

Beam collimator of electrostatic septum for high-intensity heavy-ion accelerator facility booster

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The dynamic vacuum effect is the primary limitation of beam intensity in high-intensity heavy-ion synchrotrons. Although the dynamic vacuum effect in the arc section is mitigated effectively by the beam collimators, the gas desorption induced by injection beam loss occurring in the injection electrostatic septum (ESi) is still an unresolved issue. In addition, the gas desorption is enhanced due to some special mechanisms, including the ultrafast beam loss process, multiple traversals of wire surfaces, and high-voltage breakdown. Mitigating the dynamic vacuum effect in the ESi is a critical approach to achieve a higher beam intensity. Therefore, a novel ES collimator is proposed to reduce beam deposition on the septum. Dynamic simulation of the dual-plane painting injection of BRing reveals the excellent performance of this scheme by a tenfold reduction in beam loss. The features associated with collimation efficiency and structure optimization are analyzed in detail.

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I. INTRODUCTION

The high-intensity heavy-ion accelerator facility (HIAF) [1] is a mega accelerator cluster under construction in Huizhou, China. It aims to establish a next-generation frontier research platform for nuclear physics, astrophysics, atomic physics, high-energy-density physics, and beam applications [2]. Figure 1 shows the layout of the HIAF project. It consists of the fourth-generation superconducting ECR ion source (SECR), the superconducting linac (iLinac), the booster ring (BRing), and six experiment terminals. HIAF can deliver low energy, high-power cw heavy-ion beam up to 100 kW for the low energy multidisciplinary terminal. It can also provide extremely high-intensity pulsed primary and secondary beams for the high energy multidisciplinary terminal, fragment separator,

external target terminal, and spectrometer ring (SRing). The main parameters of HIAF are shown in Table I.

It is challenging to prepare high-intensity heavy-ion beams, especially uranium ions. The SECR provides an intermediate charge state $^{238}\text{U}^{35+}$ beam up to 1.7 emA. Then it is accelerated to 17 MeV/u by iLinac. The beam is injected to BRing and accumulated to 1.0×10^{11} particles per pulse (ppp) through the multiturn injection method. The conventional multiturn injection method utilizing horizontal phase space painting can only achieve an intensity gain of $10 \sim 20$, which falls far short of the required factor of 56 for HIAF [3]. Therefore, a dual-plane painting injection scheme is proposed, which performs horizontal and vertical painting simultaneously using a tilted electrostatic septum. According to the empirical formula [4], an intensity gain of $80\text{--}100$ is achievable without the space charge effect. In high-intensity synchrotrons, however, beam loss usually occurs in the early acceleration stage, when the beam energy is low and emittance is large. Nonlinear effects, such as the space charge effect, the dynamic vacuum effect, and the collective instability, dominate the beam dynamics. Over the past 20 years, the dynamic vacuum effect has been identified as one of the most critical intensity limitations [5].

The dynamic vacuum effect is a specific instability in heavy-ion synchrotrons [6]. As ions travel through the

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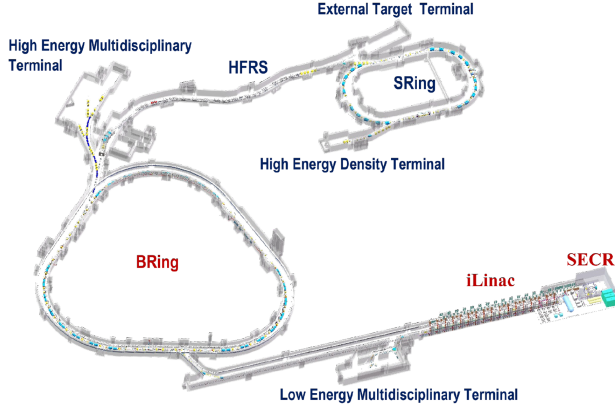


FIG. 1. Layout of HIAF. The accelerator chain is composed of the ion source SECR, the linear accelerator iLinac, and the synchrotron BRing. It provides high-intensity beams for six experiment terminals, including the low energy multidisciplinary terminal, the high energy multidisciplinary terminal, and others.

vacuum pipe, they can lose or capture electrons after colliding with residual gas molecules. Even when the average vacuum pressure reaches the ultrahigh vacuum level of 1.0×10^{-9} Pa, the charge exchange cross section for intermediate charge state heavy ions in the injection and early acceleration stage (at tens of MeV/u) remains significant [7]. The charge-exchanged ion, e.g., $^{238}\text{U}^{35+}$ turning into $^{238}\text{U}^{36+}$, introduces a significant change of magnet rigidity and exceeds the momentum acceptance. These ions will bombard the vacuum chamber walls, causing residual gas desorption. The resulting vacuum degradation leads to more charge exchange and further beam loss. In the high-intensity synchrotron, this beam loss and residual gas desorption create a divergent positive feedback loop, resulting in significant beam loss and rapid vacuum degradation. Since 1997, extensive research on the dynamic vacuum mechanism has been conducted at facilities such as ISR [8], LEAR [9], AGS [10], and SIS18 [11]. Various measures have been developed and proven effective in mitigating beam lifetime reduction, including fast acceleration [12], ion catchers [13], and enhanced pumping power [14]. Nevertheless, the dynamic vacuum effect continues to dominate beam intensity limitations, which remain well

below the space charge limit. The primary issue is the abundant gas desorption occurring in the injection electrostatic septum (ESi) [15].

The paper is organized into four sections. In Sec. I, the specific mechanisms of beam loss and gas desorption in the ESi are presented. In Sec. II, a novel collimator is proposed as an ion catcher to suppress the dynamic vacuum effect. To achieve efficient collimation, the relevant collimator parameters are analyzed. Section III presents injection dynamics simulation results for the BRing, demonstrating the feasibility of the ES collimator. Finally, Sec. IV illustrates the mechanical design of the collimator.

II. DESORPTION MECHANISM IN ESI

A. Abundant beam loss

The multiturn injection system of the synchrotron typically consists of a magnetic septum, an electrostatic septum (ESi), and four bump magnets. The incident beam from the injector is sequentially deflected by the magnetic septum and the ESi to enter the acceptance locally shifted by the bump magnets [16]. The ESi is the component closest to both the incident and circulating beams. Therefore, most beam loss during injection occurs at the ESi [17]. As a result, abundant gas desorbs into the local space.

Beam loss at the ESi can be categorized into two types: return beam loss and incident beam loss. Return beam loss results from the overlap between the trajectory of the return beam and the septum wires. A faster falling bump pulls the return beam down more rapidly and mitigates the loss. However, it reduces the effective intensity gain. As a result, the bump ramping speed is usually set to a moderate range to strike a balance between minimizing beam loss and maximizing injection gain. Incident beam loss occurs as the beam passes through the injection channel. The distance between the incident beam and the septum is a critical parameter affecting beam loss. A larger distance reduces the incident beam loss but increases the return beam loss due to larger effective septum thickness. In general, this distance is set to be smaller than the incident beam envelope to achieve higher injection gain, particularly for Gaussian-distributed beams characterized by low-density edges. Consequently, particles located in the edge region are inevitably lost at the septum. The incident beam envelope remains small and stationary during the injection process, resulting in a higher energy deposition density for incident beam loss compared to return beam loss.

At the septum, high-speed particles travel almost parallel to its surface, forming a very small intersection angle. In this grazing impact scenario, gas desorption yield increases by a factor of five compared to perpendicular impacts, as demonstrated by both simulations and experimental results on the dynamic vacuum effect [18,19]. The increased release of gas molecules degrades the vacuum, exacerbating beam loss.

TABLE I. Main parameters of HIAF.

Section	Length (m)	$B\rho$ (Tm)	Energy (MeV/u)	Intensity
SECR	1.5	0.12	$0.014(^{238}\text{U}^{35+})$	1.7 emA
iLinac	99.6	4.1	$17(^{238}\text{U}^{35+})$	1.0 emA
BRing	569.1	34	$835(^{238}\text{U}^{35+})$	1.0×10^{11} ppp
HFRS	191.9	25	$800(^{238}\text{U}^{92+})$	7.0×10^{10} ppp
			$740(^{132}\text{Sn}^{50+})$	1.0×10^8 ppp
SRing	277.3	15.8	$800(^{238}\text{U}^{92+})$	7.0×10^{10} ppp
			$740(^{132}\text{Sn}^{50+})$	1.0×10^8 ppp

B. Ultrashort desorption duration

Injection beam loss occurs in an ultrafast process, with the multiturn injection cycle lasting only several tens to hundreds of microseconds. The average velocity of the gas molecules at room temperature is several hundred m/s, e.g., the average velocity of CO is 514 m/s [20]. During the injection process, gas molecules drift at most several hundred millimeters. This drift distance is even smaller than the diameter of the ESi tank. Consequently, the vacuum near the septum suddenly degrades, triggering a serious dynamic vacuum phenomenon.

C. Special multipenetration of septum wires

Both the incident and return beams are nearly parallel to the septum wires. As a result, the beam deposition region occupies only small portions of the wires, due to shielding by upstream wires, as illustrated in Fig. 2. The thickness of the edge region is not enough to stop the ions. Ions injected into the edge of the wires will penetrate the wires and eject from the opposite side. The ion trajectory is illustrated by a dashed line in Fig. 2. The penetration depth indicates the length of this trajectory in the first injected wire. If the penetration depth is smaller than the range, the ion ejects from the opposite side, otherwise the ion stops in the wire. In the BRing, the wire of ESi is 100 μm in diameter, as listed in Table II. While the range of the typical ion, such as $^{238}\text{U}^{35+}$ at 17 MeV/u in tungsten, is approximately 49.3 μm . A simulation of the penetration depth of lost ions is performed using MATLAB. In the simulation, the spatial distribution, the shielding by upstream wires, and the bending by the electrostatic field are taken into account. While the multiple scattering and nuclear interaction are ignored to simplify the analysis. The distribution of the

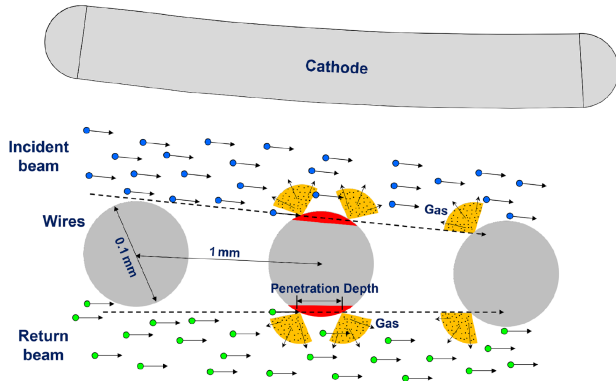


FIG. 2. Diagram of multipenetration. The particles travel nearly parallel to the wire array. Due to shielding by upstream wires, the impact parameter is close to the radius of the wire. The beam deposition region is located in the small edge section of the wire. Subsequently, the particles pass through this wire and collide with additional wires downstream. It should be noted that the source of increased desorption in fact could as well be from the surface of the completely grazed wire and the heating of the wires surface.

TABLE II. Main parameters of BRing electrostatic septums.

	Injection ESi	Extraction ESe02
Length (mm)	695	1500
Gap (mm)	26	15
Septum height (mm)	50	60
Bending angle (mrad)	10.5	1.6
Designed voltage (kV)	110	160
Radius (m)	130	1200
Septum thickness (mm)	0.1	1
Wire spacing (mm)	1	Plate

penetration depth in Fig. 3 indicates that almost all of the lost particles, both from the incident beam and return beam, have smaller penetration depths than the range. These particles penetrate the wire edge. The ejected ions retain considerable energy and are subsequently deposited on downstream wires or the vacuum chamber after further penetrations. Therefore, these particles pass through at least three surfaces. Every time a particle passes through the wire surface, gas molecules are desorbed. Therefore, at least 2 times more gas molecule desorption is expected at the ESi. For lighter or higher-energy ions, the number of penetrations increases due to their larger range in tungsten wires.

D. High-voltage (HV) breakdown

As described above, an abrupt release of abundant gas occurs into the injection channel before it propagates and is absorbed by the vacuum pump. This can result in an HV

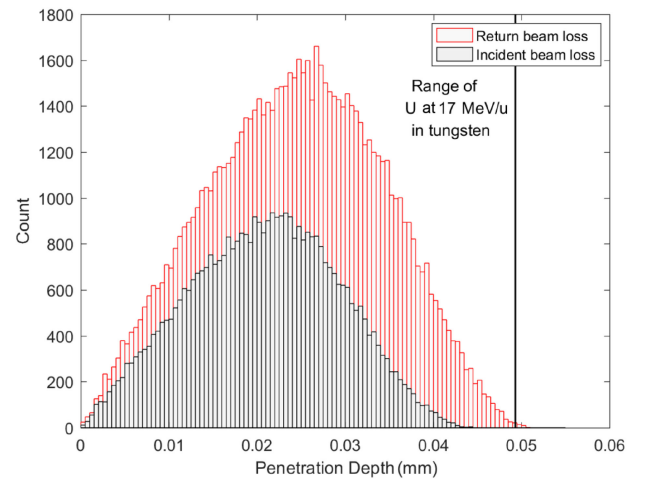


FIG. 3. Penetration depth distribution of lost particles during the first collision. When particles collide with wire edges for the first time, most of them cannot be stopped, as shown in Fig. 2. The count is a histogram of penetration depth. The bin width is 0.5 μm . The total return beam loss and incident beam loss on septum is 83,902 and 41,709 in macroparticles, 2.5×10^9 , and 1.24×10^9 in real particles. The range of U at 17 MeV/u in tungsten is 49.3 μm . Only 30 macroparticles of return beam loss are stopped in the first tungsten wires they hit.

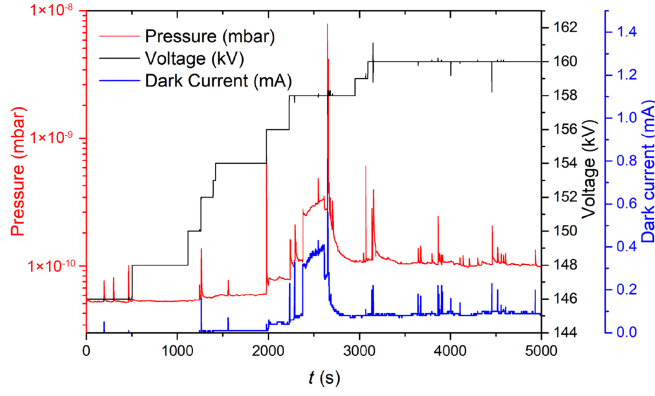


FIG. 4. Vacuum evolution during BRing extraction ESe02 commissioning. Each spike in dark current curve corresponds to a spark in the ES. It always results in an instant vacuum degradation of 1–2 orders. ESe02 is the second of the three electrostatic septums for slow extraction. Its parameters are listed in Table II.

breakdown, which in turn causes further gas desorption and vacuum pressure degradation by 1–2 orders of magnitude. This phenomenon was also observed during the commissioning of BRing extraction ES. Each spark induces a dark current spike pulse and significant vacuum degradation, as shown in Fig. 4. Additionally, the particles injected after the HV breakdown enter the synchrotron with an incorrect incident angle, leading to uncontrolled losses in subsequent propagation. More critically, any HV breakdown interrupts high-intensity injection for several seconds. The phenomenon was proved during the high-intensity commissioning at SIS18 [21].

The analysis above reveals that a series of desorption generation and enhancement effects most likely originate at the ESi and propagate throughout the synchrotron in high-intensity heavy-ion cases. Therefore, it is essential to mitigate injection beam loss at the septum [22]. Several mitigation strategies have been developed over the past decades. For example, GSI employs a set of collimators in the transfer channel TK [23] to trim the tail of transverse phase space. The intensity gain increases while the injection loss decreases. In addition, SIS18 applies NEG panels in the injection septum to increase the beam lifetime by nearly one order of magnitude [24]. However, the $^{238}\text{U}^{28+}$ intensity in SIS18 remains 6 times lower than the space charge limit [25].

III. A NOVEL ELECTROSTATIC SEPTUM COLLIMATOR

Figure 5(a) illustrates the multiturn injection trajectory. The trajectories of the incident beam and the return beam are represented in blue and red, respectively, with the corresponding beam losses indicated in dark blue and dark red. By collimating these particles upstream, the dynamic vacuum effect at the septum can be mitigated without significantly impacting the surviving particles. Based on this principle, two specialized collimators are proposed, as

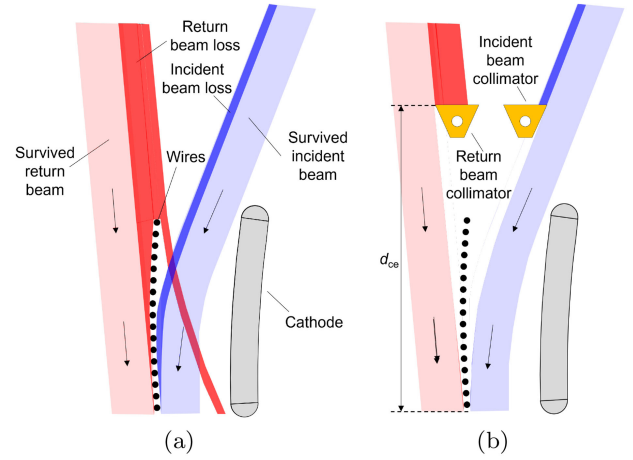


FIG. 5. Diagram of the ESi and collimators. The panel (a) illustrates the trajectories of beam loss on the septum. If the collimators are mounted upstream of the septum, the beam no longer deposits on the wires, as shown in the panel (b).

shown in Fig. 5(b). The inner collimator is designed to capture the return beam, while the outer collimator is dedicated to the incident beam. To achieve ideal collimation efficiency, the key parameters of the collimators are analyzed and optimized below.

A. Tilted angle of collimator in dual-plane multiturn painting scheme

For standard multiturn injection painting performed solely in the horizontal plane, the collimators are parallel to the wires, as shown in Fig. 6(a). However, the situation

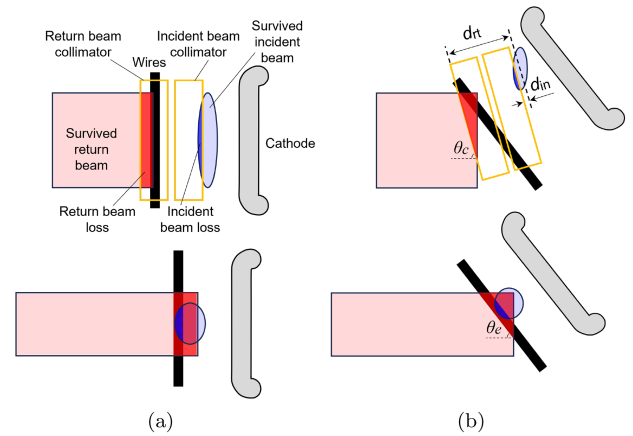


FIG. 6. Cross section of the beam profile in the ESi. (a) Shows the normal multiturn injection and (b) shows the dual-plane multiturn injection. The upper and lower panels illustrate the cross section at the entrance and exit of the ESi, respectively. The tilted angle of the demarcation line between retained particles and lost particles at the collimators is illustrated by θ_c , while at the exit of septum it is illustrated by θ_e . d_{ri} denotes the position of return beam collimator, while d_{in} denotes the position of incident beam collimator.

changes for dual-plane multiturn injection as the shape of the beam profile varies when the beam propagates in the ESI. The demarcation line between retained particles and lost particles at the exit of septum is determined by the tilted wires, as shown in Fig. 6(b). Upstream at the collimators, this demarcation line has a different tilted angle with the downstream one, which is illustrated by θ_c and θ_e , respectively. If the collimator coincides with the demarcation, the beam loss can be absorbed effectively without significantly impacting the surviving particles. Therefore, it is essential to get θ_c . In real space, the demarcation is a narrow line as shown by the (p_{1e}, p_{2e}) in Fig. 7(b). But in horizontal phase space, it corresponds to a wide region due to velocity deviation of particles, as shown by the gray area in Fig. 7(c). The deviation of the mean horizontal velocity of these particles can be expressed as

$$\Delta x'_e = -\frac{\alpha_{xe}}{\beta_{xe}} \Delta x_e, \quad (1)$$

where α_{xe} and β_{xe} are the horizontal Twiss parameters at exit of septum, and Δx_e is the horizontal projection of the demarcation.

The horizontal projection of demarcation at collimator is presented as

$$\Delta x_c = \Delta x_e + \frac{\alpha_{xe}}{\beta_{xe}} \Delta x_e d_{ce}, \quad (2)$$

where d_{ce} is the longitudinal distance between the collimator and the septum exit. Similarly, the parameters in vertical phase space are defined in the same way.

The slope of the demarcation at the collimator is:

$$\begin{aligned} \tan \theta_c &= \frac{\Delta y_c}{\Delta x_c} = \frac{\Delta y_e + \frac{\alpha_{ye}}{\beta_{ye}} \Delta y_e d_{ce}}{\Delta x_e + \frac{\alpha_{xe}}{\beta_{xe}} \Delta x_e d_{ce}} \\ &= \frac{1 + \frac{\alpha_{ye}}{\beta_{ye}} d_{ce}}{1 + \frac{\alpha_{xe}}{\beta_{xe}} d_{ce}} \frac{\Delta y_e}{\Delta x_e} = \frac{1 + \frac{\alpha_{ye}}{\beta_{ye}} d_{ce}}{1 + \frac{\alpha_{xe}}{\beta_{xe}} d_{ce}} \tan \theta_e. \end{aligned} \quad (3)$$

B. Position of the collimators

Ideally, all particles lost at the injection septum can be collimated if the collimator coincides with the demarcation line. However, due to velocity deviations of the particles, the demarcation line broadens and becomes indistinct, as shown in Fig. 7. Therefore, a few originally survived particles will get lost inevitably while some originally lost particles are not effectively collimated. The longitudinal distance between collimators and septum exit, denoted by d_{ce} , determines the degree of demarcation indistinctness. The transverse positions of collimators, which is denoted by d_{rt} and d_{in} in Fig. 6(b), impact the collimation process directly. A simulation for different transverse and longitudinal positions of collimators is performed. The basic parameters are listed in Table III. The simulation model and process are described below. (i) The cross section of the absorber is an isosceles trapezoid. Its bottom base faces the incoming beam and has a width of 4 mm. The base angles of the trapezoid are 85° to avoid grazing incidence. The thickness of the absorber is set to 4 mm to enhance thermal conduction capability and stop all of the designed injected beam reliably. (ii) The range of $49.3 \mu\text{m}$ means that particles are stopped in the surface of the absorbers. Multiple scattering process impacts minimal on the desorption. To simplify the analysis, multiple scattering and

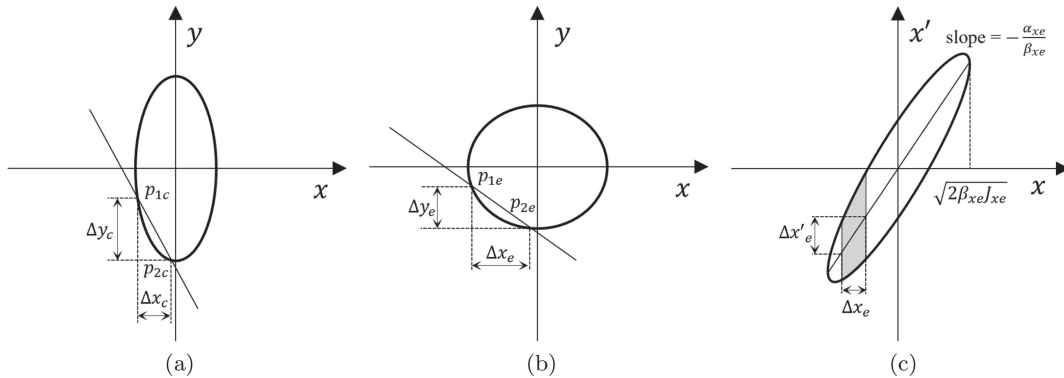


FIG. 7. Comparison of demarcations at the exit of the septum and the collimator. (a) Demarcation in real space at the exit of the collimator, represented by the line (p_{1c}, p_{2c}) . Its horizontal and vertical projections are denoted by Δx_c and Δy_c , respectively. (b) Demarcation in real space at the exit of the septum, represented by the line (p_{1e}, p_{2e}) . Its horizontal and vertical projections are denoted by Δx_e and Δy_e , respectively. (c) Demarcation in horizontal phase space at the exit of the septum. Its horizontal position and average velocity projections are denoted by Δx_e and $\Delta x'_e$, respectively.

TABLE III. Basic parameters for collimation simulation.

Parameters	Values
Ring parameters	
Circumference	569.1 m
Horizontal acceptance	200π mm mrad
Vertical acceptance	100π mm mrad
Momentum acceptance	$\pm 5 \times 10^{-3}$
Tune (x/y)	9.47/9.43
Natural chromaticity (x/y)	-11.324/-11.586
Ring parameters at injection point	
$\beta_{x,\text{ring},\text{inj}}/\beta_{y,\text{ring},\text{inj}}$	17.563/8.624 m
$\alpha_{x,\text{ring},\text{inj}}/\alpha_{y,\text{ring},\text{inj}}$	-2.614/1.574
$D_{x,\text{ring},\text{inj}}/D'_{x,\text{ring},\text{inj}}$	0 m/0
BUMP height (x/y)	66/32.4 mm
BUMP angle (x/y)	10.125/-7.21 mrad
Painting turns	65
Incident beam parameters at ESi	
Ion species	$^{238}\text{U}^{35+}$
Energy	17 MeV/u
Intensity	1.0 emA
$\epsilon_{x,\text{inj}}/\epsilon_{y,\text{inj}}$	$1.0/1.0\pi$ mm mrad, truncated by 5ϵ
$\sigma_{\Delta p/p}$	6.7×10^{-4} , truncated by $\pm 3\sigma$
$\beta_{x,\text{in},\text{entrance}}/\beta_{y,\text{in},\text{entrance}}$	3.697/3.140 m
$\alpha_{x,\text{in},\text{entrance}}/\alpha_{y,\text{in},\text{entrance}}$	-0.674/0.768
$\beta_{x,\text{in},\text{exit}}/\beta_{y,\text{in},\text{exit}}$	4.833/2.312 m
$\alpha_{x,\text{in},\text{exit}}/\alpha_{y,\text{in},\text{exit}}$	-0.949/0.414
$D_{x,\text{in},\text{exit}}/D'_{x,\text{in},\text{exit}}$	0 m/0
Beam center at entrance (x/y)	65.801/40.031 mm
Beam angle at entrance (x/y)	2.830/-13.042 mrad
Beam center at exit (x/y)	70.591/33.259 mm
Beam angle at exit (x/y)	10.855/-6.308 mrad
Septum parameters	
Position at entrance (x/y)	65.366/31.868 mm
Position at exit (x/y)	66.207/32.574 mm
Tilted angle	50°
Gap	26 mm
Electric field strength	34.54 kV/cm

nuclear scattering processes are not taken into account. (iii) Each wire of ESi is set as calculation node to locate the beam loss precisely. The longitudinal positions of collimators d_{ce} vary between 0.25 and 1 m. While the transverse positions of collimators d_{rt} and d_{in} vary between nothing collimated and lost beam fully collimated.

The simulation results for different d_{ce} values are presented in Figs. 8(a) and 8(b). The solid lines indicate the beam loss on wires. The lower beam loss on wires means the higher collimation efficiency. It is evident that as d_{ce} increases, the collimation efficiency decreases, and the additional loss—defined as the difference of total losses and original septum loss—increases. However, a shorter distance d_{ce} requires a higher electrostatic field to maintain

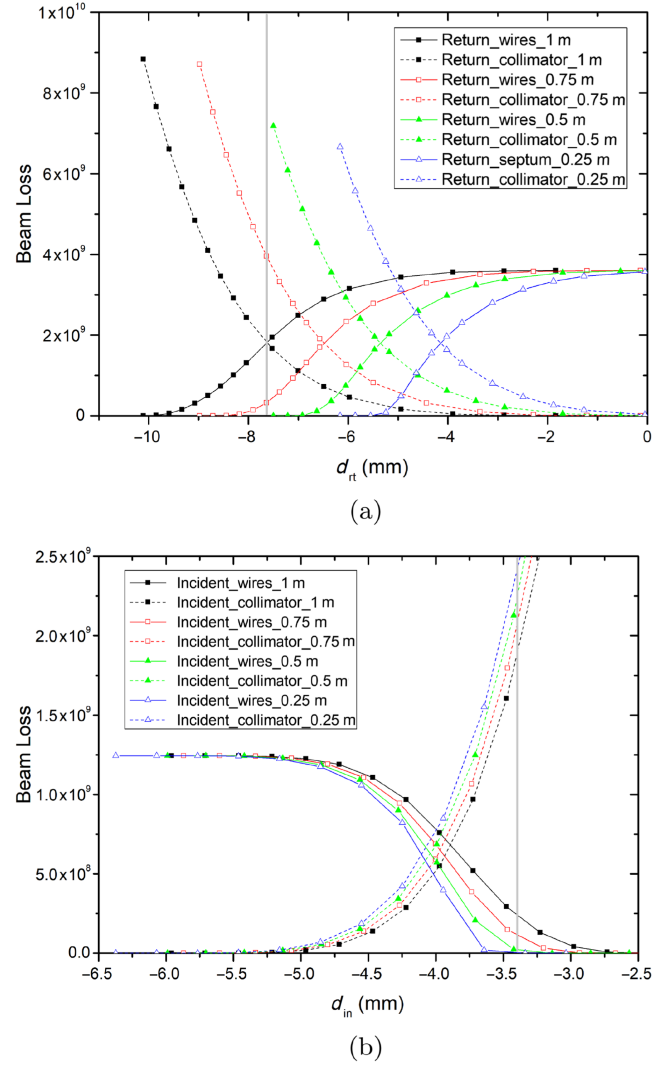


FIG. 8. Collimation efficiency of the collimators. (a) Return beam collimator and (b) incident beam collimator. The distance d_{ce} varies from 0.25 to 1 m. The abscissa represents the relative position of collimators with respect to the incident beam center, as shown in Fig. 6(b). The solid lines indicate the beam loss on wires, while the dashed lines indicate the beam loss on collimators. The lower beam loss on wires means the higher collimation efficiency. The gray lines refer to the optimized collimator positions.

the beam bending angle, which is limited by HV sparks. For BRing the optimized d_{ce} is 0.75 m, corresponding to the HV of 108 kV.

The transverse position of collimator is also important for the collimation efficiency and additional loss. The optimized d_{rt} of -7.6 mm achieves tenfold reduction of return loss on septum. While the additional loss increase by 7.0×10^8 ppp, as shown in Fig. 8(a). It is negligible compared to the total accumulated intensity of 1.0×10^{11} ppp. The optimized d_{in} of -3.4 mm achieves a tenfold reduction of incident loss on septum. While an additional loss increase by 9.0×10^8 ppp, which is also negligible, as shown in Fig. 8(b).

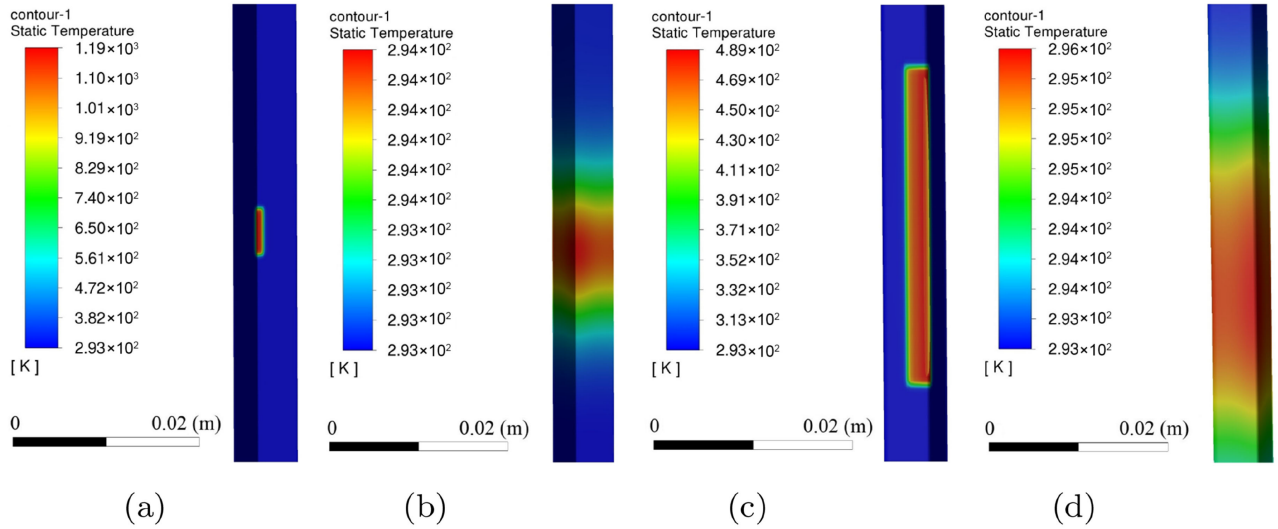


FIG. 9. Temperature distribution after injection and before next injection. (a)–(d) are incident beam collimator and return beam collimator, respectively.

IV. THERMAL SIMULATION AND MECHANICAL DESIGN

The deposited power of impact ions on the collimator is estimated to be 12 W in 3 Hz high-power operation mode. Therefore, water cooling is essential to avoid considerable outgassing rate increase at high temperature [26]. The deposited density can be modeled as Gaussian distribution in the height direction and half Gaussian distribution in the width direction. As a conservative thermal simulation, the beam deposition region is set to a rectangular shape covering the real beam, as shown in Fig. 9. The height is $\pm 2\sigma_h$, while the width is $2\sigma_w$. The deposition density in this region is uniform and consistent with the real beam maximum deposition density. Therefore, the total deposited power for thermal simulation is larger than the real one, $8/\pi$ times in fact. The parameters for simulation are listed in Table IV. Due to the injection process is faster than the thermal diffusion and the range is small, the temperature of the bombarded part rises significantly, as illustrated in Fig. 9. The deposition thickness is so small that the heat in

this region is transferred to the adjacent part in an instant. Then the heat is transferred to the whole absorber and taken away by water. The evolution of the maximum temperature in absorbers is illustrated in Fig. 10. The maximum instantaneous temperature of incident beam collimator and return beam collimator are 1188 and 490 K, respectively. It is safe for the physical properties of tungsten.

The collimator consists of absorber, motion mechanism, and cooling structure, as shown in Fig. 11. The return beam collimator and incident beam collimator are installed upstream of the wires, where the leaked electrostatic field declines a lot. Both their horizontal position and tilted angle are adjustable to optimize collimation efficiency and additional beam loss. The horizontal motion is performed by a ball screw, while the angular motion is performed by a rack and pinion structure inside the vacuum.

TABLE IV. Parameters for collimator thermal simulation.

Parameters	Incident beam collimator	Return beam collimator
Height ($4\sigma_h$, mm)	5	32
Width ($2\sigma_w$, mm)	0.8	2.5
Thickness (mm)	0.05	0.05
Material	Tungsten	Tungsten
Peak power density (kW/mm ³)	16.9	3.08
Pulse length (ms)	0.65	0.65
Repetition (Hz)	3	3
Average power (W)	6.6	24

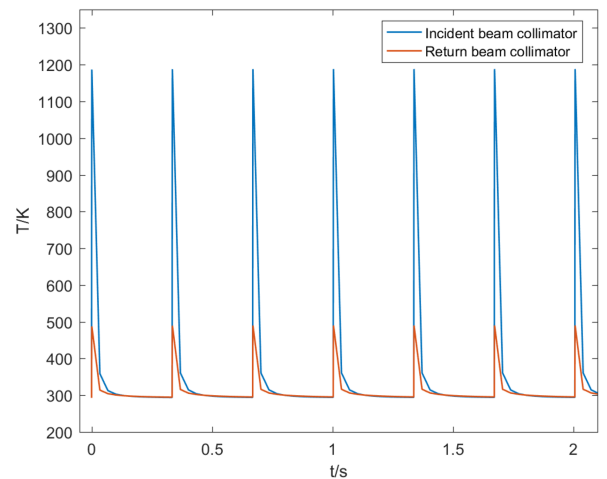


FIG. 10. Evolution of the maximum surface temperature of collimators.

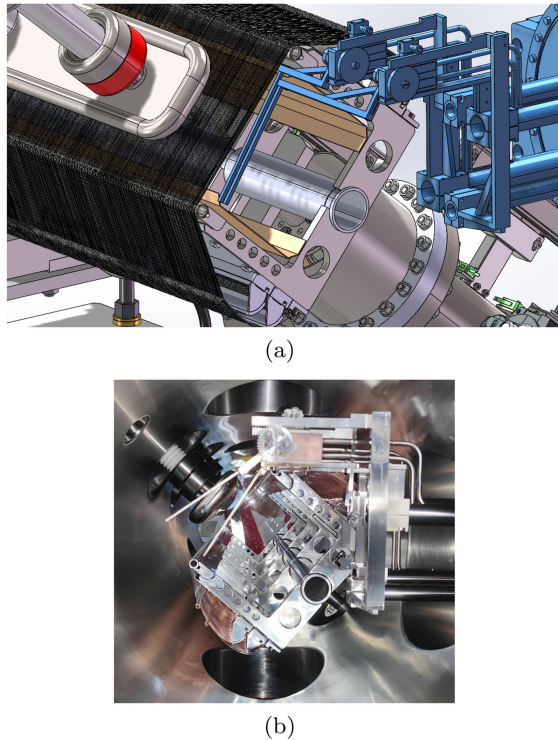


FIG. 11. Mechanical design and assembly of the BRing ESi and collimators. Two blue strips on the left in the draft indicate the return beam absorber and incident beam absorber, respectively. The horizontal position and tilted angle of the collimators are adjustable to optimize collimation efficiency and additional beam loss.

V. CONCLUSION

The wire structure electrostatic injection septum generates significant gas desorption during the high-intensity heavy-ion injection process. This desorption is a result of the abundant and rapid beam deposition, multipenetrations, and HV breakdown. To address this issue, a novel electrostatic septum collimator scheme is proposed to absorb particles that would otherwise be lost on the septum. The collimation efficiency is analyzed in detail, showing that the use of two tilted collimators can mitigate more than 90% of the beam loss on the septum. The dynamic vacuum effect in BRing is expected to be relieved by this measure. The mechanical design takes the position adjustment, angle adjustment, and heat dissipation into account. The fabrication and integration are finished. A demonstration experiment is foreseen during the commissioning of BRing in the end of 2025. In the future work, it would be interesting to study the detailed process of outgassing at the septum wires due to multiple penetrations with more detailed simulations including scattering of incident beam and heat distribution in the septum wires.

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DATA AVAILABILITY

The data that support the findings of this article are openly available [27].

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