed Monte Carlo simulations of the three principal backgrounds, bismuth 212 and 214 and thallium 208, and determined that they can be modelled as straight lines in this energy region. We are currently fitting the $0^+ \rightarrow 2^+$ Monte Carlo simulation and will carry out a maximum likelihood analysis of the data to determine what fraction of the events are background and what fraction are $0^+ \rightarrow 2^+$ event candidates. A very preliminary estimate of the lower limit on this lifetime, based on all the events between 2.1 and 2.5 MeV and including one of the experimental runs which has subsequently been discarded, is 2.3×10^{21} years. This will certainly go up after the analysis described above is complete. (We had originally hoped that we could extract a two neutrino double beta decay lifetime from the data as well, but we do not believe we understand the backgrounds sufficiently well below 2.1 MeV to make a reliable measurement of the two neutrino spectrum.)

Figure 1a

Spectrum of All Events

Figure 1b

Spectrum of All Events after Cuts

Figure 2a

Figure 2b

We are currently preparing a Physical Review Letter which we expect to submit for publication by the end of the summer. A longer Physical Review article describing the experiment and the analysis in more detail should be submitted for publication around the end of the 1992 calendar year.

In addition to the work on the double beta decay experiment, Professor Nicholson has worked extensively with Steve Gushue of Brookhaven Laboratory during the past year to develop a scintillating fiber detector (C1) for a Brookhaven National Laboratory Alternating Gradient Synchrotron experiment (AGS experiment 850) to study color transparency in nuclei from 6 to 20 GeV/c. A general description of the EVA detector was given in last year's annual progress report.

The scintillating fiber detector, which is designed to run in the EVA superconducting solenoid in magnetic fields up to 1 Tesla, is shown schematically in Figure 3. For the May - July 1992 run of the AGS this detector consisted of two complete layers, each made up of 326 1 mm circular Kiowa SCSF-38 scintillating fibers oriented parallel to the detector's center line, and a partial third layer of 20 identical fibers oriented in a spiral around the fibers in the lower two layers and crossing them at 15° . The 1.2 meter long fibers were mounted along a carbon fiber tube approximately 10 cm in diameter for a length of approximately 70 cm using low temperature curing epoxy and then curved away from the tube to make a butt, optical grease covered joint with a single pixel in one of three Hamamatsu H4140 256 multianode photomultiplier tubes used to readout the detector.

For the initial tests of C1 carried out in June, ribbon cable outputs from the phototubes were connected to lemo bulkhead connectors which carried the phototube pixel signals to NIM X10 amplifiers outside the EVA solenoid and only 60 pixels were instrumented. For the later test carried out in July,

Figure 3
Cylinder C1 The Scintillating Fiber Detector

homemade 64 channel pixel termination and amplifier cards were connected to the end of a short (2 inch) ribbon cable on each of the 4 output connectors on each of the 3 phototubes, and 30 nsec lemo cables on the output of these cards were used to connect the tube outputs to electronics outside the solenoid. (For the actual runs, the X10 hybrid amplifiers were not used and their sockets were jumpered since the tube gain was sufficient in .2 Tesla fields to detect single photoelectron events.) In both cases, the signal was discriminated by LeCroy ECL 4413 discriminators whose outputs, in turn, were connected to LeCroy 4291B Camac TDC's for computer readout.

The overall performance of this detector proved to be disappointing. The multiplicity of fibers firing over a fixed discriminator threshold on most events was quite high (Figure 4a). In addition, the efficiency of one fiber layer to detect a hit when the detector was triggered on a fiber in the other layer was quite poor (Figure 4b) and appears to be due to the variability and gradual deterioration (due to stress fractures and cracks) of the transmission characteristics of the fibers. Correlations between pixels and straw tube tracks were also poor and estimated to lie between 10 and 30 percent based on scanning good geometry triggers during the run.

There were, in addition, problems with the multianode phototubes in the C1 environment. The variability of light reaching the phototubes from the fibers and the fact that pixels immediately adjacent to a central pixel receive between 5 and 8 percent of the electronic shower hitting the central pixel in a .1 - 1.0 Tesla magnetic field means in order to achieve high efficiency for pixels receiving low light levels, there will be cross talk to adjacent channels when pixels see high light levels. (To reduce or eliminate cross talk within the phototube, the dynamic range of incident light must be

Figure 4a

Figure 4b

Hits when Fiber 79 Fires

less than or the order of 10). In addition, because of the common dynode structure of the phototubes, a large pulse in any single pixel generates a large electronic fluctuation on the last dynode which capacitively couples to many and sometimes virtually all of the other anode pixels. This occurs in our detector when beam halo or a small angle scatter from material near or in the beam upstream of the target traverses a fiber longitudinally and generates two orders of magnitude more light than a minimum ionizing particle travelling through the fiber in a transverse direction. Moreover, there is considerable variability in the quality of the output signal from different pixels on the same tube. An attempt to optimize the base circuit supplied by Hamamatsu by varying the damping resistor used on the last dynode, a modification which Dr. S. Majewski and coworkers at CEBAF have used with some success on the Hamamatsu R4760 photomultiplier tube, ("Studies of a New 16 Channel Photomultiplier Tube for Scintillating and Waveshifting Fiber Readout", A Weisenberger, et al, draft copy of a paper to be submitted to Nucl. Instr. and Meth.) yielded little improvement in our case. Finally, although the H4140 phototubes will handle the current associated with high rates, tests using the Mount Holyoke Van de Graaff accelerator suggest that in practice the tube is unlikely to handle more than a 3 to 5×10^6 counts/sec which would not be adequate for the anticipated several 10^5 counts/pixel the C1 detector will eventually be required to handle.

We are still in the process of examining the data from the AGS run which ended on July 31. At the present time, a variety of alternative options for the C1 detector are being considered. One of these is a detector made of small diameter (3 mm) straw tubes. A second option, one that we originally considered, is to use a larger fiber (1.5 - 2.0 mm) with a longer attenuation length (SCSF-81) carefully overlapped to improve resolution and read out these

fibers with individual, existing phototubes. We are also reexamining the possibility of coupling scintillating fibers to low attenuation length clear plastic fibers ("Plastic optical fiber splicing by thermal fusion", Apollinari et al., Nucl. Instr. and Meth. A311 (1992) pp.520-528) and studying other technologies for fiber readout including cryogenic diodes. A hybrid detector using multianode phototubes and individual phototubes is also a possibility.

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