Status and Upgrade of REX-ISOLDE ◇

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REX-ISOLDE has been the dominant experiment at ISOLDE for the past two running periods. In 2002 first experiments with radioactive nuclear beams have been carried out with the radioactive beam experiment at ISOLDE (REX-ISOLDE). Since end of 2001 the LINAC provides radioactive beams from the ISOLDE online separators with energies of 2.3 MeV/u towards two target stations. One target station is used for the γ-ray MINIBALL array and one target station is dedicated for smaller experimental set-ups. In order to make the full variety of beams from ISOLDE available for nuclear physics experiments the method of charge breeding of the singly charged radioactive ions has been employed successfully [1]. In 2003 beam experiments were running at REX-ISOLDE for seven weeks. Approximately the same amount of time was needed for tests and optimisation of the machine, so in total the time of operation of REX in 2003 was about three months.

The nuclear physics experiments were performed with isotopes on the neutron rich side of the nuclear chart. Until now only the highest beam energy of 2.2-2.3 MeV/u has been required by experiments. The different LINAC structures have been tuned with rest gas beams from the EBIS with A/q=4 in order to determine the right amplitude and phase settings. After problems with the beam quality at the target during a first MINIBALL ^{30}Mg run in July, an additional commissioning beam time of the LINAC was necessary [2]. In August/September MCP beam monitors at the target position of the two REX beam lines were used for optimisation of the spot size at the target. After this optimisation procedure the following experiments (Coulomb excitation of ^{74,76}Zn (IS412) and of ^{30}Mg (IS410)) could benefit from a significantly reduced background and produced very good results. Especially the ^{30}Mg run was a full success. After a preliminary analysis of the Coulomb excitation of ^{30}Mg [3] there is strong evidence that the B(E2) value is about a factor of two smaller than so far reported [4,5,6]. This might imply that measurements at intermediate energies (¿ 30 MeV/u) are not as accurate as previously thought. If confirmed, this could be explained by Coulomb-nuclear interference effects not considered properly in the analysis of these experiments or by unobserved feeding from higher lying states. As a classical advantage of the ISOL method, at REX both of these uncertainties are not present or strongly suppressed.

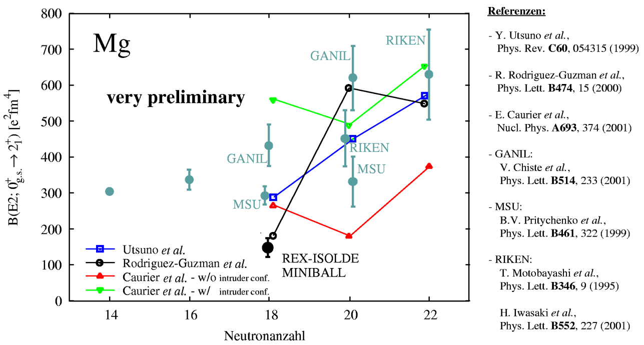

Fig. 1: Known B(E2)-values from intermediate energy experiments for Mg isotopes in comparison with the measured value from REX-ISOLDE.

The following Lithium run (IS376, IS371, IS399) in the end of October suffered from a sparking extraction electrode of the REXEBIS and later on from problems with the rf-amplifier of the second 7-gap resonator. The scheduled measurement time of one week was thus reduced to one day at a too low count rate. The measurements will partially be redone in the beam time period 2004. The final experiment in 2003 was a test for the acceleration of ^{70}Se (IS405). The beam time was switched to measurement of ^{88}Kr when it became clear that the ^{70}Se, which arrives at REXTRAP as a SeCO molecular beam could not pass the trap without break-up at the injection. The Kr-measurement shows after first analysis promising results. The charge breeding of the Se - and of molecular beams in general - will be investigated in detail for future experiments.

In parallel to the running experiments in 2003 an additional accelerator cavity was installed in the REX beam line behind the existing 7-gap resonators (see fig.2). It is a 9-gap IH resonator, which will raise the final energy at REX from 2.3 to 3.0 MeV/u. The 9-gap cavity is designed for a resonance frequency of 202.56 MHz and a maximum duty cycle of 10%. Due to the higher shunt impedance of IH-structures a higher resonator voltage in combination with a very compact design can be achieved with the same rf-power compared to split ring resonators like the 7-gap resonators of REX-ISOLDE. The 9-gap set-up required for the first step energy upgrade has been examined with oxygen beams at the MLL test bench. A O^{5+}-beam at 2.2, 2.25 and 2.3 MeV/u from the Munich tandem was used to test the ability of the 9-gap IH-structure to post accelerate at power levels from 5 to 70 kW. An energy spectrum is shown for 70 kW rf-power in fig.4. The tandem peak has

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been used for energy calibration. The drift tube structure was adjusted with constant cell length of 55 mm.

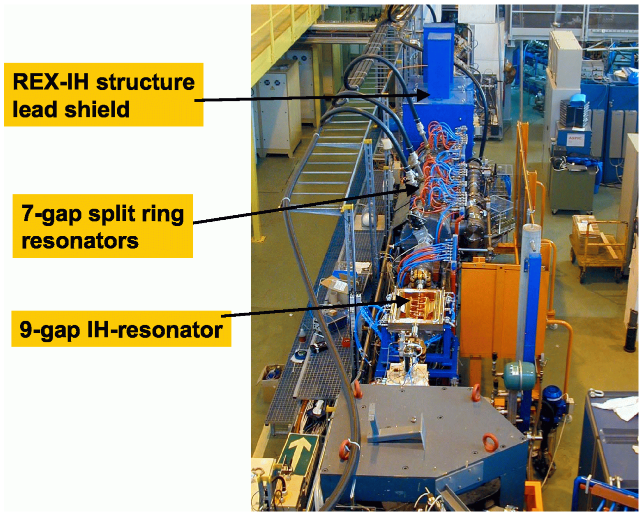

Fig. 2: Picture of the REX-ISOLDE accelerator including the new 9-gap IH-cavity.

The measured effective shunt impedance shows changes with the rf-power level, which corresponds to small values of the TTF below 0.8. This is a result of the cell length which was kept constant at 2.5 MeV/u synchronous particle energy. Therefore a higher injection energy led to higher effective shunt impedances shown. As a result the drift tube structure has to be installed according to the velocity profile in case of the 9-gap set-up, otherwise the required energy gain for REX-ISOLDE will not be possible [7]. A lead shield to reduce the X-ray emission was installed as well as the water cooling system and the rf-power line. The Amplifier was installed in the end of 2003 and the low level rf-cabling has been started and the whole system will be fully operational for the first experiments in 2004.

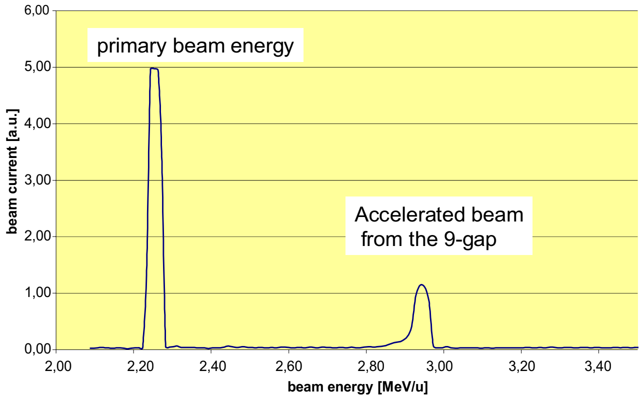

Fig. 3: Energy spectrum from the 9-gap IH-cavity on the test bench in Munich. The rf-power has been 70 kW, at 0.2% duty cycle

The concept of REX-ISOLDE comprises the charge state breeder based on an Electron Beam Ion Source (EBIS) and the LINAC itself. The beam preparation is done by the charge state breeder consisting on the large Penning trap REXTRAP, a transfer beam line, the REXEBIS and an A/q-separator [8]. For the energy upgrade a bunch of tests has been carried out and will still follow, in order to investigate accumulation and breeding of heavier isotopes. Therefore, a ^{133}Cs beam from the test source of REXTRAP was injected into the EBIS. At a breeding time of 160 ms the maximum charge state was 32+. The acceleration tests had to be been done with $^{133}Cs^{32+}$ (A/q=4.16) at a non optimized breeding efficiency of about 1%. Another point to mention in connection with the change to heavier isotopes is the test of a new cooling method, the "rotating wall principle", in the REXTRAP. Since the breeding times of heavy isotopes in the EBIS are nearly a factor of ten longer than for the lighter elements, a more efficient trapping and cooling mechanism than the conventional side band cooling is needed to store the larger amount of ions in the trap for a longer time. First tests with the rotating wall principle look very promising. Storage times of more than 200 ms and storage capacities of $5*10^7$ particles have been reached with the rotating wall technique.

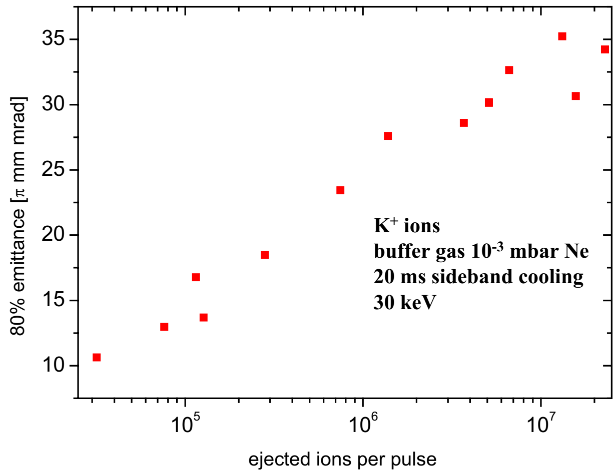

Fig. 4: Beam emittances of REXTRAP in dependence on the particle number accumulated in one pulse.

One important part of the REX-ISOLDE charge state breeder is the beam matching of beams from the ISOLDE target ion sources to the EBIS acceptance. Therefore the beam emittance from the REXTRAP is an important parameter, which influences the injection efficiency drastically. Measurements with the MUNICH low intensity, low beam energy emittance meter have been performed, in order to determine the emittance of the REXTRAP in dependence on the beam intensity. If no cooling is applied the ISOLDE beam emittance has been determined to 30 π mm mrad (80%, 30 keV) for ^{39}K beam has been determined. Applying side-band cooling the value drops significantly to 10.6 π mm mrad, which matches the EBIS acceptance. The beam emittance in case of the side band cooling technique, shows a strong dependence on the ion beam intensity, which is shown in fig.4. Thus very high intensities beyond 10^7 ions/pulse or 10^9 ions/sec, sideband cooling does not allow any further emittance reduction. Above 10^5 ions/pulse no appropriate matching of the beam to the EBIS acceptance is possible. Therefore the rotating wall cooling technique and it's benefits for the beam matching of higher beam intensities is explored.

The electrode structure of REXTRAP has been changed in order to apply a rotating quadrupolar field in the transverse direction, which results in a better confinement of the ions. The rotating wall cooling technique compresses a large ion cloud using rotating electric multipole fields, which create a Lorentz force in direction towards the trap beam axis. It could be shown that rotating wall cooling increases the trap capacity as well as the maximum confinement time. Breeding of heavier masses needs significantly longer breeding times, hence longer confinement time in the trap are required. Therefore rotating wall cooling can solve that problem. First measurements have been carried out with a rotating dipole field, using ^{39}K ions delivered from the REXTRAP test ion source. The first result are the compression of the ion cloud into a density of 15-20% of the Brillouin density, which is the ultimate density one can reach with the rotating wall cooling method. Using rotating wall cooling in combination with REX-EBIS the efficiency in one single charge state ($^{39}K^{9+}$ was chosen) is smaller compared to the sideband cooling for low intensities. The efficiency drops significantly for the sideband cooling technique, when higher beam intensities are injected into the trap, whereas the efficiency for the rotating wall cooling remains constant. Thus indicates that the rotating wall compression is not yet sufficient to match the beam to the EBIS acceptance. One has to note that the rotating wall cooling is not optimised yet and therefore the efficiencies can be optimised in future measurements as well.

A systematic study of the structure of exotic nuclei is now possible at REX-ISOLDE. The nuclei that are accessible will be mainly investigated with standard nuclear reactions like Coulomb excitation, transfer, and fusion-evaporation reactions in inverse kinematics, allowing a detailed study of collective and single particle properties of nuclei far from stability. The cross sections for these reactions are rather high: about 1 b for Coulomb excitation and about 100 mb for neutron-pickup reaction from deuterium and ^{9}Be. In conclusion, REX and MINIBALL are fully operational and first physics experiments focusing on the nuclear structure of the neutron-rich Na and Mg isotopes were performed. A preliminary analysis shows the high quality of the data that can be obtained with MINIBALL at REX-ISOLDE with a radioactive, low-energy and low-intensity beam.

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