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Accelerated radioactive beams from REX-ISOLDE

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Abstract

In 2001 the linear accelerator of the **R**adioactive beam **EX**periment (REX-ISOLDE) delivered for the first time accelerated radioactive ion beams, at a beam energy of 2 MeV/u. REX-ISOLDE uses the method of charge-state breeding, in order to enhance the charge state of the ions before injection into the LINAC. Radioactive singly-charged ions from the on-line mass separator ISOLDE are first accumulated in a Penning trap, then charge bred to an $A/q < 4.5$ in an electron beam ion source (EBIS) and finally accelerated in a LINAC from 5 keV/u to energies between 0.8 and 2.2

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MeV/u. Dedicated measurements with REXTRAP, the transfer line and the EBIS have been carried out in conjunction with the first commissioning of the accelerator. Thus the properties of the different elements could be determined for further optimization of the system. In two test beam times in 2001 stable and radioactive Na isotopes (^{23}Na–^{26}Na) have been accelerated and transmitted to a preliminary target station. There ^{58}Ni- and ^{9}Be- and ^{2}H-targets have been used to study exited states via Coulomb excitation and neutron transfer reactions. One MINIBALL triple cluster detector was used together with a double sided silicon strip detector to detect scattered particles in coincidence with γ-rays. The aim was to study the operation of the detector under realistic conditions with γ-background from the β-decay of the radioactive ions and from the cavities. Recently for efficient detection eight tripple Ge-detectors of MINIBALL and a double sided silicon strip detector have been installed. We will present the first results obtained in the commissioning experiments and will give an overview of realistic beam parameters for future experiments to be started in the spring 2002.

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1. Introduction

The study of the nuclear structure far from the valley of β-stability is the most exciting frontier in nuclear physics today. Current nuclear physics programs focus on nucleonic matter under extreme conditions. Nuclei far from stability allow to amplify and isolate particular aspects of the nuclear interaction and dynamics. The radioactive beam experiment REX-ISOLDE at ISOLDE/CERN has been designed [1] to deliver post-accelerated radioactive ion beams with a variable energy between 0.8 and 2.2 MeV/u. In order to address many nuclear physics aspects, the full variety of beams available at ISOLDE should become accessible as accelerated beams for experiments. Thus a new technology of charge multiplication and post acceleration was introduced for the first time. The task of the charge breeder is the preparation of the beam concerning the time structure (bunching), concerning the transverse emittance (phase space cooling) and concerning the charge state of the ions to a mass to charge ratio below 4.5. Despite the moderate size of the accelerator the charge multiplication of the radioactive ions allows access to the heavier mass region of the nuclear chart, which cannot be reached by accelerating monocharged ions [2]. All accelerators are designed for a certain A/q range of the ions within which they can be accelerate to the nominal design energy. For singly charged ions the mass limit corresponds simply to the maximum A/q which can be accelerated, which implies e.g. ^{4}He for the REX-LINAC and $A = 30$ for ISAC-I (TRIUMF). In order to accelerate heavier masses, the charge state of the ions needs to be higher to stay within the A/q-limit of the accelerator. An EU-RTD network that explores the possibilities of charge breeding with the two high charge state ion sources (EBIS and ECRIS) demonstrates the importance of the charge breeding concept for radioactive beam facilities.

The concept of REX-ISOLDE (Fig. 1) comprises a large Penning trap for the accumulation of the radioactive ions that come continuously from one of the ISOLDE on-line separators. In addition, the REXTRAP improves the transverse emittance of the ion beam by application of buffer gas and sideband cooling technique [3,4]. Together REXEBIS and REXTRAP define the time structure of REX-ISOLDE and thus the repetition rate. Depending on the breeding time of the EBIS, the repetition frequency of REX-ISOLDE can be varied between 1 and 50 Hz. The latter is given by the maximum repetition rate of the LINAC. The cooled ions are transfered via a beam line with five differential pumping stages to the REXEBIS. One of the established sources for highly charged ions is the EBIS [5]. In this type of ion source an intense electron beam ionizes trapped ions stepwise by electron impact ionization. The REXEBIS operates under UHV conditions (10^{-11} mbar), whereas

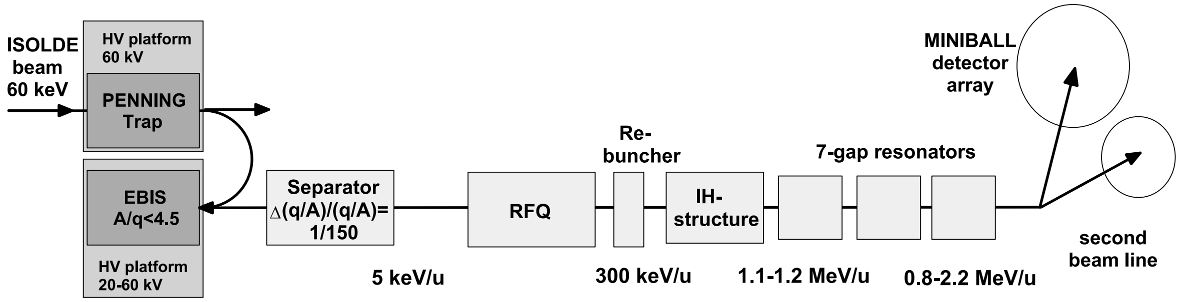

Fig. 1. Schematic representation of the REX-ISOLDE concept.

the REXTRAP operates at buffer gas at a pressure of 10^{-3} mbar. Therefore decoupling the EBIS vacuum via the transfer line is mandatory. The breeding cycle is typically below 20 ms for ions with $A < 50$. For higher masses longer breeding times are required. For the mass region up to $A = 150$, breeding times of 200 ms are calculated. After charge breeding, the ions are extracted from the EBIS within typically 50 μs and mass analysed via the s-shaped achromatic separator [6] which also prepares the beam for injection into the REX-LINAC. Due to the required low injection energy (5 keV/u) of the RFQ the EBIS platform potential has to be lowered from the REXTRAP platform potential (nominally 60 kV) to a potential of $(A/q)^{*}5$ kV, where A/q is the mass to charge ratio of the radioactive ions to be accelerated. Finally the LINAC consists of a radio frequency quadrupole (RFQ) accelerator, which accelerates the ions up to 0.3 MeV/u, the lowest energy the REX-LINAC can provide. After a matching section an interdigital H-type (IH) structure boosts the energy to 1.2 MeV/u. At present the exit energy of the IH-structure can be slightly varied between 1.15 and 1.20 MeV/u. Three seven gap split-ring resonators allow the variation of the final energy between 0.8 and 2.3 MeV/u. For experiments at RFQ energy, the energy can be adjusted with the three gap re-buncher of the matching section, which is able to shift the RFQ beam to 280–320 keV/u, as shown in Fig. 2. After a momentum analysis in a dipole magnet, the ions are transported to the target, which is surrounded by a highly efficient detector system MINIBALL [7]. An additional beam line will be used for experiments that do not require the MINIBALL γ-detector array.

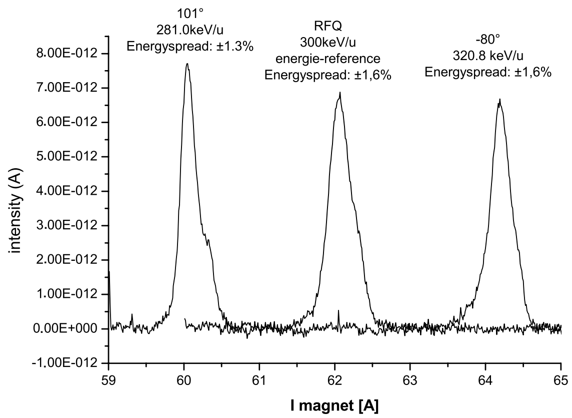

Fig. 2. Change of the RFQ beam energy using the re-buncher of the matching section with different rf-phases.

2. The charge breeder

The charge breeder of REX-ISOLDE comprises the REXTRAP, the transfer line towards the EBIS, REXEBIS and the achromatic A/q-analyser which bends down the beam towards the LINAC beam line. The beam from REXTRAP is re-accelerated to 60 keV and injected into the EBIS. Due to the small transverse acceptance of the EBIS of about 5π mm mrad at 60 keV [8], the beam from ISOLDE is too large for direct injection. Measurements of the REXTRAP emittance revealed an emittance of the beam of about 20π mm mrad at 30 keV without cooling and about 7π mm mrad with cooling [9]. The transmission through the trap depends on the number of ions accumulated in the trap. The transmission is typically around 40% for intensities below 10^7 s^{-1} and down to 10% for intensities up to 10^9 s^{-1}. Investigations of different cooling methods are planned and mentioned in the upgrade chapter. Due to restrictions from the power supplies of the EBIS einzel-lens the beam energy at present is limited to 30 keV. For the mass region of the isotopes which are required for the commissioning experiments, the trap and the EBIS are running with a repetition frequency of 50 Hz. The ion injection into the EBIS needs less than 50 μs and the breeding time is variable between 5 and 19 ms (at 50 Hz). In this way an optimal charge state with $A/q < 4.5$ and little residual gas contamination can be selected. The centroid of the charge distribution is determined by the product of the confinement time and the electron beam current density. In the REXEBIS presently a 0.2 A electron current is compressed by the magnetic field into a current density of about 150 A/cm^2. The electron beam has an energy of 5 keV. A superconducting solenoid creates the magnetic field of 2 T, with a homogeneity of about 0.25% along the confinement length of 0.8 m. In principle the REXEBIS can store up to 2×10^{10} positive charges per breeding cycle, which is about two orders of magnitude more than REXTRAP can handle with reasonable transmission.

During the first half of 2001 an extensive upgrade of the REXEBIS took place as the previous tests showed some vacuum and structural problems. Mapping and fine-tuning of the solenoid field reduced the electron losses by more than a factor of 10 to less than 1 mA. The perforation of the drift tubes with more than 2000 holes lowered the rest-gas background by more than an order of magnitude. A coating of the collector (ZrTiV alloy) improved the pressure in the collector region and also suppressed secondary electron emission. The REXEBIS has now seven drift tubes, three of them trapping, combinable to trap lengths of 200, 400, 600 and 800 mm. Lanthanum and boron from the cathode ionised in the first drift tube can now be reflected at the inner barrier back to the cathode keeping most of them out of the extracted ion beam. For 20 ms breeding time the La^{20+} peak is reduced from about 2 pA to about 0.05 pA by proper setting of the inner barrier tube. Despite some problems with the electron gun, which had one breakdown after about 1500 h of operation and displayed slow changes of the emission conditions, the EBIS is remarkably stable. Presumably a change of the cathode will be necessary every 2–3 months, but alternative gun designs with different cathodes will be tested in the future. The theoretical lifetime of a LaB_6 cathode crystal would be more than one year determined by the evaporation rate. The charge state breeder of REX-ISOLDE has successfully bred ions from a test ion source as well as radioactive ions from the ISOLDE mass separators. This is the first charge state booster which breeds very low intensities of radioactive ions before injection into a LINAC. Tests have been done with Na-, K- and Al-isotopes [10]. It has delivered stable $^{39}K^{10+}$ and $^{23}Na^{6+}$ beams. The Na^{7+} current exceeded 70 pA or 6×10^7 p/s. Stable $^{27}Al^{7+}$ and $^{23}Na^{6+}$ from ISOLDE and also the first radioactive $^{26}Na^{7+}$ and $^{24}Na^{7+}$ beams (just 5×10^5 p/s) have been charge bred and accelerated for detector tests. A breeding efficiency of about 15% in one charge state could be reached for Na and K, where the trap efficiency of about 40% is not included. In Fig. 3 an example of a charge state spectrum with and without injected Na ions from REXTRAP is shown.

The S-shaped beam line between the EBIS and the LINAC consists of a mass separator which separates the few highly-charged radioactive ions from the ions bred from the residual gas. The separator is achromatic as it is based on a Nier-type set-up using a cylindrical electrostatic deflector to compensate the energy dispersion of the separator magnet. The separator has been designed with the code Cosy Infinity with a theoretical resolution of $(A/q)/\Delta(A/q) = 110$. Isotopes from the EBIS could be separated by the REX mass separator with a resolution of $(A/q)/\Delta(A/q) = 100$ (Fig. 3). A proper focusing of the EBIS beam into the entrance of the mass separator is mandatory to attain the full resolution. The resolution is not energy dependent, but depends strongly on the emittance of the beam coming from the EBIS, since the peak width in the charge state spectrum is related to the beam emittance.

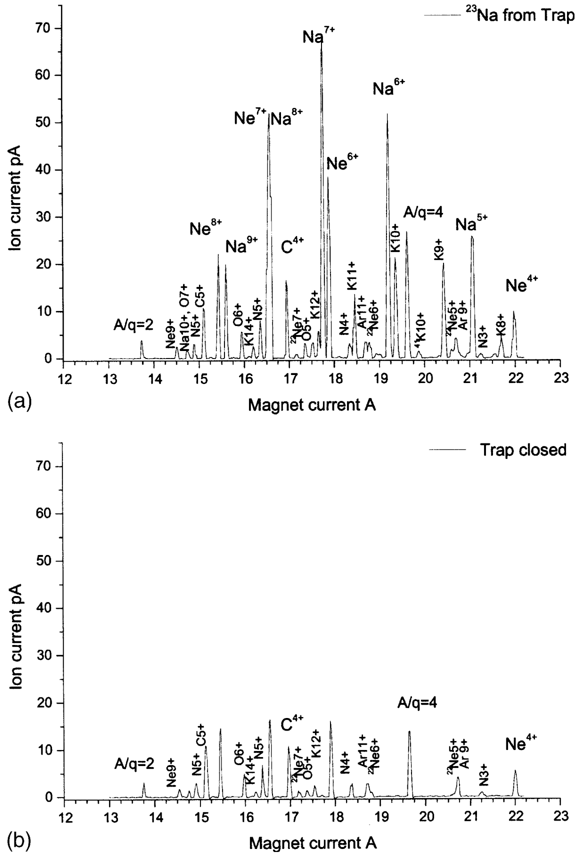

Fig. 3. Charge state spectrum with and without Na injected from REXTRAP into REXEBIS. The rest gas background is very small, because of the very good vacuum conditions inside the EBIS.

Peak intensities down to 100–200 fA could be separated from rest gas peaks which comprise several pA. The total transmission of the mass separator is about 75–90%. Losses due to charge exchange in the separator result from the rather high rest gas pressure of 10^{-6} mbar. Therefore UHV-diagnostic boxes are planned for the separator section in order to reduce the outgasing rate of those devices.

3. The REX-ISOLDE LINAC

The linear accelerator of REX-ISOLDE consists of different types of resonant structures to meet the requirements of the experiments [1]. The RFQ and IH-structure take the ions to an intermediate energy of 1.2 MeV/u where they are post accelerated or decelerated by the seven-gap resonators. Except for the seven-gap resonators the LINAC is similar to the GSI-HLI LINAC [11] and to the CERN LINAC 3 [12]. All structures operate at 101.28 MHz, which is half of the CERN proton LINAC frequency, and with maximum 10% duty cycle. At 50 Hz repetition rate the maximum rf-pulse length is therefore 2 ms. The transverse design acceptance of 0.6π mm mrad (normalized) of the REX-ISOLDE LINAC is large in comparison to the EBIS emittance of about 0.06π mm mrad. This conservative design of the acceptance is based on typical extraction emittances from an ECR sources. The macrostructure of the accelerated beams has a typical bunch width of 10–50 μs and a pulse distance of 20 ms. The calculated micro structure (bunch length) has a pulse width depending on the final energy between 0.3 ns at 2.2 MeV/u and 13 ns at 0.8 MeV/u. The time between the bunches is 10 ns. Thus at 0.8 MeV/u the beam will be continuous over the length of the macro pulse. The expected energy spread of the beam at the target is 1.5% at 2.2 MeV/u and 5% at 0.8 MeV/u [13]. All resonators are located in the experimental area of the ISOLDE hall (Fig. 4). Due to space restrictions, no additional concrete shielding could be installed in the hall. Therefore the structures with the highest gap voltages (380 kV) must be shielded with lead. From safety restrictions we have to stay below 10 μS/h at the lead shield surface for the highest power level and for the 10% duty cycle. Especially the pumping ports of the seven-gap cavities had to be shielded, as X-rays escaping via those ports can disturb the measurements at the MINIBALL. A lead wall has been installed next to the seven-gap resonators to shield the target region.

The different LINAC structures have been successively tested with beams from the rest gas of the EBIS in order to determine the right amplitude and phase settings. Due to a temporary lack of the high resolution phase shifter modules, the commissioning is not yet completed. Thus except for RFQ and re-buncher, neither measurements of the beam energy spread from the different cavities nor

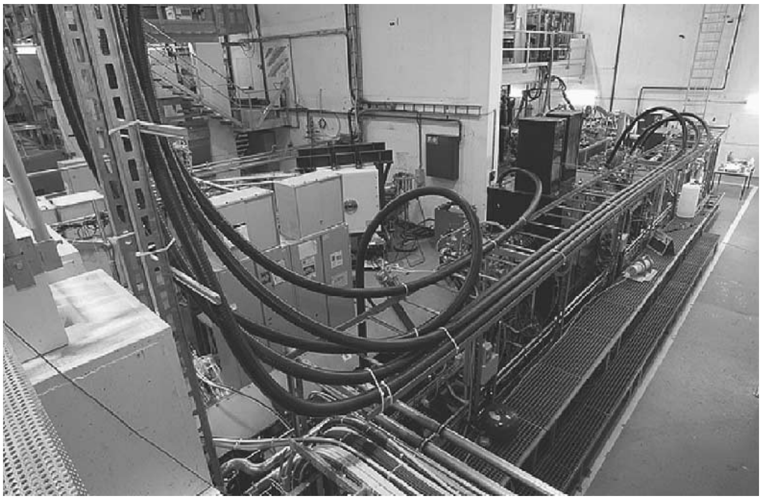

Fig. 4. Picture of the REX-ISOLDE LINAC.

transverse beam emittances have been performed so far. In addition, the adjustment of different energies in the range of 0.8–2.2 MeV/u has not been done either. However in two beam times during last fall, the REX-ISOLDE LINAC could accelerate charge bred ions of ^{23}Na, ^{24}Na, ^{25}Na, ^{26}Na and ^{39}K to 2 MeV/u with only two of the three seven-gap resonators. Due to a broken pre-amplifier, the power amplifier of the last seven-gap resonator could not be run in that beam time. However, the scaling of the beam line settings and of the resonator power levels was tested using the above set of isotopes. The whole LINAC follows very accurately a linear scaling of all elements with the A/q of the ions. It could be proved that the LINAC beam line is able to transport beams with $A/q < 4.5$ to the target region at 0.3 MeV/u (RFQ-energy) and at 1.2 MeV/u without major losses. The transmission of the LINAC has been 70–80% without steering and with no fine adjustment of the phases. The beams could be focused through a 3 mm aperture in front of the target. In the test beam time in November an overall transmission of Na-isotopes of about 2% through the whole REX-ISOLDE system starting from the ISOLDE ion source to the REX-ISOLDE target station could be reached. The transmission from the entrance of REXTRAP to the target station is about 4% for Na- and K-isotopes. For lighter ions the transmission through the EBIS can be increased significantly due to the smaller charge state distribution. If fully stripped ions can be resolved from rest gas contaminants, the EBIS can collect all injected ions in one charge state, reaching up to 90% transmission in that charge state.

In the commissioning beam time radioactive sodium beams have been guided on a ^{58}Ni target for Coulomb excitation experiments and on a ^{9}Be-target to study neutron pickup reactions. For that purpose a temporary target set-up including a Si-strip-detector and one MINIBALL triple cluster detector had been installed. Thus the γ- and particle detection and the data acquisition system could be tested. An example is given in Fig. 5, which shows a γ-spectrum taken from the n-transfer reaction between ^{24}Na and ^{9}Be in coincidence with the two particle detection in the Si-detector. The ^{8}Be$\rightarrow 2\alpha$ decay allows a clean signature for the n-transfer, which can be seen in Fig. 5. The high resolution γ-spectra allow identification of the populated levels. The spectra reveal that very little is known about nuclei only one or two neutrons away from stability. The γ-background in the target area, competitive reaction channels and different target materials have been studied as well. Gating of the detector with the

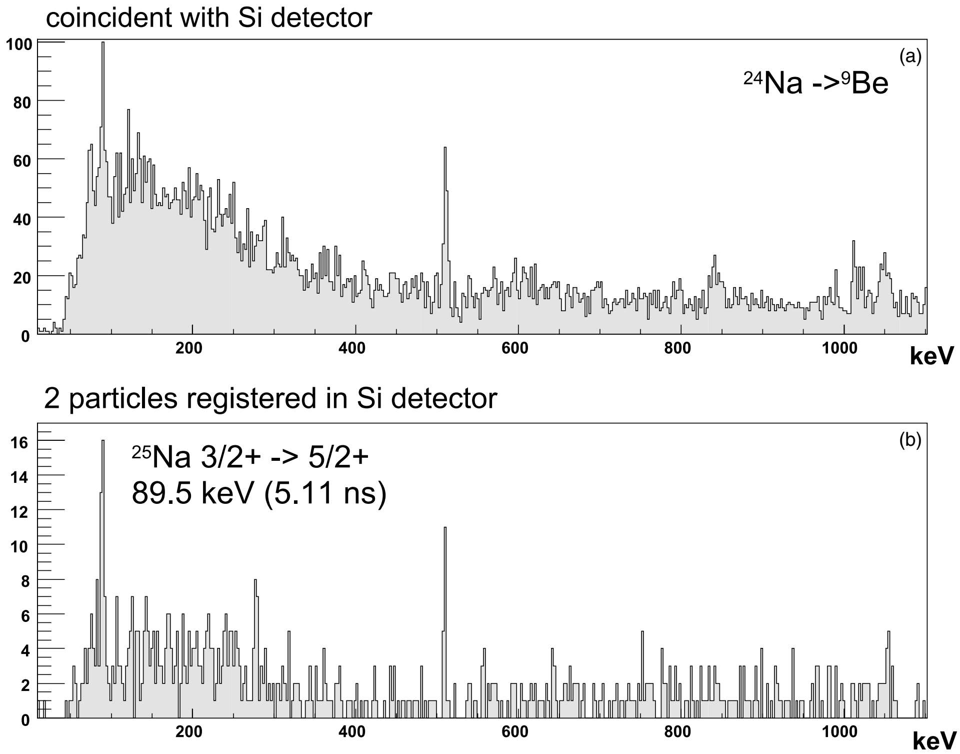

Fig. 5. γ-ray spectrum of ^{24}Na in coincidence with the SI-detector from the second commissioning run.

short EBIS extraction pulse allows a considerable background reduction. The commissioning of the LINAC will be completed using a test ion source which delivers several nA of $^4He^+$ ions. This ion source is being installed in front of the REX-separator magnet. It will allow for tuning of the LINAC in advance of an experiment. Measurements of the energy spreads, emittance measurements and fine tuning of the phase- and amplitude settings are foreseen using that source. Four beam times are scheduled in 2002, starting with a further run with Na-isotopes, followed by ^{9}Li run and thereafter Mg-isotopes and a test with fission fragments. Meanwhile a nearly full MINIBALL setup including eight triple cluster Ge-detectors has been assembled at the 65°-beam line of REX-ISOLDE (Fig. 6), as well as a 160-fold segmented DSSSD-ring detector. The Li-experiment will be performed using the second beam line in the 20°-direction. Both beam lines are available now.

4. REX-ISOLDE upgrade

To make full use of the broad range of isotopes available at ISOLDE an upgrade of REX-ISOLDE is being prepared, which includes different projects. In order to extend the mass range from $A < 50$ to the mass region up to $A = 150$, longer breeding times up to 200 ms have to be explored. In addition longer accumulation times and storage of higher ion numbers in the trap have to be investigated. Presently, the maximum beam energy of REX-ISOLDE is 2.2 MeV/u. At this energy the Coulomb barrier limits the mass A and nuclear charge Z of the projectiles that can be used to induce nuclear reactions. Therefore an energy upgrade of REX-ISOLDE to 3.1 MeV/u is being prepared and a further future upgrade to 4.3 MeV/u is under consideration according to the structure of the LINAC shown in Fig. 7. The maximum useful projectile mass number, assuming

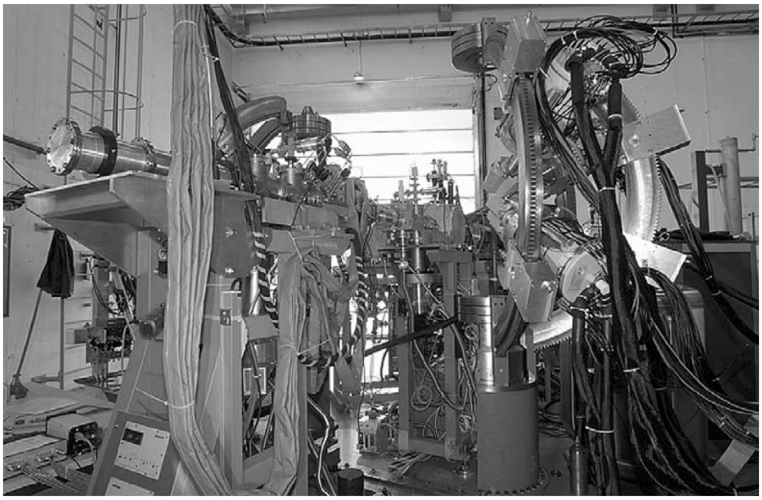

Fig. 6. Picture of the MINIBALL set-up.

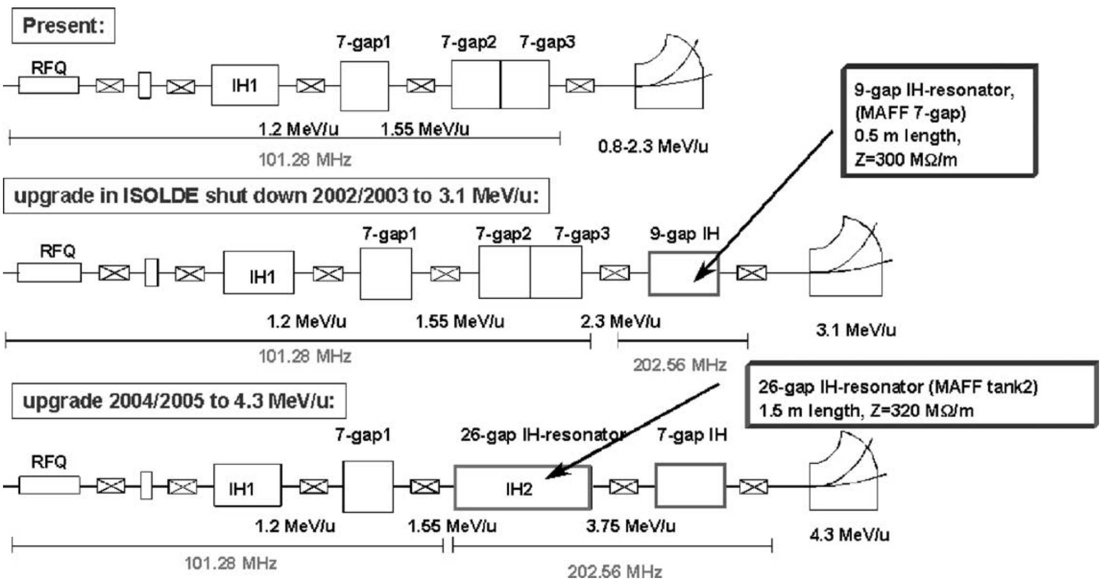

Fig. 7. Scheme of the LINAC structure for the two upgrade steps to 3.1 and 4.3 MeV/u, respectively.

$A \sim 2.5\ Z$ and a beam energy of 2.2 MeV/u, is for a deuterium target $A = 55$ and for an approximately symmetric projectile-target system $A = 50$. With an increase of the beam energy to 3.1 MeV/u these numbers increase significantly to 90 and 85, respectively, and for 4.3 MeV/u to $A = 140$ for both cases.

The first energy upgrade to 3.1 MeV/u is planned to include a nine-gap IH-resonator which will be installed in the next shutdown period. The new cavity will be set-up in the drift space between the last seven-gap resonator and the bending magnet. The new resonator has a resonance frequency of 202.56 MHz and is derived from the seven-gap

IH-resonators of the MAFF LINAC [14,15]. In a short IH-cavity the drift tube structure can be changed to adapt to a different synchronous particle velocity and within the entire energy range. The synchronous particle velocity for REX-ISOLDE is 7.4% of c, corresponding to a cell length of 55 mm. In order to preserve the resonator frequency smaller drift tubes are required. They lower the resonator's capacity and increases the shunt impedance. In addition a change from seven to nine acceleration gaps is needed. The high shunt impedance of this structure of about 300 MΩ/m results in a total resonator voltage of 3.7 MV for 90 kW rf-power fed into the cavity. Assuming a transit time factor of 0.9 for the cavity at 0°-synchronous phase and an $A/q = 4.5$ of the radioactive ion beam a maximum energy gain of 0.74 MeV/u is possible. When the three seven-gap spiral resonators of REX-ISOLDE are operated at 0°-synchronous phase an energy of 2.3 MeV/u for $A/q = 4.5$ is achieved at the exit of the last resonator. This energy corresponds to the injection energy of the new nine-gap IH-resonator. Due to the higher resonance frequency of 202 MHz all dimensions of the resonator are reduced by roughly a factor two in comparison to the 101 MHz booster cavity of the REX-ISOLDE LINAC. Thus a space-saving and energy efficient solution for the upgrade becomes possible. A further energy upgrade cannot be accomplished in such a simple manner. In order to achieve a final energy of 4.3 MeV/u two of the seven-gap split ring structures have to be replaced by a 202 MHz IH-cavity, driven by a 250 kW power amplifier. This resonator needs 26 gaps and will have a length of about 1.5 m and boost the energy of the ions from 1.55 to 3.75 MeV/u. The final step to 4.3 MeV/u will be accomplished by a IH-seven-gap resonator, which corresponds to the MAFF seven-gap resonator. Due to the significantly higher energy new magnetic lenses and a new bending magnet will be required in the LINAC high energy beam line.

While reasonable charge breeding times are reached for light ions, heavier beams require more intense electron beams in REXEBIS. Presently a current density of only 150 A/cm^2 is used, while the system was designed for 250 A/cm^2, which will be reached in the near future. Moreover, other cathode designs are now available, which would allow for 500 A/cm^2. Since the breeding times are proportional to the current density a significant shortening of the breeding times is expected. The maximum A/q value of 4.5 for the radioactive ions, which can be accelerated via the REX-LINAC, requires charge breeding of the heavier masses to higher charge states up to 30 in REXEBIS. Assuming an electron beam current density of 250 A/cm^2 and a beam energy of 5 keV, the breeding time for mass $A = 120$–150 increases significantly to about 100–160 ms and the repetition rate of the breeding cycle would have to be decreased from 50 to 5–6 Hz. For the heaviest nucleus considered for the upgrade (^{148}Ba) with charge state 33^+ the ionization energy for the last electron is 2.1 keV. Since the Lotz formula for ionization shows a maximum of the ionization cross section for electron beam energies of about three-times the ionization energy the available electron beam energy of 5 keV is sufficient. On the other hand, an increase of the electron beam current density of the REXEBIS by a factor of two would reduce the breeding times below 100 ms. The study of breeding of heavier masses can easily be done using La-ions desorbed from the LaB_6 cathode used in the REXEBIS.

A reduced repetition rate of the breeding cycle requires a longer accumulation and cooling cycle of REXTRAP. This could deteriorate the beam intensity as the maximum number of ions in REXTRAP is limited by space charge effects and storage halflife. So far the ions in REXTRAP were cooled via the buffer-gas side-band cooling scheme [16]. If we consider a number of singly charged ions in excess of 10^5 per cycle for the sideband cooling method, space charge effects become important and the resonance frequencies for driving the different motions start to shift [16]. Simulations for a cloud of 10^7 ions of $^{23}Na^+$ showed that the ion cloud rotates as a whole with a frequency of some kHz, a value which can be extracted also from measured shifts in the cyclotron resonance frequency when side-band cooling is applied [17,16]. In the future we therefore want to apply a new cooling scheme, the so called "rotating wall" scheme [18–20]. The idea is to balance the plasma expansion of the rotating plasma by a "rotating wall'' electric field, which spins up the ion cloud and causes a plasma compression close to the Brillouin limit from the $v \times B$ force. This has been studied for Mg^{+} ions with laser diagnostics [19] as well as for electron plasmas and positron plasmas [18]. The heating produced by the applied rotating electric field has to be compensated by some cooling mechanism. Since the tangential friction by the buffer gas for rigid rotation is linear in r, a quadrupole field with a radially linear increasing E-field appears most appropriate. For first tests a rotating electric dipole field was applied to the presently existing four-fold segmented electrode. An increase in the stored ions per bunch from about 10^7 with side-band cooling to 5×10^7 with rotating wall cooling was observed for ^{23}Na-ions. This number was limited by the number of injected ions for this test. For this rotating wall scheme also an increase of the storage time from 50 to more than 200 ms was observed. Thus the ion losses by radial expansion were suppressed. In the future we want to spin up the ion cloud close to the to the maximum rotational frequency with an axial rotating quadrupole E-field. With this field a further increase in the ion density compared to the cyclotron resonance side-band cooling scheme is expected. The rigid rotation of the ion cloud with friction and energy loss in the rest gas and its balance with the driving force of rotation has to be studied. Also the time required to spin up the ion cloud to its maximum rotational frequency has to be investigated, as well as the emittance after extraction from the Penning trap solenoid. In this way REXTRAP may be capable of handling much higher intensities of up to 10^{10} ions/s.

5. Physics program

In the wide field of physics opened up by the availability of radioactive beams provided by REX-ISOLDE, the physics program pursued will be centered around the following three key issues, each arising some intriguing questions [1].

- Nuclear structure
  - How are level schemes, $B(E\lambda)$-values and quadrupole deformations changed in a region closer to the drip lines? How do the pairing gaps change [21]?
  - What is the most appropriate nuclear model far away from stability? How do the magic numbers change for exotic nuclei [22]?
  - Are there new collective modes to be found with stable octupole, oblate or triaxial nuclear shape?
  - Neutron halo nuclei: how many are there and do more forms exist?
- Nuclear astrophysics
  - Investigation of the properties of low lying (p,γ)-resonances for the rp-process and of (n,γ)-resonances for the r-process in nuclei, where low level density does not allow for a statistical treatment of the astrophysical processes.
  - What is the magnitude of the astrophysical S-factor, and how can we contribute to the solar neutrino problem?
- Solid state physics
  - How will radioactive implantation, creating point defects and impurities, on a deep level in the semiconductor affect its properties?

The systematic study of nuclear structure will be divided in three blocks comprising Coulomb excitation reactions, transfer reactions and fusion–evaporation reactions. Because of the charge-state breeder a significant fraction of isotopes of the nuclear chart are available for experiments. Thus, REX-ISOLDE can investigate bound and unbound nuclei in the dripline region for light nuclei, as well as heavy fission fragments and nuclei close to the $N = Z$ line. With the Coulomb excitation reaction one has a simple reaction mechanism with high cross section (up to 1 b), where new physics in neutron rich nuclei at low spin can be explored. For example the decoupling of valence neutrons from the proton core can be investigated measuring the $BE(2)$ values and the transition energy of the 2^+ state. Transfer reactions can help to identify fractional single particle energies and allow for extraction of l-values from the particles angular distributions. In addition, vanishing magic numbers, the so called shell quenching, can be examined in transfer reactions as well. In addition the occurance of new magic shells can be encountered as the *n*-pickup reaches out to even more *n*-rich nuclei. Fusion evaporation reactions will enable investigation of neutron rich compound nuclei and the enhanced sub-barrier fusion by neutron transfer. These investigations will be a first step towards the production of very heavy elements using fission fragments in fusion reactions.

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