Justification of RHIC EBIS vacuum system.

A. Pikin

1. Requirements to the pressure of residual gas inside the ionization region.

To generate highly charged ions (like Au^{32+}) in EBIS the initially injected ions of working element has to spend certain time in a potential ion trap within the electron beam. This time is determined by the current density of the electron beam and the required final charge state of these ions. To generate ions Au^{32+} in EBIS with electron current I_{el}= 10 A (current density j_{el}= 500 A/cm^2) the required time is approximately 40 ms. During this confinement time the atoms of residual gas can be ionized, the ions will be trapped and accumulated in the same volume of the ion trap together with working ions. Since the capacity of the ion trap is limited to the space charge of electrons within the ion trap volume, the influx and accumulation of residual gas ions reduces the number of working ions in a trap and therefore effectively reduces the intensity of EBIS. One way of preserving the EBIS intensity is reducing the pressure of residual gas in a region of ion trap.

Assume we can tolerate a space charge share of residual gas ions in the total extracted ion charge in the amount of 10% and the energy of electron beam is E_{el}= 20.0 keV. If the content of residual gas is 70% of H_2 (Hydrogen) and 30% of CO (carbon monoxide) the pressure of this gas according to our calculations should be not higher than $P=1.2x10^{-9}$ Torr. If the residual gas consists only of CO or N_2 the required pressure for the same neutralization is $P=4.2x10^{-10}$ Tor. For lower tolerable contamination the required vacuum is even higher.

2. Vacuum solutions.

As one can see the requirements to the vacuum level are high and therefore the design of vacuum structure, materials used for internal elements, technology of processing and equipment should be adequate.

The components of the gas load in the central vacuum chamber (CVC) are:

1. Gas generated inside CVC itself
2. Gas flow from the electron gun region
3. Gas flow from the electron collector region

The goal of EBIS vacuum system design is to provide conditions for achieving pressure in the central vacuum chamber in the range of low 10^{-10} Torr and for this reason the tolerable contribution to this pressure of gas flow from sides of the central vacuum chamber (from the gun and EC volumes) should be in a range 1-2x10^{-10} Torr.

2.1. Central vacuum chamber

The main pumping of CVC is with vacuum pumps located on the both sides of this chamber: on gun-transition chamber (GTC) and electron collector-transition chamber (ECTC). These pumps provide preliminary evacuation (turbopump), pumping during bakeout (turbopump) and pumping during EBIS operation in a high-vacuum range (cryopumps).

The schematic of the cross-section of the CVC is presented on Fig. 1.

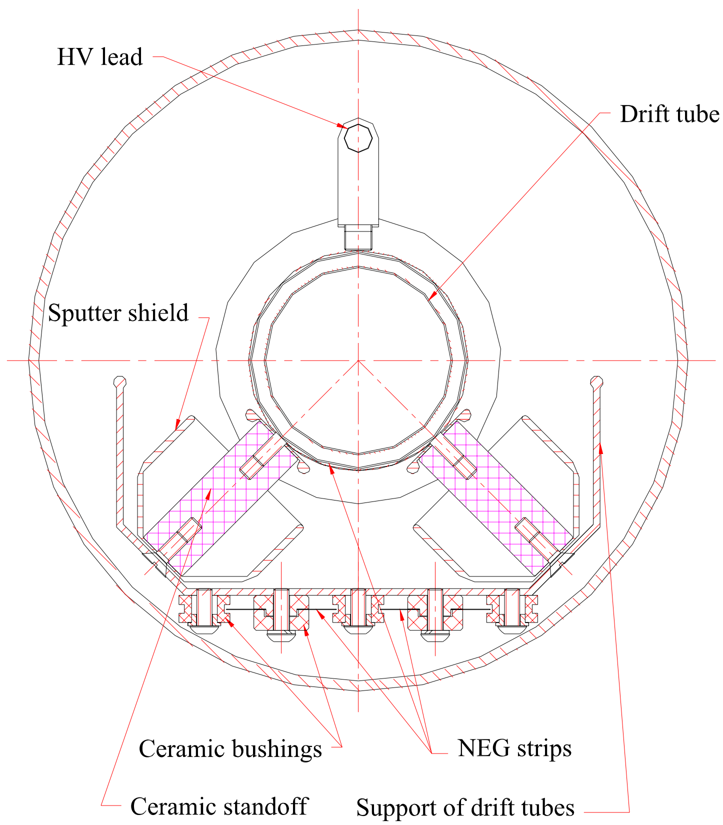

Fig.1. Cross-sectional view of the central vacuum chamber.

An annular gap between drift tubes and inner wall of CVC contains a support of the drift tube structure, high voltage leads, insulators with sputter shields etc. with total outgassing area of S_{outgas} =3.8 m^2. Using [1] the vacuum conductance of this chamber from center to outside chambers was calculated to be F=250 l/s (N_2, 300^0C). This means to provide pressure of residual gas in the central region P=4.0x10^{-10} the average outgassing rate of all materials in the central vacuum chamber should be q = 5.5x10^{-12} Tor·l/s·cm^2.

Since the drift tubes and their potential leads are held at high voltage during the ionization process (~20 kV) and the trap is located in an axial magnetic field B=6.0 T of the superconducting solenoid, an additional outgassing is possible as a result of a Penning and ExB discharges. This additional outgassing can result in increased pressure inside the central chamber compare with calculations based on just thermal outgassing. To reduce this component of outgassing EBIS operates in pulsed mode with high voltage on drift tubes and electron beam running only during the required confinement time and are off between pulses.

To suppress the discharge and to reduce pressure of the residual gas the requirements to the outgassing rate of the materials of the CVC should be even stricter. This means attaining outgassing rates in the range of $q \approx 5x10^{-13}$ Tor·l/s·cm^2 and low values of electron– and ion-induced desorption yields (molecules/electron and molecules/ion).

Methods to achieve low outgassing rate and low coefficient of electron– and ion-induced desorption are known:

- Vacuum firing of stainless steel parts (requires use of steel SS 316LN for ConFlat flanges)
- Cleaning all parts before installation
- Bakeout at T=400^{0}C for at least 24 hours after exposure the vacuum chamber to atmosphere
- Coating the internal surfaces of the central vacuum chamber with NEG material.

A complimentary approach to reducing the residual gas pressure is to introduce a distributed pumping inside the central vacuum chamber with NEG strips in field-free areas of the CVC (electron current- heated NEG strips between drift tube support and vacuum wall and also passively heated NEG strips inside the drift tubes themselves, where NEG material will be exposed to the ionization volume directly). The NEG strip has width of active material 2.7 cm on each side and at room temperature has initial specific pumping speed for CO s_{CO}=0.25 l/(s·cm^2) and for Hydrogen s_H=0.6 l/(s·cm^2). With length of the NEG strip 2.4 m and total active area 724 cm^2 its initial equivalent pumping speed for CO is approximately 356 l/s (CO). This will be a substantial increase in pumping speed in an area of ionization volume. Capacity of NEGs after many activations for CO is 0.3 Torr·l/(s·cm^2) and for Hydrogen 0.1 Torr·l/(s·cm^2). Periodically the NEG strips will require activation by direct heating with electric current.

Calculated axial pressure distribution inside vacuum chamber is presented in Fig. 2 for outgassing rate from vacuum chamber materials $q=5.7x10^{-12}$ Torr·l/(s·cm^2). and for different degrees of NEGs efficiency (100% corresponds initial pumping speed of NEG, 0% - completely saturated NEG).

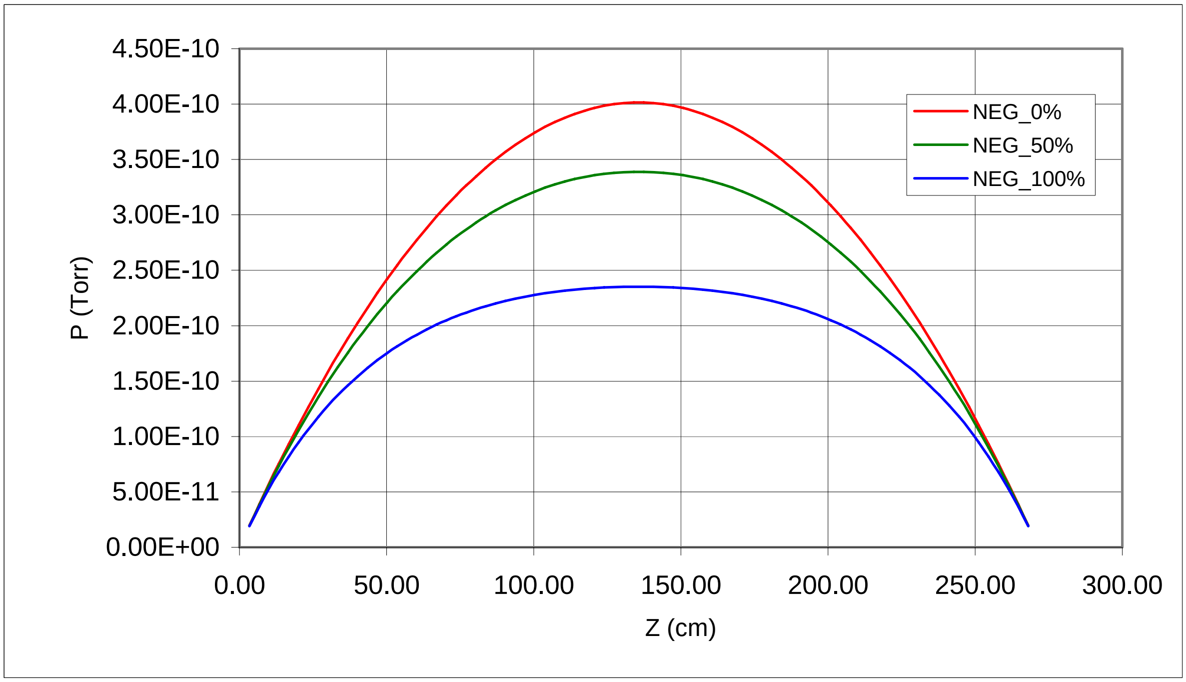

Fig. 2. Calculated pressure distribution along central vacuum chamber for outgassing rate $q=5.7x10^{-12}$ Torr·l/(s·cm^2) with a single NEG strip for different values of NEG efficiency (100%, 50%, 0%).

The effective pumping speed of cryopump in the GTC, which is attached to CVC on a gun side, is approximately 1000 l/s and in the ECTC, which is attached to CVC on a collector side, it is approximately 500 l/s. To maintain pressure in CVC in a low 10^{-10} Torr range with NEGs saturated the reasonable allowed pressure contribution from gas flow coming from either gun- or electron collector sides of CVC should be $\Delta P= 1\text{-}2x10^{10}$ Torr, which corresponds to gas flow $Q_{side}=1\text{-}2x10^{-7}$ Torr·l/s from either of these sides.

2.2. Gun/central vacuum chamber vacuum separation

The electron gun is one of sources of the gas load for the CVC. The major source of outgassing is hot cathode with focusing electrode. Anode is also heated by the cathode radiation. The vacuum walls of the gun chamber are not cooled and therefore have temperature higher than room temperature. This chamber is pumped with a combination of turbopump and titanium sublimation pump. Normally pressure in the gun chamber is $P\_gun=1x10^{-8}$ Torr. As mentioned above the tolerable pressure increase in GTC because of gas flow from the gun chamber $\Delta P=1x10^{-10}$ Torr the vacuum conductance between the gun chamber and GTC should be not higher than 10 l/s. Such vacuum conductance will be provided with vacuum separation of these two chambers. The preliminary design of this EBIS section without magnet coils is presented in Fig. 2.

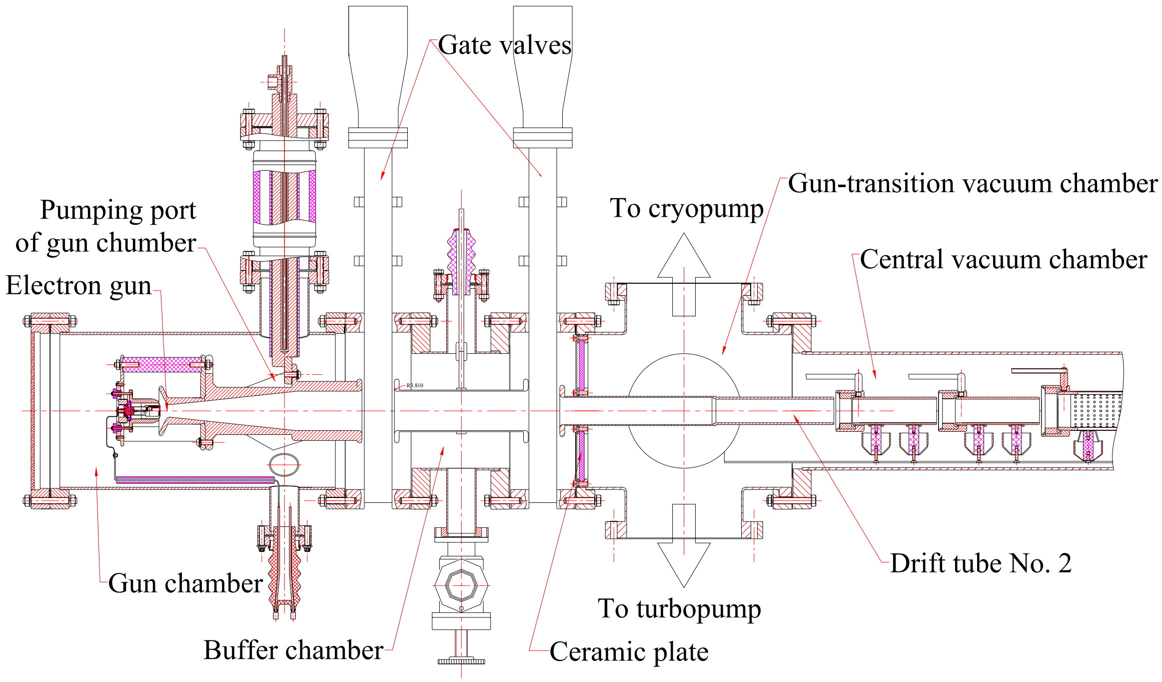

Fig. 3. Vacuum structure of EBIS gun side with vacuum separation.

Gun chamber together with buffer chamber are separated from the GTC with a ceramic plate. The only vacuum connection between these two parts is through a channel inside drift tube No.2. With inner diameter 30 mm and length 354 mm the vacuum conductance of this channel is 9.3 l/s, which satisfies the requirement for limiting the gas flow from the gun chamber into CVC. Minimum value of ID for drift tube No.2 is determined by the requirement of clean transmission of the electron beam through this region with low magnetic field.

The vacuum structure of EBIS gun side contains two gate valves and a buffer chamber with separate valve for preliminary pumping. This structure allows replacement of the gun chamber with another one without exposing either of them to atmosphere. The only volume vented to atmosphere is the buffer chamber with relatively small volume. This structure is expected to significantly reduce a turnaround time needed to replace the electron gun in case of its failure.

2.3. *Electron collector*

2.3.1. Electron collector outgassing

As mentioned above, the tolerable gas flow from the electron collector side into CVC is approximately $1x10^7$ Torr·l/(s·cm^2). A 20.0 A electron beam dissipates on the electron collector (EC) an average power of P_{aver}=60 kW and peak power P_{peak}= 300 kW. The gas desorption from EC surfaces bombarded by electrons is by far the biggest source of the residual gas in EBIS. With strict requirements to the pressure of the residual gas in an ionization region the reduction of gas emission from EC surfaces and restricting gas flow from EC to the central chamber are important tasks in the design of vacuum structure and selecting the technology of reducing the rate of electron-induced molecular emission.

The estimated effective pumping speed from the EC internal volume is S_{EC}=300 l/s. The total area bombarded by electrons is $F_{EC}=2.2x10^3$ cm^2. The average current density is $j_{EC}=5.8x10^{16}$ el/cm^2. For the required pressure $P_{EC}=5x10^{-8}$ Tor inside EC volume with electron beam running the total outgassing should be not higher than $Q_{EC}=1.5x10^{-5}$ Tor·l/s. With duty factor 0.2 the required maximum coefficient of the electron-induced desorption should be $K_{EID}=2.1x10^{-5}$ mol/el. According to [2] such value of K_{EID} can be reached with vacuum bakeout and training with electron beam.

The vacuum volume of electron collector is connected to the rest of EBIS with an EC entrance diaphragm, which has diameter 2.0 cm (conductance 31.4 l/s for CO). The gas flow from EC volume through this diaphragm is $Q_{EC}=3.14x10^{-6}$ Tor·l/s. This value exceeds the allowed gas flow into CVC approximately 31 times and therefore EC cannot be connected to CVC directly.

2.3.2. EC vacuum separation

To reduce the pressure rise in a central chamber from such gas flow an additional stage of vacuum separation is designed between the central chamber and the electron collector. The schematic of this vacuum separation is presented in Fig. 3.

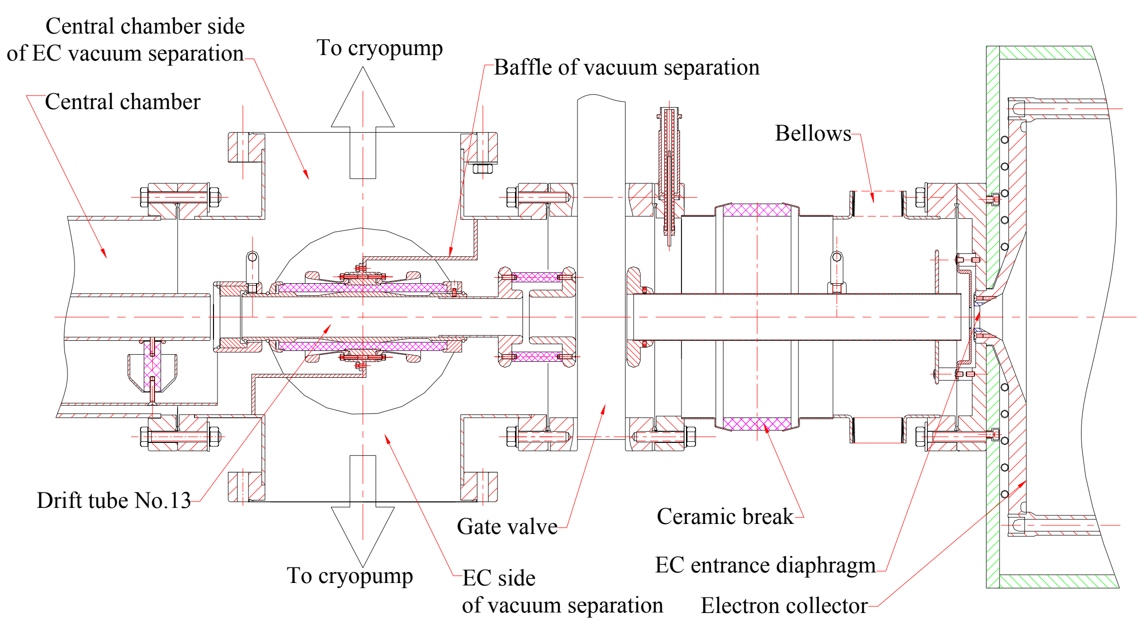

Fig. 4. Structure of EC vacuum separation

The vacuum separation is provided with a baffle structure separating a 6-way ConFlat cross into 2 halves. Each one has vacuum connection to 3 flanges and is pumped with a separate cryopump. Two halves of an EC-transition chamber are connected with a drift tube, which has vacuum conductance $F_{tube\ 13}$= 11.6 Tl/s. All gaps between baffle and the vacuum wall may have an additional conductance estimated to be F_{baffle}=10 l/s. So the total conductance between two parts of EC-transition chamber is $F_{EC\ vac\ sep}$=21.6 l/s. The cryopumps on both EC side and central chamber side of the vacuum separation have effective pumping speed of S=500 l/s each.

Inside the EC side of ECTC the pressure is expected to be $P_{EC\ side}=Q_{EC}/S$. $P_{EC}=3.1\times10^{-9}$ Tor. This pressure and vacuum conductance between two parts of ECTC provides total gas load from EC side into CVC of $Q_{EC\_sep}=P_{EC\_side}xF_{EC\ vac\ sep}=6.7\times10^{-8}$ Tor·l/s. This value of gas flow increases pressure in the central chamber side of EC-transition chamber $P_{central\ ch.\ side}=1.4x^{-10}$ Torr, which satisfies the required range of pressure raise caused by the gas flow from EC side of 1-2x10^{-10} Torr.

A gate valve between EC and EC-transition chamber allows venting the volume of EC and extraction ion optics of EBIS without exposing the central part to atmosphere.

3. Summary

To provide the required pumping speed in a pressure range of 10^{-10} Torr the cryopumps with pumping speed S≈1500 l/s (CO, CO_2, H_2) with 10" ConFlat flanges will be used. Additionally, turbopumps will be installed on the central chamber for pumping of helium and neon when gas injection is used. These pumps will be used also for preliminary pumping and for the bakeouts. The schematic of EBIS vacuum system is presented in Fig. 4.

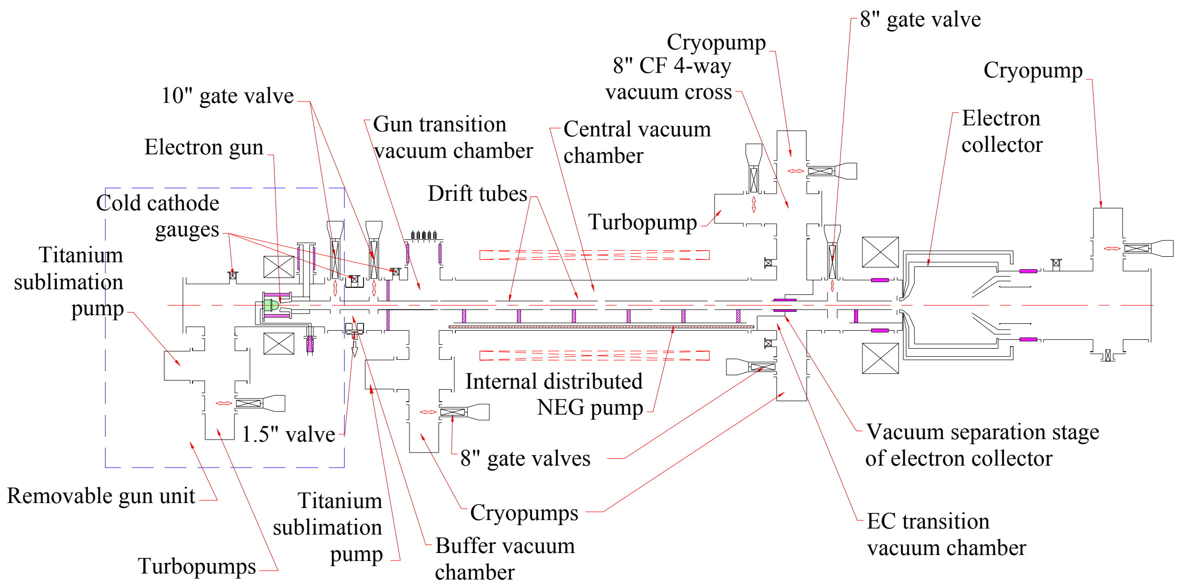

Fig. 4. Schematic of EBIS vacuum system

In addition to vacuum pumps, valves and vacuum gauges the vacuum system also includes electrical heaters of vacuum chambers with temperature sensors and computer control. The water-cooled thermal shield protecting the inner bore of superconducting solenoid from overheating during the bakeout of the central chamber is also part of vacuum system.

References:

1. http://jetep.rma.ac.be/rl-m01-vacuum-cond-of-anular-cavity.pdf
2. R.S.Vaughan-Watkins and E.M.Williams, Electron bombardment and plasma conditioning of copper surfaces, 8-th International Vacuum Congress, Cannes (1980), V.2, p. 387-390.