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Design improvements to cables and connectors in the MAJORANA DEMONSTRATOR

C R Haufe^{1,2}, A L Reine^{1,2}, N Abgrall³, S I Alvis⁴, I J Arnquist⁵, F T Avignone III^{6,7}, A S Barabash⁸, C J Barton⁹, F E Bertrand⁷, T Bode¹⁰, A W Bradley³, V Brudanin¹¹, M Busch^{12,2}, M Buuck⁴, T S Caldwell^{1,2}, Y-D Chan³, C D Christofferson¹³, P-H Chu¹⁴, C Cuesta^{4,a}, J A Detwiler⁴, C Dunagan¹³, Yu Efremenko^{15,7}, H Ejiri¹⁶, S R Elliott¹⁴, T Gilliss^{1,2}, G K Giovanetti¹⁷, M P Green^{18,2,7}, J Gruszko⁴, I S Guinn⁴, V E Guiseppe⁶, L Hehn³, R Henning^{1,2}, E W Hoppe⁵, M A Howe^{1,2}, K J Keeter¹⁹, M F Kidd²⁰, S I Konovalov⁸, R T Kouzes⁵, A M Lopez¹⁵, R D Martin²¹, R Massarczyk¹⁴, S J Meijer^{1,2}, S Mertens^{10,22}, J Myslik³, C O'Shaughnessy^{1,2}, G Othman^{1,2}, W Pettus⁴, A W P Poon³, D C Radford⁷, J Rager^{1,2}, K Rielage¹⁴, R G H Robertson⁴, N W Ruof⁴, B Shanks^{1,2}, M Shirchenko¹¹, A M Suriano¹³, D Tedeschi⁶, J E Trimble^{1,2}, R L Varner⁷, S Vasilyev¹¹, K Vetter³, K Vorren^{1,2}, B R White¹⁴, J F Wilkerson^{1,2,7}, C Wiseman⁶, W Xu⁹, E Yakushev¹¹, C-H Yu⁷, V Yumatov⁸, I Zhitnikov¹¹, and B X Zhu¹⁴

¹Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC, USA

²Triangle Universities Nuclear Laboratory, Durham, NC, USA

³Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

⁴Center for Experimental Nuclear Physics and Astrophysics, and Department of Physics, University of Washington, Seattle, WA, USA

⁵Pacific Northwest National Laboratory, Richland, WA, USA

⁶Department of Physics and Astronomy, University of South Carolina, Columbia, SC, USA

⁷Oak Ridge National Laboratory, Oak Ridge, TN, USA

⁸National Research Center "Kurchatov Institute" Institute for Theoretical and Experimental Physics, Moscow, Russia

⁹Department of Physics, University of South Dakota, Vermillion, SD, USA

¹⁰Max-Planck-Institut für Physik, München, Germany

¹¹Joint Institute for Nuclear Research, Dubna, Russia

¹²Department of Physics, Duke University, Durham, NC, USA

¹³South Dakota School of Mines and Technology, Rapid City, SD, USA

¹⁴Los Alamos National Laboratory, Los Alamos, NM, USA

¹⁵Department of Physics and Astronomy, University of Tennessee, Knoxville, TN, USA

¹⁶Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka, Japan

¹⁷Department of Physics, Princeton University, Princeton, NJ, USA

¹⁸Department of Physics, North Carolina State University, Raleigh, NC, USA

¹⁹Department of Physics, Black Hills State University, Spearfish, SD, USA

²⁰Tennessee Tech University, Cookeville, TN, USA

²¹Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, ON, Canada

²²Physik Department, Technische Universität, München, Germany



^aPresent Address: Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT, 28040, Madrid, Spain

E-mail: crhaufe@live.unc.edu | reineal@live.unc.edu

Abstract. The MAJORANA DEMONSTRATOR is an experiment constructed to search for neutrinoless double- beta decays in germanium-76 and to demonstrate the feasibility to deploy a ton-scale experiment in a phased and modular fashion. It consists of two modular arrays of natural and ^{76}Ge -enriched germanium p-type point contact detectors totaling 44.1 kg, located at the 4850' level of the Sanford Underground Research Facility in Lead, South Dakota, USA. The DEMONSTRATOR uses custom high voltage cables to bias the detectors, as well as custom signal cables and connectors to read out the charge deposited at each detectors point contact. These low-mass cables and connectors must meet stringent radiopurity requirements while being subjected to thermal and mechanical stress. A number of issues have been identified with the currently installed cables and connectors. An improved set of cables and connectors for the MAJORANA DEMONSTRATOR are being developed with the aim of increasing their overall reliability and connectivity. We will discuss some of the issues encountered with the current cables and connectors as well as our improved designs and their initial performance.

1. Introduction

The MAJORANA DEMONSTRATOR is a neutrinoless double-beta decay experiment using Germanium as source and detector. The DEMONSTRATOR contains 44.1-kg of Ge detectors divided between two independent cryostats [1]. In total, the two modules contain 14.4 kg of $^{\text{nat}}\text{Ge}$ and 29.7 kg of germanium enriched to 88% Ge-76 , the double beta decay isotope. The goals for the DEMONSTRATOR are to demonstrate background levels low enough to justify building a tonne scale experiment, establish the feasibility of constructing and fielding modular arrays of Ge detectors, and search for additional physics beyond the Standard Model, such as solar axions and dark matter. The DEMONSTRATOR is operating underground at the 4850 level of the Sanford Underground Research Facility with the best energy resolution of any $0\nu\beta\beta$ experiment. Initial results based on datasets 3 and 4 indicate a 2.4 keV FWHM at 2039 keV and a projected background of $5.1^{+8.9}_{-3.2}$ c/(ROI-t-y), which is in good agreement with the DEMONSTRATOR's background goals [2].

Numerous measures are responsible for the DEMONSTRATOR's low background levels. In addition to the shielding provided by the rock overhead, the detector array is surrounded by a low-background passive Cu and Pb shield with an active muon veto. Ultra-low-activity components and construction techniques are also used to limit contaminants. In particular, the cryostats and other copper components were constructed using ultra-clean, electroformed copper. Current assay upper limits predict a background of ≤ 2.45 counts/ROI-t-y based on the DEMONSTRATOR's achieved resolution [1] [3]. In addition to these hardware-based background reduction techniques, the p-type point-contact detector design allows for optimal pulse shape discrimination to distinguish candidate double beta decay events from background events.

The DEMONSTRATOR's background goal presents unique challenges in designing high voltage and signal cable systems. Cables and connectors must be kept as low mass as possible to limit radioactive backgrounds. Strict radiopurity requirements also control what materials can be used, meaning that standard commercial products are often not an option. Custom-made components were designed and implemented to meet these requirements, but connectivity problems and high voltage breakdowns have necessitated a redesign of some of these components.

The DEMONSTRATOR is currently operating 41 of 58 installed detectors. 7 of the non-operating detectors have problems associated with the signal connectors that are located on the cryostat cold plate or with damaged Low Mass Front End boards. The other 10 non-operating

detectors cannot be electrically biased because of problems with HV cables, connectors, and in one instance a likely detector problem. The improvements to cables and connectors discussed here are aimed at raising the percentage of operational detectors to $> 90\%$.

2. High Voltage Cables and Connectors

In the DEMONSTRATOR, high voltage (HV) is applied to the outer contact of P-Point Contact (PPC) High Purity Germanium (HPGe) detectors. An HV card supplies voltage to radiopure, in-vacuum HV cables through custom pin connectors on a vacuum flange. Each HV cable carries this voltage to a detector through a custom electroformed Cu HV fork connected to a copper ring that makes contact with the outer surface of a detector, opposite the point contact.

The HV cable is constructed with a picocoax design, in which a central conductor is wrapped in a layer of FEP insulation, a tightly wound copper ground shield, and finally a second layer of FEP insulation that serves as the outer jacket. These cables, manufactured by Axon', are rated to carry 5kV DC. They exhibit a low linear mass density of 3 g/m and have an outer diameter of 1.2mm. The Cu ground shield has a gauge of 50 AWG.

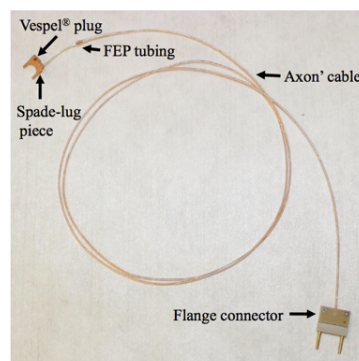


Figure 1: MAJORANA DEMONSTRATOR HV cable. The copper HV fork is shown in the upper left-hand corner of the photo. The flange connector is connected at the opposite end of the cross-arm at the vacuum flange.

During initial operations multiple detectors exhibited HV “breakdowns” in which there were significant discharges. These detectors were fully or partially biased down to prevent damage to associated electronics. It was determined the breakdowns were occurring between the central conductor and the outer ground shield. These breakdowns were largely eliminated when the HV cable Cu ground shields were disconnected from ground. Of the detectors that are currently operating, 11 were brought on-line due to this change.

A series of stress tests were performed on a sample HV cable to determine possible failure modes. It was determined that kinked cables can lead to the same breakdown signatures observed in the DEMONSTRATOR commissioning phase. The likely cause of HV breakdowns is a deformity in the layer of insulation separating the Cu ground shield from the central conductor due to kinked or crushed cables. Damage to these cables likely occurred during installation, as no significant breakdowns were detected in cable testing following production and preceding installation.

The collaboration has encountered additional problems with the current design of the HV cables and connectors. The Vespel clamp plug that covers the exposed end of the central conductor at the HV fork was found to not be secure for all detectors. Additionally, collaborators have identified a risk of intermittent connection at the vacuum flange.

To address these issues, the collaboration plans on undertaking a full replacement of HV cables and connectors installed in the DEMONSTRATOR. An existing set of Axon' HV cables

will be installed with the same specifications as before. To avoid the damaging of cables during installation, improved baffle plates will be set within the cross-arm to manage and direct cables to the detector cryostat. Additionally, ePTFE thread will be used to bundle the cables together, providing further management and protection within the cross-arm.

Rather than using a Vespel clamp plug to cover the exposed end of the central conductor at the HV fork, a crimped connection will lock the central conductor in place with the HV fork, improving security. A new set of PEEK connectors will be assembled to provide improved connectivity of the high voltage cable at vacuum flange, with new sockets that have a higher clamping force.

3. Signal Cables and Connectors

The MAJORANA signal cable and connector system is designed to transmit electronic pulses containing information about events in the germanium detectors. When an event occurs, charge is collected at the point contact and transmitted to a Low Mass Front End board (LMFE) with a FET that amplifies the signal[4]. Each LMFE is connected to the preamp using four coaxial Axon' cables. Each set of four cables is divided into two separate cable bundles: one connecting the LMFE to a Vespel connector at the coldplate and another running between the coldplate and the D-sub connectors at the vacuum flange.

The Axon' signal cables have the same picocoax design as the HV cables described above. However, the signal cables have a smaller outer diameter of 0.4 mm, leading to a reduced linear mass density of 0.4 g/m. The cables have an impedance of 50 Ω and a capacitance of 87 pF/m.

The main challenge presented by the MAJORANA signal cable system is the difficulty of fabricating Vespel connectors that are robust enough to withstand temperature cycling without the use of conventional spring components that fail the DEMONSTRATOR's radiopurity requirements. The beryllium copper (BeCu) contacts used in many commercial connectors have unacceptably high ^{232}Th and ^{238}U activities. The Vespel connectors currently installed in the DEMONSTRATOR are instead designed to avoid the need for contact springs, but this design requires very precise machining to ensure a secure connection. The machining constraints of the DEMONSTRATOR's underground machine shop have led to unreliable connectors.

While the vacuum-side D-sub connectors are not responsible for observed connectivity issues in the DEMONSTRATOR, installation problems in the D-sub connectors reduced the number of viable spare channels. There is also evidence of damage to the signal cables during installation. Observed instances of electrical shorts between signal cable ground shields and the coldplate indicate problems with at least one detector's signal cables.

In order to improve the reliability of Vespel connectors at the coldplate, the signal connector design has been modified to incorporate a fuzz button contact. These fuzz button contacts are manufactured out of gold-plated molybdenum wool by Custom Interconnects. Unlike the BeCu contacts typically used to provide springiness in commercial connectors, fuzz buttons are expected to meet the DEMONSTRATOR's stringent radiopurity requirements based on assay results from the SuperCDMS collaboration [5]. The new connector design also provides a more secure connection using a mechanical locking mechanism. Prototypes of the improved connector design have passed 100% of initial liquid nitrogen dunk tests, indicating that they will be able to withstand temperature cycling. A comparison of the old and new Vespel connector designs can be seen in Figure 2.

The improved Vespel connectors will be installed during a replacement of the entire signal cable and connector system, planned to take place concurrently with the HV cable system upgrade. During this upgrade, the D-sub connectors at the vacuum flange will be replaced with more reliable commercial connectors from Glenair. Based on the evidence of damage to some existing signal cable ground shields, increased measures will be taken to protect signal cables during installation. Like the HV cables, signal cables will be bundled using ePTFE thread.

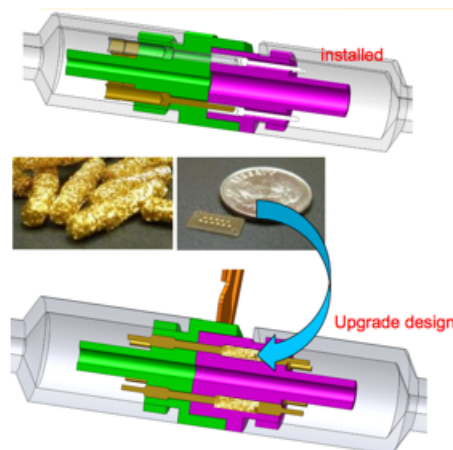


Figure 2: Comparison of the installed and upgraded Vespel connector designs. A close-up of the fuzz button contacts and a size comparison are shown in the center images.

4. Status and Outlook

The upgrades to HV and signal cables and connectors discussed in sections 2 and 3 will undergo thorough testing. A test stand using the DEMONSTRATOR prototype cryostat will be used with a string of detectors to test upgraded HV cables and read out signal into upgraded signal cables. An assay of the materials that will be used for the upgrade is also underway. The manufactured cables to be used in the upgrade will be assembled with their corresponding connectors at UNC before shipment to the DEMONSTRATOR site. Installation in Module 1 is scheduled to begin in the summer of 2018.

5. Conclusion

The MAJORANA DEMONSTRATOR uses low-mass high voltage and signal cables that must meet stringent radiopurity, thermal stress, and mechanical stress requirement. Issues with connectivity and stability have necessitated a cable and connector upgrade.

Thorough testing of all new high voltage and signal cables and connectors is underway. Upon completion of testing, cables assembled will be shipped to the DEMONSTRATOR site at SURF. Data collection following the upgrade should commence sometime in Q4 2018.

Acknowledgments

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