Repairing TAGH Scintillator Counters Report

Submitted to

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Introduction:

The Broadband Tagger Hodoscope, hence forth referred to as the "TAGH," is to be used in the coming fall of 2019 in part of the Primexd project. In order for the TAGH to be fully utilized it must accurately be able to detect electrons' energies to find the corresponding energy of the photons. In January of 2019, multiple scintillators counters were found to be loose and corresponded to counters that were suspicious and believed to no longer be functioning properly. To prepare the Broad Tagger Hodoscope for its use in the fall, these suspicious counters were removed, inspected, and repaired over the summer.

The purpose of this report is to go over the repair process, document new techniques used to ensure the longevity of the counters, and to allow for repairs made in the future to have a reference on how to do it. This report provides a brief background theory needed for working with the counters, details of equipment used, the procedure to repair and examine, results of tests done to repaired counters, and a short discussion.

Summary:

24 scintillator counters from the TAGH were identified as having loose scintillators and were removed from the TAGH examined, repaired accordingly, and made light tight again. After being repaired, they were tested using an oscilloscope detecting cosmic rays. All 24 detectors were able to detect the cosmic rays on both of their respective channels.

Besides for the loose scintillators, other problems such as bent scintillators and disconnected wires were also found in several of the counters. This raises concern over how many of the other nearly 200 counters have similar problems that could be affecting data acquired with them.

Background Theory:

Broadband Tagger Hodoscope:

According to the Hall-D main page wiki, after the electron beam is accelerated, it is directed into a diamond radiator. The electrons collide with the diamond and the Bremsstrahlung process occurs, where electrons release large amounts of energy in the form of photons upon hitting the diamond. Magnets then guide the electrons along the path of the TAGH scintillator counters. The electrons are then sent into an electron beam dump and the photons energy can be calculated using the information on the change of energy of the electrons. The photons then carry on towards the collimator and so forth.

A more detailed look at the TAGH can be found on the Hall D wiki (https://halldweb.jlab.org/wiki/index.php/Main_Page).

Scintillator Counter:

The general process for the way a scintillator counter works is that a radioactive particle hits the counter and results in an amplified current that can be used to determine characteristics of the particle. As is explained in more detail in W. R. Leo's textbook on nuclear physics experiments (1994), the scintillator, in the case of the TAGH counters, are made of a special crystal that upon being hit by a radioactive particle, releases a photon of light. This photon is directed towards the photomultiplier tube (PMT) by the light-guide. In the PMT, the photo-cathode is hit by the photon and an electron is released from the cathode, this is Einstein's photo-electric effect. There is an applied voltage that varies for each section of the PMT. The first section has the highest voltage and acts to create an electric field to accelerate the electron into the first dynode. Upon hitting the dynode, more electrons are released, which then are accelerated by another electric field towards then next dynode, and even more electrons are released. This results in a cascade of electrons that eventually end up hitting the photo-anode at the other end of the PMT, resulting in a current that can be detected. This effectively amplifies the current, which at first is nearly undetectable, into a detectable current.

Further reading on scintillators and PMTs can be done in chapters 7, 8, and 9 in *Techniques for Nuclear and Particle Physics Experiments: A How-to Approach* by W. R. Leo.

Muons created by cosmic rays:

According to Wikipedia, cosmic rays that interact with particles in Earth's atmosphere, result in pion's, which can decay into muons. Muons make up some of the natural background radiation on earth.

Further reading on this subject can be found at https://en.wikipedia.org/wiki/Muon#Muon_sources.

Repairing the scintillator Counters:

Process for selecting counters:

Counters were initially chosen to be repaired based on the coupling of the scintillator to the light-guide. A small amount of force was used to check and see of the scintillator was held fast to the light-guide or was loose. The scintillators that were able to be wiggled were removed and set aside to inspect and to ultimately repair. Groups ranging from 5 to 8 counters were taken at a time for repairing and then re-installed before the next group of counters was taken. One of the electrical engineers was tasked with removing and re-installing counters into the TAGH.

Counters are labeled with a specific number ranging from 1 to the upper 200's. Each hole that the counter is placed in should be numbered and should coincide with the counter number that was in it. In multiple cases, counter number and hole number did not match, therefore, a new label was placed next to the hole that coincided with the counter that was in it. This was done to ensure counters removed were returned to the same spot they were taken from.

Each of the counters were inspected by RadCon to ensure that it could be safely removed from the Tagger and brought into the EEL building, room 118. All the counters surveyed were deemed acceptable to be removed and brought back to the EEL building, where they were examined, repaired, and tested.

Inspection of the counters:

The counters were completely wrapped in black electrical tape (Figure 1). The electrical tape above the joint coupling the light-guide to the PMT was removed along with the mylar and tedlar covering the scintillator and the top part of the light-guide (Figure 2). In every case, the scintillator was either loose enough that it easily came out of the light-guide, was only held in place with the electrical tape covering or was broken with its base still held fast by the epoxy and the upper part completely split from the base (Figure 3). Scintillators were handled while wearing gloves. Scintillator removed from the counter and the counters were placed on a soft white cloth. The scintillator was kept with its counter and its position on the white cloth was numbered corresponding to its counter number (Figure 1).

Figure 1. Initial state of the scintillator counters before any work was done to them.

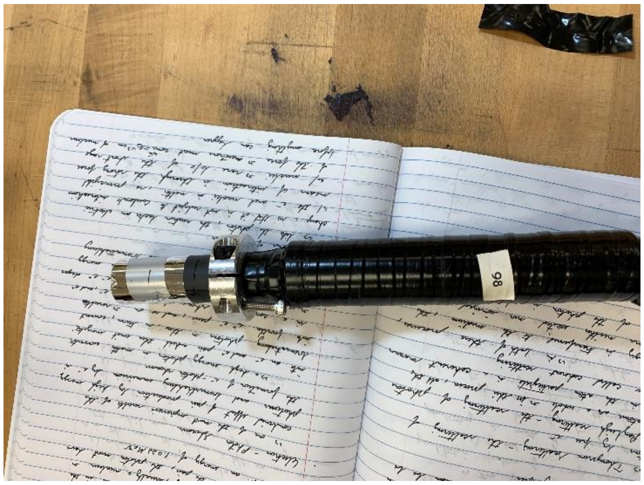

Figure 2. Counter 98 with its electrical tape above the collar removed as well as most of its tedlar.

Figure 3. The picture on the write shows how the scintillator, from counter 98, just came right out of most of the counters with just a small amount of force. Also note, there is a white film on the scintillator in the left picture. The picture on the right shows a scintillator that was found to have been split into two pieces.

Scintillators were examined initially for any damage. As elluded to above, 2 counter's scintillators were broken into two pieces – one piece still in the slotted light-guide and the other still in the wrapping (Figure 3). Two scintillators were found to have a pronounced bend (Figure 5). All scintillators were found to have a white film over the bottom part where they rested on the light-guide, as seen in the left picture in Figure 3. This white film severely hindered light from passing through, as it was hardly transparent. Several scintillators had light scratches on towards their bases parallel to the edge of the slot of the light guide (Figure 6).

Figure 5. This scintillator was found to have a bend to it and was replaced with a straight one.

Figure 6. Towards the left part of the scintillator is a chip missing where it would have rested against the edge of the slot of the light-guide.

Light-Guides were also checked for damage, such as scratches, and to see if there were any air bubbles between the PMT and the light-guide, and on cloudiness. Light-Guides had epoxy in their slots where they had held the scintillators fest (Figure 7). As in figure 7, some light-guides had residue of adhesive from direct contact with black electrical tape. One light-guide was noticeably cloudy, even after polishing and another had a large air bubble between the PMT and light-guide (Figure 8).

Figure 7. View of counter 98’s light-guide. The indention in the epoxy is where the scintillator once rested. Also note the black-electrical tape adhesive found on the light-guide.

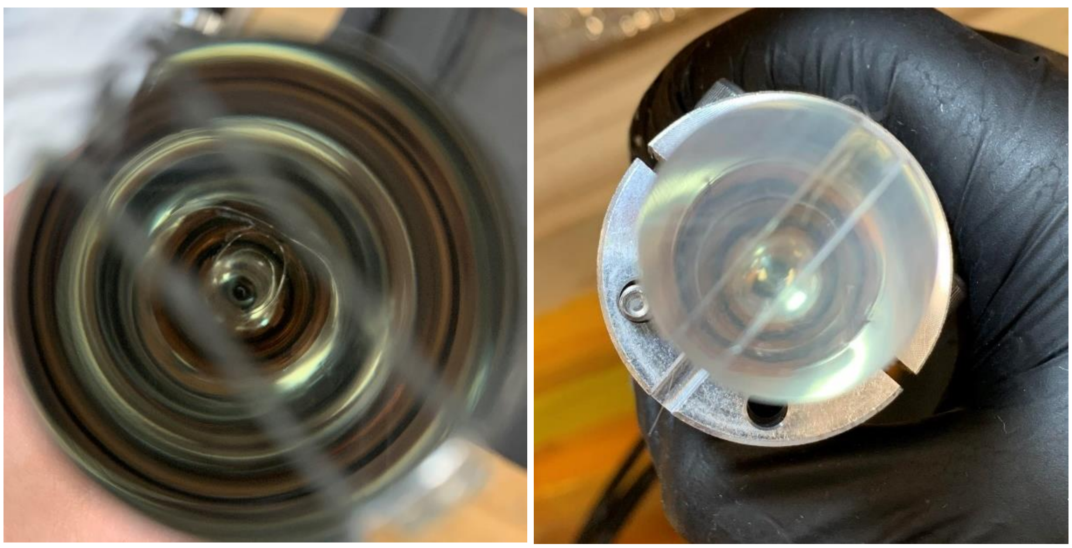

Figure 8. The left picture was shot looking through the light-guide towards the PMT. There is a clear air bubble between the two. The right picture shows a murky light-guide, counter 170.

Cleaning and polishing the counters:

Scintillators:

Scintillators were all polished to remove the white film on the ends connected to the light-guides. Novus Heavy Scratch Remover and Fine Scratch Remover was used as the polish. A cloth that was soft on one side and hard on the other was used with the polish (Figure 9). The polish was applied, a small dab, to the soft side of the cloth and the scintillator rubbed in a circular motion in the polish against the cloth. Gloves were worn while this was done. First the heavy scratch remover was used. A small dab of the polish was used, and the scintillator rubbed against the polish and cloth until polish was dry. This was repeated three or more times. Then the same was done with the fine scratch remover. Once the scintillator has the white film removed and can be seen through longitudinally relatively clearly, any fibers from the cloth were removed with gloves (Figure 10).

Figure 9. This is a picture of the cloth used to polish the light-guides and scintillators. The soft side was used for rubbing against the surfaces with the polish.

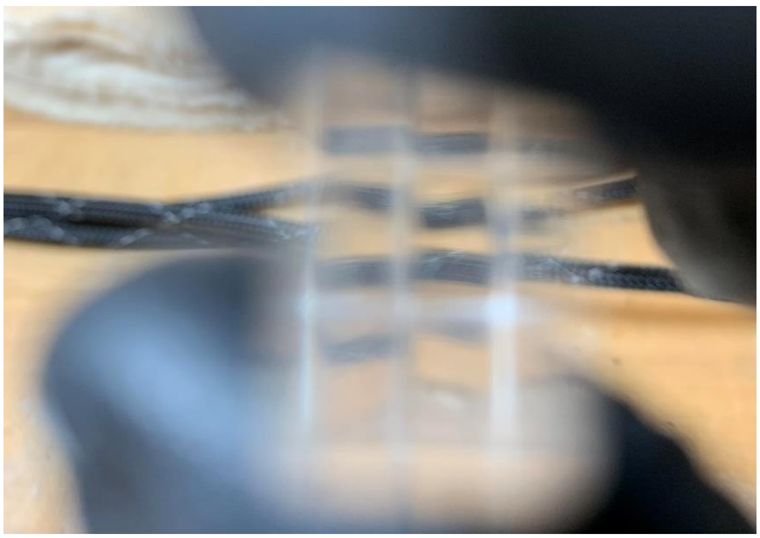

Figure 10. Picture looking through polished scintillator.

Light-guides:

To remove the old epoxy a Westward 4HWK1 heat gun was used at 250 degrees Fahrenheit low power for up to 15-20 seconds. The heat gun was held approximately 4 inches away from the light-guide. The heat gun was held nearly perpendicular to the light-guide's longitudinal axis, aimed at the epoxy. After 7-10 seconds, the light-guide was rotated 180 degrees while under the heat gun. A poking/ prodding tool was used to delicately lift off the heated epoxy (Figure 11). An exacto-knife was originally used but resulted in too many scratches to the light-guides, so was no longer used with the later counters. The poking tool also sometimes results in small scratches to the light-guides but caused less severe scratches than the exacto-knife (Figure 12).

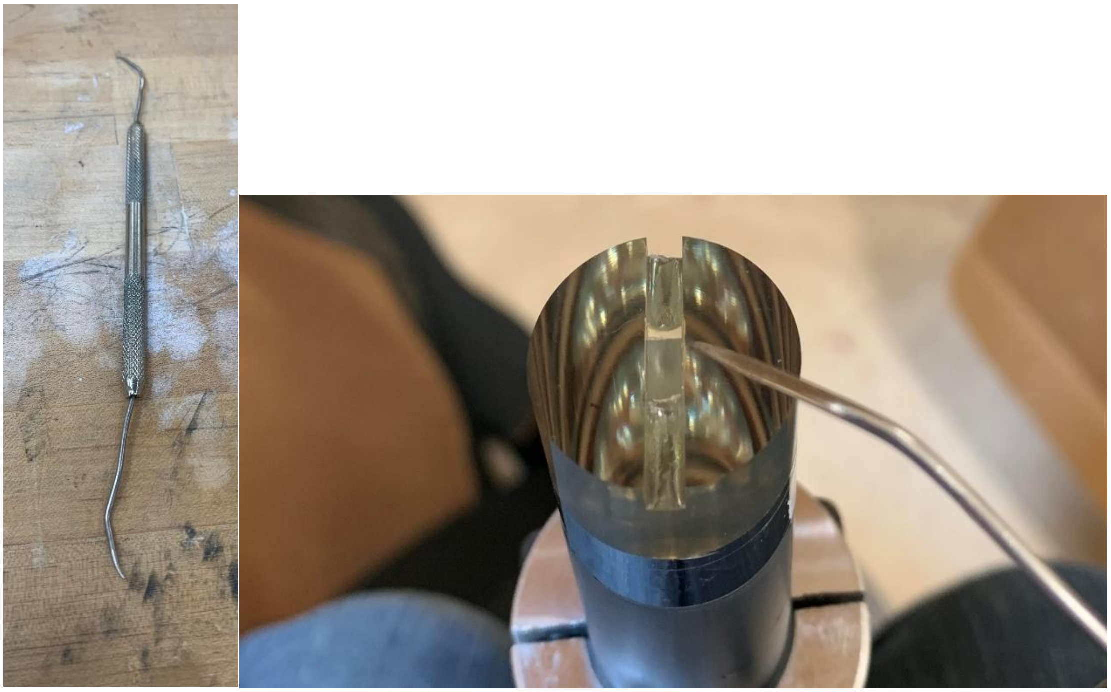

Figure 11. Poking tool used to remove heated epoxy.

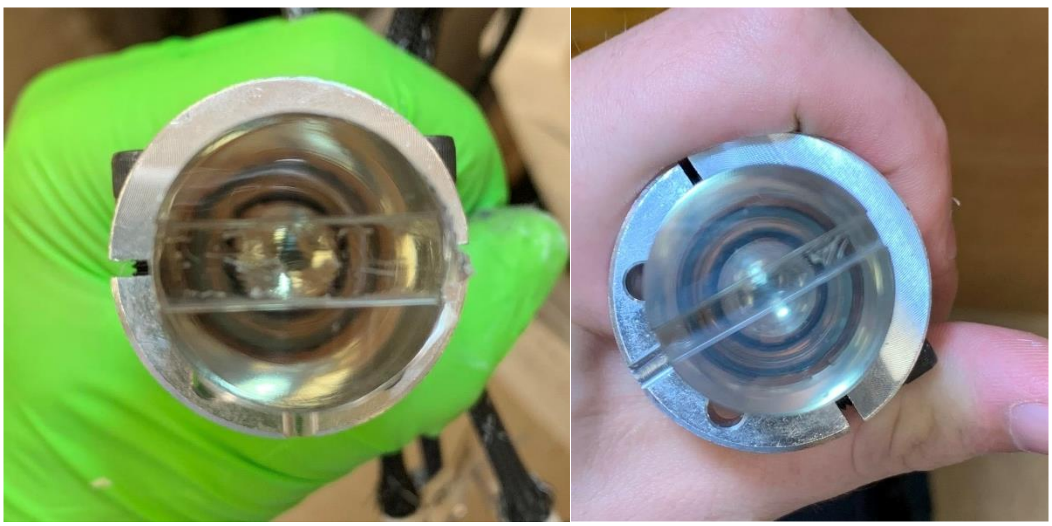

Figure 12. Comparison between scratches left by exacto knife, left picture, and poking tool for removing epoxy from the light-guides, right picture. Both have been polished.

After the epoxy was removed, isopropanol was lightly applied to the soft side of the cloth and then rubbed onto the light-guides. This removed bits of epoxy and any adhesive that was on the light-guides from electrical tape directly touching them (Figure 7). Then Novus Heavy Scratch and Fine Scratch Remover were used on the light-guides. Like the scintillators, the heavy scratch remover was applied to the soft side of the cloth and rubbed in the slot of the light-guide on any scratches or thin layers of leftover epoxy. This was repeated 5 times. Then the fine scratch remover was rubbed in the same fashion at least 5 times, until a clear visual of the top of the PMT was achieved looking down through the light-guide (Figure 13). Isopropanol was then applied to a cloth again and used to clean off any remaining dried polish. Leftover cloth fibers were wiped away with gloves.

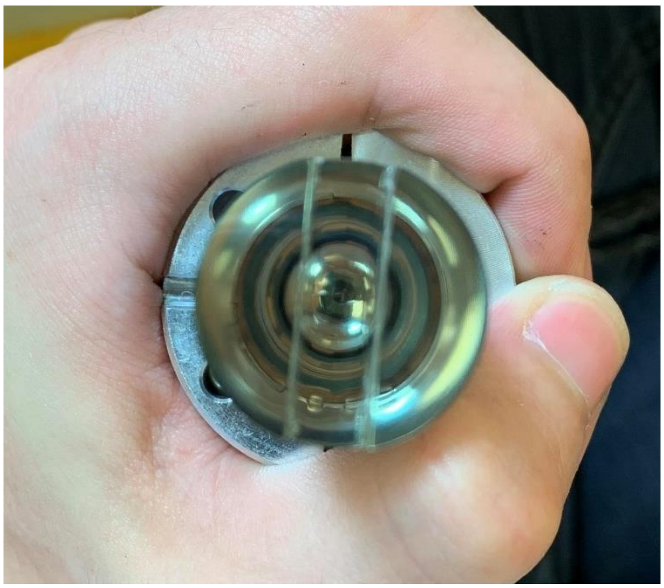

Figure 13. Light-guides were polished until the PMT coupled side were as clear as possible.

Coupling the scintillator to the light-guide:

A UV curing epoxy, Ultra Light-Weld Adhesives and Coatings 3094 by Dymax, was used to attach the scintillators to the light-guides along with a UV pen (Figure 14). After the UV pen had warmed up, two people were required, one to hold the counter and the other the hold the UV pen. Safety eye wear were worn to ensure protection from the UV light. A moderate dab of epoxy was placed in the middle of the slot of the light-guide. Then the scintillator was placed in the middle, ensuring that it was straight and directly in the middle of the slot. The UV pen was held at each of the four sides of the scintillator pointed diagonally down towards the epoxy for 15 seconds a side. Then the UV light was shined down the scintillator to ensure the epoxy under the scintillator cured properly, again for 15 seconds. The UV pen was held approximately 1-2 inches away from the epoxy.

Figure 14. Picture showing the UV pen being used on the epoxy that mounts the scintillator to the light-guide securely.

Making the counters light tight:

Once the scintillator is glued back into its place an initial layer of mylar, with length slightly larger than the scintillator, is wrapped around the scintillator. A piece of mylar tape is then used to keep the mylar tight against the surface of the scintillator. The extra mylar wrap above the scintillator is folded down and taped. Next a rectangular piece of mylar is used to wrap around the light-guide and taped using the mylar tape. Then a square piece of mylar is cut with a small rectangle the size of the scintillator is cut out of its middle, so that it may slide down over the scintillator and on top of the light-guide. Opposite end of this piece is then tapped down. Next two cuts are made in the other two ends of the now taco shaped piece of mylar and folded around and down the side of the light-guide. This wrap of mylar is essential to reflect the light from the scintillator and keep ambient light outside of it out. Figure 15 shows pictures of this process.

Figure 15. This figure shows pictures in order of the processes detailed above. First mylar is wrapped around the scintillator, then cylindrical part of the light-guide, followed by the top part of the light guide. Everything is taped using a mylar tape.

Tedlar is then wrapped around the scintillator and light-guide in the same way the mylar was; no tedlar piece is inserted over the scintillator to rest on the top of the light guide though. Next electrical tape starting at the base of the light-guide and spiraling up just above the base of the scintillator is employed. Then liquid electrical tape is placed on the tedlar of the scintillator and on top of the electrical tape on top of the light-guide. This ensures light does not leak into or out of the top side of the counter. Figure 16 shows pictures of this process.

Figure 16. The picture to the left shows the tedlar around the scintillator and cylindrical portion of the light-guide. A mylar tape was used on the tedlar. The right picture shows the black electrical tape wrap starting at the joint and extending up to the base of the scintillator. The scintillator and top of portion of the light-guide were then covered in liquid black electrical tape.

Testing with an oscilloscope:

The test set up for the counters is as follows: a Tektronix DPO 4034 Digital Phosphor Oscilloscope and a C.A.E.N. power supply delivering 900 volts are connected to the counter. The counter is further wrapped in a black plastic sheet while being tested. The counter is checked to see if it can detect cosmic rays in both of its channels, which is displayed on the oscilloscope as a large signal voltage relative to background noise. The trigger was set to look at large signals above several 100mV, these were thought to be cosmic rays. Figure 17 shows both the setup for the tests and an example of a positive test for detecting cosmic rays.

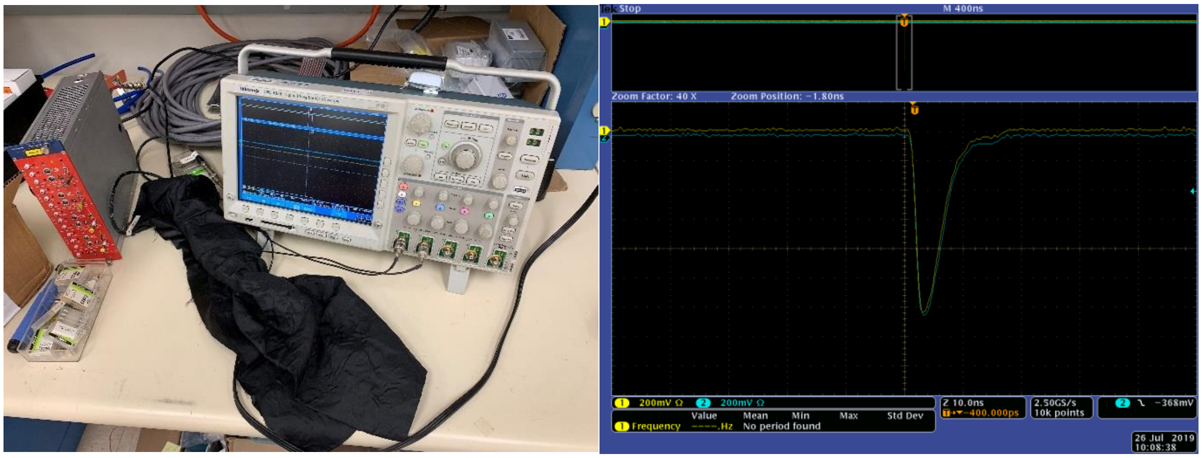

Figure 17. Picture on the left shows the set-up with the counter wrapped in the black tarp connected to the power supply on the far left and the oscilloscope on the right. The right-hand picture is from the oscilloscope – these were the type of readings that positively identified that both channels of the counter were working.

Unsuccessful counters have their bottom ends unwrapped and mu-metal shields and keplar wrap removed so that the wires can be examined. In all three cases where channels were not functional, wires were detached from the circuit board, as seen in figure 18.

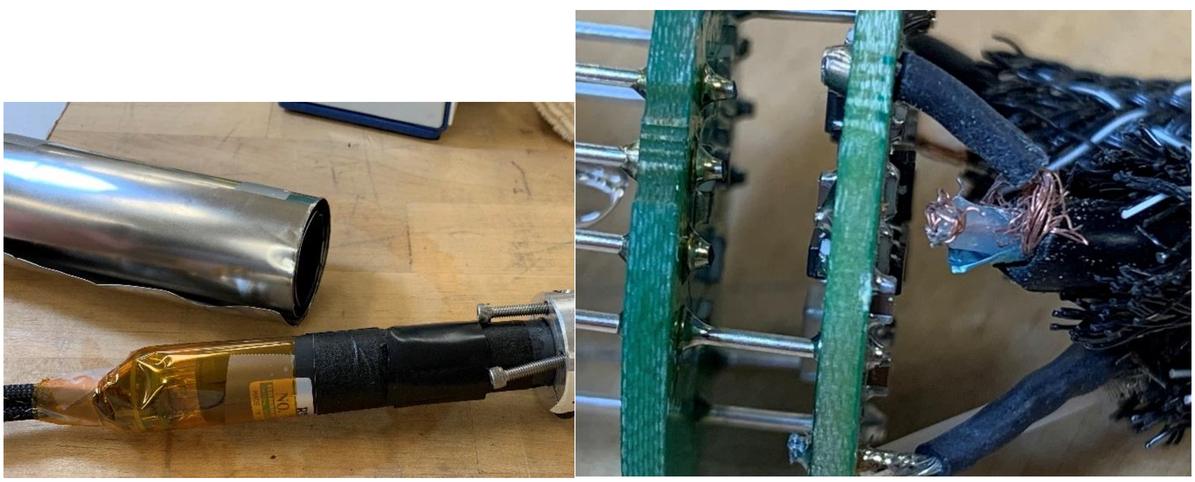

Figure 18. The left picture shows the exposed PMT with keplar wrapped around it still and the mu-metal shielding removed. The right picture shows a wire disconnected from the circuit board, counter 125.

Replacing broken or defective parts:

The following lists broken or defective parts and remedies to these problems: Bent scintillators were replaced with straight edged ones. The issue of the air bubble between the PMT and light-guide was remedied through replacing the light-guide and PMT with a similar sized one without an air bubble. An electrical engineer soldered the wires back to the circuit board in all three cases where the wire had been reattached.

To ensure further wires would not be pulled off their circuit boards, Joshua Krafts devised a novel way of securing them to the mu-metal housing. He took a plastic dowel and machined it into what is depicted in figure 19. This machined piece of plastic was placed an inch inside the mu-metal and the outer part taped with black masking tape to hold and keep the part from coming loose. Then the wires were held fast to the part through use of a zip-tie. This was all then wrapped in electrical tape to about an inch below where the wires came out of the machined part. This transferred the stress of tugging wires from the soldered joints on the circuit board to the mu-metal housing.

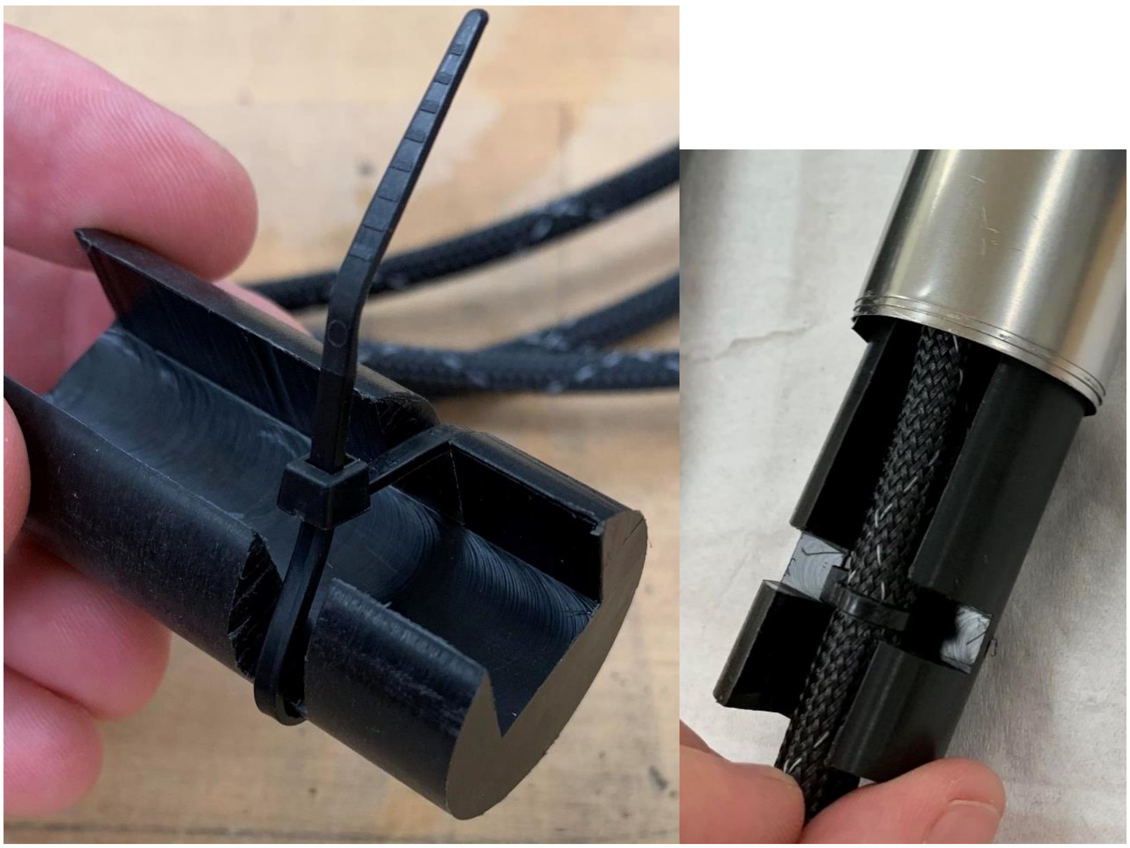

Figure 19. The plastic insert was built to ensure future wires would not become disconnected from the circuit board. The right picture shows how it is inserted into the mu-metal shielding of the PMT.

Re-installment of the counters:

Counters were re-installed by an electrical engineer, just as they had been removed by one.

Table of the scintillator counters:

The following table lists counters worked on, reason for their removal, problems they had, fixes, and dates of removal and re-installation.

Scintillator Counter #	Why it was removed from TAGH	Problems Found	What was repaired	Date Taken Out	Date Reinstalled
83	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/10/2019	7/17/2019
84	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/10/2019	7/17/2019
92	Loose scintillator	Scintillator no longer securely attached to light-guide, scintillator bent	scintillator replaced, plastic endpiece added	7/10/2019	7/17/2019
98	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/17/2019	7/26/2019
101	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/17/2019	7/26/2019
110	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/17/2019	7/26/2019
113	Loose scintillator	Scintillator broken in two towards base	scintillator replaced, plastic endpiece added	6/10/2019	7/2/2019
116	Loose scintillator	Scintillator broken in two towards base, 1 disconnected wire at the circuit board	scintillator replaced, wire reattached, plastic endpiece added	6/10/2019	7/2/2019

119	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/2/2019	7/10/2019
123	Loose scintillator	Scintillator no longer securely attached to light guide, large air bubble between light-guide and PMT	scintillator reattached, light-guide and PMT were replaced for one without a bubble	7/10/2019	7/17/2019
125	Loose scintillator	Scintillator no longer securely attached to light guide, 1 disconnected wire at the circuit board	scintillator reattached, wire reattached, plastic endpiece added	6/10/2019	7/2/2019
126	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/10/2019	7/17/2019
138	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/10/2019	7/17/2019
144	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	6/10/2019	7/2/2019
161	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	6/10/2019	7/2/2019
170	Loose scintillator	Scintillator no longer securely attached to light guide, light-guide very cloudy	scintillator reattached, plastic endpiece added	7/17/2019	7/26/2019
184	Loose scintillator	Scintillator no longer securely attached to light guide, 1 disconnected wire at the circuit board, amplifier	scintillator reattached, plastic endpiece added, wire reconnected	7/10/2019	7/17/2019

		and divider not proper distance apart (was an 1/8th an inch apart)			
187	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/2/2019	7/10/2019
196	Loose scintillator	Scintillator no longer securely attached to light guide, scratches on scintillator around base	scintillator replaced, plastic endpiece added	7/2/2019	7/10/2019
212	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/2/2019	7/10/2019
228	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/2/2019	7/10/2019
229	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/10/2019	7/17/2019
230	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/10/2019	7/17/2019
231	Loose scintillator	Scintillator no longer securely attached to light guide	scintillator reattached, plastic endpiece added	7/17/2019	7/26/2019

Results:

24 total counters were repaired, and results showed that all the channels were able to display signals from cosmic rays on the oscilloscope. Fixing just the counters with loose scintillators revealed more problems with the counters than just the scintillator's connection, but wires disconnected, air bubble's between PMT and light-guides, bent scintillators, circuit boards too close to each other, and adhesive on the light-guides from where electrical tape was placed instead of mylar.

Conclusion: The scintillator counters fixed should work in the coming fall experiments that require the use of the TAGH. The manifestation of other problems with the counters that were less obvious than loose scintillators is concerning. Further testing is going to be needed to ensure the accuracy of the TAGH scintillator counters that were and were not examined.

Of the counters with suspicious channels that were noticed in January of 2019 (counter numbers: 84, 92, 110, 113, 116, 119, 125, 138, 144, 161, 179, 184, 187, 196, 212, and 228), all of them had loose scintillators and were part of the ones fixed. Counter 179, though, was not removed for having a loose scintillator, meaning that it was either not noticed during the inspection in June 2019, or does not have a loose scintillator and may have something else wrong with it.

Discussion:

Testing of the counters was based on qualitative results using an oscilloscope. The trigger was set to look at signals above several hundred mV. This was assumed to be cosmic rays. The reason for not quantitively examining the counters is largely because the problem was clearly identifiable in each of the counters, namely a loose scintillator, and the goal was to fix the counters that had something clearly wrong with them.

Ideally, if time was not an issue, each of the detectors could have been examined with an oscilloscope before and after the repairs to be able to quantitatively assess the benefit of reattaching the scintillator and fixing other various problems found.

Future repairs made to the counters need to make sure that the black electrical tape cover does not touch the light-guide. It should just touch the mylar and tedlar. On several counters, electrical tape was found to be present on the light-guide, this may affect the amount of light that is transferred to the PMT.

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