UNLAC-UPGRADE PROGRAMME FOR THE HEAVY ELEMENT RESEARCH AT GSI-SHIP

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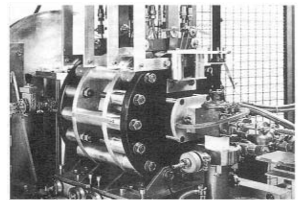
Abstract

In the field of heavy-element research using the velocity separator SHIP significant achievements were made at GSI during the last 30 years. The experiences obtained of experiments clearly show that superheavy-element research was always based on efforts to extend the limits of technical possibilities - of these the increase of beam intensity is one of the major contributions. This paper provides for technical information on the already planned upgrades of the present facility, which results in a significant overall increase of the experimental sensitivity. It is foreseen to build and to investigate a superconducting 28 GHz-ECR ion source, which should increase the primary beam intensities. The beam coming from the new ECR source will be delivered to the GSI-High Charge State Injector by a second LEBT-system. An upgrade program for the rf-amplifiers and the rf-structures is intended to increase the duty factor from 30 % to 50 %. Besides the ECR-source a new Radio Frequency Quadrupole-accelerator (RFQ) and the IH structure may alternatively serve as an injector for a new advanced stand alone accelerator providing for 100 % duty factor. Two different linac-layouts will be discussed.

INTRODUCTION

The velocity filter SHIP was designed for separation of nuclei of superheavy elements (SHEs). High beam transmission and high background suppression were the requirements. First experiments started at the end of 1975. During the first years of operation auxiliary equipment was developed, among which the rotating target wheel synchronized to the beam macro-pulses and the position-sensitive detector system, were the most important. The range of measurable lifetimes was considerably broadened, down to microseconds due to separation of the reaction products in flight and up to hours due to the newly developed position-time correlation method. After five years of development and testing, the new elements bohrium, meitnerium, and hassium were discovered in 1981, 1982, and 1984, respectively. The cross-sections for the synthesis of the new elements continuously decreased, and a value of 10 pb was measured for the production of meitnerium. Theoretical estimates for the synthesis of elements beyond meitnerium were depressing both, for cold fusion based on Pb or Bi targets as well as for hot fusion based on actinide targets.

Despite of the pessimistic prognosis technical developments were proposed and supported in the last 1.5 decades. Higher beam currents were achieved from an improved ECR source (gain factor 3.5) and by an increase of the accelerator duty factor from 22 to 28 % (factor 1.3) which became possible due to higher charge states of the projectiles from the ECR ion source (see Fig. 1). The upgrade was finished in 1994 and the three elements darmstadtium, roentgenium, and 112 were measured within two years [1,2,3]



Source and LEBT	
Ion source	ECR-type, 14.5 GHz
Charge-to-mass ratio	0.105 to 1
Extraction voltage	23.8 kV
Energy	2.5 keV/u (β = 0.0023)
Radial emittance	
(norm.)	0.46 π•mm•mrad
(unnorm.)	200 π•mm•mrad
Mass resolution	$\Delta m/m$ = 3•10^{-3}

Fig. 1: GSI-14.5 GHz-ECR ion source.

STATUS QUO

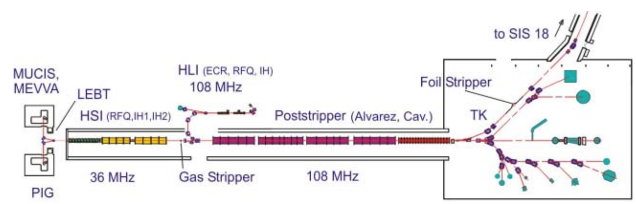


Fig. 2: Schematic overview of the GSI UNILAC and experimental area.

The layout of the GSI heavy ion linac UNILAC is shown in Fig. 2. The High Current Injector (HSI) delivers low charge state ions at 1.4 MeV/u to the gas-stripper section. Highly charged ion beams from the ECR ion source of CAPRICE-type are accelerated in the High Charge State Injector (HLI) consisting of an RFQ and an IH-resonator to a final beam energy of 1.4 MeV/u (see Fig. 3). Both injectors serve in a time-sharing mode for a 108 MHz Drift Tube Linac (DTL) of Alvarez-type and a subsequent single-gap resonator chain. Then the ion beam may either be injected into the SIS via a transfer channel or delivered to an experimental hall.

In the following years several changes at the HLI led to a significant gain in transmission of 40 % (from the RFQ to the target). A solenoid magnet behind the ECR permits

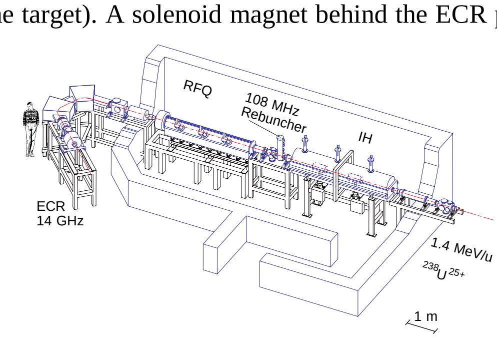


Fig. 3: Status Quo of the High Charge State Injector.

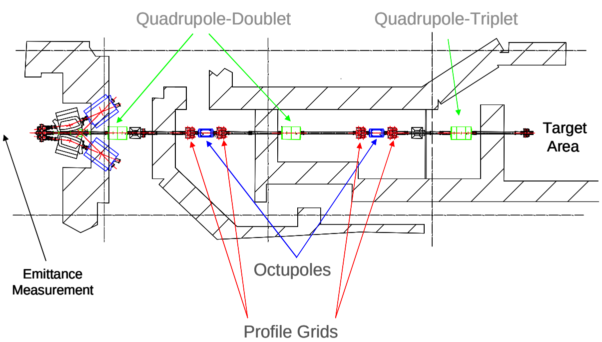


Fig. 4: Upgrade of the beam transport line to the SHIP; two quadruple duplets provide for a sufficient beam spot (measurable at four SEM-profile grids) performing rectangular profile shaping with two octupole lenses.

for better matching to the analyzing spectrometer magnet. The electrical field distribution in the IH structure was optimized by trimming the plungers. The improved longitudinal beam quality led to an almost loss-free beam transport through the 180º transport channel. The complete realignment of the HLI and beam transport lines contributed additionally to the better transmission. The beam from the HLI is mainly delivered to the set-up for super heavy element production (SHIP). Typical beam energies are roughly 5 MeV/u. Due to the peaked intensity distribution on centre of the target, the high thermal stress limited the tolerable beam intensity. In order to accumulate the same deposited dose within reduced beam time a transition from a nearby Gaussian to a uniform distribution was demanded. The use of octupoles in the beam transfer line to the experiment allows generating a nearby rectangular beam (see Fig. 4) [5]

UNILAC-UPGRADE PROGRAM

Three possible versions of accelerator upgrades for the GSI heavy element program have been worked out. All three upgrades are based on a new high charge state

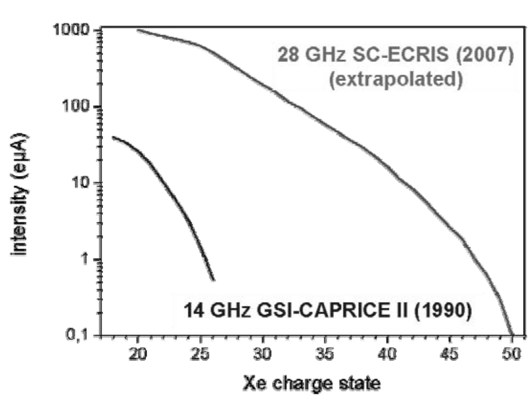


Fig. 5: Comparison of ECR-ion source types; mainly the increase of microwave frequency and the higher magnetic flux density (superconducting magnets) is responsible for the increased intensity of the sc-ECRIS-type ECR.

injector front-end consisting of an advanced ECR ion source and an improved RFQ-accelerator.

The biggest step for the increase of the beam intensity is expected from a new 28-GHz ECR ion source - this activity is supported through EURONS European Commission Contract No. 506065.

At a charge state of 18^+ of ^{136}Xe (A/q = 7.6), which was actually used in recent experiments, an increase of the beam intensity by a factor of 25 is expected. Important for the accelerator design is the fact, that also at higher charge states up to 30^+ higher particle numbers are obtained as possible presently (see Fig. 5). Besides the new branch starting with the 28 GHz-ECR source the existing 14-GHz ECR source will be still available. The

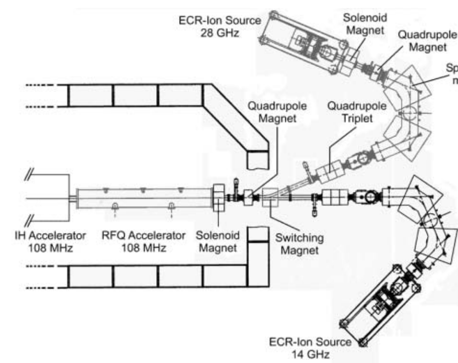


Fig. 6: Upgrade of the High Charge State Injector Front-end-System (schematic view); 28 GHz-ECR source, new LEBT, switching magnet and the new RFQ (in red).

beam coming from the new ECR source will be delivered to the HLI by a second LEBT-system. A new RFQ for high duty factor-operation and an improved beam dynamics design is proposed (see Fig, 6). An upgrade program for all rf-amplifiers and rf-structures is foreseen to increase the duty factor from 28 % to 50 % for medium heavy projectiles like ^{70}Zn, e.g. The following topics have to be investigated in the next future:

a. New LEBT (beam dynamics study for a beam from the new ECRIS)

b. Integration of a second LEBT-system

c. Matching to the RFQ (new RFQ input energy)

d. Beam dynamics design of a new RFQ (improvement of longitudinal beam dynamics)

e. Mechanical design of a new 50 % duty factor RFQ (cooling of electrodes)

f. Upgrade of the whole HLI for multi beam operation

g. Upgrade of the IH-structure allowing for the high duty factor-operation

The two other versions represent stand alone linear accelerators, both with a 100 % duty factor. In the first version the maximum energy is 6 MeV/u achieved by normal conducting IH structures subsequent to the existing 1.4 MeV/u injector. Finally, the second version uses a sc-linac behind the normal conducting injector.

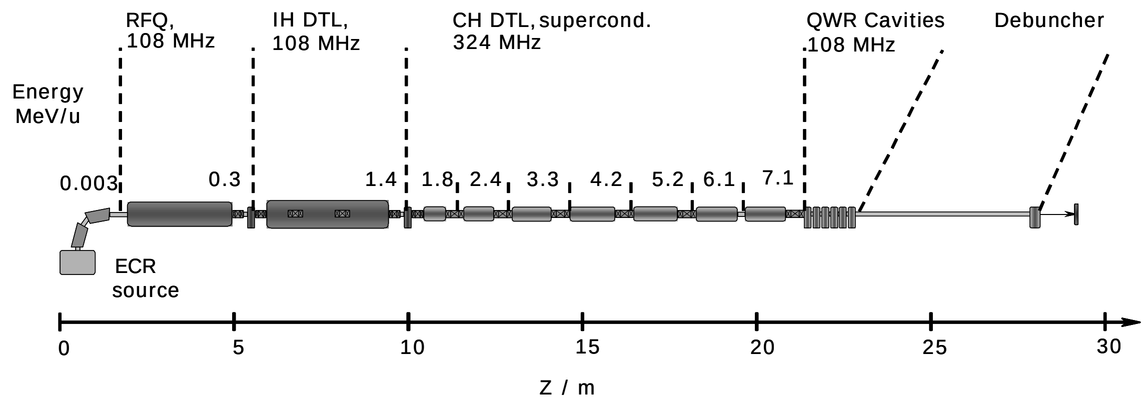


Fig. 7: Proposed layout of a cw-superconducting LINAC. [4]

LAYOUT OF A DEDICATED CW-LINAC

A first accelerator scenario has been developed and studied for the sc-version: An ECR ion source delivering a beam with a mass-to-charge ratio A/q below 7 is assumed. The final energy of the linac should allow for experiments at the Coulomb-barrier and has to be variable between 4.0 and 7.5 MeV/u. To reach high luminosities the linac operates in cw. Special care was taken to minimize the energy spread at the linac exit. Up to an energy of 1.4 MeV/u the linac looks like the HLI: Behind the ECR ion source the particles are accelerated by a 4-rod RFQ up to 0.3 MeV/u, followed by a room temperature IH-resonator. The electrical power needed to feed the rt IH cavity with its high shunt impedance of around 300 MV/m is comparable to a super-conducting linac consisting of sc quarter wave resonators. At 1.4 MeV/u the beam enters the super-conducting section of the linac. This part consists of 7 CH-resonators (Crossbar) [6]. The accelerating gradient inside these resonators were assumed to be 6 MV/m even for cw-operation, leaving a large safety margin. The final energy adjustment (+/- 0.5 MeV/u) between the rough steps delivered from the CH-cavities (typ. 1 MeV/u) has to be done by using short cavities (quarter wave resonators) due to the large velocity acceptance needed. The energy spread at the linac exit was found to +/-3 keV/u over the whole energy range (4.0 - 7.5 MeV/u).

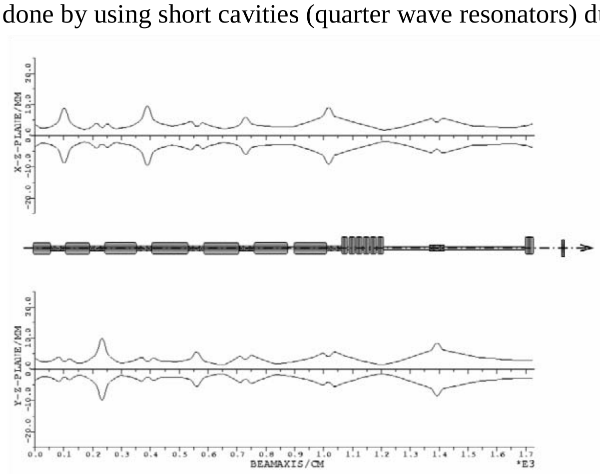


Fig. 8: First beam dynamics layout (transversal beam envelopes) of the sc-CH-drift tube linac.

OUTLOOK

For the next future it is intended to increase the projectile dose which can be achieved from the accelerator. This value determines the cross-section limits which can be reached or, at a given cross-section, the number of atoms which can be produced. As a reference we use ^{70}Zn and the expected currents for the sc-linac: During a period of 10 years and a beam availability of 300 days per year a maximum projectile dose of $1.8 \cdot 10^{22}$ can be obtained. At such a beam dose the number of experiments that can be performed at a cross-section level of 55 fb amounts to 593. A cross-section level of 0.093 fb can be reached in a 10 years experiment including pauses and breaks (present UNILAC: 196 years, UNILAC-upgrade: 34 years, nc-version: 22 years). This number appear peculiar, however, it reflects the number of experiments which can be performed presently and at the different versions of accelerator upgrades. [7]

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