# RECENT DEVELOPMENTS OF THE EXCYT RADIOACTIVE BEAM DIAGNOSTICS

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## *Abstract*

The EXCYT radioactive beam facility at LNS, based on the ISOL technique, will start producing its first radioactive beams during 2004. We have set up a suitable high sensitivity diagnostics, in order to guarantee a real time monitoring of the beam parameters (transversal profiles, ion composition and current), also for very low intensity values (well below $10^5$ particles per second). By making use of a simple technique based on a thin CsI(Tl), we can also efficiently image beams of very low kinetic energy (50 keV).

## 1 INTRODUCTION

At INFN-LNS Catania the EXotics with CYclotron and Tandem (EXCYT) facility, based on the Isotope Separator On-Line (ISOL) technique, is going to start the production of radioactive ion beams. The beam energy will range from 0.2 MeV up to 8 MeV/A, its emittance is expected below $1\pi$ mm·mrad, with an energy spread of $10^{-4}$ [1]. The ISOL technique consists of stopping a stable primary beam, in our case $A < 48$ $E < 80$ MeV/A produced by a superconducting cyclotron, inside a thick target. There nuclear reactions give rise to a wide variety of radioactive species, which are extracted and transported to a high resolution magnetic isobaric separator, in order to pick out the ions of interest. The EXCYT isobaric separator consists of two main stages, each one composed of two magnetic dipoles. The first stage is placed on a 250 kV platform, while the second is grounded. The beam is finally accelerated by means of a Tandem accelerator ($V \leq 15$ MV). The typical particle rate will fall in the range between $10^3$ and $10^8$ pps, depending on the intensity of the primary beam (< 1 pμA), on the production cross section in the target and on the overall efficiency from the ion source to the experimental area.

The beam diagnostics is an important issue of the facility, since it allows to check on-line the beam properties along the transport line, in order to perform the tuning operations. To this purpose we have developed suitable easy-to-use devices, capable of fulfilling the requirements of sensitivity and reliability [2, 3].

LEBI (Low Energy Beam Imager / Identifier) is a compact device used for stable and radioactive low energy beams (50 – 300 KeV), capable of beam imaging, particle rate measurement and identification of nuclei.

GFIBBS is a scintillating-fibre based system, operating with both stable and unstable beams, which can reconstruct with remarkable sensitivity the transverse X and Y profiles after the final acceleration. The identification of the accelerated nuclear species is performed by means of a high resolution silicon telescope.

## 2 PREACCELERATION, BEAM IMAGING AND IDENTIFICATION

### *2.1 The LEBI device*

LEBI exploits the radioactivity of the beam particles, which are implanted onto a thin Mylar tape placed in contact with a CsI(Tl) plate [4]. The emitted radiation (mainly β and γ rays) crosses the plate, thus producing a light spot representing the transverse profile of the beam, that is watched by a high sensitivity CCD camera (~$10^{-4}$ lux). LEBI can also be employed with stable beams, in order to set up the transport elements along the beam line (quadrupoles, magnetic dipoles of the isobaric separator, etc). In this latter case LEBI is positioned a little bit lower, in order to allow the beam to hit directly the scintillating plate (Fig. 1).

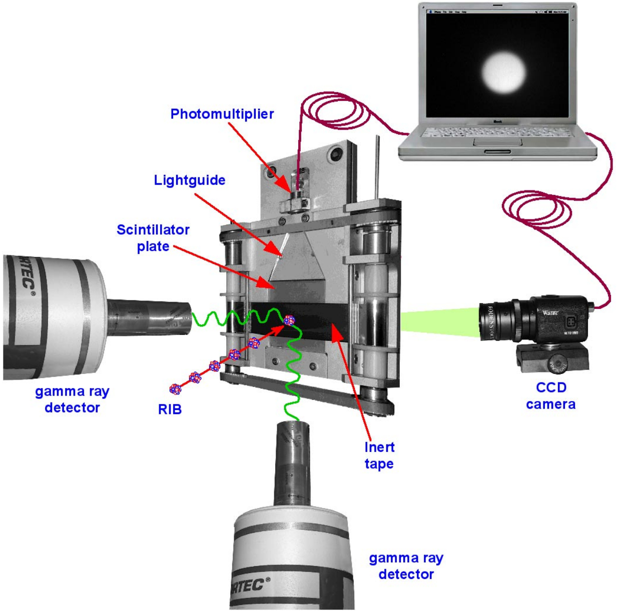

Figure 1: Sketch of the LEBI device for low energy beam imaging and identification.

The plate is enveloped into a grid made of thin metallic wires connected to ground potential; this prevents the plate charge-up, which would deflect the incoming low energy ions thus producing image distortions or no image at all.

For decays in which the daughter nuclei emit gamma rays, a couple of high purity germanium detectors, installed close to the plate, allow a suitable identification of the radioisotopes. Since the gamma ray spectrum is a fingerprint of the emitting nucleus, the recognition of well defined peaks by means of gamma spectroscopy, allows to tag the nuclear species present in the beam. These detectors are positioned close to the Mylar tape, at a relative angle of 90°. They should collect events with at least two gamma rays emitted in coincidence, so that the background can be strongly reduced, highlighting the gamma cascades bound to the selected gammas. In such a way, it is possible to perform a strong selection of the nuclear species, provided that it has at least a couple of gammas in cascade.

By replacing the CsI(Tl) plate with a 5x5x5 cm$^3$ plastic scintillator, beta counting and spectroscopy can be performed. These measurements allow to identify the implanted radioactive nuclei, by means of the spectrum shape and of the decay constant $\lambda$. The wound used tape is well shielded by means of small plastic slabs, in order to prevent residual beta rays of previous implantations from reaching the scintillator. Further anticoincidence detectors, made of CsI(Tl) plates coupled with photodiodes and encapsulating the plastic scintillator, will be exploited to reduce the background radiation.

### 2.2 *Off line testing and simulation*

The spatial resolution of LEBI is mainly affected by the isotropical emission of the radiation from the implanted nuclei. If we imagine to use a point-like source placed on the plate, the radiation will cross it in all directions (in such a case the plate covers a solid angle of $2\pi$ sr), thus producing a light spot with a halo around it. The expected FWHM of the spot is of the order of the plate thickness.

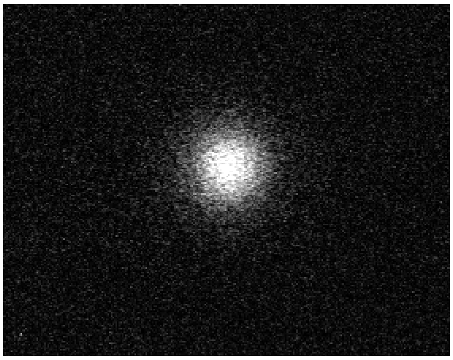

Figure 2: Picture of a beta-electrons beam, produced by means of a collimated $^{90}$Sr hitting the LEBI scintillating plate.

An experimental test, in which a pencil-like $\beta$ beam was exploited, has been performed by using a 1 mm collimated $^{90}$Sr source, with intensity below $10^3$ pps. It was placed in front of a CsI plate 2 mm thick. The profile of the observed light spot shows a FWHM $\approx$ 1.7 mm (Fig. 2). By means of a simple quadratic subtraction, we can evaluate a spatial resolution of about 1.5 mm.

We have also developed a Monte Carlo simulation code, based on the energy loss of beta rays inside the CsI(Tl) crystal, which is capable of reproducing the shape of the light spot created when the plate is crossed by the radiation. As an example where a realistic beam is simulated, we assumed to produce a $^{18}$F beam that contains $^{18}$N as a contaminant, see Fig. 3. The predominance of the contribution due to $^{18}$N ions depends on the value of its decay constant ($\lambda_{18N}$ = 1.11·sec$^{-1}$), much larger than $^{18}$F ($\lambda_{18F} = 1.05 \cdot 10^{-4}$ sec$^{-1}$).

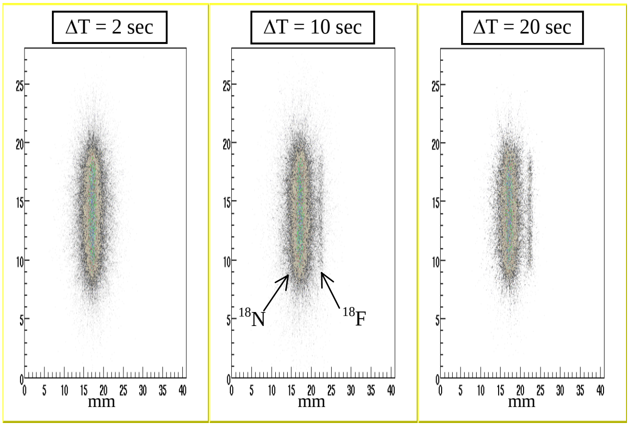

Figure 3: Simulated response of LEBI, placed after the 2nd stage of the mass separator, to a $^{18}$F beam and its contaminant $^{18}$N. ΔT is calculated starting from the beam implantation.

A simple test of radioactive isotope recognition by means of a couple of germanium detectors, was performed with a $^{60}$Co source. We observed that a strong background suppression is achieved when both detectors are used, showing, if needed, that the technique is reliable.

### 2.3 *Imaging of stable beams*

In order to test the effectiveness of LEBI to operate with very low energy beams, we produced several different beams of energy down to 50 keV, spanning from hydrogen to silver [5]. For this purpose we employed the ion source of our Tandem accelerator. The measured sensitivity, in terms of beam current, is tipically less than 1 pA, and for the lightest elements we were able to display beams with intensities of tens of fA. In Fig. 4 we show a spot corresponding to a $^{109}$Ag beam, at 170 keV energy and 4 pA intensity.

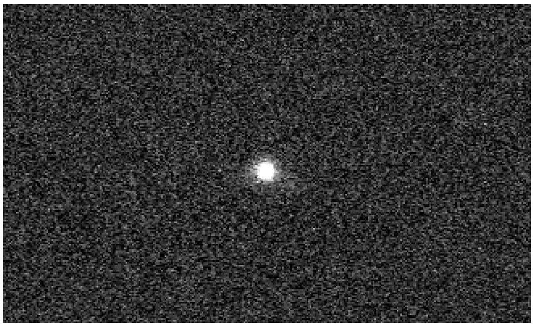

Figure 4: On-line picture of a 4 pA $^{109}$Ag beam at 170 keV. The spot size is about 1 mm.

## 3 POST-ACCELERATION

### 3.1 *Beam profiling*

The Glass FIbre Based Beam Sensor (GFIBBS) represents our general solution for beam profiling, since we proved it is reliable, cheap and simple. It is based on a pair of glass or plastic scintillating fibres scanning the beam. The two fibres are mutually perpendicular and are readout by means of a single compact PMT, Fig. 5. It allows to reconstruct the X and Y beam profiles in a single scan with high efficiency. Since plastic fibres are not radiation hard, they are mainly used at low particle rates, when single particle counting can also be performed. Several tests with glass fibres, carried out by exploiting different beams [6], have shown a beam current sensitivity typically well below $10^5$ pps.

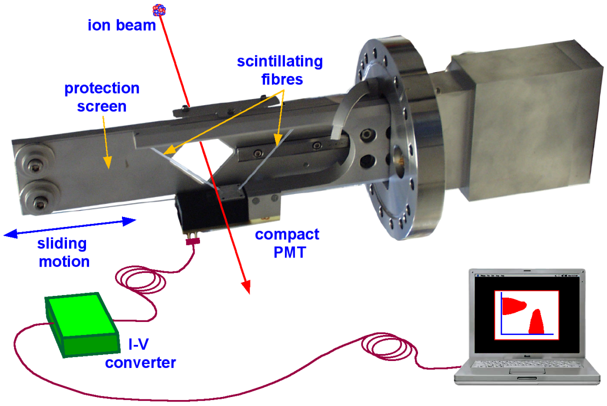

Figure 5: Sketch of the GFIBBS device, for beam profiling after the acceleration.

### 3.2 *Beam identification*

The identification of the accelerated ions is performed by means of a silicon telescope. The capability of such a detector to efficiently identify in Z the nuclei, combined with the strong selection in A operated upstream by the mass separator, allows to uniquely determine the nuclear composition of the beam. The silicon telescope can be accurately positioned around a target (typically gold), placed along the beam line, in order to intercept the scattered ions. The angle where the telescope must be placed is chosen as a function of the expected intensity and energy, in order to have a detected intensity not larger than $10^4$ particles per second on the telescope. This prevents a quick detector damage. In order to estimate the discrimination efficiency between the ions of interest and the isobaric contaminant species, a test was done by exploiting elastic scattering from the reaction $^{16}$O + $^{196}$Au. At the same time a three-peaks alpha source, placed close to the telescope, was used to perform the energy calibration. This data allowed to measure the experimental error, useful for extrapolating the expected errors when detecting other ion species foreseen with EXCYT. As an example we took into consideration three elements: $^{11}$Be, $^{17}$F and $^{18}$F. Based on the measured data with the oxigen beam, for each species and their isobaric contaminants we estimated the energy loss in the ΔE detector; then we built the related ΔE-E scatter-plot with the realistic error bands. In Fig. 6 we show the resulting plot for the $^{11}$Be case. These plots allowed to calculate the probability of misidentification, that between contiguous elements stays below $10^{-10}$.

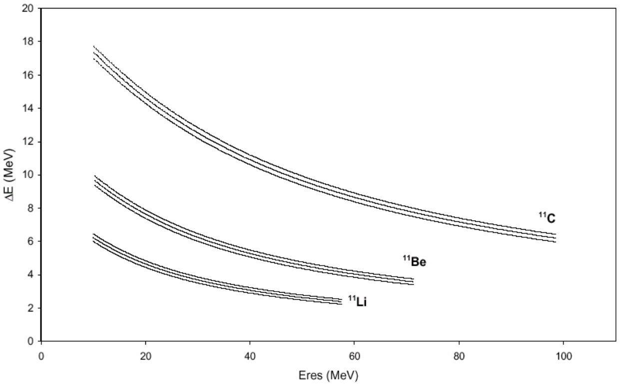

Figure 6: Discrimination plot (±σ) for $^{11}$Be. The two main contaminants, $^{11}$Li and $^{11}$C, are shown.

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