A highly sensitive resonant Schottky detector developed for the HIAF-SRing

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Date: 2026-03-25T19:49:26+00:00

Abstract

Resonant cavity Schottky detectors are powerful beam diagnostic devices which have been widely used in heavy-ion storage ring facilities worldwide. Aiming for a high signal-to-noise ratio and superior time resolution, a new cylindrical Schottky cavity detector with copper coating on the inner surface was developed and deployed in the HIAF-SRing Spectrometer Ring. The ultimate goal of the novel detector is to detect a single particle with a high signal-to-noise ratio (SNR). The detector operates at a nominal resonance frequency of 308 MHz (2.75 MHz tunable) and achieves a loaded Q-factor of 10, 000, ranking it as the top performer for heavy- ion detection among similar devices globally. The design considerations, simulation results, and measured performance of this cavity are presented in this work.

Full Text

Preamble

A highly sensitive resonant Schottky detector developed for the HIAF-SRing∗

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Resonant cavity Schottky detectors are powerful beam diagnostic devices which have been widely used in heavy-ion storage ring facilities worldwide. Aiming for a high signal-to-noise ratio and superior time resolution, a new cylindrical Schottky cavity detector with copper coating on the inner surface was developed and deployed in the HIAF-SRing Spectrometer Ring. The ultimate goal of the novel detector is to detect a single particle with a high signal-to-noise ratio (SNR). The detector operates at a nominal resonance frequency of 308 MHz (2.75 MHz tunable) and achieves a loaded Q-factor of 10, 000, ranking it as the top performer for heavyion detection among similar devices globally. The design considerations, simulation results, and measured performance of this cavity are presented in this work.

Keywords

Spectrometer ring (SRing); Non-destructive diagnostics; Schottky mass Spectrometry; Resonant cavity; Copper coating

INTRODUCTION

Ion Research in Europe (FAIR) CR in Darmstadt, Germany [12] and the High Intensity heavy-ion Accelerator Facility 30 (HIAF) SRing in Huizhou, China [13], which are expected 31 to further enhance the research capabilities of heavy-ion stor32 age ring mass spectrometer. It will have a profound impact 33 on fundamental nuclear physics research, the advancement of 34 nuclear structure theories, and simulations in nuclear astro35 physics.

Currently, there are three operational heavy-ion storage ring facilities in the world, namely the experimental stor4 age ring (ESR) at GSI [1], the experimental Cooler Storage 5 Ring (CSRe) at the Heavy Ion Research Facility in Lanzhou 6 (HIRFL) [2] and the Rare-RI Ring at RIKEN [3]. Schottky 7 mass spectrometry was implemented at all three of these fa8 cilities [4–6]. A 245 MHz resonant pick-up for the detection 9 of heavy ion Schottky noise was successfully designed, man10 ufactured, and commissioned for the ESR storage ring at GSI 11 in 2010 [7]. A similar 245 MHz resonant cavity detector was 12 also installed at the cooler storage ring CSRe at IMP in 2011 13 [8, 9], where the ceramic pipe with a thickness of 9.5 mm and 14 a length of 67 mm in the beam direction is used to form a 15 gap and to seal the vacuum tube. The loaded QL values of 16 both Schottky resonant pick-ups are approximately 500. In 17 2015, a 173 MHz resonant Schottky pick-up was developed 18 and installed in the Rare-RI Ring at RIKEN with QL 940 19 [10]. In 2018, an improved design of a longitudinally sen20 sitive 410 MHz resonant cylindrical Schottky cavity pickup, 21 installed on ESR and finally on the heavy-ion storage rings of 22 the

FAIR project, was reported with loaded QL 1500 [11]. 23 The main advantage of using resonant cavities as Schottky 24 pickup is the increased sensitivity at the cavity’ s resonance 25 frequency, allowing a higher signal-to-noise ratio.

Schottky mass spectrometry is also planned for the future 27 storage ring facilities under construction: the Antiproton and

∗ Supported by the National Key Research and Development Program of

China (2023YFA1606401), NSFC(Grants No. 12121005, Young Scholar of Regional Development, CAS ([2023] 15), Major Science and Technology Projects in Gansu Province under Grant No.24GD13GA005. Corresponding authors: Junxia Wu: wujx@impcas.ac.cn, Xinliang Yan: yanxinliang08@impcas.ac.cn.

The HIAF project was proposed by the Institute of Modern Physics (IMP) of the Chinese Academy of Sciences (CAS) 38 to provide high-intensity heavy ion beams for nuclear and 39 atomic physics, as well as other applications [14]. The HIAF 40 facility consists of a superconducting electron cyclotron res41 onance ion source (SECR) [15, 16], an ion Linac accelera42 tor (iLinac) [17–20], a booster ring (BRing) [21–23], a high43 energy radioactive beamline (high energy fragment separator 44 (HFRS)) [24–26], a spectrometer ring (SRing) [13, 27–29] 45 and several experimental terminals.

The Spectrometer Ring (SRing) is an essential part of the HIAF in China. It is designed as a multifunctional experimen48 tal storage ring that will operate in three ion-optical modes. 49 The SRing will be used as a time-of-flight (TOF) mass spec50 trometer for short-lived, especially neutron-rich nuclei. How51 ever, Bρ-calibrated IMS based on TOF detectors [30, 31] has 52 inherent limitations: TOF detectors typically employ a car53 bon foil approximately 100 nm thick, which generates sec54 ondary electrons as ions pass through, producing a signal. 55 However, this process causes energy loss in the ions, limit56 ing their maximum storage time to typically less than 1 ms 57 and thus preventing accurate lifetime measurements. In addi58 tion, the SRing will be used to collect and cool Rare Isotope 59 Beams (RIBs) and highly charged stable ion beams for nu60 clear and atomic physics experiments. The normal mode of 61 the High-Precision SRing is designed to prepare high-quality 62 RIBs for Schottky mass spectrometry experiments [13]. The 63 scientific objectives of the HIAF SRing storage ring Schot46

tky spectrometer include precise measurements of the masses, lifetimes, and exotic decay modes of short-lived atomic numodes. The kinetic quantities are calculated for the isochronous 66 clei; studies of nuclear structure, symmetries, and nuclear ions. 67 processes in astrophysical environments; and single-ion senIsochronous mode 68 sitivity.

As mentioned above, one of the aims of SRing Schottky β (v/c) frev (MHz) 70 mass spectrometry experiments is to achieve single-ion meaEk (MeV u-1) 71 surement with a higher signal-to-noise ratio. To achieve a 72 high signal-to-noise ratio and better time resolution, enabling 73 detection of important physical information about fast pro74 cesses, an improved design of a longitudinally highly sensi75 tive resonant cylindrical Schottky cavity detector with a cop76 per coating for the HIAF project is reported in the paper. 77 In addition, in order to improve the measurement accuracy 78 of isochronous mass determination for short-lived radio nu79 clides, a position-sensitive Schottky resonant cavity is under 80 development and will be installed near the longitudinally res81 onant cylindrical Schottky cavity for SRing in the next step.

The remainder of this paper is organized as follows. Sec83 tion II is devoted to describing the requirement specifications 84 of the cavity, including the choice of resonant frequency and 85 minimum R/Q calculation, RF simulation design using both and two cylindrical cavities, with and without copper coating, are 86 CST software and ANSYS high-frequency structure simulainstalled on symmetrical arc segments. 87 tion (HFSS), and the mechanical structure design and con88 struction of the cavity, including the total deformation and 89 static structural equivalent stress of the cavity calculation us118 A. Requirement Specifications 90 ing ANSYS software. Section III presents the measured per91 formance of the cylindrical cavity, including resonant fre119 The revolution frequency, frev , of an ion depends on its 92 quency, unloaded Q (Q0), loaded Q (QL), bandwidth and 120 mass-to-charge ratio m/q and velocity v. The quantitative 93 R/Q map for SRing resonant Schottky detectors. In addition, 121 relation among their relative deviations can, to a first-order 94 the resonant Schottky pick-up hardware system for SRing 122 approximation, be formulated as [32]: 95 is described. The summary and the concluding remarks are 96 given in Section IV. γ 2 δv 1 δ(m/q) δfrev + 1− 2 γt (m/q)

Where γ is the relativistic factor of the beam and γt is the transition energy of the ring, which is governed by the ion 126 optics.

Suppose we require that the cavity allows for a competitive The SRing can be operated as an isochronous mass spec- 128 mass resolving power m of 4.0 × 105 within a short time 100 trometer once the ion optics is tuned isochronously [13]. 129 of 13.11 ms. The frequency resolution δf is then 76.29 Hz, 101 To accommodate a broader nuclide region near the nuclear 130 according to the reciprocal relation of the Fourier transfor102 drip lines, the SRing will incorporate three isochronous ion131 mation. To retain mass resolving power, the cavity must res103 optical settings with transition energies of 1.43, 1.67, and 132 onate at a higher harmonic. The formula for calculating mass The comparison among these isochronous modes is 133 resolving power is as follows [33]: 105 presented in Table 1 . Figure 1 [FIGURE:1] shows the layout of SRing. 1 1 f0 106 Two Schottky cavities with and without copper coating are inR= 107 stalled in the symmetrical arc segment of SRing. The SRing 2.35 γt2 δf 108 Schottky experiment employs a two-stage measurement strat109 egy. In the first stage, a non-copper-coated cavity with a low 135 The resonant frequency f0 can be estimated from Eq. (2): 110 Q factor (i.e., wide bandwidth) is used to perform particle f0 = 2.35γt2 δf = 242.7 MHz 111 identification over a broad frequency range, enabling simul- 136 112 taneous monitoring of multiple ion species in the beam. In 113 the second stage, a copper-plated cavity with a high Q fac- 137 Since γt = 1.84 represents the least favourable scenario in 114 tor (narrow bandwidth, high sensitivity) is utilized for single- 138 Table 1, any resonant frequency higher than 242.7 MHz will 115 particle Schottky signal detection, which is essential for high- 139 deliver a better mass resolving power than 4$×$10 for all three 116 precision mass measurements or studies of short-lived sec- 140 modes. 117 ondary beams with lifetimes on the order of milliseconds.

Assume that the rectangular beam pipe is 309 mm ×

DESIGN AND CONSTRUCTION OF THE RESONANT CAVITY

90 mm, the first mode of the rectangular beam pipe is the TE10 mode, and the cut-off frequency is:

= 485.4 MHz

Where c is the speed of light, and a is the length of the rectangular beam pipe. λc is the cut-off wavelength. To prevent 147 the excited electromagnetic wave from propagating along the 148 rectangular pipe, the resonant frequency of the Schottky cav149 ity should be less than the cut-off frequency of 485.4 MHz. 150 Therefore, the Schottky cavity’ s resonant frequency must be 151 between 242.7 MHz and 485.4 MHz.

The Schottky signal power PSch of the ion: PSch = (qfrev)

The power of thermal noise, Pth , is given by: Pth = kB T δf

tuner ports, and one coupling port, the rectangular beam pipe located in the cavity centre with 309 mm × 90 mm aperture size.

where kB is the Boltzmann constant, and T is the absolute temperature of the detection system.

Suppose that a single ion with a moderate charge state of 159 16 is circulating in the SRing, the ion optics of the SRing is 160 assumed to be stable during 13.11 ms (δf = 76.29 Hz), the 161 signal-to-noise ratio is estimated to be 4:1 for the ion on the 162 central orbit, QL is moderately assumed to be 10000, note 163 that frev is the revolution frequency. Then Rsh /Q0 can be 164 estimated using Eqs. (5) and (6):

2kB T δf PSch = 45.8 Ω QL (qfrev)2 Pth

RF simulation of cylindrical cavity

Two commercial simulation software packages, Computer Simulation Technology (CST) [34] and ANSYS High169 Frequency Structure Simulation (HFSS) [35], are used to per- 189 that the larger the side length of the tuner, the larger the tun170 form numerical simulations of the cavity’ s electromagnetic 190 ing range of the tuning frequency. For square plunger side 171 parameters. Figure 2 [FIGURE:2] shows the CST simulation model of the 191 lengths of 40 mm, 60 mm, and 80 mm, the tuning frequency 172 SRing cylindrical cavity with

Figure 3

Figure 1: Figure 3

Figure 7

Figure 2: Figure 7

two frequency-tuning ports and 192 ranges are approximately 1 MHz, 2.3 MHz, and 5 MHz, re173 one coupling port. The diameter of 752 mm and a 309 mm 193 spectively. At the same time, when side length D = 40 mm, 174 × 90 mm rectangular beam pipe located in the cavity centre. 194 60 mm and 80 mm, the unloaded Q value of stainless steel 175 The cavity length in the beam direction is 200 mm. The dis- 195 cavity reduced by 350, 250, and 100 from 5200, as shown in 176 tribution of TM010 mode electromagnetic fields in the cross- 196 figure 5 FIGURE:5. 177 section of the cavity shows that the electric field amplitude is 197 The simulated unloaded Q and R/Q for different cavity 178 maximum and the magnetic field is minimum at the centre of 198 lengths L of stainless steel cavity are shown in Table 2 , where 179 the cylindrical cavity, as shown in Figure 3

. The resonance 199 L is the length of the cavity in the beam direction. From Table 180 frequency simulation results of the cylindrical cavity using 200 2, the larger the cavity length L, the larger the R/Q and the 181 both CST and HFSS are 308.5 MHz and 308.6 MHz, respec- 201 unloaded Q of the cavity, so we finally choose L = 200 mm. 202 Fig. 6 [FIGURE:6] shows the calculated transit time factor as a function of 182 tively.

Two symmetrical square plungers are mounted on the cav- 203 β. For a typical kinetic energy during experiments of about ($\beta = 0.73$), the transit time factor is approxi184 ity to tune the resonant frequency, as shown in Figure 4 [FIGURE:4]. D is 204 430 MeV u 185 the side length of the square tuner, and the blending radius of 205 mately 0.8 when L = 200 mm,according to Fig. 6. The tran186 the square tuner is 10 mm. The Depth = 0 means the square 206 sit time factor approaches zero at low velocities near $\beta = 0.1$, 187 plunger is outside the cavity, and the Depth = 150 means the 207 indicating that the resonant Schottky cavity is better suited 188 square plunger is inserted into the cavity. Fig. 5(a) shows 208 to a high-beta situation. Fig. 7

shows the calculated R/Q

beta is larger than 0.5 (145 MeV u−1), the R/Q is maximum for L = 200 mm. To evaluate the welding deformation and 212 thermal expansion and contraction deformation after 250 °C 213 bake-out of the cavity, the resonant frequency of the cavity 214 for the fundamental monopole mode for different L values in 215 0.1 mm steps are simulated, as shown in Fig. 8 [FIGURE:8]. When the L 216 size changes by 0.5 mm and 1 mm, the frequency shifting of 217 8.5 kHz and 16.3 kHz occur, respectively.

cavity without copper coat, where the symmetrical square plungers are driven by the Beckhoff motor.

monopole mode at the geometric centre and for different relativistic beta values in 0.05 steps.

mm, 60 mm and 80 mm when tune Depth is from 0 to 150 mm (a) resonant frequency, (b) unloaded Q value.

the beam direction. Unloaded Q L = 110 mm L = 150 mm L = 200 mm β = 0.73 L = 110 mm L = 150 mm L = 200 mm

mode at the geometric centre and for different relativistic beta values in 0.05 steps.

as a function of β for different lengths of cavity L. When

mm steps.

the mechanical setup with the double-step Beckhoff servo motors is shown, which allows a remote control of the frequency tuners' movement. The diameter of the main coupler port is 50 mm. The thickness of the end plates at both ends of the 316L stainless steel cavity is 15 mm. The thickness of the 316L stainless steel body is 8

Mechanical design of cylindrical cavity

The resonant cavity is a pillbox with an inner diameter of 752 mm and a length of approximately 200 mm. The fre221 quency tuners are moved left and right by a step motor mech222 anism, as shown in Fig. 9 [FIGURE:9]. To ensure a frequency shift of 223 somewhat more than 2 MHz without perturbing the field ge224 ometry too much, two frequency tuners are mounted, one for 225 each dee. The entire resonant cavity body must be bakeable 226 to 250 °C to achieve a vacuum of 1.0 × 10 mbar for SRing. 227 To mitigate vacuum pressure-induced deformation, 15 mm228 thick end plates at both ends of the 316L stainless steel cav229 ity are selected. In addition, 20 × 20 mm stiffening ribs are 230 chosen to further reduce the cavity deformation. The total de231 formation and static structural equivalent stress of the cavity 232 are calculated using ANSYS. Figure 10 [FIGURE:10] shows that the max233 imum deformation and static structural equivalent stress are 234 0.45 mm and 72 MPa, respectively, under the vacuum condi235 tion. The frequency shift is approximately 8.5 kHz when the 236 cavity deformation is 0.45 mm, which is much smaller than 237 the tunable frequency of 2.75 MHz, thereby meeting the de238 sign requirements.

m; (right) static structural equivalent stress calculation.

MEASURED PERFORMANCE OF THE CYLINDRICAL CAVITY

For a cavity, three different quality factor relations are defined:

In general, the quality factor Q of a resonant circuit is de242 fined as the ratio of the stored energy W to the energy dissi251 Where Q0 (unloaded Q) is the Q factor of the unperturbed 243 pated in one cycle, power loss P : 252 system, Q (loaded Q) is the Q factor of the cavity when con250

nected to the generator and measurement circuits, and Qext (8) 254 (external Q) is the Q factor that describes the degeneration 255 of Q0 due to the generator and diagnostic impedances. By 256 adjusting the main coupler, when the cavity is at a critical 245 The Q factor for a resonance cavity can be calculated via the 257 coupling condition (Qext = Q0), the relation simplifies to 246 3 dB bandwidth Δf and the resonance frequency f0 : 258 QL = Q0 /2.

Two Schottky resonant cavities are manufactured and in247 (9) 260 stalled on the SRing symmetrical arc segments, where the

dispersion is maximum. One of the stainless steel cavities is coated with copper to detect a single particle with a high 263 signal-to-noise ratio, as shown in Fig. 11 [FIGURE:11]. Fig. 12 [FIGURE:12] shows the 264 magnitude of S11 in dB measurement results for both cav265 ities with and without a copper coat are obtained using the 266 Rohde and Schwarz (R&S) ZVN-20 2-port vector network 267 analyzer (VNA). The resonant frequency can be tuned from 268 308.45 MHz to 311.20 MHz, with a tuning range of approx269 imately 2.75 MHz when the double tuners are moved from 270 outside (tuner depth = 0 mm) to inside (tuner depth = 140 mm) 271 of the cavity. When the double frequency tuners are outside 272 the cavity (tuner depth = 0 mm), the smith chart of S11 of the 273 cavity with and without a copper coat are measured by VNA, 274 and the cavity is on critical coupling condition, as shown in 275 Fig. 13 [FIGURE:13]. The resonant frequency, bandwidth, unloaded Q and 276 loaded Q measurement results are summarised in Table 3 . 277 The loaded Q value of the SRing resonant cavity with cop278 per coat is larger than 10000, which is 20 times higher than 279 500 for the CSRe and ESR 245 MHz Schottky cavities. Fur280 thermore, the vacuum of the two cavities after baking out at 281 250 °C for 72 hours is better than 1.0 × 10 mbar, meeting 282 the vacuum requirements for the SRing.

outside of the cavity and the tuner depth = 0 mm, (b) when the double tuners are inside of the cavity and the tuner depth = 140 mm. The tunable frequency is around 2.75 MHz.

SRing, (right) detailed views of an inside corner of the stainless steel 288 Where lrod is the efficient length of the ceramic rod, Vrod cavity with copper coating with 180 µm to 200 µm thickness. 289 is the volume of the rod, ϵr is the relative permeability,

$ $0 = 8.85 × 10−12 F m−1 is the vacuum permittivity, Δf is 291 the difference between the resonant frequencies of an empty 292 cavity and one with a rod inserted into the centre, and f0 is 293 the resonant frequency of the empty cavity. A long, thin celoaded Q for SRing stainless steel cavities without and with a copper coat. Here, the double tuners are outside the cavity, with a tuner 294 ramic alumina rod with permittivity ϵr = 9.9 is used for the 295 measurement. The measured R/Q contour map is shown in depth of 0 mm. 296

Figure 14 [FIGURE:14]; the measurements indicate that R/Q is approxiCavity type Resonant freq (f0) Q0 QL Bandwidth 297 mately 149 when the ceramic rod is located at the cavity cenWithout copper coat

308.66 MHz

4719 2410 128 kHz 298 tre, which agrees with the simulated R/Q value of 163 (see With copper coat

308.45 MHz

20563 10278 30 kHz 299 Table 2). Based on the difference between the resonant frequency of 300 A 100 MHz - 2 GHz low noise amplifier (LNA) with 39.5 284 the empty cavity and the cavity with a ceramic rod inside, an 301 dB gain and less than 0.7 dB noise figure (B&Z-Technologies 302 BZP102UB1) is connected to the main critical coupling port Q0 value at the rod position can be calculated using Ehren303 of the resonator. Since the B&Z LNA is a wide-band am286 fest' s theorem [7]: 304 plifier, a bandpass filter (f0 = 308 MHz, Insertion loss = 2 1 lrod 305 1.8 dB@308 MHz, BW−3dB = 50 MHz) is necessary to pre287 306 vent inter-modulation in the following amplifier caused by π Vrod \$ 0(\$r − 1) f02

with highly permeable iron tape material developed by CERN [5] is used at SRing. The second B&Z LNA amplifies the sig312 nal to a level sufficient to transport it through the long coaxial 313 cable to the real-time spectrum analyzer (R&S FSVR7), as 314 shown in Fig. 15 [FIGURE:15]. The spectral noise power versus frequency 315 is recorded by the real-time spectrum analyzer, as shown in 316 Fig. 16 [FIGURE:16].

for SRing. A one-meter coaxial cable is used to connect the cavity and the first low noise amplifier. A 50 MHz bandpass filter added between the two B&Z low noise amplifier.

these points is Re(Z) = ± Im(Z) with the resonance circle in the detuned short position. The loaded Q can be determined from M4 and M5. The condition to find these points is |Im(S11)| → max. M3 is the resonant centre frequency of the cavity[36].

FSVR7 real time spectrum analyzer, when VBW = 1 kHz, RBW = 100 Hz, sweep time = 100 ms.

The first beam (18 O6+) was delivered by the HIAF facil2025. Two months later, on December 209 31+ beam was successfully produced, with a ceramic rod is 3 mm, the rod is driven by the Beckhoff servo motors, 319 27, 2025, a maximum extracted particle number of 3.166 × 1010 particles in the horizontal plane, the ceramic rod moved from -50 mm to 50 mm, in the vertical plane, the rod moved from -25 mm to 25 mm, 321 per pulse being achieved from the BRing. Pulses of exotic, the minimum movement step of ceramic rod is

5 mm. 322 short-lived ions were then injected into the SRing, where the 323 first Schottky mass spectrometry experiments in isochronous 324 mode were performed. During these experiments, a single 307 the wideband noise from the LNA. In addition, to minimize 325 Hg80+ particle was detected and recorded by the SRing 308 electromagnetic interference for the Schottky signal measure- 326 resonant Schottky system, which was observed to survive 309 ment, a 90 m long low transfer impedance (LTI) coaxial cable 327 in the SRing for approximately 200 seconds, as shown in

330 in Fig. 18 [FIGURE:18]. 343 achieves a loaded quality factor QL exceeding 10000 un344 der critical coupling conditions—representing a more than 345 20-fold improvement in sensitivity compared to the earlier 346 245 MHz Schottky detector (QL 500) used at the HIRFL347 CSR in Lanzhou and ESR at GSI and more than 6 times im348 provement compared to the new 410 MHz GSI Schottky cav349 ity. Furthermore, the cavity offers a tuning range of approx350 imately 2.75 MHz, providing sufficient flexibility to accom351 modate various isochronous operating modes of the SRing.

The cavity also meets stringent ultra-high vacuum require—11 353 ments, maintaining a pressure better than 1.0 × 10 354 after a 72-hour bake-out at 250 °C.

The measured reso355 nant frequency (308.4 MHz) and R/Q value (149 Ω) align 356 well with the simulated prediction (308.5 MHz and 163.7 Ω), 357 confirming the accuracy of the design methodology.Single358 particle sensitivity is the major goal for the development of 359 such detectors for the HIAF-SRing. A single Hg80+ partiFig. 17 [FIGURE:17]. A single 205 Hg80+ ion survived in the SRing for approx- 360 cle was detected successfully by the SRing resonant Schottky imately 200 seconds after injection; the main beams of 209 Bi31+ 361 detector with high SNR. In addition, the isomer decay prowere injected with 1 × 1010 particles per pulse, note that the discon- 362 cess also measured using the SRing highly sensitive resonant tinuity in the power spectrum of the 205 Pb80+ after the second in- 363 Schottky cavity system. jection results from the ongoing frequency sweaping using the tuner This high-performance detector lays a solid foundation of the Schottky detector. 365 for single-ion detection, high signal-to-noise ratio, and high 366 time-resolution Schottky mass spectrometry at HIAF-SRing. 367 It will significantly advance studies of fundamental proper368 ties—such as precise masses and lifetimes—of exotic nuclei 369 far from the β-stability line.

To eliminate measurement uncertainties arising from ve371 locity spread, a new position-sensitive Schottky detector sys372 tem for the HIAF-SRing has been developed and is under con373 struction. In the next step, it will be installed adjacent to the 374 308 MHz longitudinally intensity-sensitive resonant Schottky 375 cavity. This cavity doublet, consisting of an intensity cavity 376 and a position cavity, will further improve mass measurement 377 accuracy by correcting for intrinsic anisochronisms.

Acknowledgments The authors thank the staff of the ac379 celerator division of IMP for providing stable beam. 380 would like to extend our gratitude to Yuri A. Litvinov from Author Contributions GYZ: project management, matenant Schottky detector. Two ions, namely 207 Hg80+ and 207m Tl80+ , 382 were injected into the ring. The excited isomeric states decay into 383 rial preparation, data collection and analysis, first draft. JXW: ground state after. 384 conceptual design. XLY: funding management, set physical 385 parameters, and oversaw design, calibration, and manuscript 386 revision. DZ: Mechanical design and fabrication. JCZ: Me387 chanical control. Simulation and data acquisition are done IV. SUMMARY AND OUTLOOK 388 by YHW and ZSQ. All authors read and approved the final 389 manuscript.

In this work, we have successfully developed and char333 acterized a highly sensitive 308 MHz longitudinal resonant 334 Schottky pickup cavity with copper plating, specifically de335 signed for the SRing of the High-Intensity heavy-ion Accel- 390 DECLARATIONS 336 erator Facility (HIAF). The detector is engineered to enable 337 non-destructive single-particle beam diagnostics and support Conflict of interest The authors declare that they have no 338 high-precision mass measurements of short-lived exotic nu392 competing interests. 339 clei.

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