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Scope

Specification for the MACS Cryo Filter Exchanger (CFX) elements

Purpose

To provide specifications for the MACS Cryo Filter Exchanger to allow the corresponding sub-projects to proceed in parallel with general development of MACS.

Description

Text and images that specify the requirements for the MACS Cryo Filter Exchanger and that define the interface with the rest of MACS. The mechanical interface is defined in terms of a hard bounding box to which there must be a specified internal clearance. An accompanying solid body submission to the C-100 database further describes this bounding box. This is the actual specification that was transmitted to vendors in the JHU RFQ process.

Filing

When filed as a submittal, this form and the information attached to it transforms into a released document when it is signed by all parties named in it. The form with attachments is kept on file in the office of the NIST chief engineer. When attachments are electronic in nature (such as electronic CAD data) that information and its hierarchical position in the project design tree shall be identified in or under this submittal. Information Requests, Submittals and Releases are numbered separately, yet sequentially.

Change Process

Anyone can propose a change to documentation that is released under this form. To such end an Engineering Change Request (ECR) is filed. A priori, the change board is composed of the individuals that signed the submittal against which the ECR is drawn. Approval of the ECR turns it into an Engineering Change Notice (ECN), which gives authority to prepare a new submittal. The new submittal covers at least the fully executed ECN. Approval of the new submittal signifies close-out (full implementation) of the ECN.

Endorsements (list composition is part of release and determines Change Board for ECR/N's)

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S 038-0016

General Specification for Development of the Cryo Filter Exchanger

for the

Multi-Axis Crystal Spectrometer (MACS)

National Institute of Standards and Technology

Center for Neutron Research

Specification NG-0 1.2 CFX

Revision 1

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1.0 General Requirements

This specification is for the design and fabrication of the Cryogenic Filter Exchanger (CFX) for the Multi-Axis Crystal Spectrometer (MACS). The CFX Assembly contains devices for conditioning a polychromatic neutron beam emanating from an upstream shutter before it reaches a downstream monochromator cask. The conditioning system consists of three filter elements, sapphire, beryllium, and graphite, which are arranged such that one, two or three of the elements can be positioned between the beam shutter and the cask. The filter positioning is accomplished semi-automatically under remote operator control. To enhance the performance of the three filters the enclosure that contains the conditioning elements allows for cryogenic cooling of the filters whether they are in or out of the neutron beam.

1.1 Environment

The CFX will be located at the NCNR and situated in a large air-conditioned experiment hall.

1.2 Fabrication and Materials

Materials and techniques of construction shall be in according with the best cryogenic, vacuum and nuclear engineering practices to provide years of trouble-free service. Special attention should be paid to the selection of materials and components to be used at high pressure, low temperatures, in radiation fields and under conditions of high vacuum. Components deemed inappropriate for its intended service cannot be accepted. For example, the CFX Assembly will be exposed to a very strong radiation field; materials within 300 mm of the active beam height shall be radiation resistant to 10^8 rad. In general, organic materials are not to be used.

All volumes of the CFX not required for beam transmission, mechanical clearance, or cryogenic insulation shall be filled with shielding material. Acceptable materials for shielding are listed below.

1.2.1 Shell Material

All shielding shells shall be fabricated from A-36 mild steel or aluminum alloy 6061.

1.1.2 Fill Materials

Materials used as fill material shall meet the following criteria (material certification required):

Steel Shot:	A36 mild steel, one size, (S200 to S780) per SAE J444
Lead Shot:	No. 8, Pure, Uncoated
Wax:	Paraffin wax, melting point: 120-130°F
Boron Carbide (B_4C):	Technical grade or better, 60 mesh or smaller

Borated Aluminum (furnished by JHU):	9 sheets (5.02 m^2) of 300 mm $\times$1800 mm$\times$1 mm 1 sheet (0.55 m^2) of 300 mm$\times$1800 mm$\times$6 mm

1.3 Interface

The CFX Assembly together with the vacuum pumping station and refrigerator shall be designed and equipped with sufficient instrumentation to enable operators to remotely control, monitor and maintain proper operation of the system. Remote operation will be accomplished through commands from an existing instrument control computer (e.g. PLC).

Operations such as, but not limited to, filter position control, insulating vacuum and cooling system startup and shutdown shall all be interfaced to the instrument control computer (PLC).

In addition, logic for converting the PLC generated output into the desired filter location, is also the responsibility of the contractor.

1.4 Cleaning

All surfaces shall be free from moisture, dirt, organic compounds, scale or other foreign matter.

1.5 Finish

The CFX assembly shall be finished as per the contractor supplied, JHU approved, paint specification.

1.6 Reference Information

Included at the end of this specification are numerous tables and figures to be used for reference. The figures represent a conceptual design and should only be used as engineering guides. The layouts refer to items along the beam-line both upstream and downstream of the CFX.

Table 1 details the elements "seen" as the beam traverses the CFX beginning from the upstream (south) end of the CFX. Values shown in boxes are fixed. All other values are for reference and are subject to modification based on CFX performance criteria and contractor design engineering efforts.

2.0 Performance Requirements

The MACS Cryogenic Filter Exchanger (CFX) contains all the elements required for inserting one, two, or three cryogenically cooled neutron filters into a neutron beam. The neutronic input is a diverging polychromatic cold neutron beam with a circular cross section. The neutronic output is a conditioned diverging polychromatic beam also with a circular cross section. The beam cone has a 1.600-degree taper per side, or 3.200-degrees included. The active filter elements, figure 4, are Al_2O_3 (sapphire), Be, and Pyrolytic Graphite in that order. Each Filter has the shape of a truncated right-circular cone; formed to match the beam cone, see the attached drawings 038-0024, 038-0013, and 038-0014 for specific dimensions and tolerances. The actual filter materials will be purchased separately and are not part of this contract. In lieu of the actual filter materials, Proxy Elements, similar in mass and thermal properties, shall be used for performance acceptance tests.

2.1 Thermal

2.1.1 Operating Temperature

The three internal filter elements shall operate at a temperature at or below 77 K in or out of the neutron beam. To prevent water condensation during normal operation, no point on the external surfaces of the CFX shall be less than 18 ºC.

2.1.2 Cool down

The three filter elements shall be cooled to their operating temperature from ambient conditions in less than forty-eight hours. If necessary, a pre-cooler, permanently attached to the CFX, utilizing liquid nitrogen, may be used to satisfy this requirement.

2.1.3 Heat Load

The heat load due to the influence of the neutron beam is twenty-five watts, divided fifteen for sapphire, five for beryllium and five watts for graphite. The remaining heat load is design based and therefore, the responsibility of the contractor.

2.2 Mechanical

2.2.1 Dimensions

The CFX can be seen, figure 1, as comprised of three basic assemblies: the Base (lower shield), the Filter Enclosure, and the Cap (upper shield). The CFX shall occupy the overall dimensions detailed in figure 6.

2.3 Filter Movement

The functional elements of the CFX are the movable filter elements. Normal operation of the CFX may have all three filters in the beam and will require at least one of the three filters in the beam. Operation of the CFX with any filter in an intermediate position is not acceptable. Travel of the filters shall be sufficient to allow complete clearance of the beam when each filter is lifted out of the beam. Conversely, the filters shall be fully within the beam when lowered fully. Thus, the nominal travel of each filter is nominally the diameter of the filter plus accommodations for holding devices and required clearances.

Each filter shall be independently actuated by means of a pneumatic cylinder or cylinders; filters are lowered into the active or down position, and raised into the idle or up position. The cylinders shall be operated by facility air.

2.3.1 Positional Accuracy

The Positional accuracy for the filters, when in the beam, is such that the beam axis shall be within ±1.5 mm of the filter axis for each filter.

2.3.2 Filter Velocity and Travel Time

Maximum time to lift or lower all three filters shall be less than fifteen seconds; the preferred time is eight seconds. The maximum velocity of all filter assemblies shall be set by the use of precision orifices in the air input and or output to each cylinder. Maximum filter assembly velocity shall not exceed 0.05 meter per second.

2.3.3 Lifetime and Maintenance

The motive and bearing systems shall allow for 200,000 full travel cycles of each filter over the anticipated device life of twenty years.

2.4 Mounting

The CFX is supported by a horizontal surface of a radiation shield within the MACS instrument. The three-point horizontal kinematic mounting pads that align the CFX base to the MACS instrument and beam-line shall afford easy removal and repeatable positioning.

2.5 Power

The total power consumed by the vacuum pumping station, the closed cycle cooling system, and other devices must not exceed the available resources (see section 5.2).

2.6 Insulating Vacuum

The insulating vacuum system, consisting of the vessel surrounding the filters, flanges, fittings, feedthroughs, hoses and other components shall have a total helium leak rate less than 1.0×10^{-9} $stdcm^3$/second.

3.0 Fabrication Requirements

The CFX assembly must be constructed as several easily removable and replaceable enclosures or shells to facilitate maintenance of the CFX, possible replacement of the beam conditioning filters or even planned or emergency maintenance of the MACS instrument. In addition, it follows that all cables, wires, hoses and other external parts and components must also be designed to be easily removed and replaced. The centroid of the lifting eyes shall coincide with the center of mass of the CFX assembly within fifty mm. Due to limited crane travel, the maximum height of the CFX in the hoist-ready condition shall be less than 1800 mm. Threaded receivers for lifting eyes, shown in figure 6, shall facilitate the installation and removal of the CFX and its components using an overhead crane.

The principle components of the CFX assembly, shown in concept as figure 1, are the CFX Cap, the CFX Filter Enclosure and the CFX Base.

3.1 CFX Cap

The CFX Cap includes the motion control components, equipment chase, lifting receivers, and radiation shielding. The Cap shall be secured to the base such that the entire CFX can be lifted as one body.

3.1.1 Motion Control

Air cylinders (double-acting) shall be used to actuate the filter mechanisms and shall be of commercial quality. The suggested motion coupling for filters to the motion of the air cylinders is with magnetic couplings employing radiation resistant samarium cobalt (Sm_2Co_{17}) permanent magnets. The magnetic coupling segment within the vacuum of CFX Filter Enclosure should interface through thin-wall tubing to the magnetic coupling segment. Sensors or switches shall be mounted on each air cylinder to provide positive feedback of the state of each filter: fully in the beam, in transit, fully out of the beam. These items are in addition to switches or sensors mounted in the CFX Filter Enclosure.

3.1.2 Equipment Chase

All cables and plumbing shall be confined to routing within the Equipment Chase volume. Exit will be on the top face of the Equipment Chase volume, see figure 3.

3.1.3 Material and Shielding

The CFX Cap shall be fabricated from steel or aluminum and all voids shall be filled with steel shot and wax as per this specification

3.2 CFX Filter Enclosure

The filter enclosure consists of a vacuum vessel that contains the three neutron beam filters, the respective filter holders, cryogenic components, shielding and two neutron beam windows. Fittings shall be provided for the mechanical lifting of the filters, cooling system attachment, and for temperature sensors.

An insulating vacuum, required so that the filters can be adequately cooled, shall be achieved and maintained by a continuous duty rated, remote turbo-molecular pumping station. Consideration shall be given to the fact that the vacuum source will be located up to five meters from the CFX. The vacuum shall be sufficient to maintain the three internal filter elements at the required operating temperature.

Although the illustrations show a rounded upper surface for the CFX Filter Enclosure, a flat or other shaped surface on the top will be acceptable provided the thermal shell and the filter holders conform on the inner surfaces and void spaces are minimized or filled with shielding material.

3.2.1 Vacuum Vessel

The walls of the vacuum vessel shall be formed from aluminum alloy 6061.

3.2.2 Filter Holders

A separate, but similar filter holder secures each filter. Filter holders provide three primary functions: physical connection to the pneumatic actuators, thermal path to the cold head, shielding above and around the filter elements. Two primary components compose each filter holder, the filter holder shells, and the rings. The filter holder shells shall be fabricated from aluminum and filled with a fully contained 50%-50% by volume shielding mixture of lead shot and B_4C powder as per this specification. Each ring has an outside diameter greater than the adjacent thermal shell openings with a tapered inner bore to match the associated filter. Filter rings shall be fabricated from borated aluminum which will be provided to the vendor by JHU.

3.2.3 Thermal Transfer Elements

The thermal path of the energy within the CFX Filter Enclosure may be approximated as coming from the vacuum vessel with ambient conditions existing on the outer surface and energy produced by neutronic heating of the filter elements. The thermal shell and filter holders shall be designed to efficiently transfer energy produced in the filters and the associated shielding to the thermal conduit, and ultimately to the closed cycle cooling system. The energy path to the cooling system from the thermal shell shall be by virtue of a continuous solid thermal conductor. The conduit shall have a high coefficient of thermal conductivity, and may serve as a thermal spreader to the near and far elements of the thermal shell.

The thermal shell shall be made from ^{10}B:Al so it serves as a neutron aperture, or beam-defining device (see Fig. 4). Neutron transparent openings in the thermal shell shall be sufficiently large in diameter to admit the full beam and the associated positional tolerances for both the thermal shell and CFX assembly. These openings can be covered with thin aluminum foil as required for thermal radiation shielding.

3.2.4 Position Detection

Sensors or switches shall be mounted within the vacuum shell to provide positive feedback of the state of each filter: fully in the beam, in transit, fully out of the beam. These items are in addition to switches or sensors mounted on each air cylinder in the CFX Cap.

3.2.5 Temperature Sensors

Thermocouples shall be mounted on the interior of the CFX to provide real-time monitoring of the temperature of the filter elements. Thermocouples shall be mounted on the perimeter of the circular faces. Lead wires or thermocouples shall not be allowed to enter the beam. Each filter shall have two metal clad type T thermocouples diametrically opposed close to the top and to the bottom of each filter.

3.2.6 Neutron Beam Windows

The neutron beam windows shall be fabricated from aluminum alloy 1060 or 5005 and be provided on both the upstream and downstream faces of the filter enclosure, concentric with the filters in the active position. The surfaces shall provide a projected length of no more than 1.5 mm of aluminum along the beam axis within the volume of the beam cone and its positional tolerance zone. At the contractor’s option, upstream and downstream windows may be identical.

3.2.7 Access Flanges

The filter enclosure shall be separable for internal access and maintenance. Access shall be facilitated by means of a flange as shown in figure 3. Flanges and feedthroughs shall also be supplied for the cold head attachment, heaters, thermocouple connections and a pre-cooling vessel (if this is needed to meet the cool-down performance criteria). All flanges shall be high-vacuum metal seal type (Cu not permitted).

3.2.8 Fittings and Feedthroughs

All vacuum fittings and feedthroughs shall be high-vacuum metal seal type.

3.2.9 Material and Shielding

The CFX Filter Enclosure shall be constructed of aluminum alloy 6061. Borated aluminum (furnished by JHU) shall be incorporated into the internal design of the Filter Enclosure as described above to absorb neutrons scattered from the filter elements.

3.3 CFX Base

The CFX Base provides the mechanical interfaces to the rest of the MACS instrument as well as the force transfer points for the filter lifter actuators.

3.3.1 Material and Shielding

The CFX Base shall be fabricated from steel or aluminum and shall be filled with steel shot and wax as per this specification.

4.0 External Equipment

4.1 Cooling System

A closed-cycle Pulse-Tube Two-Stage Refrigerator shall be used to maintain the filter elements at the required operating temperature. The refrigerator will be positioned on the east side of the CFX assembly and attached by means of a commercially available UHV flange. The refrigerator may be located up to five meters from the CFX.

4.2 Vacuum Pumping Station

A continuous duty rated remote turbo-molecular pumping station shall be used to achieve and maintain the insulating vacuum. The pumping station shall be of sufficient capacity to bring the out-gassed filter enclosure from one atmosphere of N_2 at room temperature to less than 10^{-3} torr within six hours. The pumping station may be located up to five meters from the CFX.

5.0 Available Services

5.1 Air

Facility air is available at a nominal pressure of 90 psig.

5.2 Power

Electrical power is available as single phase 110 vac at 20 amps, single phase 230 vac at 30 amps and three phase 208 vac, at 30 amps.

5.3 Liquid Nitrogen

Liquid nitrogen is available in 250 liter Dewars.

6.0 Tables

No.	Item	Material	CFX Datum Entrance	CFX Datum Exit	Thickness mm	MACS Datum Entrance	MACS Datum Exit
1	Bounding Box	None	**0**	450	450	**3475**	3925
2	Window Crown	None	0	20	**20**	3475	3495
3	Beam Entrance Window	1100 Aluminum	20	21.5	**1.5**	3495	3496.5
4	Vacuum	Vacuum	21.5	26.5	**5**	3496.5	3501.5
5	Thermal Shell (1)	10B:Al	26.5	28.5	**2**	3501.5	3503.5
		Mechanical Clearance	28.5	35	**6.5**	3503.5	3510
6	Filter 1	Al3O2	35	185	150	3510	3660
		Mechanical Clearance	185	191.5	6.5	3660	3666.5
7	Thermal Shell (2)	10B:Al	191.5	193.5	2	3666.5	3668.5
		Mechanical Clearance	193.5	200	6.5	3668.5	3675
8	Filter 2	Be	200	300	100	3675	3775
		Mechanical Clearance	300	306.5	6.5	3775	3781.5
9	Thermal Shell (3)	10B:Al	306.5	308.5	2	3781.5	3783.5
		Mechanical Clearance	308.5	315	6.5	3783.5	3790
10	Filter 3	Graphite	315	415	100	3782	3882
		Mechanical Clearance	415	421.5	6.5	3890	3896.5
11	Thermal Shell (4)	10B:Al	421.5	423.5	2	3896.5	3898.5
12	Vacuum	Vacuum	423.5	428.5	5	3898.5	3903.5
13	Beam Entrance Window	1100 Aluminum	428.5	430	1.5	3903.5	3905
14	Window Crown	None	430	450	20	3905	3925
15	Bounding Box		0	**450**	0	3475	3925

1. Bounding Box: Upstream Dimensional limit for CFX elements along the beam line
2. Window Crown: Beam line measurement of void space created by the crown of the beam entrance window
3. Beam Entrance Window: Thickness of beam entrance window; 99.9% pure aluminum
4. Vacuum: Typical gap for cryogenic vacuum
5. First Thermal Shell Wall: Thickness of 10B:Al (10Boron Aluminum) NCNR Provided
6. First Filter: Thickness of Al_2O_3 (Sapphire) Density = 3.98 g/cm^3
7. Second Thermal Shell Wall: Thickness of 10B:Al (10Boron Aluminum) NCNR Provided May be equal to value in section 4.5.
8. Second Filter: Thickness of Be (Beryllium) Density = 1.85 g/cm^3
9. Third Thermal Shell Wall: Thickness of 10B:Al (10Boron Aluminum) NCNR Provided May be equal to value in section 4.5.
10. Third Filter: Thickness of PG (Pyrolytic Graphite) Density = 2.2 g/cm^3
11. Fourth Thermal Shell Wall: Thickness of 10B:Al (10Boron Aluminum) NCNR Provided May be equal to value in section 4.5.
12. Vacuum: Typical gap for cryogenic vacuum May be equal to value in section 4.3.
13. Beam Exit Window: Thickness of beam entrance window; 99.9% pure aluminum May be equal to value in section 4.3.
14. Window Crown: Beam line measurement of void space created by the crown of the beam entrance window May be equal to value in section 4.2.
15. Bounding Box: Downstream Dimensional limit for CFX elements along the beam line

Table 1. Beam Line Stack-up

Element	_X	_Xi	__Xi	x	y	2y	2Y
					Radius	Diameter	Clearance Diameter
Theoretical Beam Convergence Point				**-1600**	0		
Cold Source Face				0	44.7	89	101
Beam Hole 184 ref				1654	90.9	182	205
Face of Bio Shield @ E	781			2435	112.7	225	254
Forward Edge of Bio Shield				2600	117.3	235	264
Shutter In				**2650**	118.7	237	267
Anti-Streaming Dome (In)		50		**2700**	120.1	240	270
Anti-Streaming Dome (Out)		50		**3400**	139.7	279	314
Shutter Out		700	800	**3450**	141.1	282	317
Cryo Filter Exchanger		CFX	450	**3475**	141.8	284	319
Sapphire	43	150		**3510**	142.7	285.9	322
	7			3660	146.9	294.3	
Beryllium		100		**3675**	147.3	294.7	332
	7			3775	150.1	300.3	
Pyrolytic Graphite		100		**3790**	150.6	300.7	338
	43			3890	153.3	306.3	
				3925	154.3	309	347
	10						
Choke Entrance	120			**3935**	154.6	309.2	348
Exit				4055	158.0	315.9	355
	39						
Cask In				**4094**	159.0	318.1	358
	56						
In-line Collimator Exchanger		ICX	355	**4150**	160.6	321	361
		140		4290	164.5	329	370
	5			**4295**	164.7	329	371
		210		4505	170.5	341	384
	45						
Variable Beam Aperture		VBA	205	**4550**	171.8	344	387
		100		4650	174.6	349	393
	5			**4655**	174.7	349	393
		100		4755	177.5	355	399
Monochromator		DFM					
Leading Edge	38			**4793**	178.6	357	402
Axis 35	300			**5093**	187.0	374	421
Axis 90		Total Travel		**6200**	217.9	436	490
Axis 105.4		1757		**6413.5**	223.8	448	504
Axis 130				**6850**	236.0	472	531
Trailing Edge				**7150**	244.4	489	550
	300						
Cask Out	2150		3356	**7450**	252.8	506	569
Beam Dump				**9600**	312.8	626	704

Table 2. 1.600-Degree Divergence Beam Equation

7.0 **Figures**

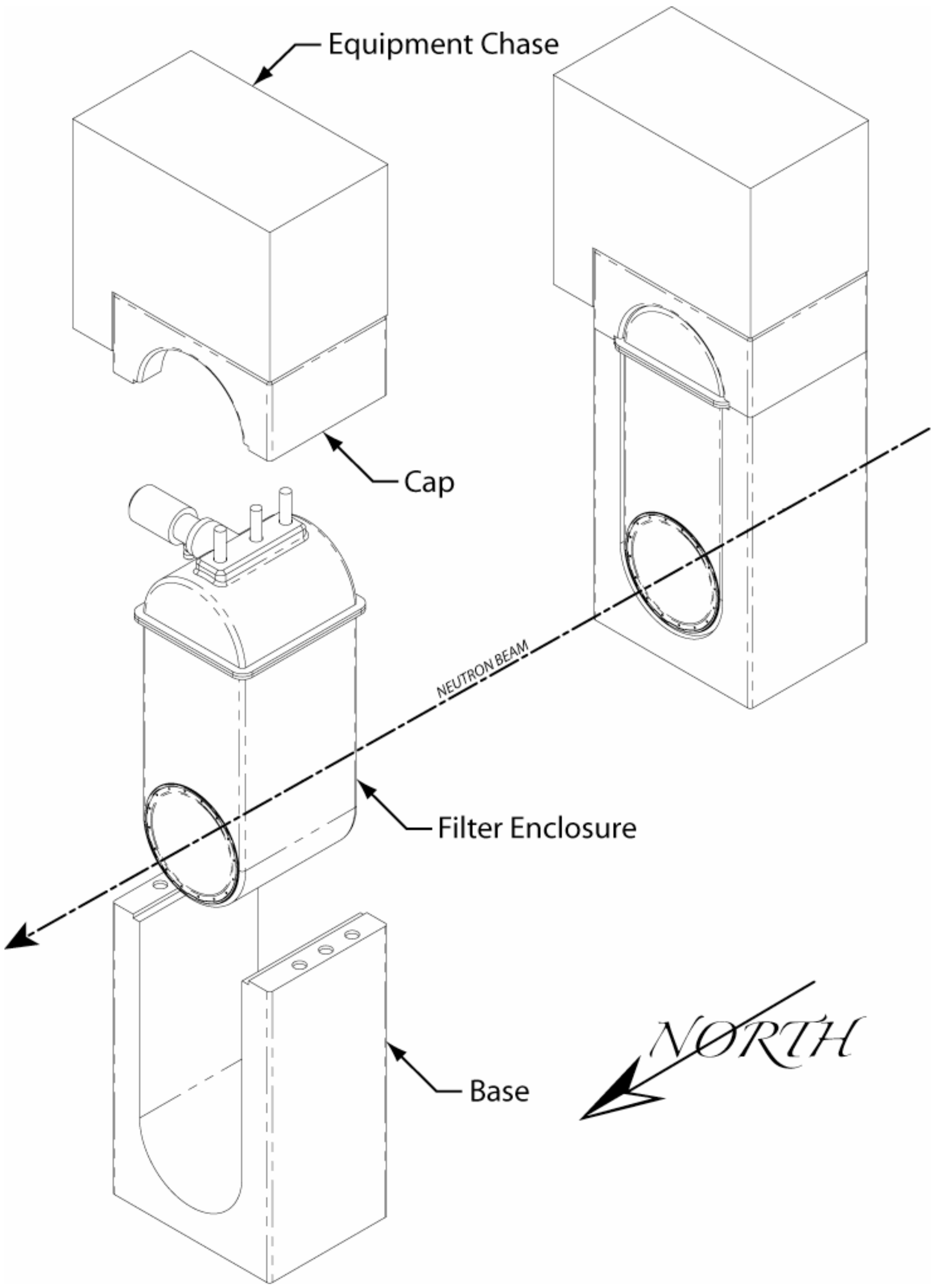

Figure 1. CFX Major Elements.

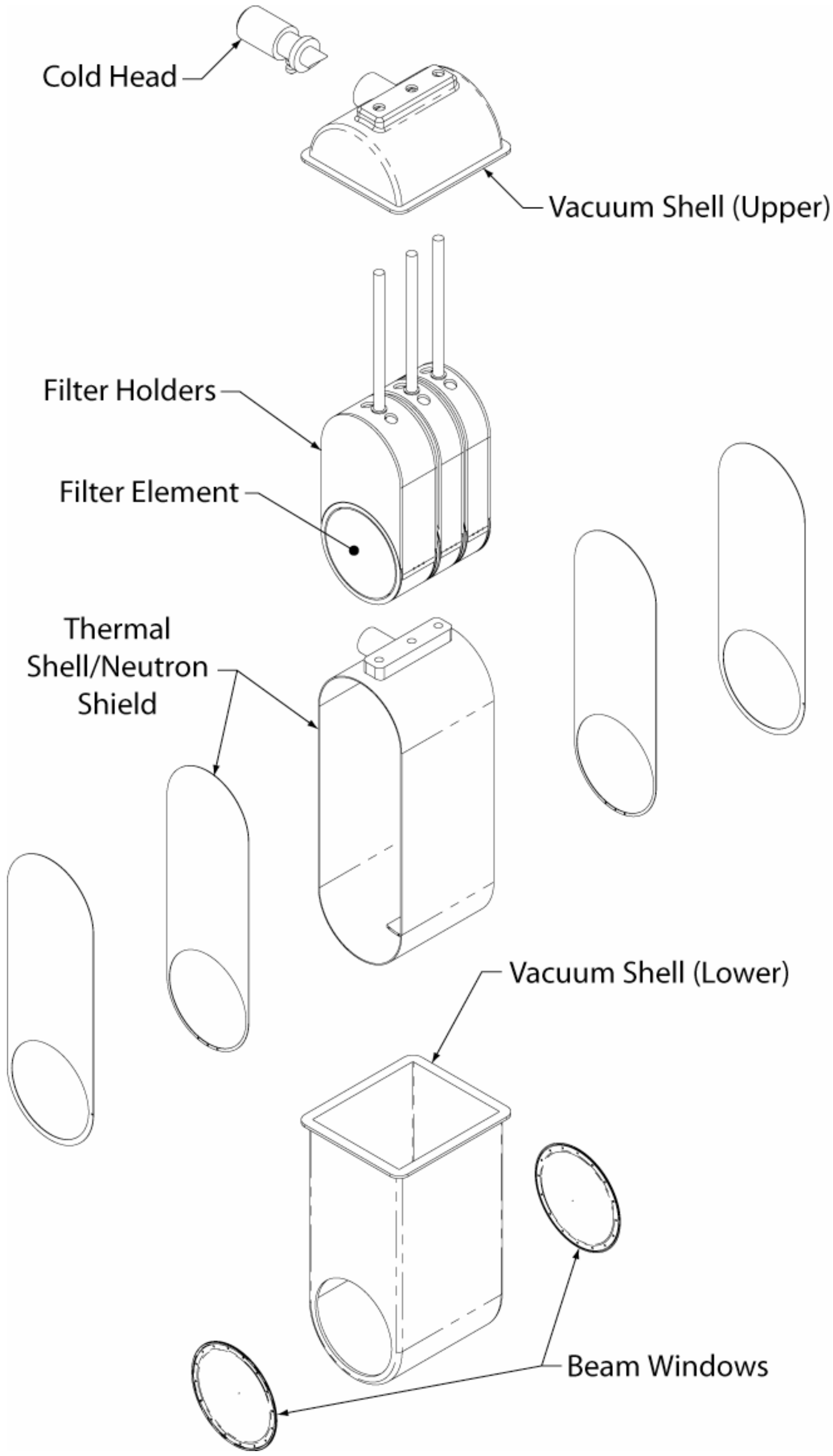

Figure 2. CFX Exploded View

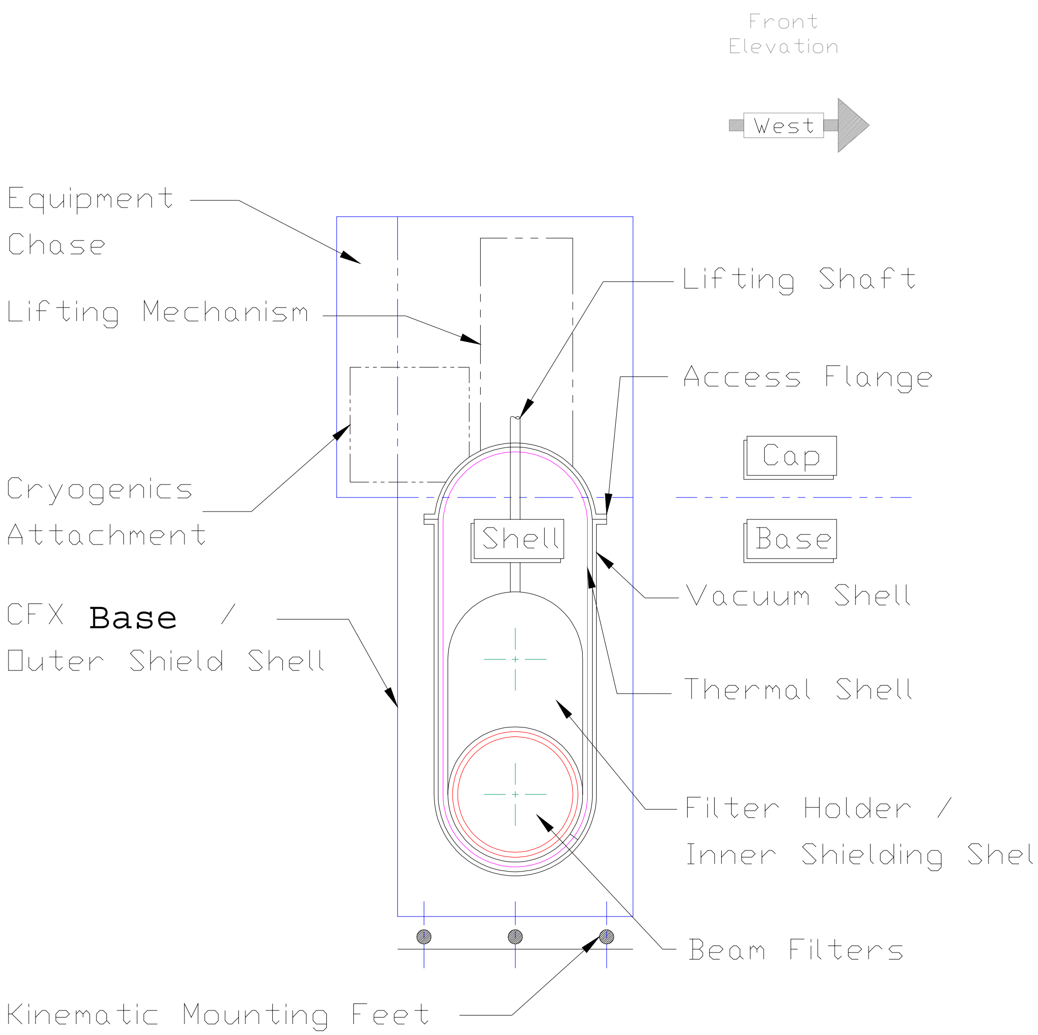

Figure 3. CFX Internal Elements

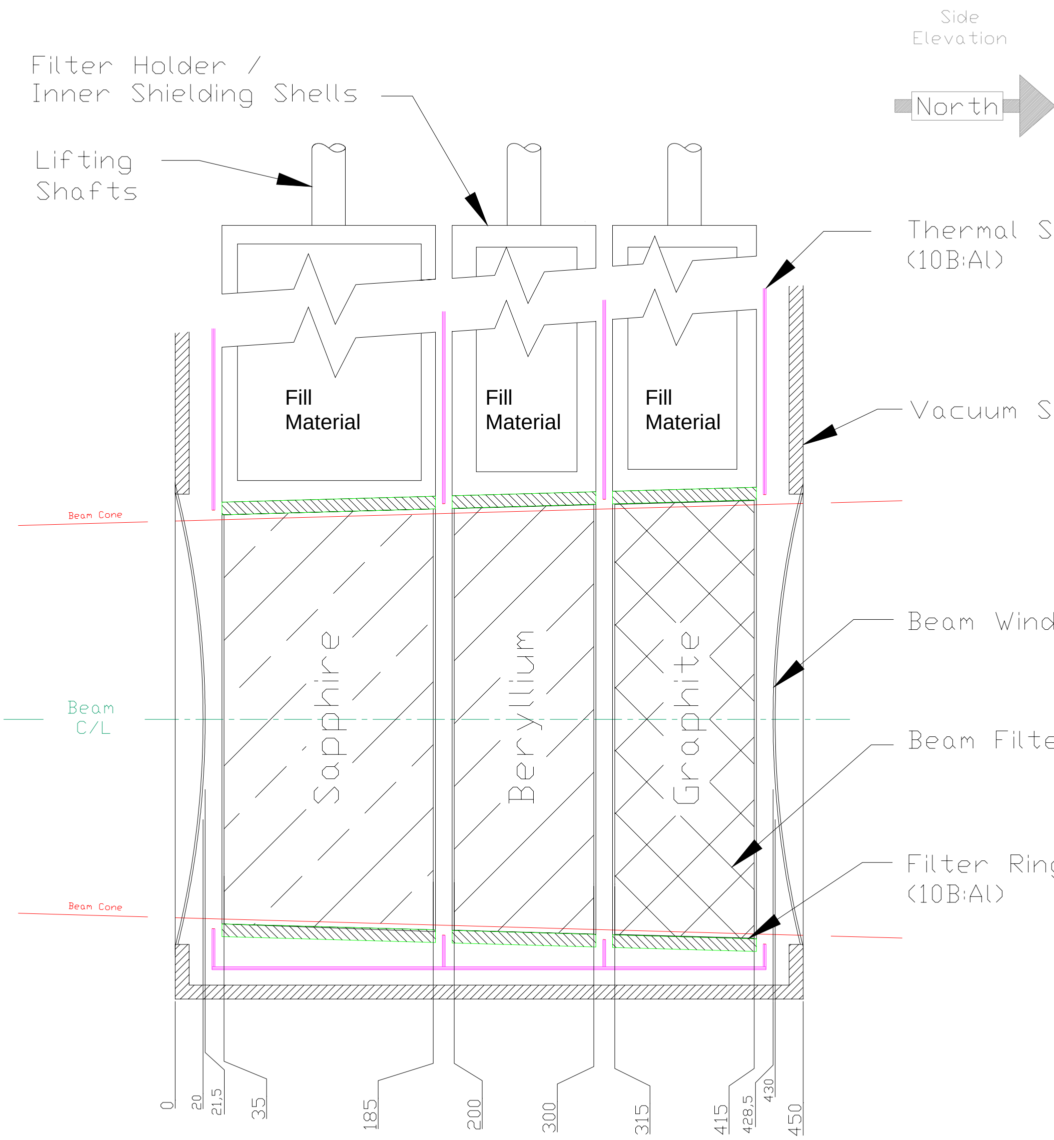

Figure 4. CFX Beam Path Details

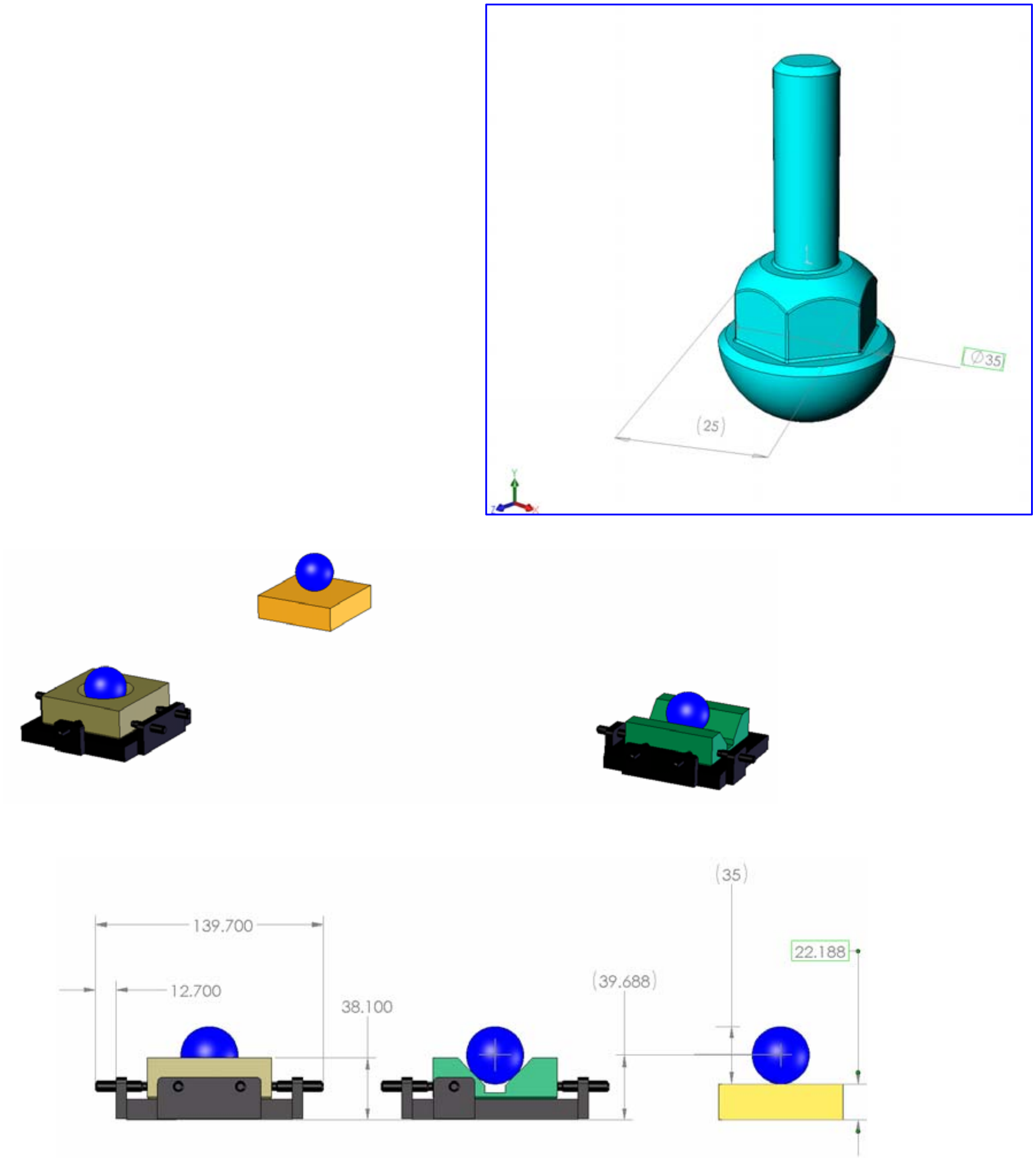

Figure 5. Kinematic Mounting System

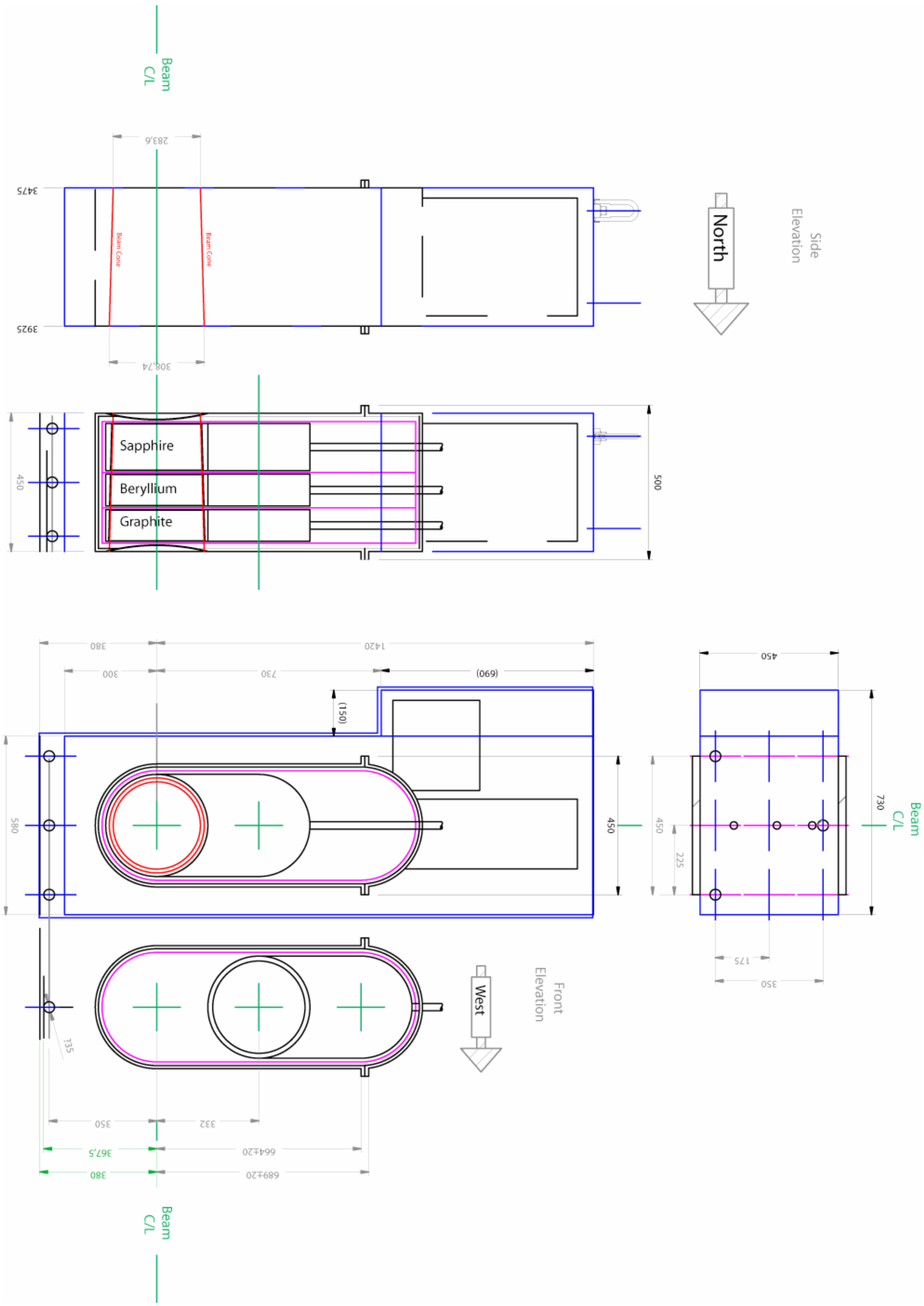

Figure 6. Dimensions