ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLO03

RHIC BEAM ABORT SYSTEM UPGRADE OPTIONS*

W. Fischer†, M. Blaskiewicz, M. Mapes, M. Minty, C. Montag, S. Nayak, V. Ptitsyn, J. Sandberg, P. Thieberger, N. Tsoupas, J. Tuozzolo, K. Yip,
Brookhaven National Laboratory, Upton, NY, USA

Abstract

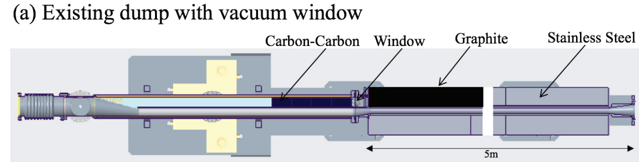
The RHIC ion (polarized proton) beam intensity has increased to 4x (1.1x) of the original design specifications. For heavy ions the beam dump window has limited the beam intensity. In 2014 the beam dump vacuum window was changed from stainless steel to a titanium alloy and the adjacent beam diffuser block carbon material was changed to allow for higher ion intensities. A thicker beam pipe was installed to prevent secondaries from quenching the adjacent superconducting quadrupole. For high intensity proton operation heating of the abort kicker ferrites had limited the intensity, leading to a reduction in kicker strength. Also in 2014, the abort kicker ferrites were changed, the eddy current reduction design was upgraded, and an active ferrite cooling loop was installed to prevent heating. With these upgrades the intensity was raised to new records for Au+Au operation in 2016, and for p+p operation in 2015 (100 GeV) and 2017 (255 GeV). A further increase in the beam intensity is planned for the RHIC program with the sPHENIX detector, and the Electron-Ion Collider eRHIC. We evaluate the need for upgrades and upgrade options for the beam abort system to accommodate these intensity increases.

INTRODUCTION

The current focus of the RHIC physics program is the Beam-Energy Scan II (BES-II) in search of a critical point in the nuclear physics phase diagram. This requires collisions at and below the nominal injection energy [1]. After completion of the BES-II in 2021 RHIC is expected to return to high-energy operation with the sPHENIX detector [2], presently under construction. With sPHENIX Au+Au, p+p and p+Au collisions with higher intensity beams are planned [3]. Higher beam intensities are also planned for the Electron-Ion Collider eRHIC [4, 5]. Table 1 list the main parameters relevant for the abort system design. For the beam dump design the heavy ion beams are more demanding, and for the abort kicker ferrite heating the polarized proton beams are more demanding. Shown are values achieved and planned for RHIC and eRHIC, for Au and polarized p beams.

BEAM DUMP UPGRADES

The RHIC beam dump is an internal dump inside the tunnel but outside the vacuum, separated from the beam vacuum by a Ti alloy vacuum window. It was originally designed for 60 Au bunches with 1.0×10^9 intensity (0.12 MJ) and upgrades several times. The last upgraded in 2014 to allow for higher Au intensity with a new Ti alloy vacuum window [6, 7] and new carbon-carbon blocks that disperse the energy of the extracted beam (Fig. 1). A thicker beam pipe was installed to shield the adjacent superconducting Q4 quadrupole from secondary particles. The beam dump is surrounded by marble slabs. During an abort the beam is swept in the horizontal plane across the window but not in the vertical plane. With these upgrades RHIC operated at 100 GeV/nucleon with Au bunch intensities of up to 2.0×10^9 in 2016 (Table 1).



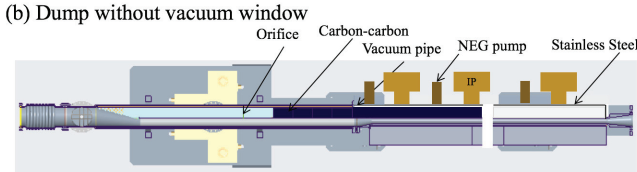


Figure 1: (a) Existing RHIC beam dump with vacuum window. (b) Possible upgrade without a vacuum window. The external marble shielding is not shown and may affect the location of the vacuum pumps. In both cases the view is from the top and the beam enters from the left.

For a further intensity increase the following upgrades are under consideration for the beam dump:

- a different Ti alloy window
- the addition of a vertical kicker
- a beam dump in vacuum without a window

The first two options have been previously considered [7], and the first option was implemented in the last upgrade.

Ti window upgrade. The energy deposition in the vacuum window was calculated with the MCNP6.2 code [8], which simulates the heavy ions directly, not approximated by protons multiplied by the charge number Z. It must be possible to abort the beam at any energy safely. In the RHIC energy range the highest energy deposition in the window is at the highest beam energies. Figure 2 shows the calculated energy density profiles in the horizontal (a) and vertical (b) plane for the case of the planned RHIC upgrade with Au beams (Table 1).

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.
† Wolfram.Fischer@bnl.gov

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLO03

Table 1: Main beam parameters relevant for the abort system design. The operating modes shown are for the highest energy deposition in the dump window for Au beams, and for the highest abort kicker ferrite heating for p beams.

quantity	unit	Au beam RHIC 2016	Au beam RHIC planned	Au beam eRHIC planned	p beam RHIC 2017	p beam RHIC planned	p beam eRHIC planned
energy E	GeV/nucleon	100	100	110	255	255	275
no of bunches k_b	...	111	111	1160	111	111	290
bunch intensity N_b	10^9	2.0	3.0	0.5	185	300	198
total intensity N_{tot}	10^{11}	2.3	3.3	5.8	205	329	574
stored energy/beam	MJ	0.71	1.05	2.0	0.84	1.34	2.53
normalized rms emittance $\varepsilon_{x,y}$	µm	2.0	2.0	5.0/0.36	2.7	2.5	4.2/0.9
lattice function at dump window $\beta_{x,y}$	m		10/48			10/48	
rms beam size at dump window $\sigma_{x,y}$	mm	0.43/0.95	0.43/0.95	0.65/0.38	0.33/0.71	0.31/0.69	0.38/0.38
bunch spacing	m	31.9	31.9	3.0	31.9	31.9	12.2
bunch frequency	MHz	9.4	9.4	98.5	9.4	9.4	24.6
rms bunch length σ_s	m	0.3	0.3	0.07	0.6	0.5	0.06
average beam current I_{avg}	mA	224	330	574	264	417	719
peak beam current I_{peak}	A	10.3	15.1	10.8	6.1	11.6	63.2

A window material with higher yield stress σ_y, higher specific heat C, lower Young's modulus E and lower thermal expansion coefficient ε allows for a larger energy deposition. A Figure Of Merit (*FOM*) for the window performance can be defined as

$$FOM = \frac{\sigma_y C}{E\varepsilon}. \tag{1}$$

The present vacuum window is a Ti 6-2-4-2 (Ti-6Al-2Sn-4Zr-2Mo) alloy with $FOM = 474$ and can be replaced with a Ti 15-3-3-3 (Ti-15V-3Cr-3Al-3Sn ST 850C) window with $FOM = 669$. However, based on the energy deposition profile for the existing Ti alloy window (Fig. 2), it will be able to withstand a 110 GeV/nucleon gold beam with 1160 bunches and 0.5×10^9 ions per bunch (Au beam, eRHIC planned in Table 1) while achieving safety factor of almost a factor of 4 (yield stress over stress, σ_y/σ). For the planned RHIC upgrades the safety factor is an order of magnitude.

Vertical kicker. The abort kicker is in the horizontal plane only, and the addition of a small vertical kicker can distribute the energy further on the window (Fig. 3). This was analyzed in Ref. [7] with the conclusion that a small vertical kicker can increase the intensity damage threshold to the window by approximately 50%.

Beam dump in vacuum. To overcome the limitation of the vacuum window the beam dump can be placed in the vacuum enclosure. During a beam abort there will then be outgassing from the dump materials. Data exist for carbon outgassing rates [9, 10], and one to two decades higher outgassing rates than stainless steel are expected. A preliminary vacuum design, shown in Figure 1 (b), has the vacuum window replaced by an orifice and vacuum pumps are added. Outgassing measurements of the materials used in vacuum and a full analysis of the temperature rise in the carbon-carbon and stainless-steel blocks are planned. This upgrade is an option if the beam parameters considered (Table 1) change significantly in the future.

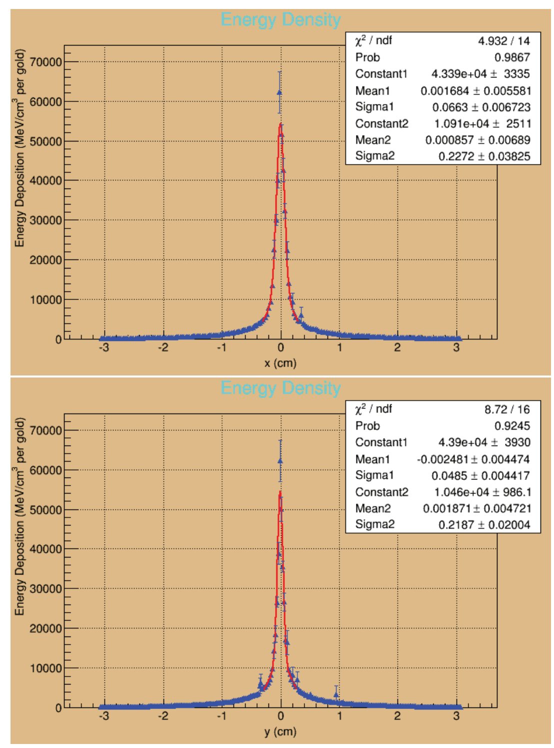


Figure 2: Energy deposition per Au ion in the Ti alloy dump window in the horizontal (top) and vertical (bottom) plane. The spacial distribution is for the case of Au beam, eRHIC planned (Table 1), and fitted to a double Gaussian function.

ABORT KICKER UPGRADES

With high-intensity proton beams it was observed in previous years that the abort kicker strength was reduced after many hours of store time, which was found to be due to heating of the abort kicker ferrites [11]. In response, the abort kicker ferrites were changed from CMD5005 to CMD10, the eddy current reduction design was upgraded, and an active

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLO03

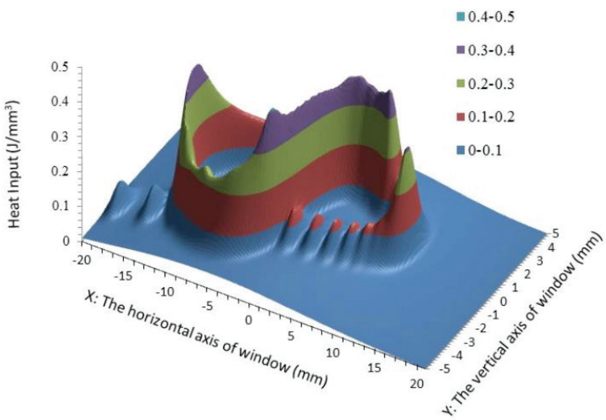


Figure 3: From Ref. [7]. Energy density deposited in the window using an additional vertical kicker for 111 bunches with 0.7×10^9 Au ions per bunch and an normalized rms emittance of 0.7 µm.

ferrite cooling loop was installed to prevent heating. The primary advantage of the new ferrites is the higher Curie temperature. The cooling is designed for a 1 kW heat load in each of the five abort kicker magnet. The longitudinal impedance of an abort kicker was measured [11, 12], and the energy deposition in the ferrites can be calculated with the bunch number, bunch intensity and bunch length. For the proton eRHIC case in Table 1 a heat load of 5 kW per abort kicker is estimated, while the RHIC upgrade case is less than 1 kW. This requires an increase in the cooling capacity for eRHIC, or an current-carrying insert which will modify the electrodynamic properties of the kicker and requires further analysis [13].

SUMMARY

Higher beam intensities are planned for the future RHIC physics program, and the Electron-Ion Collider eRHIC. We evaluated the need for upgrades and upgrade options for the beam dump vacuum window, which has limited the heavy ion intensity in the past, and the abort kicker, whose ferrites were heating up with high proton beam currents in the past.

With the presently anticipated heavy ion beam currents no upgrade of the dump kicker vacuum window is necessary. For the cases under consideration a minimum safety factor of almost four for the stress was estimated. Upgrade options exist in a different Ti alloy for the window, the addition of a vertical kicker, or a beam dump in vacuum.

For the abort kicker with high-intensity proton operation in eRHIC the estimated power loss in the ferrites of the existing abort kickers will exceed the present design cooling capacity of 1 kW for one of the five abort kickers by a factor of five. As upgrade options the cooling can be improved with a higher flow rate of the coolant, or an insert.

ACKNOWLEDGMENTS

We are thankful to the RHIC operations and eRHIC design teams for discussion, and G. Robert-Demolaize for providing lattice information.

REFERENCES

[1] C. Liu, "Accelerator Performance During the Beam Energy Scan II at RHIC in 2019", presented at the North American Particle Accelerator Conf. (NAPAC'19), Lansing, MI, USA, Sep. 2019, paper MOYBA6.

[2] A. Adare et al. (sPHENIX Collaboration), "sPHENIX: An Upgrade Proposal from the PHENIX Collaboration", arXiv:1501.06197.

[3] W. Fischer, *et al.* , "RHIC Performance with Stochastic Cooling for Ions and Head-on Beam-beam Compensation for Protons", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 2055–2060. doi:10.18429/JACoW-IPAC2016-WEZA01

[4] C. Montag *et al.*, "eRHIC Design Update", presented at the North American Particle Accelerator Conf. (NAPAC'19), Lansing, MI, USA, Sep. 2019, paper MOYBA4.

[5] W. Fischer *et al.*, "eRHIC in Electron-Ion Operation", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 738–741. doi:10.18429/JACoW-IPAC2019-MOPRB072

[6] S. Nayak, K. Yip, L. Ahrens, and C. Montag "Calculation of Mechanical and Thermal Stress in the RHIC Beam Dump Windows ", BNL-98703-2012-TECH, C-A/AP/456 (2013).

[7] C. Montag *et al.*, "Upgrading the RHIC Beam Dump for Higher Intensity", in *Proc. North American Particle Accelerator Conf. (NAPAC'13)*, Pasadena, CA, USA, Sep.-Oct. 2013, paper THPHO10, pp. 1322–1324.

[8] C.J. Werner (editor), "MCNP Users Manual - Code Version 6.2", LA-UR-17-29981 (2017).

[9] G.A. Beitel and D.K. Benson "UHV Outgassing Measurements on Various Carbons", Journal of Vacuum Science and Technology 10, 201 (1973). doi:10.1116/1.1317939

[10] J.M. Jimenez, J-P. Bojon, D. Le Ngoc, and B. Versolatto, "Graphite and C-C materials for UHV applications", presentation of the CERN AT/VAC/SL Section, 25 June 2003.

[11] C. Montag *et al.*, "Observation of Beam-induced Abort Kicker Ferrite Heating in RHIC", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 3648–3650. doi:10.18429/JACoW-IPAC2016-THPMW043

[12] N.P. Abreu, "Measurement and Simulation of the RHIC Abort Kicker Longitudinal Impedance", BNL-99511-2013-TECH, C-A/AP/362 (2013).

[13] F. Ruggiero, J. S. Berg, O. Br, F. Caspers, M. Morvillo, and M. D, "Summary of the Single-Beam Collective Effects in the LHC", in *Proc. 17th Particle Accelerator Conf. (PAC'97)*, Vancouver, Canada, May 1997, paper 7P008, pp. XX–XX.