STATUS OF THE SUPERCONDUCTING CW LINAC AT GSI

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The Helmholtzcenter for Heavy Ion research (GSI) is focusing on the Facility of Antiproton and Ion Research (FAIR) strongly. Providing highest energy beams the new facility will offer outstanding research opportunities and discovery potential in future [1]. Nevertheless, regarding the public impact the discovery of new elements is next to the cancer therapy with heavy ions still the flagship of GSI. It is an ongoing process to keep the super heavy element (SHE) program at GSI together with its international collaborations competitive on a high level. Providing high primary beam intensity by a dedicated accelerator is one import part therefore. A cost-benefit analysis has shown, that a superconducting (sc) continuous-wave (cw) linear accelerator (LINAC) in combination with the upgraded GSI High Charge Injectior (HLI) fits the requirements for the GSI SHE program at best [2]. A predicted increase of the beam intensity by a factor of 10 to 20, depending on the ion and charge state, would keep the successful and popular SHE program competitive with remarkable reduced operational costs in comparison with the existing accelerator at GSI. In the following the status of the cw LINAC project is reported and its perspectives are discussed.

1. HLI

The GSI HLI was commissioned in 1992 as the third injector for the Universal Linear Accelerator (UNILAC). The HLI is one of the reasons for the successful SHE program at GSI comprising a 14 GHz ECR ion source and a combination of a radio frequency quadrupole (RFQ) and an IH-type drift tube LINAC. The main aspect of the HLI upgrade is a second sc 28 GHz ECR ion source together with a new low energy beam transport (LEBT) and a new cw capable RFQ and IH (fig.1) [3].

The obvious arguments to start developing a new source are two:

i) The new source provides higher charge states, which has a positive influence on the accelerator design as the beam becomes less rigid. Lower electromagnetic fields are applied, which reduces the power consumption during operation.

ii) The predicted intensities of the new source are by a factor of 20 to 25 higher than the intensities measured for the existing 14 GHz source, the CAPRICE (fig.2).

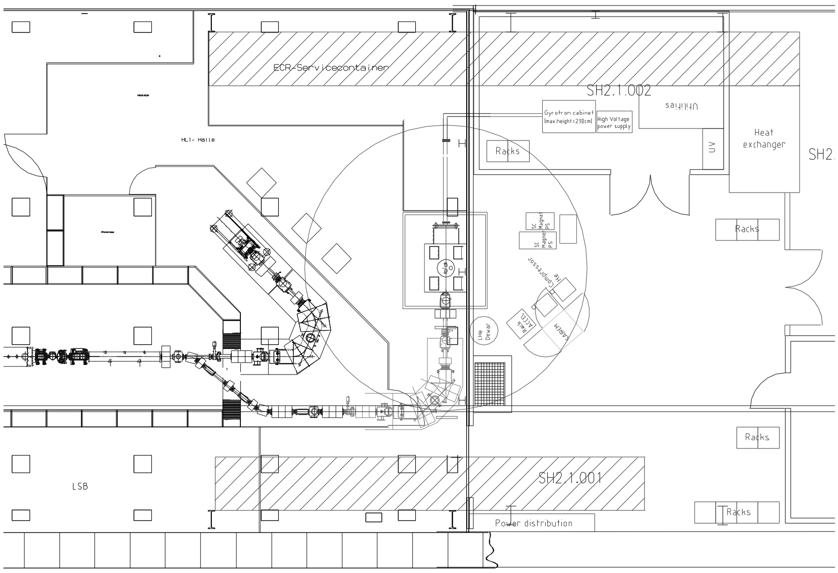

Fig.1 The upgraded HLI with the existing 14 GHz ECR (CAPRICE) and the planned 28 GHz ECR (MSECRIS), marked by a pink circle, is shown. A second LEBT is connected to the existing beamline.

The development of GSI, the MSECRIS, is still in the phase of research and development (R&D). A main challenge is the fully sc magnet system, which comprises three solenoids and one hexapole (fig.3).

Due to the superposition of the magnetic field forces of 30 tons have to be managed. The coils are fixed by a magnetic clamping system, which enhances the magnetic flux considerably, but doesn't limit the movement of the conductors within the required tolerances of 10^{-6} meters reliably.

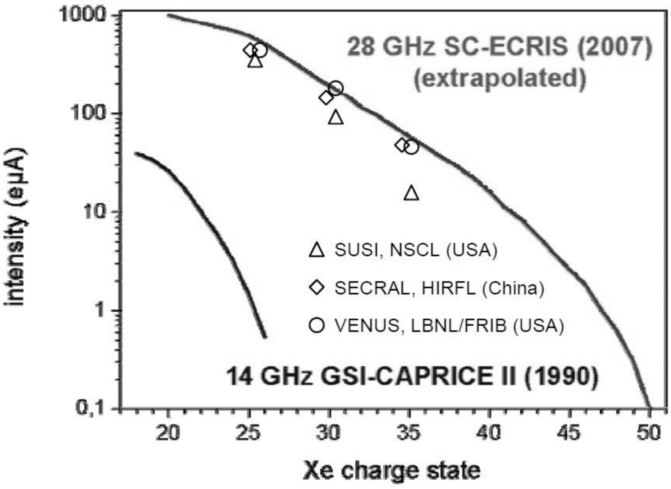

Fig.2 A comparison between the predicted intensities of the MSECRIS and the existing CAPRICE. In addition the intensities of other prominent 3rd generation ECR sources are shown, which were not measured in long-run operation [4].

Prominent ECR sources of the 3rd generation, which were developed by different institutes, are commissioned and tested already. The measured intensities are in the predicted range of the GSI 28 GHz Source, since they were not measured in long-run operation [4].

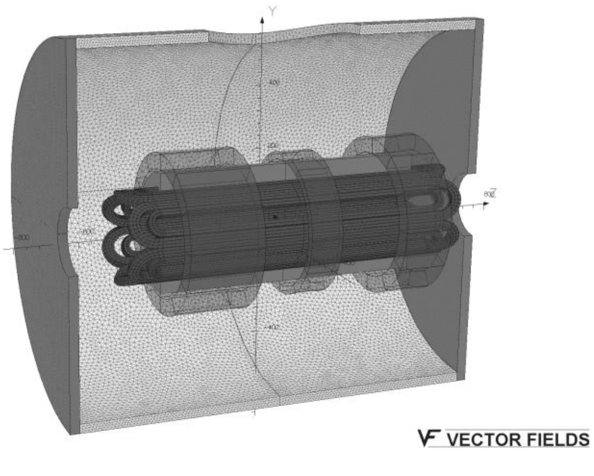

Fig.3 The fully sc magnet system of the MSECRIS comprising three solenoids and one hexapole.

Connecting the new 28 GHz ECR to the existing HLI a new LEBT is required. A conceptual layout was worked out comprising an analyzing magnet, deflecting and switching magnets, beam focusing elements, and the required beam diagnostics (fig.1). The components could be specified immediately and tendered. The new cw capable RFQ was commissioned in 2010 successfully. The working point of the RFQ amplitude could be defined straight forward by measuring the main output parameters. The emittance, the ion energy, and the transmission through the RFQ were measured as expected. The cw operation could not be established so far. The structure is very sensitive to thermal load, so as tuning the operational frequency is challenging [5]. Further R&D-activities are necessary for a reliable cw operation. Activities for an IH upgrade aiming at cw operation are discussed, but they are not yet worked out in detail.

2. Cw-LINAC and Demonstrator

The upgraded HLI is proposed to be the injector for the sc cw LINAC, which comprises nine sc cavities and seven sc solenoids. The conceptual layout was worked out with the general parameters according to table 1 [6].

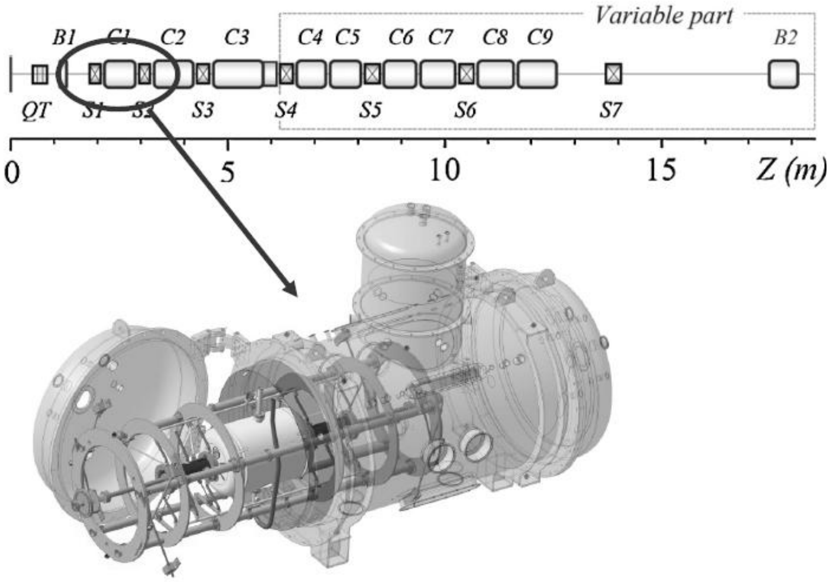

Fig.4 Conceptual layout of the cw LINAC comprising nine sc cavities (Ci) and seven sc solenoids (Sj). The realization of the first section is the Demonstrator.

Table 1: General parameters of the cw LINAC [6].

Mass/Charge		6
Frequency	MHz	217
Max. beam current	mA	1
Injection Energy	AMeV	1.4
Output Energy	AMeV	3.5 – 7.3
Output Energy Spread	AkeV	+/- 3
Length	m	12.7

The realization of the first part, i.e. one cavity embedded by two solenoids, is the Demonstrator project (fig.4). The components are mounted on a support frame, which can be slid into the cryostat. The operational temperature is 4.4 Kelvin, which allows a cryostat bath cooling with liquid helium (LHe) of the components. The thermal shield is cooled with liquid hydrogen (LN). The Demonstrator is a collaboration project between the GSI, IAP and HIM. The latter is financing the project mainly. In addition it is supported by the Accelerator R&D - programme (ARD) of the Helmholtz Association (HGF). The aim is a full performance test of the key component, the sc Crossbar H-Mode (CH) cavity. This will be the first test with heavy ion beams of this type of cavity, which was developed recently at the IAP [7]. It will be a proof of principle on the technology. In straightforward direction to the GSI-HLI the existing beamline can be used to transport the beam to the Demonstrator (fig.5). Only one additional transverse focusing lense is needed.

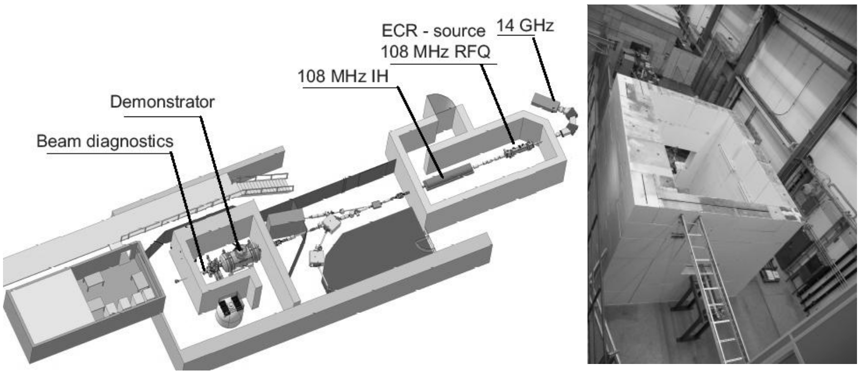

Fig.5 The Demonstrator setup at the GSI HLI as planned (left) and a photograph of the radiation protection cave (right) is shown.

The commissioning of the Demonstrator at GSI HLI is depending on the delivery of the main components. The delivery of the cavity is expected in the second half of 2013 as are the cryostat and the solenoids. The test environment at the GSI HLI is almost completed, e.g. the radiation protection cave was mounted in July 2012. First results of the beam tests are expected in 2015. In parallel the beam characteristics at the exit of the HLI were measured with a temporary emittance meter setup. The analysis of the measurements allows detailed beam dynamical investigations with respect to a realistic input particle distribution. The simulations are aiming at both, a best setting for matching the beam to the Demonstrator, and to adapt the conceptual layout of the whole cw LINAC step by step towards realistic boundary conditions.

3. Perspectives of a cw LINAC

Obviously the future GSI is focusing on FAIR. The existing UNILAC is optimized as an injector for FAIR. From 2014 on a long-lasting shutdown is planned. A major activity is the substitution of the rf-supplies. The new hardware is limited to short-pulse operation according to the requirements for FAIR, i.e. pulse lengths of 100 μs, a repetition rate of 4 Hz, and intensities of $3*10^{11}$ Uranium particles per pulse behind the UNILAC. A further step towards a short-pulsed accelerator comes along with the substitution of the Alvarez section by the so called High Energy (HE) LINAC [8], which is scheduled from 2019 on. Such a short-pulse operated injector restricts a number of established experiments at GSI fundamentally like the SHE program. In the same way the activities of the material research at GSI are restricted for example, which were concentrated at GSI after the closing-down of the Berlin Ion Beam Laboratory (ISL) and by commissioning a new dedicated beamline at GSI in 2009.

All the experiments, which were concerned about such a limitation to a short pulse operation, require an almost continuous intensive beam at energies in the range of the Coulomb barrier, i.e. pulse lengths of 20 ms at the maximum repetition rate of 50 Hz, which could be provided by a new sc cw LINAC.

Table 2: Schedule of the cw-LINAC

Kick-off	1st Results of the Demonstrator (expected in 2015) Funding is approved
+1 year	Tendering for components
+1 year	Placing orders
+ 3years	Delivery of the components Assembling the accelerator
After 5 years	Commissioning

In 2010 and 2011 the first and the follow-up proposal for an sc cw LINAC were evaluated "excellent" by the HGF. One important milestone towards a funding for a new LINAC is a successful Demonstrator project. The other point is the activation of a strong future user community, which applies for this new LINAC and prepares a technical design report (TDR). First activities aiming at a TDR have started. Assuming that first reliable results of the Demonstrator project are available and second, that the LINAC is funded, five years are estimated for its realization, tendering, placing orders, delivery of the components, mechanical assembling, and commissioning inclusively (tab.2).

Regarding a realisation of the cw LINAC three scenarios are under discussion presently:

i) The discussion of a standalone LINAC, independent from the GSI campus, is helpful to get a feeling about the costs.

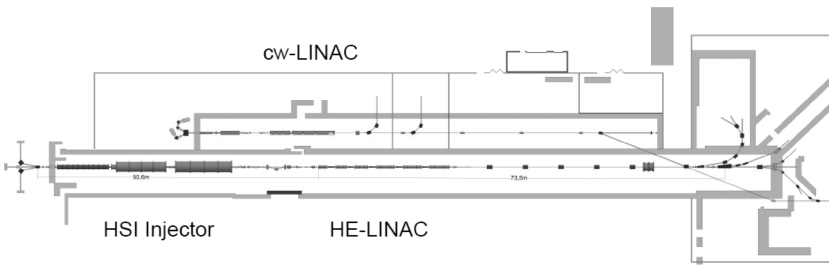

Fig.6: The scenario, cw LINAC in parallel to the HE-LINAC, is show. This version is favored by the user community.

The Demonstrator, comprising one cavity and the complete infrastructure to operate one cavity, costs less than 2 Mio EUR. Regarding the existing LINAC design with 9 cavities, i.e. an output energy of 7.3 AMeV, and a mass to charge ratio A/Q=6, the cold part of the cw LINAC is estimated at 18 Mio EUR.

Table 3: A first order estimate of costs for the different versions of the cw LINAC is shown.

[Mio EUR]	**Standalone cw LINAC**	**Cw LINAC & HE LINAC**	**Cw LINAC @ FAIR**
Cold part (infrastructure incl.)	18	18	18
New ECR Source	3	3	3
New RFQ + IH	5	5	5
Acc. Building	3	1	3
Laboratories & working stations	25[1)]	-	25[1)]
Reaccelerator	-	-	20[2)]
Experiment transfer	10[3)]	-	10[3)]
TOTAL	**64**	**27**	**84**

1) comparable to the costs of the new HIM building
2) comparable to the cold part of the cw LINAC
3) twice the costs of the experiment transfer from ISL to GSI in 2009

On the first view a linear correlation between the number of cavities and the costs of the whole LINAC leads to an overestimation, because with increasing the number of fabricated cavities the price is expected to decrease. On the other hand the complexity of the required infrastructure, like LHe-Supply and beam diagnostics, increases with each cavity and leads to higher costs. In addition a new ECR source (3 Mio EUR) and a new cw capable RFQ-IH combination (5 Mio EUR) are needed. Another 28 Mio EUR is assigned to civil constructions housing the accelerator, working stations and laboratories (tab.3).

ii) A favoured scenario due to the minimized investments is the installation of the cw LINAC in parallel to the existing UNILAC tunnel at GSI (fig.6). The main advantage is the existing building and infrastructure. Working stations and laboratories can be used. Even the existing beam transport lines to the experiments can be used and the experiments itself have not to move. The cw

LINAC can be used as a redundant injector for FAIR next to the HE LINAC additionally. The ECR source provides a variety of ions with intensities and low mass to charge ratio, which are interesting for future FAIR experiments.

iii) An integration of the cw LINAC at FAIR is discussed providing two operational modes: a) Using the cw LINAC as a reaccelerator for radioactive ions behind the FAIR Superfragment Separator (SFRS), b) connecting an additional ECR-source the cw LINAC can be used to provide experiments within the SHE or material research programme with beam for instance.

In the reaccelerator mode the radioactive ions from the SFRS have to be stopped at a gas cell. Afterwards a charge state breeder system can be applied and the required ions can be separated by a following A/Q separator. An RFQ IH combination is used as an injector to the cold part of the LINAC

4. Outlook

The Demonstrator project is a proof of principle on a new accelerator technology. The key technology is the CH cavity, for which a new beam dynamical concept, the EQUUS concept, was developed. This concept is the continuation of the successful applied KONUS concept, for IH structures. Applying the EQUUS concept is the more challenging the more cavities are used. From this point of view a continuation of the Demonstrator project is discussed. The idea is to extend the cryostat in that way, that a string of five CH-cavities can be mounted. The infrastructure of the new HIM building fits the required conditions to process a cw accelerator string R&D project. The new building comprises facilities for the cavity surface preparation, an rf-teststand, and a cleanroom complex for assembling the accelerator string. The GSI HLI could be used in the same way as for the Demonstrator as an injector, testing the string with heavy ions.

The aim of the cw string R&D project is a well working and well tested accelerator module as a prototype, which provides a more reliable basis, which allows a very fast transfer to future applications. Next to the cw LINAC further future applications, e.g. the MYRRHA project in Belgium [9], could benefit therefrom (tab.4).

Table 4: Four types of sc CH cavities are and were developed at the IAP so far. Each cavity is optimised for its planned application

No	Freq. [MHz]	Beta	Status	Application
1	360	0.1	1st prototype, successful rf-tests @IAP in 2007	Accelerator Driven System (ADS) „EUROTRANS“
2	325	0.16	Delivery in Nov 2012 1st test @ IAP	Energy Booster LINAC 2nd stage upgrade option for UNILAC
3	217	0.06	In fabrication Delivery in Sep 2013	Sc cw LINAC @GSI
4	176	0.12-0.18	Under development	MYRRHA, Mol/Belgium

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