REX-ISOLDE FACILITY AND THE IMPORTANCE OF BEAM TIME STRUCTURE TO DATA ACQUISITION AND PROCESSING—THE EXPERIMENTALIST'S VIEW*

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Abstract

The REX-ISOLDE radioactive ion beam facility at CERN makes great demands also on the experimentalists due to its specific duty cycle and the time structure with short beam pulses and large intensities. This paper describes the experimentalist's point of view, how to obtain sufficient and correct statistics under the special circumstances arising from the beam time structure. In particular, the case of Coulomb excitation experiments, where a large total cross section is ultimately desired, is studied in greater detail.

REX-ISOLDE

At the On-Line Isotope Mass Separator ISOLDE at CERN, radionuclei are produced in thick high-temperature targets, which are hit by a 1.0 or 1.4 GeV proton beam. The nuclear reaction products from spallation, fission or fragmentation reactions are converted in a radioactive ion beam (RIB). The **R**adioactive beam **EX**periment at ISOLDE (REX-ISOLDE) bunches, charge breeds and post-accelerates the already existing radioactive ions. Thus the full variety of radioactive ions available at ISOLDE becomes accessible as accelerated beams for experiments at the super-efficient and segmented gamma-ray MINIBALL array.

The radioactive 1^+ ions from the separators are first accumulated, bunched and cooled in a Penning trap, REX-TRAP (compare Fig. 1). The trap stores the ions during the breeding in the subsequent charge breeder. Bunches of ions are then transferred to an electron beam ion source, REXEBIS where the ions are charge bred to a mass-to-charge ratio below 4.5. This processes result in the complex time structure as shown in Fig. 2 with a short bunch length of approx. 150μs combined with a small repetition rate of 3Hz. This causes a large effective rate of particles during a pulse and is the main problem for the experimentalists as they have to adept the setup and the DAQ to this specific conditions. Before the ions reach the target they are finally injected into a compact linear accelerator via a mass separator. The charge multiplication of the radioactive ions allows access to the heavier mass region of the nuclear chart.

The post-accelerated radioactive ions are delivered to

Table 1: REX-ISOLDE facts. The data may vary for different radioactive ion beams. (Table taken from [1].)

Part	Aspect	Information
Charge Breeding System	Cooling time	< 20ms
	Breeding time	3-200ms
	Trap efficiency	> 40%
	EBIS efficiency (in one charge state)	< 30%
	Beam intensity	$< 10^9$ ions/s
LINAC	Resonance frequency	101.28 and 202.56MHz
	Duty cycle	10%
	Design transmission	90%
	EBIS pulse	50 - 250μs
	Repetition rate	max. 50Hz
	Bunch length at target	0.3ns (2.2 MeV/u) 13ns (0.8 MeV/u)
	Beam energy	0.8 - 3.0 MeV/u

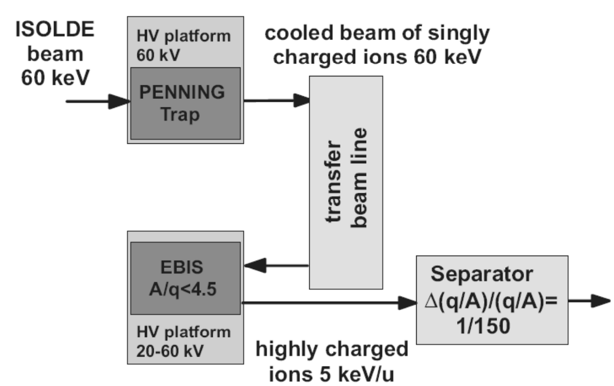

Figure 1: The Trap-EBIS combination. (Picture taken from [1].)

the target position where they are used in gamma spectroscopy experiments. The MINIBALL array for Gamma spectrocopy is built by eight cluster detectors, each of them consisting of three individually encapsulated six-fold segmented high purity germanium detectors. It was optimized for the total full-energy peak efficiency to fit the requirements of radioactive beams. For particle identification a CD detector, a highly segmented **D**ouble-**S**ided **S**ilicon **S**trip **D**etector (DSSSD) is used [1].

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EXPERIMENTS

In an experiment REX-ISOLDE offers not just a radioactive beam but also comes along with some features that can become a problem for the experimentalists. They can be summarized in three fields:

- High counting rates
- Effects of background radiation on coincidence measurements
- Isobaric and other beam contaminants

In the following subsections a detailed description of them is given.

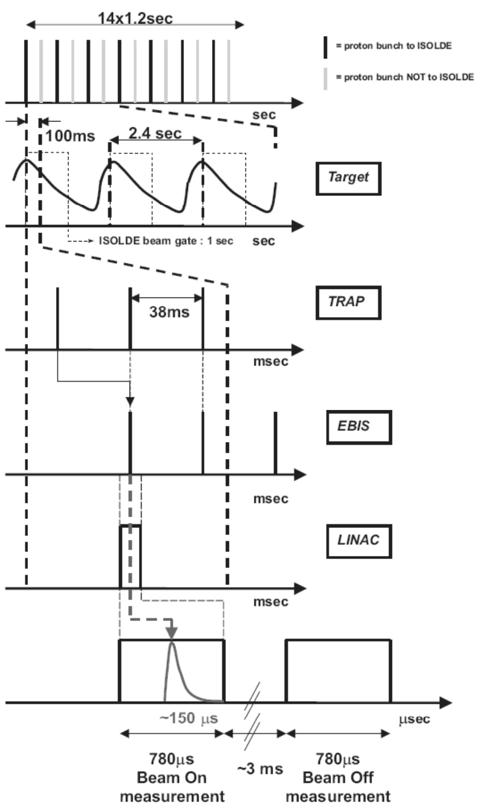

Figure 2: The time structure of the different stages in the ISOLDE laboratory. Every 2.4 seconds a bunch of protons hits the production **Target**. The ions diffuse out of the target and are injected in the **TRAP** where they are cooled with the help of buffer gas. The ions are extracted from the trap in short bunches of 10-50μs and transfered to the **EBIS** to charge breed them (milli-second range). The **LINAC** post-accelerates the pulses from the EBIS and delivers particles in pulses of approx. 150μs to the target. In this case a window of 780μs is used for Beam on/off measurements. (Picture taken from [2].)

High Counting Rates

To estimate the number of events which have to be processed by the data aquisition a small calculation is done. A typical intensity of a radioactive ion beam is 10^5-10^6 particles/sec. This corresponds to an instantaneous rate of 10^8-10^9 particles/sec. As an example the Coulomb excitation experiment IS411 is taken, where ^{140}Ba and ^{142}Ba were impinging on a ^{96}Mo target with a thickness of F_ρ=0.9mg/cm^2. The rate of particles in the beam (projectiles) is given by the following formula:

$$n(t) = n \cdot \vec{j} \cdot \sigma \cdot \epsilon \simeq 450 \frac{1}{s} \qquad (1)$$

$n = \frac{F_\rho \cdot N_A}{M_A}$	:	Number of particles
$\vec{j}$	:	Particle current density
σ	:	Integrated Coulex cross section
$\epsilon = \epsilon_{Si} \cdot \epsilon_{MB}$	:	Efficiency (coincidence trigger)

That means there are 450 particles/sec from Coulex scattering hitting the CD while a coincident photon was detected for each. The number of particles from Rutherford scattering is even about a magnitude higher. Because of the short duty cycle there are just 3 pulses of approx. 150μs during a second. One expects around 150 Coulex events per pulse. This is a great challenge for the experimentalists and very fast preamplifiers with very short time constants (approx. 1μs) must be used to avoid pile-up.

To overcome this problem a segmented particle detector and ADCs which have a buffer of 32 events per channel have to be used. Each segment of the DSSSD is read-out by a single ADC and the instantaneous rate is thereby divided by the number of segments. Another advantage of this method is the fact that there is almost no deadtime because the buffer can be processed during the waiting time for the next pulse and the DAQ happens “offline” in this context.

Effects of Background Radiation on Coincidence Measurements

A second major problem occurs because dealing with radioactive beams always causes a lot of unwanted background radiation from radioactive decay. To make a particle-γ coincidence the detected photon opens a gate where you wait for a particle (projectile or target) or vice versa. Due to the high particle rate during a beam pulse the probability of accumulating random particles from Rutherford scattering is much higher compared to more DC like beams. The so called random coincidences can be the dominating part and would make the coincidence measurement inefficient or almost impossible (see Fig. 3). The problem is even worse because additionally to the *beam-independent* accumulated radiation from the radioactive ions one has *beam-correlated* X-radiation up to ~300keV from the 9-gap resonator at the end of the LINAC.

This case is treated by two approaches. To reduce the number of low-energy gamma rays first of all shielding is

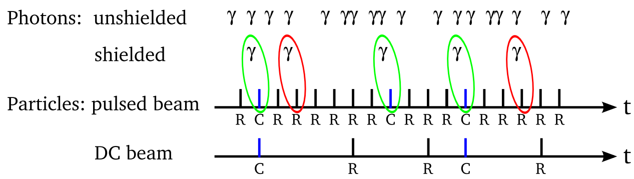

Figure 3: Timeline of γ-particle coincidences. (C and R for Coulomb and Rutherford particles.)

very important and a combination of lead, copper and aluminum is used. Furthermore the accelerator side invented the so called "slow extraction" to gain longer pulses and thereby reduce the counting rate per pulse.

Isobaric and other Beam Contaminants

The purity of REX-ISOLDE beams may suffer from contaminants. They consist on the one hand of isobaric components if isobars could not be removed after the production target by chemical processing (diffusion time) or laser ionization. On the other hand products from different stages of the beam production, e.g. buffer gas from the REXTRAP, can appear in the beam. For some ion beams these contaminations are too large to perform Coulex experiments which depend on the measurement of relative Coulex yields. The contaminating particles will excite the target as well and no calibration is possible when the beam impurities cannot be quantitatively identified.

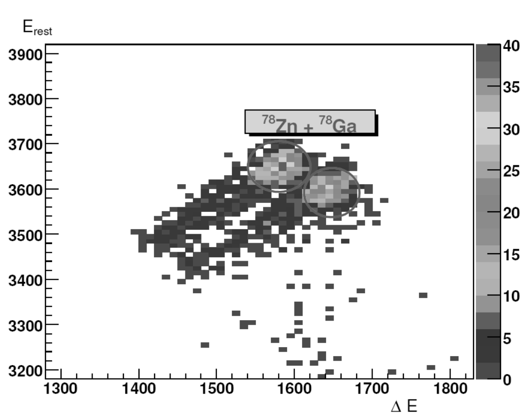

Figure 4: Identification of beam content by the Bragg chamber. (Picture taken from [3].)

First you can set a gate on the EBIS pulse to improve the ratio of desired beam to contaminants because the isotopes appear at slightly different times in the pulse [2]. If it is necessary for the analysis one can extract the ratio from the experimental data as described in [2]. The post-accelerated beam is sent into a Bragg chamber, where a ΔE(gas)-E(Si) measurement allows the identification of the beam content as shown in Fig. 4.

CONCLUSION

It is obvious that the highly complex production of a bunched beam of radioactive ions at REX-ISOLDE, which is possible just since 2001, also produces a bunch of challenges for the experimentalists. Those problems were solved by the time although there is still some space for optimization from both sides, the machine and the experiment. Nevertheless with the spectroscopy of radioactive nuclides a big new field of nuclear research has been established with the help of REX-ISOLDE.

REFERENCES

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