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Applying Heavy-Ion Storage Rings for Precision Experiments at the Intersection of Atomic, Nuclear and Astro-Physics

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The storage of freshly produced radioactive particles in a storage ring is a straightforward way to achieve the most efficient use of such rare species as it allows for using the same rare ion multiple times. Employing storage rings for precision physics experiments with highly-charged ions (HCI) at the intersection of atomic, nuclear, plasma and astrophysics is a rapidly developing field of research.

Until very recently, there were only two accelerator laboratories, GSI Helmholtz Center in Darmstadt, Germany (GSI) and Institute of Modern Physics in Lanzhou, China (IMP), operating heavy-ion storage rings coupled to radioactive-ion production facilities. The experimental storage ring ESR at GSI and the experimental cooler-storage ring CSRe at IMP offer beams at energies of several hundred A MeV. The ESR is capable to slow down ion beams to as low as 4 A MeV (β=0.1). Beam manipulations like deceleration, bunching, accumulation, and especially the efficient beam cooling as well as the sophisticated experimental equipment make rings versatile instruments. The number of physics cases is enormous. The focus here will be on the most recent highlight results achieved within FAIR-Phase 0 research program at the ESR.

First, the measurement of the bound-state beta decay of fully-ionized ^{205}Tl was proposed about 35 years ago and was finally accomplished in 2020. Here, the ESR is presently the only instrument enabling precision studies of decays of HCIs. Such decays reflect atom-nucleus interactions and are relevant for atomic physics and nuclear structure as well as for nucleosynthesis in stellar objects.

Second, the efficient deceleration of beams to low energies enabled studies of proton-induced reactions in the vicinity of the Gamow window of the p-process nucleosynthesis. Proton capture reaction on short-lived ^{118}Te was attempted in 2020 in the ESR. Here, the well-known atomic charge exchange cross-sections are used to constrain poorly known nuclear reaction rates.

The performed experiments will be put in the context of the present research programs at GSI/FAIR and in a broader, worldwide context, where, thanks to fascinating results obtained at the presently operating storage rings, a number of new exciting projects is planned. Experimental opportunities are being now dramatically enhanced through construction of dedicated low-energy storage rings, which enable stored and cooled secondary HCIs in previously inaccessible low-energy range. The first such facility, CRYRING, has been employed at GSI for first experiments with decelerated beams of HCIs from the ESR.

Thanks to the fascinating results obtained at the ESR and the CSRe as well as to versatile experimental opportunities, there is now an increased attention to the research with ion-storage rings worldwide. An isochronous storage ring for mass measurements, R3, has just been commissioned at RIKEN. Dedicated ring facilities are proposed for ISOLDE at CERN, TRIUMF, FRIB, LANL, and JINR.

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