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STATUS OF THE SIS/ESR-FACILITY AT GSI-DARMSTADT

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Abstract The heavy ion accelerator project SIS/ESR at GSI–Darmstadt was funded in 1985. Construction of buildings started in November 1986, a first beam was injected to the 18 Tm-synchrotron SIS [1] in November 1988, and a first acceleration of xenon ions to 100 MeV/u took place in May of this year. At present, in parallel to the commissioning of SIS, the 10 Tm-storage ring ESR [2] and the high energy beam transport lines between rings and to experimental areas are being assembled. First experiments with the SIS-beam shall start in January 1990 simultaneously to the commissioning of the ESR.

THE GSI HEAVY ION FACILITY

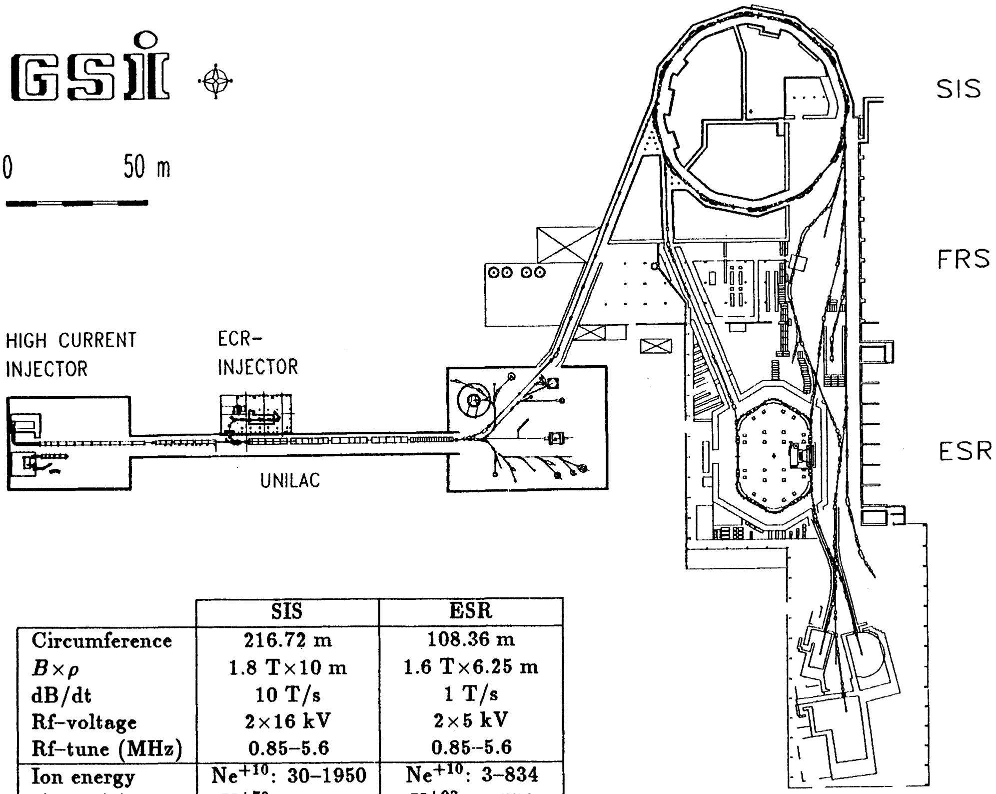
Studies of a new high energy heavy ion facility at GSI were started as early as 1975, when the Unilac was just run in. For several years there was a strong trend to strive for an energy far beyond the 2 GeV/u of the Bevalac, since very high energies were demanded for studies of quark–gluon plasma effects. In the meantime CERN has accelerated oxygen and sulfur ions to 200 GeV/u. Consequently a new concept had to be defined, which concentrated on detailed studies of nuclear reactions at medium energy, atomic physics with electron poor heaviest ions, and application of ion beams in radiobiology and radiotherapy [3].

As shown in Fig. 1, a heavy ion synchrotron SIS, which is designed for the acceleration of all kinds of heavy ions to an energy of 1 GeV/u for uranium, 2 GeV/u for neon, and 4.5 GeV for protons, was combined with a storage and cooler ring ESR, which has exactly half the SIS circumference. The maximum ESR bending power of 10 Tm allows the storage of U^{+92}–ions up to 560 MeV/u, Ne^{+10}–ions up to 830 MeV/u, and protons up to 2.2 GeV. At 500 MeV/u even uranium ions can be fully stripped with a yield of about 50 %.

The SIS high energy beams will be delivered either to several experiments in the target area, or directly to the ESR through a beam line with stripper and charge separator, or to a production target for secondary beams. The fragment separator (FRS) behind this target combines a magnetic Z/A-separation with the Z^2-dependent energy loss of ions in a thick moderator target [4]. Thus any interesting nuclear fragment, i. e. neutron rich or proton rich isotope, can be used for experiments directly behind the FRS or stored in the ESR.

The ESR shall be used in different ways. As a stretcher/cooler ring it will increase the macroscopic SIS beam duty factor to nearly 90 % and reduce transverse beam emittances and momentum spread by beam cooling. By this way high quality beams especially of ions like Au, Pb, and U can be delivered to all experiments in the target area. Even more interesting should be experiments with ion beams circulating in the ESR. It is planned to investigate the interaction of stored ions with laser radiation, electrons in the cooler beam, or atomic nuclei in the internal gas jet target. Internal experiments can be done with all kinds of beams from the SIS and moreover also with beams of exotic isotopes from the FRS, for which stochastic precooling is provided. Finally, the ESR beams can be transferred back into the SIS for further acceleration, e. g., up to 1.35 GeV/u with fully stripped uranium ions.

The Unilac [5], which is still in use for a flourishing program in the 5 to 20 MeV/u range, was up-graded for its new role as SIS injector. A new high current RFQ injector for the preacceleration of, e. g., U^{+2}-beams shall increase the pulse current for heaviest ions from pμA to pmA. Another injector with an ECR ion source, a short RFQ-section, and an IH-linac will be installed next year midway to the original Unilac. Both injectors can be used in a time sharing mode with the Unilac poststripper for the low energy experiments as well as for SIS injection.



	SIS	ESR
Circumference	216.72 m	108.36 m
$B\times\rho$	1.8 T×10 m	1.6 T×6.25 m
dB/dt	10 T/s	1 T/s
Rf-voltage	2×16 kV	2×5 kV
Rf-tune (MHz)	0.85–5.6	0.85–5.6
Ion energy (MeV/u)	Ne^{+10}: 30–1950 U^{+78}: 30–950	Ne^{+10}: 3–834 U^{+92}: 3–556
Ions/cycle[1)]	Ne^{+10}: 2×10^{11} U^{+78}: 5×10^{10}	Ne^{+10}: 7×10^{10} U^{+92}: 1×10^{10}

Figure 1: Plan view of the SIS/ESR-facility with experimental areas.

SIS DESIGN

A strictly periodic ring lattice with 12 identical cells was chosen [6]. The focusing changes during acceleration from triplet to doublet structure. The first leads to fairly large machine acceptances of $A_{h/v} = 200/50\ \pi$ mm mrad whereas the latter requires less strength and makes beam extraction and chromaticity control easier. The variable grouping from twelve to six focusing periods was originally conceived to shift the transition point beyond 4 GeV in case of proton acceleration, but it is also helpful for the extraction of beams with 1–2 % momentum spread.

In each of the twelve identical cells there are two bending magnets and the triplet group with two long and one short quadrupoles. At 1.8 T dipole field the total stored energy is 3.2 MJ and the resistive losses are 2 MW. The four converter/rectifier sets of the dipole power supply can be grouped at will in series for a 10 T/s ramp up to 1.2 T (2300 A) or in parallel with two pairs of power sets for a reduced ramp rate of 4 T/s up to 1.8 T (3500 A). Four power supplies are used for the 24 long quadrupoles in order to provide separate F and D-focusing and quadrupole grouping with six focusing periods. Another power supply feeds the twelve short lenses.

In all dipole and quadrupole supplies the usual active and passive filters are replaced by a current injection supply parallel to the load (PCI), which superimposes a correction of up to 10 % on the main converter current. With this novel PCI scheme the actual load current follows immediately the reference value with an accuracy of a few microseconds, while the conventional design with passive and active filters would lead to a variable delay in the order of 10 ms. On the other hand, a precise presetting of the load voltage is required, including the effects of iron saturation and of eddy currents.

At the maximum dipole ramping rate of 10 T/s the required effective accelerating voltage of 22 kV is provided by two rf–stations, which are designed for operation at the 4th harmonic of the revolution frequency in the frequency range from 0.85 to 5.6 MHz at a peak voltage of 16 kV. Two rf–stations are also necessary for merging the four circulating ion bunches in two bunches, which fill only half of the SIS circumference, for a single shot transfer into the ESR.

The multi turn injection system is designed for injection of up to 40 turns assuming a beam emittance of 5 π mm mrad. The injector channel with inflector magnet and electrostatic wire septum can be adjusted to different beam parameters in a pulse to pulse mode. Four bumper magnets are used to shift the central orbit at constant dipole field. By means of a chopper in the injector line ion pulses of variable length between 1 and 400 μs are injected at an optimized position on the falling slope of the bumper field.

The fast extraction system can be used for the extraction of one, two, or three SIS bunches. The standard procedure will be the transfer of two bunches by two consecutive shots with a delay of about 20 ms. An alternate method is single shot transfer after "four in two" bunch merging as mentioned above. As standard procedure for the extraction of beams for target experiments 3rd integer resonance extraction is provided. For that purpose six of the twelve chromaticity sextupoles are used to shape the separatrix, two special quadrupoles shift the machine tune into resonance at 4 1/3, and an electrostatic wire septum deflects the unstable particles into the ectraction channel. This channel with three septum magnets, which are connected in series to the main bending magnets, is used for both fast and slow extraction. Since several target experiments require rather low intensities in the range of 10^4 ions/s ultra slow extraction similar to that used in the LEAR shall be included in 1990 [7].

COMMISSIONING OF SIS

On the 23rd of November 1988 an argon beam was turned around the synchrotron without any difficulties, four months ahead of the scheduled date. It was a great pleasure to present this first turn experiment to Prof. Christoph Schmelzer at the occasion of his 80th birthday celebration at GSI. However, until April 1989 still a lot of work had to be done. The vacuum chamber bake–out equipment was installed, the power supplies and the rf–system were completed, and many additional modules were included in the control software package.

In April 1989 the first turn experiment was repeated. This time the profile grid, which showed the beam after the first turn, was also used to determine Q–values. Fig. 2 shows two examples of horizontal profiles: the first one was taken with $Q_h \approx 4.25$, where the position of the forth turn approximately coincides with the first one, the second resulted for $Q_h \approx 4.0$, where the position shift from turn to turn is rather small. In this way it was possible to determine Q-values with an accuracy of about 0.01. The results have shown, that the theoretical values for the quadrupole strengths had to be corrected by a few percent.

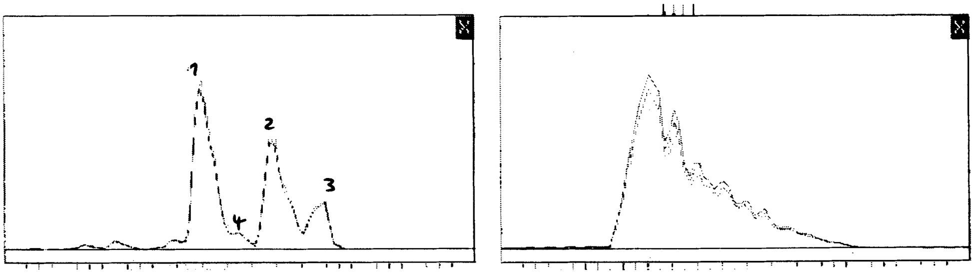


Figure 2: Horizontal profiles of the injected beam.
The position is shifted from turn to turn due to radial oscillation and the intensity decreases by losses at the profile grid. Left: $Q_h \approx 4.25$, right: $Q_h \approx 4.0$.

With these results for the setting of quadrupoles multi turn injection of an argon beam at 5.9 MeV/u was soon achieved. Fig. 3 shows the fast transformer signal of the injected current and the dc transformer signal of the stored beam as measured in the next run with a xenon beam at the standard injection energy of 11.4 MeV/u. For Unilac beams with an emittance of 5 to 10 π mm mrad about 25 turns were stored in the 200 π mm mrad horizontal SIS acceptance. The life time of the stored beam is limited by stripping processes at residual gas molecules in the vacuum chamber. The observed intensity decay to 1/e within about 700 ms is consistent with estimated total charge changing cross sections and with an average pressure around the machine of about 2×10^{-10} mbar.

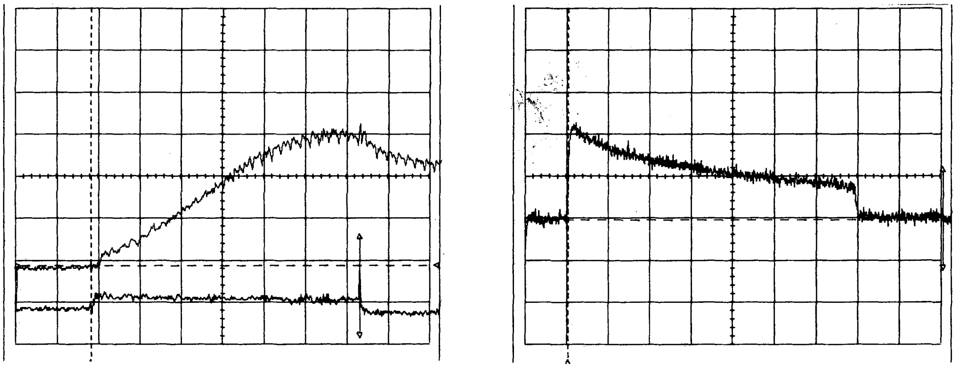


Figure 3: Beam transformer signals at injection energy.

Left: 25 turn injection of Xe^{+21}–beam at 11.4 MeV/u, right: stored 50 μA–beam showing charge changing losses over 700 ms.

The next eight day commissioning period in May was used to study rf–bunching and acceleration of xenon beams at 11.4 MeV/u injection energy. Bunching was achieved immediately by tuning the rf to the forth harmonic at 0.8633 MHz with an accuracy of a few hundred Hertz. Bunching at higher harmonics up to 4.3165 MHz was also possible without additional fine tuning.

The accuracy of the rf–setting was encouraging to try immediately ion acceleration without B–train control of the frequency program. The experiment was immediately a success and the energy was raised step by step to 100 MeV/u for a Xe^{+21}–beam, where dipole fields reached a flat top level of 0.9 T. This result shows that acceleration of low intensity beams without any beam feedback is well feasible.

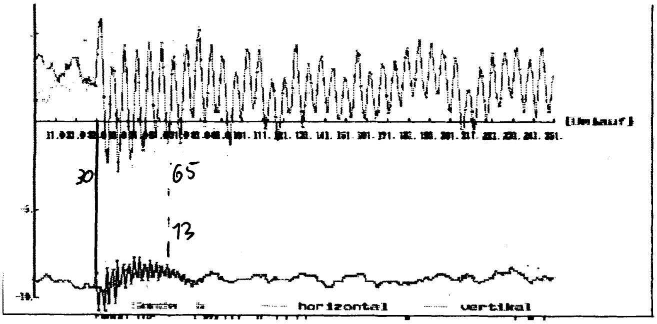


Figure 4: Horizontal (top) and vertical (bottom) beam oscillations after a fast kick.

The third and, for the present, last run was mainly used for Q–measurements and preliminary extraction tests. Fig. 4 shows horizontal and vertical oscillations of the stored beam, which were exited by a fast kicker rotated by 45°. The horizontal oscillations are easily observed for more than 200 turns, while the vertical oscillations are strongly damped within about 50 turns. Systematic Q–measurements in the coming weeks are necessary to achieve precise calibration of quadrupole current settings for both the triplet- and the doublet focusing.

STATUS OF THE ESR

Specific properties of the ESR are rather large transverse and momentum acceptances and ion optical flexibility. The first is required mainly for the injection of secondary beams, for beam accumulation by rf–stacking, and for simultaneous storage of multi component beams [8]. The flexibility is necessary because of the large number of rather different tasks for the ring. The combination of large useful magnet apertures, 200(h)×70 mm^2 in dipoles and 300(h)×120 mm^2 in quadrupoles, with a triplet/doublet focusing structure turned out to be a reasonable solution. The ion optical flexibility is based mainly on a large number (10) of independently controlled quadrupole power supplies, each feeding a pair of magnets, whereas the six C-shaped bending magnets and three septum magnets are switched in series and excited by a single supply. Main ESR parameters are given in Fig. 1 as well as a rough impression of the ring structure (see also Fig. 5). Details of the design have been described previously [2]. The following status information is combined with brief remarks on special features of the ring and its components.

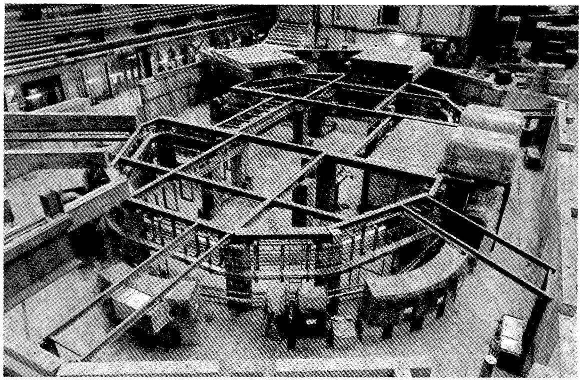


Figure 5: Appearance of the ESR in January 1989

In the meantime, the view is obstructed by concrete shielding.

Magnets and power supplies: All main ring magnets are on place, aligned and connected to corresponding power supplies by water cooled cables. At this time, the bending magnets are being mapped and quadrupole power supplies are being put into operation step by step until end of September. Most of the auxiliary magnets and correction coils are ready for installation: 6 sextupole magnets, 12 coil pairs in the main dipoles for horizontal steering, 8 vertical steering magnets, 23 pole face windings in dipoles compensating saturation effects, two solenoid and two combined h/v-steering magnets provided to compensate for effects of the electron cooler magnets on the ion beam, and three septum magnets for beam injection and extraction.

Rf-cavities: Two ferrite loaded rf–stations, designed for a voltage amplitude of 5 kV and a tune range from 0.85 to 5.6 MHz, are provided for all kind of beam control in the longitudinal phase space: acceleration, deceleration, debunching, rebunching, and, not least, rf-stacking. The cavities are mostly assembled and the power amplifiers equipped with Siemens RS 2058 CJ tetrodes are in preparation. Two 500 W drivers, and all necessary power supplies for the tubes and for the bias windings of ferrites are installed. Amplitude, phase and frequency regulation have been developed and manufactured together with the identical units for the SIS.

Fast injection and ejection: Fast beam injection and ejection is done by three ferrite kicker modules with C-shaped cross section. At present, the modules are completely installed in their UHV–chamber and going to be finally tested as well as corresponding 80 kV charging and switching units, which are identical to those used at the SIS.

Slow extraction: Besides the 3rd integer betatron resonance, also charge changing of ions in the electron cooler or in the in the internal target is planned to be applied for slow beam extraction [9]. We will try to provide a nanosecond pulse structure in the extracted beam by means of simultaneous application of electron cooling and rf–bunching. The electrostatic wire septum for the deflection of beam particles into the extraction channel is assembled, and the final vacuum test including the high voltage conditioning with the pulsed 160 kV–supply is in preparation.

Beam diagnostics: The ESR beam diagnostics is quite similar to that used already in the SIS: Three profile grids and two Faraday cups for first turn diagnosis, 12 horizontal and 12 vertical capacitive position probes, a fast and a dc beam transformer, and two horizontal and one vertical beam scraper. In addition to this more conventional components, there are a special resonant pickup station for Schottky diagnosis and several position sensitive particle detectors for the observation of charge changing processes in electron cooler and internal target. They will be helpful for ring control as well as for atomic physics experiments. Most of the mentioned components are in the assembly and test phase and will hopefully be available for the early commissioning phase.

Ultra high vacuum: The ultra–high vacuum is designed for a residual gas pressure of 10^{-11} mbar. In the worst case of high ionic charge states at lowest energies beam life times are expected to be in the order of 100 s, increasing steeply with increasing energy up to many hours. The complete UHV-system with 150 m^2 inner surface area will be baked out at 300 °C. About 40000 ℓ/s pumping speed should be sufficient to live with mean outgassing rates of 2.5×10^{-12} mbar ℓ cm $^{-2}$ s^{-1}. All UHV-chambers inside magnets, i. e. 80 % of the ring, are complete and finally tested. The insertion of capacitive position probes into the quadrupole chambers is underway.

Beam cooling: The stochastic pre–cooling system [10] provided for the accumulation of secondary beams from the FRS has been postponed to 1991, whereas the 2.5 m long electron cooler [11] is in the assembly and test phase. The electron beam (10–310 keV, 1–10 A) has to be recovered by the collector with an efficiency of better than 99.9 %. The magnetic solenoid/toroid system of the cooler is complete and has been mapped already at maximum field of 0.25 T. Presently, necessary correction coils are being prepared. So far, electron gun and collector were tested with 250 kV on a linear assembly and power tests with a 50 kV/5 A–beam are underway.

Internal target: The assembly of the supersonic gas jet apparatus is mostly finished and first operation with jet will begin in the coming weeks. The design [12] provides variable target thickness in the range 10^{11} to 10^{14} molecules per cm^2. The gas load for the ESR is minimized by 4-stage skimming and differential pumping between the nozzle and the interaction chamber. Only a small, well collimated (3–5 mm diam.) fraction of the original jet crosses the interaction chamber and is dumped then in a differentially pumped 4–stage recipient.

Outlook to ESR commissioning: The ring vacuum chamber of the ESR shall be closed end of this year. Injection of a low energy dc–beam is envisaged for January next year, followed by the running in of bunch injection and rf-stacking. A first test with electron cooling is planned for April 1990, a date, which might be considered also as the beginning of experimental activities at the ESR.

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