Cold UHV pipe for the GBAR antiproton trap

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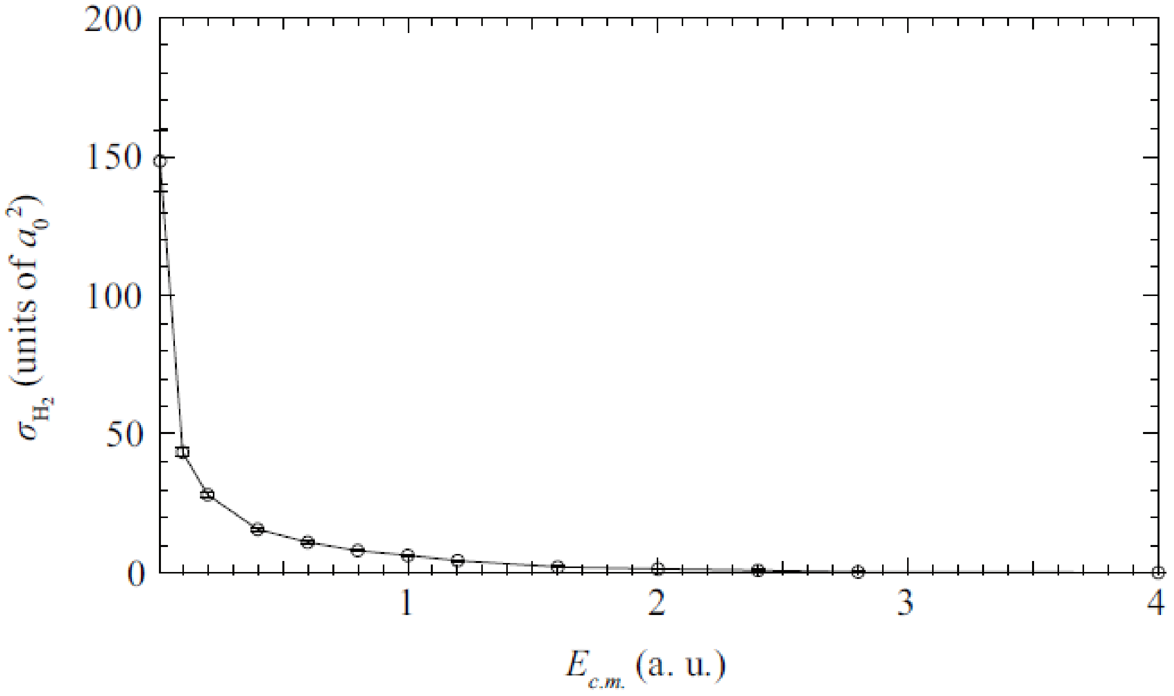
- Multi-Ring Electrodes(MRE)
- Cold UHV pipe for the GBAR antiproton trap drawing
- UHV pipe cooling system & Heat Loading
- Vacuum Test in room temperature
- Vacuum Control System

Why UHV is needed

Collision frequency : $\nu_{H_2} = \sigma_{H_2} v n (/\mathrm{s})$

Cross section of hydrogen molecule and antiproton :



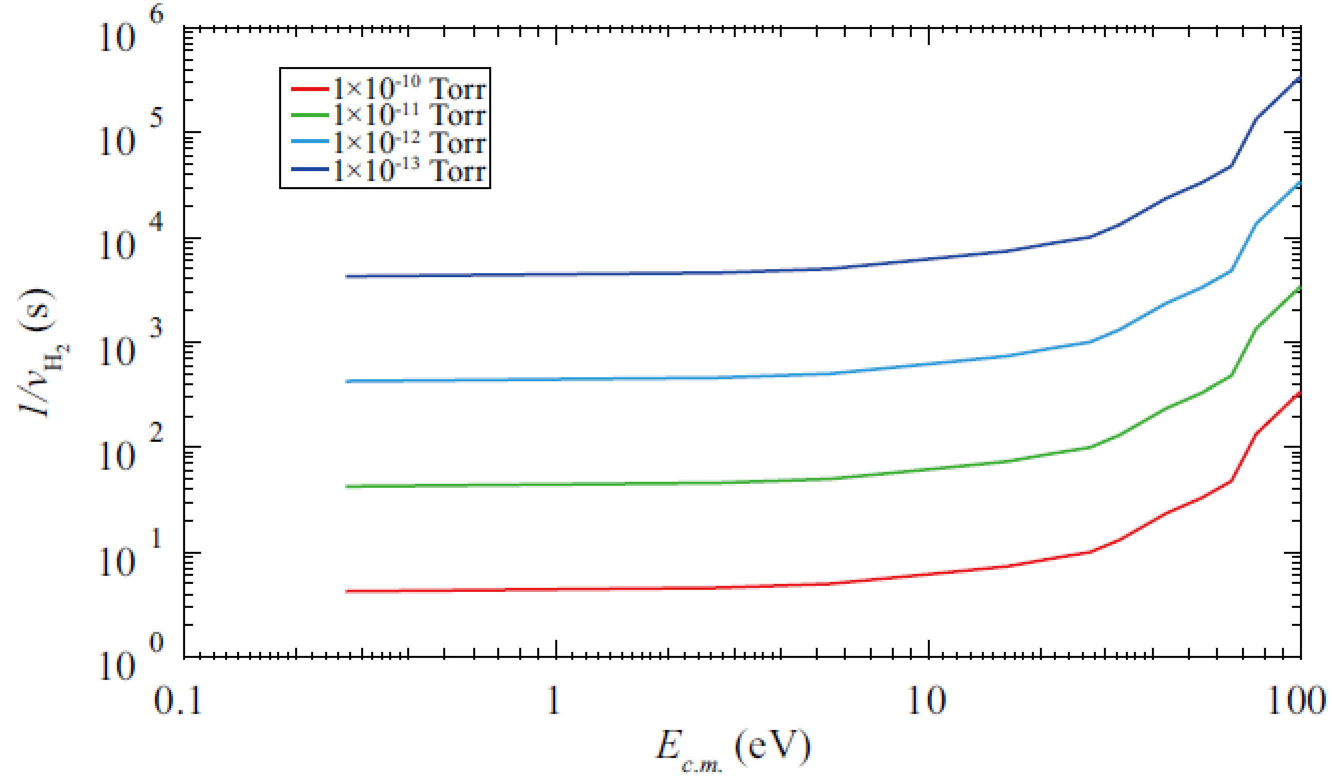
J.S. Cohen. Molecular effects on antiproton capture by H_2 and the states of $p\bar{p}$ formed. *Physical Review A*, 56(5):3583, 1997.

$a_0^2 = 2.5\text{x}10^{-21}\ (m^2)$

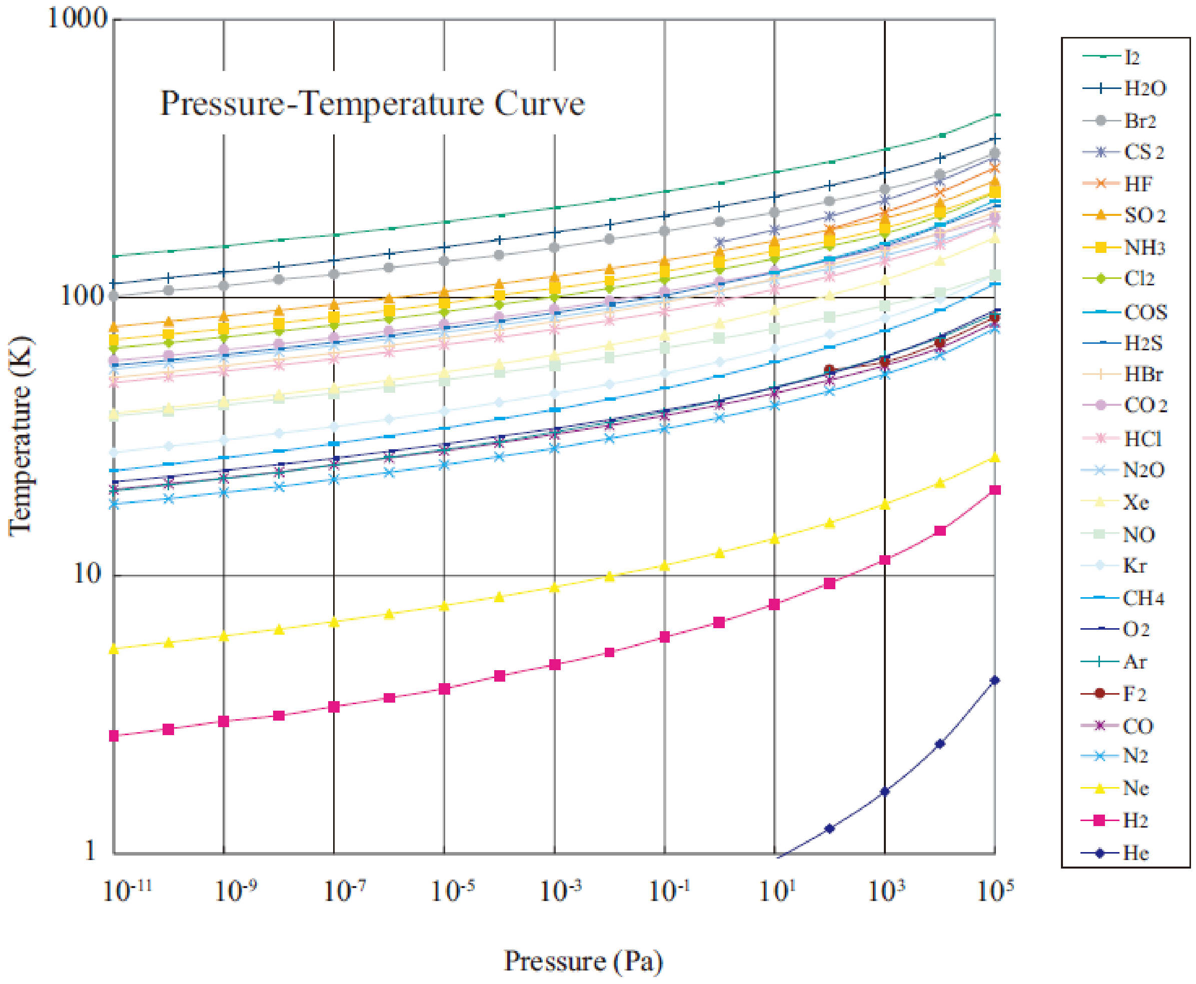
a. u. = 931.494 (MeV/c^2)

Number density of the hydrogen molecules : n = N/V = P/kT

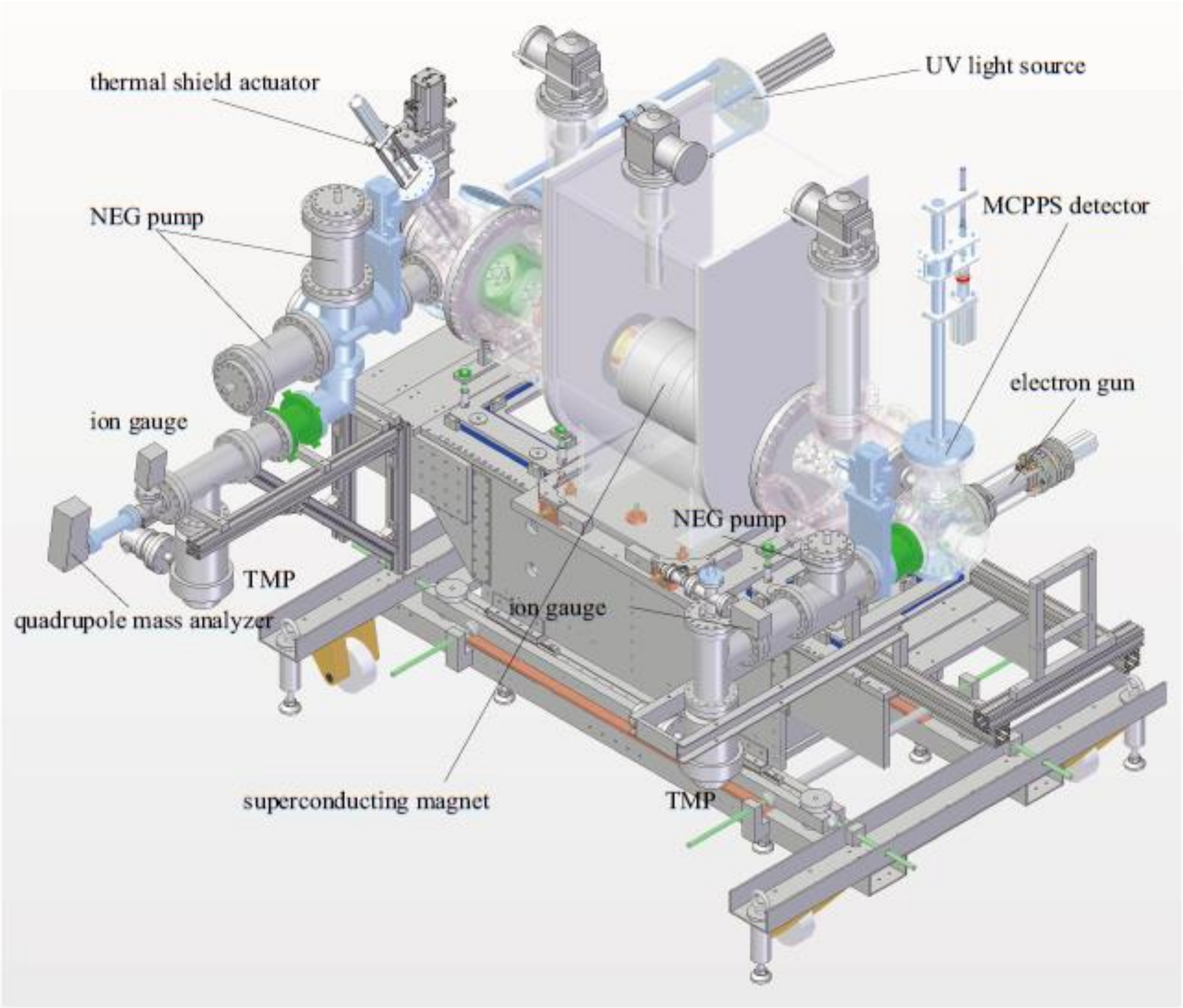
Mean free time($1/\nu_{H_2}$) of antiproton for several different hydrogen pressures



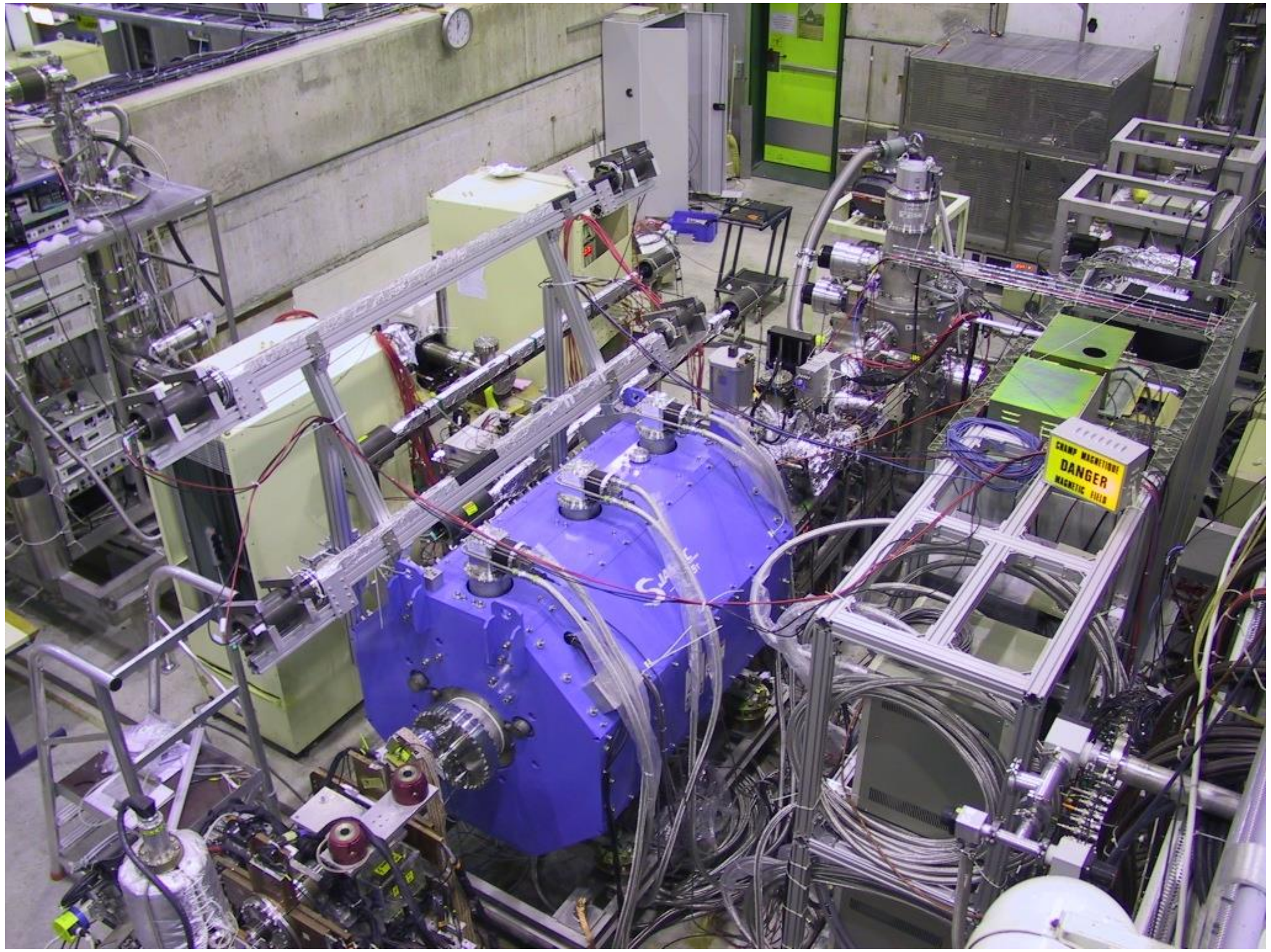
The vapor pressure of most of the gases can be reduced by cooling the apparatus down to about 10K



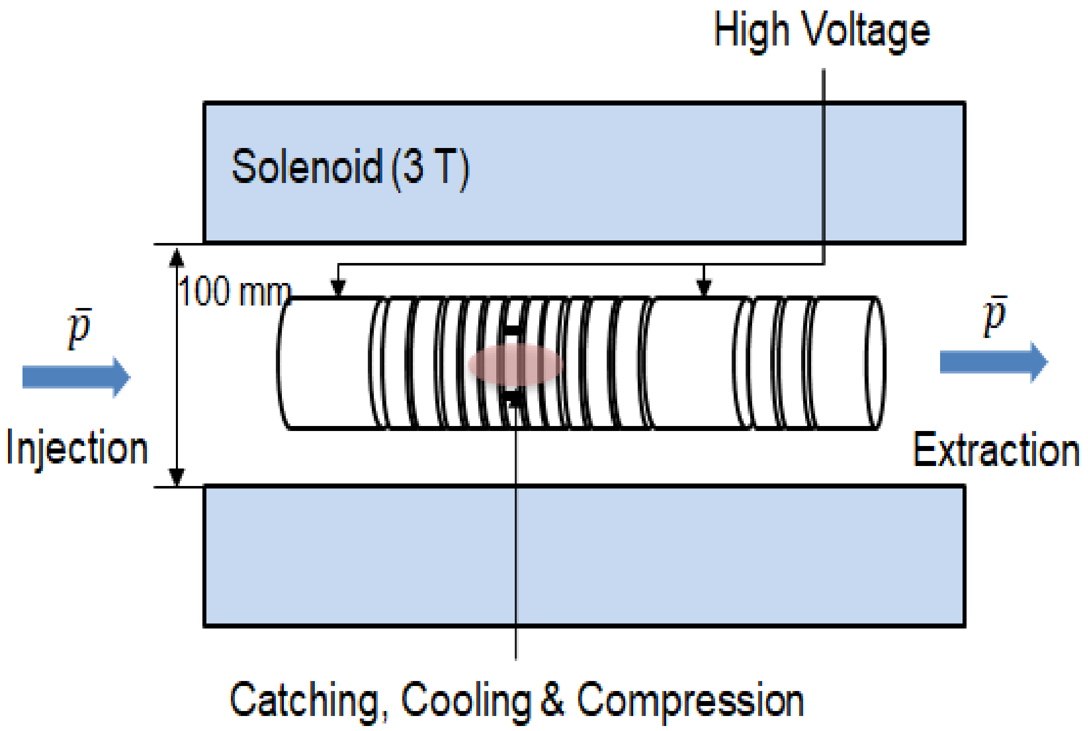
Reference Research 1 - Cusp Trap

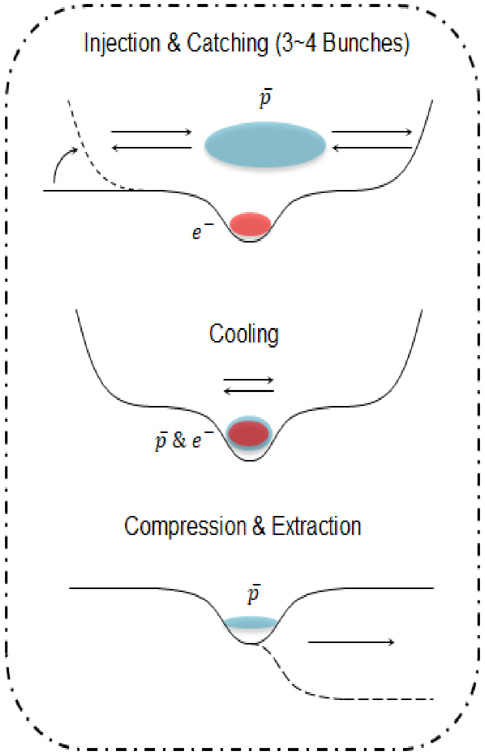


Reference Research 2 - Musashi Trap



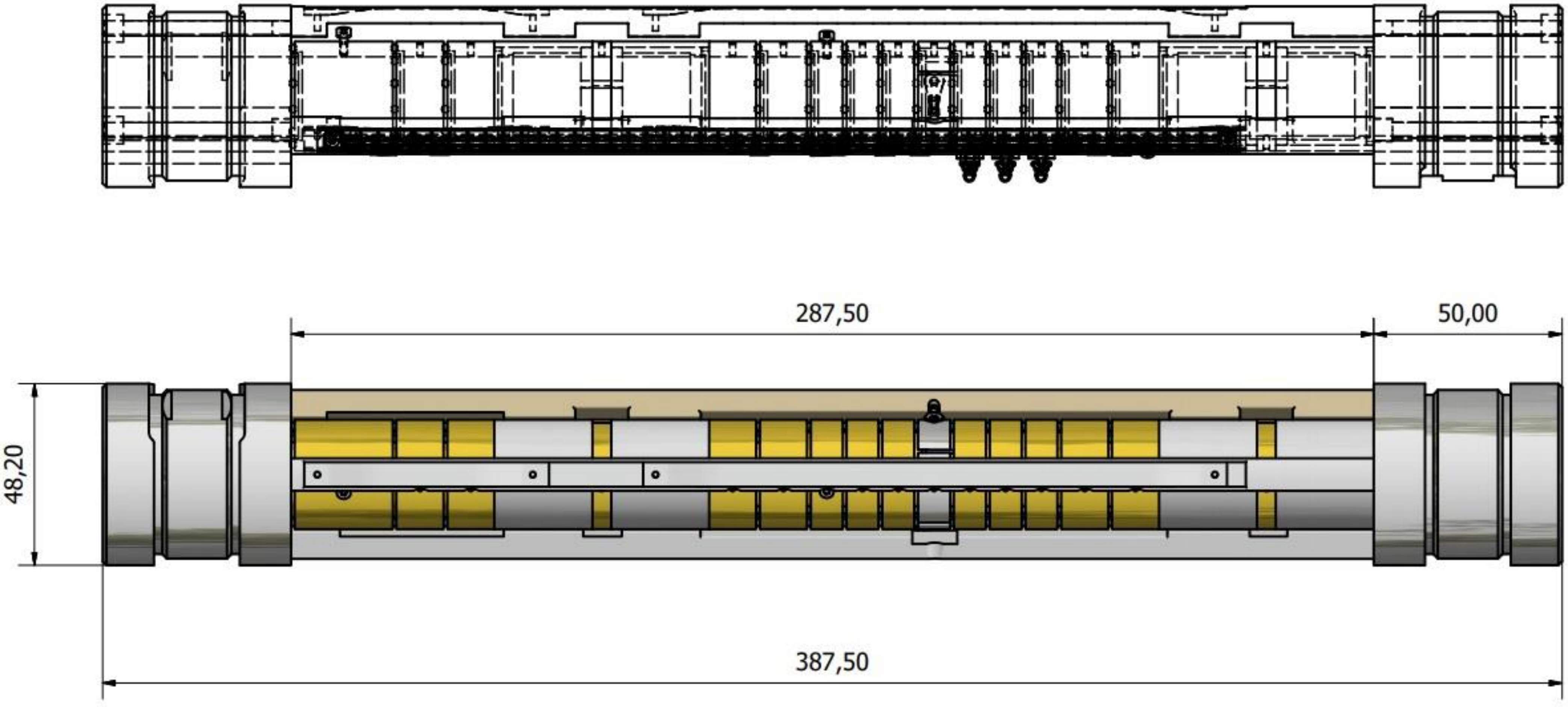
Multi-Ring Electrodes



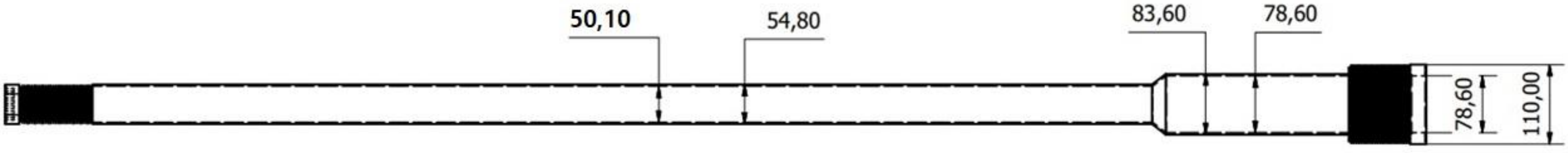


To make a large number of antihydrogen atom efficiently, trapping and cooling of antiproton beam before the reaction is important. A penning trap composed of high field superconducting solenoid and multi-ring electrodes(MRE) to form a harmonic electric potential is designed.

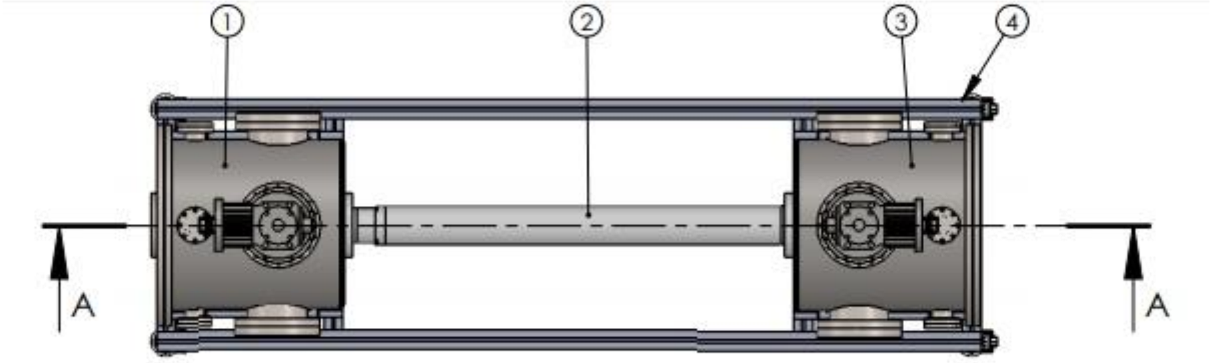
Multi-Ring Electrodes

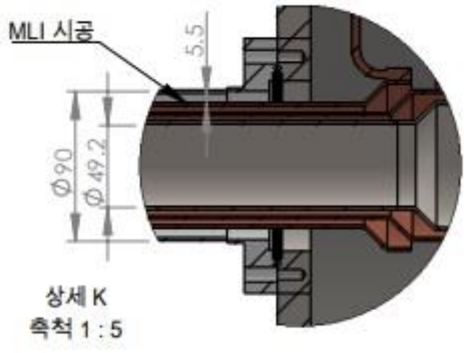


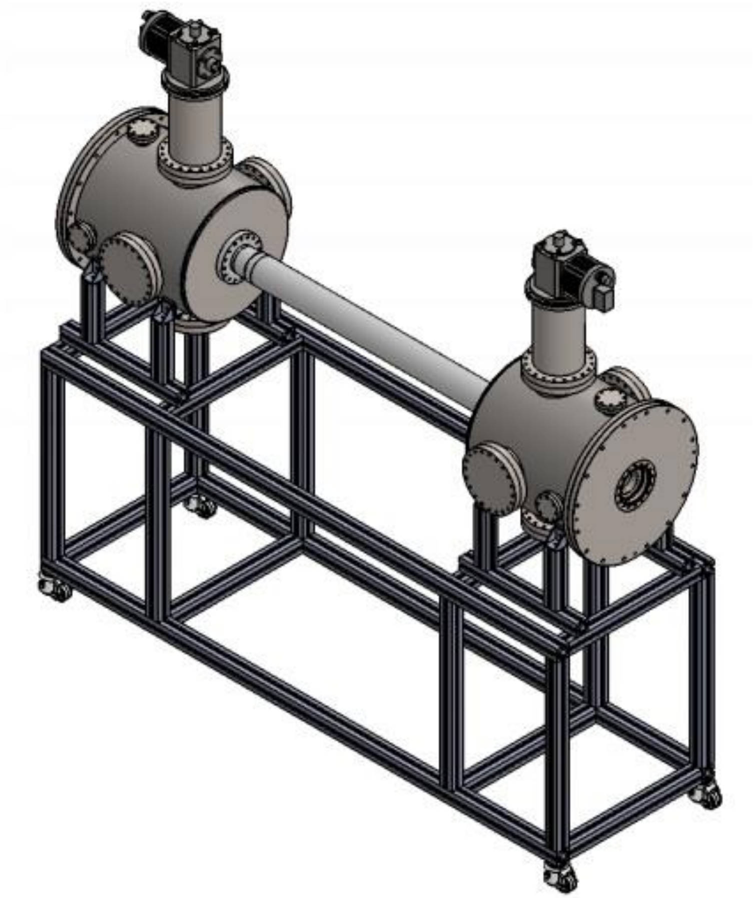
Cold UHV pipe for the GBAR antiproton trap drawing



Cold UHV pipe for the GBAR antiproton trap drawing



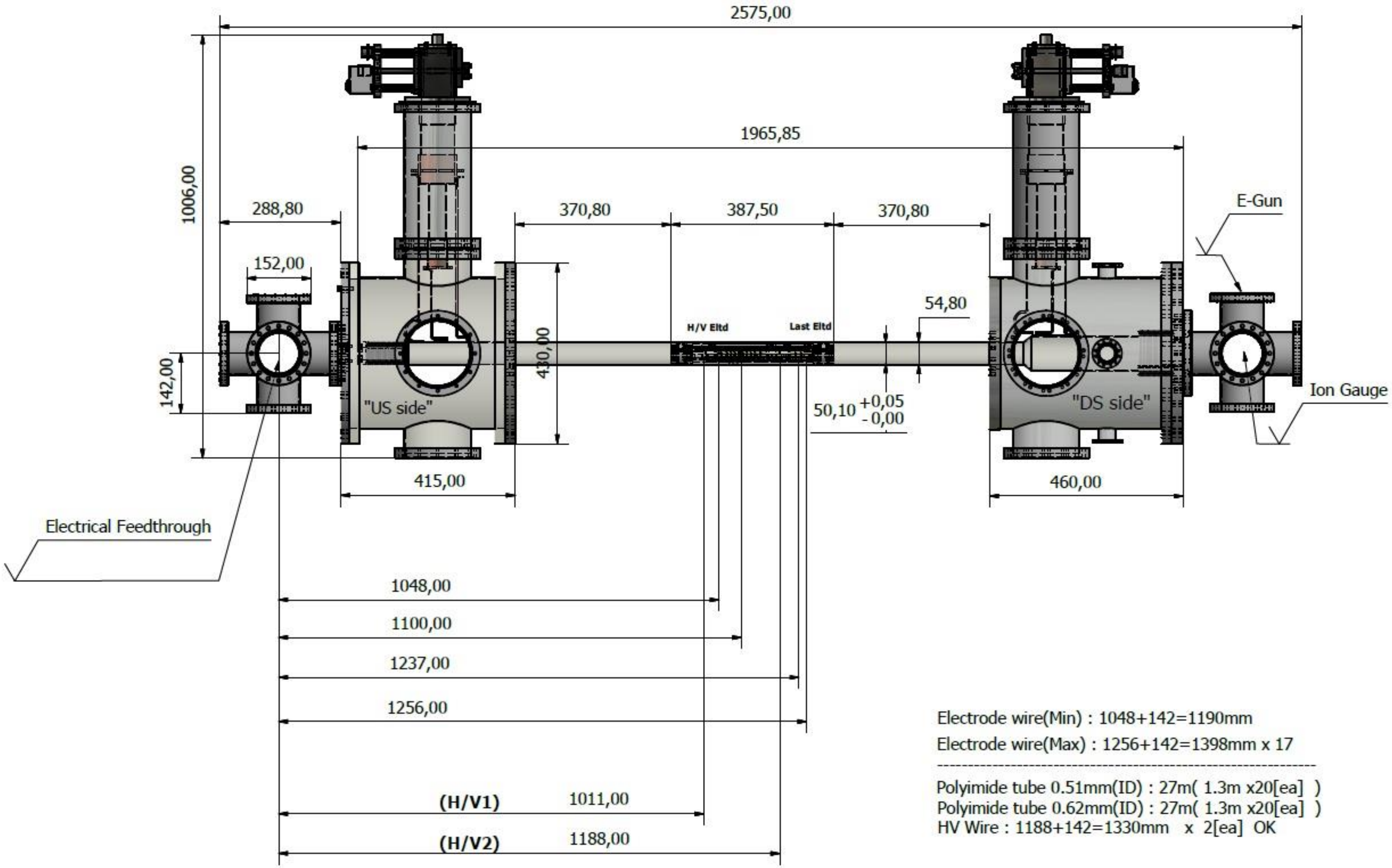




In order to cool down antiproton beam, and make ultra-high vacuum lower than 10^-12 Torr, temperature under 10K is needed. So, Cold UHV chamber at 4.2K temperature is designed.

MRE is in the UHV bore tube, whose length is 1944mm. Cryocooler is installed both side of UHV bore tube, and OVC(outer vacuum chamber) is outside of the bore tube and cryocooler.

Cold UHV pipe for the GBAR antiproton trap drawing



Electrode wire(Min) : 1048+142=1190mm

Electrode wire(Max) : 1256+142=1398mm x 17

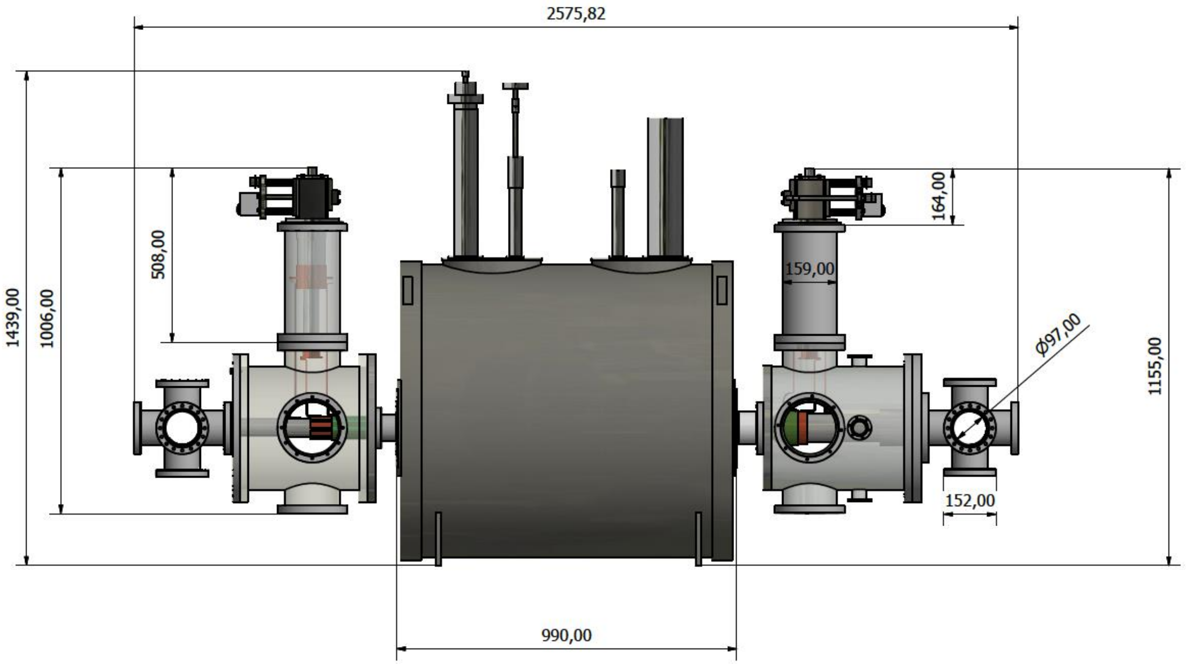
Polyimide tube 0.51mm(ID) : 27m(1.3m x20[ea])

Polyimide tube 0.62mm(ID) : 27m(1.3m x20[ea])

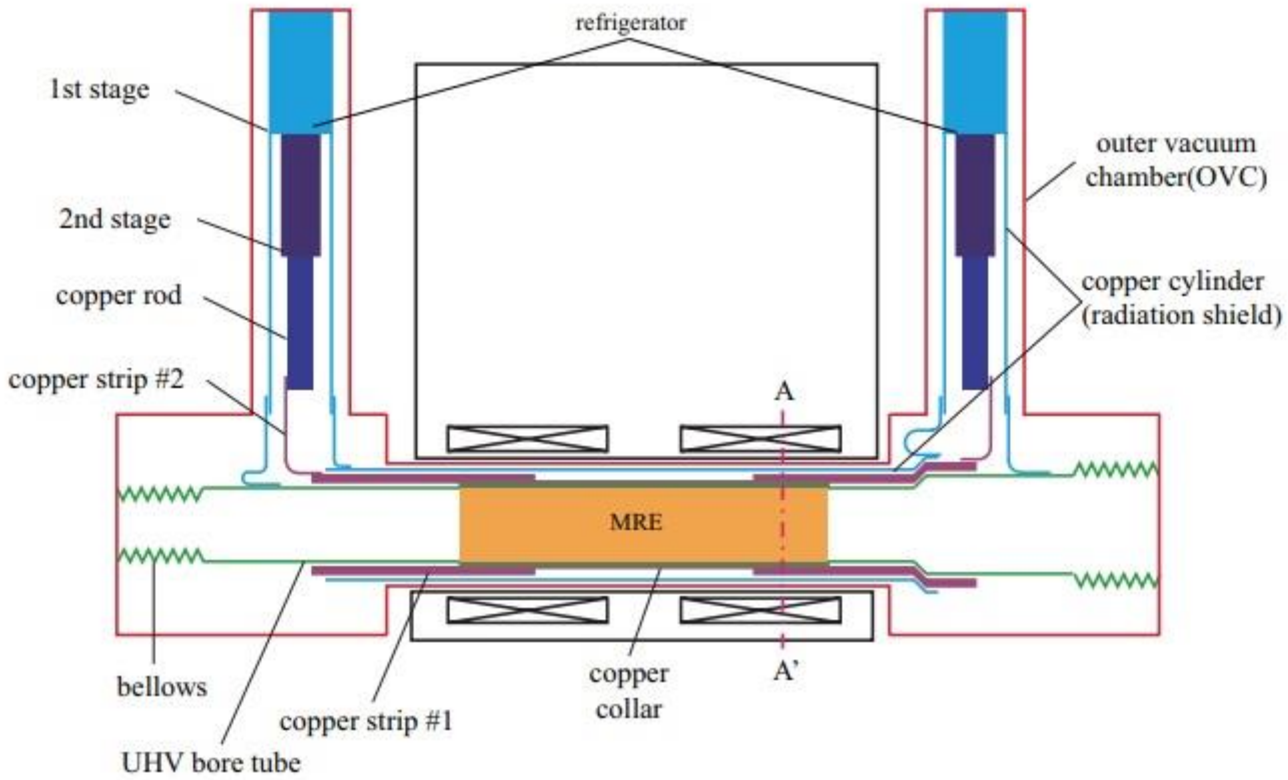
HV Wire : 1188+142=1330mm x 2[ea] OK

A Trap view

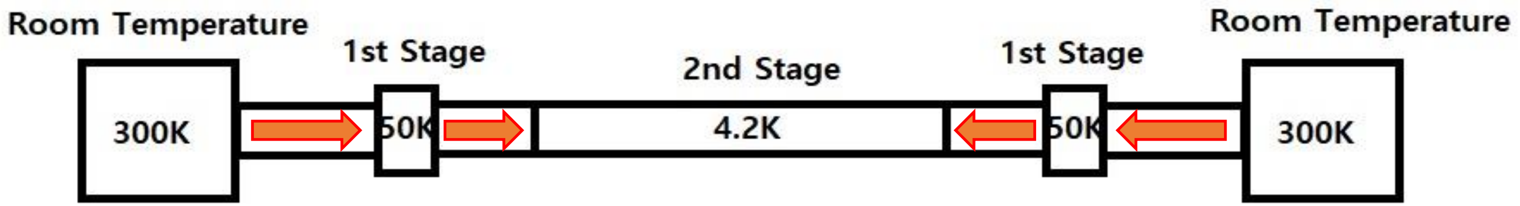
Cold UHV pipe for the GBAR antiproton trap drawing

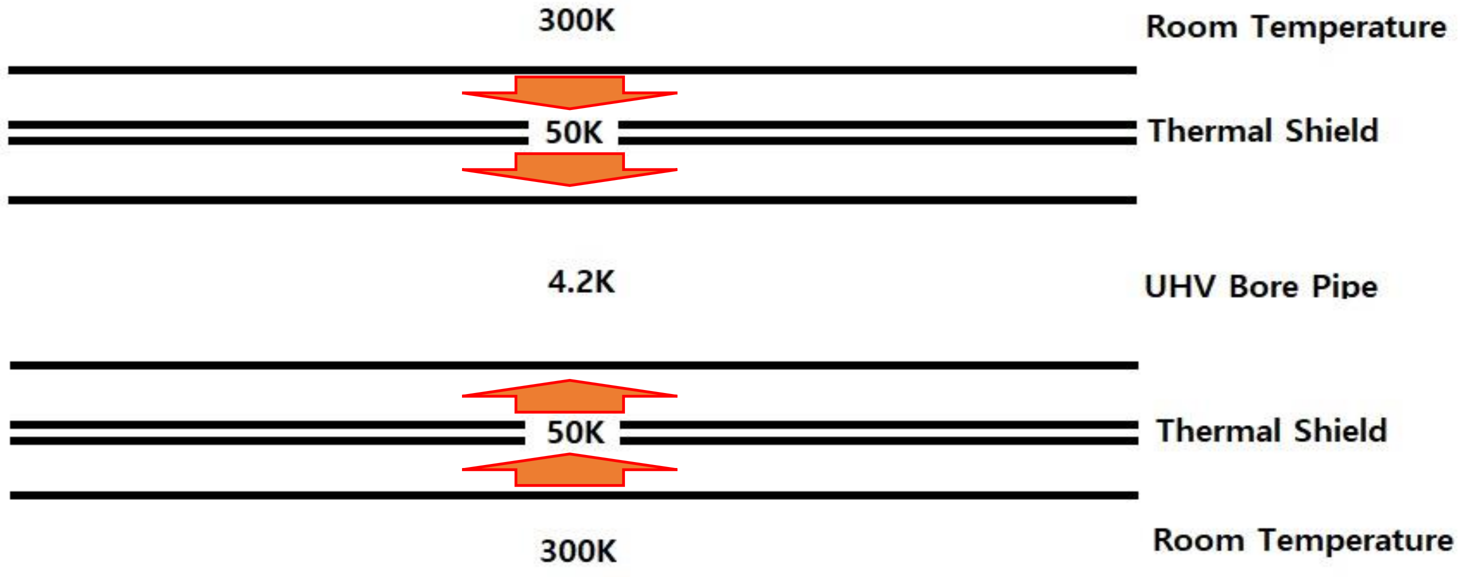


Schematic Drawing of the UHV pipe cooling system



Heat Loading and Radiation





$$Q_{Heat\ Load} = \frac{kA(T_H - T_C)}{L_t}$$

$$Q_{H\_300K\_50K} = 0.894$$

$$Q_{H\_50K\_4.2K} = 0.817$$

$$Q_{Radiation} = \sigma * A * E * (T_H^4 - T_C^4)$$

$$E_{300K\_50K} = \frac{1}{\frac{1}{\varepsilon_2}+\frac{A_2}{A_1}\left(\frac{1}{\varepsilon_1}-1\right)} = 0.109$$

$$Q_{R\_300K\_50K} =$$

$$(5.67\times 10^{-8}) * (0.31) * (0.109) * (300^4 - 50^4)$$

$$= 15.514$$

$$E_{50K\_4.2K} = \frac{1}{\frac{1}{\varepsilon_2}+\frac{A_2}{A_1}\left(\frac{1}{\varepsilon_1}-1\right)} = 0.1884$$

$$Q_{50K} =$$

$$(5.67\times 10^{-8}) * (0.26) * (0.1884) * (50^4 - 4.2^4)$$

$$= 0.017$$

Radiation

Shield 복사열침입량 계산

Q=σ*A*E*(Th4-Tc4)

온도조건	구분	수치
50K shield Vessel	Outer Dismeter	78 mm
	Inner Diameter	74 mm
	Length	1230 mm
	Temperature (Tc)	50 K
	material	Cu
	emissivity (εc)	0.3
Vacuum Vessel	Outer Dismeter	93 mm
	Inner Diameter	89 mm
	Length	1230 mm
	Temperature (Th)	300 K
	material	SUS316L
	emissivity (εh)	0.13
원주율	π	3.1416
스테판-볼쯔만 상수	σ	5.67E-08 W/m^2*K^4
Shield Vessel 표면적	옆	0.30 m2
	상하	0.01 m2
	전체 (A)	0.31 m2
Vacuum Vessel 표면적	옆	0.34 m2
	상하	0.01 m2
	전체	0.36 m2
실효방사율	E	1.09E-01
단열재 효과		0.2
복사열전달량	Q옆 (εh로 계산)	17.981 W
	Q상하 (εh로 계산)	0.570 W
	Q전체 (εh로 계산)	18.552 W
	Q옆 (E로 계산)	15.037 W
	Q상하 (E로 계산)	0.477 W
	Q전체 (E로 계산)	15.514 W
복사열전달량 단열재효과 반영	Q옆 (εh로 계산)	3.596 W
	Q상하 (εh로 계산)	0.114 W
	Q전체 (εh로 계산)	3.710 W
	Q옆 (E로 계산)	3.007 W
	Q상하 (E로 계산)	0.095 W
	Q전체 (E로 계산)	3.103 W

Radiation

헬륨조 복사열침입량 계산

$Q=\sigma*A*E*(Th4-Tc4)$

온도조건	구분	수치
Bore Pipe	Outer Dismeter	66 mm
	Inner Diameter	62 mm
	Length	1230 mm
	Temperature (Tc)	4.2 K
	material	Cu
	emissivity (εc)	0.3
50K Shield	Outer Dismeter	78 mm
	Inner Diameter	74 mm
	Length	1230 mm
	Temperature (Th)	50 K
	material	Cu
	emissivity (εh)	0.3
원주율	π	3.1416
스테판-볼쯔만 상수	σ	5.67E-08 W/m^2*K^4
Lhe Vessel 표면적	옆	0.26 m2
	상하	0.01 m2
	전체 (A)	0.26 m2
Shield Vessel 표면적	옆	0.30 m2
	상하	0.01 m2
	전체	0.31 m2
실효방사율	E	1.884E-01
단열재 효과		0.2
복사열전달량	Q옆 (εh로 계산)	0.027 W
	Q상하 (εh로 계산)	0.001 W
	Q전체 (εh로 계산)	0.028 W
	Q옆 (E로 계산)	0.017 W
	Q상하 (E로 계산)	0.000 W
	Q전체 (E로 계산)	0.017 W
복사열전달량 단열재효과 반영	Q옆 (εh로 계산)	0.005 W
	Q상하 (εh로 계산)	0.000 W
	Q전체 (εh로 계산)	0.006 W
	Q옆 (E로 계산)	0.003 W
	Q상하 (E로 계산)	0.000 W
	Q전체 (E로 계산)	0.003 W

Heat Loading

구분			온도(K)			열전도율(W/m.K)	Pipe 외경(m)	두께(m)	면적(m2)	전체길이(m)	열부하(W)	수량	총 열부하(W)	비고
						k	OD	t	A	Lt	Q		Qt	
50K Thermal shield	전도	Left 측	300	-	50	9.76	0.0532	0.00015	2.49992E-05	0.2	0.304991	1	0.305	
		Right 측	300	-	50	9.76	0.077	0.0002	4.82549E-05	0.2	0.588709	1	0.589	
												합계(전도)	**0.894**	
	복사	표면적	300	-	50								15.514	단열재 효과 무시
												합계(복사)	**15.514**	
												합계(Total)	16.408	

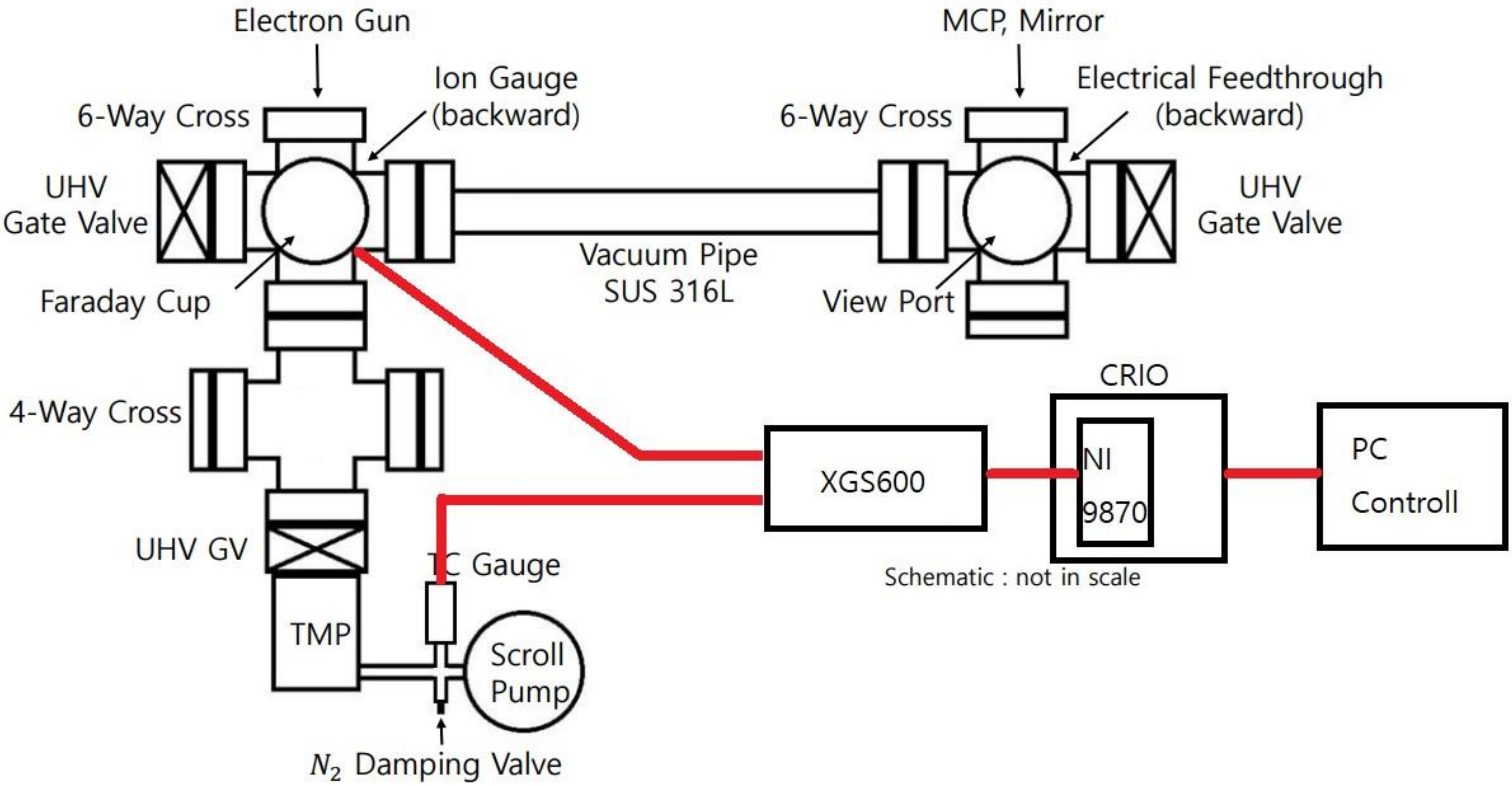
구분			온도(K)			열전도율(W/m.K)	Pipe 외경(m)	두께(m)	면적(m2)	전체길이(m)	열부하(W)	수량	총 열부하(W)	비고
						k	OD	t	A	Lt	Q		Qt	
4.2K	전도	Left 측	50	-	4.2	3.24	0.0532	0.002	0.000321699	0.144	0.331511	1	0.332	
		Right 측	50	-	4.2	3.24	0.077	0.002	0.000471239	0.144	0.485612	1	0.486	
												합계(전도)	**0.817**	
	복사	표면적	50	-	4.2								0.017	단열재 효과 무시
												합계(복사)	**0.017**	
												합계(Total)	0.835	

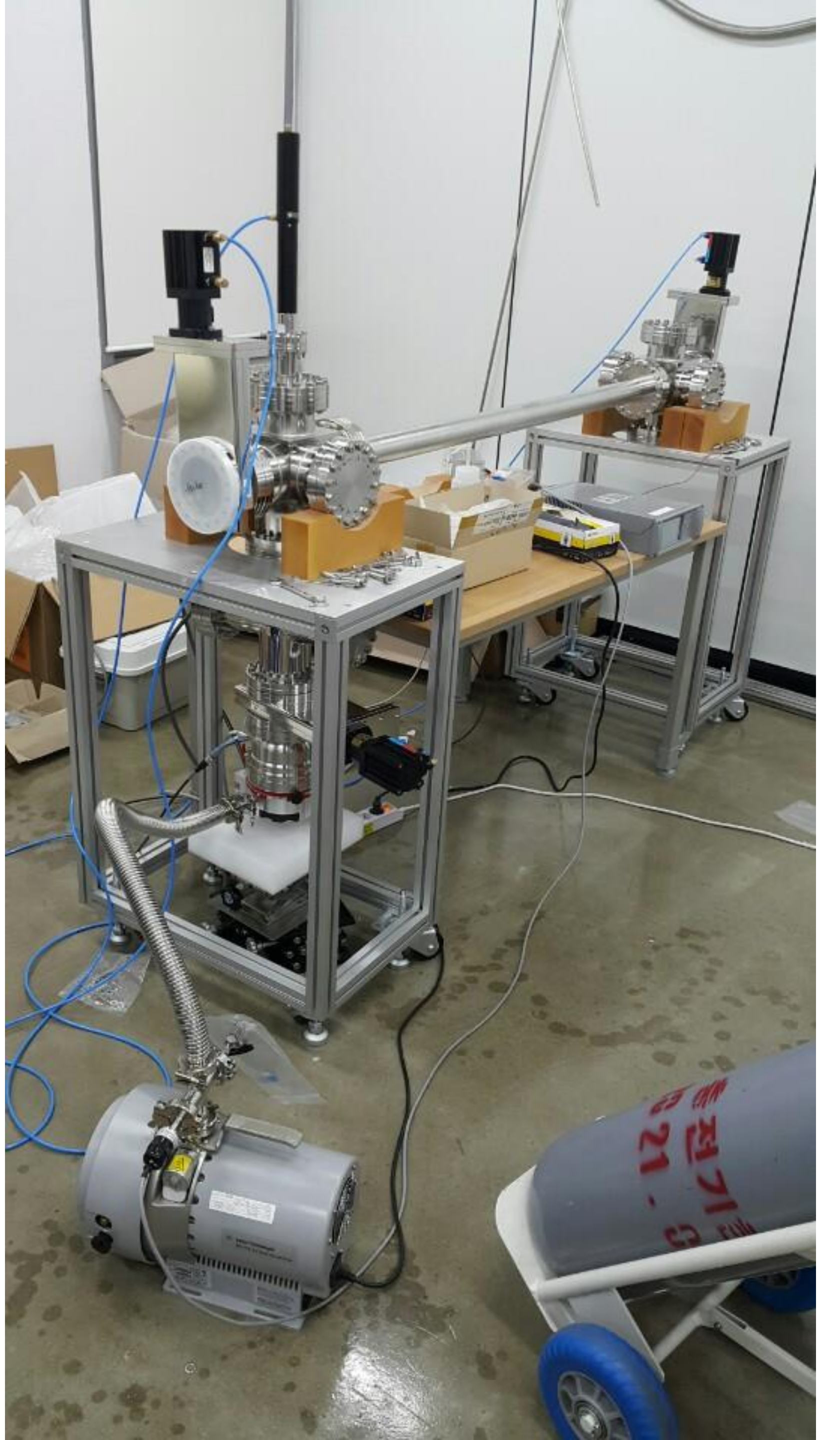
Sumitomo Cryocooler : RDK-415D		2대 적용
Cooling power@4.2K	1.5W	3 W
Cooling power@30K	15W	30 W

Cooling Power @ 4.2K 0.835W < 3W : Enough

Cooling Power @ 30K 16.408W < 30W : Enough

Vacuum Test in Room Temperature

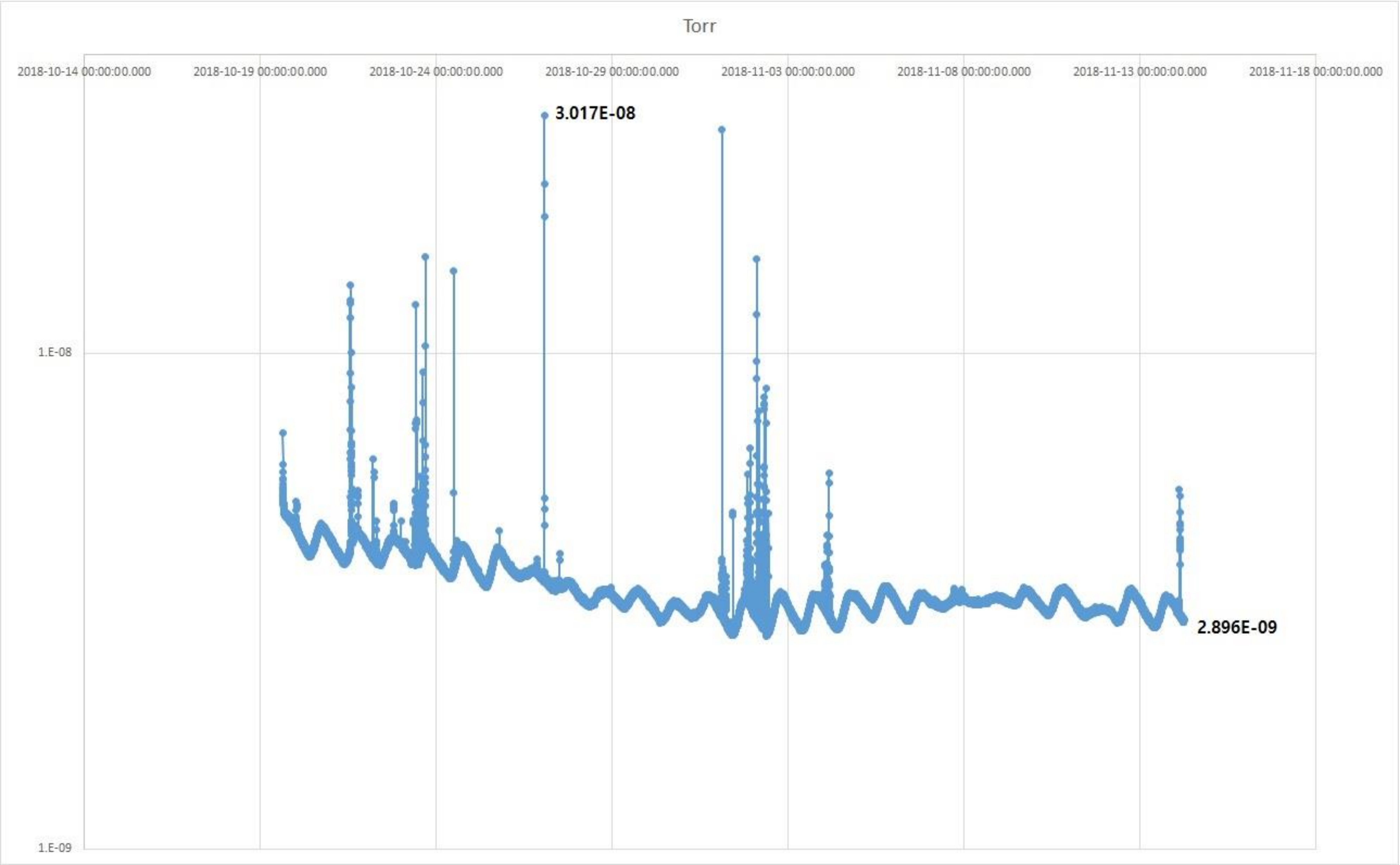




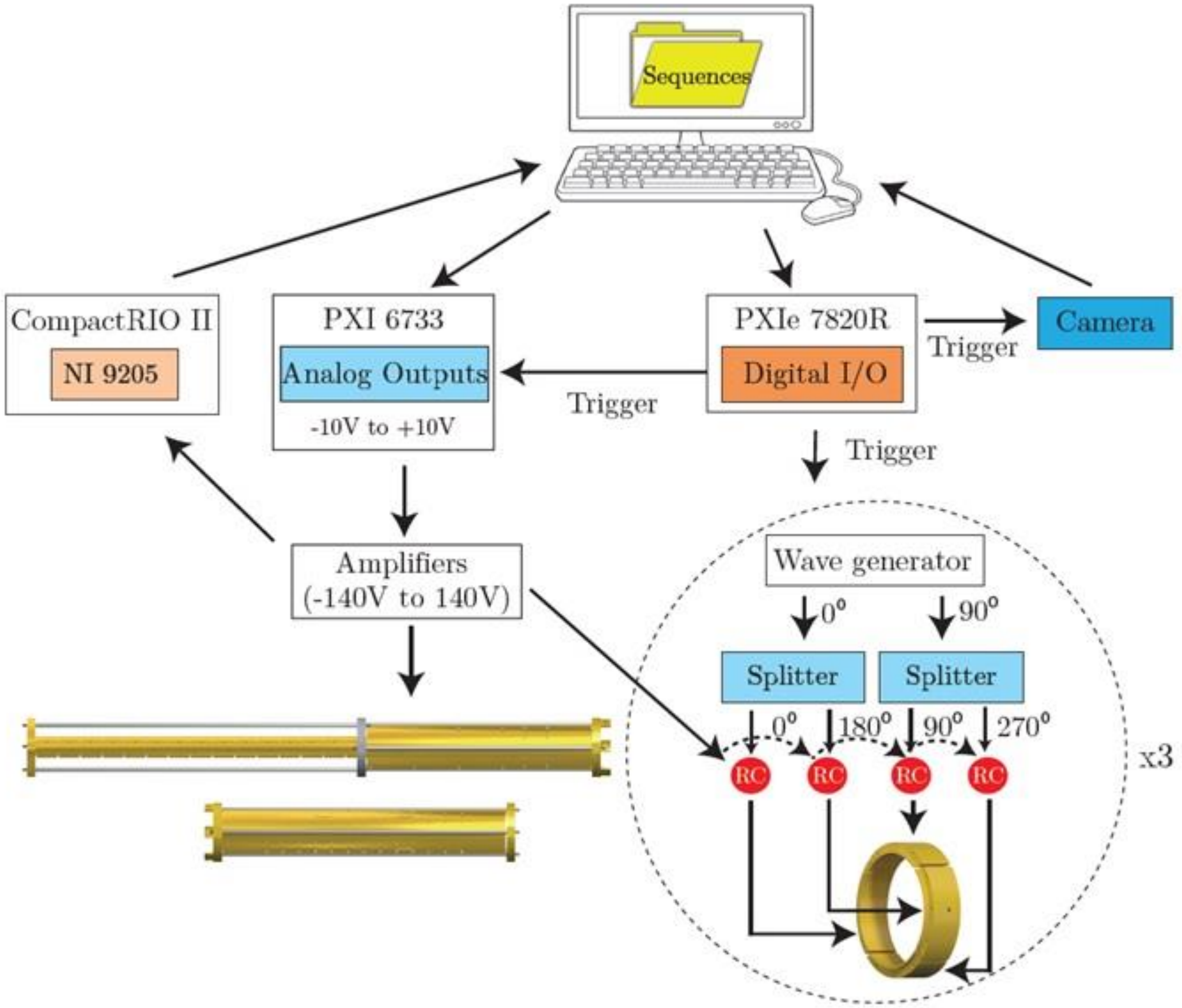
This is the photo of room temperature vacuum test. The conductance and volume of this vacuum system is close to the GBAR cold UHV vacuum pipe.

This chamber is not only for vacuum test, but also for electron test in room temperature. Trapping electron in MRE and observing by MCP is possible under 1x10^-7Torr in room temperature. For the electron test, we are preparing Electron Gun, Faraday Cup, MCP/PS.

Vacuum Test in Room Temperature



Vacuum Control System

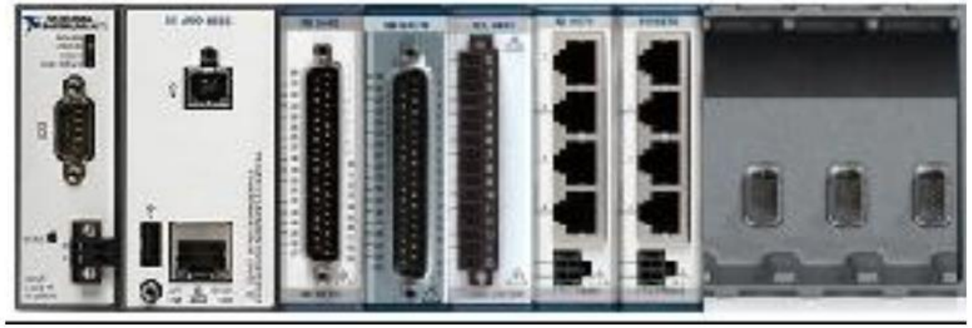


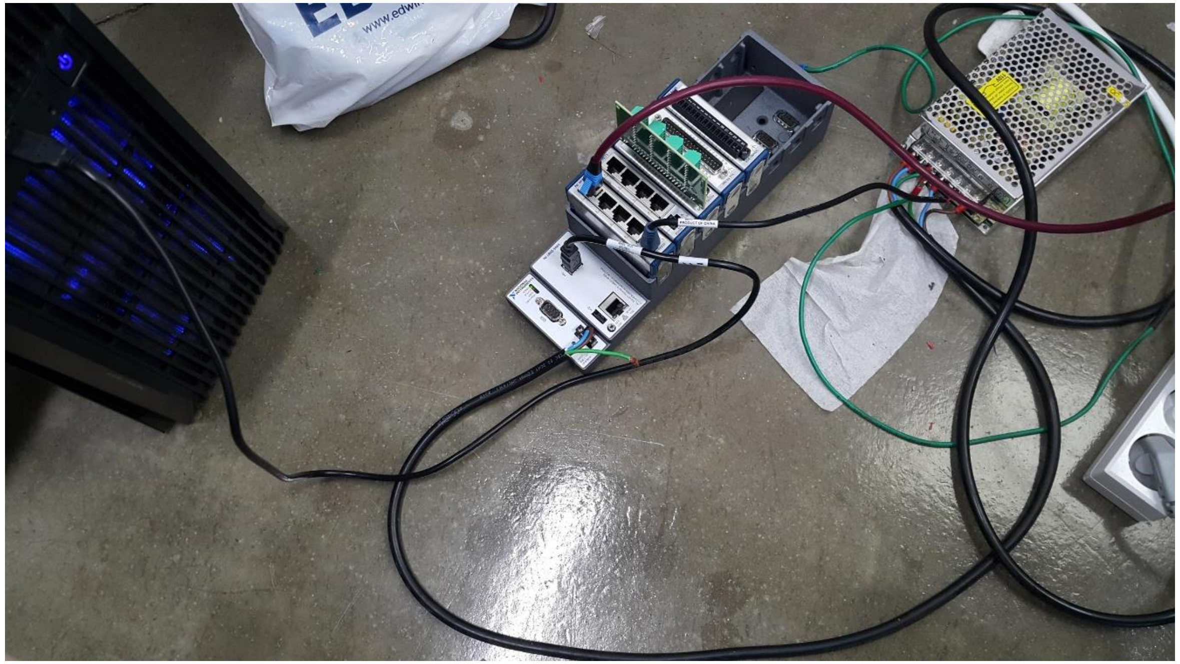
National Instrument's 'Compact RIO' system is used for control of vacuum system. Overall control system using 'PXIe' system is designed like this.

Vacuum Control System

NI CRIO

Configuration ID: CR5457792





MRE Control System

NI PXI System

Configuration ID: PX5457782

Thank You!