Eur. Phys. J. A **20**, 67–68 (2004)
DOI 10.1140/epja/i2002-10324-1

THE EUROPEAN
PHYSICAL JOURNAL A

First γ-rays from radioactive beams at REX-ISOLDE

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Received: 8 November 2002 /
Published online: 24 February 2004 –

Abstract. In order to demonstrate a novel scheme to accelerate radioactive ions and to provide radioactive ion beams for physics experiments, the radioactive beam experiment (REX) was installed at ISOLDE, CERN. One of the main experimental devices that will use these beams is the newly commissioned HPGe array MINIBALL featuring an excellent granularity, energy resolution, and rate capability. First experiments have been performed using beams of neutron-rich Na and Mg isotopes.

PACS. 41.75.Lx Other advanced accelerator concepts – 29.30.Kv X- and γ-ray spectroscopy – 25.60.Je Transfer reactions

The Radioactive beam EXperiment (REX) is a pilot experiment to demonstrate the feasibility of an efficient and cost-effective way to accumulate, bunch, charge breed, and accelerate radioactive exotic ions. In addition, beams of these nuclei should be produced for physics experiments, *e.g.* investigating the structure of nuclei far from stability. The REX accelerator is situated at the ISOLDE facility at CERN, which routinely provides a multitude of exotic nuclei for its users [1,2].

The main components of the REX accelerator are a trap (REX-TRAP), an ion source (REX-EBIS), a mass separator and the actual accelerator consisting of a radio frequency quadrupole, a re-buncher, an IH-structure and three 7-gap resonators. REX-TRAP is a buffer-gas–filled Penning trap that continuously traps the ions (with a charge state 1+) coming from the ISOLDE beam line. The accumulated ions are cooled and form bunches which are periodically (typically every 20 ms) transferred to the electron beam ion source REX-EBIS. Here charge breeding takes place and when a charge state to mass number ratio of $q/A > 1/4.5$ is reached the ions are extracted, mass separated (mainly to remove copious residual gas ions) and accelerated to around 0.8–2.2 MeV/u. It should be noted that in an EBIS the average charge state depends mainly on the breeding time and always a large fraction (about 15% for $A \sim 20$) of the ions is in one charge state. Still, as only one charge state of the ions can be accelerated, the largest reduction in transmission occurs after the EBIS. The total transmission from the ISOLDE target to the REX target is about 1% sofar but will be improved to about 5% in the near future.

The first radioactive nuclear beam was accelerated in October 2001 to an energy of 2 MeV/u and in 2002 already several radioactive beams were produced with an energy of 2.2 MeV/u. Plans for an intensity and energy upgrade should lead to a beam energy of 3.1 MeV/u in 2003 and a beam energy of 4.3 MeV/u in 2005, which will significantly extend the accessible region of nucleids toward heavier isotopes especially for Coulomb excitation experiments. For more details on the REX accelerator, ref. [3] should be consulted.

In April of 2002 (start of the ISOLDE running period), the MINIBALL HPGe array was installed at the 65° beamline of REX. Currently, the array consists of 24 six-fold segmented individually capsuled high-purity germanium detectors arranged in 8 triple cryostats. The shape and size of the individual germanium crystals is the same as that of the EUROBALL cluster detectors. In the final stage, a total of 40 detectors will be available with the additional 16 germanium capsules arranged in four quadruple cryostats. The detectors are mounted on a flexible frame, allowing for an easy reconfiguration of the detector geometry.

All preamplified segment and core signals are processed by digital electronics, which not only allows a quasi–deadtime-free measurement (when the macro time structure of the REX beam, 400 μs beam every 20 ms, is exploited for the data readout) but also for a user-programmed on-board and on-line pulse shape analysis (PSA). Only the information relevant for the determination of the photon interaction position (and not the full pulse trace) is stored for off-line analysis. The segmentation and the PSA is used to improve the granularity of the array allowing the determination of the interaction position of the photons in the Ge crystal with a resolution of about 8 mm (FWHM) for a photon energy of 1332 keV. This corresponds to an increase in granularity of about 100 in comparison to an unsegmented detector.

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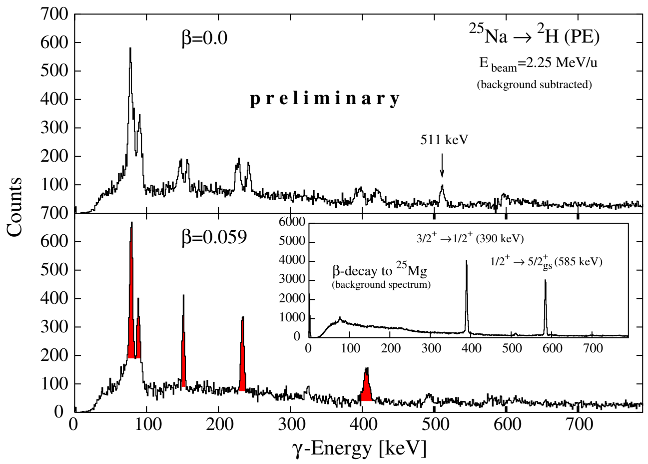

Fig. 1. Doppler-corrected (bottom) and uncorrected (top) γ spectra taken in 7 hours with a ^{25}Na beam ($3 \cdot 10^6 s^{-1}$, $E_{beam} = 2.25$ MeV/u) on a deuterated polyethylene target (7 μm).

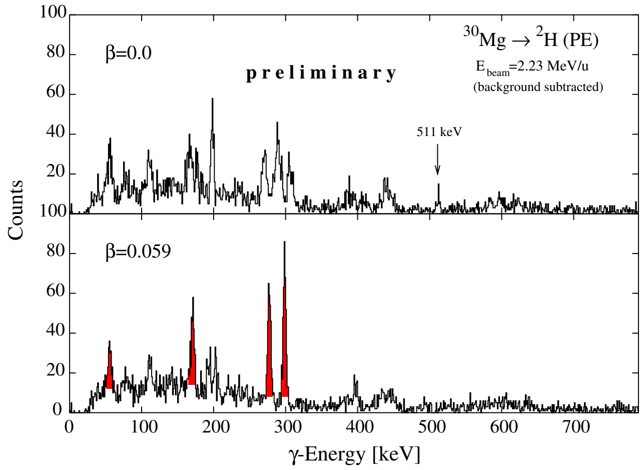

Fig. 2. Doppler-corrected (bottom) and uncorrected (top) γ spectra taken in 20 hours with a ^{30}Mg beam ($1 \cdot 10^4 s^{-1}$, $E_{beam} = 2.23$ MeV/u) on a deuterated polyethylene target (10 μm).

This information is used to Doppler-correct the measured γ energies as the γ-rays are emitted by fast-moving reaction products due to the inverse kinematics. More information on the MINIBALL array can be found in [4,5].

The first nuclear-physics experiments with MINIBALL using the radioactive beams provided by the REX accelerator were performed in 2002. The aim of the experiments was to commission the accelerator and the MINIBALL array and to start an investigation on the collective and single-particle properties of the neutron-rich Na and Mg isotopes using Coulomb excitation on a Ni target and neutron-pickup reactions on ^{9}Be (^{9}Be,2α) and ^{2}H (d,p) targets. The neutron-rich Na and Mg isotopes are especially interesting because of the rapid changes in nuclear structure around the $N = 20$ nucleus ^{32}Mg. In addition, the Na and Mg isotopes are produced with high yields at ISOLDE. For both elements a uranium carbide production target was used. To ionize the produced atoms, surface ionization and laser ionization were used for the Na and Mg isotopes, respectively. The current of the 1.4 GeV proton beam from the CERN PS was typically 1-2 μA.

In addition to the MINIBALL array, a highly segmented double-sided Si strip detector (DSSD) with 64 annular and 96 radial segments was employed to detect charged reaction products at forward angles from about 15° to 50° [6]. At zero degrees a parallel plate avalanche counter was installed to monitor the beam [7].

At this stage of the analysis only preliminary γ spectra can be shown. Figure 1 shows a spectrum taken with a ^{25}Na beam of 2.25 MeV/u incident on a deuterated polyethylene target (7 μm thickness). The beam intensity was $3 \cdot 10^6$ s^{-1} on target (about $3 \cdot 10^8$ s^{-1} from ISOLDE) and the measurement lasted for about 7 hours. A signal above threshold was required in the DSSD and only events with a γ fold of one were included in the analysis. The top panel shows the γ spectrum in the energy range up to 800 keV. Sharp lines and broad structures can be seen. After correction for the Doppler shift (bottom panel) several lines show up or improve, clearly proving that these γ-rays were emitted by a fast-moving source. Presently, only the detector (Ge crystal) positions are used for the Doppler correction; the segmentation and the PSA data are not yet analyzed and should improve the Doppler correction considerably, especially at high γ energies. Moreover, the directional information from the DSSD is not yet used; so far, it was assumed that the direction of the γ-emitting nuclei corresponds to the beam direction. The observed γ-rays do *not* necessarily originate from neutron-pickup, since other reaction channels cannot be excluded at this stage of the analysis. However, the peaks at 151.1 keV and 233.6 keV are known transitions [8] in the neutron-pickup product ^{26}Na. Moreover, a state at 420(15) keV is known, but no transition has been observed. Therefore, the line around 410 keV *might* be the transition of this level to the ground state. The spectra are background subtracted. A background spectrum is plotted in the inset, showing the well-known β-decay γ lines of ^{25}Na.

In fig. 2 a γ spectrum taken with a ^{30}Mg beam at an energy of 2.23 MeV/u is shown. The deuterated polyethylene target was 10 μm thick, the beam intensity was only 10^4 part/s, and the measurement lasted about 20 hours. Known transitions in the neutron-pickup product ^{31}Mg with an energy of 50 keV and 170 keV can be seen in the spectrum. The two strong lines at 277 and 298 keV are transitions in ^{16}N due to reactions of the residual gas ^{15}N, contained in the beam, with the target.

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