Central Time-of-Flight Magnetic Shield Attachment Procedures

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ctof_shield.tex

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Abstract

This document details the procedures and QA requirements for installing the magnetic shields and PMTs for the CLAS12 CTOF counters. It is designed to provide an illustrated guide to all assembly steps.

1 Overview

The Central Time-of-Flight (CTOF) system is the CLAS12 detector used to measure the flight time of charged particles emerging from interactions in the target in the angular range from 35° to 125°. The system specifications call for an average time resolution for each counter along its full length of σ_{TOF}=60 ps. The CTOF detector surrounds the experimental target at a radial distance of 25 cm and consists of 48 92-cm-long scintillation bars having a trapezoidal cross section that form a hermetic barrel (see Fig. 1). The barrel will be positioned inside of the CLAS12 5-T superconducting solenoid magnet. Each counter is read out via a PMT on each end through long light guides to position the field-sensitive PMTs in reduced field regions. However, even in these positions, the PMTs will reside in inhomogeneous fringe fields from the magnet at levels as large as 1 kG at the location of the upstream PMTs and as large as 400 G at the location of the downstream PMTs. In order to allow for operation of the PMTs in this environment, they must be operated within specially designed multi-layer magnetic shields.

The full details of the design and performance tests of these shields can be found in Ref. [1]. The CTOF PMT magnetic shield system includes three passive layers and one active layer. The passive layers are made up of an external heavy shield made from 1006 steel, an intermediate layer composed of the ferromagnetic Hiperm-48, and an inner layer composed of the ferromagnetic Co-netic. With these three layers, tests of prototype shield systems were able to reduce an external 1 kG field to below 1 G at the position of the PMT photocathode. To reduce the field levels to below 0.5 G, an active shield layer is provided. The active shield consists of two sets of coils that are wrapped in two positions about a mandrel that positioned just outside of the inner shield layer. Note that the shields for the upstream and downstream PMTs are identical in their designs.

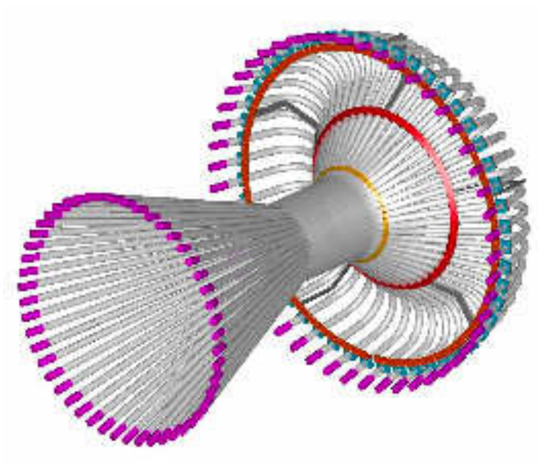

Figure 1: View of the Central Time-of-Flight (CTOF) system for CLAS12. The scintillation bars form a hermetic barrel and the PMTs are attached to the ends of long light guides. The beam enters this detector from the lower left side.

Fig. 2 shows the results of a 3-D magnetic field calculation for the three-layer passive CTOF shield system in a 1 kG external field. The calculation plots the field profile as a function of coordinate across the shield system showing field levels below 1 G at the photocathode location.

2 Shield Components

Fig. 3 shows an "exploded view" assembly drawing of the different parts that make up the CTOF PMT shield system to highlight the components that make up the different layers and their positioning with respect to each other. Fig. 4 shows a photograph of the layout of the full set of the actual shield components. The labels are shown with the names used to identify the different parts. Note that both the external and the intermediate shield layers consist of a cylindrical section with conical endcaps. The PMT itself fits within the inner cylinder and the light guides feed into the opening on the downstream end of the shield assembly. The relevant drawings for the CTOF magnetic shield system are as follows:

- B00000-01-04-2200 - *CTOF Shielding Assembly*
- B00000-01-04-2201 - *Heavy Cone Cap* - referred to as the *downstream heavy cone*
- B00000-01-04-2204 - *Heavy Cone* - referred to as the *upstream heavy cone*
- B00000-01-04-2205 - *Centering Spacer*
- B00000-01-04-2207 - *Exchange Block*
- B00000-01-04-2208 - *Retention Ring*
- B00000-01-04-2400 - *Active Shielding Assembly*

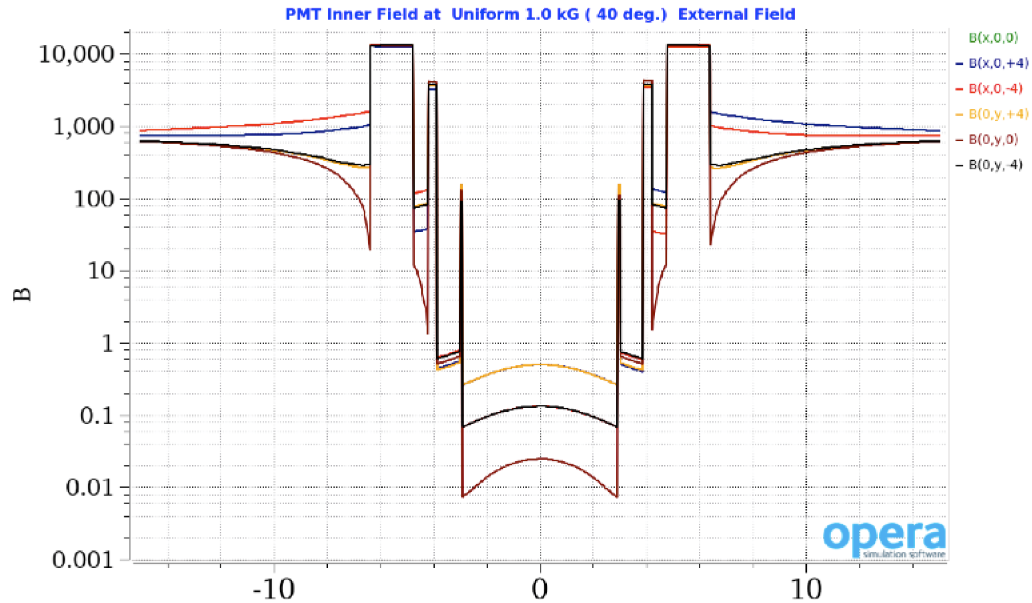

Figure 2: 3-D magnetic field calculation using the code suite Opera [2]. The calculation plots the field profile (in G) across the transverse coordinate (in cm) of the CTOF three-layer passive magnetic shield system. The different curves correspond to different coordinates along a line perpendicular to the counter axis. For this calculation the external field lines were at an angle of 40° relative to the shield axis of symmetry to reflect the expected operational configuration of the shields.

- B00000-01-04-2401 - *Active Base*
- B00000-01-04-2402 - *Active Clamp*
- B00000-01-04-2405 - *Inner Clamp*

In Fig. 4 there are several components that are not part of the passive shield layers. They include:

- the *wave spring* and *retention ring* are used to provide the force to keep the PMT up against the end of the light guide
- the *centering spacer* is designed to keep the shield centered with respect to the light guide and the PMT
- the *exchange block* with its spokes is used to keep the parts of the shield up against each other without gaps
- the *active clamp* is used to fix the position of the shield along the light guide up against the *inner clamp*.

In the remainder of this document, step-by-step procedures for the proper installation of the CTOF magnetic shield system are detailed through a series of photographs. The relevant quality assurance (QA) steps for the different processes are also explained.

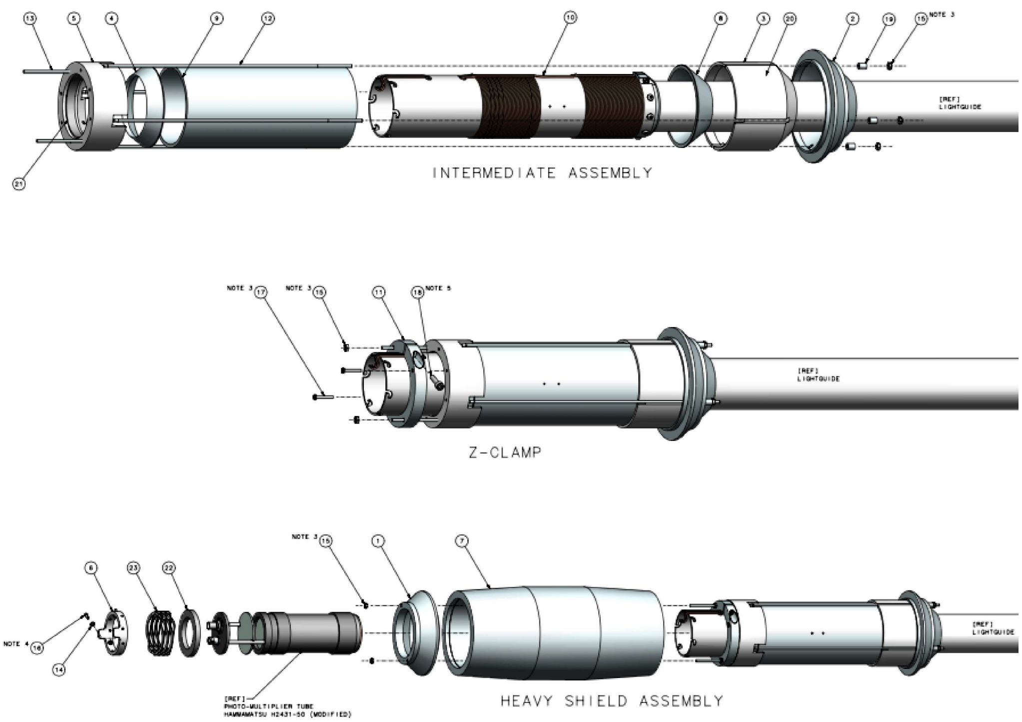

Figure 3: CTOF magnetic shield assembly drawing showing all of the components of the system and their relation to each other. Drawing ref. B00000-01-04-2200.

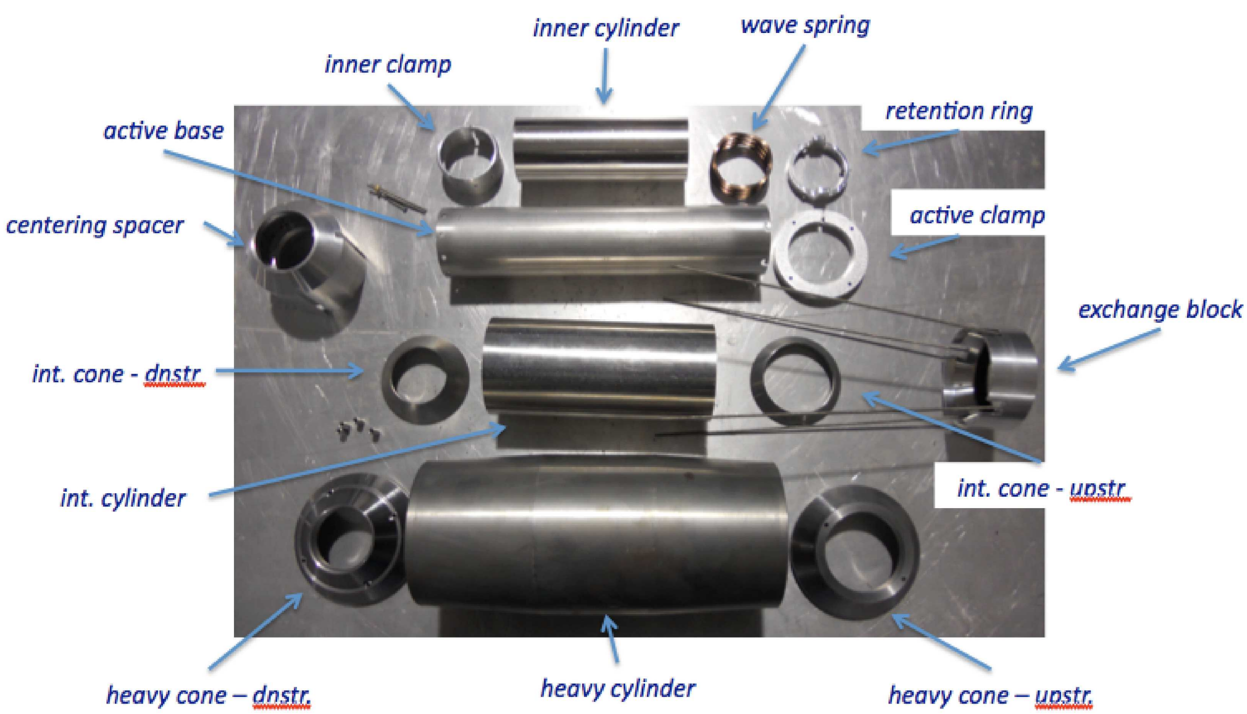

Figure 4: Photograph of the components that make up the CTOF magnetic shield system. Shown are the external heavy shield (1006 steel), the intermediate shield (Hiperm-49), and the inner shield (Co-netic). The mandrel used to wind the compensation coils is labeled as the *active base*.

3 Installation Procedures

3.1 Pre-Assembly Steps

3.1.1 Step #1: Install Light-Tight Foam Seal in Centering Spacer

The first pre-assembly step is to install a foam ring within the *centering spacer* to act as a light seal. The specifications on the foam are:

- 1-in-wide neoprene foam, 0.375-in-thick, 7.9-in-long, adhesive backing

The foam is installed with a diagonal cut so that when the ends join, there is not a straight path for a light leak. Fig. 5 shows a photograph of the foam installed into the *centering spacer* in its machined groove. In order to prepare the *centering spacer* for installation on the light guide, the 0.375-in-thick foam must be pre-compressed to reduce friction. To prepare for this installation step, the foam surface should be dusted lightly with baby powder that serves to reduce friction. The *centering spacer* is then installed onto a bare light guide (see Fig. 6). This serves to compress the foam so that it can be installed onto the counter light guide without tearing the Tedlar or pulling off the Kapton tape on the reflector cone.

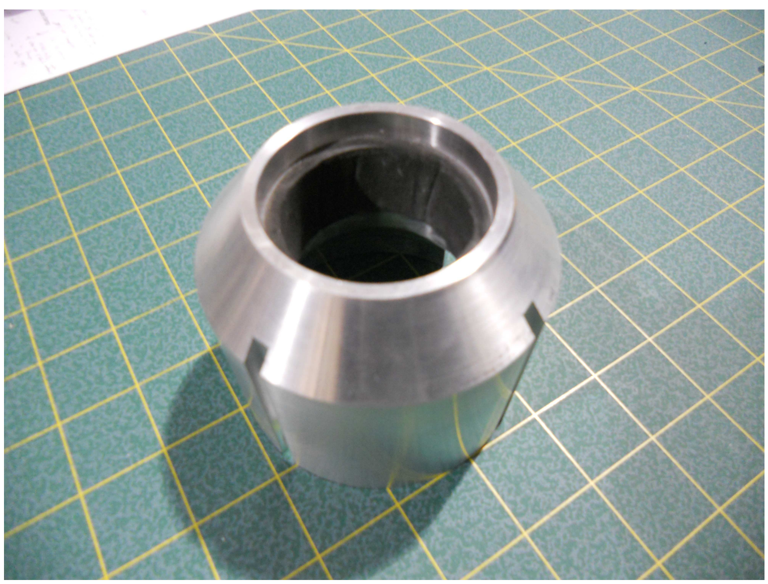

Figure 5: Photograph of the *centering spacer* showing the installed foam strip used to provide a light seal at the downstream end of the shield. The faint white tint on the foam is a dusting of baby powder used to reduce friction when installing this part on the light guide.

3.1.2 Step #2: Install the Foam Strips on the PMTs

Two thin foam strips are wrapped once around the body of the PMTs to provide a light seal as well as to center the PMT within the inner magnetic shield (see Fig. 7). The first foam strip uses 0.19-in-thick, 0.38-in-wide neoprene foam with adhesive backing and is wrapped

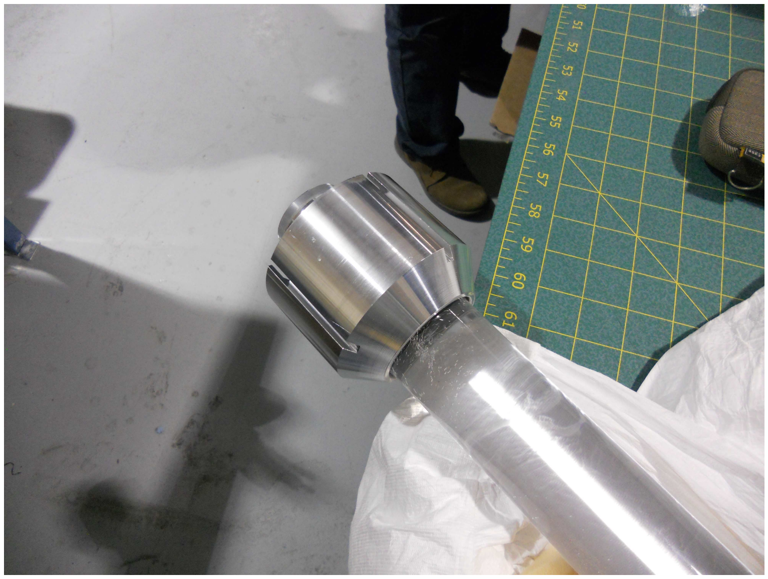

Figure 6: Photograph of the *centering spacer* fitting onto a bare light guide to pre-compress the foam strip to reduce the considerable resistance during installation of this part on the light guide.

about 2 in from the glass face of the PMT. The foam is then covered tightly with 3/4-in-wide electrical tape. The second foam strip, 0.375-in-thick, 1-in-wide with adhesive backing, is attached into the groove just above the plastic endcap on the PMT near the voltage divider. This foam is then taped over with 3/4-in-wide electrical tape.

3.1.3 Step #3: Prepare the Exchange Block

The first step to prepare the *exchange block* is to install the light-tight foam seal in the machined groove on the upstream end of the block (see Fig. 8. The specifications on the foam are:

- 0.38-in-wide neoprene foam, 0.19-in-thick, 9.7-in-long, adhesive backing

The next step is to attach the four spokes that are used to compress the shield assembly together and thread them 1/2 in deep into their tapped holes on the downstream face of the *exchange block* (see Fig. 9).

3.1.4 Step #4: Prepare the Active Shield Assembly

Begin by wrapping 3/4-in-wide electrical tape at each end of the *inner shield* so that it fits snugly inside the *active base* (see Fig. 10). It was found that two layers of electrical tape were appropriate. After the tape has been wrapped about the *inner shield*, insert it into the downstream end of the *active base* cylinder that has already been wound with the magnet wire and over-wrapped with the protective Kapton sheets (see Fig. 10). The depth of the

Figure 7: Photograph of the CTOF PMT/divider assembly. Two foam strips are attached to the outside of the PMT at the downstream end ($\sim$2 in from the glass face) and at the upstream end (in the groove just above the plastic endcap of the PMT) to center the PMT within the Co-netic shield layer.

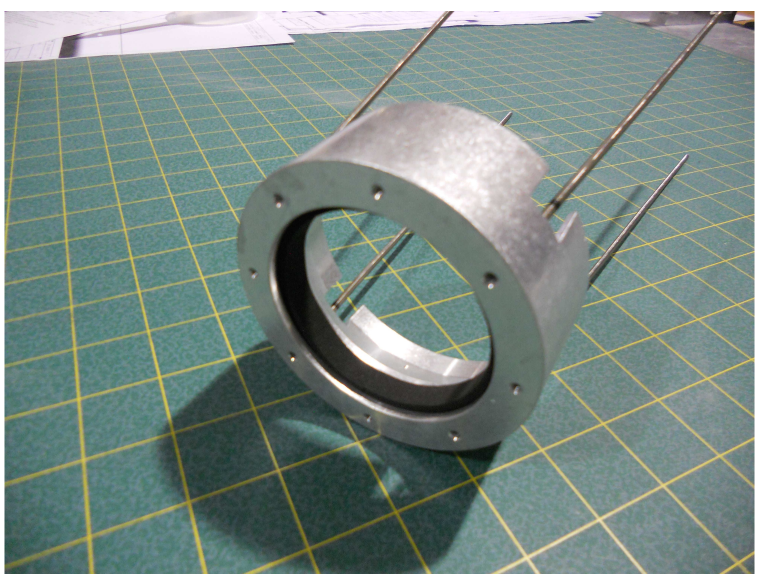

Figure 8: Photograph of the *exchange block* showing the installed foam strip used to provide a light seal at the upstream end of the shield.

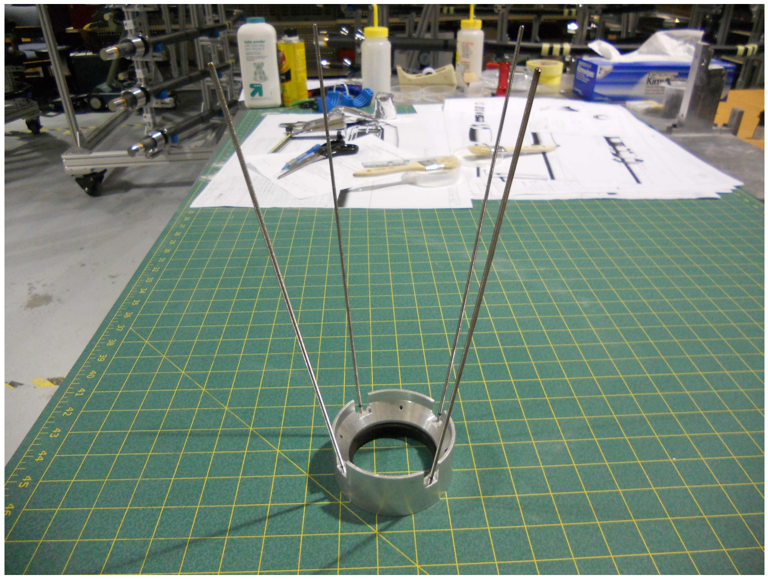

Figure 9: Photograph of the four spokes installed into the *exchange block*. These spokes go on the outside of the intermediate shield, across the slots in the *centering spacer*, and through the holes in the downstream heavy cone.

inner shield within the *active base* is set using an *inner clamp* piece by pushing the *inner clamp* into its nominal position within the *active base* (see Fig. 11).

The next step in the preparation of the *active shield assembly* is to electrically connect the *inner shield* and the *active base* using a 1-in-long strip of copper tape. This connection is necessary to ensure that the *inner shield* is not electrically floating (see Fig. 12).

The final step in preparation of the *active shield assembly* is to route the four wires for the two compensation coils through the downstream hole in the *active base*. Note that the four wire leads have already been covered with heat-shrink tubing to protect them. However, care should be taken to ensure the leads are not rubbed along the edges of the cut-out. The four wires should lie within the center of the *active shield assembly* as shown in Fig. 13. Fig. 14 shows how the heat-shrink tubing colors identify the different coil leads on each of the *active shield assemblies*. Before connecting an assembly into the shield system, a final inspection should be carried out to verify that the heat shrink tubing has been applied as show. The color coding is necessary to easily identify the different coil leads for connection to the power supply.

3.2 Shield Assembly

3.2.1 Step #1: Pre-Installation

Place the following components onto the light guide in their proper orientation in the following order:

1. *downstream heavy cone*
2. *centering spacer*

Figure 10: Photograph of the *inner shield* cylinder being installed in the *active clamp*. Note that the *active clamp* has already been wound with the compensation coils. The orange outer wrapping is the Kapton that covers the coils. The two rings of black electrical tape are used to center the *inner shield* cylinder within the *active clamp* and to provide friction to keep it in position.

Figure 11: Photograph showing how an *inner clamp* is used to properly position the *inner shield* cylinder within the *active clamp*.

Figure 12: Photograph looking down the inside of the *active shield assembly* showing the strip of copper tape that electrically connects the assembly to the *inner shield*.

Figure 13: Photograph showing the upstream end of the *active shield assembly* with the routing of the coil leads into the center of the assembly. Note that the coil leads are protected by a layer of heat shrink tubing. Each lead has a different color of tubing (red, black, white, clear) to identify the different coil leads.

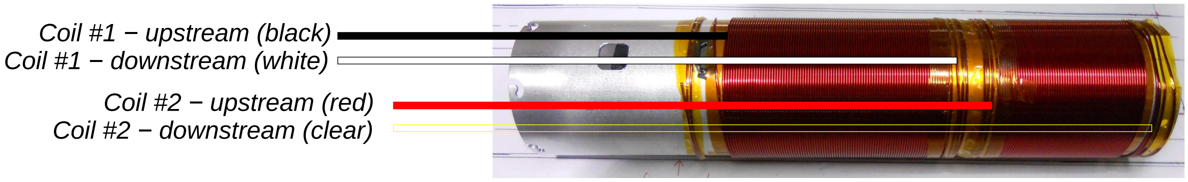

Figure 14: Diagram showing the color scheme used for the heat shrink tubing on the compensation coil leads.

3. *downstream intermediate cone*

4. *inner clamp*

Fig. 15 shows the configuration of the shield installation after this step. Note that due to the extremely tight fits of the *downstream heavy cone* and *centering spacer*, the Tedlar wrap along the end of the light guide was dusted with a layer of baby powder to reduce friction. After the installation of the *downstream heavy cone* and the *centering spacer*, the light guide was cleaned off using compressed air and wiping it down with a water-moistened Kimwipe. After cleaning, the *downstream intermediate cone* and *inner clamp* were then installed onto the light guide.

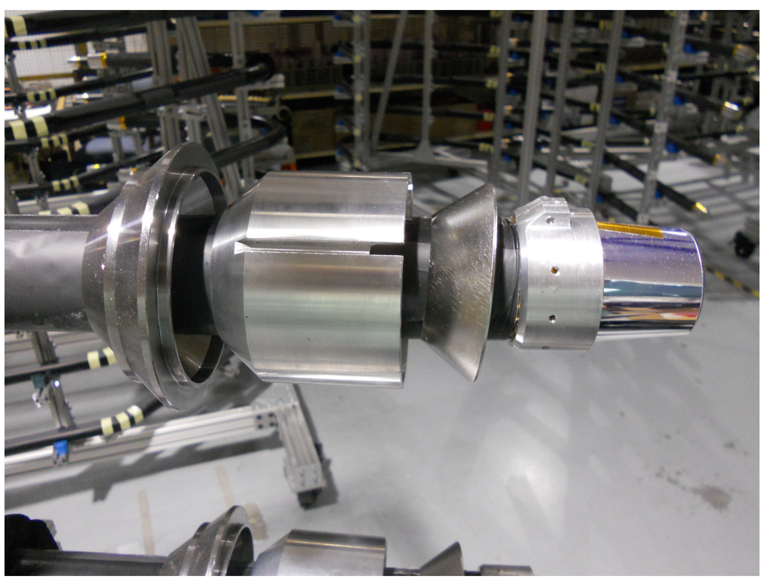

Figure 15: Photograph of a CTOF light guide showing the pre-installation (from left to right) of the *downstream heavy cone*, the *centering spacer*, the *downstream intermediate cone*, and the *inner clamp*.

To set the position of the *inner clamp* along the light guide, the depth tool was used as shown in Fig. 16. The end of the light guide should be protected with a piece of Kimwipe or Acetate to prevent scratching. Care should also be taken to ensure the depth tool is flush with the end of the light guide and that the *inner clamp* is flush against the depth tool. The orientation of the *inner clamp* should be such that the screw position to attach the clamp is on the top side of the counter as it is positioned in its storage cart (see Fig. 16). This choice is arbitrary but the installation goal was install all of the shield assemblies in the same manner. When the *inner clamp* is positioned properly, install the proper screw and torque down to the required specification:

- Hex socket head cap screw, 316 stainless steel, 6-32 (thread class UNC 3A), 0.63-in-long, τ=10 in-lbs (Ref. Drawing B00000-01-04-2400)

After the *inner clamp* is attached and the depth tool and protective light guide covering are removed, use a flashlight to inspect the end of the light guide (see Fig. 17). If there are any light scratches they should be buffed out using the appropriate buffing tools and compounds. Also, the end of the light guide should receive a final cleaning an ethanol-damped Kimwipe to remove dust, smudges, and fingerprints.

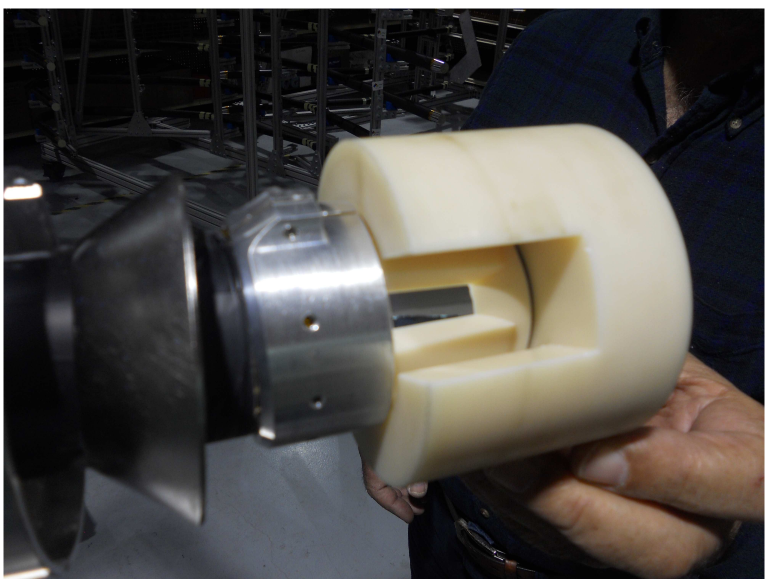

Figure 16: Photograph showing the depth tool used to properly position the *inner clamp* relative to the end of the light guide.

3.2.2 Step #2: Install Active Shield Assembly

Next, install the *active shield assembly* onto the *inner clamp* (see Fig. 18). The notch in the *active shield assembly* mates with the top of the *inner clamp*. When the *active shield assembly* is positioned properly, installed the proper screws (8) and torque down to the required specification:

Figure 17: Photograph showing the inspection of the exposed end of the light guide after the first shield installation sequence. After the first four shield components are installed, the end of the light guide is cleaned of fingerprints and smudges. If there are any light surface scratches, they are buffed/polished out.

- Hex socket button head screw, 316 stainless steel, 6-32 (thread class UNC 3A), 0.19-in-long, τ=10 in-lbs (Ref. Drawing B00000-01-04-2400)

3.2.3 Step #3: Install Intermediate Shield Assembly

Place the following components onto the *active shield assembly* in their proper orientation in the following order:

1. *intermediate shield*
2. *upstream intermediate cone*
3. *exchange block*

Fig. 19 shows the configuration of the shield installation after this point. Note that:

- care must be taken when handling the ferromagnetic shield parts so that they do not receive any mechanical shocks. They are not to be dropped or banged against other parts. This is necessary so that their performance as shield parts is not compromised.
- due to tight tolerances the fit of the *upstream intermediate cone* will be tight, but it should slide along the surface of the *active shield assembly* without marring the surface in any way. If it does not fit over the surface of the *active shield assembly* it will need to be carefully reamed out by a few mils using a deburring tool until the clearance is sufficient.

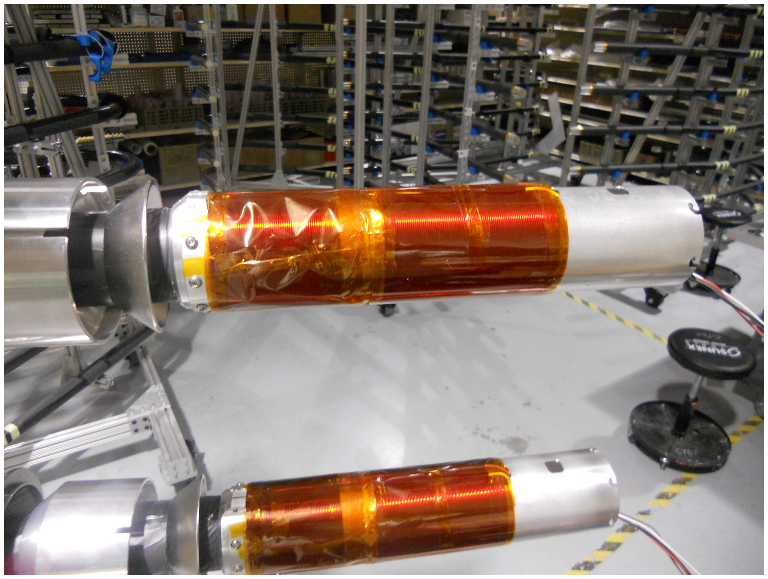

Figure 18: Photograph showing the *active shield assembly* attached to the *inner clamp*.

- care must be taken when positioning the *upstream intermediate cone* so that it does not pinch the wire leads on the coils. The edge of the *upstream intermediate cone* that is in contact with the *active shield assembly* should be positioned so that it just covers the downstream opening through which the wires go through in the *active shield assembly*.

- due to the inclusion of the foam in the *exchange block*, it is best installed at a slight angle so that the edge of the foam is engaged and mechanical pressure can be applied to compress the foam to allow the *exchange block* to slide along the *active shield assembly*.

The next step in the installation process is to fit the parts of the intermediate shield together so that they are properly captured within the *centering spacer* and the *exchange block*, and so that they are positioned properly along the counter with respect to the *inner clamp*. This process begins with inserting the *downstream intermediate cone* and the downstream end of the *intermediate shield* within the *centering spacer*. Be sure that the welding seam on the *intermediate shield* is located within one of the notches on the *centering spacer*. Then pull this part of the assembly upstream so that it is firmly against the *inner clamp*. Then insert the *upstream intermediate cone* and the upstream end of the *intermediate shield* within the *exchange block*. Again, be sure that the welding seam on the *intermediate shield* is located within one of the notches on the *exchange block*. This part of the assembly requires a bit of "wrestling" as the clearances on the parts are tight. However, care must be taken not to flex the counter as this could lead to a broken glue joint at the light guide/scintillator junction. When complete, recheck that the welding seams on the *intermediate shield* are within the notches on the *centering spacer* and the *exchange block* and that this intermediate shield assembly is fully up against the *inner clamp*. You should also look into the gaps at the four notches on the *centering spacer* and the *exchange block* to make sure there are no gaps between the *intermediate shield* and either of the intermediate cones. The installation

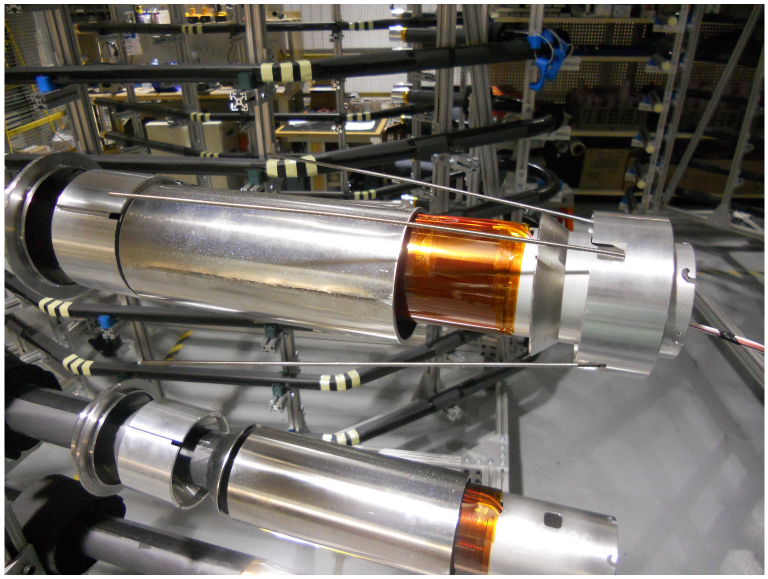

Figure 19: Photograph showing the light guide with the *intermediate shield*, the *upstream intermediate cone*, and the *exchange block* loosely installed on the light guide.

of the shield at this stage can be seen in Fig. 20.

3.2.4 Step #4: Secure Shield Assembly

Next position the four long spokes attached to the *exchange block* into the corresponding notches on the *centering spacer* and feed them through the holes in the *downstream heavy cone*. The parts may need to be rotated about the counter to mate them properly. If so, take care to ensure that the Tedlar wrapping on the light guide does not wrinkle excessively. The rods should stick out of the holes in the *downstream heavy cone* by just a little more than 0.5 in. Install the following hardware on the threaded rods:

- unthreaded spacer, 316 stainless steel, 0.115 in I.D., 0.25 in O.D., 0.5-in-long
- hex machine nut, brass, 4-40 (thread class UNC 2B) (Ref. Drawing: B00000-01-04-2200)

The nuts should be attached only loosely to allow for final inspection of the intermediate shield assembly. At this stage the shield assembly should appear as in Fig. 21. Next give a final inspection in the four notches on the *centering spacer* and the *exchange block* to be sure that there are no gaps between the *intermediate shield* and either the *downstream intermediate cone* or *upstream intermediate cone* as shown in Fig. 22. Verify that the *intermediate shield assembly* is as far upstream as possible, i.e. that it is fully up against the *inner clamp*. Also ensure that the orientation of the assembly about the light guide is according to design with the hole for the compensation coil wires pointing upwards with the counters in their storage cart. Next torque down the brass nuts on the threaded rods using a cross pattern to their specifications:

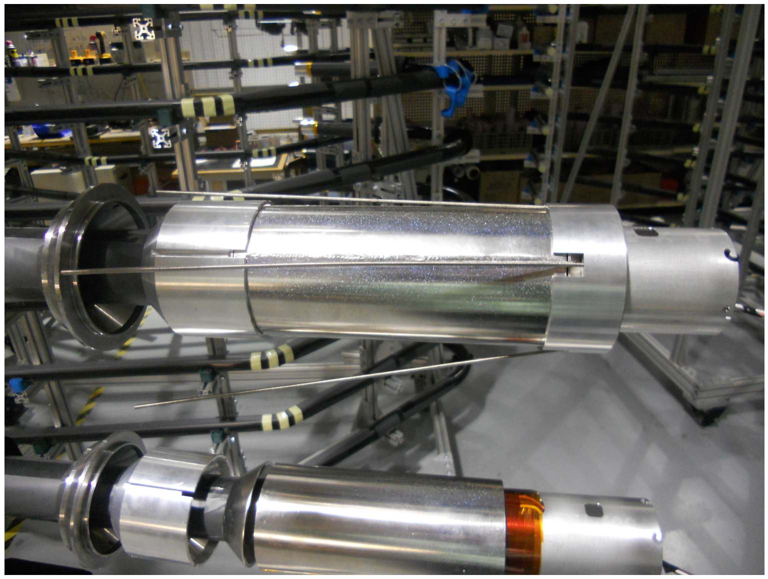

Figure 20: Photograph showing the welding seam of the intermediate shield positioned within the notch cut-outs of the *centering spacer* on the downstream end of the shield and the *exchange block* on the upstream end of the shield. The *centering spacer* and the *exchange block* have been positioned over the intermediate shield cylinder and intermediate shield cones, but the shield assembly has not been set along the light guide in its final position.

- τ= 5 in-lbs (Ref. Drawing: B00000-01-04-2200)

3.2.5 Install Active Clamp

The next step in the shield installation is to lock the *intermediate shield assembly* to the counter to prevent movement by installing the *active clamp*. To begin this step, insert two threaded rods into opposite sides of the *exchange block*. The positioning of these threaded rods can be seen in Fig. 23. The rods should be threaded into the *exchange block* until they bottom out. The rods are specified as:

- threaded rod, 316 stainless steel, 4-40 (thread class UNC 1A), 2.5-in-long (Ref. Drawing: B00000-01-04-2200)

Then install the *active clamp* over the end of the *active shield assembly*. After sliding it along the *active shield assembly*, guide it along the threaded rods already installed into the back of the *exchange block* until the *active clamp* is flush against the back of the *exchange block*. If the *intermediate shield assembly* is up against the *inner clamp* in its design position, the upstream face of the *active clamp* should be flush with the downstream edge of the upstream wire cut-out in the *active shield assembly* as shown in Fig. 24. With this properly positioned, attach the hardware to lock down the *active clamp* to the *exchange block* (two nuts on the threaded rods and two screws in the other two attachment holes on the *active clamp*) using the following specifications:

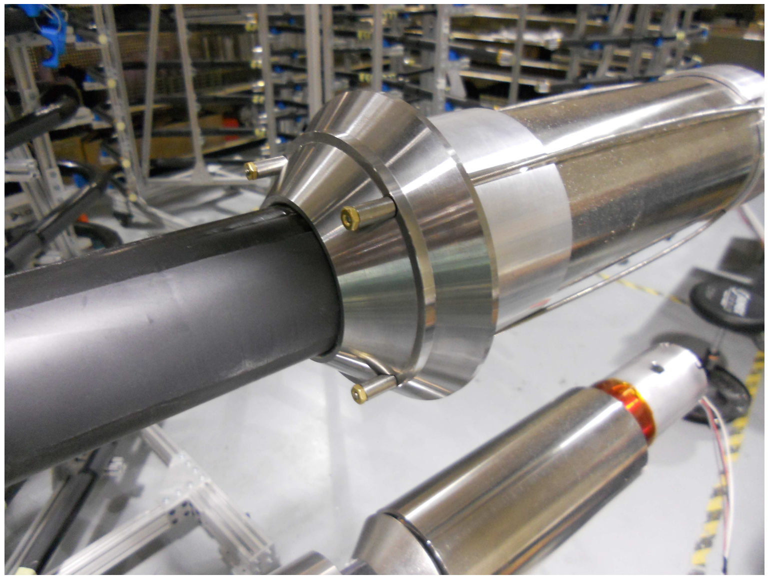

Figure 21: Photograph showing the spokes from the *exchange block* fed through the holes in the downstream heavy cone. Small cylindrical sleeves are placed over the ends of the spokes and the nuts are attached.

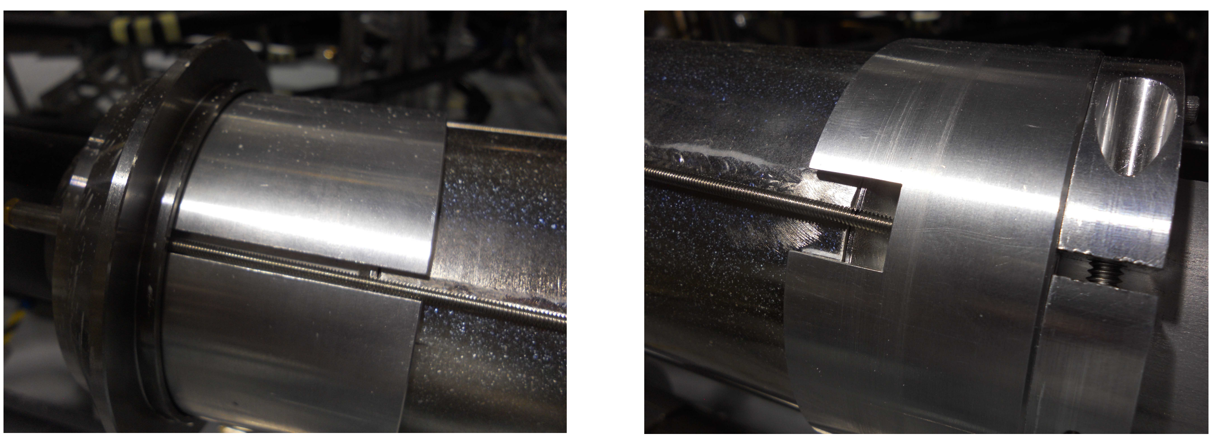

Figure 22: Close up views of the downstream end of the intermediate shield assembly as seen through the notch in the *centering spacer* (left) and the upstream end of the intermediate shield assembly as seen through the notch in the *exchange block* (right). Note that the gaps between the *intermediate shield* cylinder and intermediate shields cones have been reduced to zero.

- hex machine nut, brass, 4-40 (thread class UNC 2B), τ=5 in-lbs
- hex socket cap screw, 316 stainless steel, 4-40 (thread class UNC 3A), 0.75-in-long, τ=5 in-lbs (Ref. Drawing: B00000-01-04-2200)

Finally, attach the clamp screw and torque down according to specifications:

- hex socket cap screw, 316 stainless steel, 10-24 (thread class UNC 3A), 0.75-in-long, τ=24 in-lbs (Ref. Drawing: B00000-01-04-2200)

Figure 23: Photograph showing the attached *active clamp*. The small threaded rods feed through the corresponding mating holes in the *upstream heavy cone*. However, this part of the installation takes place in Hall B after the counter is attached to its installation strongback.

3.2.6 Apply Sealant

The final step in the shield installation procedure in the CTOF assembly area is to apply a ring of sealant around the downstream edge of the *downstream heavy cone* where the light guide emerges. We have chosen to employ a black silicone caulk.

3.3 PMT Installation

To begin the PMT installation, route the magnet wire leads up through the upstream hole in the *active shield assembly* using care not to kink the wires. When they are in position, the four wires need to lie flush against the inner surface of the *active shield assembly* so that they will not be in the way of the PMT insertion (see Fig. 25).

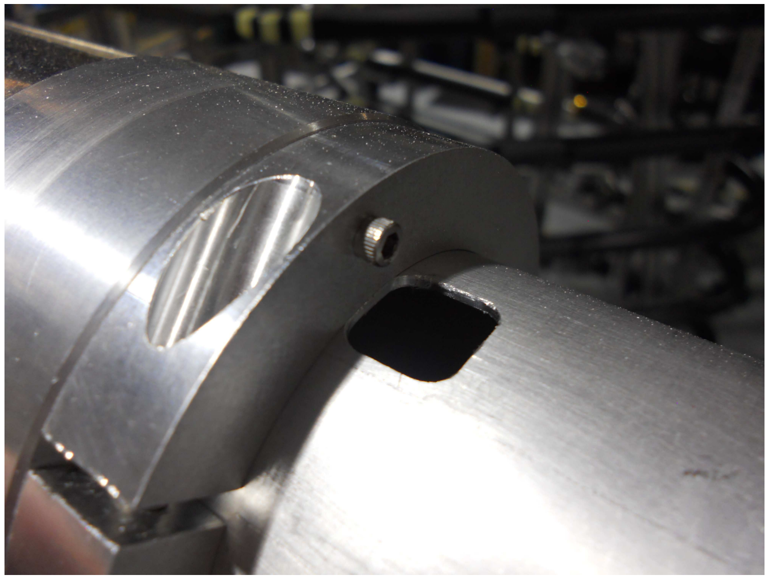

Figure 24: Photograph of the *active clamp* positioned up against the upstream end of the *exchange block*. Note that the upstream face of the *active clamp* is flush with the downstream edge of the cut-out in the *active shield assembly* when properly positioned along the light guide. The leads of the compensation coils will be routed through this cut-out before installation of the PMTs within the shield.

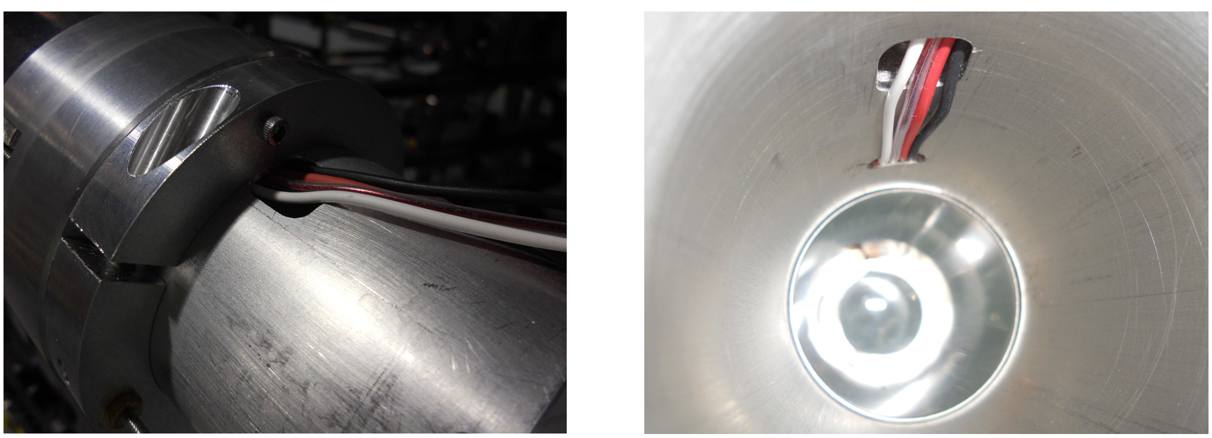

Figure 25: Close up views of the four magnet wire leads routed through the upstream hole in the *active shield assembly* (left) and on the inside of the *active shield assembly*.

Then apply a small amount of BC-603 silicone optical grease to the face of the PMT and spread evenly across the surface using a wooden tongue depressor. There should be no evidence of air bubbles in the grease. Then insert the PMT into the *active shield assembly* so that the signal and HV connectors on the voltage divider are aligned vertically with the counter lying on its side in the storage cart (see Fig. 26). This orientation positions the accelerating structures to minimize the photoelectron losses in the remnant magnetic field at the PMT location. Be sure the PMT is fully inserted and the glass of the PMT is in contact with the light guide. The upstream plastic face of the voltage divider should be 1.125 in past the upstream end of the *active shield assembly*. When the PMT is in position, rotate it back and forth several times to evenly distribute the optical grease. Do not over-pressure the PMT which could crack the glass of the PMT.

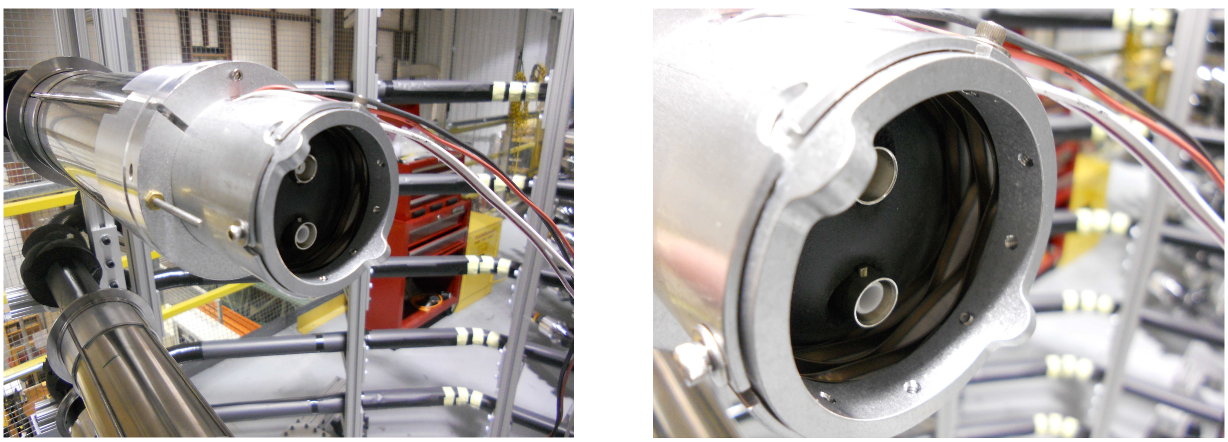

Figure 26: (Left) Photograph of the PMT/voltage divider assembly installed in the shield system with proper azimuthal orientation relative to the external field lines generated by the CLAS12 superconducting solenoid. (Right) Close-up view of the upstream end of the PMT/divider assembly showing the foam light seal disk, the *wave spring*, and the *retention ring*.

During PMT installation we found that the plastic endcap on the end of the PMT would often catch on the lip of the *inner shield* precluding insertion of the PMT into its nominal position. This issue was likely caused by the compensation coil wire leads forcing a slight angle to the PMT during insertion, although slight eccentricities of the *inner shield* also contributed some insertion problems. The solution was to use a Dremel tool to round off the corners at the face of the PMT plastic endcap. Fig. 27 shows how this machining was completed. Ultimately 2/3 of the PMTs (62) were modified in this manner.

Next install the pre-made foam disks against the back of the voltage divider. The two holes cut into the foam disk go over the HV and signal connectors on the voltage divider. The foam disk should sit flush with the plastic endcap of the voltage divider. Finally the *wave spring* and the *retention ring* are inserted into the end of the *active shield assembly* (see Fig. 26). The *retention ring* locks into the notches on the upstream end of the *active shield assembly* using three pre-installed bolts attached to the *retention ring* according to

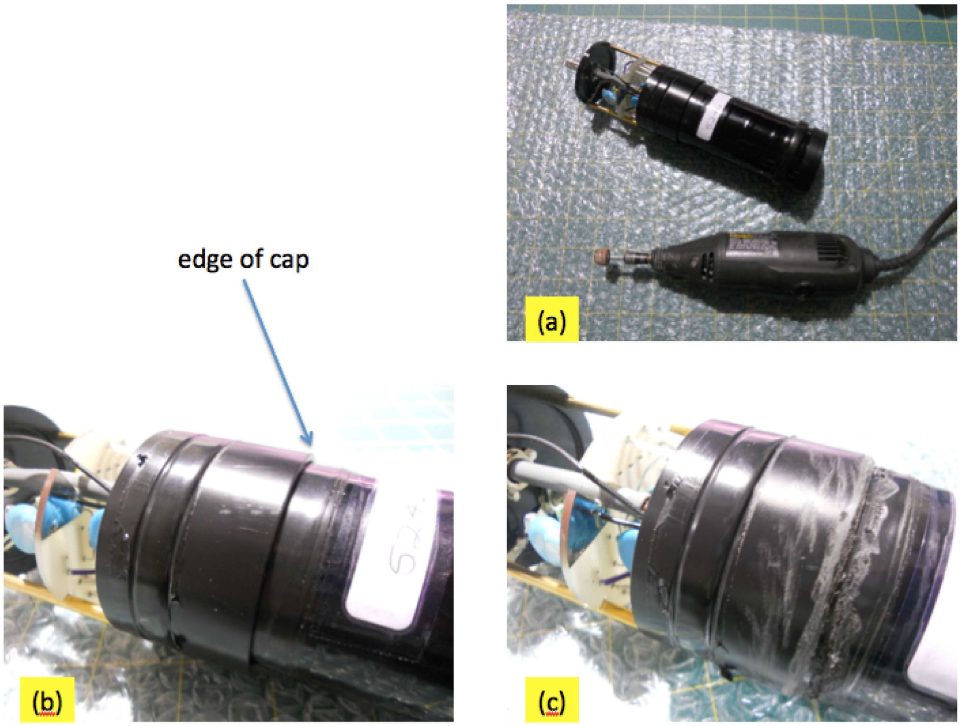

Figure 27: (a),(b) Photographs of a PMT/divider assembly before modifications. (b) shows the offending face of the PMT plastic endcap that conflicted with the lip of the *inner shield*. (c) shows the plastic endcap after machining with the Dremel tool setup shown in (a).

the following specifications:

- Flat washer #4, 316 stainless steel
- Hex socket head cap screw, 316 stainless steel, 4-40 (thread class UNC 3A), 0.31-in-long, τ=6 in-lbs (Ref. Drawing B00000-01-04-2400)

A photograph of a completed CTOF magnetic shield with installed PMT/voltage divider assembly is shown in Fig. 28.

References

[1] V. Baturin, *Performance Tests of the Dynamical Magnetic Shield for the Central Time-of-Flight Detector*, see http://www.jlab.org/Hall-B/ctof/notes/ctof-shield-design.pdf.

[2] Opera 3-D magnetic field computations, see http://operafea.com/.

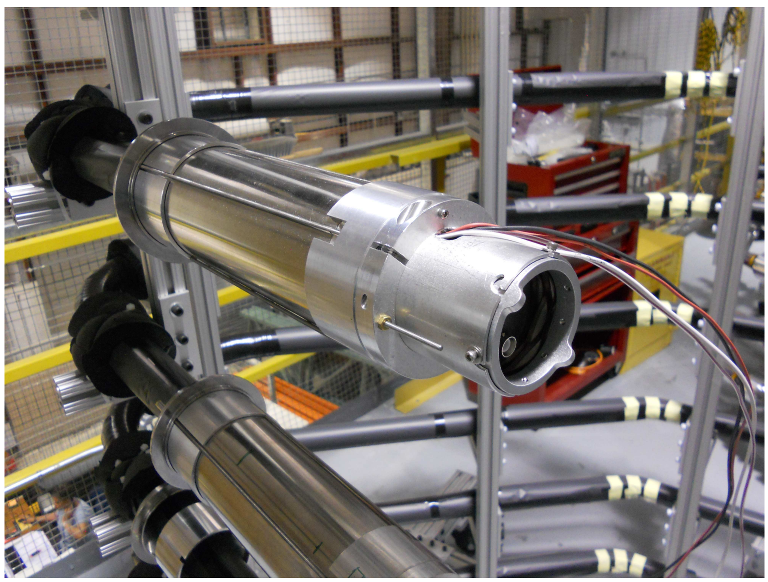

Figure 28: Photograph of a completed CTOF magnetic shield with installed PMT/voltage divider assembly.