ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPG10

DESIGN OF THE CRYOGENIC BPM PICK-UP FOR THE EIC HADRON STORAGE RING*

M. Sangroula[†], J. Bellon, A. Blednykh, D. Gassner, C. Hetzel, R. Hulsart, C. Liu, K. Matsushima, R. Michnoff, F. Micolon, I. Pinayev, V. Ptitsyn
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

Designing the cryogenic BPM pick-up for the Hadron Storage Ring (HSR) of the Electron-Ion Collider (EIC) is a challenging task as it needs to provide reliable beam position measurements over a variety of beam species and operating modes with various energies. The existing RHIC BPM stripline pick-up are not compatible with the planned HSR beam parameters as the HSR beam, compared to RHIC, will have a factor of 10 shorter bunch length (to 6 cm rms), a factor of 3 more currents (0.69 Amps, with 290 bunches), and will have a large radial offset (± 20 mm) to adjust the path length for different beam energies. The BPM pick-up design takes into consideration the potential elevated heating concerns caused by resistive wall loss due to radial beam offset and heat conduction through cryogenic BPM signal cables. The geometric impedance associated with the button configuration and housing transition to the adjacent HSR beam screen must also be minimized. This paper focuses on the design of the HSR cryogenic BPM pick-up and describes simulation results of the position-related voltage signals, and beam-induced losses on the metallic BPM buttons due to the radial offsets.

INTRODUCTION

The EIC [1–4] is currently in its design phase, utilizing a ring of the existing Relativistic Heavy Ion Collider (RHIC) rings as the HSR [5]. Designing the cryogenic BPM pick-up for the HSR presents several challenges due to specific requirements.

Firstly, compared to the RHIC, the HSR features significantly shorter bunches (up to 10 times shorter) and higher beam intensity, as indicated in Table 1. Additionally, during a physics store the hadron beam undergoes a large radial offset of up to ± 20 mm [6], near some of the BPMs, to allow variations in the HSR beam path circumference to synchronize the hadron and electron beams for collision at different energies.

Furthermore, the HSR BPM must accommodate a wide range of beam species, horizontal offsets, bunch lengths, and bunch charges in various operational modes. Additionally, the shorter and more intense hadron bunches, combined with the large radial offset, lead to higher peak voltages on the BPM pick-up and its housing. This results in elevated temperatures on these surfaces, potentially causing unwanted desorption of condensed gases. Moreover, heat conduction via the cryogenic cables from the tunnel (at room temperature) to the cryogenic BPM exacerbates these temperature elevations, particularly on the BPM button and cryogenic feedthroughs [7, 8].

Table 1: Comparison of the Proton Beam Parameters at Maximum Store Energy Between the EIC and RHIC Demonstrated

Parameters	EIC	RHIC demo
Energy (GeV/A)	275	255
RMS bunch length (mm)	60	550
Charge/bunch (nC)	30.5	36
Max. number of bunches	1160	110

A feasibility study to use the existing BPM for the HSR with RF-shielding can be found in Ref. [9]. Although the incorporation of RF shielding showed a great reduction in the peak voltage signal for the on-axis beam, the issue with the impedance mismatch created by the RF slots along the BPM pick-up was of large enough concern to make this approach unsuitable for the HSR. In this paper, we summarize our efforts in designing of a new HSR cryogenic BPM pick-up.

HSR BPM PICK-UP DESIGN

In general, stripline BPM pick-ups are used for beams with longer bunch length (hadron beam) while the button BPM pick-ups are utilized for shorter bunches (typically for electron beam) to monitor corresponding beam position. The HSR proton bunch length is about an order of magnitude shorter than that of the current RHIC and has to satisfy a wide variety of beam modes. To prepare an appropriate design the HSR cryogenic BPM pick-up, we analyzed different models, starting from the nominal orthogonal button design. We used CST [10] wakefield solver with the most challenging HSR beam parameters listed in Table 2, to simulate and analyze the output signals as well as to evaluate beam-induced resistive wall (RW) heating.

The initial BPM pick-up design featured four orthogonal buttons to monitor beam position on both planes. However, an offset beam in this design produced a very large RW loss compared to the button farther away. Elevated temperatures on the cryogenic BPM button surface due to RW heating, combined with heat conduction through cryogenic signal cables, posed significant design challenges. Consequently, we discarded this design.

We investigated another design called the side-by-side button design, which features four buttons arranged in a top-

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.
† msangroul@bnl.gov

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPG10

Table 2: HSR Proton Beam Parameters that Generates the Highest RW Heating

Parameters	Value	Unit
RMS bunch length (σ_{rms})	60	mm
Average beam current	0.69	A
Charge per bunch (Q_b)	30.5	nC
Number of bunches (M)	290	NA
Beam energy	275	GeV

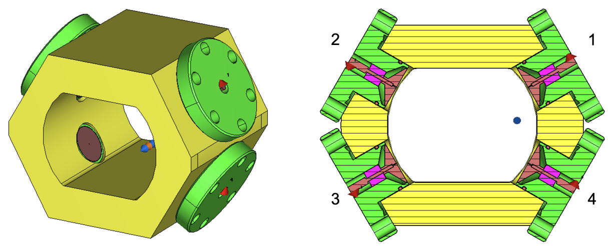


Figure 1: Corner button designs: perspective view (left), and cut view with labelled output ports (right).

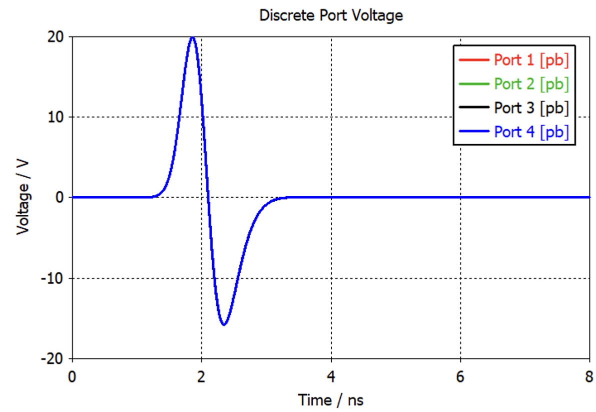
bottom symmetry, with two buttons on top and two at the bottom. This design aims to address the large asymmetric RW loss due to an offset beam observed in the initial orthogonal design. Despite the improvement in the asymmetric RW loss reduction, the side-by-side button configuration had issue with beam position sensitivity and the noise sensitivity. Furthermore, the BPM pick-up feedthroughs and cryogenic cables must be connected in the vertical plane in both orthogonal and side-by-side designs which introduces interference and complexity during their installation and replacement due to unavoidable hardware elements such as the He-cooling channels residing the the vertical plane.

Thus, we also discarded this design. Finally, we developed another BPM pick-up geometry, by rotating the buttons at the corner of the beam screen profile which we called *corner-button design*. we discuss this design in the following section.

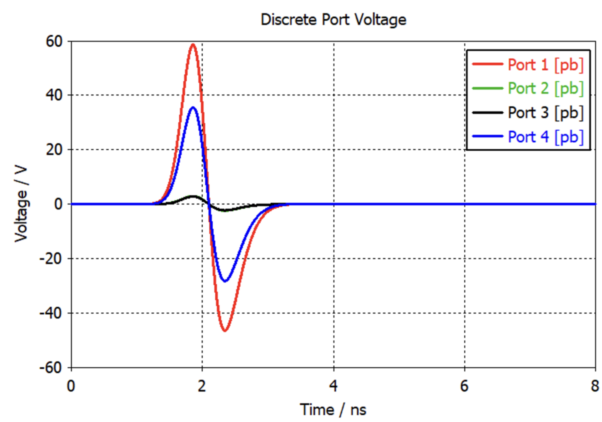
CORNER BUTTON DESIGN

The BPM pick-up with corner button design involves rotated buttons from the horizontal and vertical planes and are placed at the four corners of the BPM housing as shown in Fig. 1. Recently updated corner button design has flat buttons having a diameter of 18 mm, and 250 μm gap between the button and its housing (also called button body). The buttons and their bodies (green colored geometry in Fig. 1) are recessed to 225 μm from the profile of BPM pick-up housing to provide enough tolerances for fabrication and not protrude buttons inside the housing.

Initial corner button design had curved buttons to match the profile of the BPM housing and to avoid discontinuities. However, the fabrication cost associated with the curved buttons having tight tolerances ($\sim \mu m$) is very high compared



(a) Beam on-axis



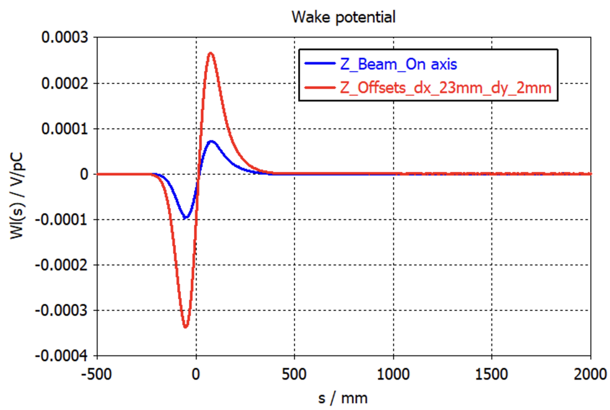
(b) Beam with dx = 23 mm, and dy = 2.0 mm

Figure 2: Voltage signals produced by the HSR cryogenic BPM with corner button design, where the red, green, black, and blue respectively denote the output signal from port 1, port 2, port 3, and port 4.

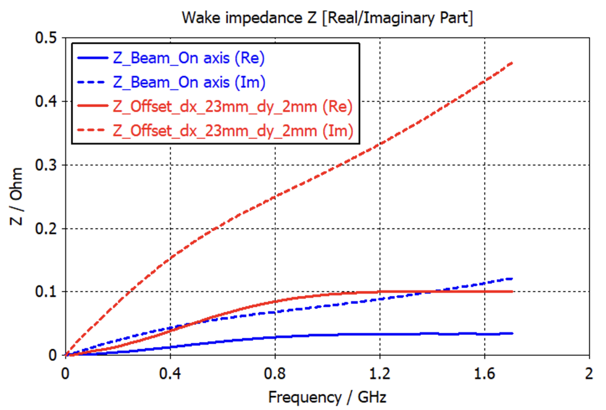
to the flat buttons. In addition, the initial design had slightly larger button diameter (20 mm) and the wider gap between the button and its housing (500 μm). We reduce the button diameter from 20 mm to 18 mm to reduce beam-induced heating without compromising the signal strength. The gap between the button and its housing is lowered from 500 μm to 250 μm to reduce beam coupling impedance.

We performed CST simulations for this corner button design using the HSR proton beam parameters listed in Table 2 to analyze the output signals. We placed four discrete ports to record the output signals as labelled in Fig. 1 (right). For the on-axis beam, all four buttons remain geometrically symmetric, and hence the corresponding output signals overlap with each other as shown in Fig. 2 (a). In contrast, for the offset beam with horizontal offset, dx = 23 mm (20 mm from radial offset and an additional 3 mm associated with the mechanical tolerance of the BPM-bellows assembly) and vertical offset, dy = 2 mm, the amplitude of voltage signals differs significantly. The pick-up closer to the beam (port 1) receives the highest voltage while the pick-up far from the beam (port 3) receives the lowest voltage, Fig. 2 (b). The

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPG10



(a) Wakefield comparison



(b) Impedance comparison

Figure 3: Wakefield and Impedance comparison between the beam on axis and beam with radial offset.

amplitude of the voltage signal at the port 2, and port 3 are mostly the same.

We also simulated the longitudinal wakefield and the corresponding beam coupling impedance for the latest BPM pick up geometry with the HSR proton beam parameters listed in Table 2. Fig. 3 (a) depicts the longitudinal wakefield comparison between the on axis beam (blue curve), and the beam with horizontal offset, dx = 23 mm and the vertical offset, dy = 2 mm (red curve). Similarly, Fig. 3 (b) compares the longitudinal impedance between the on axis beam (blue curves) and the beam with radial offsets: dx = 23 mm and dy = 2 mm (red curves). In Fig. 3 (b), the solid curves represent the real part of the impedance while the dashed curves denote the imaginary part. The beam with radial offsets produces larger wakefield and impedances as expected.

RW LOSS CALCULATION

Finally, we evaluated beam-induced RW losses on the individual components of the HSR cryo-cooled BPM pick-up, with beam parameters specified in Table 2, along with a horizontal beam offset of 23 mm and vertical offset of 2 mm. Moreover, we assumed the buttons and BPM housing are made of annealed copper with a room temperature conductivity of 5.8×10^7 S/m. Fig. 4 shows the RW losses obtained from CST simulation, where we observed maximum loss on the top right button and its housing as it is very close to the radially offset beam. We have performed thermal analysis by using the value of these RW losses along with the heat conduction via cryogenic cables from room temperature to cryogenic temperature for the initial corner button design with curved buttons. The thermal analysis for the cryogenic BPM pick up, is found in [7, 11–13].

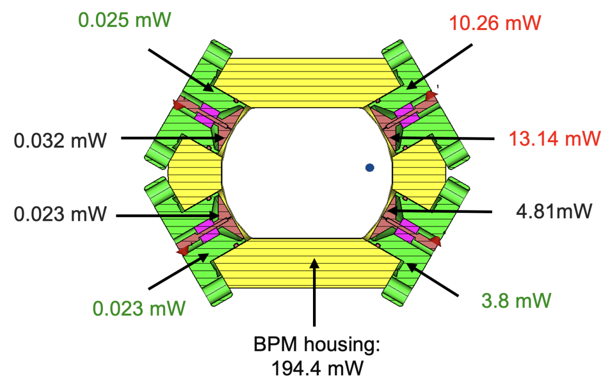


Figure 4: RW losses on the individual components of the HSR BPM pick up.

SUMMARY

In this paper, we presented the design of the EIC HSR cryogenic BPM pick-up. The latest corner button design with flat buttons seems to be the best choice from both physics and mechanical engineering perspective. In this design, the button near the offset beam receives an acceptable amount of beam induced heating. In addition, we have sufficient room to control the tolerance of the buttons in the BPM housing so that they don't protrude inside the housing profile. Finally, this design minimizes the chance of beam directly hitting the button surface since they are rotated up and down from the horizontal plane. We plan to investigate on the position and noise sensitivity for this design in future.

ACKNOWLEDGEMENTS

We acknowledge the U.S. Department of Energy, Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 for providing the funding for this research.

REFERENCES

[1] Electron-Ion Collider. `https://www.bnl.gov/eic/`

[2] C. Montag, E. C. Aschenauer, *et al.*, "Design Status Update of the Electron-Ion Collider", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 2585–2588. `doi:10.18429/JACoW-IPAC2021-WEPAB005`

[3] F. Willeke and J. Beebe-Wang, "Electron Ion Collider Conceptual Design Report", *Office of Scientific and Technical Information (OSTI)*, 2021. `doi:10.2172/1765663`

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPG10

[4] C. Montag *et al.*, “Electron-Ion Ccollider Design Status”, in *Proc. IPAC’22*, Bangkok, Thailand, June 2022, pp. 1954–1957. doi:10.18429/JACoW-IPAC2022-WEPOPT044

[5] F. Micolon *et al.*, “From RHIC to EIC hadron storage ring – overview of the engineering challenges”, presented at IPAC’24, Nashville, TN, USA, May 2024, paper TUBD1, this conference.

[6] S. Peggs *et al.*, “Large Radial Shifts in the EIC Hadron Storage Ring”, in *Proc. IPAC’21*, Campinas, Brazil, May 2021, pp. 1443–1446. doi:10.18429/JACoW-IPAC2021-TUPAB042

[7] F. Micolon, D. Gassner, C. Hetzel, I. Pinayev, M. Sangroula, and S. Verdu-Andres, “Thermal simulation of the HSR arc BPM Module for EIC”, Brookhaven National Lab.(BNL), Upton, NY (United States), Tech. Rep., 2023. doi:10.2172/1969913

[8] P. Thieberger *et al.*, “High intensity RHIC limitations due to signal heating of the cryogenic BPM cables”, Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider, Tech. Rep. BNL-101119-2013-CP, 2013. doi:10.2172/6923284

[9] M. Sangroula, C. Liu, M. Minty, and P. Thieberger, “Feasibility of using the Existing RHIC stripline BPMs for the EIC”, in *Proc. IPAC’21*, Campinas, Brazil, May 2021, pp. 3077–3080. doi:10.18429/JACoW-IPAC2021-WEPAB194

[10] CST Studio Suite. https://www.3ds.com/products-services/simulia/products/cst-studio-suite/solvers/

[11] F. Micolon and others., “Thermal Engineering of the Cryogenic Beam Position Monitors for the EIC Hadron Storage Ring”, in *Proc. CEC-IMC 23*, 2023.

[12] M. Sangroula *et al.*, “Beam Induced Heating Analysis Update For The EIC Vacuum Chamber Components”, Brookhaven National Laboratory (BNL), Upton, NY (United States), Tech. Rep., 2023.

[13] M. Sangroula *et al.*, “Update on the beam-induced heating and thermal analysis for the EIC vacuum chamber components”, presented at IPAC’24, Nashville, TN, USA, May 2024, paper MOPS21, this conference.