Design Report – Vacuum Housing

Version 1.6.1

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13 June, 2007

1) Overview of complete system:

The principal components of the detector vacuum housing is shown in figure 1,

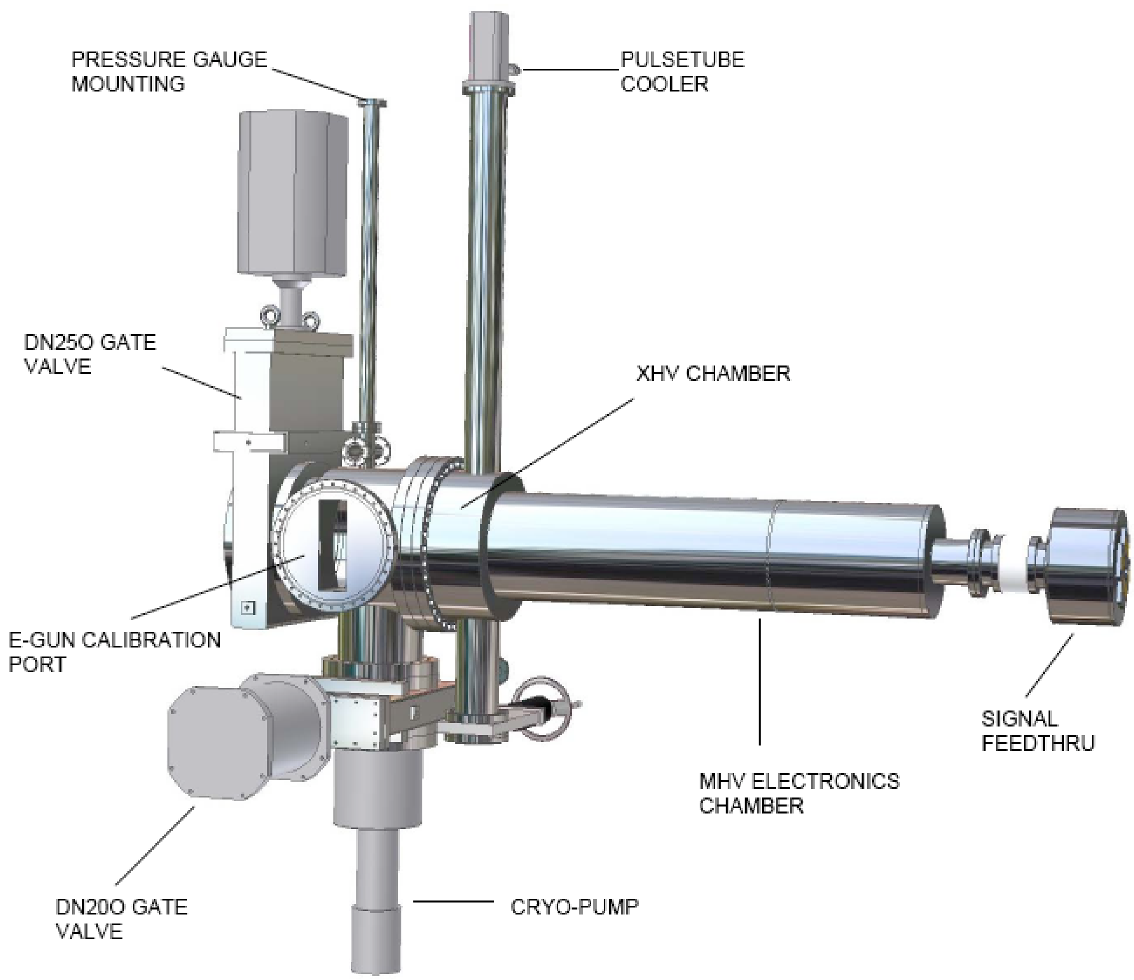

Figure 1 principal components of the detector vacuum housing

The housing system consists of two vacuum regions, the extreme high vacuum region (XHV region 10^{-10} mTorr) that houses the detector and a medium high vacuum region (MHV region 10^{-7} mTorr) that provides thermal insulation and houses the electronics. The details of the pumping systems are given in the vacuum design document[1].

The vacuum chamber is constructed of type 316, non-magnetic stainless steel, pre-selected for low radioactivity. All welds are performed using non-thoriated welding rods[2]. All surfaces will be electro-polished and cleaned using the approved techniques for extreme high vacuum contained in reference 1.

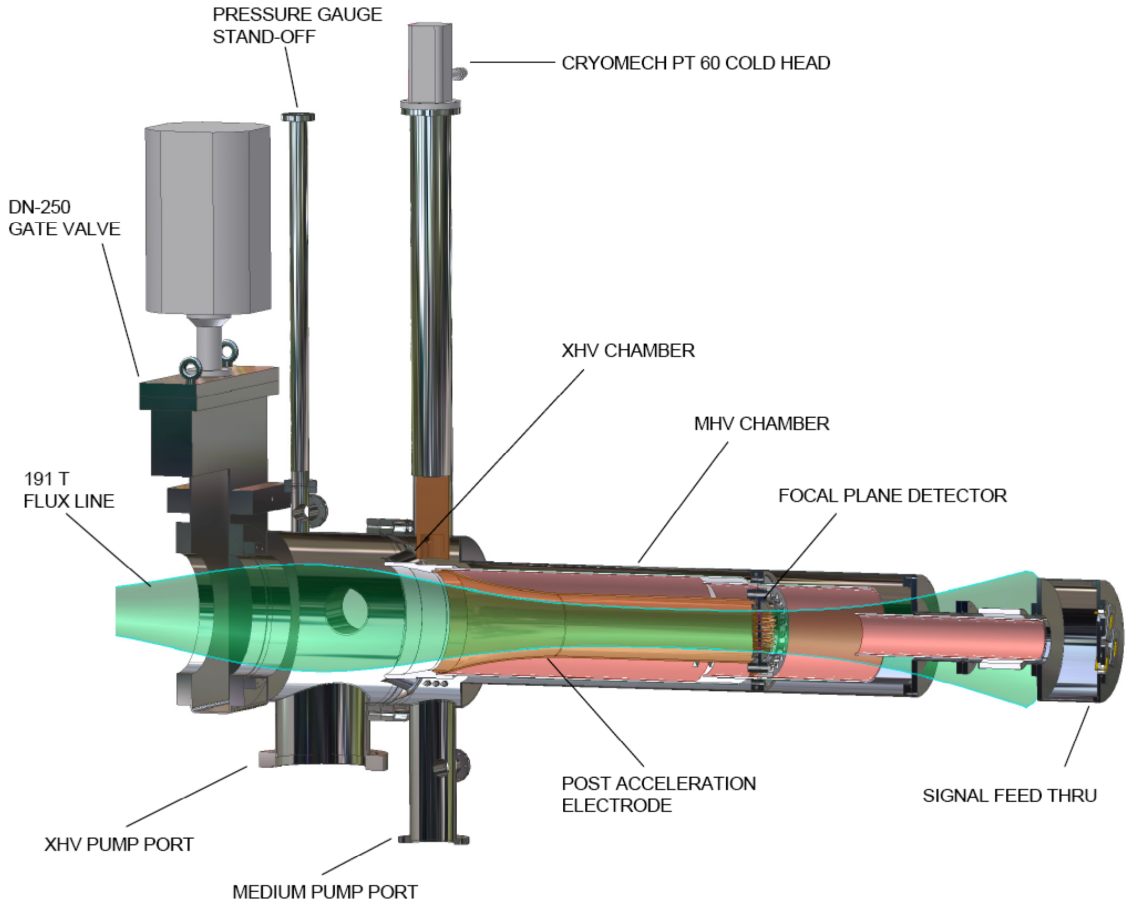

Figure 2 Internal components of the extreme (XHV) and medium (MHV) vacuum regions. The magnetic flux tube is shown in green.

XHV Chamber. The main vacuum chamber is a stainless steel cylinder 355mm diameter by 303mm long with a 3mm wall thickness and is shown in figure 3 below. It is essential that the 191 T cm flux lines clear all hardware. The design provides a minimum of 15mm radial clearance for the flux lines. All seals for the XHV chamber are metal seals. The components attached to this chamber are described below.

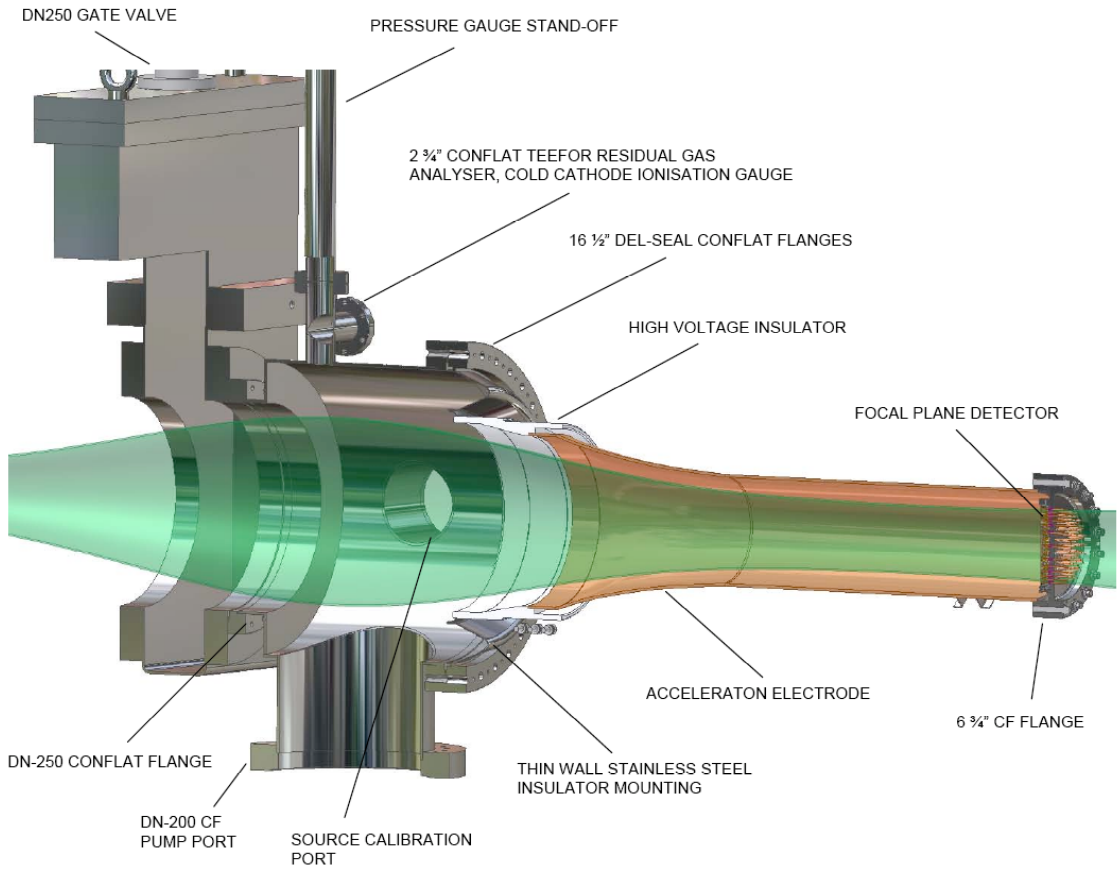

Figure 3 Cross section of the XHV chamber and Ports, not shown is the square aperture electron gun calibration port.

The gate valve connecting the vacuum housing to the main spectrometer is a DN 250mm, all-metal, pneumatically operated valve. This valve is interlocked to the cold cathode gauge to protect both the detector and the main spectrometer in the event of vacuum failure in either system.

The primary XHV pump[3] has a DN200 Conflat flange that attaches to an existing, custom DN200-DN250 gate valve all metal (Series 48). This in turn is mounted to a DN250 flange on the main XHV chamber. The gate valve is interlocked to the same gauge as the main spectrometer gate valve.

If it proves necessary for additional hydrogen pumping capacity a DN100 (6 inch O.D. Conflat) port is located on the XHV chamber to allow mounting a NEG pump[4]. This pump will not require an isolation valve. See reference 1 for more details.

The XHV system is roughed down by the dedicated, mobile turbo pumping station. This station is connected to the XHV system via a DN63 (4.5 inch O.D. Conflat) all metal, manually operated gate valve.

There are two calibration ports on either side of the main vacuum chamber. The electron gun calibration port is a DN250 (12 inch O.D. Conflat) flange with a rectangular aperture, 66mm by 200mm through which the electron gun is inserted. The size of the aperture allows the electron gun to traverse the entire flux tube. Opposite the electron gun

port is the source insertion port consisting of a DN100 (6 inch O.D. Conflat) flange mounted on a 100mm (4 inch) diameter pipe.
The custom built insulator supporting the copper post acceleration electrode system is mounted on a 16 ½ inch O.D. Del-Seal Conflat flange. This nominally operating conditions are 30 kV and 100° K. A total of 80 W of heat from the electronics is dissipated through the insulator to a low vibration pulse tube cooler[5].
A DN63 (2 ¾ inch O.D. Conflat) four-way cross is located on top of the vacuum chamber. A cold cathode ionization gauge, extractor gauge and a residual gas analyzer are mounted on this cross. The cold cathode ionization gauge and the extractor gauge are mounted using a 750mm extension tube. The extension tube is necessary to locate the instruments away from the high magnetic field region. It is also necessary that the two gauges do not "see" each other. Although this results in a reduction of the precision of the vacuum pressure measurement, it will be sufficiently precise to monitor the system pressure for interlock purposes. See reference 1 for details. The remaining ports of the four-way cross are spare ports.
The tables below summarize the XHV ports and their associated hardware.

Main spectrometer	DN250
Ultra high chamber	16½ inch O.D. Del-Seal Flange
High voltage insulator	16½ inch O.D. Del-Seal Flange
Main pump port	DN200
Calibration (e-gun)	DN250 (12 inch O.D. Conflat)
Calibration (source)	DN100 (6 inch O.D. Conflat)
Post acceleration electrode	16½ inch O.D. Conflat
Detector flange	6.75 inch O.D. Conflat
Spare (NEG pump port)	DN100 (6 inch O.D. Conflat)
Pressure gauge flange	DN35 (2.75 inch O.D. Conflat)
Signal output feedthru's	To be specified by electronics task

Table 1 XHV ports and their intended use.

Main spectrometer	DN250 servo gate valve all metal VAT Series 48
XHV vacuum system	DN200-DN250 gate valve all metal VAT Series 48
Roughing vacuum system	DN63 gate valve all metal VAT Series 10

Table 2 XHV valves

MHV Chamber. The medium vacuum chamber is a stainless steel cylinder 250 mm diameter by 1500 mm long with a wall thickness of 3mm. The MHV chamber contains two, concentric insulating cylinders that reduce the possibility of enhanced vacuum breakdown in the presence of crossed E and B fields. The design attempts to minimize the restrictions to the pumping path. Details of the MHV chamber can be seen in figure 4 below.

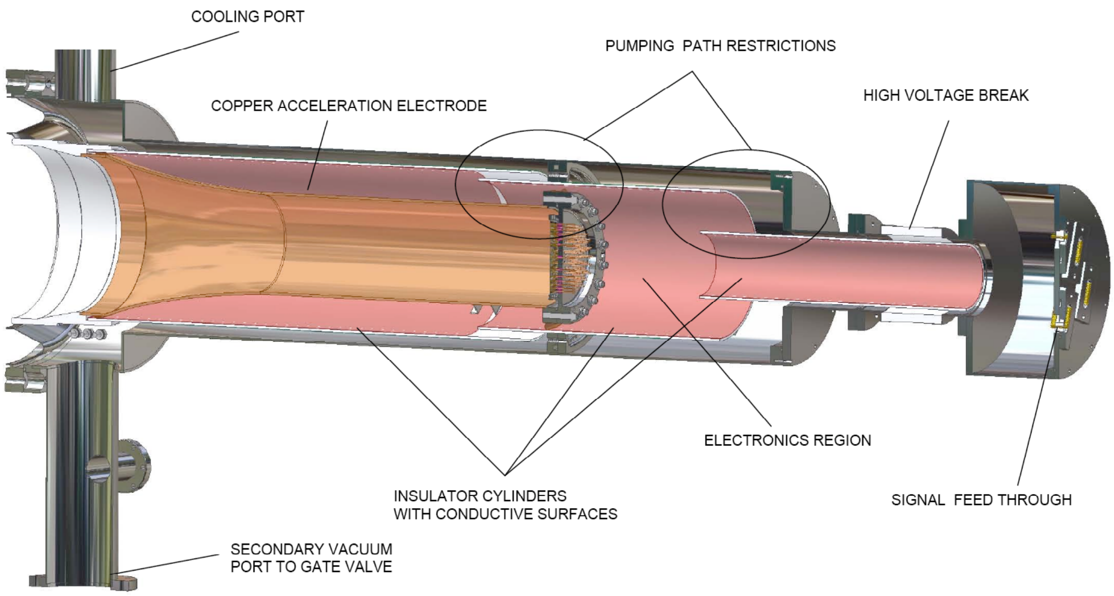

Figure 4 The MHV chamber

The primary MHV pump has not yet been identified but for ease of operation is expected to be a mechanically cooled cryopump, similar to the main XHV pump. The pump is mounted to a DN100 (6 inch O.D. Conflat), Viton sealed, manually operated gate valve (VAT series 10) which is connected to the MHV chamber via a DN100 Conflat flange. The MHV system is roughed down by dedicated, mobile turbo pumping station. This station is connected to the MHV system via a DN63 (4.5 inch O.D. Conflat), Viton O-ring sealed, manually operated gate valve.

The MHV chamber is mounted to the XHV chamber using a custom O-ring sealed flange that mounts to the 16.5 inch Del-Seal flange that supports the insulator for the post acceleration electrode.

Also attached to the ceramic mount of the post acceleration electrode is the cold head of the pulse tube cooler used to remove the heat from the electronics front-end components. This connection is made through the cooling ports which is sealed with a 3.125 I.D. O-ring.

The MHV housing is at ground potential while the signal feedthroughs are at the nominal 30 kV post acceleration potential. The electrical break is achieved using a commercial, 4 inch I.D. standoff with O-ring seals. The standoff is rated for 60 kV maximum operating voltage.

The MVH is monitored using cold cathode and thermal conductivity gauges appropriately located with respect to the magnetic field.

Front housing flange	14 inch dia. x 0.25 inch x-sect. O-ring (custom)
Rear housing flange	9 inch dia. x 0.25 inch x-sect. O-ring
Cooling port	3.125 inch dia. x 0.25 x-sect. O-ring
HV break	Ceramaseal, Model #17141-02-W, 4 inch I.D.

Table 3 MHV flanges, ports and fittings. The dimensions refer to the ID and cross section of the O-ring in the custom made flange.

Medium vacuum system	DN100 O-ring sealed manual gate valve VAT Series 10
Roughing vacuum system	DN63 O-ring sealed manual gate valve VAT Series 10

Table 4 MHV valves

Chamber mounting:

The chamber, and all hardware is mounted on an aluminum frame that attaches to the same roller-rail system that supports the pinch and detector magnets. As seen in figure 5, each magnet and the chamber require separate stands and adjustment hardware with respect to the roller-rail system and can be adjusted independently.

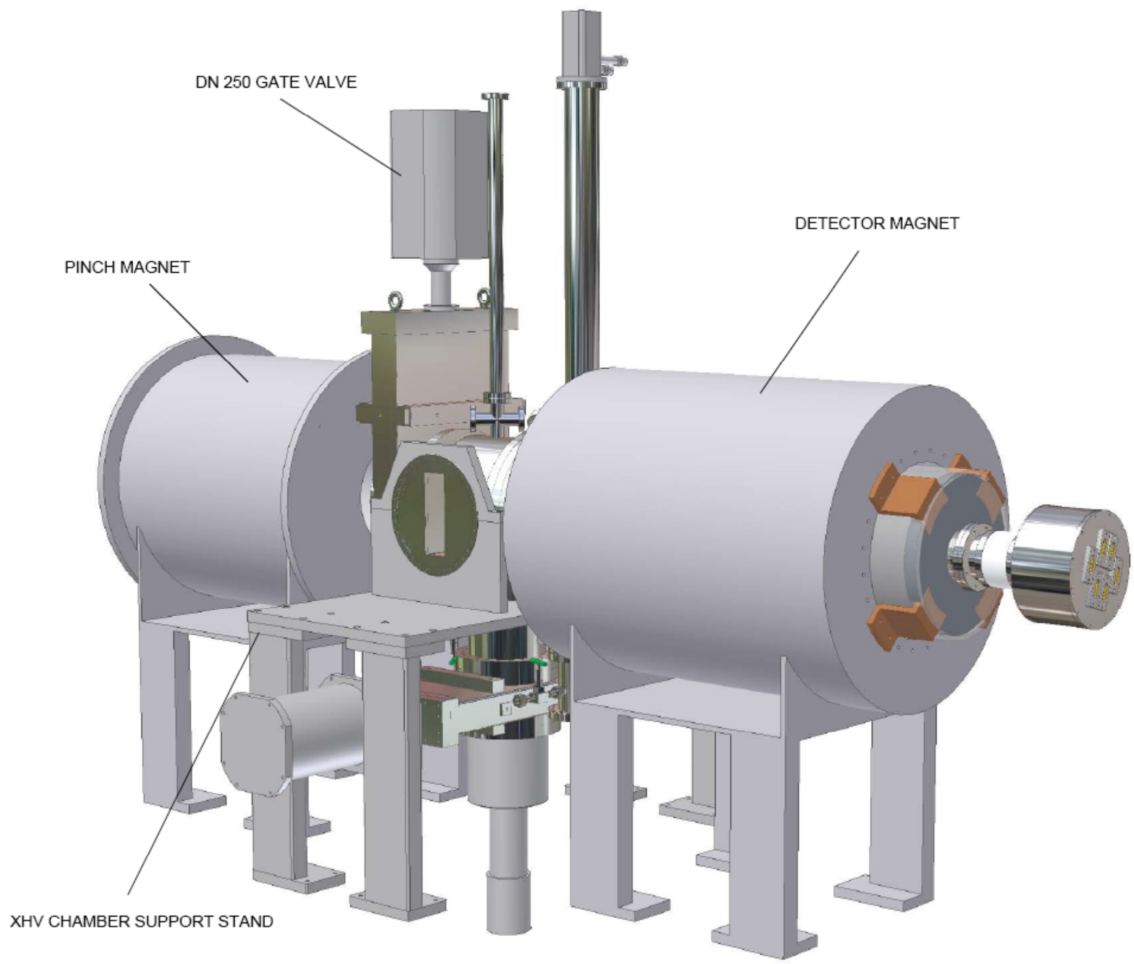

Figure 5 XHV chamber support stand and magnets.

The chamber stand allows for fine adjustments of ±25 mm in the vertical direction and ±10mm in the horizontal direction. An adjustment screw allows the rear of the chamber to be raised/lowered by 13m, resulting in an angular tilt of +-3° of the chamber. Once adjusted the chamber is locked in place with respect to the magnet system. Under bake-out of the main spectrometer the entire system (magnets plus vacuum housing) is able to move with respect to the main spectrometer.
The roller-rail system will be provided by the FZK. For commissioning at UW the support frames will be mounted on a similar rail system using rollers provided by the FZK.

Cooling system:
The cooling system is responsible for cooling the Si PIN diode array and removing heat from the preamplifier electronics housed in the medium vacuum region. The main features of the cooling system are shown in figure 6.

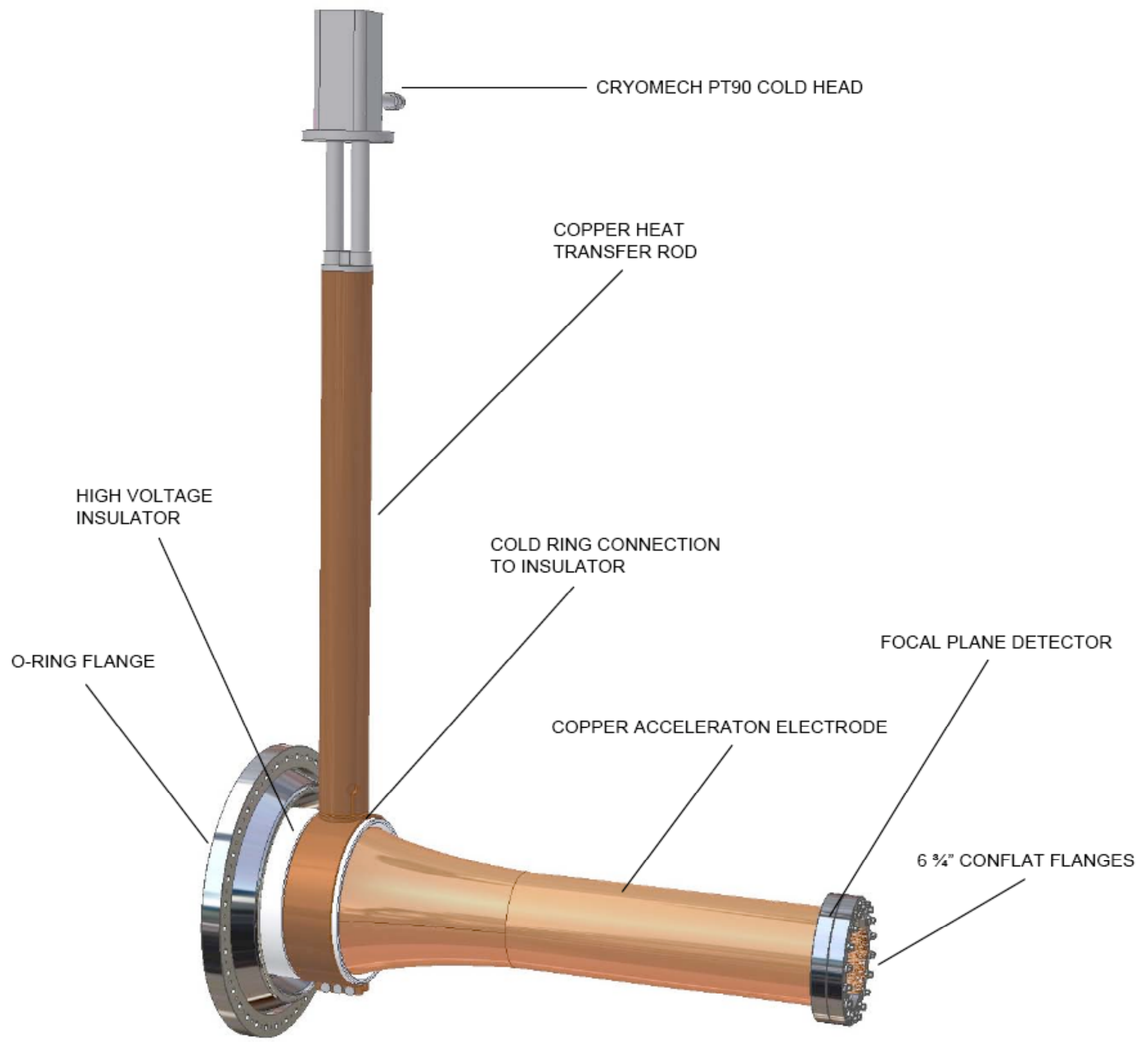

Figure 6 Main features of the detector and electronics cooling system.

Cooling is provided by a Cryomech PT-90, single stage, pulse tube cooler which provides 90 W at 80°K. The model provides very low levels of vibration and has a remote motor capability. The cold head can only be operated in fields of less that 500 Gauss and is therefore stood off from the vacuum vessel by a 750 mm long copper cooling rod.
The cooling rod penetrates the MHV vacuum jacket via an o-ring flange and is connected to the copper cooling ring encircling the insulator which supports the copper post acceleration electrode. The copper electrode is thermally connected to both the Si PIN diode array and the preamplifier electronics.

Anticipated heat loads, temperatures:

Electronic heat load 10 W
Radiative heat load 80 W
Temperature of detector ~ 120° K

Thermal details are given in appendix 1

Details of the post acceleration insulator are shown in figure 7.

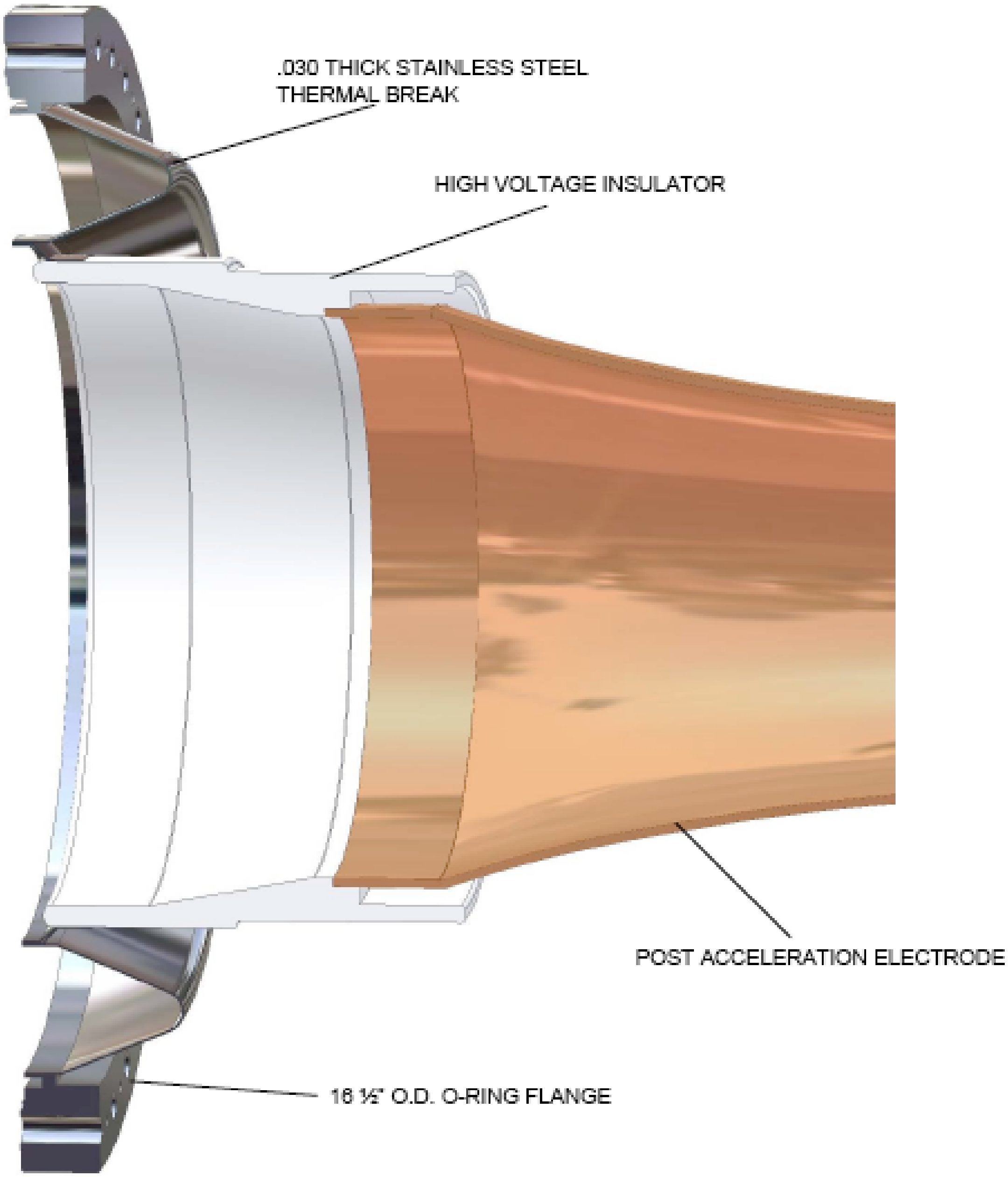

Figure 7 Details of the post acceleration insulator.

The insulator, which is nominally at 120K is attached to the room temperature flange by a 0.76 mm thick stainless steel thermal break. This thermal break must be thin to prevent thermal loss to the flange yet thick enough to resist the bending moments imposed by the post acceleration electrode and the detector mount.

The thermal break must also be capable of resisting atmospheric pressure from either side without excessive movement. Figure 8 shows the displacement that results from a vacuum on one side and atmospheric pressure on the other. The displacement is approximately the same which ever side the load is applied to.

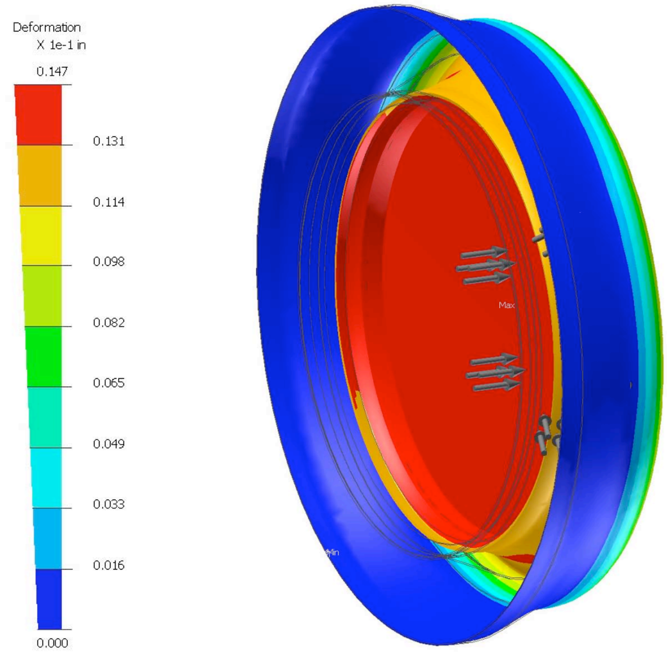

Figure 8 Deflection of the thermal break with vacuum on one side and atmosphere on the other. The total deflection is .015”or .37mm.

7) Preventing enhanced vacuum breakdown:

Under XHV conditions it is possible for vacuum breakdown to be enhanced in the presence of crossed E and B fields. To prevent the possibility of enhanced vacuum breakdown, insulating cylinders, whose inner and outer surface are coated with a conductor, are used. This “cylindrical capacitor” arrangement ensures that the high E fields only appear inside the bulk of the insulator removing the possibility of enhanced E cross B breakdown.

The telescoping insulator cylinders with their conducting surfaces can be seen in figure 9. The inner conductive coatings are maintained at the same potential as the copper electrode. This is achieved using contact rings located at the post acceleration electrode inside the insulator and again at the 6 3/4” O.D. CF flanges at the detector. The outer conducting surfaces of the cylinders have grounding strips connecting them to the wall of the MHV chamber. There are segments at the cylinder ends which have no conductive surfaces in order to prevent breakdown between the two conducting surfaces.

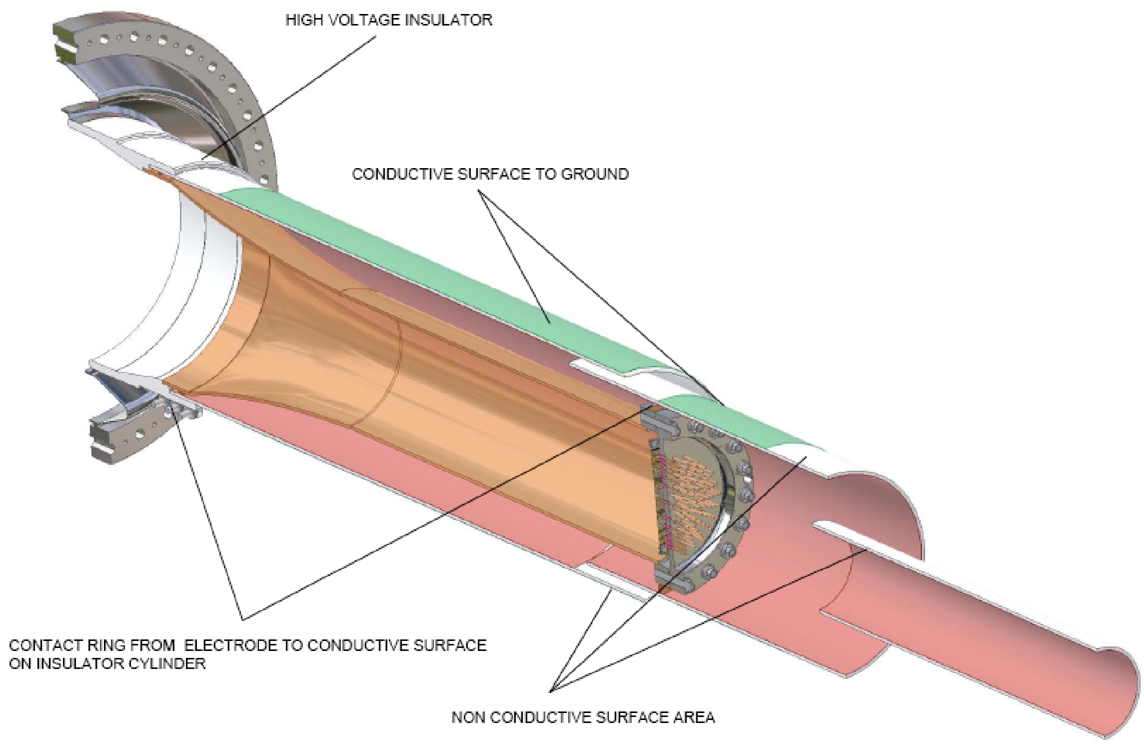

Figure 9 Cylindrical, telescoping insulators intended to prevent enhanced vacuum breakdown in the presence of crossed E and B fields

Relatively large gaps are maintained between the telescoping cylinders in order to provide efficient pumping paths. The diameter of the rear insulator, through which the readout cables pass, is as small as possible in order to maintain the effectiveness of the veto shield, which it penetrates.

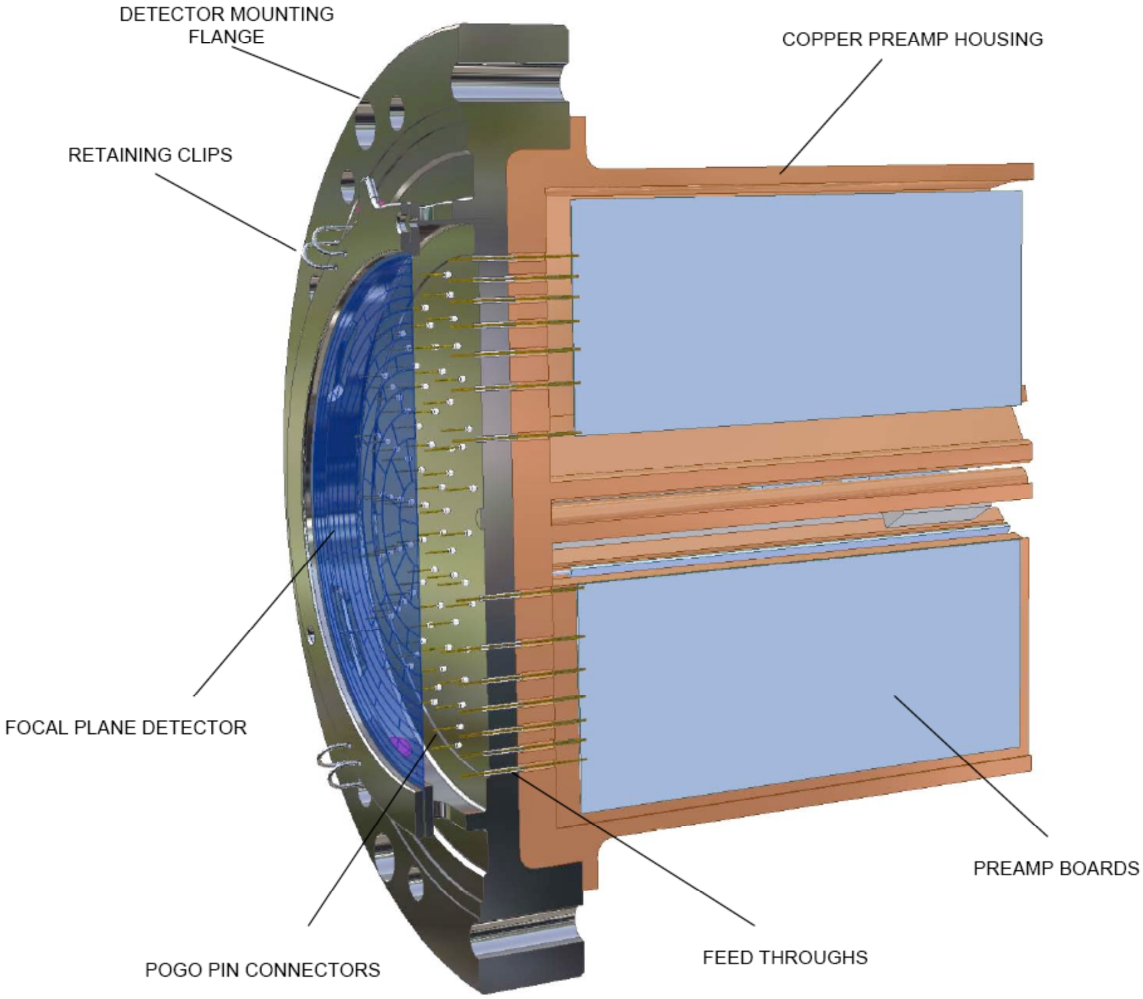

Figure 10 Section through the detector mounting flange and electronics housing.

10) Detector mount:

As shown in figure 10, the detector is mounted on a modified 6-3/4"O.D CF Flange. The flange is thermally connected to the post acceleration electrode, through which it is cooled. The detector wafer is held in place on the modified flange by spring clips that accommodate the differences in thermal expansion.

Electrical contacts to the 148 pixel diode are made by non-magnetic pogo pins mounted on the signal feedthrough posts that penetrate the mounting flange. Bolted onto the MHV side of the detector mounting flange is a copper plate that is part of the electronics housing cylinder described below. This plate ensures a uniform temperature across the mounting flange and also shields the detector against radiation coming from the electronics components.

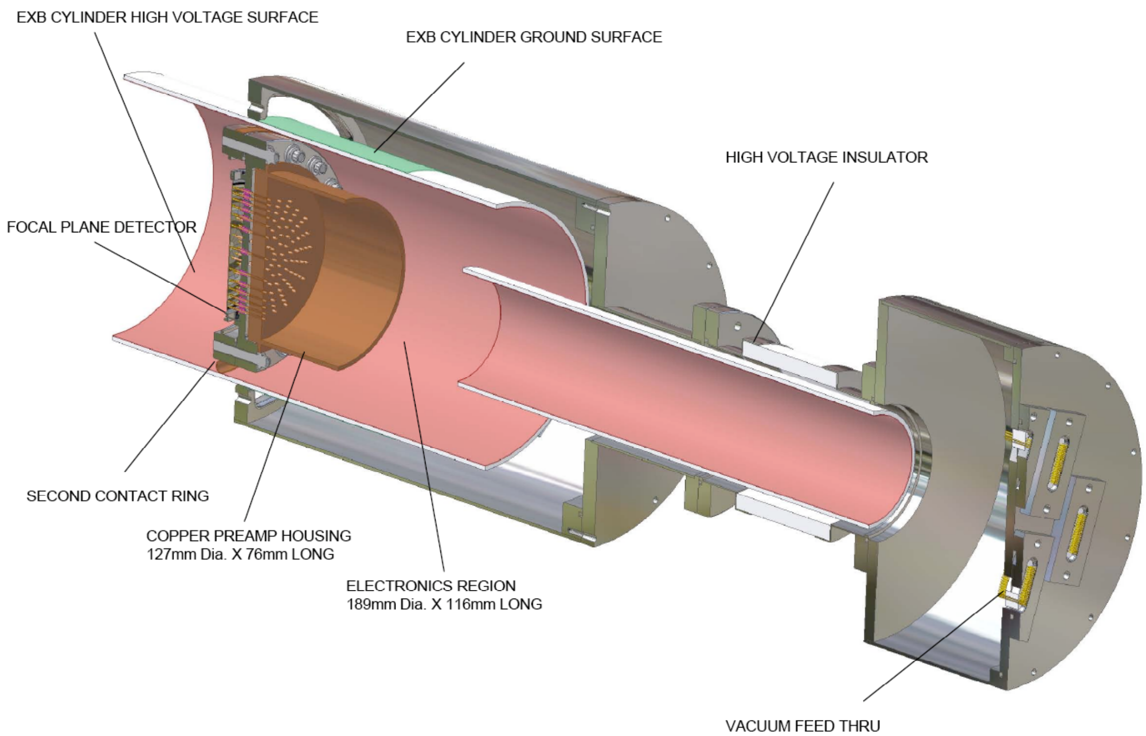

Figure 11 Electronics region:

11) Electronics region

The electronics are housed in the medium vacuum region. Details of the electronics mounting are given in the electronics design document[6]. The general layout of this region is shown in figure 11.

The preamplifier electronics are housed in a copper cylindrical can 127 mm diameter by 76 mm long that is thermally and electrically connected to the detector mounting flange as described above and shown in figure 10. The feedthrough pins penetrate the bottom of the copper can. The walls of the can contain channels which act as guides for the 24 preamplifier boards. The boards slide into these channels and mate directly to the feedthrough pins.

Coaxial signal cables from the preamplifiers pass through an 82 mm diameter high voltage insulator which is connected to the signal feedthrough chamber. This chamber is at the same potential as the electronics and post acceleration electrode. The choice of feedthroughs will be made by the electronics group.

12) Principal Dimensions

Figure 12 shows the principal dimensions of the detector system.

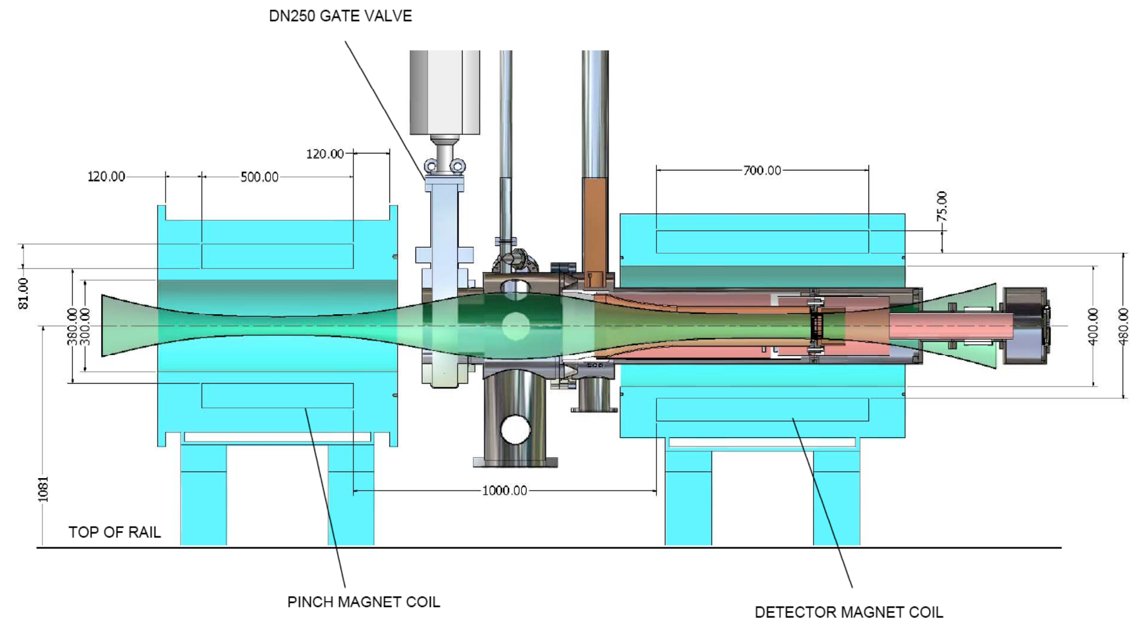

Figure 12 Principal dimensions of the layout of the components of the detector system

The height of the magnet axis above the mounting rail has to be confirmed. For the magnet coils in the locations shown in figure 12, the flux tube corresponding to 191 Txcm^2 and a field of 3.6 T at the center of the detector magnet is shown in figure 13, which also gives the diameter of the flux tube and adjacent hardware at critical points. A design criteria was to maintain a minimum clearance of 15 mm between the flux tube and the hardware. The principal dimensions of the XHV region are given in figure 14.

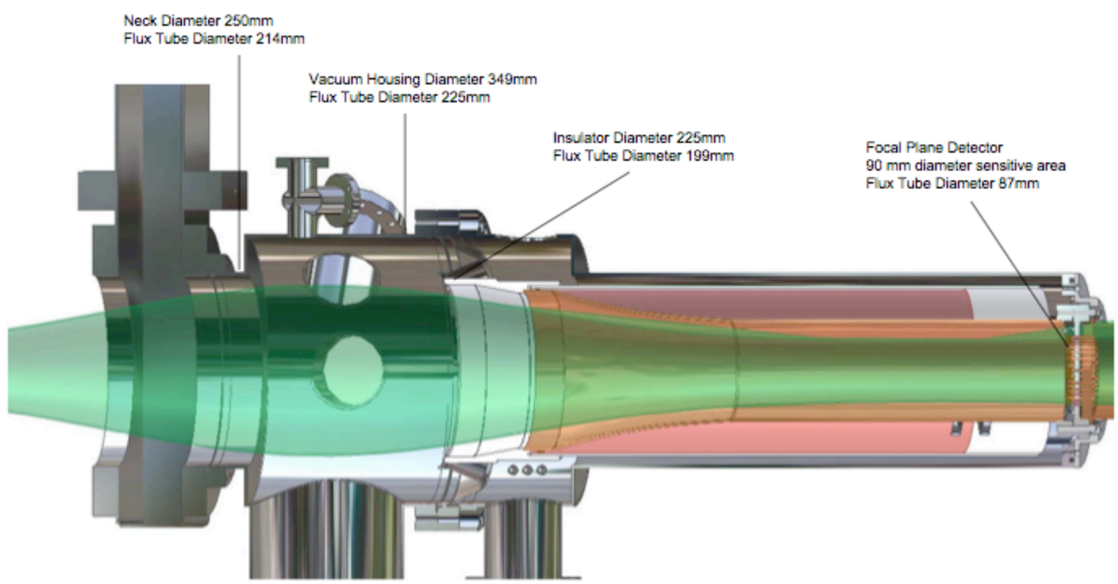

Figure 13 Clearances for the flux tube designated "18 April 2007". The field at the center of the detector solenoid is 3.6T.

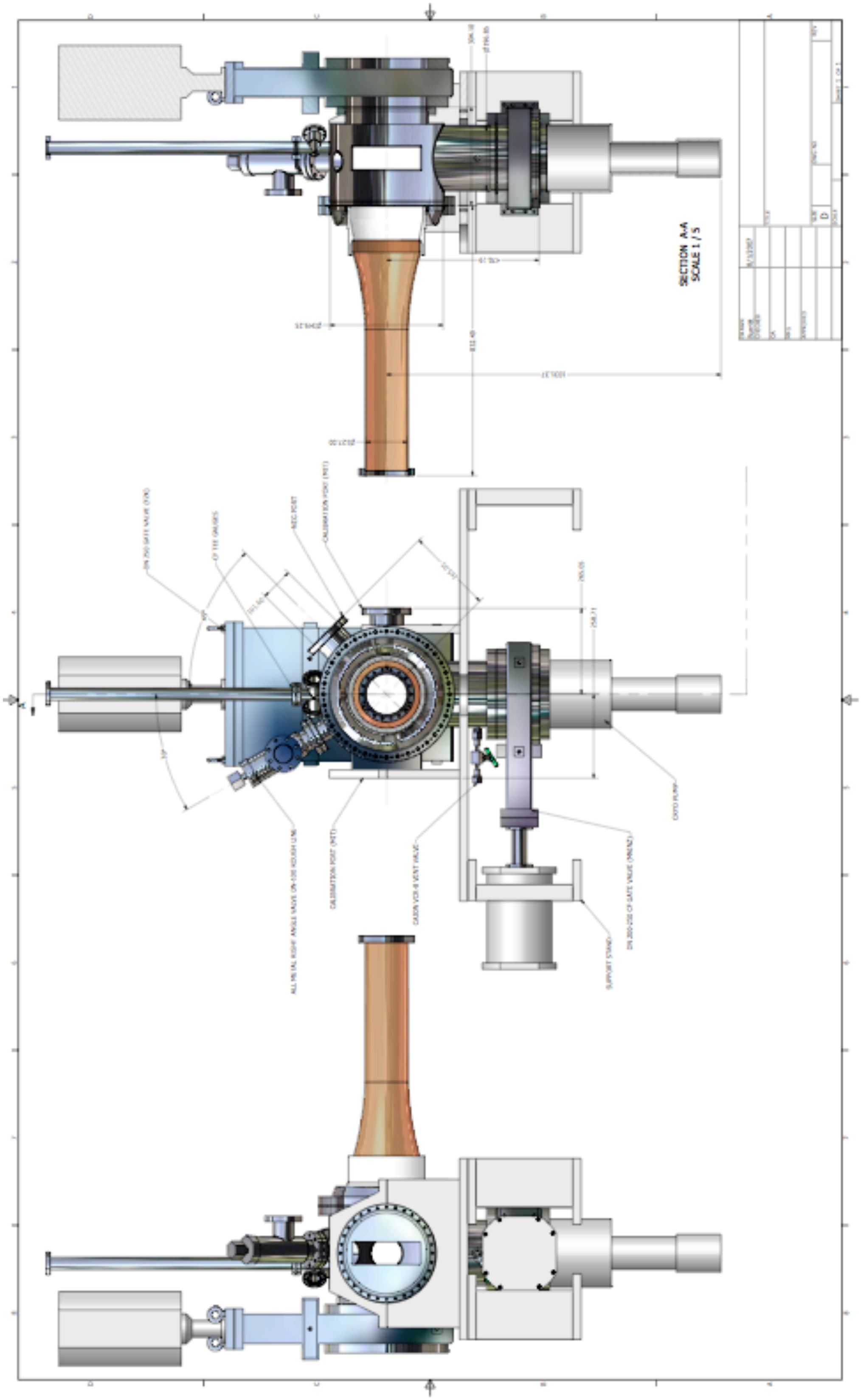

Figure 14 Principal dimensions of the XHV region

13) Quality Assurance and Quality Control

The vacuum housing will be fabricated to within the dimensional tolerance given in the fabrication drawings using the quality assurance programs in existence at the fabrication shops.
There are two requirements of the vacuum housing chamber that are not generally covered by the QA programs in fabrications shops. These requirements are radioactivity and XHV surface. They will require special QA plans which are outlined below.

Radioactivity: The natural radioactivity associated with hardware in the immediate region of the detector must contribute less that I mHz to the overall rate of the detector. To achieve this level of activity all materials and components used in the construction housing must be carefully screened for activity. Upper limits for the radioactivity of major components of the vacuum housing are given in the radioactivity design document[7].
Materials such as copper and stainless steel used in the construction of the vacuum housing will be radio assayed and only used if the activity is less that the upper limit given in reference 7.
All welding rods must be of the low activity, non-thoriated type, see reference 2 for further guidance.
The ingredients that are used in the manufacture of components that are provided by outside vendors (custom insulators, feedthroughs) must be radio assayed and only used if the activity is less that the upper limit given in reference 7.
Off-the-shelf components such as flanges and valves should be radio assayed to ensure that the activity of these components are within the acceptable limits of reference 7.

XHV surface finish: The surface finish and cleaning of all components used in the XHV section of the vacuum housing must be compatible with XHV practice. These are described in the QC chapter of reference 1, which also lists the QC procedures that will be employed in the construction, finishing and cleaning of the XHV hardware. All components supplied by outside vendors must be specified as compatible with the XHV environment as certified by the vendors own QC program.

14) List of outstanding vacuum chamber design issues:

- Selection of manufacturer for post acceleration electrode insulator.
- Quench forces on post acceleration electrode.
- qualification of insulator design + radioactivity
- Selection of low force pogo pins
- Selection of low radioactivity signal feedthroughs
- Selection of ExB insulator material

[1] KATRIN Detector – Final Vacuum Design Document, Keith Middleman.
[2] For more information concerning non-radioactive welding materials see: www.sylvania.com/BusinessProducts/MaterialsandComponents/ThermalSprayWelding/TungstenWeldingElectrodes/
[3] Marathon CP-8 cryopump, Sumitomo Heavy Industries. www.shicryogenics.com.
[4] Capacitorr B1300-2-MKS. www.saesgetters.com
[5] Cryomech PT90 pulse tube cooler. wwwcryomec.com
[6] Focal plane detector electronics, Sascha Wuestling.
[7] Radioactive backgrounds of the focal plane detector system, Michelle Leber.

Appendix 1

Calculation of thermal behavior – Hamish Robertson, October '06

K1	Thermal Cond. of Cu at 100K	4.5	W/cm K
K2	Thermal Cond. of Alumina at 100K	0.3	W/cm K
t	Wall thickness of Cu horn	3	mm
w	Length attached to Alumina ring	12	mm
Ri	Inner radius of Alumina ring	116.5	mm
Ro	Outer radius of Alumina ring	138.5	mm
r0	Cu tube radius at detector end	76	mm
Z	Total length of horn	560	mm
zt	Length of straight tube section	280	mm
T0	Temperature at cold end	100	K
QE	Electrical Heat load	10	W
Q1	Radiative Heat load to tube	29	W
Q2	Radiative Heat load to cone	34	W
QI	Radiative Heat load to interior	17	W
T1	Temp at inner surface of ring	106.87	K
T2	Temp at end of cone	120.45	K
T3	Temp at end of tube	124.80	K
Radiation Load:			
sigma	Stefan-Boltzmann constant	5.67×10^{-12}	$W/(cm^2 K^4)$
epsilon1	Emissivity to beam axis	1	
epsilon2	Emissivity to exterior	0.5	
TR	Room temp	293	K
	exterior radiative power to tube	30.67	W
	exterior radiative power to cone	34.35	W
	radiative power to interior	17.30	W
	Total radiative power	82.32	W