5.9 SILICON TRACKER

In combination with the Superconducting Cryomagnet, the Silicon Tracker represents the centerpiece of the AMS-02 suite of detectors. The Tracker (Figure 5.9-1) consists of eight layers of double-sided silicon micro-strip detectors (ladders) on five support planes. The spatial resolution will be better than 10 µm in the magnet's bending plane and 30 µm perpendicular to that. The planes are placed inside the bore of the magnet, with the six innermost combined to build pairs. The two outermost layers serve as the entrance and outlet windows. All eight tracker planes together comprise 192 silicon ladders corresponding to an active area of about 6 m^2 of silicon and 200,000 readout channels. The entire tracker electronics consume 800 W of power.

In addition, the Tracker is equipped with an infra-red (IR) laser Tracker Alignment System (TAS). It will periodically monitor the X- and Y-position of the tracker layers with respect to each other. The principle of this system is to pass a laser beam of IR wavelengths, through selected spot areas - the so called "Alignment Holes" - in each detector plane where the laser can penetrate and still be detected by the layer. Benefiting from the partial transmittance of crystalline silicon at IR wavelengths, a signal in all eight tracker planes can be generated from only one beam. For redundancy, the full alignment system will consist of five pairs of beams, placed in the center of the tracker, one pair set traversing the beams up and the other set down.

The AMS-02 Tracker is the second generation of the Tracker that flew on STS-91 (AMS-01). It utilizes the same honeycomb panels and exterior cylindrical shell (Figure 5.9-2). The flat flanges on both the top and bottom of the AMS-01 Tracker have been replaced by conical flanges on the AMS-02 detector (Figure 5.9-3) and the Tracker feet were redesigned to interface with the Vacuum Case. The Tracker mounts at eight attach locations (4 at the top, 4 at the bottom) to the Vacuum Case conical flanges. Data from accelerometers flown on STS-91 was used to lower the load factors for AMS-02.

Three additional layers of silicon ladders have been added to the AMS-02 Tracker by placing ladders on both sides of the three interior planes. The three inner planes are ≈ 3.6

ft (1.1 m) in diameter and the top and bottom planes are a ≈ 4.9 ft (1.5 m) in diameter. The Tracker is ≈ 3.9 ft (1.2 m) high and weighs ≈ 438 lbs (198.5 kg).

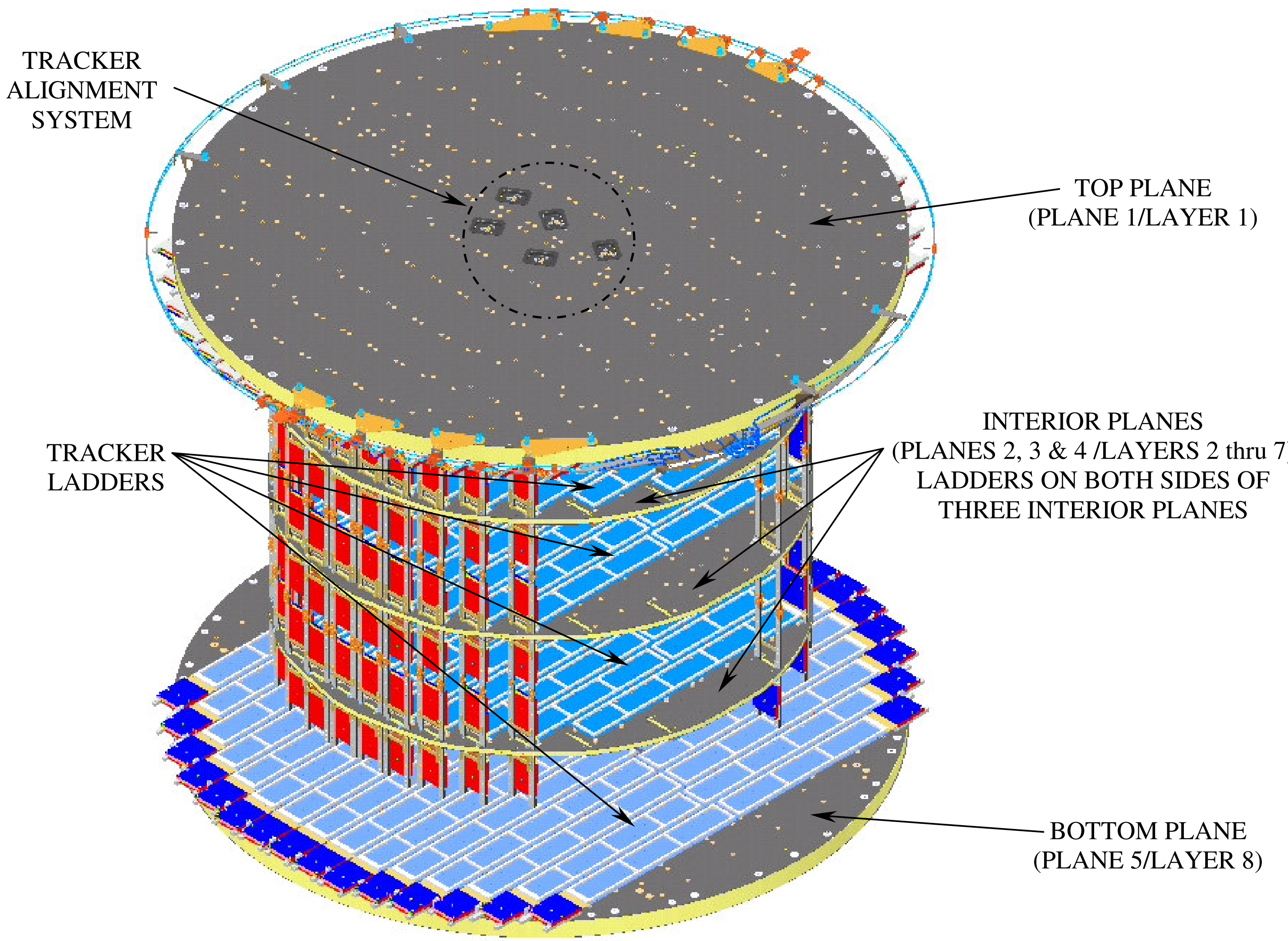


Figure 5.9-1 Layout of the AMS-02 Silicon Tracker

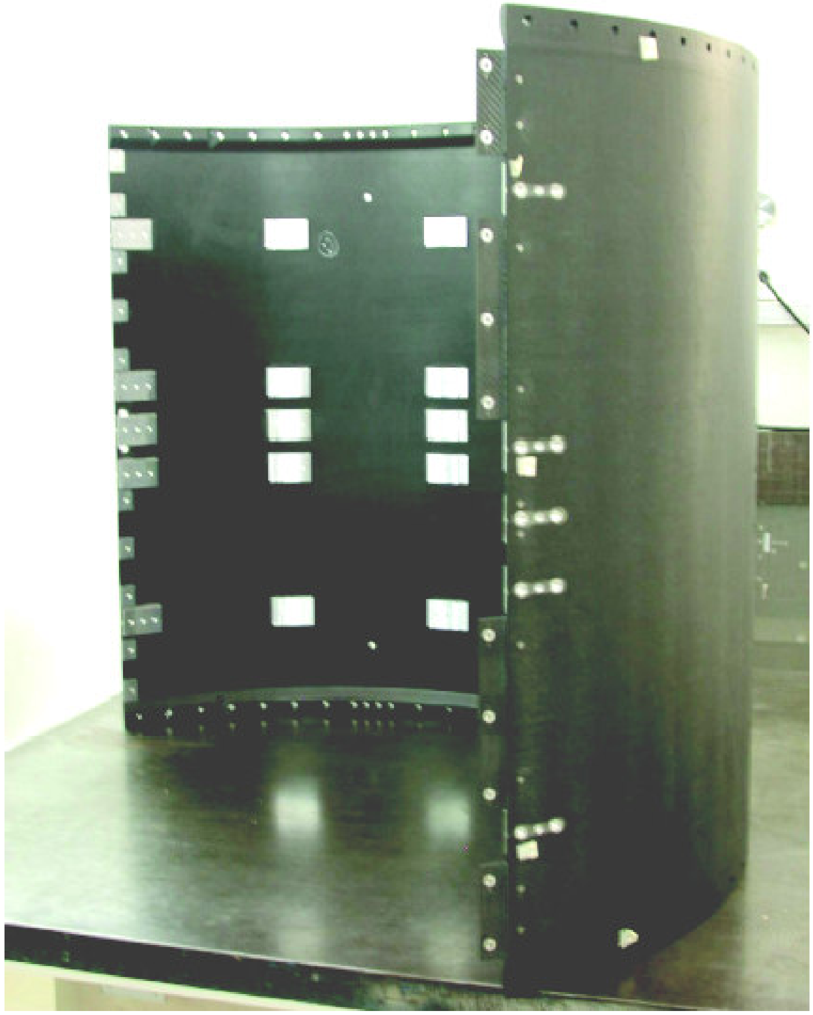


Figure 5.9-2 A Section of the Tracker Support Structure Cylindrical Shell

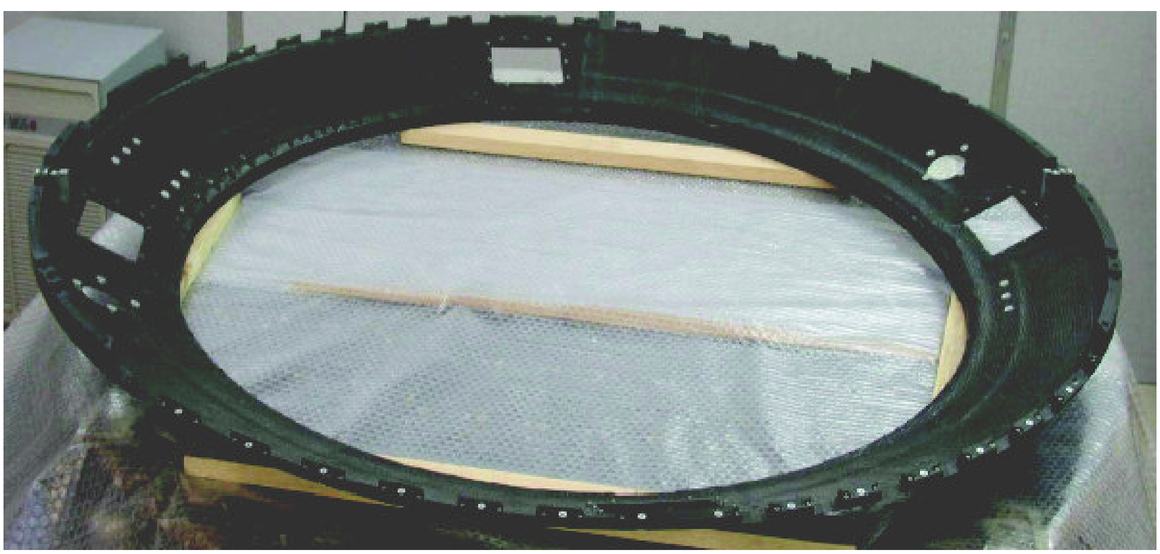


Figure 5.9-3 Tracker Support Structure – Upper Conical Flange

5.9.1 Silicon Sensors and Ladders

The AMS experiment silicon detector assemblies (Figure 5.9.1-1) contain silicon ladders made up of a series of 2.836 inches (72.045 mm) x 1.628 inches (41.360 mm) x 0.012 inches (0.300 mm) double-sided silicon micro-strip sensors, electrically connected by microbonds. The silicon sensors are reinforced by sandwich structures made of foam with light-weight carbon composite backing. Hybrid boards at the ends of the ladders enable the sensors to be electrically connected to the tracker electronics. The ladder assemblies vary in length from ≈ 11.47 inches (290 mm) to ≈ 40.75 inches (1035 mm), and are 2.836 inches (72.045 mm) wide and ≈ .394 inches (10 mm) thick.

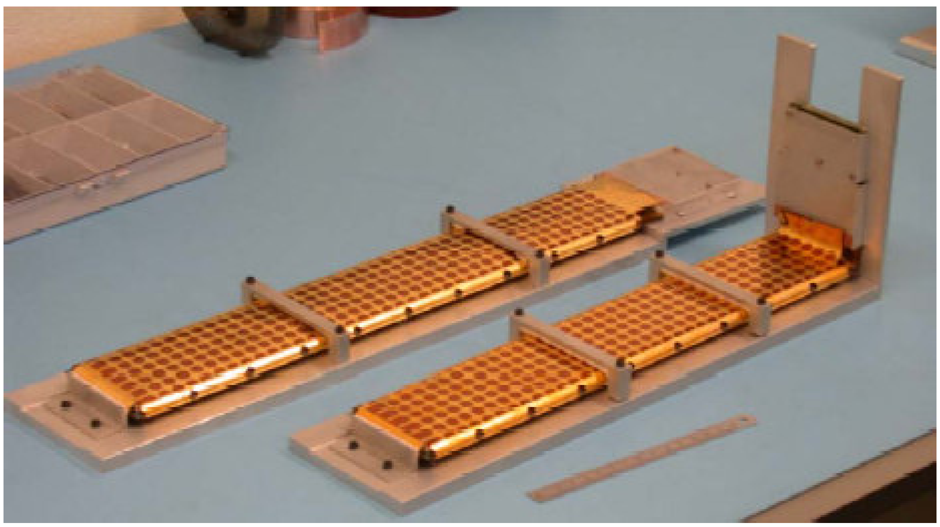


Figure 5.9.1-1 Tracker Ladders (typical) prior to mounting on a Tracker Support Plane

Figure 5.9.1-2 shows the principal elements of the silicon ladder and the main components of the readout hybrids. Thin-film, 50 µm Upilex (an ultra-high heat-resistant polyimide film) is used extensively in the ladder. A metalized Upilex film, glued directly to the silicon sensors, serves as a routing cable to bring the n-side signals to the n-side front end hybrid, which is located at the ladder end closest to the magnet wall. The flexible Upilex film and a second short Upilex film joining the p-side strips to their hybrid allow the hybrids to be placed back-to-back, perpendicular to the detection plane, thus minimizing the material in the sensitive region of the tracker. Finally, an electromagnetic shield in the form of a doubly-metalized Upilex film surrounds each ladder.

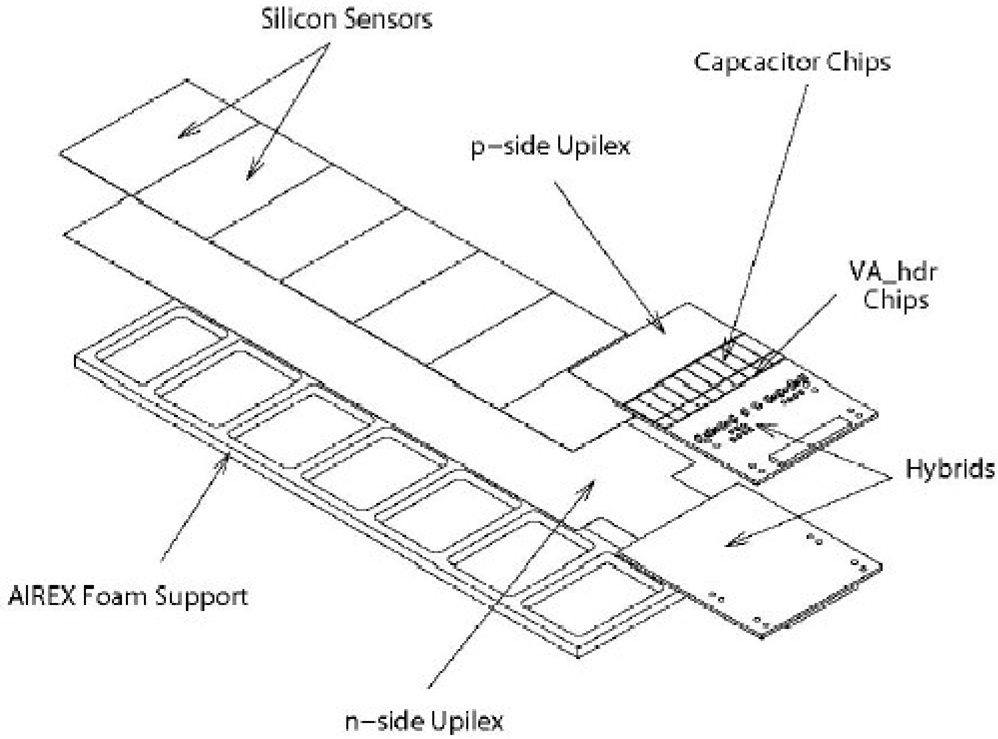


Figure 5.9.1-2 The principle components of the Silicon Ladder

The silicon sensors of each ladder are supported by a 0.2 inch (5 mm) thick Airex foam that is glued to the n-side Upilex film. The exposed surface of the foam is covered with a 100 µm thick layer of carbon fiber. Small (5 mm^3) 7075 aluminum support feet are glued to the carbon fiber surface; the exact number depends on the ladder length. The feet contain screw fixation holes which are used to attach the ladder to its tracker plane.

The silicon sensors are grouped together, for readout and biasing, in ladders of different lengths to match the cylindrical geometry of the AMS magnet (Figures 5.9.1-3 and 5.9.1-4). The maximum combined strip length in the silicon for a single readout channel is 23.6 in (60 cm).

Figure 5.9.1-3 Tracker Support Plane 2 with Ladders installed

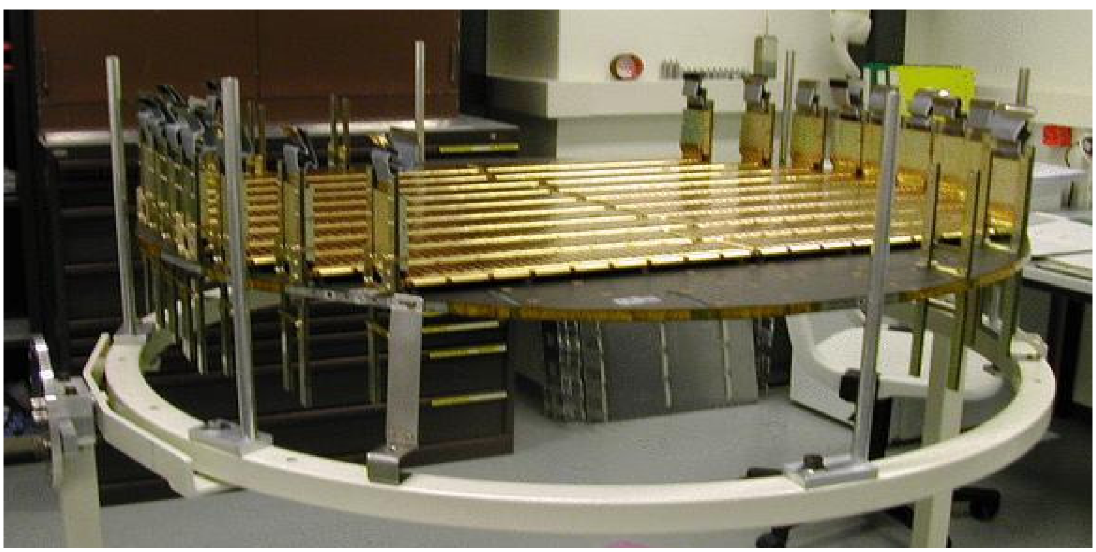


Figure 5.9.1-4 Tracker Support Plane 3 with Ladders installed

5.9.2 Tracker Support Structure

The tracker support structure is divided into three sections: a carbon fiber cylindrical shell which supports the planes 2 to 4 located inside the magnet, and two carbon fiber flanges which support the exterior planes 1 and 5. The tracker planes located inside (outside) the magnet are the same as those used for AMS-01. They have a composite structure with two 220 (700) µm thick layers of carbon fiber surrounding a 12 (40) mm thick, low density aluminum honeycomb interior, ρ = 16.02 (32.0) kg/m^3. The diameter of the interior (exterior) planes is 1.0 (1.4) m. The AMS-01 interior planes have been modified to accommodate the second layer of ladders; the latter increases the material thickness of an interior plane to 1% of a radiation length at normal incidence. In view of the marginal increase of the plane hermeticity, and the very significant complication of the mechanical design, there is no overlap between the ladders in the planes of the tracker. To equalize the pressure inside the Tracker with the pressure in the payload bay during launch and landing, the Upper and Lower Conical Flanges each contain two light tight, filtered vents (Figures 5.9.2-1 through 5.9.2-3) that permit air to exit or enter the enclosed Tracker volume of 40.26 ft^3 (1.14 m^3).

The Tracker Support Planes, Cylindrical Shell, and Conical Flanges are fabricated from M55J Fiber/Cyanate Ester Composite face sheet with a Hexcell Composite Honeycomb Core. The Tracker Support Feet are made from Titanium Ti6AlV4.

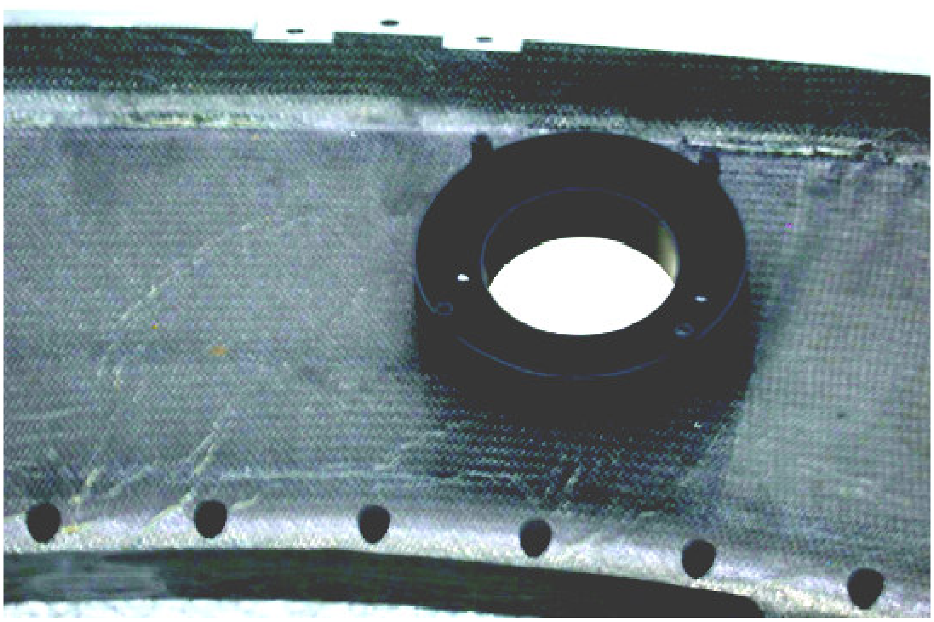


Figure 5.9.2-1 Light Trap/Vent Hole (with cover and filter mesh removed) – Upper Conical Flange

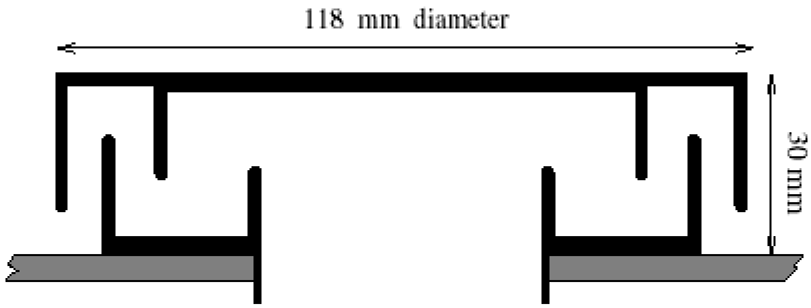


Figure 5.9.2-2 Schematic of Light Trap/Vent Hole (Cross Section) – Filter not shown

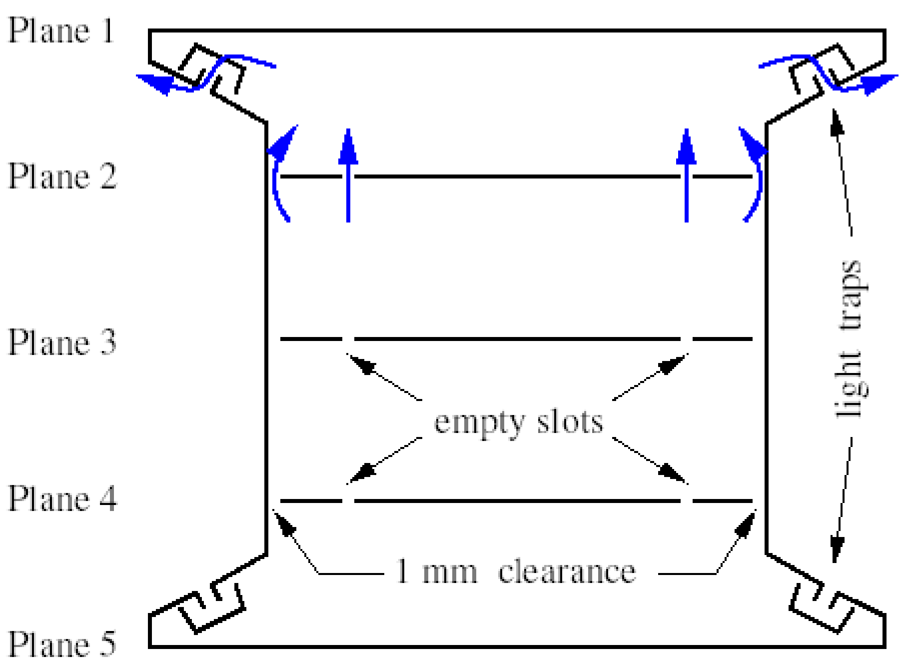


Figure 5.9.2-3 Cross Section of Tracker Showing Typical Vent Paths During Depressurization

5.9.3 Tracker Alignment System (TAS)

The Tracker Alignment System (TAS) provides optically generated signals in the 8 layers of the silicon tracker that mimic straight (infinite rigidity) tracks of particles. It has been shown with AMS-01 that these artificial straight tracks allow the tracing of changes of the tracker geometry with a position (angular) accuracy of better than 5 µm (2 µrad). The system uses the same silicon sensors for both particle detection and control of the alignment. It serves to generate position control data within seconds at regular time intervals (4 to 6 times per orbit), for example, while the ISS flies into the shadow of the Earth or comes back into the sunlight.

As shown in Figure 5.9.3-1, the AMS-02 tracker is equipped with 2 x 10 pairs of alignment control beams. The beams are narrow (diameter < 0.5 mm) and of small divergence (< 1 mrad). The TAS generates laser energy from ten independent laser diodes, pairs of the diodes contained within five Laser Fiber Coupler (LFCR) boxes (Figure 5.9.3-2). This energy is generated by Eagleyard EYP-RWL-1083 infrared (1083 nm) laser diodes with a maximum power output of 80 mW. Each laser will emit at a 1 Hz interval with a 4 μs pulse duration when operating. Each laser diode's emissions are split into four output mono-mode optical fibers, each with approximately one quarter of the total power output. The LFCR boxes are light tight and cannot release any laser emissions with the exception of the fiber ports where laser emissions are nominal design features.

The beams enter the tracker volume through 2 x 5 beamport boxes (LBBX) mounted on the outer face of the two outer tracker support plates (Figures 5.9.3-3 thru 5.9.3-5). The tracker sensors on the alignment beams are equipped with antireflective coatings (SiO_2 and Si_3N_4) optimized for the wavelength chosen (residual reflectivity ~ 1%). In addition, the readout strip metallization width was reduced to 10 μm width in the coated areas and the other implants not metallized. Together these measures have resulted in a transparency of the alignment sensors of 50% and the 8th layer of the tracker receives about 0.8% of the intensity coming out of the LBBX. Alignment beams are arranged in pairs in order to distinguish between changes in beam geometry and sensor displacements. Laser alignment will be performed coincident with data taking. The operation of the TAS consists of less than 1% of the AMS-02 operational time.

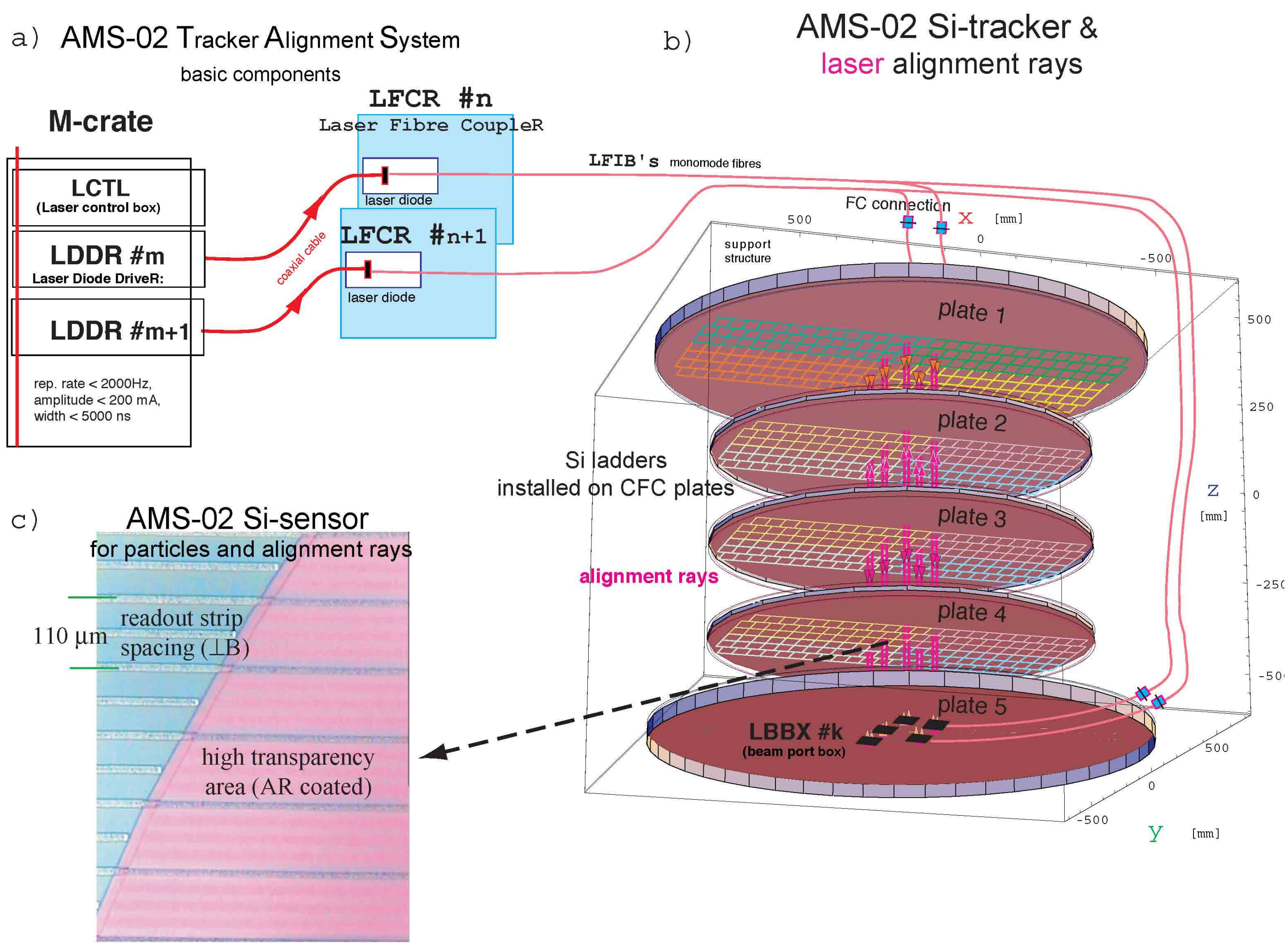


Figure 5.9.3-1 AMS-02 Silicon Tracker Laser Alignment System Overview

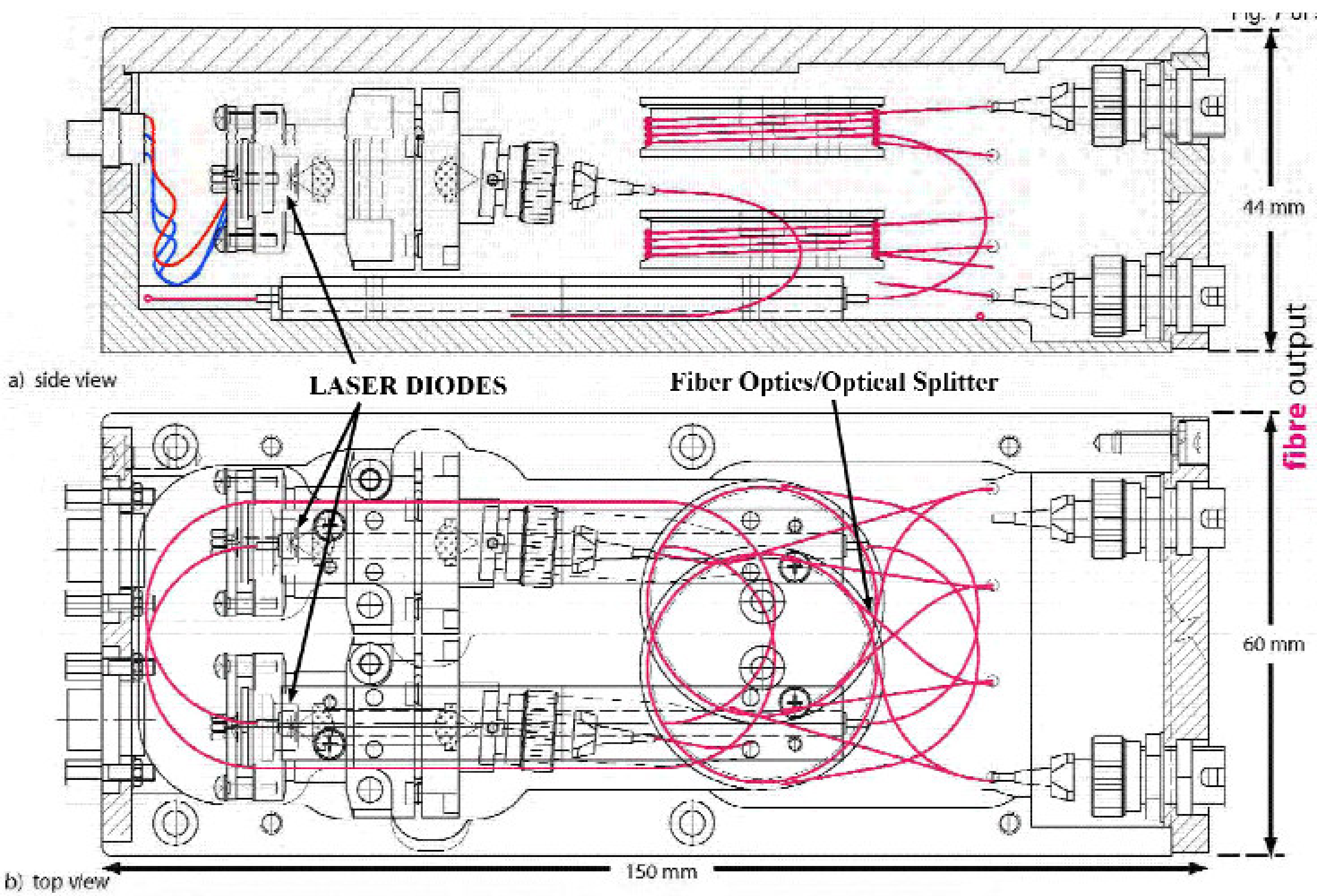


Figure 5.9.3-2 LFCR Box Design

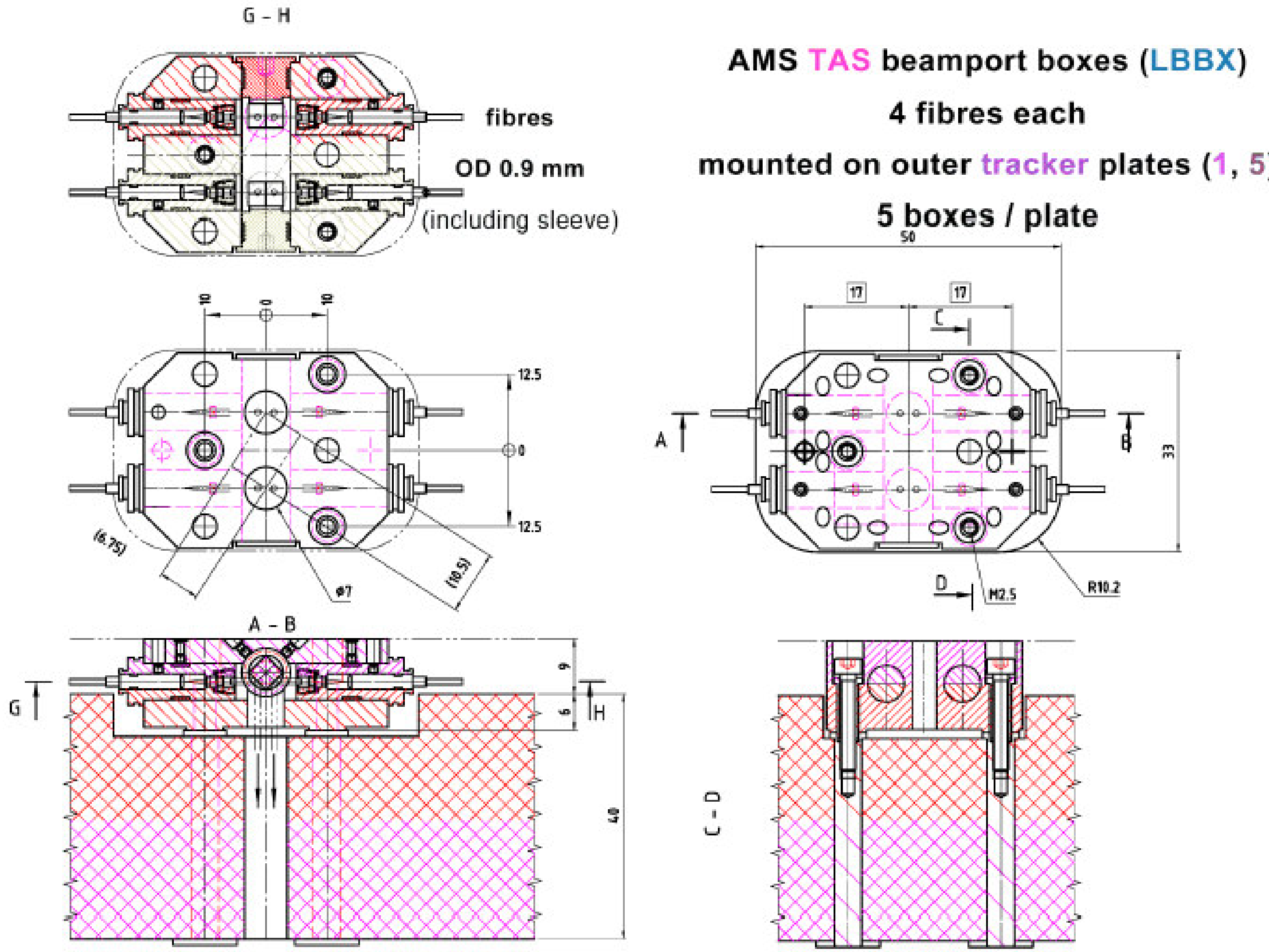


Figure 5.9.3-3 Tracker Laser Alignment System Beamport Design

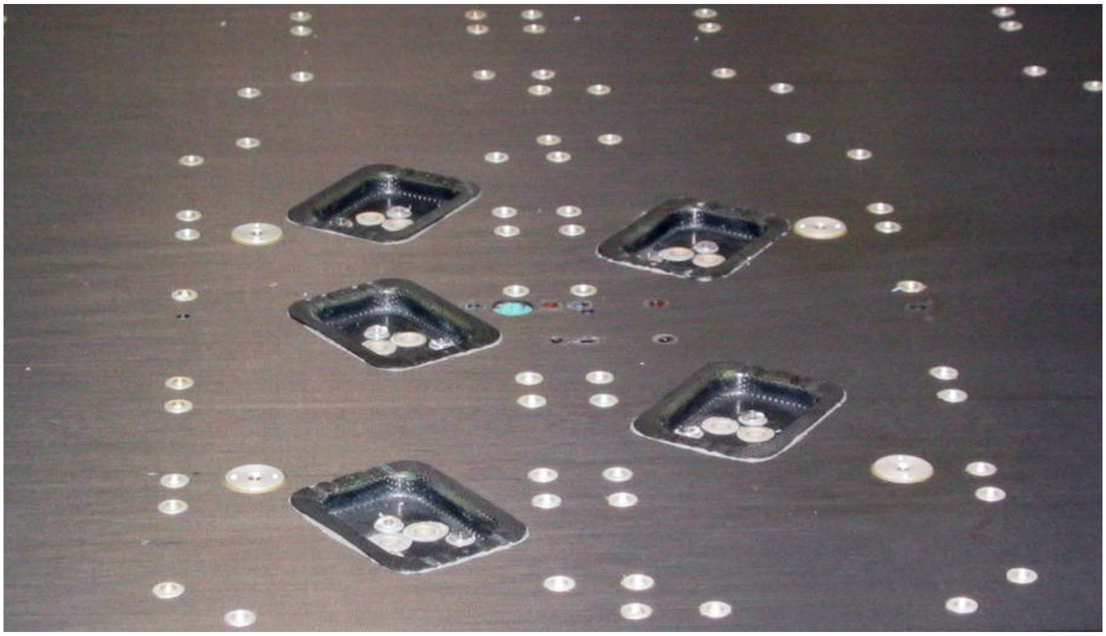


Figure 5.9.3-4 Close up of Tracker Plane 1 showing mounting locations for Laser Beamport Boxes (LBBXs)

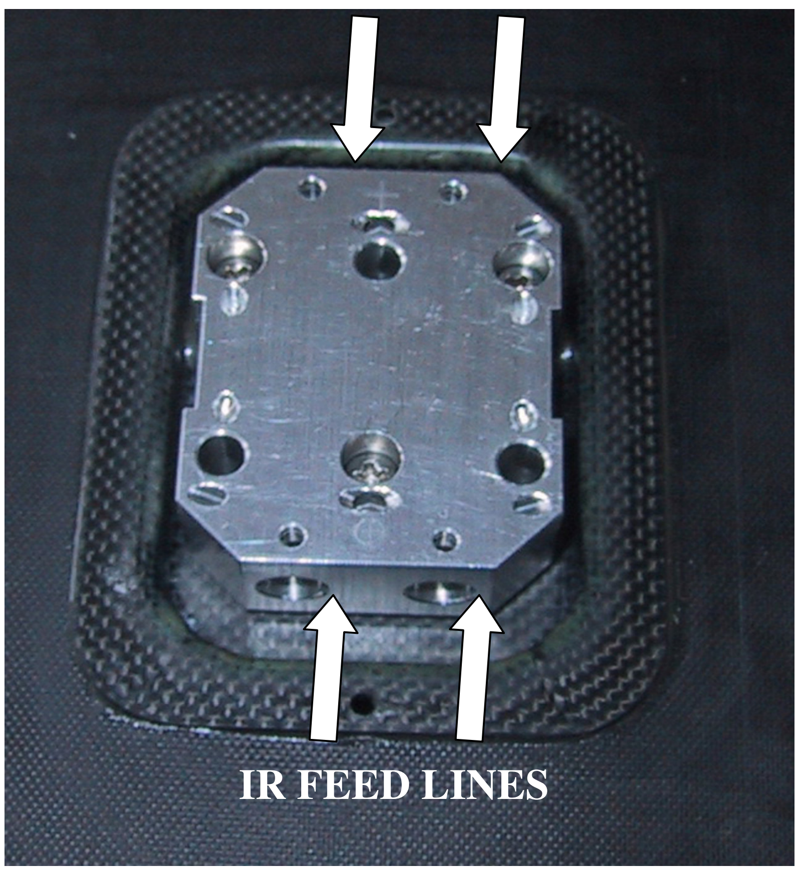


Figure 5.9.3-5 A Laser Beamport Box (LBBX) installed on Tracker Plane 1

5.9.4 Tracker Thermal Control System (TTCS)

The TTCS is one of the most complex thermal control systems used on AMS-02. The Tracker, which is completely encased inside the inner bore of the Vacuum Case, generates 144 watts which need to be rejected while minimizing heat flow to the vacuum case inner cylinder. The TTCS thermal design includes thermal bars, a pumped CO_2 cooling loop, radiators, manifolds, accumulators and numerous other components. A detailed description of the TTCS is included in Section 5.13.7 of this SDP.

5.10 RING IMAGING CERENKOV COUNTER (RICH)

The RICH is located near the bottom of the experiment stack, below the Lower TOF and above the ECAL. The RICH is used in conjunction with the Silicon Tracker to establish the mass of particles that traverse the AMS-02. The function of the Silicon Tracker is capable of establishing the momentum of the particle with a relative accuracy of approximately 1%. The RICH is able to determine the velocity of charged particles based on the Cerenkov Effect as the particle passes through the mass of the silica aerogel or sodium fluoride blocks. Cerenkov radiation is emitted as a charged particle passes through a transparent non-conducting material at a speed greater than the speed of light in that material. The use of a high efficiency reflector ring allows for greater data acquisition than direct incident of the photons on the PMTs alone.

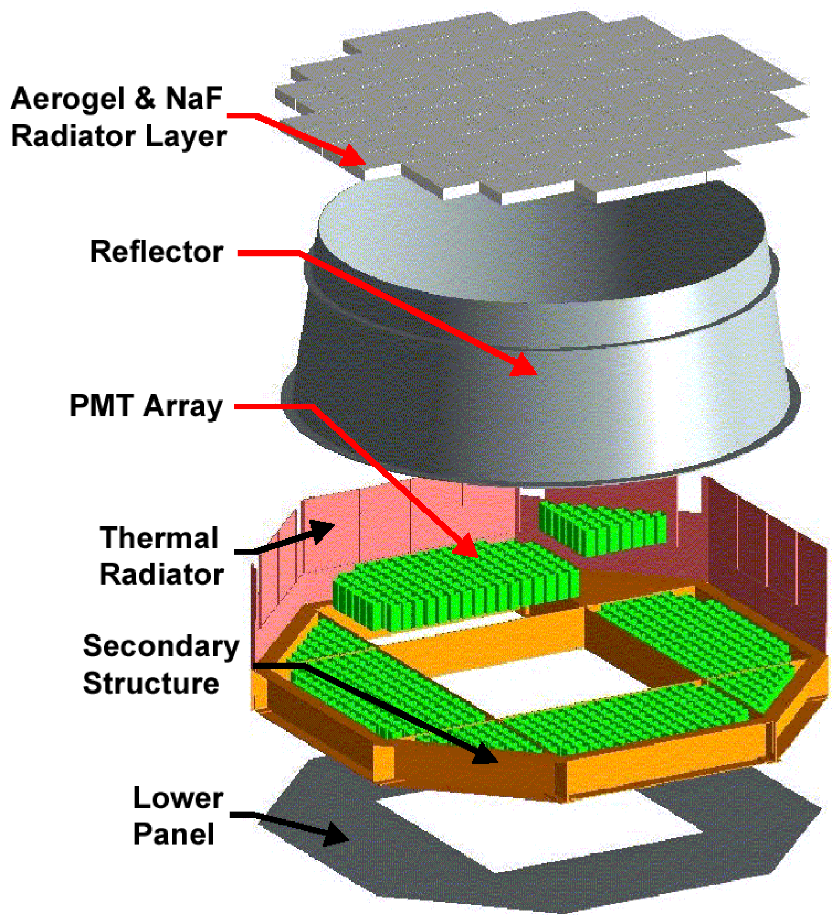


Figure 5.10-1 RICH Basic Elements

Functionally the RICH is composed of three basic elements, the top layer, the Cerenkov radiator, is composed of silica aerogel and sodium fluoride (NaF) blocks that serve as sources for the Cerenkov radiation generated by the passage of the high energy particles. The intermediate layer is the conical mirror and the lower the PMT and structural interfaces.

In the top layer the aerogel and NaF blocks are mounted between a PORON spacer and carpet and a PMMA cover, all supported by a carbon fiber reinforced composite (CFRC) structure. The entire structure is sealed with a viton gasket between the PMMA cover and the composite structure. The PMMA cover allows the photons generated by the passage of the high-energy particles to be observed by the photomultipliers.

Figures 5.10-2, 5.10-3 and 5.10-4 show the general construction of the assembly. Polymethylmethacrylate (PMMA, Acrylic, Plexiglas) is used to contain the aerogel and crystalline NaF blocks and allow the photons to enter the zone of the conical mirror and the PMTs.

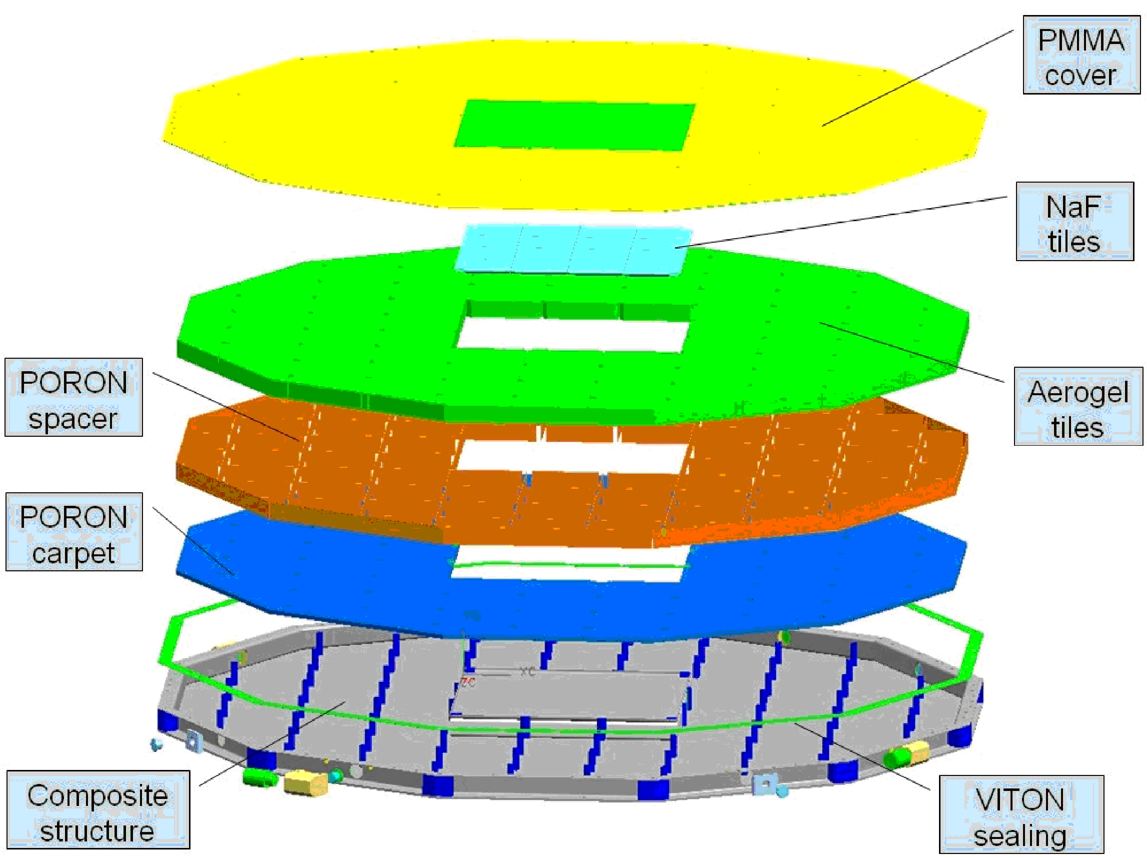


Figure 5.10-2 RICH Aerogel & NaF Container

The RICH upper assembly of aerogel and NaF blocks is vented during ascent by four vent valves and during descent repressurization is controlled by three vent valves. In order to protect this volume once constructed it will be purged through a dedicated valve port with dry nitrogen to provide a clean controlled environment within the Cerenkov Radiator. 50 μm filter screens on the valves will prevent large aerogel or NaF particles that could possible evolve from being released or exterior contaminants becoming ingested. The locations of these valves are shown in Figures 5.10-3 and 5.10-4 and a cross section of the selected breather valve is shown in Figure 5.10-6. These valves will be Halkey Roberts C770RP 1.0 one way valves that have a cracking pressure with a 1 psi differential. The valves will be interfaced to the 50 μm filter screens through a polyetheretherketone (PEEK) interface block as shown in Figure 5.10-7. During ground handling/transportation and processing this interior volume is protected from thermal and atmospheric pressure variation introducing humidity into the interior of the Cerenkov Radiator by having a buffer volume contained within an expandable reservoir (0.5 1) made of Teflon®/Tedlar® supported within a vented enclosure. This expandable reservoir is represented in Figures 5.10-5 and 5.10-8 a-c. Design of this assembly assures that there will not be more than a 1 psi differential between the interior and exterior pressure. Reentry loads of pressure loading on the aerogel during repressurization have been conservatively established to be approximately 1/15th of aerogel compression allowable. The aerogel is considered the most sensitive element of the sandwich of materials.

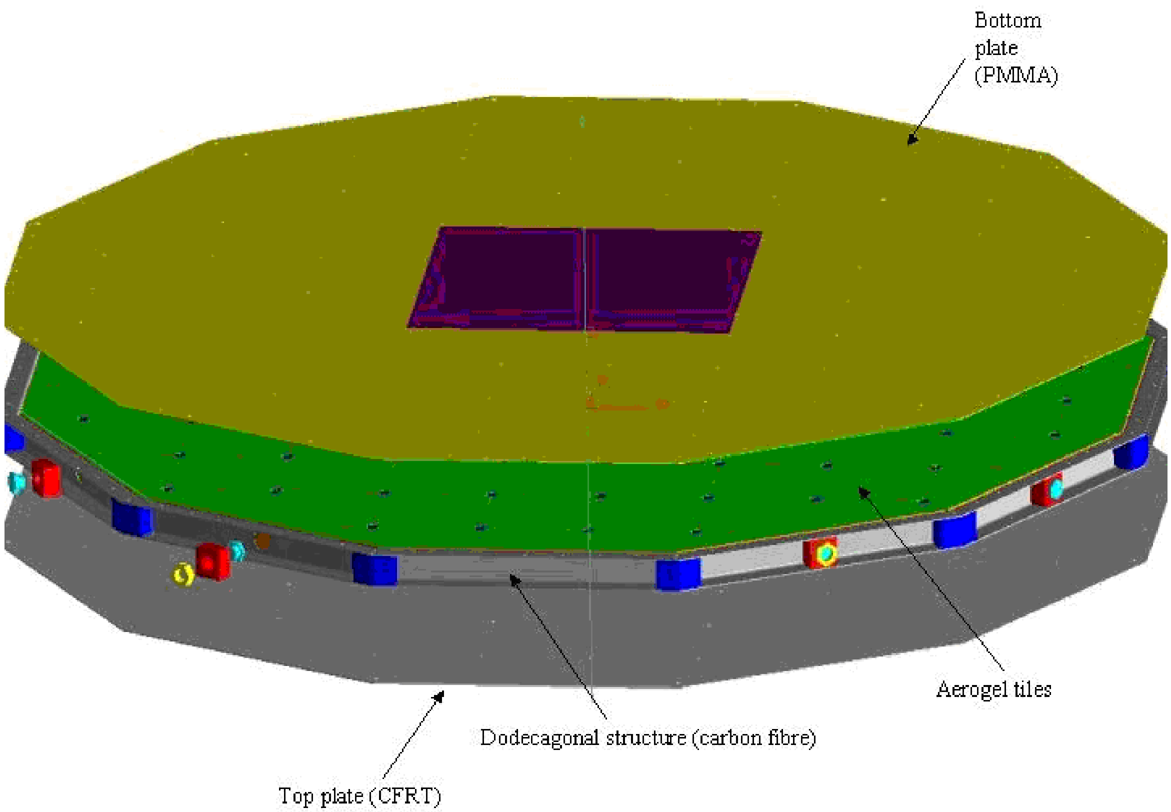


Figure 5.10-3 RICH Aerogel and NaF Assembly

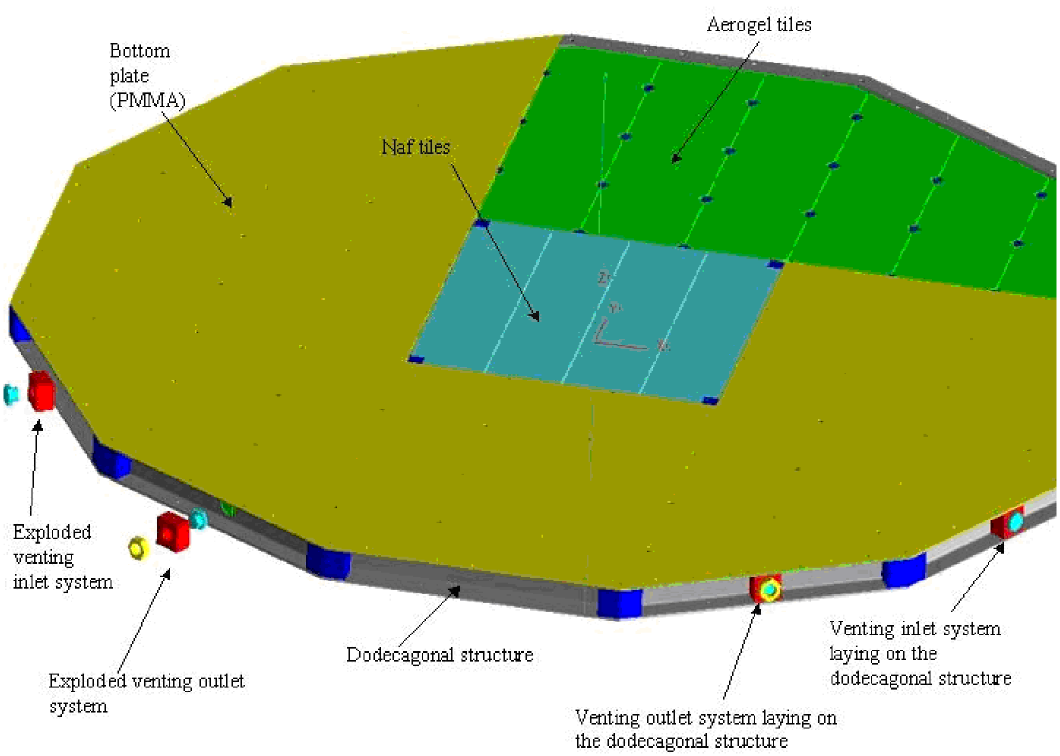


Figure 5.10-4 RICH Aerogel and NaF Assembly

(Vent interface updated in Figure 5.10-7)

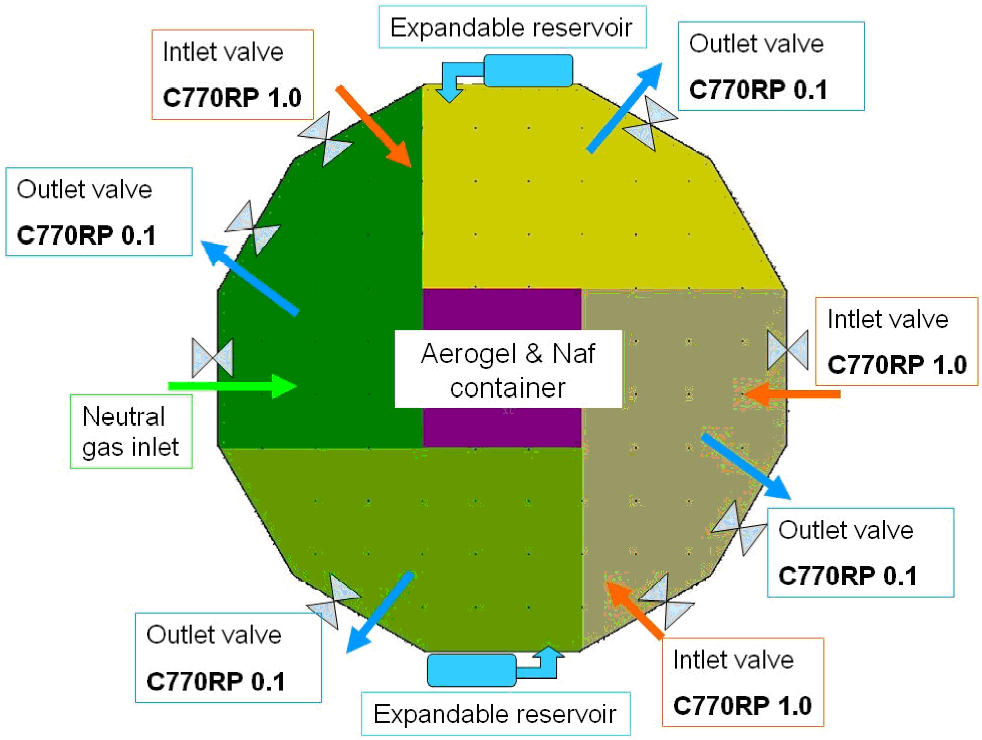


Figure 5.10-5 RICH Functional Venting, Interior Environment Control

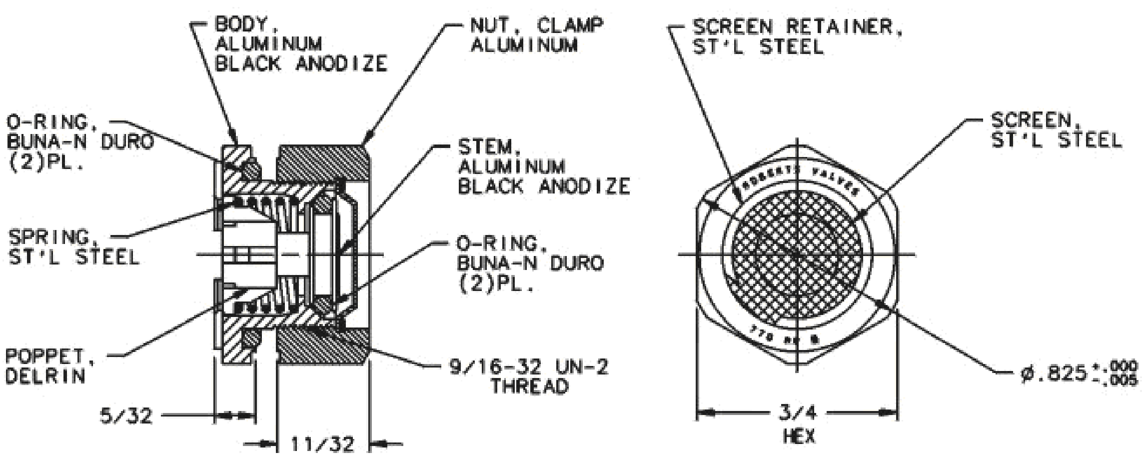


Figure 5.10-6 RICH Halkey-Roberts C770RP 1.0 (Cracking Pressure =- 1.0 psi)

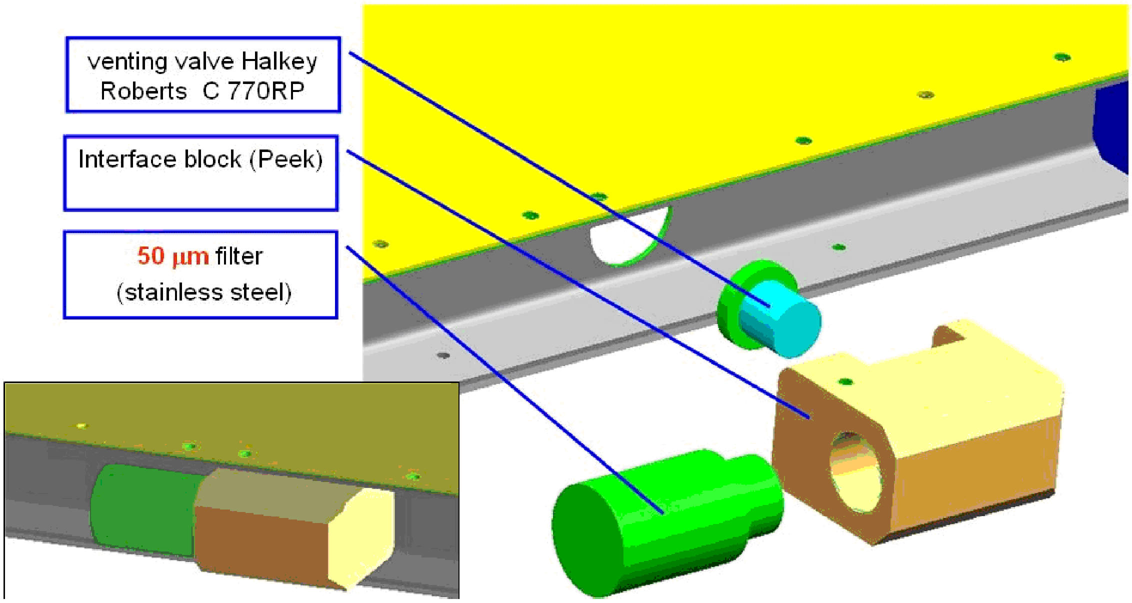


Figure 5.10-7 RICH Vent Valve and Filter Installation

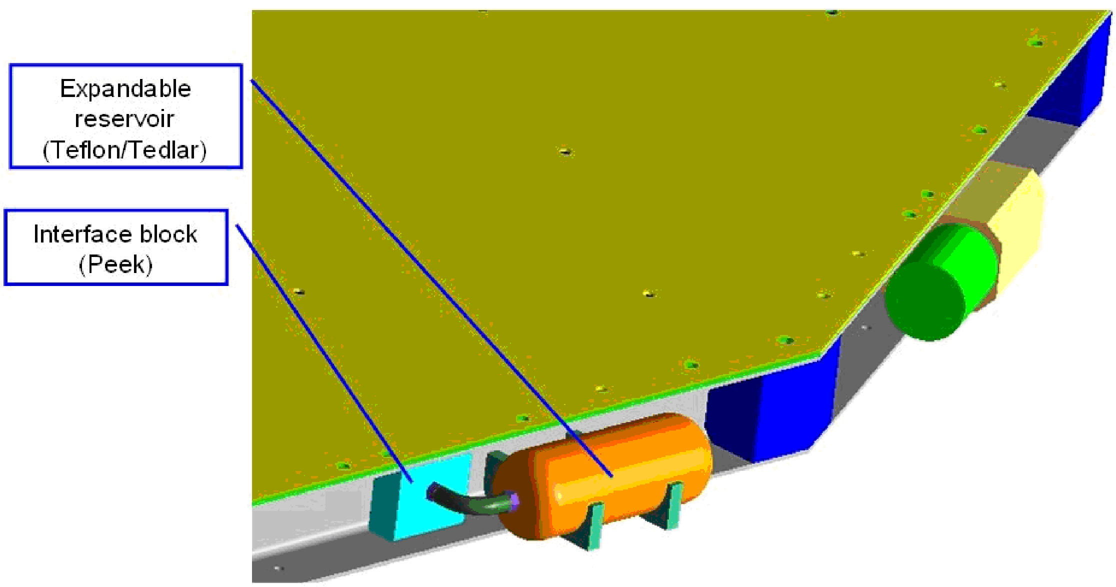


Figure 5.10-8a RICH Expandable Reservoir

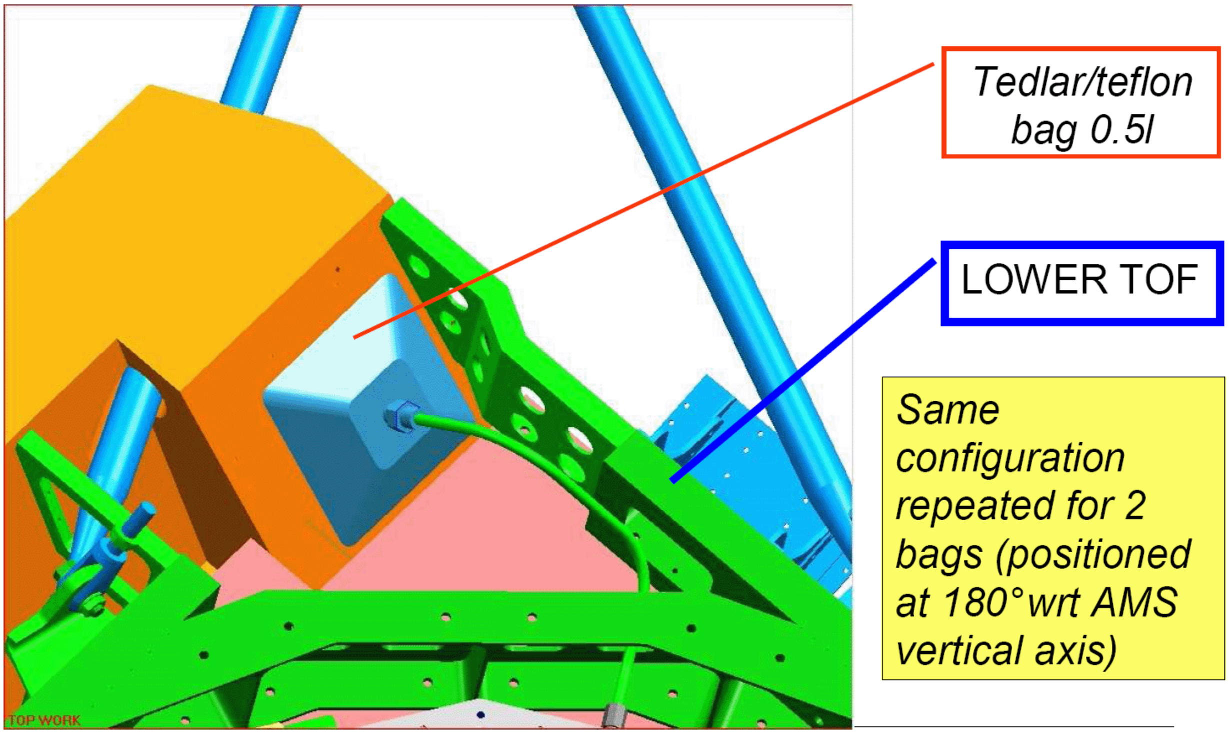


Figure 5.10-8b RICH Expandable Reservoir

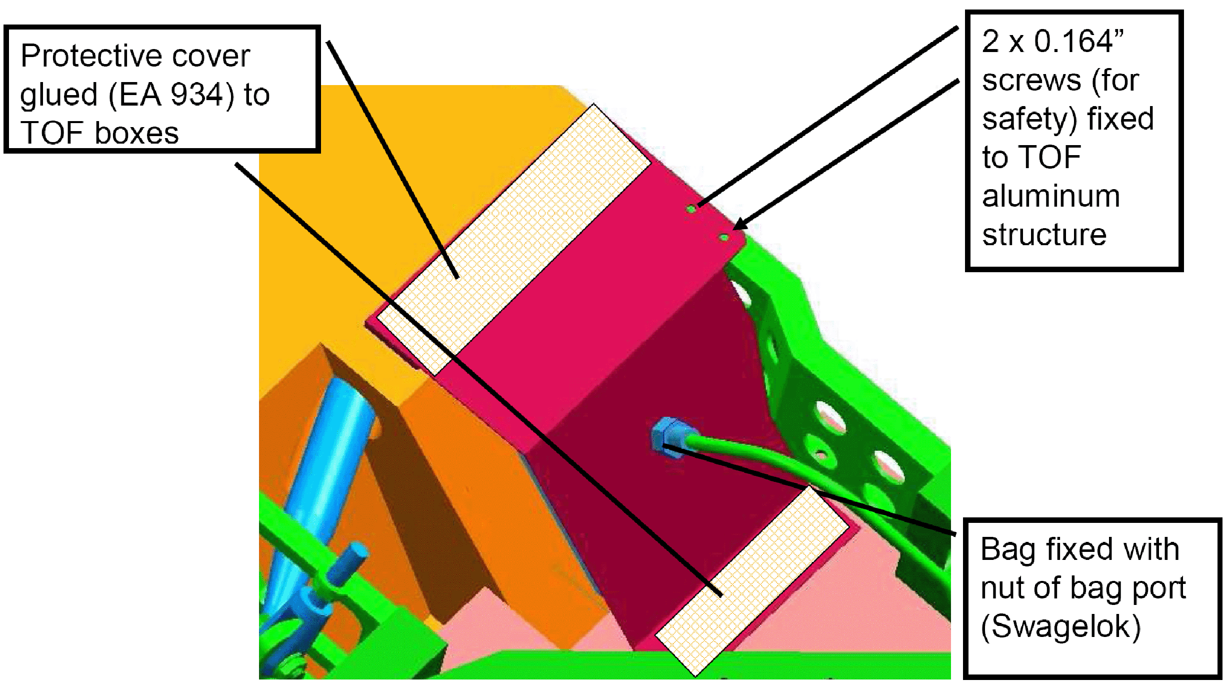


Figure 5.10-8c RICH Expandable Reservoir Cover

The second layer of the RICH is a reflector that is shaped as a truncated cone, described by a trapezoid rotated about its centroid. The interior surface of this element is a highly polished composite/metal mirror. The mirror is manufactured in three pieces (Figure 5.10-9) to be very light and have a precise, highly reflective, surface. The reflector is made of composite material with layers of deposited gold, alumina, chromium, and quartz. A debris shield consisting of eight aluminum panels surround the reflector to protect it from penetrations that would damage the mirrored surface and allow light to enter the RICH and disturb detection.

TABLE 5.10-1 RICH MIRROR COMPOSITION

Al_3O_3/TiO_3	1 mm
Epoxy Resin	400 μm
Gold	0.2 μm
Chromium	150 μm
Aluminum	0.1 μm
Quartz	0.1 μm

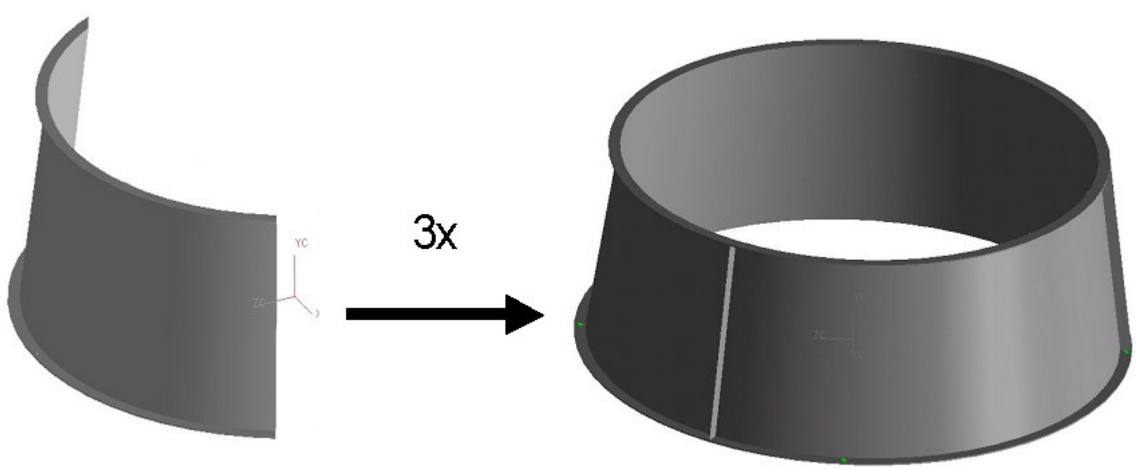


Figure 5.10-9 RICH Reflector Construction

The lower layer of the RICH construction contains the primary structure that supports the RICH and interfaces to the Lower USS-02. Within the secondary structure of the lower assembly are the rectangular and triangular arrays of photomultiplier tubes that will detect the photons from the Cerenkov radiation. Construction of the Lower RICH support structure and PMT support grids are shown in Figure 5.10-10.

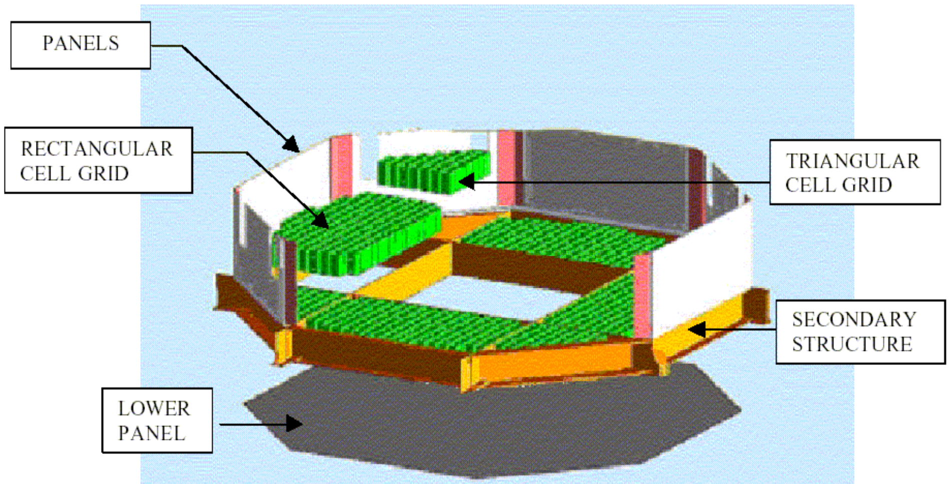


Figure 5.10-10 Lower RICH Construction

The PMTs for the RICH are constructed using Hamamatsu R7600 M16 photomultiplier tubes and a 4x4 matrix of light guides to correlate with the 4x4 photocathode grid of the photomultiplier tube. An optical pad assures the proper transmission of light into the photomultiplier tube and also seals off the glass front of the vacuum tube. The light guides are compressed into this optical pad using Nylon cords to assure good light transmissivity. The assembly of an individual PMT is shown in Figure 5.10-11.

The base of the photomultiplier tube is potted and the boards of the PMT are conformally coated to protect the electronics and to limit the coronal breakdown potential for the high voltage system. This can be seen in the upper left image of Figure 5.10-12. The welded soft iron outer body provides attenuation of the magnetic fields and support interfaces for integrating into the RICH secondary structures as shown in the lower graphic of Figure 5.10-12.

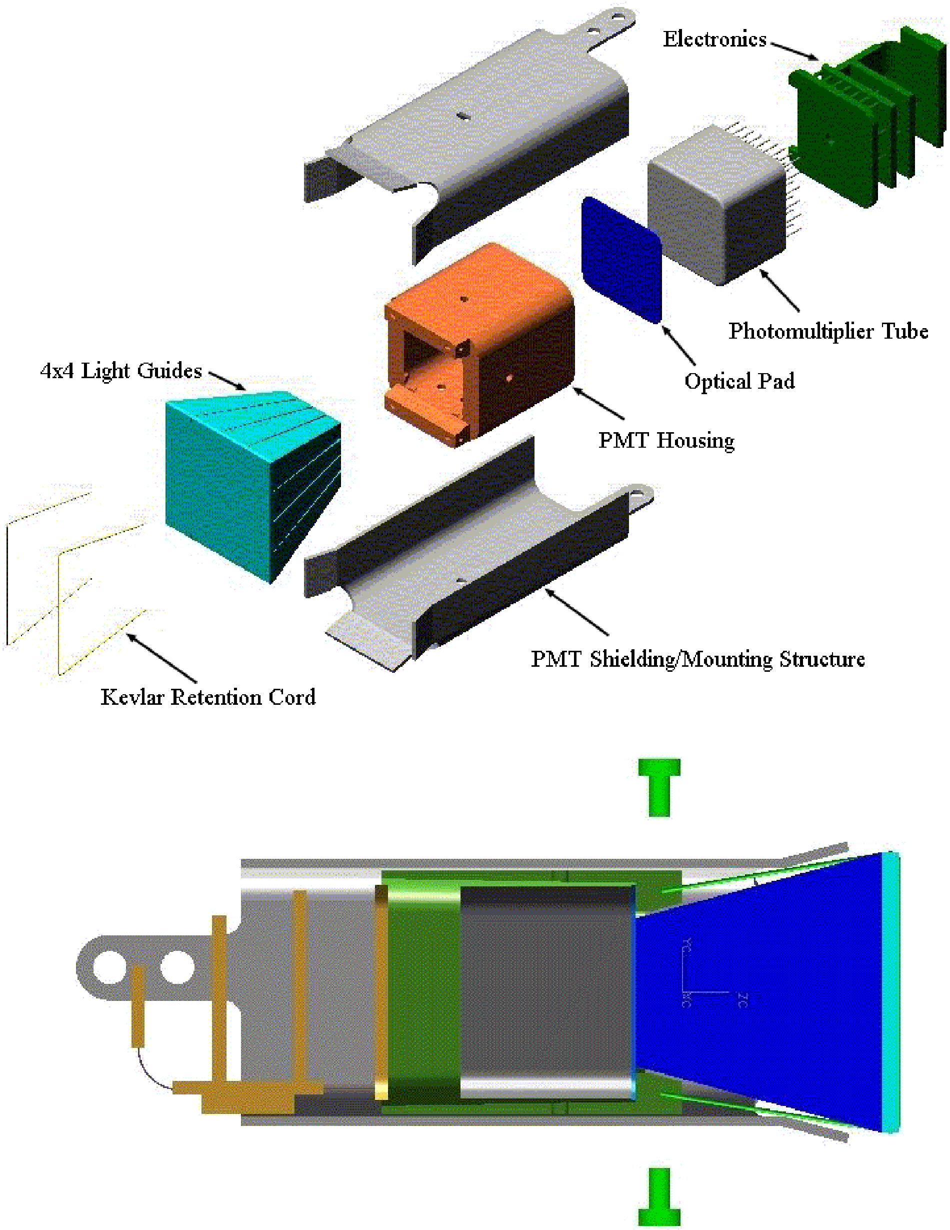
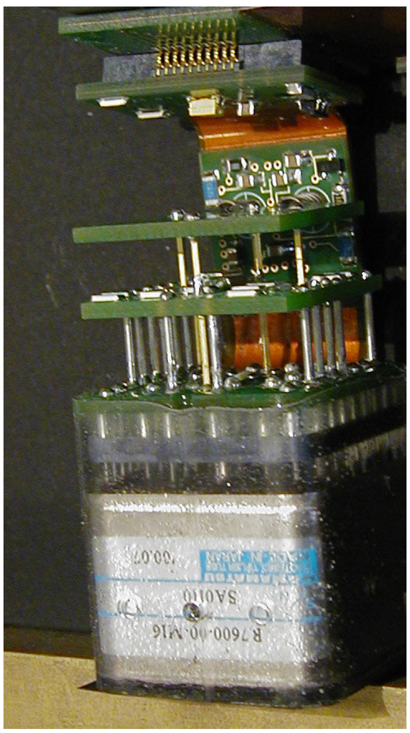


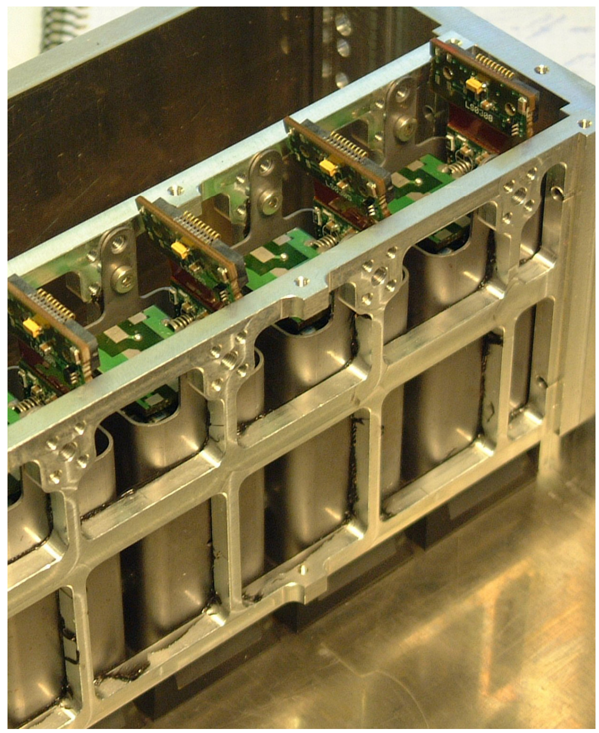
Figure 5.10-11 RICH PMT Construction (Kevlar cord replaced with Nylon wire)

The individual PMTs are mounted to the triangular and rectangular grids shown in Figure 5.10-10. The upper right image of Figure 5.10-12 shows the mounting technique used within the grids.

The RICH PMTs are powered by four RICH high voltage bricks attached to the Lower USS-02 structure. Each of these bricks generates voltages at 1000 VDC and supplies this voltage to the PMTs. The RICH high voltage bricks are fully potted as are the high voltage electronics on the PMTs. The cabling used to route this power is rated in excess of the voltages present and use high voltage connection techniques to eliminate possible sources for discharge, corona and electrical shock. Figure 5.10-13 shows the mounting locations for the high voltage bricks.

The signals from the PMTs are sent to the R Crate for data processing to establish the high energy particle or radiation incident characteristics.





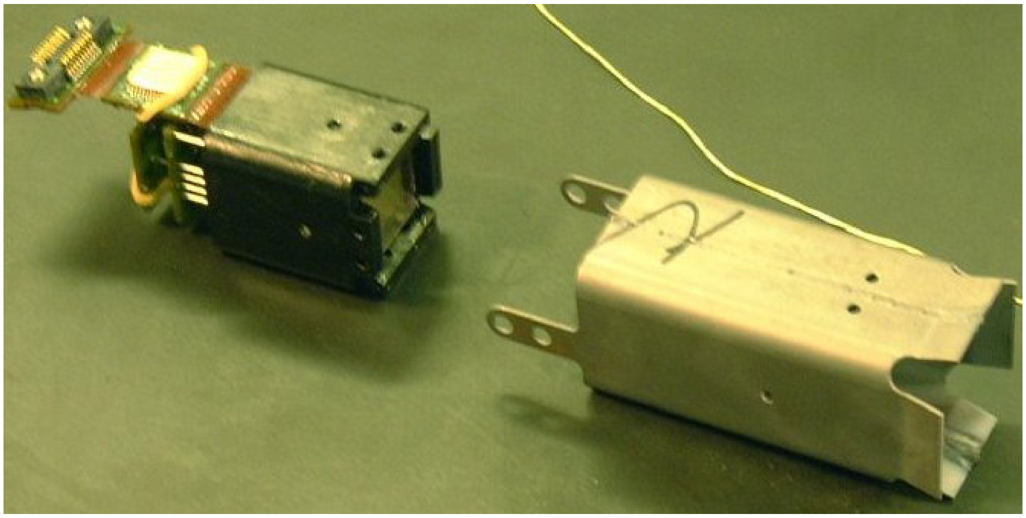


Figure 5.10-12 RICH PMT Construction and Mounting

The 406 lb (184 kg) RICH interfaces with 8 flanges on the Lower USS-02 as shown in Figure 5.10-14. Each interfaces uses 2 bolts per flange (16 total) secure the RICH to the Lower USS-02. Each of these flanges is riveted to the Lower USS-02 box beams with 24 structural rivets.

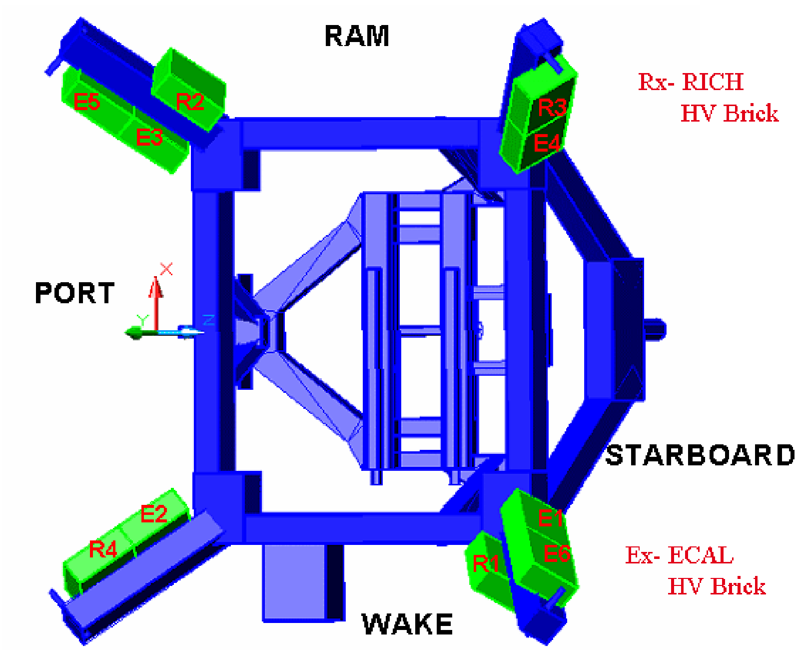


Figure 5.10-13 HV Brick Mounting for RICH and ECAL on Lower USS-02

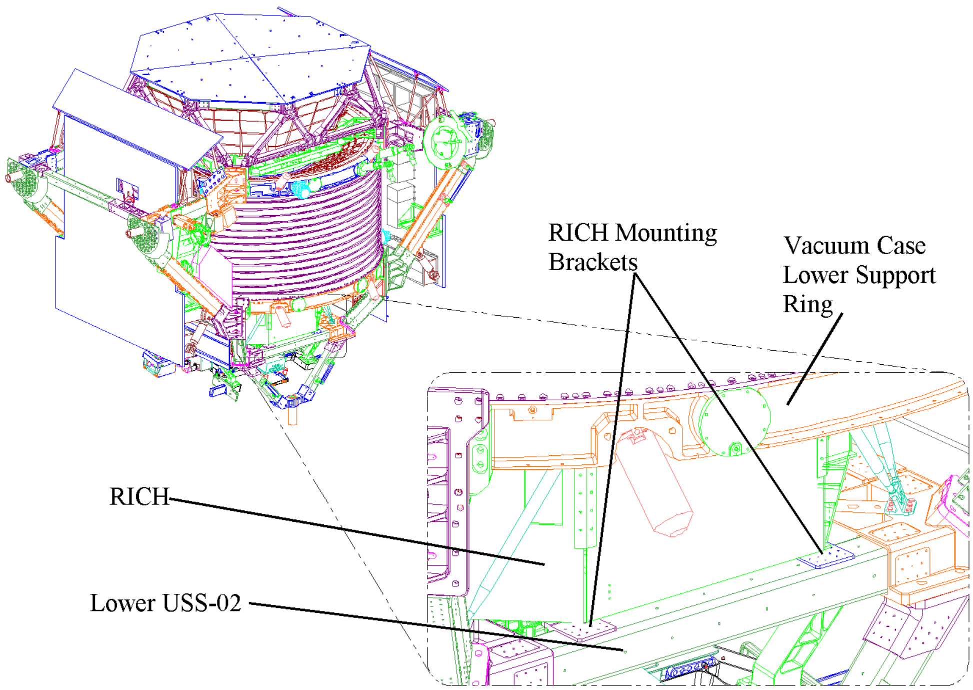


Figure 5.10-14 RICH Structural Interface