BEAM DIAGNOSTICS FOR LOW-INTENSITY RADIOACTIVE BEAMS

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Abstract

In order to perform imaging, profiling and identification of low intensity ($I_{beam}<10^5$ pps) Radioactive Ion Beams (RIB), we have developed a series of diagnostics devices, operating in a range of beam energy from 50 keV up to 8 MeV/A. These characteristics do them especially suitable for ISOL RIB facilities.

1 INTRODUCTION

At INFN - LNS Catania the ISOL (Isotope Separator On-Line) EXCYT facility (EXotics with CYclotron and Tandem) is under development [1]. It allows the production of radioactive beams with energies from 0.2 up to 8 MeV/A, emittance less than 1π mm·mrad and energy spread below 10^{-4}.

The radioactive beam is produced by stopping a stable primary beam ($A < 48$, $E \leq 80$ MeV/A) inside a thick target. The produced radioactive species are extracted and transported to a high resolution magnetic isobar separator ($\Delta M/M = 1/20000$), which separates the ions of interest from the isobaric contaminants. The separator consists of two main stages composed of two magnetic dipoles each one, arranged so that the first stage is placed on a 250 kV platform, while the second is grounded. After it the radioactive beam has a kinetic energy of 300 keV and can be directly used for the experiments or accelerated by the 15 MV Tandem. Its intensity falls in a range from 10^3 pps up to 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 extraction efficiency from the ion source.

In this paper we report on diagnostics devices developed for the beam pipe before the acceleration (kinetic energy from 50 keV to 300 keV), and for the accelerated beams (up to 8 MeV/A).

For the low energy regime, a device for imaging/identification of the beam has been developed. It is based on a CsI(Tl) scintillator plate and exploits the decay of radioactive ions of the beam, since the energy of the emitted radiation (β and γ) is typically above 1 MeV, enough to produce a detectable signal.

Regarding the high energy range, we make use of a couple of devices, capable of identifying and profiling the beam by directly detecting the accelerated ions. The background due to radioactive ions implanted inside the devices does not represent a problem, since its contribution to the overall signal is negligible.

2 PREACCELERATION BEAM IMAGING AND IDENTIFICATION

2.1 The LEBI device

The beam diagnostics in the preacceleration stage (low energy) is a crucial point, since a quick beam tuning needs an efficient real-time check of the beam properties. The devices should be able to locate the beam position, to measure its transversal size and to identify its nuclear composition. The device named LEBI (Low Energy Beam Imager / Identifier) permits to attain the beam imaging and identification by exploiting the radiation emitted by the radioactive ions, Fig. 1. The core of this system is a scintillator plate of CsI(Tl) and a thin mylar tape arranged in front of the plate. When the film and the scintillator are placed along the beam line in order to intercept the beam, the ions get implanted onto a small film area, which thus becomes a radioactive source. The emitted radiation (mainly β and γ rays) crosses the plate, so producing a light spot. A CCD camera watching the plate allows to determine the beam location and roughly measure its transversal size.

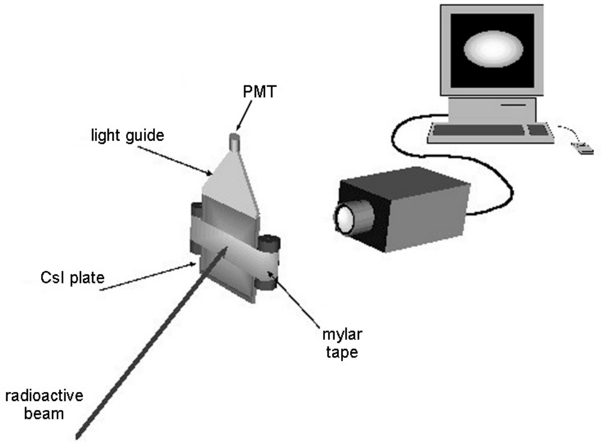

Figure 1: Sketch of the LEBI device for low energy beam imaging and identification.

In order to get as much information as possible to identify the beam, a small photomultiplier (Hamamatsu R7400) used in pulse counting mode is optically coupled to a side of the plate, by means of a light guide. Its main application concerns the identification of implanted nuclear species, by measuring the particle count rate at fixed time intervals, in order to estimate the decay constant λ.

For decays in which the daughter nuclei emit gamma ray, a couple of high purity germanium detectors installed close to the plate, allow a most suitable identification of the isotopes. Since the gamma ray spectrum is typical of each nucleus, the recognition of well defined peaks by means of gamma spectroscopy allows the identification of the different nuclear species present in the beam.

2.2 Off line testing and simulation

The spatial resolution of LEBI is rather modest, mainly because the radiation is emitted isotropically. So, if we use a hypothetical point like source placed in front of the plate, the radiation crosses the plate in all directions (the plate covers a solid angle of about 2π sr), thus producing a light spot with a halo around it. The FWHM of the spot is of the order of the plate thickness.

An experimental test has been performed by using a 1mm collimated ^{90}Sr, which emits a β particles micro beam with intensity below 10^3 pps. It was placed in front of a CsI plate of thickness 2 mm. The light spot was observed by a CCD camera and had a FWHM ≈ 1.8 mm. Using the rule of the sum of the squares, we calculated a spatial resolution of about 1.5 mm.

The germanium detectors for gamma identification are positioned very 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 gamma rays in cascade. We have tested this technique with two germanium detectors and a ^{60}Co source, showing that it is reliable.

We have also developed a Monte Carlo simulation code, based on the energy loss of beta rays inside the crystal, which is capable of simulating the shape of the light spot produced 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. 2. The predominance of the contribution due to ^{18}N ions depends on the value of its decay constant (λ_{18N} = 1.11 sec^{-1}), much larger than ^{18}F (λ_{18F} = 1.05 10^{-4} sec^{-1}).

2.3 The prototype

The LEBI prototype we have built is made of a spherical vacuum chamber containing the plate-tape set-up. The tape is rolled up in two spools and can be slid on by means of a DC motor (Minimotor 3557K012), whenever it becomes contaminated. An external high sensitivity CCD camera (Watec WAT – 902H, sensitivity of 3·10^{-4} lux) watches the plate and is connected to a frame grabber for the acquisition by a pc. A pneumatic cylinder allows to insert and remove the plate-tape set-up from the beam line, via a remote control. The germanium detectors are arranged by using two cups assembled in the vacuum chamber.

When LEBI will be operative, a set of software tools will offer enough flexibility for managing the different peculiarities of each produced beam.

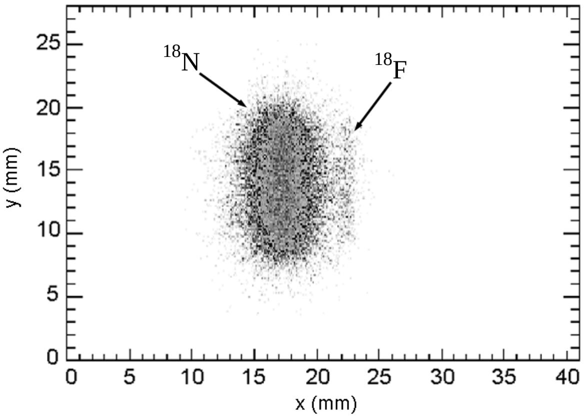

Figure 2: Simulated response of LEBI for a ^{18}F beam and its contaminant ^{18}N.

3 POST-ACCELERATION

3.1 Beam profiling

In order to develop new beam diagnostics tools, which should be able to cover the wide intensity range of the beams, different techniques have been considered based on gas detectors, secondary emission and scintillators.

In gas detectors the signal is produced by ionization due to the energy lost by the ions in a chamber, filled with a suitable gas, or by interaction with the residual gas present along the beam pipe. In the last case, the very few ionizing collision events need some sort of physical amplification; therefore a microchannel plate (MCP) is generally used, onto which the incoming electrons or ions produced by ionization are driven by a transverse electric field [2]. Another technique, that requires a MCP for low intensity beams, exploits the secondary emission of electrons from wires (tungsten) and/or thin foils (carbon or aluminium) when hit by energetic particles [3].

Thin scintillator plates and thicker Scintillating FiberOptic Plates (SFOP) that the beam directly impinges on, have been characterized and they showed to be useful for low intensity beam imaging with CCD cameras. The device named SBBS (Scintillator Based Beam Sensor) is a moving slit sensor, and consists of a CsI(Tl) plate placed behind a thick graphite screen with a 0.5 mm slit. The scintillator is optically coupled with a compact photomultiplier, and the whole structure can be moved to scan the beam. It allows the self-calibration (light versus counts) for very low beam intensity (<10^6 pps). We also proved that this device could operate at very low energy, by easily sensing a 1 pA beam of ^{12}C at 50 keV [4].

The Glass FIbre Based Beam Sensor (GFIBBS) [5] allows to reconstruct the X and Y beam profiles in a single scan with high sensitivity ($I_{beam} < 10^5$ pps). 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.

3.2 *Beam identification*

The beam identification after acceleration has to be performed from a device named HEBI (High Energy Beam Identifier), based on a high resolution silicon telescope, that can revolve around a target. The capability of this system to identify the nuclei with high efficiency, allows to determine the nuclear species present in the beam. It can be accurately positioned around a target (typically gold) placed along the beam line, so being able to intercept the scattered ions.

In order to study the discrimination efficiency, a test has been done performing elastic scattering from the reaction $^{16}O + ^{196}Au$, see Fig. 3. An alpha source placed close to the telescope has been used to perform the calibration procedure of the system. These data have allowed to measure the experimental error, useful for extrapolating the foreseen errors of other hypothetical elements hitting the telescope, since one wants to study the performance of HEBI for the nuclear species produced with EXCYT. We have taken into consideration the elements: ^{11}Be, ^{17}F and ^{18}F. For each of these and their isobaric contaminants, we calculated the energy loss in the ΔE detector, in order to build the relative ΔE-E plot with the error bands, as shown in Fig. 4. These plots have allowed to calculate the probability of misidentification, that between the contiguous elements is always below 10^{-10}.

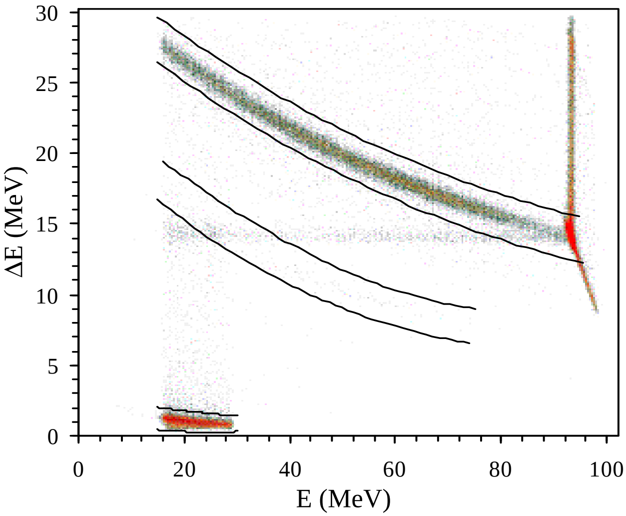

Figure 3: Calibrated bands (±σ) superimposed to the experimental data taken with HEBI. From the $^{16}O + ^{196}Au$ reaction we get mainly elastic scattering, plus many alphas and some C product.

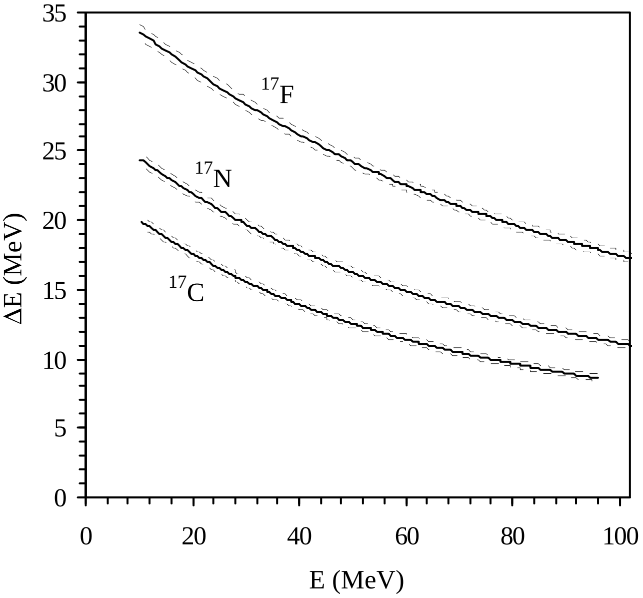

Figure 4: Discrimination plot (±σ) for ^{17}F. The two main contaminants are shown.

REFERENCES

[1] G. Ciavola et al., Nucl. Instr. and Meth. B126 (1997) 258-261;

[2] P. Finocchiaro, DIPAC 97, 3rd European Workshop on Beam Diagnostic and Instr. for Particle Accel., Lab. Naz: Frascati, October 14th, 1997;

[3] P. Finocchiaro, CAARI 98, 15th Internat. Conf. on the Appl. of Accel. In Research and Industry, Univ. of North Texas Denton, November 4-7, 1998;

[4] P. Finocchiaro et al., Nucl. Instr. and Meth. A437 (1999) 552-556.

[5] P. Finocchiaro et al., Nucl. Instr. and Meth. A419 (1998) 83-90.